

# **15th International Conference on Topics in Astroparticle and Underground Physics, TAUP2017**

Monday 24 July 2017 - Friday 28 July 2017

Other Institutes

## **Book of Abstracts**



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**New Technologies / 5****Status and Physics of the SHiP experiment at CERN****Author:** Daniel Bick<sup>1</sup><sup>1</sup> *DESY***Corresponding Author:** daniel.bick@desy.de

SHIP is a new general purpose fixed target facility, whose Technical Proposal has been recently reviewed by the CERN SPS Committee and by the CERN Research Board. The two boards recommended that the experiment proceeds further to a Comprehensive Design phase in the context of the new CERN Working group “Physics Beyond Colliders”, aiming at presenting a CERN strategy for the European Strategy meeting of 2019. In its initial phase, the 400GeV proton beam extracted from the SPS will be dumped on a heavy target with the aim of integrating  $2 \times 10^{20}$  pot in 5 years. A dedicated detector, based on a long vacuum tank followed by a spectrometer and particle identification detectors, will allow probing a variety of models with light long-lived exotic particles and masses below  $O(10)$  GeV  $/c^2$ . The main focus will be the physics of the so-called Hidden Portals, i.e. search for Dark Photons, Light scalars and pseudo-scalars, and Heavy Neutrinos. The sensitivity to Heavy Neutrinos will allow for the first time to probe, in the mass range between the kaon and the charm meson mass, a coupling range for which Baryogenesis and active neutrino masses could also be explained. Another dedicated detector will allow the study of neutrino cross-sections and angular distributions.  $\nu\tau$  deep inelastic scattering cross sections will be measured with a statistics 1000 times larger than currently available, with the extraction of the F4 and F5 structure functions, never measured so far and allow for new tests of lepton non-universality with sensitivity to BSM physics.

**Dark Matter / 6****Directional detection of Dark Matter with a nuclear emulsion based detector****Author:** Murat Ali Guler<sup>1</sup><sup>1</sup> *Middle East Technical University (TR)***Corresponding Authors:** giovanni.de.lellis@cern.ch, ali.murat.guler@cern.ch

Direct dark matter searches are promising techniques to identify the nature of dark matter particles. A variety of experiments have been developed over the past decades, aiming at detecting Weakly Interactive Massive Particles (WIMPs) via their scattering in a detector medium. Exploiting directionality would give a proof of the galactic origin of dark matter making it possible to provide a clear and unambiguous signal to background separation. In particular, the directionality appears as the only way to overcome the neutrino background that is expected to finally prevent standard techniques to further lower cross-section limits. The directional detection of Dark Matter requires very sensitive experiment combined with highly performing technology. The NEWSdm experiment, based on nuclear emulsions, is proposed to measure the direction of WIMP-induced nuclear recoils and it is expected to produce a prototype in 2017. We discuss the discovery potential of a directional experiment based on the use of a solid target made by newly developed nuclear emulsions and read-out systems reaching sub-micrometric resolution.

**New Dark Matter Search Strategies at DUNE / 8****Directional Dark Matter Searches****Authors:** Jason Kumar<sup>None</sup>; Seongjin In<sup>None</sup>; Carsten Rott<sup>None</sup>; David Yaylali<sup>None</sup>

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We consider the use of directionality in the search for monoenergetic sub-GeV neutrinos arising from the decay of stopped kaons, which can be produced by dark matter annihilation in the core of the Sun. When these neutrinos undergo charged-current interactions with a nucleus at a neutrino detector, they often eject a proton which is highly peaked in the forward direction. The direction of this track can be measured at DUNE, allowing one to distinguish signal from background by comparing on-source and off-source event rates. We find that directional information can enhance the signal to background ratio by up to a factor of 5.

**Cosmology, Gravitational Waves, & Cosmic Rays / 9**

## Gravity and antimatter: the AEGIS experiment at CERN

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From the experimental point of view, very little is known about the gravitational interaction between matter and antimatter. In particular, the Weak Equivalence Principle, which is of paramount importance for the General Relativity, hasn't been directly probed with antimatter yet. The main goal of the AEGIS experiment at CERN is to perform a direct measurement of the gravitational force on antimatter. The idea is to measure the vertical displacement of a beam of cold antihydrogen atoms, traveling in the gravitational field of the Earth, by the means of a moiré deflectometer. An overview of the physics goals of the experiment, of its apparatus and of the first results is presented.

**Labs and Low Background / 10**

## VIP2 at Gran Sasso - Test of the validity of the spin statistics theorem for electrons with X-ray spectroscopy

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In the VIP2 (VIolation of the Pauli Exclusion Principle) experiment at the Gran Sasso underground laboratory (LNGS) we are searching for possible violations of standard quantum mechanics predictions. With high precision we investigate the Pauli Exclusion Principle and the collapse of the wave function (collapse models). We will present our experimental method of searching for possible small violations of the Pauli Exclusion Principle (PEP) for electrons, via the search for "anomalous" X-ray transitions in copper atoms, produced by "new" electrons (brought inside a copper bar by circulating current) which could have the probability to undergo Pauli-forbidden transition to the ground state (1 s level) already occupied by two electrons. We will describe the concept of the VIP2 experiment taking data at LNGS presently. The goal of VIP2 is to test the PEP for electrons with unprecedented accuracy, down to a limit in the probability that PEP is violated at the level of  $10E-31$ . We will show preliminary experimental results obtained at LNGS and discuss implications of a possible violation.

**Neutrino Parallel / 11**



## Non-Standard Interactions: oscillation versus scattering data

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In presence of non-standard neutrino interactions the neutrino flavor evolution equation is affected by a degeneracy which leads to the so-called LMA-Dark solution. It requires a solar mixing angle in the second octant and implies an ambiguity in the neutrino mass ordering. In this work, we explore the possibilities for resolving this degeneracy using a combination of oscillation results with past data from scattering experiments (CHARM and NuTeV). We also simulate future data from the COHERENT experiment and study the constraints that could be derived from its combination with current oscillation bounds.

**New Technologies / 12**

## MADMAX: A new road to axion dark matter detection

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The Axion is a hypothetical low-mass boson predicted by the Peccei-Quinn mechanism solving the strong CP problem. It is naturally also a cold dark matter candidate, thus, simultaneously solving two major problems of nature. All existing experimental efforts to detect QCD axions focus on a range of axion masses below 20 ueV. The mass range above  $\sim 40$ ueV, preferred by models in which the Peccei-Quinn symmetry was restored after inflation, could not to be explored so far.

The MADMAX project is designed to be sensitive for axions with masses 40ueV –400 ueV. The experimental design is based on the idea of enhanced axion photon conversion in a system with several layers with alternating dielectric constants.

The experimental idea and the proposed design of the MADMAX experiment will be discussed. First results from measurements with a prototype dielectric haloscope will be discussed. The prospects for reaching sensitivity enough to cover the parameter space predicted for QCD dark matter axions with mass in the range 40-400 ueV will be presented.

**Poster Session / 13**

## Detection of primary photons in high energy cosmic rays using $\nu$ {C}erenkov imaging and surface detectors

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Discovered by Hess during some experiments about air ionization, cosmic rays are constituted by particles coming from the space. In the past, cosmic rays allowed the development of Particle Physics; indeed, thanks to their high energy not achievable in laboratories, they enabled new particles discovery. Today, interest about this radiation concerns both Astrophysics and Particle Physics. Indeed on the one hand, their knowledge allows formulation about new models of Universe structure and evolution or to acquire new knowledge about final objects of stars evolution; on the other hand cosmic rays allows us to study fundamental processes, as for example acceleration and interaction mechanisms of particles at energies not achievable in laboratories. Although it has passed more than a century after their discovery, there are many questions to which it isn't possible to answer yet or to which there isn't certainty about formulated theories. Some examples are about objects that can accelerate particles to high energy and acceleration mechanisms; indeed, even if there are some theories, we don't have experimental certainty. Moreover, although measured in many experiments, energy spectrum shows, especially in the region called "Knee", some differences between measuring made by experiments. Since magnetic fields deflect charged particles, their observation doesn't allow to go back to the source, so in cosmic rays study it's very important  $\gamma$  rays observation because they aren't deflected by magnetic fields. In 1989 *Whipple* experiment allowed to observe, for the first time,  $10^{11}$   $\text{TeV}$  energy  $\gamma$  rays coming from Crab Nebula. Thanks to many experiments made to answer questions about cosmic rays, more than 100  $\text{VHE}$   $\gamma$  rays sources were observed since then; 60 out of 100 have galactic origin, as for instance Supernova Remnants or Pulsars; for the rest, apart from those not identified, they have extra-galactic origin. In this perspective, *LHAASO* experiment is currently in planning phase; it will be composed by *LHAASO-KM2A* (it will be composed by *ED* and *MD*) to measure number and arrival time of particles, *LHAASO-WCDA* a water  $\text{Cherenkov}$  detector to study cosmic rays of energies higher than  $10^3$   $\text{TeV}$  and *LHAASO-WFCTA* a  $\text{Cherenkov}$  telescope system to measure longitudinal development of cosmic rays and to obtain information about primary cosmic rays. After the building at Daochen in China, *LHAASO* will allow to study the "High Energy Universe", allowing observation of  $\gamma$  rays of energies in the range  $10^3$   $\text{GeV} \div 10^5$   $\text{PeV}$  observing secondary particles of showers called *EAS*, result of interaction between primary particles and atmosphere. One other important experiment, currently in planning phase, it's *CTA*. It will be built in two sites, at La Palma in Spain and at Parana in Chile. It will be the biggest  $\text{Cherenkov}$  imaging telescope array built so far and, although using different kind of detectors, *CTA* final goals are the same of *LHAASO*. Improving instrumentation respect to current and past experiments, they will allow observations not possible up to now and they will improve results as well. To allow observation of  $\gamma$  rays of energies in the range  $10^2$   $\text{GeV} \div 10^3$   $\text{TeV}$ , *CTA* will be composed by three kind of telescopes, the *LST* to make observations in the range  $10^2$   $\text{GeV} \div 10^3$   $\text{GeV}$ , the *MST* for observations in the range  $10^3$   $\text{GeV} \div 10^4$   $\text{TeV}$  and the *SST* for observations in the range  $10^4$   $\text{TeV} \div 10^5$   $\text{TeV}$ . Although *LHAASO* and *CTA* will have same final goals, since they will have different detectors, they will offer distinct opportunities to Astroparticle Physics; for example, *LHAASO* will have a better resolution at energies higher than  $10^3$   $\text{TeV}$  and it will allow observation of high section of the sky, *CTA* at energies approximately  $10^4$   $\text{TeV}$  and focused about single source. Thanks to specific simulation software it's possible to simulate *EAS* on the basis of theoretical models and to use simulations both to study detector performances during fulfillment phase and to compare simulation results to experimental data in order to prove models during detector data acquisition; one of these software is, for example, *CORSIKA*. Since in  $\gamma$  astronomy experiments it's very important adrons rejection, some simulations made by *CORSIKA* were analyzed to compare *EAS* induced by protons in the range  $10^3$   $\text{GeV} \div 10^5$   $\text{GeV}$  and power law  $\frac{dN}{dE} \propto E^{-2}$  to *EAS* induced by  $\gamma$  in the same energetic range and same power law. First of all, it was studied first interaction height of primary particles showing that, due to different values of radiation length about electromagnetic showers and interaction length about adronic showers,  $\gamma$  rays interact previous to protons in atmosphere; in addition, by

calculating mean values of first interaction heights in the ranges  $[unit[20]GeV \div unit[50]GeV]$ ,  $[unit[50]GeV \div unit[100]GeV]$ ,  $[unit[100]GeV \div unit[200]GeV]$ ,  $[unit[200]GeV \div unit[350]GeV]$ ,  $[unit[350]GeV \div unit[600]GeV]$  and  $[unit[600]GeV \div unit[1000]GeV]$  it was showed that first interaction height of gamma rays is almost constant in energy; instead, due to  $pp$  cross section, protons first interaction height mean values are a bit higher for energies  $E < unit[100]GeV$  than for higher energies. Later, concentration was focused about \ac{EAS} to study differences between the showers on the basis of primary particle. For this reason, first of all, arbitrarily choosing two primary particles energies  $E \sim unit[150]GeV$  and  $E \sim unit[1]TeV$ , it was plotted secondary particles distributions at observation level (setted on  $unit[4300]m$  above sea level); by plots we can see that secondary particles of  $\gamma$  rays showers are arranged on surfaces centered in \ac{EAS} core smaller than particles of proton showers. Later it was observed the difference between number of secondaries  $e^\pm$  and  $\mu^\pm$  produced by  $\gamma$  rays showers and proton showers; by plots it's clear that  $\frac{e^\pm}{\mu^\pm}$  ratio is higher for  $\gamma$  rays showers than for proton showers, because in proton showers we have higher  $\mu^\pm$  than in  $\gamma$  rays showers. Additionally, calculating  $e^\pm$  and  $\mu^\pm$  mean values in energy ranges, it was showed their increasing production for higher primary particles energies. Very important is the difference about lateral development of the \ac{EAS}; indeed, to confirm what showed by plots about distributions at observation level, it was calculated particles density in circular crowns centered in the \ac{EAS} core up to  $unit[10]Km$  from it. Plots showed that, increasing distance from core, density decreasing of secondary particles produced by  $\gamma$  rays showers is faster than secondary particles produced by proton showers, so probability to find particles of  $\gamma$  rays showers faraway from the core is smaller than to find particles of proton showers. Lastly, arbitrarily choosing 3 distances from the core  $unit[10]m$ ,  $unit[100]m$  and  $unit[600]m$  it was calculated particles density for energy ranges of primary particles  $[unit[20]GeV \div unit[50]GeV]$ ,  $[unit[50]GeV \div unit[100]GeV]$ ,  $[unit[100]GeV \div unit[200]GeV]$ ,  $[unit[200]GeV \div unit[350]GeV]$ ,  $[unit[350]GeV \div unit[600]GeV]$  and  $[unit[600]GeV \div unit[1000]GeV]$ ; as result it's clear that for fixed distances, increasing primary particles energy, secondary particles density increases too. Obtained results are based on theoretical models of interaction processes between cosmic rays and atmosphere; for the future, when \ac{LHAASO} and \ac{CTA} will start to take data, it will be important to compare simulation data to experimental data. It's essential a careful experimental test that, thanks to improvements that \ac{LHAASO} and \ac{CTA} will have compared to current \ac{SD} and \textit{\textbf{\ac{IACT}}}, it will allow to acquire new knowledge about cosmic rays, their acceleration in galactic and extragalactic sources, propagation in Universe and interaction in atmosphere. However, obtained results are important because analysis of  $\gamma$  rays showers and proton showers, produced by \ac{CORSIKA}, it allows us to test theories at the basis of \ac{LHAASO} and \ac{CTA} realization, that is thanks to algorithms based on differences between lateral developments of showers in atmosphere, lateral distribution at observation level about charged and neutral particles around shower core, number of  $\mu^\pm$ , it will be possible to discern  $\gamma$  rays showers from proton showers ( $\frac{protonacEAS}{\gamma acEAS} \sim 100$ ) to acquire events and to reject adronic background. Finally, comparing experimental data to obtained mean values of studied physical quantities in function of primary particles energies, it will be possible to estimate the latter.

Neutrino Parallel / 14

## Flavor evolution in astrophysical environments and nonlinear feedback

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Since the discovery of neutrino oscillations in 1998 and the assessment of the Mikheev-Smirnov-Wolfenstein (MSW) effect, steady progress had been made in understanding neutrino flavor conversions in astrophysical environments. Neutrino self-interactions have proven to complicate the problem, making the evolution equations intrinsically nonlinear, and have triggered a decade of theoretical investigations. A variety of flavor instabilities has been uncovered, depending on the physical

conditions and the geometry of the environment considered. In anisotropic media, the most general mean-field equations include corrections to the relativistic limit, due to the nonzero neutrino mass. This contribution creates a coupling between neutrino and antineutrino referred as *helicity* or *spin coherence*.

In this talk, we focus on the progress made in neutrino flavor evolution in astrophysical environments, and we discuss the effects of helicity coherence on propagation in binary neutron star mergers and core-collapse supernovae [1]. Such studies are crucial to assess the actual impact on the supernova dynamics and on the nucleosynthetic abundances.

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## Poster Session / 15

### Different Conception to the Universe: The Nested Vortexes

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The accredited contemporary theories to describe the universe are not complete or accurate to understand the structure of the universe matter and the nature of the energies. It failed to interpret many phenomena as how a particle affects another with electrical, magnetic, or gravitational force without physical contact. It does not give a meaning of how the space is curved around the stars, the meaning that a particle has a charge, or is the light is photons or waves. This paper interprets all these phenomena in a dynamic perspective. It first introduces a new conception about the structure of the universe. It assumes that the universe is a media of ultra-tiny homogeneous particles which is still undiscovered, and as any media with certain movements, probably by the big bang, vortexes could be occur. The vortex could condense the ultra-tiny particles in its center forming a bigger particle. The bigger particles in turn could be trapped in a bigger vortex and condensed in its center forming a much bigger particle and so on. This conception describes galaxies, stars, neutrons as particles at different levels and unifying the description of their behavior. This conception supports the aether and superfluid theories and violates Einstein interpretation about the gravity.

## Cosmology, Gravitational Waves, & Cosmic Rays / 16

### Measurement of the knees of proton and H&He spectra below 1 PeV

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Light component (H&He) energy spectrum of 125 TeV - 3 PeV is measured by the ARGO-YBJ detector with a wide field-of-view imaging Cherenkov telescope.

1.filling the gap between the direct observations of CREAM and the EAS xperiment, such as KASCADE;

2.The knee of (700±230\_stat.±70\_sys.) TeV is found with a significance of 4.2 sigma;

3.Spectra index:  $\beta_1 = -2.56 \pm 0.05$  below the knee;  $\beta_2 = -3.24 \pm 0.36$  above the knee;

4.Energy resolution: ~25% with offset <3%.

With the minimal assumption, the knee of the pure proton spectrum is derived to be at the same energy of 700 TeV. Taking into account the constraint of CREAM's measurement at energies below

100 TeV, the proton and Helium spectra above the knee are discussed even if they are model dependent. The bending energy of Helium spectrum above 4X700 TeV, as the expectation of the model with  $E_b$  proportional to  $A$ , seems to be ruled out. A high precision measurement of the H&He and pure proton spectra in the energy range from 0.7 to 3 PeV is very crucial. LHAASO as the next generation high altitude EAS array with a combination of many detecting techniques will finish the measurement in few years.

**Neutrino Parallel / 18**

## Testing the Neutrino Mass Ordering with Multiple Years of IceCube/DeepCore

**Authors:** Martin Leuermann<sup>None</sup>; Martin Leuermann<sup>None</sup>; The IceCube Collaboration<sup>None</sup>

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The measurement of the Neutrino Mass Ordering (NMO), i.e. the ordering of the three neutrino mass eigenstates, is one of the major goals of many future neutrino experiments. One strategy is to measure matter effects in the oscillation pattern of atmospheric neutrinos as proposed for the PINGU extension of the IceCube Neutrino Observatory.

Already, the currently running IceCube/Deepcore detector can explore this type of measurement. Albeit with lower significance, such measurement can contribute to the current understanding. Furthermore, such an analysis exercises the measurement principle and evaluation of systematic uncertainties and thus prototypes future analyses with PINGU.

We present a three-dimensional likelihood analysis for multiple years of IceCube data searching for indications of the NMO with a data sample reaching to energies below 10GeV.

**Neutrino Parallel / 19**

## Overview on neutrino electromagnetic properties

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A review of the theory and phenomenology of neutrino electromagnetic properties is presented. A massive neutrino even in the easiest generalization of the Standard Model inevitably has nonzero electromagnetic characteristics, at least nonzero magnetic moment. Although its value, determined by the neutrino mass, is very small, in other BSM theories much larger values of magnetic moments are predicted.

A discussion on a derivation of the general structure of the electromagnetic interactions of Dirac and Majorana neutrinos is given. Then we discuss experimental constraints on neutrino magnetic and electric dipole moments, electric millicharge, charge radius and anapole moments from the terrestrial laboratory experiments. A special credit is done to bounds on neutrino magnetic moments obtained by the reactor (MUNU, TEXONO and GEMMA) and solar (Super-Kamiokande and Borexino) experiments.

A thorough account of electromagnetic interactions of massive neutrinos in the theoretical formulation of low-energy elastic neutrino-electron scattering is discussed on the basis of our recently published paper [2]. The formalism of neutrino charge, magnetic, electric, and anapole form factors defined as matrices in the mass basis with account for three-neutrino mixing is presented.

The effects of neutrino electromagnetic interactions in astrophysical environments are also reviewed. The main manifestation of neutrino electromagnetic interactions, such as: 1) the radiative decay in vacuum, in matter and in a magnetic field, 2) the Cherenkov radiation, 3) the plasmon decay, 4) spin light in matter, 5) spin and spin-flavour precession, 6) neutrino pair production in a strong magnetic field, and the related processes along with their astrophysical phenomenology are also considered. The best world experimental bounds on neutrino electromagnetic properties are confronted with the predictions of theories beyond the Standard Model. It is shown that studies of neutrino electromagnetic properties provide a powerful tool to probe physics beyond the Standard Model.

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## Cosmology, Gravitational Waves, & Cosmic Rays / 20

### A new method of determination of the mass of primary cosmic ray particles

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This paper studies the influence of the Earth’s magnetic field on the extensive air shower particles generated by CORSIKA code. The effect causes an azimuthal asymmetry especially on positive and

negative muons in highly inclined showers. This asymmetry is quantified by introducing a new observable in terms of a transverse distance (TD) between the positive and negative muon barycenters across shower core in the shower front. It is found that the TD and its maximum value clearly show primary mass sensitivity. An experimental feasibility of the new method in a sea level experiment is also discussed.

#### Poster Session / 21

### Study of solar Transients causing intense GMSs with $Dst \leq -100nT$ during the period 1999-2010

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The effect of solar features on geospheric conditions leading to geomagnetic storms(GMSs)with Dst index  $Dst \leq -100nT$  has been investigated using interplanetary magnetic field(IMF),solar wind data(SWP) and solar geophysical data with CMEs that erupted between 1999 and 2010, all 51 events were considered .The study investigated the relationship coronal mass ejection (CME) and their influence on Earth's geomagnetic field, i.e. storms and sub storms .The study is performed mainly considering intense geomagnetic storms that occurred during Solar Cycle 23 and ascending phase of 24 Solar Cycle . It has been analysed and estimated by cross correlation method that there is a delay of 17 to 96 hours in happening GMSs on the Earth after the happening of the CME on the sun

#### Xenon 1T Results / 22

### Direct dark matter search with XENON1T

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The talk will cover the latest status and results for direct dark matter search with XENON1t and it will give an outlook on the planned improvements and upgrades.

#### Neutrino Parallel / 23

### Three-flavour neutrino oscillations and beyond

**Author:** Mariam Tórtola<sup>1</sup>

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In this talk, we will summarize the current status of global neutrino oscillation analyses in the three-neutrino framework. We will also discuss some scenarios where the measurement of the CP violation phase could be significantly affected by the presence of neutrino physics BSM.

## Neutrino Parallel / 24

**Investigation of double beta decay of  $^{58}\text{Ni}$  at the Modane Underground Laboratory****Author:** Ekaterina Rukhadze<sup>1</sup><sup>1</sup> *IEAP CTU in Prague***Corresponding Author:** ekaterina.rukhadze@utef.cvut.cz

Investigation of double beta decay ( $\beta$ +EC, EC/EC) of  $^{58}\text{Ni}$  was performed at the Modane underground laboratory (LSM, France, 4800 m w.e.) using the ultra-low background spectrometer Obelix and a sample of natural Ni. Spectrometer Obelix is based on P-type coaxial HPGe detector with a sensitive volume of 600 cm<sup>3</sup> and relative efficiency of 160 %. The detector part of the cryostat is encircled by several layers of roman and low-active lead and flushed with radon-depleted air. The sample of natural nickel, containing ~68% of  $^{58}\text{Ni}$  with a total mass of ~21.7 kg was prepared in a shape of Marinelli beaker and placed on the Obelix detector. Three experimental runs were performed with the investigated sample in 2014 - 2017 years. New experimental limits (at 90% CL) on half-lives of  $\beta$ +EC and EC/EC decays of  $^{58}\text{Ni}$  to excited states of  $^{58}\text{Fe}$  were obtained in these investigations, improving the previous experimental limits by approximately two orders of magnitude.

## Cosmology, Gravitational Waves, &amp; Cosmic Rays / 25

**A study on the reconstruction of  $f(T)$  gravity with interacting variable generalized Chaplygin gas and the consequences****Author:** Surajit Chattopadhyay<sup>None</sup>**Corresponding Author:** surajitchatto@outlook.com

The present paper reports a study on variable generalized Chaplygin gas (VGCG) interacting with pressureless dark matter (DM) with interaction term  $Q$  chosen in the form  $Q=3H\delta\rho\Lambda$ , where  $\rho\Lambda$  denotes the density of the VGCG. Detailed cosmology of the interacting VGCG has been studied and a quintom behaviour of the equation of state (EoS) parameter has been observed. A statefinder analysis has shown attainment of  $\Lambda$ CDM fixed point by the interacting VGCG. Subsequently, a reconstruction scheme for  $f(T)$  gravity has been presented based on the interacting VGCG with power-law form of scale factor. The EoS parameter corresponding to the reconstructed  $f(T)$  has shown quintom behaviour. Finally we have studied the generalized second law (GSL) of thermodynamics in reconstructed  $f(T)$  cosmology considering the universe as a closed bounded system with future event horizon as the cosmological boundary. We have associated two different entropies with the cosmological horizons with a logarithmic correction term and a power-law correction term. We have studied the validity of the GSL for both of these corrections. Our result deviates from Bamba et al., *Astrophys. Space Sci.* 344, 259 (2013) (2013) in the sense that in the said reference, the GSL had a conditional validity for both of the corrections in the case of future event horizon. However, in the present case the GSL has failed to hold in power-law correction and has unconditional validity in logarithmic correction with future event horizon as the enveloping surface of the universe.

## Poster Session / 26

**Consequences of correspondence between Modified Chaplygin gas and extended holographic Ricci dark energy in the framework of bulk viscosity****Author:** Surajit Chattopadhyay<sup>None</sup>



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The present paper reports a study on modified Chaplygin gas (MCG) based reconstruction scheme for extended holographic Ricci dark energy (EHRDE) in the presence of viscous type dissipative term. The dissipative effect has been described by using Eckart approach. Under the assumption that the universe is filled with MCG-EHRDE under the influence of bulk viscosity we have studied the cosmological dynamics, where the bulk viscosity coefficient has been chosen in a particular time varying form  $\xi = \xi_0 + \xi_1 H + \xi_2 (\dot{H} + H^2)$ , where  $\xi_0$ ,  $\xi_1$  and  $\xi_2$  are constant coefficients and  $H$  is the Hubble parameter. Furthermore, we have reconstructed the potential and dynamics of viscous MCG-EHRDE as scalar field. Thereafter we have studied the statefinder trajectories to discern its departure from  $\Lambda$ CDM and finally investigated validity of the generalized second law of thermodynamics (GSL) considering event horizon as the enveloping horizon of the universe.

**Dark Matter / 27**

## STUDIES OF NEUTRINO PROPERTIES AND INTERACTIONS AT THE KUO-SHENG REACTOR NEUTRINO LABORATORY WITH SUB-KEV GERMANIUM DETECTORS

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Germanium detectors with sub-keV sensitivities [1] offer a unique opportunity to study neutrino interactions and properties [2] as well as to search for light WIMP Dark Matter and axion-like particles [3]. The TEXONO Collaboration has been pursuing this research program at the Kuo-Sheng Neutrino Laboratory (KSNL) in Taiwan. We will highlight our results on neutrino electromagnetic properties, search of sterile neutrinos, as well as studies towards observation of neutrino-nucleus coherent scattering. The detector R&D programs which allow us to experimentally probe this new energy window will be discussed. The efforts set the stage and complement the CDEX dark matter experiment and beyond at the new China Jinping Underground Laboratory (CJPL) in China.

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**Cosmology, Gravitational Waves, & Cosmic Rays / 28**

## Horizon-T experiment and detection of Extensive air showers with unusual structure

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Horizon-T is a newly completed (Oct. 2016) innovative detector system constructed to study temporary structure of Extensive Air Showers (EAS) in the energy range above  $\sim 10^{16}$  eV coming from a wide range of zenith angles (0 - 80 degrees). The system is located at Tien Shan high-altitude Science Station of Lebedev Physical Institute of the Russian Academy of Sciences at approximately 3340 meters above the sea level. It consists of eight charged particle detection points separated by the distance up to one kilometer as well as optical detector subsystem to view the Vavilov-Cherenkov light from the EAS. The time resolution of charged particles passage of the detector system is a few ns. This level of resolution allows conducting research of atmospheric development of individual EAS.

The total of  $\sim 7200$  Extensive Air Showers (EAS) with the energy above  $10^{16}$  eV have been detected during the  $\sim 3500$  hours of Horizon-T detectors system operations since October 24, 2016. Among these EAS, a large amount had a spatial and temporary structure that showed the pulses with several maxima (modals or modes) from several detection points of the Horizon-T at the same time. These modes are separated in time from each other starting from tens to thousands of ns. These EAS are called multi-modal. Some are further classified as unusual.

Analysis shows that the multi-modal EAS that have been detected by Horizon-T have the following properties:

- 1) Multi-modal EAS have energy above  $\sim 10^{17}$  eV;
- 2) Pulses with several modes are detectable at large distances from EAS axis.

The presentation will briefly overview a general performance of the detector system, then the latest results from the collected data including the multi-modal and unusual EAS events will be presented.

**Neutrino Parallel / 29**

## Updating neutrino magnetic moment constraints

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The study of the neutrino electromagnetic (EM) properties opens a door to explore physics beyond the Standard Model. The neutrino magnetic moment (NMM) have been the most studied neutrino EM property since the neutrino was proposed in 1930 by Wolfgang Pauli. If we consider Majorana neutrinos, the NMM matrix will be composed by three transition magnetic moments (TMM) which give us information about the neutrino-electron EM interaction. We have obtained an updated analysis of the constraints on the magnitudes of the TMM and the role of the CP violating phases. A combined study of reactor, accelerator and solar neutrinos was made in order to achieve these limits. The most stringent restrictions are provided by the Borexino experiment, where the limit obtained on the effective neutrino magnetic moment was  $3.1 \times 10^{-11}$  Bohr Magneton (BM). This corresponds to the individual transition magnetic moment constraints:  $5.6 \times 10^{-11}$  BM,  $4 \times 10^{-11}$  BM and  $3.1 \times 10^{-11}$  BM, respectively. In this talk, we are going to discuss about these results.

**Neutrino Parallel / 30**

## The neutrino mass experiment KATRIN

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The Karlsruhe TRITium Neutrino (KATRIN) experiment is a large-scale experiment with the objective to determine the effective electron anti-neutrino mass with an unprecedented sensitivity of 0.2 eV/c<sup>2</sup> at 90% C.L. in a model-independent way. The measurement method is based on precision beta-decay spectroscopy of molecular tritium.

The experimental setup consists of a high luminosity windowless gaseous tritium source, a magnetic electron transport system with differential and cryogenic pumping for tritium retention, and an electro-static spectrometer section for energy analysis, followed by a segmented detector system for counting transmitted beta-electrons. First commissioning measurements of the complete beamline were performed in November 2016.

This talk will give an overview of the KATRIN experiment and its current status. Furthermore, results of the recent commissioning measurements of the complete KATRIN beamline will be presented.

**Poster Session / 31**

## **Extensive air showers event reconstruction using spatial and temporary particle distribution at Horizon-T experiment.**

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Horizon-T (HT) is a newly completed (Oct. 2016) innovative detector system constructed to Extensive Air Showers (EAS) in the energy range above  $\sim 10^{16}$  eV coming from a wide range of zenith angles (0° - 80°). The system is located at Tien Shan high-altitude Science Station of Lebedev Physical Institute of the Russian Academy of Sciences at approximately 3340 meters above the sea level. It currently consists of eight charged particle detection points separated by the distance up to one kilometer. The ability to record each detector response with accuracy of few ns gives HT ability to study the temporary structure of EAS disk and apply the results to the event reconstruction. The reconstruction is therefore based on chronotron (< 0.5 ns), spatial and temporary distribution of charged particles within the detected EAS event.

The poster will show the simulated time distribution of charged particles in the EAS disk vs. distance from the axis and the correspondence to the data. A flow of the reconstruction of standard EAS events and the event display will be presented as well as recent HT results.

**Neutrino Parallel / 32**

## **Neutrino geoscience and reactor monitoring with direction-sensitive detectors**

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The Earth is an anti-neutrino star, radiating more than  $10^{25}$  anti-neutrinos to space every second. This immense luminosity is fueled predominantly by the  $\beta^-$  decays of radiogenic isotopes in the Earth's crust and mantle. The anti-neutrinos produced by these decays, called geo-neutrinos due to their geophysical origin, give us important clues about the composition of the Earth's interior and the size and sources of the Earth's radiogenic heat flow, both in the current epoch and throughout its evolution. In this talk, we present a novel method for measuring previously unresolved components of Earth's internal heating due to radioactivity, specifically those associated to potassium, the mantle and the core. The technique exploits the directional information of neutrino-electron elastic scattering and estimates the exposures needed to probe these contributions to the total geo-neutrino flux. These results chart the course for pioneering exploration of the veiled inner workings of the Earth. To conclude, we discuss the implications of ktonne-scale direction-sensitive detectors on nuclear non-proliferation by examining their prospects to remotely monitor nuclear reactors.

**Dark Matter / 33**

## Effects of Threshold Energy on Determinations of Properties of Low-Mass WIMPs from Direct Dark Matter Detection Experiments

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In this talk, we discuss the effects of a non-negligible threshold energy on our model-independent methods developed for reconstructing WIMP properties by using measured recoil energies in direct Dark Matter detection experiments directly. Our expressions for reconstructing the mass and the (ratios between the) spin-independent and the spin-dependent WIMP-nucleon couplings have been modified. We will focus on low-mass ( $m_{\chi} \lesssim 50$  GeV) WIMPs and present some (preliminary) numerical results obtained by Monte-Carlo simulations.

**Neutrino Parallel / 34**

## The Super-Kamiokande Gadolinium Project

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Supernova explosions in our galaxy may be rare, but supernovae themselves are not. On average, there is one ccSN somewhere in the universe each second. The neutrinos emitted from all of these ccSN since the onset of stellar formation have suffused the universe. We refer to this thus-far unobserved flux as the "relic" supernova neutrinos.

The flux of the supernova relic neutrinos is expected to be several tens per square centimeter per second. Theoretical models vary, but as many as five supernova relic neutrinos per year above 10 MeV are expected to interact in Super-Kamiokande. However, in order to separate these signals from the much more common solar and atmospheric neutrinos and other backgrounds, we need a new detection method.

Two years ago, the Super-Kamiokande Collaboration approved the SK-Gd project. It is the upgrade of the SK detector via the addition of water-soluble gadolinium (Gd) salt. Since then, we have been conducting many dedicated study and developments for deploying Gd to SK. This modification will enable it to identify low energy anti-neutrinos for the world's first observation of the relic supernova neutrinos via inverse beta decay.

## Poster Session / 37

## Improved detector simulation and neutron tagging study for the SK-Gd project

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Super-Kamiokande Gadolinium (SK-Gd) project is an upgrade proposed to the SK detector by dissolving a Gd-compound into the detector water. With this upgrade, electron antineutrino events can be efficiently identified by tagging the 8 MeV gamma cascade emitted by a neutron capture on Gd. Utilizing this technique, we are aiming to make the first observation of the supernova relic neutrinos, as well as improving many physics programs that are currently pursued at SK.

In order to accurately estimate the impact of the upgrade, we have updated the SK detector simulation package, called SKDETSIM, to include neutron capture on Gd. We will present how we interface SKDETSIM, which is GEANT3-based, with the interaction packages in GEANT4 to utilize its comprehensive neutron data library. The simulation code have been validated with neutron gun and atmospheric neutrino simulations. Finally, the current status of developing a neutron tagging algorithm specific to Gd-capture will be discussed.

## New Technologies / 38

## ZICOS –Neutrinoless double beta decay experiment using Zr-96 in organic liquid scintillator-

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A liquid scintillator containing a tetrakis (isopropyl acetoacetato) zirconium (Zr(iprac)<sub>4</sub>) has been developed for new project of neutrinoless double beta decay search using Zr-96 isotope, which is called ZICOS experiment. The liquid scintillator has 10 wt.% concentration of Zr(iprac)<sub>4</sub>, a light yield of 48.7±7.1% for BC505, and an energy resolution of 4.1±0.6% at 3.35 MeV assuming 40% photo coverage of the photomultiplier.

In order to investigate a half-life over 10 to the 26th years, which corresponds to neutrino mass below 0.1 eV, we have to use a ton scale of Zr-96 isotope, and have to remove background events such as Tl-208, which come from the surface of inner balloon as observed by KamLAND-Zen, over one order magnitude. For this purpose, we have developed new technique to use Cherenkov light in order to distinguish the signal and backgrounds using their characteristic hit pattern of photomultiplier, and then have got a method which has ability of 93% background reduction even though remaining 80% of double beta decay signal in study of the Monte Carlo simulation. In this case, we need to separate Cherenkov light and Scintillation light even for a few MeV electron. Using difference of the light emission mechanism, we could also identify the shapes of time profile for Cherenkov light and Scintillation light with FADC data.

Here we will report recent results of our measurement and the conceptual design of ZICOS detector from the study.

**Poster Session / 39**

## The Main Structure of the Central Detector of JUNO

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Abstract

Jiangmen Underground Neutrino Observatory (JUNO) is under construction in Southern China which aims to measure the neutrino mass hierarchy and neutrino oscillation parameters using primarily the reactor neutrinos from two nearby nuclear power plants 53km away. JUNO's central detector is designed to measure reactor antineutrinos via inverse beta decay with 20k tons of liquid scintillator as the target. The detector is designed to reach  $(3\%)/\sqrt{(E/\text{MeV})}$  of energy resolution. The central detector system consists of an inner transparent sphere of 35.4 m in diameter and an outer support structure of 40.1 m in diameter. The inner sphere is made of acrylic and contains the 20 ktons of liquid scintillator. About 17000 photomultiplier tubes (PMTs) are mounted on the outer structure, covering  $\sim 75\%$  of surface to detect the scintillating photons. Such a big detector with such a high energy resolution places a big challenge to massive liquid scintillator technology. Here the design and R&D progress of the main structure of the central detector are introduced.

**Neutrino Parallel / 40**

## Status of JUNO

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The Jiangmen Underground Neutrino Observatory (JUNO) is a multi-purpose underground experiment and the largest liquid scintillator (LS) detector going for neutrino mass hierarchy, precise neutrino oscillation parameter measurement and studies of other rare processes which include but not limited to solar neutrino, geo-neutrino, supernova neutrinos and the diffuse supernova neutrinos background. The R&D of the detector system is going, including central detector, LS, water Cherenkov veto, PMT system, top track etc. In this talk, we will try to overview the latest progress of the JUNO project in physics and hardware development.

**Neutrino Parallel / 41**

## Search for light sterile neutrinos with the CeSOX experiment

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The CeSOX experiment will search for light sterile neutrinos with an intense  $^{144}\text{Ce}$ - $^{144}\text{Pr}$  antineutrino generator deployed next to the Borexino detector located at the Laboratory Nazionali del Gran Sasso. Data taking is expected to start during spring 2018.

**New Technologies / 42**

## Status of the TREX-DM experiment at the Canfranc Underground Laboratory

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Looking for low-mass WIMPs ( $<10$  GeV) which could be pervading the galactic dark halo requires the use of light elements as target and detectors with very low energy threshold. The TREX-DM (TPC Rare Event eXperiment for Dark Matter) experiment is conceived to fulfil these requirements by means of a gas time projection chamber (TPC) equipped with novel micromesh gas structures (Micromegas) readout planes. The detector can hold, in the fiducial volume,  $\sim 20$  litres of pressurized gas up to 10 bar, which corresponds to  $\sim 0.300$  kg of Ar at 10 bar, or alternatively 0.160 kg of Ne. The Micromegas are highly segmented and will be read with a self-triggered acquisition, allowing for effective thresholds below 0.4 keV (electron equivalent). An exhaustive material screening campaign has allowed to design and construct the detector and shielding with the state-of-the-art radiopurity specifications. The preliminary background model suggests that levels of the order of 1-10 counts keV<sup>-1</sup> kg<sup>-1</sup> d<sup>-1</sup> are expected in the region of interest, making TREX-DM competitive in the search for low mass WIMPs. The experiment has been approved by the Canfranc Underground Laboratory (Laboratorio Subterráneo de Canfranc, LSC) and after completion of a series of measurements at ground level is expected to be installed at the LSC facilities by the end of the current year. A tentative schedule foresees a data-taking campaign of approximately 3 years starting with Ne, with the option to change to (depleted) Ar. Latest experimental results, status of the commissioning, description of background model and the corresponding WIMP sensitivity will be presented.

**Dark Matter / 43**

## Impeded Dark Matter

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We consider dark matter models in which the mass splitting between the dark matter particles and their annihilation products is tiny. Compared to the previously proposed Forbidden Dark Matter scenario, the mass splittings we consider are much smaller, and are allowed to be either positive or negative. To emphasize this modification, we dub our scenario "Impeded Dark Matter". We demonstrate that Impeded Dark Matter can be easily realized without requiring tuning of model parameters. For negative mass splitting, we demonstrate that the annihilation cross-section for Impeded Dark

Matter depends linearly on the dark matter velocity or may even be kinematically forbidden, making this scenario almost insensitive to constraints from the cosmic microwave background and from observations of dwarf galaxies. Accordingly, it may be possible for Impeded Dark Matter to yield observable signals in clusters or the Galactic center, with no corresponding signal in dwarfs. For positive mass splitting, we show that the annihilation cross-section is suppressed by the small mass splitting, which helps light dark matter to survive increasingly stringent constraints from indirect searches. As specific realizations for Impeded Dark Matter, we introduce a model of vector dark matter from a hidden  $SU(2)$  sector, and a composite dark matter scenario based on a QCD-like dark sector.

**Dark Matter / 44**

## Dark Gamma Ray Bursts

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Many theories of dark matter (DM) predict that DM particles can be captured by stars via scattering on ordinary matter. They subsequently condense into a DM core close to the center of the star and eventually annihilate. In this work, we trace DM capture and annihilation rates throughout the life of a massive star and show that this evolution culminates in an intense annihilation burst coincident with the death of the star in a core collapse supernova. The reason is that, along with the stellar interior, also its DM core heats up and contracts, so that the DM density increases rapidly during the final stages of stellar evolution. We argue that, counterintuitively, the annihilation burst is more intense if DM annihilation is a p-wave process than for s-wave annihilation because in the former case, more DM particles survive until the supernova. If among the DM annihilation products are particles like dark photons that can escape the exploding star and decay to Standard Model particles later, the annihilation burst results in a flash of gamma rays accompanying the supernova. For a galactic supernova, this “dark gamma ray burst” may be observable in CTA.

**New Technologies / 45**

## PandaX-III: Searching for Neutrinoless Double Beta Decay with High Pressure Xe-136 Gas Time Projection Chambers

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The PandaX-III project at China Jinping Underground Laboratory (CJPL) will search for neutrinoless double beta decay of Xe-136 with high pressure xenon gas Time Projection Chambers (TPC). PandaX-III exploits the tracking capability of gaseous TPC to effectively identify possible signal and suppress background. The first TPC will contain 200 kg of enriched xenon at 10 bar and will be equipped with Micromegas charge amplification and readout modules. The projected energy resolution is 3% (FWHM at Q-value) and spatial resolution on millimeter level. We are commissioning a prototype TPC with up to 20 kg of xenon in the effective volume to validate our design of high voltage feedthrough, field cage, Micromegas readout plane, and to develop algorithms of track reconstruction. In this talk, I will give an overview of the PandaX-III design features, projected sensitivity, and the latest results of the prototype TPC.



**Dark Matter / 46****The R&D progress of the Jinping Neutrino Experiment****Author:** Shaomin Chen<sup>1</sup><sup>1</sup> *Tsinghua University***Corresponding Author:** chenshaomin@tsinghua.edu.cn

The Jinping Neutrino Experiment will perform an in-depth research on solar neutrinos, geo-neutrinos and supernova relic neutrinos. Many efforts were devoted to the R&D of the experimental proposal. A new type of liquid scintillator, with high light-yield and Cherenkov and scintillation separation capability, is being developed. The assay and selection of low radioactive stainless-steel (SST) was carried out. The U and Th concentration is less than 1e-8 g/g for selected SST samples. A wide field-of-view and high-efficiency light concentrator is developed. Previous designs of light concentrators were optimized to attain a wide field view, 90 degree and a high efficiency, above 98%. At the same time a 1-ton prototype is constructed and placed underground at Jinping laboratory to 1) test the performance of several key detector components, like acrylic, pure water, using of ultra-high molecular weight polyethylene rope, 2) understand the neutrino detection technology with liquid scintillator and slow liquid scintillator and 3) measure the in-situ Jinping underground background, like fast neutron. The design, construction and initial operation of the 1-ton prototype will be discussed. A simulation framework is also developed to facilitate the experimental study of the 1-ton prototype and future detector design.

**Neutrino Parallel / 47****Updates on atmospheric neutrino and proton decay results in Super-Kamiokande****Author:** Kimihiro Okumura<sup>1</sup><sup>1</sup> *ICRR, Univ. of Tokyo***Corresponding Author:** okumura@icrr.u-tokyo.ac.jp

Super-Kamiokande (SK) is a 50 kilotonne water Cherenkov detector aiming for the detection of several physics such as solar, atmospheric, astrophysical neutrinos, proton decay, WIMP dark matter, etc. It has been running over 20 years since 1996, and achieved several remarkable outcomes in the field of the particle and astrophysics, one of which is the discovery of the neutrino oscillation, bringing the Nobel Prize in physics 2015.

SK still accumulates a large number of neutrino events, and simultaneously the physic target and its sensitivity are extended along with the improvement of the analysis method, such as event reconstruction and background rejection. For example, a new technique to detect the recoiled neutron has been developed and utilized for the atmospheric and proton decay analysis recently.

One of the strong motivations for the atmospheric neutrino oscillation measurement is to measure the mass ordering (hierarchy) between  $\nu_2$  and  $\nu_3$ . The atmospheric neutrino is sensitive to the mass hierarchy with help of the matter effect which is given when passing through the Earth. We have performed a detailed analysis to discriminate small signature of the mass hierarchy due to the matter effect.

Proton decay is a direct signature anticipated by the grand unified theory (GUT) which is the physics beyond the standard model. Though the major decay modes and GUT models are excluded by the past searches, the efforts to search a glimpse of the proton decay signal are being continued with better event reconstruction and analysis method.

In this talk we will review the status and the results of the atmospheric neutrino measurement and proton decay search using the most updated dataset taken until 2017 spring.

## Neutrino Parallel / 48

**First results from the CUORE experiment****Authors:** Oliviero Cremonesi<sup>None</sup>, Francesco Terranova<sup>1</sup><sup>1</sup> *Universita & INFN, Milano-Bicocca (IT)***Corresponding Authors:** oliviero.cremonesi@mib.infn.it, francesco.terranova@cern.ch

The Cryogenic Underground Observatory for Rare Events (CUORE) is the first bolometric experiment searching for neutrinoless double beta decay that has been able to reach the 1-ton scale. The detector consists of an array of 988 TeO<sub>2</sub> crystals arranged in a cylindrical compact structure of 19 towers. The construction of the experiment and, in particular, the installation of all towers in the cryostat was completed in August 2016 and commissioning started in fall. The experiment has completed the pre-operation phase and data taking is commencing. In this talk, we will present the achievements of the CUORE construction phase, the performance of the detector during pre-operation and the first results from the full detector run. Physics results from CUORE-0, the first CUORE-style tower operated in 2013-2015, will also be updated.

## Cosmology, Gravitational Waves, &amp; Cosmic Rays / 49

**Distinguishing between Warm Dark Matter and Late Kinetic Decoupling using CMB spectral distortions.****Authors:** James Diacoumis<sup>1</sup>; Yvonne Wong<sup>2</sup><sup>1</sup> *University of New South Wales*<sup>2</sup> *The University of New South Wales***Corresponding Authors:** yvonne.y.wong@unsw.edu.au, j.diacoumis@unsw.edu.au

The damping of perturbations in the early universe produces a distortion in the energy spectrum of the CMB photons which depends intimately on the properties of the photon temperature transfer functions. Here we propose a new method for probing dark matter models on extremely small-scales ( $1 \lesssim k \lesssim 10^4 \text{ Mpc}^{-1}$ ) by looking at how these models affect the evolution of the photon transfer functions. We explore the dependence of the distortion on different dark matter models including warm dark matter and dark matter with elastic scattering off a relativistic species (we consider both photons and neutrinos). The photon temperature transfer functions are determined for each model and used to calculate the heating rate of the CMB photons and the distortion signatures in each case. We place constraints on the dark matter-radiation elastic scattering cross-sections and show the projected constraints for future experiments. We show that the distortion signal differs between all 3 dark matter models under consideration and can thus shed light on the small-scale problems associated with conventional Cold Dark Matter models.

## Neutrino Parallel / 50

**Sensitive search for double electron capture on <sup>124</sup>Xe in XMASS****Author:** Katsuki Hiraide<sup>1</sup><sup>1</sup> *the University of Tokyo*

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Double electron capture is a rare nuclear decay process in which two orbital electrons are captured simultaneously. Recently, this process has been attracting attention both theoretically and experimentally. Natural xenon contains the double electron capture nuclei  $^{124}\text{Xe}$  with an abundance of 0.095%. Even two-neutrino mode has not been observed for the nuclei so far. The XMASS program is designed for multiple goals in particle and astroparticle physics using liquid xenon. We performed a search for two-neutrino double electron capture in a limited fiducial volume using 132 days of the commissioning data and set the most stringent limit on the half-life as  $4.7E21$  years. Owing to the detector refurbishment after the commissioning, we could increase the fiducial volume for this analysis by a significant amount, and hence more sensitive search is possible. In this talk, we will present a new result from 2 years of the XMASS data.

**Labs and Low Background / 51**

## GINGERino and the GINGER Project

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GINGER (Gyroscopes IN General Relativity) is a proposal aiming at measuring the Lense-Thirring effect with an experiment based on Earth. It is an array of ring lasers, which are the most sensitive inertial sensors to measure the rotation rate of the Earth. GINGERino is a ring laser prototype installed inside the underground laboratory of Gran Sasso, it is aiming at understand whether the Gran Sasso laboratory would be a good location for GINGER. We describe the preliminary actions and measurements already under way and present the full road map to GINGER. The prototypes GP2 and GINGERino are described and the preliminary results reported.

**Dark Matter / 52**

## Dark matter self-interactions from a general spin-0 mediator

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Dark matter particles interacting via the exchange of very light spin-0 mediators can have large self-interaction rates and obtain their relic abundance from thermal freeze-out. At the same time, these models face strong bounds from direct and indirect probes of dark matter as well as a number of constraints on the properties of the mediator. We investigate whether these constraints can be consistent with having observable effects from dark matter self-interactions in astrophysical systems. For the case of a mediator with purely scalar couplings we point out the highly relevant impact of low-threshold direct detection experiments like CRESST-II, which essentially rule out the simplest realization of this model. These constraints can be significantly relaxed if the mediator has CP-violating couplings, but then the model faces strong constraints from CMB measurements, which can only be avoided in special regions of parameter space.

**Poster Session / 53**

## Time dependence of the proton and helium flux measured by PAMELA

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The energy spectra of galactic cosmic rays carry fundamental information regarding their origin and propagation, but, near Earth, cosmic rays are significantly affected by the solar magnetic field which changes over time. The time dependence of proton and electron spectra were measured from July 2006 to December 2009 by PAMELA experiment, that is a balloon-borne experiment collecting data since 15 June 2006. These studies allowed to obtain a more complete description of the cosmic radiation, providing fundamental information about the transport and modulation of cosmic rays inside the heliosphere. In this talk the study of the time dependence of the cosmic-ray protons and helium nuclei from the unusual 23rd solar minimum through the following period of solar maximum activity is presented.

**Poster Session / 54**

## The High Energy Particle Detector calorimeter

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The High-Energy Particle Detector (HEPD) is one of the payloads of the CSES space mission. The HEPD is built by the Italian "Limadou" collaboration and has different goals. It will study the temporal stability of the inner Van Allen radiation belts, the precipitation of trapped particles in the atmosphere and the low energy component of the cosmic rays (5 - 100 MeV for electrons and 15 - 300 MeV for protons). It has been tested at the Beam Test Facility of the INFN National Laboratory of Frascati, for electrons, and at the Proton Cyclotron of Trento, for protons. Here is presented a study of the performance of the apparatus to separate electrons and protons and identify nuclei up to iron.

**New Technologies / 55**

## MADMAX: A new way of probing QCD Axion Dark Matter with a Dielectric Haloscope - Foundations

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WISPy Dark Matter candidates have increasingly come under focus of scientific interest. In particular the QCD Axion might also be able to solve other fundamental problems such as strong CP-violation and could be responsible for inflation and structure formation in the early universe. Galactic Axions, Axion-Like-Particles and Hidden Photons can be converted to photons employing a surface boundary of different dielectric constants under a strong magnetic field. Combining many such surfaces, one can enhance this conversion significantly utilizing constructive interference. The proposed MADMAX setup containing 80 high dielectric discs in a 10T magnetic field might probe the well-motivated mass range of (40-400) $\mu\text{eV}$ , a range which is inaccessible by existing cavity searches. We present the foundations of this approach, discussing implications on the accuracy of disc placement, dark matter velocity effects and expected sensitivity.

**Long Baseline Neutrinos Present / 56**

## Long-baseline neutrino oscillations

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Long-baseline neutrino experiments use neutrino beams produced at accelerators to study the oscillation of neutrino flavours as they traverse hundreds of kilometers between the primary beam target and a far detector. Current long-baseline experiments have the world's best sensitivity to the neutrino mixing angle  $\theta_{23}$  and the mass splitting  $\Delta m^2_{32}$ . They additionally provide the only available data about the complex phase of the PMNS matrix that is a source of CP violation in the neutrino sector. In this review talk I will examine the methodology and results from long-baseline experiments and discuss future prospects.

**Cosmology, Gravitational Waves, & Cosmic Rays / 57**

## The status of KAGRA underground cryogenic gravitational wave telescope

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KAGRA is a 3-km interferometric gravitational wave telescope, which is being built at the underground site of Kamioka mine in Gifu prefecture, Japan. It is the first km-scale interferometer constructed at a quiet and stable underground site to reduce seismic and Newtonian noise. Also, it will be the first km-scale interferometer to utilize cryogenic mirrors to reduce thermal noise.

The project started in 2010, and the construction of the basic infrastructure including the tunnel and the vacuum system was completed in 2015. In March and April 2016, we performed the first test

run with a simplified configuration, i.e., 3-km Michelson interferometer at room temperature. Here we present some of our recent results of the test run, and show the development status for the full configuration of KAGRA.

**GERDA Results / 58**

## Searching for the neutrinoless double beta decay with GERDA

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The GERmanium Detector Array (GERDA) experiment at the INFN Gran Sasso Laboratory, Italy, is searching for the neutrinoless double beta ( $0\nu\beta\beta$ ) decay of the isotope  $^{76}\text{Ge}$ . High-purity germanium crystals enriched in  $^{76}\text{Ge}$  are the source and the detector simultaneously. The key design feature of GERDA is that detectors are deployed directly into an ultra-pure cryogenic liquid (liquid argon), acting both as cooling medium and radiation shield against the external radiation. The signature of the  $0\nu\beta\beta$  decay would be a mono-energetic peak at the  $Q_{\beta\beta}$ -value of the process, namely 2039 keV for  $^{76}\text{Ge}$ .

Data from the first phase of GERDA (Phase I), collected between 2011 and 2013, gave no positive indication of the  $0\nu\beta\beta$  decay of  $^{76}\text{Ge}$  with an exposure of about 20 kg yr. GERDA Phase I reached a background index at the  $Q_{\beta\beta}$ -value of  $10^{-2}$  counts/(keV kg yr) and set a lower limit on the half-life of the process of  $T_{1/2} > 2.1 \cdot 10^{25}$  yr (90% C.L.).

The second Phase of the experiment is taking data since 2015 with a doubled mass of enriched Ge detectors. The goal of Phase II is to collect a “background-free” exposure of 100 kg yr, thus to reduce the background to  $10^{-3}$  counts/(keV kg yr). Newly developed custom-made BEGe-type Germanium detectors add 20 kg of mass and allow for a superior background rejection by pulse shape discrimination. The other key handle for the background suppression in Phase II is the instrumentation of the cryogenic liquid surrounding the detectors for light detection serving as additional active veto.

Initial results from Phase II with about 10 kg yr exposure (published in Nature vol. 544, April 6th 2017) allow to improve the limit on the half-life of  $0\nu\beta\beta$  decay of  $^{76}\text{Ge}$  to  $T_{1/2} > 5.3 \cdot 10^{25}$  yr (90% C.L.) and indicate that the target background is achieved, thus making GERDA the first experiment in the field which will be “background free” up to the design exposure. A total Phase II exposure of about 40 kg yr is expected to be available at the time of the Conference. All data collected after the initial data release are “blinded”, i.e. events in  $Q_{\beta\beta} \pm 25$  keV are not available for analysis, in order to prevent any selection bias. Preliminary analysis of the available data outside the blinded region confirms the background performance.

This presentation will summarize the basic concept of the GERDA design, the data taking and the physics results obtained in Phase II. A special focus will be given to the background achieved at  $Q_{\beta\beta}$  and to the analysis of the residual background components. A new data unblinding is foreseen to take place shortly before the Conference; if confirmed, new physics results on  $0\nu\beta\beta$  decay with about 40 kg yr exposure will be also presented and discussed.

**Neutrino Parallel / 59**

## Latest results from NEMO-3 and commissioning status of SuperNEMO

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Experimental searches for neutrinoless double-beta decay ( $0\nu\beta\beta$ ) are one of the most active research topics in neutrino physics. Its observation is in fact of major importance since it will prove the Majorana nature of neutrinos and may give access to their absolute mass scale.

Installed at Modane Underground Laboratory (LSM), the NEMO experiments provide a unique approach combining a calorimetric and a tracking measurement of  $\beta\beta$  events emitted by a separated isotopic source. This approach allows to search for  $0\nu\beta\beta$  decays among several isotopes with good background discrimination. Furthermore, the NEMO experiments are able to measure all kinematical parameters of the event(s) which might allow to determine the process leading to  $0\nu\beta\beta$ .

The talk will briefly review the latest results of the NEMO-3 experiment and will then focus on the status of installation and commissioning phase of the SuperNEMO demonstrator.

**Poster Session / 60**

## Thermal management and modeling for precision measurements in Borexino's SOX and solar neutrino spectroscopy programs

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The Borexino liquid scintillator neutrino observatory is set to perform the first direct, high-precision, wideband solar neutrino spectroscopy of the solar neutrino spectrum's main components, including improving the knowledge of the CNO  $\nu$  flux. Additionally, its next-generation short-baseline  $^{144}\text{Ce}$ - $^{144}\text{Pr}$   $\bar{\nu}_e$  source program (CeSOX) intends to unambiguously measure or disprove signs of anomalous oscillatory behavior in the low L/E regime, also exploring the anomaly-favored  $\sin^2(\theta_{14})/\Delta m_{14}^2$  sterile neutrino phase space. Both programs rely on the detector's unprecedented and record-setting background levels, which are tightening its requirement for background stability. Aiming to minimize background fluctuations (particularly in  $^{210}\text{Po}$ ), a new Temperature Monitoring and Management System was deployed. Computational Fluid Dynamics (CFD) simulations are also being actively developed in order to model, characterize and ultimately predict the subtle fluid currents ( $\sim 10^{-7}$  m/s) that might prove to be a hindrance for the required background stability.

**Neutrino Parallel / 61**

## Solar neutrino flux at keV energies

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We calculate the solar neutrino and antineutrino flux in the keV energy range. The dominant thermal source processes are photo production ( $\gamma e \rightarrow e \nu \bar{\nu}$ ), bremsstrahlung ( $e + Ze \rightarrow Ze + e + \nu \bar{\nu}$ ), plasmon decay ( $\gamma \rightarrow \nu \bar{\nu}$ ), and pair emission in free-bound and bound-bound transitions of partially ionized elements heavier than hydrogen and helium. To calculate the latter we use libraries of monochromatic photon radiative opacities in analogy to a previous calculation of solar axion emission. Our overall flux and many details differ significantly from previous works. While this low-energy flux is not measurable with present-day technology, it could become a significant background for future direct searches for keV-mass sterile neutrino dark matter.

## Cosmology, Gravitational Waves, & Cosmic Rays / 62

### Results from the Pierre Auger Observatory

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The Pierre Auger Observatory has been designed to investigate the origin and the nature of Ultra High Energy Cosmic Rays.

The combination of information from a surface array, measuring the lateral distributions of secondary particles at the ground, and the fluorescence telescopes, observing the longitudinal profile, provides an enhanced reconstruction capability and opens the way for a multi-messenger approach.

A review of selected results is presented, covering the measurement of energy spectrum, arrival directions, and chemical composition and the search for primary photons and neutrinos. Finally, the motivation and the status for the ongoing major upgrade of the Observatory, AugerPrime, will be discussed with the emphasis given to its expected performance and future perspectives.

## Dark Matter / 63

### Annual modulation search by XMASS-I

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A search for dark matter was conducted by looking for an annual modulation signal due to the Earth's rotation around the Sun using XMASS-I detector at Kamioka. It is a single phase Xe detector with 832 kg surrounded by low radioactive 642 PMTs with a water tank for cosmic muon veto. The detector has been performed satisfiable operation over 3 years with a very high light yield of 15 photoelectron/keVee. In this presentation, a new result with 1keVee energy threshold will be shown with 800 live days x 832 kg exposure in total by adding about 450 live days to previous result in 2016.

## Poster Session / 64

### Multi purpose detector using high light yield CaI2 crystal



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Detection of dark matter and double beta decay are ones of the most important issues in the present astro-particle physics and reveal the history of our universe. Inorganic scintillator detector, such as NaI(Tl) scintillator, is one of the major techniques for direct dark matter search. In addition, inorganic scintillator including double beta decay isotope can be used for double beta decay experiment.

We have been developing calcium iodide (CaI<sub>2</sub>) scintillator which has more than twice larger light yield compared with NaI(Tl) scintillator for the purpose of future dark matter and double beta decay experiment. Although CaI<sub>2</sub> has very good properties as a scintillator, it is not commonly used due to its deliquescence and cleavability. In May 2016, we have grown a one inch size CaI<sub>2</sub> crystal using Bridgman crystallization furnace in Institute for Materials Research, Tohoku University. Very high light output of 106,000 photon/MeV, energy resolution of 3.2% @662keV, and scintillation decay time of 834ns (84%) 1460ns (16%) were obtained. This light output is 2.7 times larger than NaI(Tl) scintillator which is most commonly used inorganic scintillator. In this presentation, we discuss results of performance evaluation for CaI<sub>2</sub> scintillator.

**Cosmology, Gravitational Waves, & Cosmic Rays / 65**

## **Exploring calorimetry new dimensions: a novel approach to maximize the performances of space experiments for high-energy cosmic rays.**

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Calorimeters are the key detectors for future space based experiments focused on high-energy cosmic rays spectra measurements.

Thus it is extremely important to optimize their geometrical design, granularity and absorption depth, with respect to the total mass of the apparatus, which is among the most important constraints for a space mission.

Calocube is a homogeneous calorimeter whose basic geometry is cubic and isotropic, so as to detect particles arriving from every direction in space, thus maximizing the acceptance; granularity is obtained by filling the cubic volume with small cubic scintillating crystals.

A prototype, instrumented with CsI(Tl) cubic crystals, has been constructed and tested with particle beams. An overview of the obtained results will be presented and the perspectives for future space experiments will be discussed.

**Neutrino Parallel / 66**

## **nEXO: a tonne-scale next-generation double-beta decay experiment**

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The nEXO Collaboration is designing a 5-tonne detector with initial neutrinoless double-beta decay sensitivity close to  $10^{28}$  years. The nEXO detector will be a homogeneous liquid xenon-136 time projection chamber inspired by the very successful EXO-200 detector. Energy resolution, event topology and event localization in the large homogeneous detector will work in concert to measure and eliminate backgrounds. In this talk we will describe the detector design choices and show the sensitivity that the detector can reach, using only materials whose radiopurity has been already demonstrated.

**Dark Matter / 67**

## Darkside Status and Prospects

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DarkSide uses dual-phase Liquid Argon Time Projection Chambers to search for WIMP dark matter. The current experiment, DarkSide-50, has a 50-kg-active-mass TPC surrounded by a borated-liquid-scintillator neutron detector and a water Cherenkov detector. DarkSide-50 has been running continuously since 2013, initially with atmospheric argon and then, starting in mid-2015, with argon from underground. The underground argon (UAr) is measured to contain lower Ar-39, the largest source of background, than atmospheric argon by a factor of  $>1000$ . After initial analyses of 50 live-days of atmospheric argon and 70 live-days of UAr, we have now collected 500 live-days of additional WIMP search data with UAr. This is being analyzed in a blind analysis. The proposed next stage of the DarkSide program is DarkSide-20k, a 20-tonne fiducial mass TPC designed to have background well below that from coherent scattering of solar and atmospheric neutrinos.

**Labs and Low Background / 68**

## Low Radioactivity Argon for Rare Event Searches

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The DarkSide-50 two-phase liquid argon (LAr) detector has been searching for weakly interacting massive particle (WIMP) dark matter for the past three years, and during the last two years has been successfully operating the detector with argon that was extracted from underground CO<sub>2</sub> wells in Cortez, Colorado in the US. This source of argon has been long shielded from cosmic rays entering Earth's atmosphere, and thus should have a lower concentration of the cosmogenically produced isotope of <sup>39</sup>Ar that beta decays with an endpoint energy that causes the beta spectrum to entirely cover the LAr WIMP search region. A 70-day exposure of the underground argon (UAr) inside DS-50 demonstrated that the UAr extracted from Colorado contains <sup>39</sup>Ar a factor  $>1000$  less than atmospheric argon. This large reduction in <sup>39</sup>Ar opens the door for the construction of much larger LAr detectors that can be used for the direct detection of WIMP dark matter, as well as other rare-event searches. This talk will focus on the details of two new projects called Urania and Aria, which aim to extract 100 kg/day of UAr from the same source of gas as that used to extract the UAr for DS-50 and then further purify it, in an effort to procure 50 tonnes of detector grade UAr for use in a 20-tonne fiducial volume detector called DarkSide-20k and set to begin operations at the beginning of the next decade.

**Labs and Low Background / 69****SiPM at Cryogenic Temperatures for Dark Matter Searches****Author:** Graham Giovanetti<sup>1</sup><sup>1</sup> *Princeton***Corresponding Author:** gkg@princeton.edu

DarkSide-20k is a proposed 20 tonne fiducial mass liquid argon TPC that will perform an instrumental background-free search for WIMP dark matter. The TPC will be outfitted with more than 125,000 silicon photomultipliers (SiPM) grouped into 5210 single-channel, 25 cm<sup>2</sup> photosensors that are sensitive to single photoelectrons. We will present the performance of the photosensor and associated low-noise electronics at liquid argon temperature and discuss the strategy for scaling up production for DarkSide-20k.

**Neutrino Parallel / 70****Measuring the neutrino mass hierarchy with KM3NeT/ORCA****Author:** Jannik Hofestädt<sup>1</sup><sup>1</sup> *ECAP***Corresponding Author:** jannik.hofestaedt@physik.uni-erlangen.de

ORCA is the low-energy branch of KM3NeT, the next-generation underwater Cherenkov neutrino detector currently being built in the Mediterranean Sea. The detector will be used to determine the neutrino mass hierarchy, i.e. whether the third mass eigenstate is heavier or lighter than the other two states.

Atmospheric neutrinos traversing the Earth are affected by matter effects, which lead to modifications in the oscillation probabilities that are sensitive to the mass hierarchy. The technical design of the ORCA detector foresees a dense configuration of optical modules, optimised for the study of interactions of neutrinos with energies down to a few GeV. With ORCA, both cascade events involving mostly electron neutrinos and track events of mostly muon neutrinos can be accurately reconstructed thanks to the excellent optical properties of deep-sea water. With the total instrumented volume of ORCA of several megatons of sea water, it will be possible to probe with high event statistics a wide range of baselines through the Earth allowing for a 3-sigma determination of the neutrino mass hierarchy after 3-4 years of operation.

In this contribution we review the methods and technology of ORCA and present its sensitivity to the neutrino mass hierarchy and other oscillation parameters such as  $\theta_{23}$ . Additionally, the detector construction status and further science opportunities with ORCA are presented.

**Dark Matter / 71****Modulations in Spectra of Galactic Gamma-ray sources as a result of Photon-ALPs mixing.****Author:** Jhilik Majumdar<sup>1</sup>**Co-authors:** Dieter Horns<sup>2</sup>; Francesca Calore<sup>3</sup><sup>1</sup> *Doctoral Student, University of Hamburg*

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Axion like particles (ALPs) are fundamental pseudo particles with properties similar to Axions that have been involved to solve the strong CP problem in Quantum Chromodynamics. ALPs can oscillate into photons and vice versa in the presence of an external magnetic field. This oscillation of Photon and ALPs could have important implications for astronomical observations, i.e. a characteristic energy dependent attenuation in Gamma ray spectra for astrophysical sources. Here we have revisited the opportunity to search Photon-ALPs coupling in the disappearance channel. We use eight years of Fermi Pass 8 data of a selection of promising galactic Gamma-ray source candidates and study the modulation in the spectra in accordance with Photon-ALPs mixing and estimate best fit values of the parameters i.e. Photon-ALPs coupling constant ( $g_{\alpha\gamma}$ ) and ALPs mass ( $m_{\alpha}$ ). For the magnetic field we use large scale galactic magnetic field models based on Faraday rotation measurements and we have also studied the survival probability of photons in the Galactic plane.

**Neutrino Parallel / 72**

## Recent results from NOvA

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NOvA is a long-baseline neutrino oscillation experiment utilizing the NuMI beam from Fermilab and a 14 kton liquid scintillator far detector in northern Minnesota. Recent results for both the muon-neutrino disappearance and the electron-neutrino appearance channels will be discussed, as well as improvements and cross-checks for our next round of analyses.

**Dark Matter / 73**

## Solar axion search by annual modulation with XMASS-I detector

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The axion is a hypothetical particle invented for solving the CP problem in strong interactions. The XMASS-I detector with 832 kg of natural xenon has the sensitivity for searching for axions produced in the Sun thanks to its low energy threshold and low background. In the XMASS commissioning run, we obtain the model independent limit on the coupling for mass  $\ll 1$  keV is  $g_{aee} < 5.4 \times 10^{-11}$  (90% C.L.) for solar axion analysis. As expected event rate of solar axion signal has the seasonal variation depending on the distance from the Sun, such information can enhance the detection sensitivity and its evidence. In this talk, we will present the result of a search for solar axion by annual modulation with about 1 year of XMASS-I data.

**Poster Session / 75**

## Calibration campaign of the Borexino detector for the search of sterile neutrinos with Sox

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The SOX experiment aims to investigate possible anomalous oscillatory behavior in neutrinos, including the existence of sterile neutrinos, by exploiting the very low radioactive background of the Borexino detector. A calibration campaign is crucial to achieve a deeper understanding of the energy response and the spatial reconstruction accuracies of the detector. It will be performed with a suite of low-activity radioactive sources which will map the whole active volume, especially nearby the inner vessel. The calibration points at large radii will be extremely important to study the neutron detection efficiency at the border of the active zones. The calibration system, already used in Borexino Phase-I, allows to insert the sources without perturbing the radio-purity of the detector. The calibration campaign will take place in Fall 2017, a few months before the beginning of the SOX experiment. In this poster, we describe in detail both the calibration hardware and the calibration strategy.

Poster Session / 76

## Calibration of the high voltage and the energy scale of the KATRIN experiment

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The KATRIN (KARlsruhe TRitium Neutrino-) experiment will measure the endpoint region of the tritium- $\beta$ -decay spectrum to determine the neutrino mass with a sensitivity of 0.2 eV/c<sup>2</sup>. To achieve this sub-eV sensitivity the energy of the decay electrons will be analyzed using a MAC-E-filter type spectrometer. The retarding potential of the MAC-E-filter of -18.6 kV has to be monitored with a precision of 60 mV (3 ppm) over a measurement period of two month.

The potential will be measured directly via two custom made precision high voltage (HV) dividers, which were developed in cooperation with the German national metrology center PTB. In order to determine the absolute values and the stability of the scale factors of the voltage dividers, regular calibration measurements with ppm precision are essential.

To guarantee a redundant monitoring system two independent HV calibration methods are used: electrical calibrations with different reference HV dividers showed sub-ppm-stability of the scale factors over the last years.

In addition to that the HV will be compared to a natural standard given by monoenergetic conversion electrons from the decay of <sup>83m</sup>Kr. This is done with three independent sources (implanted, condensed and gaseous) distributed over different locations of the experiment.

The poster will give an overview of the HV calibration of the KATRIN experiment and will show a summary of the calibration measurements over the last years as well as first results of the HV commissioning recently performed at the experiment.

This project is supported by BMBF under contract number 05A11PM2.

**Labs and Low Background / 77****The new LUNA-MV facility at Gran Sasso****Authors:** Paolo Prati<sup>1</sup>; The LUNA Collaboration<sup>None</sup><sup>1</sup> *INFN - National Institute for Nuclear Physics***Corresponding Author:** paolo.prati@ge.infn.it

About 25 year ago LUNA (laboratory for Underground Nuclear Astrophysics) opened the era of underground nuclear astrophysics installing a home-made 50 kV ion accelerator under the Gran Sasso mountain. A second machine, with a terminal voltage of 400 kV, was then installed and it is still in operation. Most of the processes so far investigated were connected to the physics of solar neutrinos and hence to the hydrogen burning phase in stars. The interest to next and warmer stages of star evolution (i.e. helium and carbon burning) pushed a new project based on a ion accelerator in the MV range called LUNA-MV. Thanks to a special grant of the Italian Ministry of Research (MIUR), INFN is now building, inside one of the major hall at Gran Sasso, a new facility which will host a 3.5 MV single-ended accelerator able to deliver proton, helium and carbon beams with intensity in the mA range. Details on the new facility and on the foreseen experimental program will be given in the talk.

**High Energy Neutrinos / 78****High-Energy Neutrinos****Author:** Claudio Kopper<sup>1</sup><sup>1</sup> *University of Alberta***Corresponding Author:** kopper@ualberta.ca

With the recent discovery of high-energy neutrinos of extraterrestrial origin by the IceCube neutrino observatory, neutrino astronomy is entering a new era. The highest energy neutrinos observed to date exceed 1 PeV in energy, a regime of particular interest because the neutrinos should point back to the still elusive accelerators of the highest energy Galactic and extragalactic cosmic rays. This review will cover currently operating high-energy neutrino detectors in water and ice, the latest results from searches for a flux of extraterrestrial neutrinos, current efforts in the search for steady and transient neutrino point sources and the exciting physics program these detectors offer in studies of atmospheric neutrinos and indirect searches for dark matter. In addition, current and future detector upgrades such as KM3NeT in the Mediterranean Sea and "IceCube-Gen2"/PINGU will be discussed.

**Poster Session / 79****Initial performance of the CUORE detector****Author:** Jeremy Cushman<sup>1</sup><sup>1</sup> *Yale University***Corresponding Author:** jeremy.cushman@yale.edu

CUORE (Cryogenic Underground Observatory for Rare Events) is an array of 988 TeO<sub>2</sub> bolometers arranged in 19 towers with a total active mass of 742 kg located at the Laboratori Nazionali del Gran Sasso (LNGS) in Italy. The primary purpose of CUORE is to search for the neutrinoless double

beta decay of  $^{130}\text{Te}$ , which if observed, would establish the Majorana nature of neutrinos as well as providing information on the absolute mass scale of the neutrino. The CUORE detector reached a base temperature below 10 mK in early 2017 and recently completed commissioning and began physics data-taking. We will discuss the status of the CUORE experiment, review the commissioning phase, and present the initial performance parameters of the CUORE detector. In particular, we will present results on energy resolution, noise mitigation and stability of response for the bolometers. The performance of front-end electronics and DAQ during the first full detector run will also be discussed.

**Neutrino Parallel / 80**

## **The latest T2K results on neutrino oscillations and neutrino-nucleus interactions**

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T2K is a long-baseline neutrino oscillation experiment taking data since 2010. A neutrino beam is produced at the J-PARC accelerator in Japan and is sampled at a Near Detector complex 280 m from the neutrino production point and at the far detector, Super-Kamiokande. Beams predominantly composed of muon neutrinos or muon anti-neutrinos have been produced by changing the currents in the magnetic focusing horns. The additional neutrino-mode data collected with T2K in 2017 have doubled the statistics relative to previous analysis releases.

This presentation will show the most recent T2K oscillation results obtained from a combined analysis of the entire available data set in the muon neutrino and muon anti-neutrino disappearance channels, and in the electron neutrino and electron anti-neutrino appearance channels. Using these data, we measure four oscillations parameters:  $\sin \theta_{23}$ ,  $\sin \theta_{13}$ ,  $|\Delta m_{32}^2|$  and  $\delta_{CP}$ , as well as the mass ordering.

T2K also has new neutrino cross-section measurements. In addition to being interesting in their own right, measuring neutrino cross sections is vital as they correspond to a major systematic uncertainty for neutrino oscillation analyses. In particular, the new results focus on exploiting the water targets in the T2K off-axis near detector, ND280, updating our charged-current measurements with a wider phase space, and addressing in more detail the neutrino interaction vertex. This talk will give an overview of the T2K neutrino cross-section measurements, focusing on the latest results.

**Poster Session / 81**

## **New results from CUORE-0: double beta decay to excited states and low energy rare event searches**

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CUORE (Cryogenic Underground Observatory for Rare Events) is an array of 988 TeO<sub>2</sub> bolometers to search for the neutrinoless double beta decay (NDBD) of  $^{130}\text{Te}$ . CUORE-0, the first CUORE-style detector with 1/19 of the mass was taking data from 2013 to 2015. Besides producing the world-leading  $^{130}\text{Te}$  NDBD half-life limits, CUORE-0 is also suitable for searching for  $^{130}\text{Te}$  double beta

decay to excited states and low energy rare events, such as solar axions or WIMP dark matter in the galactic halo. In this poster, results from those analyses will be presented and its implication to CUORE will be discussed.

**Poster Session / 82**

## Data selection strategy for the solar neutrino analysis with Borexino

**Author:** Silvia Caprioli<sup>1</sup>

**Co-authors:** Chiara Ghiano<sup>2</sup>; Alessandra Carlotta Re<sup>1</sup>; Mariia Redchuck<sup>3</sup>

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The Borexino experiment at the INFN Gran Sasso Laboratory is following a rich solar neutrino physics program. The Borexino most recent results are the precise measurements of the  ${}^7\text{Be}$ ,  $\text{pep}$  and  $\text{pp}$  solar neutrino fluxes as well as the observation of season modulation of the  ${}^7\text{Be}$  solar neutrino rate. These results were derived from the so-called Borexino Phase-II data (i.e. data collected after some intense purification campaigns in 2010-2011) and were achieved thanks to advanced data analysis techniques that allowed to maximize the signal/noise ratio.

In this contribution, we present the data selection strategy of the Borexino solar neutrino analysis: we describe how the neutrino-like scintillation events are selected according to event-based cuts which eliminate most of the external and cosmogenic backgrounds. These cuts include the definition of a fiducial volume and time-correlation techniques with the muon veto events. Moreover, the spatial distribution of events and a  $\beta^+/\beta^-$  pulse shape discrimination variable are used in a multivariate fit approach to additionally constrain the residual cosmogenic  ${}^{11}\text{C}$  and external backgrounds.

**Poster Session / 83**

## Analytical response function for the Borexino solar neutrino analysis

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Borexino experiment is located at the Laboratori Nazionali del Gran Sasso (LNGS) in Italy, and its primary goal is detecting solar neutrinos, in particular those below 2 MeV, with unprecedentedly high sensitivity. Its technical distinctive feature is the ultra-low radioactive background of the inner scintillating core, which is the basis of the outstanding achievements obtained by the experiment (fluxes of  ${}^7\text{Be}$ ,  $\text{pep}$ ,  $\text{pp}$ , and limit on CNO).

A spectral fit in the whole energy range from  $\sim 200$  keV up to  $\sim 2$  MeV has been performed for the first time, allowing to obtain simultaneously fluxes of all the solar neutrino components. To make



such a fit possible, one requires the exact shapes of neutrino signals and backgrounds, as seen in the detector. Therefore, the transformation of the spectra from the original energy scale to the scale of the desired energy estimator, such as the number of hit PMTs or photoelectrons, is one of the key steps of the analysis. This conversion accounts for the energy scale non-linearity and the detector's energy response, and can be performed using two approaches: the Monte Carlo simulation and the use of analytical models. The details and advantages of the analytical approach will be presented in this poster.

## Cosmology, Gravitational Waves, & Cosmic Rays / 84

### Optically Levitated Microspheres as a Probe for New Interactions

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We have demonstrated a novel technique for measuring microscopic forces acting on optically levitated dielectric microspheres. The radiation field at the focus of a laser beam is used to levitate a microsphere in a harmonic trap where the displacement of the microsphere can be determined by the pattern of scattered light. Optical levitation isolates the microsphere from the surrounding environment at high vacuum, making exceptionally sensitive force measurements possible. We have demonstrated a preliminary sensitivity of  $5 \times 10^{-17} \text{ N} / \sqrt{\text{Hz}}$  for forces acting on  $5 \mu\text{m}$  microspheres and expect to be able to improve this by several orders of magnitude by eliminating non-fundamental sources of noise. The electric charge of a microsphere can be determined by applying an electric field and measuring the resulting force. We have demonstrated the ability to control the charge of the microspheres with single electron precision, which eliminates the main component of the electrostatic backgrounds from force measurements. As a demonstration of this technique we have searched for the presence of unknown charged particles with charge  $> 5 \times 10^{-5} e$  in bound in our microspheres, and for the presence of screened interactions associated with dark energy. Here we discuss the apparatus, our previous results, and outline our plans for future measurements that will include the investigation of gravity at short distance.

## Dark Matter / 85

### Low-mass WIMP searches with the EDELWEISS experiment

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The EDELWEISS collaboration is performing a direct search for WIMP dark matter using an array of up to twenty-four 860g cryogenic germanium detectors equipped with a full charge and thermal signal readout. The experiment is located in the ultra-low radioactivity background of the Modane underground laboratory, in the French-Italian Frejus tunnel. We present the analysis of data obtained in extended data taking periods. WIMP limits, background rejection factors and measurements of cosmogenic activation are used to assess the performance of the third generation of EDELWEISS detectors in view of the search for WIMPs in the mass range from 1 to 20 GeV/c<sup>2</sup>. The developments in progress to pursue this goal in the coming years are also presented.

Neutrino Parallel / 86

## The Monte Carlo simulation of the Borexino detector

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Borexino is a 300 tons sub-MeV liquid scintillator solar neutrino detector which has been running at the Laboratori Nazionali del Gran Sasso (Italy) since 2007. Thanks to its unprecedented radiopurity, it was able to measure the flux of  $^7\text{Be}$ ,  $^8\text{B}$ , pp, and pep solar neutrinos and to detect geo-neutrinos. A reliable simulation of the detector is an invaluable tool for all the Borexino physics analyses.

The measurement of the solar neutrino interaction rates requires the highest level of accuracy from the simulation, which is used to generate the energy spectra of all the components used in the final fit of the recorded energy spectrum. The simulation accounts for the energy loss of particles in all the detector components, the generation of the scintillation photons, and their propagation within the liquid scintillator volume. Moreover, each time a photomultiplier detects a photon, the algorithm proceeds with a detailed simulation of the electronics chain.

Finally, a novel efficient method for simulating the external background which survives the Borexino passive shield has been developed. This technique allows to reliably predict the effect of the contamination in the peripheral construction materials.

The techniques developed to simulate the Borexino detector and their level of refinement are of possible interest to the neutrino community, especially for current and future large-volume liquid scintillator experiments, and for dark matter community, given the wide use of veto systems made of liquid scintillators. The contribution will show the level of accuracy of the simulation and will highlight the fundamental aspects to implement a high precision simulation of a liquid scintillator detector.

Neutrino Parallel / 88

## First results of CUPID-0

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CUPID-0 (former LUCIFER experiment) represents the first demonstrator towards CUPID (Cuore Upgrade with Particle IDentification). CUPID-0 -consisting of an array of 24 enriched  $^{\text{Zn}}_{82}\text{Se}$  scintillating bolometers totalling  $3.5 \cdot 10^{25}$   $^{\text{Zn}}_{82}\text{Se}$  emitters- has started its background measurement on March 2017. Thanks to the scintillation signal readout, the troublesome alpha-induced background is identified, allowing to reach an extremely low background above the environmental 2615 keV gamma-line. We will present the first results of the background in the RoI of  $^{\text{Zn}}_{82}\text{Se}$  as well as the future perspectives.

Neutrino Parallel / 89

## Limiting the effective magnetic moment of Solar neutrinos with the Borexino detector

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A minimal extension of the electroweak standard model with a massive neutrino allows a non zero magnetic moment, with the neutrino magnetic moment proportional to the neutrino mass. The experimental evidence from solar, reactor, atmospheric and accelerator neutrinos has demonstrated that neutrinos are massive, and may thus possess a non-null magnetic moment.

The limits of the effective magnetic moment of Solar neutrinos can be obtained studying the deviations from the standard shape of the electron recoils in neutrino-electron scattering. Recent improvements of the description of the Borexino energy scale allowed to include the low energy part of the neutrino spectrum in the analysis, namely the pp-neutrino contribution, improving significantly the sensitivity to the non-standard contributions in the weak  $\nu$ -e scattering. Applying independent constraints on the neutrino fluxes from the radiochemical experiments, we obtain the best up-to-date limit of the effective magnetic moment of Solar neutrinos.

**Cosmology, Gravitational Waves, & Cosmic Rays / 90**

## PeVatron Search Using Radio Measurement of Extended Air Showers at the South Pole

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IceCube-Gen2, the proposed extension of the IceCube Neutrino Observatory, will enhance both the surface and in-ice capabilities of the facility. Ideas for adding surface radio antennas are under discussion in addition to the upgrade and extension of the IceTop surface array using scintillator detectors. While the scintillators will primarily be used for improving the calibration and lowering the veto energy threshold for distinguishing cosmic ray from astrophysical neutrino events, they can also be used with radio antennas to search for photons of PeV energies from the Galactic Center.

The Galactic Center is visible from the South Pole throughout the year, at an inclination of around 61 degrees. Photons arriving at the South Pole from this direction, will produce inclined air showers in the atmosphere. Since radio emission of inclined showers leaves a large footprint on the ground, a measurement of the electromagnetic shower component using the radio technique is possible. It is already known that radio detection of air showers helps in the reconstruction of  $X_{\max}$  and the energy of the air showers with a very good accuracy. Using radio detectors along with particle detectors enhances the detection accuracy of the air shower events and helps in separating the photon induced events. Using such a setup at the South Pole can help in the identification of the Galactic Center as a PeVatron. In particular, the key for such a search is to use frequencies different from the standard frequencies used by air shower radio experiments. The first results will be presented in this talk.

**Cosmology, Gravitational Waves, & Cosmic Rays / 91**

## High energy neutrino astronomy with KM3NeT

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The KM3NeT Collaboration aims at the discovery and subsequent observation of high neutrino sources in the Universe (ARCA) and at the determination of the neutrino mass hierarchy (ORCA). This talk is focused on ARCA. The deployment of the firsts Detection Units at 3500 m depth offshore CapoPassero (Italy) started and two strings are in operation and data taking. ARCA will made of two buildings blocks made of 115 Detection Units corresponding to an instrumented volume of about 1 km<sup>3</sup> and will provide a very large coverage of the neutrino sky (87% for up going muon neutrinos). The superior angular resolution (0.1° at energy higher of 10 TeV) will be very important for source search. In this talk the detector technology, status and perspectives for detection of high energy neutrinos signals from different candidate sources are discussed.

**Neutrino Parallel / 92**

## Atomic Many-Body Effects in Neutrinos and Dark Matters Detection

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The studies on neutrinos and dark matters rely on the direct detection with detectors composed by pure atom or crystal. As current experimental searches for neutrinos and dark matters have lowered the detector threshold down to the sub-keV regime [1, 2], accurate many-body calculations for atomic ionization are warranted for giving reliable results of experimental comparisons. With the benchmark of comparisons with photoionization data [3] and analytic hydrogen calculations [4, 5], we perform *ab initio* many-body methods [6-9] to show how atomic effects modify the cross sections of neutrino or dark matter scattering with electrons in Ge, Xe and other targets within 5-10% accuracy [10-12]. In this presentation, we apply these methods to study low-energy electronic recoil caused by solar neutrinos in multi-ton xenon detectors [13], which is an important subject not only because it is a source of the irreducible background for direct searches of weakly-interacting massive particles (WIMPs), but also because it provides a viable way to measure the solar *pp* and <sup>7</sup>Be neutrinos at the precision level of current standard solar model predictions.

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**Dark Matter / 93**

## Dark matter search with the SABRE experiment

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The SABRE (Sodium Iodide with Active Background Rejection) experiment will search for an annually modulating signal from Dark Matter (DM) using an array of ultra-pure NaI(Tl) detectors surrounded by an active scintillator veto to further reduce the intrinsic background. The expected rate of interactions between DM particles and the detector in fact modulates due to Earth's changing velocity relative to the DM halo.

The first phase of the experiment is the SABRE Proof of Principle (PoP), a single 5kg crystal detector operated in a liquid scintillator filled vessel at the Laboratori Nazionali del Gran Sasso (LNGS). The PoP installation is underway with the goal of running in 2017 and performing the first in situ measurement of the crystal background, testing the veto efficiency, and validating the SABRE concept. As part of this effort, GEANT4-based Monte Carlo simulations have been developed to estimate the background in the PoP based on radio-purity measurements of the detector components. The most recent simulations include detailed versions of the detector part geometries.

The second phase of SABRE will be twin arrays of NaI(Tl) detectors operating at LNGS and at the Stawell Underground Physics Laboratory (SUPL) in Australia. By locating detectors in both hemispheres, SABRE will minimize seasonal systematic effects.

In this talk, the status report of the SABRE PoP activities at LNGS will be presented as well as results from the most recent Monte Carlo simulation.

**Dark Matter / 94**

## International Axion Observatory (IAXO): status and prospects

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International Axion Observatory (IAXO) is a new generation axion helioscope aiming to search for solar axions and axion-like particles (ALPs) with a signal to background ratio of about 5 orders of magnitude higher than the one achieved by currently the most sensitive axion helioscope, CAST. IAXO relies on large improvements in magnetic field volume and extensive use of x-ray focusing optics combined with low-background detectors. IAXO will probe a substantial unexplored region of the axion and ALP parameter space which is theoretically and cosmologically motivated, and thus will have significant discovery potential. IAXO could also be used to test models of other proposed particles at the low energy frontier of particle physics, like hidden photons or chameleons. In addition, the IAXO magnet could accommodate new equipment to search for relic axions or ALPs potentially composing the galactic halo of dark matter.

**Poster Session / 95**

## **The mass of the Universe**

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I will talk about the following calculations: The mass of the core of universe:  $1.44 \cdot 10$  raised to the power of 59 kg. The mass of the galaxies of universe:  $1.44 \cdot 10$  raised to the power of 56 kg. The mass of the stars of universe:  $8 \cdot 10$  raised to the power of 52kg. The radiating energy of the Core of Universe:  $3 \cdot 10$  raised to the power of 56watt

**Dark Matter / 96**

## **Direct dark matter search with the CRESST-III experiment**

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The CRESST experiment, located at Laboratori Nazionali del Gran Sasso in Italy, searches for dark matter particles via their elastic scattering off nuclei in a target material.

The CRESST target consists of scintillating  $\text{CaWO}_4$  crystals, which are operated as cryogenic calorimeters at millikelvin temperatures. Each interaction in the  $\text{CaWO}_4$  target crystal produces a phonon signal and a light signal that is measured by a second cryogenic calorimeter.

With the CRESST-II result in 2015, the experiment is leading the field of direct dark matter search for dark matter masses below  $1.7\text{GeV}/c^2$ , extending for the first time the reach of a direct search to the sub- $\text{GeV}/c^2$  mass region.

For CRESST-III, whose Phase 1 started data taking in August 2016, detectors have been optimized to reach the performance required to further probe the low-mass region with unprecedented sensitivity.

In this contribution the achievements of the CRESST-III detectors will be thoroughly discussed together with preliminary results and perspectives of Phase 1.

**Neutrino Parallel / 97**

## **Search for the Two Neutrino Double Electron Capture with XENON1T**

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XENON1T, widely known as the next step in the challenging hunt for direct dark matter detection, provides the possibility for the study of interesting physics beside its main purpose. One promising example for this is the search for different beta decay modes of  $^{124}\text{Xe}$ . Here the process of Two Neutrino Double Electron Capture ( $2\nu\text{DEC}$ ) is the first one to look for as it is predicted by the Standard Model and is favored compared to any process involving the creation of positrons (e.g.  $2\nu\text{EC}\beta^+$ ,  $2\nu\beta^+\beta^+$ ). However, an observation of this decay would be the first direct evidence for this decay

mode, since so far there is only an indication for  $^{78}\text{Kr}$  and an indirect observation for  $^{130}\text{Ba}$ . The detection for  $^{124}\text{Xe}$  would shed light on uncertainties coming from nuclear matrix element(NME) calculations and can help to distinguish the viability of different NME determination methods. For  $^{124}\text{Xe}$  there is only a lower limit on the half-life set by the XMASS experiment at  $4.7 \times 10^{21}$  yrs. A previously conducted search using the XENON100 data showed the possibility of the XENON detectors to search within this region due to the advantageous low background. For XENON1T the background around the signature of this decay at around 64 keV has been improved by more than one order of magnitude and combined with the large mass of the detector (>1 ton fiducial) it will be the most sensitive detector in the world and has a fair chance to find the  $2\nu\text{DEC}$ . Since the data used for this search is the same as for the dark matter run, there has been data acquired since November 2016 and the results of this data set will be shown within this contribution. The work of the contributor is supported by BMBF under contract number 05A14PM1 and DFG (GRK 2149).

**Labs and Low Background / 98**

## Characterization of a High-Sensitivity Radon Emanation System

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Radon is an important background consideration for rare-event searches such as dark matter direct detection and neutrinoless double-beta decay experiments. Materials of construction for these experiments often require screening of ultra-low radon levels, sometimes as few as tens of atoms in equilibrium. Radon emanation is one of the most sensitive and robust ways of making these measurements. A system for low-level measurements has been commissioned at the Pacific Northwest National Laboratory (PNNL) that achieves high sensitivity through use of custom high-efficiency ultra-low-background proportional counters. The system includes small and large radon emanation chambers coupled to a custom-built gas handling system with a cryogenic radon trap. The emanation system and detection method will be described, and characterization of backgrounds and efficiencies using a calibrated radon source will be discussed.

**Neutrino Parallel / 100**

## Recent Solar neutrino Results from Super-Kamiokande

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Super-Kamiokande (SK), a 50 kton water Cherenkov detector in Japan, is observing neutrinos and searching for proton decay and dark matter decays. The installation of new front-end electronics in 2008 marks the beginning of the 4th phase of SK (SK-IV). With the improvement of the water circulation system, calibration methods, reduction cuts, this phase achieved the lowest energy threshold thus far: 3.5 MeV kinetic energy.

SK studies the effects of both the solar and terrestrial matter density on neutrino oscillations: a distortion of the solar neutrino energy spectrum would be caused by the edge of the Mikheyev-Smirnov-Wolfenstein resonance in the solar core, and terrestrial matter effects would induce a day/night solar

neutrino flux asymmetry. A global oscillation analysis using SK-I,II,III, and SK-IV data and combined with the results of other solar neutrino experiments as well as KamLAND reactor experiment has been carried out. The results of this global analysis will be presented as well. SK observed solar neutrino interactions for more than 20 years. This long operation covers about  $\sim 2$  solar activity cycles. An analysis about a possible correlation between solar neutrino flux and 11 year activity cycle will be presented.

## New Technologies / 101

### Results of the first NaI scintillating calorimeter prototypes by COSINUS

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The COSINUS (Cryogenic Observatory for Signals seen in Next-generation Underground Searches) was brought to life to give new insight to the long-standing dark matter claim of the DAMA/LIBRA experiment. To be immune to potential target-material dependencies also COSINUS, as DAMA-LIBRA, uses NaI as target material. Our detectors are cryogenic calorimeters with phonon-light-readout - unique in the field of NaI-based dark matter searches. This experimental approach provides particle discrimination on an event-by-event basis and, therefore, even with a moderate exposure COSINUS will be able to reject or confirm a dark matter - nucleus interaction as the origin of the DAMA/LIBRA signal.

In this talk we present results of the first COSINUS prototypes which, to our knowledge, are the first measurements of NaI crystals as cryogenic calorimeter.

Florian Reindl on behalf of the COSINUS collaboration

## Neutrino Parallel / 102

### Secret interactions for sterile neutrinos and cosmological implications

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It has been recently speculated that new “secret” interactions among sterile neutrinos, mediated by a gauge boson X, can inhibit or suppress the sterile neutrino thermalization, due to the production of a large matter potential term in the flavour evolution equation for the active-sterile system. In this way it would be possible to relieve the tension among laboratory sterile neutrinos and cosmological data.

This scenario is particularly interesting since it could have important consequences for the small scale structure of dark matter if the mediator X couples also to dark matter.

We constrain the secret interactions scenario using the Big Bang nucleosynthesis data, the mass limit from Large Scale Structures of the Universe and the latest Planck data on Cosmic Microwave Background anisotropies.



**Neutrino Parallel / 103**

## **Hyper-Kamiokande**

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Hyper-Kamiokande is a next generation water Cherekov detector consisting of 2 tanks, each with 187 kton fiducial mass, to be built in a staged approach. Hyper-Kamiokande will detect neutrinos produced by the upgraded J-PARC accelerator complex, as well as atmospheric neutrinos. It will enable us to search for CP violation in the lepton sector with an order of magnitude more data than current long baseline experiments will collect. Hyper-Kamiokande will also make precision measurements of the phase  $\delta_{cp}$  and the atmospheric mixing parameters by a combination of accelerator and atmospheric neutrinos. Hyper-Kamiokande also aims to discover the proton decay. This talk will discuss overview of the Hyper-Kamiokande project and its physics programs, focusing on neutrino oscillation physics and proton decay search.

**Dark Matter / 104**

## **The ANAIS-112 experiment at the Canfranc Underground Laboratory**

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The ANAIS (Annual modulation with NaI(Tl) Scintillators) experiment aims at the confirmation of the DAMA/LIBRA signal using the same target and technique at the Canfranc Underground Laboratory (LSC). Several 12.5 kg NaI(Tl) modules produced by Alpha Spectra Inc. have been operated in Canfranc during the last years in various set-ups; an outstanding light collection at the level of 15 photoelectrons per keV, which allows triggering at 1 keV of visible energy, has been measured for all of them and a complete characterization of their background has been achieved. The crystal contamination is the main background source in the very low energy region of interest and the activity of the main contributors, like 40K and 210Pb, has been assessed; improvements implemented during the manufacture of the different detectors have resulted in a reduction of the activities in the last crystals produced. In the first months of 2017, the full ANAIS-112 set-up consisting of nine Alpha Spectra detectors in a 3x3 matrix configuration with a total mass of 112.5 kg has been commissioned at LSC. The latest results on the detectors performance and measured background will be presented and the excellent sensitivity prospects of the ANAIS 112 experiment for the confirmation of the DAMA/LIBRA signal will be discussed.

**Neutrino Parallel / 105**

## **The NEXT experiment for neutrinoless double beta decay searches**

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The goal of the NEXT collaboration is to observe neutrinoless double beta decay in gaseous  $^{136}\text{Xe}$  using a time projection chamber (TPC) capable of doing both energy and tracking reconstruction from light produced via electroluminescence (EL).

The collaboration is now taking data with NEXT-White (NEW), phase-I of the NEXT-100 detector. With about half of the NEXT-100 linear dimensions (about 10 kg of xenon), NEW has the right size for demonstrating and fully understanding the different technological solutions to be implemented in NEXT-100. Furthermore, NEW is the first NEXT detector that is built with highly radio pure materials and operates underground in the Laboratorio Subterráneo de Canfranc (LSC), where NEXT-100 will be located. Its operation will permit a first in-situ measurement of the backgrounds to be expected in NEXT-100.

Overview of the NEXT experiment will be presented in this talk including a description of NEXT unique advantages over other detection techniques. Latest results of the NEW detector will be shown and discussed.

**Neutrino Parallel / 106**

## **Status of the DANSS project: in pursuit of a light sterile neutrino**

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The main goal of the DANSS project is to probe SBL reactor antineutrino oscillations to the sterile state with a compact cubic meter highly segmented neutrino spectrometer made of 2500 plastic scintillator strips ( $100 \times 4 \times 1 \text{ cm}^3$ ) covered with gadolinium loaded reflective coating and read out by 2500 SiPMs and 50 PMTs via WLS-fibers. The DANSS detector has been built under a 3 GW commercial reactor (the Kalinin NPP, Russia). The spectrometer has passive shield, active muon veto, and can be positioned in 10-12 m from the center of the reactor due to a vertically mobile platform. It is registering 5000 reactor antineutrinos per day via inverse beta decay with an excellent discrimination of all types of background. Preliminary results of analysis of one year data collected in 2016-2017 will be presented. These data provide sensitivity in the most interesting region of the phase space, where sterile neutrino is predicated by RNA and other anomalies in SBL oscillation data.

**Neutrino Parallel / 107**

## **The SoLid experiment: Search for sterile neutrinos at the SCK•CEN BR2 reactor**

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The neutrino spectra and flux were reevaluated during the preparation of the current experiments devoted to the measurement of  $\theta_{13}$ . Some discrepancies between data and the theoretical predictions in some neutrino experiments at short distances were observed when using the new predicted flux and spectra. This problem has been called the Reactor Antineutrino Anomaly (RAA), which together with the gallium anomaly, both show discrepancies with respect to the expectations at the  $\sim 3\sigma$  level. Oscillations into a light sterile neutrino state ( $\Delta m^2 \sim 1eV^2$ ) could account for such deficits. The SoLid experiment has been conceived to give an unambiguous response to the hypothesis of a light sterile neutrino as the origin of the RAA. To this end, SoLid is searching for an oscillation pattern at short baselines (5-9 m) in the energy spectrum of the electron antineutrinos emitted by the SCK•CEN BR2 reactor in Belgium.

The detector uses a novel technology, combining PVT (cubes of 5 cm<sup>3</sup>) and <sup>6</sup>LiF:ZnS (sheets) scintillators. The PVT acts as an antineutrino target for Inverse Beta Decay (IBD) process, which yields a positron plus a neutron. The positron interacts mostly in the PVT, while the neutron thermalize and is captured some  $\mu s$  later on the <sup>6</sup>Li, giving rise to a prompt-delayed signal correlated in time and distance.

The detector is highly segmented (modules of 10 planes of 16x16 cubes), and is read out by a network of wavelength shifting fibers and MPPCs. Then, high experimental sensitivity can be achieved, which allows to the precise localization of the IBD products, increasing the power of the background discrimination through topological cuts. A 300 kg prototype was deployed in 2015, showing the feasibility of the detection principle. A full scale detector (~2 tons) is currently under construction and data taking with the first detector modules will start by summer of 2017.

Poster Session / 108

## GPU based spectral-fitter for Borexino solar neutrino analysis

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A spectral fitter based on the graphics processor unit (GPU) has been developed for Borexino's solar neutrino analysis. It is able to shorten the fitting time to a superior level compared to the CPU fitting procedure. In Borexino solar neutrino spectral analysis, fitting usually requires around one hour to converge since it includes time-consuming convolutions in order to account for the detector response and pile-up effects. Moreover, for the CNO-neutrino analysis the convergence time is more than two days due to extra computations for the discrimination of <sup>11</sup>C and external  $\gamma$ s. In sharp contrast, with the GPU-based fitter it takes less than 10 seconds and less than four minutes, respectively. This fitter is developed utilizing the GooFit project with customized likelihoods, pdfs and infrastructures supporting certain analysis methods. In this poster the design of the package, developed features and the comparison with the original CPU fitter are presented.

Dark Matter / 109

## GAPS: A search for dark matter signals in cosmic ray antinuclei

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The sub-GeV spectrum of cosmic ray antinuclei is a largely unexplored hunting ground for products of dark matter decay or annihilation. Because the conventional astrophysical background is extremely low, detection of even a few antideuterons in this regime would be a strong hint of a dark matter source. Meanwhile, measuring the low-energy antiproton spectrum will constrain both dark matter models and parameters of cosmic ray propagation. The General Antiparticle Spectrometer (GAPS) will perform the first measurements of this kind using the novel technique of exotic atom identification. Currently, the GAPS collaboration is developing the large, lithium-drifted silicon detectors that are key to this technique. GAPS is scheduled for deployment on long-duration balloon flight over Antarctica in late 2020.

**Neutrino Parallel / 110**

## Latest Results from Double Chooz

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Double Chooz (DC) is a reactor neutrino oscillation experiment based at the Chooz nuclear power plant in Northern France. In 2011 DC was the first reactor neutrino experiment to report indication of non-zero  $\theta_{13}$ , the last unmeasured neutrino mixing angle of the PMNS matrix. This result was confirmed in 2012 by independent experiments. Before the completion in December 2014 of the Near Detector (ND), situated  $\sim 400$  m from the reactors, DC performed  $\theta_{13}$  measurement using data from the Far Detector (FD), sitting at  $\sim 1$  km from the reactors. Over the past years DC has vastly improved its analysis techniques and its sensitivity to  $\theta_{13}$ . The inclusion of ND data improves sensitivity even further, owing to the near iso-flux position of the two detectors, as well as identical detector design resulting in suppressed detection systematics. In its latest analysis, DC has boosted the event statistics by adopting a novel approach on the candidate selection, considering Inverse Beta Decay (IBD) events with neutrons captured on both Gadolinium (which is the preferred event sample in reactor neutrino experiments) and Hydrogen. This effectively increases the detection volume by more than three times and was made possible due to improved background rejection and reduced systematics.

Precision and accuracy of  $\theta_{13}$  have a leading impact on the current explorations of neutrino CP violation and atmospheric mass ordering. Thus the redundancy of multiple  $\theta_{13}$  measurements is critical.

In this talk the latest results of  $\theta_{13}$  by DC will be showed. Some of the DC analyses beyond  $\theta_{13}$  will also be addressed.

**Cosmology, Gravitational Waves, & Cosmic Rays / 111**

## Advanced Virgo Status

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The detection of a gravitational wave signal in September 2015 by LIGO interferometers, announced jointly by LIGO collaboration and Virgo collaboration in February 2016, opened a new era in Astrophysics and brought to the whole community a new way to look at - or “listen” to - the Universe.

In this regard, the next big step will be the joint observation with at least three detectors at the same time. This configuration will provide a twofold benefit: increase the signal-to-noise ratio of the events by means of triple coincidence and allow a narrower pinpointing of GW sources, and, in turn, the search for Electromagnetic counterparts to GW signals.

Advanced Virgo (AdV) is the second generation of the gravitational-wave detector run by the Virgo collaboration. After a shut-down lasted 5 years for the upgrade, AdV is being now commissioned to get back online and join the two aLIGO interferometers to realize the aforementioned scenario.

We will describe the challenges and the current status of the commissioning of AdV, and its current performances and perspectives.

## Dark Matter / 112

### Direction-sensitive dark matter search with three-dimensional gaseous tracking detector

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**Co-authors:** Kentaro Miuchi<sup>1</sup>; Kiseki Nakamura<sup>1</sup>; Takashi Hashimoto<sup>1</sup>; Tomonori Ikeda<sup>1</sup>; Ryosuke Taishaku<sup>1</sup>; Miki Nakazawa<sup>1</sup>; Toru Tanimori<sup>2</sup>; Hidetoshi Kubo<sup>2</sup>; Atsushi Takada<sup>2</sup>; Hiroyuki Sekiya<sup>3</sup>; Atsushi Takeda<sup>3</sup>

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NEWAGE is a direction-sensitive direct dark matter search experiment with a three-dimensional gaseous tracking detector (micro-TPC). Our goals are detection of dark matter - nucleus scattering signal in the micro-TPC and investigation of the characteristics of the kinematics of dark matter in the Galaxy. Our direction-sensitive dark matter search by NEWAGE-0.3b' has been performed in Kamioka underground laboratory in Japan since Jul. 2013. A dark matter search experiment was performed from Jul. 2013 to Aug. 2016 (RUN14-17) with a total live time of 230.16 days which is about seven times larger than that of previous result (PTEP 2015, 043F01. DOI: 10.1093/ptep/ptv041). In the analysis, we improved the event selection and the background was reduced to 1/3 at 50 keV. In order to perform a direction-sensitive experiment with higher sensitivity, we also have studied a three-dimensional head-tail recognition of recoil nuclear tracks. This work is important to investigate the properties of dark matter in the Galaxy in the future dark matter research. We will present the latest results of NEWAGE with the three-dimensional head-tail recognition analysis, R&Ds and future prospects.

## Poster Session / 113

### Potential to constrain the relic neutrino background with KATRIN

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The Karlsruhe Tritium Neutrino (KATRIN) experiment - currently in its final construction and commissioning phase at the Karlsruhe Institute of Technology (KIT) - will determine the neutrino

mass with an unprecedented sensitivity of 200 meV at 90% C.L. by high-precision tritium beta-decay spectroscopy. Its unique high-intensity tritium source opens up the possibility to search for the elusive relic neutrinos via the process of neutrino capture. Here, we report the potential of KATRIN to probe the relic neutrino density in the form of a local overdensity relative to the average relic neutrino density in the universe.

Current estimates show that KATRIN will be able to set a limit on the local relic neutrino overdensity of the order  $10^9$ .

#### Poster Session / 114

### Sterile neutrino oscillation studies with the T2K far detector Super-Kamiokande

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T2K (Tokai-to-Kamioka) is a long-baseline accelerator neutrino experiment in Japan. The physics program is focused on the study of neutrino oscillations. For the oscillation analysis, events induced by a generated neutrino beam are measured in a set of detectors close to the beam source and compared with observations of beam-induced events in a far detector (Super-Kamiokande) at a distance of 295 km.

This poster explores the potential use of the T2K far detector to search for neutrino oscillations due to the presence of sterile neutrinos. The existence of sterile neutrinos is an open question. They are singlet fermions which can contribute to weak interactions only through mixing with active neutrinos and may explain some observations which appear anomalous in the standard three-neutrino scenario.

This study shows the effect of the sterile neutrino mixing parameters on various samples of the far detector: single and multi-ring muon and electron as well as neutral current pi-zero and de-excitation gamma samples.

#### Dark Matter / 115

### Directional Dark Matter Detection with MIMAC

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In order to perform Directional DM detection, low energy nuclear recoil tracks have to be detected. The MIMAC collaboration has recently reported the first detection of 3D nuclear tracks coming from

the Radon progeny confirming the possibility to perform this kind of measurement with an ionization quenching measurement on these heavy nuclei. The nuclear recoils produced by monochromatic neutron fields have been detected by a MIMAC chamber, allowing the experimental determination of the electron-nuclear recoil discrimination at the same time that the angular distribution of the Fluorine recoils produced by the neutron elastic collision has been experimentally described.

A new facility called COMIMAC has been developed at the LPSC (Grenoble) to perform the 3D characterization of nuclear tracks of known kinetic energies. The first measurements performed by the Sino-French MIMAC collaboration will be reported showing clear differences with respect to the best simulation available.

We also report here the implementation of the measure of the signal induced on the cathode by the motion of the primary electrons toward the anode in a MIMAC chamber. As a validation, we performed an independent measurement of the drift velocity of the electrons in the considered gas mixture, correlating in time the cathode signal with the measure of the arrival times of the electrons on the anode.

We will also say few words about the status of the m3 detector based on MIMAC cells witch will be installed in Modan underground laboratory as well as about the ongoing effort to build the next generation directional Dark Matter detector : Cygnus.

**Dark Matter / 116**

## Recent Results from the SuperCDMS Soudan Experiment

**Authors:** Jodi Cooley<sup>1</sup>; The SuperCDMS Collaboration<sup>None</sup>

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Over the last two decades, astrophysicists and astronomers have produced compelling evidence on galactic and cosmological scales indicates that ~80% of the matter density of the Universe consists of non-luminous, non-baryonic dark matter. Despite this fact, the composition of the dark matter remains unknown. One compelling candidate for particle dark matter is the Weakly Interacting Massive Particle (WIMP). Working in a low-background environment in the Soudan Underground Laboratory, located in northern Minnesota, the SuperCDMS experiment is designed to directly detect interactions between WIMPs and nuclei in its target Ge crystals. In this talk I will present the latest results from the SuperCDMS experiment including a high mass search with the SuperCDMS iZIP detectors, low mass searches with CDMSlite and results from a search for the signature of an annual modulation.

**Dark Matter / 117**

## NEWS-G, a spherical TPB with low Z target to search for sub-GeV Weakly Interacting Particles.

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Despite several large-scale direct detection experiments worldwide, dark matter remains elusive. Not favored by theory, the low mass region of the weakly interacting particles parameter-space (<1GeV) has been largely ignored until now, and time has come to broaden the search.

The NEWS-G project builds on the experience gathered with the SEDINE detector, which has been operated for several years at the Laboratoire Souterrain de Modane (FRANCE). The goal is to build a 1.4m diameter low-background spherical gaseous TPC with a single central electrode. It is designed to work with a gas pressure up to 10 bars and to use light target materials such as Ne, He and H in order to look for WIMP mass down to 0.1 GeV. This will be possible by the use of low activity materials, and by the selection of SNOLAB (CANADA) as location for the detector.

In this presentation, I will present the concept of spherical gaseous TPC, validated by the data taken with SEDINE. I will then introduce the NEWS-G detector whose construction is ongoing for a deployment at SNOLAB planned at the end of 2017.

## Poster Session / 118

### Search for sterile neutrinos with SOX: Monte Carlo studies of the experiment sensitivity and systematic effects

**Author:** Davide Basilico<sup>None</sup>

**Co-authors:** Birgit Neumair<sup>1</sup>; Johann Martyn

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The SOX experiment aims to test the hypothesis of existence of sterile neutrinos with  $\Delta m^2 \sim \text{eV}^2$  through a short baseline (distance  $\sim 10$  m) disappearance experiment performed with the liquid scintillator detector Borexino. The SOX experiment will detect MeV-energy electron anti-neutrinos, produced by an intense source of  $^{144}\text{Ce} - ^{144}\text{Pr}$  (activity between 4 PBq and 5 PBq) placed beneath the detector itself. By resolving the interaction position and the energy, an oscillated signature can be observed in case of a sterile neutrino. The SOX sensitivity under this hypothesis is predicted in a wide sterile mass range through Monte Carlo simulations. In this contribution we show studies of systematic effects related to the position reconstruction. We analyzed their importance in order to understand their impact on the total rate of events and the shape of the event distributions, and thus on the SOX exclusion power.

## Dark Matter / 119

### Rare Particle Search Results from the LUX Experiment

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The LUX experiment has been searching for direct evidence of rare events including the interactions galactic dark matter. LUX is a 250 kg active liquid-xenon target situated 1.5 km underground at the Sanford Underground Research Facility in Lead, South Dakota (USA).

It is a liquid/gas time projection chamber capable of 3-D position reconstruction and nuclear recoil discrimination. We will present the latest results for analyses based on LUX data taken during the full operations period. These results will include world-leading results in WIMP direct detection based on spin independent and spin dependent couplings, and also using more generalized Effective Field Theory calculations. We will report results from searches for Axion and Axion-like particles. We will also report on searches for evidence of neutrinos with Majorana mass. We can also reported on significant and surprising findings concerning the response of the LUX to electron and nuclear recoil events spanning energies from 170 eV to MeV-scale.



## New Technologies / 120

**Probing the absolute neutrino mass scale with the Ho-163: the HOLMES project.**

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The HOLMES project aims to directly measure the electron neutrino mass using the electron capture decay (EC) of  $^{163}\text{Ho}$  down to the eV scale. It will perform a precise measurement of the end-point of the  $^{163}\text{Ho}$  calorimetric energy spectrum to search for the deformation caused by a finite electron neutrino mass. The choice of  $^{163}\text{Ho}$  as source is driven by the very low Q-value of the EC reaction (around 2.8keV), which allows for a high sensitivity while keeping the overall activities to reasonable value ( $O(10^2)\text{Hz/detector}$ ), thus reducing the pile-up probability.

A large array made by thousands of Transition Edge Sensor based micro-calorimeters will be used for a calorimetric measurement of the EC  $^{163}\text{Ho}$  spectrum. The calorimetric approach, with the source embedded inside the detector, eliminates systematic uncertainties arising from the use of an external beta-source, and minimizes the effect of the atomic de-excitation process uncertainties.

The commissioning of the first implanted sub-array is scheduled for the end of 2017. It will provide useful data about the EC decay of  $^{163}\text{Ho}$  together with a first limit on neutrino mass. In this presentation the current status of the main tasks will be summarized: the TES array design and engineering, the isotope preparation and embedding, and the development of a high speed multiplexed SQUID read-out system for the data acquisition.

## Dark Matter / 121

**Dark matter hunt with XENON1T: the analysis challenge**

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XENON1T, the largest xenon TPC ever built, is performing the most sensitive direct search for WIMP dark matter on earth. As xenon TPCs become larger, long drift times and extreme fidelity requirements challenge the data acquisition, processing, and modeling. This talk explores how XENON1T dealt with these challenges for its first results, and what this implies for XENON1T's future physics prospects. (The results themselves are discussed in prof. Lindner's talk.)

## New Technologies / 122

**CONUS: Towards the detection of coherent elastic neutrino nucleus scattering**

**Authors:** Christian Buck<sup>1</sup>; Janina Hakenmüller<sup>1</sup>; Gerd Heusser<sup>1</sup>; Manfred Lindner<sup>1</sup>; Werner Maneschg<sup>1</sup>; Thomas Rink<sup>1</sup>; Tobias Schierhuber<sup>1</sup>; Herbert Strecker<sup>1</sup>; Victoria Wagner<sup>1</sup>

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The newly established CONUS (COherent NeUtrino Nucleus Scattering) project by the Max-Planck-Institut für Kernphysik (MPIK), Heidelberg, will be presented. The project aims at detecting coherent elastic neutrino nucleus scattering (CE $\nu$ NS) with high-purity Germanium (Ge) detectors with an extremely low threshold, surrounded by an elaborated shield and exposed to a very high flux of anti-neutrinos from a nuclear power plant. CE $\nu$ NS is one out of six neutrino interactions predicted by the standard model, but the only one yet to be detected. While the coherence condition, fulfilled for (anti)neutrinos with energies below 30 MeV, enhances the cross section, only a fraction of the nucleus recoil energy is available for detection via ionization (quenching). Thus, a signal is expected at energies below a few keV and for Ge detectors such low detection thresholds are just achieved in recent technological developments.

For the CONUS project, up to four of these low threshold Ge detectors are to be setup at the commercial nuclear power plant at Brokdorf (Germany). The thermal power output of the plant of 3.9 GW and a high duty cycle as well as the experimental site closer than 20 m to the reactor core guarantee a high anti-neutrino flux with energies well within the coherent regime. At the site an overburden of up to several tens of meters of water equivalent provides shielding against cosmic rays. Furthermore, a massive shell-structured shield including an active muon veto and passive shield layers is built up. With these measures it is aimed at to achieve a background index of 1 count/(daykeVkg) at energies below a few keV for a high signal-to-background ratio.

The presentation will cover the design, preparations, realization and status of the experiment.

## Dark Matter / 123

**Dark matter searches at Super-Kamiokande**

**Author:** Piotr Maciej Mijakowski<sup>1</sup>

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This work presents indirect searches for dark matter (DM) as WIMPs (Weakly Interacting Massive Particles) using atmospheric neutrino data of Super-Kamiokande-I, -II, -III and -IV (1996-2016). The latest results of the search for WIMP-induced neutrinos from the Sun, the Earth's core and the Milky Way are discussed.

We search for an excess of neutrinos as compared to the expected level of atmospheric neutrino background using a fit method. The fit is based on angular and momentum distributions of simulated background and various signal hypotheses of DM-induced neutrinos. It includes all event samples of fully-contained, partially-contained and upward-going muons. This allowed us to test wide range of WIMP masses spanning in maximum from 1 GeV up to 10 TeV, varying and depending on WIMP annihilation source and assumed annihilation channel. Super-Kamiokande sensitivity for masses of DM particles in the GeV scale is the best among neutrino experiments. In case of Solar/Earth WIMP search, obtained limit on DM-induced neutrino flux was related to limit on spin-dependent (Solar/Earth) and spin-independent (Solar) WIMP-nucleon cross section and compared against results of direct detection experiments. In case of Milky Way analysis, the upper limits on the self-annihilation cross-section were derived.

## Poster Session / 124

**Electromagnetic interactions of neutrinos in processes of low-energy elastic neutrino-electron scattering****Authors:** Konstantin Kouzakov<sup>1</sup>; Alexander Studenikin<sup>None</sup><sup>1</sup> *Lomonosov Moscow State University***Corresponding Authors:** studenik@srd.sinp.msu.ru, kouzakov@gmail.com

In the standard model neutrinos are massless left-handed fermions which very weakly interact with matter via exchange of the W and Z0 bosons. The development of our knowledge about neutrino masses and mixing provides a basis for exploring neutrino properties and interactions beyond the standard model (BSM). In this respect, the study of nonvanishing electromagnetic characteristics of massive neutrinos is of particular interest. It can help not only to shed light on whether neutrinos are Dirac or Majorana particles, but also to constrain the existing BSM theories and/or to hint at new physics.

The possible electromagnetic properties of massive neutrinos include the electric charge (millicharge), the charge radius, the dipole magnetic and electric moments, and the anapole moment. Their effects can be searched in astrophysical environments, where neutrinos propagate in strong magnetic fields and dense matter, and in laboratory measurements of neutrinos from various sources. In the latter case, a very sensitive and widely used method is provided by the direct measurement of low-energy elastic (anti)neutrino-electron scattering in reactor, accelerator, and solar experiments. A general strategy of such experiments consists in determining deviations of the scattering cross section differential with respect to the energy transfer from the value predicted by the standard model of the electroweak interaction.

The experimental bounds for the neutrino millicharges and charge radii discussed in the literature have been obtained under an implicit assumption that neutrinos do not change flavor when scattering on electrons in the detector. However, making this assumption for neutrino-electron scattering due to weak interaction is not necessarily justified in the case of electromagnetic interaction. It means that possible contributions from the neutrino flavor-transition electromagnetic properties should also be taken into account in the data analysis. Therefore, the present contribution aims at filling the lacuna in the basic theoretical apparatus usually employed for interpretation and analysis of the data of experiments searching for electromagnetic interactions of massive neutrinos in the elastic neutrino-electron scattering.

A thorough account of electromagnetic interactions of massive neutrinos in the theoretical formulation of low-energy elastic neutrino-electron scattering is given. The formalism of neutrino charge, magnetic, electric, and anapole form factors defined as matrices in the mass basis is employed under the assumption of three-neutrino mixing. The flavor change of neutrinos traveling from the source to the detector is taken into account and the role of the source-detector distance is inspected. The effects of neutrino flavor-transition millicharges and charge radii in the scattering experiments are pointed out.

## Poster Session / 125

**The INFN-TUM calorimeter for the sterile neutrino hunt****Authors:** Lea Di Noto<sup>1</sup>; Konrad Altenmüller<sup>2</sup>; Laszlo Papp<sup>2</sup><sup>1</sup> *Istituto Nazionale Fisica Nucleare Sez. Genova*<sup>2</sup> *Technische Universität München***Corresponding Authors:** lea.dinoto@ge.infn.it, konrad.altenmueller@ph.tum.de, laszlo.papp@tum.de

The SOX (Short distance neutrino Oscillations with BoreXino) experiment aims to confirm or confute the eV mass sterile neutrino hypothesis by the standard disappearance technique and possibly by the direct observation of the oscillation pattern. Both the measurements will be performed with a very intense (5 PBq)  $^{144}\text{Ce}$ - $^{144}\text{Pr}$  antineutrino source placed under the large scale and very low radioactive background Borexino detector at the Gran Sasso Laboratory (LNGS) in Italy. The knowledge of the source activity with better than 1% accuracy is fundamental for the disappearance measurement and it will be achieved by a carefully designed and precisely calibrated calorimetric apparatus in which the source together with its biological tungsten alloy shield will be inserted for 6 days of measurement before the 1.5 years of data taking with Borexino.

In the last three years the Istituto Nazionale di Fisica Nucleare of Genoa (INFN) and the Technical University of Munich (TUM) groups developed and built a compact vacuum calorimeter, where the activity is measured through a very precise knowledge of the heat released in a water coil enveloping the source by measuring the water mass flow and the temperature difference between the input and output with a very high accuracy.

In the poster a detailed description of the apparatus will be presented and the final results of the calibration measurements performed with an electrical mockup source will be shown. The precision expected for the final measurement with the  $^{144}\text{Ce}$ - $^{144}\text{Pr}$  radioactive source will be discussed as well.

**Dark Matter / 126**

## SuperCDMS SNOLAB - Status and Plans

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The Super Cryogenic Dark Matter Search (SuperCDMS) and its predecessor CDMS have been at the forefront of the search for Weakly Interacting Massive dark matter Particles (WIMPs) for close to two decades. Significant improvements in detector technology have opened up the low-mass parameter space ( $< 10 \text{ GeV}/c^2$ ) where the experiment broke new ground with the CDMS low ionization threshold (CDMSlite) experiment. Building on this success, SuperCDMS is preparing for the next phase of the experiment to be located at SNOLAB near Sudbury, Ontario. The new experimental setup will provide space for up to  $\sim 200 \text{ kg}$  of target mass in a considerably lower background environment. The initial payload of  $\sim 30 \text{ kg}$  will be a mix of germanium and silicon targets in the form of both background discriminating iZIP and low-threshold HV detectors, pushing the sensitivity towards WIMPs with even lower masses and improving the cross-section reach of SuperCDMS by more than an order of magnitude. The long-term goal is to reach the neutrino-floor below  $10 \text{ GeV}/c^2$ . In this talk I will present the status of and plans for SuperCDMS at SNOLAB.

**Poster Session / 127**

## CUTE - A Cryogenic Underground TEST facility at SNOLAB

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The excellent energy resolution and low threshold of cryogenic detectors have brought them to the forefront of the search for low-mass WIMPs (Weakly Interacting Massive Particles). The next generation of large cryogenic detectors for dark matter search promises further improvements in sensitivity, yet it is difficult and in some cases impossible to test and fully characterize these detectors in an unshielded environment. Therefore the Queen's SuperCDMS team is installing a well shielded Cryogenic Underground detector TEST facility (CUTE) at SNOLAB to support detector testing and

characterization for SuperCDMS and future cryogenic rare event search experiments. Significant effort is put into achieving a very low background environment which may open the door for early science results with the first set of SuperCDMS detectors during the time the main experimental apparatus is being installed.

This poster discusses some of the challenges and solutions implemented in the design of this facility as well as the status and schedule for the start of operations underground at SNOLAB.

**Poster Session / 128**

## Cosmogenic Background in CDMSlite

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The Super Cryogenic Dark Matter Search (SuperCDMS) experiment uses state-of-the-art cryogenic germanium detectors designed to detect Weakly Interacting Massive Particles (WIMPs). WIMPs are a class of candidate particles for the elusive dark matter, which constitutes approximately 27% of the Universe. The CDMS Low Ionization Threshold Experiment (CDMSlite) used a modified operational mode, sacrificing background discrimination to reach lower energy thresholds and thus sensitivity to lower mass WIMPs than reached by most other techniques. The observed CDMSlite spectrum shows clear evidence for contributions from a number of cosmogenically activated isotopes (<sup>68</sup>Ga, <sup>65</sup>Zn, <sup>55</sup>Fe, <sup>3</sup>H, and <sup>71</sup>Ge, which is also radiogenically produced in SuperCDMS). A maximum likelihood fit is performed to extract rates for several of these contributions. Particular focus is placed on tritium, which is expected to be a limiting background for the next-generation experiment SuperCDMS SNOLAB.

**Poster Session / 129**

## Neutrino spin and spin-flavour precession in transversally moving or polarized matter and arbitrary constant magnetic field

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It was shown for the first time in [1] that neutrino spin (or spin-flavor) precession can be engendered not only by neutrino interaction with the transversal magnetic field but also by neutrino interaction with matter in the case when there is a transversal matter current or matter polarization. The generalized Bargmann-Michel-Telegdi equation [2-4] for description of the neutrino spin evolution in moving matter was used in [1].

Recently the effect of neutrino spin precession in transversally moving matter has attracted reasonable interest within studies of neutrino fluxes from supernovae [5-8]. In [9] we have demonstrated a consistent derivation of the effect of the neutrino spin and spin-flavor oscillations in the transversal matter currents based on the direct calculation of the neutrino evolution effective Hamiltonian. In the proposed presentation we continue this line and present a regroups derivation of neutrino spin and spin-flavor evolution effective Hamiltonians accounting for effects of neutrino vacuum mixing, neutrino mass states interaction with a constant magnetic field (the

transversal and longitudinal components) with a particular focus on effects of neutrino flavour interactions with matter transversal and longitudinal currents. The neutrino spin and spin-flavor oscillation probabilities are obtained for different cases that are of interest for astrophysical applications.

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#### Poster Session / 130

## Neutrino quantum decoherence due to entanglement with magnetic field

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The origin of neutrino oscillations phenomena emerges due to coherent superposition of different neutrino states. Such superposition can be destroyed by quantum decoherence that appears from entanglement of neutrino with environment. This quantum decoherence can cause suppression of different neutrino oscillations. In this work we study suppression of neutrino-antineutrino oscillations as a result of coupling with a magnetic field. For this aim we describe system composed of neutrinos and a magnetic field by density matrix. It gives an opportunity to trace out degrees of freedom of magnetic field and thus to get reduced system, which consists of only neutrinos. The reduced system is described by non-Hermitian Hamiltonian that provides suppression of neutrino-antineutrino oscillations. It is shown that this new effect of quantum decoherence is important in strong magnetic fields peculiar for neutron stars.

#### Poster Session / 131

## Spin-light of neutrino in astrophysical media

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The Spin Light of Neutrino (SLnu) is a magnetic moment electromagnetic radiation of a massive neutrino moving under the influence of external conditions (matter or external fields) [1]. The effect, being proportional to the second power of the neutrino magnetic moment, is very faint for the moderate neutrino energies. However it has a strong energy dependence and in the light of the recent discovery of the ultra-high-energy neutrinos from the PeV band by the IceCube collaboration [2] the question of the SLnu effectiveness becomes meaningful. In this study we consider several astrophysical settings in which the effect is in principal possible: a neutron star, supernova, gamma-ray burst, and relic neutrino background. We defined conditions and corresponding settings which most of all favor the effect manifestation. These are provided by an ultra dense matter of neutron stars and neutrinos bound within galaxy clusters, and also by neutrinos generated by GRBs during the afterglow phase. Due to the specific polarization properties we propose the SLnu to be possibly connected with the observed polarization in GRB emission [3].

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**Dark Matter / 132**

## Recent PandaX-II results on dark matter search and PandaX-4T upgrade plan

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PandaX experiment, located at China JinPing underground Laboratory (CJPL), is a 500kg scale liquid xenon dark matter direct detection experiment. With the first 98.7-day data, PandaX-II experiment obtained stringent upper limits on the spin-independent (SI) and spin-dependent (SD) WIMP-nucleon elastic scattering cross sections. Alternative models of dark matter are also explored using this data. Meanwhile, PandaX collaboration has launched an upgrade plan to build PandaX-4T detector with 4-ton liquid xenon in the active volume. The PandaX-4T experiment will be relocated to CJPL-II and is expected to run after 2020. Detailed simulation indicates that the sensitivity on SI WIMP-nucleon scattering cross section could reach  $6 \times 10^{-48} \text{ cm}^2$  after two-year's running.

**Labs and Low Background / 133****SuperCDMS & Radon****Author:** Raymond Bunker<sup>1</sup><sup>1</sup> *Pacific Northwest National Laboratory***Corresponding Author:** raymond.bunker@pnnl.gov

Dark matter constitutes over 80% of the matter in the Universe, but its composition remains one of the most profound mysteries in modern science. The Super Cryogenic Dark Matter Search at SNOLAB will use germanium and silicon ultra-high-resolution detectors to search for small energy depositions from galactic dark matter particles with masses below  $10\times$  the mass of the proton. Decay of radon daughters on or near the detector surfaces can lead to background events capable of masking the (small) anticipated dark matter interaction rate. To address this background concern, we have conducted a test measurement campaign to validate the cleanliness of critical detector fabrication processes for the surfaces of the detector crystals and their copper housings. I will describe these measurements and discuss the results, including implications for the expected dark matter sensitivity. I will also discuss the overall program for control of radon-related backgrounds in SuperCDMS SNOLAB.

**Cosmology, Gravitational Waves, & Cosmic Rays / 134****VERITAS****Authors:** Michael Daniel<sup>1</sup>; VERITAS Collaboration<sup>None</sup><sup>1</sup> *Harvard-Smithsonian Center for Astrophysics***Corresponding Author:** michael.daniel@cfa.harvard.edu

VERITAS has been observing the northern sky at TeV energies with full sensitivity since 2007. Consisting of a ground based array of four 12m imaging atmospheric Cherenkov telescopes sited in southern Arizona it is one of the world's most sensitive detectors of gamma-rays between 85GeV to 30TeV. VERITAS maintains a broad scientific programme in many areas of astroparticle physics, including, but not limited to: studies of the acceleration, propagation and indirect measurements of cosmic rays and their spectra; searching for indirect detection signatures of dark matter candidates; and tests of fundamental physics, such as setting constraints on Lorentz invariance violation. There is also an active multi-messenger programme with partners in the electromagnetic, neutrino, and gravitational wave sectors. We review here the current status and some recent results from VERITAS and examine the prospects for future studies.

**Outreach / 135****Muon Hunter: a Zooniverse project****Author:** Michael Daniel<sup>1</sup>**Co-authors:** Lucy Fortson<sup>2</sup>; Amy Furniss; David Williams<sup>3</sup>; Rene Ong<sup>4</sup>; Hugh Dickinson<sup>2</sup>; Qi Feng<sup>5</sup>; Johanna Jarvis<sup>6</sup>; Reshmi Mukherjee<sup>7</sup>; Ralph Bird<sup>4</sup>; Iftach Sadeh<sup>8</sup><sup>1</sup> *Harvard-Smithsonian Center for Astrophysics*<sup>2</sup> *University of Minnesota*<sup>3</sup> *UCSC*<sup>4</sup> *UCLA*



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The large datasets and often low signal-to-noise inherent to the raw data of modern astroparticle experiments calls out for increasingly sophisticated event classification techniques. Machine learning algorithms, such as neural networks, have the potential to outperform traditional analysis methods, but come with the major challenge of identifying reliably classified training samples from real data. Citizen science represents an effective approach to sort through the large datasets efficiently and meet this challenge. Muon Hunter is a project hosted on the Zooniverse platform, wherein volunteers sort through pictures of data from the VERITAS cameras to identify muon ring images. Each image is classified multiple times to produce a “clean” dataset used to train and validate a convolutional neural network model both able to reject background events and identify suitable calibration data to monitor the telescope performance as a function of time.

New Technologies / 136

## Neutrinoless double-beta decay search with CMOS pixel charge plane in gainless TPC

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High pressure gaseous Time Projection Chamber (TPC) provides a unique combination of excellent energy resolution, event tracking for background discrimination, and scalability, which are ideal for neutrinoless double-beta decay searches. To harness the power of such a TPC, a suitable charge readout scheme has to be realized. We are developing a pixelated charge readout plane filled with an array of CMOS sensors. Each CMOS sensor has an exposed metal patch for direct charge collection, and integrates charge sensitive amplifiers as well as signal processing and digitization/transmission circuitry. The electronic noise is suppressed to a point that no additional electron-gas avalanche gain is necessary. It provides competitive energy resolution while improves on tracking capability, stability, complexity and scalability compared to alternative readout schemes. Moreover, ions drifting in the gas can be read directly since the otherwise prohibitive avalanche gain is unnecessary. It enables the use of alternative gases and double-beta decay candidate isotopes such as <sup>82</sup>SeF<sub>6</sub> gas, in which only ion drifting is possible.

With moderate modifications, such a readout plane could be used in liquid noble gas and organic liquid TPCs for a broad range of applications.

New Technologies / 137

## CALDER: Cryogenic light detectors with excellent resolution for rare event searches

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Active background rejection can be achieved in next generation bolometric experiments for rare event searches by detecting the light (scintillation or Cherenkov) that follows an energy deposition. The CALDER (Cryogenic wide-Area Light Detectors with Excellent Resolution) project is part of the R&D activities under development for the upgrade of the CUORE experiment, a ton-scale neutrinoless double beta decay experiment recently started at the Laboratory Nazionali del Gran Sasso (LNGS).

The CALDER goal is to develop large-area high-sensitivity light detectors with a resolution of 20 eV RMS, using phonon-mediated superconducting kinetic inductance detectors (KIDs).

Here we present the latest results obtained with aluminum KIDs and promising measurements done recently with multilayer titanium-aluminum chips

featuring a remarkable sensitivity. Once the target resolution is achieved, in the last phase of the project we plan to

demonstrate the performances of the new light detectors in a small prototype experiment with TeO<sub>2</sub> bolometers at LNGS.

**Dark Matter / 138**

## **KDK: measuring a rare decay of potassium with implications for dark matter searches**

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Potassium-40 is a contaminant found in many rare-event searches. Its decay by electron capture to argon-40 emits X-rays and Auger electrons at energies of 3 keV and below, right in the region where direct searches for dark matter expect their signal. Most of the electron capture decays are to an excited state of 40Ar which emits a 1.461 MeV gamma ray allowing identification of the low-energy quanta. However, it has been pointed out by Pradler et al (PLB 720 399 2013), that an untaggable

direct decay to the ground state is also expected, and that it has implications for the long-standing DAMA/LIBRA claim of dark matter detection. The KDK (potassium decay) experiment aims to make the first measurement of this decay to the ground state. The experiment involves a 40K source and a sensitive X-ray detector, surrounded by a unique, very efficient detector for the 1.461 MeV gamma rays, the Modular Total Absorption Spectrometer (MTAS), at Oak Ridge. We present the experimental setup, including calibrations of the X-ray detector, preparations of the 40K source, and an experimental determination of the better-than-98% tagging efficiency of MTAS, as well as the status of measurements.

**Poster Session / 139**

## **Studies on muon veto in the JUNO liquid scintillator neutrino detector**

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The Jiangmen Underground Neutrino Observatory (JUNO) is a 20 kt liquid scintillator detector. Its main goal is the determination of the neutrino mass hierarchy with neutrinos from two nuclear power plants at 53 km baseline. Fast and effective muon tracking is essential for the veto of atmospheric muons and the cosmogenic background they produce as well as the detection of atmospheric muon neutrinos. An expected muon rate of 3 / second inside the detector makes a partial veto of volume along the track mandatory. To achieve this, JUNO features an outer water Cherenkov detector around its liquid scintillator central detector. Due to the isotropic emission of light, tracking in liquid scintillator is more difficult than in water. Results for muon tracking in both subdetectors of JUNO are presented together with a realistic dead time estimation.

**Neutrino Parallel / 140**

## **PROSPECT: The Precision Reactor Oscillation and Spectrum Experiment**

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The PROSPECT experiment is designed to make a reactor model-independent search for short-baseline neutrino oscillations and measure the antineutrino spectrum associated with <sup>235</sup>U to high-precision. PROSPECT consists of a 4 ton highly-segmented <sup>6</sup>Li-loaded liquid scintillator detector and will be operated at the High Flux Isotope Reactor (HFIR) at ORNL at baselines ranging from 7 to 12 m. Extensive prototyping has shown excellent light collection efficiency and background rejection capabilities. This talk will discuss the design, experimental program, and discovery potential of PROSPECT and present the status and performance results of the detector.

**Neutrino Parallel / 141**

## **Recent results of Daya Bay Reactor Neutrino Experiment**

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The Daya Bay Reactor Neutrino Experiment utilizes three pairs of powerful nuclear reactors as anti-neutrino sources, and employs eight functionally identical detectors with large target volume for near-far relative measurement. The detectors were placed underground with mountains to provide enough shielding for cosmic rays induced background reduction.

Now, the experiment has achieved unprecedented precision in measuring  $\theta_{13}$  and the neutrino mass squared difference  $|\Delta m_{2ee}^2|$ . The experiment can also perform a high-statistics determination of the absolute reactor antineutrino flux and spectrum, as well as a search for light sterile neutrino. An overview and the most recent results from Daya Bay will be presented.

**Dark Matter / 142**

## Indirect dark matter searches in IceCube

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The IceCube Neutrino Observatory searches for a neutrino signal from dark matter self-annihilations in the Sun, the Earth, and the halo of the Milky Way among other targets. The signal neutrinos are identified as events with reconstructed energies and arrival directions that correspond to the distribution expected in dark matter self-annihilations. The latest results from IceCube will be presented with focus on the recent updates of the search from the center of the Milky Way. Two new analyses have been carried out that are sensitive to different energy scales and together cover an energy range from 10 GeV to 300 TeV in dark matter particle mass. Sensitivities as well as experimental exclusion limits will be presented for both analyses.

**Neutrino Parallel / 143**

## CAPTAIN: Current Neutron and Future Stopped Pion Neutrino Measurements

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All neutrino oscillation experiments face the problem of reconstructing the incoming neutrino energy using only the visible interaction products. Unfortunately, the initial neutrino interaction is not well understood, and some of the interaction products are not visible. In preparation for the analysis of neutrino oscillation data collected using liquid argon time projection chambers, the Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos (CAPTAIN) program makes crucial measurements addressing these problems in two distinct phases. The first uses Mini-CAPTAIN to measure the cross section of neutrons impinging on an argon target with a kinetic energy of more than 50 MeV. This measurement will help determine the signature of neutrino generated neutrons in a LArTPC. Mini-CAPTAIN, a LArTPC with 400 kg of instrumented mass, is currently deployed in a neutron beamline at the Los Alamos Neutron Science Center (LANSCE) at Los Alamos National Laboratory (LANL). The LANSCE beam provides a well-known flux of neutrons up to a kinetic energy of 800 MeV. The total cross section will be measured as a function of neutron kinetic energy, and partial cross sections for  $n + \text{Ar} \rightarrow p + X$  and  $n + \text{Ar} \rightarrow \pi^\pm + X$  will be measured above the threshold for the produced protons and pions. I will report results from a February 2016 engineering run during which Mini-CAPTAIN collected neutron data with a photon-detection system, discuss

the upcoming neutron data and their implications for the long-baseline oscillation analysis at DUNE. Finally, I will discuss a future deployment of CAPTAIN, a LArTPC with 5 tons of instrumented mass, at a stopped-pion neutrino source and the implications of the measurements for the future DUNE supernova physics program.

**Dark Matter / 144**

## The DARWIN Observatory

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Liquid xenon is an ideal target material to probe Dark Matter and neutrino physics well beyond the sensitivity of ongoing projects. The DARWIN observatory is a proposed detector with a multitude of physics channels spanning particle, astroparticle, and nuclear physics. DARWIN will probe vanilla WIMPs down to the signal from atmospheric neutrinos, and search for light WIMPs, solar axions, axion-light particles and signatures of sterile neutrinos. The detector will be capable of accurately measuring solar pp neutrinos as well as the signal from coherent neutrino-nucleus scattering of solar boron-8 neutrinos. The detector will also be sensitive to neutrinoless double-beta decay of xenon-136 as well as rare nuclear physics processes such as double electron capture.

**Cosmology, Gravitational Waves, & Cosmic Rays / 145**

## The observations of the very-high-energy gamma-ray sky by HAWC

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The High Altitude Water Cherenkov (HAWC) observatory is an air shower detector designed to study very-high-energy gamma rays ( $\sim 100$  GeV to  $\sim 100$  TeV). It is located in the slopes of the volcano Sierra Negra in the state of Puebla, Mexico at an elevation of 4100 m. HAWC has a instantaneous field of view of 2 sr and a duty cycle of  $>95\%$ , scanning  $2/3$  of the sky everyday. In this talk we will report the observations by HAWC that include the detection of  $\sim 40$ , point and extended, gamma-ray sources (already known and new) as well as their physical properties. Also HAWC monitors the flux from the Crab Nebula and two nearby active galactic nuclei, Mrk 421 and Mrk 501, every day as well as searching for transient on various timescales from other sources. HAWC also provides follow-up observations for alerts sent by other instruments like LIGO and IceCube.

**Dark Matter / 146**

## Backgrounds in the planned SuperCDMS SNOLAB dark matter experiment

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The planned SuperCDMS SNOLAB dark matter experiment will seek direct detection of WIMP-like dark matter with masses in the 0.5-10 GeV/c<sup>2</sup> mass range. The experiment will employ four types of cryogenic radiation detectors sensitive to phonon and ionization signals. At the lowest recoil energies electron recoil backgrounds are expected to limit the cross section reach to  $\sim 10^{-43}$  cm<sup>2</sup> near 1 GeV/c<sup>2</sup> dark matter mass. At higher recoil energies electron recoil and nuclear recoils are distinguishable on an event-by-event basis and it is expected for some recoil energy ranges solar neutrinos scattering coherently off detector nuclei will be the limiting background. This presentation will review the primary backgrounds expected in the SuperCDMS SNOLAB experiment, detailing their sources, and respective contributions. Discussion will include measures planned to mitigate and control the most significant background sources.

**Dark Matter / 147**

## WIMP search from the XMASS-I fiducial volume data with background prediction

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XMASS is multi-purpose experiment using a single phase liquid xenon technology located underground at Kamioka Observatory in Japan.

XMASS-I detector aims mainly for direct detection of dark matter particles with 832 kg of liquid xenon.

The key idea to reduce the background at low energies in XMASS is to use liquid xenon itself as a shield. The clean core of the 832 kg liquid xenon volume is used as sensitive fiducial volume by eliminating the volume near the wall which suffers from beta and gamma rays from the outside.

In this talk, we will present the physics results for our WIMP search using this fiducial volume of the XMASS-I detector with precise prediction of background events.

**Neutrino Parallel / 148**

## Local density of relic neutrinos with minimal mass

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Nonzero neutrino masses are required by the existence of flavor oscillations, with values at least of the order of 50 meV. We consider the gravitational clustering of relic neutrinos with minimal masses at the Earth neighborhood, where their number density is enhanced with respect to the average cosmic density. The local overdensity is found using N-one-body simulations, including an improved treatment of matter distribution in the Milky Way, both baryonic and dark matter. Our results could

be interesting for future experiments aiming at detecting the relic neutrino background, such as the PTOLEMY project.

**Poster Session / 149**

## **Data quality assurance for the MAJORANA DEMONSTRATOR**

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The MAJORANA DEMONSTRATOR is an experiment constructed to search for neutrinoless double-beta decays in germanium-76 and to demonstrate the feasibility to deploy a large-scale experiment in a phased and modular fashion. It consists of two modular arrays of natural and <sup>76</sup>Ge-enriched germanium detectors totalling 44.1 kg, located at the 4850' level of the Sanford Underground Research Facility in Lead, South Dakota, USA. Any neutrinoless double-beta decay search requires a thorough understanding of the background and the signal energy spectra. This talk will discuss the various techniques employed to ensure the integrity of the measured spectra. Data collection is monitored with a thorough regimen, and subsequent careful analysis of the collected data is performed to ensure that there are no deeper issues. Instrumental background events are tagged for removal, and problematic channels are removed from consideration as necessary.

**Labs and Low Background / 150**

## **Low Background Measurement Capabilities At SNOLAB**

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Experiments currently searching for dark matter and studying properties of neutrinos require very low levels of radioactive backgrounds both in their own construction materials and in the surrounding environment. These low background levels are required so that the current and next generation experiments can achieve the required sensitivities for their searches. This presentation will describe the low background measurement facilities currently operating at SNOLAB and will discuss plans and options to expand these facilities to allow for the increased sensitivity required by the next generation of experiments.

**Neutrino Parallel / 151**

## **Astroparticle Physics in Hyper-Kamiokande**

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## Astroparticle Physics in Hyper-Kamiokande

The Hyper-Kamiokande is a next generation water Cherenkov detector consisting of two tanks, each with 187 kton fiducial mass, to be built in a staged approach. The total fiducial mass will be nearly 20 times larger than the highly successful Super-Kamiokande while significantly improved photodetectors will be used with the same 40 % photocoverage. The resulting sensitivity improvements will particularly benefit astroparticle physics at low energies.

This talk will present its projected physics reach in the areas of supernova neutrinos, solar neutrinos and indirect dark matter searches, based on the current design report.

## Neutrino Parallel / 152

**Search for eV Sterile Neutrinos –The Stereo Experiment**

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In the recent years, major milestones in neutrino physics were accomplished at nuclear reactors: the smallest neutrino mixing angle  $\theta_{13}$  was determined with high precision and the emitted antineutrino spectrum was measured at unprecedented resolution. However, two anomalies, the first one related to the absolute flux and the second one to the spectral shape, have yet to be solved. The flux anomaly is known as the Reactor Antineutrino Anomaly and could be caused by the existence of a light sterile neutrino eigenstate participating in the neutrino oscillation phenomenon. Introducing a sterile state implies the presence of a fourth mass eigenstate, while global fits favour oscillation parameters around  $\sin^2(2\theta) = 0.09$  and  $\Delta m^2 = 1.8\text{eV}^2$ .

The Stereo experiment was built to finally solve this puzzle. It is one of the first running experiments built to search for eV sterile neutrinos and takes data since end of 2016 at ILL Grenoble (France). At a short baseline of 10 metres, it measures the antineutrino flux and spectrum emitted by a compact research reactor. The segmentation of the detector in six target cells allows for independent measurements of the neutrino spectrum at multiple baselines. An active-sterile flavour oscillation could be unambiguously detected, as it distorts the spectral shape of each cell's measurement differently.

This talk will give an overview on the Stereo experiment, along with details on the detector design, detection principle and the current status of data analysis.

## Dark Matter / 153

**Surface background rejection using tetraphenyl-butadiene**

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We directly measure exceptionally long ( $\sim$ ms) scintillation lifetimes of tetraphenyl-butadiene, a common wavelength shifter used on surfaces in liquid argon detectors. The magnitude of the scintillation tail relative to the prompt signal is found to differ under alpha, beta, and UV excitation, allowing for



pulse-shape discrimination (PSD). Using PSD we show that surface backgrounds from Radon daughters in liquid argon detectors can be suppressed by a factor of  $10^3$  with negligible loss of nuclear recoil acceptance.

**Neutrino Parallel / 154**

## Spectral analysis for the MAJORANA DEMONSTRATOR experiment

**Author:** Lukas Hehn<sup>1</sup>

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The MAJORANA DEMONSTRATOR is an experiment constructed to search for neutrinoless double-beta decays in germanium-76 and to demonstrate the feasibility to deploy a large-scale experiment in a phased and modular fashion. It consists of two modular arrays of natural and <sup>76</sup>Ge-enriched germanium detectors totaling 44.1 kg, located at the 4850' level of the Sanford Underground Research Facility in Lead, South Dakota, USA.

Data taken with this setup since summer 2015 at different construction stages of the experiment show a clear reduction of the observed background index around the ROI for  $0\nu\beta\beta$ -decay search due to improvements in shielding. In this talk we discuss the analysis approaches of the different datasets. Using models based on Monte Carlo simulations, the contribution of different background components - such as  $2\nu\beta\beta$ -decay, cosmogenic activation, and external radiation - can be quantified. In addition we discuss the statistical approaches to quantify the physics sensitivity of a possible  $0\nu\beta\beta$ -signal.

**New Technologies / 155**

## Results of nEXO detector development

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The nEXO collaboration is developing a low-background detector to search for neutrinoless double beta decays in 5 tonnes of liquid xenon enriched in the isotope Xe-136. The detector concept is based on the success of the EXO-200 detector. However, the more than 20-fold increase in xenon mass would benefit greatly from the development of new technologies to record 175 nm scintillation light and charge signals of events within the detector. The nEXO collaboration identified Silicon photon multipliers (SiPMs) and charge readout tiles as the devices of choice for this application. Inside the detector, an area of about  $4\text{m}^2$  has to be covered with SiPM devices to achieve an anticipated energy resolution of  $< 1\%$  with nEXO. Recent measurements with small-scale prototypes of these devices demonstrated their suitability for the application in nEXO. Parallel to these developments, radioactivity studies of materials for the construction of nEXO are performed and HV tests are conducted to ensure that a drift field of at least 400 V/cm can be applied to nEXO without causing HV breakdowns. The development of the nEXO baseline concept is well advanced and results of the development will be presented.

**Neutrino Parallel / 156**

## The 2nd Hyper-Kamiokande detector in Korea

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Hyper-Kamiokande (Hyper-K) is a next generation water Cherenkov detector in Japan consisting of two identical detectors (2x260 kton) with a staged construction. Main goals of Hyper-K are a definitive measurement of CP violation and neutrino mass ordering determination using beam neutrinos from J-PARC. By relocating the 2nd detector in Korea with more than 3 times longer baseline and more matter effect the sensitivities on the two measurements and non-standard neutrino interaction are improved.

Thanks to a larger overburden in Korean candidate sites, sensitivities on solar, supernova, and supernova relic neutrinos are also improved.

In this talk I introduce this interesting option of having the 2nd tank in Korea and present the physics potentials.

**Neutrino Parallel / 157**

## New Results from RENO

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RENO (Reactor Experiment for Neutrino Oscillation) is the first reactor neutrino experiment which began data-taking using both near and far detectors in 2011.

The last unknown neutrino mixing angle  $\theta_{13}$  in the PMNS matrix was successfully measured in 2012 by RENO using 220 days of data from 6 reactors in Yonggwang, Korea.

In 2015 RENO made the first measurement of  $|\delta m^2_{ee}|$  and obtained a more precise measurement of  $\theta_{13}$  based on the energy dependent antineutrino disappearance using 500 days of data. Roughly 2000 days of data have been accumulated.

In this talk we present new results with more statistics and reduced systematic errors.

**Poster Session / 158**

## Preliminary Design of Readout Electronics for CDEX-10 in CJPL

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CDEX (China Dark Matter Experiment) is now upgraded to about 10Kg HPGe (High Purity Germanium) detectors and the new suitable dedicated readout electronics is on demand. The readout system is interfaced to the front preamplifiers, which has three “slow” outputs with typical 20uS shaping time and one “fast” output with typical 200nS shaping time. The 8 channels 14-Bits 100MSPS FADC and 2 channels 12-Bits 2000MSPS FADC are embedded in the readout 6U prototype board. The RAIN1000Z2 readout module based on ZYNQ SoC is used for readout with Gigabit Ethernet. The preliminary design’s details will be illustrated.

**Dark Matter / 159**

## **COSINE-100**

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Astrophysical observations give overwhelming evidence for the existence of dark matter. While the DAMA collaboration has asserted for years that they observe a dark matter-induced annual modulation signal in their NaI(Tl)-based detectors, their signal has not been confirmed independently. Moreover, DAMA’s observations are inconsistent with those from other direct detection dark matter experiments under most assumptions of dark matter. I will describe the COSINE-100 experiment, the current status and prospect for low-background NaI(Tl)-based dark matter experiments, and our strategy for resolving the current stalemate in the field.

**Dark Matter / 160**

## **An Overview of the LUX-ZEPLIN Experiment**

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LUX-ZEPLIN (LZ) is a forthcoming experiment designed to directly detect WIMP dark matter. It aims to detect WIMP interactions with a liquid xenon time projection chamber containing 5.6 tonnes of xenon in the fiducial volume. LZ is projected to have a sensitivity to the spin-independent WIMP-nucleon cross section of  $2.3 \times 10^{-48} \text{ cm}^2$  for a 40 GeV/c<sup>2</sup> mass WIMP after 1000 days of livetime. An overview of LZ’s design and progress towards fabrication and installation in the Sanford Underground Research Facility, where data-taking is scheduled to commence in 2021, will be presented.

**Dark Matter / 161**

## **Impact of Galactic subhalos on indirect dark matter searches with cosmic-ray antiprotons**

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The AMS-02 experiment has recently released a new measurement of the cosmic-ray antiproton spectrum. Assuming that cold dark matter (CDM) is made of self-annihilating particles, the AMS-02 data can be used to constrain the annihilation cross section. It is known however that CDM structures itself on scales much smaller than typical galaxies. This structuring translates into a very large population of subhalos which must impact predictions for indirect searches. I will present a dynamically constrained and consistent semi-analytic model of Galactic subhalos (based on arXiv:1610.02233) and discuss its impact on current constraints (or hot spots) inferred from the AMS-02 antiproton data.

**Neutrino Parallel / 162**

## Initial Results from the MAJORANA DEMONSTRATOR

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The MAJORANA Collaboration has assembled an array of high purity Ge detectors to search for neutrinoless double-beta decay in  $^{76}\text{Ge}$  with the goal of establishing the required background and scalability of a Ge-based next-generation tonne-scale experiment. The MAJORANA DEMONSTRATOR consists of 44 kg of high-purity Ge (HPGe) detectors (30 kg enriched in  $^{76}\text{Ge}$ ) with a low-noise p-type point contact (PPC) geometry. The detectors are split between two modules which are contained in a single lead and high-purity copper shield at the Sanford Underground Research Facility in Lead, South Dakota. Following a commissioning run that started in June 2015, the full detector array has been acquiring data since August 2016. We will discuss the status of the MAJORANA DEMONSTRATOR and initial results from the first physics run; including current background estimates, exotic low-energy physics searches, projections on the physics reach of the DEMONSTRATOR, and implications for a tonne-scale Ge based neutrinoless double-beta decay search.

**Labs and Low Background / 163**

## Measurement of the cosmogenic activation of germanium detectors in EDELWEISS-III

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<sup>1</sup> *SNOLAB*

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Activation of germanium crystals due to cosmic rays becomes a serious hazard for experiments searching for rare events with germanium detectors.

Cosmic ray induced activation of the detector components and, even more importantly, of the germanium itself during production, transportation and storage at the Earth's surface, might result in the production of radioactive isotopes with long half-lives, with a possible impact on the expected background. We present a measurement of the cosmogenic activation in the cryogenic germanium detectors of the EDELWEISS III direct dark matter search experiment. The decay rates measured in detectors with different exposures to cosmic rays above ground are converted into production rates of different isotopes. They are compared to model predictions present in literature and to estimates calculated with the ACTIVIA code.

## Dark Matter / 164

**A method to reanalyze Dark Matter experimental results in different theoretical scenarios**Author: Franco Giuliani<sup>1</sup><sup>1</sup> *Shanghai Jiaotong University*

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There are a number of papers that calculate how the limits or positive results of current experiments would be if some specific twist is applied to the standard interpretation framework (e.g., SI interactions with  $f_p \neq f_n$ ). These works are usually not performed by members of the experiments, and therefore make very simple assumptions on experimental details like efficiencies. Nevertheless, it is possible to retain this type of information without actually knowing it, by starting from the final exclusion plots and working backwards. This possibility is discussed and exemplified.

## Dark Matter / 165

**Singlet-Doublet fermion dark matter, neutrino mass and collider signatures**Author: Narendra Sahu<sup>1</sup><sup>1</sup> *Indian Institute of Technology Hyderabad*

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The galaxy rotation curve, gravitational lensing and the existence of large scale structure imply that the present Universe is filled with a mysterious form of invisible matter, called “dark matter (DM)”, which is about 27% (roughly 5 times of visible matter) of the total energy budget. Hitherto the existence of DM has been consolidated via its gravitational interaction in a cosmological scale, starting from galaxy size. The main challenge at present is to probe the DM in a small scale, typically in an earth bound laboratory. The only information so far we know about DM is its relic density. However, the microscopic structure of DM is completely unknown. Unfortunately the standard model (SM) of particle physics, the best model that describes the fundamental interactions of visible matter, does not accommodate any such particle. In this talk we explore certain aspects of physics beyond the SM to include dark matter as well as non-zero neutrino mass confirmed by oscillation experiments. In particular, we extend the SM by including a light scalar triplet with hyper charge two and two vector-like fermions: one singlet and a doublet. A discrete symmetry is imposed on the additional vector-like fermions so that the dark matter arises as a mixture of the neutral component of the doublet and singlet. The scalar triplet acquires an induced vacuum expectation value after electroweak symmetry breaking and thereby inducing sub-eV masses to the neutrinos. We then obtain the parameter space satisfying relic density and to probe the model at collider.

## Poster Session / 167

**Data-Quality and Run Selection for the SNO+ experimen**

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The SNO+ detector main physics goal is the search for neutrinoless double-beta decay, a rare process which if detected, will prove the Majorana nature of the neutrinos and provide information on the absolute scale of the neutrino absolute mass. Additional physics goals of SNO+ include the study of solar neutrinos, anti-neutrinos from nuclear reactors and the Earth's natural radioactivity as well as Supernovae neutrinos. Located in the SNOLAB underground physics laboratory (Canada), it will re-use the SNO experiment ~9300 PMTs looking at a 12 m diameter spherical volume filled with 780 tons of Te-loaded liquid scintillator. A short phase with the detector completely filled with water has started at the end of 2016. It will be followed by a scintillator phase expected to start at the end of this year. A careful monitoring of the detector state such as its hardware configuration, slow control information, data handling and triggers has to be performed at any time to ensure the quality of the data taken. Several automatic checks have been put in place for that purpose. This information serves as input to higher level run selection tools that will ultimately perform a final decision on the goodness of a run for a given physics analysis. In this poster, we will describe in details the tools that the collaboration has developed to ensure the quality of the data taken and select golden runs for physics analysis.

## Dark Matter / 168

### Dark Matter Searches with HAWC

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The High Altitude Water Cherenkov (HAWC) gamma-ray observatory is a continuously operated, wide field-of-view (FOV) observatory sensitive to 100 GeV - 100 TeV gamma rays and cosmic rays. HAWC has been making observations since summer 2012 and officially commenced data-taking operations with the full detector in March 2015. With a FOV of 2 steradians, HAWC observes 2/3 of the sky in 24 hours and can be used to search for astrophysical signatures of dark matter (DM) and primordial black holes (PBHs). Within HAWC's field of view there are many dark matter candidate sources for which the upper limits from HAWC are the most sensitive for dark matter of mass > 10 TeV. I will present HAWC's latest results on searches for dark matter signals from dwarf spheroidal galaxies and galaxy clusters, and for evaporating PHBs. HAWC's measurement of TeV gamma ray emission from the region surrounding nearby pulsars is also relevant to interpretation of the excess of positrons observed at Earth, and I will present our measurements on emission near Geminga and the Monogem pulsars.

## Poster Session / 169

### Nuclear recoil calibration for PICO bubble chambers

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Due to lack of event-by-event energy resolution, the nuclear recoil calibration for PICO bubble chambers is much harder than other direct detection methods. In order to overcome this innate problem of threshold detector, PICO collaboration has taken multiple set of neutron calibration data with different energy spectrum in order to unfold the true nuclear recoil efficiency. In this talk I'll show the new analysis of neutron calibration from Montreal test beam, AmBe and SbBe neutron sources. I'll also discuss our new Markov Chain based algorithm to constrain C3F8 nuclear recoil efficiency for PICO bubble chambers and present our latest results.

**Neutrino Parallel / 171**

## Supernova Neutrinos at the DUNE Experiment

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The Deep Underground Neutrino Experiment (DUNE) experiment, a 40-kton underground liquid argon time-projection-chamber detector, will have unique sensitivity to the electron flavor component of a core-collapse supernova neutrino burst. We present expected capabilities of DUNE for measurements of neutrinos in the few-tens-of-MeV range relevant for supernova detection, and the corresponding sensitivities to neutrino physics and supernova astrophysics. Recent progress and some outstanding issues will be highlighted.

**Neutrino Parallel / 172**

## Sensitivity of the DUNE Experiment to CP Violation

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The Deep Underground Neutrino Experiment (DUNE) is a long-baseline neutrino oscillation experiment with primary physics goals of determining the neutrino mass hierarchy and measuring  $\delta_{CP}$  with sufficient sensitivity to discover CP violation in neutrino oscillation. CP violation sensitivity in DUNE requires careful understanding of systematic uncertainty, with contributions expected from uncertainties in the neutrino flux, neutrino interactions, and detector effects. In this presentation, we will describe the expected sensitivity of DUNE to long-baseline neutrino oscillation parameters, how various aspects of the experimental design contribute to that sensitivity, and the planned strategy for constraining systematic uncertainty in these measurements.

**Labs and Low Background / 173**

## The DUNE Far Detector

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DUNE, the DEEP Underground Neutrino Experiment, will be a groundbreaking experiment for long-baseline neutrino oscillation studies, and for neutrino astrophysics and nucleon decay searches. Planning of DUNE continues to proceed rapidly. The DUNE Far Detector will consist of four 10-kiloton fiducial volume modular liquid argon time-projection chambers (LArTPC) placed deep underground at the Sanford Underground Research Facility in Lead, South Dakota, USA. The Far Detector will be coupled to the LBNF multi-megawatt wide-band neutrino beam planned for Fermilab. The LArTPC technology allows for detailed reconstruction of neutrino interaction and nucleon decay final states

over an energy range from a few MeV to many GeV, providing high resolution vertex determination, precision charged particle tracking, particle identification, and calorimetry. Photon detector systems embedded within the LArTPC add precise timing capabilities for non-beam events. Designs for both single phase and dual phase LArTPC have reached advanced stages; and these designs will be tested through a full-scale prototyping program called ProtoDUNE, to be executed at CERN over the next few years.

**Neutrino Parallel / 174**

## Measurements of the Neutrino Flux Using the DUNE Near Detector

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The reference design of the near detector for the LBNE/F experiment is a high-resolution Fine-Grained Tracker (FGT) capable of precisely measuring all four species of neutrinos. Other detector options under consideration are liquid-argon and gaseous-argon TPCs, as well as a hybrid between the detector concepts. The goal of the ND is to constrain the systematic errors below the corresponding statistical error in the far detector, for all oscillation studies; and to conduct a wide range of precision measurements and searches in neutrino physics. We present sensitivity studies of the measurements –critical to constraining the systematics in oscillation searches –of the absolute and relative neutrino flux using various techniques. The precision in the determination of the absolute and relative fluxes achieved in DUNE ND will allow to fully exploit the potential of the (anti)-neutrino probe.

**Multimessenger Astronomy / 175**

## Multimessenger Astronomy

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The realization of multimessenger astrophysics will open up a new field of exploration of the most energetic phenomena in the universe. Astrophysical messengers associated with each of the four fundamental forces reach detectors buried deep underground or underwater, spread across wide swaths of land, and orbiting high above us in space. Detecting coincident signals amongst these experiments in real time will herald the birth of high energy multimessenger astronomy and will enable us to begin exploring and understanding their astrophysical sources. The Astrophysical Multimessenger Observatory Network (AMON) is currently linking multiple current and future high-energy neutrino, cosmic ray, gamma ray and gravitational wave observatories into a single virtual system, facilitating near real-time coincidence searches for multimessenger astrophysical transients. AMON will generate alerts that will enable rapid follow-up of potential electromagnetic counterparts. In this talk, we will present the science case, design elements, partner observatories, and status of the AMON project, followed by examples of AMON-enabled multimessenger analyses with archival data.

**Neutrino Parallel / 176**

## Neutrino Oscillation Physics with IceCube Gen2/Phase1



**Author:** Ken Clark<sup>1</sup>**Co-author:** Douglas Cowen<sup>2</sup><sup>1</sup> SNOLAB<sup>2</sup> Pennsylvania State University**Corresponding Author:** cowen@phys.psu.edu

The IceCube Gen2/Phase1 detector has been proposed to in-fill IceCube's DeepCore region with seven new, densely-instrumented strings. These strings would provide the world's best sensitivity to tau neutrino appearance, with a precision of better than 10%, providing the most stringent test of unitarity in the tau sector to date. Gen2/Phase1 would also have improved sensitivity to muon neutrino disappearance and dark matter searches, and would provide a calibration platform that will improve our understanding of the optical properties of the ice, with positive impact on current and future IceCube analyses at all energy scales. The strings would be placed on a grid consistent with expansion to the future proposed PINGU array. In this presentation we describe the sensitivities of Phase 1 to neutrino oscillations and dark matter, the new calibration devices planned for co-deployment, and the impact those devices will have on future analyses.

**Poster Session / 177**

## DynHo: A New Trap For Dark Matter

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We investigate a new method to search for keV-scale sterile neutrinos that could account for Dark Matter. Neutrinos trapped in our galaxy could be captured on stable <sup>163</sup>Dy if their mass is greater than 2.83 keV. Two experimental realizations are studied, an integral counting of <sup>163</sup>Ho atoms in dysprosium-rich ores and a real-time measurement of the emerging electron spectrum in a dysprosium-based detector. The capture rates are compared to the solar neutrino and radioactive backgrounds. An integral counting experiment using several kilograms of <sup>163</sup>Dy could reach a sensitivity for the sterile-to-active mixing angle  $\sin^2(\theta)$  of  $1e-5$  significantly exceeding current laboratory limits. Smaller mixing angles may be explored with a real-time experiment.

**Poster Session / 178**

## A Sensitive Assay Technique for <sup>210</sup>Pb In Water Developed For The SNO+ Experiment

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SNO+ is a multipurpose neutrino physics experiment, located 2 kilometers underground in the SNO-LAB facility in Sudbury, Canada. It is the successor of the SNO experiment, replacing the heavy water in the Acrylic vessel (AV) with 780 tonnes of liquid scintillator, Linear Alkyl Benzene (LAB). The AV is surrounded by 7000 tons of ultrapure light water, which shields the detector from naturally occurring radioactivity in the surrounding rock, PMTs, and PSUP. To achieve the radiopurity

requirements, the water should be very clean and levels of U and Th contamination in the shielding water must be carefully controlled. A water assay technique, based on the capture of Ra and Th radioisotopes using Hydrous Titanium Oxide (HTiO), was developed by the SNO experiment. Ra sensitivities equivalent to  $^{232}\text{Th}$ :  $4 \times 10^{-16} \text{ gTh/gD}_2\text{O}$  and  $^{238}\text{U}$ :  $3 \times 10^{-16} \text{ gU/gD}_2\text{O}$  were achieved with this technique (NIM A 604: 531-535 (2009)). The HTiO technique will be used in SNO+ to monitor  $^{238}\text{U}$  and  $^{232}\text{Th}$  contamination levels in the shielding water and the performance of the water purification system.

For the lower energy measurements of interest to SNO+, radon daughter radioisotopes, especially  $^{210}\text{Po}$  and  $^{210}\text{Bi}$  supported by  $^{210}\text{Pb}$ , are also important. Since water will be used in the purification of both the liquid scintillator and tellurium that will be chemically loaded in SNO+ to search for neutrinoless double decay, a technique to assay for  $^{210}\text{Pb}$  in water was desirable. The SNO+ collaboration has extended the HTiO assay technique to allow measurement of  $^{210}\text{Pb}$  in the water. This technique is capable of measuring  $0.4 \pm 0.13 \text{ mBq/m}^3$  of  $^{210}\text{Pb}$  for a 10 tonne assay. The measured background of the SNOLAB underground HPGe well detector is  $0.8 \pm 0.3 \text{ mBq}$ . The method developed and results of initial  $^{210}\text{Pb}$  measurements are presented.

**Poster Session / 179**

## Supernovae and SNO+

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At the end of a massive star's life, a violent explosion known as a supernova occurs and releases 99% of the star's gravitational binding energy in the form of neutrinos. Although the explosion generates a huge burst of neutrinos, the large distance to earthbound detectors, low cross sections, and flavour changing oscillations can make detection and analysis challenging. Only one neutrino burst from a supernova has ever been detected, but neutrino detectors have been waiting patiently for another. The SNO+ detector at SNOLAB can be used as a supernova detector during both regular operation and calibrations by measuring the burst of neutrinos from a supernova. We present the neutrino detection method and analysis of potential galactic supernova with the SNO+ detector.

**Poster Session / 180**

## SNO+ Calibration Hardware

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The SNO+ experiment has a varied neutrino physics program that includes a neutrino-less double beta decay experiment in addition to reactor, solar, and geoneutrino measurements. SNO+ uses the architecture of SNO, using an acrylic vessel filled with scintillator as its neutrino target suspended in a water volume. At this time data is being collected with the acrylic vessel filled with water in preparation for the scintillator phase. An essential component to the successful execution of this physics program is a calibration of the optical and energetic response of the detector. Calibrations are underway using a laser-driven light source and radioactive gas sources, such as Nitrogen-16, that are to be lowered into the detector vessel on an umbilical. The position can be manipulated in 1-D using the umbilical

retrieval mechanisms (URM) or in 2-D using ropes to guide the source off-axis. The sources and drive systems will be presented here with the goals of the calibration in the context of its impact on the SNO+ physics program.

**Dark Matter / 181**

## Status and prospect of the ANKOK project: Low mass WIMP dark matter search using double phase argon detector

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Liquid argon is known as an excellent target material for WIMP dark matter direct search experiment. Use of its ionization and scintillation signals, and scintillation pulse shape provides strong discrimination between the electron and nuclear events. Relatively small atomic mass ( $A=40$ ) gives higher nuclear recoil energy for WIMP-Ar nuclear scattering, thus it potentially has higher sensitivity for low mass WIMP ( $\sim 10$  GeV/ $c^2$ ). On the other hand, the 128 nm VUV scintillation light of argon is relatively hard to detect with nominal photo sensors, and use of wavelength shifter lowers the light detection efficiency and likewise the spatial resolution of the reconstructed event. At present, there are no liquid argon detectors which prove their sensitivity for the low mass WIMP.

The ANKOK project is a dark matter search experiment in Japan using the double phase argon detector which is specialized for the low mass WIMP detection. Using a prototype detector, we are proceeding R&D efforts to establish its physics sensitivity. A detector with fiducial mass of about 30 kg is under construction.

We plan to operate the detector at surface within a year, following collection of the underground physics data in the next few years.

**Neutrino Parallel / 182**

## Recent Results from the ANTARES Neutrino Telescope

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The ANTARES deep sea neutrino telescope, installed at the bottom of the Mediterranean Sea, has been continuously taking data for more than ten years. Thanks to its excellent angular resolution in both the muon channel and the cascade channel (included by all neutrino flavours), ANTARES offers unprecedented sensitivity for neutrino source searches in the Southern sky in the TeV-PeV energy range, so that already valuable constraints have been set on the origin of the cosmic neutrino flux discovered by the IceCube detector.

Assuming various spectral indexes for the energy spectrum of neutrino emitters, the Southern sky and in particular central regions of our Galaxy are studied searching for point-like objects and for several interesting extended regions of emission like the Galactic Plane or the Fermi Bubble. For the first time, cascade events are used for these searches with a median angular resolution of about 3 degrees.

ANTARES is also embedded in a manifold multi-messenger program with radio, optical, X-ray and gamma-ray follow-up observations of promising cosmic neutrino candidates. ANTARES is also looking for neutrino events in spatial and temporal correlation with astrophysical transient sources observed by other instruments, such as AGN flares, Gamma Ray Bursts, Fast Radio Bursts or with the newly discovered gravitational wave signals.

Strong constraints have also been set on the Dark Matter annihilation cross section and the spin dependent WIMP-nucleon cross section from the search of neutrinos potentially produced by annihilations of WIMPs trapped in massive objects such as the Sun and the Galactic Centre. Searches for signals of other exotic physics such as magnetic monopoles and nuclearites are also of interest for ANTARES.

Neutrino Parallel / 183

## The sterile neutrino: a combined view of cosmological limits with oscillation searches

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A light sterile neutrino that mixes with the active states has been proposed to explain anomalies in short baseline neutrino oscillation data. Constraints on the mass and mixing parameters are usually presented by showing results from complementary neutrino oscillation experiments. However, measurements of the Cosmic Microwave Background, most recently by the Planck satellite, constrain the radiative degrees of freedom in the early universe, which would be affected by a sterile neutrino. We have for the first time translated these Planck constraints into the parameter space of neutrino oscillation, that of mixing angles and mass splittings. We will show these constraints from Planck compared to the muon-neutrino disappearance oscillation limits on sterile neutrinos from MINOS and IceCube, and also compare them with the recent electron-neutrino disappearance limits from reactor experiments such as Daya Bay and NEOS. Finally we will present new results of the cosmological limits in the context of muon-to-electron-neutrino appearance searches.

Neutrino Parallel / 184

## The Large Enriched Germanium Experiment for Neutrinoless Double Beta Decay (LEGEND)

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Fifty years ago, Ettore Fiorini and collaborators published the first results of a  $^{76}\text{Ge}$  based search for neutrinoless double beta decay ( $0\nu\beta\beta$ ). In the ensuing five decades, the sensitivity for  $0\nu\beta\beta$  searches using  $^{76}\text{Ge}$  has increased by five orders of magnitude, from the 1967 limit of  $T_{1/2} \geq 3 \times 10^{20}$  years to GERDA's recent result of  $T_{1/2} \geq 5.3 \times 10^{25}$  years. The current generation  $^{76}\text{Ge}$  experiments, GERDA and the MAJORANA DEMONSTRATOR, have now achieved the lowest backgrounds in the  $0\nu\beta\beta$  region of interest of any  $0\nu\beta\beta$  experiments. These results, coupled with the intrinsic superior energy resolution of Ge (0.1%) demonstrate that germanium is an ideal isotope for a large next generation experiment. The LEGEND collaboration, with 220 members from 47 institutions around the world, has been formed to pursue a ton scale  $^{76}\text{Ge}$  experiment. Building on the successes of GERDA and the MAJORANA DEMONSTRATOR, the LEGEND collaboration aims to develop a phased  $0\nu\beta\beta$  experimental program with discovery potential at a half-life significantly longer than  $10^{27}$  years, using

existing resources as appropriate to expedite physics results. This talk will present an overview of LEGEND and discuss its envisioned first phase, a 200 kg measurement utilizing the existing GERDA cryostat at LNGS.

**New Technologies / 185**

## **Towards 60eV FWHM Pulsar Resolution in 2.5kg HPGe Point Contact Detectors**

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Neutrino and astroparticle physics experiments involving detection of rare and weak interactions, like GERDA, MAJORANA, TEXONO, CDEX, CoGeNT have driven the development of large mass ultra low noise detectors.

With respect to other solid-state materials, germanium presents major advantages for high-sensitivity  $\gamma$ -ray detection. Its excellent electrical properties (lowest band gap and good carrier mobility) are coupled with the best energy resolution of any material. Large single crystals of HPGe (several kg), with impurity concentrations in the range can be grown on an industrial scale, which lead to high levels of detection efficiency.

Low-noise electronics have become key features in the design of high-purity germanium (HPGe) detectors, and has allowed the reach of record detector resolutions. At the same time, as relevant events sometimes have a detection rate as low as 1 event/year/kg of HPGe, an ultra-low radioactive background for all the detector parts, including the front end electronics, is also crucial to the success of these experiments.

This work focuses on the results obtained in the efforts of designing a large (>2 kg) HPGe detector having a modified "point contact" central electrode, combined with an ultra-low noise electronic front end. Measurements on manufactured detectors show record electronic noise performances (65eV FWHM pulser resolution on a 1.5kg HPGe crystal), which translate into a noise threshold below 200eV, making it the ideal instrument for Dark Matter and neutrino experiments. This paper will describe the progress towards reaching similar or better electronic noise performance in even larger HPGe detectors, with current focus to go towards 2.5kg crystals.

**Neutrino Parallel / 186**

## **Rare Low-Energy Event Searches with the MAJORANA DEMONSTRATOR**

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The MAJORANA DEMONSTRATOR is currently searching for neutrinoless double-beta decays in germanium-76 and will demonstrate the feasibility to deploy a tonne-scale experiment in a phased and modular fashion. It consists of two modular arrays of natural and <sup>76</sup>Ge-enriched germanium detectors totaling 44.1 kg, of which 29.7 kg is enriched, located at the 4850' level of the Sanford Underground Research Facility in Lead, South Dakota, USA. The low-backgrounds and low thresholds (< 1keV) achieved by the DEMONSTRATOR allow for additional rare-event searches at low-energies, e.g. searches for bosonic dark matter, solar axions, pauli exclusion principle violation, and electron decay. In this work, we will present recent results on rare event searches and discuss the future reach of MAJORANA.

**Poster Session / 187****Progress toward a two-neutrino double-beta decay measurement for the MAJORANA DEMONSTRATOR****Author:** Thomas Gilliss<sup>1</sup><sup>1</sup> *University of North Carolina at Chapel Hill***Corresponding Author:** gilliss@live.unc.edu

The MAJORANA DEMONSTRATOR is a  $^{76}\text{Ge}$ -based neutrinoless double-beta decay ( $0\nu\beta\beta$ ) experiment. Staged at the 4850' level of the Sanford Underground Research Facility, the DEMONSTRATOR operates an array of high-purity p-type point contact Ge detectors deployed within a graded passive shield and an active muon veto system. The present work concerns the two-neutrino double-beta decay mode ( $2\nu\beta\beta$ ) of  $^{76}\text{Ge}$ . For Ge detectors, with superior energy resolution (0.1%), this mode poses negligible background to the  $0\nu\beta\beta$  mode, even for a ton-scale experiment. However, a precision measurement of the  $2\nu\beta\beta$  shape allows for searches for new physics such as Majoron-accompanied  $0\nu\beta\beta$ . The measurement of the  $2\nu\beta\beta$  mode also allows for careful systematic checks of pulse shape discrimination cuts related to both the  $0\nu\beta\beta$  and  $2\nu\beta\beta$  decay modes. Work is underway to construct a full experimental background model enabling a Bayesian fit to the measured energy spectrum and extraction of a precise  $2\nu\beta\beta$  spectrum and half-life determination.

**Poster Session / 188****PICO-60: World's largest bubble chamber for dark matter detection****Author:** Usman Chowdhury<sup>1</sup>**Co-author:** PICO collaboration<sup>1</sup> *SNOLAB***Corresponding Author:** usman@triumf.ca

The evidences of large amount of missing-mass (or dark matter) in the universe are multiple. The widely accepted hypothesis is, that the particles that carry the missing mass are Weakly Interacting (and) Massive Particles (WIMP). In the experimental efforts of the direct detection of WIMPs, alpha, beta and gamma radiations are the primary sources of background that experiments are continuously trying to understand and discriminate from the candidate WIMP events. PICO-60, currently worlds largest bubble chamber, uses super-heated fluids as the target. This gives PICO an unique advantage of both tuning its sensitivity to a broad range of nuclear recoil energy and also discriminate between the backgrounds and a candidate event. We give a detailed description of PICO-60 detector and its most recent result which was background free and excluded the spin dependent dark matter cross-section to  $3.4 \times 10^{-41} \text{ cm}^2$  in a 1167 kg-day live time run. We will give a brief introduction of the next generation PICO detectors which will further reduce the backgrounds and explore the WIMP search parameter space exhaustively.

**Poster Session / 189****Search for Invisible Nucleon Decay in the SNO+ Experiment****Authors:** Ian Coulter<sup>1</sup>; Kevin Labe<sup>2</sup><sup>1</sup> *University of Pennsylvania*

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SNO+ is a multipurpose, large-scale neutrino experiment located deep underground in Sudbury, Ontario, whose aims include studies of neutrinoless double beta decay, solar neutrinos, reactor neutrinos and other more exotic physics. SNO+ is currently taking data in its initial water-fill phase, which will be used to commission upgrades to the electronics and calibration sources. During this phase, SNO+ has a unique sensitivity to certain invisible modes of nucleon decay, in which the nucleon decays to some undetected final state, such as  $n \rightarrow 3\nu$ . Nucleon decay in O16 can lead to excited states of O15 or N15 which will deexcite, emitting a gamma which can be detected.

The current limits on this model-independent mode are from SNO and Kamland. However, SNO+ can improve upon these in its relatively short water phase as SNO's use of D2O brought higher backgrounds from the neutral current events while Kamland's limit suffers from the lower branching ratio to a visible signal in carbon. The major backgrounds to this search will come from solar and reactor neutrinos and radioactivity from the U and Th chains. With just 3 months of data taking, SNO+ expects to achieve world-leading sensitivity to these modes.

**New Technologies / 190**

## Status of the Project 8 Phase II

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The Project 8 collaboration aims to measure the absolute neutrino mass scale using cyclotron radiation emission spectroscopy on the beta decays of tritium. The second phase of the project will measure a continuous spectrum of molecular tritium beta decays and extract the tritium endpoint value with an eV or sub-eV scale precision. Monoenergetic electrons emitted by gaseous <sup>83m</sup>Kr atoms are used to determine the relationship between the cyclotron frequency and the electron energy and to optimize the instrument configuration for the tritium measurement and the electron signal reconstruction algorithm. Phase II will benefit from precise magnetometers and a gas system combining krypton and tritium that allow to measure and correct offline for the magnetic field fluctuations. We present the recent progress in understanding the electron kinematics and implementing the magnetic field calibration.

**Dark Matter / 191**

## Update on the MiniCLEAN Experiment

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One technology being examined for future direct dark matter searches is a single-phase noble liquid detector. The MiniCLEAN experiment is a test of such an approach, using liquid argon to search for WIMPs via nuclear recoils. The detector, located at SNOLAB, will have a 500 kg (150 kg) target (fiducial) mass and is instrumented with cold photomultiplier tubes. Pulse-shape discrimination will be used to reject the large Ar-39 radioactive background. The CLEAN design allows the argon target to be

exchanged with neon, meaning that a potential signal can be checked via the dependence on nuclear mass. MiniCLEAN will also be run with an enhanced Ar-39 “spike” to demonstrate the pulse shape discrimination capability. An update on the commissioning status of the experiment will be presented.

**Neutrino Parallel / 192**

## **Searches for Tau Neutrino Appearance in IceCube-DeepCore**

**Author:** Michael Larson<sup>1</sup>

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The IceCube-DeepCore detector has unambiguously observed muon-neutrino disappearance due to oscillations of atmospheric neutrinos. The associated tau-neutrino appearance may be measured as a statistical excess of cascade-like events in the detector. New high statistics event selections, optimized for the study of oscillations around 10 GeV, provide increased sensitivity for the measurement of muon neutrino disappearance as well as the potential for strong constraints on tau neutrino appearance. This talk will discuss the ongoing efforts to measure the tau neutrino appearance in the atmospheric neutrinos observed by the current DeepCore array.

**New Technologies / 193**

## **Status of the AMoRE experiment searching for neutrinoless double beta decay of $^{100}\text{Mo}$**

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The goal of the Advanced Mo-based Rare process Experiment (AMoRE) is to search for neutrinoless double beta decay of  $^{100}\text{Mo}$  using low-temperature detectors consisting of Mo-based scintillating crystals and sensors based on metallic magnetic calorimeters (MMCs). The detector system operates at millikelvin temperatures, which are reached using a dilution refrigerator, and performs simultaneous measurements of heat and light signals. The AMoRE-Pilot experiment, using five  $^{100}\text{Mo}$ -enriched,  $^{48}\text{Ca}$ -depleted calcium molybdate crystals with a total mass of about 1.5 kg, has been running in the 700-m-deep Yangyang underground Laboratory as the pilot phase of the AMoRE project. Several setup improvements through different runs allowed us to achieve high energy resolution and efficient particle discrimination. The current status of AMoRE-Pilot, as well as the plans for the next, higher-scale, experimental stages, will be presented.

**Neutrino Parallel / 194**

## **The ICARUS detector**

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The 760 ton liquid argon ICARUS T600 detector performed a successful three-year physics run at the underground LNGS laboratories, studying neutrino oscillations with the CNGS neutrino beam from CERN, and searching for atmospheric neutrino interactions in cosmic rays. A sensitive search for LSND like anomalous  $\nu_e$  appearance was performed, contributing to constrain the allowed parameters to a narrow region around  $\Delta m^2 \sim eV^2$ , where all the experimental results can be coherently accommodated at 90% C.L.

The T600 detector will be redeployed at Fermilab, after a significant overhauling, to be exposed to the Booster Neutrino Beam acting as the far station to search for sterile neutrino within the SBN program.

The proposed contribution will address ICARUS LNGS achievements and the ongoing analyses also finalized to the next physics run at Fermilab.

**Poster Session / 195**

## Design Improvements to Cables and Connectors in the MAJORANA DEMONSTRATOR

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The MAJORANA DEMONSTRATOR is an experiment constructed to search for neutrinoless double-beta decays in germanium-76 and to demonstrate the feasibility to deploy a large-scale experiment in a phased and modular fashion. It consists of two modular arrays of natural and 76Ge-enriched germanium p-type point contact detectors totaling 44.1 kg, located at the 4850' level of the Sanford Underground Research Facility in Lead, South Dakota, USA. The DEMONSTRATOR uses custom high voltage cables to bias the detectors, as well as custom signal cables and connectors to read out the charge deposited at each detector's point contact. These low-mass cables and connectors must meet stringent radiopurity requirements while being subjected to thermal and mechanical stress. A number of issues have been identified with the currently installed cables and connectors. An improved set of cables and connectors for the MAJORANA DEMONSTRATOR are being developed with the aim of increasing their overall reliability and connectivity. We will discuss some of the issues encountered with the current cables and connectors as well as our improved designs and the initial performance of the new cables and connectors.

**Poster Session / 196**

## High precision modeling of germanium detector waveforms using MCMC machine learning

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The MAJORANA DEMONSTRATOR is a neutrinoless double-beta decay experiment using high purity p-type point contact germanium detectors. The waveforms produced in these detectors exhibit subtle variations related to the detailed energy deposition and drift path information for each event.

In addition, the waveforms depend sensitively on crystal impurity levels, temperature, and operating voltage. We have developed a machine learning algorithm which, given a set of calibration waveforms, can infer detector parameters. Once these parameters are known, this high precision detector model can be used to fit the drift paths of individual waveforms. This method can be used as a sensitive background rejection technique for the DEMONSTRATOR or the proposed future LEGEND experiment.

**Neutrino Parallel / 197**

## Latest Results of EXO-200

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The EXO-200 experiment has made both the first observation of the double beta decay in Xe-136 and the most precisely measured half-life of any two-neutrino double beta decay to date. Consisting of an extremely low-background time projection chamber filled with ~150 kg of enriched liquid Xe-136, it has provided one of the most sensitive searches for the neutrinoless double beta decay using the first two years of data. After a hiatus in operations during a temporary shutdown of its host facility, the Waste Isolation Pilot Plant, the experiment has restarted data taking with upgrades to its front-end electronics and a radon suppression system. This talk will cover the latest results of the collaboration including new data with improved energy resolution.

**New Technologies / 198**

## Indirect searches for Dark Matter Signatures at INO

**Author:** Deepak Tiwari<sup>1</sup>

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Weakly Interactive Massive Particles (WIMPs) are among the most favored Dark Matter candidates. As the Solar System moves through Dark Matter halo, the WIMPs may scatter on the nuclei in the Sun/Earth, lose energy, and get trapped by their gravitational potentials. Their capture and subsequent annihilations in the core of the Sun/Earth may subsequently give rise to neutrinos, through various annihilation channels.

We look at the possibility of detection of such neutrinos at INO (India-Based Neutrino Observatory), which will house a 50-kt Iron Calorimeter (ICAL) detector. Detection of these neutrinos and studying their properties would help us to reconstruct nature of light Dark Matter.

In the present analysis, we give an estimate of the muon events at the detector due to WIMP annihilations in the Sun and the Earth; 10 years of ICAL running. For our work, WIMP masses upto 100 GeV have been considered.

The atmospheric neutrinos in GeV range will pose background to the signal neutrinos. However, exploiting the excellent angular resolution of the ICAL detector, the background can be suppressed considerably. We also perform a  $\chi^2$  analysis to obtain 90% upper limits on Spin-dependent and Spin-Independent WIMP-nucleon cross sections.

**Labs and Low Background / 199****An ultra-low radioactivity measurement facility at the Center for Underground Physics in Korea****Author:** Moo Hyun Lee<sup>1</sup><sup>1</sup> *IBS***Corresponding Author:** mhlee@ibs.re.kr

As a few ultra-low background rare decay experiments at the Yangyang underground laboratory in Korea are being prepared and under operation, a number of ultra-low radioactivity measurement detectors have been developed. For a screening of raw materials or detector components, an ICP-MS, an argon gas ionization counter, a ZnS counter, and a number of HPGe detectors are operating. A silicon PIN photodiode based radon detector has been upgraded for a measurement of the air from a radon reduction system in a radon level of 10 mBq/m<sup>3</sup>. An array of 14 HPGe detectors was installed for an efficient measurement of background gamma rays from bigger samples than those could be tested in two single crystal HPGe detectors. As candidates of detector materials, various types of scintillation crystals such as CaMoO<sub>4</sub>, Li<sub>2</sub>MoO<sub>4</sub>, and NaI(Tl) have been grown with purified raw materials and tested for their radioactivity background levels with the above mentioned instruments. A summary of their developments and preliminary performances together with a future plan will be presented.

**Dark Matter / 200****Solar Atmospheric Neutrinos: A New Neutrino Floor for Dark Matter Searches****Author:** Kenny Chun Yu Ng<sup>1</sup>**Co-authors:** John Beacom<sup>2</sup>; Annika Peter<sup>2</sup>; Carsten Rott<sup>3</sup><sup>1</sup> *Weizmann Institute of Science*<sup>2</sup> *Ohio State University*<sup>3</sup> *Sungkyunkwan University***Corresponding Authors:** peter.33@osu.edu, beacom.7@osu.edu, chun-yu.ng@weizmann.ac.il, carsten.rott@gmail.com

As is well known, dark matter direct detection experiments will ultimately be limited by a “neutrino floor,” due to the scattering of nuclei by MeV neutrinos from, e.g., nuclear fusion in the Sun. Here we point out the existence of a new “neutrino floor” that will similarly limit indirect detection with the Sun, due to high-energy neutrinos from cosmic-ray interactions with the solar atmosphere. We have two key findings. First, solar atmospheric neutrinos  $\gtrsim 1$  TeV cause a sensitivity floor for standard WIMP scenarios, for which higher-energy neutrinos are absorbed in the Sun. This floor will be reached once the present sensitivity is improved by just one order of magnitude. Second, for neutrinos  $\gtrsim 1$  TeV, which can be isolated by muon energy loss rate, solar atmospheric neutrinos should soon be detectable in IceCube. Discovery will help probe the complicated effects of solar magnetic fields on cosmic rays. These events will also be backgrounds to WIMP scenarios with long-lived mediators, for which higher-energy neutrinos can escape from the Sun.

**Poster Session / 201****Liquid scintillator for search of double beta decay with Tin****Author:** Oleg Chkvorets<sup>1</sup>

**Co-authors:** Julia Forner ; Christine Kraus ; Valentina Lozza ; Kai Zuber <sup>2</sup>

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Tin-124 is one of the double beta decay isotopes where no measurement of the double neutrino decay rate has been performed. The abundance of the isotope is 5.79%, fairly low, however it can be compensated for by the high loading potential of the natural isotope up to 10% into liquid scintillator without light quenching. This work presents results of LAB based Tin loaded liquid scintillator stability, light yield and possible purification technique.

**Dark Matter / 202**

## Energy response and position reconstruction in the DEAP-3600 dark matter experiment

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DEAP-3600 is a dark matter WIMP (Weakly Interacting Massive Particles) search experiment, which aims to detect nuclear recoils from WIMP scattering in an argon target located 2 km underground at SNOLAB. At WIMP masses of 100 GeV, DEAP-3600 has a projected sensitivity of  $10^{-46}$  cm<sup>2</sup> for the spin-independent elastic scattering cross section of WIMPs. The beta emissions from the intrinsic <sup>39</sup>Ar present in the natural Ar target, as well as external calibration sources, can be used to understand the detector energy response and position reconstruction in the energy region of interest for WIMP signals. This talk will present the techniques and results of the energy response and position reconstruction calibration in DEAP-3600.

**New Technologies / 203**

## 3D digital SiPM for large area and low background experiments

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Large area and low background experiments such as nEXO (next Enriched Xenon Observatory, a proposed 5 tonne-scale detector) are looking for new and innovative ways to improve the sensitivity of their detectors. Installing the photodetectors and their electronic readout directly in the detector active medium is among promising approaches. In turn, this introduces new constraints on the radioactivity background and on the power consumption of the electronics. While the common baseline is to use silicon photomultipliers (SiPM), the Sherbrooke radiation instrumentation team is

proposing a vertically integrated and digitally controlled SiPM (3D-dSiPM). The digital readout takes advantage of the inherently binary nature of the Geiger-mode avalanche photodiode, provides fast in-chip processing and overcomes the output capacitance challenge. Moreover, the 3D structure allows for an independent optimization of the photosensing layer and the electronic readout layer. This talk presents Sherbrooke's 3D-dSiPM technology and its first prototype results. The work done shows no systematic degradation compared to its 2D equivalent architecture. Furthermore, the readout and trigger algorithm is presented as well as the current work underway to develop a 3D integration process with industrial partners. This last effort aims at providing high yield capability for large area tiles production.

**Neutrino Parallel / 204**

## The Electron Capture in $^{163}\text{Ho}$ Experiment

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The Electron Capture in  $^{163}\text{Ho}$  (**ECHO**) experiment is designed to investigate the electron neutrino mass  $m_{\nu_e}$  with sub- $eV$  sensitivity by the analysis of the electron capture (**EC**) energy spectrum of  $^{163}\text{Ho}$ .

The sensitivity on the electron neutrino mass is crucially related to the energy available for the decay  $Q_{EC} = 2833(30\text{stat})(15\text{sys}) eV$ , which has been precisely determined by the ECHO collaboration. Accordingly, a sensitivity below  $10 eV$  is expected to be attained at the end of the present phase of the experiment, ECHO-1k.

In this phase, about  $1 kBq$  of high purity  $^{163}\text{Ho}$  is going to be implanted in multiplexed arrays of low temperature metallic magnetic calorimeters which are operated in a reduced background environment.

The goals of ECHO-1k are the precise characterization of the parameters describing the spectrum, optimizing the implantation process of  $^{163}\text{Ho}$  into the detector arrays, optimization of detector production and identification and reduction of the background in the experimental setup.

The results will pave the way to a future phase of the experiment, where activities of the order of  $MBq$   $^{163}\text{Ho}$  will be used.

This second phase aims to approach sub- $eV$  sensitivity on the electron neutrino mass.

Furthermore, the high statistics and high resolution measurement of the  $^{163}\text{Ho}$  electron capture spectrum will allow the investigation of the existence of  $eV$  and keV-scale sterile neutrinos.

In this contribution, a general overview of the ECHO experiment is presented and the current status as well as the future perspectives are discussed.

**Neutrino Parallel / 205**

## Overview of Project 8 and Progress Towards Tritium Operation

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Project 8 is a tritium endpoint neutrino mass experiment utilizing a phased program to achieve sensitivity to the range of neutrino masses allowed by the inverted mass hierarchy. The Cyclotron Radiation Emission Spectroscopy (CRES) technique is employed to measure the differential energy spectrum of decay electrons with high precision. We present an overview of the Project 8 experimental program, from first demonstration of the CRES technique to ultimate sensitivity with an

atomic tritium source. We then highlight recent advances in preparation for the first measurement of the continuous tritium spectrum with CRES.

**Dark Matter / 206**

## Backgrounds in the DEAP-3600 Dark Matter Experiment

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The DEAP-3600 experiment is searching for dark matter with a single phase liquid argon (LAr) target, located at SNOLAB. For a background-free exposure of 3000 kg·yr, the projected sensitivity to the spin-independent WIMP-nucleon cross section at 100 GeV/c<sup>2</sup> WIMP mass is 10<sup>-46</sup> cm<sup>2</sup>.

The experimental signature of dark matter interactions is keV-scale argon recoils producing 128 nm LAr scintillation photons which are wavelength shifted and observed by 255 PMTs. To reach the large background-free exposure, a combination of careful material selection, passive shielding, active vetoes, fiducialization and pulse shape discrimination (PSD) is used. The main concept of the background rejection in DEAP is the powerful PSD, employing the large difference between fast and slow components of LAr scintillation light. Discrimination of electronic and nuclear recoils on the order of 10<sup>10</sup> can be achieved, which is sufficient to successfully reject <sup>39</sup>Ar beta-decays with a specific activity of 1 Bq/kg in argon with natural isotopic composition.

The designed background level of DEAP-3600 is less than 0.6 events in a 3000 kg·yr exposure. The experiment was filled in November 2016 and is currently taking dark matter search data. This talk will report on the measured background levels in DEAP based on first data.

**Dark Matter / 207**

## Calibrating Inner-Shell Electron Recoils in a Xenon Time Projection Chamber

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Dark matter direct detection experiments rely heavily on calibrations to understand each detector's response to predicted backgrounds. Certain backgrounds, such as neutrino-electron scatters, cannot be directly calibrated, and so beta- or gamma-decay sources are often used as a proxy. This treatment inherently assumes that interaction type and energy do not affect detector response to electron recoil scatters. The PICO bubble chambers have recently discovered that this assumption breaks down under certain conditions in a way that critically impacts detector performance. We have constructed a xenon time projection chamber at Fermilab to directly compare electron capture decays from Xe-127 against tritium beta decays, to determine if second-order differences will contribute to the profile likelihood analysis used by the LZ and XENON collaborations.

**Poster Session / 208**

## The PICO-40L Detector Design

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The PICO collaboration employs bubble chambers to search for direct interactions with dark matter particles. The operating parameters of these detectors can be tuned so that they are almost completely insensitive to gamma rays and other near-minimum-ionizing radiation that is the main background for most dark matter detectors. PICO 40, the next generation detector, will incorporate several design improvements that will reduce backgrounds from neutrons and particulate contamination. I will present an overview of the detector's operating principles and design with focus on the most recent improvements.

**Poster Session / 209**

## Search for CPT-violation in Positronium

**Authors:** Chelsea Bartram<sup>1</sup>; Reyco Henning<sup>1</sup>

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We search for CPT-violating correlations between gamma rays in the decay of ortho-positronium (o-Ps) with CALIOPE, or CPT Aberrant Leptons in o-Ps Experiment. Using a tagged source flush against a cylindrical piece of aerogel, we generate positronium at the center of an annular array of 24 NaI(Tl) bars. We present the capabilities of the DAQ, which uses QDCs and TDCs to record the charge amplitude of pulses and timing information. We have characterized each bar in the detector and demonstrated the ability to create and detect positronium. We also include a study of systematics resulting from detailed Monte Carlo simulations.

**New Technologies / 210**

## Progress in Barium tagging at the single atom/ion level for nEXO

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The ability to detect or "tag" the  $^{136}\text{Ba}$  daughter of  $^{136}\text{Xe}$  double beta decay in the nEXO liquid xenon TPC has the potential to eliminate essentially all background in the a second phase of nEXO operation. Several promising techniques for barium tagging are being developed within the nEXO collaboration. These include capturing the single  $^{136}\text{Ba}$  ion/atom in solid xenon on a cryogenic probe and detecting it by laser spectroscopy and capturing the single  $^{136}\text{Ba}$  on a conducting probe and detecting it by laser ablation and resonance ionization spectroscopy. The extraction of the  $^{136}\text{Ba}^+$  ion from the TPC and capture and detection in an ion trap is also being explored. Recent progress in barium tagging at the single ion/atom level will be presented.

**Neutrino Parallel / 211**

## Neutrino-less double beta decay of $^{48}\text{Ca}$ studied by $\text{CaF}_2$ (pure) scintillators

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Neutrino-less double beta decay ( $0\nu\beta\beta$ ) is acquiring great interest after the confirmation of neutrino oscillation which demonstrated nonzero neutrino mass. Measurement of  $0\nu\beta\beta$  provides a test for the Majorana nature of neutrinos and gives an absolute scale of the effective neutrino mass.

In order to search for  $0\nu\beta\beta$  of  $^{48}\text{Ca}$ , we proposed CANDLES detector by using  $\text{CaF}_2$ (pure). The CANDLES detector aims at a high sensitive measurement by an active shield and  $^{48}\text{Ca}$  enrichment. The complete  $4\pi$  active shield is realised by immersion of the  $\text{CaF}_2$  scintillators in liquid scintillator. The active shield leads to a low background condition for the measurement. On the other hand,  $^{48}\text{Ca}$  enrichment is also effective for the high sensitive measurement, since natural abundance of  $^{48}\text{Ca}$  is very small (0.19%).

Currently we have been developing the CANDLES III detector, which contained 350 g of  $^{48}\text{Ca}$  without enrichment, at the Kamioka underground laboratory. In 2015, we installed a shielding system in the CANDLES III detector to reduce background events by the high energy  $\gamma$ -rays, which were emitted from neutron capture reaction in surrounding materials. Using this shielding system, we reduced the background events from neutron capture by two orders of magnitude. After this upgrade, we started a double beta decay measurement in 2016.

In this paper, we will report result of the double beta decay measurement after the upgrade.

**Dark Matter / 212**

## Highly radio-pure $\text{NaI(Tl)}$ for PICOLON dark matter search experiment

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The positive observation of dark matter by the DAMA experiment has to be re-examined by a NaI(Tl) detector since there are multiple negative results shown by Xe experiments. The PICOLON experiment is trying to observe dark matter with multiple highly radio-pure NaI(Tl) scintillator detectors. In recent a couple years, 3"φx3" and 4"φx3" detectors were constructed for future target of 5"φx5" detectors. Different resins were applied for purification of NaI powder in order to remove Pb, Ra and K, also the housing material screening and purification was performed. Significant reduction on U and Th chain radio-impurities including <sup>226</sup>Ra and <sup>210</sup>Pb, as well as on <sup>40</sup>K. The background rate below 10keV is mainly suppressed to approximately 4 DRU.

The latest 4"φ detector background analysis, sensitivity of the detector to dark matter and next plans of the experiment will be reported in this talk.

**Neutrino Parallel / 213**

## Discovery probability of next-generation neutrinoless double-beta decay experiments

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The Bayesian discovery probability of future experiments searching for neutrinoless double- $\beta$  decay is evaluated under the popular assumption that neutrinos are their own antiparticles. A Bayesian global fit is performed to construct a probability distribution for the effective Majorana mass, the observable of interest for these experiments. This probability distribution is then combined with the sensitivity of each experiment derived from a heuristic counting analysis. The discovery probability strongly depends on whether the neutrino mass ordering is normal or inverted, and is found to be higher than previously considered for both mass orderings. For the inverted ordering, next-generation experiments are likely to observe a signal already during their first operational stages. Even for the normal ordering, the probability of discovering neutrinoless double- $\beta$  decay reaches  $\sim 50\%$  in the most promising experiments.

**Poster Session / 214**

## Interval estimation of bounded parameters

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We consider the construction of interval estimates for the parameters with one-sided constraints. We show that the so-called method of sensitivity limit yields a correct solution of the problem [1]. Derived are the solutions for the cases of a continuous distribution with non-negative estimated parameter and a discrete distribution, specifically a Poisson process with background. For both cases, the best upper limit is constructed that accounts for the a priori information. Particular applications to the neutrino mass measurements, rare processes (neutrinoless double beta-decay etc.) searches and cosmic ray studies are discussed.

[1] A.V. Lokhov, F.V. Tkachov. Confidence intervals with a priori parameter bounds // Phys.Part.Nucl. 46 (2015) 347-365

## Cosmology, Gravitational Waves, & Cosmic Rays / 215

### Cosmic Inflation and Neutrino Masses at POLARBEAR and the Simons Array

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POLARBEAR is a ground-based CMB polarization experiment that is designed to characterize the B-mode (curl component) signal at both degree and sub-degree angular-scales. B-modes at degree scale can reveal the existence of primordial gravitational waves and will be used for quantitative studies of inflation, such as the energy scale at which it occurred. The sub-degree polarization data are an excellent tracer of the cosmological expansion rate and large-scale structure in the universe through gravitational lensing, and can be used to constrain the sum of the Neutrino masses.

POLARBEAR-1 started observing in early 2012 at 150 GHz with an array of 1,274 polarization-sensitive antenna-coupled transition-edge sensor (TES) bolometers, and first detected the sub-degree B-mode signal using CMB data alone.

The POLARBEAR-2 is a project for receiver upgrade to cover two frequency bands with 7,600 detectors per receiver

The Simons Array is a project to deploy three POLARBEAR-2 receivers on three telescopes. Simons Array will survey of B-mode polarization at 95, 150, 220, and 270 GHz for effective monitoring and removal of foreground contamination.

The first receiver is in final stage of integration.

It is scheduled to deploy during the 2017/2018 austral summer season in the Atacama desert in Chile. The projected constraints on the tensor-to-scalar ratio (the amplitude of inflationary B-mode signal) will improve over current constraints by almost an order of magnitude to  $\sigma(r = 0.1) = 6.0 \times 10^{-3}$  ( $4.0 \times 10^{-3}$  statistical), and the sensitivity to the sum of the neutrino masses

when combined with DESI spectroscopic galaxy survey data will be 40 meV at 1-sigma after foreground removal (19 meV(stat.)).

We will describe the current status and prospects of the POLARBEAR-2 receiver system and the Simons Array project.

## Dark Matter / 216

### Dark matter velocity spectroscopy

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Dark matter decays or annihilations that produce line-like spectra may be smoking-gun signals. However, even such distinctive signatures can be mimicked by astrophysical or instrumental causes. We show that velocity spectroscopy—the measurement of energy shifts induced by relative motion of source and observer—can separate these three causes with minimal theoretical uncertainties. The principal obstacle has been energy resolution, but upcoming experiments will reach the required 0.1% level. As an example, we show that experiments with the required energy resolution can cleanly separate the signal from background. We emphasize that this new smoking-gun-in-motion signature of dark matter is general, and is applicable to any dark matter candidate which produces a sharp photon feature in annihilation or decay.

**Dark Matter / 217**

## Global Fits with GAMBIT

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The wide range of probes of physics beyond the standard model (BSM) leads to the need for tools that combine experimental results to make the most robust possible statements about the validity of theories of new physics and the preferred regions of their parameter space. In this talk, I will introduce a new code for such analyses: GAMBIT, the Global and Modular BSM Inference Tool. GAMBIT is a flexible and extensible framework for global fits of essentially any BSM theory. DarkBit, the dark matter (DM) portion of the code, contains new tools for calculation of likelihoods from gamma-ray and direct DM searches, as well as routines for the calculation of the relic density of an arbitrary model and interfaces to existing DM codes. The rest of the code provides complimentary limits on production of new particles from the LHC and LEP, complete flavour constraints from LHCb, LHC Higgs production and decay measurements, and various electroweak precision observables. I will discuss the code's capabilities, particularly focusing on the DM observable and likelihood calculators, and then present results of scans of the parameter space of the Minimal Supersymmetric Standard Model.

**Neutrino Parallel / 218**

## Crustal geoneutrino signal expected at SNO+

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Thanks to an overburden of 6 km water equivalent and to a large mass of ultrapure liquid scintillator, the SNO+ detector is designed for performing low energy neutrino physics measurements and will address several fundamental physics goals, among which the study of geoneutrinos. The geoneutrino signal produced by U and Th distributed in the whole Earth's mantle is comparable to that originated by the 50 km × 50 km Close Upper Crust surrounding SNO+. Regional characterization of the continental crust is generally performed through either geologic mapping, geochemical sampling, or geophysical surveys. Rarely are these techniques fully integrated, due to limits of data coverage, quality, and/or incompatible datasets. We combine geologic observations, geochemical sampling, and geophysical surveys to create a coherent 3D geologic model of the Close Upper Crust surrounding SNO+, which includes the Grenville Front Tectonic Zone, the Southern Province, the Superior Province, and the Sudbury Igneous Complex. Nine aggregate geological units are geologically characterized, geophysically constrained and geochemically probed with 112 rocks samples representative of the different lithologies, whose U and Th contents have been assessed via HPGe and ICPMS measurements. According to this coherent numerical 3D model, the predicted heat production at SNO+ is  $1.5+1.4-0.7 \mu\text{W}/\text{m}^3$  and the expected geoneutrino signal from the Close Upper Crust is  $7.8+8.4-3.2 \text{ TNU}$  (a Terrestrial Neutrino Unit is one geoneutrino event per 1032 target protons per year) to be compared with a total bulk crust signal of  $31.2+8.6-4.7 \text{ TNU}$ . The  $1\sigma$  variability of the geoneutrino signal given by the Close Upper Crust strongly limits the SNO+ potentials for discriminating among different BSE compositional models of the mantle on the base of geoneutrinos experimental measurements. Future works aimed at constraining the crustal heat production and the geoneutrino signal at SNO+ will be inefficient without a geophysical characterization of the 3D structure of the heterogeneous Huronian Supergroup, which provides the largest uncertainty on the expected signal.

Poster Session / 219

## Electromagnetic interactions of massive neutrinos and neutrino oscillations

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Electromagnetic properties of massive neutrinos [1,2] and their effects on neutrino oscillation phenomena are brought into focus. The searches for neutrino millicharges, charge radii and magnetic moments in astrophysics and laboratory measurements are outlined [2,3]. Prospects of probing these neutrino characteristics with JUNO are discussed.

[1] C. Giunti and A. Studenikin, *Neutrino electromagnetic interactions: A window to new physics*, Rev. Mod. Phys. **87**, 531 (2015).

[2] C. Giunti, K. A. Kouzakov, Y.-F. Li, A. V. Lokhov, A. I. Studenikin, and S. Zhou, *Electromagnetic neutrinos in laboratory experiments and astrophysics*, Ann. Phys. (Berlin) **528**, 198 (2016).

[3] K. A. Kouzakov and A. I. Studenikin, *Electromagnetic properties of massive neutrinos in low-energy elastic neutrino-electron scattering*, Phys. Rev. D **95**, 055013 (2017).

## Neutrino Parallel / 220

**More results from the OPERA experiment****Corresponding Author:** nicoletta.mauri@bo.infn.it

The OPERA experiment reached its main goal by proving the appearance of tau-neutrinos in the CNGS muon neutrino beam. A total sample of 5 candidates fulfilling the analysis defined in the proposal was detected with a S/B ratio of about ten allowing to reject the null hypothesis at 5.1 sigma. The search has been extended to nu\_tau-like interactions failing the kinematical analysis defined in the experiment proposal to obtain a statistically enhanced, lower purity, signal sample. One such interesting neutrino interaction with a double vertex topology will be reported with a high probability of being a nu\_tau interaction with charm production. Based on the enlarged data sample the estimation of  $\Delta m^2_{23}$  in appearance mode is presented. The search for nu\_e interactions has been extended over the full data set with a more than twofold increase in statistics with respect to published data. The analysis of the nu\_mu->nu\_e channel is updated and the implications of the electron neutrino sample in the framework of the 3+1 sterile model is discussed. An analysis of nu\_mu -> nu\_tau interactions in the framework of the sterile neutrino model has also been performed.

## Cosmology, Gravitational Waves, &amp; Cosmic Rays / 221

**Annual modulation of the atmospheric muon flux measured by the OPERA experiment****Corresponding Author:** nicoletta.mauri@bo.infn.it

The OPERA detector was used to measure the annual modulation of the atmospheric muon flux at the Gran Sasso underground laboratory (3800 m w.e.). We present preliminary results using 5 years of data (2008-2012) showing a flux modulation with a period of 1 year and a relative amplitude of 1.5%. The phase of the maximum intensity and the effective temperature coefficient  $\alpha_T$ , which correlates variations in the muon rate and seasonal temperature variations, are both in agreement with theoretical expectations and other experimental results at LNGS.

## Poster Session / 222

**The Euclid Near Infrared Spectro-Photometer (NISP) instrument and science****Authors:** Chiara Sirignano<sup>1</sup>; Gabriele Sirri<sup>2</sup>; Laura Patrizii<sup>None</sup>; Luca Stanco<sup>1</sup>; Nicoletta Mauri<sup>3</sup>; Stefano Dusini<sup>4</sup><sup>1</sup> *Universita e INFN, Padova (IT)*<sup>2</sup> *INFN*<sup>3</sup> *INFN, Bologna*<sup>4</sup> *INFN Padova***Corresponding Authors:** dusini@pd.infn.it, nicoletta.mauri@bo.infn.it, chiara.sirignano@cern.ch, gabriele.sirri@bo.infn.it, luca.stanco@cern.ch, laura.patrizii@bo.infn.it

Euclid is an ESA mission designed to explore the dark side of the Universe and to understand the nature of the dark energy responsible for the accelerated expansion of the Universe. Its objective is to map the geometry of the dark Universe by investigating the distance-redshift relationship and the evolution of cosmic structures.

By measuring two cosmological probes simultaneously, the Weak Gravitational Lensing and the Galaxy Clustering (BAOs and Redshift-Space distortions), Euclid will constrain dark energy, general relativity, dark matter and the initial conditions of the Universe with unprecedented accuracy. Each probe has a dedicated instrument in the payload: an imager in the visible domain (VIS) and an imager-spectrometer (NISP) covering the near infrared. Here we present the NISP (Near Infrared Spectro-Photometer) instrument operating in the spectral region 0.9-2 $\mu\text{m}$  as a photometer and spectrometer, which will allow measuring the redshifts of galaxies with an accuracy better than 0.1%. The Euclid sensitivity to cosmological parameters as the ones characterising the dark energy equation of state and the sum of neutrino masses will be also presented.

Poster Session / 223

## Background modeling for the nEXO neutrinoless double beta decay experiment

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The nEXO Collaboration is developing a tonne-scale neutrinoless double beta decay experiment employing an enriched  $^{136}\text{Xe}$  target. The enriched liquid xenon is operated as a time projection chamber (TPC) providing event timing and position reconstruction. The goal is to search for excess events at the 2458 keV end-point of the  $^{136}\text{Xe}$  double beta-decay energy spectrum. An event excess at this energy would imply the existence of a decay branch that does not emit the otherwise required two antineutrinos that should accompany the beta particles. Current measurements set a limit on the neutrinoless double beta decay of  $^{136}\text{Xe}$  at a half-life of greater than  $10^{26}$  years. To investigate the possibility of neutrinoless double beta decay with a longer half-life, a tonne-scale experiment must limit interfering background interactions in the TPC due to naturally occurring radioactive impurities in the experimental construction materials. This poster will present the modeling and methods used to evaluate the background contributions to the planned tonne-scale nEXO neutrinoless double beta decay experiment.

Poster Session / 224

## Background Studies for the ECHO Experiment

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The **ECHO** experiment is designed to measure the  $^{163}\text{Ho}$  electron capture decay spectrum up to its endpoint at 2.833 keV. Such a measurement offers great potential to reach sub-eV sensitivity on the absolute electron neutrino mass  $m_{\nu_e}$ . A crucial aspect in this effort is the thorough understanding of the low energy background to experiment below 3 keV and its reduction. Monte Carlo simulations in the GEANT4 framework have been conducted to investigate the impact on the sensitivity from radioactive contaminants in the experimental setup like  $^{40}\text{K}$ ,  $^{166\text{m}}\text{Ho}$  and  $^{210}\text{Pb}$  and muon induced cosmogenic background. In this poster, we present the results of our simulations with respect to acceptable contamination levels.

## New Technologies / 225

**Threshold verification in the PICO-60 detector and study of the growth and motion of nucleation bubbles****Author:** Pitam Mitra<sup>1</sup><sup>1</sup> *University of Alberta***Corresponding Author:** pitam@ualberta.ca

The PICO-60 experiment searches for dark matter using superheated liquid  $C_3F_8$ . The experiment is located at SNOLAB and is designed to be sensitive to spin-carrying dark matter particles. The PICO bubble chamber is a threshold detector that can be operated to be insensitive to minimally ionizing particles. Acoustic information is used to discriminate between nuclear recoil events and background alpha events.

It is very hard to directly measure the temperature and its variations inside a bubble chamber and understand the flow and heat distribution patterns in a superheated liquid. A new technique is being developed involving the growth and movement patterns of nucleation bubbles in the PICO-60 vessel to map the heat and flow distribution. The progress and results from this work will be presented in this talk. This measurement aims to verify the thermal and liquid simulations in this and future PICO detectors. Understanding the temperature profile inside the chamber allows to narrow the threshold uncertainty for dark matter searches in the future.

## Poster Session / 226

**PEV NEUTRINOS AND UHECRS CONNEXION AROUND THE LOBES OF CENTAURUS A****Authors:** Fraija<sup>1</sup>; Edilberto Aguilar Ruiz<sup>2</sup>; Antonio Galván<sup>2</sup><sup>1</sup> *Nissim*<sup>2</sup> *Instituto de Astronomía UNAM***Corresponding Authors:** agalvan@astro.unam.mx, eaguilar@astro.unam.mx, nfracija@astro.unam.mx

Ultra-high-energy cosmic ray (UHECR) detections could give an indirect signal of PeV neutrino emission. Recently, Pierre Auger observatory reported the distribution of arrival directions of the highest energy cosmic rays. These events were collected in 10 years of operations with declinations between  $-90^\circ$

and  $+45^\circ$ . The IceCube neutrino telescope reported the detection of 54 extraterrestrial neutrinos in the High-Energy Starting Events (HESE) catalog. The highest-energy neutrino event (IC35) reported in this catalog had an energy of

$2004(+236-262)$  TeV and was located centered at  $RA=208.4^\circ$  and  $DEC=-55.8^\circ$  (J2000). Being Centaurus A (CenA) the nearest radio-loud active galactic nucleus and one of the best potential candidates for accelerating cosmic rays up to  $\sim 10^{20}$  eV, we show that UHECRs with  $E > 58$  EeV around the direction of Cen A ( $15^\circ$  radius) could be accelerated inside the giant lobes. These cosmic rays unavoidably interact with external radiation fields and ambient gas whereas they propagate through the lobes and their paths to Earth. Using the buoyancy ages of the giant radio lobes instead of their spectral ages, and those UHECRs in the direction of the IC35 event, we found that although the IC35 event cannot be generated inside the giant lobes, this neutrino event could be created when ultra-relativistic protons interact outside of them in their paths to Earth. In addition, we found that through proton-proton interactions inside the giant radio lobes, the proton luminosity normalized with these UHECRs is consistent with  $\gamma$ -ray fluxes reported by Fermi Collaboration.

## New Technologies / 227

## First Demonstration of a Scintillating Xenon Bubble Chamber for Dark Matter and CE $\nu$ NS Detection

**Authors:** C Eric Dahl<sup>1</sup>; Jianjie Zhang<sup>1</sup>

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A new type of particle detector which combines the advantages of liquid noble TPCs and superheated bubble chambers has been for the first time demonstrated with a 30-gram prototype scintillating liquid xenon bubble chamber operated at Northwestern University. The new technology has the potential, which is the aim of current ongoing work, to be virtually only sensitive to nuclear recoils at thermal noise limited thresholds. We have observed simultaneous bubble nucleation and scintillation by nuclear recoils in liquid xenon with the prototype chamber. The observed single- and multiple-bubble rates when exposed to a <sup>252</sup>Cf neutron source indicate that, for a thermodynamic “Seit” threshold of 8.3 keV, the minimum nuclear recoil energy required to nucleate a bubble is between 11 and 25 keV. This is consistent with the observed scintillation spectrum for bubble-nucleating events. We see no evidence for bubble nucleation by gamma rays at the thresholds studied, setting a 90% CL upper limit of  $6.3 \times 10^{-7}$  bubbles per gamma interaction at a 4.2-keV thermodynamic threshold. This indicates stronger gamma discrimination than in CF<sub>3</sub>I bubble chambers, supporting the hypothesis that scintillation production suppresses bubble nucleation by electron recoils, while nuclear recoils nucleate bubbles as usual. This chamber is instrumented with a CCD camera for near-IR bubble imaging, a solar-blind PMT to detect 175-nm xenon scintillation light, and a piezoelectric acoustic transducer to detect the ultrasonic emission from a growing bubble. The neutron and gamma measurements establish the noble-liquid bubble chamber as a promising new technology for WIMP and CE $\nu$ NS detection.

Dark Matter / 228

## PICO-500L: Simulations for a 500L Bubble Chamber for Dark Matter Search

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The PICO-500L detector will be a 500 litre bubble chamber designed to search for weakly interacting massive particles (WIMP). The experiment will cover a large range of mass and cross section parameter space, proving a variety of theoretical models. The PICO collaboration has built a well established technology, easily scalable and relatively inexpensive with flexibility to easily exchange targets following a discovery. PICO-500L will be located two kilometres underground at SNOLAB, with the goal to maintain all backgrounds below one event per year. A careful study has been made using GEANT4 to provide guidance on the material and components purity, as well as shielding requirements, with the goal to maintain the overall neutron budget to less than one per year. Results from a detailed Monte Carlo simulation to estimate the expected backgrounds in the detector using C<sub>3</sub>F<sub>8</sub> as target material will be presented in this talk.

Dark Matter / 229

## Toward a next-generation dark matter search with the PICO-40L bubble chamber

**Author:** Scott Fallows<sup>1</sup>



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The PICO-60 bubble chamber has concluded its dark matter search runs using a superheated liquid  $C_3F_8$  target. Its replacement currently under commissioning, PICO-40L, is a redesigned bubble chamber with an inverted vertical orientation. This design allows the replacement of the water buffer with a second fused silica jar acting as a piston. The removal of the buffer fluid is intended to eliminate backgrounds caused by water droplets, particulates, and surface tension effects. This redesign also lifts buffer compatibility constraints on potential target fluids, allows a wider range of operating temperatures, and enables full target recirculation and purification. A larger stainless steel pressure vessel will reduce the expected neutron backgrounds to a level permitting a background-free 40L one-year exposure. In addition to its extended physics reach beyond that of PICO-60, this detector will act as a prototype and proof-of-principle for the proposed tonne-scale bubble chamber PICO-500.

**Dark Matter / 230**

## **Radiogenic neutron background predictions in DEAP-3600 and in situ measurements**

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Neutron-induced backgrounds are among the dominant backgrounds in low-background experiments. One of the main processes that produce these neutrons is the  $(\alpha, n)$  reaction occurring in detector components. An accurate understanding of these backgrounds is important for any low-background experiment. In this talk, we will present NeuCBOT, a new tool for calculating  $(\alpha, n)$  yields and neutron energy spectra in arbitrary materials. By combining NeuCBOT calculations with ex situ measurements of the radioactive contamination of detector components, we will predict the neutron backgrounds in the DEAP-3600 Weakly Interacting Massive Particle detector.

DEAP-3600 is a single-phase detector located at SNOLab with over three tonnes of liquid argon. When neutrons scatter in the liquid argon, they produce a scintillation signal that can be differentiated from most backgrounds using pulse shape discrimination. After the neutron scatters in the argon, it will slow down and eventually capture in one of the detector components. By detecting coincidences between the nuclear recoils in the liquid argon and the signal produced by neutron capture products, we can place an in situ constraint on the neutron background rate in the experiment. By doing so, we will show that the neutron background rate in DEAP-3600 is consistent with the predictions made by NeuCBOT.

**Poster Session / 231**

## **Resistive Materials for Low Background Time Projection Chambers**

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Time Projection Chambers (TPCs) are widely used in particle physics experiments, with noble element targets currently being used to search for neutrino-less double beta decay, look for interactions

of dark matter, and characterize the properties of neutrino oscillations. In order to further improve the sensitivity of these experiments, the next generation of proposed TPC detectors will contain tens to hundreds of tons of active target. Such large volume detectors require a large potential difference to maintain the desired drift electric field, corresponding to a significant amount of stored energy. Maintaining large voltages in noble element detectors has proven difficult and sudden discharges can damage nearby electronics and other detector components. The use of resistive materials can reduce the peak current produced during a discharge, thereby decreasing the likelihood of damage. In this poster we will survey different resistive materials for potential use in large, ultra-low background, noble TPCs, focusing on their radio-purity as well as their resistivity as a function of temperature.

**Poster Session / 232**

## Underwater Photometry System of the SNO+ experiment

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The SNO+ experiment is a large scale liquid scintillator-based experiment, adapting the Sudbury Neutrino Observatory (SNO) detector located at SNOLAB, Canada. The main physics goal is to investigate the Majorana nature of neutrinos through the search for the neutrinoless double-beta decay of  $^{130}\text{Te}$ . The camera system of the SNO+ is designed to photograph calibration sources and triangulate their locations with an accuracy of a couple of centimeters. This will lead to better calibrations and more accurate physics measurements in SNO+. The camera system, when operated in a special mode with underwater lights, turned on also allows monitoring of the physical state of the detector, including the position of the rope net using underwater cameras. Installed cameras have been used to determine the displacement of the acrylic vessel during the water fill. The LASER ball will be deployed soon in the water filled SNO+ detector which will give us an opportunity to test the position accuracy of the deployed source.

**Neutrino Parallel / 233**

## The Diffuse Supernova Neutrino Background: an update on the theory and detection prospects

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A new estimate of the diffuse supernova neutrino background (DSNB) is presented, for scenarios with different core collapse rates and different distribution of black-hole forming collapses with the progenitor mass. The  $\bar{\nu}_e$  component of the DSNB above 11 MeV of energy can be as large as  $\phi \sim 3.7 \text{ cm}^{-2}\text{s}^{-1}$ , and the contribution of black hole-forming collapses could dominate the flux above  $\sim 25 \text{ MeV}$ .

We discuss the potential of detecting the DSNB at SuperK-Gd and JUNO, in about a decade-long period of operation, including realistic neutral-current background processes. The case when results from the two detectors are examined jointly is considered as well. We also examine an example of a future  $\mathcal{O}(10) \text{ kt}$

slow liquid scintillator detector, and show that there the chances of detecting the DSNB could exceed 99%. Our results motivate stronger experimental efforts in reducing the lower energy backgrounds at SuperK-Gd.

Poster Session / 234

## The nEXO radioassay program

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The two neutrino double-beta decay of  $^{136}\text{Xe}$ , with a half-life of  $2.165 \pm 0.016(\text{stat.}) \pm 0.059(\text{syst.}) \times 10^{21}\text{y}$ , is among the rarest nuclear processes ever directly observed. The hypothesized neutrinoless double-beta decay of  $^{136}\text{Xe}$ , which nEXO aims to observe, is expected to be that much rarer, with a half-life of at least  $1 \times 10^{26}\text{y}$  at 90% C.L. Sufficient suppression of backgrounds is, therefore, crucial to making a discovery possible. The bulk of these backgrounds for nEXO are expected to result from radioactivity in the detector components. Reducing this background contribution to a sufficiently low level requires a comprehensive material screening program. This poster describes the techniques the nEXO Collaboration employs, built on the highly successful program developed by EXO-200, in the assay of candidate materials for nEXO components. A summary of recently released results of these efforts will also be presented.

Poster Session / 235

## The $\nu$ -cleus experiment: Gram-scale cryogenic calorimeters for a discovery of coherent neutrino scattering

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We investigate new gram-scale cryogenic detectors, 1-2 orders of magnitude smaller in size than previous devices. These are expected to reach unprecedentedly low energy thresholds, in the 10 eV-regime and below. This technology allows new approaches in rare-event searches, including the search for MeV-scale dark matter, detection of solar neutrinos and a rapid discovery of coherent neutrino-nucleus scattering (CNNS) at a nuclear reactor.

We show a simple scaling law for the performance of cryogenic calorimeters, allowing the extrapolation of existing device performances to smaller sizes. Measurement results with a 0.5 g sapphire detector are presented. This prototype reached a threshold of 20 eV, which is one order of magnitude lower than previous results with massive calorimeters.

We discuss an experiment, called  $\nu$ -cleus, which enables a 5- $\sigma$  discovery of CNNS within about 2 weeks of measuring time at 40 m distance from a power reactor. In a second stage, this experiment enables precision measurements of the CNNS cross-section and spectral shape for new physics beyond the Standard Model.

**Dark Matter / 236**

## **LZ Backgrounds and Mitigation**

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LZ will be a 10 ton dual-phase xenon Time Projection Chamber (TPC) searching for WIMP dark matter via direct detection. In order to achieve our desired sensitivity, we require an extremely radiopure environment. Gamma backgrounds originate outside of the bulk xenon and are mitigated by xenon's self-shielding properties, as well as our position reconstruction and veto capabilities. More challenging are Kr-85 and Rn-222 because they are dissolved throughout the active region. This talk will comprehensively address our plans to reduce and mitigate backgrounds throughout construction, operation, and analysis.

**New Technologies / 237**

## **Dark Matter Searches with the Micro-X Sounding Rocket**

**Author:** Antonia Hubbard<sup>1</sup>

<sup>1</sup> *Northwestern University*

The Micro-X sounding rocket uses a Transition Edge Sensor (TES) array to make X-ray observations. The improved energy resolution of TESs compared to traditional space-based X-ray detectors brings new precision to both supernova remnant observations and the X-ray search for sterile neutrino dark matter. Current X-ray observations disagree over the potential presence of a 3.5 keV X-ray line consistent with a sterile neutrino interaction, and Micro-X is in a unique position to establish or refute the presence of this line. I will present the construction status of the instrument and expectations for flight observations, with special emphasis given to the prospects of sterile neutrino studies.

**Neutrino Parallel / 238**

## **Status of the SNO+ Experiment**

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The SNO+ experiment is located at SNOLAB in Sudbury, Ontario, Canada. It will employ 780 tons of liquid scintillator loaded, in its initial phase, with 1.3 tons of <sup>130</sup>Te (0.5% by mass) for a low-background and high-isotope-mass search for neutrino-less double beta decay. SNO+ uses the acrylic vessel and PMT array of the SNO detector with several experimental upgrades and necessary adaptations to fill with liquid scintillator. The SNO+ technique can be scaled up with a future high loading Phase II, able to probe to the bottom of the inverted hierarchy parameter space for effective Majorana mass. Low backgrounds and a low energy threshold allow SNO+ to also have other physics topics in its program, including geo- and reactor neutrinos, Supernova and solar neutrinos. This talk will describe the SNO+ approach for the double-beta decay program, the current status of the experiment and its sensitivity prospects.

Neutrino Parallel / 239

## The Hyper-K near detector programme

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The proposed Hyper-Kamiokande experiment (Hyper-K) is a next generation large water Cherenkov (WD) detector with a broad physics program consisting of neutrino beam measurements in search of leptonic CP violation, astrophysical measurements and a search for proton decay. Hyper-K will act as the far detector to measure the oscillated neutrino flux from the long-baseline beam of 0.6 GeV neutrinos/anti-neutrinos produced by a 1.3 MW proton beam at J-PARC in Japan. To minimise systematic uncertainties, particularly due to flux and cross-section uncertainties, detailed measurements of the unoscillated flux are required with a suite of near detectors. This talk will review the challenges, and present the planned components of the near detector measurement suite, including a new intermediate Water Cherenkov Detector.

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## Stimulated X-rays in resonant atom Majorana mixing

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Massive neutrinos demand to ask whether they are Dirac or Majorana particles. Majorana neutrinos are an irrefutable proof of physics beyond the Standard Model. Neutrinoless Double Electron Capture is not a process but a virtual  $\Delta L = 2$  Mixing between a parent  ${}^A Z$  atom and a daughter  ${}^A(Z-2)$  excited atom with two electron holes. As a mixing between two neutral atoms and the observable signal in terms of emitted two-hole X-rays, the strategy, experimental signature and background are different from neutrinoless double beta decay. The mixing is resonantly enhanced for almost degeneracy and, under these conditions, there is no irreducible background from the standard two-neutrino channel. We reconstruct the natural time history of a nominally stable parent atom since its production either by nature or in the laboratory. After the time periods of Atom Oscillations and the decay of the short-lived daughter atom, at observable times the relevant “stationary” states are the mixed metastable long-lived state and the short-lived excited state, as well as the ground state of the daughter atom. Their natural population inversion is most appropriate for exploiting the bosonic nature of the observed X-rays by means of stimulating X-ray beams. Among different observables of the Atom Majorana Mixing, we include the enhanced rate of Stimulated X-ray Emission from the long-lived metastable state by a high-intensity X-ray beam. A gain factor of 100 can be envisaged in a facility like European XFEL.

Dark Matter / 241

## MiniBooNE-DM: a dark matter search in a proton beam dump

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In a dedicated run where protons from the Fermilab Booster were delivered directly to the steel beam dump of the Booster Neutrino Beamline, the MiniBooNE detector was used to search for the production of dark matter particles via vector-boson mediators, as predicted by vector portal models of dark matter. In the scenario that was considered, the interactions of the dark matter particles are mediated by a “dark photon” that kinetically mixes with the ordinary photon, and four parameters determine the physics: the dark matter mass, the mediator mass, the kinetic mixing parameter, and the dark sector coupling. The signal searched for was the elastic scattering of dark matter particles off nucleons in the detector mineral oil, with neutrinos being an irreducible background. Within the model considered, the results obtained provide the best limits on the dark matter annihilation parameter, in the dark matter mass range from 0.01 to 0.3 GeV, for a value of the dark sector coupling consistent with theoretical bounds. The result also excludes a vector mediator particle solution to the  $g-2$  anomaly. Our analysis was motivated by the vector portal model, however, other low-mass dark matter models are also possible. In this talk we will review the experiment, the analysis methods, and present the results, which demonstrate that beam dump experiments provide a novel and promising approach to dark matter searches.

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## CDEX dark matter experiment: status and prospects

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The China Dark Matter Experiment (CDEX) aims at direct searches of light Weakly Interacting Massive Particles (WIMPs) at the China Jinping Underground Laboratory (CJPL) with an overburden of about 2400m rock. Results from a prototype CDEX-1 994 g p-type Point Contact Germanium(pPCGe) detector are reported. Research programs are pursued to further reduce the physics threshold by improving hardware and data analysis. The CDEX-10 experiment with a pPCGe array of 10 kg target mass range is being tested. The evolution of CDEX program into “CDEX-1T Experiment” with ton-scale germanium detector arrays, aiming at both Dark Matter and Neutrinoless Double Beta Decay, will also be introduced in this study.

Cosmology, Gravitational Waves, & Cosmic Rays / 243

## Cosmic Rays Investigation by the PAMELA experiment

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PAMELA (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) is a satellite-borne experiment. It was launched on June 15th 2006 from the Baikonur space centre on board the Russian Resurs-DK1 satellite. For about 11 years PAMELA took data, giving a fundamental contribution to the cosmic ray physics. It made high-precision measurements of the charged component of the cosmic radiation challenging the standard model of the mechanisms of production, acceleration and propagation of cosmic rays in the galaxy and in the heliosphere.

PAMELA gave results on different topics on a very wide range of energy. Moreover, the long life of PAMELA gives the possibility to study the variation of the proton, electron and positron spectra during the last solar minimum. The time dependence of the cosmic-ray protons and helium nuclei from the solar minimum through the following period of solar maximum activity is currently being studied. Low energy particle spectra were accurately measured also for various solar events that occurred during the PAMELA mission.

In this talk a review of main PAMELA results, together with the latest analysis updates, will be shown.

**Dark Matter / 244**

## Dark Kinetic Heating of Neutron Stars

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I will discuss how future measurements of infrared emission from nearby neutron stars can be used as a largely model-independent probe of dark matter interactions with Standard Model particles. This relies on a recently discovered effect that even non-annihilating dark matter has on old neutron stars. The resulting sensitivity to dark matter interactions would exceed the reach of many terrestrial dark matter searches, extending well below the neutrino floor for both light and heavy dark matter, and would also uncover elusive “pure higgsino” dark matter.

**Dark Matter / 245**

## The DAMIC Experiment at SNOLAB

**Authors:** Alvaro Chavarria<sup>1</sup>; DAMIC Collaboration<sup>None</sup>

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Millimeter-thick charge-coupled devices (CCDs) are outstanding particle detectors. Although initially developed for near-infrared astronomy, the low pixel noise also makes them the most sensitive detectors to signals from ionizing radiation. By virtue of their very low energy threshold ( $<100$  eV of ionizing energy) and their unique capabilities for background characterization based on their high spatial resolution, CCDs are poised to become the leading technology in the search for a wide variety of dark matter candidates with masses in the range  $1$  eV/c/c –  $10$  GeV/c/c. I will present the status of the DAMIC100 experiment, an ongoing direct dark matter search consisting of an array of 16 Mpixel CCDs hosted in the SNOLAB underground laboratory. I will also discuss the recent progress toward DAMIC-1K, a lower-radioactivity 1-kg CCD dark matter detector with an ionization threshold of 2 electrons.

Poster Session / 246

## Thermal Behaviors of the Strong Form Factors of Charmonium and Charmed Beauty Mesons from Three Point Sum Rules

**Authors:** Hayriye Sundu<sup>1</sup>; Elsen Veli Veliev<sup>1</sup>; Enis Yazıcı<sup>None</sup>

<sup>1</sup> *Kocaeli University*

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In order to understand the nature of strong interactions and QCD vacuum, investigation of the meson coupling constants have an important role. The knowledge on the temperature dependence of the form factors is very important for the interpretation of heavy-ion collision experiments. Also, more accurate determination of these coupling constants plays a crucial role in understanding of the hadronic decays. With the increasing of CM energies of the experiments, researches on meson interactions have become one of more interesting problems of hadronic physics.

In this study, we analyze the temperature dependence of the strong form factor of the  $B_c B_c J/\psi$  vertex using the three point QCD sum rules method. Here, we assume that with replacing the vacuum condensates and also the continuum threshold by their thermal version, the sum rules for the observables remain valid. In calculations, we take into account the additional operators, which appear in the Wilson expansion at finite temperature. We also investigated the momentum dependence of the form factor at  $T = 0$ , fit it into an analytic function, and extrapolate into the deep time-like region in order to obtain a strong coupling constant of the vertex. Our results are consistent with the results existing in the literature.

Supernova Neutrinos / 247

## Supernova Neutrinos

**Author:** Irene Tamborra<sup>None</sup>

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Neutrinos are key particles in core-collapse supernovae. Intriguing recent developments on the role of neutrinos during the stellar collapse will be discussed, as well as our current understanding of the flavor conversions in the stellar envelope. Detection perspectives of the next galactic burst and of the diffuse supernova neutrino background will be also outlined.

Neutrino Parallel / 248

## New Measurement of Atmospheric Neutrino Oscillations with IceCube

**Author:** Tyce DeYoung<sup>1</sup>

<sup>1</sup> *Michigan State University*

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The DeepCore infill array of the IceCube Neutrino Observatory enables observations of atmospheric neutrinos with energies as low as 5 GeV. Using a set of 40,000 neutrino events with energies ranging from 5.6 - 56 GeV recorded during three years of DeepCore operation, we measure the atmospheric oscillation parameters  $\theta_{23}$  and  $\Delta m_{32}^2$  with precision competitive with long-baseline neutrino experiments, by observing distortions in the neutrino energy-zenith angle distribution. Our measurements are consistent with those made at lower energies, and prefer a value of  $\theta_{23}$  close to maximal.



**Outreach / 249**

## **How to translate $(A, Z) \rightarrow (A, Z + 2) + 2e^-$ into a Public Knowledge?**

**Author:** Hoi Cheu<sup>1</sup>

<sup>1</sup> *Laurentian Univeristy*

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This presentation will outline the basic rhetorical principles for successful translation of scientific ideas into public knowledge. It will specifically focus on the definition of humans as a “Story Species” and demonstrate the art of science communication by turning the neutrinoless double beta decay equation into an intelligent story.

**Poster Session / 250**

## **ARAPUCA: a highly efficient device for photon collection in LArTPCs**

**Authors:** Gustavo Cancelo<sup>1</sup>; Flavio Cavanna<sup>2</sup>; Carlos Escobar<sup>3</sup>; Ernesto Kemp<sup>4</sup>; Ana Amelia Bergamini Machado<sup>5</sup>; Franciole da Cunha Marinho<sup>6</sup>; Laura Paulucci Marinho<sup>5</sup>; Adam Para<sup>3</sup>; Ettore Segreto<sup>7</sup>; David Warner<sup>8</sup>

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For the next generation of large neutrino detectors the Liquid Argon Time Projection Chambers (LArTPCs) are the best choice for optimal performance in particle tracking and calorimetry. The detection of Ar scintillation light plays a crucial role in the event reconstruction as well as time reference for non beam physics such as supernovae neutrinos detection and baryon number violation studies. In this contribution we present an innovative device, the so called ARAPUCA, to enhance Ar scintillation light collection and thus the overall performance of LArTPCs. The ARAPUCA is based on a suitable combination of dichroic filters and wavelength shifters to achieve a high efficiency in light collection. We discuss the operational principles, the current design for the protoDUNE detector and the results of last laboratory tests. Moreover, after appropriate modifications, it can also be used in Dark Matter experiments based on noble gases/liquids detectors.

**Labs and Low Background / 251**

## **Ultra-Low-Background Material Screening with the BetaCage Time Projection Chamber**

**Authors:** Raymond Bunker<sup>1</sup>; Sunil Golwala<sup>2</sup>; Richard Schnee<sup>3</sup>; Boqian Wang<sup>None</sup>; Darren Grant<sup>4</sup>; Michael Bowles<sup>5</sup>; Eric Miller<sup>3</sup>

<sup>1</sup> *Pacific Northwest National Laboratory*

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High-sensitivity, low-threshold material surface screening is necessary to meet the stringent radiopurity requirements for rare-event searches. The BetaCage is a proposed ultra-low-background time projection chamber (TPC) designed to screen alphas and low-energy betas emitted from material surfaces at trace levels, providing a transformative effect on isotopic assay efforts. I will describe the TPC design, the expected backgrounds and mitigation techniques, the estimated alpha and beta sensitivity, and the commissioning of a prototype TPC currently deployed at SDSM&T.

**Poster Session / 252**

## RED SHIFT OF LIGHT FROM THE GALAXIES YES, EXPANDING UNIVERSE NO!

**Author:** satish malhotra<sup>1</sup>

<sup>1</sup> *free lance researcher, no affiliation*

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In the history of physics, ideas on space and time have changed the course of physics a number of times; this is another such event. This time, we postulate 'space and time' as a flow of quantum gravity energy, having the absolute velocity  $c$  (same as velocity of light), where time is the delay in the spread of space (delay from infinite velocity flow, when there would be no time), such a flow has to have a reverse cycle, as energy creating it (howsoever large it might be has to be limited and limited energy can only create a limited space and time energy spread) and the reverse cycle is that of the creation of fundamental particles. This explanation of the universe (space and time not spacetime), as energy flow having a reverse cycle as its base, tells us that the idea of an expanding universe is prime facie wrong.

The problem has been that we have gone along too far with the perception of the relativistic world that Einstein built over 100 years. Einstein had no hesitation in accepting the idea of absoluteness of the velocity of light but never thought of giving the same absoluteness to space (and time) as a flow having the same absolute velocity  $c$  (the universal constant of nature). We change it to add that space (and time) is an absolute flow of quantum gravity. With this change, relativity dependent cosmology, also has to change and change drastically. This new reasoning on space and time—as a flow of energy—leads us to show that expansion of the universe is only an appearance, reality is far away from it. And why is it only an appearance? The argument, in brief, is as follows: One, the universe is so large that we cannot see the edges, light from the edges takes far too long to reach us, there is a theoretical limit to possible visibility, thus, we have to refute its unlimitedness by theoretical considerations only; the reality is non-observable. Two, the process is dark, it is beyond observation, the process of creation of charge (the reflection of light starts with it), the space energy flow process is in the range of invisible (before charge emerged); it is the elusive dark energy that constitutes 74% of the total energy of the universe; we never connected space and time to flow of energy, and so did not find its connection either to its limitedness or to its dark nature (dark energy). Three, the space energy flow has a reverse process which leads to the formation of fundamental particles we have not included it in the totality of the processes of the universe, the former is the dark energy and the initial part of the reverse process—till it reaches the state of ionisation—is dark matter. In the continuity of the cycle of space flow and its reversal to matter forms, ionisation happens at a particular point and visibility comes through along with; ionisation here is a later event (which is a part of the reverse process, enters visibility). It is this reverse process which creates fundamental

particles (no big bang, the creation of particles is here and now). With no idea of space as energy flow and no idea of the reverse process, physicists could never take the step in the direction of the correct understanding of the 'dark energy' or 'dark matter'. Along with the correct understanding of the dark matter and the dark energy, enters another conclusion of great importance: the limitedness of the universe means it is closed from all ends, it is like a crucible of huge dimensions, thus CMB is not radiation from primordial past, it is something which is happening here and now. Thus, one correction—space is an absolute flow of quantum gravity, emerging probably from the binary black holes—changes every understanding of cosmology.

This is one stone—space is an absolute flow of quantum gravity—kills (correctly explains) four birds (issues): explains the not expanding universe, explain what dark energy is, explain what dark matter is and it tells us that CMB is not radiation from primordial past. The lack of one entity—absoluteness of space and time—has led us to the wrong conclusion on each of the four issues, biggest of all being: the inflationary universe (and its subsequent conclusion to its Big Bang creation).

## Poster Session / 253

### Current Status and Projected Sensitivity of COSINE-100

**Author:** William Thompson<sup>1</sup>

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COSINE-100, a direct detection WIMP dark matter search, is using 106 kg of NaI(Tl) crystals to definitively test the DAMA collaboration's claim of WIMP discovery. Despite astrophysical considerations indicating that dark matter constitutes approximately 27% of the energy content of the universe, only the DAMA collaboration claims to have observed dark matter. This observation is in the form of a dark matter-induced annually-modulating event rate within NaI(Tl) crystals, which they observe to a significance of  $9.3\sigma$ . However, this result is in conflict with other experiments in the field within most models of WIMP dark matter. To resolve the tension in the field, COSINE-100 seeks to independently observe this annual modulation using the same detector material, definitively confirming or refuting DAMA's claim of WIMP discovery. Here, I present the current status and projected sensitivity of COSINE-100, along with the projected sensitivity of the next phase of the experiment, COSINE-200.

## Labs and Low Background / 254

### The Sanford Underground Research Facility

**Author:** Jaret Heise<sup>1</sup>

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The former Homestake gold mine in Lead, South Dakota, has been transformed into a dedicated facility to pursue underground research in rare-process physics, as well as offering unique research opportunities in other disciplines. The Sanford Underground Research Facility (SURF) includes two main campuses at the 4850-foot level (4300 m.w.e.) –the Davis Campus and the Ross Campus –that host a range of significant physics projects: the LUX dark matter experiment, the MAJORANA DEMONSTRATOR neutrinoless double-beta decay experiment and the CASPAR nuclear astrophysics accelerator. Furthermore, the BHUC Ross Campus laboratory dedicated to critical material assays for current and future experiments has been operating since Fall 2015. Research efforts in biology, geology and engineering have been underway at SURF for almost 10 years and continue to be a strong component of the SURF research program. Plans to accommodate future experiments at SURF are well advanced and include geothermal-related projects, the next generation direct-search

dark matter experiment LUX-ZEPLIN (LZ) and the Fermilab-led international Deep Underground Neutrino Experiment (DUNE) at the Long Baseline Neutrino Facility (LBNF). SURF is a dedicated research facility with significant expansion capability, and applications from other experiments are welcome.

**Dark Matter / 255**

## **Dark matter in models with Higgs aligned gauge groups**

**Author:** Rainer Dick<sup>1</sup>

<sup>1</sup> *University of Saskatchewan*

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The Higgs can couple to  $SU(2) \times U(1) \times SU'(2) \times U'(1)$  models in such a way that the diagonal vector-like  $SU(2) \times U(1)$  corresponds to the electroweak gauge symmetry. This leads to a new class of Higgs portal dark matter models within reach of direct search experiments. I will introduce the corresponding dark matter models and their implications for direct search experiments. If time permits, I will also discuss renormalizable extensions of the dark sector in these models.

**New Technologies / 256**

## **Metal Loading in Organic Liquid Scintillator**

**Author:** Mark Chen<sup>1</sup>

<sup>1</sup> *Queen's University*

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This presentation will provide a review of past and current techniques used to load metals in organic liquid scintillator. Both the techniques and their applications will be discussed.

**Poster Session / 257**

## **Enriched isotopes for low background experiments: Supplier's vision**

**Author:** Olga Babintceva<sup>1</sup>

<sup>1</sup> *JSC Isotope, ROSATOM, Russia*

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The increased demand of scientific collaborations for large quantities of enriched isotopes is a growing trend and shall be taken seriously by the global suppliers of isotope products. This trend opens up new opportunities for scientists to bring their experiments to a higher level. Speaking of the next generation of low-background experiments it is important to focus on 3 key factors impacting success of cooperation between scientific collaborations and suppliers:

1. **Quality of material.** The enriched material must meet strict requirements for high chemical and radioactive purity. Apart from producing top-quality material, the supplier shall have capability to measure and certify it. For example, under clients request it makes possible to measure specific activity of Ra-226 in high-purity germanium detector situated more than 5000 meters under the sea level in the Caucasus Mountains.
2. **The Supplier's expertise and product portfolio.** Production capacities allowing to manufacture up to hundreds of kilos is a distinct advantage as well as extensive expertise in supplying enriched materials of different forms to various customer categories.
3. **Communication with the Supplier.** Before scheduling procurement it's essential for scientific collaborations to build the dialog with the Supplier and to have a clear understanding what quantities of enriched isotopes can be produced within required time. Orders for large scale production shall be placed in advance and this obvious statement shall be obligatory taken into account during preparation phase of the experiments. Close communication between Supplier and scientific collaboration is a key to make material procurement smooth and stressless.

Rosatom State Corporation isotope complex represented by JSC Isotope is the world's largest supplier of enriched isotopes. This year the company has already successfully supplied Mo-100 to AMoRE project and Ge-76 to GERDA experiment.

During the presentation the speaker will pay attention to Rosatom State Corporation capacities in the field of stable isotope production as well as share the experience of cooperating with scientists while being the supplier for international scientific experiments.

## Results PICO experiment / 258

### PICO Results and Outlook

**Author:** Carsten Krauss<sup>1</sup>

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The PICO collaboration has operated several generations of dark matter detectors at SNOLAB. The most recent results of the PICO 60 experiment and the plans for future superheated liquid dark matter detectors will be presented.

## Poster Session / 259

### UNDERSTANDING DARK ENERGY AND DARK MATTER

**Author:** satish malhotra<sup>1</sup>

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Gravity is known to be a contracting force. But if it is a constant and absolute velocity (same as velocity of light) flow— that creates space and time itself— it becomes an expanding force—of course till the backup of the constant and consistent force (putting space as a flow and time as the delay in the flow from infinite value) continues. Applied this way, gravity though a contracting force also becomes a 'pushing' force or 'an expanding' force where 'the pushing creating space (and time) flows' . We may give the analogy of two forces balancing each other (in the same way as a balloon has a balance between the pressure of the air inside which tries to expand the balloon with the same fundamental tension (by more and more energy addition), the rubber which tries to make the balloon contract) the massive force (of gravitational energy by its sheer power is pushing gravitational

energy to be retained in space flow (a contracting coiling force), and the two can only balance when the massive force has had its way to reach the end point where the two remain balanced. If the massive force weans the space at the outmost fringe end will move inwards and if more energy is added from some radiating matter, it will expand (in the balloon analogy the balloon expands or contracts according to if more air is pumped into it or some flows out of it). Space and time for us can be summed up as: a flow which is a scalar field of gravity with zero potential difference across its entire range ( $\Delta c, \Delta \text{square}=0$ ); it is the dark energy which is a constant, consistent flow which has no break in between (if one wave comes to an end there are others following it up). It has an absolute velocity, it has constant density, has no difference in its uniformity across its entirety, it also has an absolute rotation of the quanta constituting it (duration of the time created is this unchangeable rotation or the delay in the flow from infinite velocity).

Whenever and wherever energy flow weans the reverse process of the formation of fundamental particles begins (within it the process also has the creation of charge included, the presence of charge and visibility are intimately connected). The creation of fundamental particles did not happen in the big bang, the energy flow that is space (and time) in its reverse cycle creates it and up to the level of the emergence of charge this too like the energy creating the space flow do not reflect light so are dark. This is why the energy creating space flow is invisible and dark (dark energy) and its reverse cycle till the creation of charge is dark (dark matter). Dark energy and Dark matter are both objective realities of a cycle, non- expanding universe, where former is the absolute flow of gravity is space (and time) flow itself and the latter is its reverse cycle that creates fundamental particles (dark till ionization and the process of the reflection of light has not emerged). All in all space and time flow it is the quantum gravity energy flow which has constant density, no difference in its uniformity ( $\Delta c, \Delta \text{square}=0$ ), absolute velocity, absolute rotation of the quanta constituting it (duration of the time created is this unchangeable rotation and the delay in the flow from infinite velocity); it is a scalar field- constant consistent no break in between, if one wave comes to an end there are others following it up) flow- with zero potential difference at any place and absolutely flat (as long as it is away from matter forms) is dark energy and its reverse cycle is in its initial stages i.e. till ionization happens is dark energy. This model of the universe—as well as that of dark energy and dark matter—as well as the complete different explanation of physics and cosmology that goes with this new construction of space and time—is a falsifiable one. One empirical observation against it and the model goes, it is asserted that not a single observation of all the innumerable observations the experimental cosmologist have made will contradict this proposition.

## Indirect Dark Matter Plenary / 260

### Indirect Dark Matter Searches

**Author:** Carsten Rott<sup>1</sup>

<sup>1</sup> *Sungkyunkwan University*

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Indirect searches for dark matter are a cornerstone in the dark matter particle identification program. Searches for stable messenger particles produced as part of the self-annihilation or decay of dark matter have resulted in stringent bounds on dark matter properties. Searches with gamma-rays, neutrinos, and charged cosmic-rays will be summarized and constraints on the dark matter self-annihilation cross section, lifetime, and interaction with ordinary matter will be reviewed. The talk will conclude with an outlook in the discovery potential at current and next-generation dark matter search experiments.

## Direct Dark Matter Searches (WIMPS) / 261

### Overview of the Current Status of Direct Dark Matter Detection

**Author:** Nigel Smith<sup>1</sup>

<sup>1</sup> *SNOLab***Corresponding Author:** nigel.smith@snolab.ca

The direct dark matter detection field is entering an intriguing period where tonne-scale high-mass-WIMP-search detector systems are coming on-line, along with new systems focussed on low-mass-WIMP and spin-dependent-interaction searches. These detector systems open up new parameter space for detection of dark matter, with the projected sensitivities of subsequent generation detectors approaching those required to observe coherent neutrino scattering. This talk will overview the current status of the direct detection field, outlining current techniques and sensitivities, and survey the future potential of the field.

Neutrino Parallel / 262

## Scanning the Earth with solar neutrinos and DUNE

**Authors:** Ara Ioannisyian<sup>1</sup>; Alexei Smirnov<sup>2</sup>; Daniel Wyler<sup>None</sup><sup>1</sup> *A.Alikhanyan National Laboratory (AM)*<sup>2</sup> *ICTP***Corresponding Authors:** smirnov@ictp.it, wyler@physik.unizh.ch, ara.ioannisyian@cern.ch

We explore oscillations of the solar 8B neutrinos in the Earth in detail. The relative excess of night ve events (the Night-Day asymmetry) is computed as function of the neutrino energy and the nadir angle  $\eta$  of its trajectory. The finite energy resolution of the detector causes an important attenuation effect, while the layer-like structure of the Earth density leads to an interesting parametric suppression of the oscillations. Different features of the  $\eta$ -dependence encode information about the structure (such as density jumps) of the Earth density profile; thus measuring the  $\eta$  distribution allows the scanning of the interior of the Earth. We estimate the sensitivity of the DUNE experiment to such measurements. About 75 neutrino events are expected per day in 40 kt. For high values of  $\Delta m_{221}$  and  $E_{\nu} > 11$  MeV, the corresponding D-N asymmetry is about 4% and can be measured with 15% accuracy after 5 years of data taking. The difference of the D-N asymmetry between high and low values of  $\Delta m_{221}$  can be measured at the  $4\sigma$  level. The relative excess of the  $\nu_e$  signal varies with the nadir angle up to 50%. DUNE may establish the existence of the dip in the  $\eta$ -distribution at the  $(2-3)\sigma$  level.

New Technologies / 263

## Results from ANNIE Phase 1 and Plans for Phase 2

**Author:** Robert Svoboda<sup>1</sup><sup>1</sup> *UC Davis***Corresponding Author:** rsvoboda@physics.ucdavis.edu

The Accelerator Neutrino Neutron Interaction Experiment (ANNIE) has two main goals: (1) a precision measurement of final state neutron multiplicity in neutrino interactions as a function of momentum transfer in the range of 0.5-1.5 GeV, and (2) first deployment and performance characterization of Large Area Picosecond Photo Detectors (LAPPDs) for use in future neutrino experiments. ANNIE Phase 1 was constructed in 2015 in the Booster Neutrino Beam at Fermilab in order to measure the background neutron flux to confirm the feasibility of accomplishing these two goals. The preliminary results from Phase 1 are presented along with sensitivity studies for Phase 2.

**Axions / 264**

## Overview of Axion Searches

**Author:** Gianpaolo Carosi<sup>1</sup>

<sup>1</sup> *Lawrence Livermore National Laboratory*

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The nature of dark matter is one of the great mysteries of modern physics and may be the result of new particles beyond the standard model. The Axion, originally conceived as a solution to the strong-CP problem in nuclear physics, is one well-motivated candidate. In 1983 Pierre Sikivie proposed an experimental search technique, known as an axion haloscope, that relies on a large microwave cavity immersed in a strong static magnetic field to resonantly convert dark matter axions to detectable photons. This became the foundation of the Axion Dark Matter eXperiment (ADMX), which has recently began taking data at unprecedented sensitivity in the classical QCD-axion mass range of several

micro-eV. In addition, several new detection techniques have been proposed to cover a large span of potential axion masses beyond that of the classical window. There also exist a set of experiments that look for axions generated in the sun, from intense laser sources and from modifications to force of gravity at short range. In this talk I will describe the history of axion searches and give a survey of the R&D efforts currently underway to explore the entire potential axion mass window.

**New Technologies / 265**

## New Technologies for Gadolinium loading Super Kamiokande

**Author:** Matthew Murdoch<sup>1</sup>

<sup>1</sup> *Kavli IPMU, University of Tokyo*

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After more than 20 years of data taking and analysis, Super-Kamiokande (SK) will undergo a major upgrade through the addition of 0.2% gadolinium sulfate by mass to its ultra-pure water. This will allow the efficient detection of neutrons, giving access to new physics signals while improving sensitivity to existing ones.

While this upgrade promises many improvements, there were several technical challenges to overcome before its implementation. To address these challenges a dedicated 200-ton gadolinium test facility, EGADS (Evaluating Gadolinium's Action on Detector Systems), was constructed in the Kamioka mine. EGADS has now been stably taking data at the target 0.2% loading for over two years. During this period it has maintained SK levels of water transparency with no detectable loss of gadolinium, successfully proving the concept of gadolinium-doped water Cherenkov technology. With this demonstration complete, EGADS itself is currently undergoing an upgrade and re-branding to EGADS (Employing Gadolinium to Autonomously Detect Supernovae). This upgrade will see new electronics and DAQ installed and real-time reconstruction implemented so that EGADS can autonomously detect and announce a galactic supernova should one occur.

This talk will discuss new technologies developed for EGADS and a gadolinium loaded SK.

**Labs and Low Background / 266**



## The purification study on the Liquid Scintillator for JUNO

**Author:** Boxiang Yu<sup>None</sup>

**Co-authors:** Li Zhou<sup>1</sup>; Gioacchino Ranucci<sup>2</sup>; Tao Hu<sup>3</sup>; Paolo Lombardi<sup>4</sup>; Jian Fang<sup>5</sup>

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JUNO (Jiangmen Underground Neutrino observatory) will use 20 ktons high light yield, high transparency and low background Liquid Scintillator (LS). The purification of LS is very important work of JUNO construction. This talk introduced the status of the JUNO LS purification. The pilot plant of four purification systems (Al<sub>2</sub>O<sub>3</sub> absorption, distillation, water extraction and steam stripping) was constructed. The 20 tons purified LS is under the measurement. Several months later, we will get all the result of pilot plant purified LS.

**New Technologies / 267**

## Theia - A water-based liquid scintillator detector

**Author:** Leon Pickard<sup>1</sup>

<sup>1</sup> *UC Davis*

Theia is a proposed multipurpose 50kT water-based liquid scintillator (WbLS) detector that aims to use the latest high precision photodetectors. WbLS is a novel scintillation medium that combines the high light yield and low-energy threshold properties of liquid scintillation, with the directionality and low attenuation length of water. This talk will discuss the principles of WbLS, ongoing research and development, and the expansive future physics potential of Theia.

**Absolute Neutrino Mass / 268**

## Absolute Neutrino Mass

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Since the discovery of neutrino oscillation we know that neutrinos have non-zero masses, but we do not know the absolute neutrino mass scale, which is as important for cosmology as for particle physics. The direct search for a non-zero neutrino mass from endpoint spectra of weak decays is complementary to the search for neutrinoless double beta-decay and analyses of cosmological data.

The next generation experiment KATRIN, the Karlsruhe Tritium Neutrino experiment, is under commissioning. It will improve the best current limits from the tritium beta decay experiments by one

order of magnitude down to 200 meV probing the region relevant for structure formation in the universe. KATRIN uses a strong windowless gaseous molecular tritium source combined with a large acceptance and high energy resolution MAC-E-Filter as electron spectrometer. In October 2016 KATRIN celebrated “first light”: For the first time electrons from a photoelectron source were flying from the very rear over the full beamline of 70m length to the detector. In July 2017 KATRIN is performing an intensive calibration campaign with Kr-83m conversion electrons from the windowless gaseous source (still without tritium) and a condensed source.

To overcome the problem that KATRIN is using a close to opaque source already to obtain the required statistics, new technologies are developed to potentially improve the sensitivity on the neutrino mass: Project 8 is performing spectroscopy of the synchrotron radiation of gyrating electrons in a KATRIN-like source; ECHO, HOLMES and NuMECS are investigating the endpoint region of the electromagnetic deexcitation spectrum of Ho-163 electron capture with arrays of high energy resolution cryo-bolometers.

In this talk data from the commissioning of KATRIN and an outlook on the tritium data taking starting 2018 will be presented as well as a report on other up-coming direct neutrino mass approaches.

#### New Technologies / 269

### The WATCHMAN Demonstration: Remote Reactor Monitoring Using a Gadolinium-Doped Water Cherenkov Detector

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The emission of antineutrinos from fission products in nuclear reactors offers a path to discover, monitor, or exclude the existence of reactors at distances of tens to hundreds of kilometers. The WATCHMAN (WATER Cherenkov Monitor of AntiNeutrinos) experiment is a proposed kiloton volume gadolinium-doped water Cherenkov detector designed to demonstrate this capability. Antineutrinos are detected in WATCHMAN through the delayed coincidence signal produced by an inverse beta decay event. The gadolinium acts as a neutron capture agent, boosting the delayed signal energy from a 2.2 MeV gamma (released following deuteron formation) to an average of 8 MeV released following a neutron capture on gadolinium. The boost in the delayed signal energy considerably reduces otherwise overwhelming background rates; depending on the chosen construction site, WATCHMAN will observe a few antineutrino events per day, with similar background event rates. The primary goal of the WATCHMAN experiment is to demonstrate the tracking of a nuclear reactor's operation at a 10-25 km standoff. Successful deployment would also pave the path towards operating 100 kiloton –1 megaton volume gadolinium-doped water antineutrino detectors, a necessary step for ~100 km distance monitoring.

#### New Technologies / 270

### Event Reconstruction Techniques for a (Water-based) Liquid Scintillator Detector

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By reconstructing the arrival position and time of photons produced in water or liquid scintillator on highly segmented fast photo-detectors one can reconstruct tracks by using the 'drift time' of photons, much as one does with electrons in a Time Projection Chamber. I will present recent advances in event reconstruction techniques that are being developed in the context of a recently proposed THEIA detector with a broad physics program including neutrinoless double beta decay, solar neutrinos, geo-neutrinos, supernova neutrinos, nucleon decay, and long baseline neutrino physics.

**DEAP-3600 Results / 272**

## Dark Matter search with DEAP-3600 at SNOLAB

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DEAP-3600 is a novel experiment searching for dark matter particle interactions on 3.6 tonnes of liquid argon at SNOLAB. The argon is contained in a large ultralow-background acrylic vessel viewed by 255 8-inch photomultiplier tubes. Very good pulse-shape discrimination has been demonstrated for scintillation in argon, and the detector has been designed to allow control of (alpha,n) and external neutron recoils, and surface contamination from  $^{210}\text{Pb}$  and radon daughters, allowing an ultimate sensitivity to spin-independent scattering of  $10^{-46} \text{ cm}^2$  per nucleon at 100 GeV mass. After several years of construction, data collection has begun late 2016. Details of the detector construction, commissioning and first analysis results from the experiment will be presented.

**Accelerator Dark Matter Searches at CERN / 273**

## Accelerator Dark Matter Searches

**Corresponding Author:** kristian.hahn@cern.ch

Searches for dark matter (DM) have become a major focus of the LHC physics programmes. Run-2 DM results from the ATLAS and CMS experiments showcase the ability of collider searches to compliment the sensitivity of direct and indirect detection experiments. In this talk, we review the strategy and status of DM searches in ATLAS and CMS, and show how recent results strongly constrain models of WIMP DM. We explore the unique sensitivity of several DM search channels and highlight LHC constraints on low mass DM and spin-independent DM couplings. We consider the likely evolution of the ATLAS and CMS search programmes in Run-2 and conclude with a discussion of new ideas for extending the reach of future DM searches at the LHC.

**Dark Matter Theory Overview / 274**

## Dark Matter Theory

**Corresponding Author:** tslayter@mit.edu

Increasingly stringent limits on supersymmetry at the LHC and null results from direct and indirect detection are spurring wide-ranging discussions of theoretically well-motivated directions for novel dark matter searches. I will discuss recent developments in dark matter theory, covering a wide range of possible dark matter candidates and mass scales, and their interplay with cosmology and experimental probes of dark matter.

**Neutrino Theory Overview / 275**

## **Neutrino Theory Overview**

**Corresponding Author:** werner.rodejohann@mpi-hd.mpg.de

The talk summarizes general features of mechanisms that generate neutrino mass. The impact of current neutrino data on models for lepton mixing is discussed. Typical examples for new physics in neutrino experiments are given. A general prediction of almost all mechanisms for neutrino mass is the presence of neutrinoless double beta decay. The physics potential of this process is presented, both in the standard approach of light Majorana neutrino exchange, as well as in non-standard scenarios.

**Underground Science / 276**

## **Underground Lab Overview**

**Corresponding Author:** kajita.takaaki@gmail.com

“Underground” is getting more and more important for researches with very low event rate. I will give an overview of the science that is carried out in underground.

**Gravitational Waves Overview / 277**

## **Gravitational Wave Overview**

**Corresponding Author:** pshawhan@umd.edu

After the ground-breaking detection of gravitational waves from a couple of merging binary black holes in the first Advanced LIGO observing run, there is still a great deal to be learned about the population and astrophysics of gravitational-wave sources. I will share the latest news from the second observing run of the Advanced LIGO detectors, including the recently published event GW170104, and the picture we are starting to get of the masses and spins of merging binary systems. I will also give a brief update on the status of the other ground-based gravitational-wave detectors which will join LIGO over the next few years, as well as pulsar timing campaigns and the LISA space mission.

**Double Beta Decay Overview / 278**

## **Double Beta Decay Overview**

**Corresponding Author:** schoenert@ph.tum.de

Abstract: Observation of neutrinoless double beta decay would be a breakthrough in particle physics, astroparticle physics and cosmology, as it would imply lepton number violation, establish the Majorana character of neutrinos and shed light on the evolution of the early Universe. Current experiments have half-life sensitivities up to several  $10^{25}$  yr probing part of the parameter space predicted for degenerate neutrino masses. The next generation experiments aim to scrutinize half-lives up to

1027–1028 years range or effective Majorana mass of  $O(10 \text{ meV})$ , as predicted by neutrino oscillation experiments in case of inverse mass ordering. I will review the latest experimental results and discuss the future projects with their projected experimental performances and sensitivities. Critical parameters as sensitive exposure, backgrounds will be compared amongst future projects and with the experimental state-of-the-art.

**Long Baseline Neutrinos Future / 279**

## **Long Baseline Neutrinos: The Future**

**Corresponding Author:** lawwhitehead@uh.edu

Long-baseline neutrino experiments have been crucial in our understanding of neutrino oscillations. Future long-baseline oscillation experiments will seek to address the remaining questions in the standard 3-neutrino oscillation model, including CP violation, the mass hierarchy, and maximal mixing, in addition to searching for new physics. In this talk, I will give an overview of the status and prospects for future long-baseline neutrino oscillation experiments.

**Dark Matter - New Technologies / 280**

## **Dark Matter - New Technologies**

**Corresponding Author:** daniel.mckinsey@yale.edu

Direct detection of dark matter is a promising approach to discovering the nature of dark matter particles. I describe the future of this field of research, focusing on new technologies proposed for reaching the irreducible neutrino background for low-mass dark matter, with particle mass less than  $10 \text{ GeV}/c^2$ . I also describe new technologies for axion dark matter detection, again focusing on new technologies that promise to expand the mass range available to experimental inquiry.

**Cosmology Overview / 281**

## **Early Universe**

**Corresponding Author:** jan.hamann@sydney.edu.au

I will present an (entirely subjective) overview of the current status of cosmology, followed by a discussion of what we can expect in the coming years.

**Cosmology, Gravitational Waves, & Cosmic Rays / 282**

## **NO TALK**

**Cosmology, Gravitational Waves, & Cosmic Rays / 283**

**NO TALK**

**New Technologies / 284**

**NO TALK**

**Dark Matter / 285**

**NO TALK**

**Dark Matter / 286**

**NO TALK**

**New Technologies / 287**

**NO TALK**

**New Technologies / 288**

**NO TALK**

**Cosmology, Gravitational Waves, & Cosmic Rays / 289**

**NO TALK**

**Cosmology, Gravitational Waves, & Cosmic Rays / 290**

**NO TALK**

**Cosmology, Gravitational Waves, & Cosmic Rays / 291**

**NO TALK**

**Cosmology, Gravitational Waves, & Cosmic Rays / 292**

**NO TALK**

**Labs and Low Background / 293**

**NO TALK**

**Labs and Low Background / 294**

**NO TALK**

**Dark Matter / 295**

**NO TALK**

**Dark Matter / 296**

**NO TALK**

**Outreach / 297**

**ROUND TABLE**

**Dark Matter / 298**

**NO TALK**

**Dark Matter / 299**

**NO TALK**

**Dark Matter / 300**

## **NO TALK**

**Dark Matter / 301**

## **NO TALK**

**New Technologies / 302**

## **NO TALK**

**Status of Underground Labs Plenary / 303**

### **Status of Underground Labs**

Deep Underground Laboratories (DULs) with an overburden larger than 1000 m.w.e. provide unique and multidisciplinary infrastructures to carry out mainly research on extremely rare phenomena such as neutrino interactions, interactions of hypothetical dark matter particles and neutrinoless double beta decay. However, geophysics and biology in extreme environments are also studied in DULs. In this talk I will review the main characteristics of DULs worldwide. I will emphasize the multidisciplinary feature of DULs. I will report about the facilities in operation and about few new proposals.

**CUORE Results - Oliviero Cremonesi / 304**

### **First results from the CUORE experiment**

The Cryogenic Underground Observatory for Rare Events (CUORE) is the first bolometric experiment searching for neutrinoless double beta decay that has been able to reach the 1-ton scale. The detector consists of an array of 988 TeO<sub>2</sub> crystals arranged in a cylindrical compact structure of 19 towers. The construction of the experiment and, in particular, the installation of all towers in the cryostat was completed in August 2016. The detector was then successfully cooled down to a base temperature below 8 mK by the beginning of 2017. After few months devoted to the initial detector commissioning, calibrations started in April 2017 followed by a physics run in May 2017. A new campaign of optimization of the detector performance is now ongoing to be followed by a new physics run during the summer. The first physics results of CUORE, as well as a summary of the initial detector performance will be presented.

**Low Background Plenary / 305**

### **Low Background Methods in Underground Astroparticle Physics**



**Corresponding Author:** frankc@princeton.edu

The detection of rare solar neutrino signals in deep underground laboratories has confronted background challenges for more than 50 years beginning with the famous Chlorine experiment. In this talk I will review the successful background strategies employed for solar neutrino measurements, up to the present, and will summarize related strategies for background suppression for direct detection searches for dark matter particles and for neutrino-less double beta decay.

**Solar Neutrinos / 306**

## **Overview of solar neutrinos and new results from Borexino**

**Corresponding Author:** gemma.testera@ge.infn.it

Solar neutrinos are a unique probe of the neutrino oscillation physics and of solar models. An overview of the solar neutrino flux prediction and of the current available results will be presented. The new experimental data about the measurement of the flux of low energy solar neutrinos obtained with the Borexino detector (LNGS) will be shown and discussed.

**Latest Results of EXO-200 / 307**

## **New Results from EXO: Caio Licciardo**

The EXO-200 experiment has made both the first observation of the double beta decay in Xe-136 and the most precisely measured half-life of any two-neutrino double beta decay to date. Consisting of an extremely low-background time projection chamber filled with  $\sim 150$  kg of enriched liquid Xe-136, it has provided one of the most sensitive searches for the neutrinoless double beta decay using the first two years of data. After a hiatus in operations during a temporary shutdown of its host facility, the Waste Isolation Pilot Plant, the experiment has restarted data taking with upgrades to its front-end electronics and a radon suppression system. This talk will cover the latest results of the collaboration including new data with improved energy resolution.

**Neutrino Parallel / 308**

**NO TALK**

**Neutrino Parallel / 309**

**NO TALK**

**Neutrino Parallel / 310**

**NO TALK**

**New Technologies / 311**

**NO TALK**

**Outreach / 312**

**Hands On Astrophysics**

This talk will briefly outline the educational importance of play, and how and why to apply hands-on interactive learning to astrophysics outreach, following lessons learned at Science North, a third-generation science center in Sudbury, Ontario. Applying these lessons outside of the science center context will also be discussed.

**Outreach / 313**

**Outreach and Advocacy - from Phlies to Physics**

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