PIKIMO 19: Fall 2025

Saturday 8 November 2025 - Saturday 8 November 2025

Northwestern University Technological Institute

Book of Abstracts

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Can we observe new neutrino oscillation phenomenon with Standard Model physics?

Author: Shirley Li[1]

[1] *UC Irvine*

Standard calculations of neutrino oscillation are predicated on the assumption that neutrinos'wave packets maintain coherence throughout their propagation. Effects associated with neutrino wave packet decoherence—specifically, damping of the oscillation probabilities—were previously considered unobservable in terrestrial experiments. However, recent claims suggest that if sterile neutrinos exist, we could observe decoherence effects in terrestrial experiments. To test these claims, one must compute the neutrino wave packet size for a given source. In this talk, I will discuss our efforts to determine the wave packet size for neutrinos produced in accelerator-based experiments. We demonstrate that it is feasible to compute this value through a well-defined framework accompanied by precise input parameters.

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Widen the Resonance: Probing a New Regime of Neutrino Self-Interactions with Astrophysical Neutrinos

Author: Bei Zhou[1]

[1] *Fermilab*

Neutrino self-interactions beyond the standard model have profound implications in astrophysics and cosmology. In this work, we study an uncharted scenario in which one of the three neutrino species has a mass smaller than the temperature of the cosmic neutrino background. This results in a relativistic component that significantly broadens the absorption feature on the astrophysical neutrino spectra, in contrast to the sharply peaked absorption expected in the extensively studied scenarios assuming a fully nonrelativistic cosmic neutrino background. By solving the Boltzmann equations for neutrino absorption and regeneration, we demonstrate that this mechanism provides novel sensitivity to sub-keV mediator masses, well below the traditional ~ 1–100 MeV range.
Future observations of the diffuse supernova neutrino background with Hyper-Kamiokande could probe coupling strengths down to $g \sim 10^{-8}$, surpassing existing constraints by orders of magnitude. These findings open new directions for discoveries and offer crucial insights into the interplay between neutrinos and the dark sector.
(https://arxiv.org/abs/2501.07624; Accepted by Physical Review Letters)

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Axion Production and Detection Using a Dual NMR-type Experiment

Author: Fengwei Yang[1]

Co-authors: Jeff Dror [2]; Qiushi Wei [2]

[1] *University of Notre Dame*

[2] *University of Florida*

Axions that couple to nuclear spins via the axial current interaction can be both *produced* and *detected* using nuclear magnetic resonance (NMR) techniques. In this scheme, nuclei driven by a real oscillating magnetic field in one device act as an axion source, which can drive NMR in a nearby spin-polarized sample interrogated with a sensitive magnetometer. The gradient of the generated axion field can be substantial, set by the inverse distance from the source. In the near zone, it reduces to the inverse of the source's geometric size. In this talk, I will present a calculation of the experimental sensitivity. As I will show, a pair of 10-centimeter-scale NMR devices operating over a one-hour integration time can already surpass existing astrophysical bounds on the axion-nucleon coupling, including those from star cooling. This setup is capable of probing a wide range of axion masses, up to values comparable to the inverse distance between the source and the sensor.

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A ν look at the Sun: Probing the conditions of the solar core using ^{8}B neutrinos

Authors: John Beacom[1]; Melanie Zaidel[1]

[1] *Ohio State University*

In the coming age of precision neutrino physics, neutrinos from the Sun become robust probes of the conditions of the solar core. Here, we focus on ^{8}B neutrinos, for which there are already high precision measurements by the Sudbury Neutrino Observatory and Super-Kamiokande. Using only basic physical principles and straightforward statistical tools, we estimate projected constraints on the temperature and density of the ^{8}B neutrino production zone compared to a reference solar model. We outline how to better understand the astrophysics of the solar interior using forthcoming neutrino data and solar models. Finally, we note that detailed forward modeling will be needed to develop the full potential of this approach.

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Probing Neutrino Properties at Low and Medium Energies

Author: Sam Carey[1]

[1] *Wayne State University*

As neutrino experiments become more precise and explore a wide range of energies, studying how neutrinos interact with matter has become an important way to test the Standard Model and search for new physics. In this talk, I will present our work on neutrino interactions at both low (MeV) and medium (GeV) energy scales. At low energies, we consider coherent elastic neutrino-nucleus scattering (CEvNS) at current and upcoming neutrino facilities. CEvNS allows us to explore possible new physics effects such as non-standard neutrino interactions (NSI), neutrino magnetic moment, and charge radius. At energies relevant for DUNE, neutrinos interacting with nuclei or electrons can have enhanced couplings to photons if light scalar mediators are present, resulting in a potentially measurable neutrino polarizability. We identify two possible experimental signatures of such coupling - one or two separated electromagnetic showers with no associated hadronic activity and show the projected sensitivity for the DUNE near Detector.

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Upper Bound on Parity Breaking Scale for Doublet WIMP Dark Matter

Authors: Isaac Wang[None]; Keisuke Harigaya[None]; Matthew Baldwin[None]

We consider weakly interacting massive particle (WIMP) dark matter in a Parity solution to the strong CP problem. The WIMP phenomenology can be drastically affected by the presence of Parity partners of the WIMP and electroweak gauge bosons. We focus on a Parity extension of $SU(2)_L$ doublet fermion dark matter, identify the viable parameter space, and derive the predictions of the theory. We find that the Parity symmetry breaking scale is bounded from above, with the bound given by 25–60 TeV, depending on whether or not dark matter and its Parity partner coannihilate with each other. The High-Luminosity Large Hadron Collider, future colliders, and direct and indirect detection experiments can probe the parameter space further, with correlated signal rates.

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Stringent Constraints on Gravitational Wave Signatures of Dark Electromagnetism

Authors: Ian Harris[None]; Yonatan Kahn[1]

[1] *University of Toronto*

Gravitational wave interferometers have studied compact object mergers and solidified our understanding of strong gravity. Their increasing precision raises the possibility of detecting new physics, especially in a neutron star binary system that contains dark hidden-sector particles. In particular, a new vector force between binary constituents, giving rise to dark electromagnetic phenomena, could measurably alter the inspiral waveforms, and could thus be constrained by interferometer results. In this work, we examine three mechanisms for neutron stars to acquire enough hidden-sector particles with requisite couplings to furnish a detectable signature from dark electromagnetism: accretion of dark matter from the galactic halo, thermal production of hidden-sector particles in the progenitor supernova, and dark neutron decay. Without explicitly rejecting this method of constraining new physics, we demonstrate that the repulsive nature of vector forces imposes stringent constraints on any putative particle physics model or astrophysical environment which could give rise to such gravitational signatures, with existing constraints already ruling out much of the observable parameter space and requiring exquisite fine-tuning for that which remains available.

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The Bearable Inhomogeneity of the Baryon Asymmetry

Authors: Hengameh Bagherian[None]; Majid Ekhterachian[1]; Stefan Stelzl[2]

[1] *University of Maryland College Park*

[2] *EPFL - Ecole Polytechnique Federale Lausanne (CH)*

We study the implications of precision measurements of light-element abundances, in combination with the Cosmic Microwave Background, for scenarios of physics beyond the Standard Model that generate large inhomogeneities in the baryon-to-photon ratio. We show that precision Big Bang Nucleosynthesis (BBN) places strong constraints on any mechanism that produces large-scale inhomogeneities at temperatures around or below the TeV scale. In particular, we find that fluctuations of order 25% on comoving length scales larger than the horizon at T⊠3 TeV are incompatible with the observed light-element abundances. This sensitivity to early-universe physics arises because baryon-number inhomogeneities homogenize primarily through diffusion, a slow process. As a result, BBN

serves as a novel probe of baryogenesis below the TeV scale, readily ruling out some proposed scenarios in the literature. We discuss the implications for electroweak baryogenesis, and further show that precision BBN provides a new probe of first-order phase transitions that generate gravitational waves in the pHz-mHz frequency range. This yields constraints on the electroweak phase transition, as well as first-order phase transitions that have been suggested as an explanation of the pulsar timing array signal. Finally, we comment on the future prospects for improving this probe.

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Constraining the Coexistence of Freeze-in Dark Matter and Primordial Black Holes

Authors: Prolay Chanda[1]; Sagnik Mukherjee[2]; James Unwin[2]

[1] *Tata Institute of Fundamental Research*

[2] *University of Illinois Chicago*

Particle dark matter and primordial black holes (PBH) might coexist with appreciable cosmic abundances, with both contributing to the observed dark matter density $\Omega_{\rm DM}$. Large populations of PBH (with $\Omega_{\rm PBH} \sim \Omega_{\rm DM}$) are tightly constrained for PBH heavier than $10^{-11} M_\odot$. However, large fractional abundances with $f_{\rm PBH} \simeq \Omega_{\rm PBH}/\Omega_{\rm DM} \sim 0.01$ are consistent with the limits on PBH for a wide range of PBH masses. Scenarios with significant populations of both particle dark matter and PBH are intriguing. Notably, if the particle dark matter has interactions with the Standard Model, new constraints arise due to pair-annihilations that are enhanced by the PBHs, resulting in dark matter indirect detection constraints on $f_{\rm PBH}$. Here we derive the bounds on mixed scenarios in which PBHs coexist with particle dark matter whose relic abundance is set via freeze-in ("FIMPs"). We show that while the restrictions on $f_{\rm PBH}$ are less constraining for FIMPs than WIMPs, modest bounds still arise for large classes of models. We examine both IR and UV freeze-in scenarios, including the case of ''superheavy" particle dark matter with PeV scale mass.

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A Quantum Computational Determination of the Weak Mixing Angle in the Standard Model

Authors: Ian Low[None]; Qiaofeng Liu[1]; Zhewei Yin[None]

[1] *Northwestern University*

The weak mixing angle s_W is a fundamental constant in the Standard Model (SM) and measured at the Z boson mass to be $\widehat{s}^2_W(m_Z) = 0.23129 \pm 0.00004$ in the $\overline{\rm MS}$ renormalization scheme, where $m_Z = 91.2$ GeV. On the other hand, non-stabilizerness - the magic - characterizes the computational advantage of a quantum system over classical computers. We consider the production of magic from stabilizer initial states, which carry zero magic, in the 2-to-2 scattering of charged leptons in the SM at the tree level, which is mediated by the photon and the Z boson. Using the second order stabilizer Rényi entropy, and averaging over all 60 initial stabilizer states and the scattering angle, we compute and minimize the magic production as a function of s^2_W in the Møller scattering $e^-e^- \to e^-e^-$, which is free of kinematic thresholds. At the centre-of-mass energy $\sqrt{s} = m_Z$, there is a unique minimum in magic production at $\mathrm{s}^2_W(m_Z) = 0.2317$, which agrees with the measured $\widehat{s}^2_W(m_Z)$ at the sub-percent level. At higher energies, the magic-minimizing s^2_W continues to agree with the empirical value at the percent level or better, up to 10 TeV. The finding suggests the electroweak sector of the SM tends to generate minimal quantum resources from the computational viewpoint.

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Large Neutrino "Collider"

Authors: Bei Zhou[1]; Keping Xie[2]; Yang Bai[None]

[1] *Fermilab*

[2] *Michigan State University*

We propose using current and future large-volume neutrino telescopes as "Large Neutrino Colliders" (LνCs) to explore TeV-scale physics beyond the Standard Model. Cosmic neutrinos with energies above 100 PeV colliding with nucleons in the detector reach center-of-mass energies beyond the 14 TeV limit of the Large Hadron Collider (LHC). Using recently predicted and measured high-energy and ultra-high-energy neutrino fluxes from IceCube and KM3NeT, we estimate mass-scale sensitivities for representative new physics scenarios at 1–30 km^3 LνCs. Our results demonstrate that LνCs provide a novel avenue to probe multi-TeV particles with sensitivities comparable to, or even surpassing, those of the LHC.

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AXIS Can Access Dark Matter Decays with the Longest Lifetimes

Authors: Inci Karaaslan[1]; Nimrod Shapir[1]

[1] *University of Chicago (US)*

As one of NASA's proposed future Astrophysics Probe missions, the Advanced X-ray Imaging Satellite (AXIS) is designed to improve on the sensitivity and spatial resolution of the Chandra X-ray Observatory. The low-background, arcsecond imaging that AXIS will deliver over a broad energy range can probe a new region of parameter space for exploring decaying dark matter candidates, such as axion-like particles (ALPs) and sterile neutrinos, via X-ray line searches. We present an initial study of AXIS's prospects for detecting dark matter decay signals, finding potential lifetime sensitivities of order ~10^30 seconds in the keV range, surpassing current X-ray limits by several orders of magnitude.

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QED at the precision frontier: accounting for cavity shifts to $(g-2)_e$

Authors: Hannah Day[None]; Kevin Zhou[1]; Roni Harnik[None]; Shashin Pavaskar[None]; Yonatan Kahn[2]

[1] *UC Berkeley / LBNL*

[2] *University of Toronto*

The anomalous magnetic dipole moment $(g-2)$ of the electron is one of the most precisely measured quantities in the world. Experimentally, an electron is trapped in a cylindrical cavity, and the measured value of $g-2$ receives a correction due to the cavity boundary that must be subtracted off. We calculate the cavity correction using a quantum mechanical formulation and demonstrate that it not only precisely matches the classical solution for a perfect cylinder but can also be generalized to allow for cavity imperfections.

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A baryon and lepton number violation model testable at the LHC

Author: Tong Ou[None]

Proton decay experiments typically constrain baryon number violation to the scale of grand unified theories. From a phenomenological point of view, this makes direct probing of the associated new resonances, such as the X and Y bosons, out of reach for even the most optimistic future experiments. It has, however, been known that certain specific patterns of baryon and lepton number violation can suppress proton decay by multiple powers of the masses of the heavy resonances involved, opening the possibility that the observed limits on the proton lifetime are consistent with baryon number violating physics at energy scales much lower than that of grand unification. We construct an explicit example of such a model which violates baryon number by one unit, $\Delta \mathrm{B} = -1$, and lepton number by three units, $\Delta \mathrm{L} = -3$, and show that despite stringent limits on the predicted $p \to e^+/\mu^+\overline{\nu}\overline{\nu}$ mode from the Super-Kamiokande experiment, the masses of the newly introduced elementary particles can be $\mathcal{O}$(TeV). We identify interesting unique signatures of baryon number violation of this model that can be probed both with currently available LHC data and with the upcoming High-Luminosity LHC. We also present a scenario for low-scale baryogenesis within the framework of this model.

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Running with Radiative Corrections in Deep Inelastic Scattering

Author: Justin Cammarota[1]

Co-author: Susan Gardner [1]

[1] *University of Kentucky*

The factorization theorem plays an important role in the analysis of high energy quantum chromodynamic (QCD) processes, separating the nonperturbative hadronic interaction into the universal parton distribution functions (PDFs) and fragmentation functions (FFs) and the process-dependent interactions into short distance perturbative calculations, with any interference power suppressed. With a virtual photon exchange, lepton-hadron deep inelastic scattering (DIS) provides an electromagnetic hard probe for the partonic structure of colliding hadrons and has played an important role in the development of QCD factorization. However, the collision induced QED radiation can change the momentum of the exchanged but unobserved virtual photon, making the photon-hadron frame, where the factorization formalism for DIS was derived, ill defined. A new analogous factorization approach has been introduced to separate the leading power process-independent QED radiative contributions to the single photon exchange by introducing lepton distribution functions (LDFs) and lepton fragmentation functions (LFFs), while process-dependent effects are perturbatively calculated with large logarithms removed [J. High Energ. Phys. 2021, 157 (2021)]. These LDFs and LFFs are considered global, as they appear in many different interactions, such as e^+e^-, DIS and SIDIS, so data from experiments can be used to fit and describe these functions across a wide range of lepton scattering. In this work, I will apply this new hybrid factorization approach to lepton-hadron DIS and illustrate an new mechanism to constrain the running of $\alpha_{\mathrm{EM}}(Q^2)$.

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Dynamical Solution to the Eta Problem in Spectator Field Models

Authors: Keisuke Harigaya[1]; Sana Elgamal[1]

[1] *University of Chicago*

We study a class of spectator field models that addresses the eta problem while providing a natural explanation for the observed slight deviation of the spectrum of curvature perturbations from scale-invariance. In particular, we analyze the effects of quantum corrections on the quadratic potential of the spectator field given by its gravitational coupling to the Ricci scalar and the inflaton energy, so-called the Hubble-induced mass term. These quantum corrections create a minimum around which the potential is flatter and to which the spectator field is attracted. We demonstrate that this attractor dynamics can naturally generate the observed slightly red-tilted spectrum of curvature perturbations. Furthermore, focusing on a curvaton model with a quadratic vacuum potential, we compute the primordial non-Gaussianity parameter fNL and derive a predictive relationship between fNL and the running of the scalar spectral index. This relationship serves as a testable signature of the model. Finally, we extend the idea to a broader class of models where the spectator field is an angular component of a complex scalar field.

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Searching Stochastic Gravitational Wave Background Landscape From Inflated String-Wall Network Across Frequency Bands

Authors: Liantao Wang[None]; Töre Boybeyi[1]; Vuk Mandic[1]; Yunjia Bao[2]

[1] *University of Minnesota*

[2] *University of Chicago*

Gravitational wave (GW) astrophysics is entering a multi-band era with upcoming GW detectors, enabling detailed mapping of the stochastic GW background across vast frequencies. We highlight this potential via a new physics scenario: hybrid topological defects from a two-step phase transition separated by inflation. We develop a general pipeline to analyze experimental exclusions and apply it to this model. The model offers a possible explanation of the NANOGrav signal at low frequencies, and future experiments (LISA/Cosmic Explorer/Einstein Telescope) will confirm or rule it out via the higher-frequency probes, showcasing the power of multi-band constraints.

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A Quantum Description of Axion Dark Matter Detection

Authors: Dhong Yeon Cheong[1]; Joey Takach[None]; Kevin Zhou[None]; Lian-Tao Wang[None]; Nicholas Rodd[None]; Yunjia Bao[None]

[1] *University of Chicago*

In this talk, I will present a unified quantum framework for axion dark matter detection. Drawing on a quantum-optics-inspired formalism, we describe realistic axion dark matter detection schemes through a density matrix and a corresponding quasi-probability distribution. We show that the intrinsically quantum nature of the dark matter field will remain unobservable with current or foreseeable technology due to mode averaging and extremely low conversion efficiency. Our results exemplify why the classical-field treatment of wave dark matter remains both accurate and sufficient for present searches, and also provides a general method to compute effects arising from dark matter states.

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Autonomous New-Physics Discovery from Foundational Embeddings of SMEFT

Author: Brandon Kriesten[1]

Co-authors: Supratim Das Bakshi [1]; T.J. Hobbs [1]

[1] *Argonne National Laboratory*

Representing hadronic parton distribution functions (PDFs) through flexible, high-fidelity parameterizations remains a long-standing goal of particle physics phenomenology. One crucial goal is to quantitatively connect experiments'sensitivity to underlying theory assumptions, including a broad array of BSM and SMEFT scenarios, to the properties of the PDFs'flavor and x-dependence. We explore this problem by encoding many SMEFT scenarios in contrastive embedding spaces generated from simulated events. Within this space we apply evidence-based uncertainty quantification techniques to disentangle data (aleatoric) and knowledge (epistemic) uncertainty while identifying out of distribution samples. Equivalently important is the ability to exclude particular classes of theories, such as standard model-only physics scenarios, which we do through the identification of theory "superclasses."I will present the latest progress in building these embedding spaces unifying dozens of SMEFT variants, demonstrating how model discrimination and anomaly detection naturally emerge alongside generation and classification tasks with uncertainty quantification.

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Constraining General Light Massive Relics with the CMB

Author: David Imig[1]

Co-authors: Jessie Shelton [2]; Nicholas DePorzio [3]

[1] *University of Illinois Urbana-Champaign*

[2] *University of Illinois, Urbana-Champaign*

[3] *Boston University*

Cosmic light massive relics (LiMRs) exhibit unique redshifting behavior, contributing to the radiation content of the early universe while relativistic but to the matter content of the late universe when non-relativistic. While these asymptotic abundances of a LiMR species, parametrized by its radiation contribution ΔN_{eff} and its non-relativistic transition redshift z_{NR}, should source the predominant constraints on that species, they provide no insight into the shape of its distribution function. Specifically, non-thermal relics can always recover the same asymptotic abundances as their thermal counterparts via a simple mapping between mass, typical present momentum scale, and the first two moments of the distribution function. With the asymptotic abundances fixed in this way, we point out that the largest remaining physical difference between different relic distributions is the LiMR energy density during its non-relativistic transition. Identifying that the width of the distribution most directly controls this observable, we constrain the features of general LiMRs described by a phenomenological distribution of adjustable width. Finding that even a future CMB experiment would have no sensitivity to the shape of a monomodal LiMR distribution beyond ΔN_{eff} and z_{NR}, we emphasize that our constraints apply to any non-thermal LiMR production scenario characterized by a single momentum scale and thus are as model-independent as constraints on ΔN_{eff}.

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Generalized Entanglement Measures in Higher Dimensional Quantum Systems

Author: Melinda Yuan[1]

[1] *Northwestern University*

Quantum entanglement is well-understood in a two-qubit system. Concurrence is a scalar quantity that measures the degree of entanglement between two qubits. For higher dimensional systems, however, there has yet to be an established entanglement measure. This talk will attempt to generalize the idea of concurrence to qutrit, qudit, and multi-partite systems. In the qutrit case, we examine a close analog of the qubit concurrence, which involves a sum of minors. We then compare this to the Bloch sphere formulation of concurrence as proposed by Alan Barr. In a three-qubit system, we evaluate a measure proposed by Wooters, known as the three-tangle, and compare it to an entanglement triangle as outlined by Sakurai–Spannowsky. Finally, we attempt to generalize this to any n-index tensor and discuss the condition for such a tensor to be rank 1. Our goal is to both define GME (genuine multi-partite entanglement) as well as propose a unique measure of entanglement of any n-dimensional system.

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50 Years of Energy Flux in Illinois

Collider experiments offer a unique opportunity to study the Standard Model, and to search for new physics, new interactions, and new principles of nature. After a particle collision, the underlying microscopic physics gets imprinted into detailed correlations in macroscopic energy flux, much in analogy to how our cosmic history is imprinted into correlations in the Cosmic Microwave Background. In quantum field theory (QFT), energy flux in colliders is described by energy flow operators, first introduced 50 years ago this December in early studies of quantum chromodynamics. These observables, which arise as direct theoretical models of collider experiments, have also played a crucial role in contemporary developments in formal QFT and gravity. Recently it has become possible to directly measure these observables in new energy regimes, and with unprecedented precision, both at the Large Hadron Collider, and with resurrected data from the LEP experiments, establishing an exciting connection between real world phenomenology, and advances in formal QFT. In this talk I will present some recent highlights from this program, ranging from record precision extractions of Standard Model parameters, to new measurements of properties of the Quark Gluon Plasma, and searches for physics beyond the Standard Model.