Status of the SNO+ Experiment

Aksel Hallin for the SNO+ Collaboration
CAP Congress
Edmonton
June, 2015

SNO+

- 780 tonnes of liquid scintillator as active volume
  - Can be loaded with double beta decay isotope
- ~9500 PMTs
- 1500 + 5300 tons ultra-pure water shielding
- 6800’ underground in SNOLAB

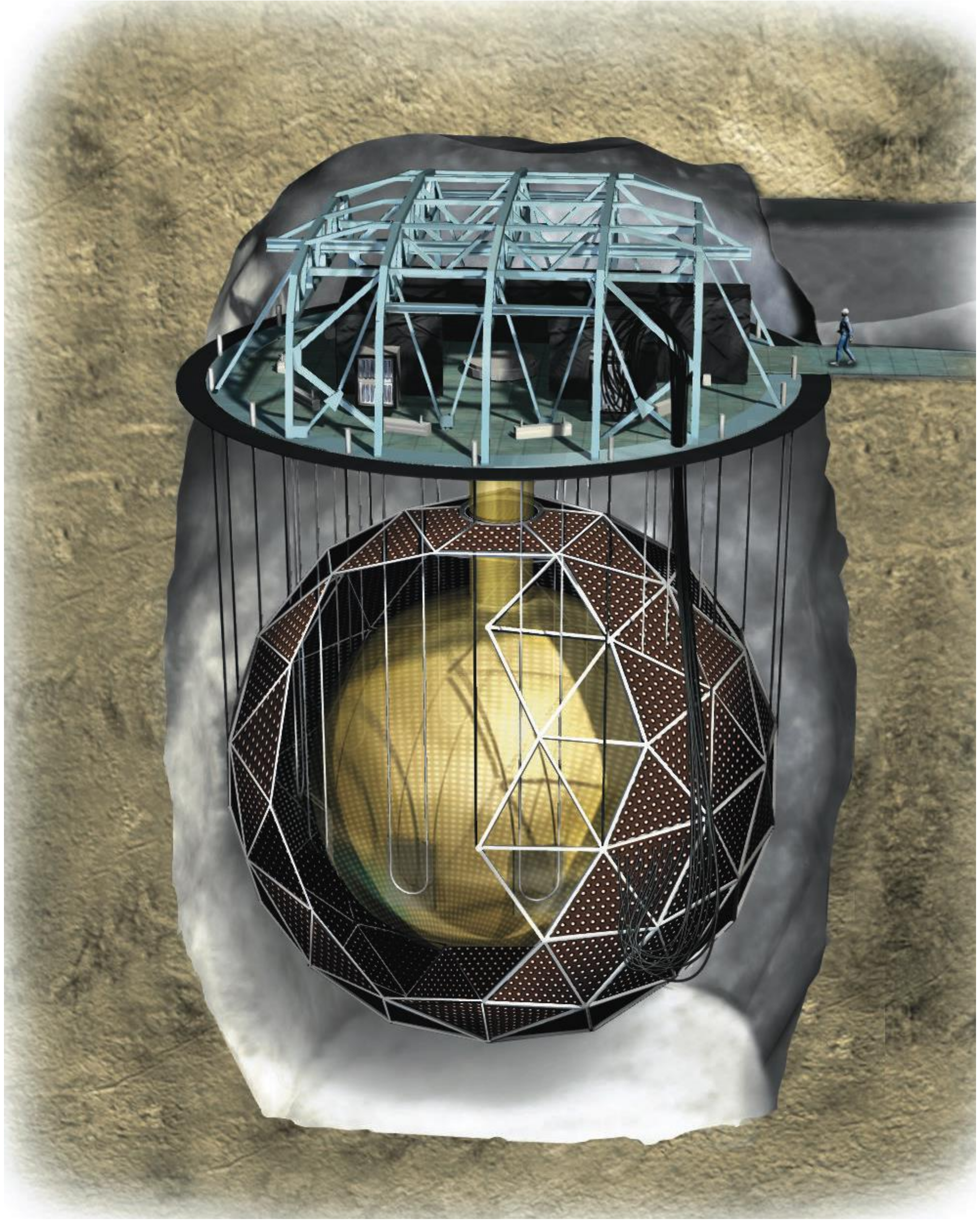
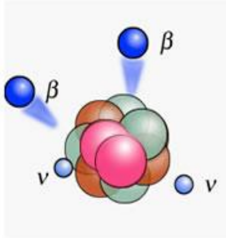
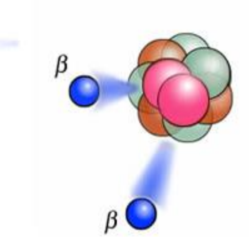


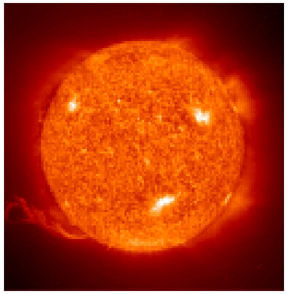
Image courtesy National Geographic

SNO+ Physics



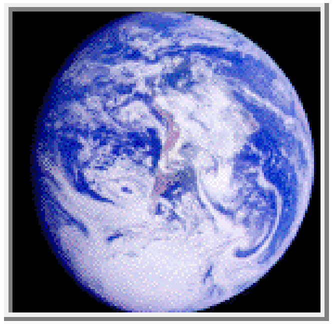
Neutrinoless Double Beta Decay





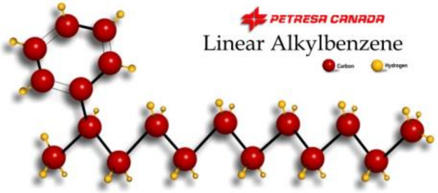
Low Energy Solar Neutrinos

Reactor Antineutrinos

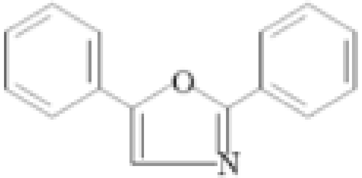


Geo-Neutrinos

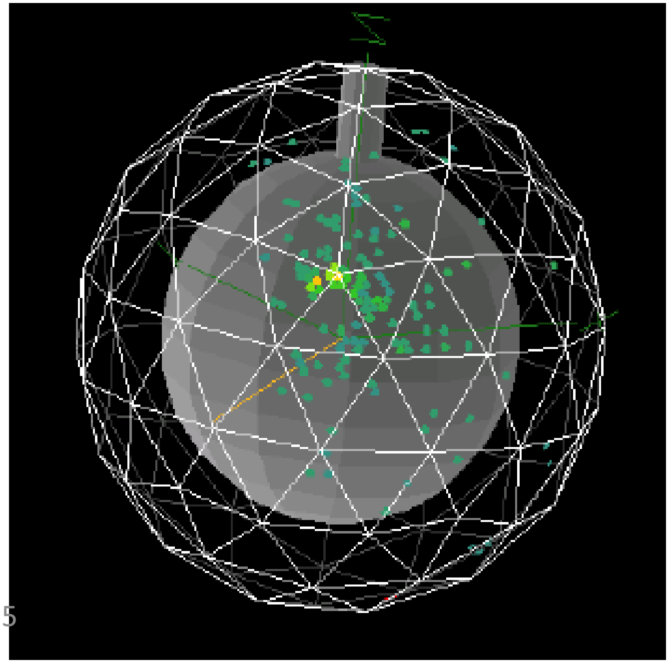
Supernova Neutrinos



Detection Principle



- Organic scintillator (LAB + PPO) produces light when excited by charged particles
- ~10,000 photons/MeV, of which a few hundred photons/MeV are detected by the PMTs
  - Can detect events depositing < 50 keV
- Calorimetric measurement + pulse shape
  - Event energy from number of photons
  - Event position from photon time-of-flight

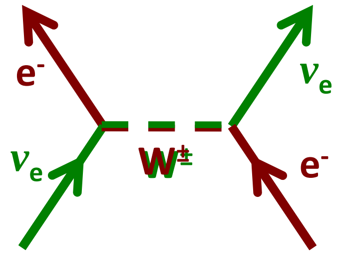


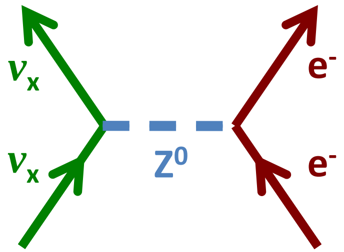
Particle Detection

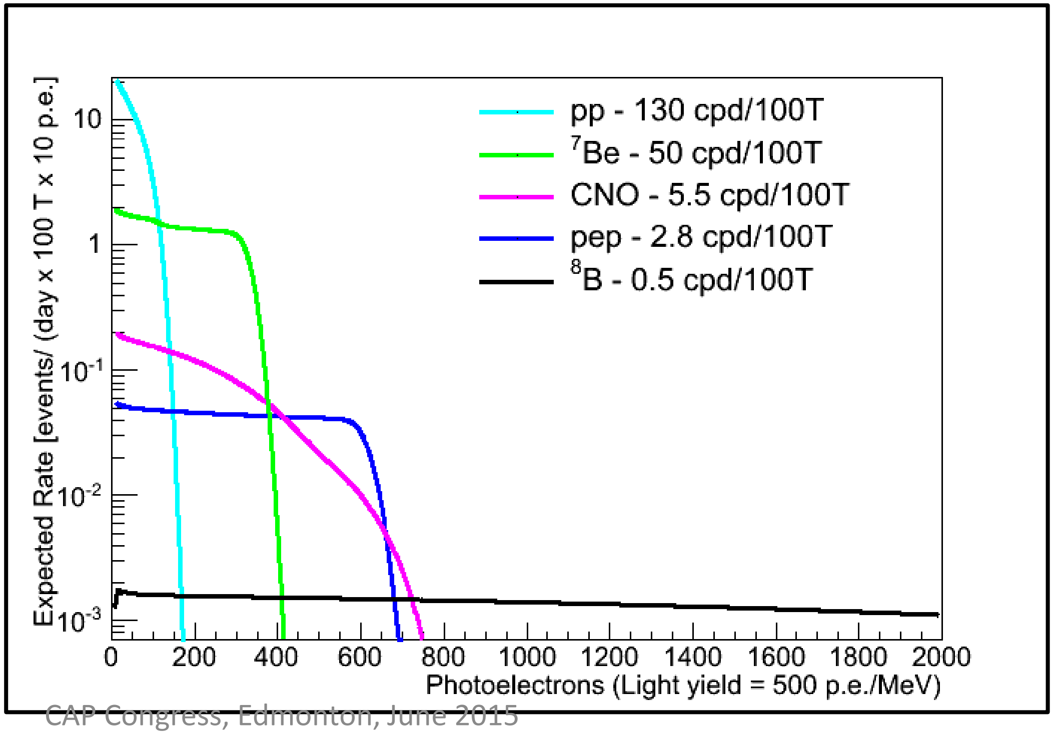
- For double beta decay, the signal is two electrons. SNO+ works as a large conventional scintillator with three important advantages:
  - Backgrounds can be reduced by chemical processing and can even be changed/tuned if necessary
  - Backgrounds can be measured with a variety of radiochemical/counting techniques and the assumption of homogeneity is physically motivated.
  - The type of isotope, amount of loading, and techniques for loading can accommodate different measurements.

Neutrino Detection

- Neutrinos interact via elastic scattering with electrons
  - Sensitive to all neutrino species, but cross section is 4-7 times larger for ν_e than $\nu_{\mu,\tau}$
  - Detect scintillation from the recoiling electron (poor energy correlation between electron and neutrino. There is good directional correlation between electron and neutrino, but that information is not transferred into scintillation light.



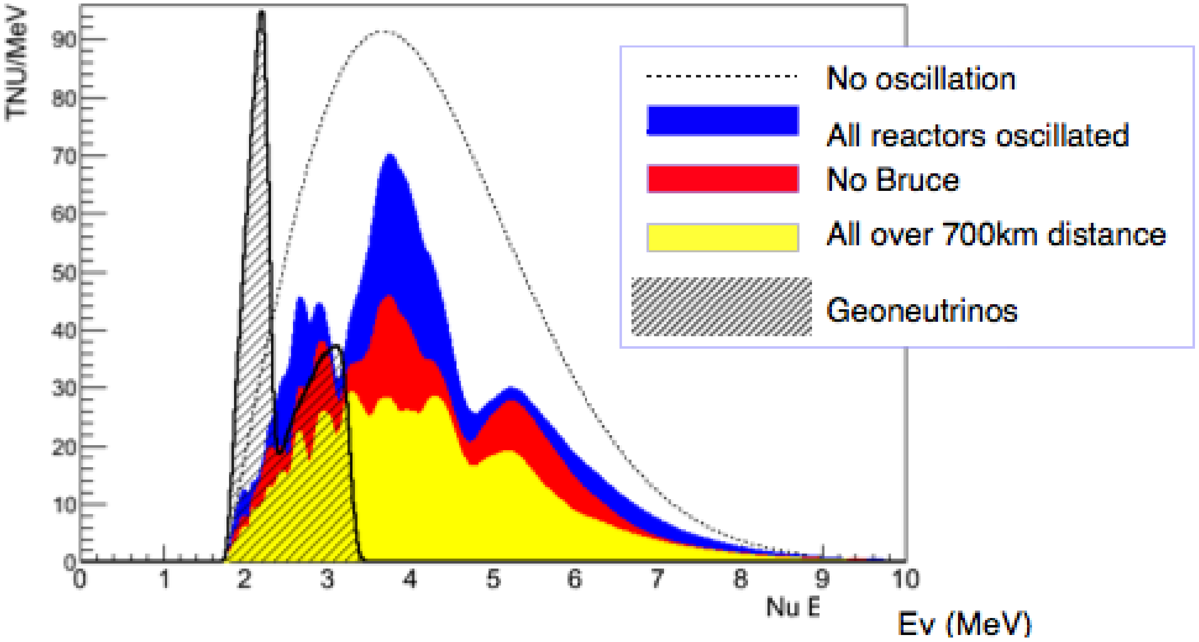




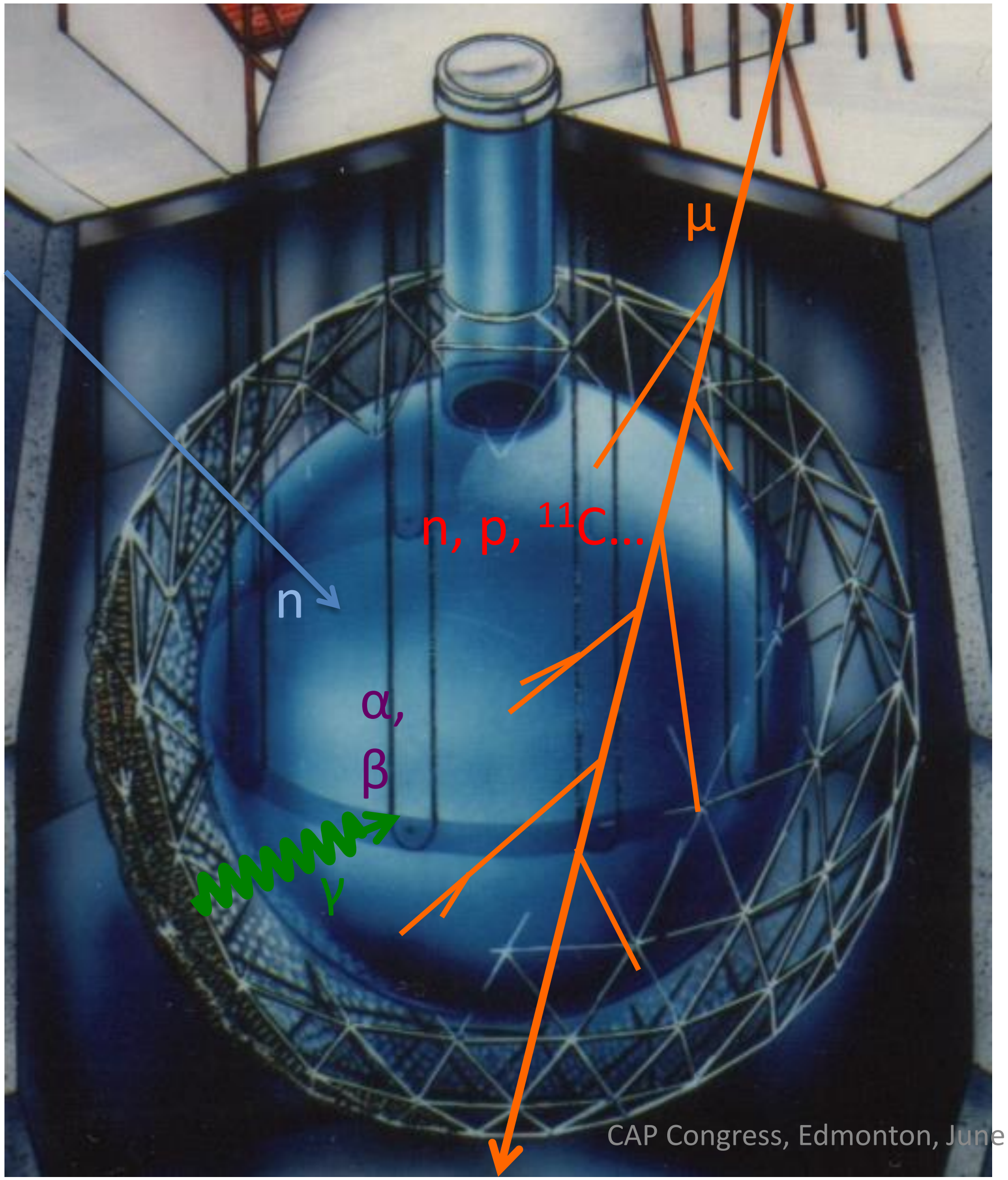
Electron Antineutrino Detection

$\overline{\nu}_e + p \rightarrow e^+ + n$

Large cross section, clean anti-coincidence tag, but low flux from reactors and earth.



Central Challenge: Backgrounds



Internal Radioactivity
traces of radioisotopes (U/Th chain, ^{40}K, etc) in the scintillator.

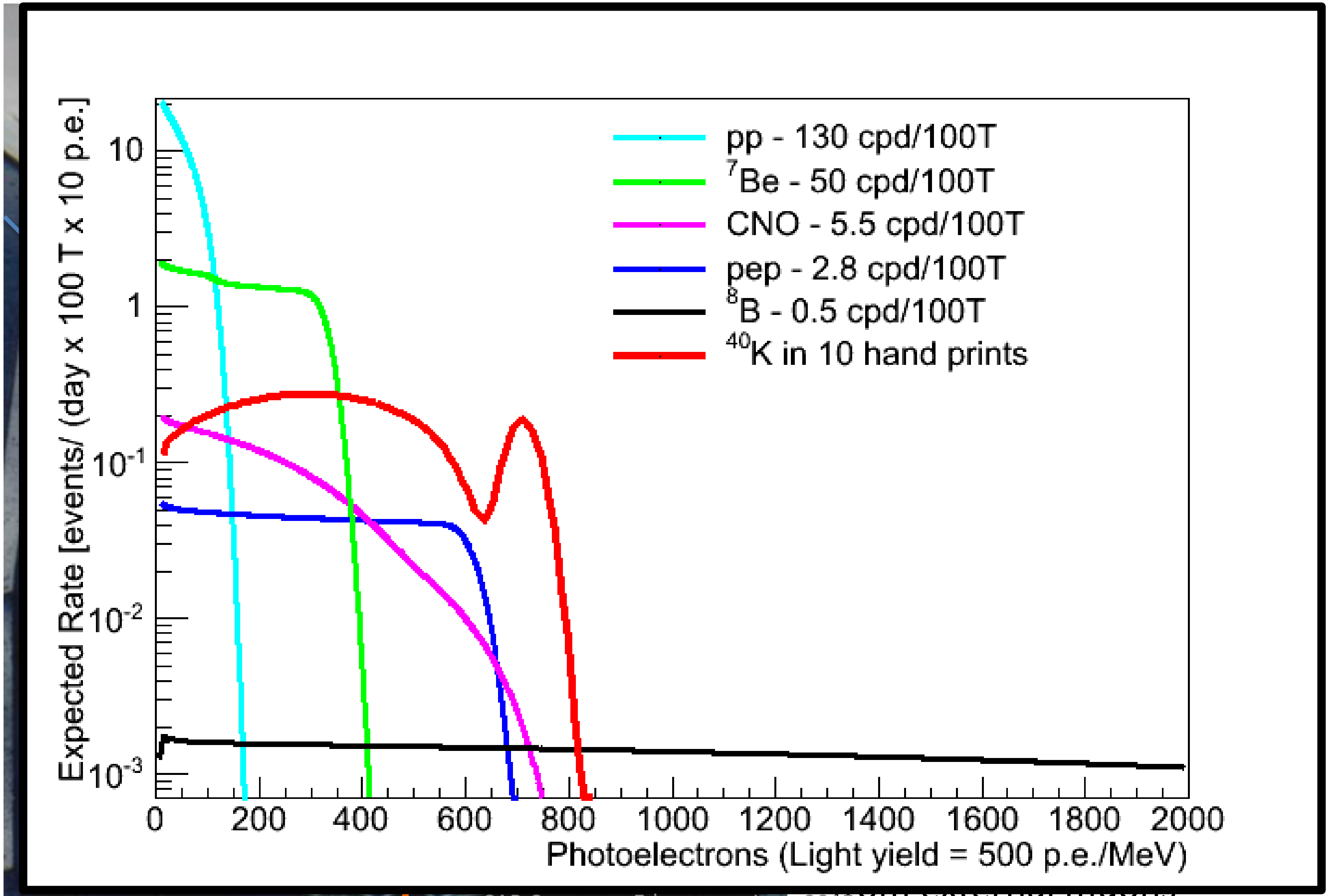
External Gammas
from decays in the acrylic, water, PMTs, etc.

Cosmic Ray Muons

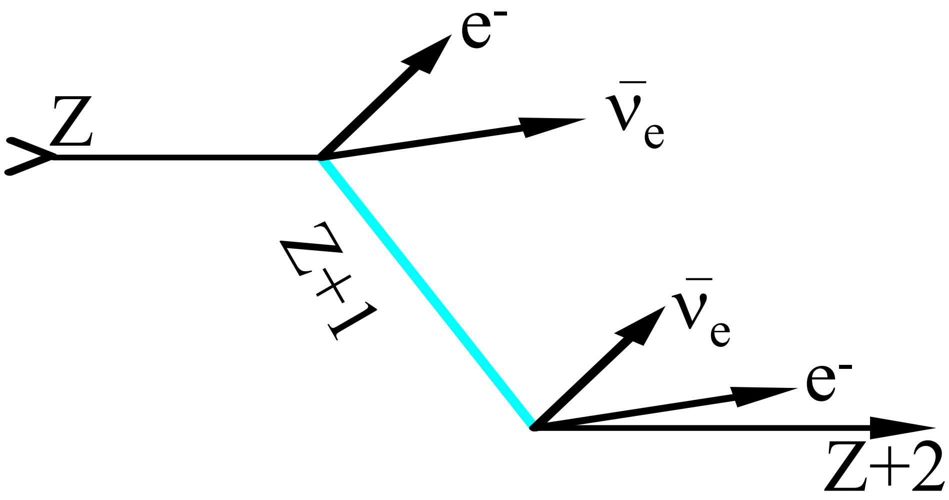
Cosmogenics
Neutrons and radionuclides from spallation and hadronic showers

Fast Neutrons
from external muons

Central Challenge: Backgrounds



om external muons

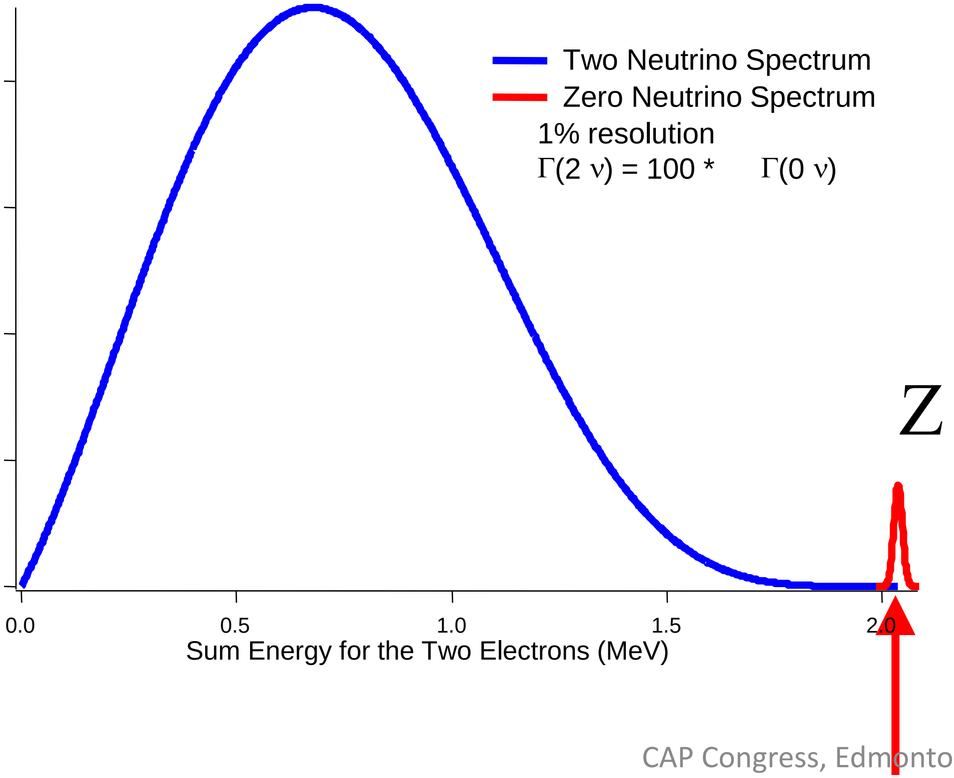


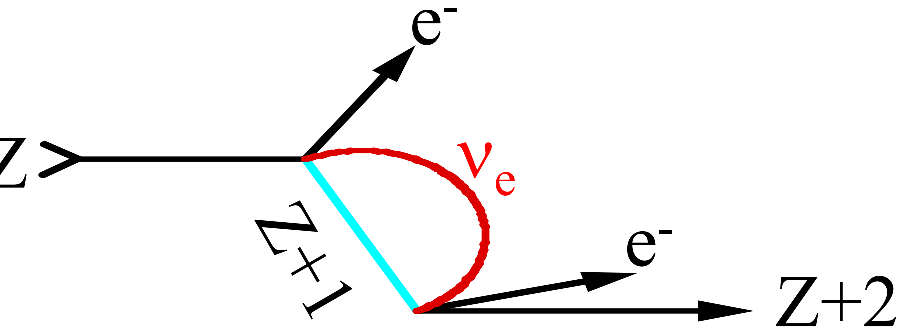
ββ Decay

Requires Massive Majorana Neutrino
ΔL=2

$$\Gamma_{0\nu} = G_{0\nu}\left|M_{0\nu}\right|^2 m_\nu^2$$

We learn $M_{0\nu}$ from nuclear physics





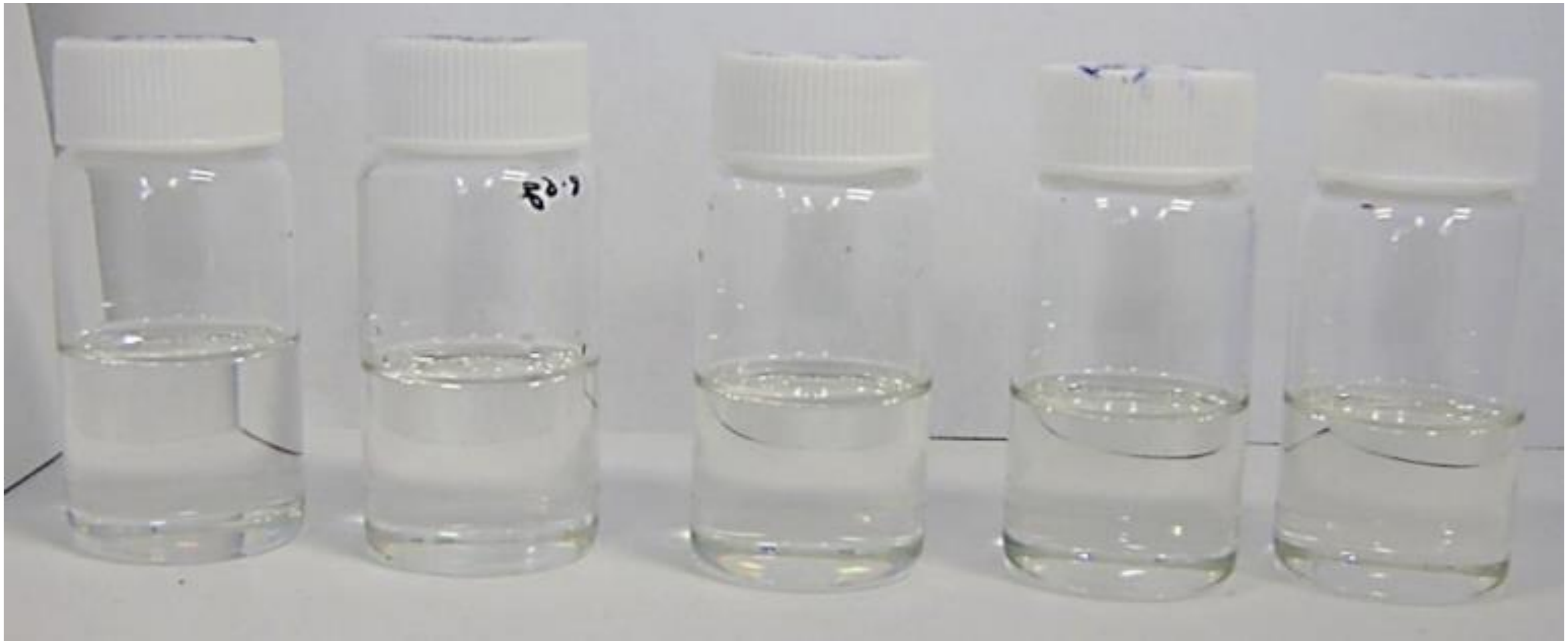
Endpoint
Energy

SNO+ with Te-Loaded Liquid Scintillator

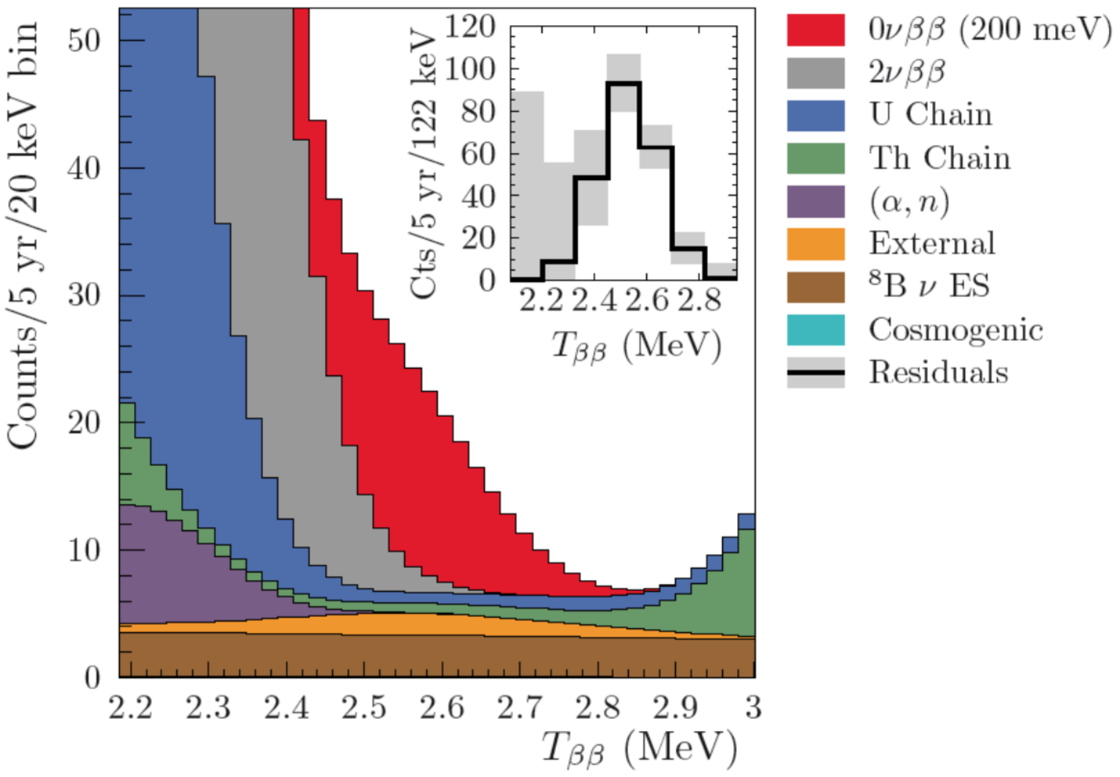
- large natural isotopic abundance 34% for ^{130}Te
  - tonne scale for ^{130}Te isotope, cost is only $1.5 million (because using natural tellurium without enrichment)
    - …compare to O($100 million) for tonne scale of enriched isotope
  - 0.3% Te (by weight) in SNO+ is 2.34 tonnes of Te or **800 kg** of ^{130}Te ***isotope***
- *recently, SNO+ received additional funding – should allow us to go to **0.5% Te loading** or **1,300 kg of isotope***

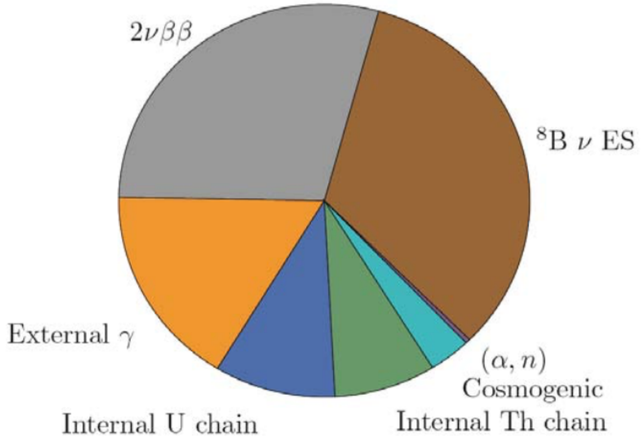
Percent Loading of Tellurium

- 0.3%, 0.5%, 1%, 3%, 5% (from left to right)



SNO+ Simulated Spectrum





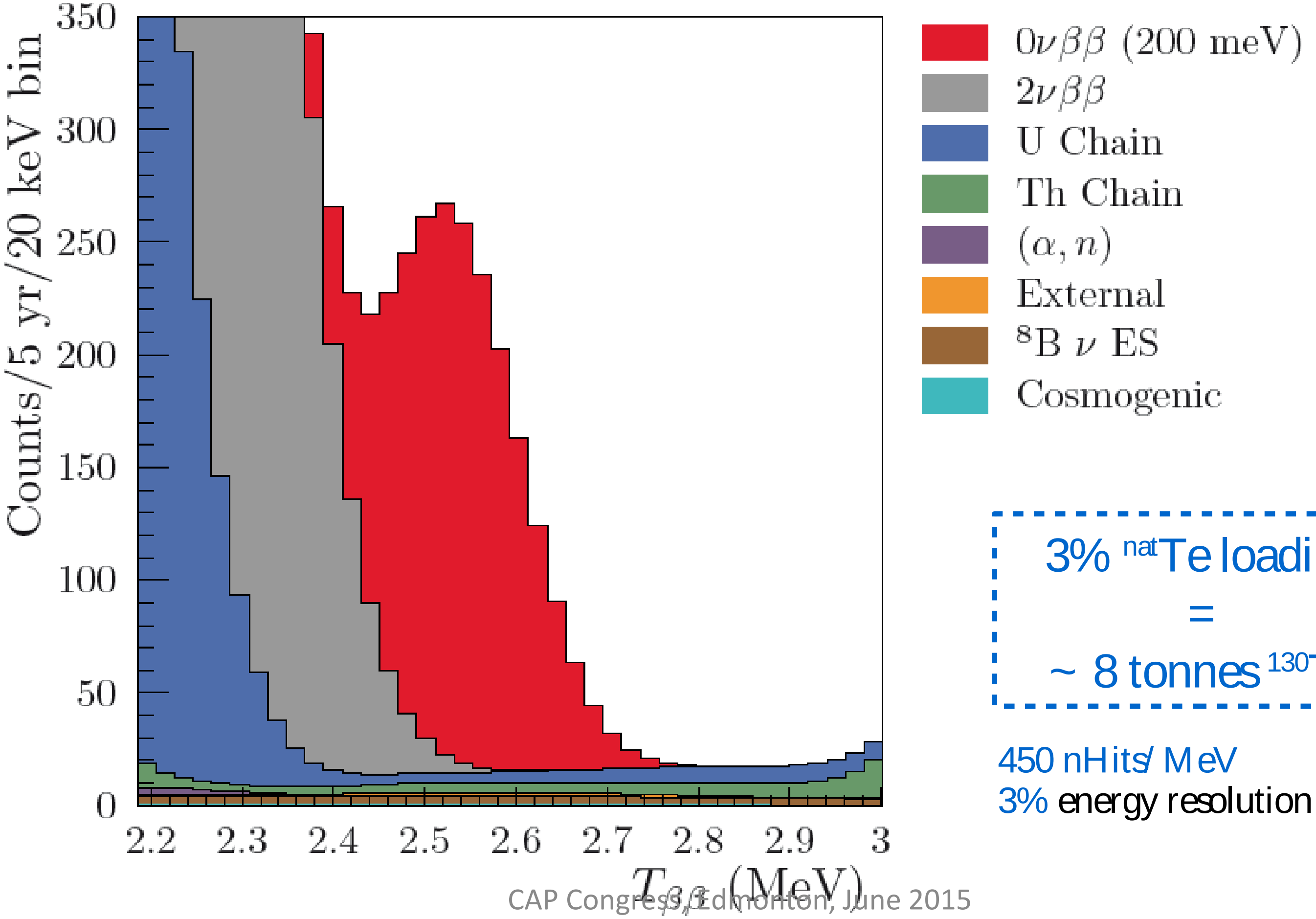
~22 events/yr

- 3.5 m (20%) fiducial volume cut
- 200 hits/MeV
- 5 years
- > 99.99% efficient ^{214}Bi tag
- >98% efficient internal ^{212}Bi tag

- Factor 50 reduction $^{212/214}$BiPo (pile-up)
- Negligible cosmogenic isotopes
- m_{0v2b}=200 meV **

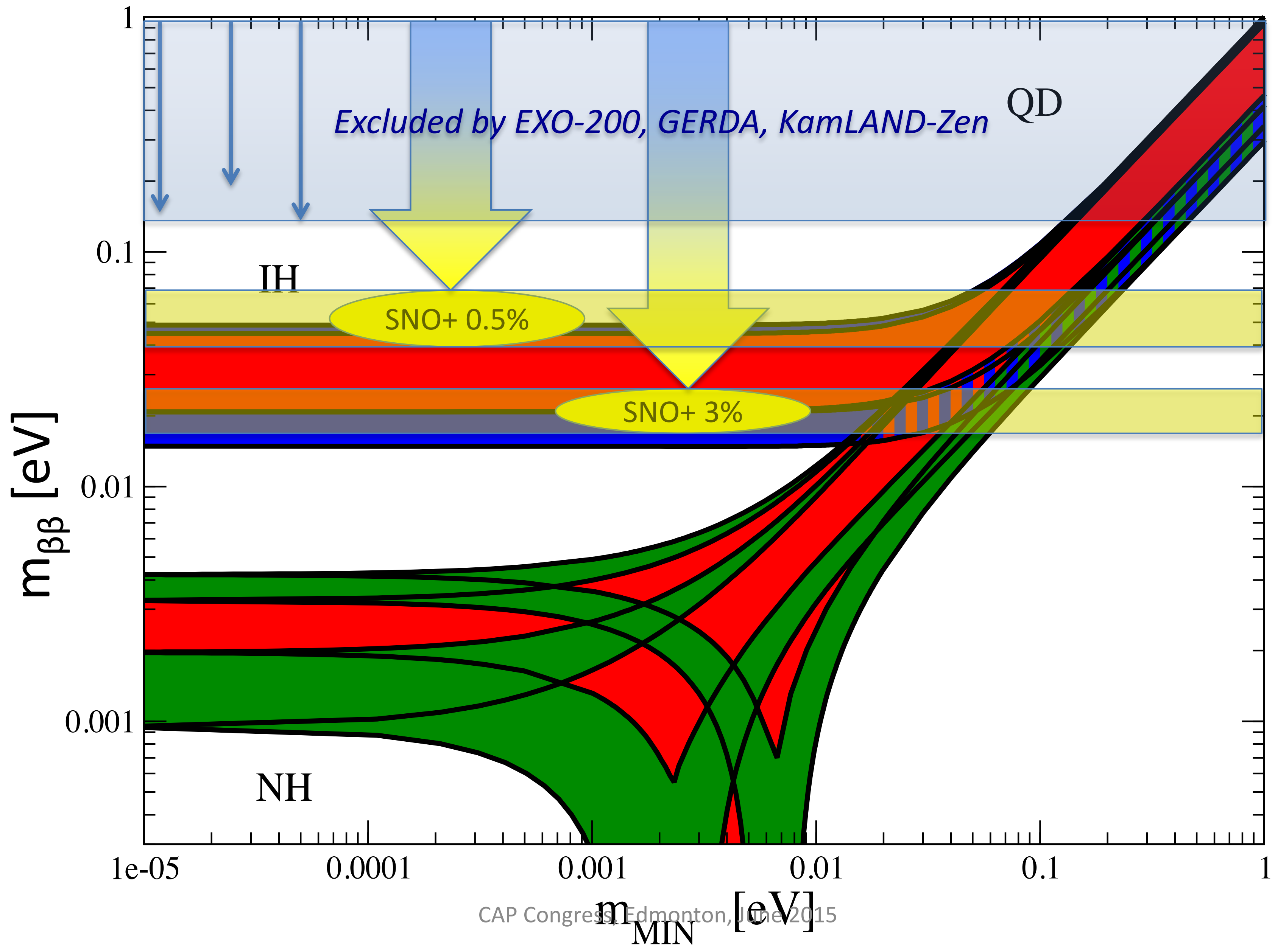
**J. Barea et al. Phys. Rev. C87 (2013) 014315
J. Kotila, F.Iachello. Phys. Rev. C 85 (2012) 034316

SNO+ Phase 2 with 3% TeLS



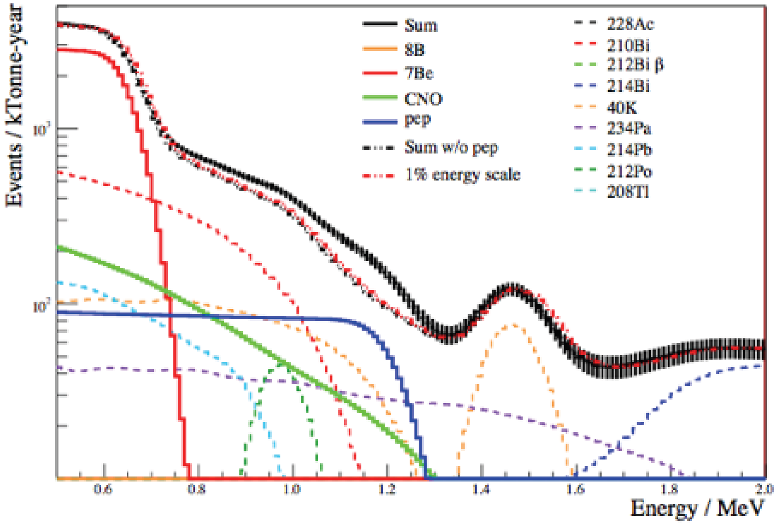
3% ^{nat}Te loading
=
~ 8 tonnes ^{130}Te

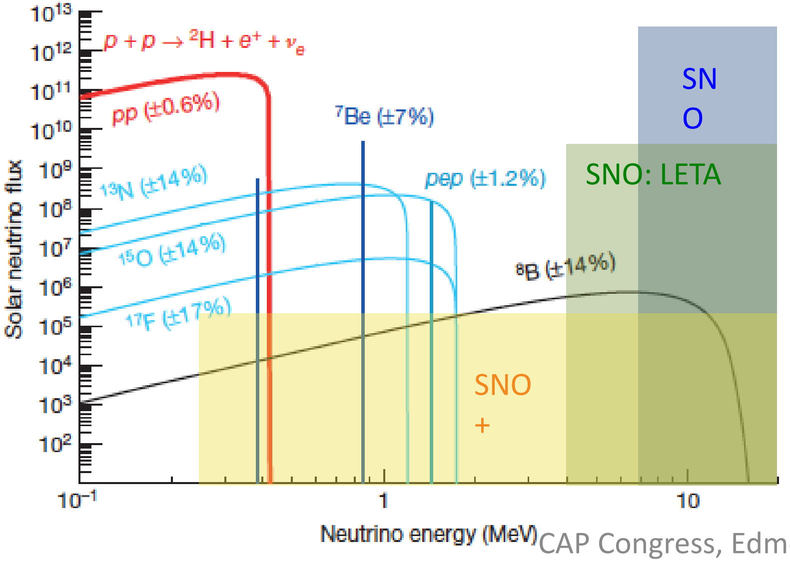
450 nHits/ MeV
3% energy resolution at Q_{bb}

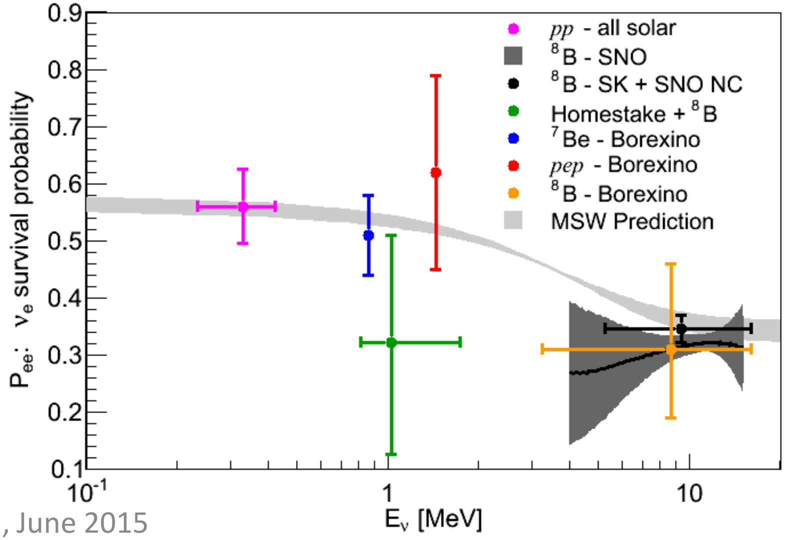

Excluded by EXO-200, GERDA, KamLAND-Zen
QD
IH
SNO+ 0.5%
SNO+ 3%
NH
1
0.1
0.01
0.001
$m_{\beta\beta}$ [eV]
1e-05
0.0001
0.001
0.01
0.1
1
m_{MIN} [eV]

Solar Neutrinos

Precise measurements of the low energy solar neutrinos can confirm that we understand the neutrino oscillation mechanism, how neutrinos interact with matter, and what’s going on inside the sun.







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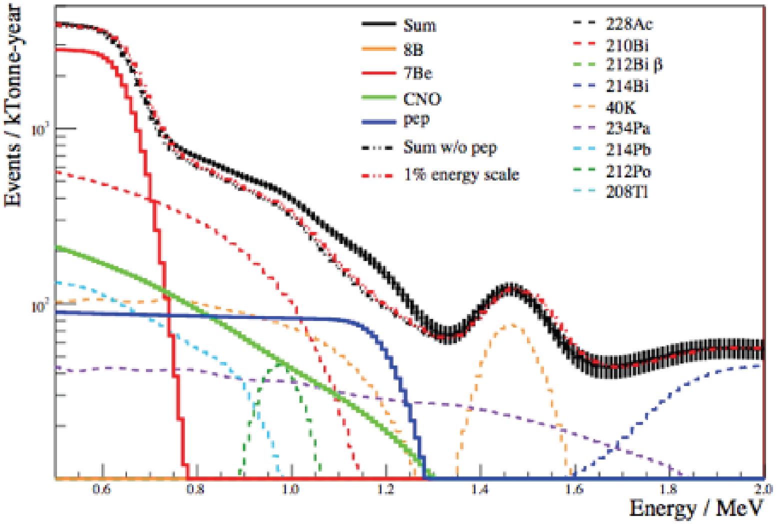
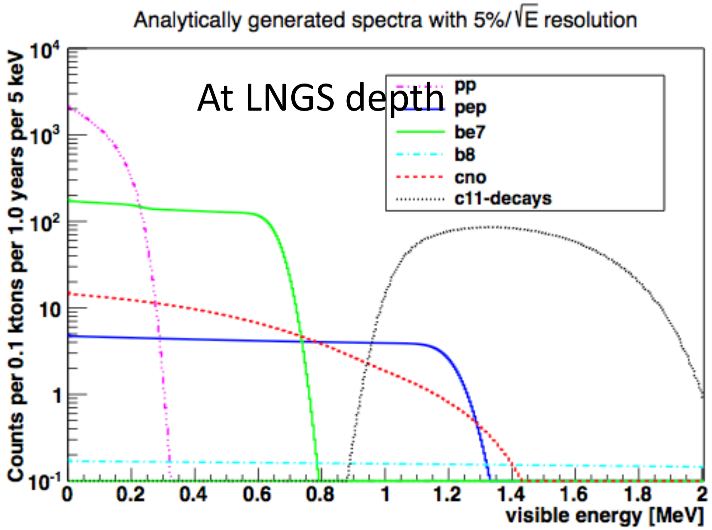
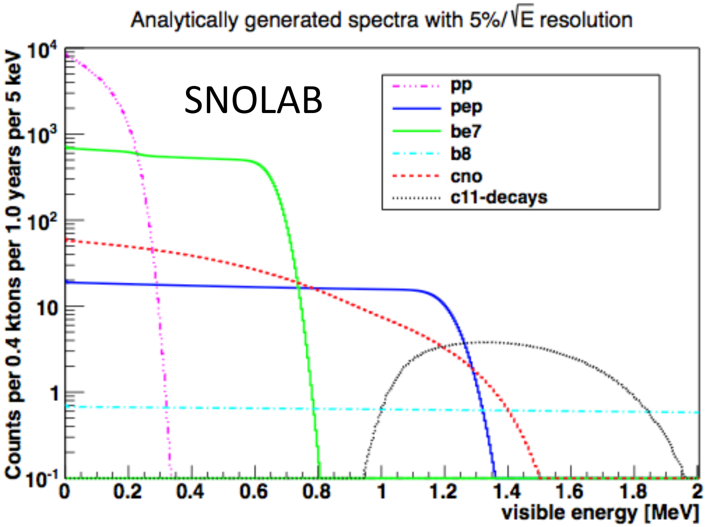






The depth of SNOLAB gives SNO+ a unique opportunity to make a precise measurement.

Solar Physics: Neutrinos and Helioseismology are Probes of the Solar Interior

Accreted Metallicity and Mass:

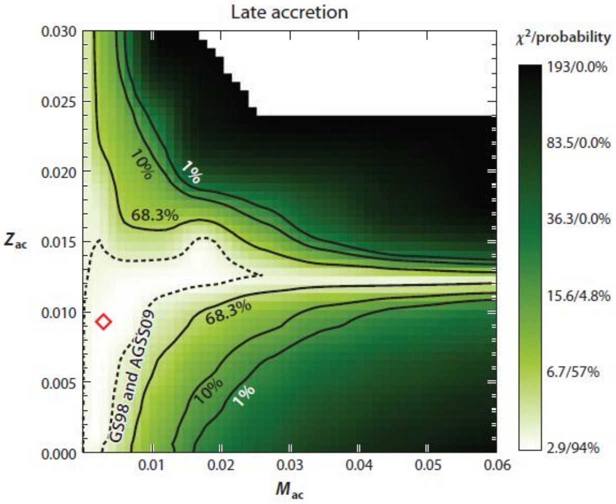
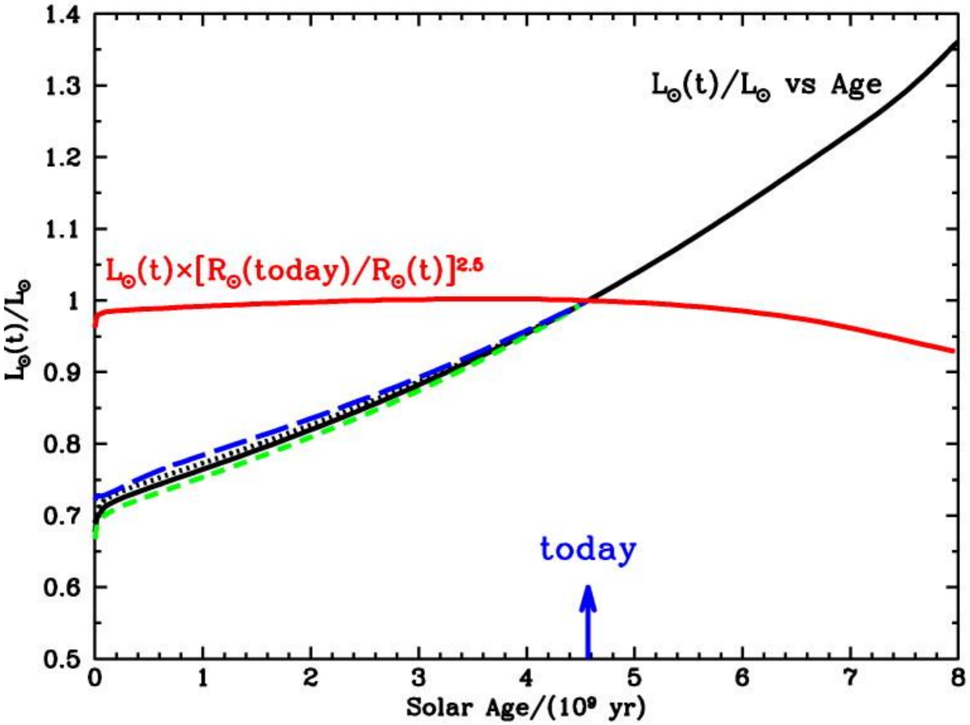


Figure 11

Global χ^2 solar neutrino analysis for the late accretion nonstandard solar model (NSSM) scenario. Contours are shown for 1%, 10%, and 68.4% confidence, with the best-fit model indicated by the red diamond. The fixed χ^2 contours corresponding to the AGSS09-SFII and GS98-SFII SSM fits are overlaid, showing the very limited parameter space where NSSMs with accretion do better than SSMs.

Annual Review of Astronomy and Astrophysics
51:21-61 (Haxton, Robertson and Serenelli)
2013

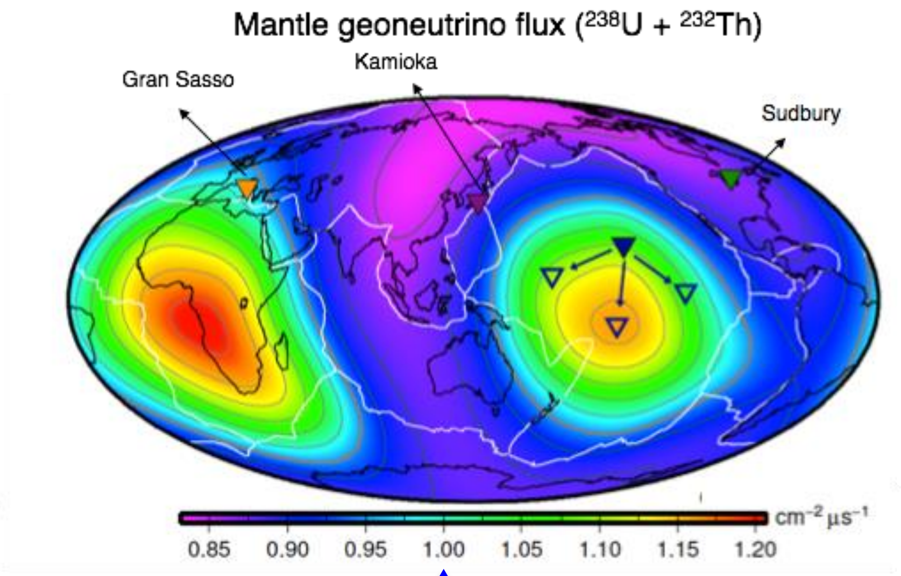


Geo- and Reactor Antineutrinos

Detect antineutrinos via:

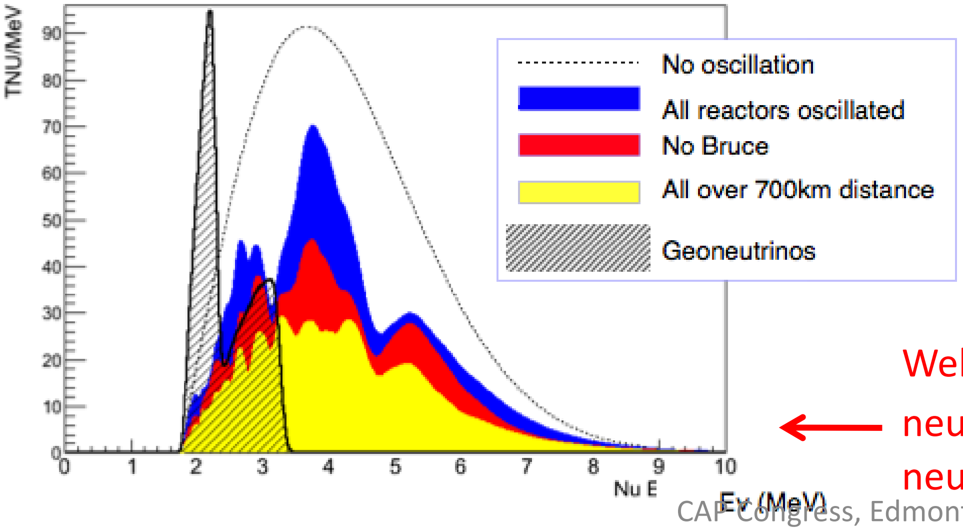
$$\overline{\nu}_e + p \rightarrow e^+ + n$$

Delayed coincidence means very low backgrounds!



Mantle geoneutrino flux ($^{238}U + {}^{232}Th$)

Measuring the geo-neutrino flux tells us about the earth's internal chemical composition, and thermal history

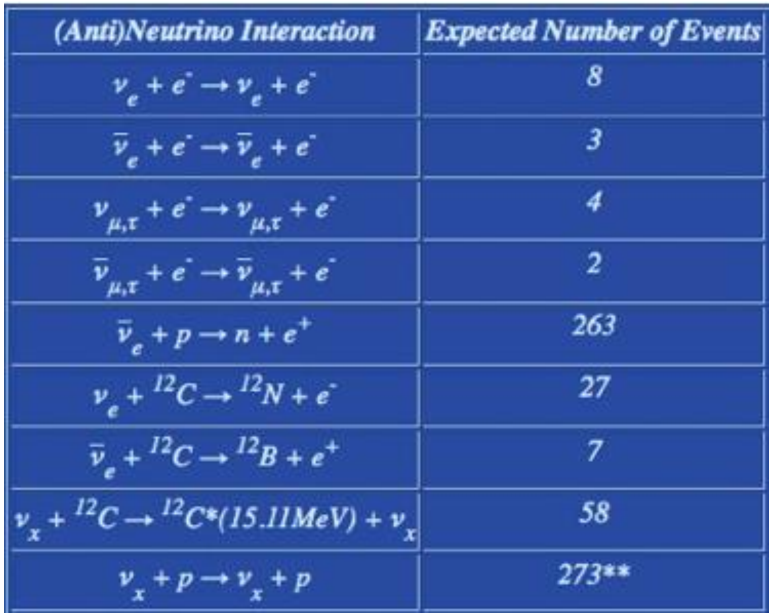


Well known fluxes and baselines for reactor neutrinos **provides** precision probe of neutrino oscillations

Supernova Neutrinos

- Type II supernovae release ~99% of their gravitational binding energy as neutrinos
  - More neutrinos in a few seconds than in the rest of the star’s life combined
  - Burst detectable at galactic distances
- Galactic supernovae estimated to happen ~once in 30 years
- Neutrinos provide “early warning” of supernova for optical observations
- Neutrinos provide information on neutrino oscillations, the supernova itself, cosmological parameters, etc.

Expected signal for a 10kPc Supernova

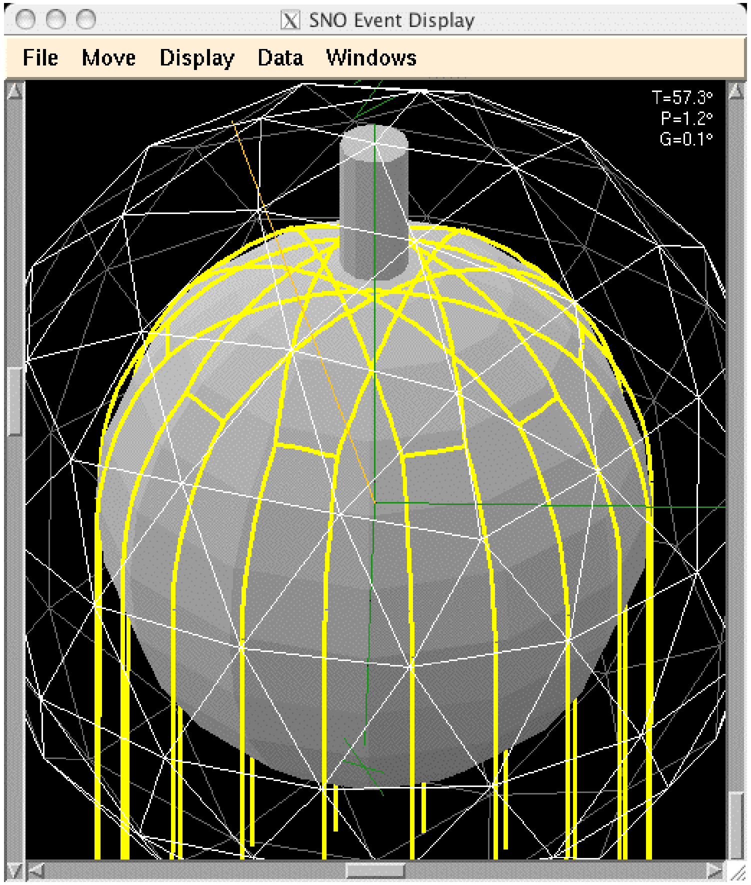


(Anti)Neutrino Interaction	*Expected Number of Events*
$\nu_e + e^- \rightarrow \nu_e + e^-$	8
$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$	3
$\nu_{\mu,\tau} + e^- \rightarrow \nu_{\mu,\tau} + e^-$	4
$\bar{\nu}_{\mu,\tau} + e^- \rightarrow \bar{\nu}_{\mu,\tau} + e^-$	2
$\bar{\nu}_e + p \rightarrow n + e^+$	263
$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$	27
$\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+$	7
$\nu_x + {}^{12}C \rightarrow {}^{12}C^*(15.11 MeV) + \nu_x$	58
$\nu_x + p \rightarrow \nu_x + p$	273**

The SNO+ Story

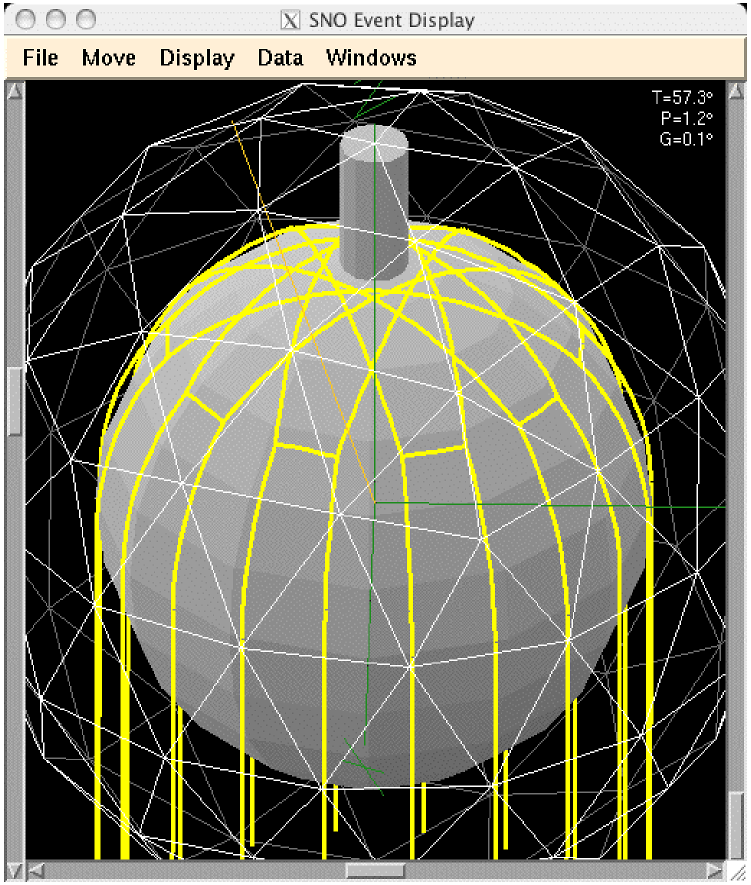
- Past
  - Identify acrylic compatible scintillator
  - Install acrylic vessel hold-down net
  - Upgrade electronics
  - Clean acrylic vessel
- Present
  - Design purification systems for tellurium and surfactant
  - Install scintillator purification plant
  - Fill detector with water
  - Upgrade calibrations and covergas systems
- Future
  - Operate water filled detector to study backgrounds and nucleon decay - 2015
  - Commission scintillator plant and fill detector with scintillator – 2015-2016
  - Install isotope and surfactant purification equipment – 2016
  - Purify and load DBD isotope – 2016-2017

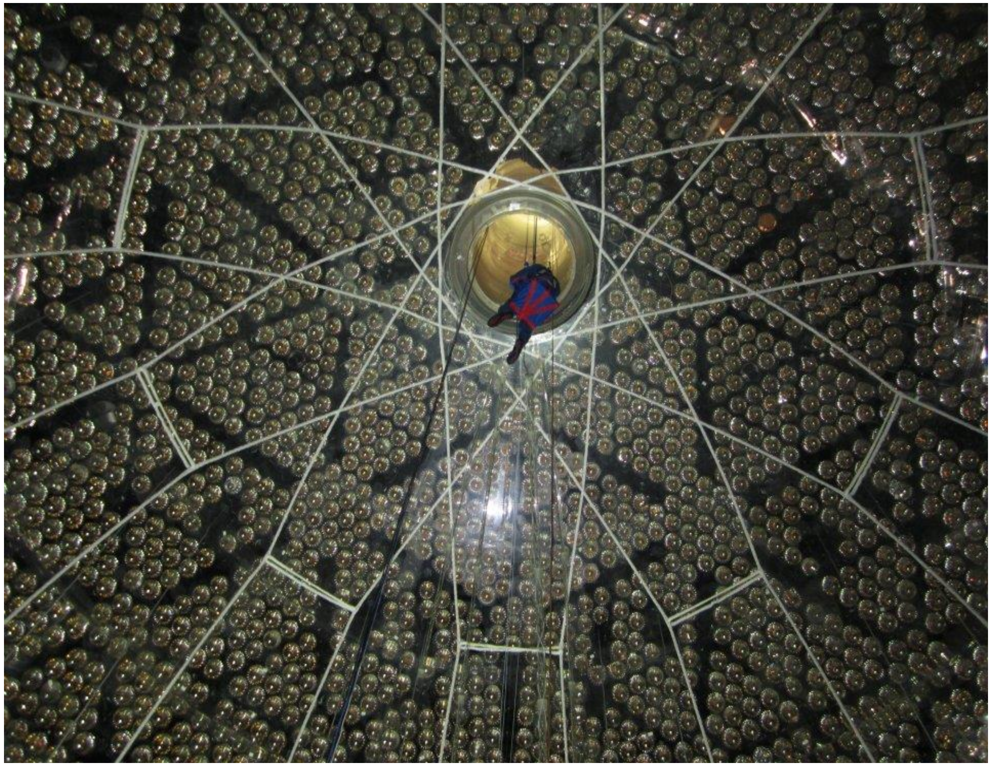
Install AV Hold-Down Net



Hold-down anchors and new floor liner installed

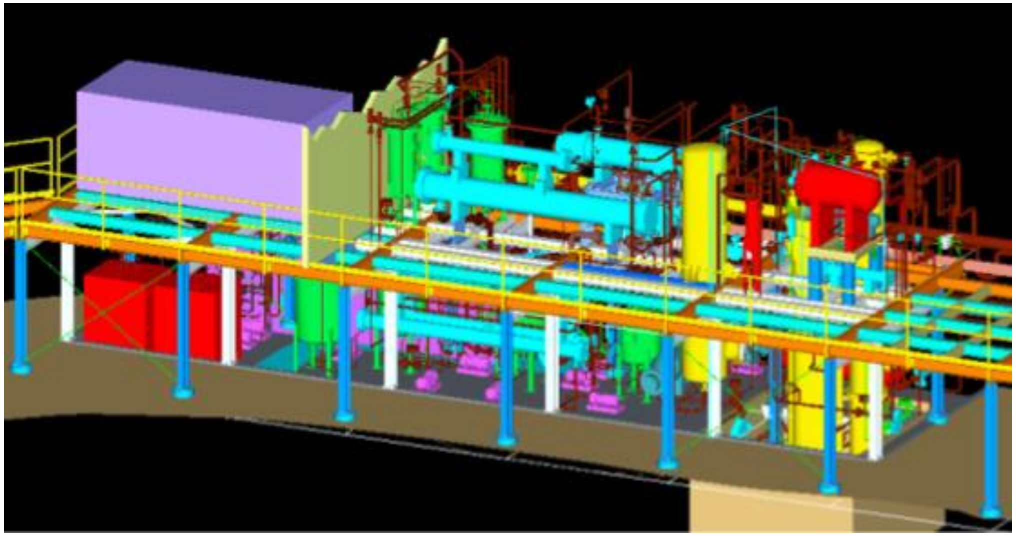
Install AV Hold-Down Net





Hold-down rope net installed, pre-tensioned, and tested by "float the boat" testing.

Scintillator Process System



Essentially had to install an industrial petrochemical processing facility underground. Major piping/vessel installation done, working on leak checking, then cleaning & passivation

Scintillator Process System

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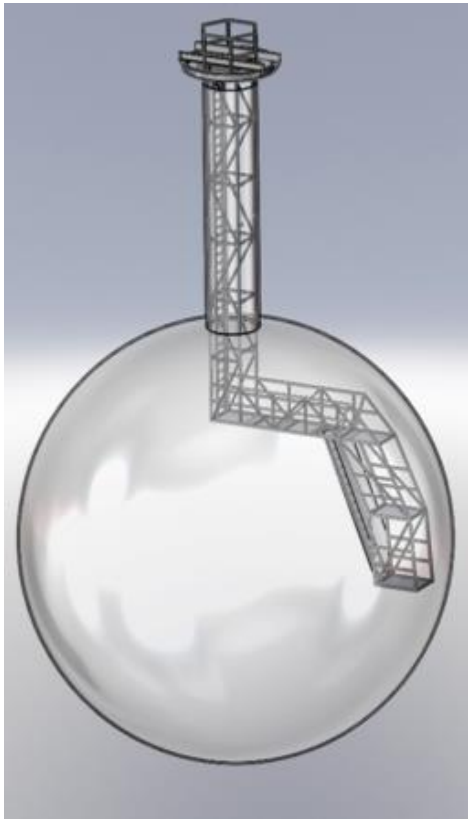
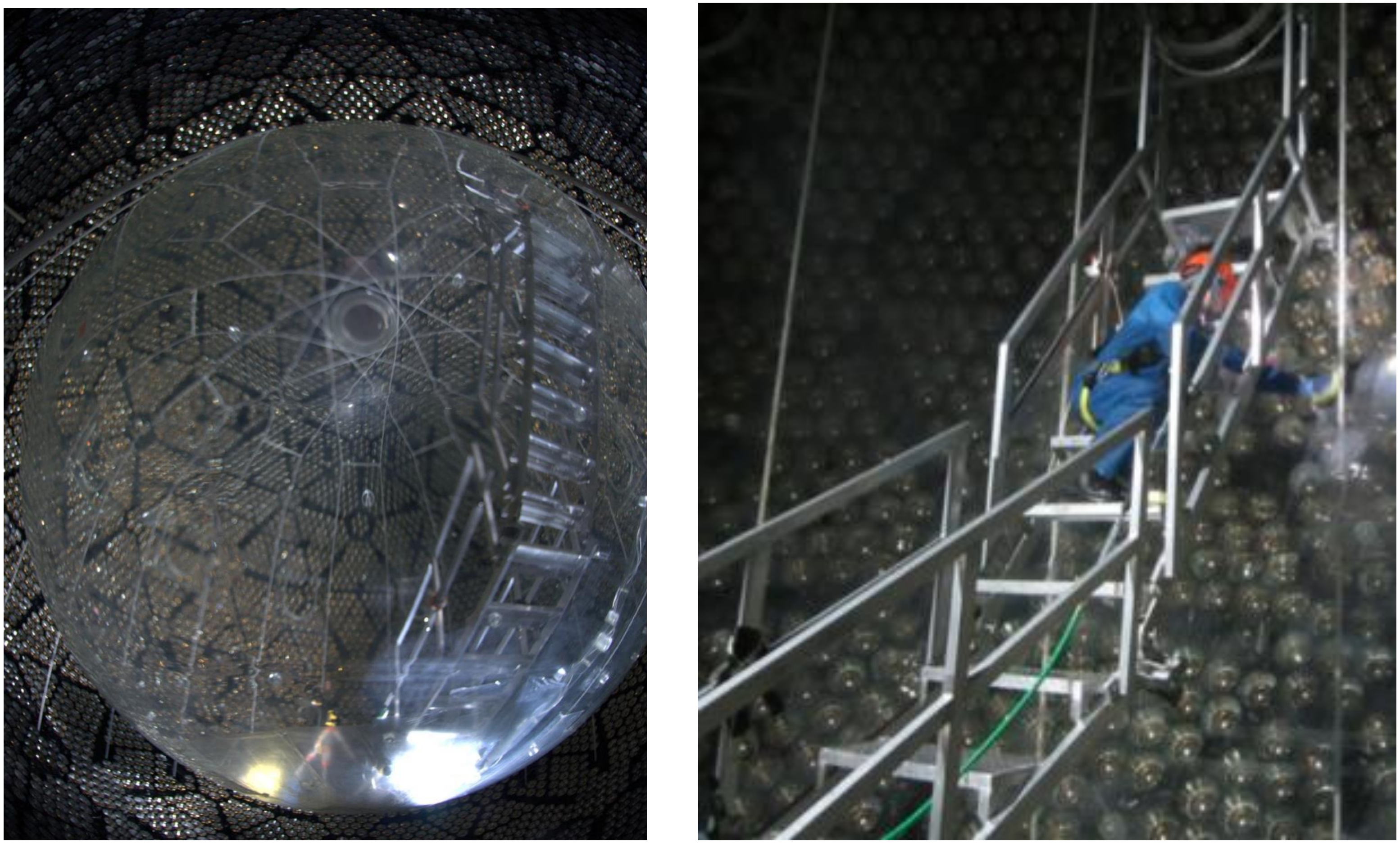
Acrylic Vessel Cleaning



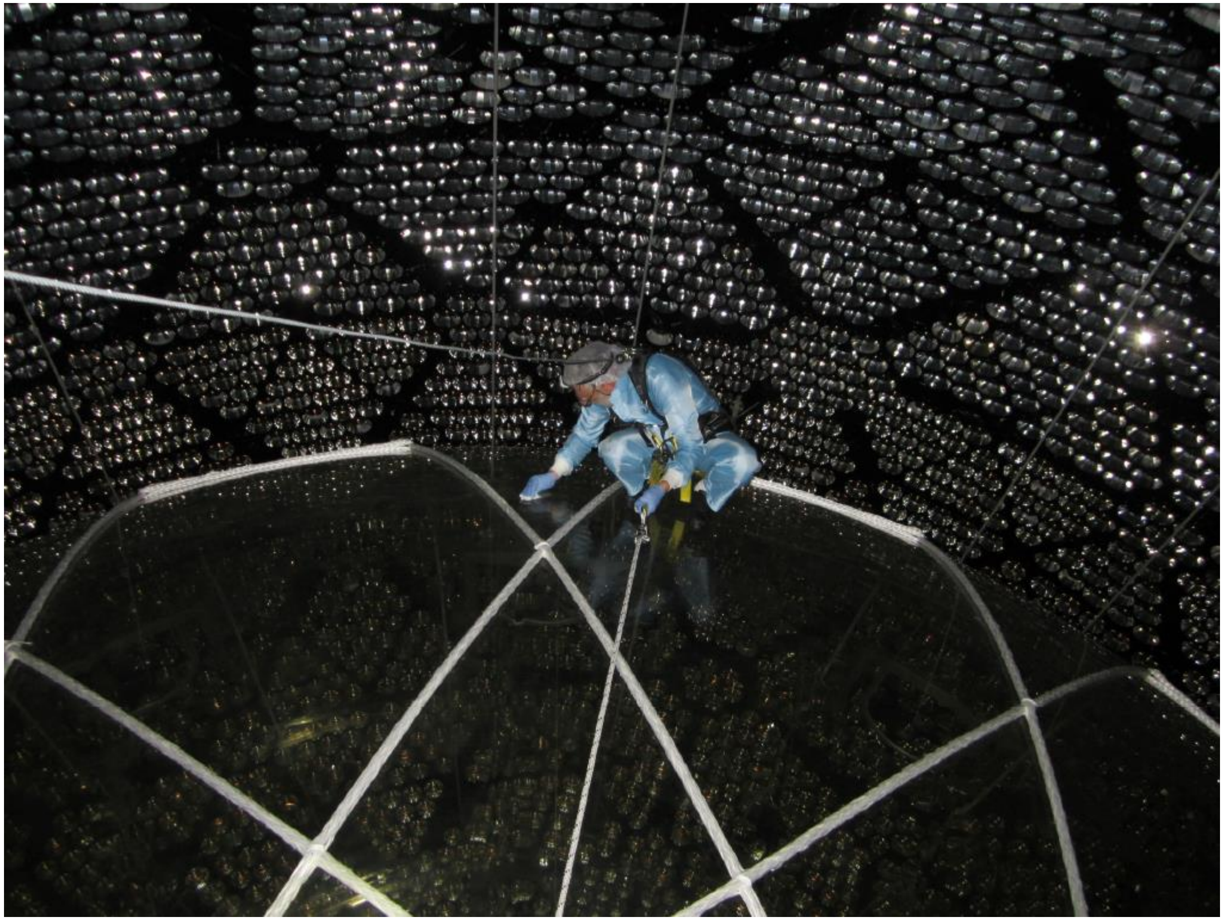
Upper hemisphere – suspended platform

Acrylic Vessel Cleaning



Lower hemisphere - rotating ladder

Acrylic Vessel Cleaning

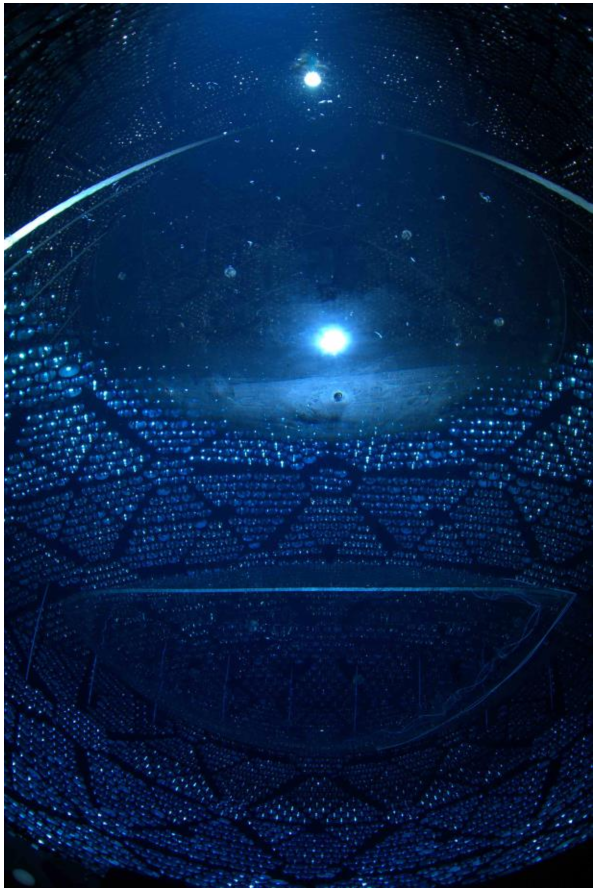


Even the outside!

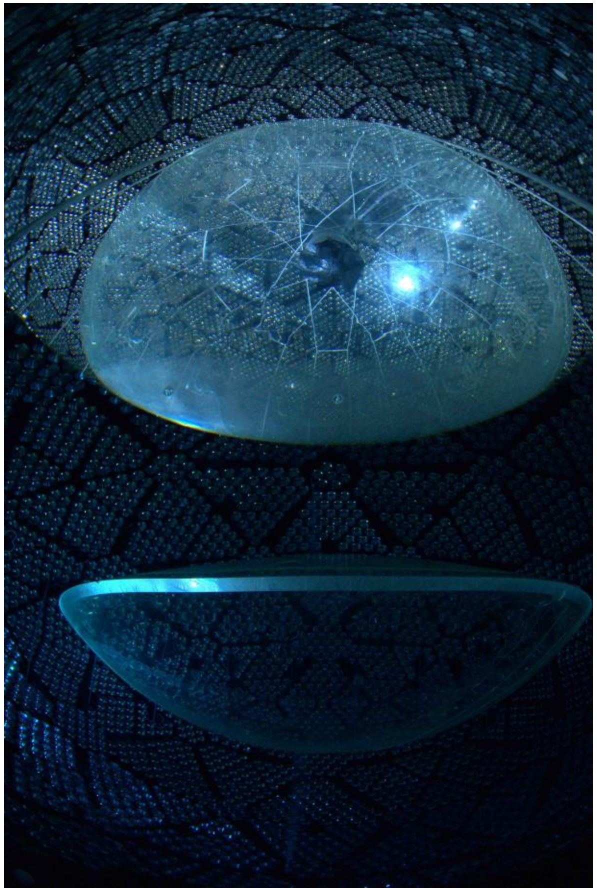
Water Filling

Camera above water

Camera and light underwater



Camera underwater, light above water



The detector and cavity are currently about half filled with water. This leads to interesting optics!

Electronics Upgrades

New crate readout interfaces (20)

- Local intelligence for independent control and data
- Rate up to 40 Mbyte/s

New central trigger boards (7)

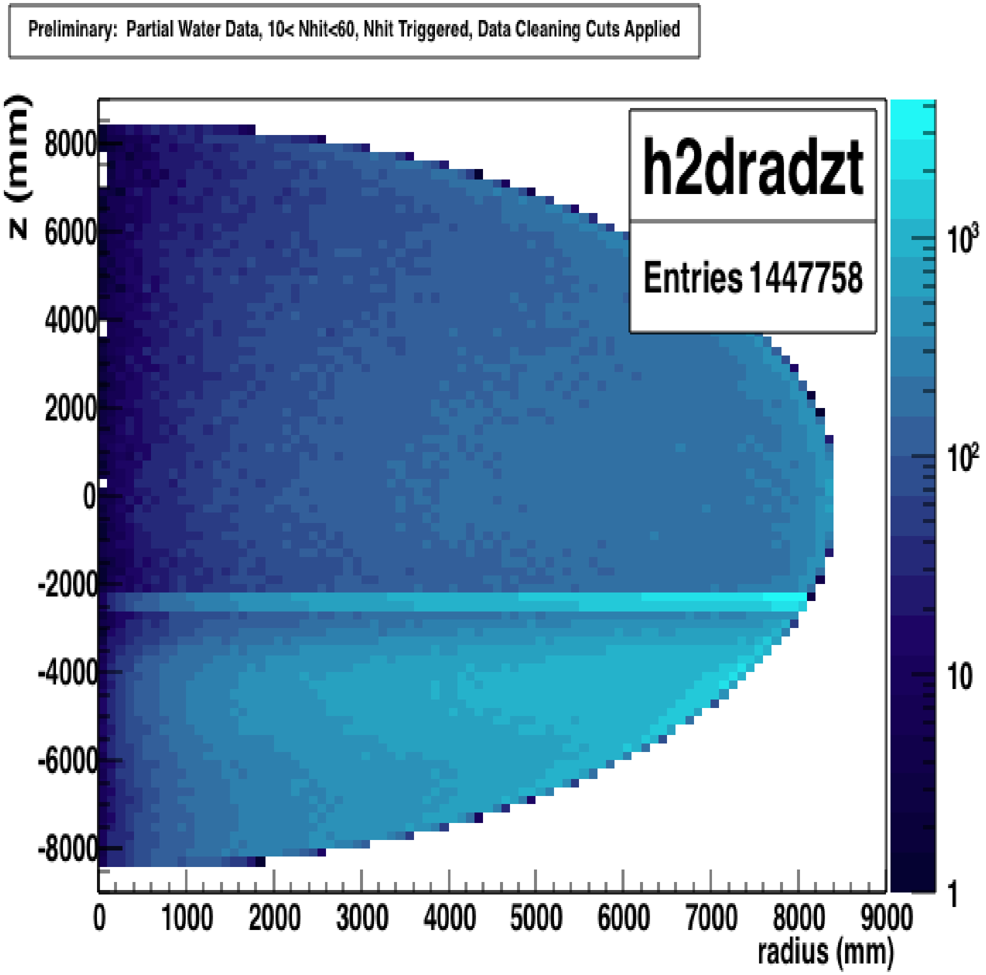
- Handles much higher currents for scintillator events
- Allows auto "re-triggering" to capture coincidences from BiPo and other backgrounds

In addition

- New DAQ
- Moved MC/Analysis framework to RAT/Geant4; code was essentially rewritten
- Repaired many of the failed PMT bases

Partial Fill Data

- See Kalpana Singh's talk on LED flasher system and extracting optics
- Have acquired data, tested data cleaning cuts, run it through reconstruction code.
- Still need to calibrate channel timings, fit resolutions and efficiencies and finalize many algorithms and fully automate processing
- In general things are functioning well…



Status

- now filling the SNO+ detector with water
- water-filled data taking starts end of 2015
  - to study external backgrounds and detector optics
- scintillator purification plant installation completion in Summer 2015
- begin commissioning scintillator purification plant in Fall 2015
- liquid scintillator filling starting in 2016
- installation of tellurium purification skid and Te purification in 2016
- addition of Te to SNO+ liquid scintillator and DBD run in late 2016 to early 2017