

Neutrinoless Double Beta Decay with SNO+

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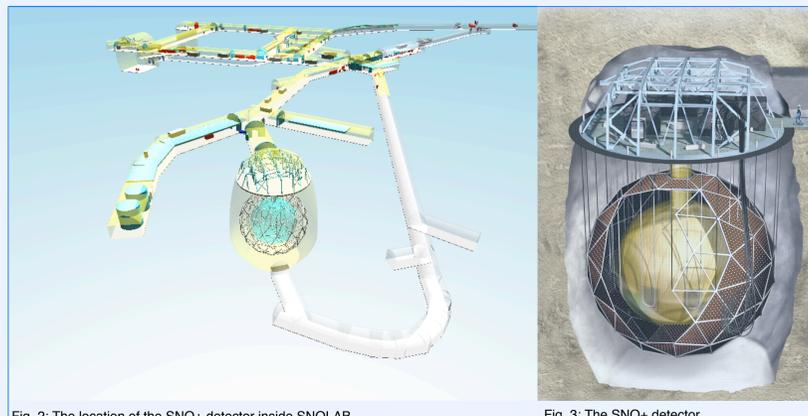
The Basics

SNOLAB



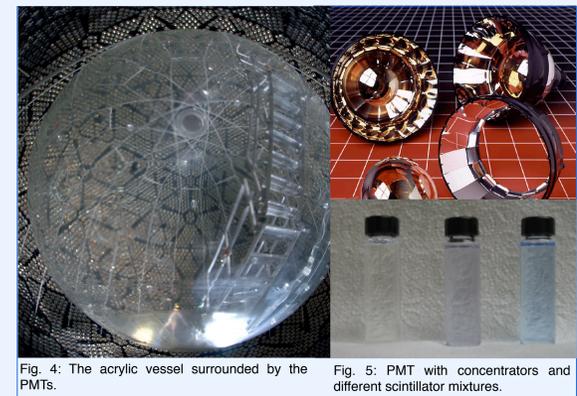
SNOLAB is located in the Creighton mine near Sudbury, Canada. It contains several neutrino and dark matter experiments. At its depth of about 2200m the flat overburden equals about 6000m.w.e.

SNO+



The SNO+ experiment uses the existing Sudbury Neutrino Observatory (SNO) detector. The main physics goal of SNO+ is to search for neutrinoless double beta decay; the detector is also sensitive to solar & supernova neutrinos and reactor & geo antineutrinos. SNO+ can also place competitive limits on nucleon decay.

SNO+ Detection Scheme



At the heart of the detector is a 12m diameter acrylic vessel filled with liquid scintillator and ^{130}Te , an isotope that undergoes double beta decay. Viewing the scintillator are $\sim 9,500$ sensitive photomultiplier tubes (PMTs). The PMTs detect light that is emitted when charged particles pass through the scintillator.

$0\nu\beta\beta$

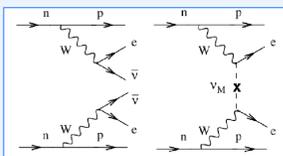


Fig. 6: Feynman diagram for $2\nu\beta\beta$ and a possible $0\nu\beta\beta$ diagram.

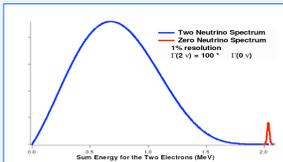


Fig. 7: Electron energy spectrum.

Perhaps the most fundamental open question in neutrino physics is the very nature of the neutrino: Majorana or Dirac.

- The neutrino is the only known fermion with the potential to be its own antiparticle, or a Majorana particle.
- The most practical way to observe Majorana neutrinos is to see the neutrinoless double beta decay ($0\nu\beta\beta$) process.
- The signature for this process is a peak at the endpoint of the two-neutrino double beta decay ($2\nu\beta\beta$) spectrum.

Advantages of SNO+

The large-scale liquid scintillator approach to a $0\nu\beta\beta$ search has many advantages:

- Simple, well-understood detector geometry.
- The ability to calibrate with different targets, including source in / source out comparisons, to understand detector response and background levels.
- Significant self-shielding.
- Potential for large mass target.
- Scintillator timing profile tags low-energy background events.
- 2km overburden shields from cosmic rays.

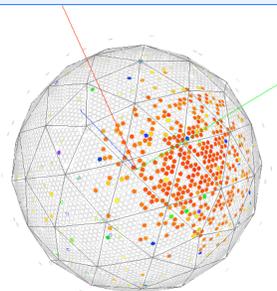


Fig. 8: A simulated $0\nu\beta\beta$ event with 0.3% Te loading in the scintillator volume.

Background Mitigation

Several radioactive isotopes produce decays in the signal region of interest. Understanding backgrounds is thus critical to the experiment's success.

- SNO+ will employ a multi-stage, on-going purification system to filter particulates and certain radioactive isotopes.
- Large detector mass allows for fiducialization.

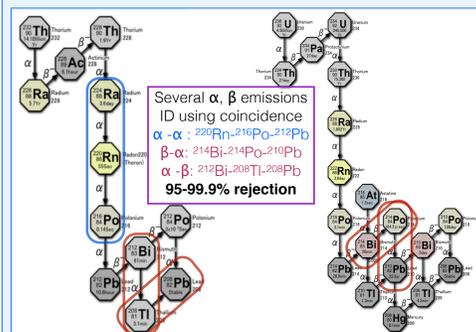


Fig. 9: Thorium and Uranium natural decay chains. Coincidence tagging methods are highlighted.

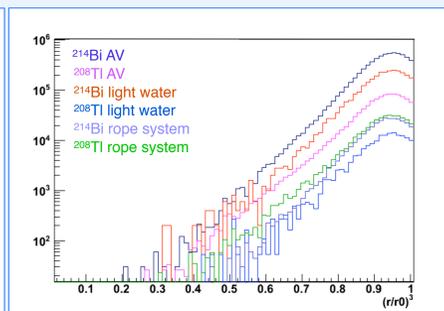


Fig. 10: Key backgrounds as a function of normalized radius. Backgrounds external to the scintillator volume can originate in many locations.

- Several novel techniques to tag and reject background events.
- Differentiate α from β events by scintillator timing profiles.
- Tag radioactive background events by α/β and α/α coincidences in the decay chains of U and Th.

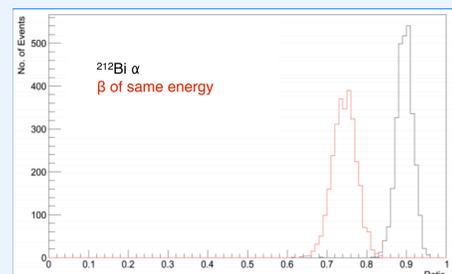


Fig. 11: Separation from timing profiles between α and β particles of equal energy. On the x-axis, "Ratio" is the ratio of early to late PMT time residuals.

Sensitivity

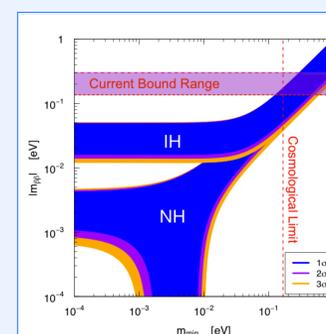


Fig. 12: Effective Majorana neutrino mass for inverted ($m_{\min}=m_1$) and normal ($m_{\min}=m_3$) hierarchies. Current bounds are from EXO-200 (Phys. Rev. Lett. 109, 032505 (2012)) and KLZ (Phys. Rev. Lett. 110, 062502 (2013)). Plot reference: arXiv:1203.5250v3

Oscillation experiments have measured three mixing angles and the magnitude of two mass differences, leaving the allowed phase space as shown in Fig. 12 for the process of $0\nu\beta\beta$. The two regions correspond to two possible orderings of the neutrino mass states.

^{130}Te has many advantages for a $0\nu\beta\beta$ search, including:

- Highest natural abundance (34.5%) of $2\nu\beta\beta$ isotopes, so no need to enrich.
- Relative $2\nu\beta\beta$ background 100 times smaller than the other candidate isotope, ^{150}Nd .
- Low inherent radioactivity of raw material.
- Affordable for high loading.

- Main internal background (^{214}Bi) removed at 99.9% efficiency with β - α tag.
- Can be loaded in scintillator to percent levels without significant detriment to optics.

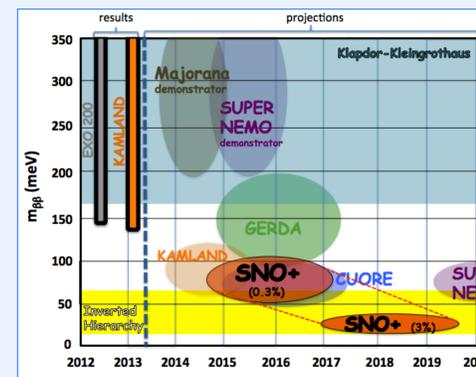


Fig. 13: Projection of SNO+ sensitivity to effective Majorana mass.

The initial 0.3% loading of Te is projected to reach the inverted hierarchy and increased loading to 3% could cover the entire inverted hierarchy. Studies are currently being done to determine the maximum Te loading potential.