Neutrinoless Double Beta Decay with SNO+

CAP Congress 2013, Montreal

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For the SNO+ Collaboration

- SNO heavy water replaced by 780 tonnes of liquid scintillator
- ~9500 PMTs
- 1500 + 5300 tons ultra-pure water shielding
- New rope net to hold down the 6m radius acrylic vessel
- 6800’ underground in SNOLAB

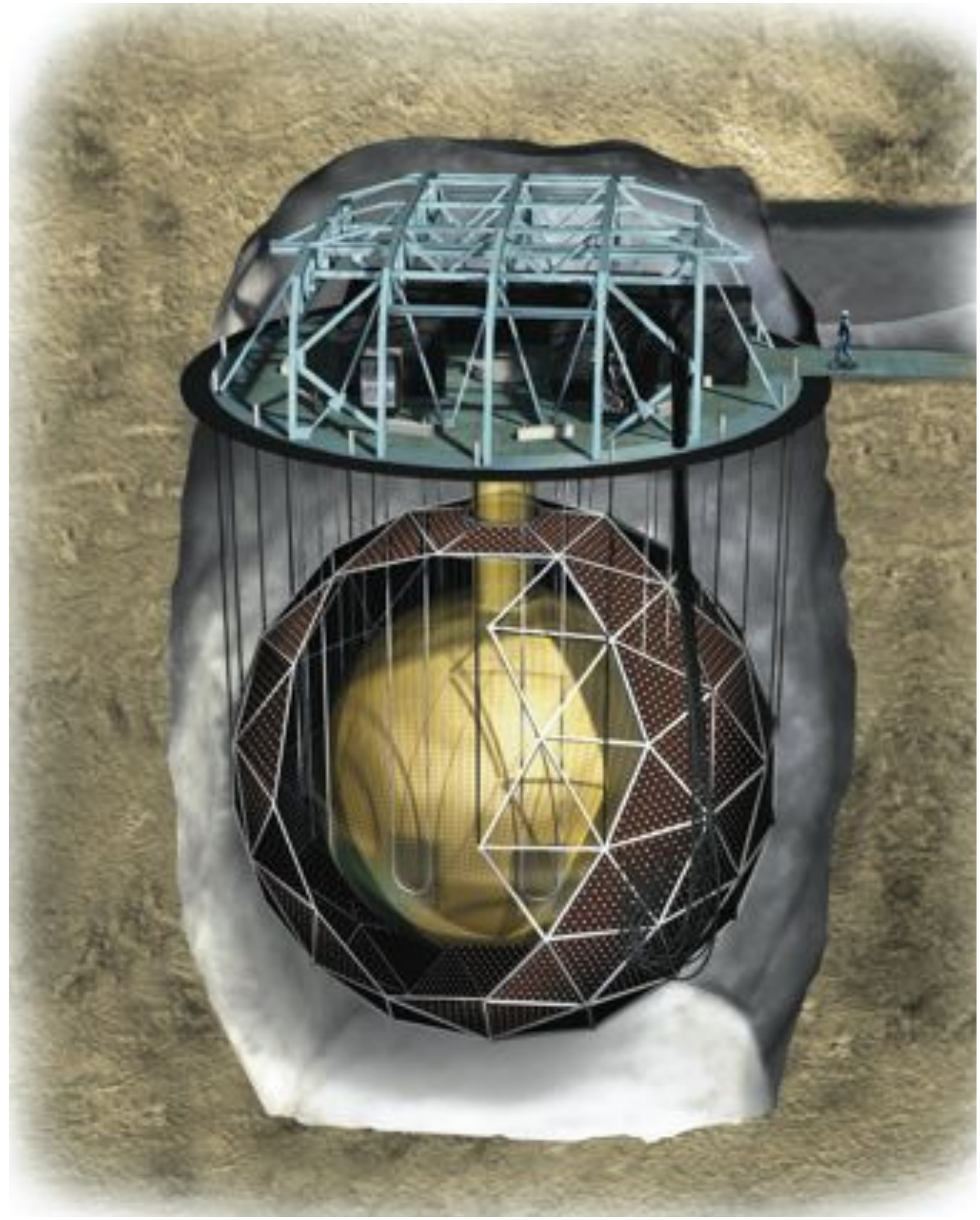


Image courtesy National Geographic

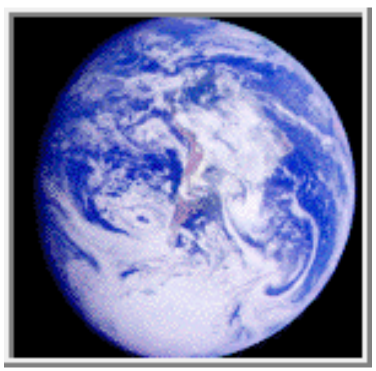
The SNO+ Collaboration

Armstrong Atlantic State University
Black Hills State University
Brookhaven National Laboratory
Laurentian University
LIP Coimbra
LIP Lisboa
Oxford University
Queen Mary, University of London
Queen's University
SNOLAB
Technical University of Dresden
TRIUMF
University of Alberta
University of California – Berkeley
& Lawrence Berkeley National Laboratory
University of Chicago
University of Liverpool
University of North Carolina at Chapel Hill
University of Pennsylvania
University of Sussex
University of Washington

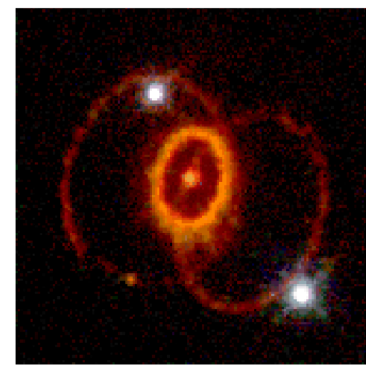
SNO+ Physics

Low Energy Solar Neutrinos

Reactor Antineutrinos

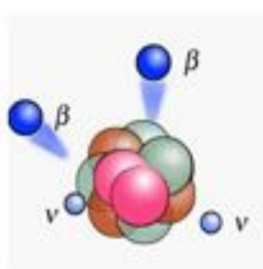


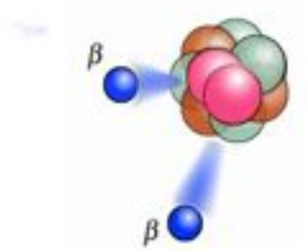
Geo-Neutrinos



Supernova Neutrinos

Neutrinoless Double Beta Decay





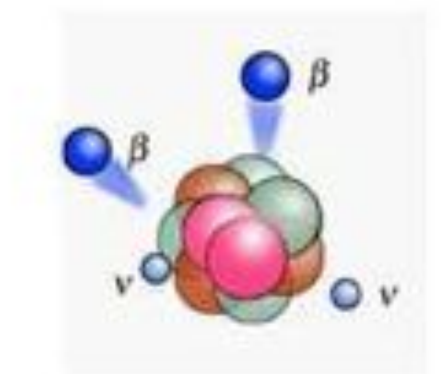
Neutrinoless Double Beta Decay

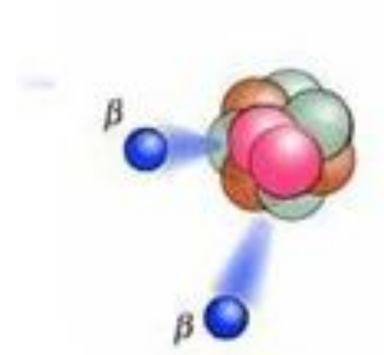
- Are neutrinos Majorana or Dirac particles?
  - Are they their own anti-particles?
- In double beta decay, a nucleus releases two electrons and two antineutrinos:

$$(A, Z) \rightarrow (A, Z+2) + 2e^{-} + 2\bar{\nu}_e$$

- If neutrinos are Majorana, sometimes neutrinoless double beta decay occurs:

$$(A, Z) \rightarrow (A, Z+2) + 2e^{-}$$





Detection of neutrinoless double beta decay proves that neutrinos are Majorana and provides information about the neutrino mass.

Searching for neutrinoless double beta decay involves looking for a tiny monoenergetic peak at the end of a large double beta decay continuum.

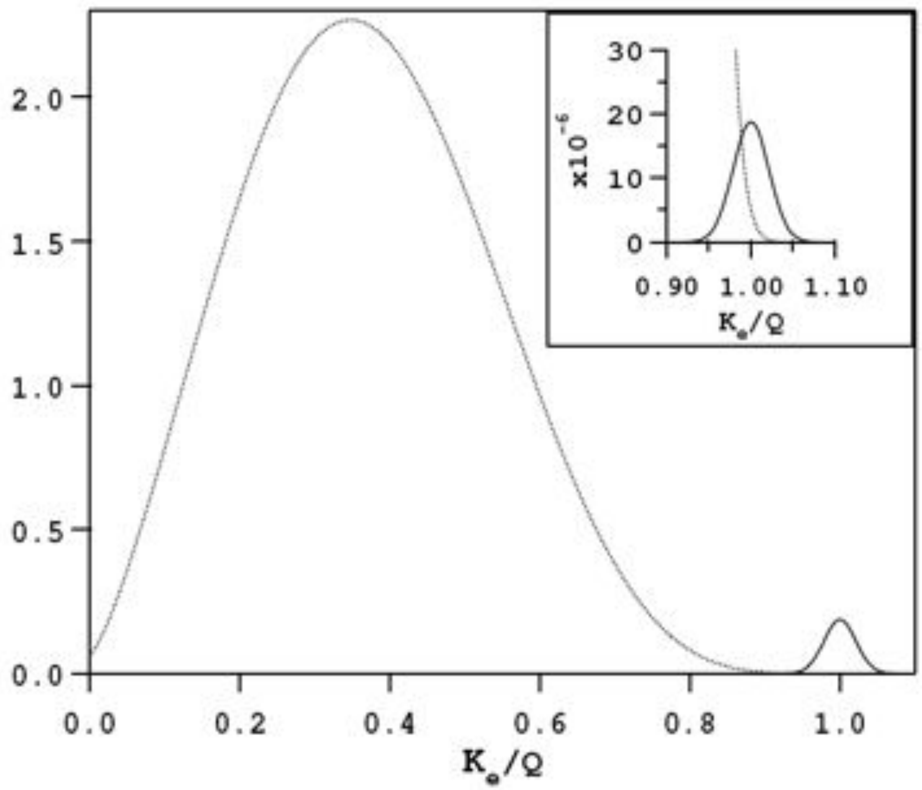
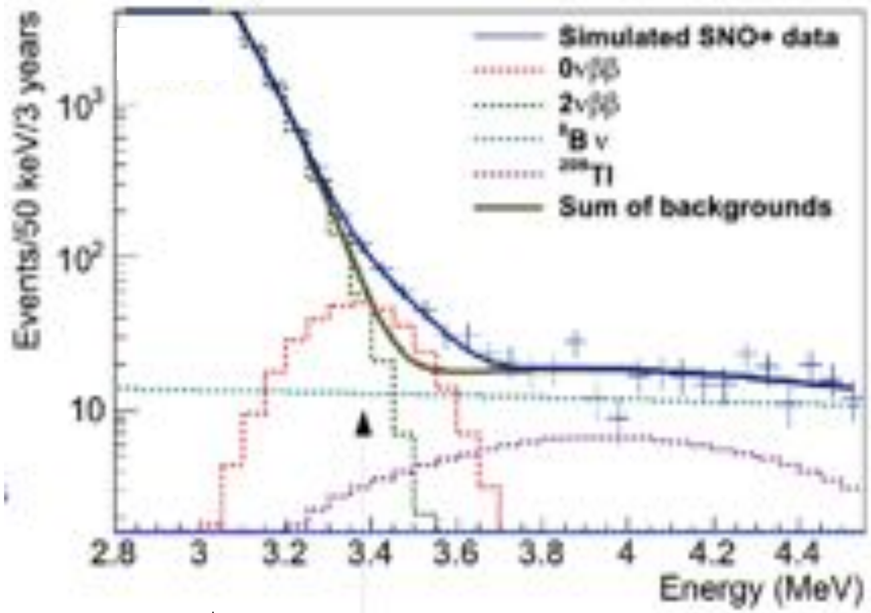


Image from Elliott and Vogel, hep-ph/0202254

D.B.D. experiments need good energy resolution, low backgrounds, and large amounts of isotope.

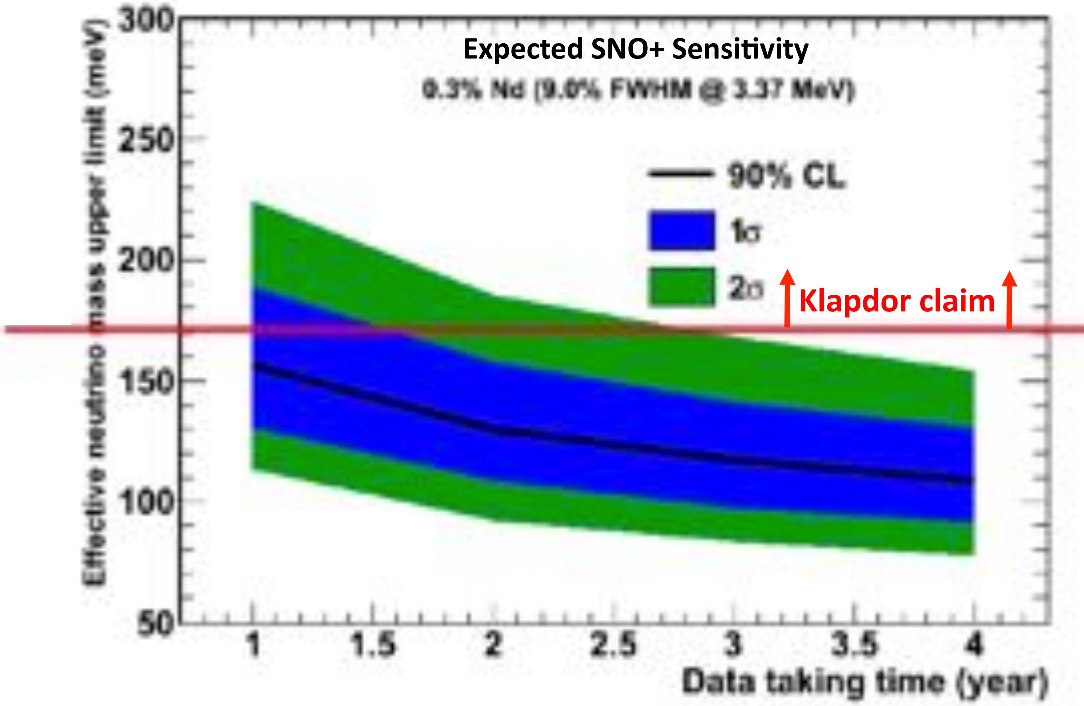
Neutrinoless Double Beta Decay in SNO+

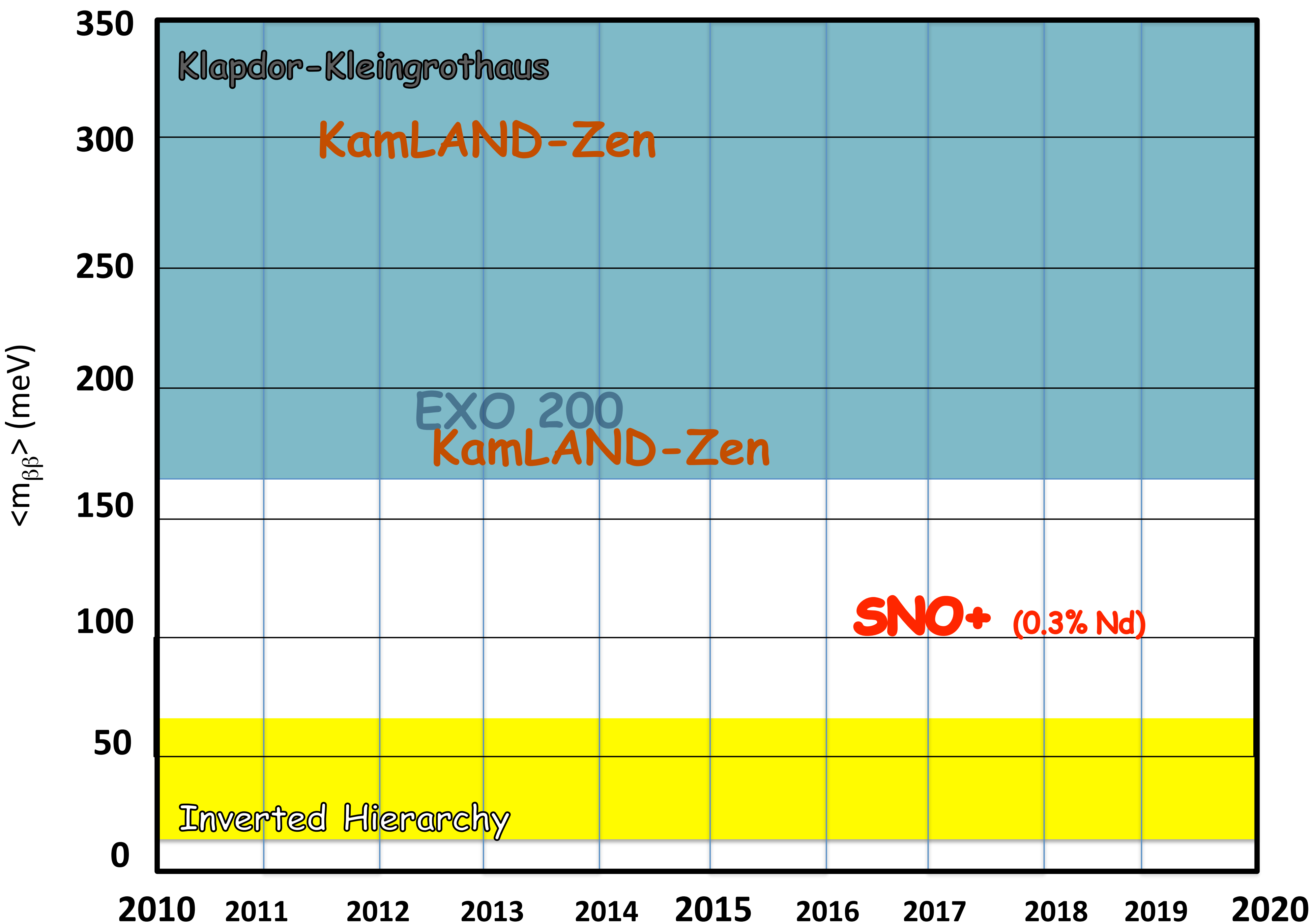
Loading neodymium into the SNO+ scintillator gives 140kg ^{150}Nd at 0.3% loading of natural neodymium (limited by optics).



Simulated SNO+ data

- Signal at Klapdor level
- 2.4 live-years of data
- 50% fiducial volume
- Borexino-level backgrounds
  - ^{214}Bi 99.9% rejection
  - ^{208}Tl 90% rejection





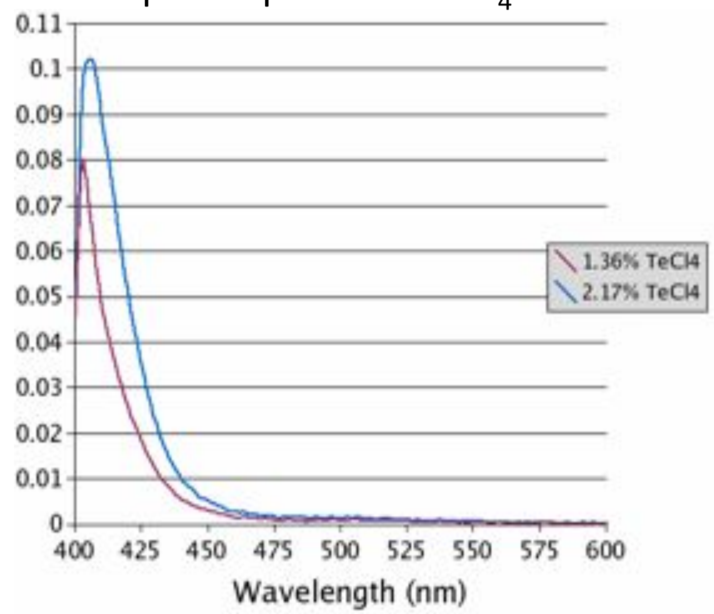
To improve the sensitivity of the SNO+ measurement, need more isotope.

ββ Isotopes with Q-values >2 MeV

isotope	Q-value [MeV]	natural abundance
^{48}Ca	4.27	0.19%
^{150}Nd	3.37	5.6%
^{96}Zr	3.35	2.8%
^{100}Mo	3.03	9.6%
^{82}Se	3.00	9.2%
^{116}Cd	2.80	7.5%
^{130}Te	2.53	34.1%
^{136}Xe	2.48	8.9%
^{124}Sn	2.29	5.6%
^{76}Ge	2.04	7.8%
^{110}Pd	2.01	11.8%

^{130}Te has highest natural abundance: *0.3% loading in SNO+ gives ~800kg of ^{130}Te isotope*

Absorption Spectra of $TeCl_4$ Solutions



Te has no absorption lines, so no a priori limit on loading concentration…

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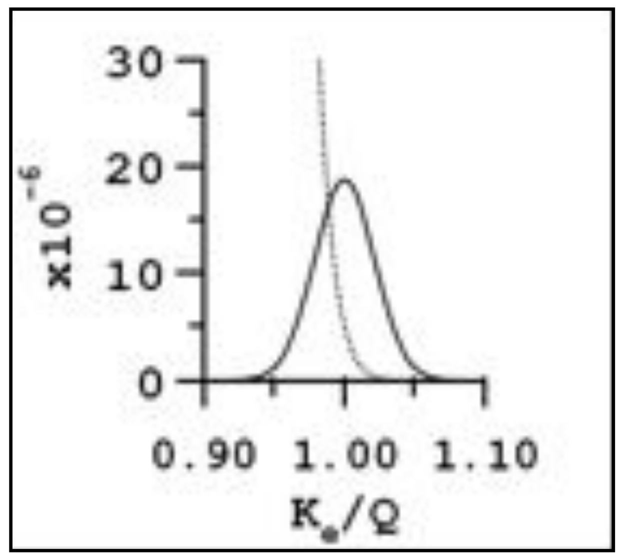
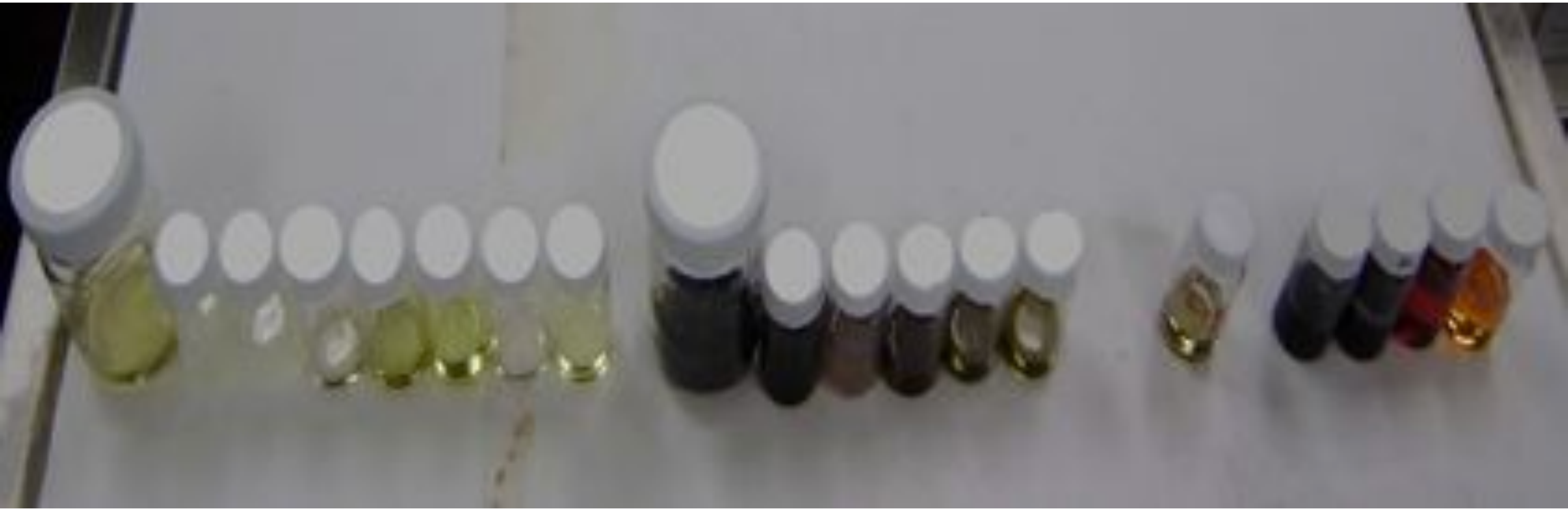
In addition, the $0\nu\beta\beta$/ $2\nu\beta\beta$ ratio is predicted to be about 100x higher in Te than Nd – this is an advantage given the limited energy resolution in scintillator.



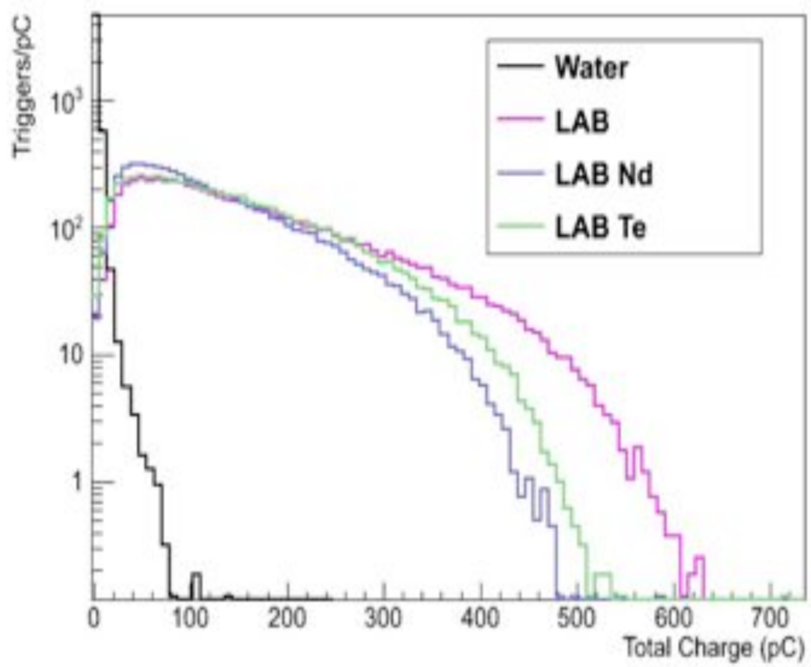
Te-Loaded "Scintillators"



Te-Loaded Scintillator

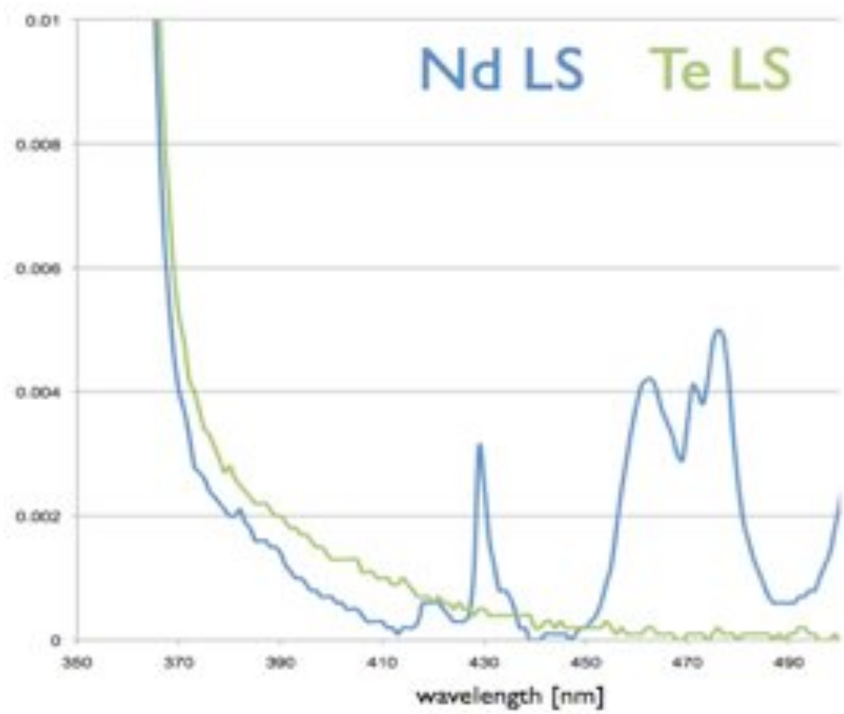
SNO+ has developed stable Te-loaded LAB with good optical properties at percent-level loading.

Te-Loaded Scintillator



Intrinsic light yield of Te-LS is good (better than Nd-LS)

- No absorption lines means that the light can be shifted out to 450-500nm
- Absorption may be further reduced by improvements in loading technique



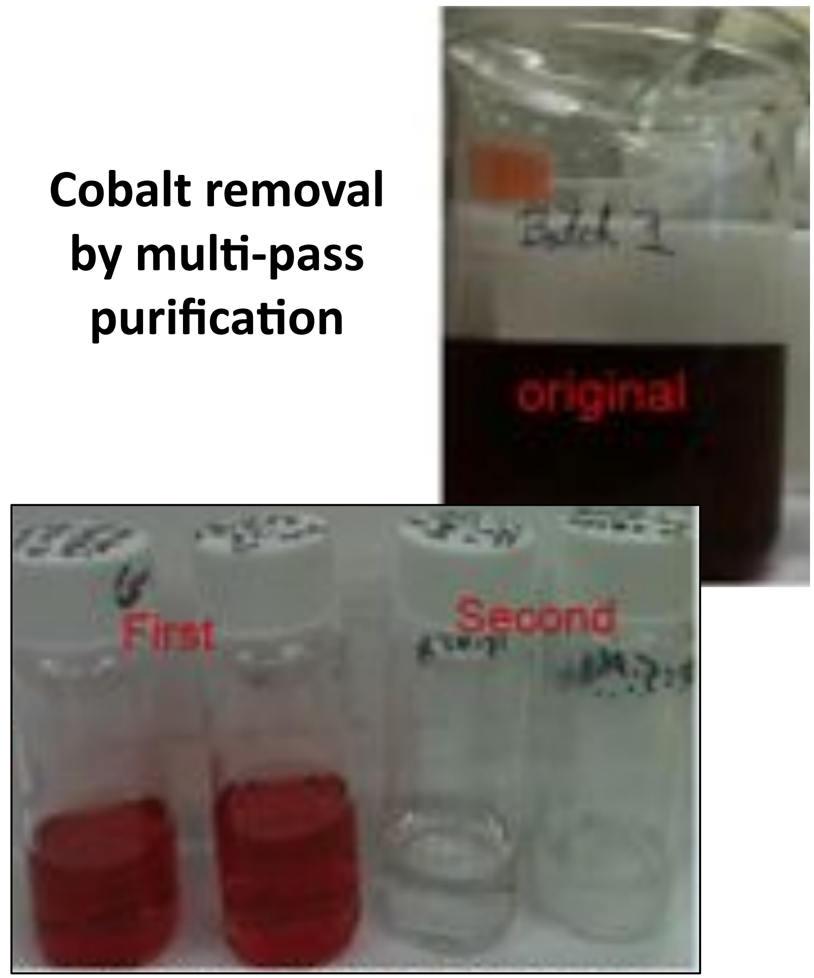
Backgrounds

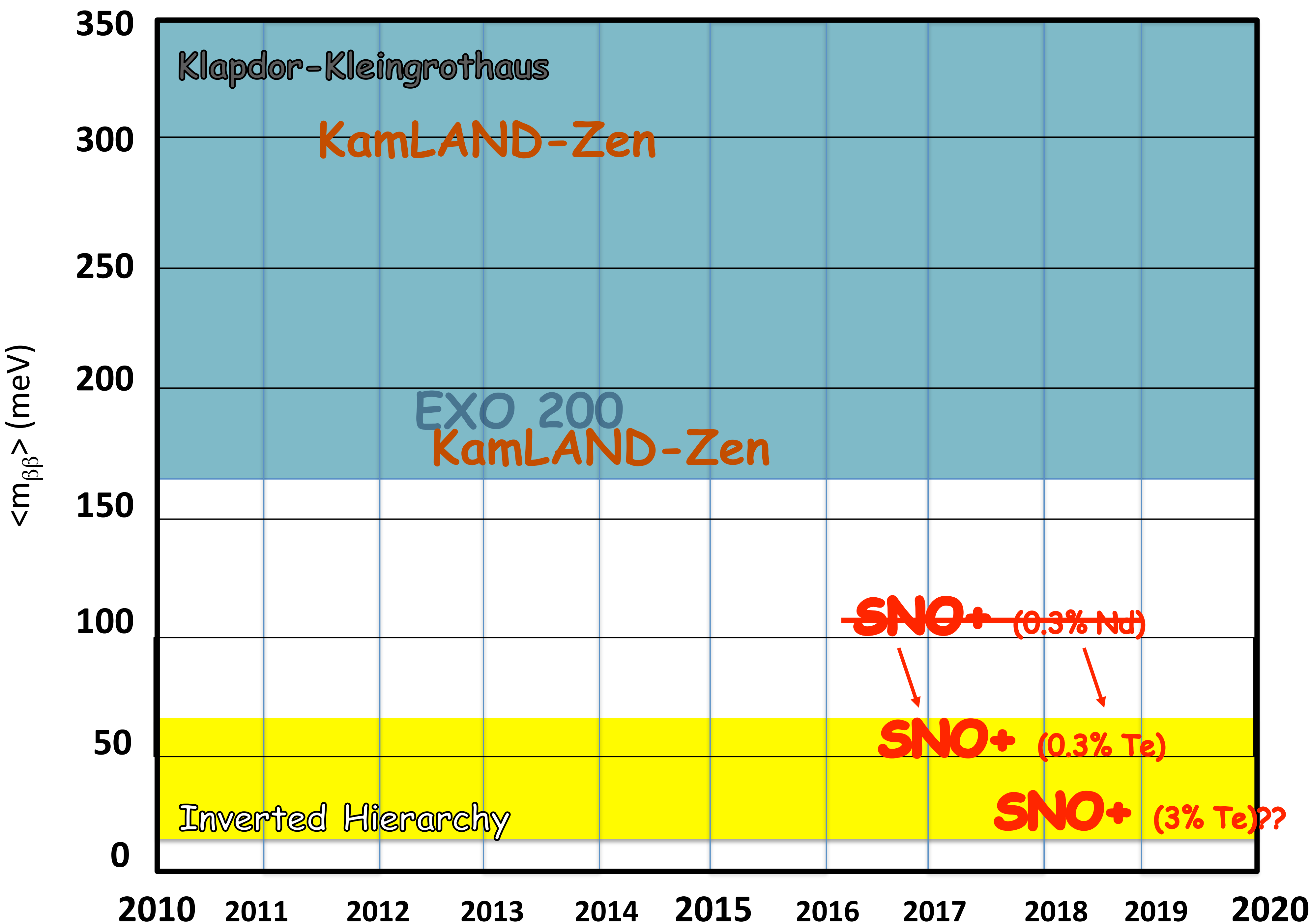
- Lower energy (2.53 MeV) endpoint makes Te susceptible to more radiogenic backgrounds than Nd
- 2.6 MeV gamma from external ^{208}Tl suppressed by fiducialization
  - Internal ^{208}Tl at higher energy
- Te endpoint overlaps with ^{214}Bi spectrum (^{238}U chain)
  - U-chain backgrounds in liquid scintillator can be extremely low (<2 decays/day/100T)
  - ^{214}Bi can be suppressed by more than a factor of 1000 using the 164μs ^{214}Bi – ^{214}Po delayed coincidence
  - SNO+ has developed techniques to purify Te to acceptable U/Th levels
  - Working to develop purification of other required chemicals

Backgrounds

- A number of isotopes that are cosmogenically produced from Te have longish half-lives and have decays that overlap the $0\nu\beta\beta$ energy region (^{214}Sb, ^{126}Sn, ^{88}Y, ^{110}Ag, etc…)
  - Effectively removed by our purification technique
  - Regrowth of cosmogenics requires at least a "polishing" purification underground

Cobalt removal by multi-pass purification



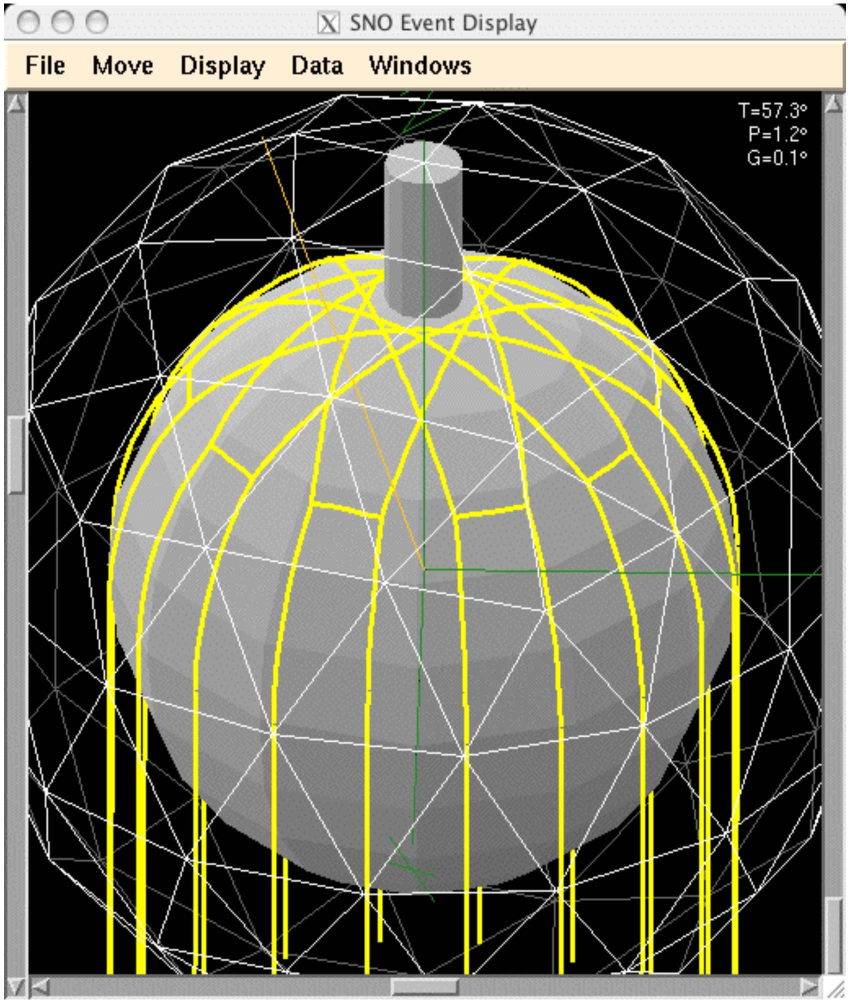


SNO+ will pursue Te deployment for double beta decay, starting with 0.3% target loading.

SNO+ Status and Schedule

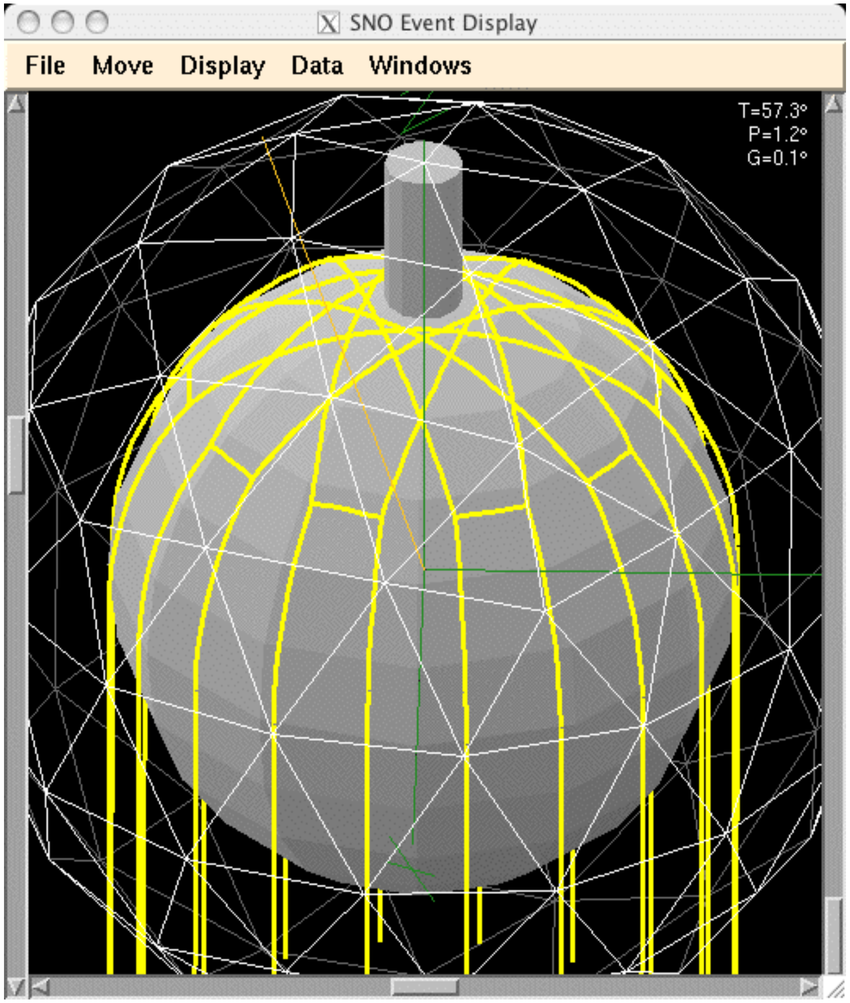
- Current: Construction phase
  - Install AV hold-down net
  - Upgrade electronics/DAQ
  - Install scintillator purification system
  - Upgrade calibration/covergas system
  - Clean Acrylic Vessel
- Summer 2013: Begin water fill
  - Buoyant test of hold-down net
  - Study backgrounds and nucleon decay
- Late 2013: Begin scintillator fill
  - Study backgrounds
- 2014: Add DBD isotope
- ~2017: Remove isotope, solar neutrino phase

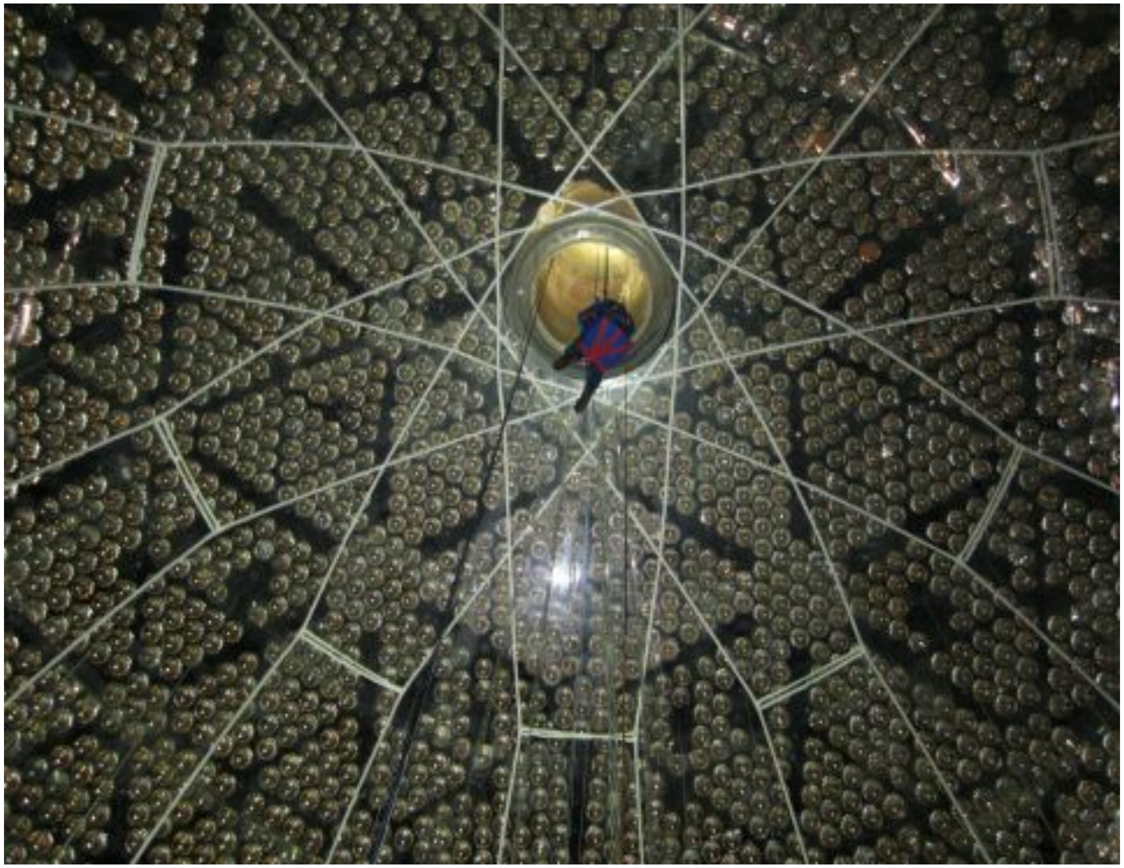
Install AV Hold-Down Net



Hold-down anchors and new floor liner installed

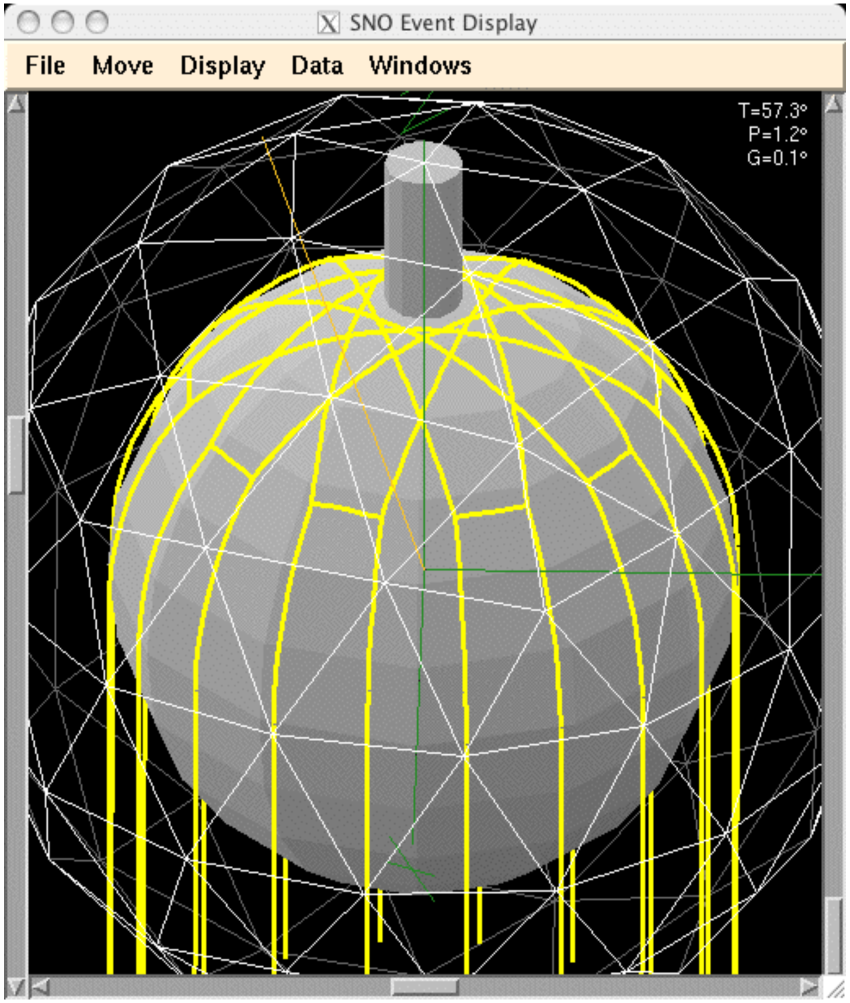
Install AV Hold-Down Net

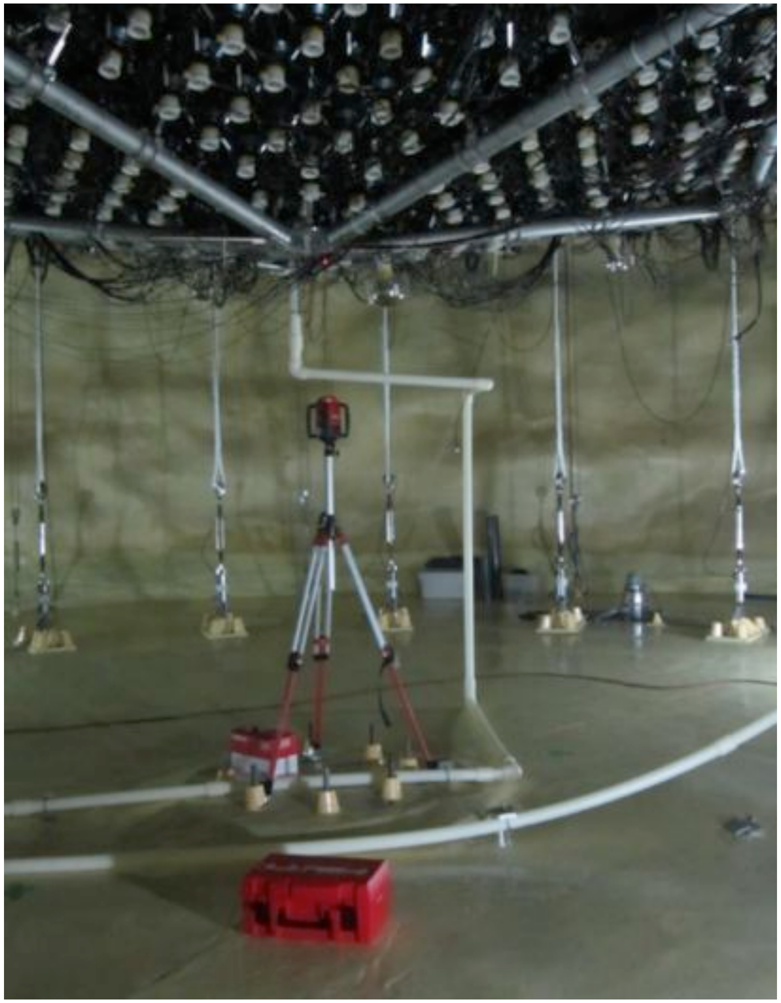




Hold-down rope net installed and pre-tensioned

Install AV Hold-Down Net





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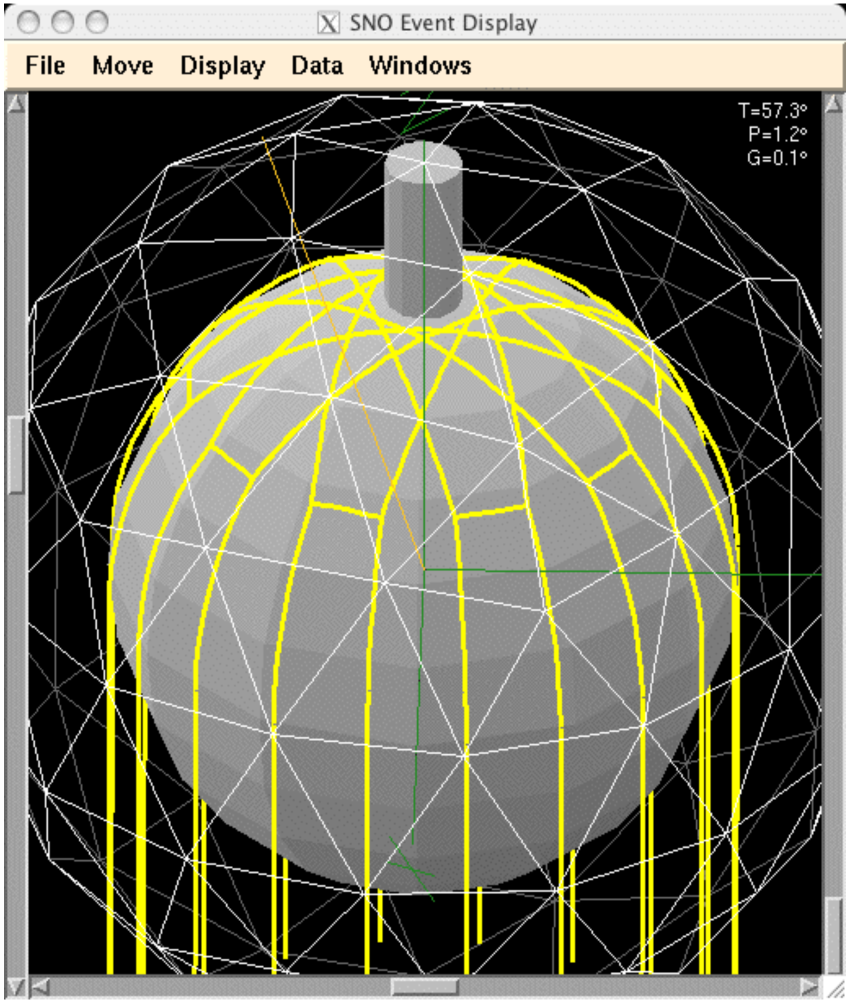
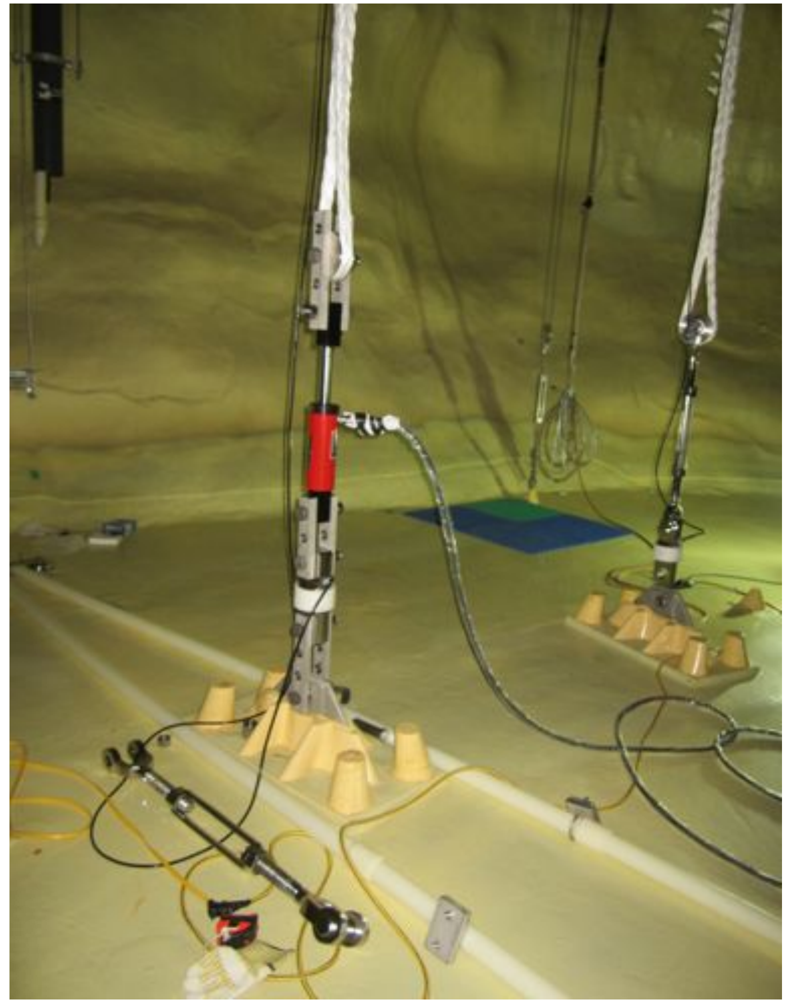




Hold-down rope net installed and pre-tensioned

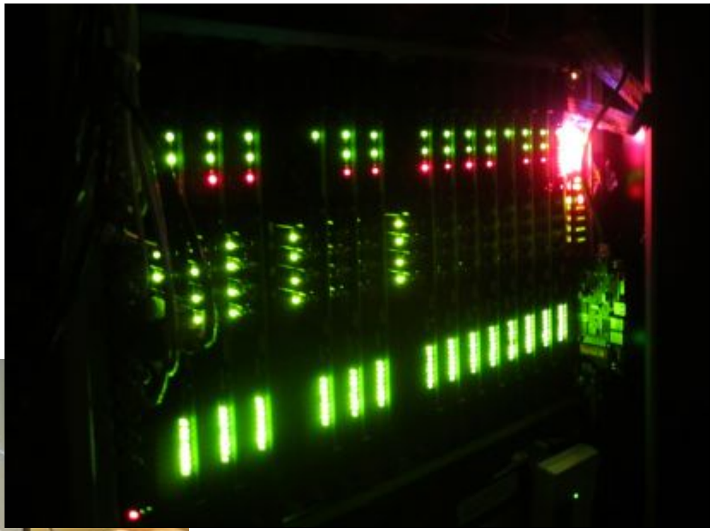
Electronics/DAQ Upgrades

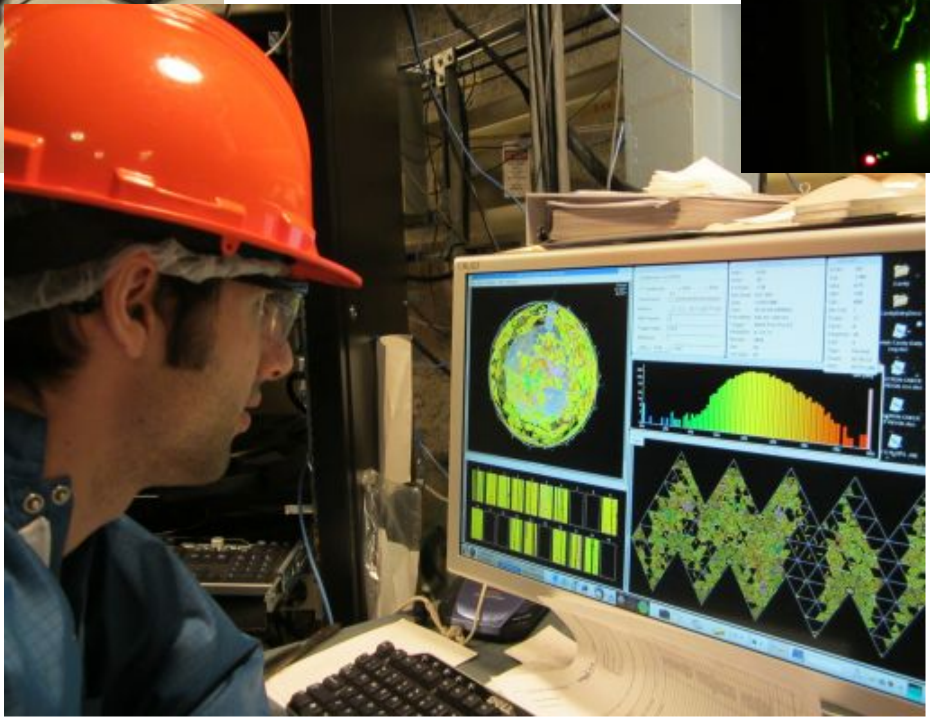
x19 in detector

x7 in detector

Data rate ~100x greater than in SNO. Spring 2012: upgrade triggers, crate readout. Top rate >40 MByte/s

Electronics/DAQ Upgrades



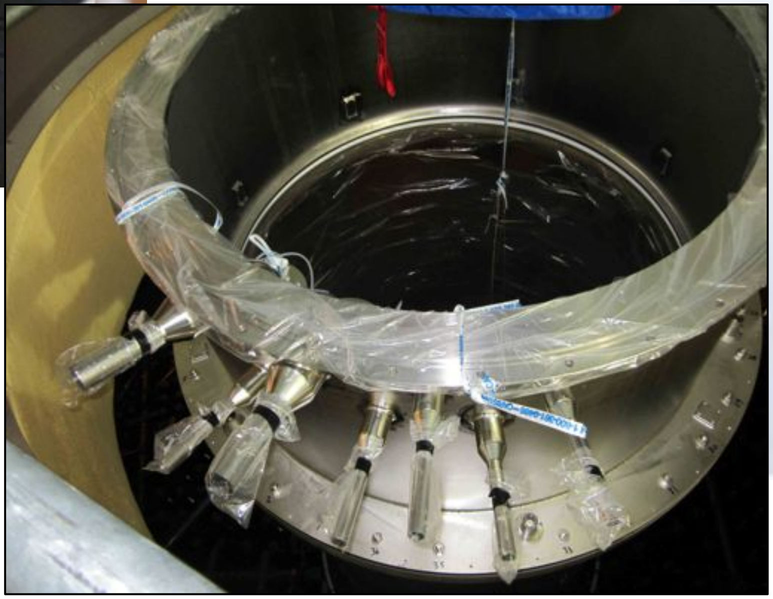


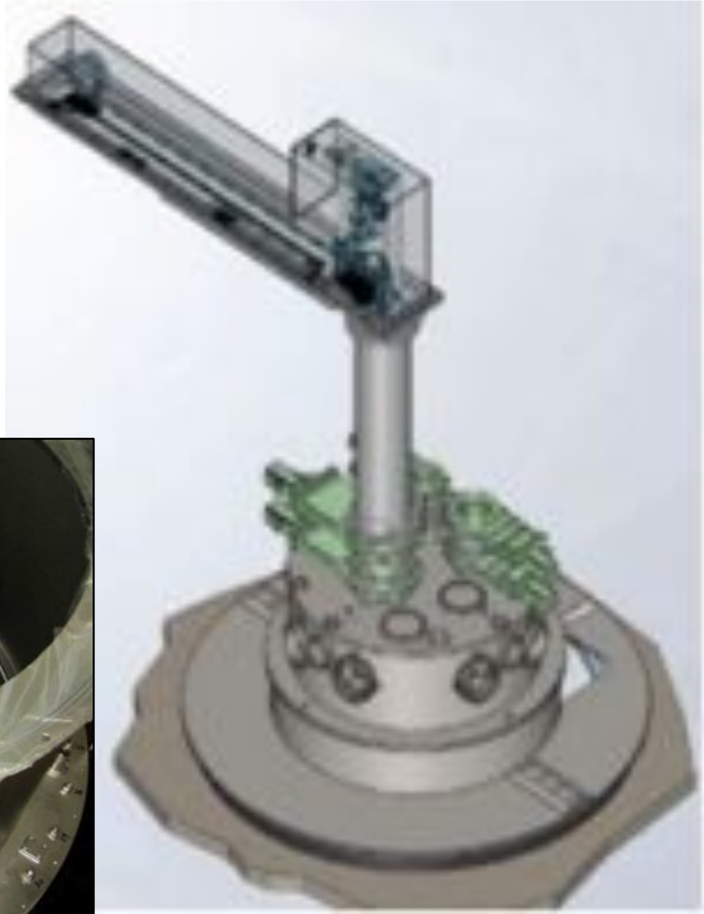
"Air Fill" running to test and integrate new DAQ and Electronics.

Scintillator Process System

All process vessels underground at SNOLAB, leak checking underway. Good progress on civil construction.

Calibration/Covergas System Upgrade





Sealed covergas system with expandable bags for pressure equalization. Airlocks for calibration source deployment.

Calibration/Covergas System Upgrade

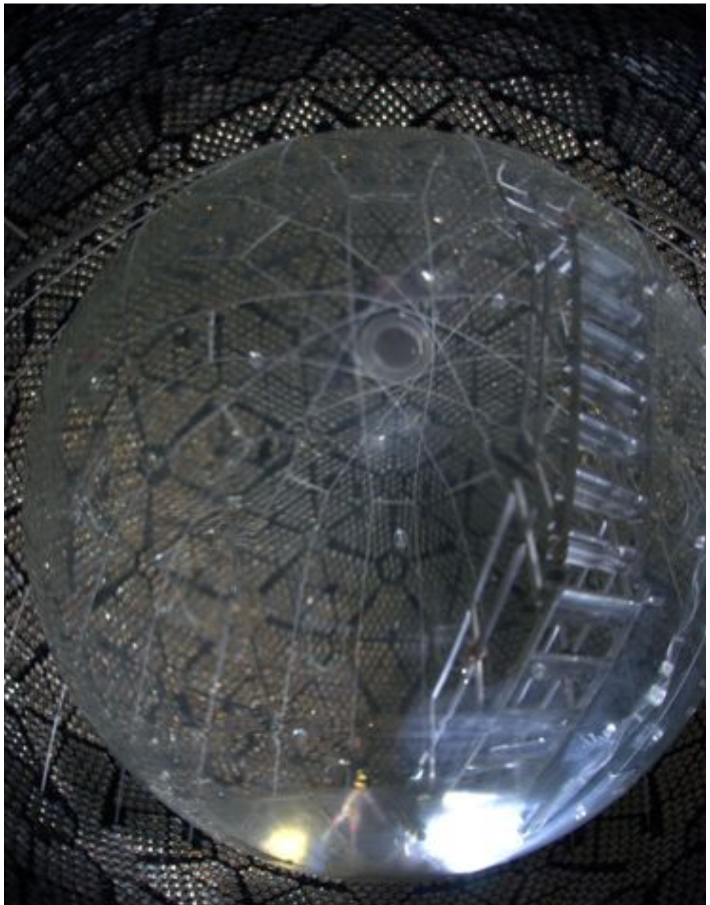
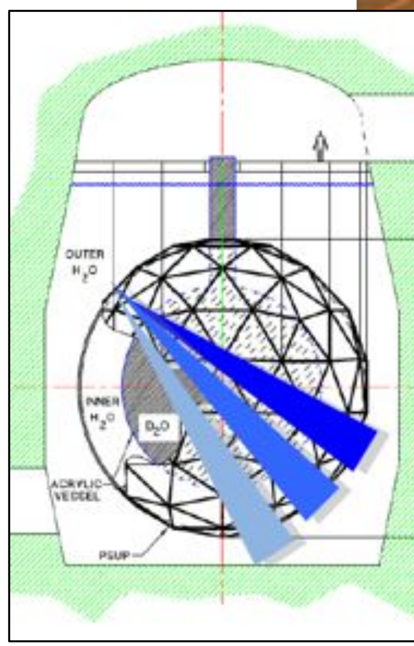
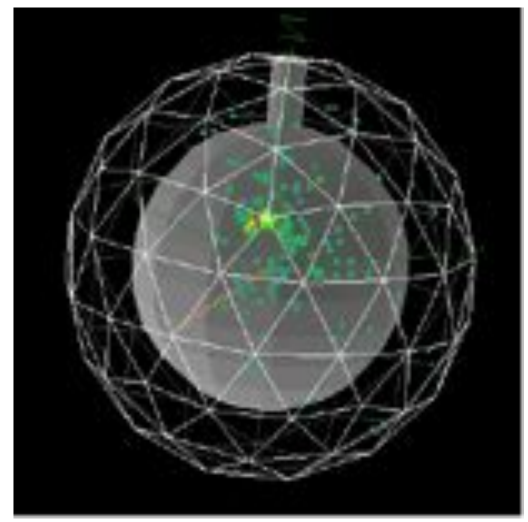


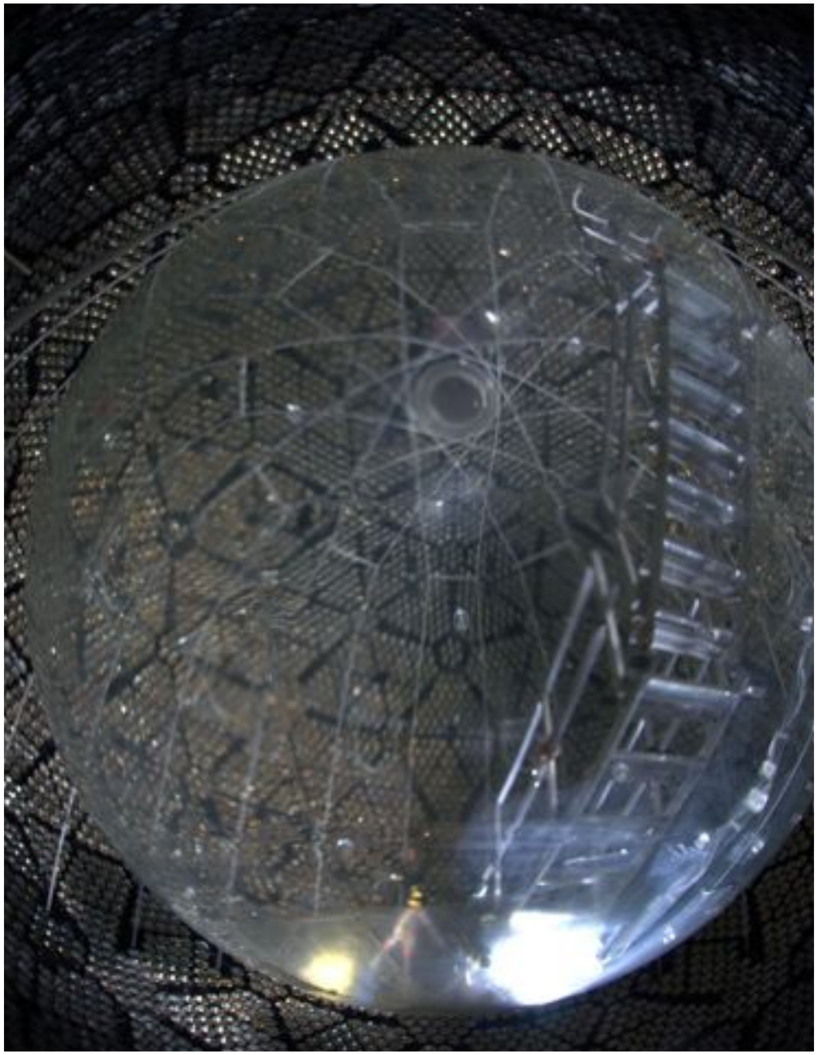
photo from newly installed calibration camera!





Underwater cameras & lights for source position measurements & AV monitoring. Fiber optics for PMT calibrations.

Acrylic Vessel Cleaning



Rotating ladder for lower hemisphere

Acrylic Vessel Cleaning

Suspended platform to reach upper hemisphere

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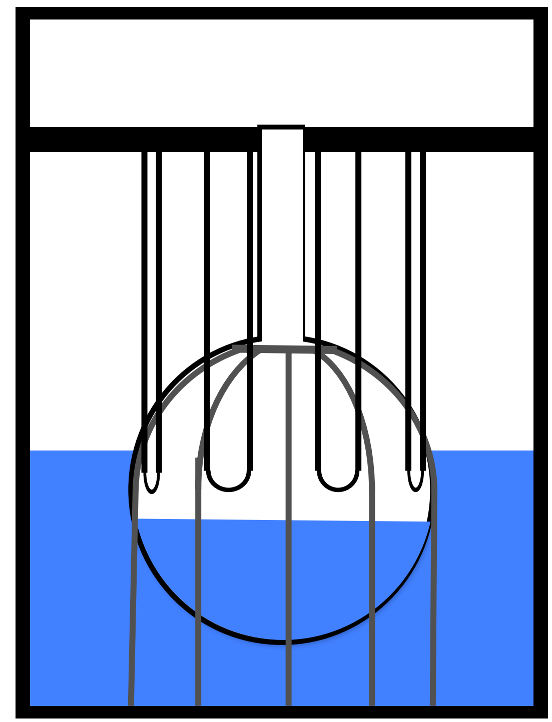

Water Fill Underway

Currently ~6' of water in the bottom of cavity. Hold this level to circulate and purify, check new floor liner for leaks.

Then, on to water fill, scintillator fill, and double beta decay!