Current Status and Commissioning of the SNO+ Experiment

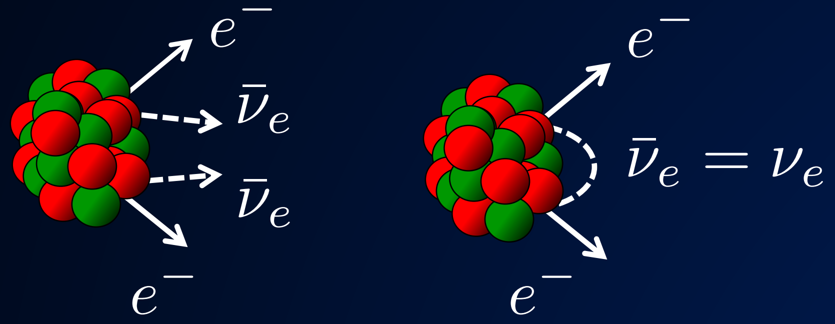
Christopher Grant
On behalf of the SNO+ Collaboration

APS | DIVISION OF PARTICLES & FIELDS
DPF 2017

BOSTON UNIVERSITY

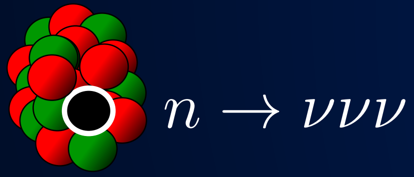
Neutrino Science with SNO+

- **Top priority - neutrinoless double beta decay**



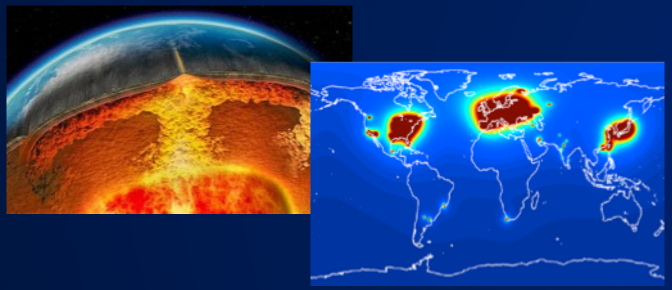
- An ultra-low background, scintillator detector can also be used to study many other topics of interest

Solar Neutrinos



Nucleon Decay

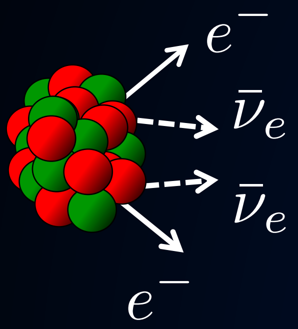
Geo and Reactor Neutrinos



Supernova Neutrinos

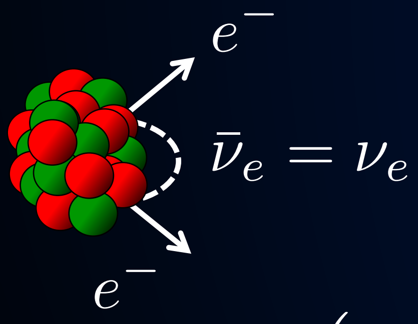
Neutrinoless Double Beta Decay

Two neutrino double beta decay:



- Allowed process by the Standard Model (conserves lepton number)
- Occurs in nuclei where single beta-decay is energetically forbidden
- Already observed for 11 nuclei – half-lives ~10^{18} – 10^{24} years

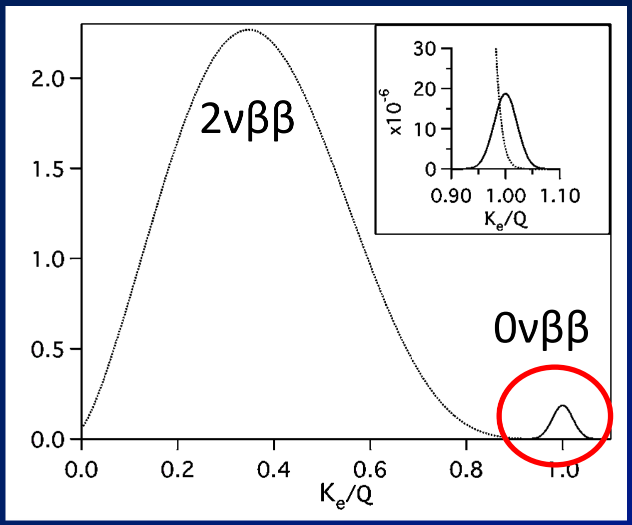
Neutrinoless double beta decay ($0\nu\beta\beta$):



- Can occur if neutrinos have a Majorana mass component
- Violates lepton number by two units

$$\left(T^{0\nu}_{1/2}\right)^{-1} = G|M|^2 \frac{|m_{\beta\beta}|^2}{m_e^2} \qquad m_{\beta\beta} = \sum_{i=1}^{3} m_i U_{ei}^2$$

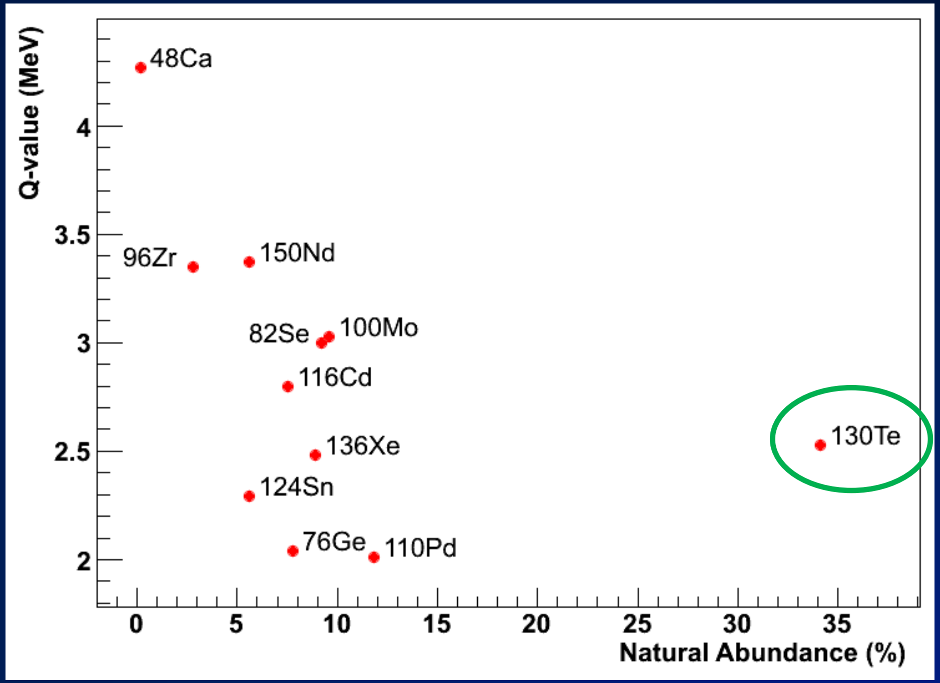
S. Elliot and P. Vogel, Ann. Rev. Nucl. Part. Sci. 52 (2002) 115-151.



$0\nu\beta\beta$ with ^{130}Te

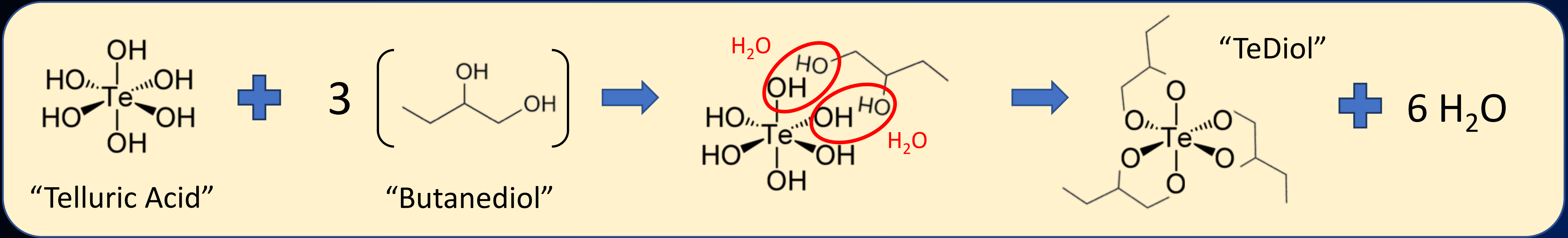
SNO+ will use ^{130}Te as a $0\nu\beta\beta$ decay candidate for the following reasons:

- Very high natural abundance (34%) means no isotopic enrichment is needed – easily scalable at low cost
- Q-value of ^{130}Te $\beta\beta$ decay is 2.527 MeV – less background contamination in the signal region and fast decay rate
- Long $2\nu\beta\beta$ half-life ($\sim$ 7 x 10^{20} years) means low $2\nu\beta\beta$ backgrounds rate
- Tellurium in scintillator provides a high light yield and good optical transparency, even at concentrations of several percent



^{130}Te Loading in Liquid Scintillator

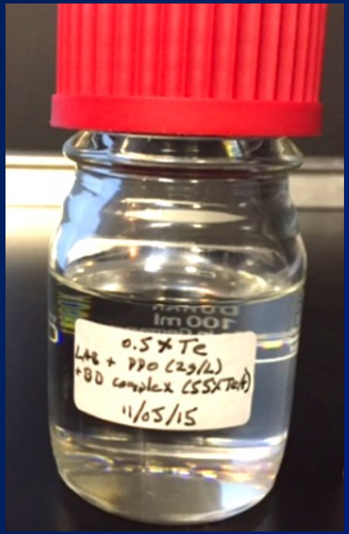
- Method for loading involves forming an organo-metallic complex from telluric acid (TeA) and butanediol (Diol)

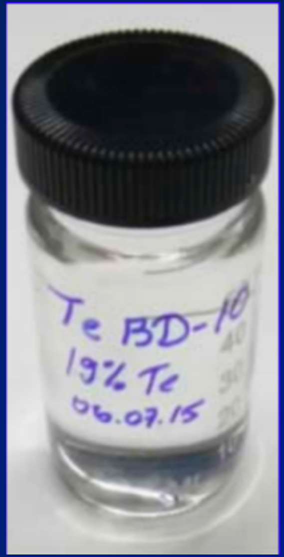


- TeDiol is mixed directly into SNO+ scintillator: linear alkyl benzene (LAB) + 2 g/l PPO

- Optical transparency and light yield of the LS cocktail remain intact (equivalent to ~ 400 p.e. / MeV)

- SNO+ "Phase I" will utilize 0.5% loading of natural Te (1,300 kg ^{130}Te)



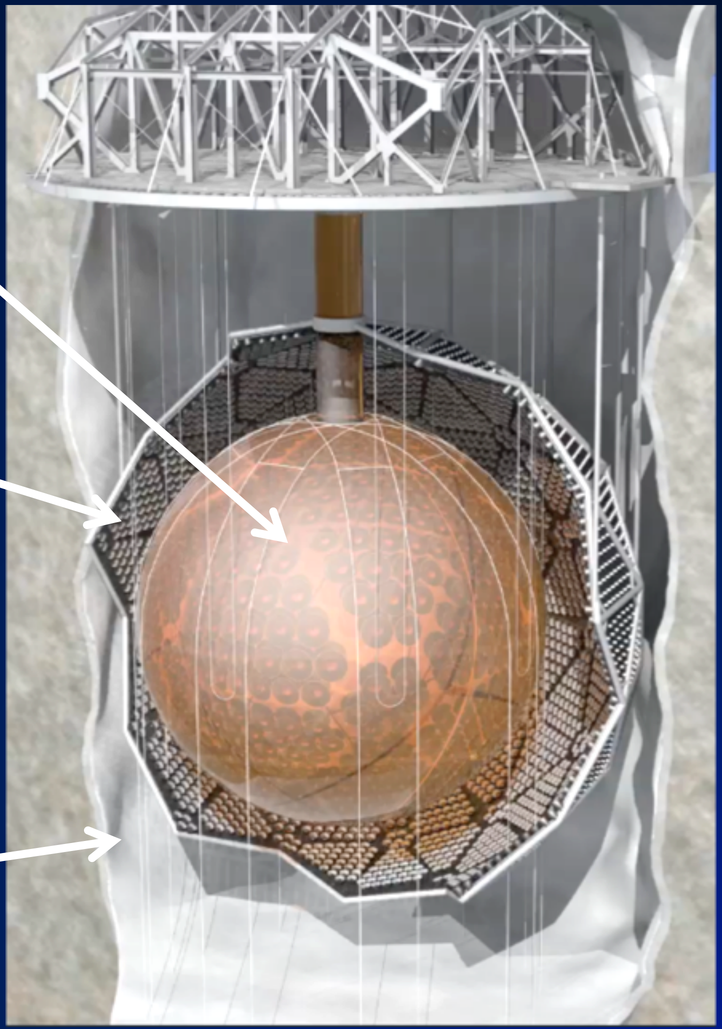


The SNO+ Detector

Building on the SNO experiment…

- ~ 780 tons of liquid scintillator filled inside a 12m diameter acrylic vessel
- ~ 9500 PMTs surrounding the acrylic vessel provide about 54% coverage
    - ~90 outward facing PMTs for tagging cosmic rays
- Light water shielding:
    - 1700 tons inside PMT support structure
    - 5300 tons outside PMTs
- Enclosed inside a Urylon-lined rock cavern

~70 muons / day at 6800 ft depth



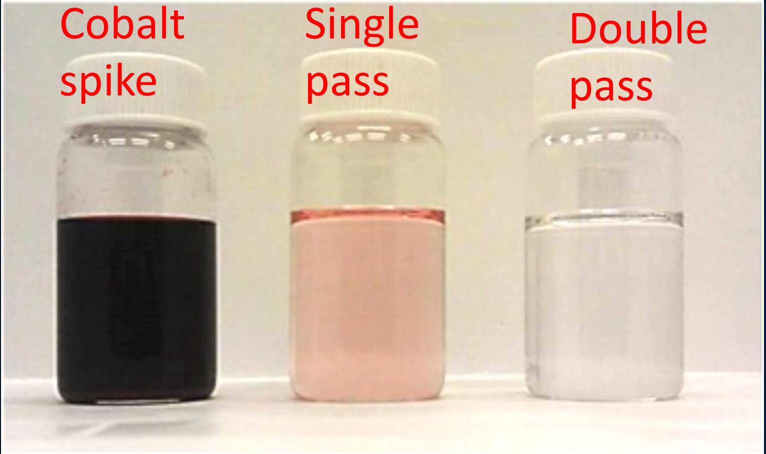
Cosmogenic Backgrounds from Tellurium

- Cosmogenic activation of natural tellurium before it was delivered underground produced many short and long lived isotopes(e.g. ^{60}Co, ^{124}Sb)
- Q-values > 2 MeV and $T_{1/2}$ > 20 days will significantly impact $0\nu\beta\beta$ search

V. Lozza and J. Petzoldt, Cosmogenic activation of a natural tellurium target, Astroparticle Physics 61 (2015) 62-71.

2-stage acid-recrystallization process

Demonstrated effectiveness with a 1% Cobalt spike in Te-H_2O

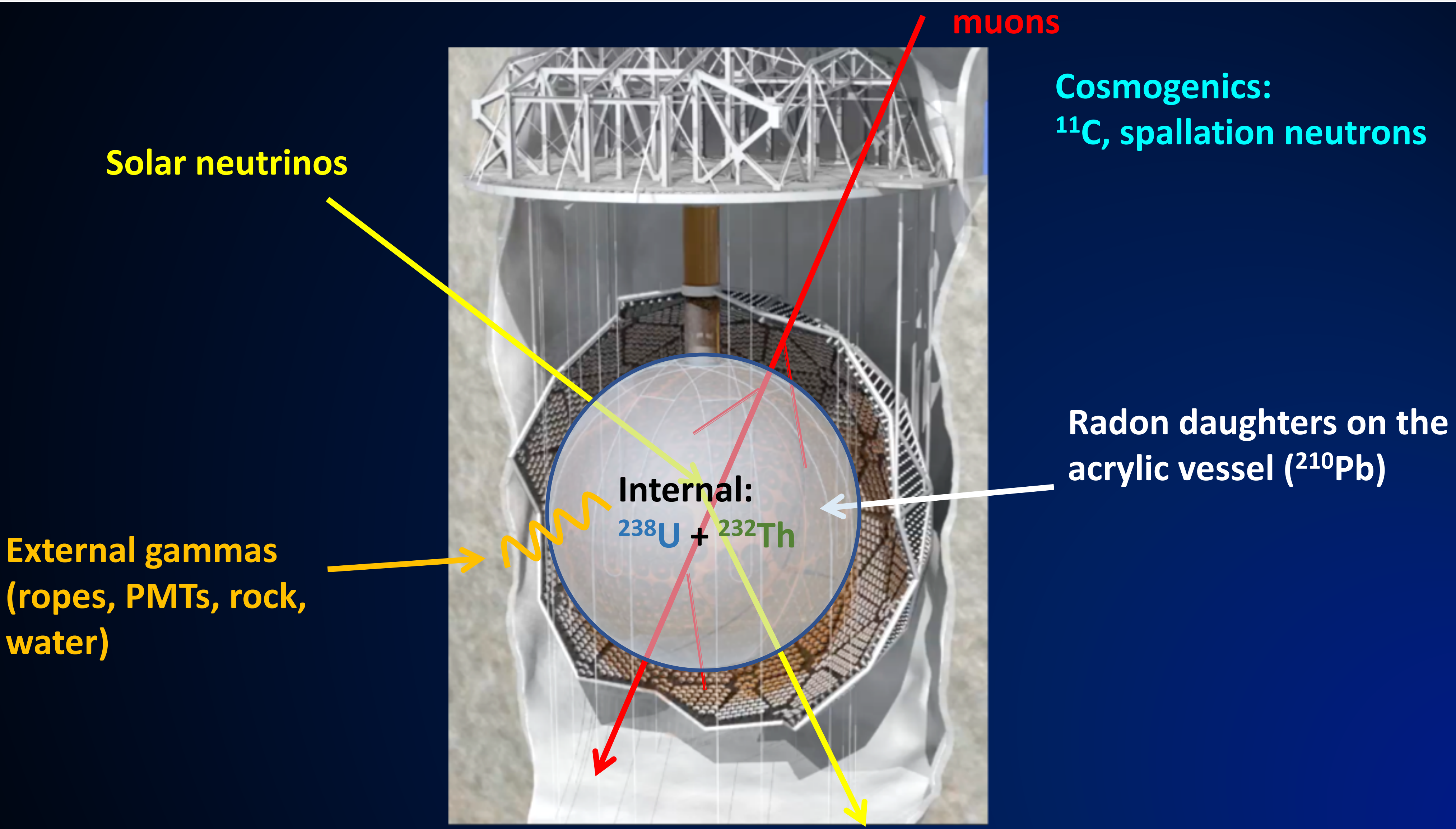


10 kg scale pilot plant was operated successfully and construction of the full scale plant is underway.

Full scale plant will operate in a batch mode, processing ~250 kg TeA per batch.

S. Hans, et al. Purification of telluric acid for SNO+ neutrinoless double beta decay search. NIM A 795 (2015) 132-139.

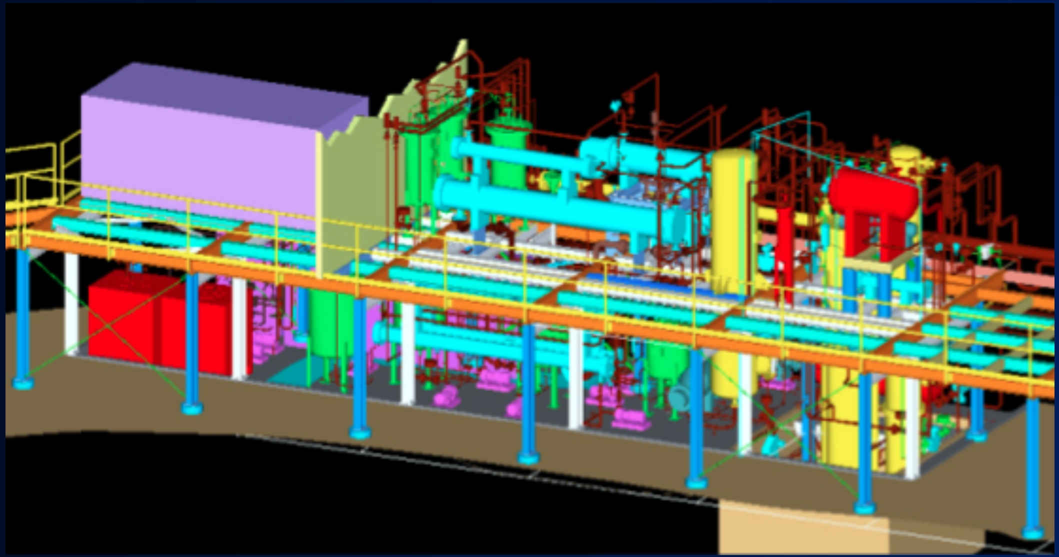
Additional Backgrounds



Background Reduction

- Fiducial volume and other analysis cuts, like beta-alpha tagging of BiPo’s are useful for reducing backgrounds

- Additional reduction of radio-impurities in the liquid scintillator will be addressed with an underground, industrial-scale purification and processing plant



Target Levels:

^{85}Kr: 10^{-25} g/g

^{40}K: 10^{-18} g/g

^{39}Ar: 10^{-24} g/g

U: 10^{-17} g/g

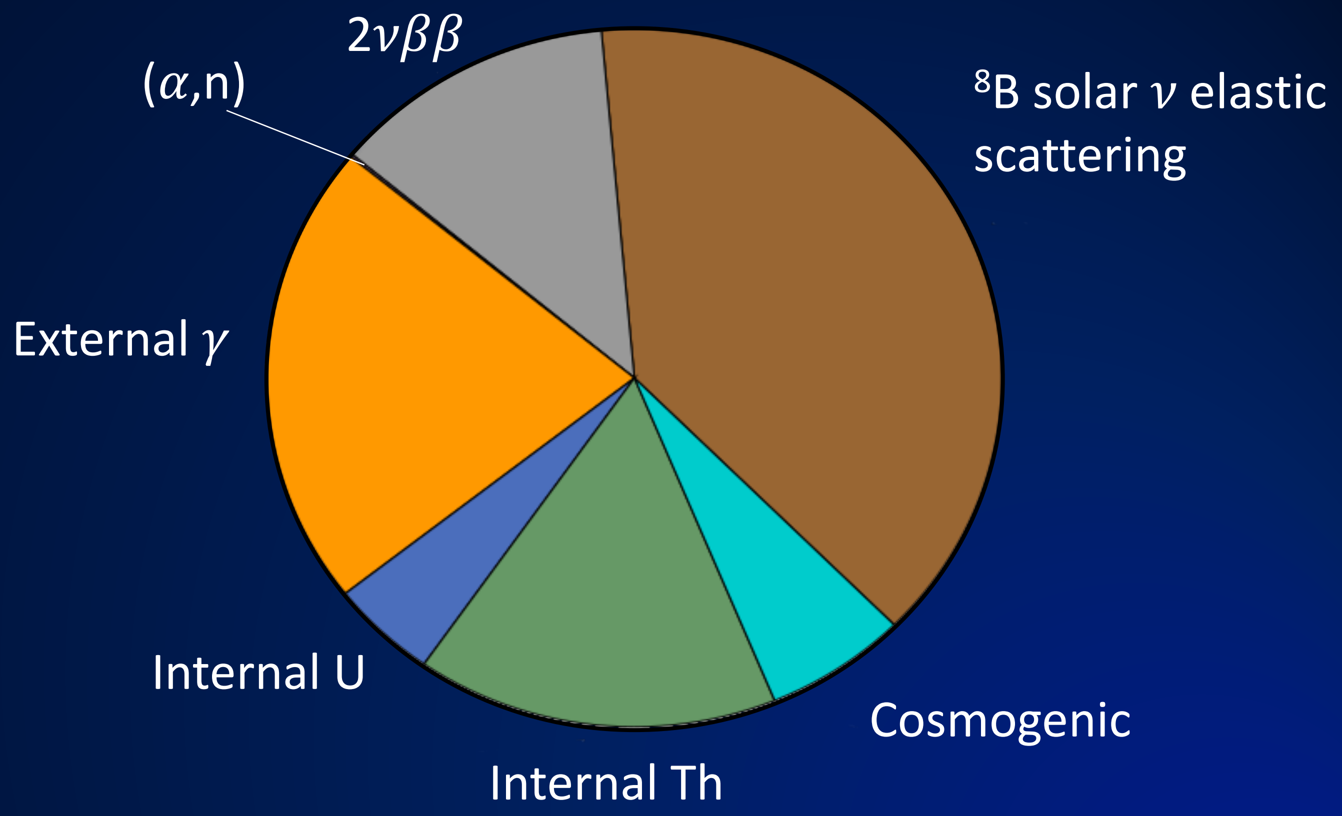
Th: 10^{-18} g/g

Distillation, water extraction, N2 gas stripping, scavenger columns, and microfiltration

SNO+ Phase I Background Predictions

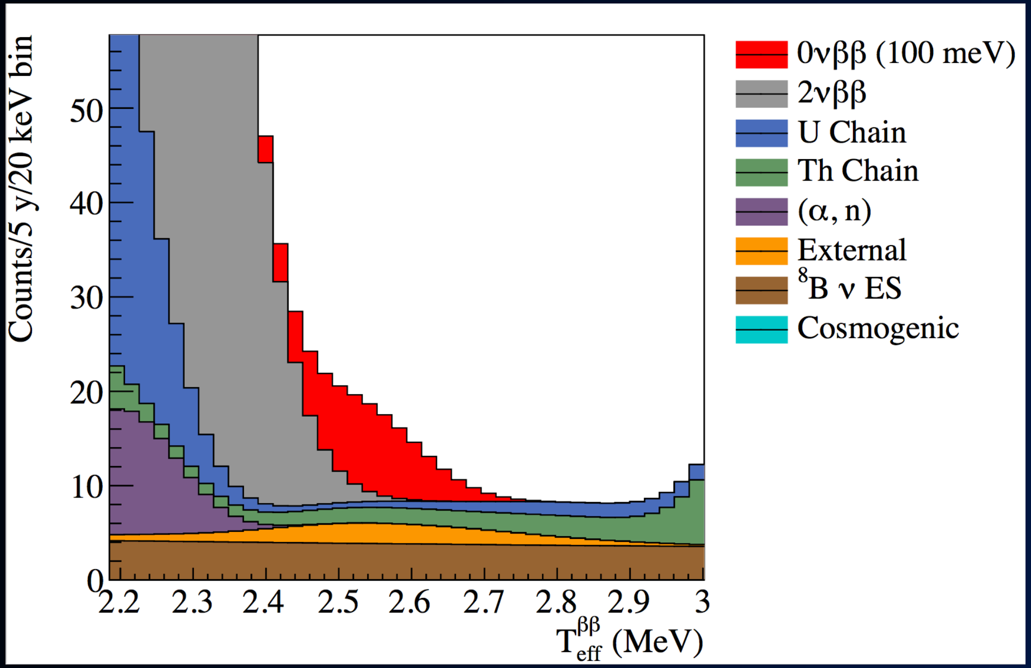
Background Budget Details:

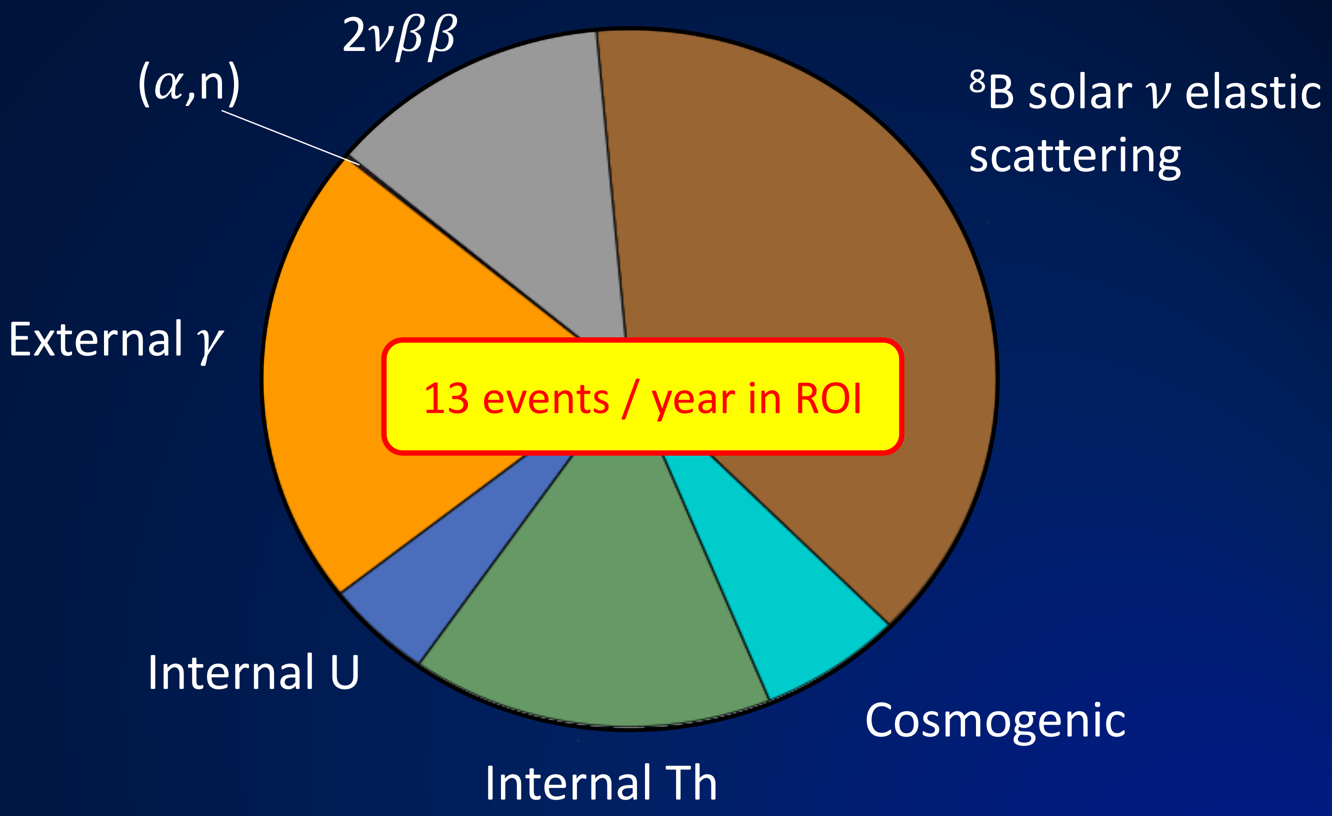
- LS cocktail with ^{nat}Te (0.5% loading)
- Fiducial Volume contained in 3.5 m radius (= 260 kg ^{130}Te)
- Near 100% rejection of ^{214}BiPo
- 98% rejection of ^{212}BiPo
- 390 PMT hits / MeV
- ROI between 2.49 – 2.65 MeV



SNO+ Phase I Sensitivity to $0\nu\beta\beta$

Predicted Signal (0.5% loading) + Background

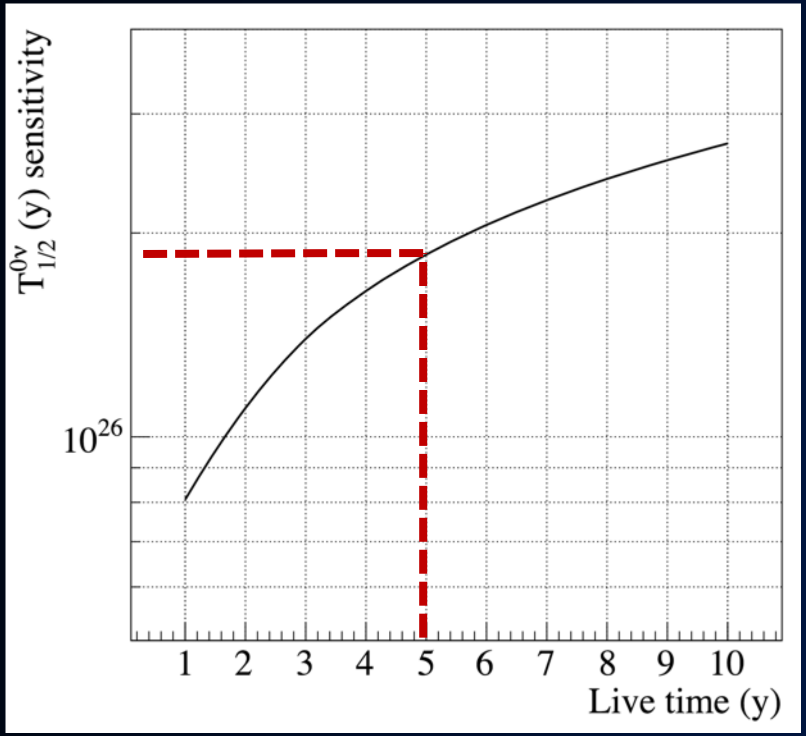


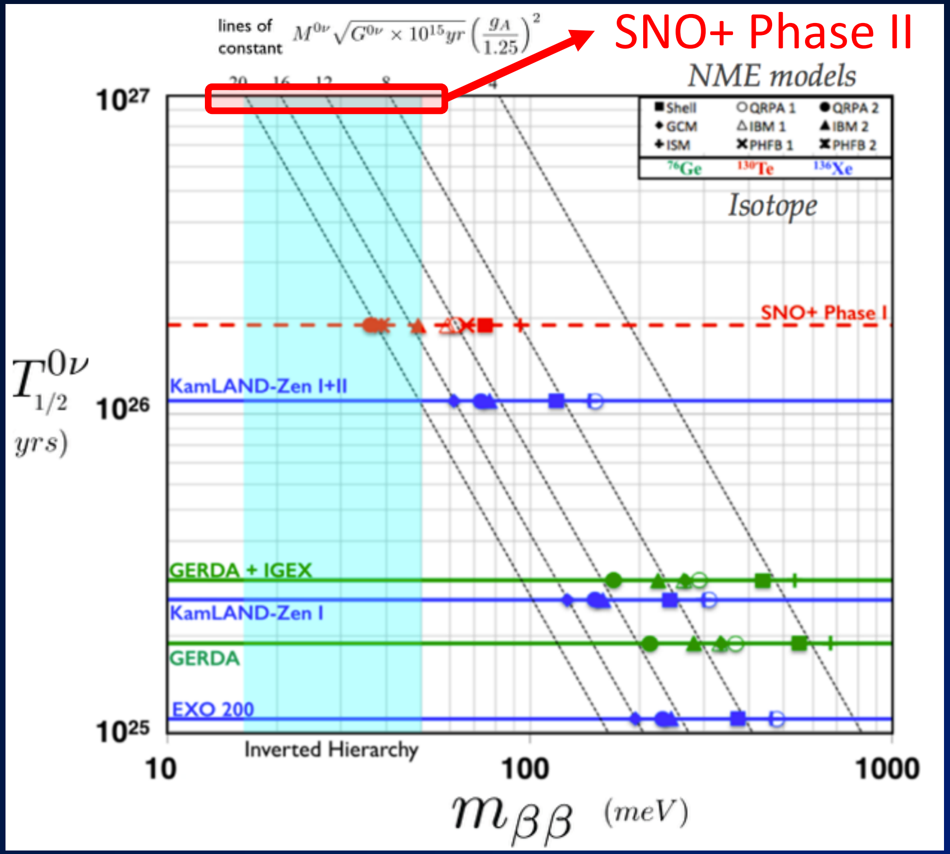


	$T_{1/2}$ (10^{26} years)	$m_{\beta\beta}$ (meV)
1 year	> 0.8 (90% C.L.)	59 – 144
5 years	> 2.0 (90% C.L.)	38 – 92

Range due to NME calculations

SNO+ Phase I Sensitivity to $0\nu\beta\beta$



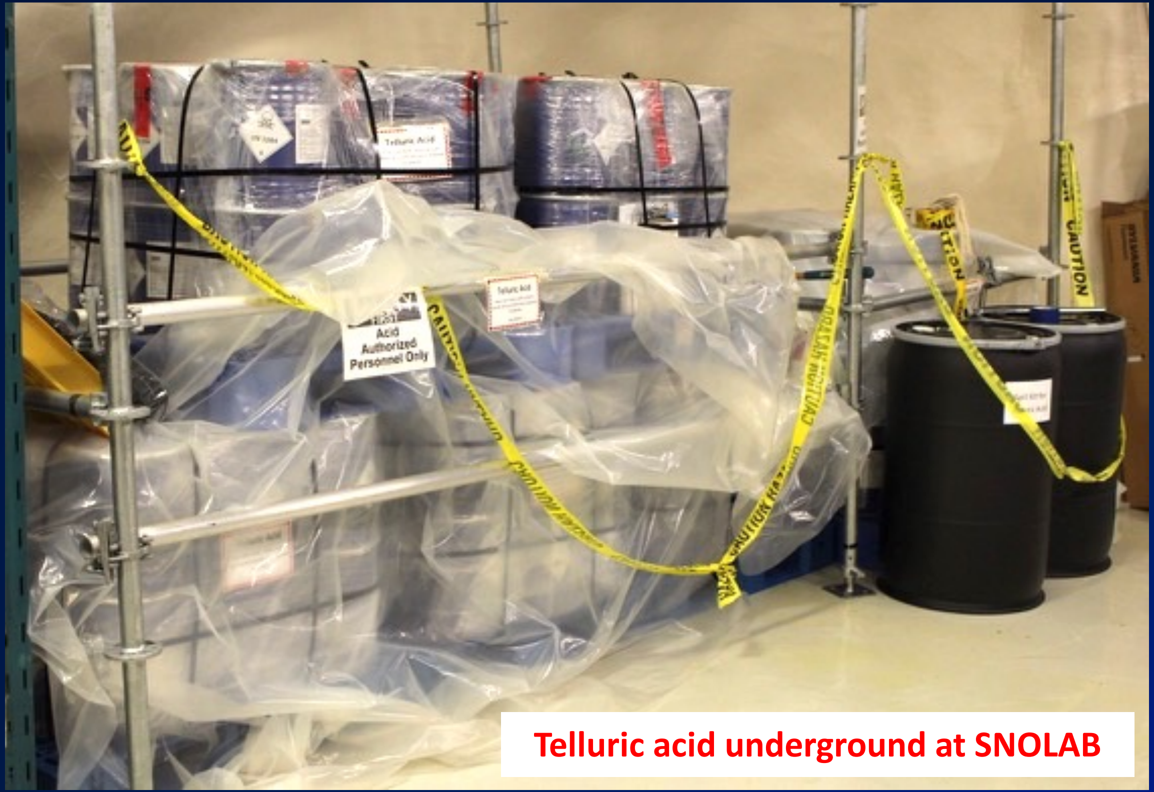


- SNO+ Phase I sensitivity will begin to target $m_{\beta\beta}$ in the Inverted Hierarchy regime
- Phase II sensitivity with higher Te loading and high quantum efficiency PMTs could span Inverted Hierarchy

Commissioning SNO+

Roughly 3.8 t of Telluric acid has been cooling underground since early 2015 – TeA purification plant is in the construction process

Telluric acid purification plant



Telluric acid underground at SNOLAB

Commissioning SNO+

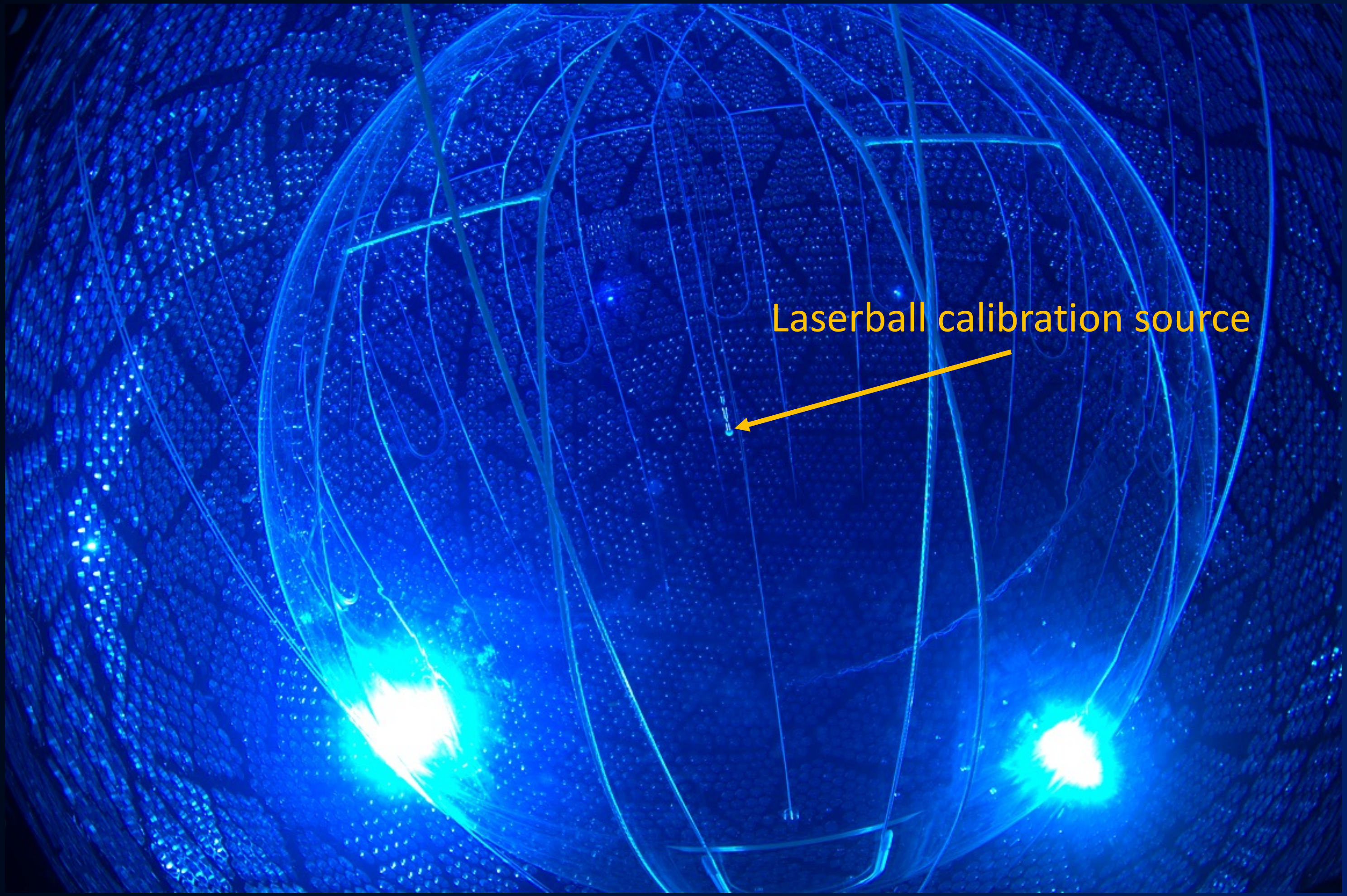
Scintillator plant has been constructed and in commissioning phase – 15 t of LAB has already been delivered underground

Scintillator purification plant

Scintillator purification plant

LAB delivery to SNOLAB

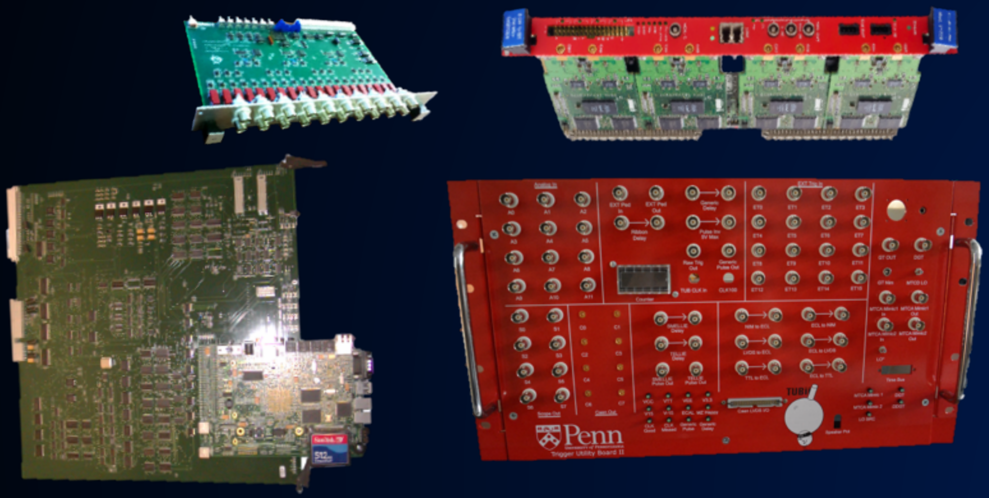
Commissioning SNO+

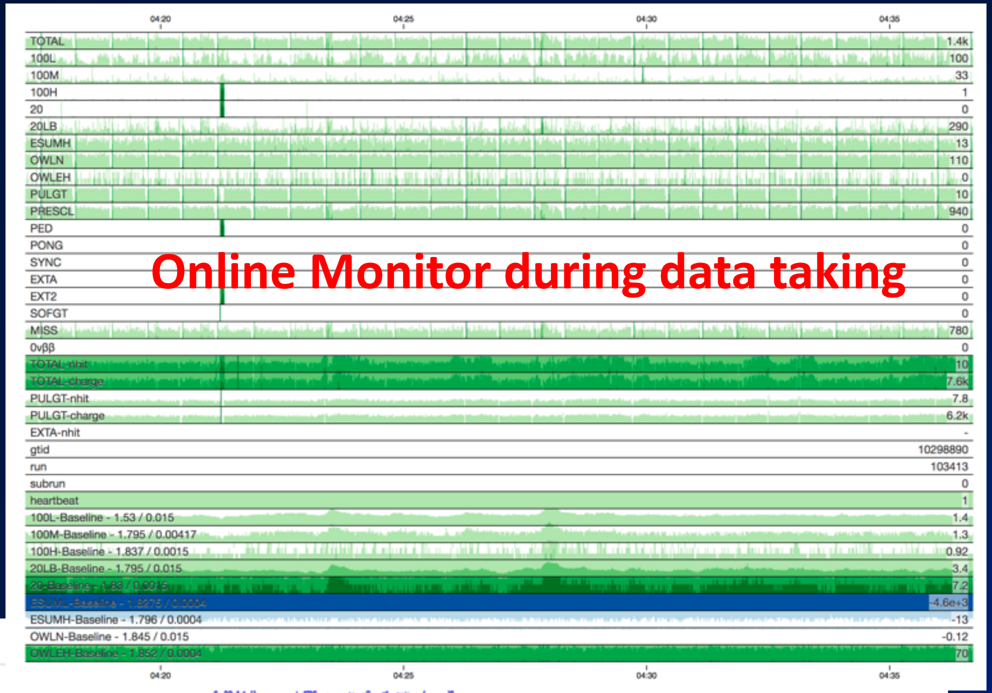


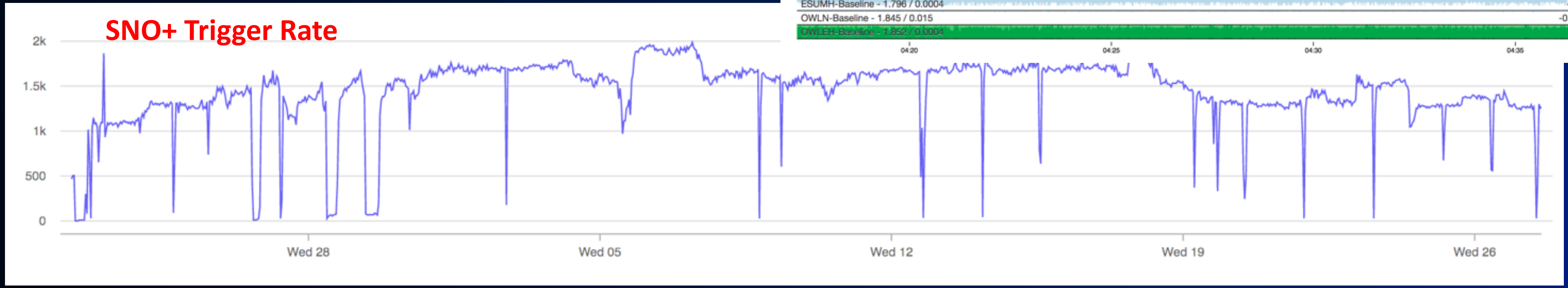
Detector and cavity have been filled with ultra-pure water (as of Feb 2017)

Commissioning SNO+

New DAQ and electronics have been commissioned – needed for higher data rates expected during scintillator phase

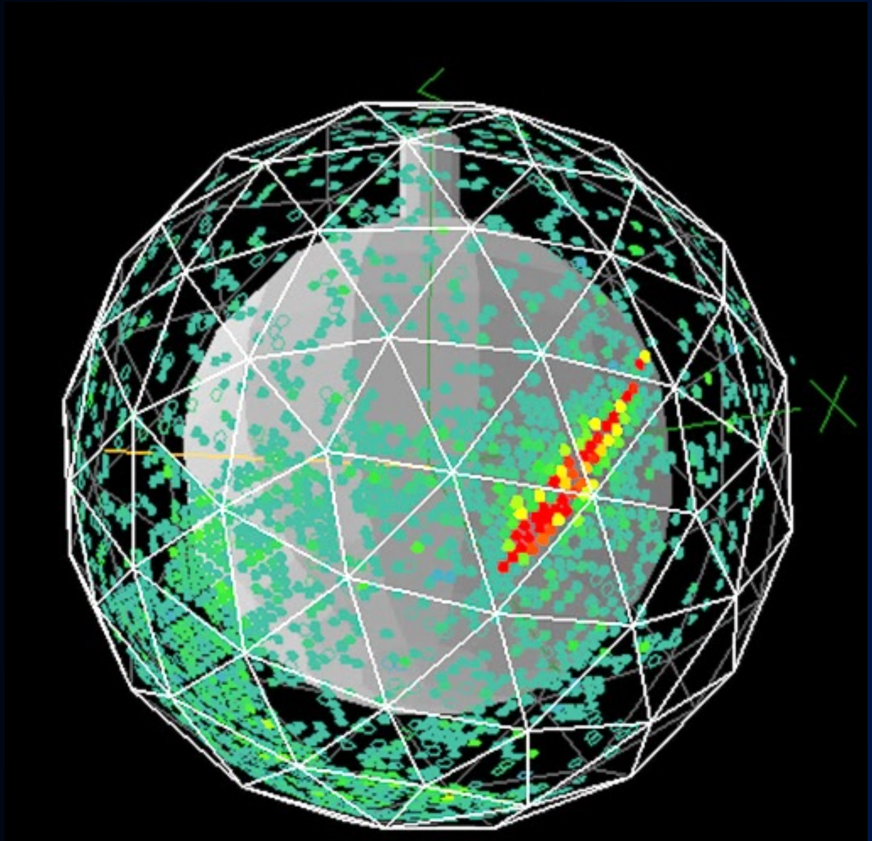




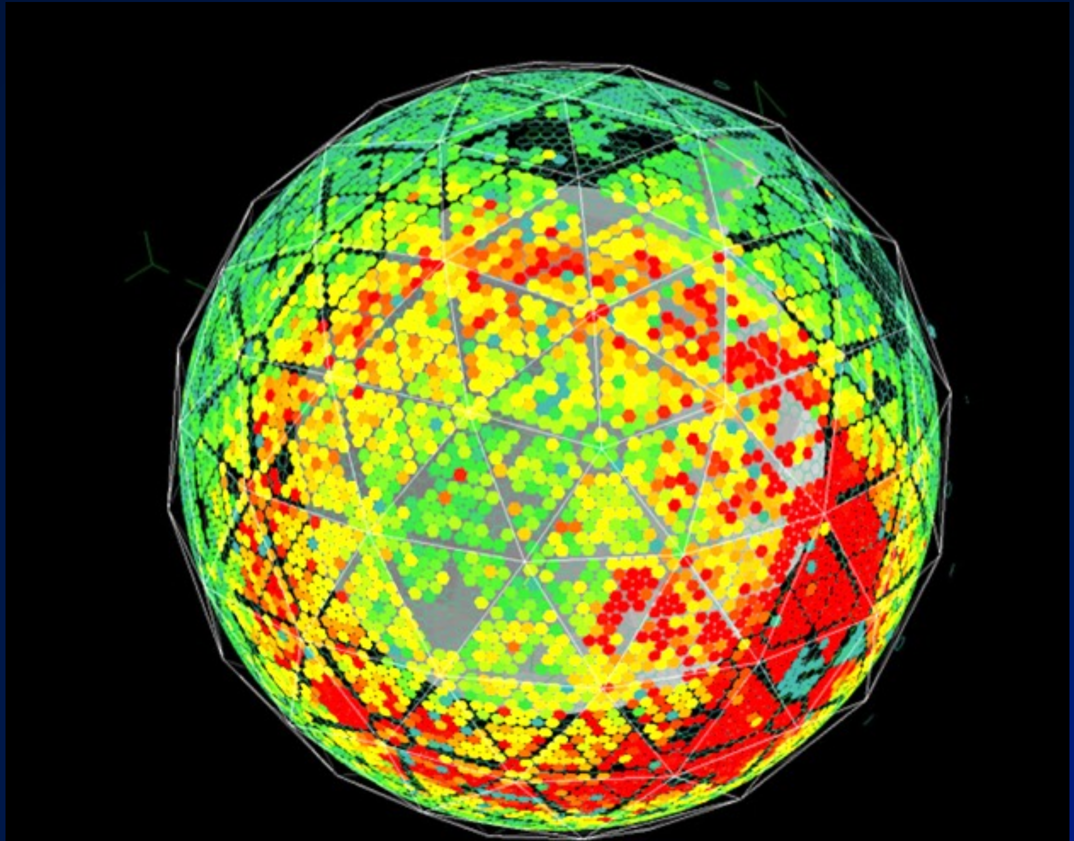


Current Status

Officially started taking physics data on May 4th



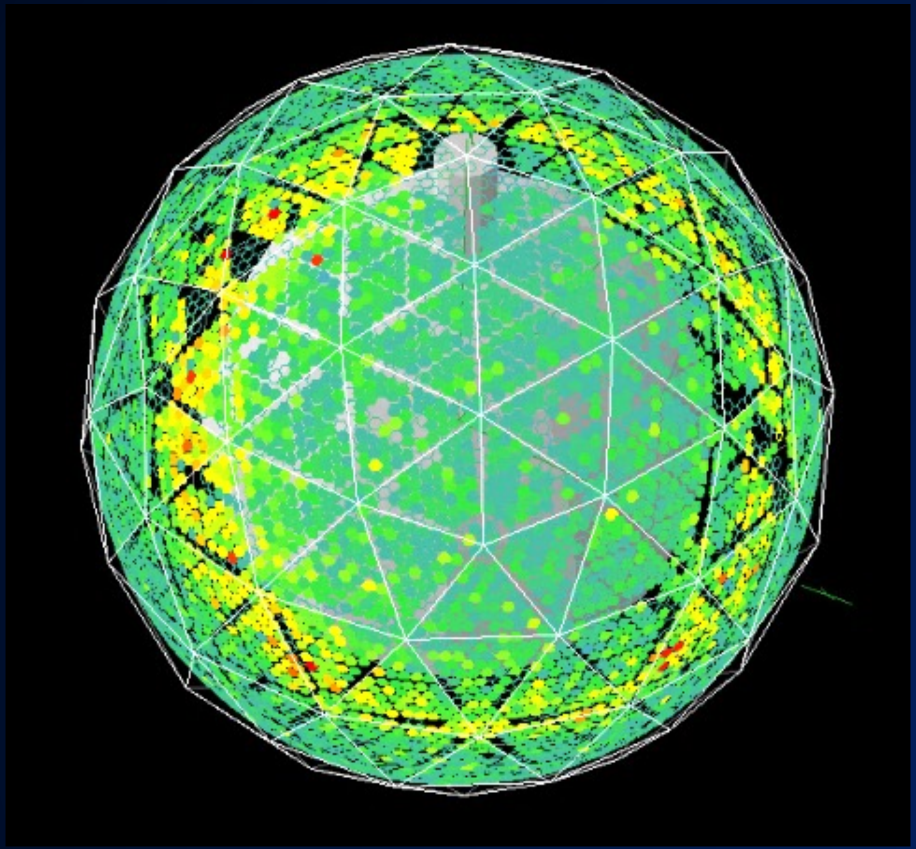
Muon candidate grazing the detector



Another muon candidate

Current Status

Officially started taking physics data on May 4th

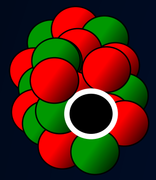


Atmospheric neutrino candidate event – large number of inner detector PMTs hit and no outward-facing PMTs triggered

Invisible Nucleon Decay in Water

Motivated by models of Universal Extra Dimensions (UEDs)

R. N. Mohapatra & A. Perez-Lorenzana, PRD 67, 075015 (2003)



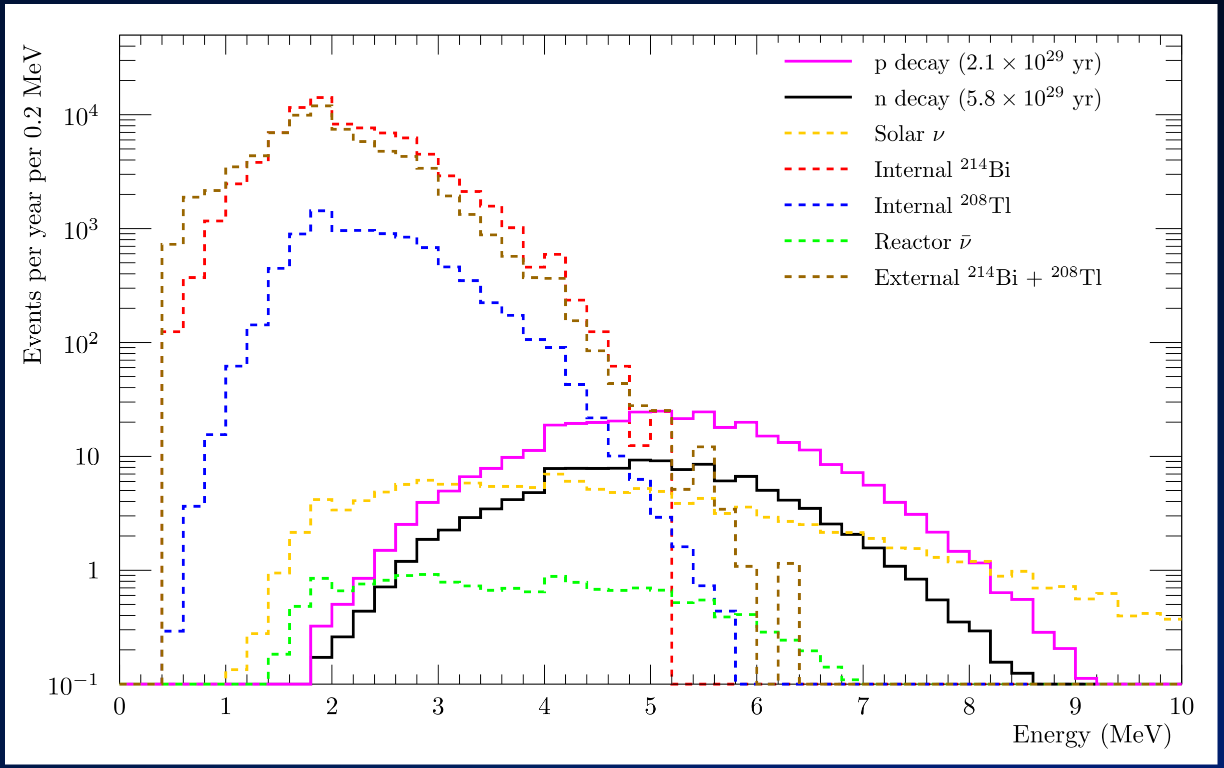
$$n \rightarrow \nu\nu\nu$$

$$p \rightarrow \nu\nu\nu$$

$$^{16}\mathrm{O} \rightarrow {}^{15}\mathrm{O}^* \rightarrow \sim 6 \text{ MeV } \gamma$$

$$(^{15}\mathrm{N}^* \rightarrow \sim 6 \text{ MeV } \gamma)$$

Signal is in the form of de-excitation gammas



Predicted sensitivity after 6 months of data taking:

$\tau_n = 1.2\times10^{30}$ years at 90% C.L. (current limit by KamLAND is 5.8×10^{29} years)

$\tau_p = 1.4\times10^{30}$ years at 90% C.L. (current limit by SNO is 2.1×10^{29} years)

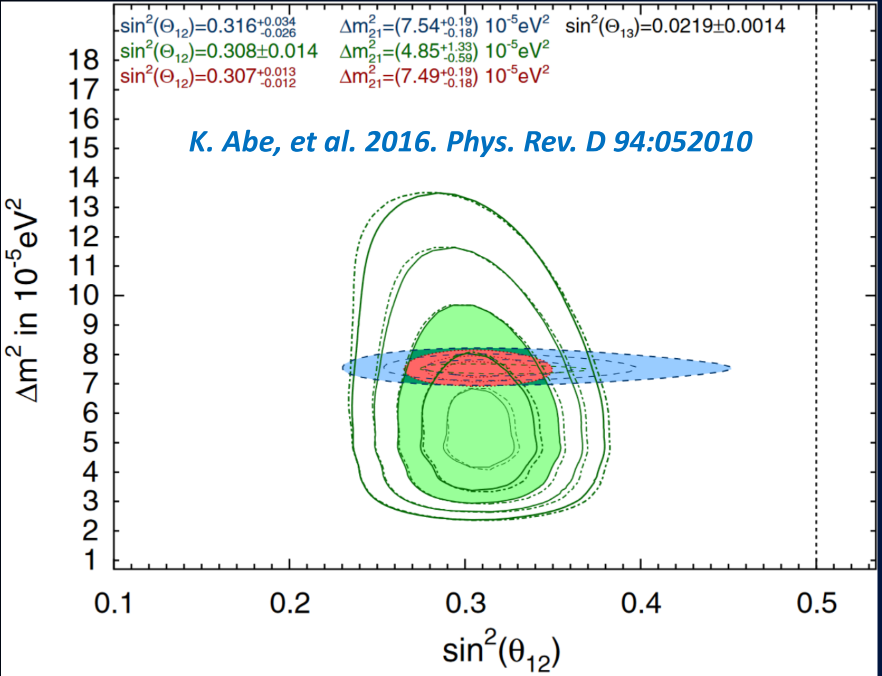
Antineutrinos in SNO+

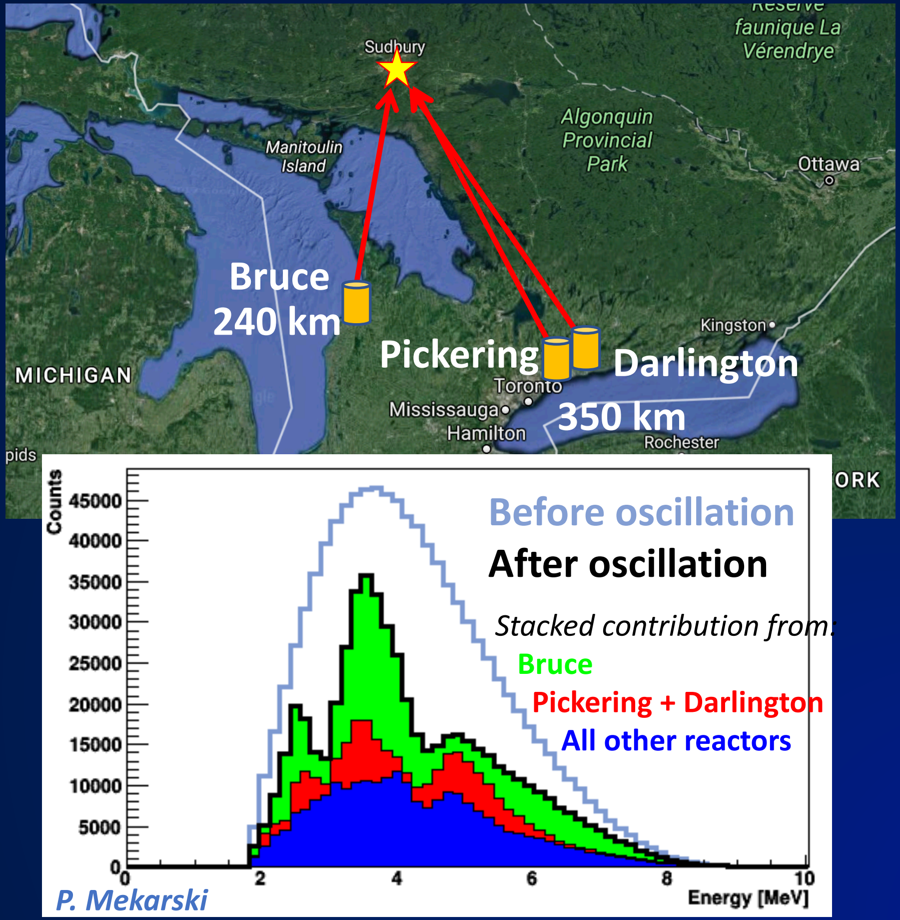
Scintillator filling starts in late 2017 and will allow the measurement of reactor and geo antineutrinos

KamLAND: $\Delta m^2_{12} = 7.54 \times 10^{-5}\mathrm{eV}^2$

SuperK: $\Delta m^2_{12} = 4.85 \times 10^{-5}\mathrm{eV}^2$

Inverse beta decay: $\bar{\nu}_e + p \rightarrow e^+ + n$





SNO+ will provide an independent measurement of this important oscillation parameter

What’s next…

Water Phase	Scintillator Phase	Tellurium Phase
NOW (started May 4th)	**Begins late 2017**	**Begins in 2018**

$0\nu\beta\beta$

- Primary target -

Nucleon Decay

Solar Neutrinos

Reactor Neutrinos

Geoneutrinos

Supernova Neutrinos

Thank you!

- University of Alberta
- Armstrong Atlantic State University
- University of California, Berkeley / LBNL
- Boston University
- Brookhaven National Laboratory
- University of Chicago
- University of California, Davis
- Technical University of Dresden
- Lancaster University
- Laurentian University
- University of Liverpool
- Universidad Nacional Autonoma de Mexico
- University of North Carolina
- Norwich University
- University of Oxford
- University of Pennsylvania
- Queen's University
- Queen Mary University of London
- SNOLAB
- University of Sussex
- TRIUMF
- University of Washington

SNO+ Collaboration

Backup