SNO+ Current Status and Future Prospects

Lorna Nolan on behalf of the SNO+ collaboration
Queen Mary University of London

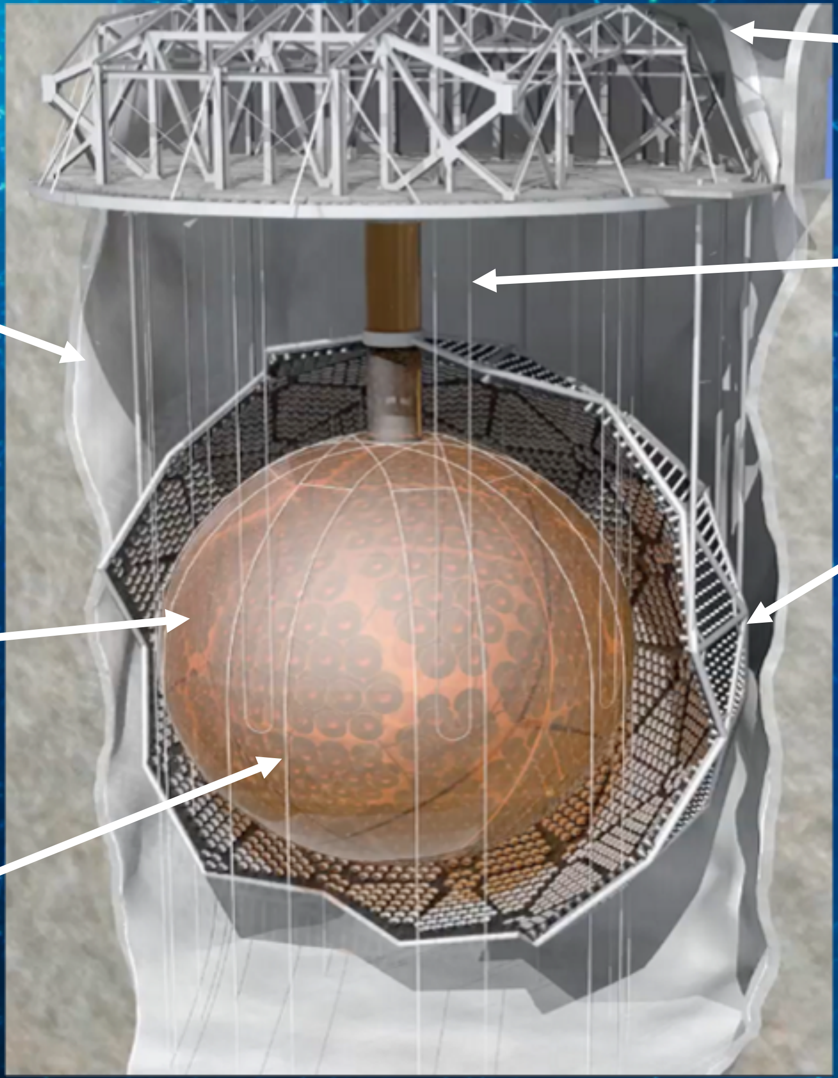
2022 Lake Louise Winter Institute

Queen Mary
University of London
School of Physical and Chemical Sciences

SNO+

The SNO+ detector

Located 2km underground in the Creighton mine, an active nickel mine in Sudbury, Ontario.



5890m.w.e. overburden -> ~3μ/h.

Hold-up ropes

Cavity filled with UPW (Ultra Pure Water)

~9300 PMTs in 9m radius spherical PMT Support System

6m radius Acrylic Vessel (AV) containing 780 tonnes of liquid scintillator

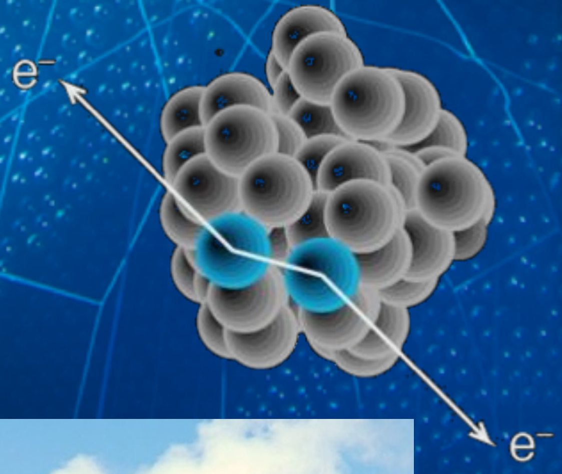
Hold-down ropes

Upgrade of SNO experiment, for which Art McDonald shared the 2015 Nobel Prize with Takaaki Kajita of Super-K for discovery of neutrino oscillations.

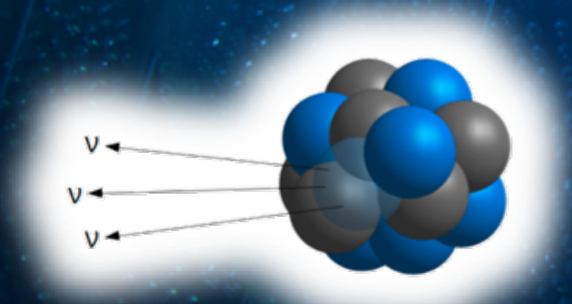
SNO+ Physics Goals

Solar neutrinos

Main goal: Neutrinoless double beta decay



Supernova neutrinos



Invisible nucleon decay

Reactor antineutrinos

Geo-neutrinos

All of these goals require as low backgrounds as possible, and an excellent understanding of the detector response.

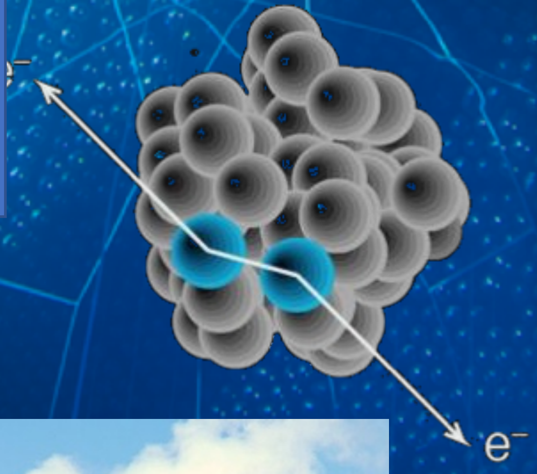
SNO+ Physics Goals

$0\nu\beta\beta$ decay candidate: **^{130}Te**

Massive detector
- High statistics
- Fiducialisation to self-shield from external backgrounds

Liquid scintillator
- Can be purified
- Measure and constrain backgrounds before adding ^{130}Te
- ^{130}Te concentration scalable

Solar neutrinos



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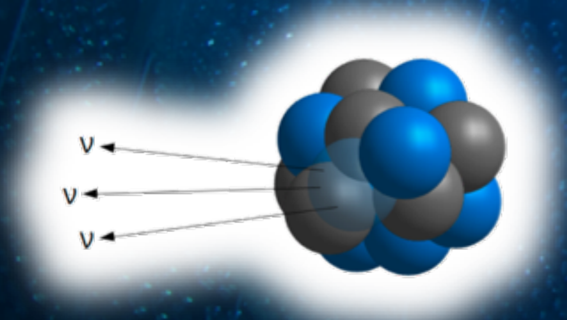

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SNO+ Timeline

2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023

December 2016: start of commissioning data

May 2017: Start of water phase

Water Phase

905 tonnes of ultra-pure water (UPW)

Dataset I: (115 live days)
May 2017 -> December 2017

Dataset II: (190 live days)
October 2018 -> July 2019

SNO+ Water Phase

Background	Rate (Fraction of Nominal)
AV+Ropes	$0.52 \pm 0.02^{+0.39}_{-0.28}$
External Water	$0.03 \pm 0.01^{+0.61}_{-0.03}$
PMT	$2.04 \pm 0.04^{+3.69}_{-1.20}$

Backgrounds

Measured those that aren’t dependant on detector medium.

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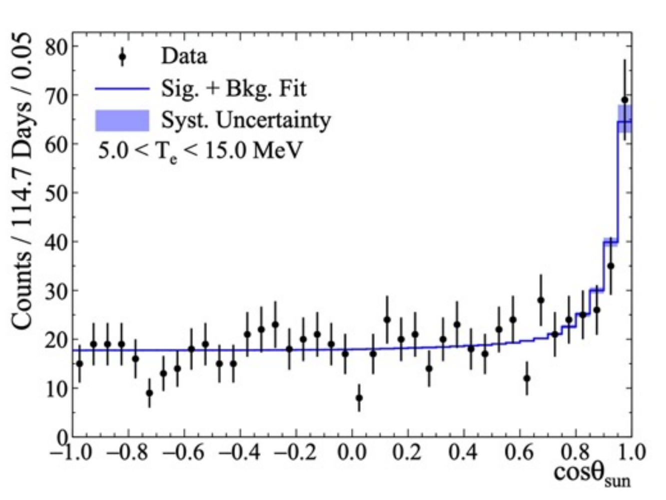

^{8}B Solar neutrino flux

Phys. Rev. D 99, 012012 (2019)

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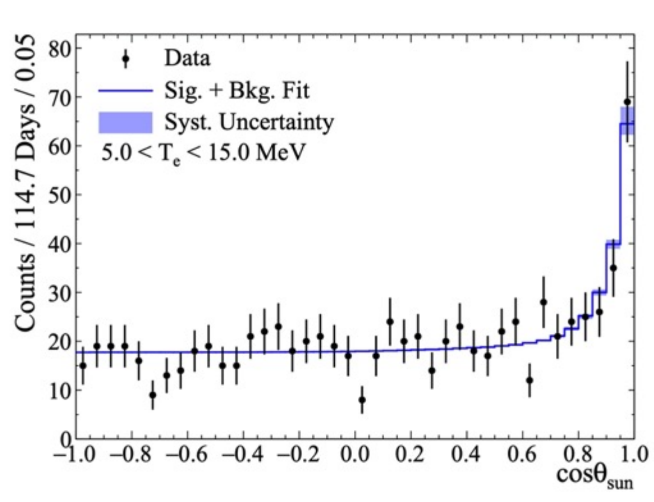

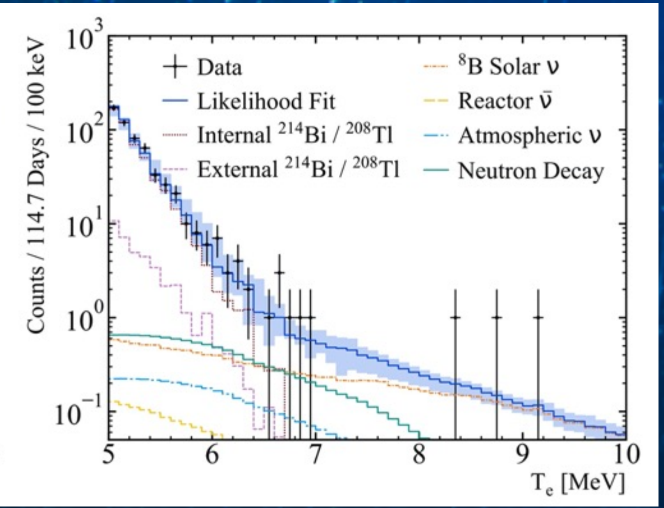

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New limits for p, pp and pn invisible nucleon decay
Phys. Rev. D 99, 032008 (2019)

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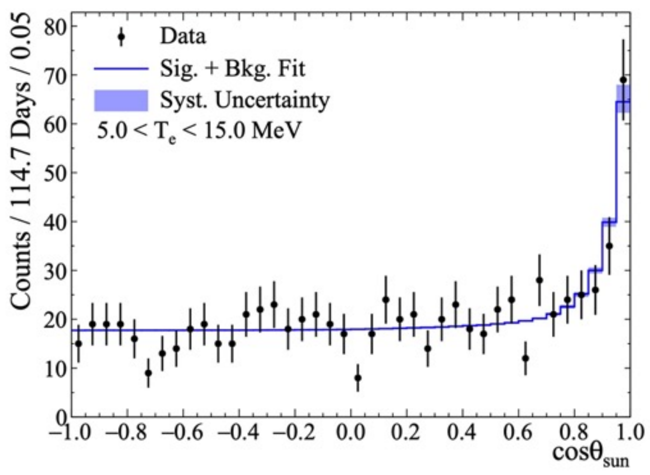
Backgrounds

Measured those that aren't dependant on detector medium.

Data Set 2: Adds 190 days, results coming soon:

- New solar flux and spectrum measurement, lower backgrounds
- New limits, extra livetime and lower backgrounds
- Measurement of reactor $\bar{\nu}$ in H_2O detector

Results from Data Set 1:



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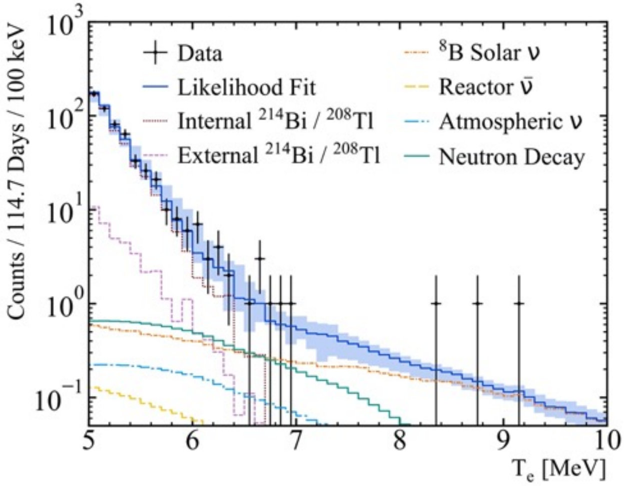

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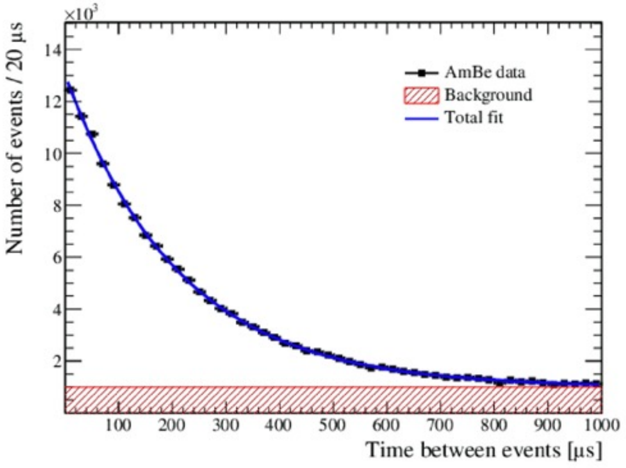

~50% efficiency for triggering on a neutron in pure water
Phys. Rev. C 102, 014002 (2020)

SNO+ Timeline

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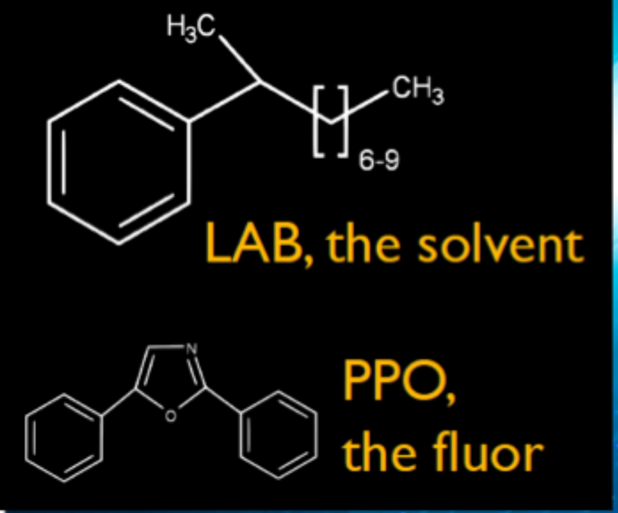
December 2016: start of commissioning data

May 2017: Start of water phase

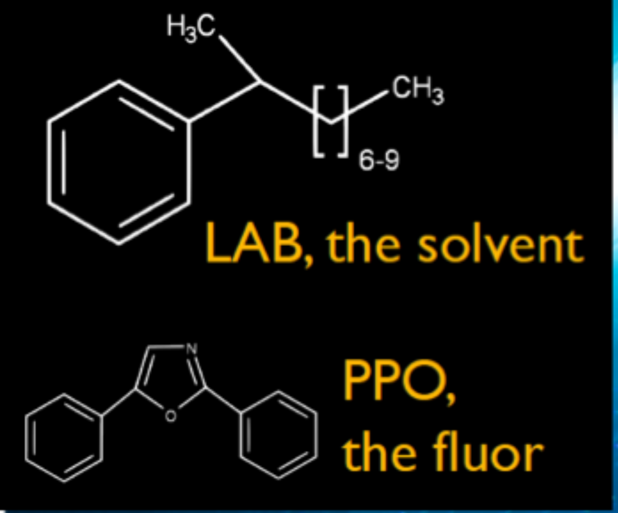
July 2019: Start of scintillator filling

SNO+ Scintillator Filling



Transportation of LAB underground:

SNO+ Scintillator Filling

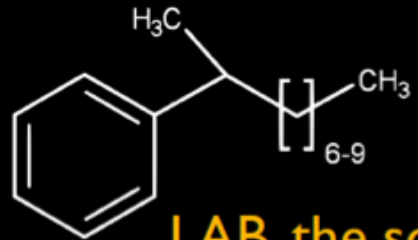


Transportation of LAB underground:

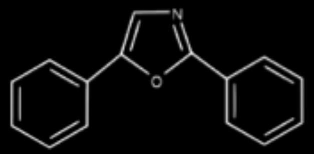
Underground Purification and Filling Systems:

Hourly checks during filling to ensure LAB and PPO is of good quality

SNO+ Scintillator Filling



LAB, the solvent



PPO, the fluor

Transportation of LAB underground:

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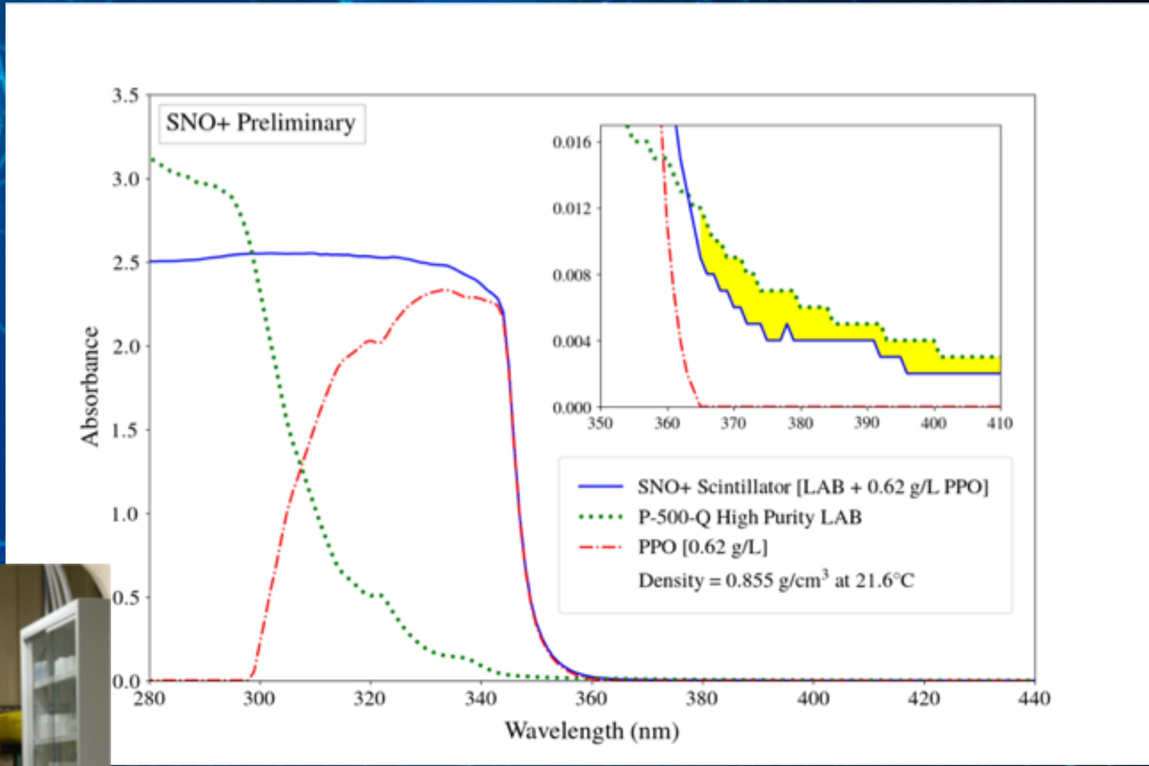

Excellent optical clarity above PPO absorption.
Light yield higher than calibration standards.

Hourly checks during filling to ensure LAB and PPO is of good quality

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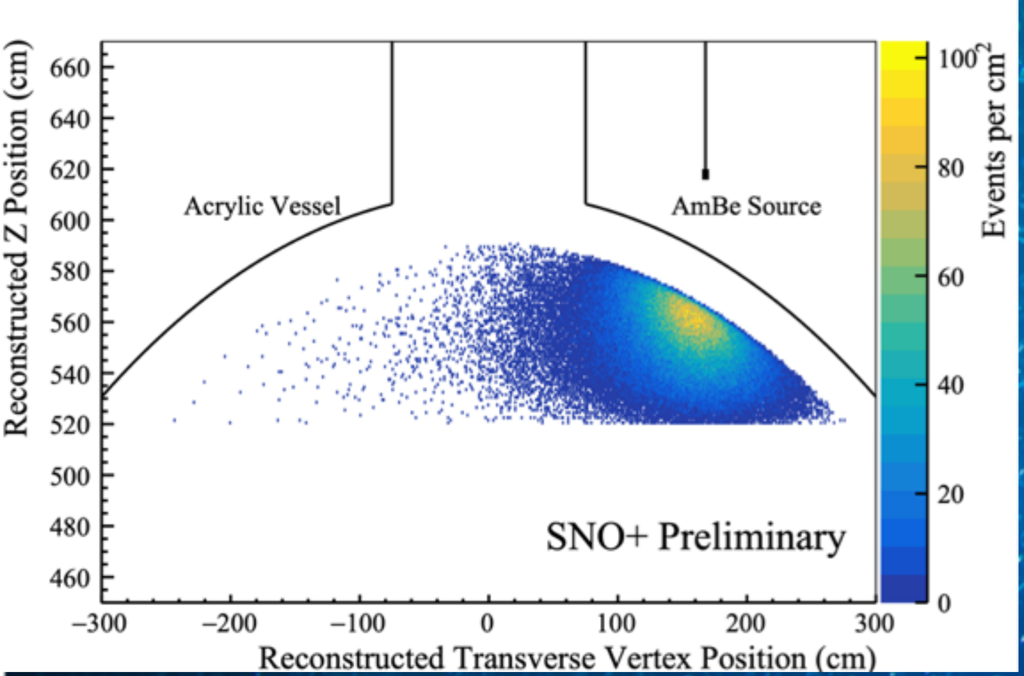
Due to Covid Pandemic, paused fill with
- 365t LAB
- 0.5g/L PPO

Partial Fill Phase

March 2021: Scintillator fill complete



SNO+ Partial Fill Phase

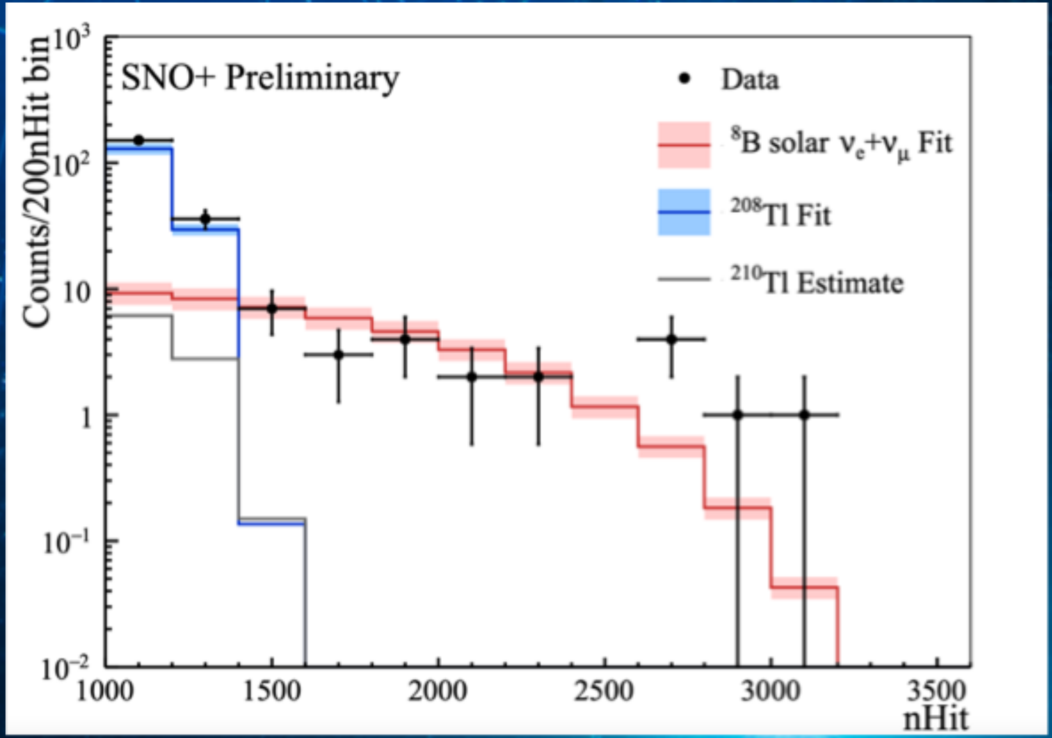
Detector response during the fill was measured with optical and radioactive source calibrations

Reactor antineutrino analysis

Also looked at directionality/separation of Cherenkov and Scintillation light

https://arxiv.org/abs/2001.10825

Preliminary ^{8}B solar ν + Bkg. Fit to the PF data, including preliminary systematics.
Fit comparable to other measurements.



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Partial Fill Phase

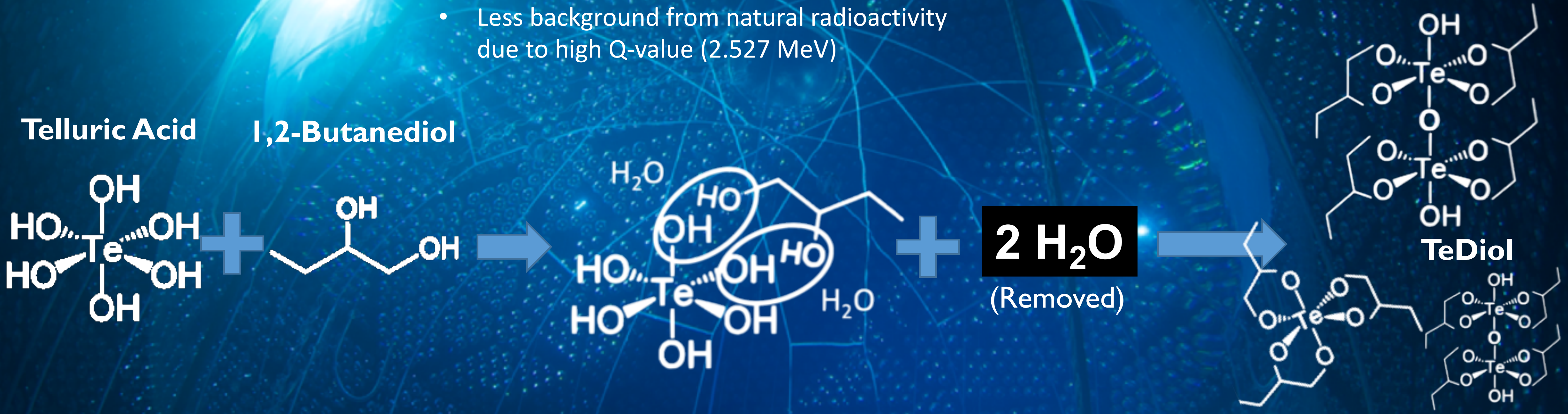
March 2021: Scintillator fill complete

End of 2023: Tellurium loading ready to start

Tellurium Loading

Why Tellurium?

- Low cost due to high natural abundance (34%)
- Less background from natural radioactivity due to high Q-value (2.527 MeV)



Tellurium Loading

Initial phase loading:
0.5% natural Te by weight
= 1333 kg of ^{130}Te.

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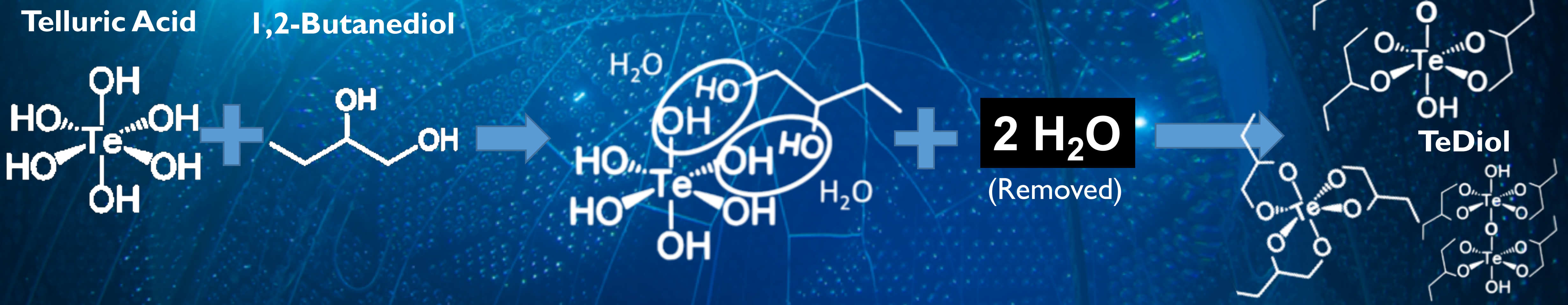
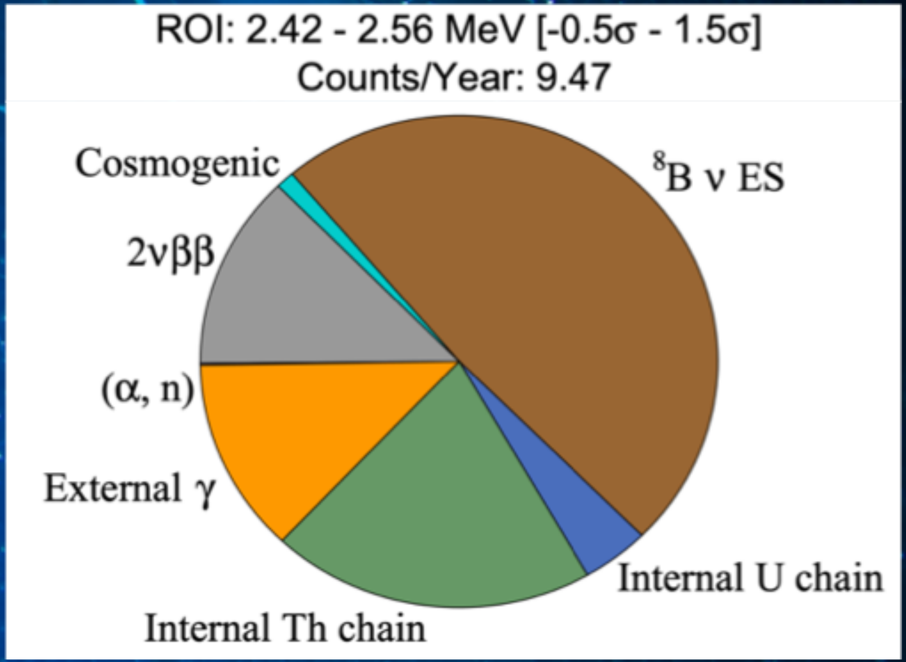


TeDiol is mixed directly into the LAB+PPO with 15 mg/L bis-MSB and a stabilizer called Dimethyldodecylamine (DDA).

Final Te-loaded LS cocktail expected to produce ~460 p.e. / MeV in SNO+ for 0.5% Te loading.

Tellurium Phase



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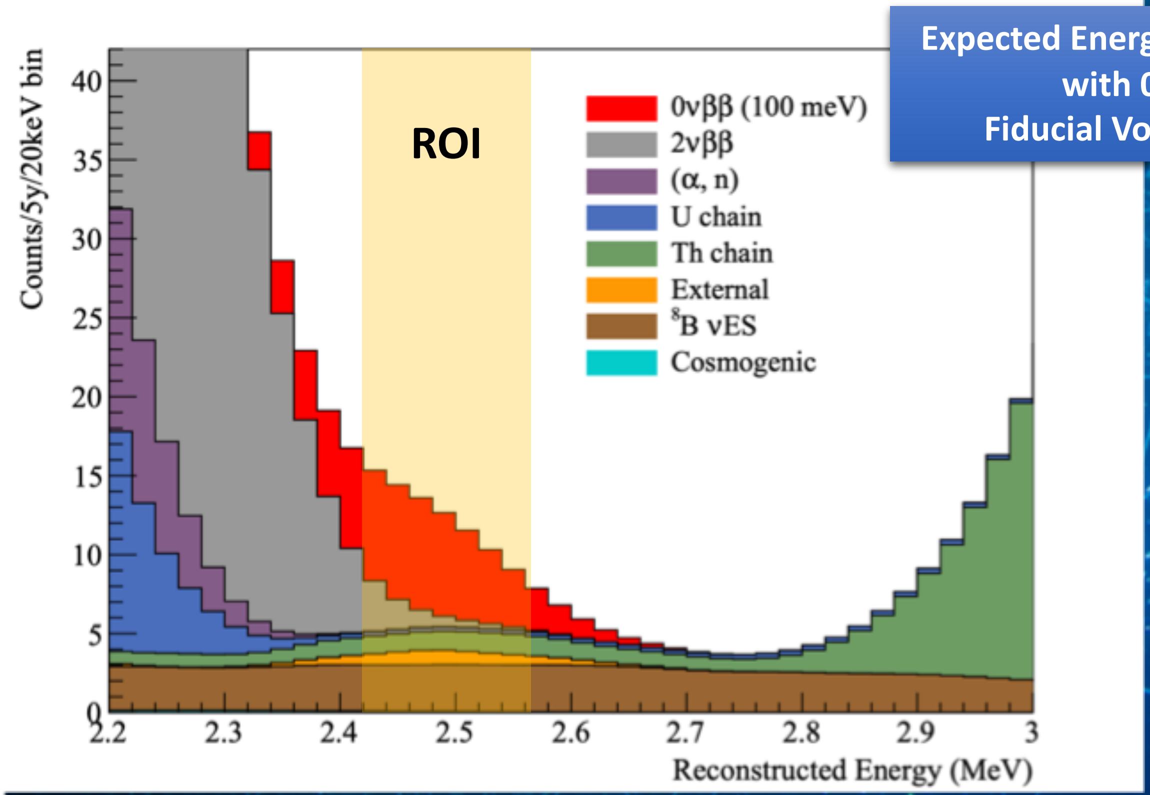
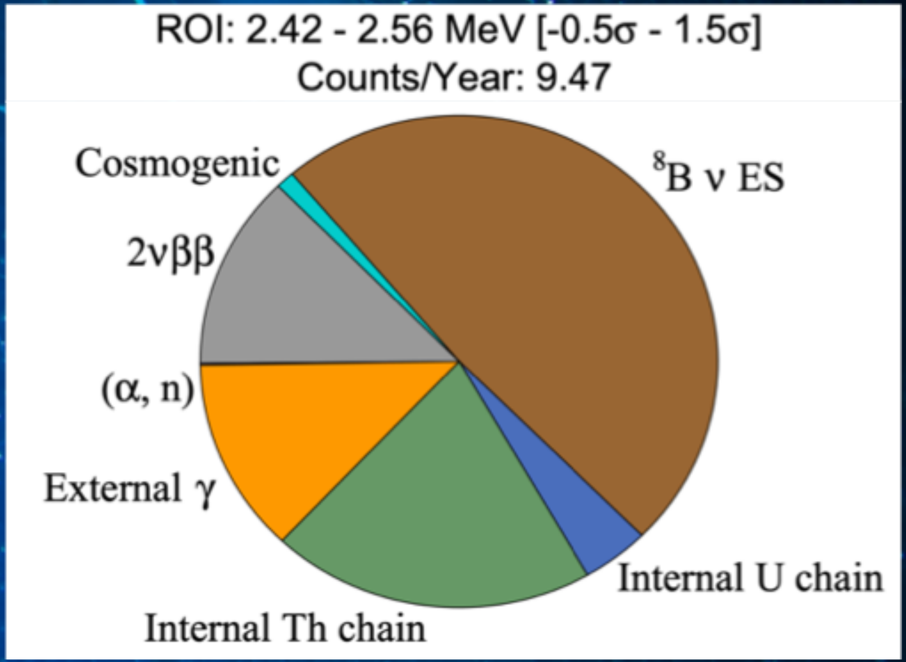




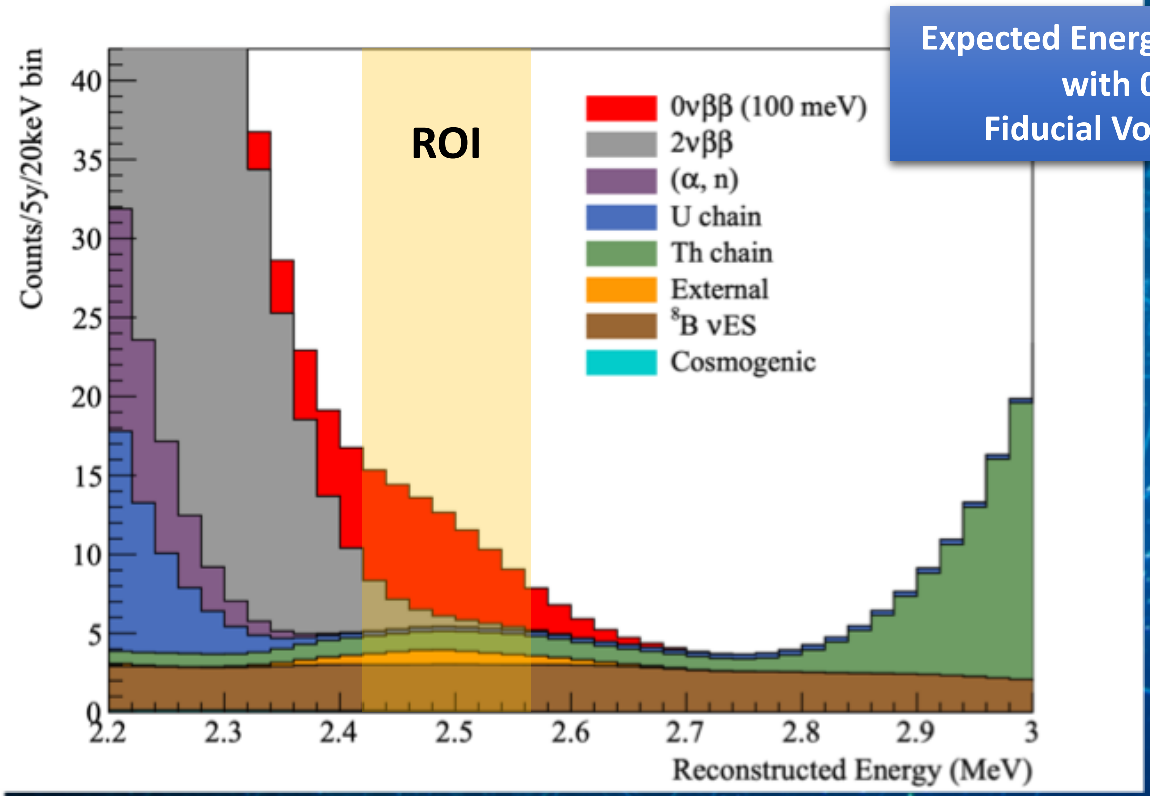
Half-life sensitivity from simple counting analysis in 5 years:

$T_{1/2} > 2.1 \times 10^{26}$ years

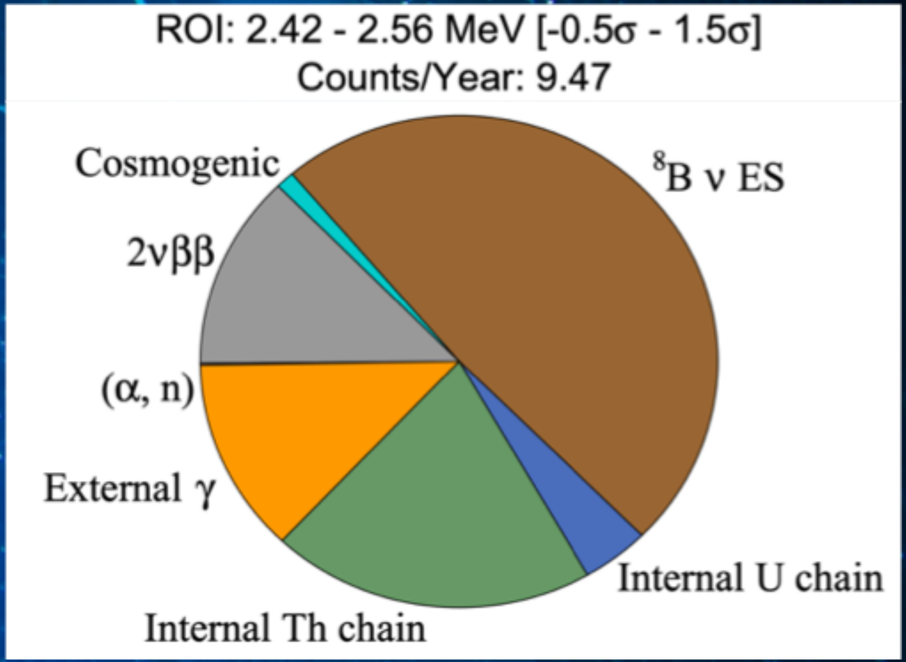
Sensitive to $m_{\beta\beta}$ = 37-89 meV (model dependant)

Can be optimised using a full likelihood fit to achieve the same result in 3 years.

Tellurium Phase



Expected Energy Spectrum after 5 Years with 0.5% Te loading, Fiducial Volume of 3.3 m radius



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SNO+ Phase II

Loading approach can be scaled up.

- Te loading up to 3% with good light yield and stability
- Cost is relatively very low (< $2M per ton of decay isotope)

Summary

- Water phase:
  - Updated results with more data in progress

- Scintillator filling:
  - Partial Fill Phase:
    - Calibrations, preliminary results, and investigation of Cherenkov/scintillation light separation
  - Scintillator Fill now complete

- Tellurium Phase:
  - 130-Te will be mixed directly into the scintillator at target concentration of 0.5% natural Te by weight
  - Expected Half-Life Sensitivity > 2.1×10^{26} years
  - $m_{\beta\beta}$ range 37-89 meV (model dependent)
  - The concentration can be scaled up in future phases.

Thank you for your attention

Any Questions?