0νββ with SNO+

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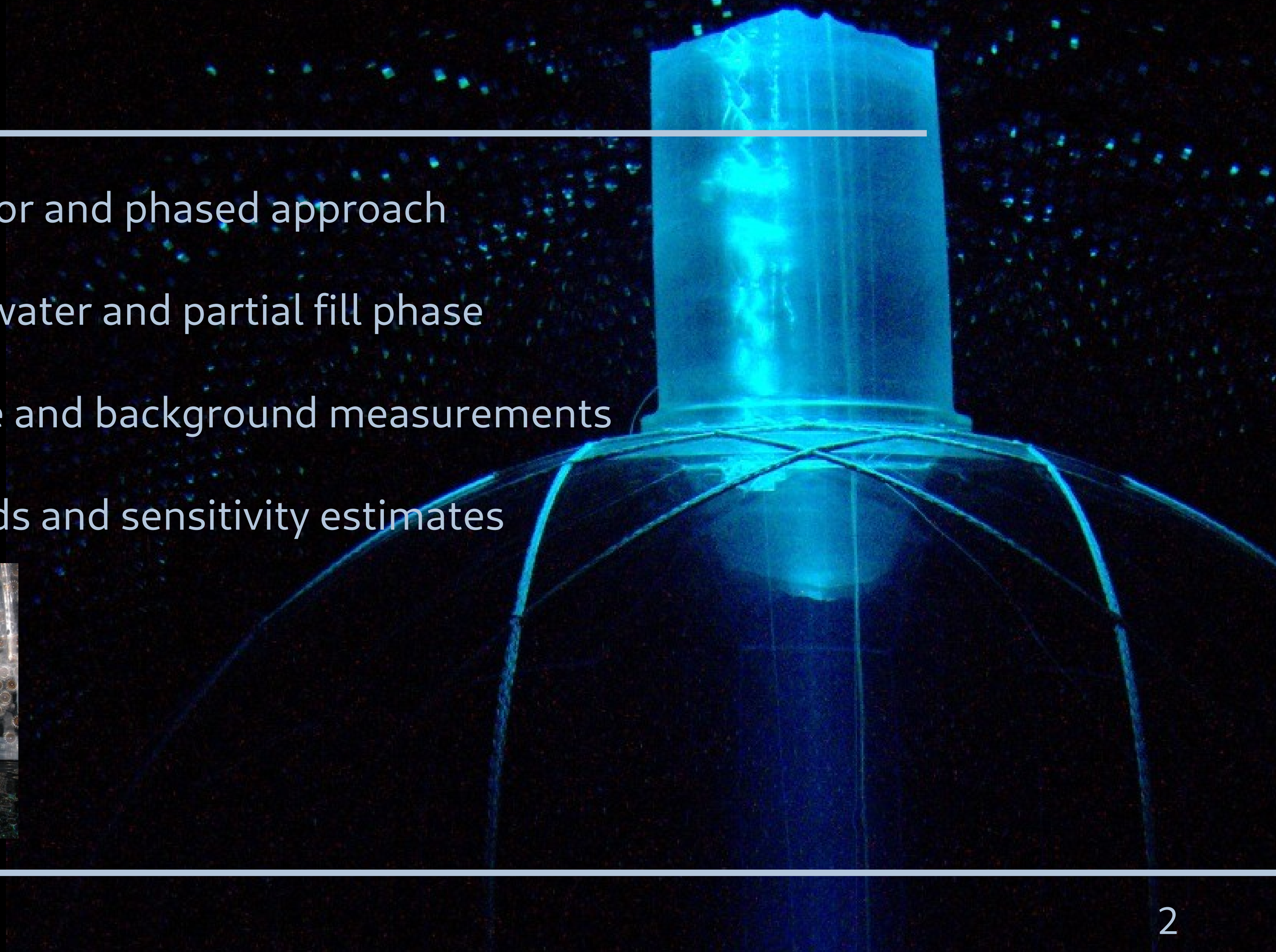
UC Berkeley
12/2/2023

Double Beta Decay Workshop

Waikoloa Village, Hawaii

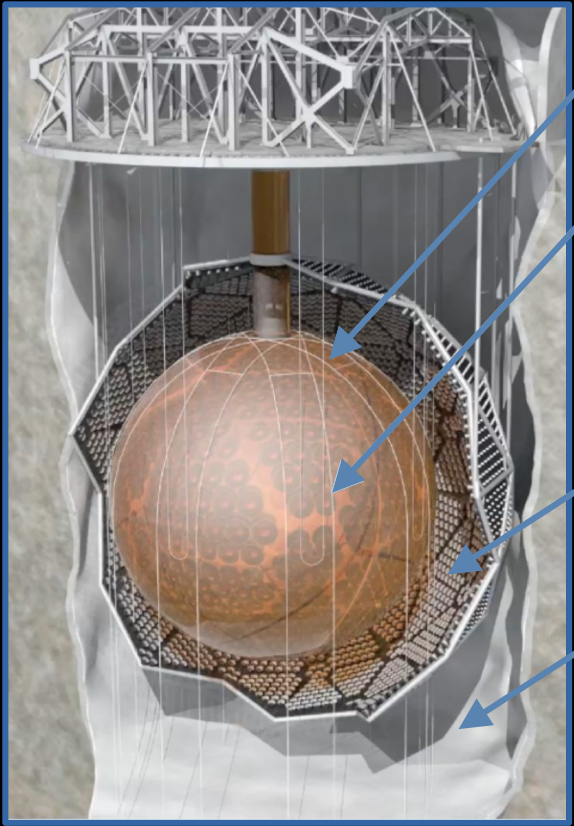
Overview

1. The SNO+ detector and phased approach
2. Highlights from water and partial fill phase
3. Scintillator phase and background measurements
4. $0\nu\beta\beta$ backgrounds and sensitivity estimates



The SNO+ Detector

SNO+ is a ktonne-scale neutrino detector, upgraded from SNO, located underground (6010 m.w.e overburden) in Sudbury, Ontario.



Phased approach

1. SNO+ first filled with ultra-pure water

calibrations, solar, reactor neutrinos 2017 – 2019

Reactor neutrinos: Phys.Rev.Lett. 130 9, 091801 (2023)
Invisible nucleon decay: Phys. Rev. D 105, 112012 (2022)
Optical calibrations: JINST 16 P10021 (2021)
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Solar neutrinos: Phys. Rev. D 99, 012012 (2019)

L12.0008, T. Kaptanoglu

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2. SNO+ filling with liquid scintillator (partial fill)

solar, reactor neutrinos 2019 – 2021

Directionality in scintillator: arXiv:2309.06341 (2023)
Reactor neutrinos: In preparation

L12.0009, A. Zummo


SNO+ with water


SNO+ partial fill

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3. SNO+ with liquid scintillator
solar, reactor, geo, **0νββ backgrounds** 2021 – ongoing

M12.0006, M. Smiley


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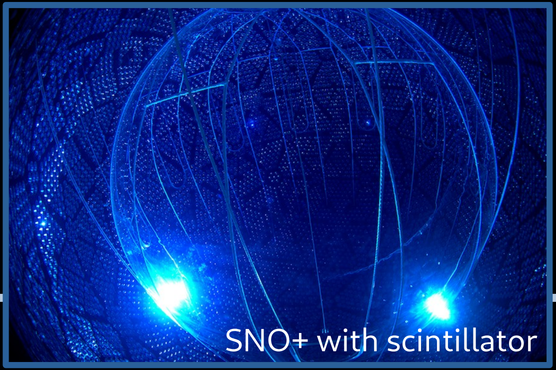
SNO+ partial fill


SNO+ with scintillator

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solar, reactor, geo, **0νββ backgrounds** 2021 – ongoing

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4. SNO+ Te-loaded liquid scinillator

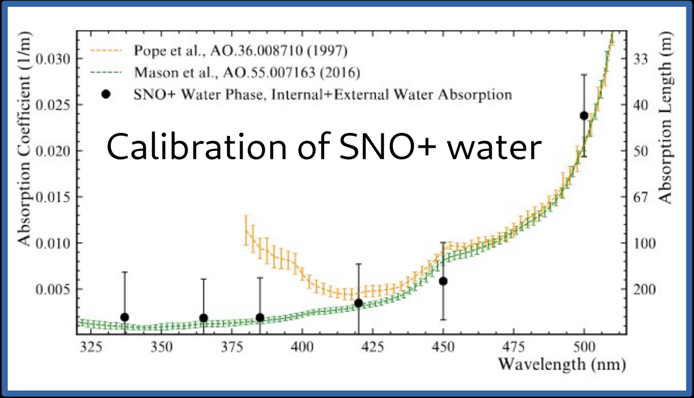
solar, reactor, geo, **0νββ** expected 2025

Underground Te

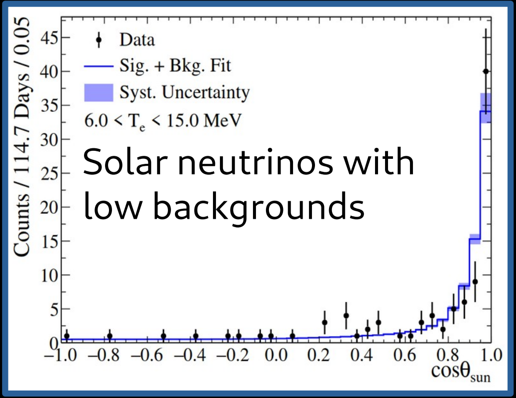
Underground scintillator and Te plants

Water phase highlights

1. Calibrated detector response using optical and radioactive sources
2. Measurement of solar neutrinos with extremely low backgrounds
3. First ever measurement of reactor antineutrinos with a water detector
4. World-leading limits on various modes of invisible nucleon decay



JINST 16 P10021 (2021)



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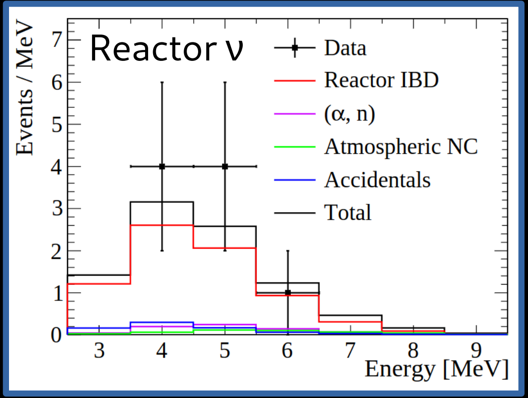

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Water phase highlights

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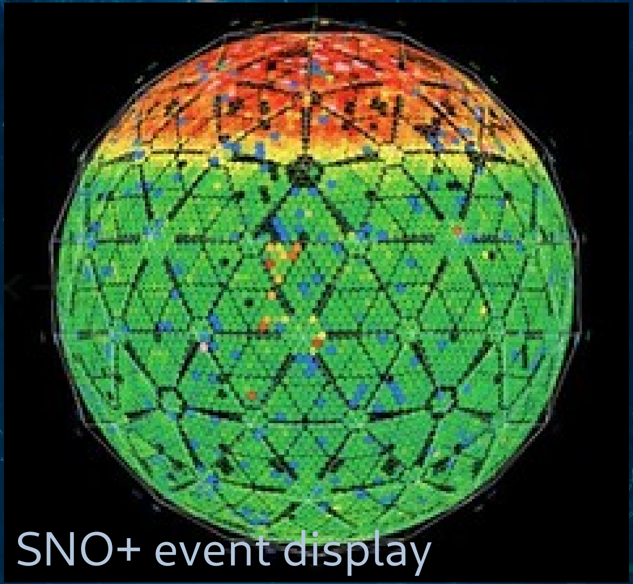
4. World-leading limits on various modes of invisible nucleon decay
5. Measurement of external backgrounds (consistent or below expectations)

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	$2.04 \pm 0.04^{+3.69}_{-1.20}$

Partial Fill Highlights

1. Detector was ~half full with LAB+PPO (0.6 g/L) for about six months during the COVID-19 pandemic

Scintillator/water interface



SNO+ event display

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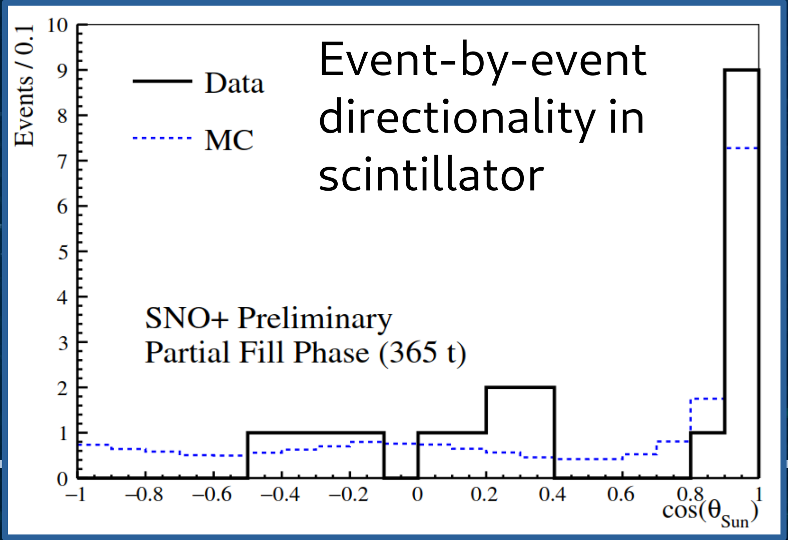
1. Detector was ~half full with LAB+PPO (0.6 g/L) for about six months during the COVID-19 pandemic
2. Achieved event-by-event directionality for recoil electrons from ^{8}B solar neutrino interactions in a high light yield scintillator (paper submitted)



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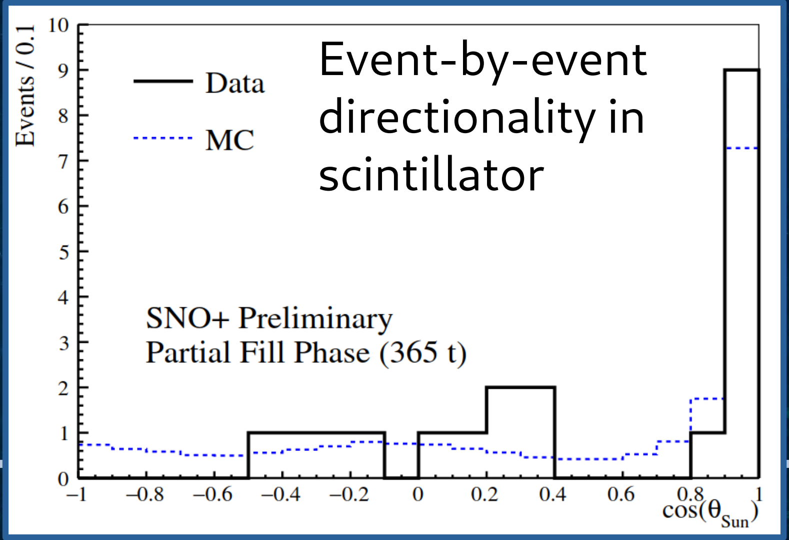
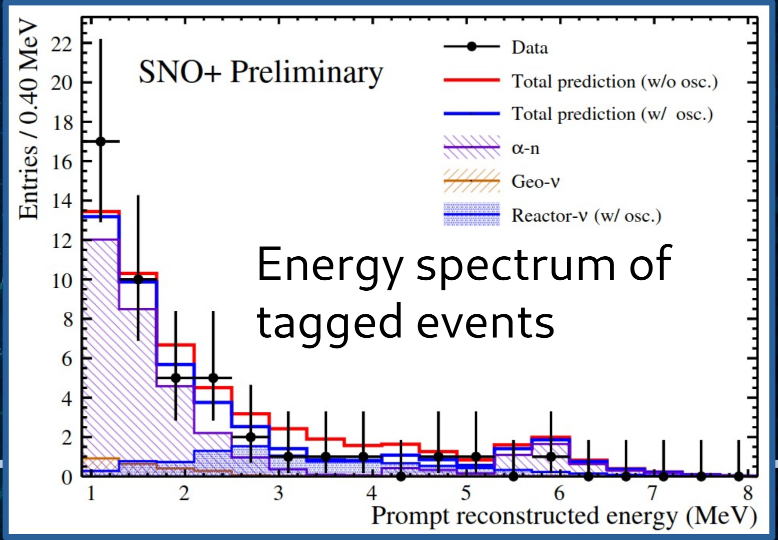
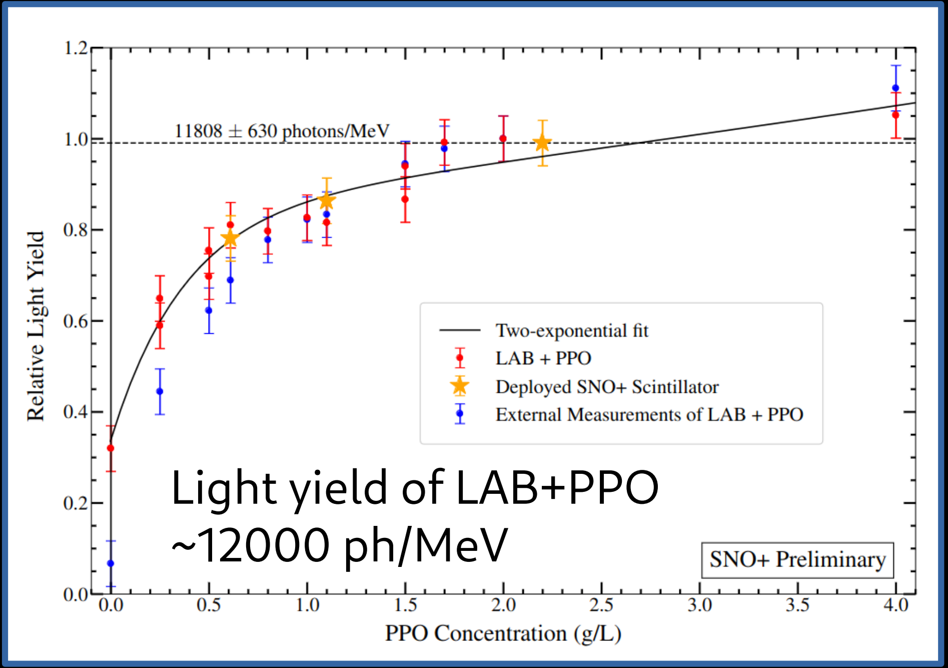
2. Achieved event-by-event directionality for recoil electrons from ^{8}B solar neutrino interactions in a high light yield scintillator (paper submitted)
3. Measurement of reactor antineutrinos in limited fiducial volume, demonstrating well understood detector & backgrounds (paper in preparation)

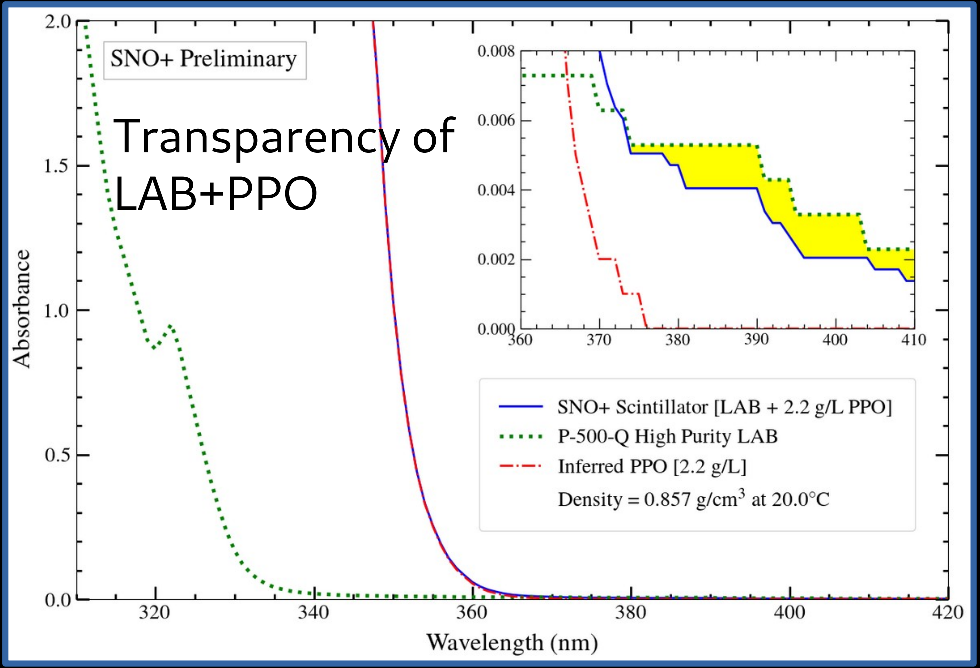




Scintillator Fill

1. Detailed bench-top characterization of well-understood scintillator (LAB+PPO)
   SNO+ Collaboration, JINST 16 (2021) P05009





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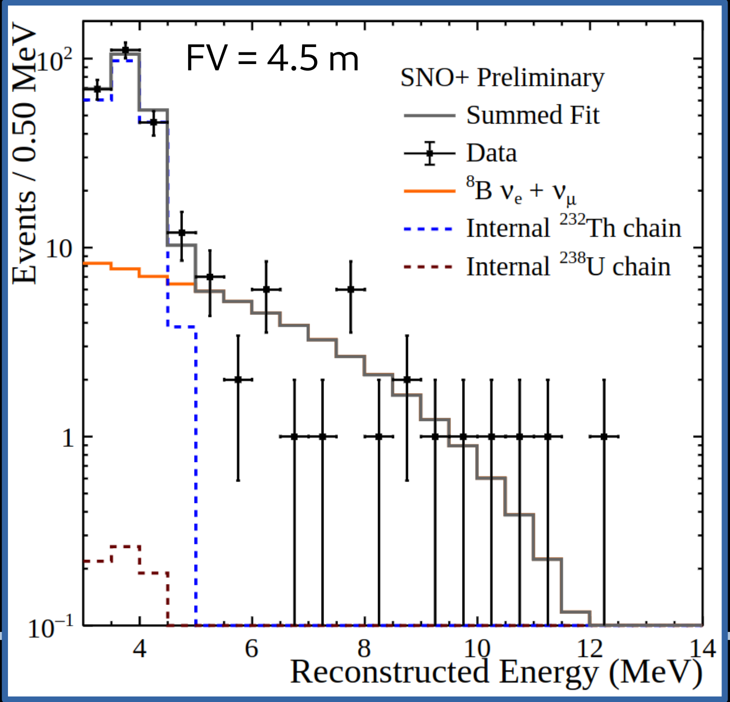

Measurement of ^{8}B solar neutrinos with small, initial dataset

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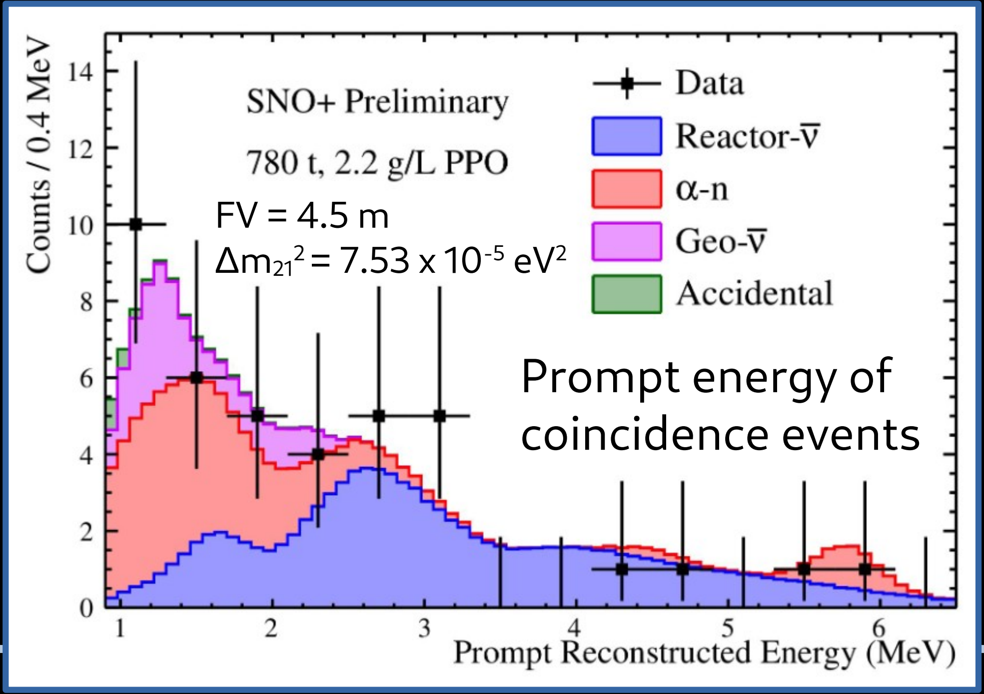

Clear indication of geo-neutrinos in SNO+!

Expect further background reduction from IBD/(α, n) classifier.

Measurement of oscillation parameters forthcoming with higher statistics.

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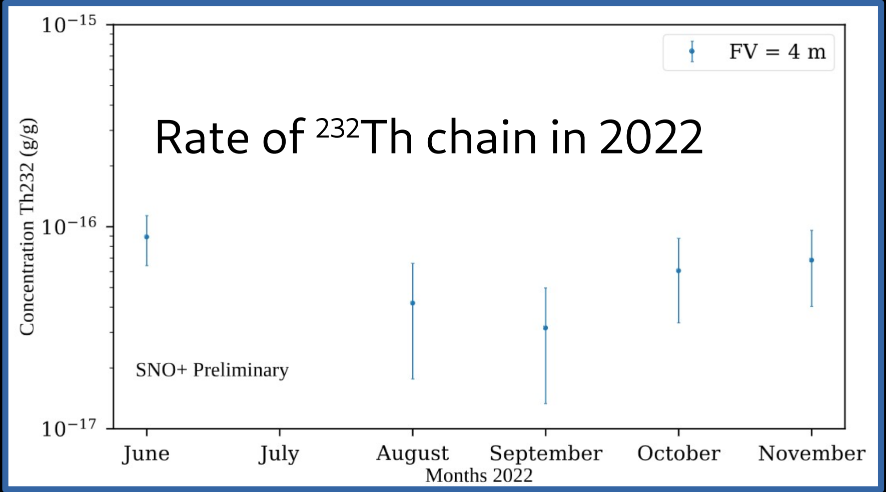
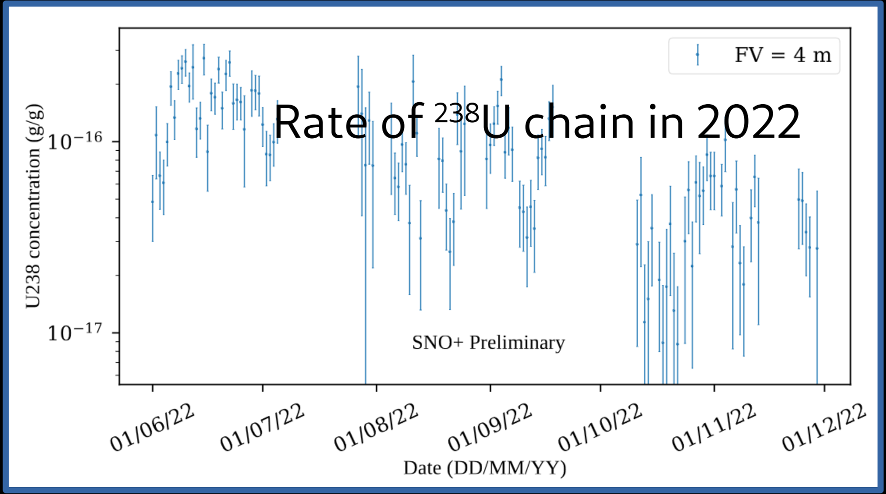
3. Measurements of backgrounds for 0νββ phase: U/Th in scintillator





U/Th concentration are ~5 x 10^{-17} g/g, below requirements for 0νββ phase

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2. Calibrations, solar, reactor, geo neutrino studies ongoing
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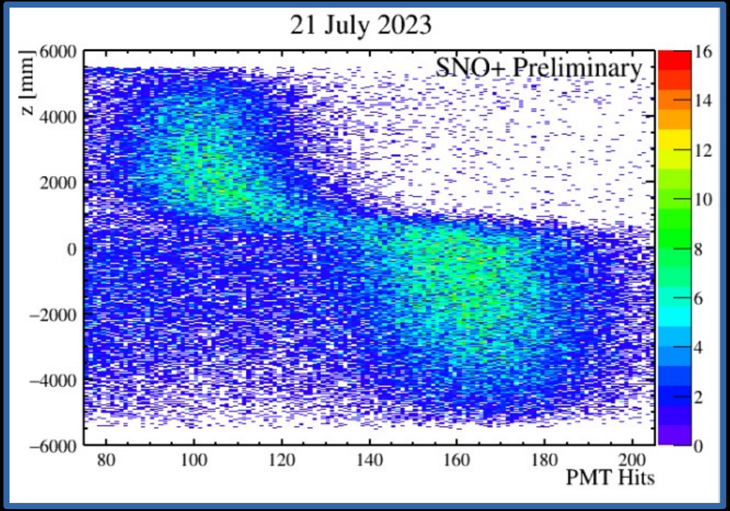
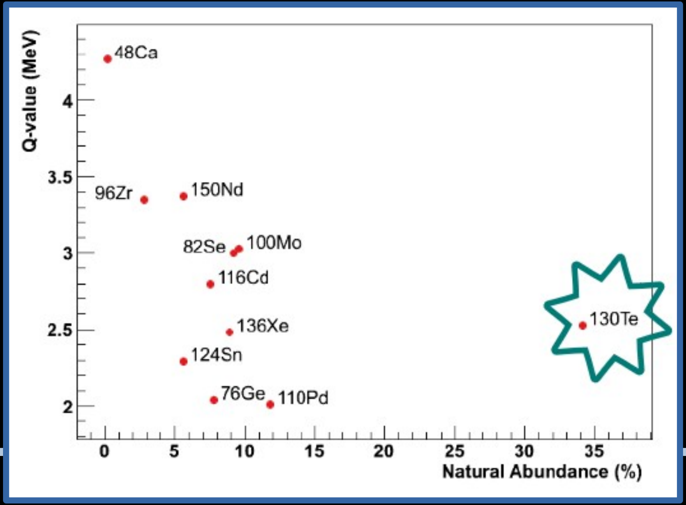
4. Recent bisMSB (fluor) loading increased detector light levels ~50%



The bisMSB, initially deployed at the bottom of the detector, increased the light level in SNO+ as it mixes (as seen here looking at ^{210}Po decays).

0νββ with SNO+: Advantages

1. Te: large isotopic abundance (34%), long 2νββ half-life, high endpoint (2.5 MeV)
2. Enormous detector allows fiducilization away from external backgrounds
3. PSD and fast-timing allows rejection of radioactive backgrounds
4. Many backgrounds measured prior to Te loading: externals, scint. U/Th, etc



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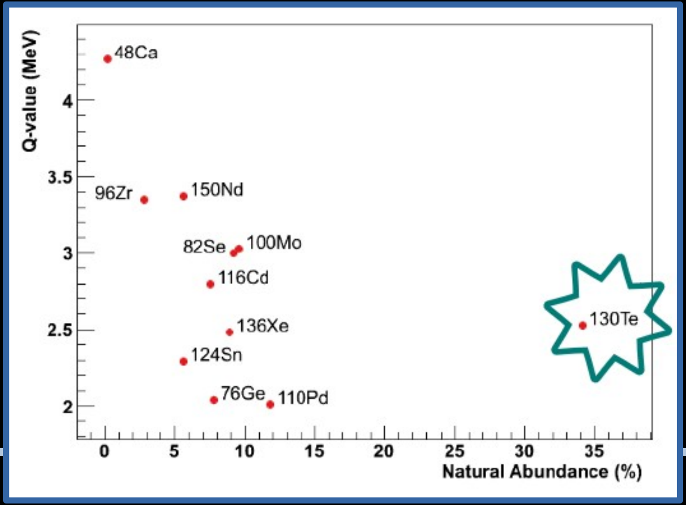
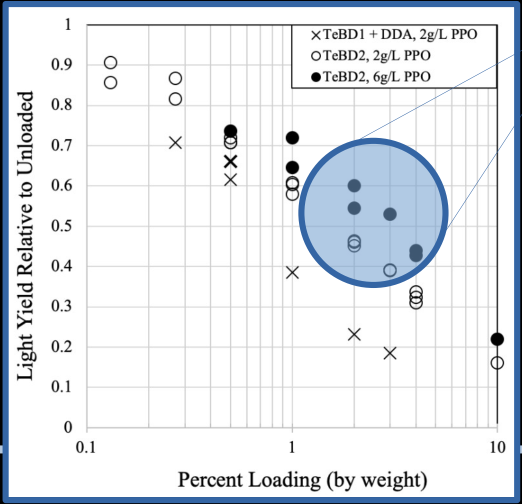
5. Te can be straightforwardly scaled or depleted for in-situ confirmation of signal

A Method to Load Tellurium in Liquid Scintillator for the Study of Neutrinoless Double Beta Decay, D. J Auty et al., NIM A 1051 (2023)





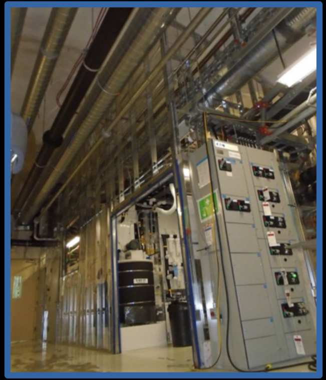
~60% of unloaded light level achieved at 1.5 – 2.5% Te loading

0νββ with SNO+: Status

1. Te has been underground since 2015
2. Underground Te purification plants have been completed are in the process of being commissioned (test batch from the TeA plant)

Underground Te

Scintillator, TeA and TeBD plants



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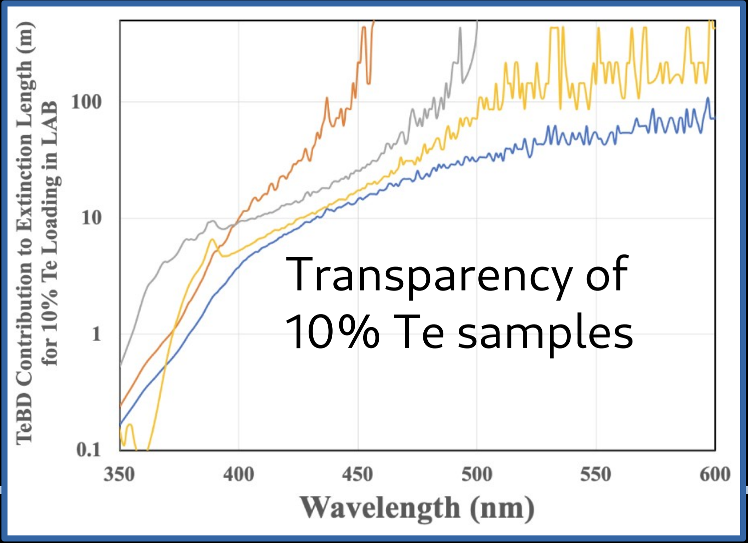

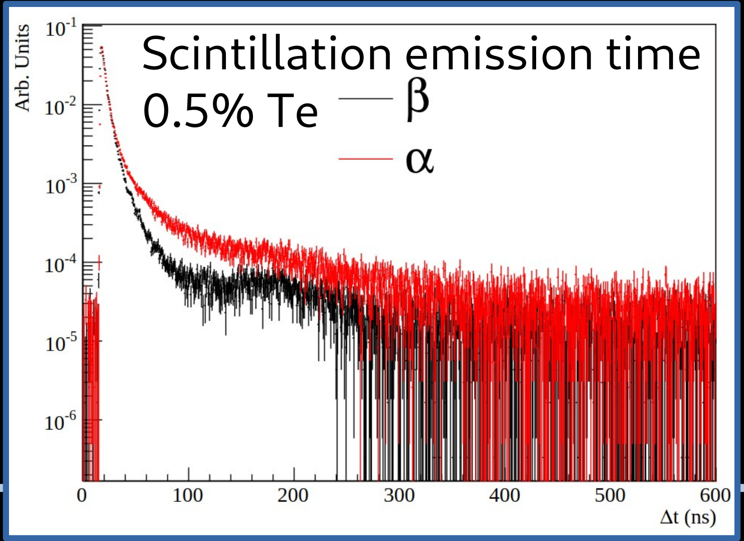

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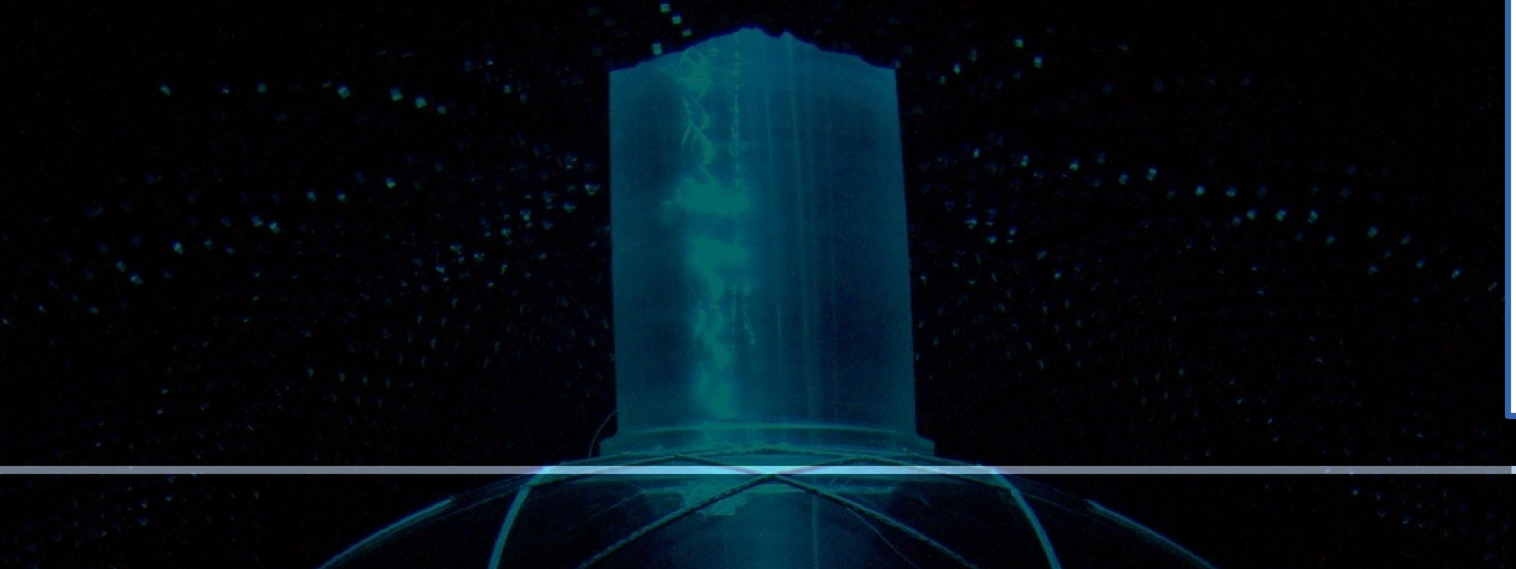
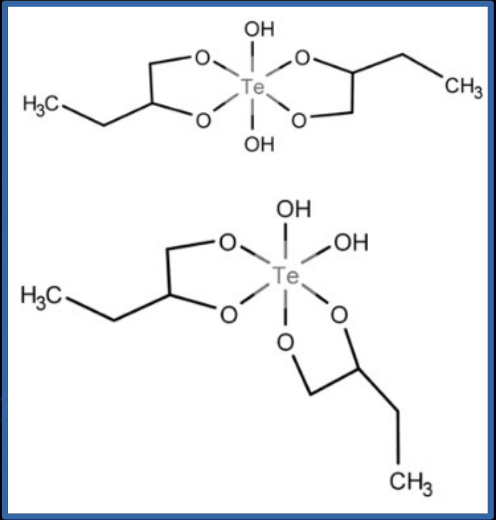
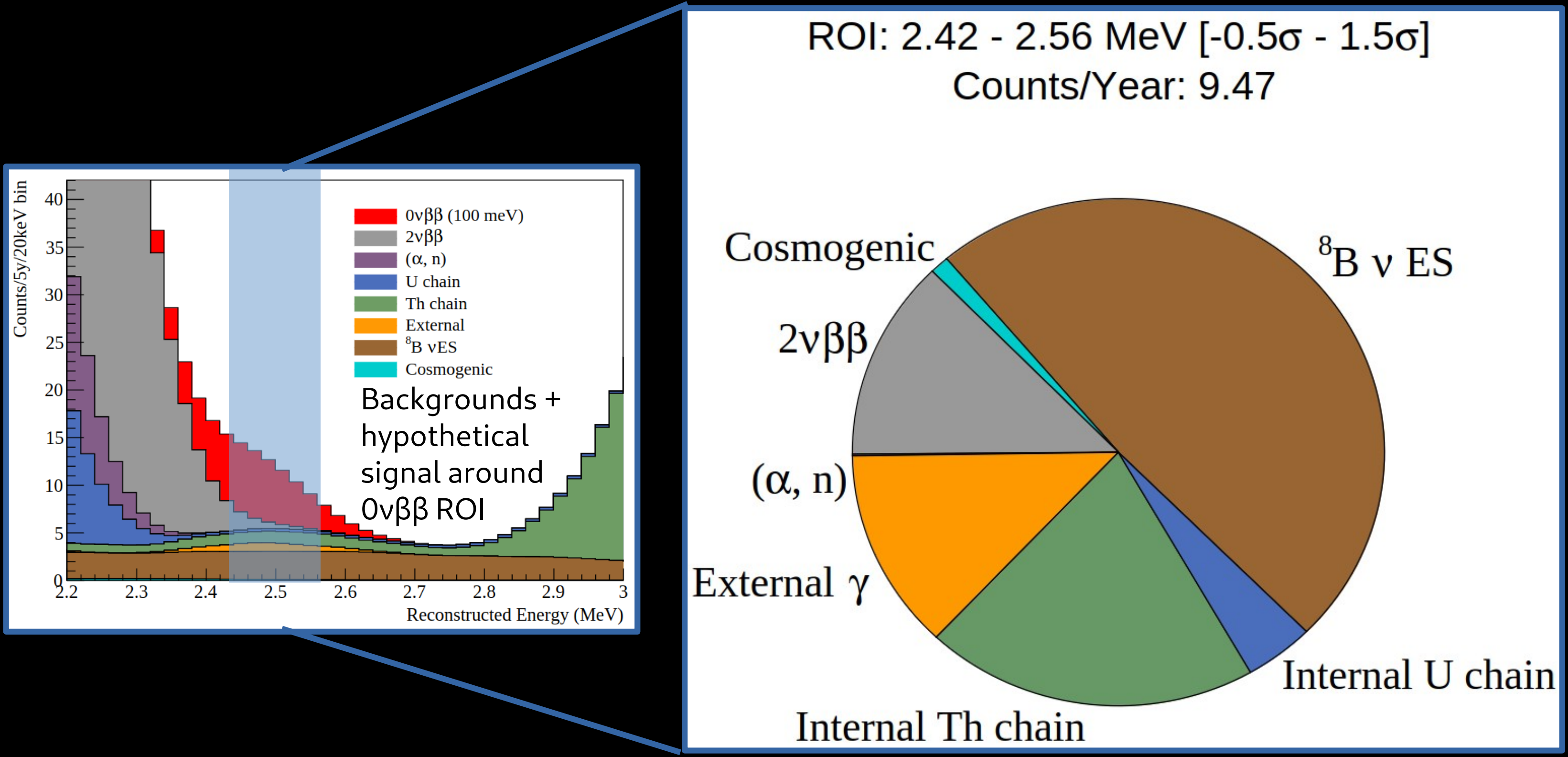
3. Bench-top studies show it is possible to load Te beyond 1.5%, maintaining stability, transparency, high light yields, and excellent PSD
4. Expect deployment of Te into SNO+ in 2025





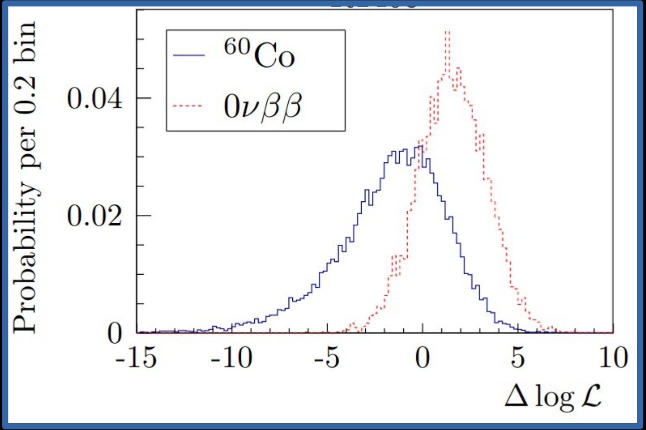
Backgrounds in 0νββ ROI



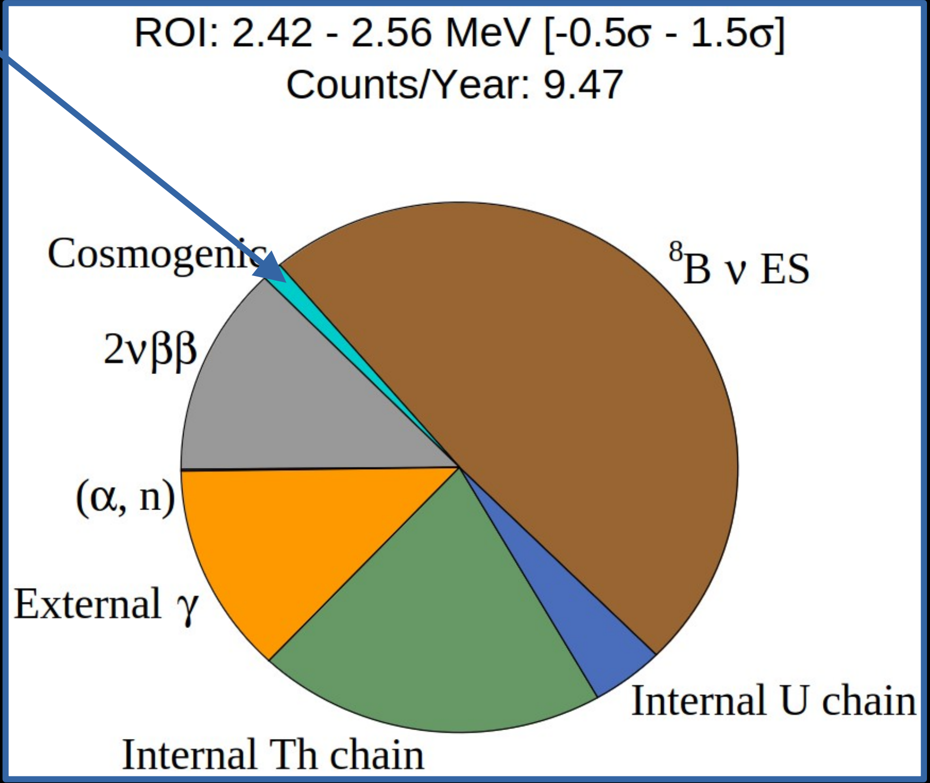
Backgrounds for 0.5% loading, FV = 3.3 m

Backgrounds in 0νββ ROI: Mitigation

Deep underground detector, underground Te, multi-site classifiers



J. Dunger, S. Biller, NIM Volume 943, 1 November 2019, 162420



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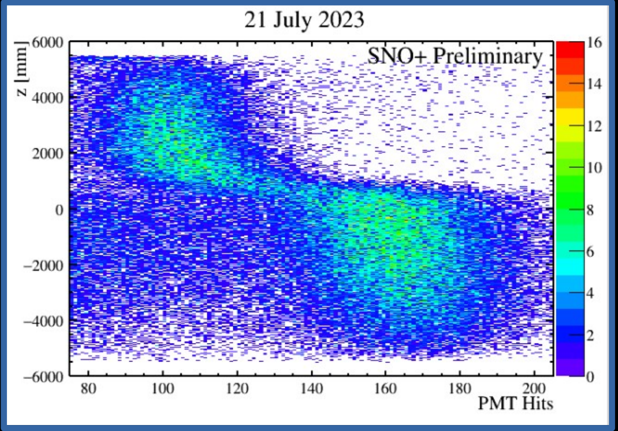
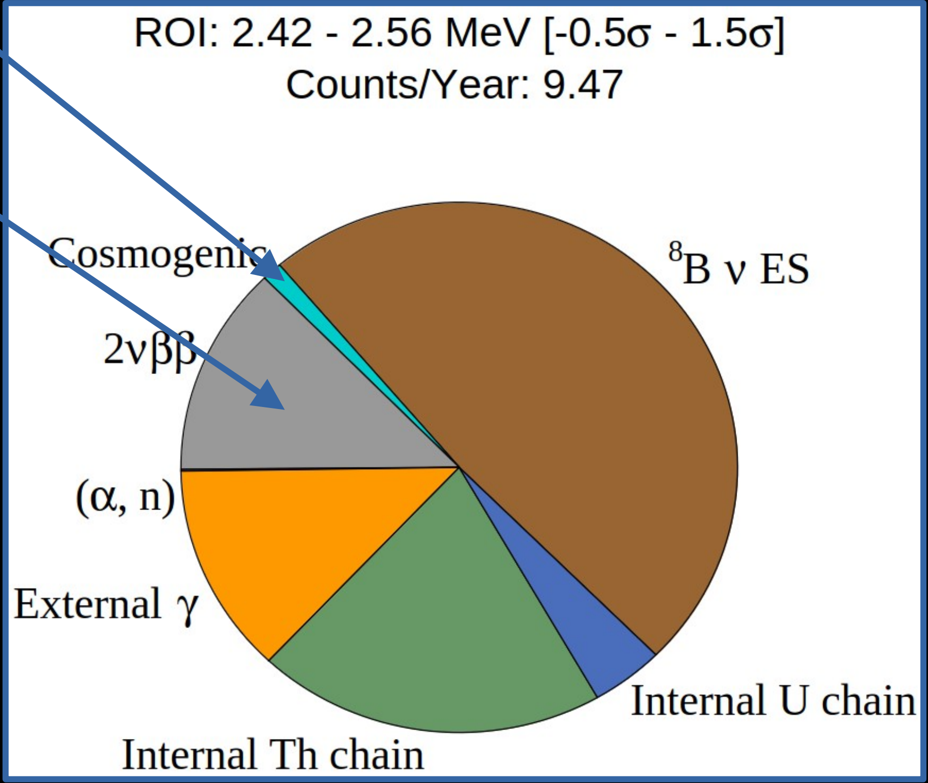
Increasing light yield from bisMSB loading





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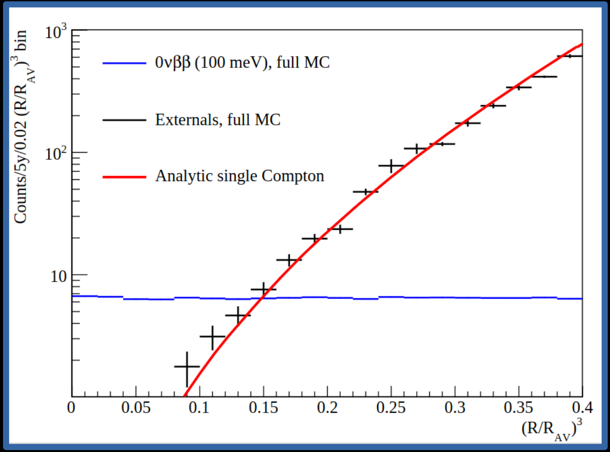
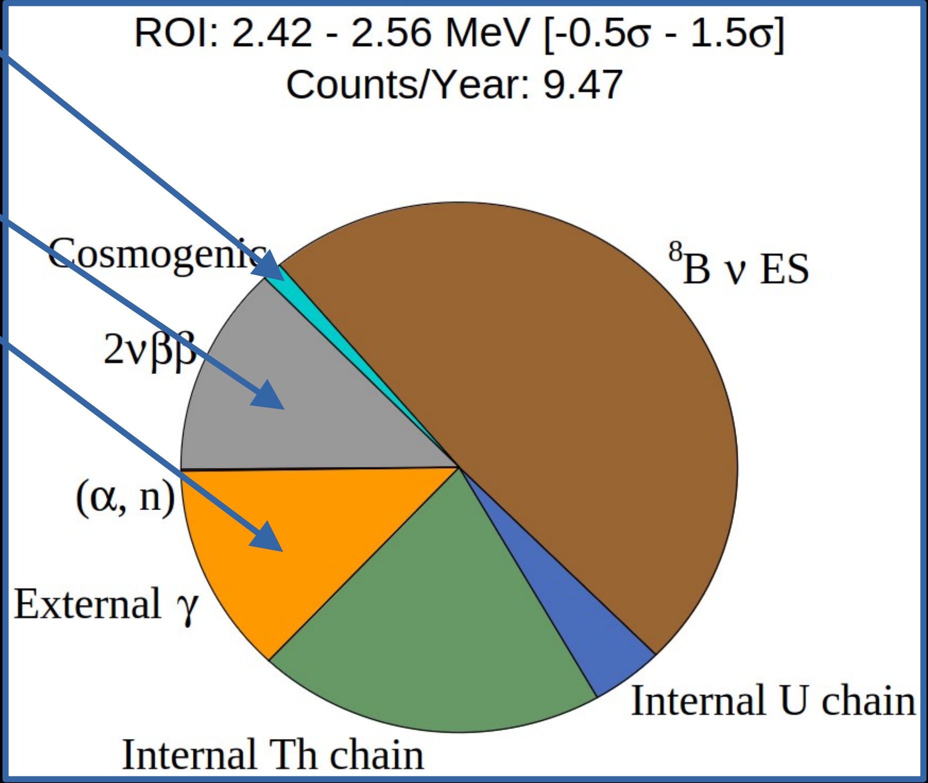
Measured in water-phase, below nominal. Fiducilization and multi-site classifiers





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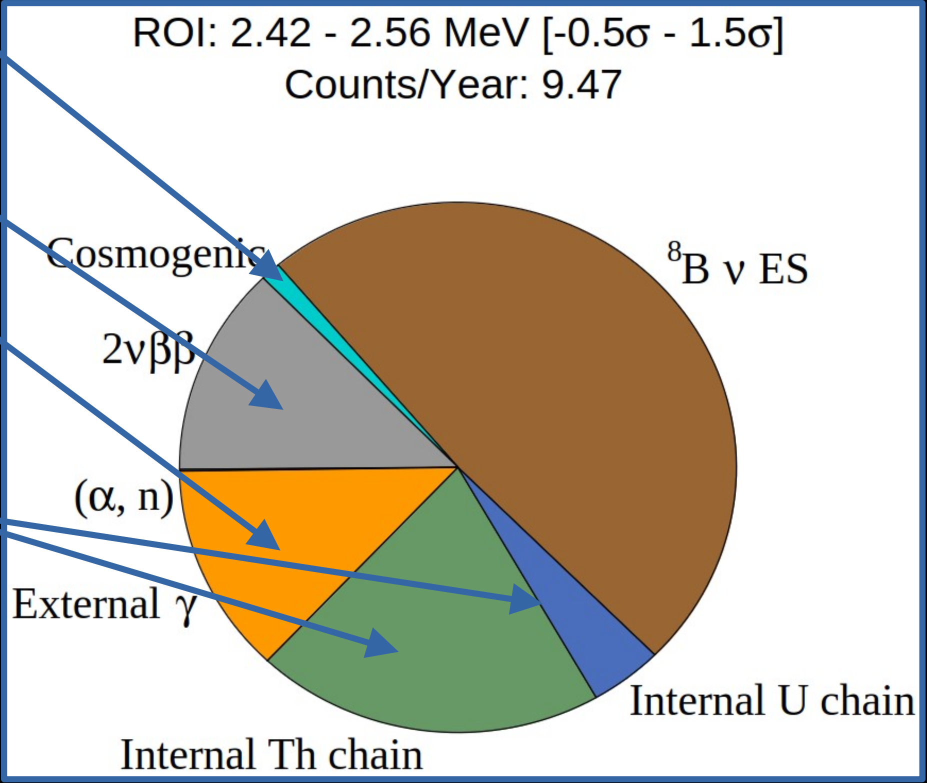
Reject using α-β coincidence & PID. Scintillator component below requirement for 0νββ phase.



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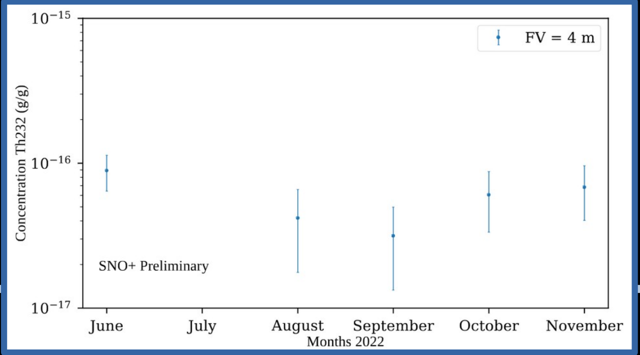

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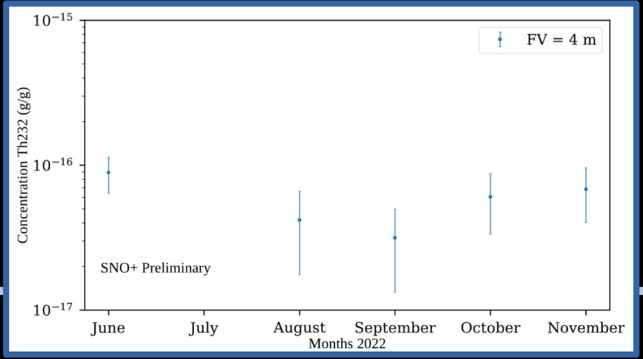
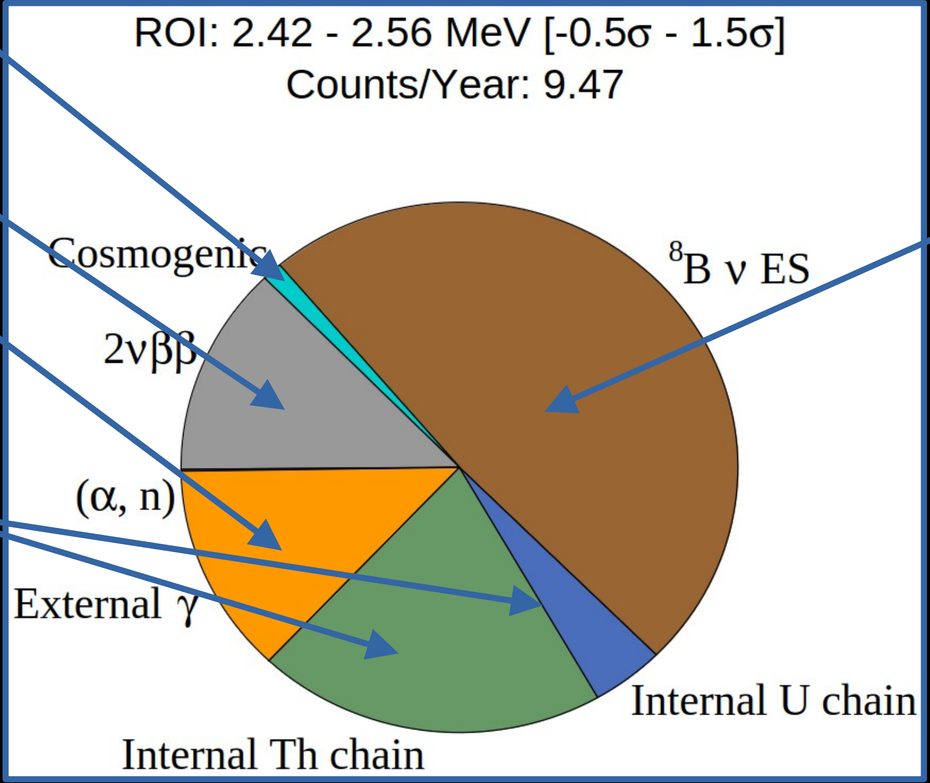
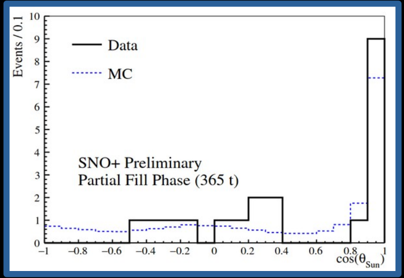




Backgrounds for 0.5% loading, FV = 3.3 m

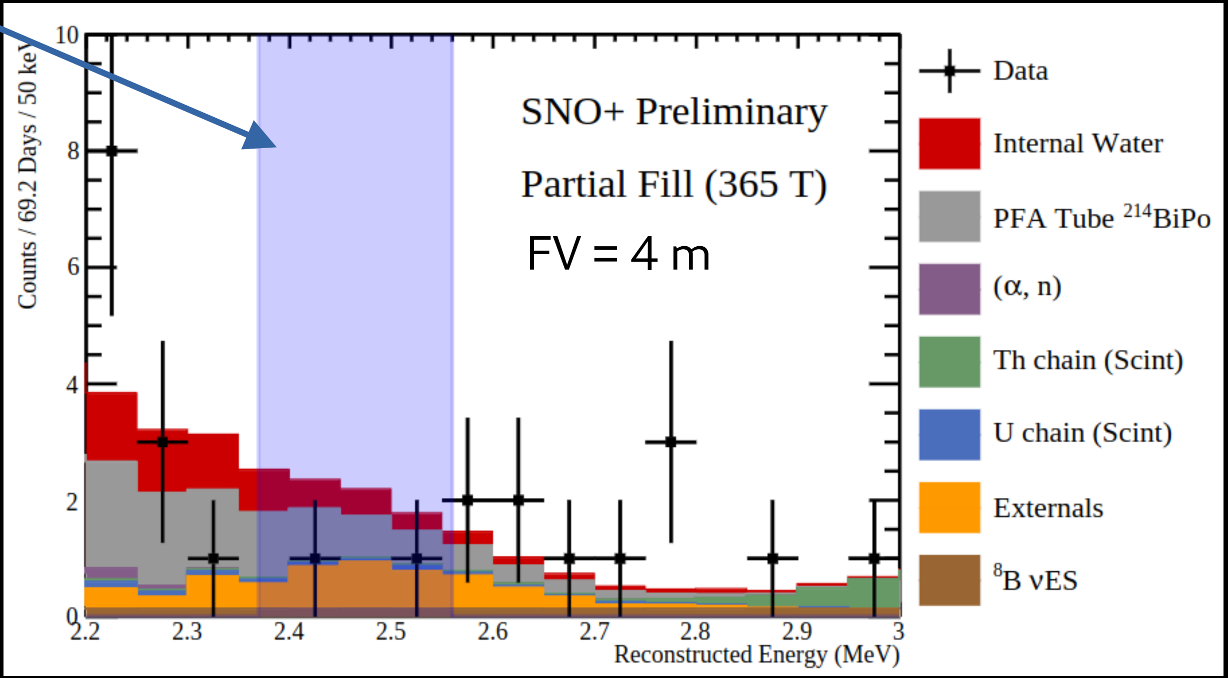
Dominant background from well-understood solar neutrino interactions. Directionality?



Backgrounds in 0νββ ROI: Measurements

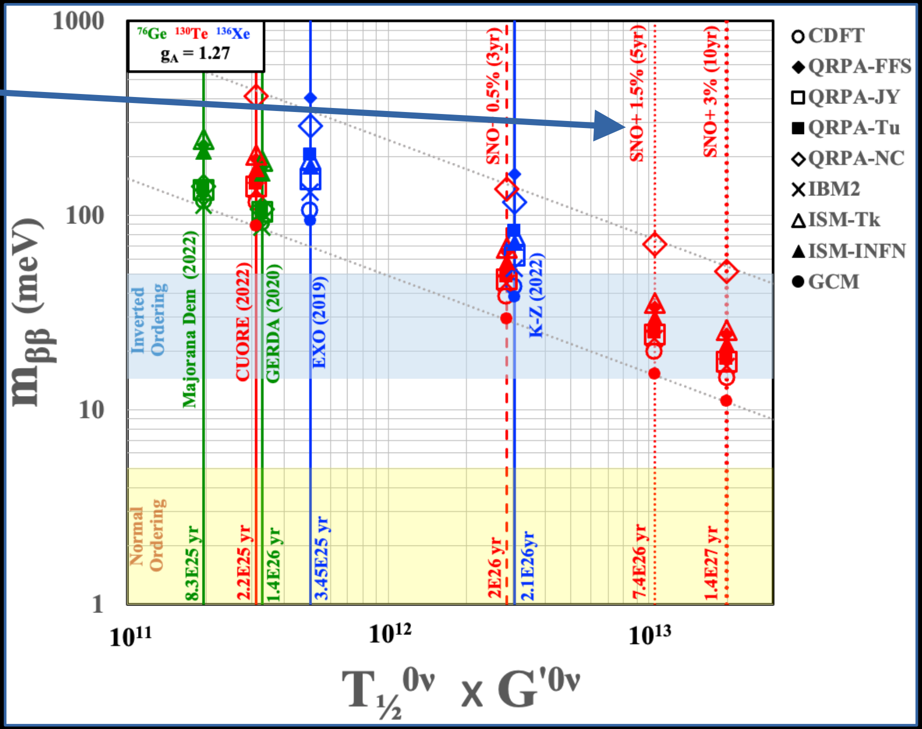
Backgrounds in the 0νββ ROI during partial fill were below nominal:
8 expected, 2 observed
and include components that have been removed from the detector (eg, internal water)

There is an ongoing analysis of the 0νββ ROI background in the scintillator phase



0νββ Sensitivity

With a Te concentration of 1.5%, SNO+ can achieve a sensitivity of
~7.4 x 10^{26} years in 5 years of data-taking



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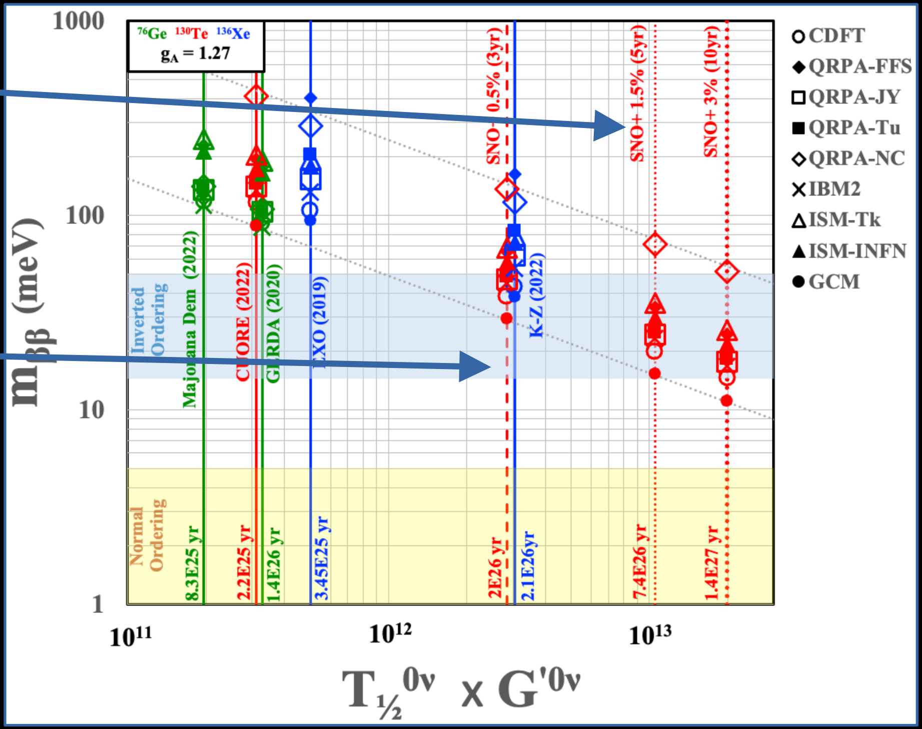
The expected sensitivity with 3 years of data-taking at 0.5% loading we achieve:

$T^{0\nu\beta\beta}_{1/2}$ > 2 x 10^{26} yrs

$m_{\beta\beta}$ ~ 37 – 89 meV



Conclusions

1. During the water and partial fill phases, SNO+ successfully calibrated the detector, made significant physics measurements, and measured external backgrounds.

2. SNO+ is currently filled with LAB+PPO and is performing calibrations, background measurements, and sensitive solar, reactor, and geo neutrino measurements.

3. SNO+ plans to deploy Te into the detector next year and the underground Te plants are currently being commissioned.

4. Effective R&D has demonstrated high (1.5%+) Te loading is possible, allowing SNO+ to push for improved $0\nu\beta\beta$ sensitivities.

Thank you for your attention!
Questions?

SNO+ 2023