XX International Workshop on Neutrino Telescopes

Istituto Veneto di Scienze, Lettere ed Arti, Venezia, Italia

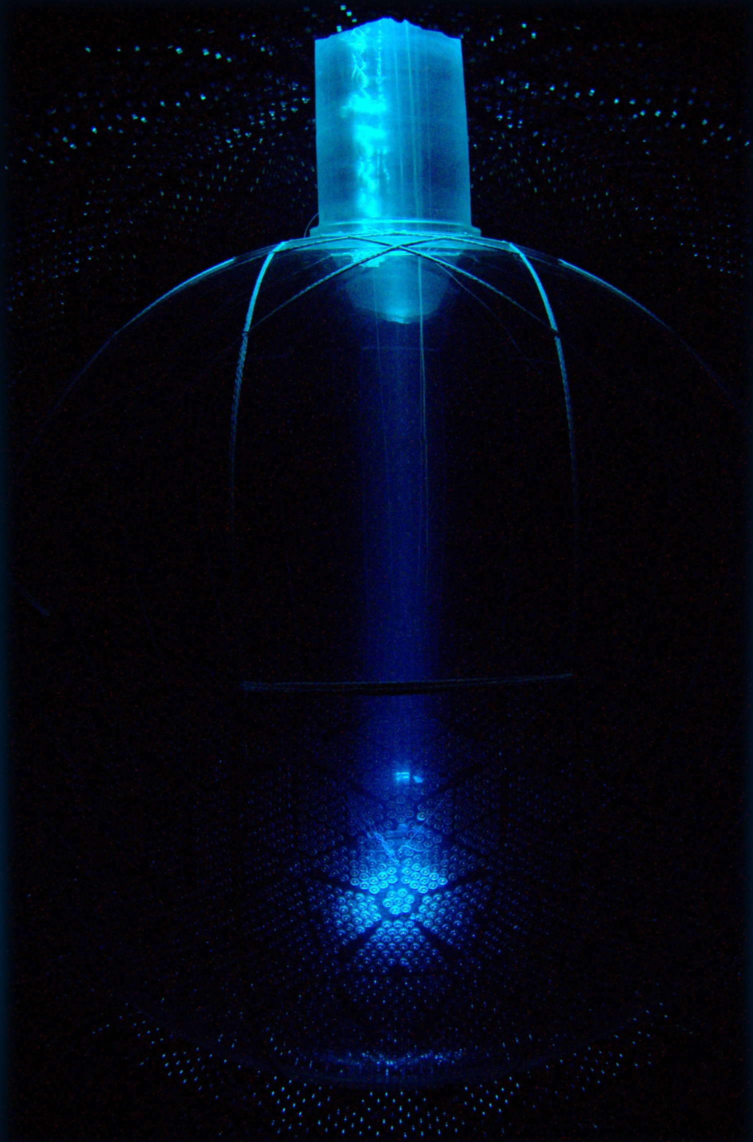
SNO+

Current results and $0\nu\beta\beta$ prospects

Ana Sofia Inácio, on behalf of the SNO+ collaboration

THE ROYAL SOCIETY

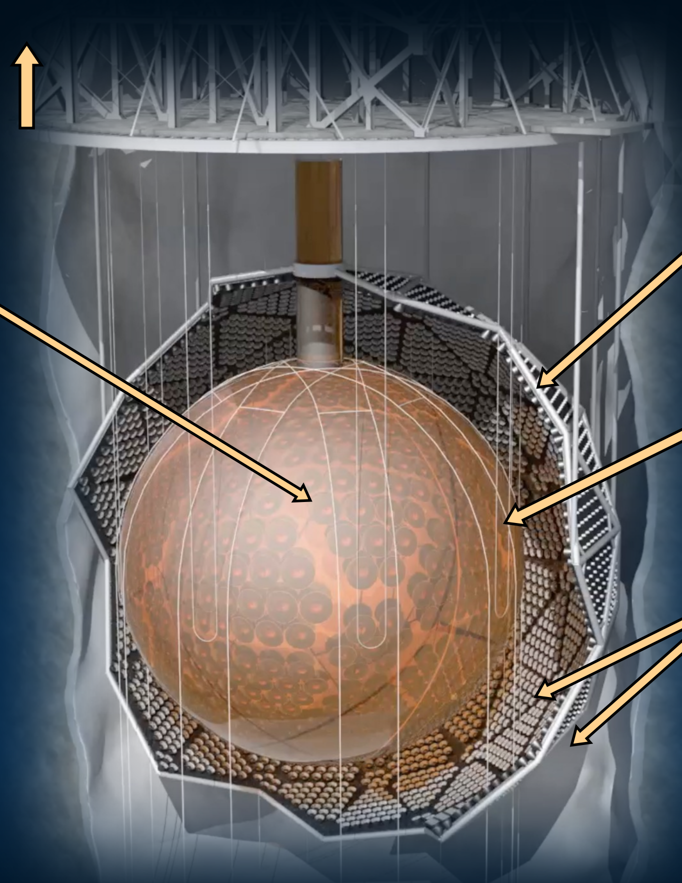
UNIVERSITY OF OXFORD



The SNO+ Detector

Multi-purpose neutrino detector located at SNOLAB in Sudbury, Ontario, Canada

2070 m of rock overburden,
~70 μ/day



Acrylic vessel (AV)
12 m diameter
5 cm thick

Holds the target medium:

I. 905 tonnes of UPW
II. 780 tonnes of LAB+PPO
III. LAB+PPO+Te cocktail

~9300 photomultiplier tubes (PMTs)

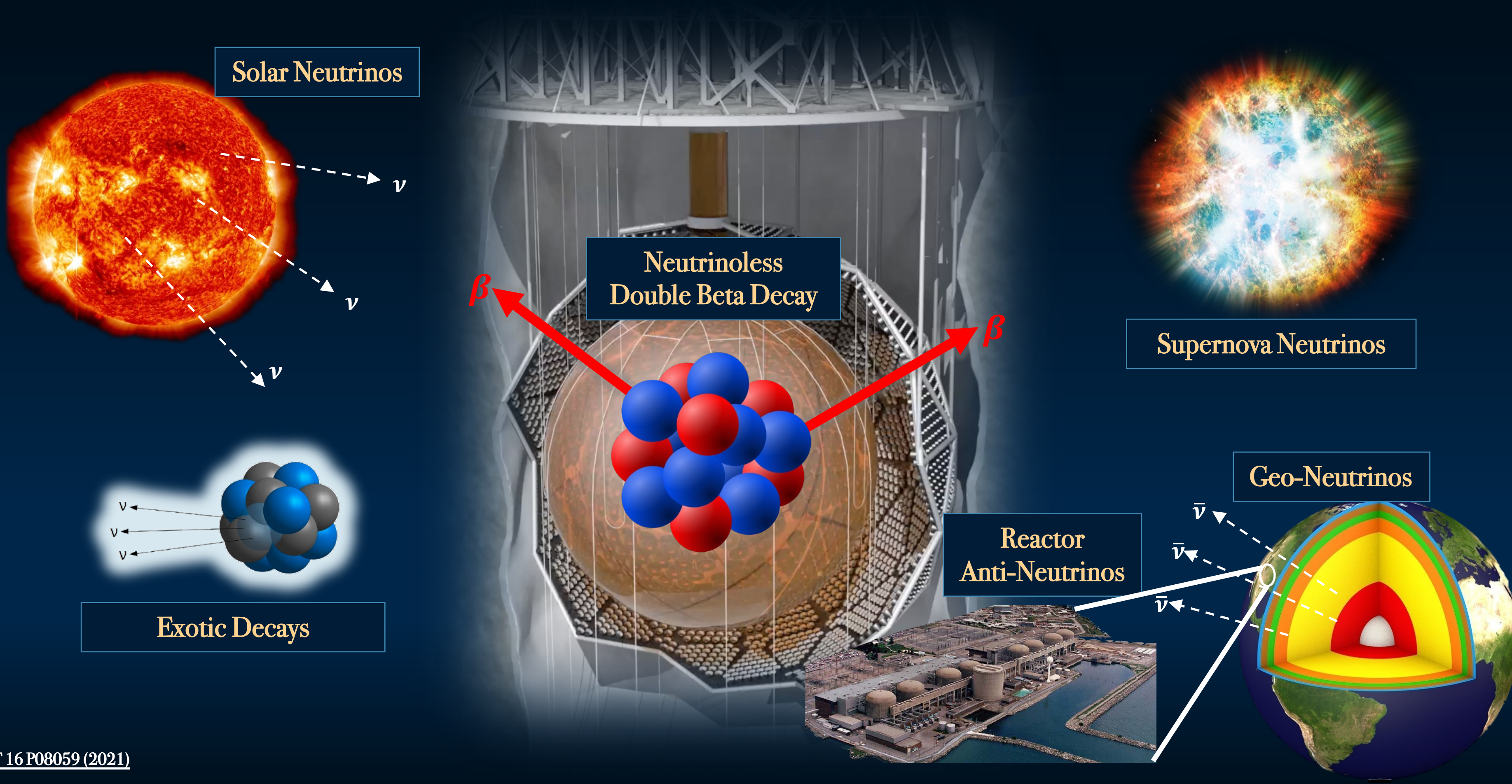
Low radioactivity hold-up
and hold-down rope systems

Ultra-pure water shielding

JINST 16 P08059 (2021)

The SNO+ Detector

Physics Programme

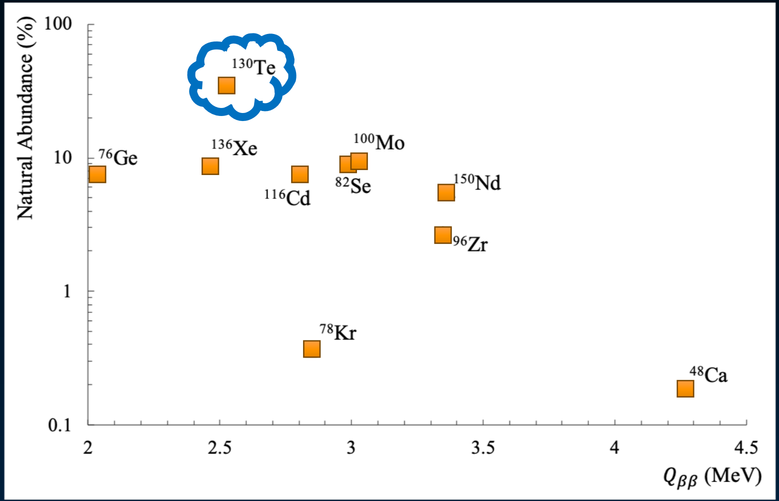


JINST 16 P08059 (2021)

Searching for 0νββ with SNO+

Major advantages of ^{130}Te

- No need for enrichment
- Long 2νββ half-life (7.7x10^{20} years)
- High Q-value at 2.527 MeV



Searching for 0νββ with SNO+

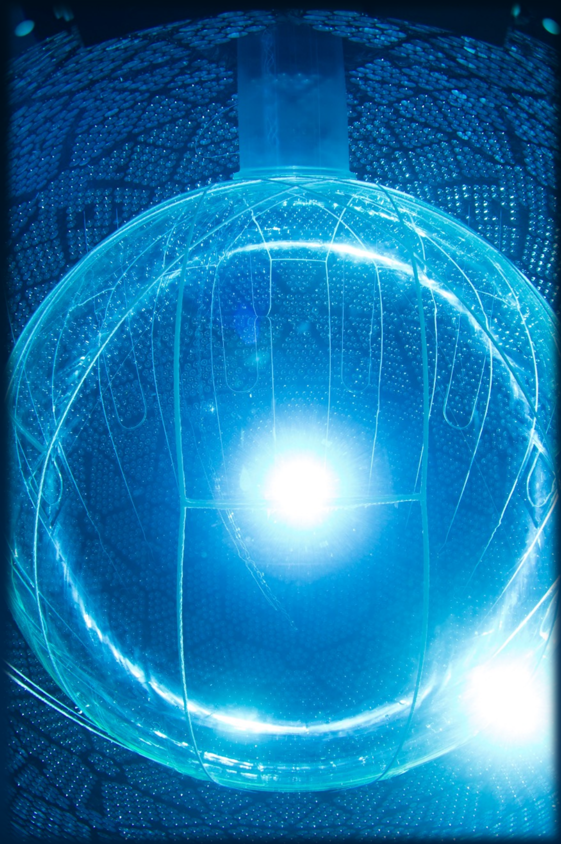
Major advantages of ^{130}Te

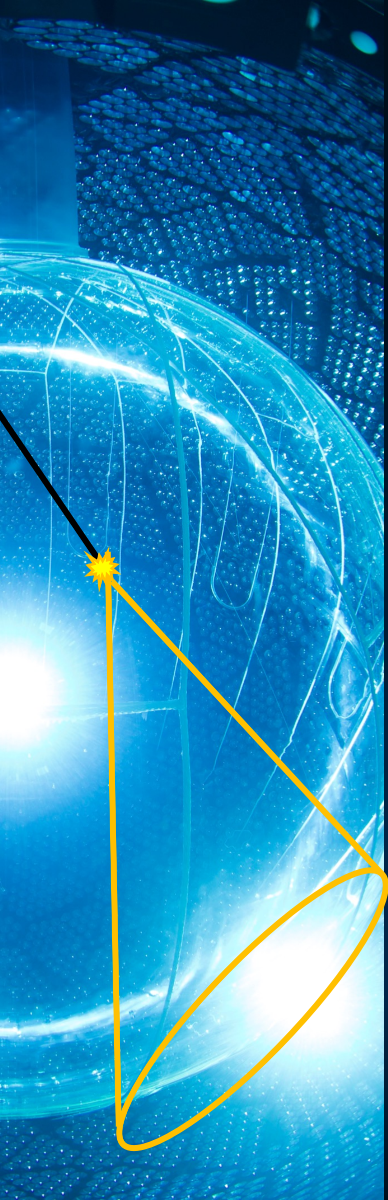
- No need for enrichment
- Long 2νββ half-life (7.7×10^{20} years)
- High Q-value at 2.527 MeV

Major advantages of SNO+

1. Large detector
   - Rejection of external backgrounds through fiducialization
2. Loaded liquid scintillator
   - Fast timing allows rejection of coincidence backgrounds
   - High light yield for good resolution = target 460 PMT hits /MeV
   - Loading can be scaled

- The phased loading approach
  - Constrain and validate the detector model
  - Target-out measurement before and during Te loading





The journey towards $0\nu\beta\beta$ Water Phase

2017 2018 2019

May – December 2017
(~115 gold physics days)
First SNO+ water phase

October 2018 – June 2019
(~185 gold physics days)
Second SNO+ water phase

Much lower Rn backgrounds from installation of cover gas shielding

Major Outcomes

- Improved limits for invisible modes of nucleon decay
  Phys. Rev. D 99, 032008 (2019) Phys.Rev.D 105, 112012 (2022)
- Measurement of ^{8}B solar neutrinos
  Phys. Rev. D 99, 012012 (2019)
- First measurement of reactor antineutrinos using pure water
  Phys.Rev.Lett 130, 091801 (2023)

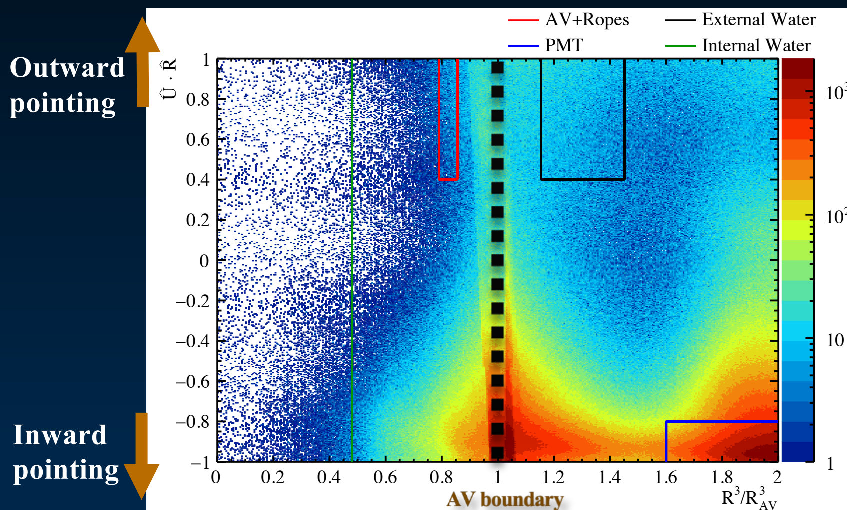
$0\nu\beta\beta$ Milestones

- Optical calibration of the detector components (external water, acrylic, PMTs)
  JINST 16 P10021 (2021)
- Measurement of external backgrounds

External Backgrounds

Water Phase

- Simple detector configuration
- Measure components that don't change with detector medium

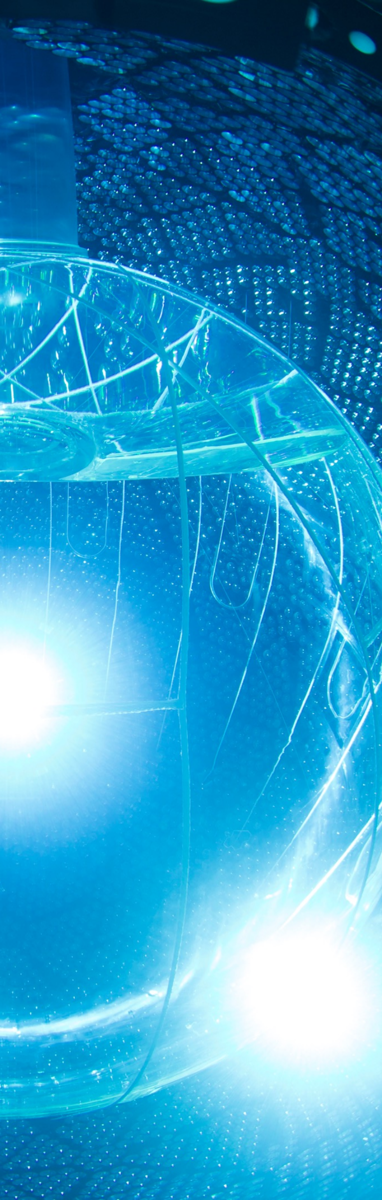


AV	$5.55\text{ m} < R_{AV} < 5.7\text{ m}$ $U \cdot R_{AV} > 0.4$
External Water	$6.3\text{ m} < R < 6.8\text{ m}$ $U \cdot R > 0.4$
PMT	$1.6 < R^3 < 2.0$ $U \cdot R < -0.8$
Internal Water	$R_{AV} < 4.7\text{m}$

Background	Rate (Fraction of Nominal)
AV+Ropes	$0.21 \pm 0.009^{+0.64}_{-0.21}$
External Water	$0.44 \pm 0.003^{+0.32}_{-0.27}$
PMT	$1.48 \pm 0.002^{+1.65}_{-0.60}$

Contribution of external backgrounds to 0νββ ROI **is 50% smaller than expectations (some based on upper limits)!**

Continuing to monitor the rate and source of the external backgrounds in the next phases



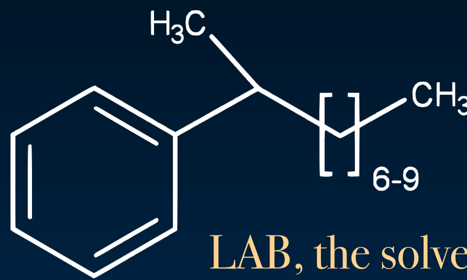
The journey towards $0\nu\beta\beta$

Scintillator Phase

2017 2018 2019 2020 2021

Scintillator Fill
JINST 16 P05009 **(2021)**

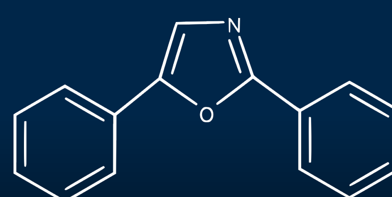
April – October 2020
(92 gold physics days)
Bonus phase: half-filled detector with 0.6 g/L PPO

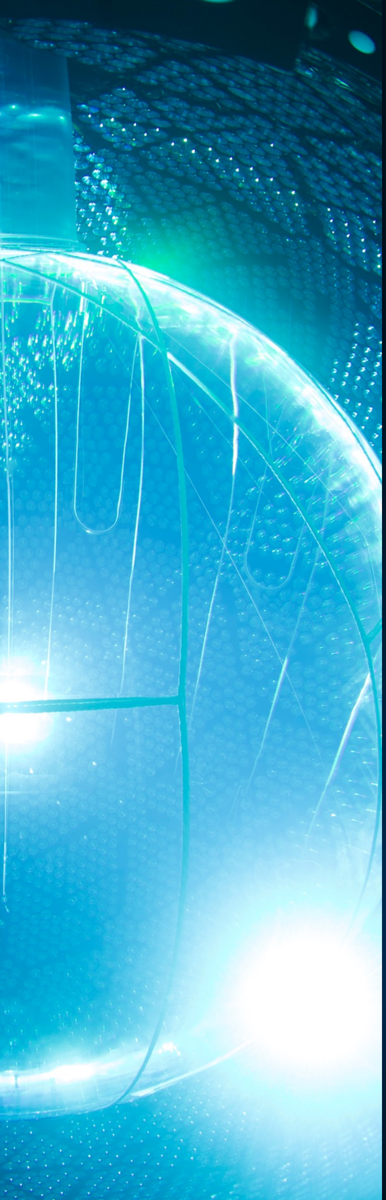


LAB, the solvent

+

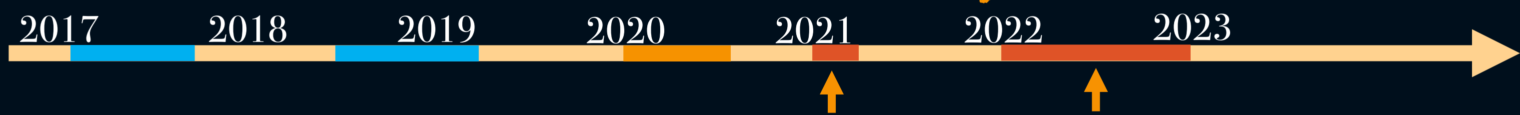
PPO, the fluor





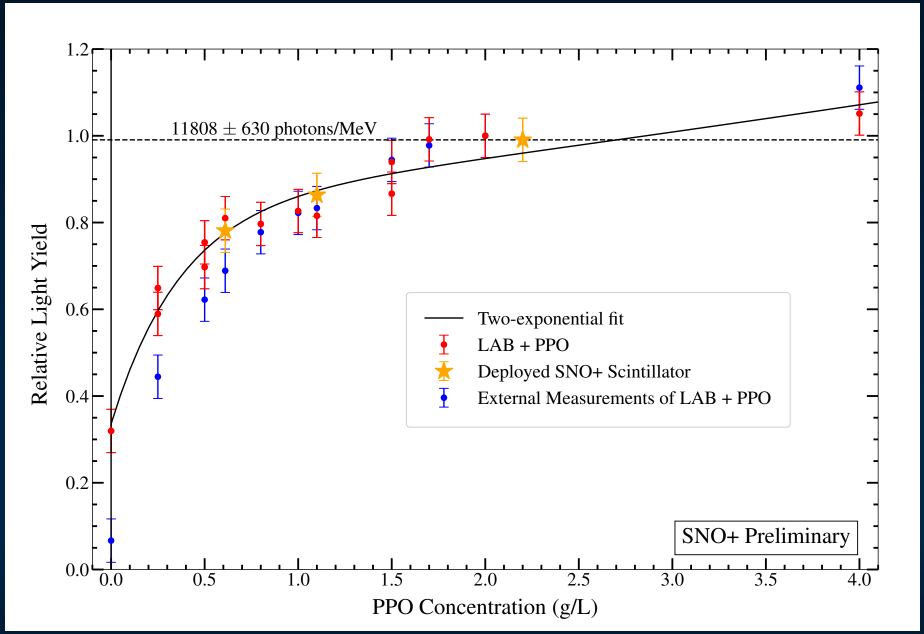
The journey towards 0νββ

Scintillator Phase



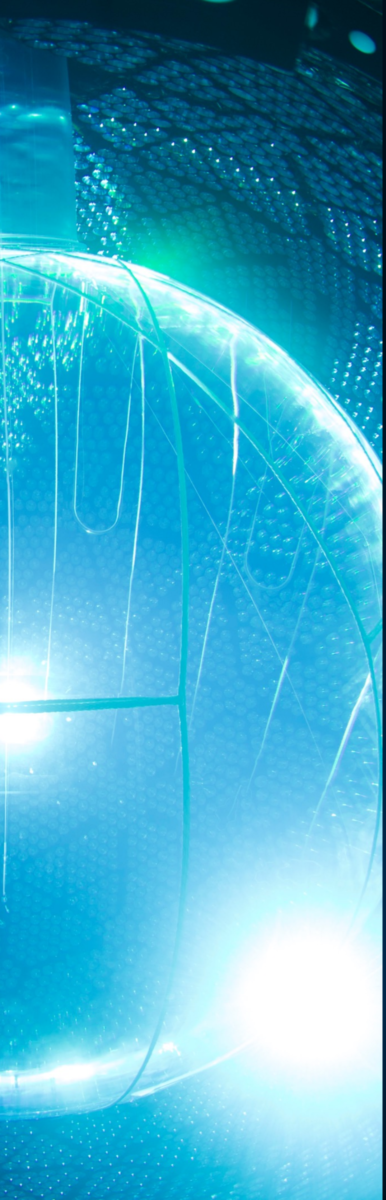
April – June 2021
Bonus phase: full-filled detector with 0.6 g/L PPO

April 2022 – March 2023
Full detector with 2.2 g/L PPO

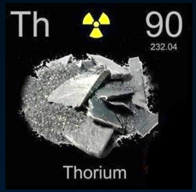


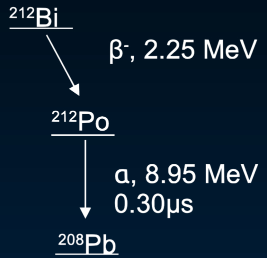
Scintillator Backgrounds

Scintillator Phase

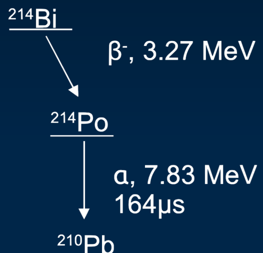


- Monitoring internal U/Th levels



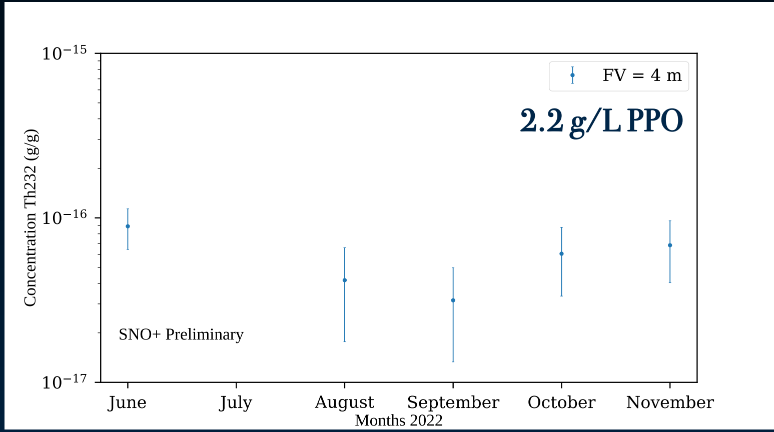


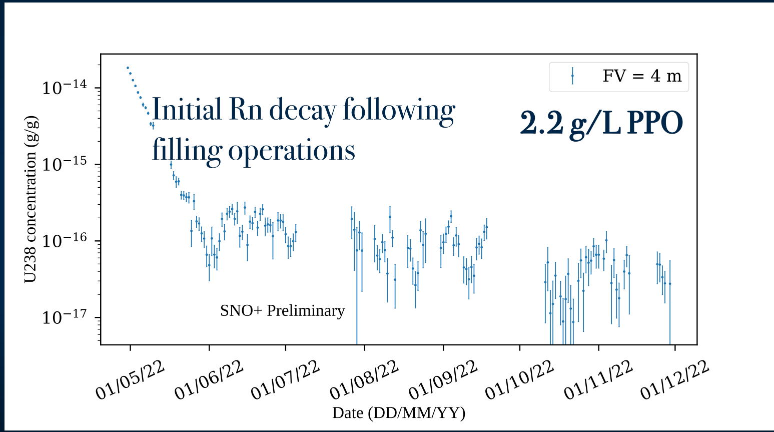
^{232}Th = $(5.7\pm0.3)10^{-17}$ g/g



^{238}U = $(5.3\pm0.1)10^{-17}$ g/g

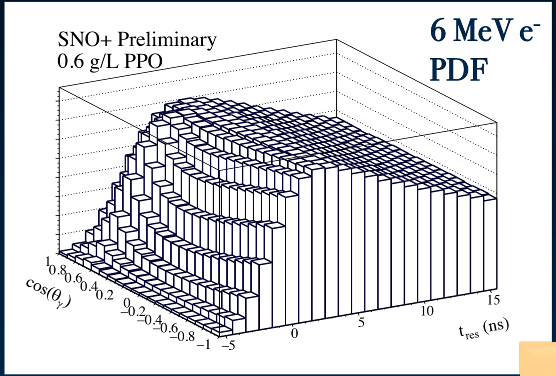
Below DBD-phase requirements!

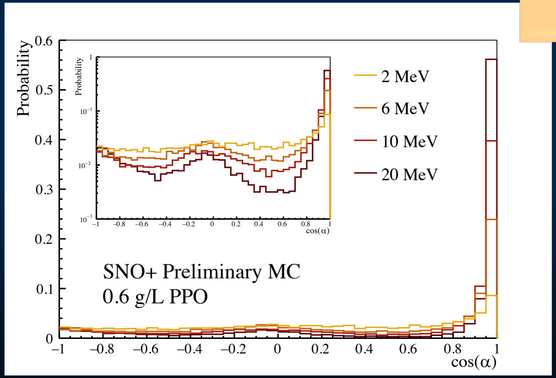


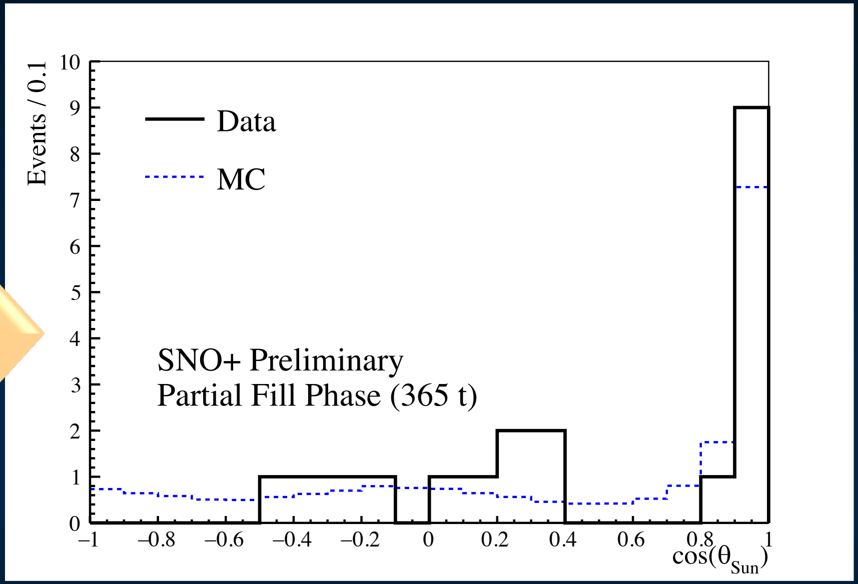


Solar Directionality in SNO+ Scintillator Phase

- Solar neutrino direction reconstructed event-by-event in 0.6 g/L PPO scintillator!
  - Directional Cherenkov light separated from isotropic scintillation light using timing information
  - First demonstration in a high light-yield, large-scale detector





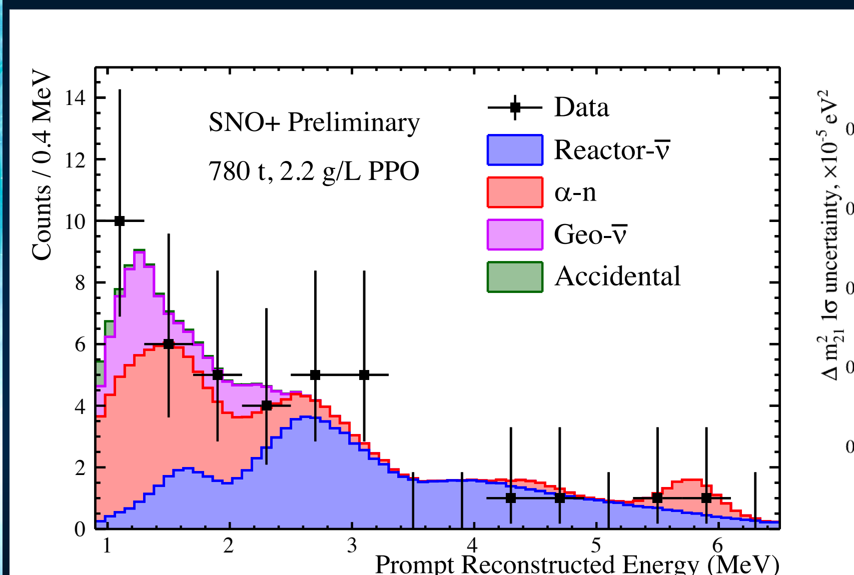


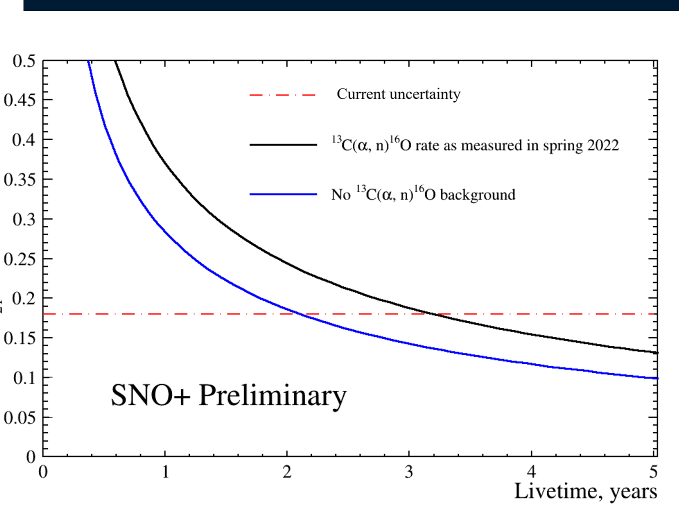
Submitted to PRL, arXiv:2309.06341 [hep-ex]

Antineutrinos in SNO+

Scintillator Phase

- On-going antineutrino analysis in scintillator
- (α,n) reactions are main background
  - Major source of α - ^{210}Po - factor ~3 smaller from partial fill to 2.2 g/L full fill phase
- Classifier will help separate ^{13}C(α,n) reactions from anti-neutrinos
- Expect sensitivity to Δm^2_{21} and geo-neutrino measurement

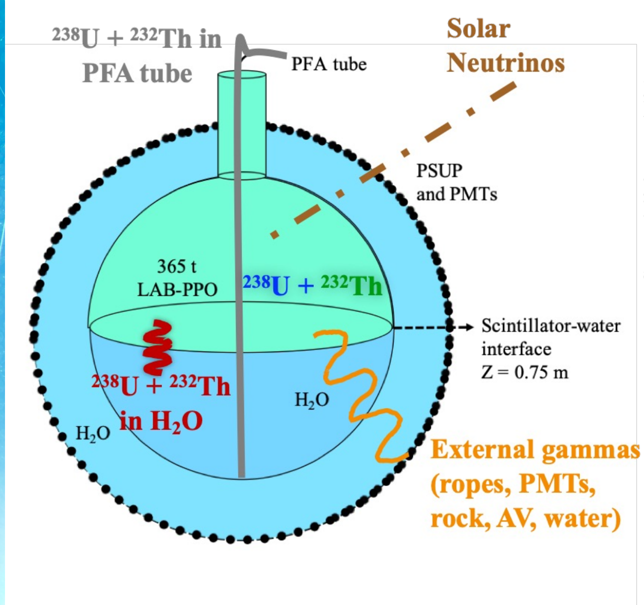


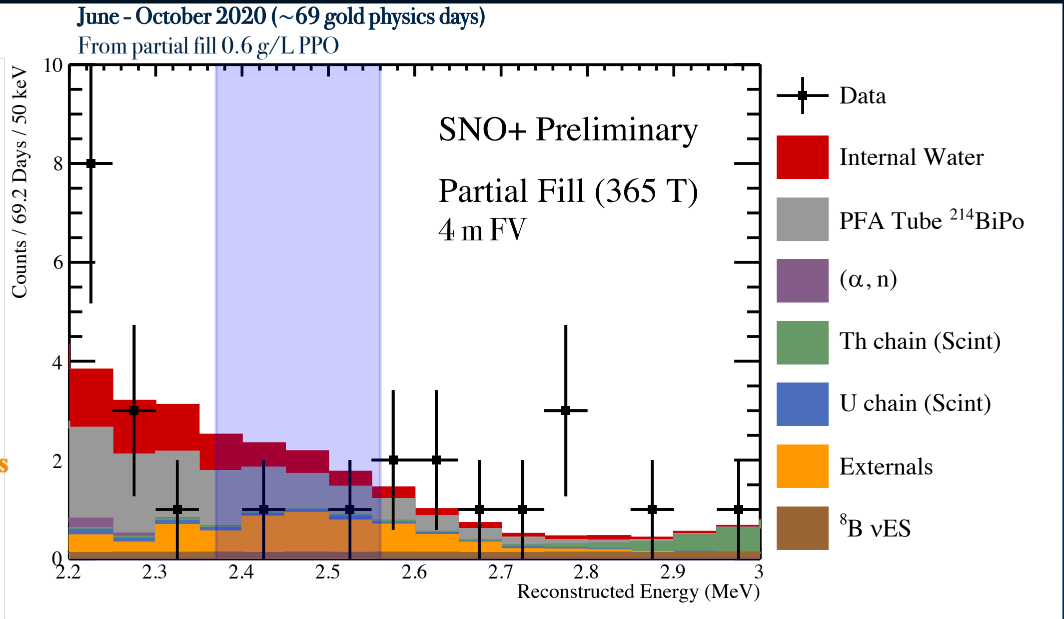


Target-Out Measurement

Scintillator Phase

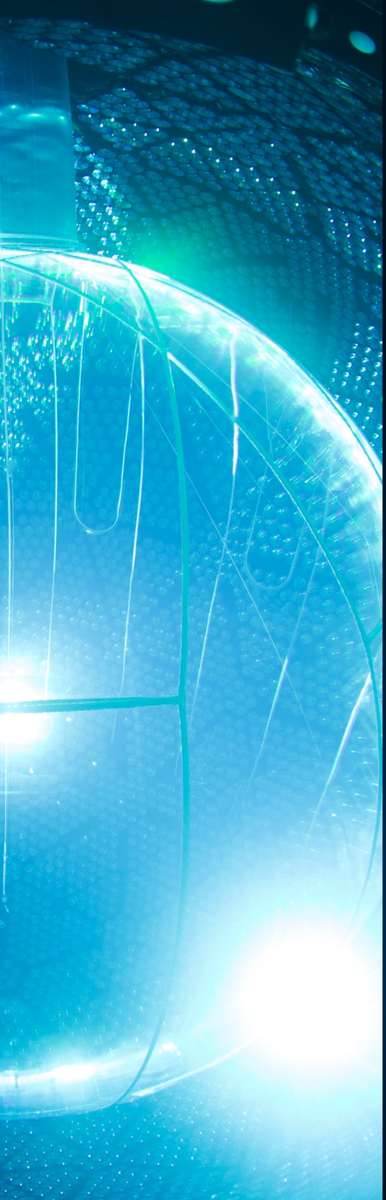
- Prepare/test analysis and techniques using real data
- Determine the count rate in the ROI in the absence of Te





Partial fill:
Expected 8 events, seen 2

Full fill + 2.2 g/L PPO:
Analysis in progress



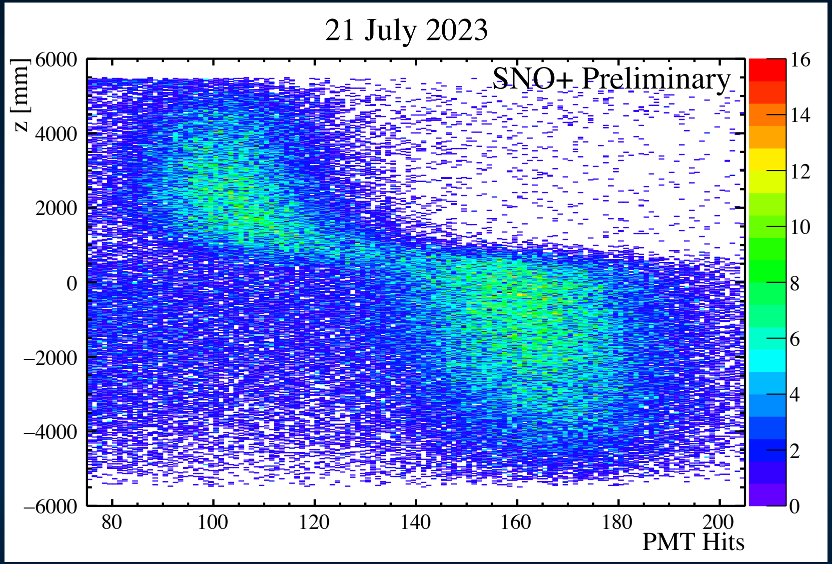
The journey towards 0νββ

Te Loading

2017 2018 2019 2020 2021 2022 2023 2024

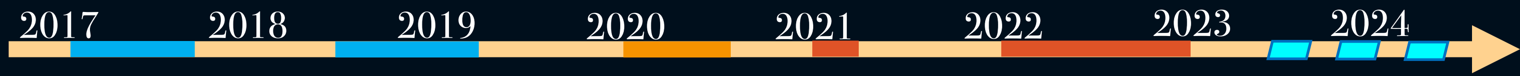
Key milestones

- July 2023 – started addition of bisMSB to detector



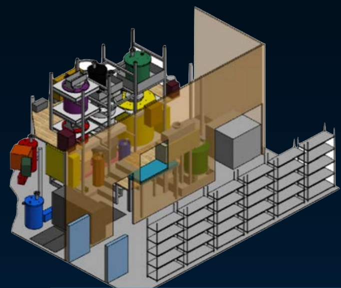
- Tracking ^{210}Po peak
- BisMSB added to bottom of AV (0.5 kg) and started to mix
- Clear improvement in light output (1.5x)

The journey towards $0\nu\beta\beta$ Te Loading

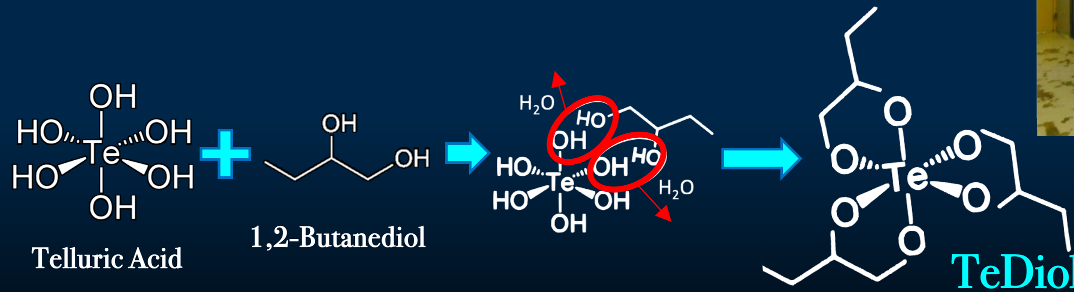


Key milestones

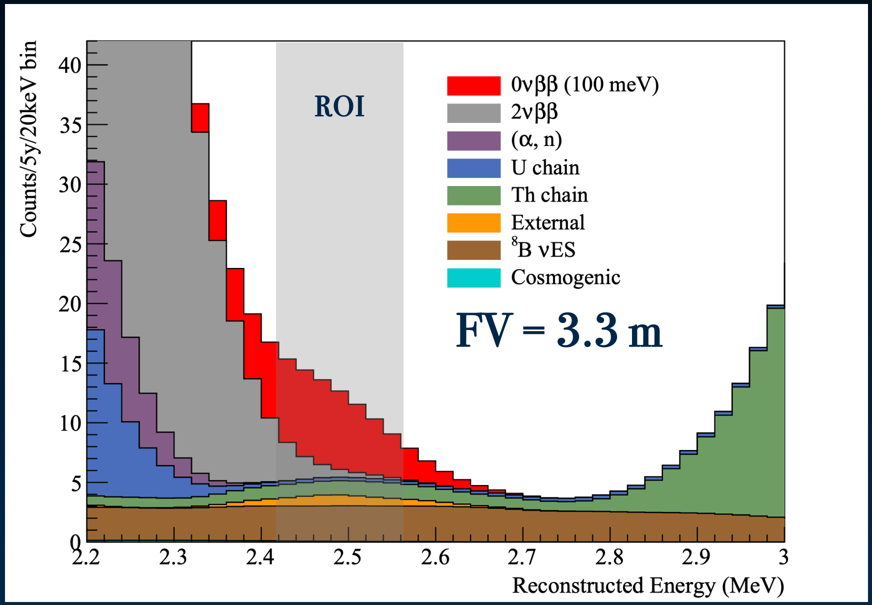
- July 2023 – started addition of bisMSB to detector
- Fall 2023 – test batch (~200 kg) of the TeA purification plant
    - First full-scale test of the SNO+ Te purification and loading systems
    - Samples will be collected for off-site ICP-MS analysis of U/Th
- From 2024 – start adding TeLS cocktail components
- From 2025 – start count with Te

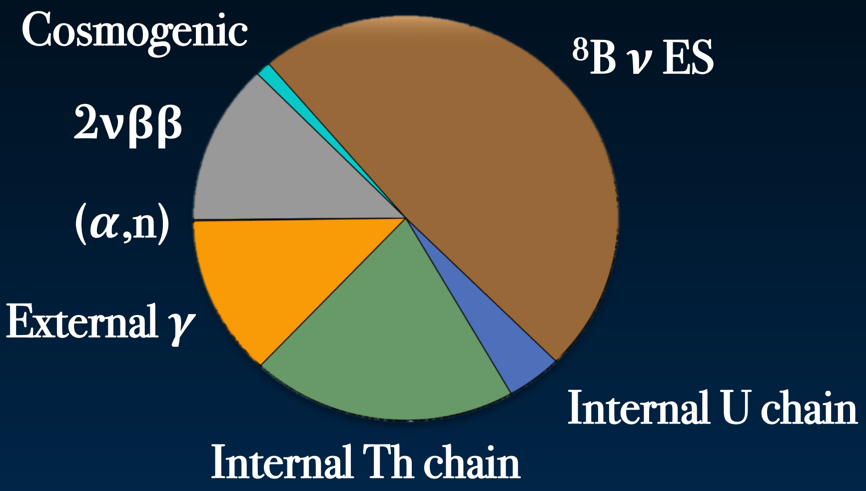


Tellurium purification plant



0νββ Prospects

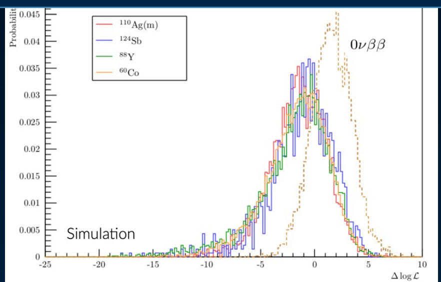




Events in the Region Of Interest + Fiducial Volume
9.47 events/yr (at nominal backgrounds)

0νββ Prospects

Telluric acid has been "cooling" underground for several years
+ Te purification
+ can be verified with multi-site analysis



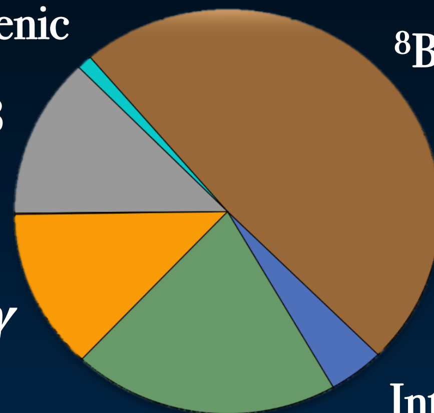
Dunger and Biller, NIM 943, 162420, (2019)

Cosmogenic

2νββ

$(\alpha$,n)

External γ



^{8}B ν ES

Well known from other measurements

Internal U chain

Internal Th chain

Suppressed by asymmetric ROI

Measured in Water Phase, below target

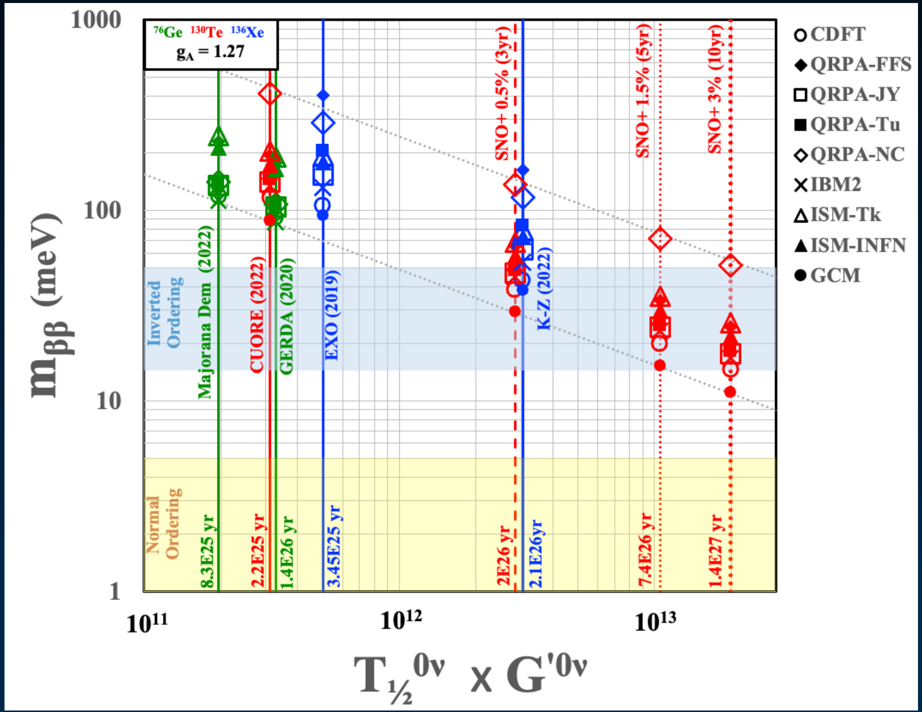
LS contribution measured, below target for $\beta\beta$

U and Th from the Te addition to be minimized with the purification systems

0νββ Prospects

- Expected sensitivity of 2x10^{26} years
  - After 3 years
  - With 0.5% natTe loading
- Planned future higher loadings
  - Potential to cover the whole inverted ordering band
  - R&D shows good optical properties and long term stability

  NIMA 1051, 168204 (2023)

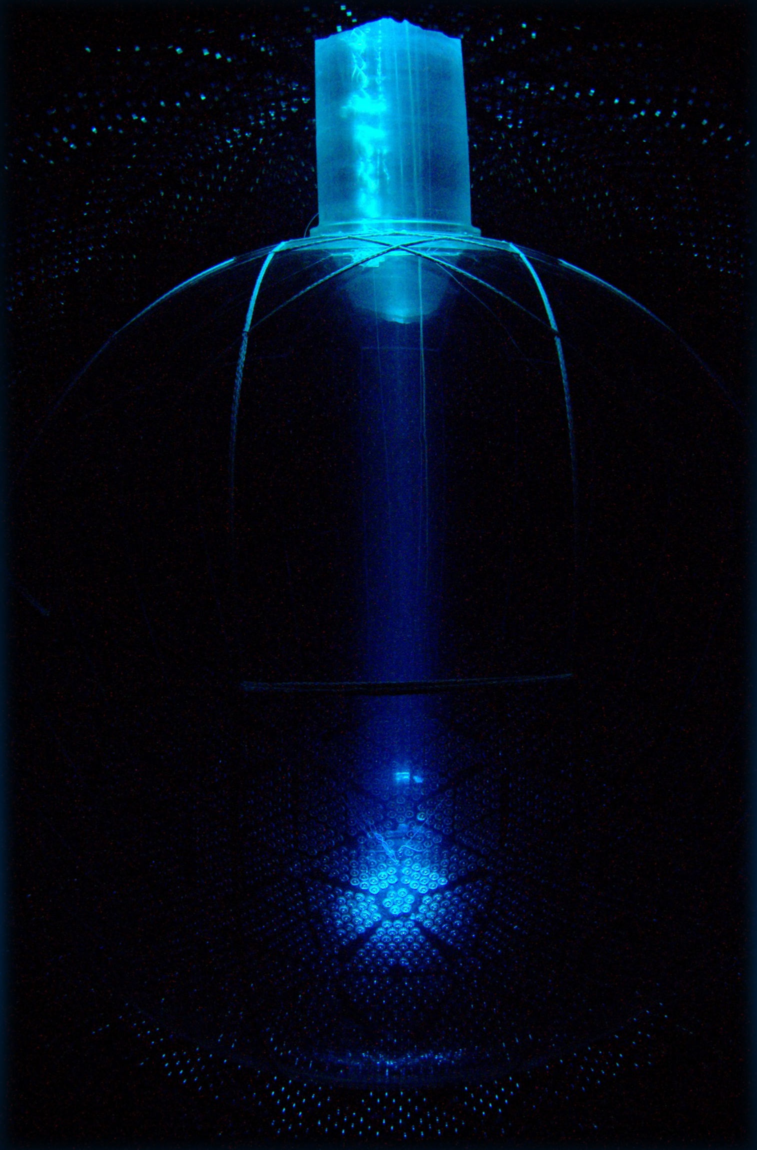


Summary

- SNO+ has successfully completed its scintillator loading and is taking data with 2.2 g/L PPO as of April 2022
- On-going addition of bisMSB in preparation for Te phase

- Much work has happened in preparation for the $0\nu\beta\beta$ searches:
  - Constant monitoring of the scintillator
  - Initial measurements show radioactive backgrounds below the targeted values

- Many exciting physics analyses on-going with scintillator data!




Thank You!
SNO+ 2023