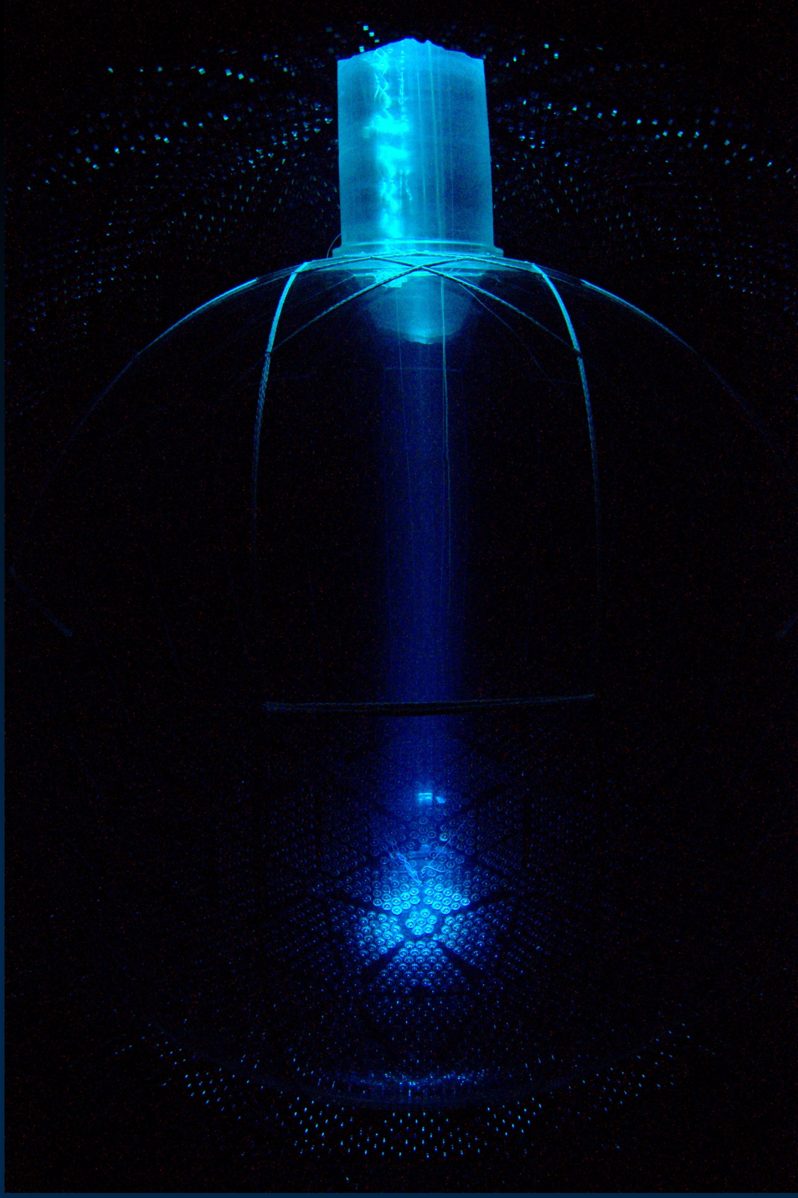
2025 European Physical Society Conference on High Energy Physics
Palais du Pharo, Marseille, France

SNO+

Physics results and 0νββ prospects

Ana Sofia Inácio, on behalf of the SNO+ collaboration



UNIVERSITY OF OXFORD

UK Research and Innovation

MARIE CURIE ACTIONS

The SNO+ Detector

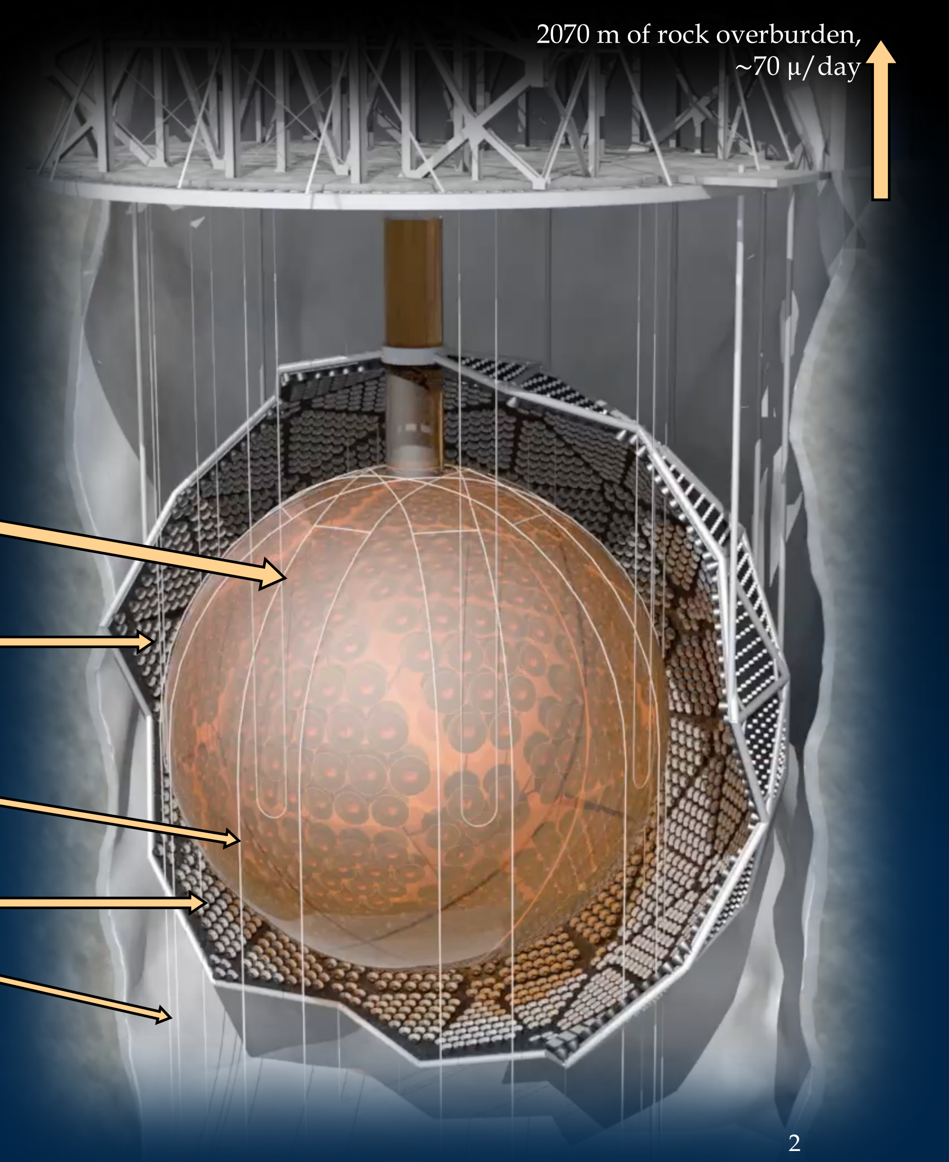
Multi-purpose neutrino detector located at SNOLAB in Sudbury, Ontario, Canada

Acrylic vessel (AV)
12 m diameter
5 cm thick

~9300 photomultiplier tubes (PMTs)

Low radioactivity hold-up and hold-down rope systems

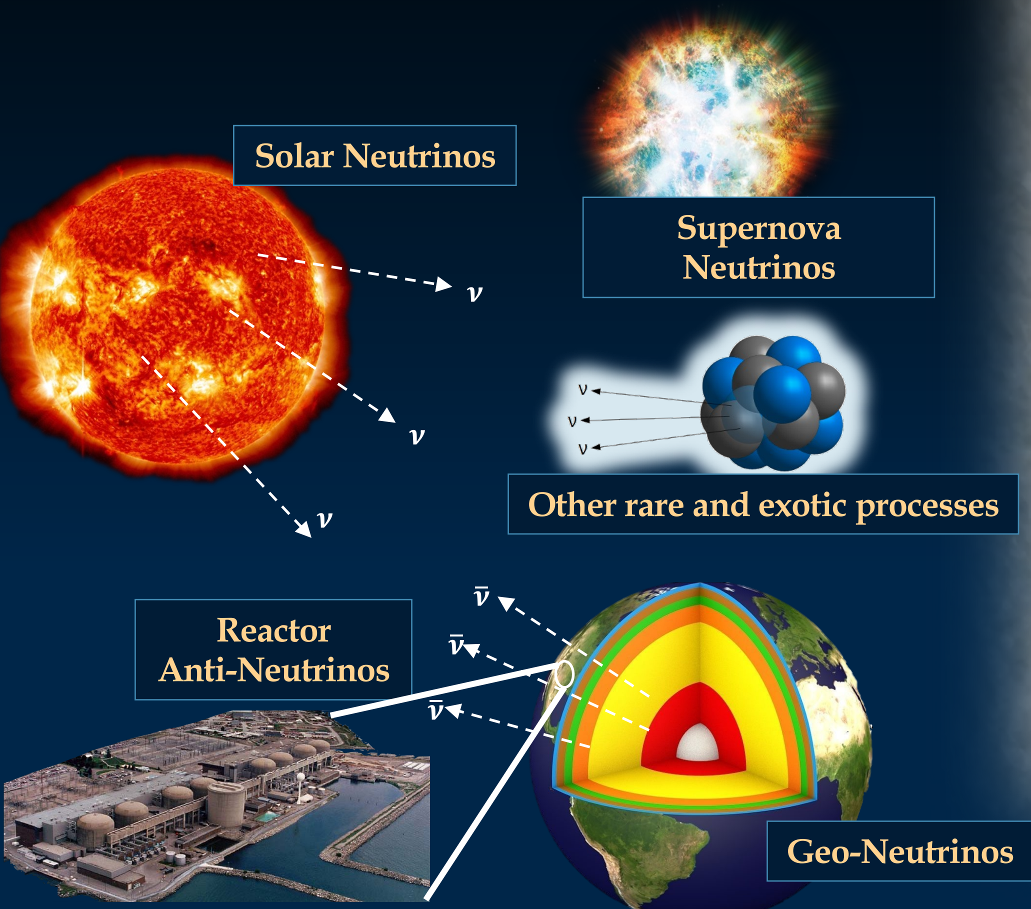
Ultra-pure water shielding

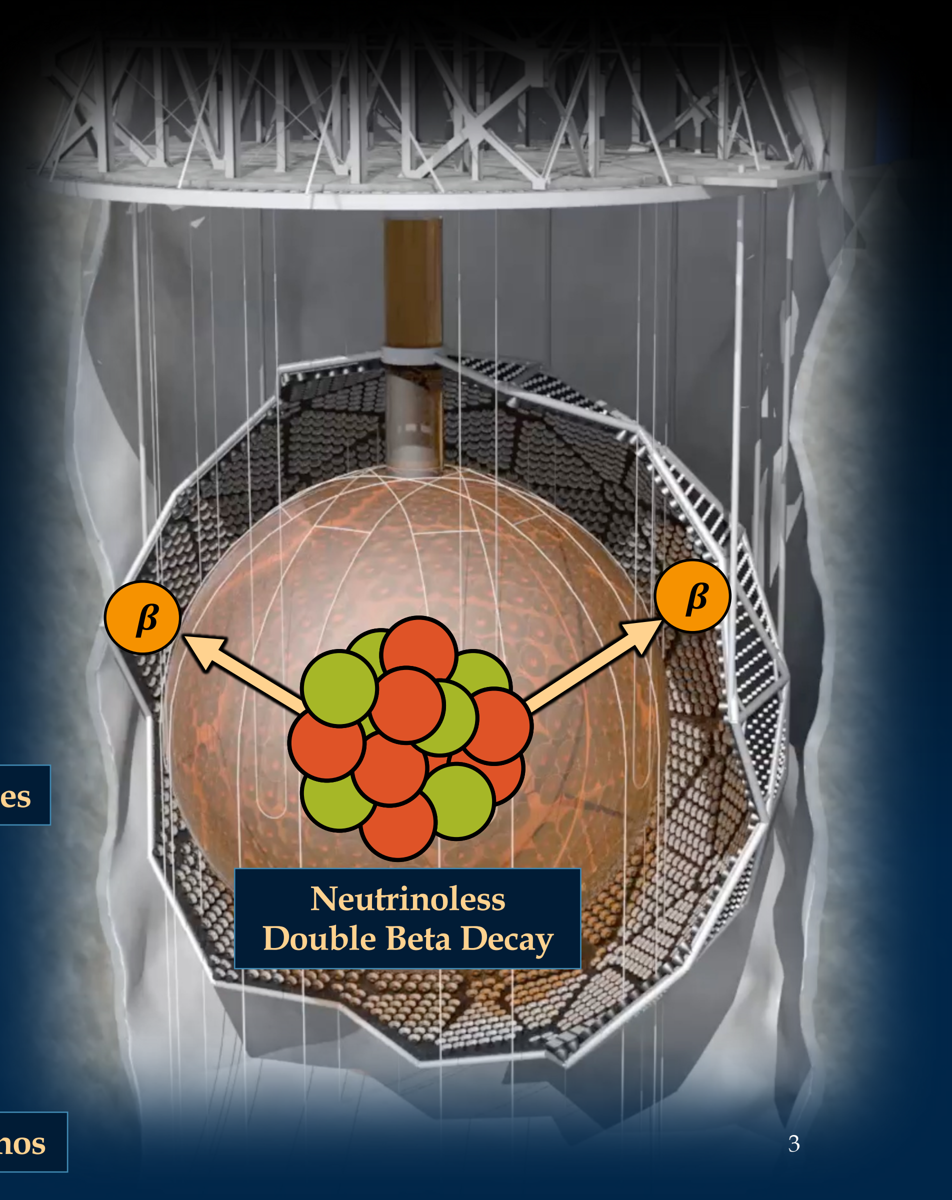


JINST 16 P08059

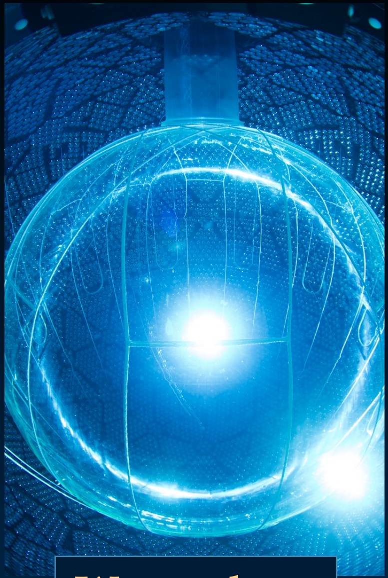
The SNO+ Detector

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





SNO+ Timeline

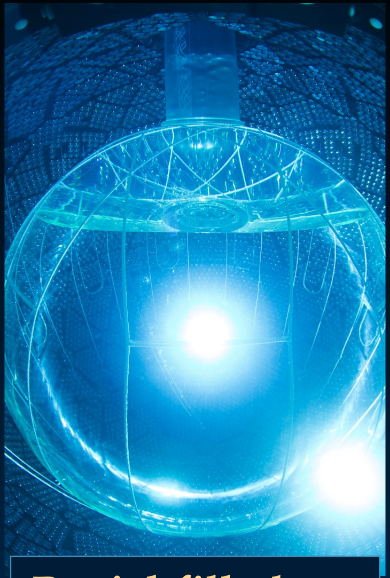


Water phase

905t ultra-pure water

detector calibration and external background measurements

Phys. Rev. D 110, 122003
Phys. Rev. D 99, 032008
Phys. Rev. Lett. 130, 091801

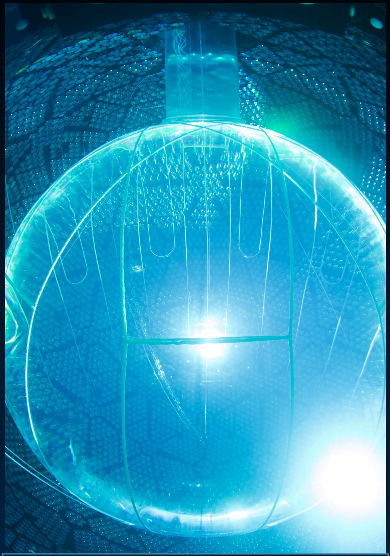


Partial-fill phase

paused filling due to COVID-19 at 370 t LS with 0.6 g/L PPO

measurement of scintillator backgrounds

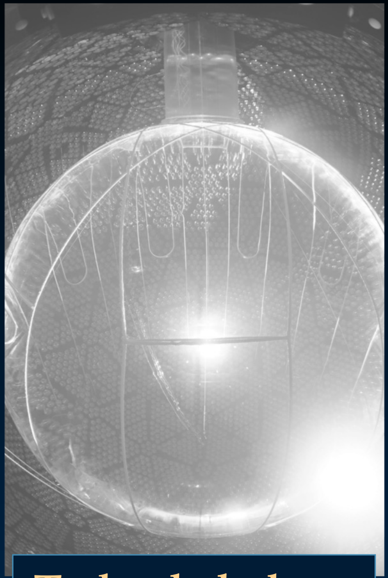
Eur. Phys. J. C 85, 17
Phys. Rev. D 109, 072002



Scintillator phase

780 t LS 0.6 - 2.2 g/L PPO, 2.2 mg/L bisMSB

characterisation of scintillator and backgrounds
solar, supernova, reactor and geo neutrinos…



Te-loaded phase

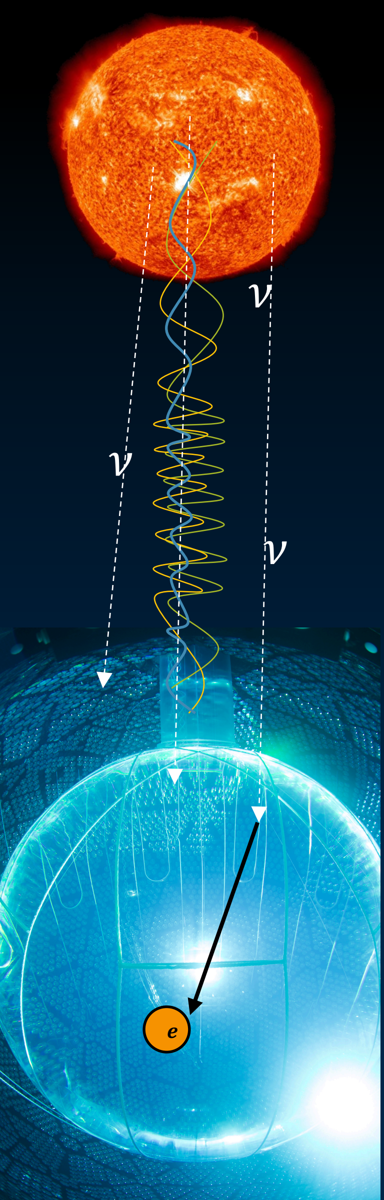
Initial Te loading: 0.5% by mass

$0\nu\beta\beta$ search

Loading to begin early 2026

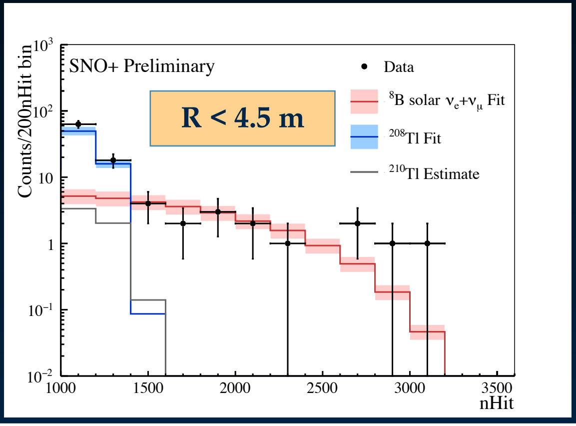
Physics results with Scintillator

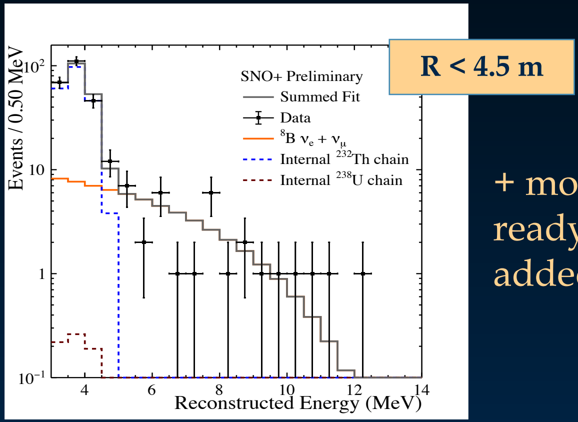
Solar Neutrinos in SNO+



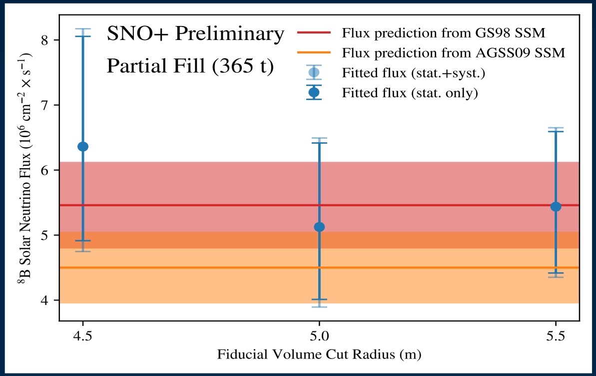
- ^{8}B solar neutrino measurements via neutrino-electron elastic scattering

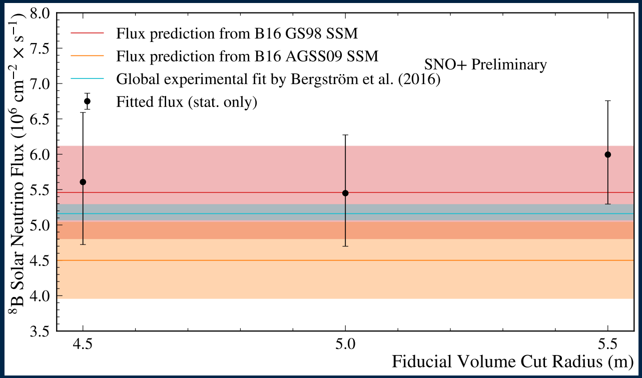
Partial-fill phase → **Scintillator phase**



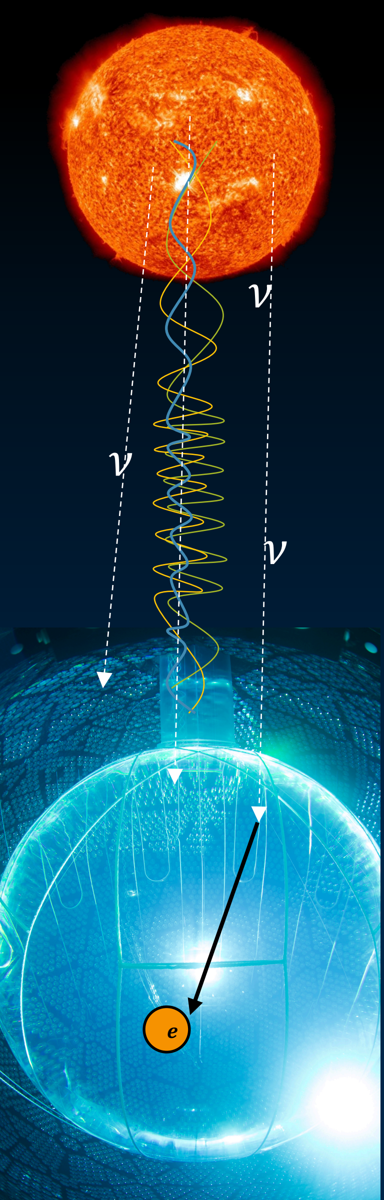


+ more data ready to be added





Solar Neutrinos in SNO+



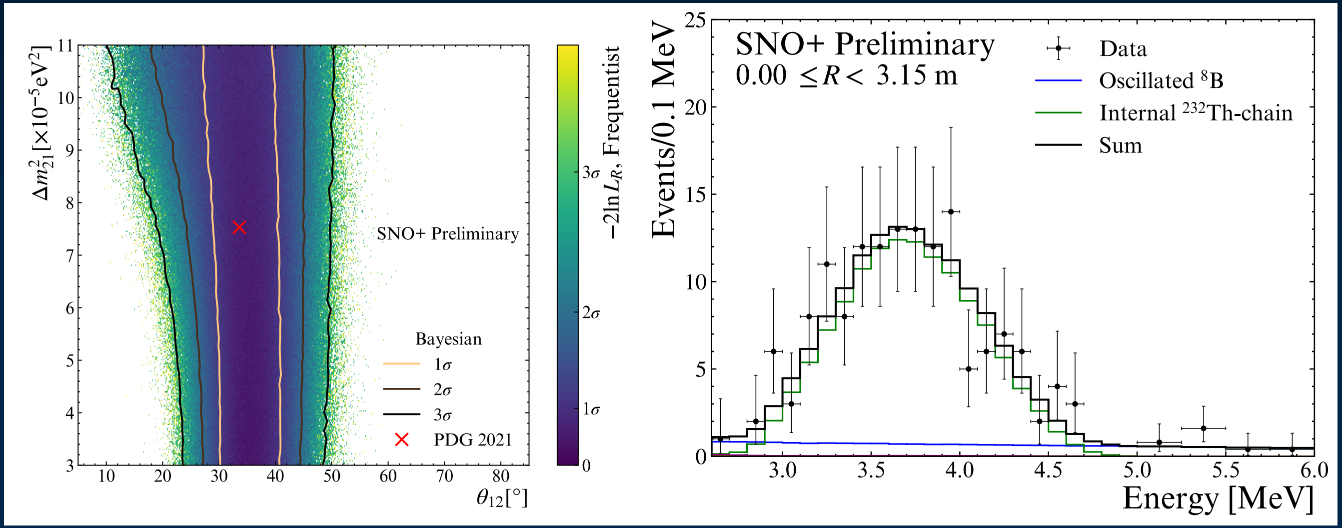
- ^8B solar neutrino measurements via neutrino-electron elastic scattering

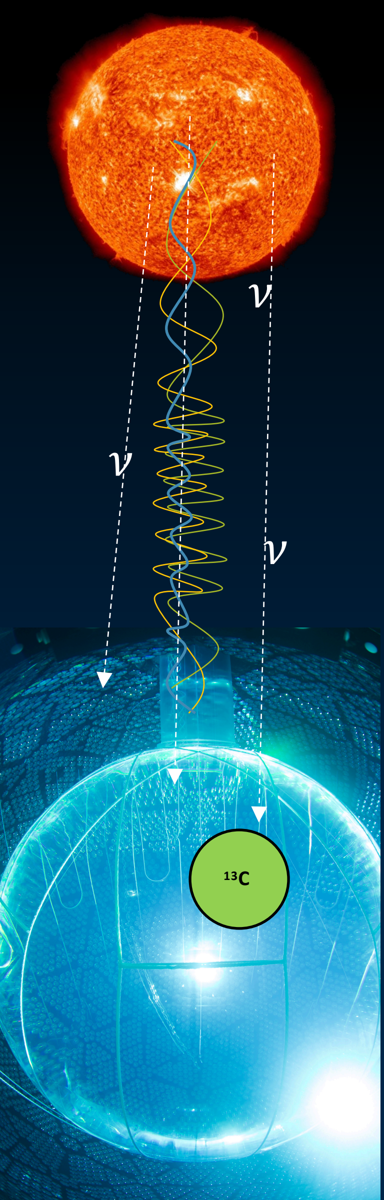
Scintillator phase

- Parallel flux and oscillation analyses
- External backgrounds become negligible in stricter fiducial volume

possible future sensitivity < 3 MeV!

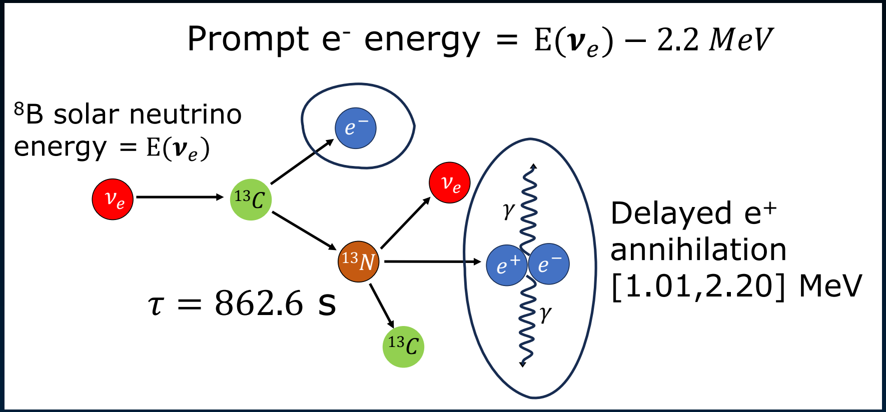
- Analyses techniques to reduce ^{208}Tl contributions: tagging, multisite discrimination



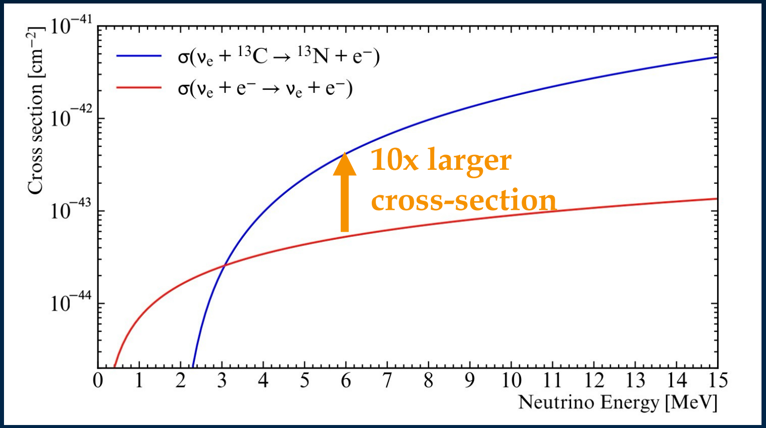


Solar Neutrinos in SNO+

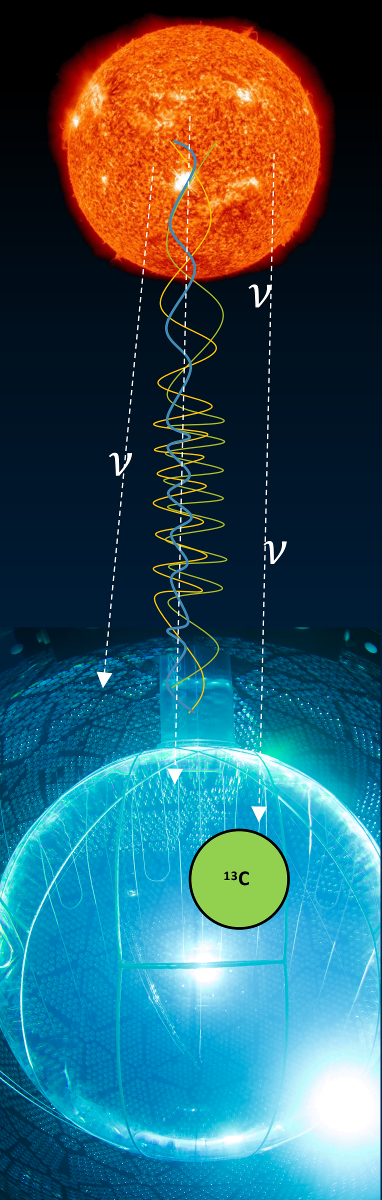
- CC interaction on ^{13}C is possible, but not yet observed with solar neutrinos



- 1.1% isotopic abundance of ^{13}C
- 17 events/year expected in SNO+
- Long half-life of 10 minutes
- Low cosmogenic backgrounds due to SNO+'s depth (0.001 ev/year after cuts)



Solar Neutrinos in SNO+



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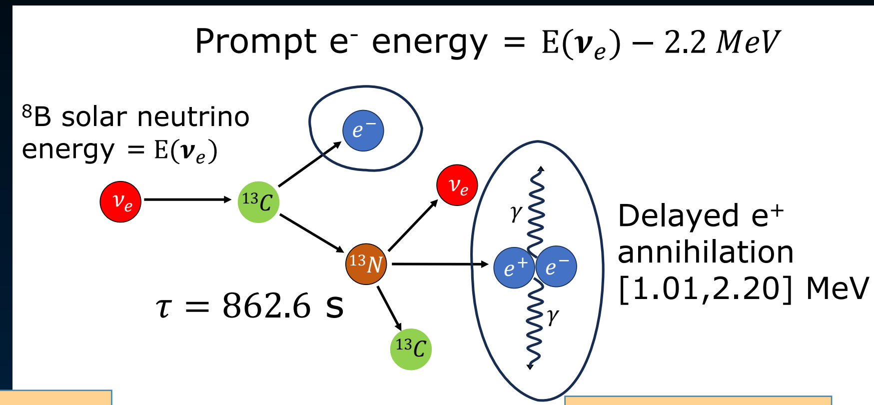

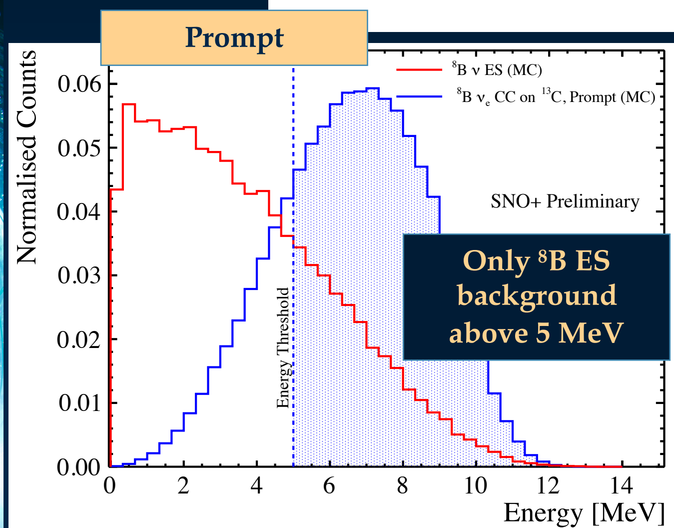

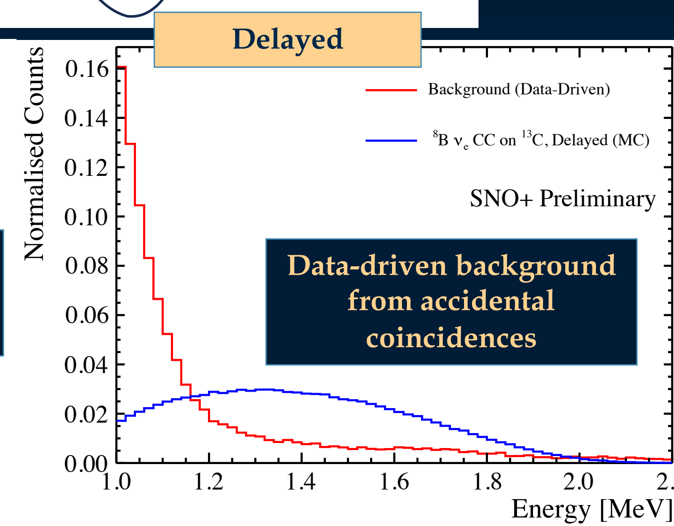

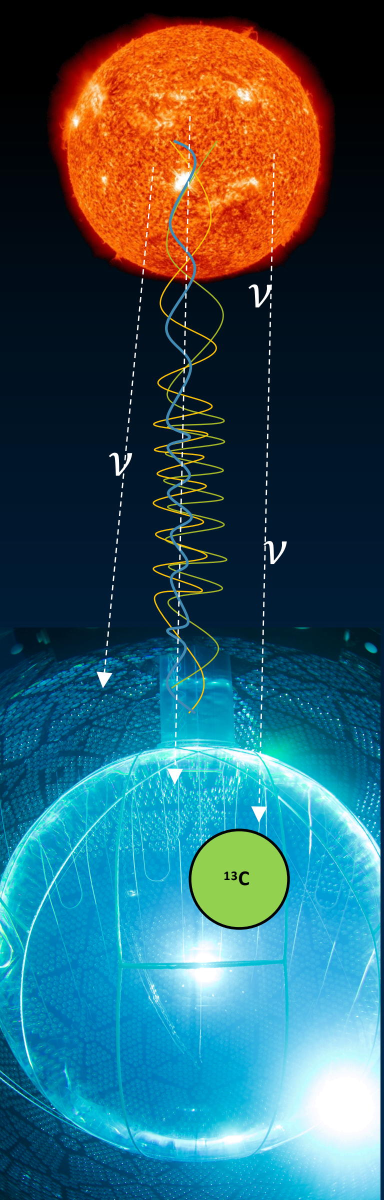

Solar Neutrinos in SNO+

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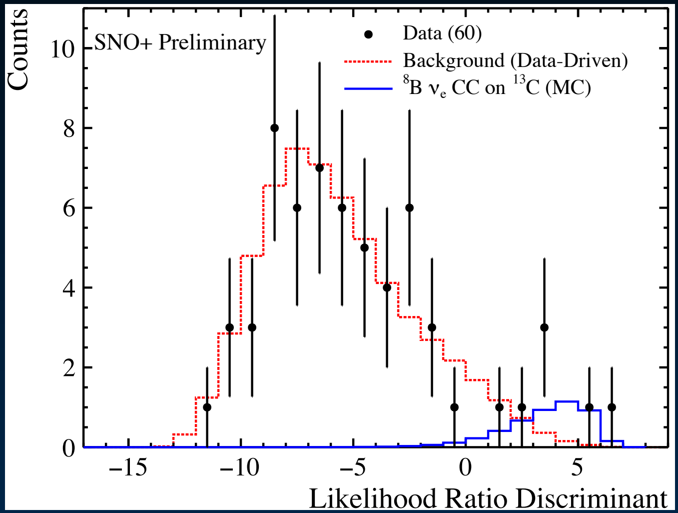
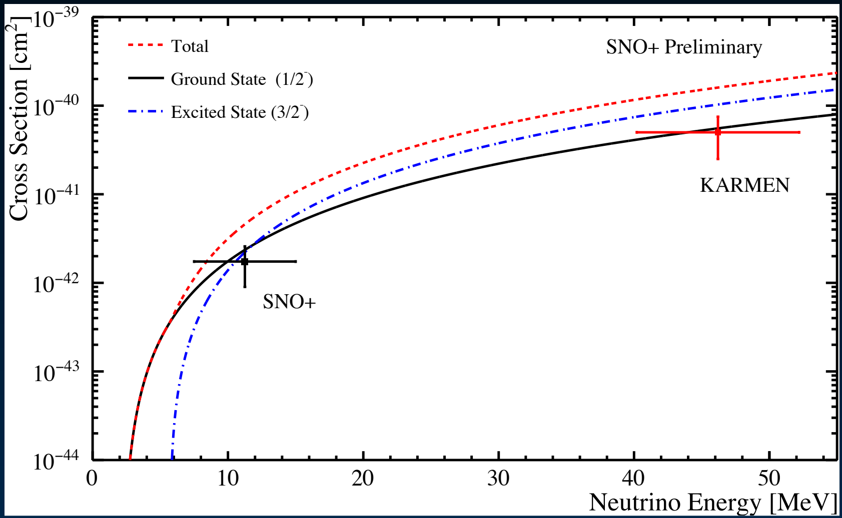


4 signal-like events detected in 225 days of data giving 3.8σ significance



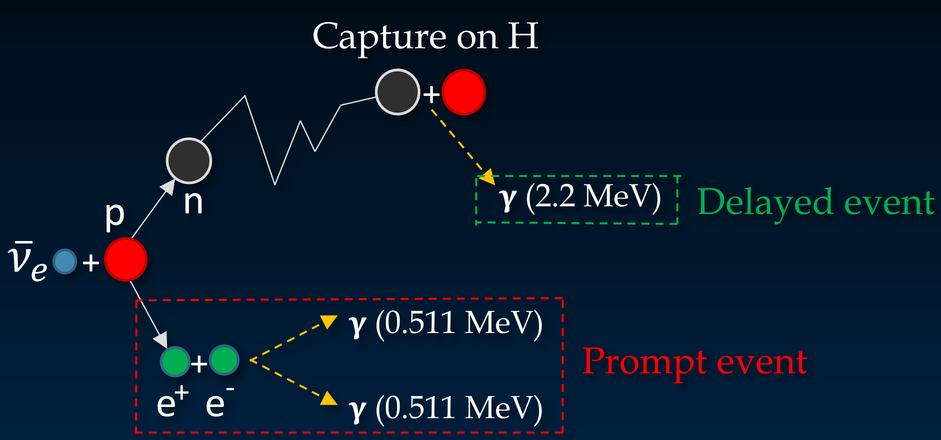
Measured cross section

$$\langle \sigma(E_\nu) \rangle = (1.7 \pm 0.8) \times 10^{-42}\ \text{cm}^2$$

First ever measurement of ^{8}B solar neutrino CC interactions on ^{13}C!

Antineutrinos in SNO+

- Antineutrinos from earth and reactors detected via Inverse Beta Decay



- Majority of antineutrinos from reactors at 240 km and 350-355 km

  + antineutrinos from reactors at varying distances

  + geoneutrinos

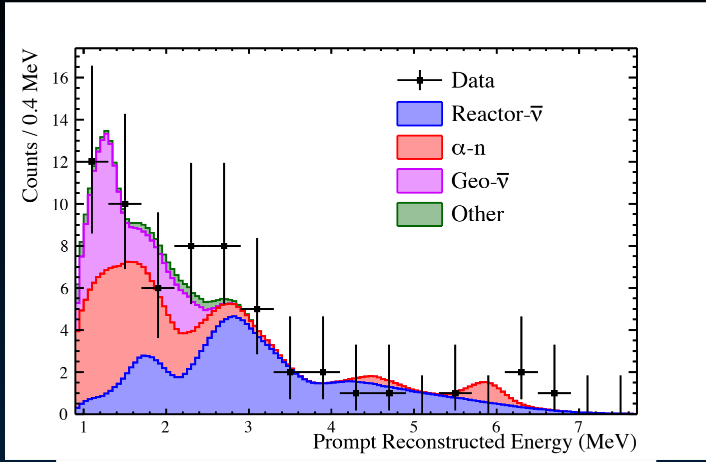
- (α,n) reactions are main background
  - Major source of α is ^{210}Po
  - Factor ~5 smaller from partial fill to full fill phase

Approximately 100 reactor-$\bar{\nu}$ IBDs are expected within the AV per year. And about 25 geo-$\bar{\nu}$ IBDs per year (after oscillations)

Antineutrinos in SNO+

- With 134.4 days of data of the full fill phase

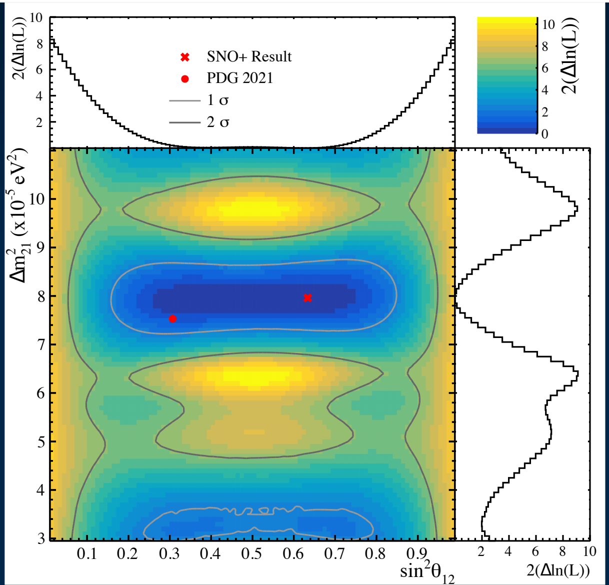
	Expectation	Fit (Uncon.)	Fit (Con.)
Reactor-$\overline{\nu}$ IBD	27.9 ± 0.8	$25.1^{+6.4}_{-2.1}$	27.5 ± 0.9
(α, n)	18.2 ± 5.2	$17.2^{+4.5}_{-4.4}$	$17.2^{+4.5}_{-4.4}$
Geo-$\overline{\nu}$ IBD	7.2	$12.0^{+7.4}_{-6.8}$	$11.1^{+7.1}_{-6.6}$
^{214}BiPo-like	1.1 ± 1.1	1.2 ± 1.1	1.2 ± 1.1
Accidental	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0
Total	54.7	55.8	57.3
Observed	59	59	59



Second-most precise measurement of

$$\Delta m^2_{21} = 7.96^{+0.48}_{-0.42}\times10^{-5}\ \text{eV}^2$$

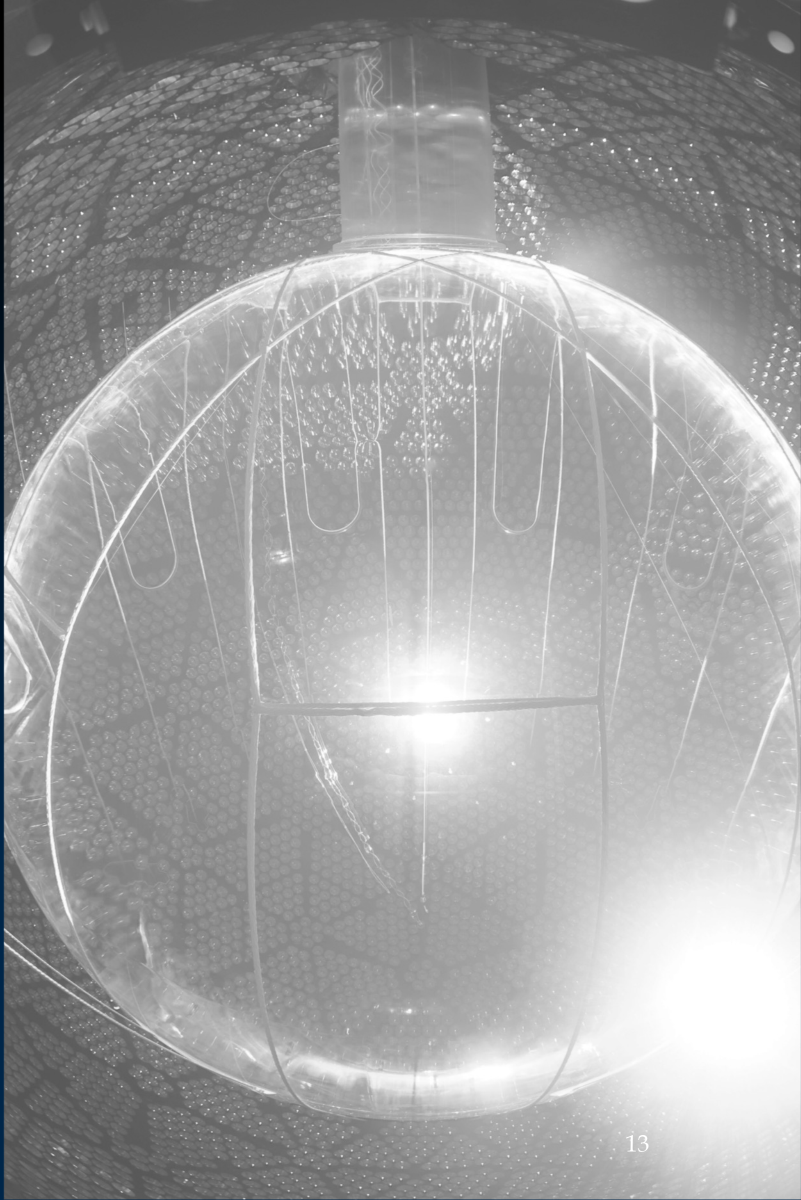
First measurement of geo-$\overline{\nu}$ in the Western hemisphere (3rd ever): 73^{+47}_{-43} TNU



- Result agrees with KamLAND, tension with solar Δm^2_{21}
- More data and analysis improvements on-going
- Addition of time-based (α,n) classifier for background reduction

arXiv:2505.04469

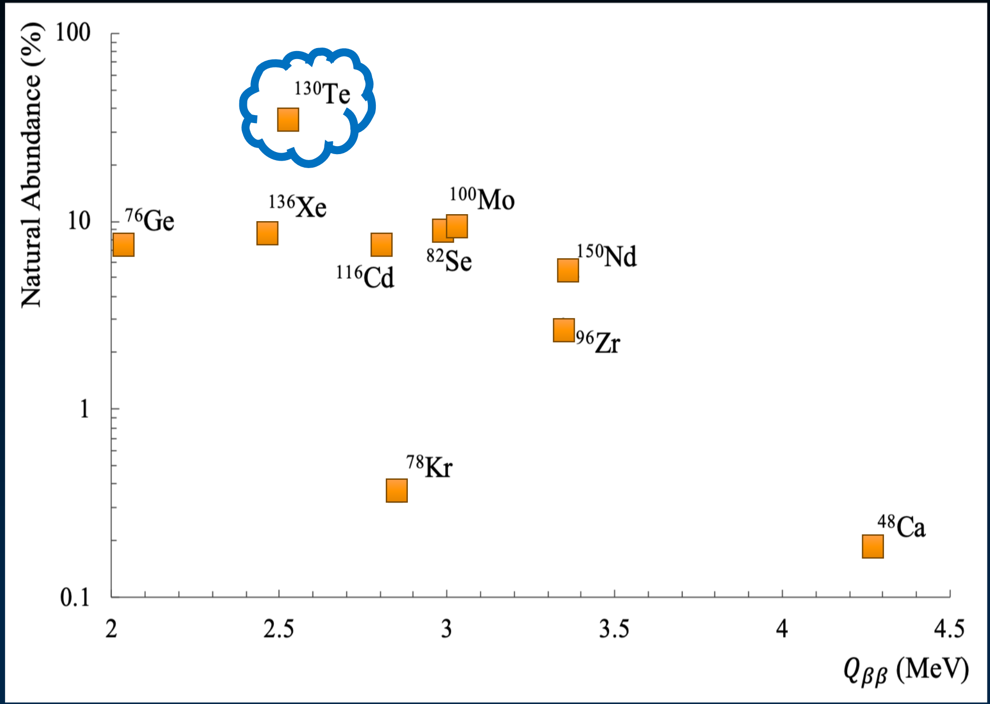
Towards a Te-loaded SNO+



Searching for 0νββ with SNO+

Major advantages of ^{130}Te

- No need for enrichment
- Long 2νββ half-life (8.76x10^{20} years*)
- High Q-value at 2.527 MeV



*Phys. Rev. Lett. **131**, 249902 (2023)

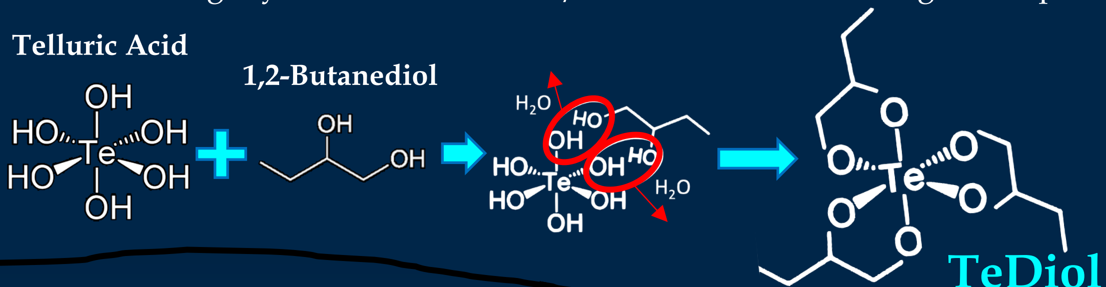
Searching for 0νββ with SNO+

Major advantages of ^{130}Te

- No need for enrichment
- Long 2νββ half-life (8.76x10^{20} years*)
- High Q-value at 2.527 MeV

0.5% Te by weight loaded in LS in the first stage → 1333 kg of ^{130}Te

Estimated light yield of 460 PMT hits/MeV with SNO+ loading technique



Soluble in LS

NIM A 1051

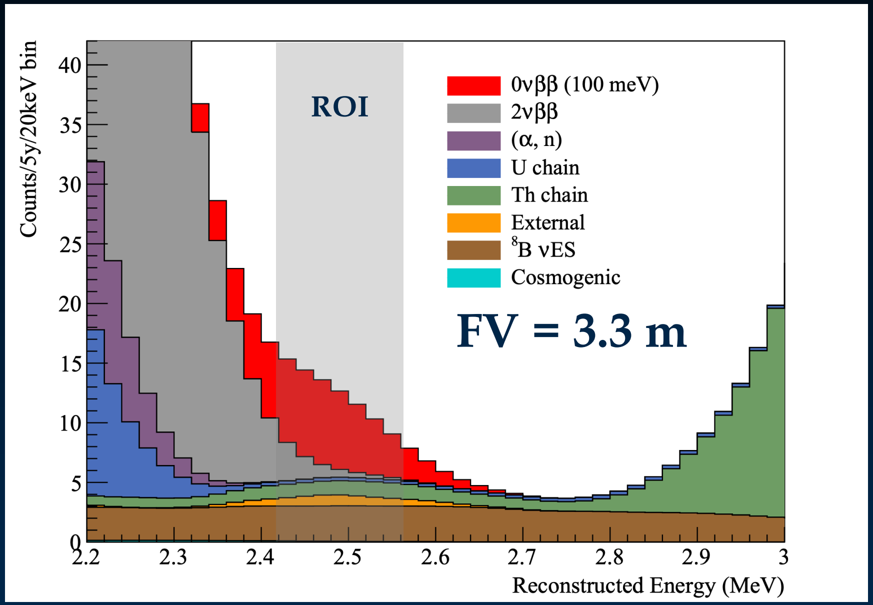
Major advantages of SNO+

1. Large detector
   - Rejection of external backgrounds through fiducialization
2. Scalable loading with good timing and resolution
3. Phased loading approach for constraints to detector model and study of backgrounds

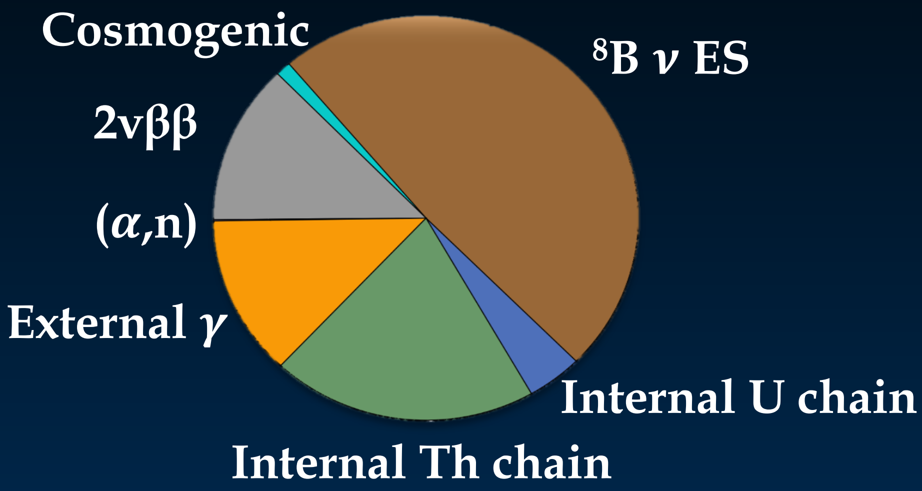
*Phys. Rev. Lett. **131**, 249902 (2023)

Searching for 0νββ with SNO+

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



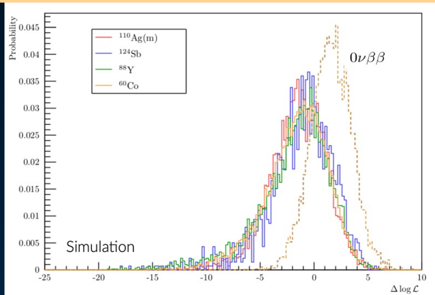
ROI: 2.42-2.56 MeV [-0.5σ - 1.5σ]



Expected sensitivity of 2x10^{26} years after 3 years (90% CL)
With 0.5% natTe loading

Searching for 0vββ with SNO+

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



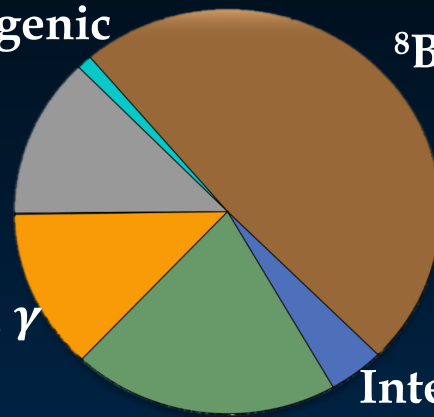
Dunger and Biller, NIM 943, 162420, (2019)

Cosmogenic

2vββ

^{8}B ν ES

Well known from other measurements



External γ

Internal U chain

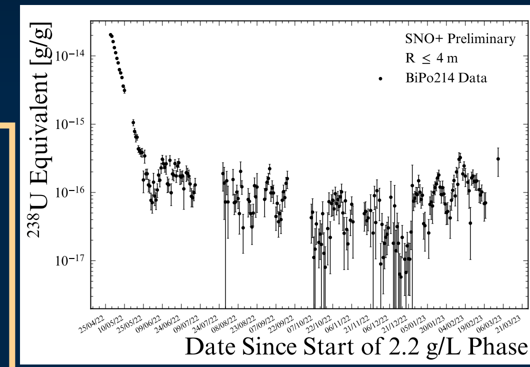
Internal Th chain

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

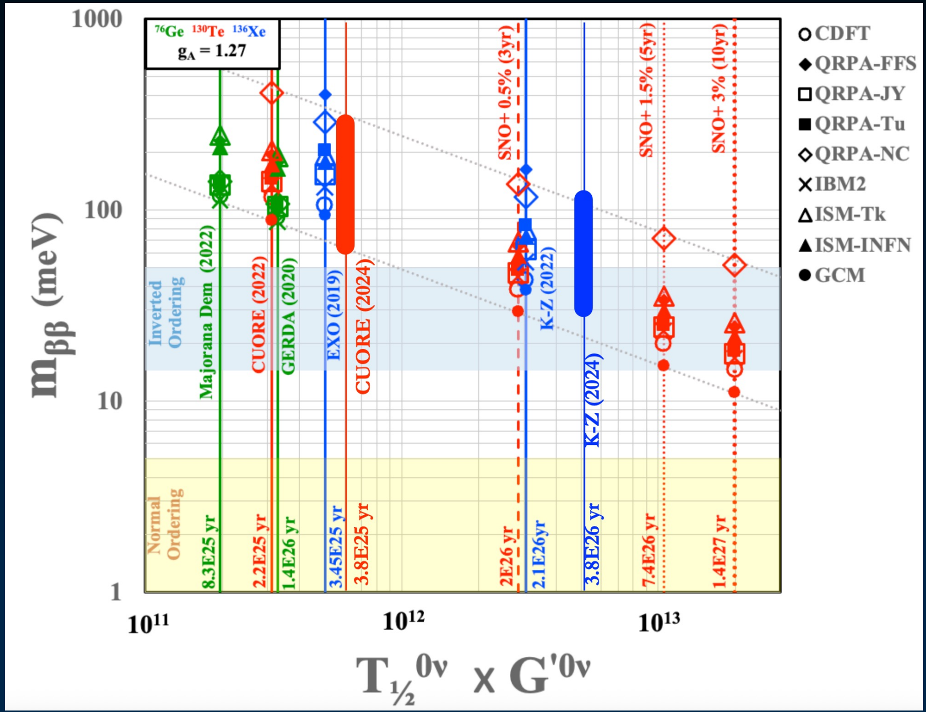


Searching for 0νββ with SNO+

- Planned future higher loadings
  - Potential to cover the whole inverted ordering band
  - R&D shows good optical properties and long term stability

- 5 years with increased 1.5% natTe loading

  $T_{1/2} > 7.4{\times}10^{26}$ years (90% CL)



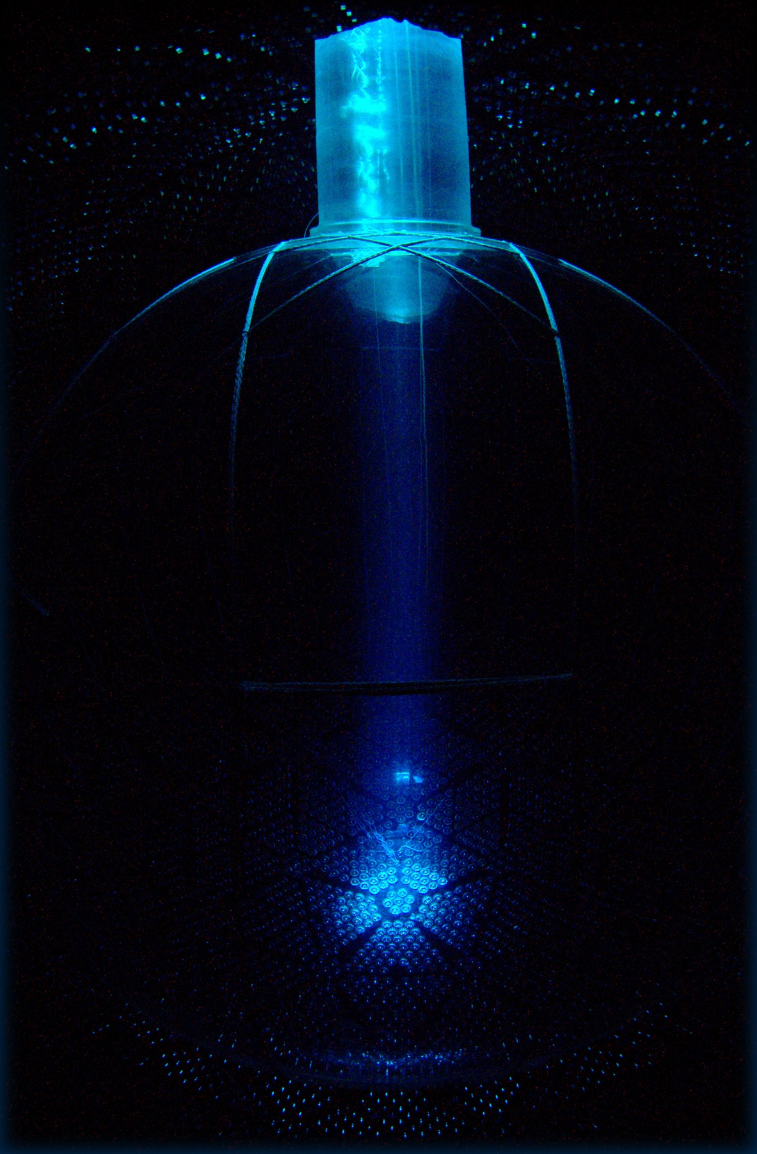
Summary

- **SNO+ is preparing to load Te into the liquid scintillator!**

- $0\nu\beta\beta$ milestones:
  - Study and monitoring of all backgrounds before Te
  - Characterization of detector response

- In the meantime, a lot of on-going analyses:
  - First observation of solar neutrino CC interactions on ^{13}C
  - Second most precise measurement of Δm^2_{21}
  - First measurement of geoneutrino flux in Western hemisphere
  - Live for supernova
  - And many more

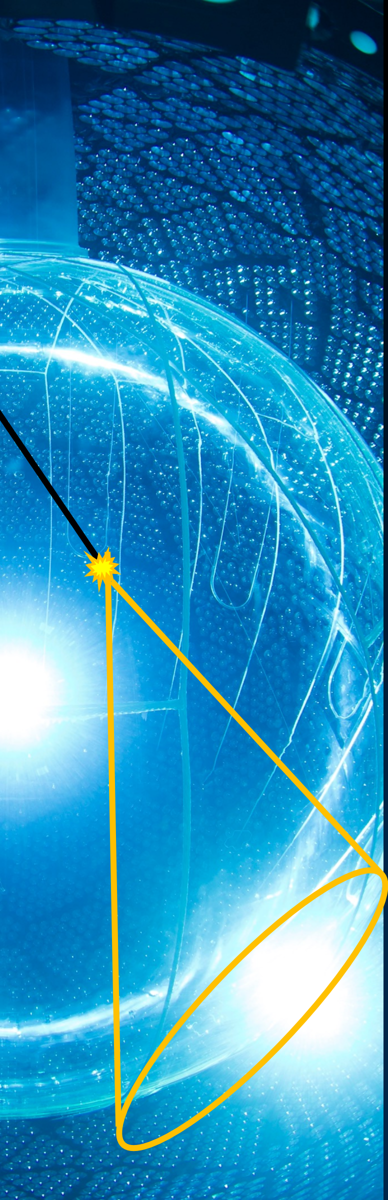
- All measurements improving with additional data



Thank you

on behalf of the SNO+ collaboration

Backup



SNO+ 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

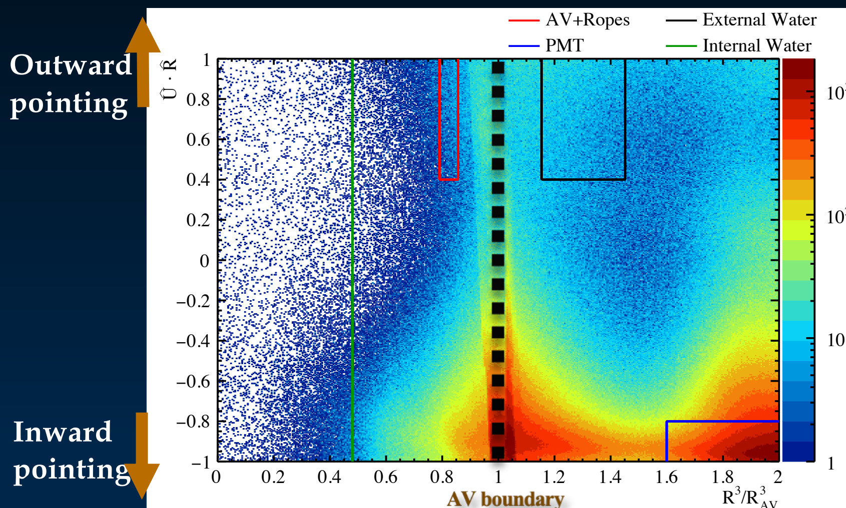
- Improved limits for invisible modes of nucleon decay
  Phys. Rev. D 99, 032008 (2019) Phys.Rev.D 105, 112012 (2022)
- Measurement of ^{8}B solar neutrinos
  Phys. Rev. D 99, 012012 (2019)
- First measurement of reactor antineutrinos using pure water
  Phys.Rev.Lett 130, 091801 (2023)

$0\nu\beta\beta$ Milestones

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

External Backgrounds in Water Phase

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

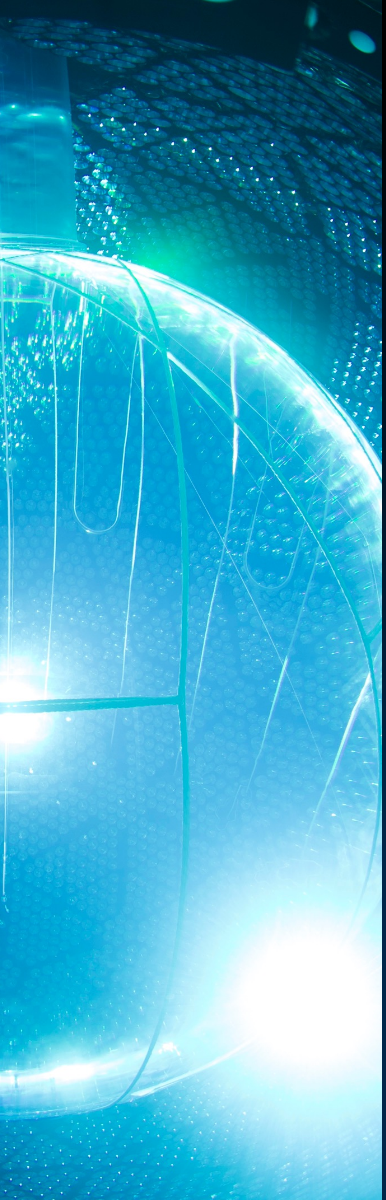


AV	$5.55\text{ m} < R_{AV} < 5.7\text{ m}$ $U \cdot R_{AV} > 0.4$
External Water	$6.3\text{ m} < R < 6.8\text{ m}$ $U \cdot R > 0.4$
PMT	$1.6 < R^3 < 2.0$ $U \cdot R < -0.8$
Internal Water	$R_{AV} < 4.7\text{m}$

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)!**

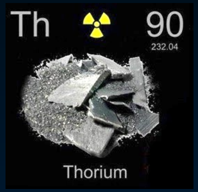
Continuing to monitor the rate and source of the external backgrounds in the next phases



Scintillator Backgrounds

Scintillator Phase

- Monitoring internal U/Th levels



^{212}Bi

β⁻, 2.25 MeV

^{212}Po

α, 8.95 MeV
0.30μs

^{208}Pb

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

^{214}Bi

β⁻, 3.27 MeV

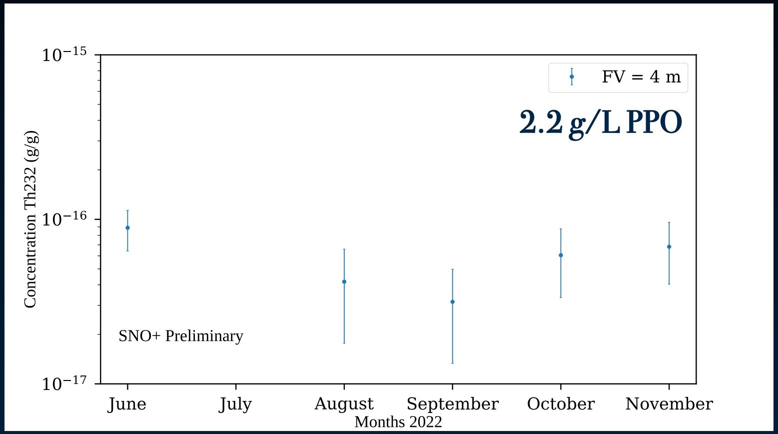
^{214}Po

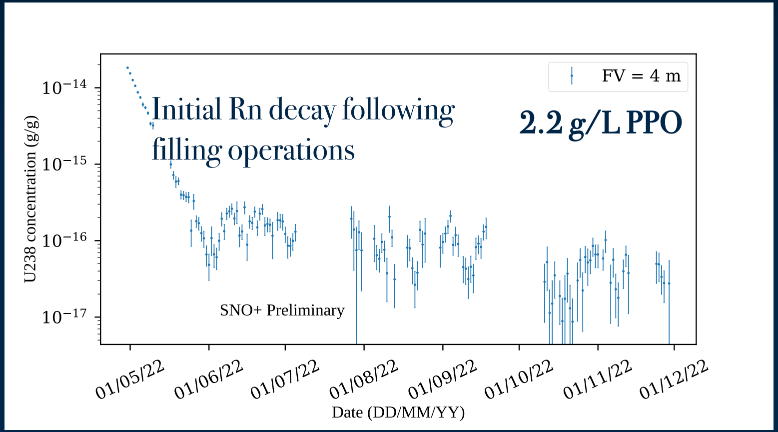
α, 7.83 MeV
164μs

^{210}Pb

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

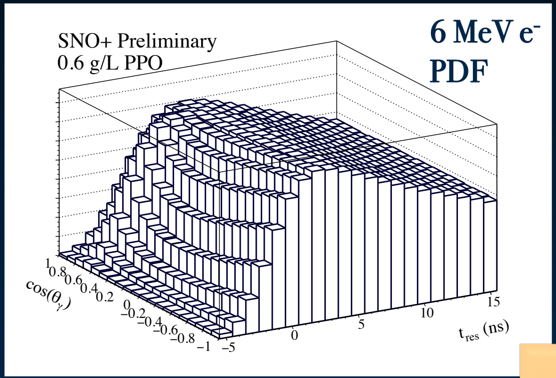
Below DBD-phase requirements!

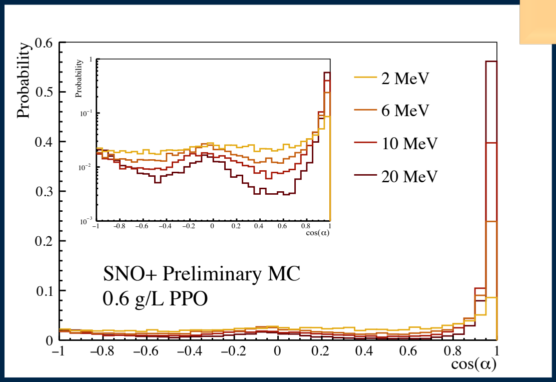


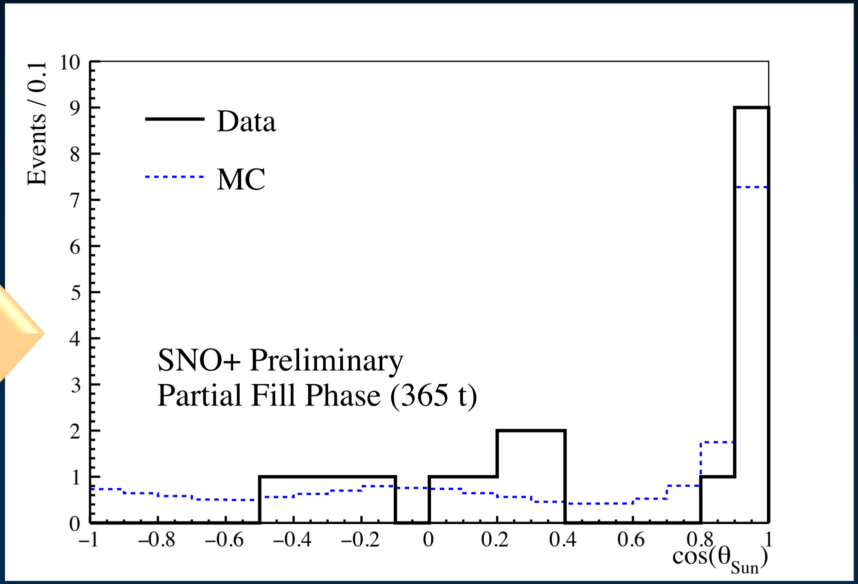


Solar Directionality in SNO+ Scintillator Phase

- **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







Phys. Rev. D 109, 072002