



SNO+

Tanner Kaptanoglu

UC Berkeley and Lawrence Berkeley National Lab

On behalf of the SNO+ collaboration

NEUTRINO 2026

XXXII International Conference on Neutrino Physics and Astrophysics

June 26, Irvine, California



Posters:

- *SNO+:* ^8B Solar Neutrino Flux Measurement from the Scintillator Phase – **Martina Hebert**
- *Progress Towards Neutrinoless Double Beta Decay at SNO+ – Sam Naugle*
- *Reactor ν Oscillation and Geo- ν 's at SNO+ – Logan Lebanowski*
- *Development and Implementation of an Alpha-Proton Scattering Model for SNO+ Background Characterization – David Drobner*
- *A Search for MeV-Scale Neutrinos Coincident with 04 Gravitational Wave Events in SNO+ – Amanda Bacon*

SNO+ detector



SNO+ is located in Sudbury, Ontario, with a 6070 m.w.e overburden.

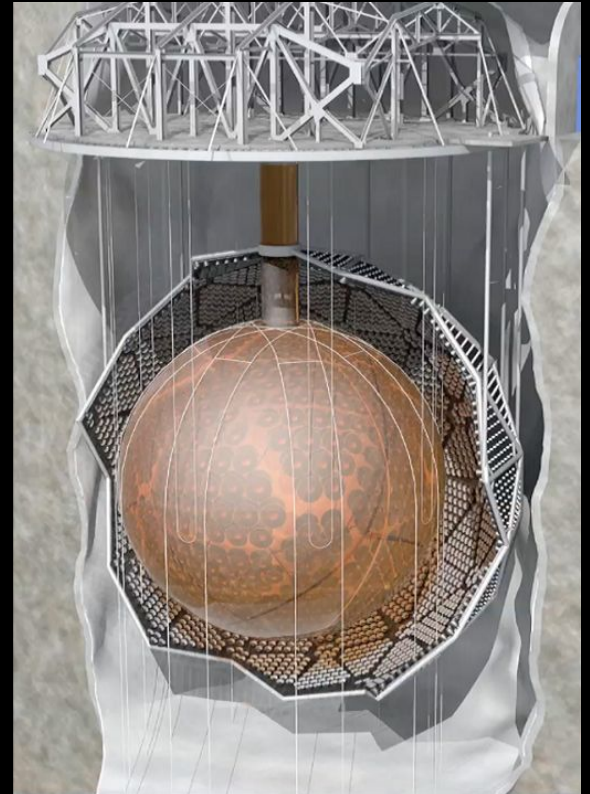
Upgraded from the SNO detector to allow for deployment of liquid scintillator in the acrylic vessel.



SNO+ detector



- Central acrylic vessel (AV) holds ~1 kt water (or ~780 t scintillator)
- 6 m radius AV viewed by ~9400 PMTs
- 7 kt buffer water in cavity (shielding)
- Hold-down rope net
- Upgraded calibration systems, electronics, DAQ, underground scintillator plants



SNO+ physics goals

SNO+ is designed to pursue a broad physics program,
including solar neutrinos, reactor+geo neutrinos, and
ultimately $0\nu\beta\beta$

SNO+ phased approach

SNO+ is designed to pursue a broad physics program,
including solar neutrinos, reactor+geo neutrinos, and
ultimately $0\nu\beta\beta$

Milestones & key dates:

2017 - 2019: Water phase campaign 

SNO+ phased approach

SNO+ is designed to pursue a broad physics program, including solar neutrinos, reactor+geo neutrinos, and ultimately $0\nu\beta\beta$

Milestones & key dates:

2017 - 2019: Water phase campaign 

2019 - 2022: Scintillator filling & partial fill 


SNO+ phased approach

SNO+ is designed to pursue a broad physics program, including solar neutrinos, reactor+geo neutrinos, and ultimately $0\nu\beta\beta$

Milestones & key dates:

2017 - 2019: Water phase campaign 





2019 - 2022: Scintillator filling & partial fill 

2022+: Currently collecting data with scintillator 

SN0+ phased approach

SN0+ is designed to pursue a broad physics program, including solar neutrinos, reactor+geo neutrinos, and ultimately $\theta\nu\beta\beta$

Milestones & key dates:

- 2017 - 2019: Water phase campaign 
- 2019 - 2022: Scintillator filling & partial fill 
- 2022+: Currently collecting data with scintillator 
- 2027: Anticipated Te loading to start $\theta\nu\beta\beta$ phase 

SN0+ phased approach

SN0+ is designed to pursue a broad physics program, including solar neutrinos, reactor+geo neutrinos, and ultimately $\theta\nu\beta\beta$

Milestones & key dates:

Covered in this talk!

2017 - 2019: Water phase campaign

2019 - 2022: Scintillator filling & partial fill

2022+: Currently collecting data with scintillator

2027: Anticipated Te loading to start $\theta\nu\beta\beta$ phase



Highlights from water fill

The primary intention of the water fill phase was the optical calibration and detector commissioning



Highlights from water fill

The primary intention of the water fill phase was the optical calibration and detector commissioning

We also performed:

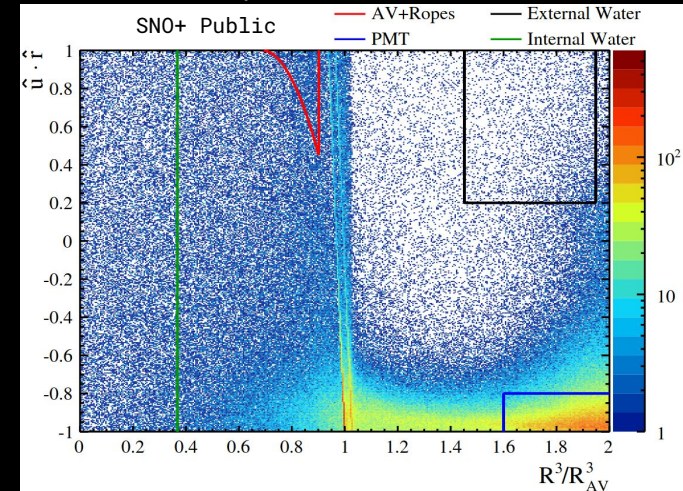
- Important background measurements for future phases
- World-leading limits on invisible nucleon decay modes
- Low background measurement of ^8B solar neutrinos
- First ever measurement of reactor neutrinos in water



Backgrounds

- Measured rate of γ -rays from external sources (e.g., PMTs)
- Relevant for all future phases, including for $\theta\nu\beta\beta$

External events identified using reconstructed position & direction



<https://snoplus.phy.queensu.ca/public.html>

| 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 | $1.48 \pm 0.002^{+1.65}_{-0.60}$ |

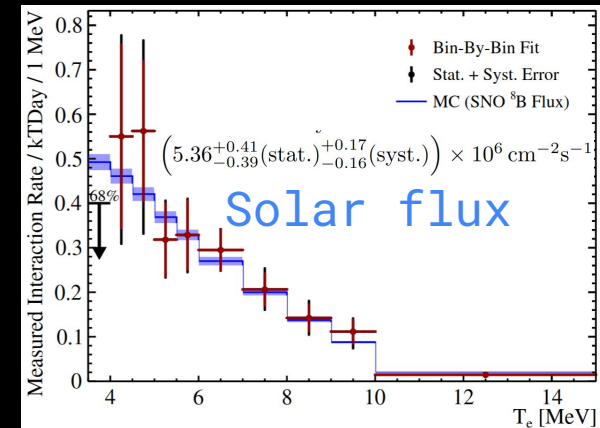
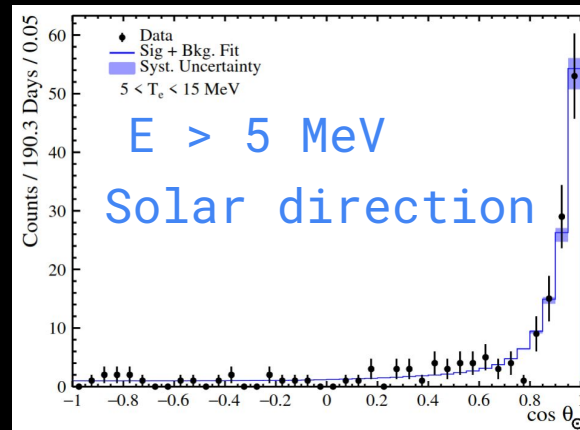
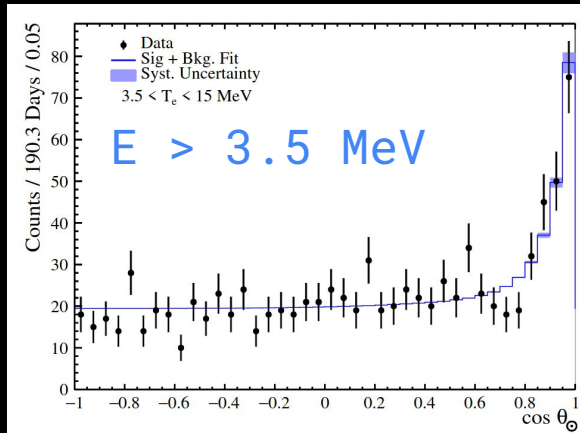
Fitted event rates, relative to expectations 13



Solar neutrinos

- Measurement of ${}^8\text{B}$ flux down to 3.5 MeV with extremely low backgrounds

[*Phys. Rev. D 110, 122003 \(2024\)*](#)

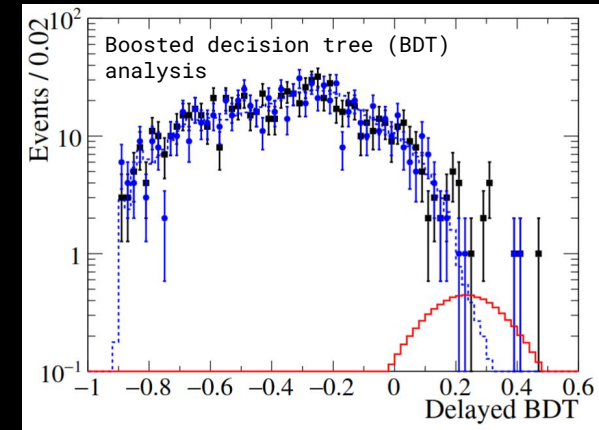
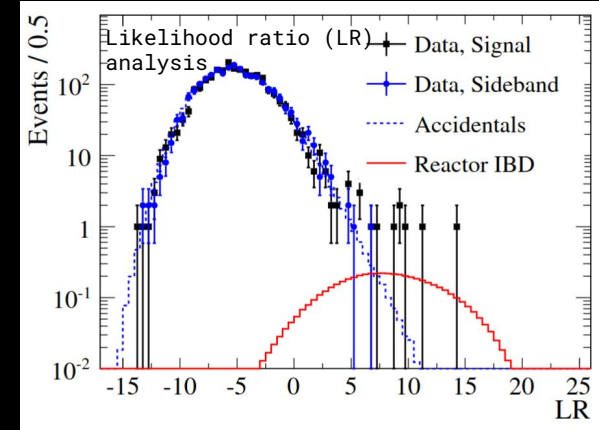




Reactor neutrinos

- First ever evidence ($\sim 3.5\sigma$) of reactor antineutrinos using a water Cherenkov detector

[Phys.Rev.Lett. 130 \(2023\) 9, 091801](#)





Reactor neutrinos

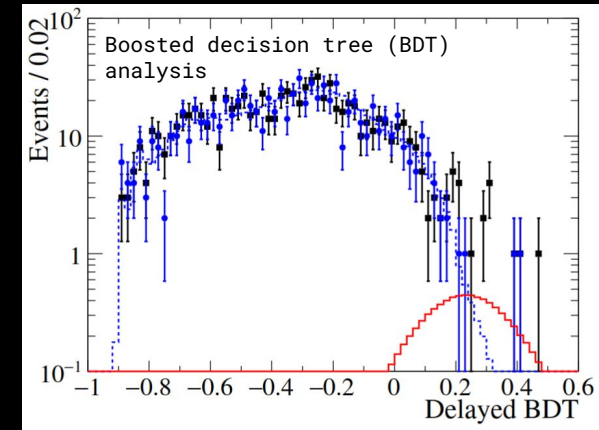
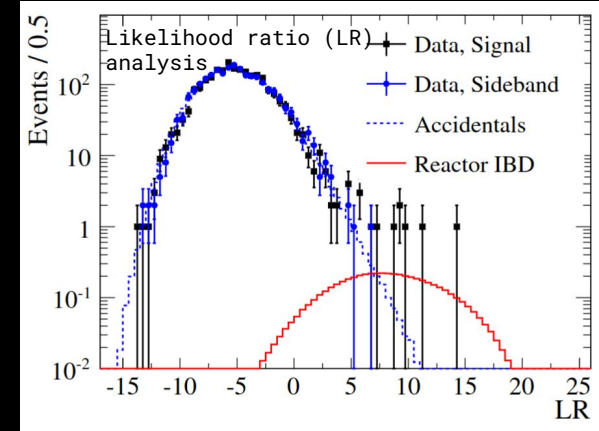
- First ever evidence ($\sim 3.5\sigma$) of reactor antineutrinos using a water Cherenkov detector

[Phys.Rev.Lett. 130 \(2023\) 9, 091801](#)

Made possible by:

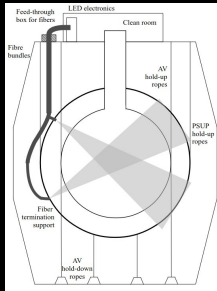
- Ultraclean and depth
- Advanced analysis techniques
- Lowest trigger threshold ever in large water Cherenkov detector

[see: *Phys. Rev. C* 102, 014002 (2020)]



Towards scintillator

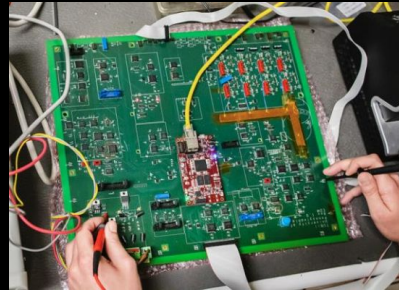
- Underground processing and purification plants
- New calibration sources and deployment system
- Upgraded electronics provide fast triggering and readout



Light injection system

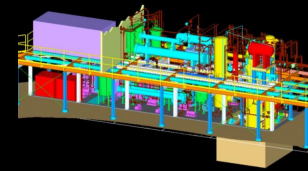
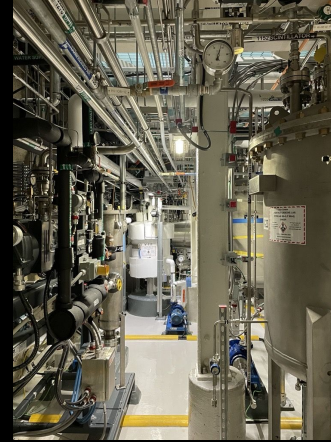


Laserball calib. source

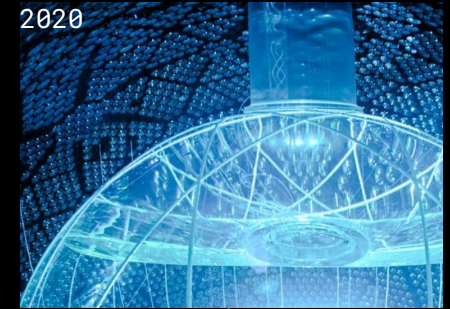


FPGA-based trigger board

Image & schematic of scint. plant



2020

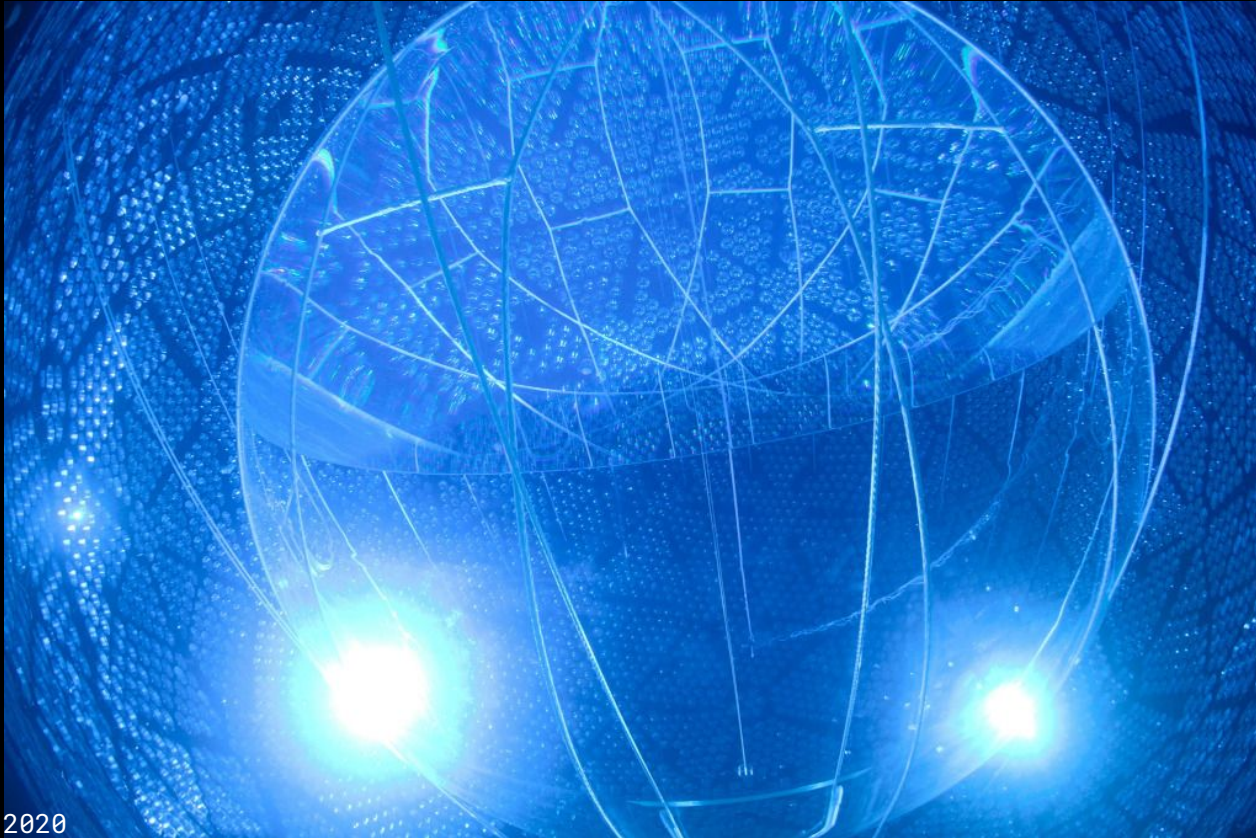


Partial scintillator fill



Scintillator arrives to SNOLAB

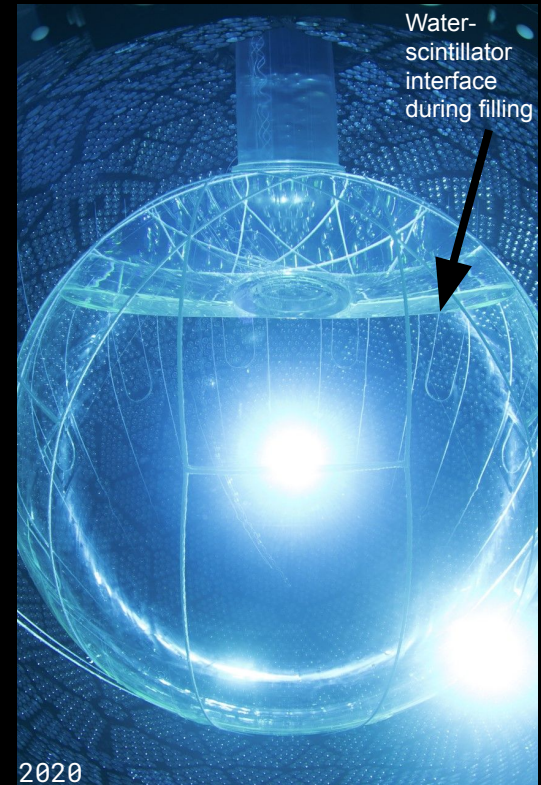
Partial fill phase





Partial fill

Operations were paused during pandemic.
Resulted in an opportunity to collect
data during a “partial fill” phase.

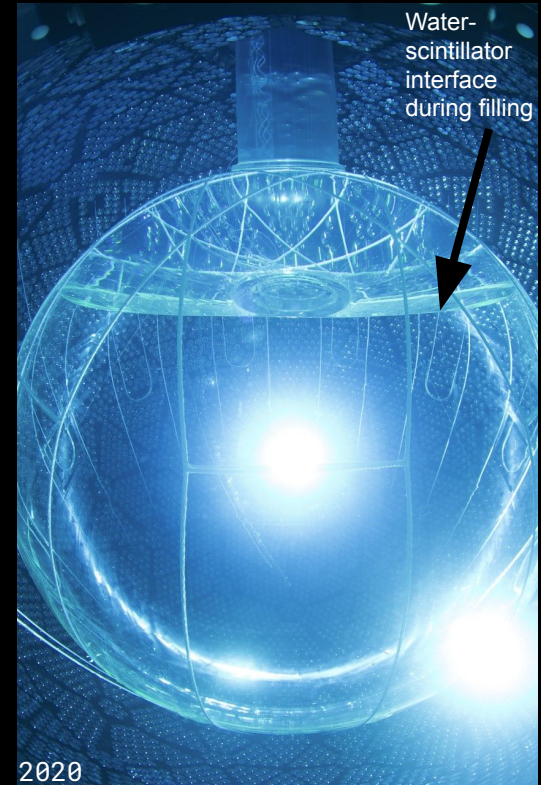




Partial fill

Operations were paused during pandemic.
Resulted in an opportunity to collect
data during a “partial fill” phase.

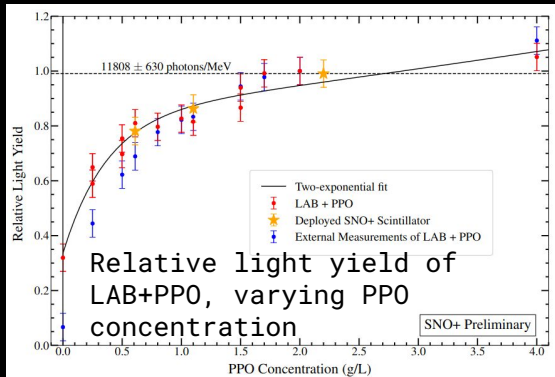
Despite complicated optics, SNO+
achieved optical calibrations,
background & physics measurements.





Partial fill

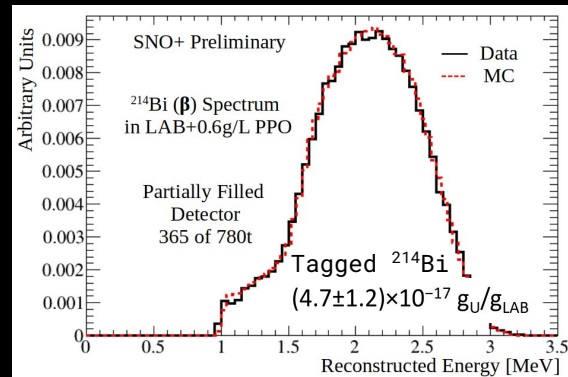
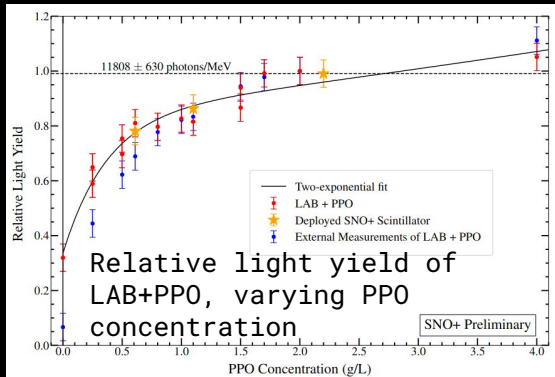
- LAB + PPO @ 0.6 g/L ~70% of the light yield of final mixture & slower emission timing





Partial fill

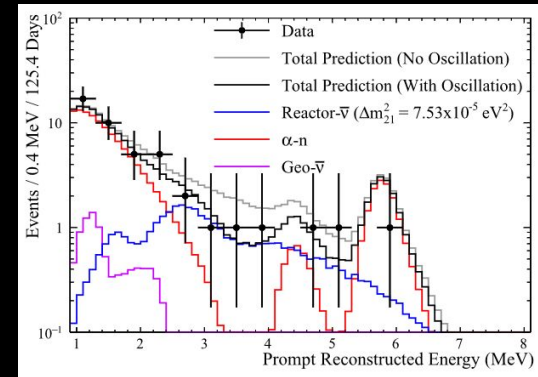
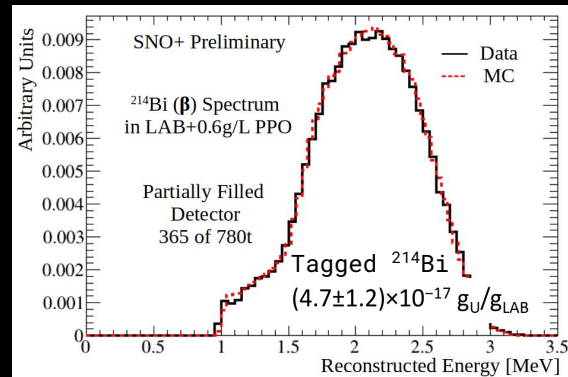
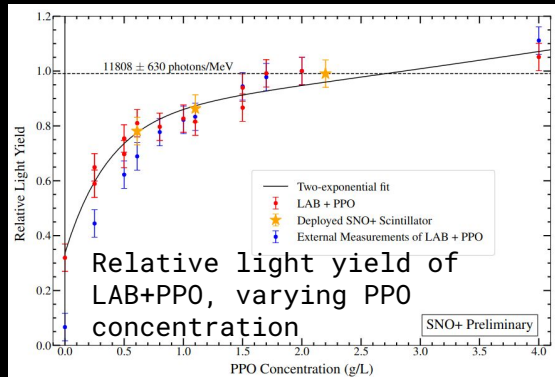
- LAB + PPO @ 0.6 g/L ~70% of the light yield of final mixture & slower emission timing
- Background $^{238}\text{U}/^{232}\text{Th}$ chain measured $\sim 5 \times 10^{-17} \text{ g}_{\text{U/Th}}/\text{g}_{\text{LAB}}$





Partial fill

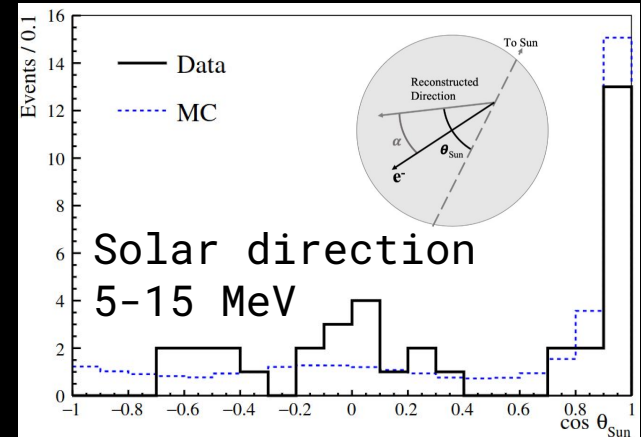
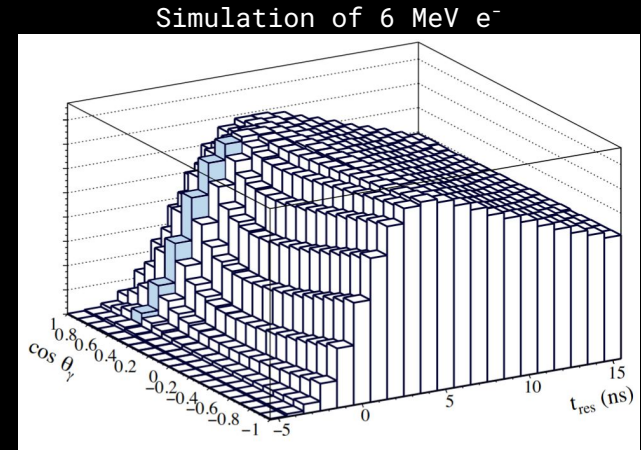
- LAB + PPO @ 0.6 g/L ~70% of the light yield of final mixture & slower emission timing
- Background $^{238}\text{U}/^{232}\text{Th}$ chain measured $\sim 5 \times 10^{-17} \text{ g}_{\text{U/Th}}/\text{g}_{\text{LAB}}$
- Spectral analysis of long-baseline reactor neutrinos



Solar neutrinos

- Clear identification of ${}^8\text{B}$ solar neutrinos ($> 5\sigma$)
- First ever event-by-event direction reconstruction in large liquid scintillator detector

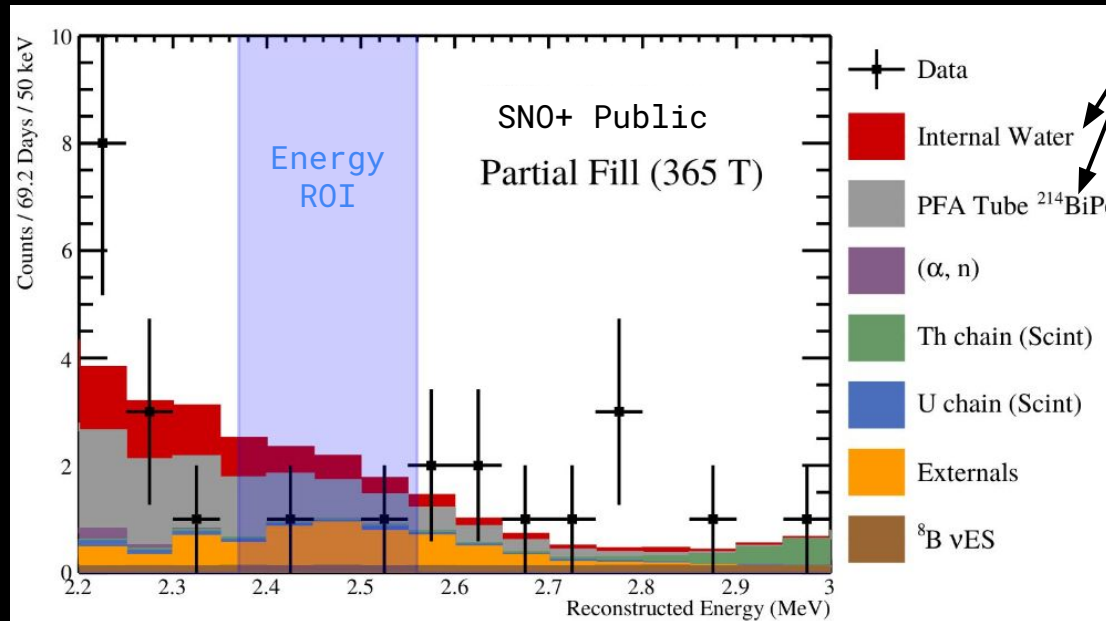
[Phys.Rev.D 109 \(2024\) 7, 072002](#)





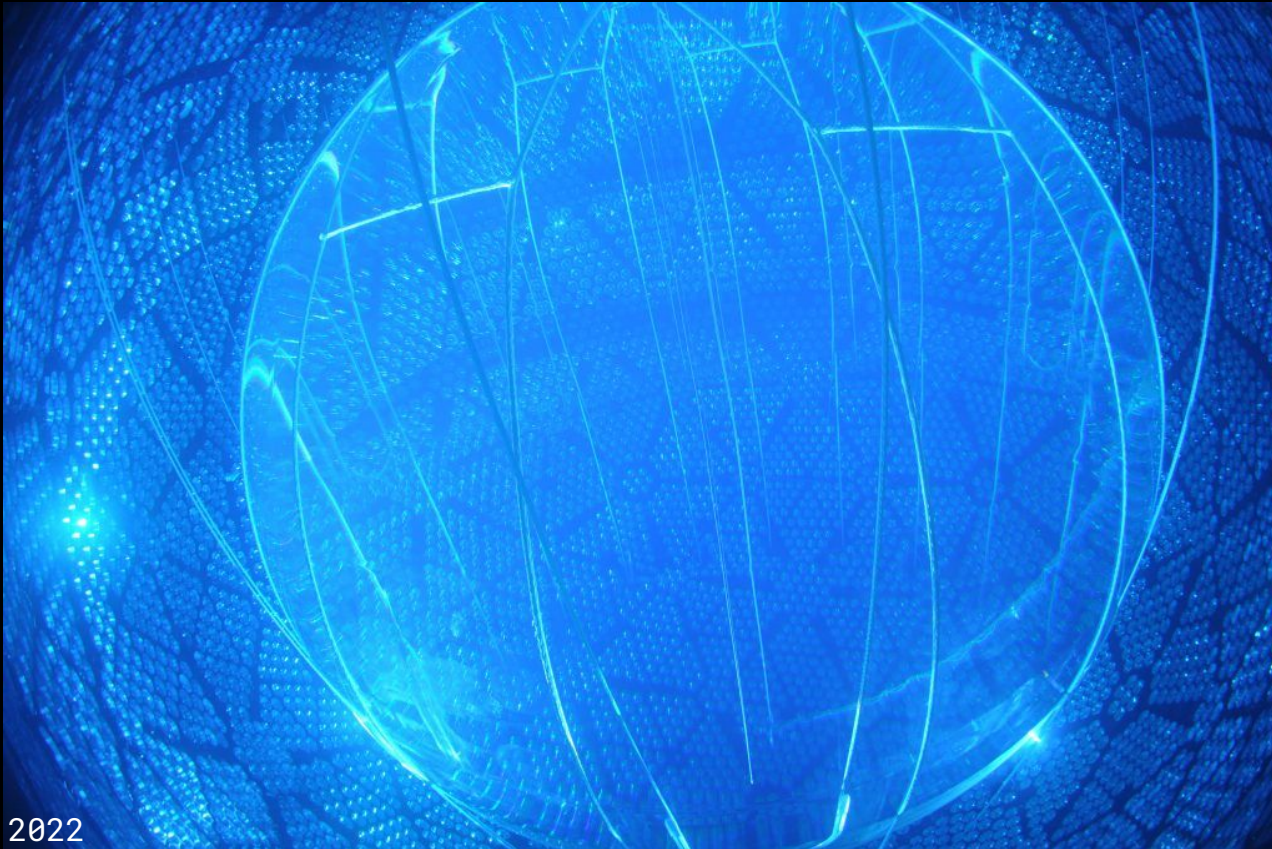
Backgrounds in $0\nu\beta\beta$ region

Backgrounds in the $0\nu\beta\beta$ energy
ROI consistent with expectations



Partial fill
phase only

Scintillator phase



2022



Scintillator fill

Beginning in 2022:

- “Standard” scintillator:
 - LAB + PPO (2.2 g/L)
 - Livetime: 245 days
 - Exposure: 0.52 ktonne-years



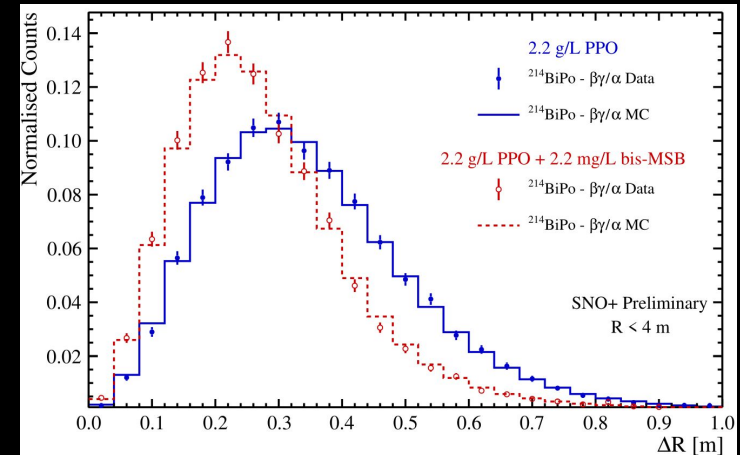
Scintillator fill

Beginning in 2022:

- “Standard” scintillator:
LAB + PPO (2.2 g/L)
Livetime: 245 days
Exposure: 0.52 ktonne-years

In 2023 upgraded to:

- “Enhanced” scintillator:
+ BHT + bisMSB (2.2 mg/L)
Livetime: 439 days
Exposure: 0.94 ktonne-years

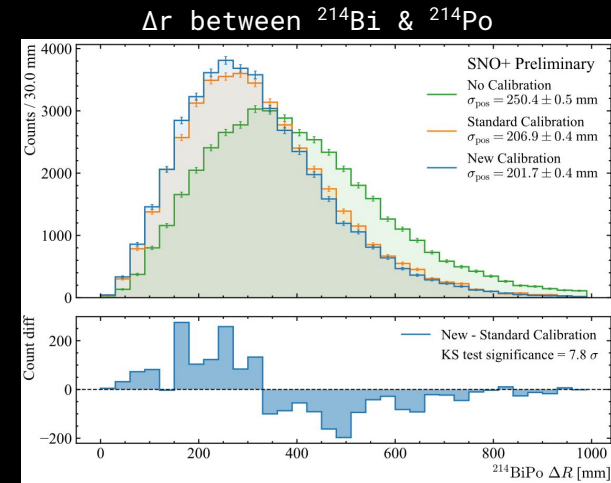


Reconstructed radial distance between tagged ^{214}Bi and ^{214}Po



Calibrations

- New ML-based PMT calibration using in-situ radioactivity



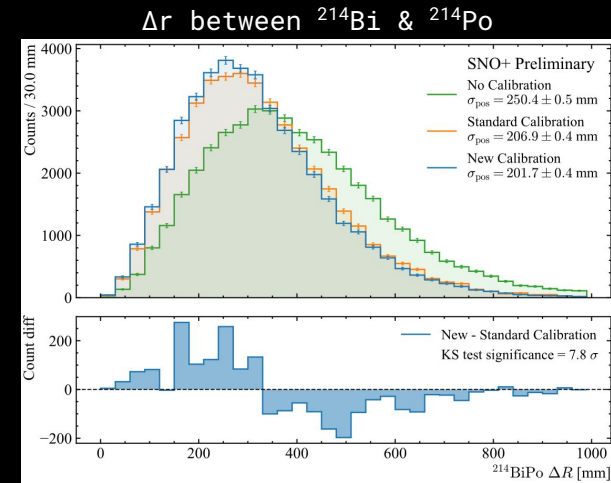
ML calibration (blue) outperforms previous calibration

S. Degraw et al., NIM A 171722 (2026)



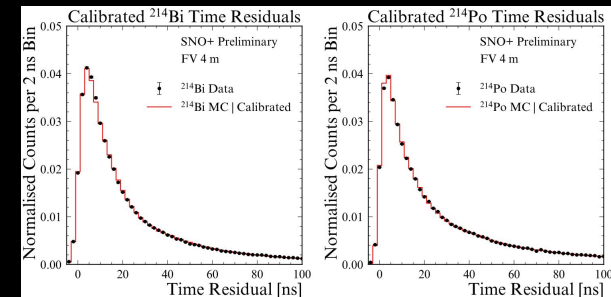
Calibrations

- New ML-based PMT calibration using in-situ radioactivity
- Scintillator attenuation, light yield, and α/β timing calibrated using the in-situ radioactivity (^{210}Po and $^{214}\text{BiPo}$)



ML calibration (blue) outperforms previous calibration

S. Degraw et al., NIM A 171722 (2026)



Time-residuals of ^{214}Bi (β) & ^{214}Po (α)

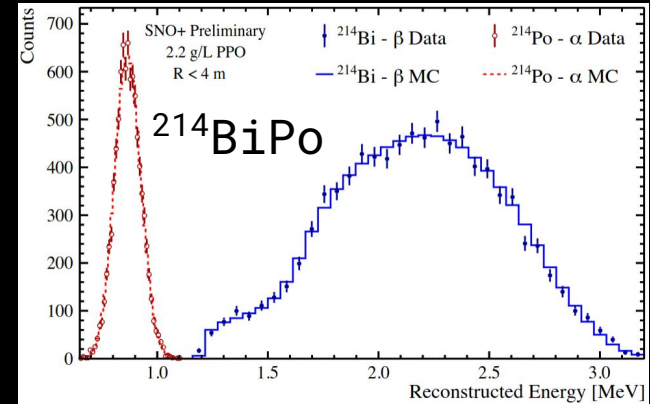


Backgrounds

Evaluating the backgrounds in the standard scintillator:

^{238}U chain from ^{214}Bi - ^{214}Po tagging:

$$(6.2 \pm 0.1) \times 10^{-17} \text{ g/g}_{\text{LAB}}$$





Backgrounds

Evaluating the backgrounds in the standard scintillator:

^{238}U chain from ^{214}Bi - ^{214}Po tagging:

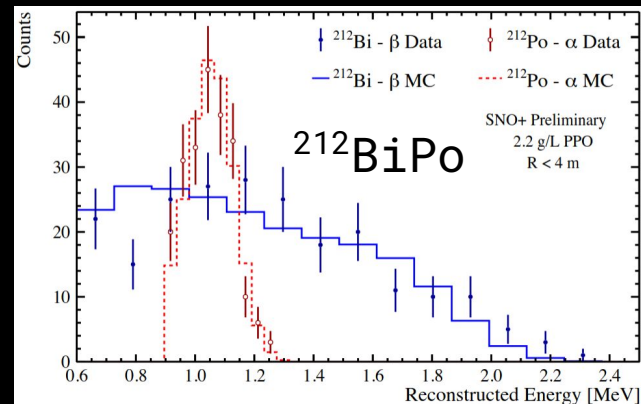
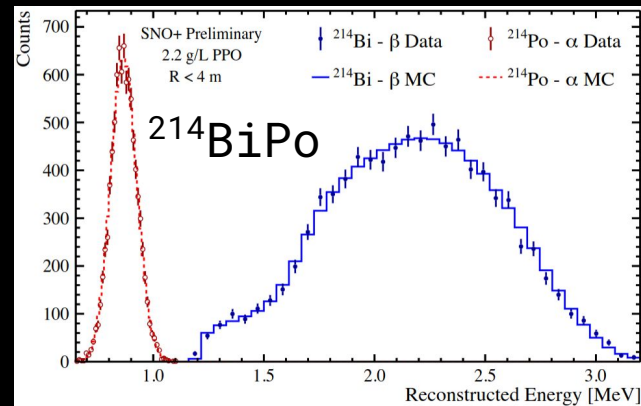
$$(6.2 \pm 0.1) \times 10^{-17} \text{ g/g}_{\text{LAB}}$$

^{232}Th chain from ^{212}Bi - ^{212}Po tagging

$$(7.5 \pm 0.7) \times 10^{-17} \text{ g/g}_{\text{LAB}}$$

[consistent rate with ^{224}Ra - ^{220}Rn - ^{216}Po - ^{212}Pb tagging]

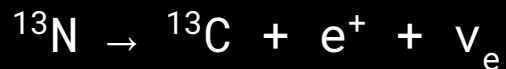
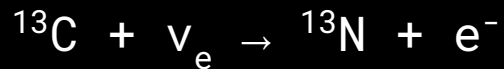
[$^{238}\text{U}/^{232}\text{Th}$ background rates comparable in enhanced scint]





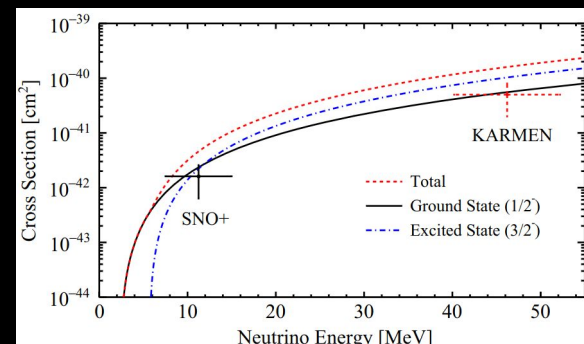
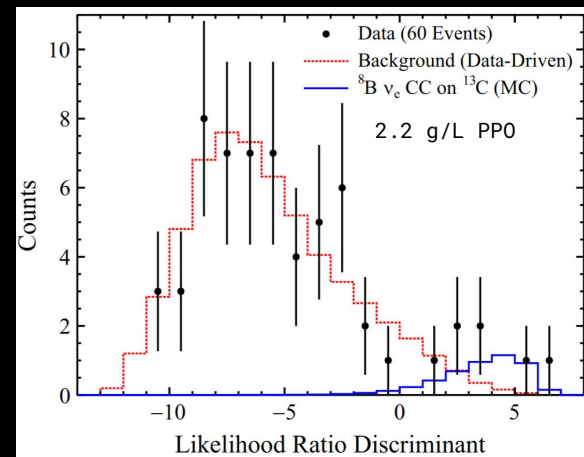
Solar neutrinos on ^{13}C

- First evidence ($> 4\sigma$) of solar neutrino interactions on ^{13}C



[^{13}N : $\tau \sim 10$ mins; $Q \sim 2.2$ MeV]

[Phys.Rev.Lett 135, 241803 \(2025\)](#)

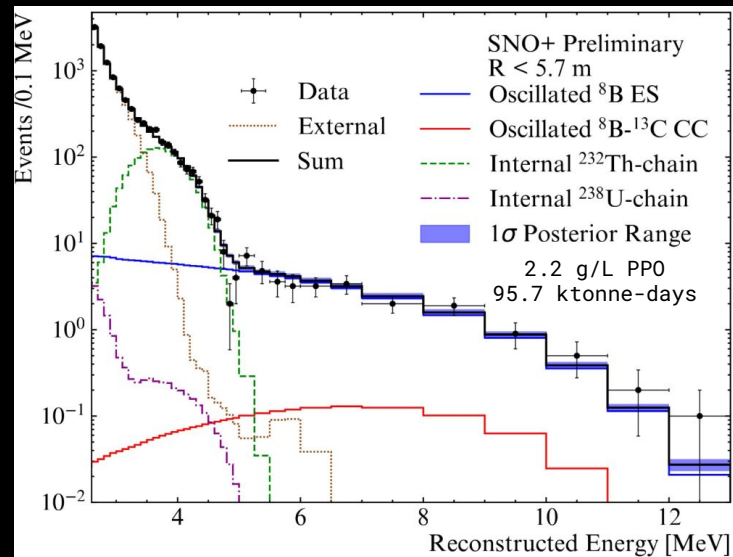




^8B solar neutrinos

Two ongoing parallel analyses:

1. Fit Δm_{21}^2 and $\sin^2(\theta_{12})$ using ^8B flux from SNO 3-phase
2. Fit ^8B flux using PDG oscillation parameters

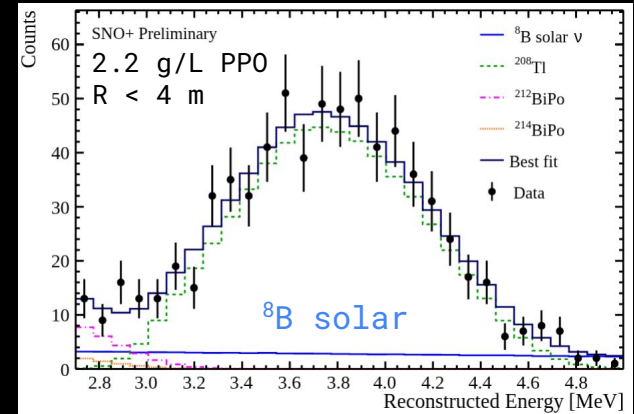


Poster: ^8B Solar Neutrino Flux
Measurement from the Scintillator
Phase **Martina Hebert**



Low energy ^8B solar neutrinos

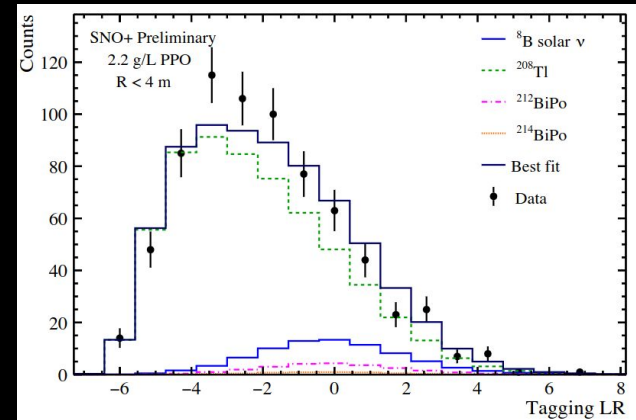
- Investigating low energy ^8B measurement down to ~ 2.2 MeV





Low energy ^8B solar neutrinos

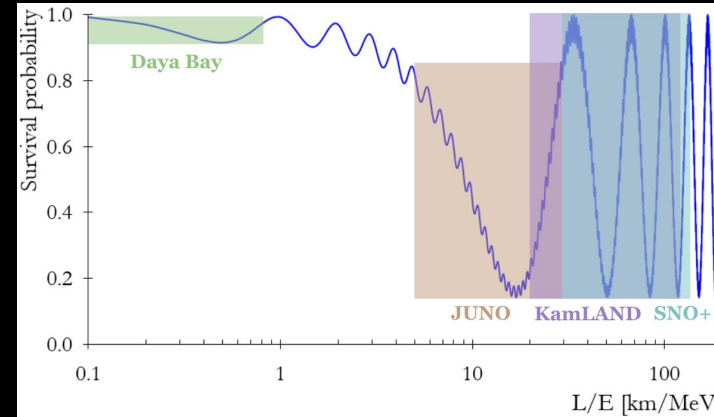
- Investigating low energy ^8B measurement down to ~ 2.2 MeV
- Investigating variety of methods for reducing the ^{208}Tl background:
 1. Energy
 2. Multi-site
 3. Coincidence tagging
 4. Integrated solar directionality





Reactor measurements

SNO+ measures reactor antineutrinos with the longest average baseline (653 km) [closest reactor is 240 km]



Poster: *Reactor v Oscillation and Geo- ν 's at SNO+*
Logan Lebanowski



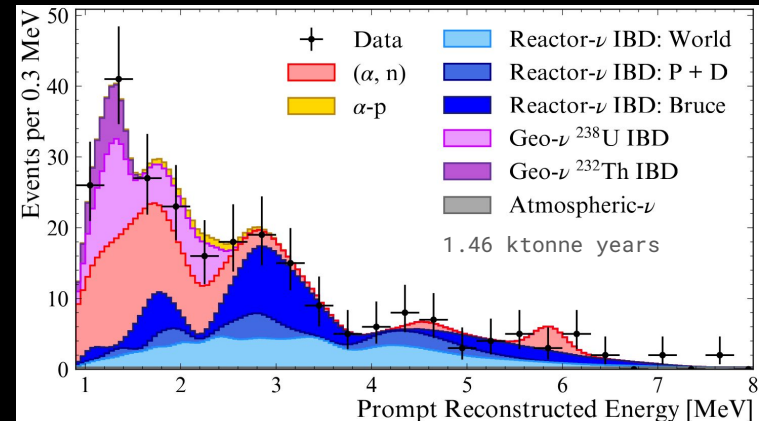
Reactor + geo

- New results use full scintillator dataset through July 2025
- First to identify (α, p) background, important for JUNO and others
- Dominant background, below 3 MeV is from (α, n) reactions, important for geoneutrino measurement

First antineutrino results:

[Phys. Rev. Lett. 135, 121801 \(2025\)](#)

SNO+ Collaboration,
arXiv:2511.11856 [hep-ex]



Poster: *Development and Implementation of an Alpha-Proton Scattering Model for SNO+ Background Characterization*
David Drobner



Geoneutrinos

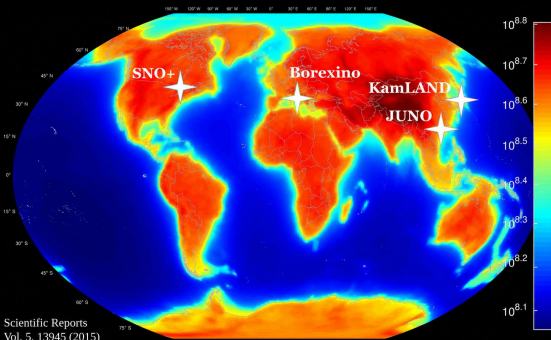
- Developed (α , n) classifier, removes dominant background

First geoneutrino measurement in Western Hemisphere

$$\frac{\text{KamLAND}}{28.6 \pm \frac{5.1}{4.8} \text{ TNU}^*}$$

$$\frac{\text{SNO+}}{49 \pm \frac{13}{12} \text{ TNU}}$$

$$\frac{\text{Borexino}}{47 \pm \frac{8.7}{7.9} \text{ TNU}^{**}}$$

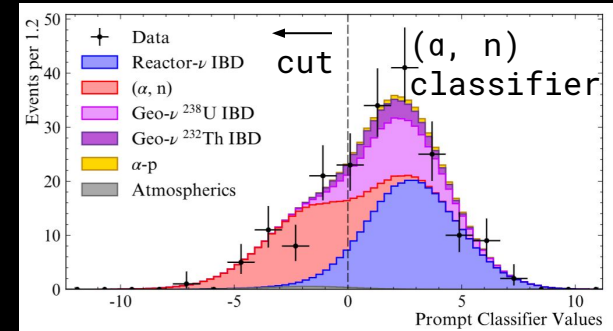


Scientific Reports
Vol. 5, 13945 (2015)

$$\frac{\text{JUNO}}{73 \pm 11 \text{ TNU}}$$

Result from this conference!

SNO+ Collaboration,
arXiv:2511.11856 [hep-ex]



| Fit (α, n) cut | |
|--|------------------------|
| Δm_{21}^2 [$\times 10^{-5} \text{eV}^2$] | 7.56 ± 0.17 |
| $\sin^2 \theta_{12}$ | 0.311 ± 0.012 |
| Geo- $\bar{\nu}$ [TNU] | 49^{+13}_{-12} |
| Geo- $\bar{\nu}$ U/Th | $3.29^{+1.42}_{-1.48}$ |

Oscillation parameters constrained to PDG values in geoneutrino analysis

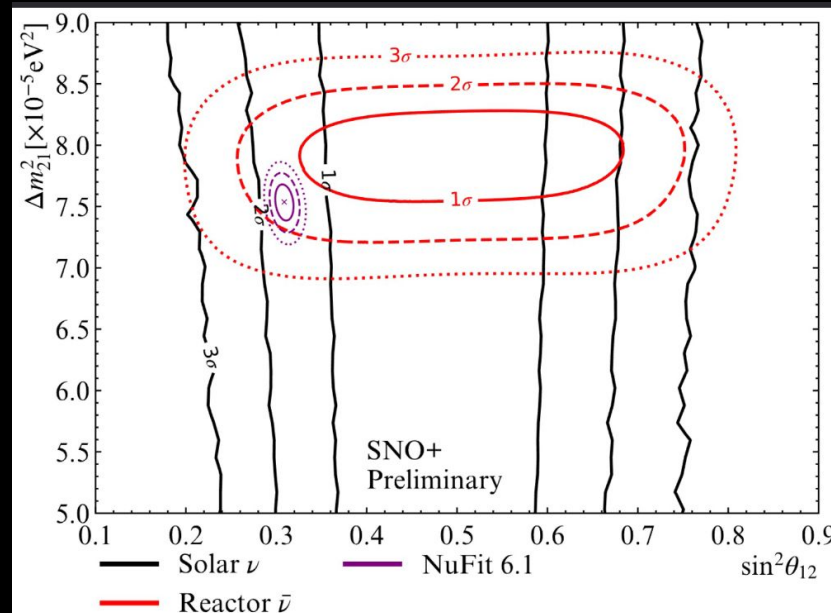
* KamLAND collaboration, [https://indico.global/event/14476/contributions/136079/attachments/63833/123305/Geoneutrino observation with KamLAND Neutrino Geoscience 2025.pdf](https://indico.global/event/14476/contributions/136079/attachments/63833/123305/Geoneutrino%20observation%20with%20KamLAND%20Neutrino%20Geoscience%202025.pdf)

**Borexino Collaboration, Phys. Rev. D 101, 012009 (2020)



Solar + reactor results

First experiment to report solar + reactor fit to Δm_{21}^2 & $\sin^2(\theta_{12})$ in the same detector

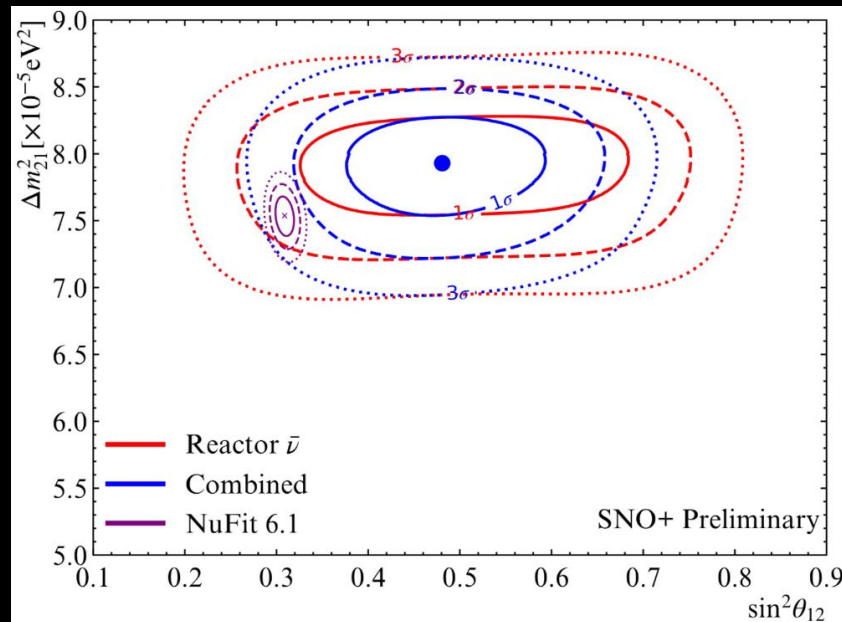


NuFit 6.1
includes JUNO
59.1-day spectrum



Solar + reactor combined

First experiment to report solar + reactor fit to Δm_{21}^2 & $\sin^2(\theta_{12})$ in the same detector

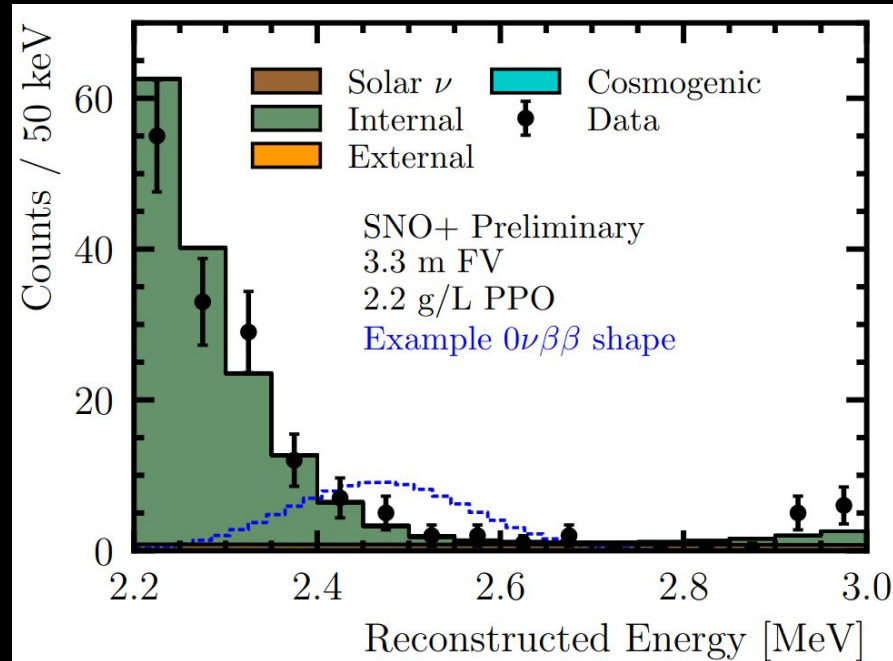


NuFit 6.1
includes JUNO
59.1-day spectrum



Backgrounds in $0\nu\beta\beta$ region

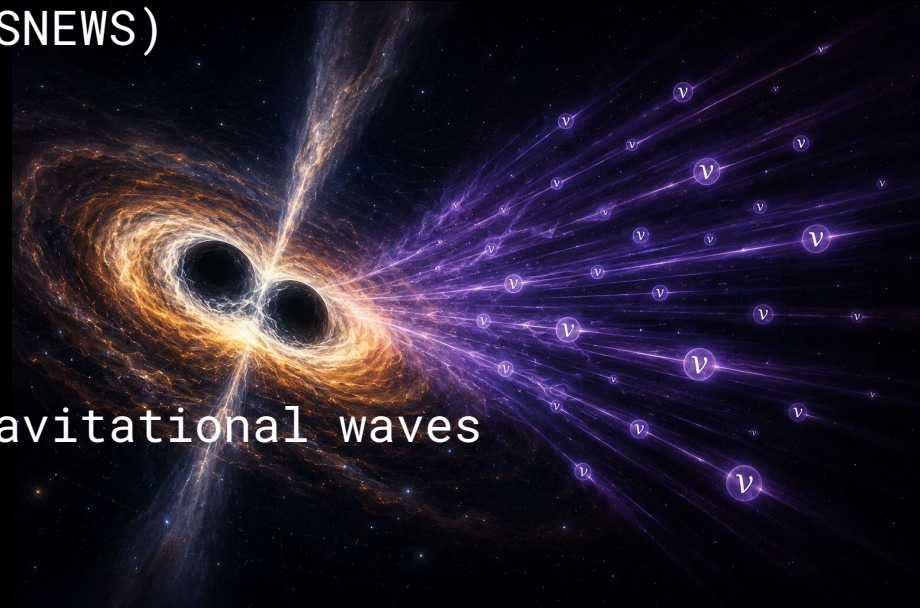
Backgrounds in the $0\nu\beta\beta$ energy
ROI consistent with expectations





Other ongoing analyses

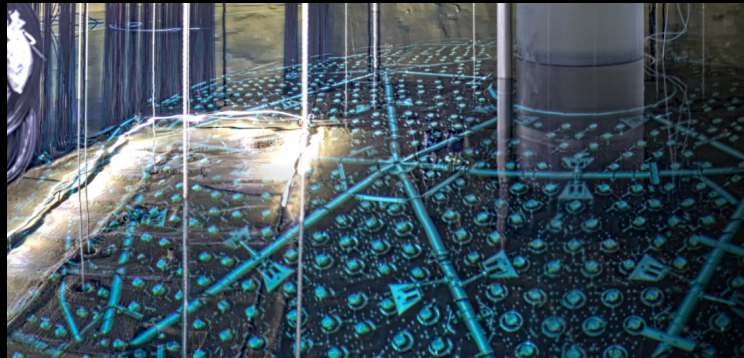
- Supernova burst monitoring (SNEWS)
- Cosmogenic neutrons
- MIMP search
- Neutrinos coincident with gravitational waves



Poster: A Search for MeV-Scale Neutrinos
Coincident with 04 Gravitational Wave
Events in SNO+ Amanda Bacon

Current status & plans

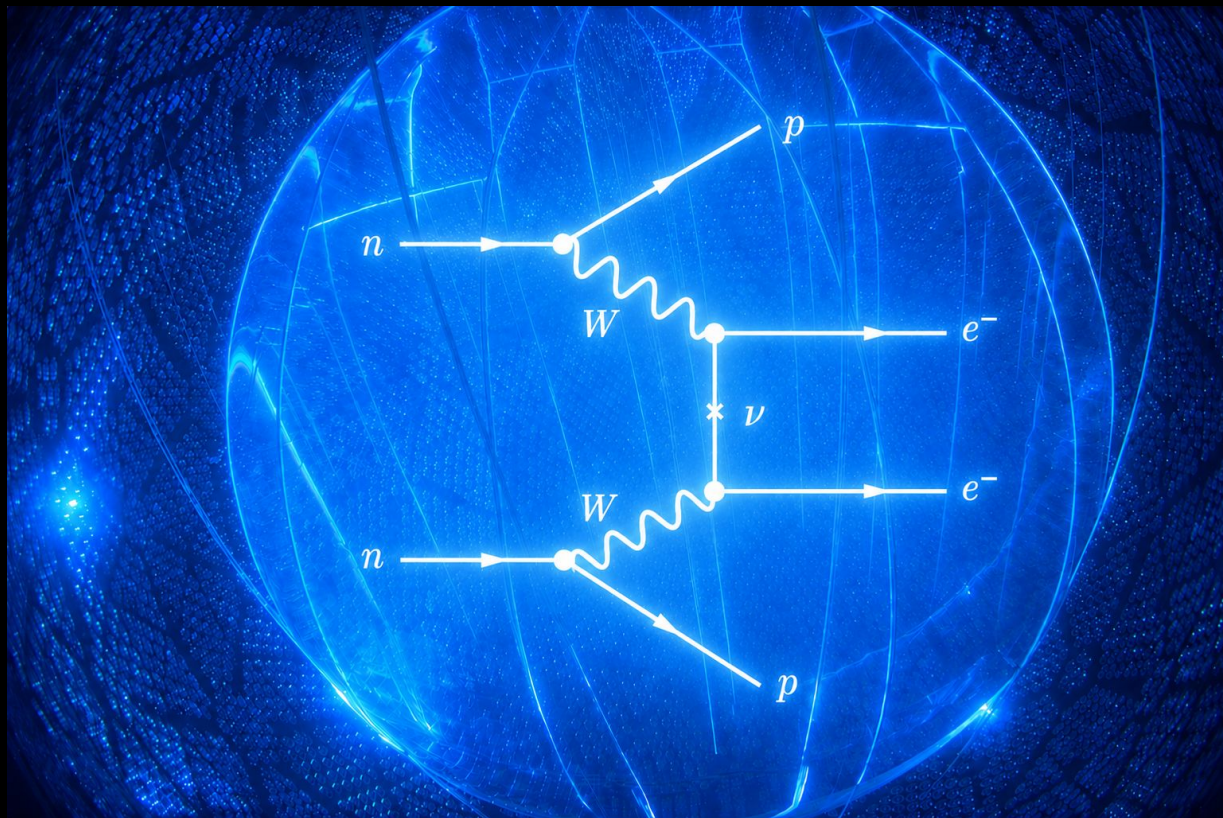
- In 2025 SNO+ identified a leak near the top of the acrylic vessel, allowing a small amount of water to enter the scintillator volume.
- SNO+ is currently draining to repair the leak. Projected fix by Nov. 2026.



Current status & plans

- After fixing the leak, the entire scintillator will be recirculated and stripped with nitrogen, removing backgrounds. Projected finish date is March 2027.
- During that time the commissioning and operation of tellurium plants will continue. Tellurium loading planned for September of 2027.

$0\nu\beta\beta$ phase



$0\nu\beta\beta$ with SNO+

- Scintillator is loaded with natural tellurium ($\sim 34\%$ ^{130}Te)
- Tellurium for 0.5% loading (3.9 tonnes) has been underground ~ 10 yrs
- Sensitivity estimates now using measured optics & measured backgrounds
- Bench-top studies show possible to load to 1.5%, maintaining stability, transparency, light yield, & PSD

Tellurium loading

- Pioneered novel tellurium loading of scintillator and purification technique
- Significant underground operations: construction & commissioning of chemical plants

For details on Te purification & loading:

D. Auty, et al., NIM, A 1051 (2023) 168204

C. Buck and M. Yeh, NIM, A 795 (2025) 132-139

Underground chemical plants



TeA plant



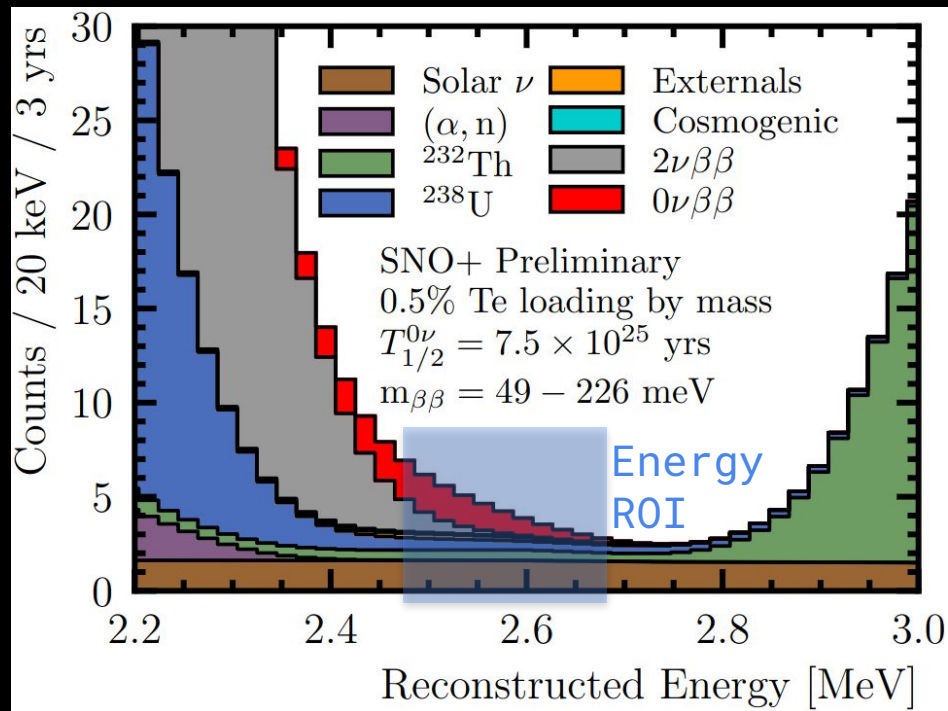
Butanediol plant



DDA plant

$0\nu\beta\beta$ with SNO+

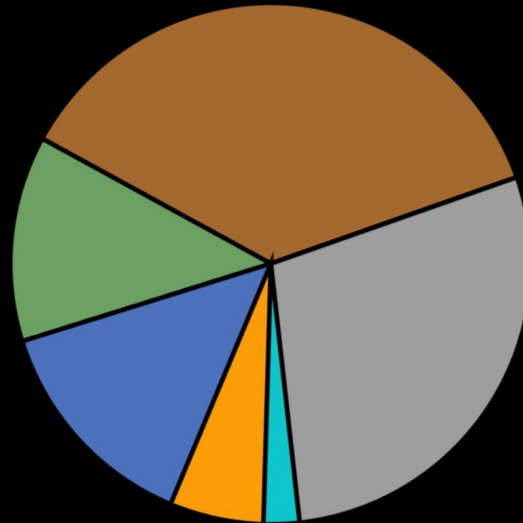
Expected energy spectrum with 0.5% tellurium loading and hypothetical $0\nu\beta\beta$ signal





Expected backgrounds

0.5% Te loading in example fiducial volume and energy ROI



Solar ν

- Measured rate
- Investigating additional rejection with directionality



Expected backgrounds

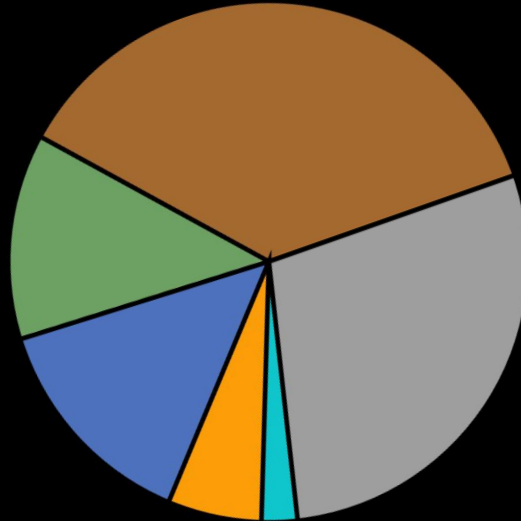
0.5% Te loading in example fiducial volume and energy ROI

Internal Th

- Measured contribution from scintillator
- Improved tagging of $^{212}\text{BiPo}$ ongoing

Internal U

- Measured contribution from scintillator



Solar ν

- Measured rate
- Investigating additional rejection with directionality



Expected backgrounds

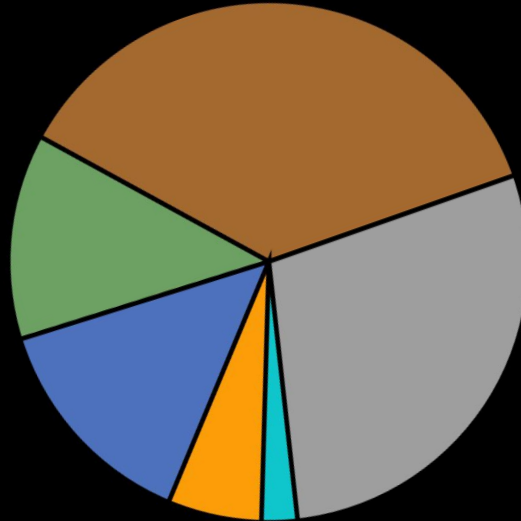
0.5% Te loading in example fiducial volume and energy ROI

Internal Th

- Measured contribution from scintillator
- Improved tagging of $^{212}\text{BiPo}$ ongoing

Internal U

- Measured contribution from scintillator



Solar ν

- Measured rate
- Investigating additional rejection with directionality

$2\nu\beta\beta$

- Asymmetric ROI

Expected backgrounds

0.5% Te loading in example fiducial volume and energy ROI

Internal Th

- Measured contribution from scintillator
- Improved tagging of $^{212}\text{BiPo}$ ongoing

Internal U

- Measured contribution from scintillator

External γ -rays

- Measured rate
- Fiducilization
- Multi-site rejection

Cosmogenic

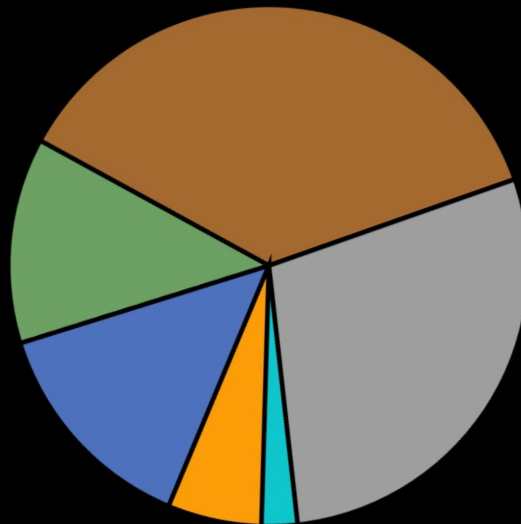
- UG tellurium (~10 years)
- Multi-site rejection

Solar ν

- Measured rate
- Investigating additional rejection with directionality

$2\nu\beta\beta$

- Asymmetric ROI



Expected backgrounds

0.5% Te loading in example fiducial volume and energy ROI

Internal Th

- Measured contribution from scintillator ✓
- Improved tagging of $^{212}\text{BiPo}$ ongoing

Internal U

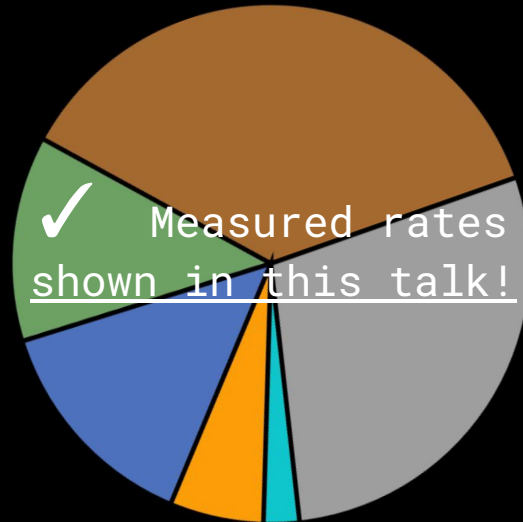
- Measured contribution from scintillator ✓

✓ External γ -rays

- Measured rate
- Fiducilization
- Multi-site rejection

Cosmogenic

- UG tellurium (~10 years)
- Multi-site rejection



Solar ν ✓

- Measured rate
- Investigating additional rejection with directionality

$2\nu\beta\beta$

- Asymmetric ROI

$\theta\nu\beta\beta$ sensitivity

3-years at 0.5%:

$$T_{1/2}^{\theta\nu} > 2 \times 10^{26} \text{ years (90\% C.L)}, m_{\beta\beta} \sim 30 - 137 \text{ meV}$$

$\theta\nu\beta\beta$ sensitivity

3-years at 0.5%:

$$T_{1/2}^{\theta\nu} > 2 \times 10^{26} \text{ years (90\% C.L)}, m_{\beta\beta} \sim 30 - 137 \text{ meV}$$

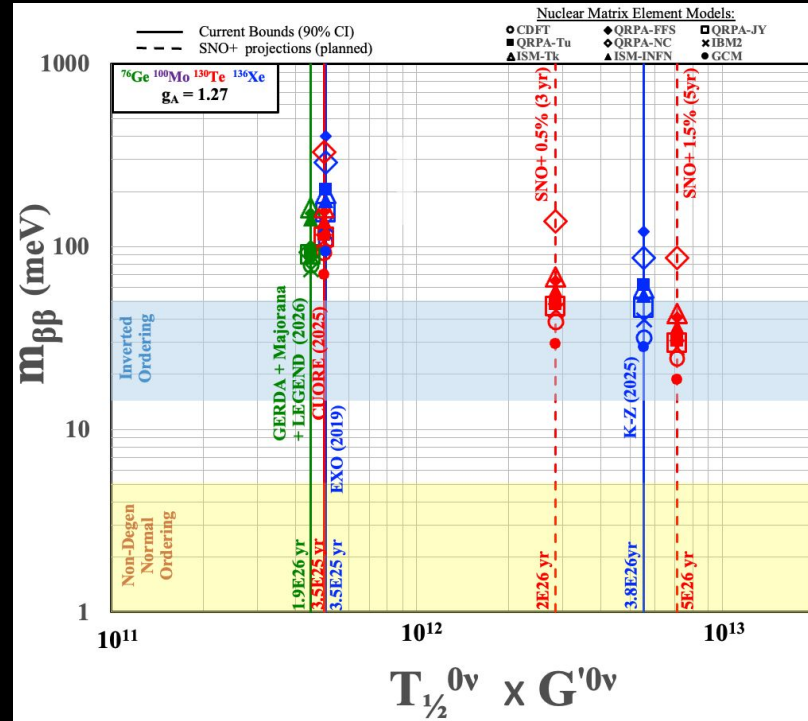
After running at 0.5%, could increment loading to 1.5%, as part of maximizing $m_{\beta\beta}$ sensitivity

5-years at 1.5%:

$$T_{1/2}^{\theta\nu} > 5 \times 10^{26} \text{ years (90\% C.L)}, m_{\beta\beta} \sim 19 - 87 \text{ meV}$$

$0\nu\beta\beta$ in context

At 1.5% loading, expect a world-leading limit.



Data from other experiments:

LEGEND: Phys.Rev.Lett. 136 2, 022701 (2026)
KamLAND-Zen: Phys.Rev.Lett. 135, 262501 (2025)

EXO-200: Phys.Rev.Lett. 123, 161802 (2019)
CUORE: Science 390,1029-1032 (2025)

Conclusion

- SNO+ is running with liquid scintillator and has new results on backgrounds, solar neutrinos, and reactor+geo neutrinos
- Background measurements in the $0\nu\beta\beta$ ROI are consistent with expectation in partial fill & scintillator phases
- The $0\nu\beta\beta$ phase is planned to start in 2027 and with 1.5% loading we plan for a world-leading limit



Acknowledgements

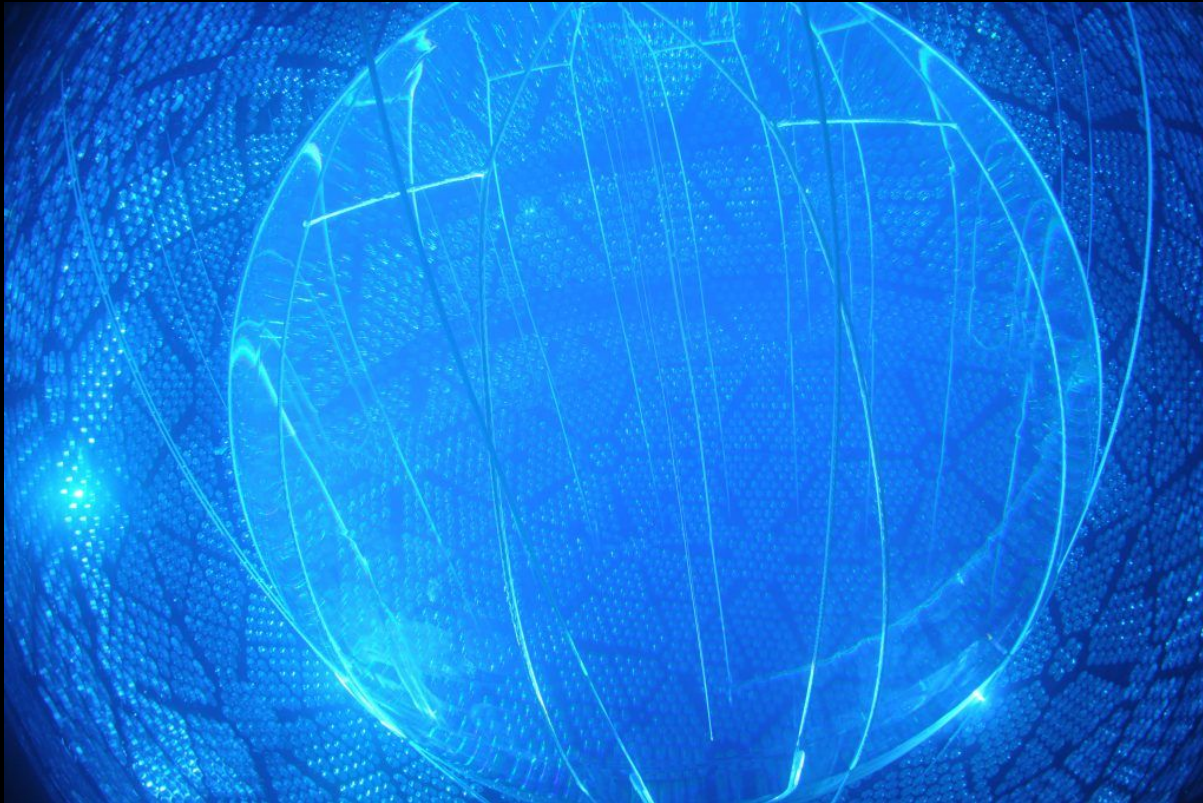
Thanks to the SNO+ collaboration!



U.S. DEPARTMENT
of ENERGY

Office of Science

Backup





Water phase papers

Please find more details in our water phase papers:

1. Invisible nucleon decay: PRD 99, 032008 (2019)
2. Solar neutrinos: PRD 99, 012012 (2019)
3. Neutron-proton capture: PRC 102, 014002 (2020)
4. Optical calibrations: JINST 16, P10021 (2021)
5. SNO+ detector: JINST 16, P08059 (2021)
6. Invisible nucleon decay: PRD 105, 112012 (2022)
7. Reactor antineutrinos: PRL 130, 091801 (2023)
8. Solar neutrinos: PRD 110, 122003 (2024)
9. Cosmogenic neutrons: PRD 113, 052014 (2026)

Scintillator fill

2019: Started filling LAB into neck

2020: Began adding PPO to the LAB

Apr. 2020: Operations paused with LAB + PPO (0.6 g/L). Led to “partial fill” phase

2021: Finished filling detector with LAB

2022: Final PPO concentration of 2.2 g/L achieved. Beginning of “scintillator fill”.

June 2023: Add BHT to LAB + PPO (2.2 g/L)

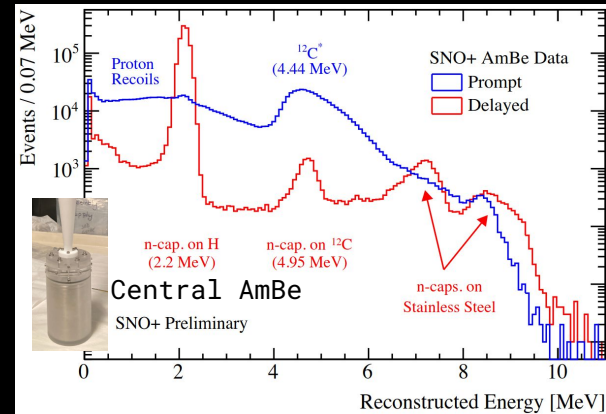
July 2023: Added bisMSB (wavelength shifter) in stages, final concentration of 2.2 mg/L



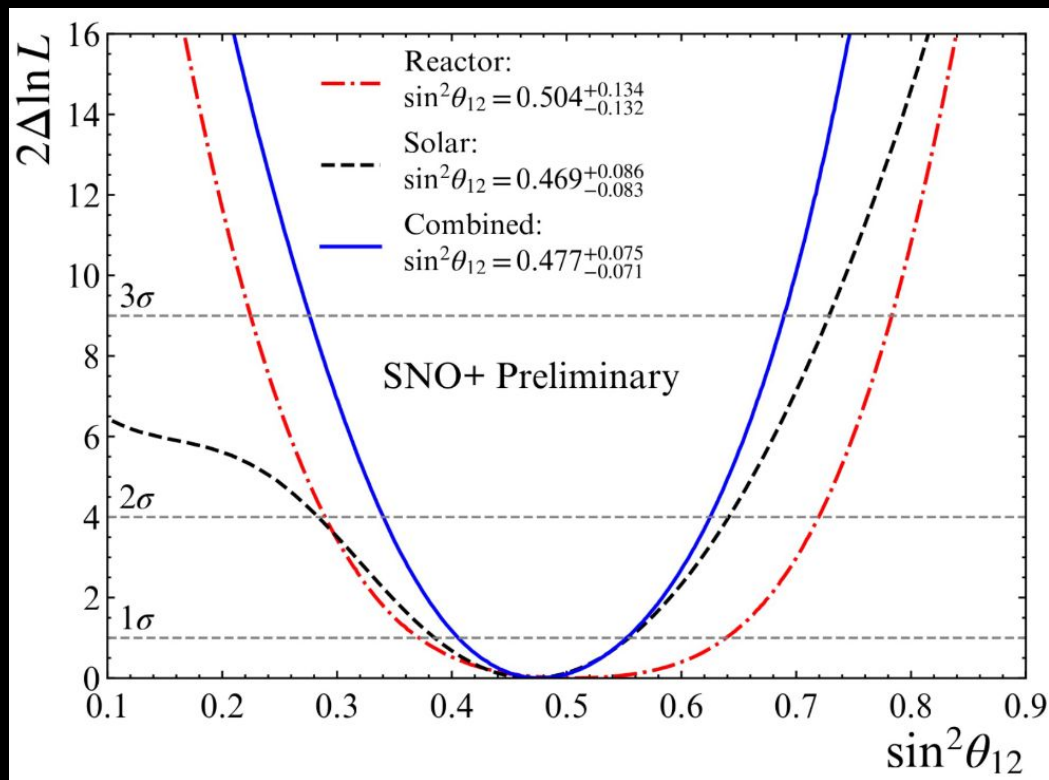
Calibrations

Deployed two calibrations sources into the scintillator:

- AmBe provides tagged, monoenergetic γ -rays and source of proton recoils
- Laserball provides light with known timing and wavelength distributions to cross-check optical modeling

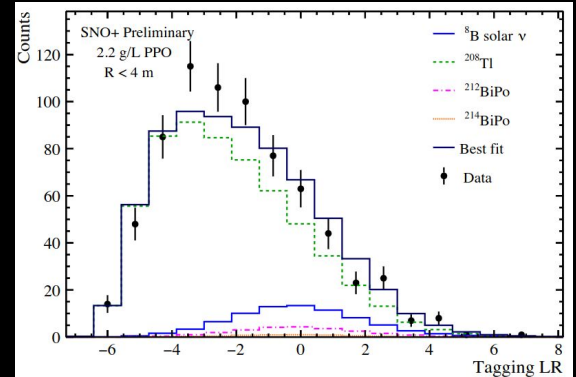
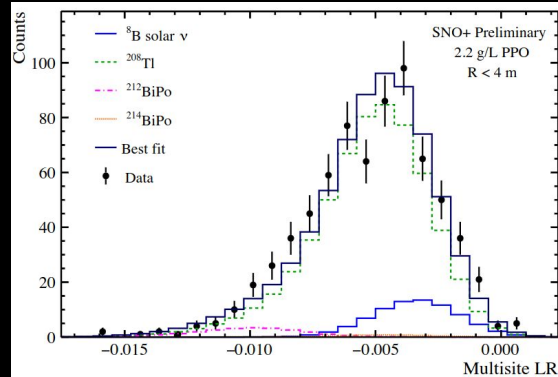
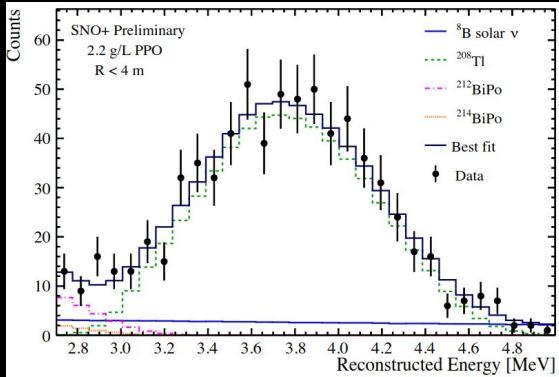


Reactor + solar

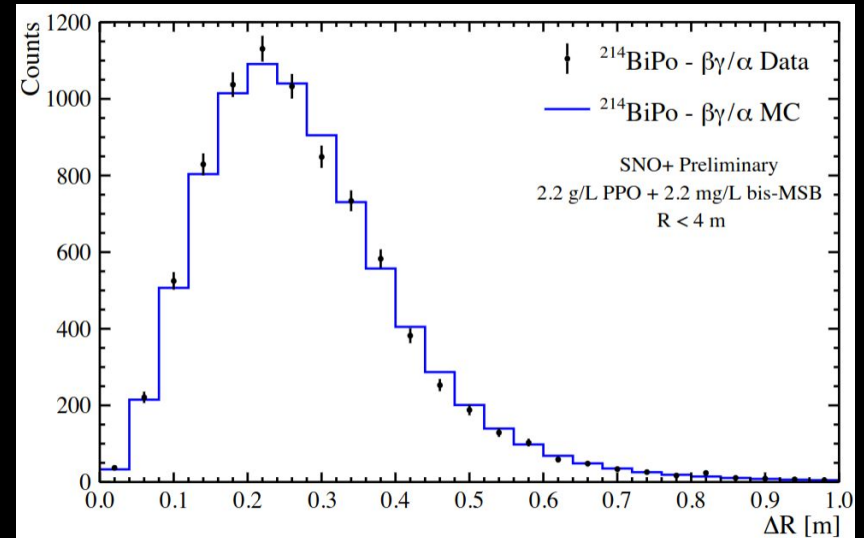
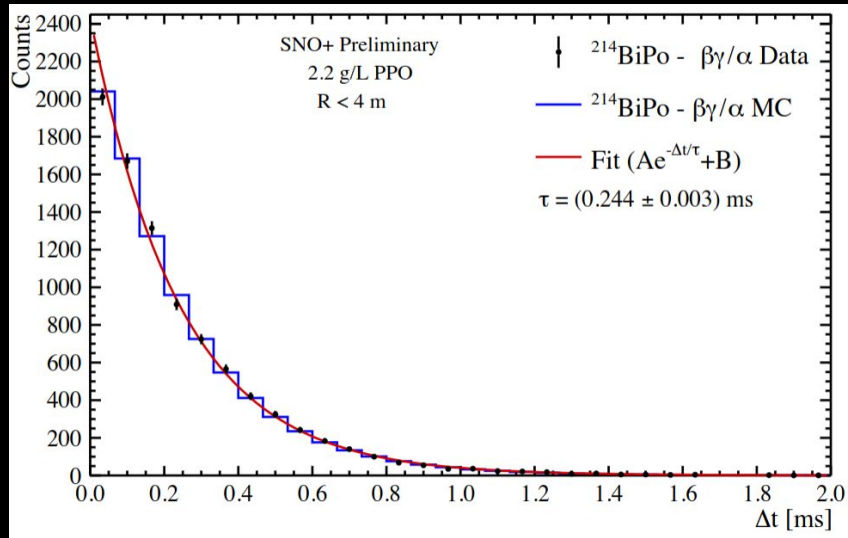


Low energy ^8B solar neutrinos

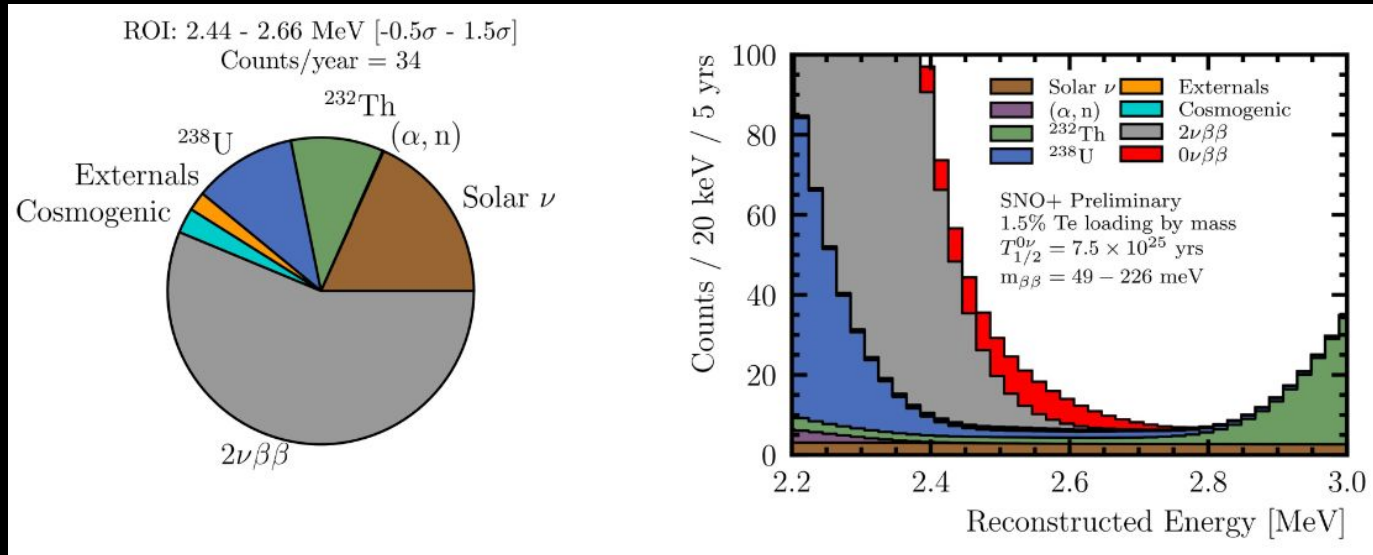
^{208}Tl tagging using multi-site & tagging



^{214}Bi tagging



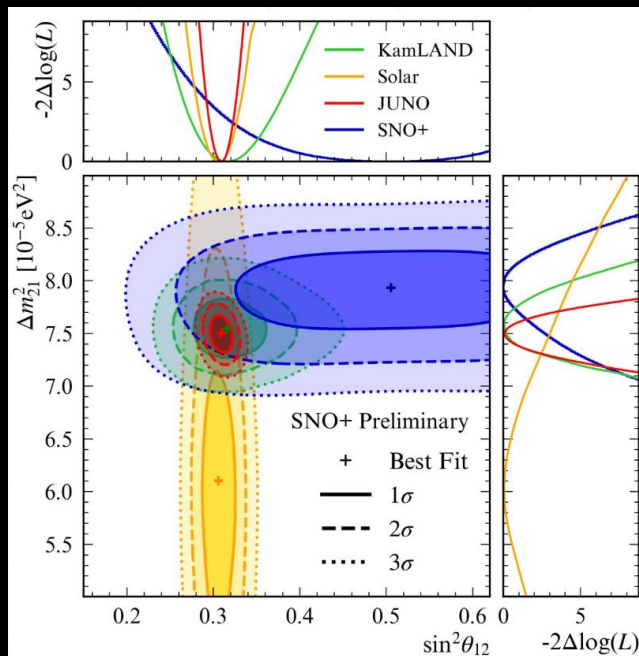
1.5% $\theta\nu\beta\beta$ spectrum





Reactor neutrinos

Unconstrained fit for Δm_{21}^2 and $\sin^2(\theta_{12})$



| Fit | |
|--|------------------------|
| Δm_{21}^2 [$\times 10^{-5} \text{eV}^2$] | $7.93^{+0.21}_{-0.24}$ |
| $\sin^2 \theta_{12}$ | 0.505 ± 0.134 |

NuFIT 6.1 (includes JUNO)

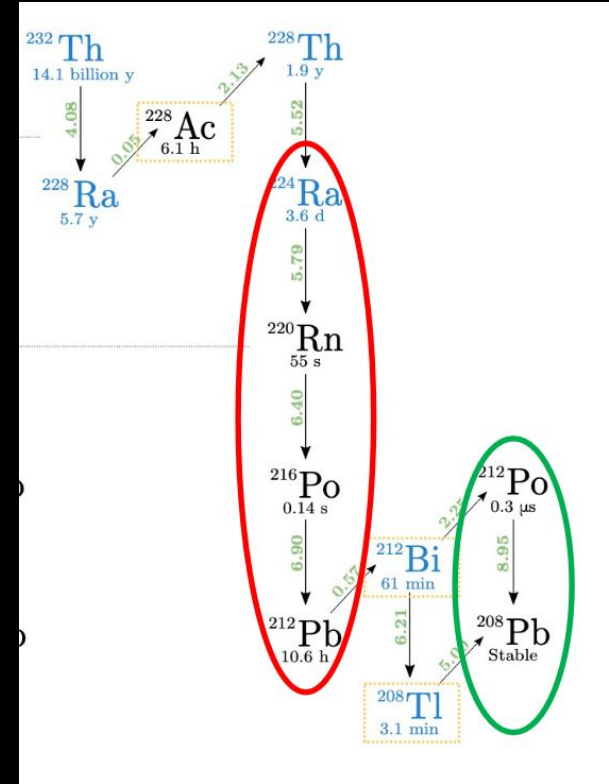
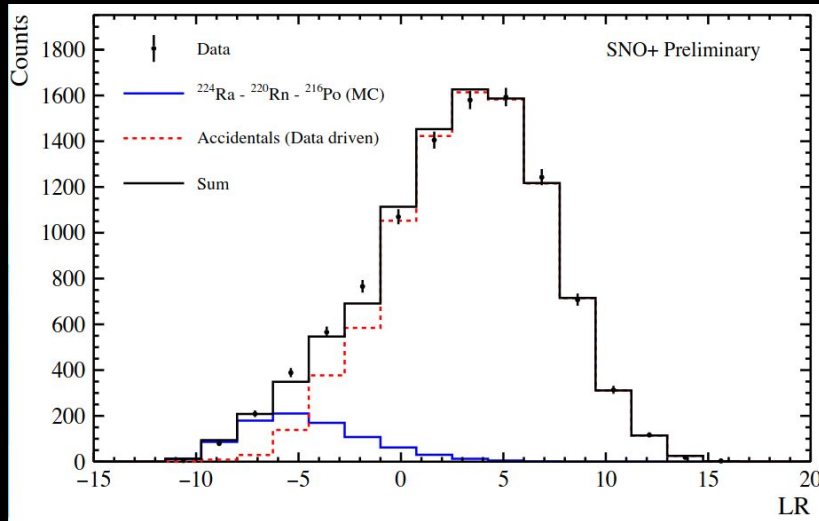
$$\Delta m_{21}^2 = 7.54 \pm 0.10 \times 10^{-5} \text{ eV}^2$$

$$\sin^2(\theta_{12}) = 0.309 \pm 0.007$$

Thorium tagging

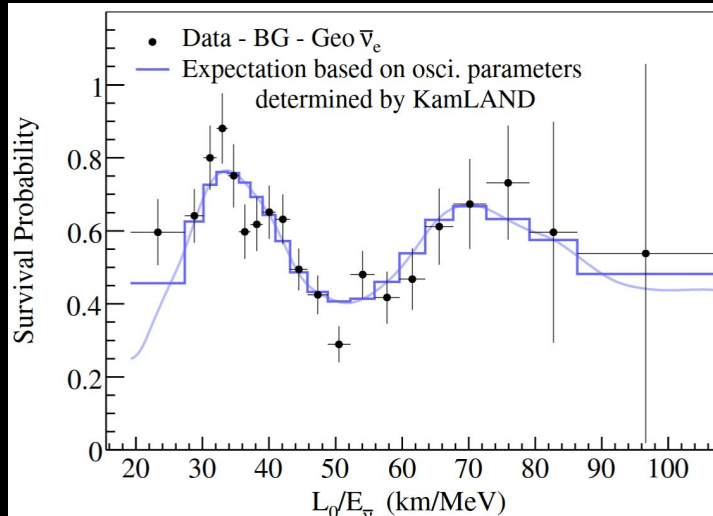
Triple tag: ^{224}Ra - ^{220}Rn - ^{216}Po

Confirms rate from $^{212}\text{BiPo}$ tagging

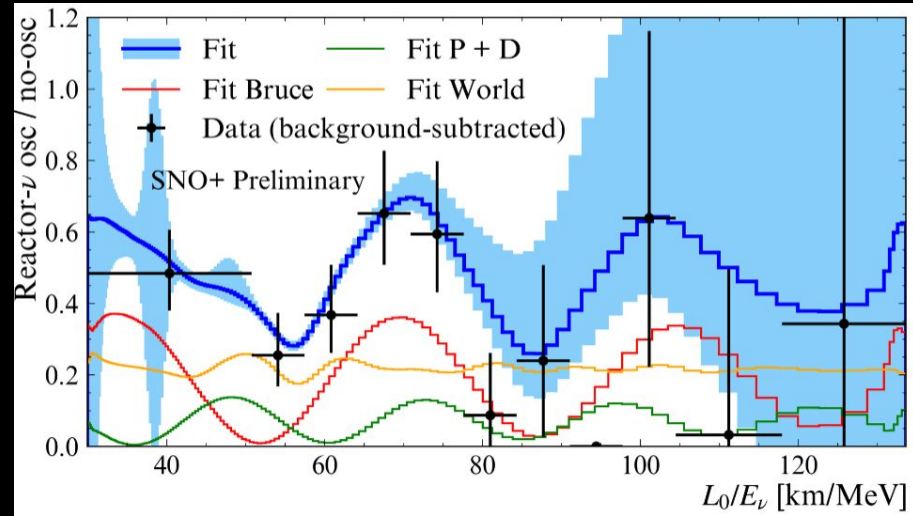




Reactor neutrinos



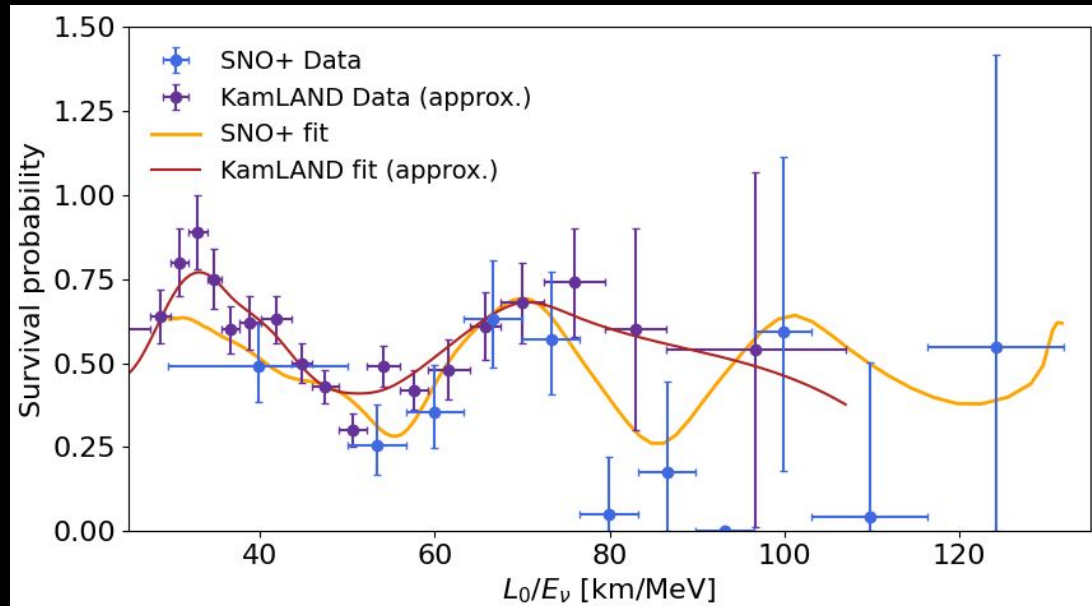
KamLAND Collaboration,
*Phys.Rev.Lett.*100:221803,20080





Reactor neutrinos

SNO+ has begun exploring disappearance minima at larger L_0/E_ν



Approximate (just for visualization)
Using $L_0=269$ km for SNO+

Solar neutrino interactions on ^{13}C tagging

