

Detector Calibration for SNO+ Antineutrino Studies

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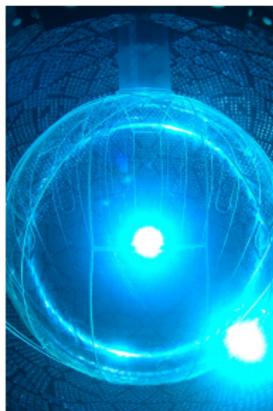


The SNO+ Experiment

- Kilo-tonne scale liquid scintillator neutrino detector located 2 km underground at SNOLAB in Sudbury, Ontario.
- 12 m diameter Acrylic Vessel (AV) containing 780 tonnes of liquid scintillator:
 - **LAB + 2.2 g/L PPO + 6.5 mg/L BHT + 2.2 mg/L bis-MSB**
- Extending 2.4 m in thickness is a 1500 ton protective layer of Ultra-Pure Water (UPW) that sits in between the Photomultiplier Tube (PMT) array.
- ~9500 PMTs mounted on a geodesic spherical support structure (PSUP).
- Structure suspended by hold-up and hold-down ropes in a 30 m tall cavity containing 5300 tonnes of UPW.

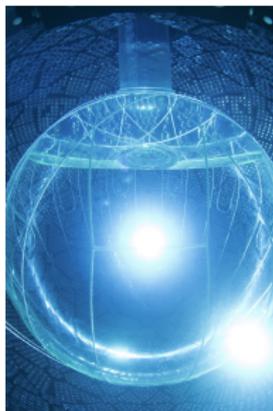


Experimental Phases



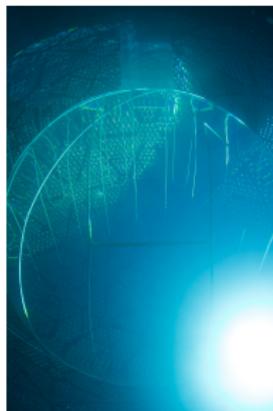
Water Phase

- May 2017 – Jul 2019
- Invisible nucleon decay.
- First-ever evidence of reactor antineutrinos in water.
- ^8B solar neutrinos.



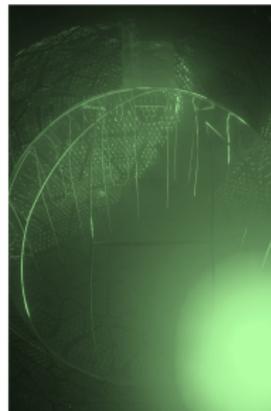
Partial-Fill Phase

- Mar 2020 – Oct 2020
- First-ever event-by-event directionality in scintillator.
- Preliminary reactor antineutrino measurement.



Full-Fill Phase

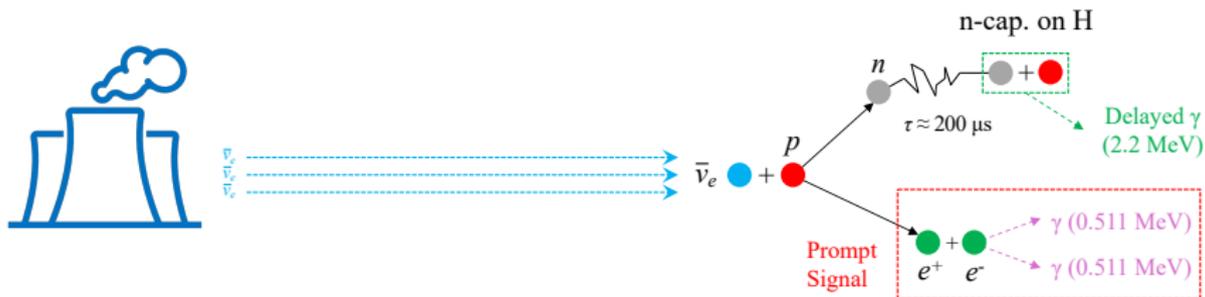
- Apr 2021 – Present
- Solar, reactor, supernova & geoneutrinos.
- Evaluate backgrounds prior to $0\nu\beta\beta$ decay search.



Tellurium Phase

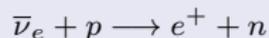
- Future
- Continuation of most of the scintillator phase physics program.
- Search for $0\nu\beta\beta$ decay in ^{130}Te .

The Antineutrino Program



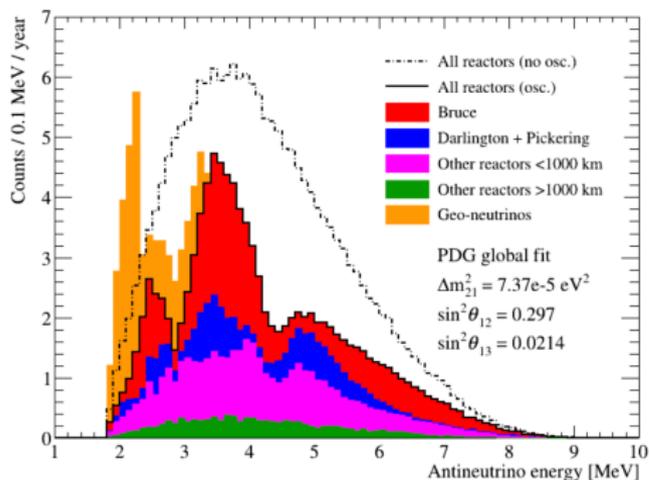
Antineutrino Detection

- Detected through the Inverse β Decay (IBD) reaction:



- Scintillation light produced by energy deposition of outgoing e^+ (**prompt signal**).
- Outgoing n thermalizes and captures on H roughly 200 μ s later, releasing a 2.2 MeV γ (**delayed signal**).
- Coincident events are closely separated in space and time, allowing for powerful background reduction.

The Antineutrino Program



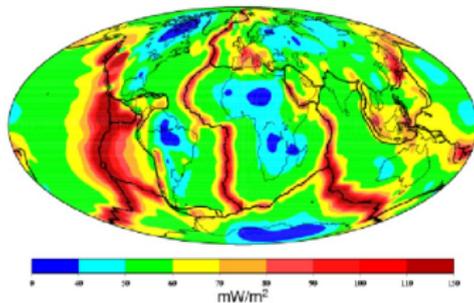
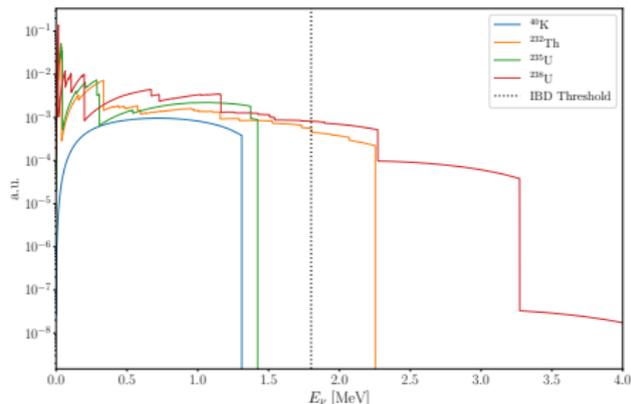
Reactor Antineutrinos

- 240-350 km baseline to Ontario nuclear reactors gives good sensitivity to oscillation parameters Δm_{21}^2 and $\sin^2 \theta_{12}$.
- Solar neutrinos provide sensitivity to the same oscillation parameters.
 - **Test the tension between solar + KamLAND (reactor) experiments.**

The Antineutrino Program

Geoneutrinos

- Antineutrinos emitted from the decay chains of heavy elements in the Earth (^{238}U , ^{235}U , ^{232}Th , ^{40}K).
- Geoneutrinos from ^{238}U & ^{232}Th decays cross 1.8 MeV IBD threshold, thus making an irreducible background to the reactor antineutrino search.
- **Reactor and geoneutrino fluxes must be fit simultaneously.**
- Likely responsible for most of the Earth's heat production.
- Can also probe the chemical composition of the Earth's interior.



Cardoso, R. & Hamza, V.. (2011).

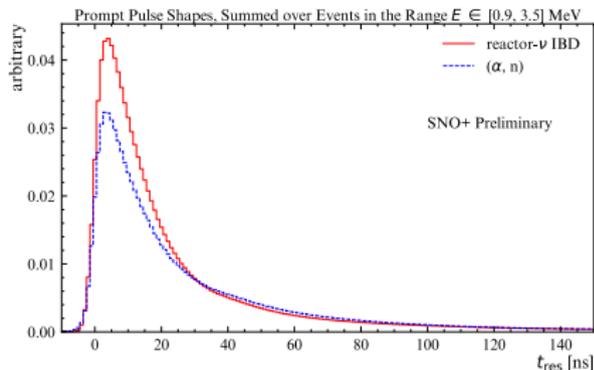
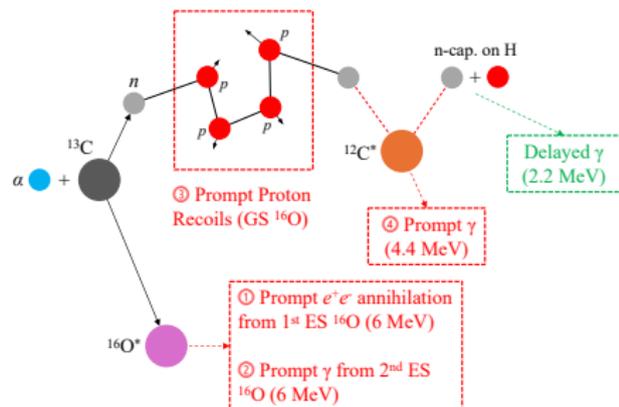
(α, n) Backgrounds

Mechanism

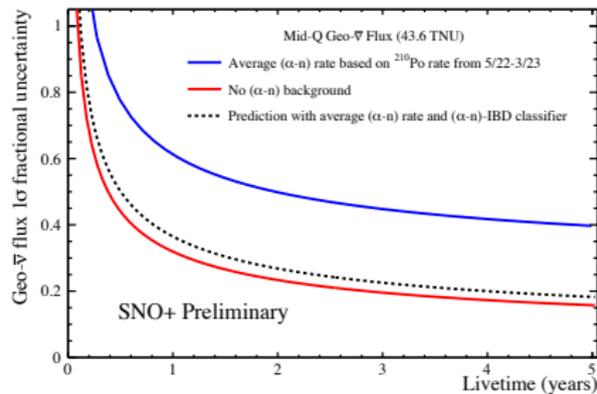
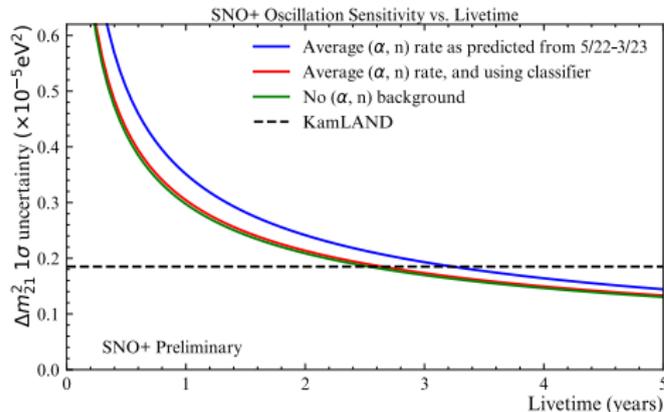
- α -Decays from ^{210}Po can produce (α, n) events:



- Reaction produces prompt γ 's at a range of energies. Higher energy neutrons can also induce prompt proton recoils.
- This, in combination with subsequent delayed neutron capture, can mimic an IBD event.
- Fortunately, (α, n) events can be classified based on their timing structure.



(α, n) Backgrounds – Impact on Antineutrino Analysis

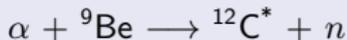


- Reduction of (α, n) background moderately improves sensitivity to Δm_{21}^2 (reactor).
- Reduction of (α, n) background *significantly* improves sensitivity to geoneutrino flux due to high correlation between (α, n) and geoneutrino energy spectra in fits.
- *Can we calibrate SNO+ to IBD-like events?*

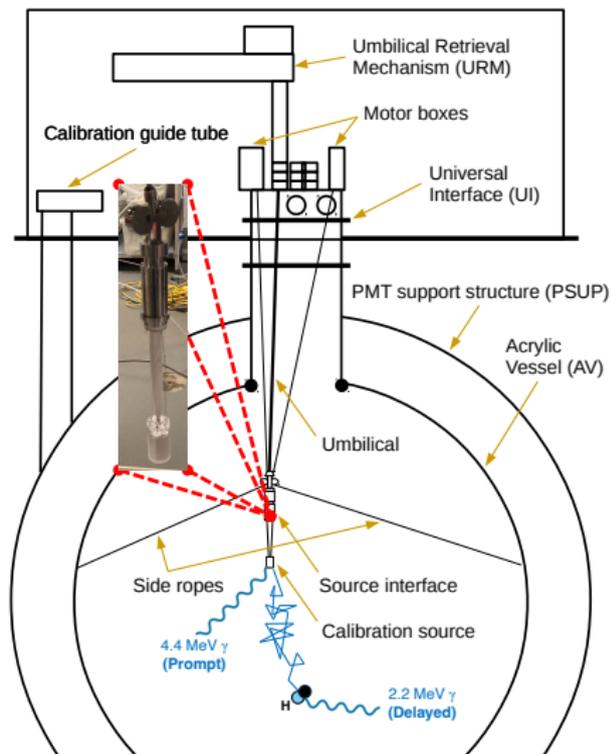
The AmBe Source

Main Calibration Points

- Following the α -decay of ^{241}Am :



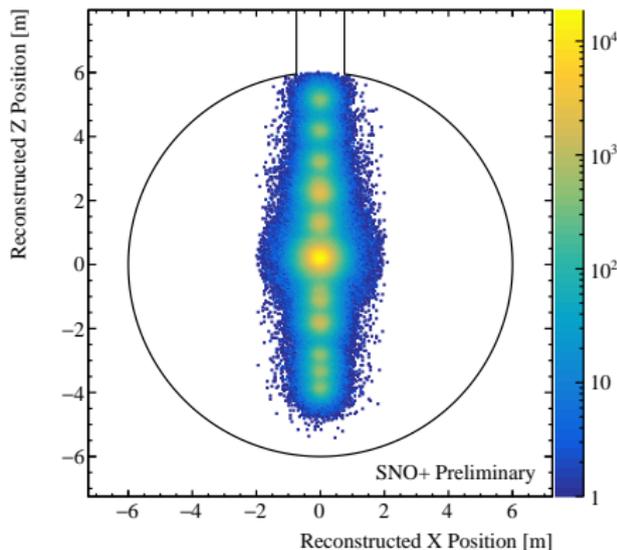
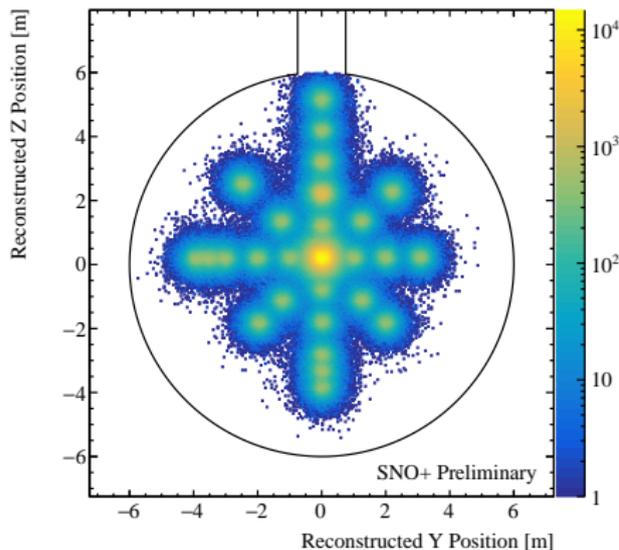
- 60% of the time, ${}^{12}\text{C}^*$ de-excites and emits a 4.4 MeV γ (**prompt**).
- About 200 μs later, the neutron captures on H, releasing a 2.2 MeV γ (**delayed**).
- Stainless steel layer on source encapsulation hardware provides additional 7.6 MeV γ 's via neutron captures on ${}^{56}\text{Fe}$.



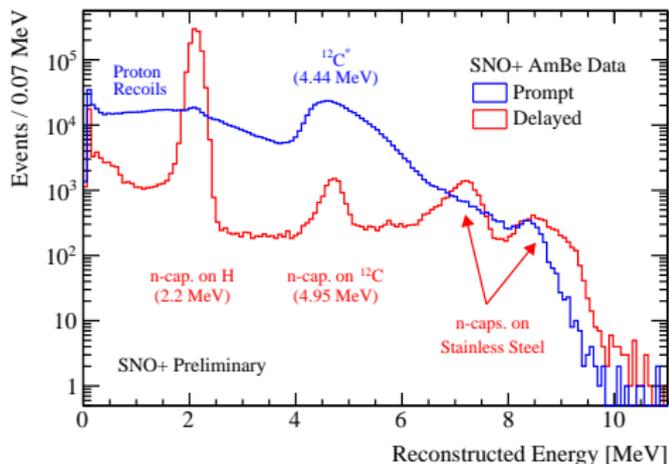
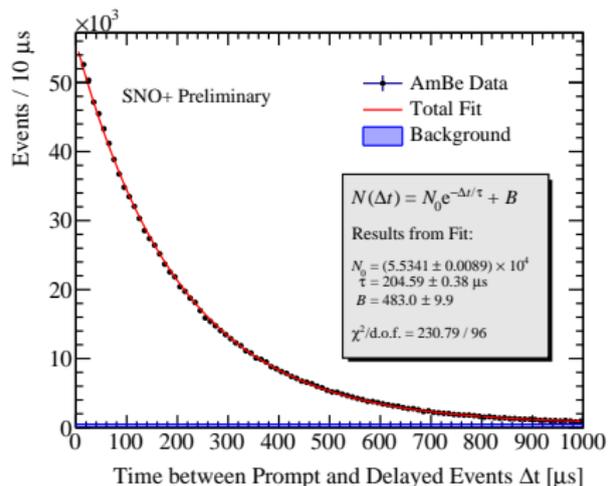
The AmBe Calibration Campaign

"We have AmBe!"

- Figure shows tagged prompt events from the AmBe scan performed in Nov 2025.



Coincident Events from the AmBe Source



- Figures associated with AmBe data collected near the centre of the detector.
- Neutron capture time constant determined to be $\tau = 204.59 \pm 0.38 \mu\text{s}$. Consistent with expectations.

Latest Antineutrino Measurements from SNO+

Pre-print available: [arXiv:2511.11856v2](https://arxiv.org/abs/2511.11856v2)

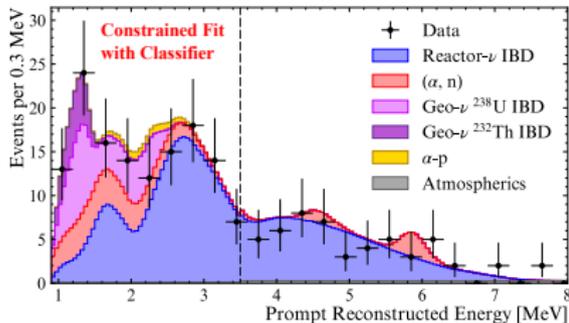
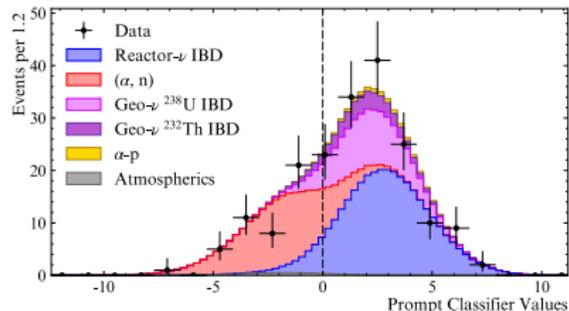
- AmBe calibration data used to quantify systematic uncertainties on (α, n) classifier.
- SNO+ provides first geoneutrino flux in the Western hemisphere:

$$\Phi_{\text{Geo-}\nu} = 49_{-12}^{+13} \text{ TNU}$$

- SNO+ provides 1st independent confirmation of KamLAND result (and now JUNO).
- In agreement with KamLAND, confirming tension in solar + reactor Δm_{21}^2 measurements:

$$\Delta m_{21}^2 = (7.93_{-0.24}^{+0.21}) \times 10^{-5} \text{ eV}^2$$

$$\sin^2 \theta_{12} = 0.505 \pm 0.134$$



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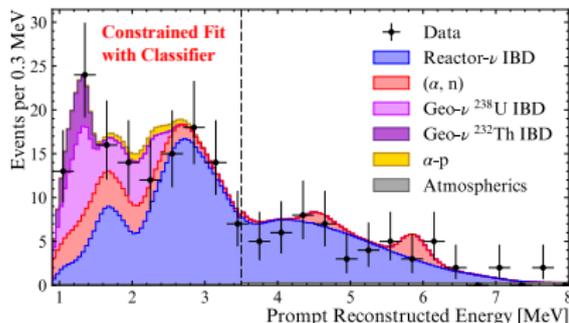
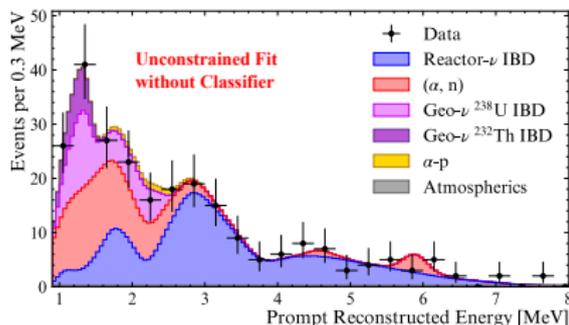
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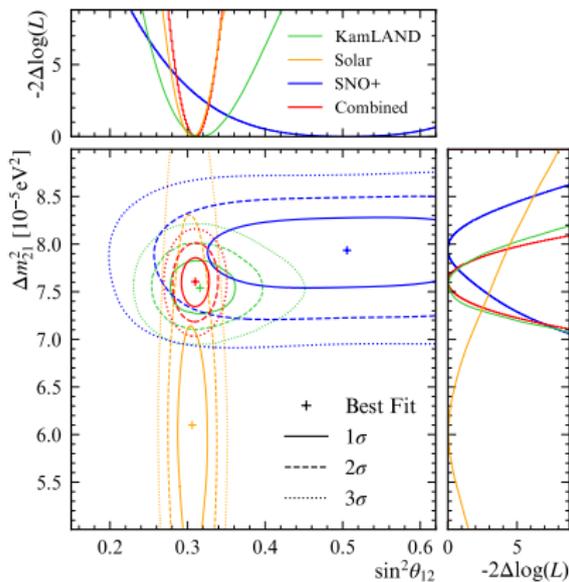
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Summary

- SNO+ is a liquid scintillator neutrino detector with many physics goals!
- The full AmBe calibration campaign spanned Jul 2025 – Nov 2025.
- Calibration results were used to evaluate (α, n) event classifier systematics for antineutrino analysis.
- SNO+ published updated results for Δm_{21}^2 , $\sin^2 \theta_{12}$ and $\Phi_{\text{Geo-}\nu}$:

$$\Phi_{\text{Geo-}\nu} = 49_{-12}^{+13} \text{ TNU}$$

$$\Delta m_{21}^2 = (7.93_{-0.24}^{+0.21}) \times 10^{-5} \text{ eV}^2$$

$$\sin^2 \theta_{12} = 0.505 \pm 0.134$$

- Results confirm solar + reactor tension and give only geoneutrino flux measurement in the Western hemisphere.

Thank You!

