Reactor ν Oscillation and Geo-ν's at SNO+

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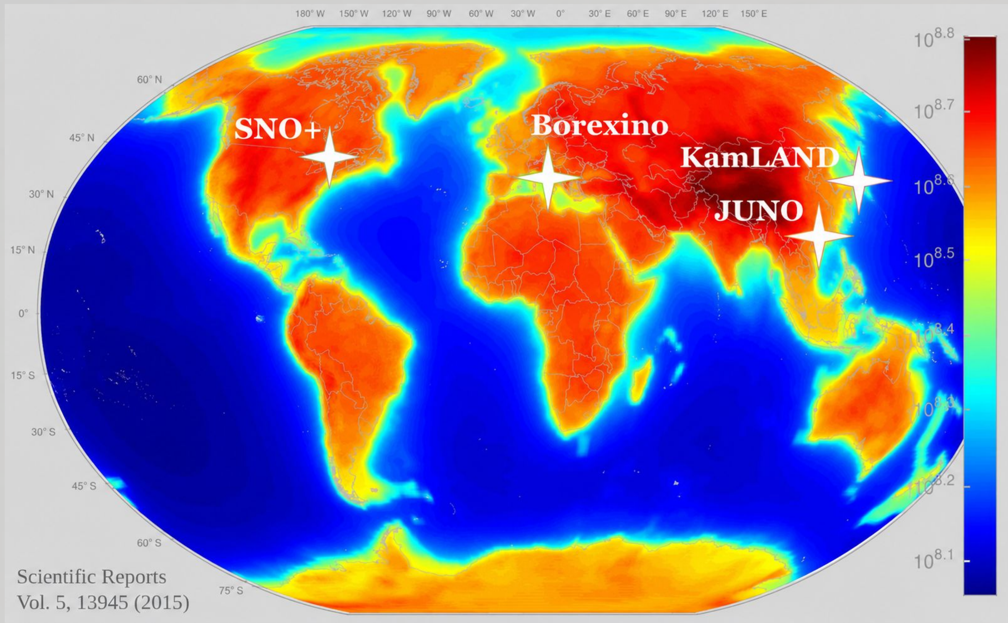
NEUTRINO '26
International Conference on Neutrino Physics and Astrophysics
June 22nd - 26th, 2026
UCI Department of Physics & Astronomy

SNO+ Experiment

- SNO+ is a liquid scintillator experiment preparing to search for neutrinoless double beta decay.
- With 780 tonnes of highly-radiopure scintillator 2 km underground in Ontario, Canada, SNO+ also studies ν's from the Sun, the Earth, and nuclear reactors.

FIG. 1. SNO+ acrylic vessel (radius 6 m), 9394 PMTs, 2.5-m water buffer.

FIG. 2. Map of predicted U+Th geo-ν flux. Measurement locations are marked.



Reactor ν and Geo-ν

- Anti-ν_e are produced by fission in nuclear reactors and by ^{238}U & ^{232}Th decay chains in the Earth.
- Detected with prompt-delayed coincidences from inverse beta decay: $\overline{\nu}_e + p \rightarrow e^+ + n$
  - Prompt e^+ energy closely follows anti-ν_e energy.
  - Delayed event is a 2.2-MeV n-capture γ.

FIG. 3. Positions of prompt and delayed events within the 5.7 m fiducial volume.

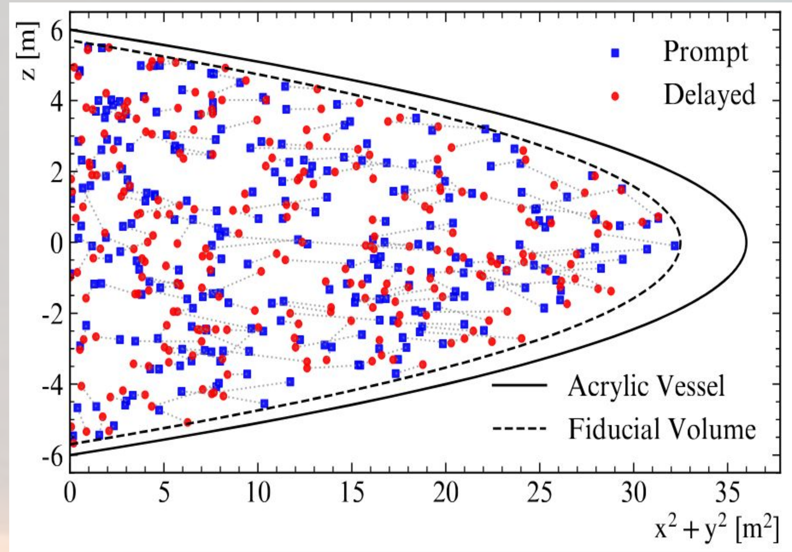


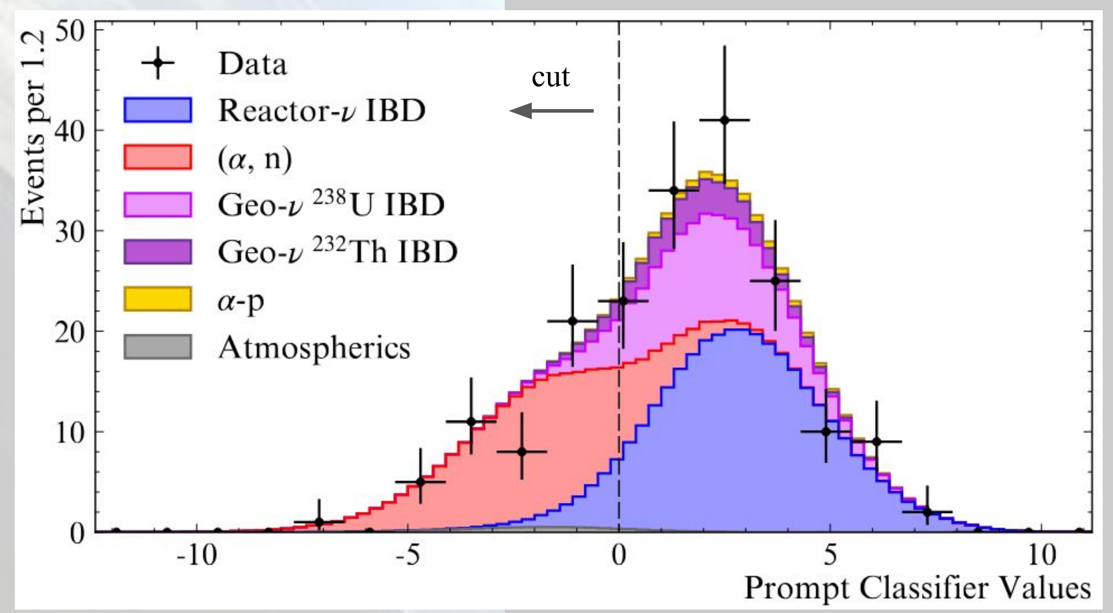
TABLE I. Expected counts in 1.46 ktonne-yrs. Syst. unc. only (geo-ν IBD rate unconstrained).

	Expected
Reactor IBD	140 ± 6
Geo ^{238}U IBD	29
Geo ^{232}Th IBD	8
(α, n) p-scatters	80 ± 24
(α, n) other	12 ± 10
α-p	7 ± 6
Atmospheric ν	4 ± 3
Sum	281
Observed	246

Suppressing (α,n)

- Largest background is from ^{13}C(α,n)^{16}O reactions induced by α's (from natural ^{210}Po) with ^{13}C in the scintillator.
- The main prompt signal is from multiple elastic scatters of the n on protons, which spans a few ns of time.
- Most of these events are rejected by a Fisher discriminant PSD applied to prompt events: the **(α,n) classifier**.

FIG. 4. Distributions of the (α,n) classifier value for prompt events with energy below 3.5 MeV.



ν Oscillation

- The nearest reactors are the Bruce complex, 240 km away.
  - Primary IBD sources: **39% Bruce**, **15% P + D**.

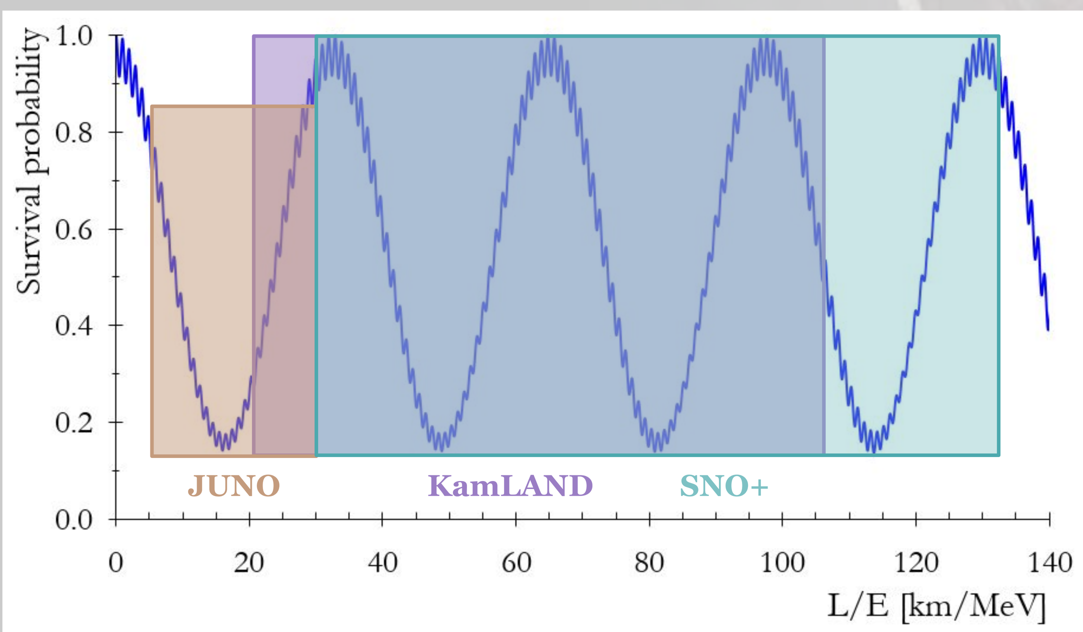
⇒ Multiple oscillation dips in prompt event energy spectrum.

- Both reactor ν_e and geo-ν_e are reduced to about 55%.

FIG 5. Electron (anti)neutrino survival probability, P_{ee}.

$$P_{ee} = 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\Delta_{21} - \sin^2 2\theta_{13}(\cos^2\theta_{12}\sin^2\Delta_{31} + \sin^2\theta_{12}\sin^2\Delta_{32}),$$

where $\Delta_{ij} \equiv 1.267\Delta m^2_{ij} L/E$



Oscillation and Geo-ν Results

https://inspirehep.net/literature/3083970

TABLE II. Best-fit values. Results are reported with no constraints on Δm^2_{21} and $\sin^2\theta_{12}$, then with PDG constraints, and finally with PDG constraints and the cut on the (α,n) classifier.

	Fit	Fit (con.)	Fit (α, n) cut
Δm^2_{21} [$\times 10^{-5}$eV^2]	$7.93^{+0.21}_{-0.24}$	7.60 ± 0.17	7.56 ± 0.17
$\sin^2\theta_{12}$	0.505 ± 0.134	0.310 ± 0.012	0.311 ± 0.012
Geo-$\overline{\nu}$ [TNU]	60^{+23}_{-22}	61^{+23}_{-22}	49^{+13}_{-12}
Geo-$\overline{\nu}$ U/Th	$3.38^{+1.39}_{-1.41}$	$3.30^{+1.41}_{-1.44}$	$3.29^{+1.42}_{-1.48}$

FIG 8. Measured and predicted reactor IBDs divided by prediction assuming no neutrino oscillations. L_0 = 269 km is the Δm^2_{21}-uncertainty-weighted average baseline.

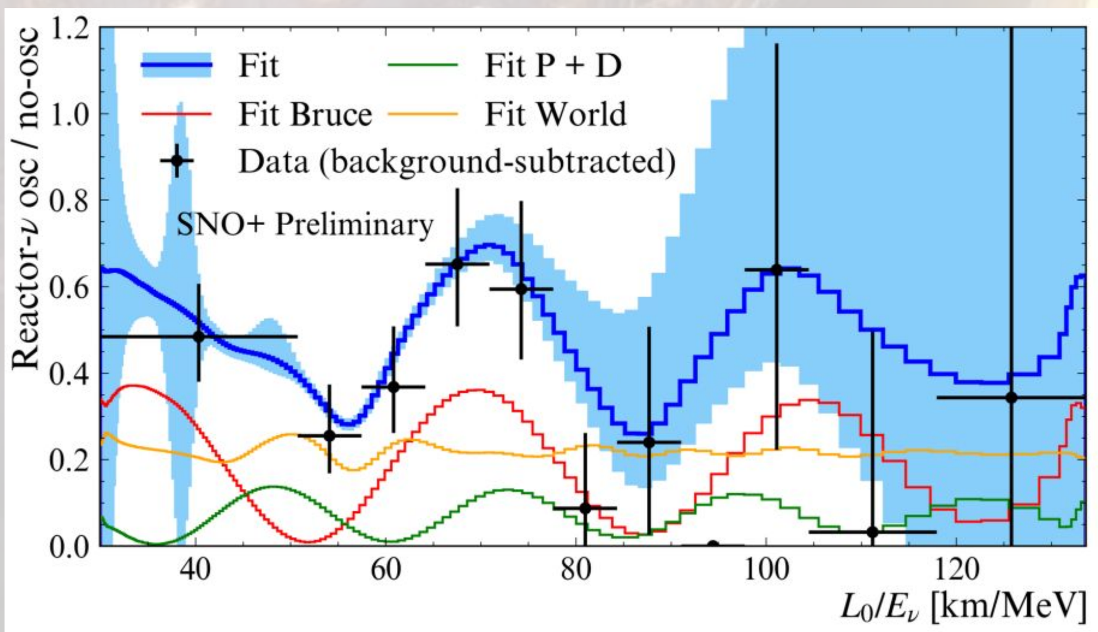


FIG 6. Likelihood fit with Δm^2_{21} and $\sin^2\theta_{12}$ unconstrained.

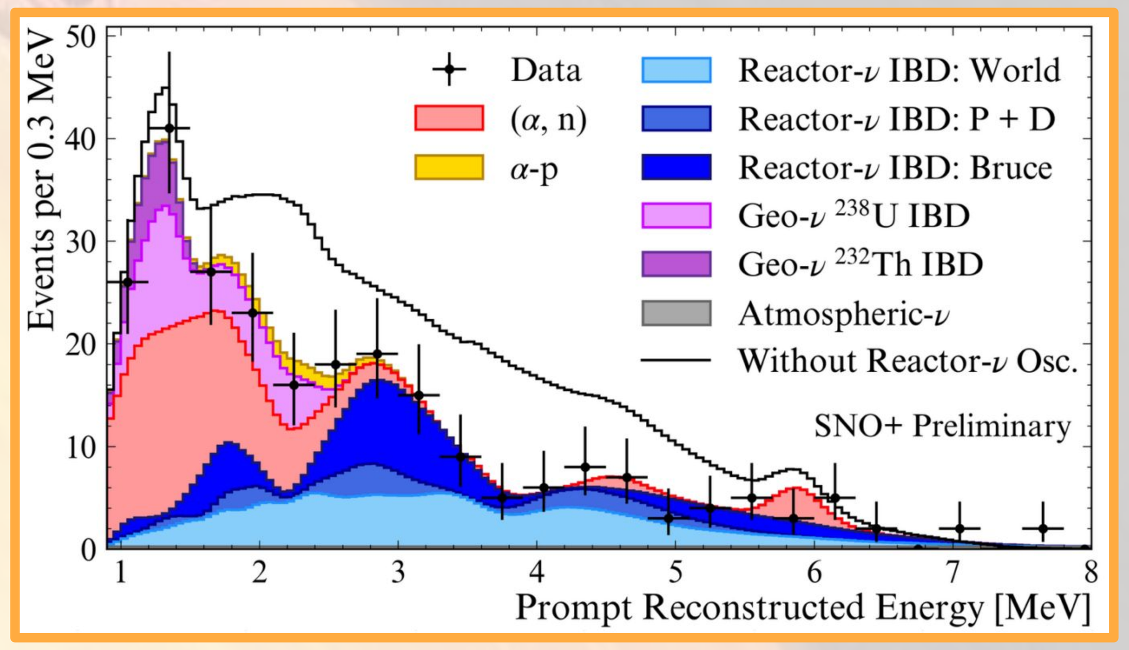
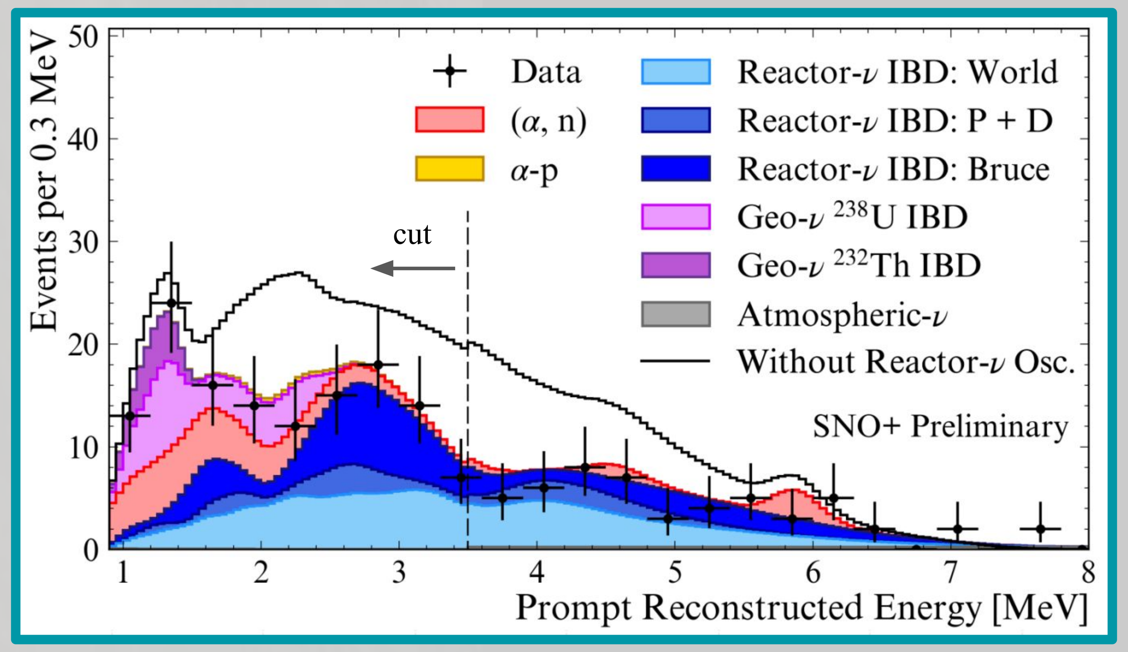


FIG 7. Fit with PDG constraints and the cut on the (α,n) classifier, which is applied only below 3.5 MeV (dashed line).



Oscillation: The 1.46 kt-year measurement of $\mathbf{\Delta m^2_{21} = (7.93^{+0.21}_{-0.24}) \times 10^{-5}}$ **eV^2** is statistics-dominated and approaching KamLAND precision. With JUNO now dominating the precision of Δm^2_{21}, SNO+ provides a complementary measurement with oscillations over greater distances and a different dominant background.

Geo-ν: The local geo-ν flux measurement of $\mathbf{49^{+13}_{-12}}$ **TNU** is also statistics-dominated. Measurements from KamLAND, Borexino, and now SNO+, will give a global picture of the Earth's radiogenic heat production.

Backgrounds: SNO+ will continue to characterize **(α,n)** and **α-p** interactions, which are important backgrounds in MeV-scale particle physics experiments.