Geoneutrino Results from SNO+

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for the SNO+ Collaboration

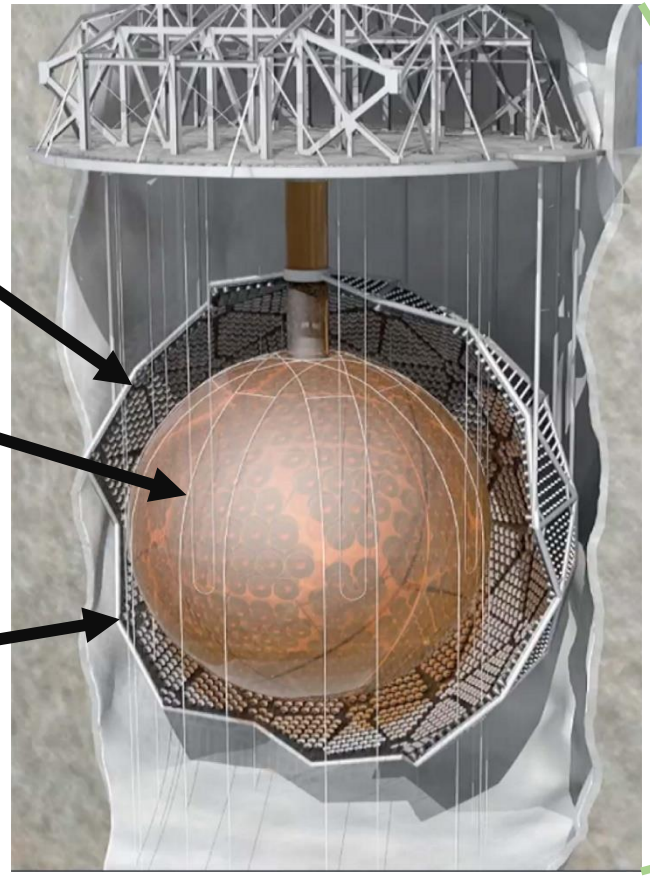
2026.11.16 Shandong University

The SNO+ Detector

PMT support structure

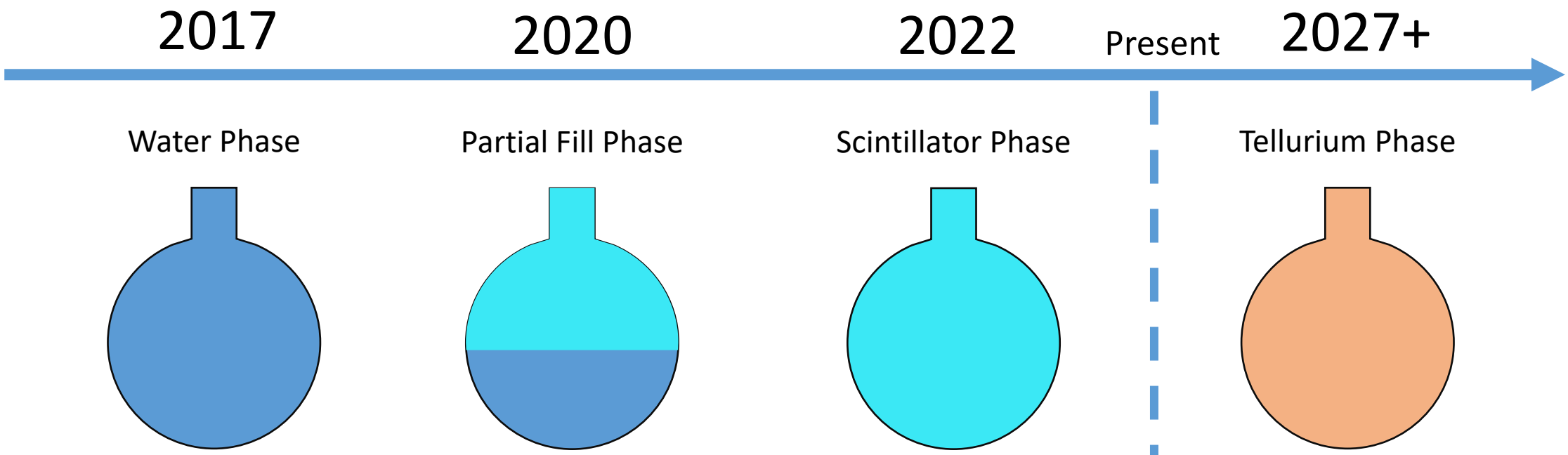
Acrylic vessel

~ 9400 PMTs

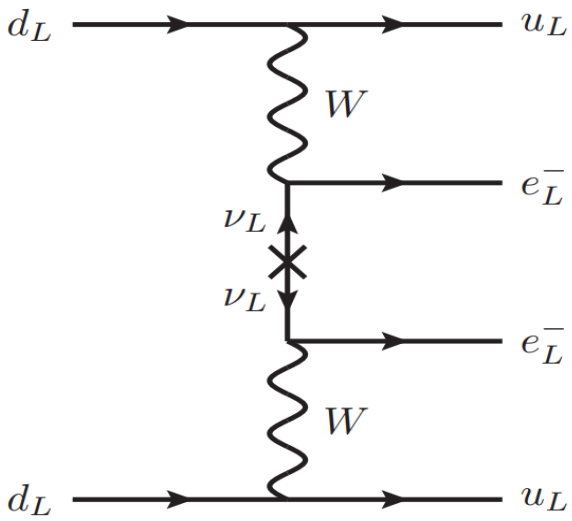




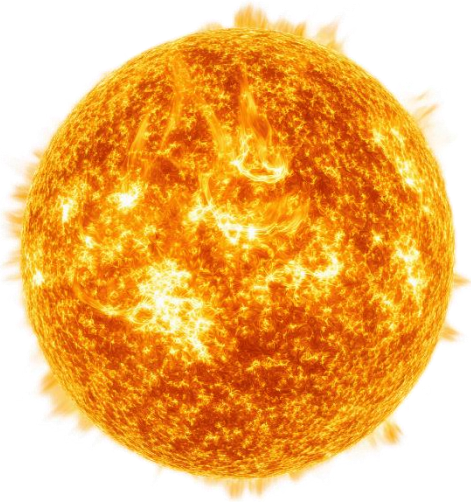
SNO+ Timeline



SNO+ Physics Goals



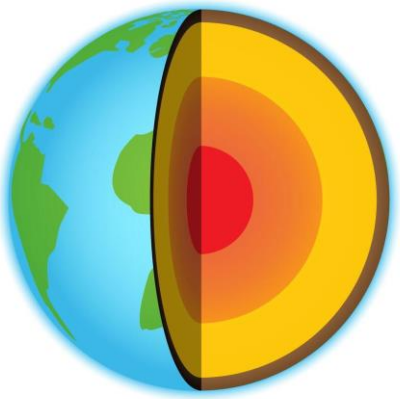
$0\nu2\beta$ decay



Solar neutrinos



Reactor neutrinos



Geoneutrinos

$0\nu2\beta$ Research

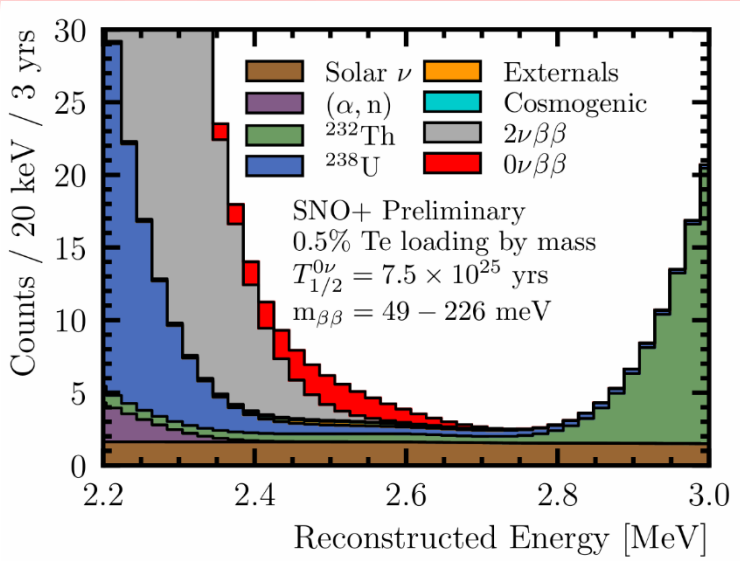
Target isotope: ^{130}Te

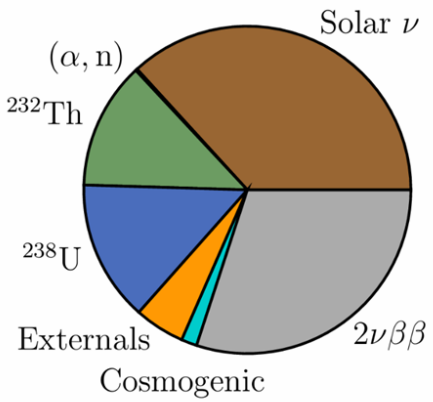
- High natural abundance: 34%
- Long $2\nu2\beta$ half-life: 8.76×10^{20} years
- High Q-value: 2.527 MeV
- Te-loading technique with good optical transparency and chemical stability

Tellurium phase

- Te loading: 0.5% by mass
- ROI: 2.42-2.62 MeV
- Expected event rate: 15 counts/year
- Sensitivity: 3 years of livetime

$$T_{1/2}^{0\nu} \sim 2 \times 10^{26} \text{ years}$$

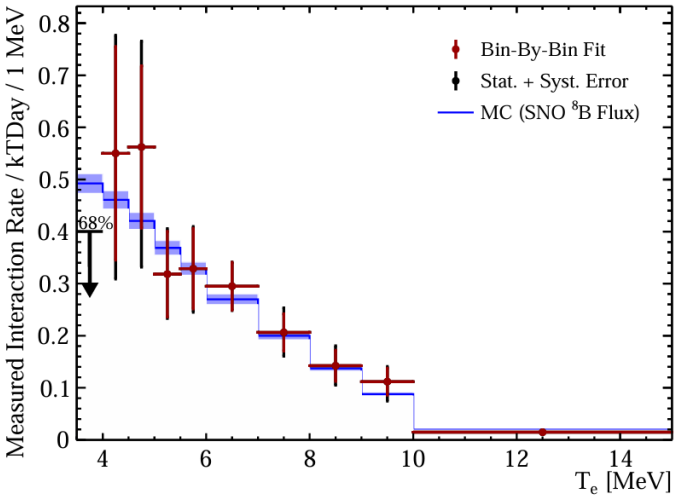




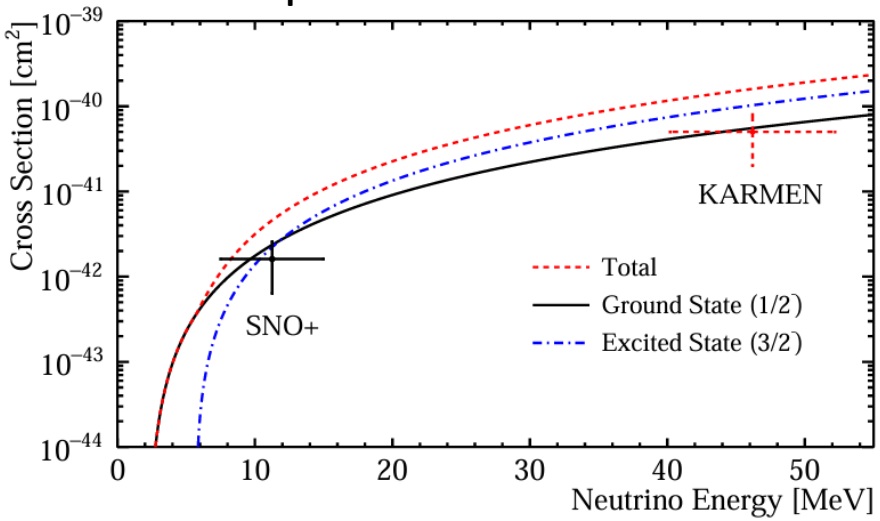
Solar Neutrinos

- ^{8}B ν on e^- (ES) in water [(Phys.Rev.D 110 (2024) 12, 122003)]
  - Flux: $5.36^{+0.41}_{-0.39}(\text{stat.})^{+0.17}_{-0.16}(\text{syst.}) \times 10^6 \text{cm}^{-2} s^{-1}$
- ^{8}B ν on ^{13}C (CC) [(Phys.Rev.Lett. 135 (2025) 24, 241803)]
  - Cross section: $16.1^{+8.5}_{-6.7}(\text{stat.})^{+1.6}_{-2.7}(\text{syst.}) \times 10^{-43} \text{cm}^2$
- Event-by-event direction reconstruction [(Phys.Rev.D 109 (2024) 7, 072002)]
  - Demonstrated with LAB + 0.6 g/L PPO for $E_e > 5$ MeV

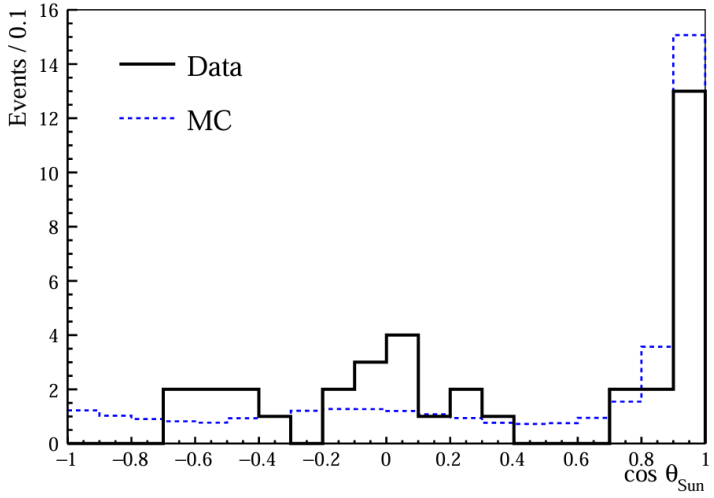
Water phase



Scintillator phase



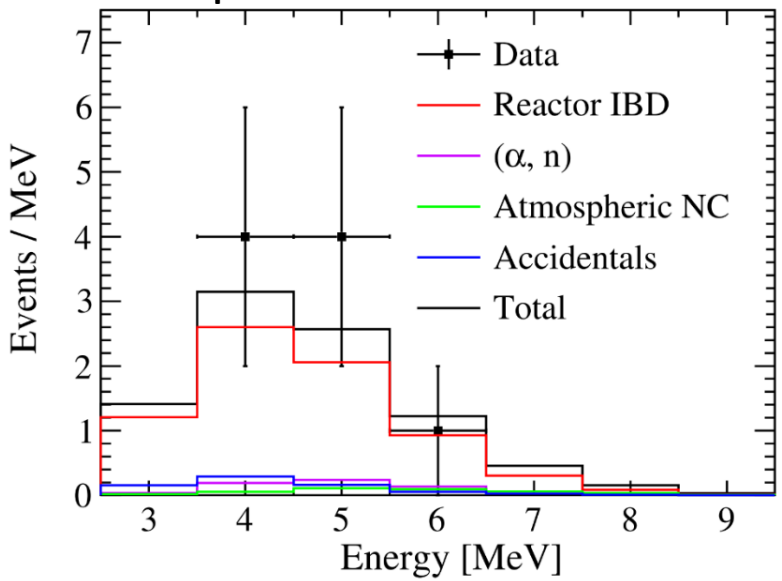
Partial-fill phase



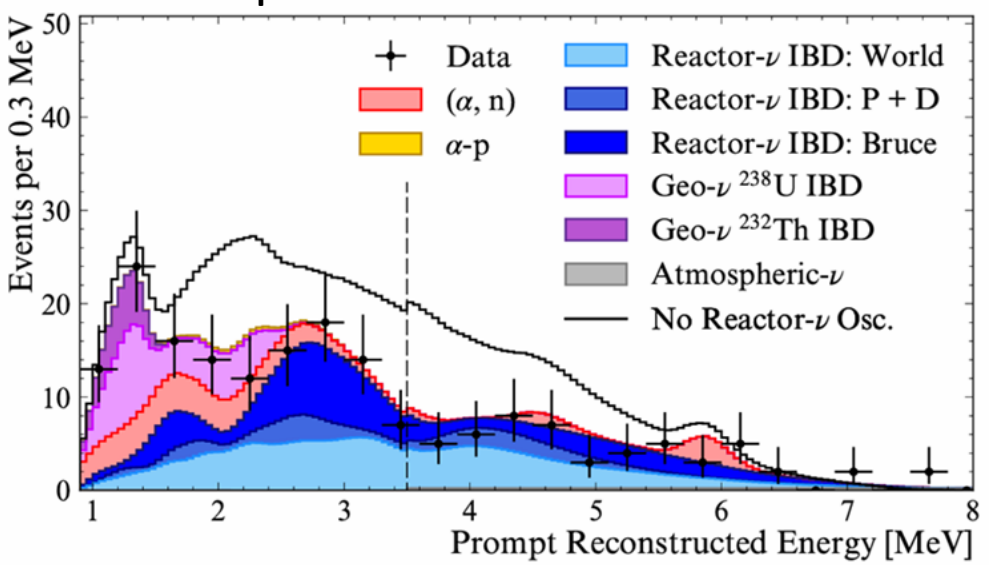
Reactor Antineutrinos

- First reactor antineutrino detected in water (Phys.Rev.Lett. 130 (2023) 9, 9)
- Reactor antineutrino oscillation in scintillator (Phys.Rev.Lett. 137 (2026) 10, 101807) :
  - $\Delta m^2_{21} = (7.63 \pm 0.17) \times 10^{-5}\ \mathrm{eV}^2$, $\sin^2\theta_{12} = 0.310 \pm 0.012$
- First in the Western Hemisphere to detect geo-ν: 48^{+14}_{-12} TNU

Water phase



Scintillator phase



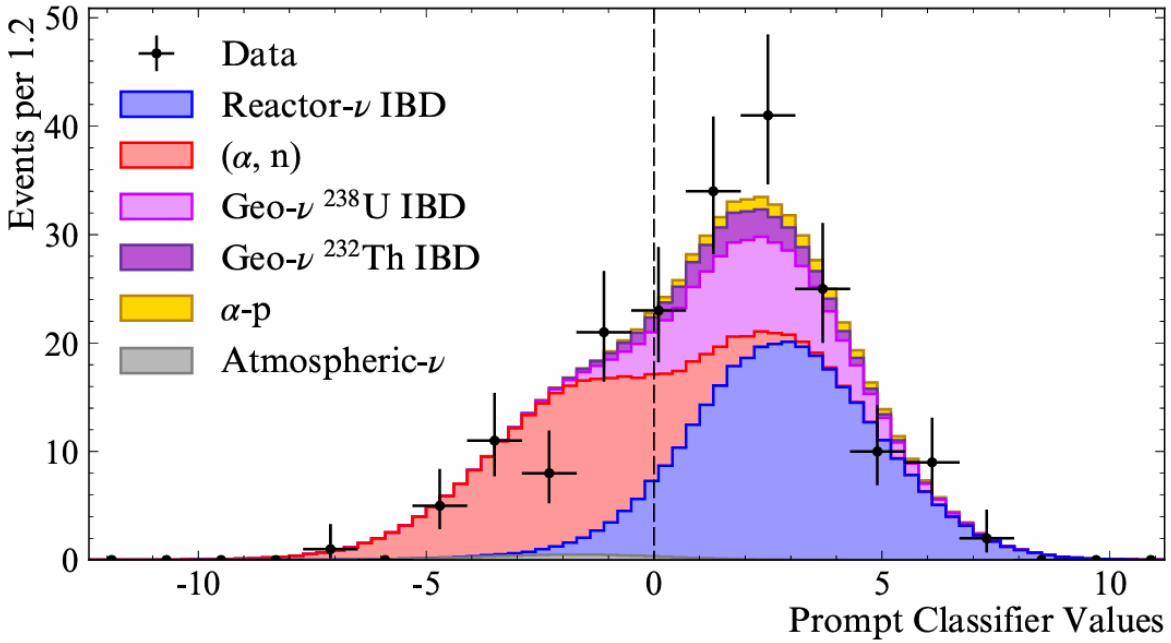
(α, n) Classifier

(α, n) reaction

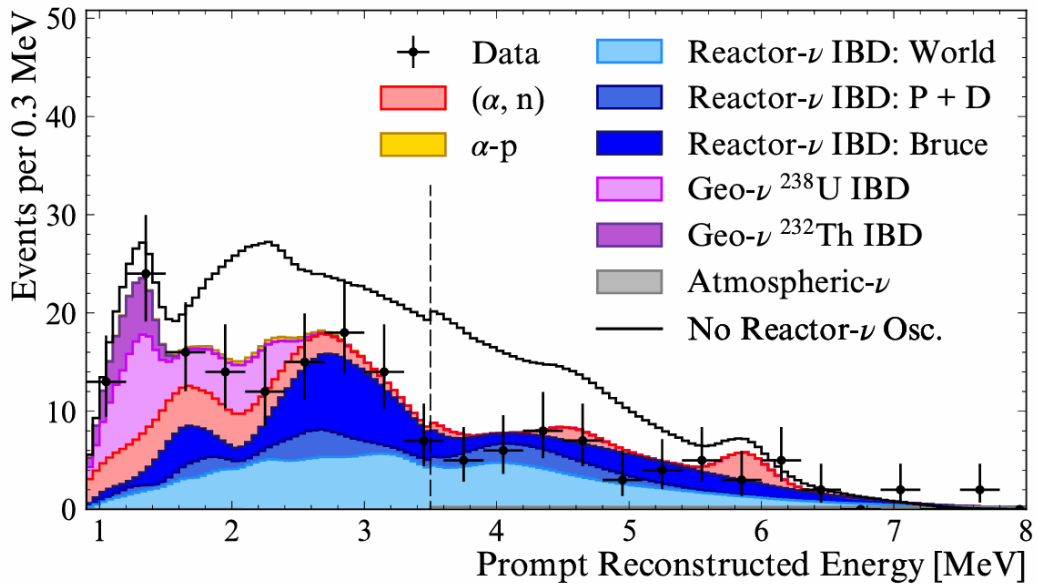
- $\alpha + {}^{13}C \rightarrow {}^{16}O + n$
- Dominant background
- Fed by α decays of ^{210}Po in LS

(α, n) Classifier

- Built with time residual information of events
- 90 % of geoneutrinos and 10% of (α, n) retain by requiring positive classifier value



(α, n) Classifier



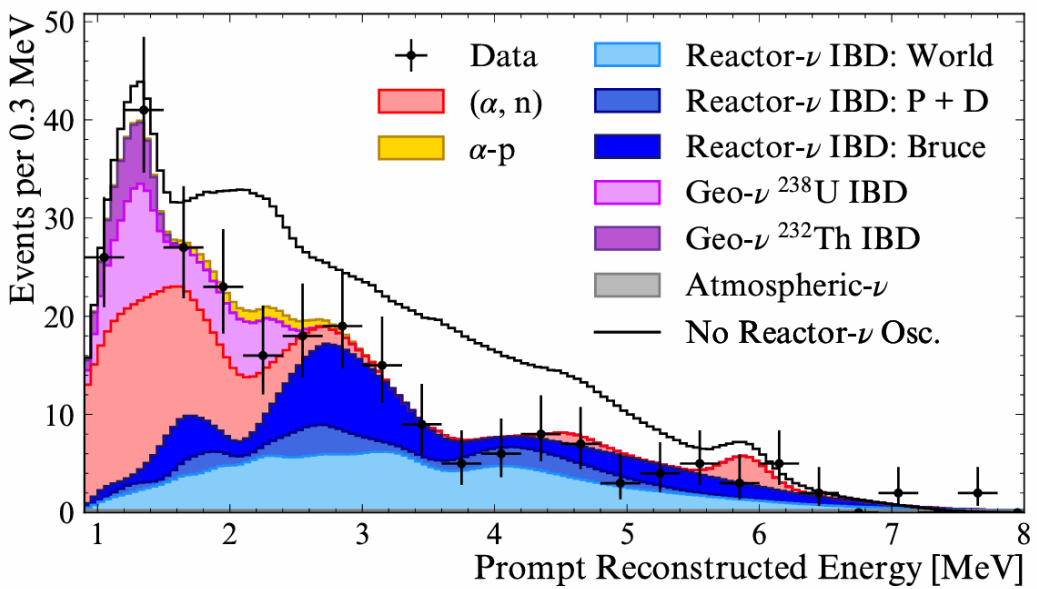
With (α, n) classifier

$\Delta m^2_{21} = (7.55^{+0.17}_{-0.16}) \times 10^{-5}$ eV^2

$\sin^2\theta_{12} = 0.311 \pm 0.012$

Geo-$\overline{\nu}$ [TNU]: 48^{+14}_{-12}

Geo-$\overline{\nu}$ U/Th: $3.23^{+1.43}_{-1.49}$



Without (α, n) classifier

$\Delta m^2_{21} = (7.59 \pm 0.17) \times 10^{-5}$ eV^2

$\sin^2\theta_{12} = 0.310 \pm 0.012$

Geo-$\overline{\nu}$ [TNU]: 50 ± 25

Geo-$\overline{\nu}$ U/Th: $3.54^{+1.36}_{-1.37}$

U/Th Constraint

With U/Th Constraint of 3.8 ± 1.3

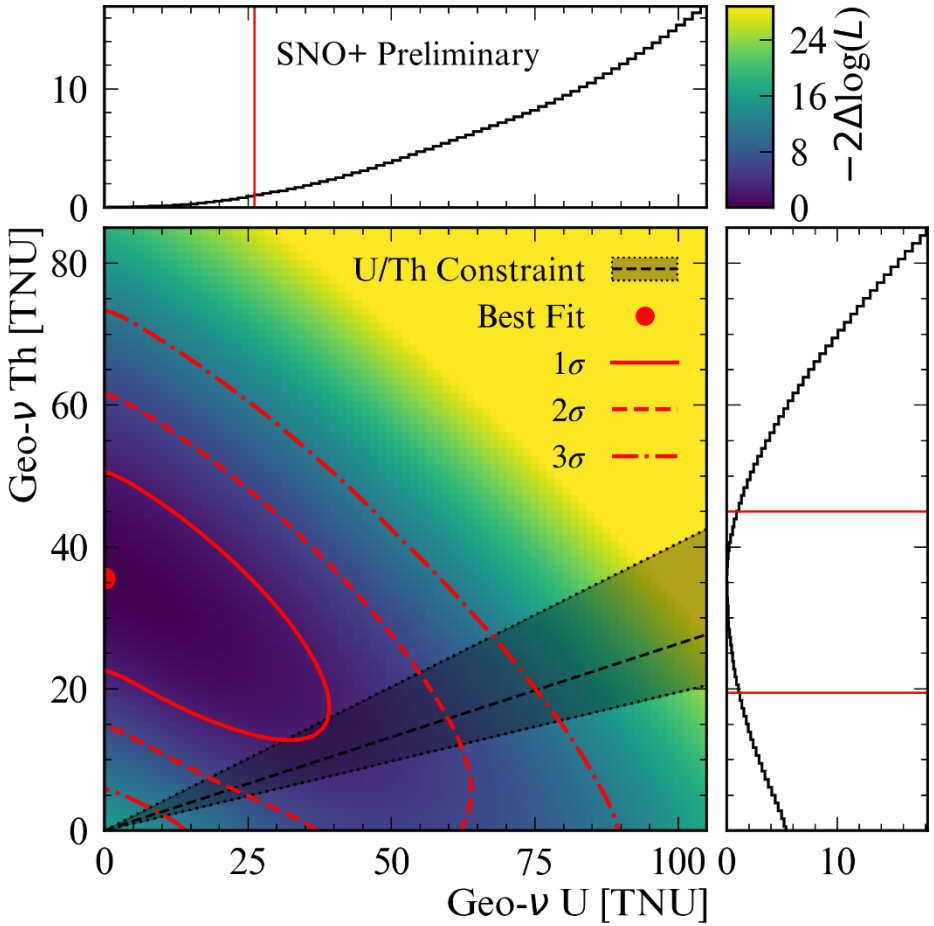
Geo-$\overline{\nu}$ [TNU]: 48^{+14}_{-12}

Geo-$\overline{\nu}$ U/Th: $3.23^{+1.43}_{-1.49}$

Without U/Th Constraint

Geo-$\overline{\nu}$ [TNU]: 37^{+15}_{-11}

Geo-$\overline{\nu}$ U/Th: —



U/Th Constraint

Asymmetry parameter

- Definition: (U-Th)/(U+Th)
- Expectation: 0.55

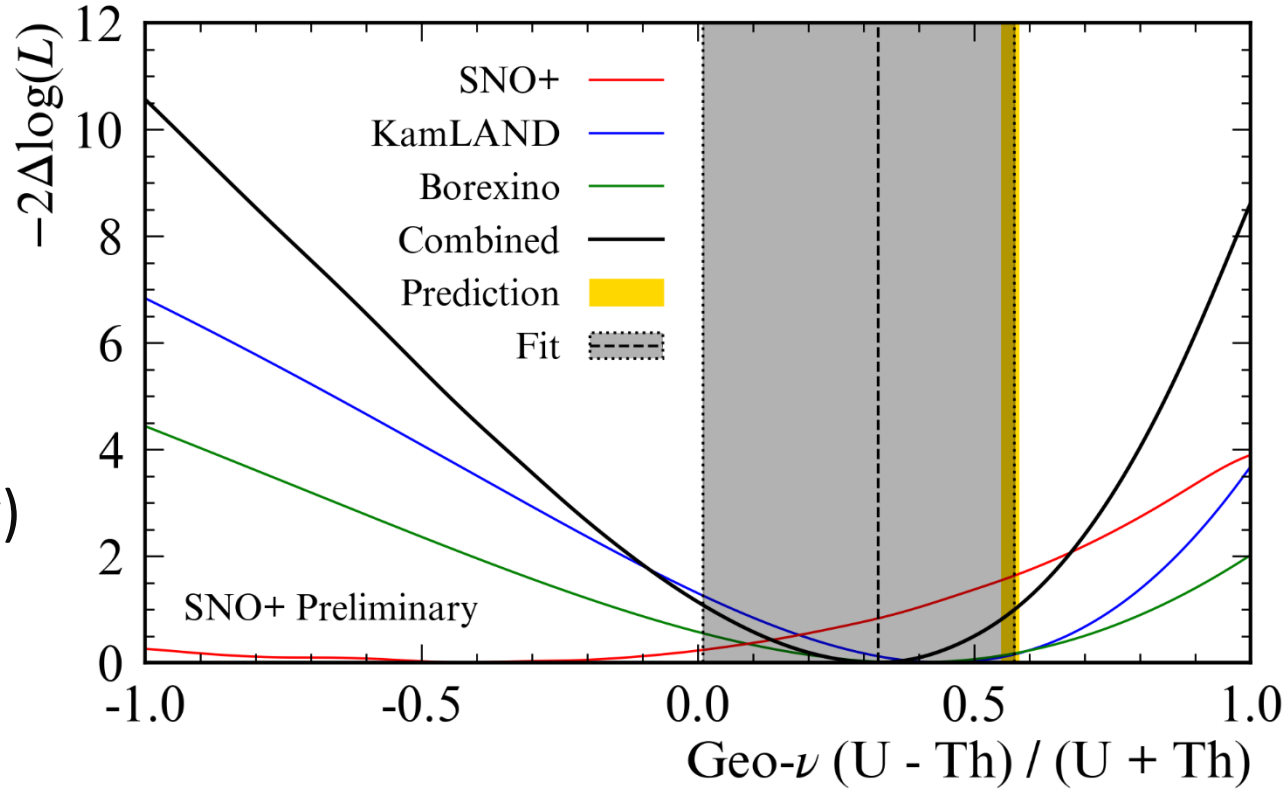
With Enomoto's spectrum

- U/Th: $3.23^{+1.43}_{-1.49}$
- Asymmetry: $0.12^{+0.27}_{-0.35}$
- Deviation: 1.7 σ (SNO+ only)

With Li & Xin spectrum

- U/Th: 3.4 ± 1.4
- Asymmetry: $0.33^{+0.25}_{-0.32}$
- Deviation: 1.3 σ (SNO+ only)

With Li & Xin spectrum

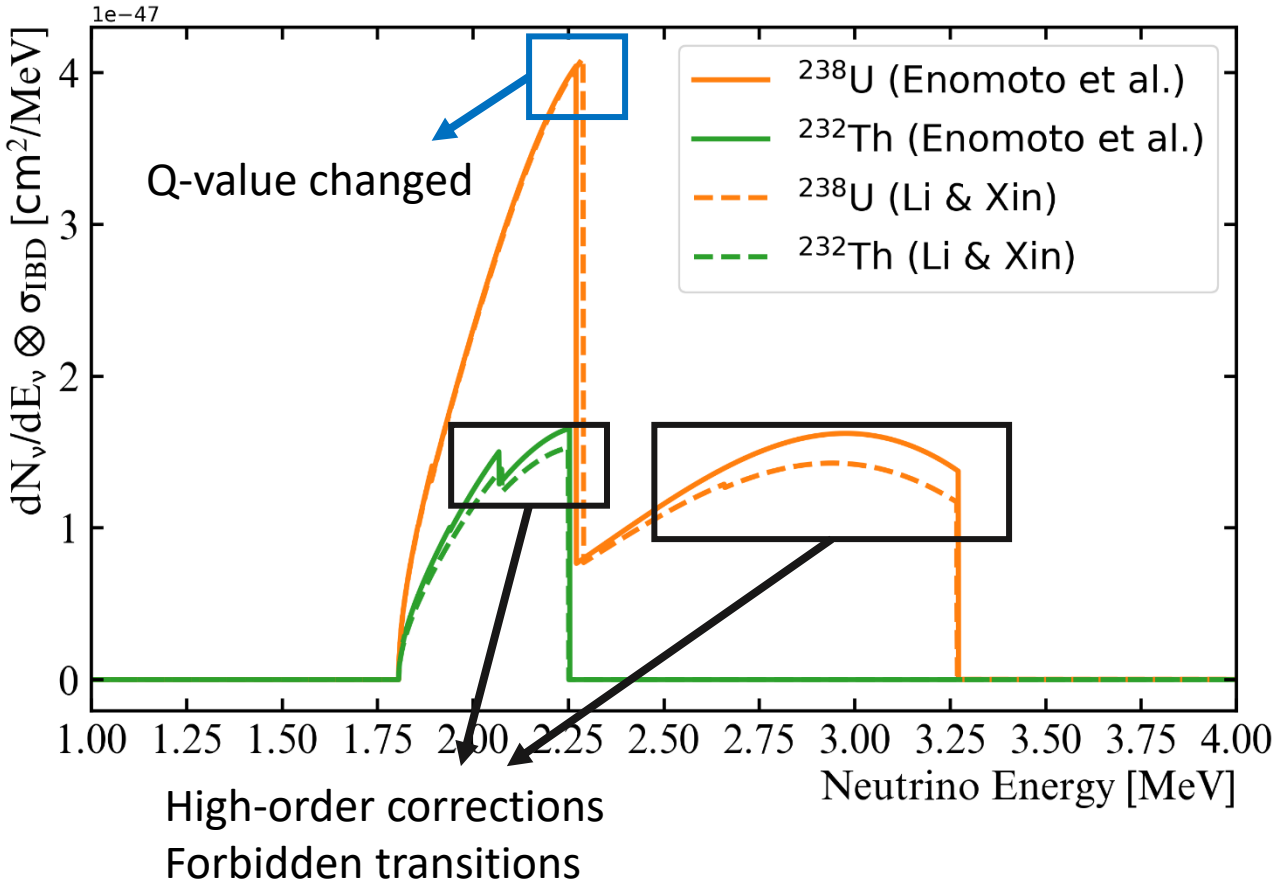


Geoneutrino Spectra

Difference

1. Overall yield
   - Decrease 4% for U, 8% for Th
2. Shifted endpoint in U

The choice of geoneutrino spectra affects the extraction of U and Th fluxes.

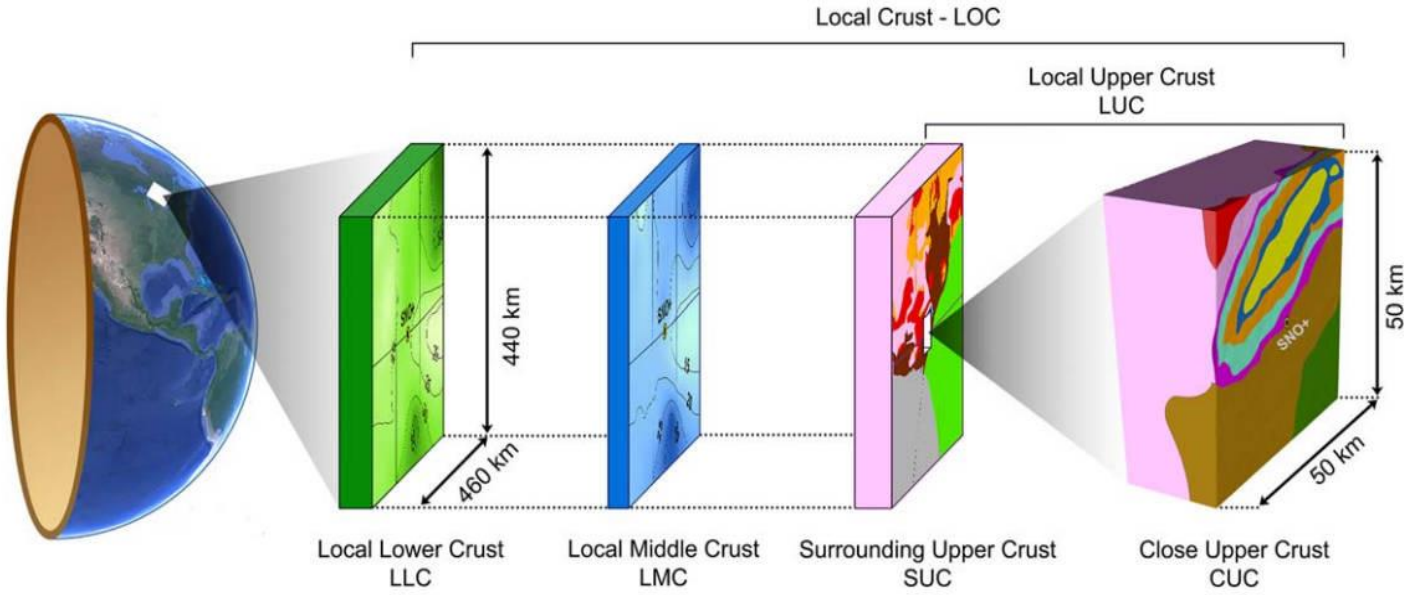


Geoneutrino Modeling

GEONUS framework

- Rewritten from GEONU (Wipperfurth et al. 2020)
- Updated physics inputs:
  - Spectrum: Enomoto, Li & Xin (default)
  - IBD cross section: Vogel & Beacom, Strumia & Vissani, Vissani et al. (default)
  - Oscillation parameters: PDG 2025
- Incorporating global and local crustal models

Geoneutrino Modeling



Predictions

	U+Th [TNU]	U [TNU]	Th [TNU]	U/Th
Lithosphere	$32.7^{+10.5}_{-7.2}$	$25.4^{+8.0}_{-5.5}$	$7.3^{+2.1}_{-1.7}$	3.5
CLM	$1.5^{+6.3}_{-1.2}$	$1.1^{+4.2}_{-0.9}$	$0.3^{+1.4}_{-0.3}$	3.4
Far Crust	$14.3^{+5.3}_{-3.9}$	$10.9^{+3.9}_{-2.9}$	$3.3^{+1.5}_{-1.0}$	3.3
Local Crust	$15.9^{+7.3}_{-5.0}$	$12.5^{+5.8}_{-3.9}$	$3.3^{+1.6}_{-1.1}$	3.8
CUC	$8.1^{+6.3}_{-3.5}$	$6.5^{+5.0}_{-2.8}$	$1.6^{+1.2}_{-0.7}$	4.1
Huronian	$3.7^{+6.7}_{-2.4}$	$3.0^{+5.4}_{-1.9}$	$0.7^{+1.3}_{-0.4}$	4.5
SIC	$2.2^{+0.6}_{-0.5}$	$1.7^{+0.5}_{-0.4}$	$0.5^{+0.1}_{-0.1}$	3.3

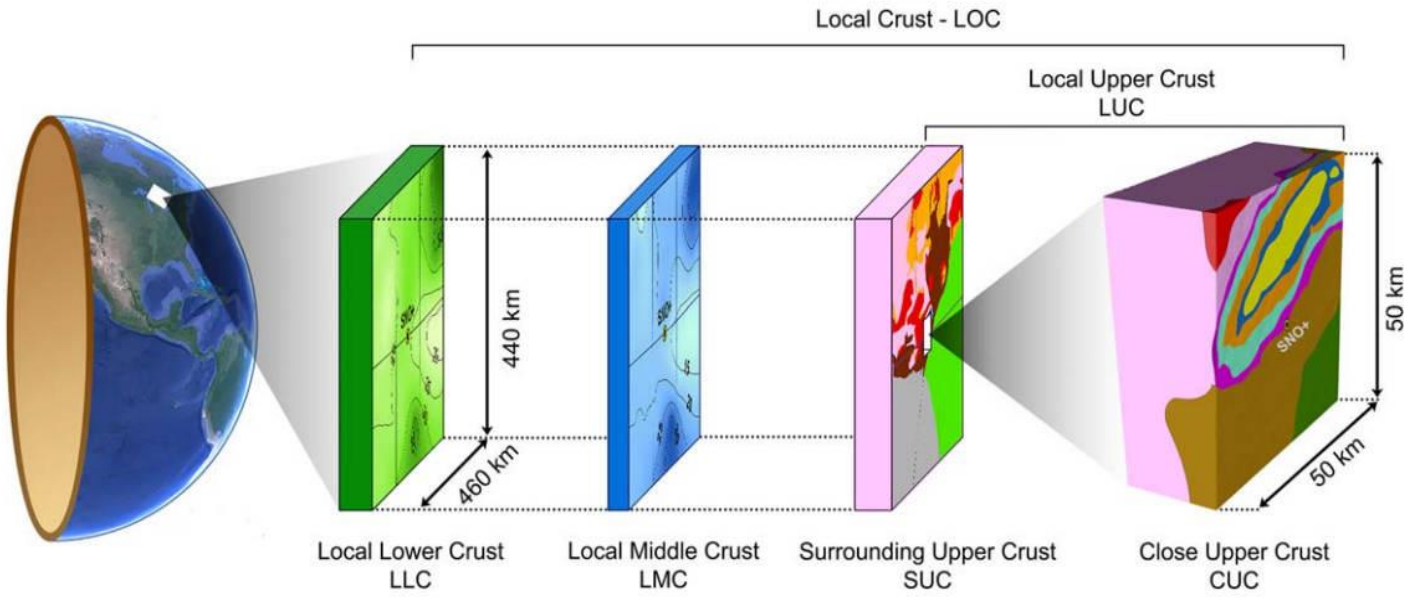
- Using Li & Xin spectrum
- Details are presented in a SNO+ technical paper (coming soon)

Global crust
- Wipperfurth et al. (2020)
- CRUST1.0

Regional local crust
- Huang et al. (2014)
- 440 km × 460 km

Fine local crust
- Strati et al. (2017)
- 50 km × 50 km

Geoneutrino Modeling



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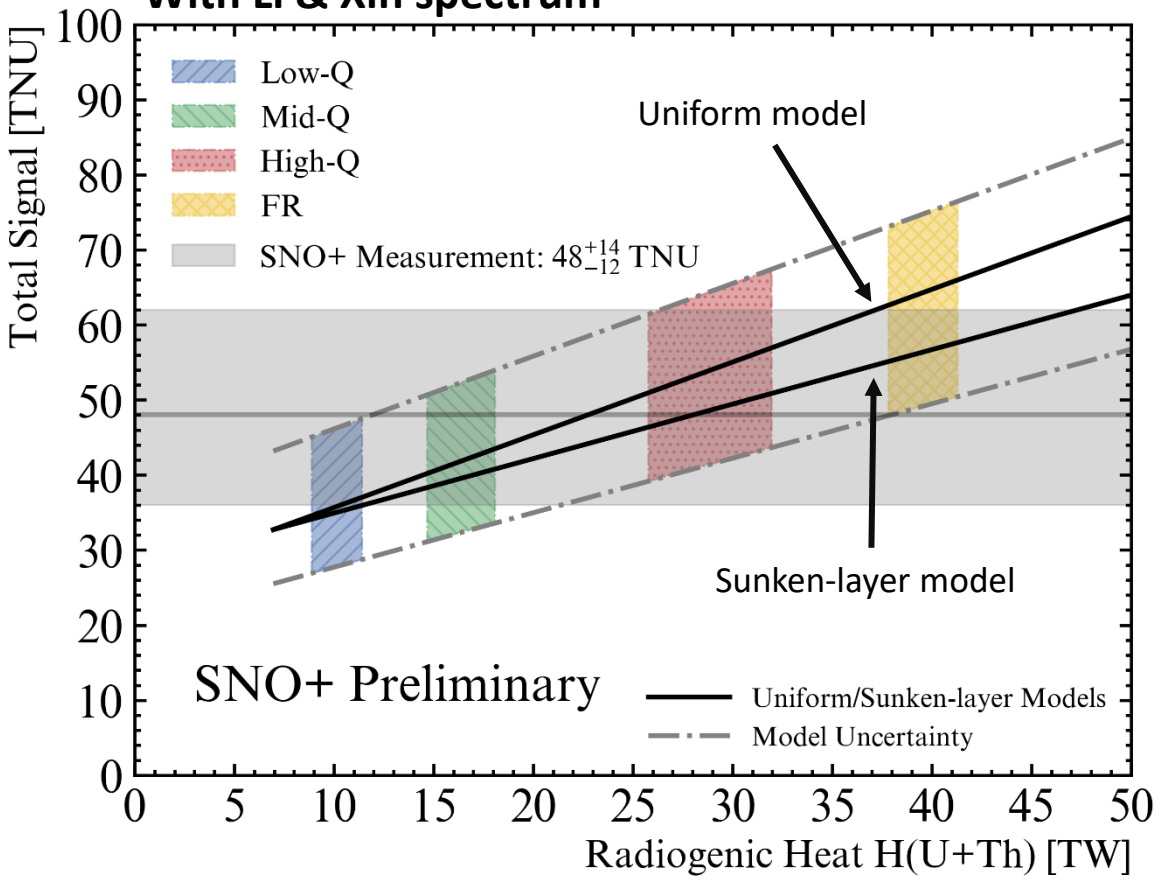
Estimated deviations

Deviations		δS(U)	δS(Th)	δS(U+Th)
Crust	LITHO1.0	+3.03%	+0.07%	+2.35%
Oscillation	$\sin^2\theta_{12}$	±1.47%	±1.52%	±1.48%
	$\sin^2\theta_{13}$	±0.12%	±0.12%	±0.12%
	Δm^2_{21}	±0.34%	±0.51%	±0.38%
	Δm^2_{31}	±0.005%	±0.010%	±0.005%
	Δm^2_{32}	±0.002%	±0.005%	±0.003%
	Total	±1.52%	±1.61%	±1.54%
IBD	1999	−2.06%	−2.21%	−2.10%
	2003	−0.77%	−0.75%	−0.76%
Spectrum	Enomoto	+3.81%	+9.08%	+4.99%

- Default: Li & Xin spectrum
- Details are presented in a SNO+ technical paper (coming soon)

Geoneutrino Interpretation

With Li & Xin spectrum



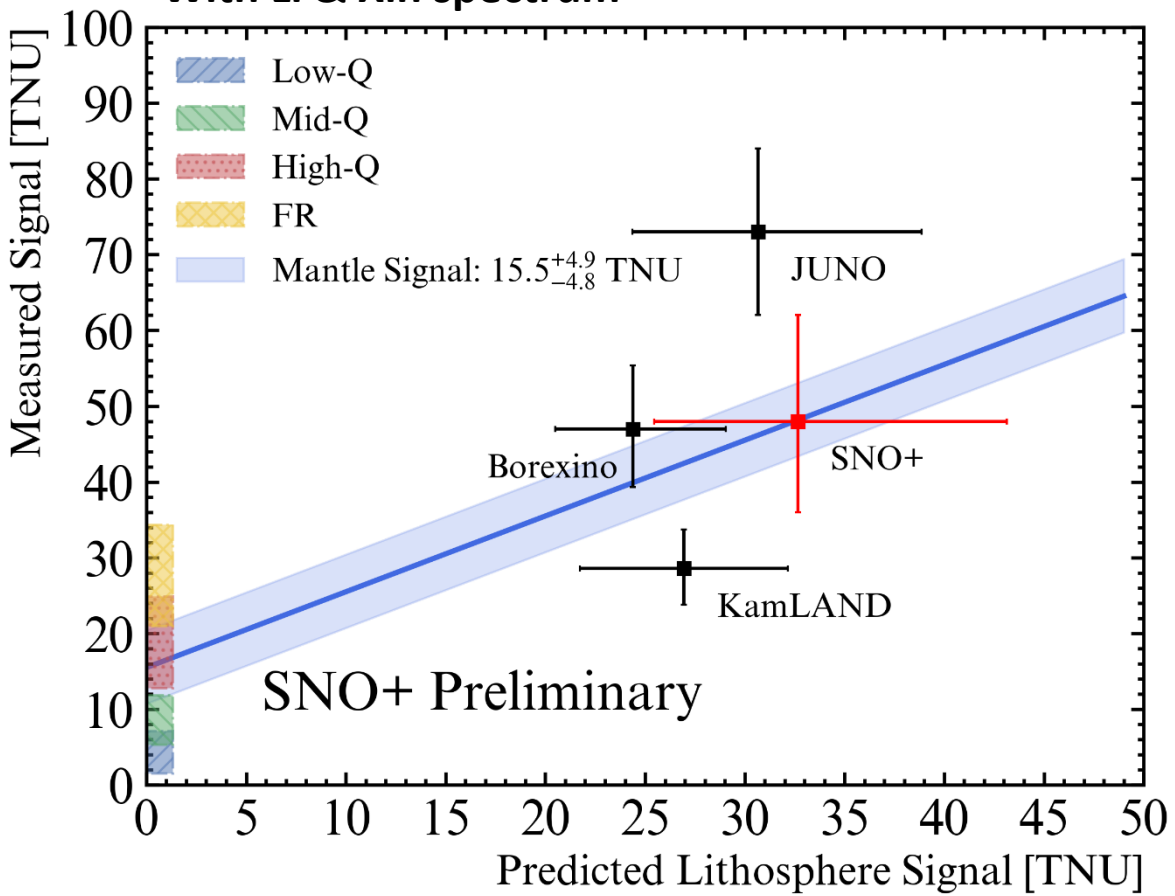
Experiment	Measured	Lithosphere	Mantle estimate
SNO+	48^{+14}_{-12}	E: $34.4^{+11.0}_{-7.6}$	$13.6^{+15.9}_{-16.3}$
		LX: $32.7^{+10.5}_{-7.2}$	$15.3^{+15.7}_{-15.9}$

BSE	Total Radiogenic Heat
Low-Q (Cosmochemical)	~10 TW
Mid-Q (Geochemical)	~20 TW
High-Q (Geodymical)	~30 TW
FR (Fully radiogenic)	~47 TW

- Lithosphere heat: 7 TW
- **Compatible with any of the BSE compositions**
- **But prefer medium-high composition**

Geoneutrino Interpretation

With Li & Xin spectrum



Experiment	Measured	Lithosphere	Mantle estimate
SNO+	48^{+14}_{-12}	E: $34.4^{+11.0}_{-7.6}$	$13.6^{+15.9}_{-16.3}$
		LX: $32.7^{+10.5}_{-7.2}$	$15.3^{+15.7}_{-15.9}$
JUNO	73^{+11}_{-11}	E: $32.3^{+8.6}_{-6.6}$	$40.7^{+12.8}_{-14.0}$
		LX: $30.7^{+8.2}_{-6.3}$	$42.3^{+12.7}_{-13.7}$
Borexino	$47.0^{+8.7}_{-7.9}$	E: $25.9^{+4.9}_{-4.1}$	$21.1^{+9.6}_{-9.3}$
		LX: $22.4^{+4.7}_{-3.9}$	$24.6^{+9.3}_{-9.0}$
KamLAND	$28.6^{+5.1}_{-4.8}$	E: $28.3^{+5.4}_{-5.4}$	$0.3^{+7.4}_{-7.2}$
		LX: $26.9^{+5.2}_{-5.2}$	$1.7^{+7.3}_{-7.1}$

Mantle signal

- Enomoto: 14.3 ± 4.9 TNU
- Li & Xin: $15.5^{+4.9}_{-4.8}$ TNU

Mantle heat

- H(U+Th): 18 ± 6 TW

KamLAND: Geophys. Res. Lett. 49, e2022GL099566 (2022); Earth Planet. Sci. Lett. 258, 147 (2007); N. Kawada, Ph.D. thesis, Tohoku University (2022).
Borexino: Phys. Rev. D 101, 012009 (2020); Geochim. Cosmochim. Acta 75, 2271 (2011).
JUNO: JUNO Experiment, Neutrino 2026; arXiv:2511.07227 (2025).

Summary & Outlook

Key Results

- **SNO+ geoneutrino measurement:** Third detection worldwide, and the first in the Western Hemisphere.
- **Improved precision:** A time-residual event classifier suppresses the dominant (α,n) background.
- **U/Th ratio:** The U/Th ratio is sensitive to the choice of geoneutrino spectra, and the result remains below the expectation.
- **BSE composition:** The measurement is compatible with all BSE compositions, but prefers medium-high composition.
- **Mantle contribution:** Global analysis favors high-Q models, with a signal of $15.5^{+4.9}_{-4.8}$ TNU and a (U+Th) radiogenic heat of 18 ± 6 TW.

Outlook

- **U/Th separation:** Future high-statistics measurements from JUNO may clarify the observed U/Th rate difference.
- **Geoneutrino network:** Measurements at different sites may reveal mantle compositional heterogeneity.



Thank you!