The SNO+ Experiment

WCD 2025

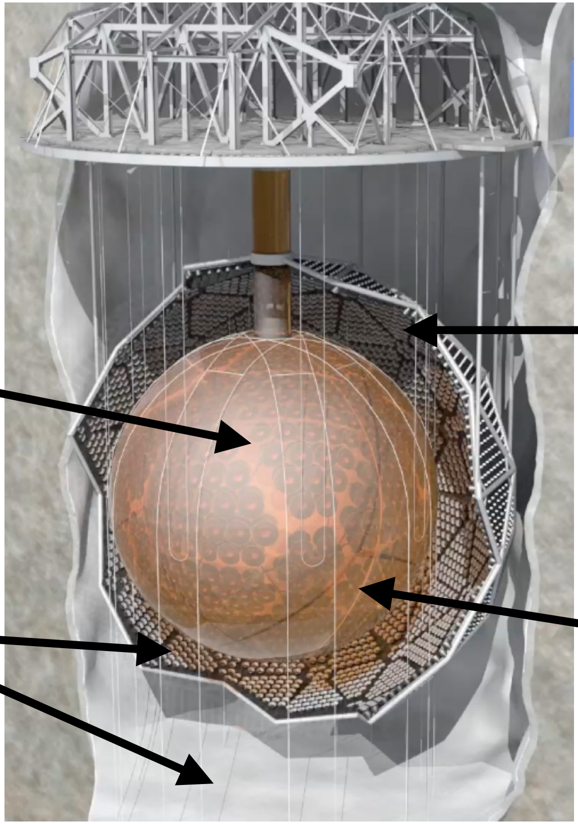
Daniel Cookman

The SNO+ Experiment

Successor to the SNO Experiment

12m diameter Acrylic Vessel (AV)

Ultra-Pure Water Shielding



2km underground at SNOLAB: ~3 muon/hour

>9000 PMTs

Varying Target:

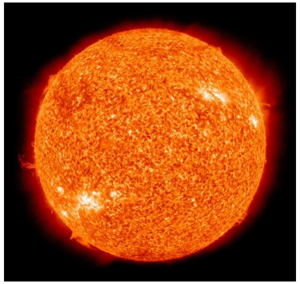
I. Water

II. LAB Scintillator

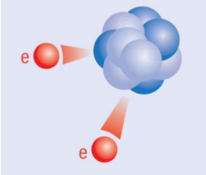
III. Tellurium Loading

JINST 16 P08059 (2021)

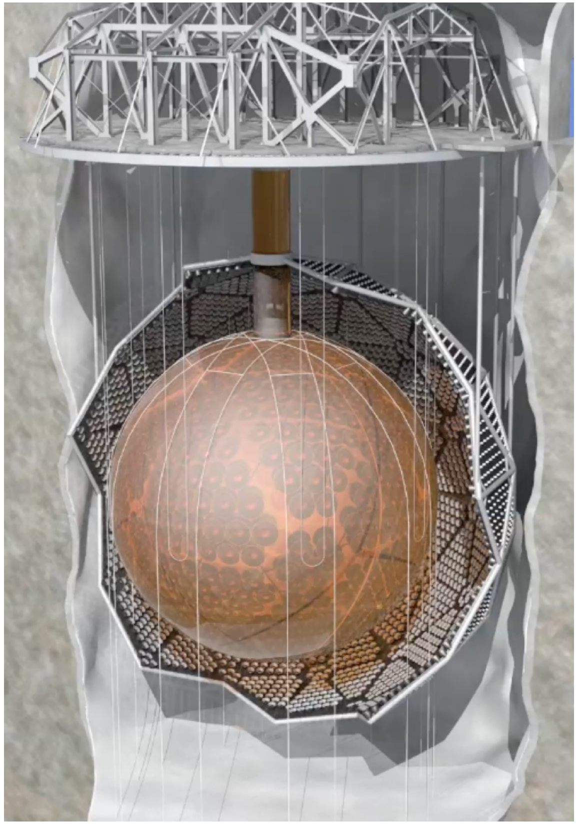
A Multi-Purpose Neutrino Experiment

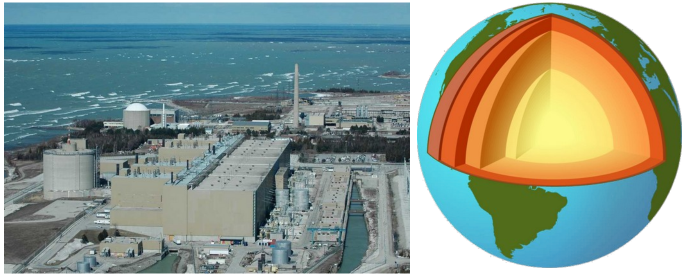


Solar Neutrinos

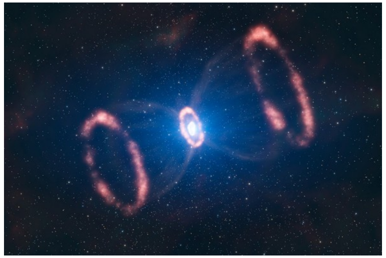


Neutrinoless
Double Beta Decay



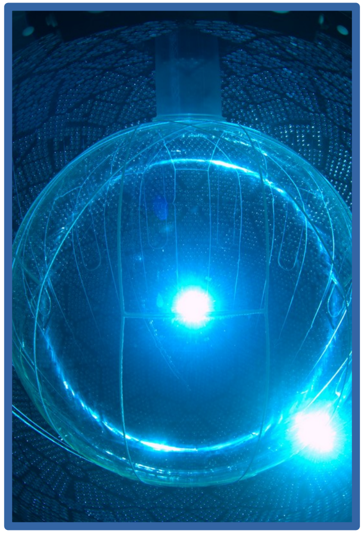


Reactor & Geo-Neutrinos

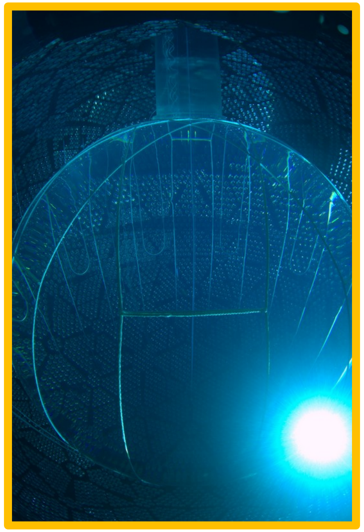


Supernova Neutrinos
& Exotics

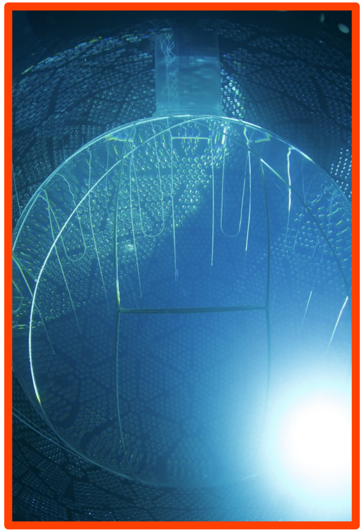
SNO+ Timeline



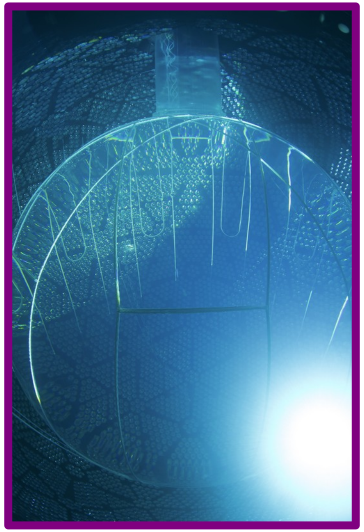
Water Phase:
- Higher Rn period
- Lower Rn period



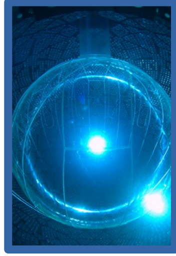
Partial-Fill Phase:
Scintillator over water
Fill paused due to COVID



Scintillator Phase:
- Low PPO period
- Nominal PPO period
- Added bis-MSB & BHT



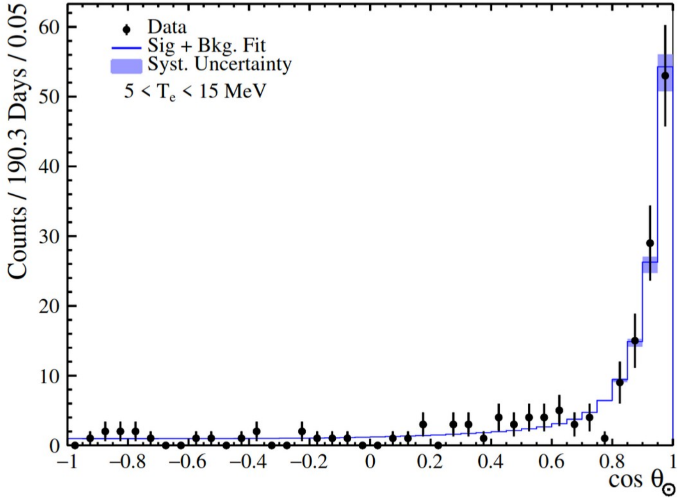
Next:
Tellurium-loaded Phase for $0\nu\beta\beta$



Solar Neutrino Flux, Water Phase

PRD 99, 012012 (2019)
PRD 110, 122003 (2024)

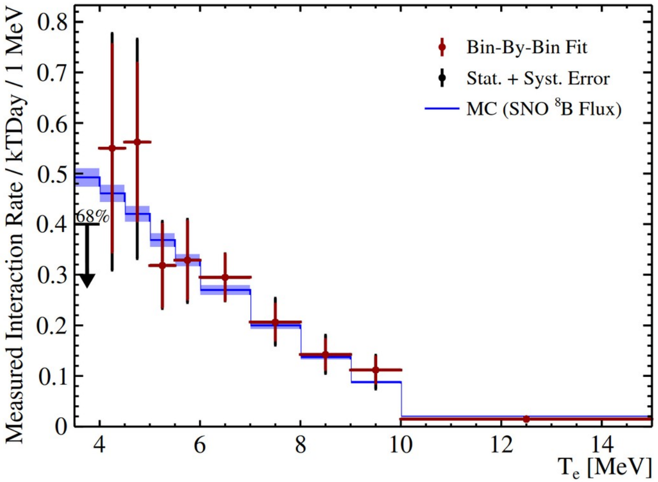
- Updated analysis with 126.6 kt-day exposure
- Includes 190 days of data with lowest background for a water Cherenkov detector > 5 MeV:
  0.32 ± 0.07 evs/kt-day



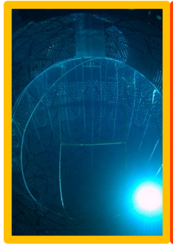
Results:

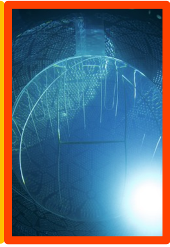
- Using 3.5 MeV threshold; large uncertainties in first bin
- Fitted flux consistent with other experiments after inclusion of oscillations:

$$\left(5.36^{+0.41}_{-0.39}(\text{stat.})^{+0.17}_{-0.16}(\text{syst.})\right) \times 10^{6}\ \text{cm}^{-2}\text{s}^{-1}$$



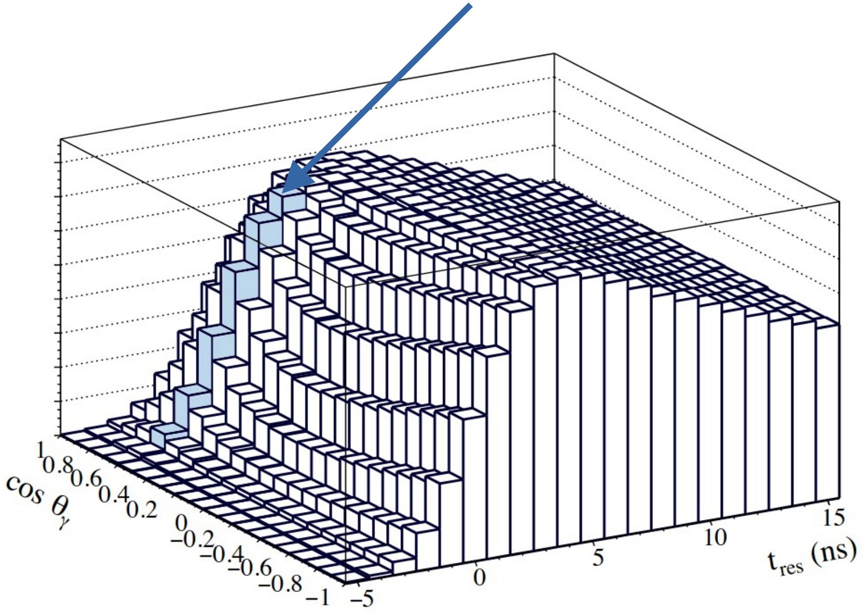
Directionality in Scintillator



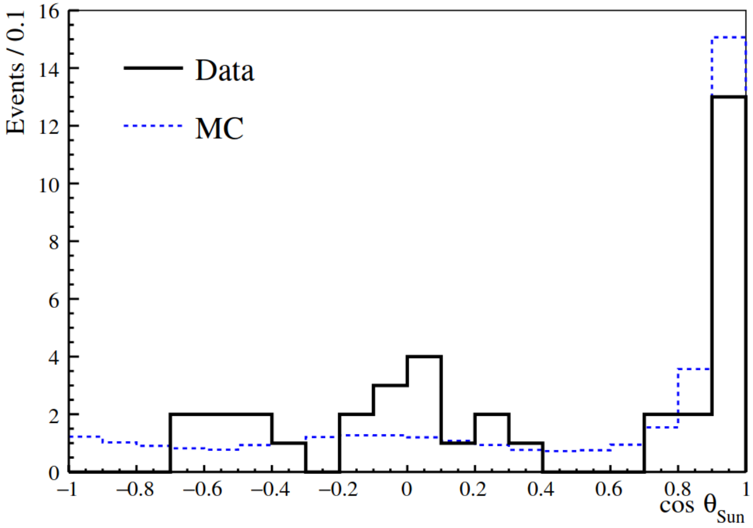


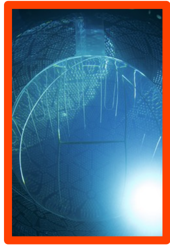
PRD 109, 072002 (2024)

- Scintillation light is isotropic, so reconstructing direction is hard…
- ...But not impossible! Cherenkov light still present if you look carefully:



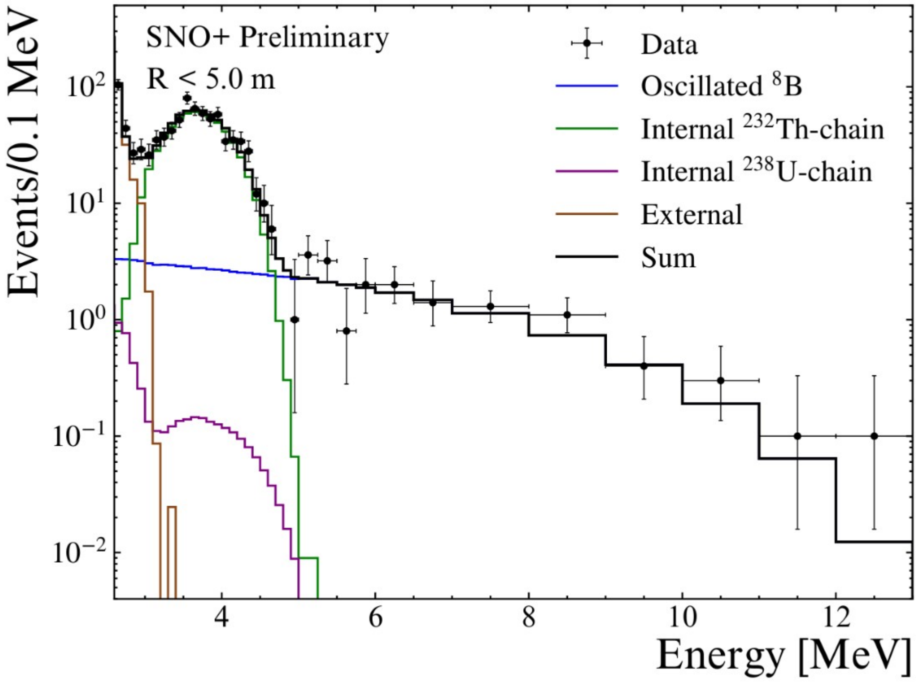
- Data from partial fill & early scint phases, where PPO loading low (0.6 g/L), leading to slow scintillation: good separation with Cherenkov light
- First event-by-event reconstruction of direction on high light yield scintillator!



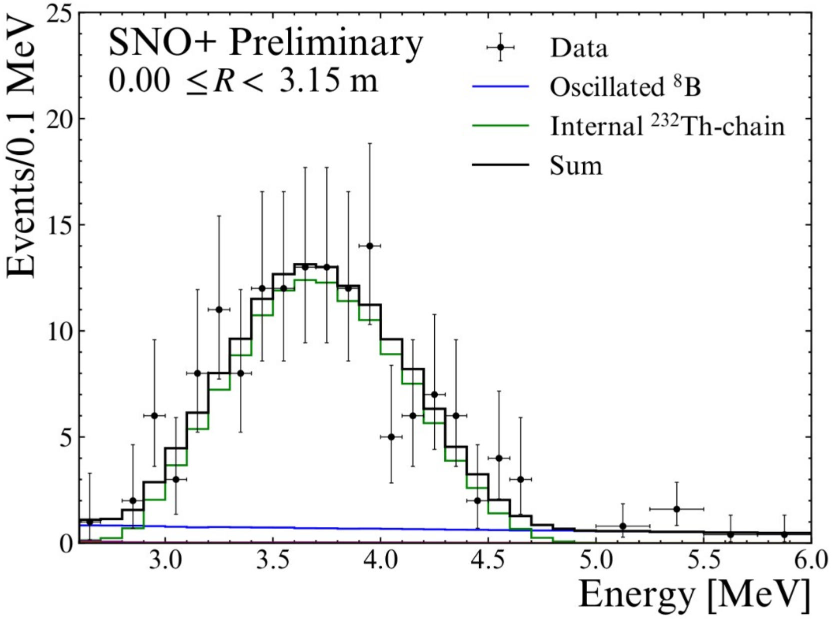


Solar Neutrino Flux & Oscillations in Scintillator

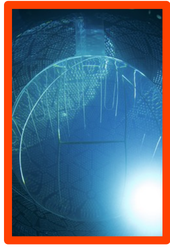
- Analysis of ^{8}B ES interactions in initial 143.1 livedays of scint. phase data



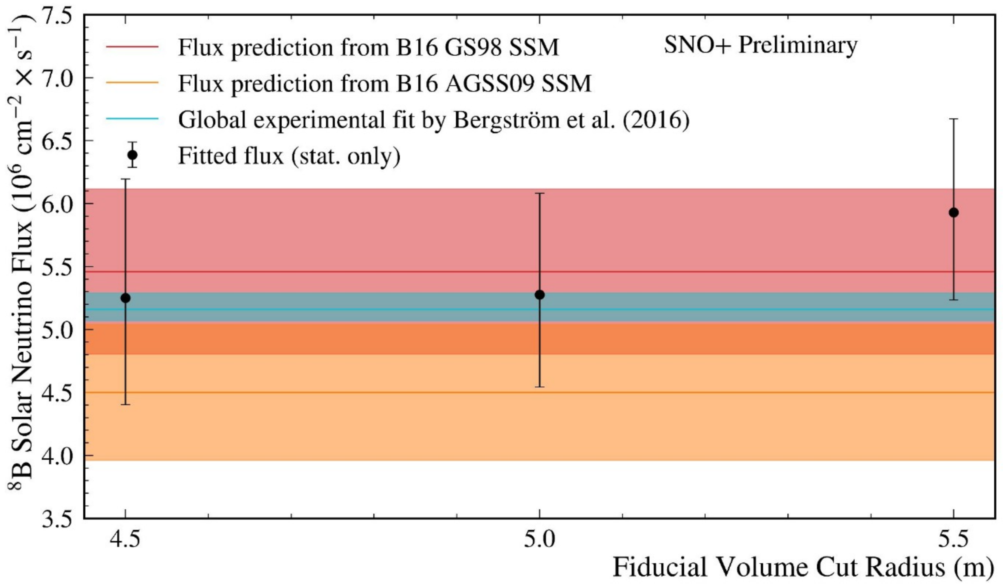
- Cosmogenic & External backgrounds become negligible in strict fiducial volume: possible future sensitivity < 3 MeV!
- Possible analysis techniques to remove dominant ^{208}Tl background: $(5.3 \pm 0.7)\times10^{-17}$ g/g ^{232}Th in 4m radial volume



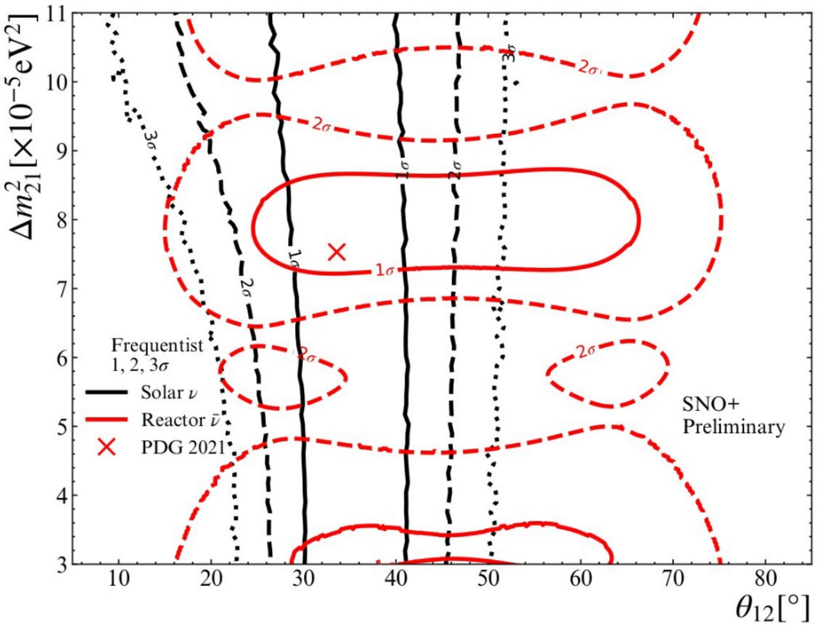
Solar Neutrino Flux & Oscillations in Scintillator



- Parallel analyses for measuring flux and neutrino oscillation parameters

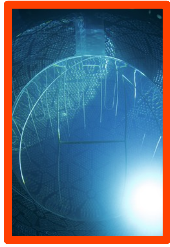


- Oscillation measurement complementary to reactor analysis: possible first-ever combined fit from the same detector?



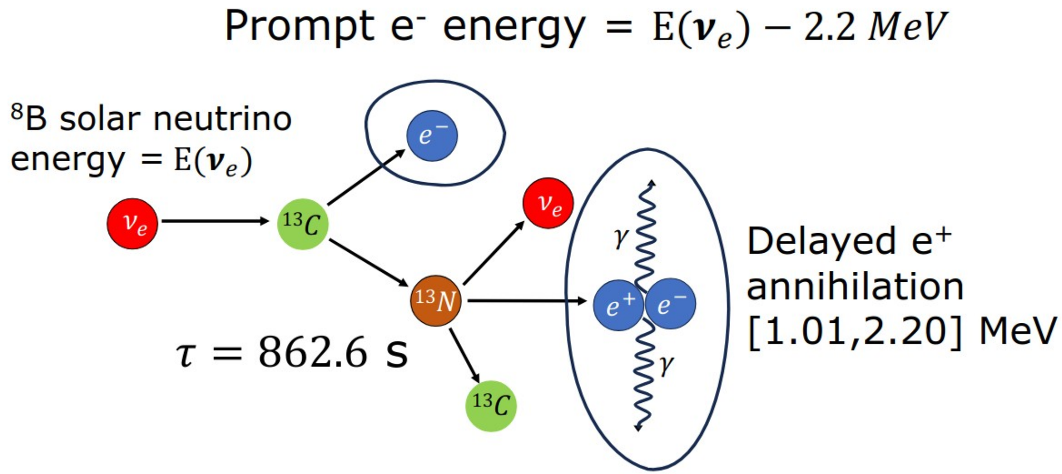
Solar osc. fit result assumes global fit flux

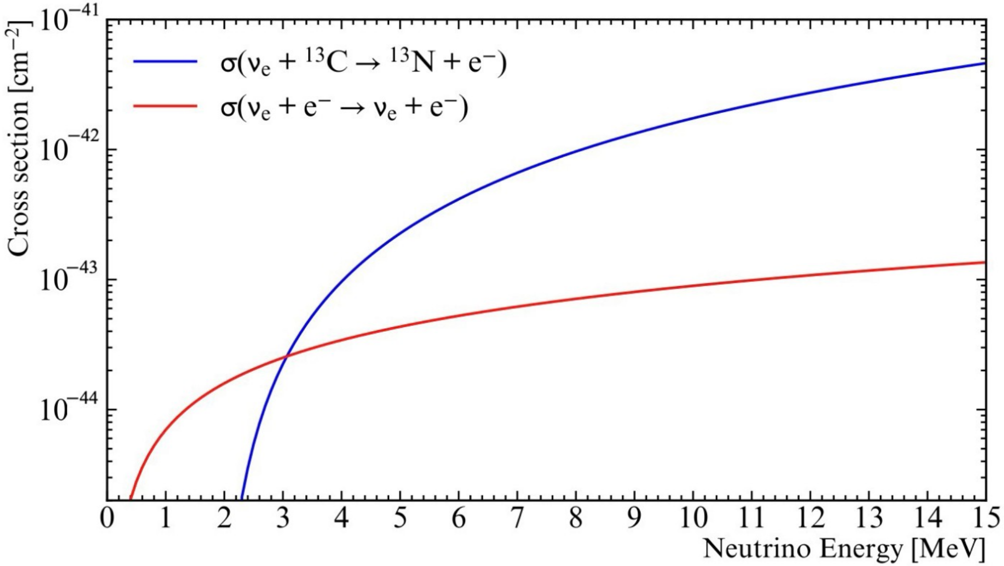
Charged-Current Interactions on ^{13}C



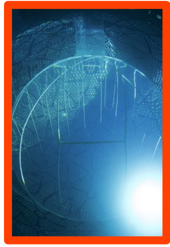
- CC interaction of solar neutrinos on ^{13}C possible, but as-yet unobserved
- 1% isotopic abundance, but O(10x) cross-section compared to ES!

- Delayed coincidence signal
- Cosmogenic background negligible at SNOLAB depth
- Accidental backgrounds determined by data-driven approach



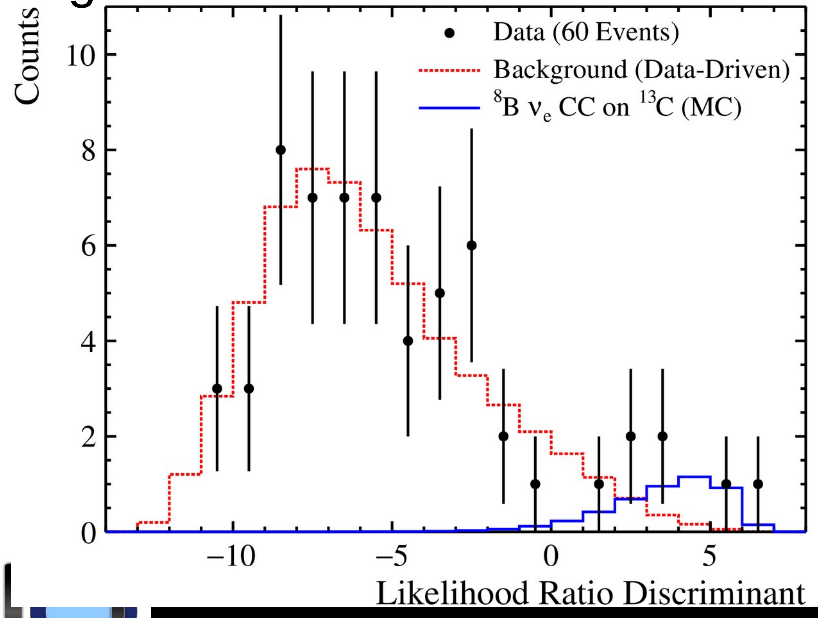


Charged-Current Interactions on ^{13}C



ArXiv:2508.20844

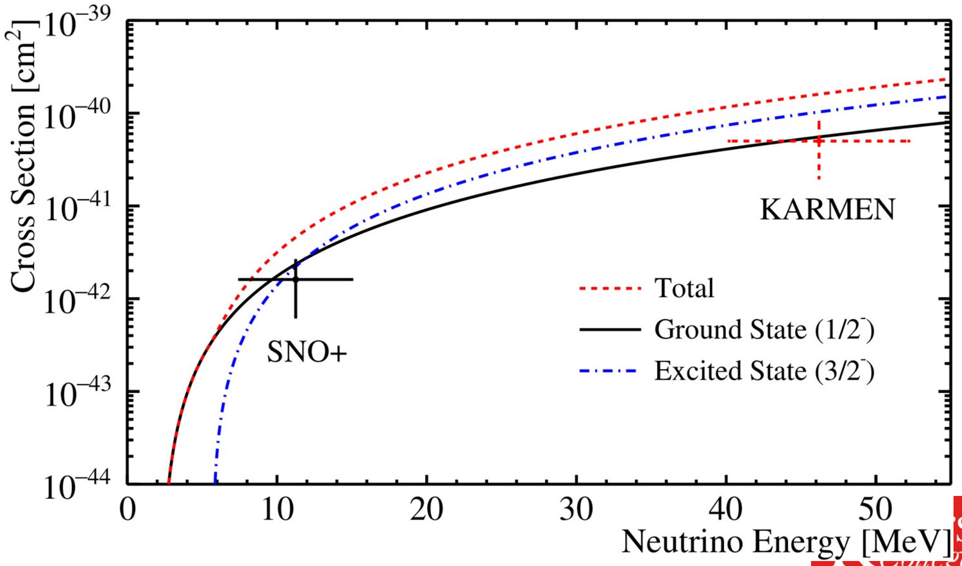
- 230.5 days of livetime (net)
- Blinded analysis performed – results of “box” and “likelihood” approaches consistent
- Significance: 4.2σ



First ever measurement of this interaction by solar νs (second-ever in general!)

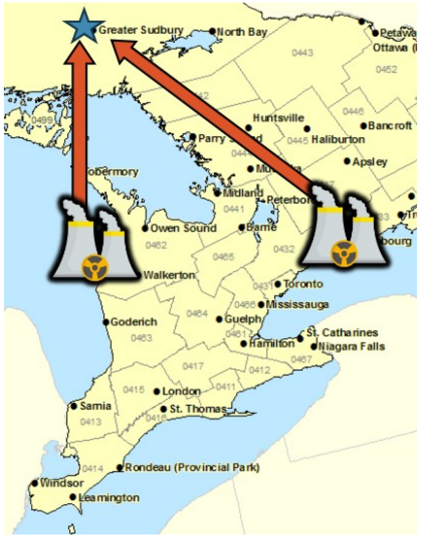
- Measured cross-section:

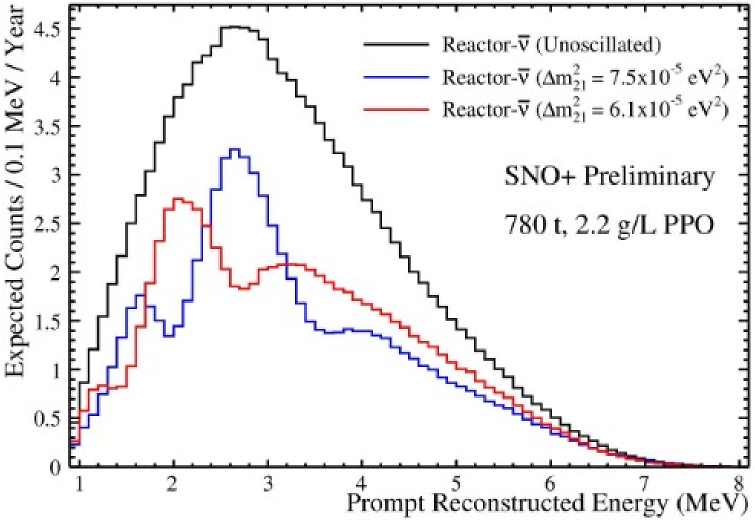
$$\langle \sigma(E_\nu) \rangle = (16.1^{+8.5}_{-6.7}(stat.)^{+1.6}_{-2.7}(syst.)) \times 10^{-43}\,\text{cm}^2$$



Antineutrinos in SNO+

- Electron antineutrinos interact with protons via inverse beta decay
- Most antineutrinos come from Canadian reactors, 240-350 km away: ~100 reactor IBD events/year expected, after oscillations
- ~25 geoneutrino IBD events/year
- Dominant background are (α,n) interactions, α coming dominantly from ^{210}Po

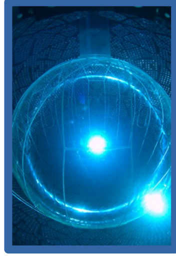




Antineutrinos in Water

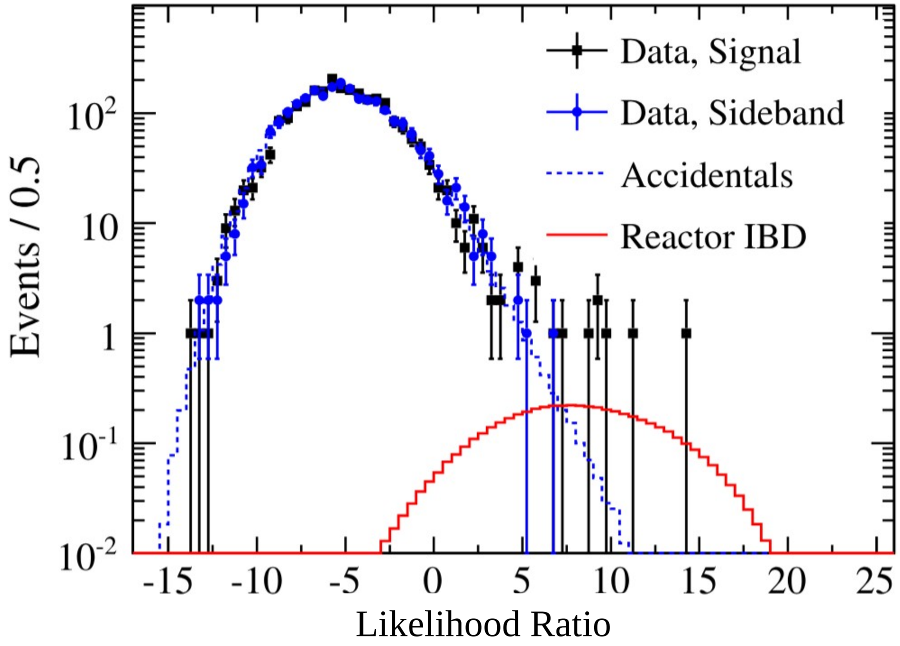
NewScientist
Physics
Antimatter neutrinos detected from a nuclear reactor 240 km away

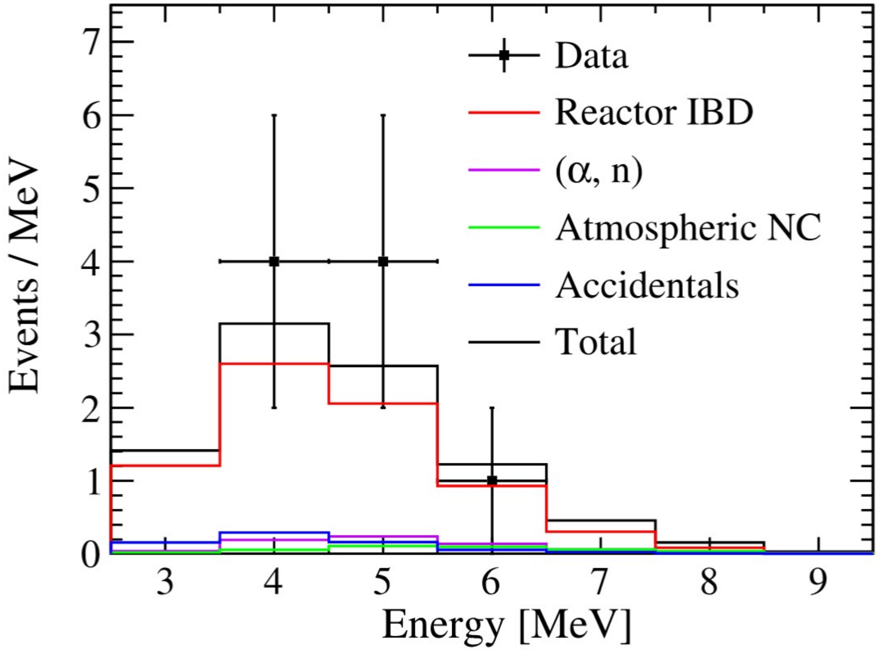
PRL 130, 091801 (2023)



- First evidence of reactor antineutrinos in a Cherenkov detector: 3.5σ
- Taking advantage of lowest-ever energy threshold for a large Cherenkov detector: ~1.4 MeV

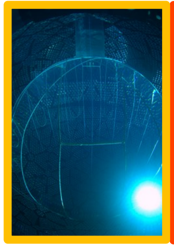
- 190 days livetime
- Two analysis methods gave comparable results: Likelihood ratio & Boosted Decision Tree





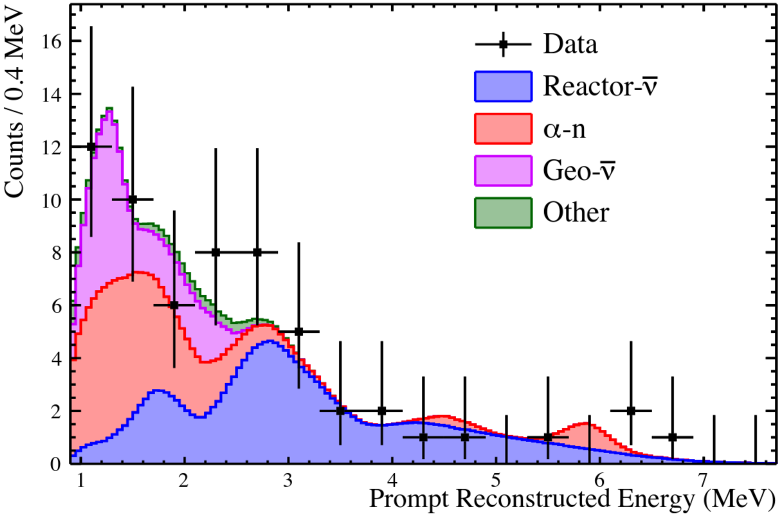
Antineutrinos in Scintillator

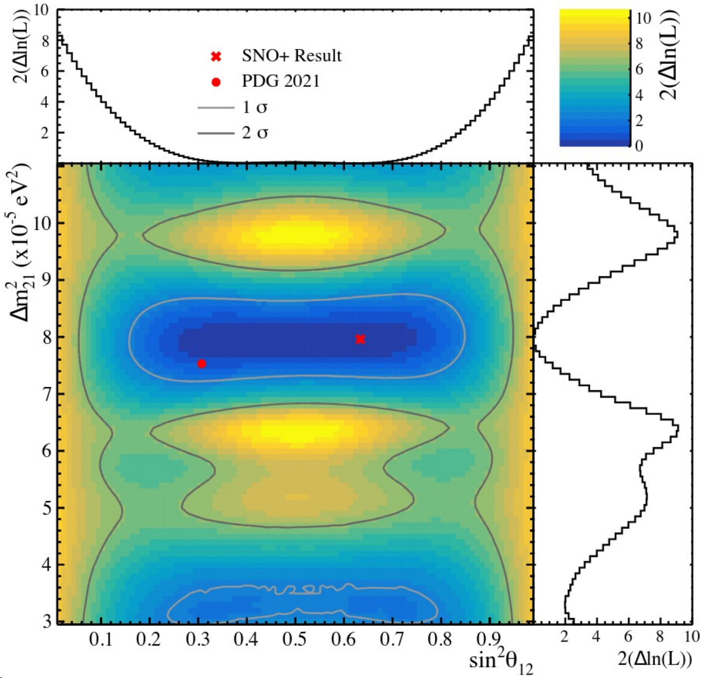
ArXiv:2505.04469, accepted by PRL



- Second-most precise measurement of Δm^2_{21} in the world
- 134.4 days of livetime
- First ever measurement of geoneutrino flux in Western Hemisphere
- Expect substantial update to this analysis soon!

	Fit (Uncon.)	Fit (Con.)
Δm^2_{21} ($\times 10^{-5}$eV^2)	$7.96^{+0.48}_{-0.42}$	$7.58^{+0.18}_{-0.17}$
$\sin^2\theta_{12}$	$0.62^{+0.16}_{-0.40}$	0.308 ± 0.013
Geo-$\bar{\nu}$ IBD rate (TNU)	79^{+49}_{-44}	73^{+47}_{-43}

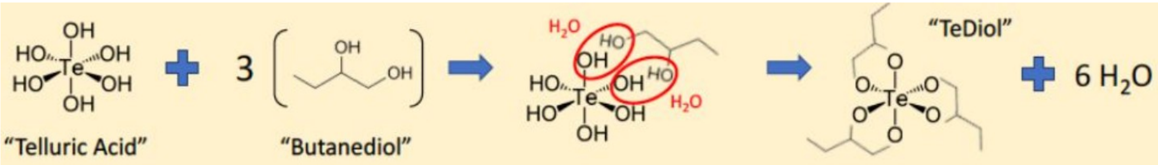




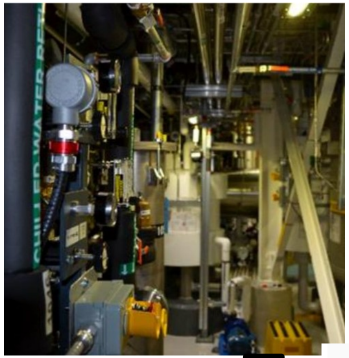
Searching for 0νββ in SNO+

NIMA 1051 168204 (2023)

- ^{130}Te to be loaded into scintillator to search for 0νββ, via novel, scalable technique

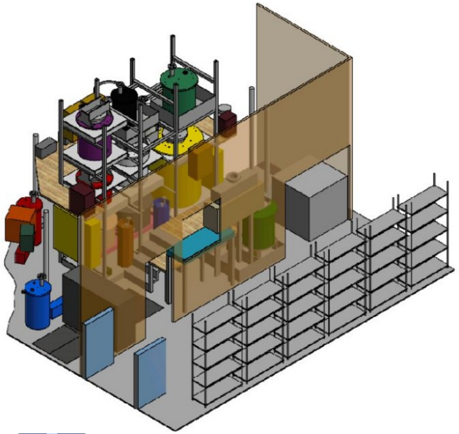


Butanediol Purification Plant (Underground)
Commissioned

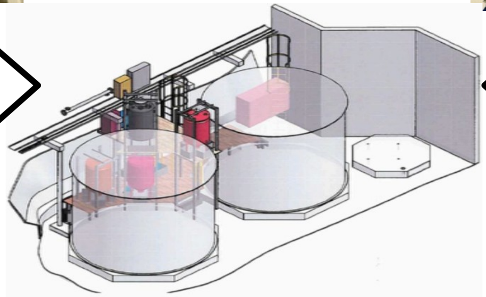


DDA Purification Plant (Surface)
Commissioned

Telluric Acid Purification Plant (Underground)
Commissioned



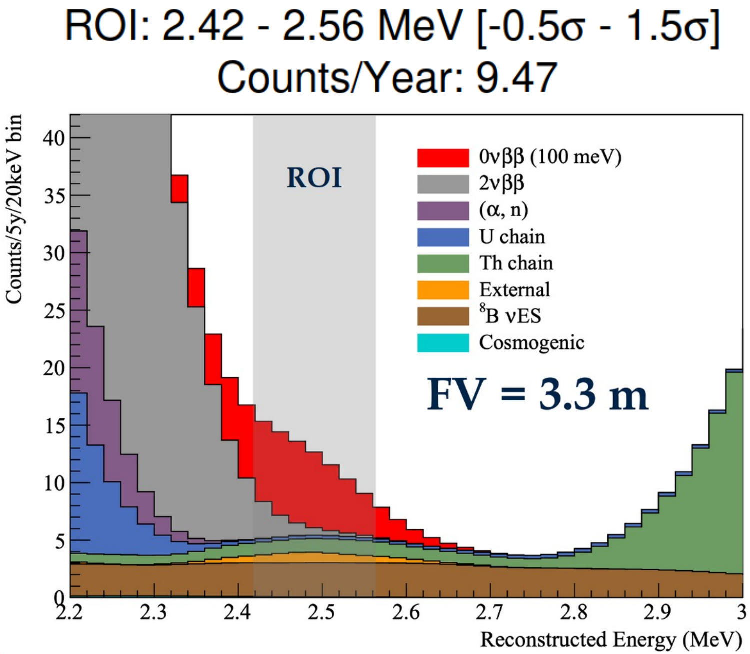
Te-BD Synthesis (Underground)
Commisioning

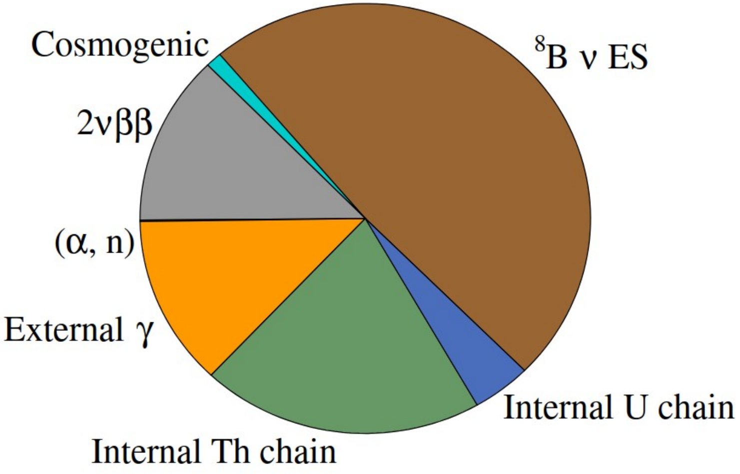


Into Detector!

Searching for 0νββ in SNO+

- No enrichment needed, high Q-value, long 2νββ half-life (lower intrinsic background)
- Initial loading planned for 2026
- Expected sensitivity after 3 years of loading 0.5% natTe: 2×10^{26} yr (90% CL)

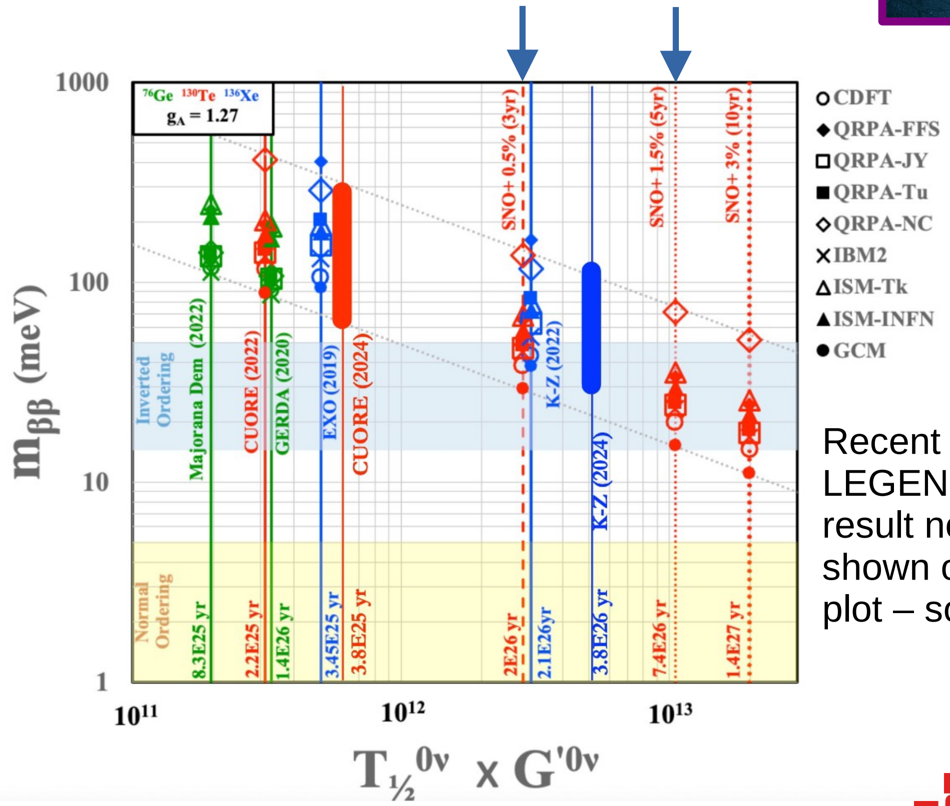




Searching for $0\nu\beta\beta$ in SNO+

PRD 104 012002 (2021)
NIMA 1051 168204 (2023)

- Higher loadings of Te planned for SNO+
- Sensitivity with 5 years with 1.5% natTe loading: $T_{1/2} > 7.4\times10^{26}$ years (90% CL)
- Good light yield & stability found at higher loadings during R&D



Recent LEGEND-200 result not yet shown on this plot – sorry!

Summary

- The SNO+ Experiment has taken water-phase data, and is currently taking scintillator-phase data
- Variety of analyses ongoing! A sample:
  - First ever observation of solar neutrinos interacting on ^{13}C
  - Second-most precise measurement of Δm^2_{21}
  - First ever measurement of geoneutrino flux in Western Hemisphere
  - ^8B Solar neutrino oscillation analysis underway with energy threshold < 3 MeV
- Major preparations underway for planned Te-loading starting next year!

On behalf of the SNO+ Collaboration...

Thank You!

Backup Slides

Other SNO+ Publications

- Nucleon decay searches in water phase:
  PRD 99, 032008 (2019)
  PRD 105, 112012 (2022)
- Partial-fill antineutrino analysis:
  EPJC 85 1 17 (2025)
- Water phase optical calibration:
  JINST 16 P10021 (2021)
- Water phase neutron-capture calibration:
  PRC 102 014002 (2020)
- SNO+ scintillator:
  JINST 16 P05009 (2021)