SNO+ EXPERIMENT UPDATE

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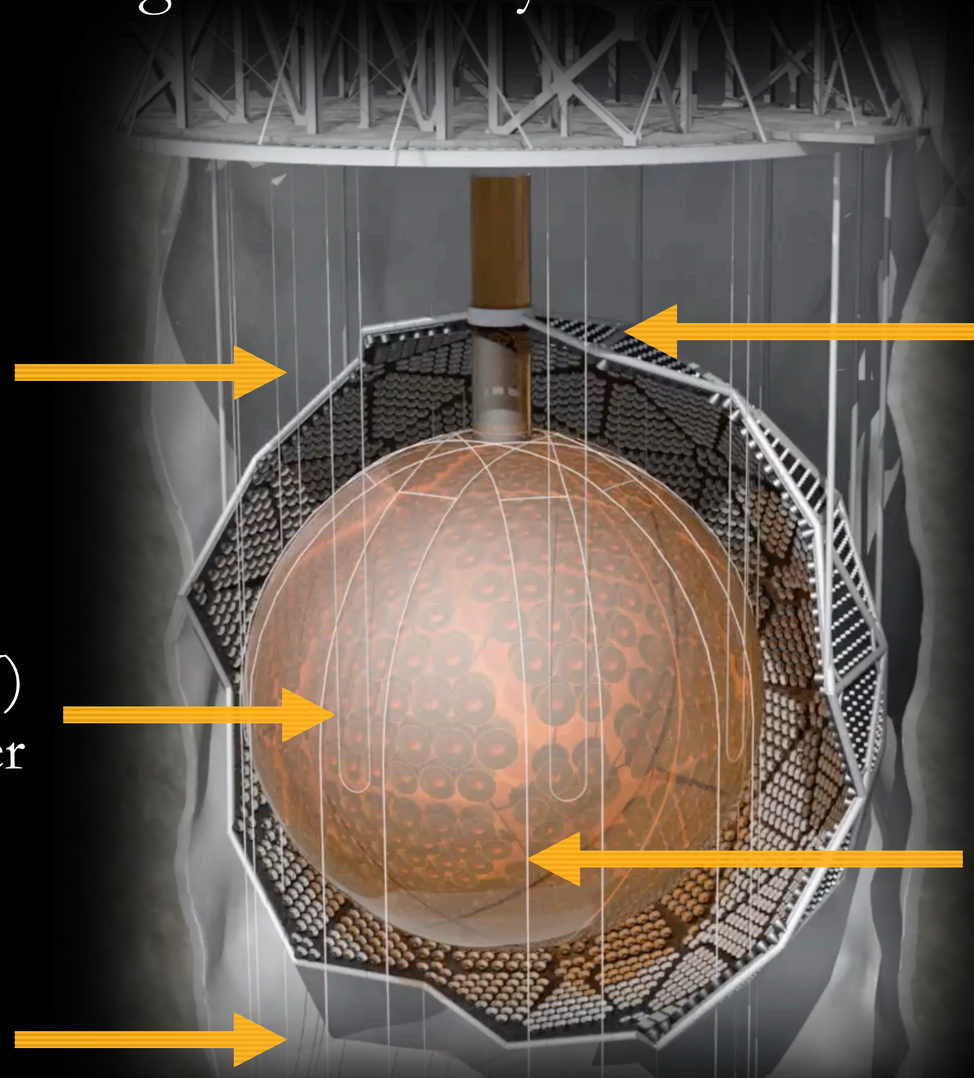
SNOLAB EXPERIMENT
ADVISORY COMMITTEE MEETING
SUDBURY, JULY 31, 2024

THE SNO+ EXPERIMENT

Repurposing the Sudbury Neutrino Observatory (SNO) detector

2 km underground
~70 muons/day

Rope system
Hold-up and -down
Low Radioactivity



~9300 PMTs

Acrylic Vessel (AV)
12 m diameter

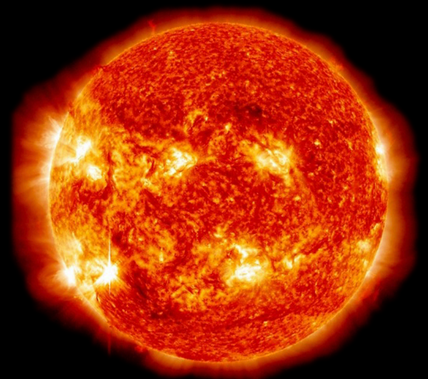
Ultra-Pure
Water

Purification plant

Target Material

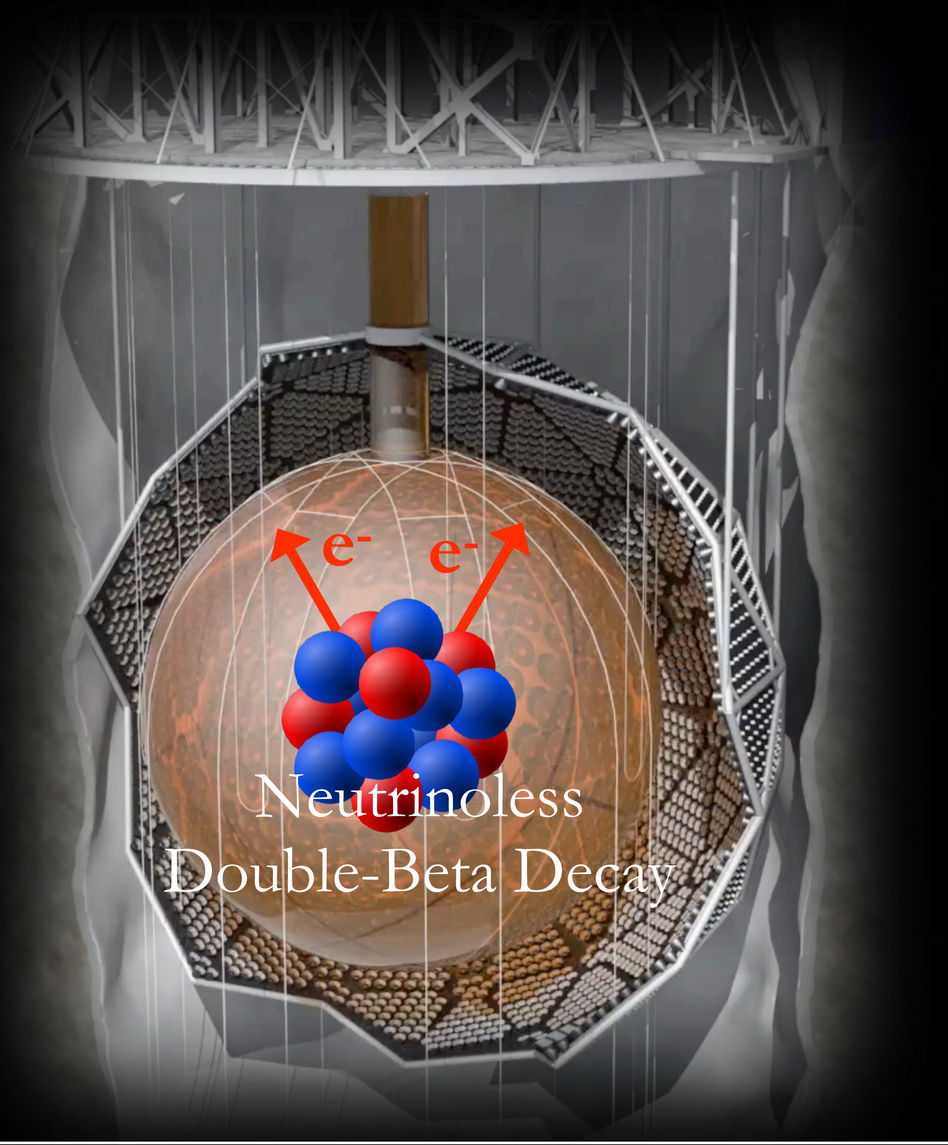
1. Water: 905 tonnes
2. LAB Scintillator: 780 tonnes
3. Tellurium loading: +3.9 tonnes

THE SNO+ EXPERIMENT



Solar Neutrinos

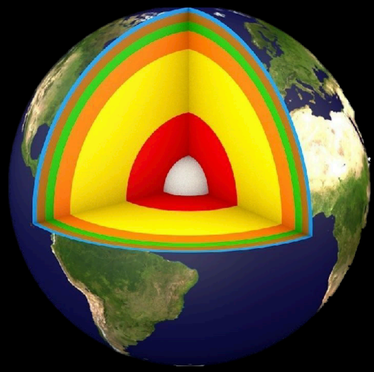
Reactor Neutrinos



Neutrinoless
Double-Beta Decay

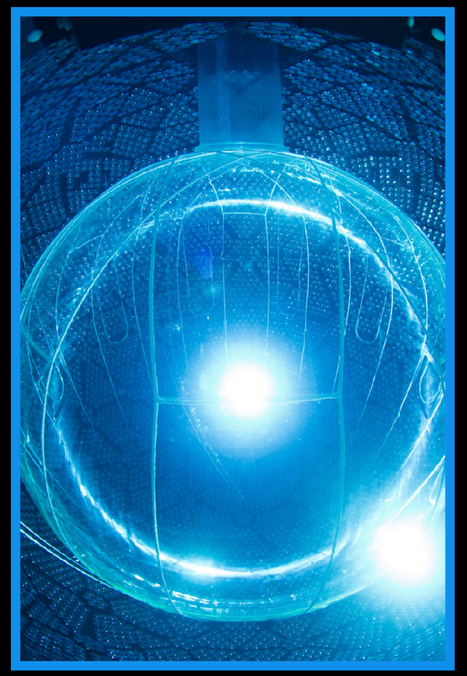
Supernova Neutrinos
+ exotics

Geo-Neutrinos



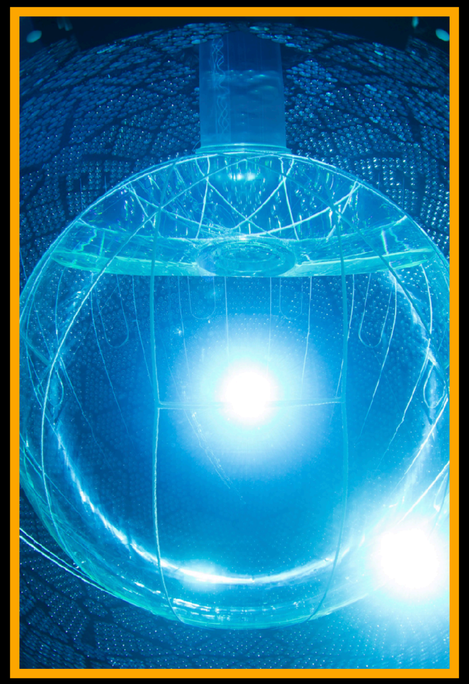
SNO+ TIMELINE

2017 2018 2019 2020 2021 2022 2023 2024 2025



Water phase

- High Rn
- Low Rn

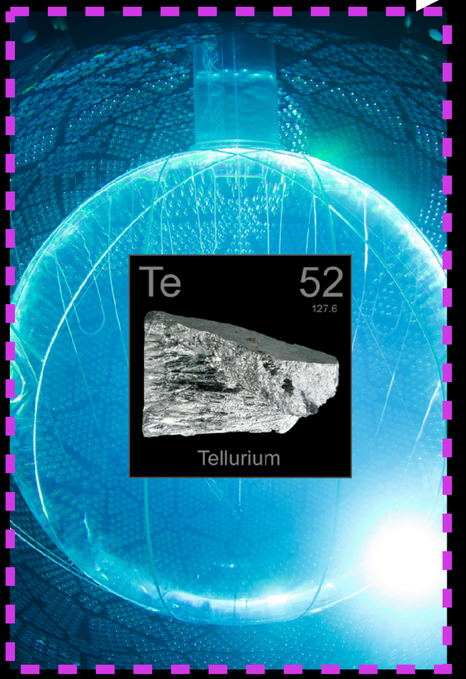


Partial fill phase

Scintillator over water.
Stop in fill due to Covid.

Scintillator phase

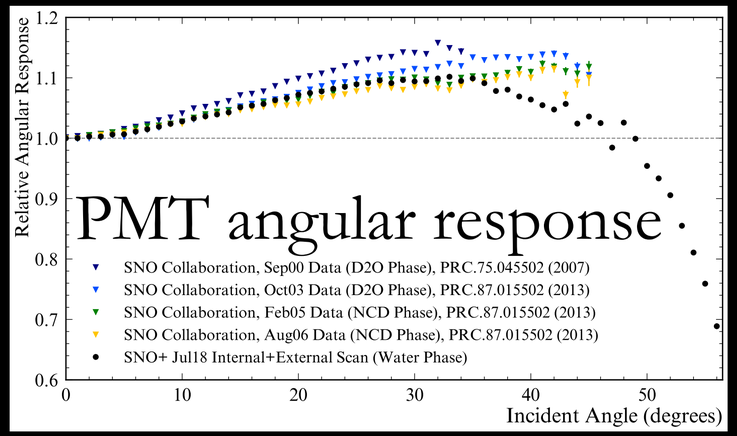
- Low PPO
- Nominal PPO
- Added bis-MSB



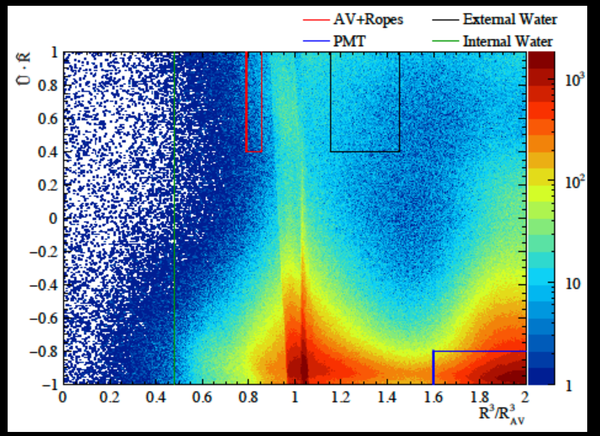
Next: Tellurium-loaded phase

SNO+ PERFORMANCE

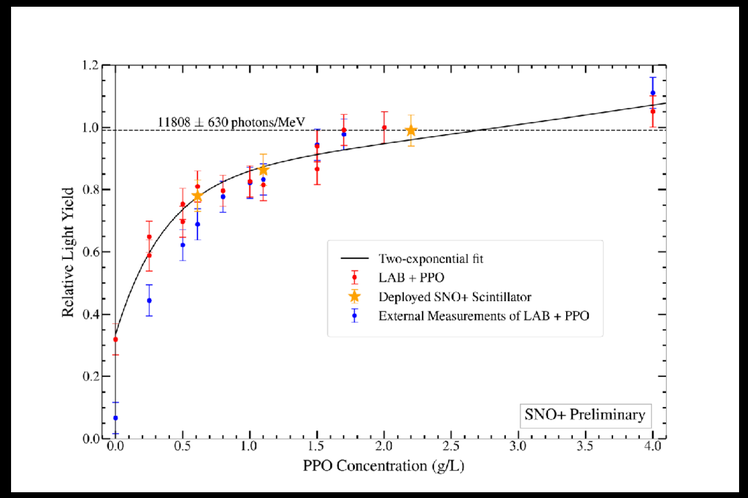
- Water Phase
  - Extensive calibrations: well-tuned detector model
  - Constraints on external backgrounds: smaller than nominal

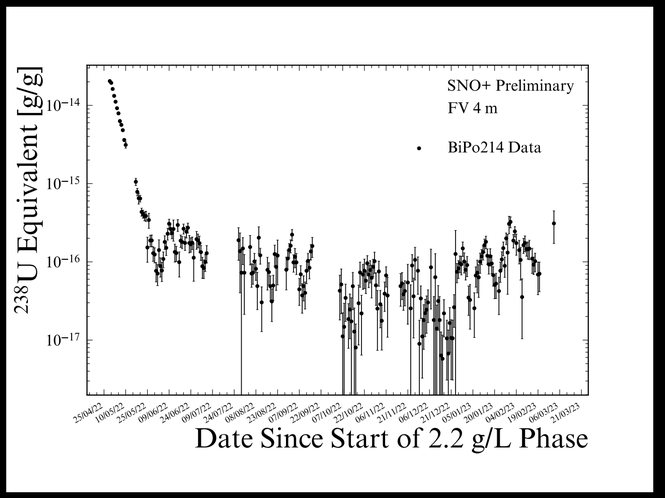


In/Out Direction



- Scintillator Phase
  - Tracking background and light levels throughout operations
  - High but decreasing level of Po210
  - BiPo214/212 segments of Uranium and Thorium chains at low level:
    - Eq. ^{238}U ~4.3×10^{-17} g/g
    - Eq. ^{232}Th ~5.3×10^{-17} g/g



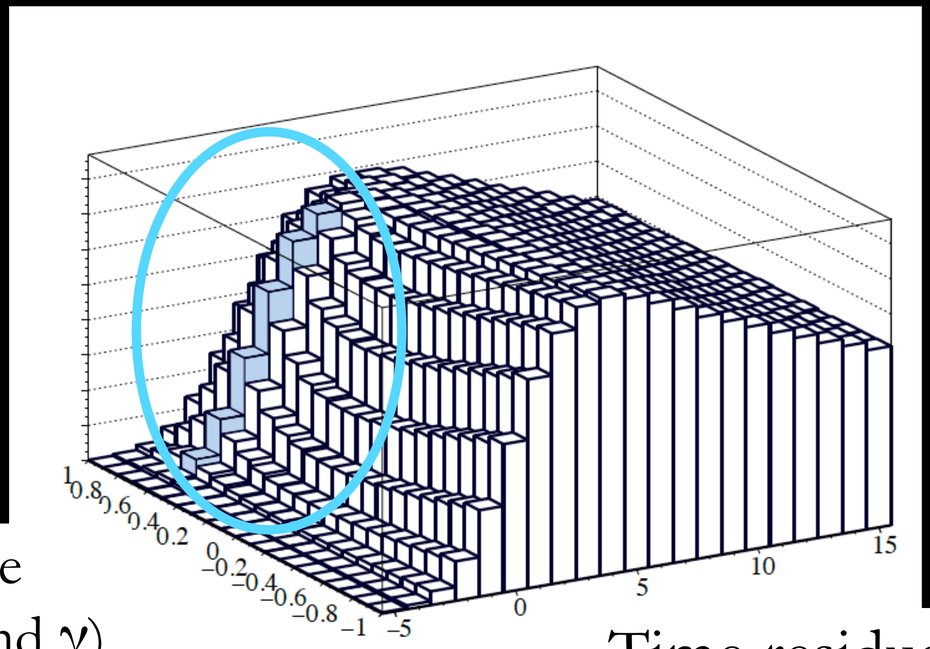


PREVIOUS RESULTS

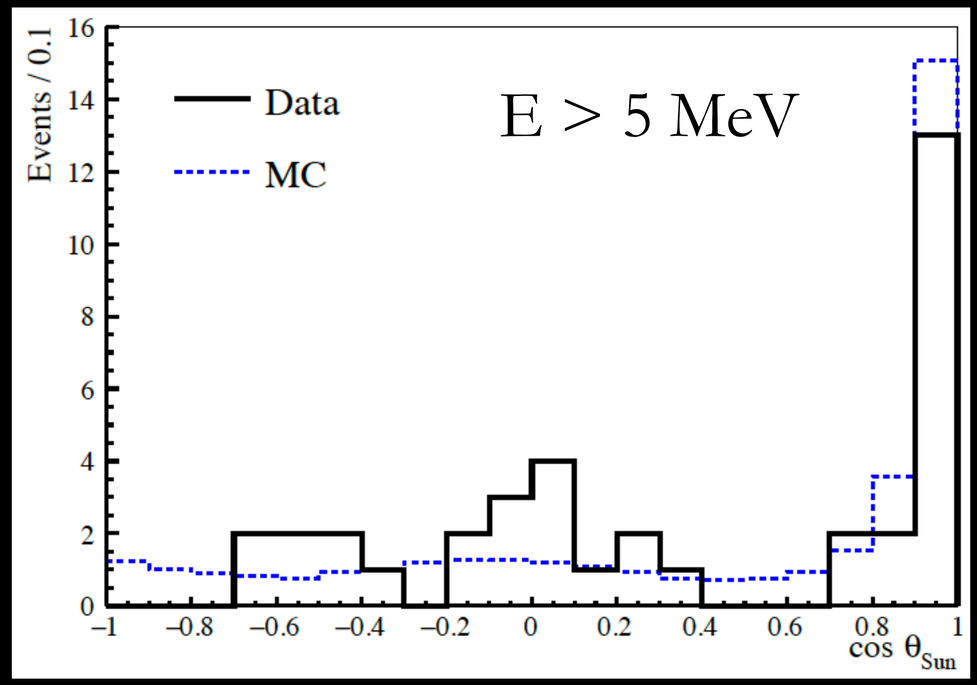
DIRECTIONALITY IN SCINTILLATOR

SNO+ Collab., Phys.Rev.D 109 (2024) 7, 072002

- Slow scintillation leads to good separation between Cherenkov and scintillation photons
- Early data with low PPO (0.6 g/L)
  - Reasonable light yield (300 pe/MeV)
  - Slow timing τ = 13. 5 ns (first comp.)



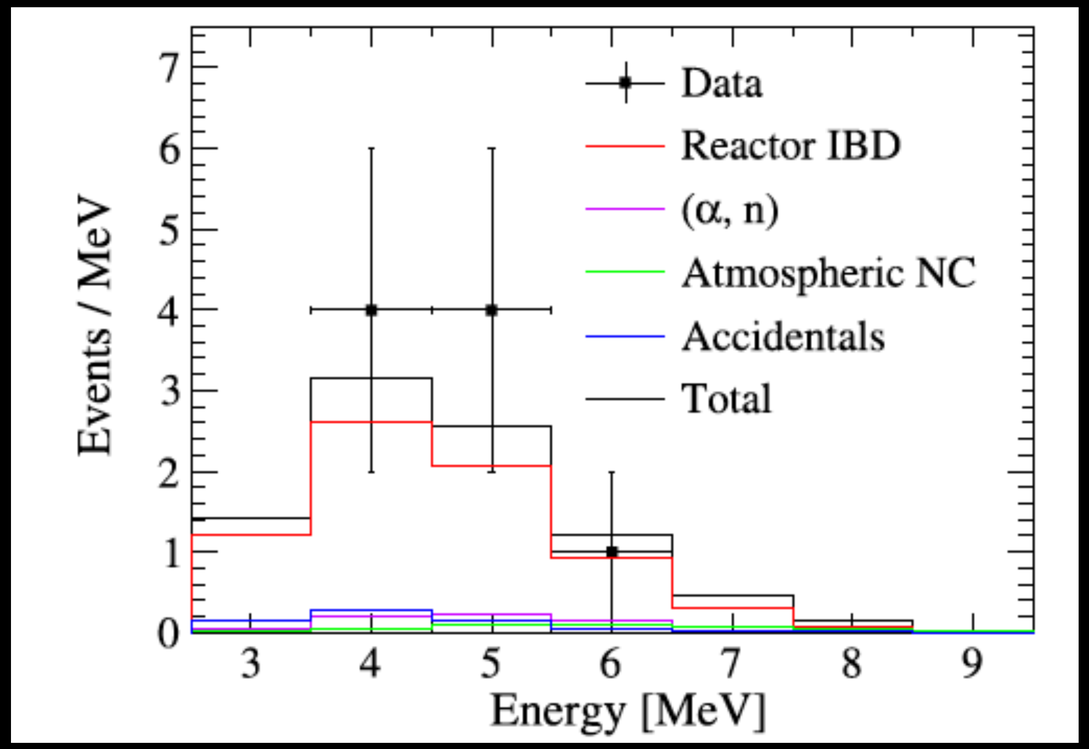
- ^{8}B solar neutrino analysis
- Data from partial fill and early scint phases (23 and 15 kt-days)



- First event-by-event reconstruction of direction in high light yield scintillator !

REACTOR NEUTRINOS IN WATER

- SNO+ exploited good trigger and light collection performance
- Detected 2.2 MeV gammas from neutron capture, in coincidence with prompt signal. AmBe source calibration showed neutron efficiency of 50%
- First detection of antineutrinos from far reactors with a water Cherenkov detector



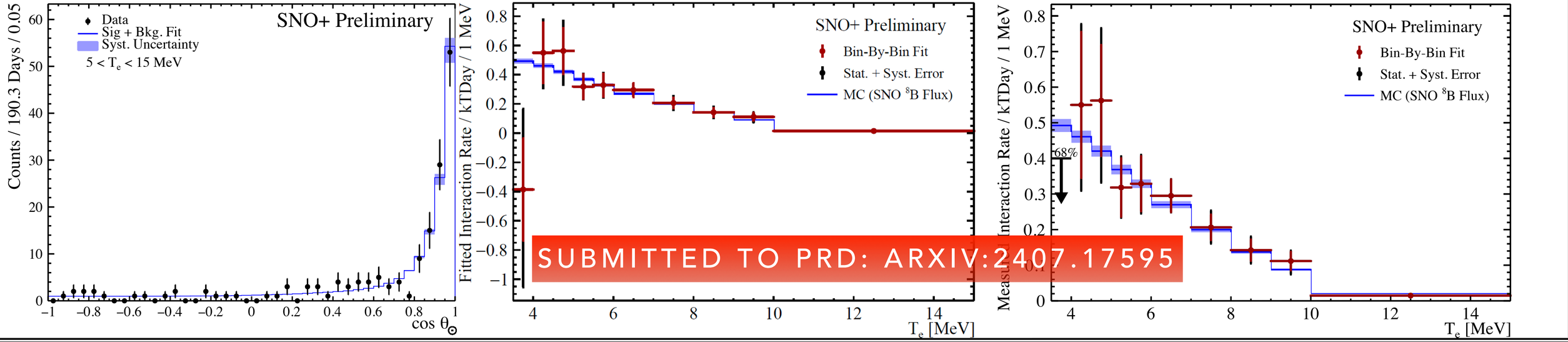
NEW RESULTS

SOLAR NEUTRINOS, WATER PHASE

- New analysis of 126.6 kt.days, including 190.3 days of low background data
  - Radon in water ~6×10^{-15} gU/g
  - Lowest background for water Cherenkov detectors > 5 MeV: 0.32 ± 0.07 ev/kt.days

- Results
  - 3.5 MeV threshold, but large uncertainties in first bins
  - Best-fit flux consistent (inc. oscillations) with other experiments, and HZ and LZ solar models

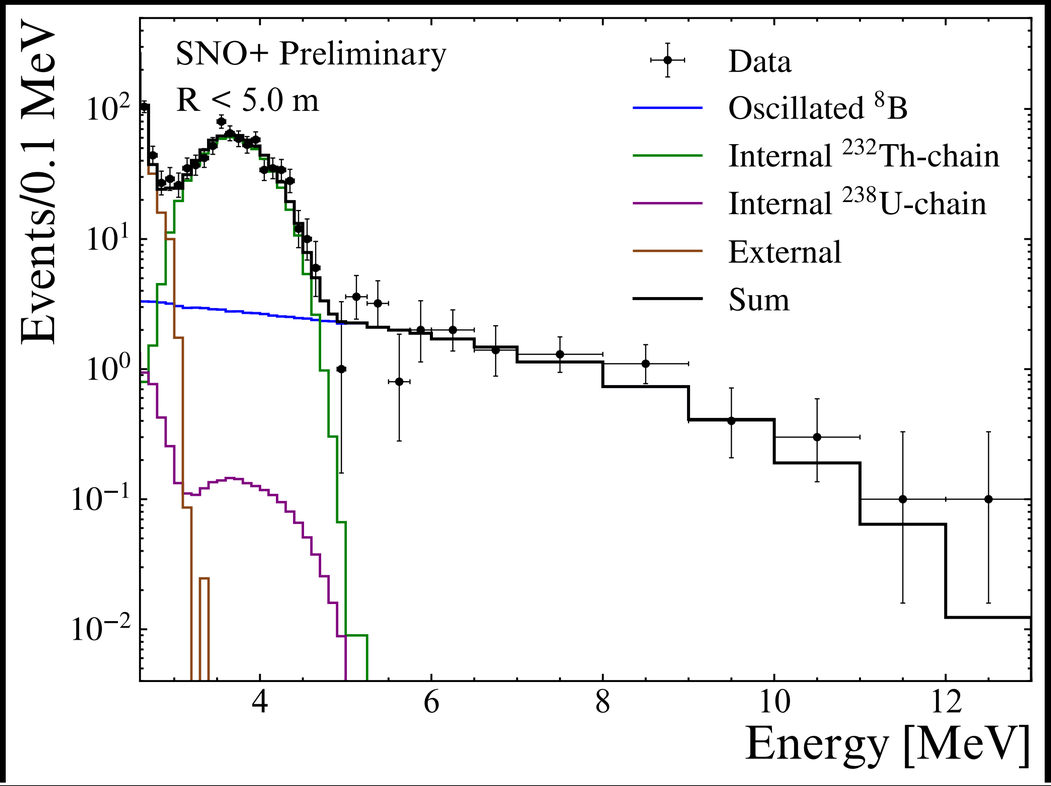
$$\left(5.36^{+0.41}_{-0.39}(\text{stat.})^{+0.17}_{-0.16}(\text{syst.})\right) \times 10^6\,\text{cm}^{-2}\text{s}^{-1}$$

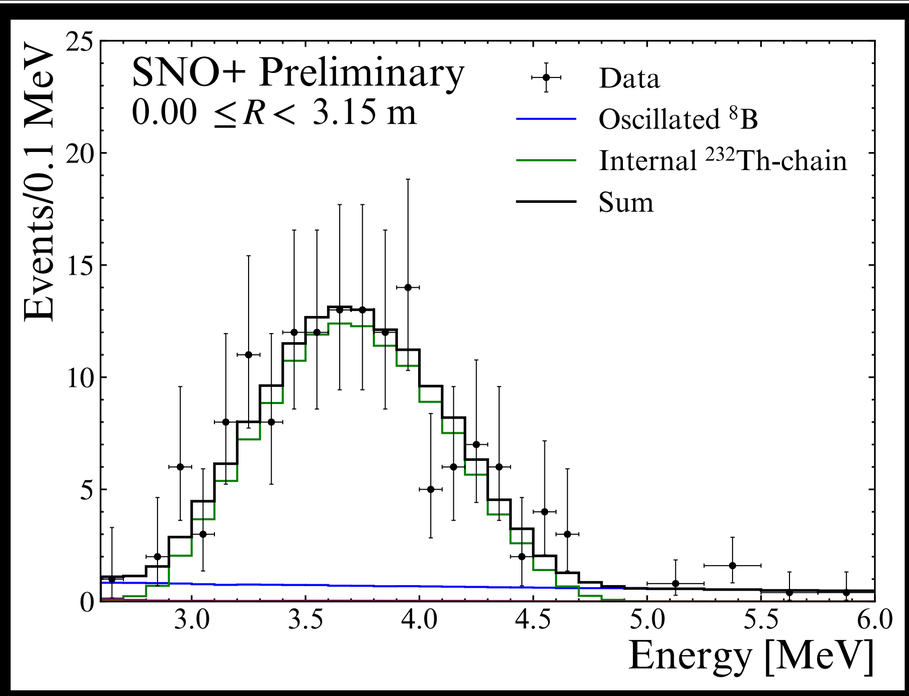


SUBMITTED TO PRD: ARXIV:2407.17595

SOLAR NEUTRINOS, SCINT. PHASE

- Analysis of ^{8}B ES interactions in 138.9 live days of scint. data
- Fitted oscillation parameters compatible with global fits





- Strict fiducial volume cut opens prospects for future sensitivity < 3 MeV !
- ^{232}Th still dominates 3-5 MeV regions, but multisite discriminant will help

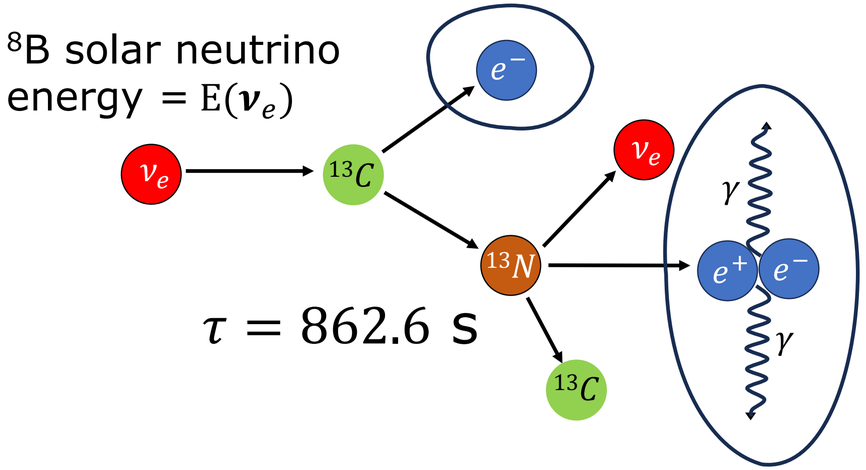
CHARGED CURRENT ON CARBON-13

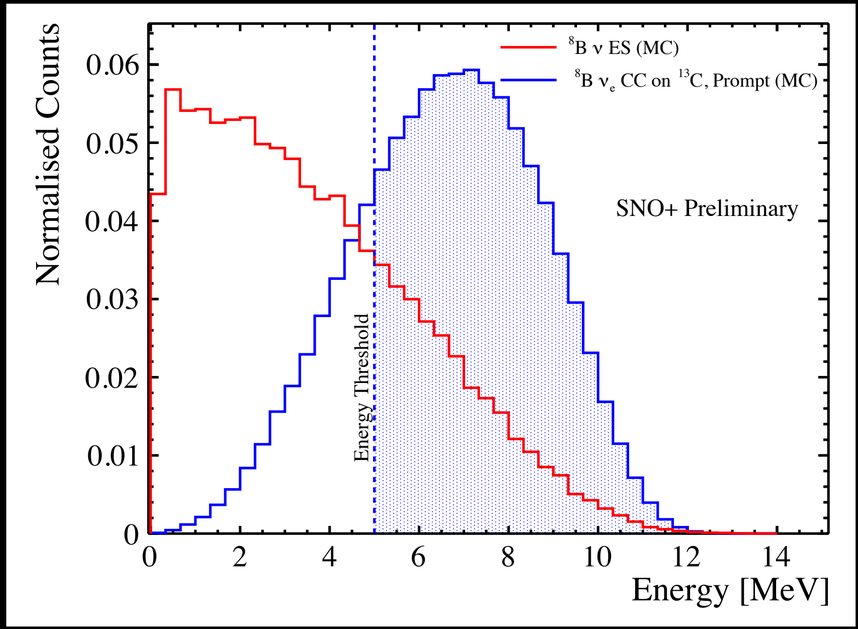
$$\nu_e + {}^{13}C \rightarrow e^- + {}^{13}N$$

$$^{13}N \rightarrow e^+ + \nu_e + {}^{13}C$$

- As yet unobserved reaction of electron neutrinos on Carbon-13
- Only 1.1% isotopic abundance, but cross section ~12× higher than ES at ^{8}B ν energies

Prompt e⁻ energy = $\mathrm{E}(\boldsymbol{\nu}_e) - 2.2\ MeV$





- Cosmogenic backgrounds from ^{11}Be: negligible at SNOLAB depth
- Dominant accidental backgrounds determined by data-driven method
  - Randomly pick fake prompt , then search for delayed signal candidates

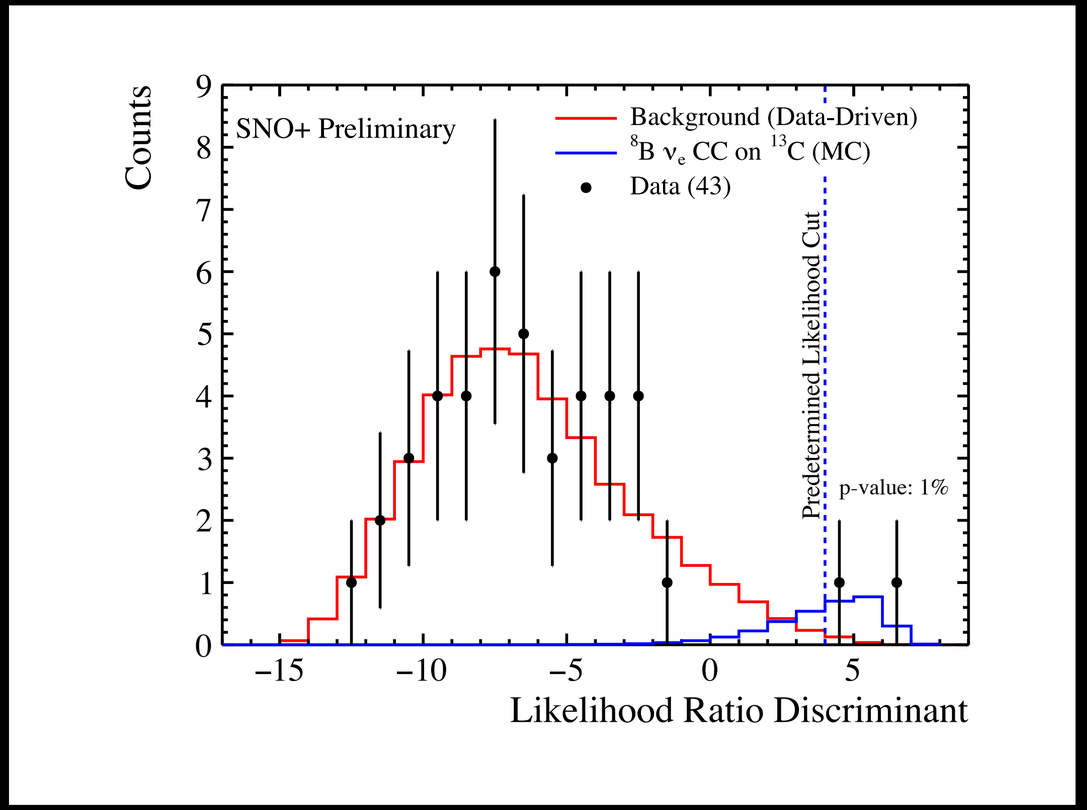
CC ON CARBON-13, RESULTS

- Cuts optimised prior to "blind box" opening:
  - Fiducial volume: R< 5.3 m
  - Prompt energy: 5.0 < E (e^-) < 15.0 MeV
  - Delayed energy: 1.14 < E (e^+) < 2.2 MeV
  - ΔR < 0.36 m
  - 0.01 < ΔT < 24 min
  - Likelihood ratio analysis
    - Wider cuts on Delayed energy, ΔR, ΔT
    - Likelihood ratio discriminant> 4

EXPECTED	BOX	LIKELIHOOD
BACKGROUND	0.31	0.17
SIGNAL	1.83	1.79

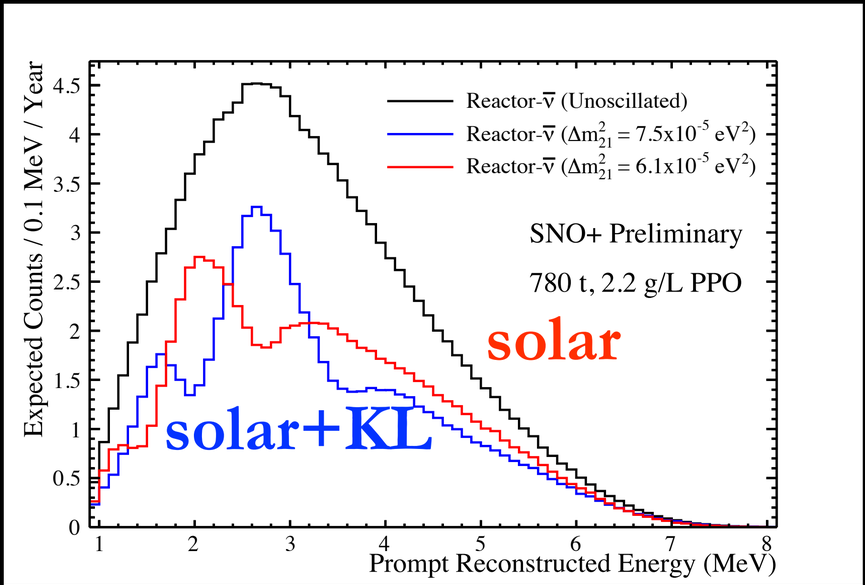
150.51 live days

2 events found !



Indicative of a signal from ^{13}C CC interactions !

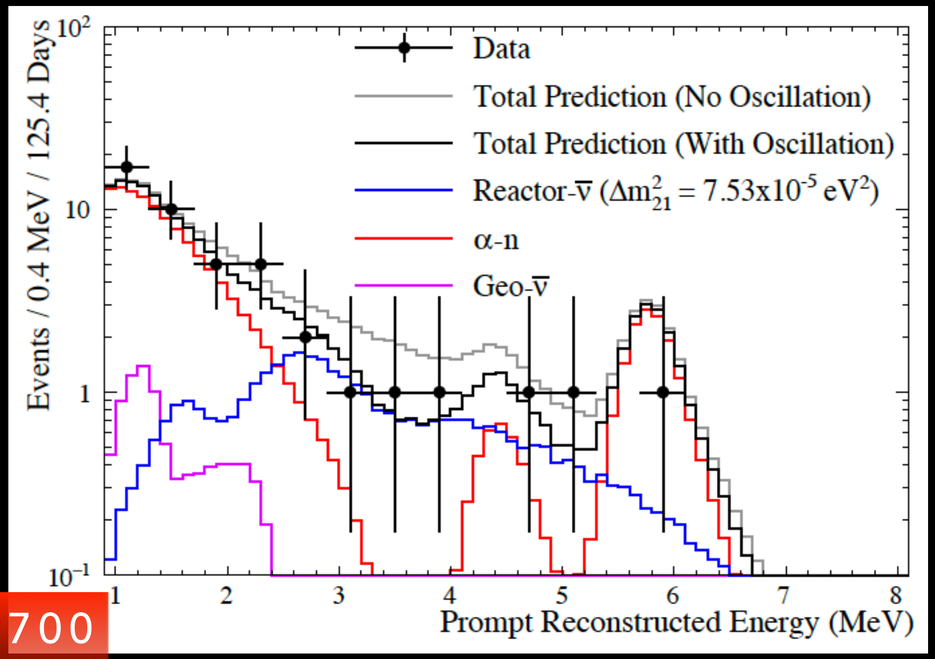
REACTOR ANTINEUTRINOS ANALYSIS



$$\bar{\nu}_e + p \rightarrow e^+ + n$$
$$n + p \rightarrow {}^2H + \gamma(2.2MeV)$$

- Prompt spectrum @ SNO+ with sharp features, due to few baselines
- Potential to shed light on solar-KamLAND tension

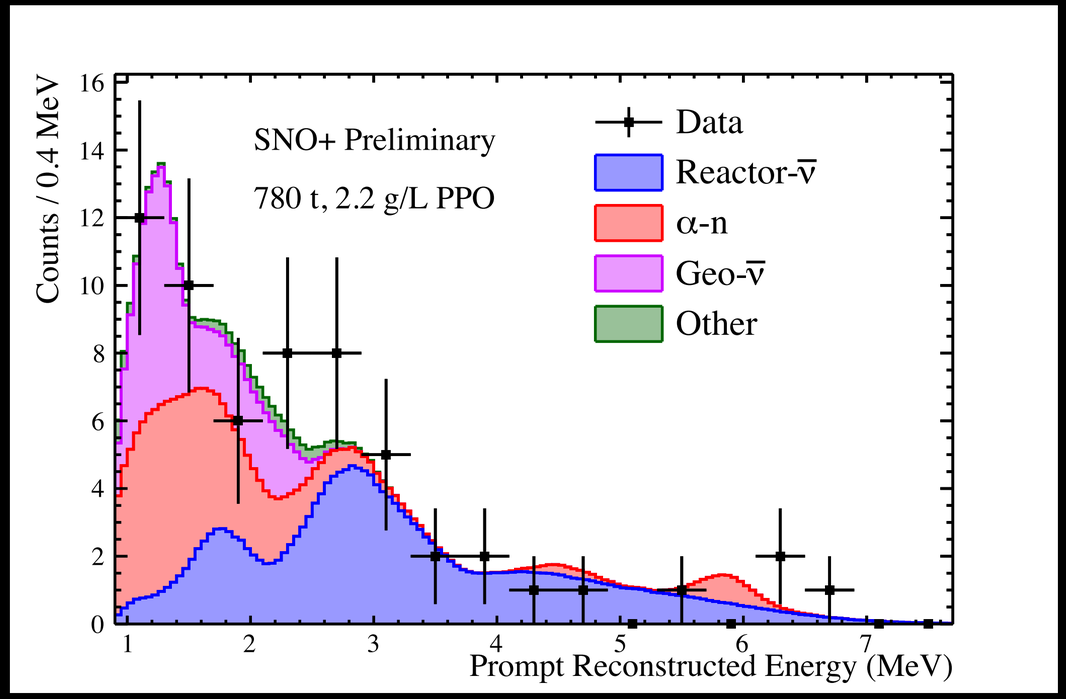
- Following first detection in a water Cherenkov detector, new results from partial and scint phases
- Main background: (α,n) reactions on ^{13}C
  - αs from high rate ^{210}Po decays
- Partial fill: 114 t.y exposure, 85 Hz of ^{210}Po
  - Stats and background-limited



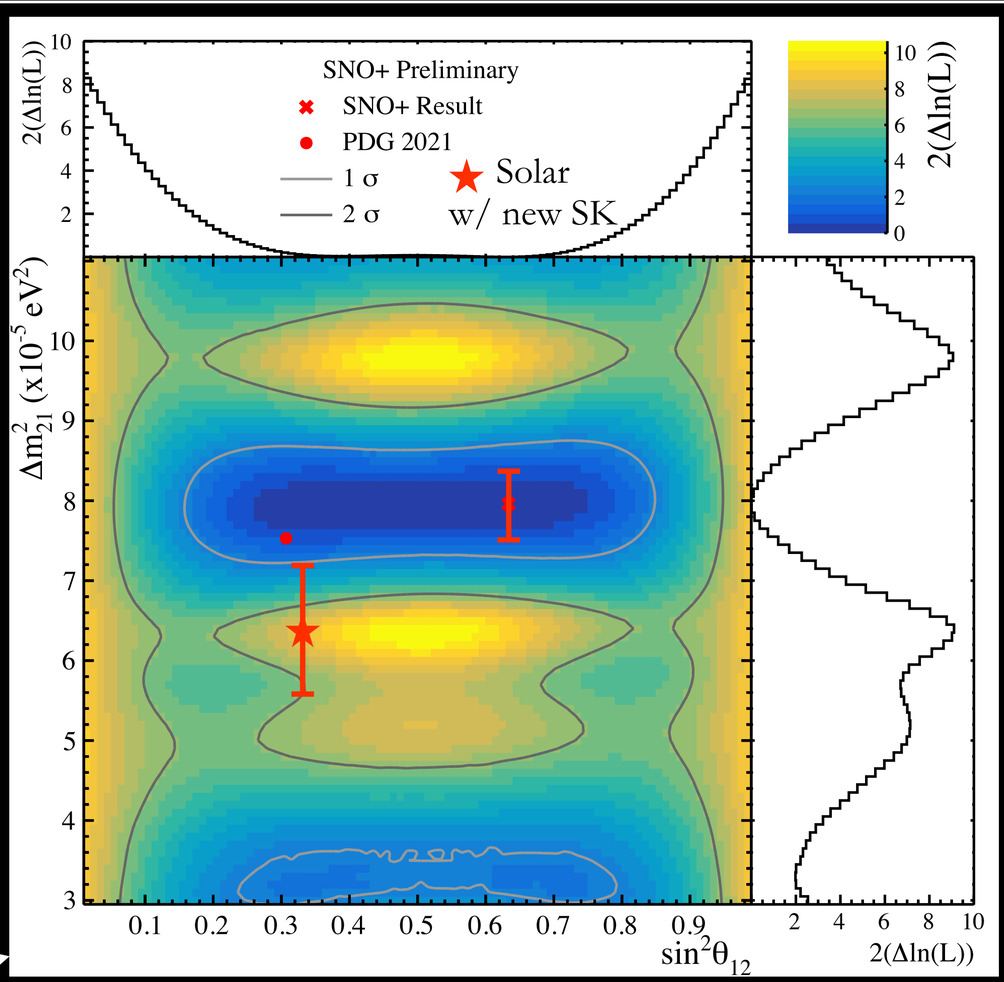
SUBMITTED TO PRD ARXIV:2405.19700

REACTOR ANTINEUTRINOS RESULTS

Scint. phase:
286 t.y
exposure,
38 Hz ^{210}Po



- Still stats limited, but lower (α,n) background
- Geo-nu 64+/- 44 TNU, will improve soon with (α,n) classifier
- Unconstrained oscillation fit



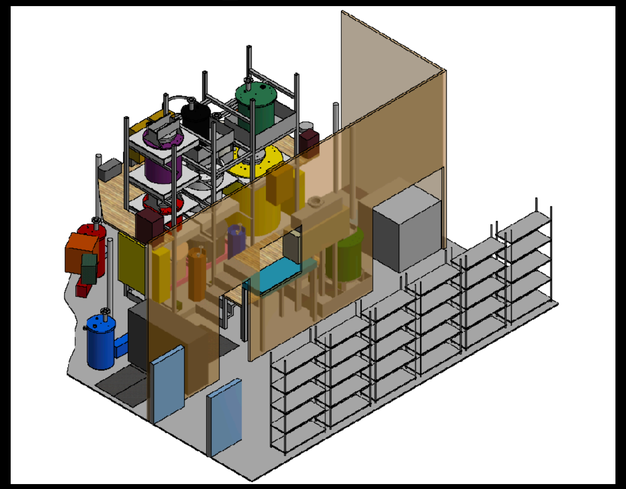
$$\Delta m^2_{21} = 7.96^{+0.48}_{-0.41} \times 10^{-5} eV^2$$

- ~1.3σ from solar only, <1σ from KL

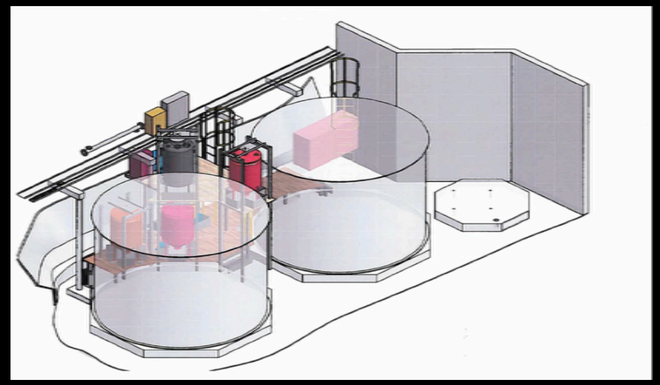
PROSPECTS FOR DOUBLE BETA DECAY

TELLURIUM SYSTEMS

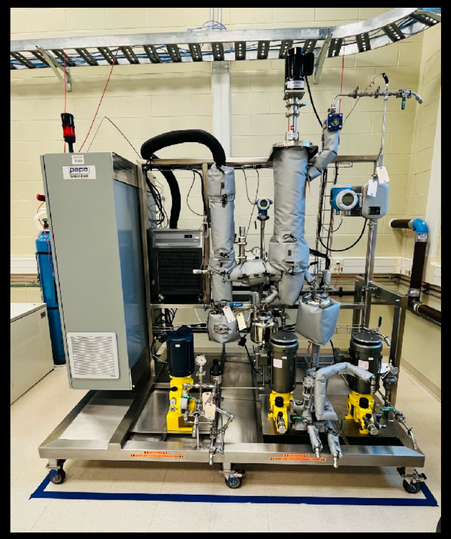
Te acid purification (UG)



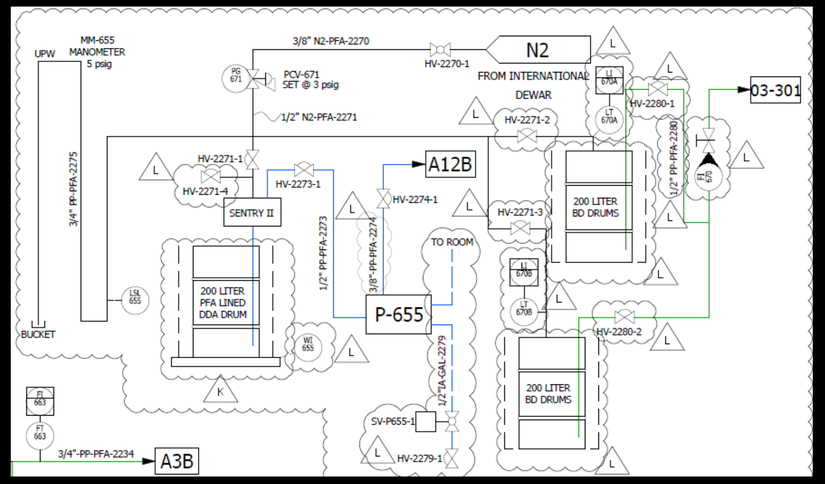
Te diol synthesis (UG)



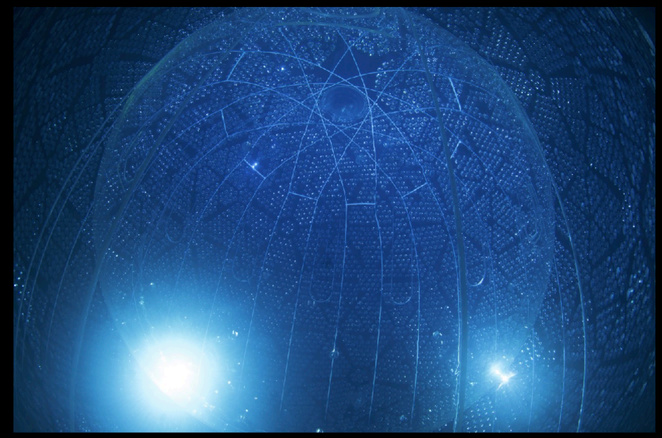
DDA distillation (surface)



DDA surface to UG transfer



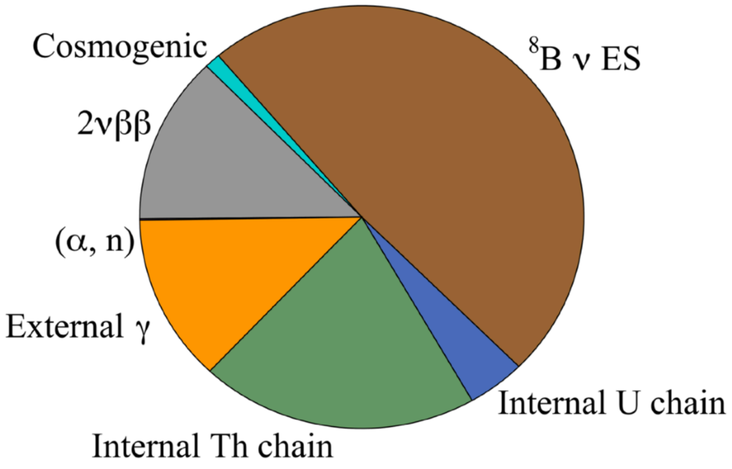
AV

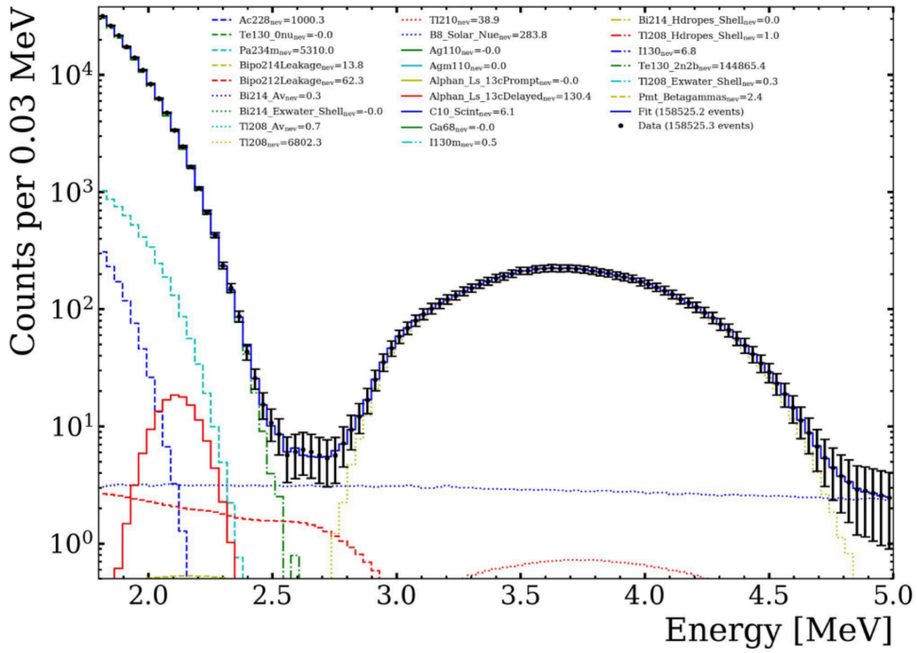


SNO+ DBD SENSITIVITY

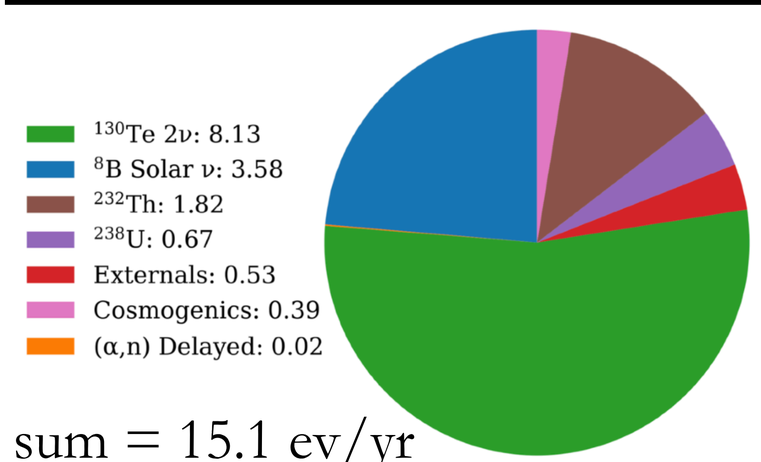
- Water phase constrained external backgrounds
- Scintillator phase constrained several internal backgrounds
- Other expectations based **conservatively** on raw purity and purification factors

initial 0.5% loading





1.5% loading

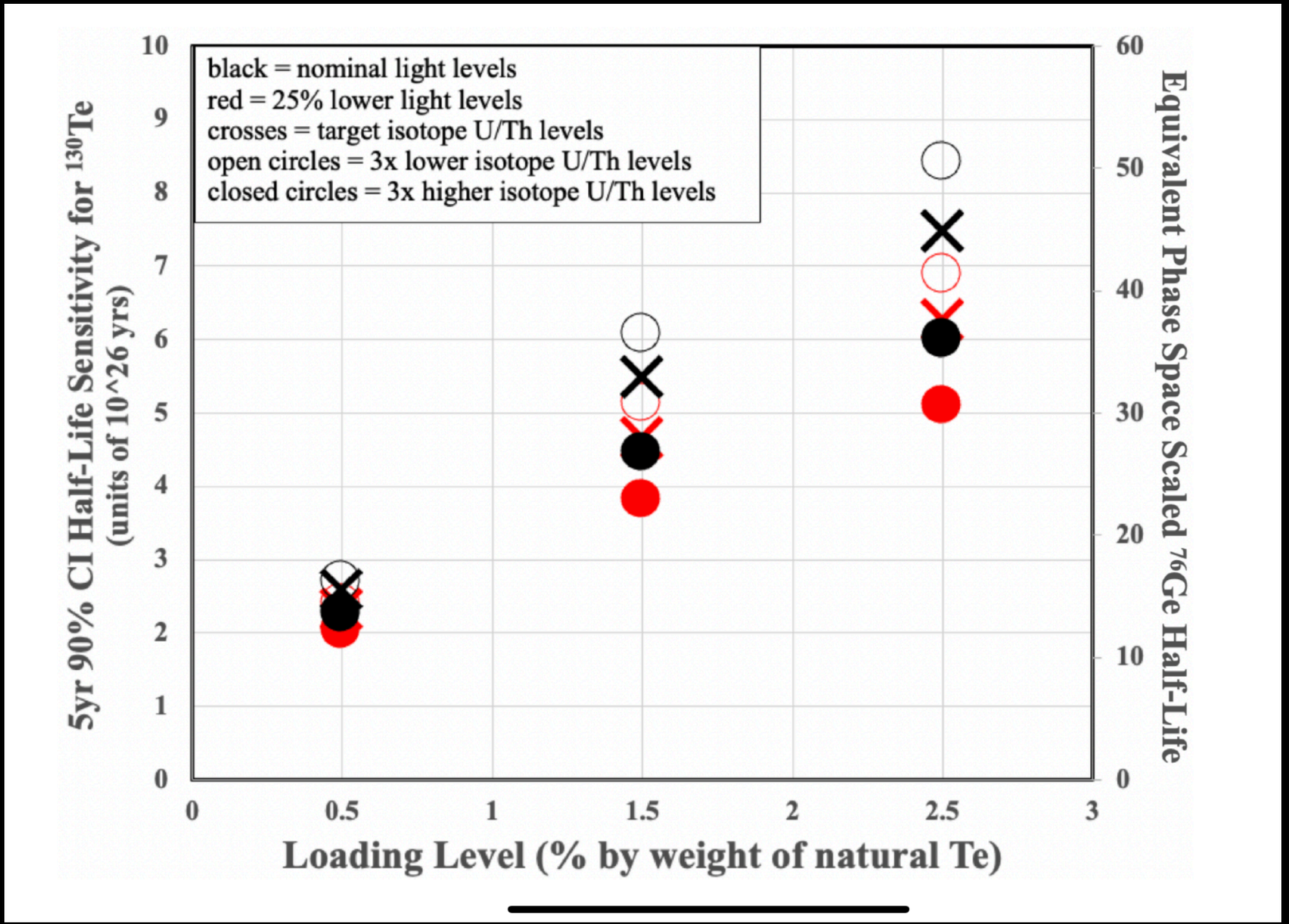


sum = 15.1 ev/yr

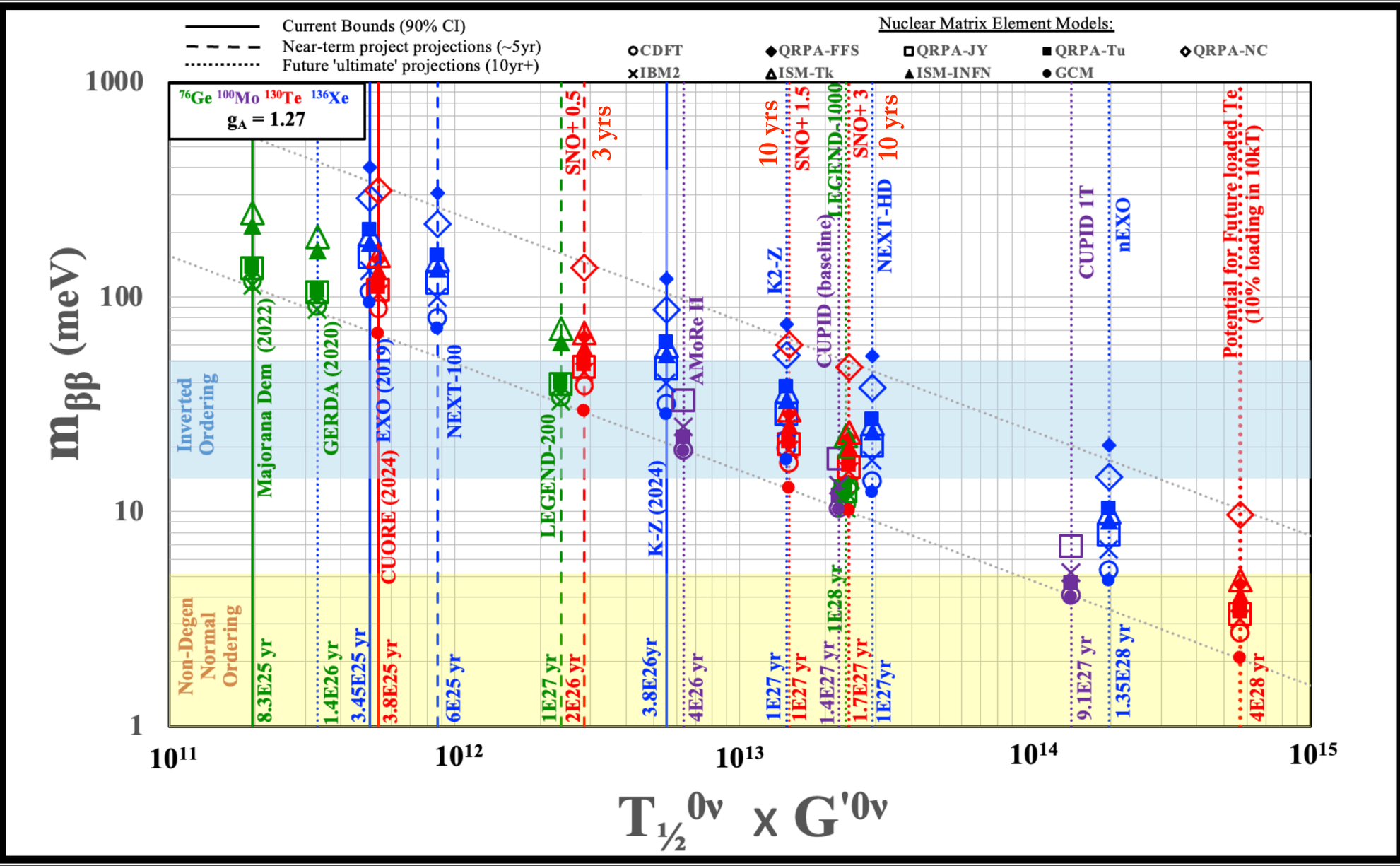
$T_{1/2} > 2 \cdot 10^{26}$ yrs, 90% C.L. 3 yrs

$T_{1/2} > 5 \cdot 10^{26}$ yrs, 90% C.L., 5 yrs

SENSITIVITY, HIGHER LOADINGS



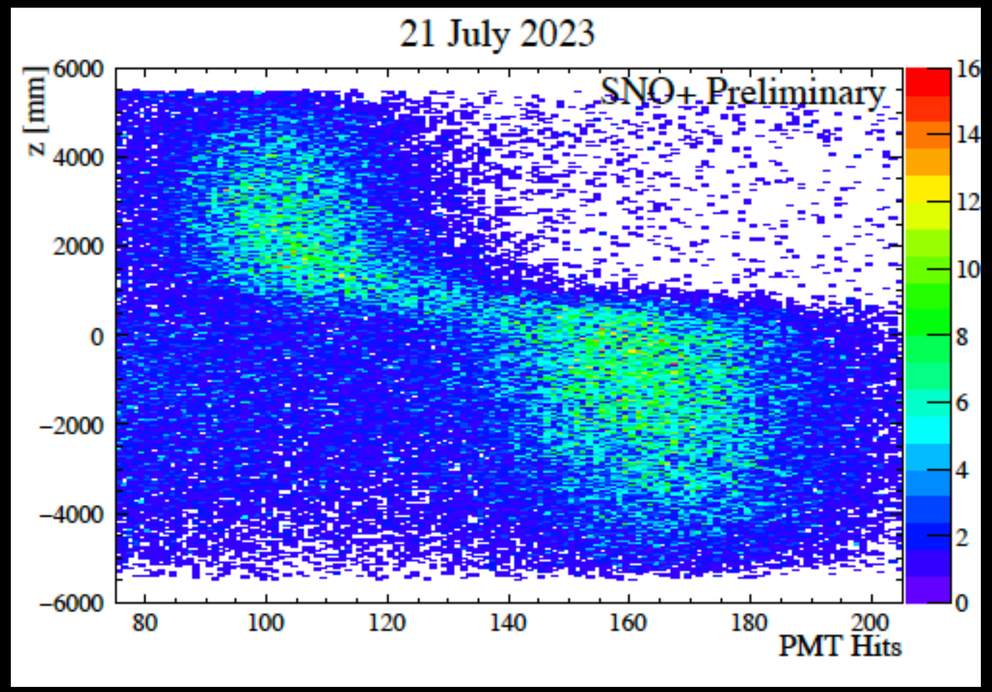
SNO+ IN CONTEXT



SNO+ COLLABORATION

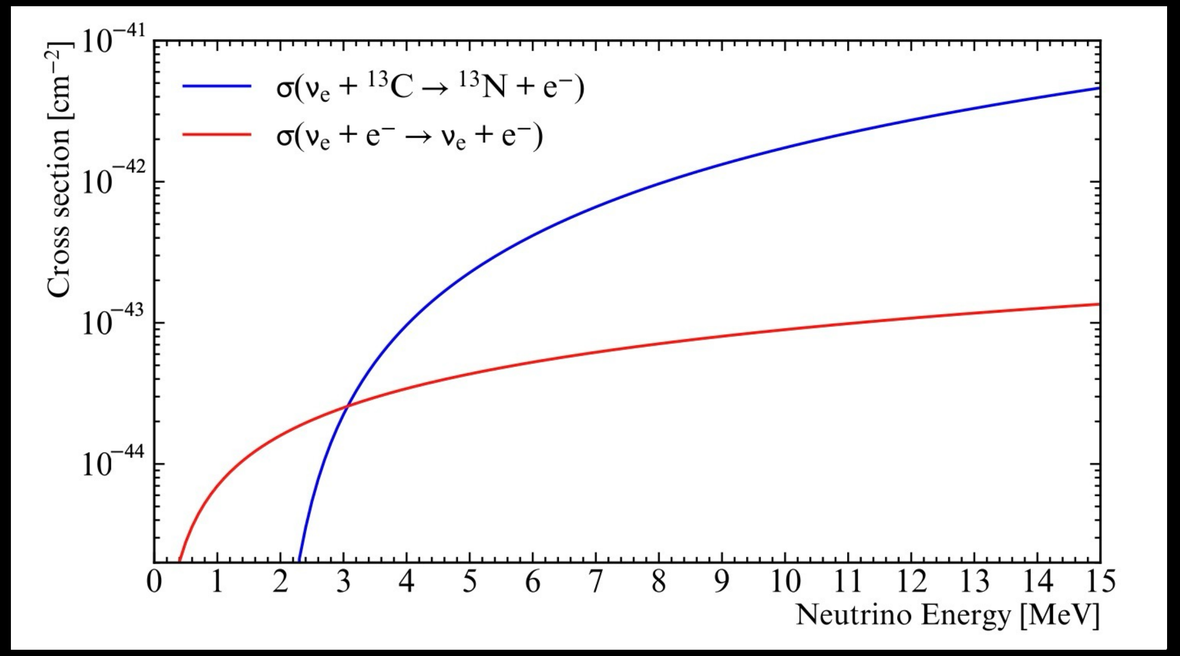
Supported by FCT, Portugal , project PTDC/FIS-PAR/2679/2021

EXTRA



Observed events prompt energy: 10.7 and 8.1 MeV

- Likelihood ratio:
  - Fiducial volume: R< 5.3 m
  - Prompt energy: 5.0 < E (e^-) < 15.0 MeV
  - Delayed energy: 1.0 < E (e^+) < 2.2 MeV
  - Delta R < 1 m
  - 0.01 < Delta T < 60 min
  - Likelihood ratio > 4



SNO+ SOLAR WATER PHASE