

# Astrophysics in SNO+

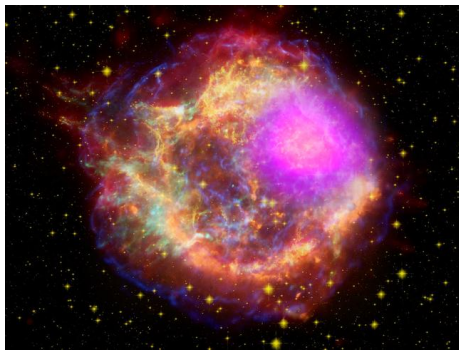
Ryan Bayes

May 26, 2026

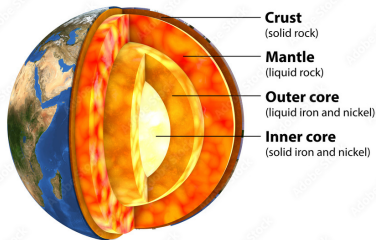


# Neutrinos in Astrophysics

- Second most common particle in the cosmos
- Only interacts via weak nuclear force ( $\sigma \sim \mathcal{O}(10^{-42} \text{ cm}^2)$ )
- Most direct probe of
  - ▶ Stellar (solar) interior
  - ▶ Geological interior
  - ▶ Interactions in supernovae

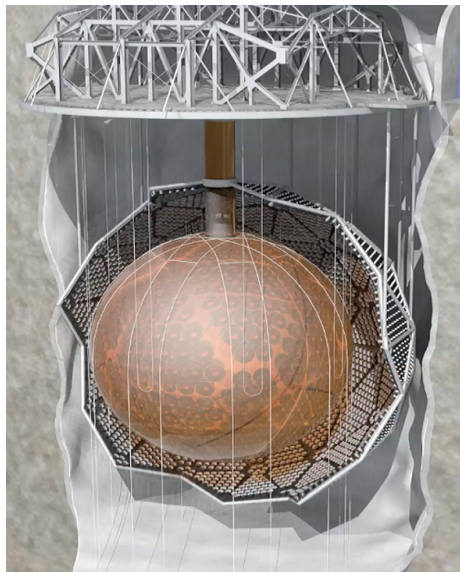


## Structure of the Earth

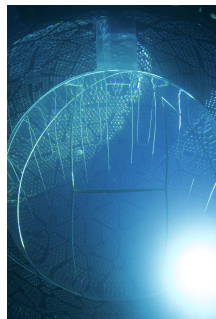
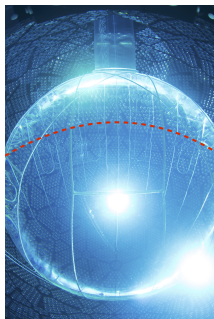
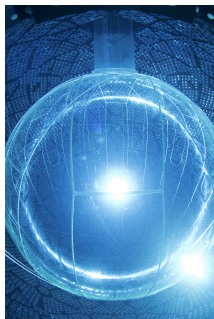


# SNO+ Neutrino Detector

- JINST 16 P08059
- 2 km underground
- 12 m diameter acrylic vessel
  - ▶ 780 tonnes liquid scintillator
- 9362 inward facing PMTs
- $\approx 17$  m diameter geodesic support structure
- UPW shielding fills surrounding cavity (external veto)



# Scintillator Fill and Phases



- Water Phase

- ▶ May 2017 - Oct 2019
- ▶ Baseline calibrations
- ▶ Nucleon decay
- ▶  $^8B$  neutrino flux

- Partial Fill Phase

- ▶ October 2019 - April 2021

- Extended pause:

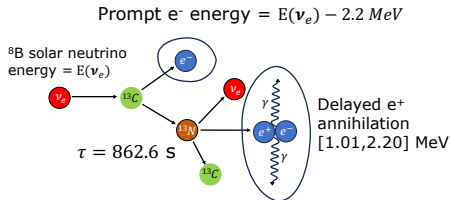
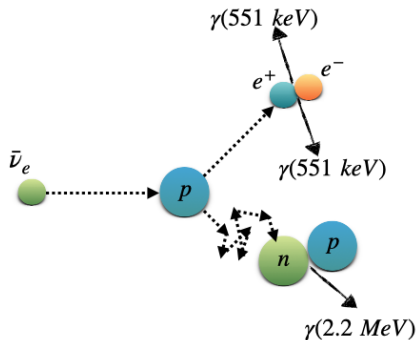
- ▶ March 2020 - November 2020
- ▶ Reactor neutrino measurements

- Scintillator Phase

- ▶ April 2021 - February 2026
- PPO, BisMSB additions
  - ▶ October 2021 - December 2023

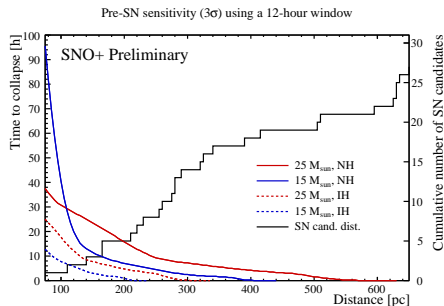
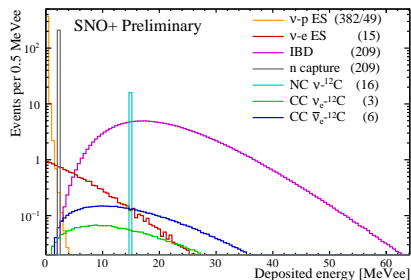
# Neutrino Detection Channels

Channel	Physics
$\nu e$ elastic scattering	$\nu e \rightarrow \nu e$
Inverse beta decay	$\bar{\nu} p \rightarrow e^+ n$
Proton elastic scattering	$\nu p \rightarrow \nu p$
Carbon inelastic scattering	$\nu^{13}\text{C} \rightarrow ^{13}\text{Ne}^+$
	Solar $\nu$ , Exotic, SN $\nu$
	Reactor, Geo- $\nu$ , SN $\nu$
	SN $\nu$
	Solar



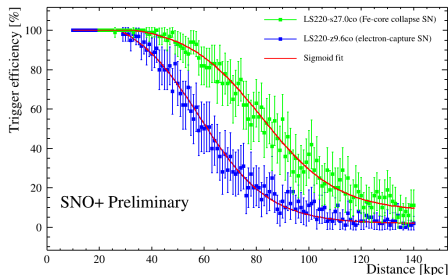
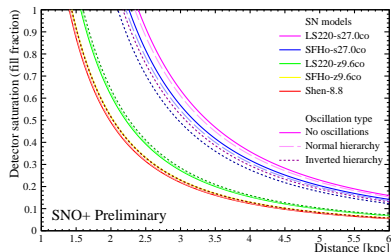
<sup>a</sup>Phys.Rev.Lett. 135 (2025) 24, 241803

# Supernovas



- IBDs provide early Supernova signal
  - ▶ Rate expected to increase on the days in advance of a CCSN
  - ▶ Online monitoring systems currently functional
- Evaluation made assuming Partial Fill ( $\alpha, n$ ) rates
  - ▶ Expect to improve sensitivity given reduced background

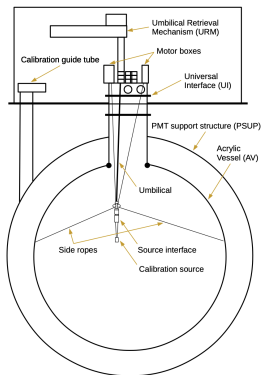
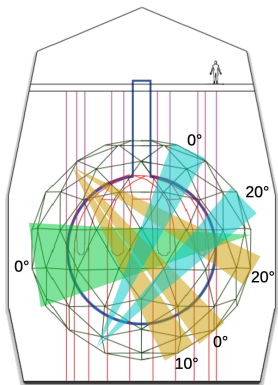
# SNO+ Supernova Detection Sensitivity



- SNO+ will saturate for close Supernova
  - ▶ Saturation limit determined by stress testing detector
  - ▶ Improved stress test in planning for coming year
- Limits are highly model dependent
- Study of IBD/ES in surrounding water could double the target mass and extend sensitivity

# Calibration Systems Tests

- Saturation limits tested with calibration systems
- PSUP embedded LED system provided first data
- Plan to drive internal light source with programmable laser
- Test detector saturation and sensitivity to time structure



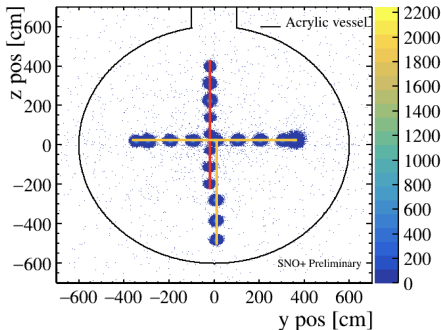
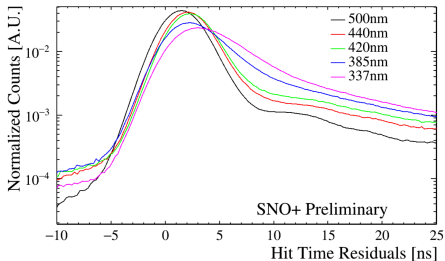
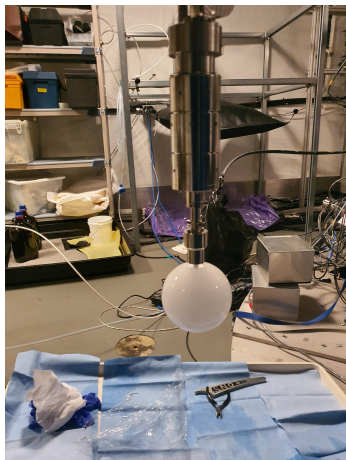
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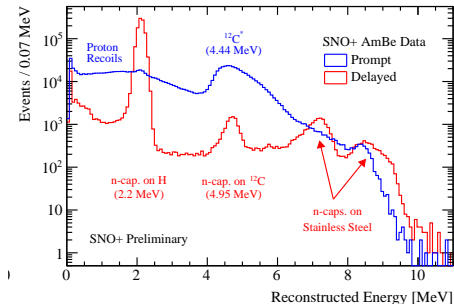
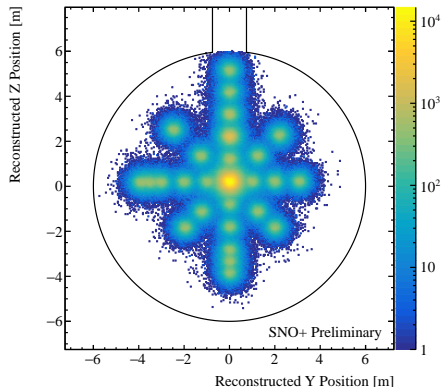
SMELLIE

# Optical Source Calibration

- Diffuser flask
- Injected monochromatic light

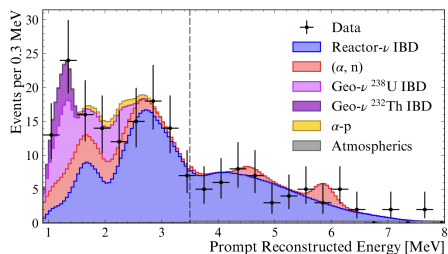


# Interaction Efficiency Tests



- Use Americium Beryllium neutron source
- Validate position and energy reconstruction
- Evaluate neutron capture efficiency

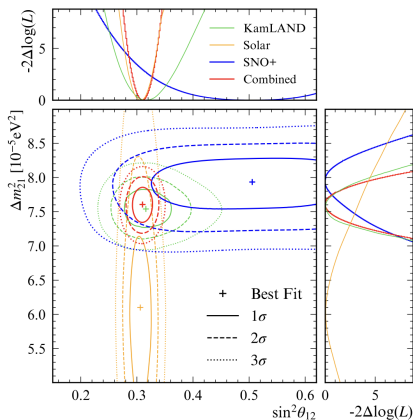
# Oscillation Measurements — Including Geo- $\nu$



- May 2022 - March 2023  
Phys Rev Lett 135, 121801

- May 2022 - July 2025  
**arXiv:2511.11856**

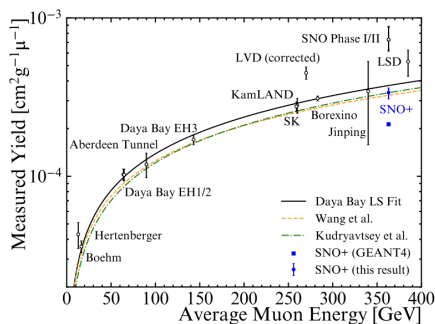
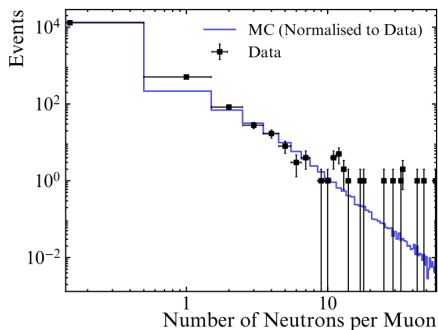
- Geo- $\nu$  Flux:  $67_{-17}^{+19}$ ,  
Geo- $\nu$  U/Th:  $3.29_{-1.48}^{+1.42}$
- Allows  $\Delta m_{12}^2, \sin^2 2\theta_{12}$  fit



- Best fit at
  - ▶  $\Delta m_{12}^2 = (7.58_{-0.17}^{+0.18}) \times 10^{-5} \text{ eV}^2$
  - ▶  $\sin^2 \theta_{12} = 0.311 \pm 0.012$

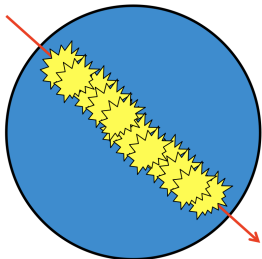
# Cosmogenic Neutron Detection

- Cosmic muons induce neutrons in detector
- Neutron yield informs experimental design (improve vetoing)
- Measurement from water phase; Phys. Rev. D 113, 052014

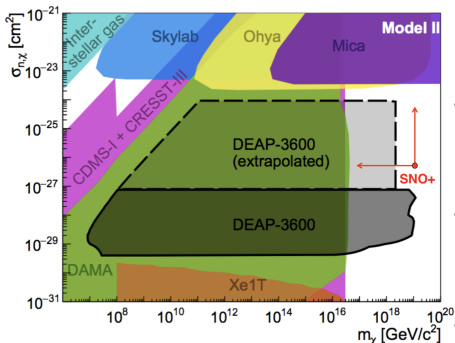
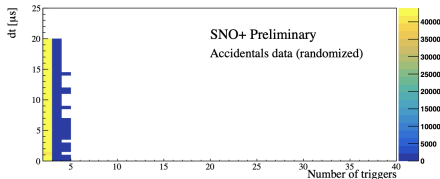
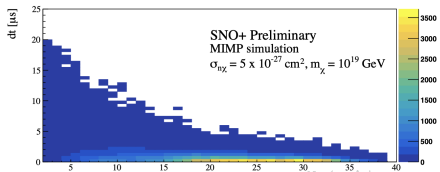


- Muon reconstruction now implemented for scintillator
- Neutron yield measurement in scintillator in progress

# Multiply Interacting Dark Matter



- Observe a line of  $\mathcal{O}(10\text{keV})$  interactions within  $\mathcal{O}(10\mu\text{s})$  window
- Look for multievent coincidence
- Set limits complementary to existing searches.



# Summary

- SNO+ preparing for imminent supernova
- Supernova monitoring in operation since 2019
  - ▶ Pre-supernova update/review in progress
  - ▶ burst monitor refinements also upcoming
- Recent oscillation measurements also relate to Geo- $\nu$ 
  - ▶ Contribute to global understanding of Earth's structure
- Study of cosmogenic neutrino flux in water now published
  - ▶ deviates from SNO
  - ▶ Inform future detector design at SNOLAB
  - ▶ Measurement in scintillator in progress
- Dark matter detection in scintillator also proceeding
  - ▶ MIMP study in progress