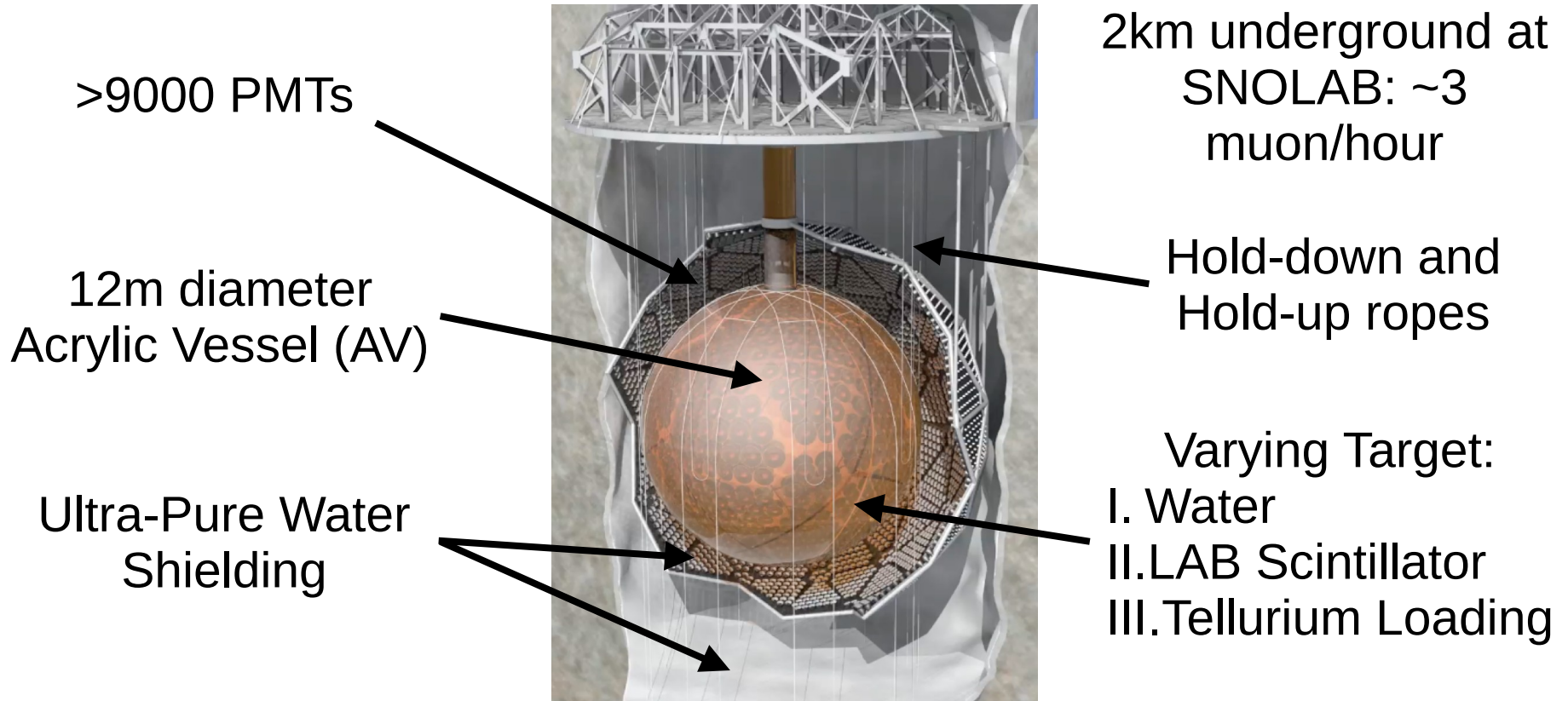


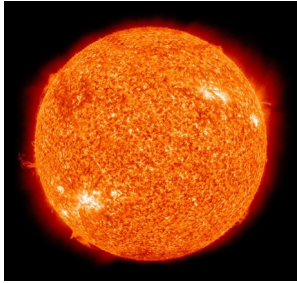
The background of the slide is a large, spherical detector, likely the SNO+ detector, filled with a complex network of blue and green light trails, suggesting particle interactions or data visualization.

Solar Neutrinos in SNO+
WIN 2025
Daniel Cookman

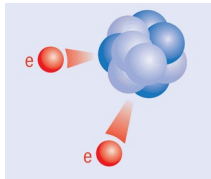
The SNO+ Experiment



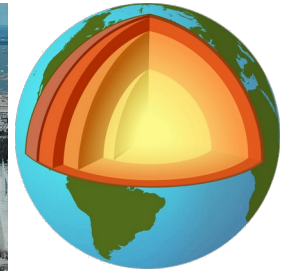
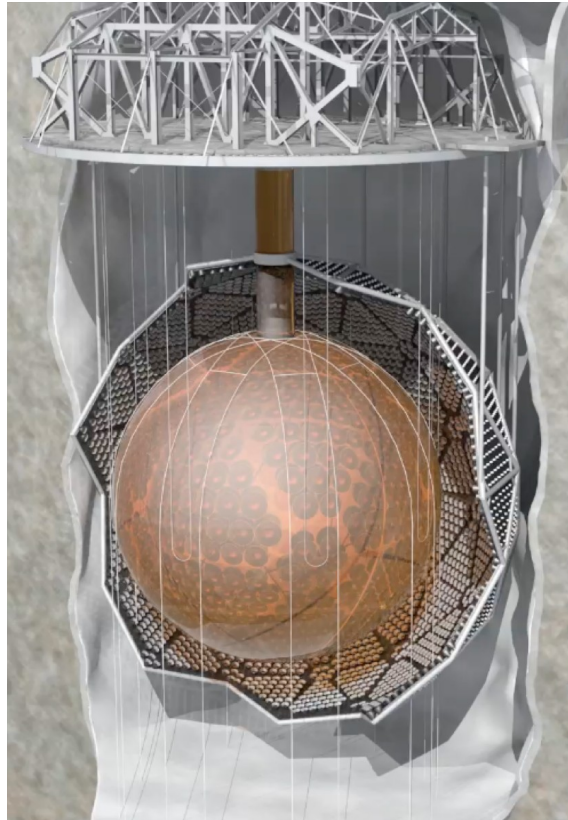
A Multi-Purpose Neutrino Experiment



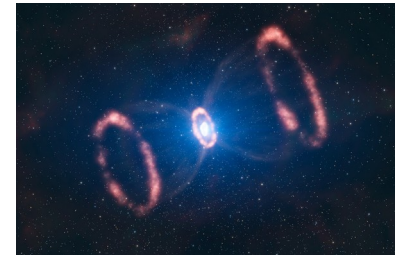
Solar Neutrinos



Neutrinoless
Double Beta Decay



Reactor & Geo-Neutrinos



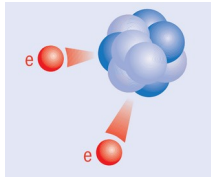
Supernova Neutrinos
& Exotics

A Multi-Purpose Neutrino Experiment

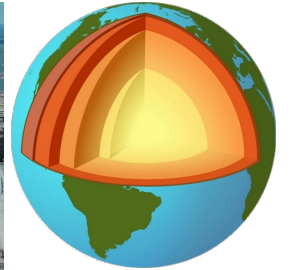
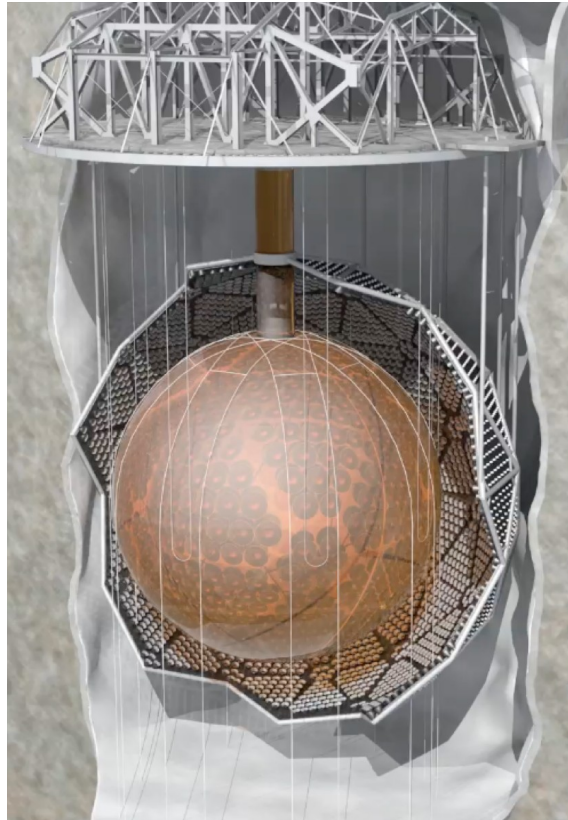


This Talk!

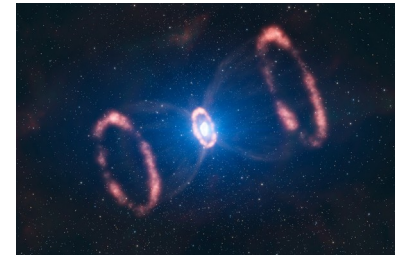
Solar Neutrinos



Neutrinoless
Double Beta Decay



Reactor & Geo-Neutrinos



Supernova Neutrinos
& Exotics

A Multi-Purpose Neutrino Experiment

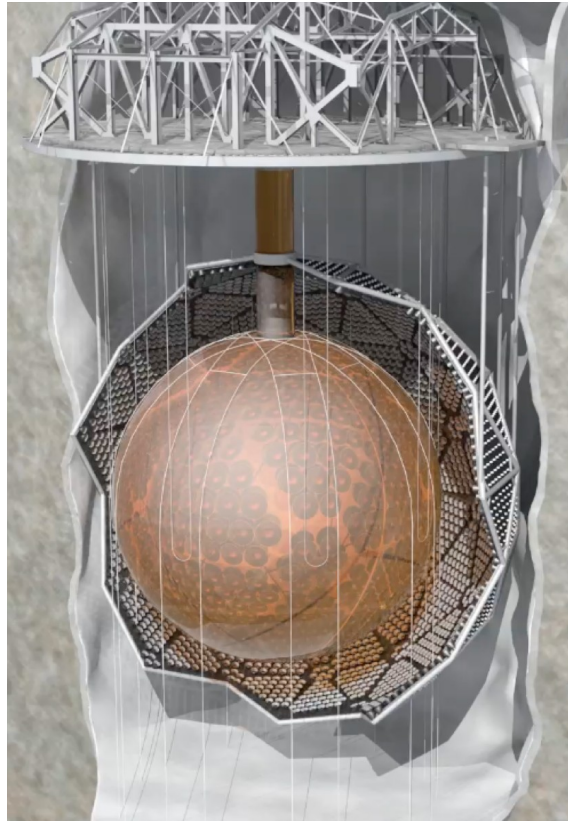


This Talk!

Solar Neutrinos

See Poster on
Monday by Ben Tam,
Talk on Thursday by
Tereza Kroupova

Neutrinoless
Double Beta Decay



See Talk on Tuesday by Sofia
Andringa



Reactor & Geo-Neutrinos

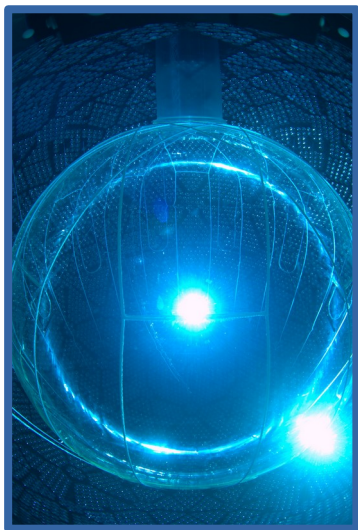


Chat to me after!

Supernova Neutrinos
& Exotics

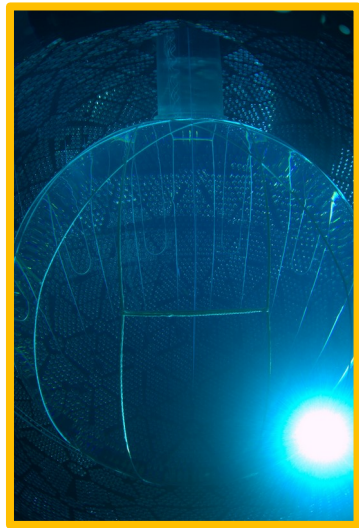
SNO+ Timeline

We are here!



Water Phase:

- Higher Rn period
- Lower Rn period



Partial-Fill Phase:

Scintillator over water
Fill paused due to
COVID



Scintillator Phase:

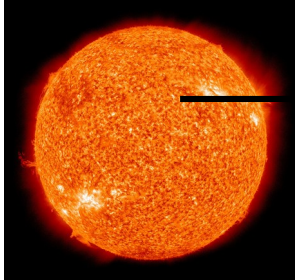
- Low PPO period
- Nominal PPO period
- Added bis-MSB & BHT



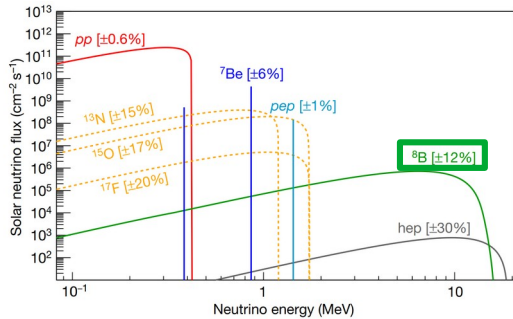
Next:

Tellurium-loaded
phase

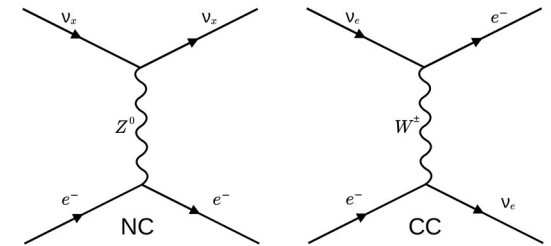
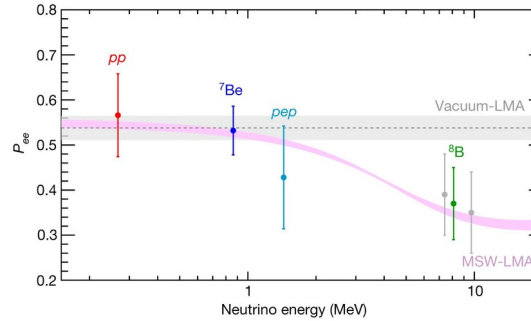
Solar Neutrino Phenomenology: At a Glance



MSW Matter effect in Sun & Earth + Vacuum Oscillations



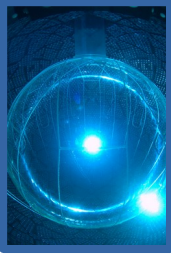
Solar ν_e Production Spectra



Primary Detection mode:
Neutrino-Electron Elastic Scattering

Solar Neutrino Flux, Water Phase

PRD 110, 122003 (2024)

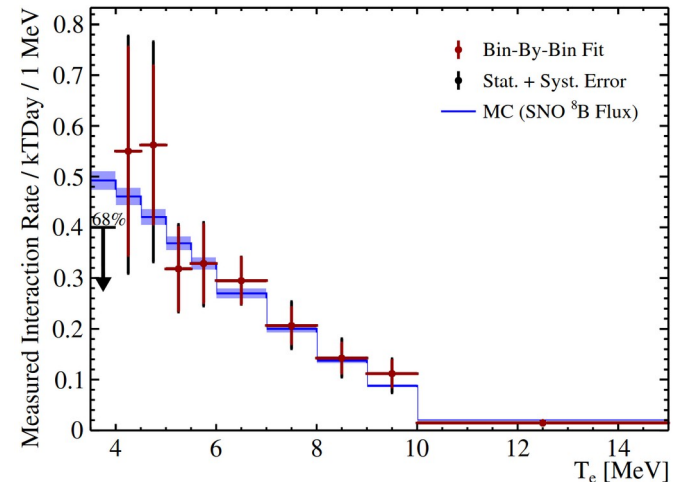
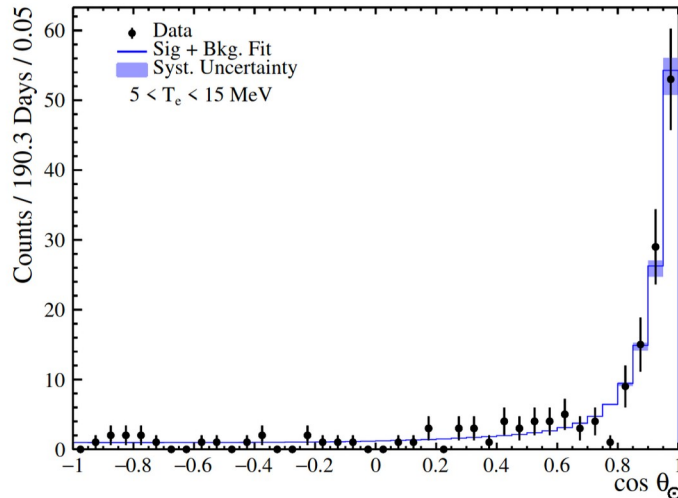


- Updated analysis with 126.6 kt-day exposure
- Includes 190 days of data with lowest background for a water Cherenkov detector > 5 MeV:
 0.32 ± 0.07 evs/kt-day

Results:

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

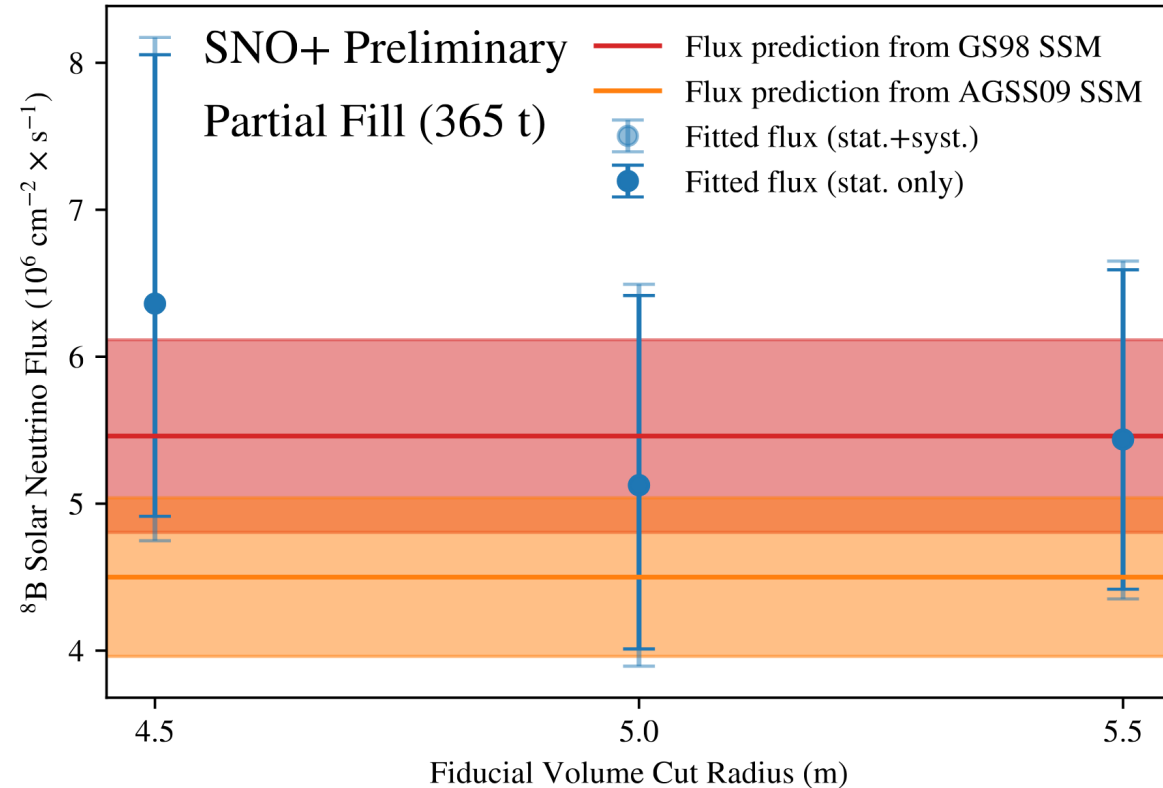
$$(5.36_{-0.39}^{+0.41}(\text{stat.})_{-0.16}^{+0.17}(\text{syst.})) \times 10^6 \text{ cm}^{-2} \text{ s}^{-1}$$



Solar Neutrino Flux, Partial Fill

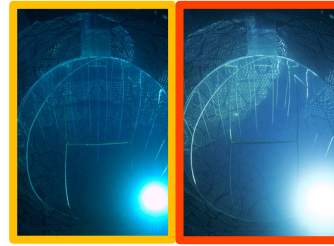


- First test of solar physics in SNO+ scintillator – flux analysis with 33.6 kt-day exposure
- Large uncertainties, but consistent with expectations



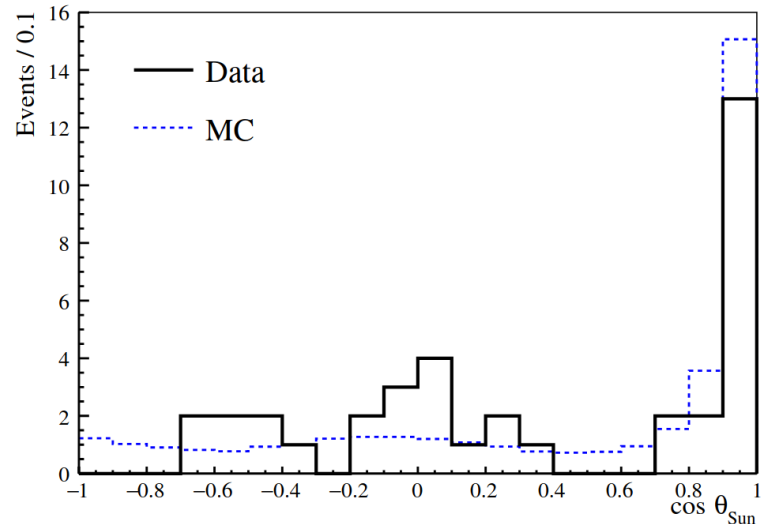
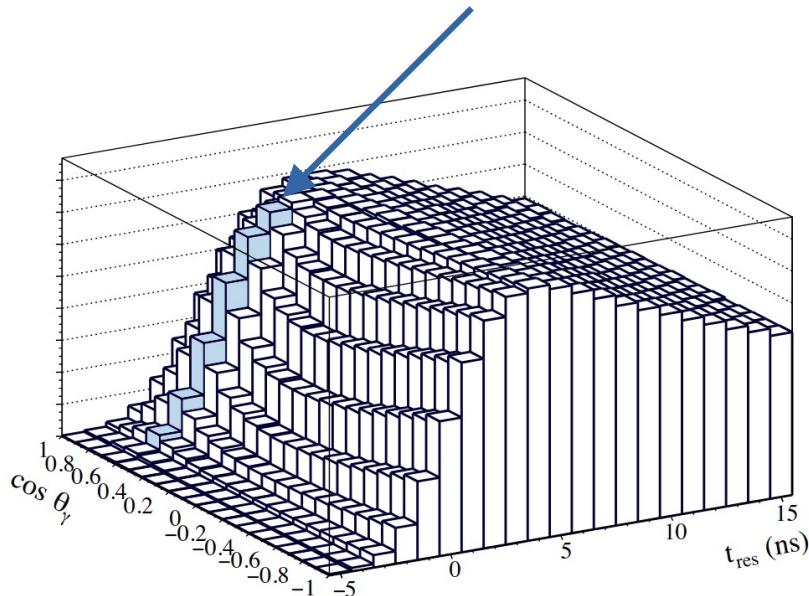
Directionality in Scintillator

PRD 109, 072002 (2024)



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

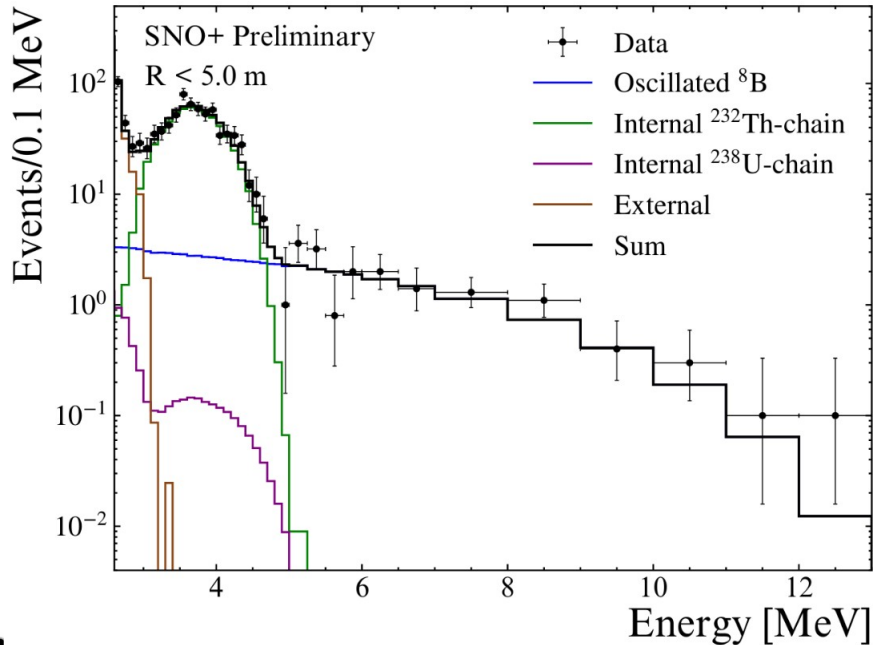
- Data from partial fill & early scint phases, where PPO loading low (0.6 g/L), leading to slow scintillation: good separation with Cherenkov light
- First event-by-event reconstruction of direction on high light yield scintillator!



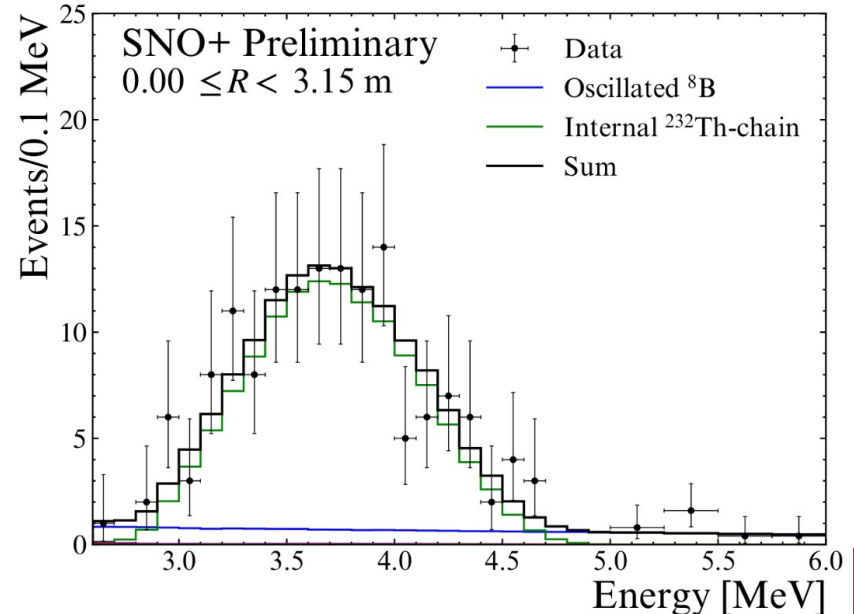
Solar Neutrino Flux & Oscillations in Scintillator



- Analysis of ^8B 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:
 $(5.3 \pm 0.7) \times 10^{-17} \text{ g/g } ^{232}\text{Th}$ in 4m radial volume

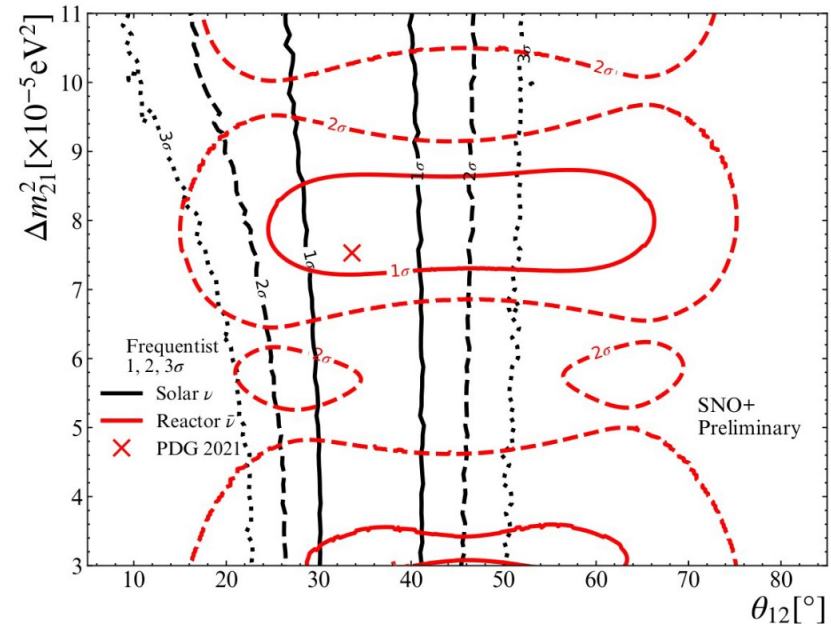
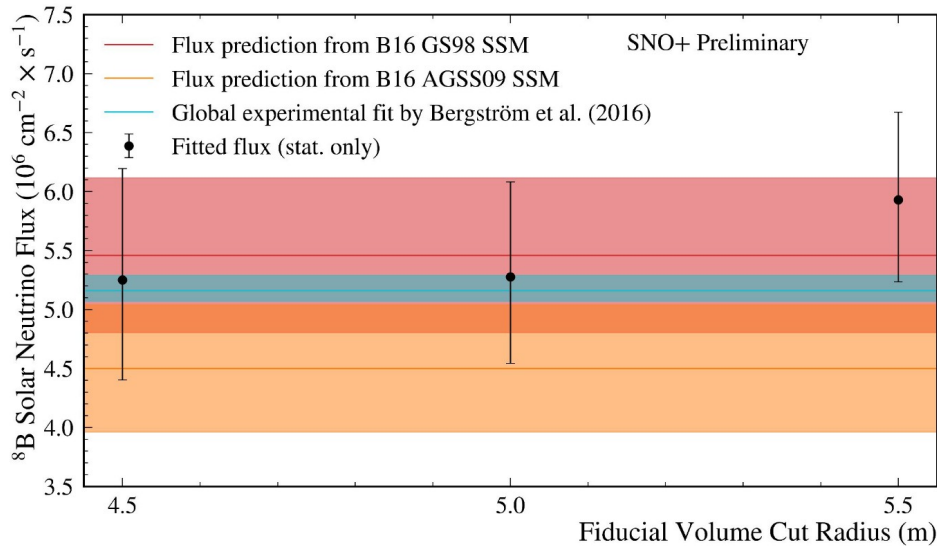


Solar Neutrino Flux & Oscillations in Scintillator

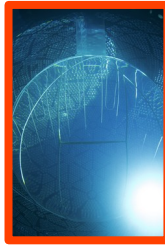


- Parallel analyses for measuring flux and neutrino oscillation parameters

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



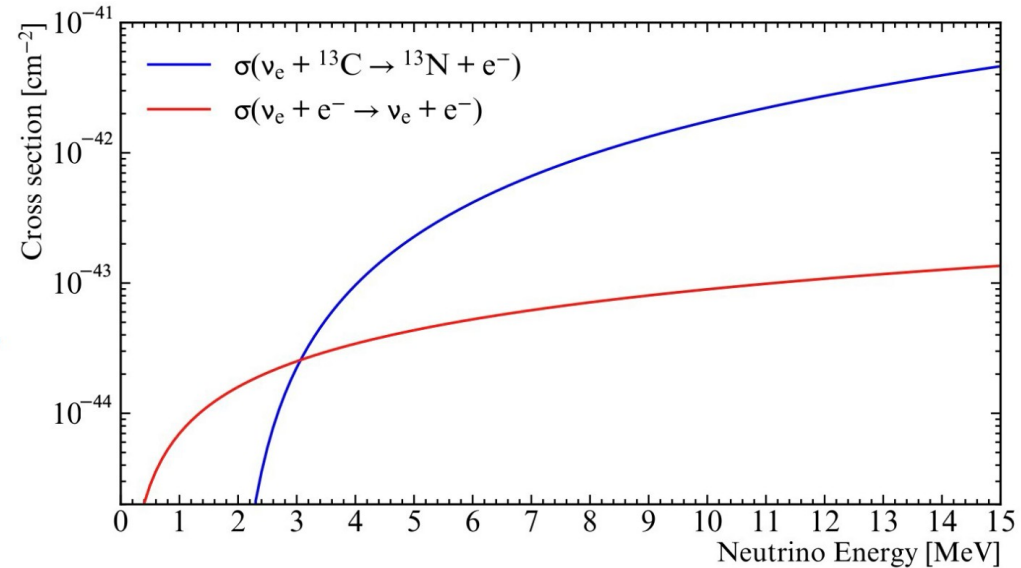
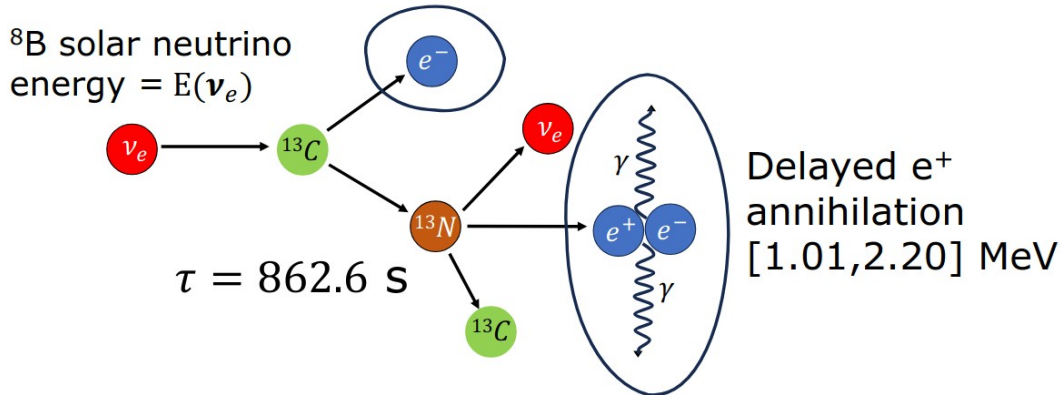
Solar osc. fit result assumes global fit flux



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

$$\text{Prompt } e^- \text{ energy} = E(\nu_e) - 2.2 \text{ MeV}$$

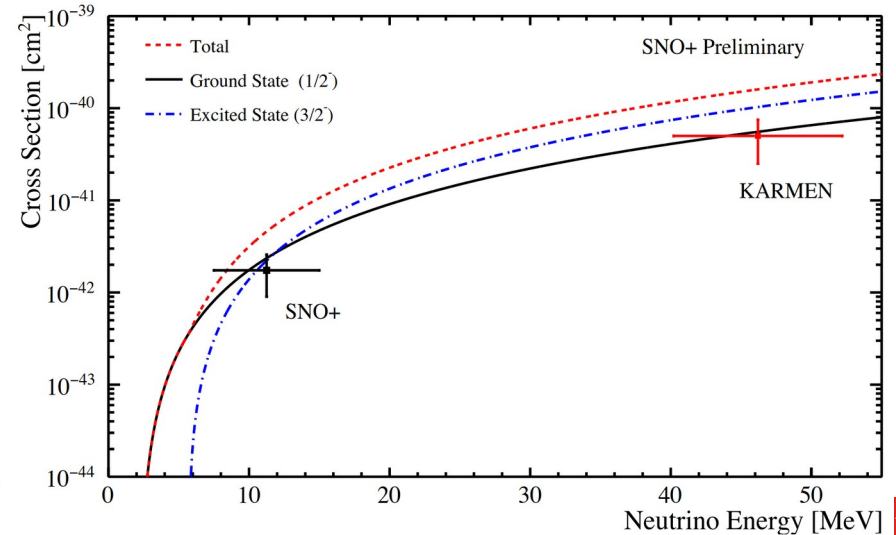
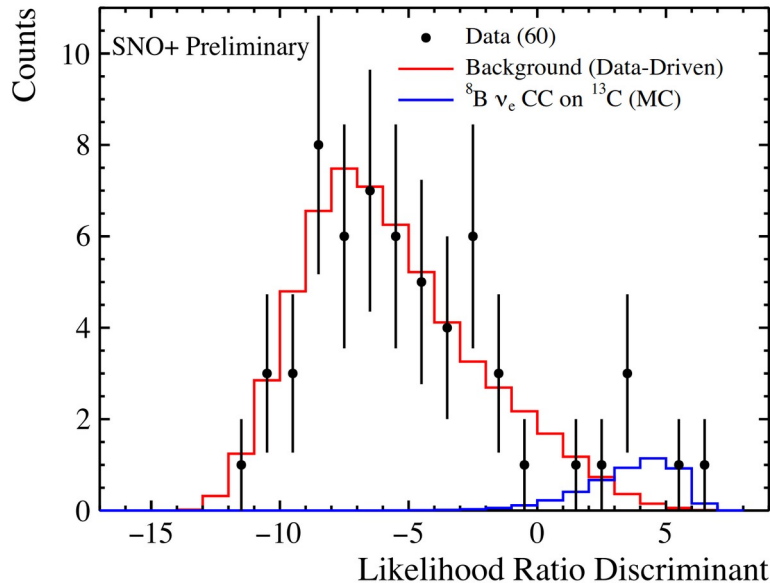




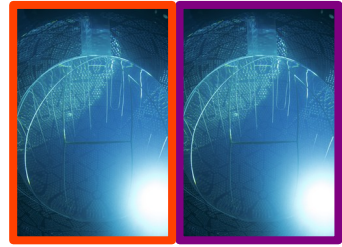
Charged-Current Interactions on ^{13}C

- 225.4 days of livetime
- Blinded analysis performed – results of “box” and “likelihood” approaches consistent
- Significance: 3.8σ
- First ever measurement of this interaction by solar vs (second-ever in general!)
- Measured cross-section:

$$\langle \sigma(E_\nu) \rangle = (1.7 \pm 0.8) \times 10^{-42} \text{ cm}^2$$



More Exciting Things to Come...



- Searching for solar anti-neutrinos
- Using PMT hit timing distributions in a classifier to distinguish multi-site events (like ^{208}Tl $\beta\gamma$ s) from single-site events (solar ES, $0\nu\beta\beta$)
- Tagging of ^{208}Tl via $^{212}\text{Bi} \rightarrow ^{208}\text{Tl}$ coincidence

Summary of SNO+ Solar Analyses

- Solar ^8B flux measured in very-low background water phase
- First-ever demonstration of event-by-event directionality in a high light-yield scintillator detector
- Scintillator phase ^8B solar neutrino flux & oscillation analyses ongoing
- First-ever observation of solar neutrino CC interactions on ^{13}C
- More analyses to come!

Thank you for Listening!