Supernovae at SNO+

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30 May 2023

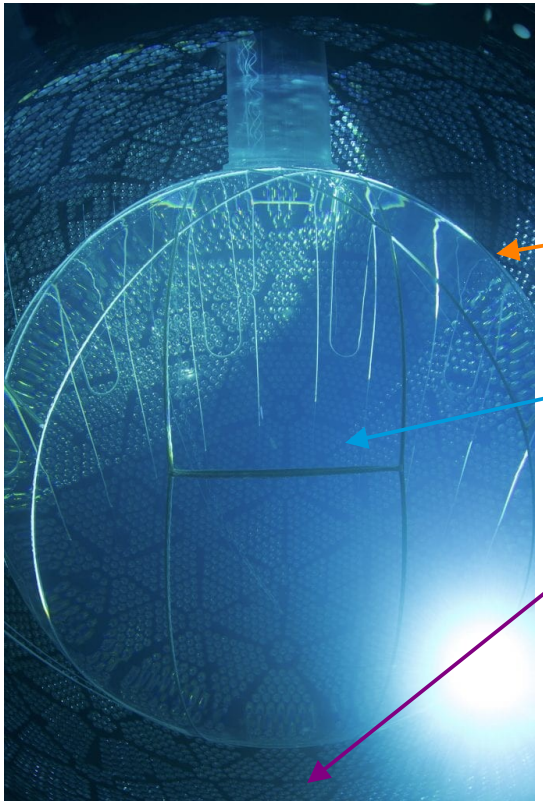
SNνD @ LNGS

Outline

- SNO+ status
- Supernova response
- Supernova trigger
- Pre-supernova monitoring
- Pointing with electron elastic scatters
- Conclusion


SNO+
August 9, 2022
NASA

SNO+

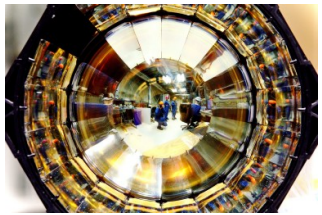


JINST 16 (2021) 08, P08059

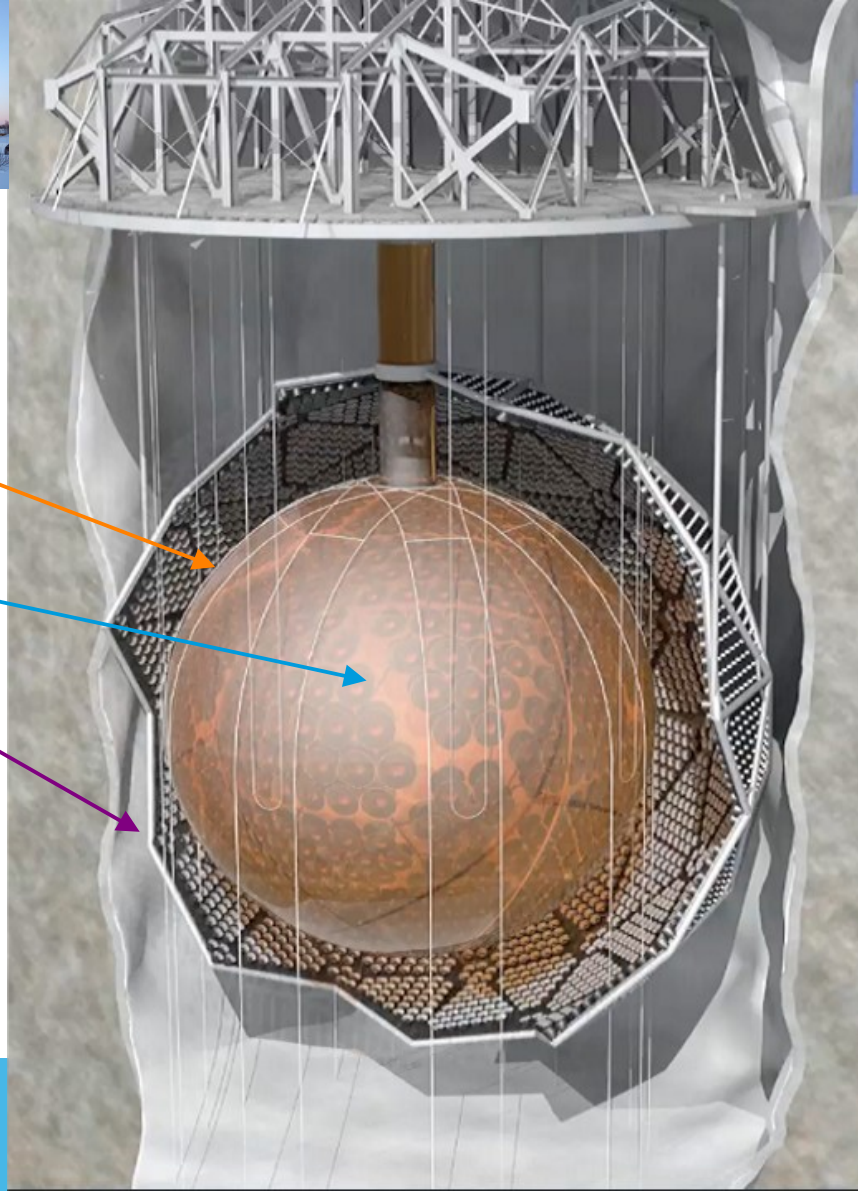
Acrylic vessel
6m radius

780T LAB+PPO

~9400 PMT's
at 9m radius incl
~90 outward-looking

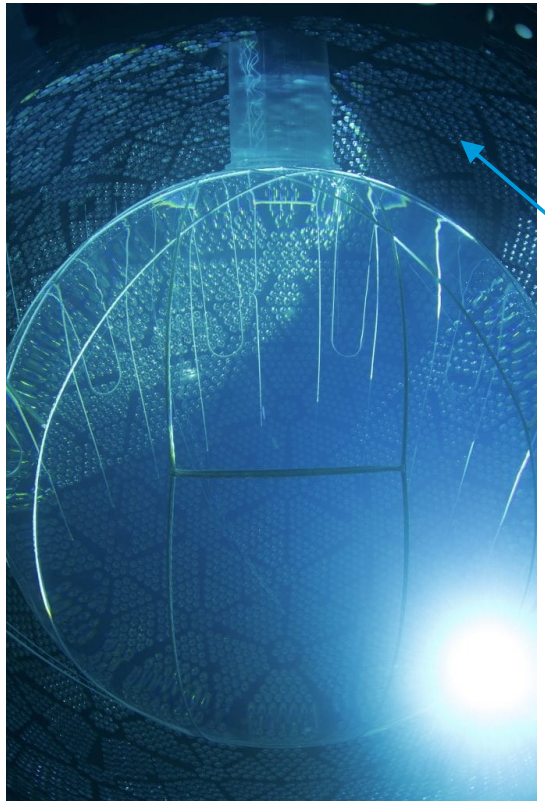


8" Hamamatsu
R1408 +
27cm-diameter
concentrator



SNO+

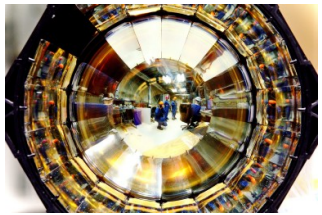
2070m rock



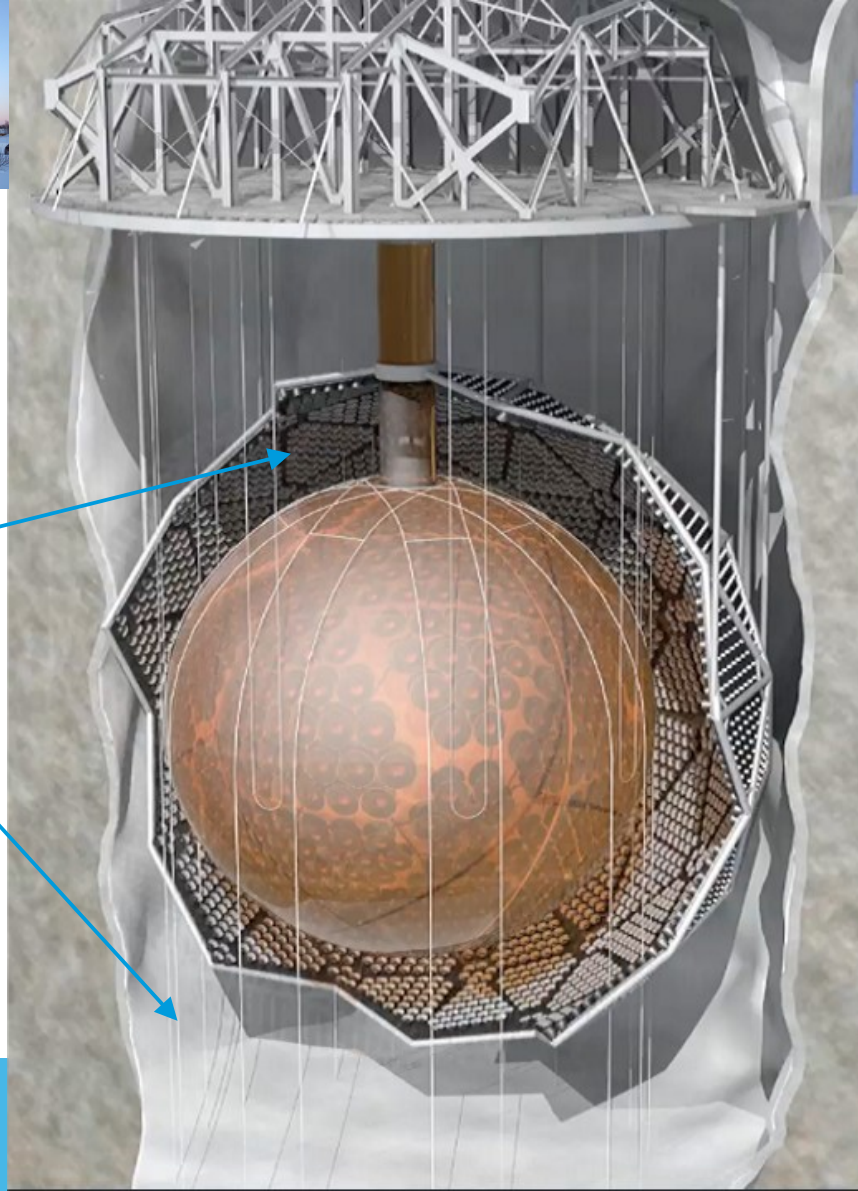
Ultra-pure water shielding

1.7kT AV-PMT

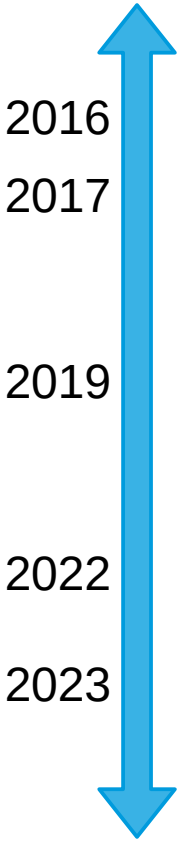
5.3kT PMT-cavity



8” Hamamatsu R1408 + 27cm-diameter concentrator



SNO+ timeline

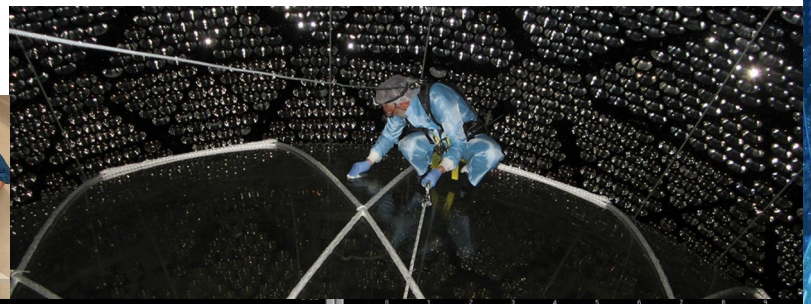


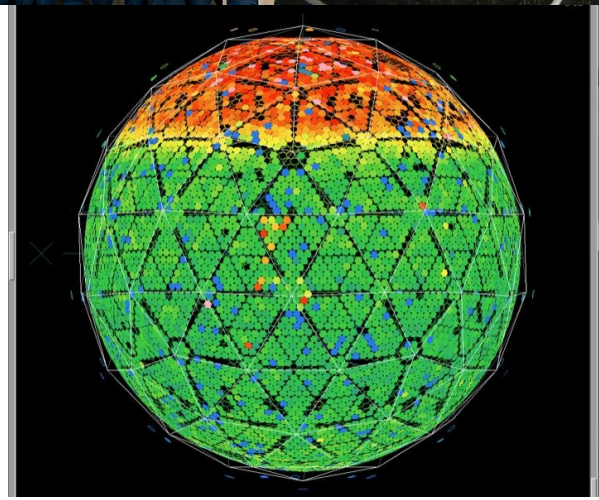
- Dec 2016: start commissioning with water
- May 2017: start of water phase

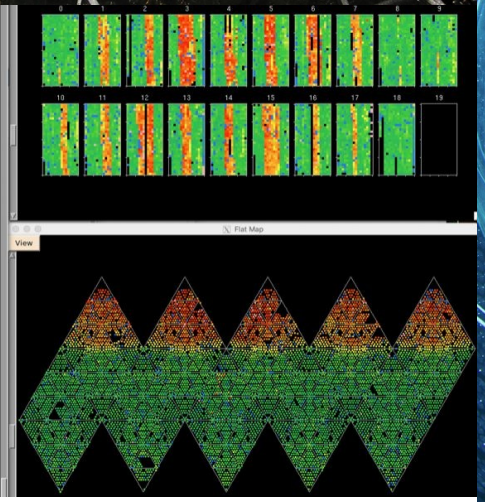
  ^{8}B Solar neutrino flux: PRD 99 (2019) 012012
  Invisible nucleon decay modes: PRD 99 (2019) 032008, PRD 105 (2022) 112012
  Neutron-proton capture: PRC 102 (2020) 014002
  Reactor neutrinos: PRL 130 (2023) 9

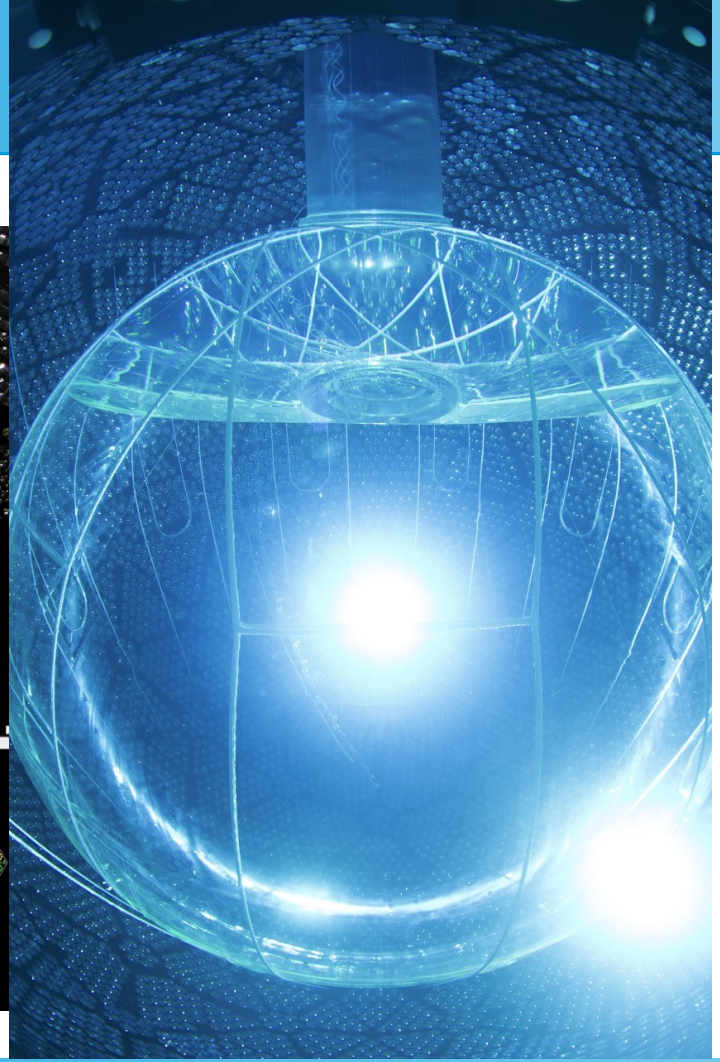
- July 2019: start filling with scintillator (LAB+PPO fluor)
  - "Partial fill" phase due to pandemic: 365T LS, 0.6g/L PPO
- April 2022: start of scintillator phase
  - 780T LS, 2.2g/L PPO
- 2023: preparation for Te loading for 0νββ phase

SNO+ timeline

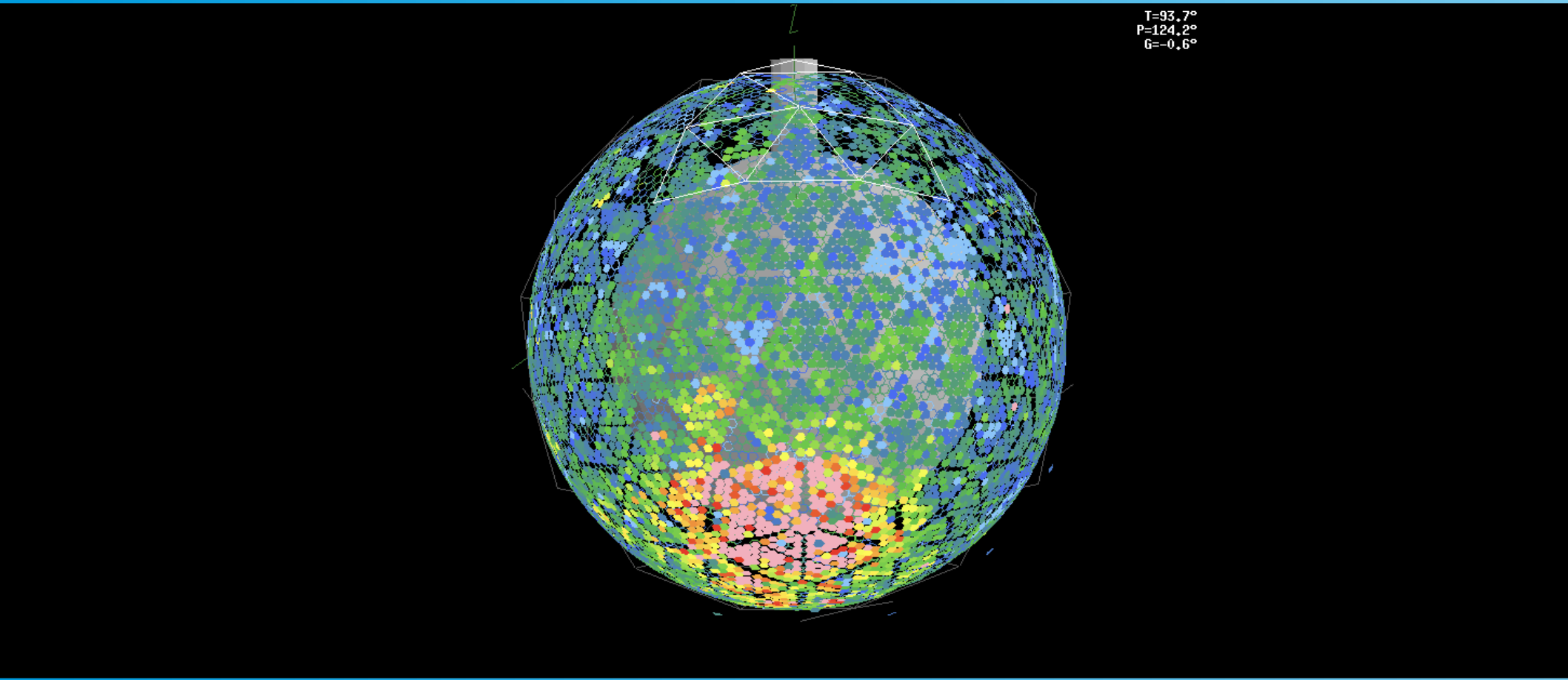






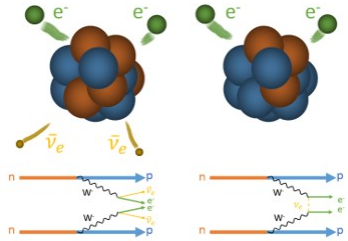


Full!

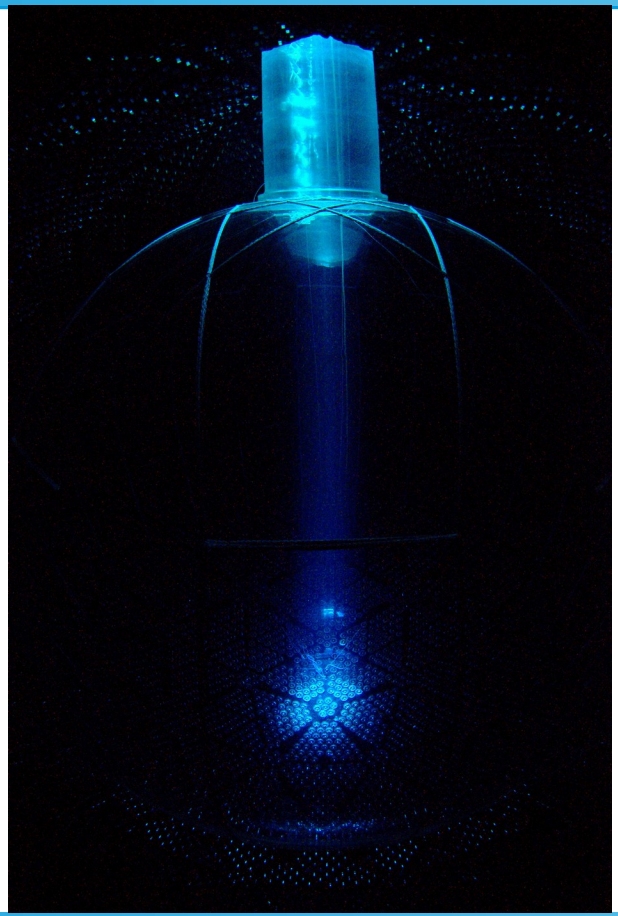


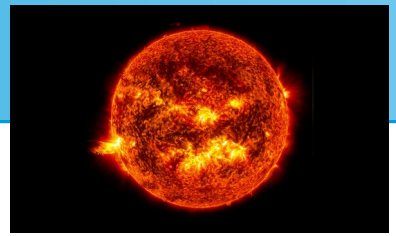
SNO+ physics

Neutrinoless double beta decay with ^{130}Te



CEA IRFU

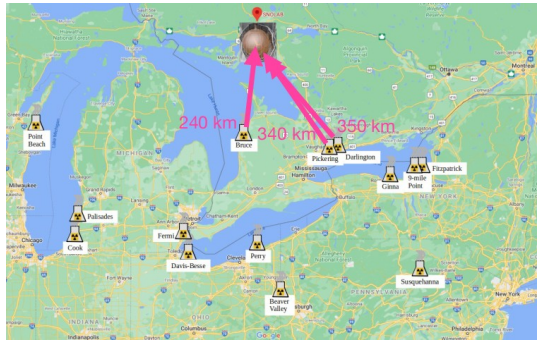




NASA/ SDO

Solar ν flux/shape

Reactor $\overline{\nu}$



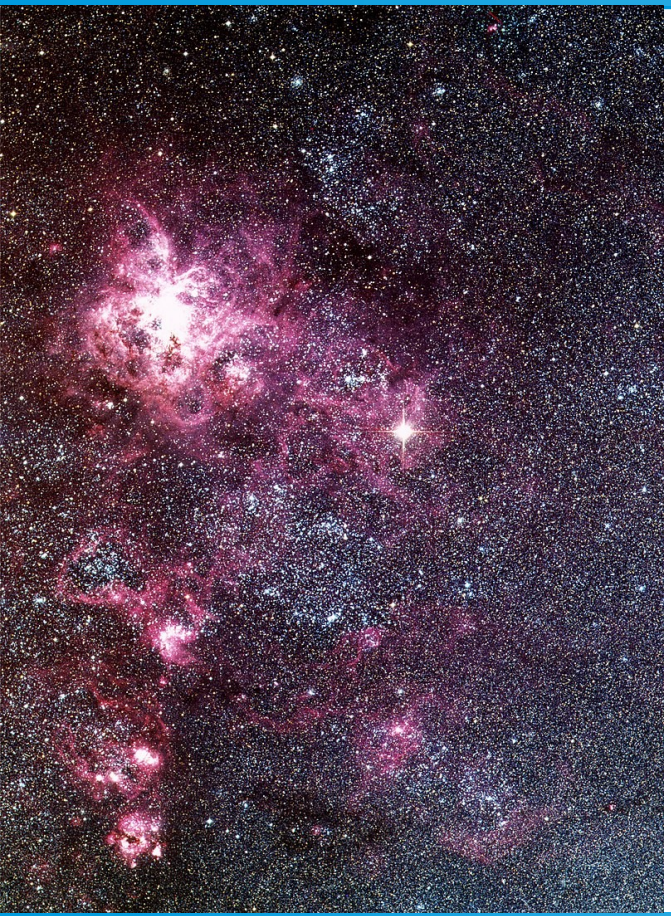
C Grant, Google Maps

Getty Images

Geo-neutrinos

AND...

SNO+ physics



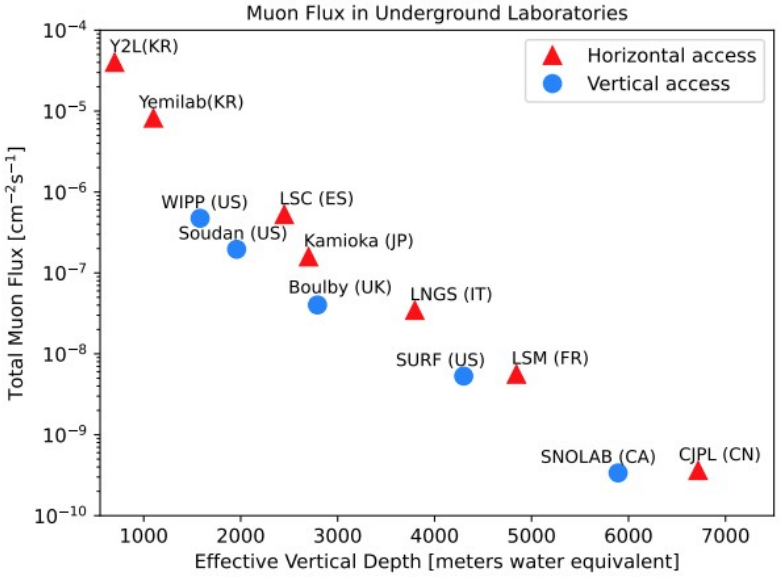
ESO/Schmidt

- Supernovae
- Low-energy astrophysical neutrinos
- Dark matter / exotics

Core-collapse supernova at SNO+

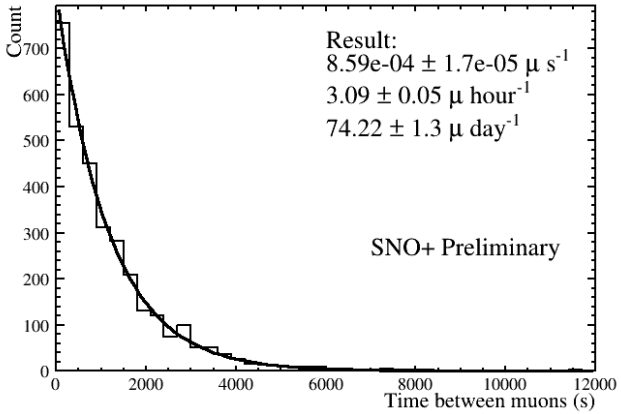
- SNO+ is “small” by standards of Super-Kamiokande, JUNO, etc
- One of the deepest → low muon/cosmogenic backgrounds
- Independent location – largest at SNOLAB
- May provide independent pointing information
- Additional pre-supernova monitoring

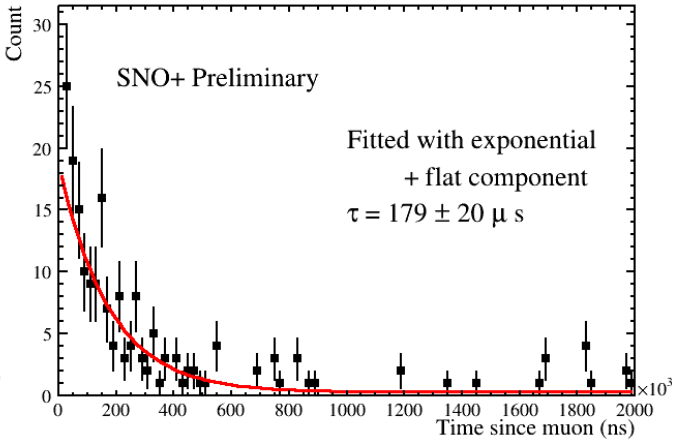
Muons at SNO+



[Erica Caden + CJPL]

- Measured to be 0.286 ± 0.009/m^2/day for 6010mwe shielding [Aharmim et al., 2009]
- Confirmed in partial fill (365T) and full fill (780T) data





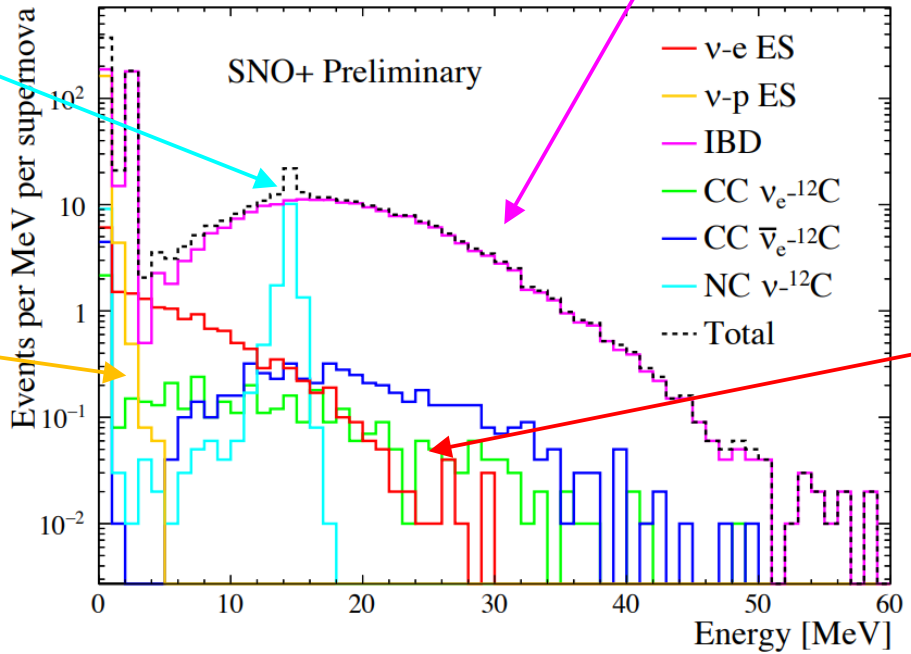
Muon-induced neutron capture

Core-collapse supernova at SNO+

$\overline{\nu}_e p \rightarrow e^+ n$ 194.7 ± 1.0 IBD

43.8 ± 8.7 NC ^{12}C
+ 15.1 MeV peak

$\nu\ ^{12}C \rightarrow \nu'\ ^{12}C^*$



$\nu p \rightarrow \nu p$

429.1 ± 12.0 PES
(118.9 ± 3.4 with
E > 200 keV)*

$\nu e \rightarrow \nu e$

13.1 EES

$\overline{\nu}_e\ ^{12}C \rightarrow e^+\ ^{12}B_{gs}$

$\nu_e\ ^{12}C \rightarrow e^-\ ^{12}N_{gs}$

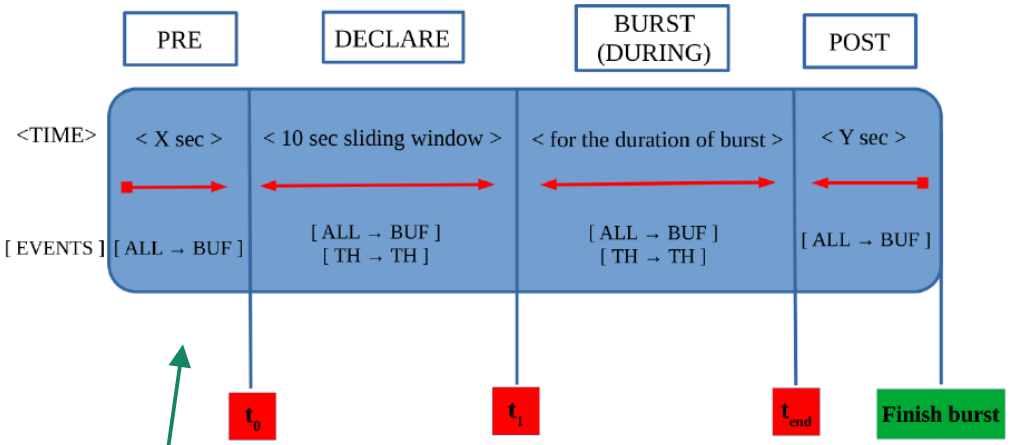
$\nu\ ^{12}C \rightarrow\ ^{11}C/B + X$

* current detector energy threshold ~75 keV

Model: 27M$_\odot$ progenitor, LS220 EOS, 10kpc, full fill Geant4 MC

Yields: Andringa et al. (SNO+), 2015

Burst trigger

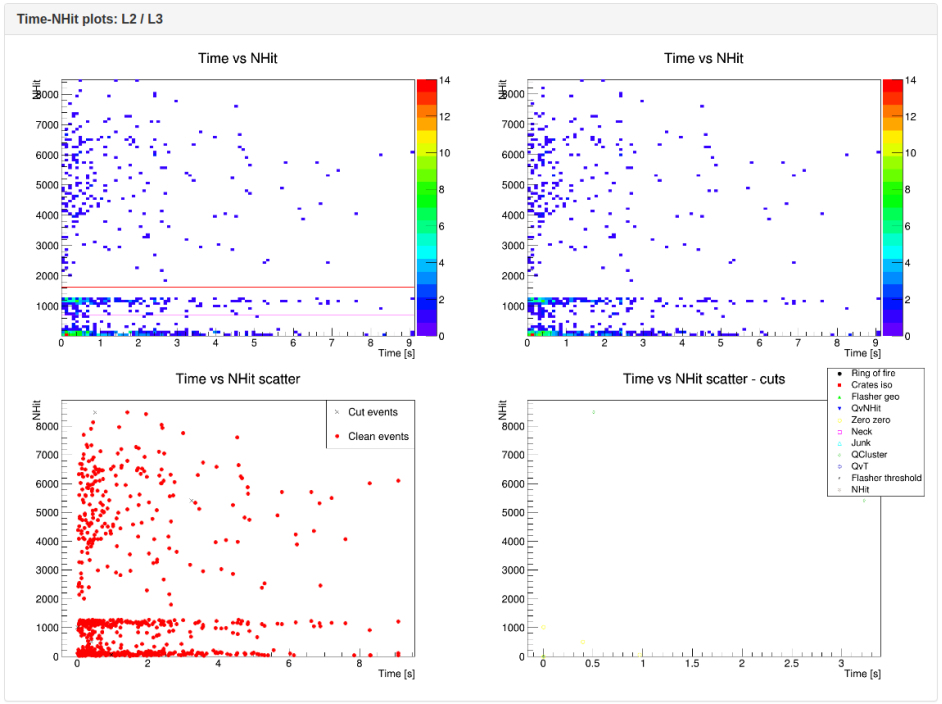


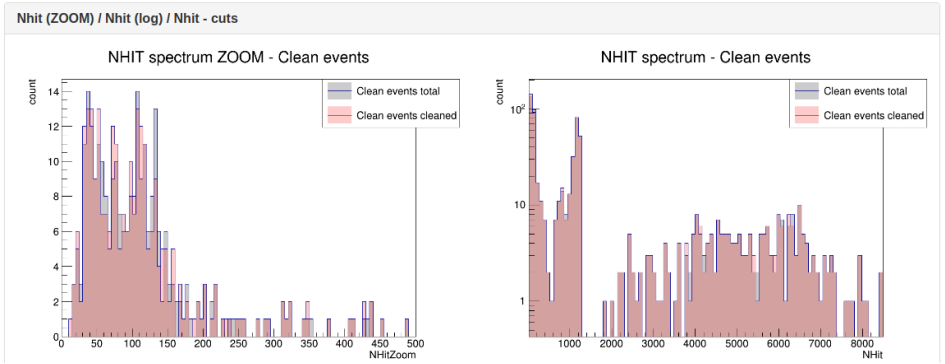
Note that burst can include buffered events before detection – useful for background determination

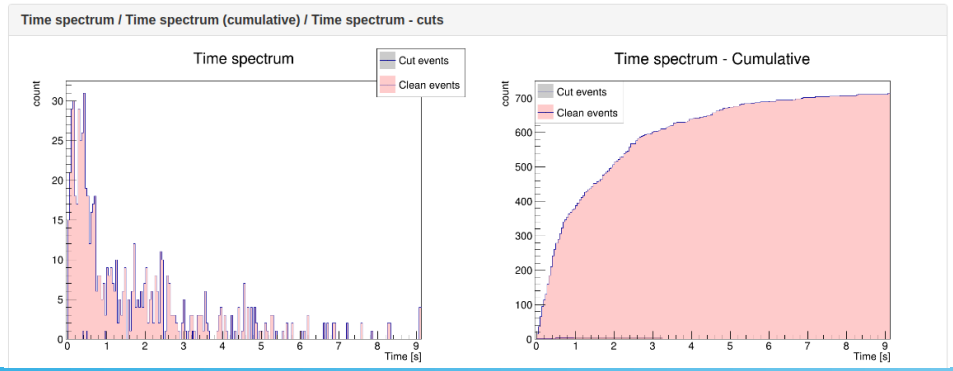
- Near real-time burst trigger in operation
  - Coincidence of multiple high-occupancy (and IBD) events
  - 1-2s latency, <30s to analyze
  - Tunable thresholds, aim for ~1 alarm/month
- Supernova shifters on call 24/7
- Sending test alarms since 2022

Burst trigger

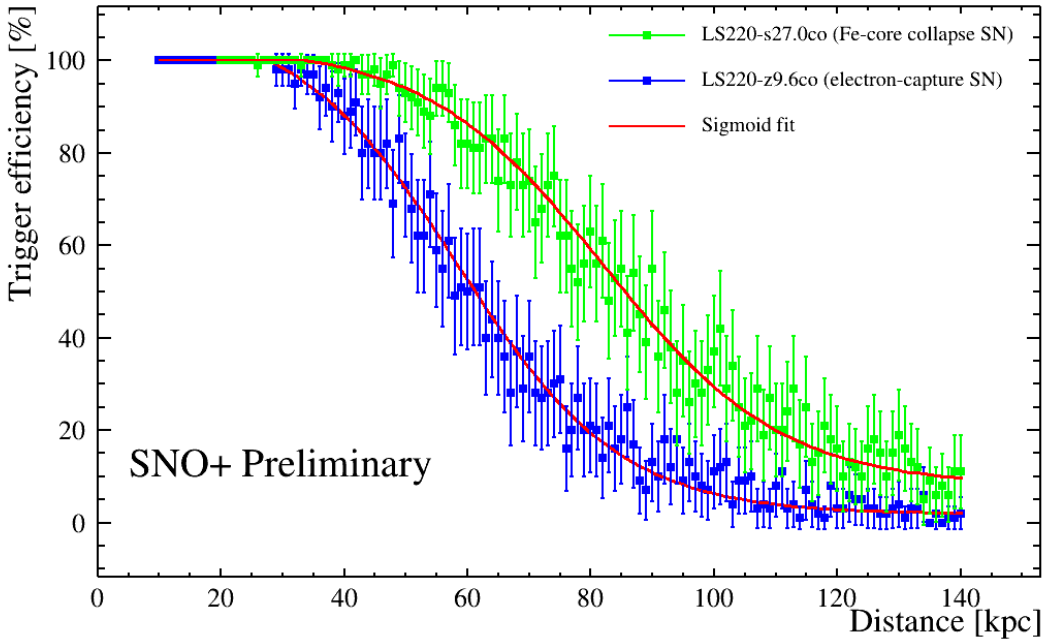
- “Nearly online” system produces diagnostics and plots (SNUGen)







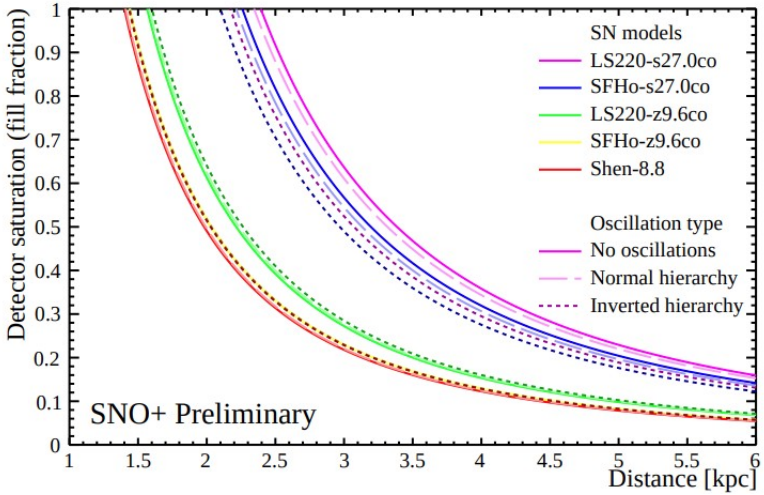
Burst trigger sensitivity



Trigger efficiency vs supernova distance
(only event coincidences, not IBD coincidence)

ALMA/NAOJ/NRAO/E O'Gorman/P Kervella

Detector saturation vs SN model/distance

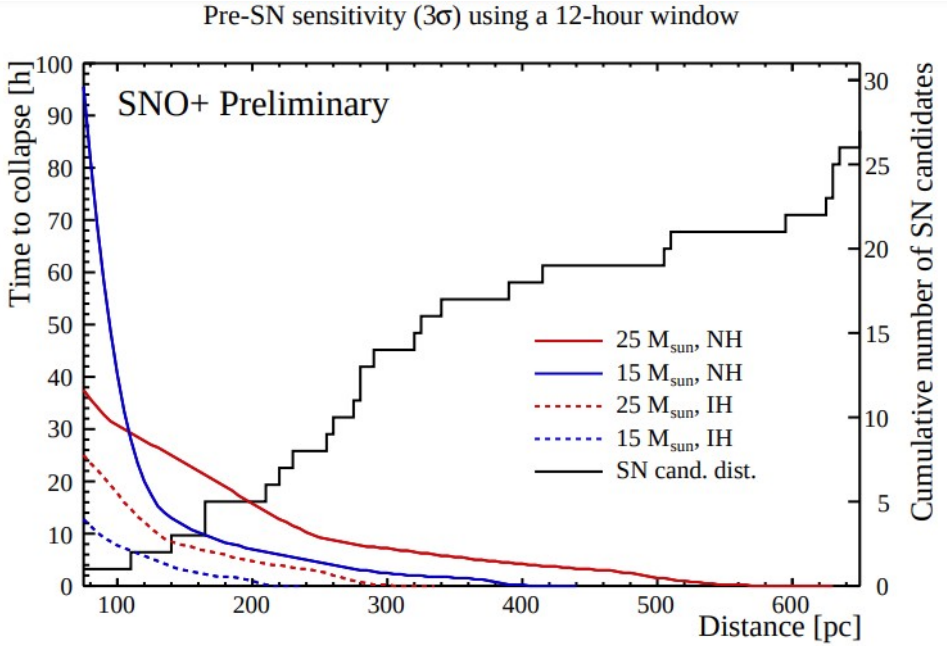


"The good news is Betelgeuse is still too far from Earth for the eventual explosion to have significant impact here." - Sci.News (2020)
https://www.sci.news/astronomy/betelgeuse-size-distance-08957.html

Pre-supernova neutrino monitoring

- "Near-line" monitoring of IBD event rate
- Status: finalizing details of nearline analysis

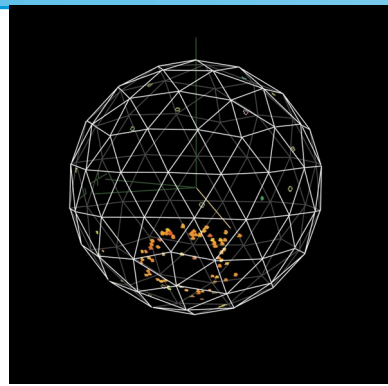
Sensitivity for background scenario:
- 110 reactor ν/yr
- 25 geo ν/yr
- 275 (α,n)/yr
- Observed backgrounds lower



- What to send to SNEWS?
  - Combine statistical significances of each experiment
  - How often to update?

A Odrzywolek et al., ACTA Physica Polonica B41 (2010) 1611; A Odrzywolek et al., Astropart Phys 21 (2004) 303; Candidate distribution: Mukhopadhyay et al., ApJ 899 (2020) 153

Pointing with EES

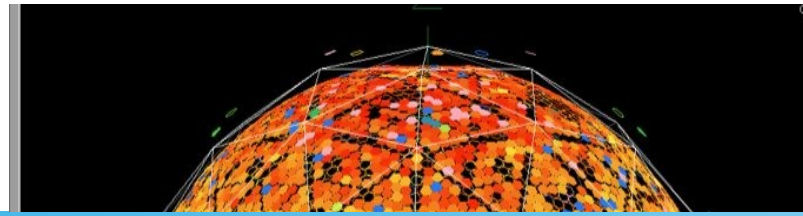


- Aim: point using electron elastic scattering events
  - In water, these leave characteristic Cherenkov ring
- Two possibilities at SNO+ with scintillator:
  - External water: 1.7kT between AV and PMT's

Challenging reconstruction with far off-center timing, optics → used in other analyses, in progress for SN

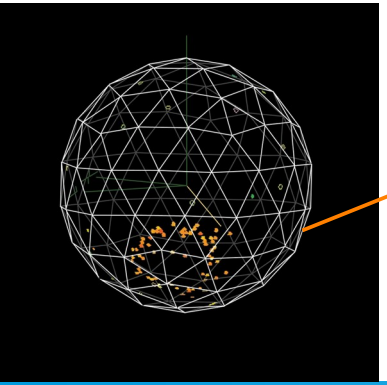
  - Disentangle Cherenkov and scintillation light

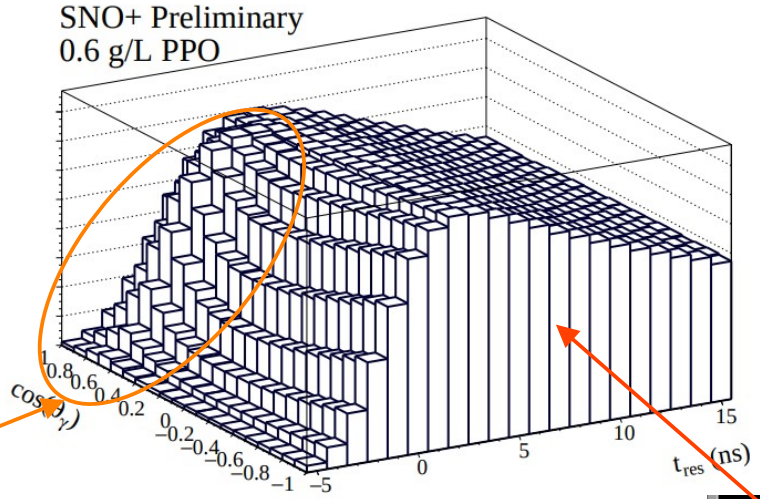
A crazy idea that *might* work



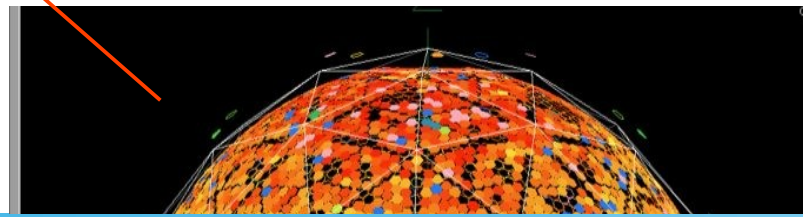
Pointing with EES

- Cherenkov light cone emitted at earlier times compared with scintillation

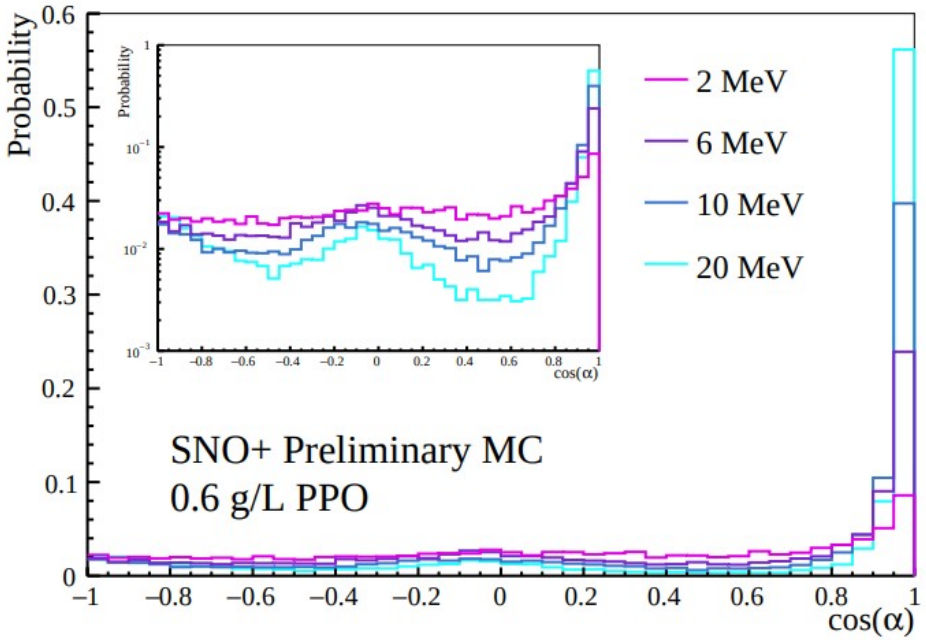




Simulated time residuals
for solar neutrinos
vs angle relative to Sun

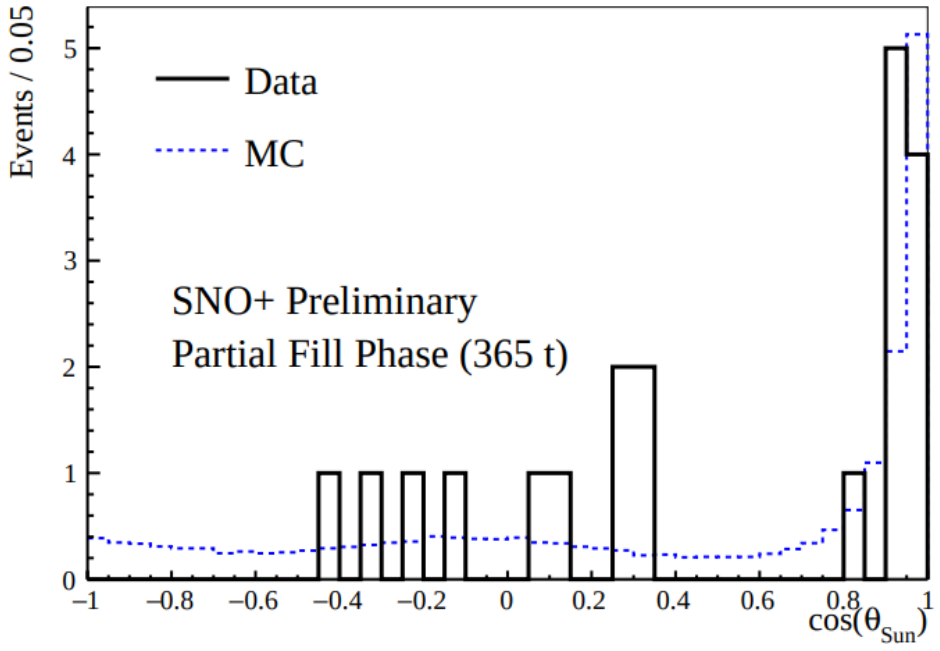


Pointing with EES



- 2D likelihood fit in solar angle and time residuals
- Events above ~5 MeV should be dominated by solar neutrinos
  - Direction expected to be peaked in direction to Sun

Pointing with EES



- Partial fill (365T LS), 0.6g/L PPO
- 92 days livetime
- Potentially even better for SN neutrinos!
- Independent direction determination
- Note: study of pointing in external water also ongoing

Conclusion

- SNO+ scintillator data-taking started in April 2021
  - Nearline systems sending SNEWS “test” alarms since 2022
- Aim to send alarms to SNEWS2 in 2023
  - Further potential alarm content to be confirmed
  - Aim to contribute to pre-SN monitoring
  - May contribute to pointing with electron elastic scatters
- SNO+ is preparing for Te/0νββ phase
  - Supernova sensitivity not diminished!

SNO+

SNEWS
SUPERNOVA EARLY WARNING SYSTEM