22nd edition
PANIC Lisbon Portugal
Particles and Nuclei International Conference

Status and Prospects of the SNO+ Experiment

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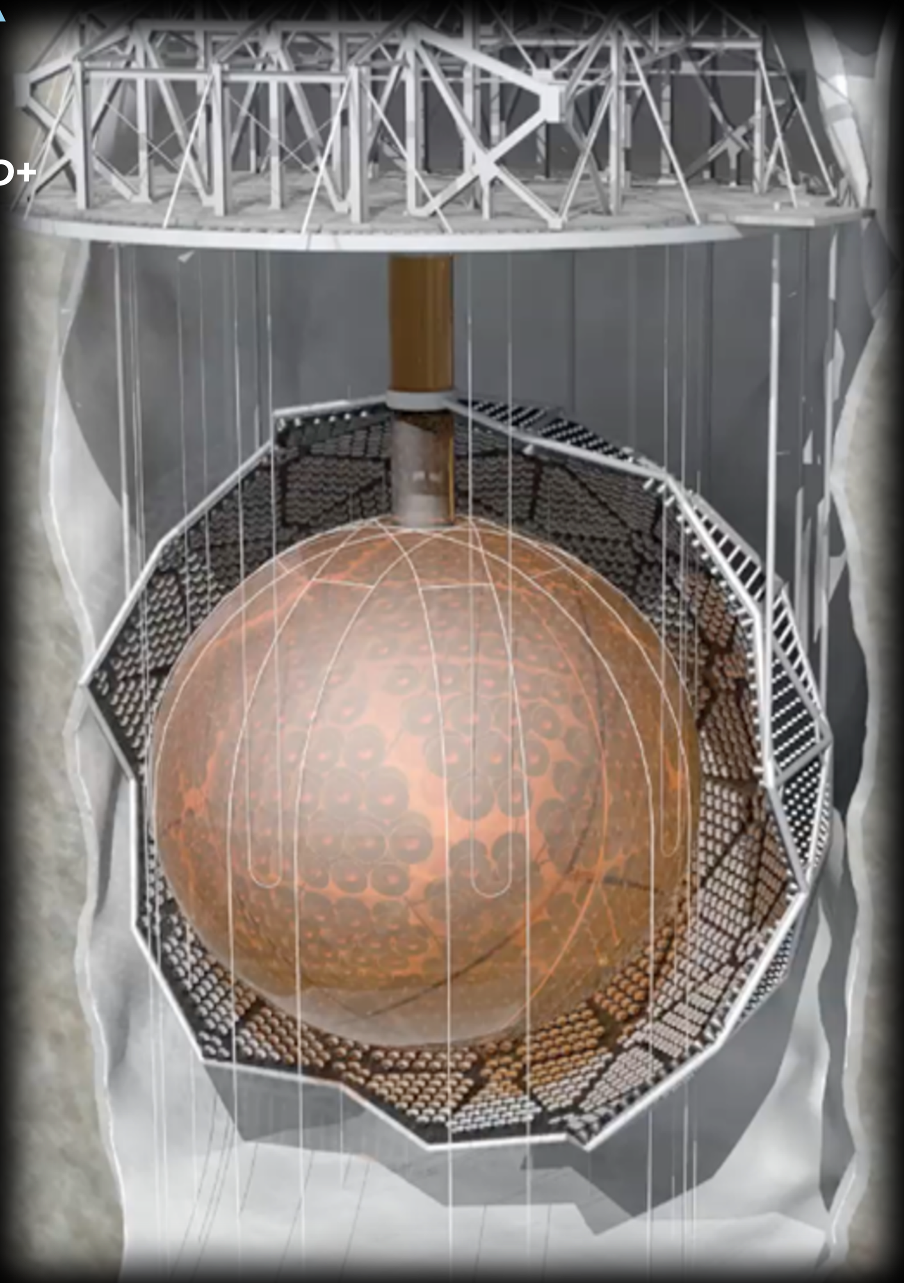
SNO+

2070 m of rock overburden, ~70 μ/day in SNO+



Multi-purpose neutrino detector located at SNOLAB in Sudbury, Ontario, Canada.

The SNO+ Experiment,
JINST 16 P08059 (2021)

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2070 m of rock overburden, ~70 μ/day in SNO+

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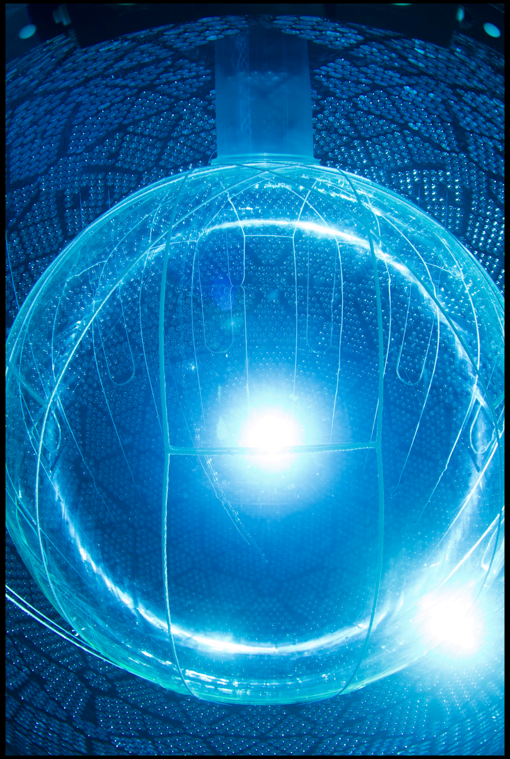
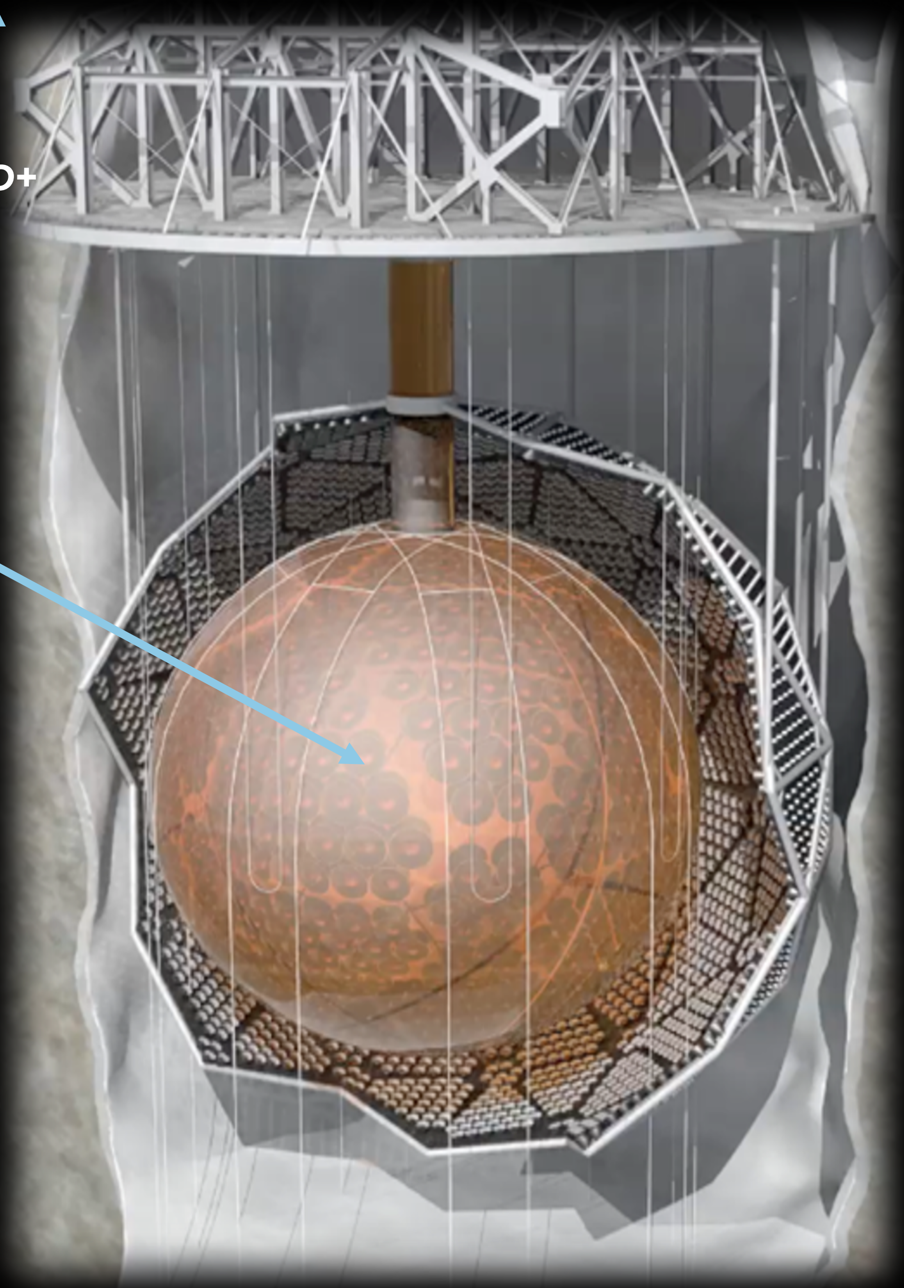


Acrylic vessel (AV)
UV-transparent
6 m radius
5.5 cm thickness



Holds the target medium:

I. 905 tonnes of UPW
II. 780 tonnes of LAB+PPO
III. LAB+PPO + Tellurium cocktail

The SNO+ Experiment, [JINST 16 P08059 (2021)]

SNO+

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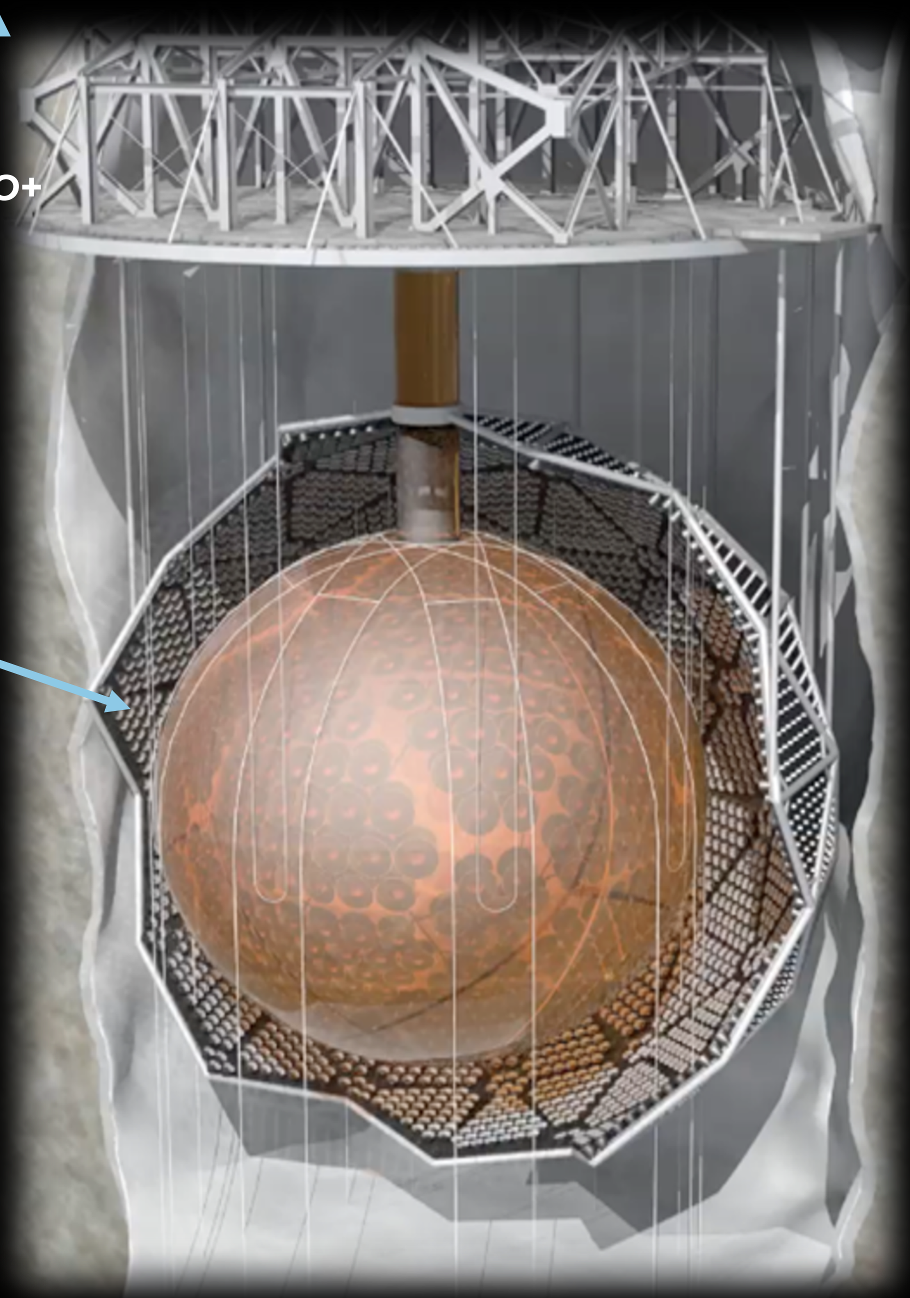


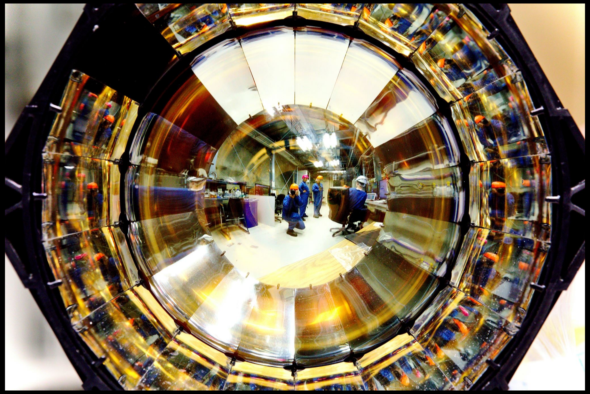
Multi-purpose neutrino detector located at SNOLAB in Sudbury, Ontario, Canada.

Acrylic vessel (AV)

~9400 photomultiplier tubes (PMTs)

54% effective photocoverage

~90 outward looking PMTs for tagging cosmic rays



8" Hamamatsu R1408 PMTs
+
27-cm diameter concentrator

The SNO+ Experiment,
[JINST 16 P08059 (2021)]

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Multi-purpose neutrino detector located at SNOLAB in Sudbury, Ontario, Canada.

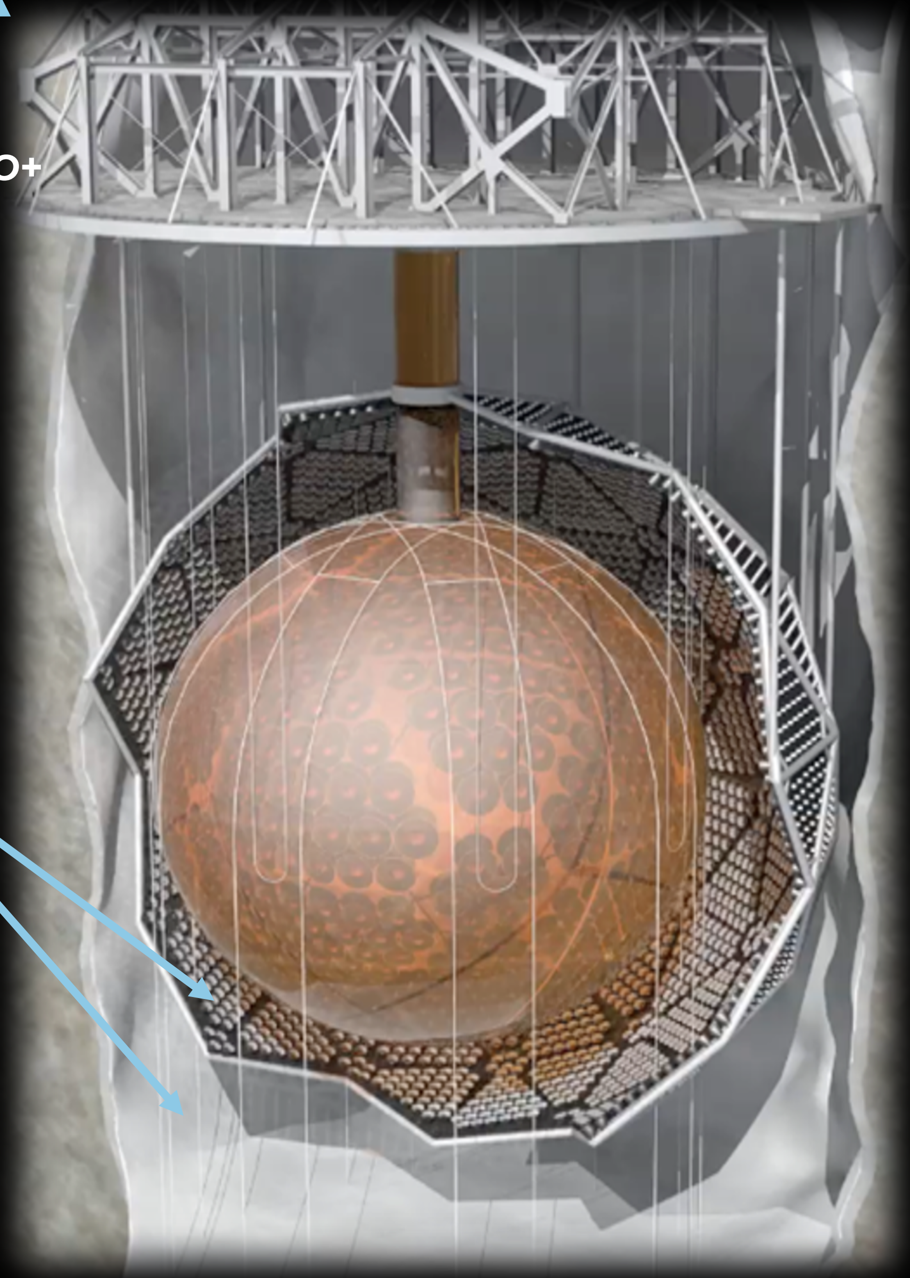
Acrylic vessel (AV)

~9400 photomultiplier tubes (PMTs)

Ultra-pure Water shielding

1.7 kt between AV and PMTs,
to reduce backgrounds from PMT materials

5.3 kt between PMTs and cavity,
to reduce background from rock wall



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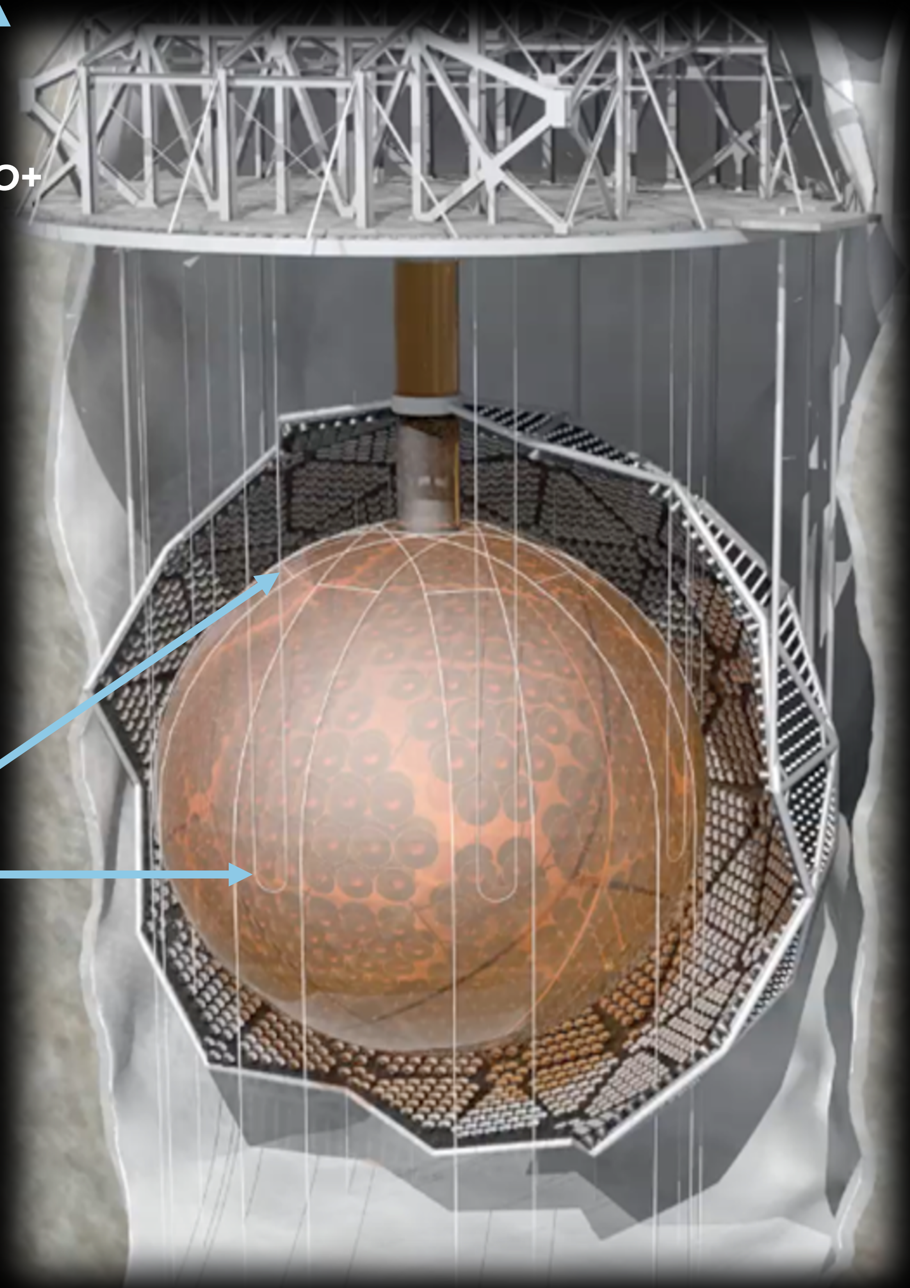
Low radioactivity hold-up and hold-down rope systems



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[JINST 16 P08059 (2021)]

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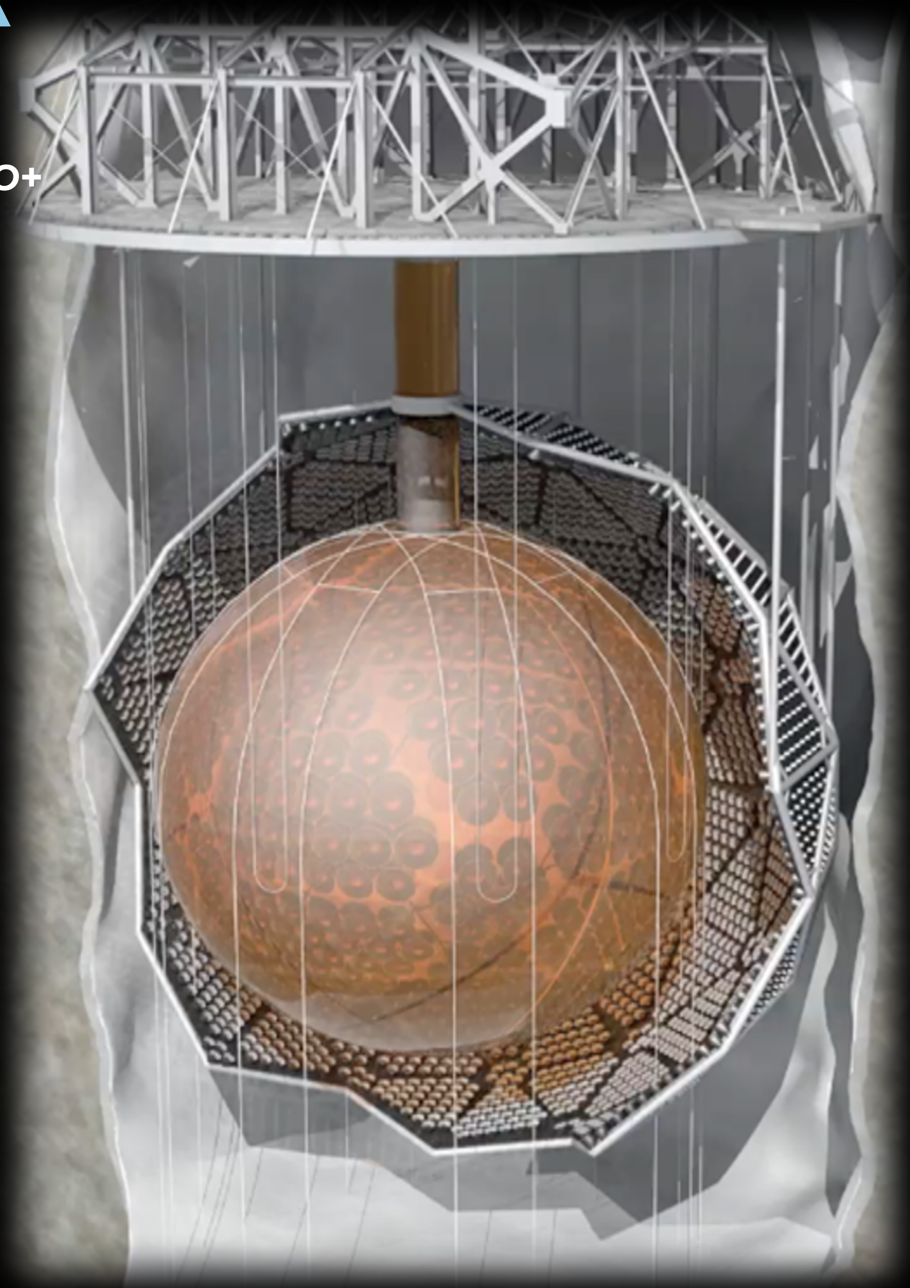


Multi-purpose neutrino detector located at SNOLAB in Sudbury, Ontario, Canada.

Acrylic vessel (AV)

~9400 photomultiplier tubes (PMTs)

Ultra-pure Water shielding

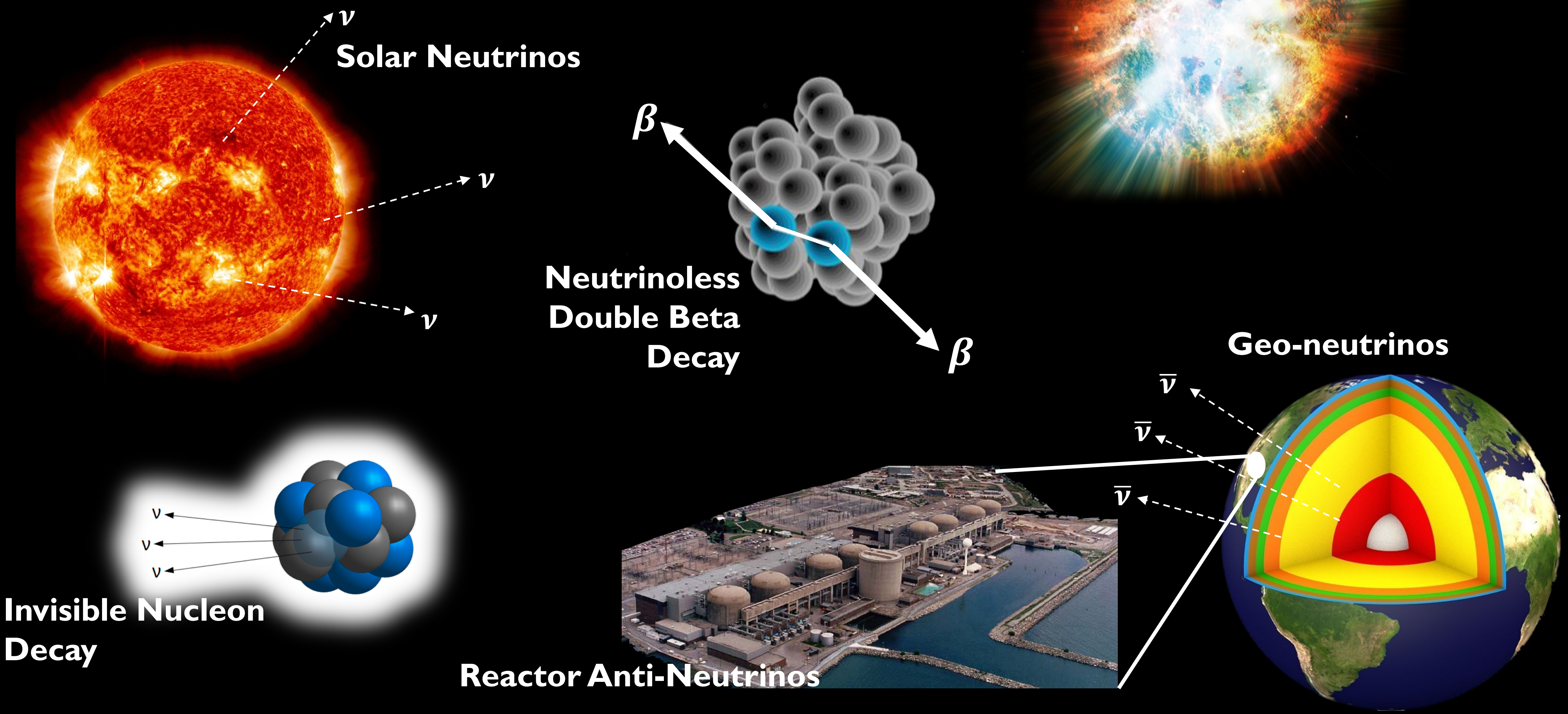
Low radioactivity hold-up and hold-down rope systems

+ Upgraded DAQ/electronics system for the low threshold and high rate,

+ New calibration hardware

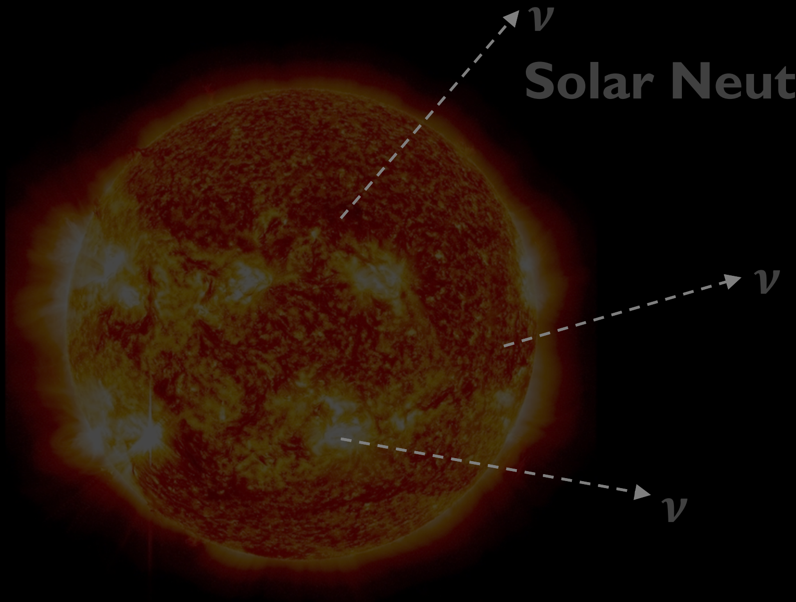
The SNO+ Experiment, [JINST 16 P08059 (2021)]

Physics Program



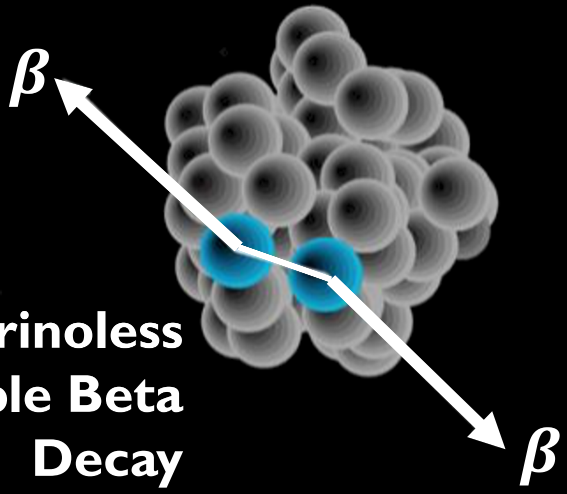
Physics Program

Supernova Neutrinos



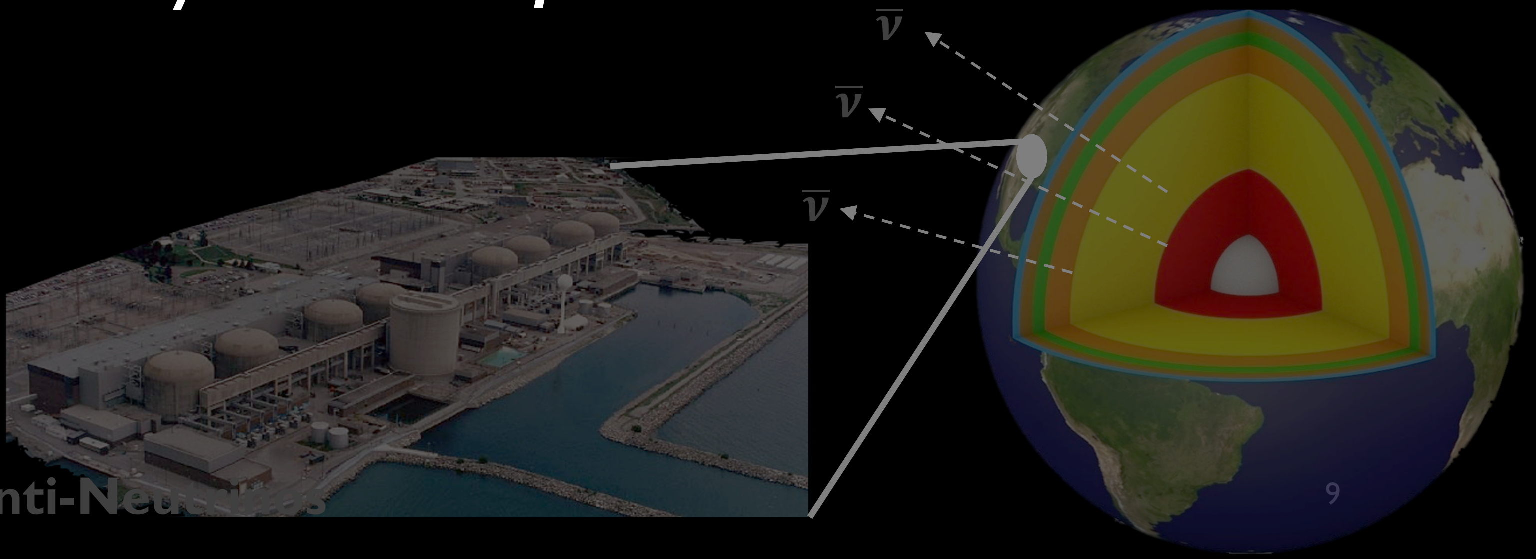
Solar Neutrinos

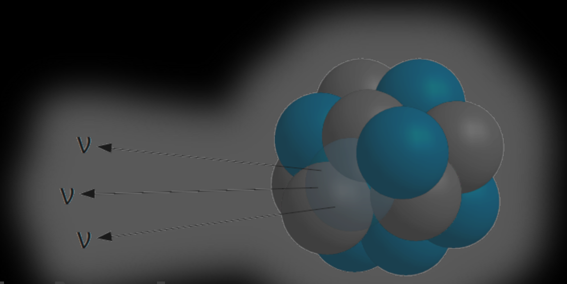
Main Goal



Neutrinoless Double Beta Decay

Geo-neutrinos





Invisible Nucleon Decay

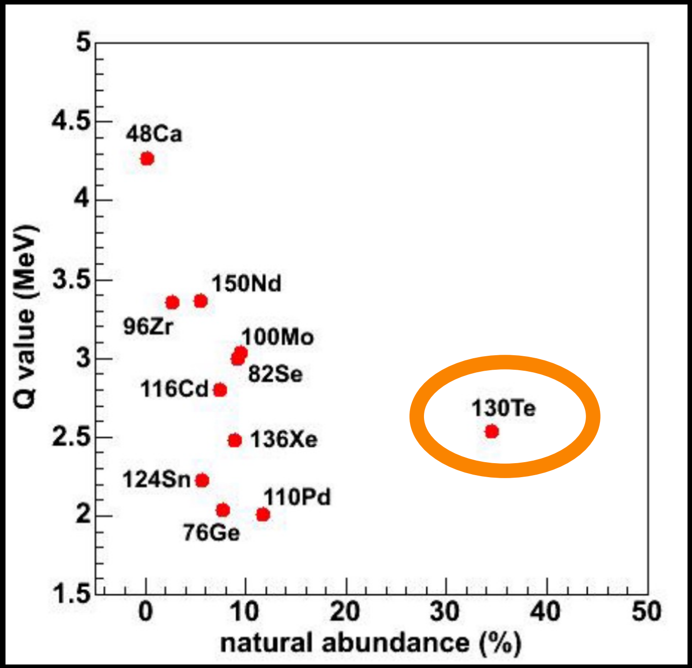
Reactor Anti-Neu…

$0\nu\beta\beta$ Decay Search in SNO+

$0\nu\beta\beta$ decay candidate: **^{130}Te**

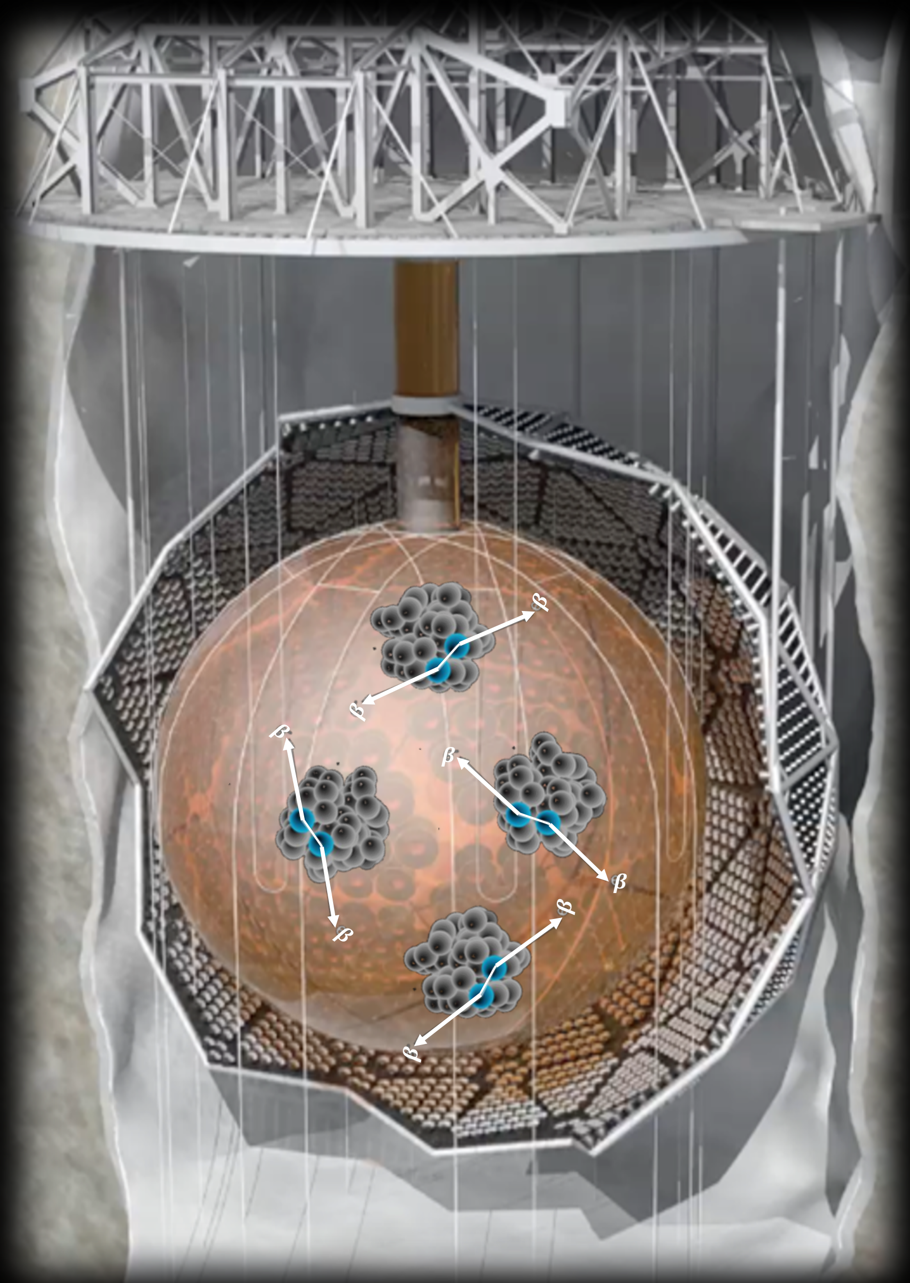
- Highest natural abundance (34%), no enrichment needed – easily scalable at low cost.
- Q-value at 2.527 MeV – less background from natural radioactivity

Better (Greater phase space and lower backgrounds)



Better (cheaper)

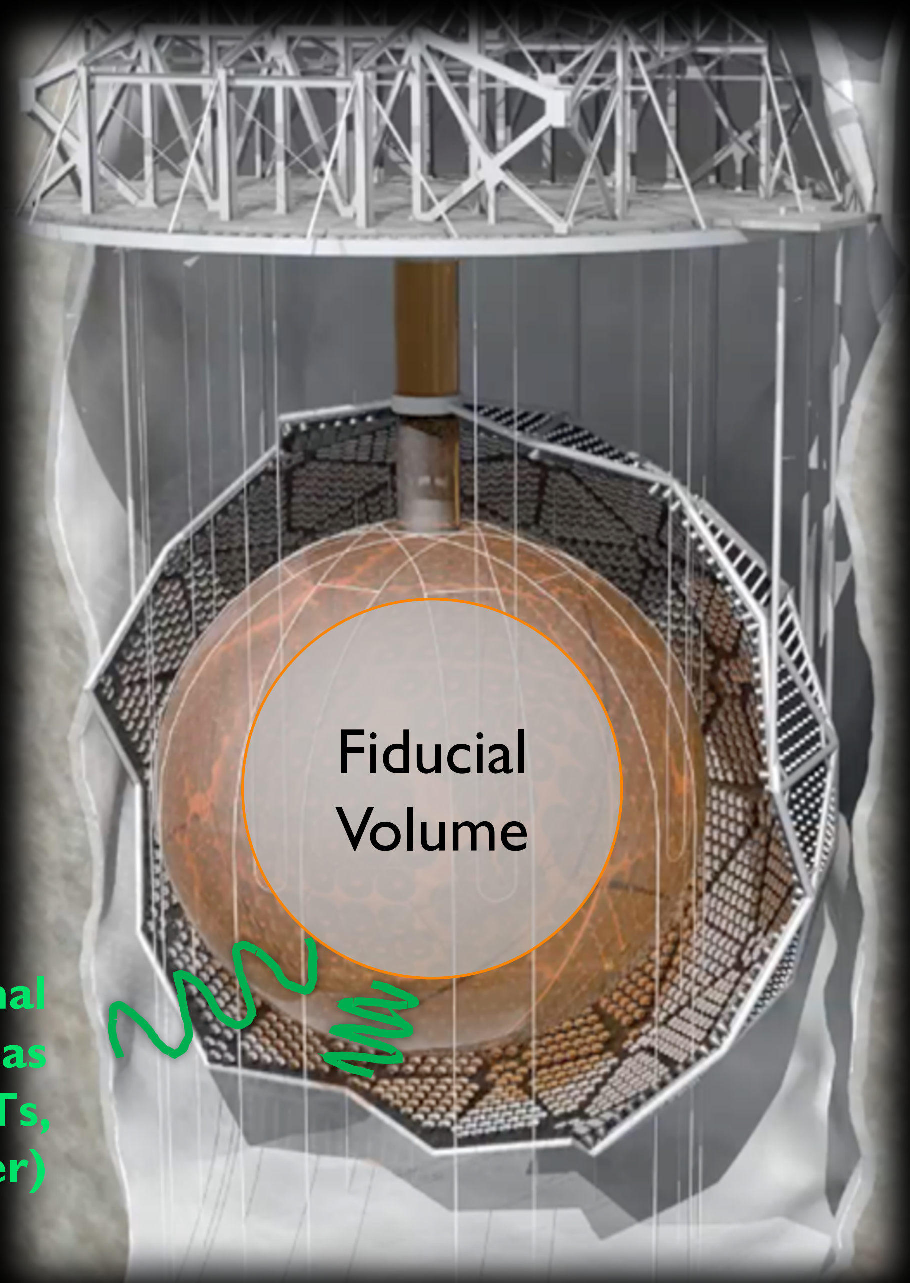
Initial phase loading:
0.5% natural Te by weight
= 1333 kg of ^{130}Te.



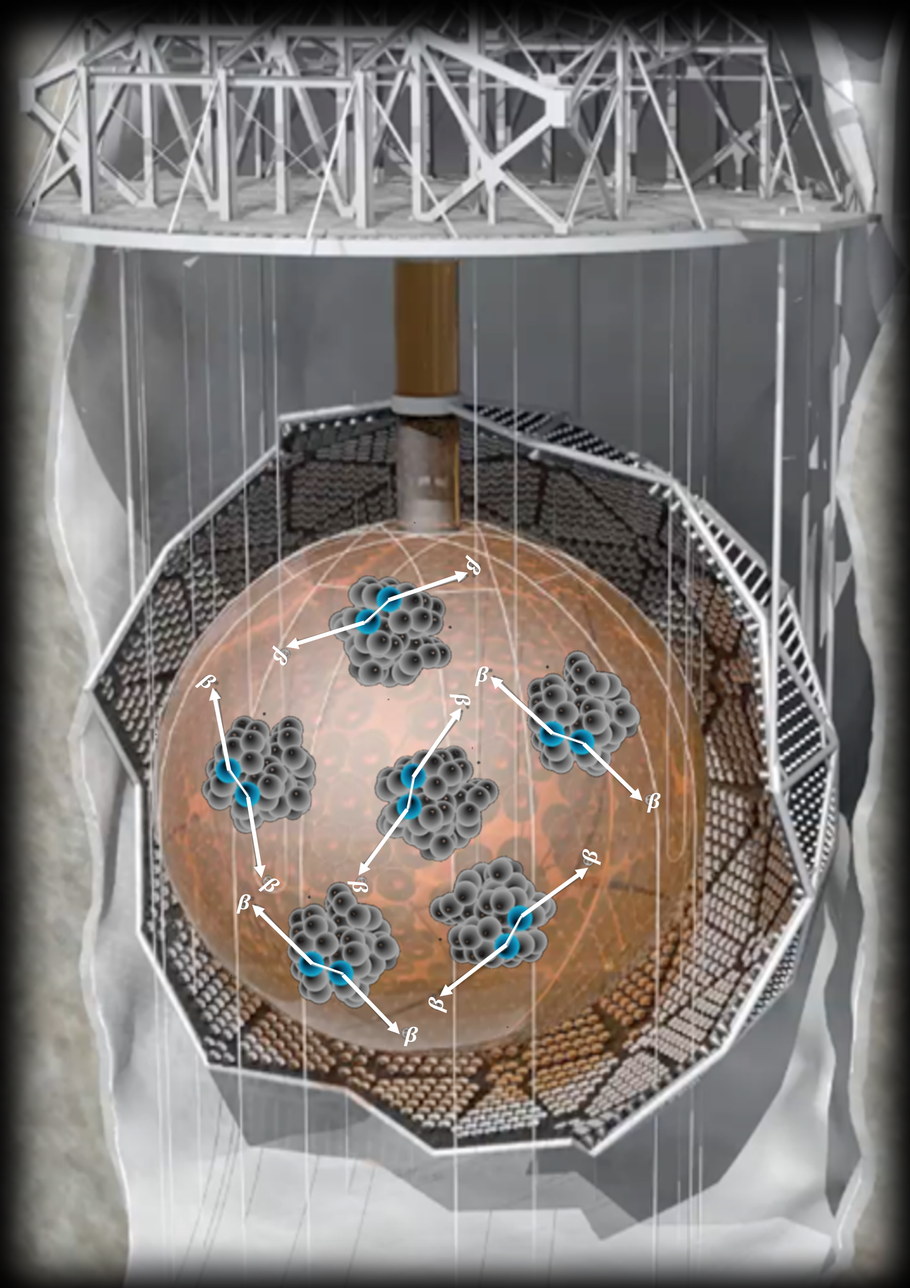
$0\nu\beta\beta$ Decay Search in SNO+

Advantages

1. Massive detector
   - High statistics
   - Self-shielding from external backgrounds through fiducialization.



$0\nu\beta\beta$ Decay Search in SNO+



Advantages

1. Massive detector
   - High statistics
   - Self-shielding from external backgrounds through fiducialization.

2. Liquid scintillator
   - Can be purified
   - Backgrounds can be measured and constrained prior to isotope addition
   - Loading can be scaled

SNO+ Timeline

2016 — 2017 — 2019 — 2021 — 2022

- **Dec. 2016**
  Started taking commissioning data
- **May 2017**
  Start of the Water Phase
- **July 2019**
  Start of Scintillator Fill
- **March 2021**
  End of Scintillator Fill
- **2022**
  Tellurium is added to the scintillator

SNO+ Timeline

2016 2017 2019 2021 2022

Dec. 2016
Started taking commissioning data

May 2017
Start of the Water Phase

July 2019
Start of Scintillator Fill

March 2021
End of Scintillator Fill

Tellurium is added to the scintillator

Water Phase

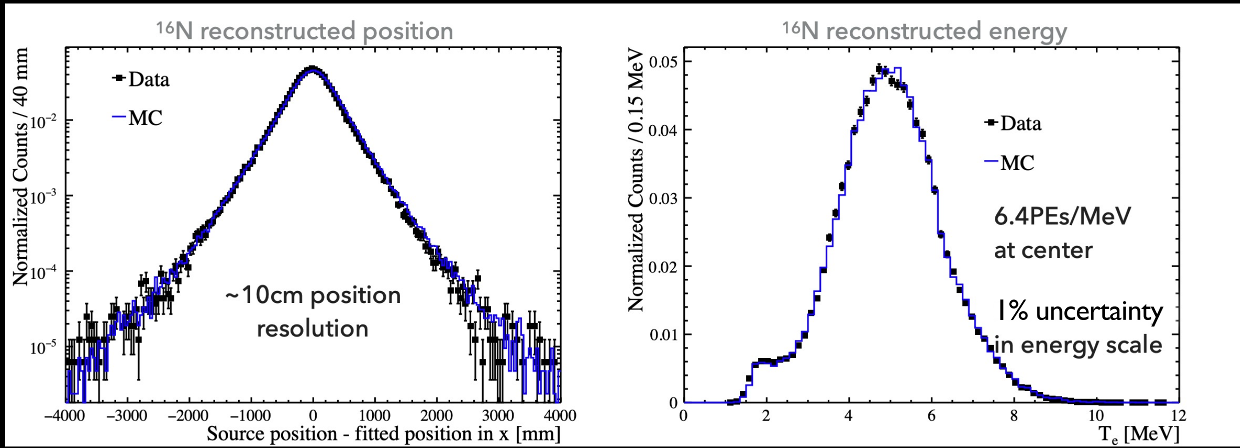
Dataset I: (115 live days)
May 2017 -> December 2017

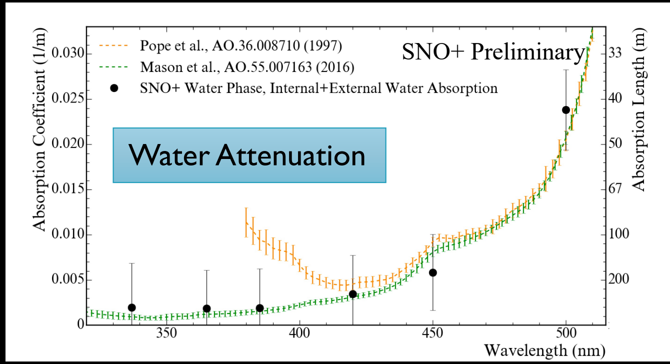
Dataset II: (190 live days)
October 2018 -> July 2019

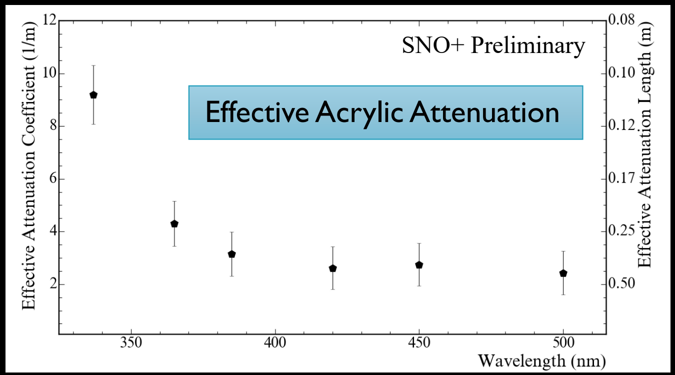
905 tonnes of ultra-pure water (UPW)

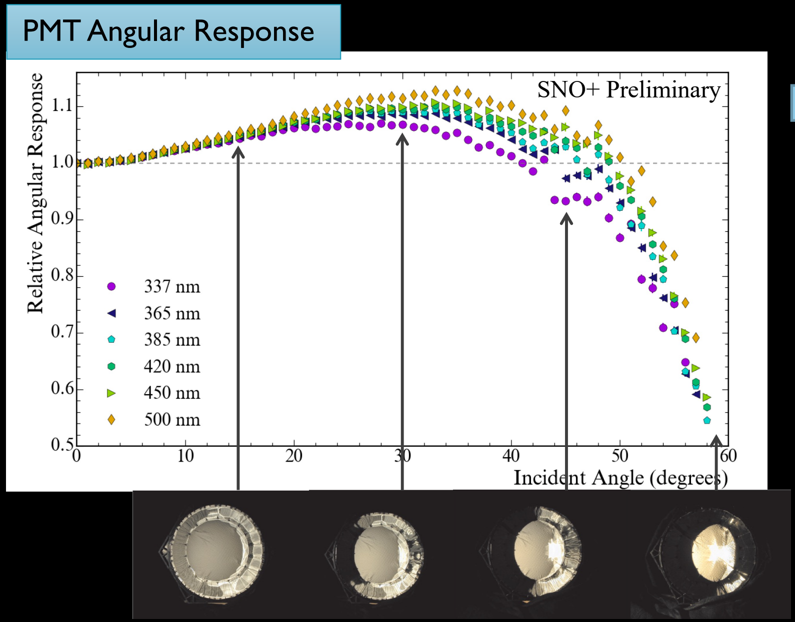
SNO+ Water Phase

- Detector calibrations:
  - Deployed and in-situ optical and radioactive sources to calibrate PMTs, measure timing and optical properties, calibrate reconstructed energy, position and direction.









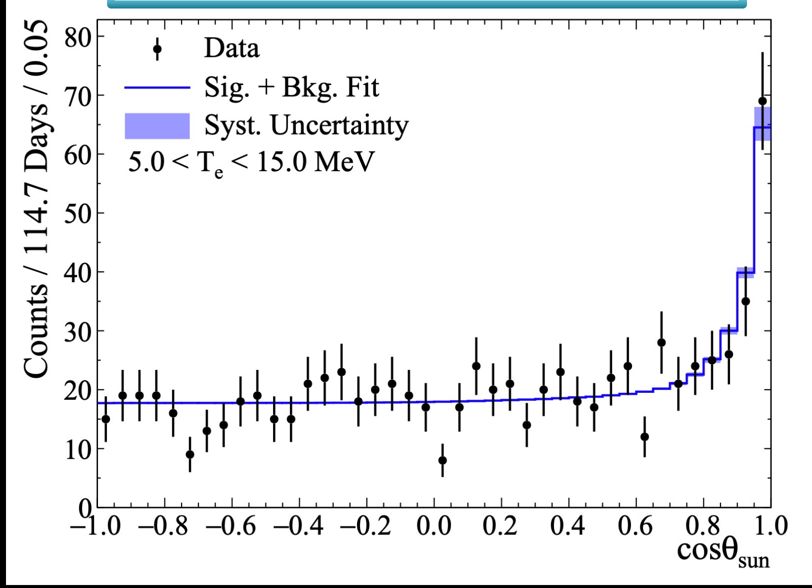
Validation using the ^{16}N source (6.13 MeV gammas), as a function of position

Data – Monte Carlo comparison shows 0.6% agreement, improvement over SNO!

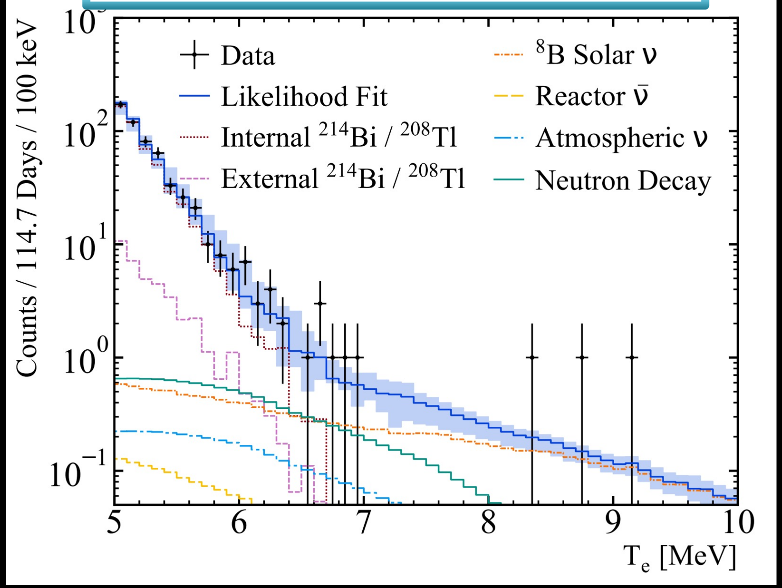
Optical calibration of the SNO+ detector in the water phase with deployed sources, [arXiv:2106.03951](https://arxiv.org/abs/2106.03951)

SNO+ Water Phase

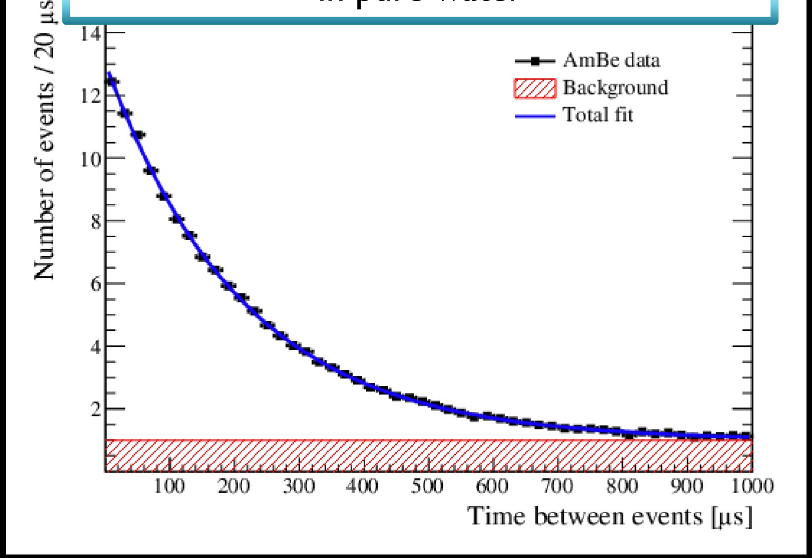
$\Phi_{^8B} = 5.95^{+0.75}_{-0.71}(\text{stat.})^{+0.28}_{-0.30}(\text{syst.}) \times 10^6 \text{cm}^{-2}\text{s}^{-1}$



Improved limits for p, pp and pn decay



~50% efficiency for triggering on a neutron in pure water



^{8}B Solar Neutrino Flux
[Phys. Rev. D 99, 012012 (2019)]

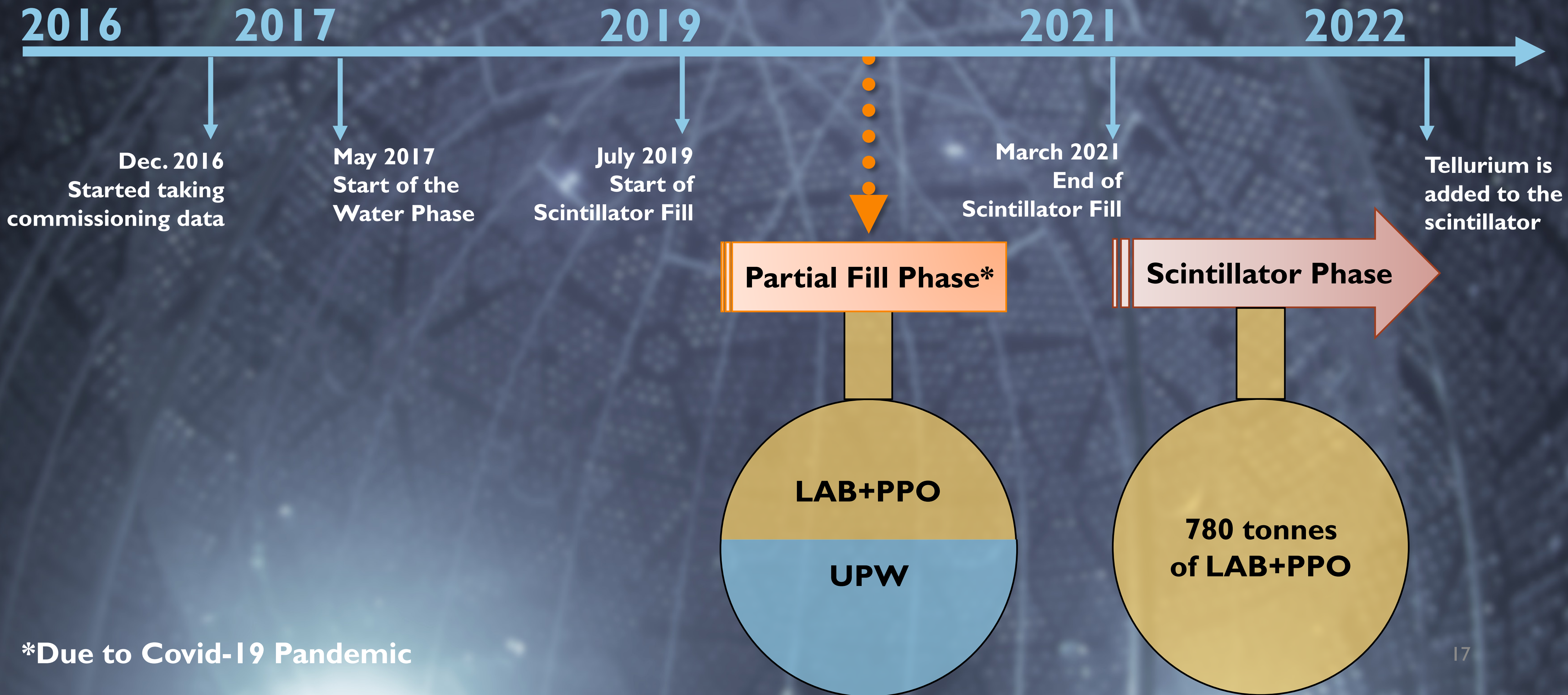
Invisible modes of nucleon decay
[Phys. Rev. D 99, 032008 (2019)]

Neutron-proton capture
[Phys. Rev. C 102, 014002 (2020)]

Updated results coming soon!

- Higher statistics (additional 190 days of data)
- Including completed optical calibration
- Lower backgrounds due to cover gas installation in October 2018 (Rn levels one order of magnitude lower)

SNO+ Timeline



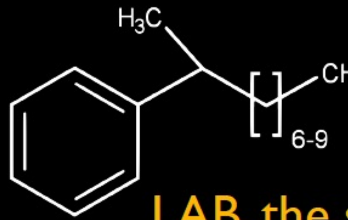
*Due to Covid-19 Pandemic

Scintillator Filling and Purification

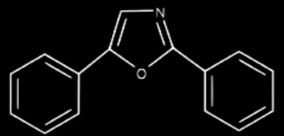
- Linear alkylbenzene (LAB) with 2g/L of PPO.
- Commissioned underground systems and began filling SNO+ in 2019.
- Pause between April and October 2020 due to the pandemic.
- Fill ended in March 2021.

➤ On-going PPO mixing campaign and recirculation.

0.5g/L → 2g/L



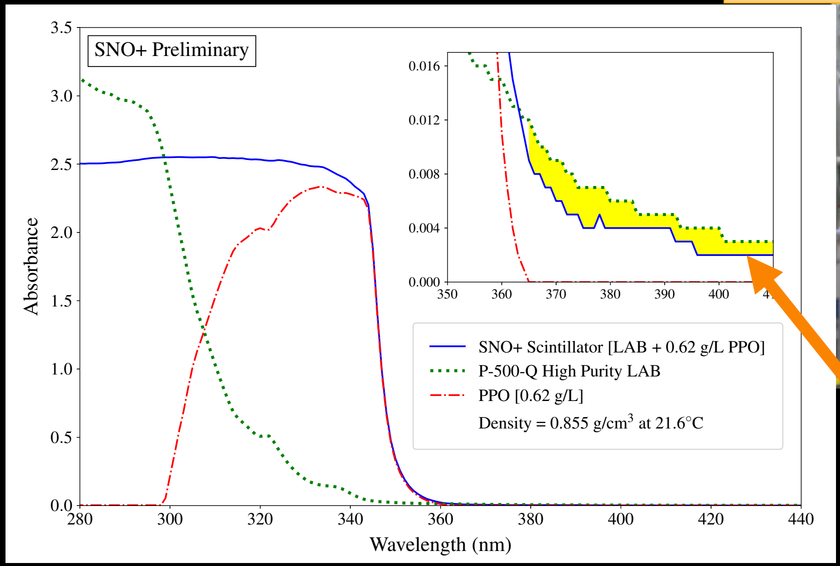
LAB, the solvent



PPO, the fluor

Transfer of LAB from surface to underground in tank railcars at SNOLAB

Purification and Filling Systems

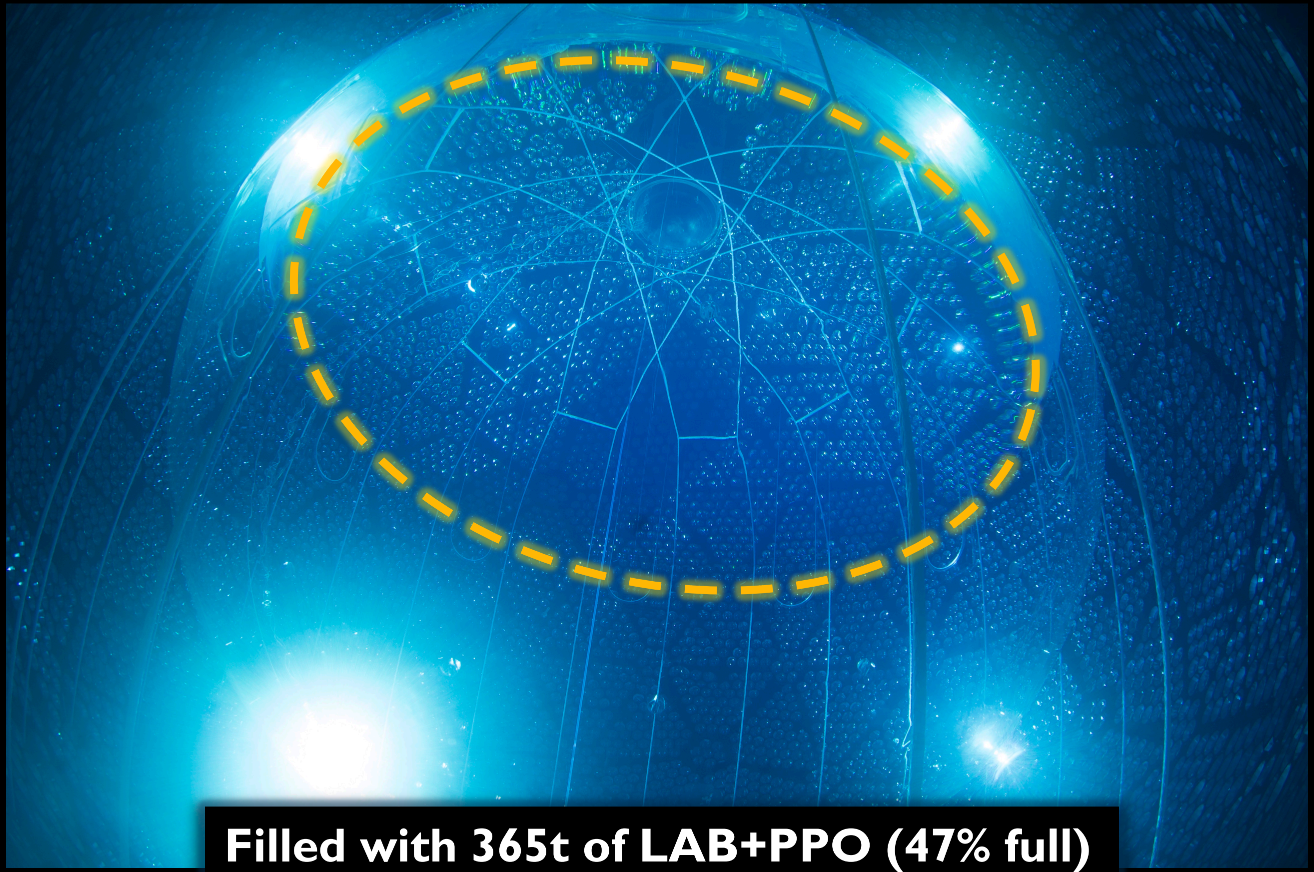


Excellent clarity above PPO absorption region!

Development, characterisation, and deployment of the SNO+ liquid scintillator, [JINST 16 (2021) P05009]

SNO+ Scintillator Phase

“Partial Fill Phase”



Filled with 365t of LAB+PPO (47% full)

PPO concentration 0.5 g/L
(25% of the nominal value)

- Almost 7 months in a half-filled configuration
- Trigger threshold lowered from 1 MeV (water) to ~40 keV (scint)
- Data during the fill used to **measure and monitor the backgrounds** in the liquid scintillator

Perform a “target out” $\beta\beta$ analysis

→ prepare/test analysis and techniques using real data

→ determine count rate in the ROI in the absence of Te

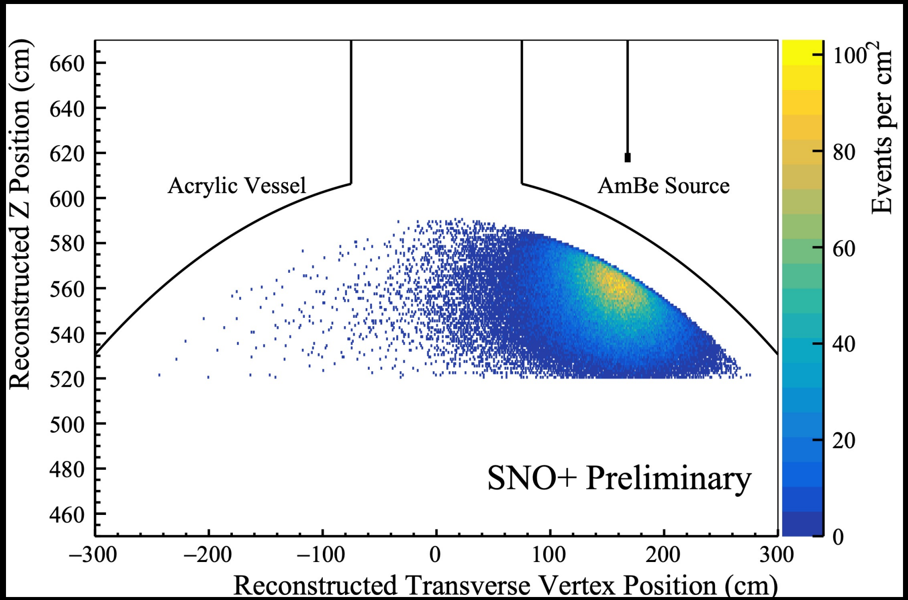
SNO+ Scintillator Phase

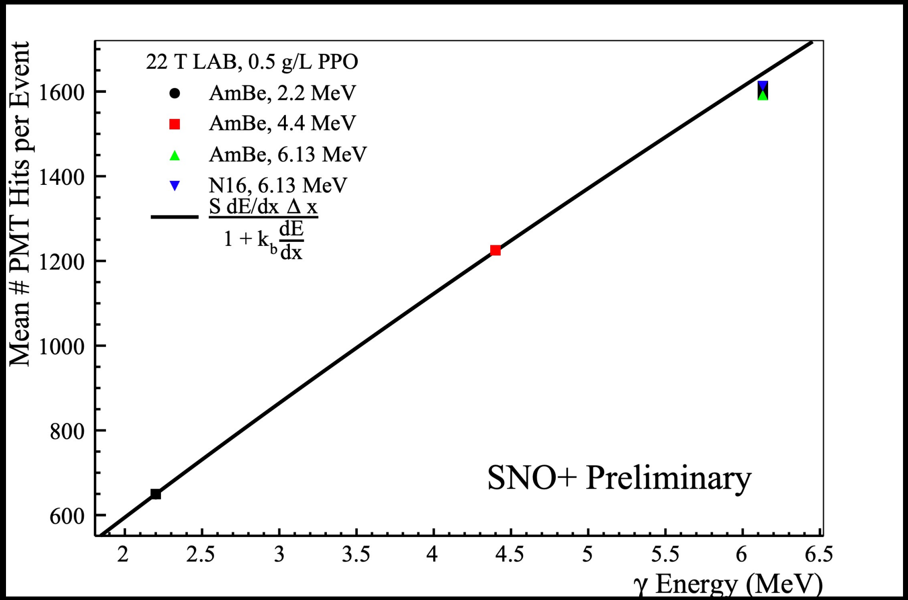
"Partial Fill Phase"

- Detector response during the fill was measured with optical and radioactive source calibrations
- Source deployments performed outside the acrylic vessel
  - Leave the scintillator undisturbed and avoid contamination
  - Demonstrated the capability to reconstruct events in a hybrid LS/water detector

With a PPO concentration of only 0.5 g/L we see a light yield equivalent to ~300 p.e. / MeV
Consistent with expectations!

Extrapolates to ~650 p.e. / MeV at 2.0 g/L PPO

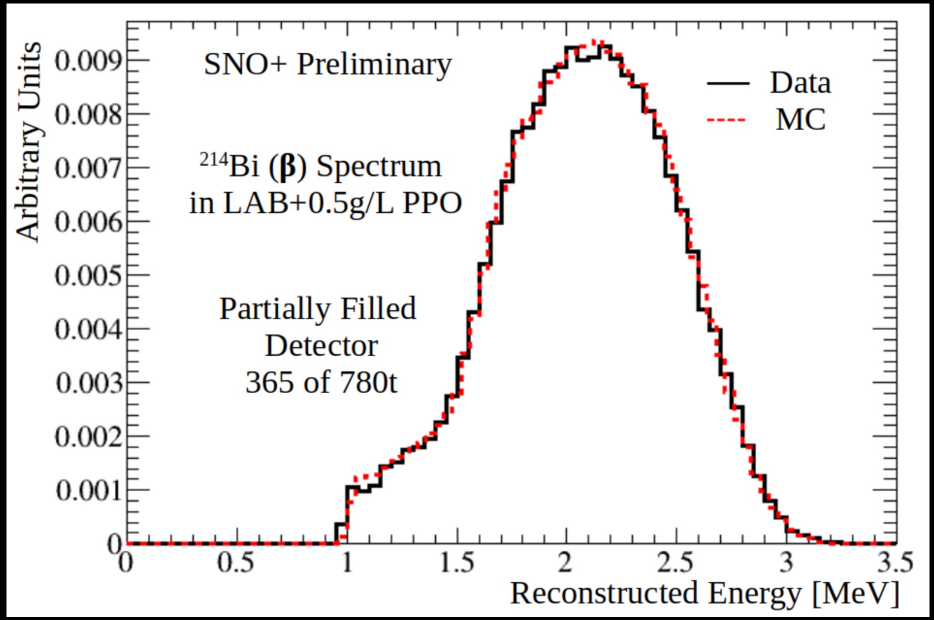


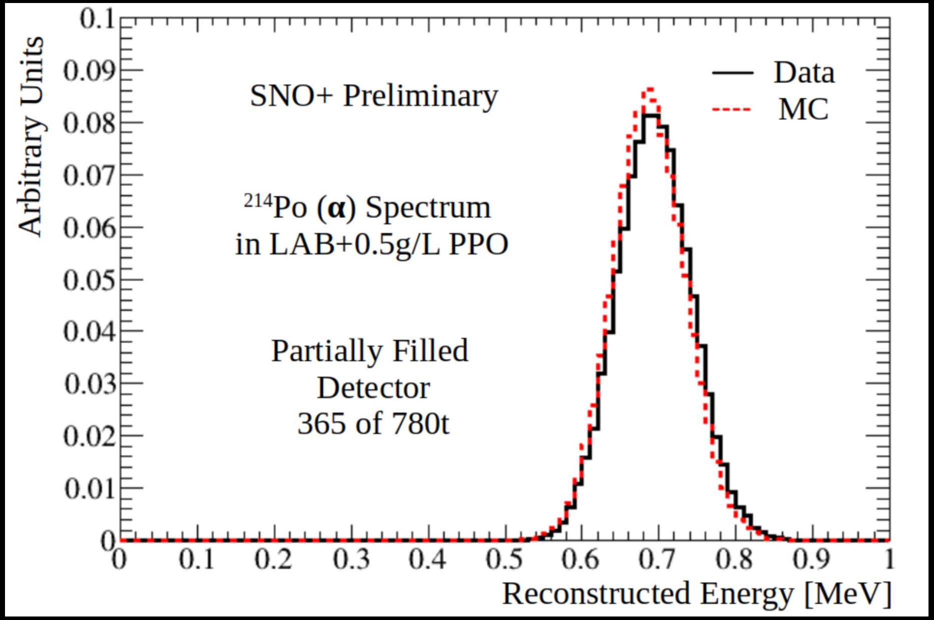


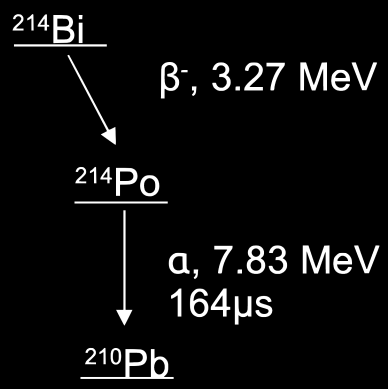
SNO+ Scintillator Phase

"Partial Fill Phase"

- Used ^{214}Bi and ^{214}Po tagged coincidences to calibrate particle timing profile, light yield and quenching.



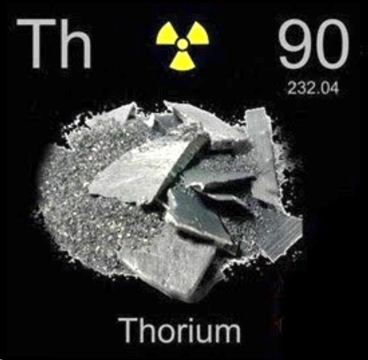


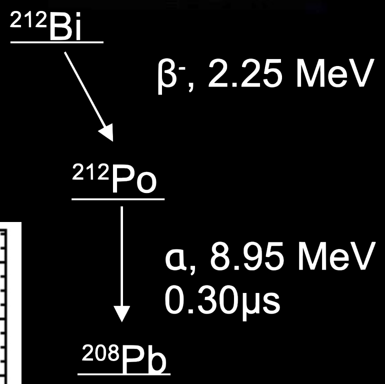


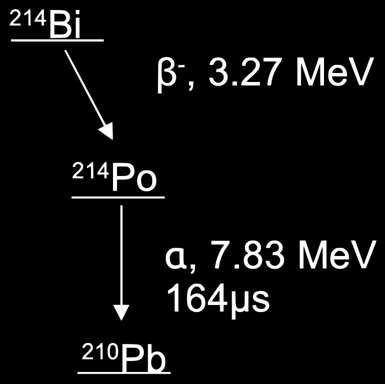
SNO+ Scintillator Phase

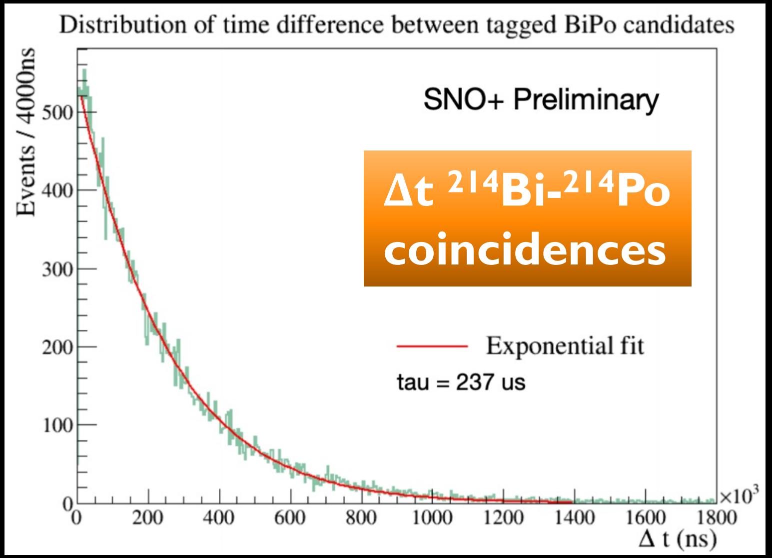
“Partial Fill Phase”

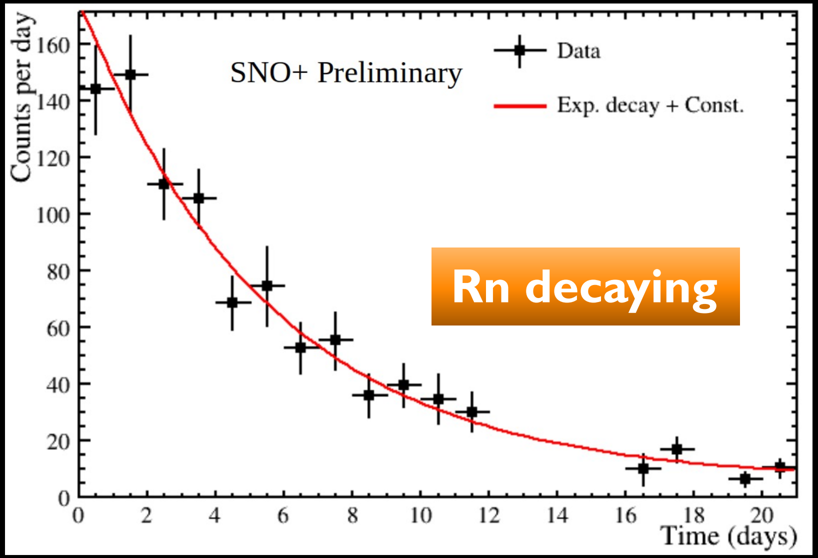
- Measure intrinsic U and Th levels in the scintillator.
  - From ^{212}Bi and ^{214}Bi, which can be tagged by looking for the Po follower.











U Rate: 4.7±1.2$\times 10^{-17}$ gU/gScint

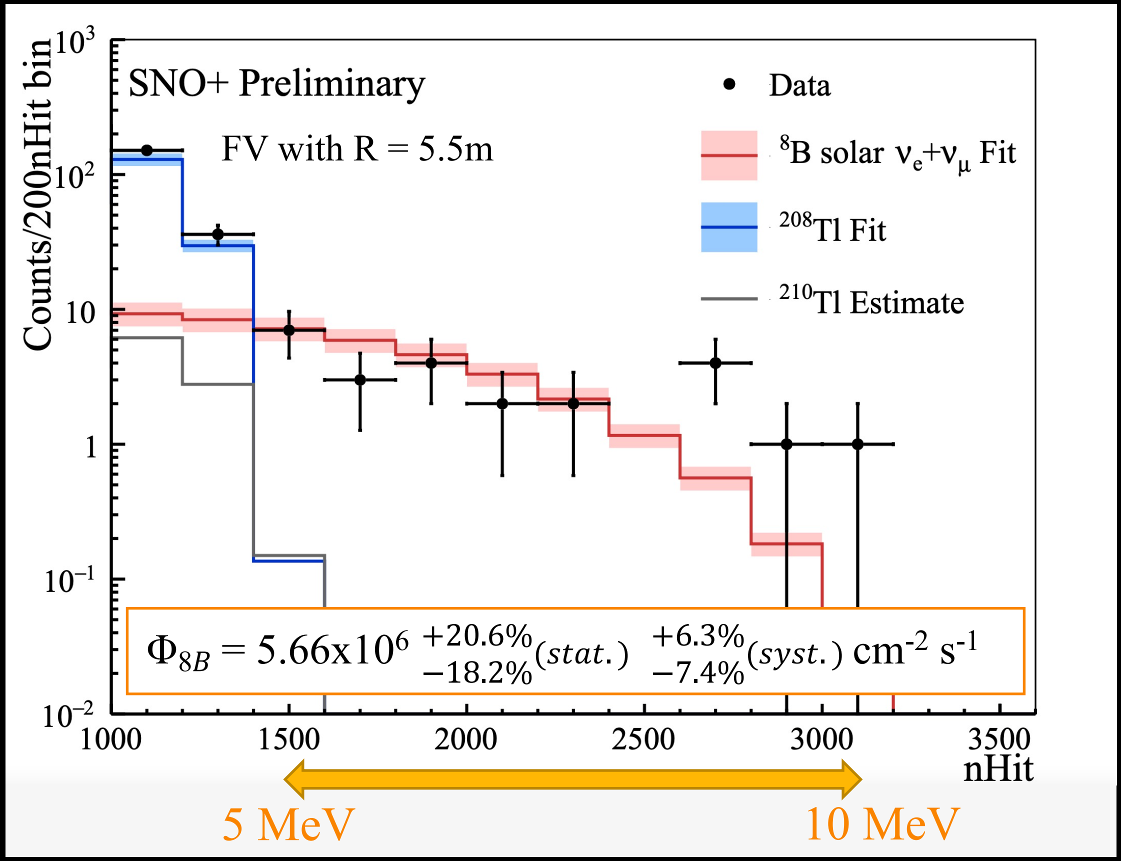
Th Rate: 5.3±1.5$\times 10^{-17}$ gTh/gScint

Measurements using the partial fill data show that our U and Th rates are below the requirements for the $0\nu\beta\beta$ search.

SNO+ Scintillator Phase

"Partial Fill Phase"

- Neutrino Physics program has begun:
  - Live for supernova neutrinos
  - Geo and Reactor anti-neutrinos
  - ^{8}B solar neutrinos



Preliminary ^{8}B solar ν + Bkg. Fit to the PF data, including preliminary systematics.
Fitted flux compatible with other measurements.

Preliminary results from the Partial Fill phase:

- ➢ Proof of concept + preparation of analysis tools for full fill phase.
- ➢ Exploring Cherenkov/Scintillation light separation and directionality in the low PPO data.

SNO+ Timeline

2016 — Dec. 2016: Started taking commissioning data

2017 — May 2017: Start of the Water Phase

2019 — July 2019: Start of Scintillator Fill

2021 — March 2021: End of Scintillator Fill

2022 — Tellurium is added to the scintillator

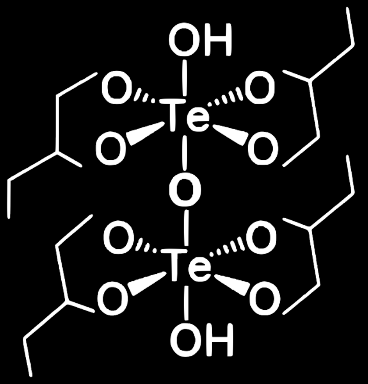
780 tonnes of LAB+PPO

+0.5% Te loading

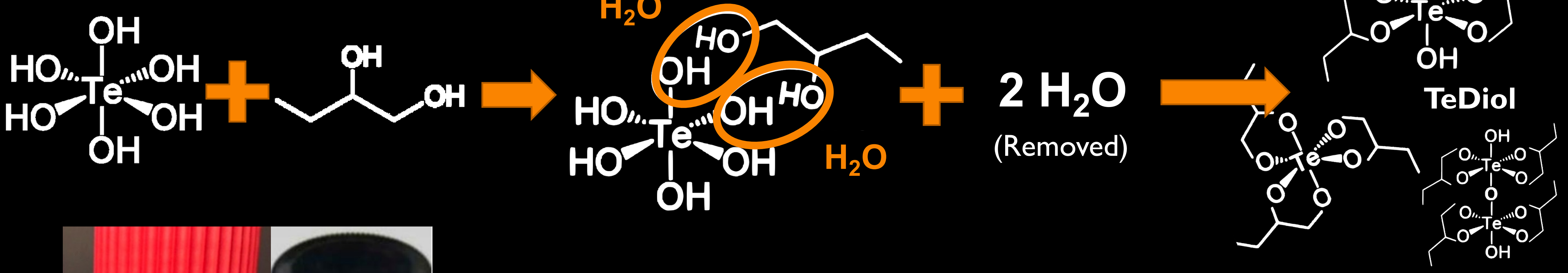
$0\nu\beta\beta$ Search

Tellurium Loading

- Forming an organometallic compound from telluric acid and butanediol:



Telluric Acid **1,2-Butanediol**



- TeDiol is mixed directly into the LAB+PPO with 15 mg/L bis-MSB and a stabilizer called Dimethyldodecylamine (DDA).

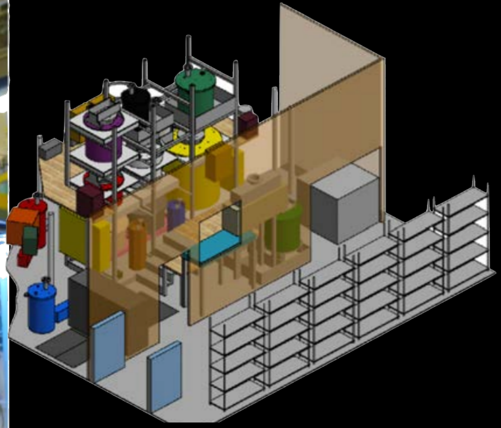
- Final Te-loaded LS cocktail expected to produce ~460 p.e. / MeV in SNO+ for 0.5% Te loading.

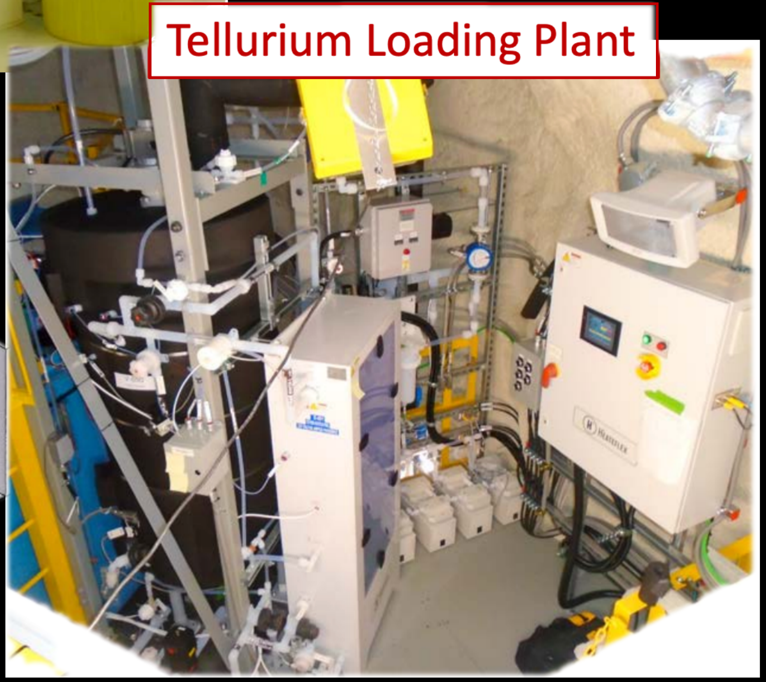
Tellurium Plants

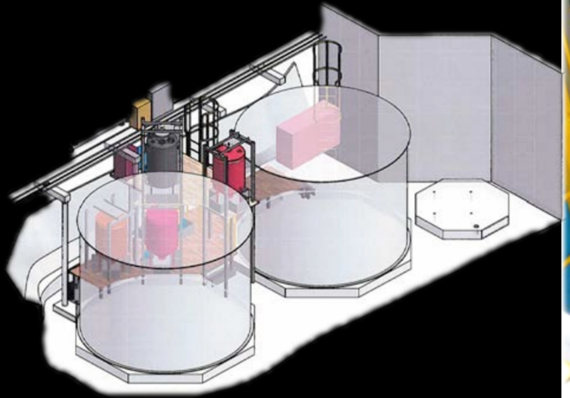
- ~8 tons of telluric acid has been “cooling” underground for several years.
- Ton-scale underground purification of telluric acid for further background reduction.
- Target purification for Te cocktail:

  ~ 10^{-15} g/g U

  ~ 10^{-16} g/g Th

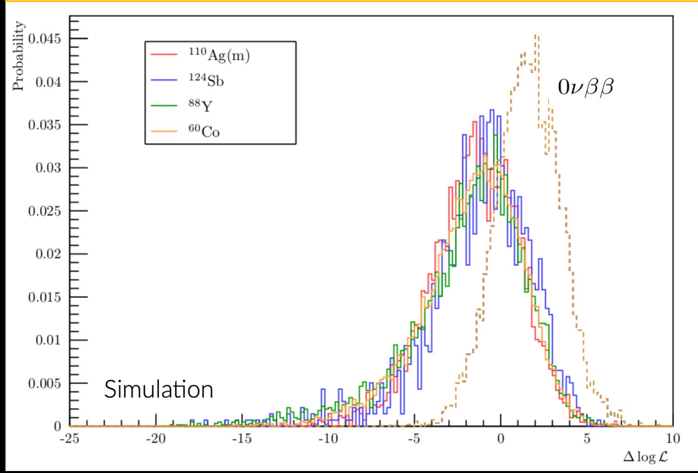






SNO+ Tellurium Phase - Prospects

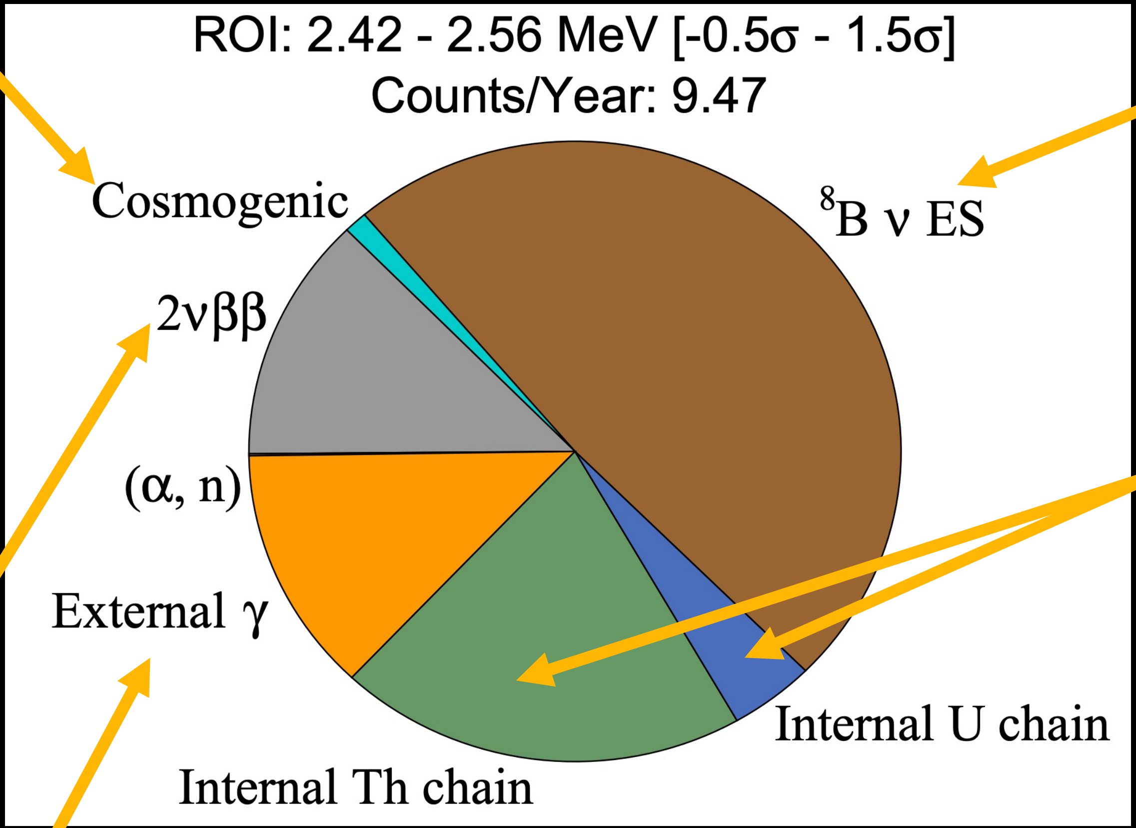
Telluric acid has been "cooling" underground for several years
+ Te purification
+ can be verified with multi-site analysis



Dunger and Biller, NIM 943, 162420, (2019)

Suppressed by asymmetric ROI

Measured in Water Phase, below target



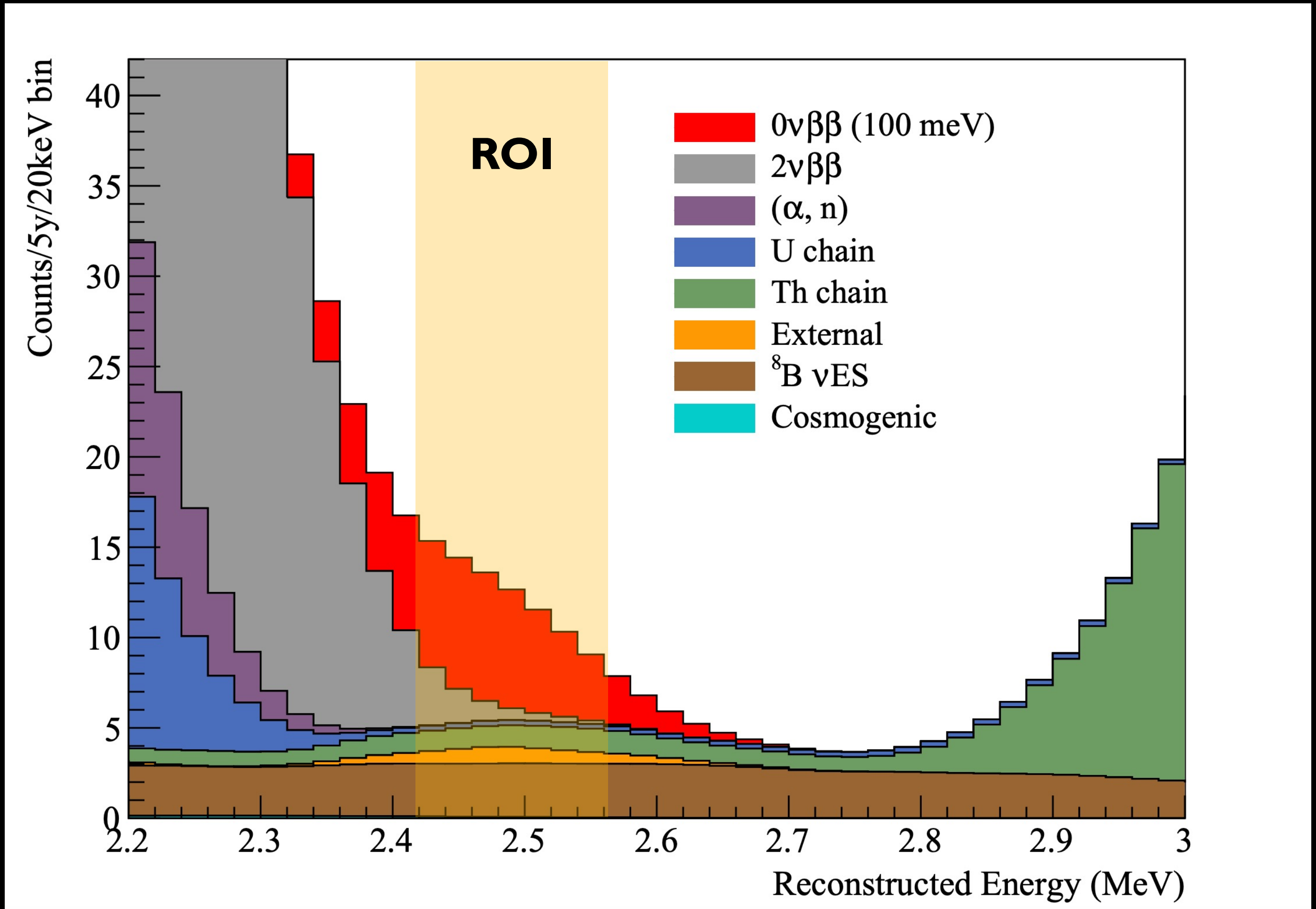
Well known from other measurements

LS contribution measured during the partial fill, below our target for $\beta\beta$

U and Th from the Te addition to be minimized with the purification systems

SNO+ Tellurium Phase - Prospects

Expected Energy Spectrum after 5 Years with 0.5% Te loading, Fiducial Volume of 3.3 m radius



Expect 9.47 events / year in this ROI (with our target background levels)

Half-Life Sensitivity > 1.8×10^{26} years

SNO+ Tellurium Phase - Prospects

- From a simple counting analysis, for 5 years, in an optimized energy ROI and fiducial volume:

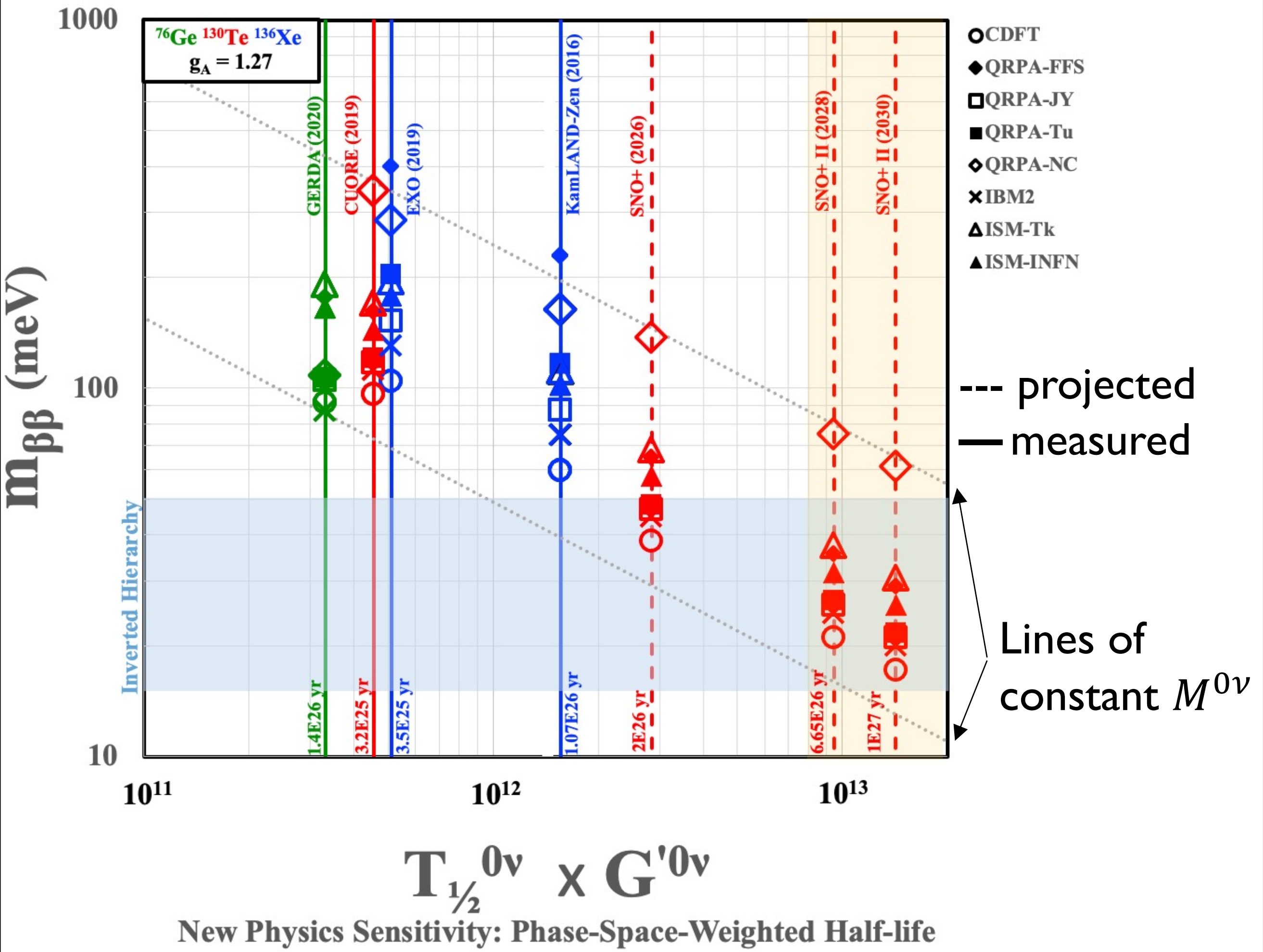
Expected Half-Life Sensitivity > 2.1×10^{26} years

$m_{\beta\beta}$ range 37-89 meV (model dependent)

- Will be further optimized with a spectral fit.

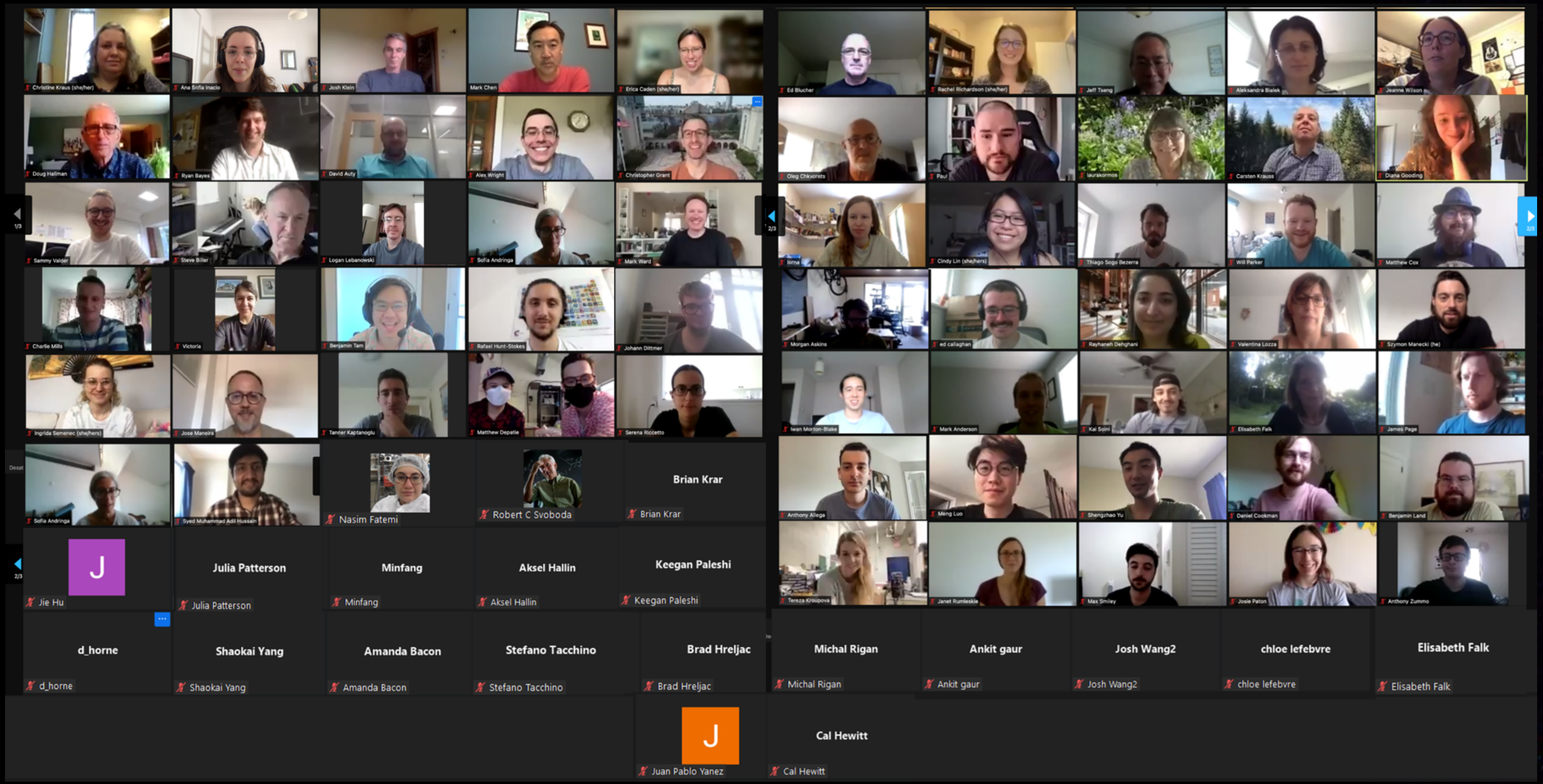
- SNO+ approach can be scaled up.
  - Te loading up to 3% with good light yield and stability
  - Cost is relatively very low (< $2M per ton of decay isotope)

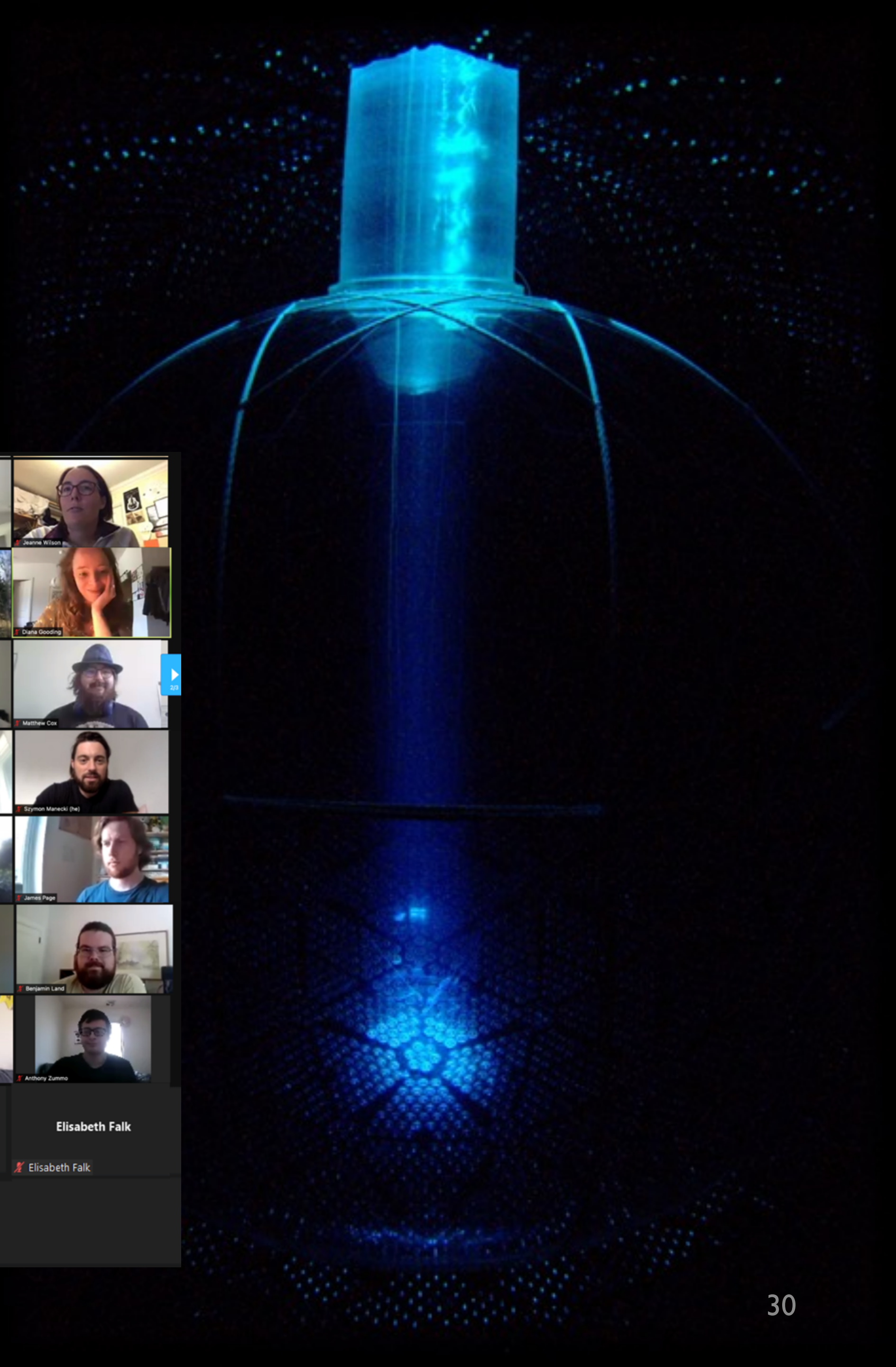
SNO+ Phase II



Thank You!

SNO+ Collaboration 2021





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