Snoplus: Recent results and status

NSD Staff Meeting

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21 September 2021

Snoplus Group at Berkeley

Group Lead

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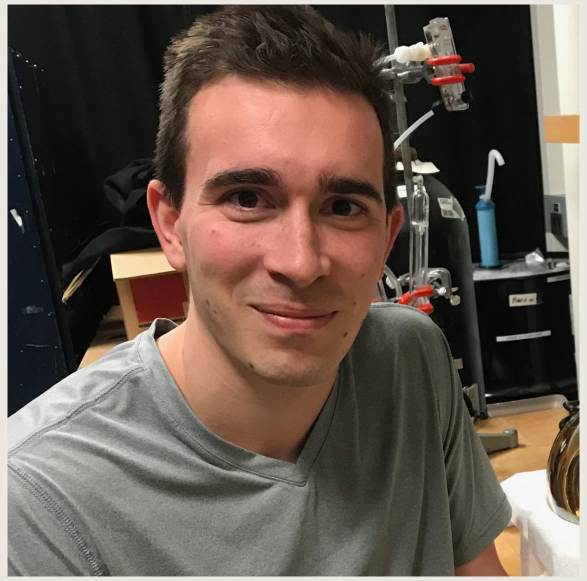
https://underground.physics.berkeley.edu/

Postdocs

Morgan Askins

Tanner Kaptanoglu



Graduate Students

Ed Callaghan

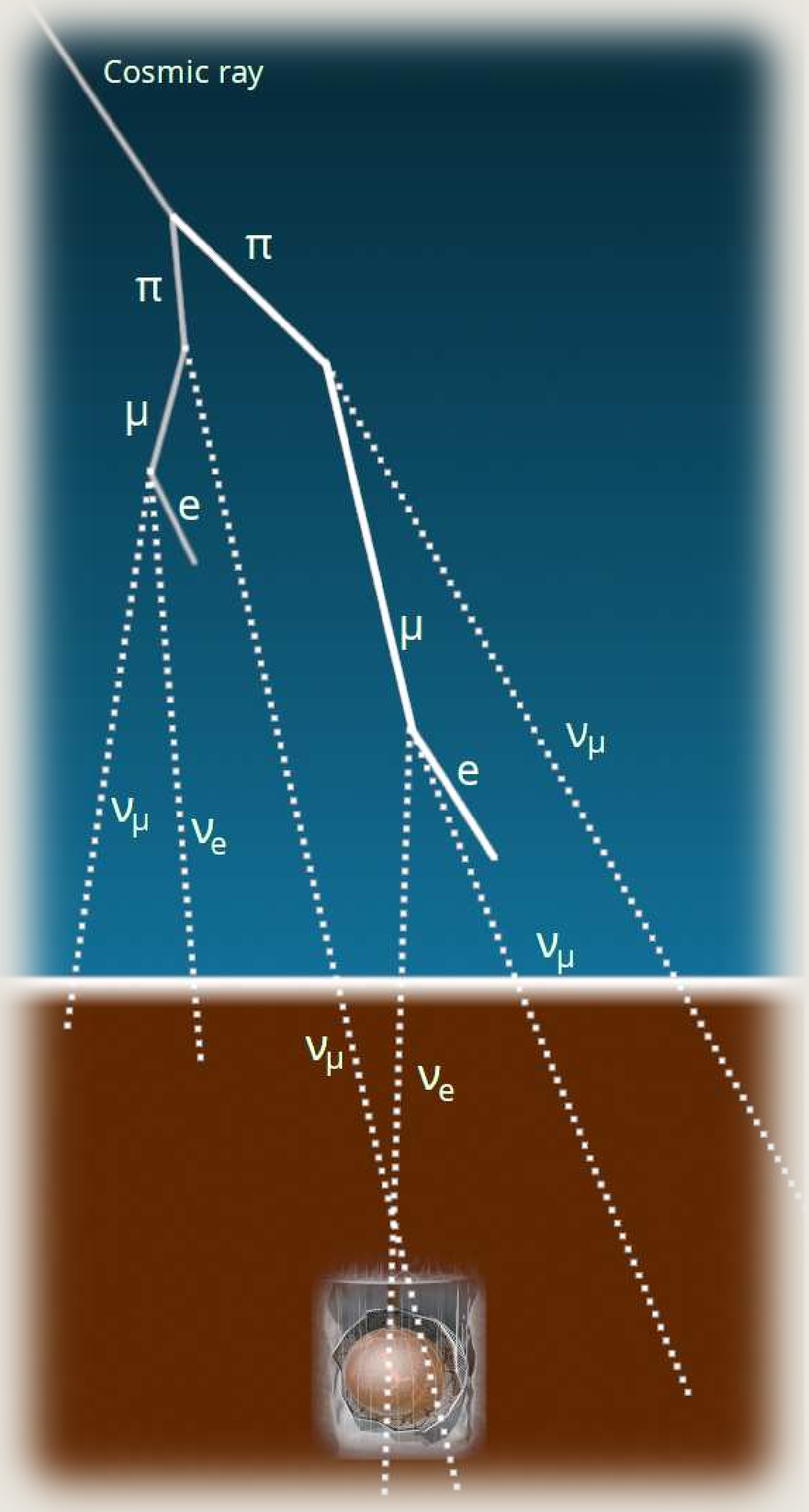
Max Smiley

Snoplus Detector

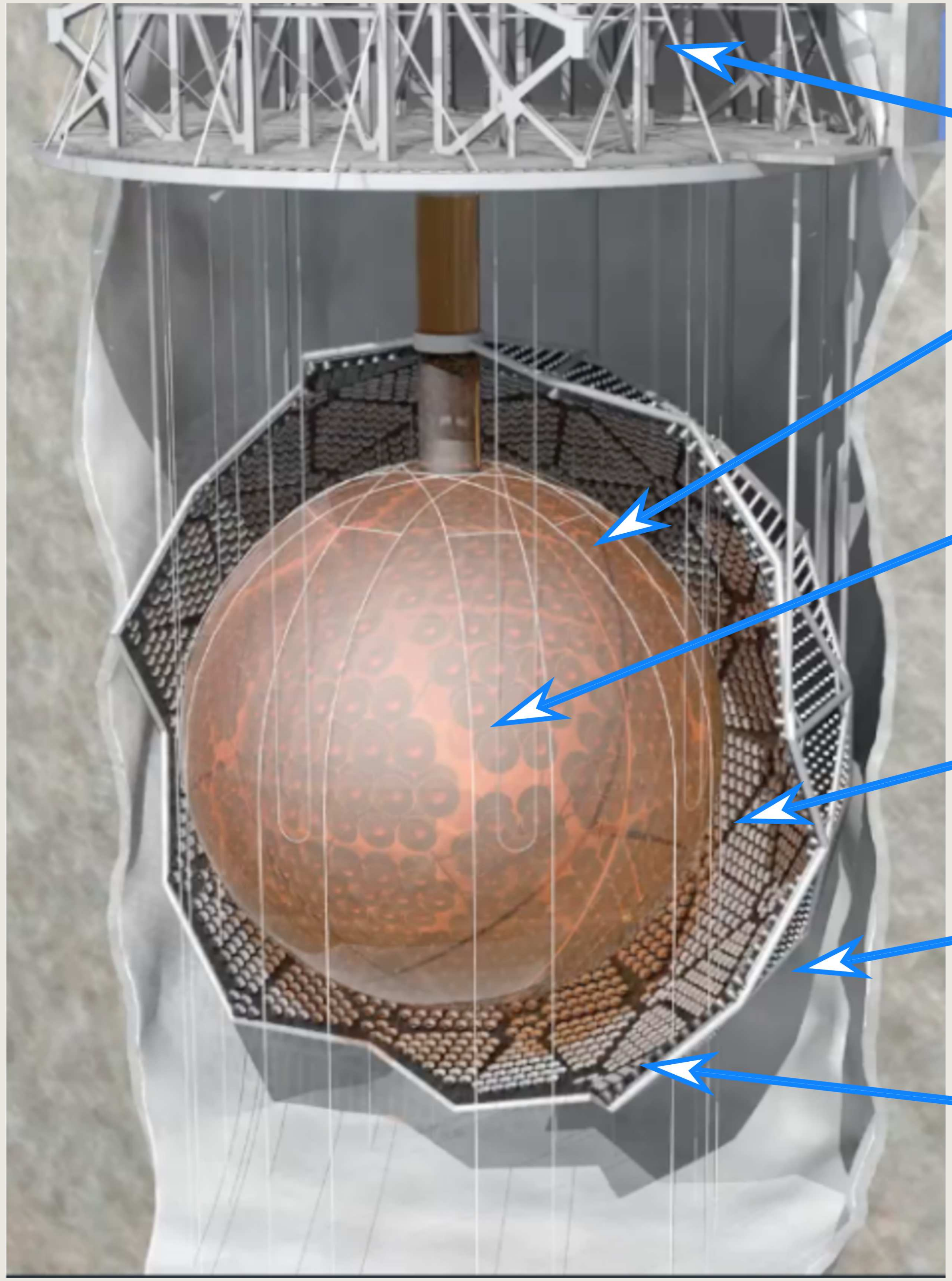
Located deep underground in Sudbury, Ontario at SNOLab, the SNO+ detector is an upgrade to the SNO detector, designed to explore many neutrino-related physics topics, and ultimately search for neutrino-less double beta decay.

- → Modern underground lab provides high levels of cleanliness
- → 6800 ft. overburden significantly reduces muon flux—ideal for rare event searches.

Full detector details:
JINST 16 (2021) 08, P08059



Snoplus Detector



Overburden: 6800 ft. (5890 m.w.e.)

Acrylic Vessel (12 m Diameter)

$\begin{cases} \text{905 Tonnes } H_2O \text{ (phase I)} \\ \text{780 Tonnes Te-doped Scintillator (phase II)} \end{cases}$

1700 Tonnes H_2O Inner Buffer

5700 Tonnes H_2O Outer Buffer

$\sim$9300 PMTs

SNO+ Physics Goals

→ Water Phase

- Search for invisible nucleon decay
- Measure ^{8}B solar ν flux
- Characterize backgrounds from detector components
- Measure neutron capture cross-section in water

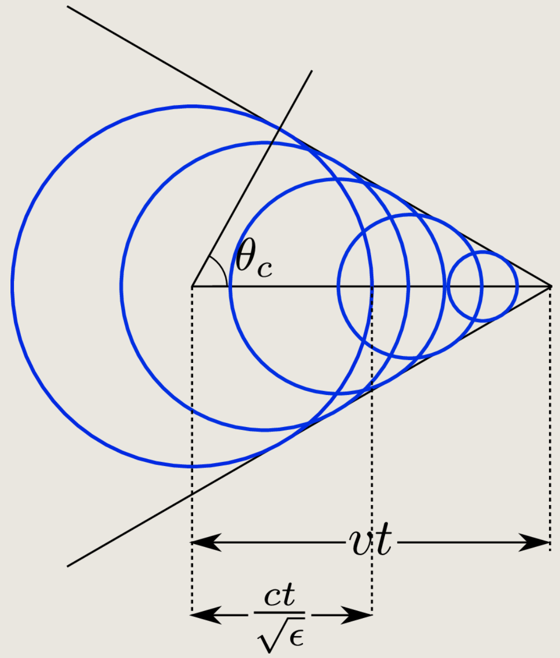
→ Pure Scintillator Phase

- Measure reactor and geo $\bar{\nu}_e$
- Ready to handle supernova burst measurements
- Characterize scintillator backgrounds
- Precision solar ν measurements
- Demonstration of directionality in liquid scintillator

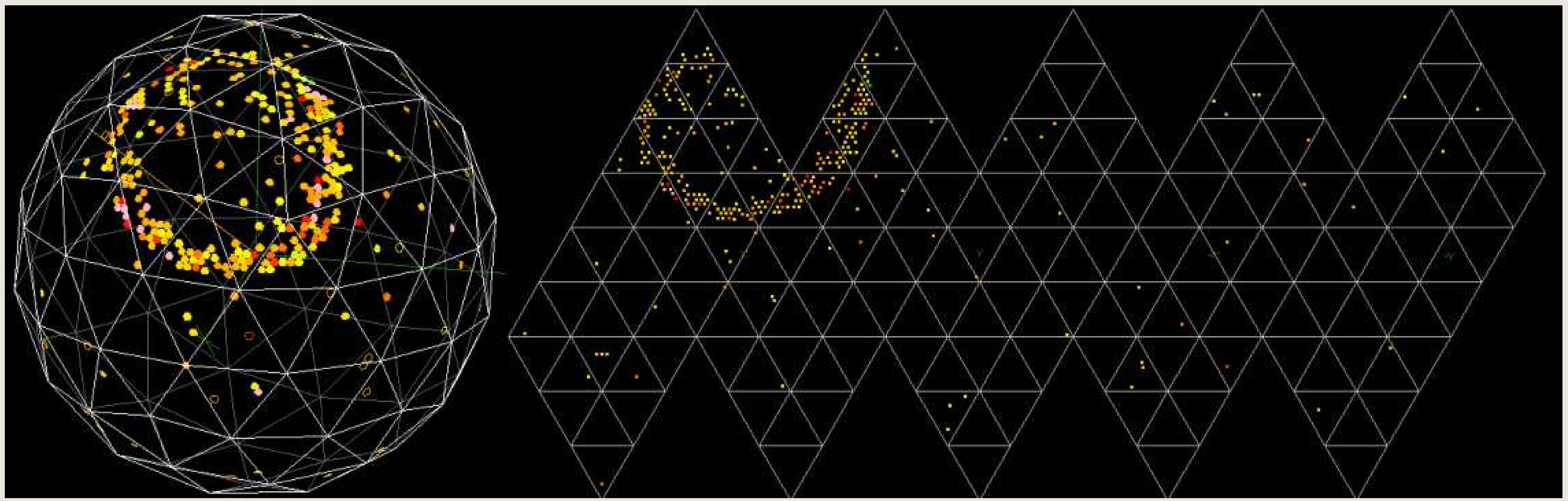
→ Te-loaded Scintillator Phase

- Search for neutrinoless double beta decay
- Continuation of pure scintillator physics

Water Phase

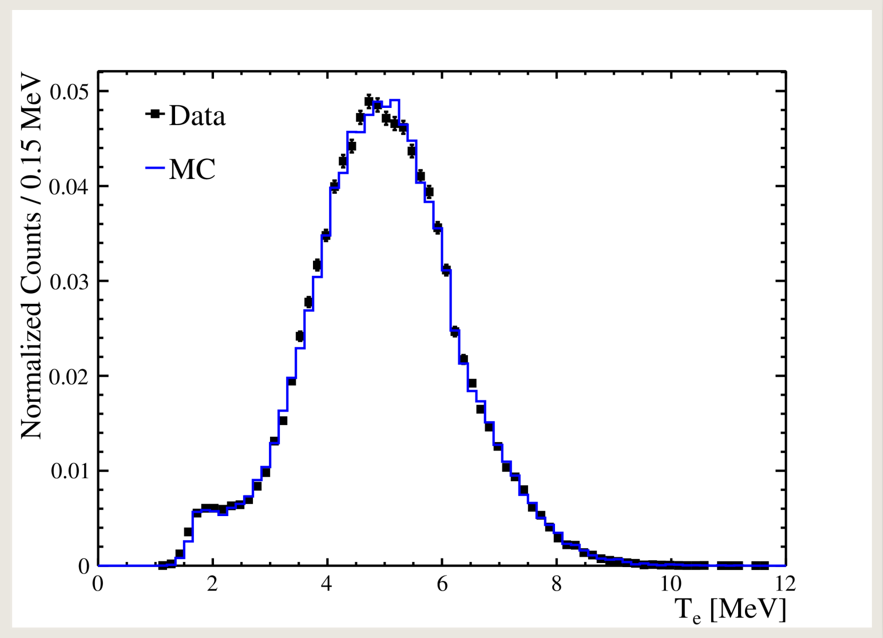


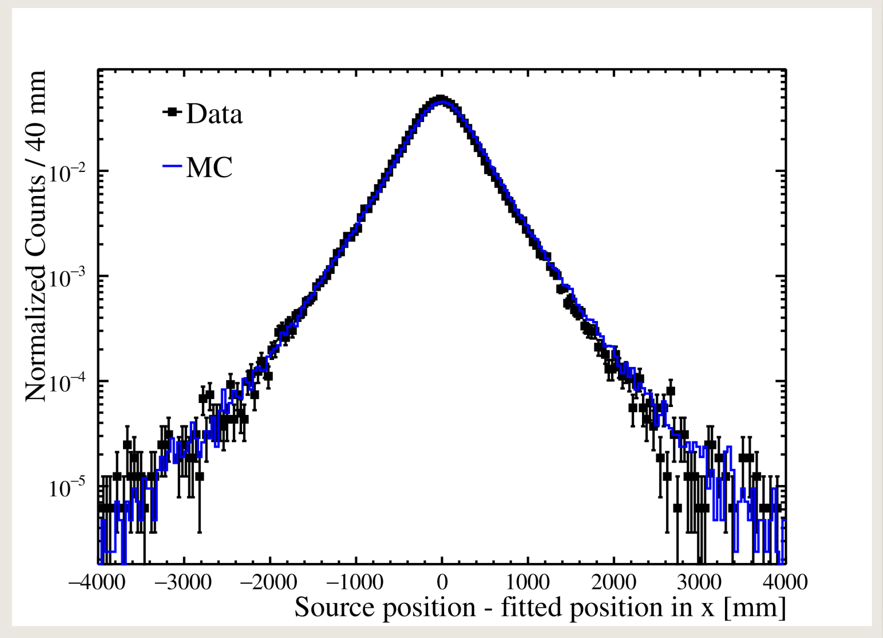
→ Water phase used for detector commissioning, as well as physics data taking.
→ Light emission only through Cherenkov radiation.
→ Cherenkov provides directional information useful for solar ν.
→ Energy resolution is statistically limited by low light output.

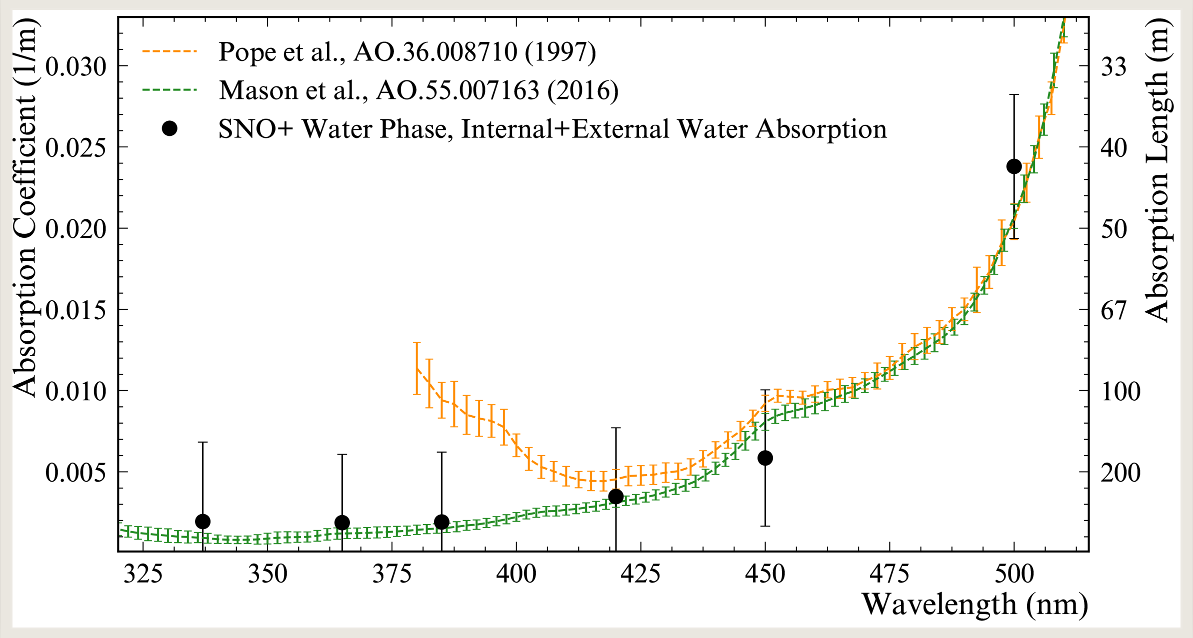


Water phase calibration

Tagged ^{16}N source used for reconstruction calibration and evaluation of systematics.



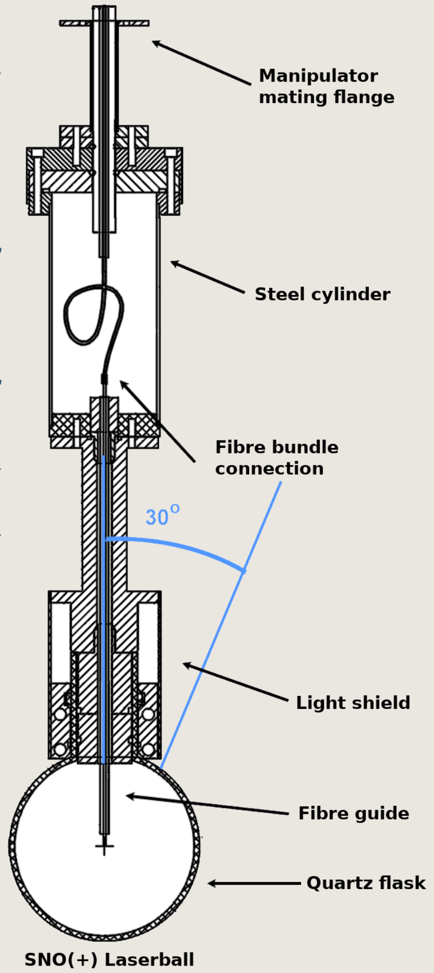




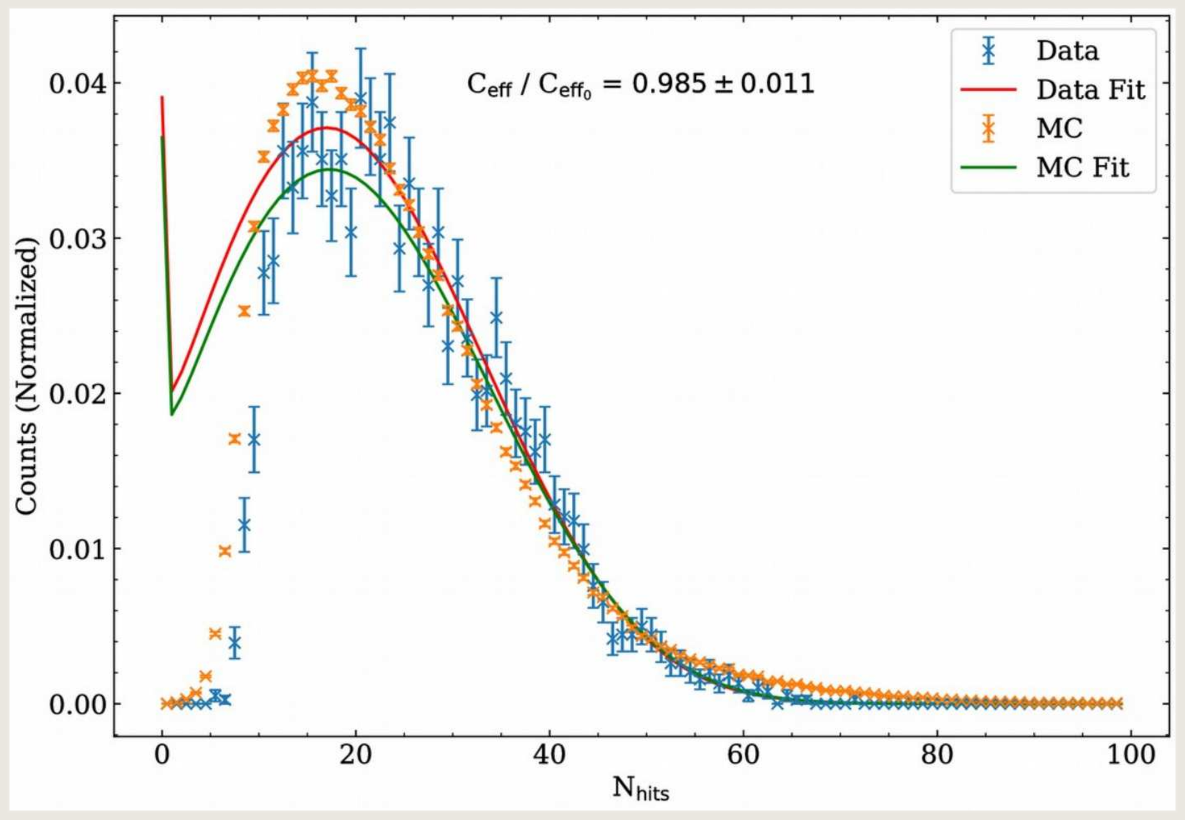
Optical Properties measured via an in-situ laser diffusion sphere.

Attenuation of the water and acrylic vessel, as well as the PMT angular response measured and verified with a deployed ^{16}N source.

arxiv:2106.03951

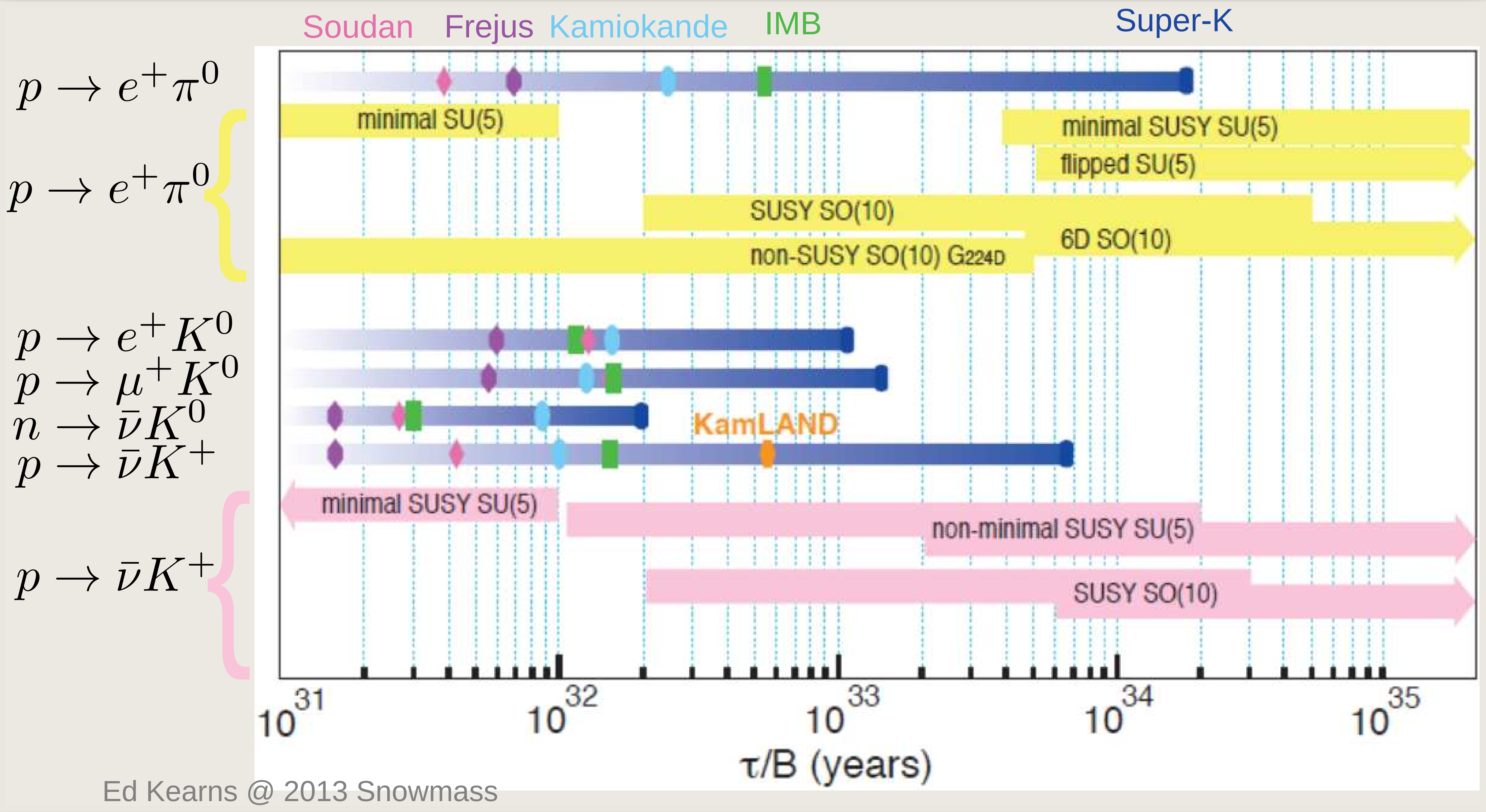


Pure Cherenkov light source developed by Berkeley, using ^{8}Li β-decays to produce light directly in an acrylic sphere.



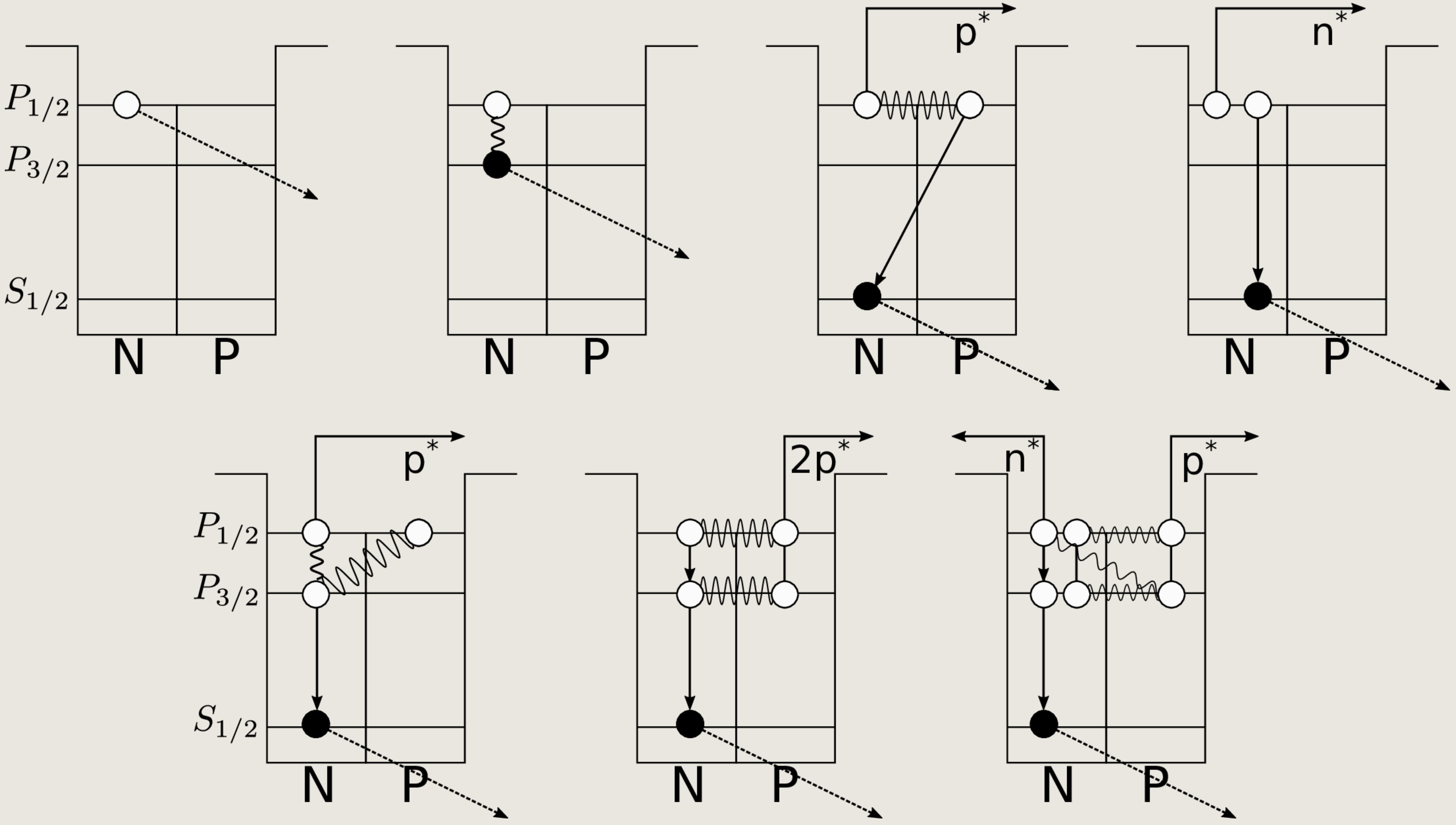
Nucleon Decay

The search for nucleon decay (particularly on free protons) has been the motivation for many large experiments.



Invisible Modes in SNO+

Deexcitation Mode of Neutron Hole in ^{15}N



Proton Decay

$^{16}O \rightarrow ^{15}N^{*}$

3%: 9.93 MeV γ

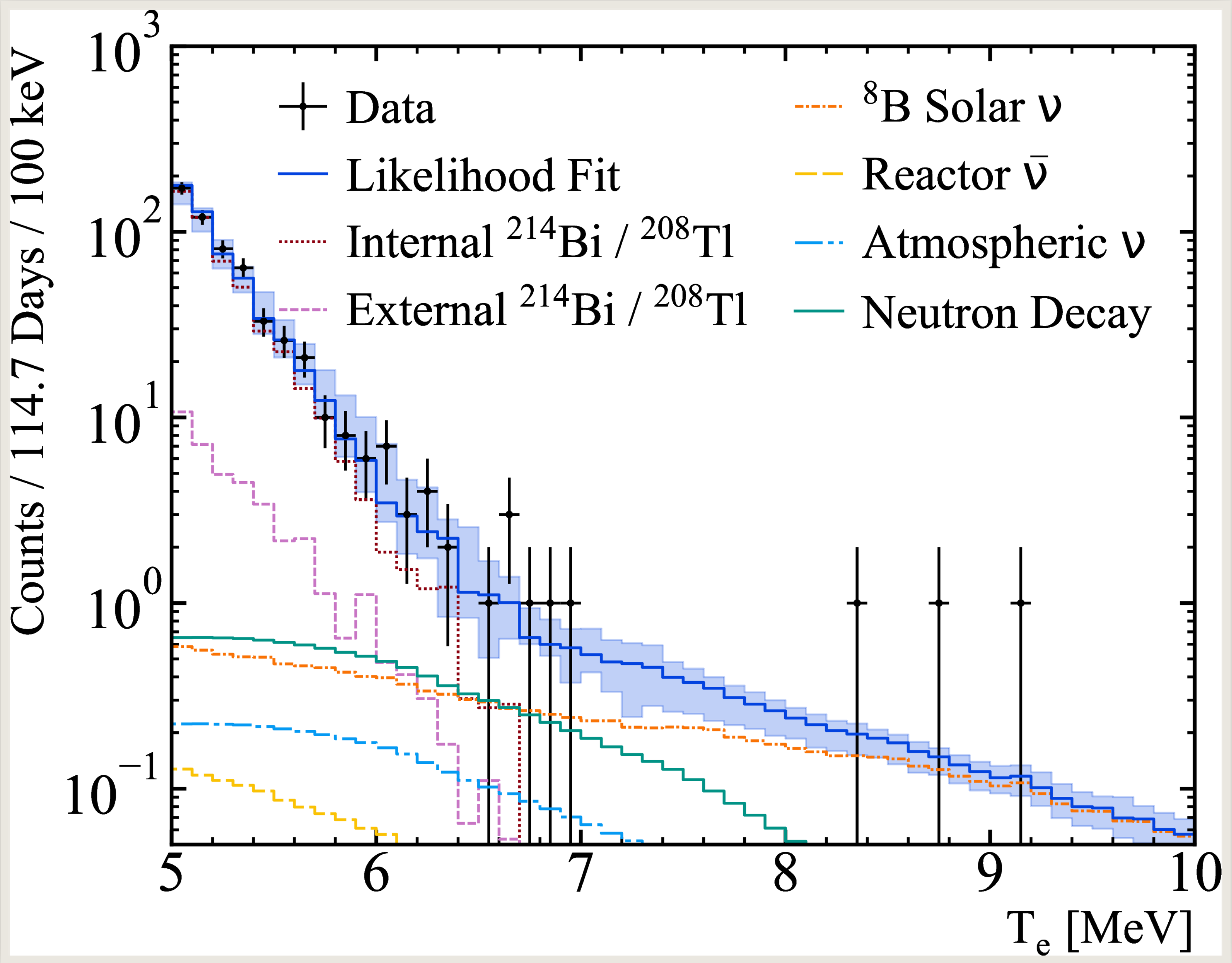
41%: 6.32 MeV γ

Neutron Decay

$^{16}O \rightarrow ^{15}O^{*}$

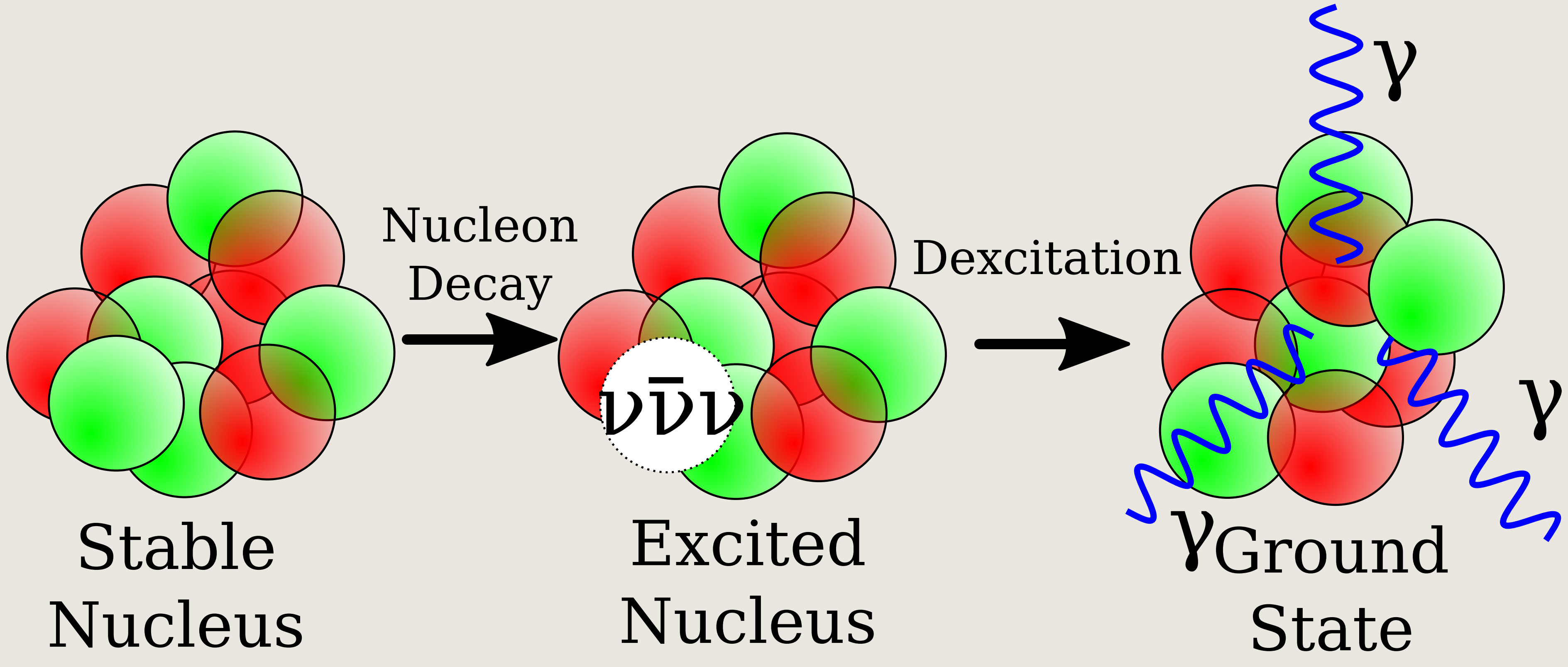
44%: 6.18 MeV γ

First Results: Invisible Nucleon Decay



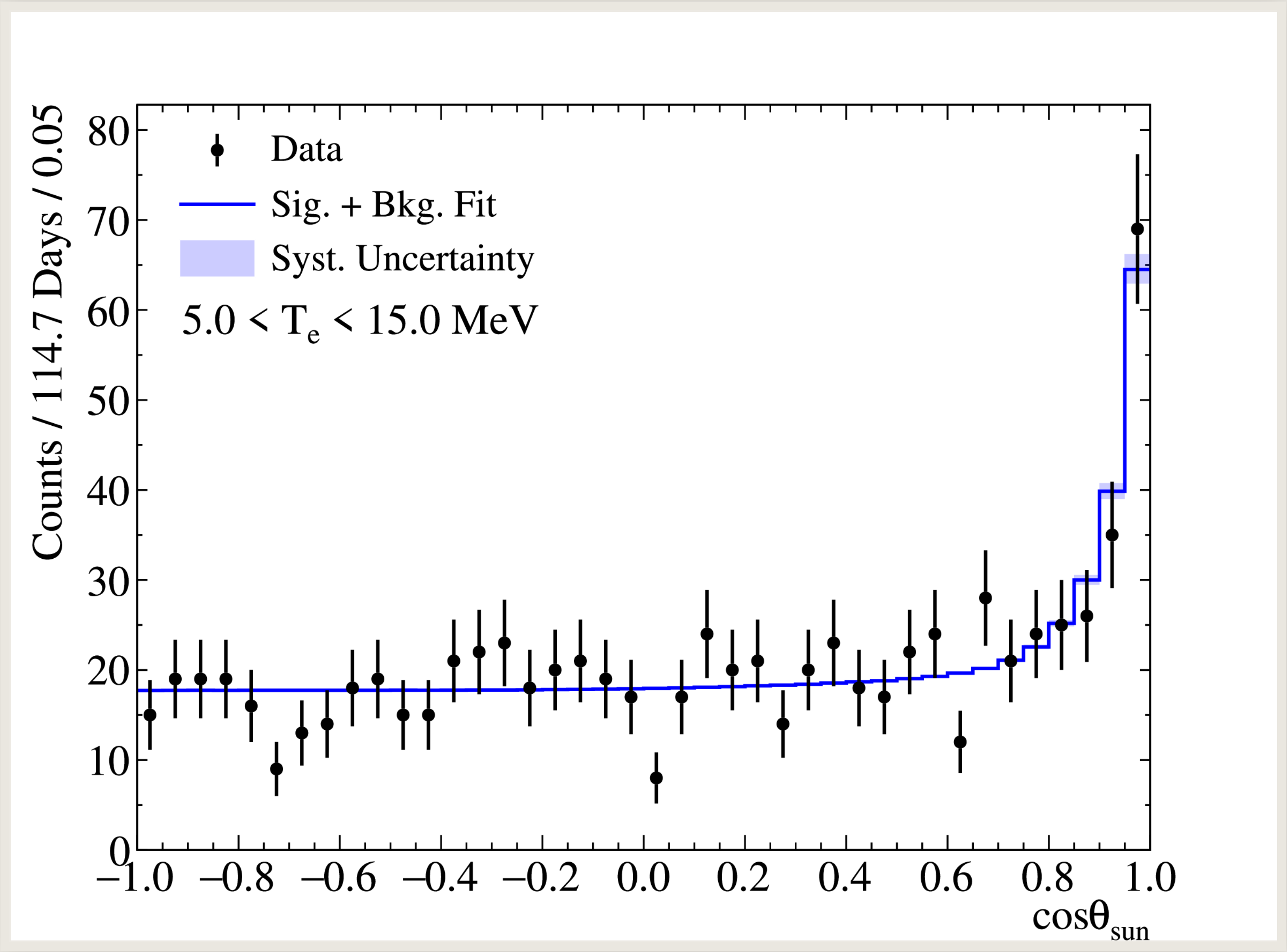
Phys. Rev. D 99 (2019) 3, 032008

Decay Mode	Partial Lifetime
n	2.5×10^{29}
p	3.6×10^{29}
pp	4.7×10^{28}
pn	2.6×10^{28}
nn	1.3×10^{28}



First Results: Solar Flux

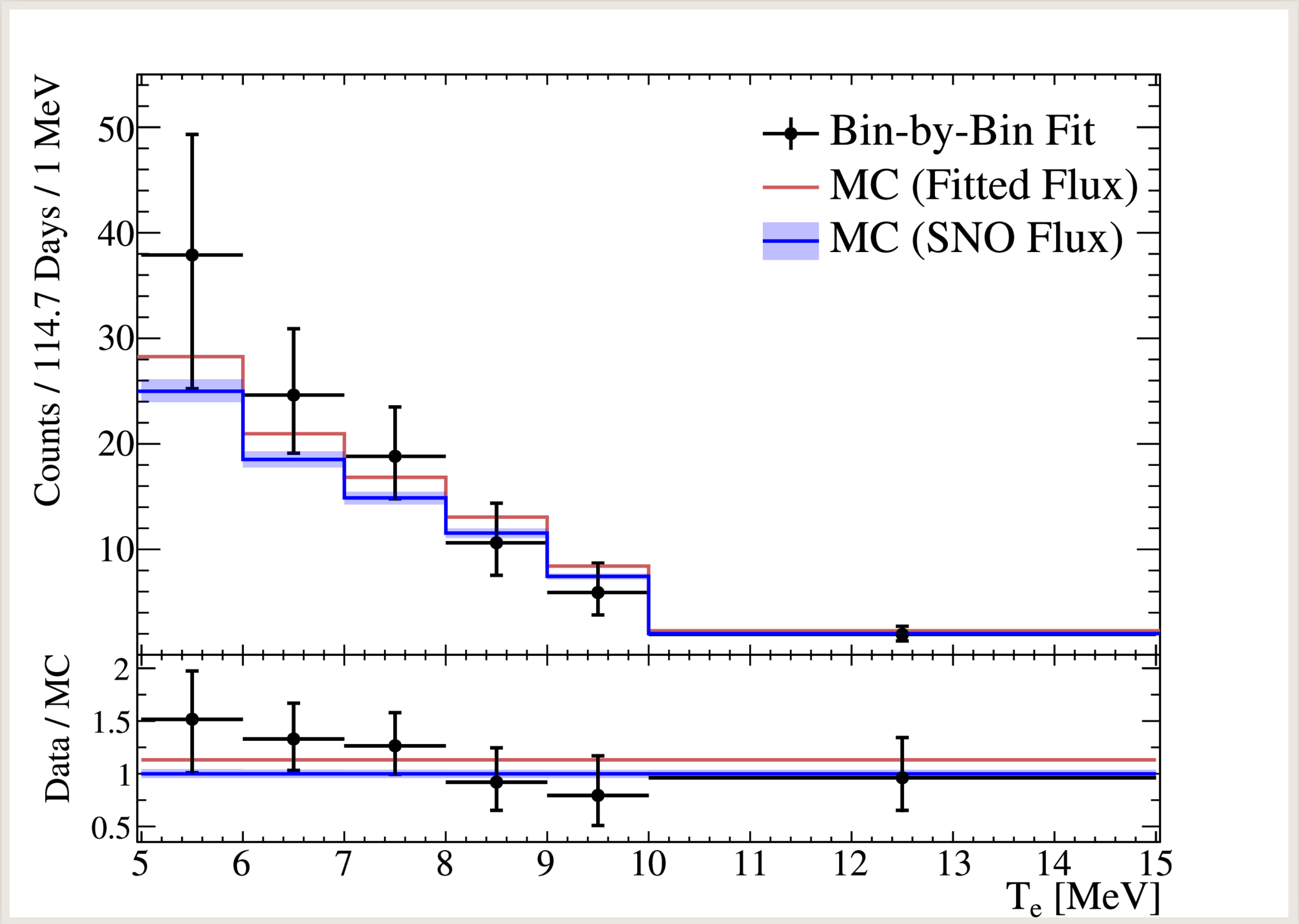
Event direction in water shows clear evidence for solar neutrinos on top of a flat background.



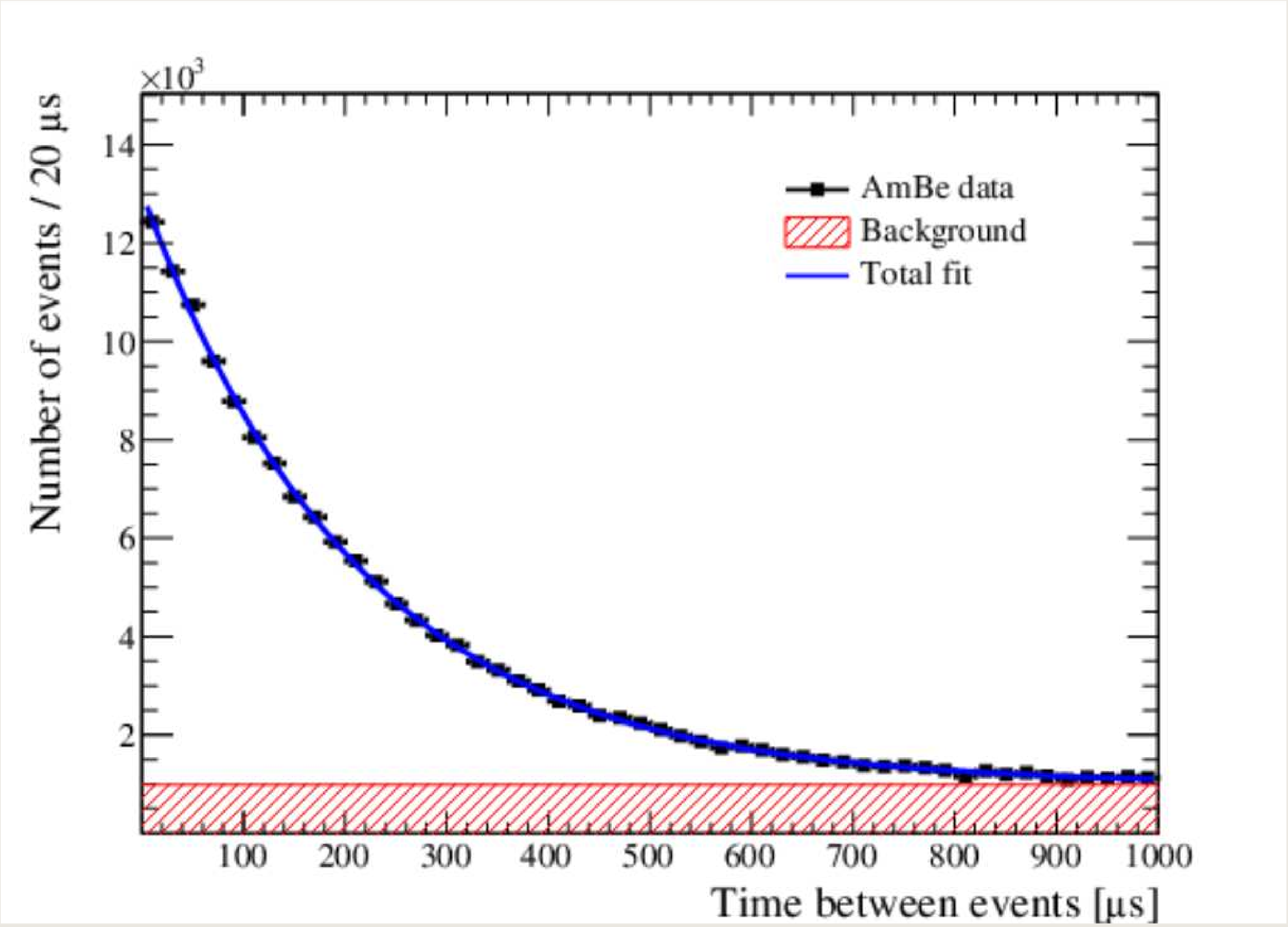
Phys. Rev. D. 99 (2019) 1, 012012

Measured flux consistent with SNO and Super-K

$$\Phi_{^8\mathrm{B}} = 5.95^{0.75}_{-0.71}(\mathrm{stat})^{0.13}_{-0.10}(\mathrm{syst}) \times 10^6\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$



First Results: Neutron Capture



Phys. Rev. C. 102 (2020) 1, 014002

Measurement of thermal neutron-proton capture cross-section with high detection efficiency in pure water.

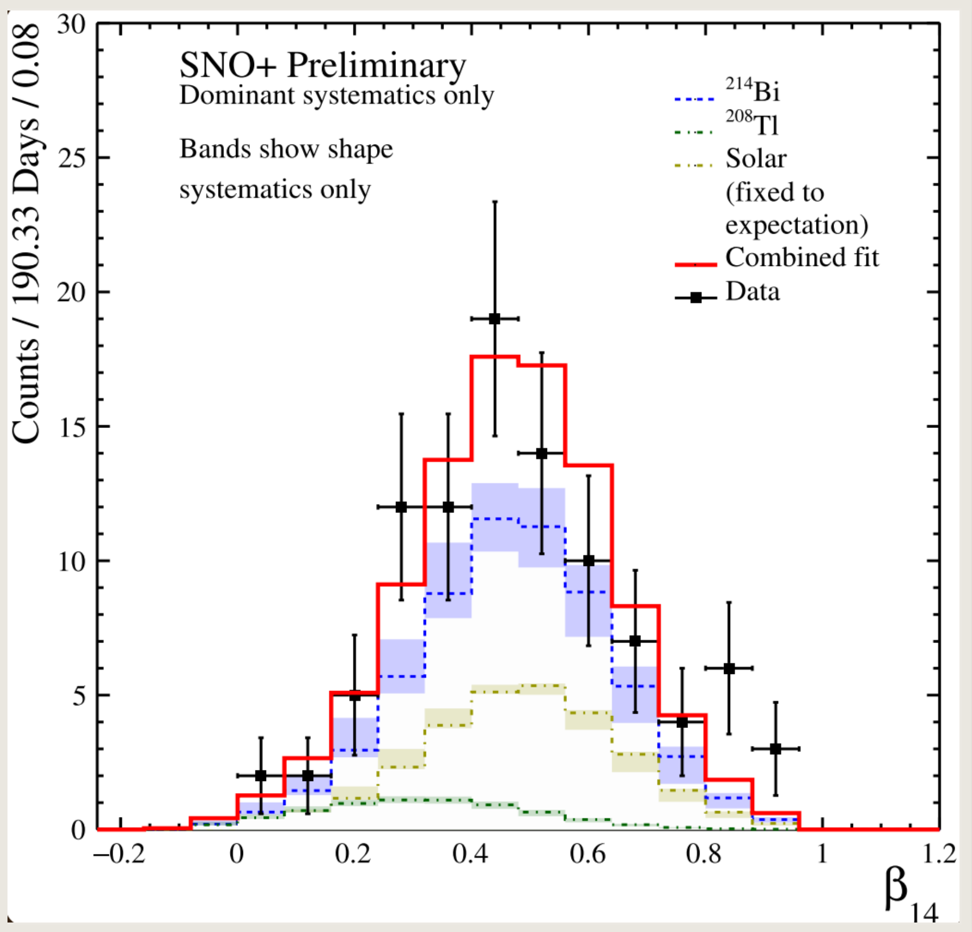
Efficiency [%]	$\tau[\mu s]$
49.09 ± 0.39	$202.35^{+0.87}_{-0.76}$

With a thermal cross-section consistent with dedicated experiments

$$\sigma_H = 336.3^{+1.2}_{-1.5}\ \text{mb}$$

Imminent water results

New low-background dataset triples the total livetime and greatly improves sensitivity due to decrease internal backgrounds.



	gU/gH$_2$O	gTh/gH$_2$O
Dataset I	$(3.6 \pm 0.9^{+1.0}_{-0.7}) \times 10^{-14}$	$< 1.3 \times 10^{-14}$(95%CL)
Dataset II	$(3.2 \pm 0.7^{+1.1}_{-0.9}) \times 10^{-15}$	$< 1.1 \times 10^{-15}$(95%CL)

→ † Improved sensitivity to invisible nucleon decay.

→ † Measurement of reactor antineutrinos.

→ Improved measurement of the solar ^{8}B flux.

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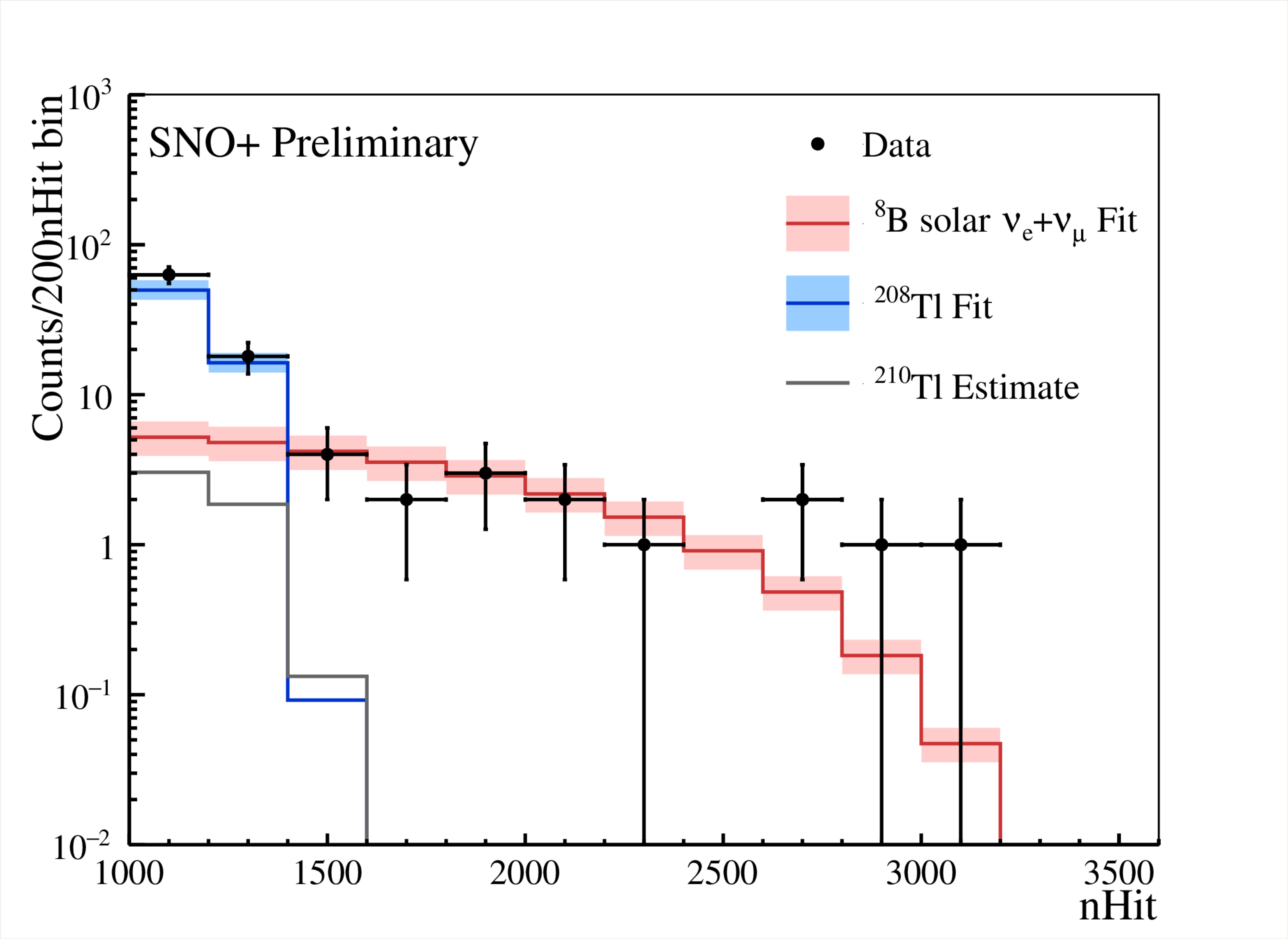
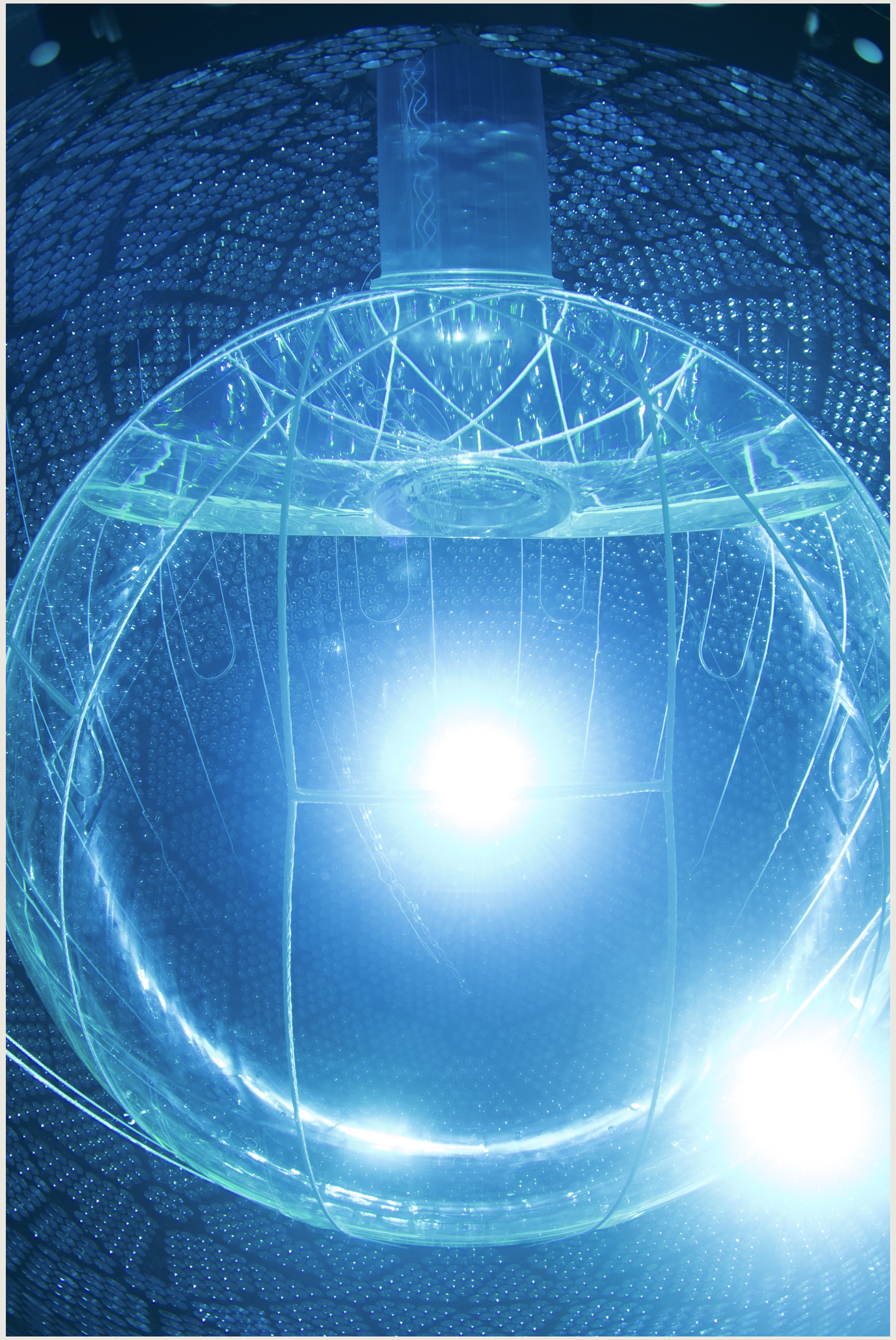
† *Berkeley lead efforts.*

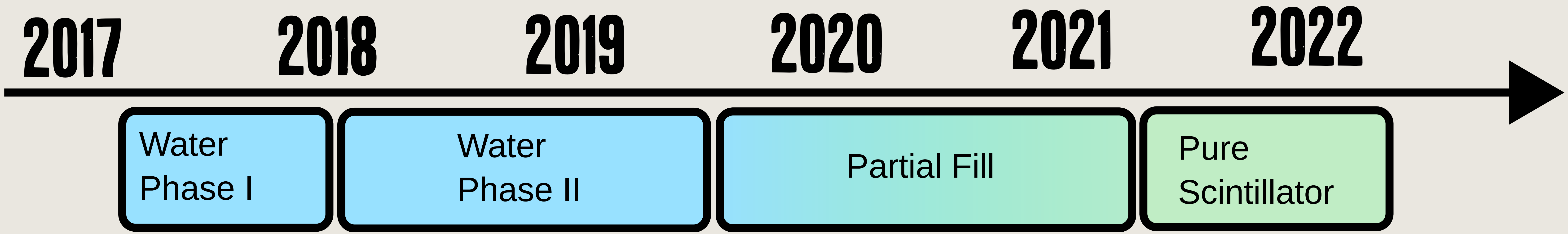
Partial-fill

Extended filling phase provided opportunity to test analysis methods prior to completing the detector. This included measurements of various internal backgrounds as well as ^{8}B solar neutrinos.





Status and Timeline

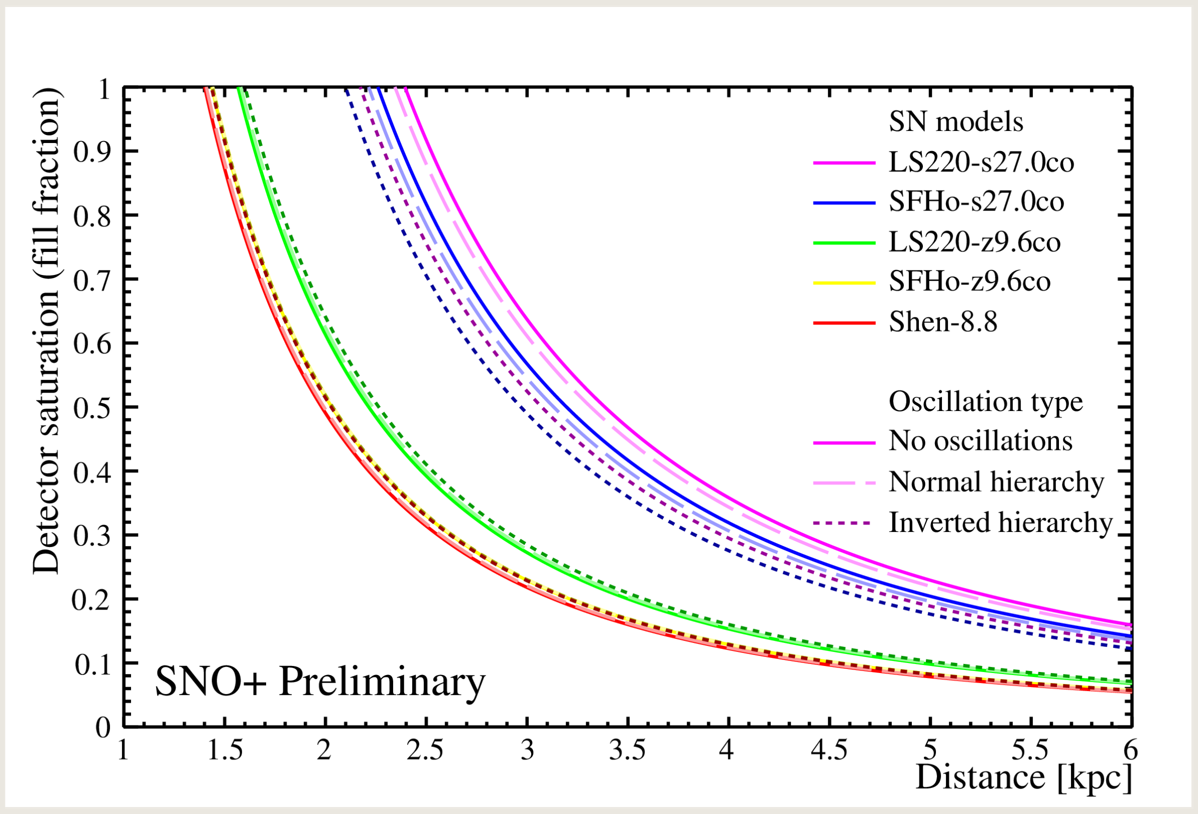


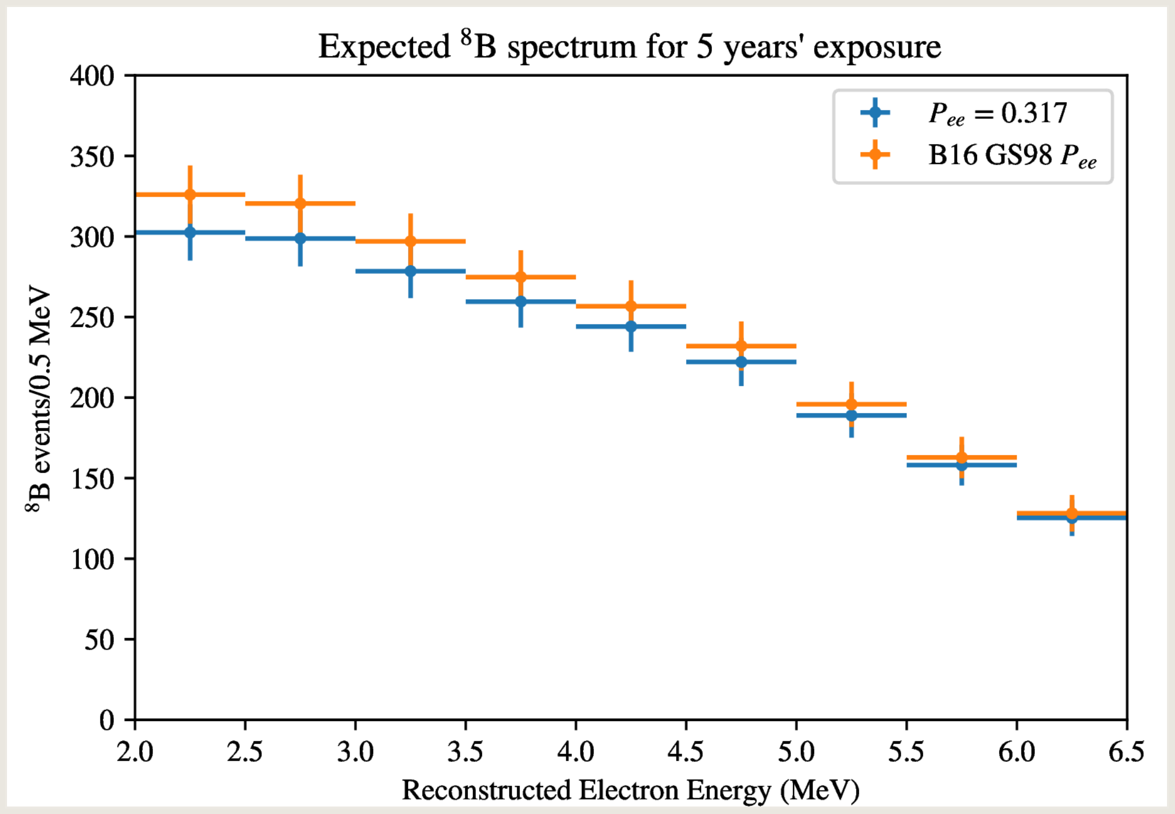
- Data from phase I water analyzed and published
- Phase II water data ready with papers under review
    - NEW: Nucleon Decay, Solar, and Reactor anti-neutrino results coming soon.
- Partial fill backgrounds analyzed to inform future analysis, understand the trigger system, and "practice" the final analysis
- Detector is currently completely filled with liquid scintillator. PPO is still being incrementally added to hit the target concentration.
- Tellurium is expected to be mixed into the detector in 2022, following a stable scintillator phase.

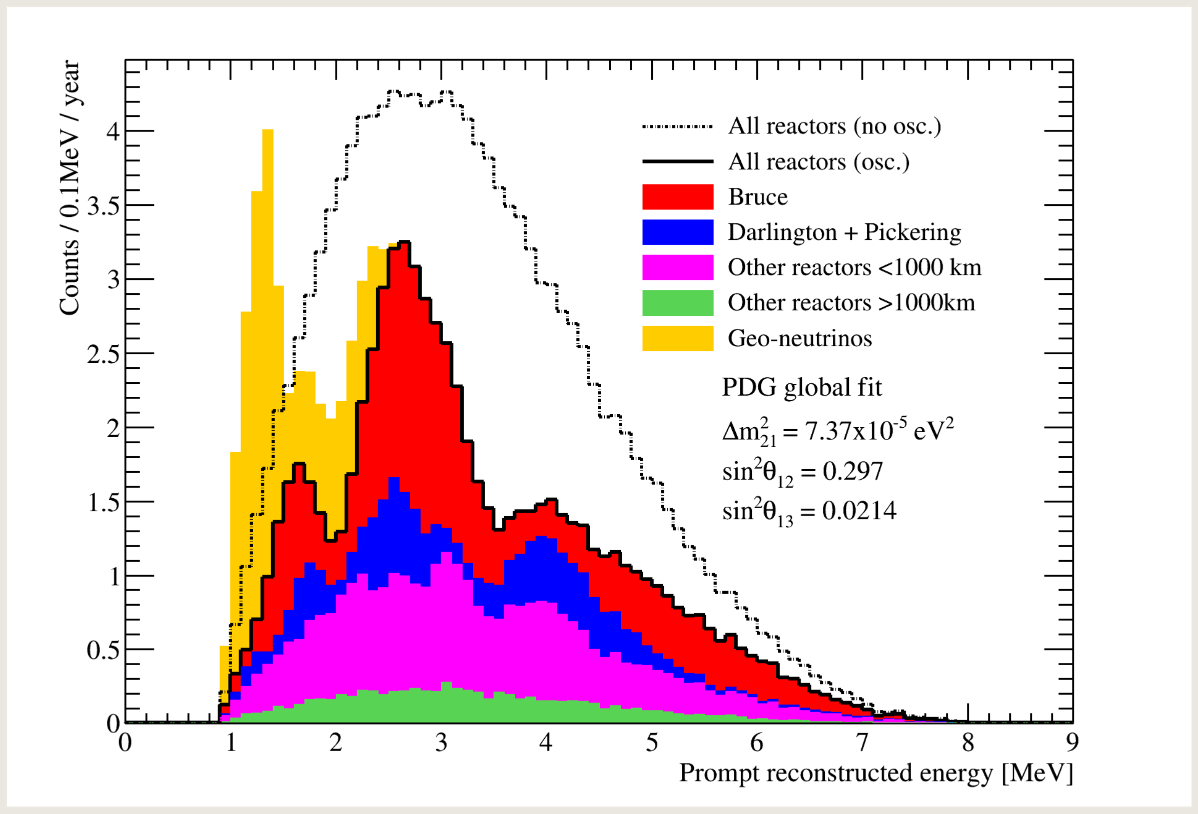
Full scintillator

Physics Program:

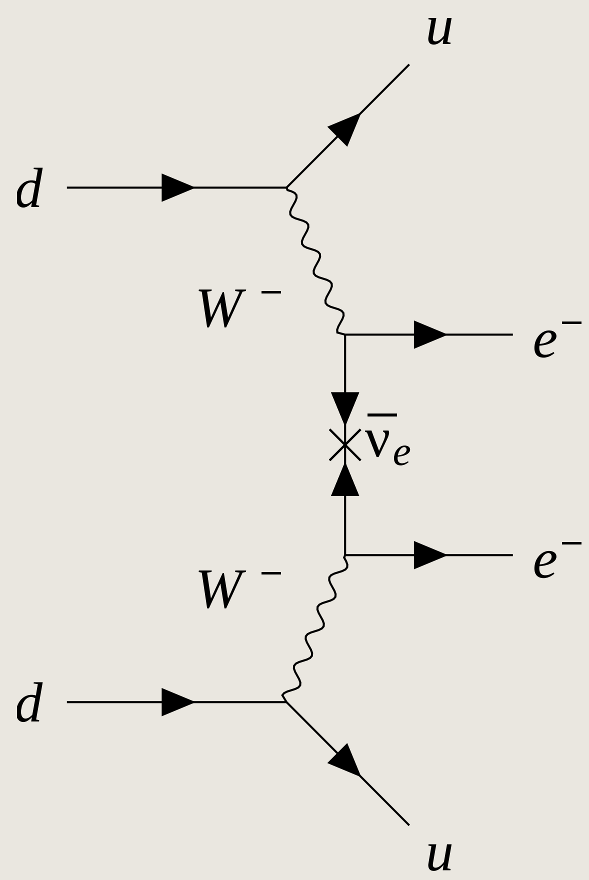
- → Supernova monitoring (join SNEWS)
- → Sensitivity to various solar neutrinos (background dependent)
- → Reactor and geoneutrino measurements



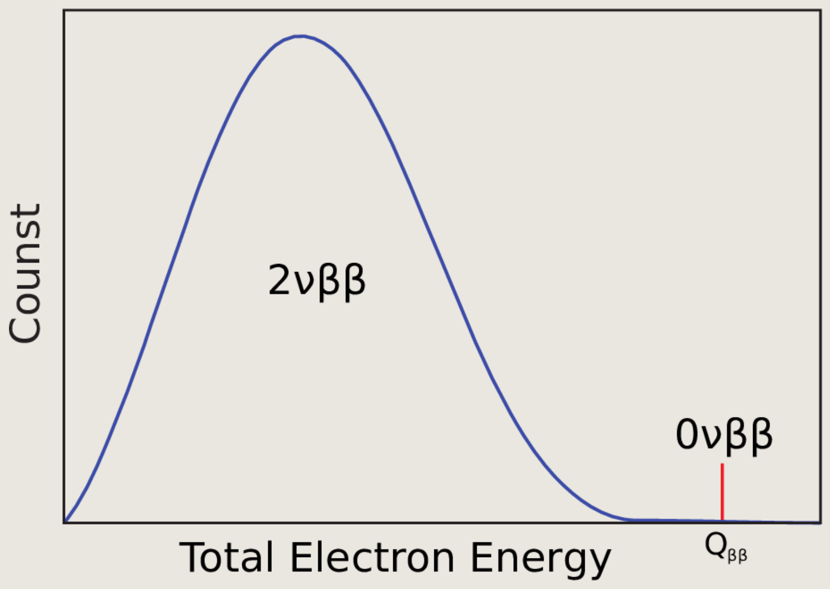


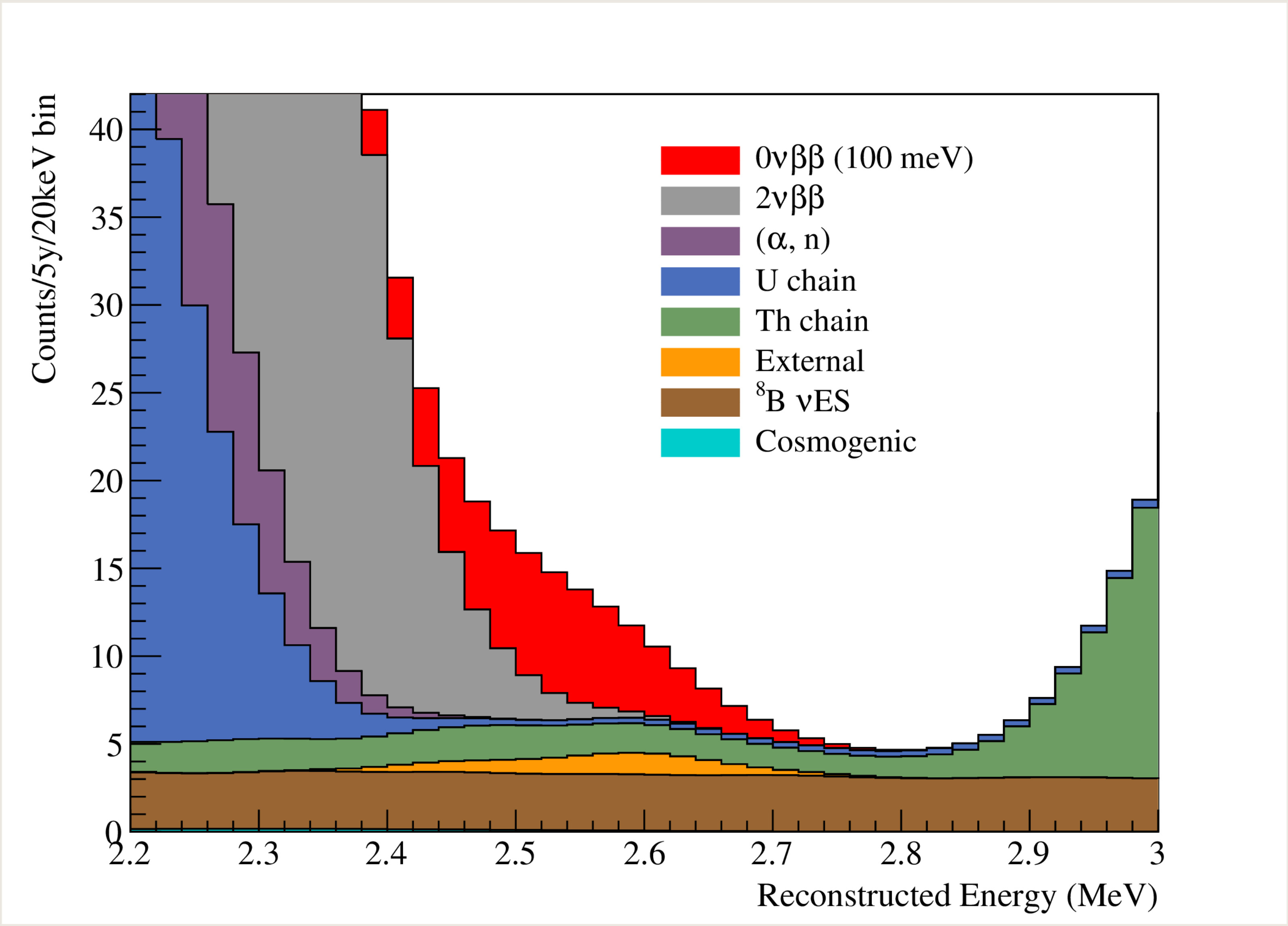


Primary Physics: $0\nu\beta\beta$

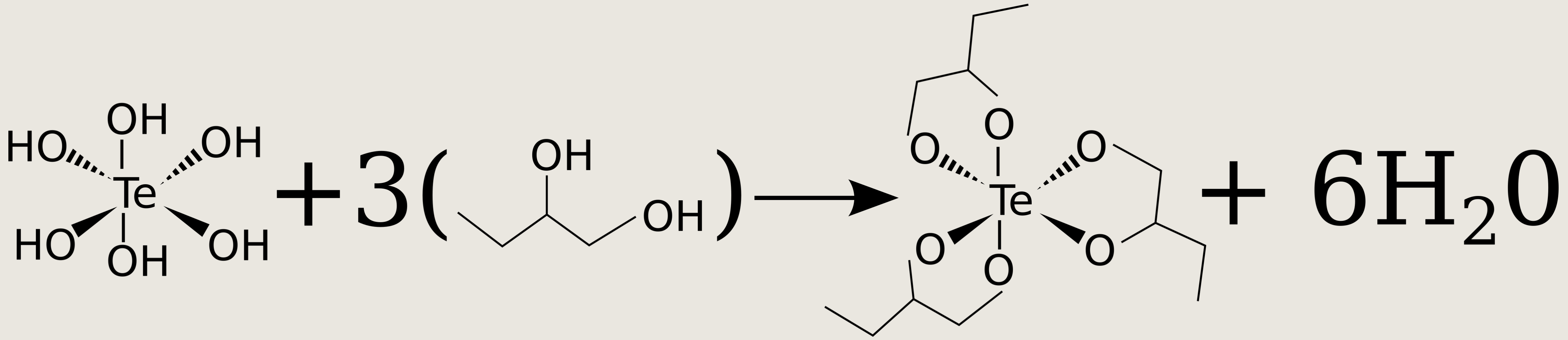


With a 2.6 MeV endpoint, the $0\nu\beta\beta$ signal sits in a region of well known backgrounds that can be supressed through fiducialization and constrained via sideband analyses.





Te-Loading

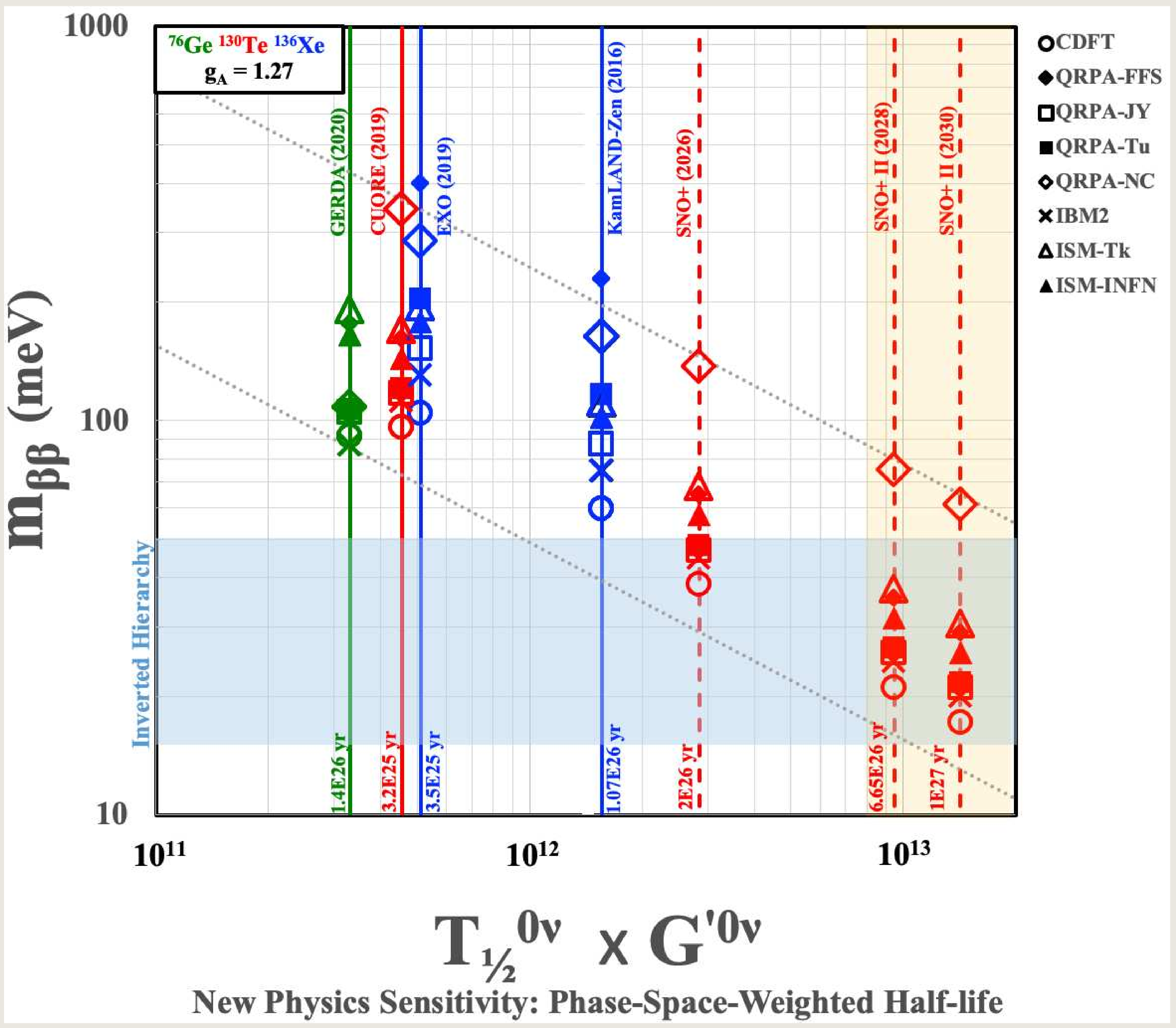


Telluric Acid   Butanediol   TeDiol

- → Scintillator consists of Linear alkyl benzene (LAB) + 2 g/l PPO.
- → Telluric acid dissolved into the scintillator using Butanediol.
- → High optical transparentcy and 50 times more light compared with water.
- → Initial loading of 0.5% natural Te by mass.
- → Plant is constructed and preparing to fill in 2022.

$0\nu\beta\beta$ Prospects

- Counting analysis for 5 years in an optimized ROI:
  - Expected half-life sensitivity $\tau > 2 \times 10^{26}$ years
  - $m_{\beta\beta}$ range 37-89 meV (model dependent)
- More detailed spectral analysis should further constrain backgrounds and improve the signal sensitivity
- SNO+ technique is scalable
  - Increased loading up to 3% with good light yield and stability
  - Component upgrades



Conclusions

→ The SNO+ detector has completed water phase and completely filled the detector with liquid scintillator.

→ PPO additions are ongoing and Tellurium additions are scheduled 2020 (much of the delay and uncertainty related to limited access and scheduling due to COVID).

→ Final water analyses completing and beginning to take data for upcoming scintillator results.