SNO+
from water to scintillator

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Weak Interactions and Neutrinos 2019
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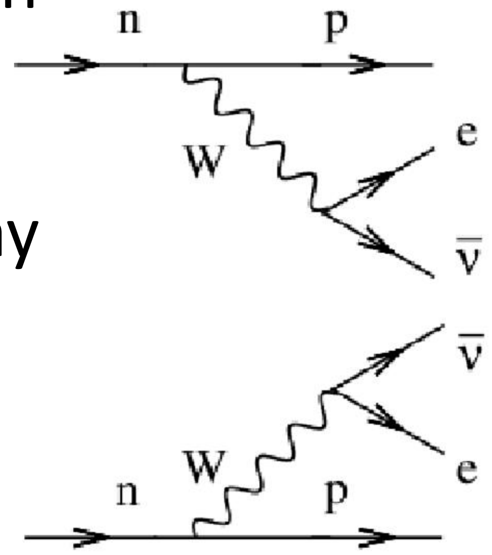
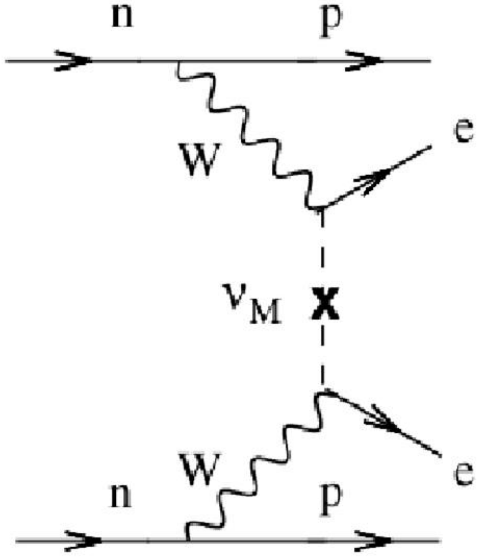
SNO+ UNIVERSITY OF ALBERTA

A matter/antimatter asymmetry search

- The neutrino could be a Majorana fermion
  - Only possible for neutral particles
  - Would be its own antiparticle
- Some isotopes undergo double beta decay
  - If the neutrino is Majorana, the decay can produce zero neutrinos
- $2\nu2\beta$ is rare; $0\nu2\beta$ would be even rarer. Detection requires to:
  - Achieve (and understand) very low background
  - Accurately determine detector response
  - Consider scalability of the technique



$2\nu2\beta$



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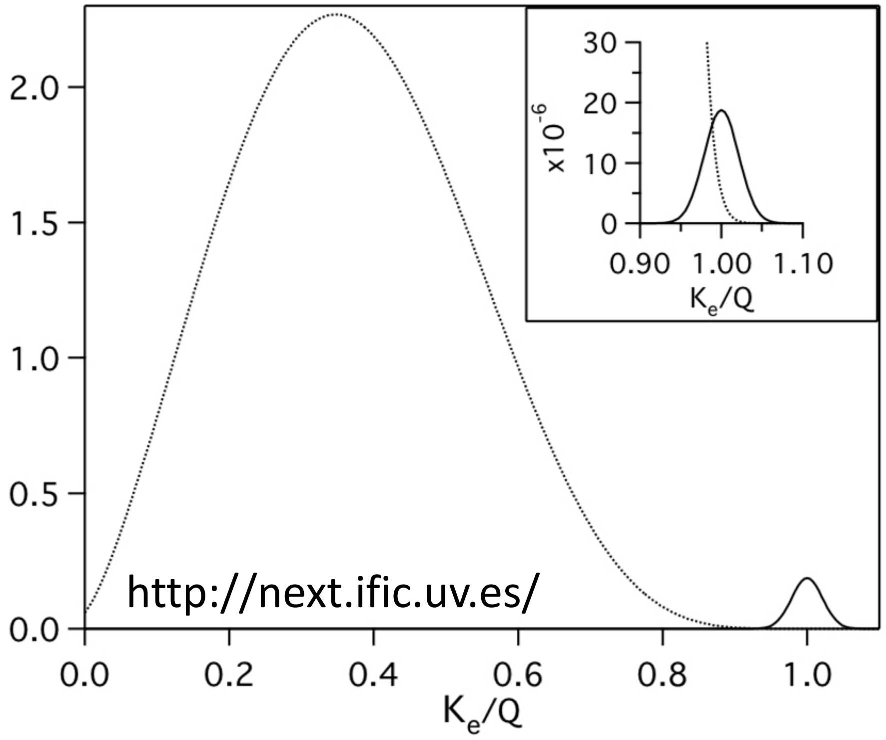
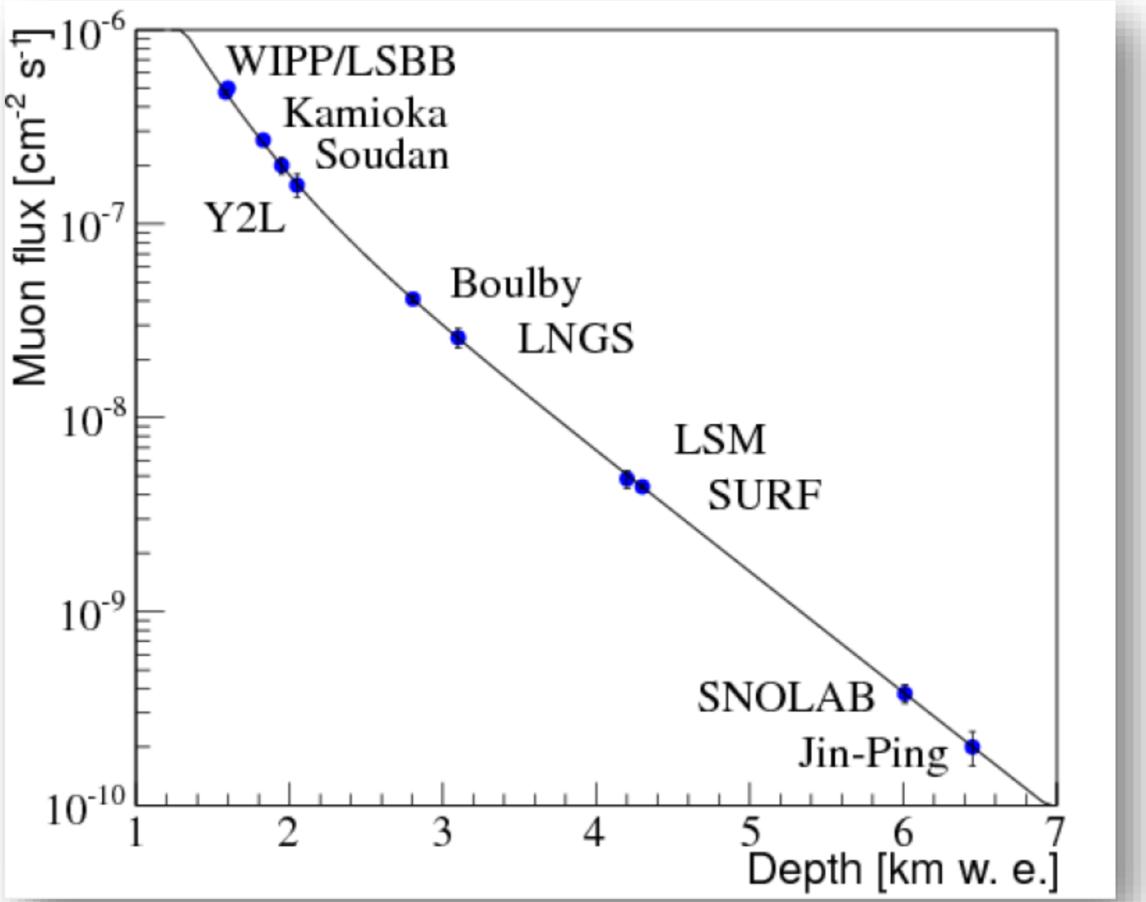


The SNO+ detector



- Very low background neutrino detector
- Located in SNOLAB
  - Sudbury, ON, Canada
- At a depth of 2km (rock, 5900 mwe)
  - About 63 cosmic muons/day

This Is What Life In The Happiest City In Canada Is Like

Welcome to Sudbury, Ontario.

Posted on April 28, 2015, at 10:10 a.m.

Amber Dowling
BuzzFeed Contributor

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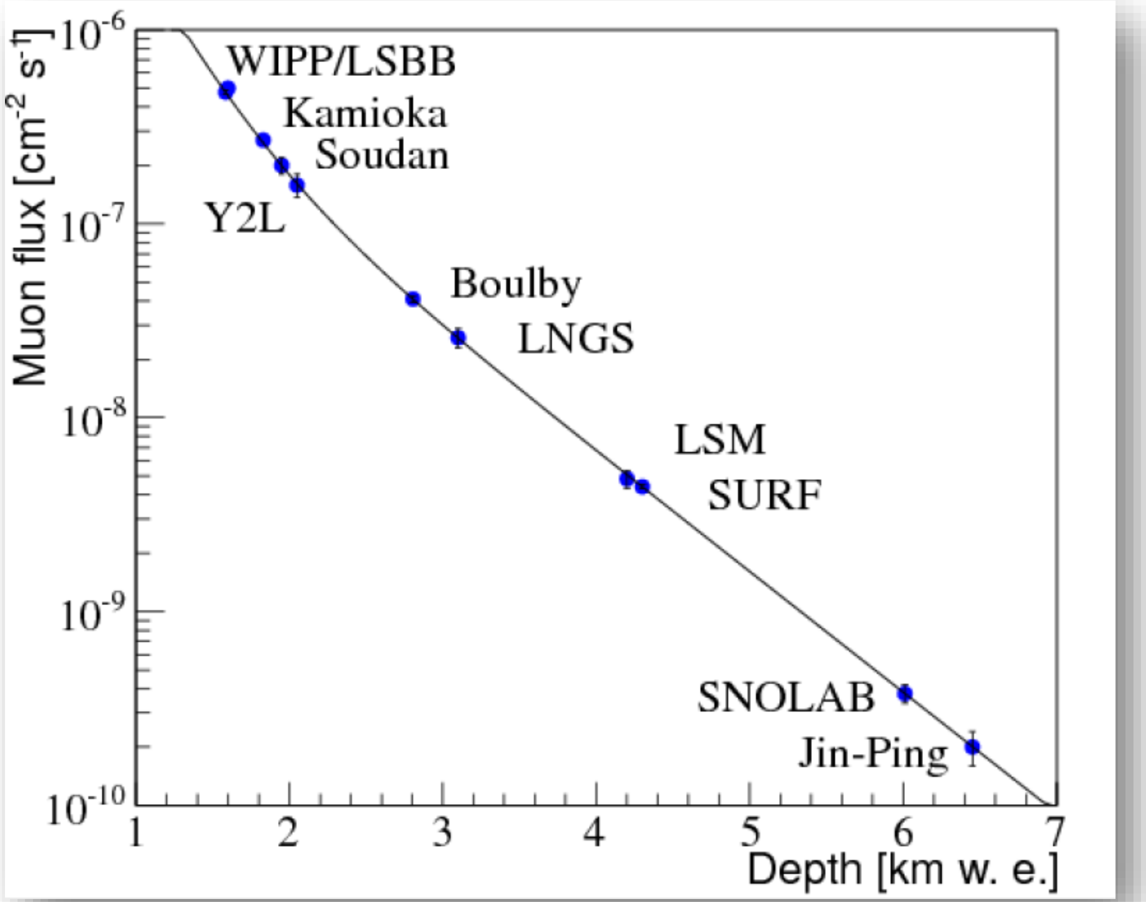

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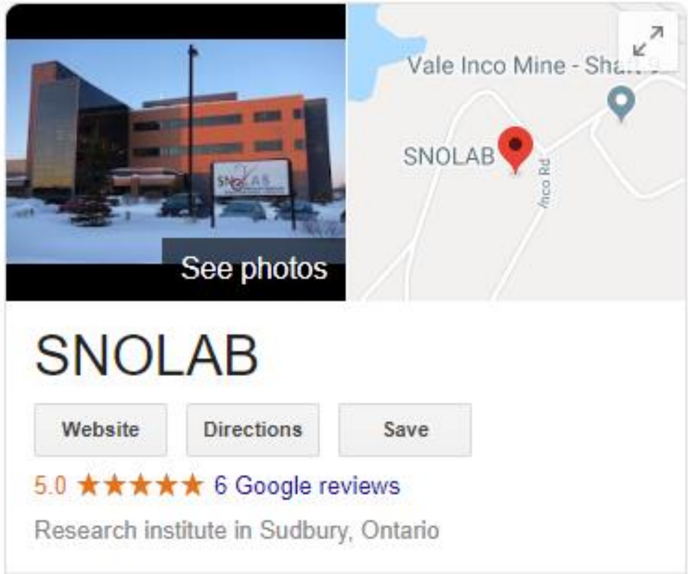
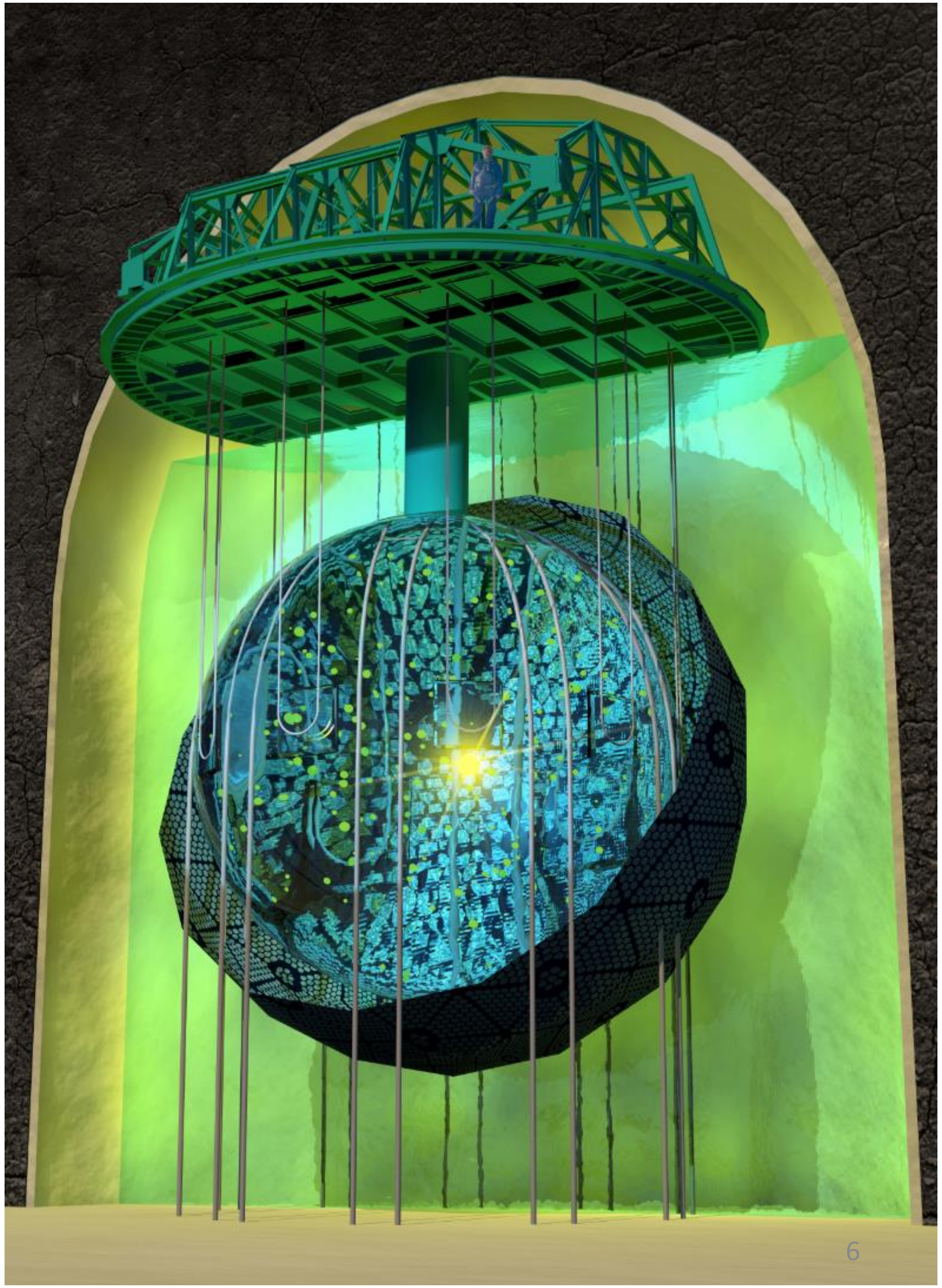


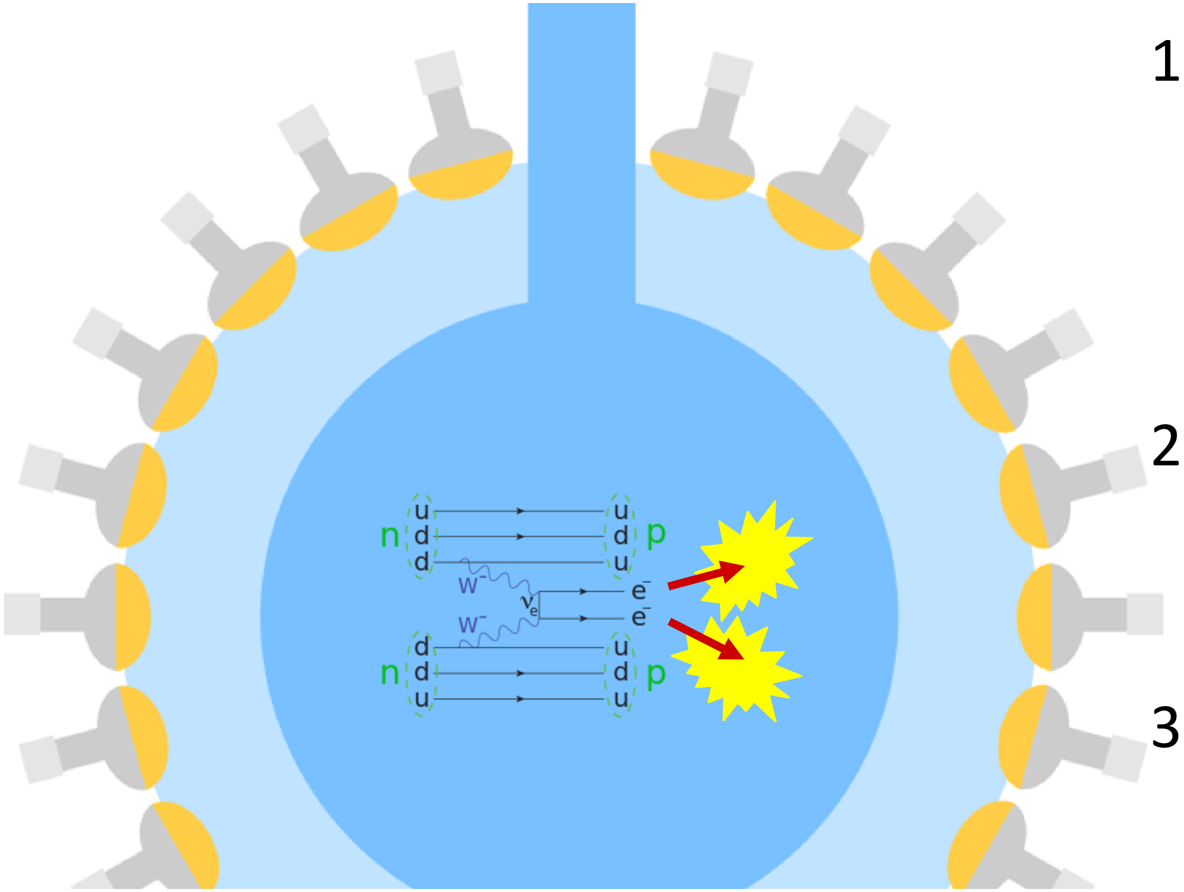
The SNO+ detector

- Detector itself is over 9000 PMTs monitoring an acrylic vessel
  - Mounted at 8.5m radius
  - 54% of photocoverage
  - Cavity is flooded with ultra-pure water

- Fiducial volume: spherical acrylic vessel
  - Radius of 6m
  - Held in place by tensylon rope systems
  - Access via neck at the top



Fiducial volume material



Material in vessel sets the physics goal

1. Ultra-pure water phase
   - Recording 7 hits/MeV deposited energy (Cherenkov)
   - Physics goals are nucleon decay, solar and reactor neutrinos
   - Understanding of detector optics and external backgrounds
2. Intermediate stage: scintillator
   - Estimated 500 hits/MeV deposited energy
   - Studies of solar, geo and reactor neutrinos
   - Understanding of scintillator backgrounds
3. Ultimate goal: Tellurium-loaded scintillator
   - Search for $0\nu2\beta$ in 130-Te (Q value 2.5 MeV)
   - Expect 400 hits/MeV deposited energy

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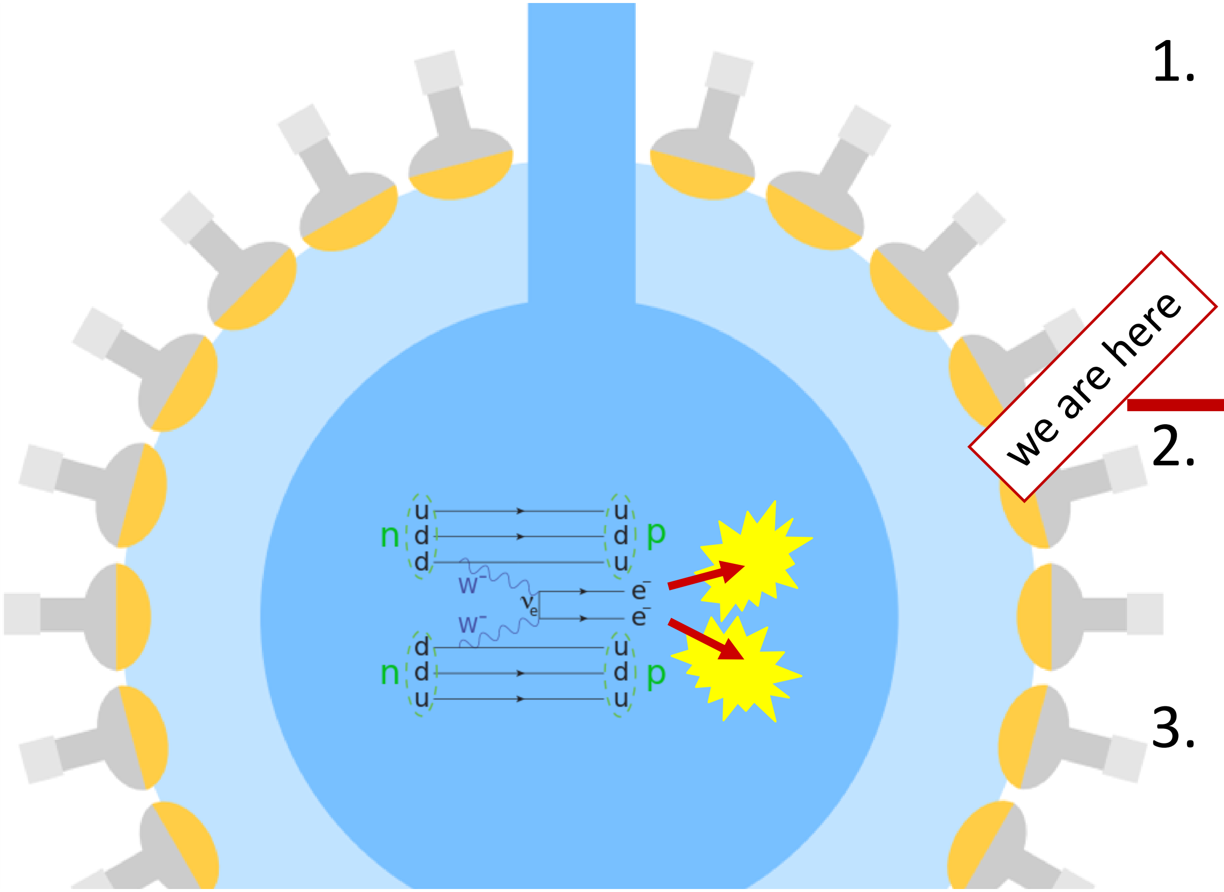

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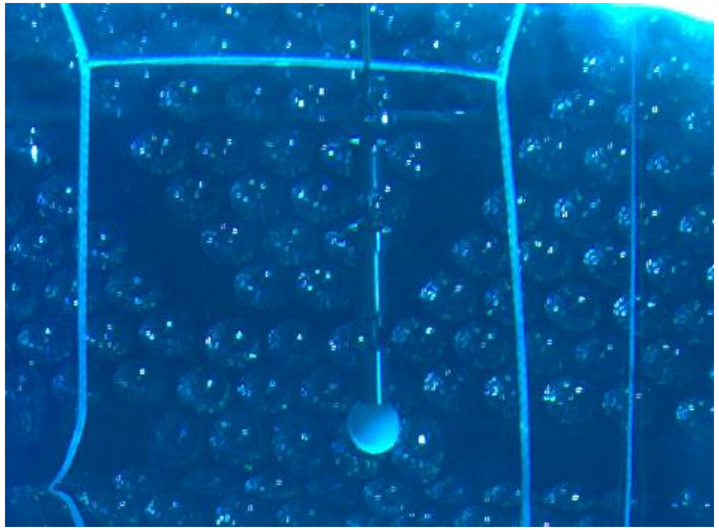
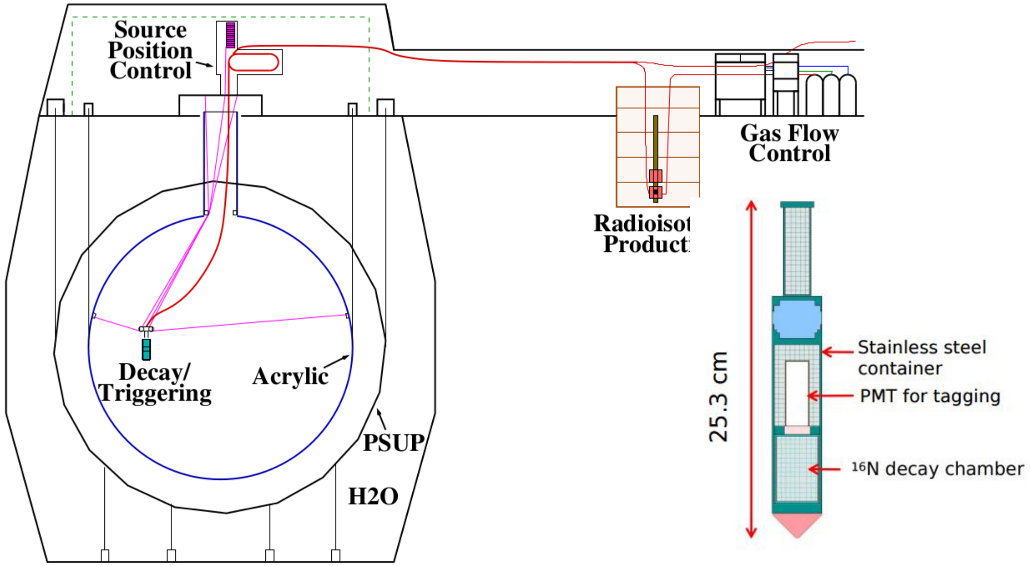
Current status

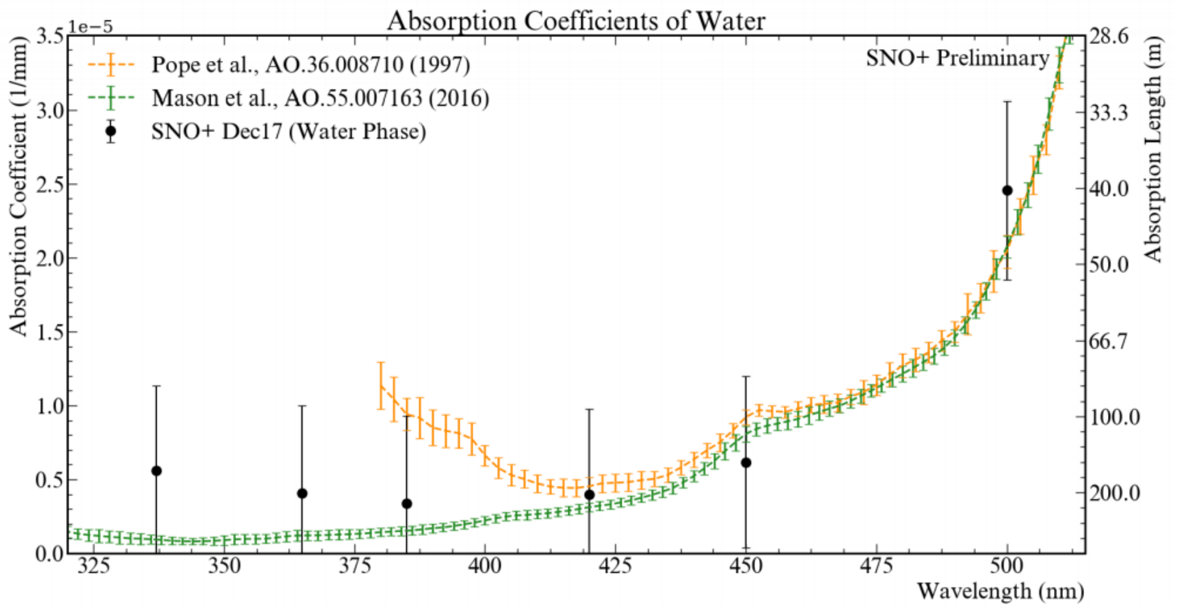
- Taking water data since early 2017
- Physics results include 114.7 days of livetime (of 235 calendar days)
  - Twice the amount of data collected in the mean time
- Extensive detector calibration with deployed and mounted sources

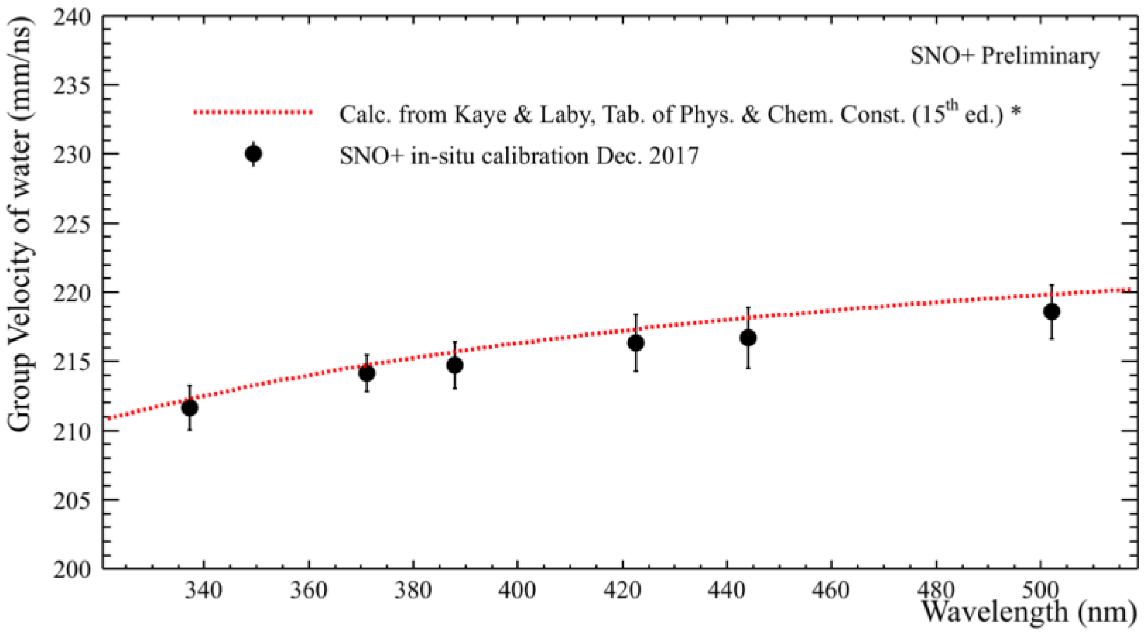




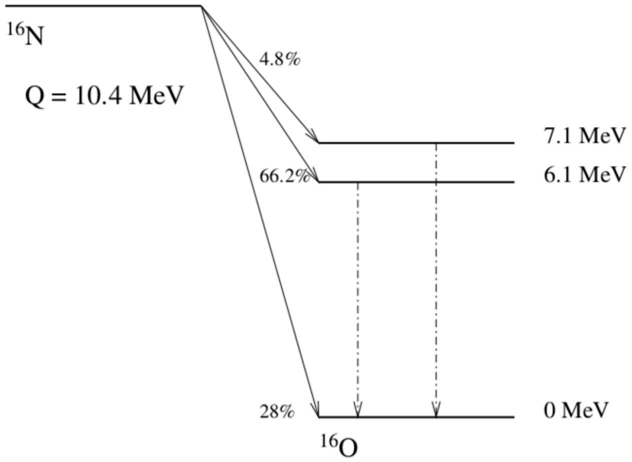
Optical calibration

- Isotropic light source deployed at multiple positions/wavelengths
- Full analysis of optical response in water conducted
  - Attenuation, group velocity, relative angular acceptance of optical sensors
- LED/laser systems mounted and being tested to do constant monitoring

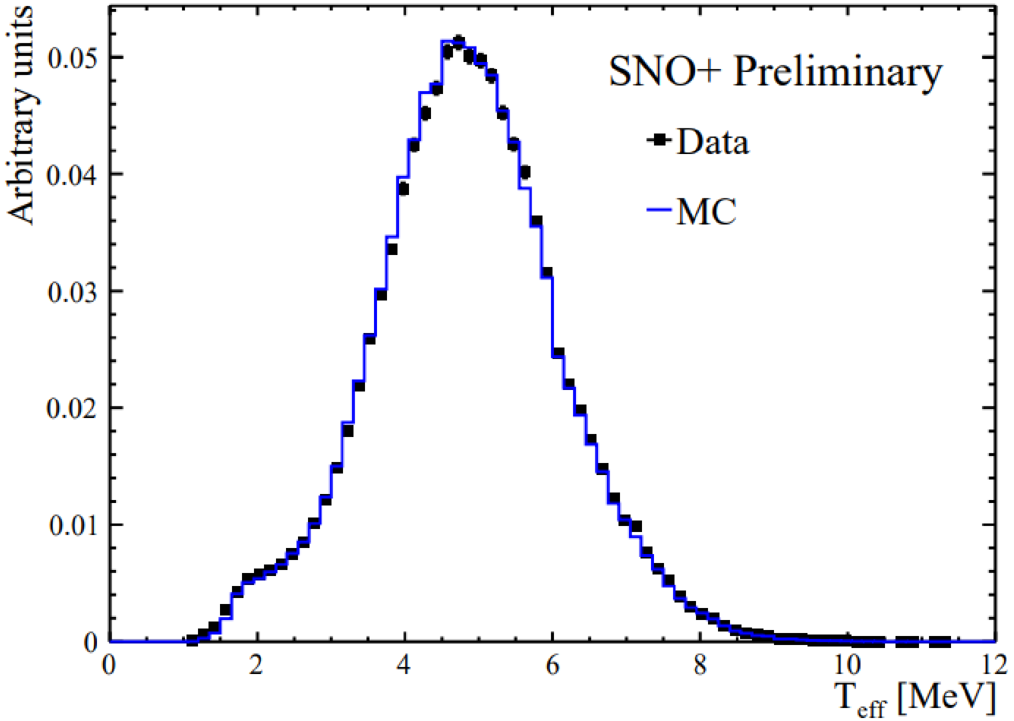


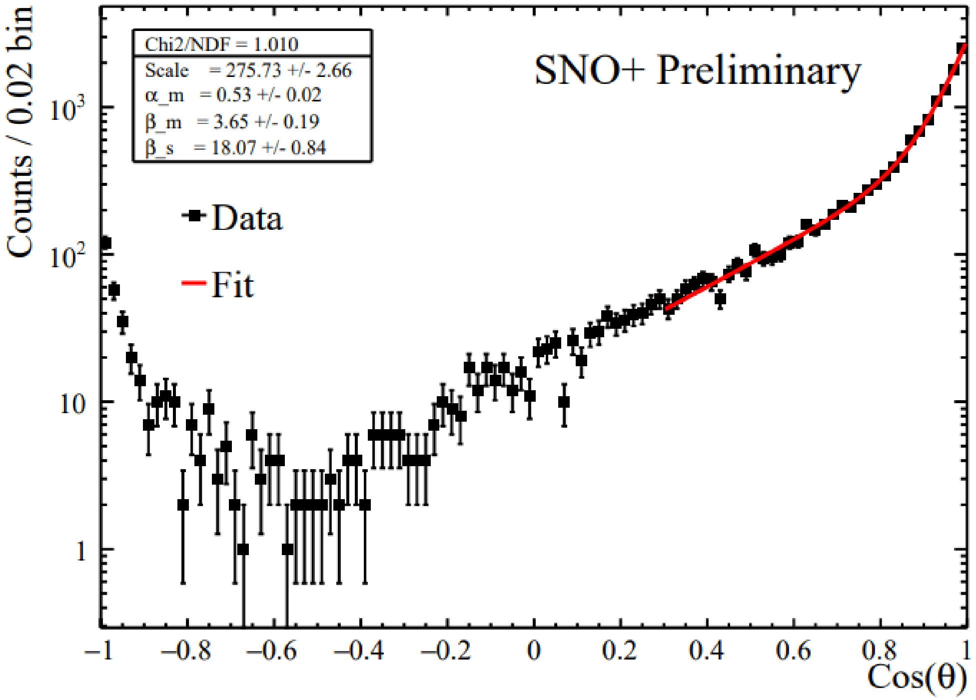


Detector response

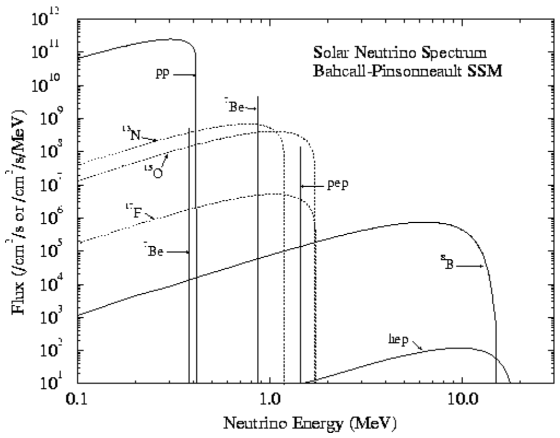


- Response calibrated using an ^{16}N source
  - Producing two gammas → Compton scatter e^-
  - Data used to characterize energy response and fit algorithms (position, direction)





Solar flux measurement in water



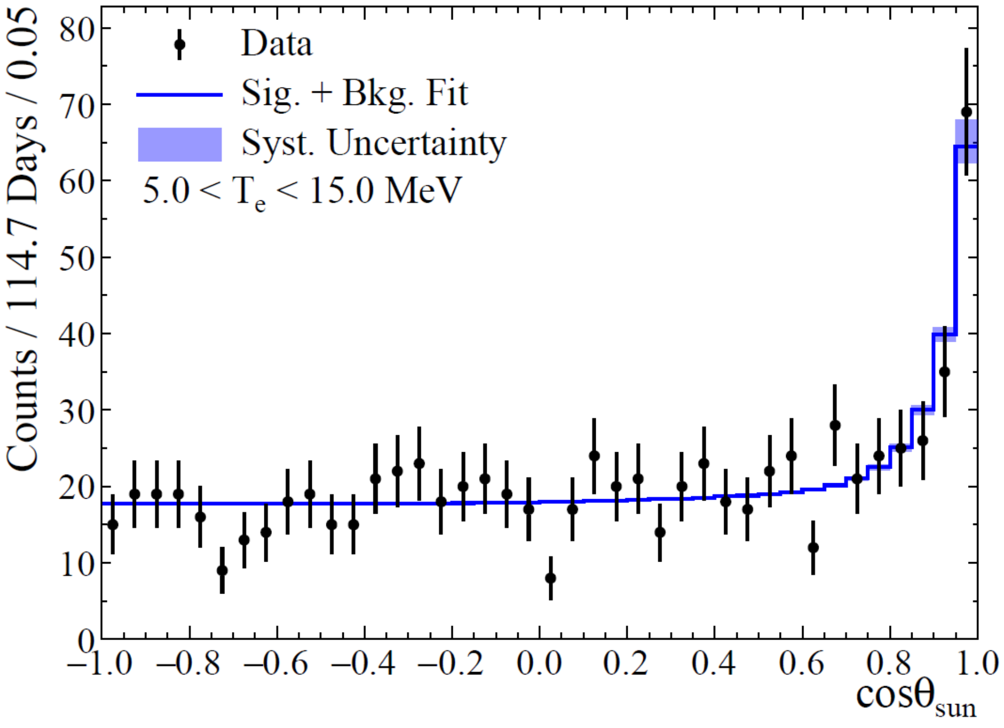
- Neutrinos from ^{8}B observed

- Flux

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

consistent with SNO

- Fit in direction of cos(θ_{sun}), backgrounds are flat



Phys. Rev. D 99, 012012 (2019)

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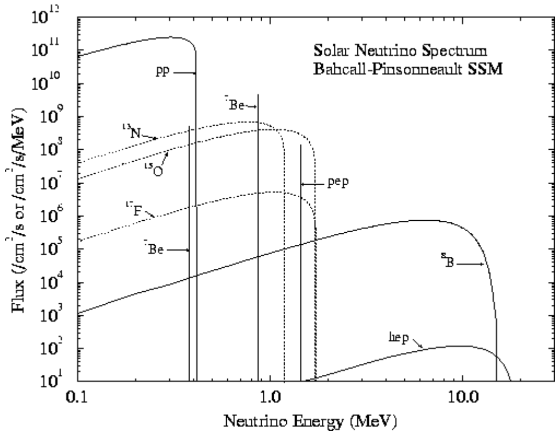

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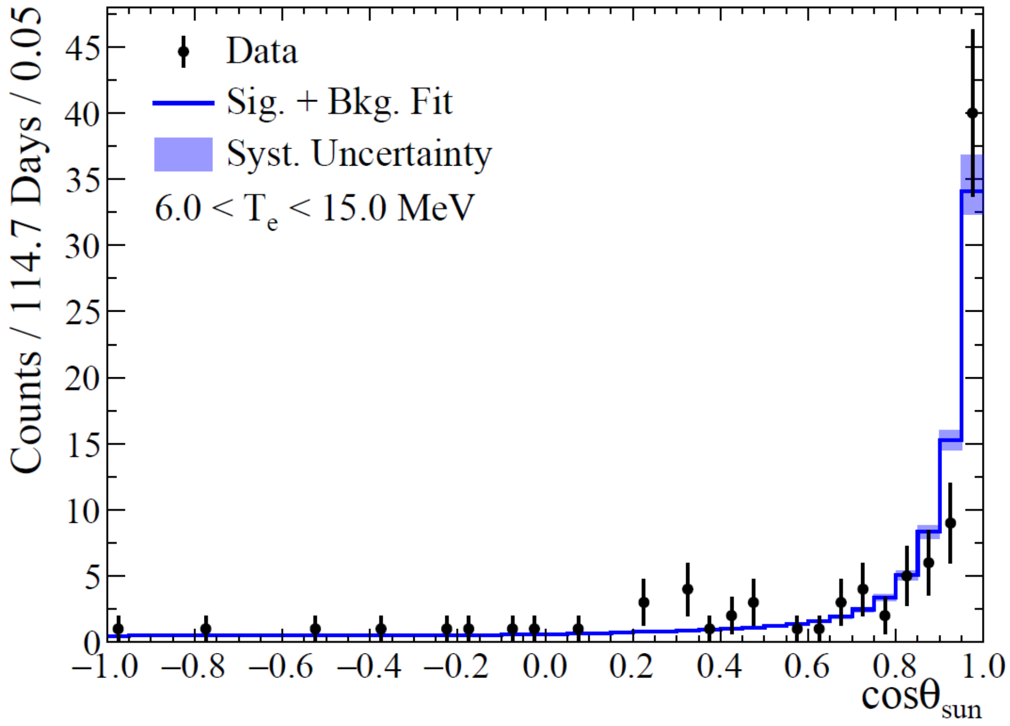
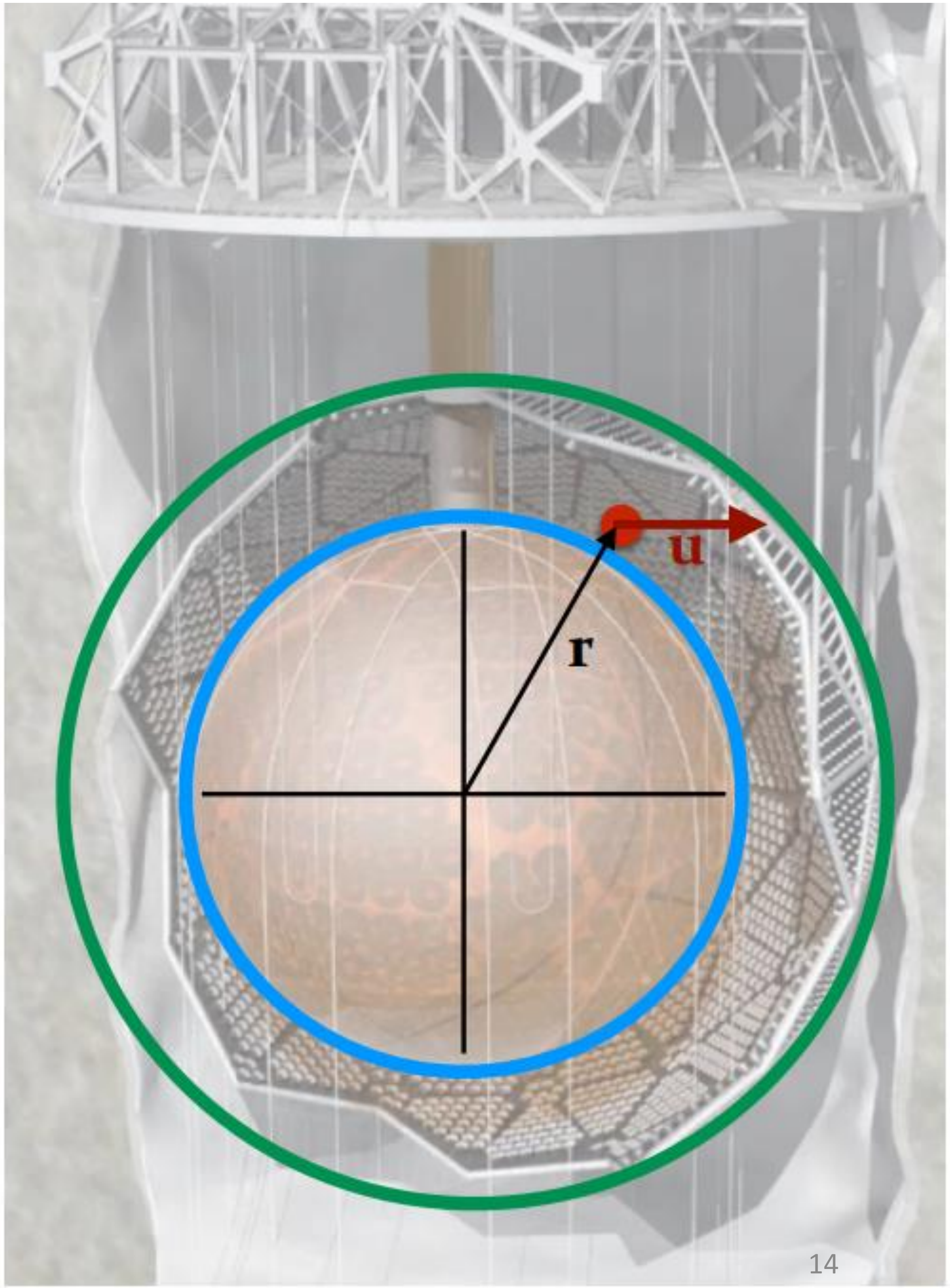


Phys. Rev. D 99, 012012 (2019)

Background levels

- Internal backgrounds
  - Intrinsic radioactivity of water in the vessel
- External backgrounds
  - Intrinsic radioactivity in vessel, ropes, PMTs and water
  - <u>Will not change in between phases</u>
- Observables to identify backgrounds
  - Energy, position, isotropy and direction



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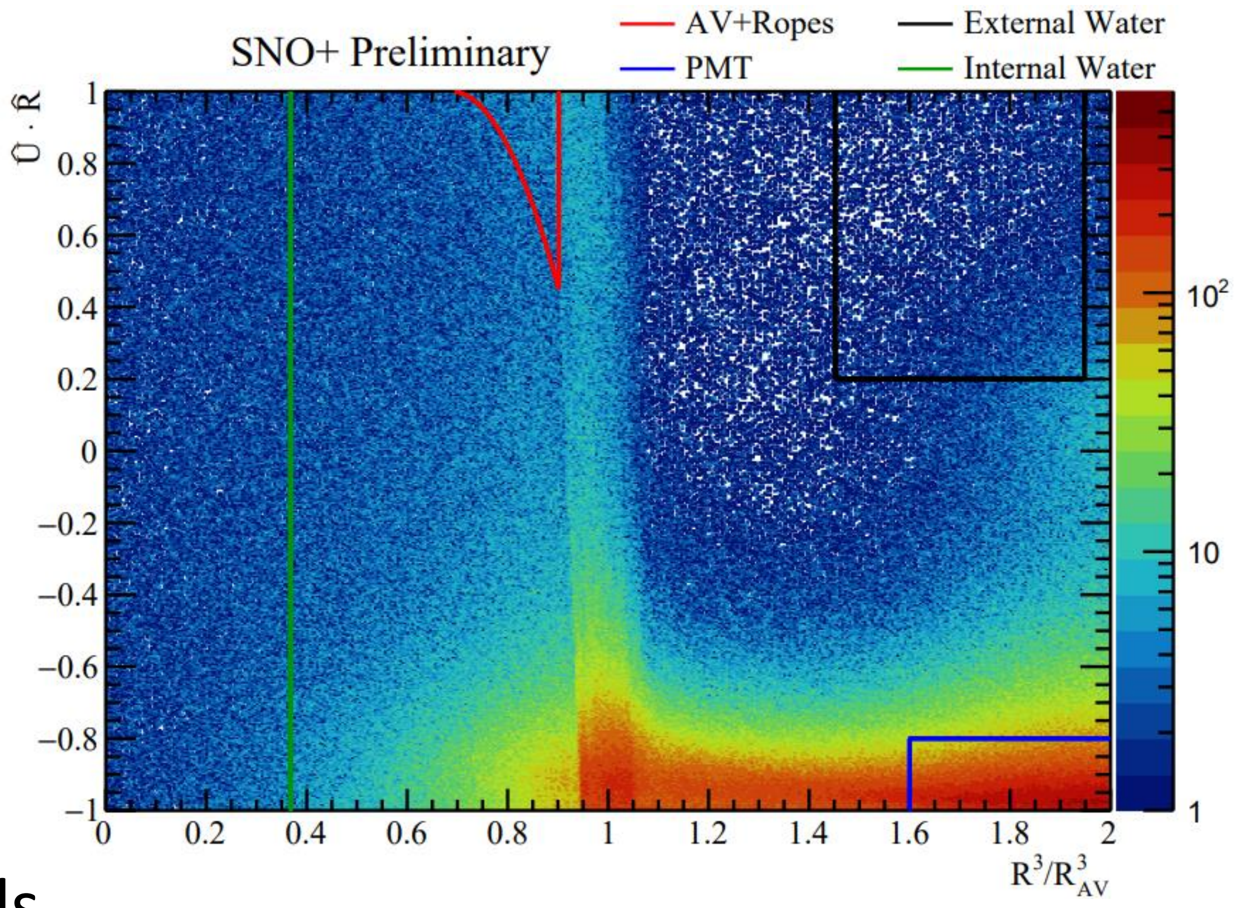


External background results

- Multiple analyses constrain the backgrounds
  - Fit to spectral shapes, counting events within a region
- Results are consistent, indicate external background at expectation

Background source	**Results (observed / expected) for latest period analyzed**	
	z > 0 (upper hemisphere)	z < 0 (lower hemisphere)
Acrylic vessel + rope system	2.2 ± 0.08 (stat) $^{+2.4}_{-1.9}$ (syst)	1.3 ± 0.08 (stat) $^{+1.0}_{-0.9}$ (syst)
External water	0.6 ± 0.06 (stat) $^{+1.9}_{-0.6}$ (syst)	1.0 ± 0.07 (stat) $^{+3.3}_{-1.0}$ (syst)
PMTs	1.2 ± 0.02 (stat) $^{+1.1}_{-0.5}$ (syst)	

Invisible nucleon decay search

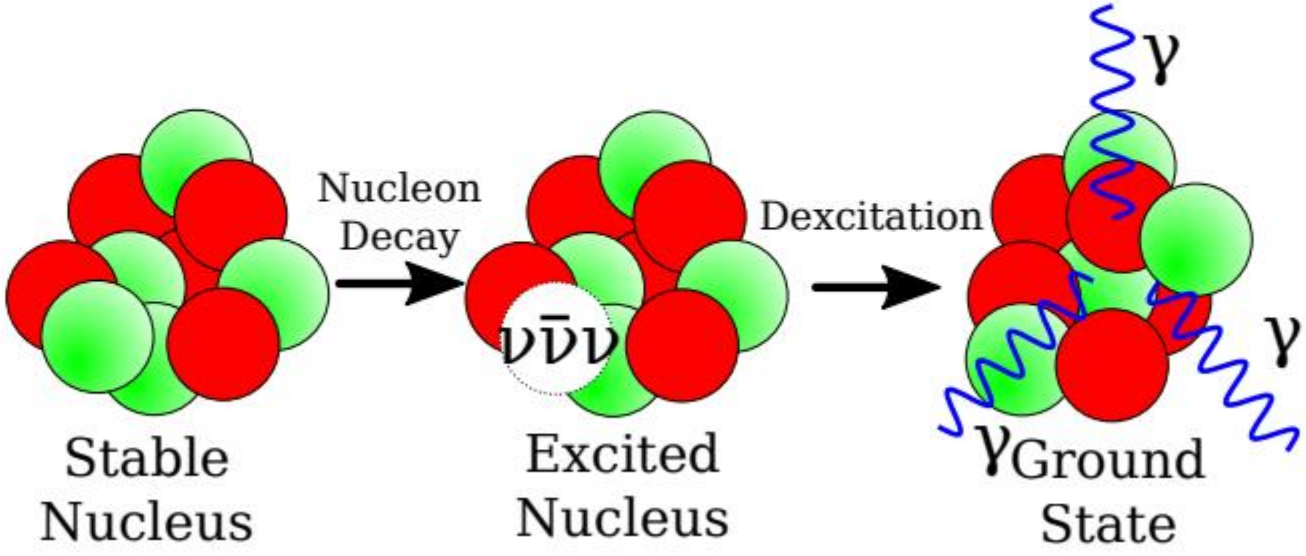
- Never observed baryon-number violating process
- Theories propose invisible decay modes (e.g. n → 3ν)
- Decay could be observed indirectly with gammas

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

$3\%: 9.932$ MeV γ
$41\%: 6.32$ MeV γ

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

$44\%: 6.18$ MeV γ

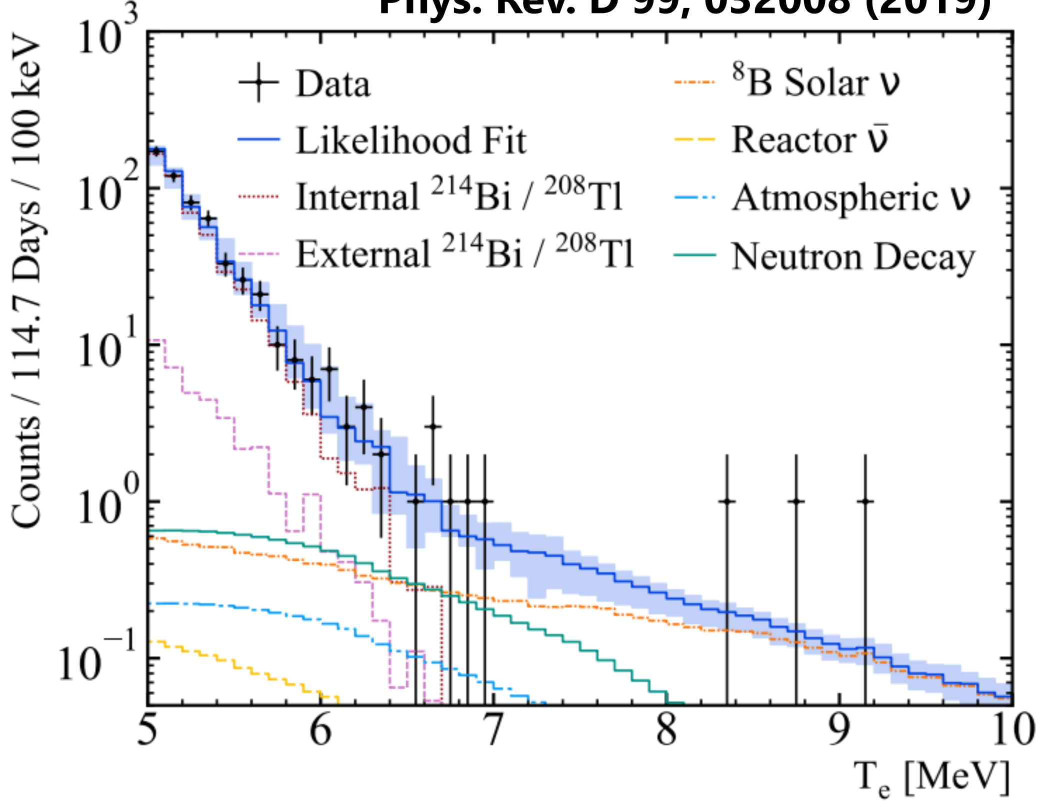


Results from nucleon decay search

- Selection based on straight cuts to remove backgrounds
- Two analysis performed: cut & count and likelihood fit
- No excesses, only limits

Data set	Observed events	Expected events
1	1	$1.17^{+4.60}_{-0.05}\ ^{+1.33}_{-0.39}$
2	2	$2.35^{+4.62}_{-0.40}\ ^{+3.44}_{-0.81}$
3	4	$3.47^{+4.60}_{-0.15}\ ^{+3.11}_{-0.96}$
4	8	$3.37^{+4.60}_{-0.17}\ ^{+2.70}_{-0.98}$
5	1	$1.46^{+4.60}_{-0.13}\ ^{+2.17}_{-0.60}$
6	6	$5.84^{+7.40}_{-2.31}\ ^{+2.68}_{-0.62}$
Total	22	$17.65^{+12.68}_{-2.36}\ ^{+6.51}_{-1.85}$

Phys. Rev. D 99, 032008 (2019)



Limits on nucleon decay

- Results and comparison with existing limits

	Spectral analysis	Counting analysis	Existing limits
n	2.5×10^{29} y	2.6×10^{29} y	5.8×10^{29} y[KamLAND]
p	3.6×10^{29} y	3.4×10^{29} y	2.1×10^{29} y [SNO]
pp	4.7×10^{28} y	4.1×10^{28} y	5.0×10^{25} y [Borexino]
pn	2.6×10^{28} y	2.3×10^{28} y	2.1×10^{25} y [Treyak et al.]
nn	1.3×10^{28} y	0.6×10^{28} y	1.4×10^{30} y[KamLAND]

Phys. Rev. D 99, 032008 (2019)

Next: scintillator fill

- Cover-gas system in place to seal the vessel
- Radon monitor in place to follow activity
- Liquid scintillator purification plant being tested
  - About 1.8 tonnes injected in the vessel thus far
- Fill had to be halted several months due to a leak in the distillation column
- Leak has been repaired – about to restart fill very soon

Tellurium process systems installed

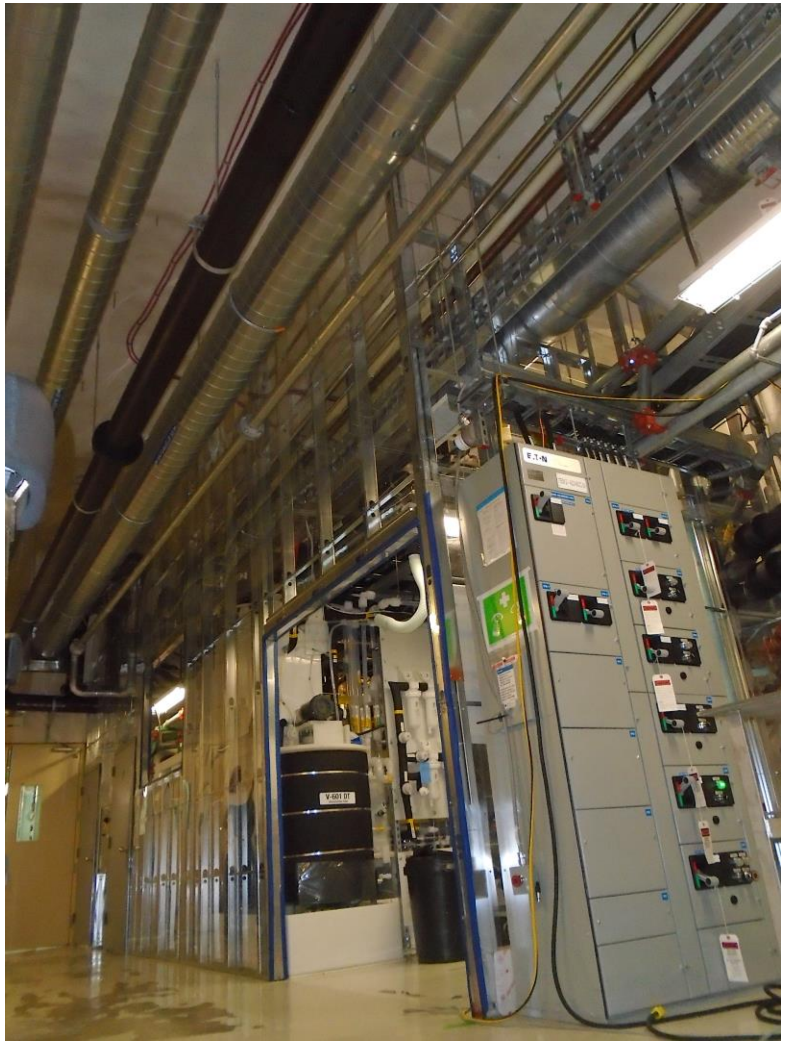
- TeA and TeDiol plants moving to commissioning

2016

2017

2018

2019



Telluric acid plant

Tellurium process systems installed

- TeA and TeDiol plants moving to commissioning

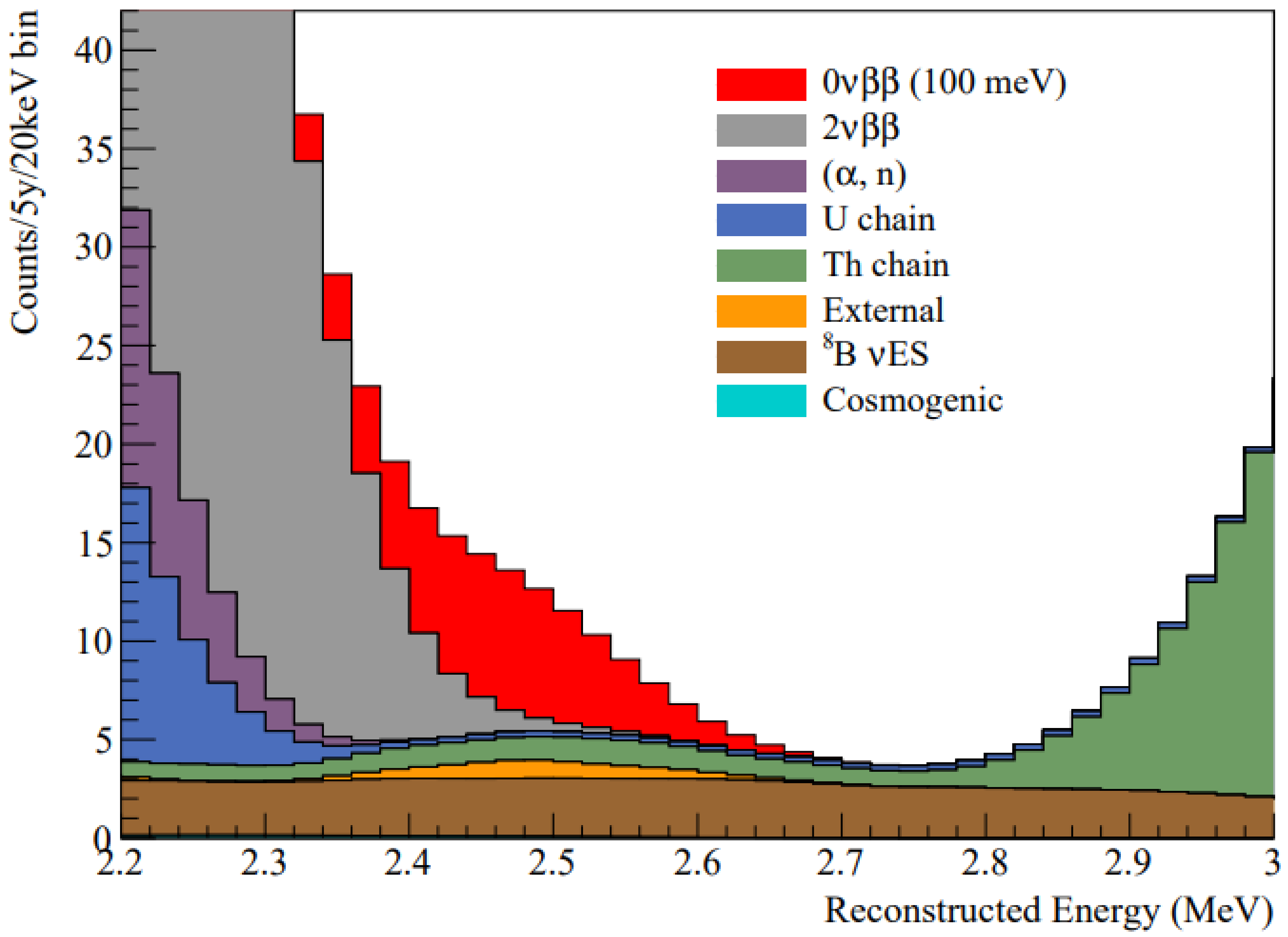
TeDiol plant

2018

2019

Majorana neutrino search

- Signal of Majorana neutrinos in the energy spectrum
- Using best knowledge of background levels
- Two analyses planned
  - Cut&count
  - Likelihood



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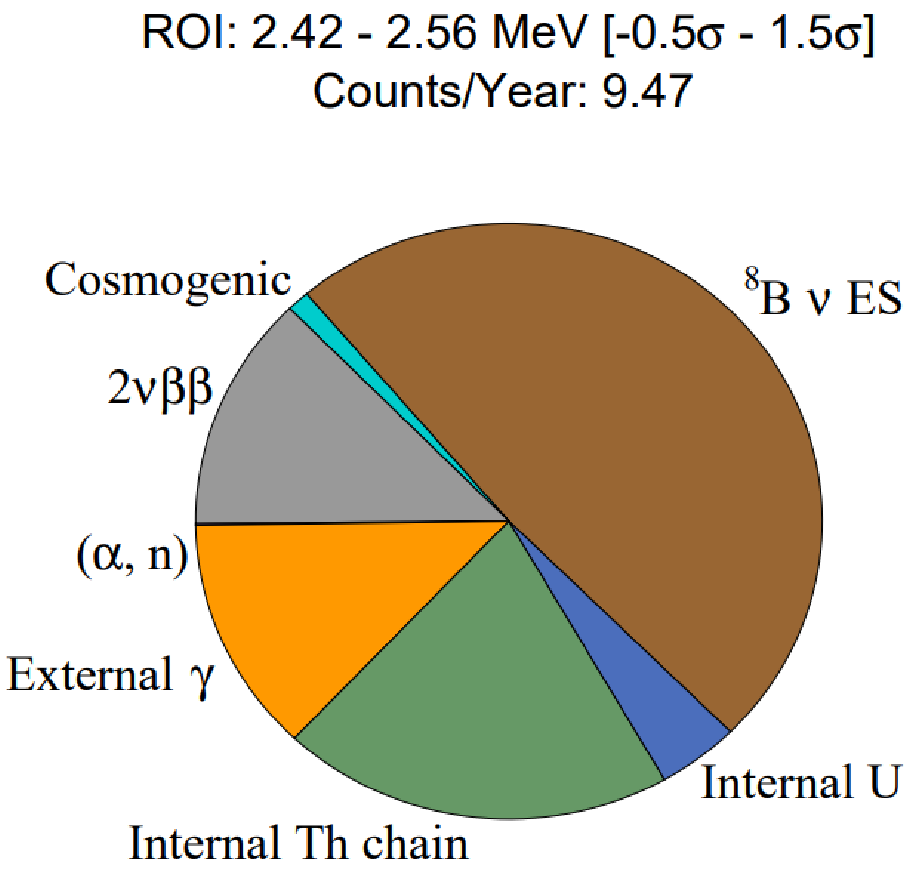

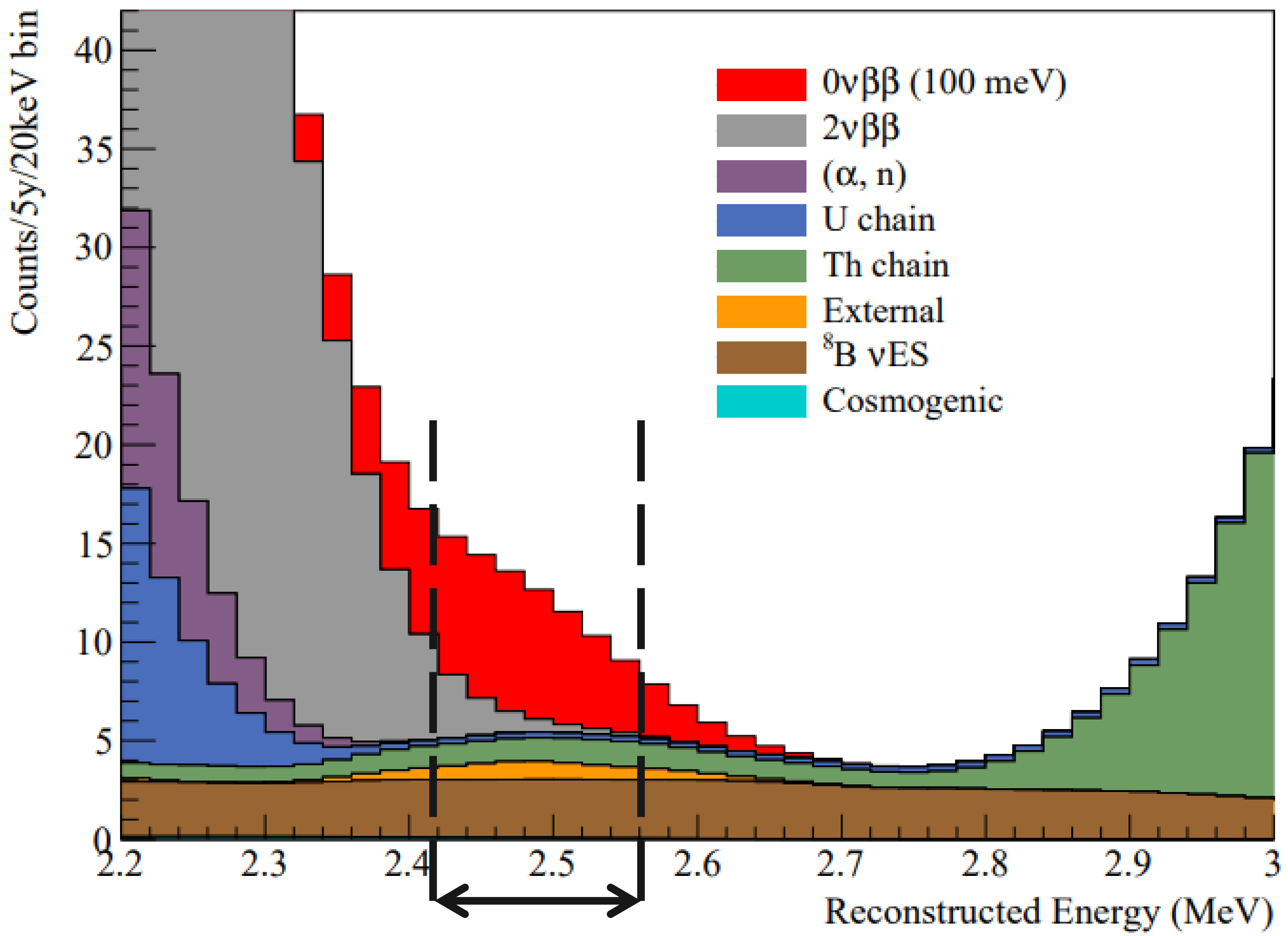

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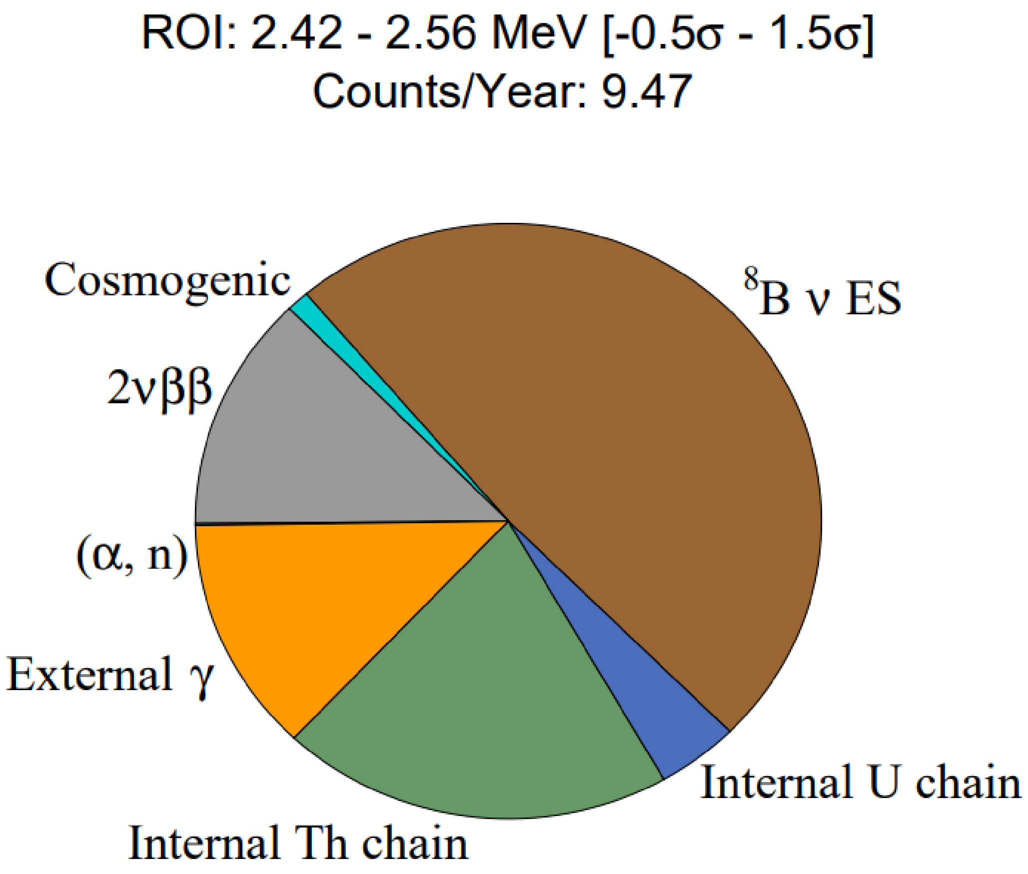
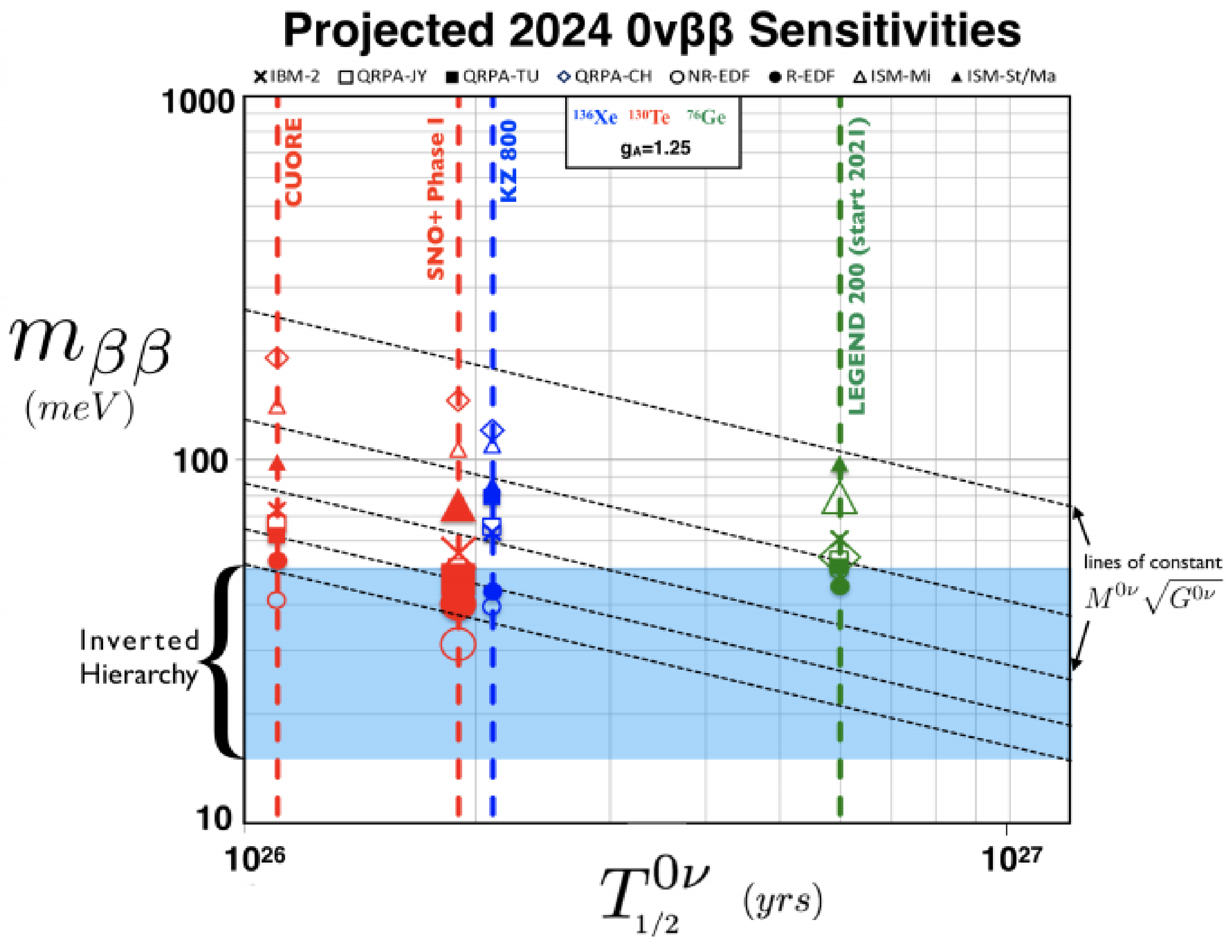
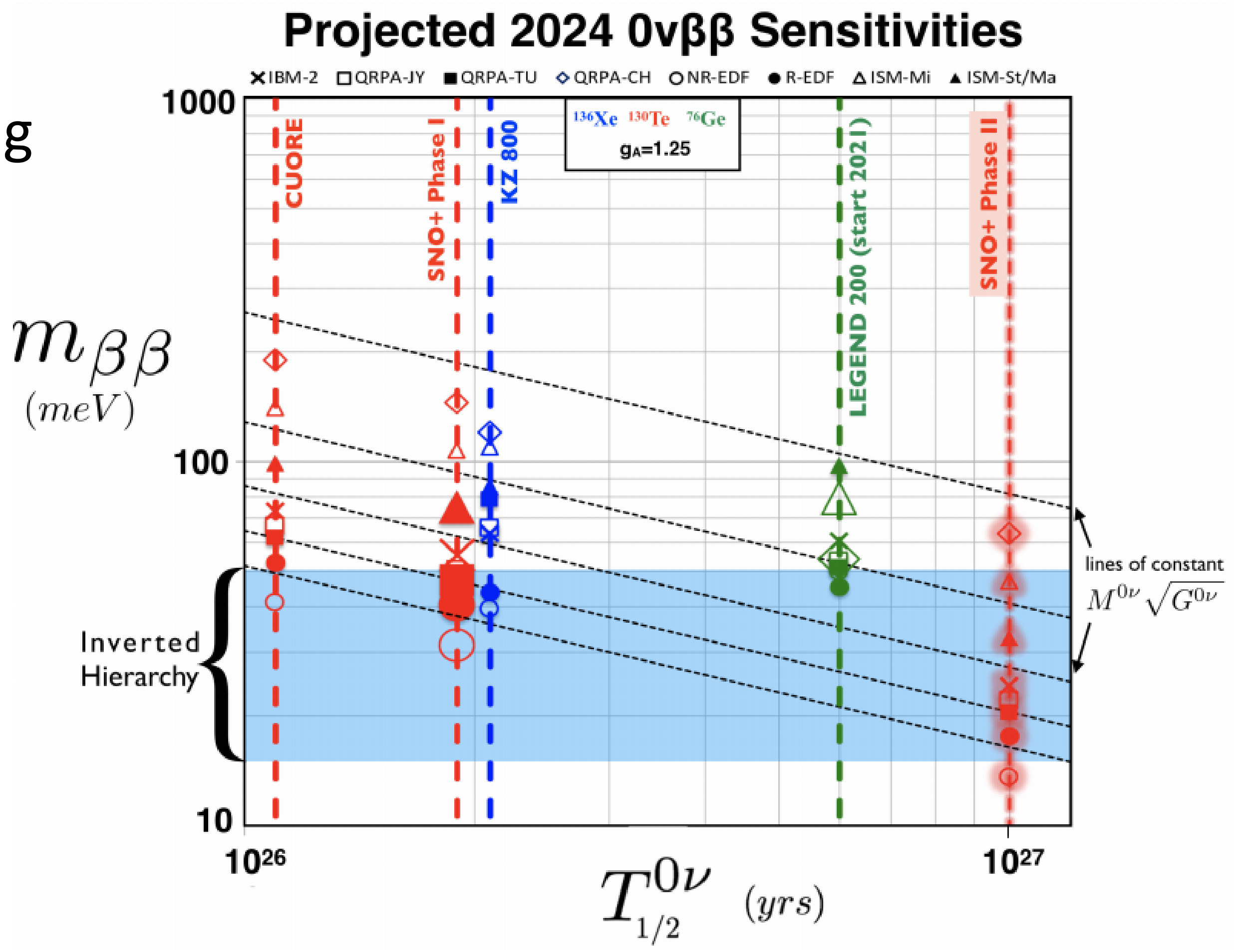




Towards the future

- SNO+ Phase I is 0.5% Te-loaded
  - Main backgrounds aren't from loading
  - Test-bed for a multi-ton experiment
- Telluric acid loading R&D
  - Chemistry studies to increase light yield
- Detector upgrade path
  - High QE PMTs being studied
  - Possible to replace PMT focusing



Summary

- Water phase wrapping up
  - Calibration systems tested
  - Detector response understood
  - Modeling of sub-leading effects with low background data

- Results from the water phase out
  - Nucleon decay limits and observation of solar neutrinos published
  - Working on neutron capture and reactor antineutrinos in water

- Scintillator phase to begin soon
  - Loading liquid scintillator this year

Thank you for your attention