Invisible Nucleon Decay in SNO+ Water Phase

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Overview

- The SNO+ experiment, detector
- Status, run plan
- Invisible nucleon decay
- Likelihood approach

SNO+

SNO+ is a multi-purpose neutrino experiment, reusing the infrastructure of SNO, located 2 km underground in Vale's Creighton nickel mine.

Physics goals:

- neutrinoless double beta decay
- supernova neutrinos
- solar, reactor, geoneutrinos
- exotic searches

Collaboration

Queen's
Alberta
Laurentian
SNOLAB
TRIUMF

BNL, AASU
U Penn, UNC
U Washington
UC Berkeley/LBNL
Chicago, UC Davis

Oxford
Sussex
Lancaster
Liverpool
QMUL

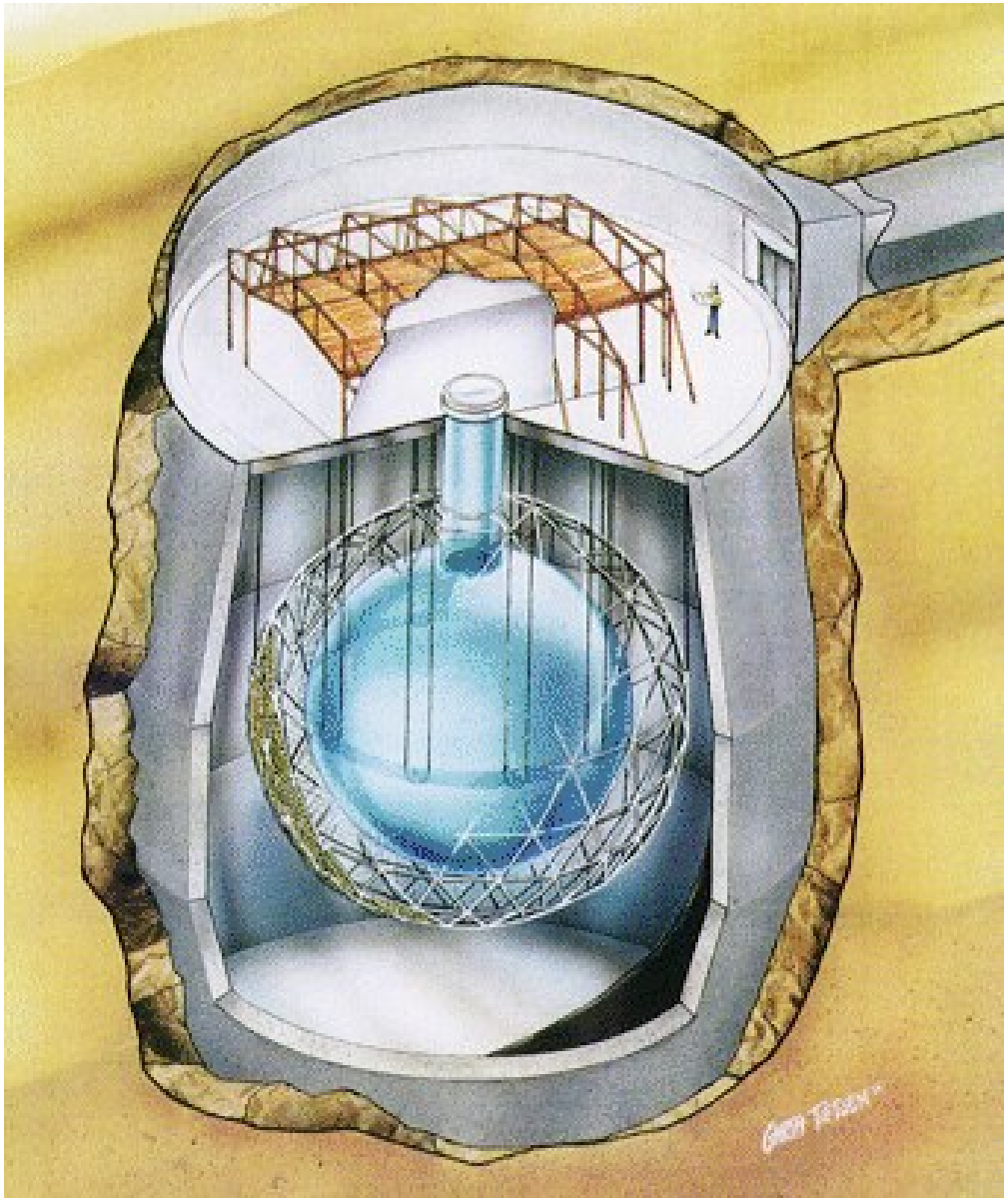
LIP Lisboa
LIP Coimbra

TU Dresden

UNAM

The Detector

Inner volume (900 m^3)
scintillator or water
Acrylic Vessel (r = 6 m)
Outer volume (1700 m^3)
water
PMTs (9300, r = 8.5 m)
Water shielding (5700 m^3)



Upgrades

We have made significant upgrades to the detector since the end of SNO:

- New calibration systems
- Improvements to the DAQ
- Hold-down rope net to enable the use of liquid scintillator
- Scintillator purification plant
- Covergas system
- PMT repairs

Run Plan

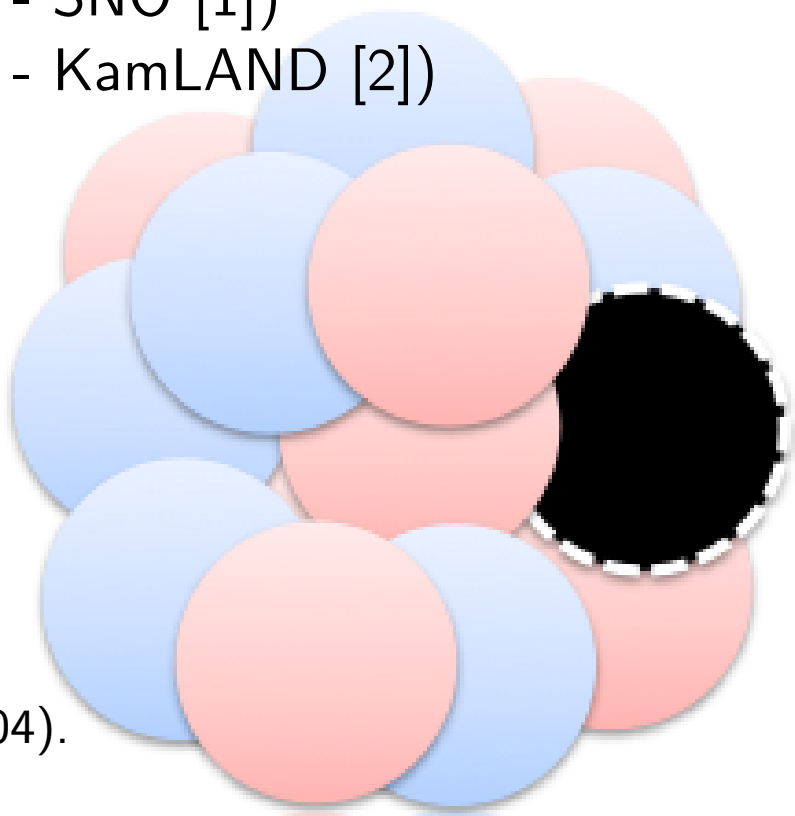
- Water phase, $\sim$ 6 months
  backgrounds, reactor, supernovae, nucleon decay
- Scintillator phase, $\sim$ 6 months
  backgrounds, reactor, solar, geo, supernovae
- Loaded scintillator phase, $\sim$ 3 years
  reactor, geo, supernovae, neutrinoless double beta decay

Invisible Nucleon Decay

Invisible nucleon decay is the model-independent class of hypothetical decays of protons or neutrons to undetected products. The best limits on this process come from SNO and KamLAND:

$$\tau_p > 2.1 \times 10^{29} \text{ years} \quad (90\% \text{ CL - SNO [1]})$$
$$\tau_n > 5.8 \times 10^{29} \text{ years} \quad (90\% \text{ CL - KamLAND [2]})$$

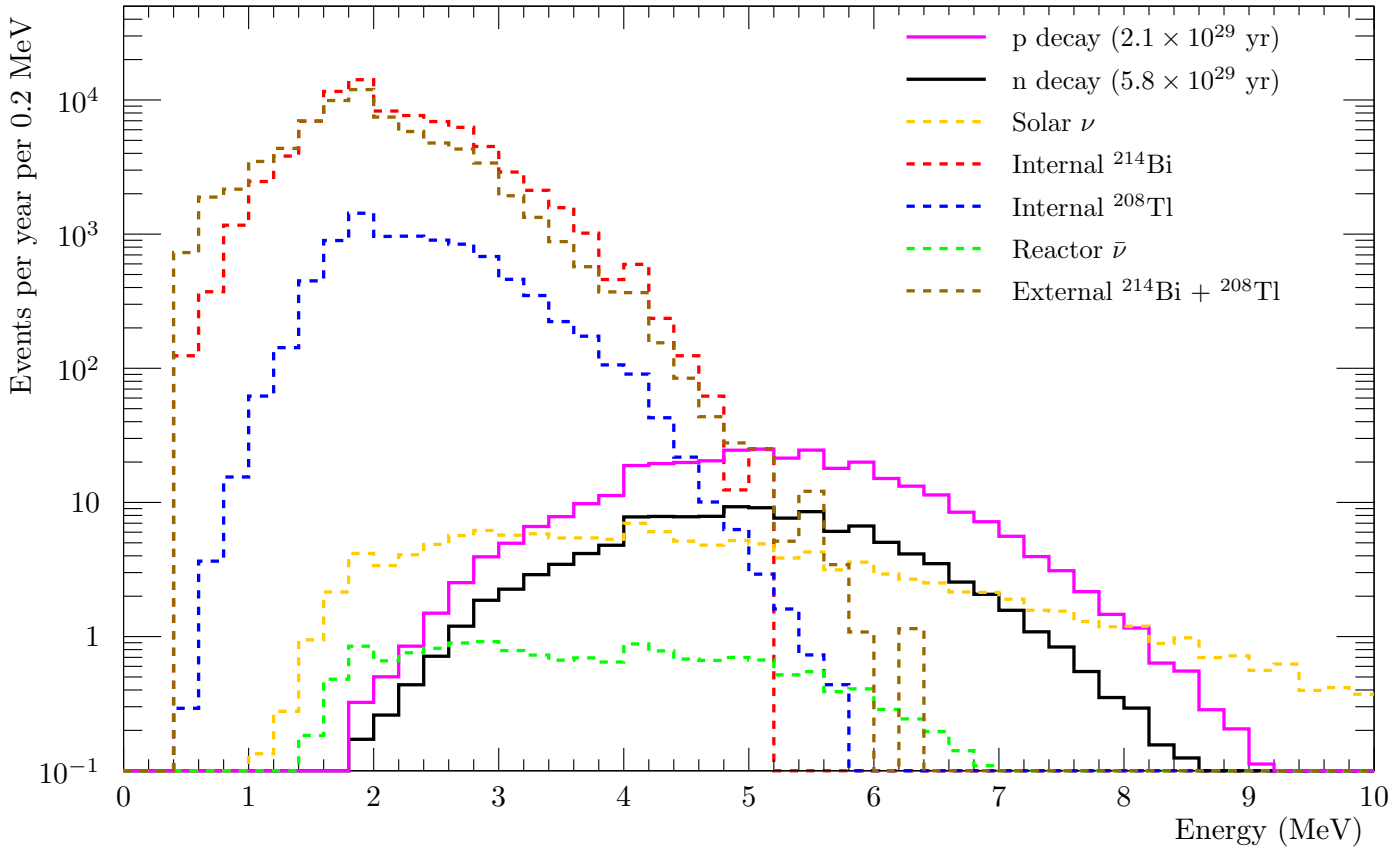
Possible examples:
n $\rightarrow \nu\nu\nu$
extra dimensions
dark matter decays



1. S. N. Ahmed et al, Phys Rev Lett 92: 102004 (2004).
2. T. Araki et al, Phys Rev Lett 96: 101802 (2006).

The Signal in SNO+

Nucleon disappearance in ^{16}O can lead to excited states of ^{15}O or ^{15}N. These deexcite via γ decay. In roughly 40% of such decays, this results in a γ of 6-9 MeV.



Strength of SNO+

Why can SNO+ improve on the limits of SNO and KamLAND?

- SNO limited by neutron capture on deuterium (NC solar signal)
- Branching ratio to signal significantly higher from oxygen than carbon

Counting Experiment Approach

Cuts:

- energy:
  5.4 MeV $\leq$ E $\leq$ 10 MeV
- radius: r $\leq$ 5.5 m
- direction: $\cos\theta_{\odot} > -0.8$

Backgrounds after cuts

Decay Source	Events in 6 mo run
^{214}Bi	0
^{208}Tl	0.6
solar ν	17.7
reactor $\bar{\nu}$	1.3
external Bi-Tl	8.9
Total	28.5
ϵ(n)	0.1017
ϵ(p)	0.1129

90% CL sensitivity:

	SNO+		Existing Limits
τ_p	$> 1.4 \times 10^{30}$ years	τ_p	$> 0.2 \times 10^{30}$ years
τ_n	$> 1.3 \times 10^{30}$ years	τ_n	$> 0.6 \times 10^{30}$ years

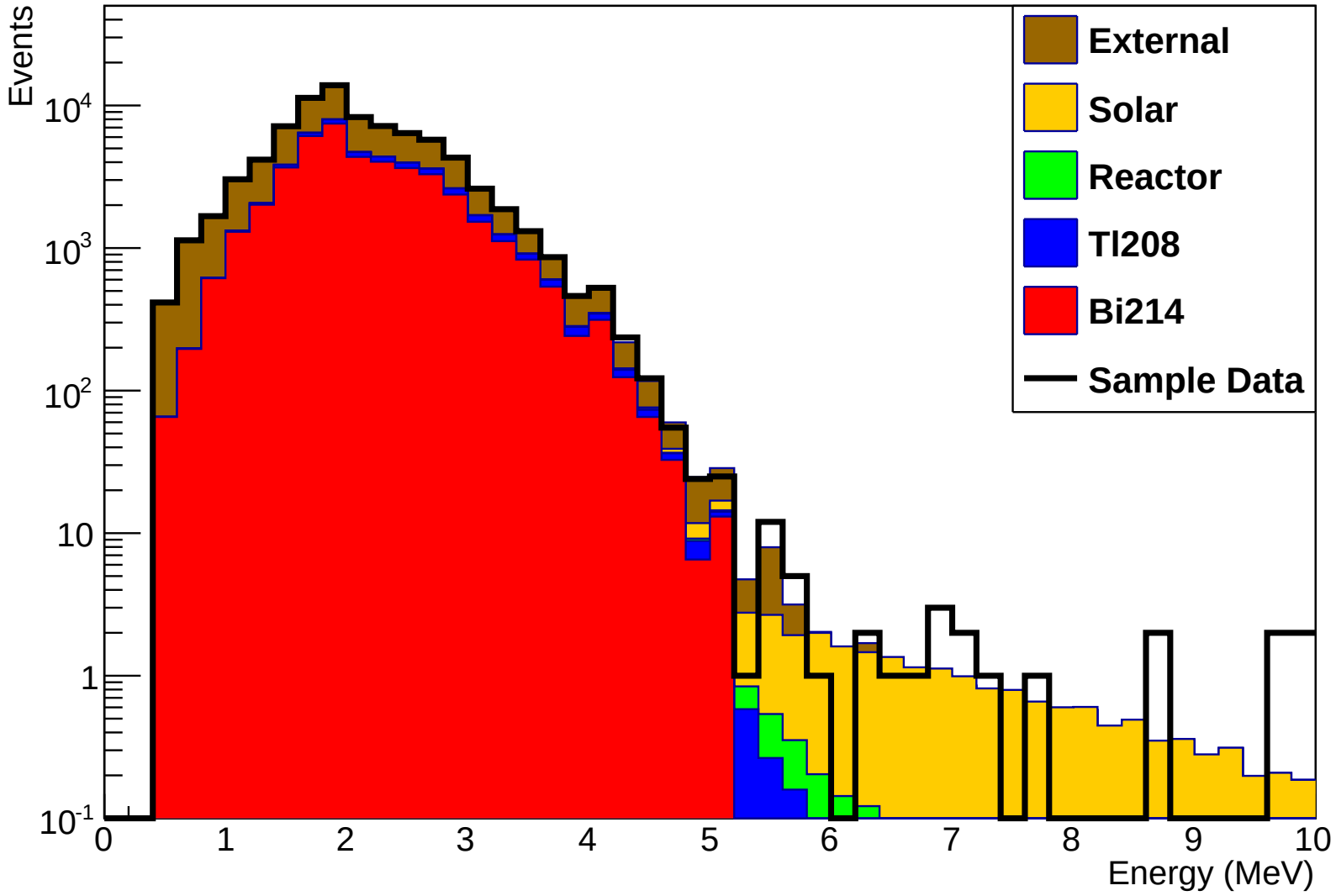
Likelihood Approach

- Replace cut in energy with fit from 5 to 10 MeV
- Binned likelihood fit in energy

$$\ln \mathcal{L} = -\sum_{\text{bins}} \left(x - d + d \ln\left(\frac{d}{x}\right)\right)$$

- Sample from background and fit to energy templates
- Assume 10% constraints on reactors, solars, 100% uncertainty on radioactive backgrounds
- Assume uniform prior on nucleon decay rate above 0

Example Spectral Fit — MC background only



Conclusion

- With 6 months of water data, SNO+ will improve the world limits on invisible nucleon decay by a factor of $2 - 7$, with a sensitivity of 1.4×10^{30} years.
- Additional improvements to sensitivity through a likelihood approach are under development.