First-Ever Direct K40 Measure in the SNO+ Neutrino Detector

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The “K40 Problem” :-

- The K40 signal is notoriously difficult to measure, because of its statistical rarity
- The signal also occurs in the same range as spectra from other radioisotopes

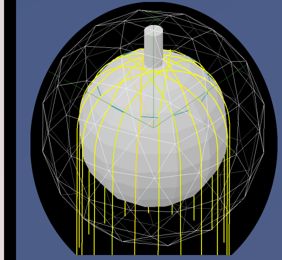
Our Solution at SNO+ :-

- SNO+ is a tonne-scale neutrino detector located 2 km underground at SNOLAB [1]
- We leverage the high sensitivity provided by the 780 tonnes of scintillator [1], together with the structural symmetry of the ropes that surround the detector
- Measurements using a Ge counter showed that these ‘hold-down’ ropes have slightly more K40 than the neighboring material [2]
- We propose a method that measures K40 by exploiting the azimuthally symmetric variation of the K40 background to differentiate it from the other activity

The Analysis:-

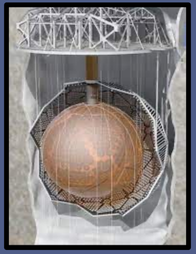
- A marked separation was seen between two signals from the detector: one azimuthally in-phase with the ropes (Dominant) and the other out-of-phase (Free)
- The separation occurred in an energy range consistent with the manifestation of the 1.46 MeV γ from K40
- Several parameters were then optimized to maximize this separation (Radial cut, angular width, etc.)
- A difference signal (Dominant – Free) showed a clear gaussian-like peak for K40
- We then quantify the azimuthal non-uniformity that produces this peak via a detailed comparison to Monte-Carlo simulation that exploits the azimuthal periodicity of this signal
- By quantifying the K40 background we can leverage it as a calibration peak in an energy range where there are no other reliable sources

The SNO+ Neutrino Detector at SNOLAB



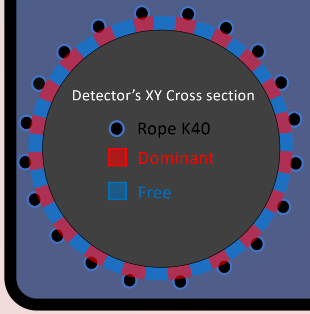
Ropes in yellow

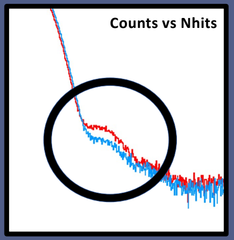
- Detector has over 9300 PMTs
- PMT Support structure is 17 m in diameter
- Structure contains an Acrylic Vessel, 12 m in diameter
- Vessel contains 780 tonnes of scintillator (Linear Alkyl Benzene)
- 20 ropes surround the Vessel, spaced evenly by 18° azimuthally



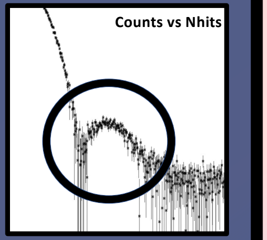
Detector is 2 km underground

Separating azimuthally symmetric K40 influence



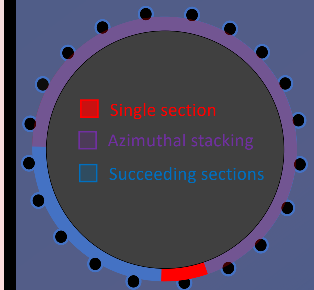


Separation consistent with expected K40 activity

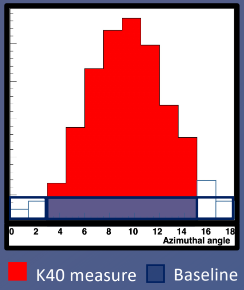


Difference signal shows clear peak for K40 γ

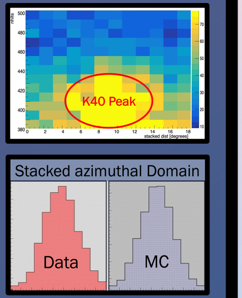
Quantitative measure by exploiting azimuthal periodicity



Finding the K40 peak in the ‘stacked’ azimuthal domain



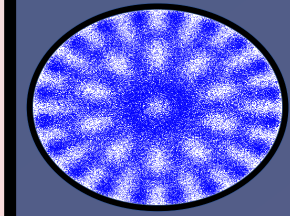
Measure of azimuthal non-uniformity via BL-removal



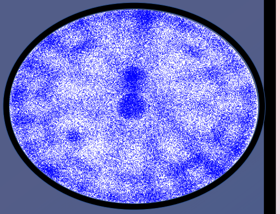
High fidelity MC comparison yields measure

Applications of this measurement:-

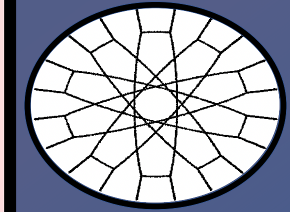
This study provides the first quantitative measure of K40, so SNO+ can account for this azimuthally non-uniform background, to attain a much higher sensitivity!



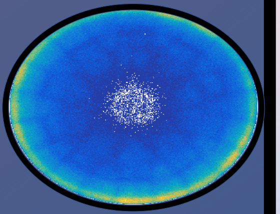
Monte Carlo simulation



Structure in data

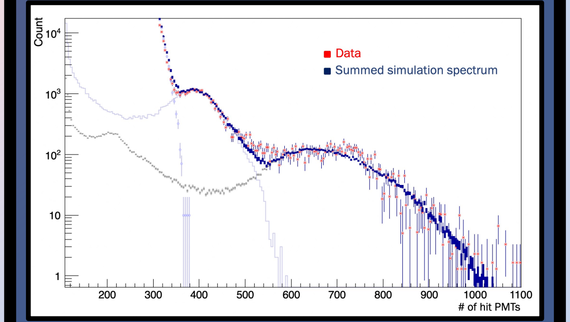


True structure



Shadow in data

We can also use this as an extremely reliable calibration point to “fit” simulation to data:-



K40 decays have a very large half life, so the signal won’t decay away anytime soon.

By quantifying and characterizing it, we turn this otherwise problematic background to our advantage!

References:
1. SNO+ Collaboration, 2021, https://arxiv.org/abs/2104.11687
2. A. Bialek, et al., 2008, https://doi.org/10.1016/j.nima.2016.04.114

Credit for images::
1. Ropes in yellow: Wikipedia, https://en.wikipedia.org/wiki/SNO%2B#/media/File:Snoplus_anchor_possibility.png
2. Detector is 2 km Underground: E. Caden, 2017, https://arxiv.org/pdf/1711.11094.pdf