Internal Backgrounds in the Water Phase of SNO+

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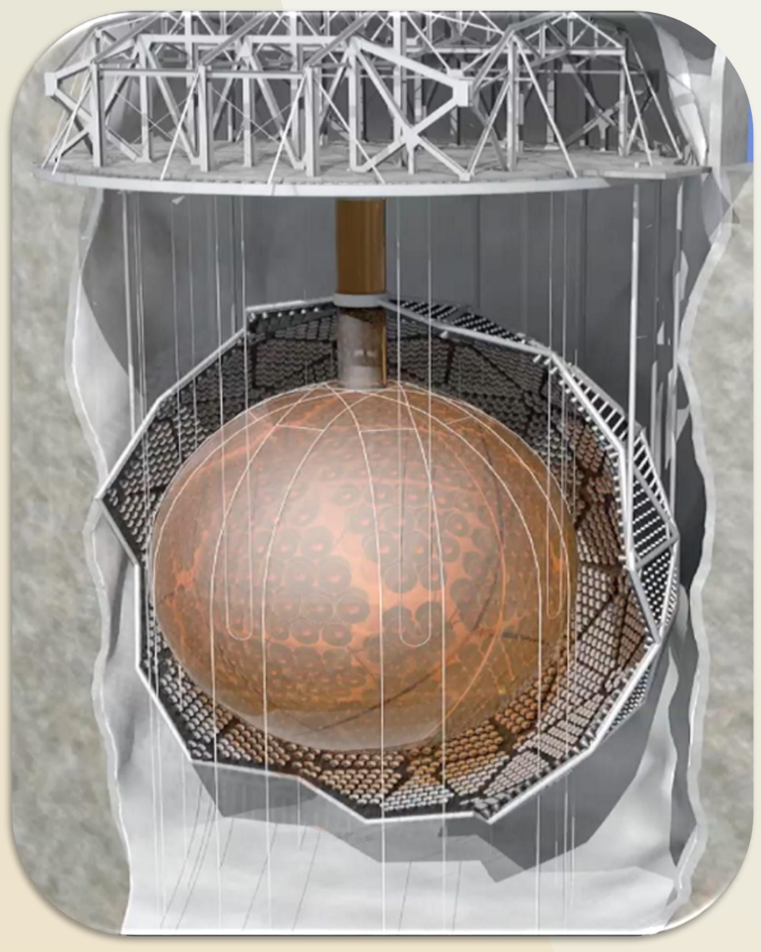
SNO+ Detector

- A neutrino experiment that will be run in three phases: water phase, liquid scintillator phase, $0\nu\beta\beta$ decay search phase using ^{130}Te-loaded liquid scintillator.[1]
- Currently in the water phase, where the acrylic vessel and the surrounding cavity is filled with ultra-pure water **(UPW)**
- Data taking for water phase is underway since May 2017.



- 2km underground at SNOLAB
- 12m diameter acrylic sphere surrounded by ~9400 photomultiplier tubes **(PMT)** held by a PMT support structure **(PSUP)**
- 40m tall cavity, filled with UPW for extra shielding.

Fig 1: Artist's rendition of SNO+

Purpose of Water Phase

- Ensure hardware is in optimum condition for scintillator phase.
- Enable initial calibration of the detector.
- Perform physics measurements such as nucleon decay search.

Nucleon Decay Search

- One of the major physics measurements of the water phase.
- In particular, we look at the "invisible" nucleon decay channels.
- An example decay would be: $^{16}O \rightarrow {}^{15}O^* + \bar{\nu}\bar{\nu}\nu$
- The de-excitation of ^{15}O would create a gamma around 6-7 MeV around 45% of the time.
- Current best limits are $\tau_n > 5.8 \times 10^{29}$ years. [2]

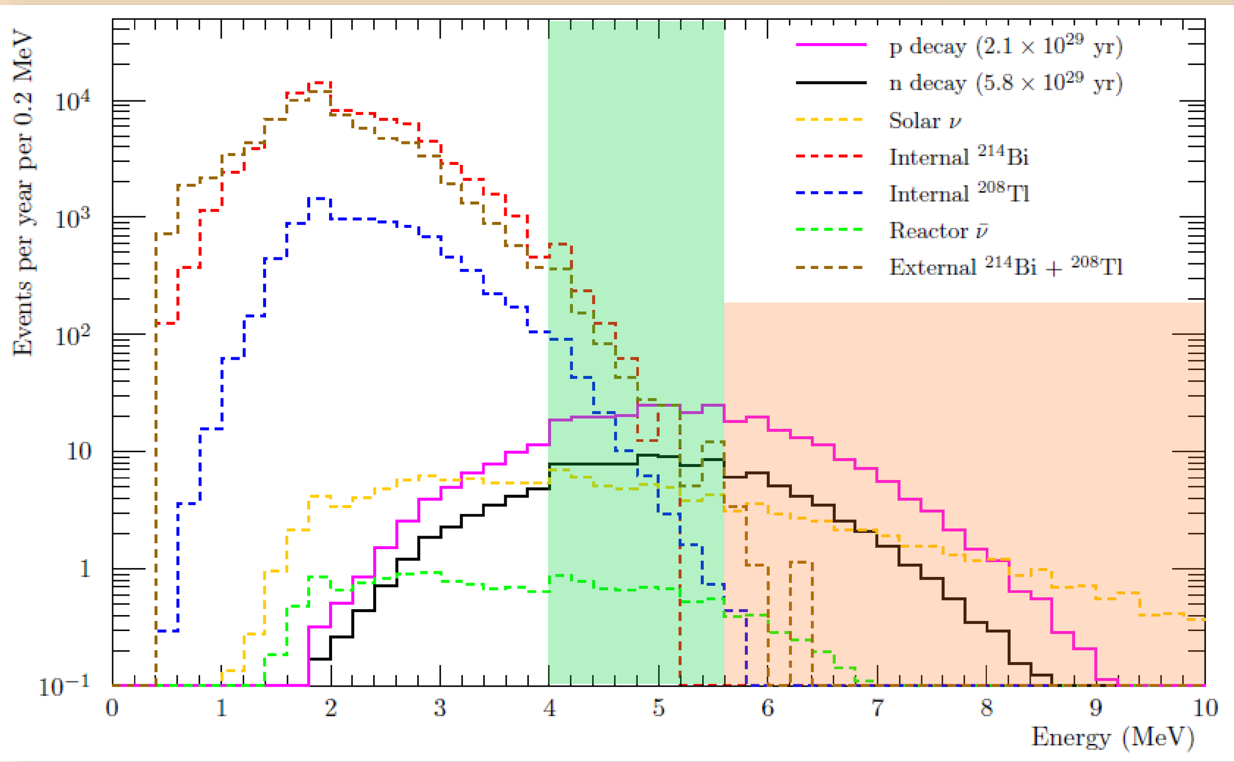


Fig 2: A simulation of a possible nucleon decay signal and expected backgrounds in SNO+ water phase. The region of interest for the ND search (orange) is currently blinded in data. A sideband region (green) is used for internal backgrounds analysis.

Internal Backgrounds

- Backgrounds within the active/fiducial volume **(FV)** of the detector.
- ^{214}Bi and ^{208}Tl are daughters from the ^{238}U and ^{232}Th chain, respectively.
- We need to discriminate them in order to estimate their amount *in situ*.
- Discriminate using difference in isotropy of the Cherenkov light of the two isotopes, which was first applied in SNO. [3]

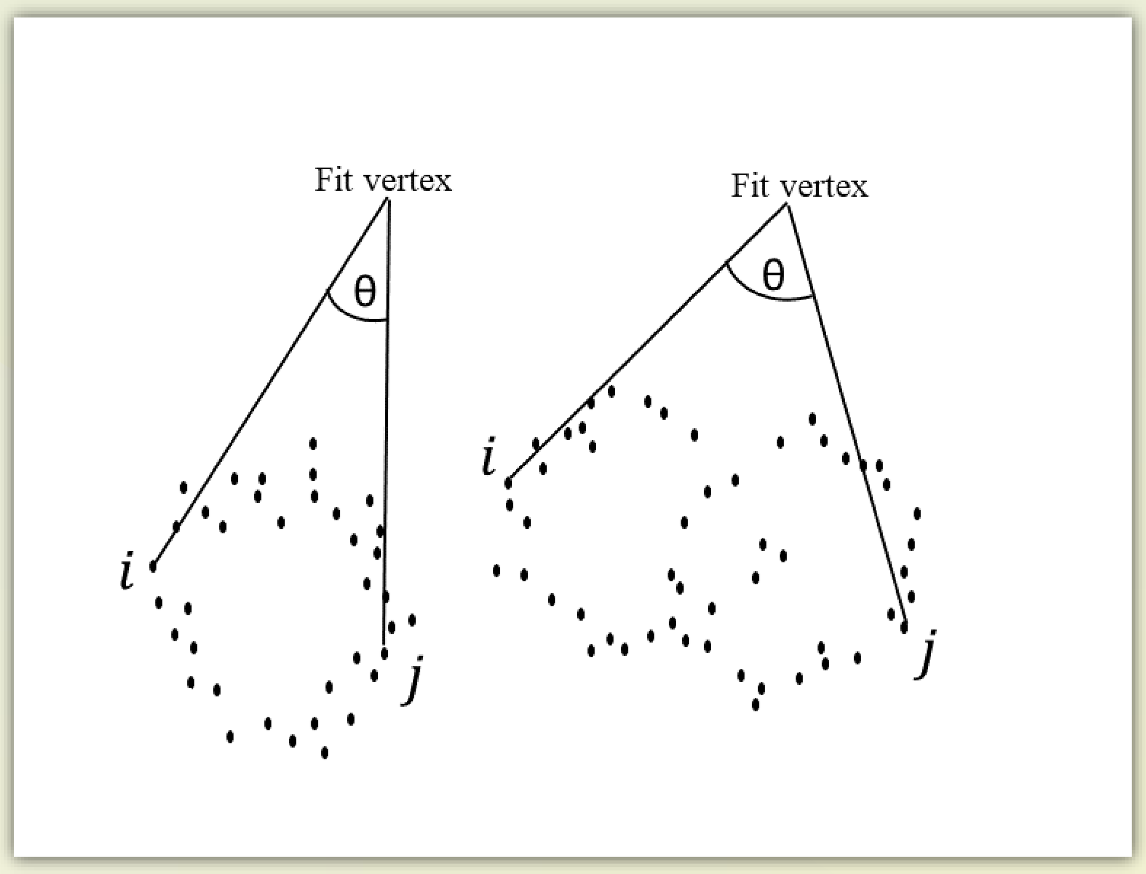


Fig 3: Parameterization of the isotropy of detected light:

$\beta_{14} = \beta_1 + 4\beta_4$, where $\beta_l = \frac{2}{N(N-1)}\left[\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} P_l(\cos\theta_{ij})\right]$ and P_l is the l^{th} Legendre polynomial.

- β_{14}, the *isotropy parameter*, is the spread of the PMTs hit with respect to the event fit vertex.

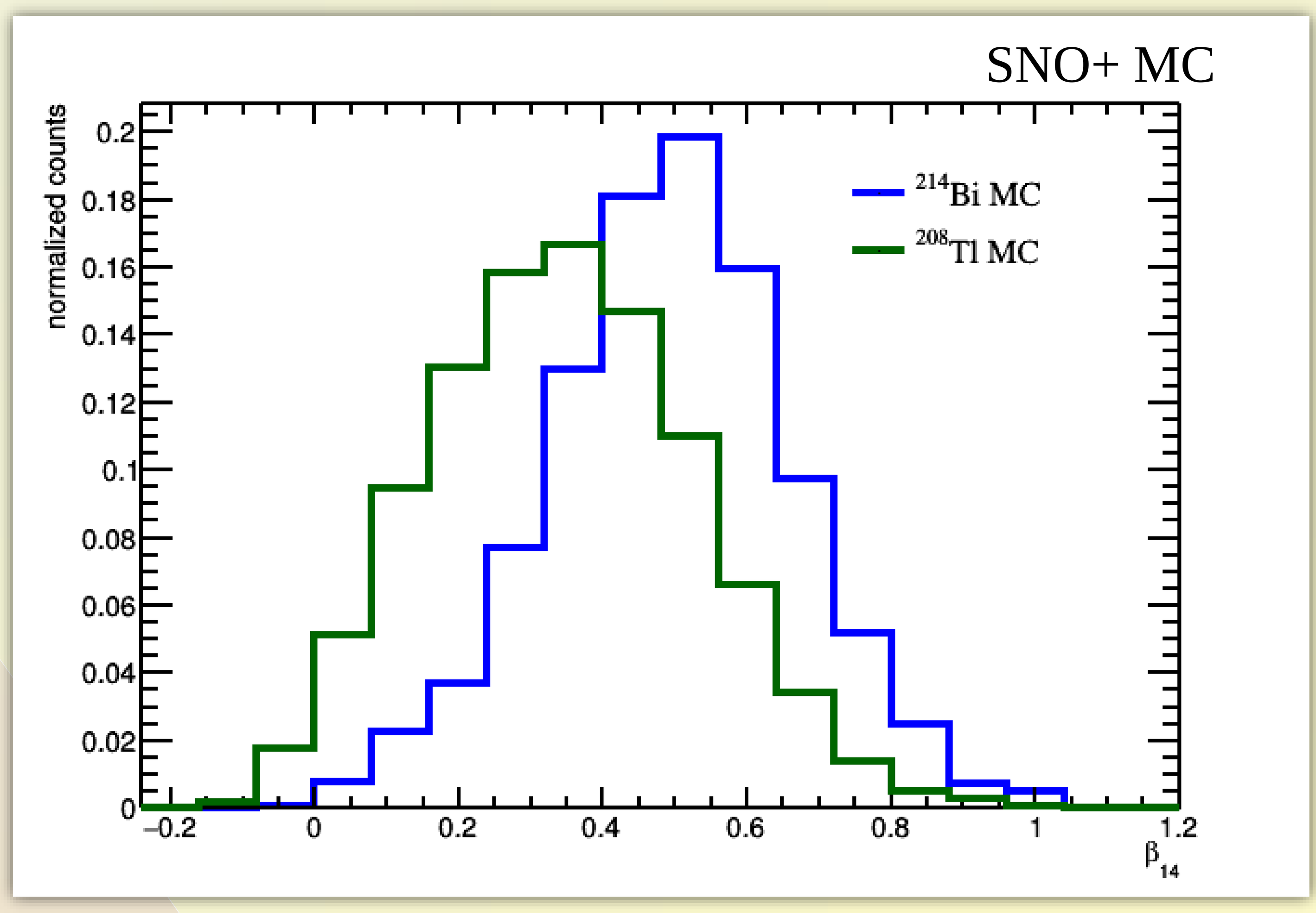


Fig 4: A simulation showing the isotropy distribution for ^{214}Bi and ^{208}Tl. There is a clear difference in the β_{14} spectrum between ^{214}Bi and ^{208}Tl, with ^{208}Tl being more isotropic that ^{214}Bi.

Preliminary Results

- The results of the energy sideband internal backgrounds analysis carried out on a subset of the water data, converted to equivalent parent concentration assuming secular equilibrium:

> - gU/gH2O = $(5.4 \pm 0.7_{(stat)} \pm 2.9_{(sys)}) \times 10^{-14}$
> - gTh/gH2O = < 2.8×10^{-14} (95% upper C.L.)

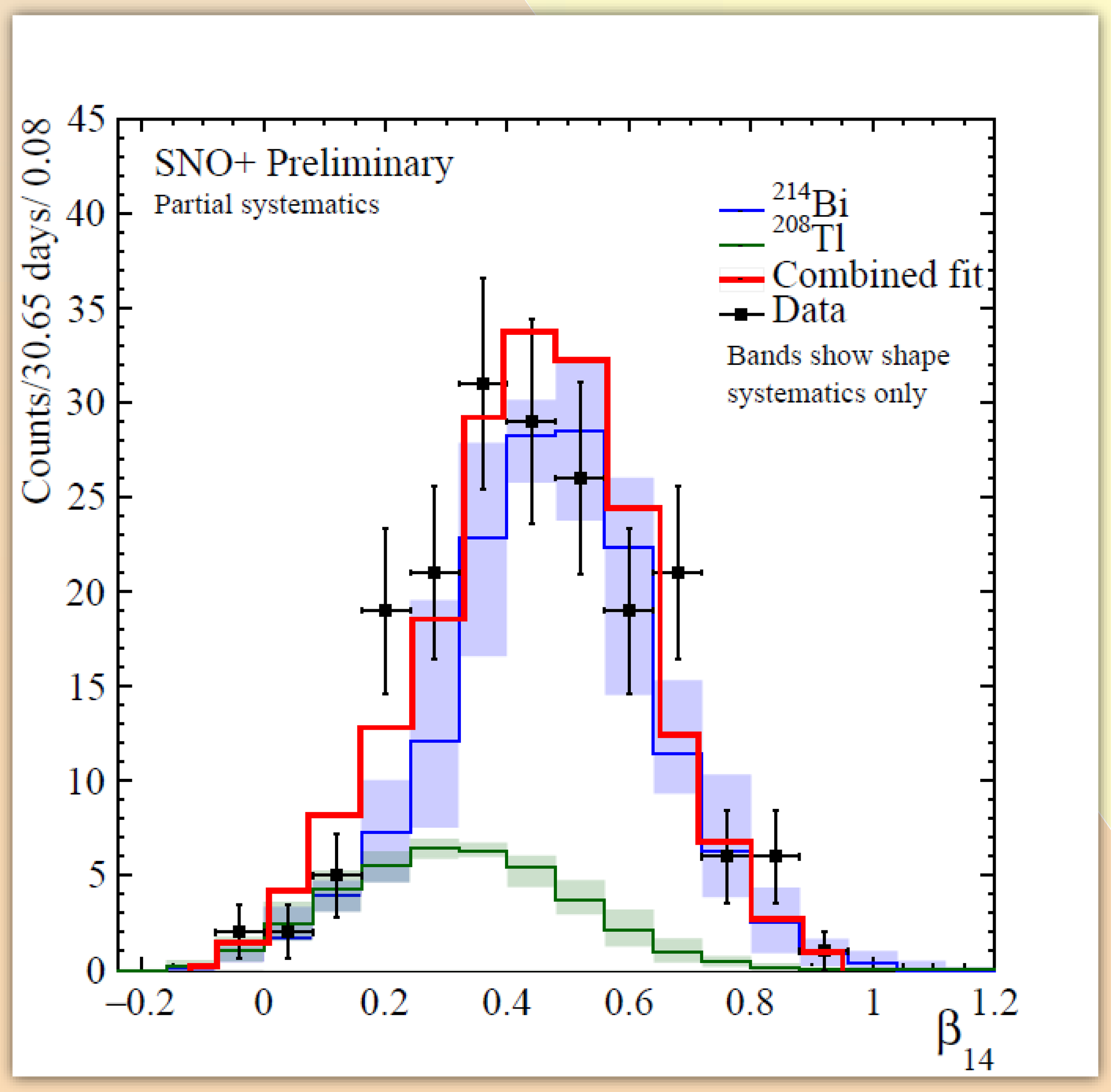


Fig 5: The fitted isotropy distribution of the events in the energy sideband analysis for a subset of the water data. The colored bands represent the systematic uncertainties in the expected isotropy distribution.

Conclusion

- Method of using isotropy to distinguish Bi and Tl shown to work.
- Internal backgrounds results are consistent with our target levels for nucleon decay analysis.

[1] Andriga, S, et al., *"Current Status and Future Prospects of the SNO+ Experiment"*, Advances in High Energy Physics, vol 2016.
[2] Araki, T, et al. (KamLAND Collaboration), *"Search for the Invisible Decay of Neutrons with KamLAND"*, Phys. Rev. Lett. **96**, 101802, 2006.
[3] Dunmore, J.A., *"The Separation of CC and NC Events in the Sudbury Neutrino Observatory"*, PhD Theses, 2004.

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