An Alpha-Proton Scattering Model for SNO+ Background Characterization

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Introduction

The SNO+ reactor antineutrino analysis revealed anomalous events near in the 1-2 MeV range.

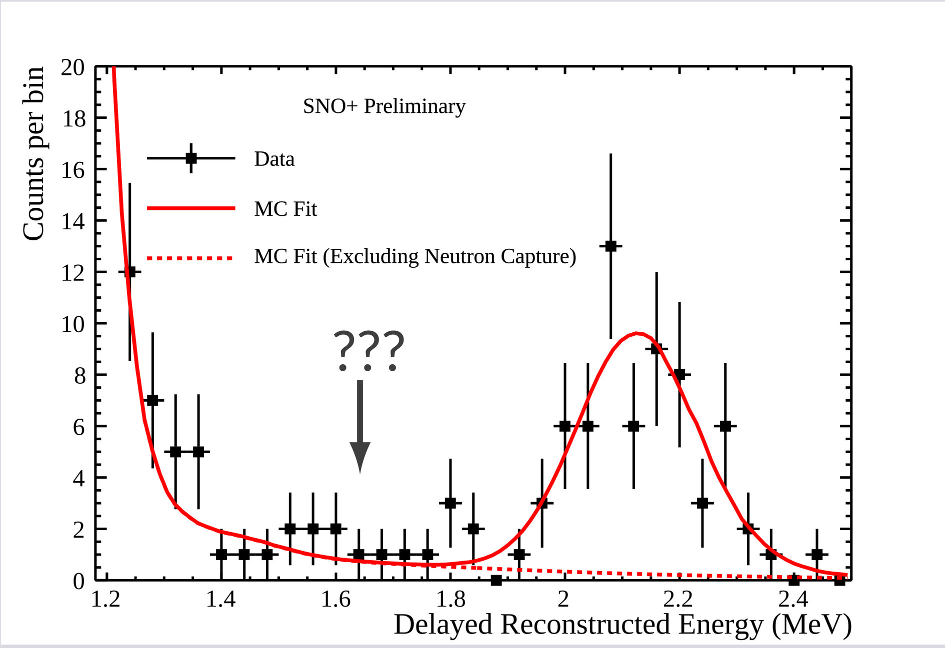


Figure 1. SNO+ sideband backgrounds and data showing the discrepancy. [1]

Initially attributed to a low-energy tail of the 2.2 MeV neutron-capture gamma ray, this feature was later identified as a high-energy tail from $\alpha - p$ scattering, previously unaccounted for due to differing quenching factors.

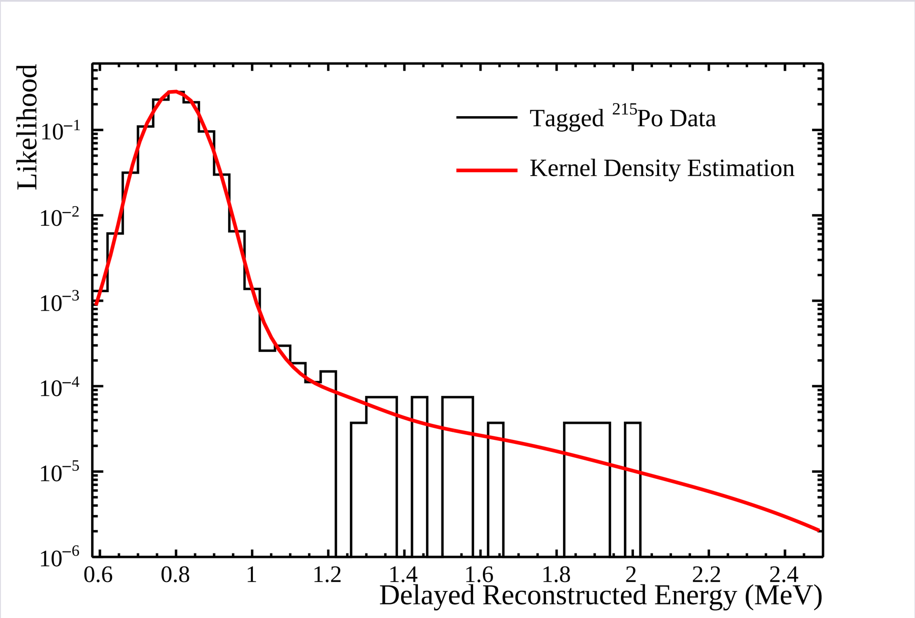
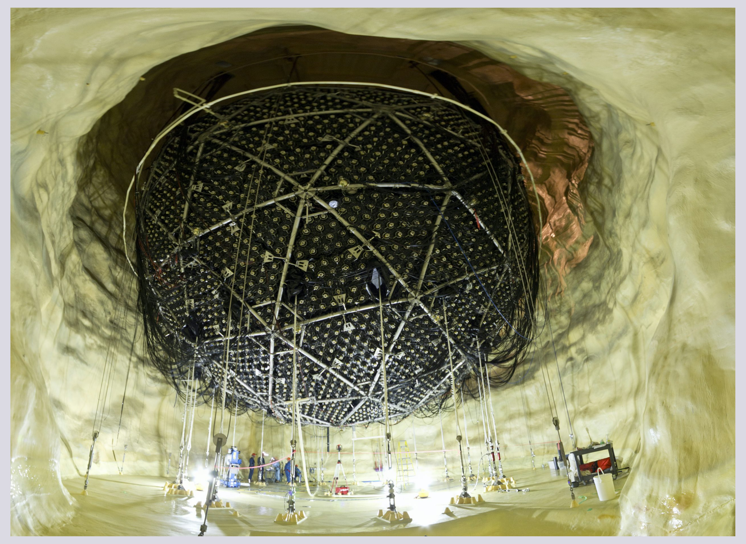


Figure 2. Energy distribution of tagged ^{215}Po events, showing correlation between the anomalous SNO+ background and tagged ^{215}Po alpha events. (Credit: Anthony Zummo [6])

We characterize this background via a GPU-accelerated simulation, forming the basis for an official SNO+ Geant4 generator.

The SNO+ Experiment



SNO+ is a liquid scintillator-based neutrino detector repurposing hardware from the Sudbury Neutrino Observatory[2], with a target medium of linear alkylbenzene[3].

Interaction Cross Section

The $\alpha - p$ elastic scattering cross section was obtained from ab-initio calculations done by [4]. To isolate the effect of the $\alpha - p$ elastic scattering (since SNO+ has an existing model for alpha deposits), we bounded the cross section below based on minimum energy transfer.

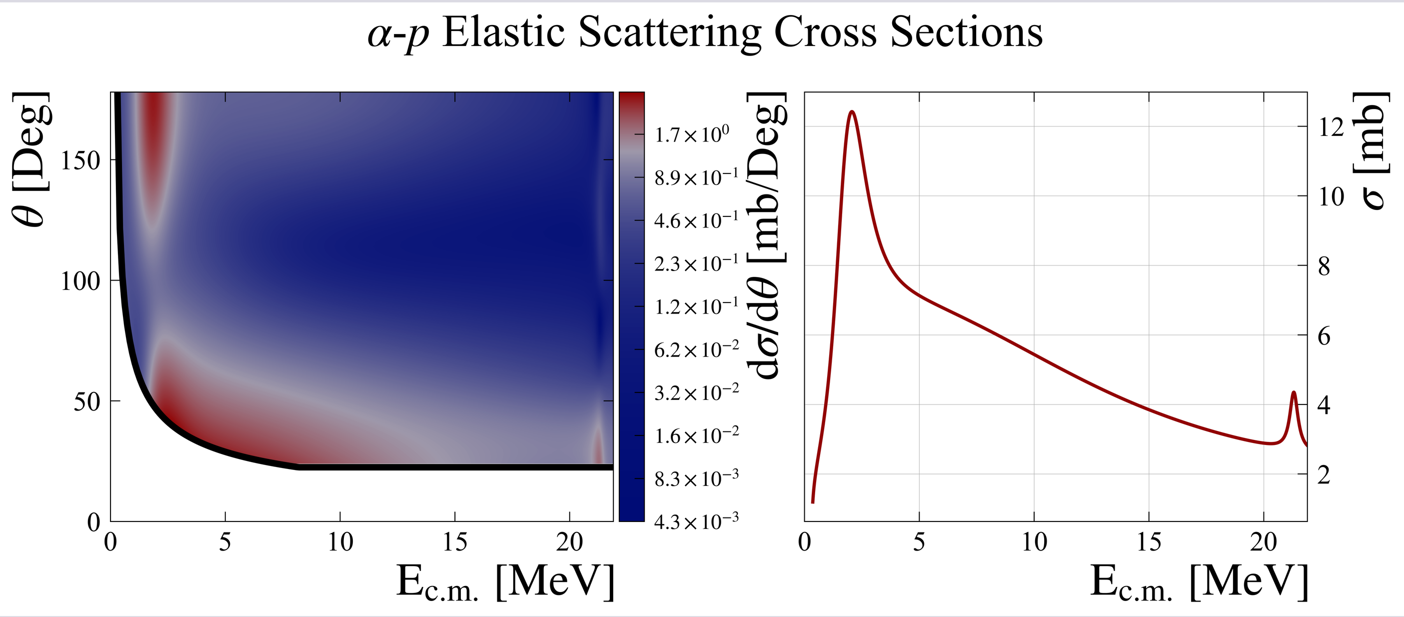


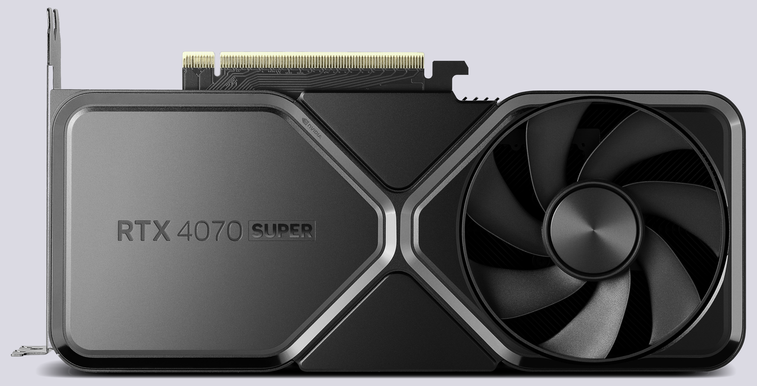
Figure 3. Processed differential (left) and integrated (right) cross sections. The black line on the differential cross section plot indicates the bounds of the cuts made.

GPU-Accelerated Simulation

Due to both the large number of alphas present and the rarity of an $\alpha - p$ event, a high-statistics simulation was required. To enable simulation on the GPU, we rephrased the problem as a matrix-vector comparison problem, using cuRAND[5] for fast random number generation.

$$\begin{bmatrix} 0.3 & 0.01 & 0.8 \\ 0.6 & 0.8 & 0.1 \\ 0.2 & 0.2 & 0.02 \end{bmatrix} \preceq \begin{bmatrix} 0.15 \\ 10^{-7} \\ 0.8 \end{bmatrix} \to \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

Figure 4. Example of the GPU simulation algorithm for a simulation of 3 alpha particles with 3 steps



Results

Running the GPU-accelerated simulation for two initial alpha particle energies representing known alpha backgrounds in SNO+ we obtain the following spectra.

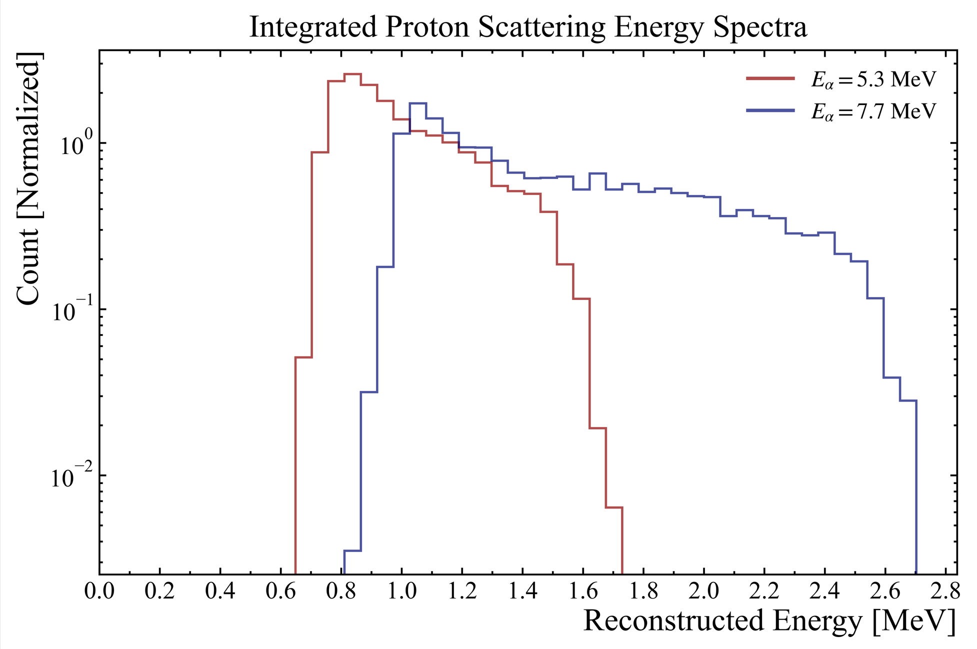


Figure 5. A simulation of the proton energy spectra for alpha particles with initial energy 5.3MeV (blue) and 7.7MeV (red).

When incorporated into the background model, these spectra improve the agreement of the model with detector data. This supports the $\alpha - p$ elastic scattering hypothesis and motivates further investigation.

Acknowledgements

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References

[1] M. Abreu et al. Measurement of reactor antineutrino oscillation at SNO+. *Phys. Rev. Lett.*, 135:121801, Sep 2025.

[2] V. Albanese et al. The SNO+ Experiment. *Journal of Instrumentation*, 16(08):P08059, August 2021.

[3] M.R. Anderson, S. Andringa, et al. Development, characterisation, and deployment of the sno+ liquid scintillator. *Journal of Instrumentation*, 16(5):P05009, May 2021.

[4] Guillaume Hupin, Sofia Quaglioni, and Petr Navrátil. Predictive theory for elastic scattering and recoil of protons from ^{4}He. *Phys. Rev. C*, 90:061601, Dec 2014.

[5] NVIDIA Corporation. *cuRAND :: CUDA Toolkit Documentation*, 2026.

[6] Anthony Zummo. *Measurement of Reactor Antineutrino Oscillation With SNO+*. PhD thesis, University of Pennsylvania, 2024.

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