Search for Coherent Neutrino Nucleus Scattering at MINER using Sapphire (Al_2O_3) Detector and a 1 MW_{th} Reactor

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Introduction

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) is a neutral-current weak interaction predicted in 1974 [1], which occurs when the momentum transfer is small ($|\vec{q}| \lesssim 1/R_N$). At this momentum, the de Broglie wavelength associated with the neutrino is comparable to or larger than the size of the nucleus. The differential cross section is given by [2]

$$\frac{d\sigma}{dT}(E_\nu, T) = \frac{G_F^2 M}{4\pi}\left(1 - \frac{MT}{2E_\nu^2}\right)\left[F(Q^2)\mathscr{Q}_W\right]^2, \quad (1)$$

where E_ν is the neutrino energy, T the recoil energy, M the nuclear mass, $F(Q^2)$ the nuclear form factor, and $\mathscr{Q}_W$ the weak nuclear charge. The cross-section scales approximately with the square of the neutron number, favouring heavy nuclei, though the resulting small nuclear recoils make detection challenging.

CEνNS probes both Standard Model and Beyond Standard Model physics, including neutrino magnetic moments and sterile neutrinos. It was first observed by the COHERENT collaboration in 2017 at the Spallation Neutron Source [3], and more recently by CONUS+ using reactor $\bar{\nu}_e$ [4]. Here, we report on a CEνNS search with MINER at the Texas A&M TRIGA reactor and outline prospects for enhanced sensitivity with the upcoming MINER@HFIR deployment at Oak Ridge National Laboratory.

MINER experiment and analysis results

The Mitchell Institute Neutrino Experiment at Reactor (MINER), located at the Texas A&M University Nuclear Science Center, is a reactor-based CEνNS experiment using a 1 MW_{th} TRIGA reactor fueled with 20% LEU. Reactors produce a large flux of antineutrinos ($\bar{\nu}_e$) via fission fragment beta decay of mainly four isotopes, ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu. The experimental setup was positioned at a baseline of $\sim$4 m as shown in Fig. 1 (*Top left*).

The detector system comprises three cryogenic sapphire detectors in a tower configuration, operated at mK temperatures, with the 4 mm primary detector sandwiched between two 10 mm veto detectors for background rejection (Fig. 1 (*Top right*)).

Data collected between August and September 2022 correspond to exposures of 158 g-days (reactor ON) and 381 g-days (reactor OFF). Reactor-ON data contain both CEνNS signal and background, while reactor-OFF data benchmark environmental and cosmic backgrounds. After reconstruction, calibration, and various selection criteria, the resulting spectra are shown in Fig. 1(*Bottom left*). Using the reactor ON–OFF residual spectra, the observed event rate exceeds the SM CENS prediction by about $\mathscr{O}(10^3)$, limiting sensitivity, and indicating that the data is dominated by background. The statistical ON–OFF subtraction shows reactor-correlated backgrounds dominate the signal region. To investigate this, we developed a GEANT4 simulation framework. Reactor gammas and fast neutrons were generated from the reactor core using the MCNP-based gamma and neutron spectra [5], and their induced backgrounds were estimated in our primary detector. Figure 1 (bottom right) compares measured data with simulated reactor-induced backgrounds, showing a spectrum dominated by reactor backgrounds, with fast neutrons contributing $> 90\%$.

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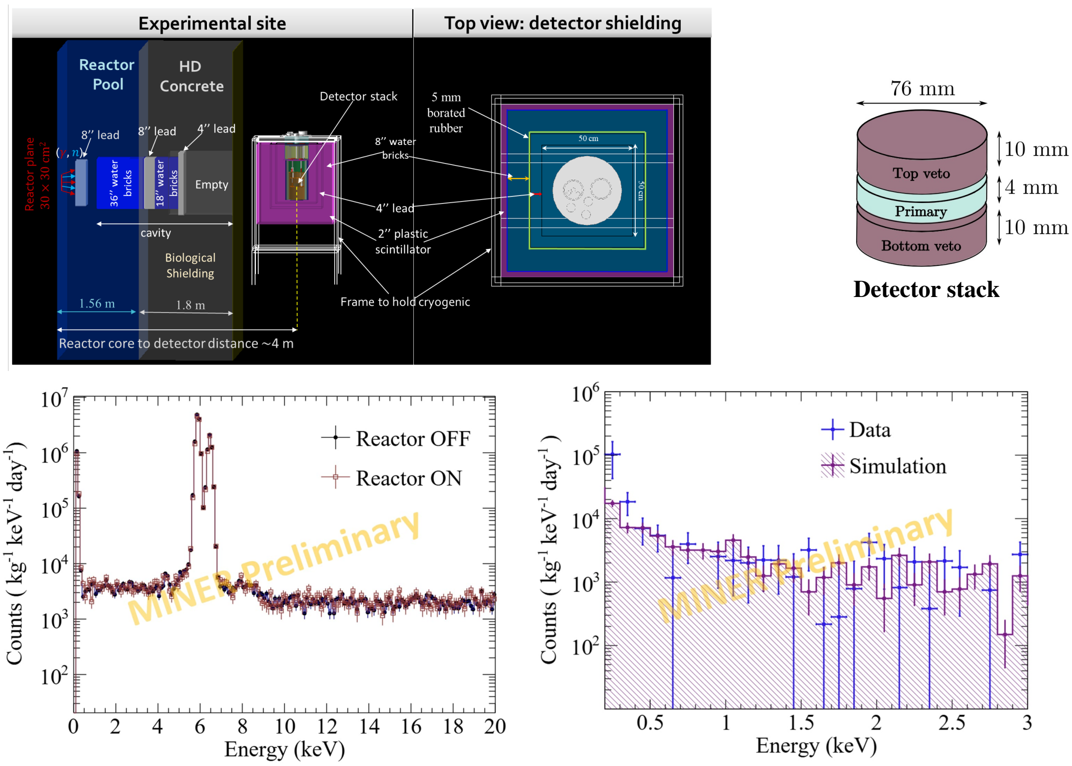

FIG. 1: *Top left*: Illustration of the experimental site. *Top right*: Schematic of the detector stack. *Bottom left:* Reactor ON and OFF energy spectra shown per keV per kg per day in the 0–20 keV range. *Bottom right*: Comparison of simulated single-scatter spectra from neutron and gamma backgrounds (GEANT4) with the measured spectrum in the primary detector.

Conclusion and Outlook

The current MINER setup shows limited sensitivity, with backgrounds dominating the signal region and the observed rate exceeding the Standard Model CEνNS prediction. To improve sensitivity, the experiment will relocate to the 85 MW_{th} HFIR at Oak Ridge (5 m baseline) with increased detector mass and compact shielding, where a 3σ observation is projected with 30 kg $\cdot$ day exposure. Commissioning is planned for late 2025 to enable CEνNS cross-section measurements and precision studies.

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