Snowmass2021 - Letter of Interest
MIνER CEνNS Experiment - A Tool for Discovery of New Physics and Applied Reactor Monitoring

MINER Collaboration[1]

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The Mitchell Institute Neutrino Experiment at Reactor (MIνER) experiment was launched to use cryogenic germanium and silicon detectors with a low nuclear recoil energy thresholds to register nuclear recoils of coherent elastic neutrino-nucleus scattering (CEνNS) at a TRIGA research nuclear reactor at the Texas A&M University. The CEνNS process allows detectors to be of kg-scale compared to usual kilo-ton scale neutrino detectors. This reactor has a movable core (1 m to 10 m) that will allow precision studies of very short baseline neutrino oscillation by comparing rates as a function of distance and largely eliminating reactor flux uncertainties. Close proximity of the detector to the reactor core, combined with multiple low threshold detectors with event-by-event discrimination between the dominant electromagnetic background and the nuclear recoil signal provides a world-leading sensitivity for physics beyond the Standard Model, sterile neutrinos that oscillate away on a few-meter scale, and above all a highly sensitive probe for applied reactor monitoring for safeguards and non-proliferation. Planned deployment of the MINνER experimental set up at the South Texas Project (3 GW) power reactor will provide significant further improvement in measurement sensitivity.

Neutrino Frontier Topical Groups:	(NF01) Neutrino Oscillations (NF02) Sterile neutrinos (NF03) Beyond the Standard Model (NF06) Neutrino Interaction Cross Sections (NF07) Applications (NF10) Neutrino Detectors (RF06) Dark Sector Studies at High Intensities

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The detection of neutrinos via new interaction channels, in new energy realms, have historically led to the discovery of physics beyond the Standard Model (SM) and to new insights into astrophysical sources. This has most famously been manifested in the fields of solar neutrinos and atmospheric neutrinos, which led to the discovery of non-zero neutrino mass. Neutrinos are now being identified from extragalactic sources, opening up a high energy realm that has been previously unaccessible. At the lowest accessible energies, neutrinos also provide a window into beyond SM physics, in particular through the detection of Coherent Elastic Neutrino Nucleus Scattering (CEνNS). This process is not only important for new physics searches through the neutrino sector, but also important because it sets a possible ultimate background for direct dark matter detection.

The Mitchell Institute Neutrino Experiment at Reactor (MIνER) is a reactor based experiment at Texas A&M university that combines well-demonstrated low-threshold cryogenic detectors developed for the SuperCDMS dark matter search with a unique megawatt research reactor that has a movable core providing meter-scale proximity to the core [1]. The low-threshold detectors ($\approx$100 eV recoil energy) will allow detection of coherent scattering of low energy neutrinos that is yet to be detected in any reactor experiment. These high resolution detectors, combined with a movable core, provide the ideal setup to search for short-baseline sterile neutrino oscillation by removing the most common systematic in current experiments, the reactor flux uncertainty. Very short baseline oscillation will be explored as a ratio of rates at various distances, with expected SM rates and known scaling of background. Hence MIνER will be largely insensitive to absolute reactor flux. Additionally, low variation in a MW research reactor power combined with meter-scale proximity to the core provides much better systematics compared to a GW power reactor, where the typical detector to core distance is of the order of 30 meters or higher resulting in similar neutrino flux incident on a detector. Utilizing multiple targets (Ge/Si) allows for detailed understanding of the signal and backgrounds in the experiment. Precise understanding of the background is important for searches of Non Standard Interactions (NSI) through a small additional signal.

Phase-1 of the MIνER experiment is already operational as a demonstration experiment with a kg-scale payload at a distance of approximately 4.5 m from the reactor core, that would provide a signal rate approaching 1000 events per year and a target background of 100 counts/keV/kg/day (DRU) [1]. Phase-2 of the MIνER experiment experiment will have a 10 kg-scale at the planned site at South Texas Project nuclear power reactor (3 GW). The operational kg-scale demonstration phase provides an excellent demonstration of the detector technologies that offer unprecedented combination of low threshold and discrimination between electron recoil/nuclear recoil events using a newly developed hybrid detector technology. There are two newly developed technologies in use in the MIνER experiment currently in operation - (a) Phonon-mediated silicon detector technology that provides a primary phonon measurement in a low-voltage region, and a simultaneous indirect measurement of the ionization signal through Neganov-Trofimov-Luke amplification in a high voltage region, both in a monolithic crystal [2], (b) Single-e sensitive high voltage detector using a contact free electrode design that allows for operation up to 400 V with minimal leakage current. [3].

The ionization to phonon energy ratio has been used as the discriminator in CDMS and the SuperCDMS experiments [4]. For the ionization measurement, due to the inherent high impedance readout noise that depends on the equivalent capacitance of the detector and the readout front-end amplifiers, this discrimination ceases to be effective for energies below a few keV. The ionization readout noise limitation can be solved by indirect detection of ionization via the measurement of the phonons released during the charge carriers' drift in the bulk of the Ge or Si crystals. This Neganov-Trofimov-Luke (NTL) phonon energy gain [5] scales linearly with the bias voltage while the phonon readout noise stays the same, up to the level where leakage current becomes the dominant noise. SuperCDMS high voltage (HV) detectors use this very low noise technology in order to detect recoils down to 100 eV and to achieve world-leading sensitivity to low-mass WIMPs ($< 10GeV/c^2$) [6]. Our recently demonstrated hybrid design takes advantage of this method to indirectly measure ionization while simultaneously measuring recoil phonons in order to discriminate signal from background event-by-event.

The MIνER experiment aims to become the first experiment to measure CEνNS at a reactor and may open windows to much exciting new physics of immediate interest:

- **Precision CEνNS** with high statistical ($\sim$1,000 events/kg/year and systematic precision using low-threshold semiconductor detectors (Ge/Si) at close proximity ($\approx$2-5 m) to core and passive/active shielding. Our measurements would be an independent confirmation of recent observations by the COHERENT Collaboration and provide important complimentarity to the prompt muon neutrino signal at SNS to constrain NSI.
- **Search for sterile neutrinos** as a possible deficit in predicted Standard Model rates using a precisely movable core. MIνER's very short baseline (1–10 m) search provides important complementarity to the PROSPECT non-coherent (IBD process) search.
- **Search for light and heavy Z' and NSI**. For light Z' down to a mass scale of 1 MeV, the sensitivity can improve upon that of fixed target and atomic parity violation experiments. For heavy Z' up to a mass scale of 4 TeV, the sensitivity is competitive with and complementary to LHC searches. Due to different flavor composition, the sensitivity to light and heavy Z' and NSI will be complementary to that of the COHERENT experiment.
- **World-leading sensitivity to axion search** MIνER will have visibility to ALP decays and inverse Primakoff and Compton scattering, providing sensitivity to the ALP-photon and ALP-electron couplings. We find that the sensitivity to these couplings exceeds existing limits set by laboratory experiments over a large portion of the sub-MeV ALP mass range. [7].

The primary obstacles to detection of at a reactor are: a) availability of low-threshold detector technology, b) backgrounds, and c) proximity to the core. The MINER experiment is designed to address all three of these challenges building on the excellent demonstration of low-threshold detector technology, shielding-based background reduction and detector-based background rejection of the SuperCDMS dark matter search experiment. The experiment is pursued by a multi-institutional collaboration, taking advantage of the broad expertise of the collaboration members in experimental techniques in neutrino, nuclear, and dark matter physics. Members of this collaboration are among key contributors to recent advances in developing ultra-sensitive high-purity cryogenic semiconductor detectors.

The initial CEνNS event sample at 4.5-m will have a relatively high statistics.We will then take advantage of the movable core of the NSC reactor that is installed on a gantry. The core can be moved between 2and 10 m that gives about a factor of 5 range in L/E which controls the Δm^2 sensitivity. Although, we can run at any specific distance (2-10 m) from the core, our run plan will be optimized for testing the currently interesting parameter space [8]. Depending on the energy threshold that our detectors can reach, our experiment can provide significant, if not decisive, constraints on the LSND effect.

MINER may have sensitivity to additional rate contribution from possible heavy Z' [9]. MINER will also be sensitive to light (less than 1 GeV) Z', which may couple directly to quarks and neutrinos, or through mixing effects which may be induced at high energies. MINER will be complementary to COHERENT in probing of heavy NSI; this complementarity is because MINER is sensitive to NSI through $\bar{\nu}_e$, which COHERENT is sensitive to ν_e and muon-type neutrinos. Overall, the sensitivity to light mediators is a very attractive aspect of the MINER experiment, providing important complementarity to other such constraints to the COHERENT, Atomic Parity Violation, and fixed target experiments. Similarly, a search for neutrino magentic moment will require significantly lower detector threshold which have only recently become available in the collaboration. Both of these searches are feasible with precision measurements with large statistics and improved systematics in a few years of running, aided by continually improving detector technology being developed for our dark matter search experiment.

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