Measuring coherent-NCνAs at Fermilab

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The coherent Neutral Current Neutrino Nucleus scattering (coherent-NCνAs) has never been observed since its first theoretical prediction in 1974 by D. Freedman. The condition of coherence requires sufficiently small momentum transfer to the nucleon so that the waves of off-scattered nucleons in the nucleus are all in phase and add up coherently. While interactions of neutrino energy in MeV to GeV-scale will have coherent-NCνAs components, neutrinos with energies less than 50 MeV largely fulfill the coherence condition in most target material with nucleus recoil energy of tens of keV. The elastic neutral current interaction, in particular, leaves no observable signature other than low-energy recoils off the nucleus. Technical difficulties of developing a large scale, low-energy threshold and low-background detector have hampered the experimental realization of the coherent-NCνAs measurement for more than three decades. However, recent innovations in dark matter detector technology have made the unseen coherent-NCνAs testable.

The proposed liquid argon neutrino detector is conceptually similar to dark matter detectors of the similar type. The detector will utilize pulse-shape discrimination of scintillation light between nuclear recoil and electron recoil interactions (and ionization yield) in the liquid argon to identify coherent-NCνAs interactions out of background events. The majority of electromagnetic and neutron backgrounds will be rejected using the standard active and passive shielding methods together with self-shielding fiducialization.

Well-defined neutrino sources are the other essential component to measure coherent-NCνAs. Fermilab has two major neutrino beam-lines; the Neutrinos at the Main Injector (NuMI) and the Booster Neutrino Beam (BNB). The energy range of these two neutrino sources at on-axis is about GeV which is the proper neutrino energy scale to evaluate atmospheric neutrino backgrounds in dark matter searches, where the coherent-NCνAs recoil energy scale is <500 keV. On the other hand, low-energy (<~50 MeV) neutrinos can be obtained through by-product neutrinos at the far-off-axis (> 45 degrees) of the BNB. The BNB source has a substantial advantage over the NuMI beam source owing to the suppressed kaon production from the 8 GeV (8~32 kW) of relatively low-energy proton beam on the target. Therefore, pion-decay and subsequent muon-decay processes are the dominant sources of neutrinos. At the far-off-axis area, the detector can be placed close enough to the target to gain an inverse-distance-squared increase of the neutrino flux. The pulsed structure of the neutrino beam leads to a substantial advantage in background reduction ($\sim 10^{-6}$) against steady-state cosmogenic and radiogenic backgrounds.

The R&D effort would result in a experiment that could go on to make the first observation of coherent-NCνAs; a step forward to comprehend the least understood fundamental particle, the neutrino. The successful experimental results of coherent-NCνAs and associated background measurements in energy range of solar and atmospheric neutrinos will be immediately useful for dark matter search experiments. The far-off-axis neutrino source, incorporated into Fermilab's future Intensity Frontier framework (e.g. Project-X's 8 GeV and 0.3 MW proton beam), may provide a well-defined intensive low-energy neutrino source. Observation of any significant deviation from the predicted neutrino-nucleus scattering amplitude would be an indication of physics beyond the Standard Model. Moreover, the entire sector of dark matter searches will face substantial retreat in the detector sensitivity and will require a new strategy for the next generation dark matter program.