Snowmass 2021 Letter of Interest: Towards Directional Nuclear Recoil Detectors: Tracking of Nuclear Recoils in Gas Argon TPCs

David Caratelli, Angela Fava, Roni Harnik, Pedro Machado, Jennifer Raaf, Jacob Zettlemoyer
Fermi National Accelerator Laboratory, Batavia, IL 60510
Contact Person: David Caratelli (davidc@fnal.gov)
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With the observation of coherent neutrino nucleus scattering (CEνNS) [1,2], and direct Dark Matter (DM) searches nearing the "neutrino floor", the measurement of nuclear recoils (NRs) in weak interaction physics has emerged as a powerful tools for probing fundamental physics in particle and nuclear physics. Advancing the capabilities of measuring NRs can further push the potential of experiments which aim to rely on this feeble signature. With this letter, we aim to express interest in advancing an R&D program which intends to study the feasibility of, and help achieve the measurement of NR directionality by tracking their ionization signatures in gaseous argon TPCs.

The ability to measure the direction of NRs, in addition to their energy, allows to fully constrain the kinematics of elastic interactions. In the case of CEνNS interactions, measuring the recoil energy and direction would allow to reconstruct the incoming neutrino's energy, shifting CEνNS measurements from performing counting experiments to full spectral measurements. Furthermore, directional detection of NRs can help improve background rejection, whether these be neutron-induced recoils in beam CEνNS measurements, or CEνNS backgrounds in future direct DM searches.

The authors of this letter are focused on developing detectors capable of tracking the O(10-100) μm ionization tracks produced by O(10-100) keV NRs from CEνNS interactions in gaseous argon employing high-granularity GEM-based GAr TPCs. Such a detector would enable a broad range of physics measurements in focused neutrino beams of O(100) MeV neutrinos as well as high-intensity stopped pion neutrino sources which are currently available or will be operational in the coming years at facilities such as the SNS at Oak Ridge National Lab and in Fermilab's next-generation neutrino beamline. A particularly interesting scenario would envision augmenting, through this effort, a DUNE-like GAr TPC detector in order to measure CEνNS interactions from sub-100 MeV neutrinos in a future underground near-detector experimental hall at Fermilab.

GAr detection of NRs is an active area of R&D with several known efforts known to us focused primarily on the application to dark matter searches [4,5,6]. This effort aims to directly collect the charge generated by NRs as opposed to the proportional light generated during amplification of the charge in the directional dark matter searches in Refs. [4,5]. The technological challenges to be addressed in order to ensure the proposed detector's ability to perform physics measurements of CEνNS events in the mentioned beamlines are:

1. Achieving O(10s) of keV thresholds in the ionization energy-loss channel in argon.
2. Achieving large enough event rates within the limitations of detector size to enable a positive observation of CEνNS events.
3. Achieving the spatial resolution needed to track the direction of NRs in GAr.
4. Though not the scope of this specific LOI, the availability of powerful beamlines capable of delivering high intensity neutrino rates with a large duty cycle plays an important role in assessing feasibility.

Achieving these goals requires optimization of several detector components. The R&D effort being proposed aims to address these by optimizing the gas pressure and exact gas mixture for the detector which impact spatial resolution, total event rate, and tracking potential for NRs. Development of GEM design focussed on optimizing the detection of NRs in particular is another important aspect of this program.

While proposing a specific experimental R&D effort in this letter, we are broadly interested in joining and contributing to build a wider community which has shown interest in developing detection techniques for NRs and explored the physics benefits which such a technological advance can bring [3]. We look forward to collaborating, within the SNOWMASS process, with all those sharing interest in the physics and R&D goals presented here.

[1] "Observation of coherent elastic neutrino-nucleus scattering", COHERENT Collaboration, Science, Vol. 357, Issue 6356, pp. 1123-1126.

[2] "First Detection of Coherent Elastic Neutrino-Nucleus Scattering on Argon", COHERENT Collaboration, arXiv:2003.10630.

[3] M. Abdullah et al., "Coherent Elastic Neutrino-Nucleus Scattering with directional detectors", Phys. Rev. D 102, 015009 (2020)

[4] CYGNUS Collaboration [https://web.infn.it/cygnus/], "*CYGNO: a CYGNUs Collaboration 1 m3 Module with Optical Readout for Directional Dark Matter Search*", INFN-19/2/LNF, arXiv:1901.04190.

[5] CYGNUS Collaboration, [https://web.infn.it/cygnus/], "CYGNO: a gaseous TPC with optical readout for dark matter directional search", arXiv:2007.12627.

[6] Y. Tao et al., "Dark Matter Directionality Detection performance of the Micromegas-based TPC-MIMAC detector", arXiv:2003.11812.