Snowmass LOI: Data Acquisition and Trigger Enhancements for Low-Energy Events in DUNE

A. B. Balantekin[1], G. Barr[2], N. Barros[3], J. F. Beacom[4], N. Buchanan[5], D. Kalra[6], C. David[7,8], R. Dorrill[9], A. C. Ezeribe[10], W. Foreman[9], A. Friedland[11], S. Gardiner[7], A. Habig[12], T. Junk[7], G. Karagiorgi[6], W. Ketchum[7], J. Klein[13], T. Kutter[14], A. Major[15], C. Mariani[16], A. Mastbaum[17], B. Messer[18], M. Nebot[19], S. W. Li[11], B. Littlejohn[9], M. Mooney[5], S. Peeters[20], G. Petrillo[11], J. Reichenbacher[21], K. Scholberg[14], M. Shaevitz[6], K. Terao[11], N. Tran[7], Y. Tsai[11], M. Wang[7], A. Weinstein[22], W. Wu[7], and T. Yang[7]

[1]University of Wisconsin, Madison
[2]University of Oxford, UK
[3]Laboratory of Instrumentation and Experimental Particle Physics, Lisbon, Portugal
[4]Ohio State University
[5]Colorado State University
[6]Columbia University
[7]Fermi National Accelerator Laboratory
[8]York University
[9]Illinois Institute of Technology
[10]University of Sheffield, UK
[11]Stanford Linear Accelerator Laboratory
[12]University of Minnesota, Duluth
[13]University of Pennsylvania
[14]Louisiana State University
[15]Duke University
[16]Virginia Tech
[17]Rutgers University
[18]Oak Ridge National Laboratory
[19]University of Edinburgh, UK
[20]University of Sussex, UK
[21]South Dakota School of Mines and Technology
[22]Iowa State University

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1 Introduction

In less than five years, the Deep Underground Neutrino Experiment (DUNE) community will be commissioning the first of its four liquid argon (LAr) time projection chamber far detector modules, 1.5 km underground at Sanford Lab in South Dakota. The DUNE Far Detector will be generating an unprecedented amount of data, in the form of a continuous, unbiased, and high-resolution "video" of ionization charge and scintillation light depositions within the detector's ultimate 40 kton-fiducial-mass LAr volume. Hidden within this data will be the signatures of thousands of neutrino interactions from the world's highest intensity neutrino beam, and, each year, tens of thousands of atmospheric neutrino interactions and millions of cosmic rays. At low energies (~ 10 MeV), there will be tens of thousands of solar neutrino interactions each year, and, if we are fortunate enough, there will also be rare signals of interactions of neutrinos from nearby supernova bursts or other astrophysical events. The LAr target of DUNE is special when it comes to neutrinos in this low energy regime, because ν_e's in this energy range have a large and exclusive charged-current cross section [1].

The current DUNE Far Detector is designed to target galactic supernova bursts, with current standard reconstruction tools resulting in a visible energy threshold of several MeV. The capabilities for low-energy reconstruction are reasonably well demonstrated with full readout, such as would follow a burst trigger. However more challenging is efficient triggering on individual neutrino events, both for the formation of a burst trigger (which consists of multiple individual events occurring in time coincidence) and for the selection of single, isolated low-energy events. With appropriate detector and data acquisition system developments, much of which are already ongoing, the reach of DUNE can be expanded to provide access to rare and low-energy events down to the ~ 1 MeV visible energy range.

Examples of such developments include a more sophisticated, powerful, and intelligent trigger (or "data selection") system, benefiting particularly from recent developments in machine learning and specialized data processing accelerators, used to extract these low-energy signals from abundant radiological backgrounds and detector noise (see, e.g. [2, 3, 4], and related efforts for other experiments or more broadly, e.g. [5, 6]). Another example is the use of low-radioactivity argon in one of the detector modules to minimize radiological backgrounds (see, e.g. [7]). Enhanced neutron shielding is another possible concept. For a partial list of such new community-driven ideas and efforts, see [8].

Through this Letter of Intent, we wish to express the interest of a broad community (both within and outside the DUNE collaboration) to continue and strengthen these efforts, in particular on Data Acquisition and Triggering, in order to expand the DUNE Far Detector's reach and deliver physics measurements that lie beyond what is currently targeted as part of the DUNE scientific scope.

2 Science Motivation

Access to low energy signals present in DUNE's data will lead to an enhanced beyond-Standard-Model, multi-messenger, and solar neutrino physics program with DUNE, and would benefit a number of scientific communities. Examples include:

- Physics associated with solar neutrinos: DUNE is in unique position to make measurements of solar neutrino mixing parameters and investigate the tension between reactor-based and past solar neutrino measured parameters, with high statistics (approximately 120 solar neutrino charged current ν_e interactions are expected in DUNE, daily). With sufficiently low energy detection threshold and low radiological and neutron backgrounds, DUNE may have access to the transition region between matter-enhanced and vacuum mixing, giving sensitivity to physics such as flavor-changing neutral currents or medium-range forces, which interplay with the interferometric effects of neutrino oscillation. Higher-energy solar neutrinos will provide access to day-night asymmetry measurements of neutrinos passing through the earth, and matter-enhanced oscillations (see, e.g. [9]).

- Physics associated with supernova neutrinos: Core-collapse supernovae will create bright, few-tens-of-second bursts bursts [1]. Lower energy thresholds, better reconstruction and background suppression will improve late-time physics within the burst [10] and help improve supernova distance reach. Thermonuclear supernovae [11, 12] are a faint target for which low-energy event detection will improve sensitivity. The low-energy presupernova neutrino flux will benefit from enhanced triggering capabilities [13]. Binary neutron star mergers will also create low-energy neutrinos [14].

- Multi-messenger astronomy: Different messengers (neutrinos, gravitational waves, or photons) provide unique, frequently complementary constraints on models of astrophysical processes, as they are associated with different phases of a rare astrophysical event, or from different processes and interactions of different particle populations within such event. Concurrent observation of an astrophysical phenomenon with multiple messengers allows for multiple probes to constrain theoretical/systematic uncertainties, and access to otherwise inaccessible physics. DUNE has a full-sky view and potential for providing directionality information to other observatories for pointing toward specific astrophysical events [15]; it may also participate in combined-detector pointing via triangulation [16]. Directionality can also be used for presupernova signals [13]. Enhancements to the trigger system can be made to provide such information promptly and accurately.

- Beyond-Standard-Model physics: One proposed method to look for heavy sterile neutrinos is by detecting "kinks" in beta decay spectra, a method that can also be used to probe the absolute mass scale for SM neutrinos [17]. A search of this nature can be done at DUNE using ^{39}Ar beta decays. DUNE's large detector size, use of atmospheric argon (^{39}Ar beta decay rate of 1 Bq/kg [18]), low thresholds (roughly 100 keV), and good energy resolution from low TPC noise levels (roughly 50 keV [19]) will allow for a search for sterile neutrinos in the 20 keV to 450 keV mass range. While a full sensitivity study has not yet been performed, significant improvement in the global limits in this mass range is expected [20, 21]. In order to make use of the full $\mathcal{O}(10^{19})$ decays expected at DUNE, development of enhanced triggering and/or continuous zero-suppressed TPC readout is necessary.

3 Summary

The future DUNE experiment has the potential to be a key player in multi-messenger astronomy, and to further advance searches for beyond-Standard-Model physics through low-energy signatures. Interest exists, both within and outside of the DUNE collaboration, to capitalize on recent developments in detector technology and data processing to enable more physics out of the future DUNE Far Detector. The interested DUNE collaborating institutions plan to submit a Whitepaper to the Snowmass 2021 planning process.

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