Snowmass2021 - Letter of Interest

Mutual Benefits derived from the Application of Neutrino Physics to Nuclear Energy & Safeguards

Neutrino Frontier Topical Groups: (NF02) Sterile Neutrinos
(NF07) Applications
(NF09) Artificial Neutrino Sources
(NF10) Neutrino Detectors

Community Engagement Frontier Topical Groups: (CommF02) Career Pipeline and Development

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The CHANDLER, NuLat, PROSPECT, ROADSTR, SoLid, and WATCHMAN Collaborations and 17 Individuals, representing 76 Institutions.

Full Author list at rear of LOI

Abstract:

Measurements of antineutrinos can provide information about the operation of a nuclear reactor while addressing unknown or unresolved fundamental questions for the Neutrino Physics community. Applications of reactor antineutrino detection technology, the development of which has largely been motivated by the pursuit of fundamental scientific discovery, enables remote monitoring of nuclear reactors which has the potential to support nuclear energy and safeguards programs. Conversely, engagement and support from these application communities could provide additional impetus for investments in improving reactor antineutrino flux predictions and detection technology, benefiting scientific efforts at such facilities. In this LOI, we describe mutual benefits that the scientific and application communities could enjoy from strong and enduring engagement. We encourage all stakeholders in these communities, including their supporting agencies, to explore ways to mutually support efforts at this nexus of neutrino science, nuclear energy, and nuclear safeguards.

Introduction

Measurement of antineutrinos can provide information about the operation of a nuclear reactor as well as addressing important science goals for the Neutrino Physics community. Application of reactor antineutrino detection technology, the development of which has largely been motivated by the pursuit of fundamental scientific discovery, enables remote monitoring of nuclear reactors which has the potential to address nuclear energy and security problems. Conversely, engagement and support from these application communities could provide additional impetus for investments in improving reactor antineutrino flux predictions and detection technology, benefiting scientific efforts at such facilities. In this LOI, we describe mutual benefits that the scientific and application communities could enjoy from strong and enduring engagement. We encourage all stakeholders in these communities, including their supporting agencies, to explore ways to mutually support efforts at this nexus of science, nuclear energy, and nuclear security.

Societal Impact

Antineutrino detection can potentially support the safe and peaceful use of nuclear energy, which presently provides up to one tenth of the world's power with minimal carbon footprint. As the global population grows and carbon emissions are restricted, nuclear energy is considered an attractive option to replace carbon-intensive baseline power sources such as natural gas and coal. However, concern over the misuse of nuclear technologies and materials is one of several impediments to the widespread adoption of this power source. Non-intrusive, remote measurements made with antineutrino detectors may provide the means to increase confidence and transparency by verifying that reactors are being used in a manner consistent with their declared purpose. Antineutrino detection could find application in several parts of the nuclear fuel cycle including monitoring of reactors, spent fuel, and non-fissile breeding blankets. Reactor antineutrino measurements, both for physics and application studies, have demonstrated the capability to identify reactor operational status and changes in fissile fuel inventory in the near-field (10-1000m baseline), and the presence of operating reactors in the far-field ($\sim$ 100km baselines). References to such measurements and several use case studies demonstrating the application of these capabilities to nuclear non-proliferation can be found in [1].

Fundamental Science Impact

The pursuit of fundamental discovery often motivates technology development that then enables new applications; however, in the context of neutrino physics there is the opportunity for the reverse to also occur. For example, detectors with the ability to deploy above-ground and packaged for mobility have been identified as attractive by potential antineutrino monitoring end-users. As described in [1], applications-focused technology R&D in this direction informed the successful design efforts of the current generation of short baseline sterile neutrino searches at reactors which must also operate with limited overburden. Looking towards future possibilities, the deployment of monitoring detectors at different reactor types could provide information to further constrain and improve flux and spectrum predictions. To give a specific example, an antineutrino-based power diagnostic for the forthcoming Versatile Testbed Reactor could support the materials science mission of that facility, while also measuring the antineutrino emissions from a reactor with exotic fuel types and non-traditional incident neutron energies [2].

Mobile detectors able to measure spectra with common systematic uncertainties would be especially beneficial and have obvious appeal for applications. Finally, if antineutrino detection is adopted as a means to monitor reactors at 10-100km standoff, this may present an opportunity for oscillation measurements at unique baselines that could reduce uncertainties on neutrino mixing parameters. Furthermore, such detectors could contribute to the Supernova early warning system.

Technology Development

Fundamental and applied neutrino science can both benefit from advances in detection technology. Co-operation on common goals and techniques can enable new physics probes and expand the application space of antineutrino detection. Methods to reduce backgrounds and improve the energy resolution and efficiency of detectors utilizing Inverse Beta Decay (IBD) would improve the sensitivity of short baseline sterile neutrino searches and application observables. Detection of coherent elastic neutrino-nucleus scattering (CEvNS) at reactors is very challenging, but if achieved with low enough threshold could provide unique measurements below the IBD threshold for applications as well as a rich physics program. Finally, directional antineutrino detection would be another advance with strong mutual benefits. This capability would mitigate declared reactor backgrounds for far-field detection of undeclared facilities, enhance searches for the diffuse supernova background and geoneutrios, and provide the source direction for optical observations of a core collapse supernova. Improvements in light collection, photo-detection, and fast inexpensive readout systems would also be of benefit to both science and applications.

Professional and Community Development Opportunities

The training early career HEP physicists receive in graduate programs related to neutrino physics experiments greatly benefit applied antineutrino research for nuclear safeguards. Alternatively, the relatively small scale of most application efforts often provides students and postdocs the opportunity to contribute to all aspects of an experimental particle physics project. Institutions that focus on nuclear energy and safeguards technology provide an additional career option that enables physicists to continue to develop HEP relevant technical skills and make important societal contributions.

Many collaborations and organizations bring together scientific and application oriented institutions for their mutual benefit. These include neutrino physics experiments, non-proliferation technology development and demonstration efforts, and Academic Consortia supported by the the primary DOE nonproliferation R&D agency [3–6]. Neutrino physics is inherently an international enterprise, which raises the possibility of scientific engagement based around this field as a component of international diplomacy and confidence building between nations.

Further exploring the mutual benefit achievable by explicitly considering both scientific and application goals when planning experiments could greatly enhance the impact of such efforts. Additionally, this may provide opportunities for funding agencies from these respective communities to leverage co-investment in such activities.

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[2] A. Hill, Applied Antineutrino Physics 2018 Proceedings, (2019), arXiv:1911.06834 [hep-ex].

[3] The Nuclear Science and Security Consortium (NSSC), `https://nssc.berkeley.edu/`.

[4] The Consortium for Nonproliferation Enabling Capabilities (CNEC), `https://cnec.ncsu.edu/`.

[5] The Consortium for Monitoring, Technology, and Verification (MTV), `https://mtv.engin.umich.edu/`.

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