Snowmass2021 - Letter of Interest

The Expanded Physics Reach of PROSPECT-II

Neutrino Frontier Topical Groups: (NF02) Sterile neutrinos (NF03) Beyond the Standard Model (NF07) Applications (NF09) Artificial neutrino sources

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PROSPECT is a short-baseline reactor antineutrino experiment consisting of a segmented liquid scintillator detector designed to probe the existence of sterile neutrino oscillations and precisely measure antineutrino production by nuclear reactors. This LOI will describe the sterile neutrino oscillation and reactor physics capabilities of a many-year program of measurement at highly-enriched and low-enriched reactor facilities with an upgraded PROSPECT detector, termed PROSPECT-II. With modest input construction, operations, and research support, PROSPECT-II can be realized in less than two years, and can deliver world-leading oscillation and spectrum/flux physics results from the early-mid 2020's through the end of the decade.

Physics Motivation

In the simplest '3+1' sterile neutrino oscillation picture [1], mixing matrix elements U_{e4} and $U_{\mu 4}$ are defined primarily by the mixing angles θ_{14} and θ_{24}. For θ_{14}, improvements in coverage by short-baseline reactor experiments like PROSPECT [2, 3] and others [4–7] are likely to drive the field for the next decade. Beyond the 3+1 scenario, these matrix elements may just as easily reflect completely different or more complex physics processes, including, for example, multiple sterile neutrino states [8, 9], CP-violation [10], non-standard neutrino interactions [11], or neutrino decay [12]. Thus, PROSPECT and its reactor experiment counterparts play an essential role in a complementary global program to probe the potential rich array of BSM physics hidden in the sterile neutrino sector. Moreover, without proper short-baseline constraints on sterile oscillations or other non-standard flavor transformations, long-baseline measurements of Standard Model neutrino properties, such as leptonic CP-violation [13], θ_{23} octant [14], and the mass hierarchy [15], may be limited or complicated.

Short-baseline reactor experiments like PROSPECT are also uniquely capable of enhancing the precision of our understanding of the complex process of antineutrino production within nuclear reactors [16]. These experiments' high detection statistics and varied site deployments allow antineutrino fluxes and spectra to be sampled at widely varying reactor fuel compositions. These datasets are essential to understanding whether existing differences between measured and predicted reactor fluxes and spectra arise from a misunderstanding of production in reactors [17–20], or of fundamental neutrino properties [21–24]. More precise spectrum and flux information from future short-baseline reactor experiments is broadly valuable for many Neutrino Frontier topics, such as Standard Model oscillation parameter measurements (NF01) sterile oscillations (NF02) and CEvNS measurements and physics (NF03 and NF06), as well as for fields beyond the Neutrino Frontier, such as fundamental and applied nuclear science [25–29]. A more complete description of the utility of enhanced reactor flux and spectrum knowledge is provided in another LOI [30].

PROSPECT-II Experimental Summary

Motivated by this physics, the PROSPECT collaboration plans to develop and deploy an upgraded inverse beta decay detector, called PROSPECT-II. PROSPECT-II will build upon the successful PROSPECT-I design [31], with three primary improvements: PMT deployment outside the liquid scintillator target region, enhanced environmental isolation and control of the target liquid, and increased target size. This evolutionary design can enable a PROSPECT-II deployment in the early 2020's and the performance of a many-year physics program encompassing deployment at multiple sites including both highly-enriched (HFIR at Oak Ridge National Laboratory) and low-enriched (US-based commercial power station) uranium reactor cores. At HFIR, the PROSPECT-II detector would be sited within the existing PROSPECT-I deployment location, while both above- and below-ground deployment options or being considered for a full-cycle measurement at a commercial core.

PROSPECT-II Sterile Oscillation Physics Goals (NF02)

As PROSPECT-I results are statistics-limited, a multi-year PROSPECT-II deployment will greatly enhance the experiment's sterile sensitivity. Figure 1 pictures the expected sensitivity of PROSPECT-II after two years of running at the HFIR HEU reactor, as well as after adding two-year follow-up runs at a commercial LEU core and then again at HFIR. After just two calendar years of data-taking, PROSPECT-II can improve upon the sensitivity of current PROSPECT-I results [3] by up to a factor of five. Additional LEU and HFIR deployments will enable PROSPECT-II to exhibit few-percent-level oscillation measurement precision over more than a decade in mass splitting, from 0.3 to 6.0 eV^2. A longer-term, multi-deployment PROSPECT-II physics program would result in world-leading limits on θ_{14} over much the eV-scale regime and fully span the phase space between high-precision measurements at low $\Delta\mathrm{m}^2$ by Daya Bay [32] and at high $\Delta\mathrm{m}^2$ by KATRIN and other tritium β endpoint measurements [33].

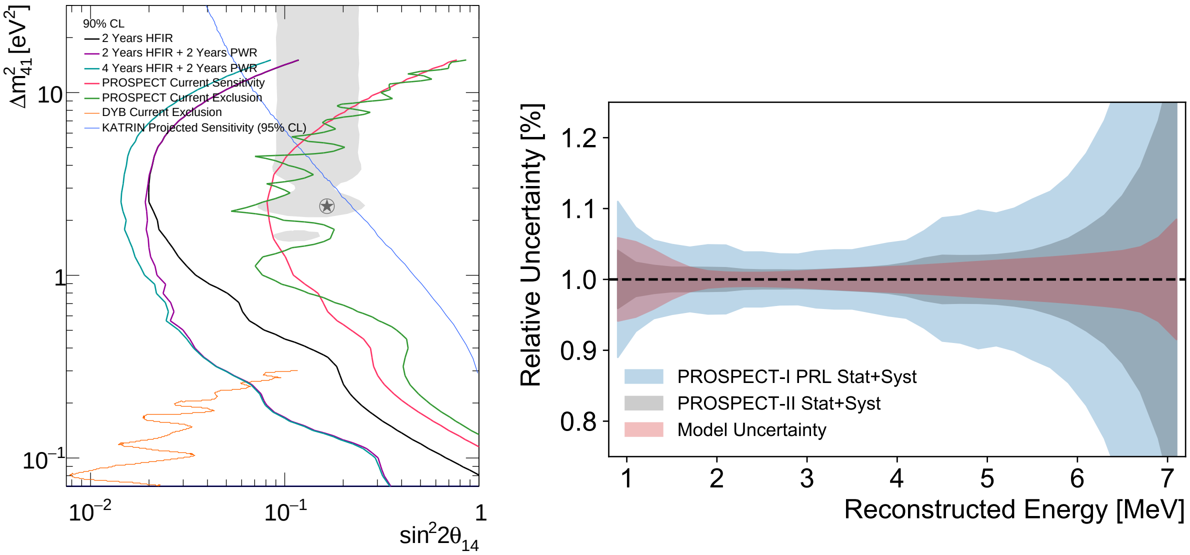

FIG. 1. Right: Comparison of sensitivities for current PROSPECT-I and future PROSPECT-II datasets. Left: Improvement to PROSPECT's ^{235}U spectrum uncertainties after two years of HFIR-based data-taking.

PROSPECT-II Flux and Spectrum Physics Goals (NF02, NF09)

A two-year deployment of the PROSPECT-II detector at HFIR will produce major improvements beyond the world-leading precision of PROSPECT-I's ^{235}U antineutrino spectrum measurements [3, 34]. As shown in Figure 1, such a deployment will result in a more than two-fold improvement beyond PROSPECT-I's measurement precision, due to expected improvements in signal statistics, background reduction, and systematic uncertainties. This measurement's precision would rival or exceed that of the theoretical ^{235}U beta-conversion model [35] over much of the spectrum. Specific scenarios of interest regarding the origin of the LEU spectrum anomaly, such as it being produced solely by ^{235}U, not at all by ^{235}U, or evenly by all fission isotopes [17], would be distinguishable from one another at more than 3σ confidence level. As statistical error will still be the dominant uncertainty contributor after two years, PROSPECT-II's ^{235}U spectrum measurement would continue to benefit with additional years of HFIR data-taking in a many-year physics program. Subsequent PROSPECT-II deployment at a commercial reactor would produce the first-ever systematically-correlated measurements of HEU and LEU antineutrino spectra, opening unique new statistical possibilities for the decomposition of results into individual isotopic antineutrino spectra.

Based on data taken during deployment at HFIR, PROSPECT-II would also be capable of producing an absolute measurement of the IBD yield of ^{235}U. PROSPECT-II's measurement would occur at a nearly identical baseline to that of the ILL neutrino experiment, which observed a 21% deficit relative to the Huber conversion prediction [36]. Such a PROSPECT measurement, combined with STEREO's recent short-baseline HEU flux measurement [37], is likely to have a significant impact on sterile neutrino oscillation and IBD yield results from global fits of reactor fluxes. Systematics-correlated flux measurements from PROSPECT-II at both HEU and LEU reactors can result in direct isotopic IBD yield determinations rivalling the precision of existing theoretical predictions for ^{235}U, ^{239}Pu, and ^{238}U [38].

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