PROCEEDINGS OF SCIENCE

Sterile at reactors: PROSPECT

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PROSPECT, the Precision Reactor Oscillation and Spectrum Experiment, is a phased experiment at the High Flux Isotope Reactor of the Oak Ridge National Laboratory. The two primary goals of the experiment are to measure the ^{235}U antineutrino spectrum and to perform a search for sterile neutrinos with a Δm^2_{14} on the 1eV^2 scale. The Phase I detector will cover a baseline range of 7-12 m from the core while the second phase will extend the baseline out to 20 m. The detection medium for the first phase is 3-tons of ^{6}Li loaded liquid scintillator in an optically segmented detector. This talk describes the current status of the experiment and the projected sensitivity in the search for an eV-scale sterile neutrino.

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1. Motivation

Reactor antineutrinos have historically galvanized the field of neutrino physics from the discovery of antineutrino to the precise measurement of the neutrino oscillation mixing angle, θ_{13}. Two methods are used to model the reactor antineutrino spectrum [1, 2]. The *ab-initio* method relies on calculations from nuclear databases to sum the energy of $\bar{\nu}_e$ from all possible decay chains. This method relies on a large databases that are incomplete where some nuclei have large errors on their decay modes and some inconsistencies exist between these databases. The conversion approach uses the measured β-spectrum to fit to virtual β branches to unfold the antineutrino energy. Early measurements suffered from low statistics and large errors. Additionally, it has not been determined if these virtual branches cover all the physics involved in creating the prompt spectra. With reevaluations of the predictions of the reactor antineutrino spectrum in the last decade in conjunction with more precise measurements, two anomalies have appeared. The first is a $\sim 5\%$ overall antineutrino flux deficit that could be evidence of a sterile neutrino [3]. Indications of a sterile neutrino are not only present in short baseline reactor experiments, but also appear in anomalous behavior in Gallium experiments and long baseline oscillation experiments such as LSND and MiniBooNE. The second is an excess in events in the prompt energy spectrum around 5 MeV seen in Daya Bay, RENO, and Double CHOOZ [4]. New high precision data of reactor antineutrino spectra are needed in order to resolve these issues.

2. The PROSPECT Experiment

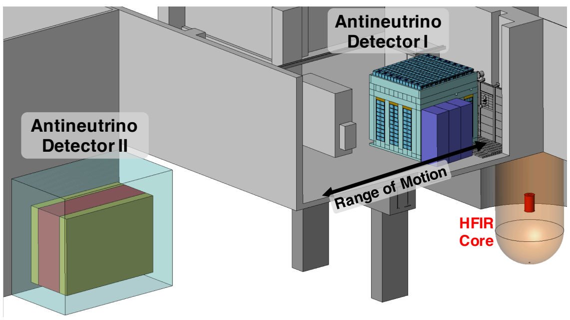

Figure 1: The arrangement of the detectors around the HFIR facility [5].

PROSPECT, the Precision Reactor Oscillation and Spectrum measurement, seeks to resolve both the flux deficit and spectrum shape anomalies. The Phase I detector will be located ~ 7 meters from the High Flux Isotope Reactor (HFIR) core at Oak Ridge National Laboratory (ORNL) in Oak Ridge, TN seen in Figure 1. Additionally, the Phase I detector can be moved to cover up to ~ 12 meters from the reactor core in order to extend the baseline used to search for sterile neutrinos. HFIR, which operates at 85 MW, is ideally suited as a source of antineutrinos due to its compact (0.4 meter diameter and 0.5 meter height) size and due to its fuel content. Unlike commercial reactors, which contain a mixture of ^{235}U, ^{238}U, ^{239}Pu, and ^{241}Pu, this research reactor is predominantly ^{235}U. This has the added benefit of removing any unfolding of the individual fission elements from the spectrum calculation and provides a constant fission fraction through the duration of the reactor on cycle. HFIR also has a significant amount of reactor off time ($\sim$ 54%) which allows for in-depth background studies. Over the last few years, several prototype deployments were performed at HFIR in order to study backgrounds and to test the mechanical components of the detector. The final PROSPECT design was developed in cooperation with HFIR engineers and is presently under construction with first data expected in 2017.

The Phase I detector will be an array of 120 segments that are 14.6 x 14.6 x 119 cm. Each end of the segment will have a 12.7 cm photomultiplier tube. This double ended readout improves both the energy and position reconstruction. The segments are optically separated by reflective panels held in place by pinwheel supports. The corner supports also provide locations for source deployments in order to calibrate the detector in situ. The detector medium has a commercial liquid scintillator base, EJ-309, that has been doped with ^{6}Li as a neutron target. In the event of an upgrade, a Phase II detector will be constructed using the same base segment but four times the size. It would be placed outside the HFIR building in order to extend the baseline from the reactor up to 20 meters.

Due to the location of the detector on the surface, the dominant backgrounds come from cosmogonics and from the reactor. To reduce these backgrounds, a multi-layered shield has been developed of water, lead and polyethylene. The segmentation provides additional rejection of background events through the use of a veto layer on the outer edge of the detector. The fiducial volume will have $\sim$ 1500 kg of target mass. The event signature of interest comes from the inverse beta decay (IBD) interaction where $\bar{\nu}_e + p \to n + e^+$. The positron annihilates producing light with energy in the 1 to 10 MeV range. The neutron provides a delay signal at 0.6 MeV electron equivalent energy after capturing on ^{6}Li. Using the temporal and spatial coincidences, the final efficiency of the detection is 42% with a signal to background ratio of 3 to 1. The Phase I detector expects to record 115,000 IBD events in the first year of data taking. The predicted energy resolution is $4.5\%/\sqrt{E}$. Further details of the projected detector performance can be found in [5].

3. Oscillation Sensitivity

The sensitivity of the PROSPECT experiment can be seen in Figure 2. By comparing the $3+1\nu$ oscillation model (M_{ij}) to the standard 3ν oscillation model (T_{ij}) with an irreducible background (B_{ij}), a χ^2 minimization was performed with

$$\chi^2 = \sum_{i,j} \frac{(M_{ij} - (\alpha + \alpha_e^i + \alpha_r^j)T_{ij} + (1+\alpha_b)B_{ij})^2}{T_{ij} + B_{ij} + \sigma_{b2b}^2 (T_{ij} + B_{ij})^2} + \left(\frac{\alpha}{\sigma}\right)^2 + \sum_j \left(\frac{\alpha_r^j}{\sigma_r}\right)^2 + \sum_i \left(\frac{\alpha_e^i}{\sigma_e}\right)^2 + \left(\frac{\alpha_b}{\sigma_b}\right)^2, \tag{3.1}$$

where parameters α account for systematic uncertainties in the signal and the background. Specifically,

$$(\sigma, \sigma_b, \sigma_e, \sigma_r, \sigma_{b2b}) = (100\%, 2\%, 10\%, 1\%, 1\%) \tag{3.2}$$

for the reactor flux normalization, the background normalization, the reactor spectrum shape, a position-dependent variation and a bin-to-bin correction respectively. Exclusion contours were calculated in the (Δm_{41}^2, θ_{14}) parameter space as seen in Figure 2. Within one year of PROSPECT

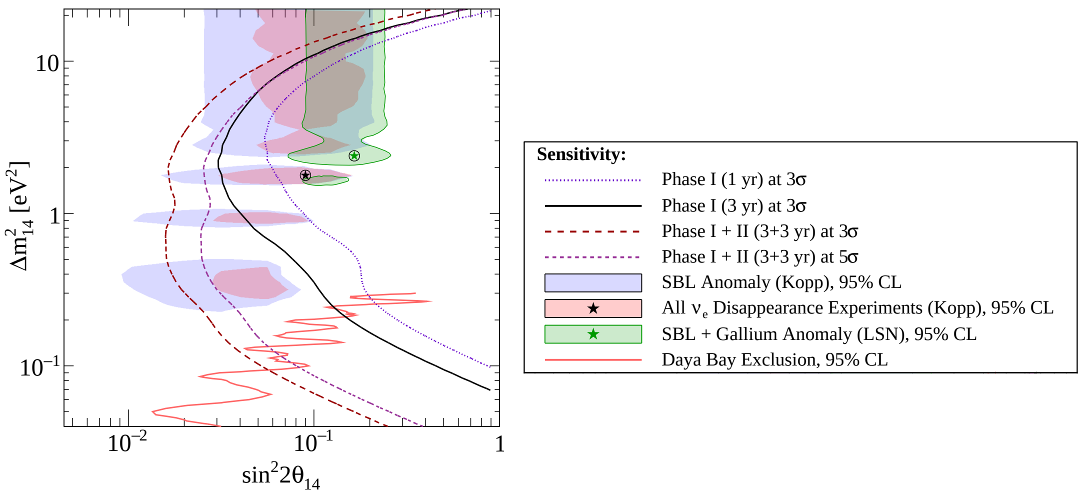

Figure 2: The predicted sensitivity reach into the $\Delta m^2_{14} - \sin^2 2\theta_{14}$ parameter space. Shown are the 3σ sensitivity curves for Phase I at 1 and 3 years of data taking and the 3σ and 5σ curves for Phase II with an additional 3 years of data taking [5]. The Daya Bay contour is from [6].

data taking, the best fit will have 3σ coverage. Within six years of Phase I + II, the majority of the current anomalous region around $\delta m^2_{14} \sim 1\text{eV}^2$ will have at least 3σ coverage.

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