PROCEEDINGS OF SCIENCE

Precision Measurement of the Reactor Antineutrino Spectrum with PROSPECT

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PROSPECT, the Precision Reactor Oscillation and Spectrum Experiment, is a multiphase short baseline reactor antineutrino experiment that aims to probe eV-scale sterile neutrinos and precisely measure the antineutrino spectrum generated from a Highly Enriched U-235 (HEU) reactor. In Phase-I, a 3-ton movable optically segmented Li-6 loaded liquid scintillator (LiLS) detector will be deployed at the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) at baselines ranging from 7-12m. With an energy resolution of $< 4.5\%$ at 1 MeV and a daily interaction rate of about 700 antineutrinos. PROSPECT will make the highest precision measurement of an HEU reactor spectrum to date. In this poster, we describe PROSPECT's spectral measurement and its ability to shed light on the recently observed spectral discrepancies observed in the θ_{13} reactor experiments.

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1. Motivation

Reactor antineutrino experiments have played important roles in the study of neutrino oscillation. The fission reactors generate $\bar{\nu}_e$ through β-decay processes that start from isotopes including primarily U-235, U-238, Pu-239 and Pu-241. The most recent achievement of these experiments is the precision measurement of the θ_{13} mixing angle. However, the antineutrino flux from reactors deviates from the theoretical fission reactor models by $\sim 6\%$. The Daya Bay experiment also found an $\sim 8\%$ excess in the antineutrino spectrum from Low Enriched U-235 (LEU) reactors, in the 5-7 MeV energy range, compared with the prediction [1]. The *ab initio* calculations of antineutrino spectra based on fission reaction databases [2] do not agree with the converted spectra from β-spectral measurement [3, 4]. The discrepancies could hint at new physics, e.g. sterile neutrino oscillation, or indicate that there is incomplete branching fraction information within the antineutrino spectra generated from fission isotopes. Thus, precision measurements of specific fission isotopes' antineutrino spectrum will aid in resolving the inconsistency among experiments and predictions.

2. Experiment Design

PROSPECT is a multiphase experiment that aims to precisely measure the antineutrino spectrum from an HEU reactor and probe for oscillation effects involving a possible $\Delta m^2 \sim 1$ eV^2 scale sterile neutrino. In Phase-I, we will deploy a movable LiLS detector near the HFIR reactor at ORNL to cover 7-12 m range of baseline. HFIR is an 85MW fission reactor with a compact size of 40 cm $\times$ 50 cm. With more than 95% U-235 loaded throughout one duty cycle, HFIR supplies antineutrinos generated >99% from U-235. The 47% duty cycle of HFIR offers a sufficient rate of antineutrino events. The data taken during the reactor off cycles will be used to constrain the backgrounds of antineutrino measurement.

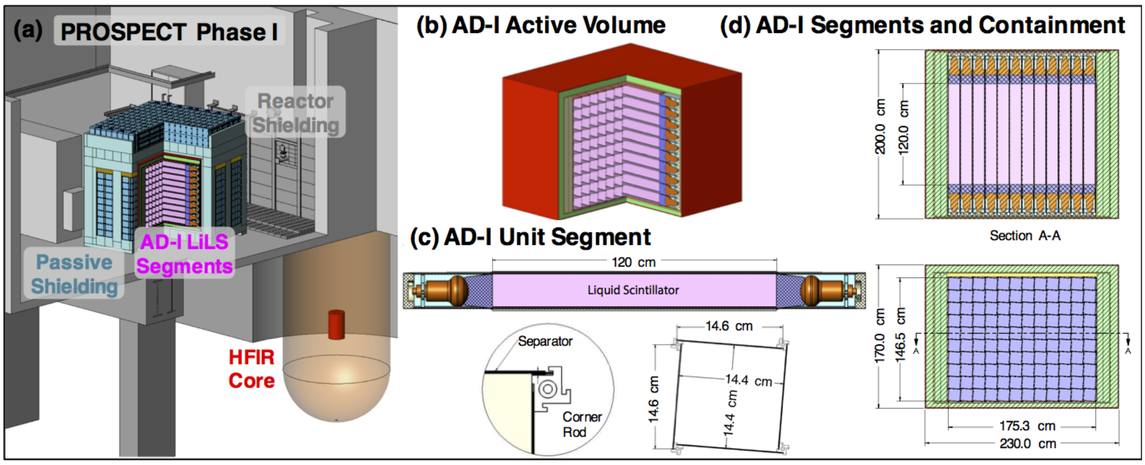

Figure 1: The design of PROSPECT AD-1 [5]. (a) The full detector deployed at a short baseline from the HFIR core. (b) The segmented LiLS detector. (c) A longitudinal segment with four rods for calibration. (d) The preliminary layout of the segmentation.

The Antineutrino Detector of PROSPECT Phase-I (AD-1) is a $\sim$ 3000 kg LS detector doped with Li-6. The detector is separated into multiple longitudinal optical segments by grids of solid specular reflectors. Each segment is 14.6 cm $\times$ 14.6 cm $\times$ 1.2 m, with PMTs at both ends. The segments on the edge of detector are used to purify the event selection. The reflectors interlock with each other so calibration tubes can be deployed down dry axes throughout the AD-1 target volume. A single segment prototype has been deployed to study the detector performance for PROSPECT [6].

3. Measurement Strategy

PROSPECT detects reactor antineutrinos through an Inverse Beta Decay (IBD) signature, which generates a positron and a neutron in the $p+\bar{\nu}_e \rightarrow n+e^+$ process. The energy deposition of the positron, which retains nearly all excess kinetic energy of the interaction, can be used to reconstruct the energy of the incident antineutrino. The neutron is captured by a Li-6 atom, which breaks up and releases $\sim$ 600 KeV of electron-equivalent energy with a time delay of $\sim 40\mu$ s relative to the positron energy deposition. Using a Pulse Shape Discrimination (PSD) method together with a prompt and delay time coincidence, we can separate the IBD events from background. Due to conservation of energy, we can measure the spectrum of the prompt events, and then convert it to antineutrino spectrum.

In preparation for PROSPECT Phase-I, we have carefully performed an on-site background study [7]. The topological, time coincidence, and PSD based event cuts will provide optimized background subtraction. Cosmogenic neutrons will be the main source of background. After the evaluation of cosmogenic background, we expect the signal to background ratio to be 3:1. The Monte Carlo simulation predicts the IBD detection efficiency to be $\sim$42%. The expected event rate is 700 events/day.

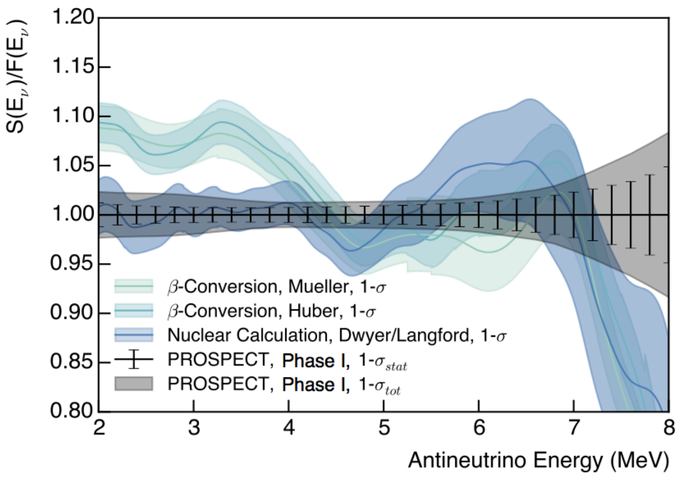

Figure 2: The precision of PROSPECT spectral measurement compared with the uncertainties of predictions [5].The black error band is the statistical uncertainty. PROSPECT can provide references for theoretical models with high resolution. The statistical error includes the uncertainty of background subtraction.

4. Precision Spectral Measurement

In PROSPECT Phase-I, the statistical uncertainty of the measured prompt spectrum will be within 1.5% in the range of 2-6 MeV. The $4.5\%/\sqrt{E}$ target energy resolution, and the statistics are sufficient to surpass the precision of the previous ILL measurement [8] in one reactor on cycle.

With more than 99% of antineutrinos are from U-235, and a simple reactor time evolution, we can directly show U-235's contribution to the excess of spectrum by comparing the measurement to theoretical predictions. In addition, an HEU measurement can be used with the other LEU experiments' measurements, so we can reduce the uncertainty on other isotopes by evaluating the difference between HEU and LEU spectra to offer a more accurate experiment reference.

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