PROSPECT
Precision Oscillation and Spectrum Experiment

Karsten M. Heeger
Yale University
on behalf of the PROSPECT collaboration
Reactor Antineutrinos

$\bar{\nu}_e$ from $\beta$-decays, pure $\bar{\nu}_e$ source
of n-rich fission products
on average $\sim$6 beta decays until stable

$> 99.9\%$ of $\bar{\nu}_e$ are produced by fissions in $^{235}\text{U}$, $^{238}\text{U}$, $^{239}\text{Pu}$, $^{241}\text{Pu}$

mean energy of $\bar{\nu}_e$: 3.6 MeV
only disappearance experiments possible
Reactor Antineutrino “Anomalies” (RAA)

Flux Deficit

Deficit due to extra (sterile) neutrino oscillations or artifact of flux predictions?

Understanding reactor flux and spectrum anomalies requires additional data

Spectral Deviation

Measured spectrum does not agree with predictions.

Daya Bay,
CPC 41, No. 1 (2017)
Reactor Antineutrino “Anomalies” (RAA)

Flux Deficit

![Graph showing flux deficit](image)

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Precision Oscillation and Spectrum Experiment

Objectives

Search for short-baseline oscillation at <10m
Precision measurement of $^{235}\text{U}$ reactor $\bar{\nu}_e$ spectrum

Relative Spectrum Measurement
relative measurement of L/E and spectral shape distortions

unoscillated spectrum
oscillated spectrum

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Moriond 2019
Experimental Site

High Flux Isotope Reactor, ORNL

Reactor Core

- **Power**: 85 MW
- **Core shape**: cylindrical
- **Size**: \( h = 0.5 \text{m} \), \( r = 0.2 \text{m} \)
- **Duty-cycle**: 46%, 7 cycles/yr, 24 days
- **Fuel**: HEU (\(^{235}\text{U}\))

- compact reactor core, detector near surface, little overburden

- highly-enriched (HEU): >99% of \( \bar{\nu}_e \) flux from \(^{235}\text{U}\) fission
PROSPECT Detector Design

Single 4,000 L $^6\text{Li}$-loaded liquid scintillator (3,000 L fiducial volume)

11 x 14 (154) array of optically separated segments

Very low mass separators (1.5 mm thick)
Corner support rods allow for full in situ calibration access

Double ended PMT readout, with light concentrators
good light collection and energy response $\sim$4.5-5% $\sqrt{E}$ energy resolution
full X,Y,Z event reconstruction

Optimized shielding to reduce cosmogenic backgrounds
Background Rejection

Detector design further optimized for background rejection

A sequence of cuts leveraging spatial and timing characteristics of an IBD yields $> 10^4$ background suppression and signal to background of $> 1:1$.

Rate and shape of residual IBD-like background can be measured during multiple interlaced reactor-off periods.

Combine:
- PSD
- Shower veto
- Event topology
- Fiducialization
Liquid scintillator was stored at BNL in 28 (55-gallon) drums. A temperature-controlled truck was used to transport the scintillator to Oak Ridge Nat. Lab. ISO tank filling mix all 6LiLS drums into one tank. February 2018 Arrival at ORNL In Position at HFIR Filling from Mixing Tank First Muon Track
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ISO tank Filling:
- Mix all 6LiLS drums into one tank.

February 2018:
- Arrival at ORNL
- In Position at HFIR
- Filling from Mixing Tank
- Hadronic Shower
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February 2018
- Arrival at ORNL
- In Position at HFIR
- Filling from Mixing Tank
- IBD Candidate
Energy Reconstruction

**Gamma sources** (\(^{137}\)Cs, \(^{60}\)Co, \(^{22}\)Na) deployed throughout detector, measure single segment response

**Fast-neutron tagged** \(^{12}\)B: High-energy beta spectrum calibration

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**Resolution and Reconstruction**

**MC/data for calibration peaks agrees to better than 1\(\sigma\)**

Full-detector \(E_{\text{rec}}\) within \(\pm 1\%\) of \(E_{\text{true}}\)

High light collection: \(795 \pm 15\) PE/MeV

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First Oscillation Analysis Data Set

33 days of Reactor On
28 days of Reactor Off
Correlated S/B = 1.36
Accidental S/B = 2.25

24,608 IBDs detected
Average of ~750 IBDs/day

IBD event selection defined and frozen on 3 days of data

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Neutrino Rate vs Baseline

Observation of $1/r^2$ behavior throughout detector volume
Bin events from 108 fiducial segments into 14 baseline bins

$40\%$ flux decrease from front of detector to back

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Neutrino Spectrum vs Baseline

Spectral Distortion vs Baseline

Compare spectra from 6 baselines to measured full-detector spectrum

Null-oscillation would yield a flat ratio for all baselines

Direct ratio search for oscillations, reactor model independent
Oscillation Search Results

- Feldman-Cousins based confidence intervals for oscillation search
- Covariance matrices captures all uncertainties and energy/baseline correlations
- Critical $\chi^2$ map generated from toy MC using full covariance matrix
- 95% exclusion curve based on 33 days Reactor On operation
- **Direct test of the Reactor Antineutrino Anomaly**

**Disfavors RAA best-fit point at >95% CL (2.2\sigma)**
New Measurement of $^{235}\text{U}$ Spectrum

Prompt Energy Spectrum

40.2 days of reactor-on exposure, 37.8 days of reactor-off exposure
~ 31,000 IBD candidate events (reactor-off candidate events scaled to match exposure)

measured spectrum with good S/B at surface 1.7/1 (0.8-7.2 MeV)
~ 6x greater statistics than ILL (1981)
Is PROSPECT consistent with Huber \( ^{235}\text{U} \) model for HFIR HEU reactor?

\[ \chi^2/\text{ndf} = 52.1/31 \]

p-value = 0.01

Huber model broadly agrees with spectrum but is not a good fit.

Deviations mostly in two energy regions.
Shape of measured $^{235}$U spectrum not inconsistent with the deviation relative to prediction observed at LEU reactors.
Summary

PROSPECT started taking data on March 6, 2018

Background rejection and energy resolution meet expectation and match Monte Carlo.

World-leading signal-to-background for a surface-based detector (<1 mwe overburden). Observed antineutrinos from HFIR with good signal/background.

First oscillation analysis on 33 days of reactor-on data disfavors the RAA best-fit at $2.2\sigma$.

Made first modern measurement of an antineutrino spectrum from a HEU reactor with a surface-based experiment.

Based on results of PROSPECT and other experiments sterile neutrinos are increasingly disfavored
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14 Institutions; 70 collaborators