PROSPECT
The Precision Reactor Oscillation and SPECTrum Experiment

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The Reactor $\bar{\nu}_e$ Flux Anomaly
Evidence For A Sterile Neutrino?

- Reactor measurements previously agreed with $\bar{\nu}_e$ flux models
- Re-evaluation of the flux model by Mueller/Huber showed them to be consistently low
- The deficit is suggested to be evidence for a sterile neutrino flavor
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Mention et al. PRD 83, 073006 (2011)
Reactor $\bar{\nu}_e$ Spectral Anomaly

“The Bump”

- Recent $\theta_{13}$ experiments at LEU reactors observe an excess between 4-6 MeV
  - Problems with one fissile isotope? Multiple isotopes?
Recently the nuclear physics community has been revisiting the $\beta^-$ decay branching ratios of the top $\bar{\nu}_e$ spectrum contributors.
A Sterile Neutrino or Erroneous Models? 
Flux Anomaly Depends On Fuel Composition

Daya Bay has **not** shown that neutrino oscillations don’t play a role. Disagreements could be a combination of effects: issues with the $\bar{\nu}_e$ yield from $^{235}\text{U}$ **and** new physics.

A Sterile Neutrino or Erroneous Models? 
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The High Flux Isotope Reactor

HFIR

• 85 MW Thermal Power Research Reactor
• ~93% enriched $^{235}$U fuel
• Very compact core (h=0.6m d=0.4m)
• Very near access available
• 24 day cycle means no $^{239}$Pu buildup (<0.5%)
• ~50% duty cycle allows good background char
PROSPECT

- Model independent search for neutrino oscillations into eV-scale sterile states
- Precision measurement of an HEU reactor spectrum with the best energy resolution to date
  - \(~160\text{k IBD/year}\)
  - Resolution \(4.5\%/\sqrt{E}\)
  - S/B of 3:1
  - Most precise \(^{235}\text{U} \) spectrum measurement
  - Compare reactor \(\bar{\nu}_e \) spectrum models
  - Provide a benchmark for future reactor \(\bar{\nu}_e \) experiments

- Complement existing LEU reactor measurements
- We also hope to:
  - Measure total absolute reactor flux
  - Observe \(\bar{\nu}_e \) from spent nuclear fuel

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Detector Design

- \(~4\text{ton}\) \(^6\text{Li}\)-loaded liquid scintillator detector
- Optically divided into 14x11 identical segments
  - \(i.e.\) 154 detectors
- Low mass optical separators
  - Minimal dead material
- Double-ended readout
- Access for calibration \textit{in-situ}
Oscillation Search

- Relative spectrum measurement between independent detectors
- Segmentation gives clear baseline dependency
- Independent of reactor flux and spectrum models
- Relative measurement and movement minimize systematic errors
R&D Progression

PROSPECT-0.1
Aug 2014
Spring 2015
5cm
0.1 liter
LS cell

PROSPECT-2
Dec 2014
Feb 2015
12.5cm
1.7 liter
LS cell

PROSPECT-20
March 2015
1m
23 liter
LS cell

PROSPECT-50
February 2016
1.2m
2x25 liter
LS segments

PROSPECT
Phase I
2017*
154x25 liter
LS segments
15x15x120cm

*under assembly
Construction

• Construction of components is progressing quickly
• Deployment to occur in 2017

Separator Panel Production

Liquid Scintillator Accumulation

PMT Housing Production Progress
Site Preparation

- Installation of shield wall for background reduction
- Leveling of floor for detector movement system
Background Characterization

Nal Rates At Multiple Locations

Nal Reactor Off Rate

Reactor Off
Background Characterization

Position Scan: 1-3 MeV
Background Characterization

Time Variations

Reactor Shutdown NaI Rate

Rate (Hz/MeV)

Date

Summary

• **PROSPECT will:**
  - Make a precision $^{235}$U spectrum measurement, complementing LEU measurements.
  - Make a model independent search that will cover the sterile neutrino oscillation best-fit point at better than $3\sigma$ in one calendar year
    • Cover favored regions at $3\sigma$ in 3 years
  - Test $^{235}$U as the source of the 4-6MeV “bump”

• Detector construction is proceeding, deployment and first data taking will begin before the end of 2017
• Preparations for deployment are in full swing
• Backgrounds, reactor on and off, have been characterized
BACKUP
The Pandemonium Effect

- Fragmentation of decay strength at high excitation energy due to high level density.
  - Low efficiency high resolution experiments overestimate the branching to low energy levels.
  - Shifts $\bar{\nu}_e$ spectra up

J.C. Hardy et al. PLB 71, 307
Detector Design: Detection

- Neutron captured by Li-6
- $Q(n, {}^6\text{Li}) = 4.78 \text{ MeV}$
- $E_{ee} \approx 0.5 \text{ MeV}$
- $t_{\text{cap}} \approx 40 \mu\text{s}$

$\bar{\nu}_e$

$E_{e^+} \propto E_{\bar{\nu}}$

2.2 MeV

$(\sim 20\%) nH$

$^6\text{Li}$-loaded Liquid Scintillator

$e^-$

$0.511 \text{ MeV}$

$\gamma$

$0.511 \text{ MeV}$

$e^-$

$\gamma$

$\gamma$

$2.2 \text{ MeV}$

$n^6\text{Li} (\sim 80\% \text{ of captures})$

$^6\text{Li}$-loaded Liquid Scintillator

$e^+$

$\gamma$

$\gamma$

$\gamma$

$\gamma$

$\gamma$

$\gamma$
Why a Movable Detector?
Oscillation Search

Sensitivity: $3 \sigma$ CL
- Phase-I (1 yr), Multiple Positions
- Phase-I (3 yr), Multiple Positions
- SBL Anomaly (Kopp), 95% CL
- All $v_e$ Disappearance Exps (Kopp), 95% CL
- SBL + Gallium Anomaly (RAA), 95% CL
- Daya Bay Exclusion, 95% CL

Mass Splitting: 1.78 eV$^2$; Osc. Amplitude: 0.09
Spectrum Measurement

![Graphs showing statistical errors and ratios to Huber HEU in visible energy (MeV).](image)
Background Reduction

IBD  Fast Neutrons
Accidentals

Delayed PSD Parameter
Prompt PSD Parameter

Counts/MeV/s

Energy (MeV)

Local shielding joining reactor wall
Multi-layer passive shielding

Water bricks Polystyrene
Outer neutron shielding for neutron moderation

Lead High Z shielding

Inner Neutron Shielding
Suppress neutrons produced from spallation on lead

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE U.S. DEPARTMENT OF ENERGY
Background Characterization

Time Variations

$^3$He Rates Vs. Time

Unmoderated

Structure Correlates With HB3 Activities

Exp 556: Scan 16

Moderated

Spark

Date

Rate (Hz)

09/20 09/21 09/22 09/23 09/24 09/25
Background Characterization

Time Variations

Nal(Tl) Rates Vs Time

Rate Per MeV Bin

Date