PROSPECT
A Precision Oscillation and Spectrum Experiment

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on behalf of the PROSPECT collaboration

TAUP, September 10, 2015
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 $^{235}\text{U}$, $^{238}\text{U}$, $^{239}\text{Pu}$, $^{241}\text{Pu}$

$$\frac{d^2N(E,t)}{dEdt} = \sum_i \frac{W_{ih}(t)}{\sum_j f_j(t)e_j} f_i(t)S_i(E)c_{ie}^\text{ne}(E,t) + S_{SNF}(E,t) \quad (1)$$

mean energy of $\bar{\nu}_e$: 3.6 MeV

only disappearance experiments possible
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
Precision Measurements with Reactor Neutrinos

Recent precision measurements with Daya Bay.

Daya Bay demonstrates L/E oscillation

Daya Bay
**Reactor Flux and Spectrum “Anomalies”**

**Flux Deficit**
Measurements compared to models

![Graph showing flux deficit measurements compared to models](image)

Extra neutrino oscillations or artifact of flux predictions?

More data needed to better understand these observations

**Spectral Deviation**
Compared to prediction

![Graph showing spectral deviation](image)

New feature in 4-6 MeV region of spectrum. Seen by Daya Bay, Double Chooz, and Reno.

arXiv:1508.04233, Daya Bay Collaboration
Additional sterile neutrinos?

Hypothesis of 3+1 scenario

Kopp et al, 1303.3011
Principle of Relative Measurement of $\bar{\nu}_e$ Flux

Relative measurements for precision physics

Absolute Reactor Flux
largest uncertainty in
previous measurements

Relative measurement
vs baseline
independent of
- flux normalization, and
- spectral shape

2 homogeneous detectors (e.g. Daya Bay)

1 segmented detector (e.g. PROSPECT)
A Short-Baseline Reactor Experiment

Short Distance (<10 m) From Point Source

Research Reactor Spectrum

Compact core (< 1m) avoids oscillation washout

HEU core provides static spectrum of mainly $^{235}$U.

US operates high-powered research reactors

arXiv:1506.03547, PROSPECT collaboration
**PROSPECT: Precision Oscillation and Spectrum Experiment**

**Physics Objectives**

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

**Phased Approach**

- **Phase 1** - one detector, near detector: ~7m
- movable detector: ~7-12 m
  - movable detector enables systematic control, background checks, and increased physics reach
  - phased approach mitigates risks

- **Phase II** - two detectors, near detector: ~7-10m
  far detector: ~16-20m

arXiv:1309.7647
PROSPECT collaboration
**PROSPECT Physics**

**A Precision Oscillation Experiment**

*An experimental approach to test for oscillation of eV-scale neutrinos*

![Diagram of a reactor core with near and far detectors, indicating distances of approximately 7m and 16m, respectively.](image)

**Objectives**

- $3\sigma$ test of best fit after 1 year
- $3\sigma$ test of favored region after 3 years
- $5\sigma$ test of allowed region after 3+3 years

![Graph showing mass splitting and oscillation amplitude with phase 1 and phase 2 results.](image)
PROSPECT Physics

A Precision Spectrum Experiment

Measurement of HEU ($^{235}$U) spectrum

A precision measurement to address spectral unknowns

Objectives

Measurement of $^{235}$U spectrum
Compare different reactor models
Compare different reactor cores

between 2-6 MeV:
average stat. precision < 1.5%, systematics < 2%

Phase 1 = Near Detector Only
PROSPECT Physics

A Precision Spectrum Experiment

A precision measurement to address spectral unknowns

Phase 1 = Near Detector Only

Objectives
Measurement of $^{235}\text{U}$ spectrum
Compare different reactor models
Compare different reactor cores

Testing models of the $^{235}\text{U} \, \overline{\nu}_e$ energy spectrum

Comparison of reactor cores
PROSPECT Phase I Detector System

Antineutrino Detector

(a) PROSPECT Phase I
(b) Antineutrino Detector (AD)
(c) AD Unit Cell
(d) AD Cells and Containment

- 3000L of $^6$Li liquid scintillator
- 120 scintillator loaded cells, ~15x15x120cm
- double ended PMT readout, light guides, <4-5%/√E resolutions
- thin optical separators, minimal dead material
- containment vessel, filled in place
PROSPECT Shielding

Reactor Antineutrino Measurement Facility (RAMF) at HFIR

- local shielding next to reactor wall
- multi-layer passive shield around detector
- general purpose digitizing electronics and DAQ
- general utilities
- easy access
PROSPECT Experimental Location

PROSPECT-20 Detector at HFIR

- established on-site operation
- easy access 24/7
- door to outside
- space for near and far detector
PROSPECT Event Detection

Event Identification

**Signal**
- inverse beta decay (IBD)
  - γ-like prompt, n-like delay

**Backgrounds**
- fast neutron
  - n-like prompt, n-like delay
- accidental gamma
  - γ-like prompt, γ-like delay

Background reduction is key challenge

IBD event in segmented $^6$LiLS detector

Prompt signal: 1-10 MeV positron from inverse beta decay (IBD)

Delay signal: ~0.5 MeV signal from neutron capture on $^6$Li

40μs delayed n capture
PROSPECT Scintillator Target

Prototype Detectors
PROSPECT-20 w/ LiLS and Unloaded LS

Light Yield/ PE Spectra

- Compton edge of $^{60}$Co and $^{217}$Bi $\gamma$-rays and the quenched (n, Li) capture peak from $^{252}$Cf neutrons
- light collection: 522±16 PE/MeV

Pulse Shape Discrimination

- n-like events
- $\gamma$-like events

PSD performance for Cf-252.

unloaded LS studies described in arXiv:1508.06575, PROSPECT collaboration
PROSPECT Backgrounds

Background Measurements at HFIR

IBD-like events for reactor-on and off
reactor generated backgrounds are minimal
IBD-like backgrounds are cosmogenic

arXiv:1506.03547, PROSPECT collaboration
Simulated Signal and Background Spectra

Signal (dashed) and background (solid) prompt spectra are shown through selection cuts.

<table>
<thead>
<tr>
<th>Cuts</th>
<th>IBD signal</th>
<th>Cosmic BG</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSD</td>
<td>1680</td>
<td>1.7e6</td>
</tr>
<tr>
<td>Time (1, 2, 3)</td>
<td>1500</td>
<td>3.2e4</td>
</tr>
<tr>
<td>Spatial (4, 5)</td>
<td>1360</td>
<td>9500</td>
</tr>
<tr>
<td>Fiducial (6)</td>
<td>610</td>
<td>390</td>
</tr>
</tbody>
</table>

S/B better than 1:1 is predicted.

Rate and shape of the residual IBD-like background can be measured with high precision during reactor off periods.
Phased PROSPECT Detectors

PROSPECT 0.1
Aug. 2014
5cm
0.1 liter
LS cell

PROSPECT 2
Dec. ‘14/Jan. ‘15
12.5cm
2 liter
LS cell

PROSPECT 20
Early 2015
1m
20 liter
\( ^6\)LiLS cell

PROSPECT N\(\times\)20

PROSPECT 2ton
Late 2016*
N\(\times\)20 liter
LS segments

* Technically driven schedule
PROSPECT R&D and Technical Activities

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PROSPECT Collaboration

Brookhaven National Laboratory
Drexel University
Illinois Institute of Technology
Lawrence Livermore National Laboratory
Le Moyne College
National Institute of Standards and Technology
Oak Ridge National Laboratory
Temple University
University of Tennessee
University of Waterloo
University of Wisconsin
College of William and Mary
Yale University

site of experiment
High Flux Isotope Reactor, Oak Ridge National Laboratory

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63 collaborators
13 institutions
3 national laboratories
Summary

• New data are needed to address the existing reactor anomalies.

• PROSPECT will
  – Probe favored region of eV-scale sterile neutrinos at 3σ with 3 years of data.
  – Measure $^{235}\text{U}\ \nu_e$ spectrum, address spectral deviation, and provide new constraints on reactor antineutrino models complementary to current and future LEU measurements.

• PROSPECT has developed LiLS detectors that can mitigate reactor- and cosmogenic related backgrounds.

• Multiple detectors have been deployed at HFIR in preparation for full-size detector.

• Completed R&D for technical verification and to mitigate technical, cost, and schedule risks. Ready to proceed with detailed design and construction.

• Data taking in 2017 with first physics results in 2018 possible.

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