Precision Reactor Oscillation and Spectrum Experiment

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On behalf of the PROSPECT Collaboration

A sterile neutrino search and reactor spectrum measurement at very short baselines
Reactor Antineutrino Flux Anomaly

Is this deficit evidence of oscillation to a fourth neutrino?
Yes: Evidence outside the reactor context. No: Could be flaws in reactor predictions

The history of the solar & atmospheric anomalies says we should look!
Reactor Antineutrino Spectrum Anomaly
Definite evidence of deficiencies in reactor predictions
Motivates a precision, short-baseline reactor antineutrino detector

Perform a **prediction-independent** search for sterile neutrinos: find oscillations in data, without reference to prediction
Measure the reactor spectrum and flux to greater precision, constraining open questions in reactor predictions

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**Graph**

- Data
- Full uncertainty
- Reactor uncertainty
- ILL+Vogel

**Legend**

- Integrated

**ArXiv Reference**

arXiv:1508.04233 (Daya Bay)
Experimental Implications

DUNE expected rates. Each colored band shows the range of possible rates varying the CP-violating phase.

Adding in a sterile neutrino, particularly at larger mixing angles, has a dramatic effect.

0νββ allowed regions change greatly under sterile neutrino hypothesis
arXiv:1512.02202
Mixing angle accessible to a detector small enough to place within meters of reactor core
The PROSPECT Antineutrino Detector

Very short baseline

Compact Core

Lithium-loaded, pulse shape discriminating liquid scintillator

Segmented

Challenge: Surface environment, not a low-background environment

Requirement: powerful discrimination for antineutrinos

Solution: clear signature in specialized scintillator, electron recoil followed by nuclear recoil

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$^6\text{Li}$-loaded EJ309 scintillator

Nontoxic, high-flashpoint light yield sufficient for 4.5% $/\sqrt{E}$ energy resolution in PROSPECT
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Simulation validated against on-site prototype data
Background discrimination

black line: coincident electron & nuclear recoil
1,2,3) Timing  4,5) topology
6) fiducialization
dotted: neutrino events

Prototype data
Simulation
The PROSPECT Antineutrino Detector

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1.75m x 1.46m x 1.2m
10 x 12 segments
2940 kg target mass
The PROSPECT Antineutrino Detector

Very short baseline

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Segmented

Cover multiple baselines with one detector

Each $L/E$ value covered by multiple segments
Assuming best-fit 3+1 model, PROSPECT would see very clear evidence of oscillation to the sterile neutrino: multiple oscillations.

No need to compare to any prediction: only compare different $L/E$ bins to each other.

Phase II (larger detector at 15 m baseline) extends baseline reach.
Physics Reach

Within 1 year, exclude or confirm “Kopp” best-fit for 3+1 (4σ)

Within 3 years, exclude large portions of remaining parameter space (>3σ)

With Phase II extension, even further reach: 5σ over majority of allowed space with $\Delta m^2_{14} < 10$ eV$^2$
Physics Reach: Reactor Neutrino Predictions

The last neutrino spectrum measurement of a HEU reactor was in 1981. PROSPECT will make a much more precise spectral measurement.

Different reactor predictions and projected measurement, relative to a smooth approximation of the neutrino spectrum.

Easier to pick out the effect of prediction differences in the HEU context.

PROSPECT will be able to differentiate between predictions.
PROSPECT Timeline

**PROSPECT-0.1**
*Characterize LS*
Aug 2014-Spring 2015
- 5cm length
- 0.1 liters
- LS, $^6$LiLS

**PROSPECT-2**
*Background studies*
Dec 2014 - Aug 2015
- 12.5 length
- 1.7 liters
- $^6$LiLS

**PROSPECT-20**
*ON SITE*
*Segment characterization*
*Scintillator studies*
*Background studies*
Spring/Summer 2015
- 1m length
- 23 liters
- LS, $^6$LiLS

**PROSPECT-50**
*Baseline design prototype*
Currently under construction
- 1x2 segments
- 1.2m length
- 50 liters
- $^6$LiLS

**PROSPECT AD-I**
*Physics measurement*
Late 2016
- 10x12 segments
- 1.2m length
- ~3 tons
- $^6$LiLS

**PROSPECT Phase-II**
*Extends Physics Reach*
Conclusion

PROSPECT detects reactor antineutrinos at very short baselines

Excludes best-fit sterile neutrino model within one year

Ready to go: successful prototypes, can do full-scale this year

Resolving anomalies is how neutrino discoveries are made. Now’s the time to tackle the reactor anomaly.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reactor</strong></td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>85 MW</td>
</tr>
<tr>
<td>Shape</td>
<td>Cylinder</td>
</tr>
<tr>
<td>Size</td>
<td>0.2 m $r \times 0.5$ m $h$</td>
</tr>
<tr>
<td>Fuel</td>
<td>HEU</td>
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<tr>
<td>Duty cycle</td>
<td>41% reactor-on</td>
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<tr>
<td><strong>Antineutrino Detector 1 (AD-I)</strong></td>
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<tr>
<td>Cross-section</td>
<td>$1.2 \times 1.45$ m$^2$</td>
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<tr>
<td>Proton density</td>
<td>$5.5 \times 10^{28}$ p/m$^3$</td>
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<tr>
<td>Total Target Mass</td>
<td>2940 kg</td>
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<tr>
<td>Fiducialized Target Mass</td>
<td>1480 kg</td>
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<tr>
<td>Baseline range</td>
<td>4.4 m</td>
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<tr>
<td>Efficiency in Fiducial Volume</td>
<td>42%</td>
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<tr>
<td>Position resolution</td>
<td>15 cm</td>
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<tr>
<td>Energy resolution</td>
<td>$4.5%/\sqrt{E}$</td>
</tr>
<tr>
<td>S:B Ratio</td>
<td>3.1, 2.6, 1.8</td>
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<tr>
<td>Closest distance</td>
<td>6.9 m, 8.1 m, 9.4 m</td>
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<tr>
<td><strong>Antineutrino Detector 2 (AD-II)</strong></td>
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<tr>
<td>Total Target Mass</td>
<td>$\sim$10 ton</td>
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<td>Fiducialized Target Mass</td>
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