PR©SPECT

Precision Reactor Oscillation and Spectrum Experiment



On behalf of the PROSPECT Collaboration

A sterile neutrino search and reactor spectrum measurement at very short baselines



LLNL-PRES-681674

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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!

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Jason Brodsky

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

PROSPECT

Measure the reactor spectrum and flux to greater precision, constraining open questions in reactor predictions



Experimental Implications



Inverted Hierarchy Normal Hierarchy 10^{3} 3+1 Flavors 3+1 Flavors 3 Flavors 3 Flavors 10^{2} 10^{1} $m_{\beta\beta} = 15 \text{ meV}$ 10^{0} 10^{2} $10^3 \quad 10^0$ 10^{2} 10^{0} 10^{1} 10^{1} 10^{3} m_3 (meV) $m_1 \,({\rm meV})$

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. Giunti & Zavanin, JHEP1507 (2015) 0vββ allowed regions change greatly under sterile neutrino hypothesis arXiv:1512.02202

3+1 Model Allowed Region

[m] for 3.6 MeV $\Delta m_{14}^2 \, [eV^2]$ neutrino 10 0.45 $\star\star$ 4.5 10^{-1} 45. =Sensitivity: v_e Disappearance (Giunti), 2σ CL SBL Reactor + Gallium Anomaly (LSN), 95% CL SBL Reactor Anomaly (Kopp), 95% CL * All v_a Disappearance Expts (Kopp), 95% CL Gallium Anomaly (Kopp), 95% CL 10^{-2} 10^{-2} 10^{-1} $\sin^2 2\theta_{14}^{-1}$

Mixing angle accessible to a detector small enough to place within meters of reactor core

Quarter-phase L

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



arXiv:1512.02202



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Simulation validated against onsite prototype data

Background discrimination Event rate [mHz/MeV] 0 10 10 10 **10**⁵ Event rate [mHz/MeV] before cuts (1), (2), (3) 10⁴ (4), (5) (6) 10³ 10 10² 10 10^{-1} **1**0⁻¹ 10⁻² . 10⁻² 2 6 8 10 4 2 10 8 12 0 4 6 prompt ionization [MeV] prompt ionization [MeV]

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

Prototype data

Simulation

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Very short baseline

Compact Core

Lithium-loaded, pulse shape discriminating liquid scintillator

Segmented

1.75m x 1.46m x 1.2m 10 x 12 segments 2940 kg target mass



Very short baseline

Compact Core

PROSPECT



Physics Reach



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 PROSPECT

Jason Brodsky

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 $\Delta m_{14}^2 < 10 \text{ eV}^2$



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

PROSPECT-2

Background studies Dec 2014 - Aug 2015 12.5 length 1.7 liters ⁶LiLS

1m length

23 liters LS, ⁶LiLS

5cm length

0.1 liters

LS, ⁶LiLS



50 liters

⁶LiLS

PROSPECT-20 ON SITE Segment characterization Scintillator studies Background studies Spring/Summer 2015

PROSPECT-50 *Baseline design prototype* Currently under construction

PROSPECT AD-I

Physics measurement 10x12 segments

Late 2016

nt 10x12 segments 1.2m length ~3 tons ⁶LiLS

PROSPECT Phase-II

Extends Physics Reach



multi-layer shielding





local reactor shielding



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.



prospect.yale.edu arXiv:1512.02202 arXiv:1506.03547

arXiv:1508.06575 arXiv:1309.7647

PROSPECT

Jason Brodsky

Reactor85 MWPower85 MWShapeCylinderSize $0.2 \text{ m } r \times 0.5 \text{ m } h$ FuelHEUDuty cycle41% reactor-onAntineutrino Detector 1 (AD-I)Cross-section $1.2 \times 1.45 \text{ m}^2$ Proton density $5.5 \times 10^{28} \text{ p/m}^3$ Total Target Mass2940 kgFiducialized Target Mass1480 kgBaseline range 4.4 m Efficiency in Fiducial Volume 42% Position resolution15 cmEnergy resolution $4.5\%/\sqrt{E}$ S:B Ratio $3.1, 2.6, 1.8$ Closest distance $6.9 \text{ m}, 8.1 \text{ m}, 9.4 \text{ m}$ Antineutrino Detector 2 (AD-II)Total Target MassFotal Target Mass ~ 10 tonEfficiency in Fiducial Volume 42% Position resolution15 cmEnergy resolution $4.5\%/\sqrt{E}$ SiB Ratio $3.1, 2.6, 1.8$ Closest distance $6.9 \text{ m}, 8.1 \text{ m}, 9.4 \text{ m}$ Antineutrino Detector 2 (AD-II)Total Target MassFiducialized Target Mass $\sim 10 \text{ ton}$ Fiducialized Target Mass $\sim 20\%$ Position resolution15 cmEfficiency in Fiducial Volume 42% Position resolution15 cmEnergy resolution $4.5\%/\sqrt{E}$ SiB ratio 3.0 Closest distance15 m	Parameter	Value
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Energy resolution $4.5\%/\sqrt{E}$ S:B Ratio $3.1, 2.6, 1.8$ Closest distance $6.9 \text{ m}, 8.1 \text{ m}, 9.4 \text{ m}$ Antineutrino Detector 2 (AD-II)Total Target Mass $\sim 10 \text{ ton}$ Fiducialized Target Mass $\sim 70\%$ Baseline range $\sim 4 \text{ m}$ Efficiency in Fiducial Volume 42% Position resolution 15 cm Energy resolution $4.5\%/\sqrt{E}$ S:B ratio 3.0 Closest distance 15 m	Position resolution	15 cm
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Energy resolution $4.5\%/\sqrt{E}$ S:B ratio 3.0 Closest distance 15 m	Position resolution	15 cm
S:B ratio 3.0 Closest distance 15 m	Energy resolution	$4.5\% / \sqrt{E}$
Closest distance 15 m	S:B ratio	3.0
	Closest distance	15 m

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