Searching for Sterile Neutrinos with the PROSPECT Experiment

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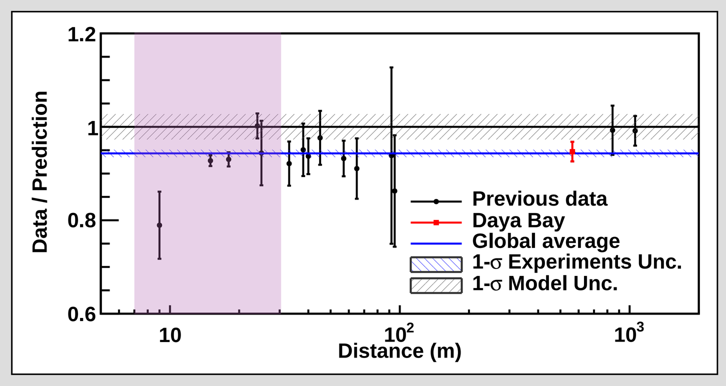
Abstract

PROSPECT, the Precision Reactor Oscillation and Spectrum Experiment, is a phased experiment at the High Flux Isotope Reactor in Oak Ridge National Laboratory. Phase I will consist of a movable 3-ton Li-6 loaded liquid scintillator detector with a baseline coverage from 7 to 12 meters from the reactor core. A larger, second detector during Phase II extends the baseline range to 19 meters. One of the main physics goals of the experiment is to measure electron anti-neutrino disappearance from the highly enriched uranium core in order to search for sterile neutrinos. This poster describes the predicted sensitivity and discovery potential of the experiment to eV-scale sterile neutrinos using a spectrum-based oscillation analysis.

Motivation: The Reactor Anomaly

- Reactor models predict more neutrinos than are observed by existing flux measurements [1,2,3].
- **Are our models wrong? Or is something else happening, such as an oscillation to sterile neutrinos?**
- We need new reactor measurements at short baselines to resolve this question.



The ratio between measured and predicted reactor fluxes. The shaded region indicates the range of baselines seen by PROSPECT [Modified from 3].

Experimental Input Parameters

Reactor: High Flux Isotope Reactor

- Compact, cylindrical core (0.5m high, 0.4m diameter).
- 85 MW power.
- Highly enriched uranium fuel.
- Seven 25-day cycles/year.

Detector

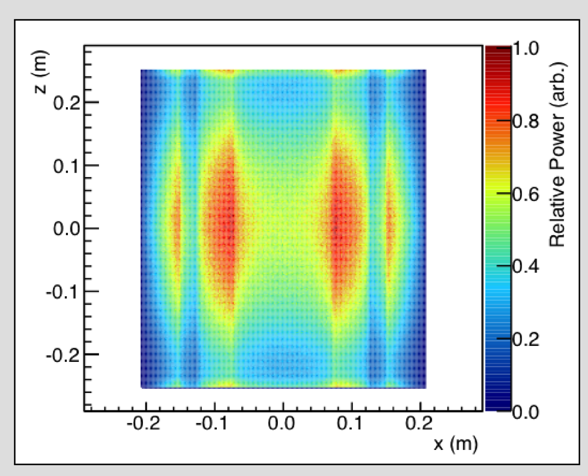
- 12x10 matrix of optically separated segments.
- 14.6x14.6x120cm segment size.
- Li-6 loaded liquid scintillator.
- 2940 (1480) kg target (fiducial) mass.
- Movable design to increase baseline coverage (7-12m).

Signal: Inverse Beta Decay

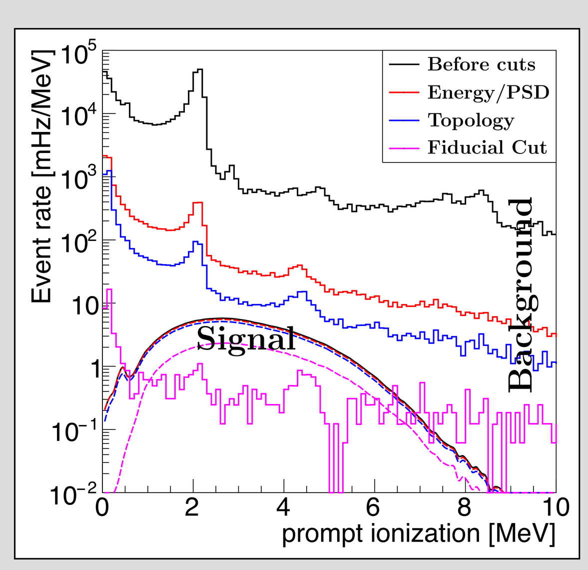
- Fiducial volume cut of the outer edge cells.
- 41.7% fiducialized efficiency.
- 4.5%/$\sqrt{E}$ target energy resolution.
- 115,000 ev/year.

Backgrounds: Primarily Cosmics

- Significant reactor downtime for background subtraction measurements.
- 3:1 signal to background based on Monte Carlo.



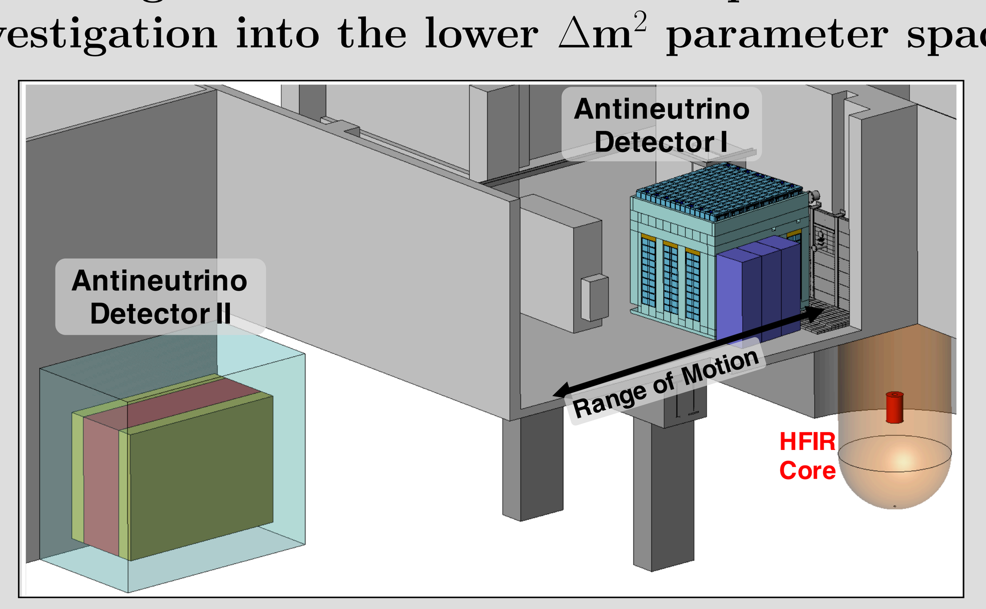
Power map of the HFIR core [Modified from 5].



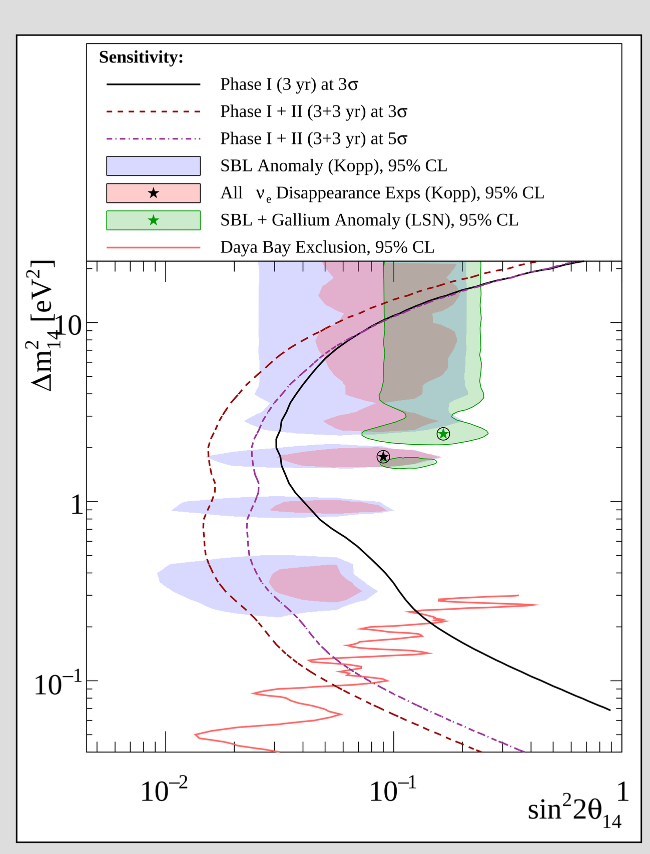
Monte Carlo simulation of the IBD event selection showing the result of successive cuts [Modified from 4].

Second Detector Extension

- Further space outside the HFIR complex is available for a larger longer-baseline detector.
- A 10-ton detector at 15-20m can investigate any oscillation signature uncovered with the first detector.
- **Extending the baseline allows an expanded investigation into the lower Δm^2 parameter space.**



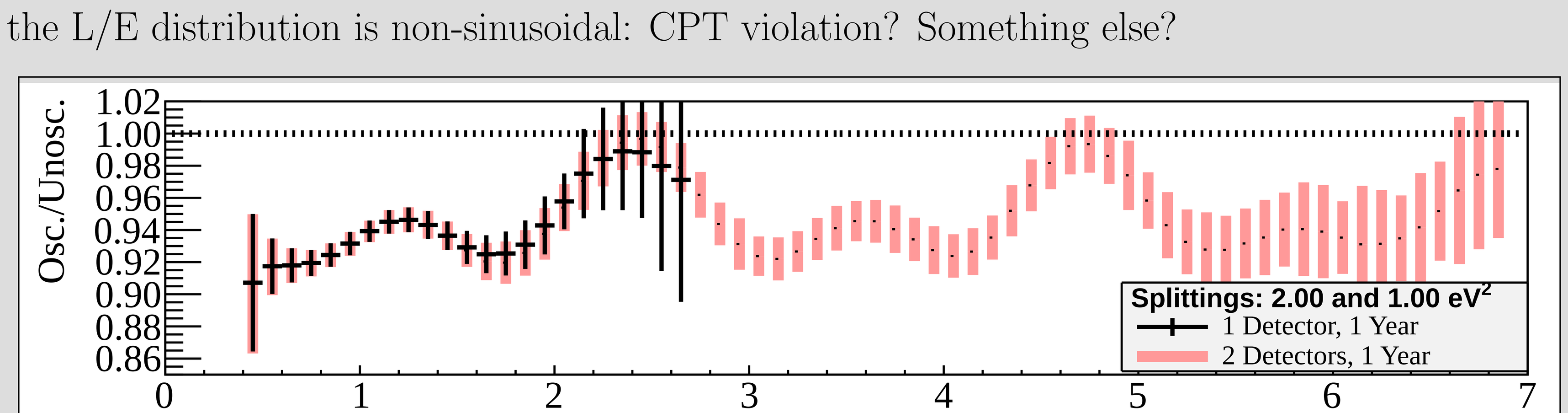
The arrangement of the detectors around the HFIR facility [4].



The increased coverage achieved by adding a second detector is shown by the dashed lines [Modified from 4].

Beyond 3+1 Oscillations

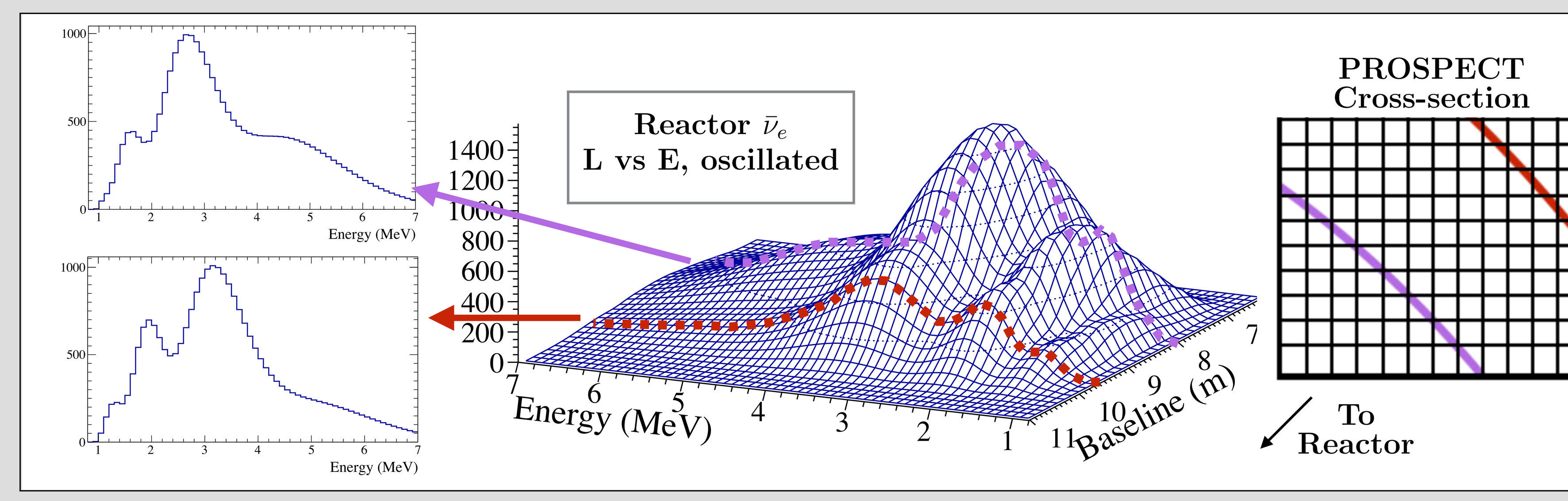
- **L/E distributions from short-baseline reactor experiments show discovery potential for other Beyond Standard Model physics.**
- If the L/E distribution fits to a complex sinusoid: 3+N oscillations.
- PROSPECT has a strong capability to distinguish 3+1 from 3+N.
- If the L/E distribution is non-sinusoidal: CPT violation? Something else?



An example of the non-sinusoidal L/E nature of the 3+N scenario [6].

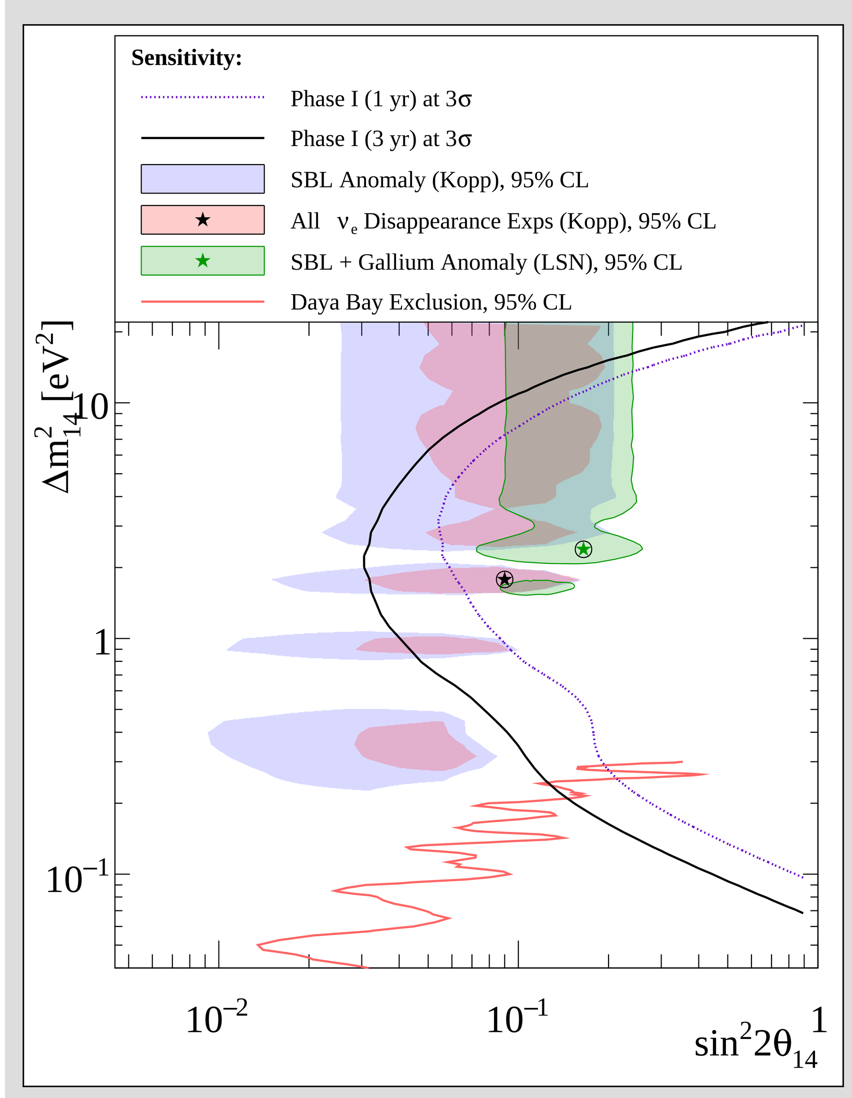
Measurement Stategy

- **PROSPECT can resolve the reactor antineutrino anomaly by probing its L/E nature.**
- HFIR core provides a pure ^{235}U flux.
- Measure inverse beta decays across a range of baselines within a segmented detector.
- Baseline-dependent changes in prompt spectrum would be a clear indication of sterile oscillations.
- Uncertainties in the reactor flux or spectrum could not reproduce this baseline-dependent feature.

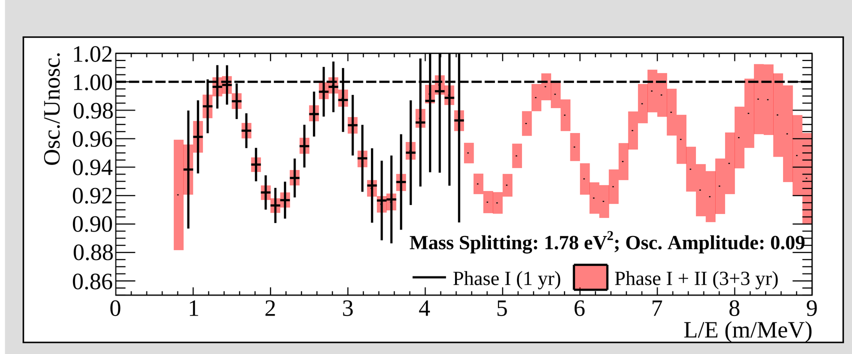


Example of the appearance of oscillation in terms of energy and baseline bins in the PROSPECT detector.

Oscillation Sensitivity



PROSPECT sensitivity with a single movable detector [Modified from 4].



Asymmetry between oscillated and un-oscillated L/E spectra using the PROSPECT detectors [4].

$$\chi^2 = \sum_{i,j} \frac{(M_{ij} - (\alpha + \alpha_e^i + \alpha_r^j)T_{ij} + (1+\alpha_b)B_{ij})^2}{T_{ij} + B_{ij} + \sigma_{b2b}^2 (T_{ij} + B_{ij})^2} + \left(\frac{\alpha}{\sigma}\right)^2 + \sum_j \left(\frac{\alpha_r^j}{\sigma_r}\right)^2 + \sum_i \left(\frac{\alpha_e^i}{\sigma_e}\right)^2 + \left(\frac{\alpha_b}{\sigma_b}\right)^2$$

$$(\sigma, \sigma_b, \sigma_e, \sigma_r, \sigma_{b2b}) = (100\%, 2\%, 10\%, 1\%, 1\%)$$

- A χ^2 test was applied between the simulated IBD prompt spectrum (T_{ij}) and background (B_{ij}) and a toy oscillated spectrum (M_{ij}).
- Parameters α account for systematic uncertainties in signal and background.
- Exclusion contours were determined from the evaluation of a null oscillation model with respect to a 3+1 neutrino model parameterized by (Δm^2_{41}, θ_{14}).
- **Best-fit values for sterile neutrinos from previous experiments can be excluded above 3σ with a single year of PROSPECT data.**
- Three years of PROSPECT data will yield high exclusion of a majority of the reactor anomaly phase space.
- Developed covariance matrix-based fit that reproduces these sensitivity contours; future functionality will fully include all expected systematics and correlations.

Need More PROSPECT?

Check out the other posters:

- T. Langford: The Development and Characterization of PROSPECT Detectors.
- P. T. Surukuchi: Design of the PROSPECT Experiment.
- X. Zhang: Precision Measurement of the Reactor Antineutrino Spectrum with PROSPECT.
- B. Littlejohn: Mitigation of Near-Surface Cosmogenic Background for the PROSPECT Experiment.

This talk:

- M. Mendenhall: PROSPECT: A short-baseline Reactor Precision Spectrum and Oscillation Experiment.

And these papers:

- arXiv:1512.02202: The PROSPECT Physics Program
- arXiv:1506.03547: Background Radiation Measurements at High Power Research Reactors
- arXiv:1508.06575: Light Collection and Pulse-Shape Discrimination in Elongated Scintillator Cells for the PROSPECT Reactor Antineutrino Experiment
- arXiv:1309.7647: PROSPECT - A Precision Reactor Oscillation and Spectrum Experiment at Short Baselines

And this website:

- http://prospect.yale.edu/

Acknowledgements

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References

1 T. Mueller, et. al, PRC 83 054615 (2011)
2 P. Huber PRC 84 024617 (2011)
3 Daya Bay Collab., PRL 116 061801 (2016)
4 PROSPECT, arXiv:hep-ex[1512.02202] (2015)
5 PROSPECT, arXiv:hep-ex[1309.7647] (2015)
6 K. Heeger et al., arXiv:hep-ex[1307.2859] (2013)