Searching for Sterile Neutrinos with PROSPECT

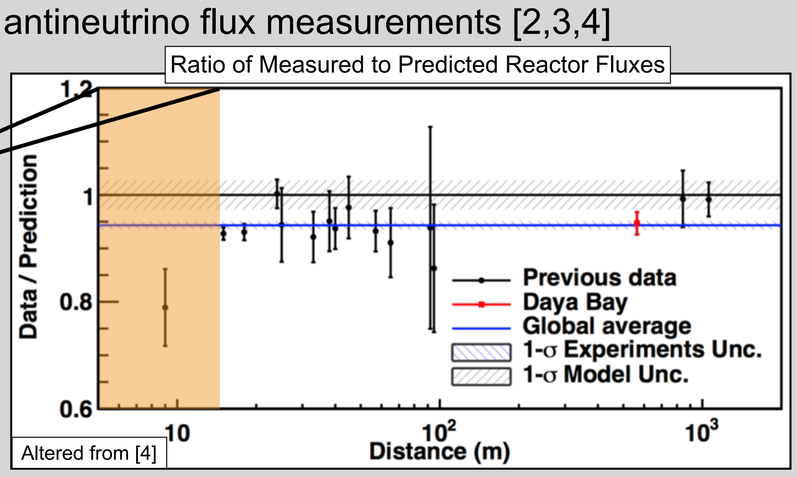
Bryce Littlejohn (Illinois Institute of Technology), on behalf of the PROSPECT Collaboration [1]

PROSPECT is a DOE-funded multi-phase short-baseline reactor experiment that will be installed at Oak Ridge National Laboratory's High Flux Isotope Reactor (HFIR). By comparing measured antineutrino spectra from 235U fission at baselines from 7-12 meters with a single detector, PROSPECT will provide new sensitivity to electron antineutrino oscillations at short baselines that is independent of the underlying reactor flu and spectrum model. PROSPECT will address the current best-fit eV-scale sterile neutrino oscillation parameter space at high confidence level with a single year of data-taking. This poster describes PROSPECT's oscillation fitting framework, input parameters, and expected sensitivities.

Motivation: The Reactor Anomaly

- State-of-the art reactor models predict more neutrinos than are observed by existing reactor antineutrino flux measurements [2,3,4]

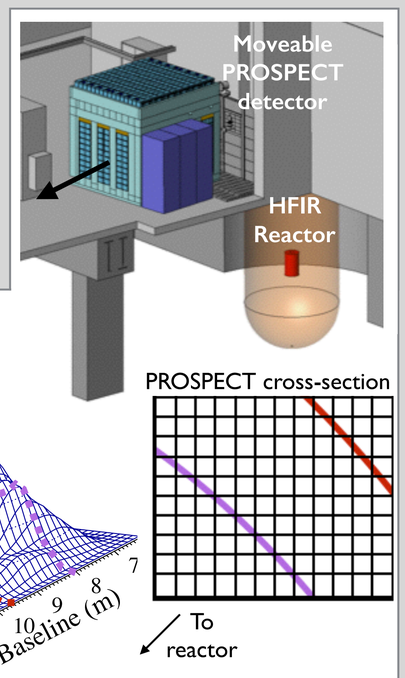
Precision measurements needed here!



- **Are reactor flux predictions wrong? Or were electron antineutrinos oscillating to sterile neutrinos before reaching these detectors?**
- New reactor measurements at short baselines can resolve this question

PROSPECT Measurement Concept

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



Experimental Input Parameters

Reactor: HFIR

- 40cm diameter, 50cm height cylinder
- 85 MW power, 95% ^{235}U enrichment
- 6 cycles/year (41% up-time)

Detector: AD1

- 10 x 12 matrix of 1.2m-long cells
- 14.6 x 14.6 cm square cell cross-section
- 2940 (1480) kg target (fiducial) mass;
- Three locations: ~7-12 meters baseline

Signal

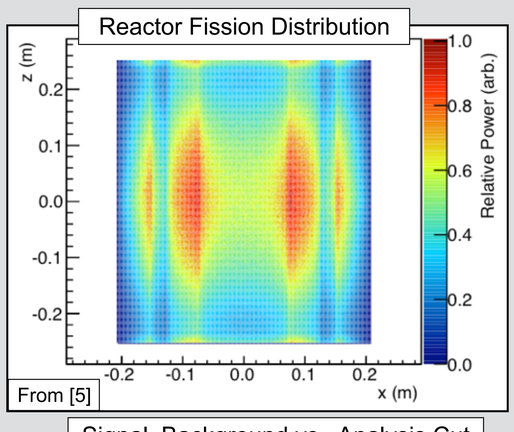
- Fiducial volume only (inner cells)
- 41% average efficiency in inner cells
- 115,000 signal events expected per year

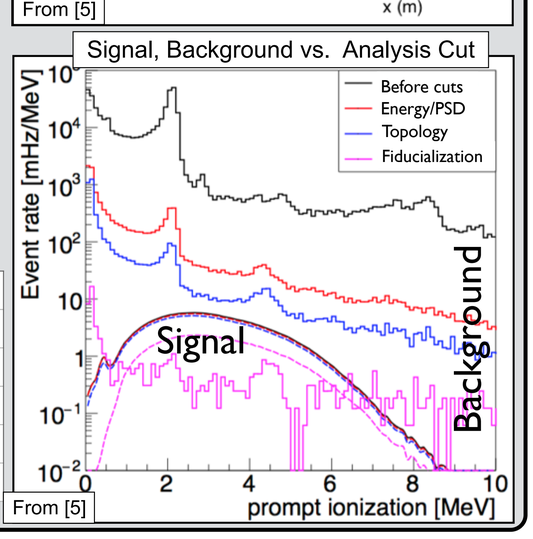
Background

- Primary source: cosmics
- 41% of down-time for background subtraction
- ~3:1 signal:background indicated by simulations

Event Rates

Case	Signal IBD
6mo, Fiducial	58000
1y, Fiducial	115000
3yr, Fiducial	345000
1y, One Cell	480
3y, One Cell	1440





Oscillation Sensitivity

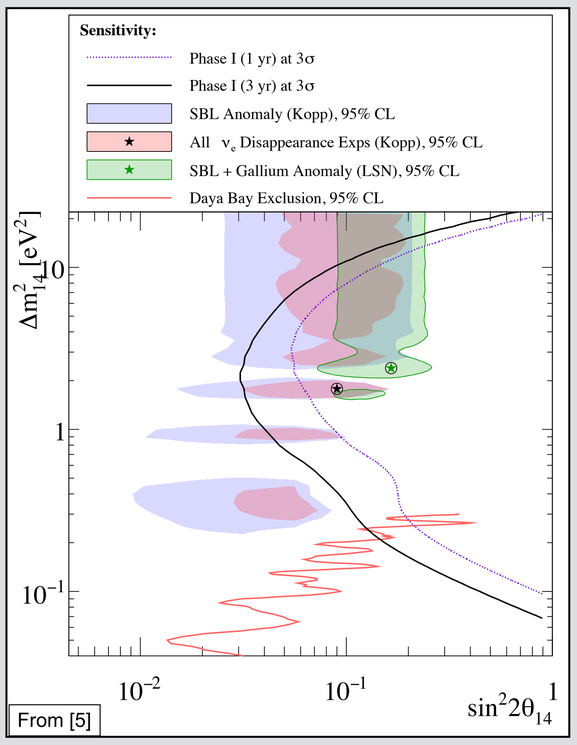
- A χ^2 test was applied to the simulated IBD prompt spectrum + background

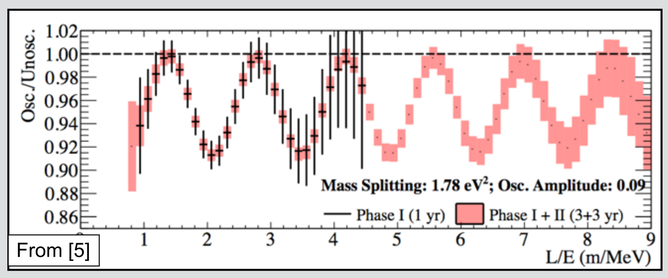
$$\chi^2 = \sum_{i,j} \frac{\left[M_{ij} - (\alpha + \alpha_e^i + \alpha_r^j)T_{ij} - (1+\alpha_b)B_{ij}\right]^2}{T_{ij} + B_{ij} + \sigma_{b2b}^2 (T_{ij}+B_{ij})^2} + \frac{\alpha^2}{\sigma^2} + \sum_j \left(\frac{\alpha_r^j}{\sigma_r}\right)^2 + \sum_i \left(\frac{\alpha_e^i}{\sigma_e^i}\right)^2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

From [6]

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

- Parameters **α** account for systematic uncertainties in signal, background
- Exclusion contours were determined from the evaluation of a no-oscillation model with respect to a 3+1 neutrino model parametrized by (Δm^2_{41}, θ_{14}).
- **Best-fit values for sterile neutrinos from other experiments can be excluded at 99.97% CL with a single year of PROSPECT data.**
- Three years of PROSPECT data will yield high CL exclusion of a majority of the reactor anomaly phase space.
- Developed covariance matrix-based fit reproduces these sensitivity curves; future functionality will fully include all expected systematics and correlations.





Parameter Optimization

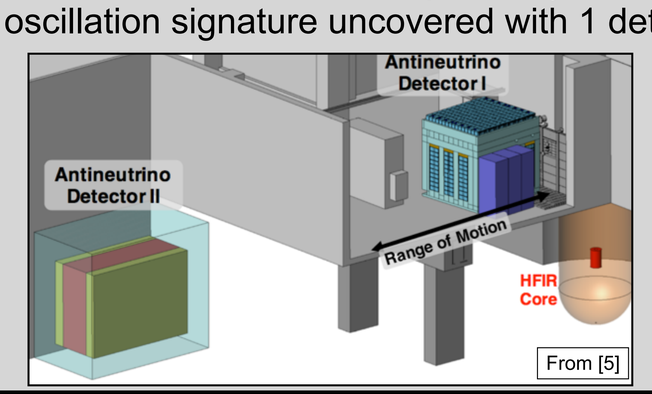
- **How well do we exclude the Kopp sterile best-fit (in σ) for various experimental scenarios?**
- Better baseline coverage provided by a moveable detector is essential
- More statistics via a larger detector or better efficiency is also very helpful
- Oscillation sensitivity is relatively insensitive to the chosen resolution and relative systematic uncertainties.

From [5]

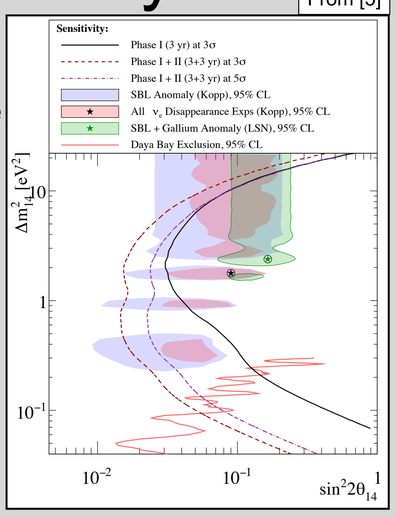
	Decreased	Nominal	Increased
Position	*Front only* 2.79	*Movable* 4.60	*Middle only* 2.37
Position Resolution	*10cm* 4.69	*14.6cm* 4.60	*20cm* 4.46
Efficiency	*32%* 3.84	*42%* 4.60	*52%* 5.26
Energy Resolution	*3%* 4.61	*4.5%* 4.60	*20%* 4.20
Background Suppression	*×0.33* 3.92	– 4.60	*×3* 5.00
Bin-to-Bin Uncertainty	*0.5%* 4.69	*1.0%* 4.60	*2.0%* 4.30
Relative Segment Normalization	*0.5%* 4.60	*1.0%* 4.60	*2.0%* 4.59
Detector Size	*10×8* 3.23	*12×10* 4.60	*14×12* 6.02

Two-Detector Sensitivity

- Further space exists outside the HFIR building for a larger longer-baseline detector
- 10-ton detector at ~15+ m can precisely investigate any oscillation signature uncovered with 1 detector

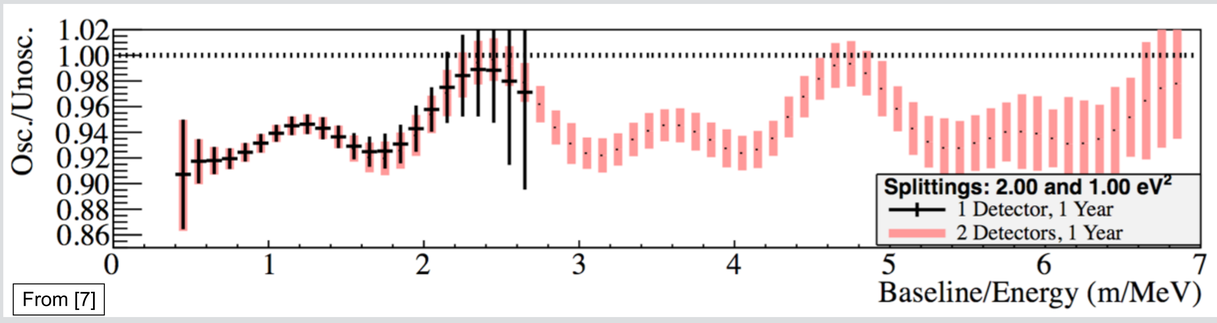


From [5]



Beyond 3+1 Oscillations

- **L/E distributions from short-baseline reactor experiments show that discovery potential also exists for other non-Standard physics**
- If a complex sinusoid in L/E is present: 3+N oscillations
- PROSPECT also has strong capability to distinguish 3+1 from 3+N
- Non-sinusoidal pattern in L/E could indicate CPT violation



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