Sterile Neutrino Search with the PROSPECT Experiment

2017 Fermilab New Perspectives

Pranava Teja Surukuchi

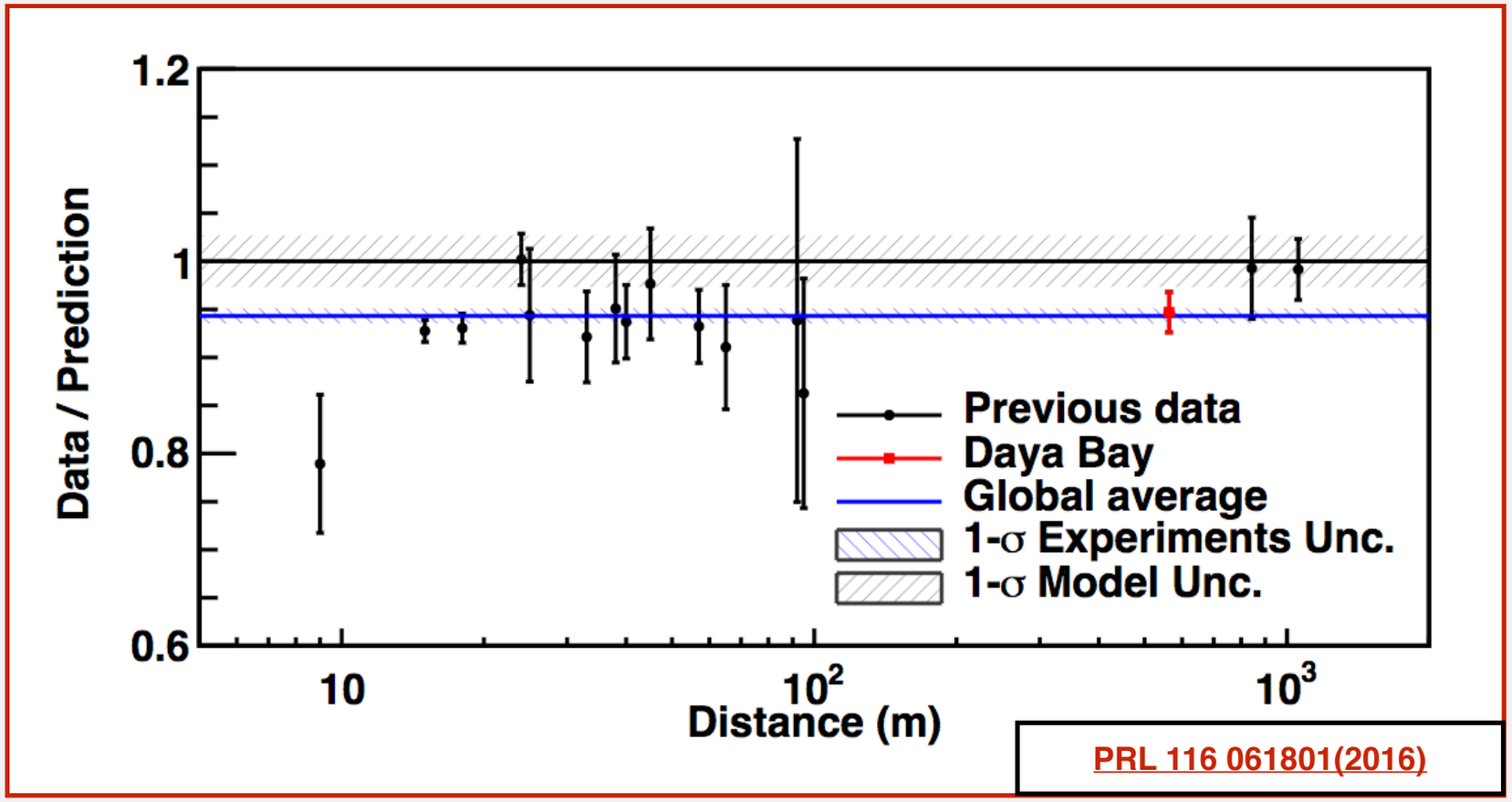
(on behalf of the PROSPECT collaboration)

Other PROSPECT talks: **X Zhang**

PROSPECT - A Precision Oscillation and Spectrum Experiment

Reactor Antineutrino Flux Anomaly

Reactor antineutrino experiments observe ~6% flux deficit compared to the predictions

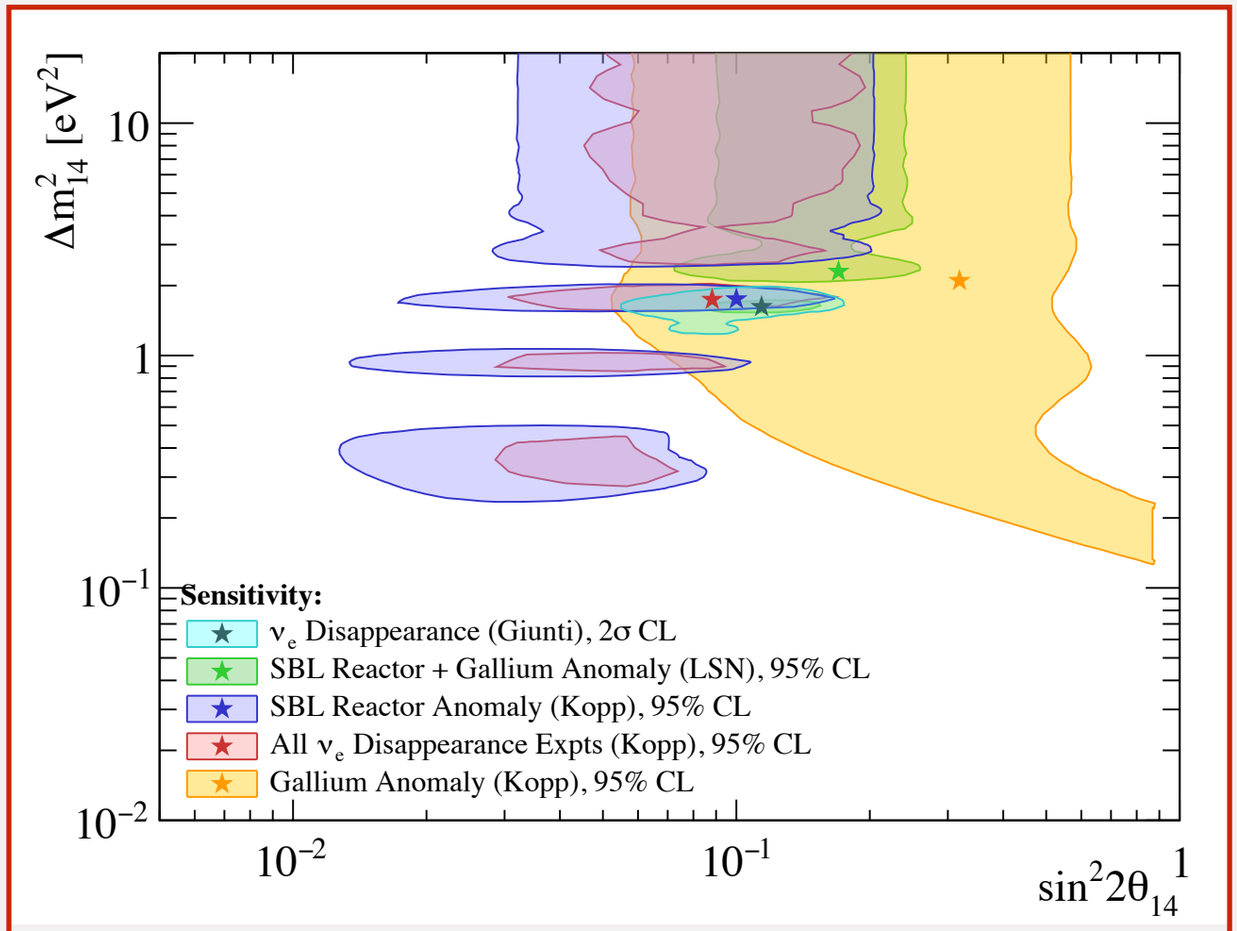


PRL 116 061801(2016)

- **Hypothesis 1: Incorrect reactor antineutrino models used for predictions**
- **Hypothesis 2: Neutrinos oscillating away into undetectable sterile states**

eV-scale Sterile Neutrinos

- ~1eV^2 sterile neutrinos (ν_s) that lead to high frequency oscillations are favored
- eV-scale ν_s could also explain some of the anomalies observed in accelerator and source neutrino experiments
- Could be tracked by the deficit in expected anti/neutrino rates at short baselines
- Nuclear reactors could act as an intense source of antineutrinos for a short-baseline experiment



Phys. Rev. D83, 073006 (2011)
JHEP 1305, 050, (2013)
Phys. Rev. D88, 073008 (2013)

New short-baseline reactor antineutrino experiment would be able to resolve the Reactor Antineutrino Anomaly

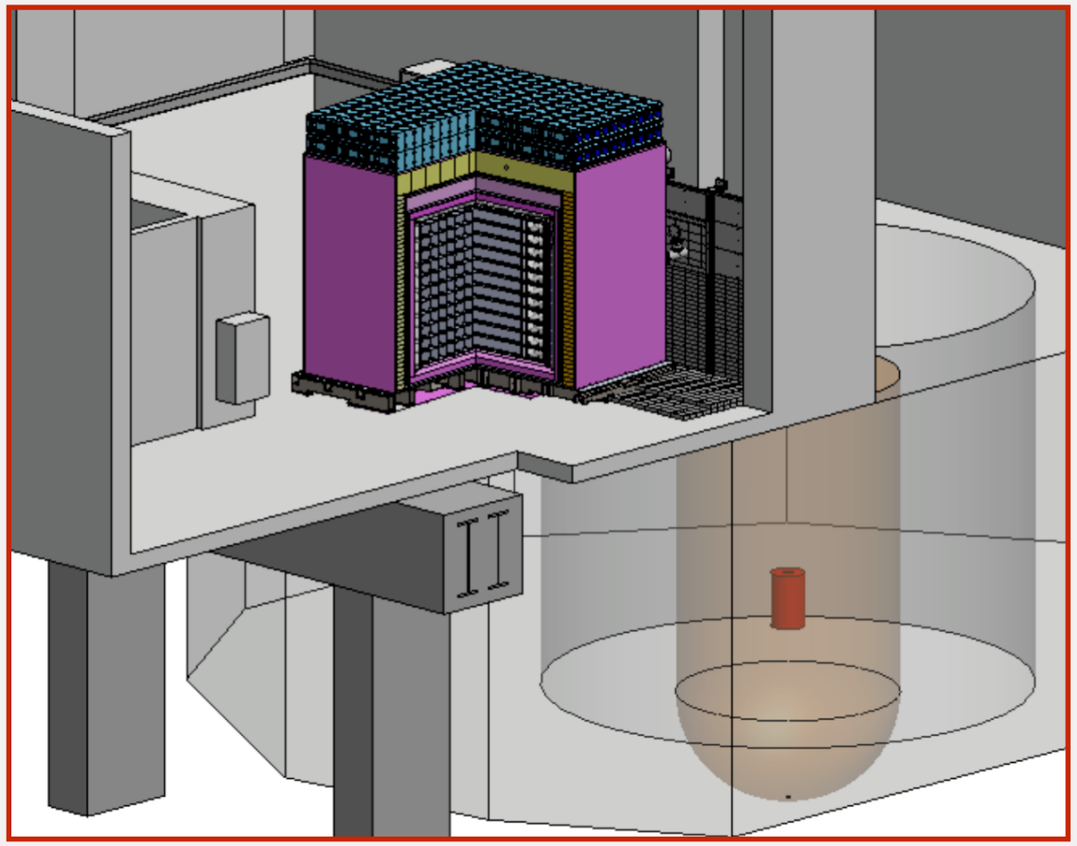
Precision Reactor Oscillation and Spectrum Experiment

Physics Goals:

1. Precisely measure reactor ^{235}U $\bar{\nu}_e$ spectrum
2. Search for short-baseline oscillations arising from eV-scale sterile neutrinos

- **Source** (High Flux Isotope Reactor at ORNL):
  - Highly Enriched Uranium Reactor (>93% ^{235}U)
  - Compact cylindrical core (0.5m high, 0.4 m wide)
- **Detector** (Li6-loaded liquid scintillator detector):
  - 14x11 matrix of optically separated segments
  - Movable
- ~160k antineutrino events/year at the closest position with S:B ~ 3:1
- Cosmics are the primary source of background

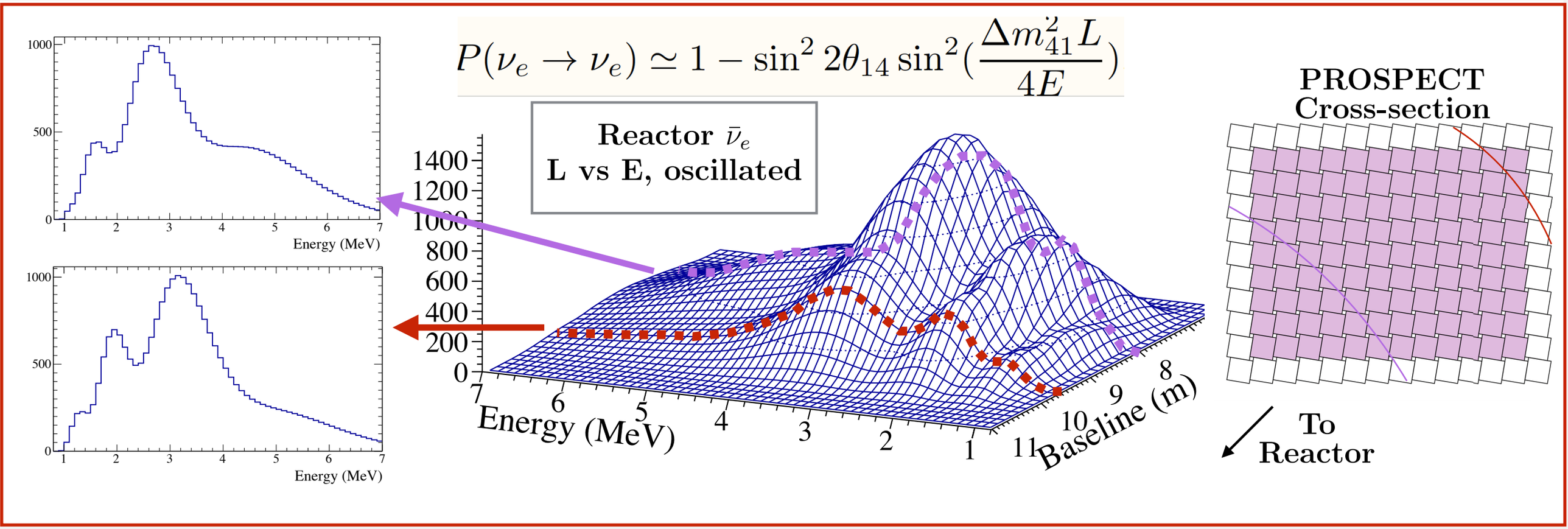
PROSPECT Detector



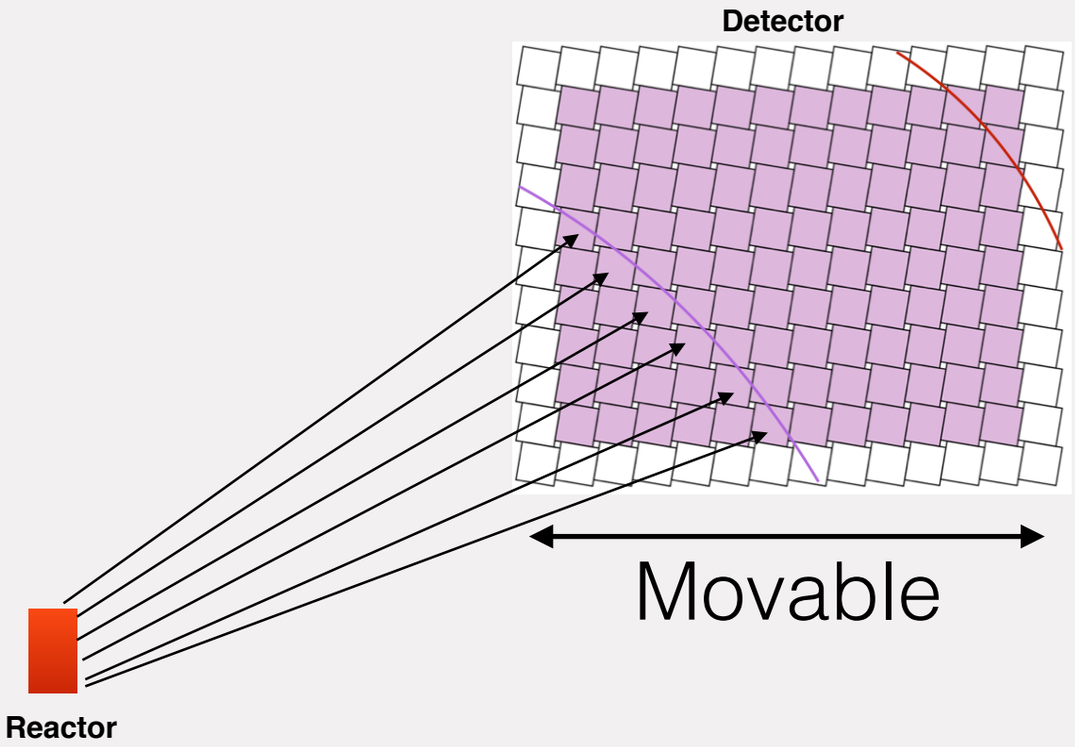
Schematic of PROSPECT Detector in HFIR

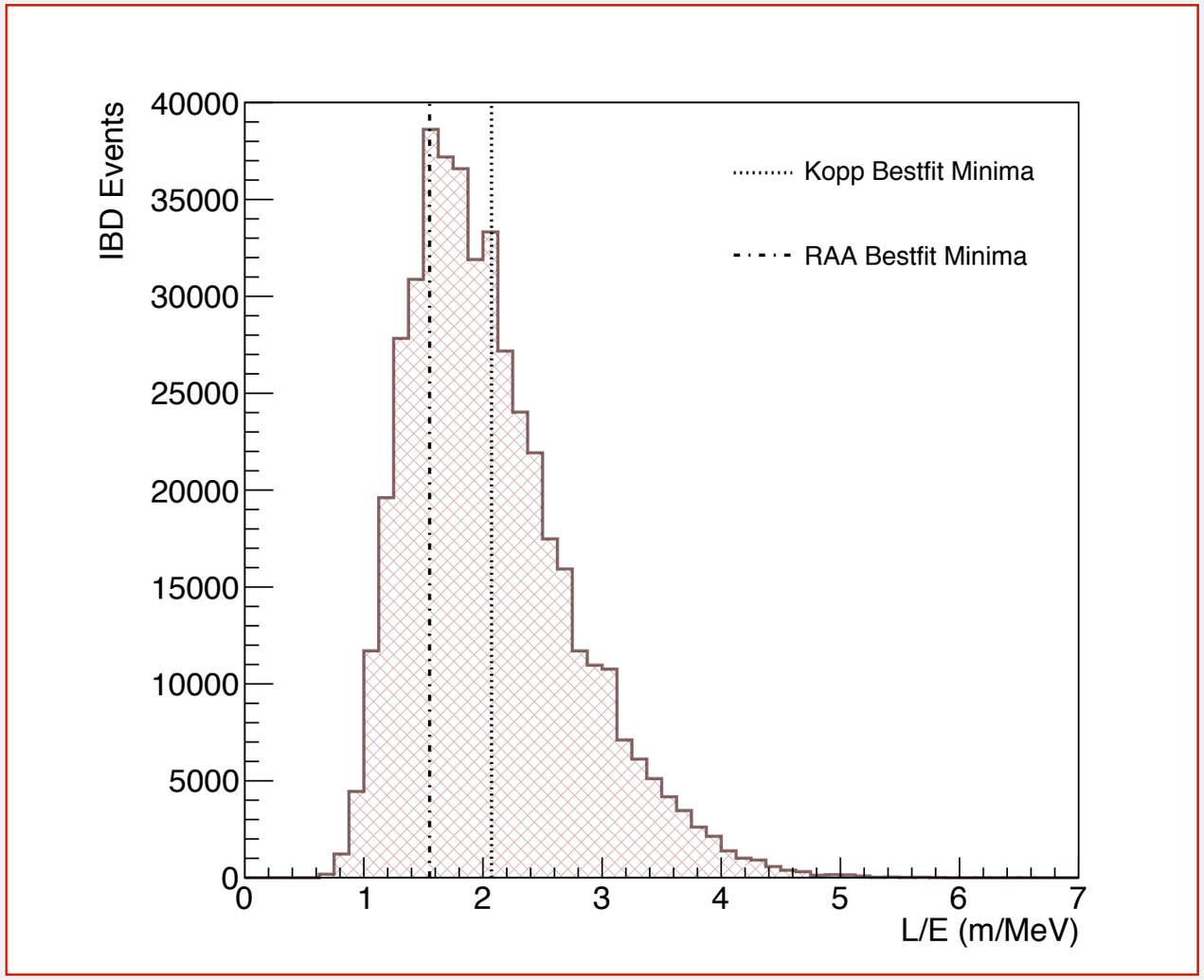
Oscillation Search Strategy

- Perform a **relative spectrum measurement** between 154 independent detectors (segments)
- Identical segments provide clear baseline-dependent spectrum
- **Independent of underlying reactor flux and spectrum models**
- Systematic effects minimized by relative search and detector movement



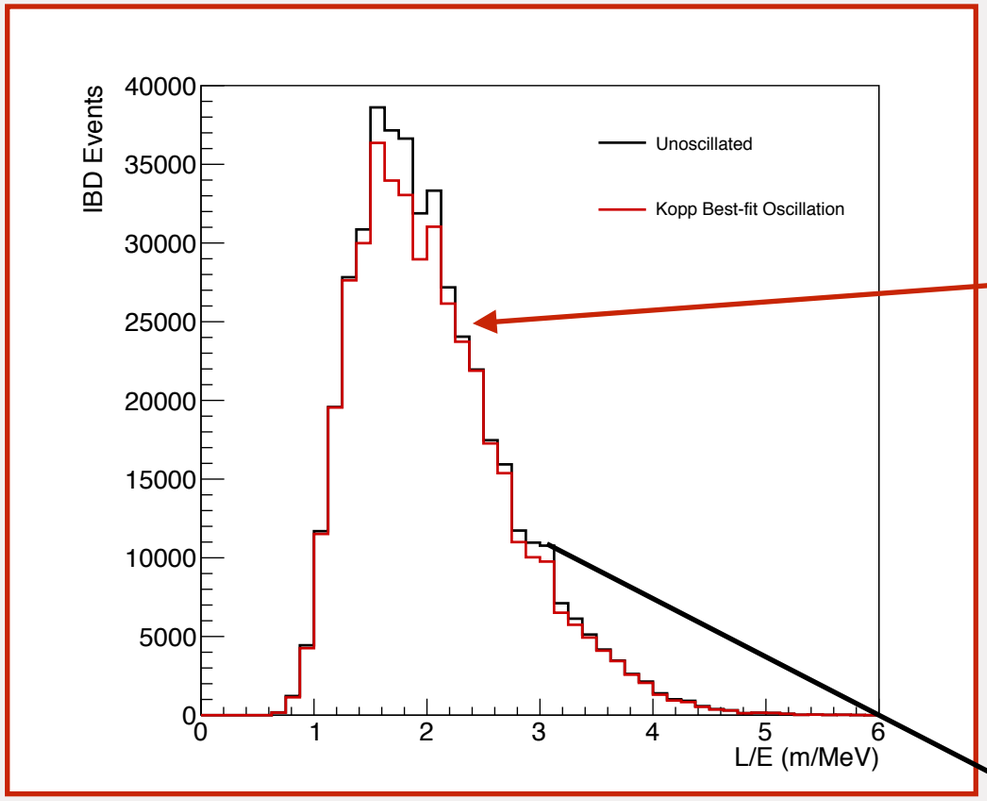
Anticipated L/E Coverage

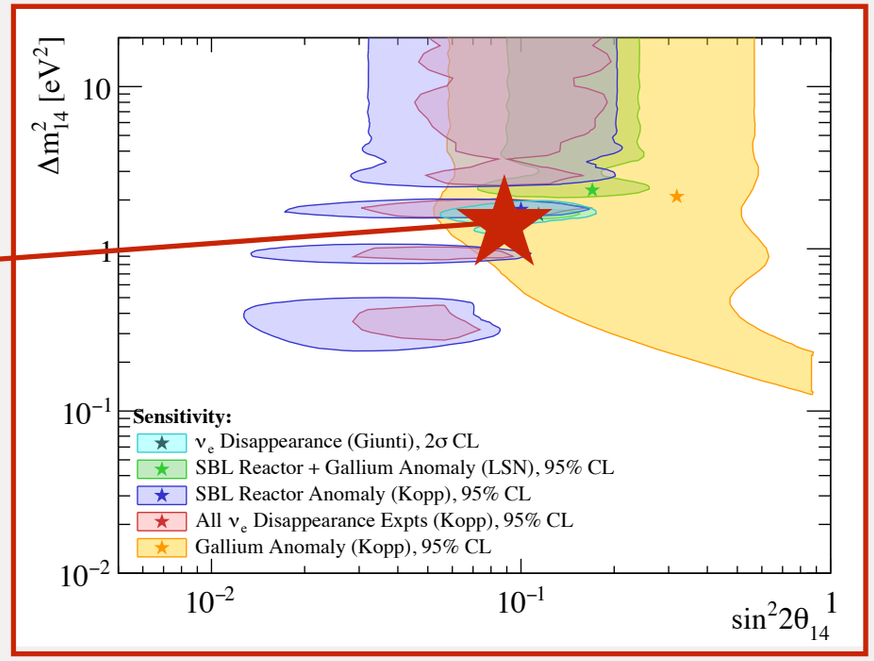




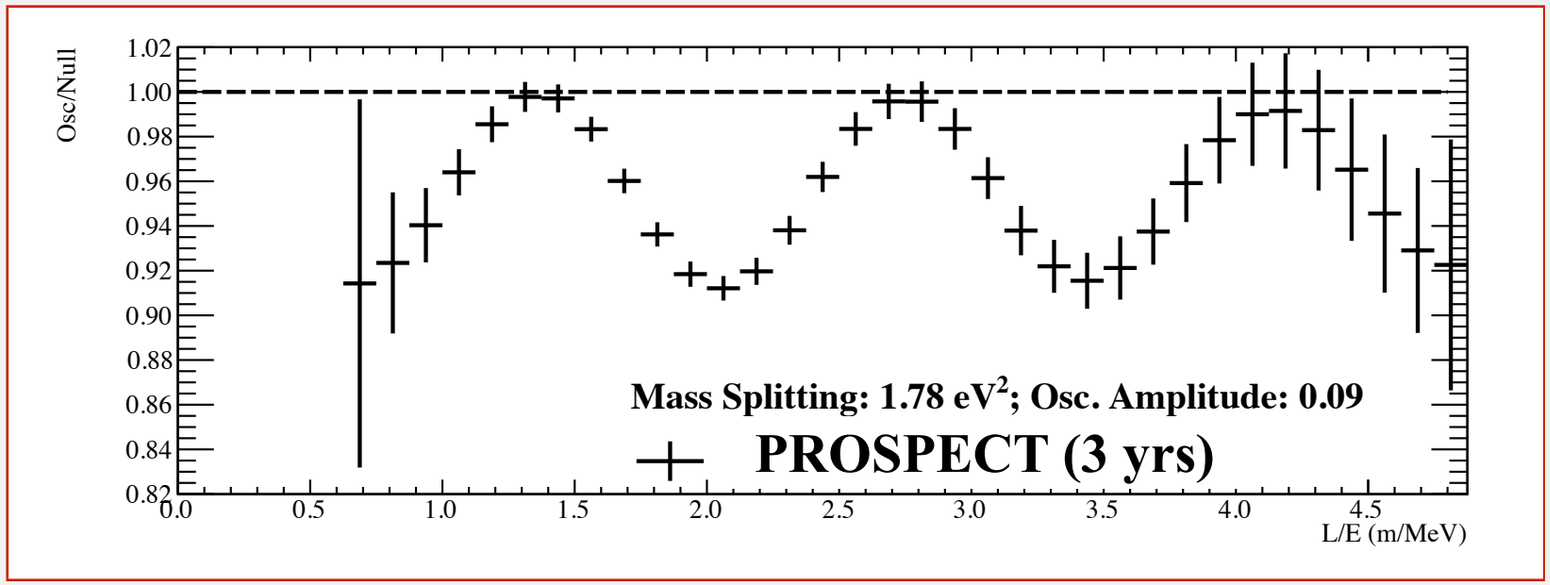
- Each segment covers multiple L/E bins
- Conversely, each L/E bin is covered by multiple segments
- Systematic biases (both correlated and uncorrelated) reduced
- Movement of the detector => varied contribution to L/E bins from each segment

L/E Signature





- L/E distribution shows variation between oscillated and unoscillated cases
- The ratio of oscillated vs unoscillated rates manifests as a sinusoidal curve as a function of L/E in presence of neutrino oscillations
- PROSPECT will cover a wide L/E range corresponding to multiple oscillation cycles



Sterile Neutrino Sensitivity

- Simulated IBD signal (M_i), background (B_i) along with toy oscillated models (T_i) are used to estimate covariance matrix based χ^2
- Covariance matrix approach provides a convenient way of including correlated uncertainties

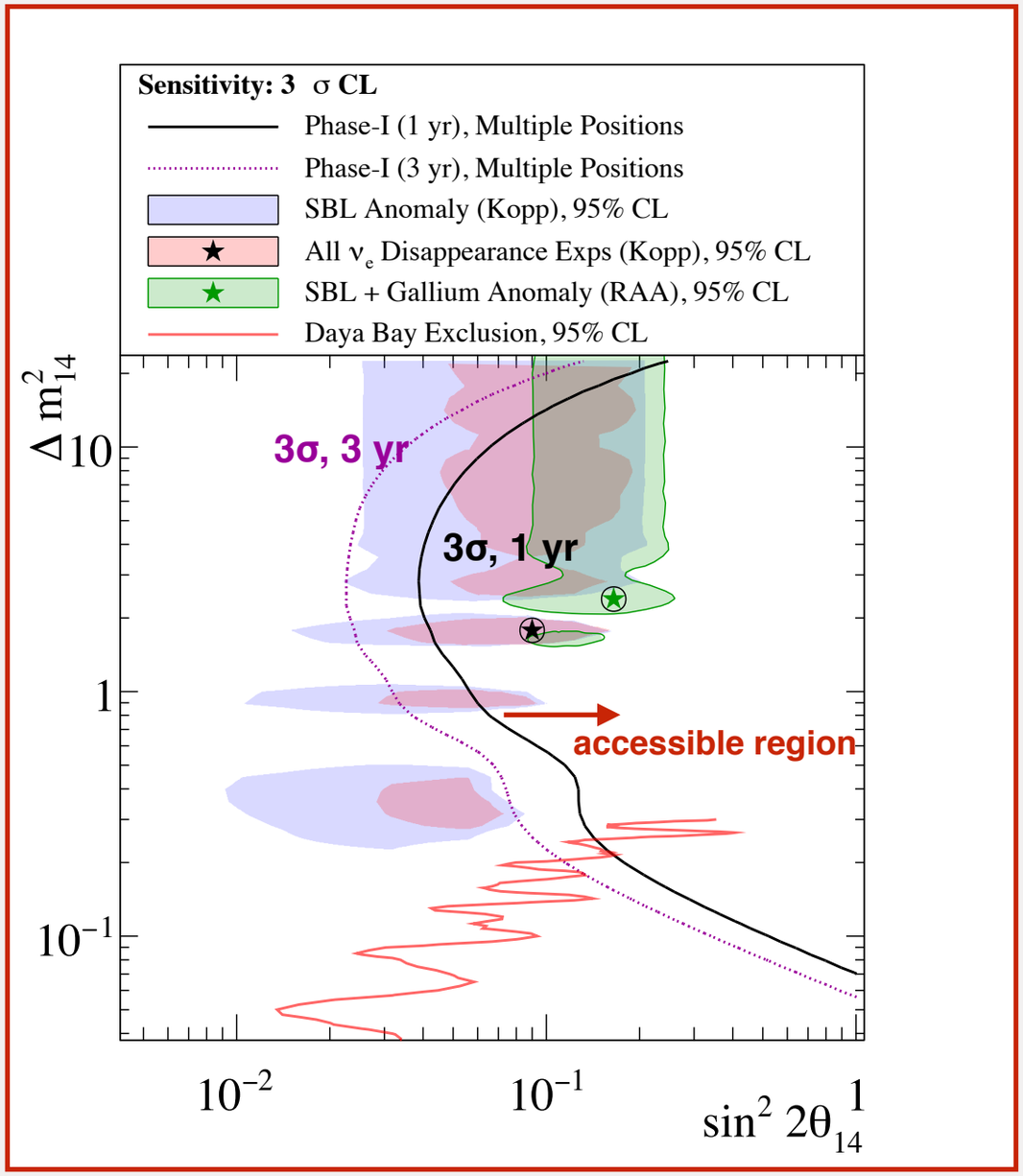
$$\chi^2_{min} = \mathbf{X^T} \mathbb{C}^{-1} \mathbf{X}$$

$$X_i = M_i - T_i - B_i$$

Uncertainties used in covariance matrices

- 100% Signal rate
- 10% Signal shape
- 1% Background shape
- 1% Bin to bin variation
- 1% Energy scale variation

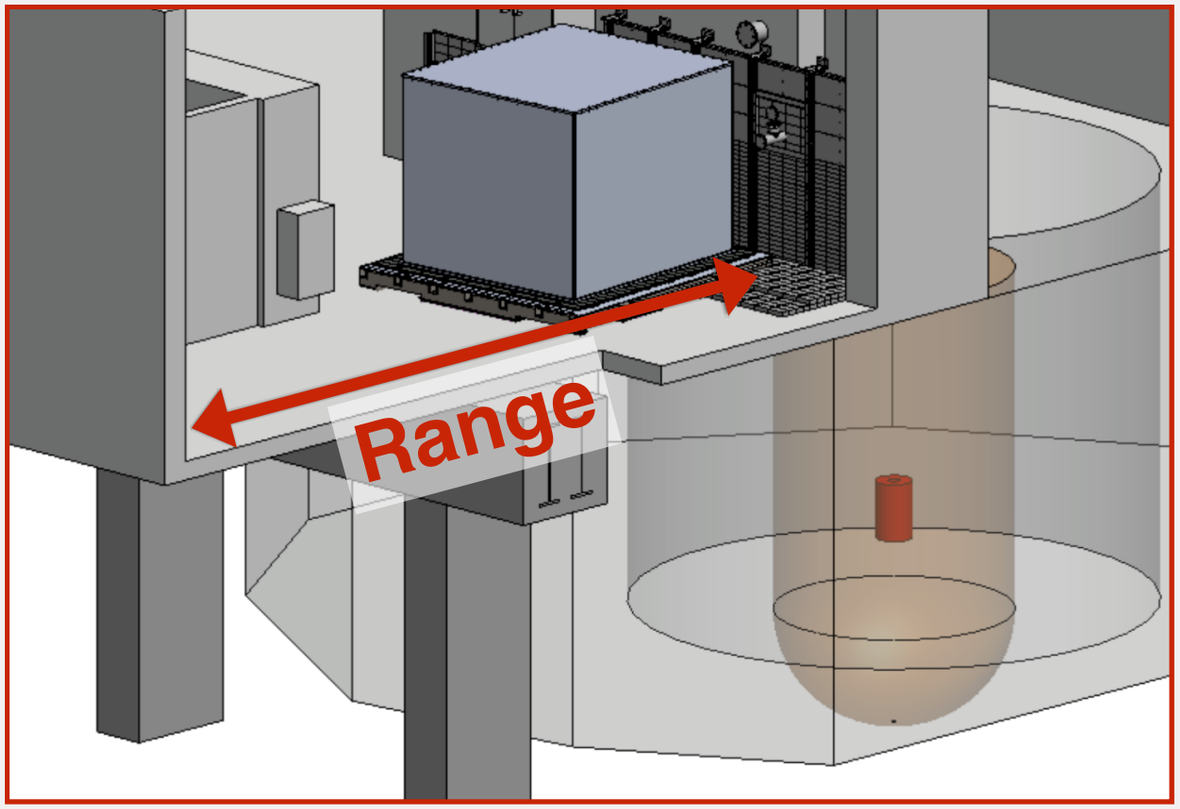
Oscillation sensitivity of PROSPECT detector



PROSPECT will be able to exclude sterile neutrino best-fit at 4σ in one year

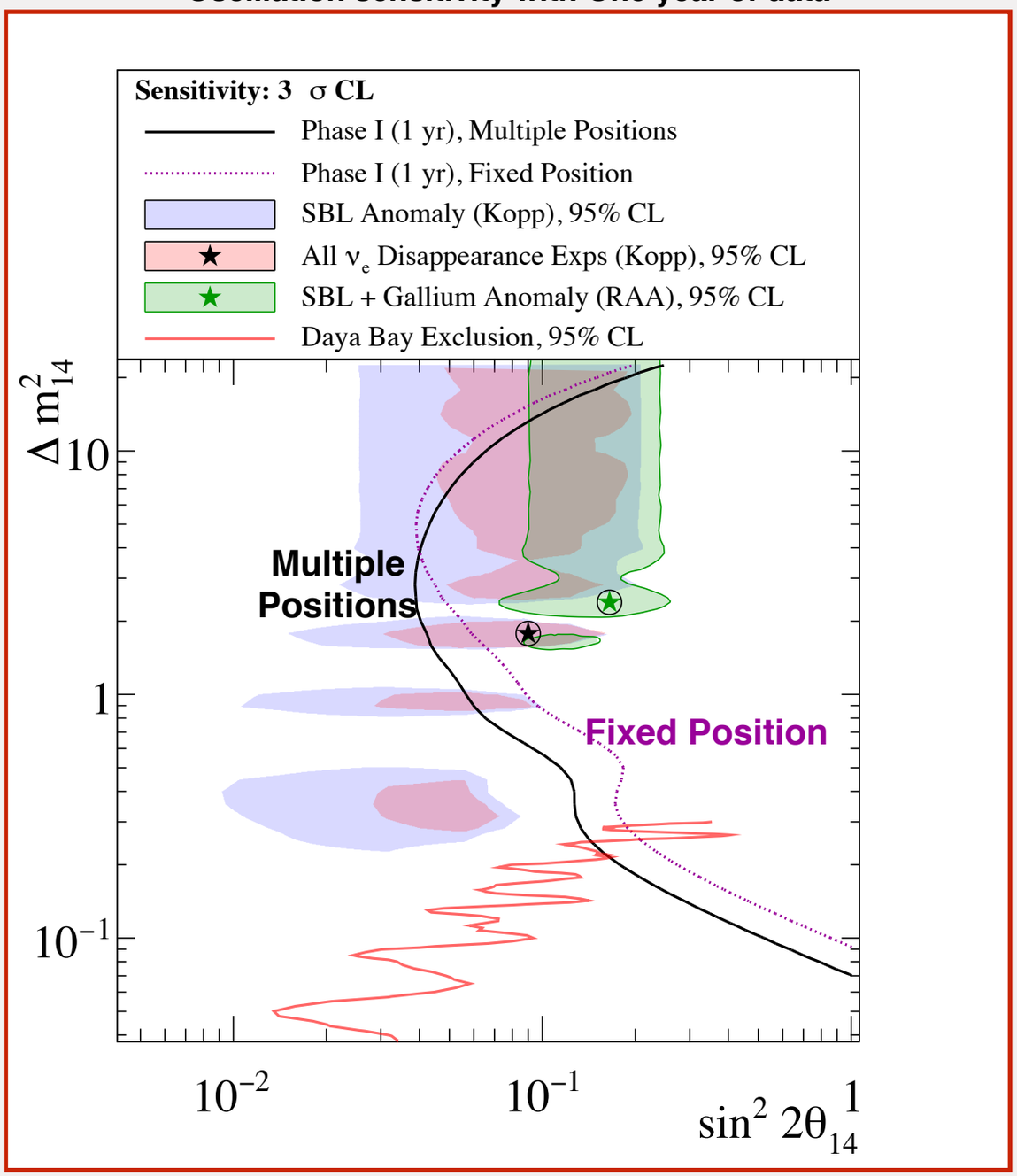
Power of mobility

Movable PROSPECT Phase-I Detector



- Movable detector allows an expanded investigation into the lower Δm^2 parameter space
- Systematic effects are also reduced with a movable detector

Oscillation sensitivity with One year of data



Movable PROSPECT detector enables coverage of desired (Δm^2,θ_{14}) parameter space

Summary

1. Reactor antineutrino experiments observe a deficit in the flux compared to the predictions
2. New short baseline reactor experiment will be able to resolve the anomaly
3. PROSPECT is designed to observe oscillations arising from sterile neutrinos with minimum dependence on reactor models
4. PROSPECT will be able to exclude current global sterile neutrino best-fit points at 4σ CL in 1 yr

Thank you

http://prospect.yale.edu

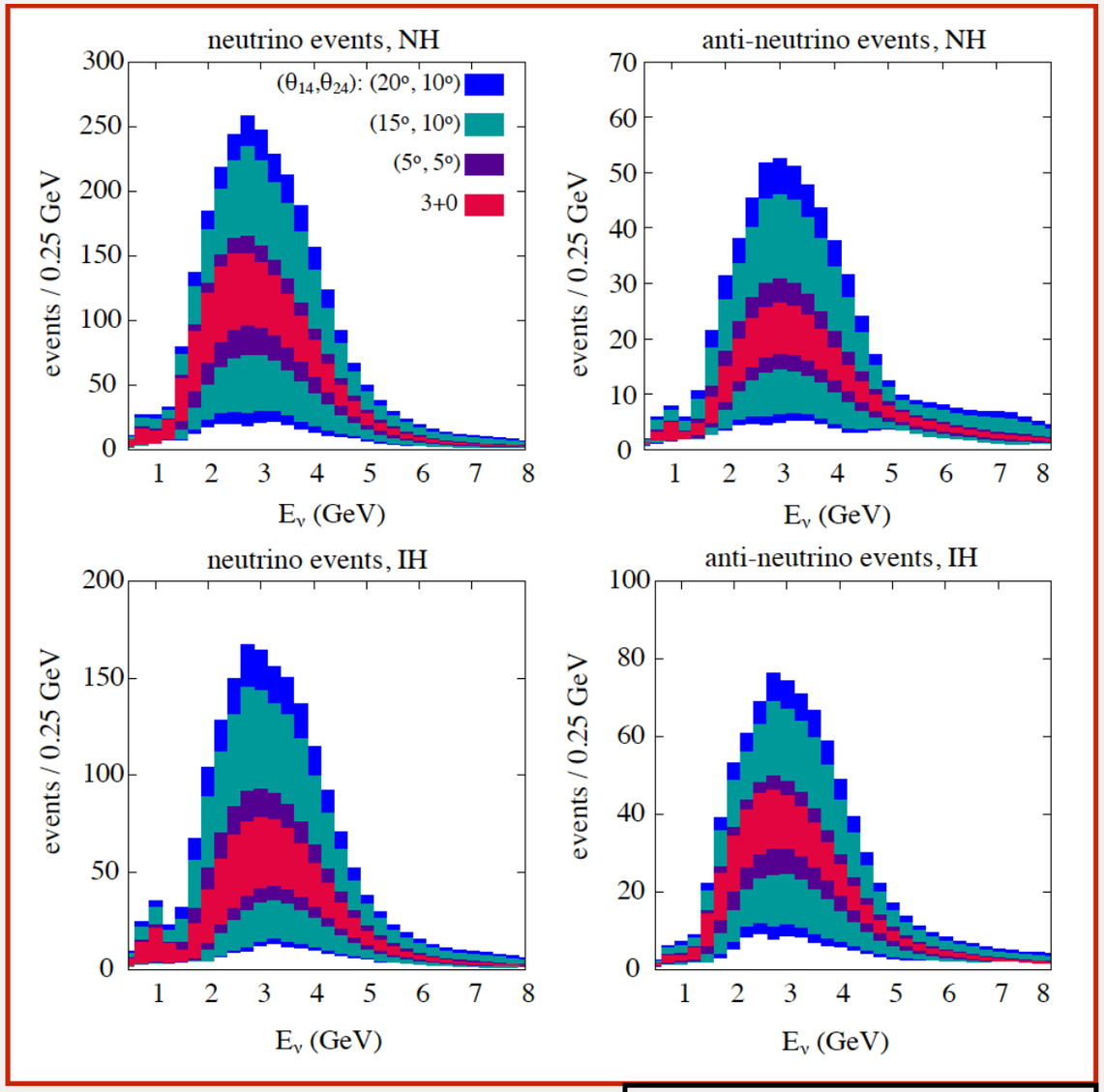
arXiv:1309.7647
Nucl. Instru. Meth. Phys. Res. A 806 (2016) 401
Journal of Phys. G 43 (2016) 11
JINST 10 (2015) P11004

Other APS Talks:
K Commeford, K11.00005
X Zhang, B9.00008
T Langford, R10.00002

EXTRAS

Implications

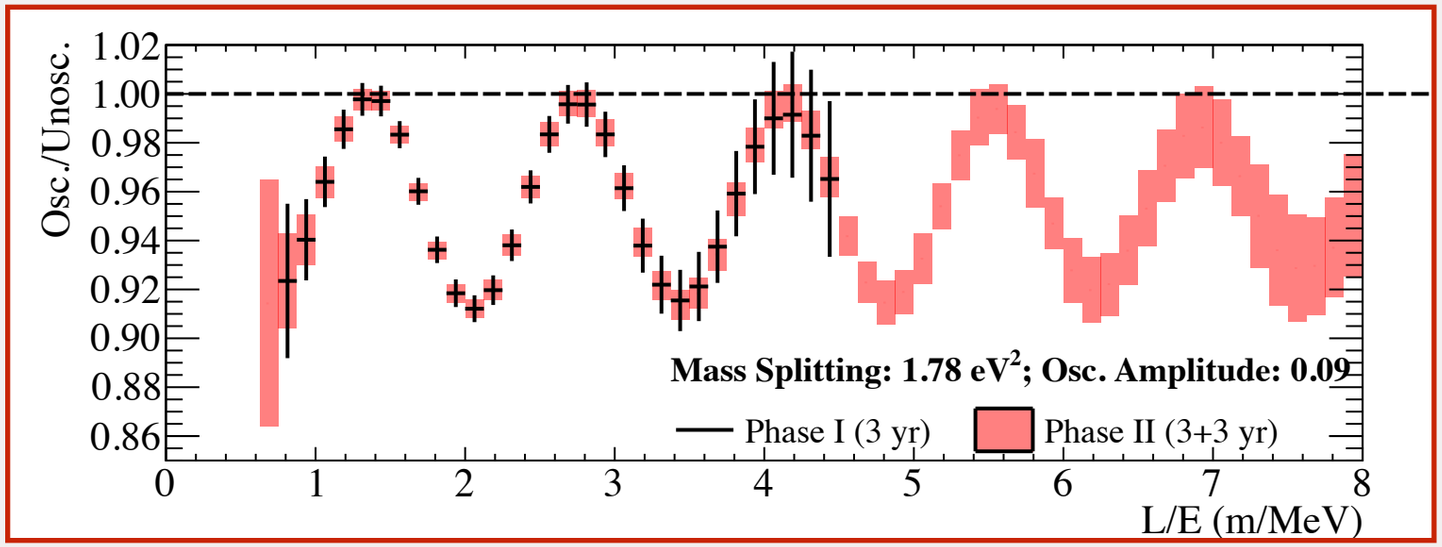
1. Existence of sterile neutrinos have far-reaching implications on particle physics and cosmology
2. Sterile neutrinos lead to complications in interpretation of CP-violation searches
3. Sterile neutrinos will alter the effective neutrino majorana mass



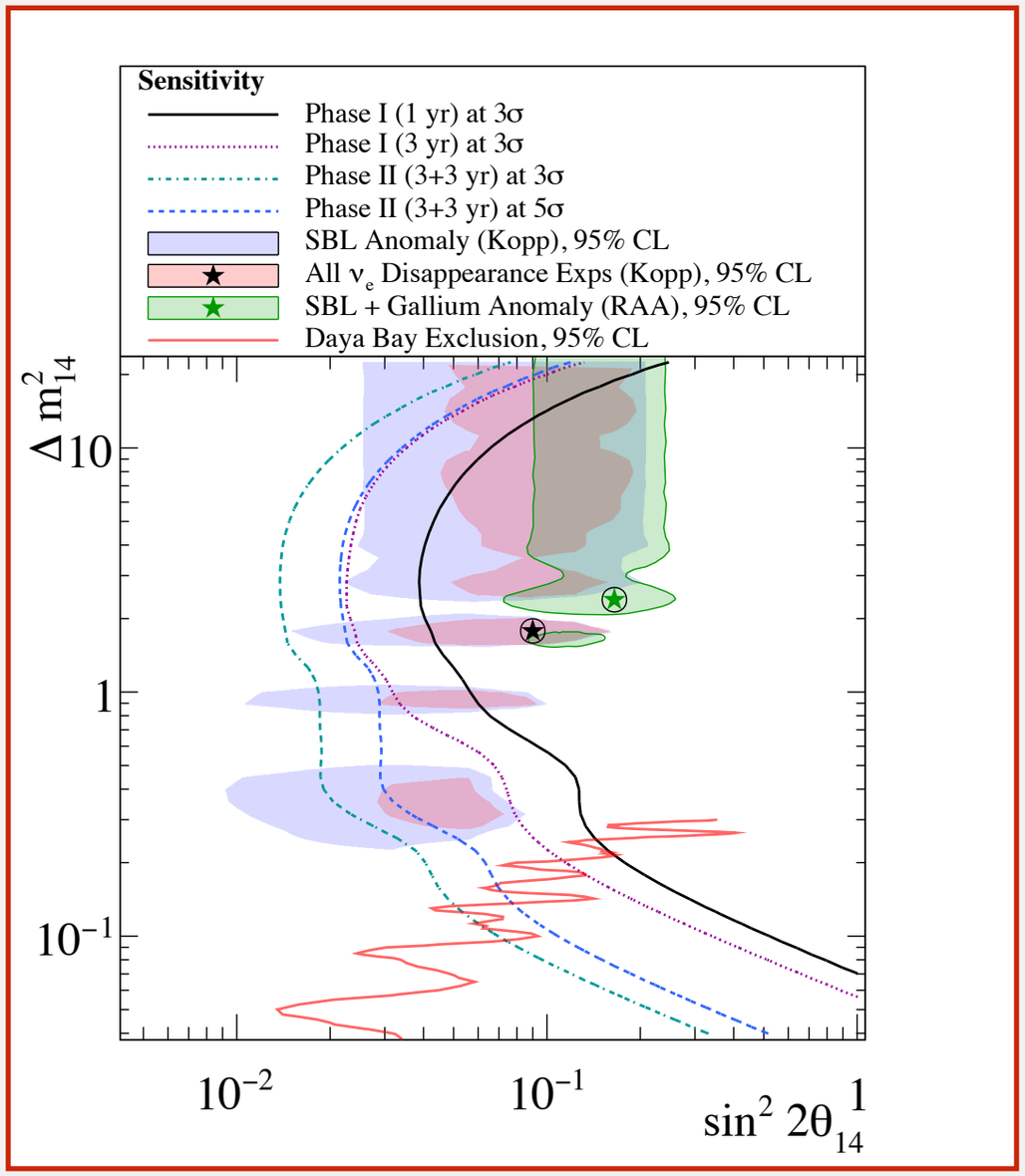
10.1007/JHEP11(2015)039

Second Detector Extension

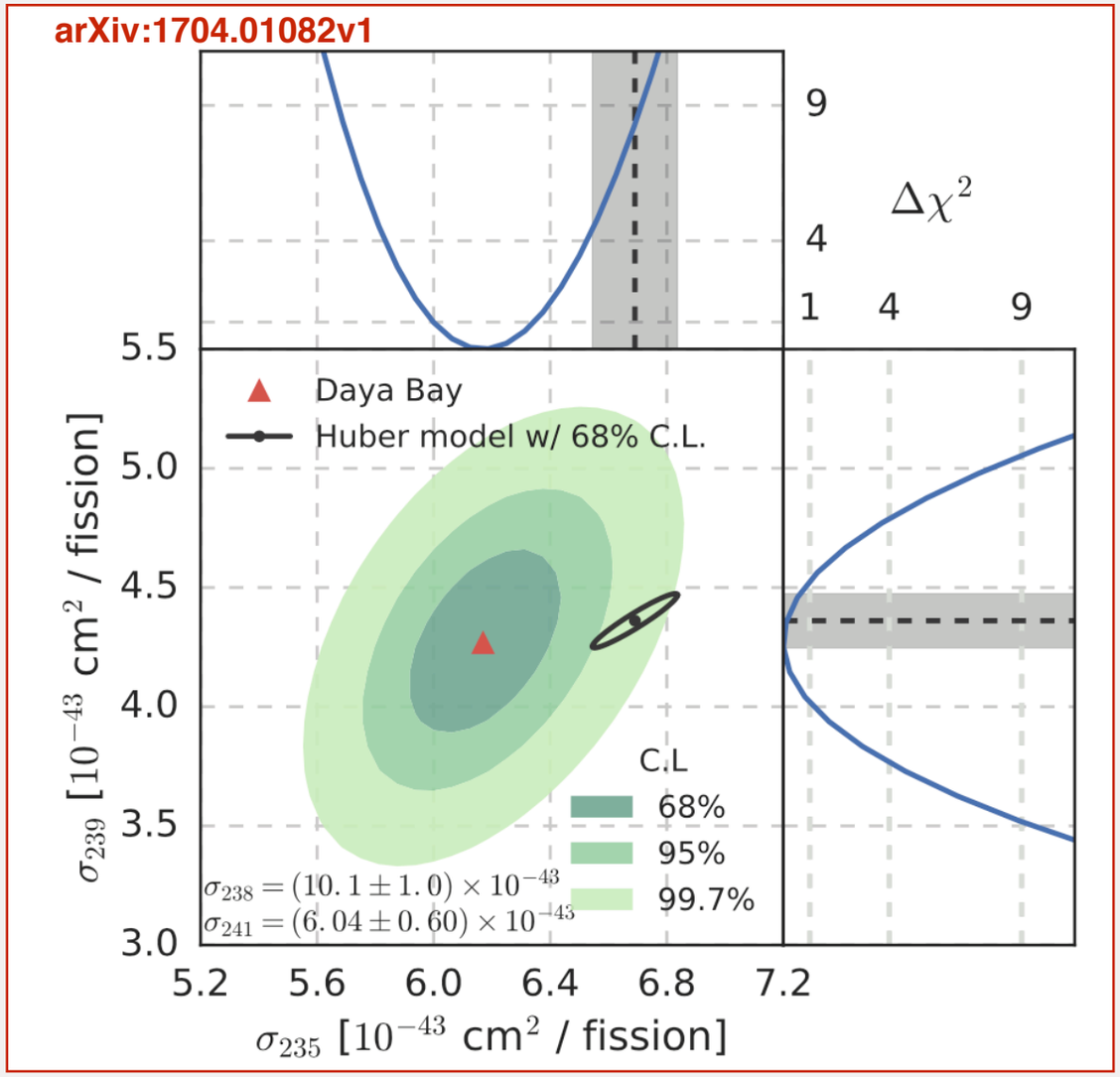
- A longer baseline detector (Phase-II) can be installed outside the HFIR complex
- A 10-ton detector at 15-20m can investigate any oscillation signature uncovered by the first detector
- Extending the baseline increases the baseline and L/E range and improves the sensitivity



L/E signature of sterile neutrino oscillations with global best-fit parameters



Recent Daya Bay Results



- Daya Bay has recently reported IBD yields of U235 and Pu239
- U235 shows a deficit of ~8% compared to predictions
- Is reactor flux anomaly only from U235 ?
- Daya Bay data seems to indicate that the anomaly could be only from U235
- The deficit could be from more than one source
- PROSPECT will conclusively test the sterile neutrino (Equal-deficit) hypothesis