PROSPECT: a Precision Reactor Oscillation and Spectrum Experiment

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For the PROSPECT Collaboration

PROSPECT: Motivation

Spectral Shape as a Function of Energy and Baseline

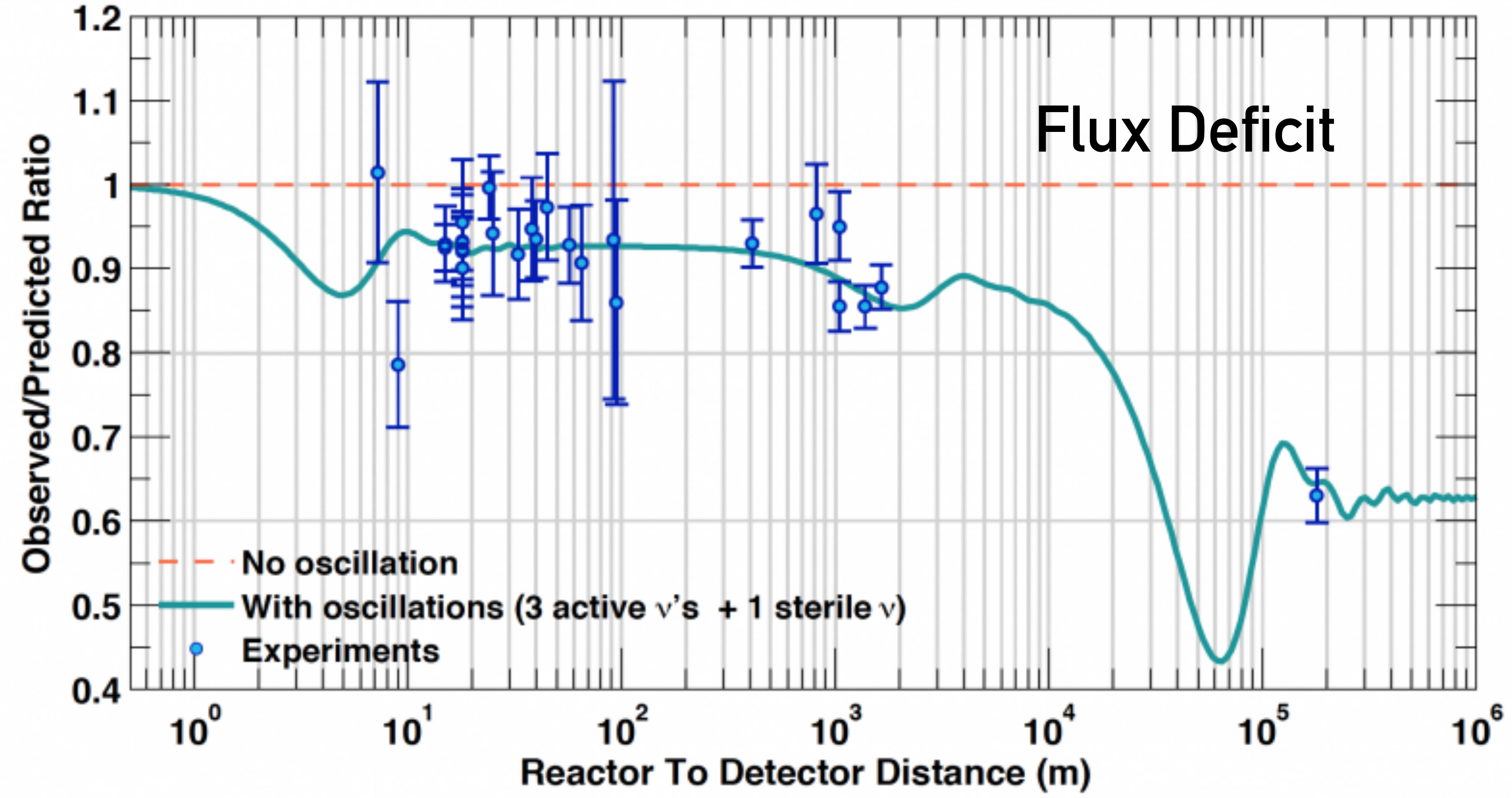
Possibility of sterile neutrino oscillation as an explanation of observed electron antineutrino deficits

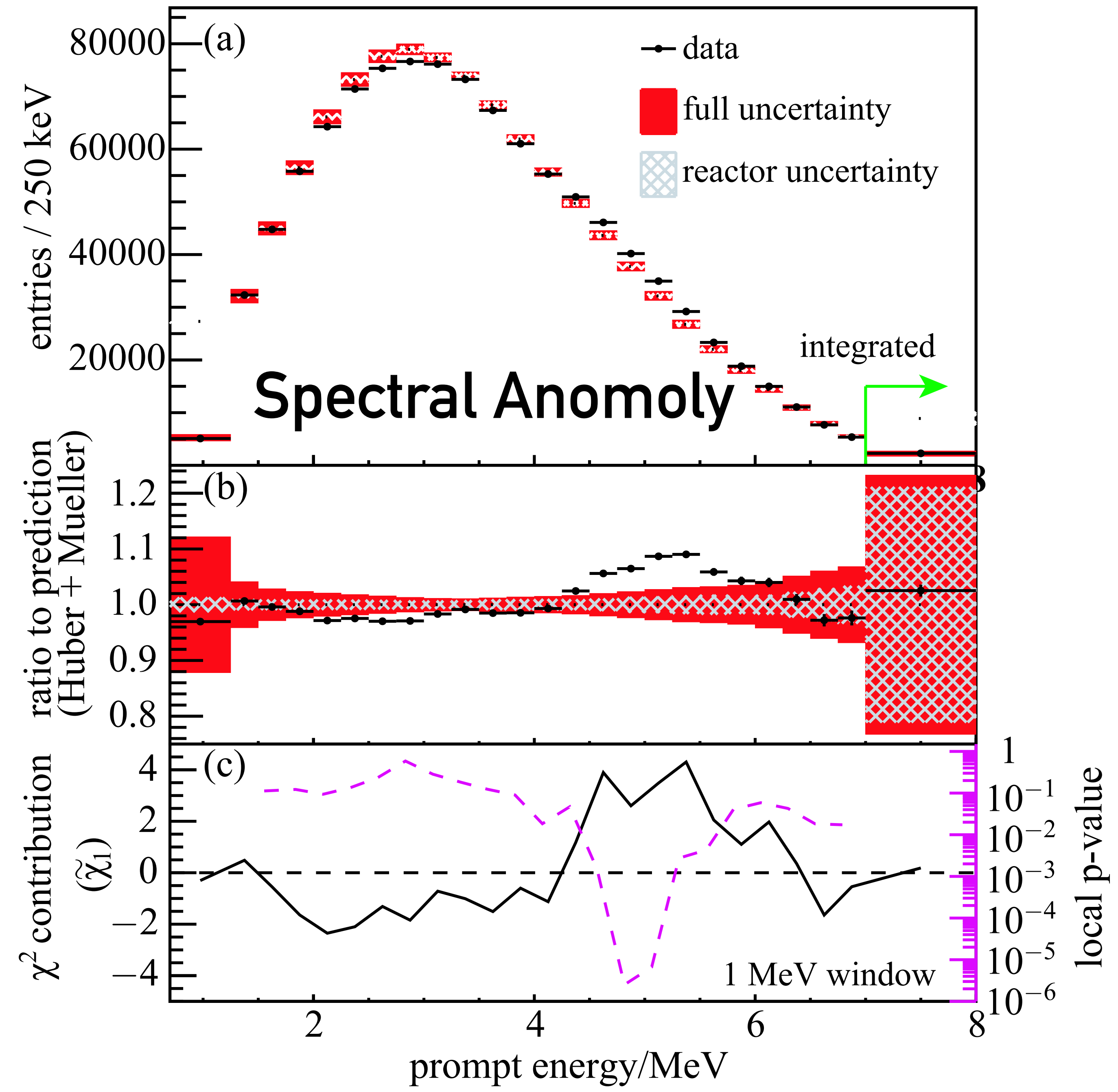
Precision Measurement of Reactor Spectrum

Anomalies in spectral shape at ~ 5-6 MeV
Provide complementary measurement of ^{235}U (fuel evolution)

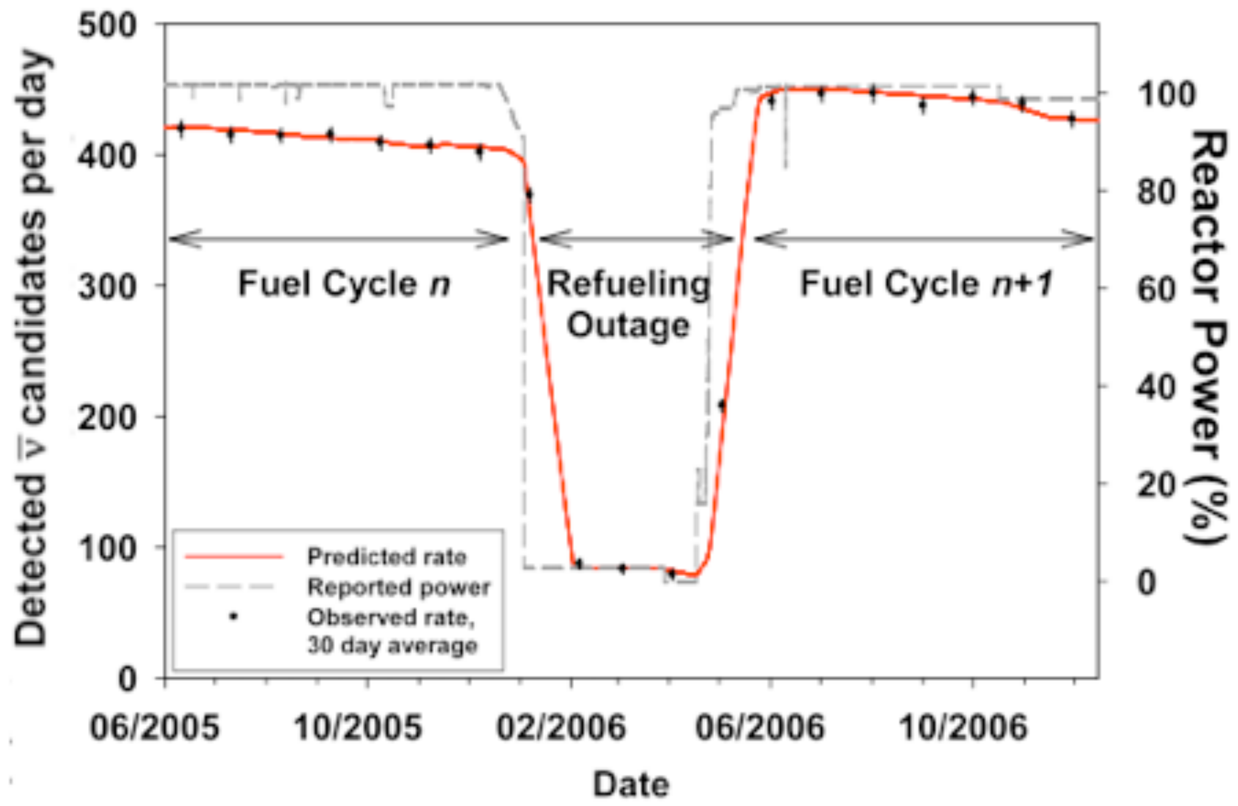
Safeguards - a Passive Standoff Capability

Provides a remote, non-intrusive reactor power and Pu production monitoring

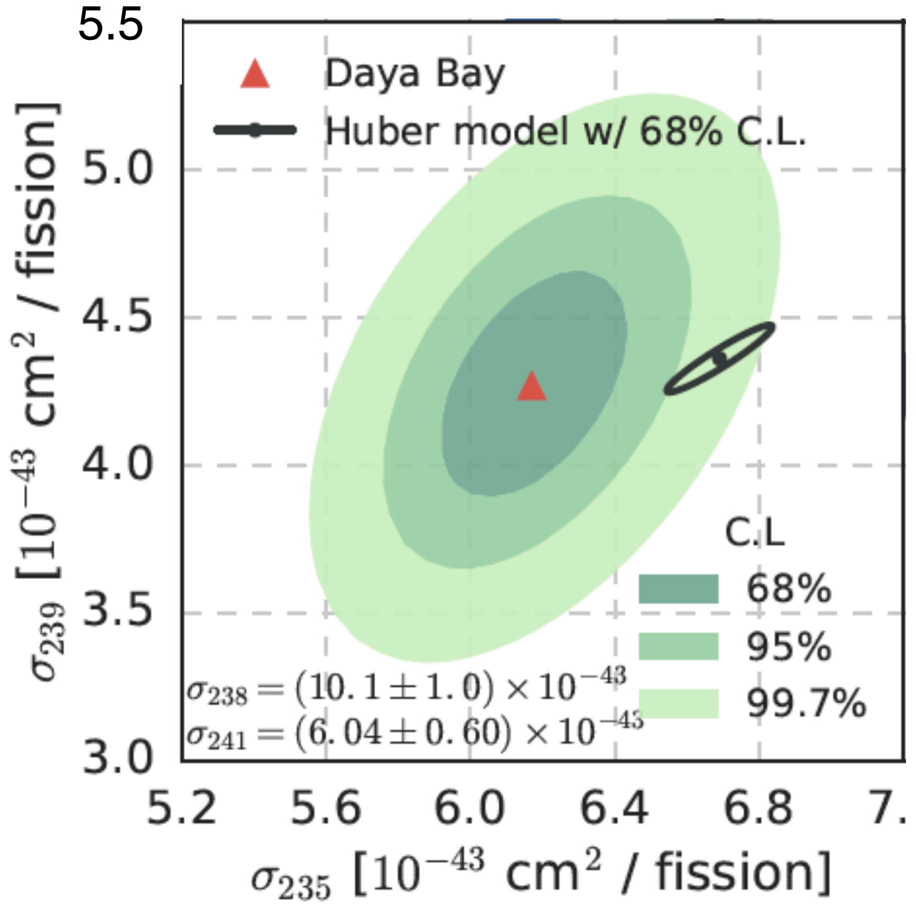




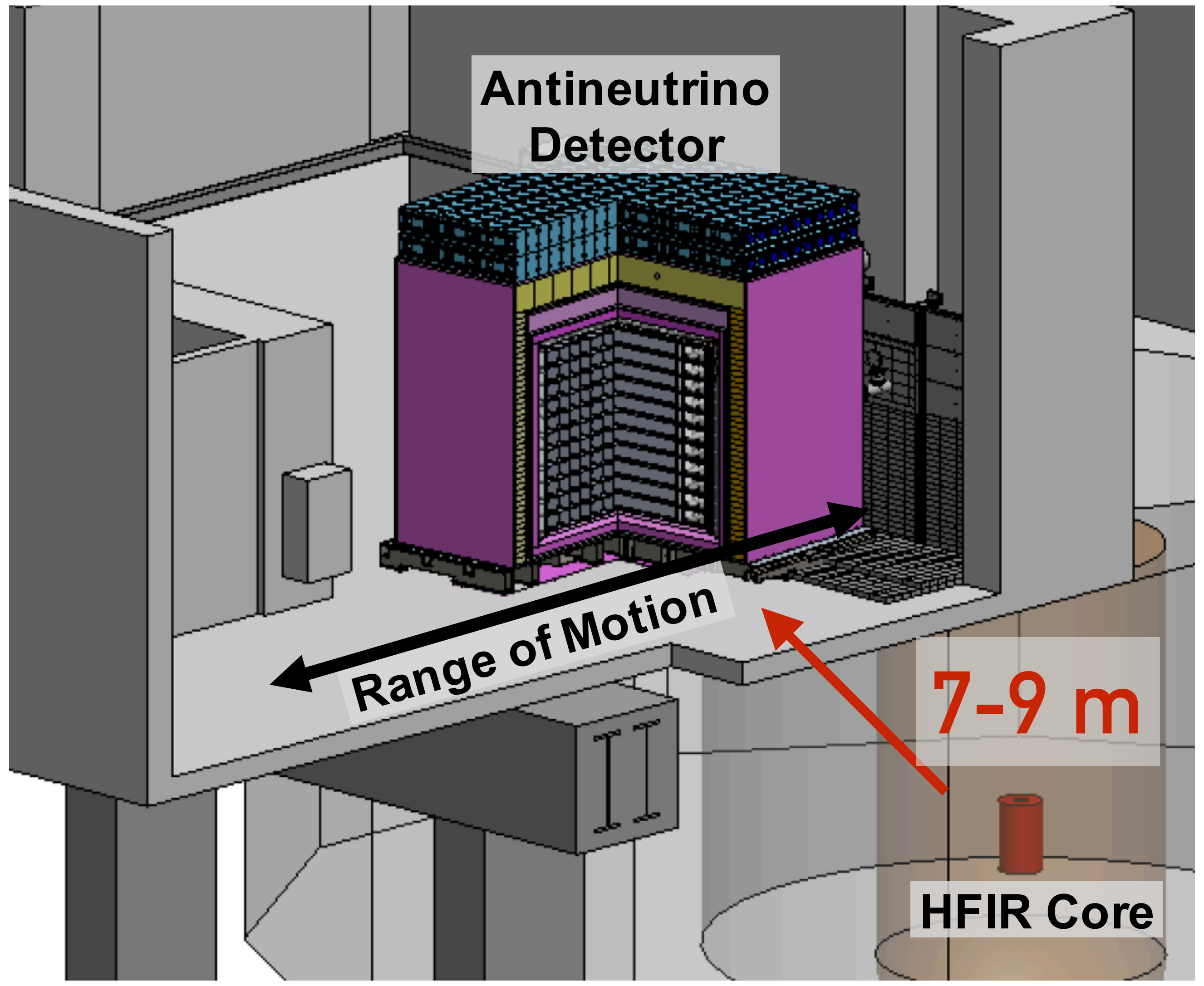
Reactor Monitoring

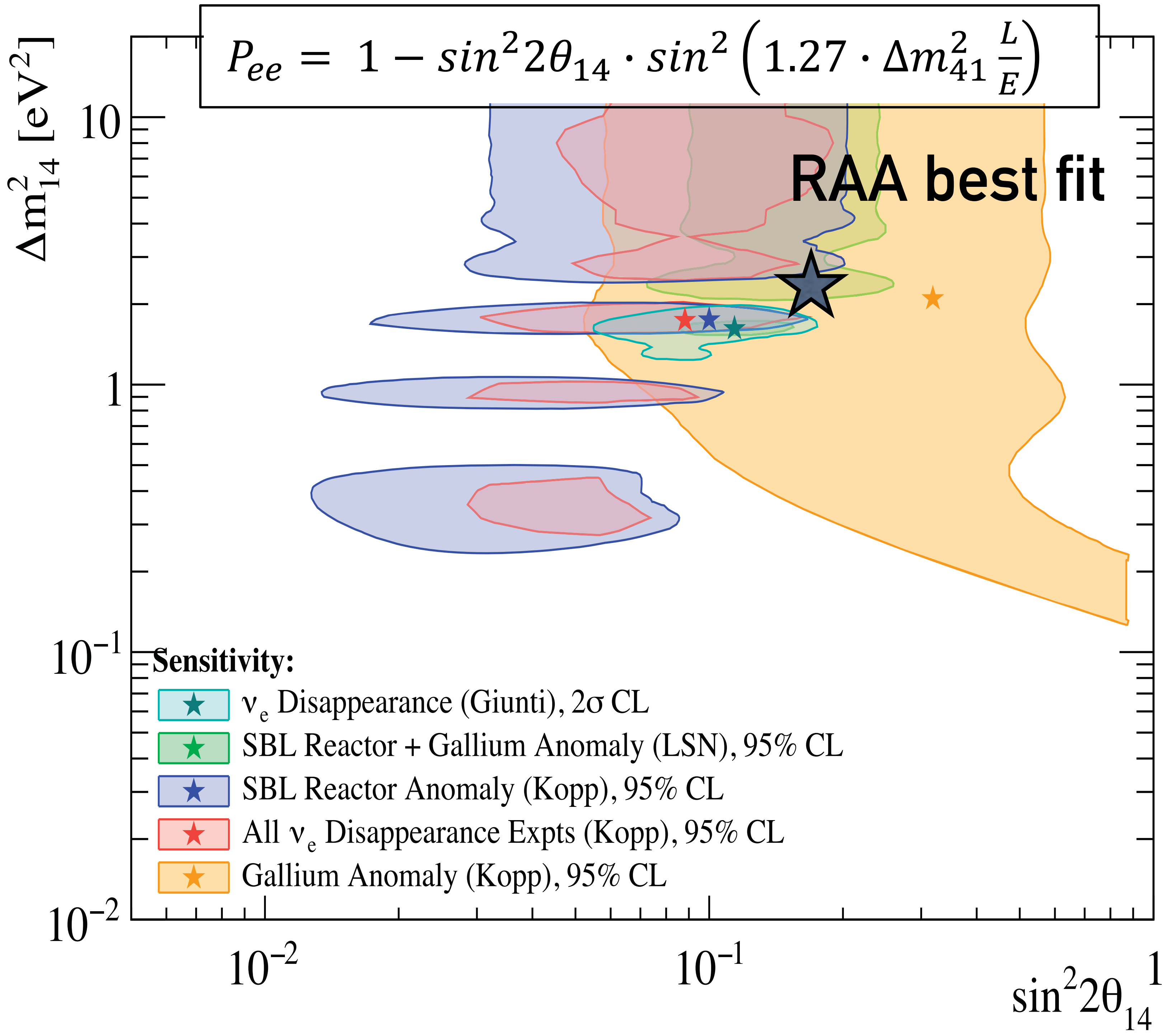


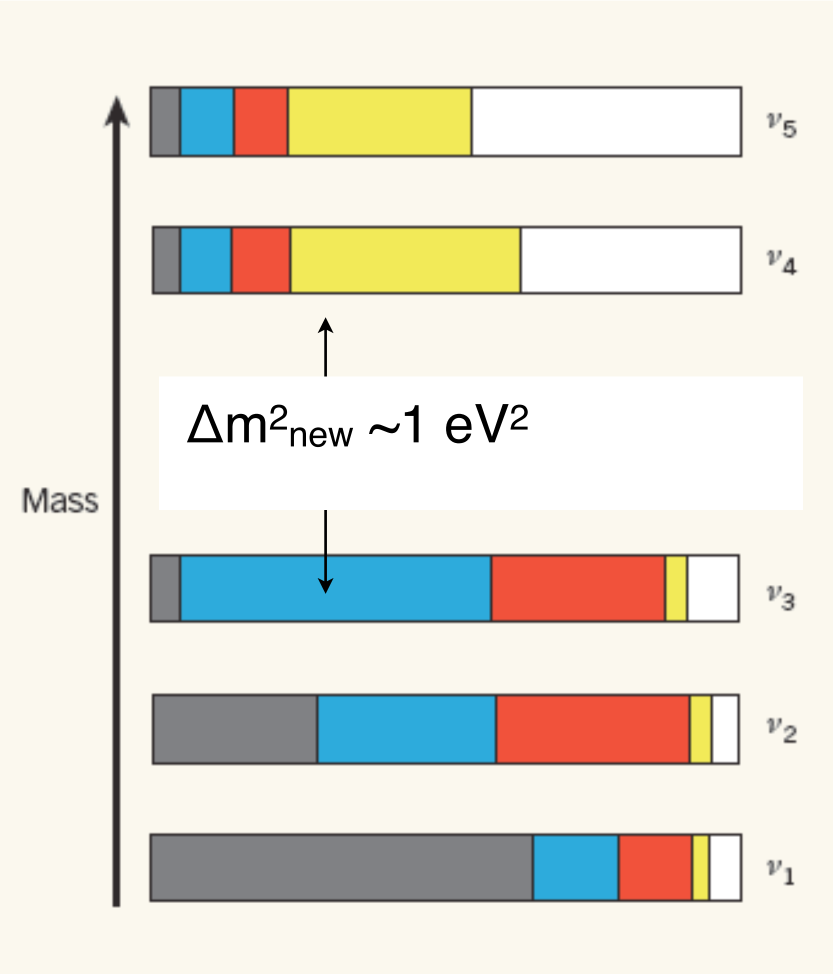
Isotopic Evolution



Search for short-baseline sterile-neutrino oscillations **independent** of reactor models

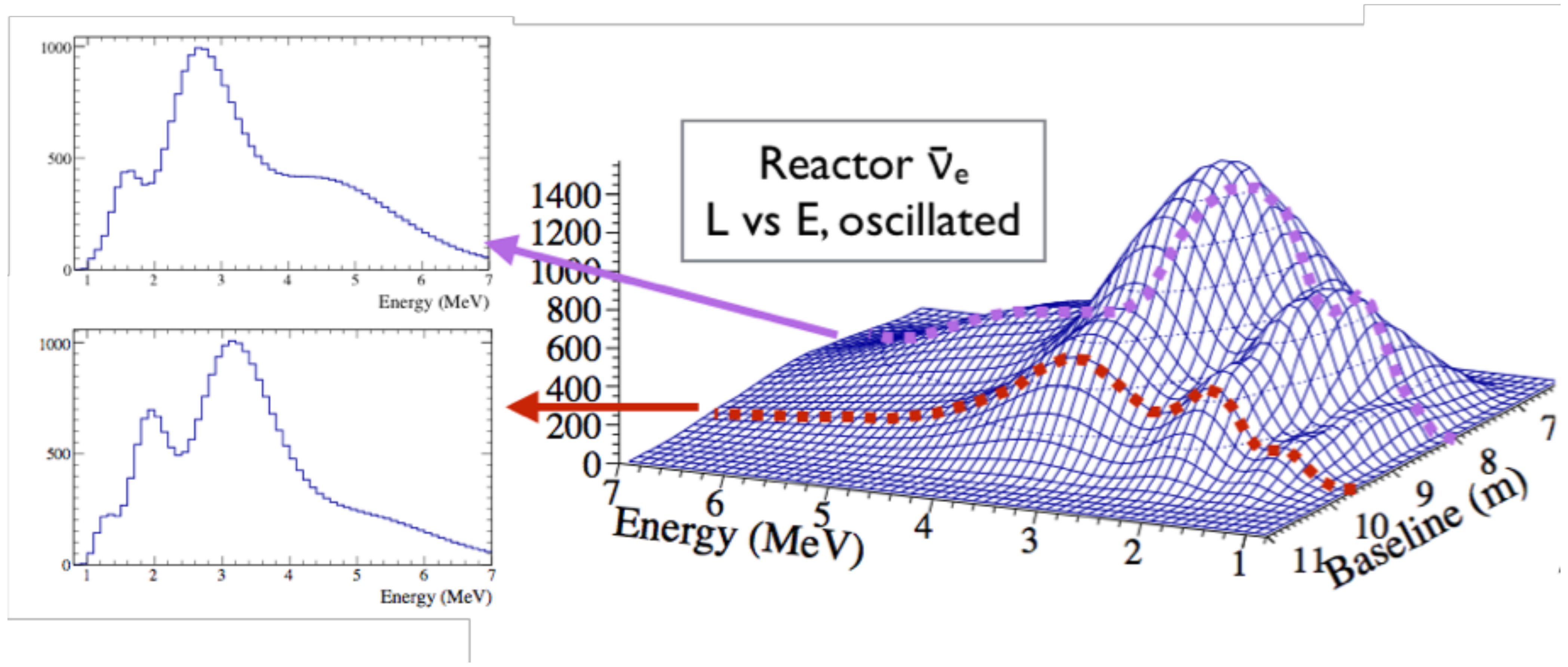






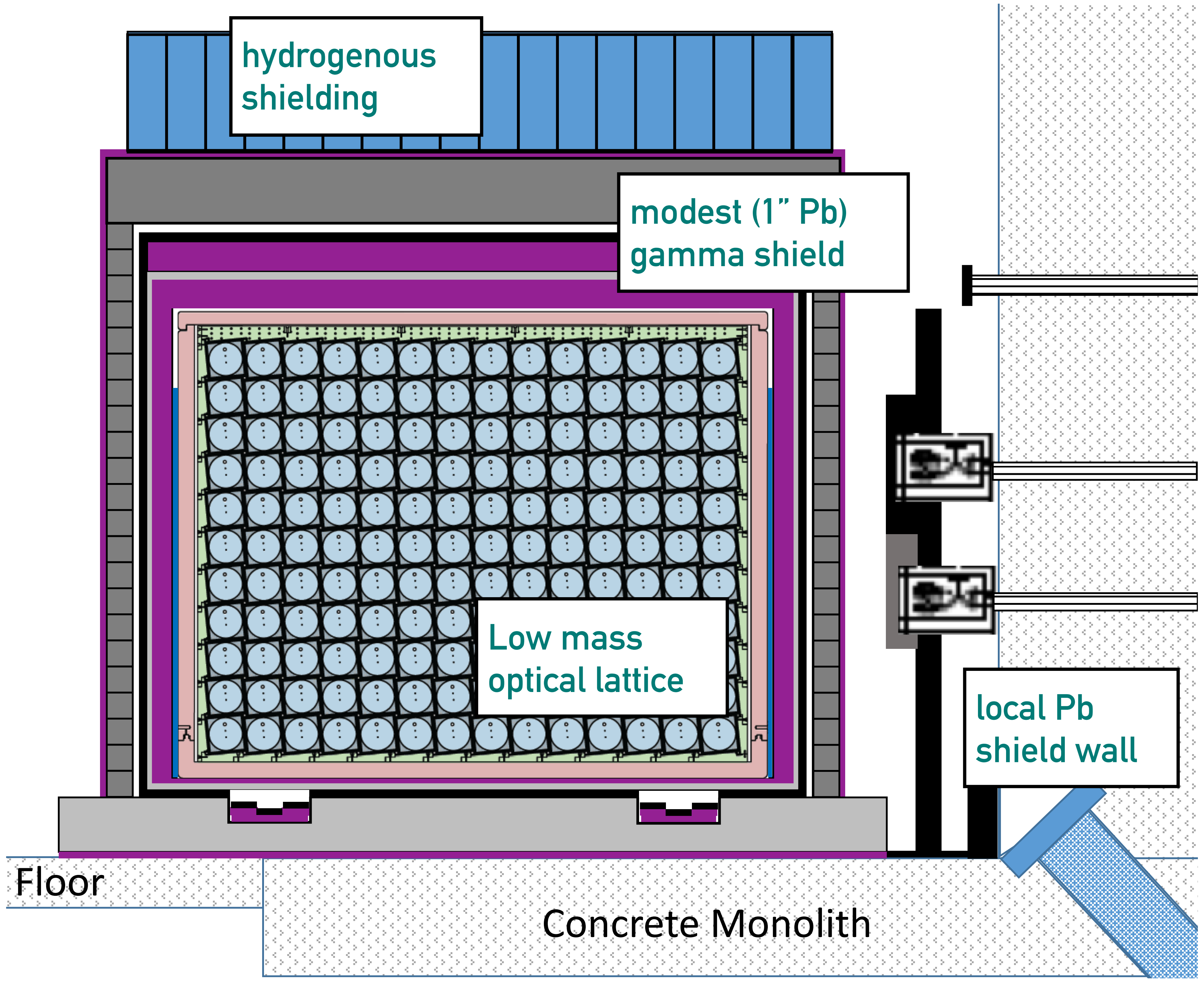
Experimental Strategy:

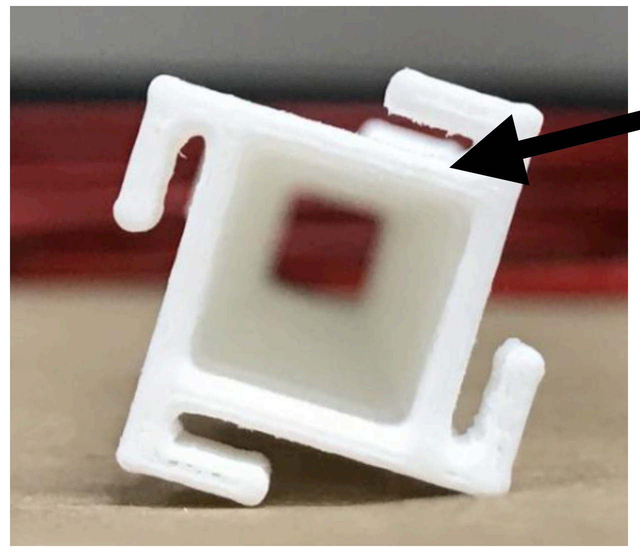
- Compact HEU research reactor (HFIR at ORNL)
- Segmented detector localizes events and supports background rejection
- Measure high-resolution spectrum at a range of baselines (7-9m in current position)
- Search for characteristic relative spectral distortions within detector volume

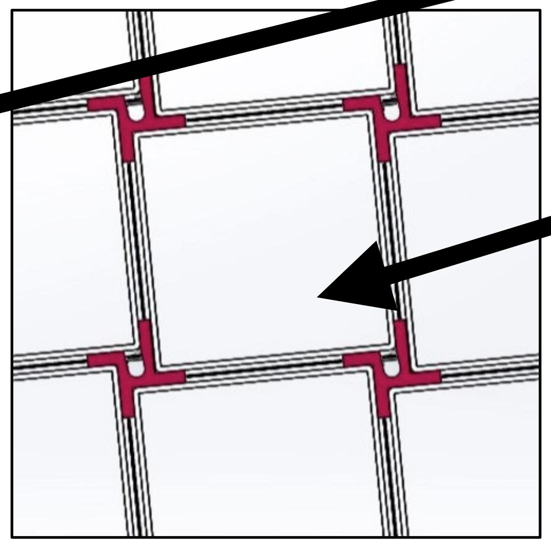


Design Overview

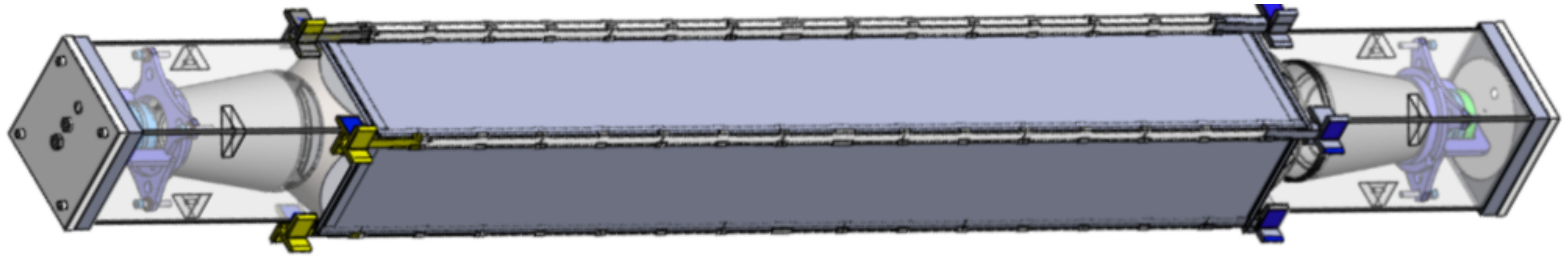
- Single 4,000 L ^{6}Li-loaded liquid scintillator (3,000 L fiducial volume)
- 11 x 14 (154) array of optically separated segments
- Very low mass separators (1.5 mm thick)
  - Corner support rods allow for full in situ calibration access
- Double ended PMT readout, with light concentrators
  - good light collection and energy response ~4.5-5%/$\sqrt{E}$ energy resolution
  - full X,Y,Z event reconstruction
- Optimized shielding to reduce cosmogenic and local backgrounds







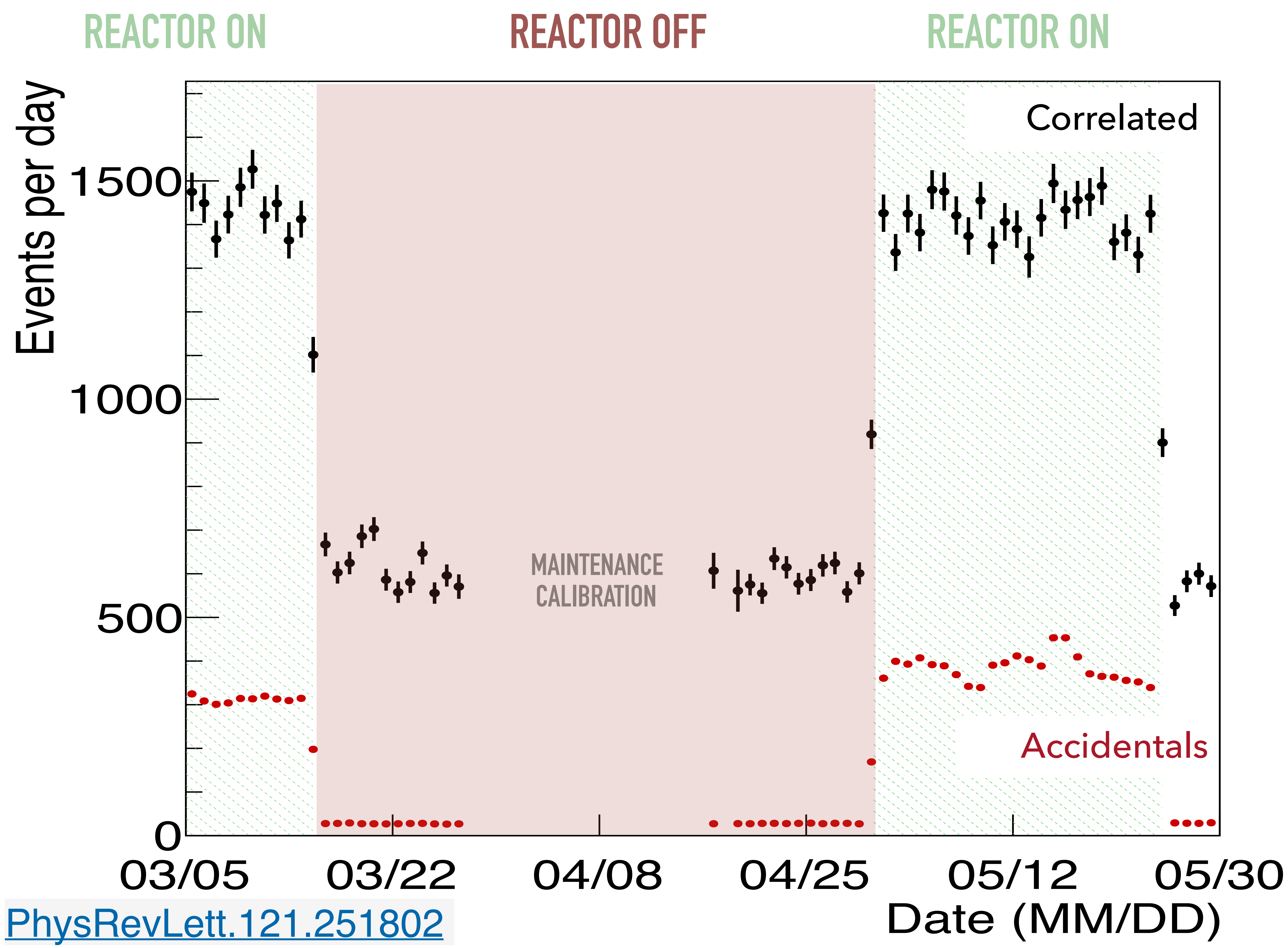
TILTED ARRAY FOR CALIBRATION ACCESS



single segment

Initial Data Set

- 33 days of Reactor On
- 28 days of Reactor Off
- IBD event selection defined and frozen on 3 days of data
- 25,461 IBDs detected (0.8-7.2 MeV)
- Average of ~771 IBDs/day
- Correlated S/B = 1.32
- Accidental S/B = 2.20

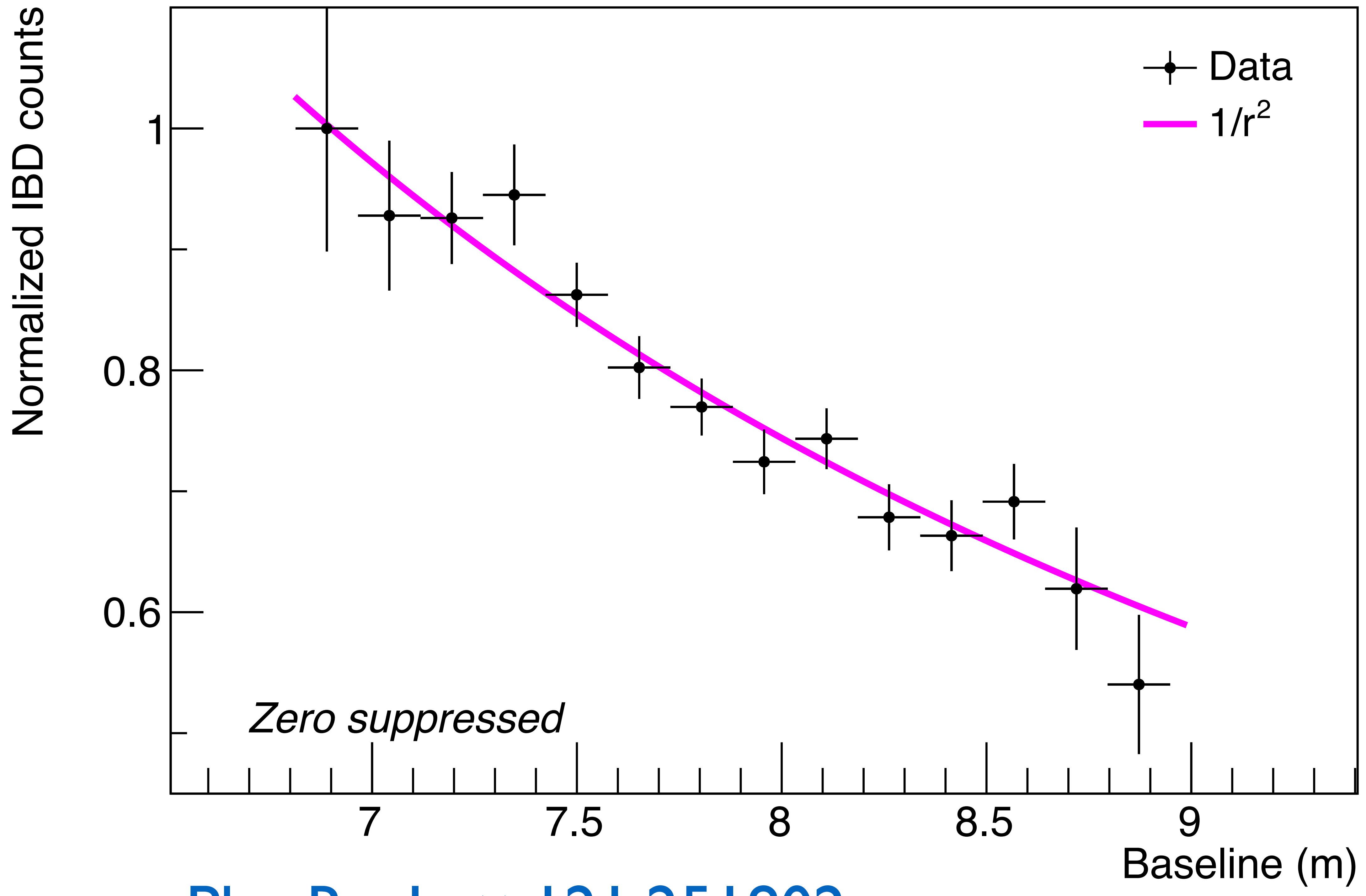


PhysRevLett.121.251802

Excellent signal-to-background for a surface detector (< 1mwe overburden)

Results From First Data Set

single detector position (near pool)

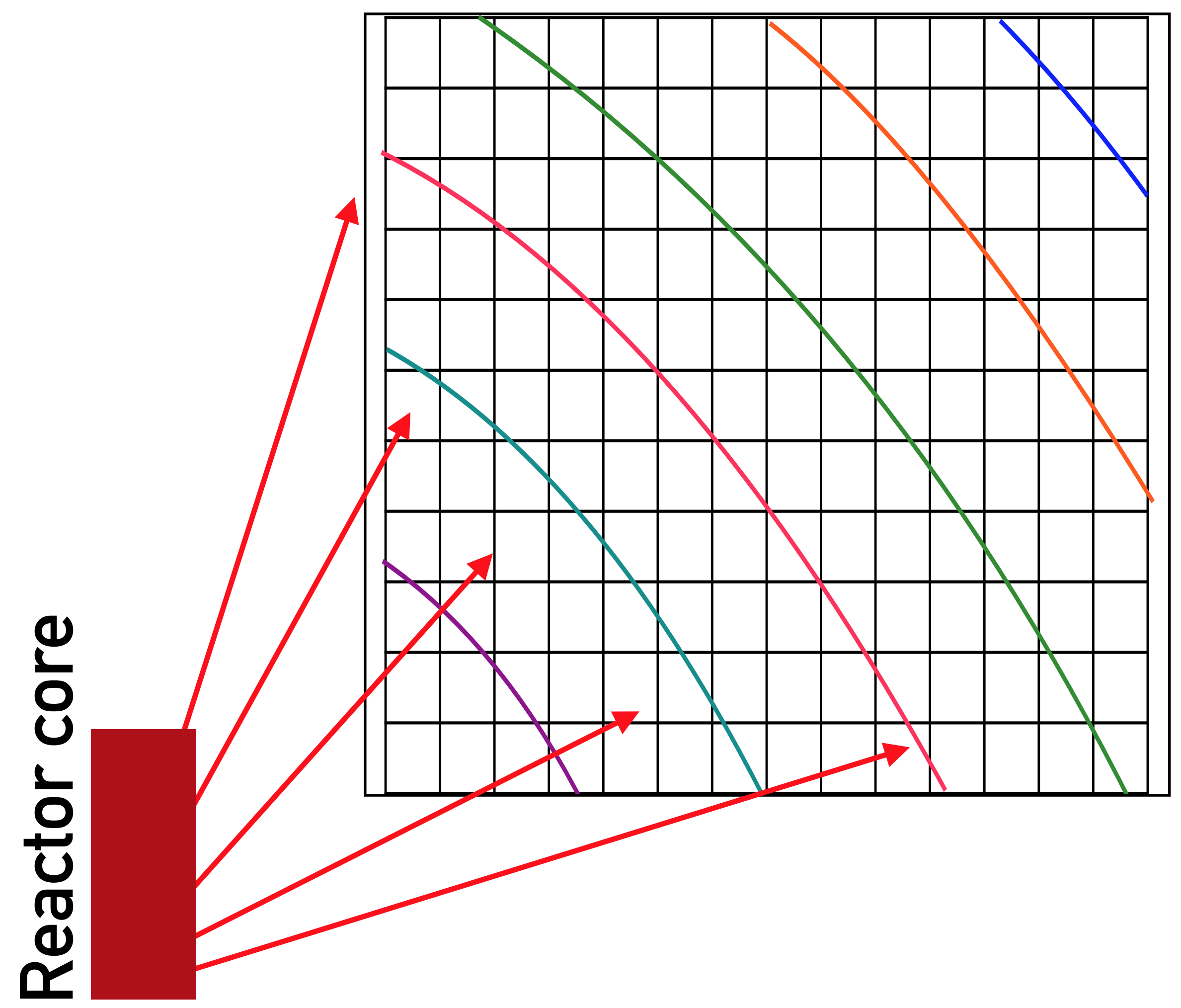


PhysRevLett.121.251802

- 108 fiducial segments binned into 14 baselines
  - Wide range of baselines accessible within detector
- Observed change in flux follows $1/r^2$
- *However, ignores information from spectral shape*

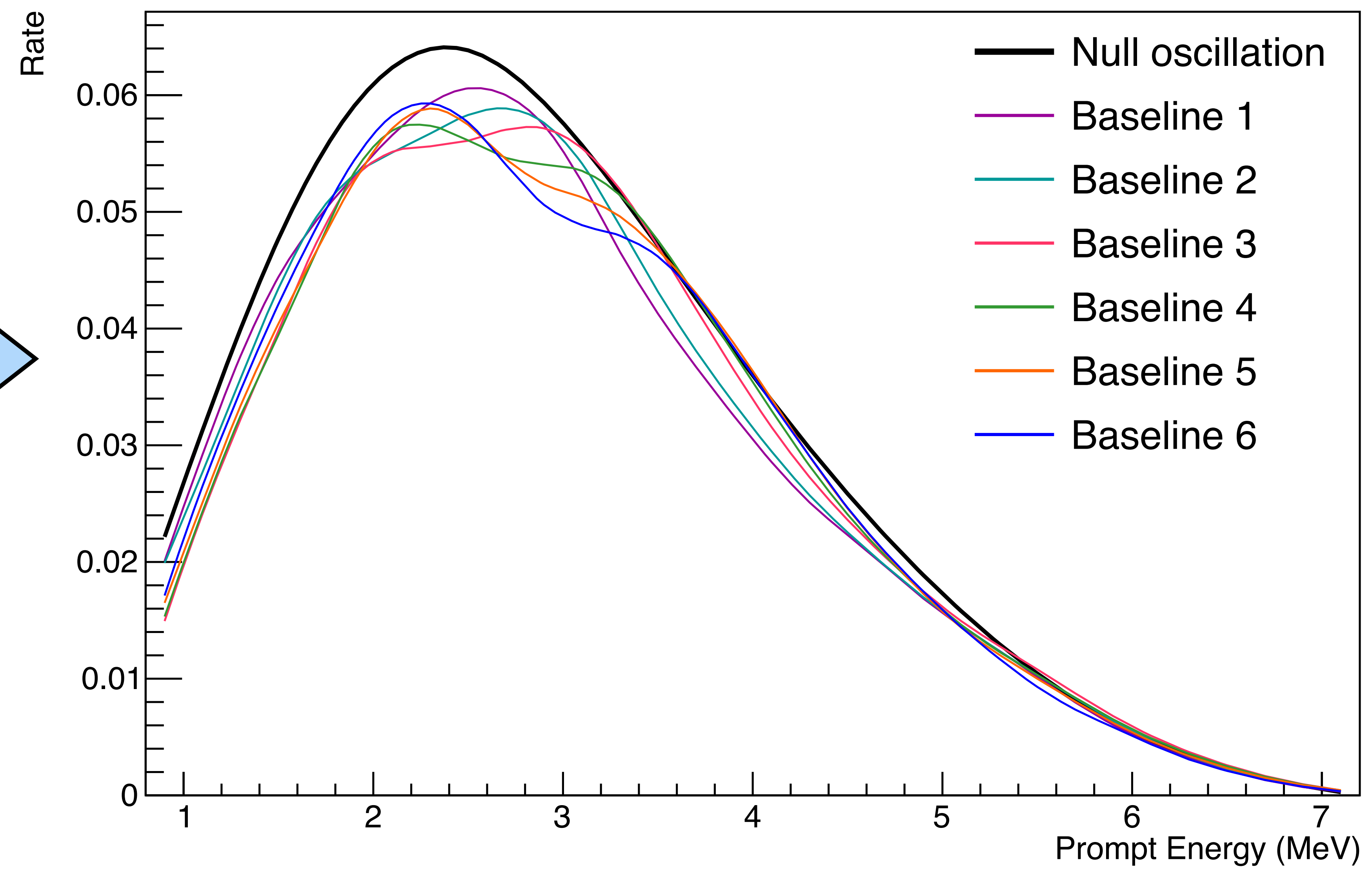
Baseline dependent spectral distortion

Detector cross-section



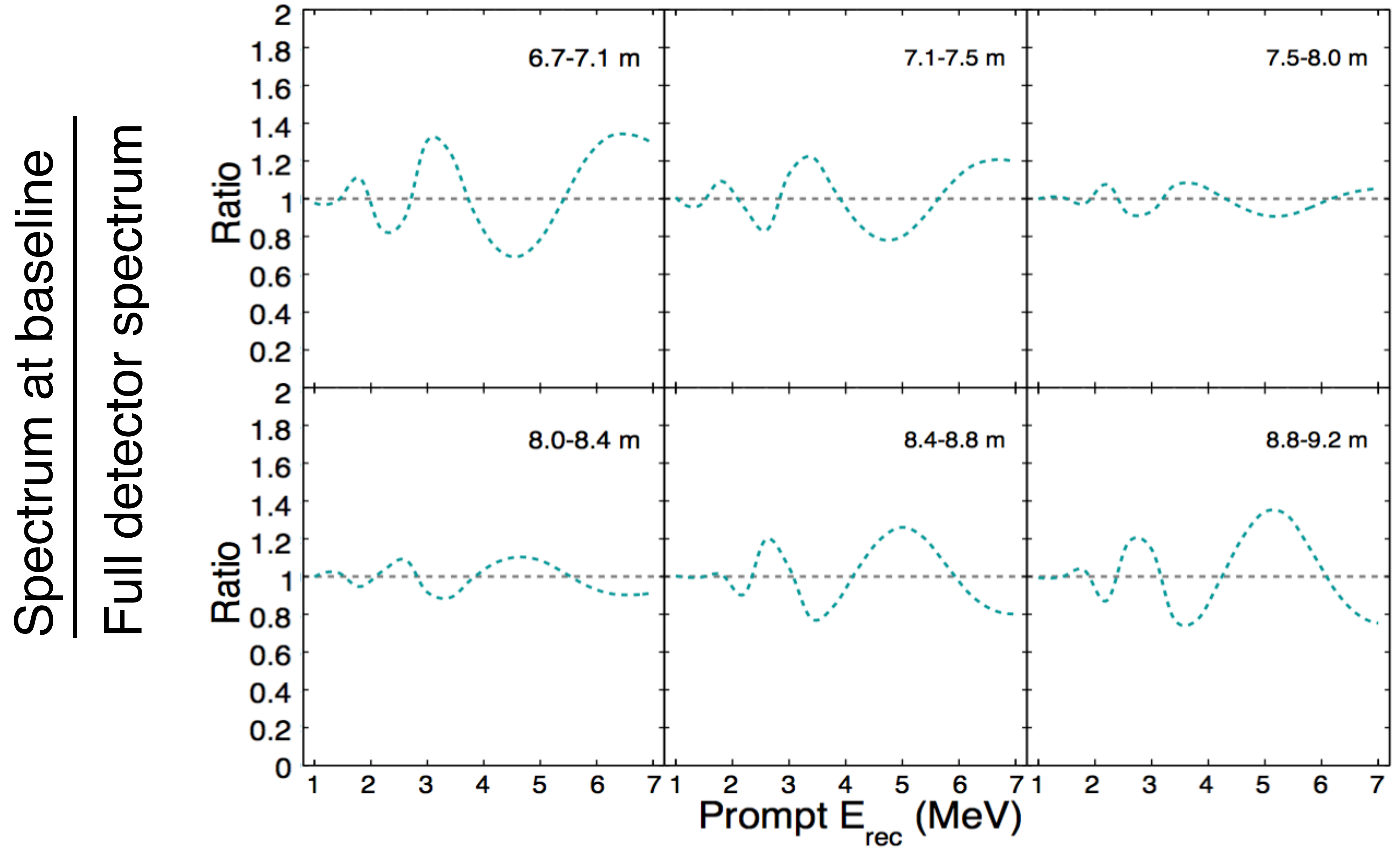
Monte Carlo oscillated spectra for different baselines and RAA best fit

$\sin^2 2\Theta_{14} = 0.165$ and $\Delta m^2 = 2.39\ eV^2$

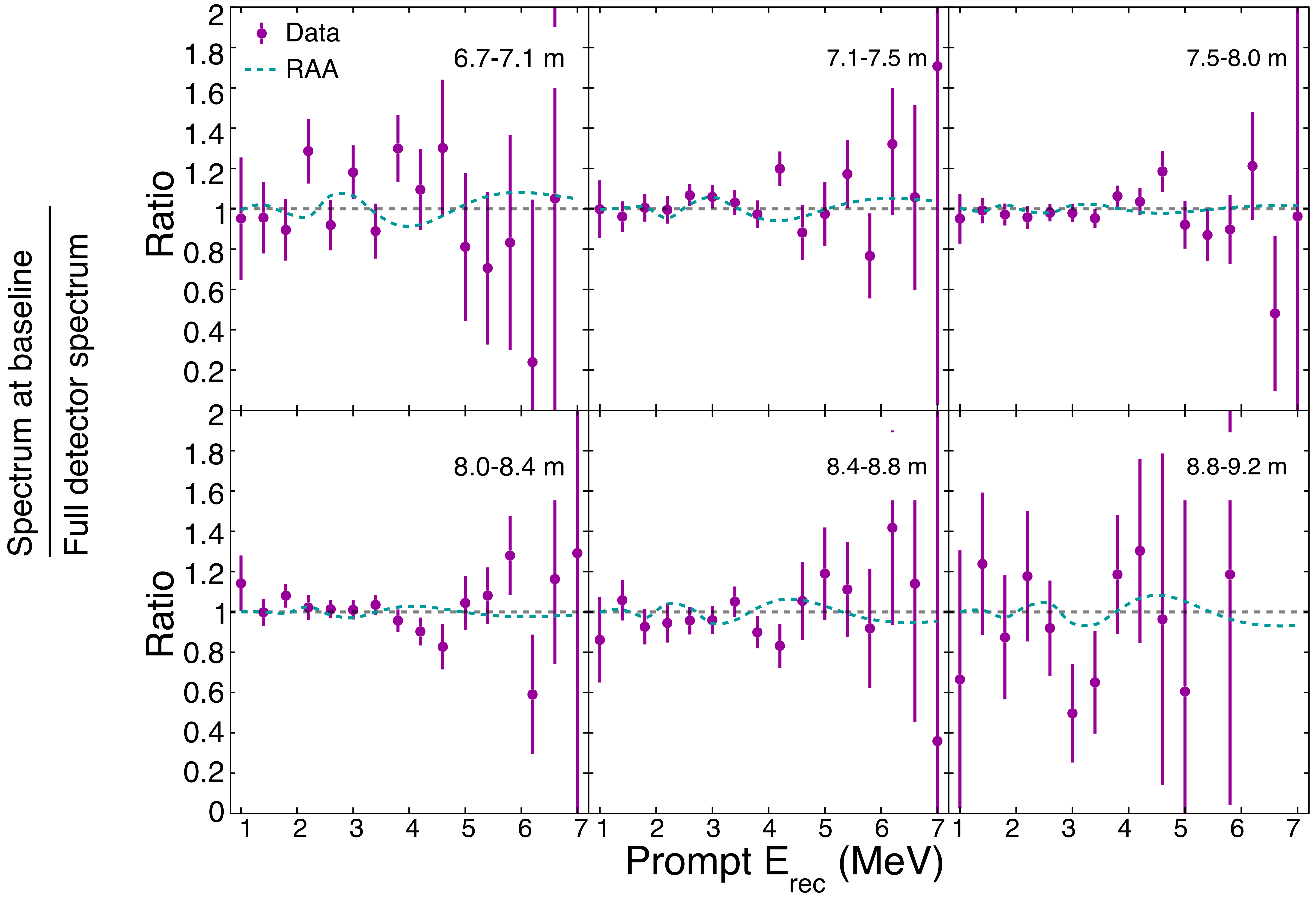


$$P_{ee} = 1 - \sin^2 2\theta_{14} \cdot \sin^2\left(1.27 \cdot \Delta m_{41}^2 \frac{L}{E}\right)$$

- Compare measured energy spectrum for 6 baselines to the scaled full-detector no-oscillation energy spectrum
- Null oscillation yields a flat spectrum
- Minimized dependence on source spectral shape



Results From First Data Set



$$\frac{O_{l,e}}{\left(O_e \frac{E_{l,e}}{E_e}\right)}$$

$O_{l,e}$ - Observed Spectrum
$E_{l,e}$ - Expected Spectrum
l - Baseline bin
e - Energy bin

$$O_e = \sum_{l=1}^{6} O_{l,e},$$

$$E_e = \sum_{l=1}^{6} E_{l,e}$$

- Measured relative spectrum for 6 baselines
- No oscillation black dashed line
- RAA green dashed line

Forming a Chi-square

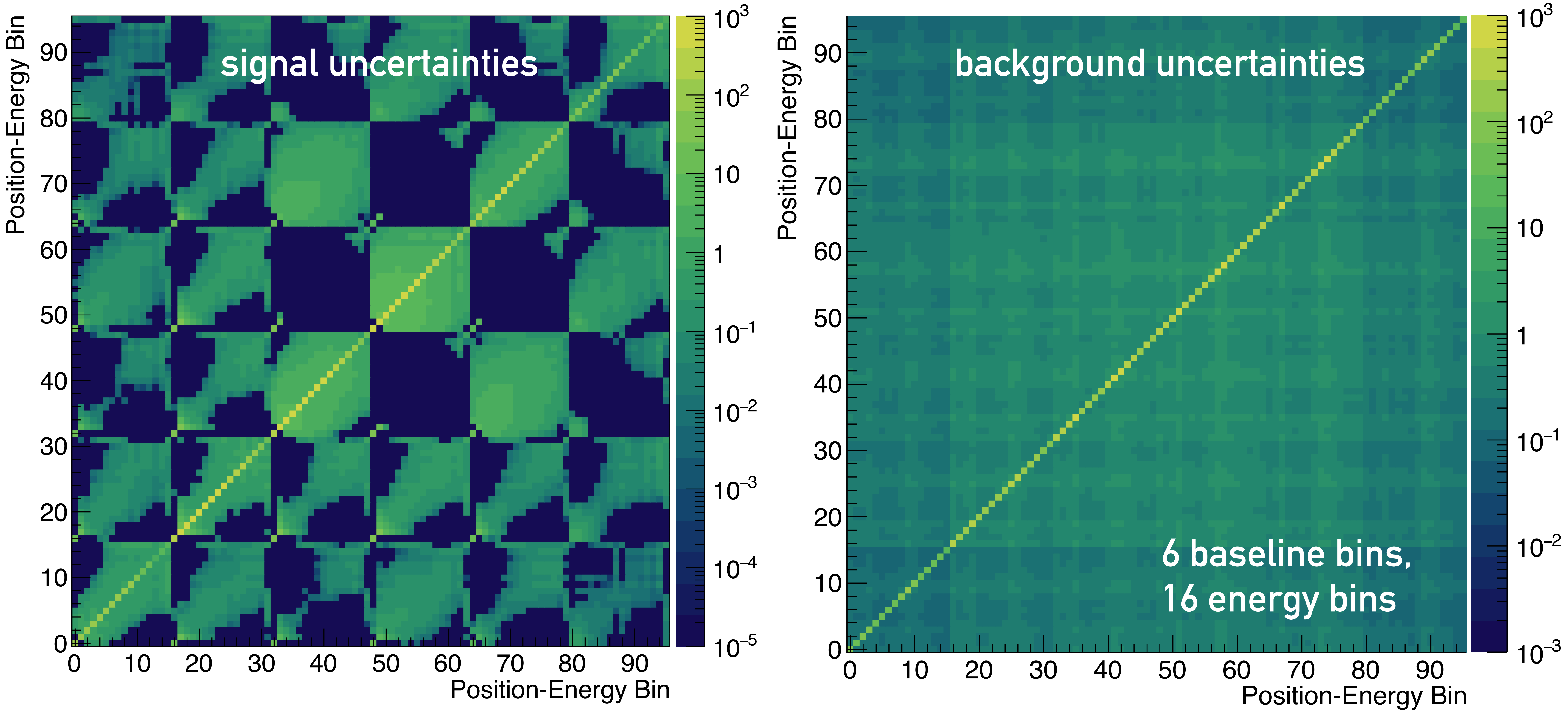
$$\chi^2_{min}(\Delta m^2, \sin^2 2\theta) = \mathbf{\Delta}^{\mathrm{T}} \boxed{\mathbf{V}^{-1}_{\mathrm{tot}}} \boxed{\mathbf{\Delta}}$$

- Covariance matrices incorporate uncertainties and baseline/energy correlations
- Systematics covariance matrices generated by using toys generated based on random fluctuations in the systematic terms

$$\mathbf{\Delta}_{l,e} = O_{l,e} - O_e \frac{E_{l,e}}{E_e}$$

- **Scaled full detector spectrum mitigates spectrum dependency**

$O_{l,e}$ - Observed Spectrum
$E_{l,e}$ - Expected Spectrum
l - Baseline bin
e - Energy bin

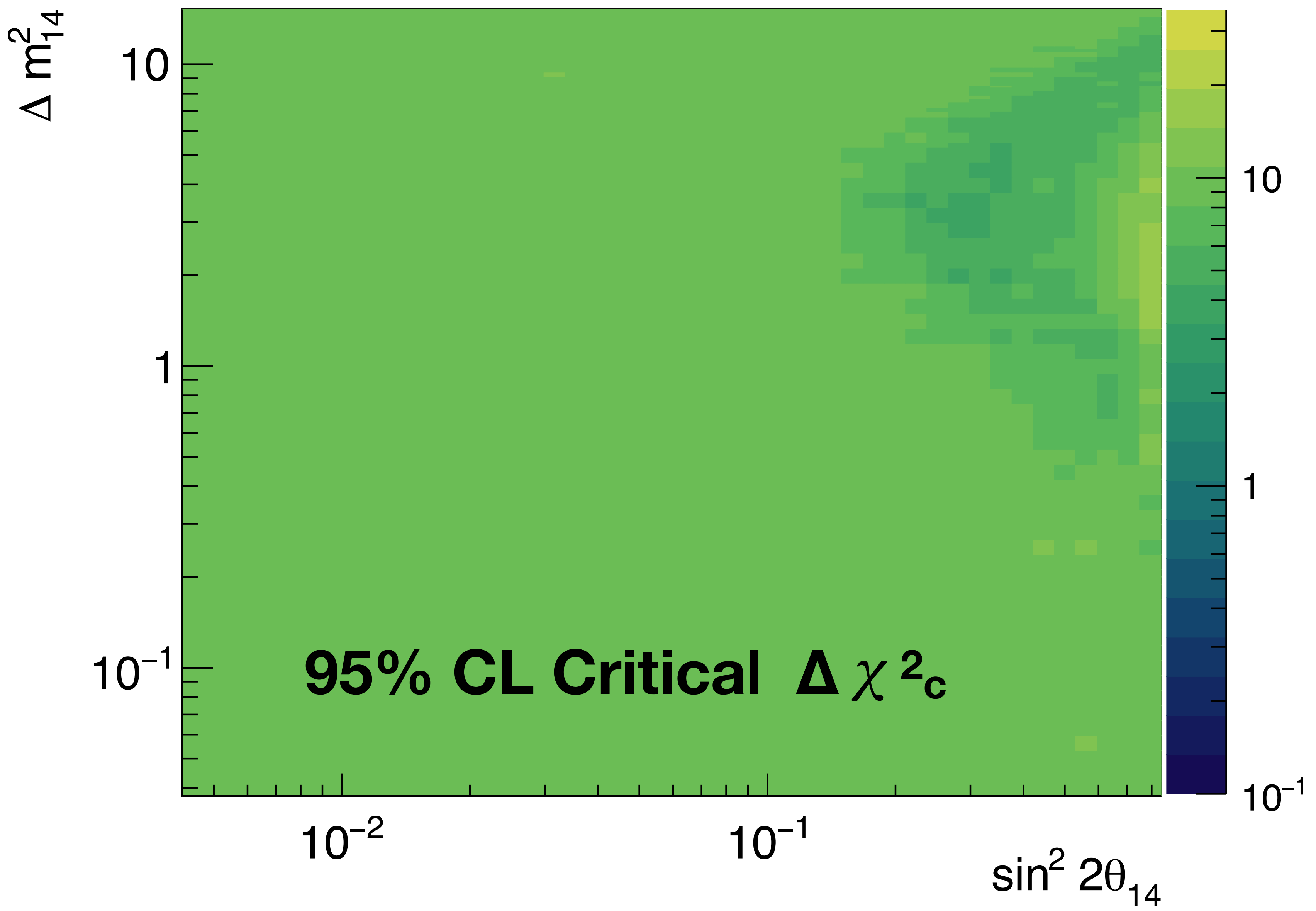


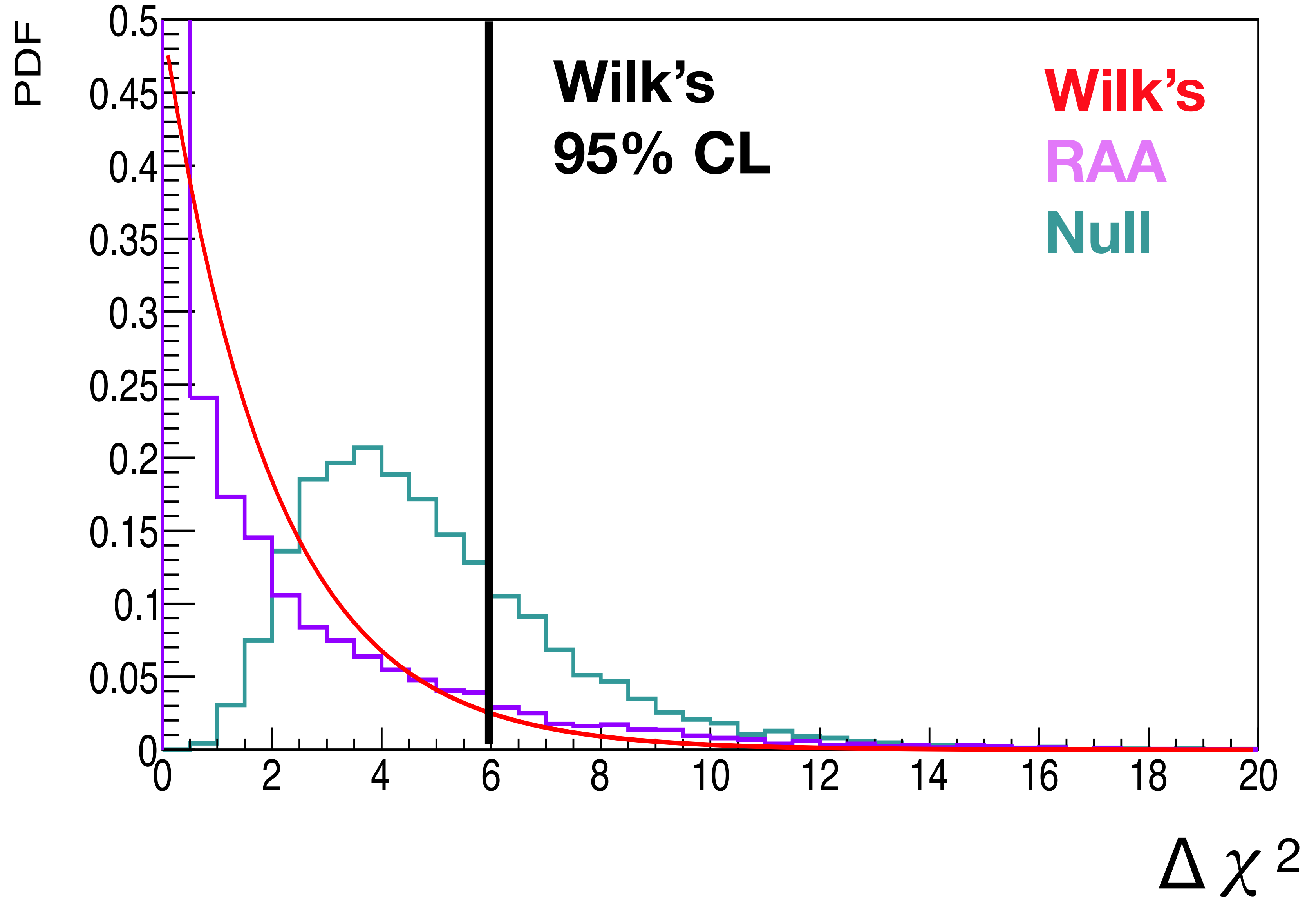
Assigning a significance

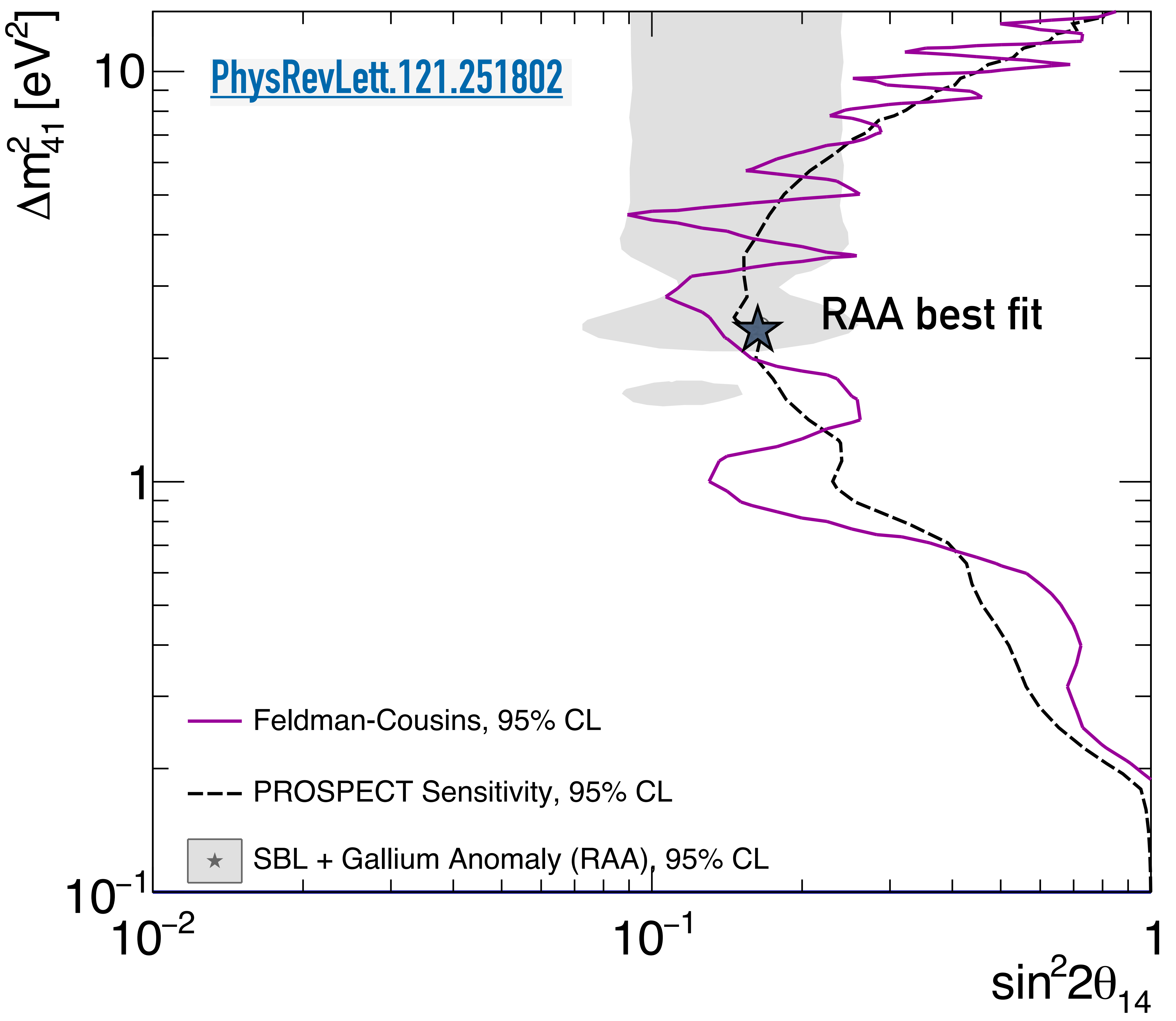
- **Feldman-Cousins based confidence intervals for oscillation search**
- **Critical χ^2 map generated from toy MC using full covariance matrix:**
  - For each point in the grid, generate an oscillated MC toy
  - Calculate χ^2_{min} for every point in the grid
  - Extract $\Delta\chi^2_{min} = \chi^2_{min,true} - \chi^2_{min,best\text{-}fit}$
  - Repeat 1-3 for all 1000 toys per point in grid
  - $\Delta\chi^2_c(\alpha)$ for all points in the grid such that it covers α of toys
- **Wilk's theorem inadequate near boundaries of sin²2Θ and as oscillation frequency approaches binning.**

Consider p-values at RAA best fit:

	3 neutrinos	3+1 neutrinos
Wilk's theorem	0.14	0.005
Feldman cousins	0.58	0.001







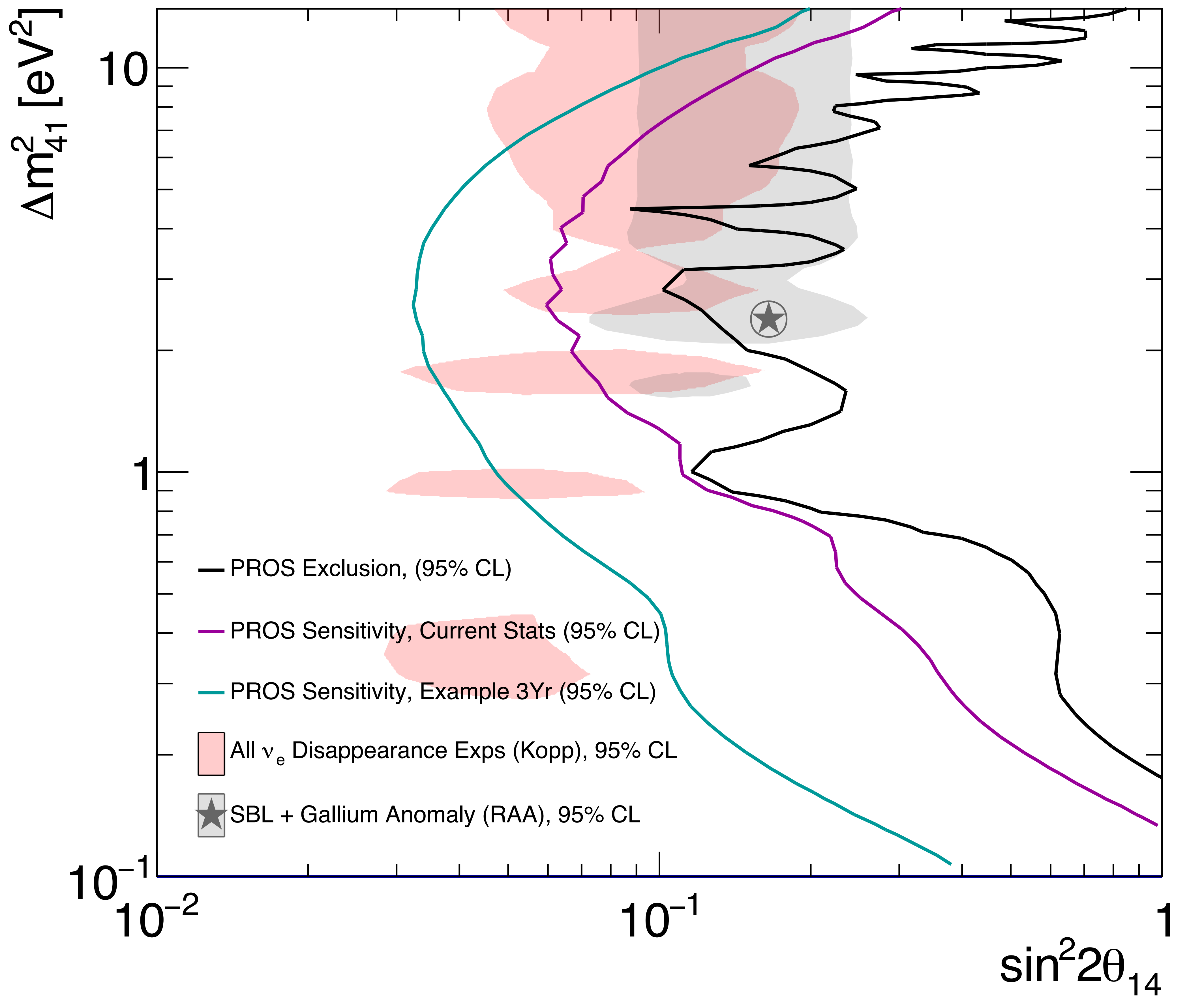
95% exclusion curve based on 33 days Reactor On operation

Reactor model independent test of reactor antineutrino anomaly

RAA best-fit disfavored at >95% (2.3σ)

Conclusions and Outlook

- PROSPECT demonstrates technical approach
  - scalable/modular (to a degree)
- Very good signal-to-background at the surface (< 1 mwe), consistent with MC/R&D-based expectations
  - Observed HEU reactor spectrum with ~1 day of data
- First 33 days of data:
  - Address RAA at >2.3 sigma (arXiv: 1806.02784)
- Currently have approximately 110/120 reactor-on/reactor off day
  - high-statistics spectral analysis (40/38 days On/Off) (arXiv: 1812.10877)
  - Updated oscillation and spectrum analysis underway



HFIR is currently down until the end of calendar year 2019- potential PROSPECT sensitivity with extended running

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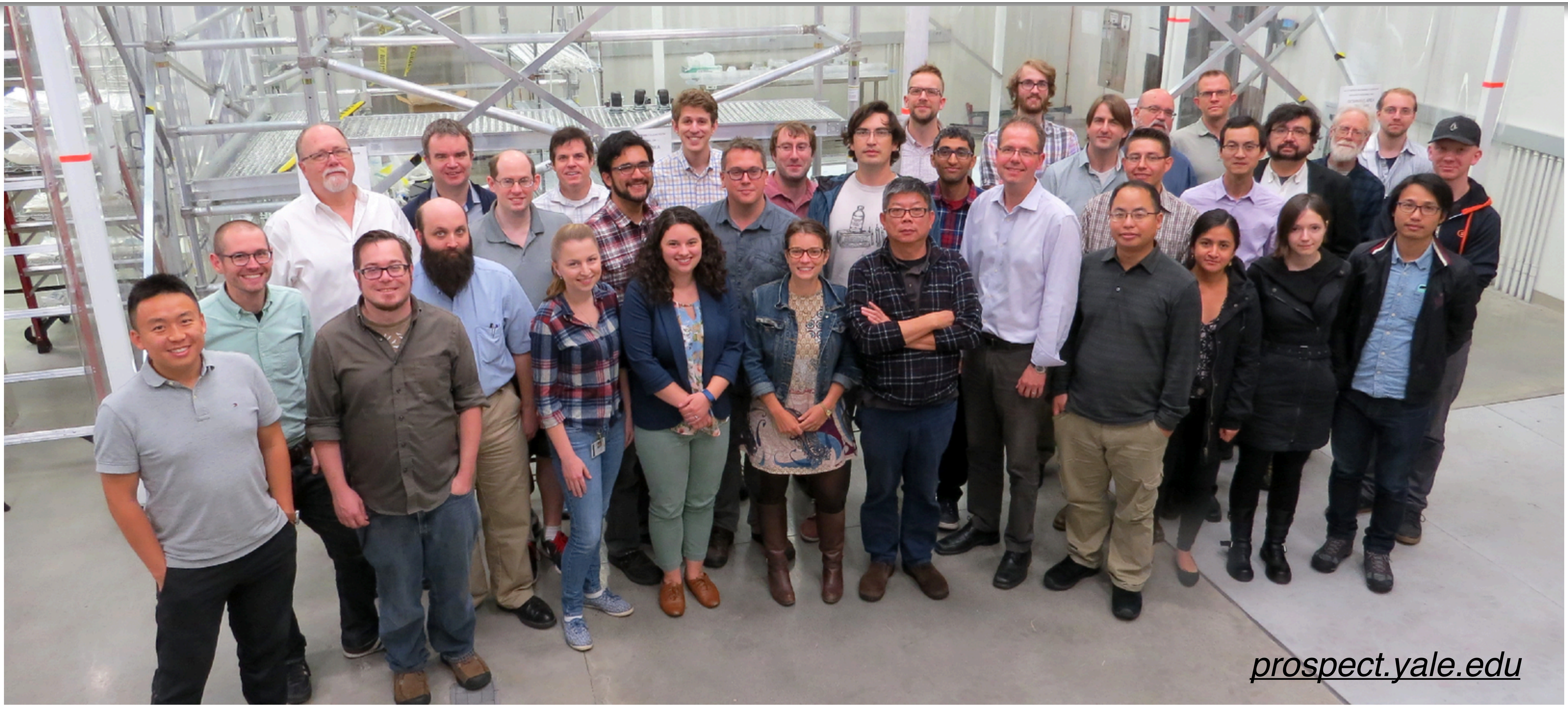
PROSPECT Collaboration



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