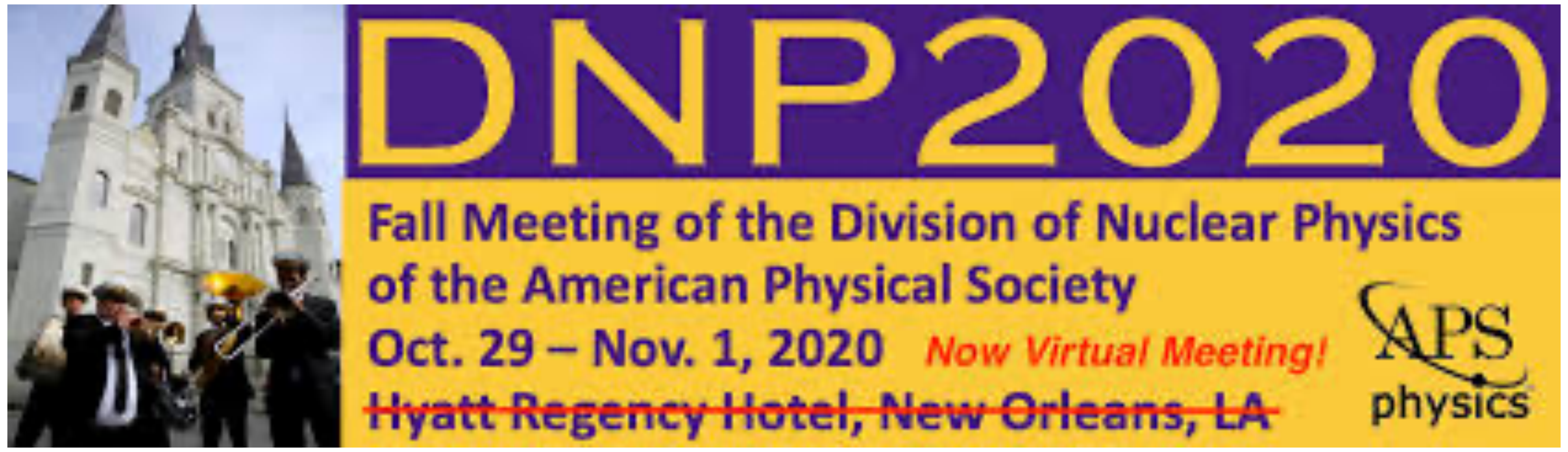


PROSPECT's latest results for Sterile Neutrino Oscillation search

Jose Palomino
On behalf of Prospect collaboration

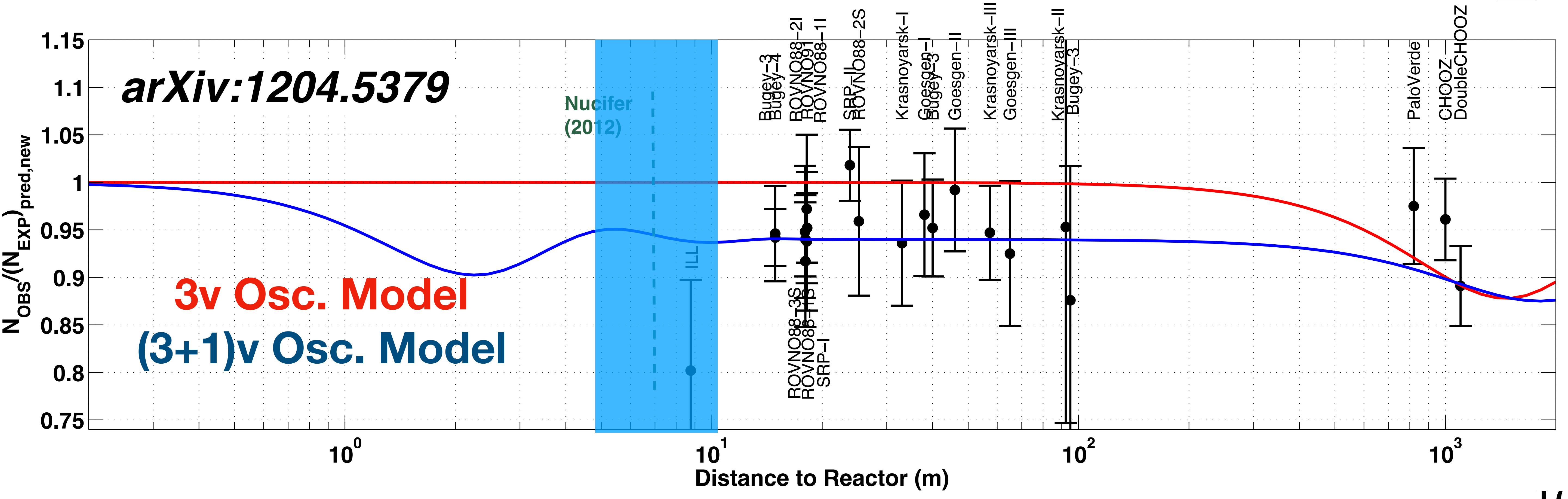
DNP 2020

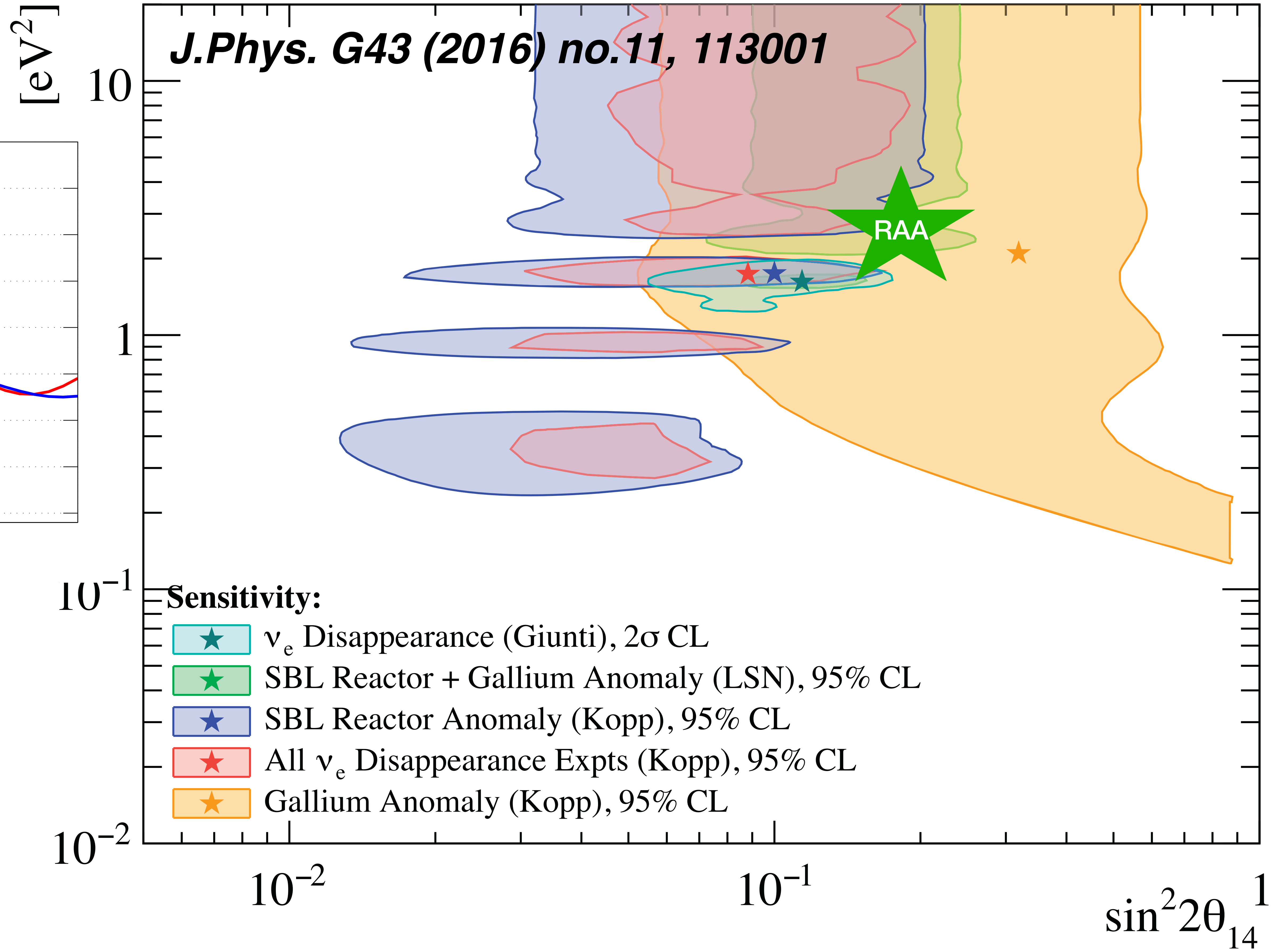
October 30th, 2020

ILLINOIS INSTITUTE OF TECHNOLOGY

PROSPECT
Precision Oscillation and Spectrum Experiment

Motivation: Reactor Antineutrino Anomaly (RAA)





- World average observed flux shows 6% deficiency with respect to theoretical predictions.
- The prediction models are based on Huber+Mueller and by 3-flavor neutrino oscillations at the distance of each experiment.

RAA best-fit point at $sin^2 2\theta$ = 0.165, Δm^2= 2.39

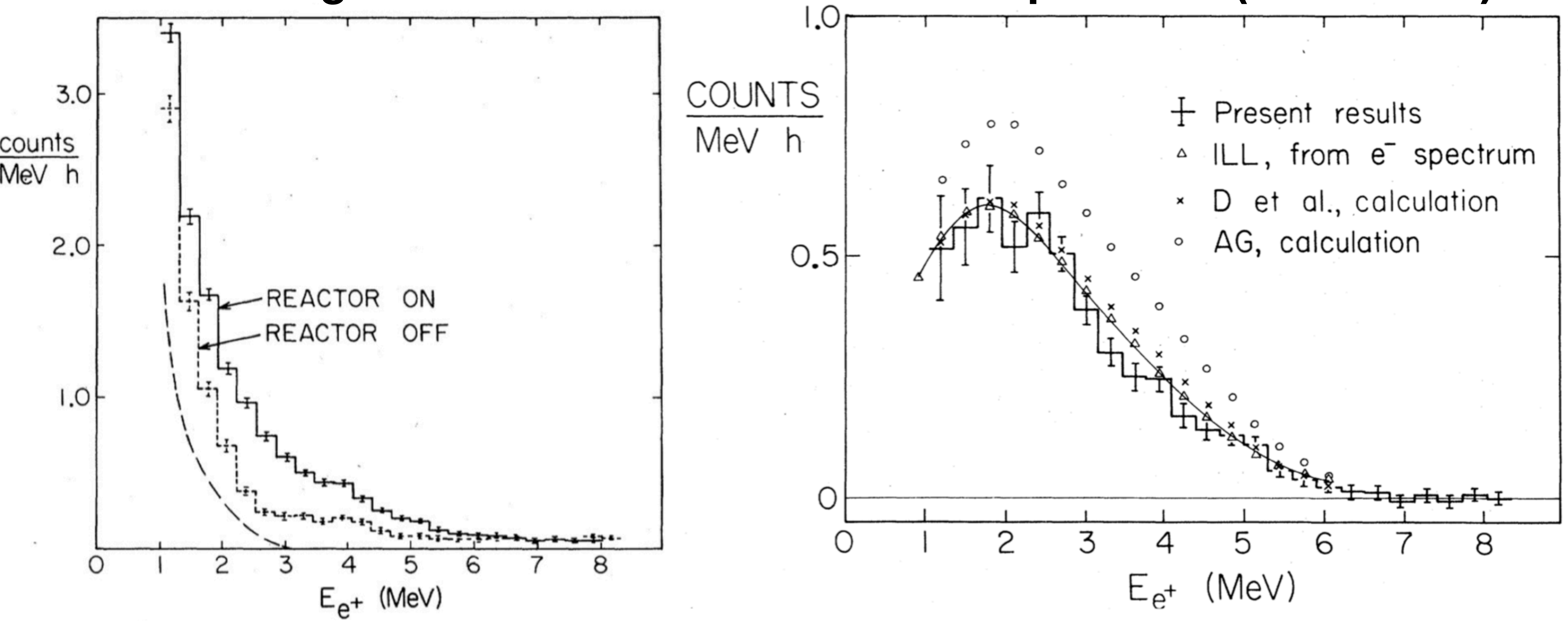
Where this global deficit is coming from?

- Reactor model predictions are not good enough
- Sterile Neutrinos:
  - high frequency oscillations (~meter baselines).
  - eV-scale mass splitting.

Physics Goals

There are not precise measurements at very short baseline.

Existing measurement from 1981 ILL experiment (~5k events).

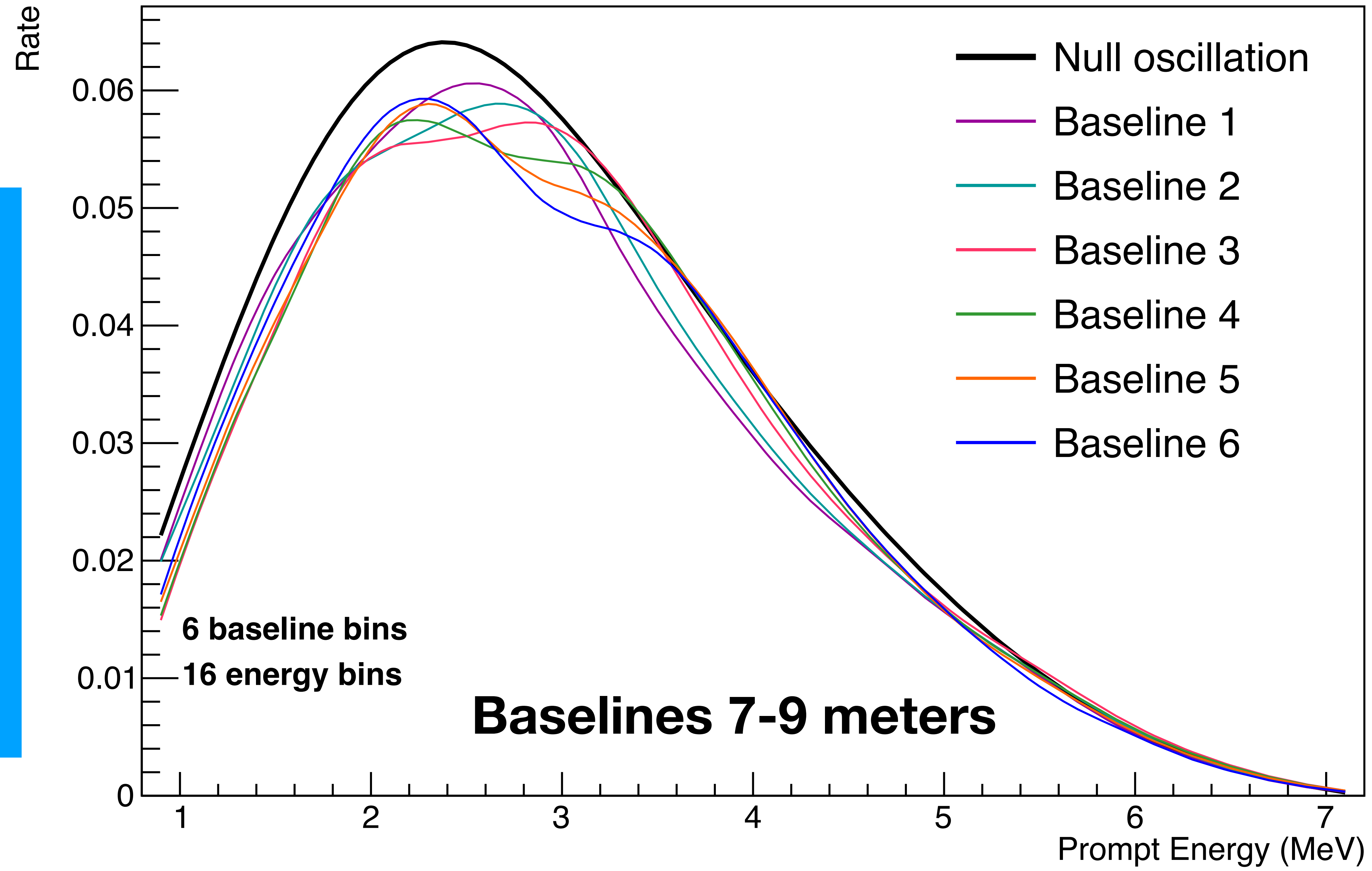


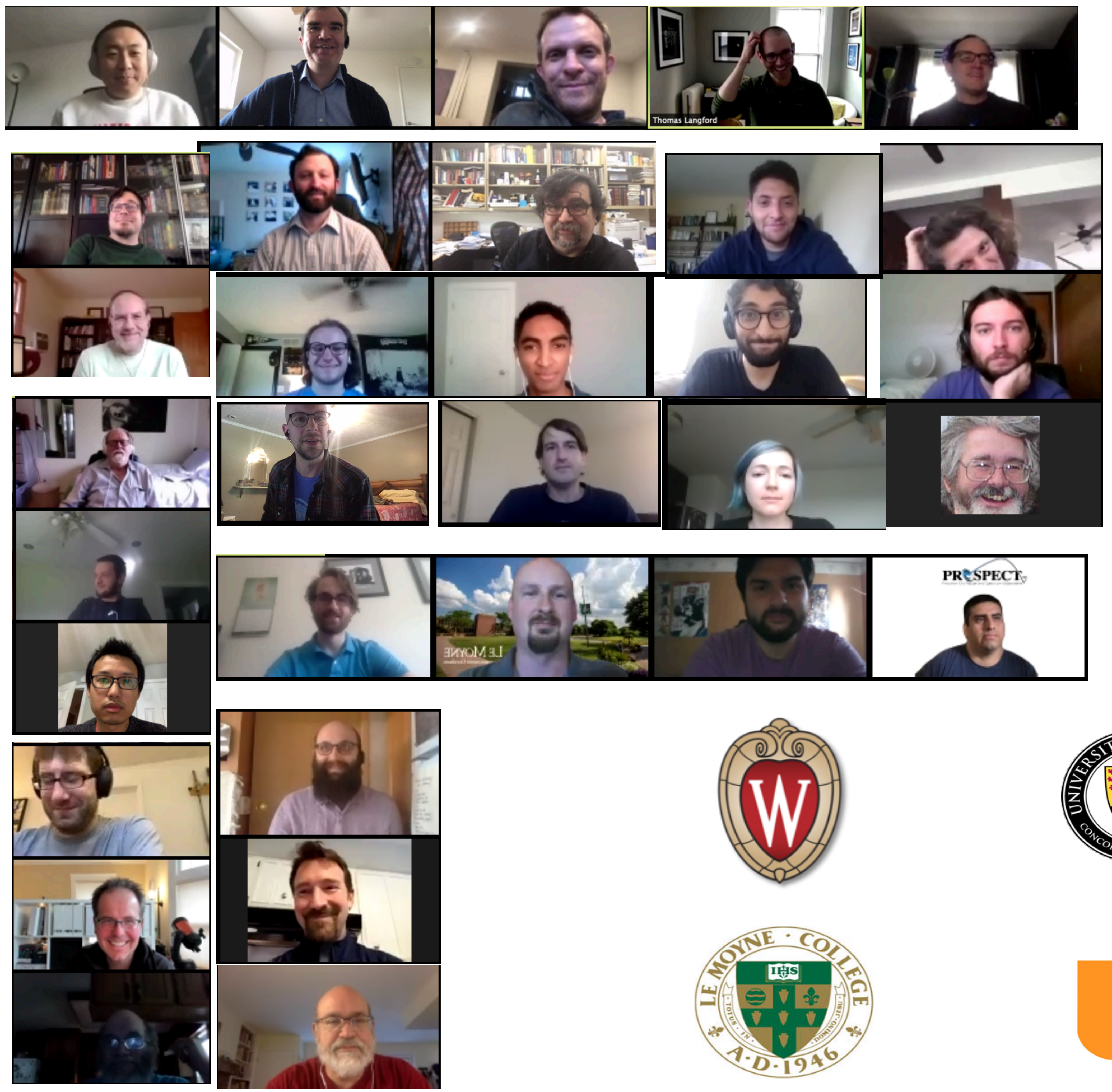
Measurement of ^{235}U antineutrino spectrum:

- High energy resolution .
- High statistics.
- Have high enriched uranium cores: 235U only.

Search for short-baseline sterile neutrinos:

- Few meters baseline variation affects the predicted spectrum assuming sterile oscillations.
- Compact research reactor is necessary to prevent washing out oscillation.
- Reactor-model independent search for oscillations throughout the detector .





*PROSPECT April 2020 Collaboration Meeting Photo

UNIVERSITY OF WATERLOO CONCORDIA CUM VERITATE

W&M

LE MOYNE COLLEGE A·D·1946

Yale

BROOKHAVEN NATIONAL LABORATORY

Georgia Tech

TEMPLE UNIVERSITY

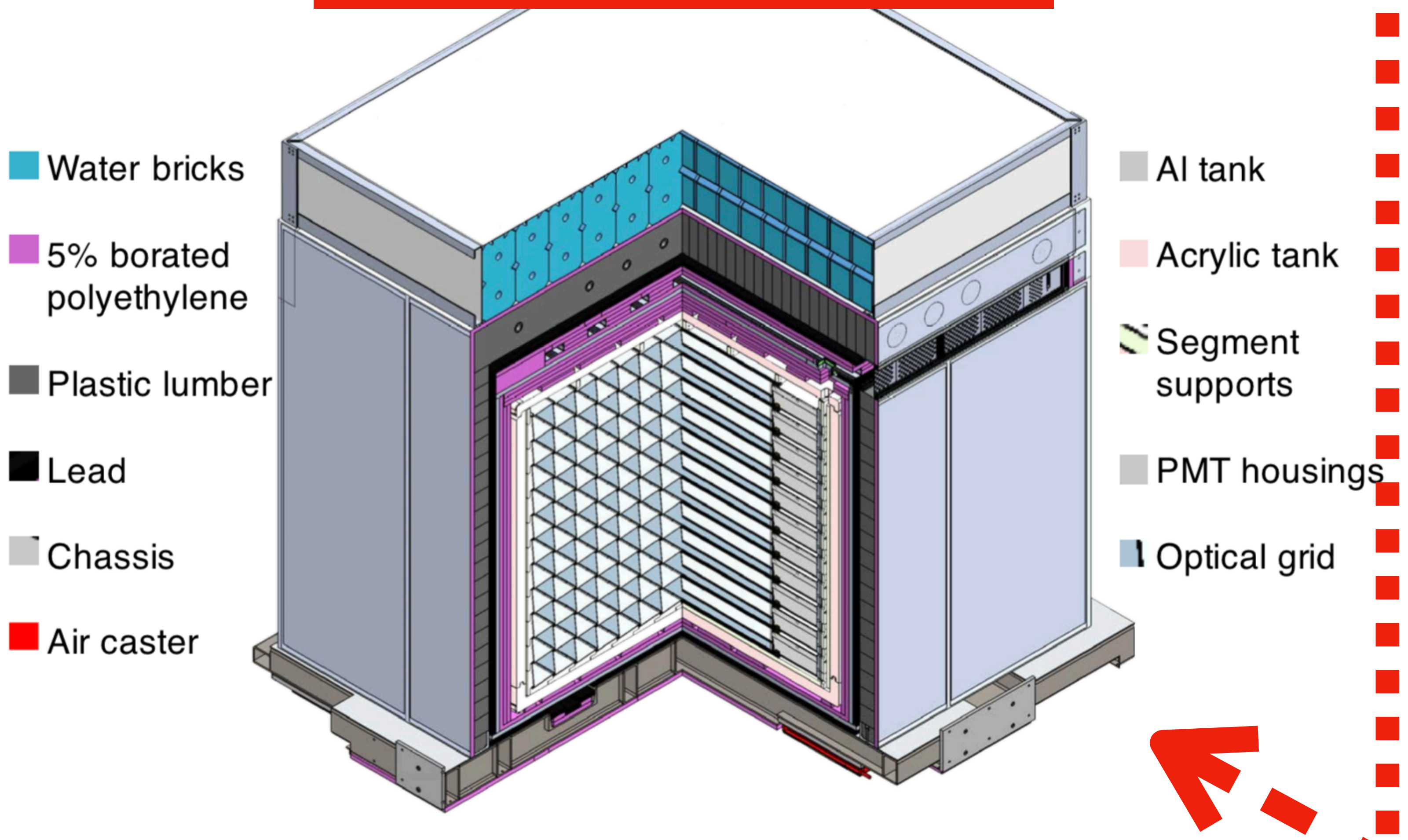
OAK RIDGE National Laboratory

NIST

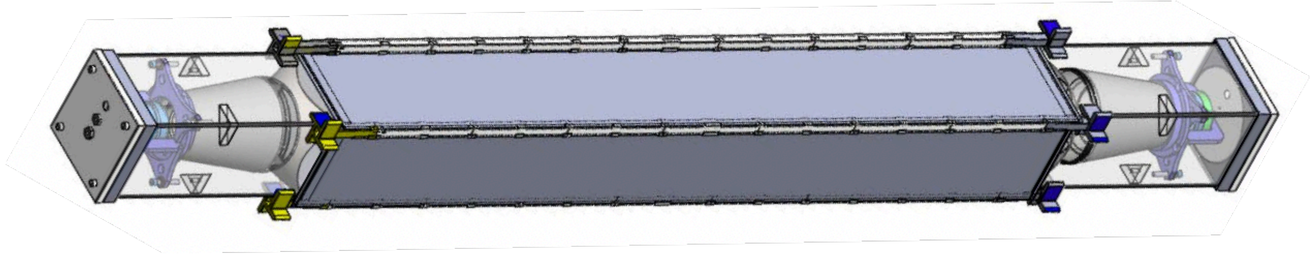
Lawrence Livermore National Laboratory

Detector Design

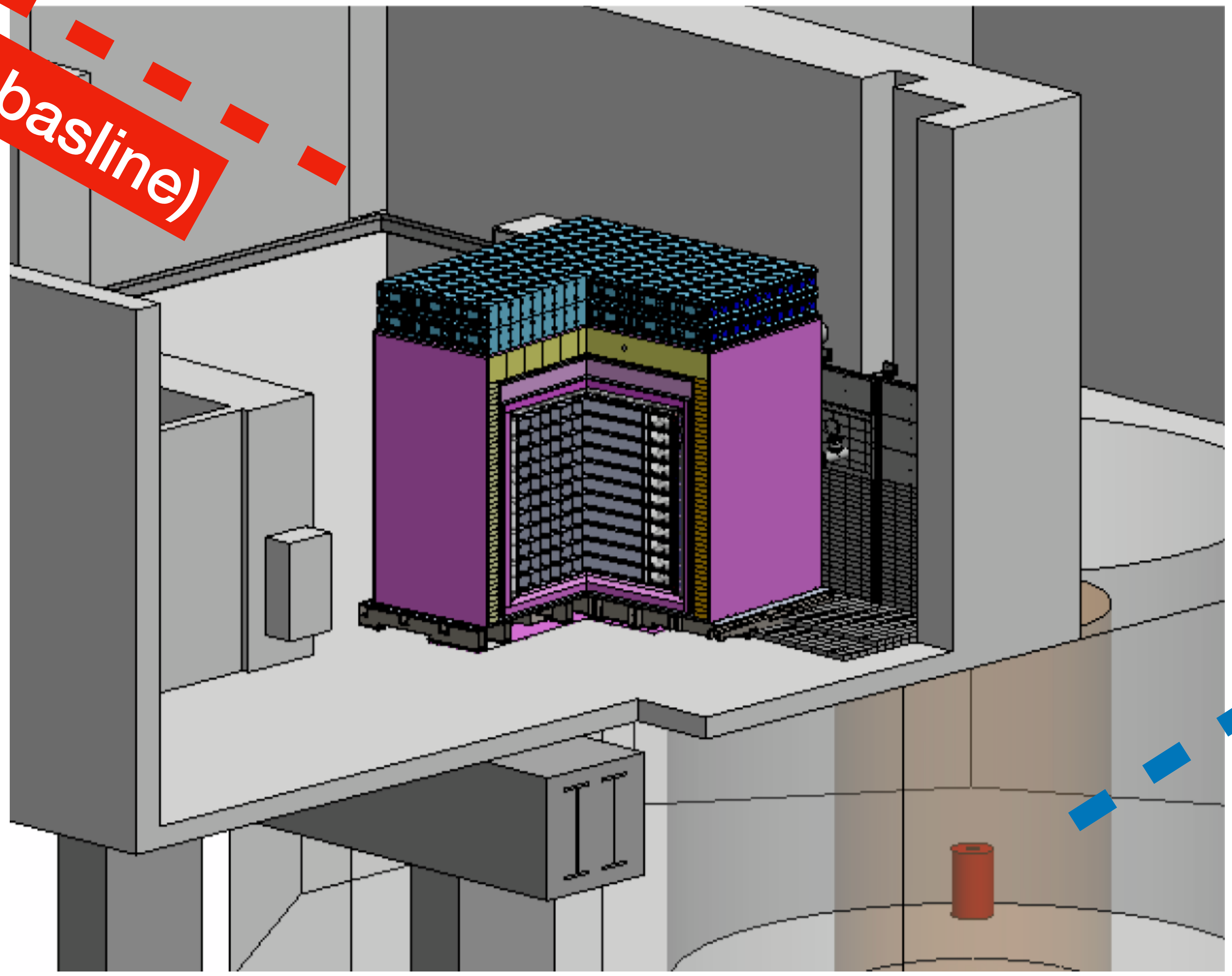
Segmented Detector



- ~3,000 L 6Li-loaded fiducial volume.
- 11 x 14 array of optically separated segments.
- 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.

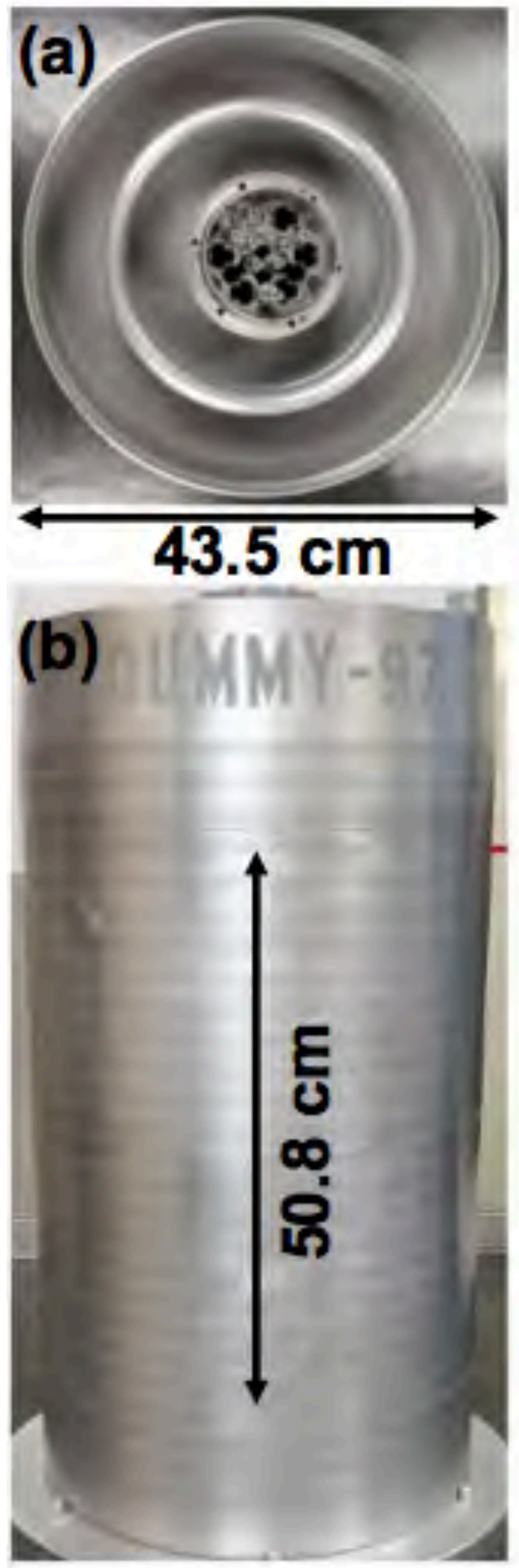


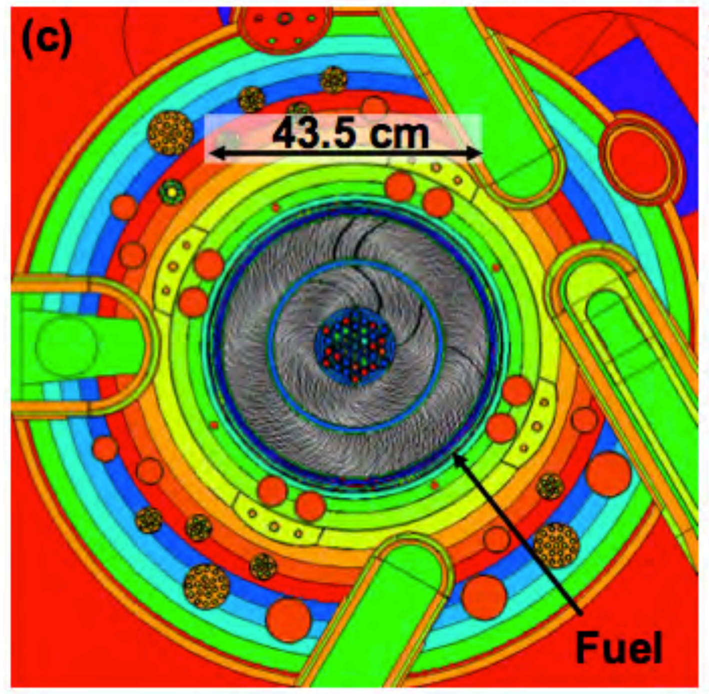
HIGH FLUX ISOTOPE REACTOR AT OAK RIDGE NATIONAL LABORATORY



Reactor Core highly-enriched (HEU): >99% of ν_e flux from ^{235}U fission:

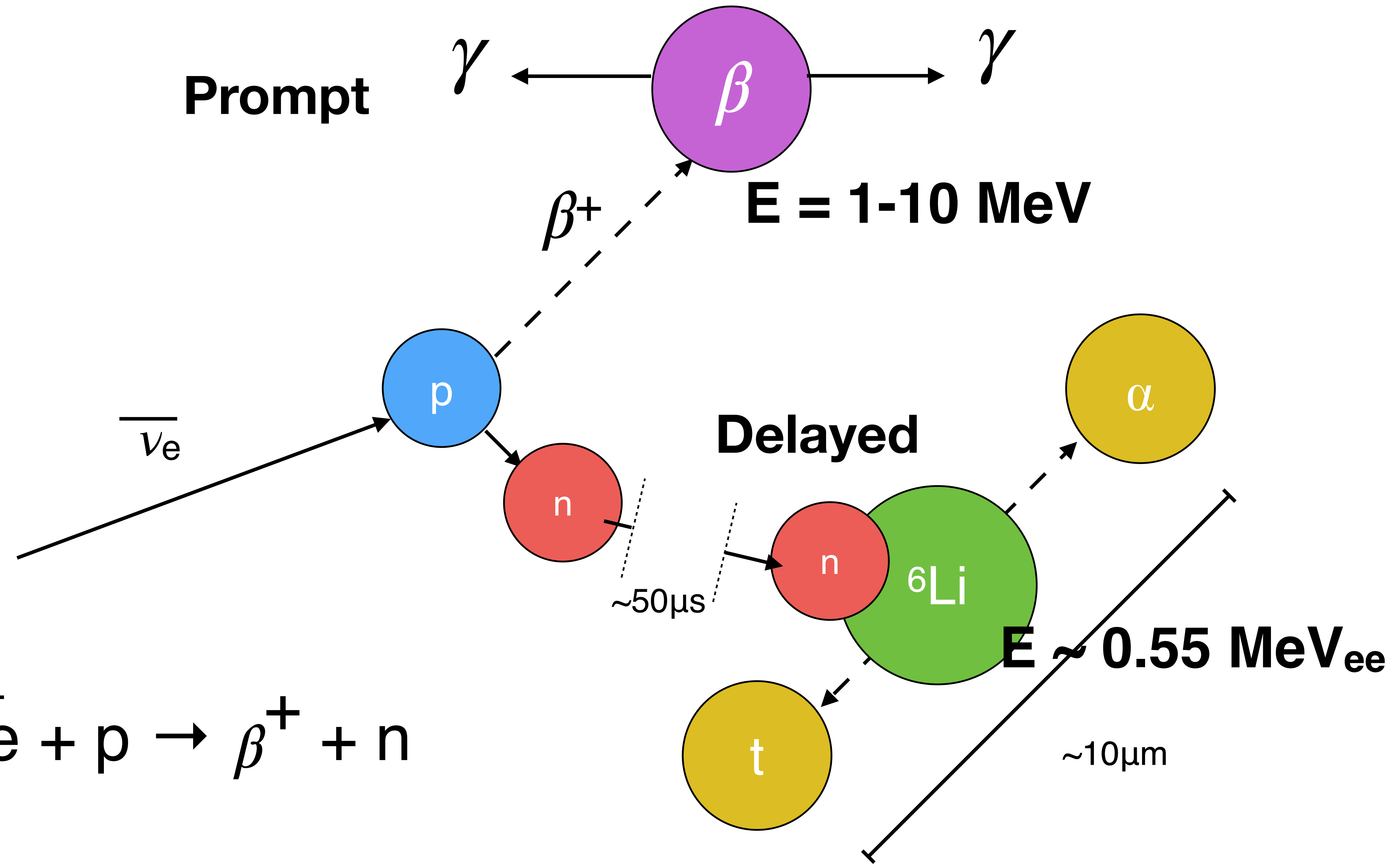
- **Power: 85 MW**
- **Core shape: cylindrical**
- **Size: h=0.5m d=0.4m**
- **Duty-cycle: 24 days cycle**





Reactor is smaller than conventional power reactors

IBD detection with ^{6}LiLS

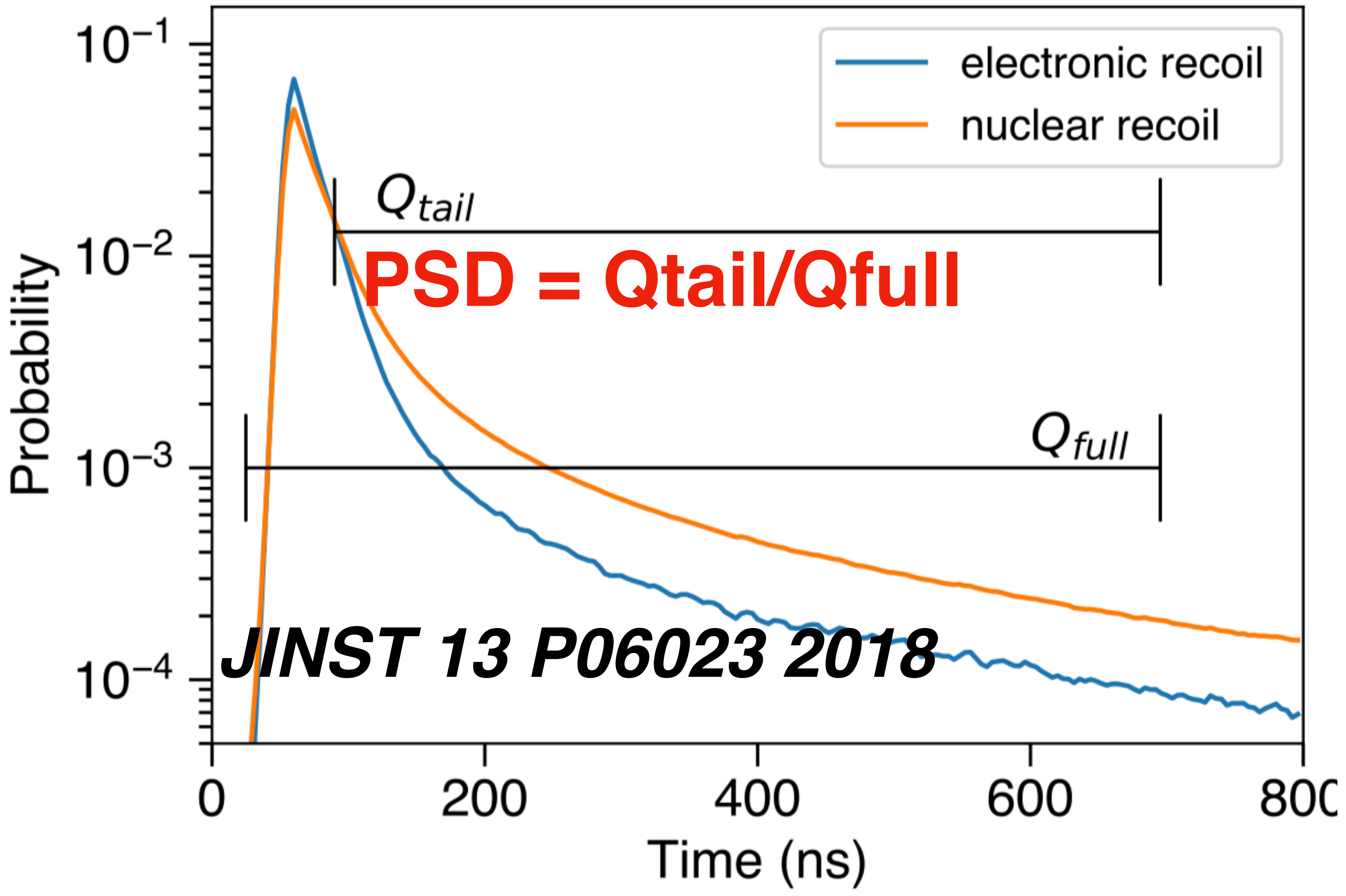


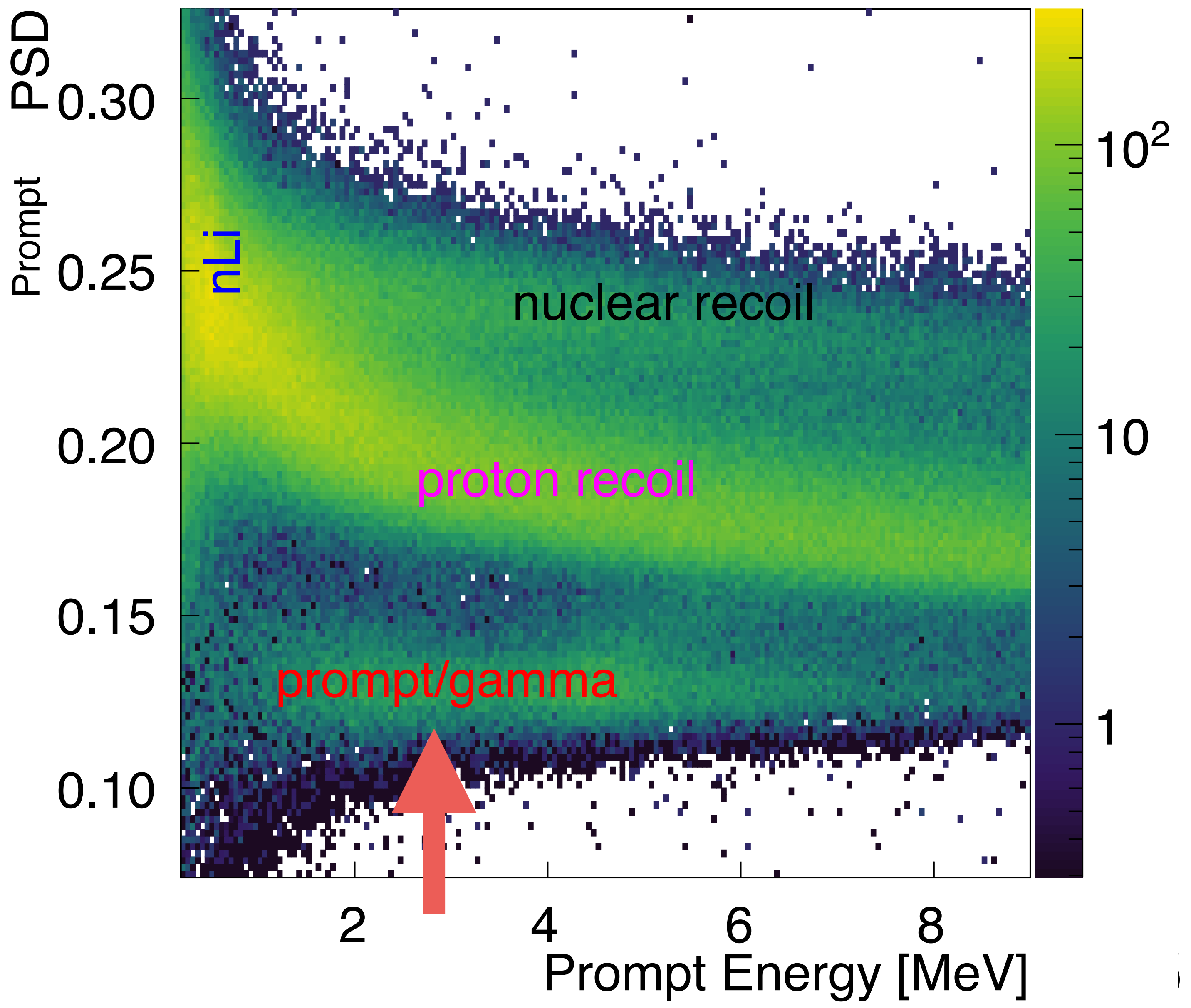
IBD: $\overline{\nu}_e + p \rightarrow \beta^+ + n$

- **1-10 MeV β+-like prompt signal (ionization and annihilation of positron).**
- **Followed by ~50μs delayed neutron (~0.55 MeV) capture on ^{6}Li.**
- **6LiLS ideal for neutron tag in compact detector as decay is highly localized in space within a segment.**

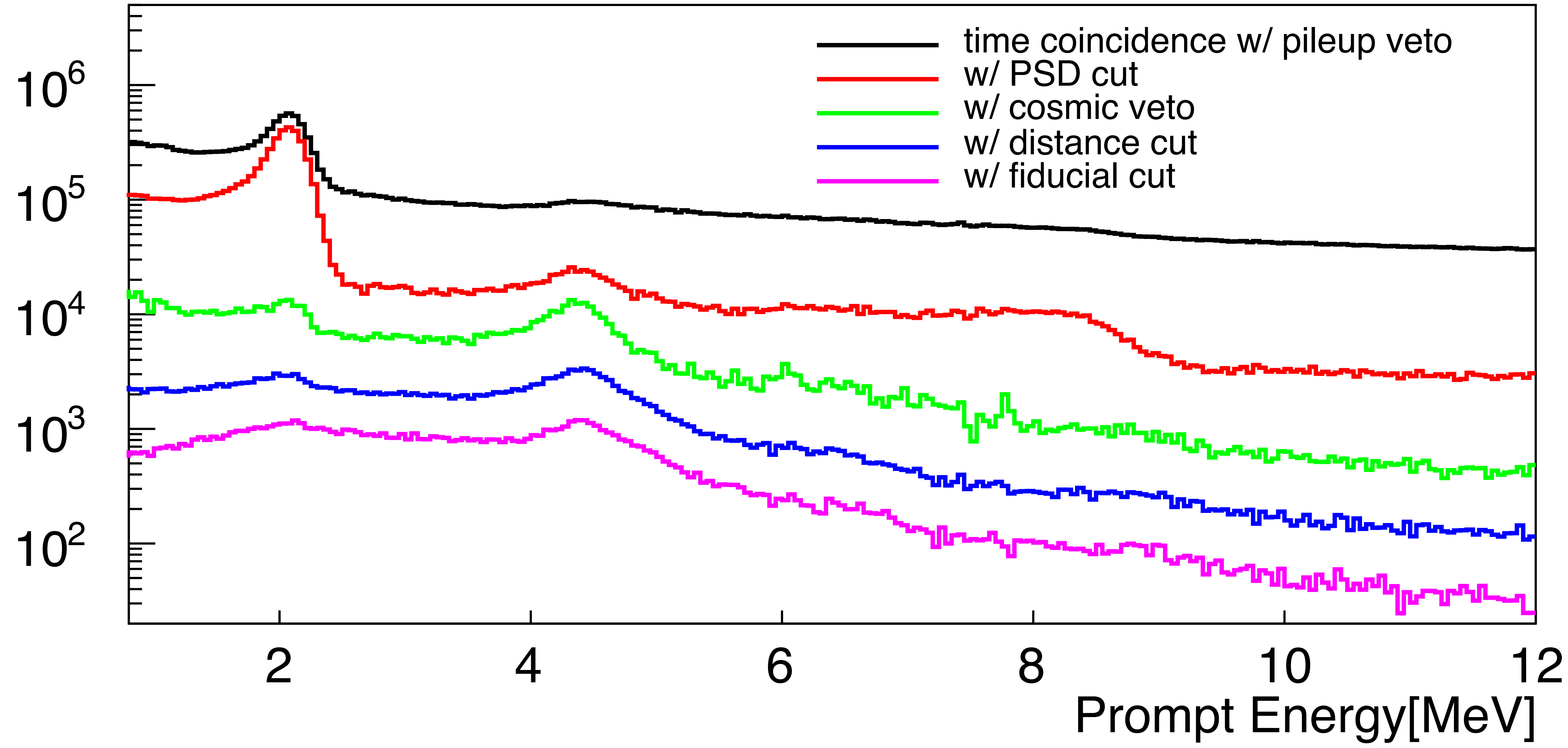
The Pulse Shape Discrimination (PSD) of scintillator works as particle identification.

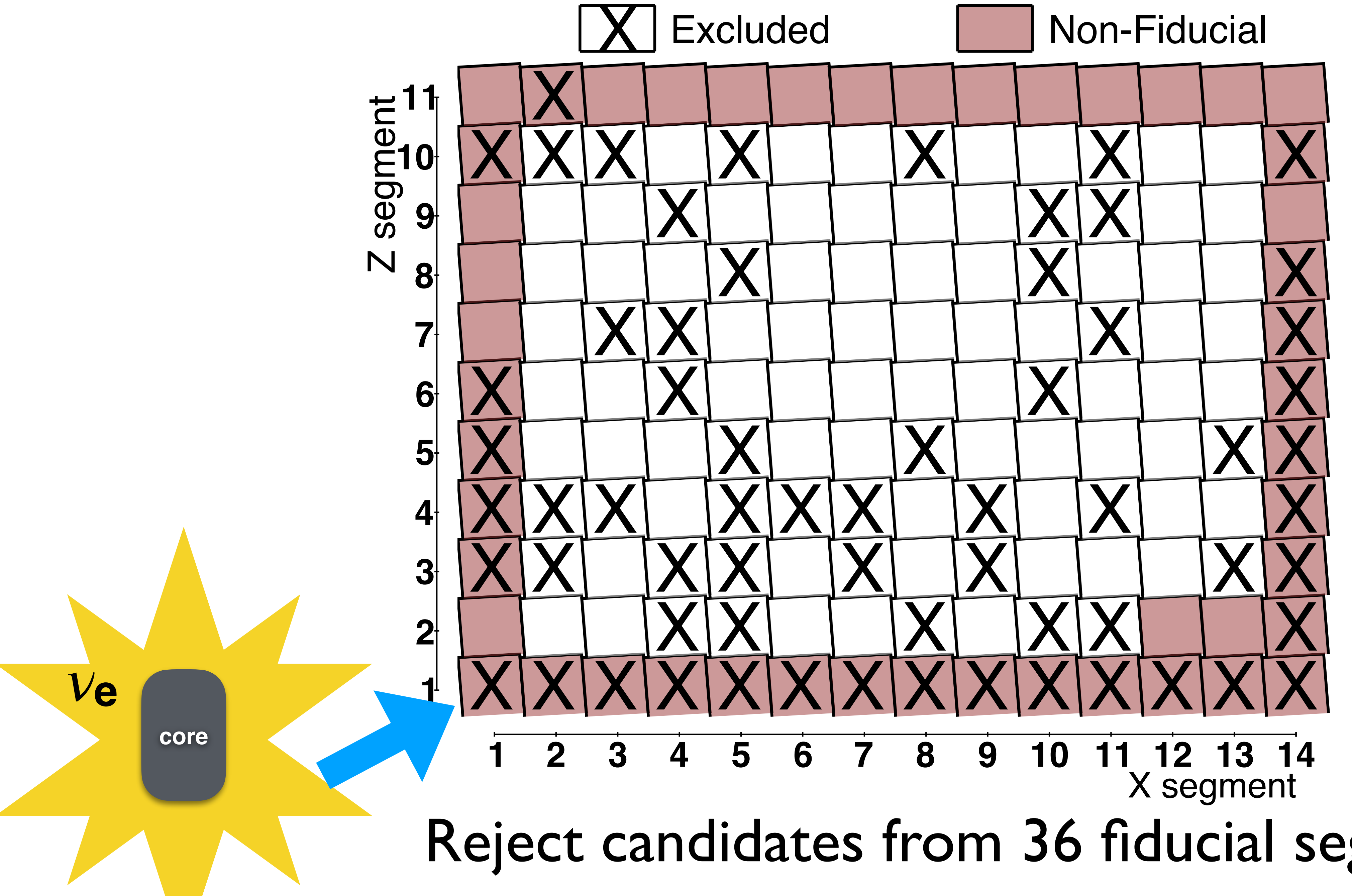
- **it can distinguishes gamma interactions, neutron capture and nuclear recoils.**
- **Essential to remove cosmogenic neutrons background.**





IBD Selection

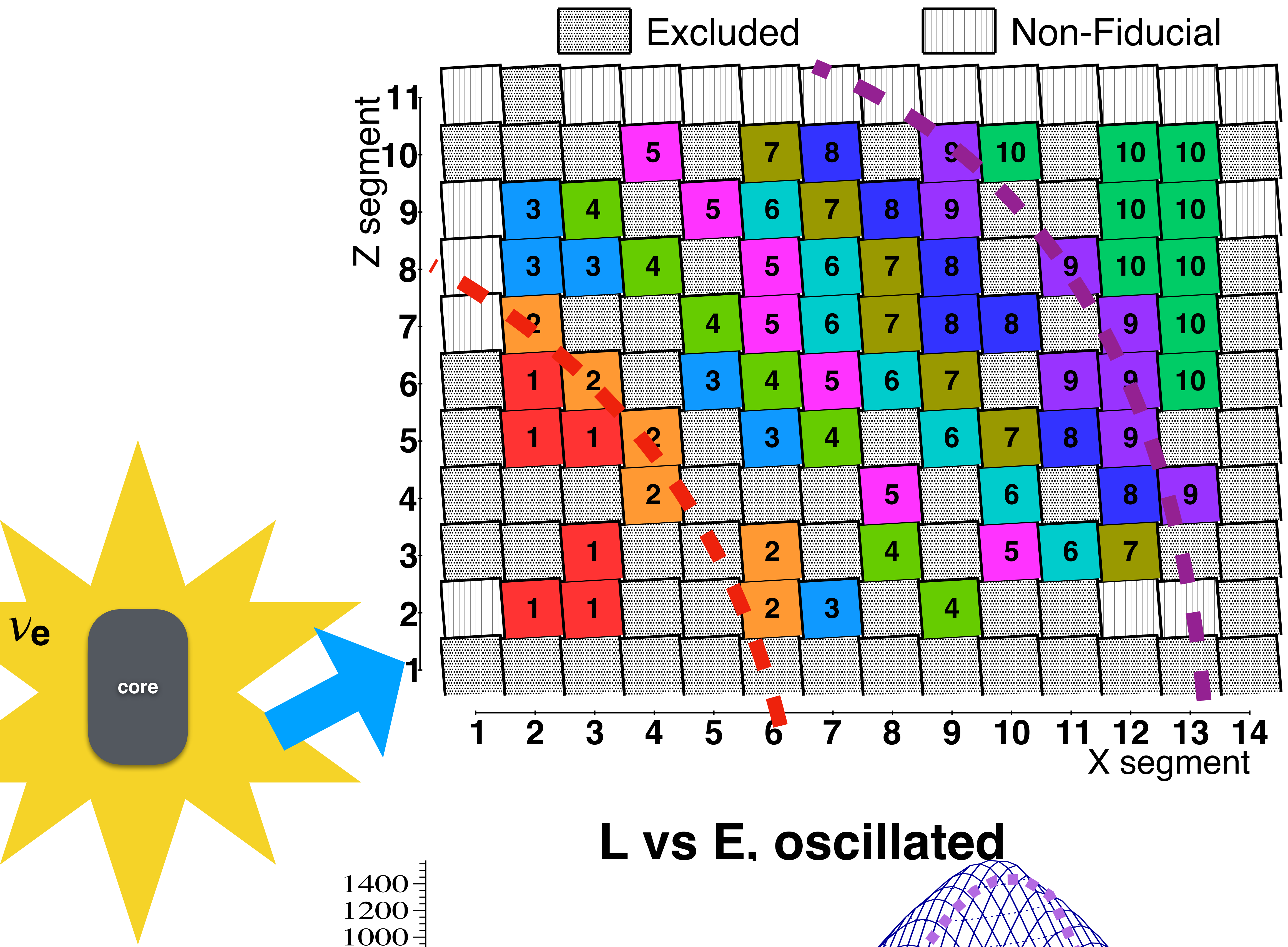


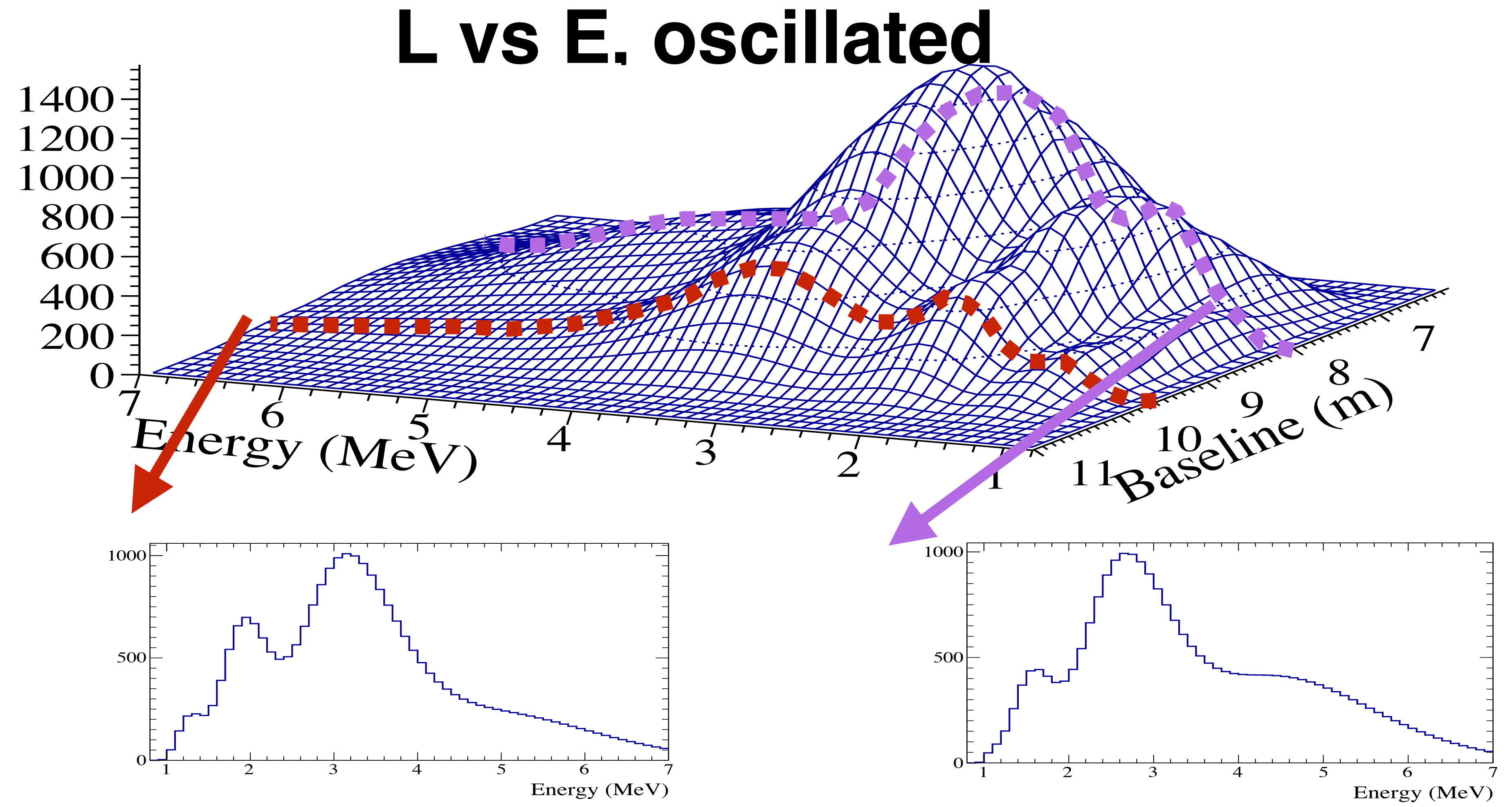


Reject candidates from 36 fiducial segments experiencing PMT current instabilities

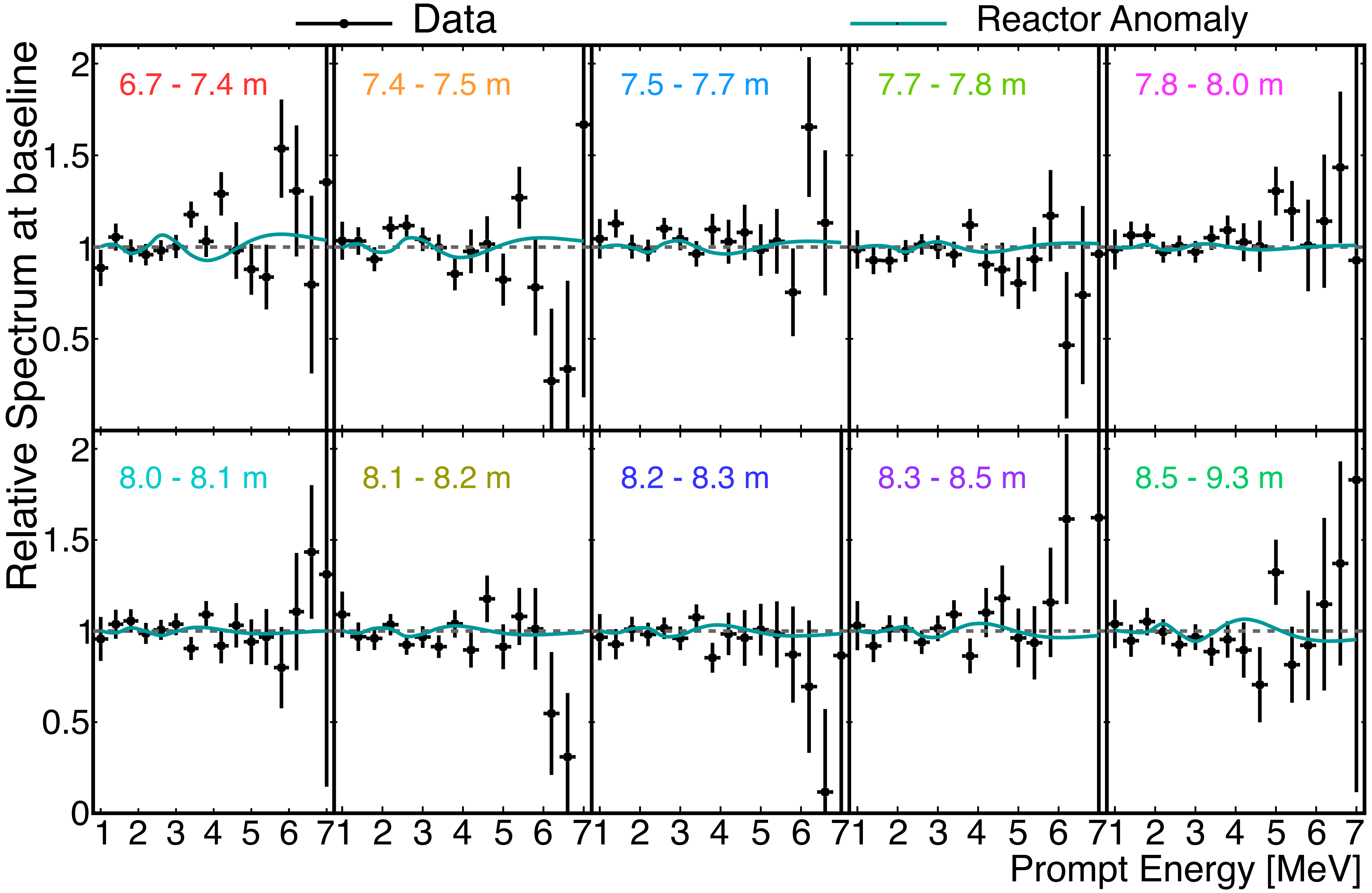
- **Time+position-coincident IBD e+ and n signals**
- **Prompt: IBD e+-like PSD+energy**
- **Delayed: n-^{6}Li PSD+energy+topology**
- **Reject if coincident with cosmic μ/n**
- **Require signals to occur in fiducial segments**
- **Primary cosmic neutrons account for most of the remaining IBD-like background**

Oscillation Strategy





Oscillations modify energy spectrum as a function of baseline



No obvious deviations from flat no-oscillation scenario

Oscillation Search: Results

- **Compare measured, predicted spectrum ratios for different (Δm^2_{41}, $\sin^2 2\theta_{14}$):**

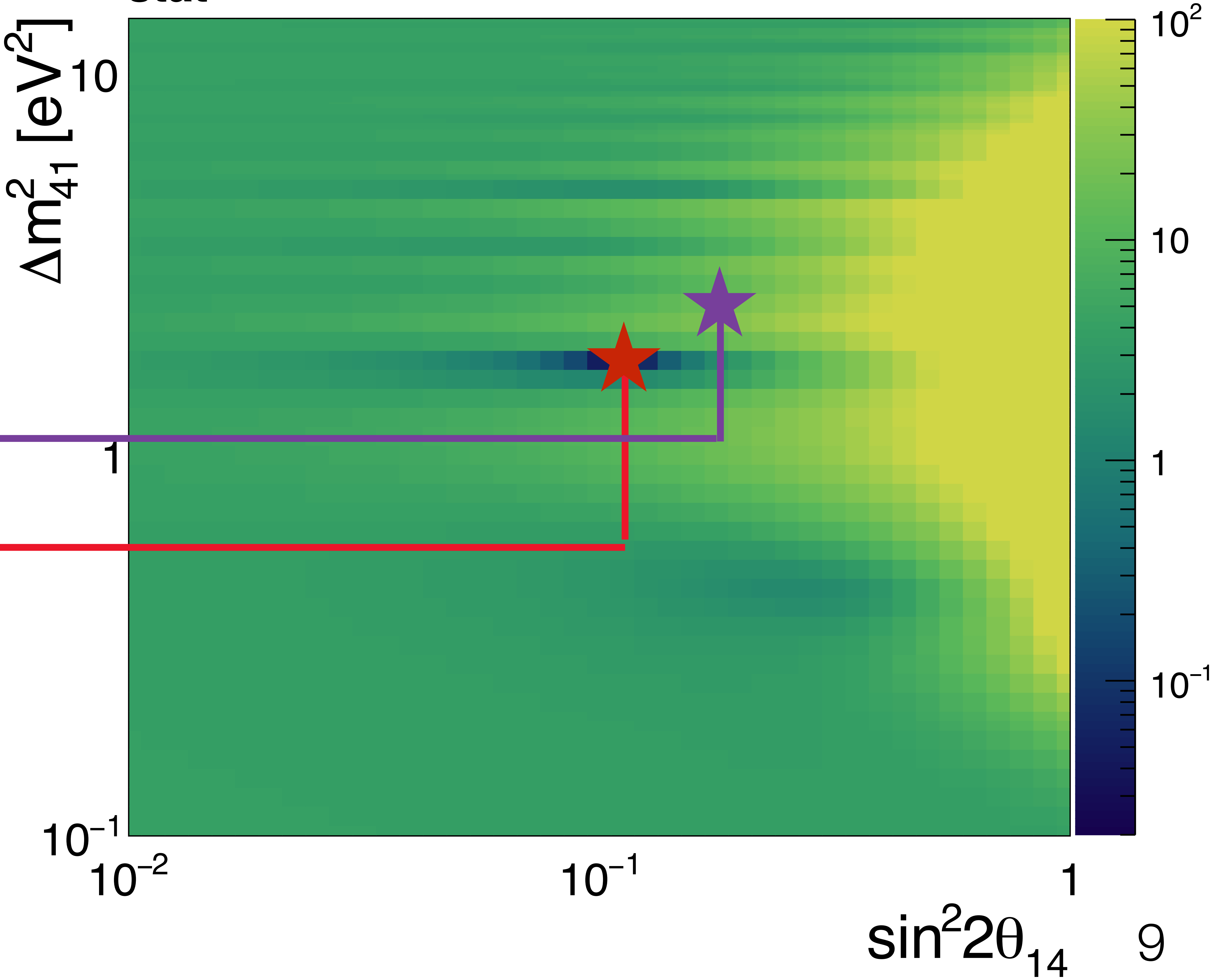
$$\chi^2_{min}(\Delta m^2, \sin^2 2\theta) = \mathbf{\Delta}^{\mathrm{T}} \mathbf{V}^{-1}_{\mathrm{tot}} \mathbf{\Delta}$$

- **Uncertainty covariance matrix $V_{tot} = V_{sys} + V_{stat}$**
  - **Statistics are the dominant sensitivity limiter**
- **Best-fit χ^2/NDF of 119.3/142 at (Δm^2_{41}, $\sin^2 2\theta_{14}$) = (1.78 eV^2 , 0.11)**
- **Pictured: $\Delta\chi^2$ with respect to this best-fit point**

Reactor Anomaly
χ^2 = 135.1

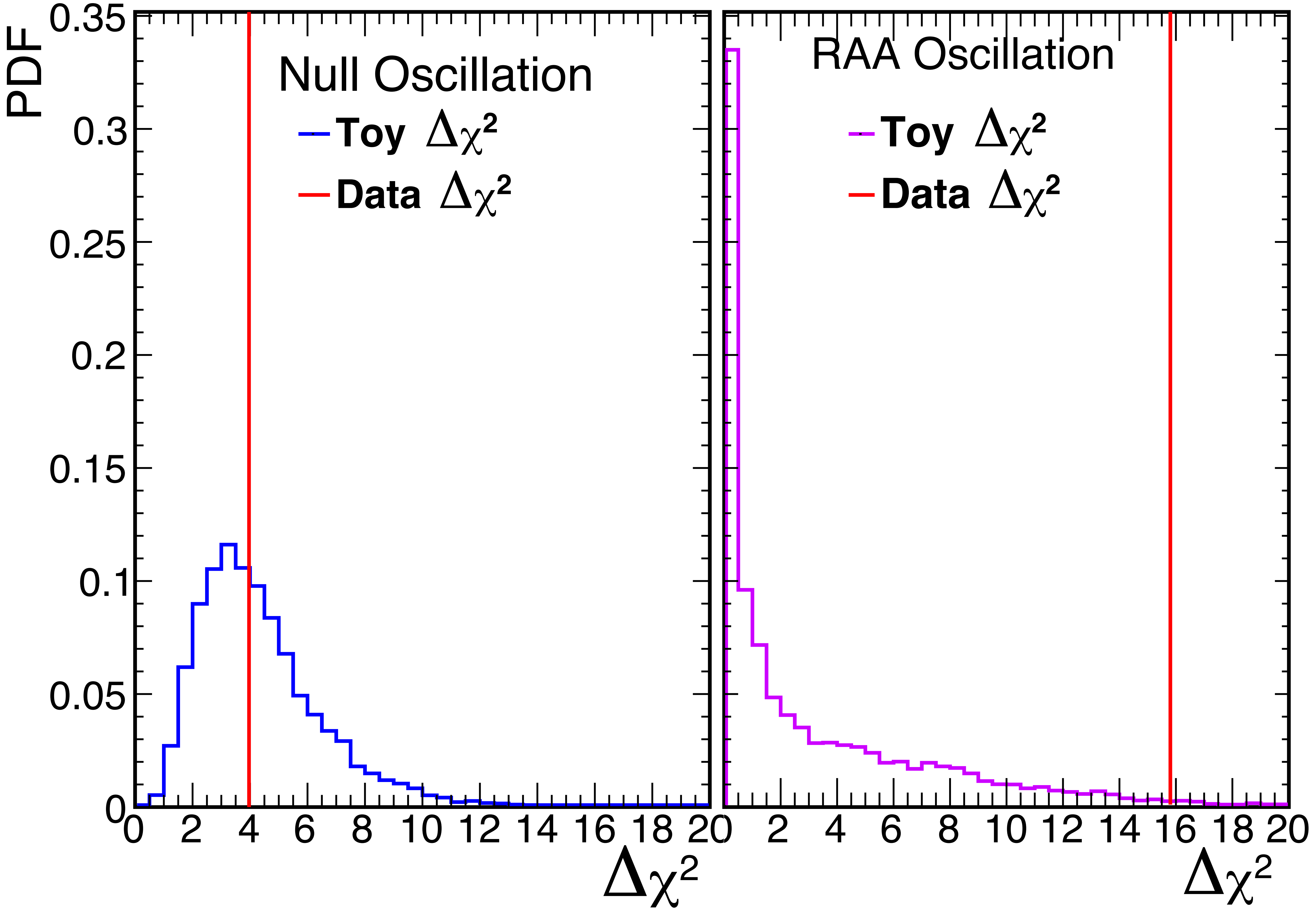
Data
χ^2 = 119.3

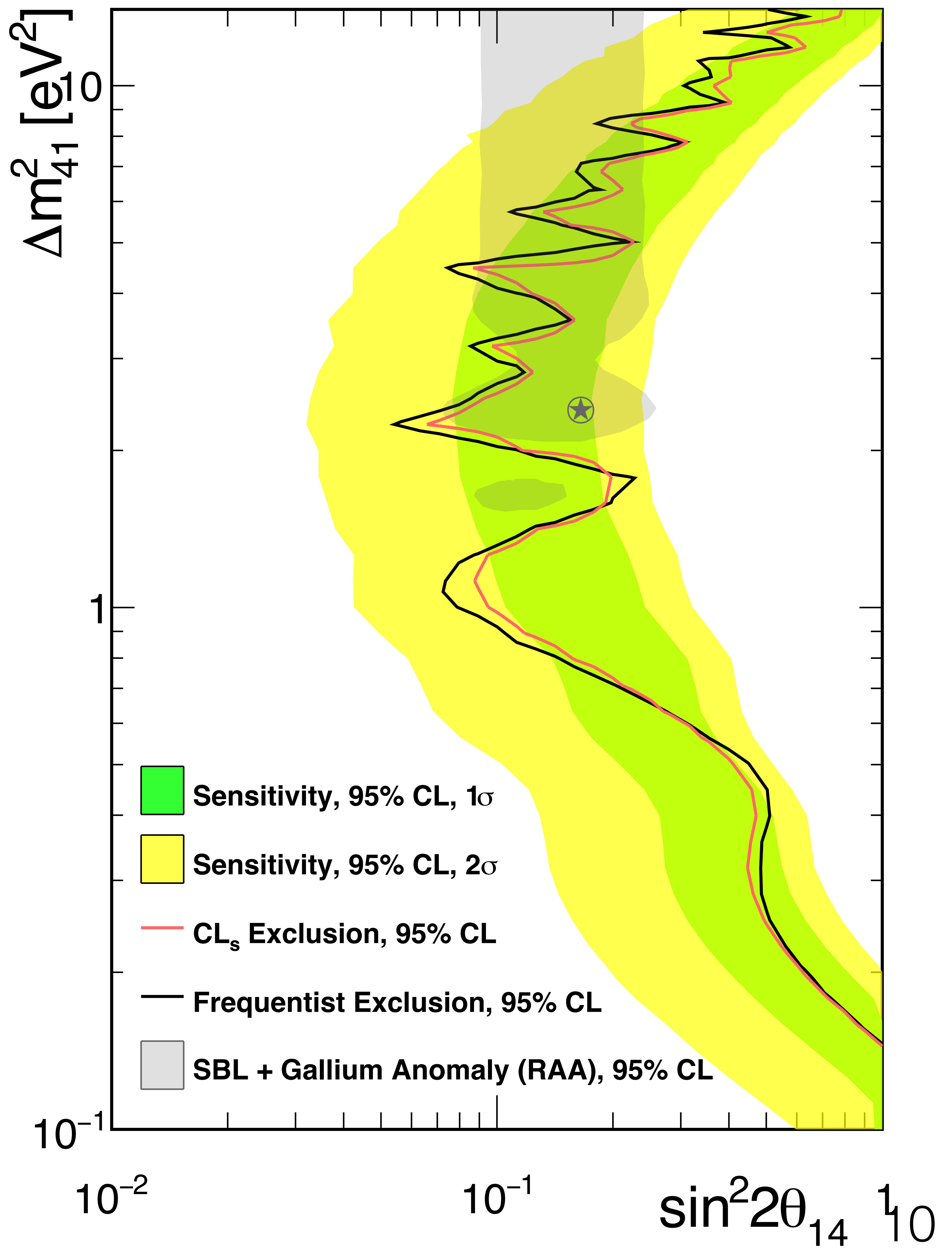
No oscillation
χ^2 = 123.3



Oscillation Search: Results

- **Feldman Cousins frequentist test and Gaussian CLs method are used to evaluate the exclusion regions in the oscillation phase space.**
  - **RAA best-fit excluded: 98.5% C.L.**
  - **Data is compatible with null oscillation hypothesis (p=0.57)**





Summary

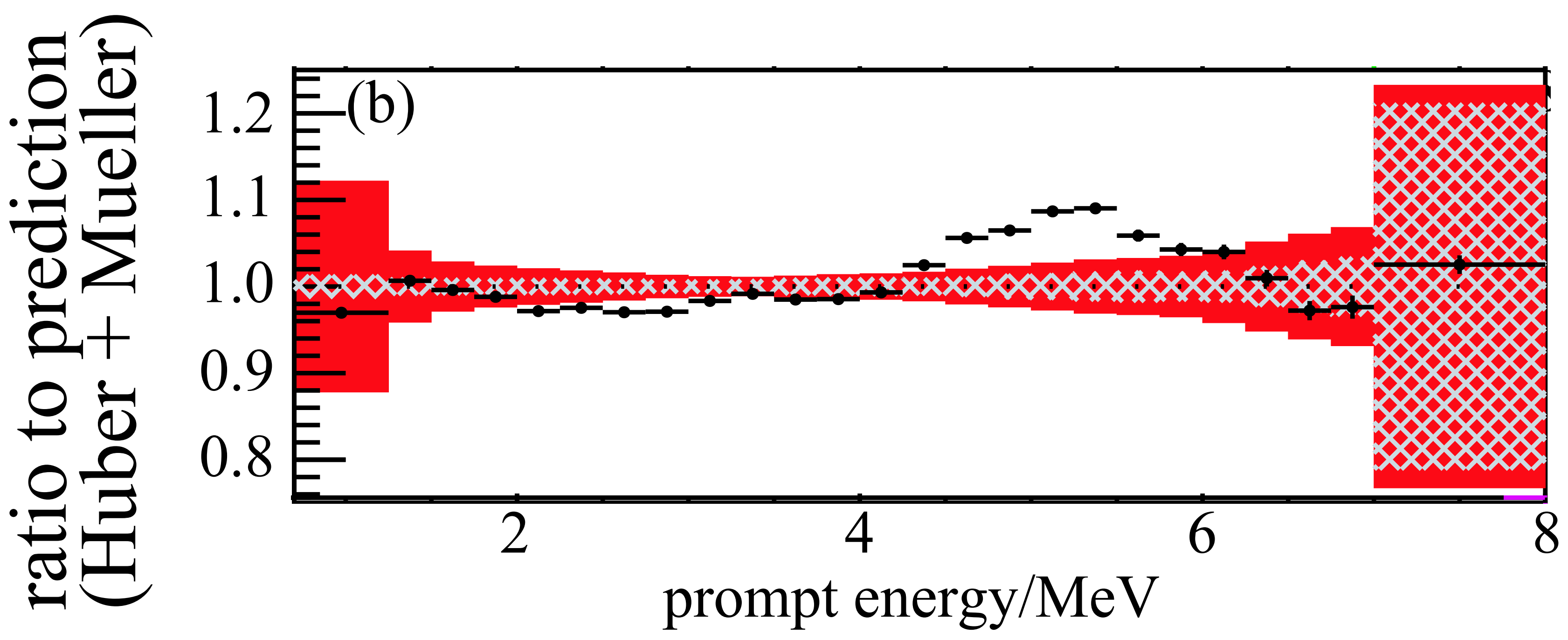
- An analysis of all PROSPECT reactor neutrino data has increased sterile neutrino sensitivity in the high-Δm2 regime.
- The ‘reactor antineutrino anomaly’ best-fit is excluded at 2.5σ CL.
- No evidence for sterile neutrino oscillations is found.
- PROSPECT’s current dataset will provide a substantially improved spectrum and oscillation measurement in the future. (EG.00004 X. Zhang)
- PROSPECT is pursuing upgraded detector deployment at HFIR that will further increase its measurement precision (EG.00005 H. Pieter)
- Latest Antineutrino Spectrum Measurement at PROSPECT (EG.00002 B. Foust)
- Check out these other PROSPECT talk(s) (EG00007 A. Delgado)

Backup Slides

Motivation: Reactor Antineutrino Spectrum Deviations

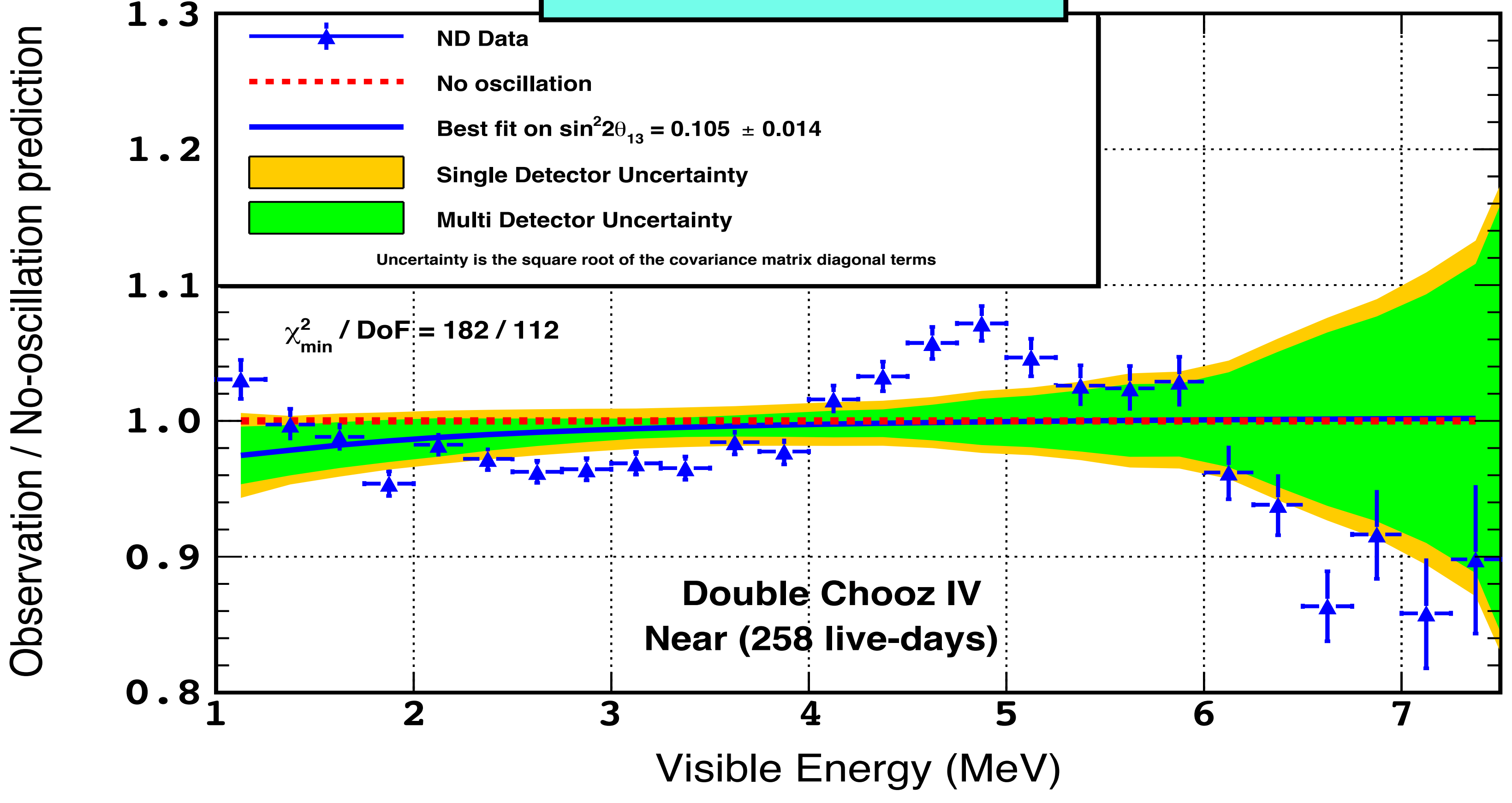
Experiments precisely measured spectrum from Low Enriched Uranium (LEU) reactors ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu

Daya Bay



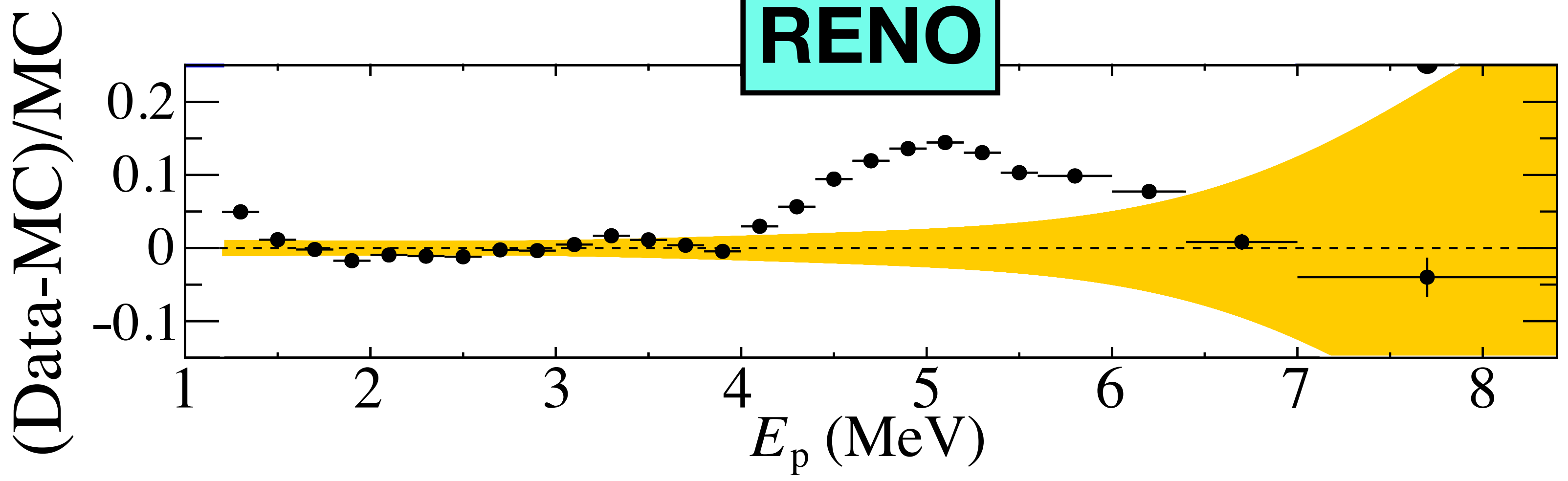
CPC Vol. 41 (1) (2017)

Double Chooz



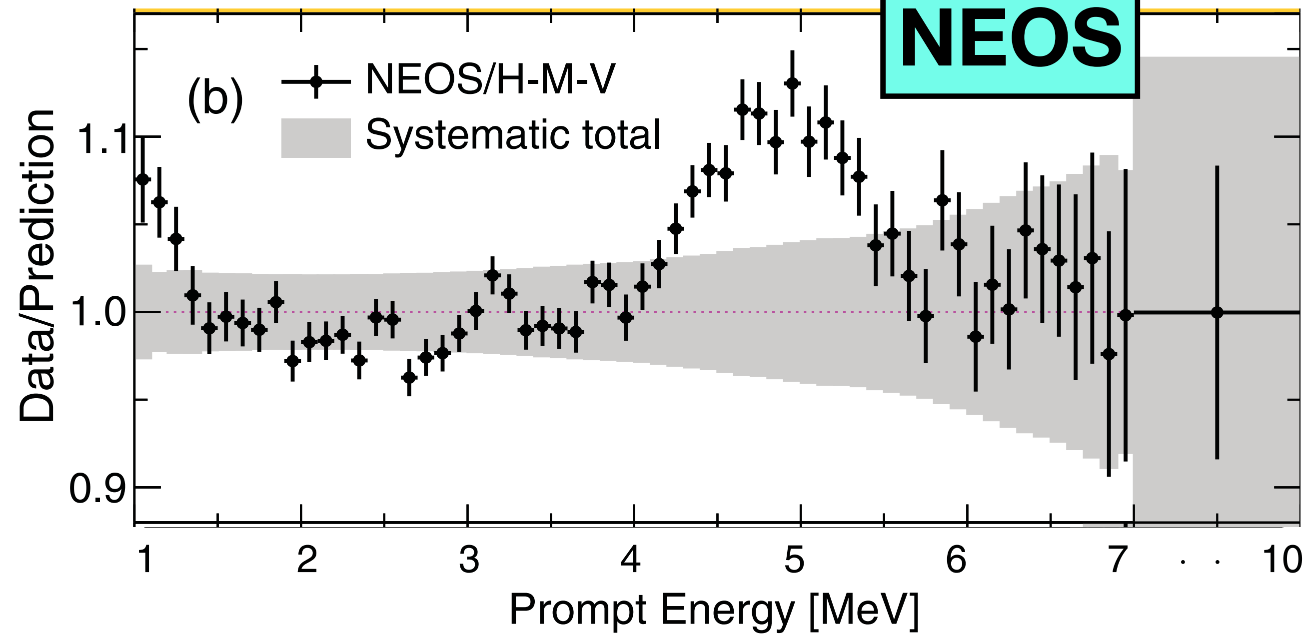
arXiv:1901.09445

RENO



PRD 98, 012002 (2018)

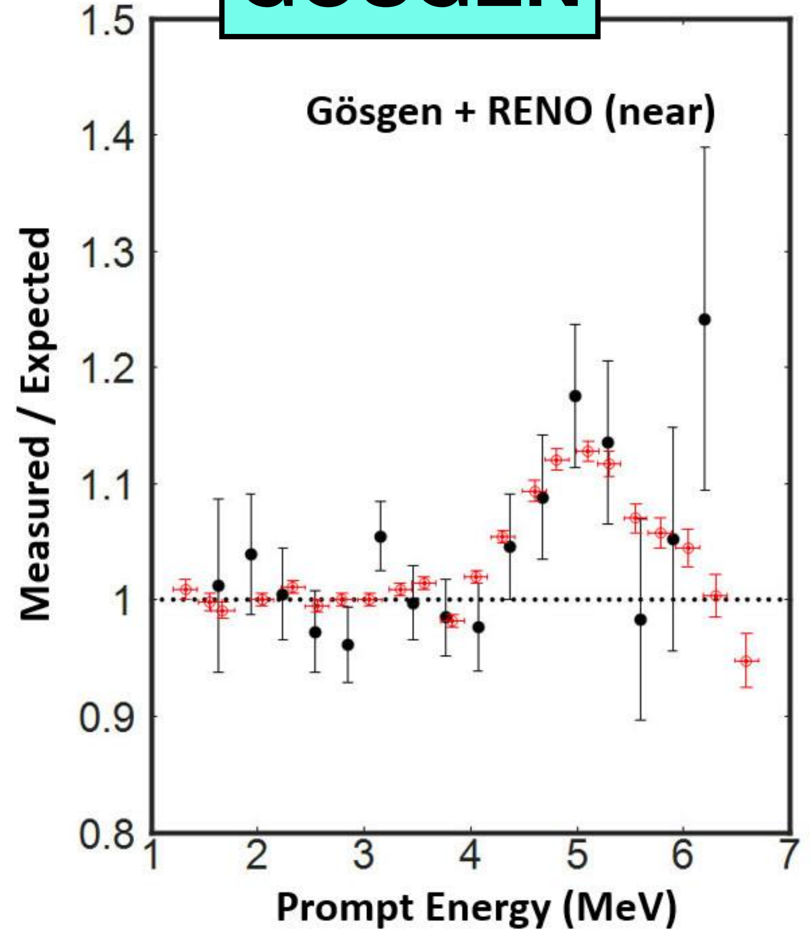
NEOS



PRL 118, 121802 (2017)

Distortion in 4-6 MeV prompt energy, not only on theta13 experiments.

GOSGEN



Re-evaluation (2018) of Gosgen(1980's) experiment also showed a deviation in 4-6 MeV region.

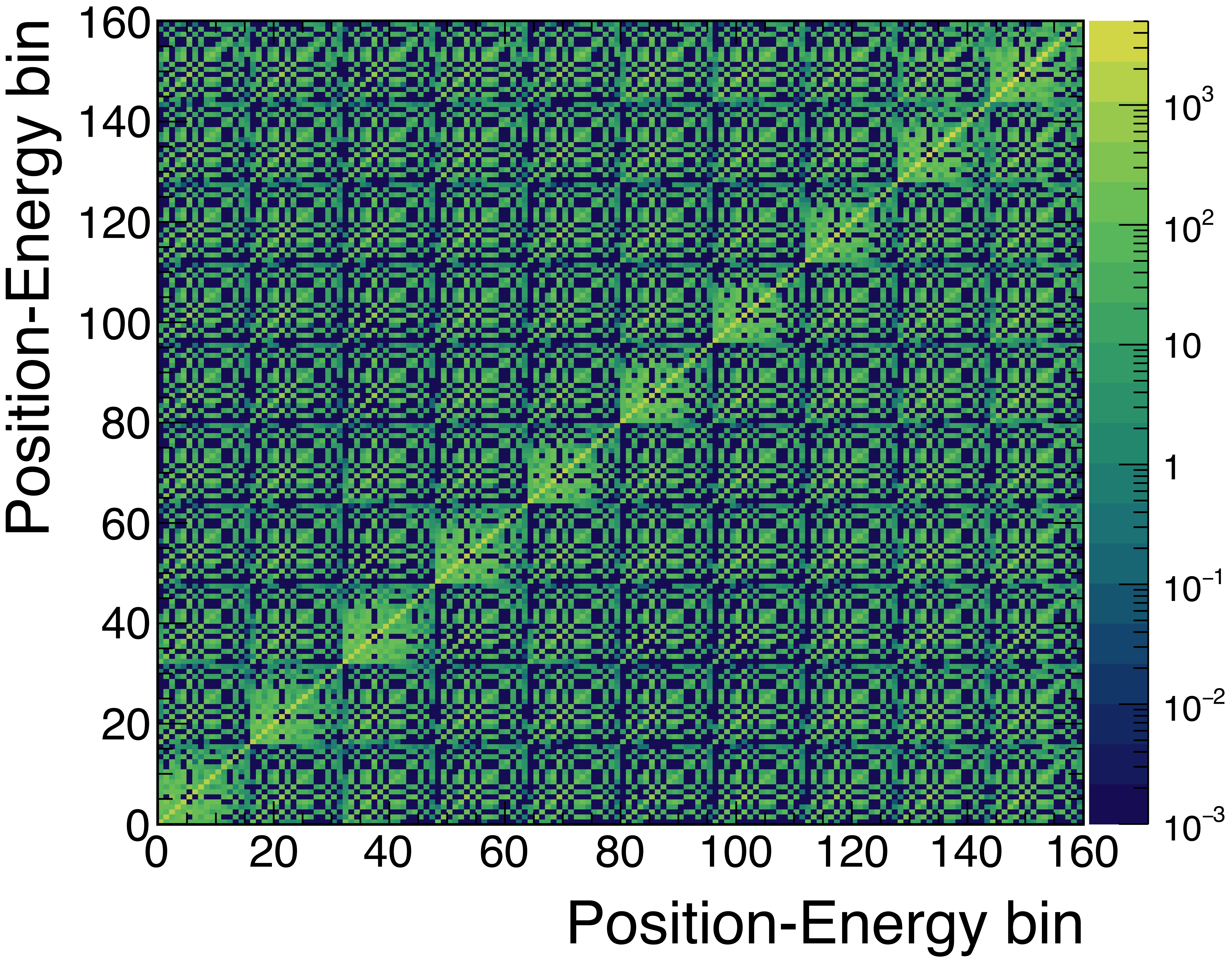
arXiv:1807.01810

Where this deviation is coming from?

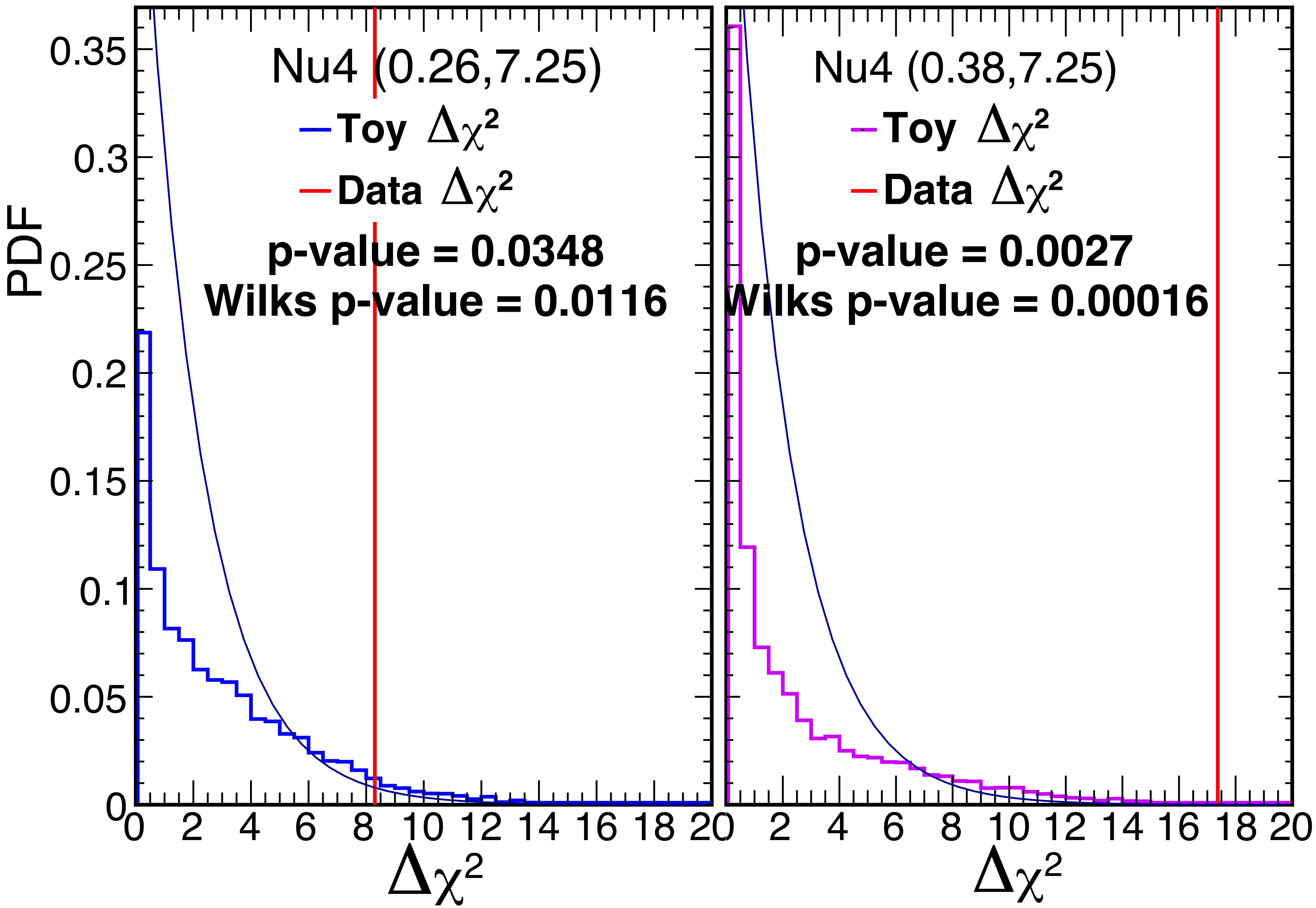
- Cannot be explained by the sterile neutrino introduced for flux deficit.
- Could be an issue with reactor models? Experiments used conventional reactors (LEU).

Systematics

Parameter	Section	Nominal Value	Uncertainty	Correlations
Absolute background normalization	VI B, VI D	-	1.0%	Correlated between energies and baselines
Absolute n-H peak normalization	VI D	-	3.0%	Correlated between energies and baselines
Relative signal normalization	V C	-	5%	Correlated between energies
Baseline uncertainty	II	-	10 cm	Correlated between energies and baselines
First-order Birks constant	IV B	0.132 MeV/cm	0.004 MeV/cm	Correlated between baselines
Second-order Birks constant	IV B	0.023 MeV/cm	0.004 MeV/cm	Correlated between baselines
Cherenkov contribution	IV B	37%	2%	Correlated between baselines
Absolute energy scale	IV B	-	0.6%	Correlated between baselines
Absolute photostatistics resolution	IV C	-	5%	Correlated between baselines
Absolute energy leakage	IV D	-	8 keV	Correlated between baselines
Absolute energy threshold	IV B, III G		5 keV	Correlated between baselines
Relative energy scale	III H, IV B	-	0.6%	Uncorrelated between baselines
Relative photostatistics resolution	III H, IV C	-	5%	Uncorrelated between baselines
Relative energy leakage	IV D	-	8 keV	Uncorrelated between baselines
Relative energy threshold	IV B, III G	-	5 keV	Uncorrelated between baselines
Reflector panel thickness	IV B	1.18 mm	0.03 mm	Uncorrelated between baselines



- The diagonal (statistical uncertainties) is clearly dominant
- Biggest systematics impact: relative segment normalization uncertainty, which effects low-dm2 values in particular


PDF
Nu4 (0.26,7.25)
Toy Δχ²
Data Δχ²
p-value = 0.0348
Wilks p-value = 0.0116
Nu4 (0.38,7.25)
Toy Δχ²
Data Δχ²
p-value = 0.0027
Wilks p-value = 0.00016
Δχ²
Δχ²
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 2 4 6 8 10 12 14 16 18 20
0 2 4 6 8 10 12 14 16 18 20

Global

- PROSPECT and STEREO dominate > 3 eV²
- DANSS and NEOS dominate at < 3 eV²
- Full PROSPECT-II dataset will provide best coverage above ~1.5 eV²