# PROSPECT's latest results

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On behalf of Prospect collaboration

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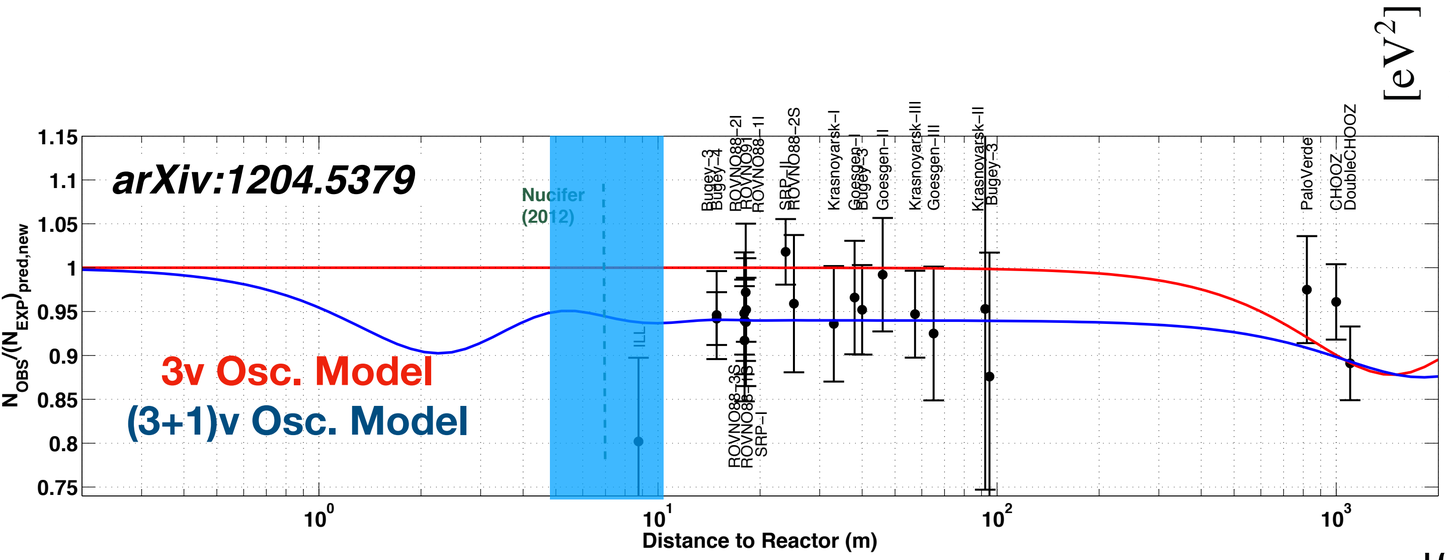
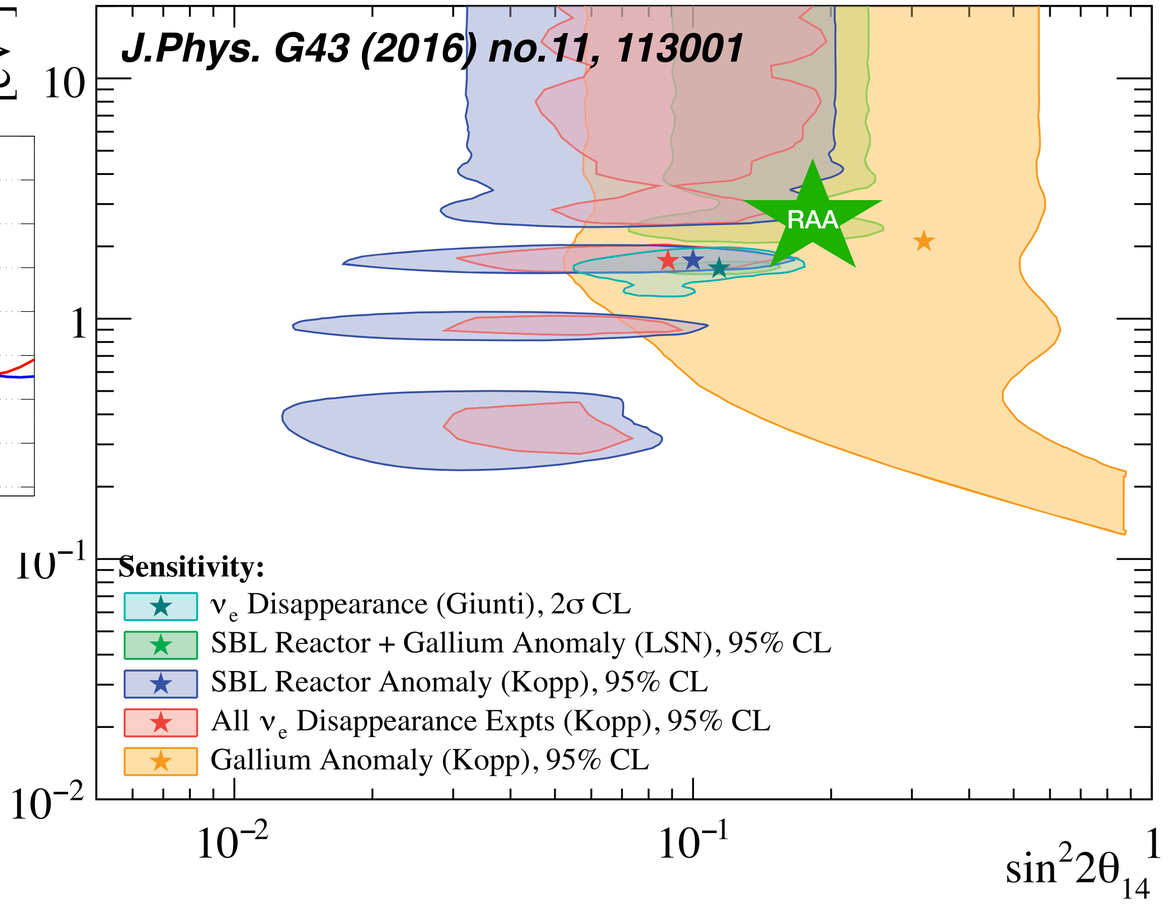
ILLINOIS INSTITUTE OF TECHNOLOGY

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.

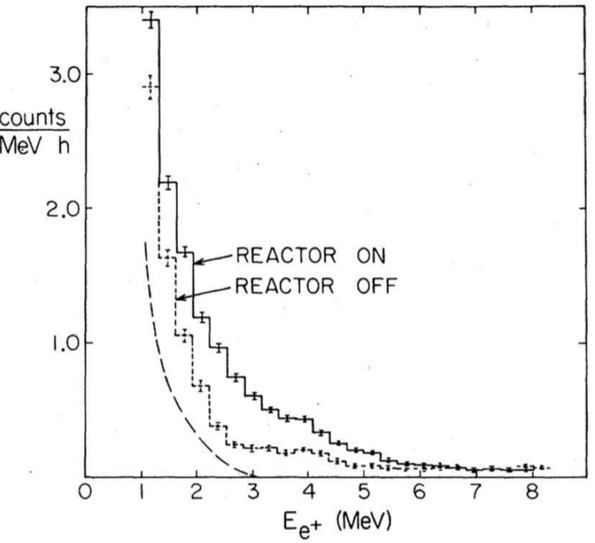
**Where this global deficit is coming from?**
- Reactor model predictions are not good enough
- Sterile Neutrinos:
  - high frequency oscillations (~meter baselines).
  - eV-scale mass splitting.

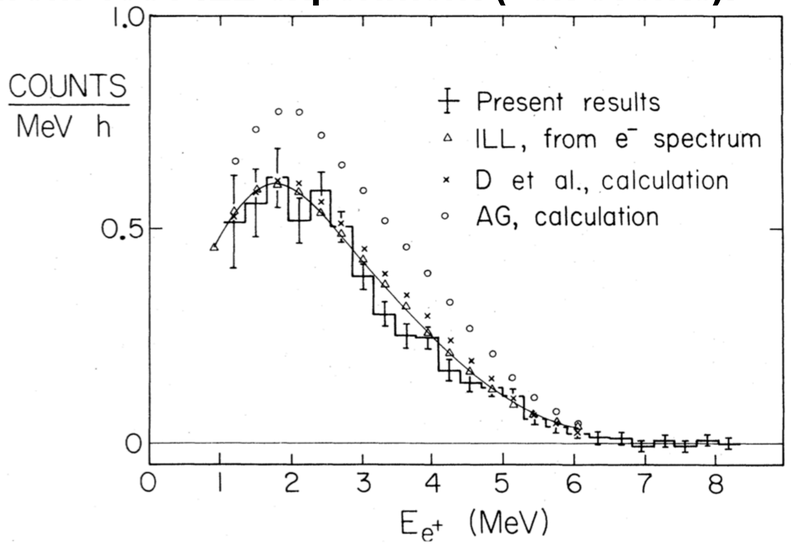
**RAA best-fit point at $sin^2 2\theta$ = 0.165, $\Delta m^2$= 2.39**

# Physics Goals

**There are not precise measurements at very short baseline.**

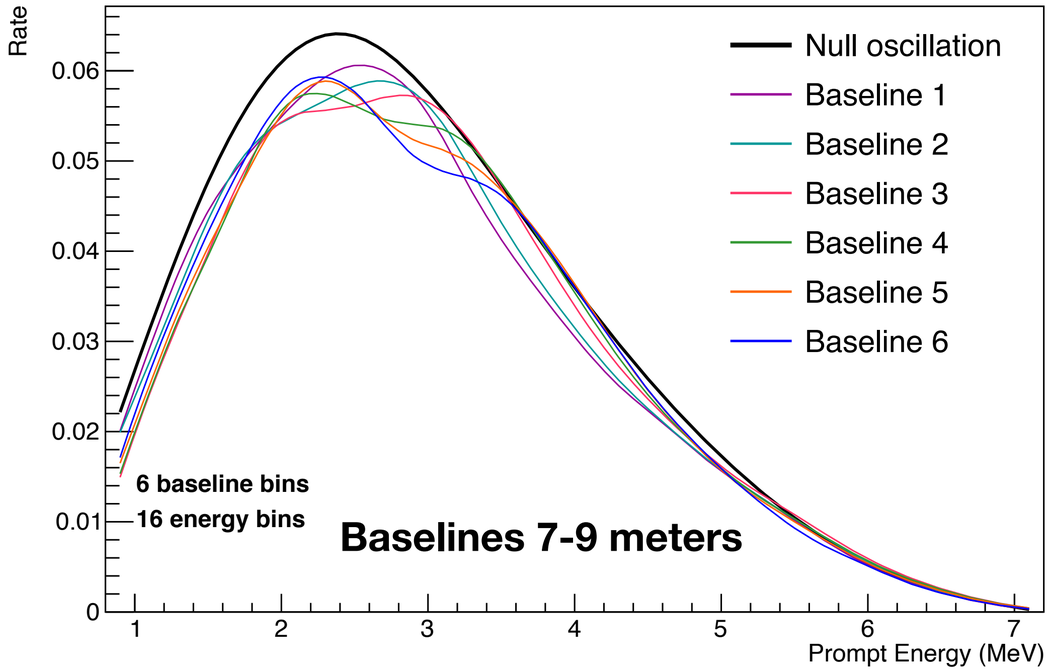
**Existing measurement from 1981 ILL experiment (~5k events).**




## 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

# Latest Prospect Results (PRD editors' suggestion)

**Nonfuel Antineutrino Contributions in the High Flux Isotope Reactor**
PhysRevC 101 (2020) 054605

**The Radioactive Source Calibration System of the PROSPECT Reactor Antineutrino Detector**
NIMA 944 ( 2019) 162465

**Measurement of the Antineutrino Spectrum from 235U Fission at HFIR with PROSPECT**
PhysRevLett 122 (2019) 251801

**A Low Mass Optical Grid for the PROSPECT Reactor Antineutrino Detector**
JINST 14 (2019) P04014

**Lithium-loaded Liquid Scintillator Production for the PROSPECT Experiment**
JINST 14 (2019) P03026

**The PROSPECT Reactor Antineutrino Experiment**
NIMA 922 (2018) 287

**First search for short-baseline neutrino oscillations at HFIR with PROSPECT**
PhysRevLett 121 (2018) 251802

**Performance of a segmented 6Li-loaded liquid scintillator detector for the PROSPECT experiment**
JINST 13 (2018) P06023

**The PROSPECT Physics Program**
Journal of Phys. G 43 (2016) 11

**Light Collection and Pulse-Shape Discrimination in Elongated Scintillator Cells for the PROSPECT Reactor Antineutrino Experiment**
JINST 10 (2015) P11004

**Background Radiation Measurements at High Power Research Reactors**
Nucl. Instru. Meth. Phys. Res. A 806 (2016) 401

Editors' Suggestion  Open Access

Improved short-baseline neutrino oscillation search and energy spectrum measurement with the PROSPECT experiment at HFIR

M. Andriamirado *et al.* (PROSPECT Collaboration)
Phys. Rev. D **103**, 032001 – Published 3 February 2021

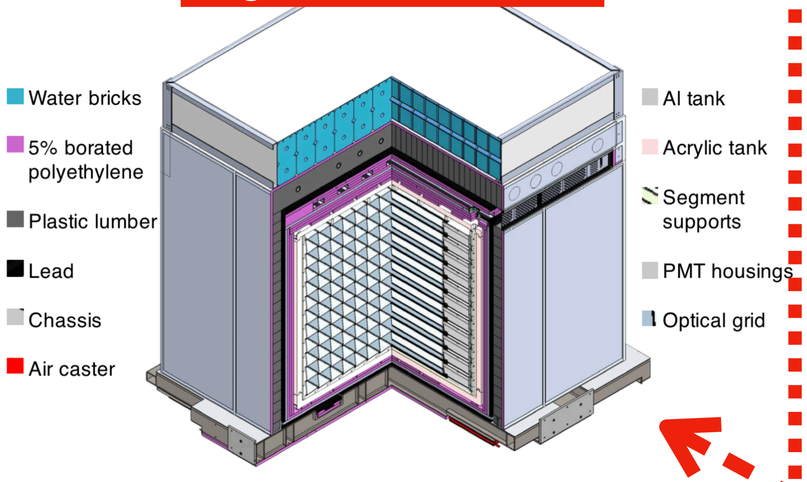
Article | References | Citing Articles (1) | Supplemental Material | PDF | HTML | Export Citation

ABSTRACT

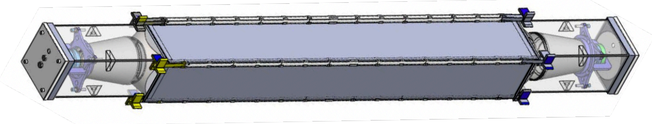
We present a detailed report on sterile neutrino oscillation and $^{235}\mathrm{U}$ $\bar{\nu}_e$ energy spectrum measurement results from the PROSPECT experiment at the highly enriched High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory. In 96 calendar days of data taken at an average baseline distance of 7.9 m from the center of the 85 MW HFIR core, the PROSPECT detector has observed more than 50,000 interactions of $\bar{\nu}_e$ produced in beta decays of $^{235}\mathrm{U}$ fission products. New limits on the oscillation of $\bar{\nu}_e$ to light sterile neutrinos have been set by comparing the detected energy spectra of ten reactor-detector baselines between 6.7 and 9.2 meters. Measured differences in energy spectra between baselines show no statistically significant indication of $\bar{\nu}_e$ to sterile neutrino oscillation and disfavor the reactor antineutrino anomaly best-fit point at the $2.5\sigma$ confidence level. The reported $^{235}\mathrm{U}$ $\bar{\nu}_e$ energy spectrum measurement shows excellent agreement with energy spectrum models generated via conversion of the measured $^{235}\mathrm{U}$ beta spectrum, with a $\chi^2/\mathrm{d.o.f.}$ of $31/31$. PROSPECT is able to disfavor at $2.4\sigma$ confidence level the hypothesis that $^{235}\mathrm{U}$ $\bar{\nu}_e$ are solely responsible for spectrum discrepancies between model and data obtained at commercial reactor cores. A data-model deviation in PROSPECT similar to that observed by commercial core experiments is preferred with respect to no observed deviation, at a $2.2\sigma$ confidence level.

# Detector Design

## Segmented Detector

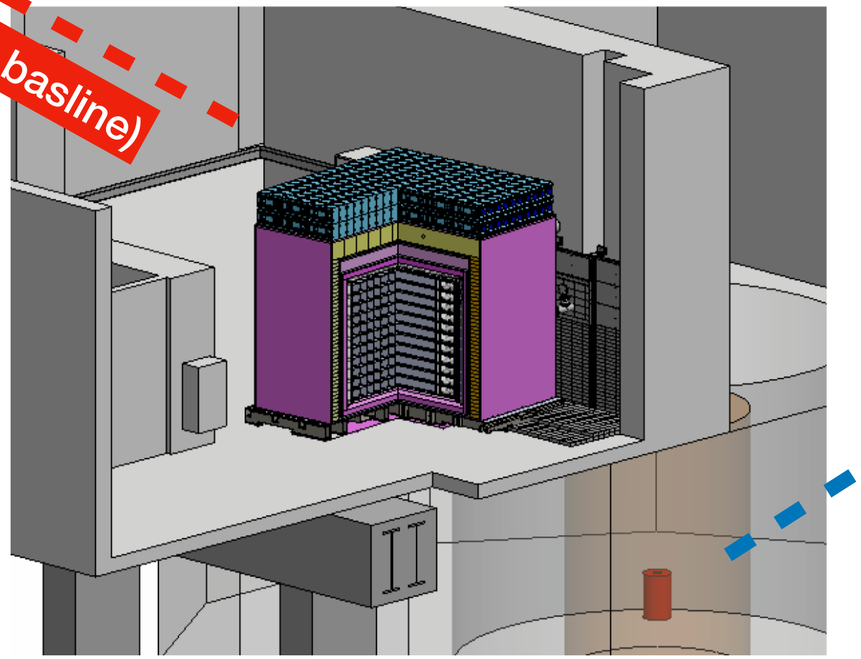



- ~3,000 L 6Li-loaded fiducial volume.
- 11 x 14 array of optically separated segments.
- Double ended PMT readout, with light concentrators.
- Good light collection and energy response ~4.5-5%√E energy resolution.
- Full X,Y,Z event reconstruction.



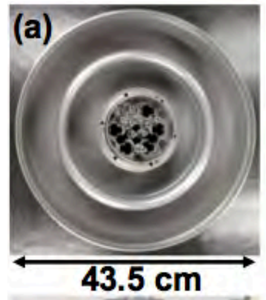
## HIGH FLUX ISOTOPE REACTOR AT OAK RIDGE NATIONAL LABORATORY

7m (short basline)

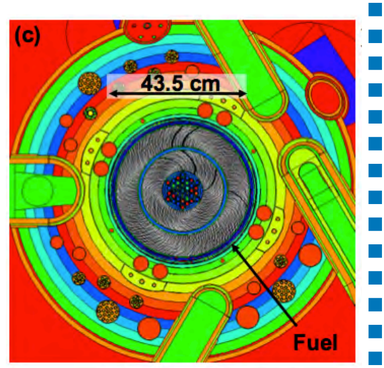


Reactor Core highly-enriched (HEU):
>99% of $\nu_e$ flux from $^{235}U$ fission:

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

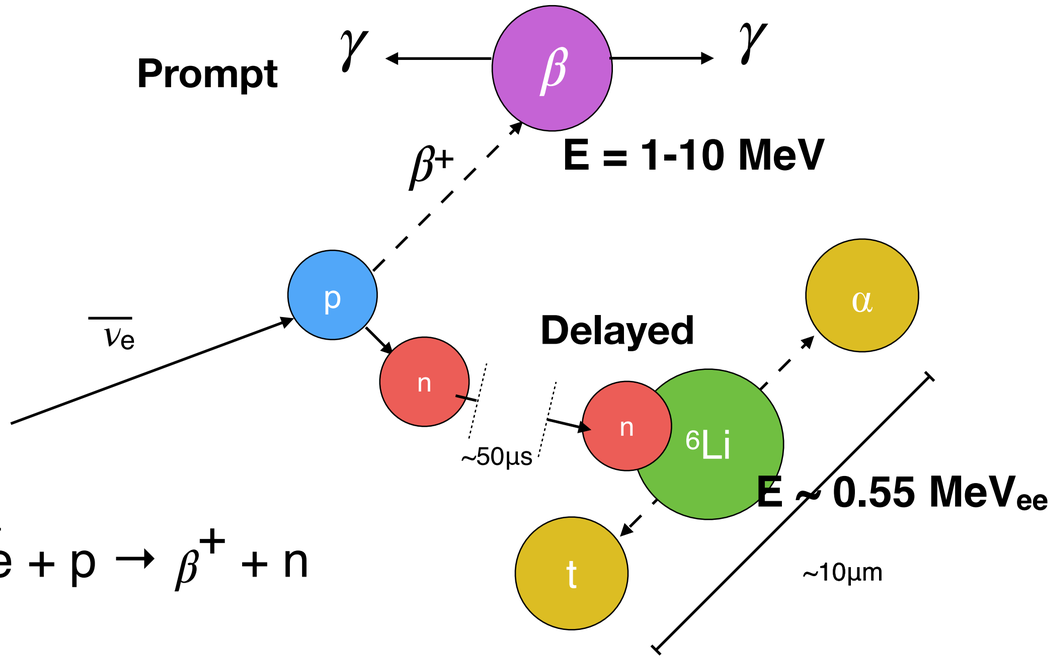







Reactor is smaller than conventional power reactors

# IBD detection with $^6$LiLS

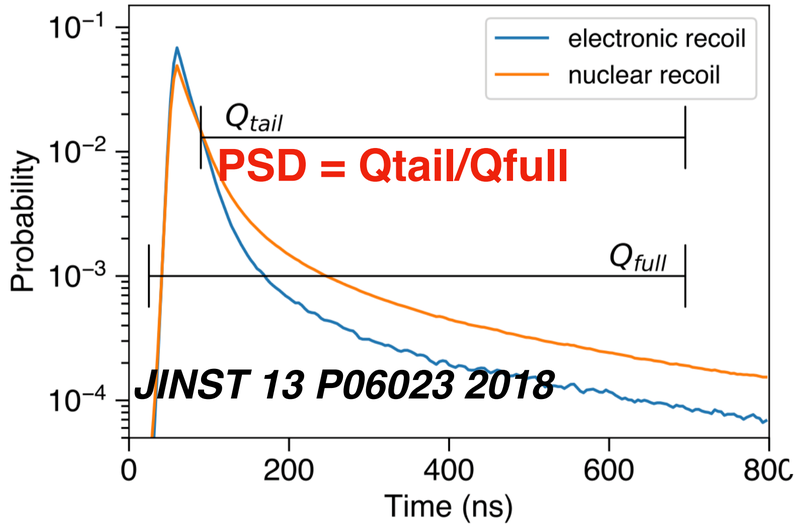


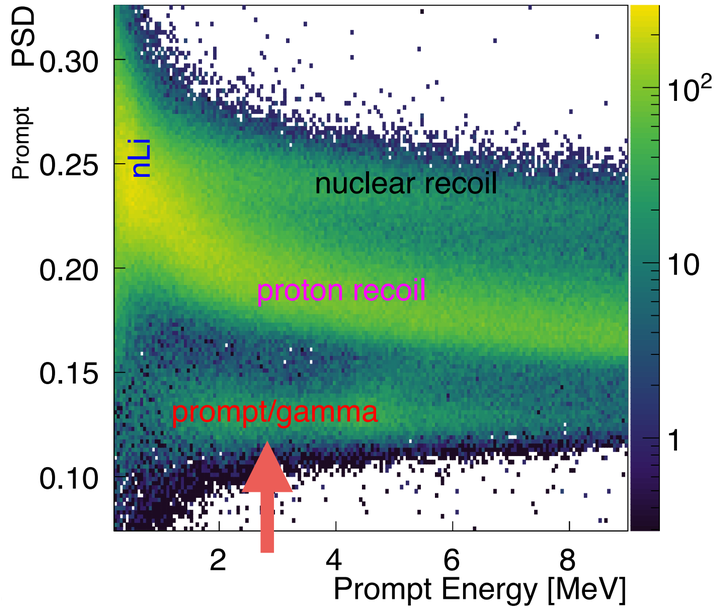

**IBD**: $\overline{\nu}e + p \rightarrow \beta^+ + n$

- **1-10 MeV β+-like prompt signal (ionization and annihilation of positron).**
- **Followed by ~50$\mu$s 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.**

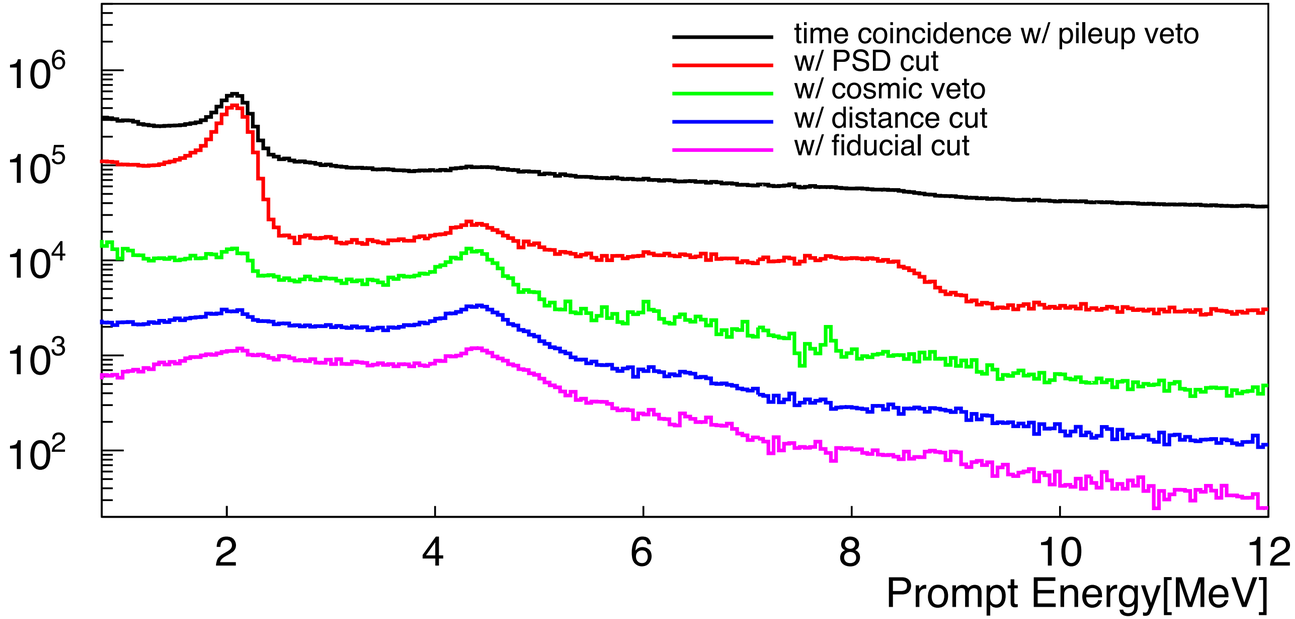
**The Pulse Shape Discrimination (PSD) of scintillator works as particle identification.**

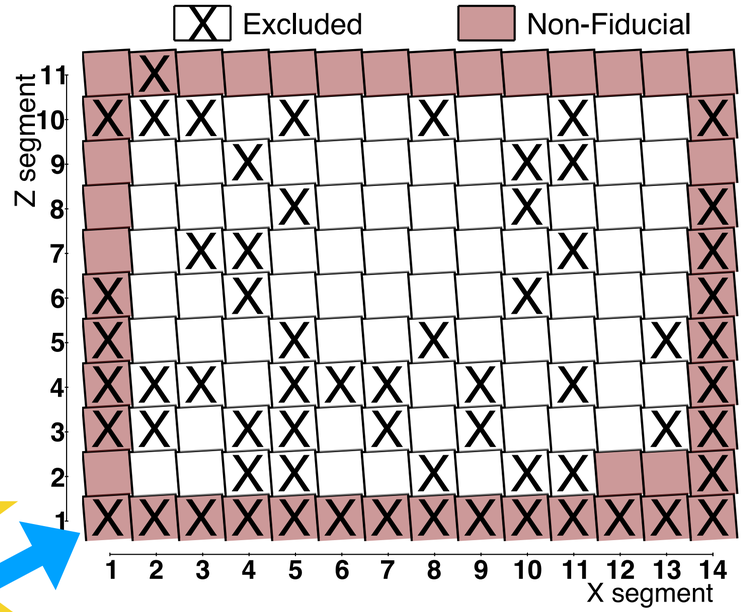
- **it can distinguishes gamma interactions, neutron capture and nuclear recoils.**
- **Essential to remove cosmogenic neutrons background.**



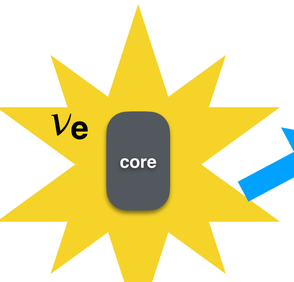



# IBD Selection



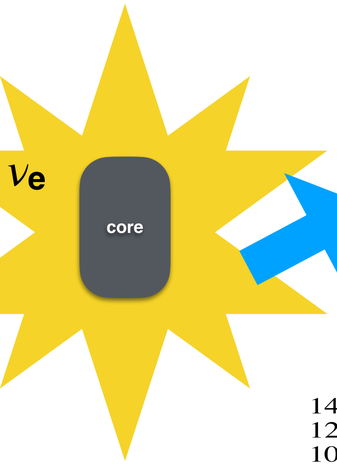



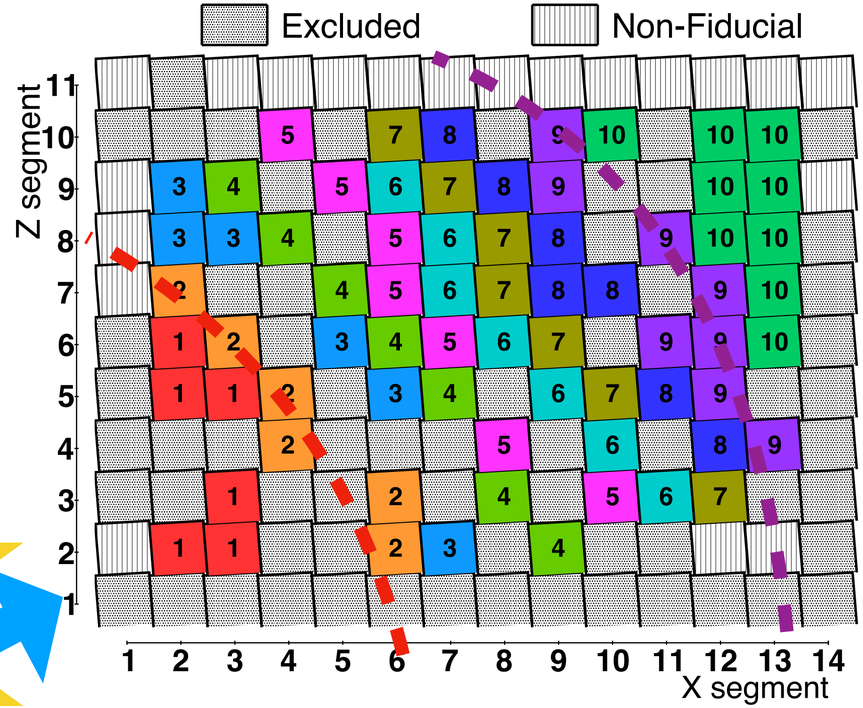

- **Time+position-coincident IBD e+ and n signals**
- **Prompt: IBD e+-like PSD+energy**
- **Delayed: n-$^6$Li PSD+energy+topology**
- **Reject if coincident with cosmic μ/n**
- **Require signals to occur in fiducial segments**
- **Primary cosmic neutrons account for most of the remaining IBD-like background**

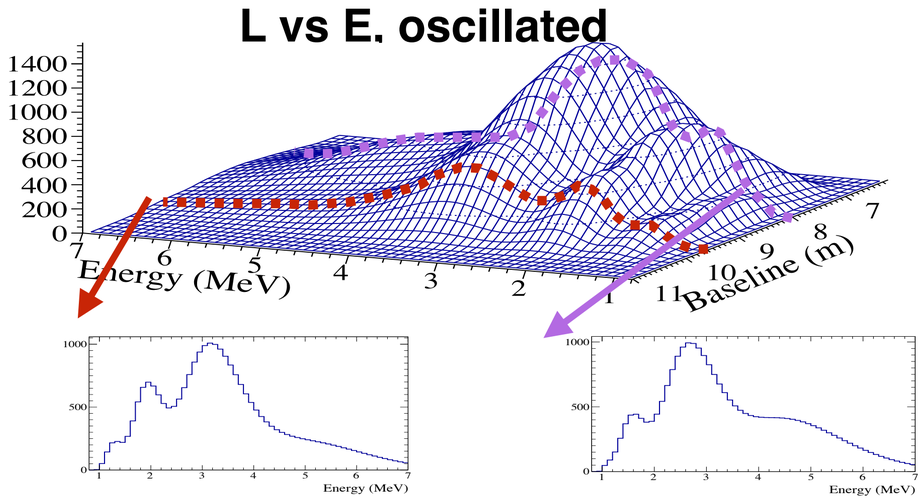



Exclude candidates from 36 fiducial segments experiencing PMT current instabilities

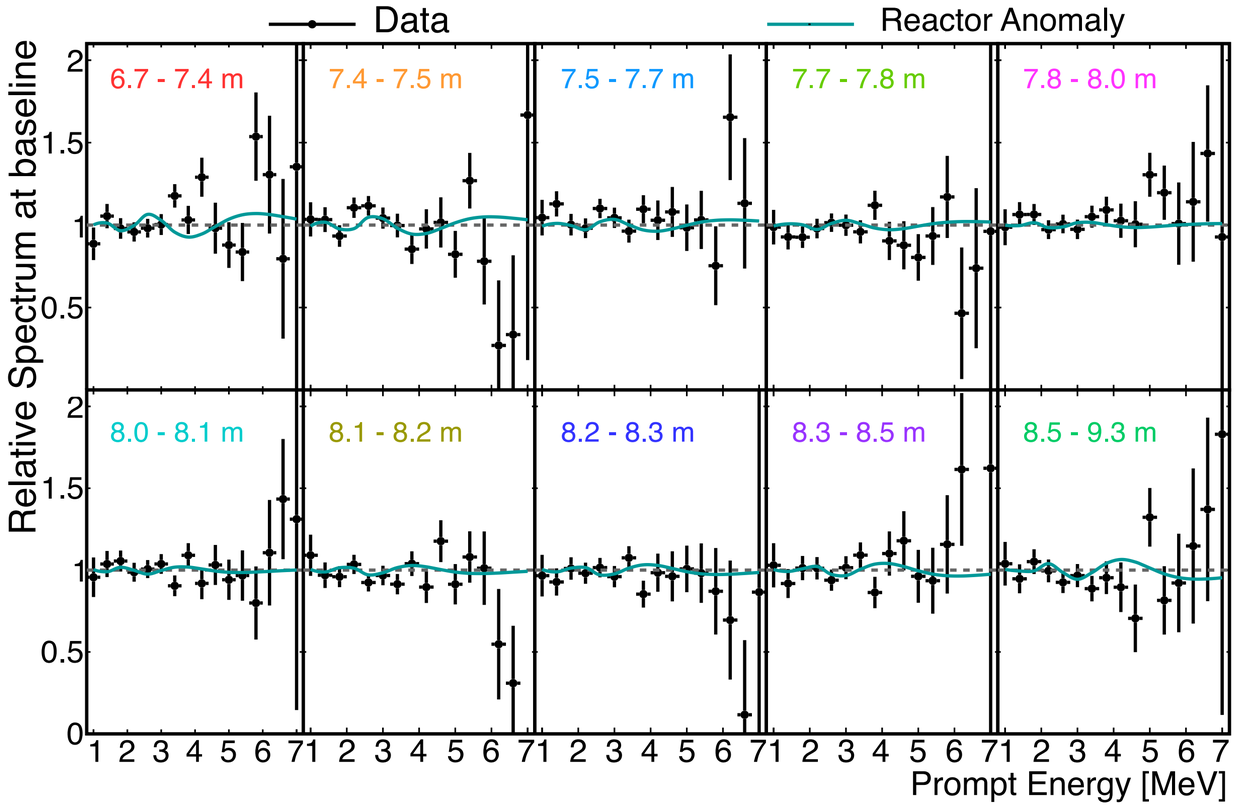
# Oscillation Strategy




Oscillations modify energy spectrum as a function of baseline



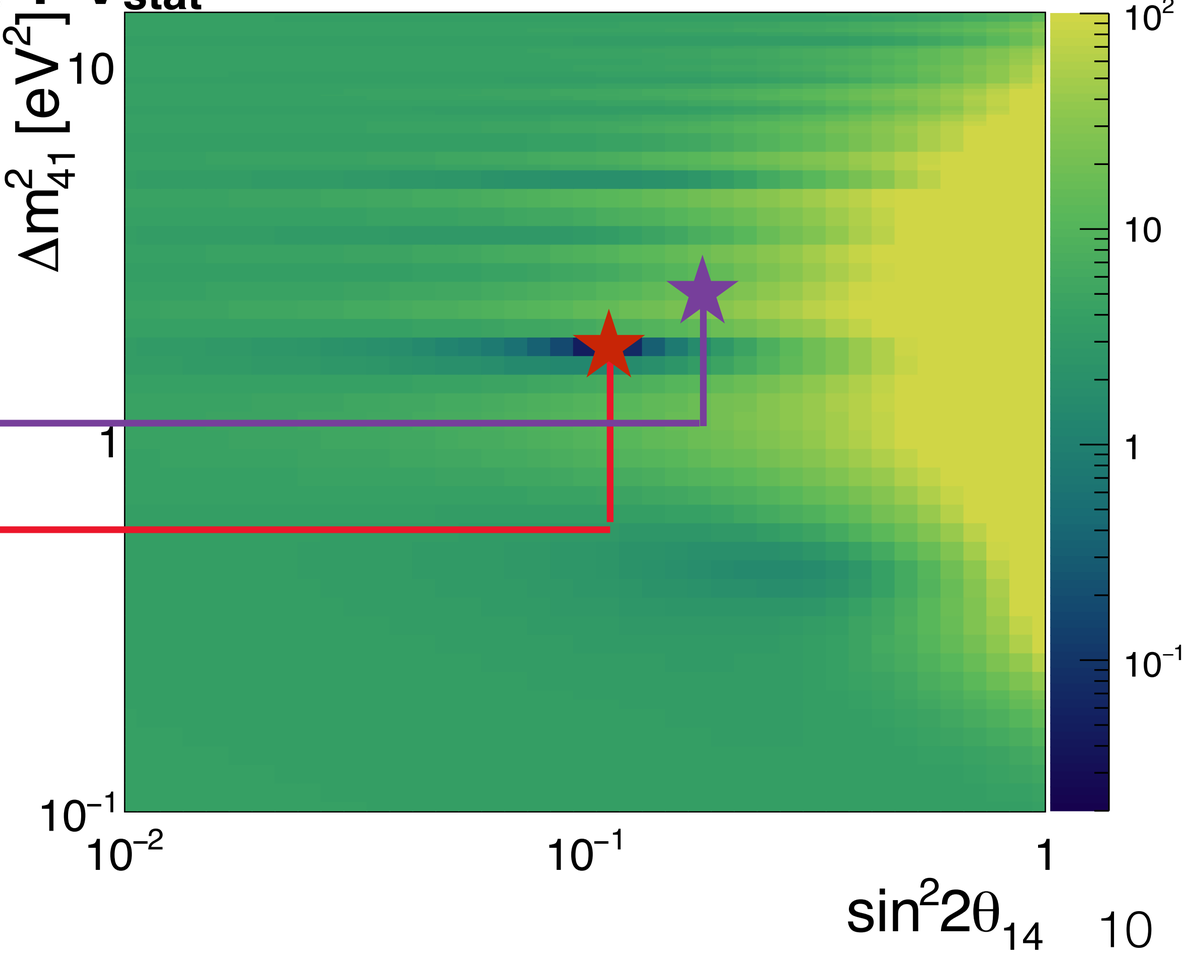

**No obvious deviations from flat no-oscillation scenario**

# Oscillation Search: Results

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

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

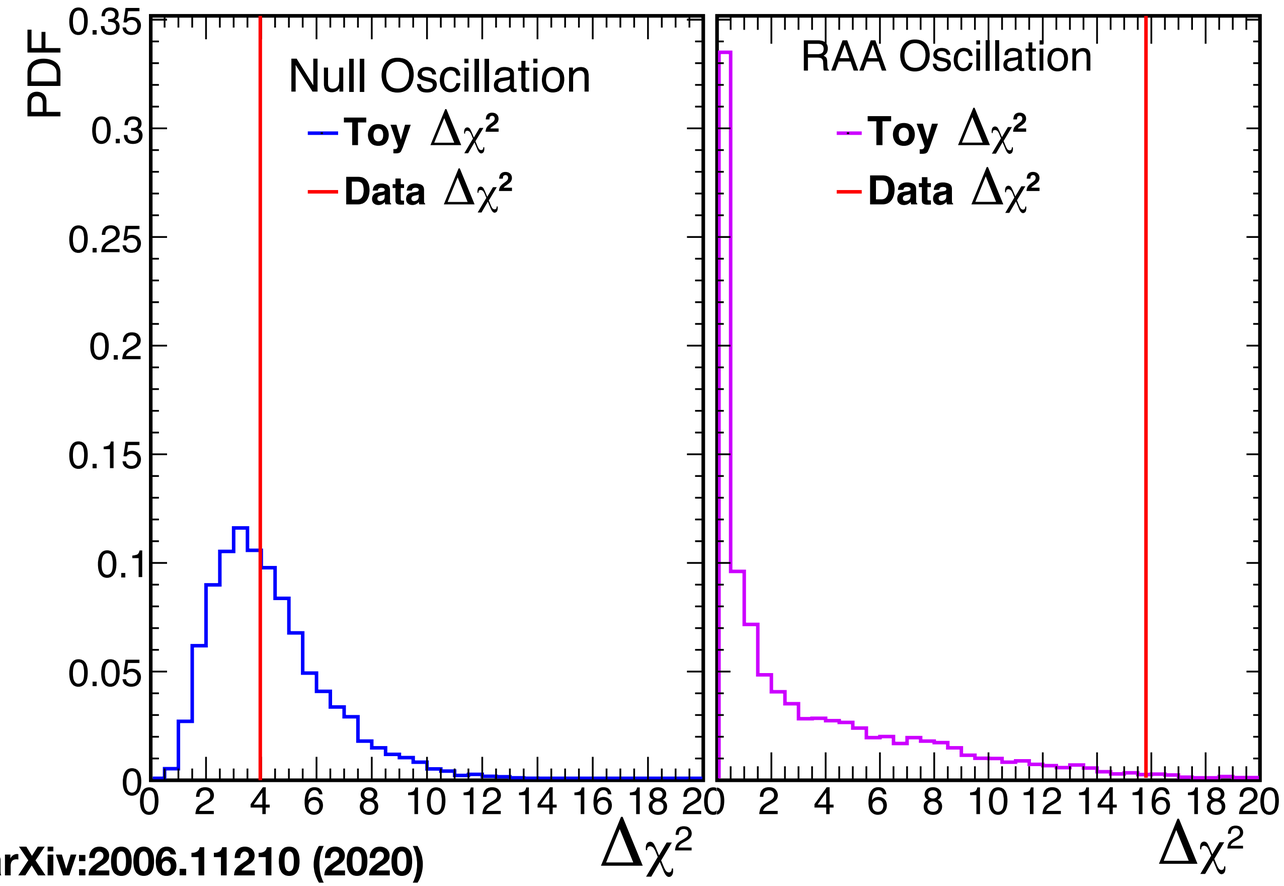
- **Uncertainty covariance matrix $V_{tot} = V_{sys} + V_{stat}$**
  - **Statistics are the dominant sensitivity limiter**
- **Best-fit $\chi^2$/NDF of 119.3/142 at ($\Delta m^2_{41}$, $\sin^2 2\theta_{14}$) = (1.78 eV$^2$ , 0.11)**
- **Pictured: $\Delta\chi^2$ with respect to this best-fit point**




arXiv:2006.11210 (2020)

# 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)**

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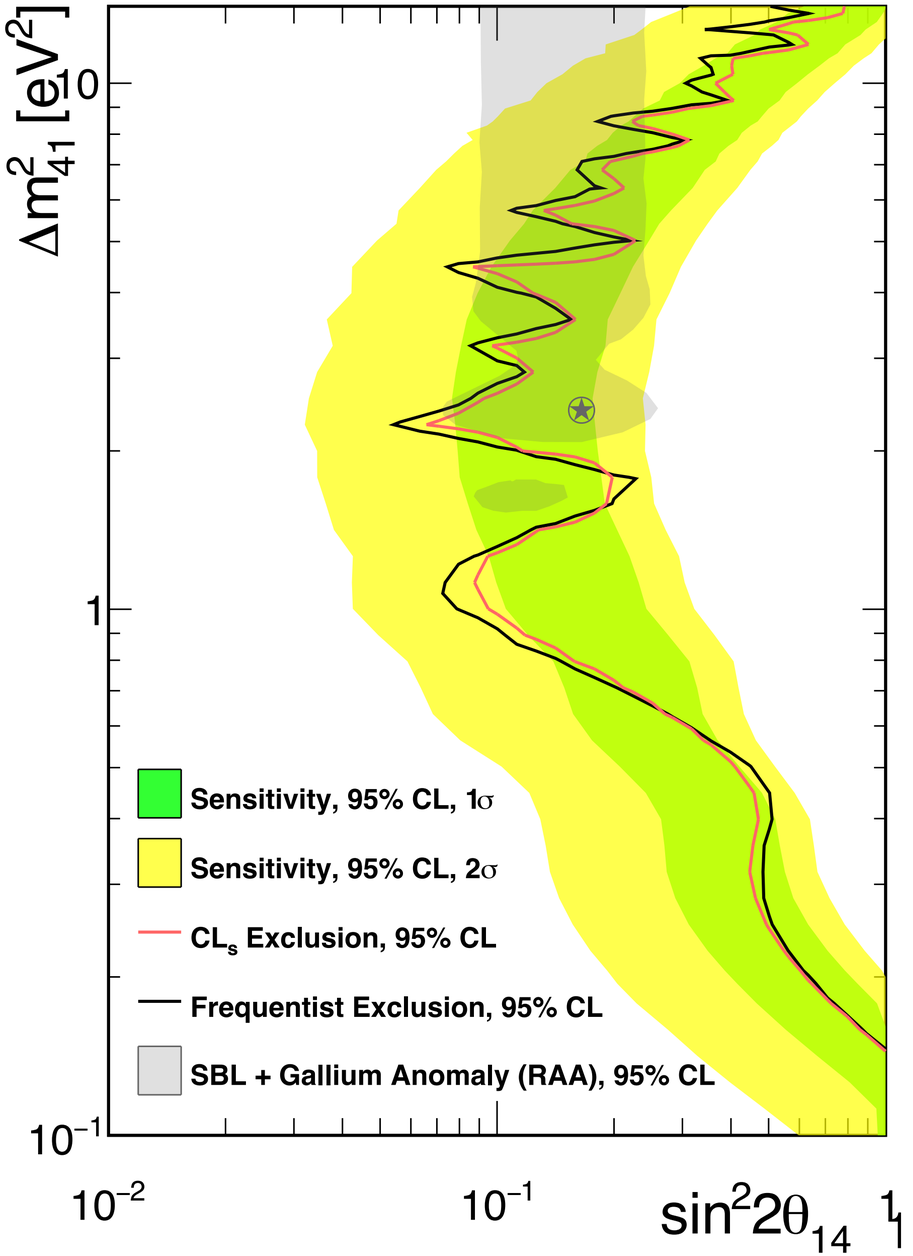

# Summary

- 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.
- The Y18.00007 presentation will describe the expected improvement in sensitivity of the current and future PROSPECT results.
- PROSPECT is pursuing upgraded detector deployment at HFIR that will further increase its measurement precision.