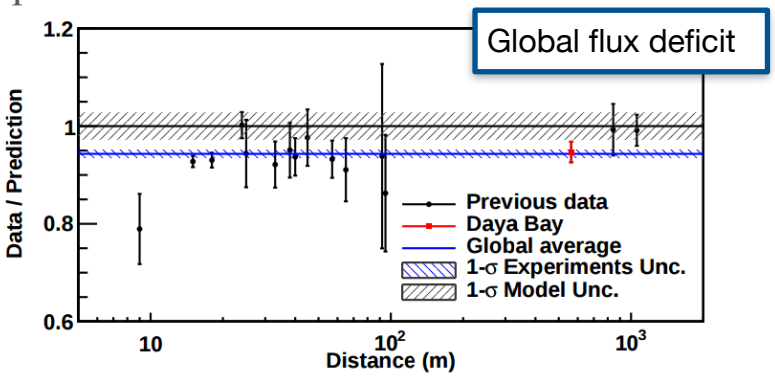
Precision Reactor Oscillation and SPECTrum Experiment

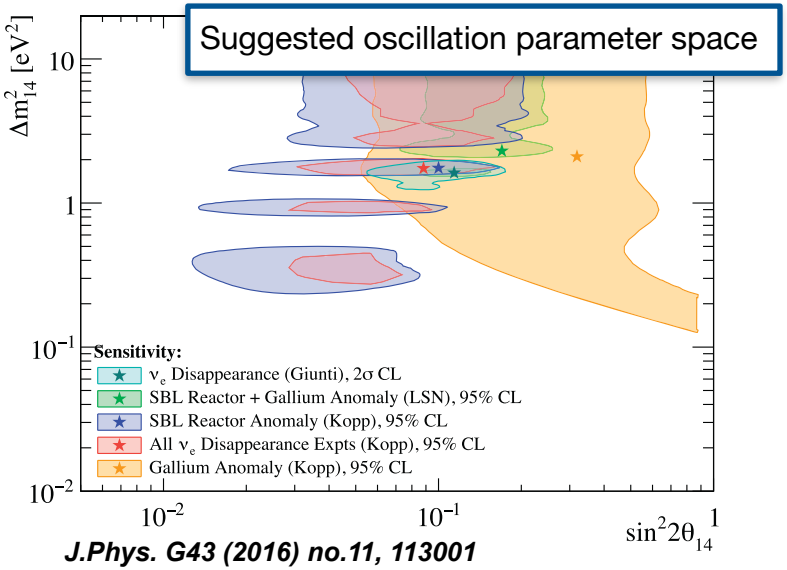
Xianyi Zhang
for the PROSPECT collaboration
ICHEP 07/07/2018

Motivation

- The antineutrino flux measured by reactor experiments showed ~6% deficit from prediction.

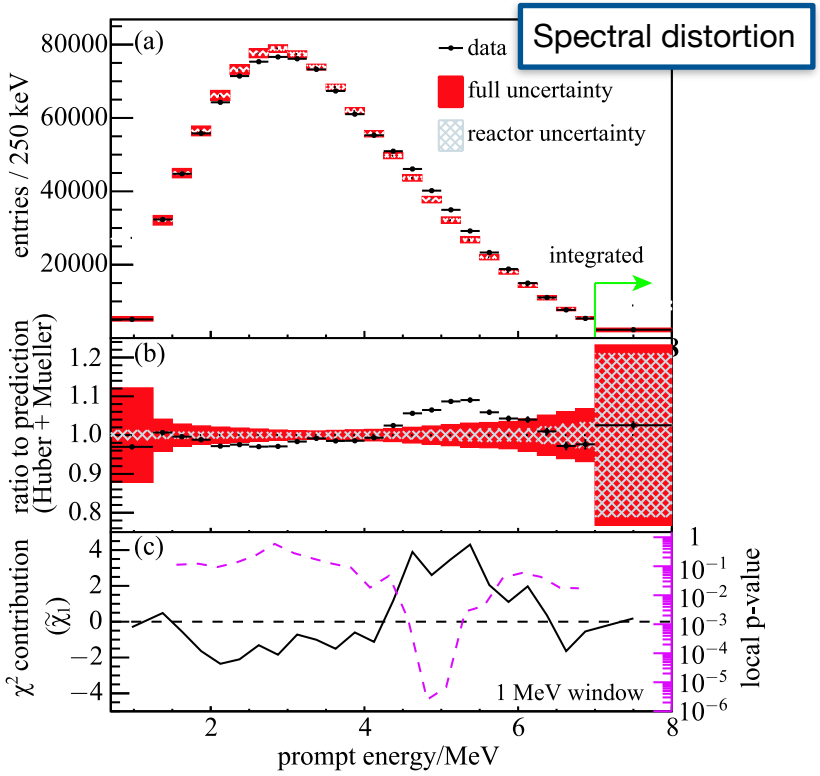


Phys. Rev. Lett. 116, 061801, 2016



J.Phys. G43 (2016) no.11, 113001

- The θ_{13} experiments' antineutrino spectral measurements indicated 8-10% excess at 4-6 MeV Inverse Beta Decay (IBD) positron energy.



Chin.Phys. C41 (2017) no.1, 013002

Experiment Design

A short baseline reactor antineutrino experiment. We aim to:

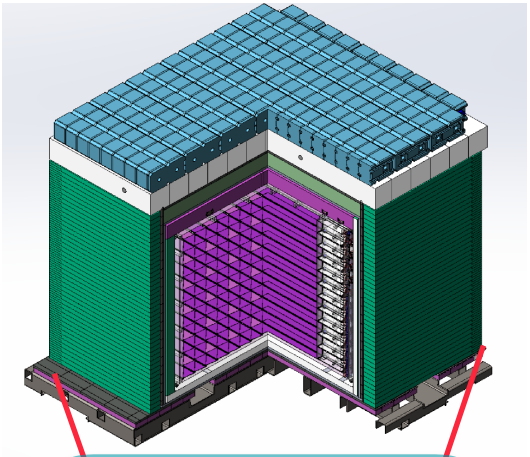
- Measure the spectrum of antineutrino from a Highly Enriched U-235 reactor (HEU).
- Probe the oscillation that involves a light sterile neutrino, model independent.

Reactor:

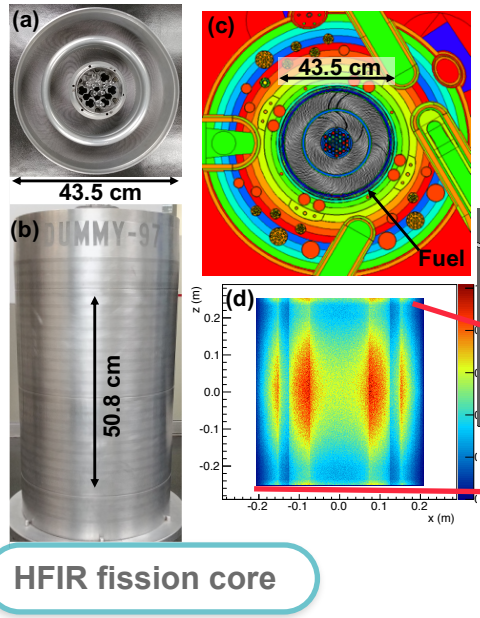
- High Flux Isotope Reactor (HFIR), at ORNL.
- Size: d x h = 43cm x 50cm.
- Power: 85 MW.
- ^{235}U enrichment > 93%.
- Antineutrino from ^{235}U > 99%
- Duty cycle: 41-47%, ~ 24 days.

Detector:

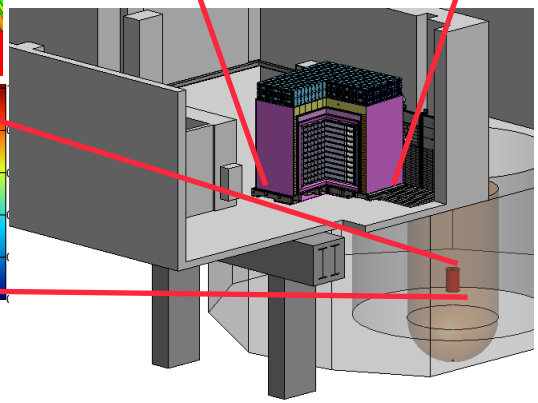
- Optically Segmented.
- ^{6}Li loaded liquid scintillator.
- Mass: ~4 ton



Segmented antineutrino detector



HFIR fission core



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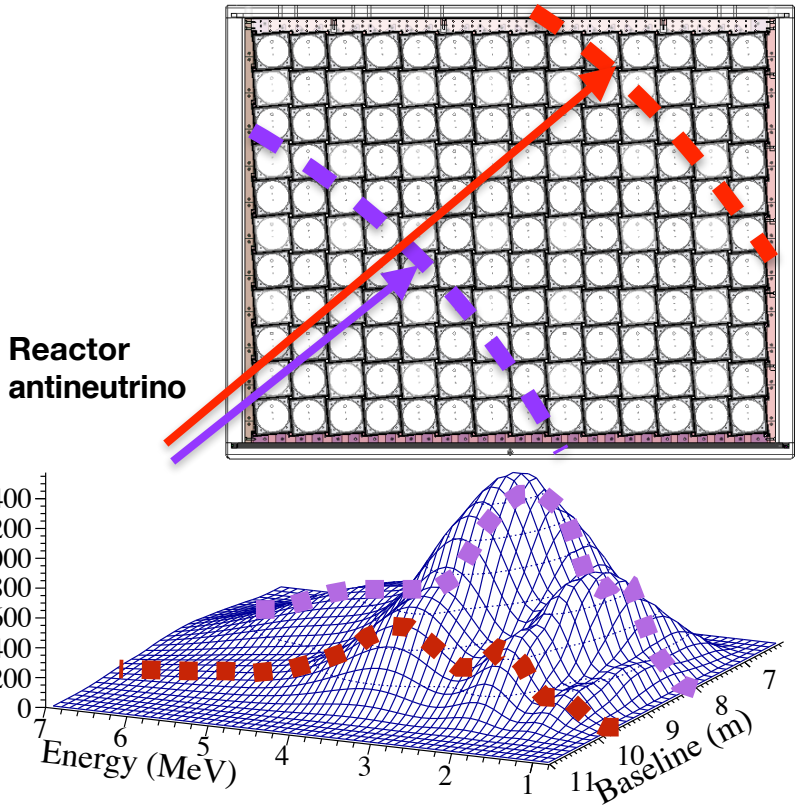
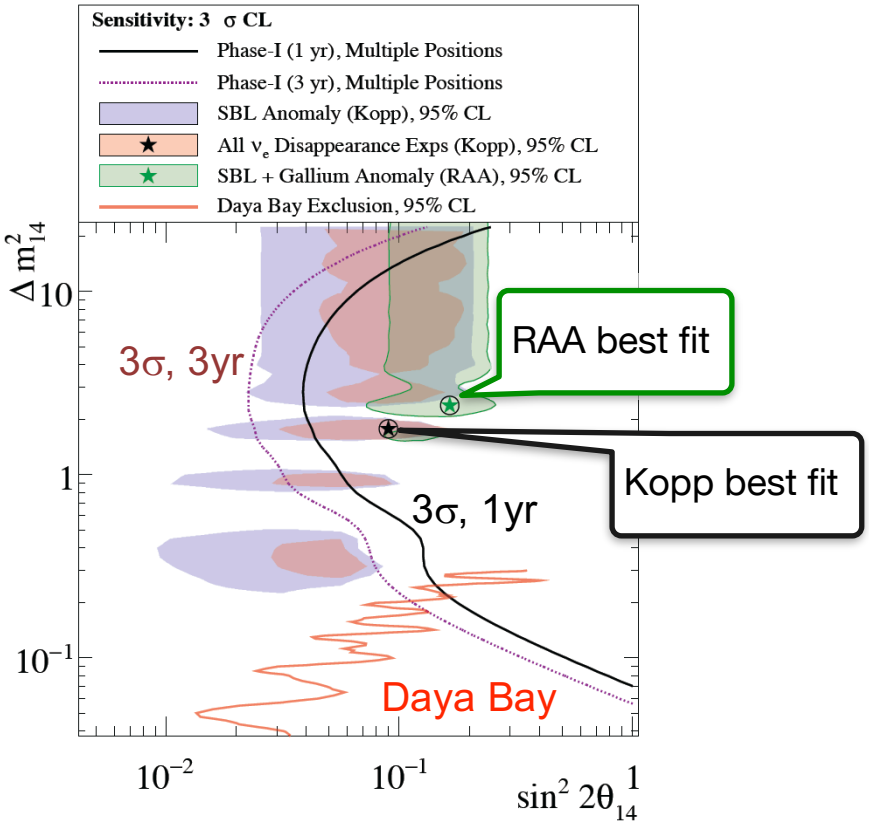
Strategy to Probe Sterile Neutrino Oscillation

- Precisely measure the antineutrino spectrum from ^{235}U dependent on baseline.
- To be reactor model independent, we compare the spectral shape of each baseline to the spectrum measured by full detector.



Example of baseline dependent spectrum



Sensitivity of probing sterile ν oscillation

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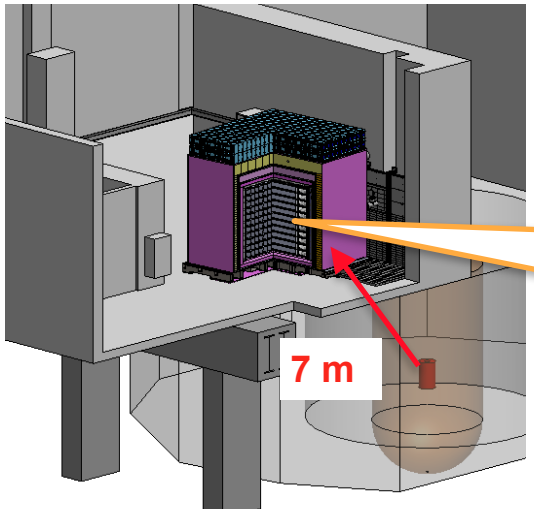
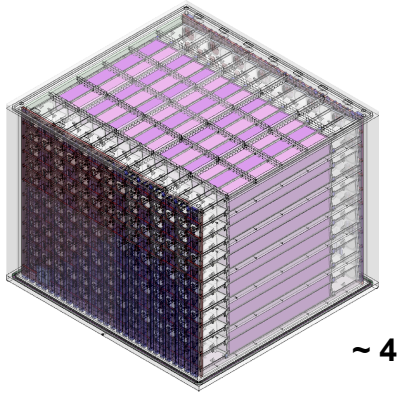
Detector Design



❖ The detector currently covers baseline in **7-9 m**.

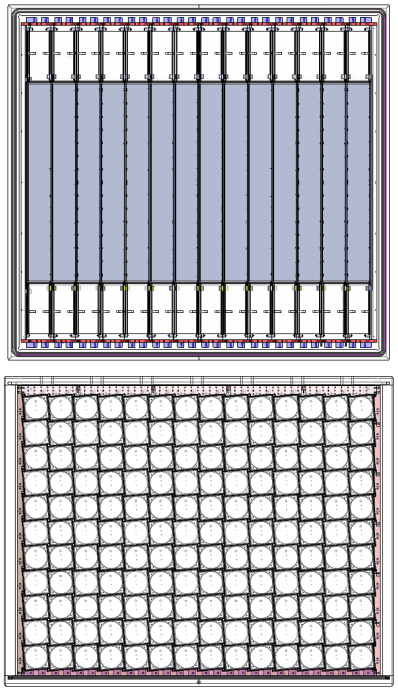
Challenges:
- Minimal overburden.
- High reactor correlated background.



~ 4 tons

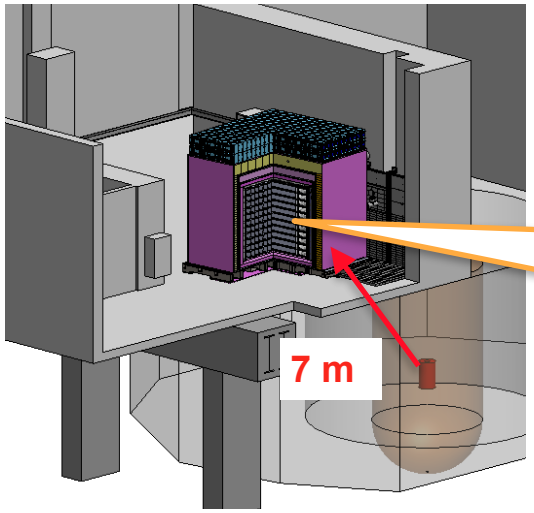
❖ Optically segmented antineutrino detector (AD) filled with **4 ton** of **^{6}Li doped EJ-309**.

❖ The **14x11** elongated elemental ADs (cells) separated by low-mass reflector panels.



14x11 Segments

Detector Design



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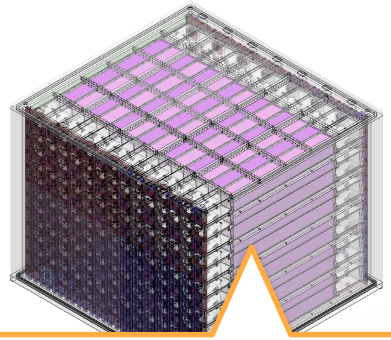
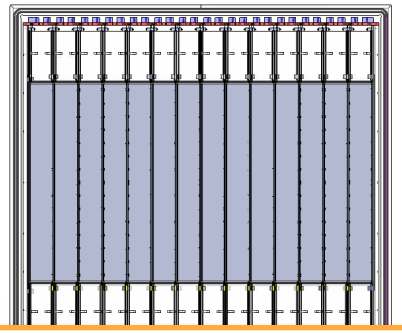
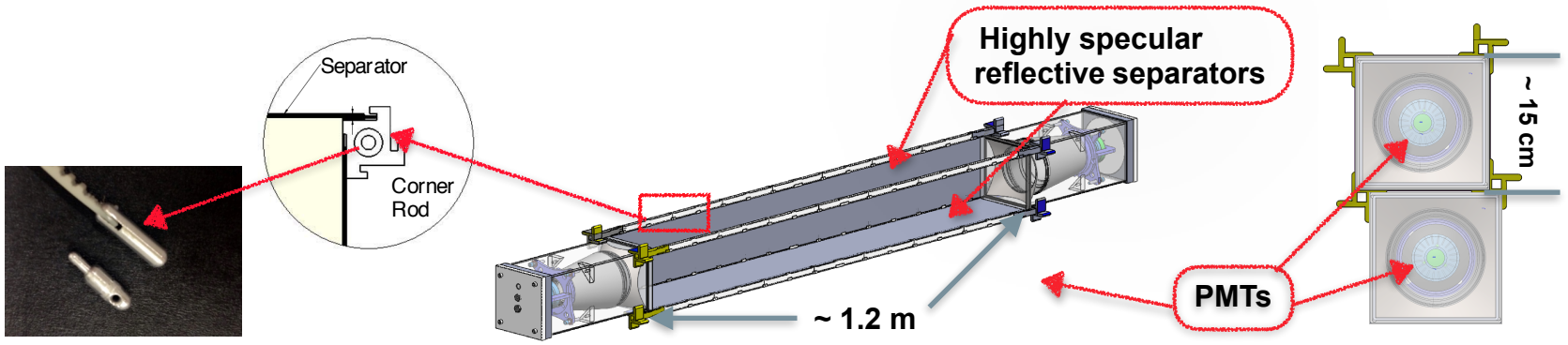
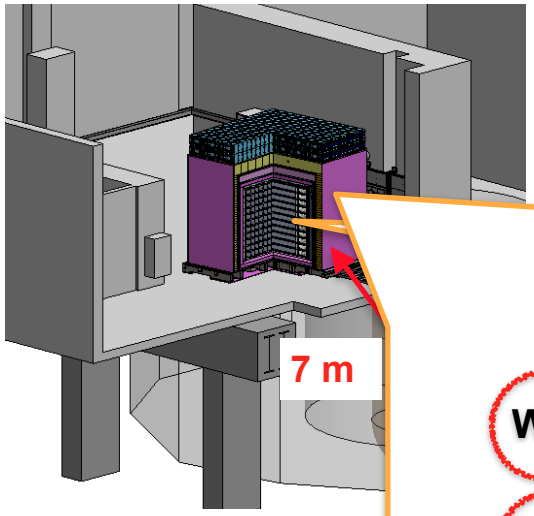




- Motor driven calibration sources through 3-D printed rods.
- Scintillation light is collected by 5” photo multiplier tubes (PMTs) at the ends of each cell.



Detector Design



Challenges:
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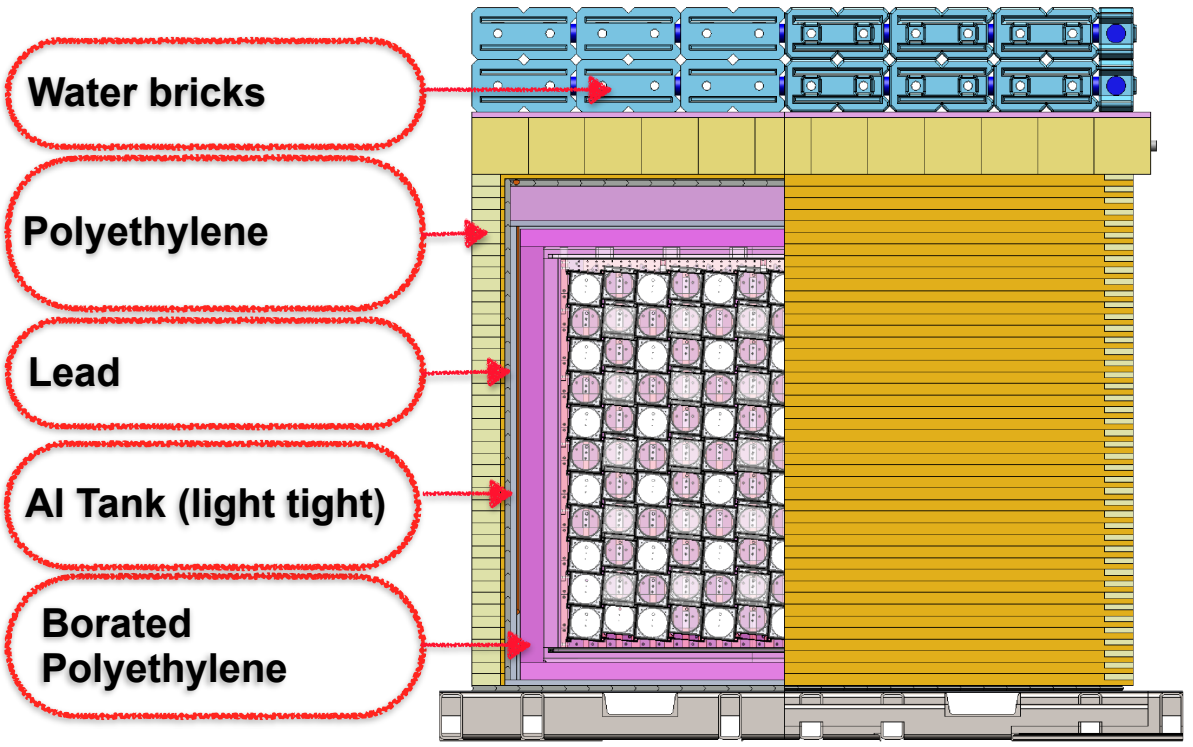
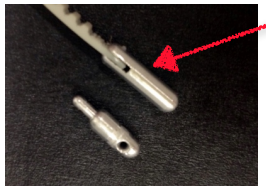
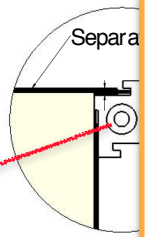
- High reactor correlated background.

Shielding

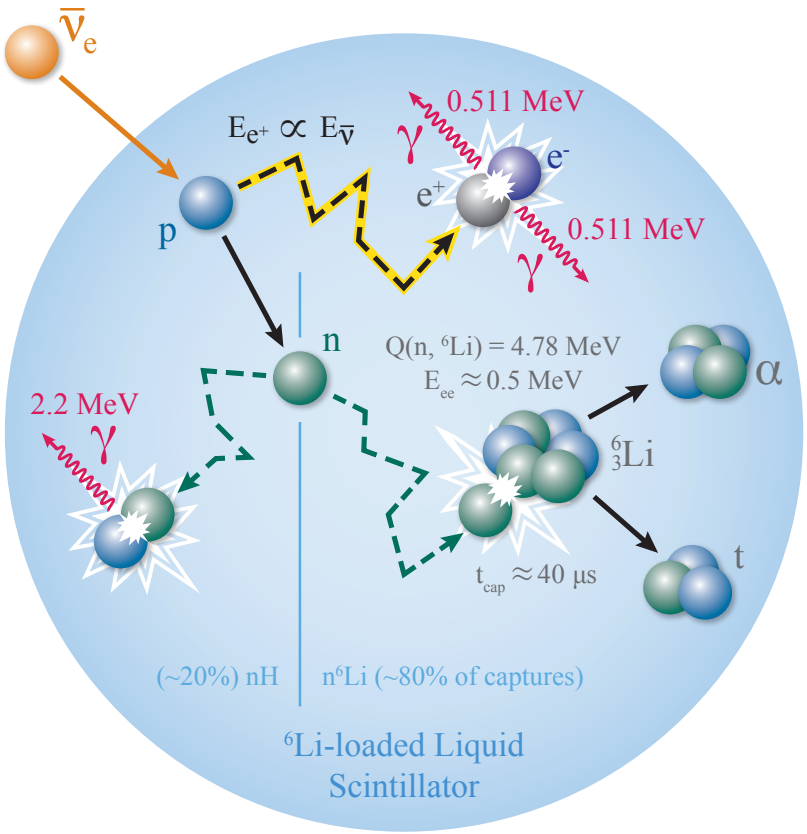


- Calibration sources m
- Scintillation light is c





Measurement Strategy

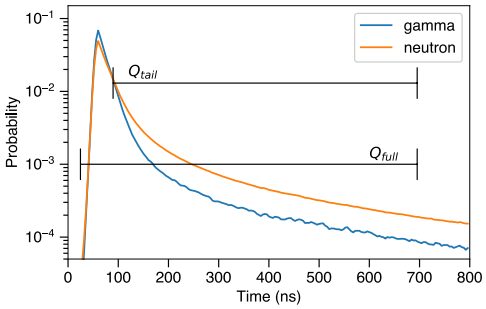


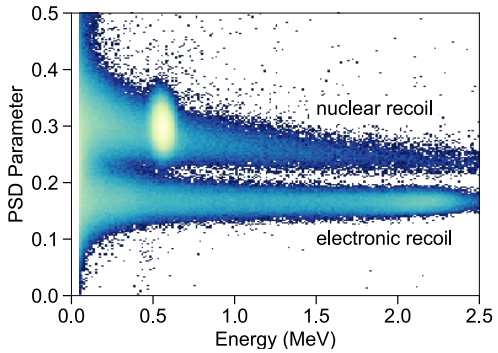
~40µs delayed

IBD Detection on LiLS

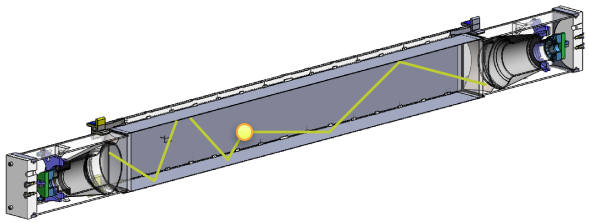
- Detect (IBD) process of antineutrinos.
- The **β⁺** event (prompt event) and ***n*-capture** event (~40µs delayed event) of LiLS generated scintillation light.
- The Pulse Shape Discrimination (PSD) of scintillator distinguishes the **β⁺-like** event and ***n*-like** events.

$$PSD = \frac{Q_{tail}}{Q_{total}}$$



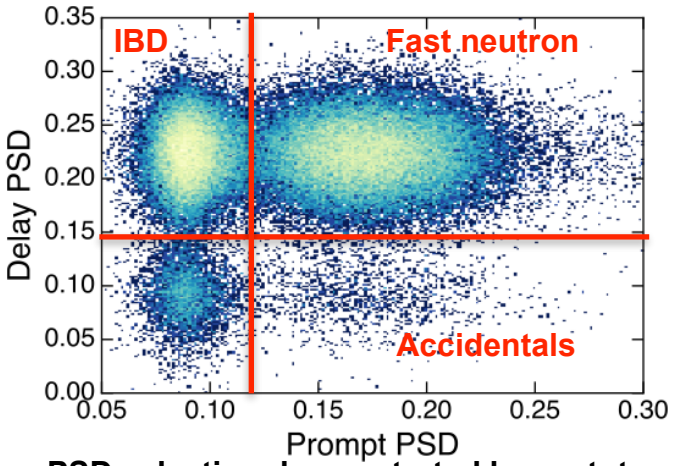


PROSPECT, 2018 JINST 13 P06023

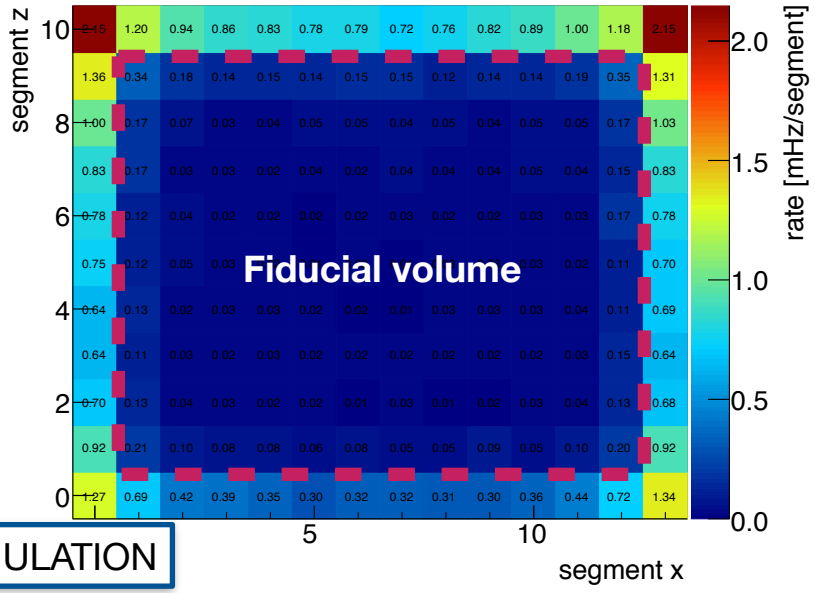


The scintillation light is constrained in each cell and collected by the PMTs, enabling event position reconstruction by timing and signal difference.

IBD Selection



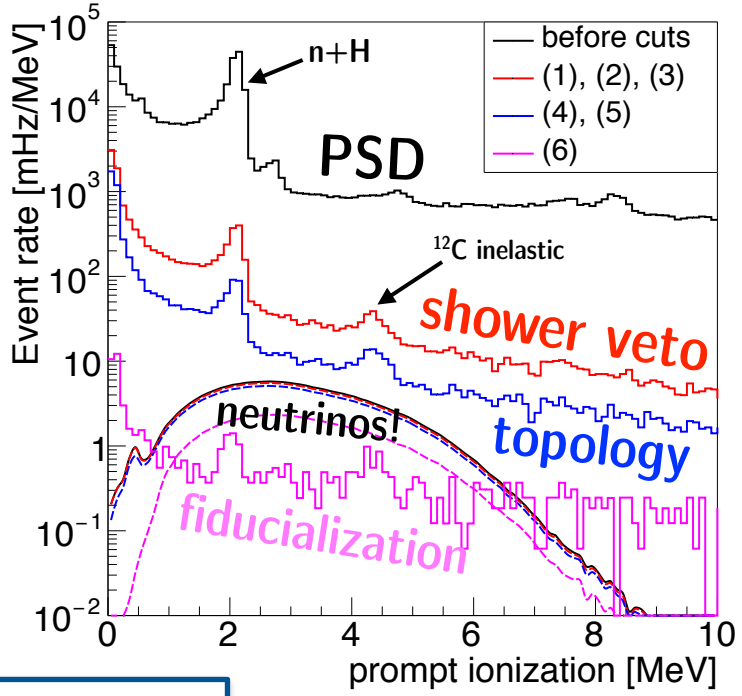
PSD selection demonstrated by prototype



SIMULATION

Simulated accidental rate in each cell

- IBD events are selected based on the PSD, timing coincidence, topology and position.
- Actively suppressed more than 10^4 background events.



SIMULATION

Simulated signal compared with background,
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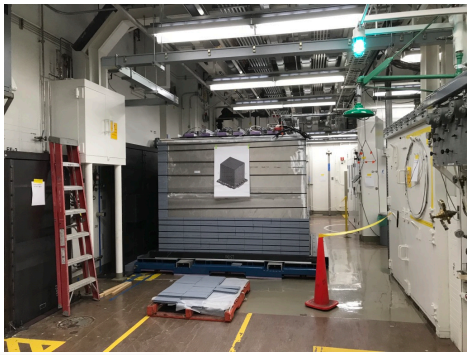
Assembly and Installation



2017

10/30/2017 - 11/17/2017
Detector assembly at Yale.

11/20/2017 - 12/16/2017
Load detector in acrylic and Al tanks. Internal shielding.

12/16/2017 - 01/14/2017
Initial dry commissioning

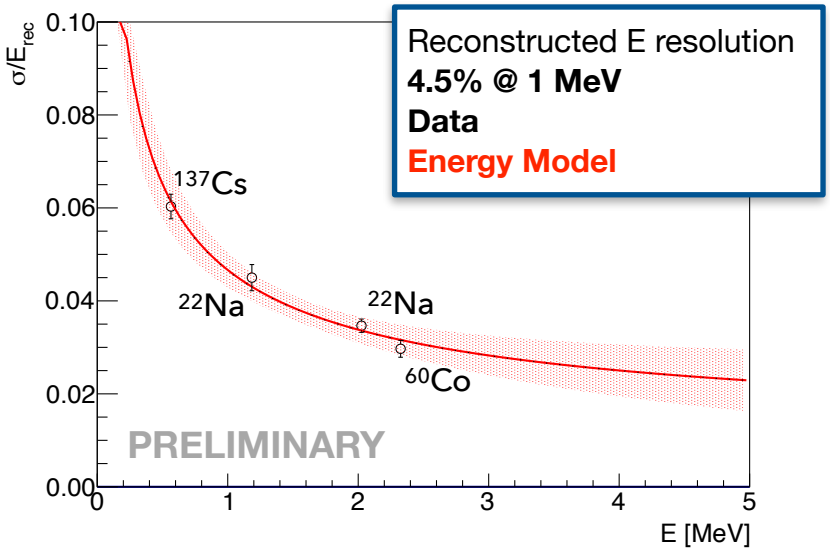
01/31/2018 - 02/24/18
Detector shipped to ORNL.
LiLS filling.

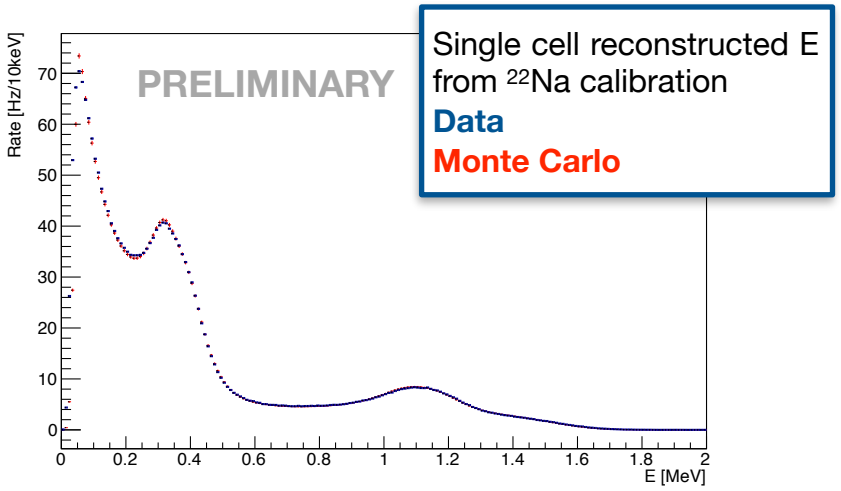
03/05/2018
Started commissioning.
5σ ν observation in 2 hrs.

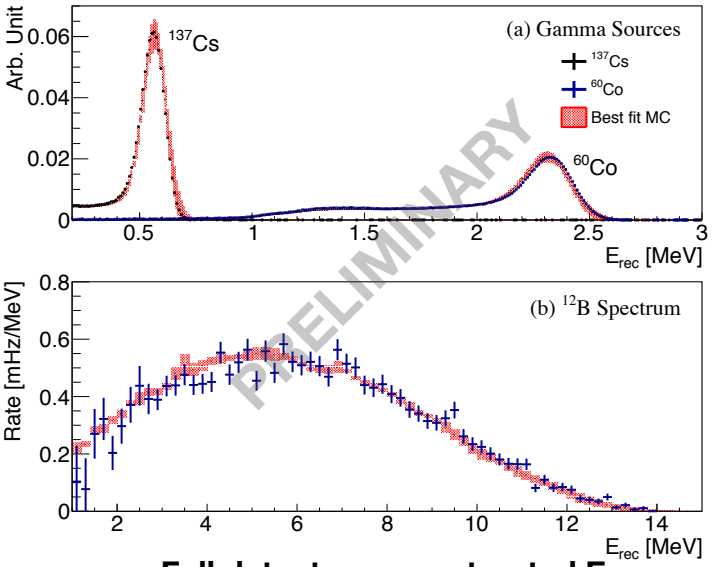
2018

Energy Reconstruction

- We utilized gamma sources to study single cell and full detector energy response.
- The cosmogenic neutron induced ^{12}B beta events used to characterize β energy reconstruction.
- Light collection: 795±15 PE/MeV.





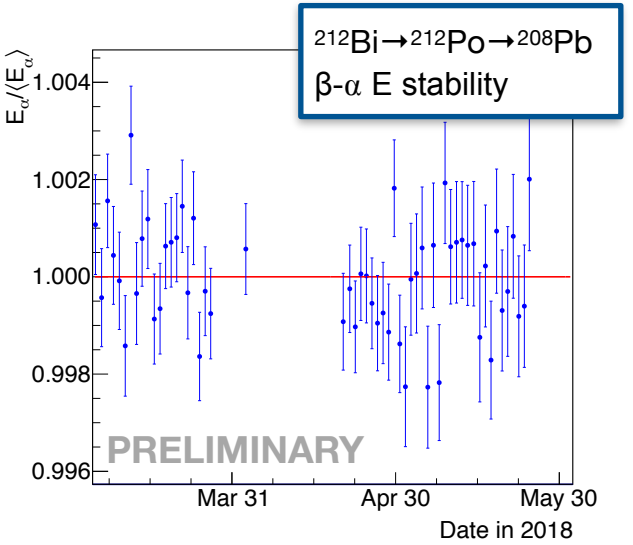


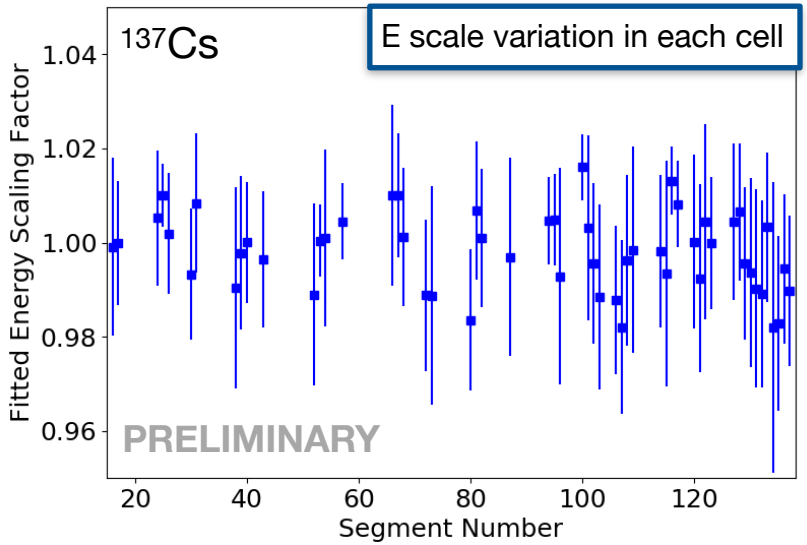
Full detector reconstructed E

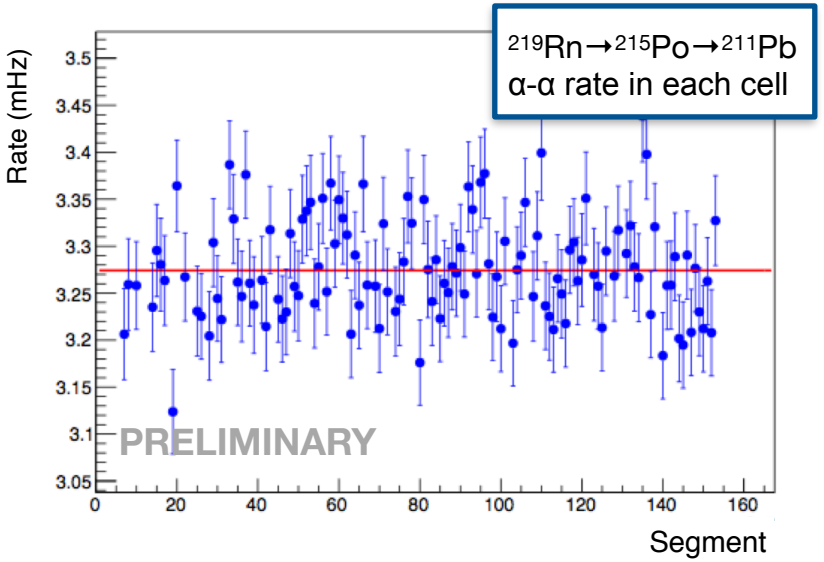
arXiv:1806.02784

Detector Stability and Uniformity

- The BiPo β-α coincident event showed reconstructed E variation over time ~1%.
- The 137Cs source was deployed through out the detector to characterize the relative E scale uniformity ~1%
- The 227Ac dissolved in LiLS allowed us to measure the relative target mass difference with its α-α rate in each cell.





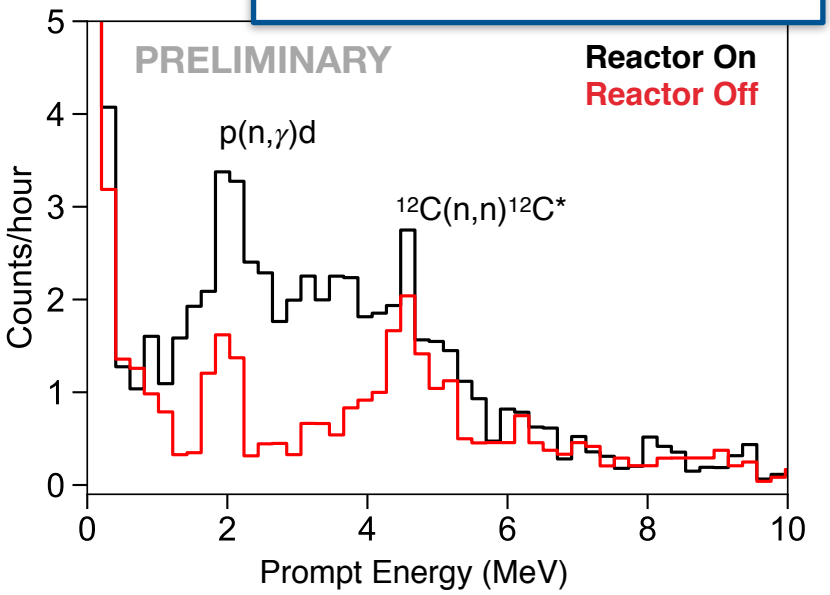


Antineutrino Observation

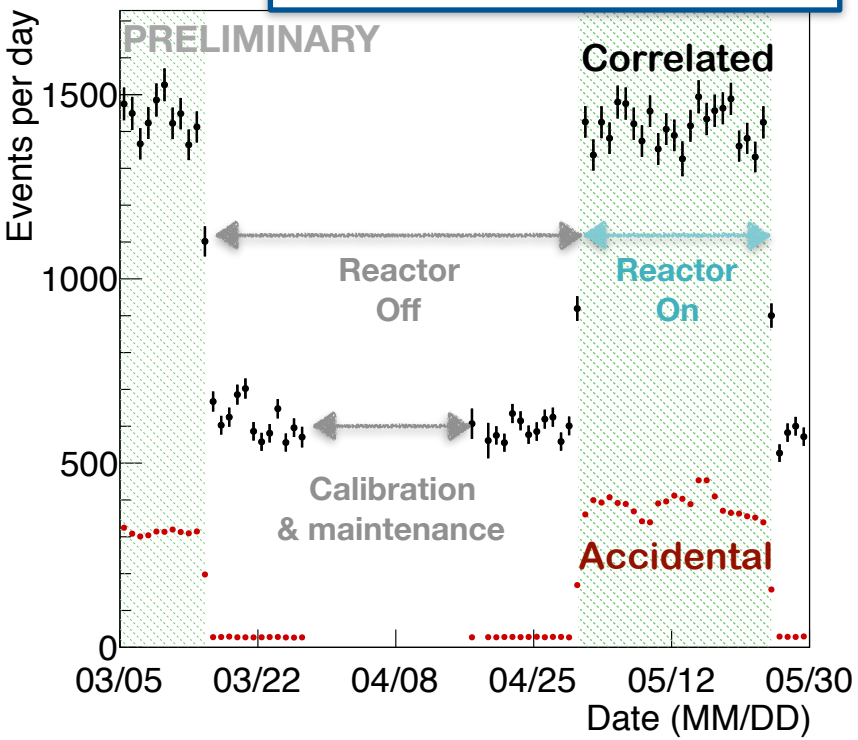
- We collected 1254±30 (614±20) correlated events during the first reactor on (off) day in energy range 0.8 - 7.2 MeV.
- The data released so far contains: **33 reactor on** days and **28 reactor off** days.
- The IBD selection was frozen based on 3 days of reactor on data.

Correlated S/B = 1.36
Accidental S/B = 2.25
Total IBD detected: **24,608**, ~750/day.

First 24 hrs of correlated events

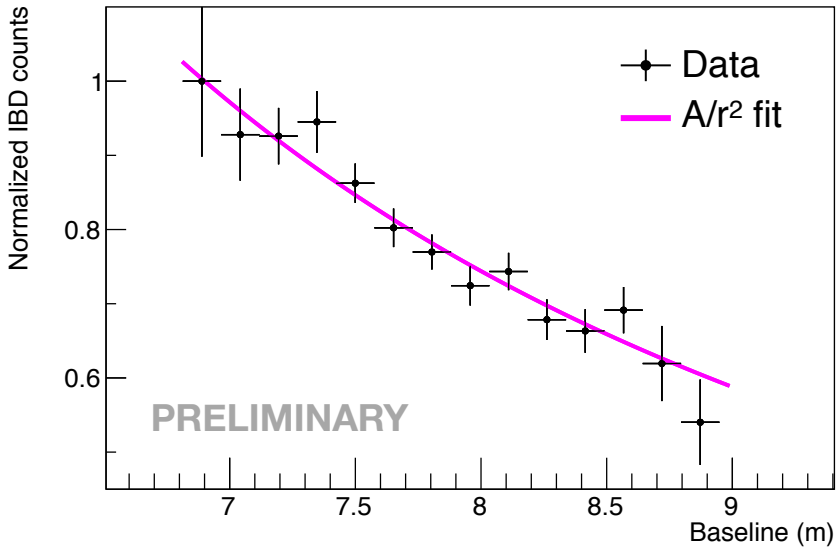


First 24 hrs of correlated events

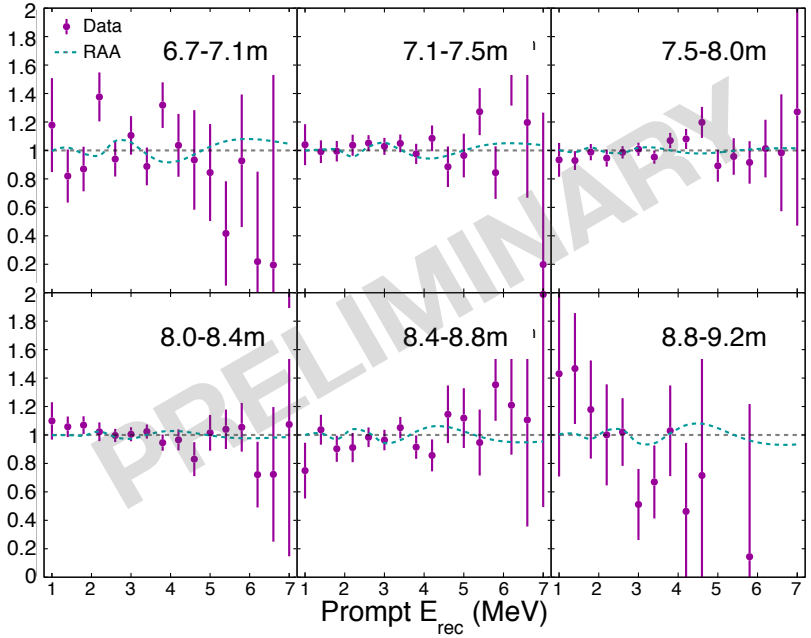


Rate and Spectrum vs Baseline

- The $1/r^2$ event rate decrease was observed in the 12x9 cell fiducial volume of detector.
- The fiducialized detector cells were zoned into 6 baseline bins to perform spectral comparison.
- To be model independent, the spectrum of each baseline was compared against to the normalized spectrum measured by full detector.



$1/r^2$ behavior of IBD event rate. ***arXiv:1806.02784***

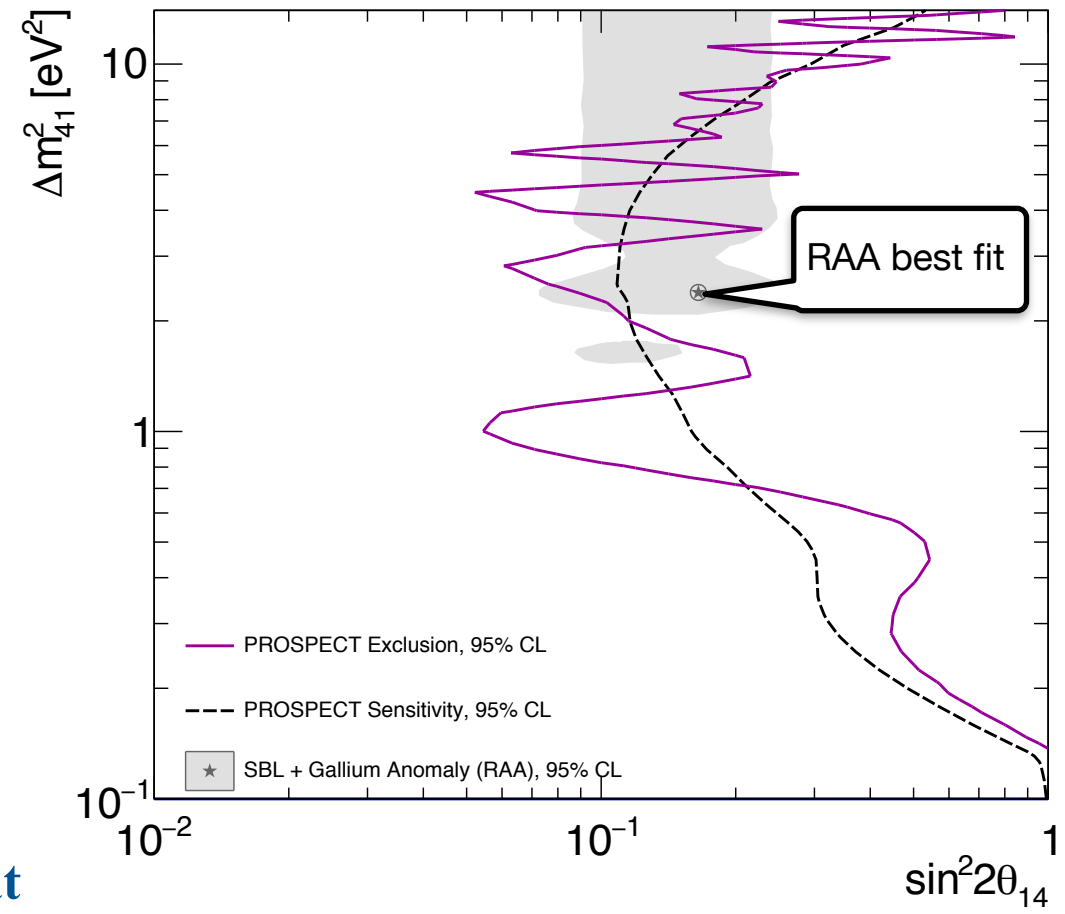


The spectral comparison with RAA and Null oscillation reference. ***arXiv:1806.02784***

Search for Sterile Neutrino Oscillation

- Feldman-Cousins based confidence intervals for oscillation search
- Covariance matrices captures both systematic and statistic uncertainties and energy/baseline correlations
- Critical χ^2 map generated from toy MC using full covariance matrix
- 95% exclusion curve based on 33 days Reactor On operation
- Direct test of the Reactor Antineutrino Anomaly.

Disfavors RAA best-fit point at >95% CL (2.3σ)



Exclusion and sensitivity of PROSPECT with current data *PROSPECT, arXiv:1806.02784*

Conclusion and Outlook

- PROSPECT started taking data on March 6, 2018
- Detector performing well. Background rejection and energy resolution meet expectation and MC.
- Observed antineutrinos from HFIR with good signal/background.
- Observation of reactor antineutrinos can be achieved in PROSPECT at 5 statistical significance within two hours of on-surface reactor-on data-taking.
- **Observed an energy spectrum of antineutrinos at the Earth's surface (1mwe overburden) with 24 hours of data**
- **Working towards a high-statistics ^{235}U spectrum measurement**
- Opportunity for detailed understanding of cosmogenic backgrounds
- **First oscillation analysis on 33 days of reactor-on data disfavors the RAA best-fit at 2.3σ (arXiv: 1806.02784)**

Thank you!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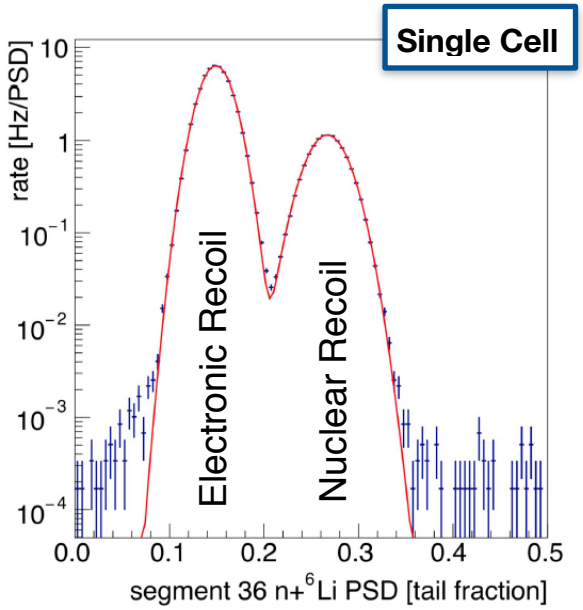
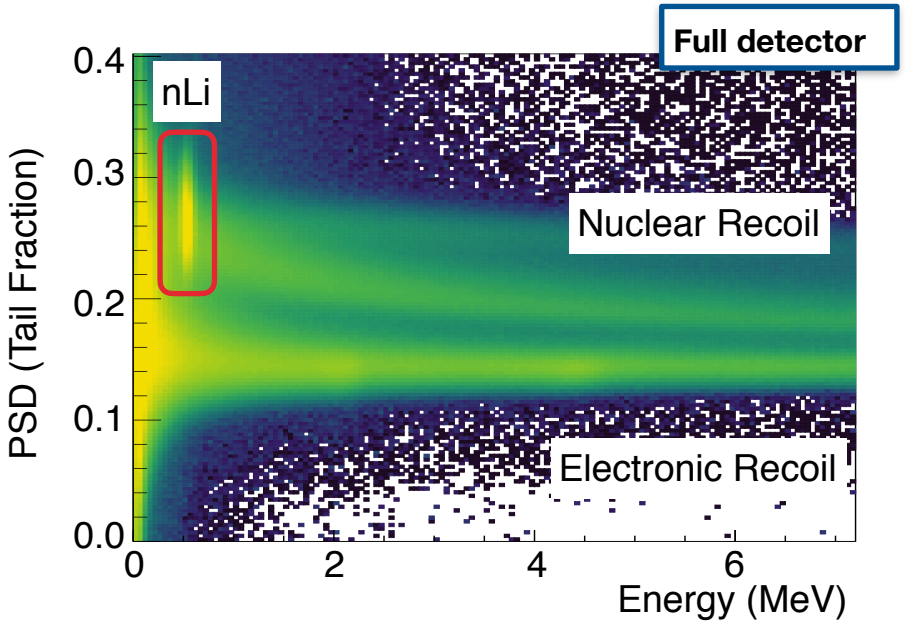
OAK RIDGE National Laboratory
Drexel UNIVERSITY
ILLINOIS INSTITUTE OF TECHNOLOGY
WISCONSIN
Yale
W&M

Backup Slides

Backup - PSD Performance





- Excellent particle ID of gamma interactions, neutron captures, and nuclear recoils
- Dominant backgrounds: Cosmogenic fast neutrons, reactor-related gamma rays, reactor thermal neutrons. (Vast majority identified and rejected by PSD for Prompt and Delayed signals)