New Results from PROSPECT

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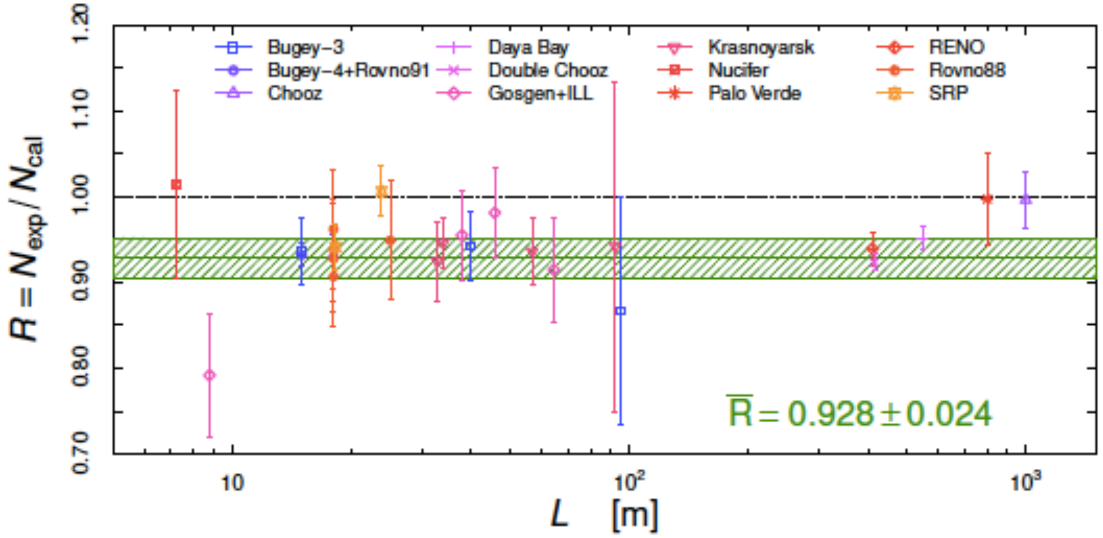
on behalf of the PROSPECT collaboration

57th Rencontres de Moriond, EW 2023

PROSPECT - Precision Oscillation and Spectrum Experiment

Model Independent search for short-baseline oscillation at distances <12m.

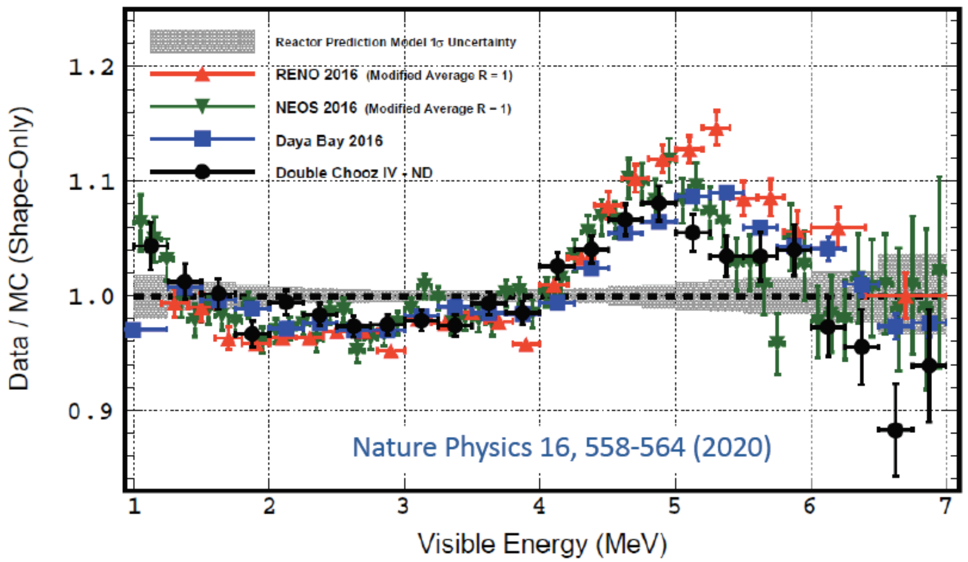
- Suggested by the Reactor Antineutrino Anomaly (RAA) and Gallium, MiniBooNE anomalies.



Phys. Rev. D 030001 (2018)

Precision measurement of the ^{235}U reactor antineutrino spectrum.

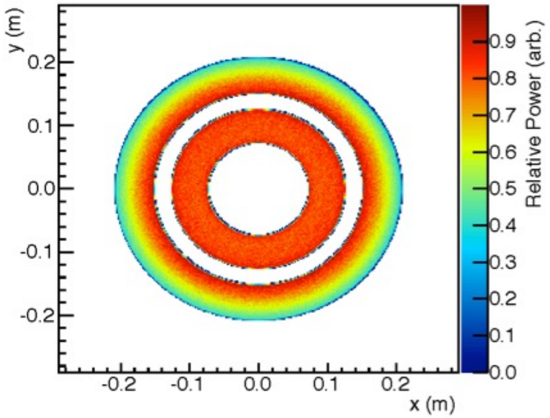
- Investigate the Reactor Spectrum Anomaly ~5-7 MeV neutrino energy (4-6 MeV visible energy).



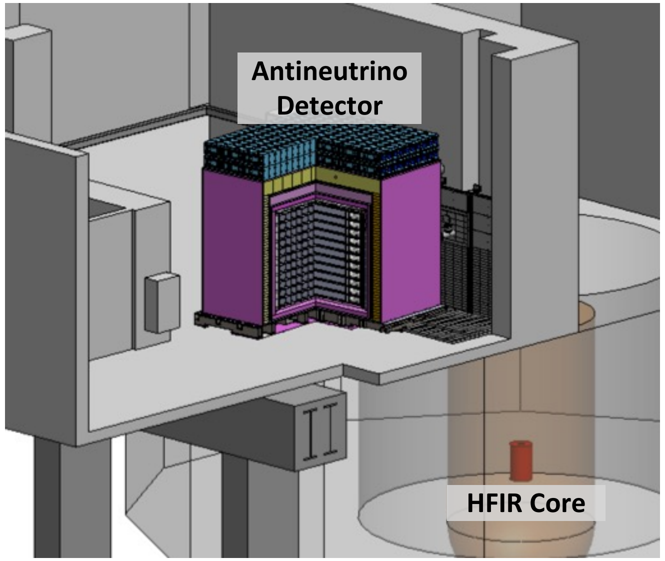
Neutrino Source: HFIR, Oak Ridge, Tennessee

Compact Reactor Core

Power: 85 MW
Fuel: HEU (^{235}U)
Core shape: cylindrical
Size: h=0.5m r=0.2m
Duty-cycle: 41%

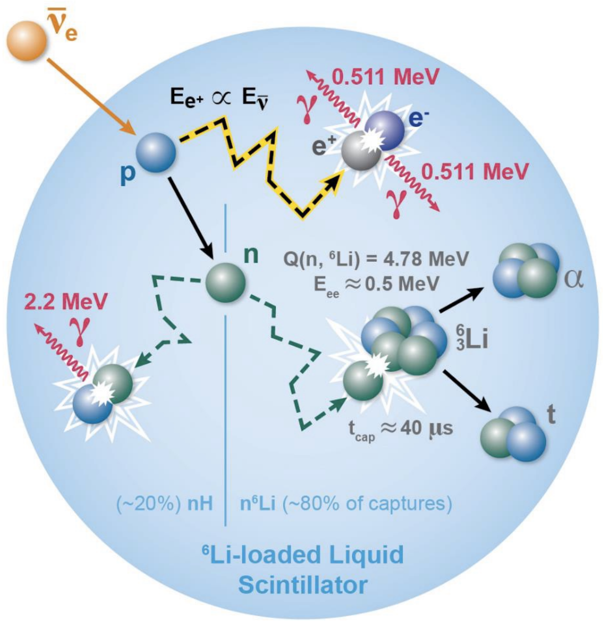


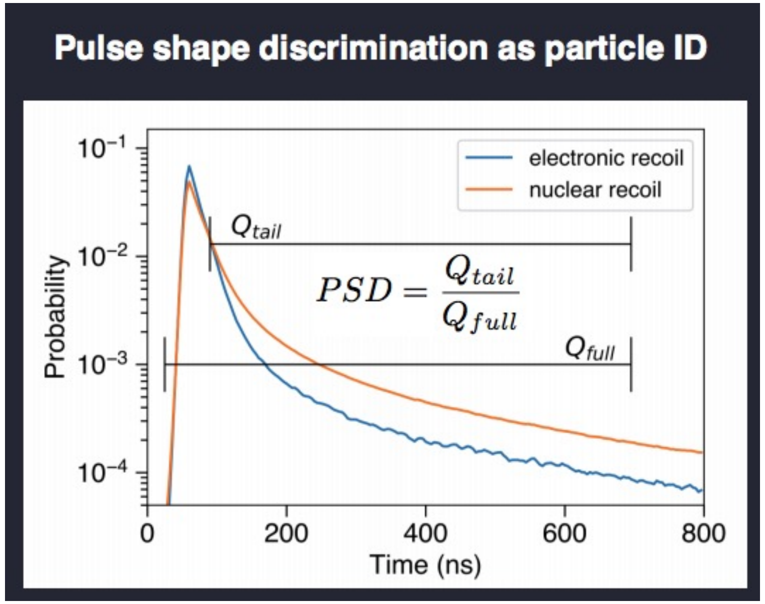
Optically Segmented Detector

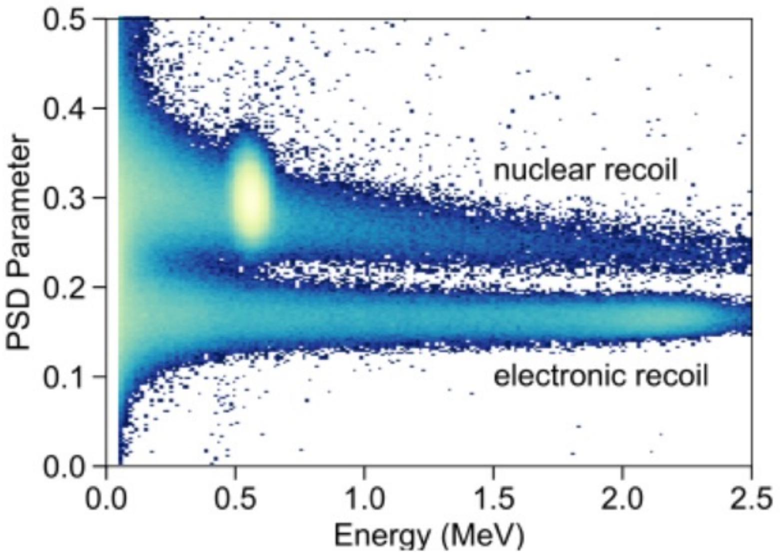


Neutrino Detection: IBD and PSD

- Inverse Beta Decay (IBD) provides distinctive neutrino signature of prompt positron and delayed neutron captures signal.
- Most neutrons (~75%) are captured on **^{6}Li doped** into the liquid scintillator detector, giving high pulse shape discrimination (PSD) delayed signal.

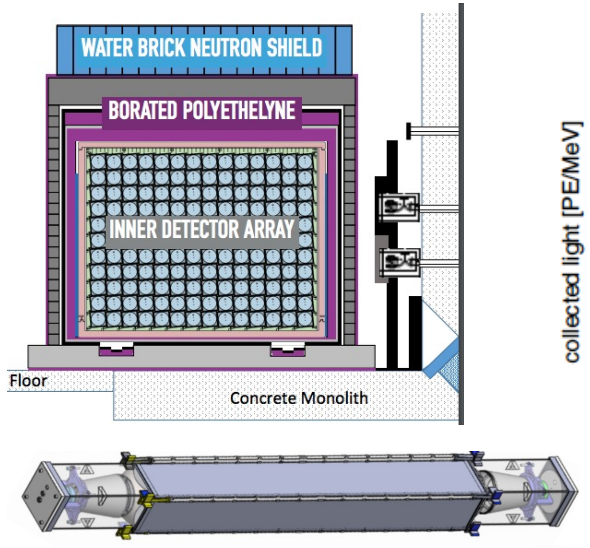


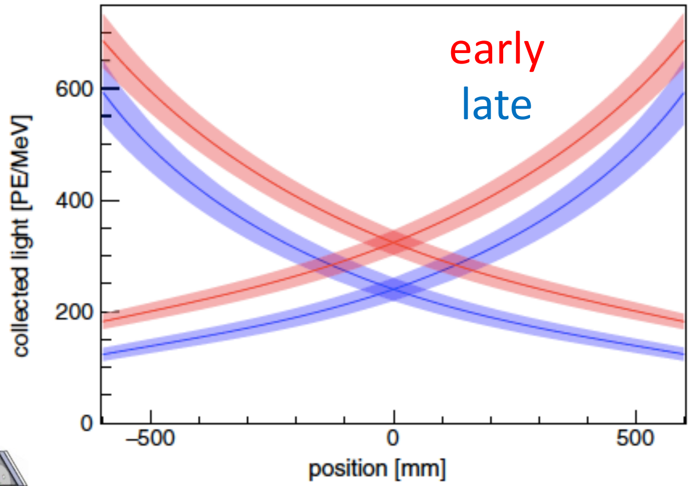




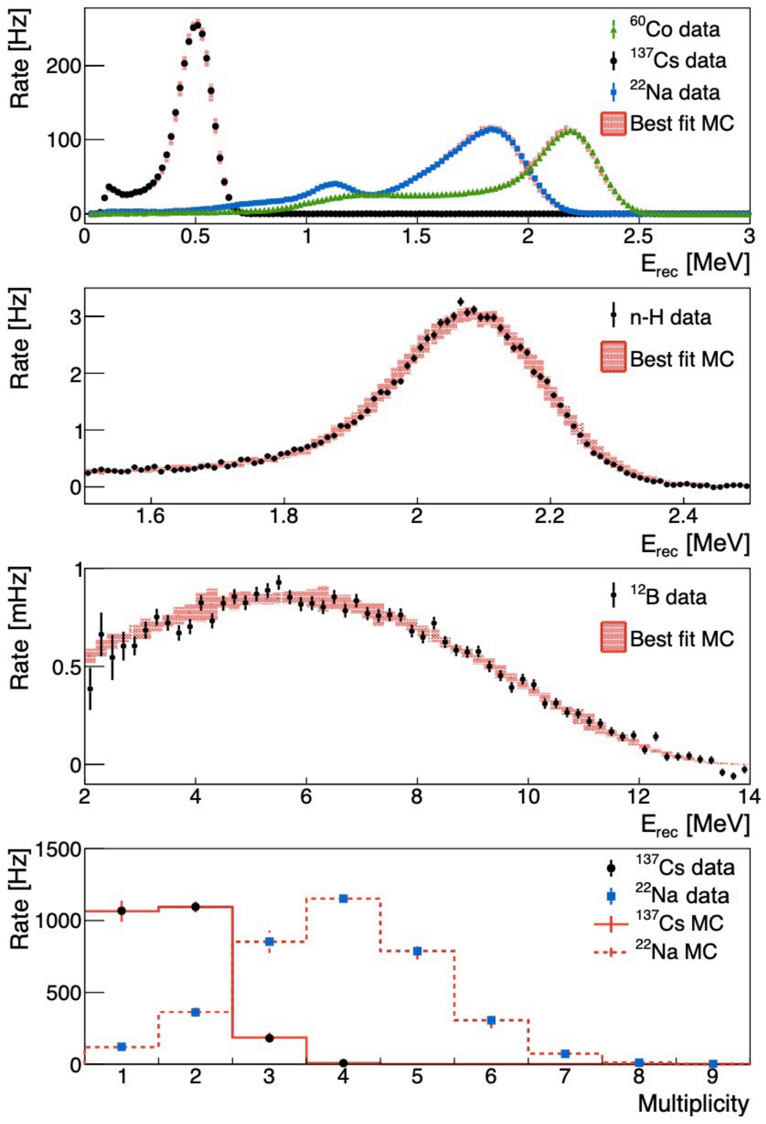
Event Reconstruction

- Detector segmentation provides 2D position reconstruction and event topology.
- Position along segment (Z) provided by relative time and amplitude of PMT signals.





- Energy response calibrated with internal gamma and neutron sources, and cosmogenic ^{12}B beta decay.



Background Rejection and Subtraction

Neutron capture PID
- *^{6}Li loading + PSD*

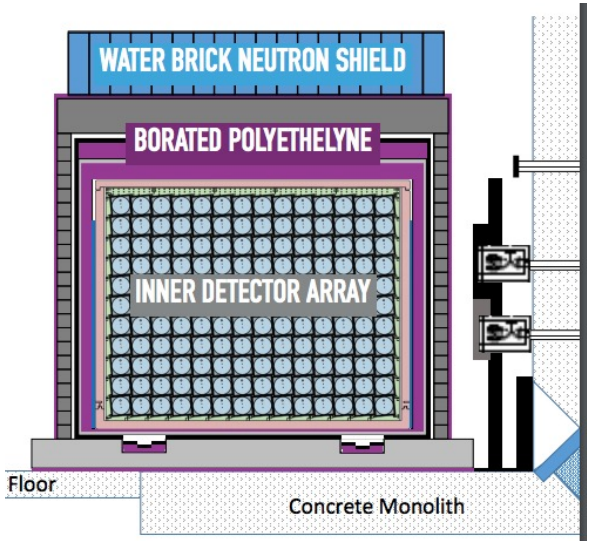
Prompt (positron) PID
- *PSD*

Shower event veto
- *Energy Reconstruction*

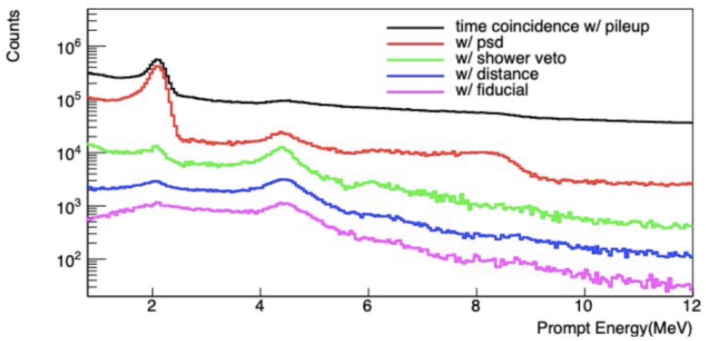
Prompt-delay distance
- *Position Reconstruction*

Fiducialization
- *Active Shielding*

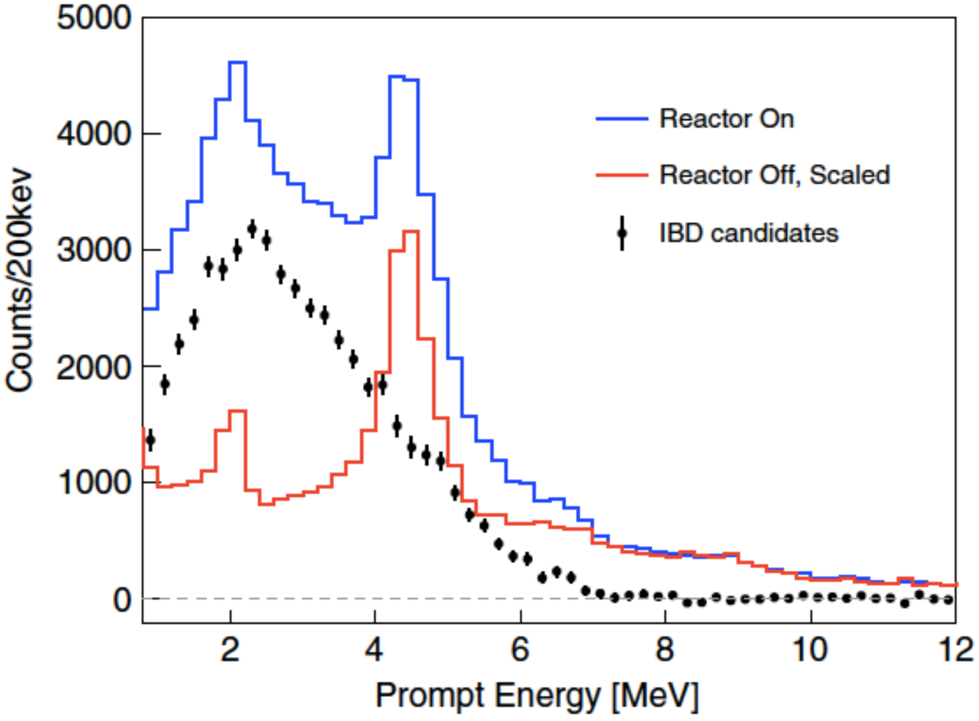
Passive shielding
- *Water, poly etc.*



Prompt Energy Distributions Under Different Cuts

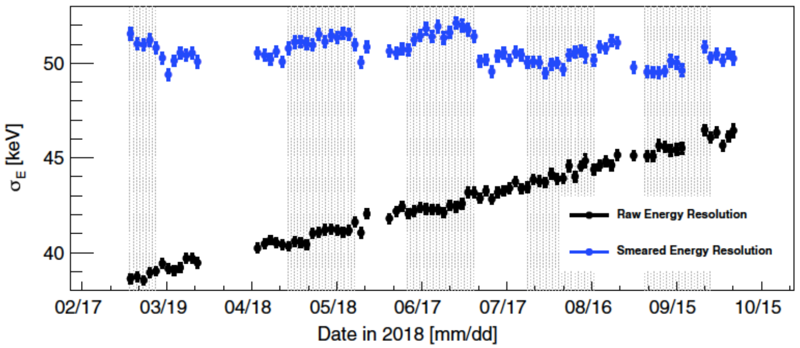


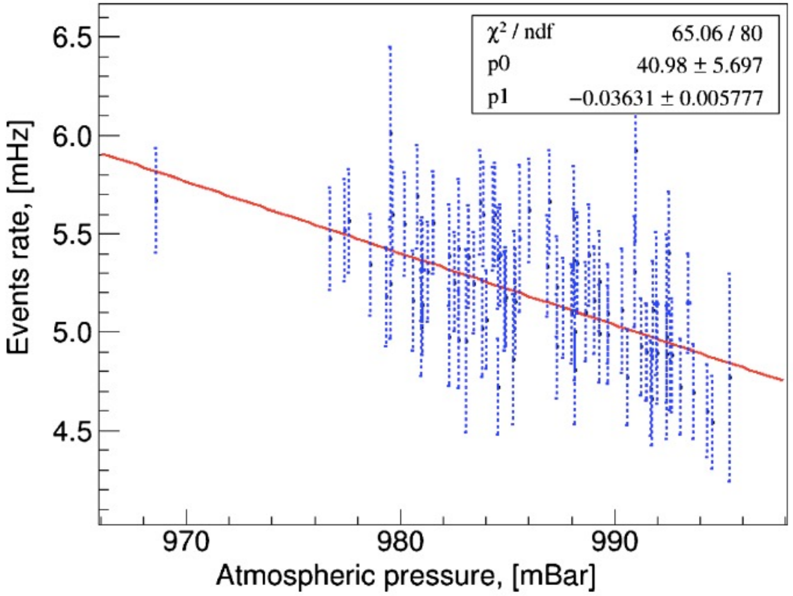
Cosmogenic backgrounds subtracted with reactor-off data.

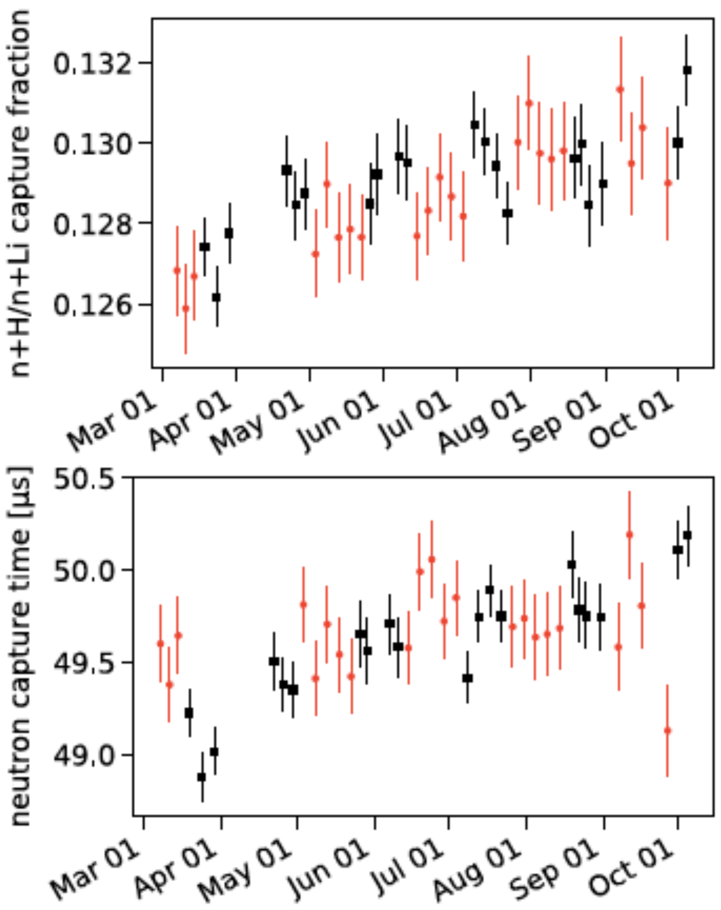


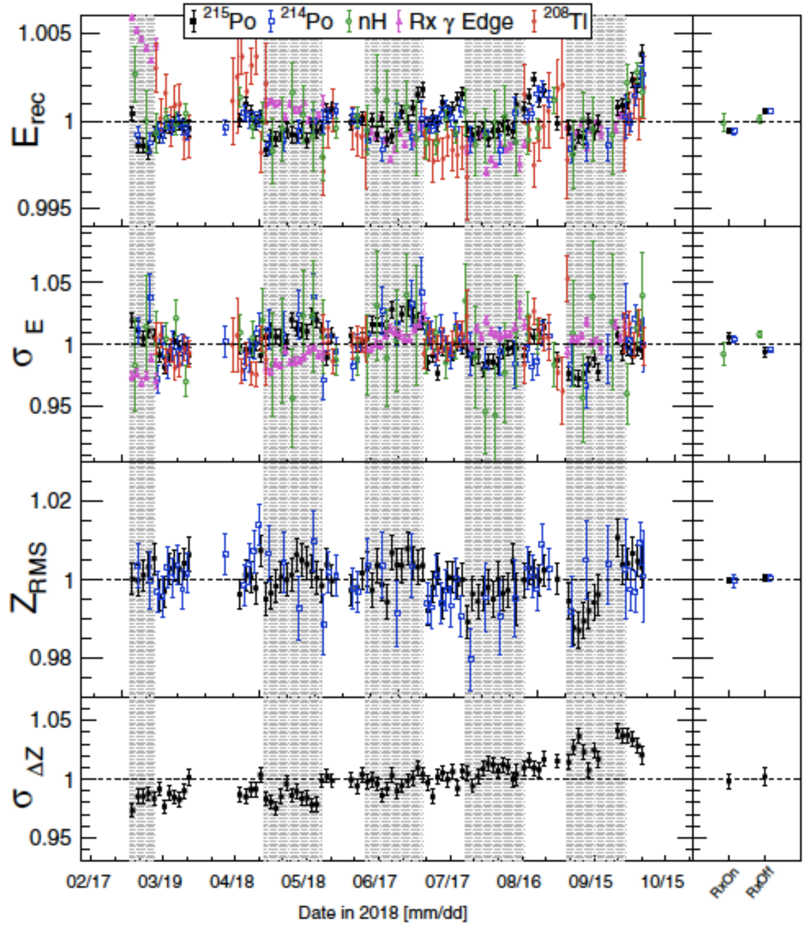
Detector Stability

Resolution vs time



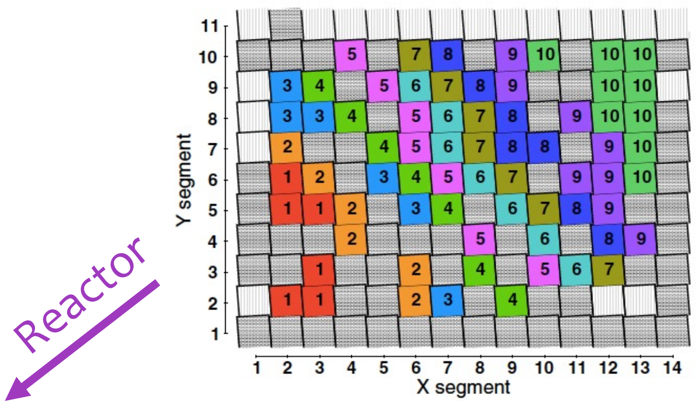






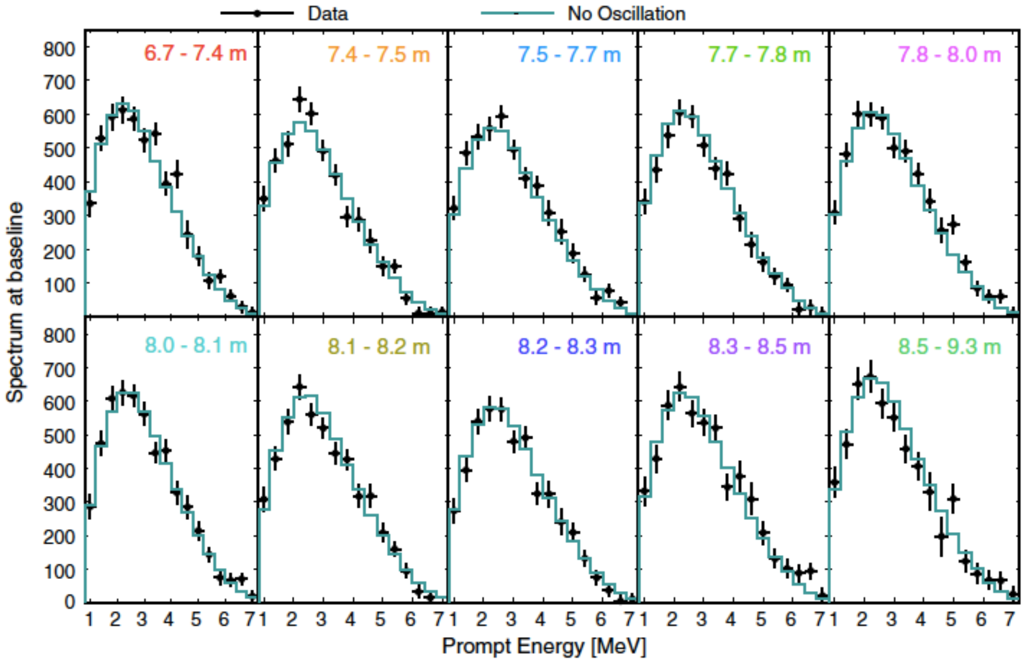
PRD 103, 032001 (2021)

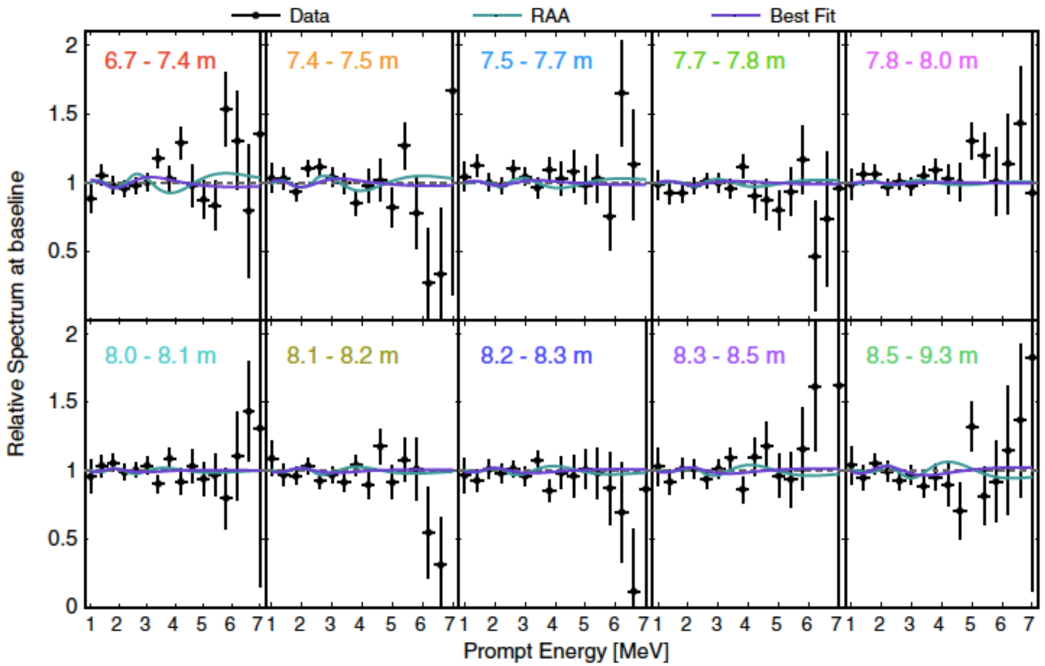
Oscillation Search Strategy: Spectrum vs Baseline



Independent of predictions of the neutrino flux and spectrum.

PRD 103, 032001 (2021)

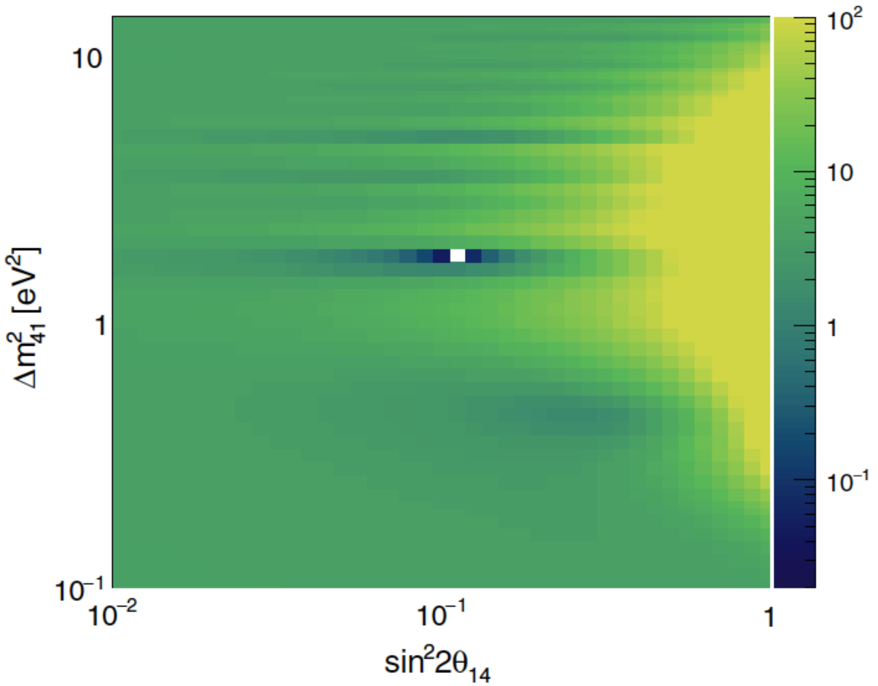




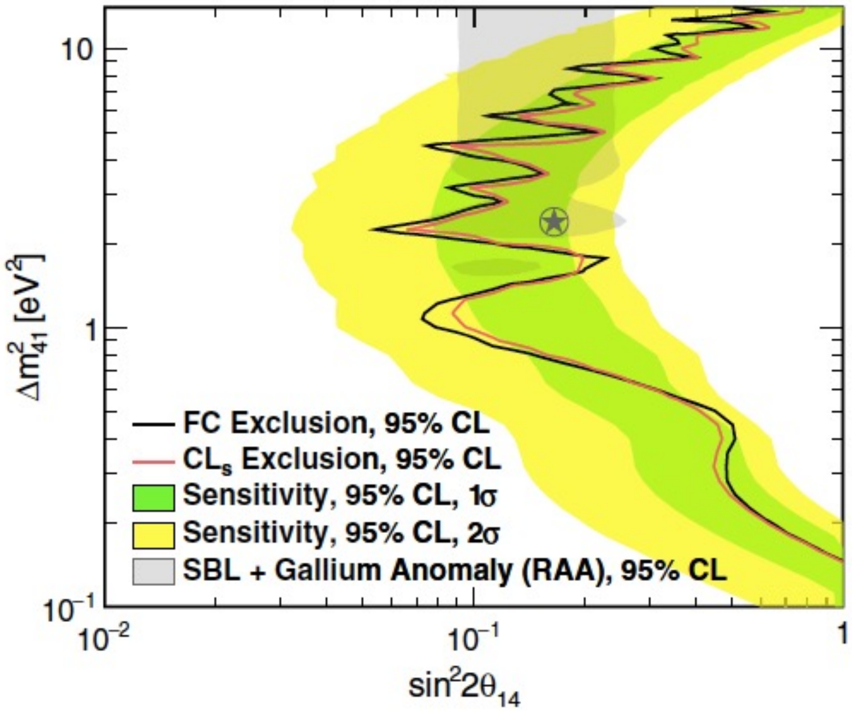
Oscillation Fit Results

- Build $\chi 2$ comparing data to oscillated prediction.
- Covariance matrices capture all uncertainties included correlations.

Δχ2 map

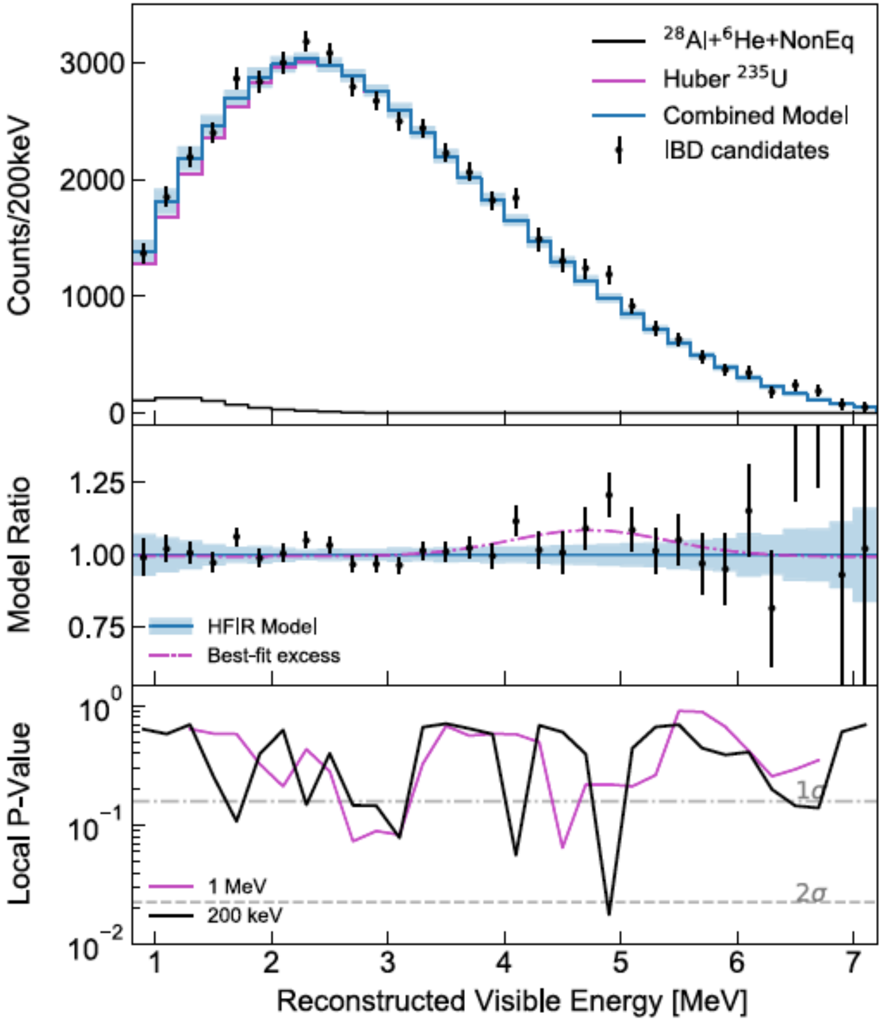


PRD 103, 032001 (2021)



- Use both Feldman Cousins (frequentist) method and Gaussian CL_s to convert $\Delta\chi 2$ values to statistically valid excluded regions of oscillation phase space.
- RAA best-fit excluded: 98.5% CL
- Data is compatible with null oscillation hypothesis (p=0.57)

Previous Spectrum Analysis

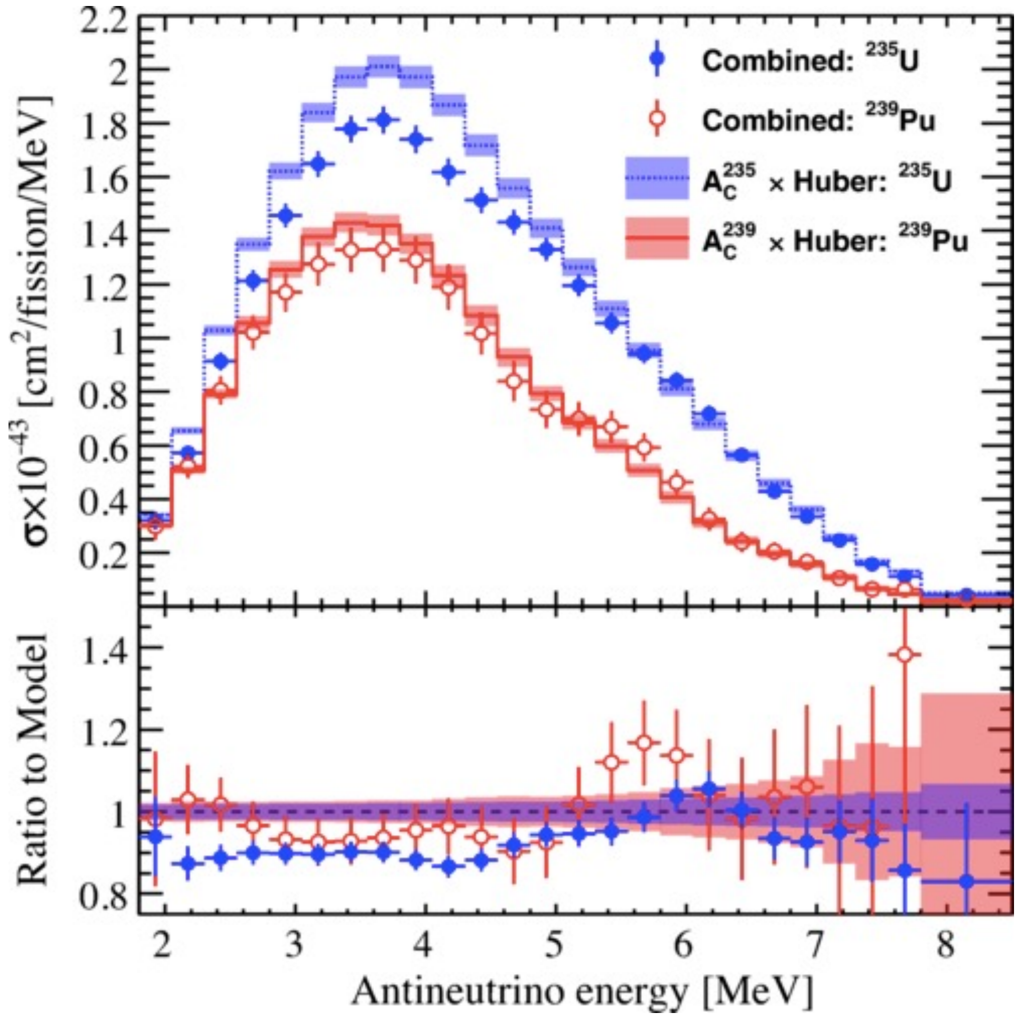


PRD 103, 032001 (2021)

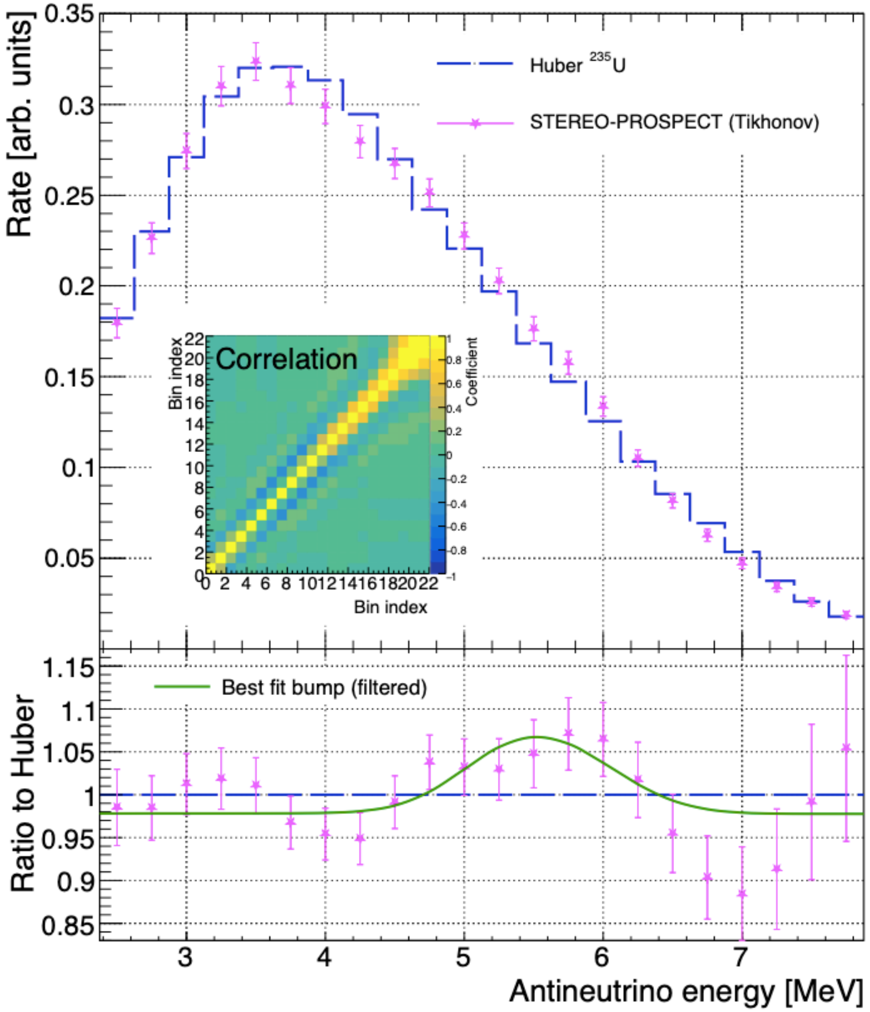
- 2.2σ excess over Huber-Mueller model in 4-6 MeV region.
- 'Bump' amplitude: A = 0.84 $\pm$ 0.39 (1 = Daya Bay bump)

Joint Spectrum Analyses

PROSPECT-Daya Bay PRL 128, 081801 (2022)

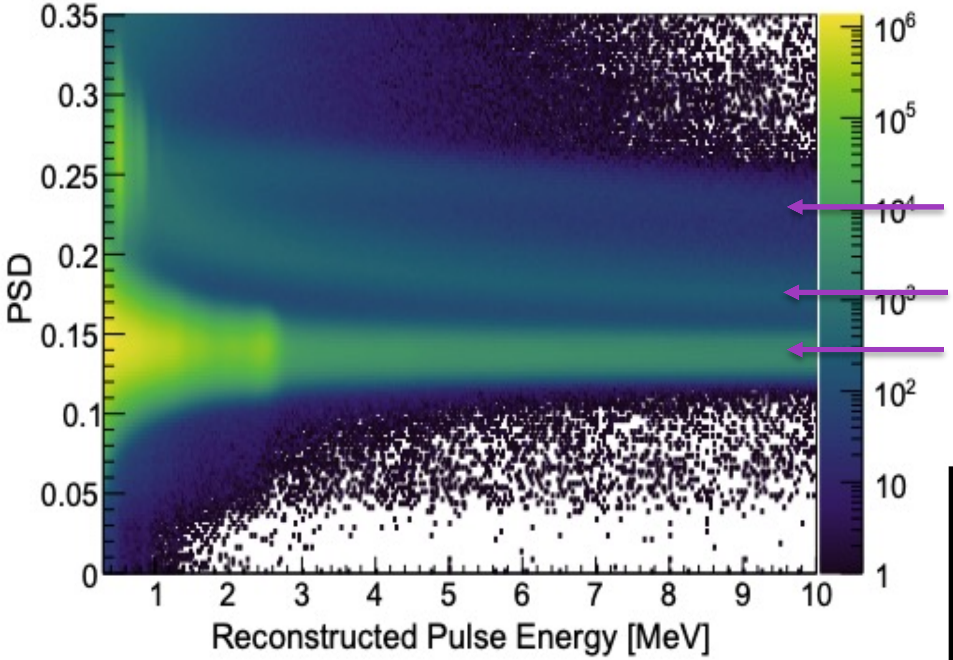


PROPSECT-STEREO PRL 128, 081802 (2022)



Boosted Dark Matter Search

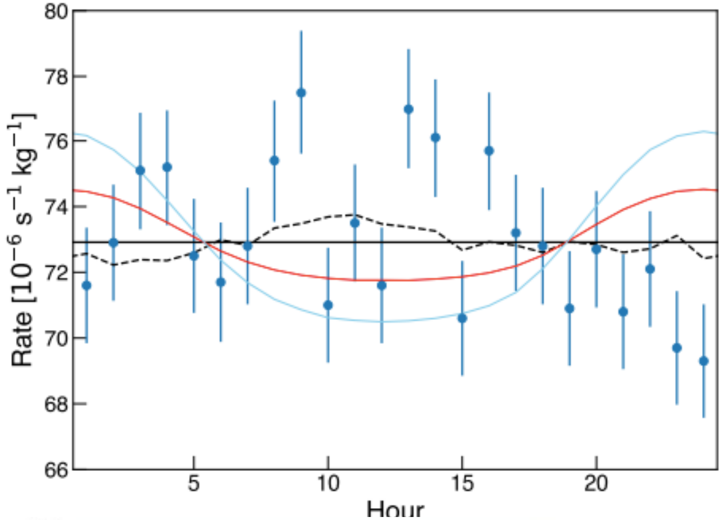
Phys. Rev. D 104, 012009 (2021)

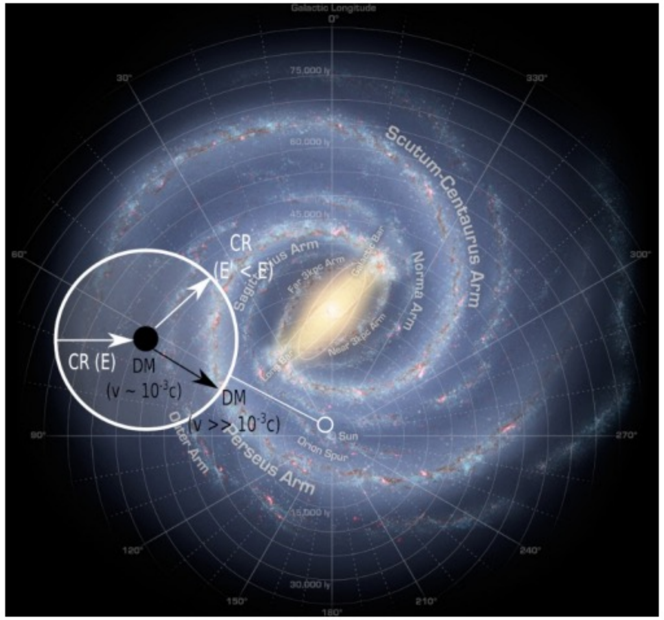


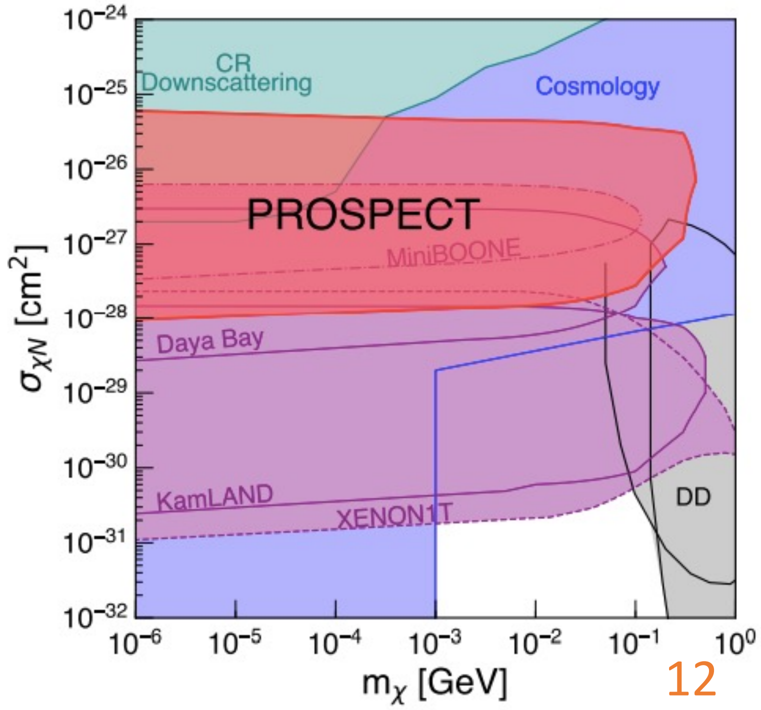
Nuclear recoils

Proton recoils

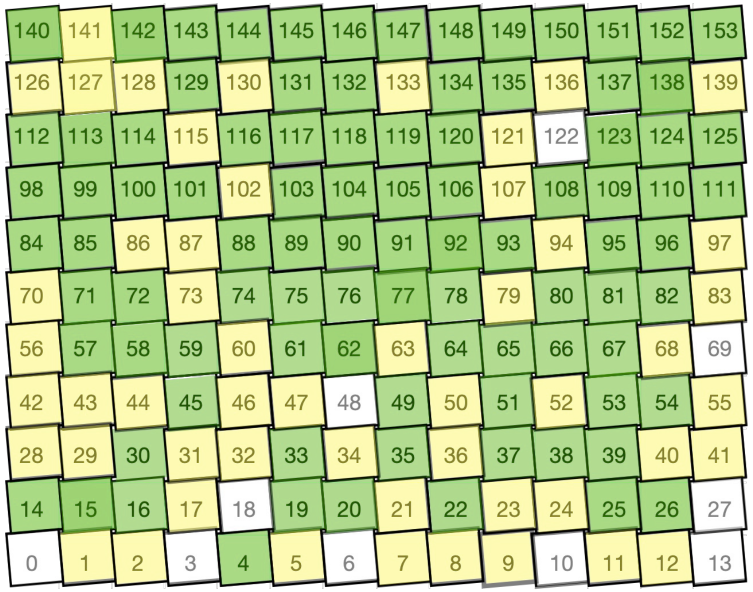
Electron recoils







New Analysis of 2018 Data



Double ended segment
Single ended segment
Blind segment

- PMT base degradation due to scintillator leaking into PMT housings.
- To maximize detector uniformity, all data from affected segments was previously excluded.
- We recover excluded data with:

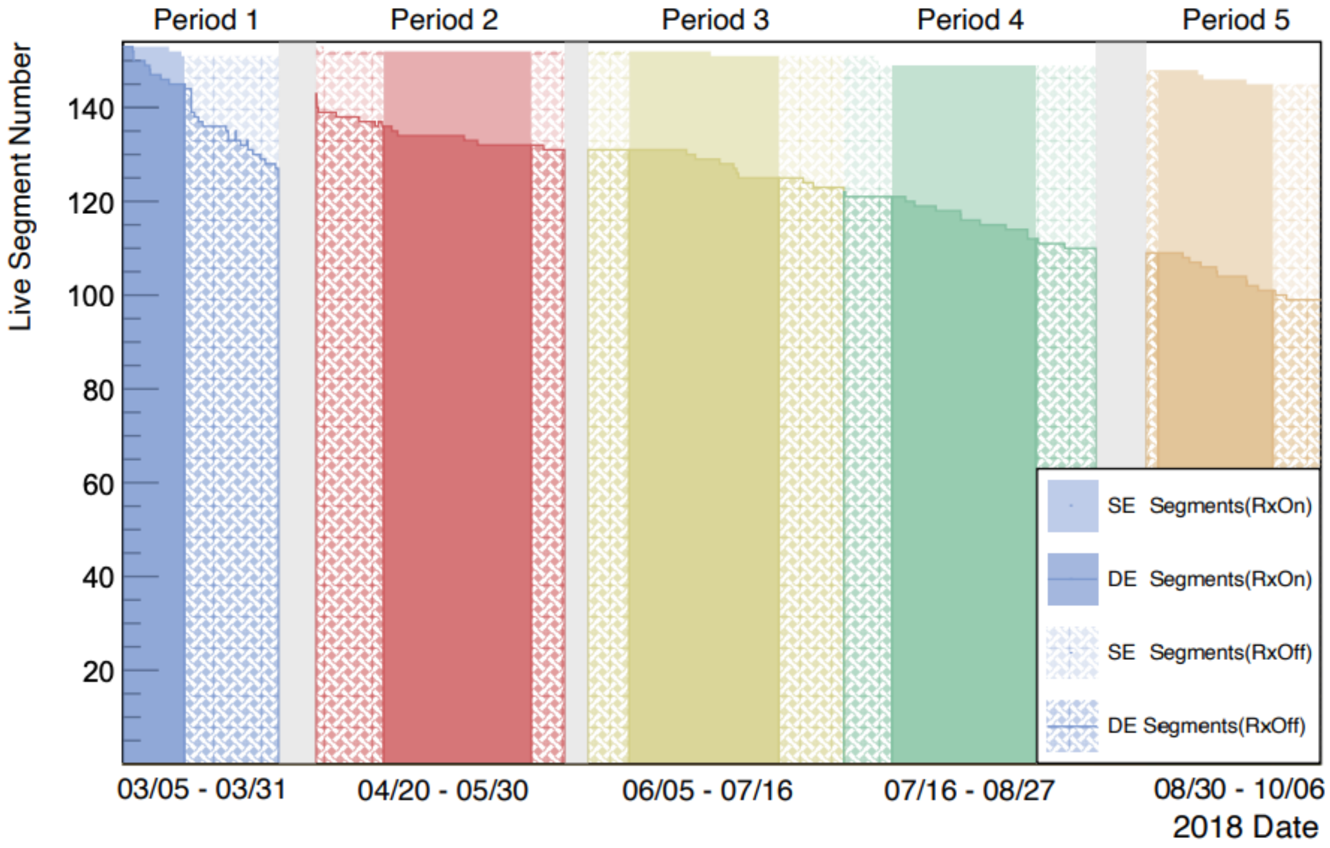
Data Splitting (DS)

and

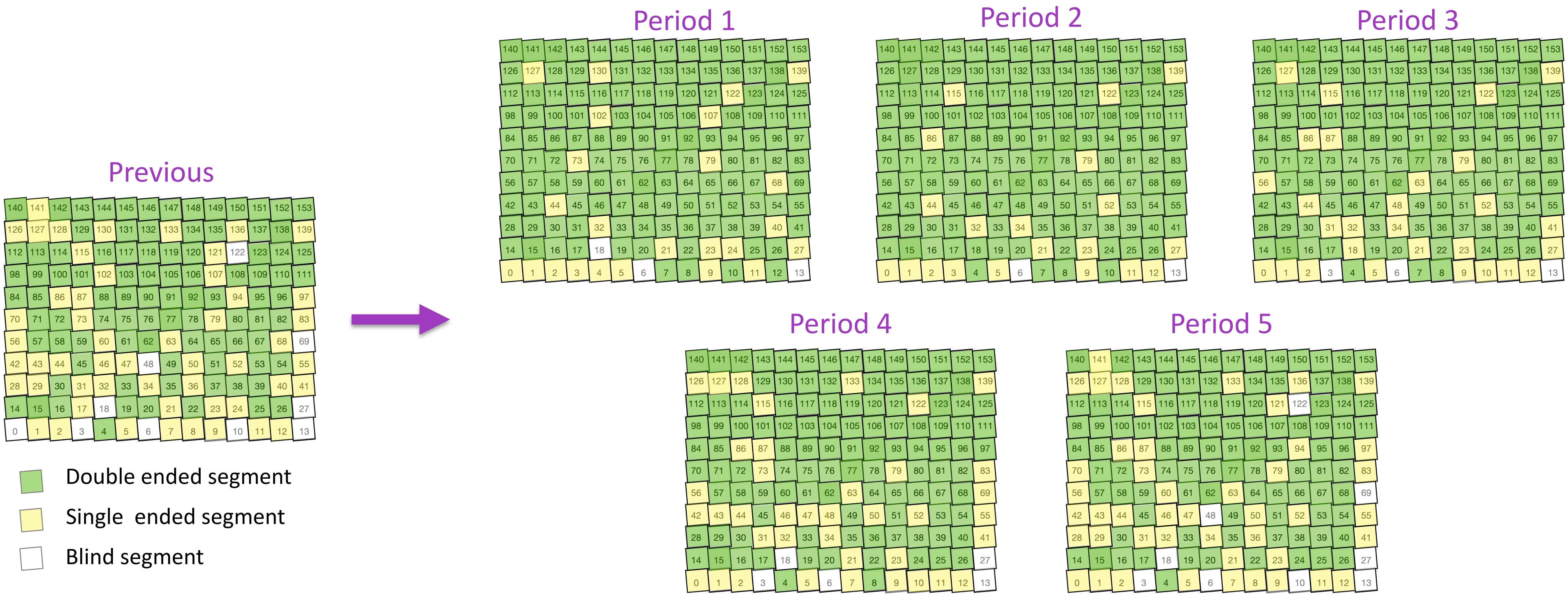
Single Ended Event Reconstruction (SEER)

Data Splitting

- Divide data into five periods, one for each reactor cycle.
- Reactor-on periods bookended by reactor-off periods for background subtraction.
- For each period use the live segments from the end of the period.



Data Splitting Configurations



SEER

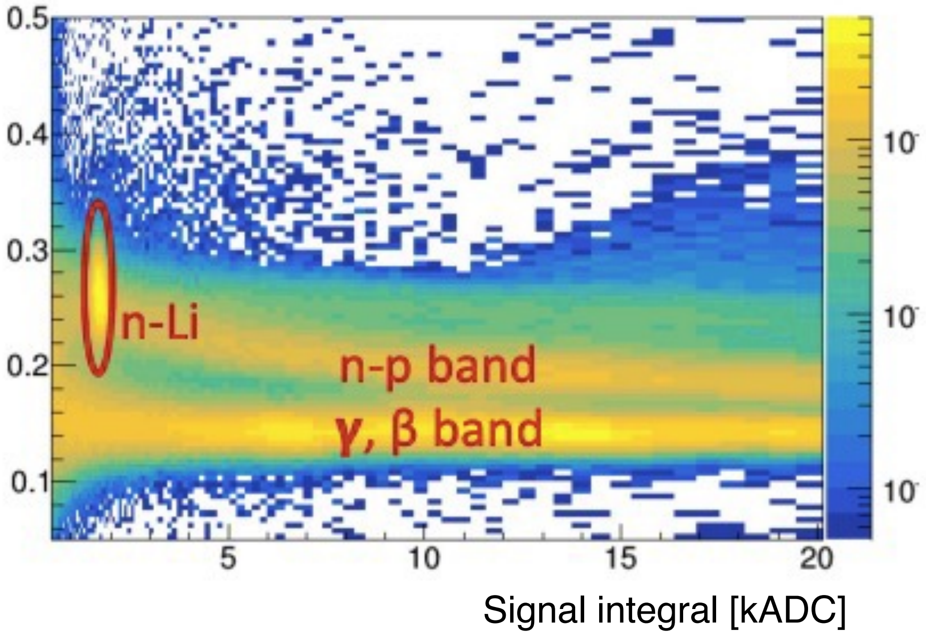
For single-ended segments event location is unknown.

- Unable to correct signal amplitude for position, therefore poor energy information and these segments not used for energy reconstruction.

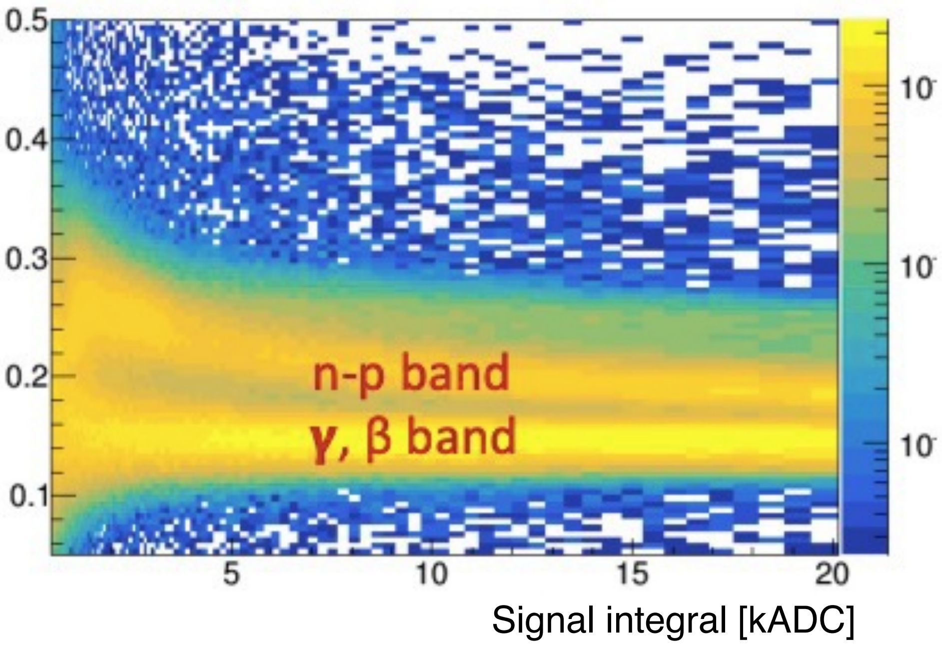
But, single-ended segments retain effective **PSD**.

- Used for background rejection.

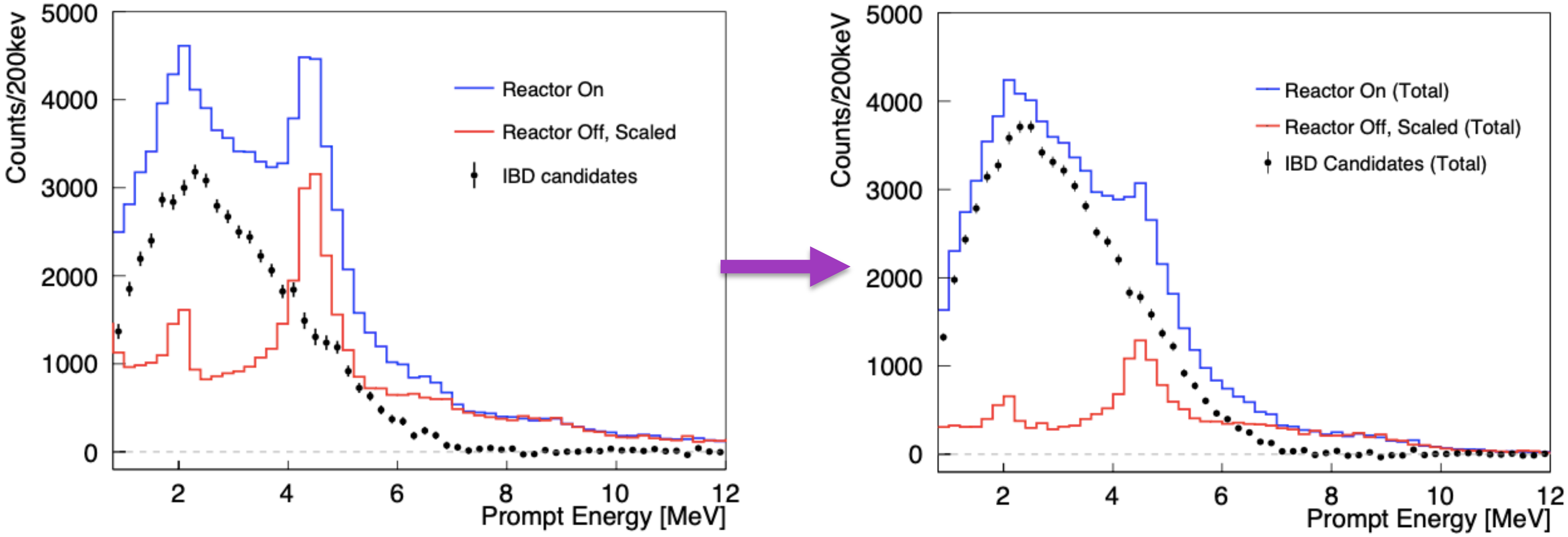
Double Ended PSD



Single Ended PSD



Signal-to-Background Improvement



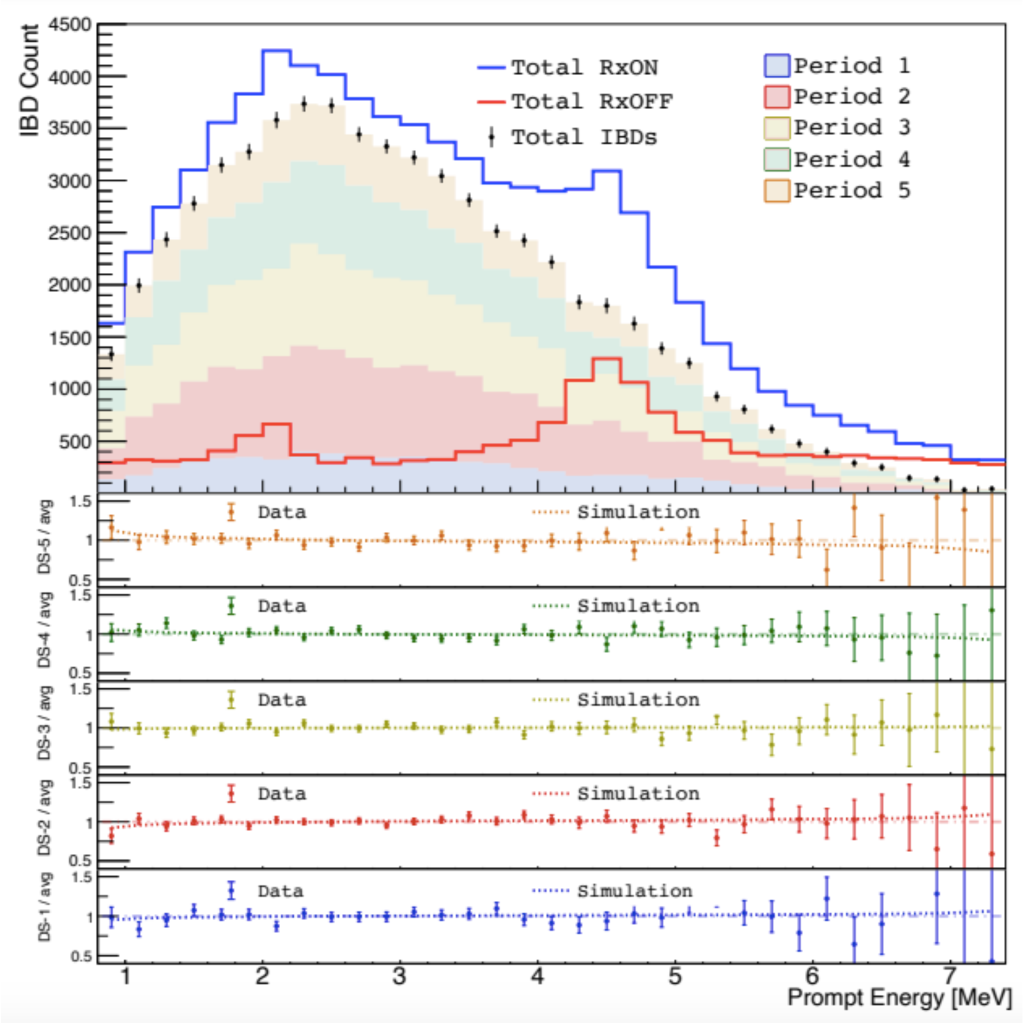
Substantial reduction of background due to SEER, especially the 4.4 MeV $^{12}C(n,n')^{12}C^*$ peak.

	IBD Effective	IBD Effective/ calendar day	Total IBD counts	Total IBD counts/ calendar day	S/CB	S/AB
Previous PROSPECT Results	18100	189	50560	528	1.37	1.78
Data Splitting + SEER	36204	379	61029	638	3.90	4.31

Improvement in:

- IBD counts ~(x1.2)
- Signal to cosmo. background (S/CB) ~(x2.8)
- Signal to accidental background (S/AB) ~(x2.4)
- IBD effective counts (x2.0) - number of events in a background-free experiment with equivalent precision

Five-Period Spectrum

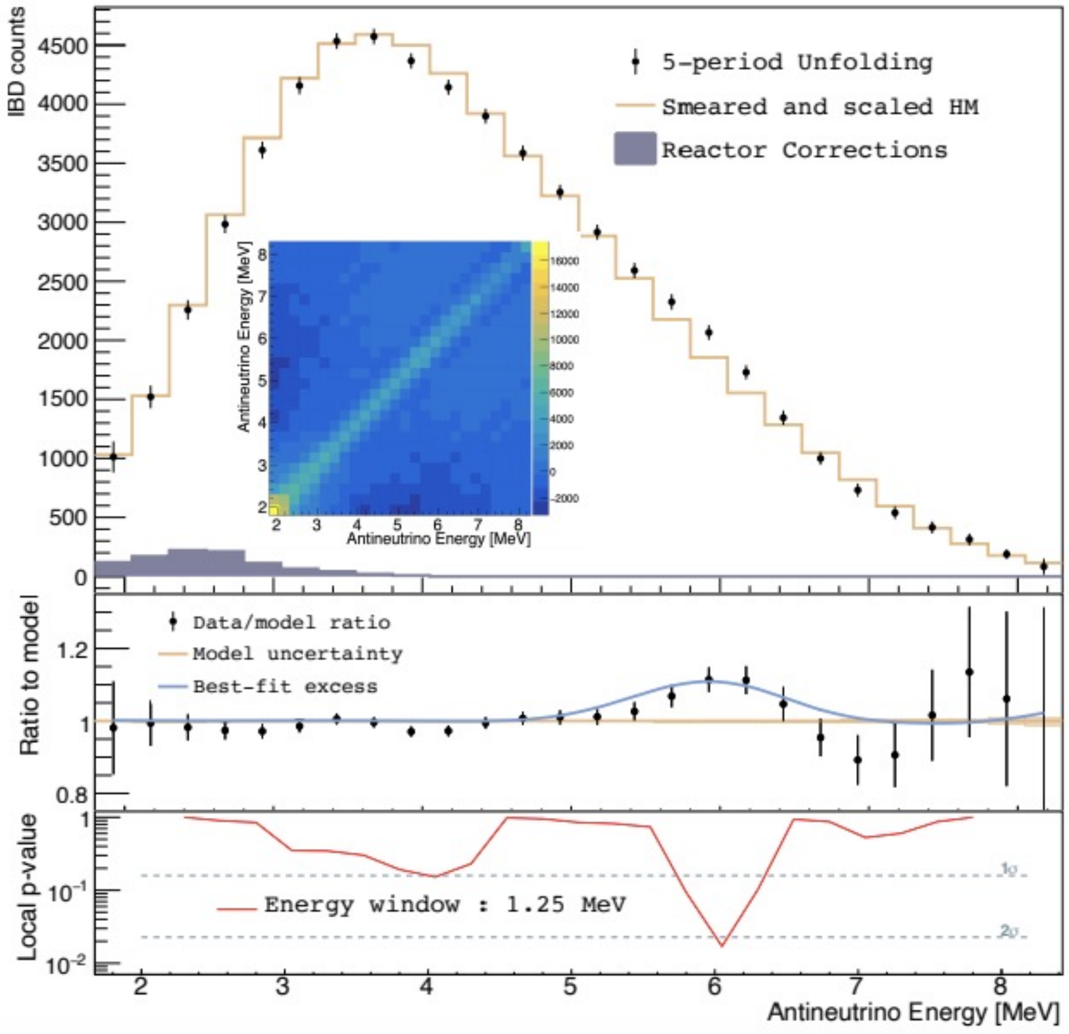


arXiv:2212.10669v2

- Comparing each period to the average confirms inter-period compatibility.
- Simulation prediction illustrates minor detector response changes.

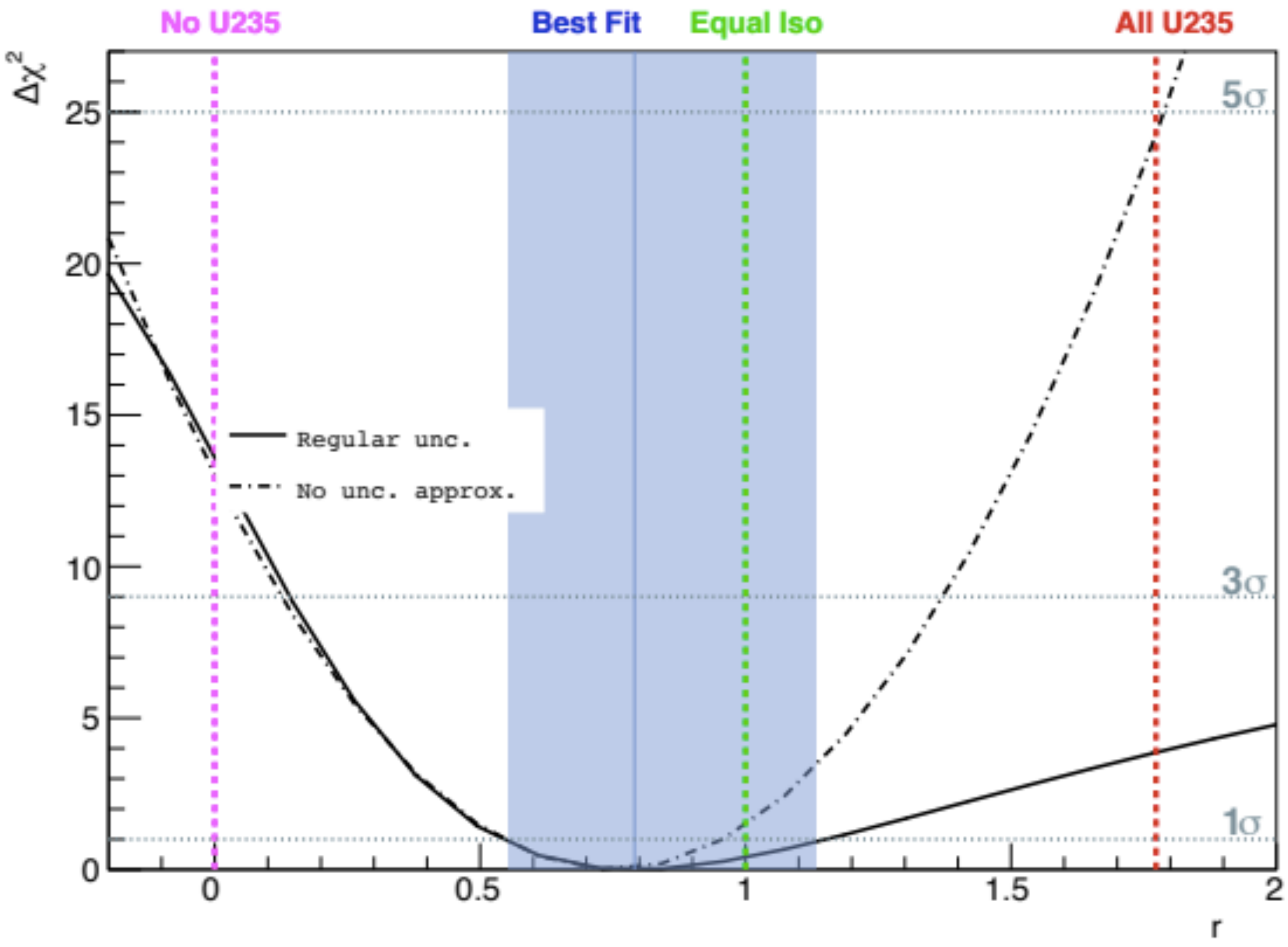
Unfolded Neutrino Spectrum

- Obtain antineutrino energy spectrum by inverting detector response over all five periods with the Weiner-SVD method.
- Systematics are treated as period-correlated (e.g. energy response) or period-uncorrelated (e.g. background subtraction).
- Same technique can be used for combining different experiments.



arXiv:2212.10669v2

Isotopic Composition of 'The Bump'



arXiv:2212.10669v2

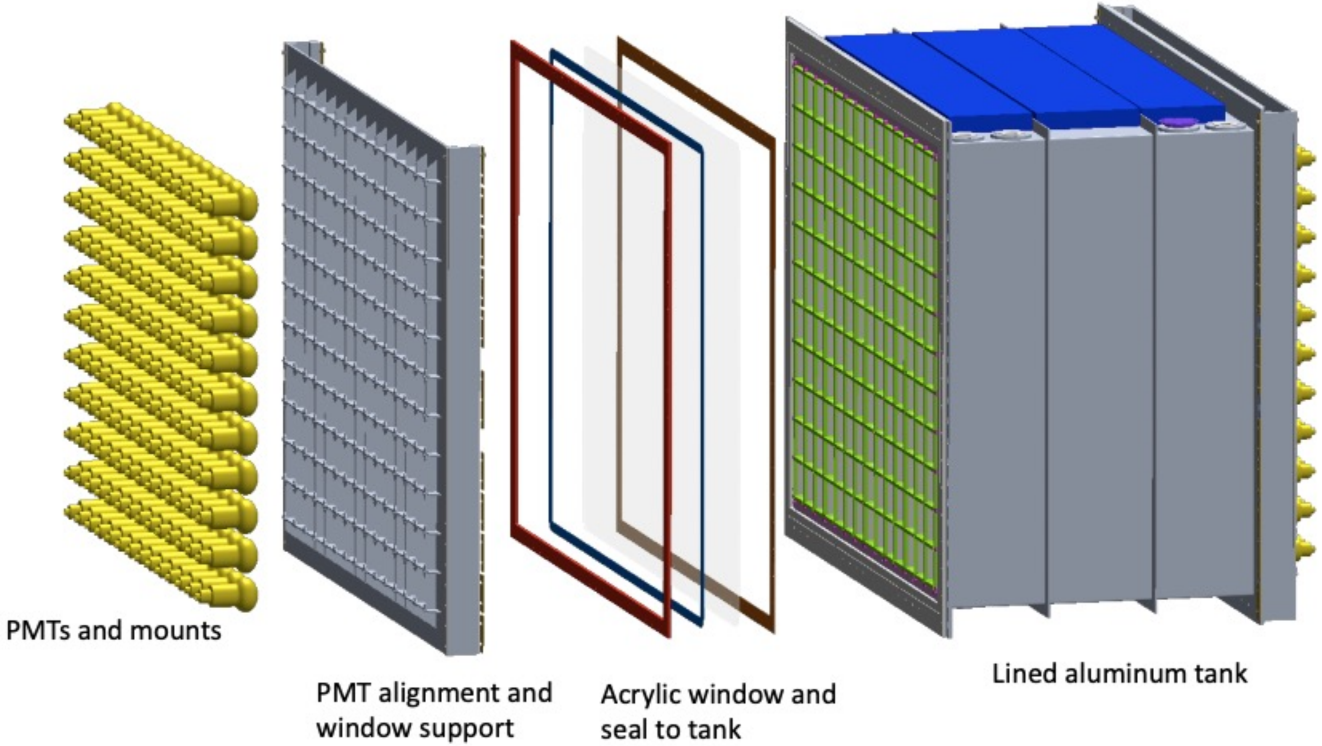
- Ratio of PROSPECT bump amplitude to Daya-Bay bump.
- Equal Isotope hypothesis preferred.
- Ratio = 0 (**no ^{235}U** bump) disfavored at **3.7σ**.
- Ratio = 1.78 (**all ^{235}U** bump) disfavored at **2.0σ**.
- Detector systematics limited. Multi-reactor measurement with correlated detector systematics (same detector) would strengthen the result.

Other Upcoming PROSPECT Results

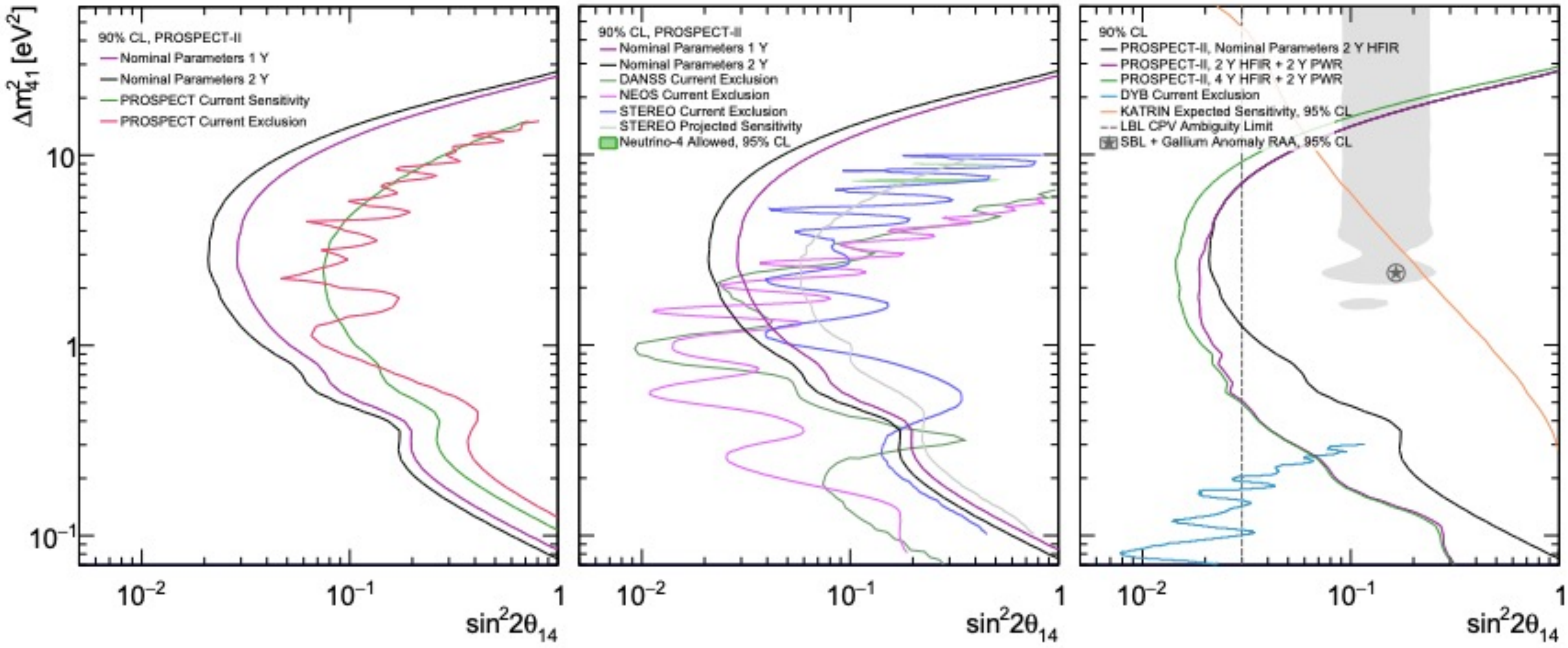
- Five-period oscillation analysis
  - Increased statistics from Data Splitting.
  - New Combined Neyman Pearson framework to allow finer binning without bias from low statistics.
- Absolute antineutrino flux
- IBD background analysis
  - Identification of background classes and data/simulation comparisons.
- Antineutrino directionality
  - Neutron displacement correlated to incoming neutrino direction.

PROSPECT-II

- Proposed upgrade to PROSPECT. Same size and location.
- PMTs separated from liquid scintillator volume by new acrylic window.
- Anticipate increase in effective statistics from 35,000 to 210,000 in 2 years at HFIR.
- Potential future deployments at other reactors.
- Design well advanced. Looking for construction funding.



PROSPECT-II Oscillation Sensitivity



J. Phys. G 49 (2022) 7 070501

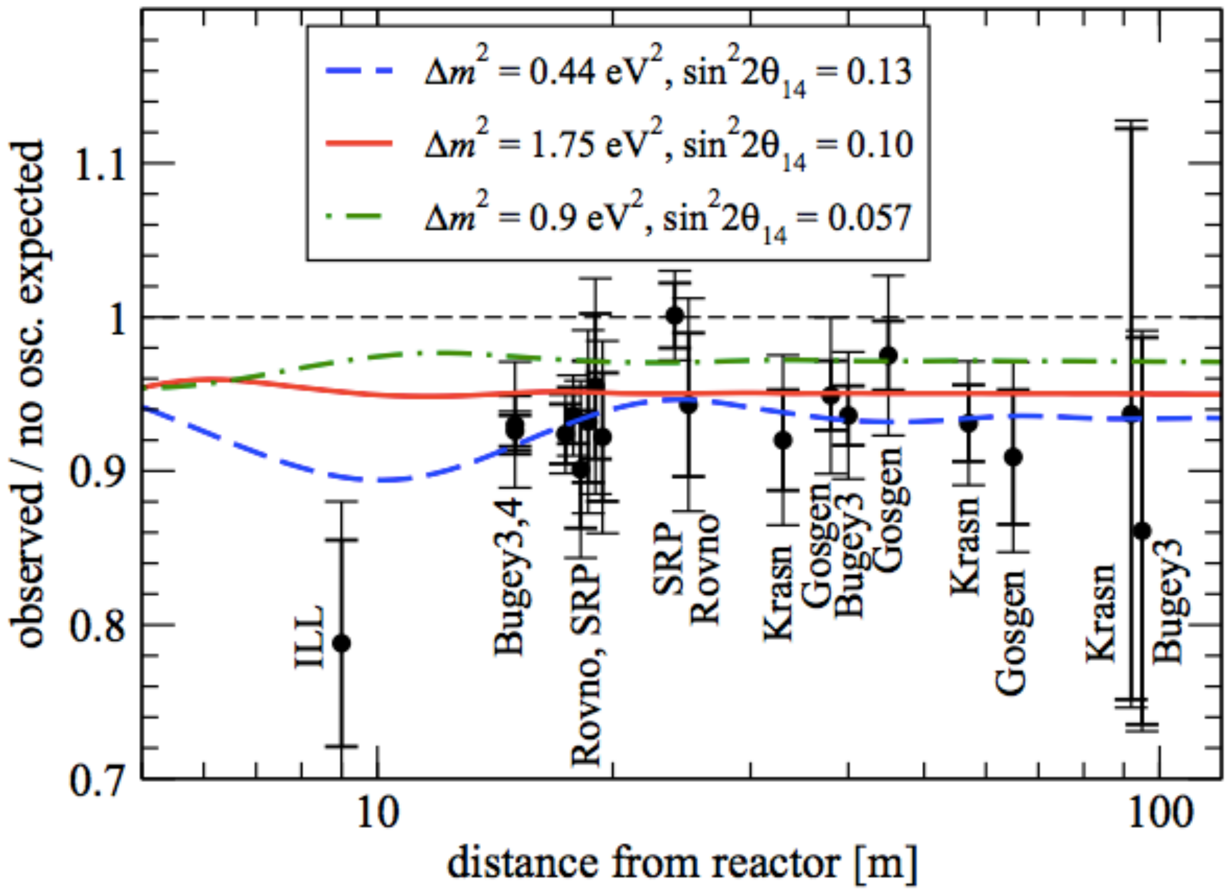
Conclusions

- The statistical power of the PROSPECT dataset has been doubled through new analysis techniques: Data Splitting and Single Ended Event Reconstruction.
- A multi-period response unfolding strengthens our observation of a spectrum excess between 5-7 MeV neutrino energy.
  - ‘Equal isotope’ hypothesis favored.
  - This approach could be extended to multi-experiment measurements.
- Expect additional PROSPECT-I results in the next year incorporating the new DS+SEER event selection.
  - SBL oscillation search, absolute flux, aboveground IBD backgrounds, antineutrino directionality.
- An upgraded PROPSECT-II experiment would increase the statistical power a further factor of ~6 at HFIR, and allow for multi-reactor deployment.

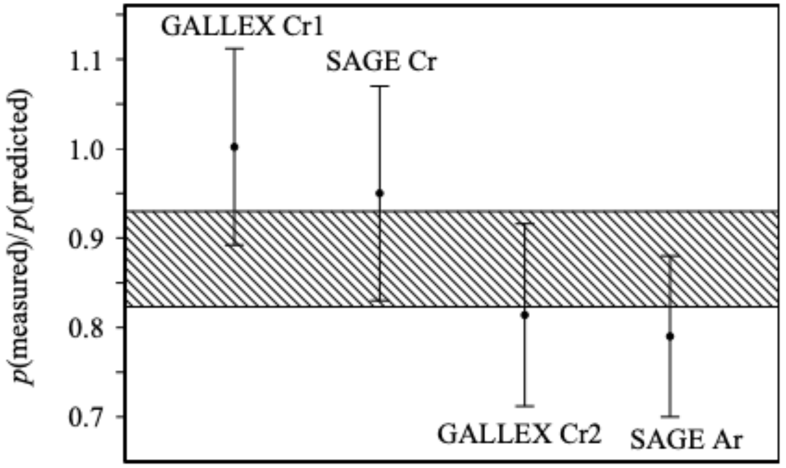
Thank You!

Extra slides

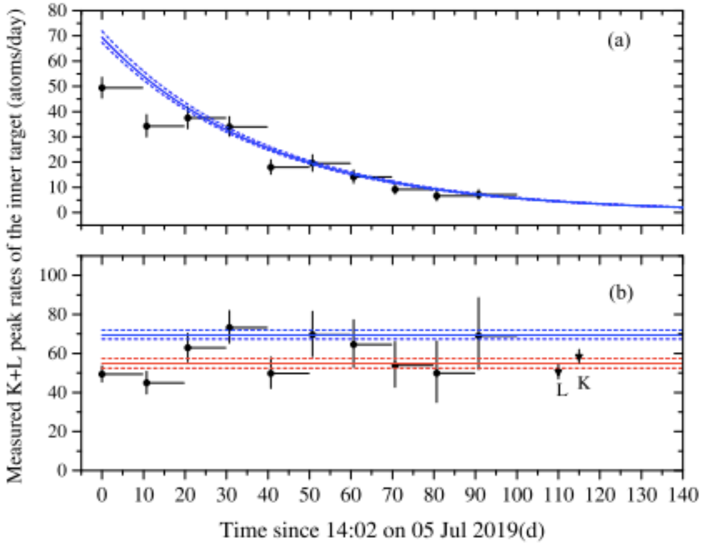
Reactor Antineutrino Anomaly



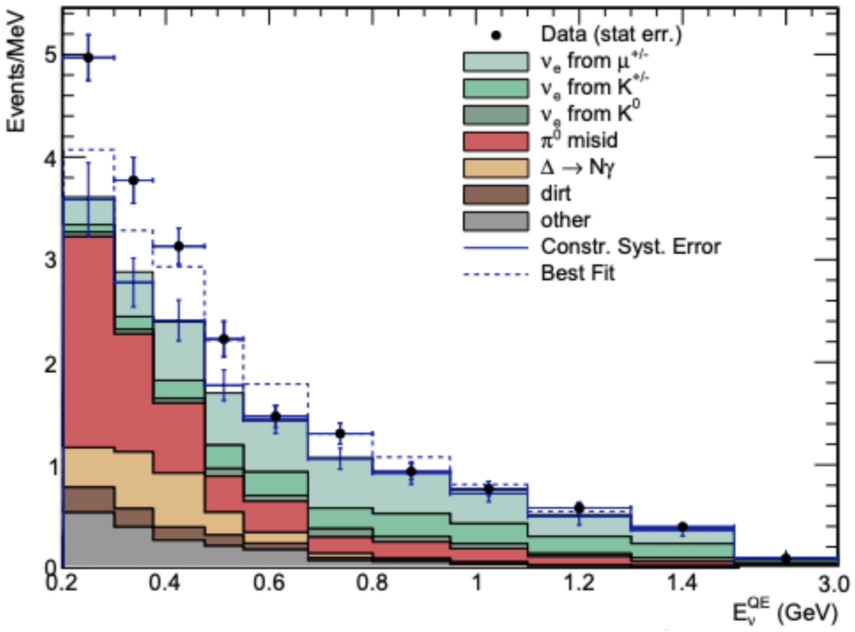
Anomalies



Gallium Anomaly Phys.Rev.C73:045805,2006

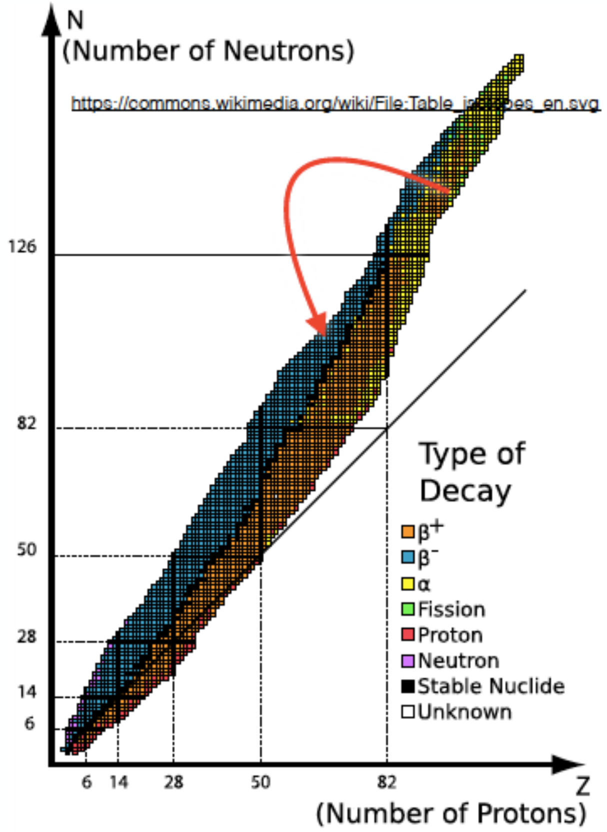


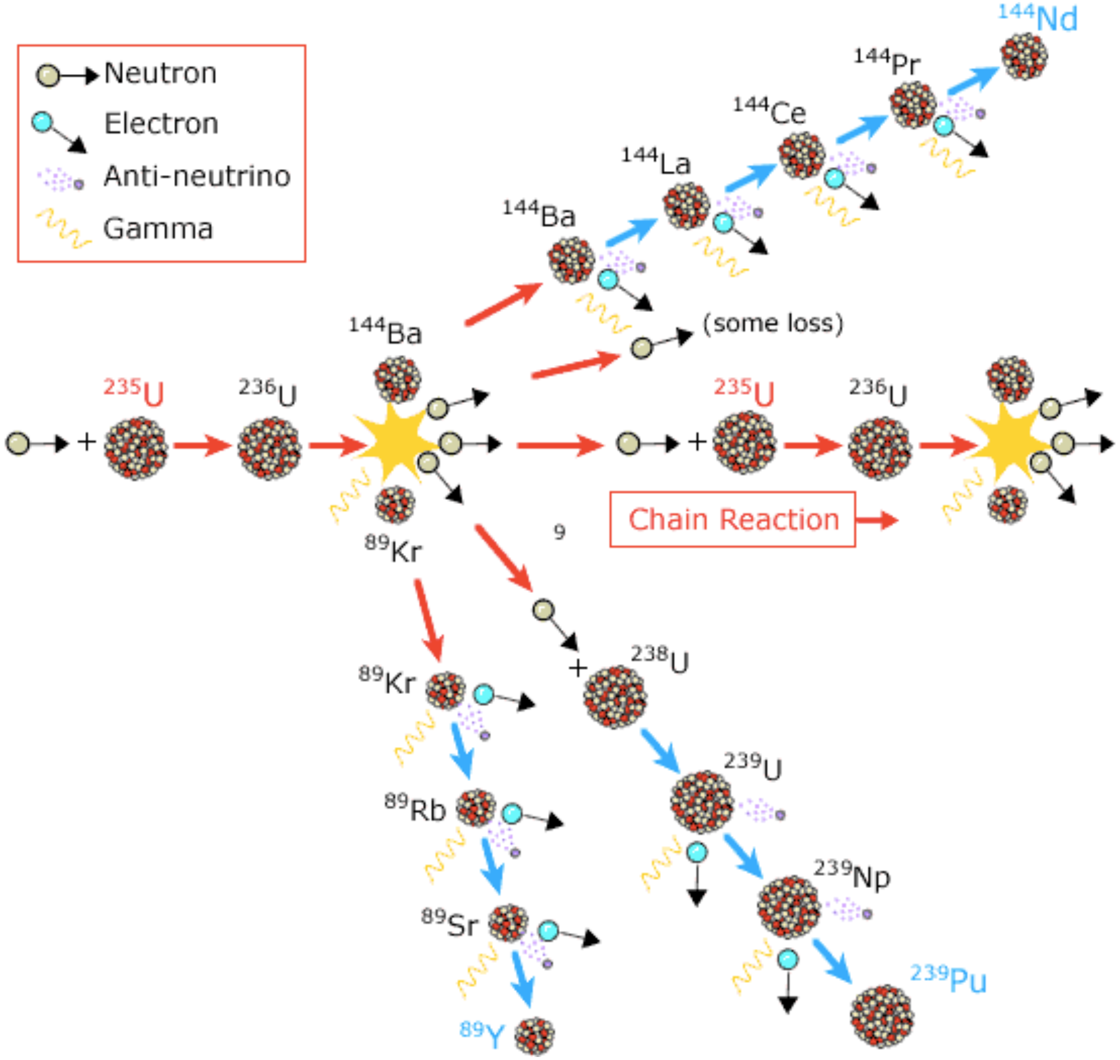
BEST arxiv.org:2109.11482



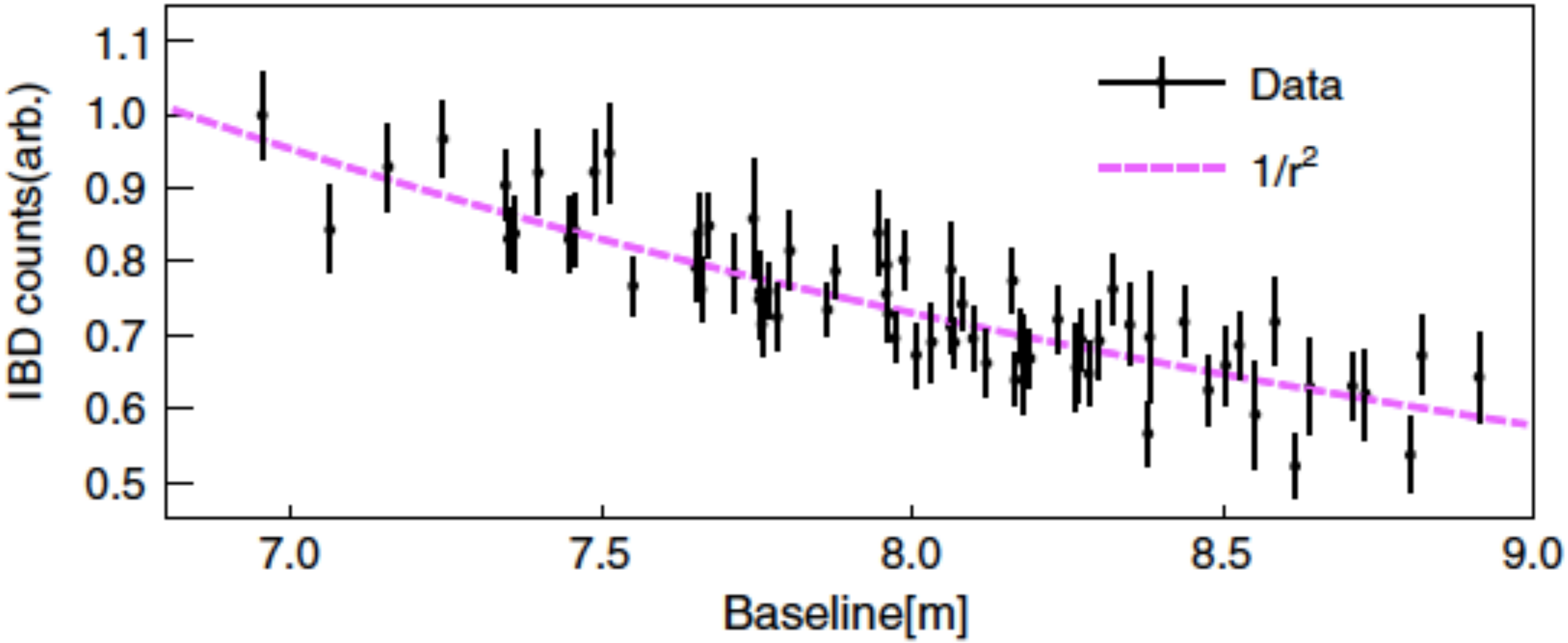
MiniBooNE low energy excess
Phys. Rev. Lett. 121, 221801 (2018)
MicroBooNE results to be announced Oct 27-28

Neutrinos from Nuclear Fission

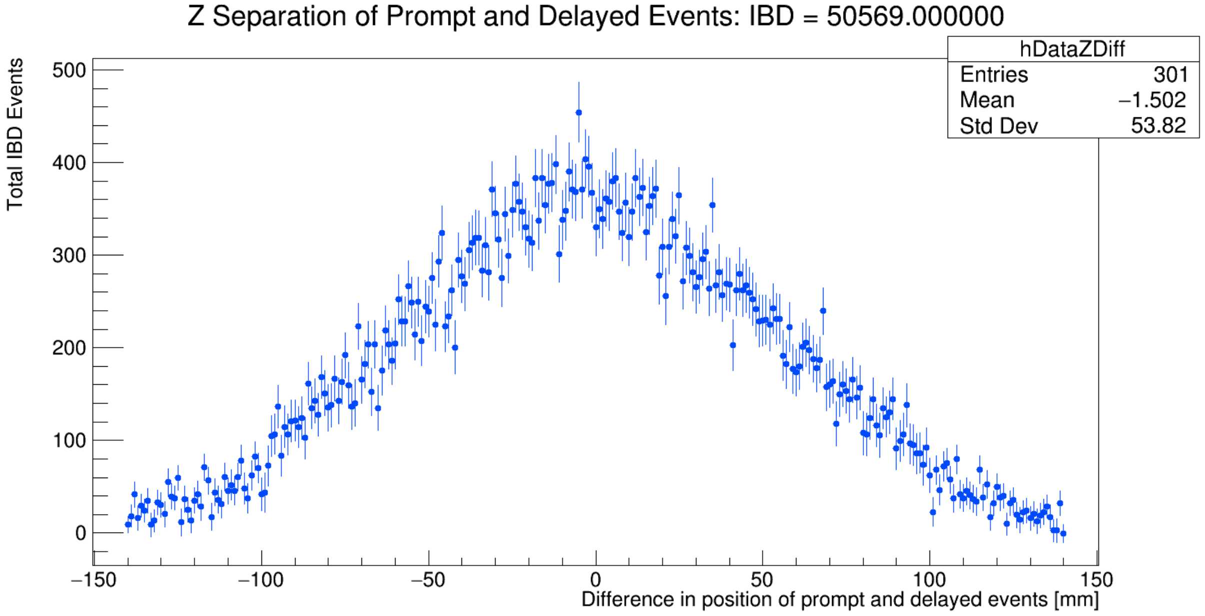


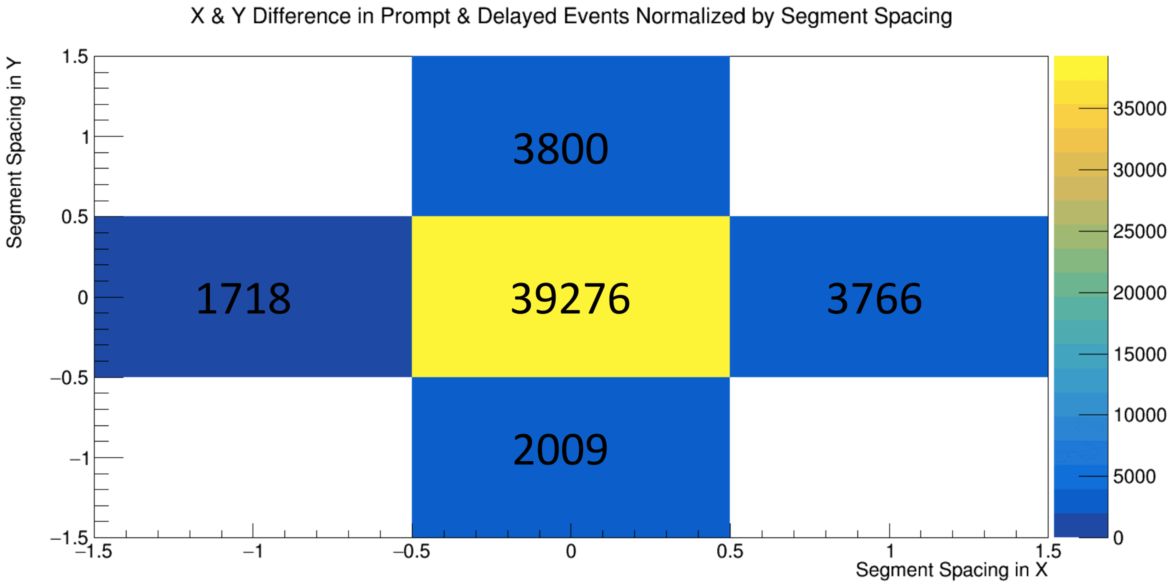


Locating the Reactor

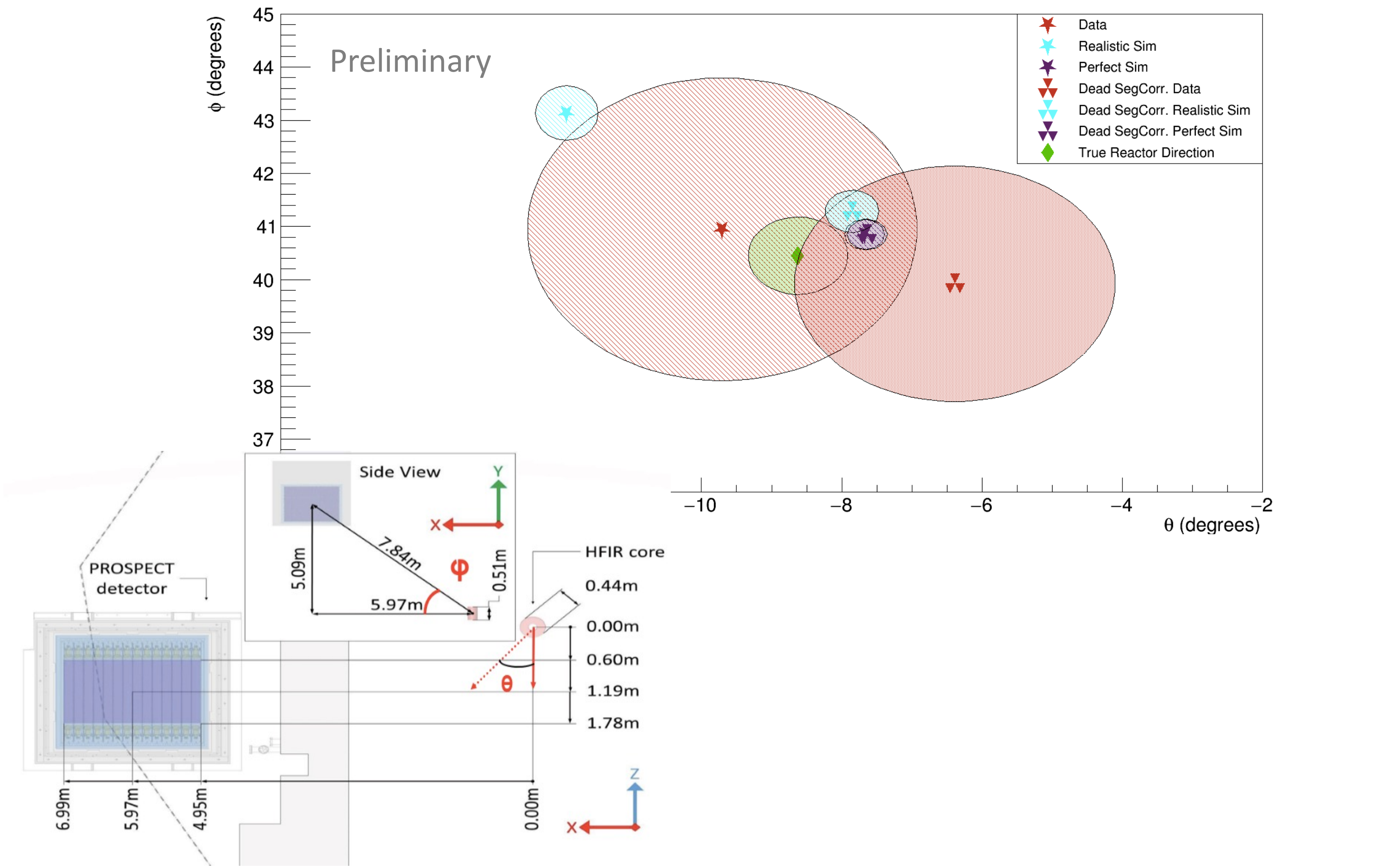


Prompt-Delayed Displacement

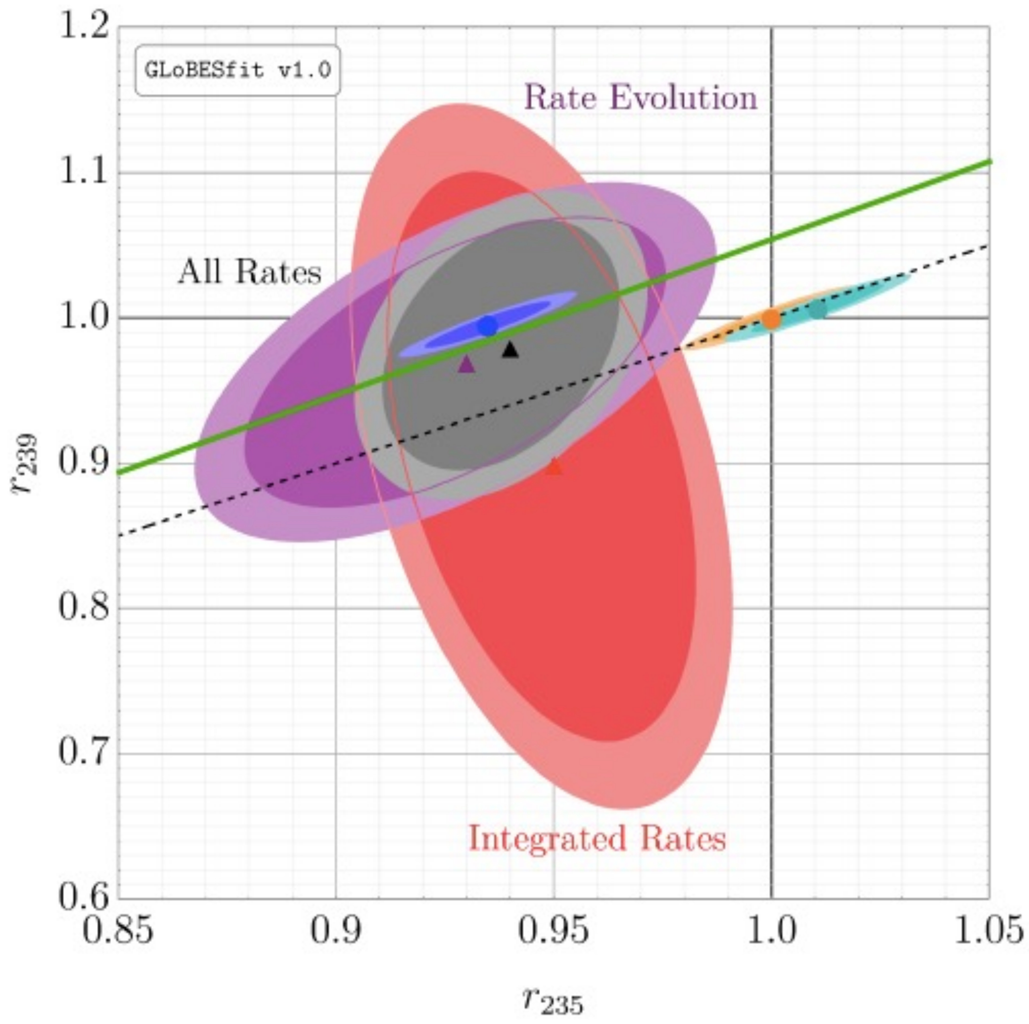




Neutrino Directionality

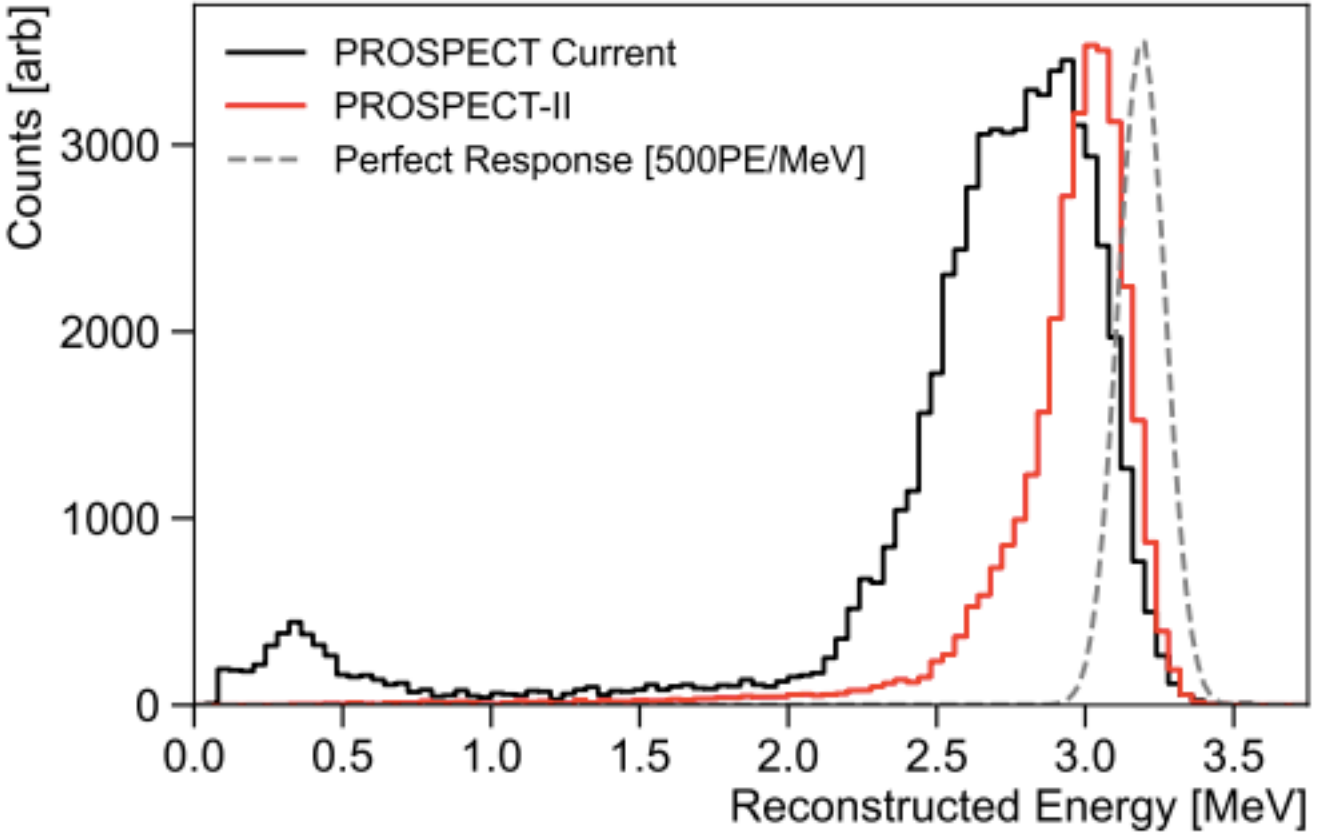


Evidence for Flux Prediction Issue



Altered from JHEP 01 167

PROSPECT-II Improved Detector Response



External Calibration

$$E_{\mathrm{MC}} = A \sum_i \left(E_{\mathrm{scint},i}(k_{B2}, k_{B2}) + E_{c,i}(k_C)\right).$$

Birks' empirical law

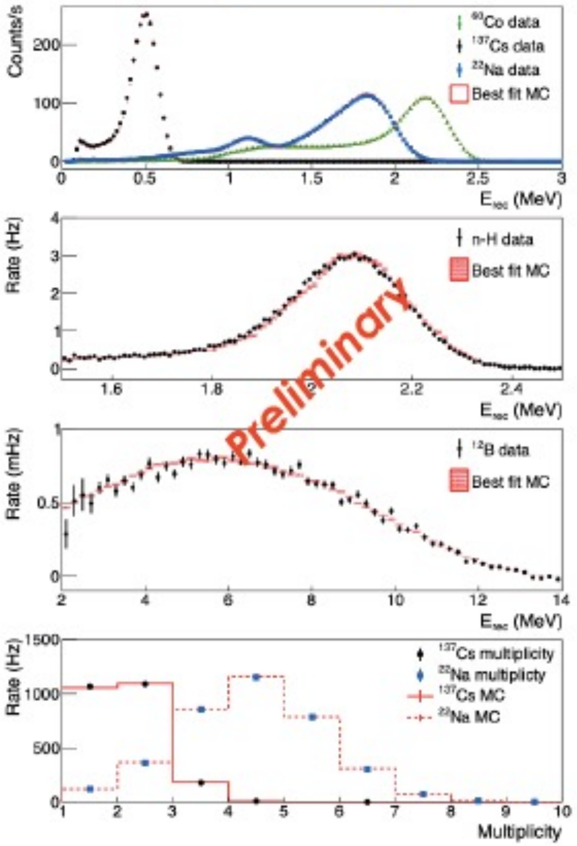
$$\frac{dE_{scint}}{dx} = \frac{\frac{dE}{dx}}{1 + k_{B1}\frac{dE}{dx}}$$

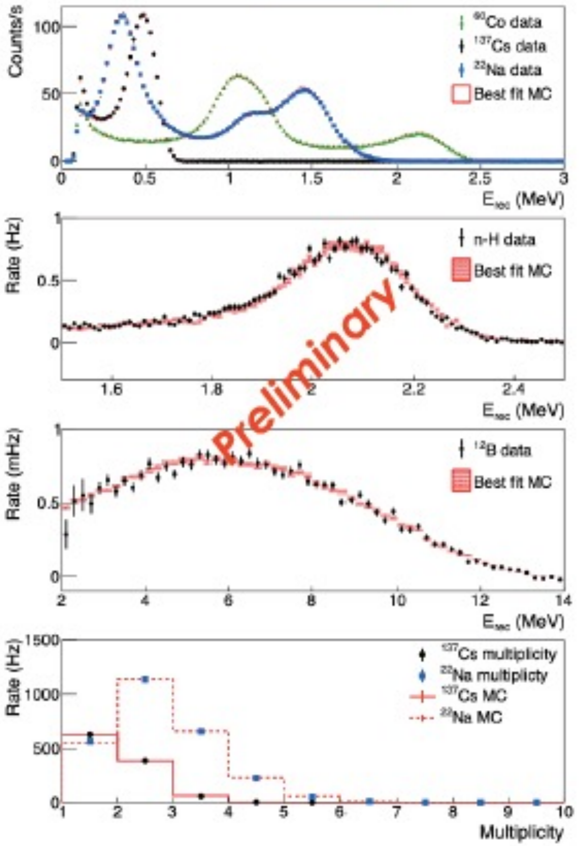
Cherenkov light production

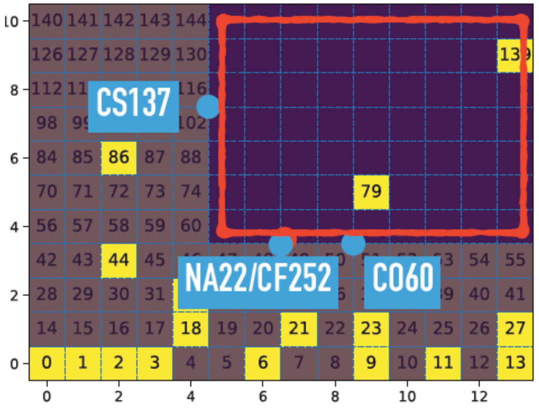
$$E_c = k_c \sum_\lambda N_\lambda E_\lambda$$

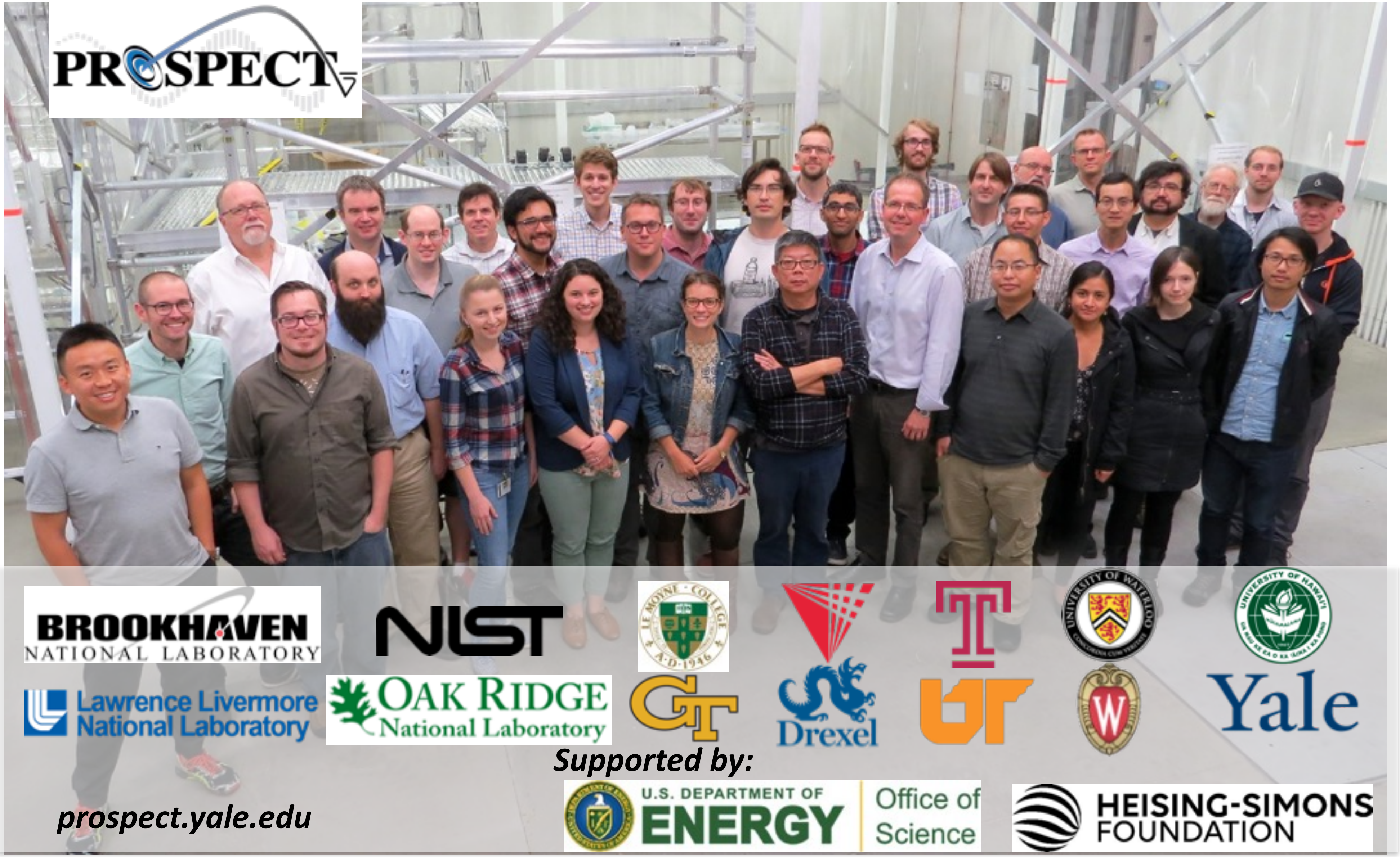
Internal

External





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