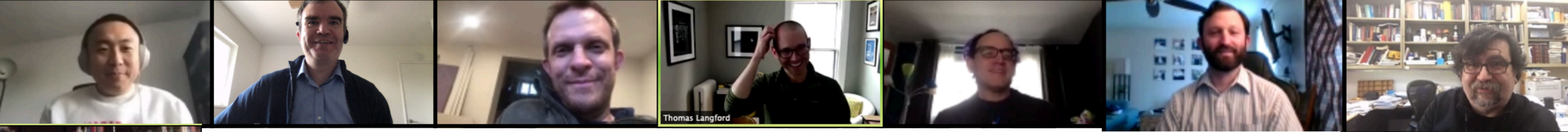
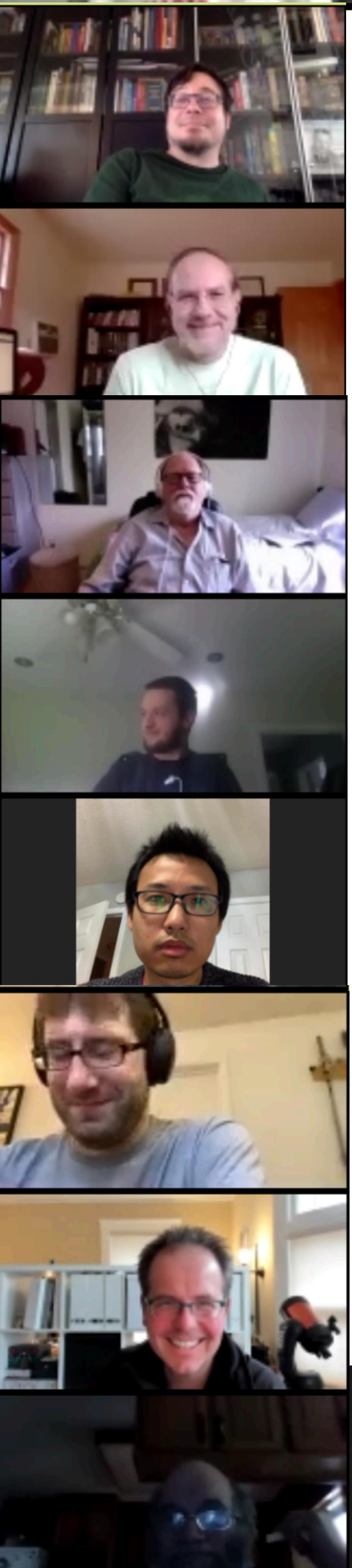
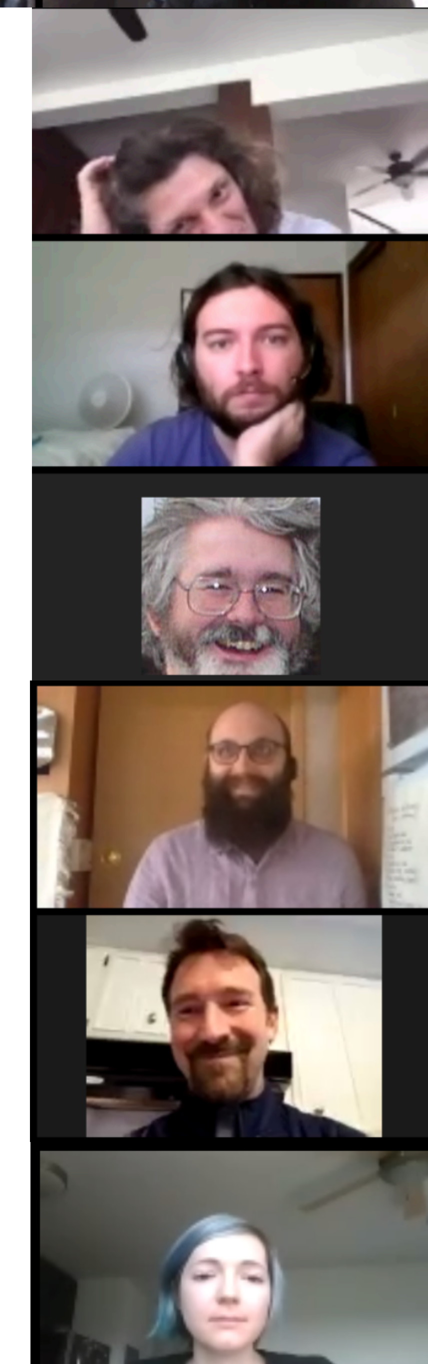






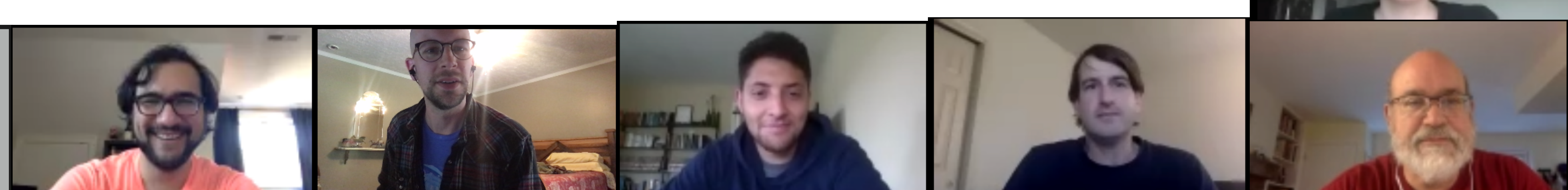
Recent Reactor $\bar{\nu}_e$ Results from the PROSPECT Experiment

June 25 2020

Bryce Littlejohn
Illinois Institute of Technology

On Behalf of the PROSPECT Collaboration

[PROSPECT Collaboration, arXiv:2006.11210 (2020)]



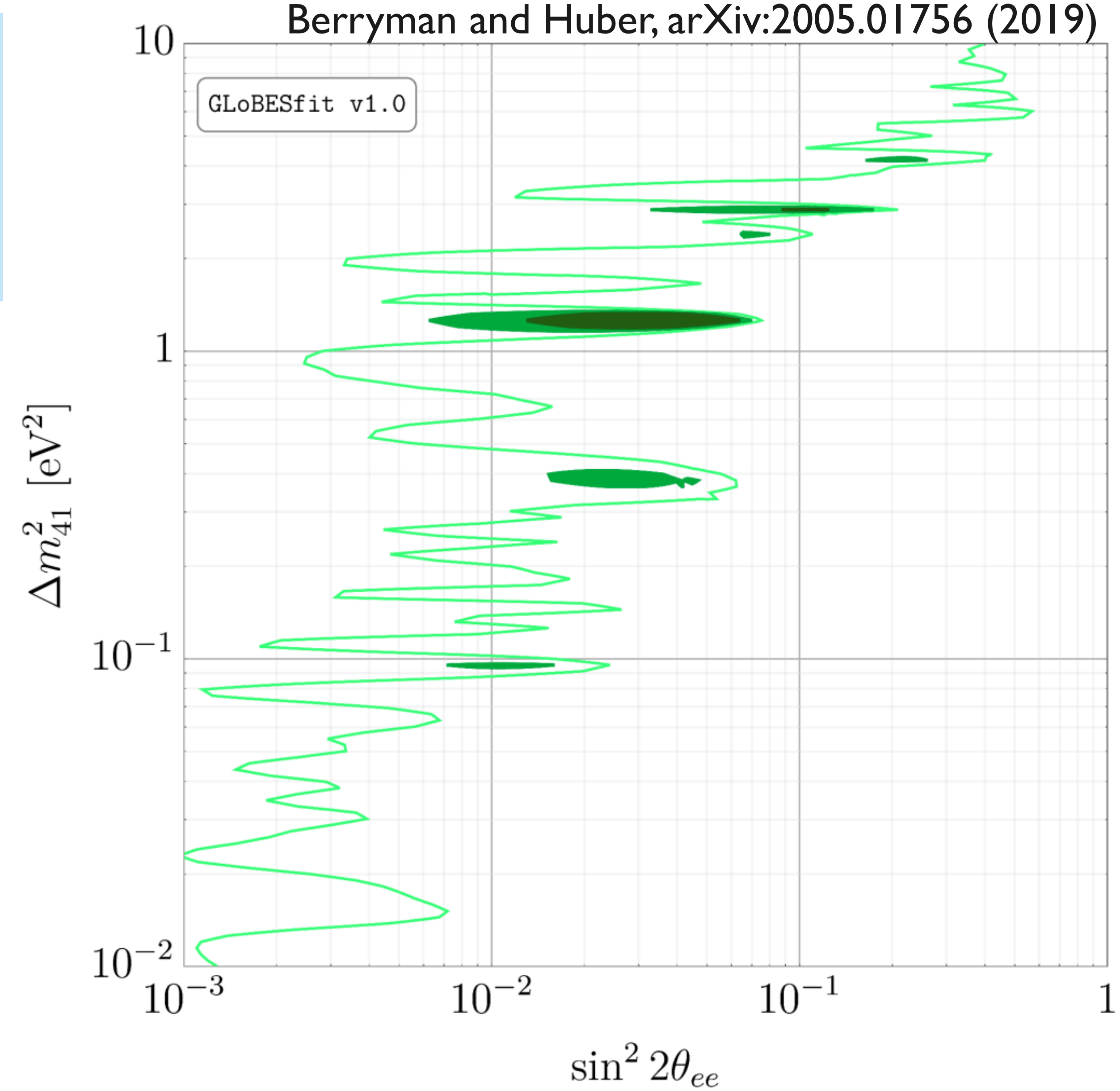
PROSPECT April 2020 Collaboration Meeting Photo

Motivation: Oscillations

- Q: Do eV-scale sterile neutrinos exist, and do they mix with the known neutrino flavors?
  - Reactor experiments provide hints of varying nature and confidence level
  - Short-baseline reactor experiments are the strongest existing method for probing sterile mixing parameter U_{e4}
  - Need to address all Δm^2 to ~%-level to enable unambiguous interpretation of LBL CPV+other measurements

D. Dutta et. al., JHEP 11:122 (2016)
S. Agarwalla et. al., PRL 118 (2017)
Many others…

Berryman and Huber, arXiv:2005.01756 (2019)

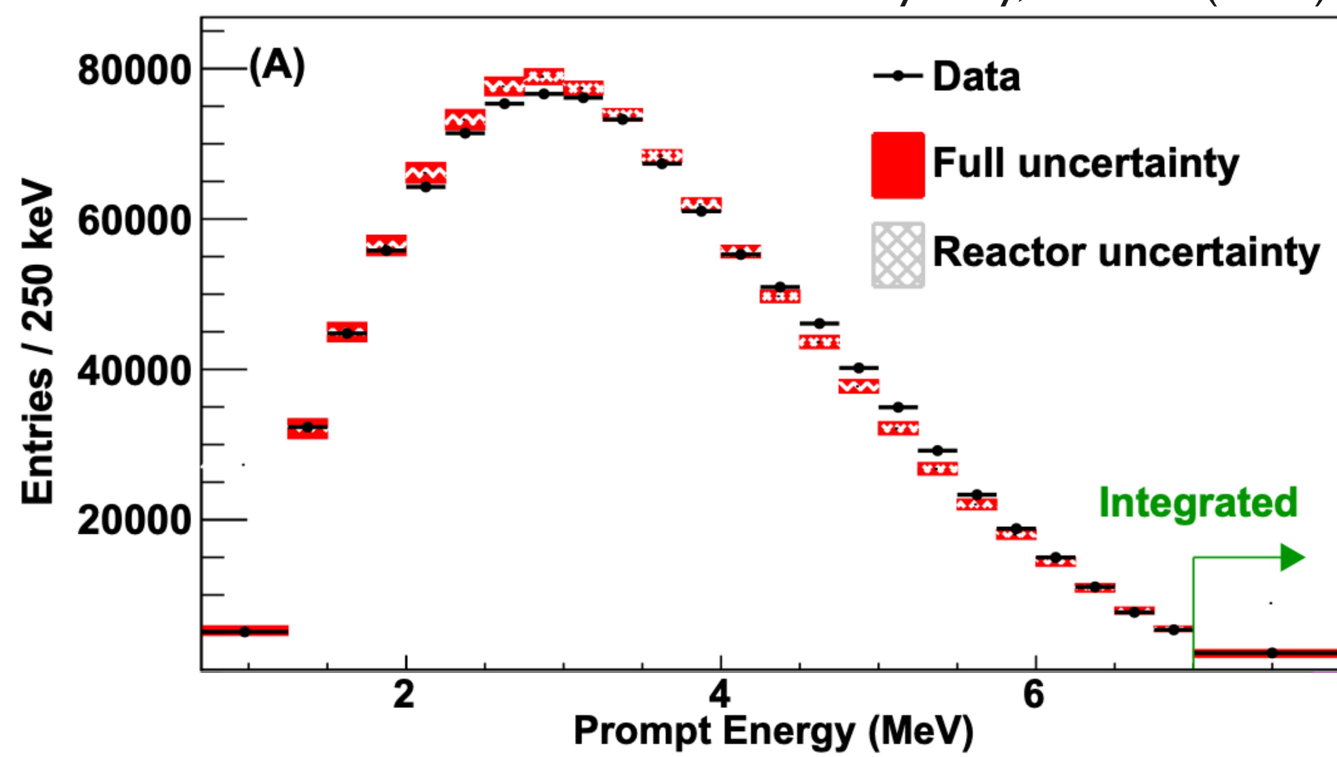


$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \end{bmatrix} = U \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} & \boxed{U_{e4}} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \end{bmatrix}$$

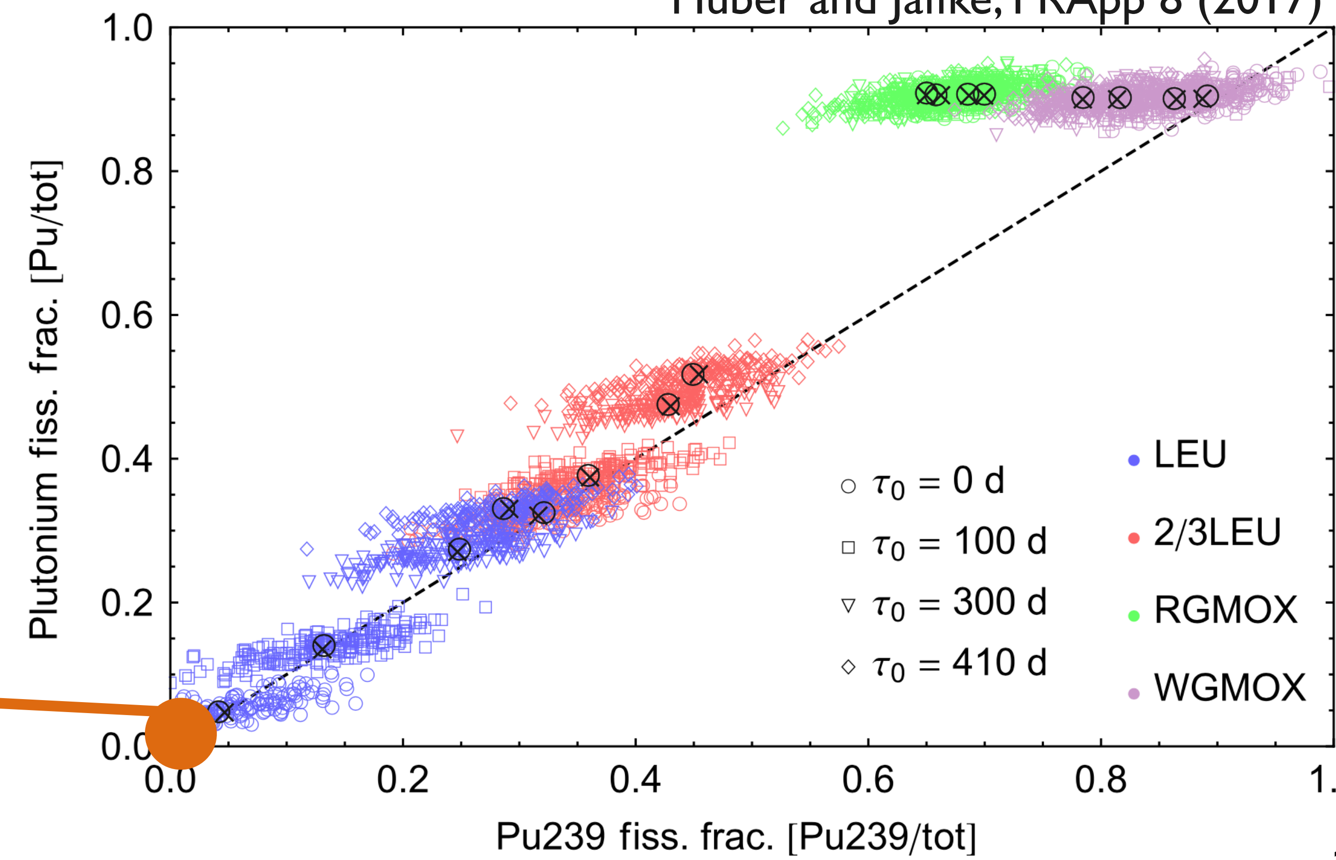
Motivation: ^{235}U $\bar{\nu}_e$ Spectrum

- Experiments at low-enriched (LEU) cores detect spectra at odds with current models
  - Particularly bad agreement at high-neutrino energy (a ‘bump’?)
- Q: What is the nature of this ‘bump’ feature?
  - Caused by mis-modeling of all fission products’ yields? decays?
  - Only some fission products?
  - Products specific to certain fissioning isotopes, like ^{235}U? ^{238}U?
- Learn by burning different fuels: in addition to LEU, measure ν_e from highly-enriched (HEU) cores

Daya Bay, CPC 41 (2017)

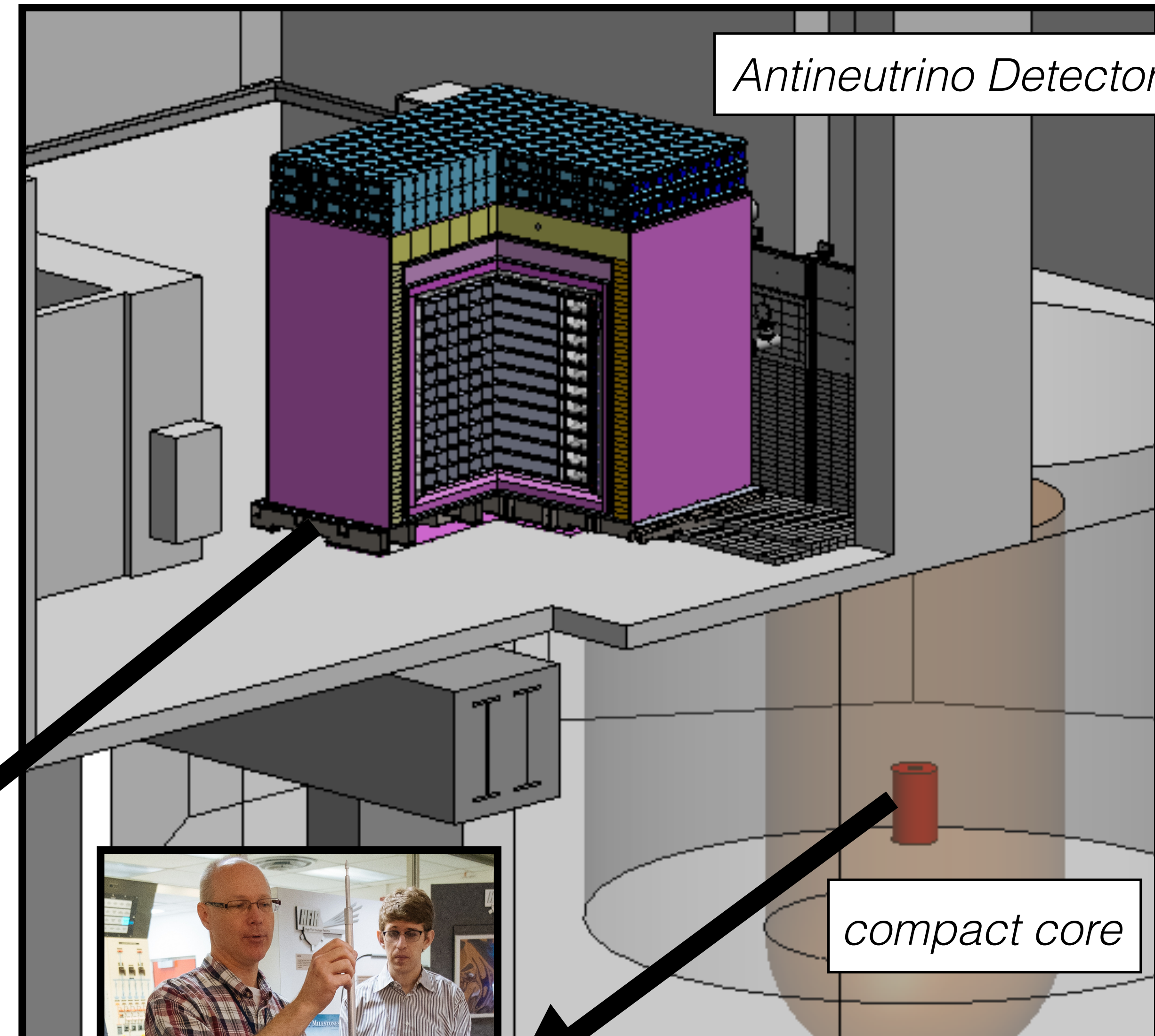


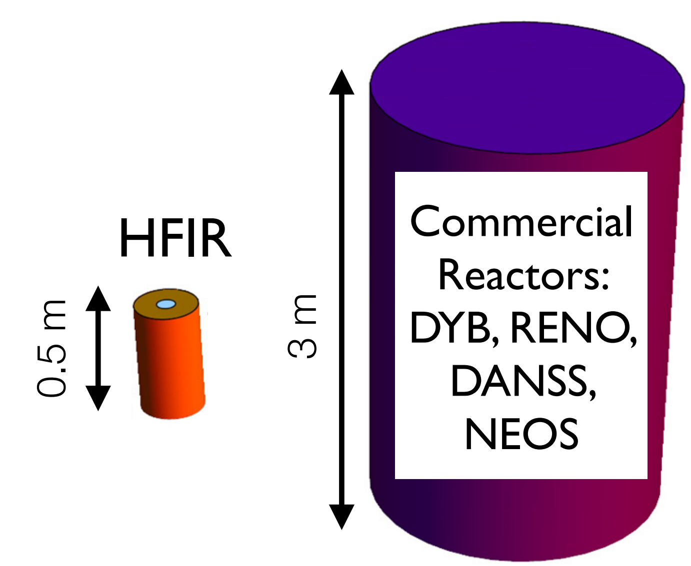
Huber and Jaffke, PRApp 8 (2017)



PROSPECT Experimental Layout

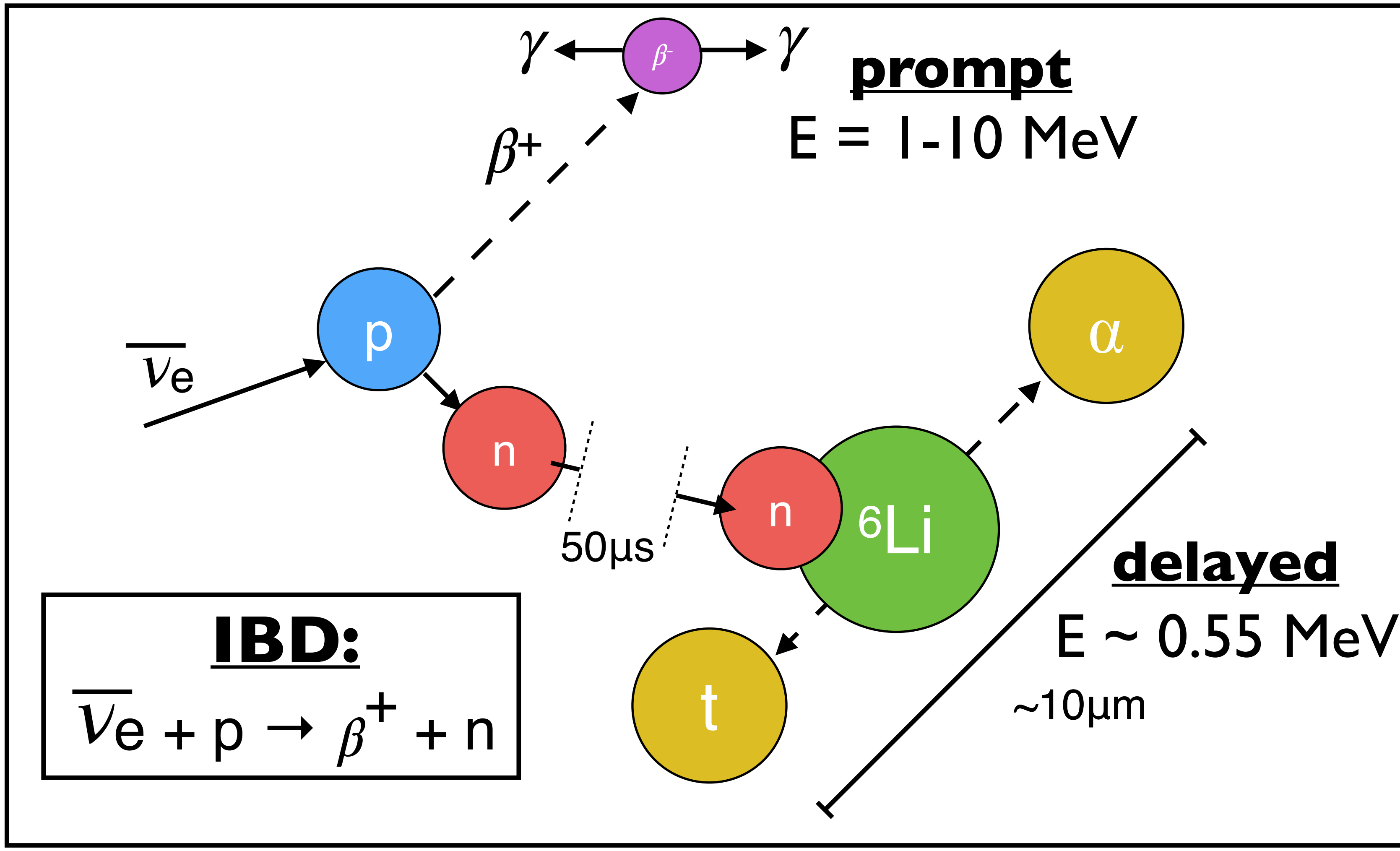
- A 4-ton ^{6}Li-doped PSD-capable segmented LS detector at the HFIR research reactor
  - HEU reactor: HFIR burns only ^{235}U
  - Very short baseline: 6.7-9.2 meters
  - Compact core: <50cm height, diameter
  - Challenging environment: <1mwe overburden, copious reactor γ



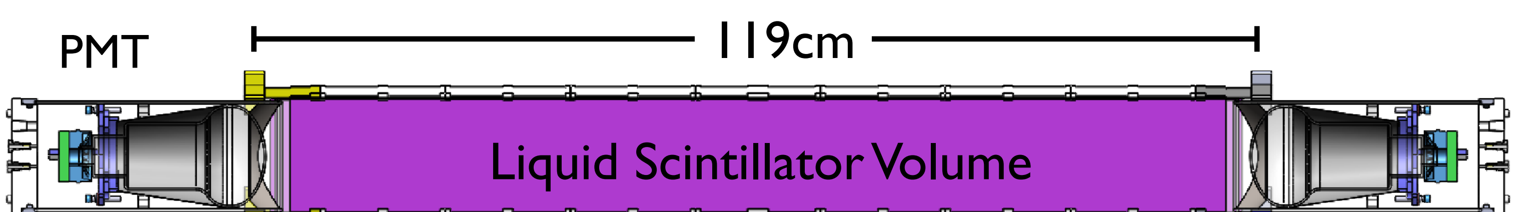


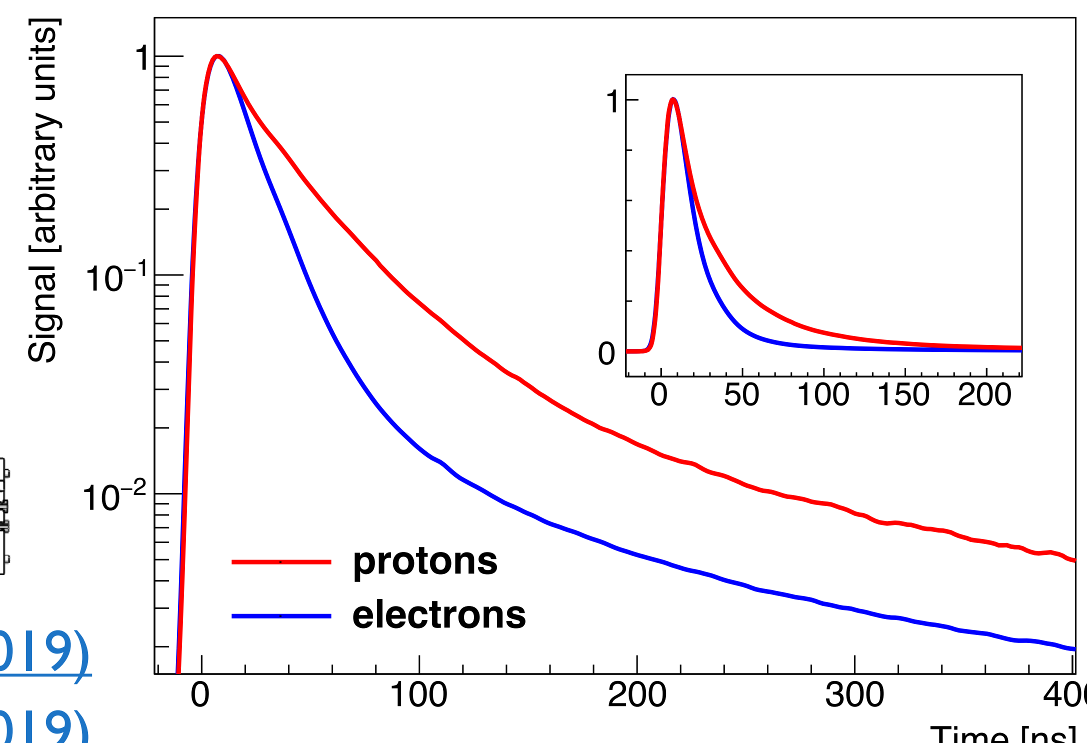
PROSPECT Design Features

- Detect $\overline{\nu}_e$ inverse beta decays (IBDs)
- Prompt e^+ provides $\overline{\nu}_e$ energy estimate
- Localized n-^{6}Li capture signal
- Prompt, delayed pulse shapes differ from most common background classes



- Segmentation enables baseline determination and topology cuts



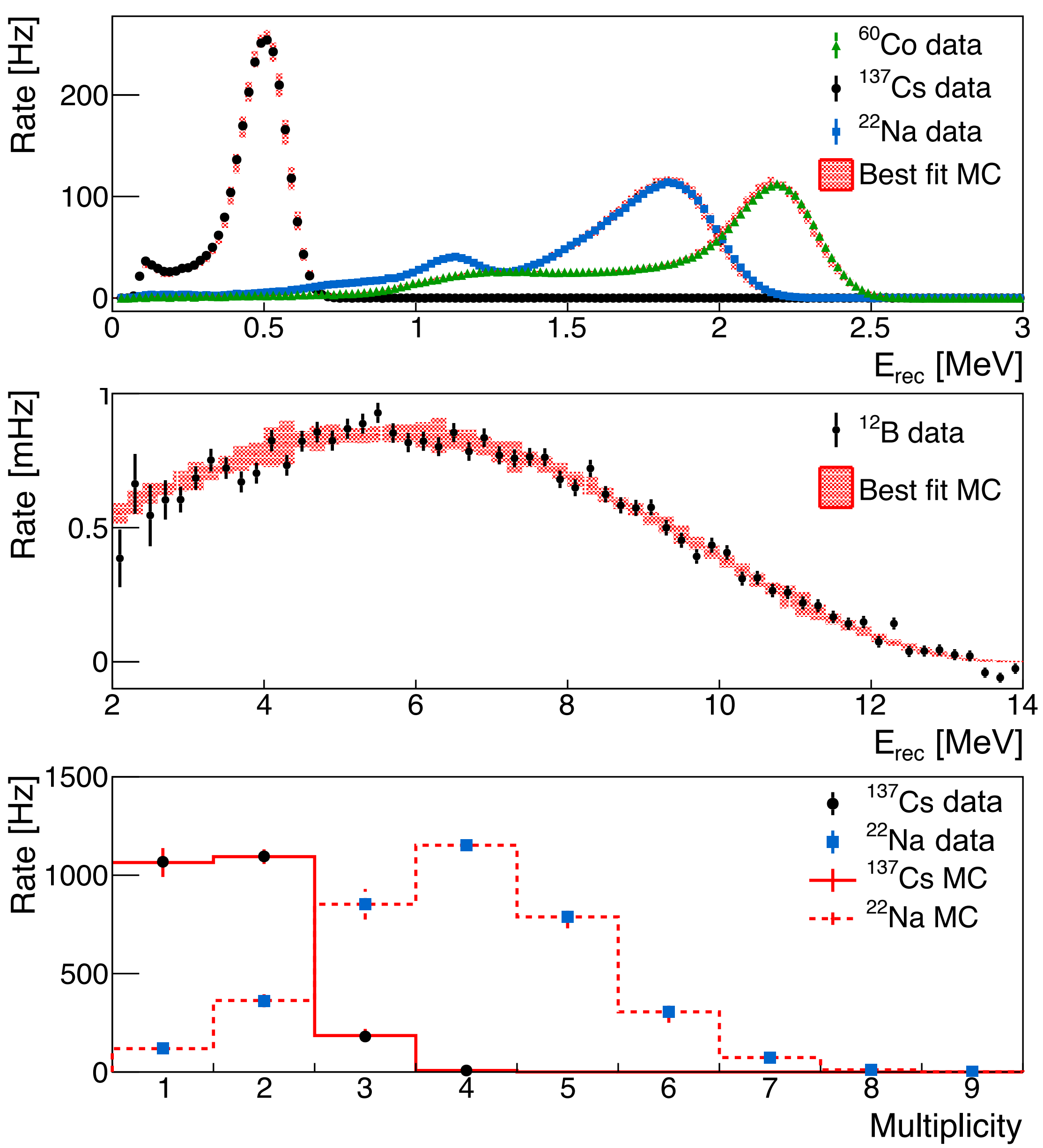


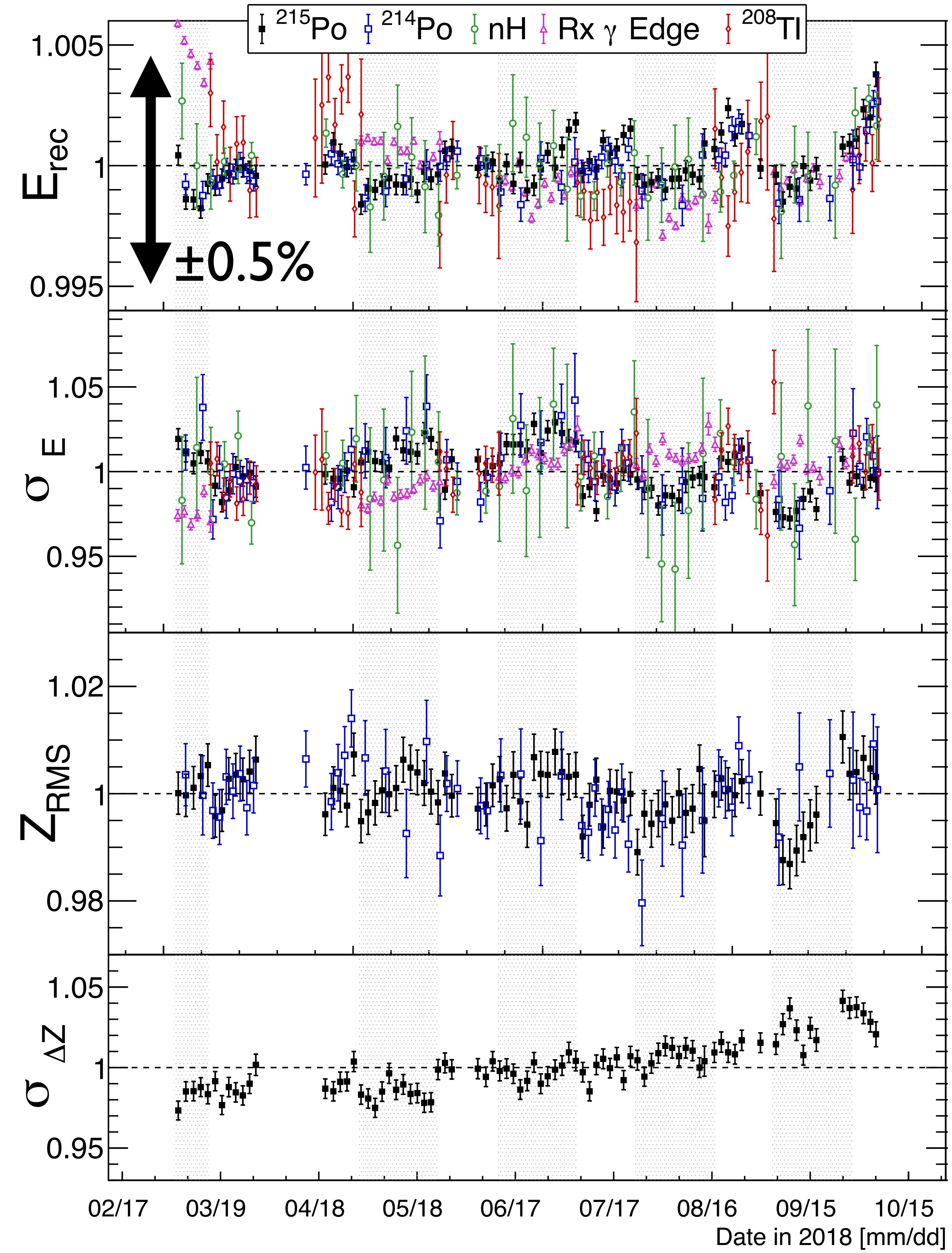
PROSPECT, NIM A 922 (2018) PROSPECT, JINST 14 P04014 (2019)
PROSPECT, JINST 13 (2018) PROSPECT, JINST 14 P03026 (2019)

Detector Calibration

X. Zhang: Poster #527

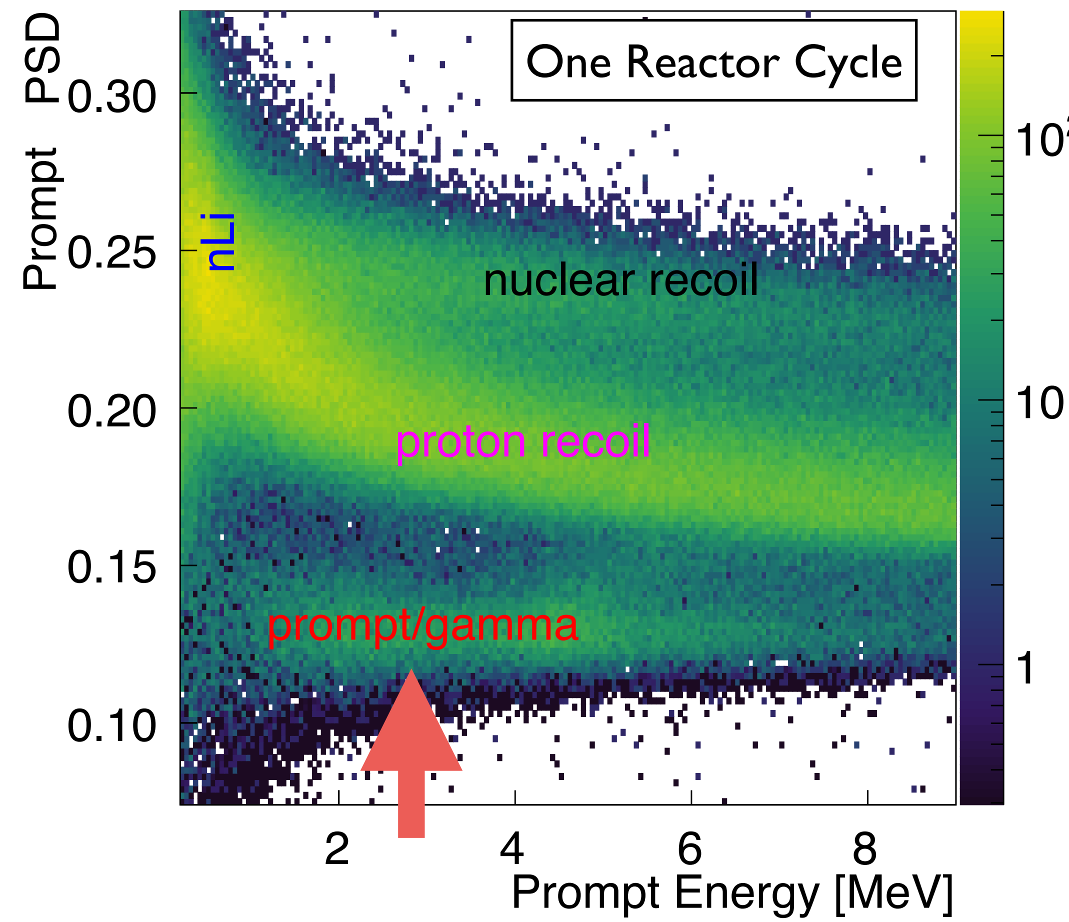
- %-level time/segment stability in reco positions, energies
- Robust (and essential!) MC model fully describes energy non-linearity and leakage

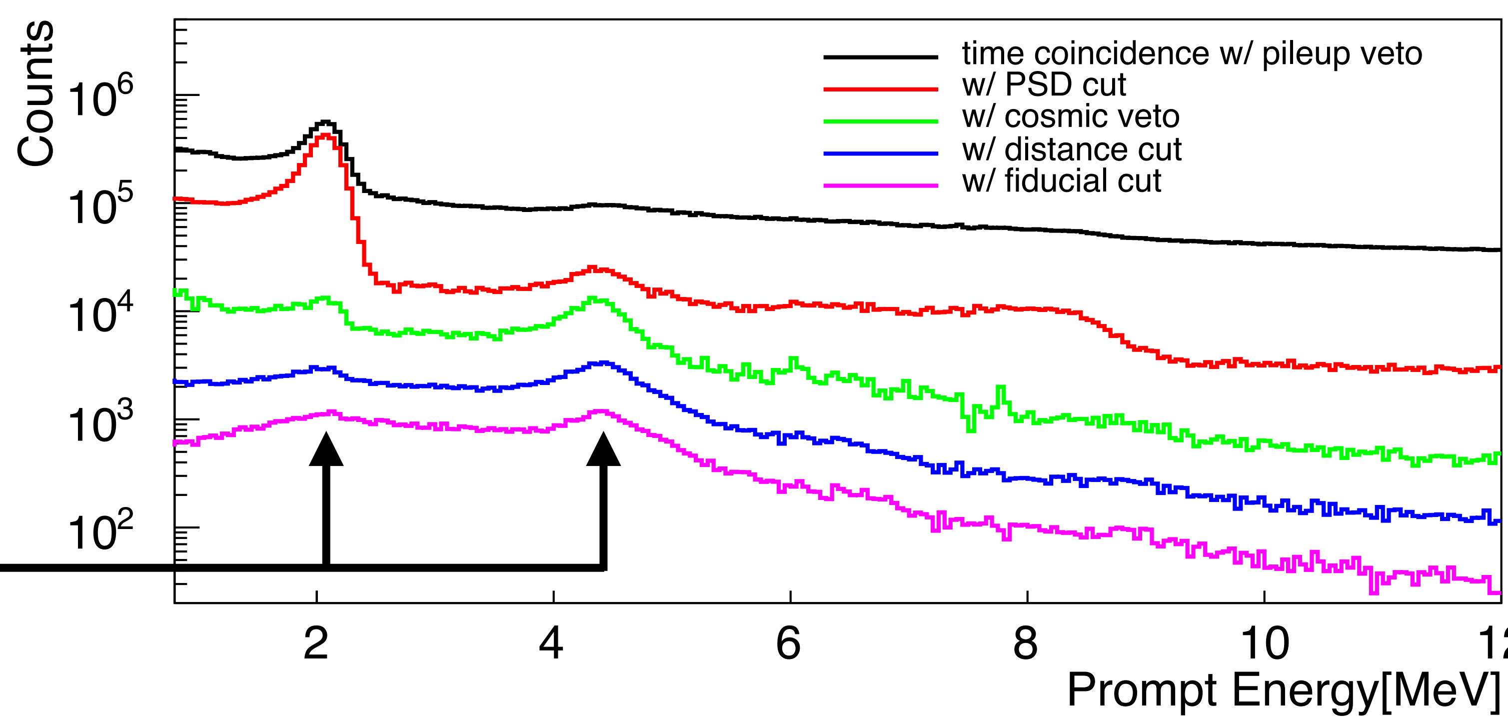


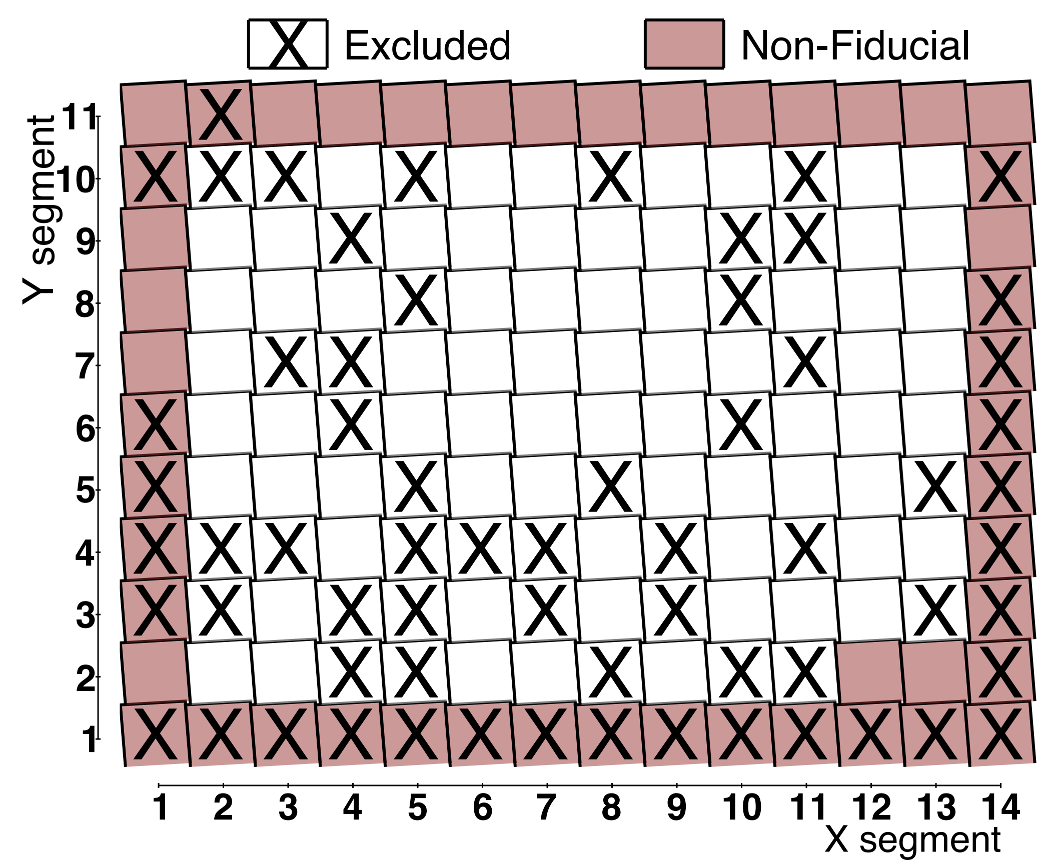


New Publication: IBD Selection

- 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
- Reject candidates from 36 fiducial segments experiencing PMT current instabilities
- Primary cosmic neutrons account for most of the remaining IBD-like background



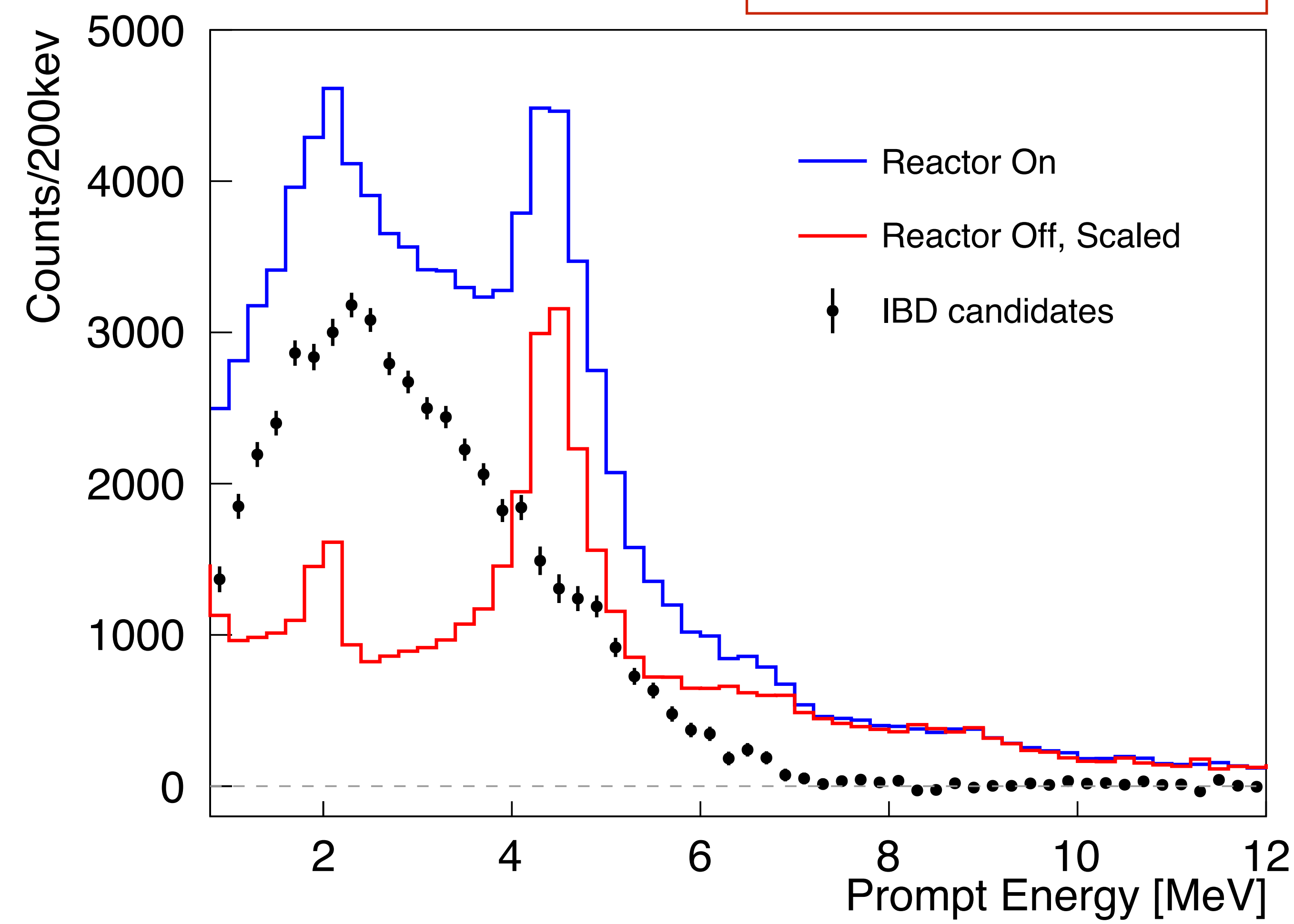


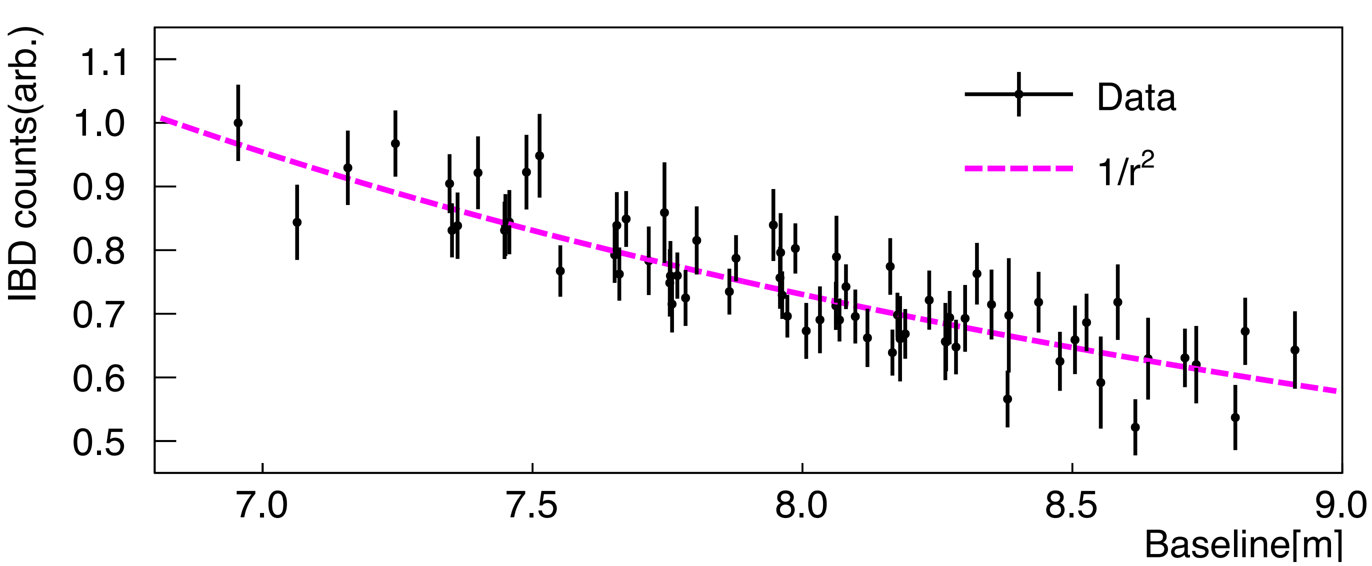


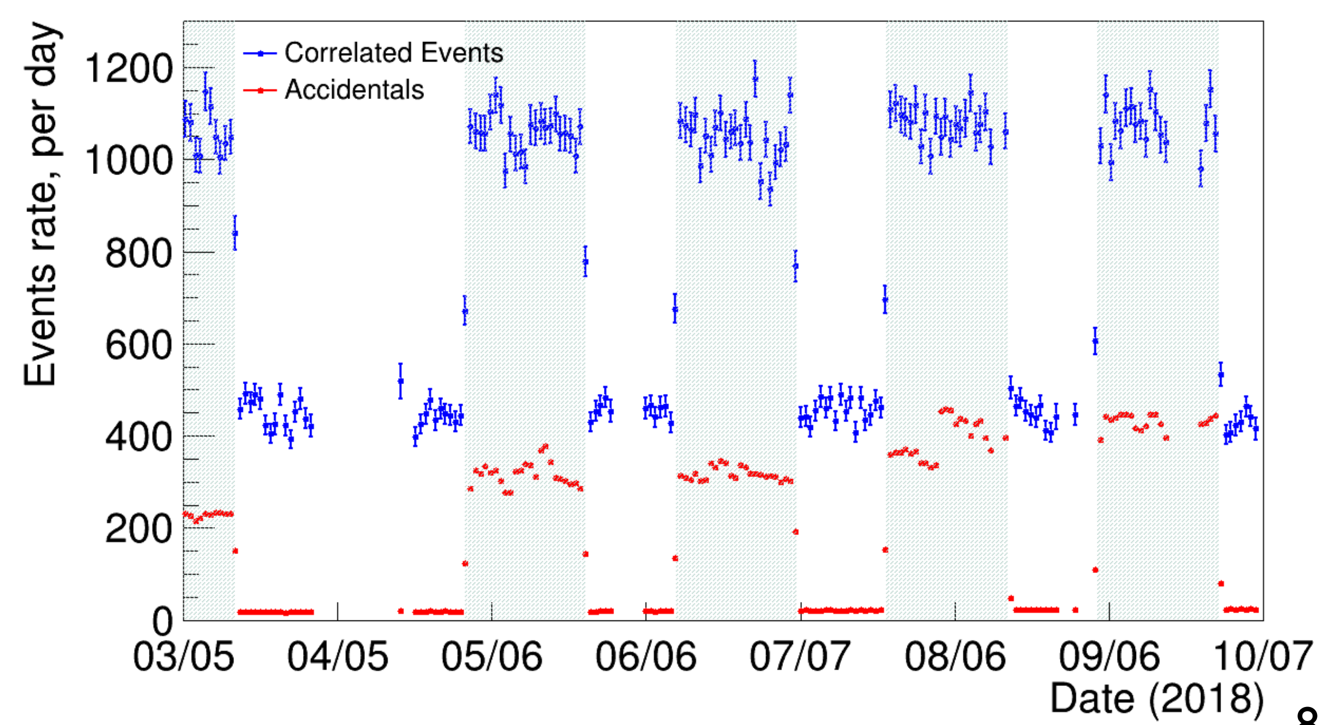
New Publication: IBD Dataset

X. Lu: Poster #158

- 95.65 reactor-on calendar days, 73.09 reactor-off
- Reactor-on excess in IBD candidates in ~1-7 MeV
  - 50560±406 IBD signal events
  - 28357±18 accidental bkg events
  - 36934±221 cosmic bkg events
  - 530 IBD signal per calendar day
- Signal follows $1/r^2$ trend

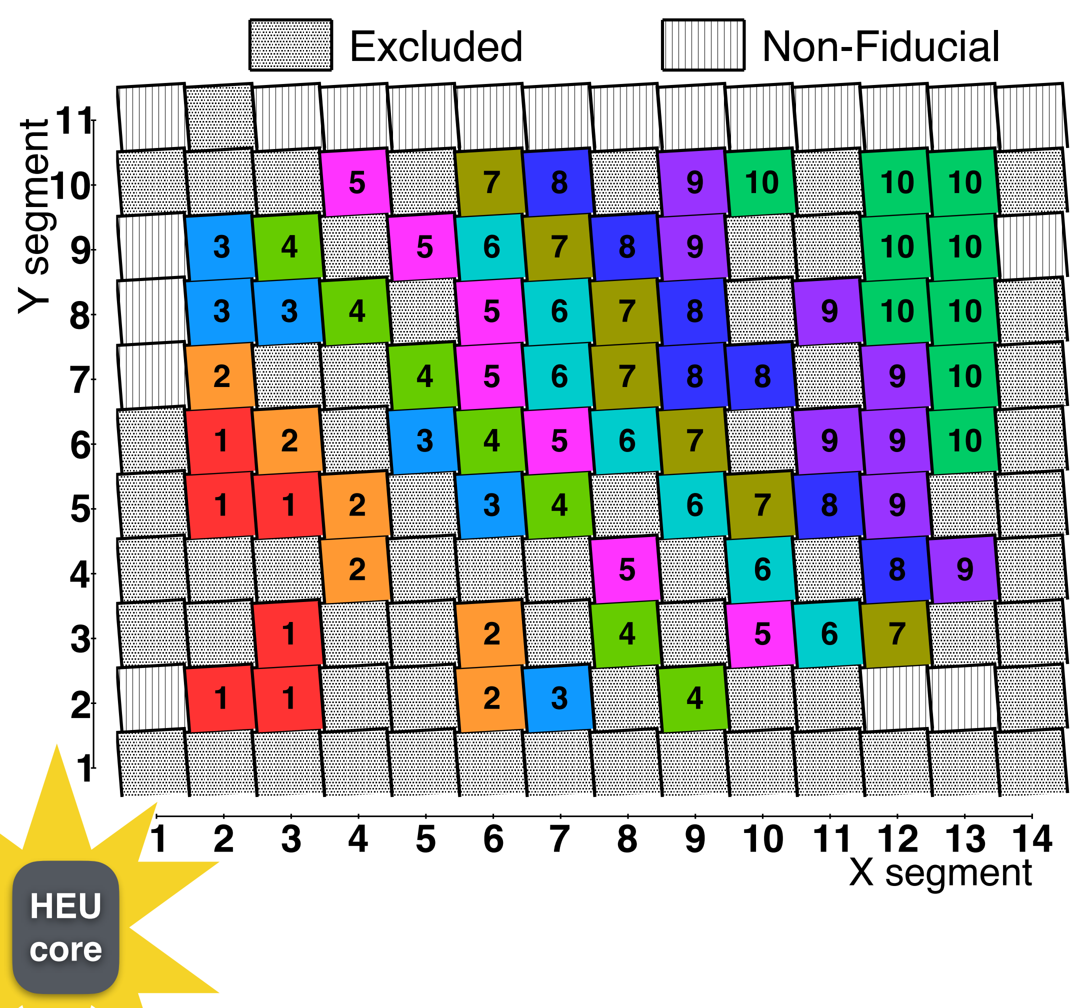


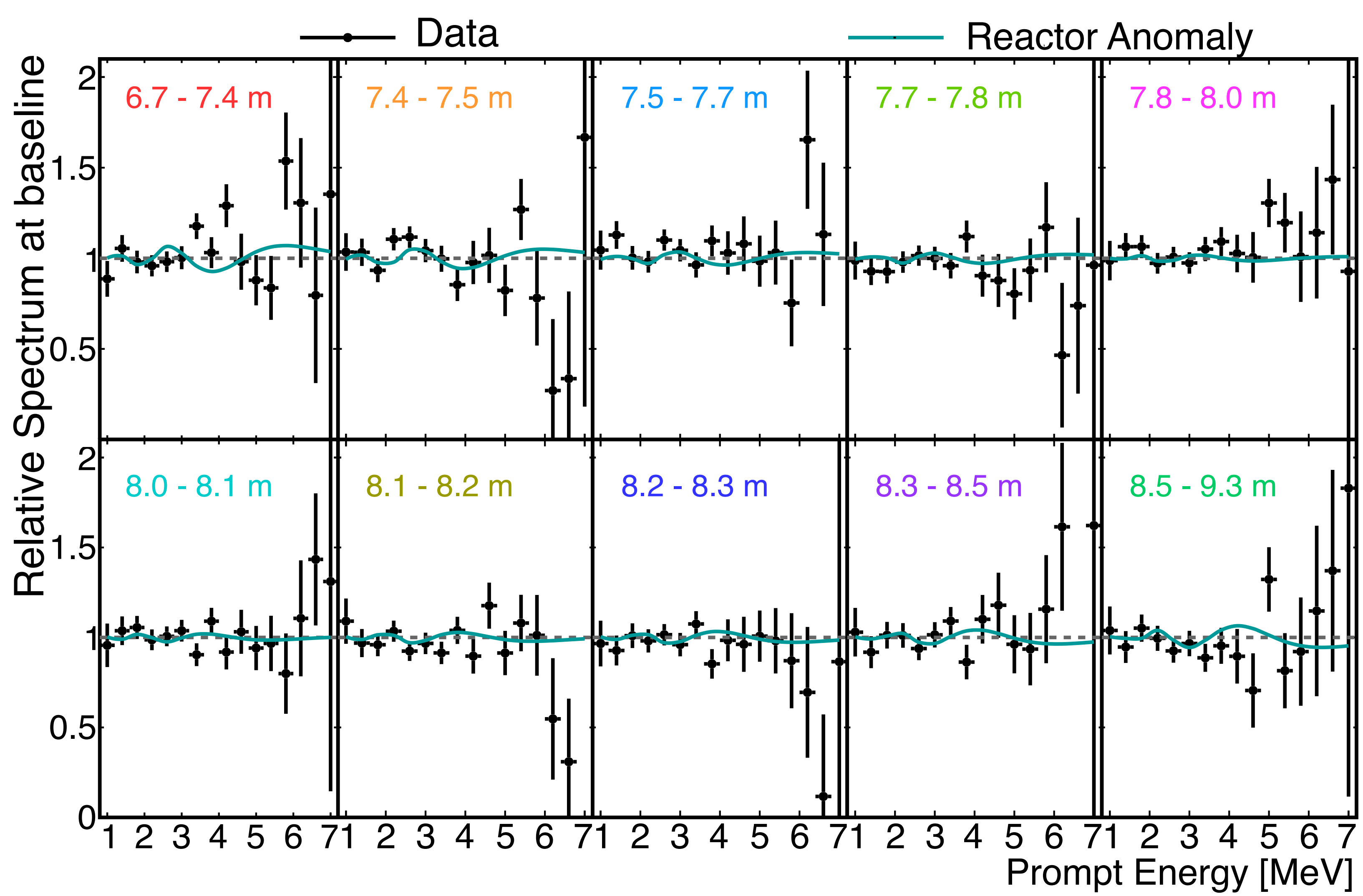




New Oscillation Search: Data

- Combine data into 16 energy, 10 baseline bins
- Remove reactor model dependence by dividing each baseline's measured energy spectrum by the full-detector spectrum
  - Also correct for MC-predicted difference in response between baseline bins
- No obvious deviations from flat no-oscillation scenario

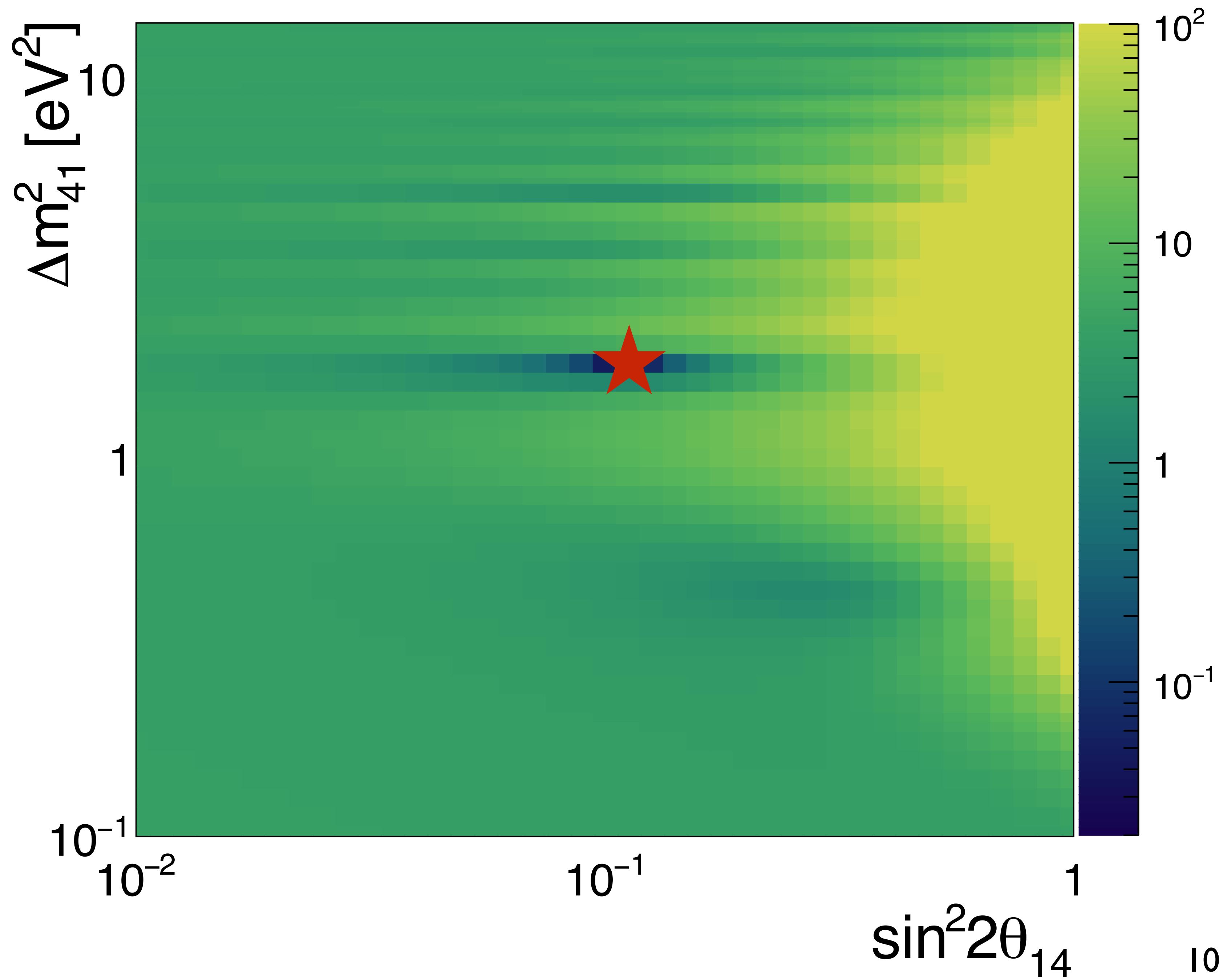




Oscillation Search: Results

J. Palomino-Gallo: Poster #408

- 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 $\mathbf{V_{tot} = V_{sys} + V_{stat}}$
  - 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



Oscillation Search: Results

PROSPECT

J. Palomino-Gallo: Poster #408

- Best-fit χ^2/NDF of 119.3/142
  - Null (reactor antineutrino anomaly) oscillation is 4.0 (15.8) higher in χ^2
- What does this mean?
  - Do we rule out null oscillations?
  - Do we rule out reactor anomaly best-fit?

Reactor Anomaly Best-fit

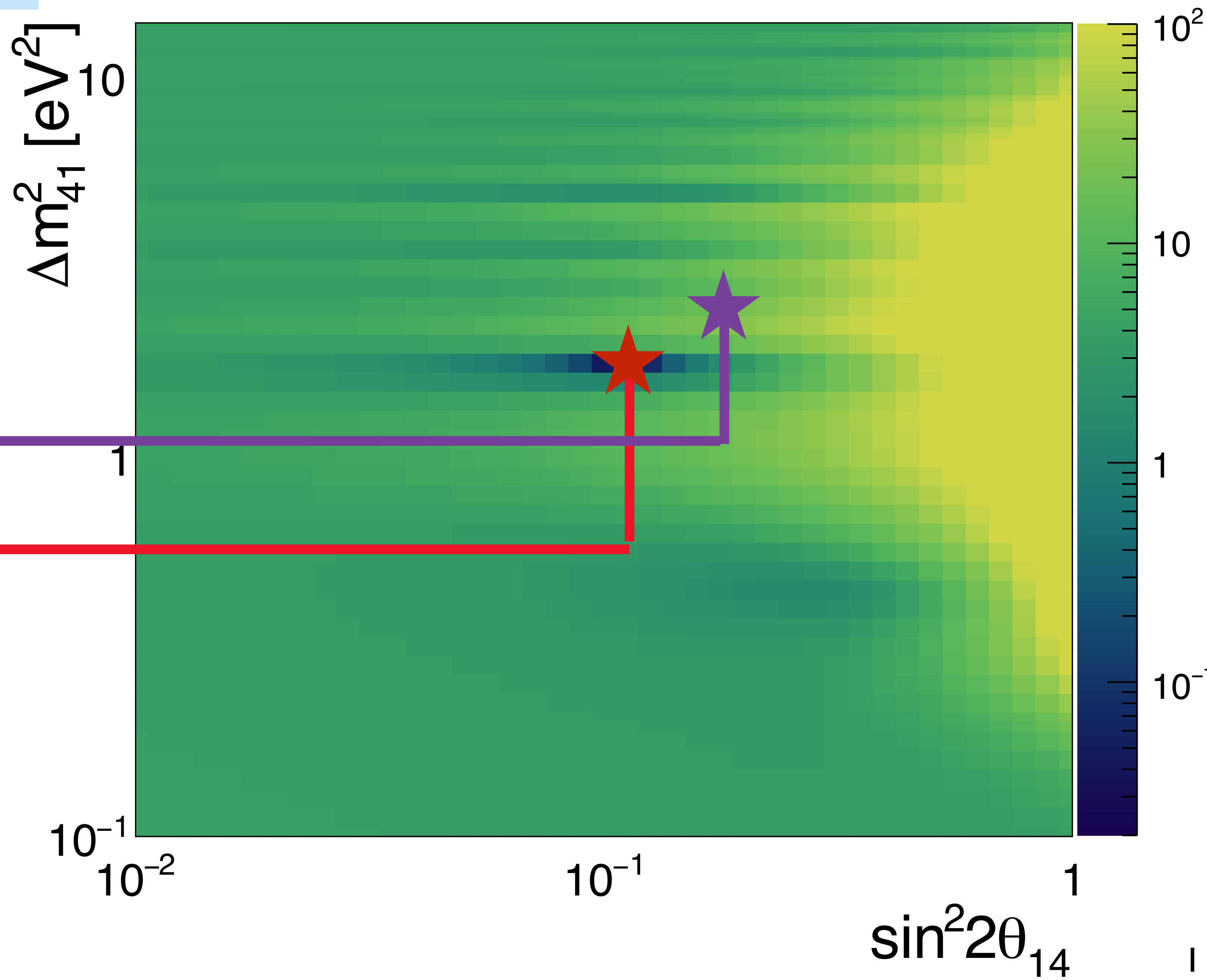
$\chi^2 = 135.1$

Best-fit

$\chi^2 = 119.3$

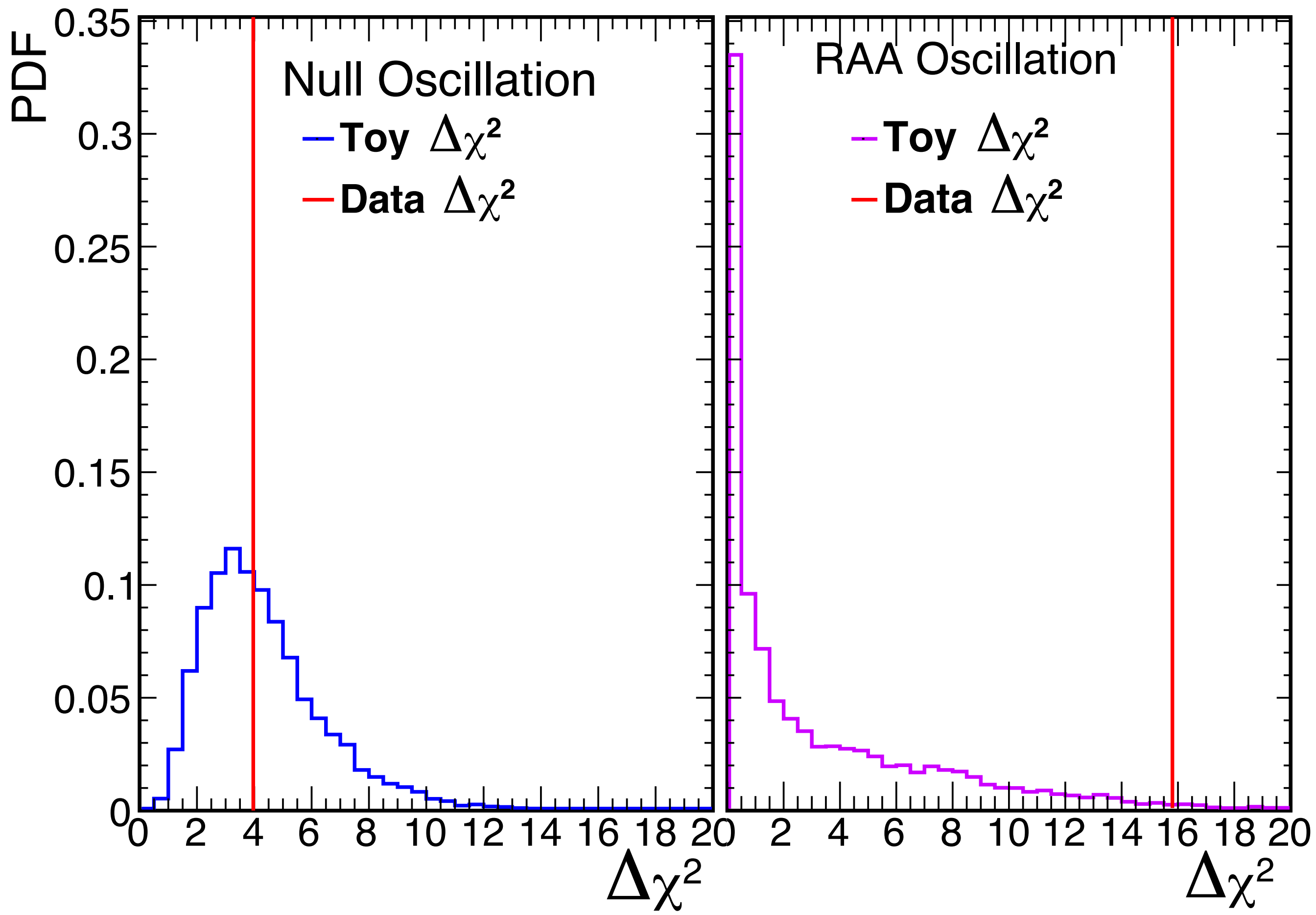
No oscillation

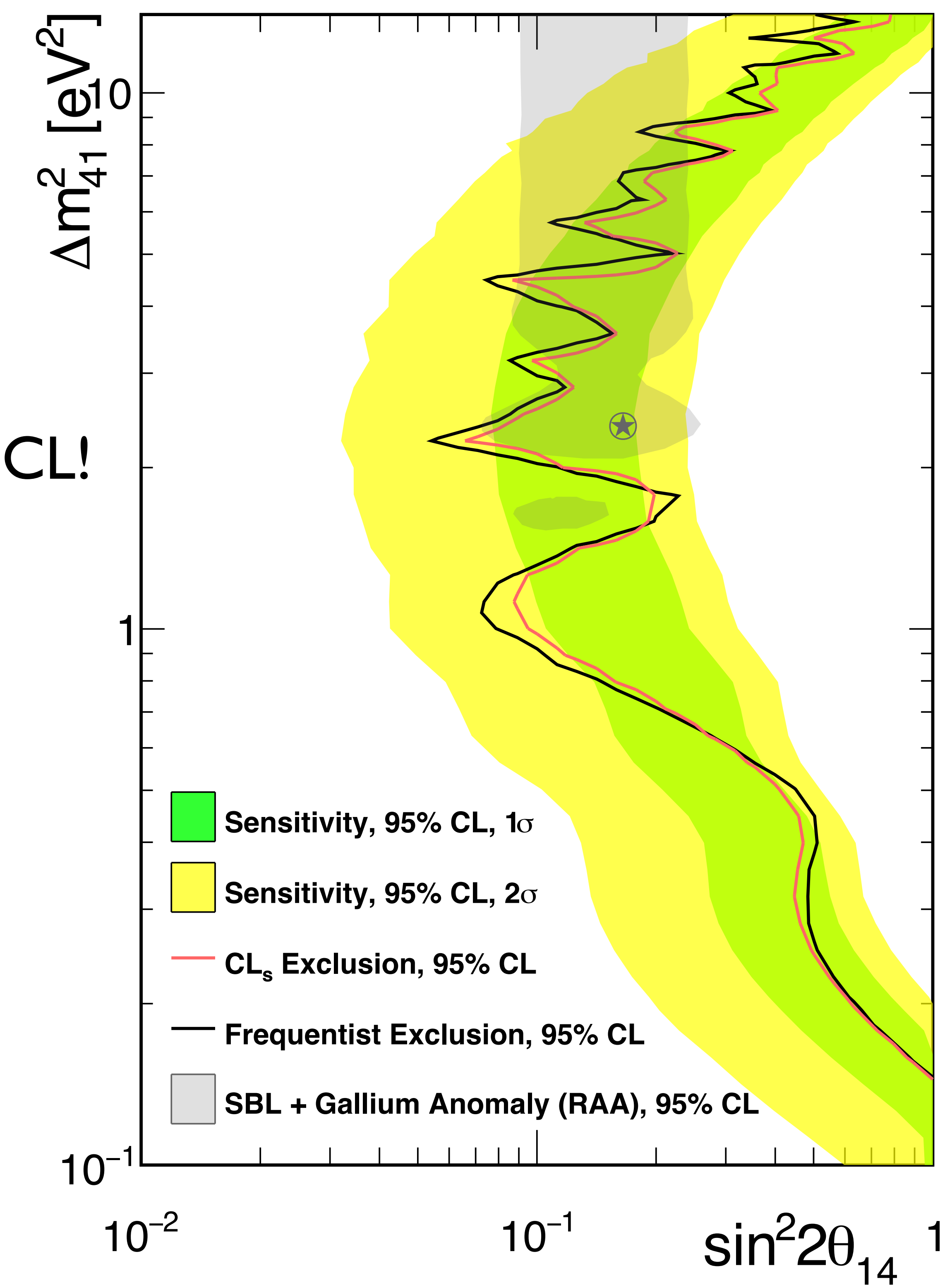
$\chi^2 = 123.3$



Sterile Search: Exclusion

- Use both Feldman-Cousins and 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)
- $\Delta\chi^2$ doesn't follow χ^2 distribution
  - Wilk's incorrectly 'excludes' RAA at 99.96% CL!

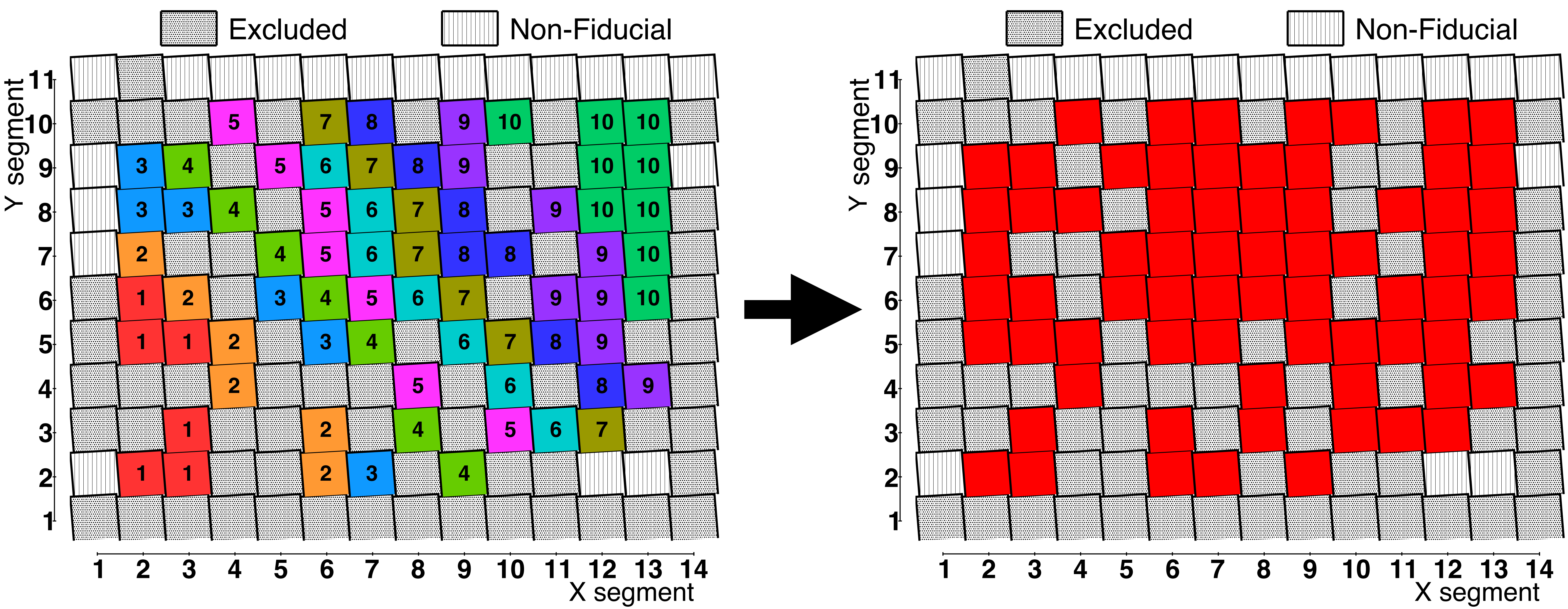




New ^{235}U Spectrum Measurement

B. Foust: Poster #516

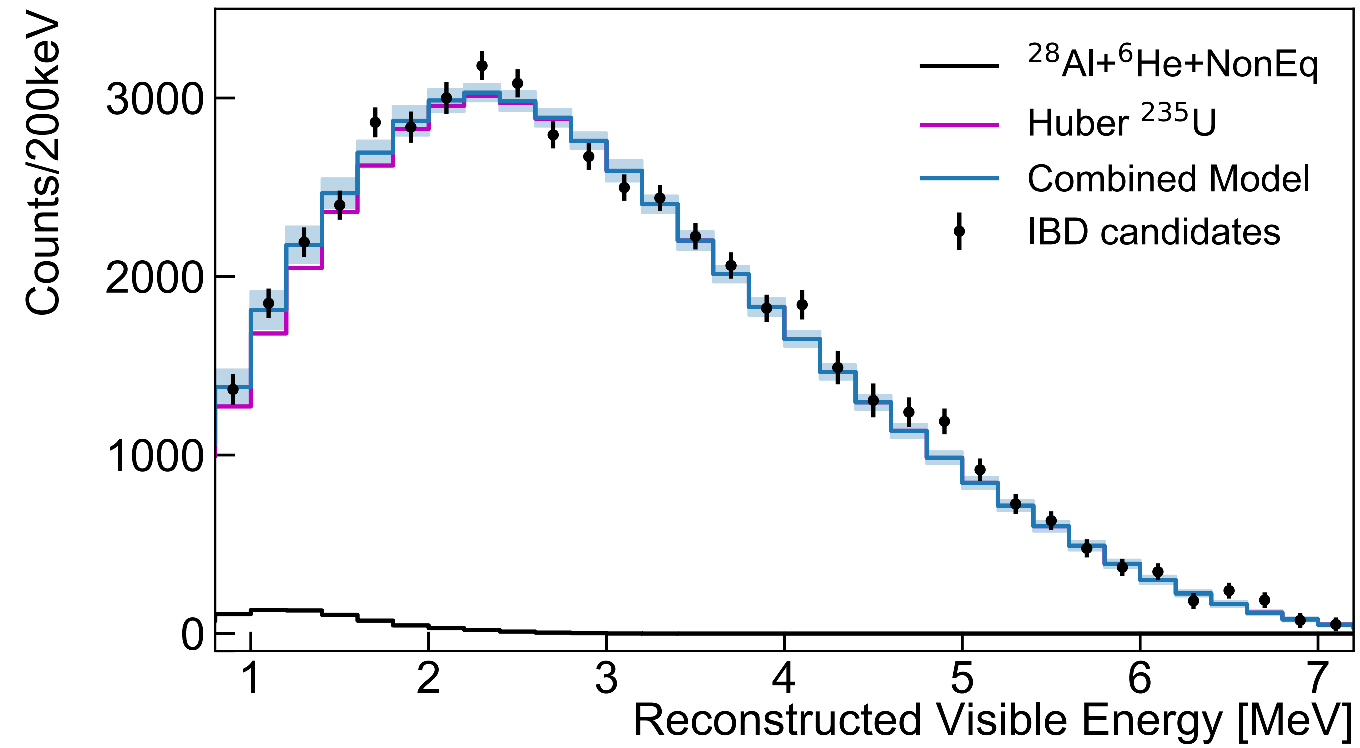
- Compared spectra between baselines for oscillation search
- Integrate all baselines to produce a pure measurement of the $\overline{\nu}_e$ energy spectrum produced by ^{235}U fission products
- Compare integrated spectrum to $\overline{\nu}_e$ production models

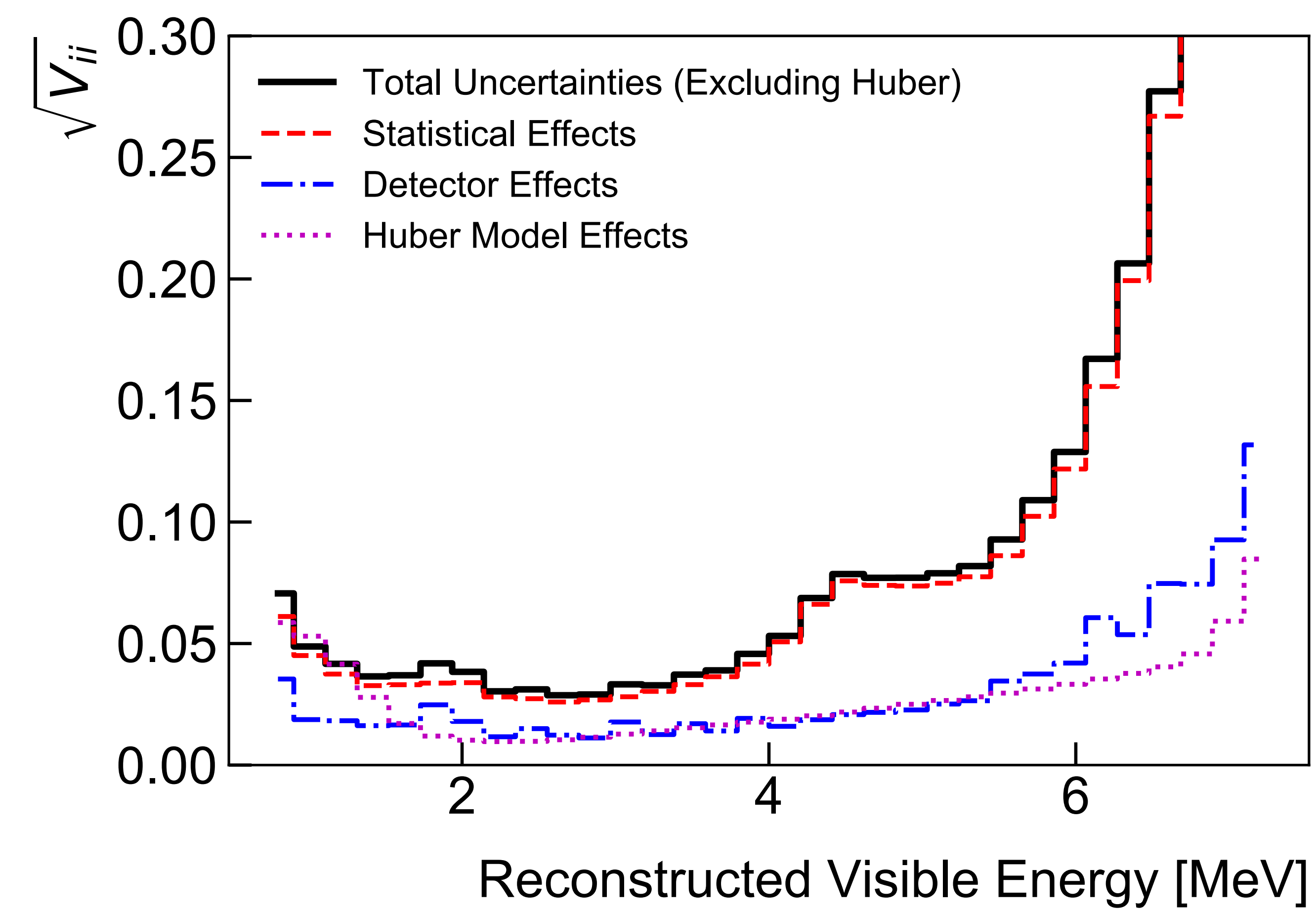


^{235}U Spectrum: Result

- **Improved ^{235}U $\bar{\nu}_e$ energy spectrum result**
  - 45% increase in IBD statistics over previous PRL

    PROSPECT, PRL 122 (2019)
  - More inactive segments produce increased cosmic background: signal:background ratio of 1.4
- **Statistical uncertainties still dominate total measurement precision**
  - Dominant systematic errors from energy non-linearity and dead mass uncertainties established with extensive calibration and MC simulation campaign

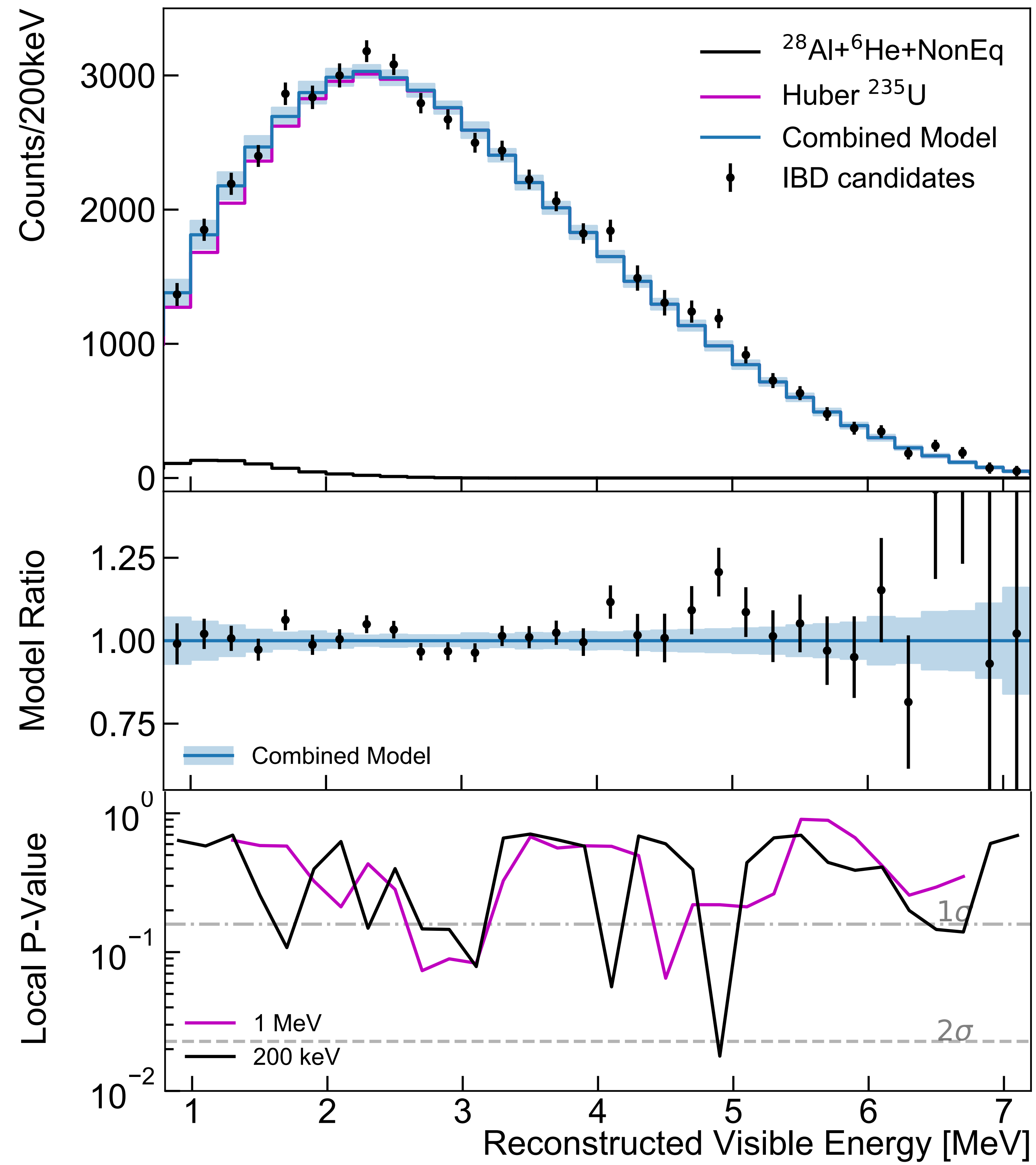




^{235}U Spectrum: Huber Comparison

- Q: Is PROSPECT consistent with Huber's ^{235}U model?
  - Must include corrections for non-equilibrium fission products and non-fuel $\bar{\nu}_e$ contributions

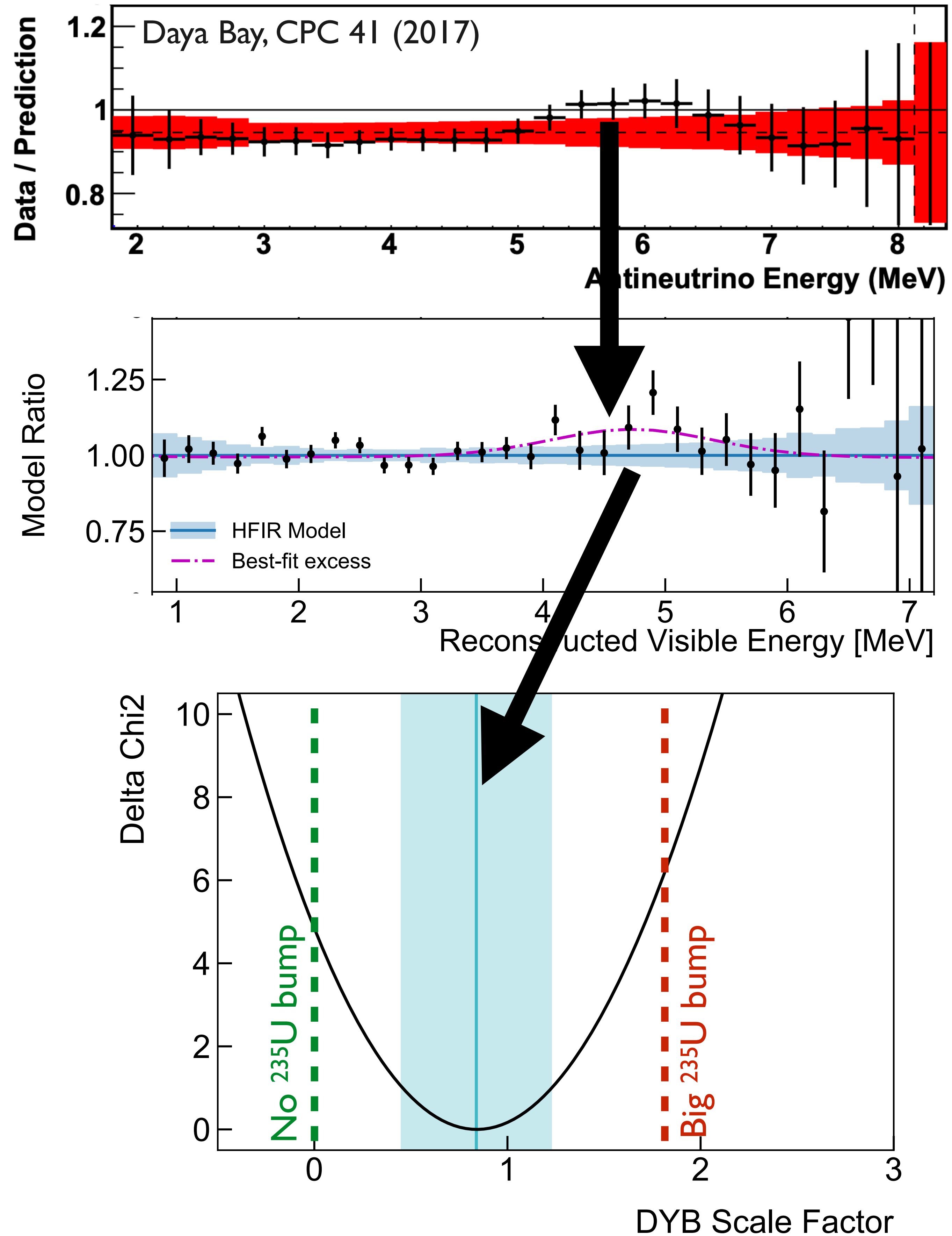
    PROSPECT, PRC 101 (2020)
  - Spectrum normalization is left as a free fit parameter
- χ^2/ndf = 30.79/31
  - Good data-model agreement across the full spectrum
  - A few local regions show modest model deviations



Probing Reactor Spectra

- Q: Does PROSPECT see 5-7 MeV bump observed at low-enriched reactors?
  - PROSPECT feature size with respect to Daya Bay: 84% ± 39%
  - ‘No ^{235}U bump’ scenario is disfavored at 2.2σ CL
  - Expect a ‘big bump’ (178%) in PROSPECT if ^{235}U is its sole producer: this is disfavored at 2.4σ CL

- PROSPECT and Daya Bay spectra are consistent with <u>all isotopes</u> playing equal roles in the 5-7 MeV data-model disagreement

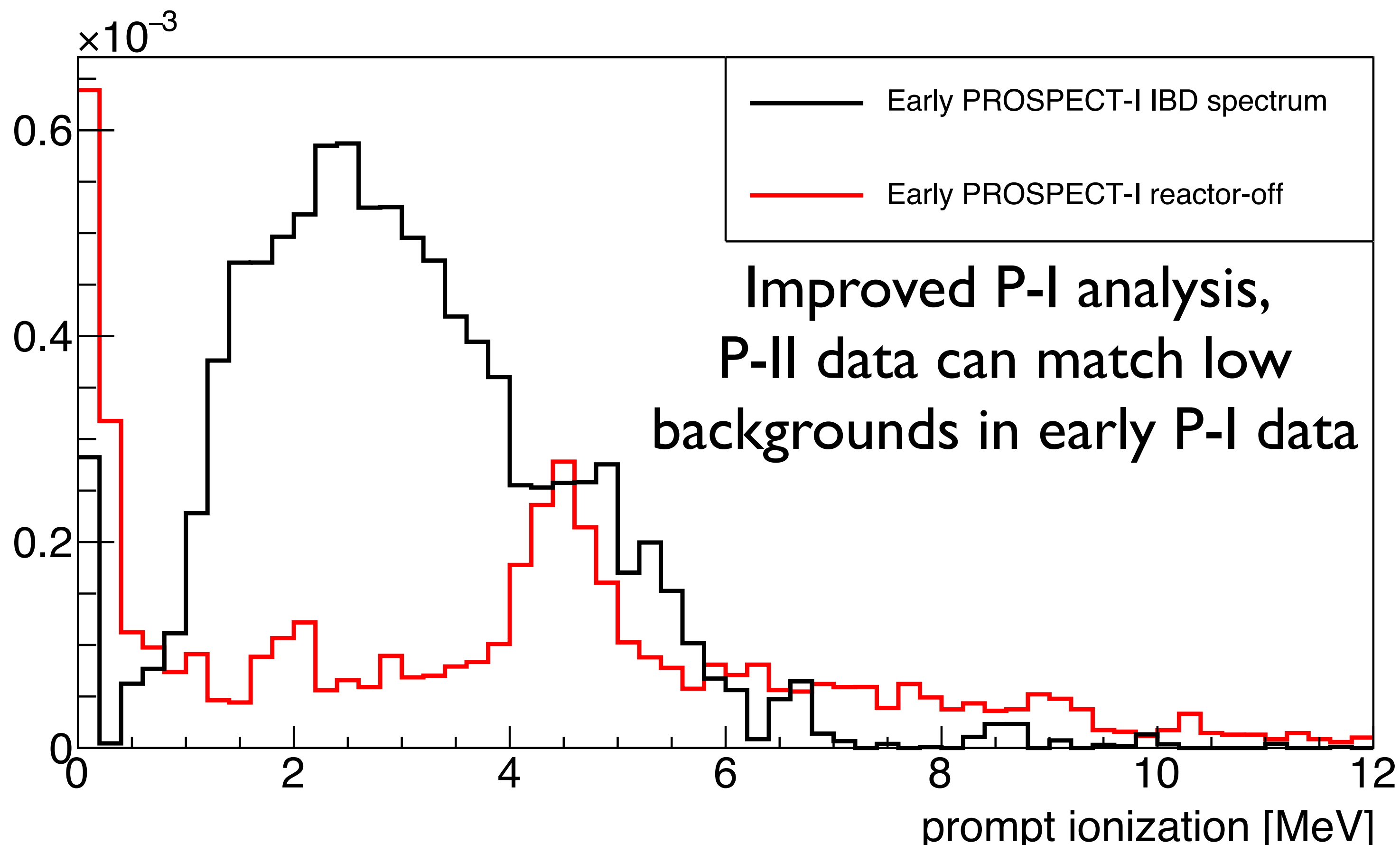


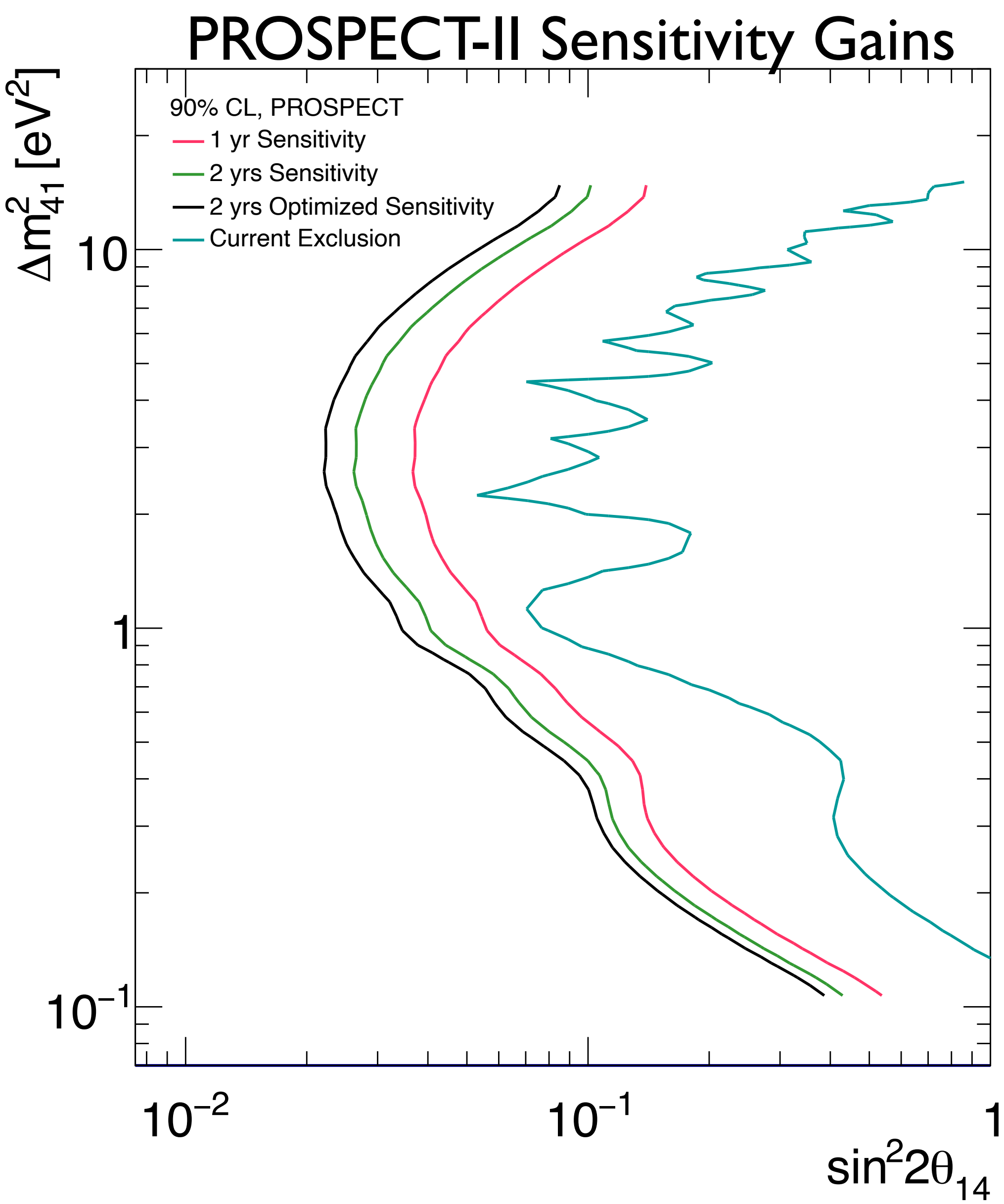
PROSPECT Prospects

J Gaison: Poster #556

P. Mumm: Poster #540

- PROSPECT will not take further data in its current form
- Improved analysis of the current dataset can enhance sensitivity
  - Expect up to 50% sterile osc improvement
- Joint analyses with Daya Bay and STEREO underway
- Pursuing upgraded deployment at HFIR that will address our primary physics limiter: total IBD statistics





Conclusions and Prospects

- An analysis of all PROSPECT reactor neutrino data has increased sterile neutrino sensitivity in the high-Δm^2 regime.
  - No evidence for sterile neutrino oscillations is found
  - The 'reactor antineutrino anomaly' best-fit is excluded at 2.5σ CL
- PROSPECT's measured ^{235}U $\overline{\nu}_e$ spectrum indicates data-model discrepancies similar to those measured at LEU experiments.
  - Supports idea that spectrum mis-modeling is present for all fission isotopes
  - Compared to this scenario, 'no ^{235}U bump' is disfavored at 2.2σ CL
  - We disfavor at 2.4σ CL ^{235}U being solely responsible for the LEU bump
- PROSPECT's current dataset will provide a substantially improved spectrum and oscillation measurement in the future
- PROSPECT is pursuing upgraded detector deployment at HFIR that will further increase its measurement precision

PROSPECT Collaboration, arXiv:2006.11210 (2020)

THANKS!

The PROSPECT Collaboration

J Gaison: Poster #556

P. Mumm: Poster #540

B. Foust: Poster #516

J. Palomino-Gallo: Poster #408

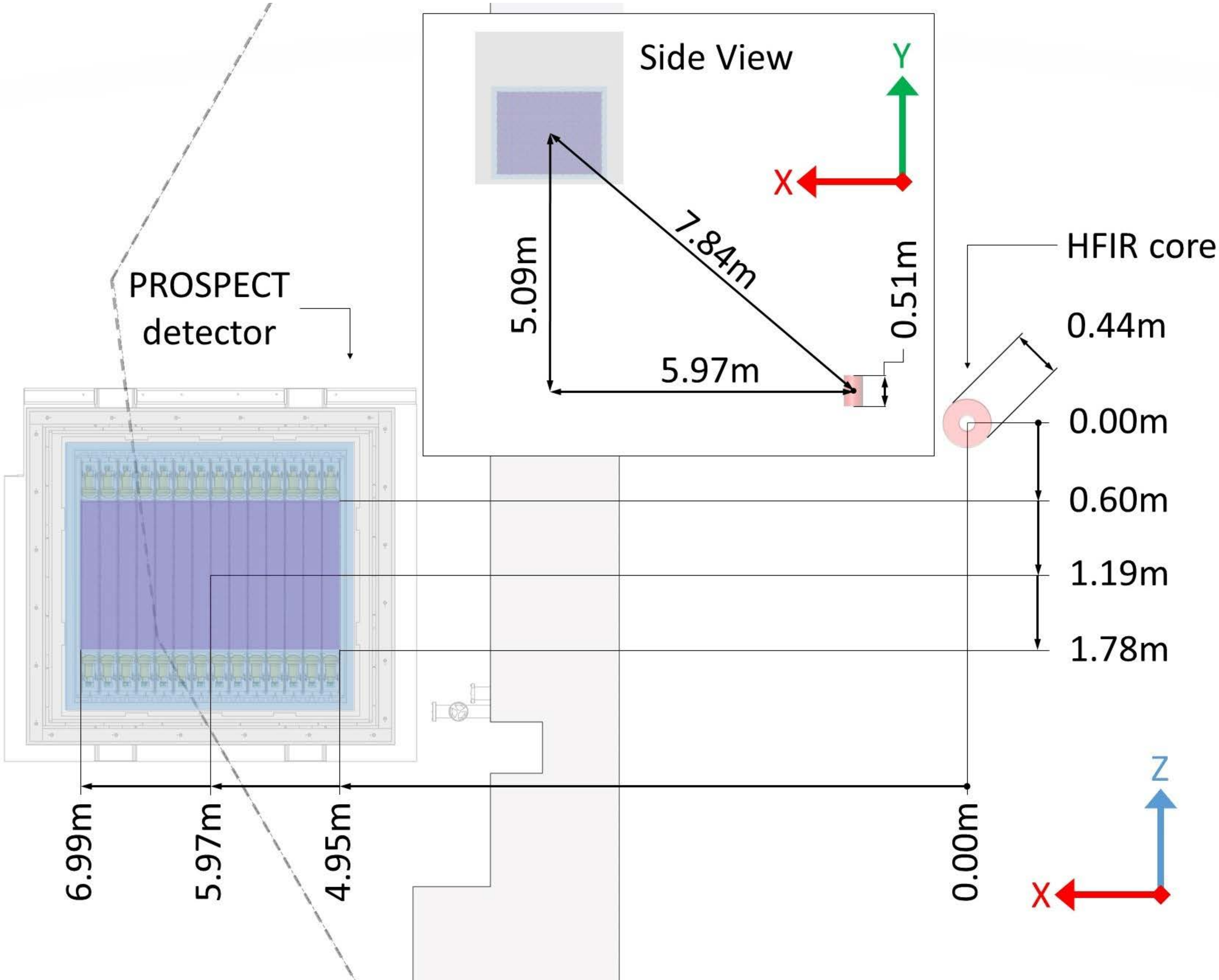
X. Zhang: Poster #527

X. Lu: Poster #158

HEISING-SIMONS FOUNDATION

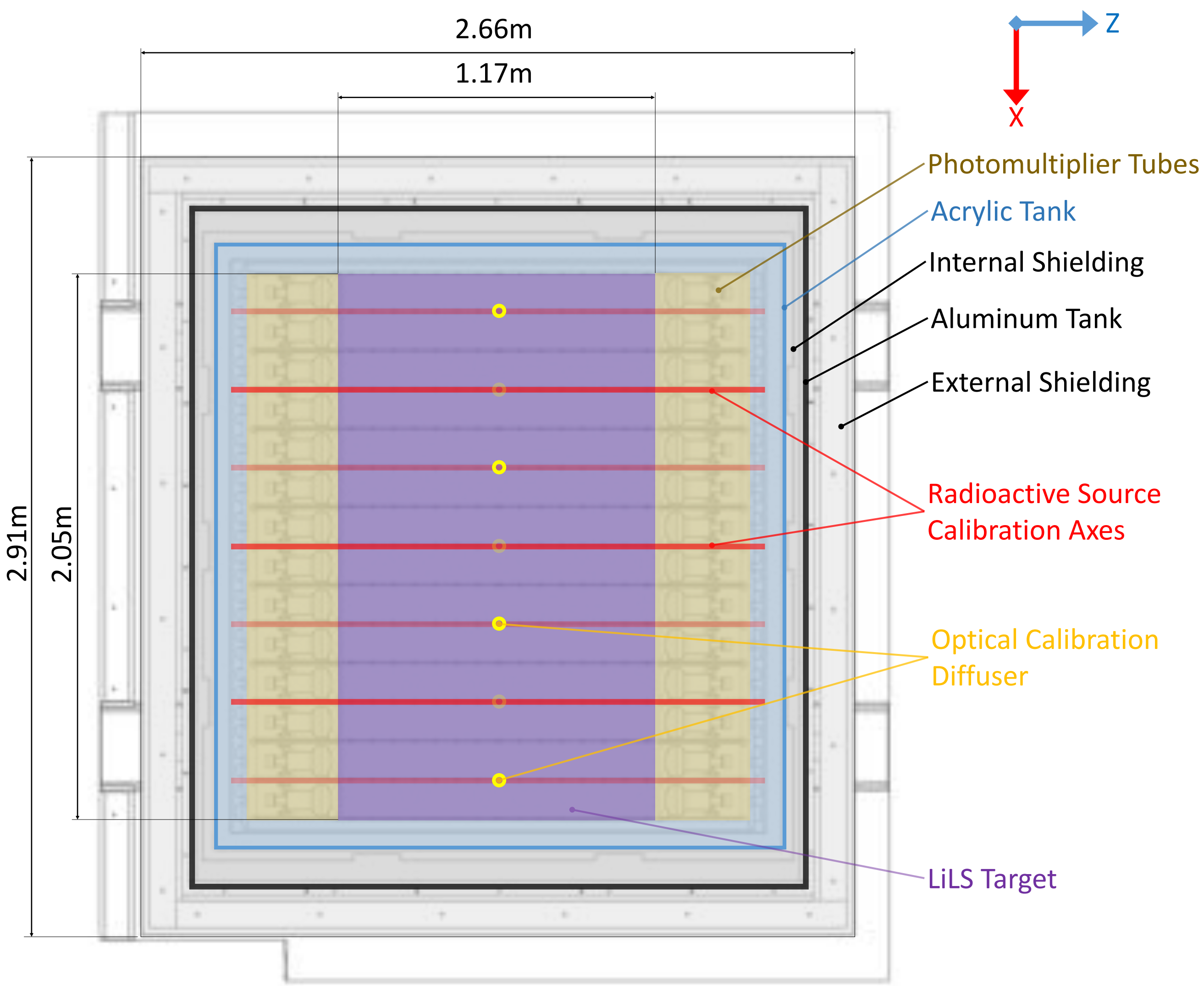
Backup

Experimental Layout

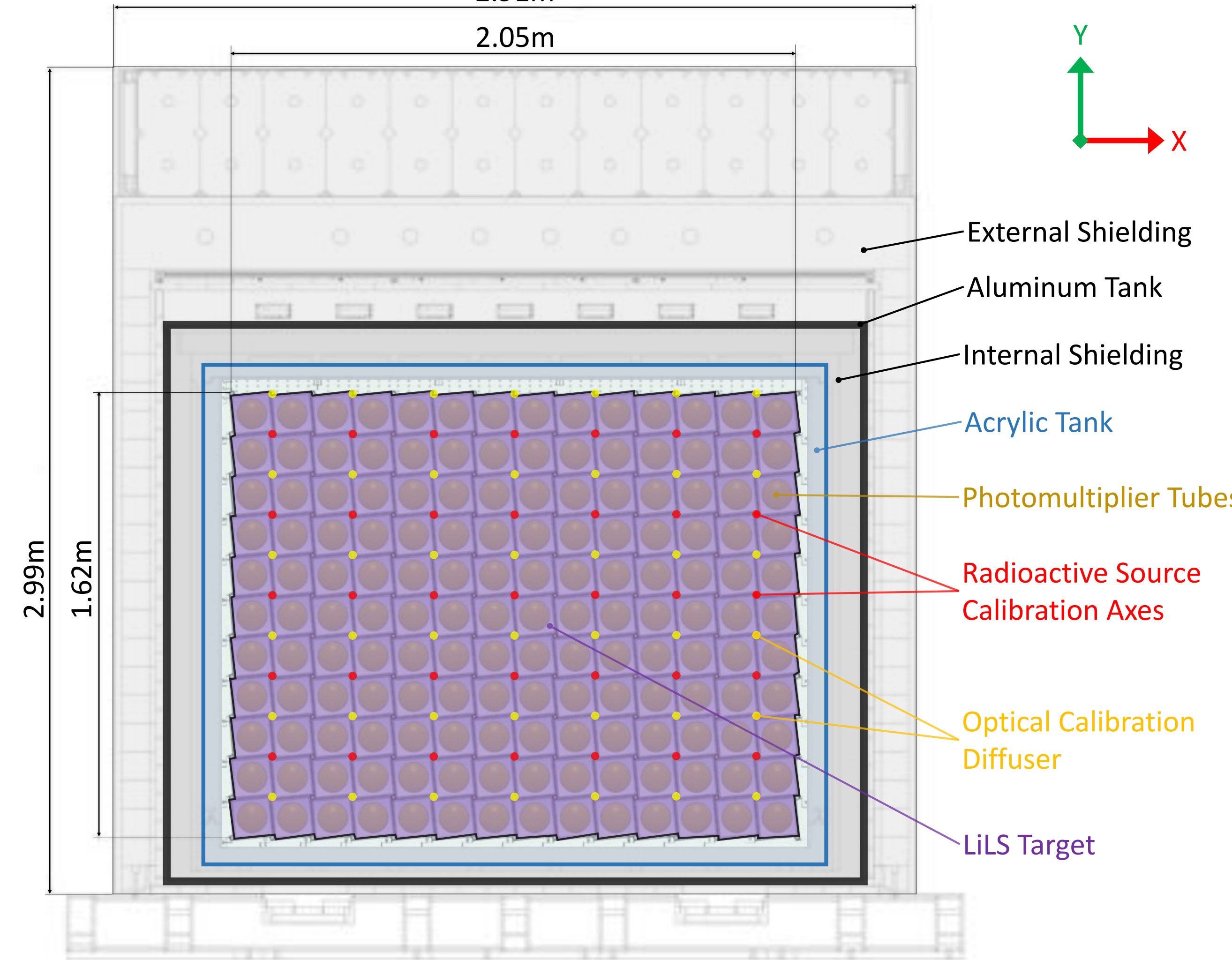


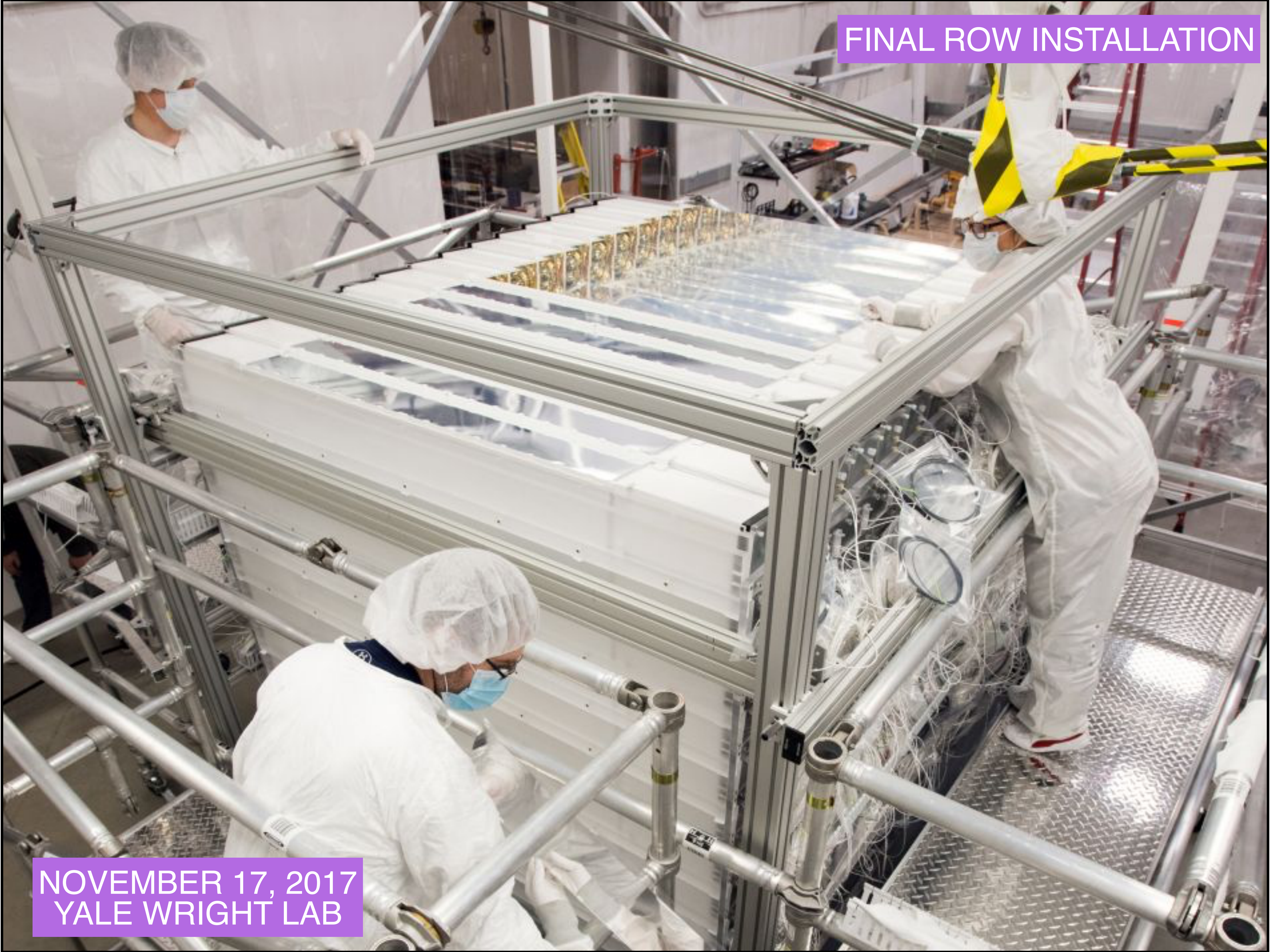
Detector Layout

Top View



Side View

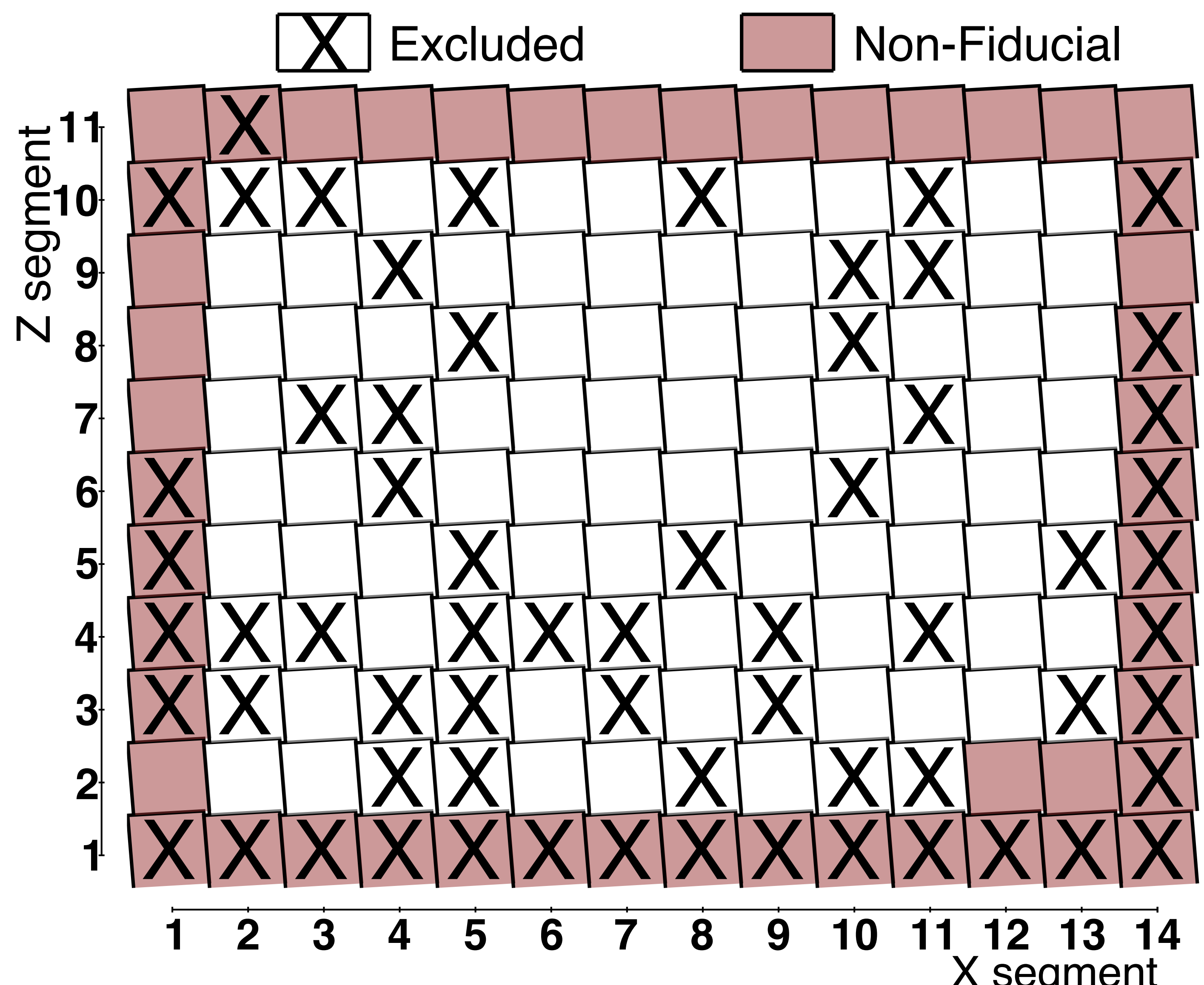



FINAL ROW INSTALLATION
NOVEMBER 17, 2017
YALE WRIGHT LAB


FEBRUARY 2018
ARRIVAL AT ORNL
IN POSITION AT HFIR
BEFORE SHIELD
YALE
DANGER
TARE
NOMINAL
CAPACITY
4 BAR
FILLING FROM
MIXING TANK
FIRST MUON TRACK

Excluded Segments

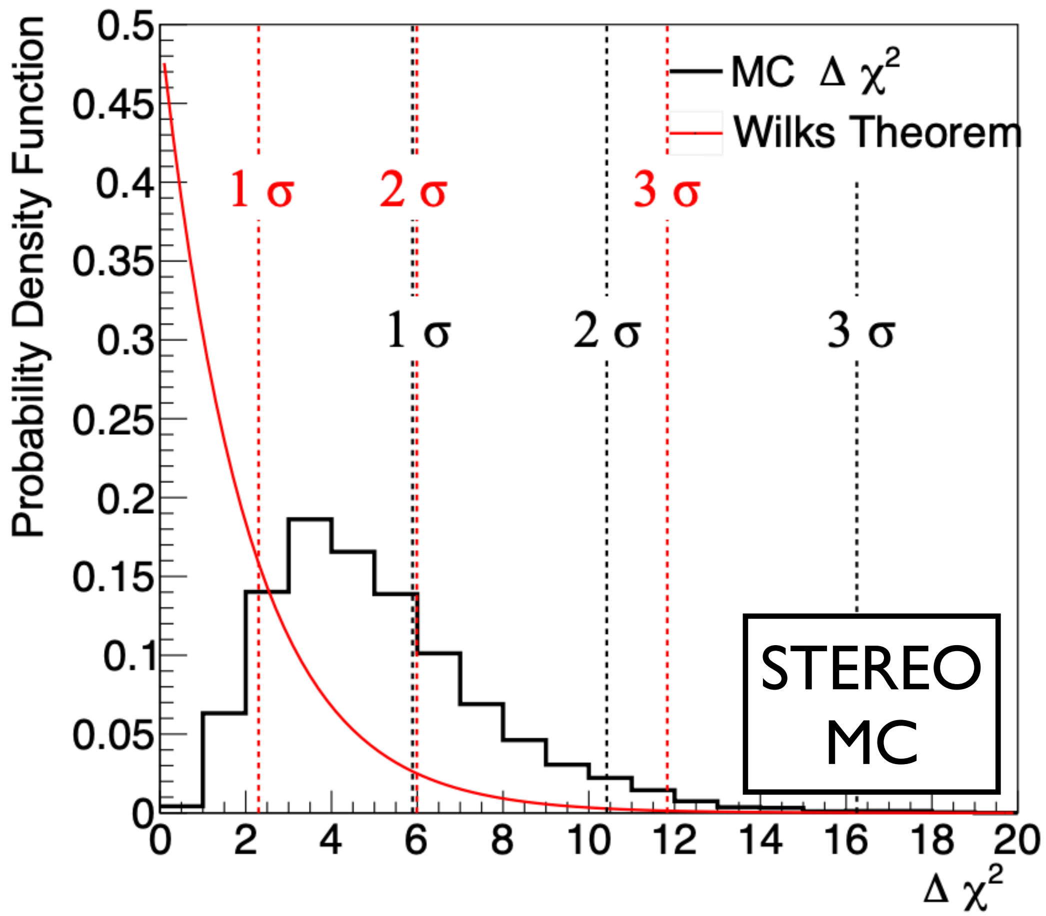
- In prototype detector dis-assembly and in PROSPECT detector data, we observe evidence of LS ingress into sealed mineral oil-filled PMT housings
- LS interacts with circuitry in the bare voltage divider, reducing its ability to hold PMTs at their designed voltages
- Any PMTs exhibiting this anomalous behavior were turned off
- Most 'inactive segments' have one operational PMT; this should enable future use of these segments for further background rejection and possibly IBD identification

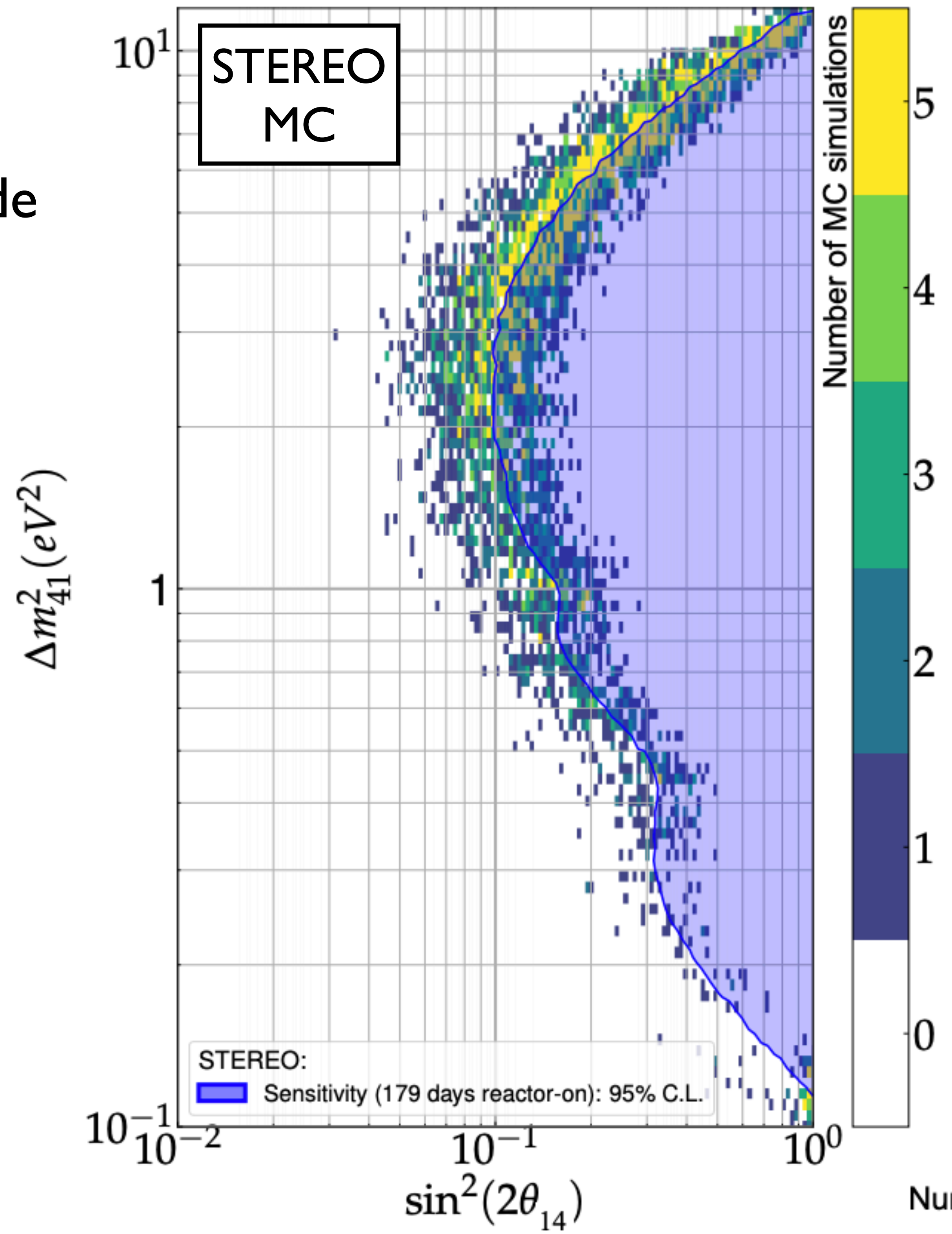


Sterile Best-Fits and CL Assignment

PROSPECT and STEREO, hep-ex[2006.13147]

- Sterile best-fits for null-osc datasets <u>often occur</u> in regions of high frequency/amplitude
- Thus, care in assigning CL is key!
  - Wilk's theorem approach will not provide proper CL. Particularly true for small or <u>**high frequency**</u> oscillations
  - Wilk's over-estimates null-osc exclusion by ~1σ; so 2.8σ is more like <2σ…

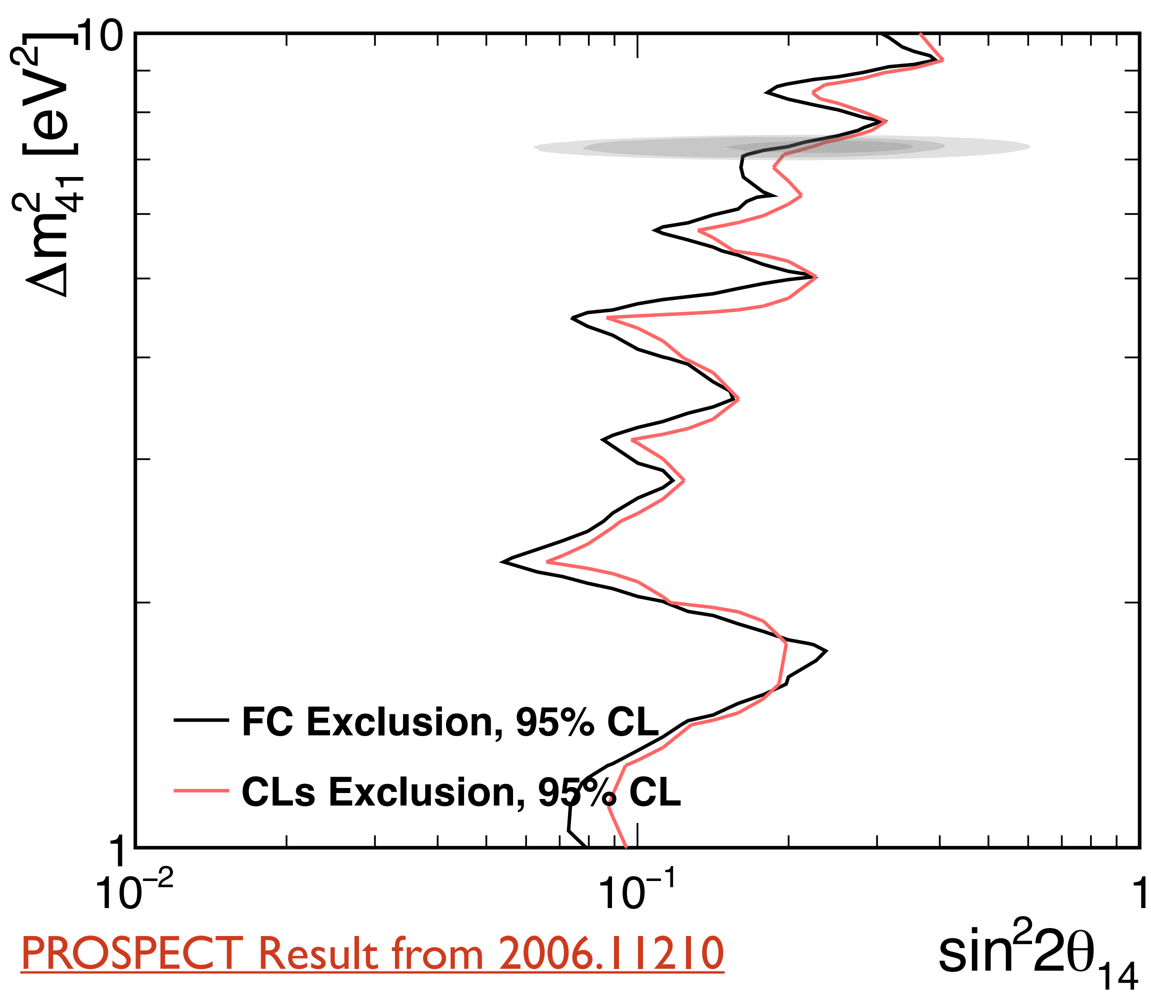




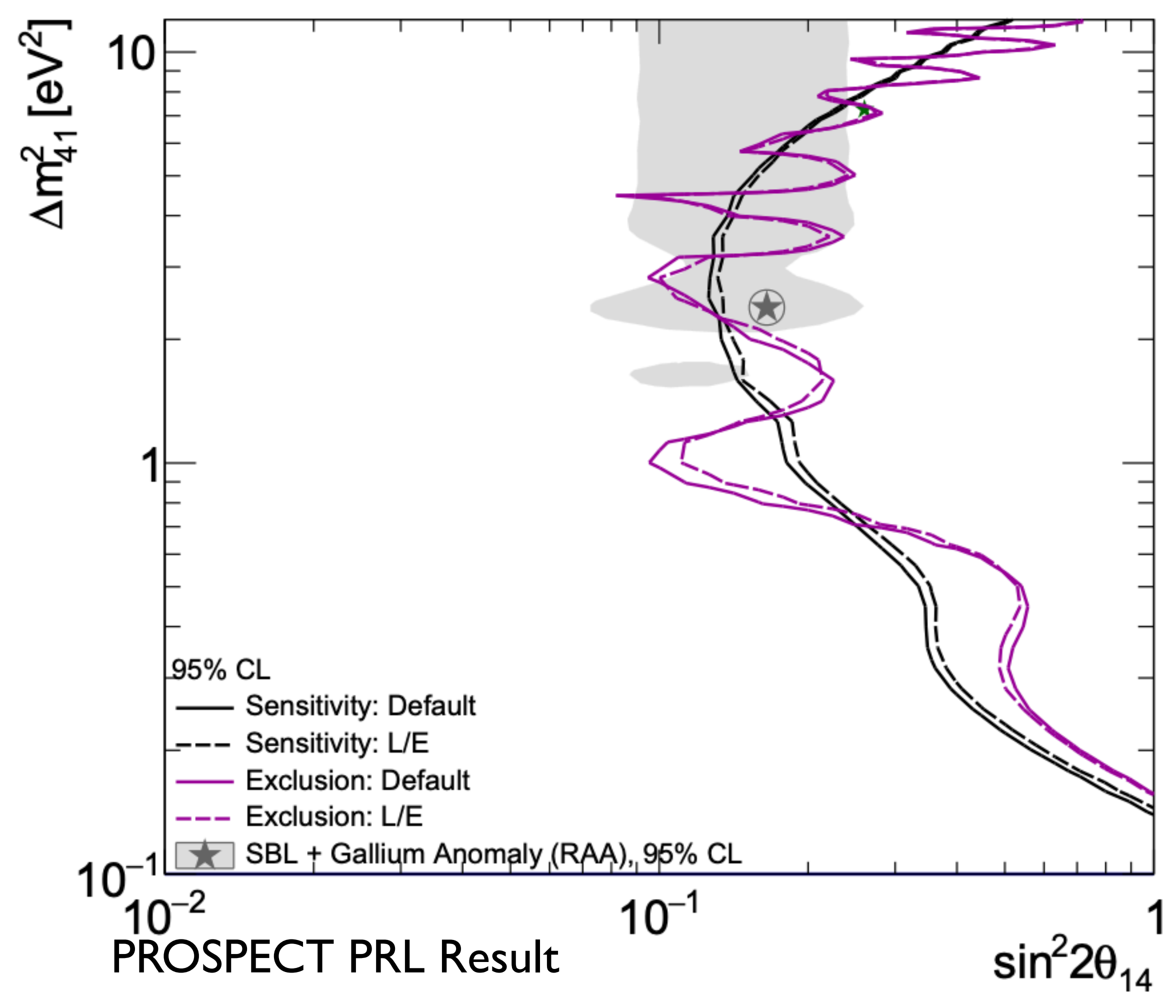
Neutrino-4 and PROSPECT

PROSPECT and STEREO, hep-ex[2006.13147]

- Taking a different view: consider N4 exclusion at face-value
  - Updated result excludes nearly all of the 68% CL N4 favored region at 95% CL
  - PROSPECT previous PRL sterile exclusion is ~identical for L/E v. L, E binning
    - This is contrary to what is claimed in Neutrino-4's various arXiv postings; this should not be viewed as an 'advantage' of Neutrino-4's presented analysis
  - PROSPECT, STEREO worked exhaustively to prove the accuracy of detector models and background estimates. Has N4 provided the same level of rigor?



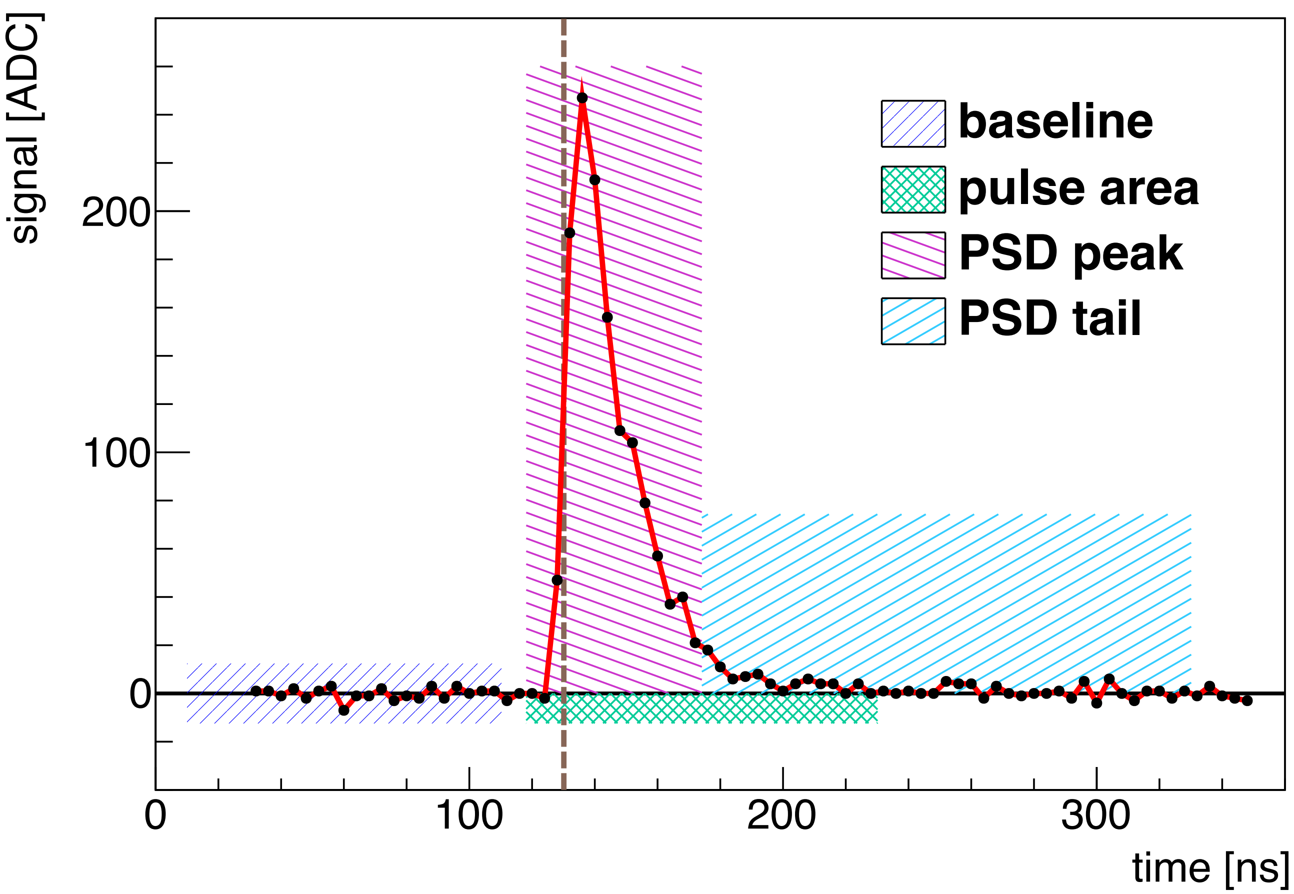
PROSPECT Result from 2006.11210

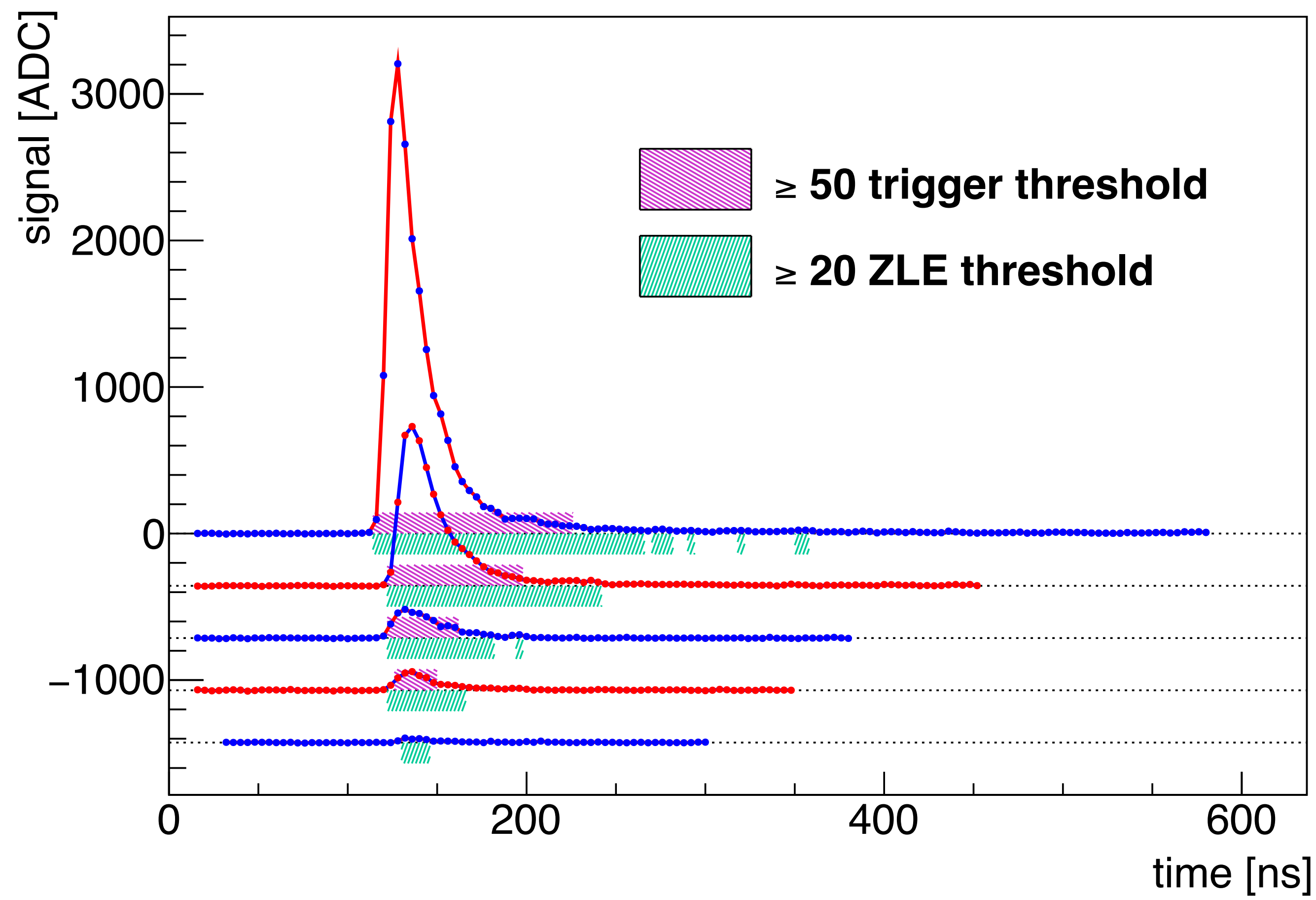


PROSPECT PRL Result

Low-Level Processing Examples

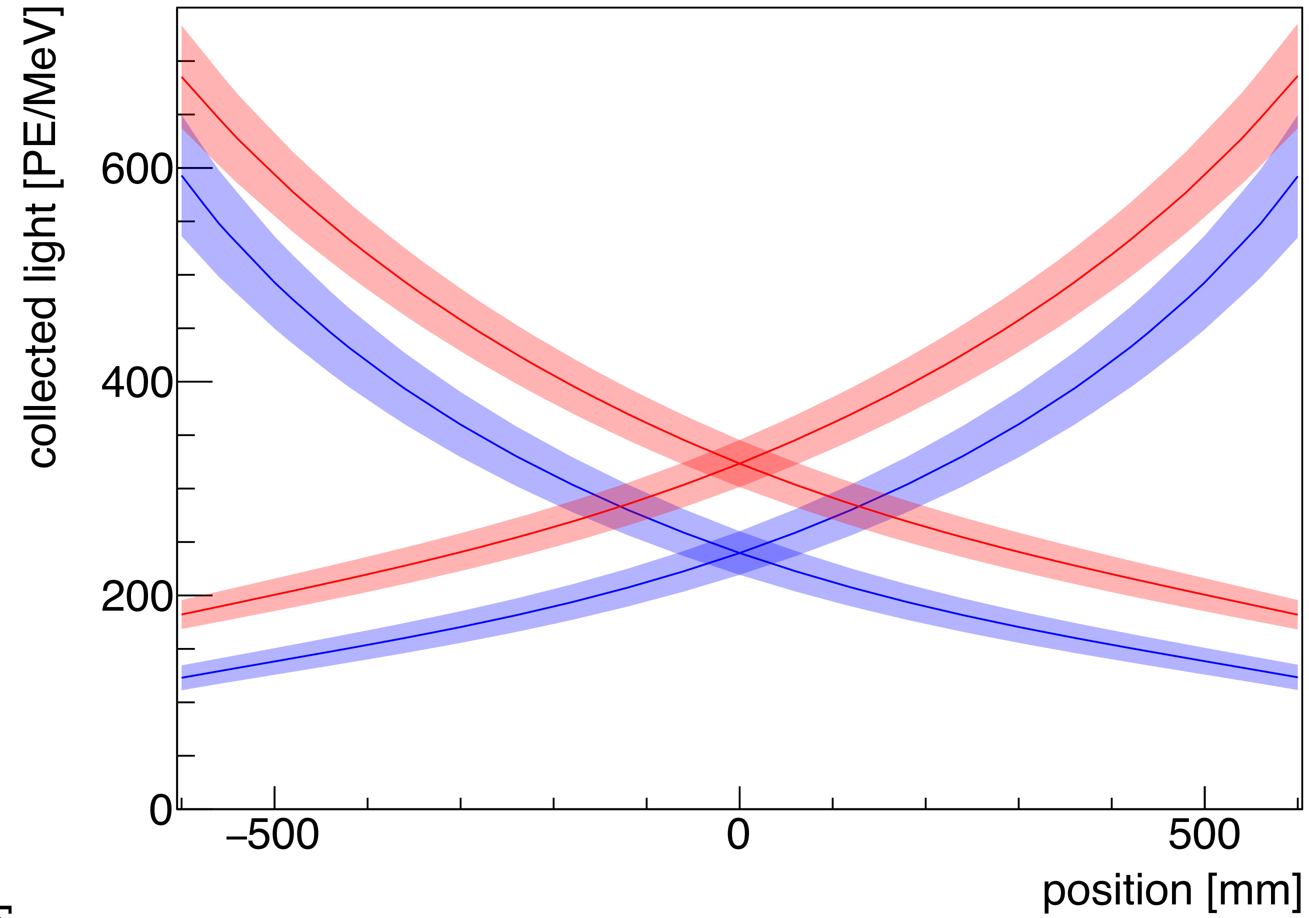
- 50 ADC (~5 PE) trigger threshold: both PMTs on a segment
- 20 ADC (~2PE) zero-suppression threshold
  - Only read out waveform chunks in the vicinity of 20+ ADC sections
- FADC low-level pulse processing quantities: baseline, pulse area, PSD peak + tail, timestamps

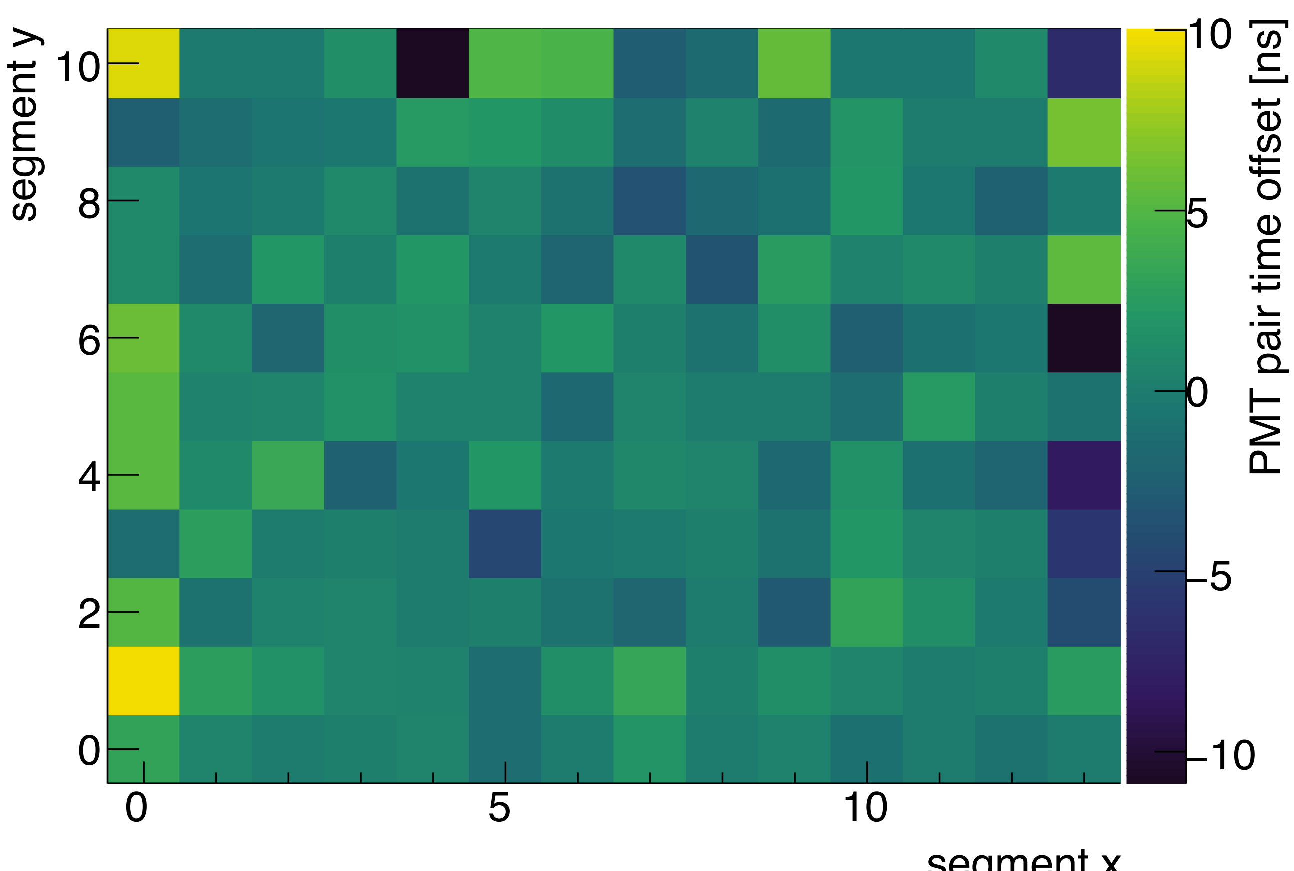


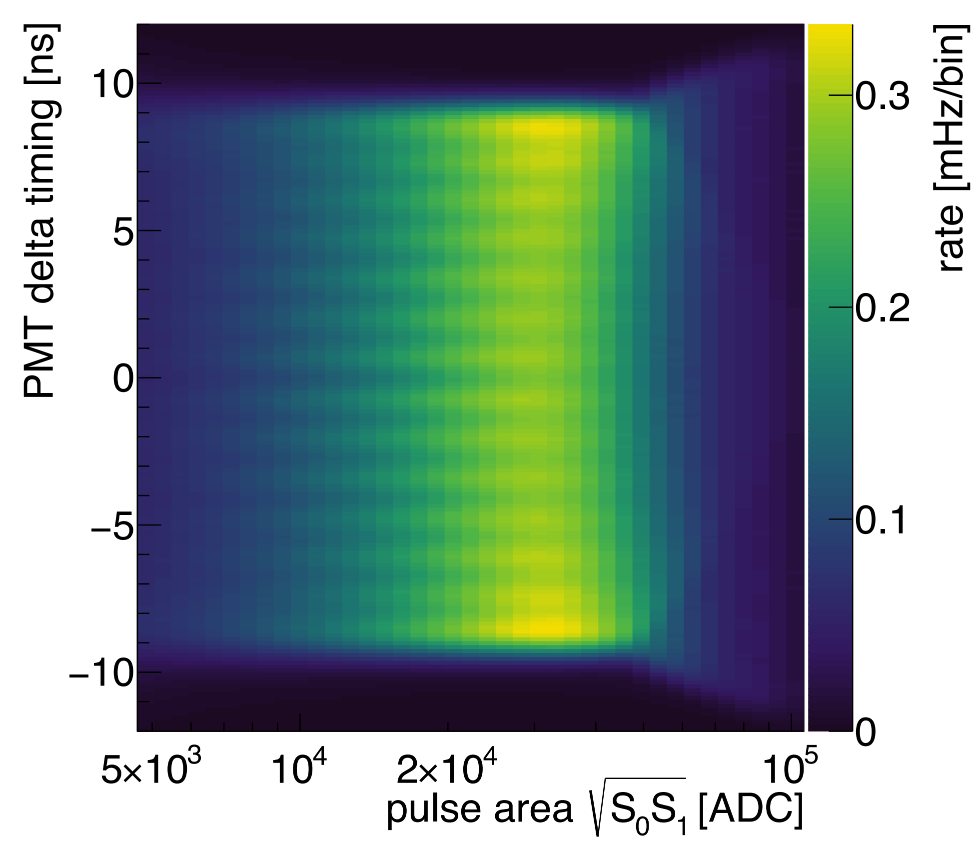


Segment Pulse Calibration

- Reconstruct time using muons to equalize PMT timing offsets
- Reconstruct z-position using timing+charge offsets between PMTs in response to corner-clipping muons
- Reconstruct energies by correcting for z-variation in n-^{6}Li signal amplitude
- Calibrate out time-dependence of reconstructed energy and position

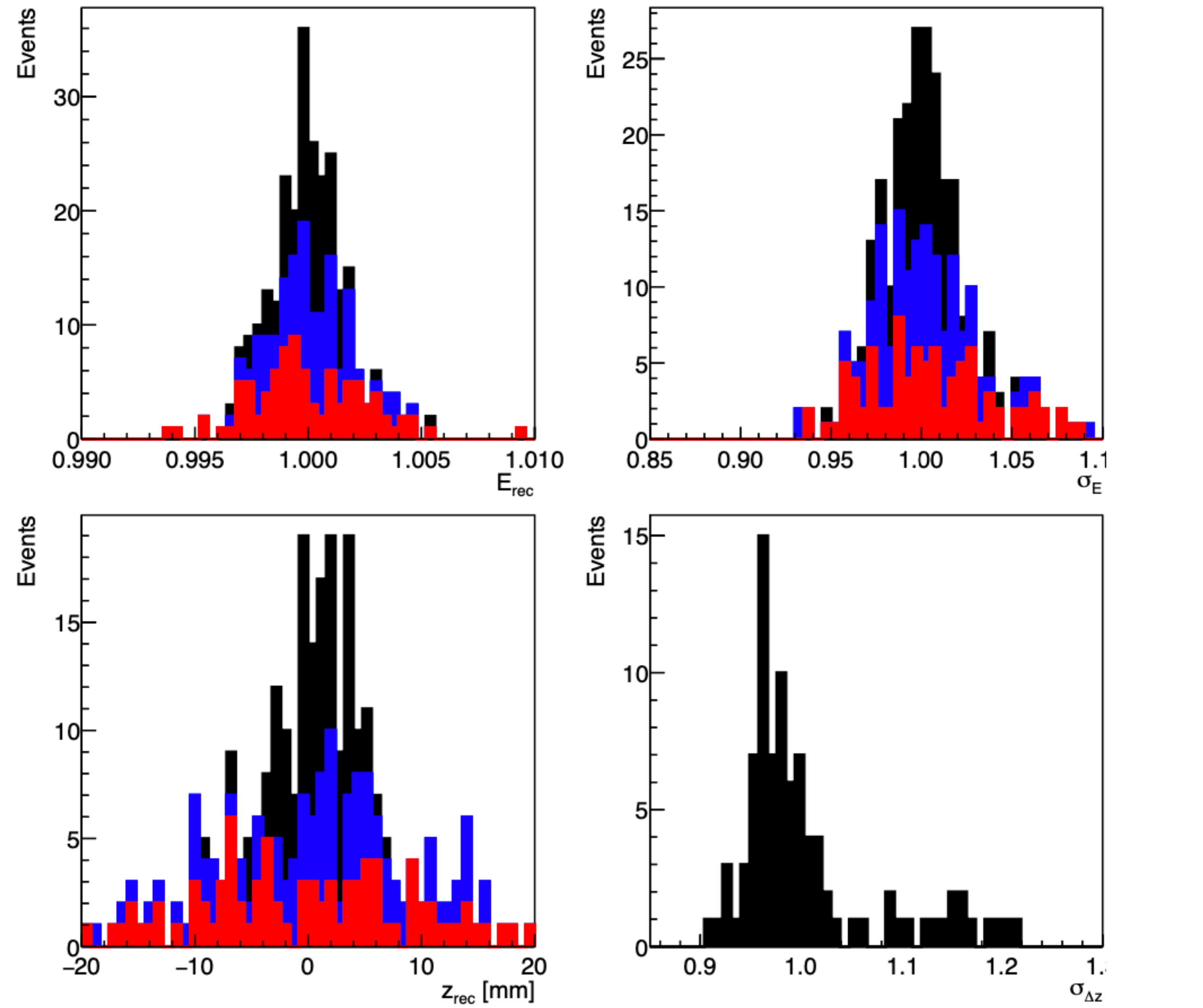


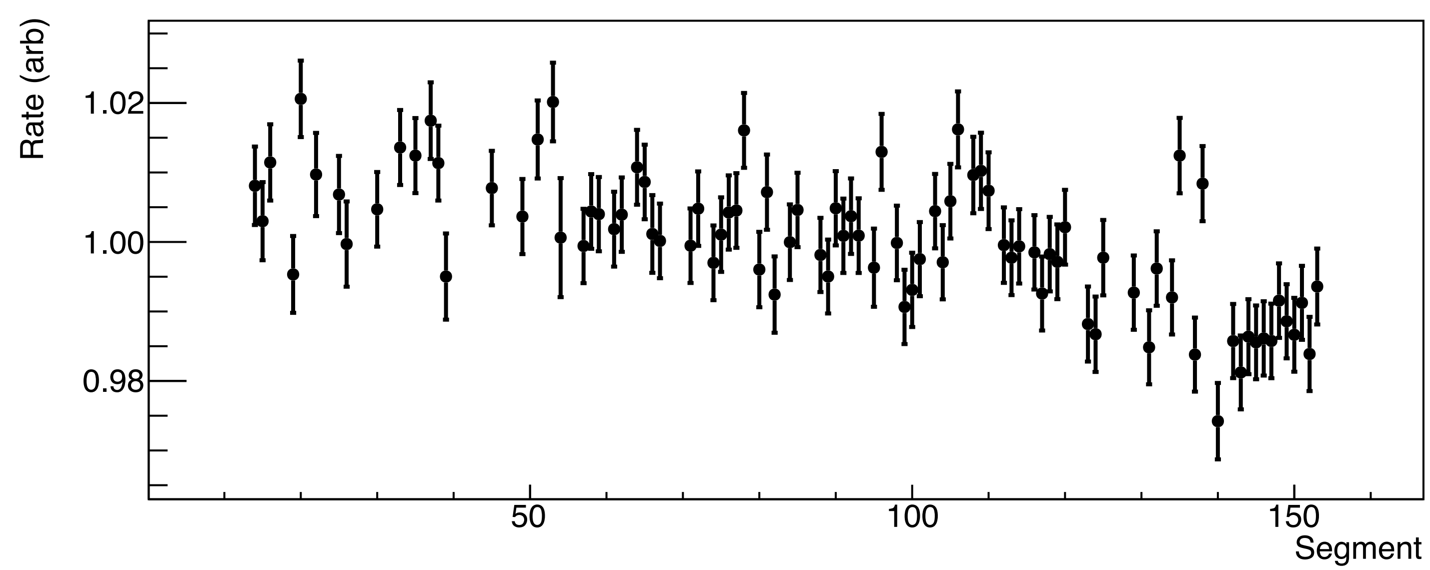




Segment Similarity

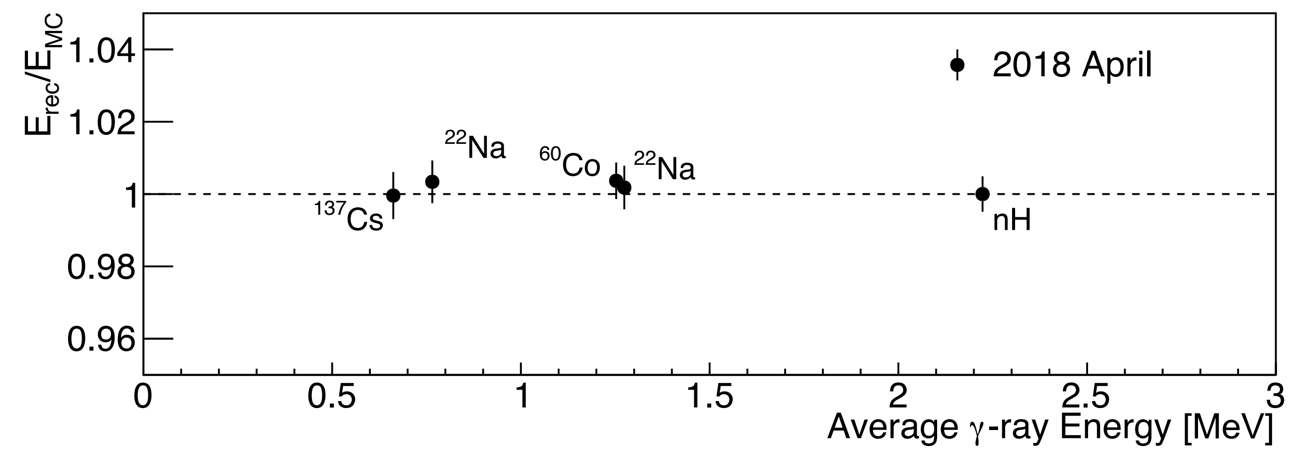
- Segments show similar response for a variety of pulse position, energy reconstruction metrics
- Using RnPo from ^{227}Ac, segment volumes look identical to the few-%-level

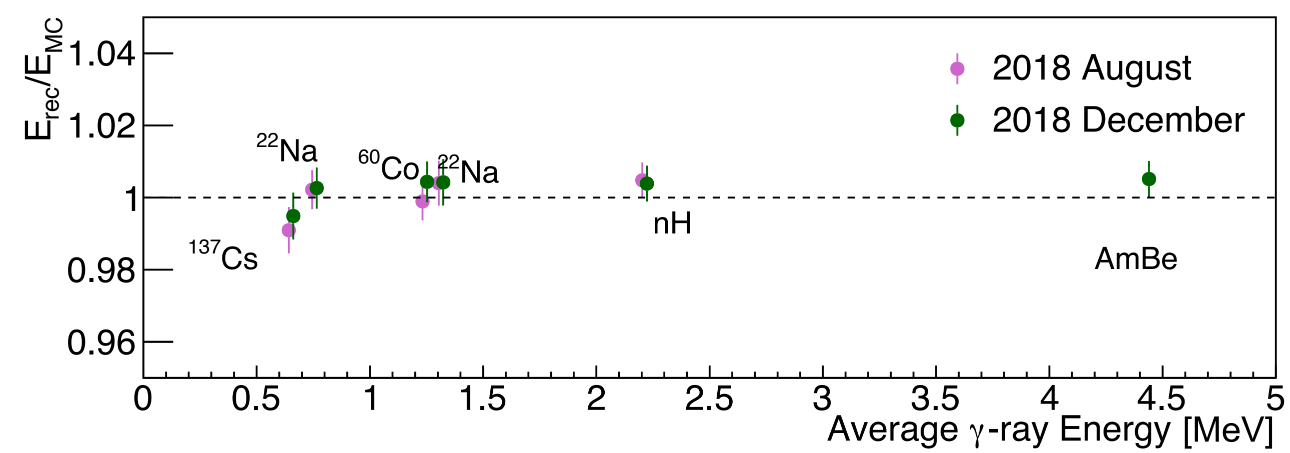


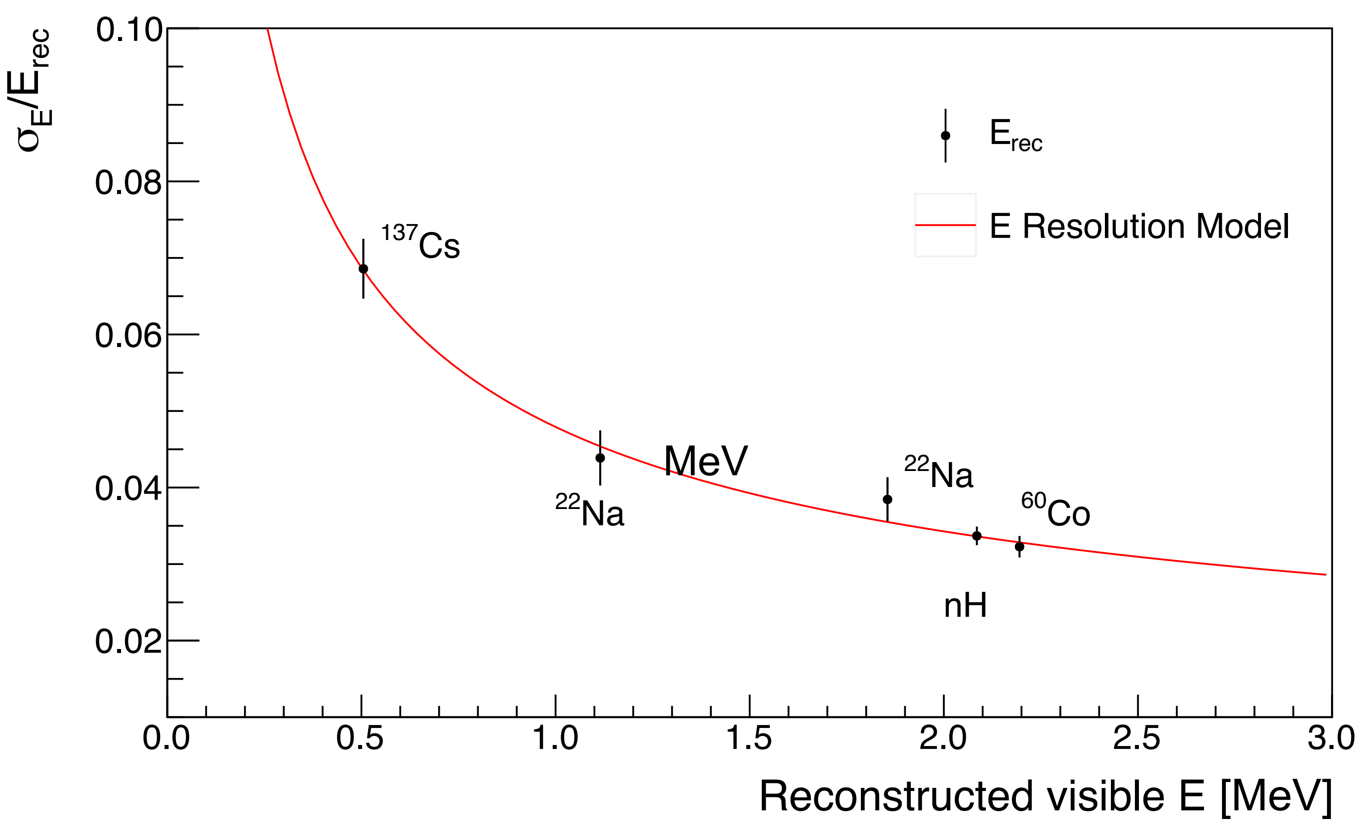


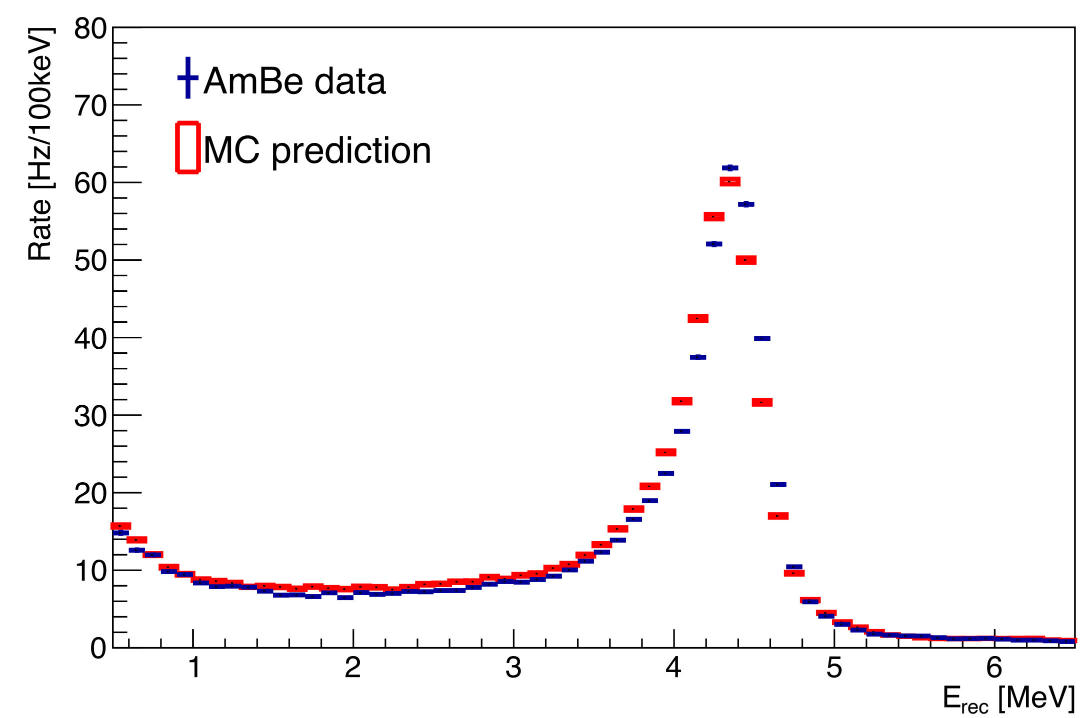
Energy Scale Calibration Extras

- For calibration sources, consistent data-MC energy scale agreement across all energy ranges: non-linearity model is clearly successful
- AmBe high-energy gamma data-MC energy agreement to <0.5%
- Data-model energy scale agreement is consistent in time to percent-level
- ~5% fitted photostatistics resolution



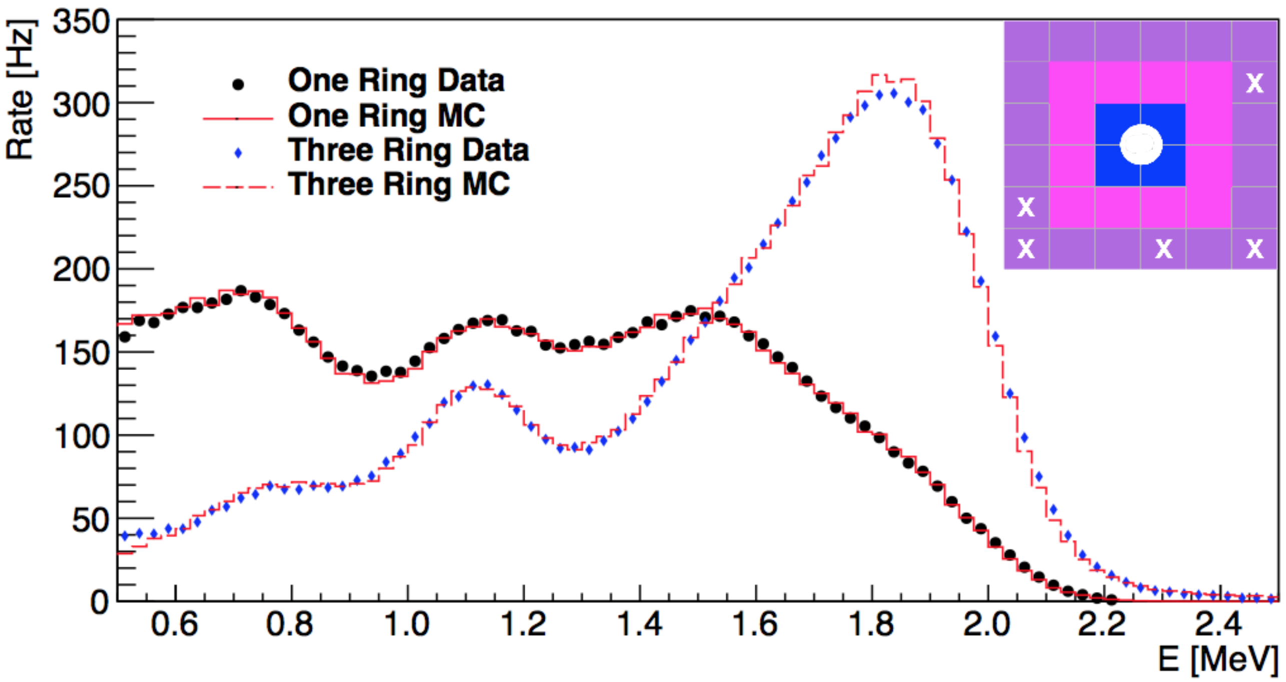


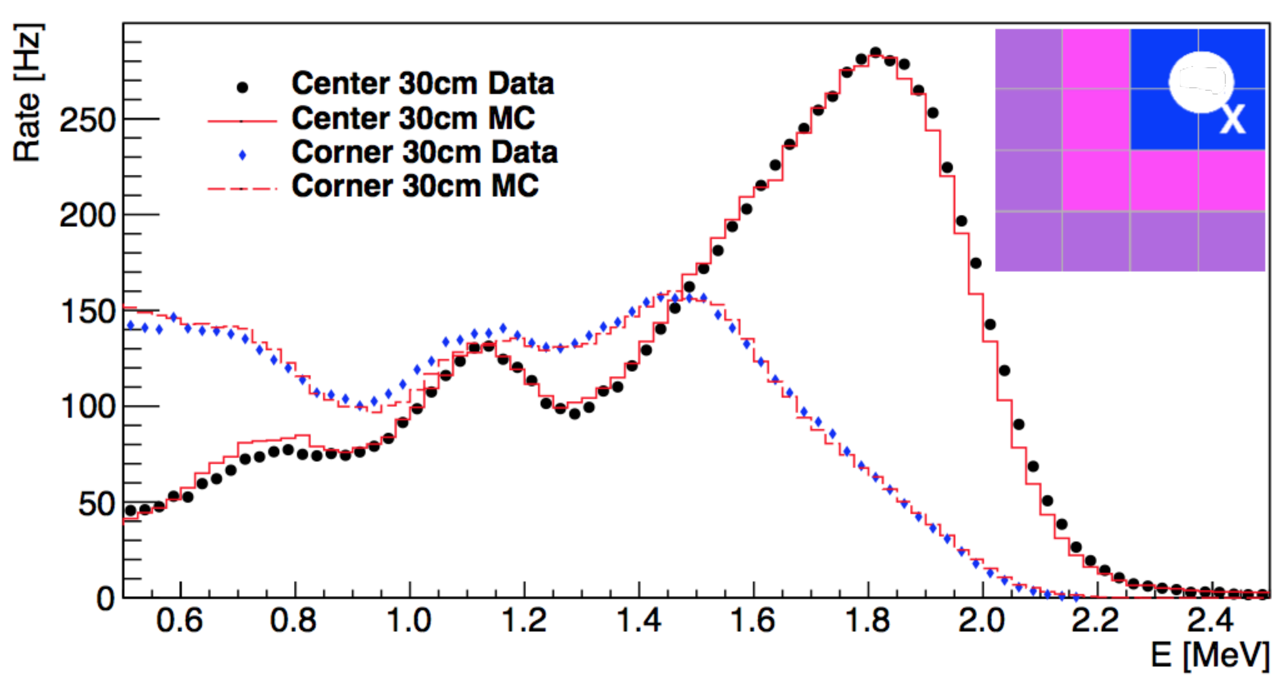




Energy Scale Calibration Extras

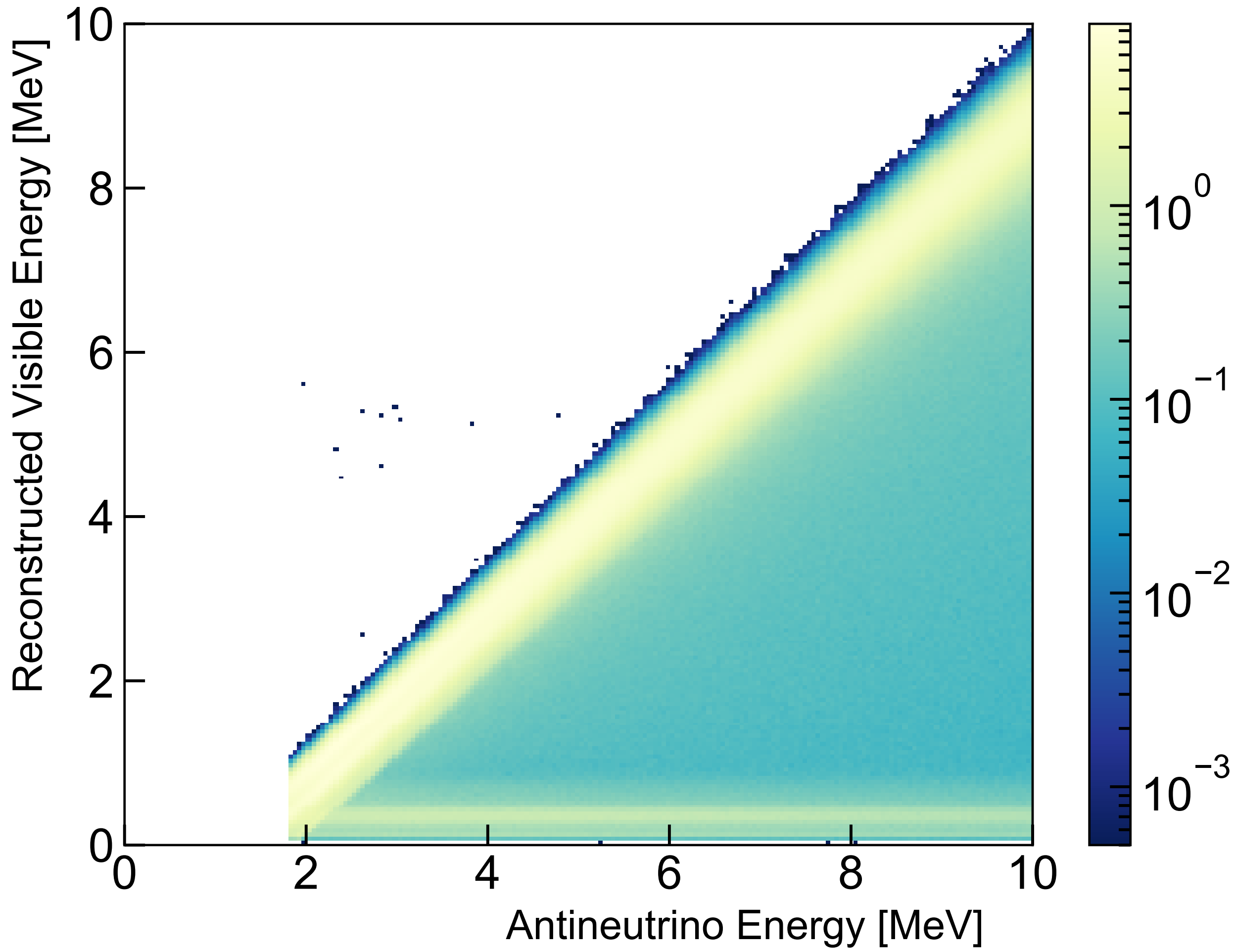
- Gamma energy leakage/loss also properly modeled in MC
- Checked via Na22 source deployment and MC modelling:
  - Compare for deployment along edge/center calibration axes
  - Compare for deployment along axis z-edge / z-center
  - For a single deployment, compare energy deposition in different segments
- Energy model uncertainty related to energy leakage: <8keV

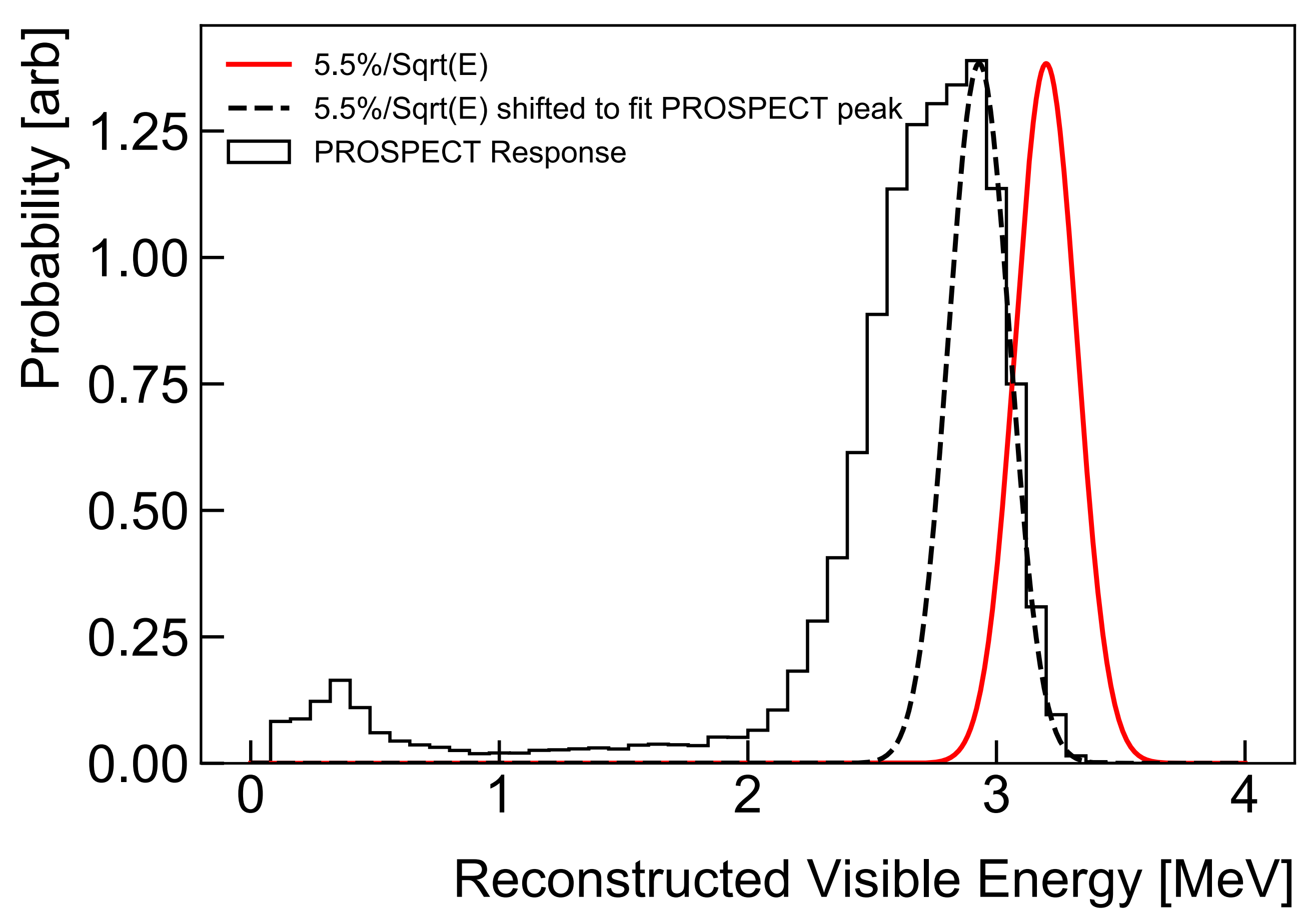




IBD MC: Predicted Energy Response

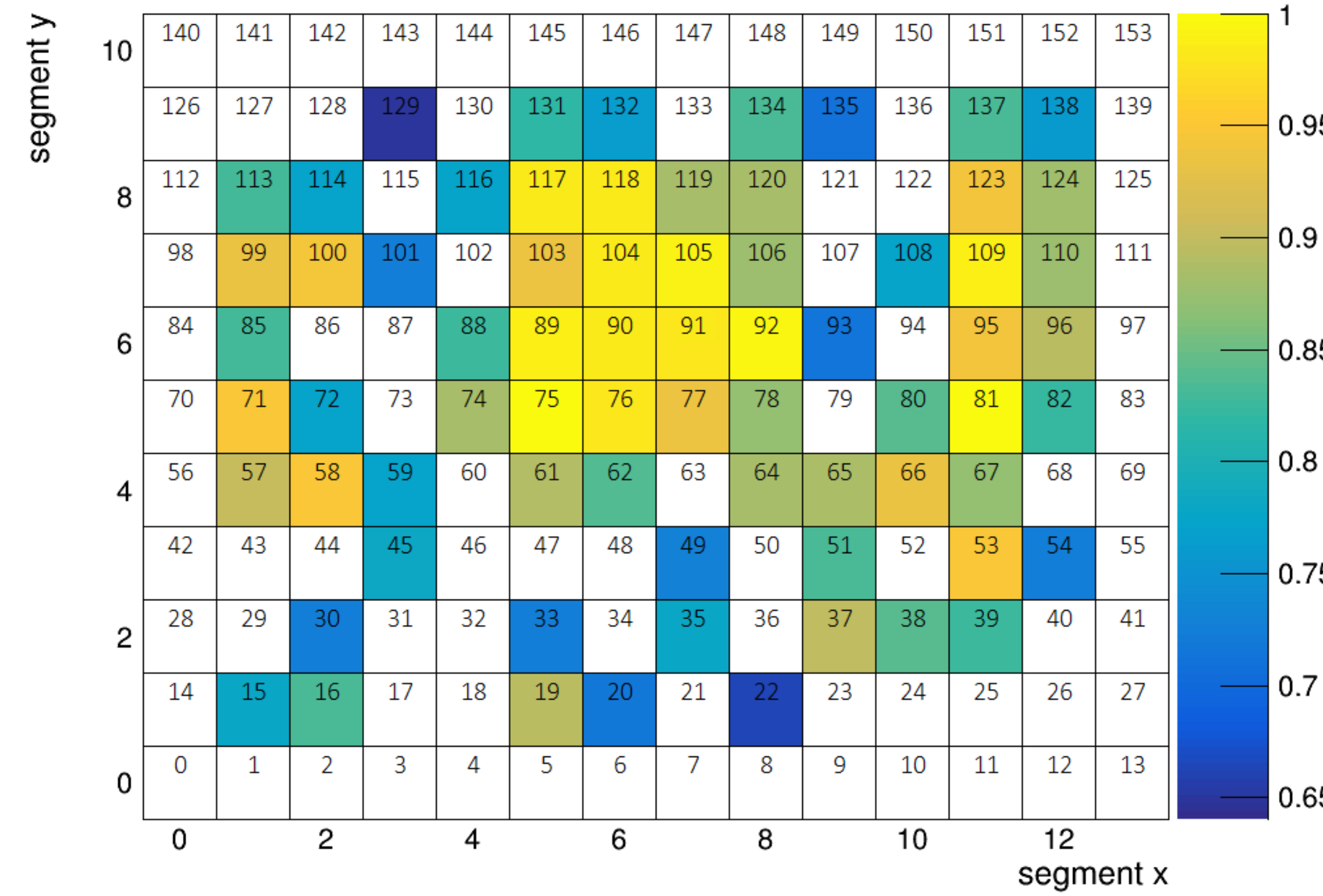
- Full-detector IBD prompt energy response modeled by PG4 IBD MC
- Substantial off-diagonal contribution from energy leakage into dead/non-fiducial segments, optical grid walls



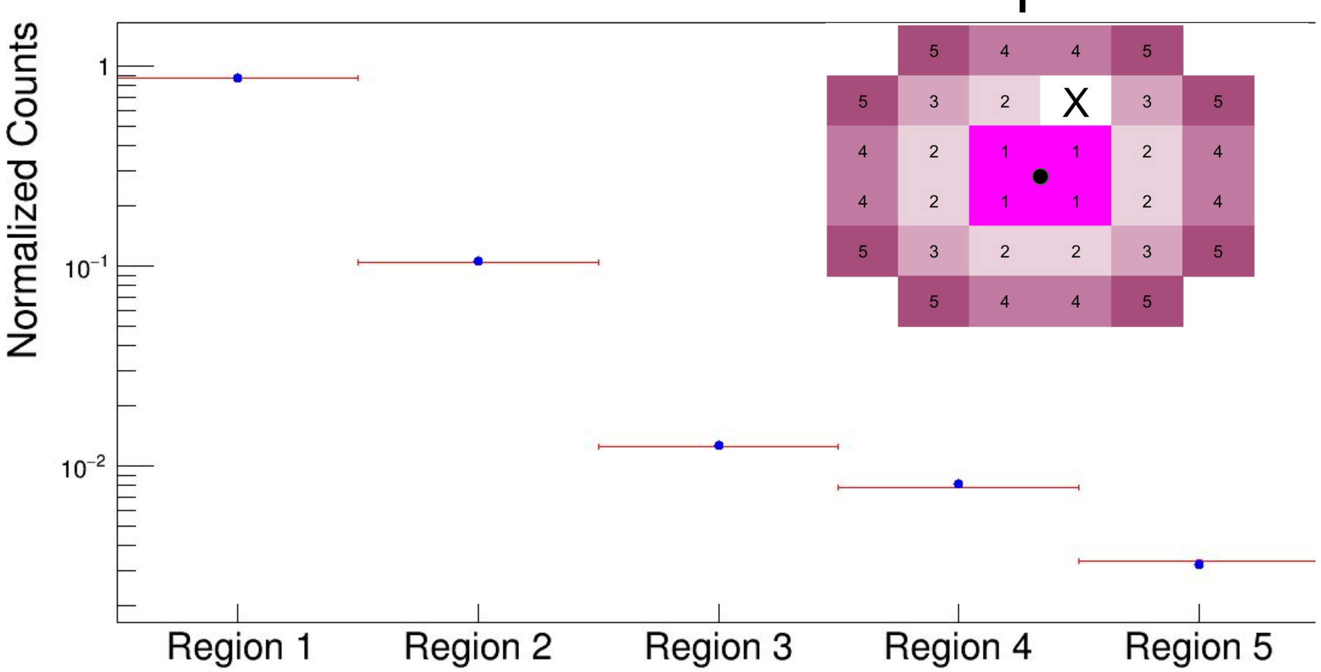


Efficiency: Segment Variation

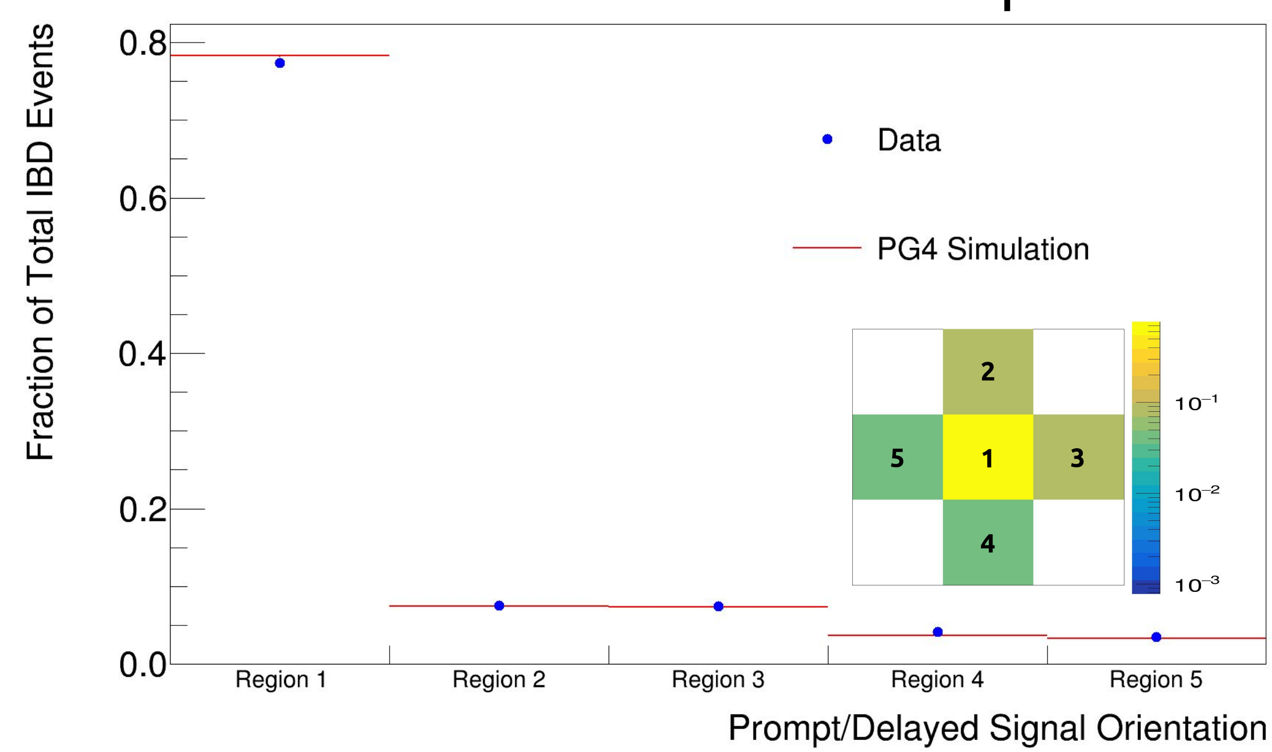
- Largest source of efficiency variation: neutron mobility into dead segments
- Segmentation allows excellent characterization of this effect.
  - Neutrons from Cf-252, IBDs
- Sub-dominant effects: IBD e+ mobility, segment volume



Where do Cf-252 neutrons capture?

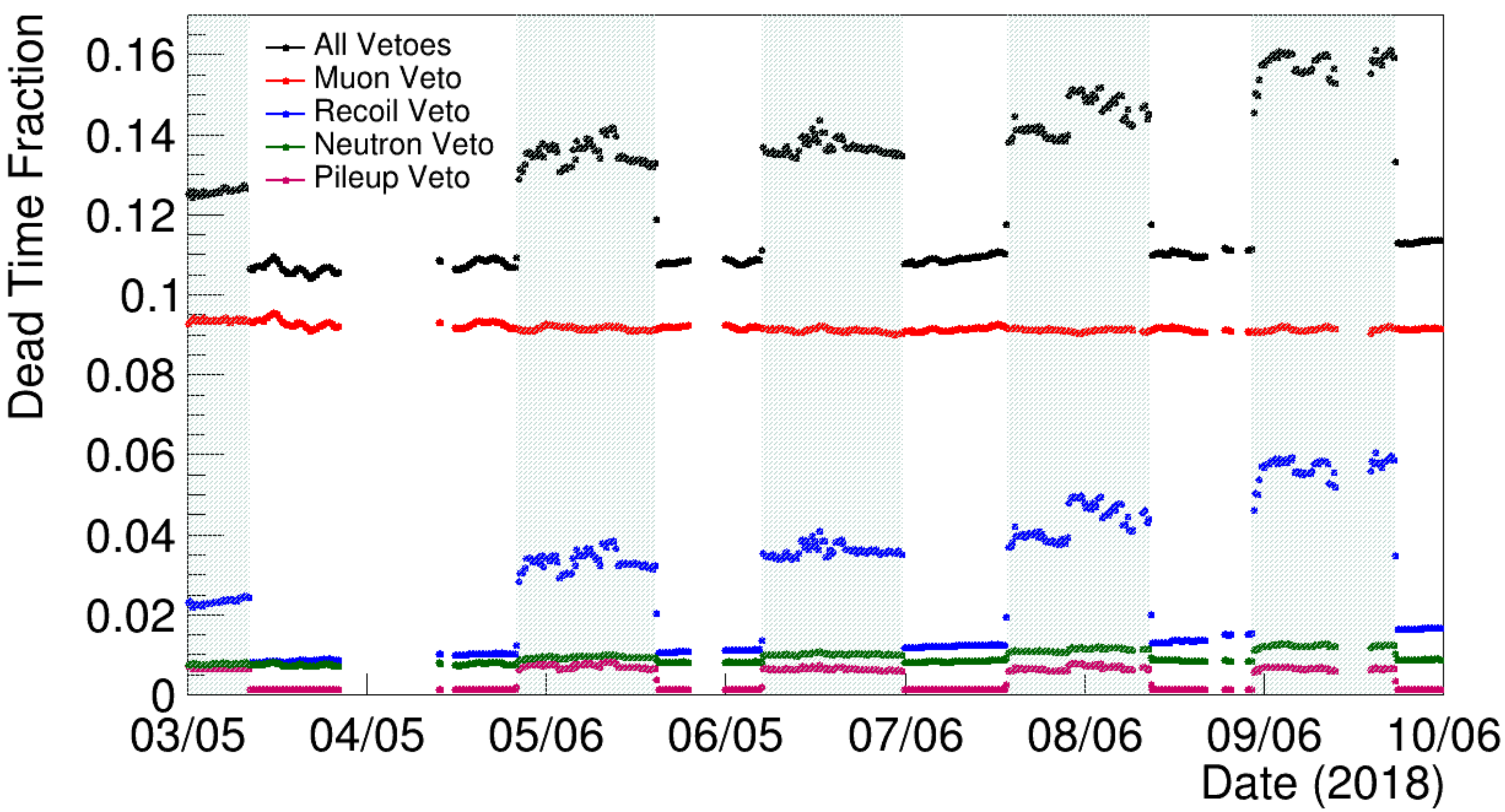


Where do IBD neutrons capture?



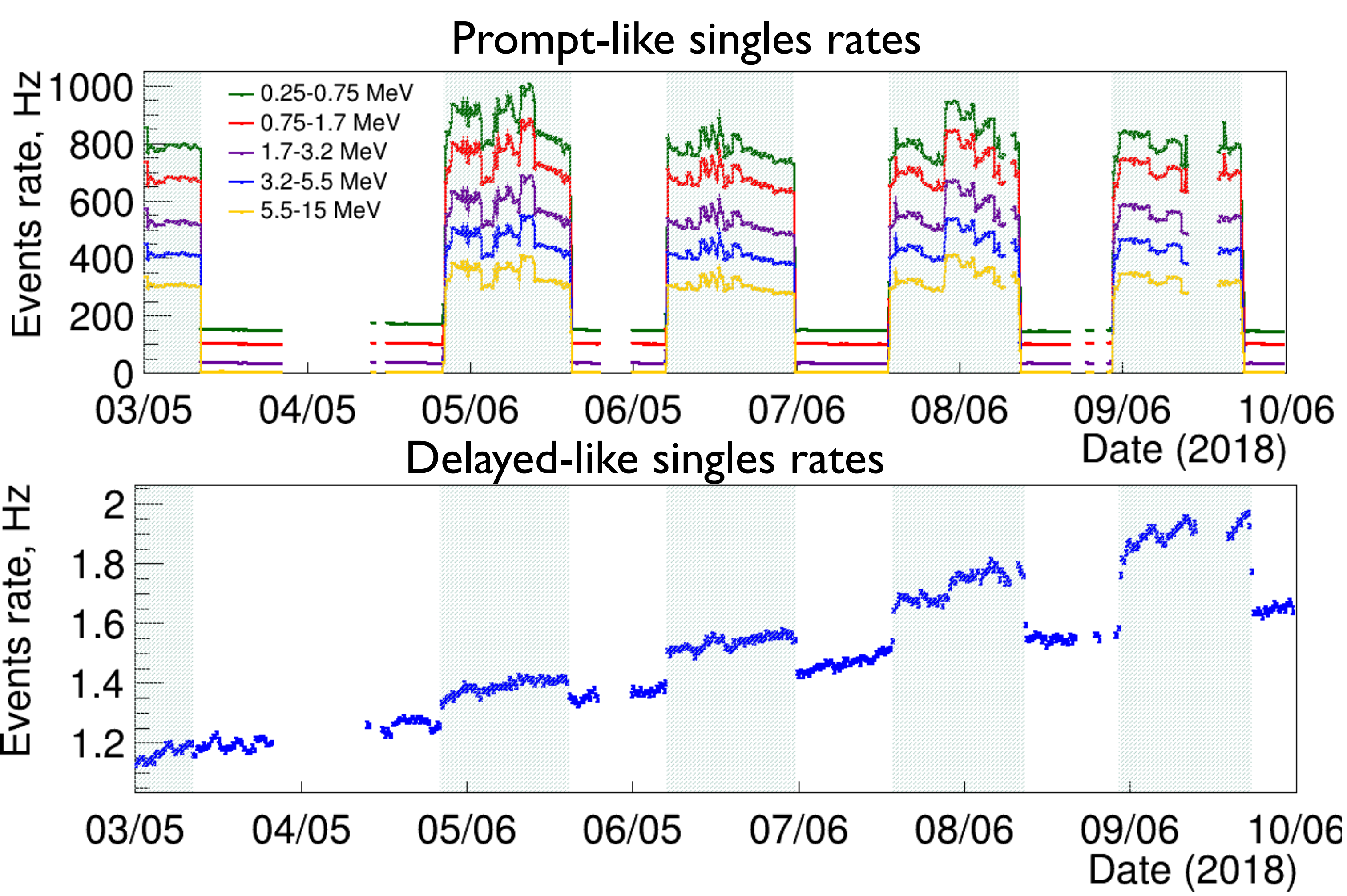
Efficiency: Time Variation

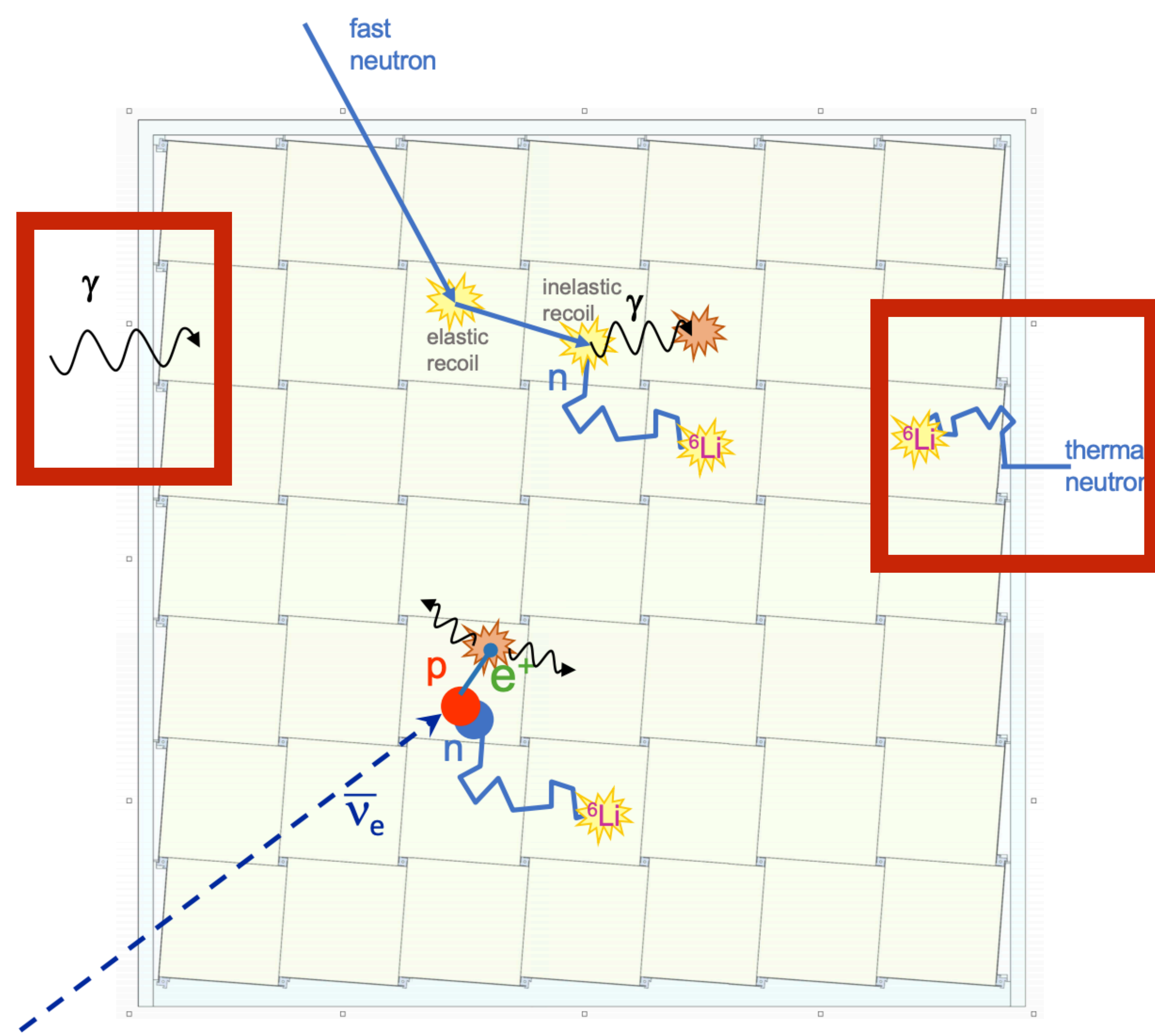
- Largest source of efficiency time-variation: veto cuts
  - Due to reactor gammas, some vetoing signals have on-off rate variation (neutron-capture signals and neutron-proton recoils)
  - Results in on-off veto time variation of as much as ~5%
  - Long-term variation from slow PSD performance degradation
- Sub-dominant effects: small drifts in nLi capture time/fraction



Accidental Backgrounds

- Random coincidence of gamma and nLi-like signal
  - Variation in delayed signals from gammas bleeding into nLi PSD region
- Estimate precisely using off-window method
  - IBD offset by few hundred <u>us</u>, accidentals offset by 1-2 <u>seconds</u>

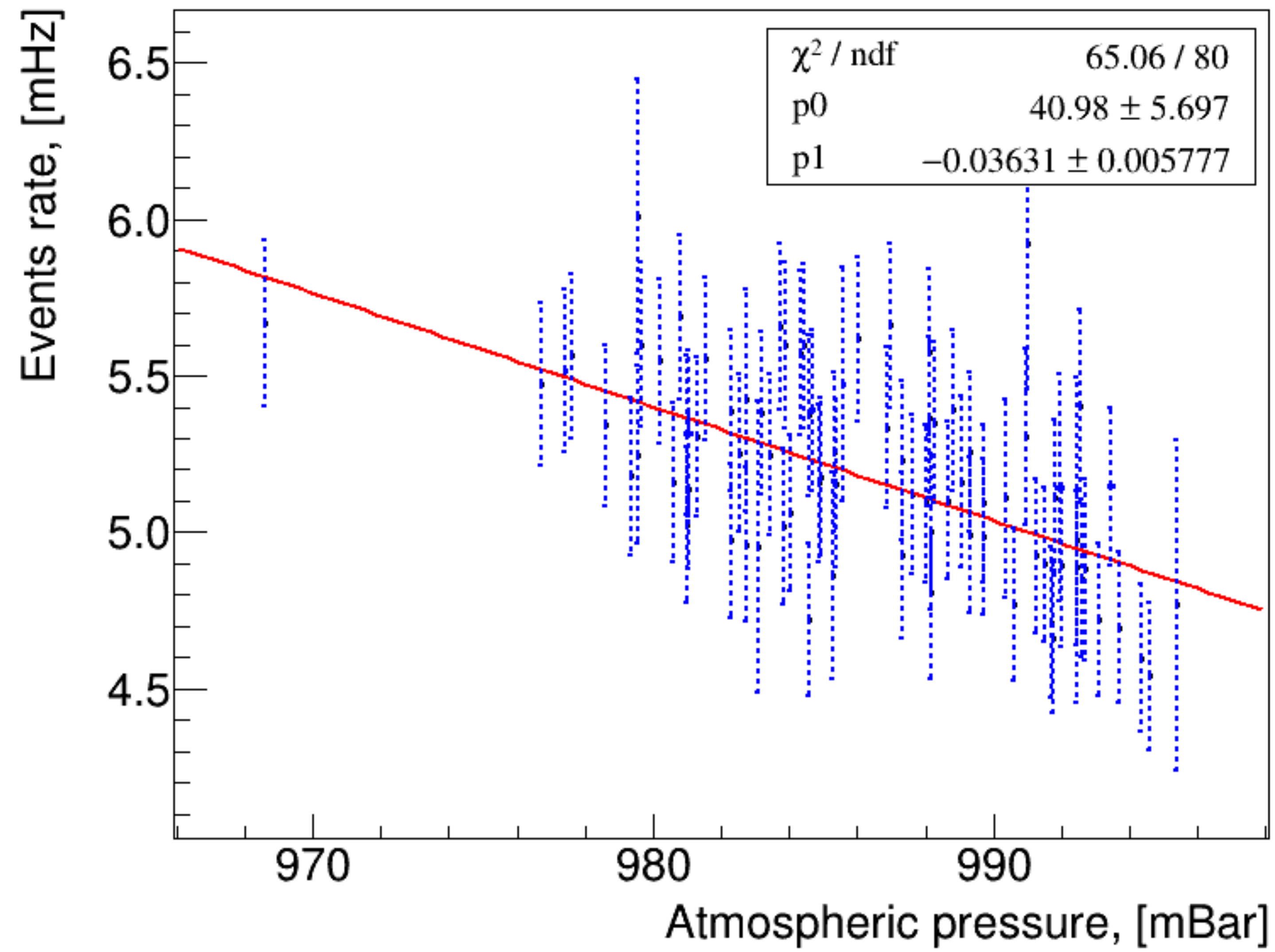




Backgrounds: Rates, Pressure Variation

PROSPECT

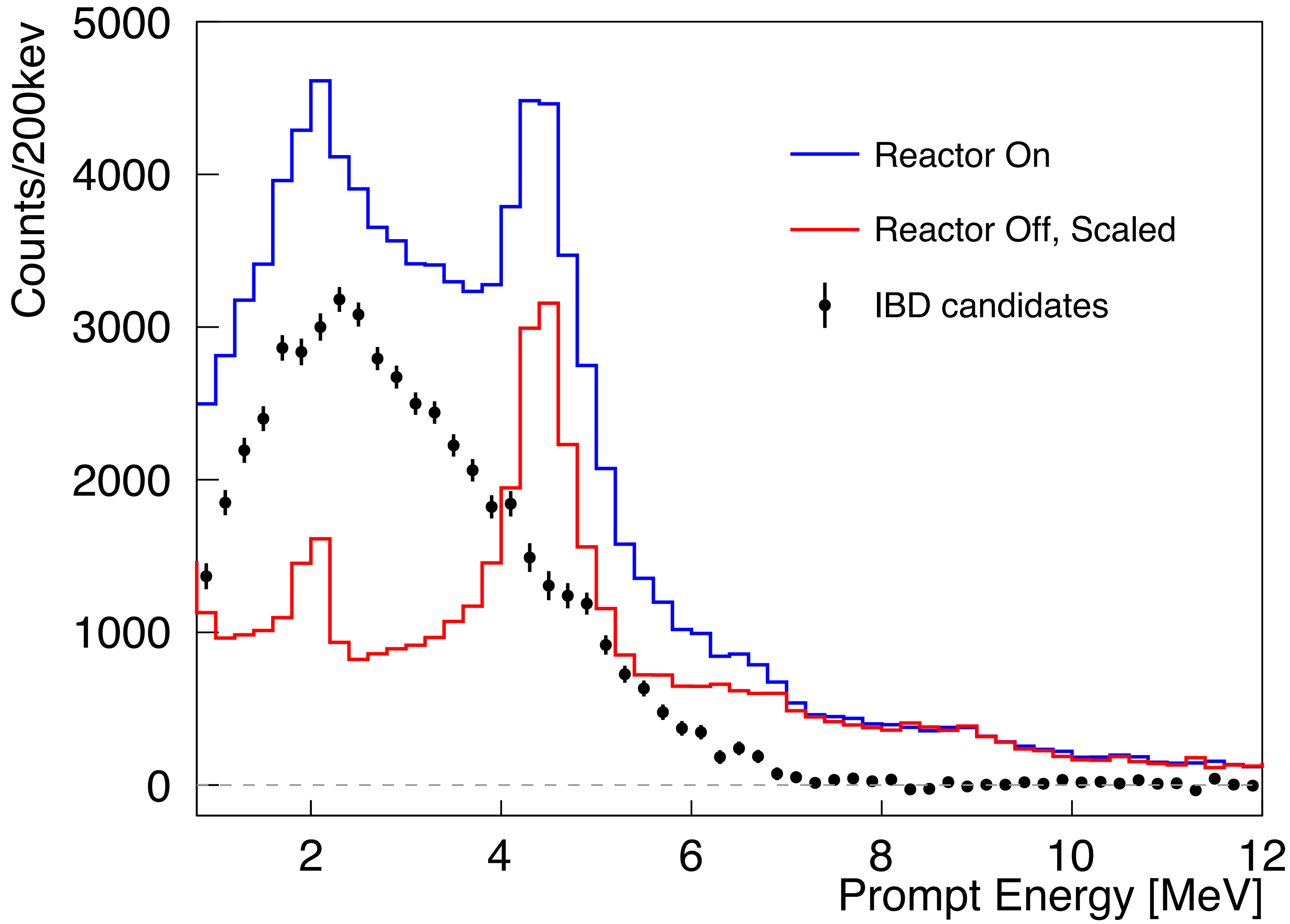
- Many background categories vary with reactor status
- Others vary with atmospheric pressure
- Correct cosmogenic background for on-off pressure variations
- Due to equal on-off integrated pressure, correction is a <0.1% normalization effect.

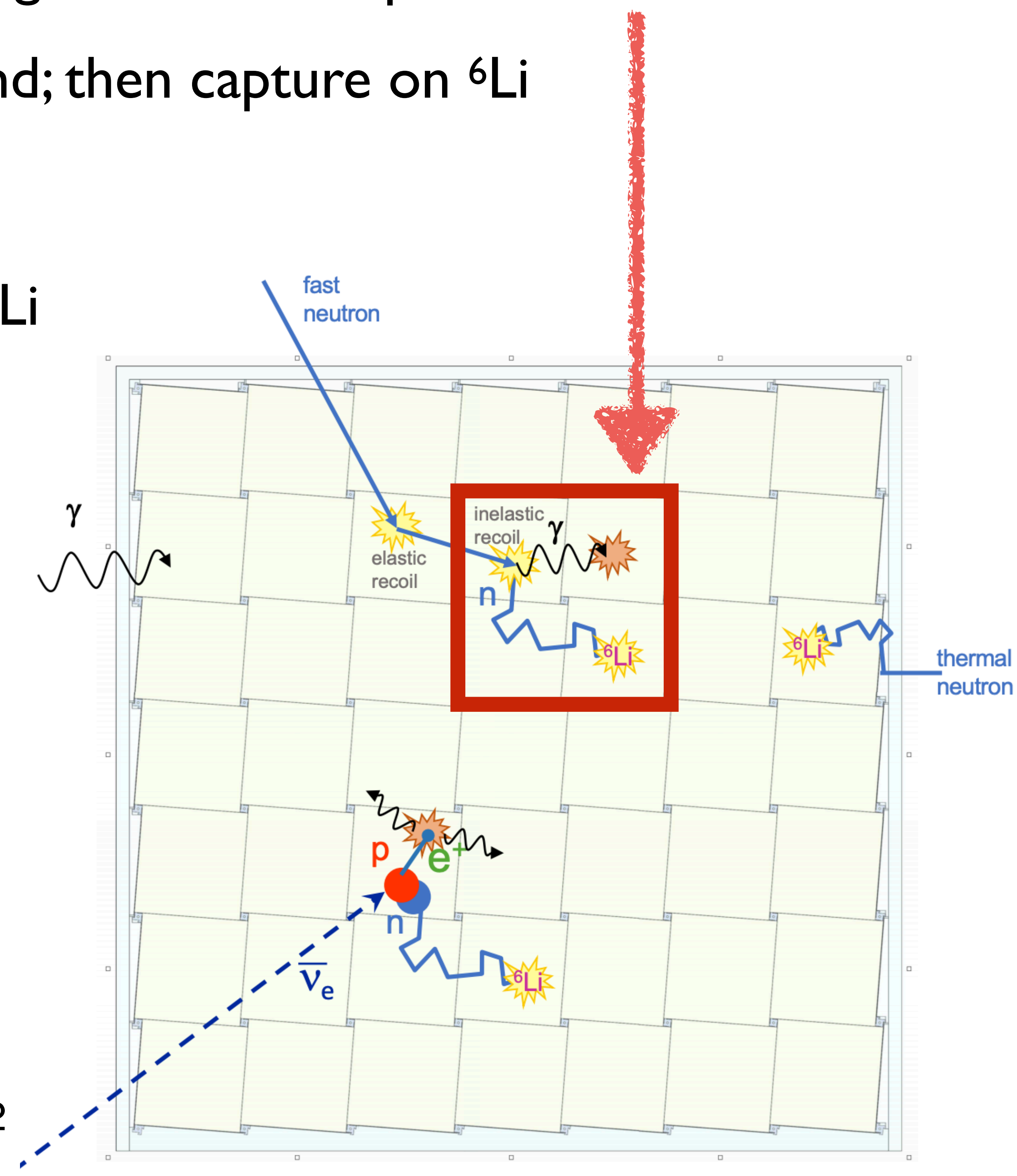


Event Type	Associated Veto	Reactor-Off Rate (Hz)	On-Off Offset (Hz)	Coefficient (%/mbar)	On-Off Scaling (%)
single cluster	Pile-up	1628	6708	-	-
single n-p	Recoil	46.8	116	-	-
single n-Li	Neutron	11.5	2.85	-0.57 ± 0.23	0.025 ± 0.015
single muon	Muon	497	-2.3	$-0.16 \pm <0.01$	0.006 ± 0.000
n-Li, n-Li	-	0.012	8.5e-4	-0.53 ± 0.01	0.022 ± 0.024
n-p, n-Li	-	0.33	4.2e-4	-0.80 ± 0.02	0.033 ± 0.007
IBD-like	-	0.0052	7.1e-3	-0.70 ± 0.01	0.028 ± 0.048

Correlated Backgrounds

- Fast neutron produced background:
  - Inelastic scatter off C-12 gives 4.5MeV gamma; then captures on ^{6}Li
  - n-p scatter in low side of high PSD band; then capture on ^{6}Li
- Multi-neutron background:
  - First neutron captures on H, next on ^{6}Li



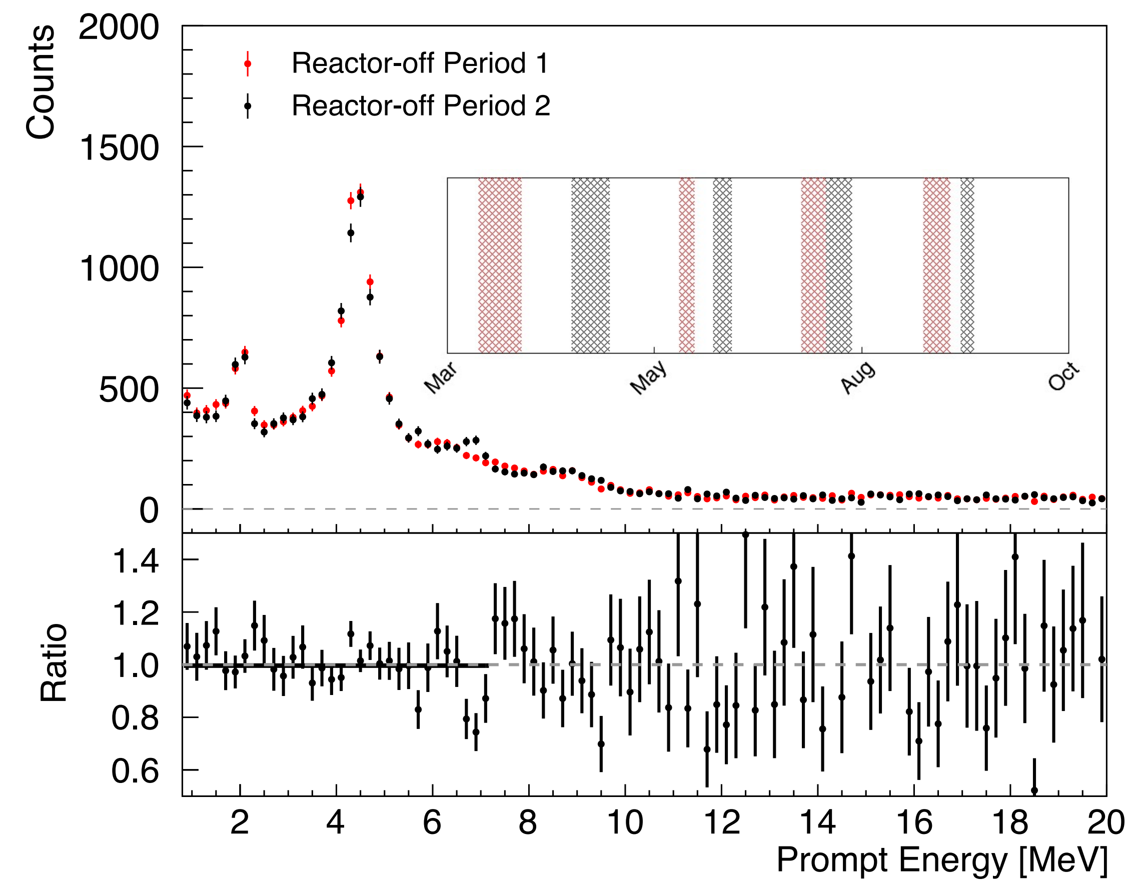


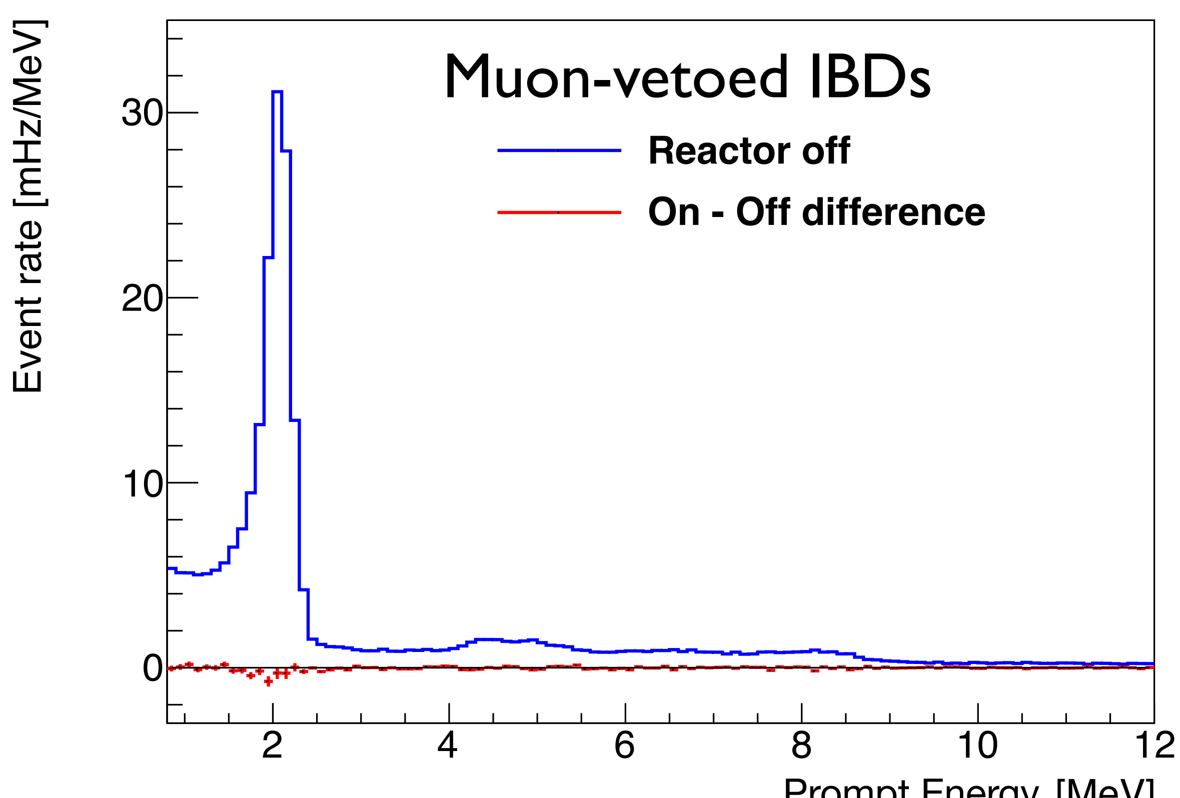
Non-Cosmic Correlated Backgrounds

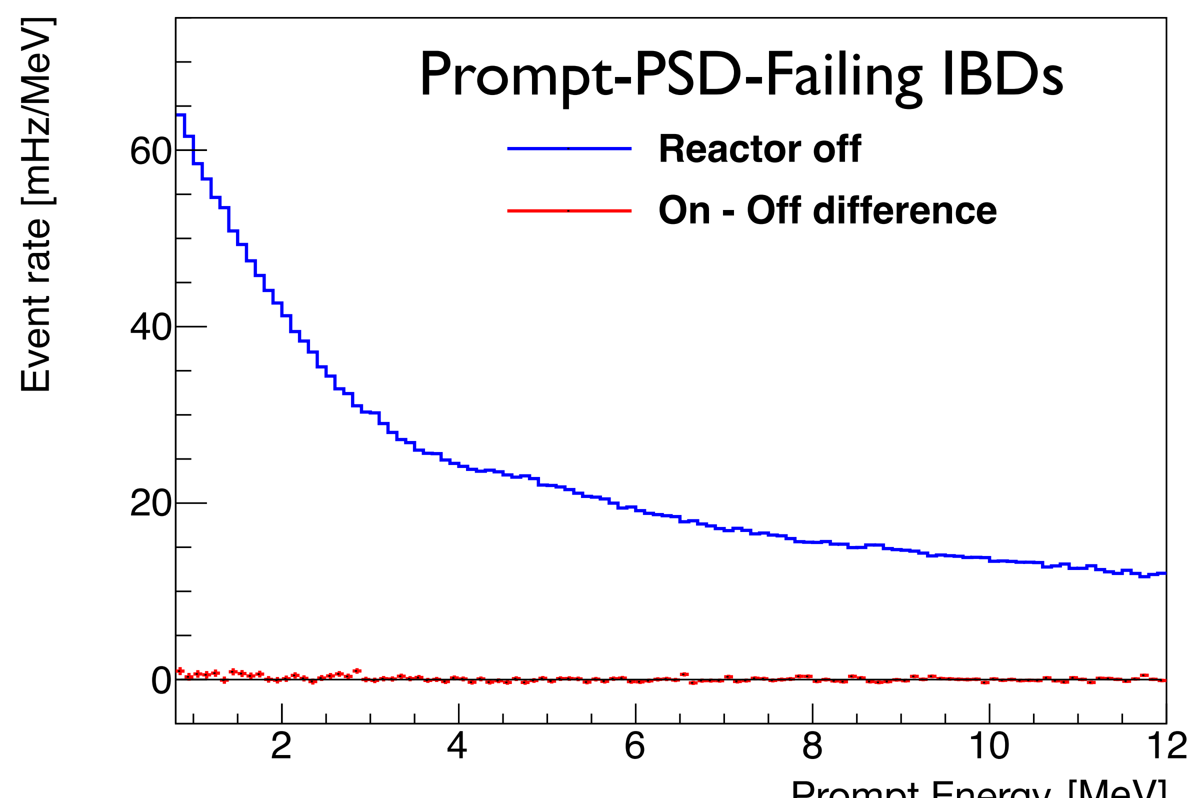
- Biggest estimated contributor: photo-neutron interactions in exterior lead shielding
  - High-energy reactor gamma releases a neutron from lead
  - Gammas and neutron reach inner detector
- Simulations show this background is negligible
  - Measure high-energy gammas in target region
  - Extrapolate this to a rate at the lead shielding using MC
  - Simulate these gamma fluxes to estimate frequency of IBD-like signals
  - Expected rate: 4/day in non-fiducial volume; <0.1/day in fiducial volume
- All other reactor neutron/gamma-produced backgrounds are estimated to be far sub-dominant to this one.

Background Cross-Checks

- Comparing different reactor-off periods gives consistent spectra
- Comparing non-IBD event classes between on and off yields %-level excesses/deficits
  - Appears consistent with a detector response time-dependence effect
  - Precise cause not determined; so, assign additional %-level background uncertainty

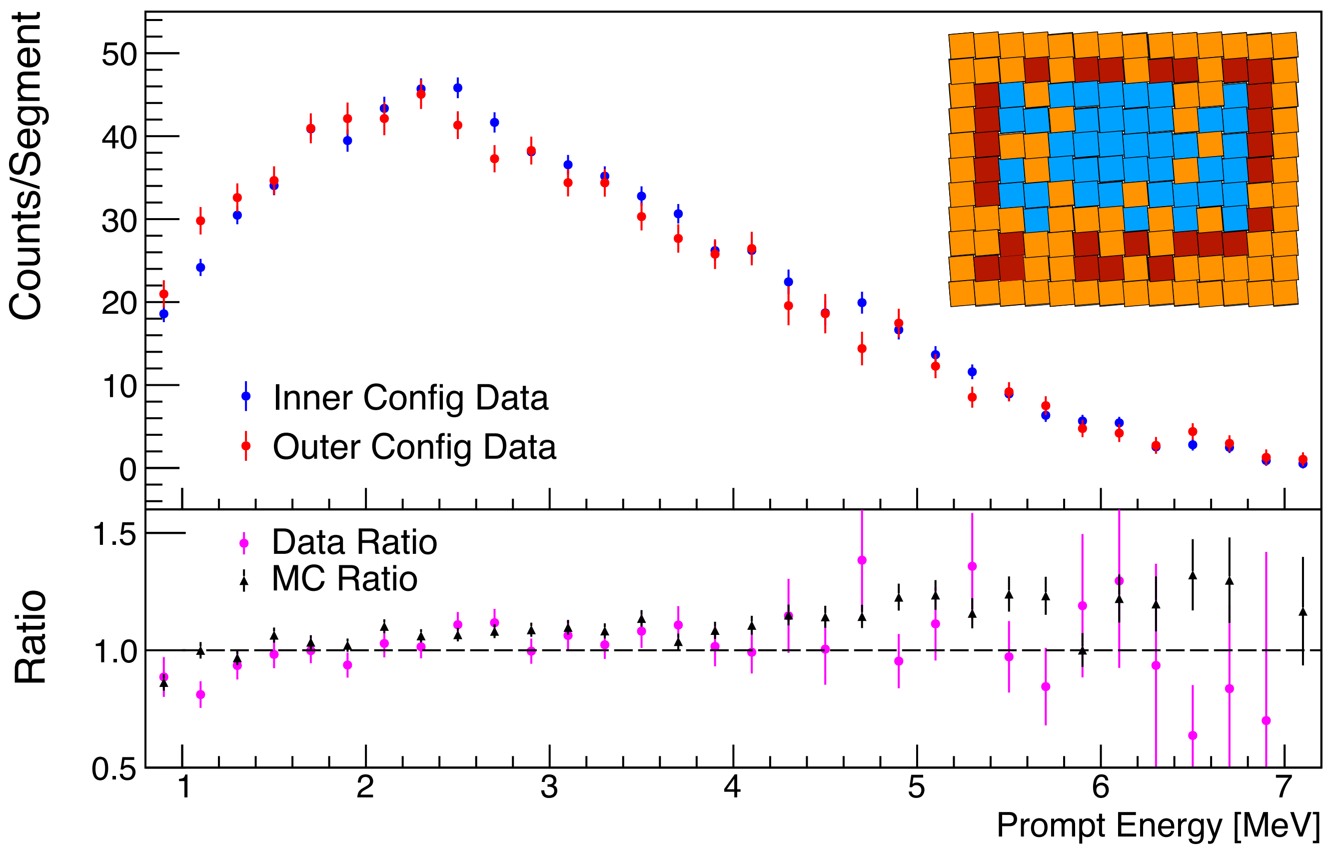


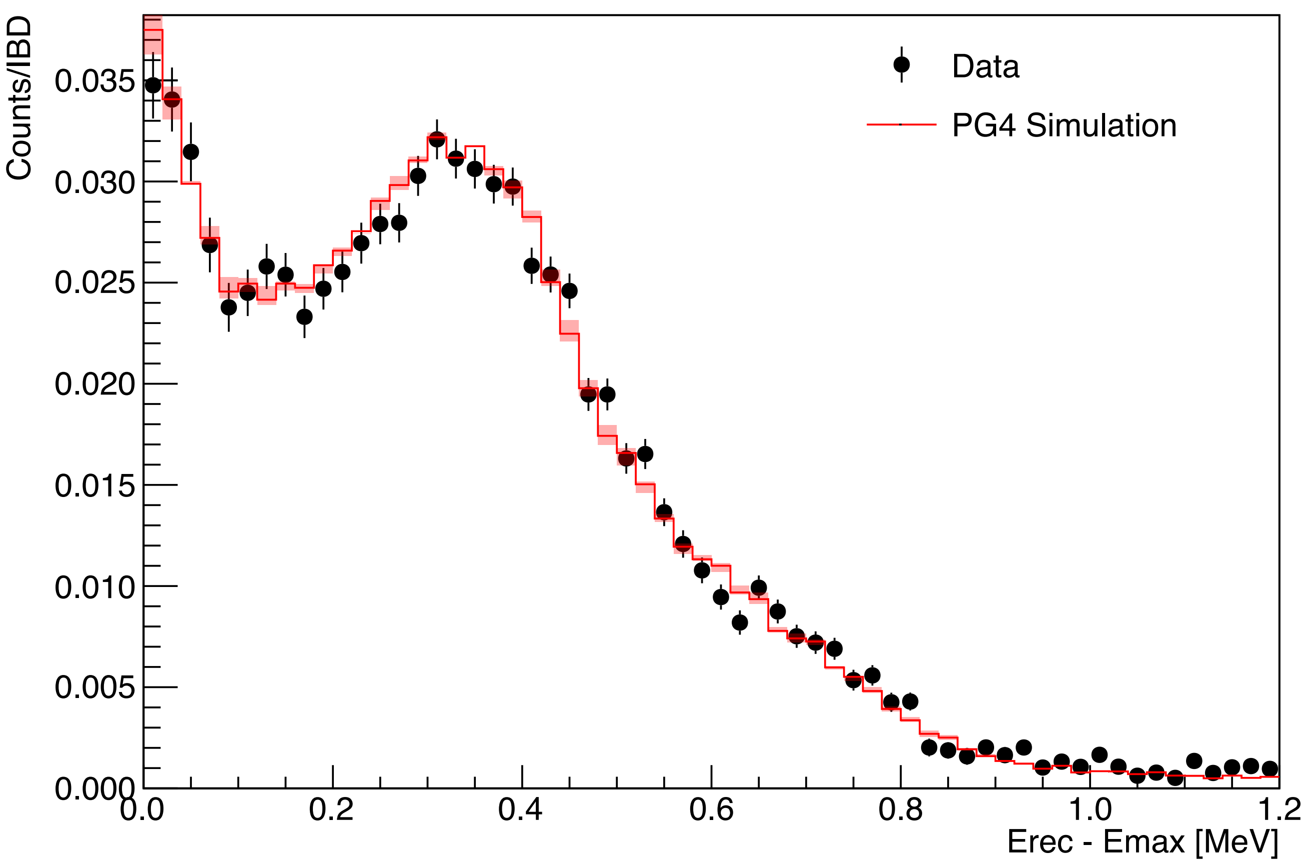


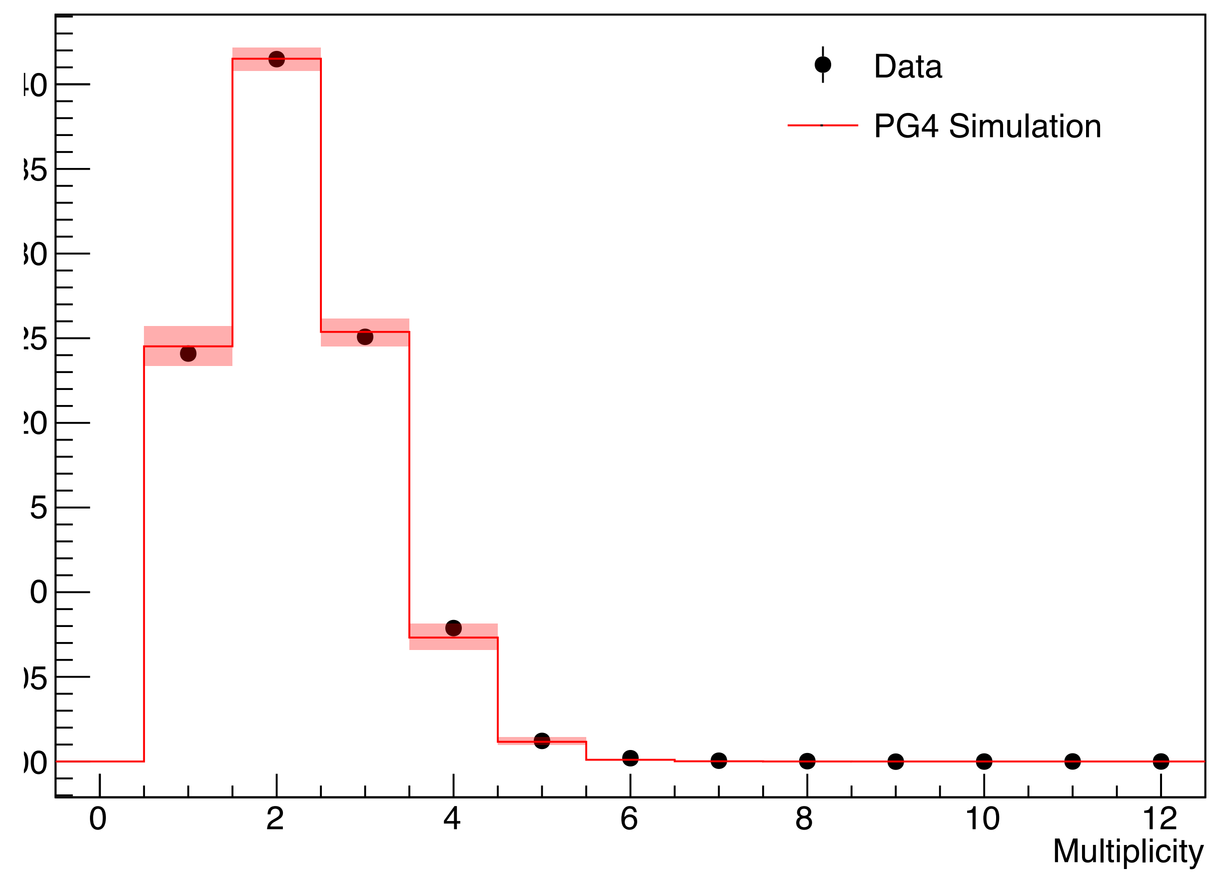


Signal Cross-Checks

- Do we properly model IBD response variations between regions? (yes!)
- Do we properly model IBD prompt multiplicities? (yes!)
- Do we properly model prompt energy leakage and annihilation gamma energy deposition? (yes!)

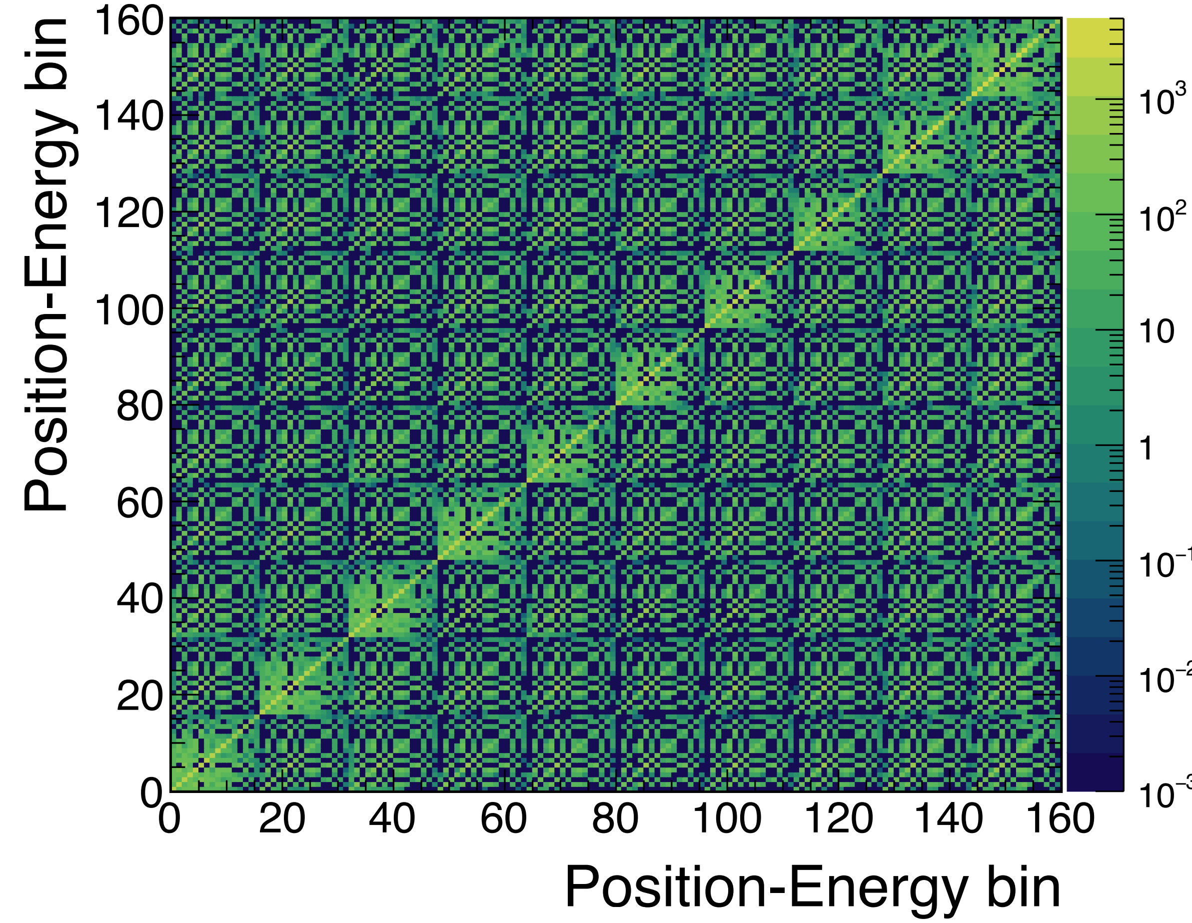






Osc Systematics

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

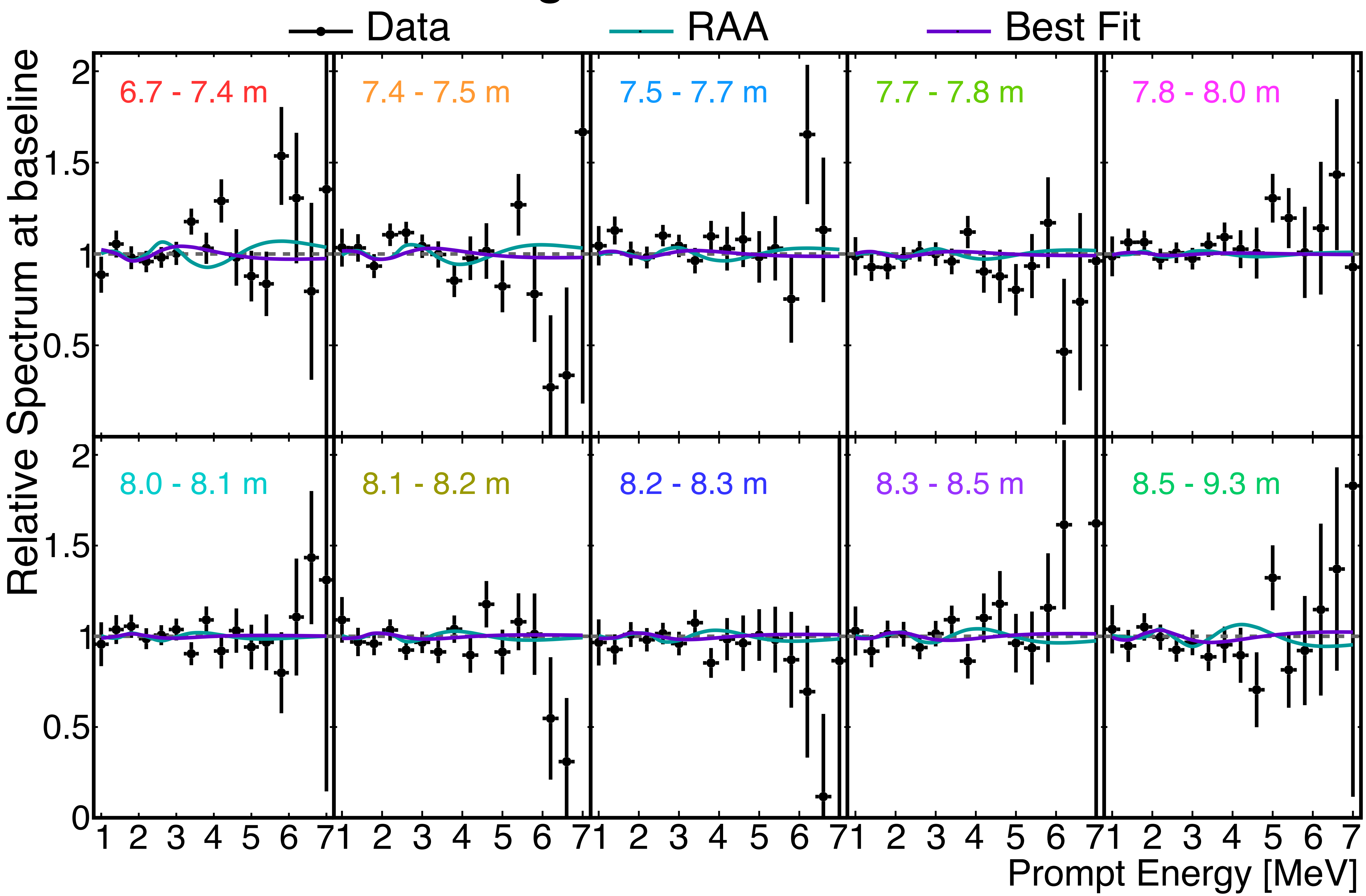


Osc Analysis Systematics

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

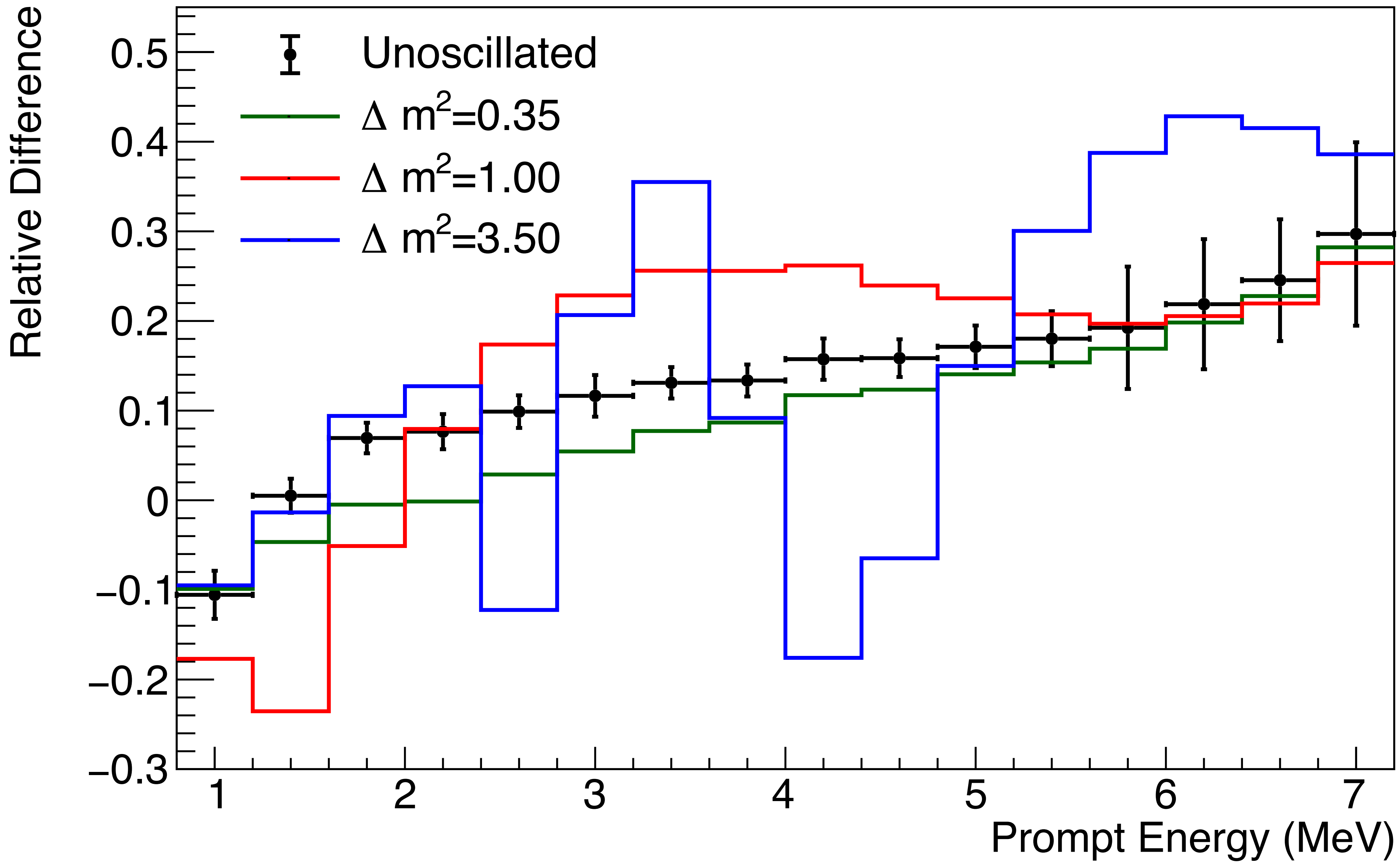
Osc Signal

- Relative ratios including the best-fit:



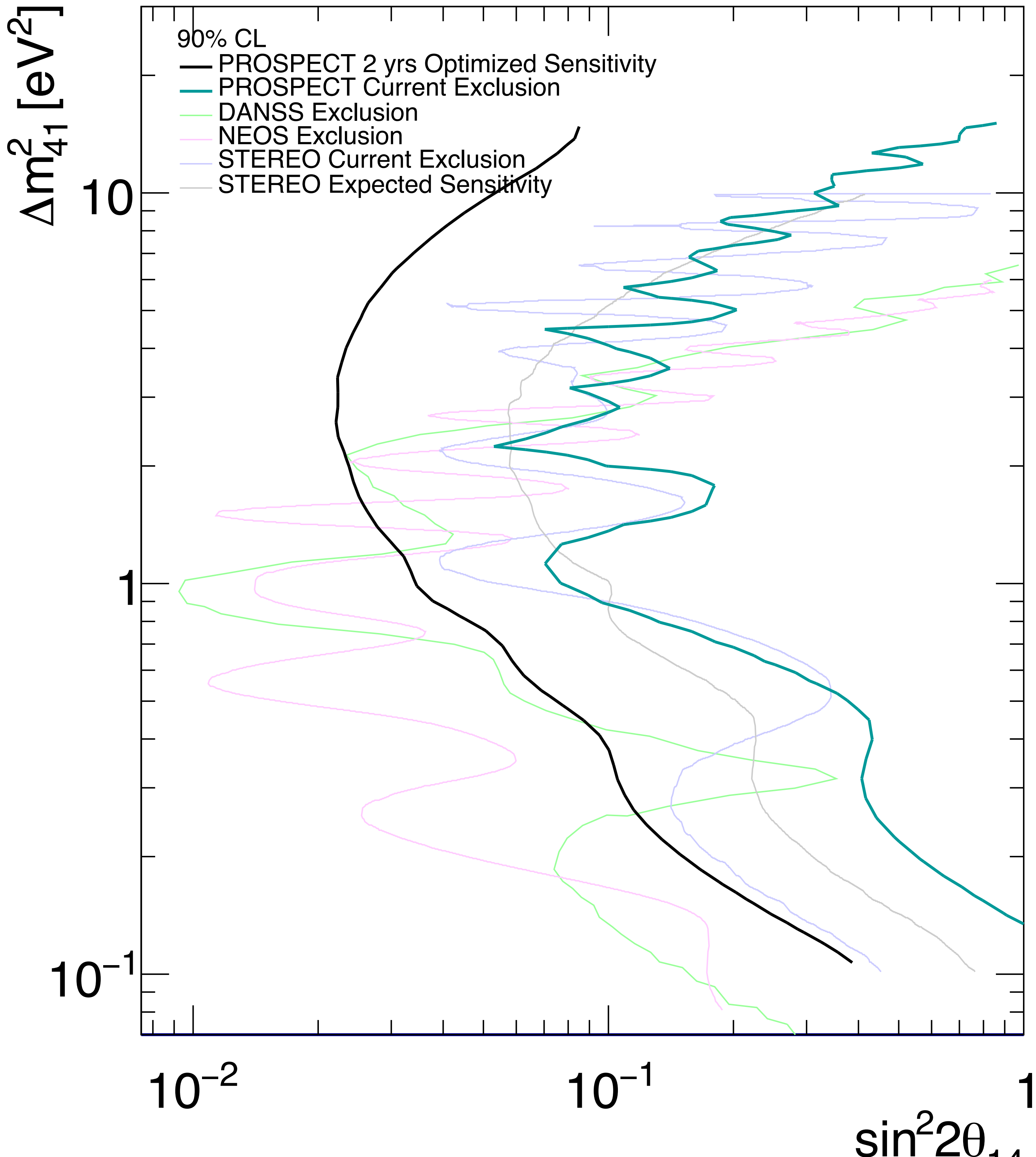
Oscillation: Relative Response Differences

- At most dm2, oscillations look much different than predicted relative response differences between baselines.



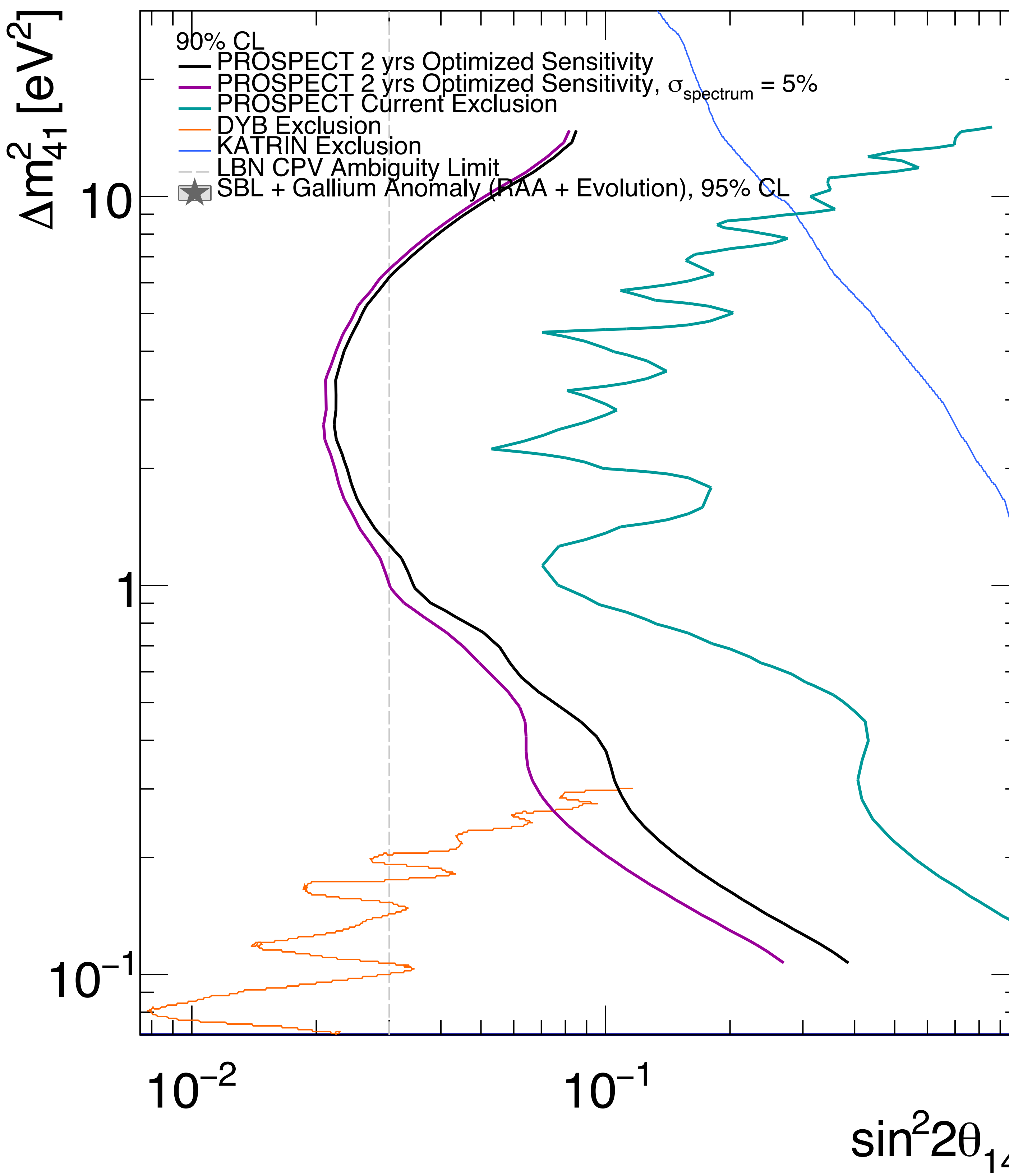
Osc Result Global Context

- 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



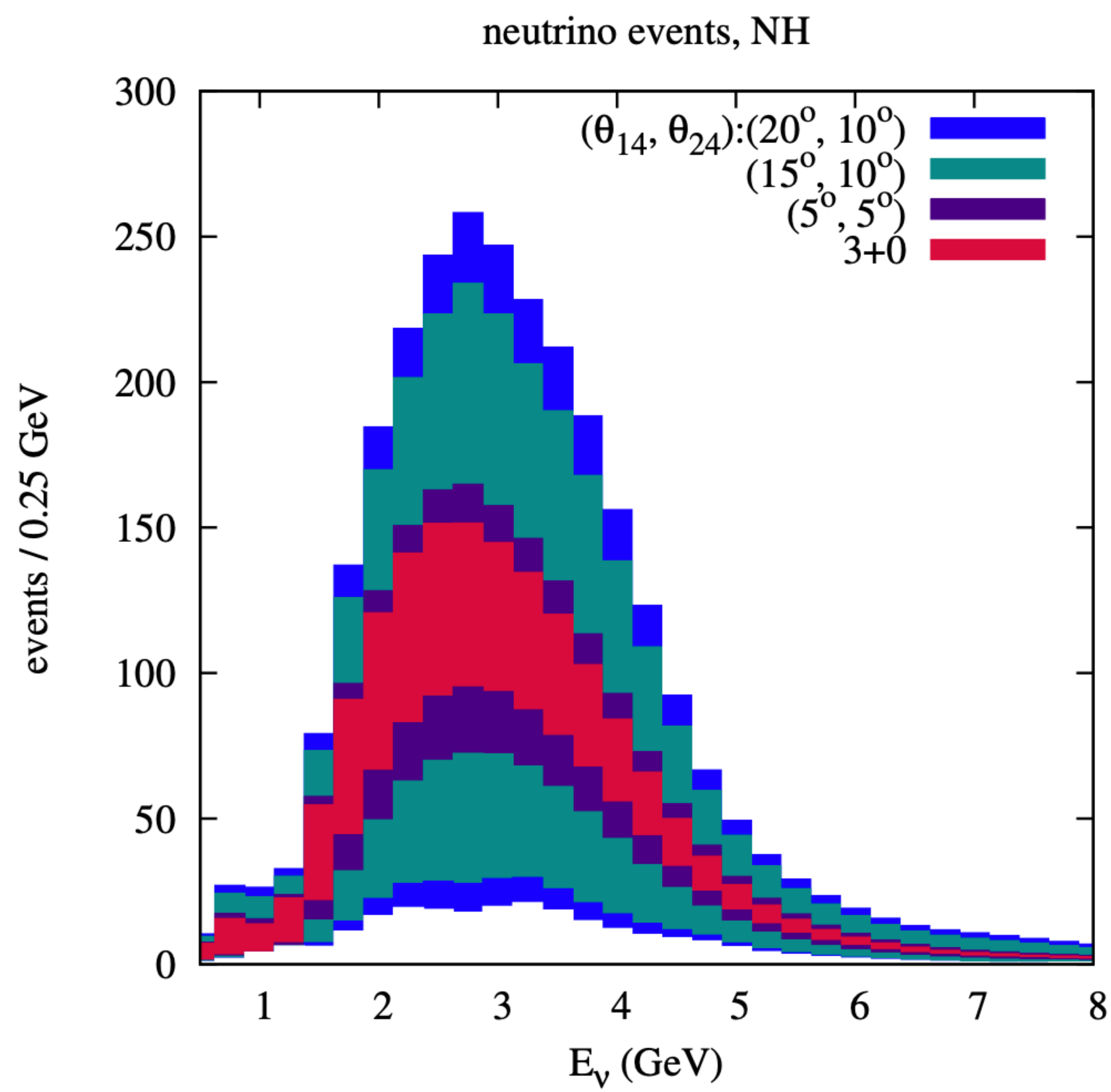
Osc Result Global Context

- Need to cover all dm2 to ~3% precision to avoid CPV measurement ambiguities
- Daya Bay will achieve this below ~0.3 eV^2
- KATRIN will eventually achieve this for ~20+ eV^2
- PROSPECT-II is needed to get the needed coverage in the >few eV^2 regime.
- NEOS and DANSS cannot achieve this.



DUNE and PROSPECT

- DUNE CPV results will be hard to interpret without nailing down θ_{24} and θ_{14} to better than ~5 degrees.
  - Could observe no CPV from sterile and active sector CPV cancelling!
  - If we observe CPV, what δ_{xx} are we actually measuring?
- DUNE baseline beam has changed in last few years, but I'm fairly sure these issues are still in play…

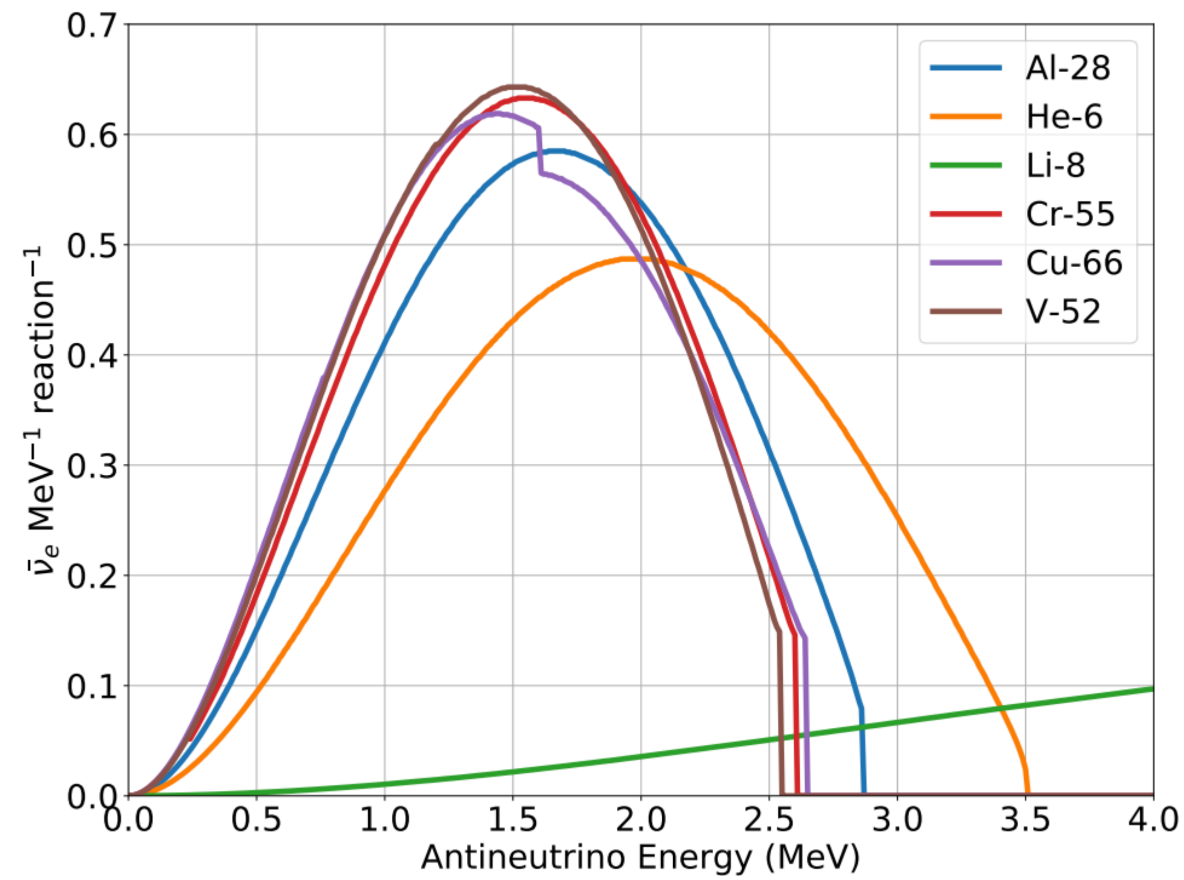


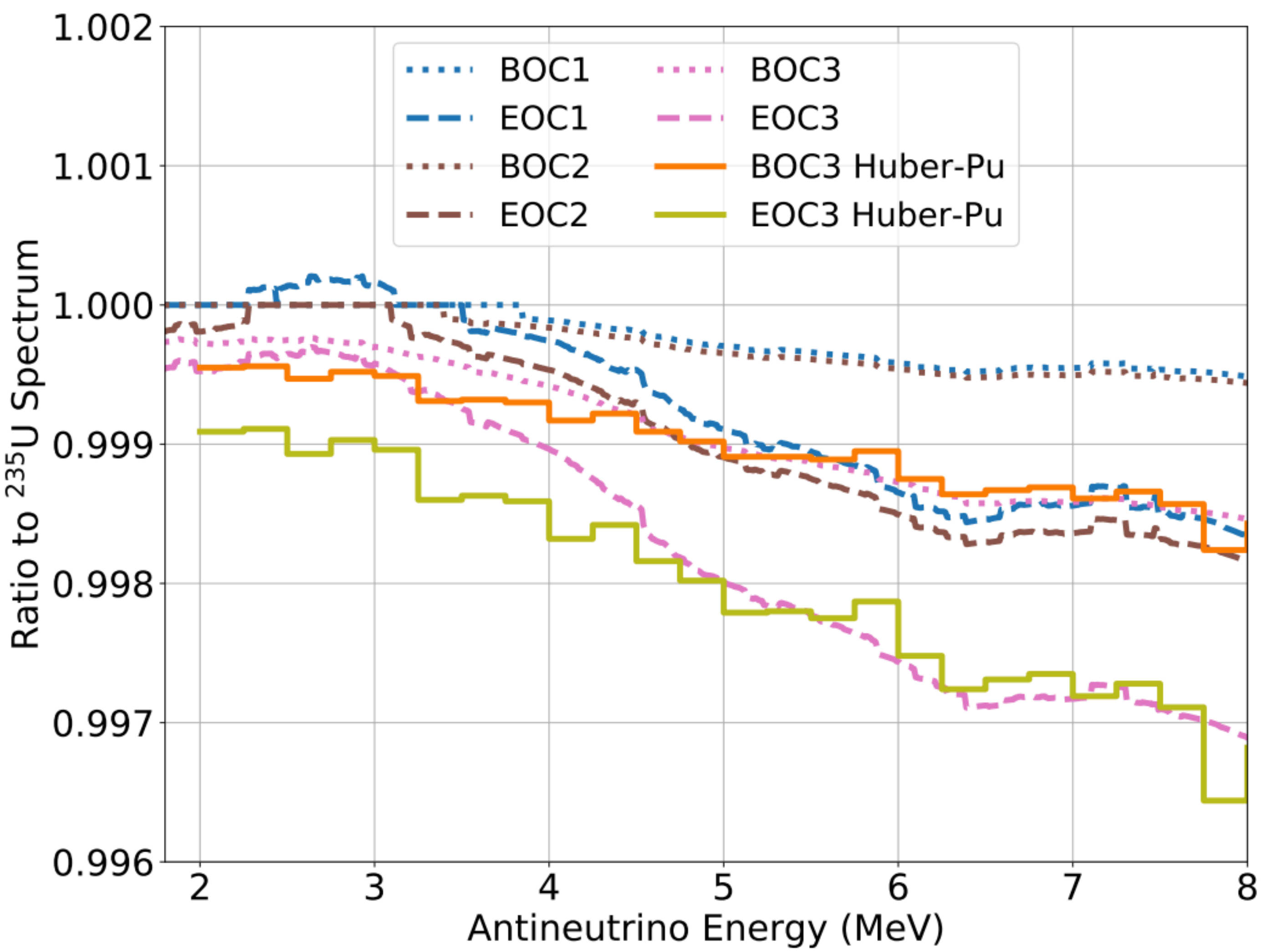
B. Kayser, et al. arxiv:[hep-ph]1508.06275

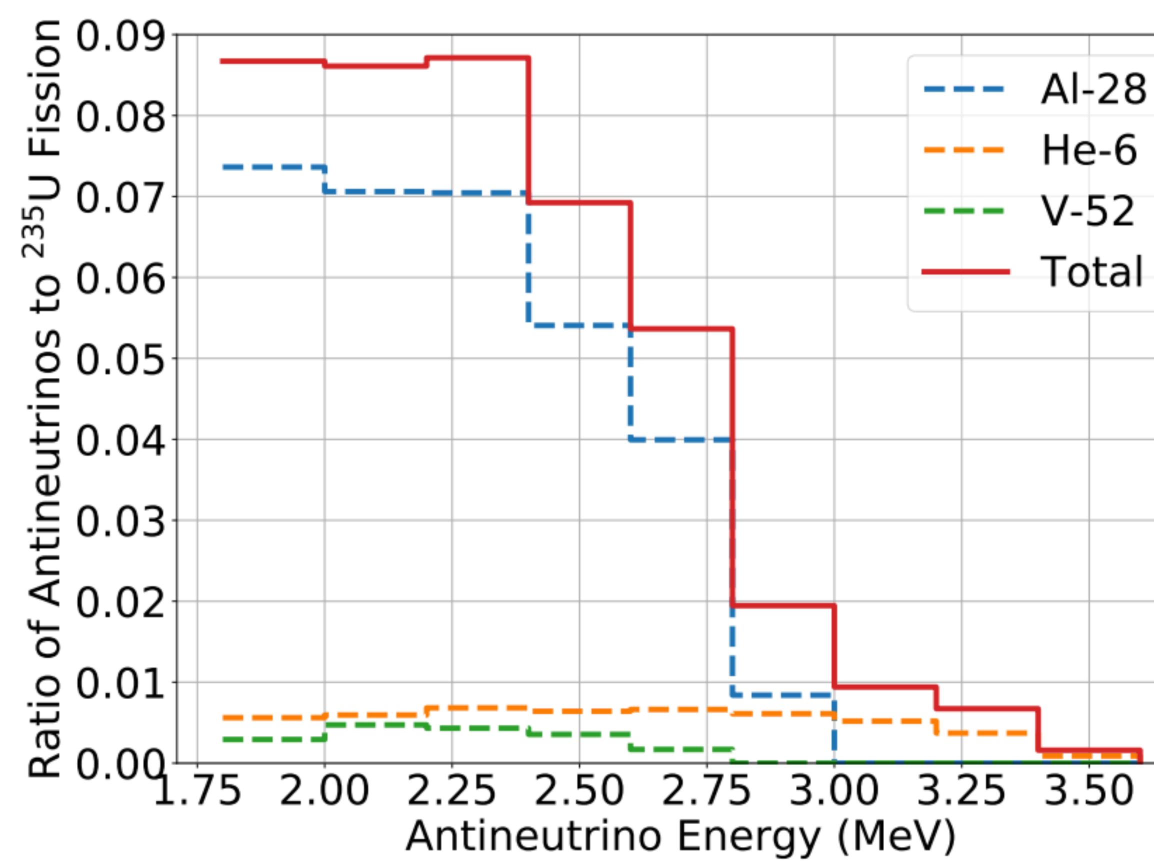
Non-Fuel Contributions

- Non-negligible neutrinos from activation of Al-28 in core structure, production of He-6 in beryllium reflector
- ~9% contribution at lowest IBD energies
- Effect is stable within 0.1% at cycle beginning and end.

PROSPECT, PRL 122 (2019)

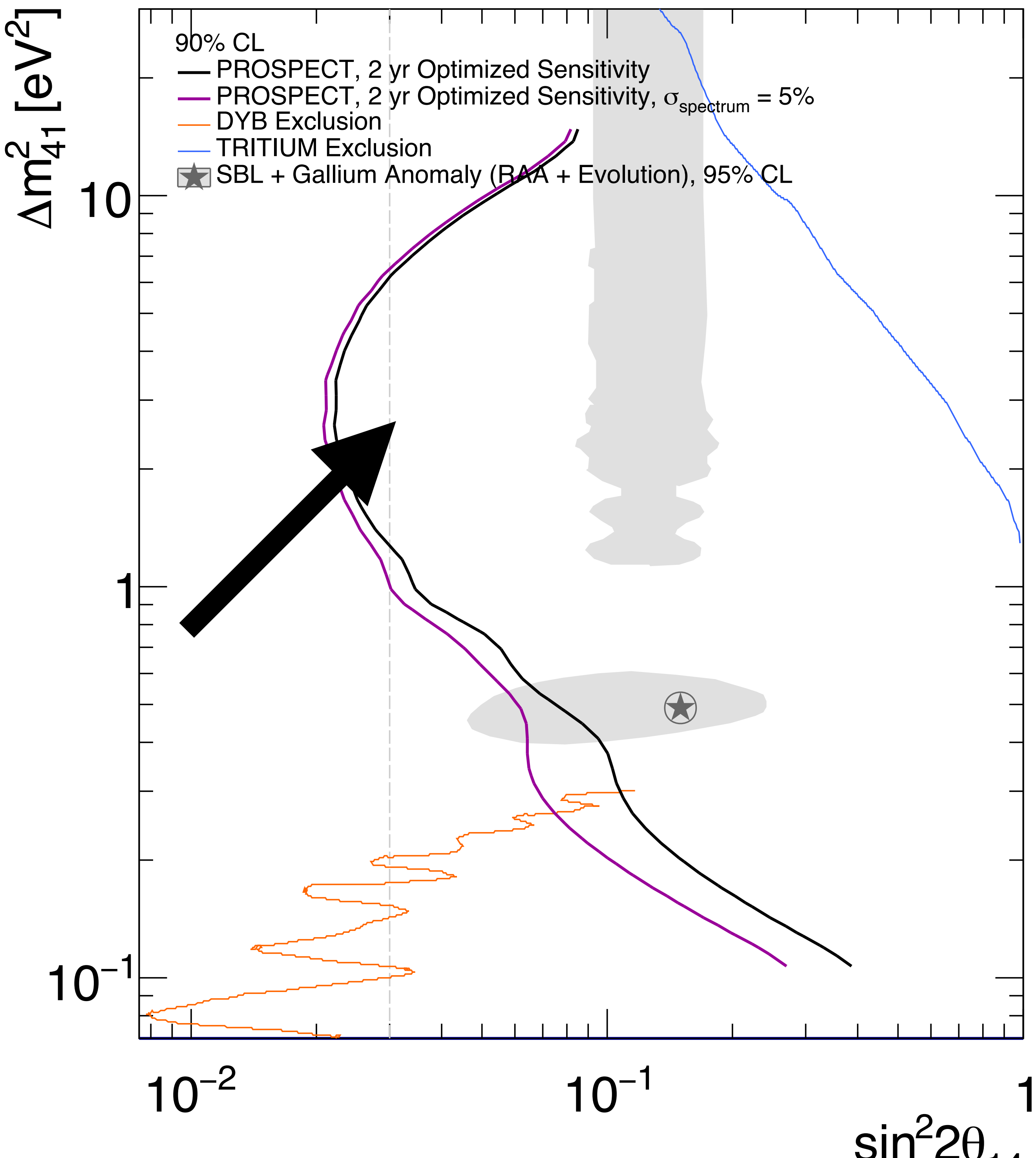




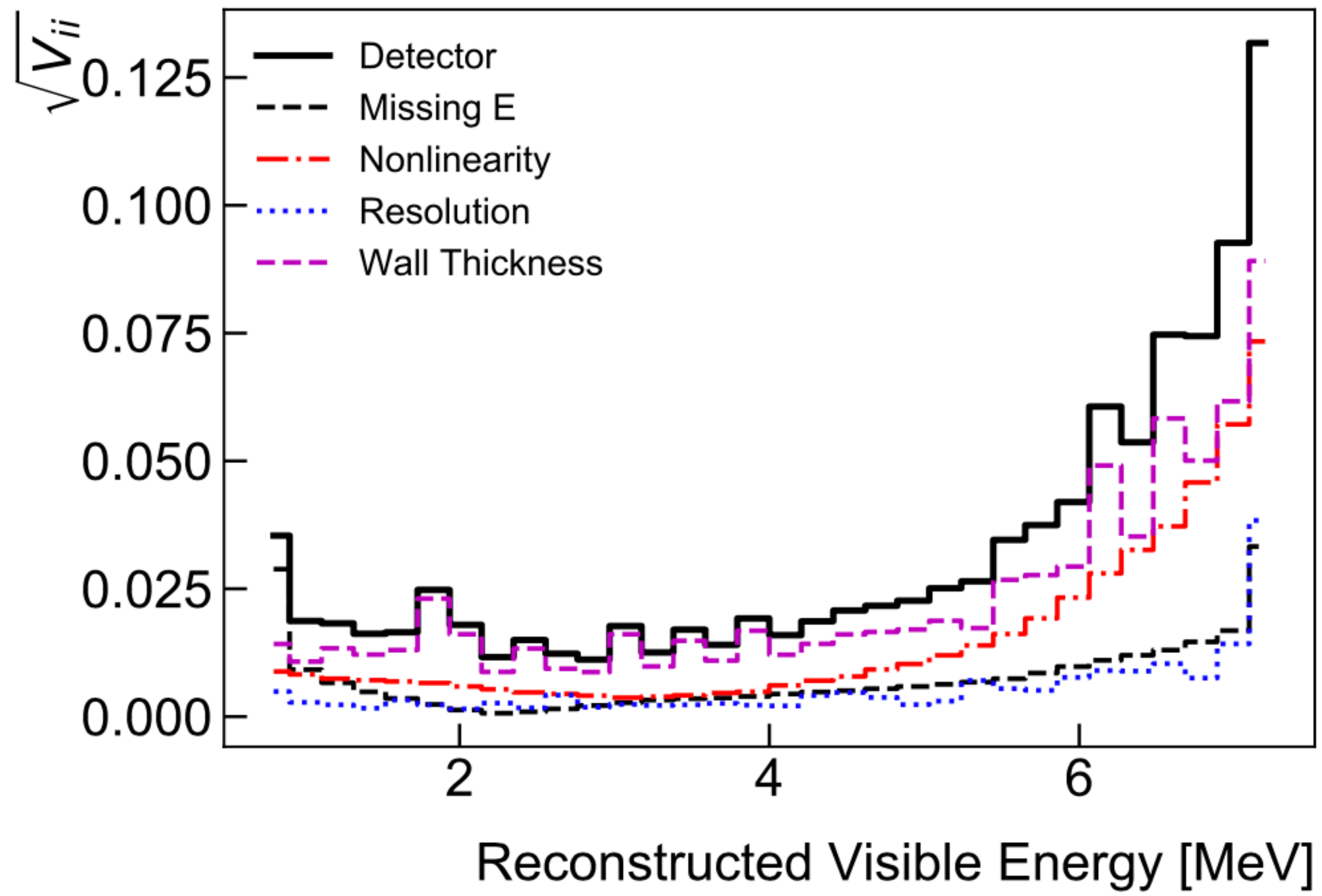


DUNE and PROSPECT

- DUNE CPV results will be hard to interpret without nailing down θ_{24} and θ_{14} to better than ~5 degrees.
- PROSPECT-I plays a role in bridging an important gap between other highly-sensitive probes of U_{e4}
    - Daya Bay below, tritium beta endpoint experiments (KATRIN)above
    - Note: both DYB and KATRIN limits will get better in future, especially KATRIN
- Also clear benefits from joint oscillation analyses



Spectrum Systematics

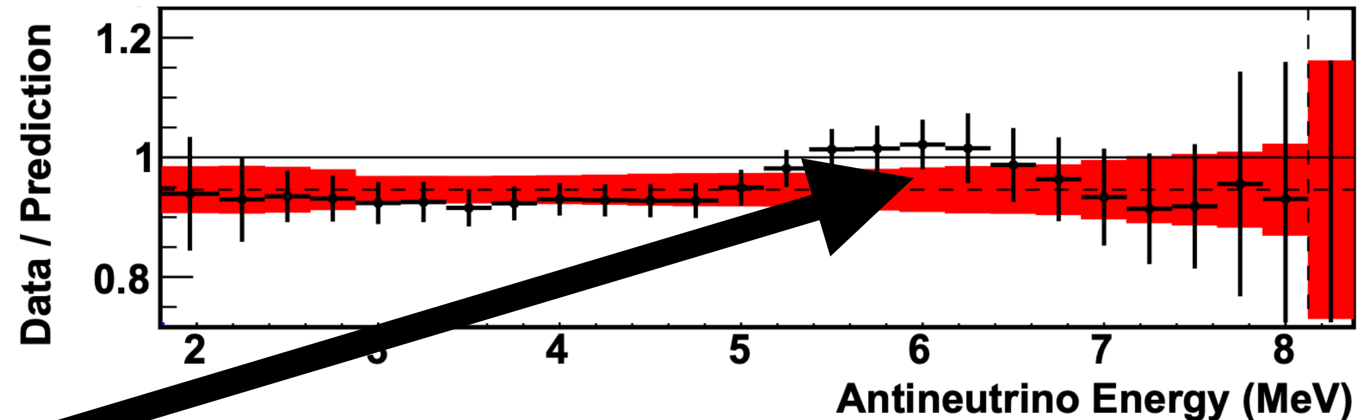


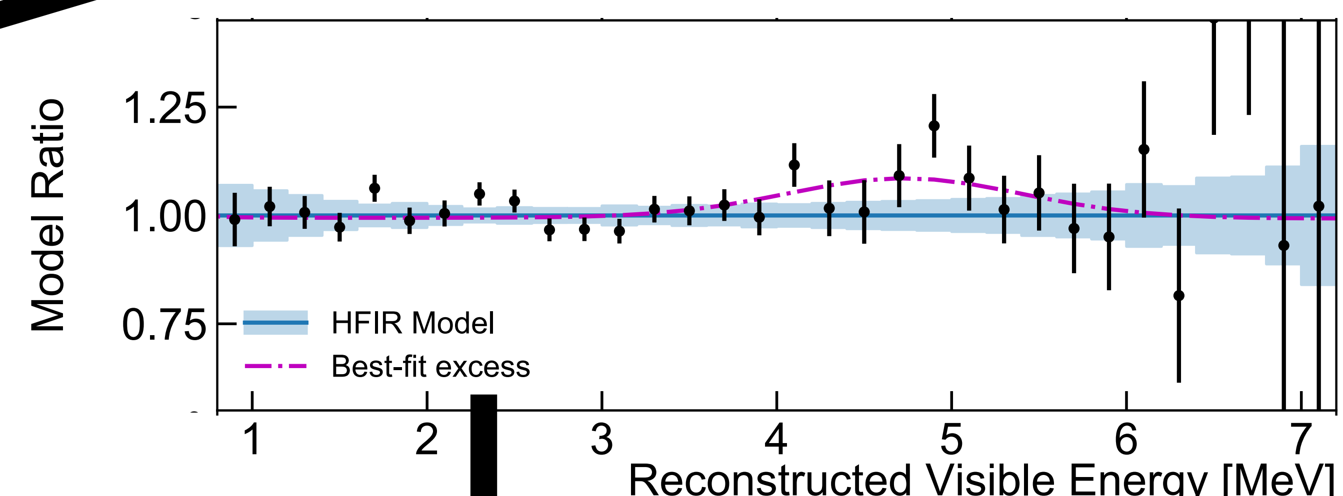
Spectrum Analysis Systematics

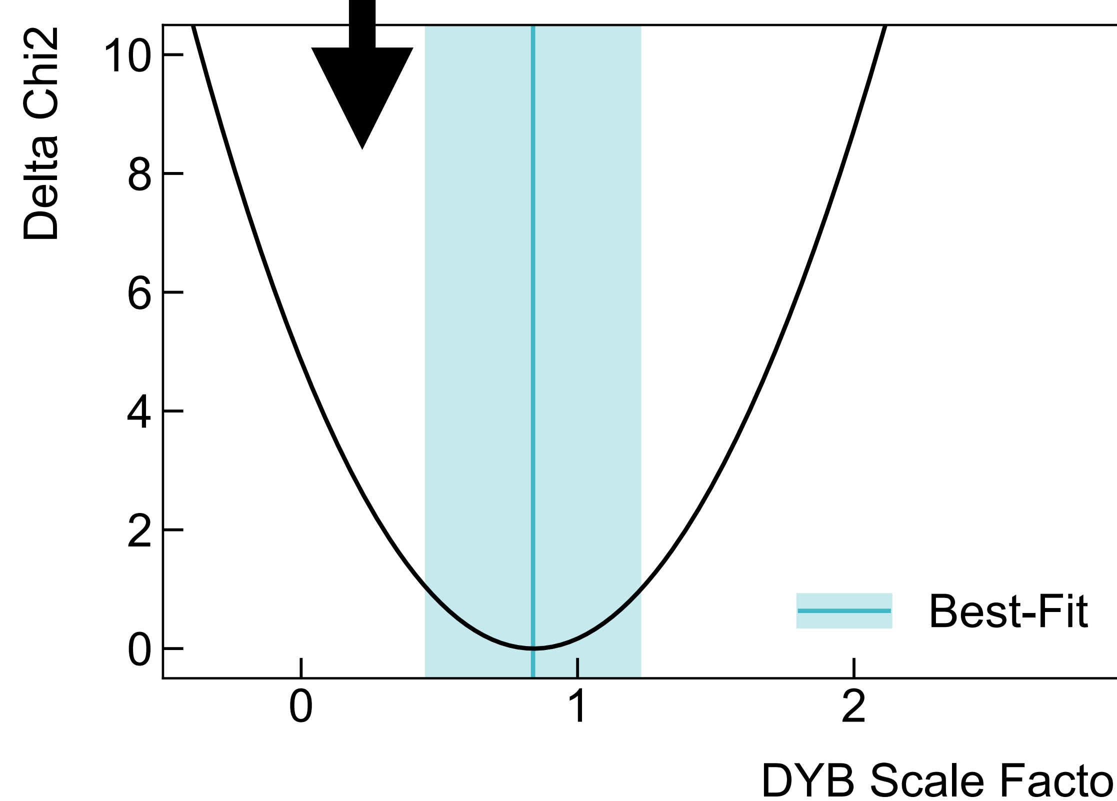
Parameter	Section	Uncertainty	Description
Background Normalization	VI B, VI D	1%	Accounts for variation between reactor-off periods
n-H Peak	VI D	3%	Accounts for uncertainty on background subtraction in the n-H peak region
Detector Non-linearity	IV B	0.002	Uncertainty for Birks non-linearity in energy deposition
Cherenkov Contribution	IV B	0.41	Uncertainty on Cherenkov contributions to collected photons
Energy Scale	IV B	0.004	Uncertainty on linear energy scale
Energy Resolution	IV C	5%	Uncertainty in photostatistics contribution to energy-dependent resolution
Energy Loss	IV D	8 keV	Uncertainty in energy lost by escaping 511 keV γ-rays
^{28}Al Activation	IX A	100%	Uncertainty in the amount of ^{28}Al contributing to the spectrum
Non-equilibrium Correction	IX A	100%	Uncertainty in extrapolating $\overline{\nu}_e$ contribution from long-lived fission daughters
Panel Thickness	IV B	0.03 mm	Uncertainty in mass of the panels separating segments
Z Fiducial Cut	V C	25 mm	Uncertainty in the position of events near the edge of the fiducial volume
Energy Threshold	IV B, III G	5 keV	Uncertainty in the segment-by-segment energy threshold cut

^{235}U Spectrum: Dial-A-Bump

- Q: Does PROSPECT see 5-7 MeV bump observed at low-enriched reactors?
  - Model feature by fitting to the Daya Bay ν_e spectrum a Gaussian on top of the Huber-Mueller prediction
  - Apply same Gaussian to the Huber ^{235}U prediction, while fitting its amplitude to PROSPECT's data
  - Gaussian center and width and fixed, while amplitude A is fitted.
  - Also fit a floating normalization of total Huber+Gaussian spectrum





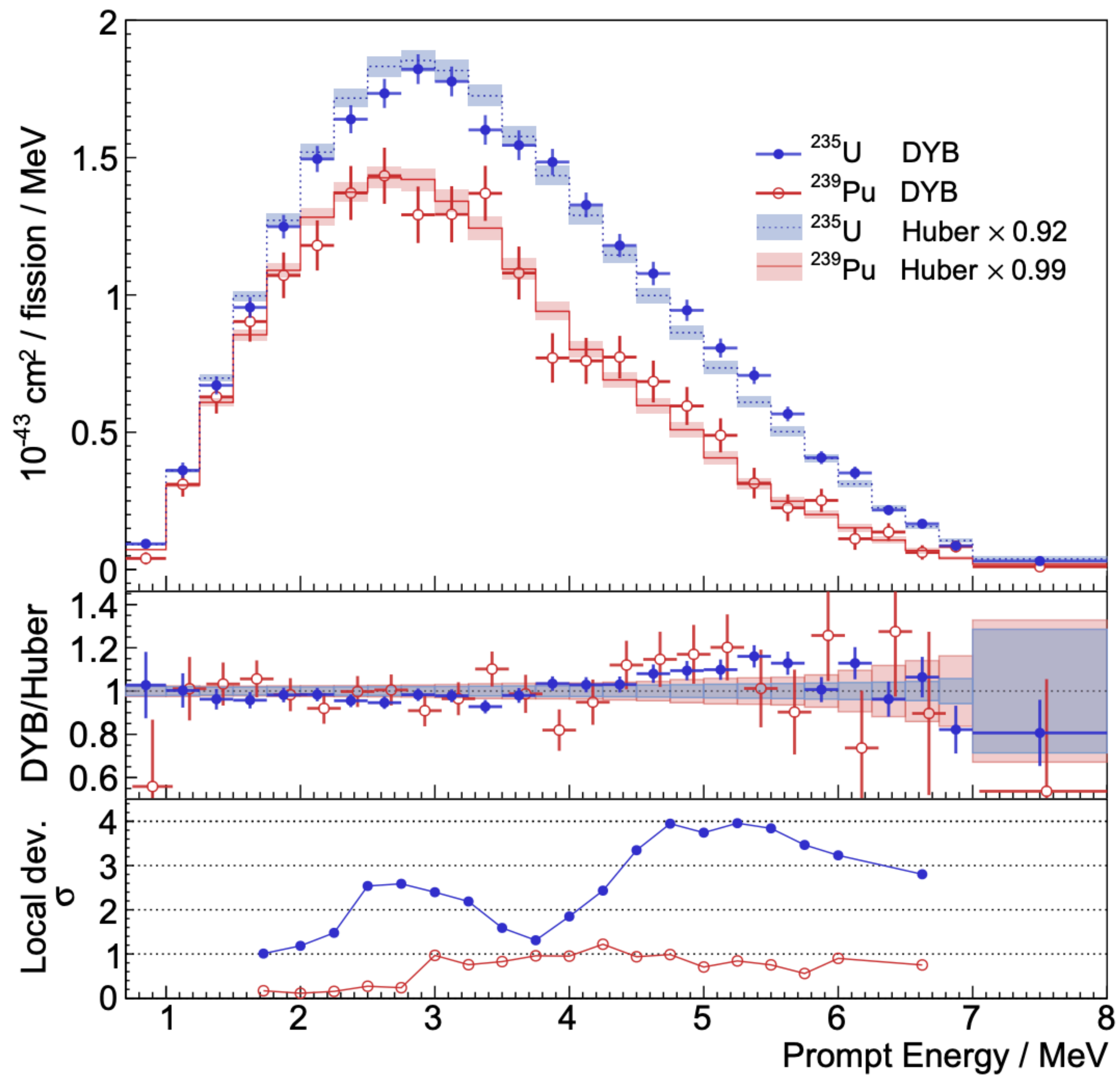


Spectrum Result Global Context: DYB

- Daya Bay sees U235 spectrum anomaly, but Pu239 uncertainties are too large to spot similar feature there

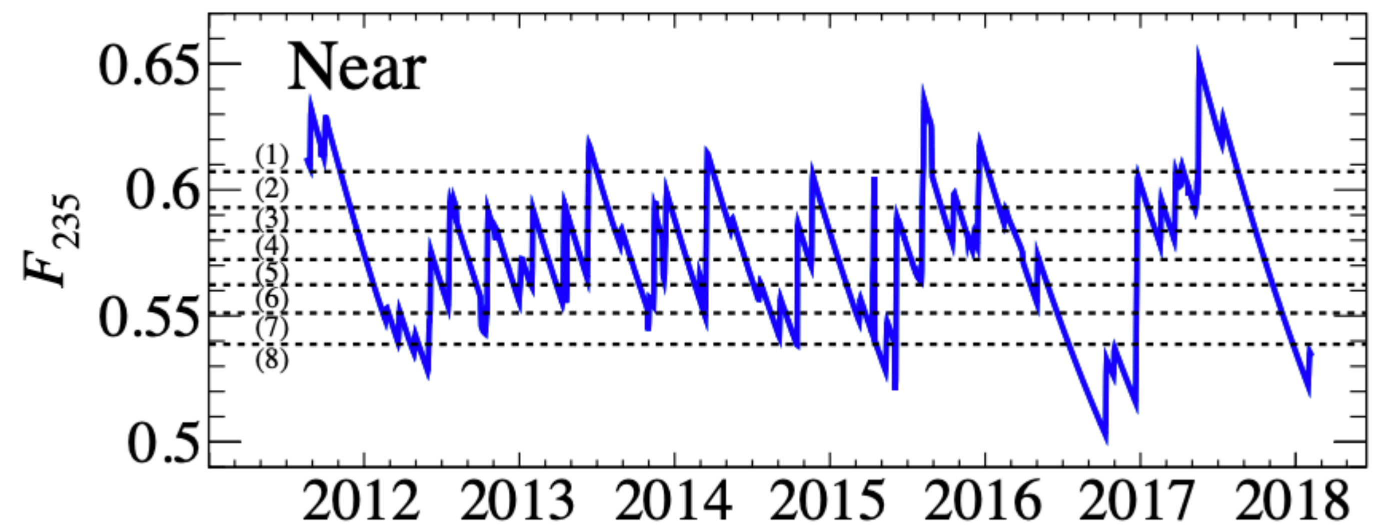
- PROS+DYB joint analysis helps to transfer more of DYB's statistical power to Pu239 spectrum

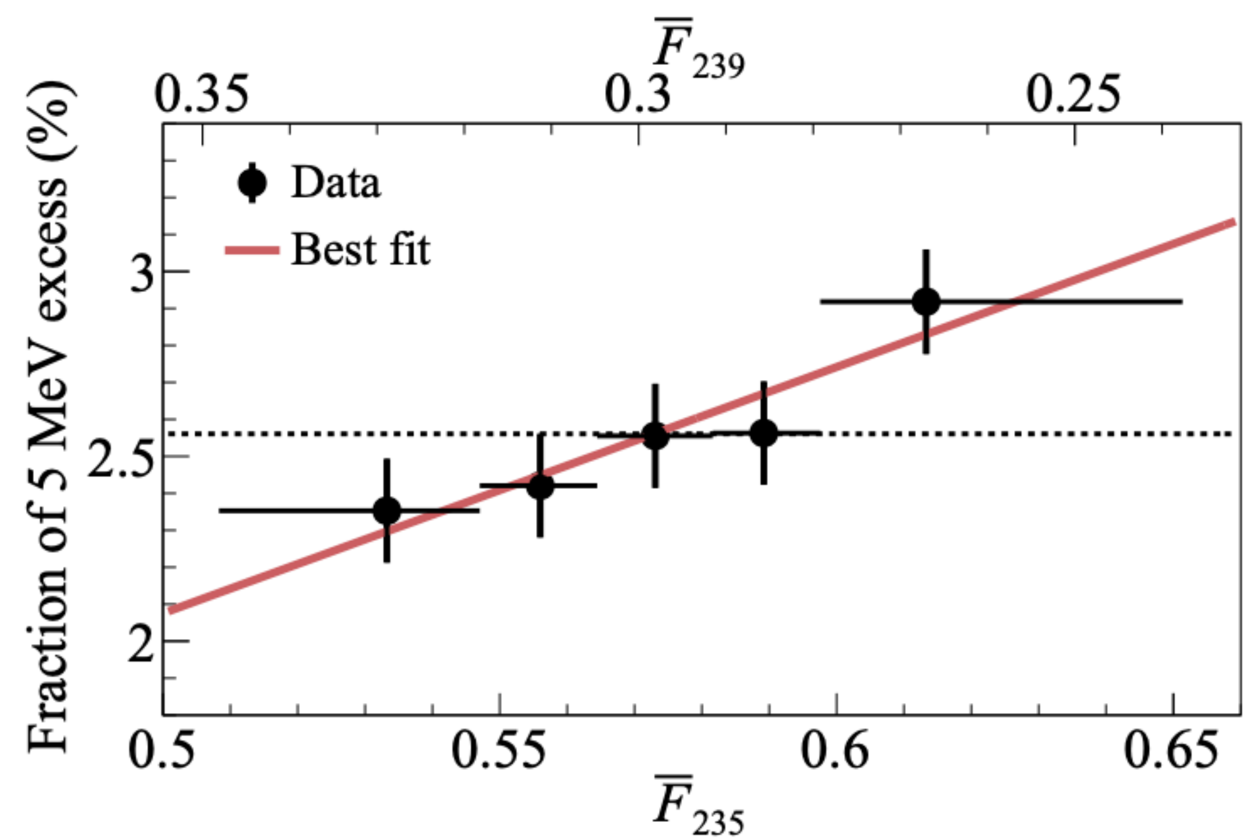
- Currently working with DYB on a joint DYB-PROS spectrum analysis.



Spectrum Result Global Context: RENO

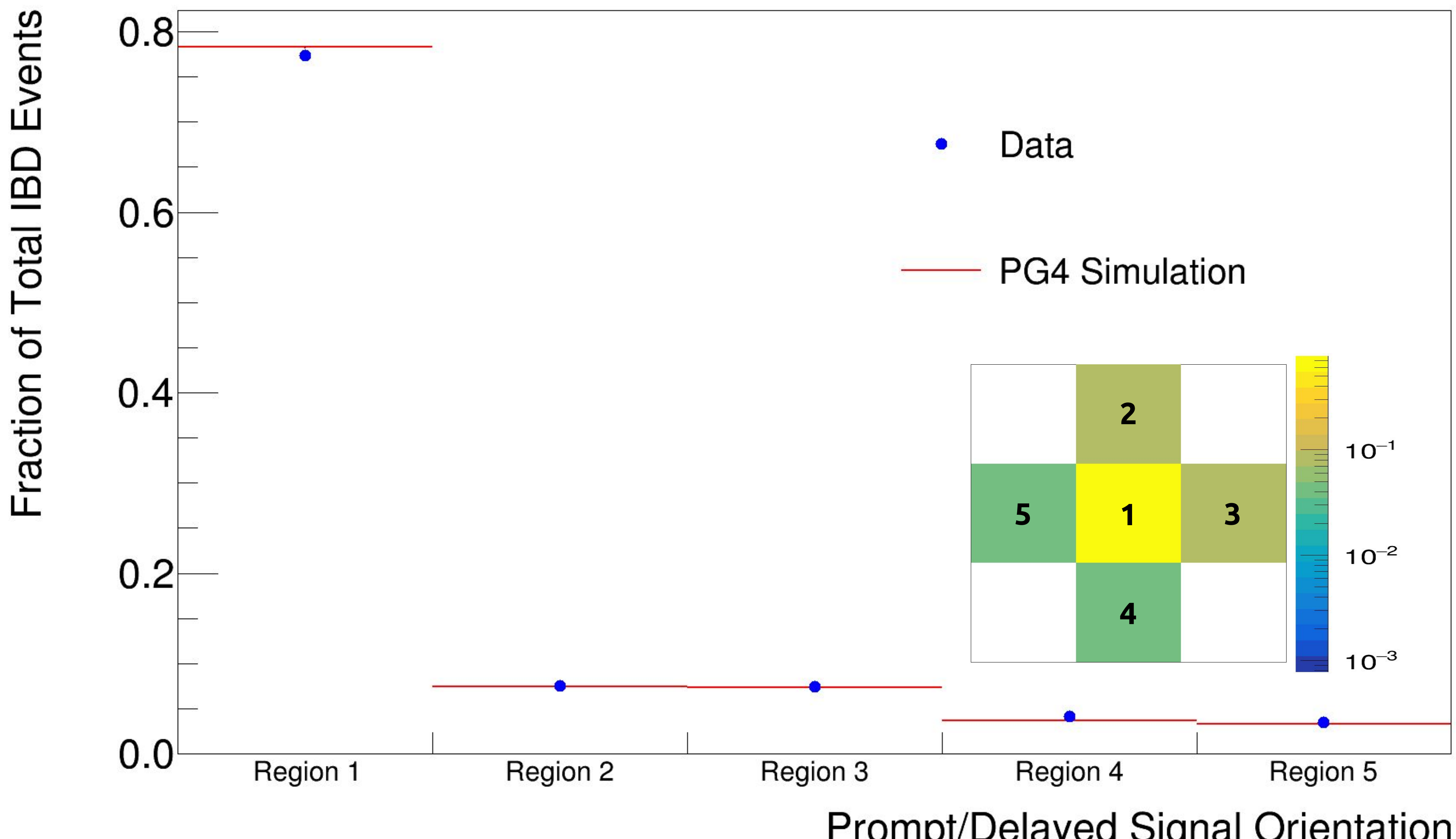
- RENO claims that 'bump size' increases with increasing U235 fission fraction
  - This would happen only if U235 has a 'larger bump' than other fission isotopes
  - Appears to contradict PROSPECT's 'bump analysis' outcomes (slide 16)
  - Best-fit red slope indicates that Pu239 spectrum contains a '5-7 MeV dip' (i.e. the intercept at F235=0 is below zero: -0.55%).
  - Best-fit red slope also indicates PROSPECT should see a ~25% excess in the 5-7 MeV region (A~2.0-2.5 in slide 16). This is not compatible with PROSPECT data.





Reactor Direction in PROSPECT

- Downstream segments see substantially more IBD neutrons
- Effect is predicted by IBD MC properly taking into account the direction of neutrino propagation
- Indicates ability of PROSPECT-style segmented detector to statistically identify reactor location

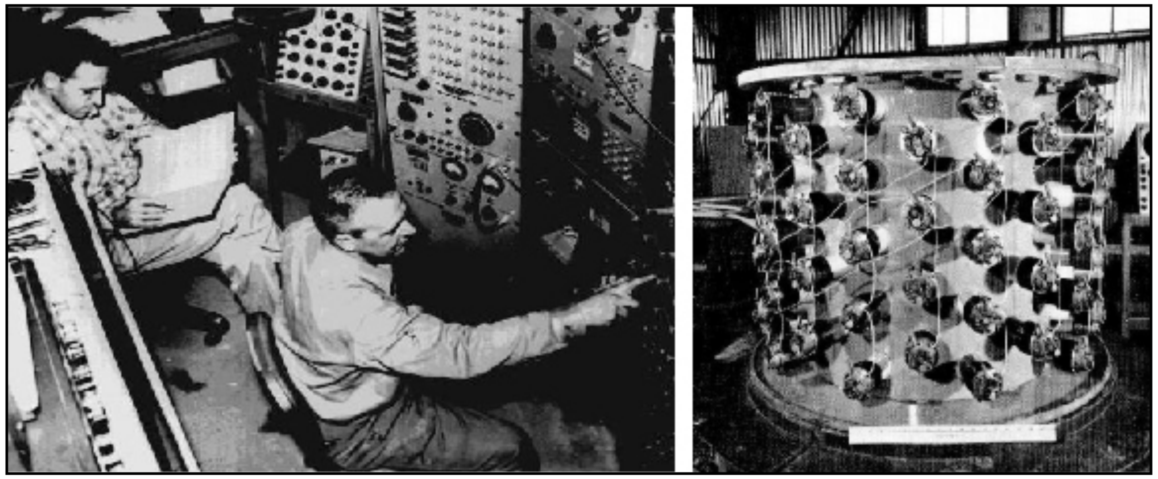


Reactor Fluxes and Nuclear Data

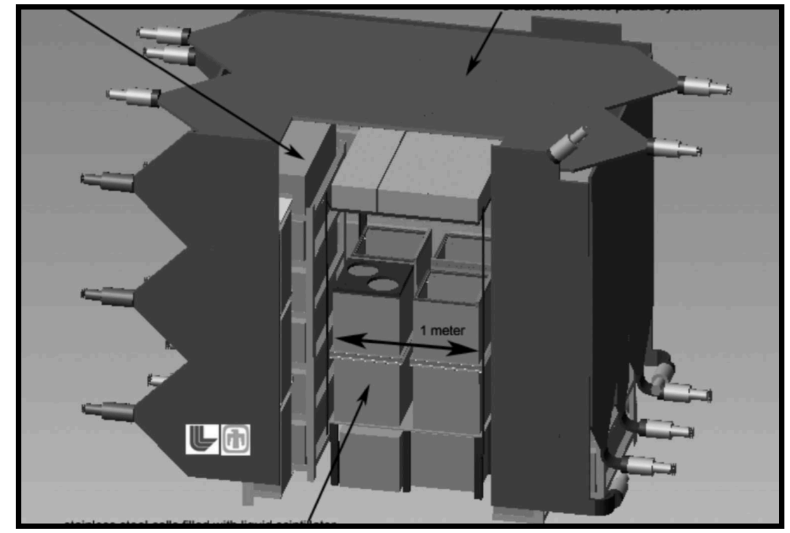
- How do reactor neutrino fluxes matter to nuclear data people?
  - Have the capability to act as a 'validation' dataset for the nuclear data pipeline; normally nuclear folks think of fission criticality experiments playing this role
    - 'If we improve some aspect of the nuclear data, do we end up getting ab into predictions closer to the measured neutrino flux?'
      - https://arxiv.org/abs/1904.09358
    - 'Do we properly predict the evolution in IBD yield of an LEU core?' —> Gives a unique window onto how well 235-239 yield differences are measured/understood
      - https://arxiv.org/abs/1707.07728
    - The authors in these papers are all hardcore nuclear theory / nuclear data folks… Not just HEP neutrino fan-boys/girls…
  - A unique opportunity to learn about U-238 and its nuclear data
    - U238 fission yields are very poorly measured; this why no model builder scoffs when we put 10-15% error bars on the 238 ab initio predicted fluxes…
  - Reactor neutrino anomalies represent excuses for nuclear experimentalists to do nuclear data experimental measurements…
      - https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.115.102503
      - https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.117.092501

Reactor Neutrino Monitoring Advances

- Last few decades have brought major advances in realized tech:

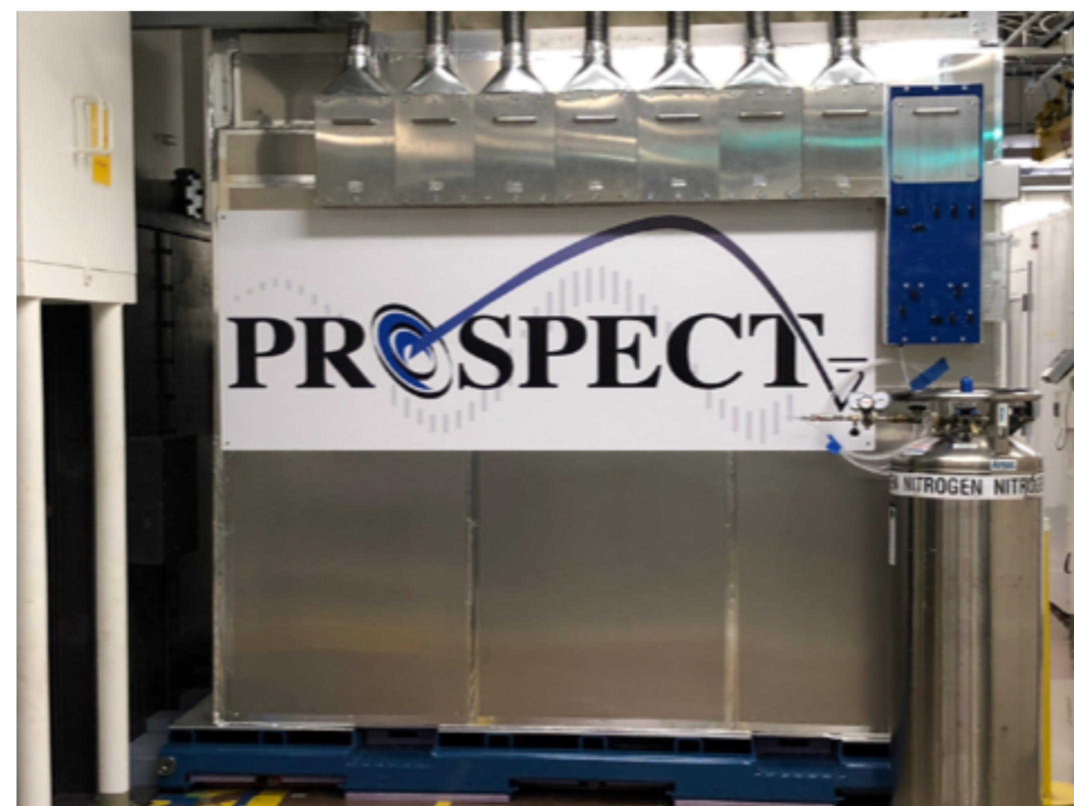


1950s: First Detection; ~1000 counts in 1 month;
5 background counts per 1 antineutrino count (S:B 1:5)



2000s: SONGS: ~230 counts per day, 25:1 S:B, but must be underground. 'semi-safe' detector liquid

1980s: Bugey: ~1000 counts per day, S:B 10:1, but only underground. flammable/corrosive solvent detector liquids



NOW: PROSPECT detector: ~750/day from only 80MW reactor, S:B 1:1 on surface, 'safe' plug-n-play detector