ROAD TO PROSPECT-II

July 8

Franz Machado

Illinois Institute of Technology

on behalf of the PROSPECT Collaboration

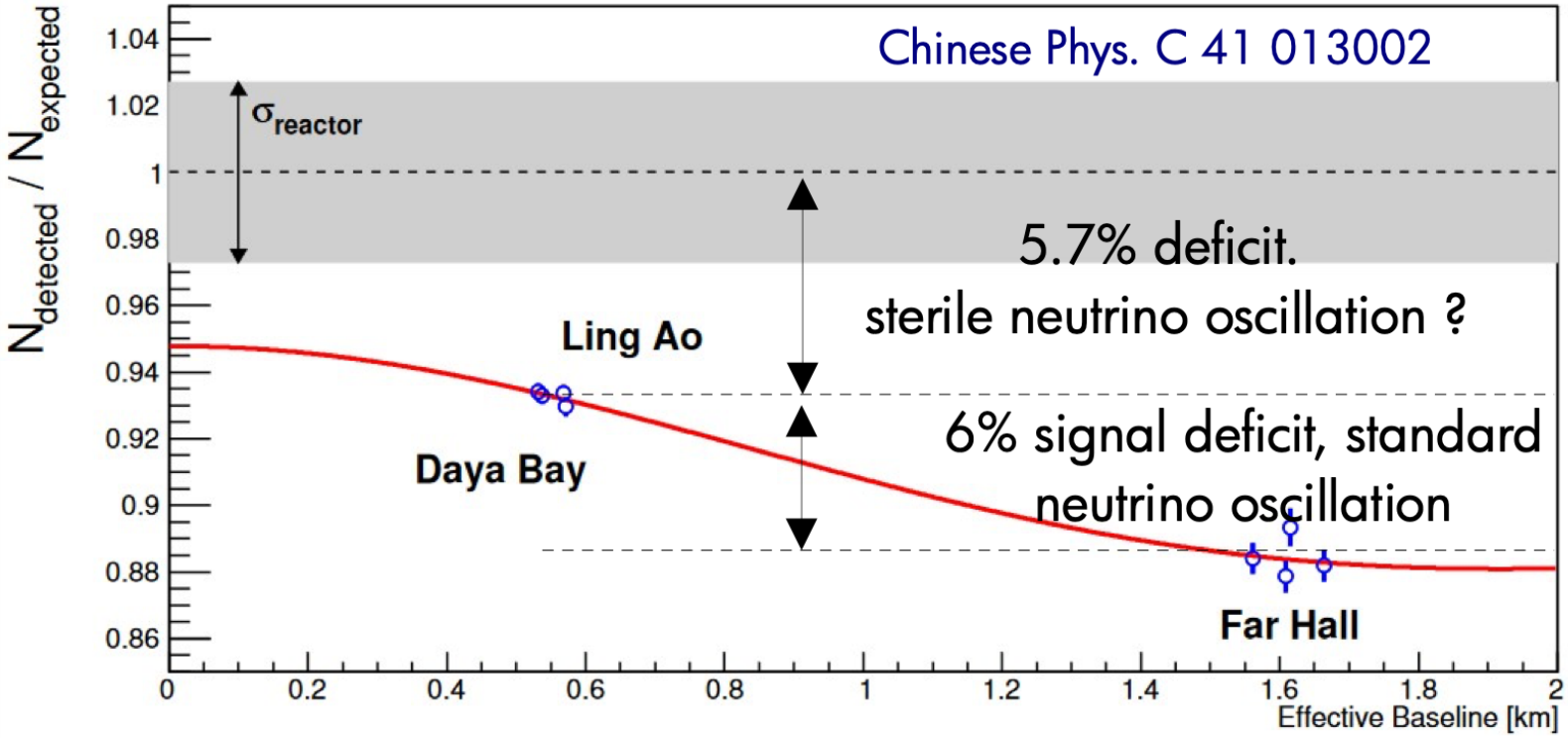
fmachado@hawk.iit.edu

DOE Report Number:
FERMILAB-SLIDES-24-0145-V

Table of content

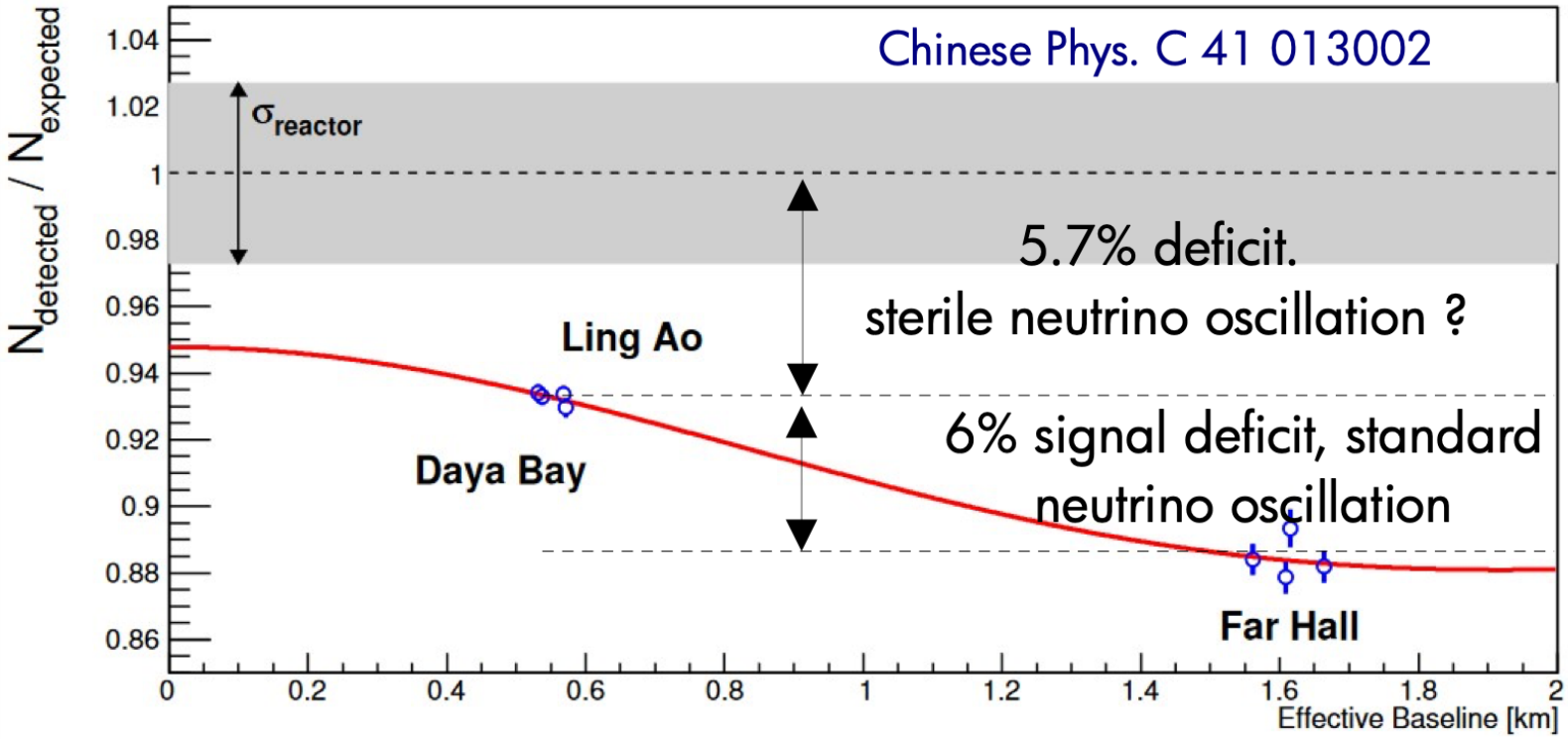
PROSPECT Motivation: Reactor Antineutrino Anomaly (RAA)

- Antineutrino flux predictions differs from precision measurements



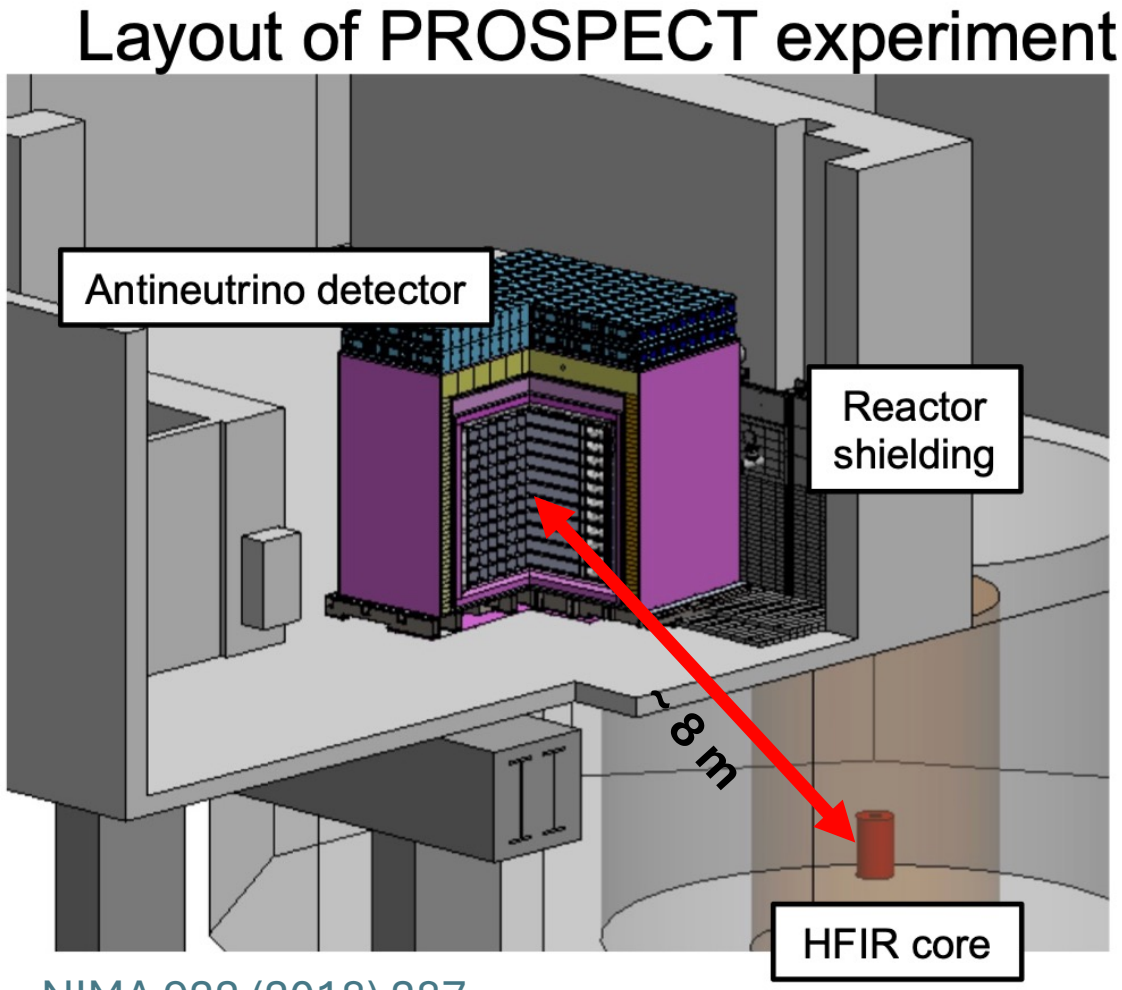
PROSPECT Motivation: Reactor Antineutrino Anomaly (RAA)

- Antineutrino flux predictions differs from precision measurements
- Possible explanations:
  - -Flux misprediction
  - -Oscillation of active antineutrinos into sterile states



PROSPECT-I Design

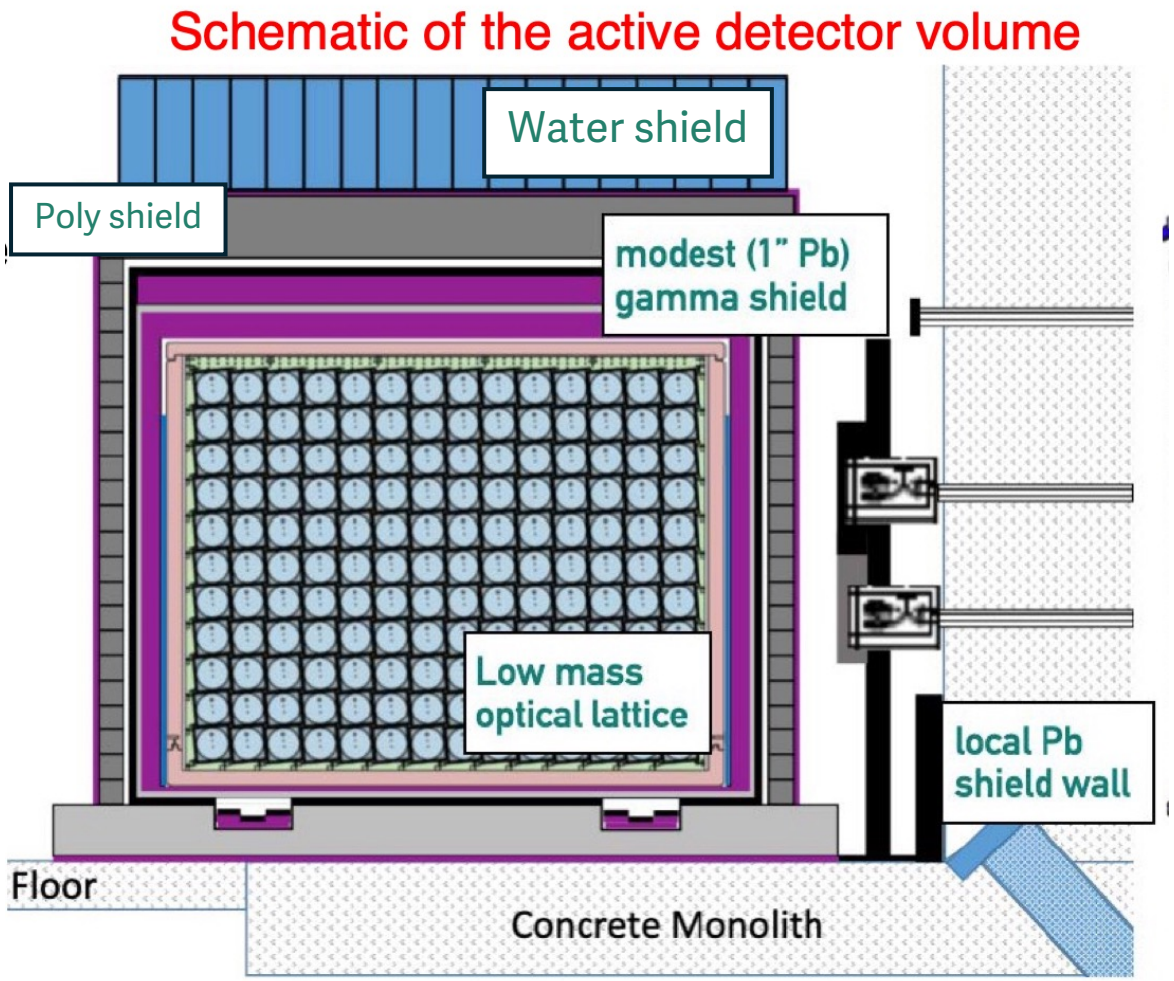
- A 4-ton, segmented detector designed to search for sterile neutrino oscillation and ^{235}U spectrum measurement.



NIMA 922 (2018) 287

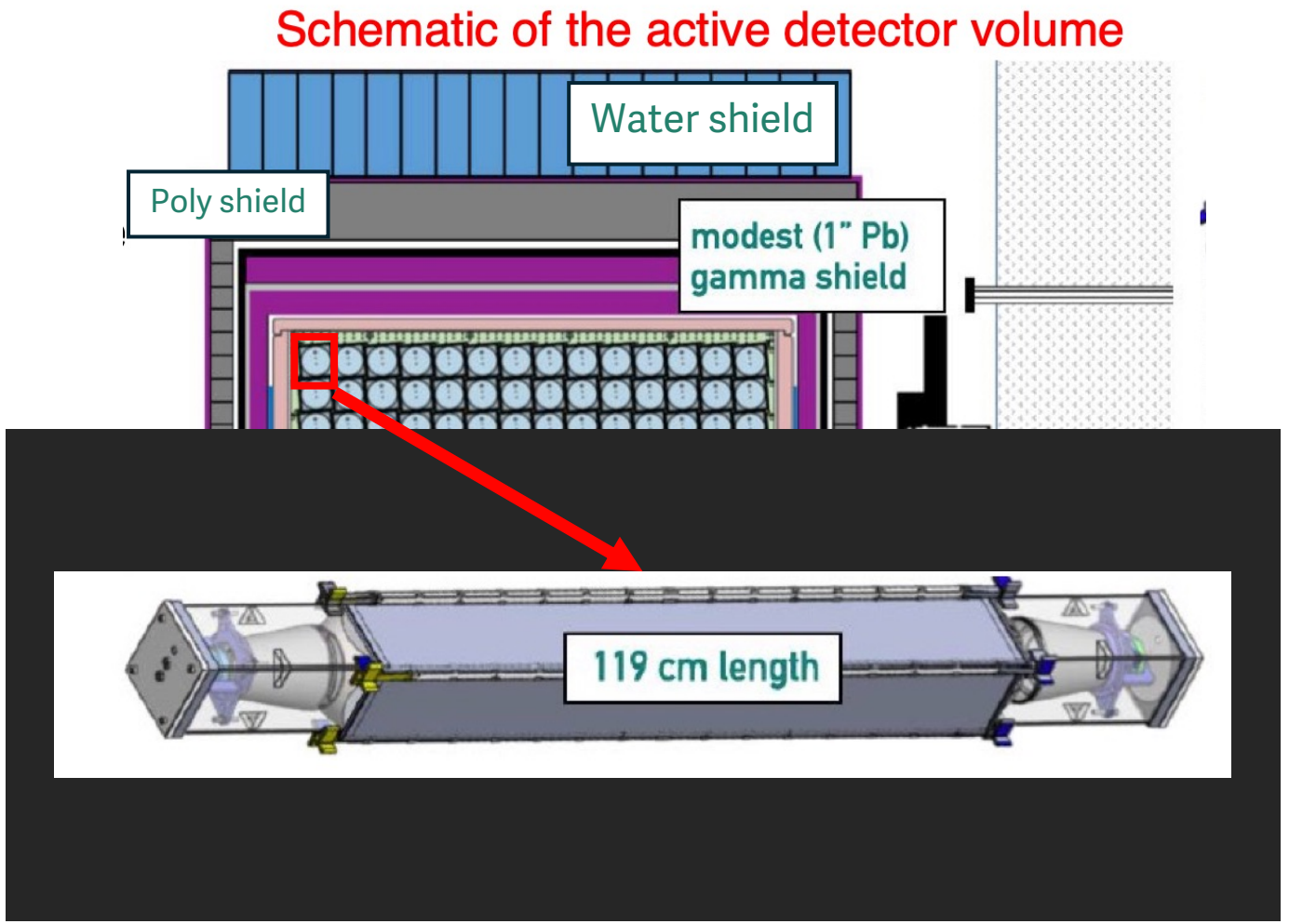
PROSPECT-I Design

- A 4-ton, segmented detector designed to search for sterile neutrino oscillation and ^{235}U spectrum measurement.
- Reactor on data from Mar - Oct 2018
- 6.7 – 9.2m from HFIR

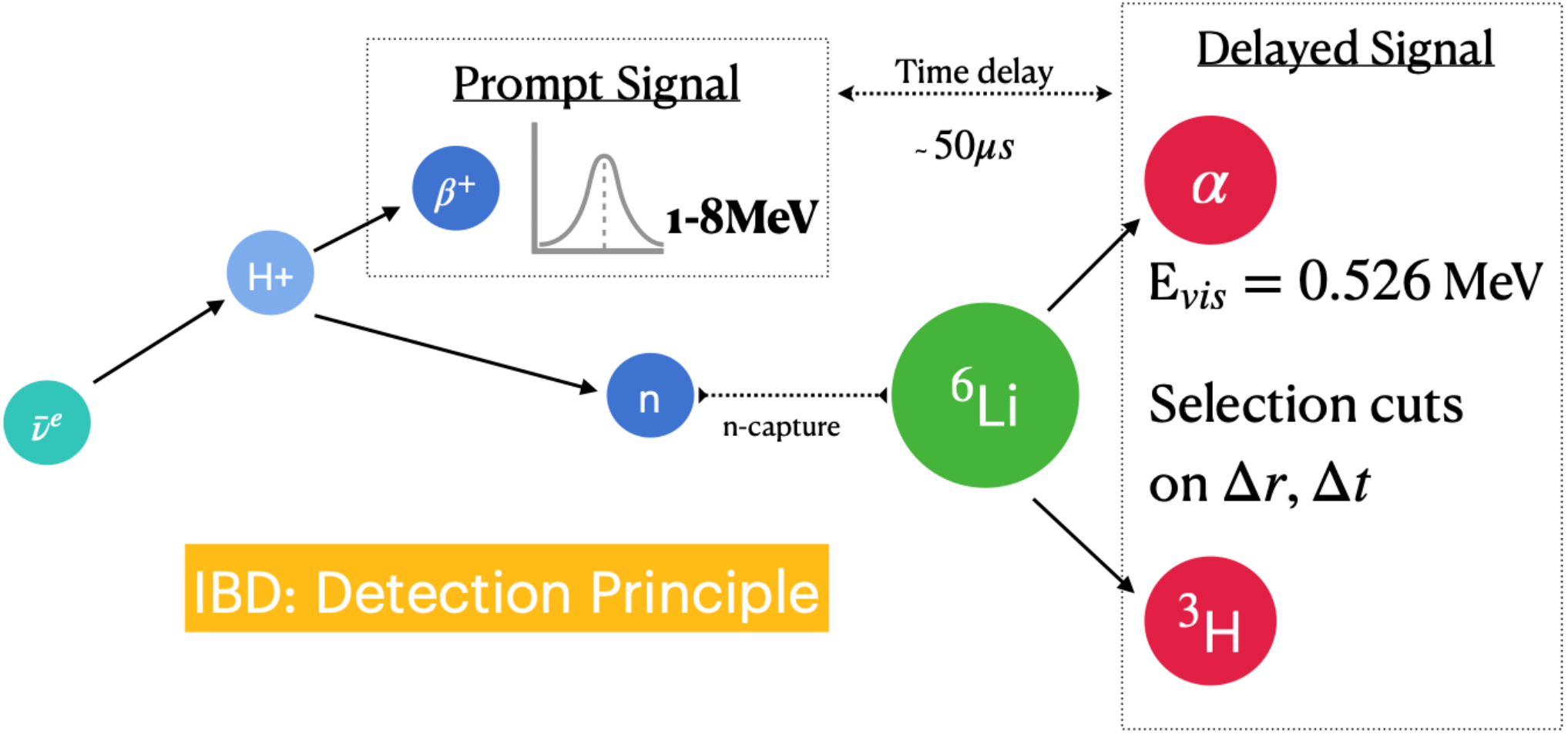


PROSPECT-I Design

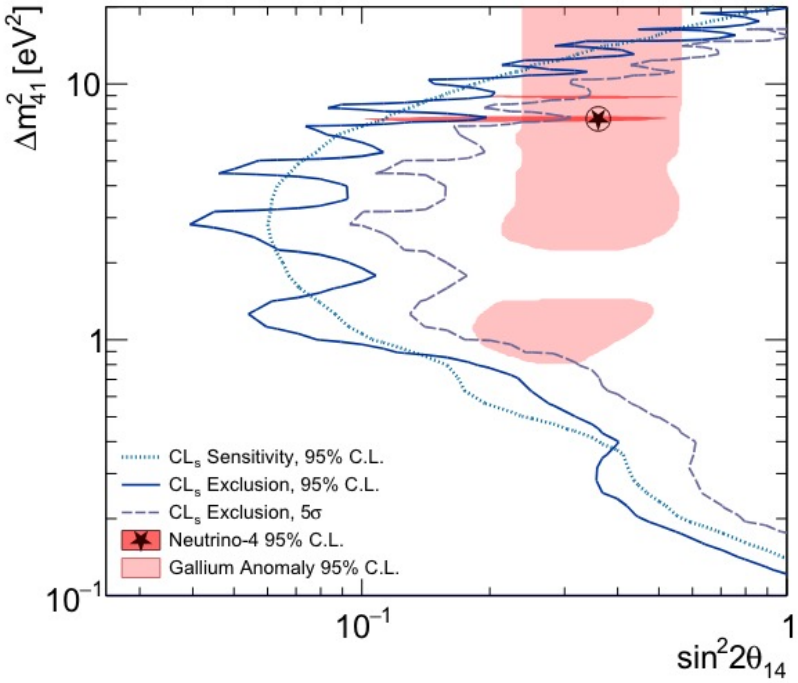
- A 4-ton, segmented detector designed to search for sterile neutrino oscillation and ^{235}U spectrum measurement.
- Reactor on data from Mar - Oct 2018
- 6.7 – 9.2m from HFIR
- 154 segments - 14 x 11 grid
- Each segment:
  - 2 PMTs
  - Filled with ^{6}Li-doped LS (LiLS)
    - Pulse Shape Discriminator

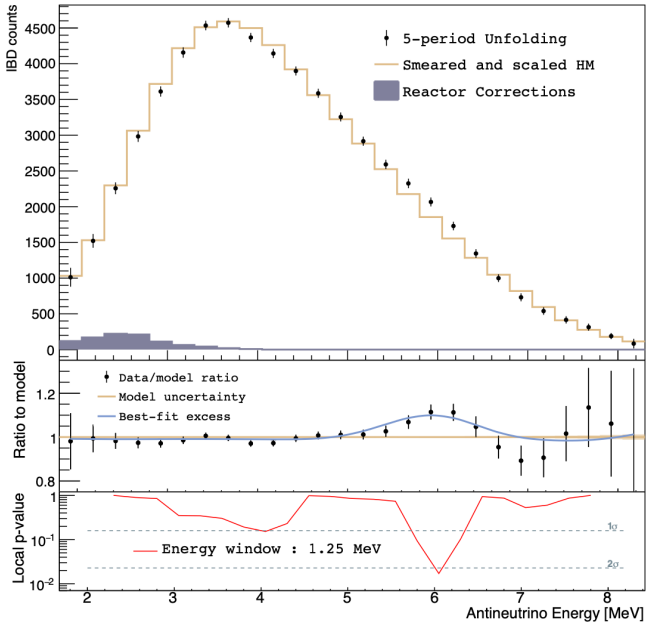


PROSPECT-I Design: IBD Detection Principle



PROSPECT-I Physics Results





Great signal to background ratio (4:1) and energy resolution.

Oscillation analysis: Neutrino-4 best-fit point is ruled out at >5σ CL

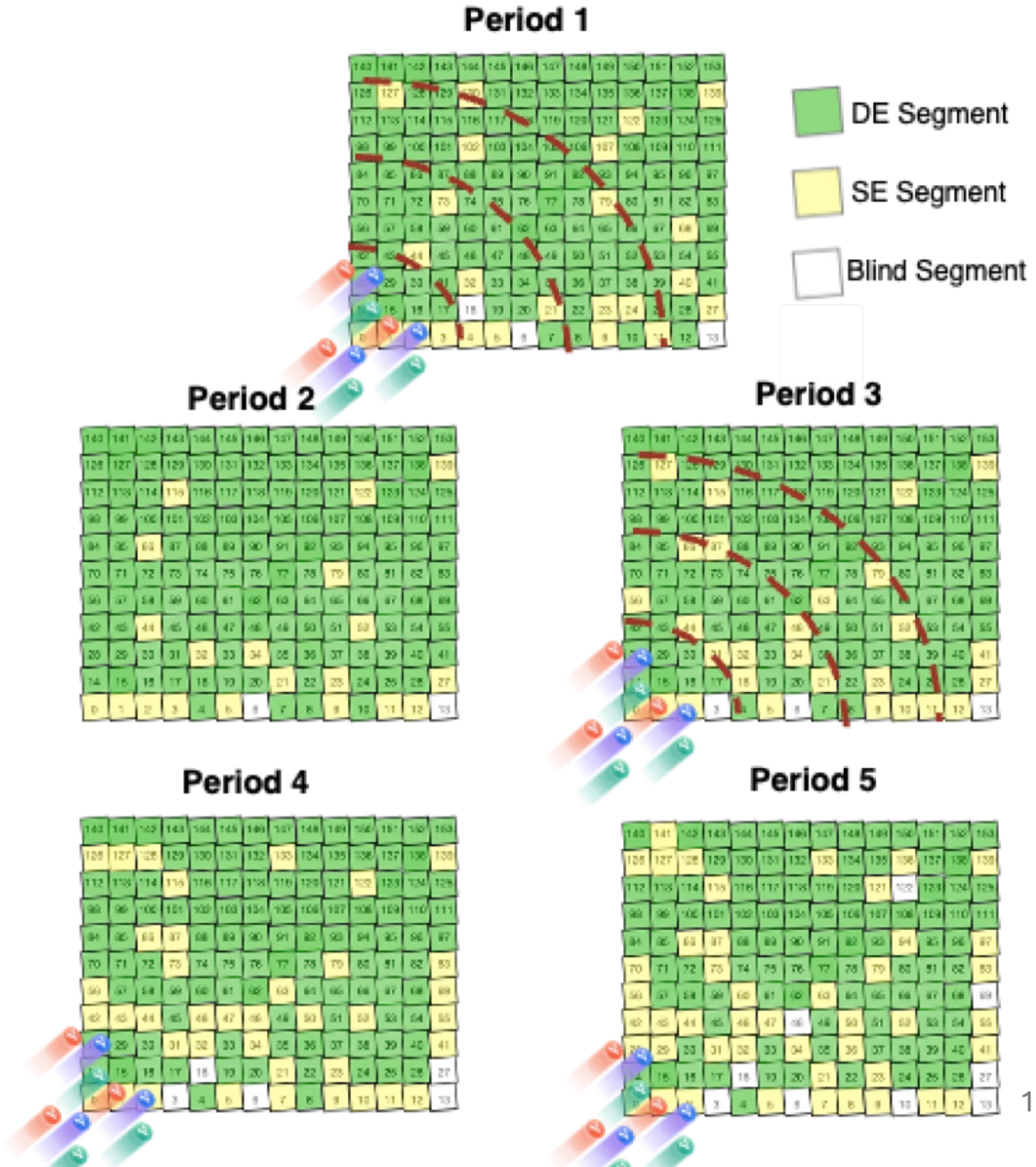
Spectrum measurement: Observation of excess at ~ 5 MeV

- Limits on Sub-GeV Dark Matter from the PROSPECT Reactor Antineutrino Experiment – arXiv:2104.11219
- Joint analysis:
  - (2022) Daya Bay – Phys. Rev. Lett. **128**, 081801
  - (2022) STEREO – Phys. Rev. Lett. **128**, 081802
- Final Oscillation Analysis – arXiv:2406.10408
- Neutrino Directionality – arXiv:2406.08359
- Final Spectrum analysis – Phys. Rev. Lett. **131**, 021802
- Coming out soon:
  - Absolute flux measurement
  - Joint-Search for Light Sterile Neutrino Oscillations by PROSPECT, STEREO, and Daya Bay

From PROSPECT-I to PROSPECT-II

- PROSPECT-I

- LiLS ingress into PMT housing caused PMT degradation
- LiLS degradation caused effective attenuation length and light collection degradation

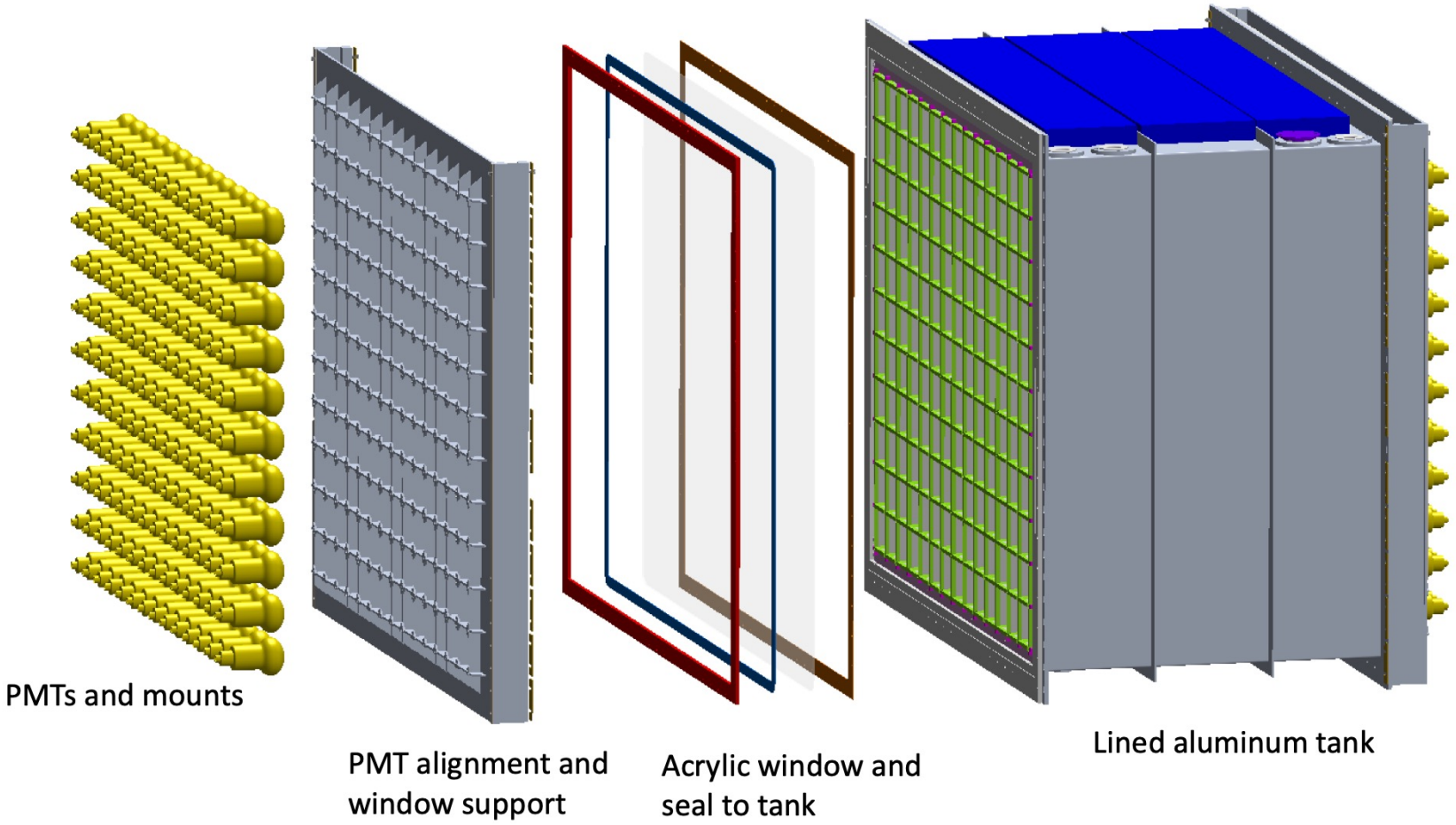


From PROSPECT-I to PROSPECT-II

- LiLS ingress into PMT housing caused PMT degradation
- LiLS degradation

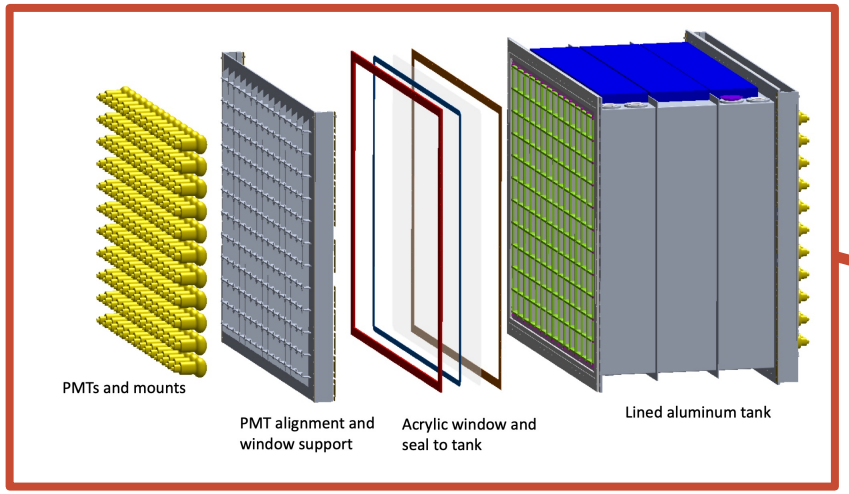
- PROSPECT-II
  - Maintain PROSPECT-I performance
  - Improve stability
    - Remove PMTs from active volume
    - Minimize LiLS contact with other materials
    - Optimize LiLS isolation

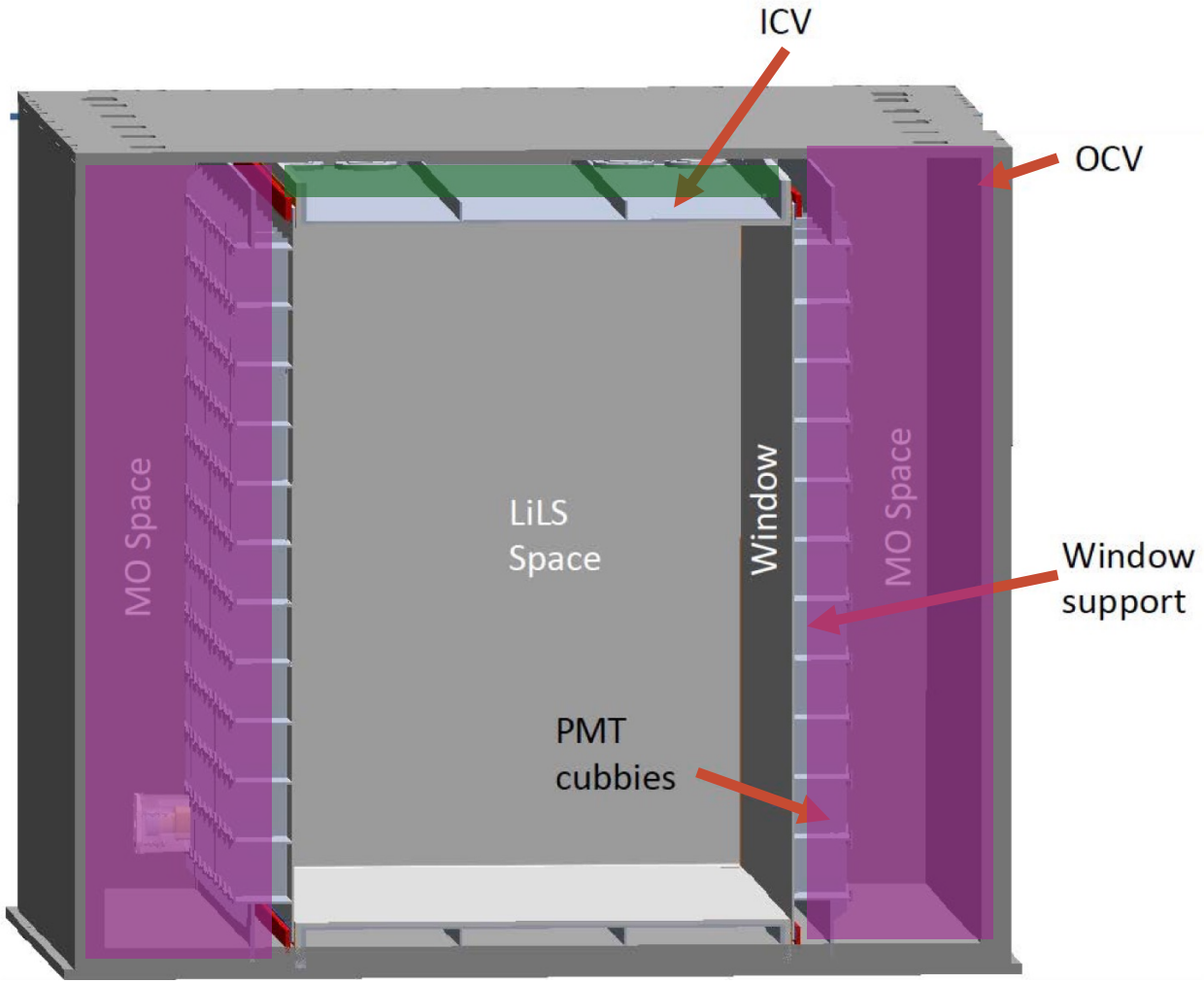
PROSPECT-II Detector Design



Slimmer design → allows 20% more active volume, keeping the vessel size the same

PROSPECT-II detector design





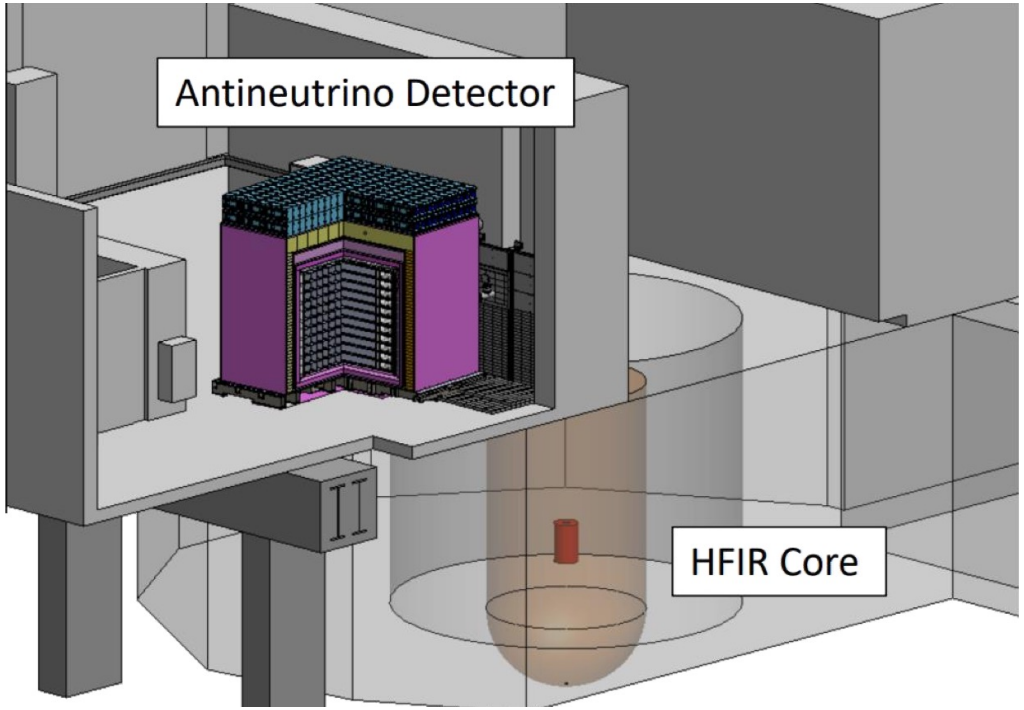
Mineral oil between ICV and OCV provides optical coupling and shielding

LiLS overflow system

Active cooling

Cabling out of LiLS volume

PROSPECT-II Deployment



HFIR remains as our target operation site for HEU measurements

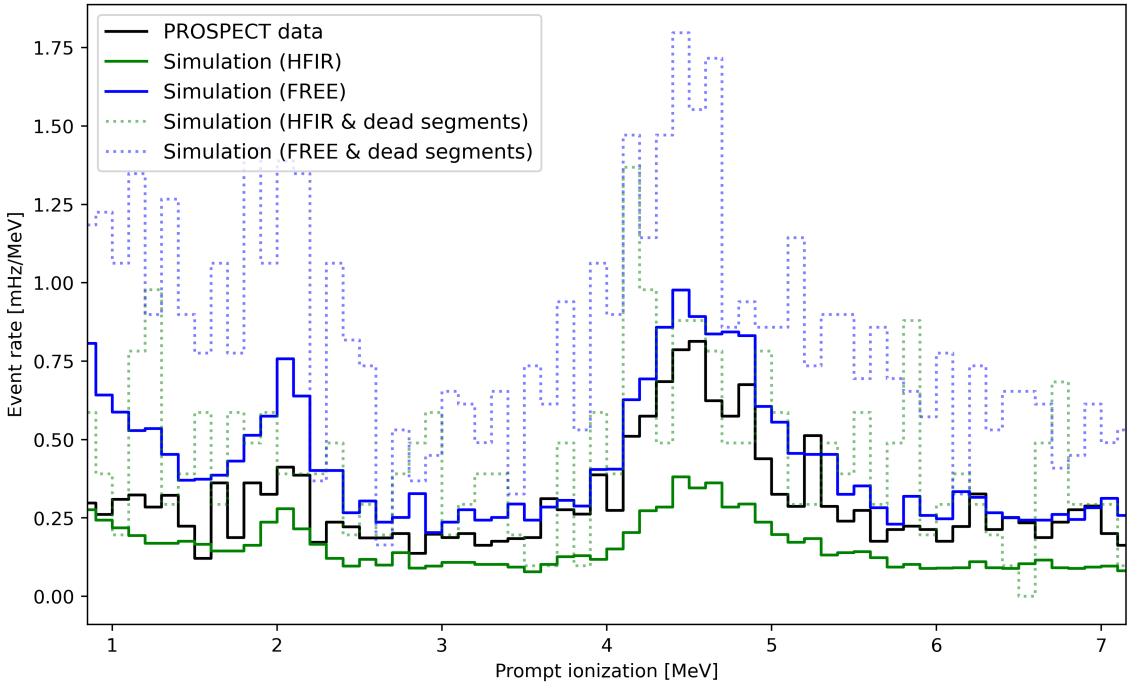
Aiming for 14 cycles recorded over a 2-3 year run period

Detector is movable → LEU site?

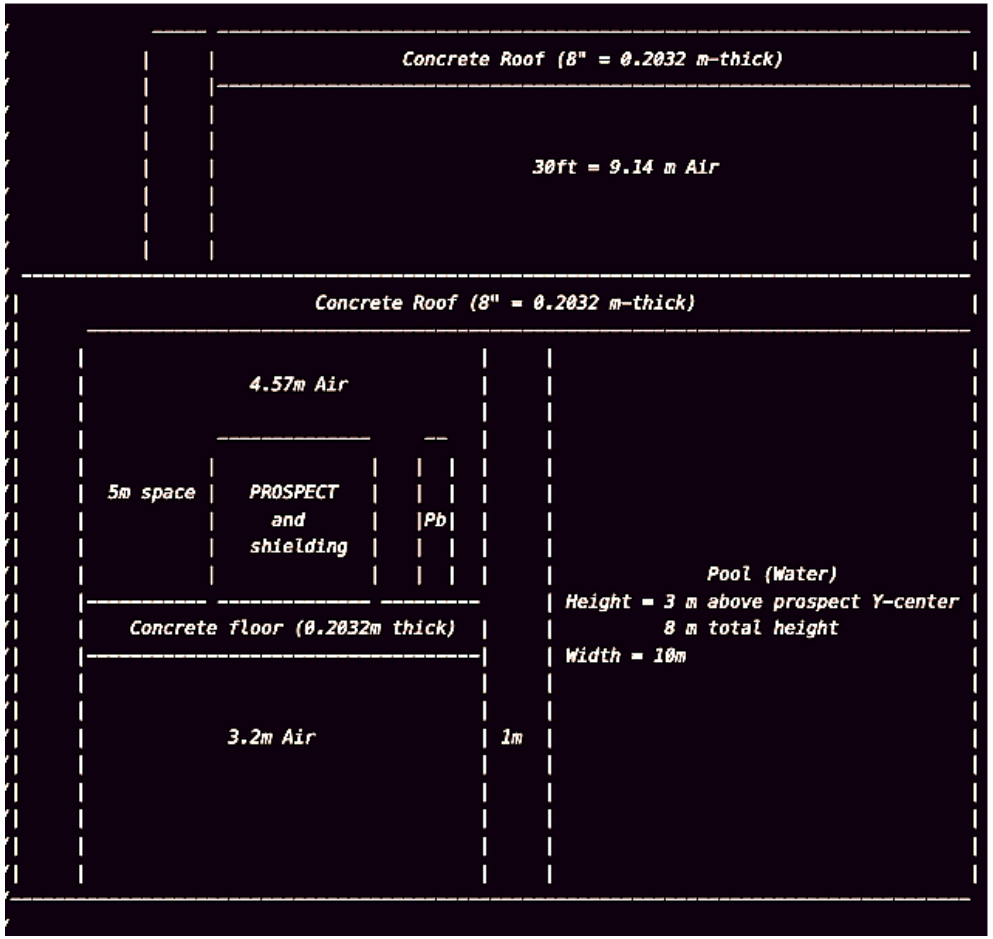
Benefits described at arXiv: 2301.13123

Oak Ridge National Laboratory Neutron Production Overview

PROSPECT Background Studies



Here we can see the effects of different background scenarios, a better understanding of those is necessary to accomplish better projected results. Longer segments have an impact in background estimates too



Simplified side view of HFIR site

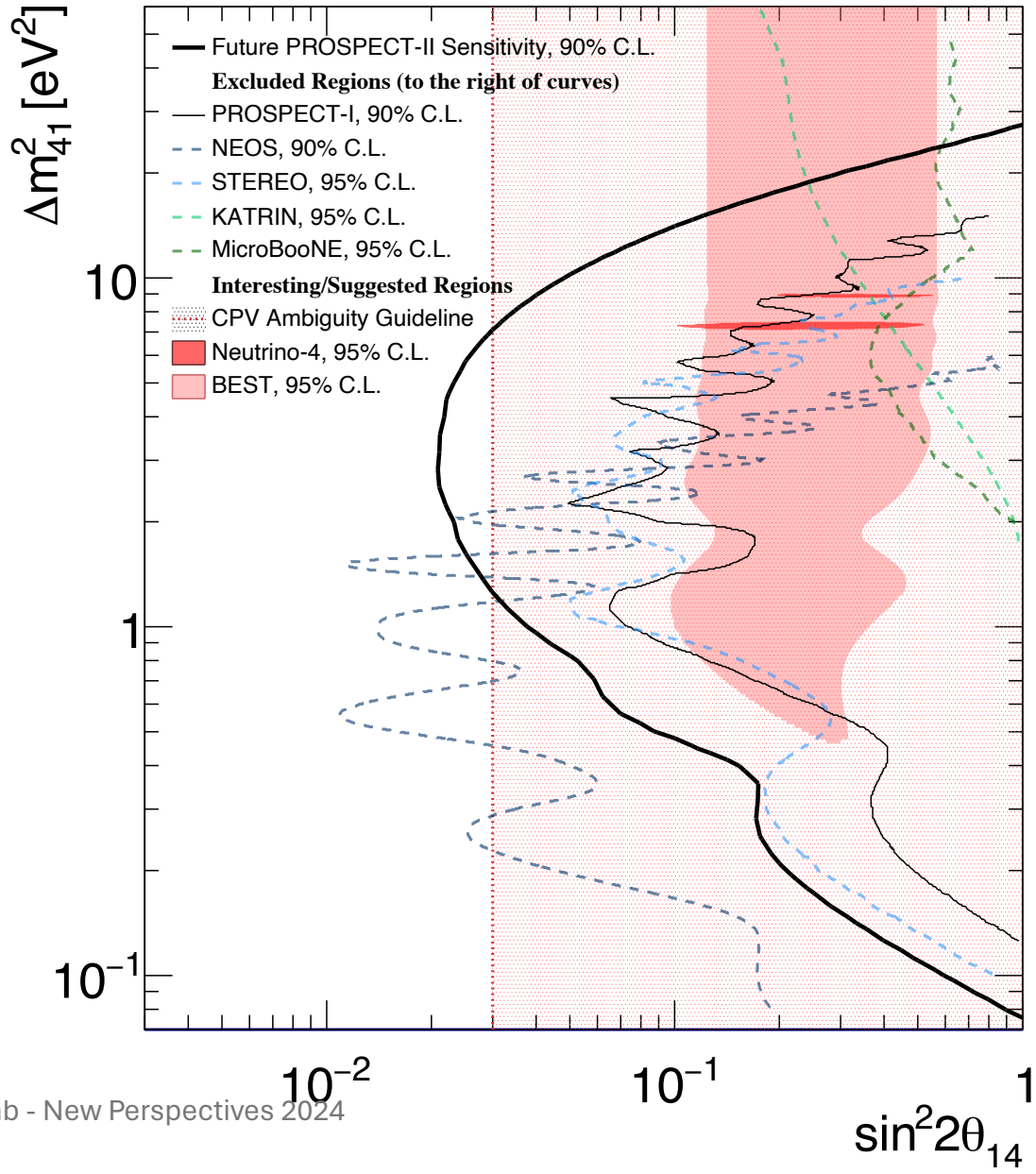
PROSPECT-II Projected Results

- Oscillation: Extended sensitivity!!

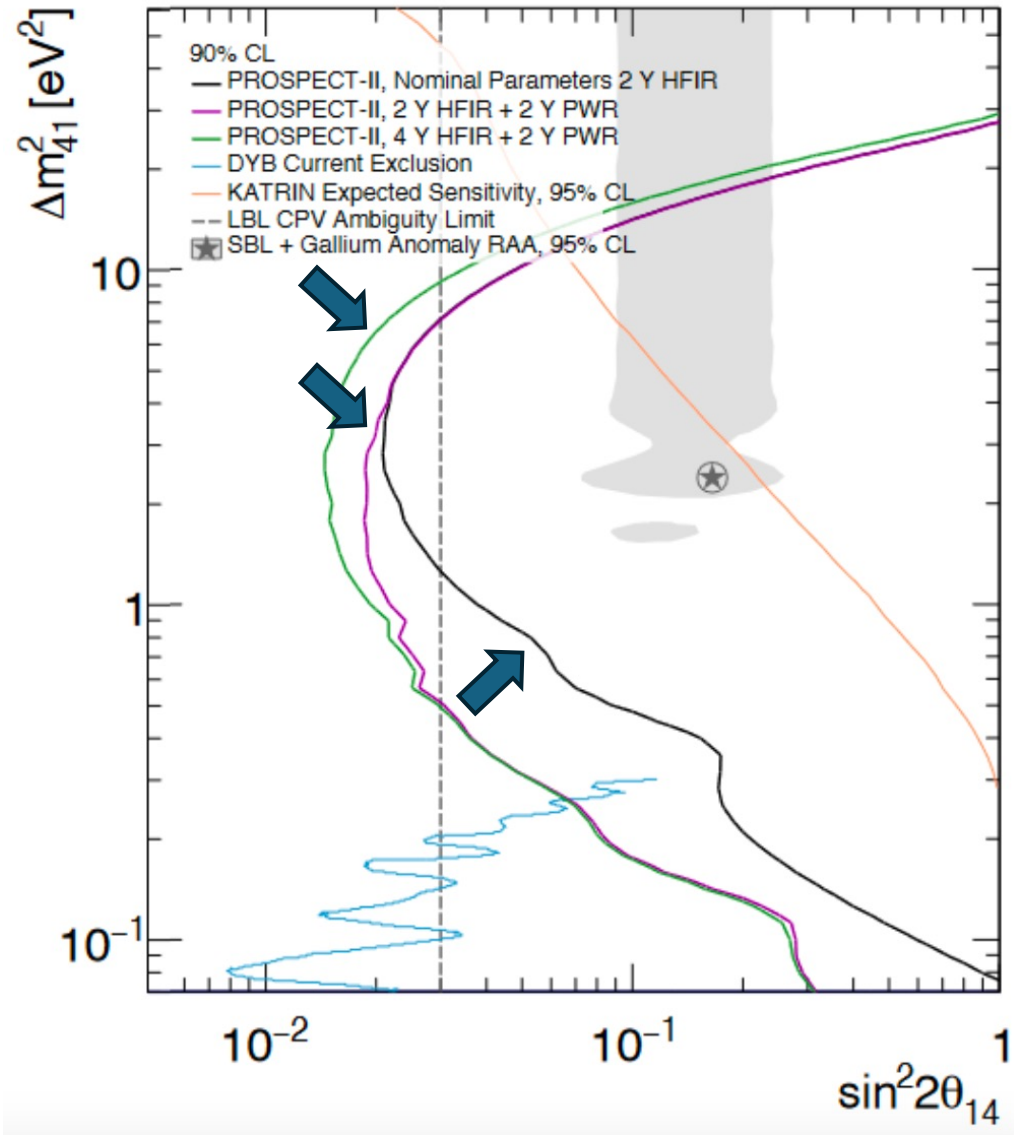
Parameter		P1	P2 at HFIR	P2 at LEU
Exposure	Average Baseline (m)	7.9	7.9	25
	Reactor-On Days (d)	105	336	548
	Reactor-Off Days (d)	78	360	61
	Signal:Background	1.4	4.3	19.3
	IBD Statistics (N_{IBD})	50560	3.74×10^5	2.72×10^6
	Effective Statistics (N_{eff})	15195	2.08×10^5	1.79×10^6

PROSPECT-II Projected Results

- Oscillation:
  - More phase-space coverage, specially at higher Δm^2_{41}
  - Addresses Neutrino-4
  - Better coverage at higher Δm^2_{41} than beam experiments
  - Help us have a clearer picture on the Long Baseline CP Violation



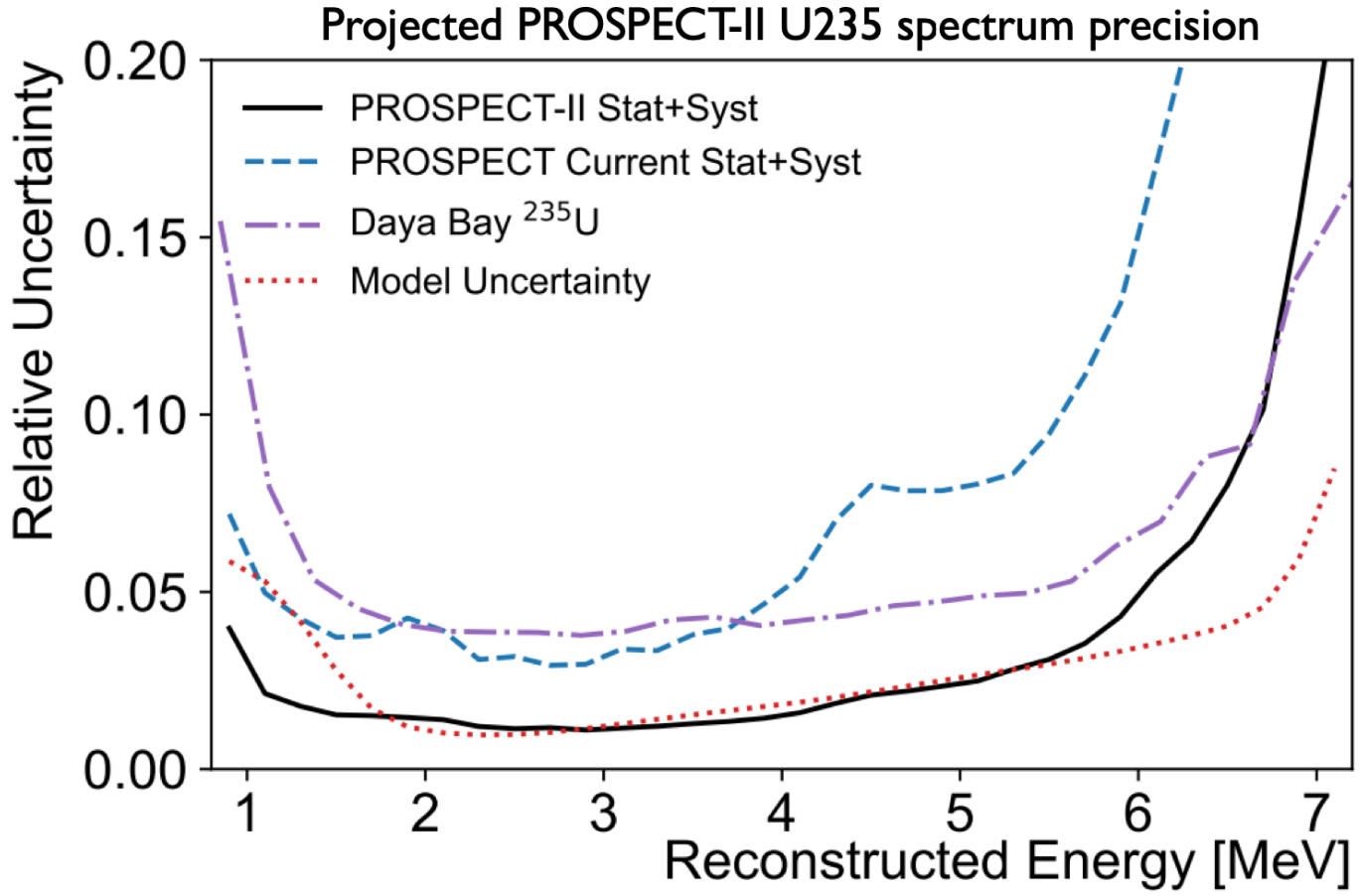
PROSPECT-II Projected Results



- HEU + LEU deployment:
  - Oscillation sensitivity extended to lower Δm^2_{41} from longer baseline

PROSPECT-II Projected Results

- Spectrum:
  - Double the precision, exceeding the model uncertainties for the majority of the antineutrino spectrum



PROSPECT-II Projected Results

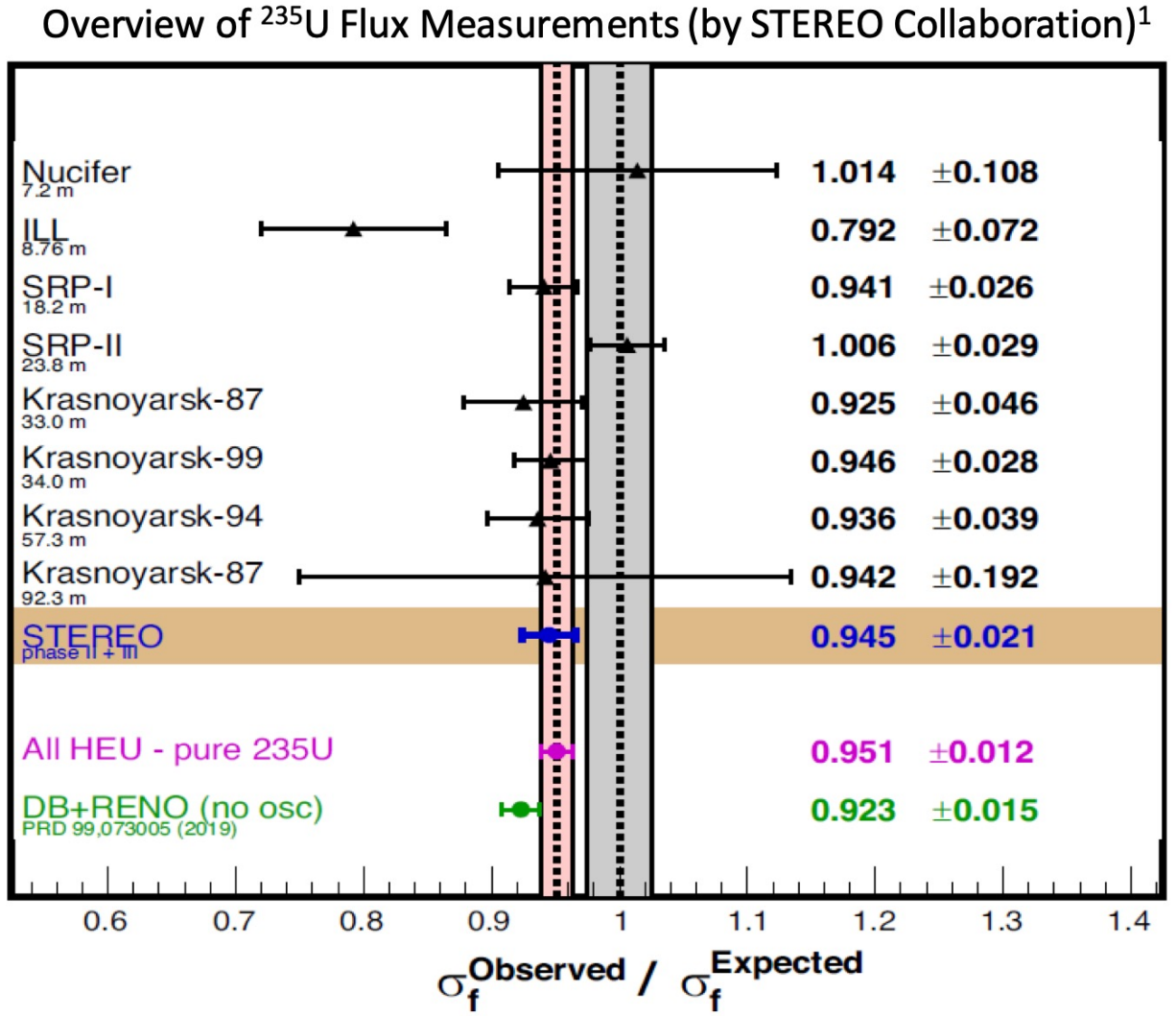
- HEU + LEU deployment:
  - Oscillation sensitivity extended to lower Δm^2_{41} from longer baseline
  - Flux measurements at both reactors yield unambiguous measure of the isotopic antineutrino yield

Case	Description	Precision on σ_i (%)		
		^{235}U	^{239}Pu	^{238}U
1	Daya Bay LEU	3.7	8.2	30
2	Daya Bay LEU + P-II HEU	2.4	6.3	21.3
3	P-II LEU + P-II HEU+	1.4	3.4	15.9
4	P-II LEU + P-II HEU+, Correlated	1.4	3.0	8.7
-	Model Uncertainty [66]	2.1	2.5	11.2

J. Phys. G: Nucl. Part. Phys. **49** 070501

PROSPECT-II Projected Results

- Flux:
  - Fundamental for reactor CEvNS experiments
  - Provide better limits on BSM phenomena
  - Current best measurement is STEREO's
  - P2 absolute flux measurement can be best: potential for lower HFIR thermal power uncertainty



Phys. Rev. Lett. **125**, 201801

Conclusion

- PROSPECT-I was a successful experiment with a number of valuable analysis

- PROSPECT-II robustness give us the chance to push even further the borders of knowledge we currently have in the field
- The collaboration is actively engaged on the design of P2

Thank you!

PROSPECT June 2023 Collaboration Meeting, IIT+Virtual

prospect.yale.edu

HEISING-SIMONS FOUNDATION

U.S. DEPARTMENT OF ENERGY

GRFP

BROOKHAVEN NATIONAL LABORATORY

NIST

Lawrence Livermore National Laboratory

OAK RIDGE National Laboratory

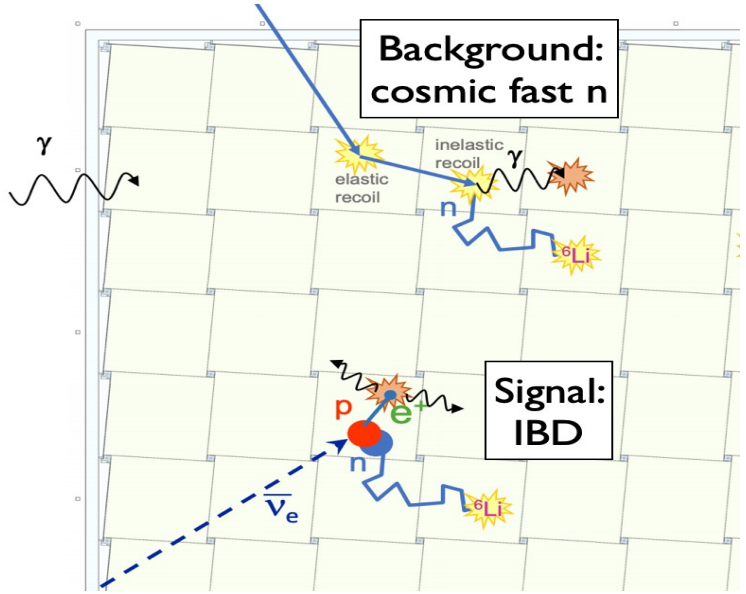
Drexel

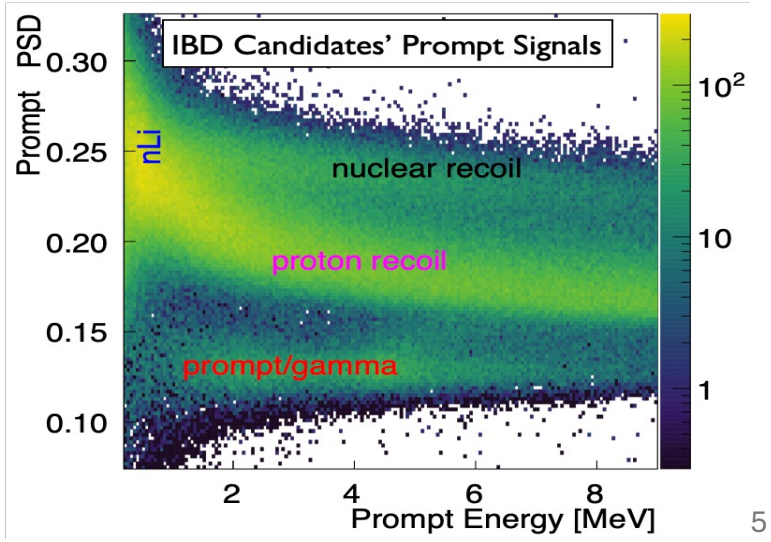
Yale

BACKUP SLIDES

Key Detector Features

- Prompt e+ gives $\bar{\nu}_e$ energyestimate (>400 pe/MeV)
- Fully-contained, single-cell delayed n-6Li signal
- Prompt, delayed PSD differ from common background classes
- Double-end PMT readout and segmentation allows XYZ reco and topology cuts

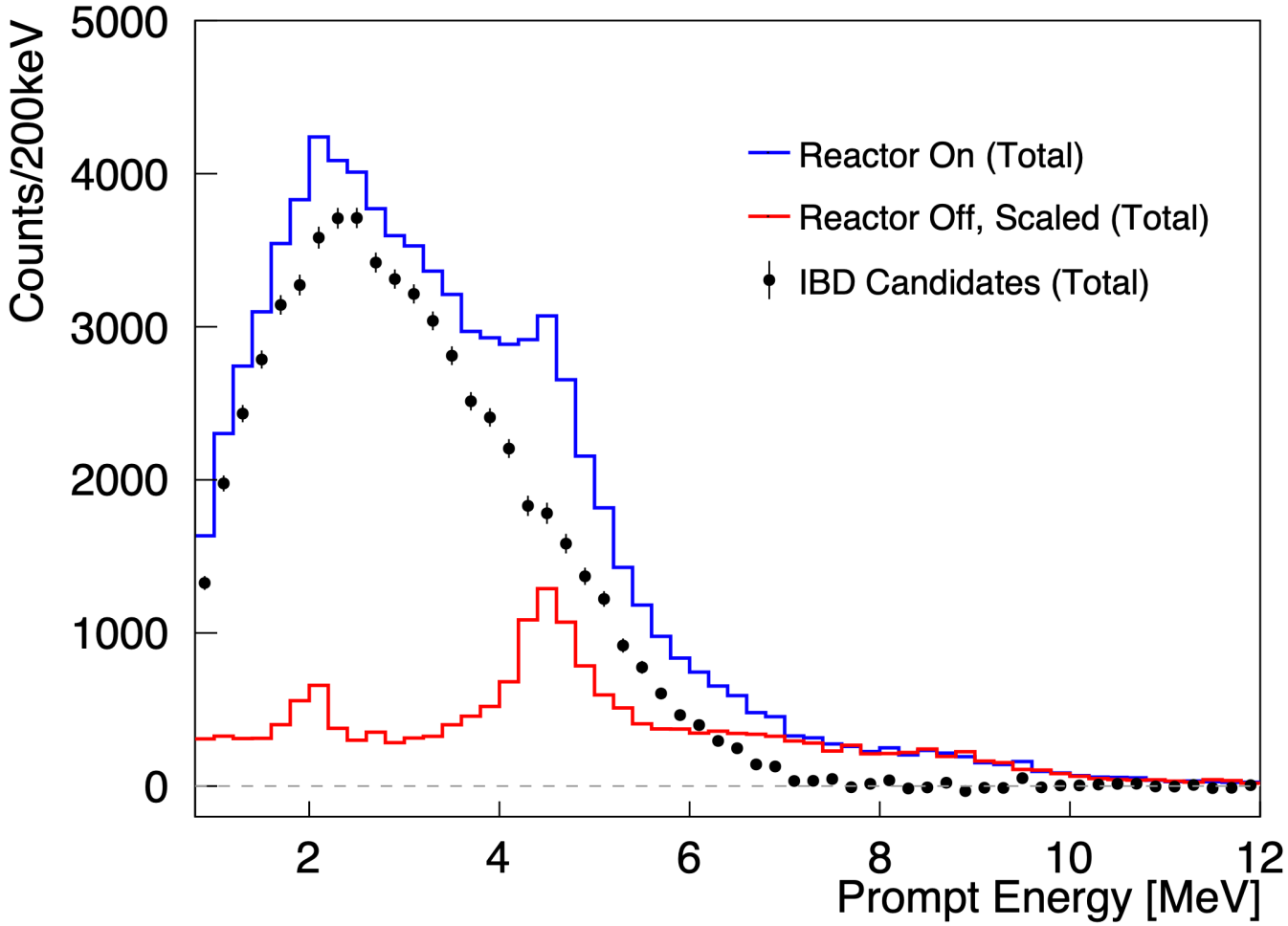




PROSPECT-I Physics Results

Great signal to background ratio and energy resolution!

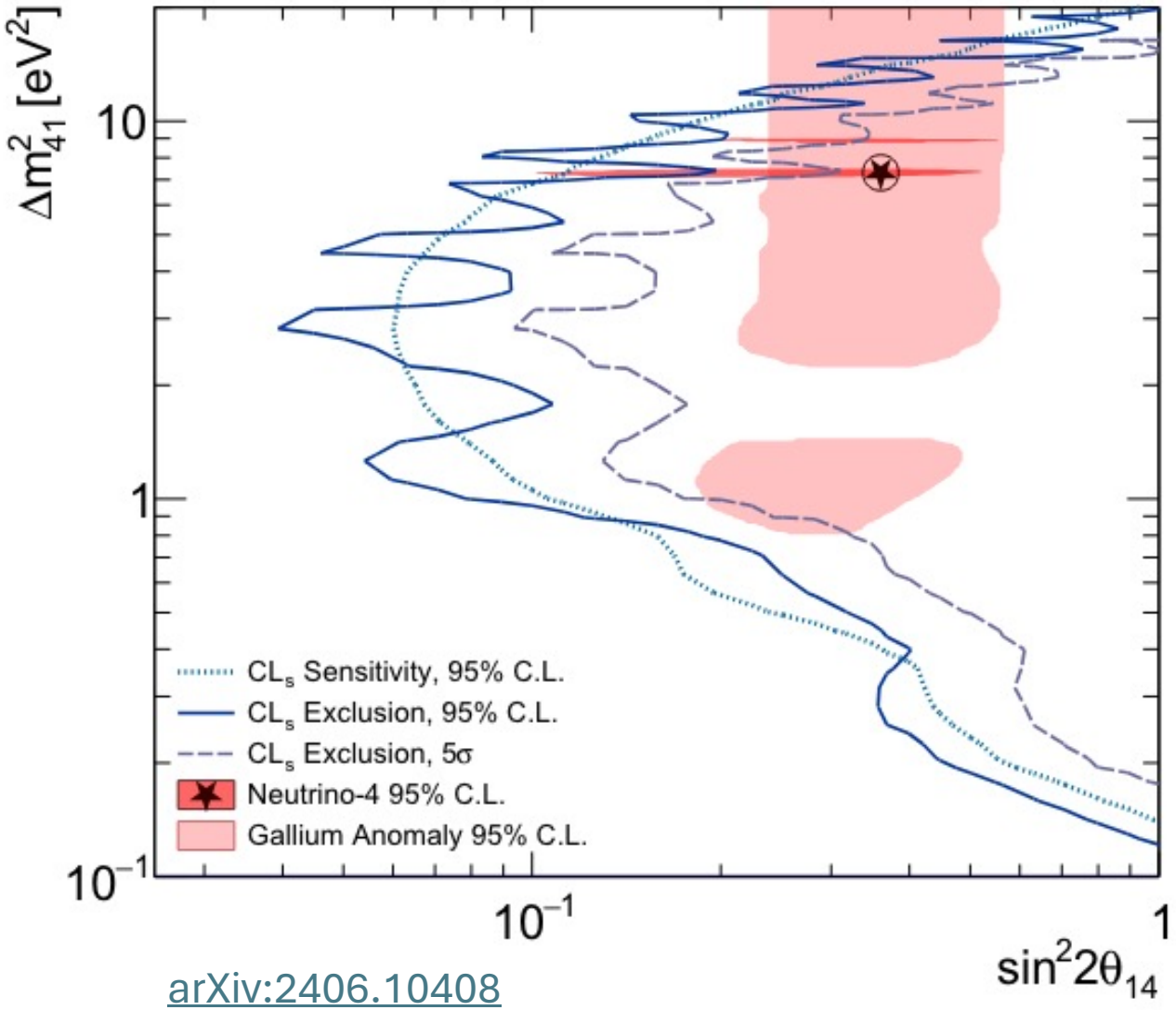
S:B of 4:1



PROSPECT-I Physics Results

Oscillation analysis:

- No indication of sterile neutrino and rejected neutrino-4 best-fit point at 5σ in final analysis



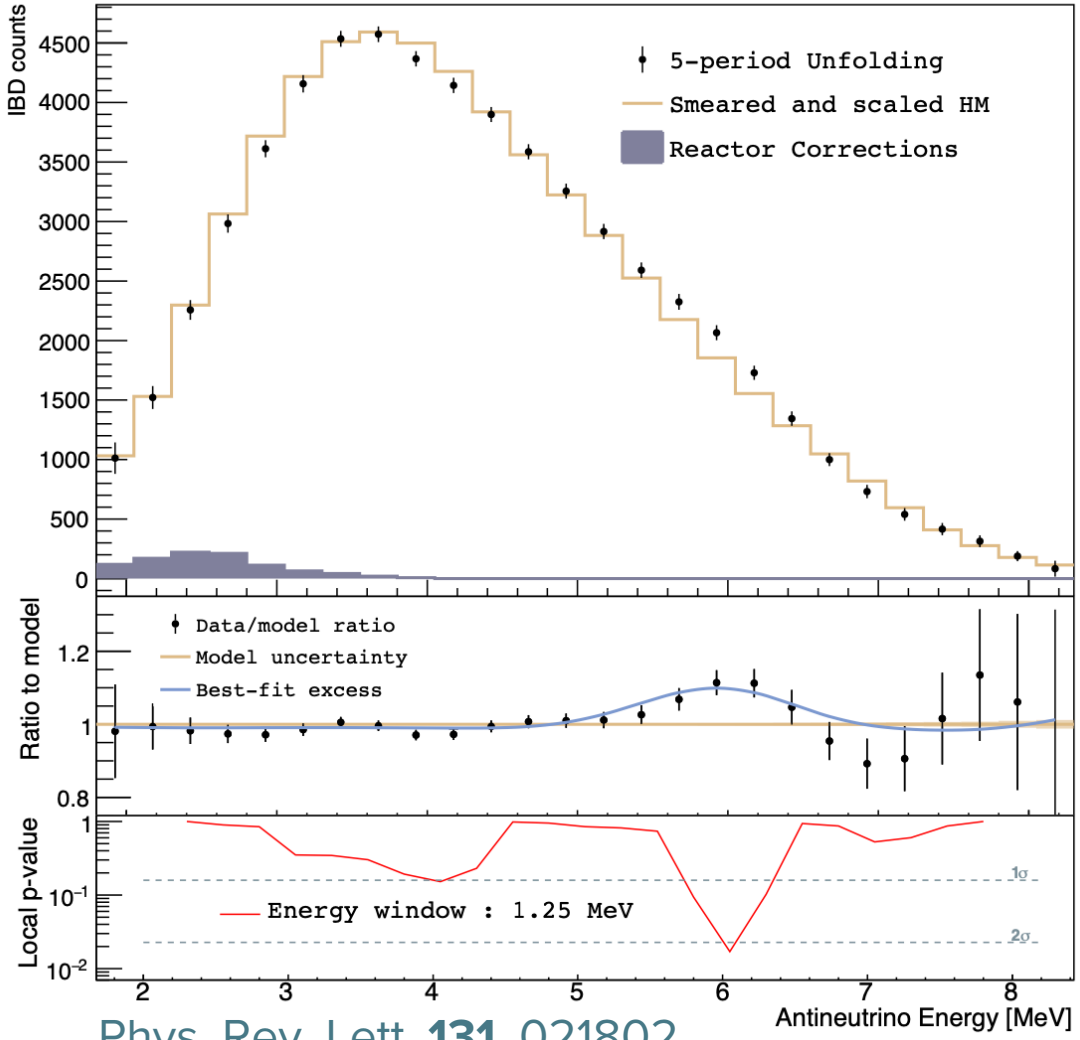
arXiv:2406.10408

PROSPECT-I Physics Results

Spectrum measurement:

- Observation of excess at ~ 5 MeV
- Isotopic composition of 'The Bump':
  - Equal Isotope hypothesis preferred:
  - No 235U disfavored at 3.2σ
  - All 235U disfavored at 2.2σ

Check this values with the source



Phys. Rev. Lett. **131**, 021802