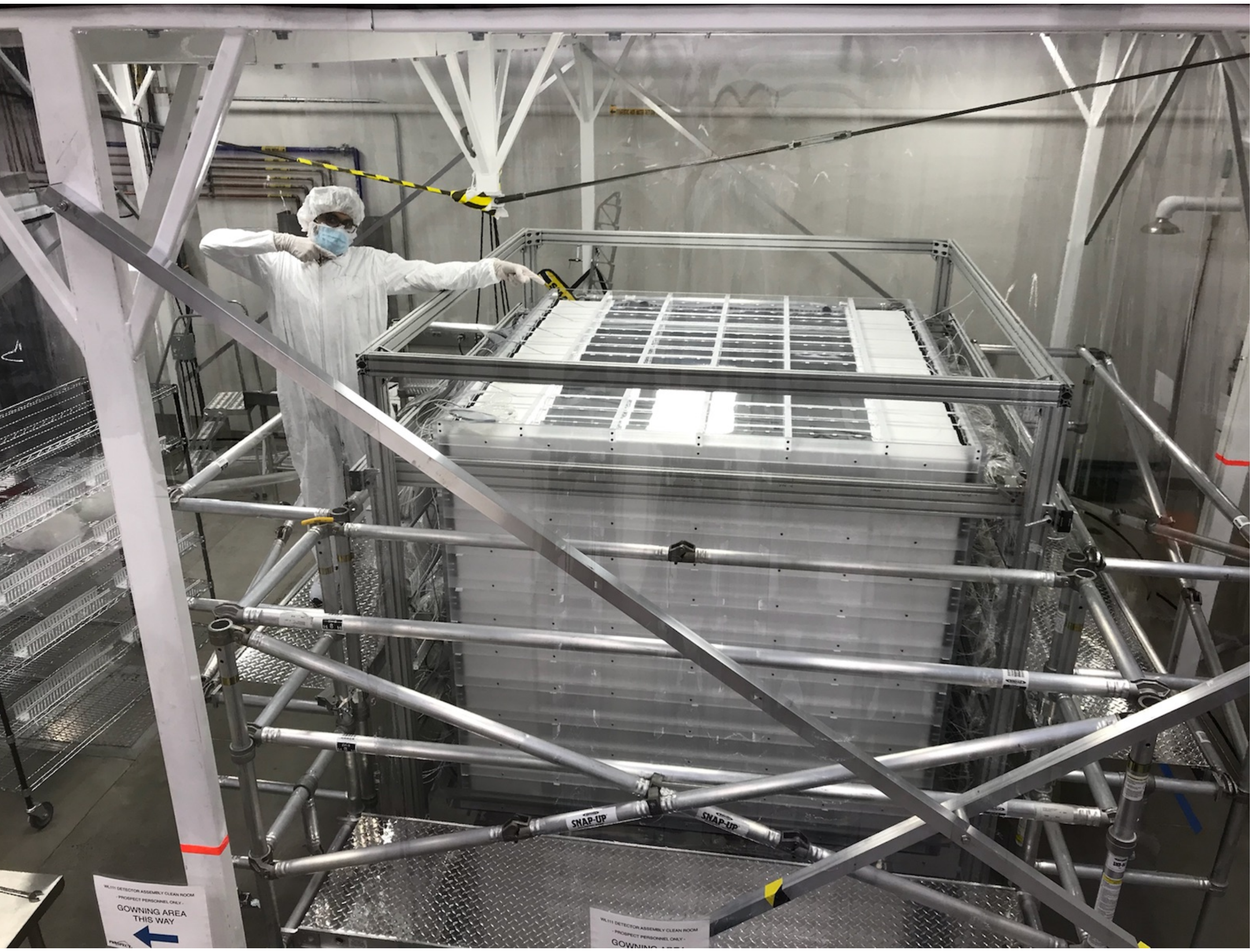
Measurement of the Reactor Antineutrino Spectrum from ^{235}U Fission using PROSPECT



Pranava Teja Surukuchi

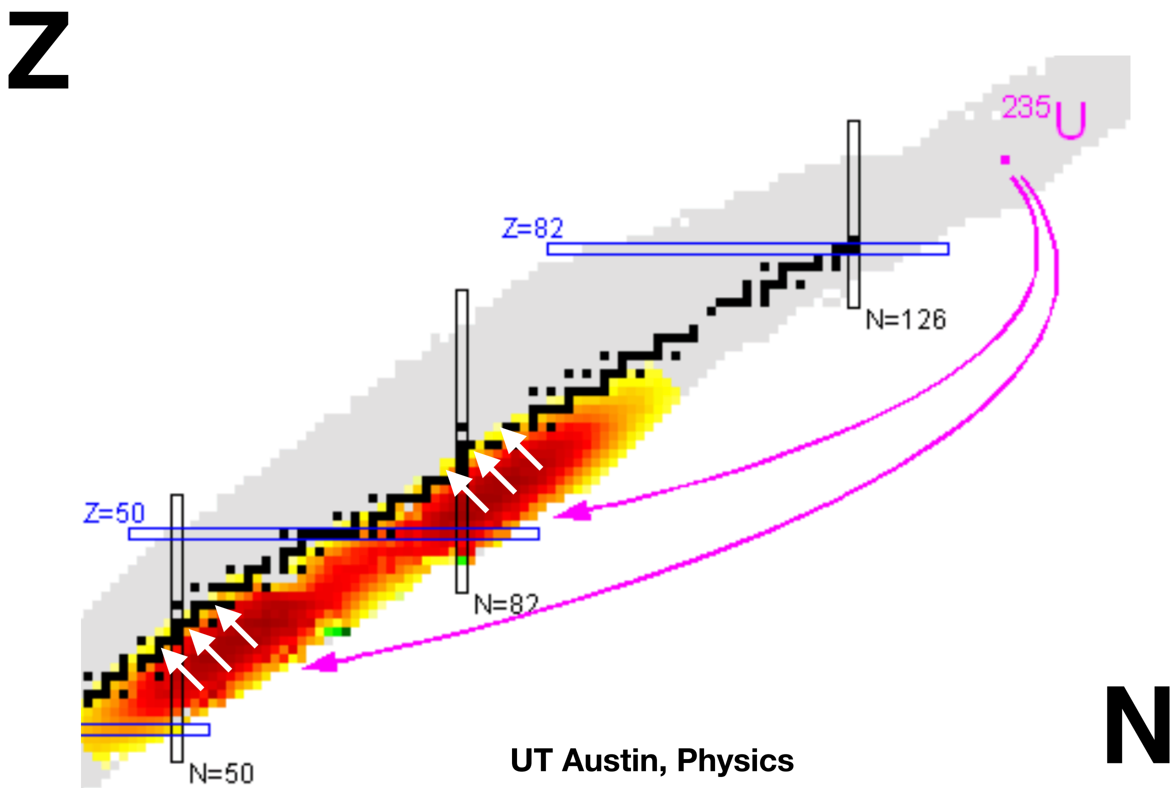
On behalf of the PROSPECT collaboration

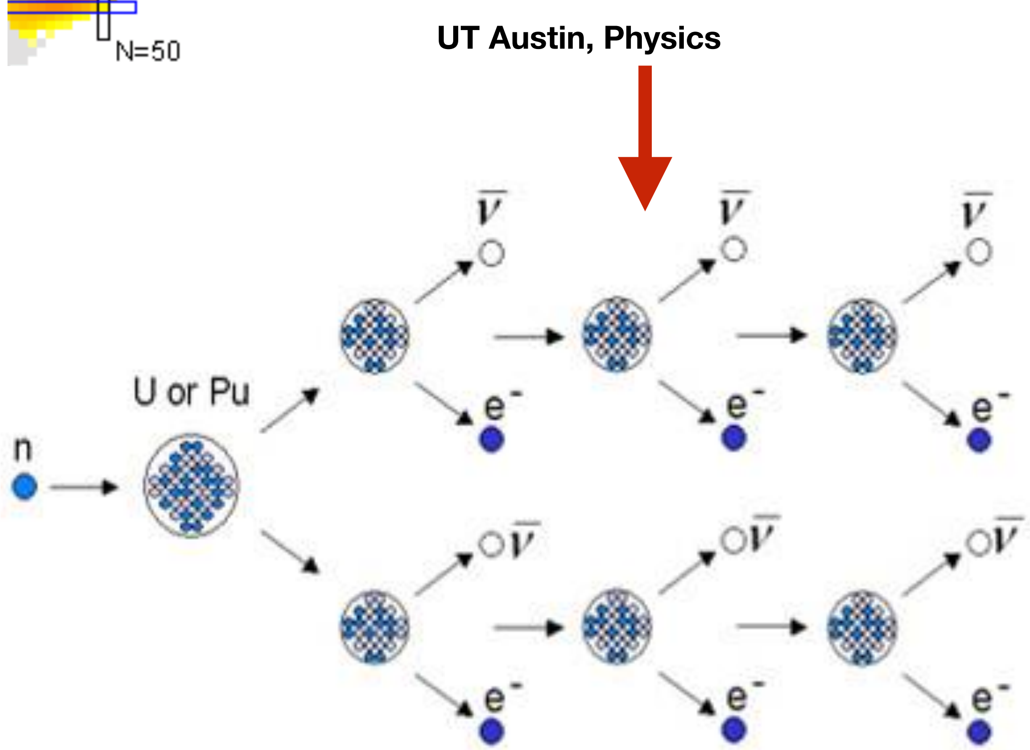
Wright Laboratory

July 30, 2019

Yale

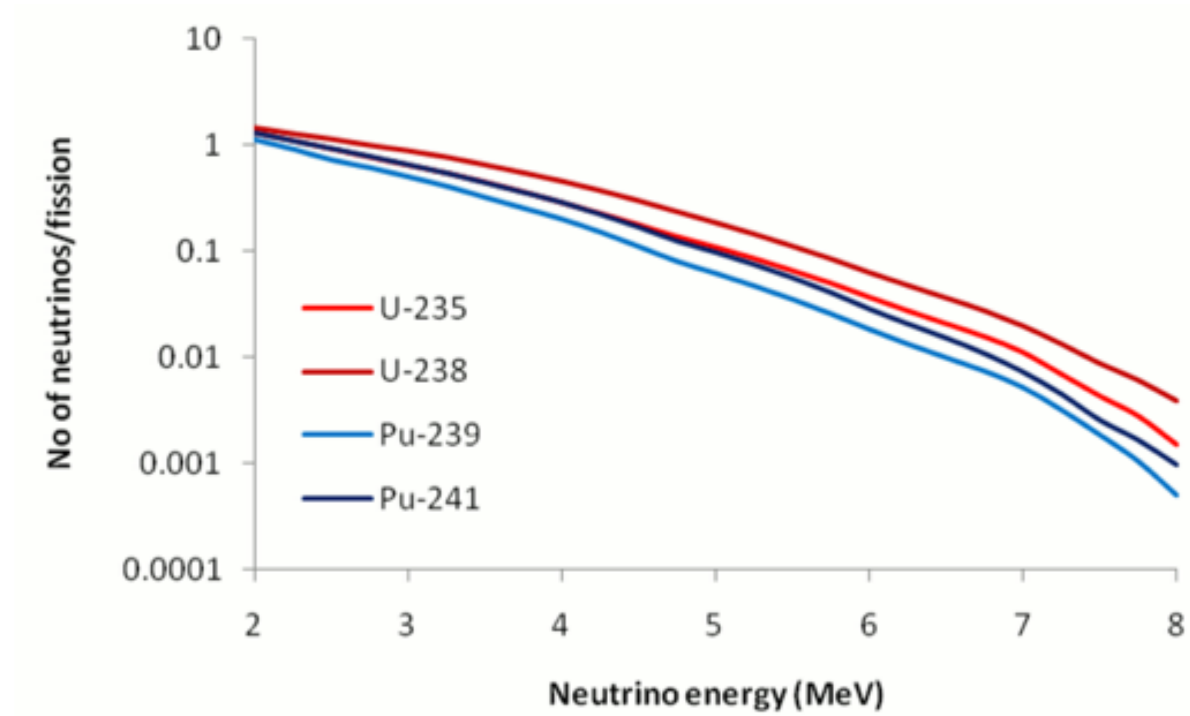
Reactor as Source of Antineutrinos





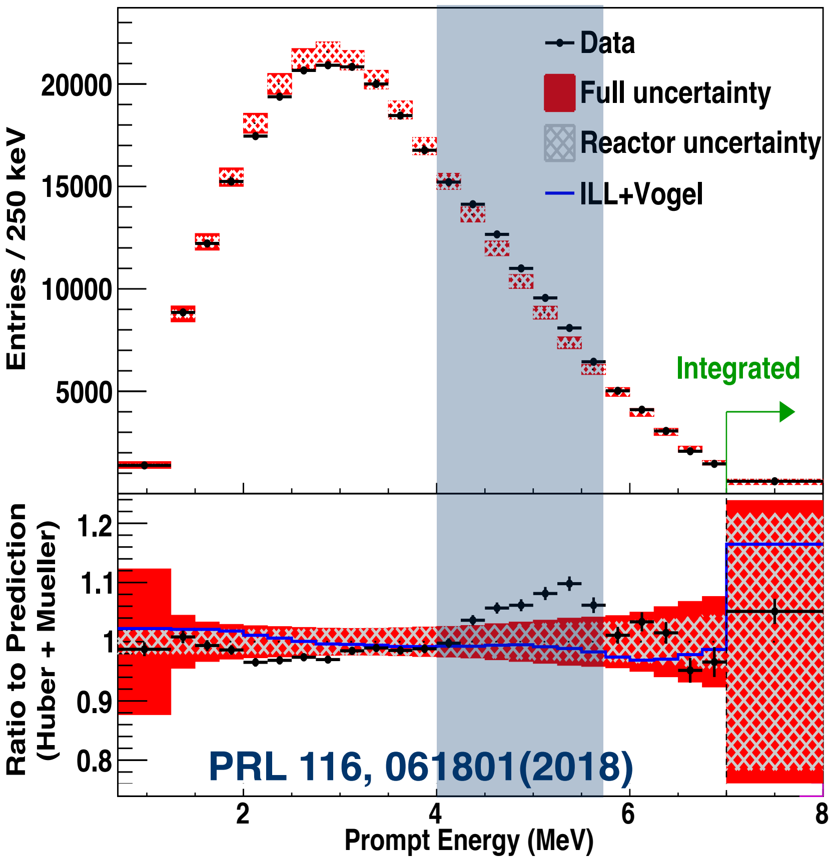
~6 $\overline{\nu}_e$ produced/fission

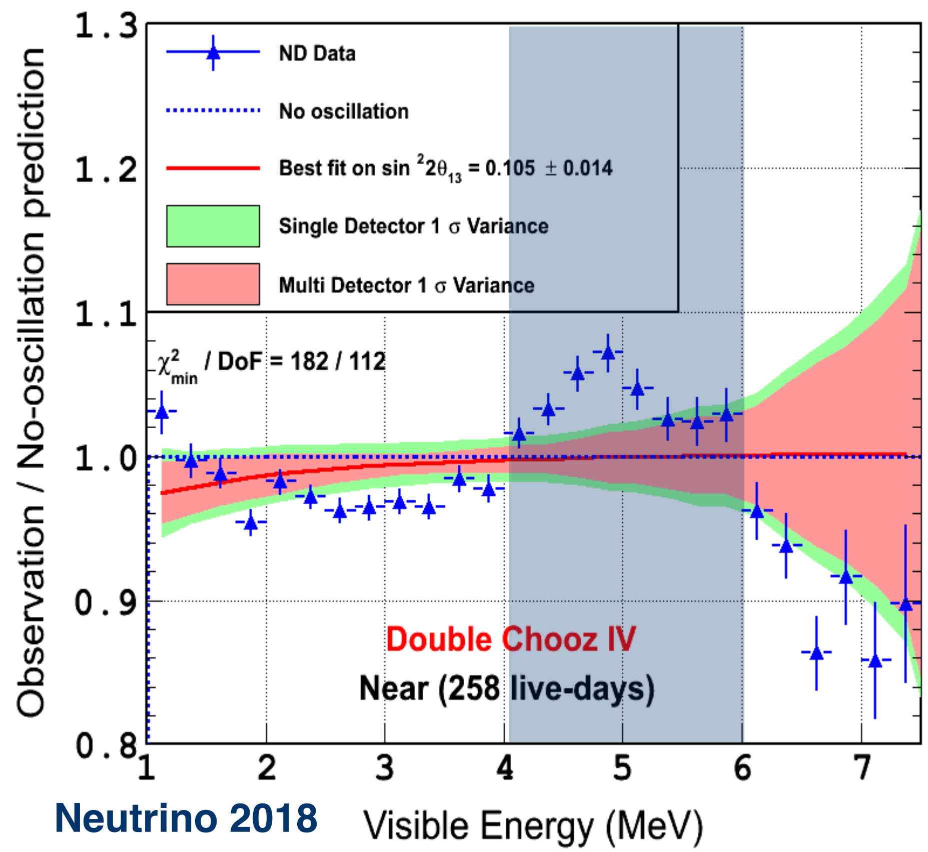
- Fission produces neutron rich daughters
- They beta decay and produce antineutrinos
- **Pure source** of electron antineutrinos
- Fissioning isotopes: **^{235}U ^{238}U ^{239}Pu ^{241}Pu**
- Spectra different for different isotopes

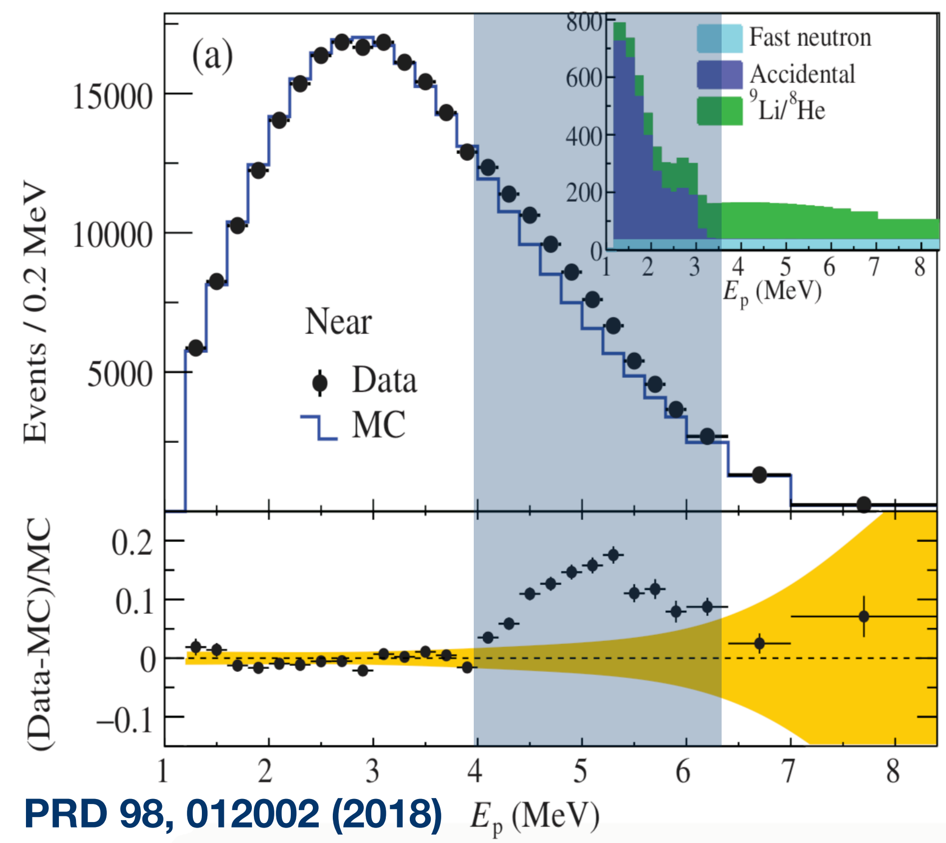


Discrepancies in Spectrum Measurements: The 'Bump'

Recent θ_{13} experiments precisely measured spectrum from Low Enriched Uranium (**LEU**) reactors







- All experiments show disagreement with state-of-the art models
- Could be a contribution from a single isotope or multiple isotopes
- Sterile neutrinos cannot explain this anomaly
- **Points towards reactor models being wrong: Need data**

LEU Reactors:
^{235}U ~ 45-65%
^{239}Pu ~ 25-35%
^{238}U,^{241}Pu < 10% each

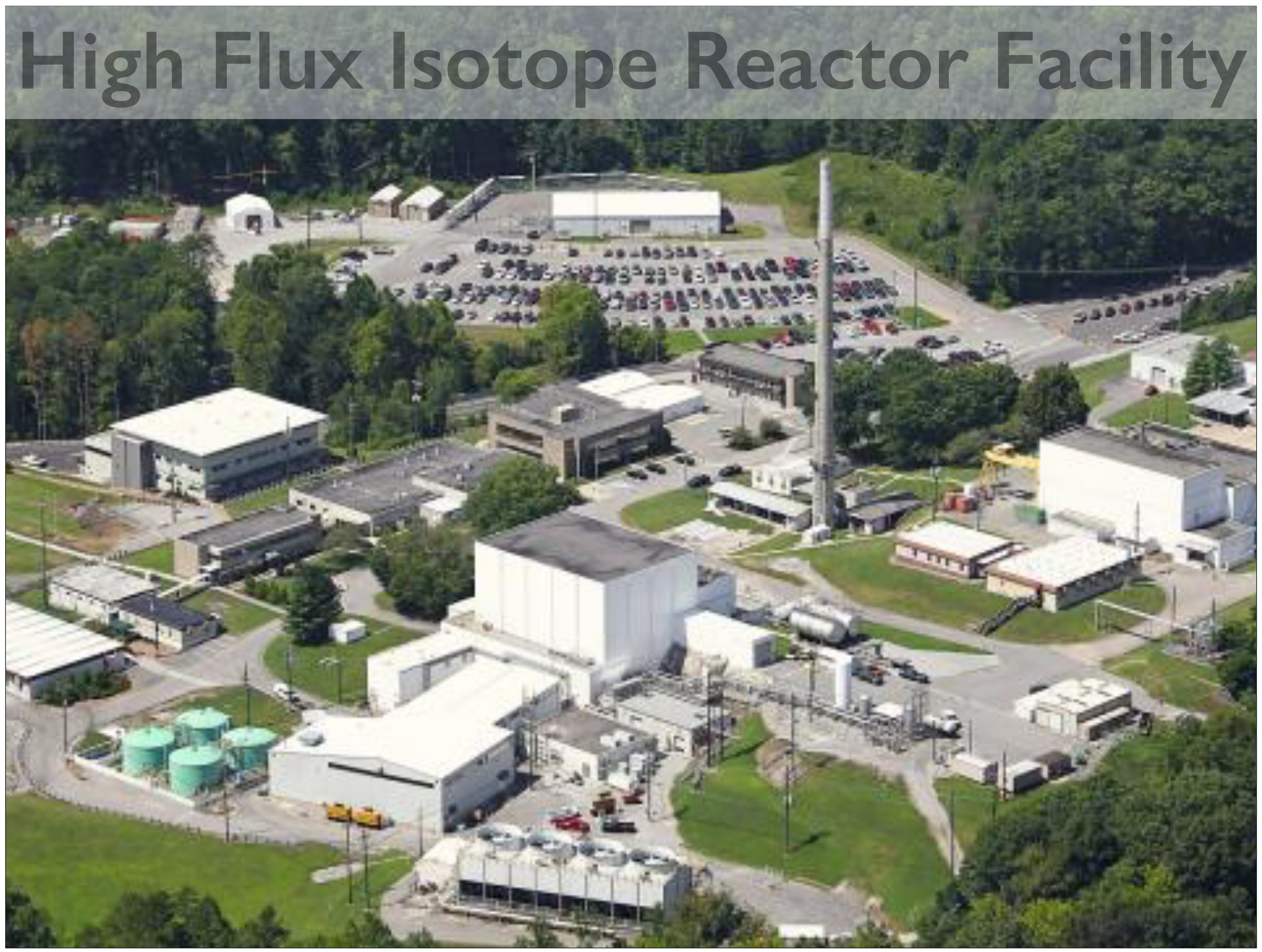
PROSPECT

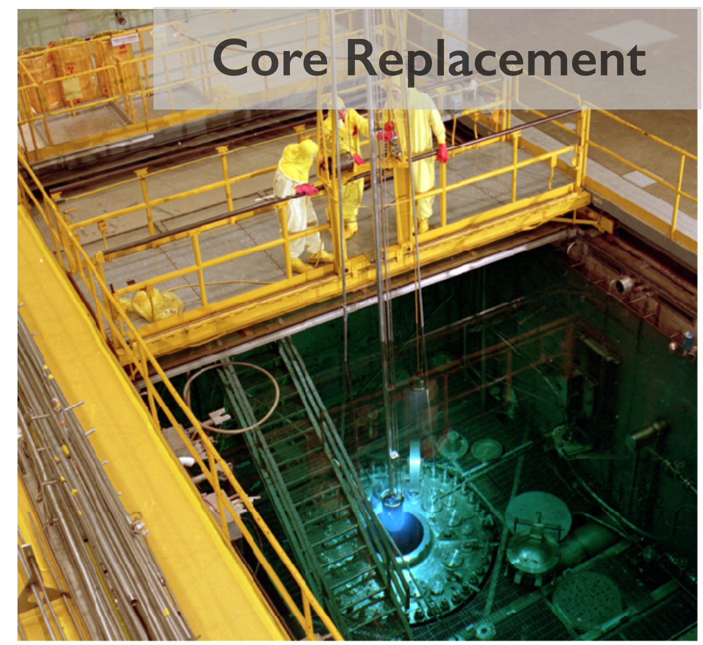
Physics Goals:

1. Reactor model independent eV-scale sterile neutrino search at short baselines
2. **Precisely measure reactor ^{235}U antineutrino spectrum**

HFIR

Highly Enriched Uranium **Research** Reactor: **>99% ^{235}U fissions**





Compact reactor core: 44 cm wide, 51 cm tall

Short reactor cycles (~25 days, 46% uptime)

Low ^{239}Pu buildup **(< 0.5%)**

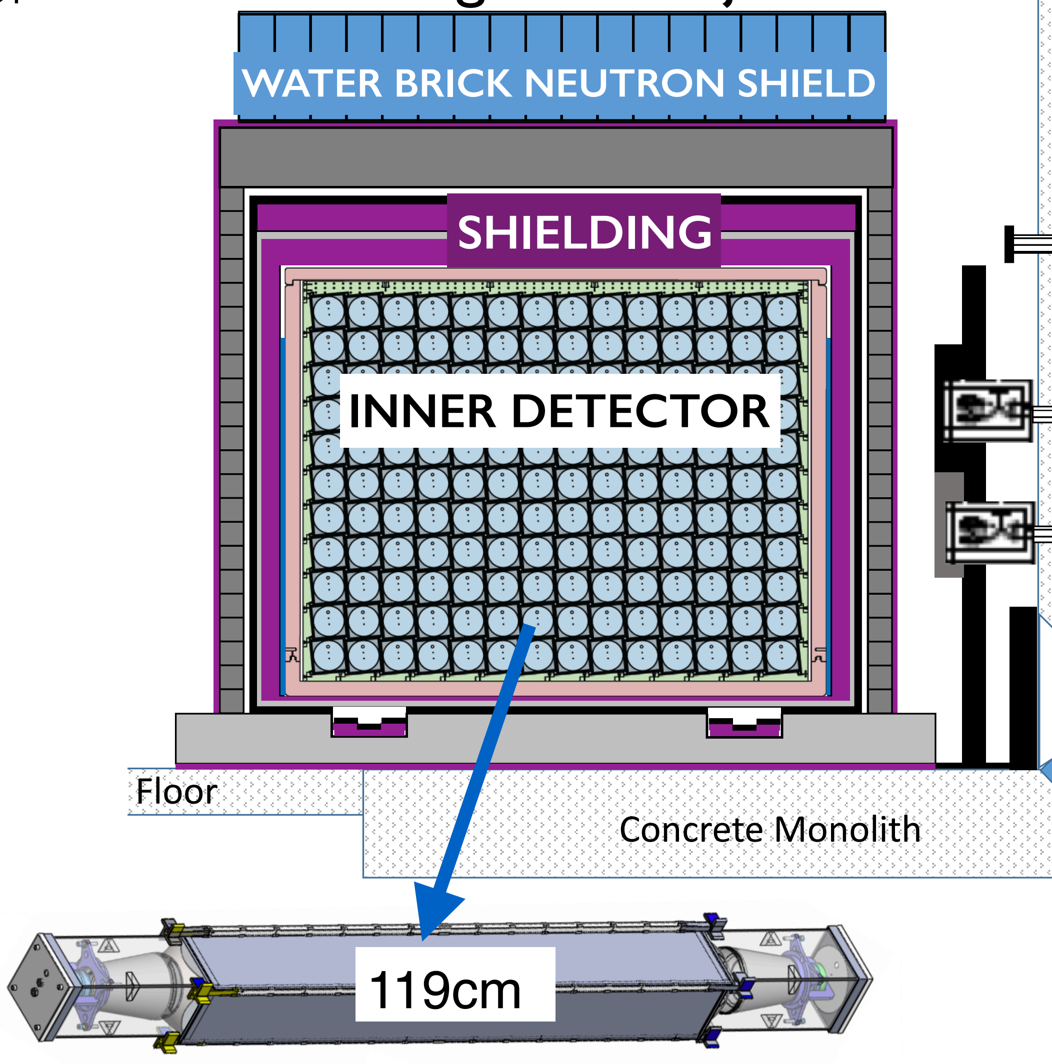
Reactor on surface: **Little overburden**

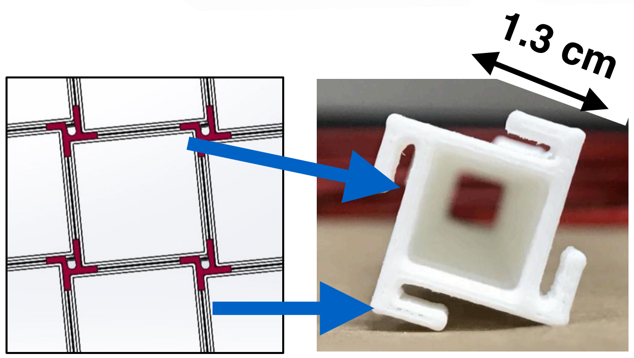
Design should overcome low overburden and high background environment

Detector Design

- Single volume ~4 ton **^{6}Li-loaded liquid scintillator** detector
- Composed of **154 (11x14) optically separated segments** (~25 liters)
- **Low mass** optical separators (~1.5 mm thick)
- Double-ended readout
- Segmentation:
  - 3D event reconstruction
  - Reactor model independent oscillation search
  - Calibration access
  - Fiducialization

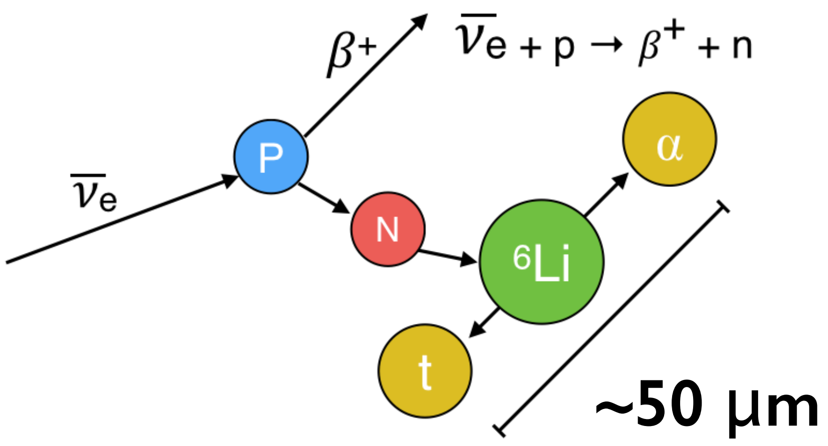
Shielding package optimized for background rejection



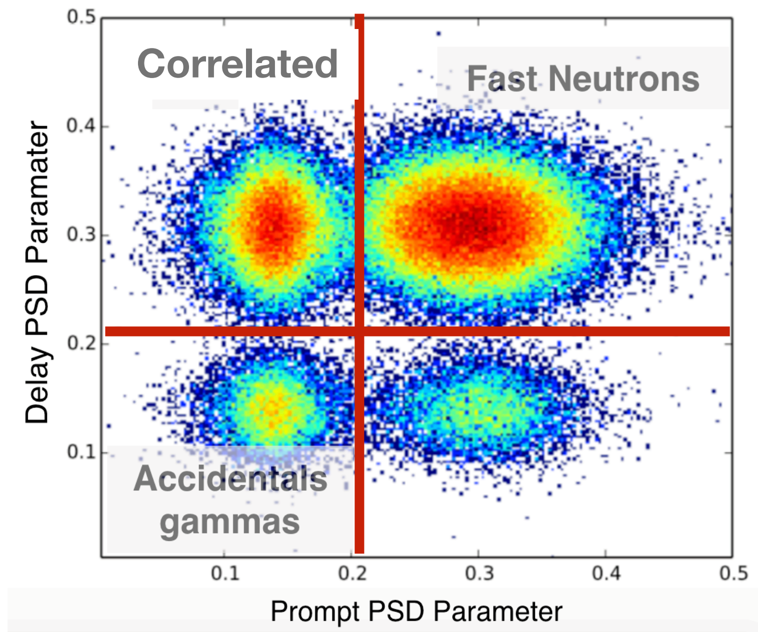


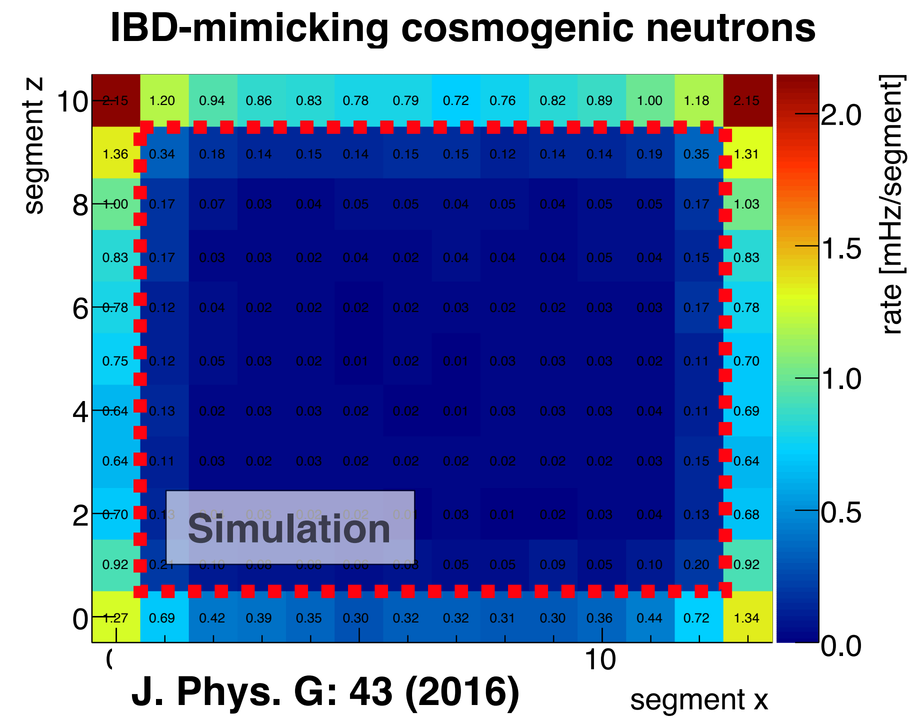
***in-situ* calibration access from tilted design**

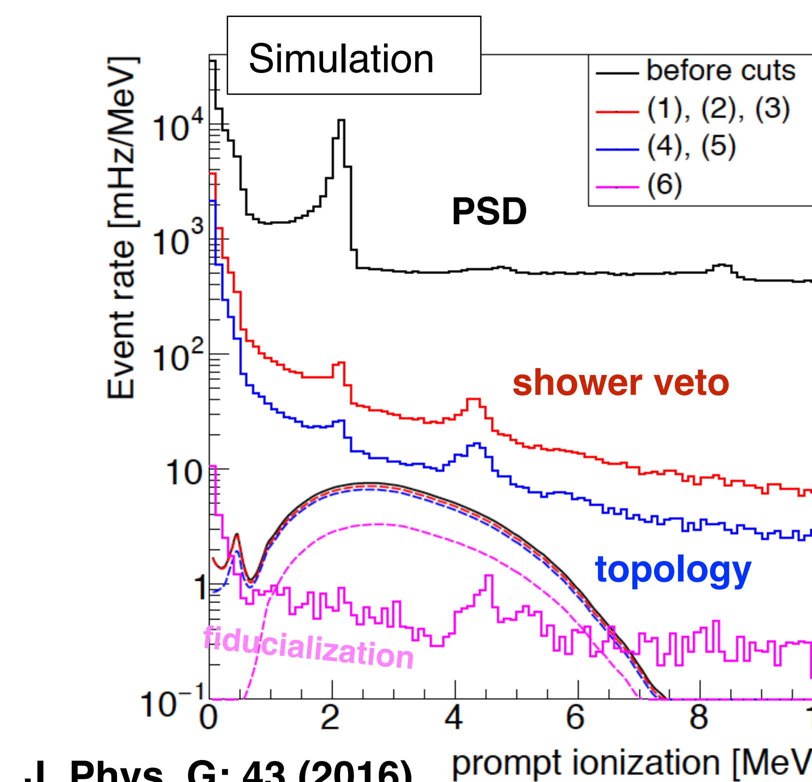
Detection and Background Rejection



IBD mechanism

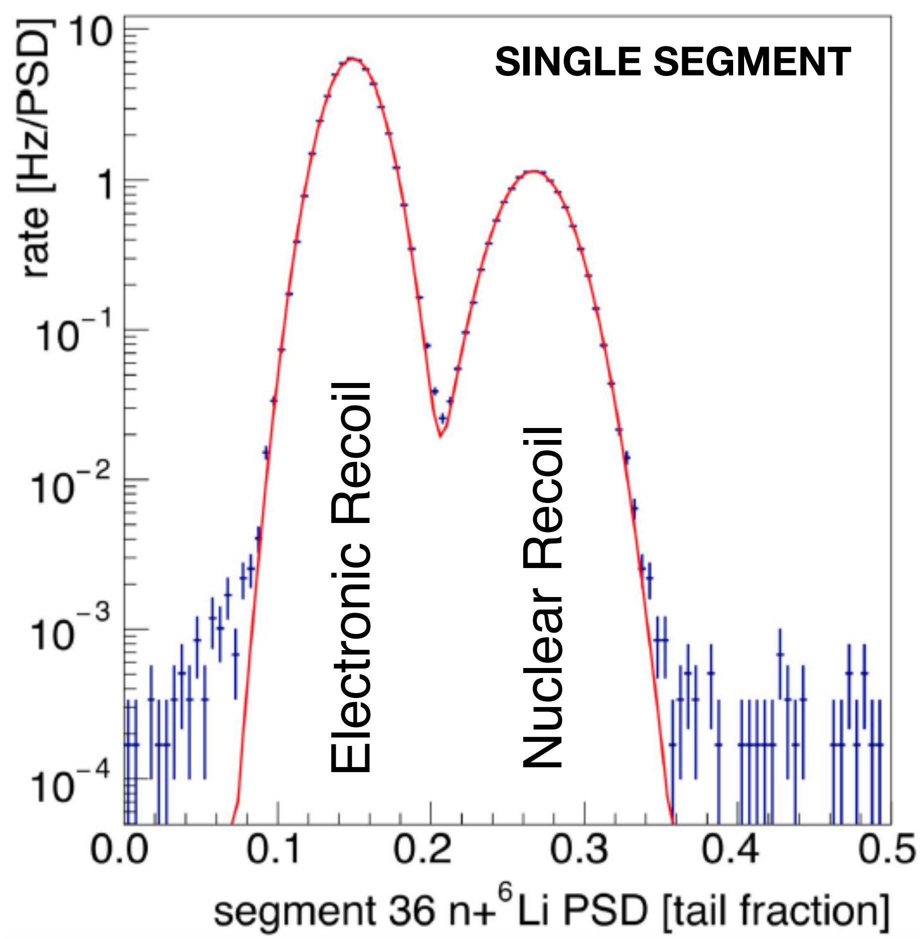


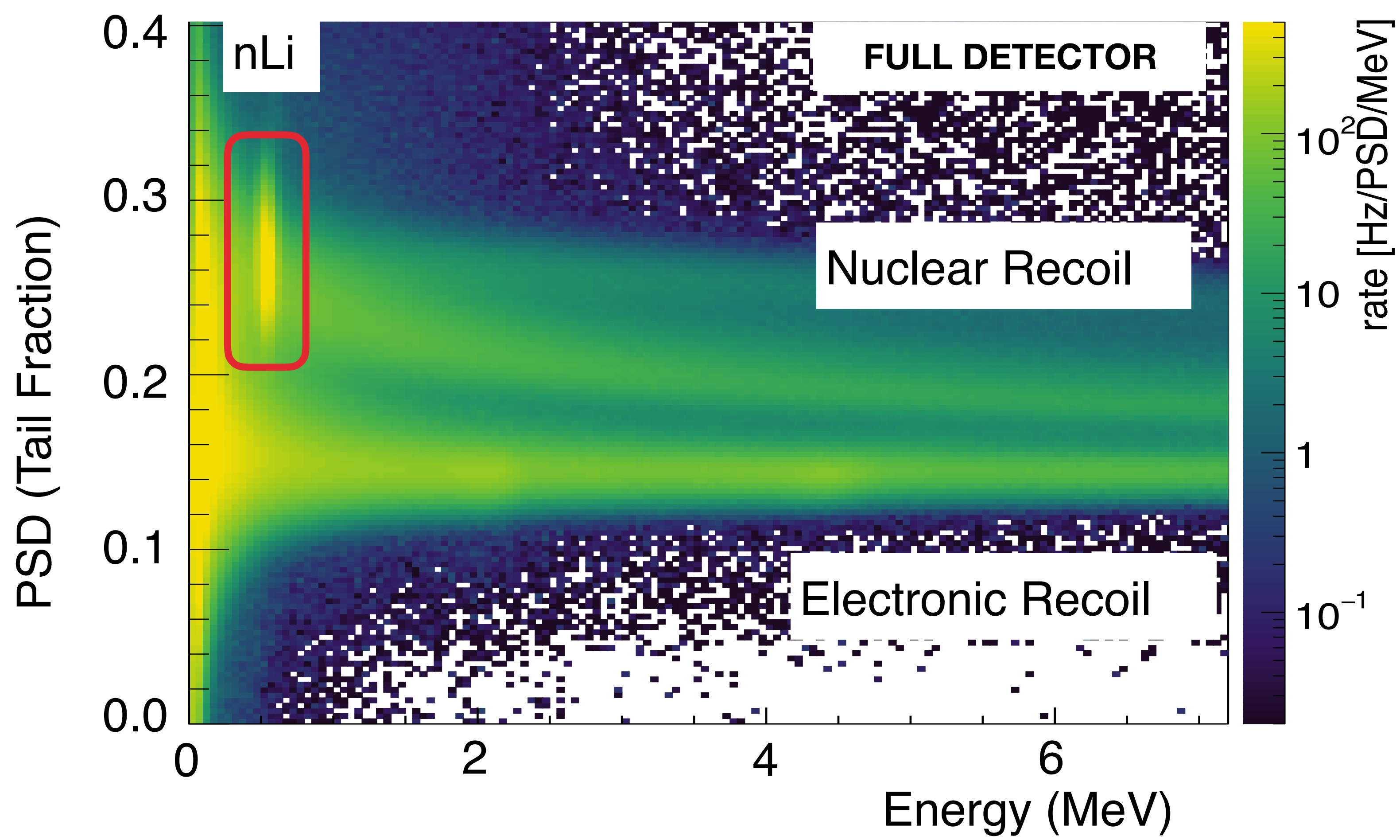




- High light yield 8200 ph/MeV - Good energy resolution
- ^{6}Li allows for spatial and temporal compact IBD events
  - Background rejection from topology cuts
- Pulse Shape Discrimination provides particle ID
- **Analysis cuts provide an ability to suppress backgrounds by ~$\mathcal{O}(4)$**

Detector Characterization: PSD Performance



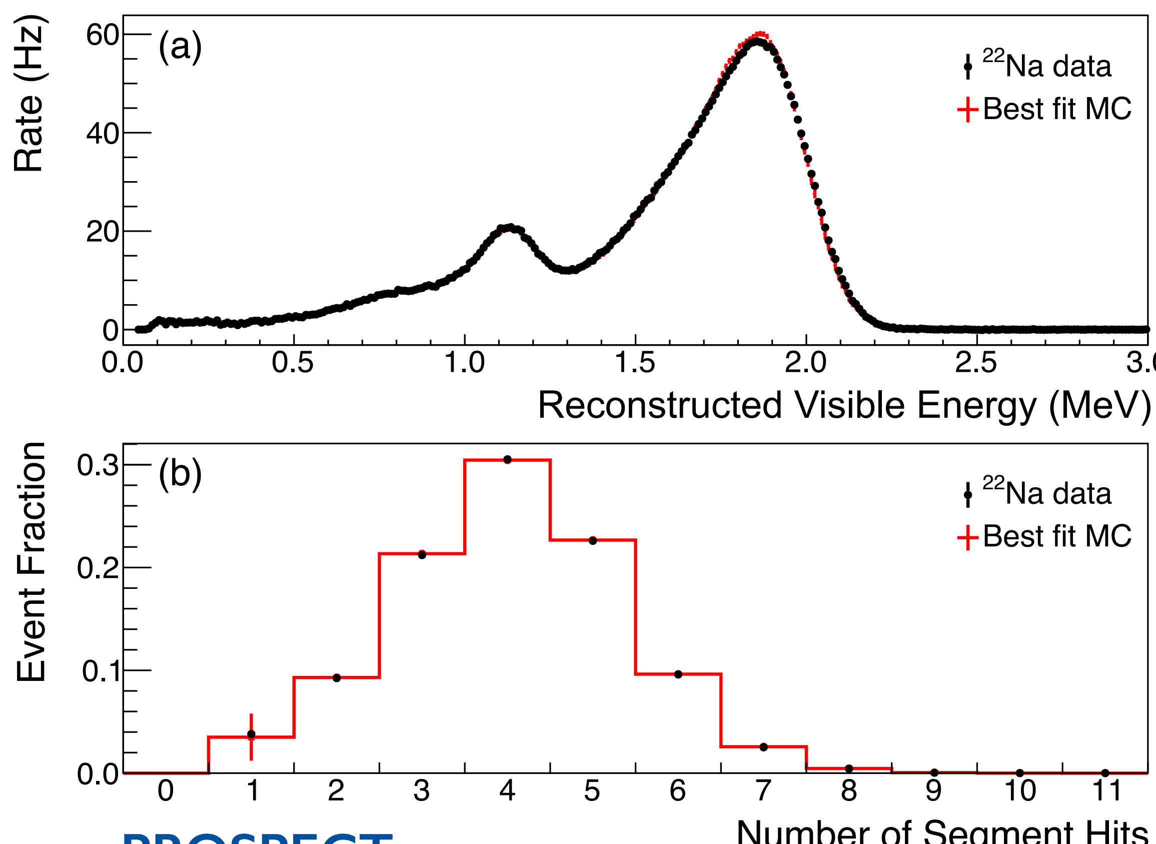


- Excellent particle ID of gamma interactions, neutron captures, and nuclear recoils
- Dominant backgrounds: Cosmogenic fast neutrons, reactor-related gamma rays, reactor thermal neutrons
  - Vast majority identified and rejected by PSD for Prompt and Delayed signals
- **Tag IBDs with high efficiency and high purity**

Detector Characterization

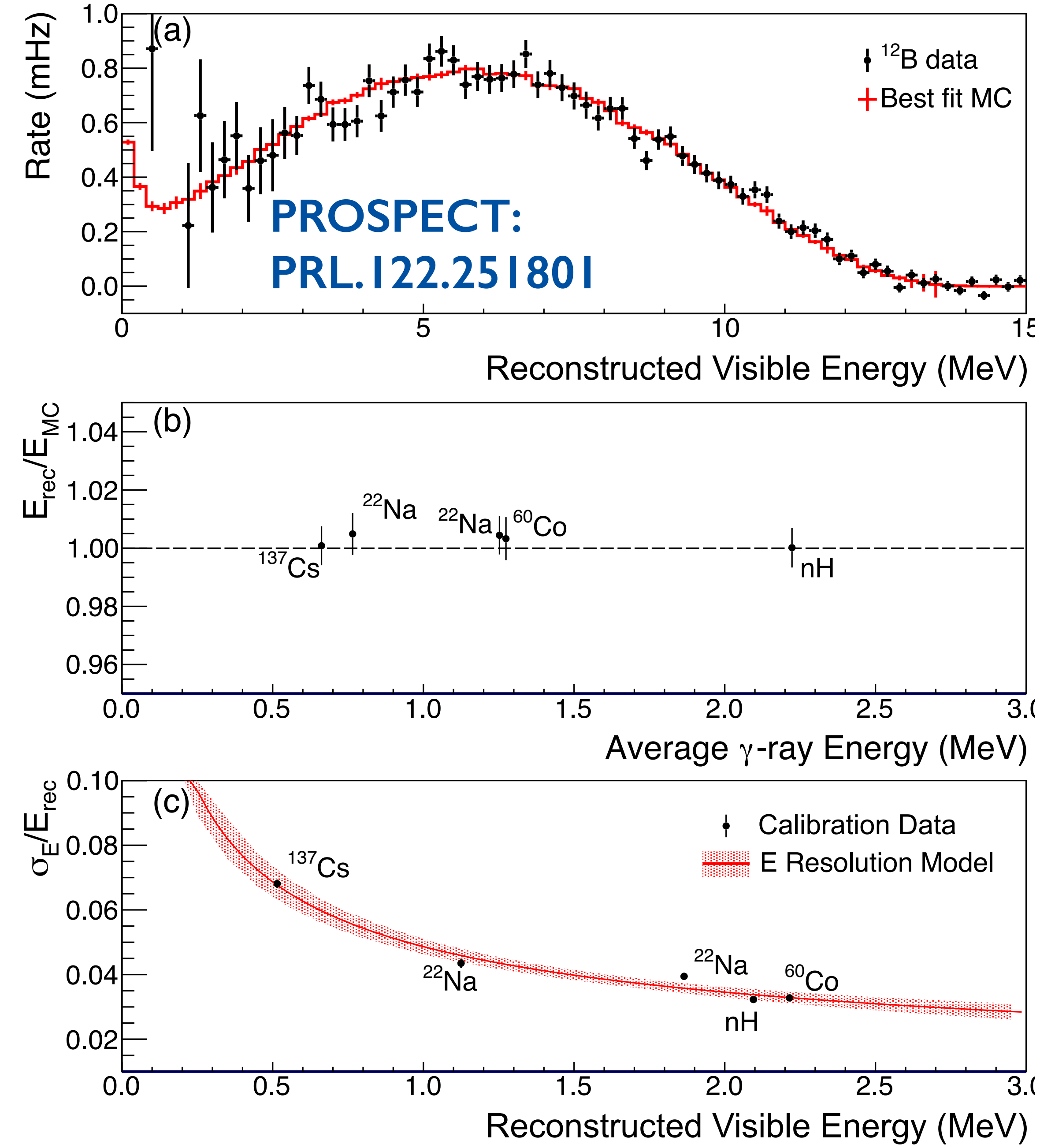
Gamma sources (^{137}Cs, ^{60}Co, ^{22}Na):
Deployed throughout detector, measure single segment response

Fast-neutron tagged ^{12}B:
Beta spectrum calibration over full antineutrino range



PROSPECT: PRL.122.251801

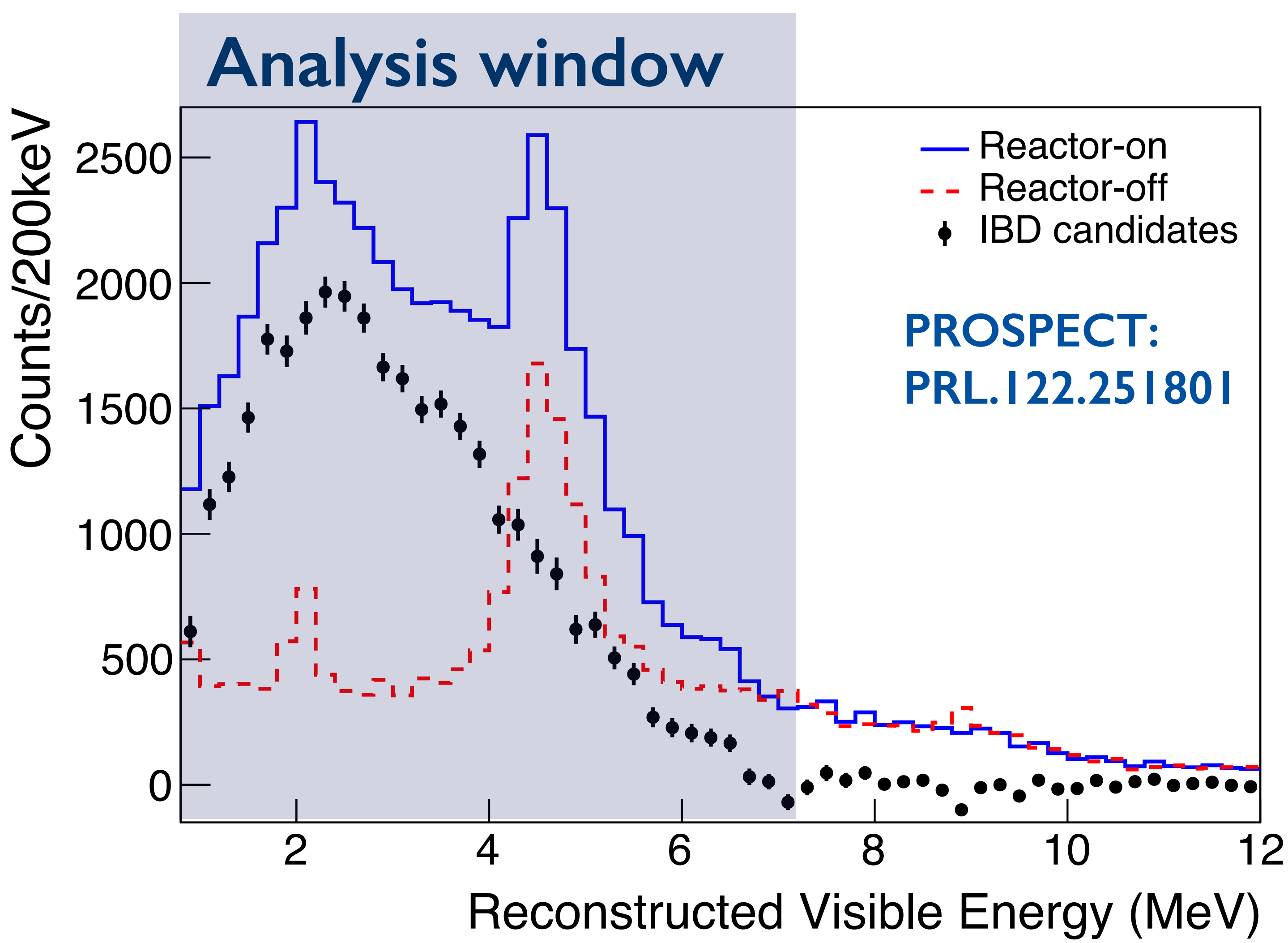
Full-detector E_{rec} within 1% of E_{true}



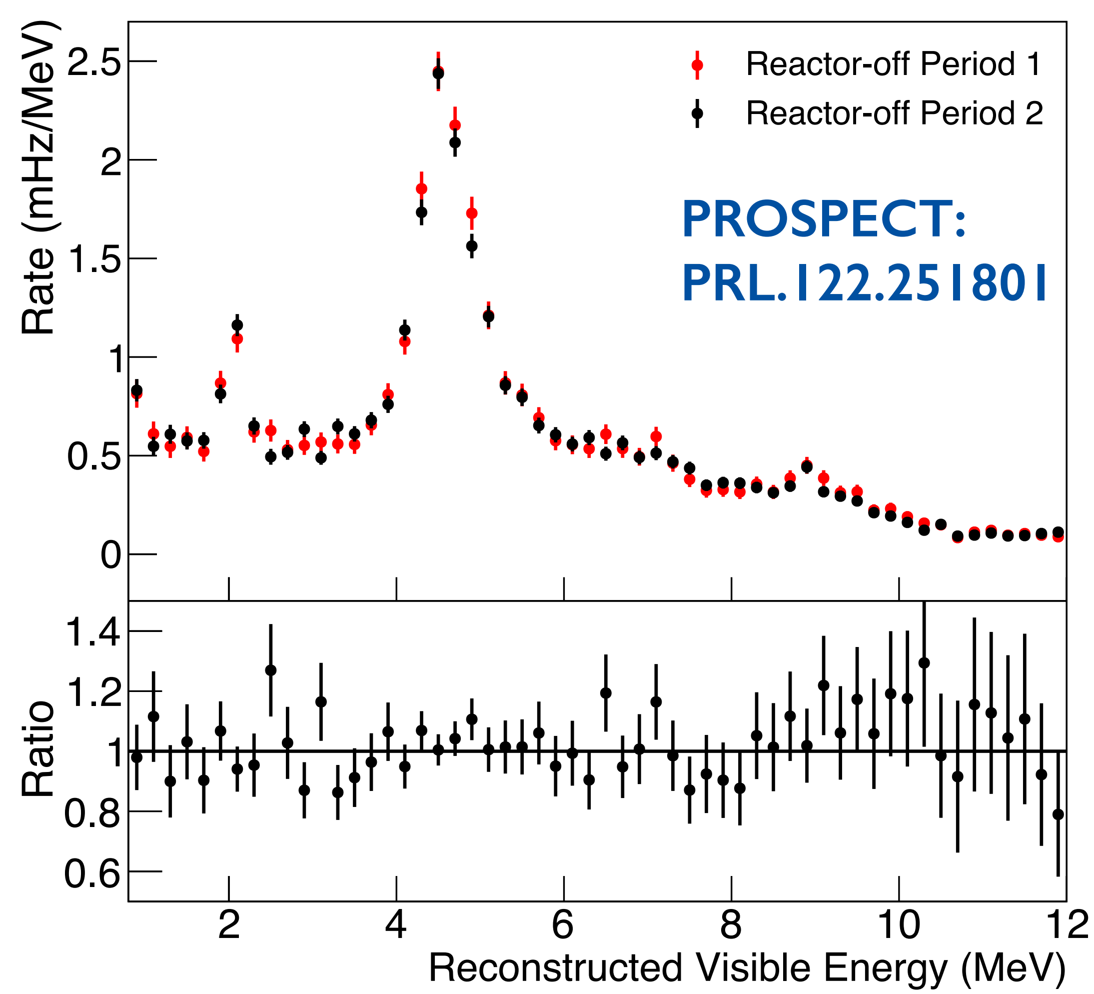
High light collection: 795±15 PE

Spectrum Measurement

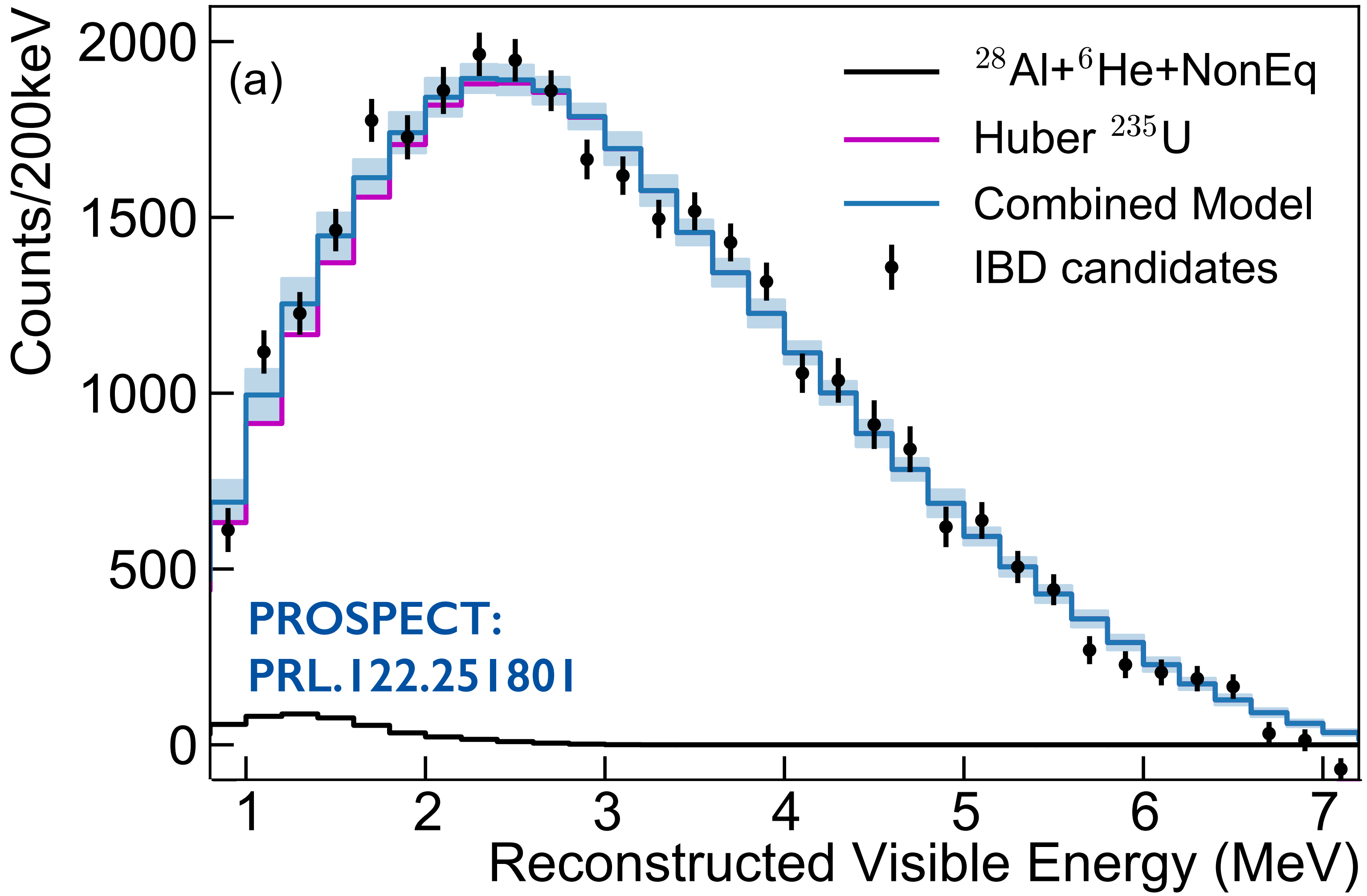
- **40.2 days** of reactor on data - Two discrete periods
- **37.8 days** of reactor off data - Two discrete periods
- IBD events obtained by scaling reactor off data by exposure
- Atmospheric pressure dependence taken into account
- **32k IBDs detected with S:B = 1.7**



Reactor-off spectrum exhibits consistency between datasets



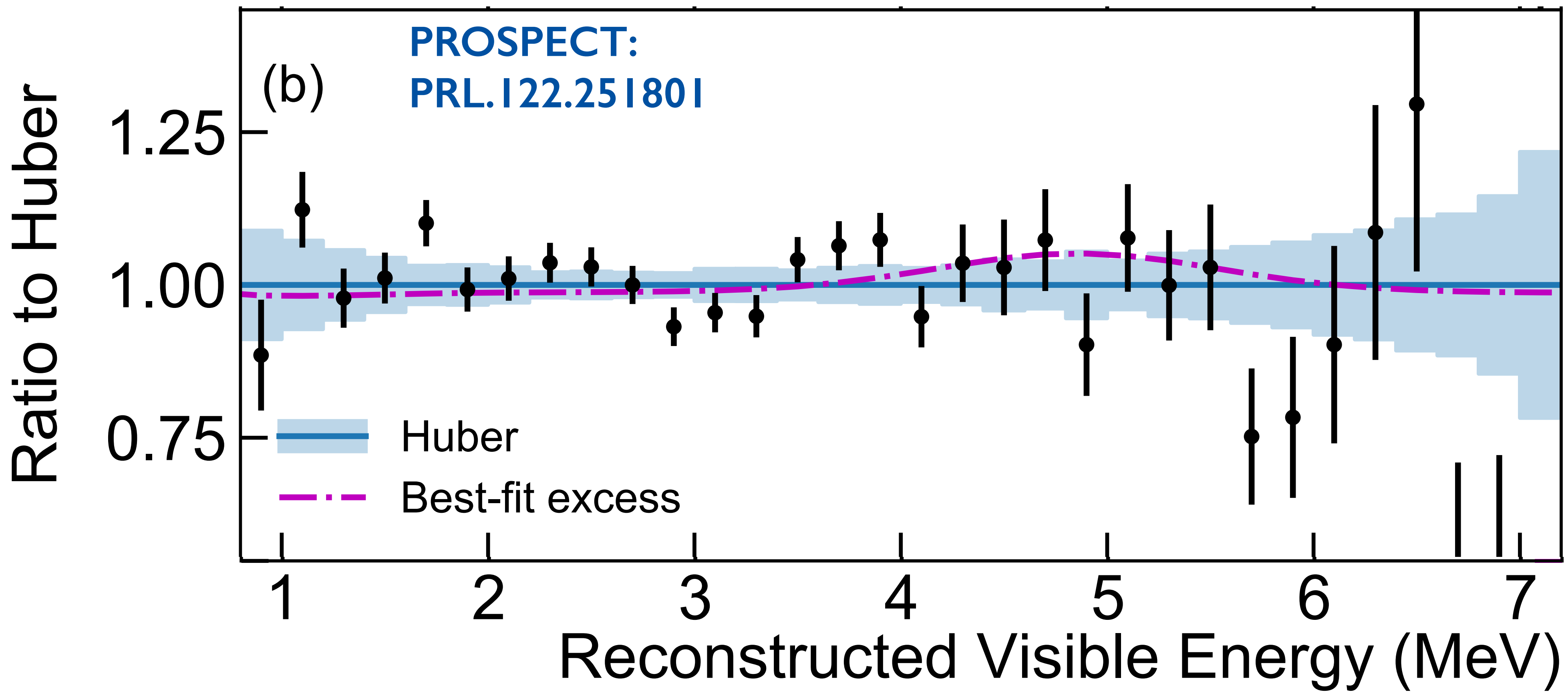
Model Comparison



Measurement currently statistic limited

- Predicted spectrum passed through detector response model
- Predicted spectrum = Huber ^{235}U+ contributions from non-fissioning and non-equilibrium isotopes
- χ^2/ndf =51.4/31 (p-value 0.01) for **shape-only** comparison with model
- Broad agreement, but overall data not in agreement with model

Testing Origin of the 'Bump'



- **Could the LEU-measured 'Bump' be solely explained by ^{235}U ?**
- Tested by comparing data to ad-hoc models
- Local deviation modeled as a gaussian based on Daya Bay measured spectrum with floating normalization
- Best-fit bump @ 69±53%
- **Disfavors bump from ^{235}U-only (178%) at 2.1σ**

Concluding Remarks

- PROSPECT started taking measurements in March 2018
- First **modern measurement of high-statistics antineutrino** spectrum from a HEU reactor
- Broad agreement with Huber model but bad fit to the data
- Currently **statistics limited**, improved comparison with more data
- **Excellent S:B (1.7:1)** achieved with an on-surface detector (<1 mwe overburden)
- Provides an opportunity for detailed understanding of cosmogenic backgrounds
- Key technology for reactor monitoring demonstrated

Thanks

BROOKHAVEN NATIONAL LABORATORY

LE MOYNE COLLEGE A.D. 1946

OAK RIDGE National Laboratory

W&M

Yale

Drexel UNIVERSITY

NIST

UNIVERSITY OF WATERLOO CONCORDIA CUM VERITATE

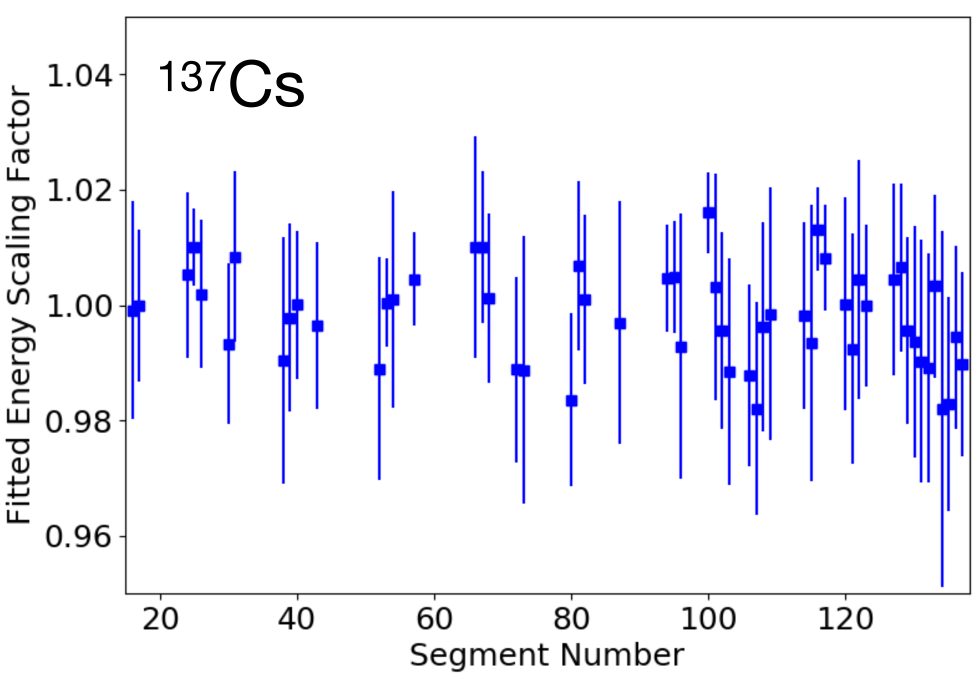
DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

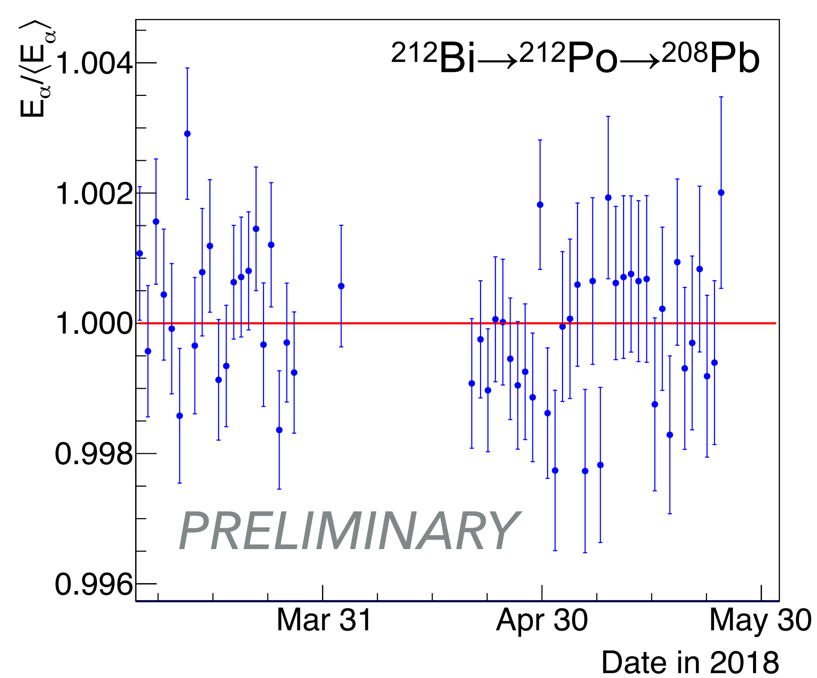
HEISING-SIMONS FOUNDATION

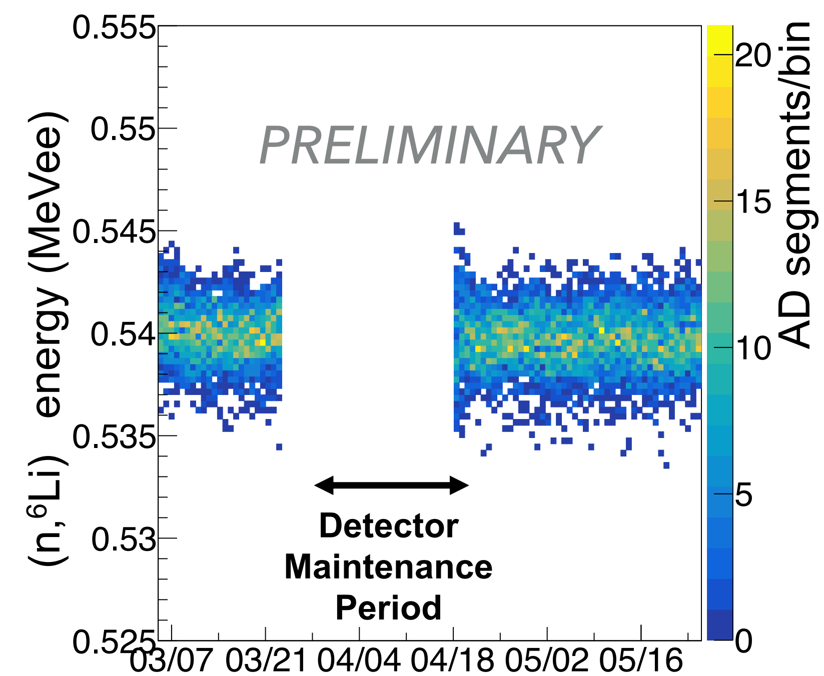
Extra

Detector Performance

- **Calibration Source Deployment:**
  - 35 *in-situ* calibration source tubes throughout detector to map energy response
  - uniform segment to segment response
  - ^{252}Cf source to study neutron capture efficiency
- **Intrinsic radioactive sources**
  - Track uniformity over time with distributed internal single-segment sources:
  - Alpha lines from $^{212}Bi \rightarrow {}^{212}Po \rightarrow {}^{208}Pb$ decays, nLi capture peak
  - Stability in reconstructed energy over time







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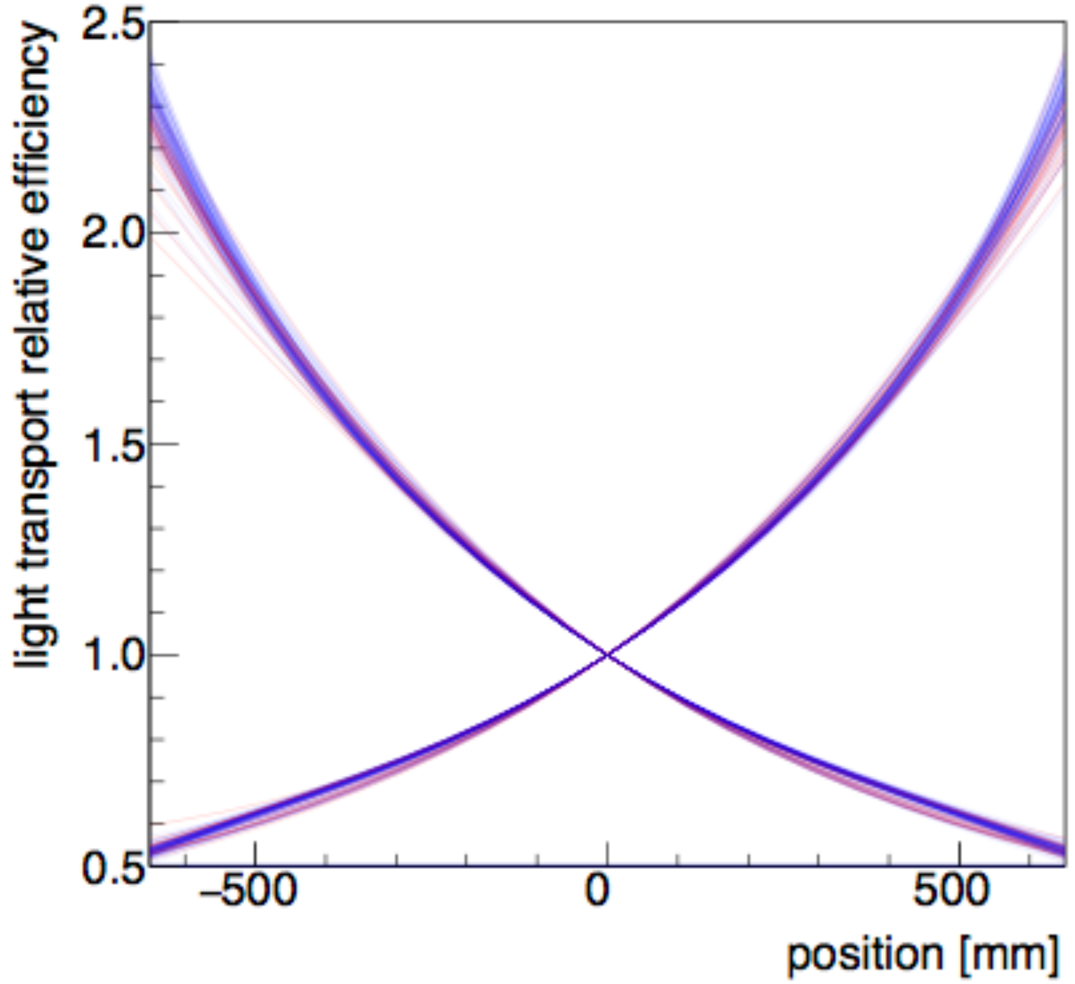
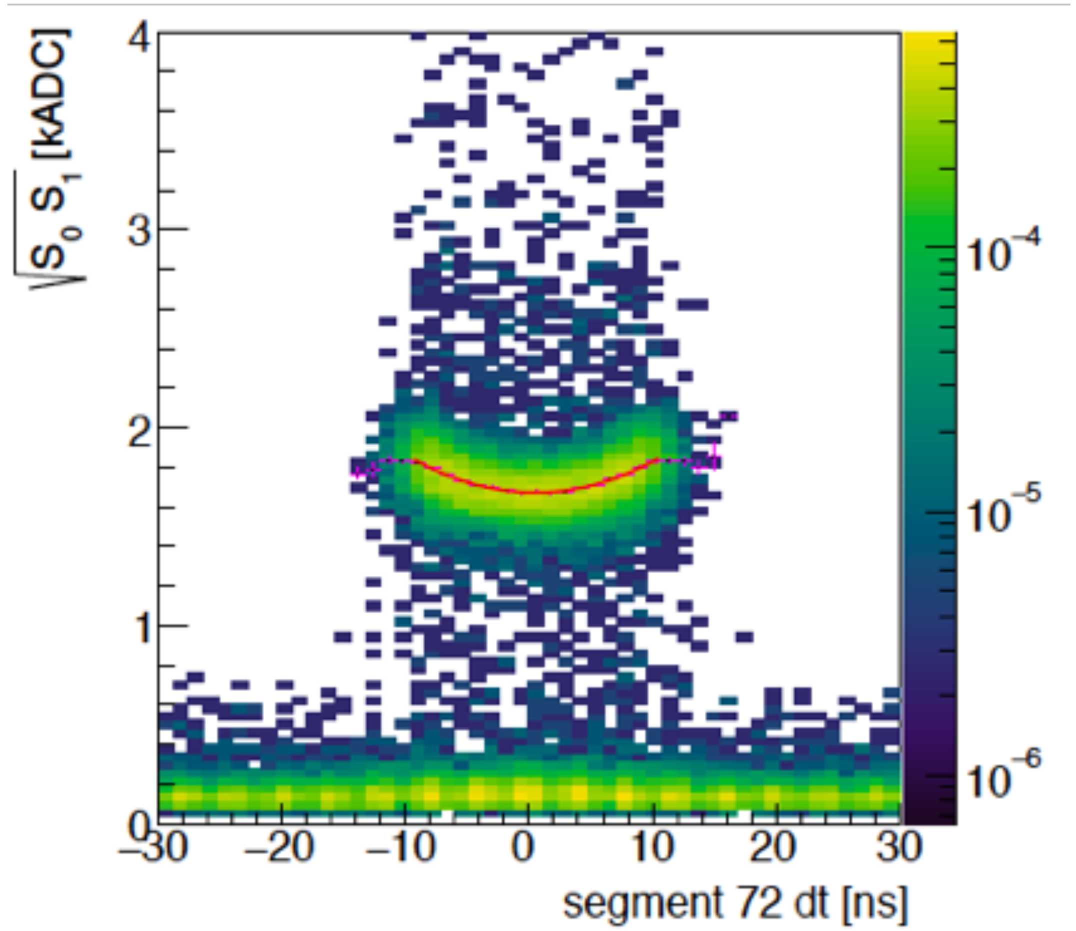
Calibration



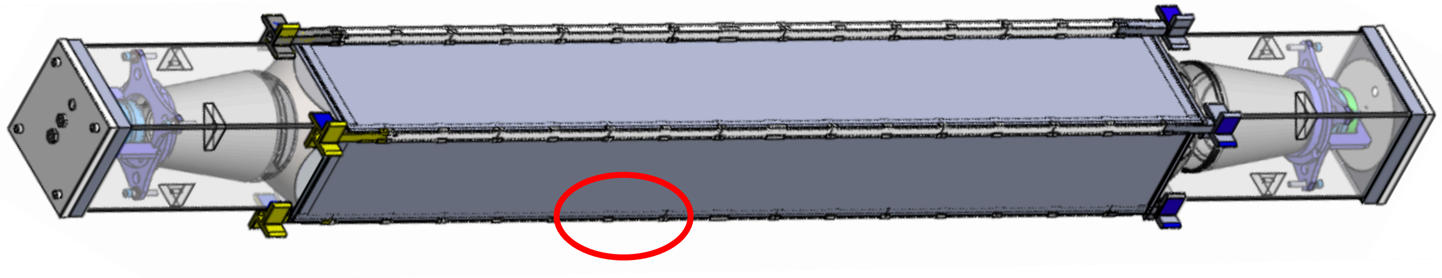
Light collection along the length of the segment for all 308 segments



Geometric mean of light collection for two PMTs in a single segment

Calibration

Position Calibration



Pinwheel tabs alter local light transport, causing 'tiger stripes'