# The Precision Reactor Oscillation and Spectrum Experiment


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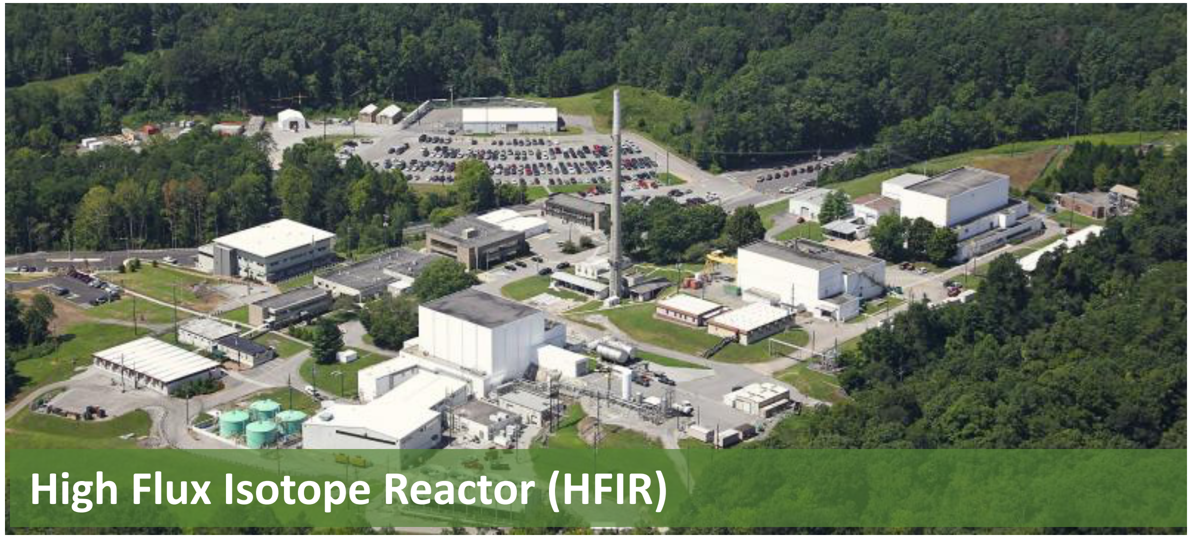
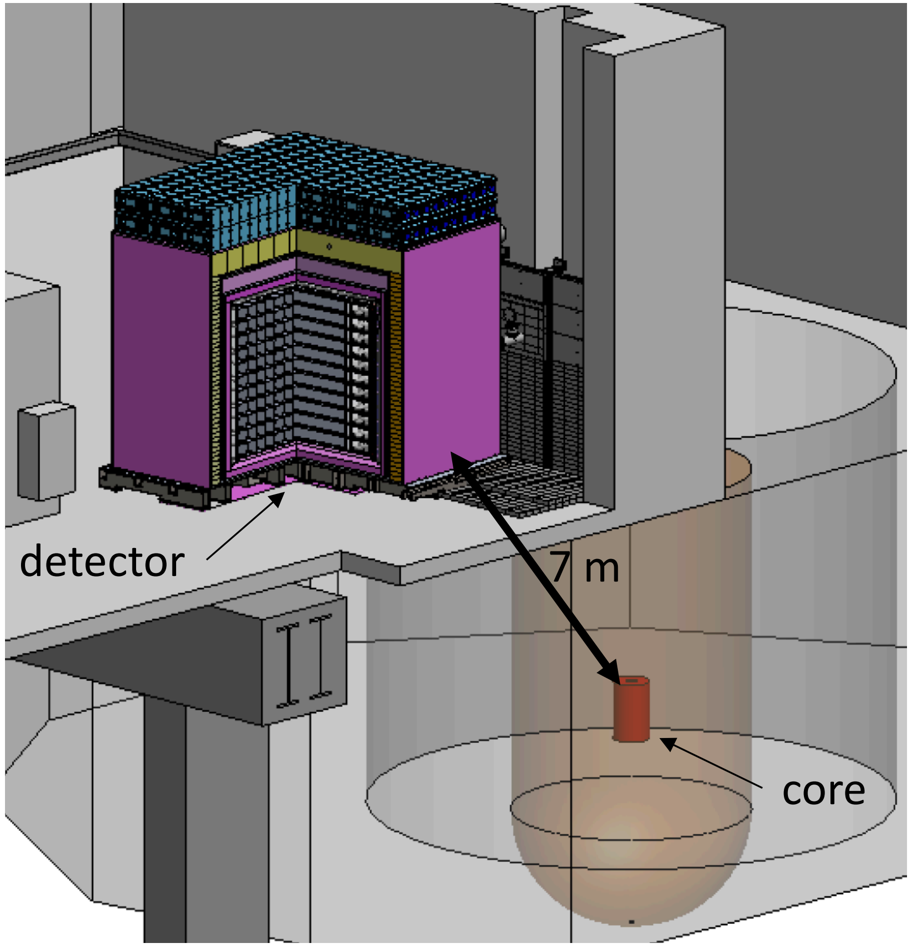
Grenoble, France

# Overview of PROSPECT

- Short baseline reactor antineutrino experiment
- Recently installed at HFIR at Oak Ridge National Lab (ORNL) in TN, USA
- Surface detector -- minimal overburden
- Aim 1. Look for eV-scale sterile $\upsilon$
  2. Measure U-235 $\bar{\upsilon}$ spectrum

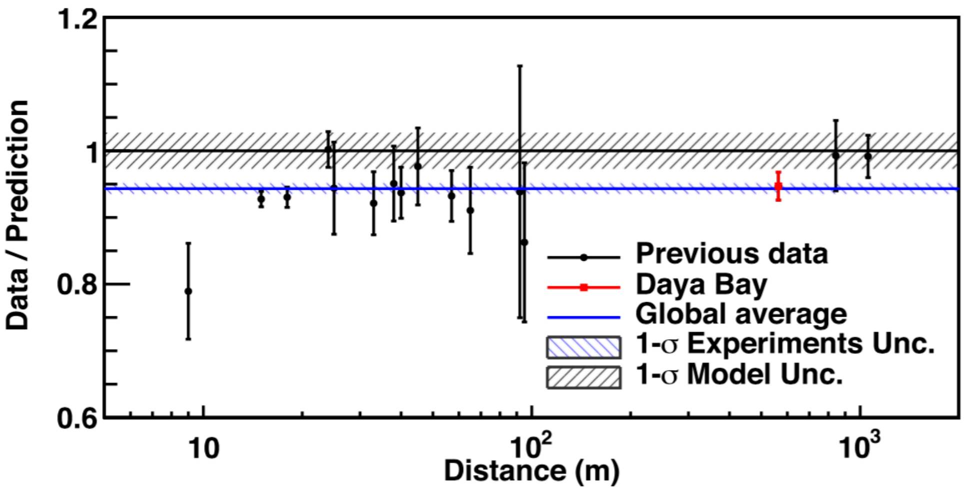


# Physics Motivation

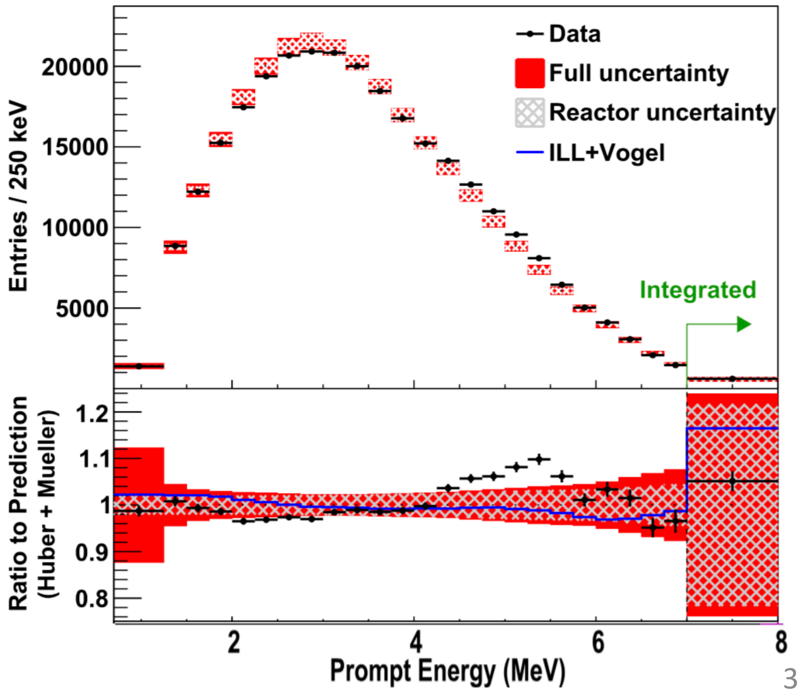
## Reactor anti-neutrino anomaly

- New flux predictions (2011) leads to 6% flux deficit for reactor neutrino experiments
- Possible explanations:
  - ~eV scale sterile neutrino
  - flux calculations and/or inputs deficient



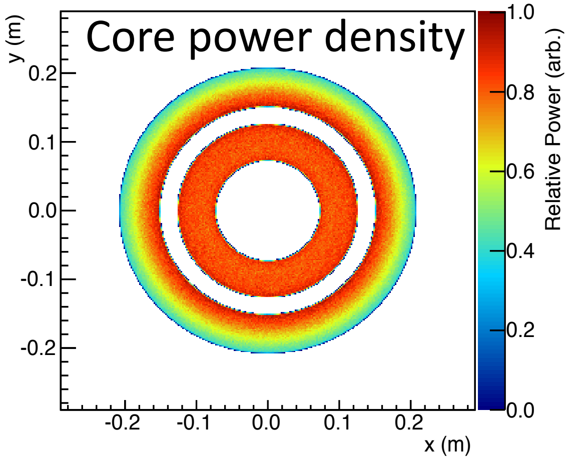

## The 5-7 MeV "bump"

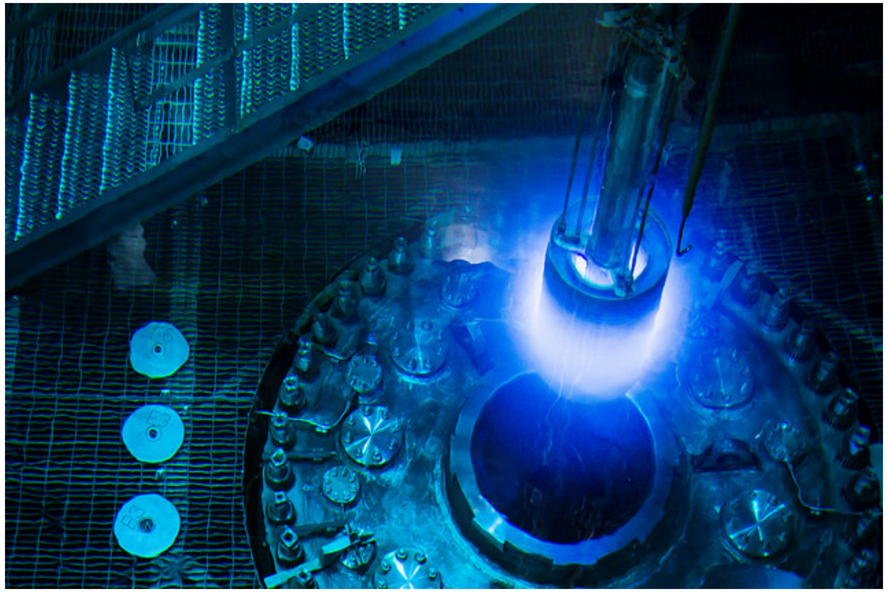
- $\theta_{13}$ experiments (Daya Bay, Reno, Double Chooz) all see excess events in 5-7 MeV neutrino energy
- Precise U-235 spectrum helpful for determining source(s) of discrepancy



# Why at HFIR?

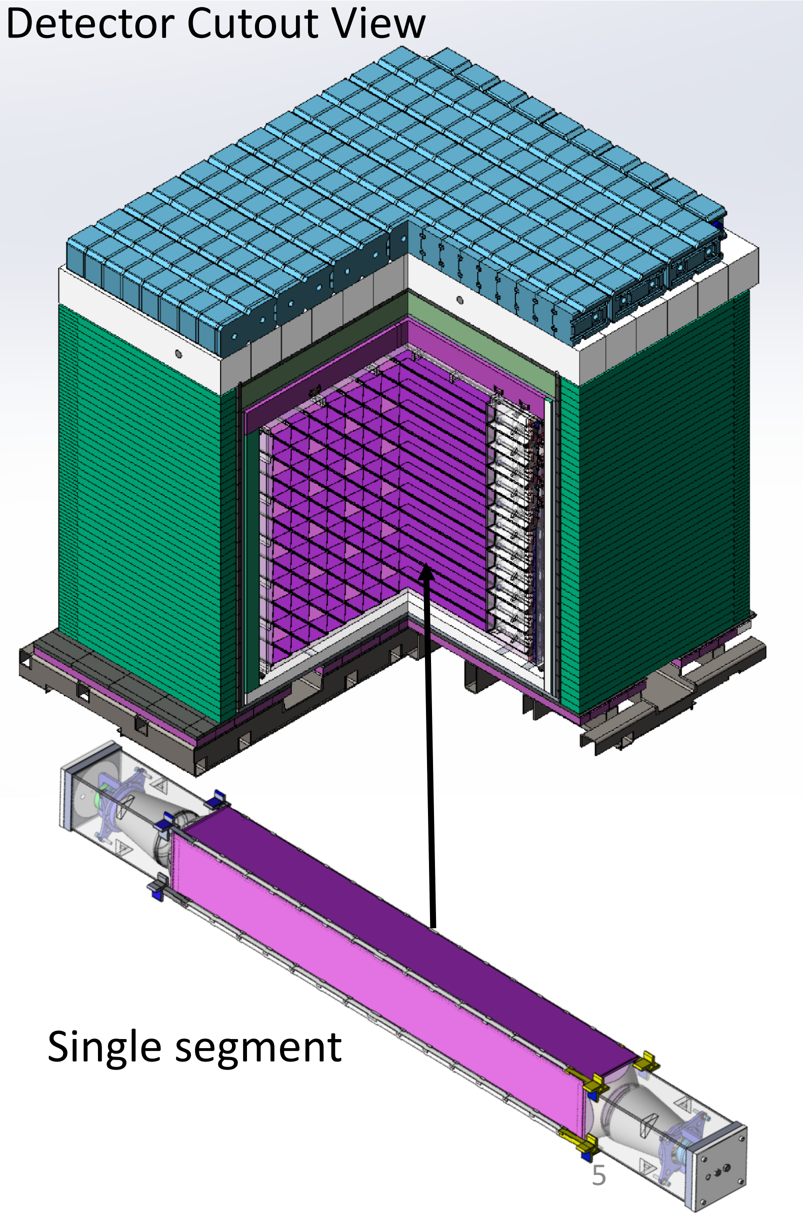
- 85 MW HEU research reactor
  - 93% U-235 fuel
  - >99% neutrinos from U-235 fissions
- Compact core (50 cm tall, 42 cm wide)
  - little oscillation washout
- Position near (7 m) the core available
- Short reactor cycles (~25 days)–fuel evolution effects negligible
- >50% reactor off time for background measurements
- Detailed core model available

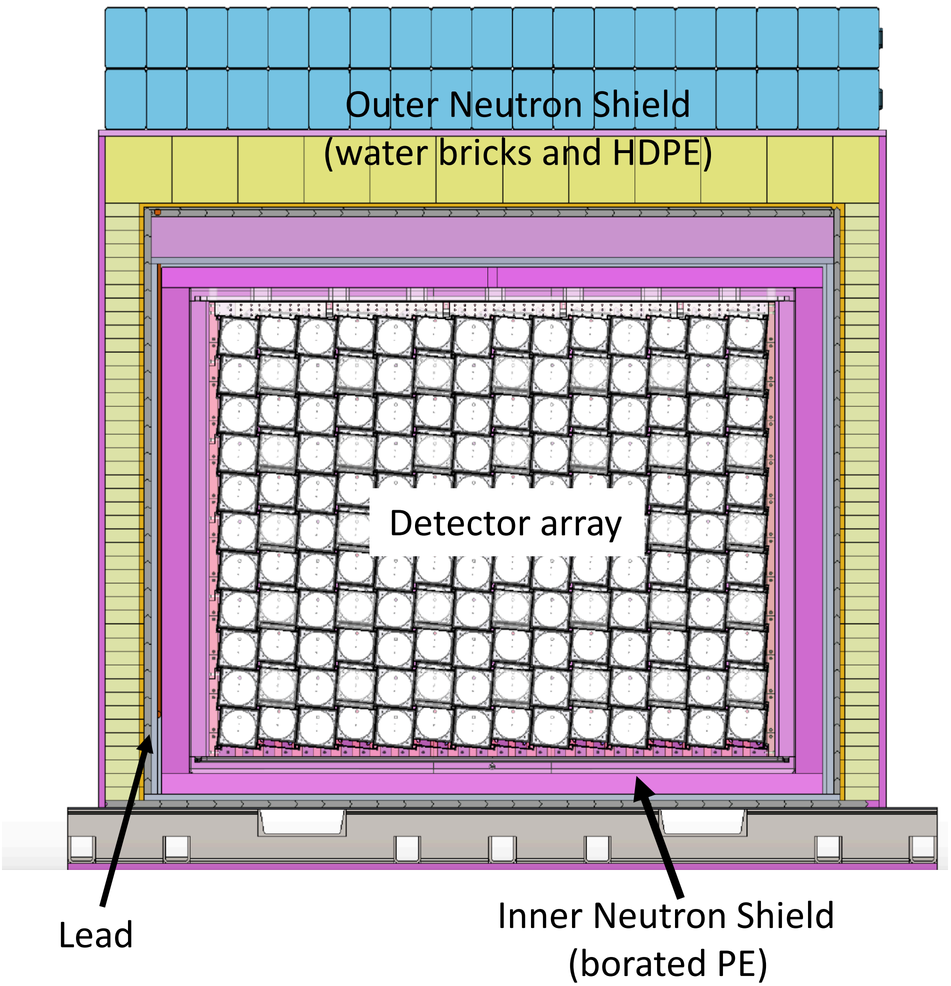
# Experimental design

- Segmented design
  - Single volume of liquid scintillator
  - Subdivided into 154 (11x14) optically isolated segments
  - Segments read out by PMT on each end
- Full waveform readout (CAEN v1725 250 MHz sampling, ~150 samples per pulse)
- Lithium-6 loaded (0.1% by wt) liquid scintillator based on EJ-309 non-flammable, non-toxic solvent mixture
- Excellent pulse shape discrimination (PSD)
  - PSD=(pulse tail integral)/(total pulse integral )
- Spiked with trace Ac-227 (parts per $10^{20}$) for relative segment volume calibration
- Entire assembly built on moveable air caster platform allowing baselines as large as 12 m



# Detector Shielding

- Considerations
  - At surface → large cosmic background
  - Near reactor → gammas and neutrons
  - Moveable platform
  - Inner detector package ~14 tons
  - Full detector ~33 tons
- ~10 MeV neutrons suppressed by hydrogenous shielding + borated polyethylene
- Primary IBD-like backgrounds from cosmogenic fast neutrons – thicker shielding on top
- Fiducialize



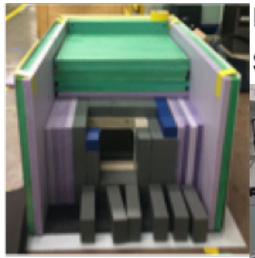
# Development Timeline

**PROSPECT-0.1**
*Characterize LS*
Aug 2014-Spring 2015

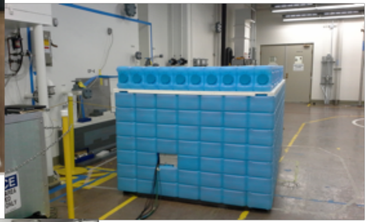
5cm length
0.1 liters
LS, $^6$LiLS

**PROSPECT-2**
*Background studies*
Dec 2014 - Aug 2015

12.5 length
1.7 liters
$^6$LiLS



multi-layer shielding



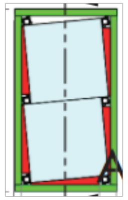
**PROSPECT-20**
*Segment characterization*
*Scintillator studies*
*Background studies*
Spring/Summer 2015

1m length
23 liters
LS, $^6$LiLS

local reactor shielding

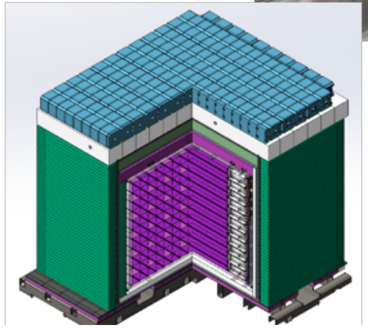
**PROSPECT-50**
*Baseline design prototype*
Spring 2016

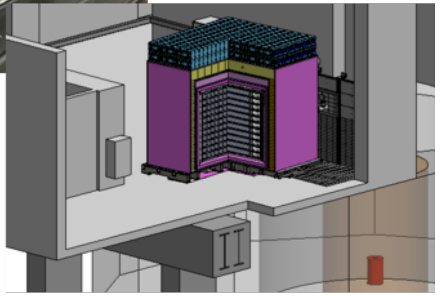
1x2 segments
1.2m length
50 liters
$^6$LiLS



**PROSPECT AD**
2017 - 2018

11x14 segments
1.2m length
~4 tons
$^6$LiLS





# Detector assembly at Yale University

Assembling PMT housings

FFirst assembled layer complete!

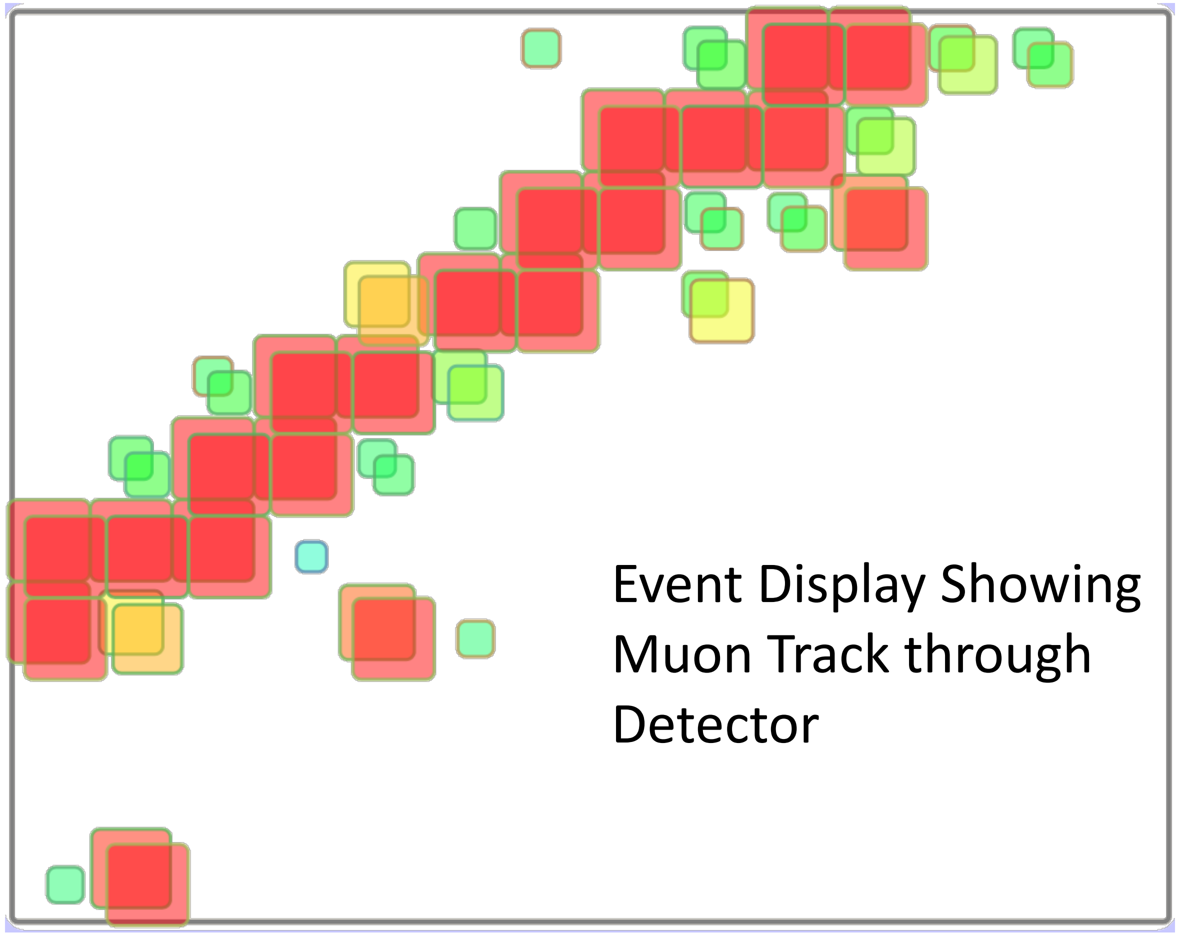
# Assembling a layer in 30 seconds

# Lifting and transport


# Final installation at HFIR


# PROSPECT is now operational

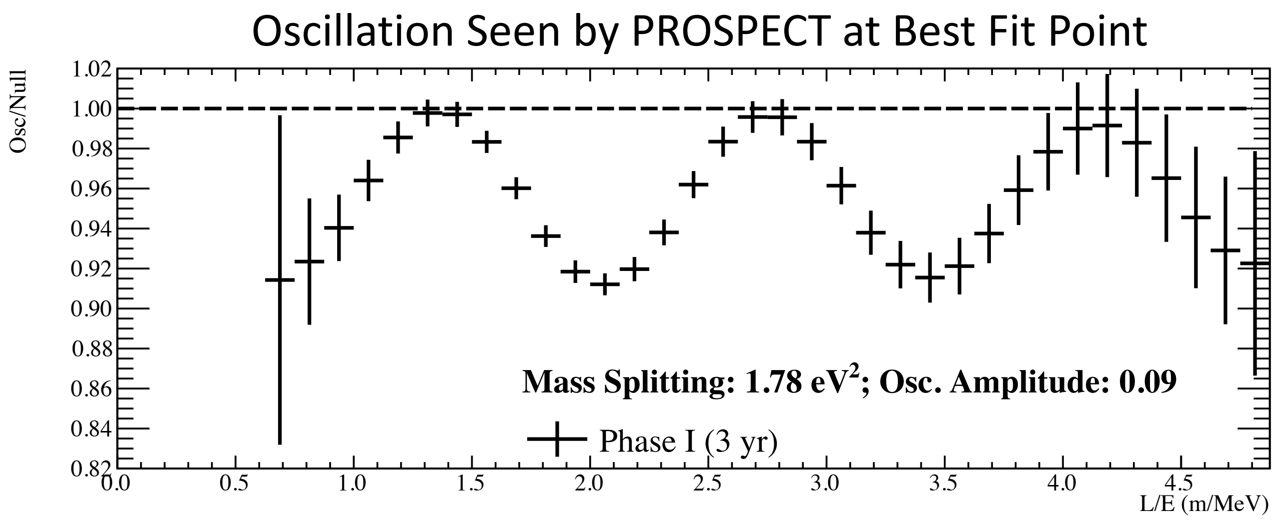
- Detector installed and filled with scintillator mid-February followed by period of commissioning
- Background data and partial calibration program during reactor off period in March-April
- Now in neutrino data-taking mode

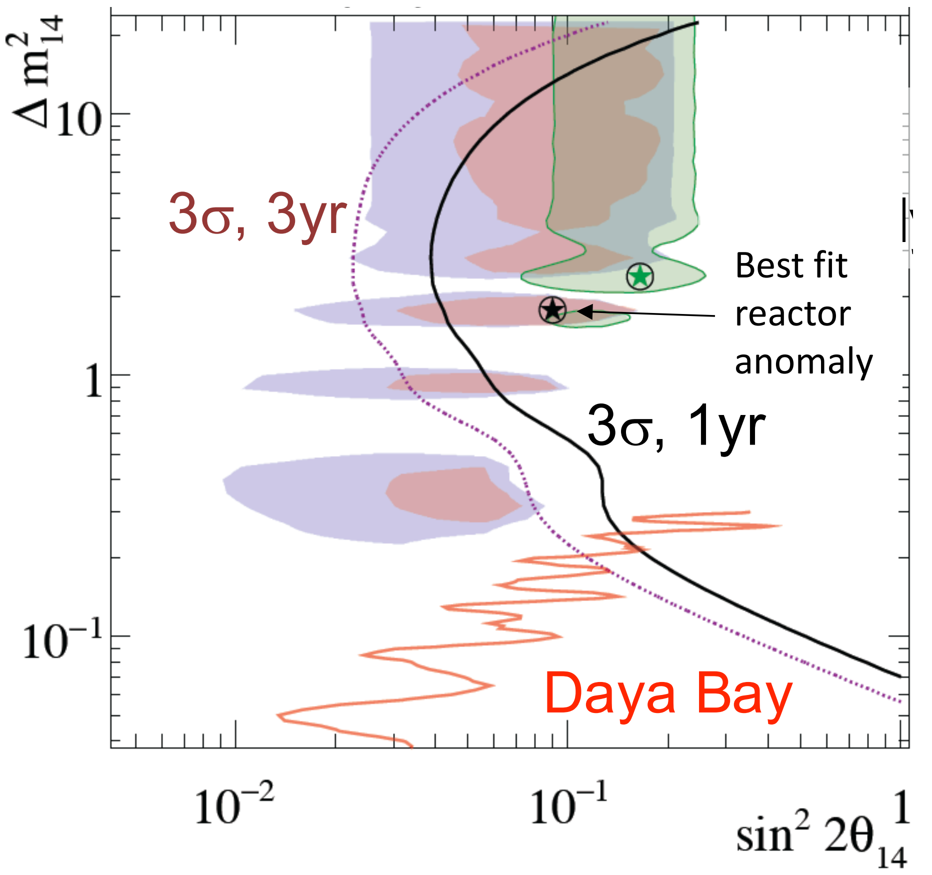


Event Display Showing Muon Track through Detector

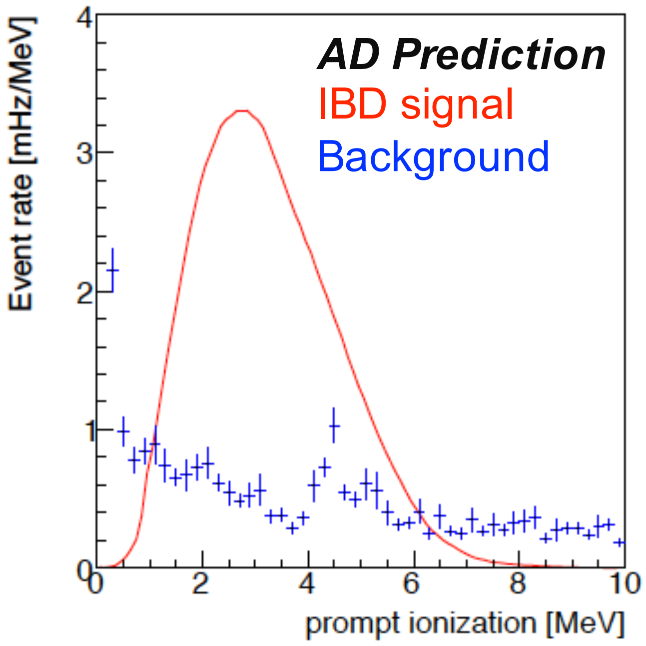
# PROSPECT's view of a sterile neutrino

- Segment to segment L/E comparison provides reactor model independent measure of oscillation
- Probe oscillation hypothesis at reactor best fit at 4$\sigma$ in 1 year.

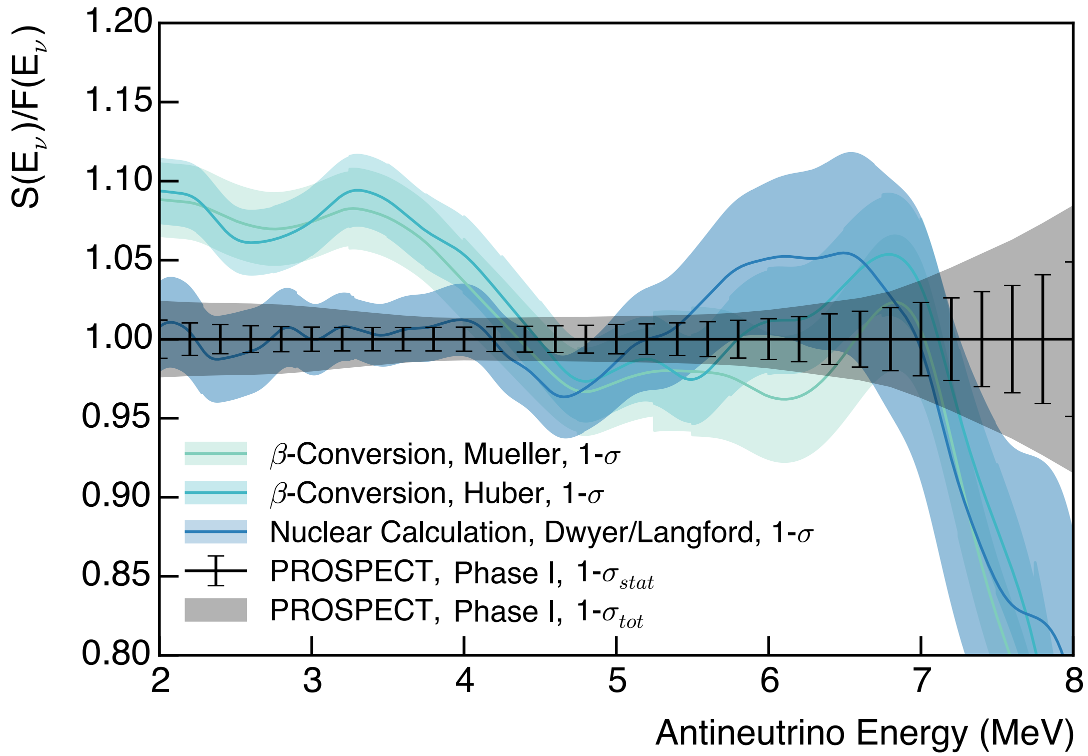


# The PROSPECTrum

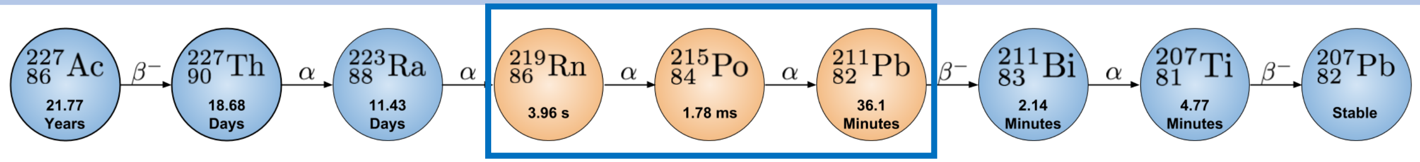



- Expect ~650 inverse beta decays detected per day, 100k/year
- Excellent energy resolution (~4.5%@1MeV)

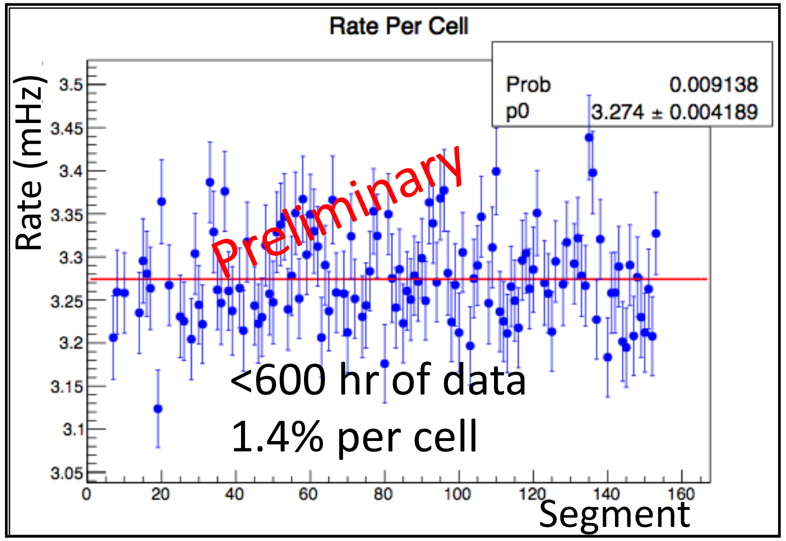


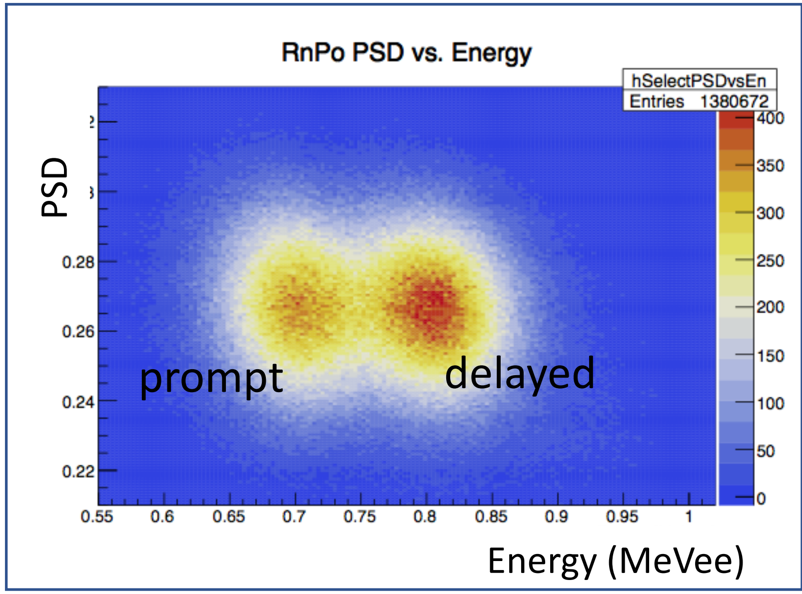

- 3 yr precision will surpass spectral model uncertainties
- Directly test reactor neutrino models
- Produce a benchmark spectrum for future reactor experiments

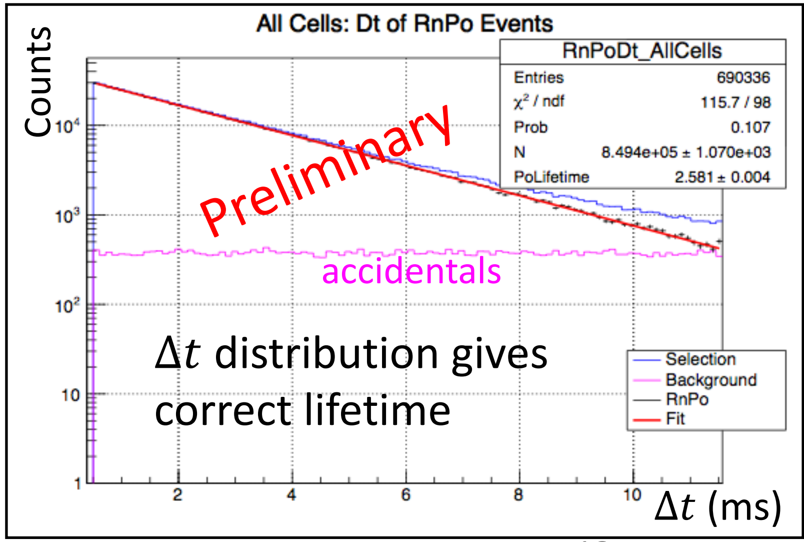
# And the only detector data I will show—relative cell volume calibration using Ac-227




- Relative cell volumes determined by coincident alpha decays in Ac-227 decay chain (Po-215: $T_{1/2} \sim$ 1.8 ms)
- Dissolved 0.5 Bq of Ac-227 in detector active volume
- Well separated from background with PSD, energy, and timing cuts
- Efficiency corrected "RnPo" rates proportional to volume



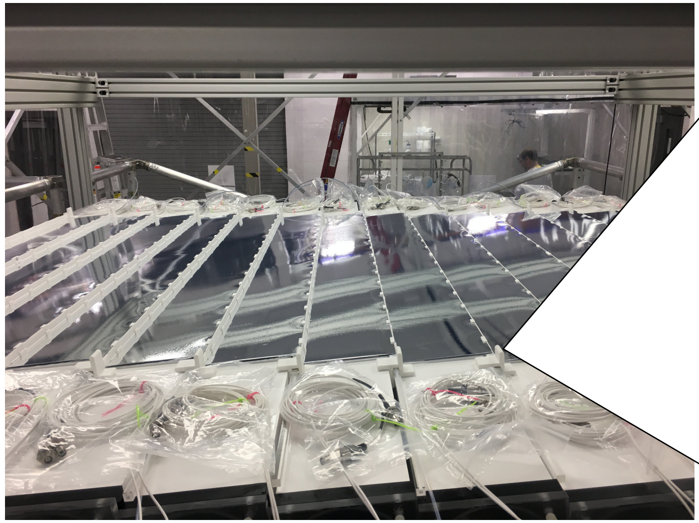
# Conclusion

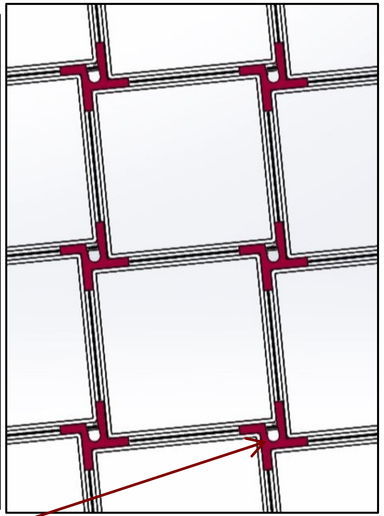
- PROSPECT is installed at HFIR and now in neutrino-taking mode
- Initial calibration program ongoing
- Successful implementation of Ac-227 spiking for determining relative cell volumes
- Excellent energy resolution
- Probe best fit oscillation hypothesis at $4\sigma$ level in 1 year
- Stayed tune for data!

# The PROSPECT collaboration

# Backup: calibration system

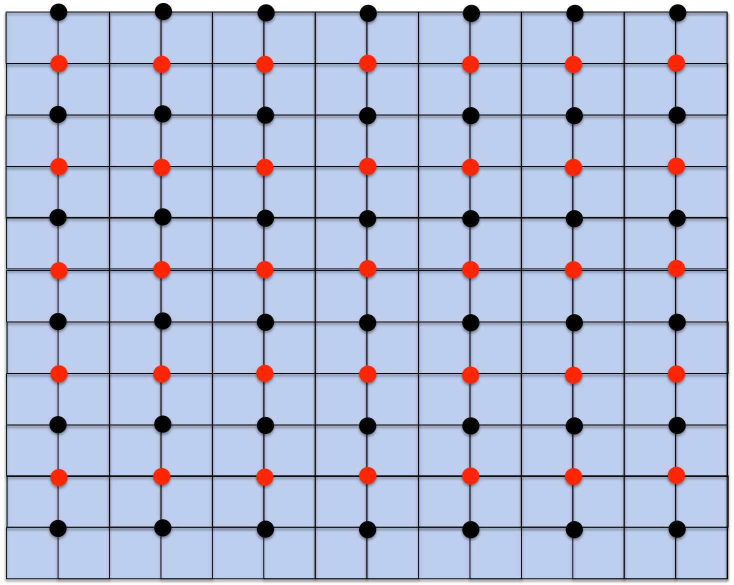
- Pitch in optical lattice allows access for calibration systems through corners
- Utilized for both radioactive source and optical calibration systems
- Both systems deployed through Teflon tubes to be scintillator compatible
  - Source calibration uses 3/8” Teflon tube
  - Optical calibration uses 10 gauge Teflon tube





½” ID Calibration Channel

Optical Lattice with Calibration Channels



● Optical Calibration Channel ● Source Calibration Channel

# Backup: detector performance

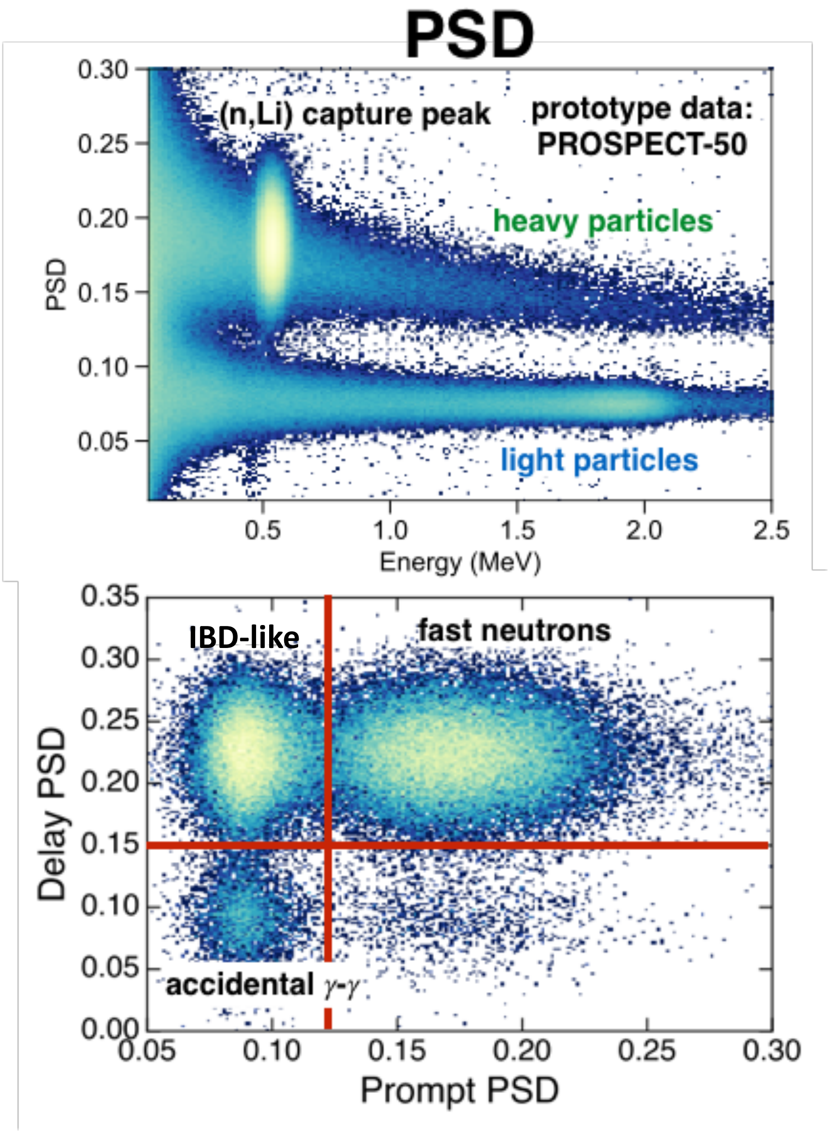
**Challenge: detect inverse beta decays (IBDs) with minimal overburden, cosmogenic and reactor backgrounds**

**Solution: segmented detector**

- ~4 ton $^{6}$Li-loaded liquid scintillator detector
- 154 (25 liter) optical segments
- double-ended PMT readout
- calibration access between segments
- novel shield to reduce neutron spallation

**with active background suppression**

- energy resolution 4.5% @ 1MeV
- pulse shape discrimination (PSD) + $^{6}$Li for particle identification
- segments = topology, fiducialization



# Backup: fiducialization, PSD and topology

**Time Topology**

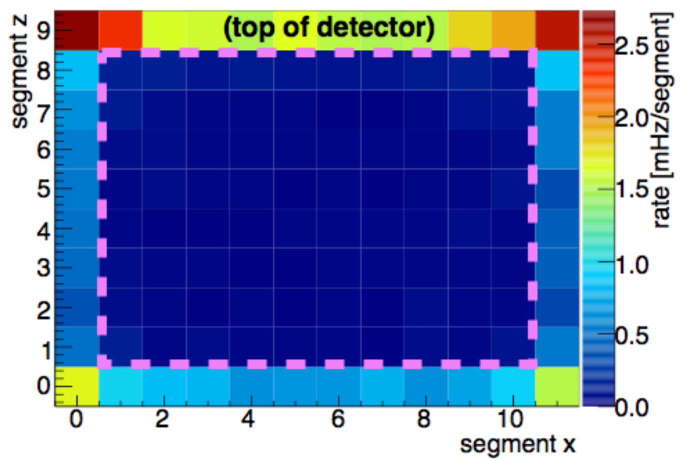
- Prompt gamma-like event followed by neutron capture within 120 $\mu s$
- Isolated from other neutron recoils or captures by $\pm 200\ \mu s$
- Veto $\pm 100\ \mu s$ around muons

**Spatial Topology**

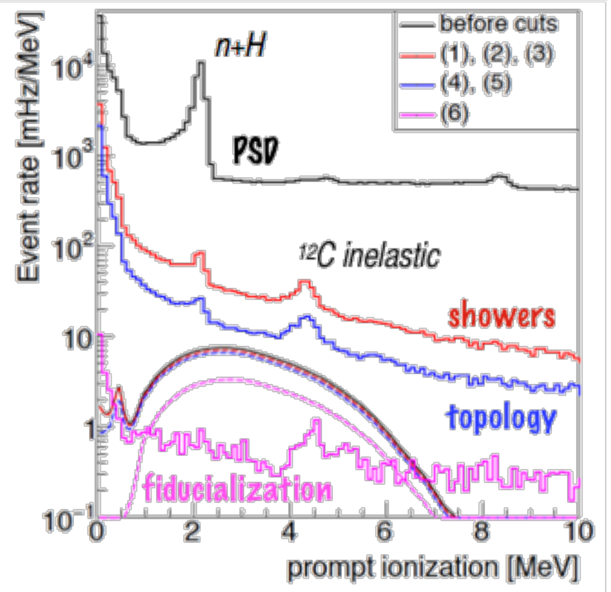
- Prompt and delayed signals proximate
- Prompt-delayed events outside fiducial volume not used (partial energy deposition reduces background rejection)

No single cut isolates IBD events, yet sequence of cuts leveraging spatial and timing characteristics of an IBD yields > 3 orders of magnitude background suppression and an expected signal to background of > 1:1.

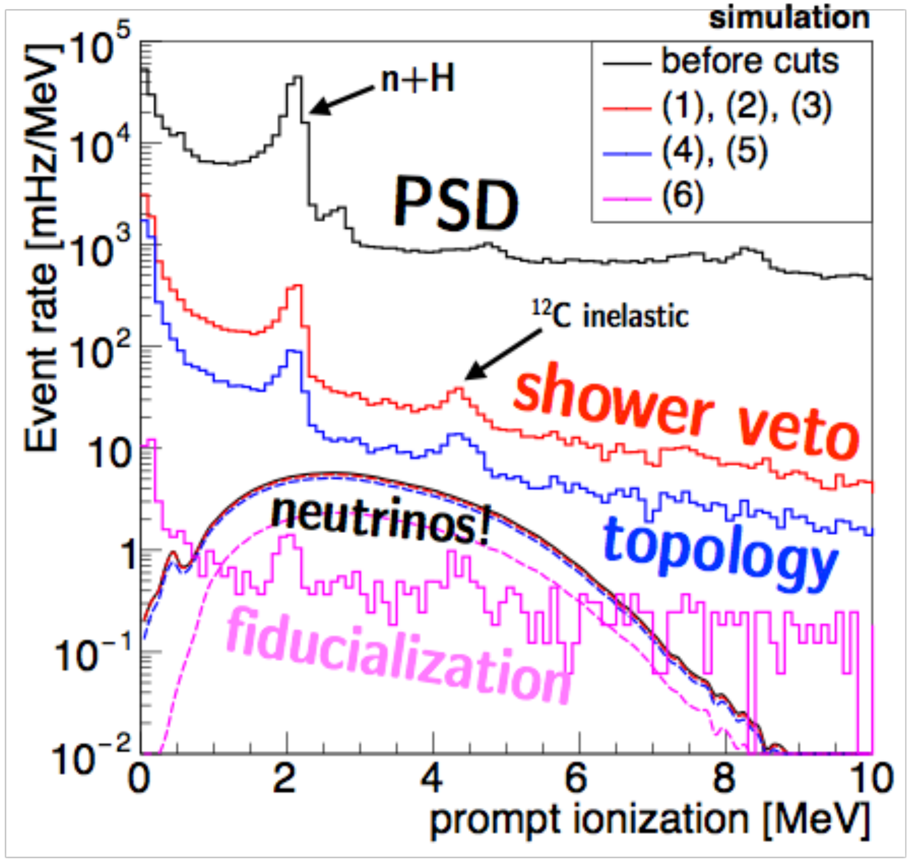
fiducialization

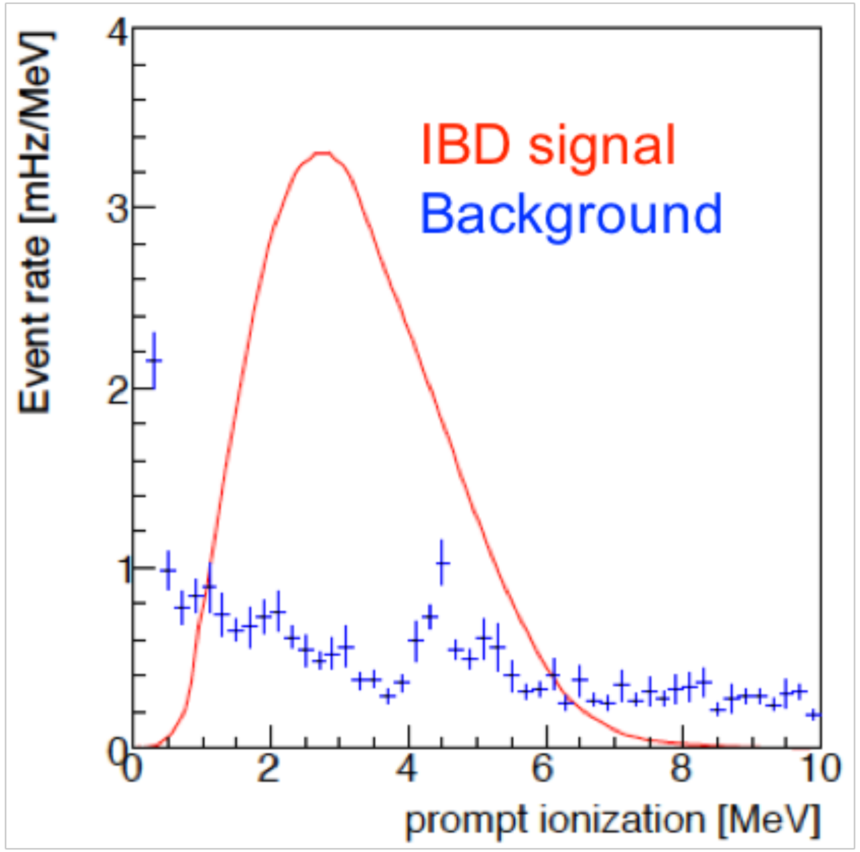



simulation



# Backup: cuts and expected rates




- MC benchmarked by detector prototype data from HFIR site
- cosmogenic backgrounds (solid) and signal (dashed) per cut selection