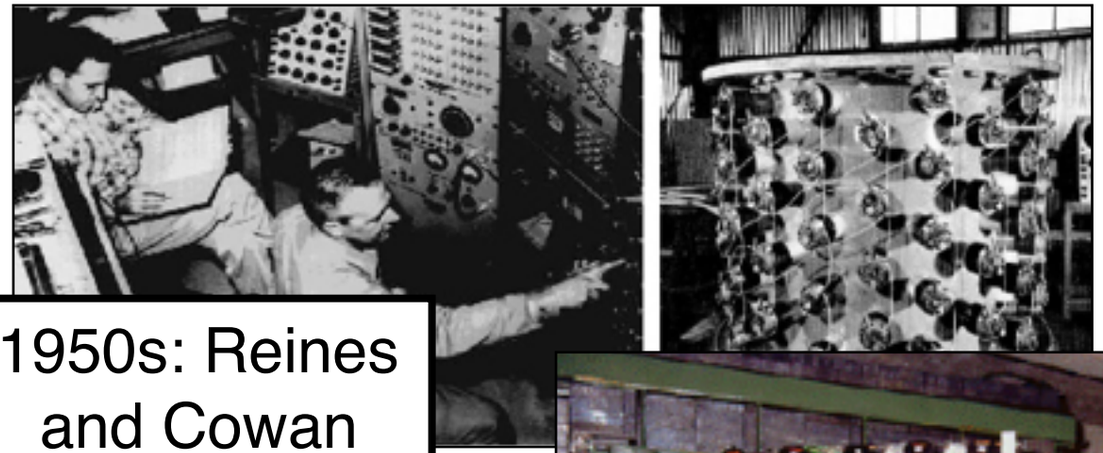
PROSPECT

A reactor oscillation and spectrum experiment at HFIR

T.J. Langford
on behalf of the PROSPECT Collaboration

July 30, 2016

Reactors: Tools for discovery

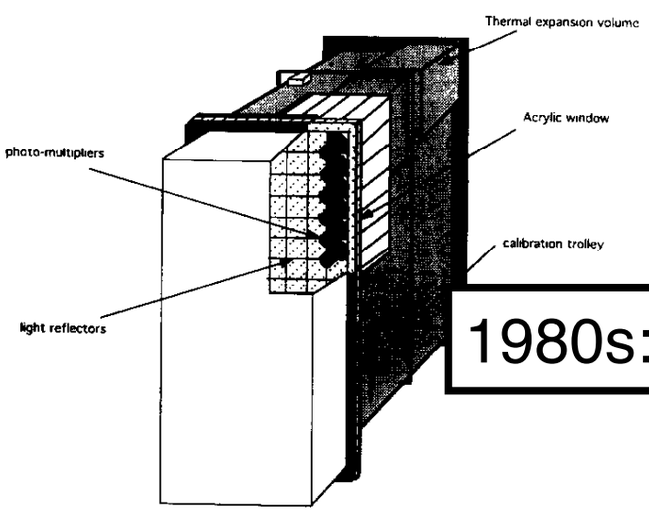


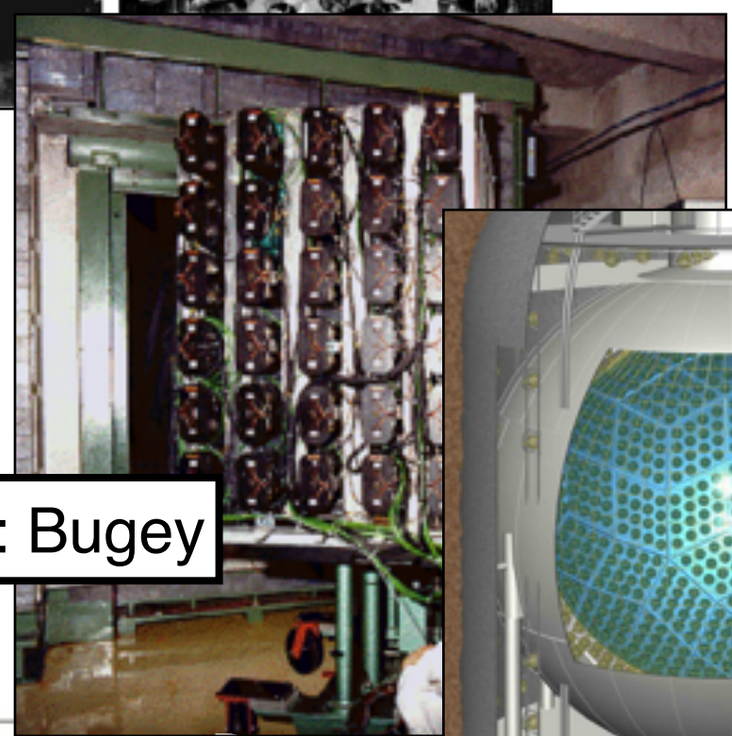
1950s: Reines and Cowan

20 July 1956, Volume 124, Number 3212 **SCIENCE**

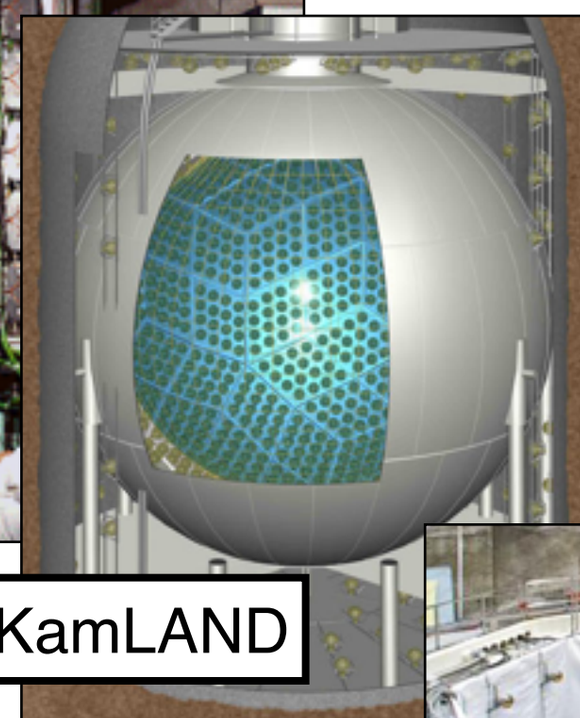
Detection of the Free Neutrino: a Confirmation

C. L. Cowan, Jr., F. Reines, F. B. Harrison, H. W. Kruse, A. D. McGuire

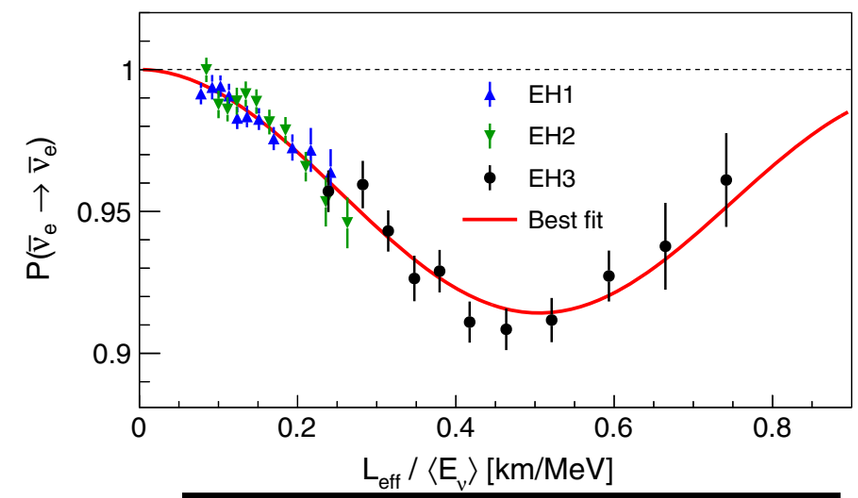




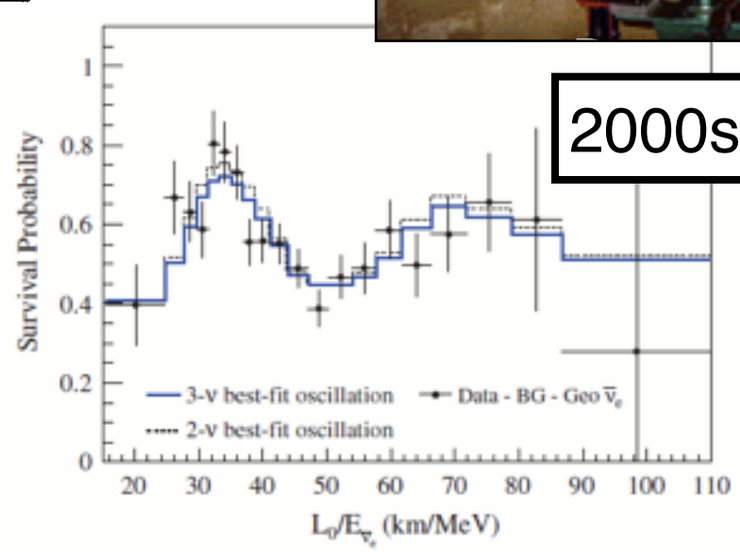
1980s: Bugey

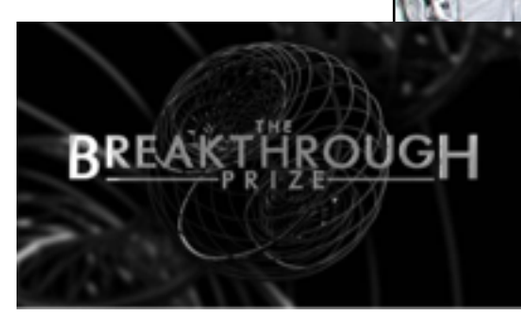


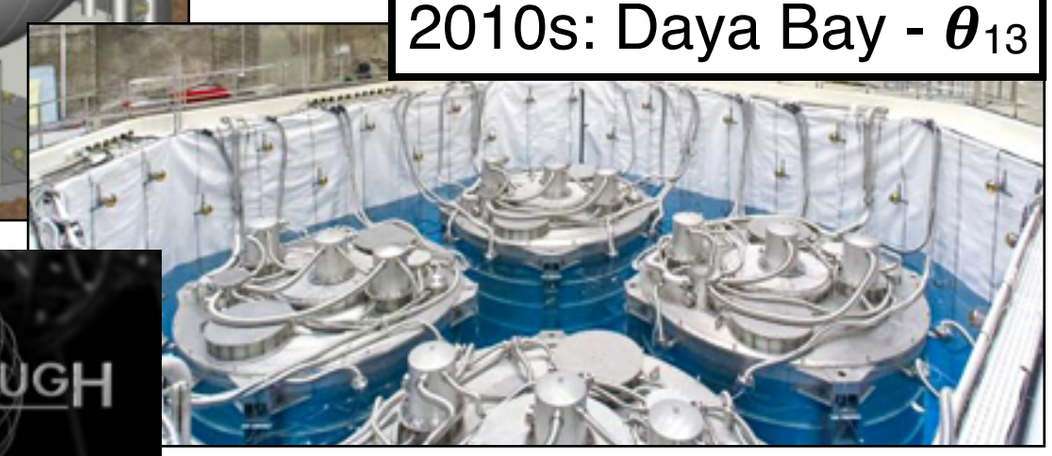
2000s: KamLAND



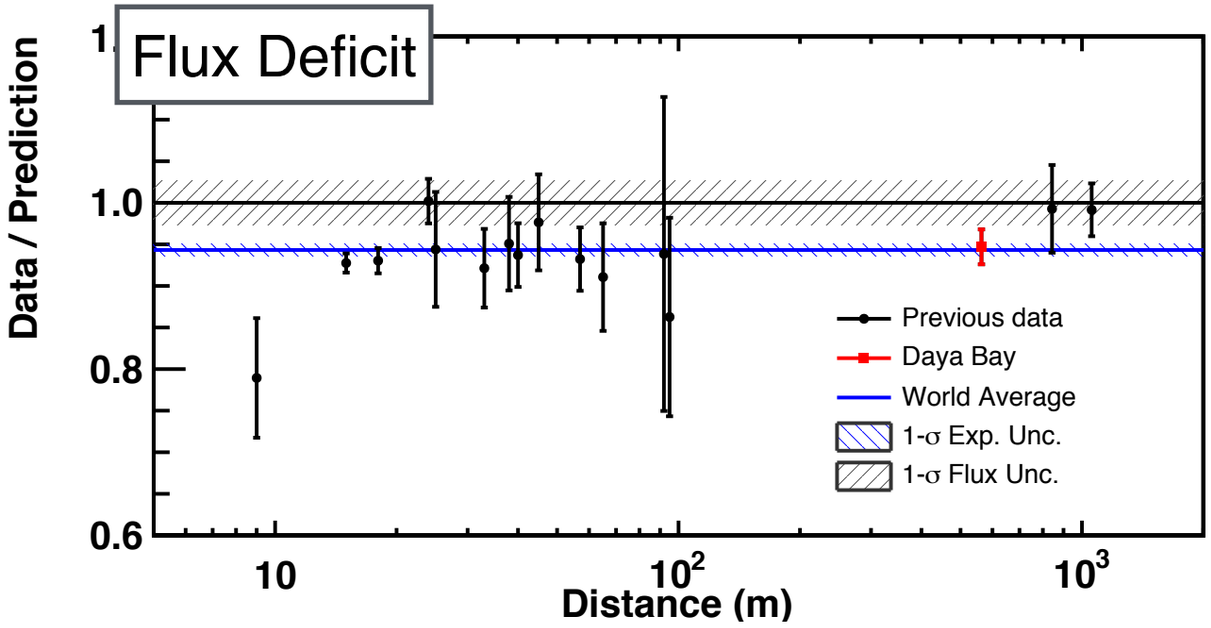
2010s: Daya Bay - θ_{13}

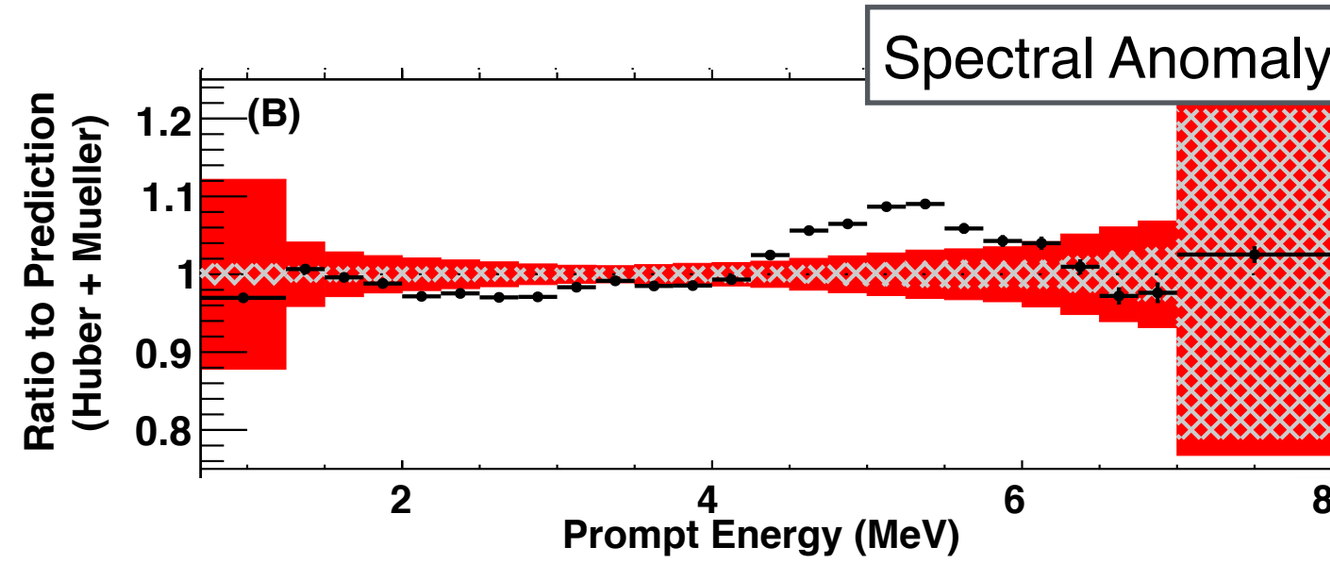




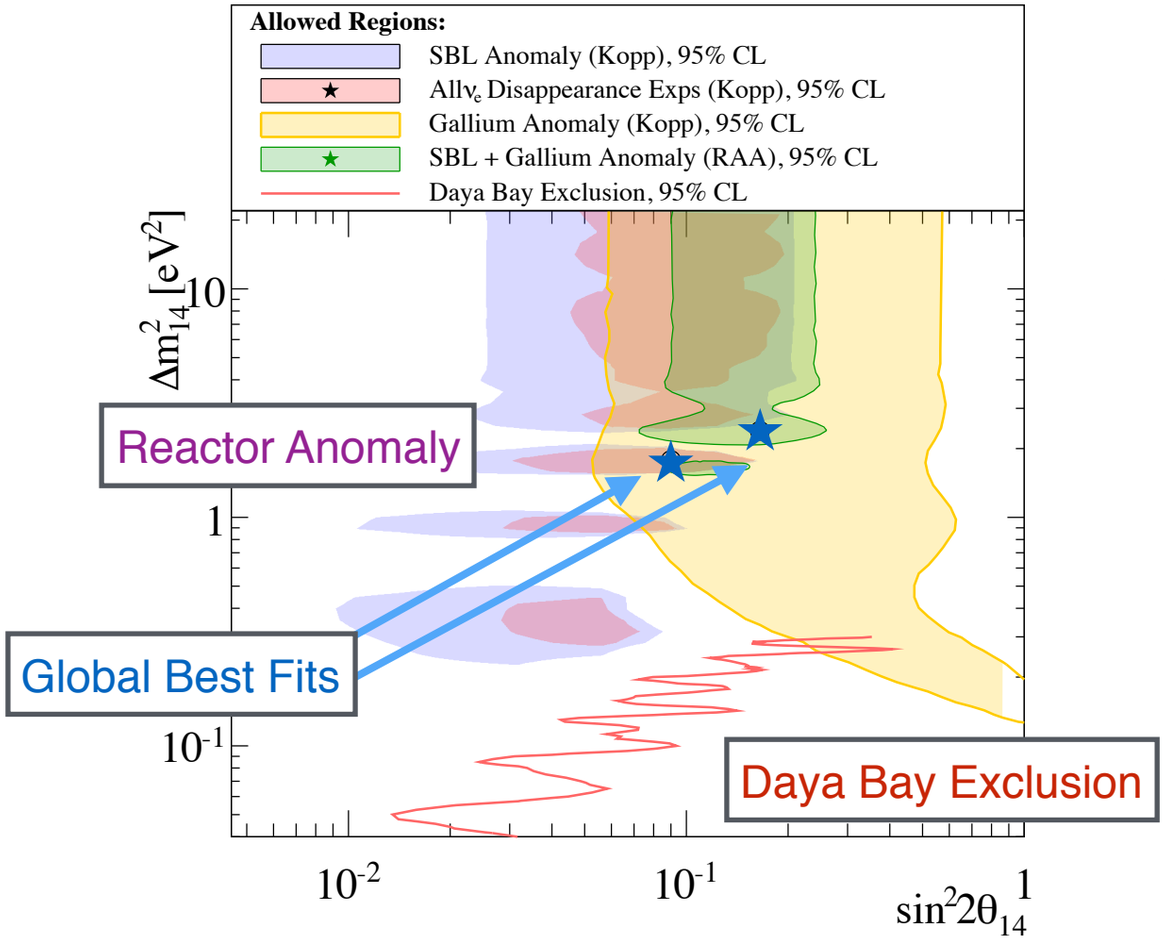


Reactor Anti-Neutrino Anomalies





Daya Bay - arXiv:1607.05378



- Flux deficit remains after blinded analysis
- Spectral anomaly questions validity of models
- **We need new data**
- Spectral anomaly could point where to look
  - All $\boldsymbol{\theta}_{13}$ measurements at LEU power reactors
  - Model-independent searches are key
  - *HEU measurement powerful input to spectral anomaly*

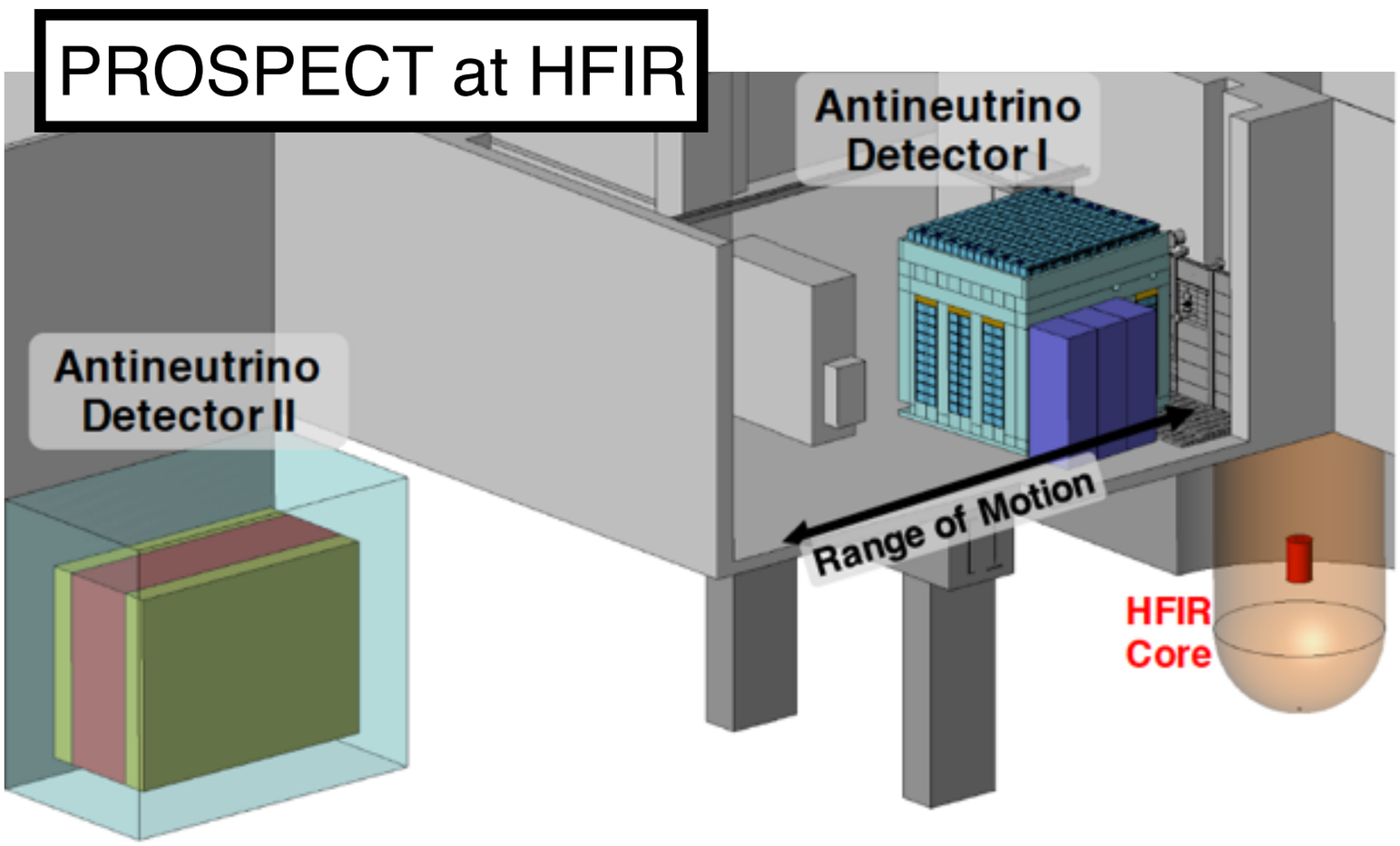
PROSPECT

The Precision Reactor Oscillation and Spectrum Experiment

Phased Experimental Plan

Physics Goals:

- Search for short baseline $\overline{\nu}_e$ oscillations using detector segmentation
  - Distortions in energy spectrum that vary with baseline
  - Independent of reactor model predictions
- Measure ^{235}U antineutrino spectrum to resolve the spectral anomaly



Experimental Strategy:

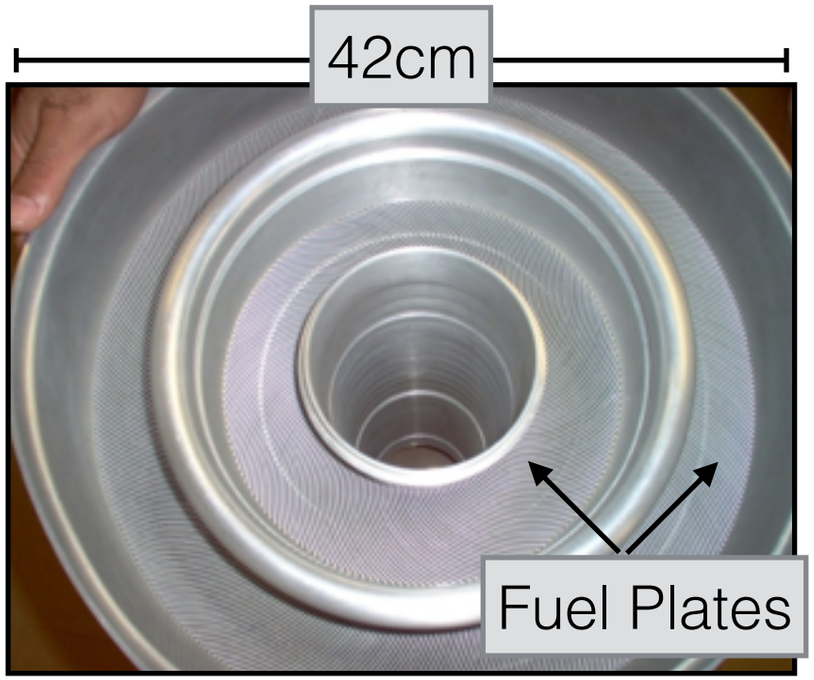
- **Phase 1:**
  - Sterile neutrino search, cover best fit region at 4σ in 1 year
  - World-leading ^{235}U spectrum with ~100k events/year
- **Phase 2:** Detailed investigation of oscillation if evidence for steriles

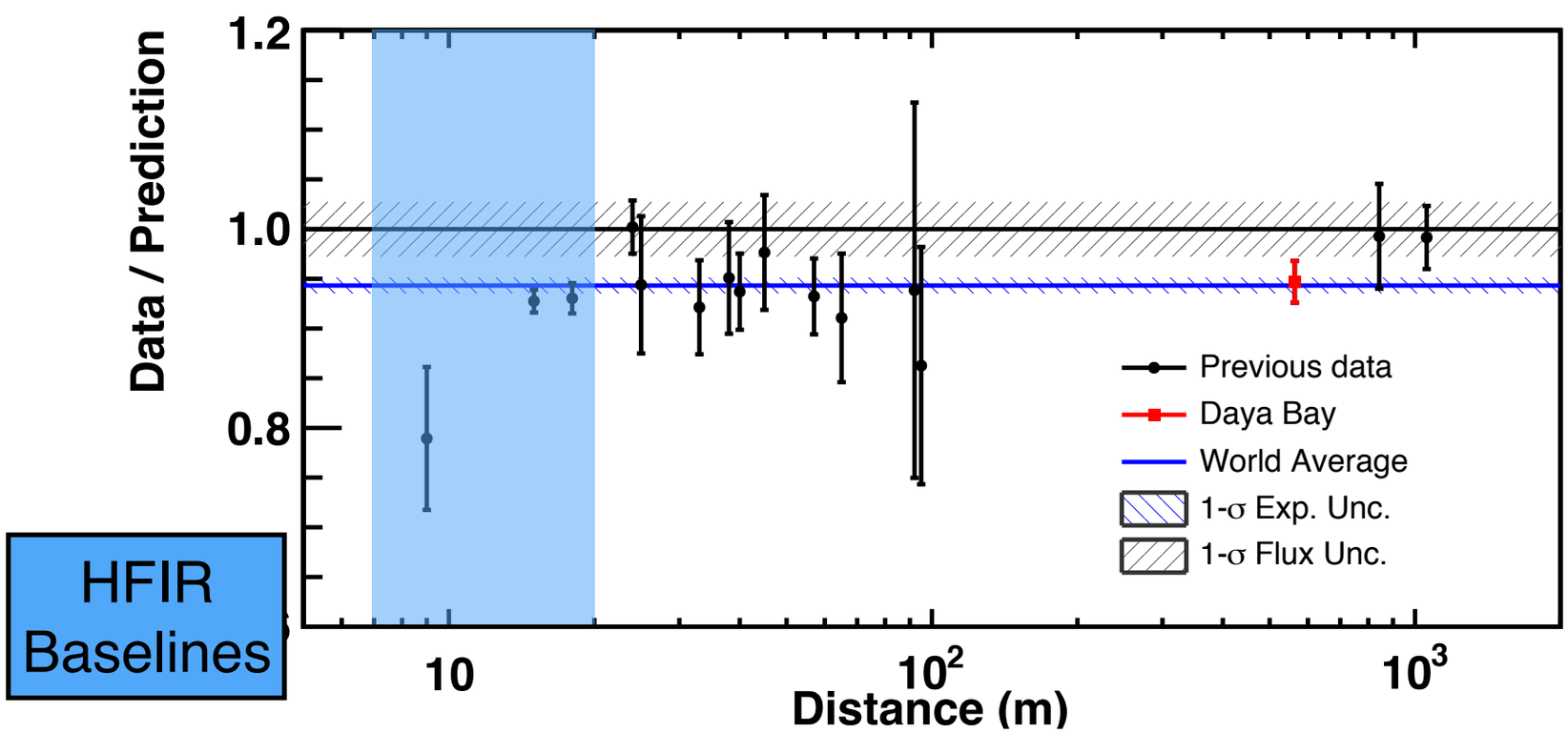
Challenges:

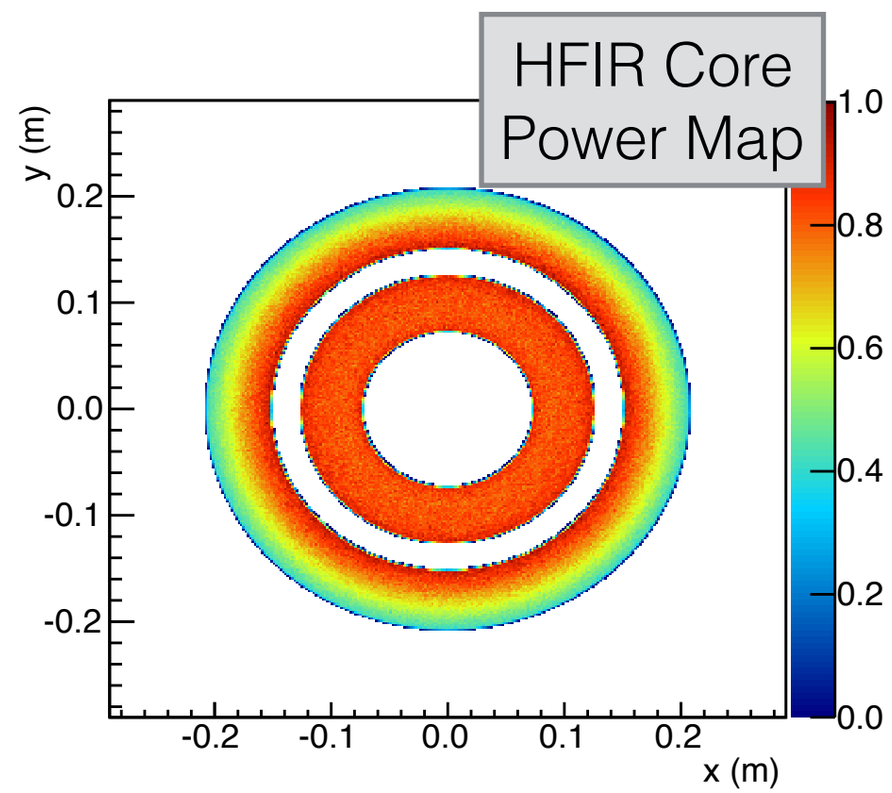
- Minimal overburden, cosmogenic backgrounds
- Reactor-related backgrounds
  - High energy (≲10MeV) gammas

HFIR Research Reactor

- High Flux Isotope Reactor at Oak Ridge National Lab
- 85MW HEU compact-core reactor, 42% uptime
- PROSPECT activity for past 3 yrs
- Backgrounds fully characterized
- Unique location for a short baseline experiment





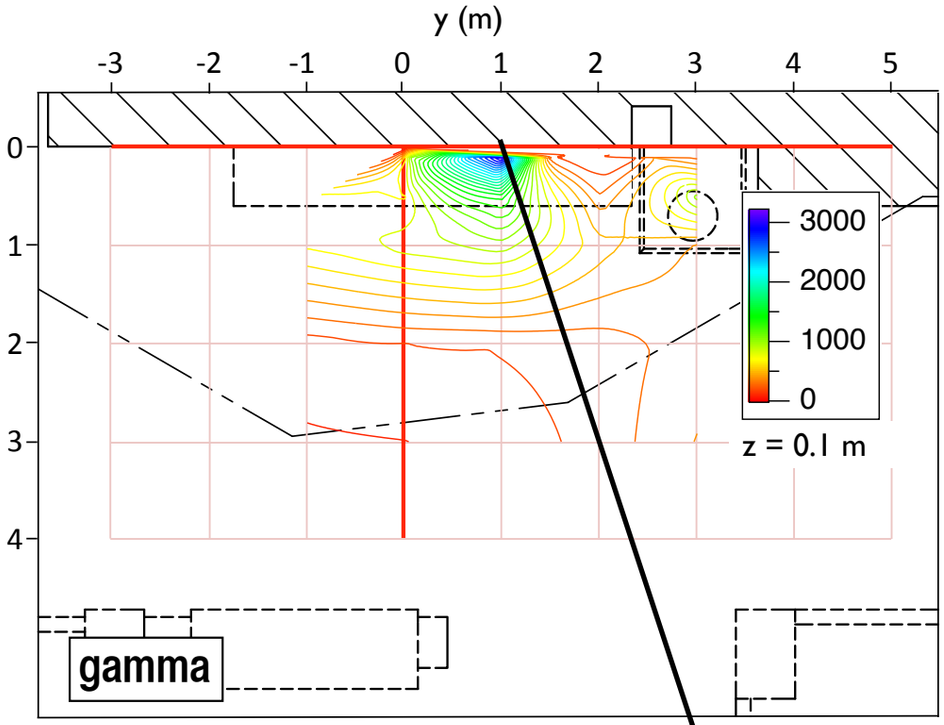


Surface Neutrino Detection

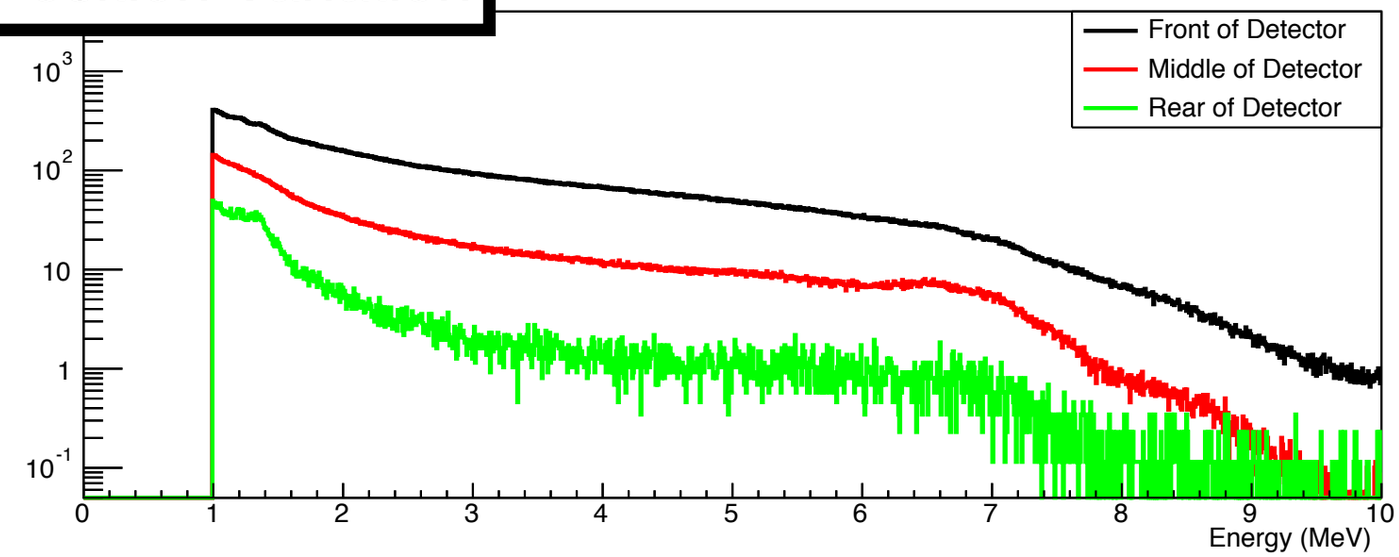
Must be very close to research reactor

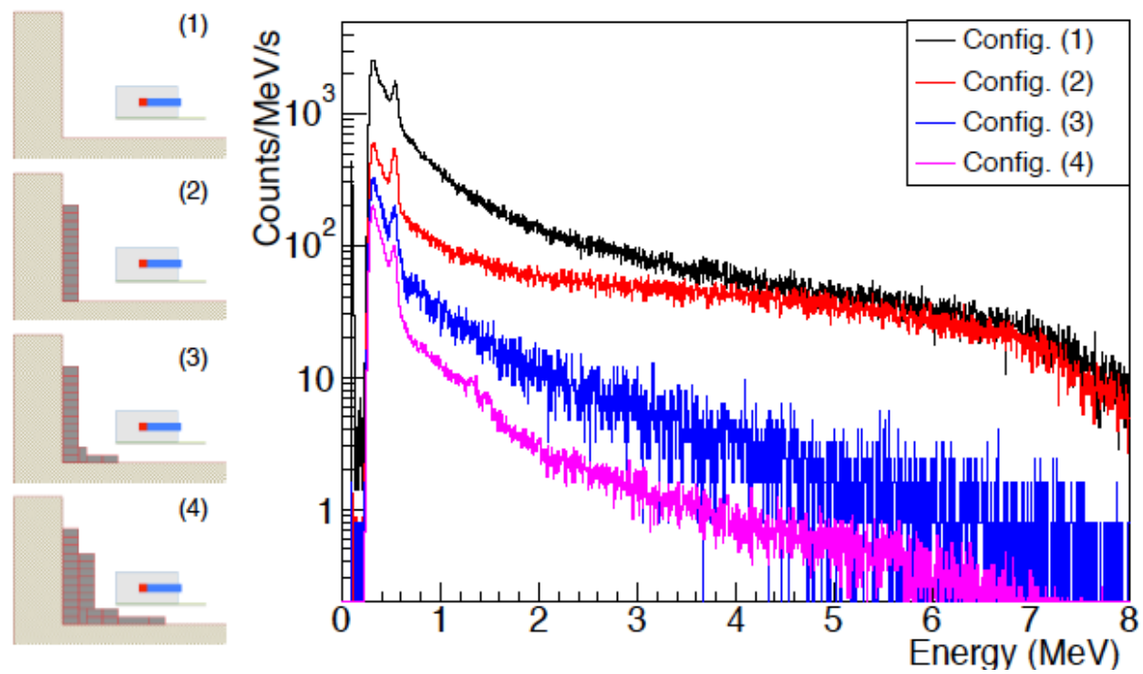
- Reactor-related backgrounds (gammas and thermal n)
- Detector will have to operate at the surface (or close to it)
- *Cosmic-rays are primary source of backgrounds*

Reactor Backgrounds



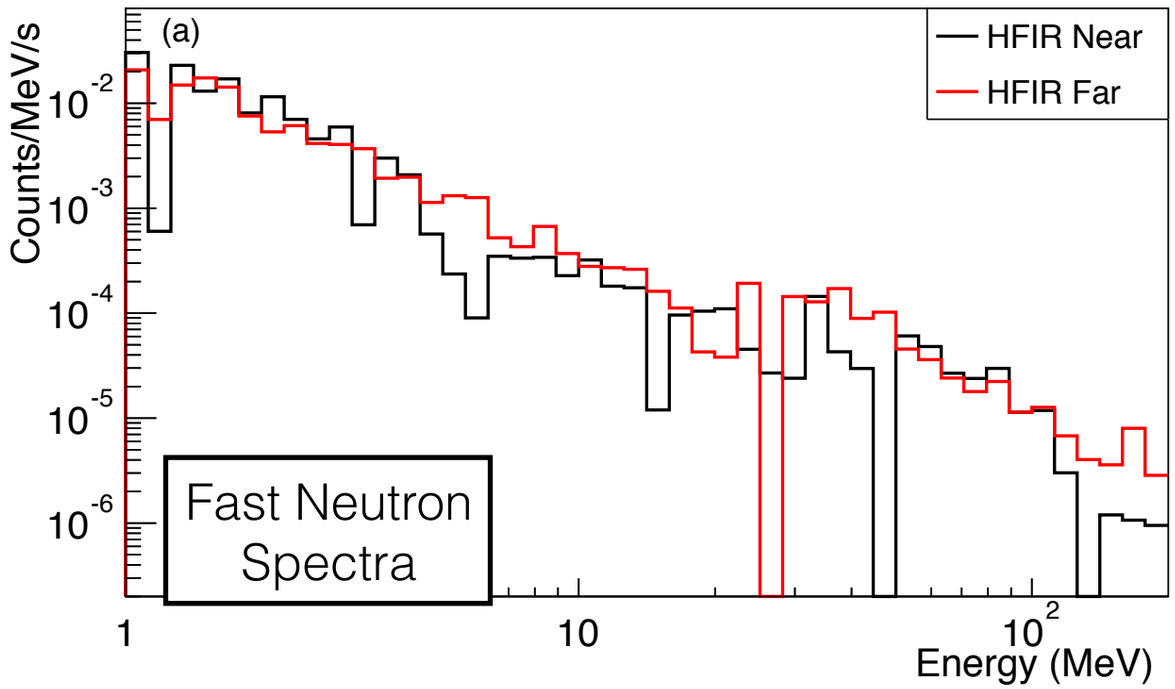
Position Variation

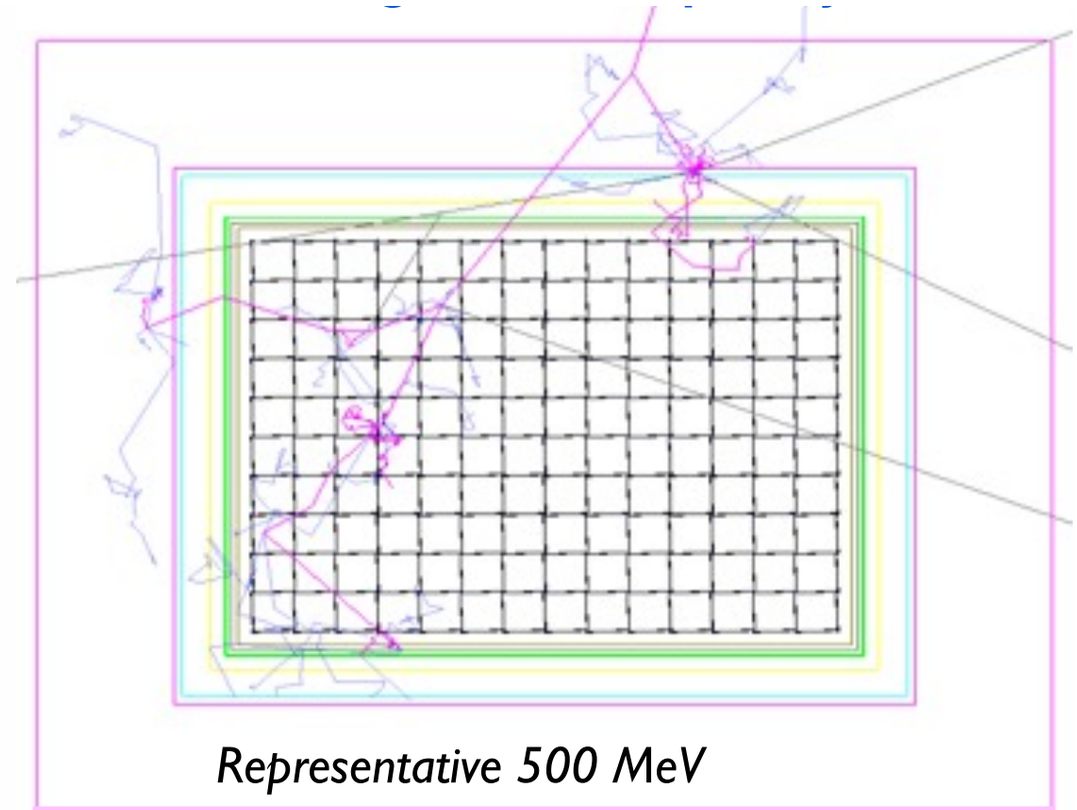




Targeted shielding effectively reduced gamma backgrounds

Cosmogenic Backgrounds





Neutron spectrometer at HFIR

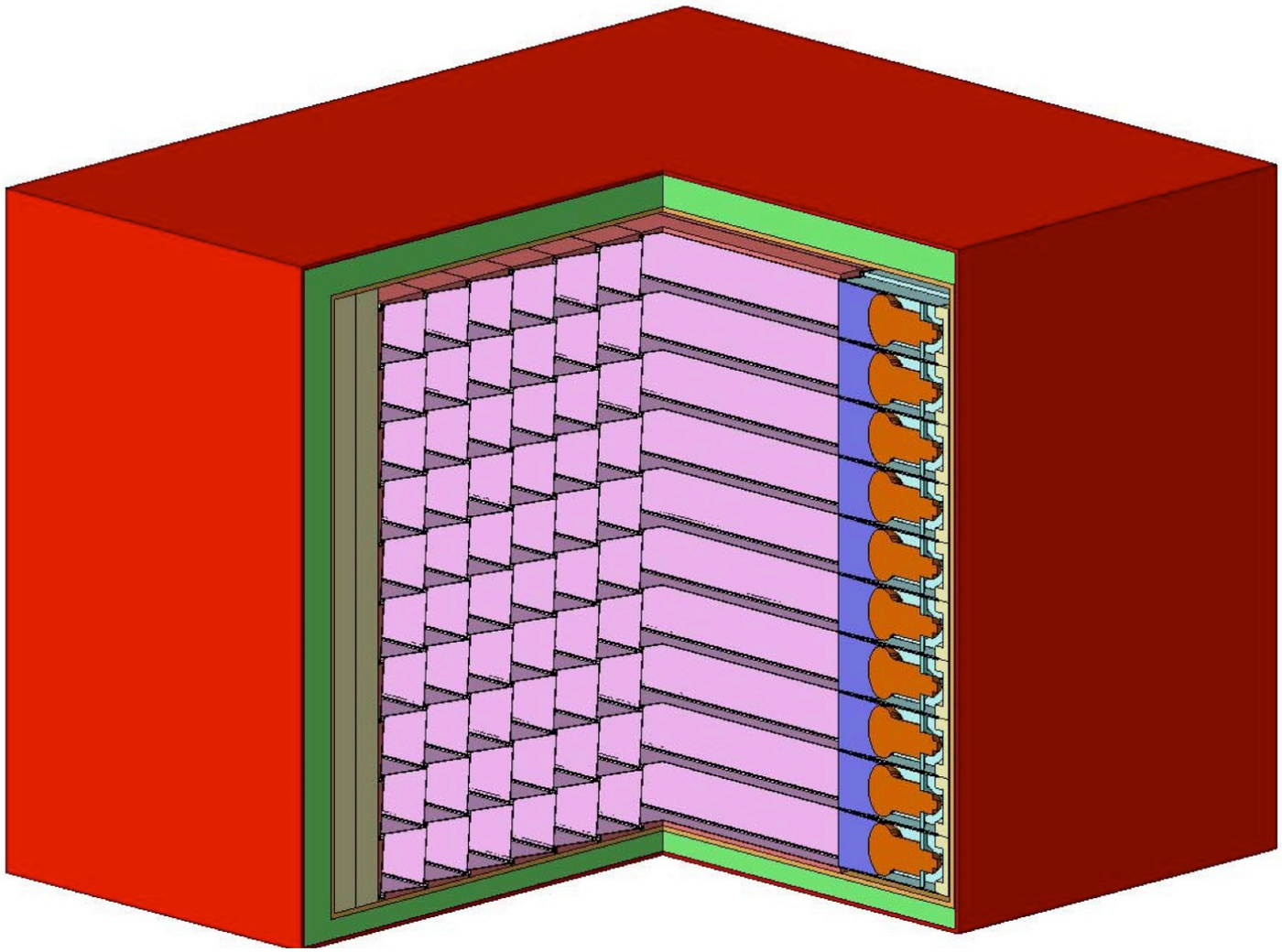
- <10MeV neutrons can be effectively shielded with hydrogenous material
- >100MeV neutrons create showers of particles and many secondary neutrons
- IBD-like backgrounds stem mainly from fast neutron interactions

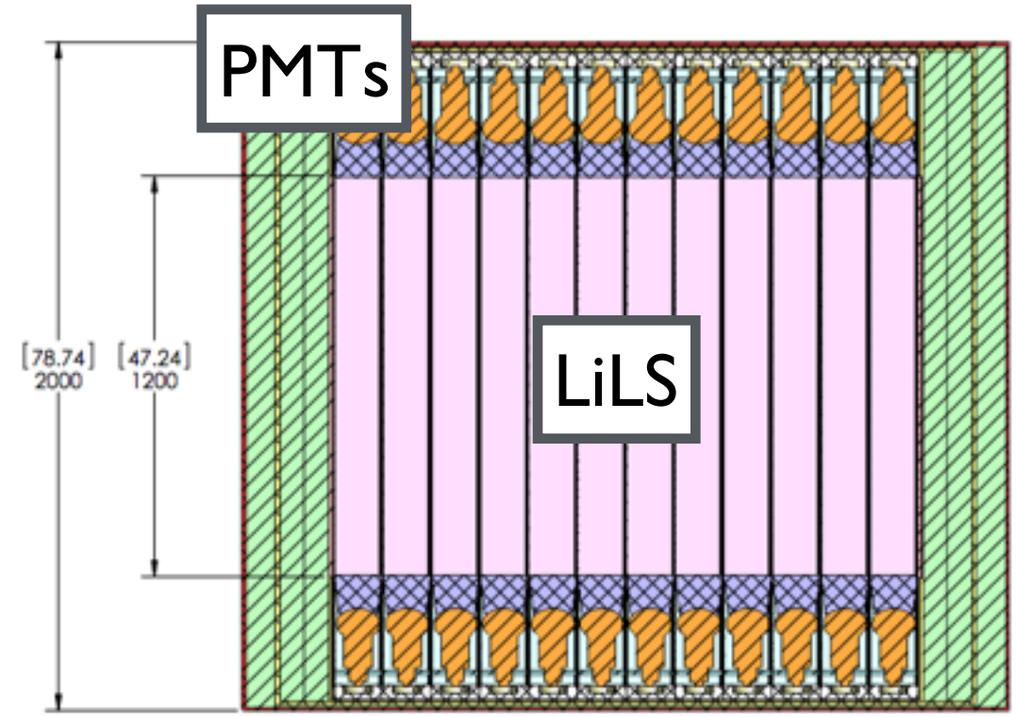
Surface Neutrino Detection

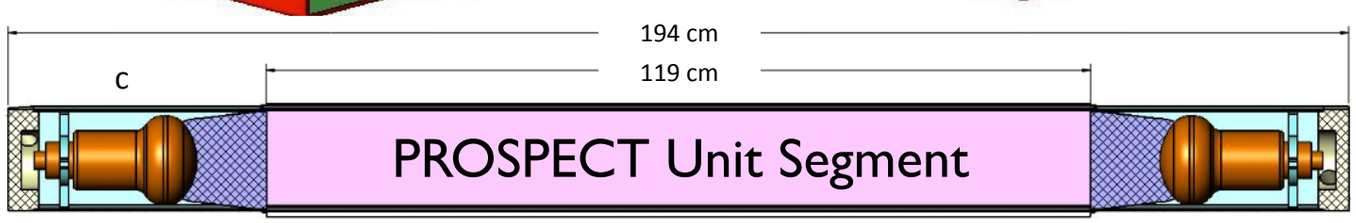
Three-pronged effort to address these backgrounds:

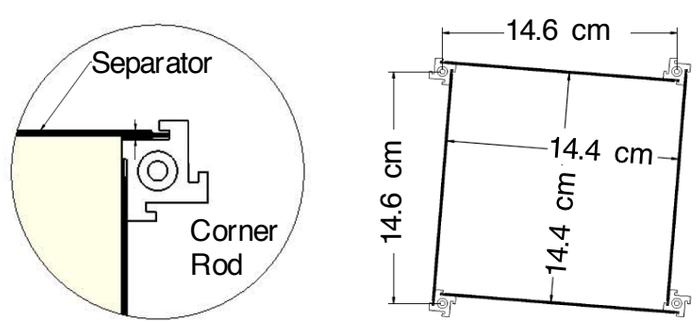
1. New detector design
2. New liquid scintillator
3. New shielding design

Segmented Antineutrino Detector



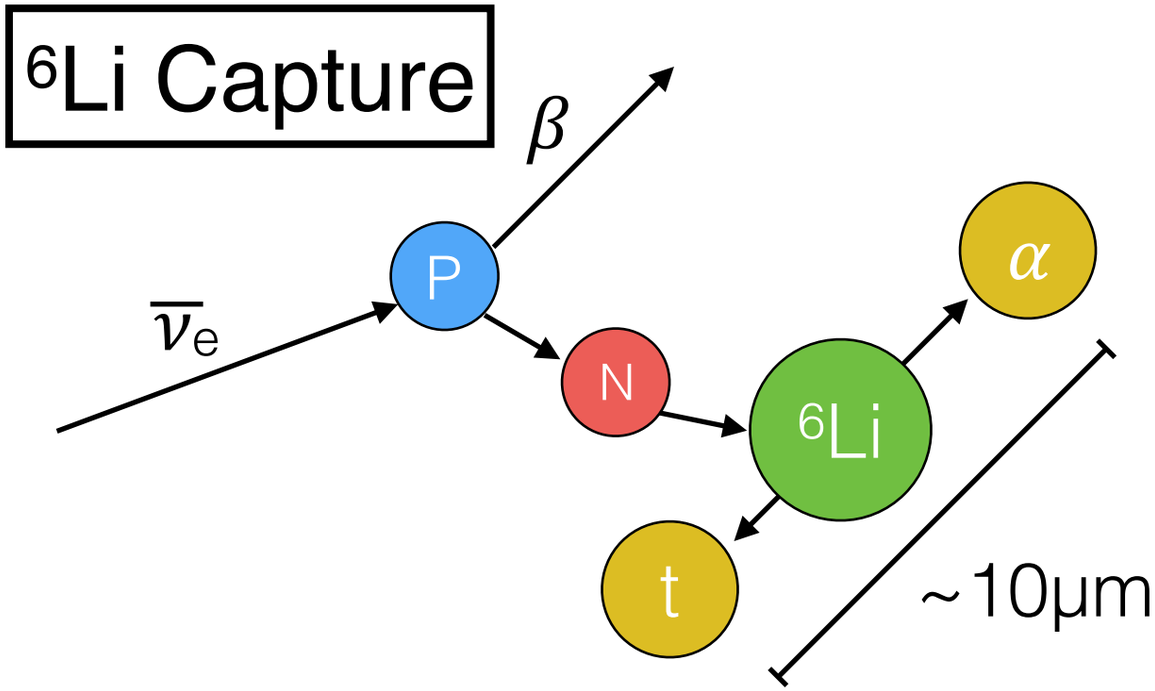






- 3ton lithium-loaded liquid scintillator (^{6}LiLS) detector
- 120 optical segments
  - 15x15x119cm^3, ~25 liters each
  - **Identify multiple particle interactions, reject showers**
- Double-ended PMT readout
- Access for calibration sources between every cell

^{6}Li-loaded Liquid Scintillator

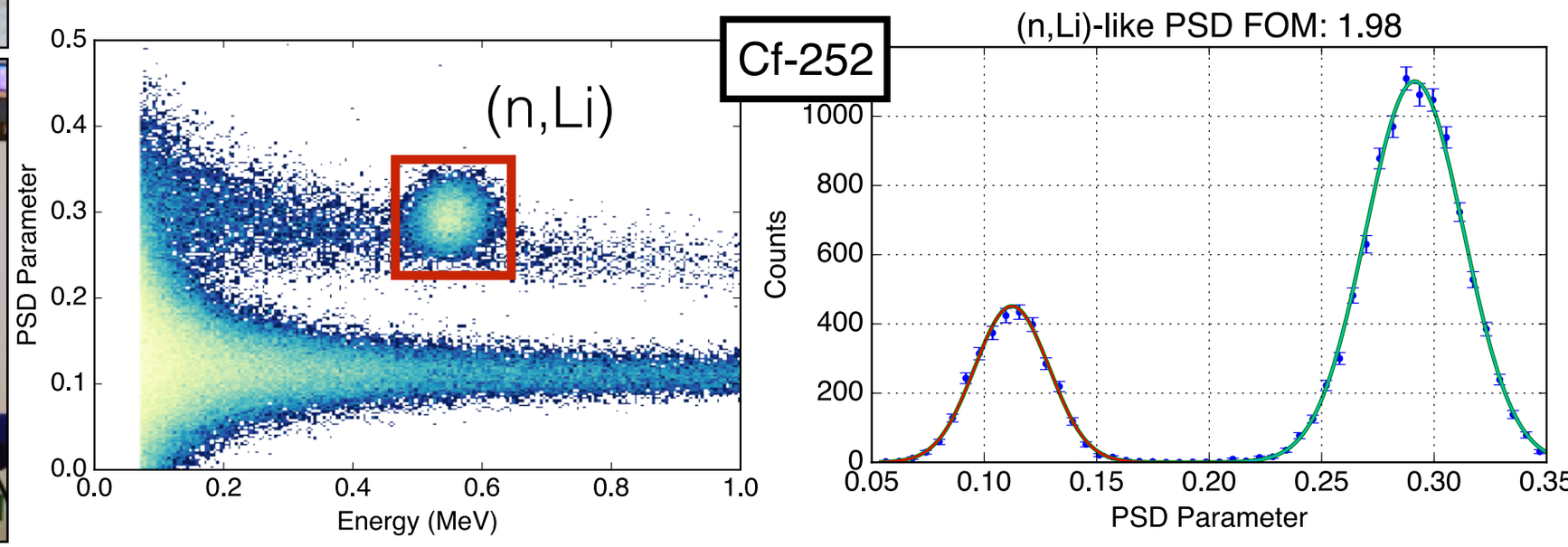


LiLS Requirements:

- High light yield (>6000ph/MeV) for energy resolution
- Excellent pulse-shape discrimination (PSD)
- Non-toxic, high flashpoint
- Stable and affordable

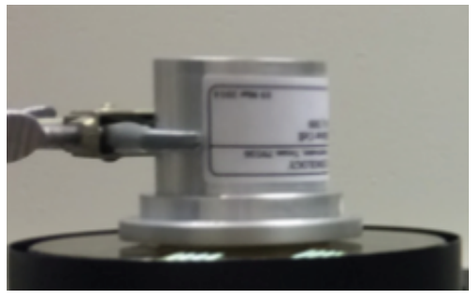
LiLS based on EJ-309 meets all requirements

- 8200ph/MeV, excellent PSD
- **Safe to operate at a reactor site**



Phased Detector Development

PROSPECT-0.1
Aug 2014
Spring 2015



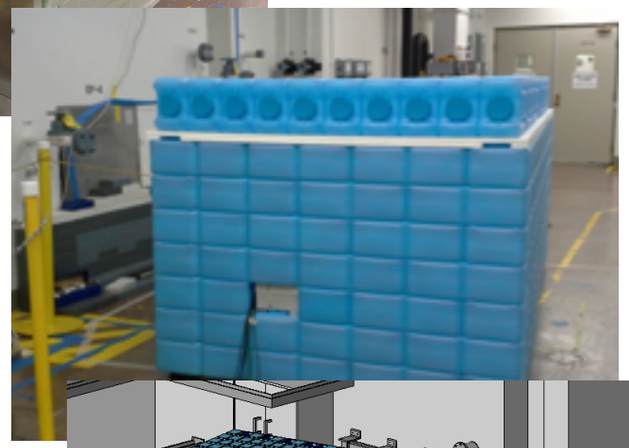
5cm
0.1liter
LS cell

PROSPECT-2
Dec 2014
Feb 2015

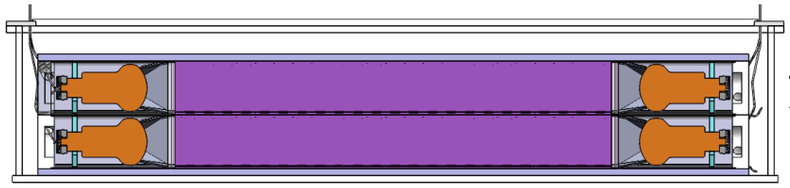
12.5cm
1.7 liter
LS cell

PROSPECT-20
March 2015

1m
23 liter
LS cell

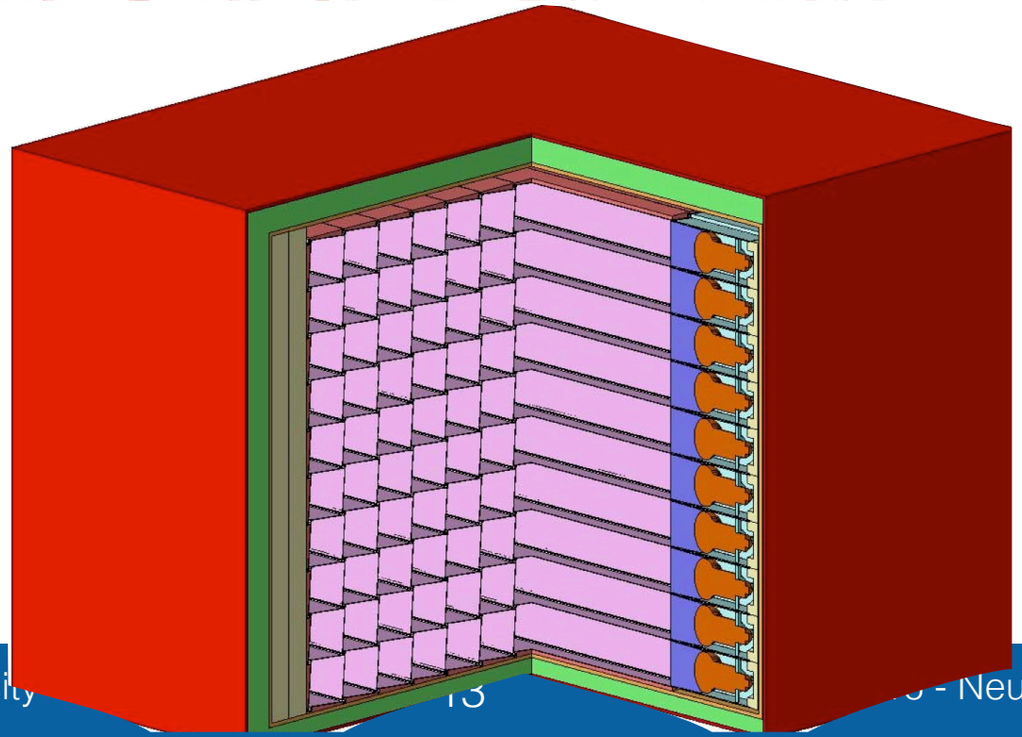


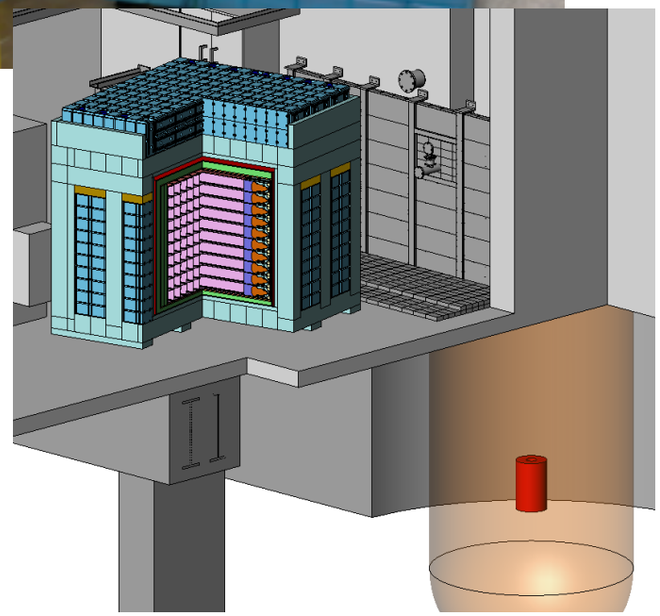
PROSPECT-50
March 2016



1.2m
2x25 liter
LS segments

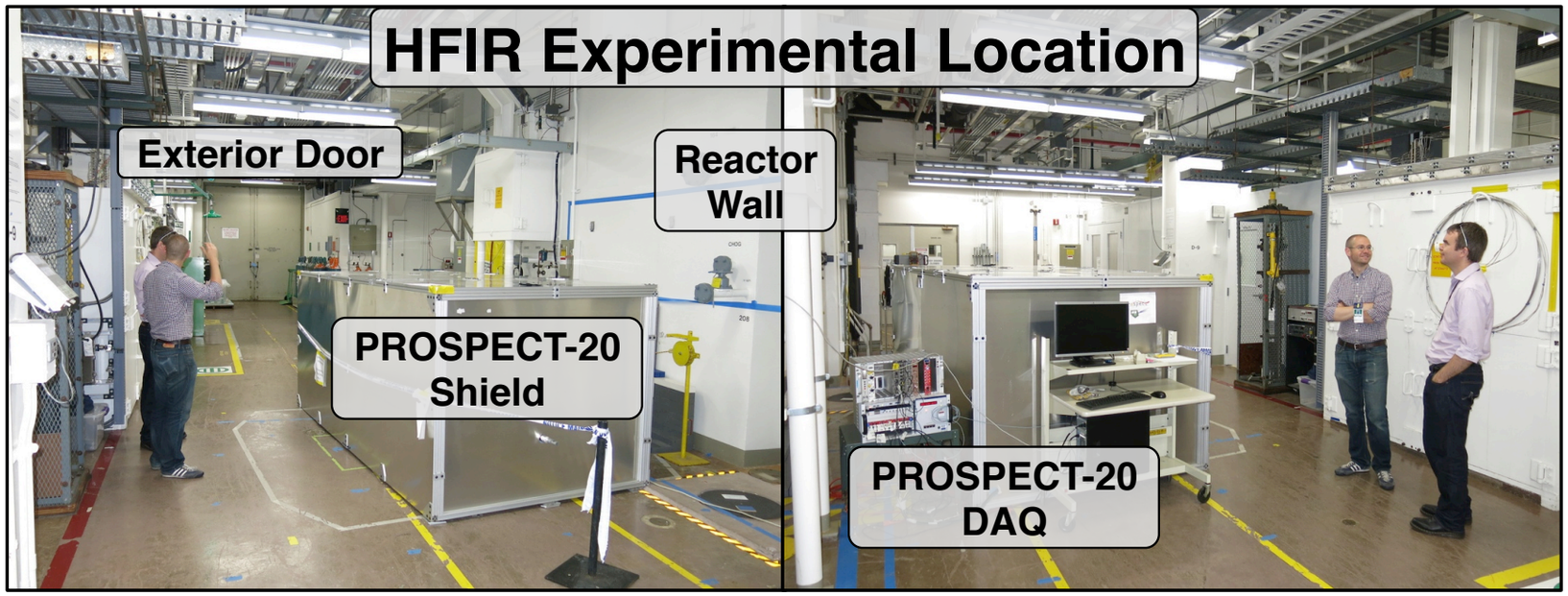
PROSPECT
Phase I
Early 2017

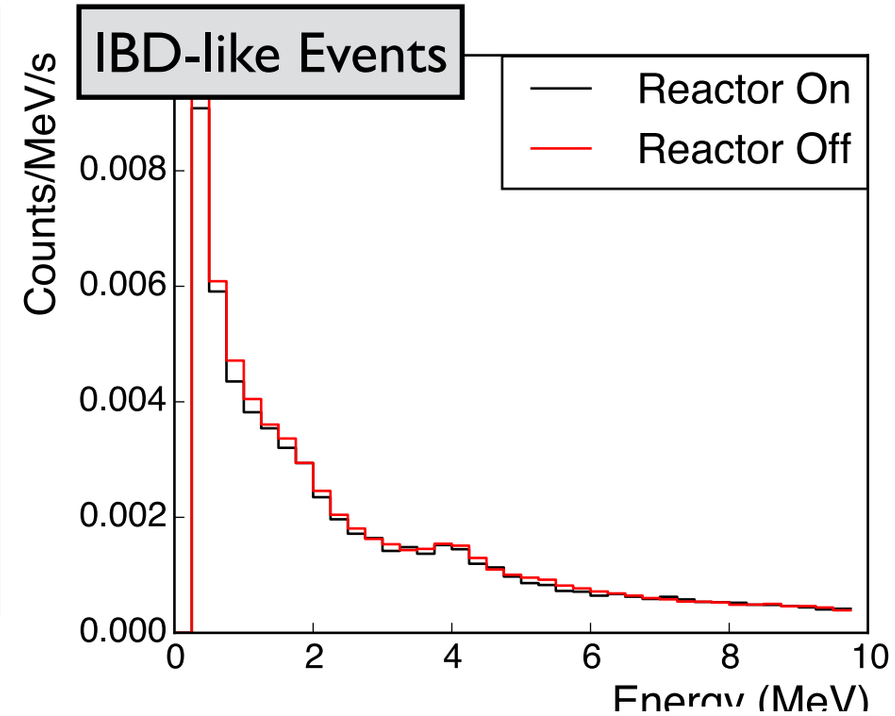




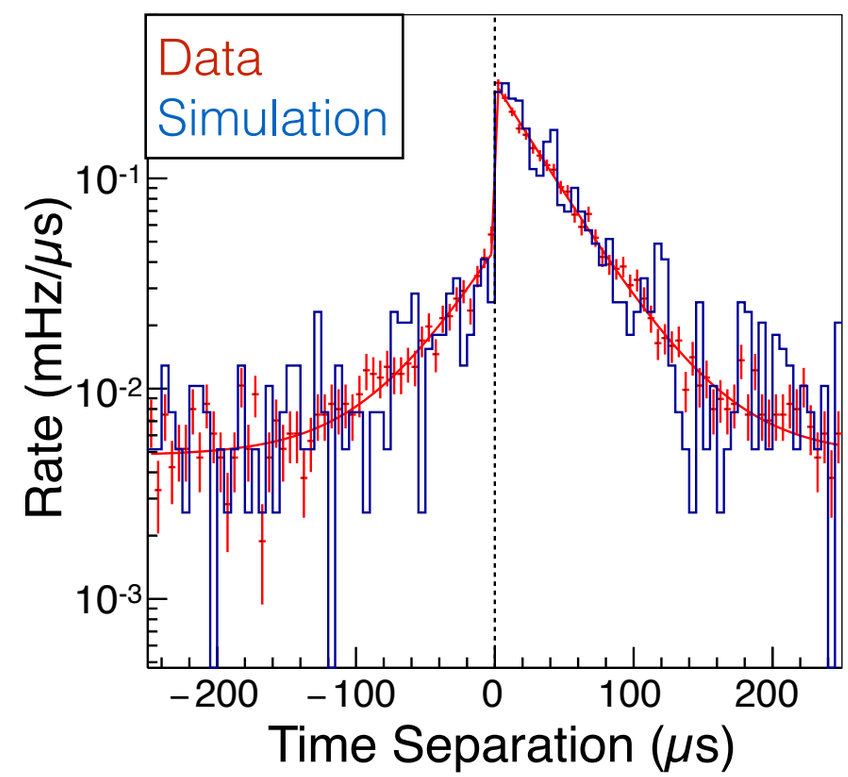
120x30 liter
LS segments
15x15x119cm

PROSPECT-20 at HFIR



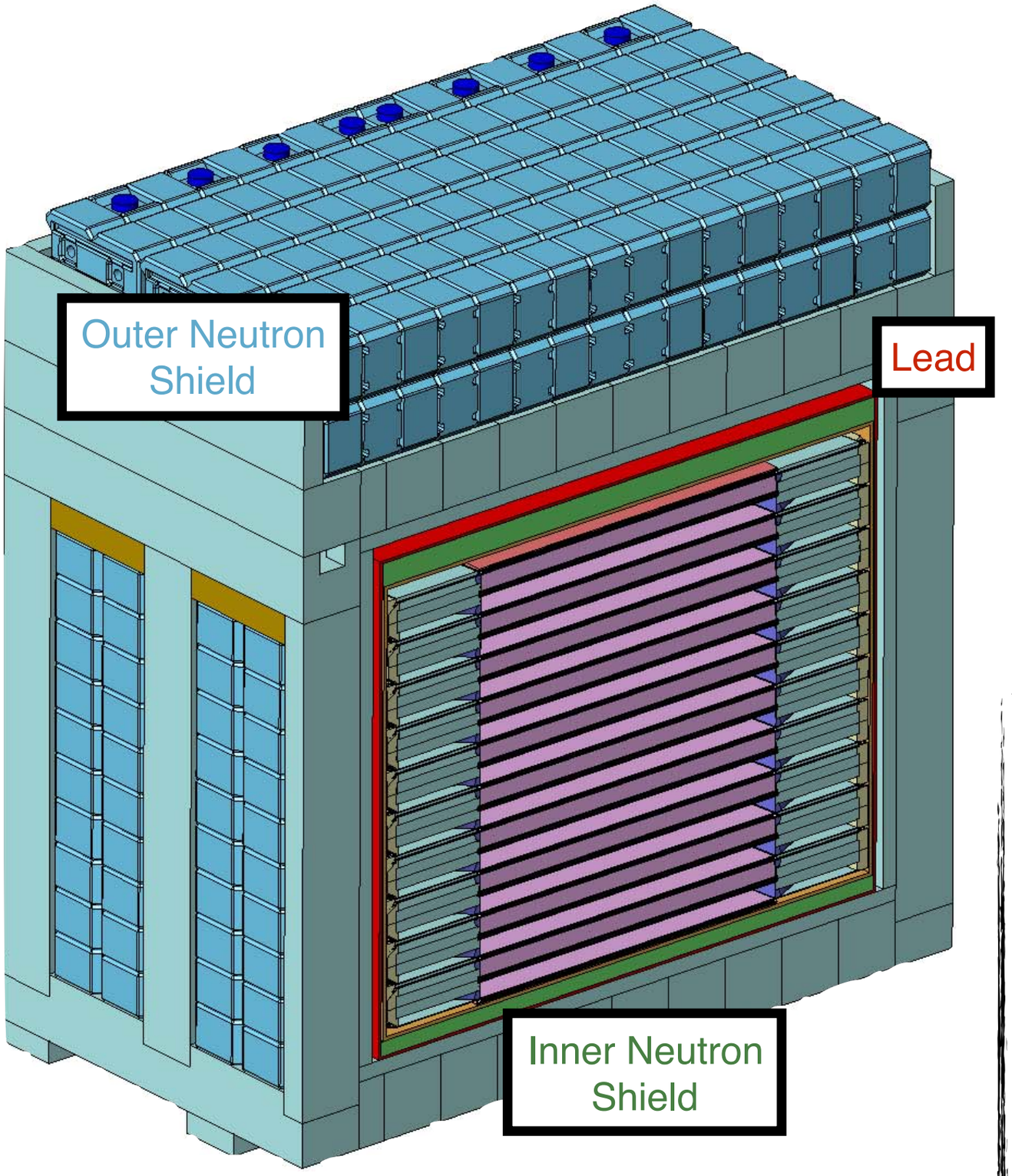


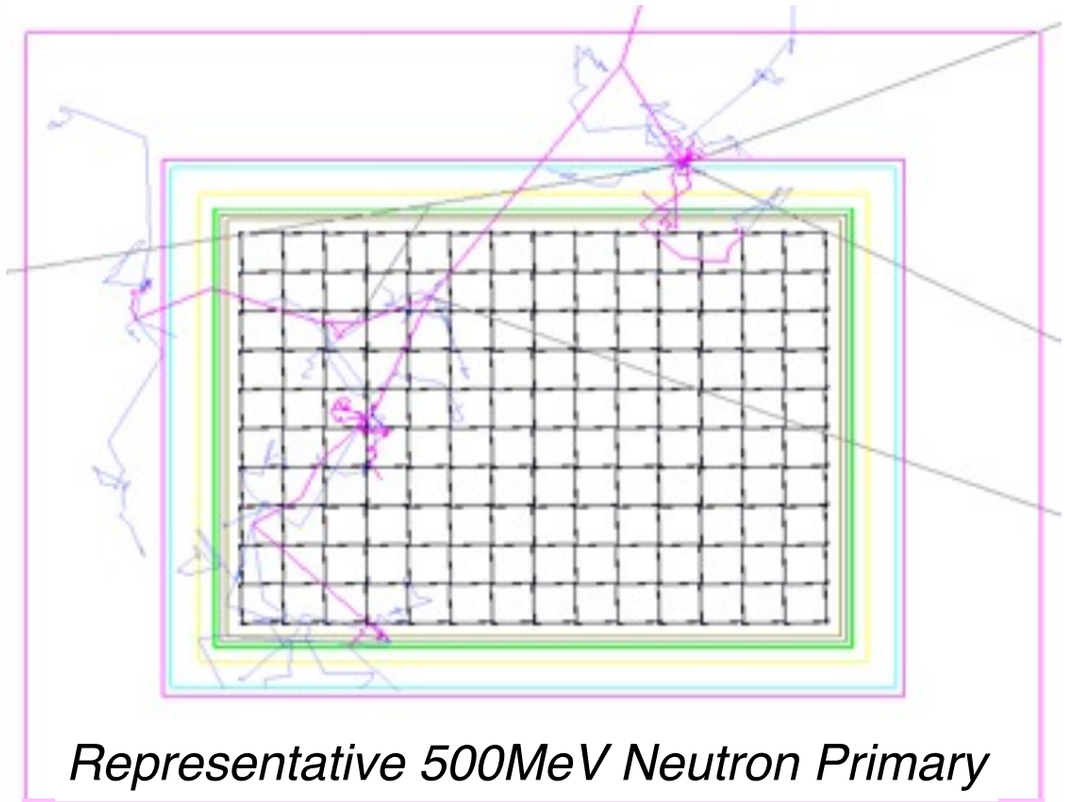
- Operated for four months at HFIR
  - Two HFIR cycles
- Shielding package roughly 25% mass of full shield
- Reactor-related backgrounds mitigated
  - Targeted local shielding
  - Active background rejection with LiLS
- **Validation of background simulations for full PROSPECT detector**



PROSPECT-20 Paper arXiv:1508.06575

Novel Shielding Design





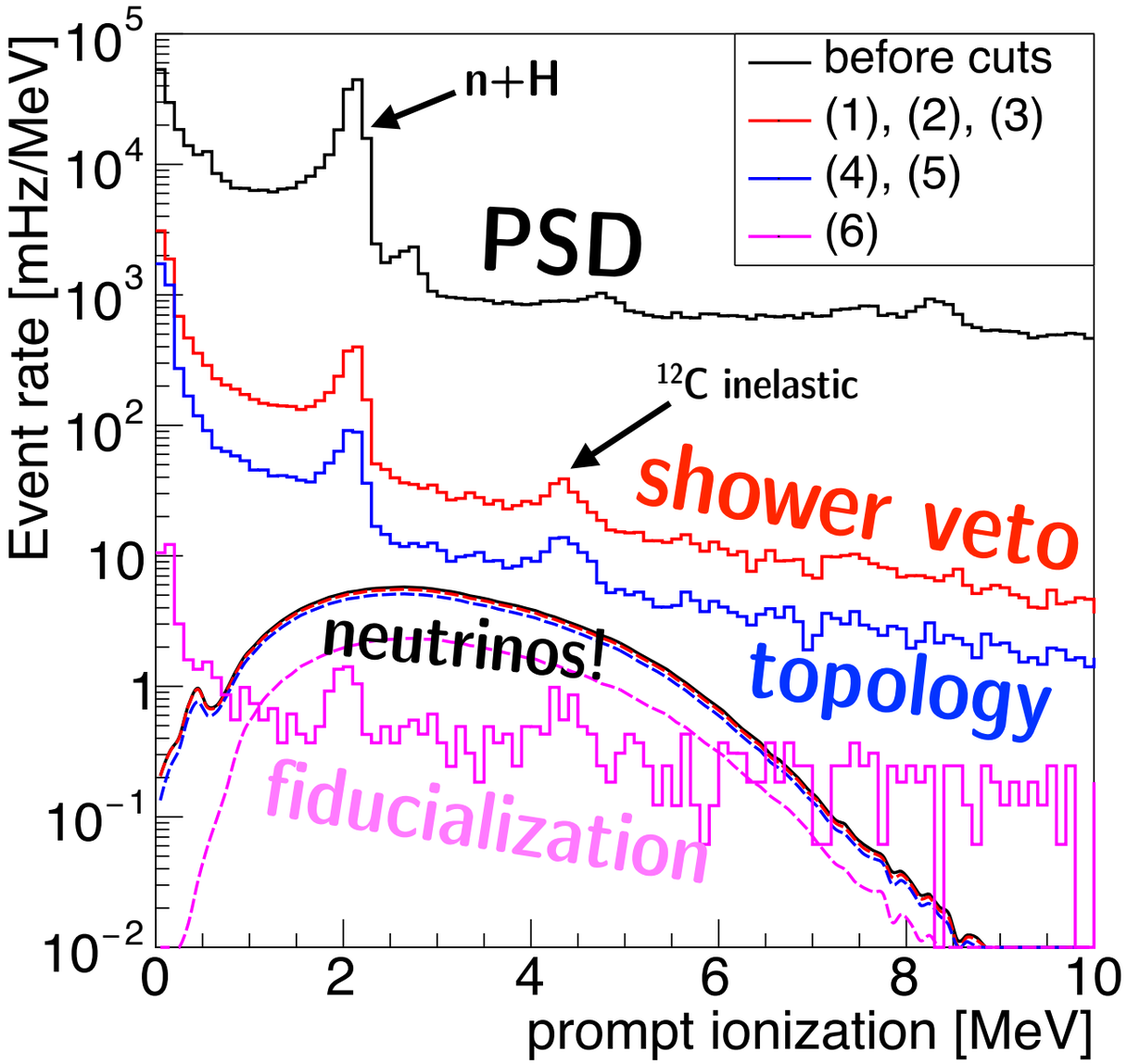
Optimize space, weight, and total background suppression

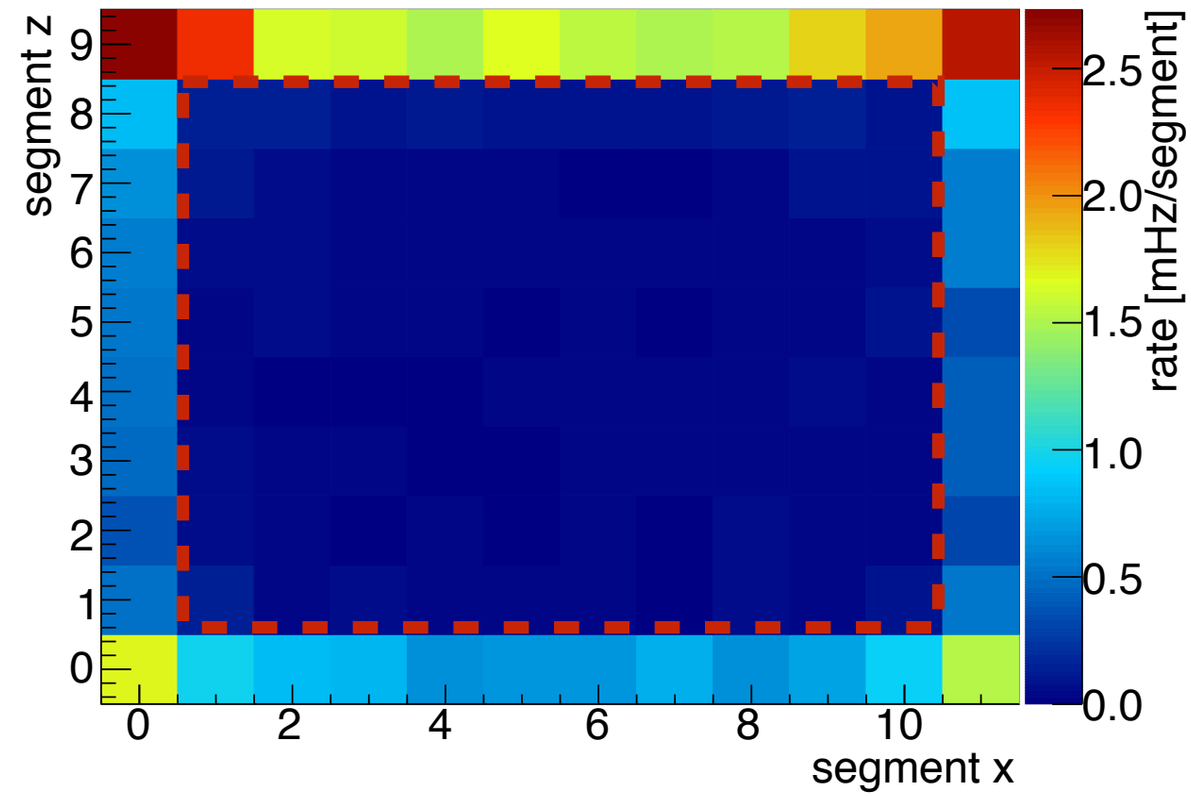
- Majority of IBD-like events are generated by ~100MeV cosmogenic neutrons
- Neutron spallation on high-Z shielding increases backgrounds
- *Need neutron shielding inside lead shielding*

BG Rejection via Detector Design

PROSPECT

Neutron coincident events



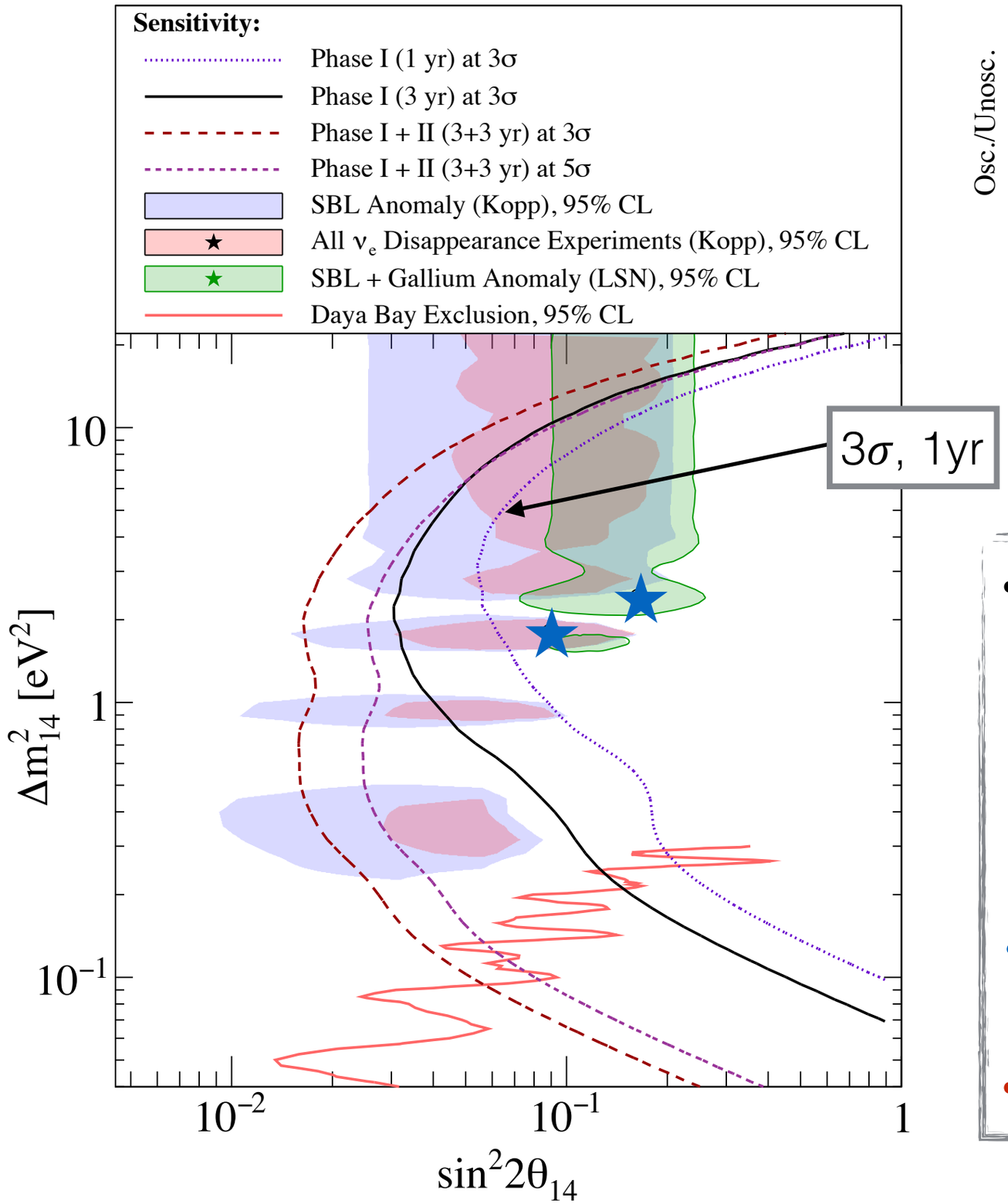


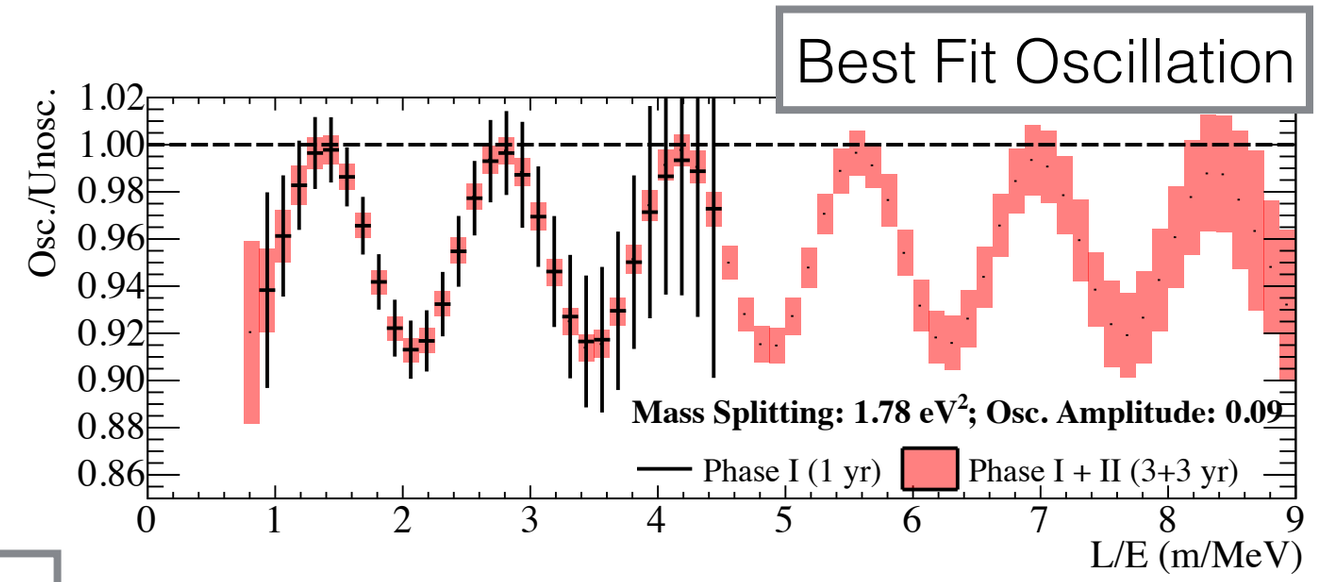
Background reduction steps:

- Efficient PSD and neutron tagging
- Identification of multiple particle interactions
- **Fiducialization**

Active suppression of >3 orders of magnitude, S:B > 1:1 expected

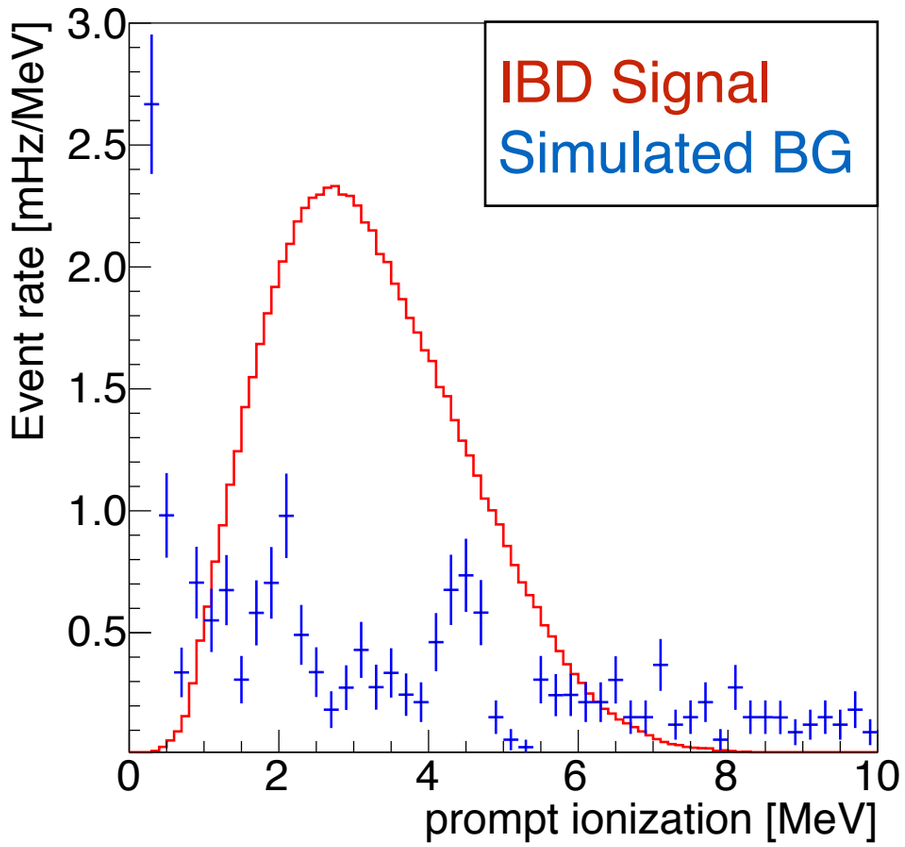
Short Baseline Oscillation Search

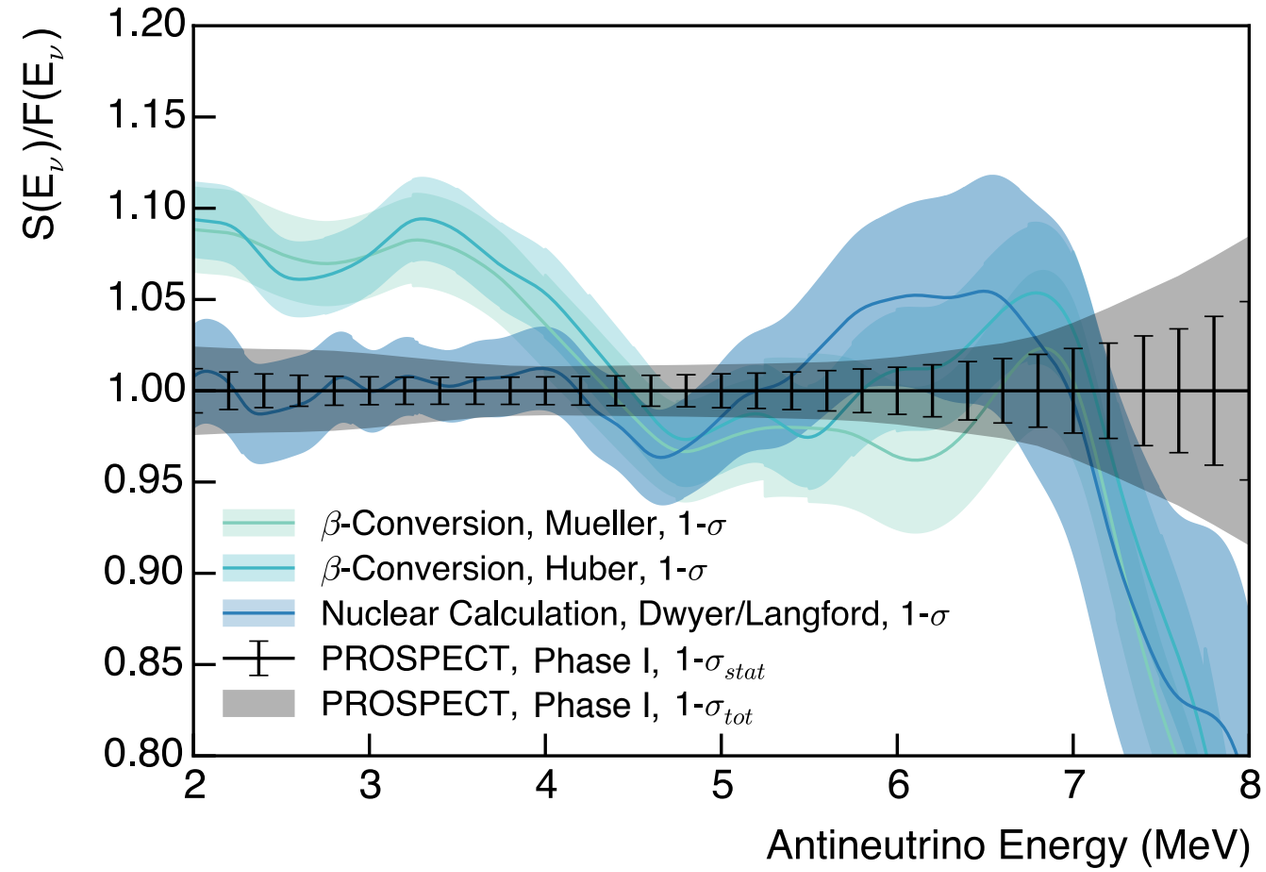




- Segmented detector designed for oscillation search
  - Each cell is a separate "detector"
  - Oscillatory L/E between segments
  - Independent from reactor models
- *True oscillometry needed for confirmation of sterile neutrinos*
- **Probe best-fit point at 4σ in 1 year**

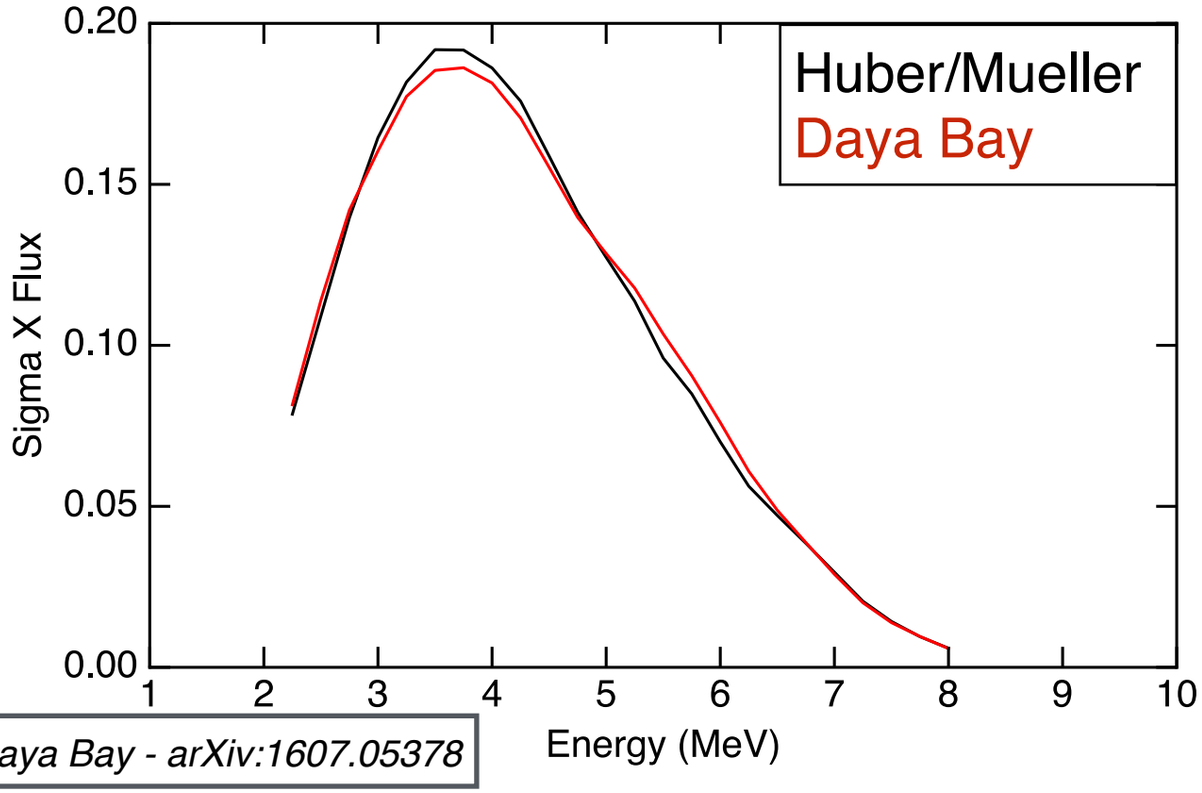
^{235}U Spectrum Measurement



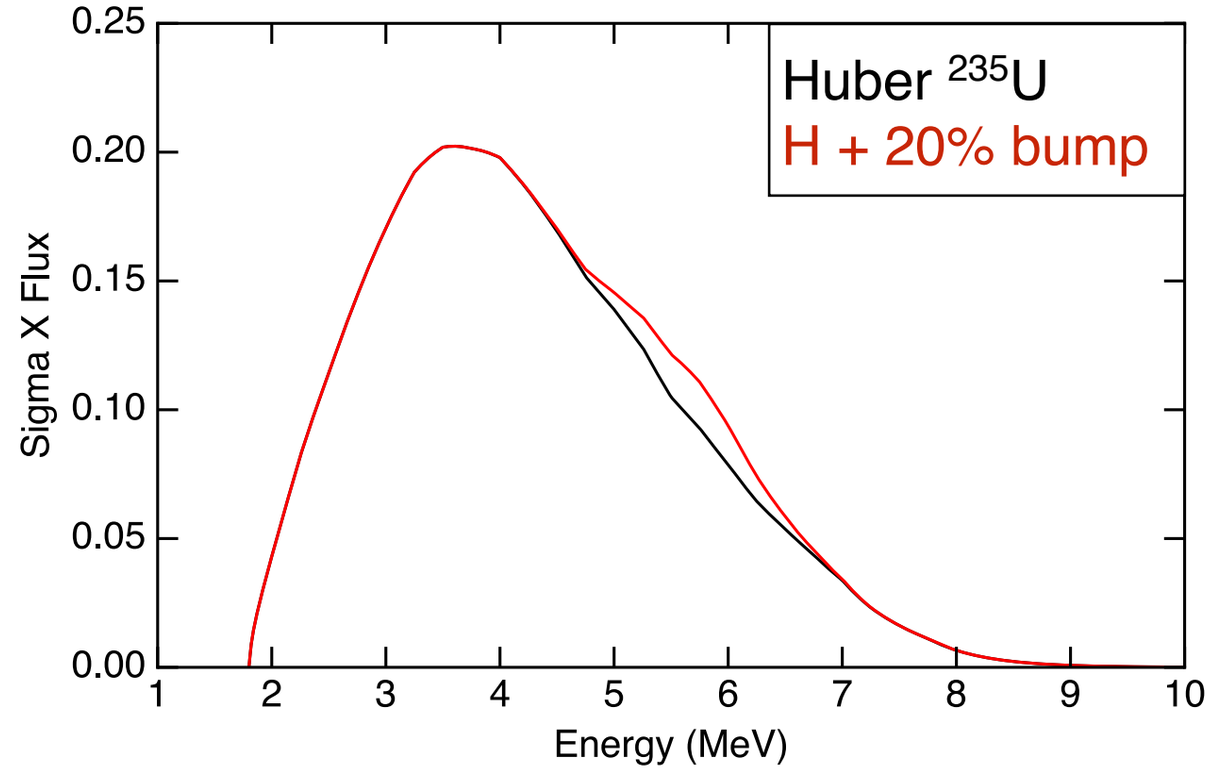


- ~700 inverse beta decays detected per day, 100k/year
- Best energy resolution of any reactor neutrino experiment (4.5%@1MeV)
- **Phase-1 precision will surpass spectral model uncertainties**
  - Directly test reactor neutrino models
  - Produce a benchmark spectrum for future reactor experiments

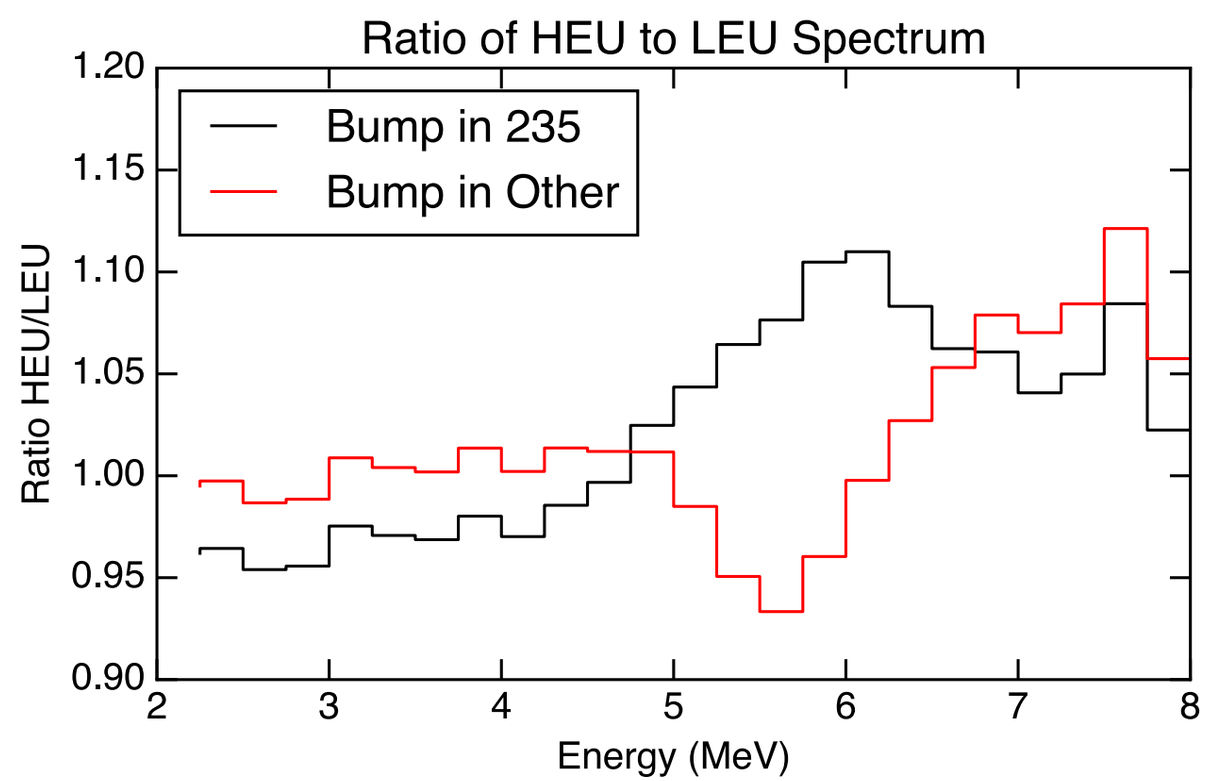
Probing the Spectral Anomaly



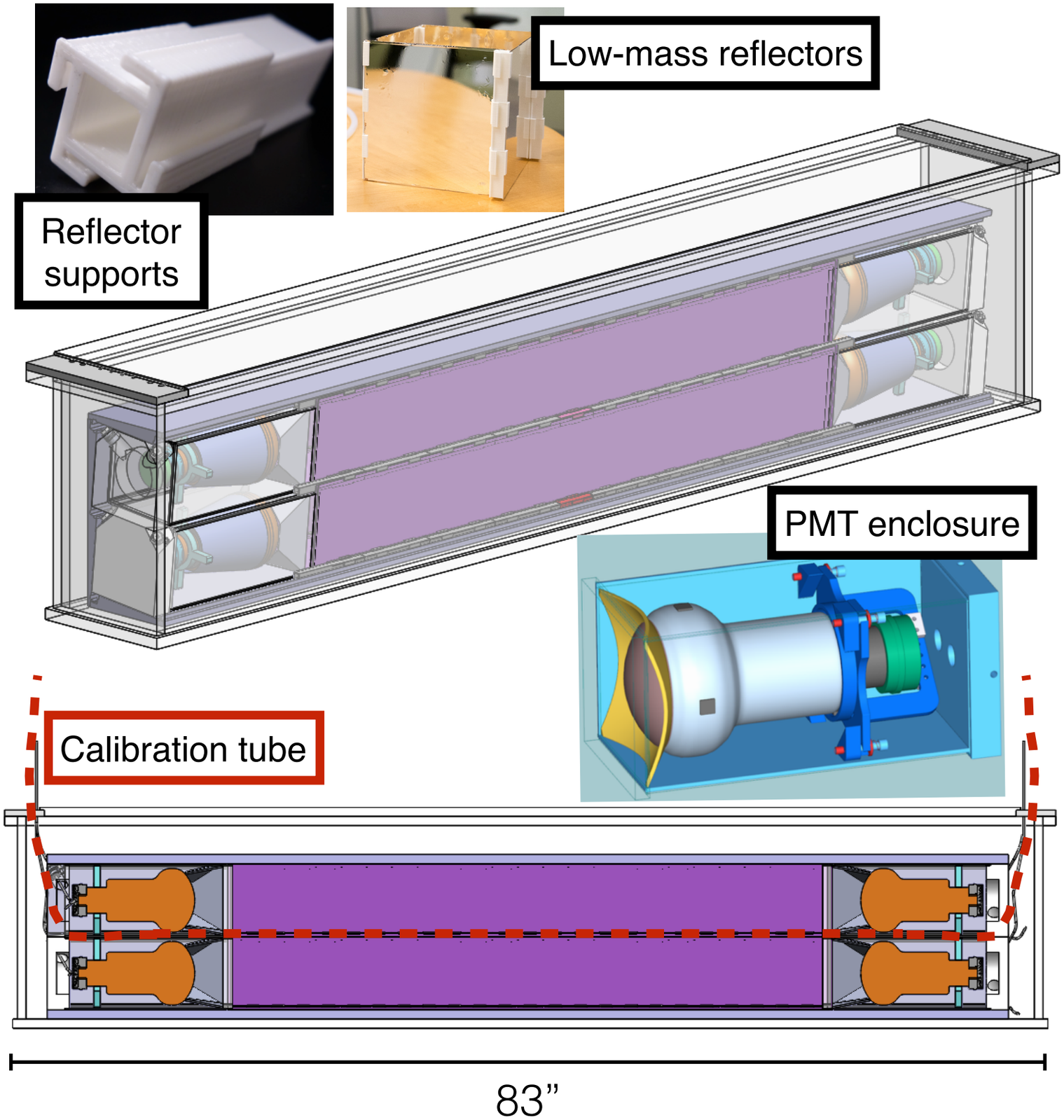
Daya Bay - arXiv:1607.05378



- ^{235}U spectrum can be combined with LEU measurements from θ_{13} experiments
- ^{235}U requires local 20% deviation to fully account for the Bump
- If the Bump is from ^{235}U, ratio displays excess in HEU spectrum
- If Bump is all in other isotopes, ratio shows a deficit



PROSPECT-50 Demonstrator

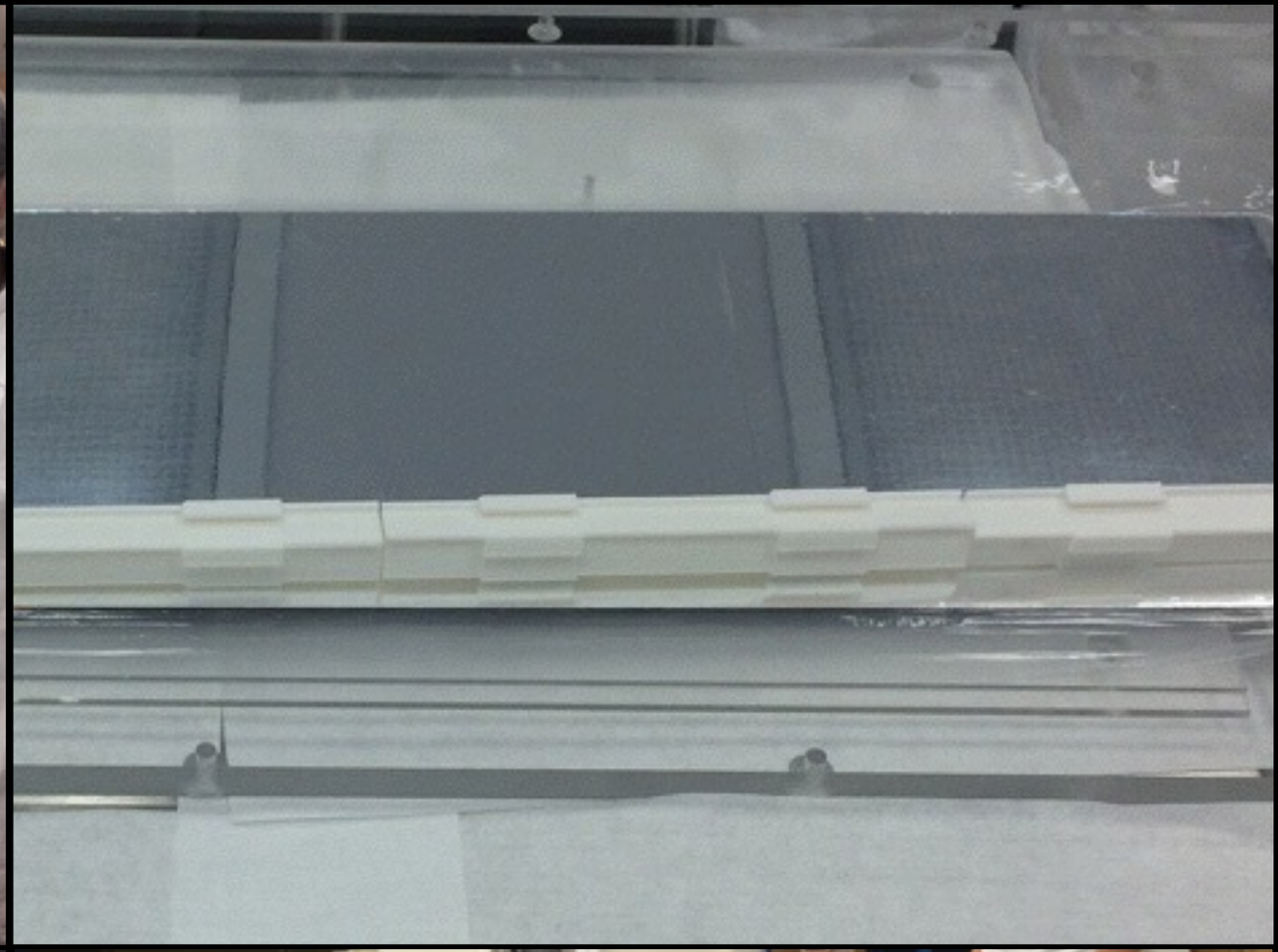


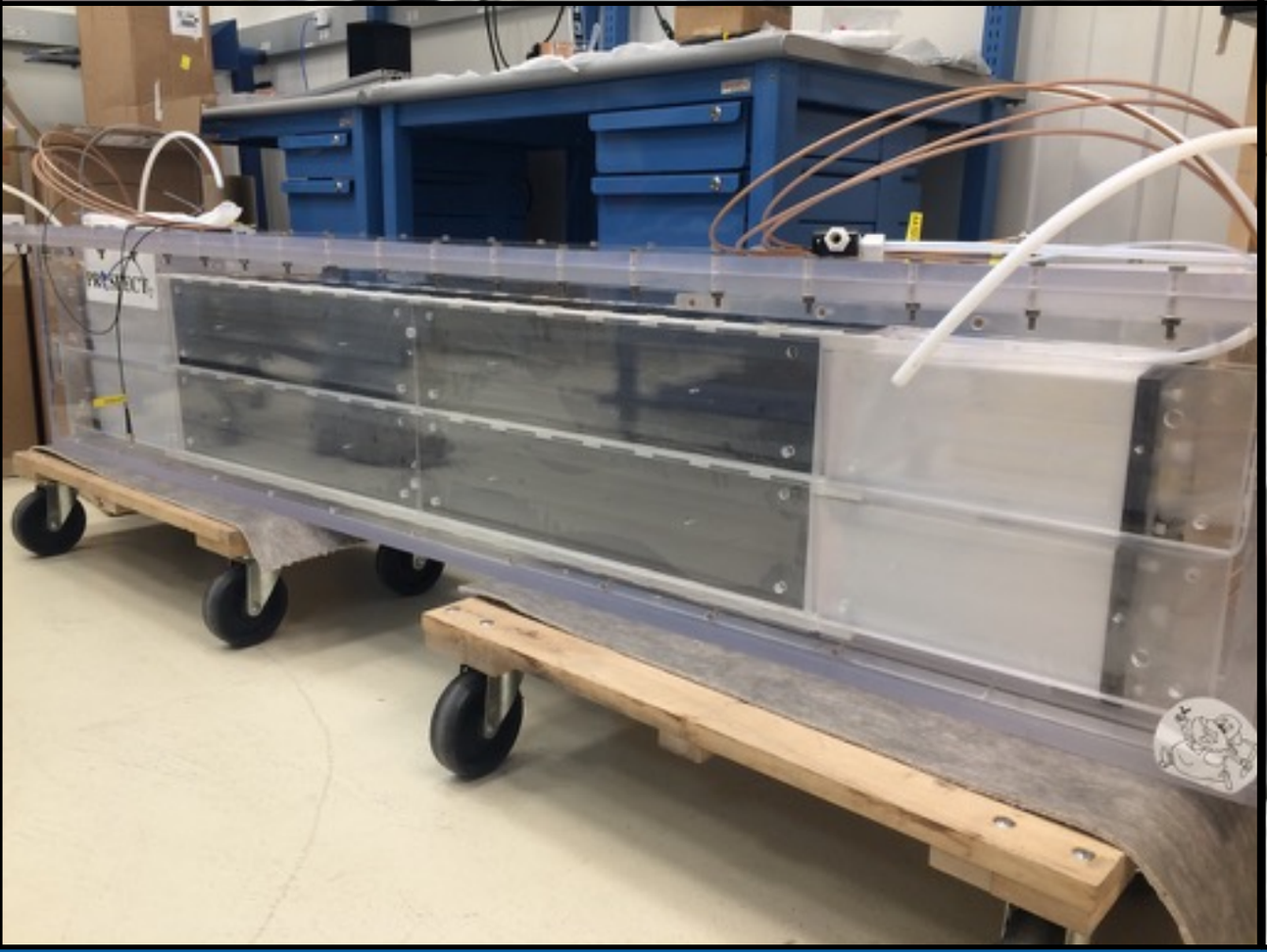
PROSPECT-50:

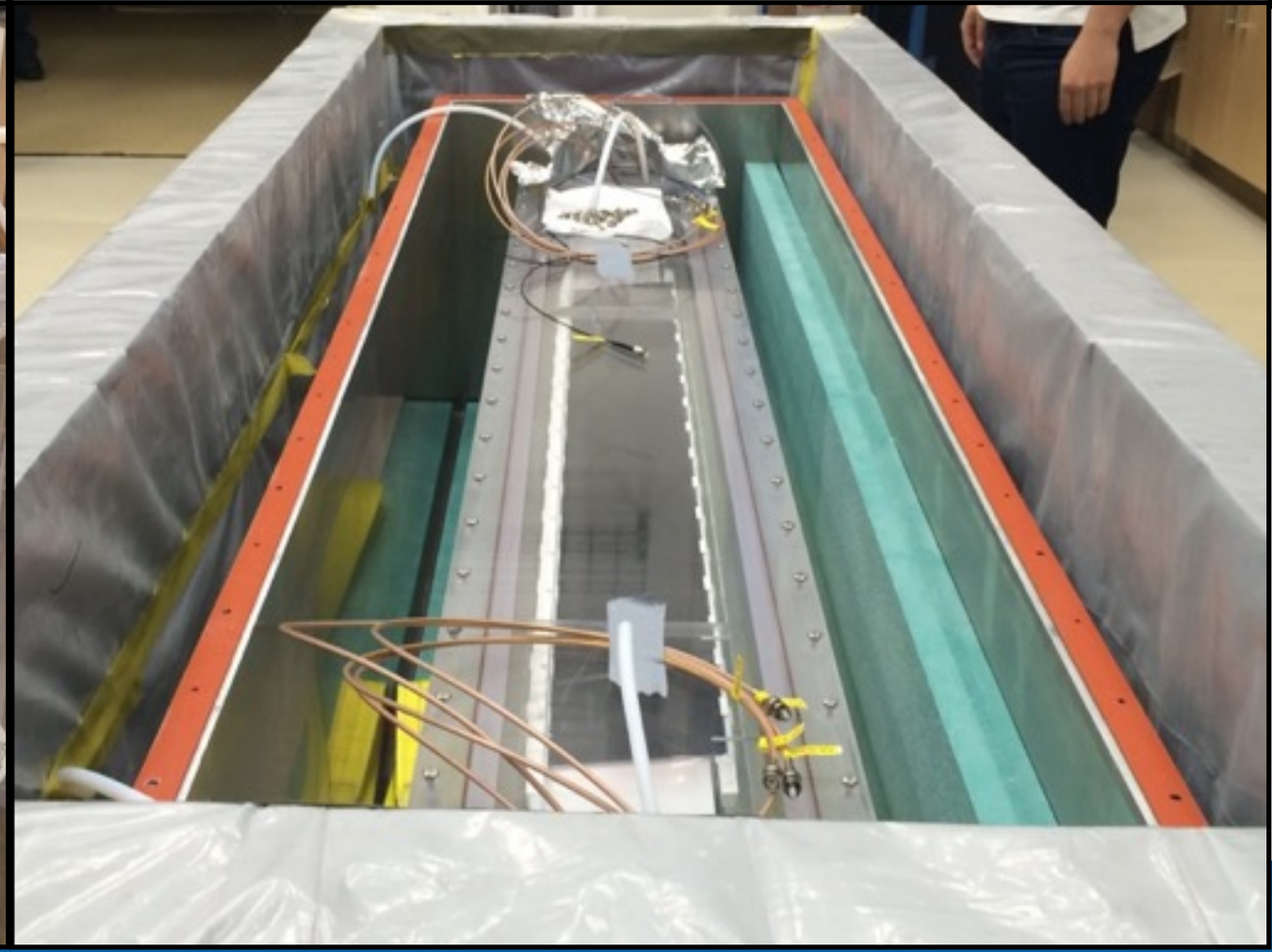
- 50 liters of ^{6}LiLS
- Two PROSPECT segments

Test platform of each subsystem

- Thin-walled reflector panels
- PMT enclosures
- Filling system and procedure
- Calibration system
  - LED optical
  - Source capsules
- Cell-to-cell variation

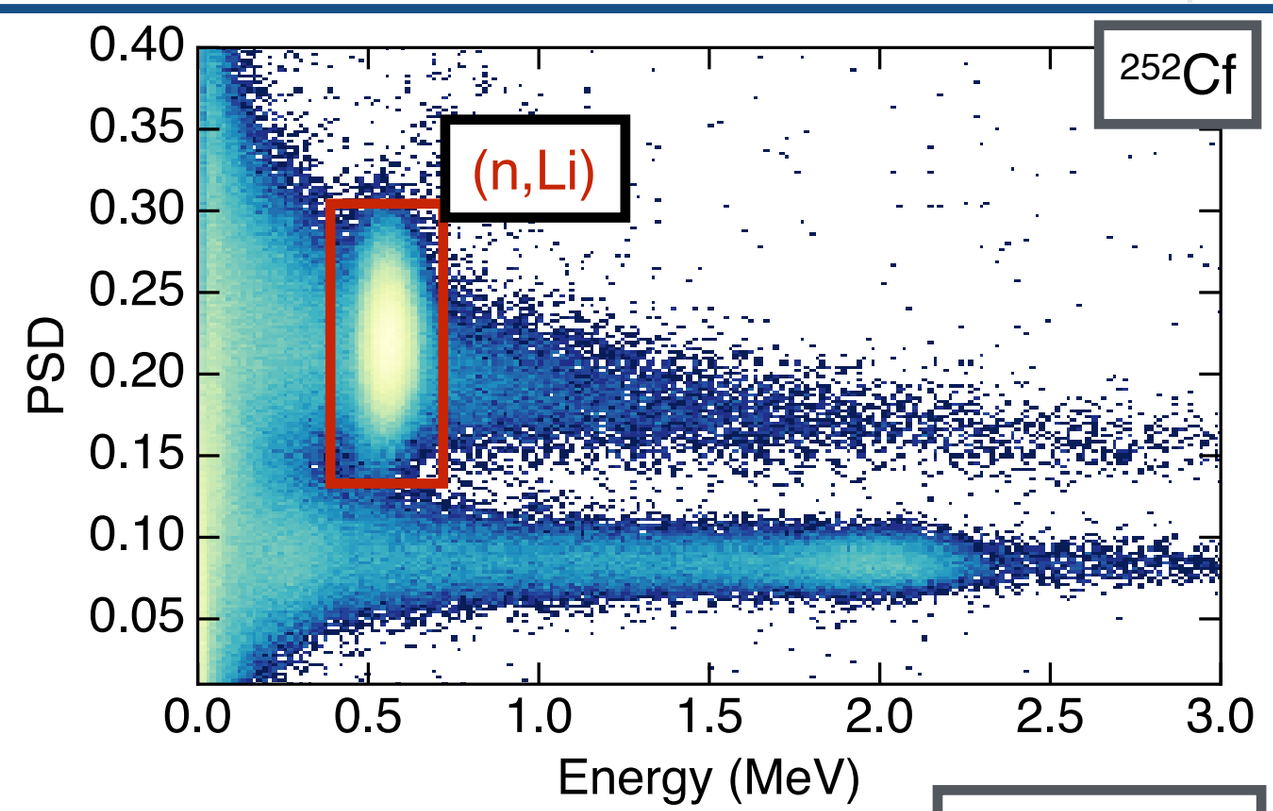


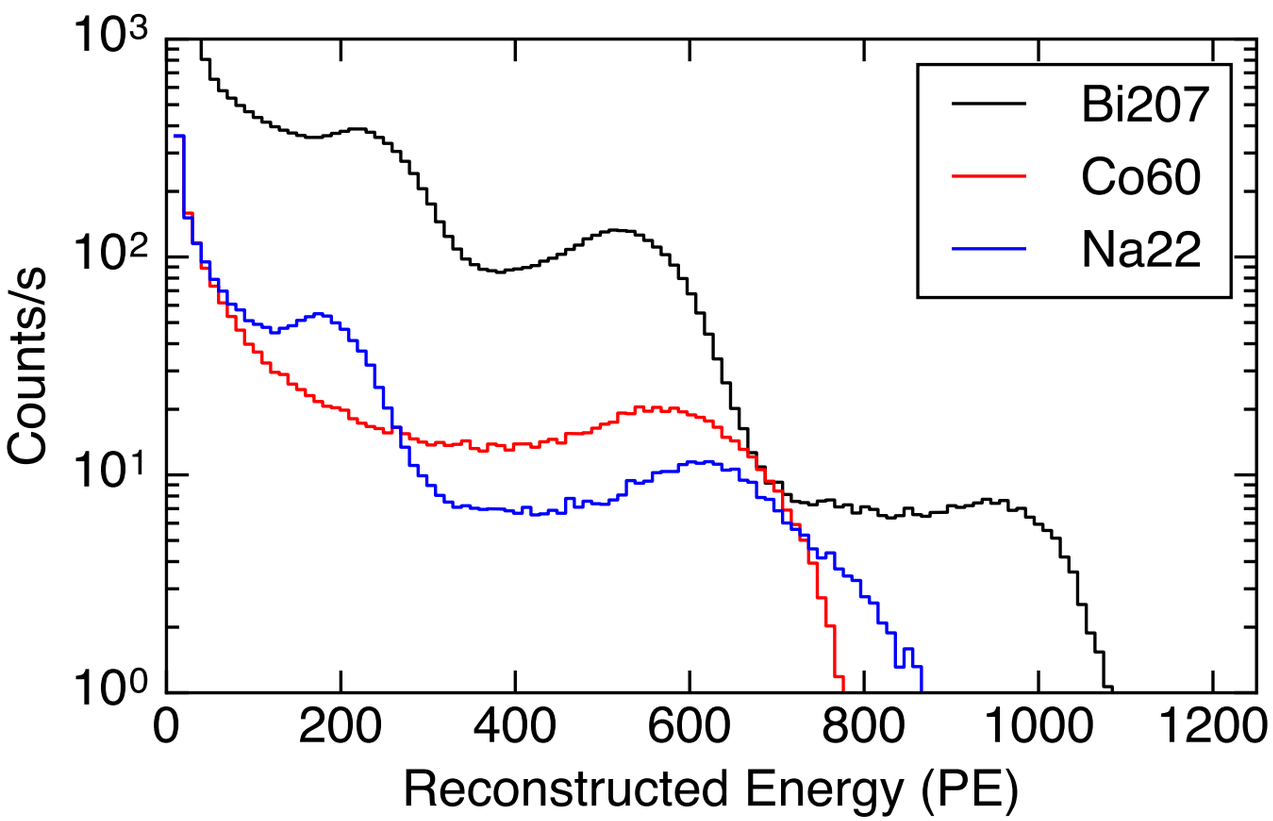


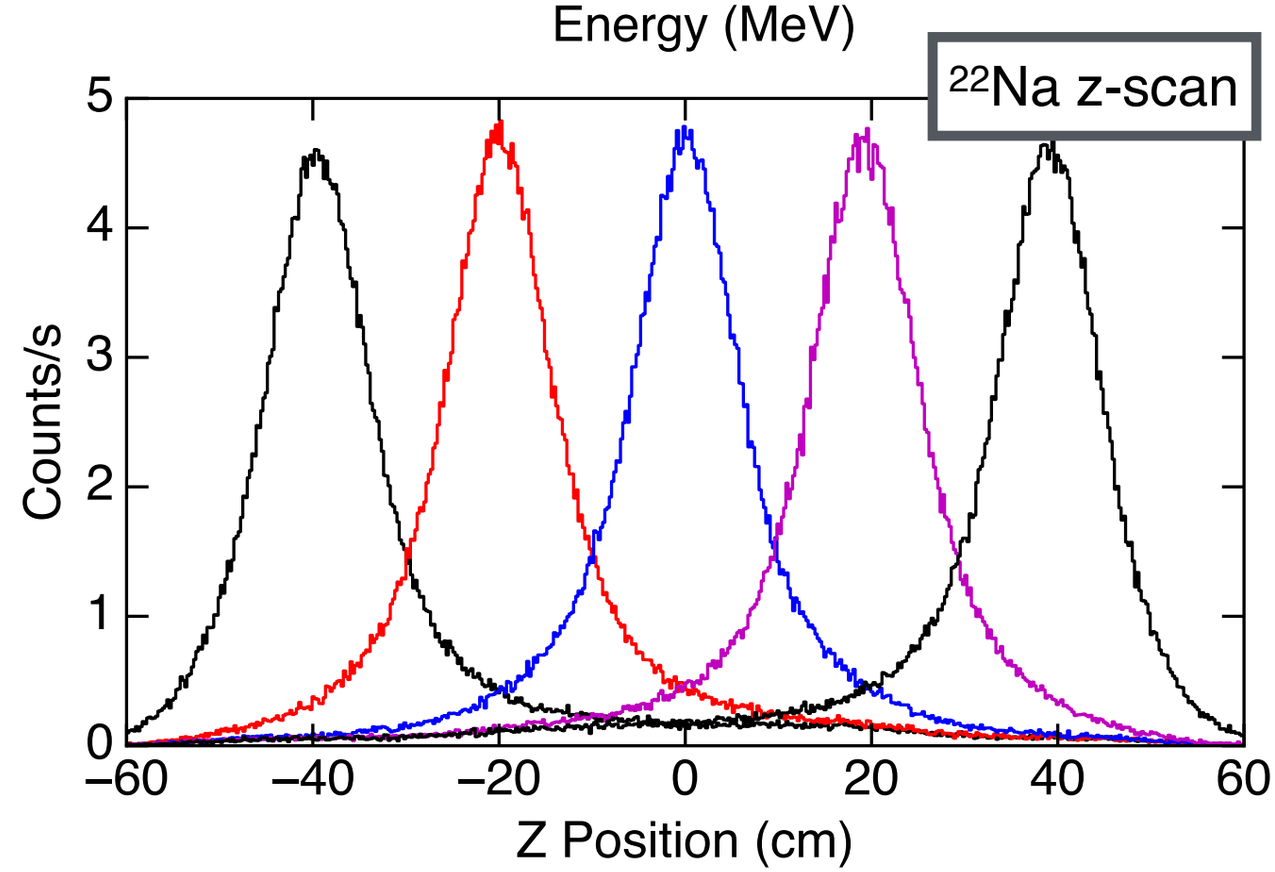


PROSPECT-50 Demonstrator

- In operation since March 2016, near continuous data-collection
- Measured light collection with ^{6}LiLS: >550PE/MeV
  - **5% energy resolution at 1MeV**
- Measured PSD Figure of Merit: 1.25 at (n,Li) capture
  - **>99.9% background rejection**
- Double-ended readout
  - Position reconstruction along cell length







Summary and Outlook

- The reactor flux and shape anomalies remain unresolved after precision θ_{13} experiments
- These may offer a window to new physics beyond the SM
- ORNL is a unique location for neutrino physics, providing complementary work between nuclear and reactor physics
- **PROSPECT will measure the ^{235}U spectrum with the highest precision to-date**
- **PROSPECT will make a model-independent search for sterile neutrinos and test best fit point at 4σ within its first year**
- The detector design has been verified and construction begins soon

Publications: arXiv: 1309.7647, 1506.03547, 1508.06575, 1512.02202

http://prospect.yale.edu