Yale

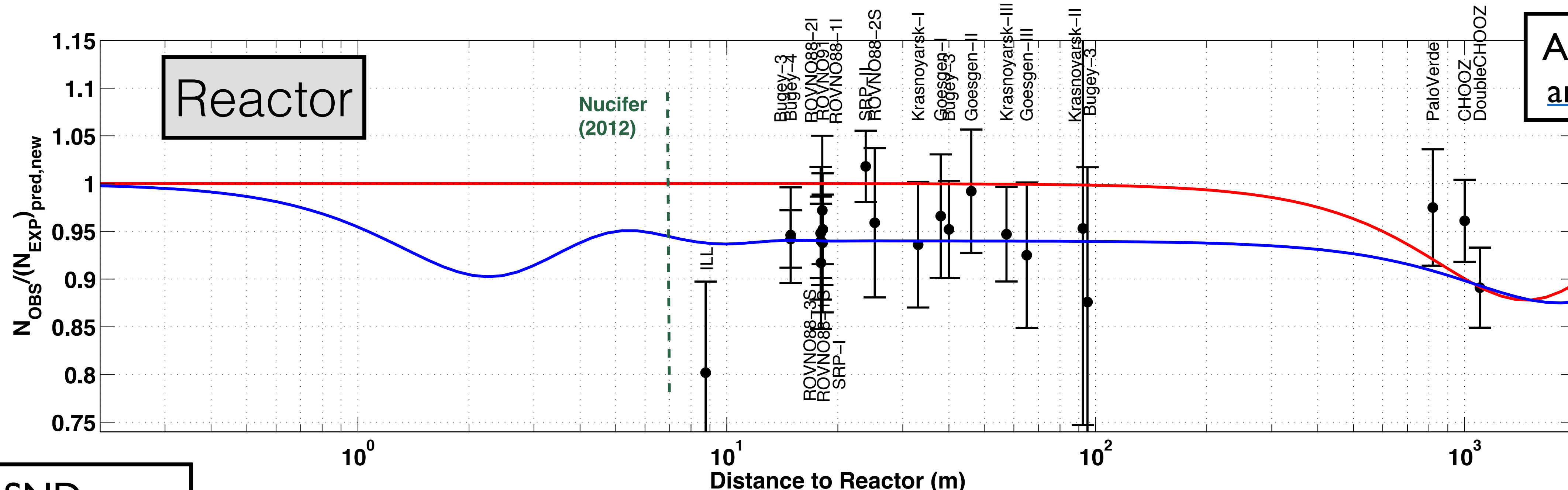
Wright Laboratory

Neutrinos
Dark Matter
Nuclear Structure
Relativistic Heavy Ions

PROSPECT
Precision Oscillation and Spectrum Experiment

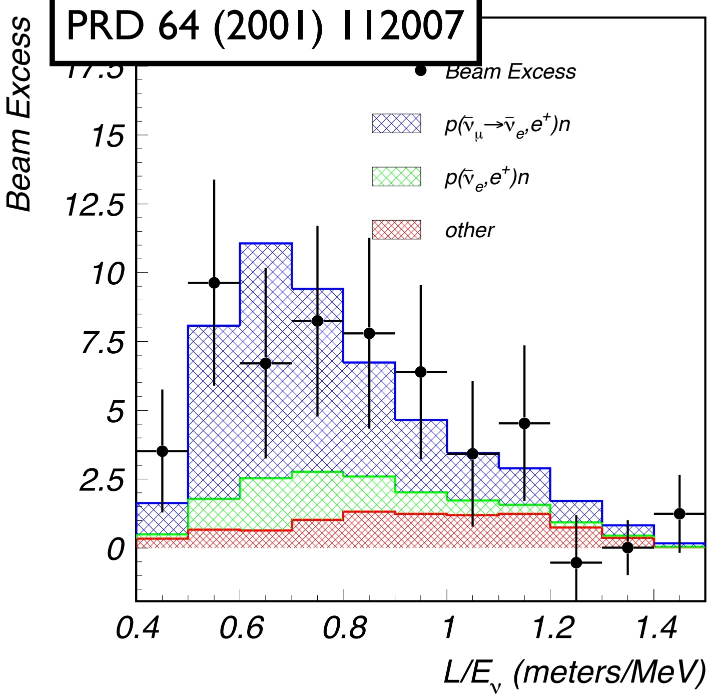
T.J. Langford
Yale University
For the PROSPECT Collaboration

Short Baseline (anti)Neutrino Anomalies



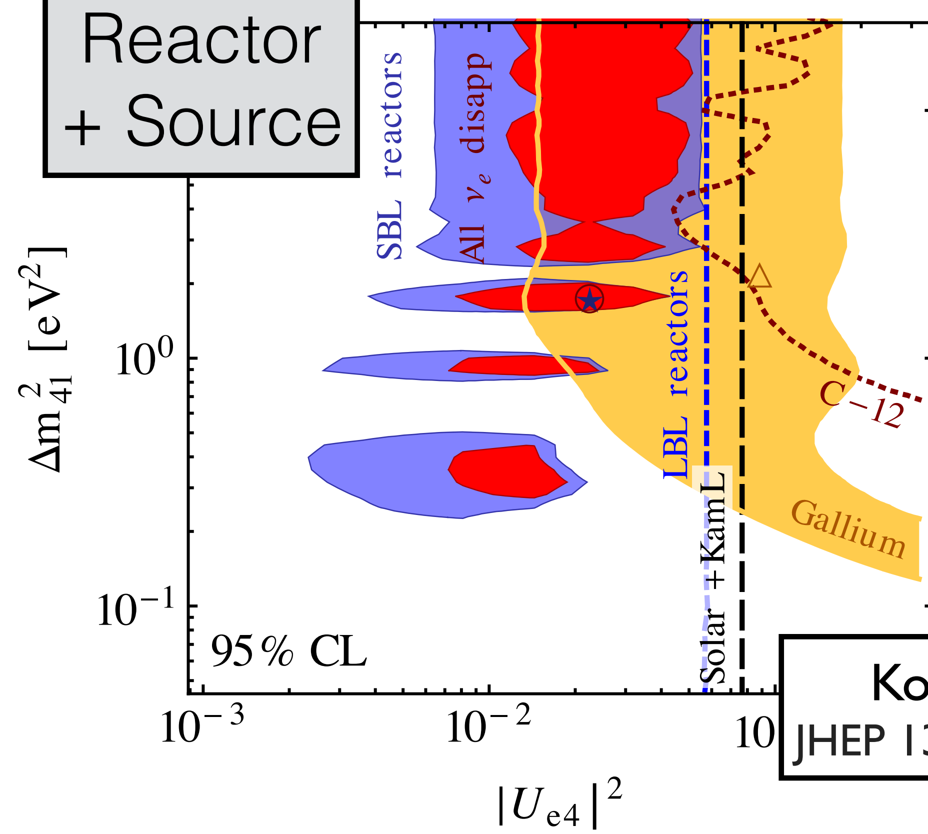
Abazajian et al.
arxiv:1204.5379

LSND
PRD 64 (2001) 112007



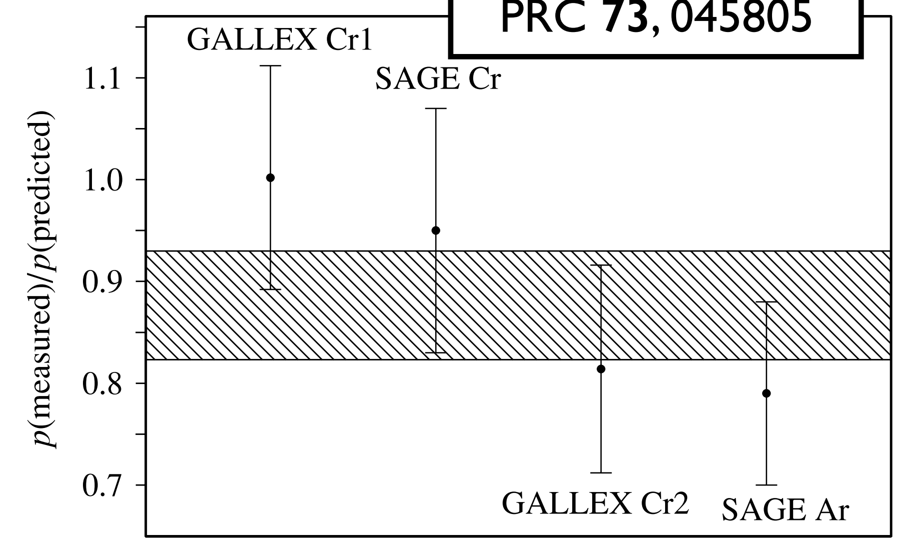
Accelerator

Reactor + Source



Kopp et al.
JHEP 1305(2013)050

Abdurashitov et al.
PRC **73**, 045805



Source

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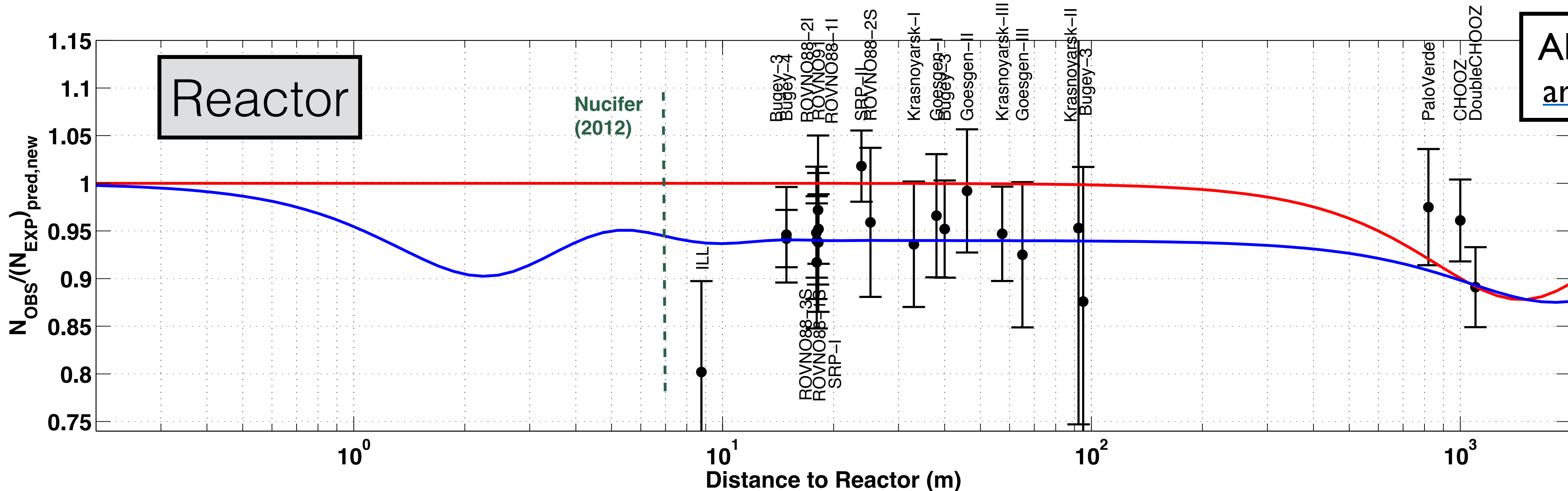
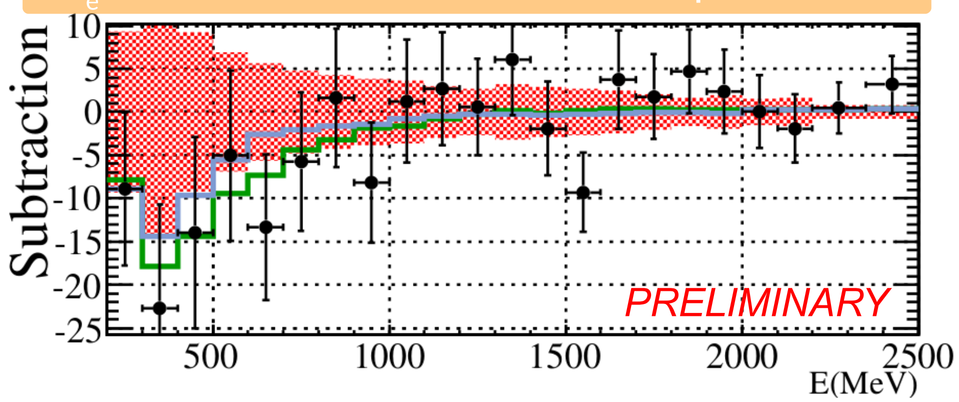
Reactor



Abazajian et al.
arxiv:1204.5379

T2K Caravaca et al.
NUFACT2014

ν_e CC: Subtraction to the nominal prediction



https://indico.cern.ch/event/300521/session/2/contribution/116

Accelerator

Reactor
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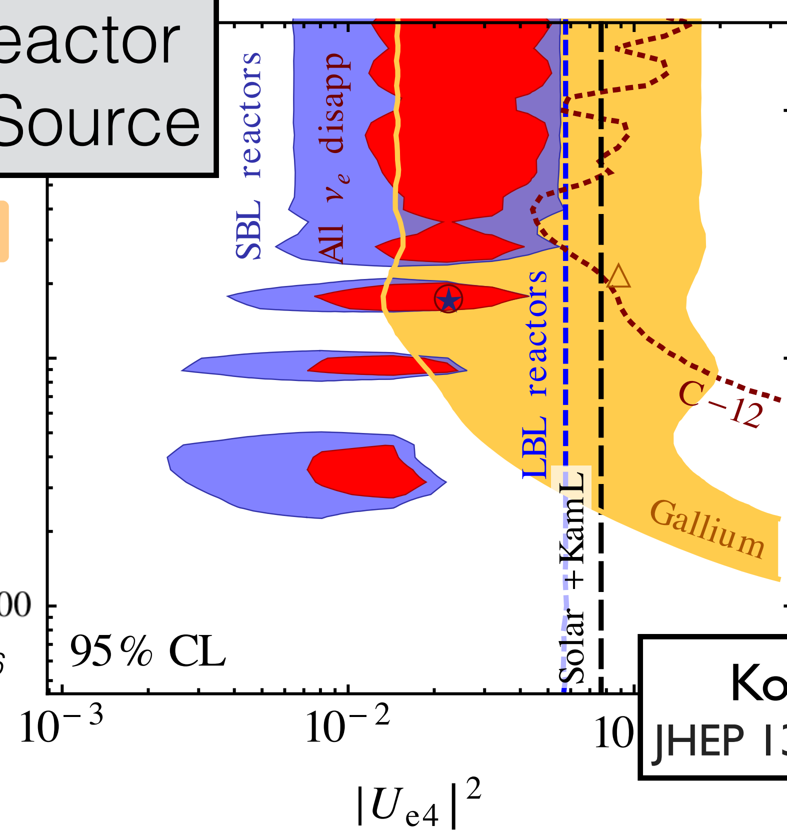

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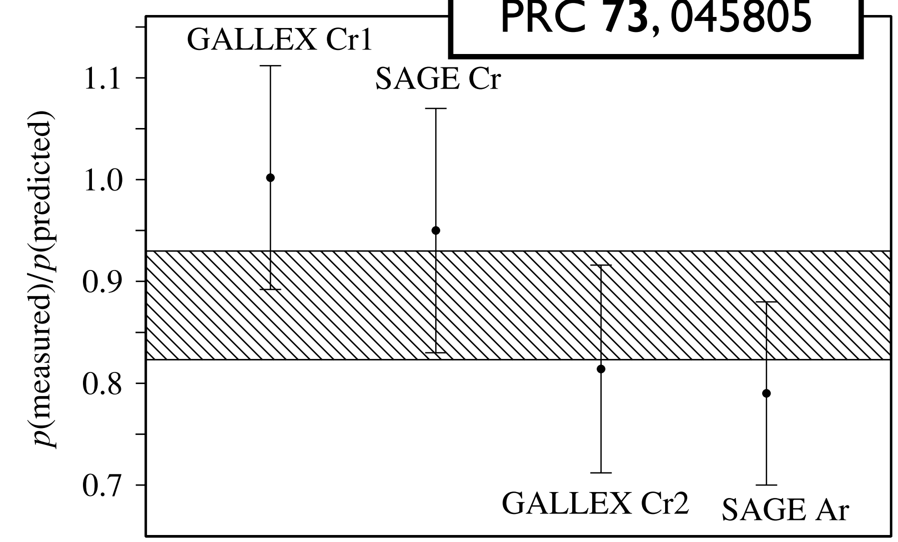
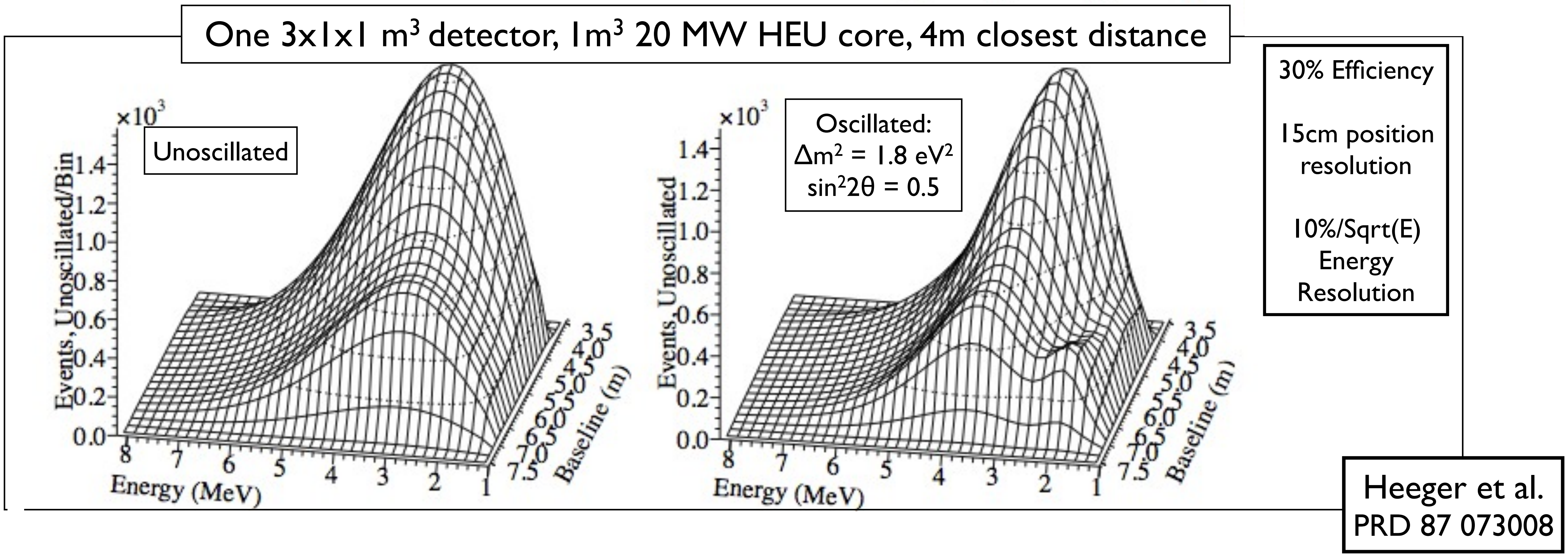


Source

Reactor $\overline{\nu}_e$ for short baseline oscillation searches

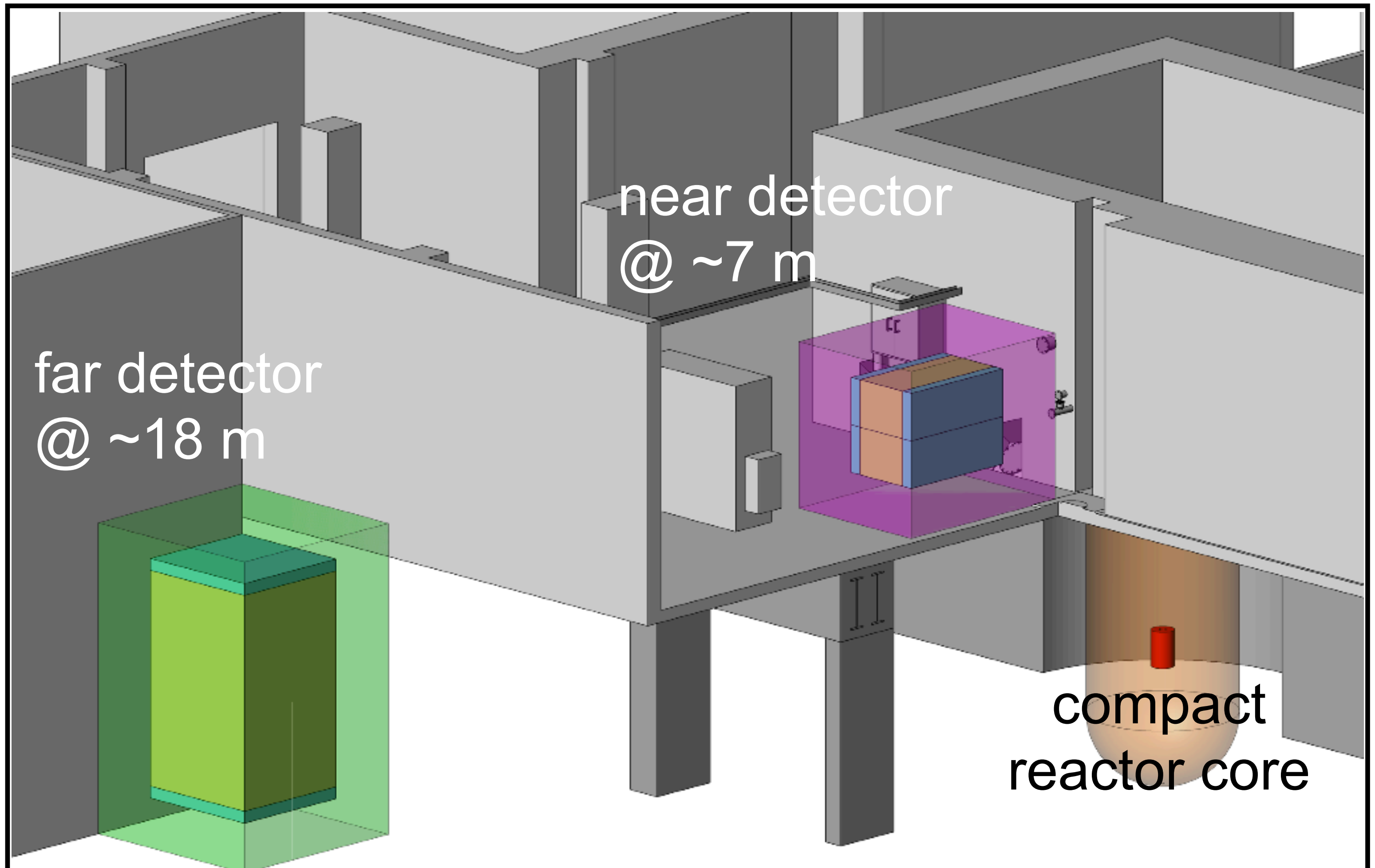
- Multi-MeV span of energies combined with multiple detectors provide broad L/E coverage
- Compact core research reactors ideal for search:
  - Small cores allow access to faster oscillations ~ Δm^2 O(1eV^2)
  - *HEU provides near static spectrum throughout cycle*
  - True reactor-off periods to measure ambient backgrounds



PROSPECT Short Baseline Reactor Experiment

Physics Goals:

- Search for short baseline ν_e oscillations (L/E ~ .5 - 7 m/MeV)
- Use segmentation to directly search for spectral distortions from sterile ν
- Precision measurement of the ^{235}U neutrino spectrum for physics and safeguards
- Develop technology to detect reactor neutrinos at minimal overburden



Proposed near and far detectors shown at HFIR

Detector Design:

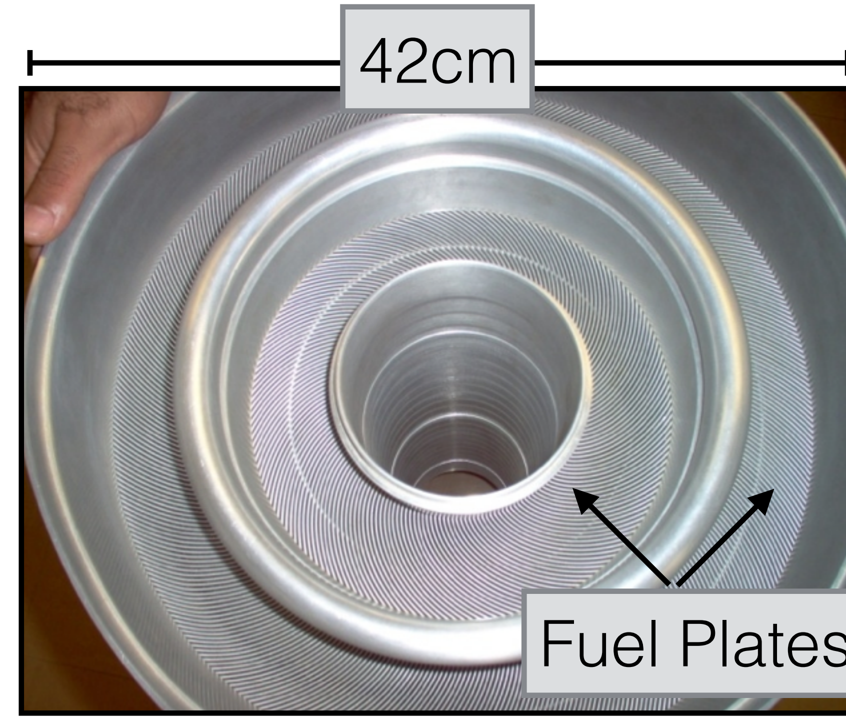
- Two-phase detector deployment:
  - Phase 1: Near Detector
  - Phase 2: Near+Far Detectors
- *Segmented detectors with pulse-shape discriminating ^{6}Li scintillator*

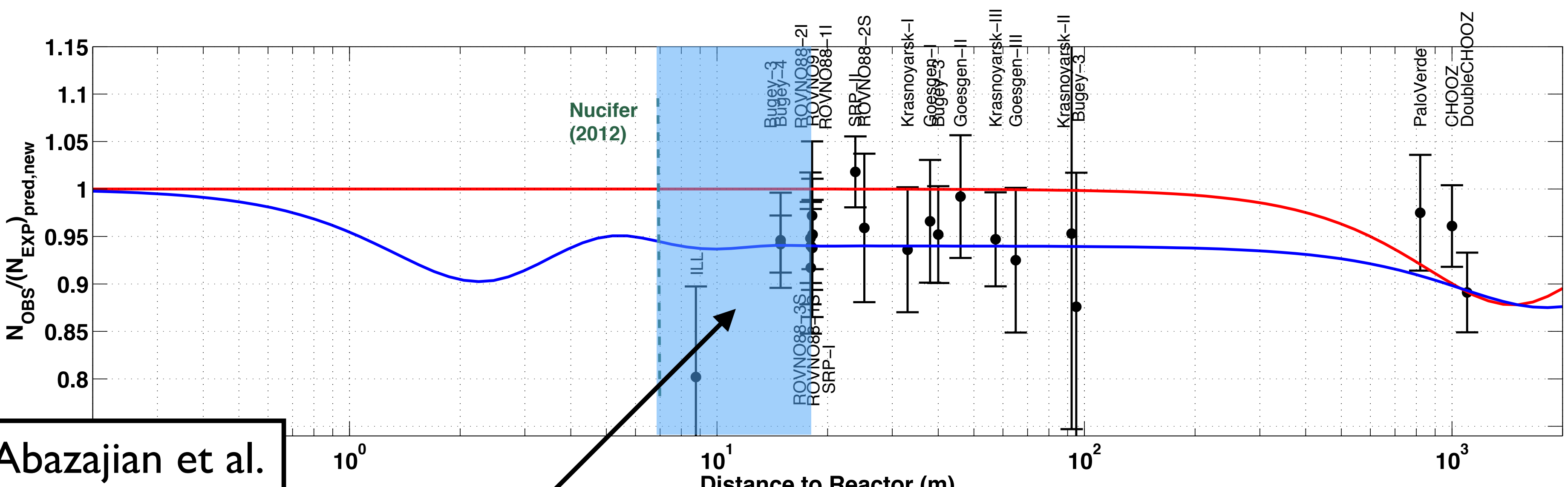
Challenges:

- Minimal overburden, cosmogenic backgrounds
- Reactor-related backgrounds
  - High energy (≲10MeV) gammas
- Relative segment variations and calibration and position-related systematics

HFIR Research Reactor

- High Flux Isotope Reactor at Oak Ridge National Lab
- 85MW HEU reactor, 42% uptime
- 42cm x 50cm cylindrical core
  - *Detailed modeling available*
- Active research program with many experiments currently running





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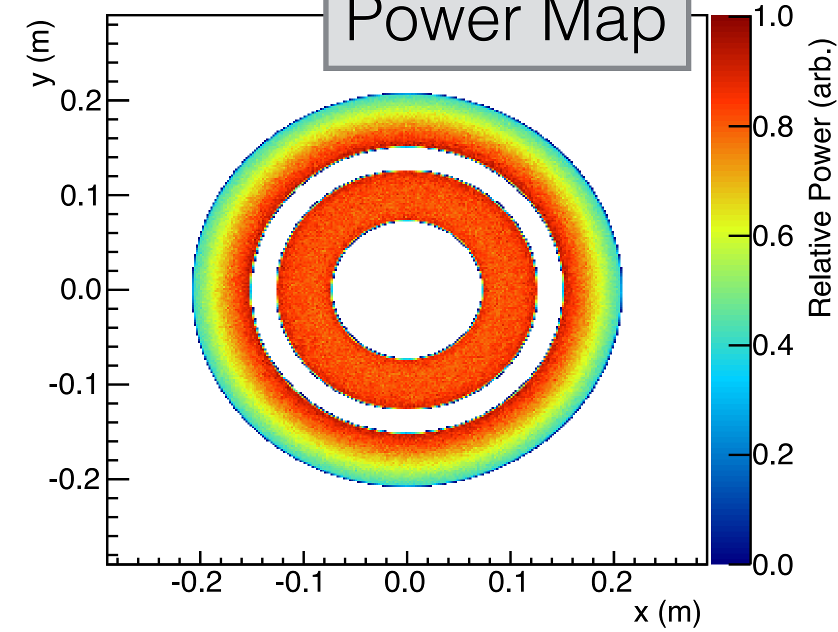
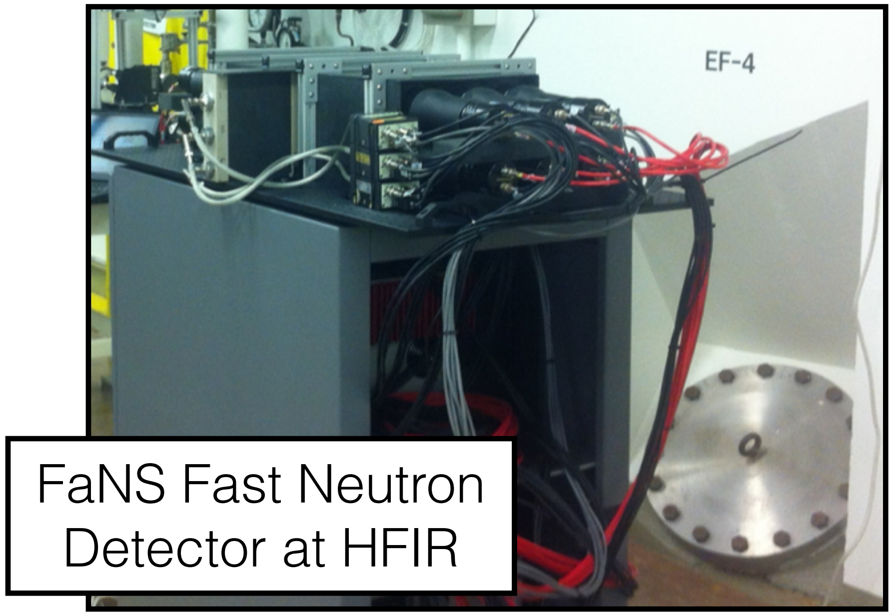
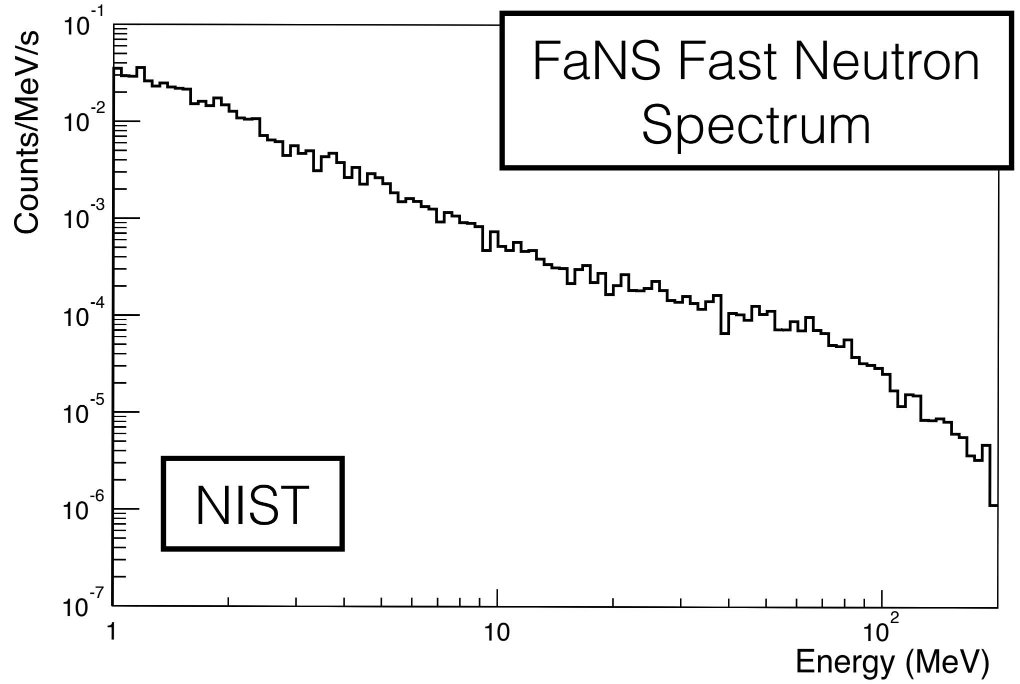
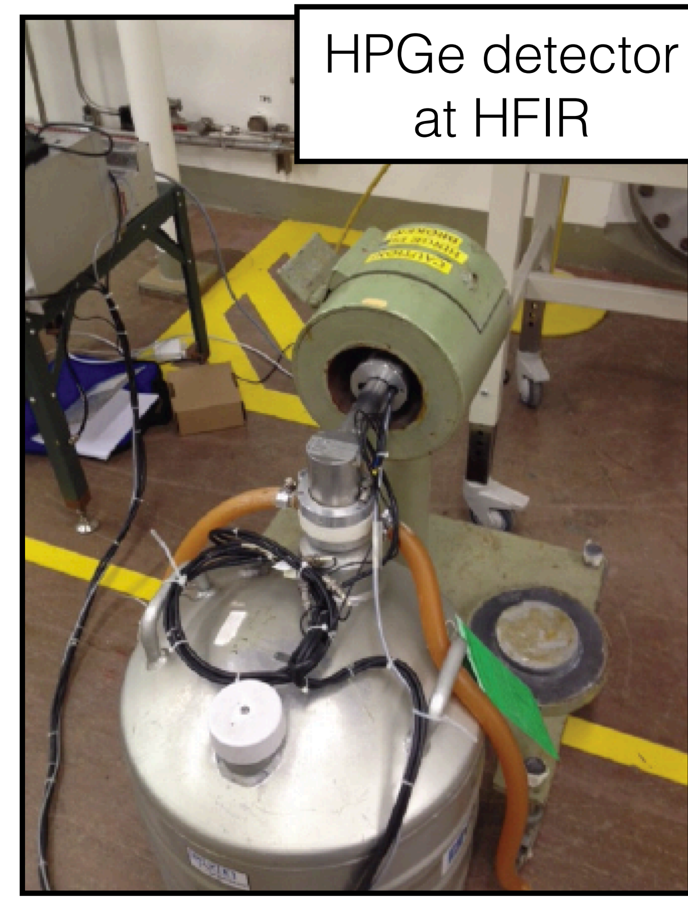
HFIR Baselines



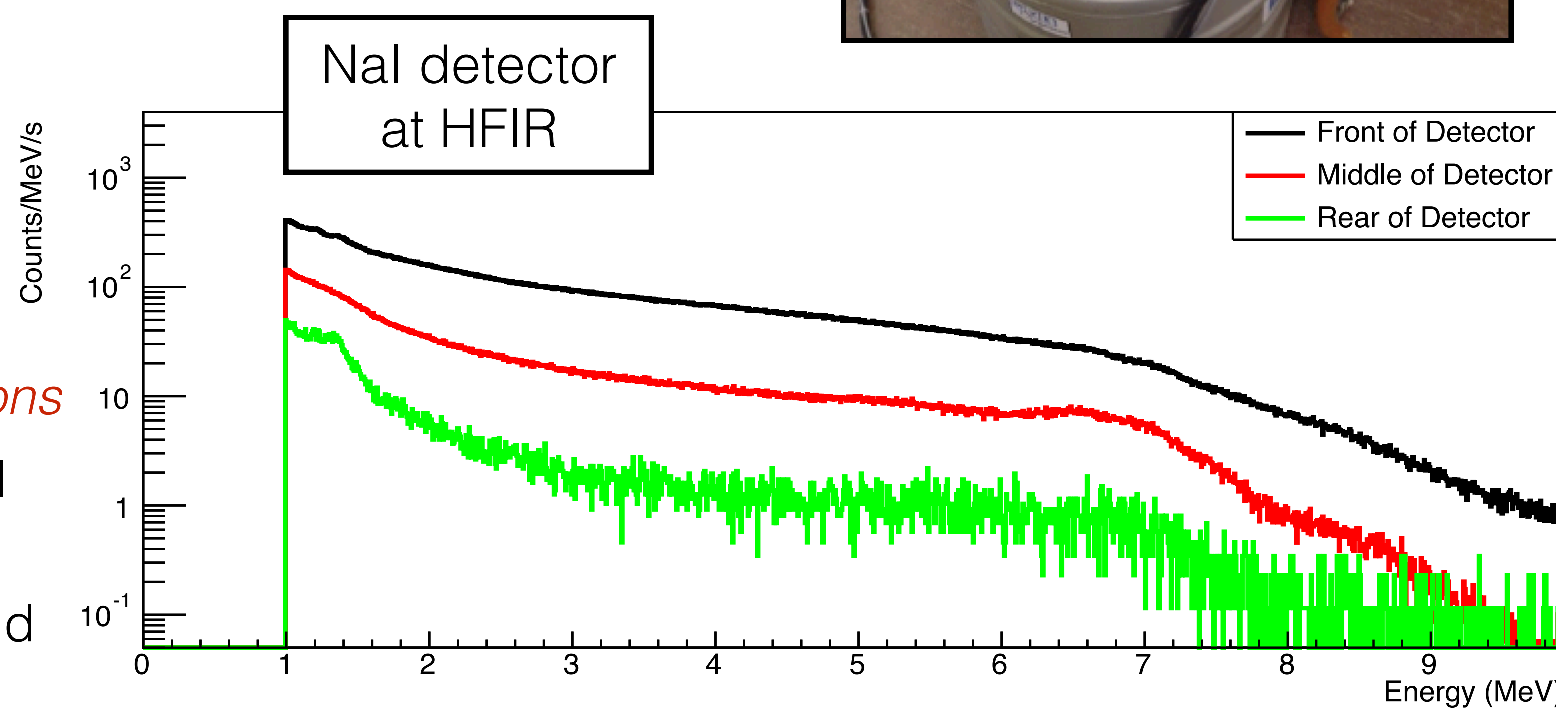
Background Characterization



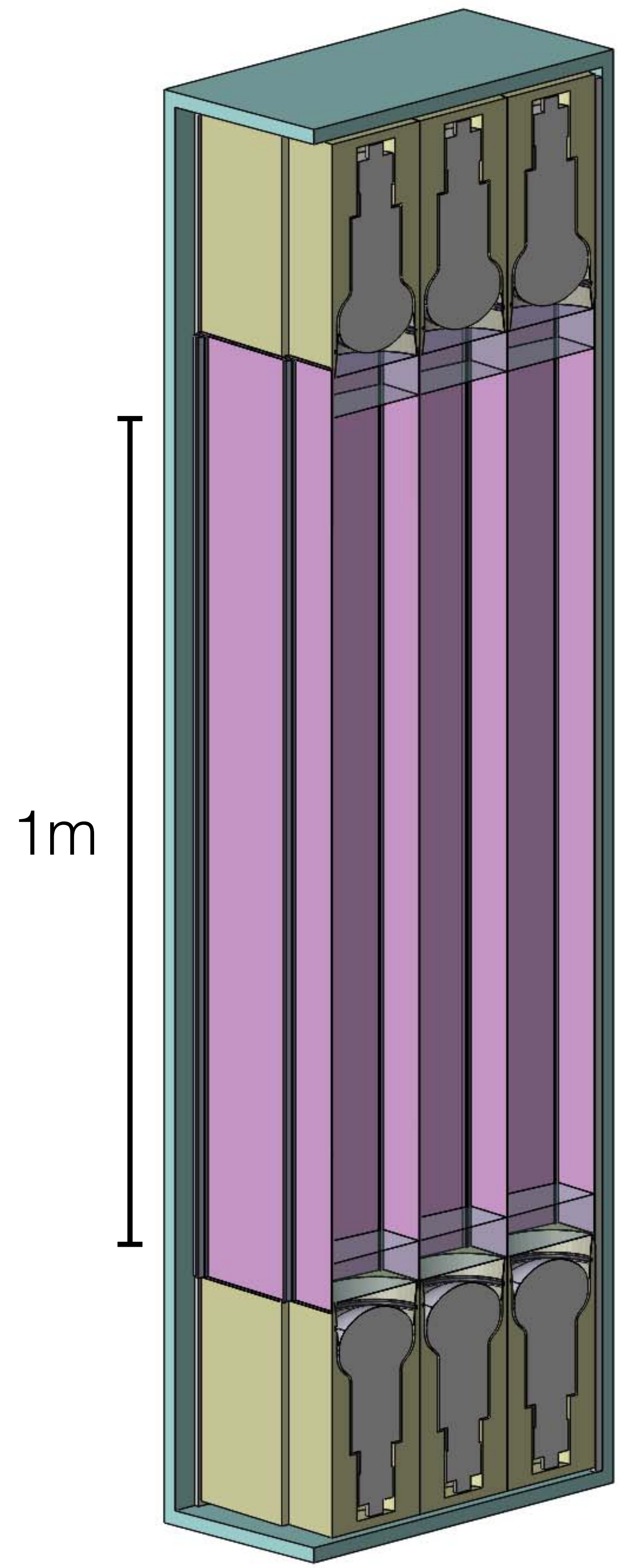




- **Extensive background characterization performed at three reactor sites (NIST, HFIR, ATR)**
  - Thermal and fast neutrons
  - γ-ray spectroscopy (NaI and HPGe)
  - Muon flux
- **Important findings:**
  - Significant temporal and *spacial variations*
  - High energy γ background from thermal neutron capture
  - Cosmogenic rates scale with altitude and overburden as expected



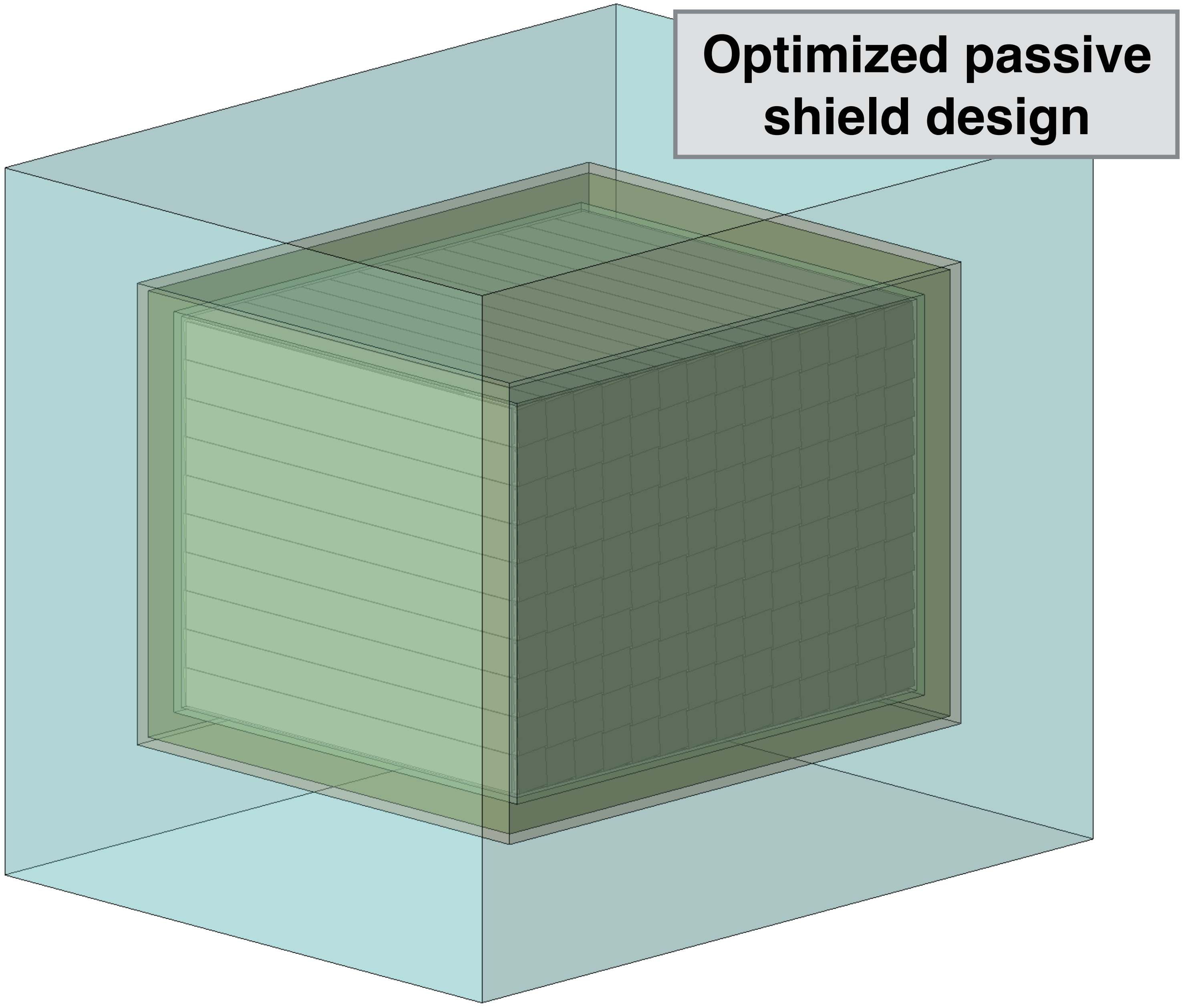
PROSPECT Detector Design



Double Ended Readout

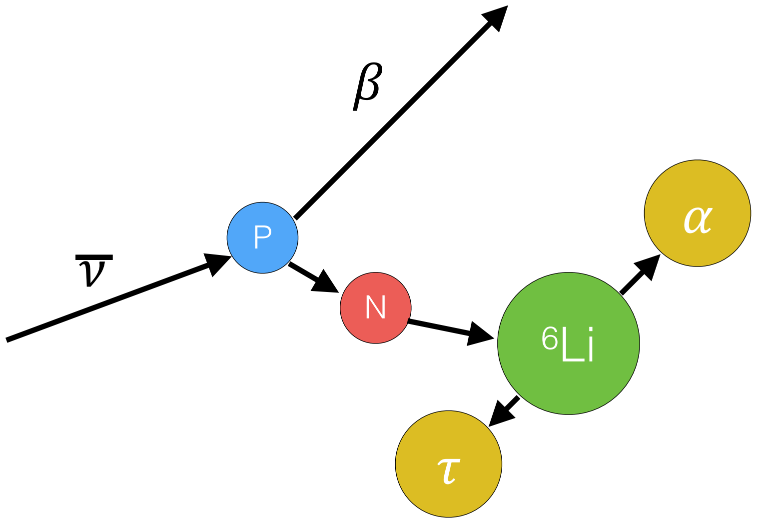
Very thin wall Segmentation

LiLS for n-tagging



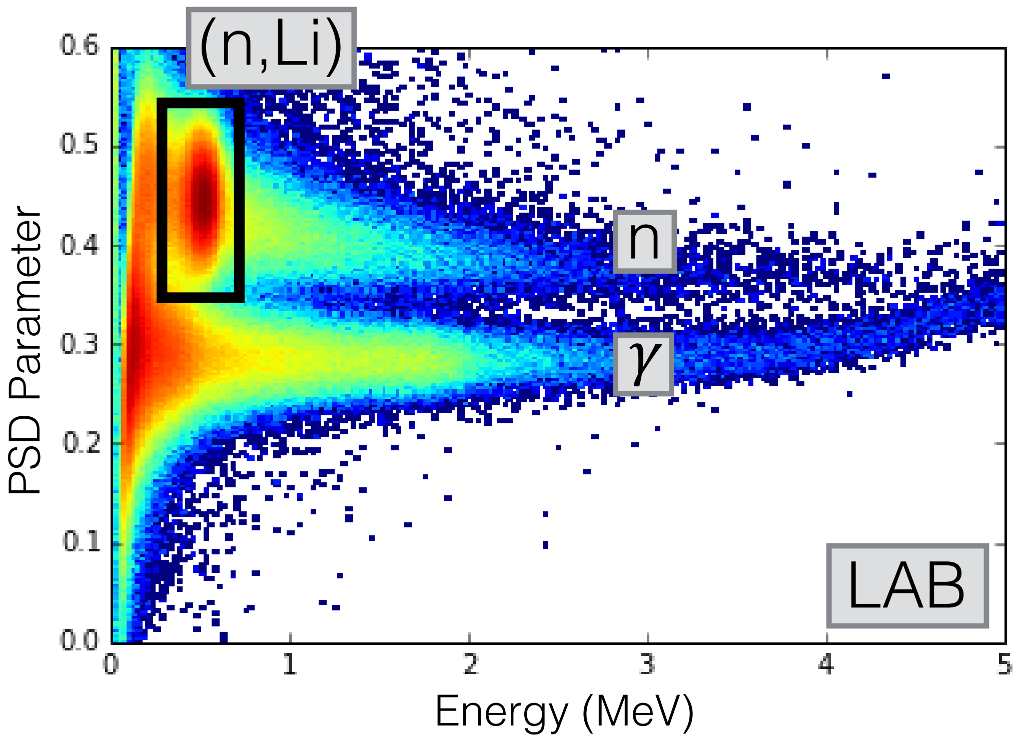
- ~2.5ton active volume of LiLS
- O(100) optical reflecting segments with very thin walls
- Can use the segmentation to create a fiducial volume

Li-loaded Liquid Scintillator

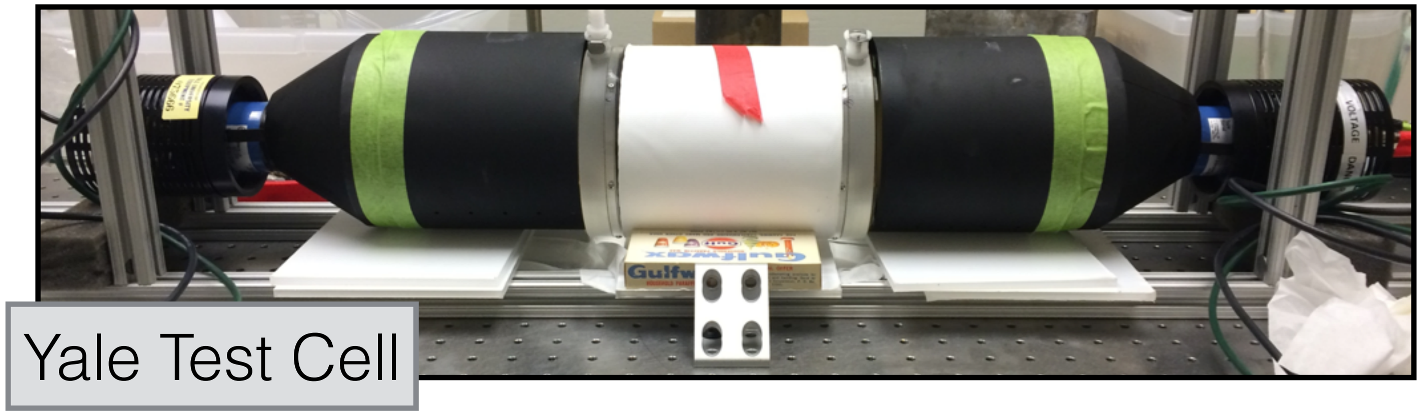


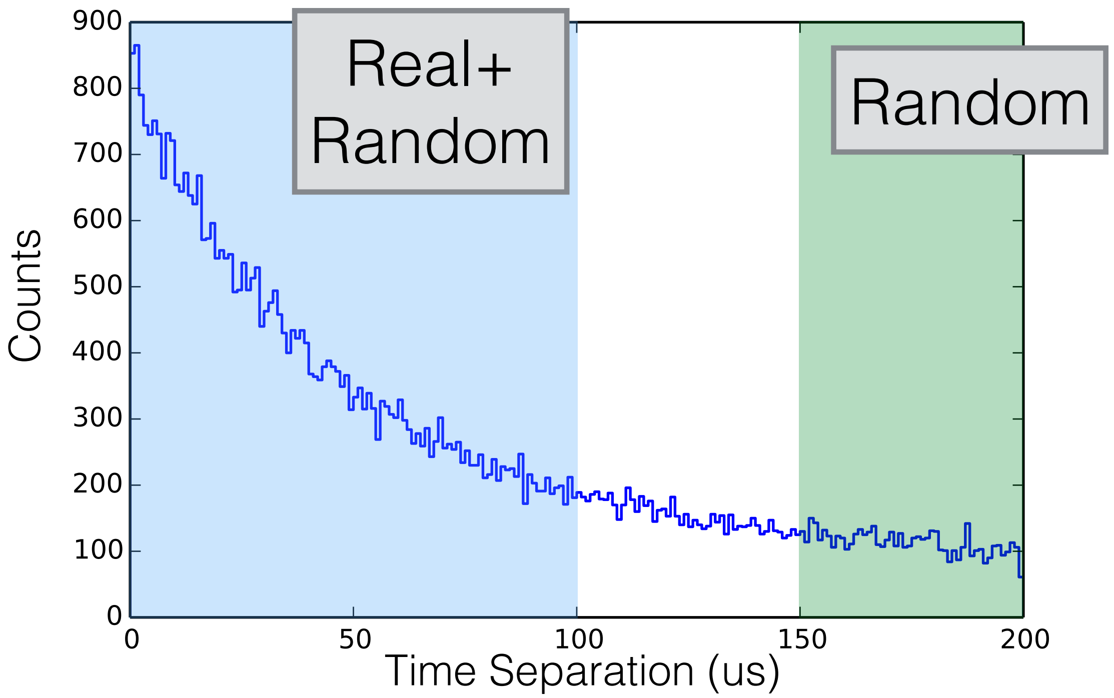
Prompt signal: 1-10 MeV positron from inverse beta decay (IBD)

Delay signal: ~0.5 MeV signal from neutron capture on ^6Li



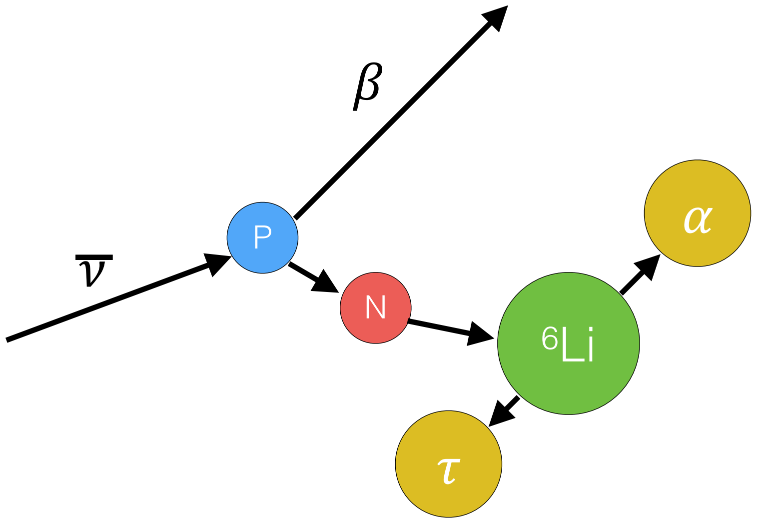
- Two types under development:
  - **LAB** and **DIPN**
- Both shown to be viable options for PROSPECT
- Optimization of light yield, pulse shape discrimination (PSD), and capture time is underway





5" Cylinder, 2Liters of LiLS, double ended readout

Li-loaded Liquid Scintillator



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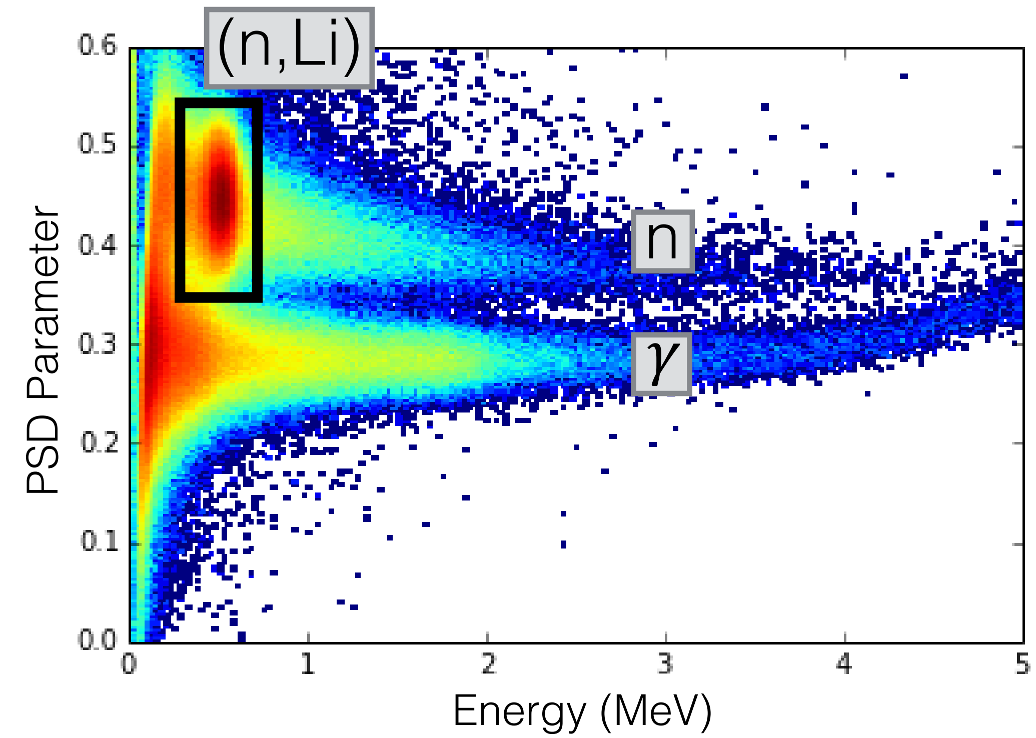

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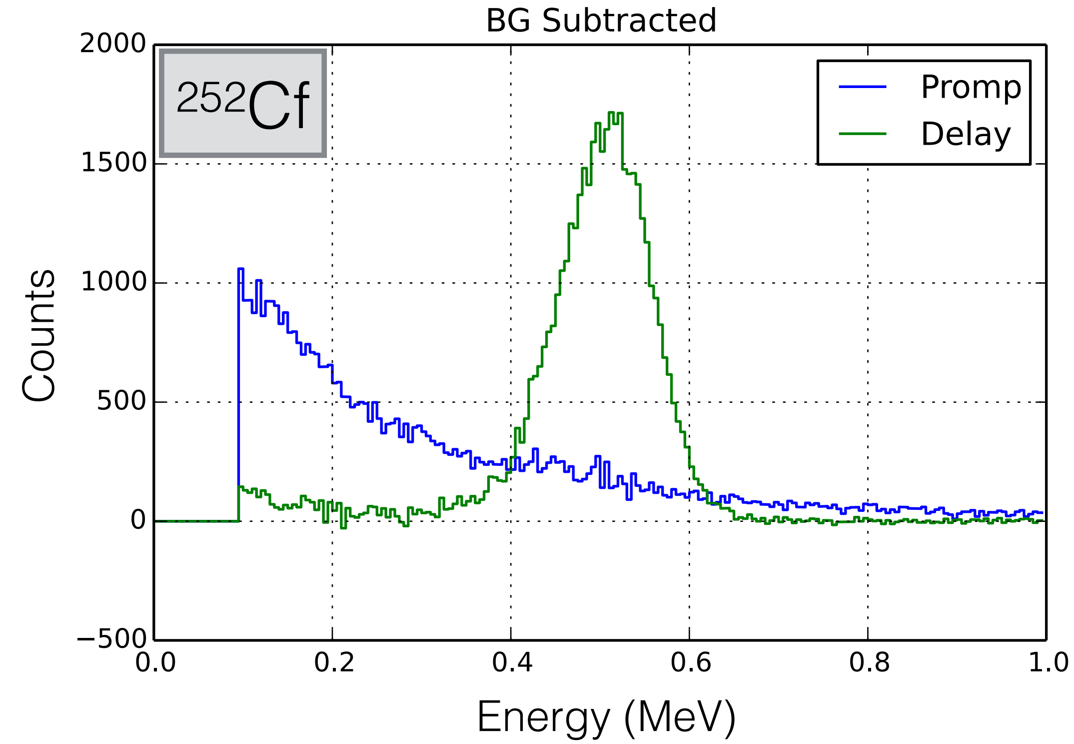
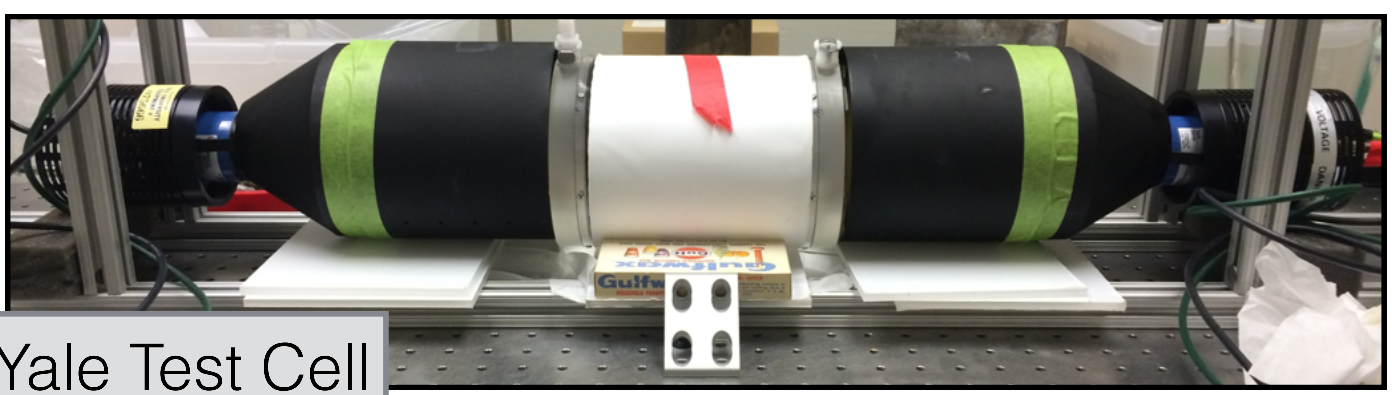




Yale Test Cell

5" Cylinder, 2Liters of LiLS, double ended readout

2D PSD for IBD Identification

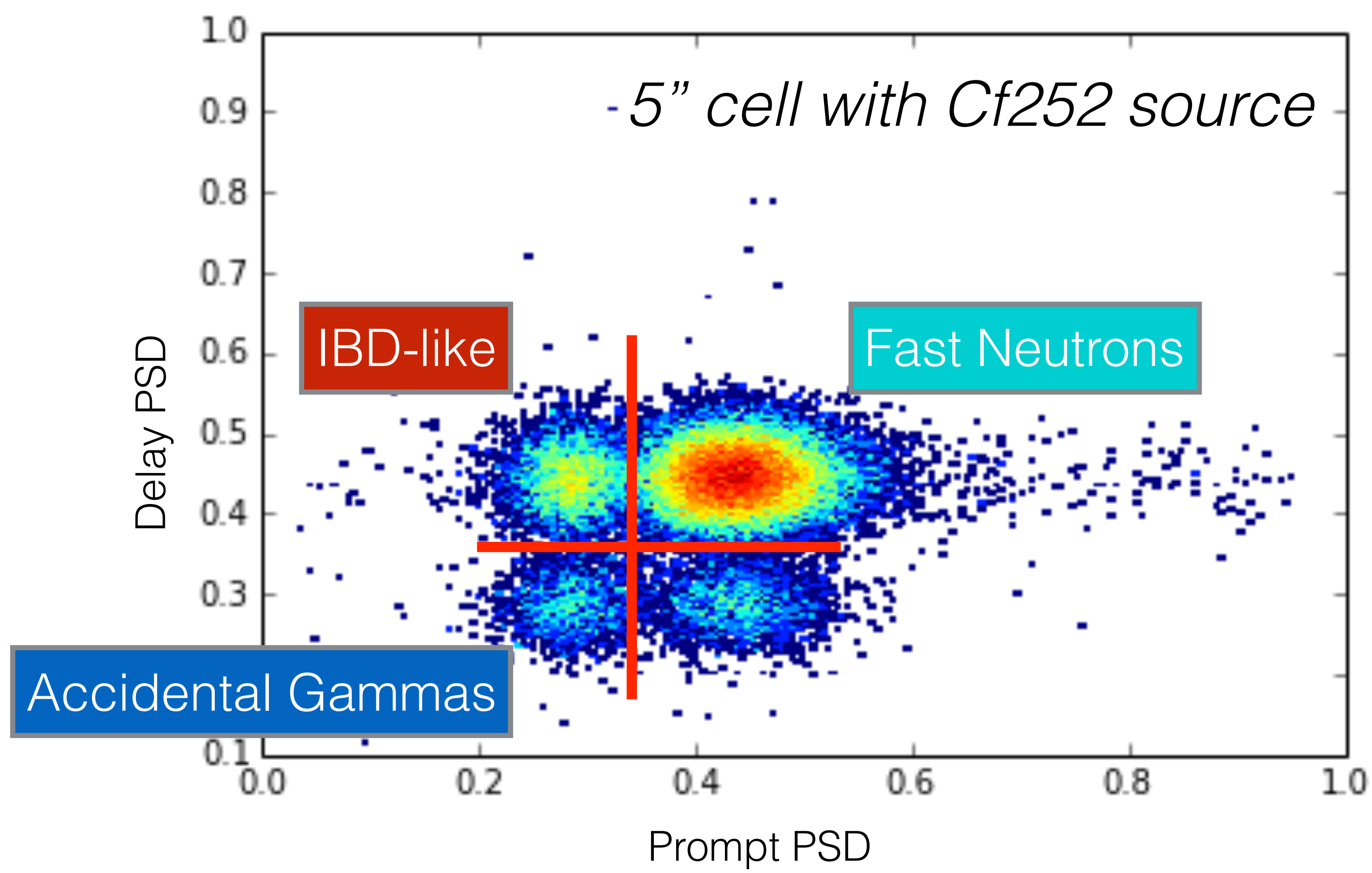
- Two dominant backgrounds at the low-overburden:
  - **Reactor-related gammas (accidental coincidences)**
  - **Cosmogenic fast neutrons (real coincidences)**
- *PSD on prompt and delayed signals rejects both types of backgrounds*

PSD Signatures

Inverse Beta Decay
γ-like prompt, n-like delay

Fast Neutron
n-like prompt, n-like delay

Accidental Gammas
γ-like prompt, γ-like delay



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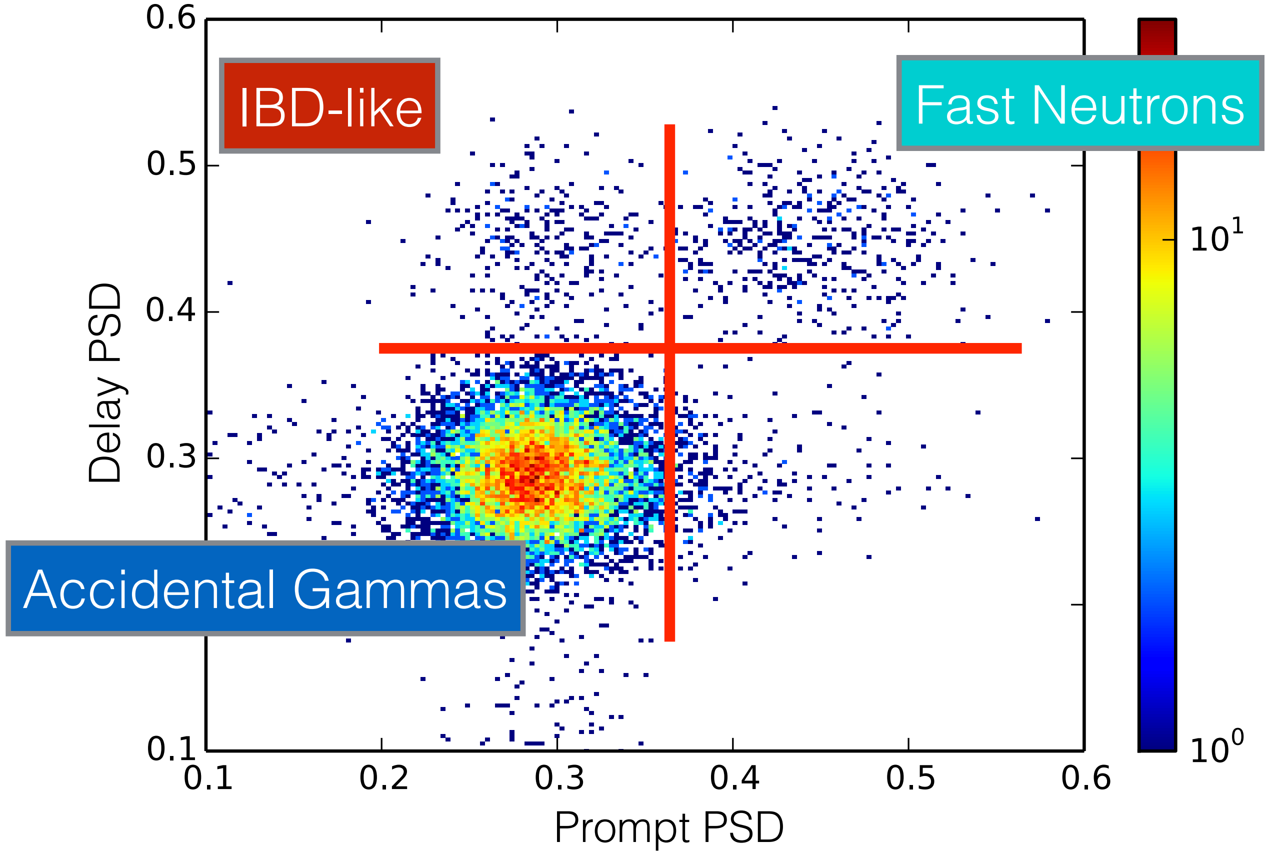
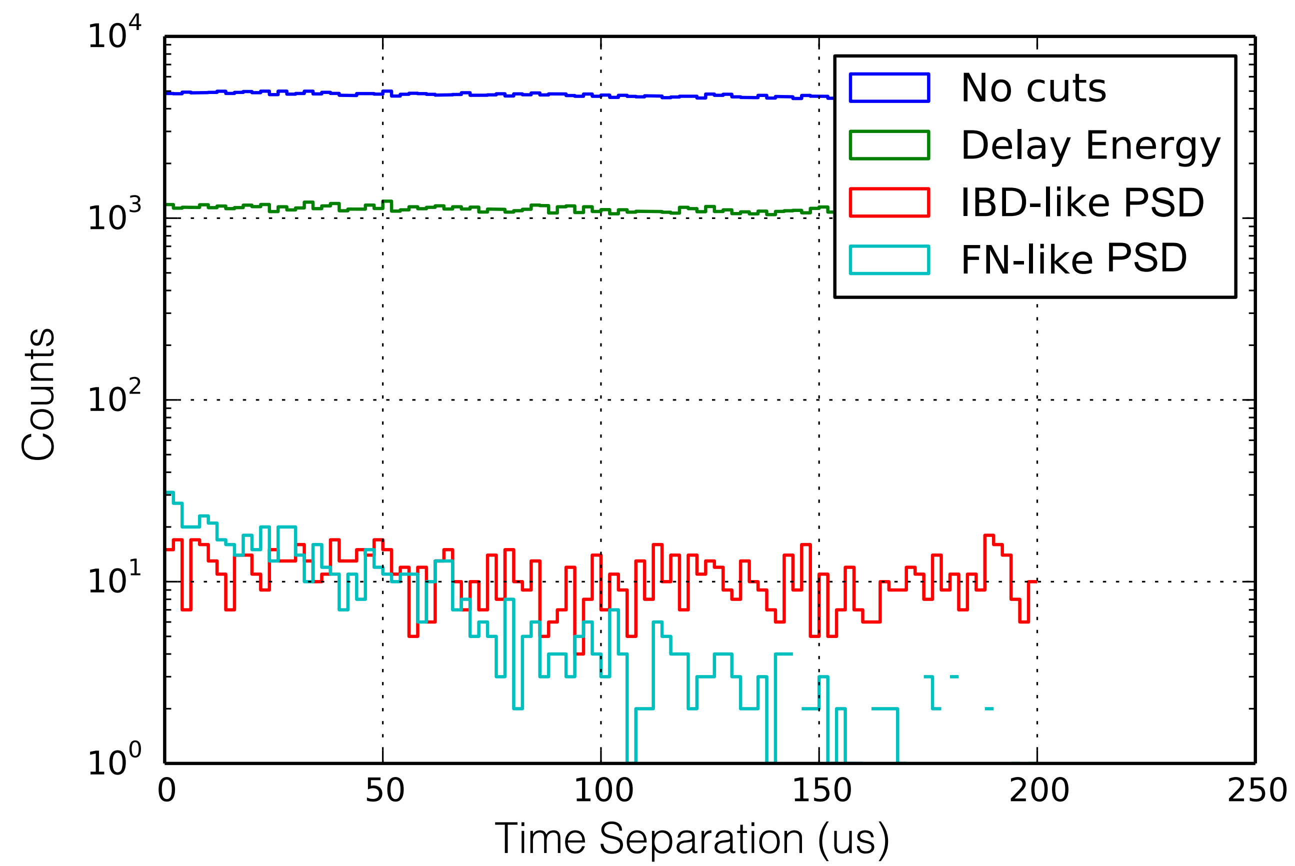
5" cell in ambient background field

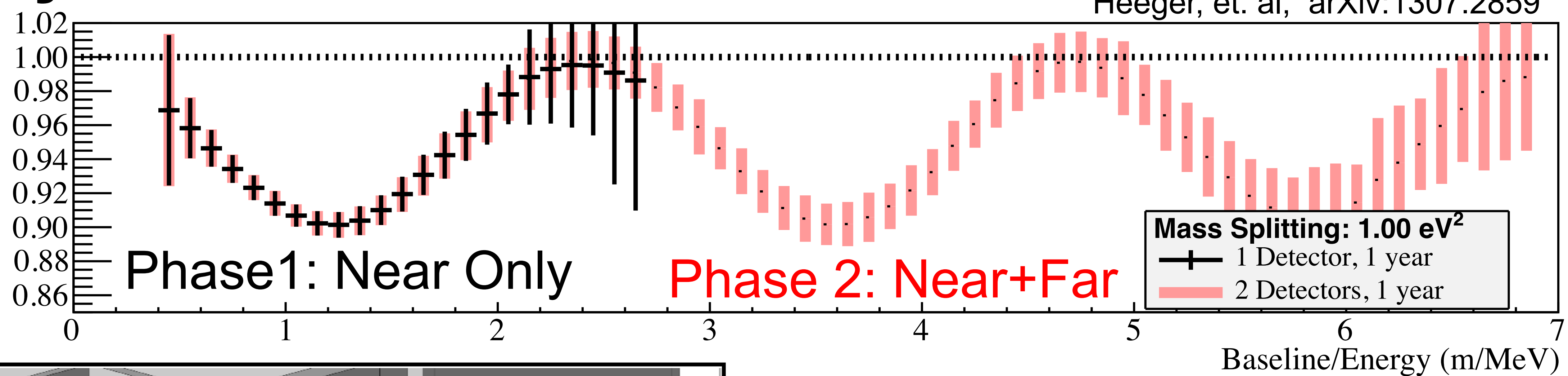


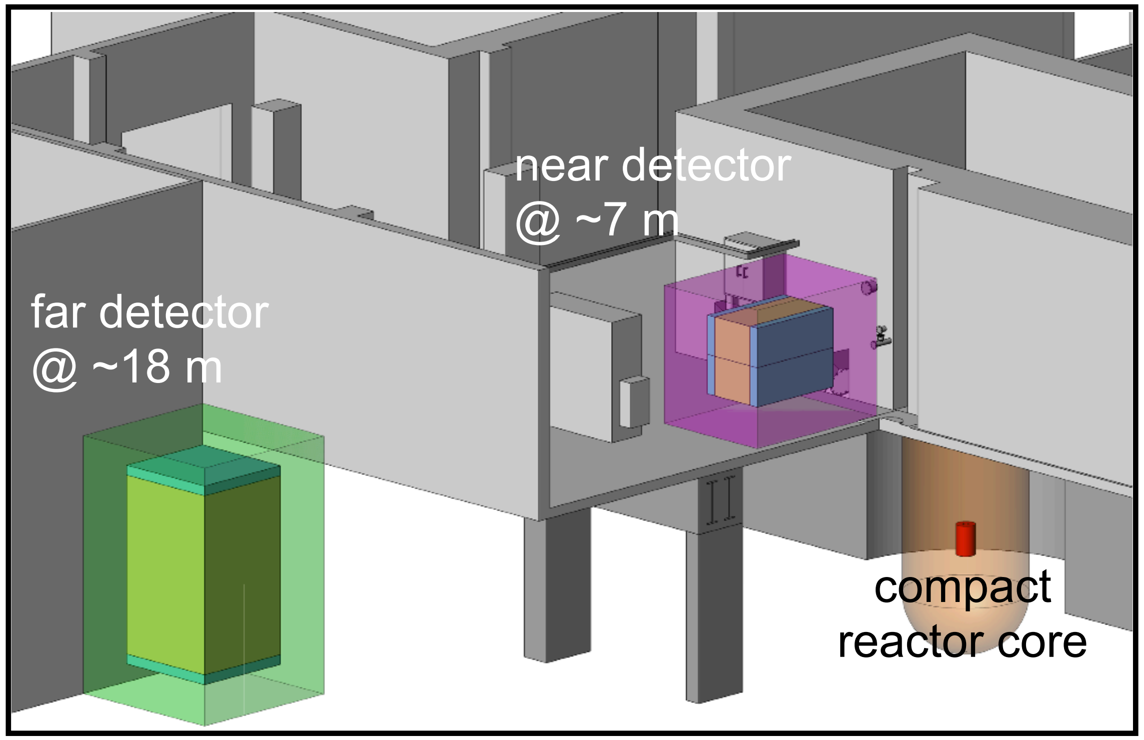
Applying cuts in energy and PSD

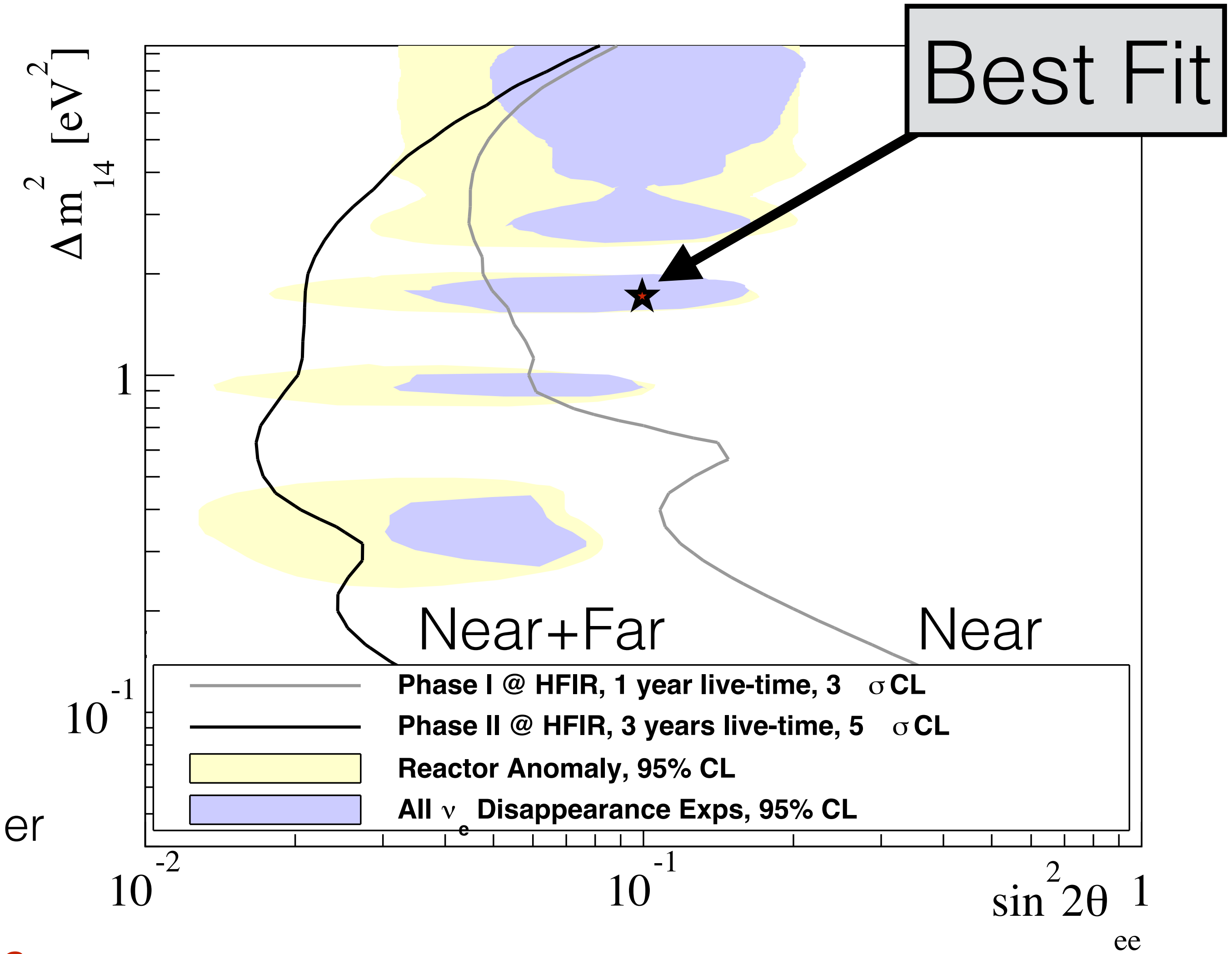


Projected PROSPECT Sensitivity

Heeger, et. al, arXiv:1307.2859





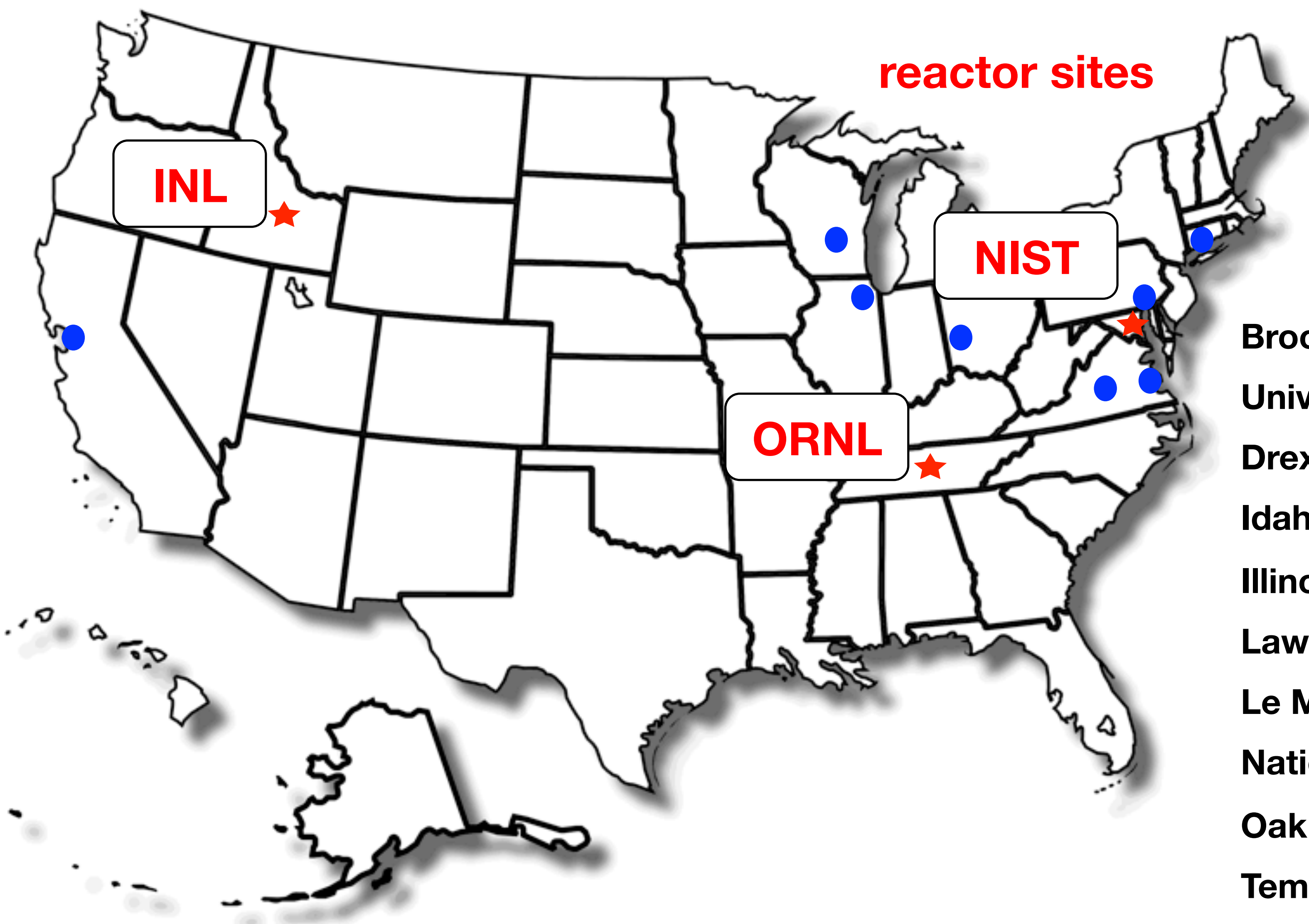


- **Phase 1:** Large near detector accumulates statistics rapidly, >1000 IBD/day
- **Phase 2:** Combined detectors cover significantly larger range of L/E
- ***"Prediction-free" analysis covers best fit in 1yr at 3σ***

Summary

- The PROSPECT experiment is a two-phase antineutrino experiment designed to make precision measurements
  - *Search for short baseline oscillations as a sign of sterile neutrinos*
  - Direct measurement of the ^{235}U antineutrino spectrum
- Backgrounds have been characterized and targeted shielding is being designed to minimize their impact
- Novel Li-loaded scintillator is ready for large scale testing and is feasible for the full experiment
- Within one year of Phase 1 operation test the best fit value of the reactor/source anomaly

PROSPECT Collaboration

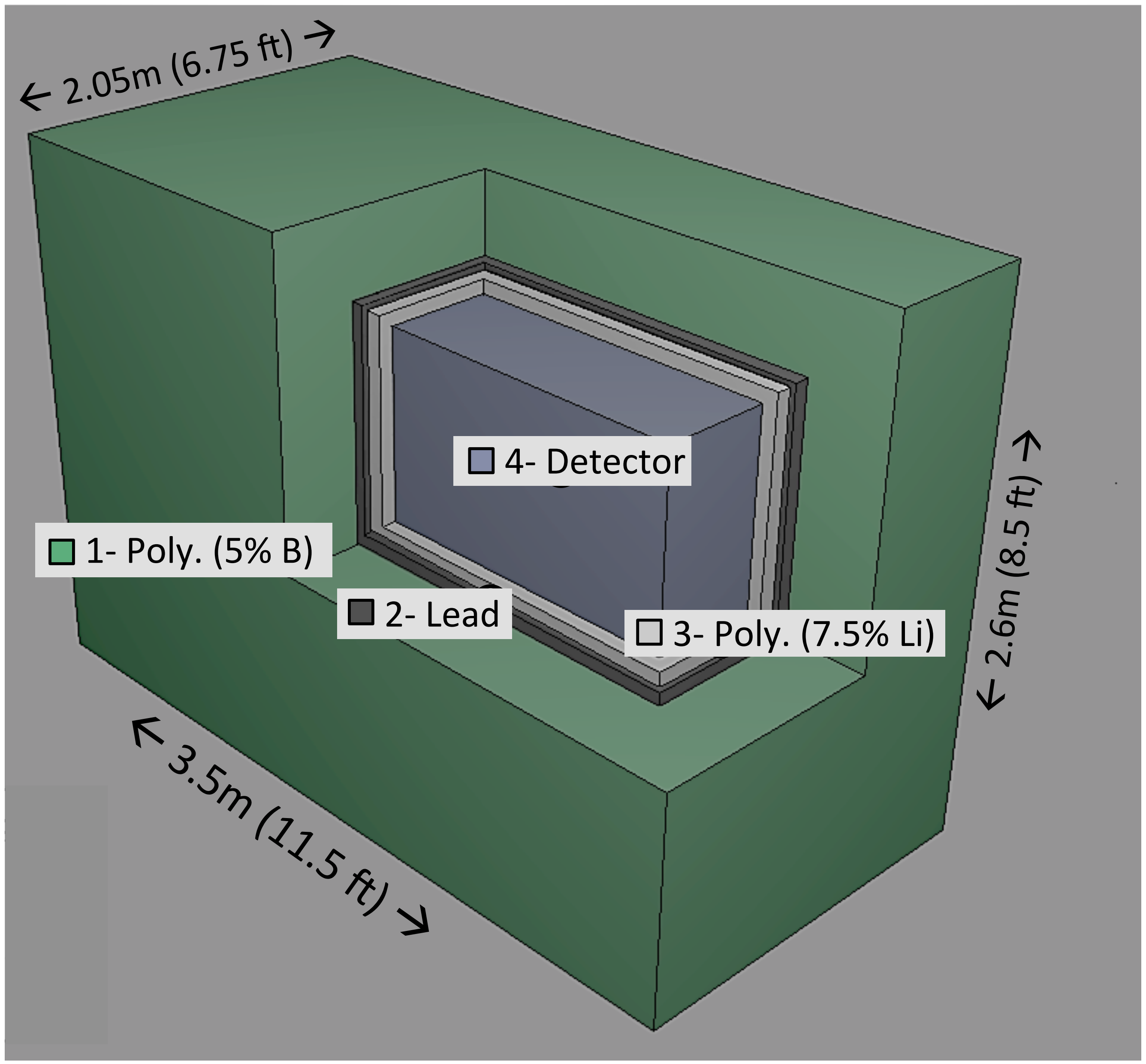


58 collaborators
11 universities
5 national laboratories

- Brookhaven National Laboratory
- University of Chicago
- Drexel University
- Idaho National Laboratory
- Illinois Institute of Technology
- Lawrence Livermore National Laboratory
- Le Moyne College
- National Institute of Standards and Technology
- Oak Ridge National Laboratory
- Temple University
- University of Tennessee
- Virginia Tech University
- University of Waterloo
- University of Wisconsin
- College of William and Mary
- Yale University

Backup

PROSPECT Shielding Design



- **Layer 1:** Borated poly to reduce thermal neutron captures on high-Z material
- **Layer 2:** Lead to shield gamma rays
- **Layer 3:** Lithiated poly to shield muon-induced neutrons from Pb.
  - Limits neutron-capture gammas from ^{10}B
- **Simulated reduction: Gammas: 4e-3, Fission-neutrons: 2e-5**
- *Currently being tested at NIST for the miniTimeCube* detector, where PROSPECT test cells will be operated and shielding models verified*

* A Portable Directional Anti-Neutrino Detector being developed by U. Hawaii, U. Maryland, and the National Geospatial Intelligence Agency