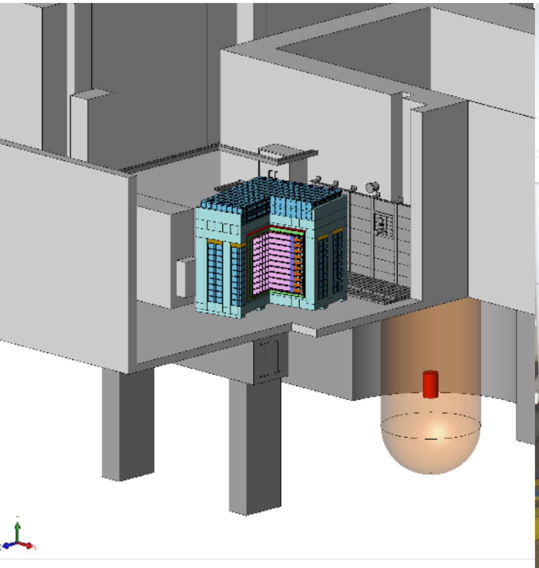
A Precision Oscillation and Spectrum Experiment

Nathaniel Bowden
For the PROSPECT collaboration

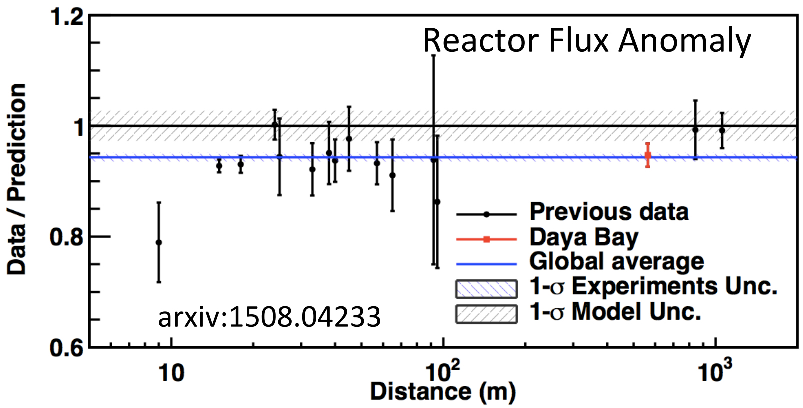
Applied Antineutrino Physics 2016



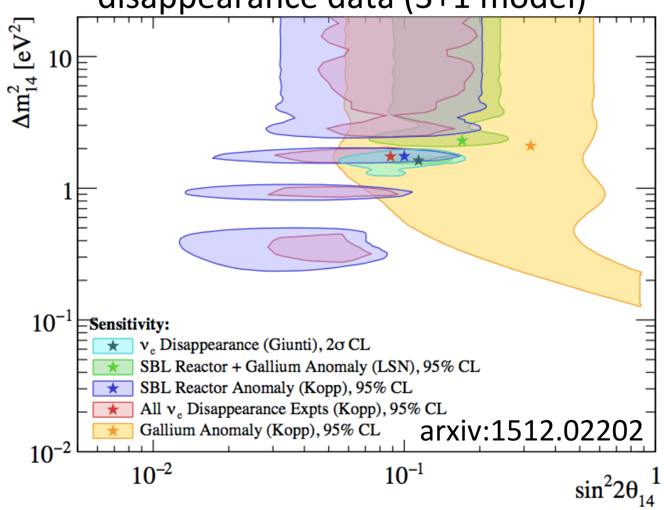
LLNL-PRES-XXXXXX
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Motivation

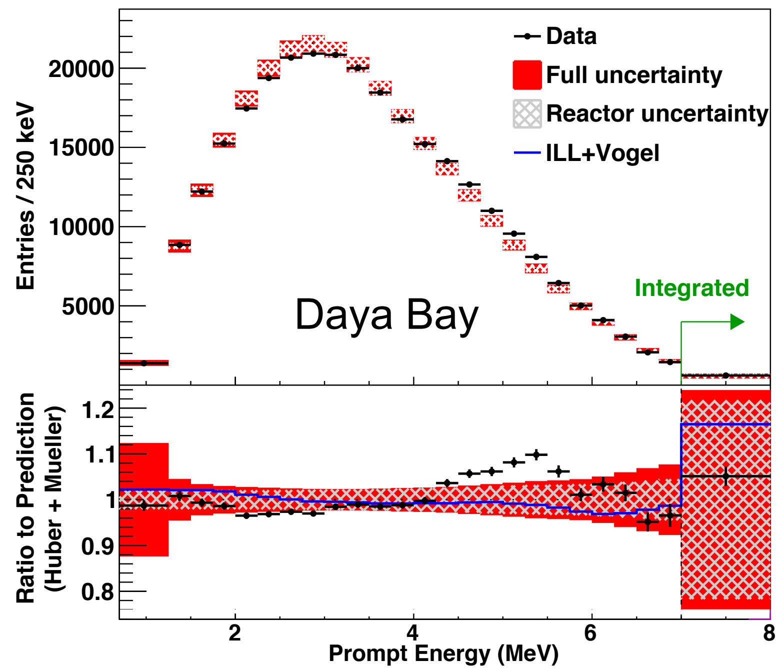
Directly test the hypothesis of a new oscillation with $\Delta m2 \sim 1$ eV^2, i.e. oscillation length of few meters



Allowed regions for ν_e disappearance data (3+1 model)



Provide new tests of reactor models by making precision measurements of novel reactor spectra, esp. ^{235}U fuel



Approach to Short Baseline Reactor Measurements

Search for relative shape distortion in identical detector segments at different baselines → eliminate reactor model dependence

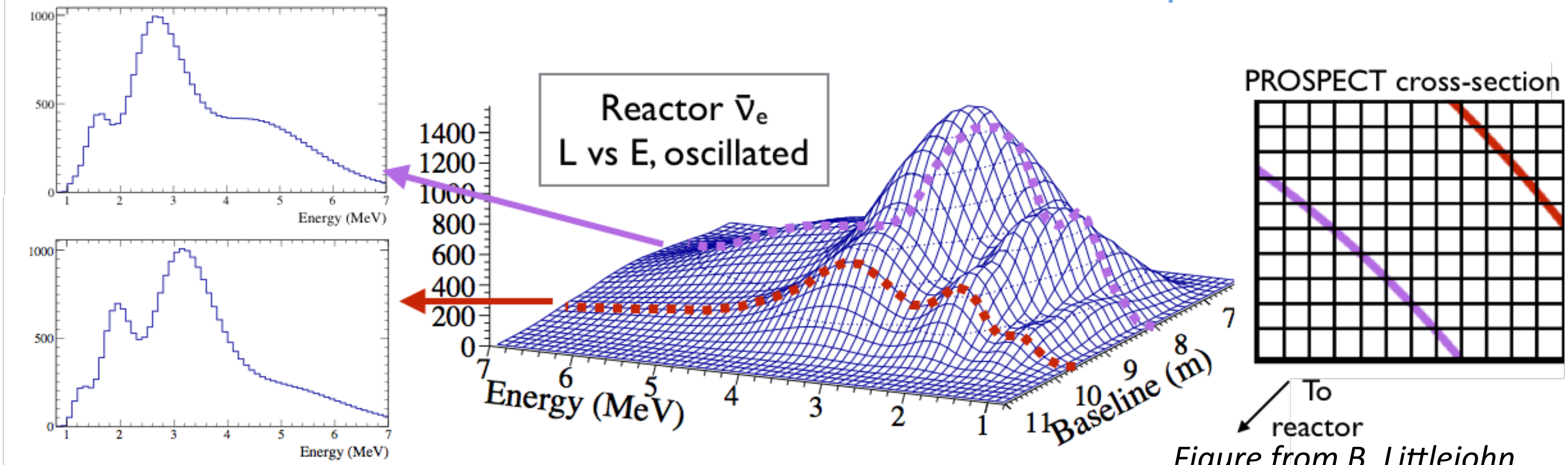


Figure from B. Littlejohn

Research reactors are *generally* preferable:

- Access to shortest baselines
- Often use ^{235}U fuel → static fissile inventory
- Compact core dimensions provide greater sensitivity at Δm2 ~ 1 eV^2

But:

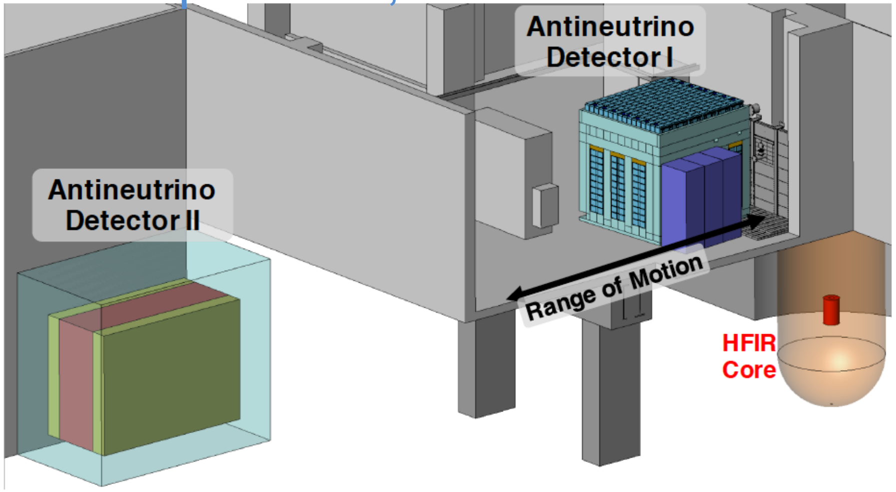
- Limited space for deployment
- Limited overburden
- Possibility of reactor generated background

PROSPECT Experiment Overview

Physics Objectives

1. Search for short-baseline oscillation at distances <10m
2. Precision measurement of ^{235}U reactor $\overline{\nu}_e$ spectrum

One Experiment, 2 Detectors



Phase I
One detector:
movable AD-I, ~7-12 m baseline

Phase II
Two detectors:
movable AD-I, ~7-12m baseline
stationary AD-II, ~15-19m baseline

- movable detector enables systematic control, background checks, and increased physics reach

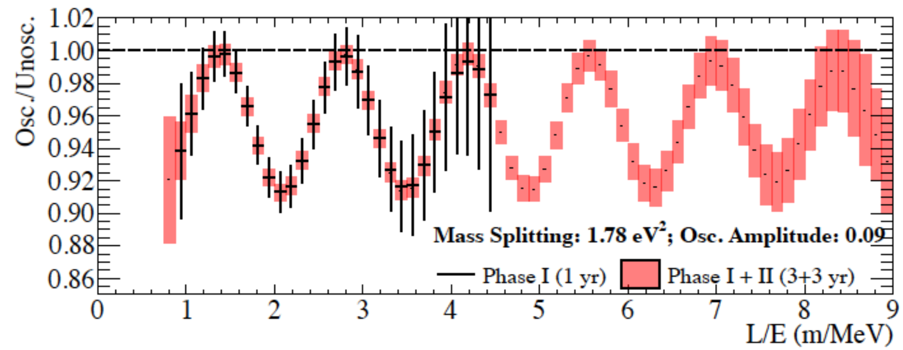
- phased approach provides path to greater senstivity

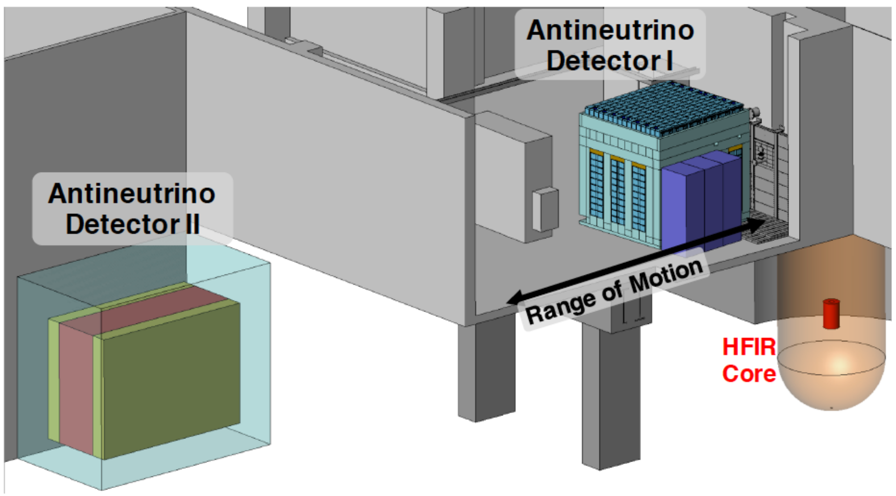
whitepaper, arXiv:1309.7647
PROSPECT collaboration

PROSPECT Physics Program
J. Phys. G, 43 113001; arXiv:1512.02202
PROSPECT collaboration

PROSPECT Physics - Precision Oscillation Experiment

A model independent experimental approach to test for oscillation of eV-scale neutrinos

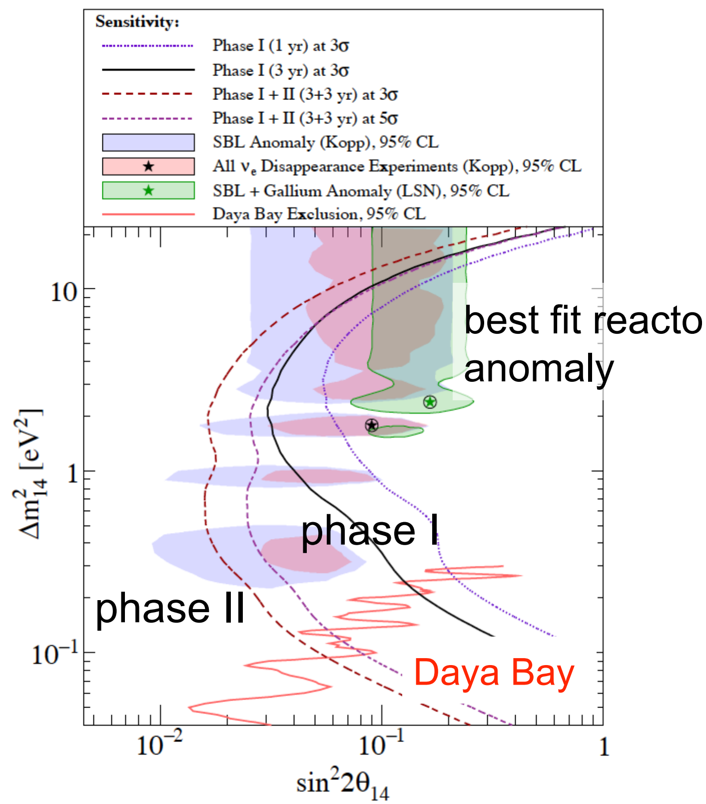




Phase I = AD-I, 3 years
Phase II = AD-I + AD-II, 3+3 years

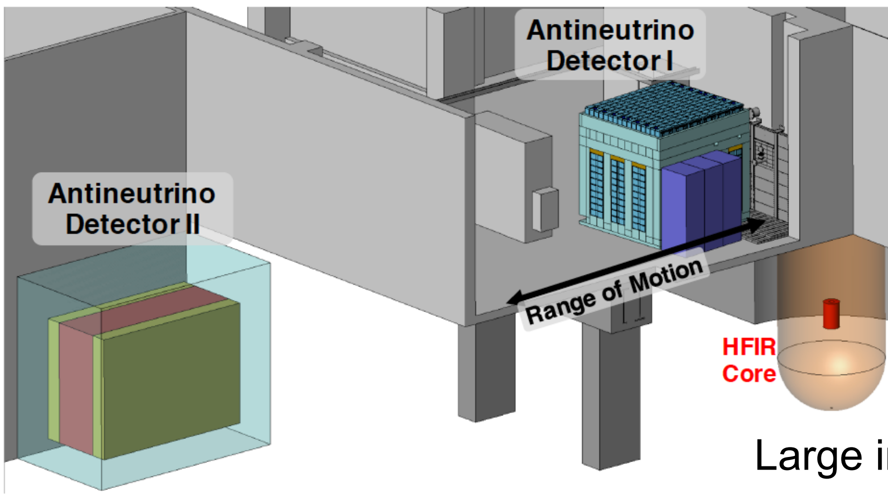
Objectives

4σ test of best fit after 1 year
>3σ test of favored region after 3 years
5σ test of allowed region after 3+3 years



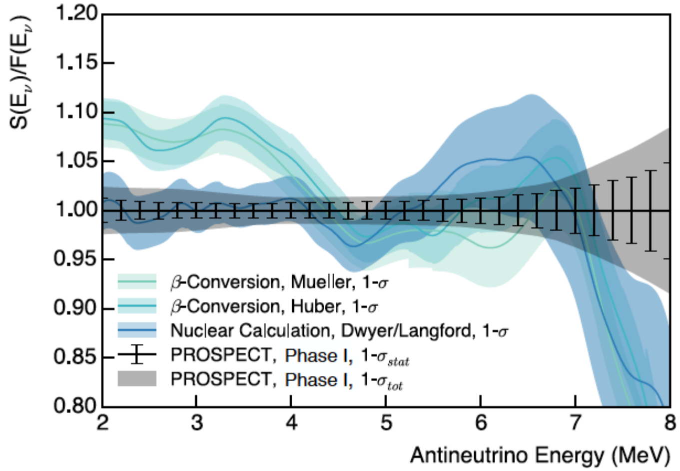
PROSPECT Physics - Precision Spectrum Experiment

A precision measurement to address spectral unknowns



Phase I = AD-I only

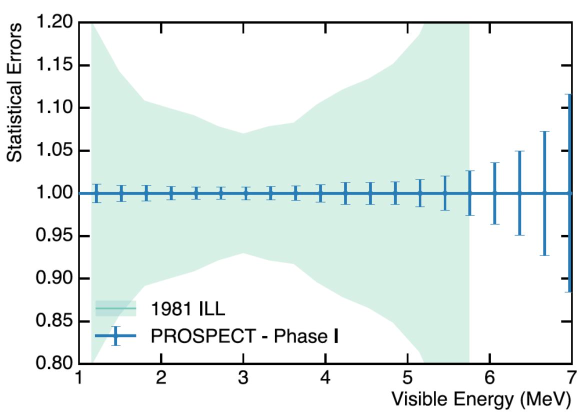
Testing $^{235}U\ \bar{\nu}_e$ spectrum models



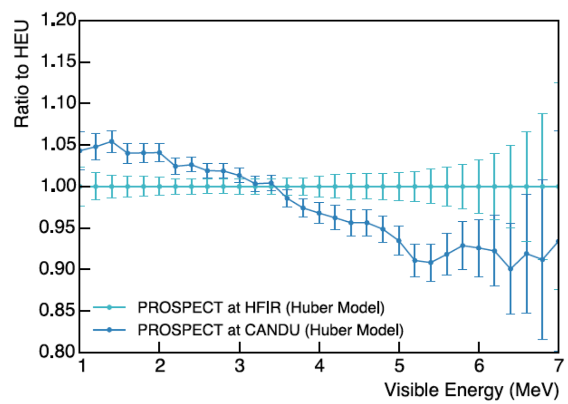
Objectives

Measurement of ^{235}U spectrum
Compare different reactor models
Compare different reactor cores

Large improvement on ILL

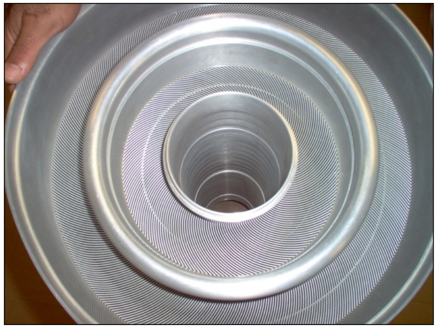


Different reactor cores

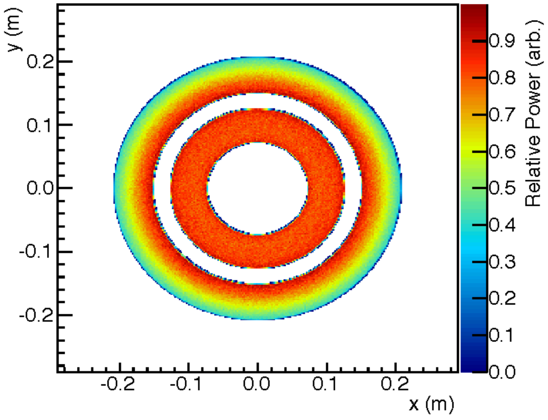


Experimental site: High Flux Isotope Reactor @ORNL

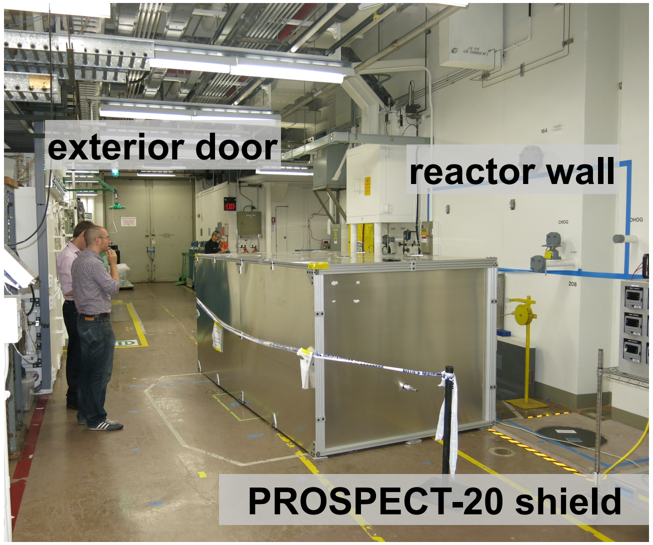
Compact Reactor Core

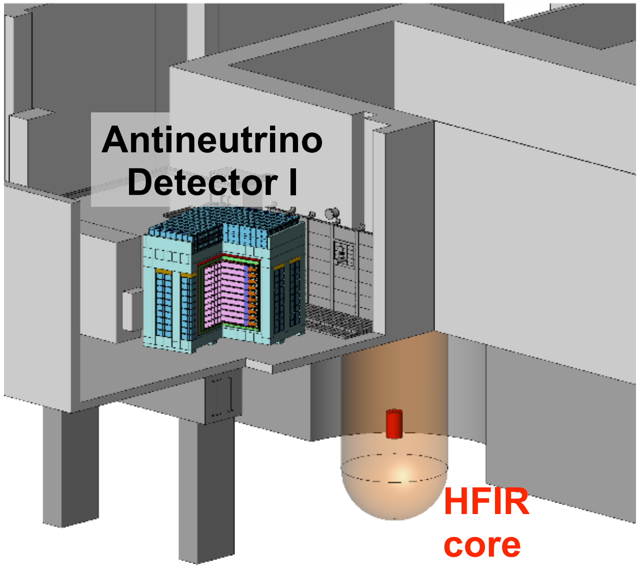


Power: 85 MW
Fuel: HEU (^{235}U)
Core shape: cylindrical
Size: h=0.5m r=0.2m
Duty-cycle: 41%

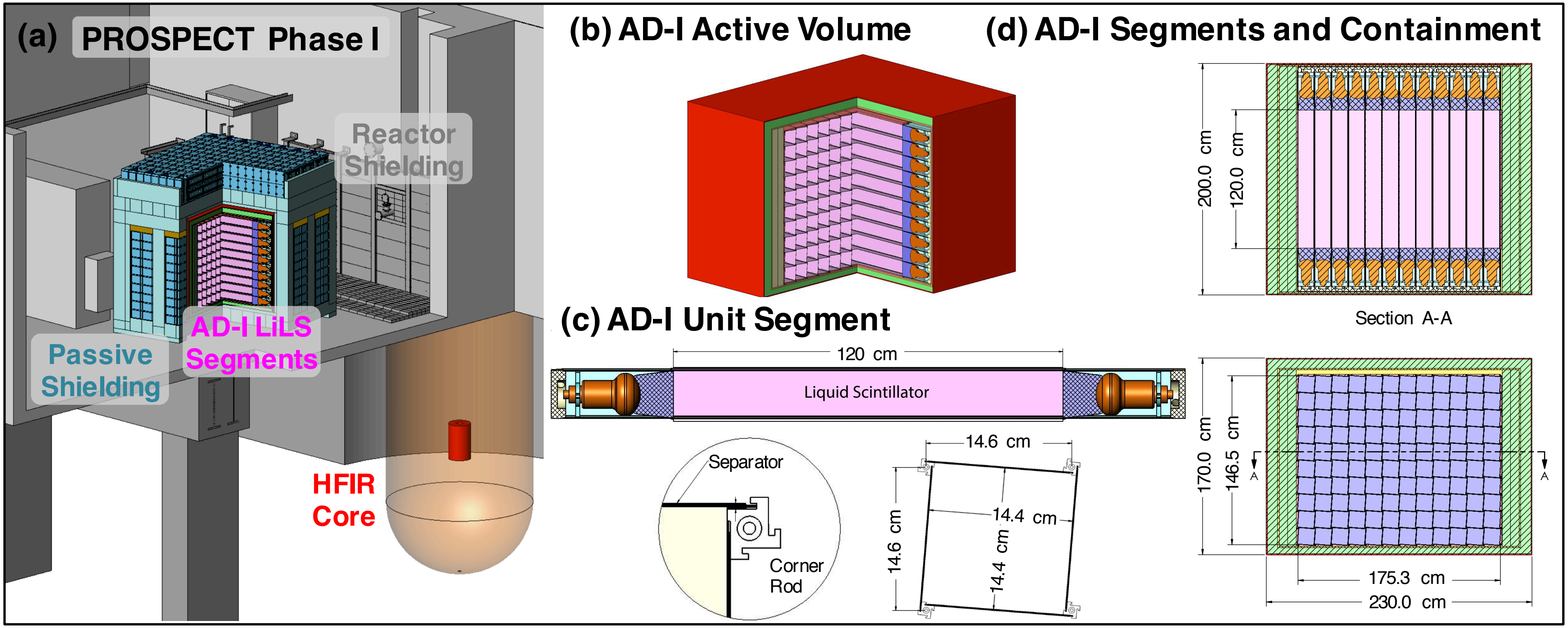


- Established on-site operation
- User facility, easy 24/7 access
- Exterior access at grade
- Full utility access, incl. internet





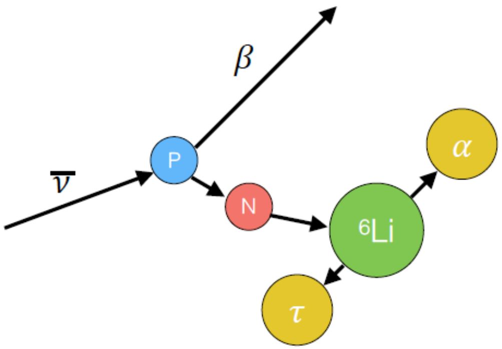
PROSPECT Phase I Antineutrino Detector



- 3000L of ^{6}Li loaded liquid scintillator
- 10x12 segmented optical array, ~15 x 15 x 120 cm^3 segment dimensions
- Double ended PMT readout, light guides, ~4.5%/√E resolution
- Low mass optical separators, minimal dead material
- Full volume calibration access
- Containment vessel, filled in place

Event Detection in PROSPECT AD-1

Event Identification



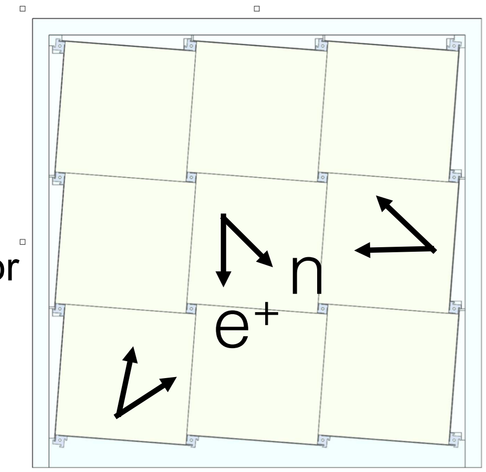
Prompt signal: 1-10 MeV positron from inverse beta decay (IBD)

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

40μs delayed n capture

Background reduction through **detector design & fiducialization**

IBD event in segmented ^{6}LiLS detector

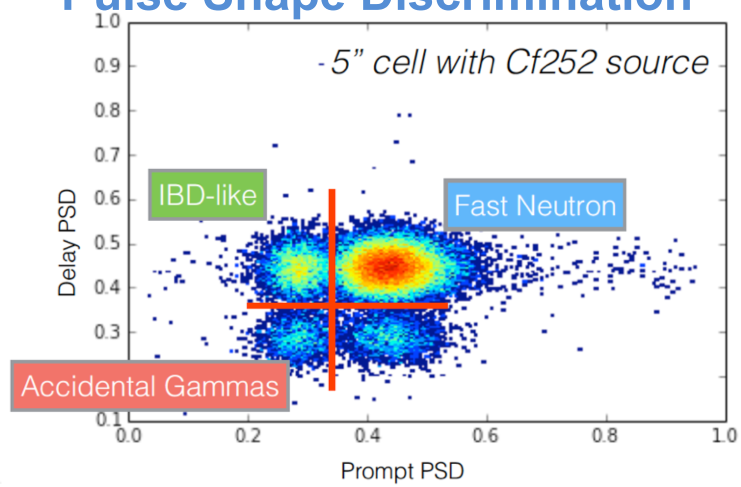


inverse beta decay (IBD)
γ-like prompt, n-like delay

fast neutron background
recoil-like prompt, capture-like delay
capture-like prompt, capture-like delay

accidental gamma background
γ-like prompt, γ-like delay

Pulse Shape Discrimination



Background reduction is key challenge

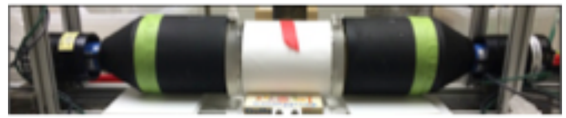
PROSPECT Detector & Shielding Development

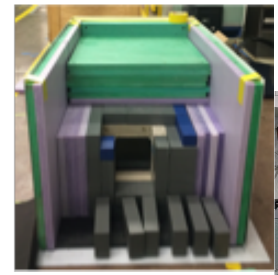
PROSPECT-0.1
Characterize LS
Aug 2014-Spring 2015

5cm length
0.1 liters
LS, ^{6}LiLS

PROSPECT-2
Background studies
Dec 2014 - Aug 2015

12.5 length
1.7 liters
^{6}LiLS

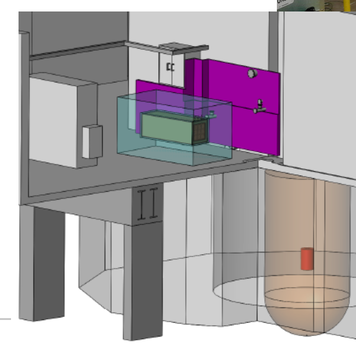




multi-layer shielding

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

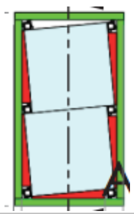
1m length
23 liters
LS, ^{6}LiLS



local reactor shielding

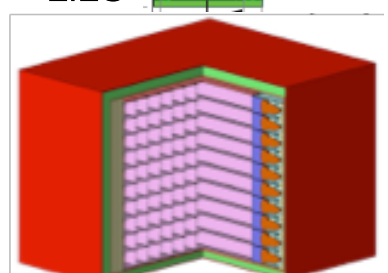
PROSPECT-50
Baseline design prototype
Spring 2016

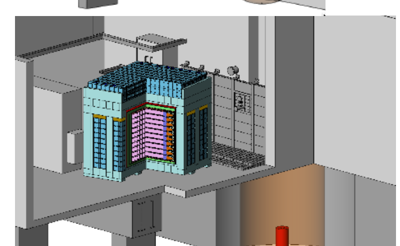
1x2 segments
1.2m length
50 liters
^{6}LiLS



PROSPECT AD-I
Physics measurement
2017

10x12 segments
1.2m length
~3 tons
^{6}LiLS

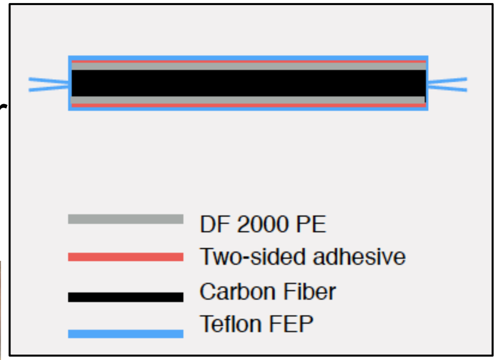




Development of PROSPECT Detector Components

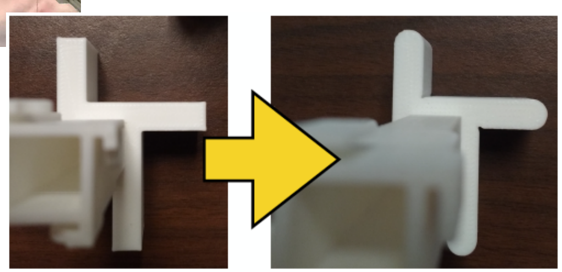
Low-Mass Optical Separators

High reflectivity, high rigidity, low mass reflector system developed

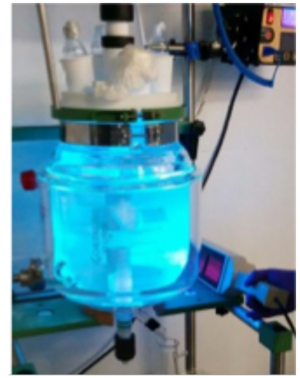


- Array formed using 3D printed “pinwheel” spacers
- Chemical compatibility of all materials validated

Component design refined for final production



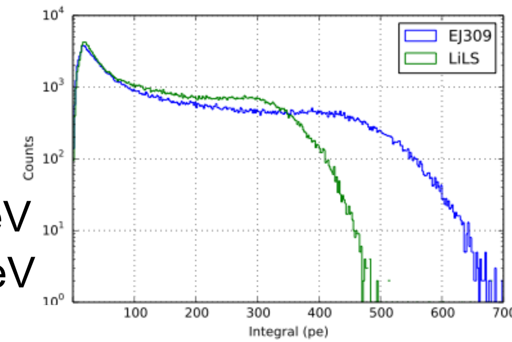
^{6}Li-Loaded Liquid Scintillator

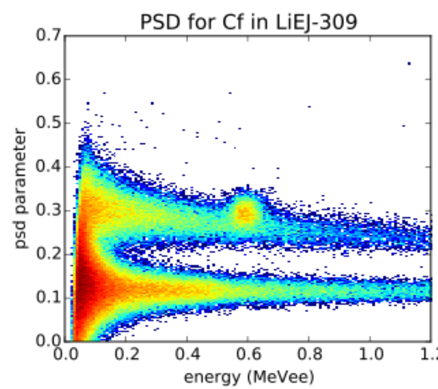


- Developed non-toxic, non-flammable formulations based on EJ-309, LAB, Ultima Gold
- EJ-309 selected as baseline

Light Yield

- EJ-309 base: 11500 ph/MeV
- LiLS: 8200 ph/MeV





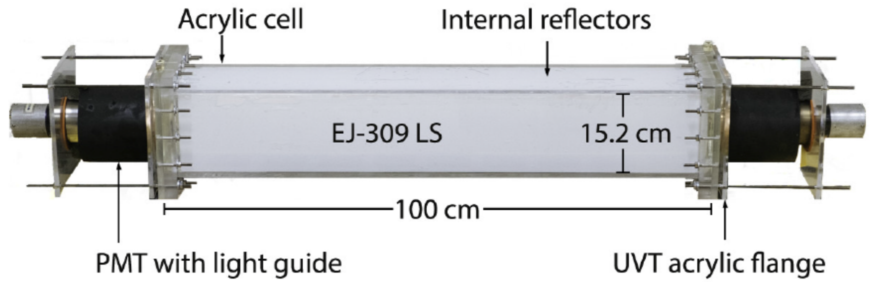
Excellent PSD performance for neutron capture & heavy recoils

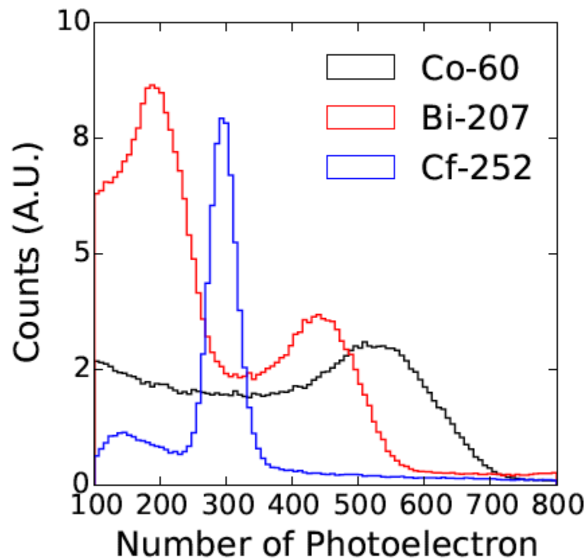
Full-scale production for PROSPECT AD-1 underway

Full Scale Prototyping - PROSPECT20

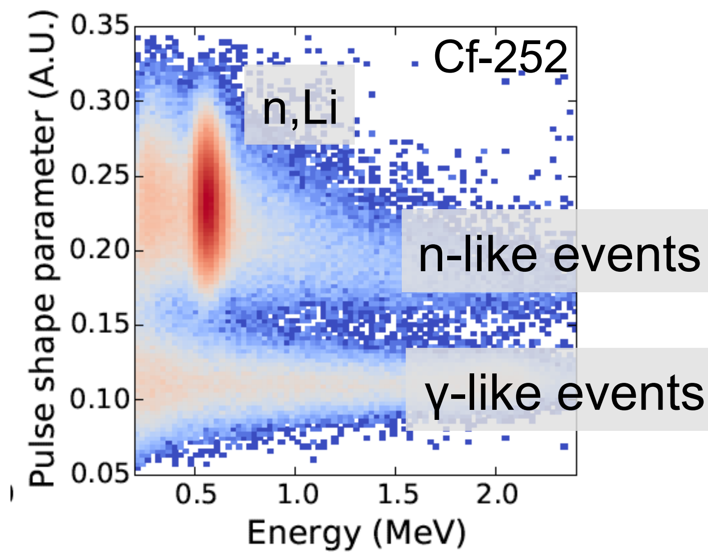
Validates optical system design

- Li-loaded liquid scintillator
- Reflector panels





Light Yield/ PE Spectra



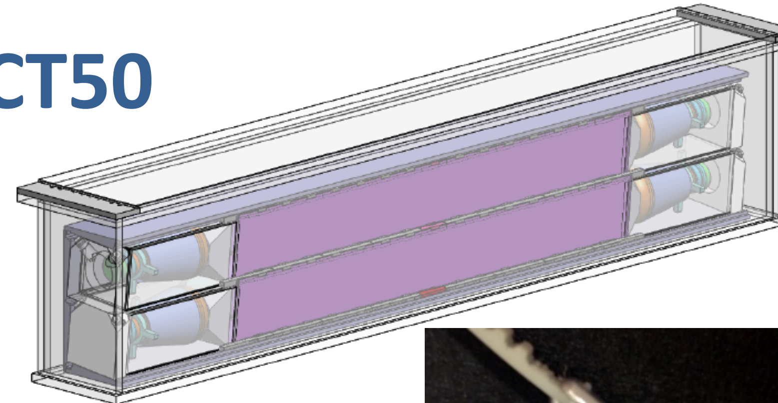
Pulse Shape Discrimination

- Compton edge of ^{60}Co and ^{217}Bi γ-rays and the quenched (n, Li) capture peak from ^{252}Cf neutrons
- light collection: **522±16 PE/MeV**

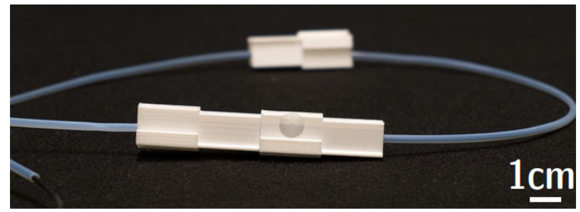
Unloaded LS studies described in 2015 JINST 10 P11004, arXiv:1508.06575, PROSPECT collaboration

System Prototyping – PROSPECT50

Validates AD-1 component design

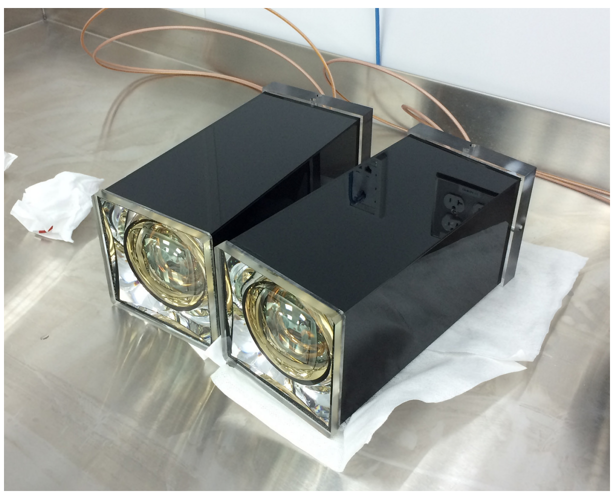


- Low-mass Optical Separators
- Support Structure
- PMT modules
- Filling System
- Calibration: LED & γ/n Sources



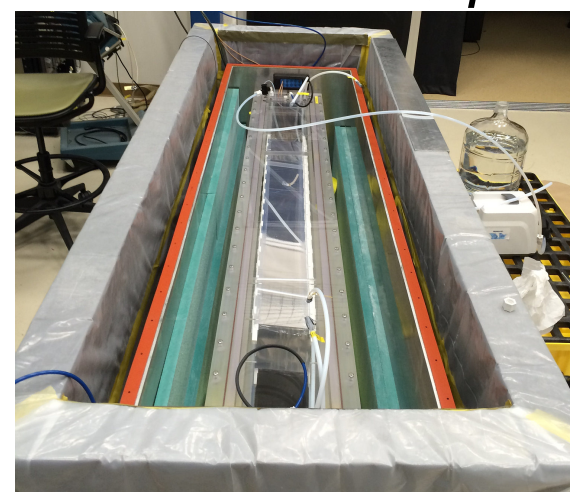
Mid-Segment LED Calibration

Source Capsule



PMT Modules

Segment Assembly



P-50 Installed in Shield

PROSPECT50 performance as expected based on earlier prototypes

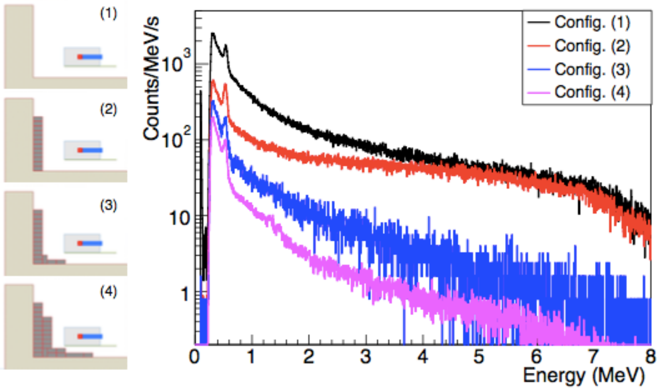
Detailed technical publication forthcoming

Reactor Background Measurement & Shield Design

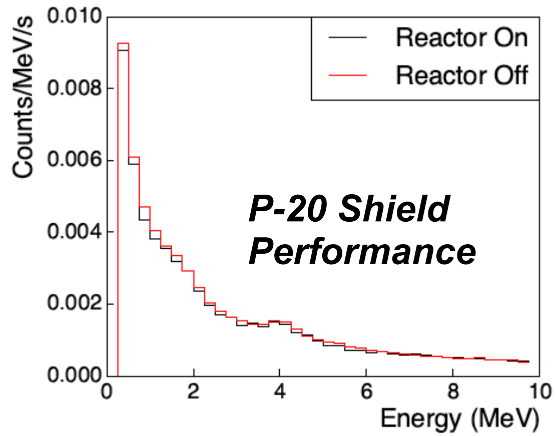
Shield design based on surveys & multiple onsite prototype deployments

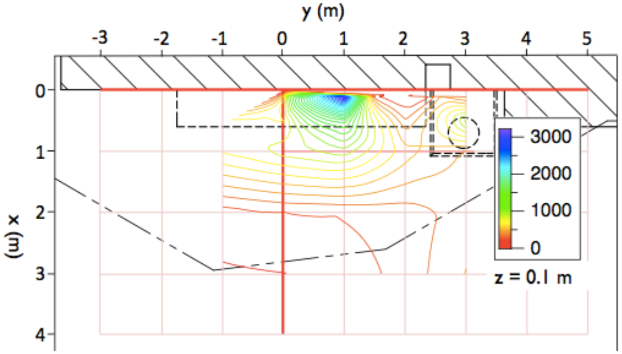
Extensive measurement campaigns (*ongoing*):

- Characterize background field at HFIR
- Emphasize importance of localized shielding of penetrations, pipes, etc



Localized shielding studies



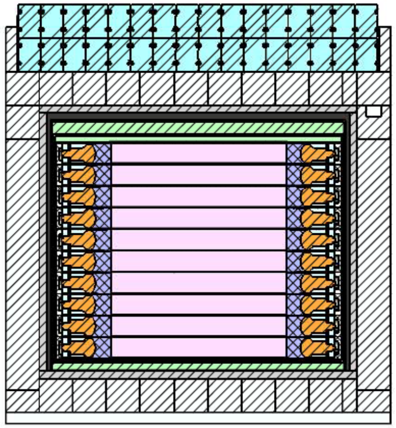


γ-ray intensity variation at HFIR

Nucl. Instrum. Meth. A806 (2016) 401–419, arXiv:1506.03547, PROSPECT Collaboration

PROSPECT AD-1 Shielding

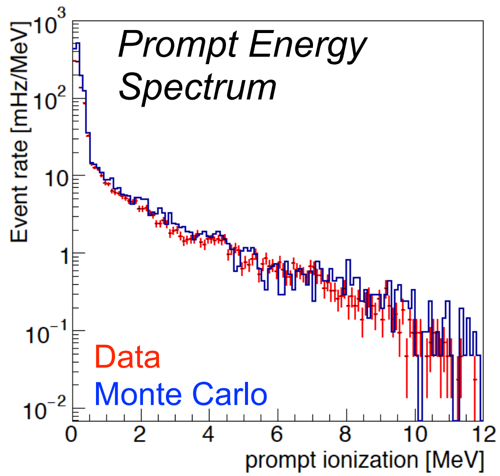
- local shielding next to reactor wall
- multi-layer passive shield:
  - water bricks, HDPE, borated HDPE, lead

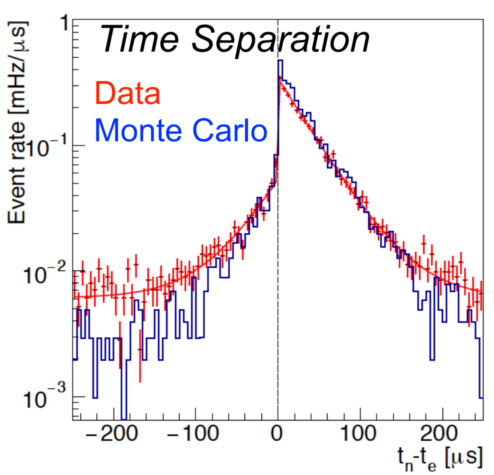


AD-1 Multi-Layer Shield

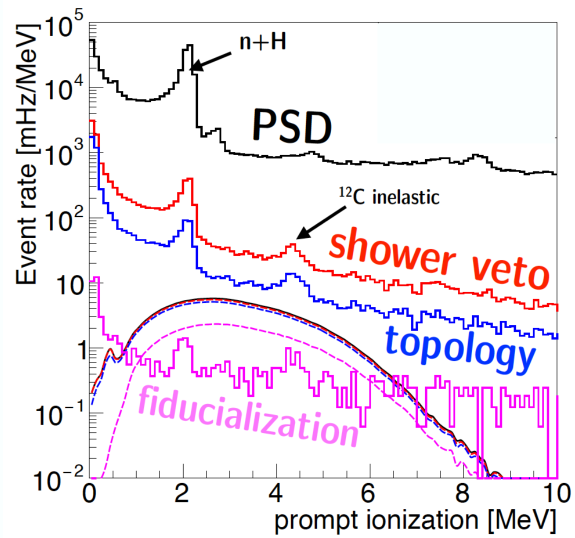
Signal to Background Prediction

Prototype systems provide benchmarking of AD-1 Monte Carlo



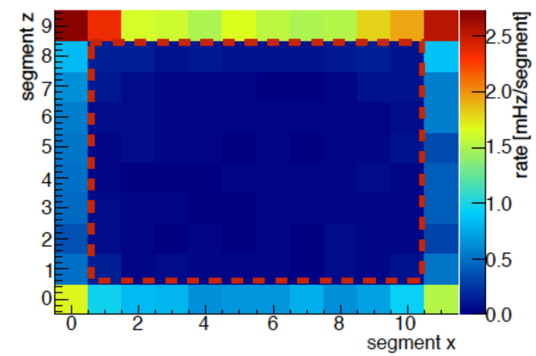


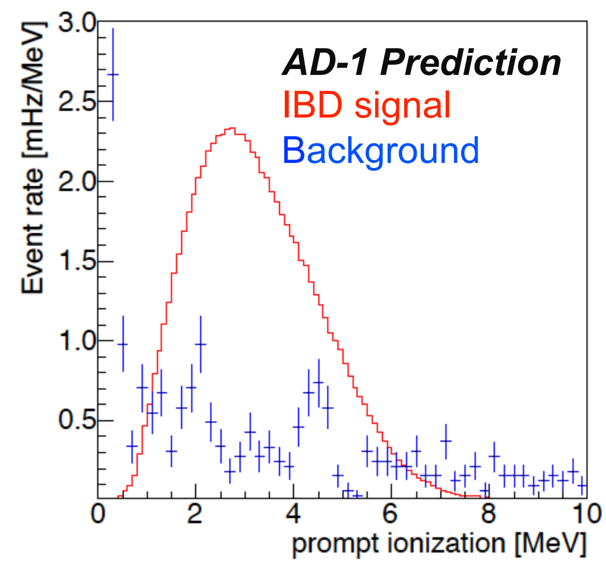
PROSPECT20 Correlated Background Measurements



Background rejection via:

- Efficient PSD & neutron identification
- Multi-interaction & multi-particle identification
- Fiducialization

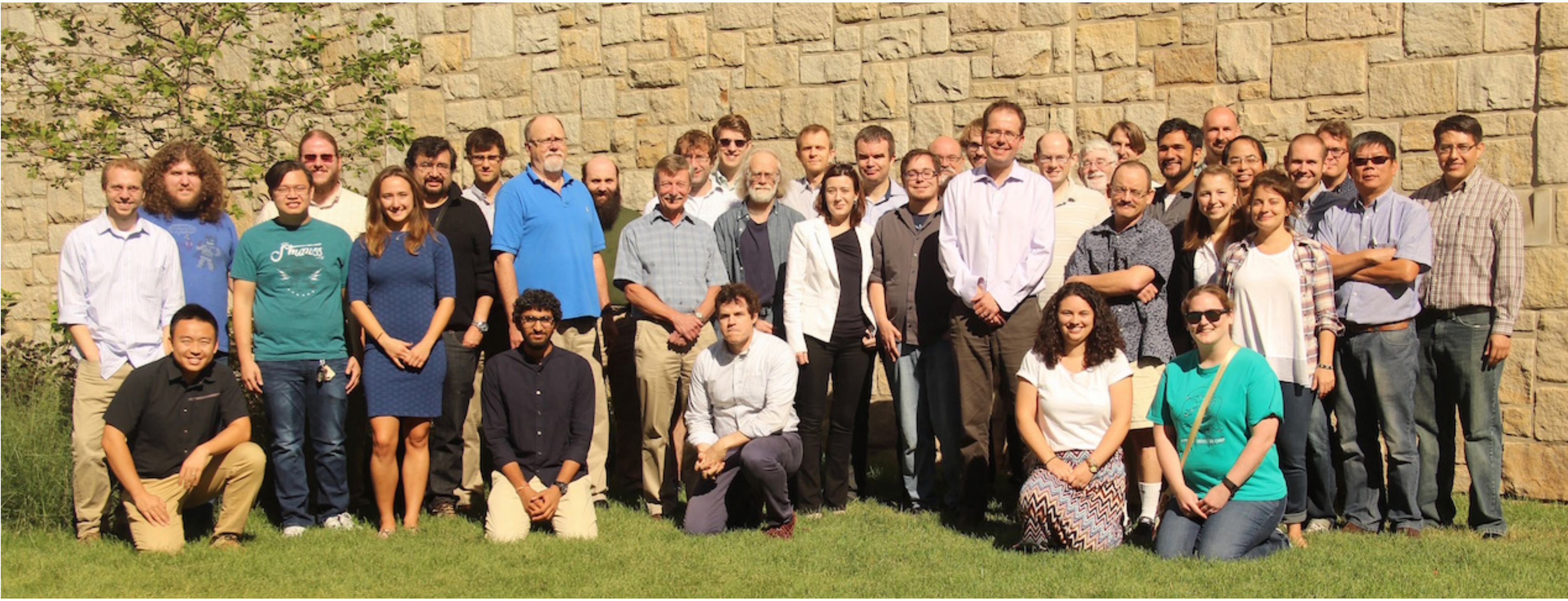




S/B better than 1:1 is predicted for PROSPECT AD-1. Rate and shape of residual IBD-like background can be measured during numerous reactor off periods.

PROSPECT Collaboration

PROSPECT



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Conclusion

- New data are required to address the rate and spectrum reactor anomalies
- PROSPECT Phase I will
  - Probe favored region for eV-scale sterile neutrinos at >3σ with 3 years of data
  - Measure the ^{235}U $\bar{\nu}_e$ spectrum, addressing the observed spectral deviation, and providing new constraints on reactor antineutrino models complementary to current and future LEU measurements
- The PROSPECT R&D Program has:
  - developed LiLS detector technology that can mitigate reactor- and cosmogenic related backgrounds
  - Deployed multiple detectors at HFIR to validate models and operating procedures and prepare for full-size system deployment
  - Completed validation of system components for full scale production
- Proceeding with construction of the Phase I Antineutrino Detector
  - Ready to proceed with Phase II development
- Data taking expected to commence in 2017