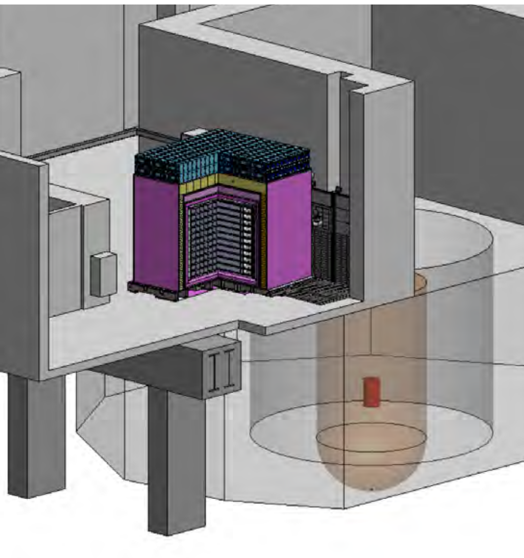
PROSPECT
Precision Oscillation and Spectrum Experiment



Karsten M. Heeger
Yale University

on behalf of the PROSPECT collaboration

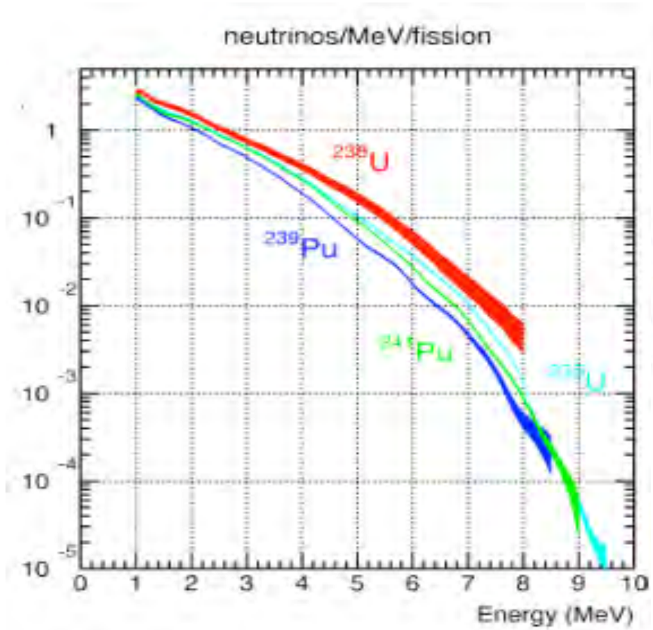
Wright Laboratory

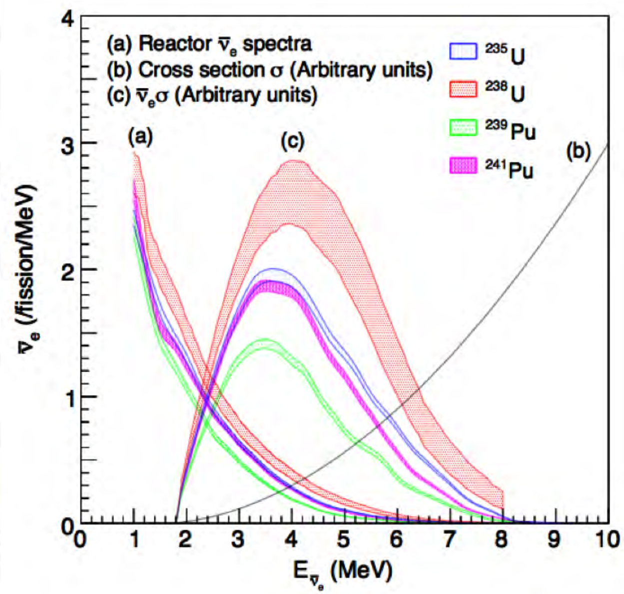
Yale

Reactor Antineutrinos

$\bar{\nu}_e$ from β-decays, pure $\bar{\nu}_e$ source

of n-rich fission products
on average ~6 beta decays until stable





> 99.9% of $\bar{\nu}_e$ are produced by fissions in
^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu

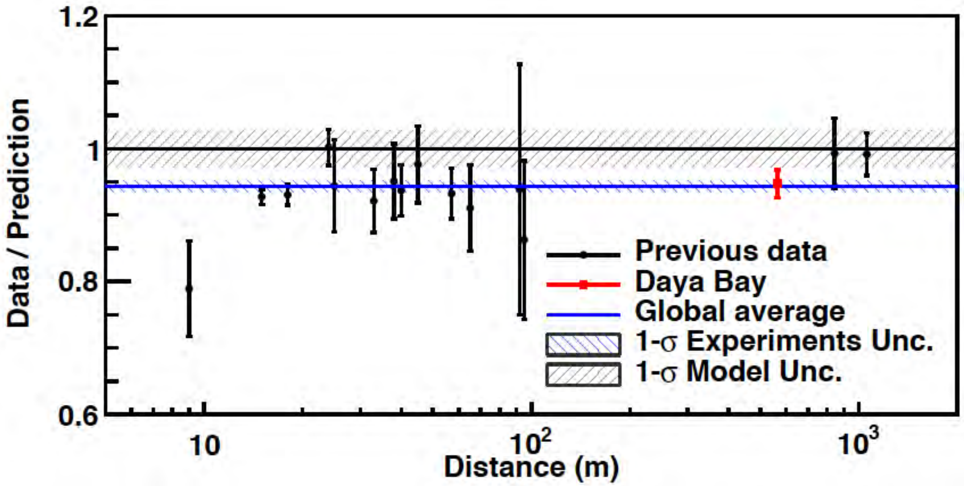
mean energy of $\bar{\nu}_e$: 3.6 MeV

only disappearance
experiments possible

Reactor Antineutrino "Anomalies"

Flux Deficit

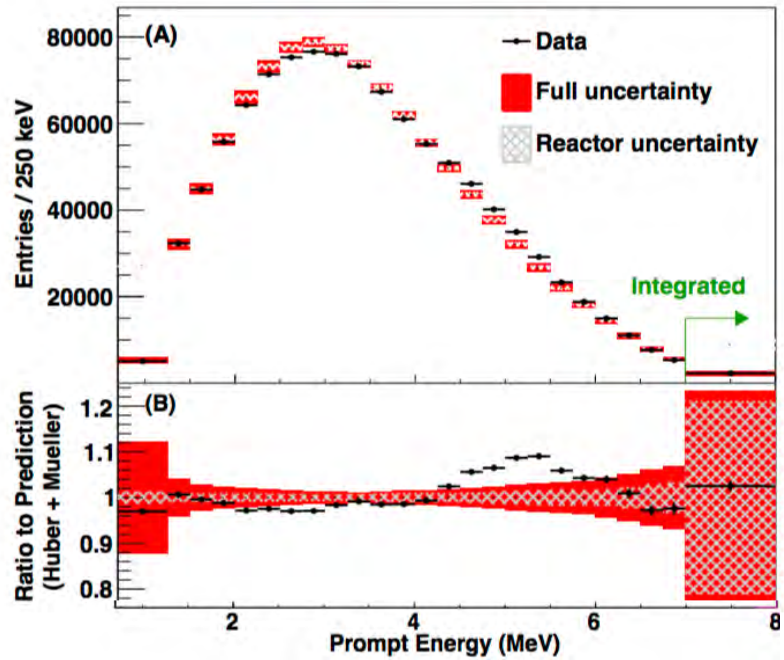
Consistent with previous experiments



Extra (sterile) neutrino oscillations or artifact of flux predictions?

Understanding reactor flux and spectrum anomalies requires additional data

Spectral Deviation



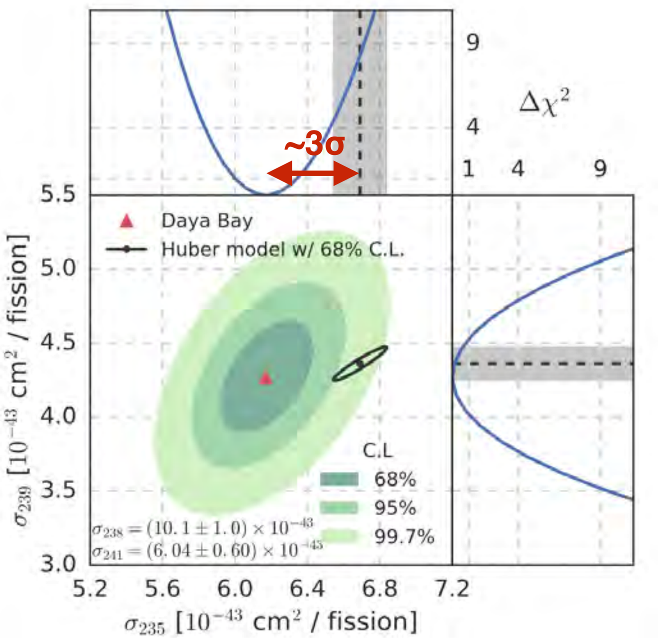
Measured spectrum does not agree with predictions.

Phys. Rev D 95, 072006 (2017).
Daya Bay collaboration

Recent Developments

Daya Bay Fuel Evolution Analysis

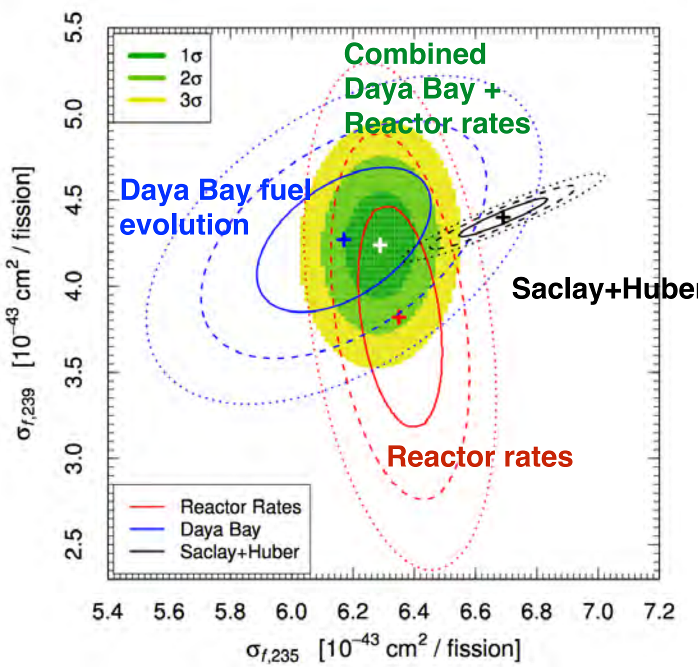
Daya Bay, arXiv:1704.01082v1



Daya Bay recently reported IBD yields of ^{235}U and ^{239}Pu using evolution of LEU reactors.
Reactor flux model found to be incorrect for ^{235}U.

Improved Determination of Fluxes

Giunti et al, arXiv:1704.02276



IBD yields calculated from reactor rates (of 26 reactor experiments) do not agree with Daya Bay measurement.

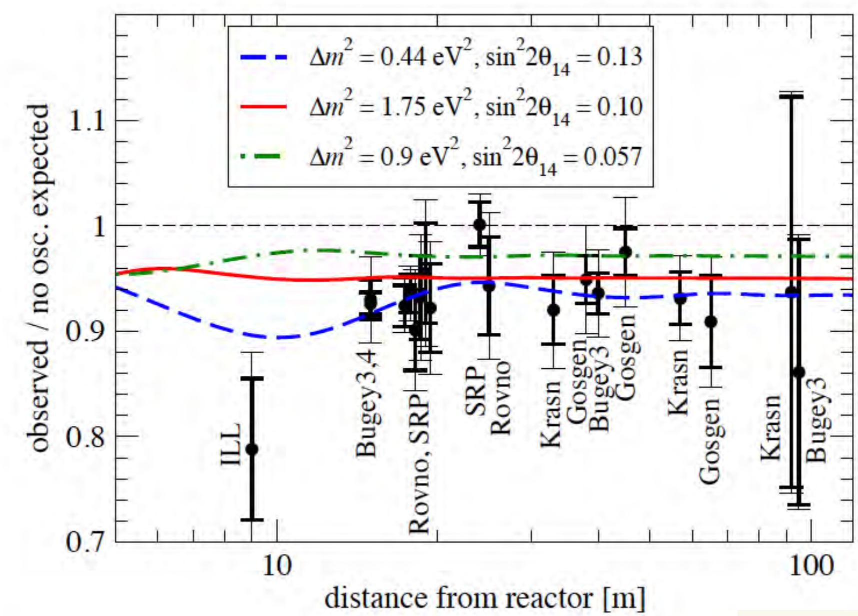
Analysis of Daya Bay with Fuel Burnup

Hayes et al, arXiv:1707.07728

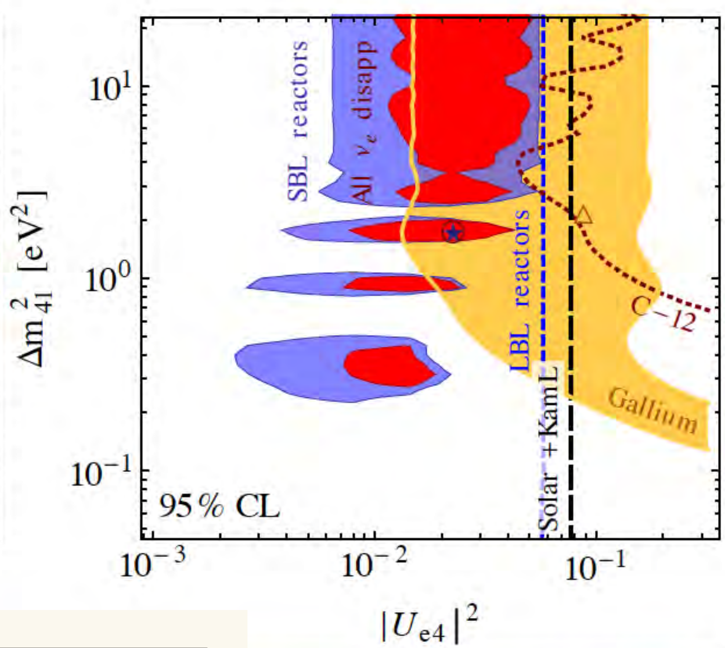
"not enough information to use the antineutrino flux changes to rule out the possible existence of sterile neutrinos"

$\overline{\nu}_e$ Disappearance and Oscillation Searches

Reactor $\overline{\nu}_e$ measurements



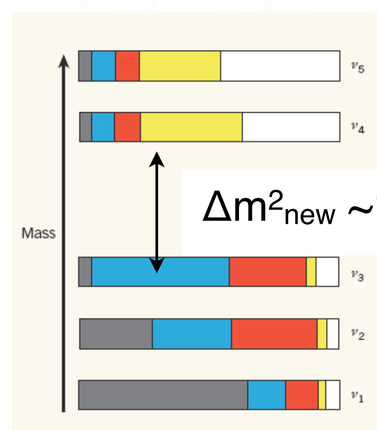
$\overline{\nu}_e$ disappearance data



Kopp et al, 1303.3011

new oscillation signal requires:

$\Delta m^2 \sim O(1 eV^2)$ and $\sin^2 2\theta > 10^{-3}$
"sterile" neutrino states

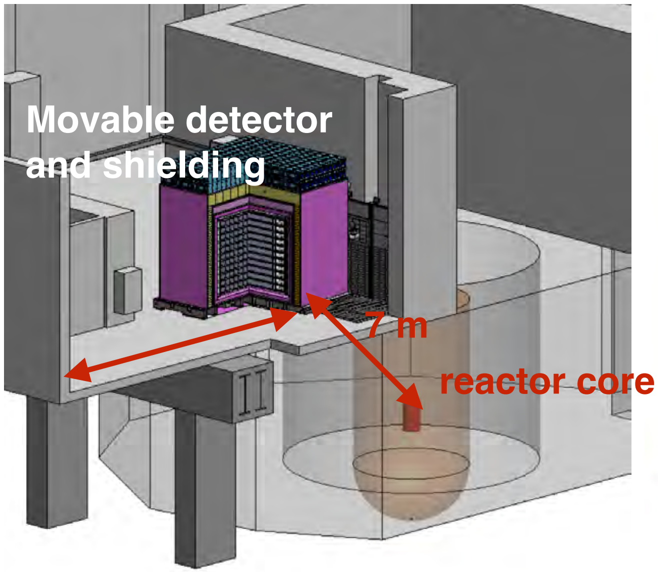


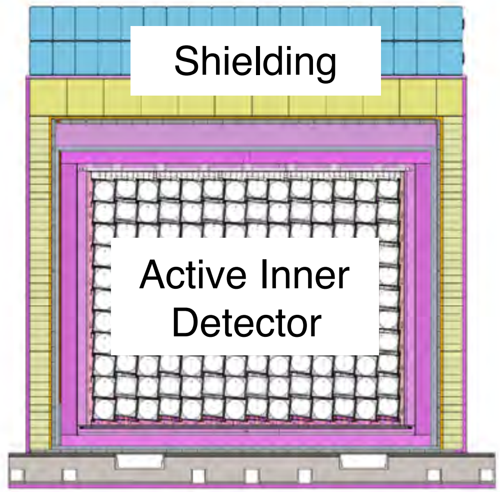
$\Delta m^2_{new} \sim 1\ eV^2$

Precision Reactor and Oscillation Experiment

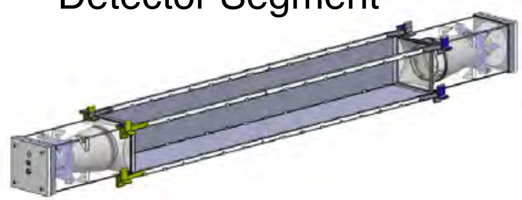
PROSPECT

Segmented, ^{6}Li-loaded Movable Detector

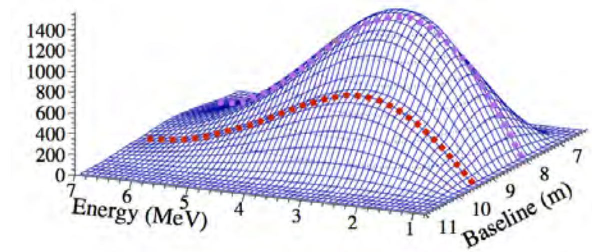




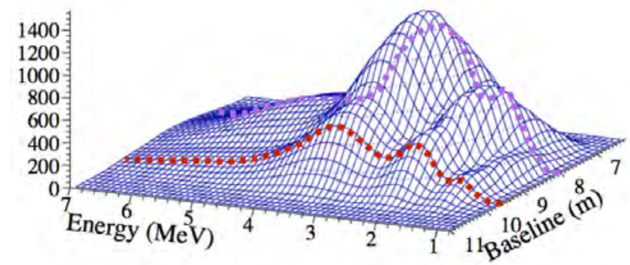
Detector Segment



unoscillated spectrum



oscillated spectrum



Detector Design

^{6}Li liquid scintillator
~4 ton
minimum dead material
movable detector
layered shielding package

Segmented Detector

14x11 segments
double-ended PMT readout
light guides, 5” PMTs
~4.5%/√E resolution

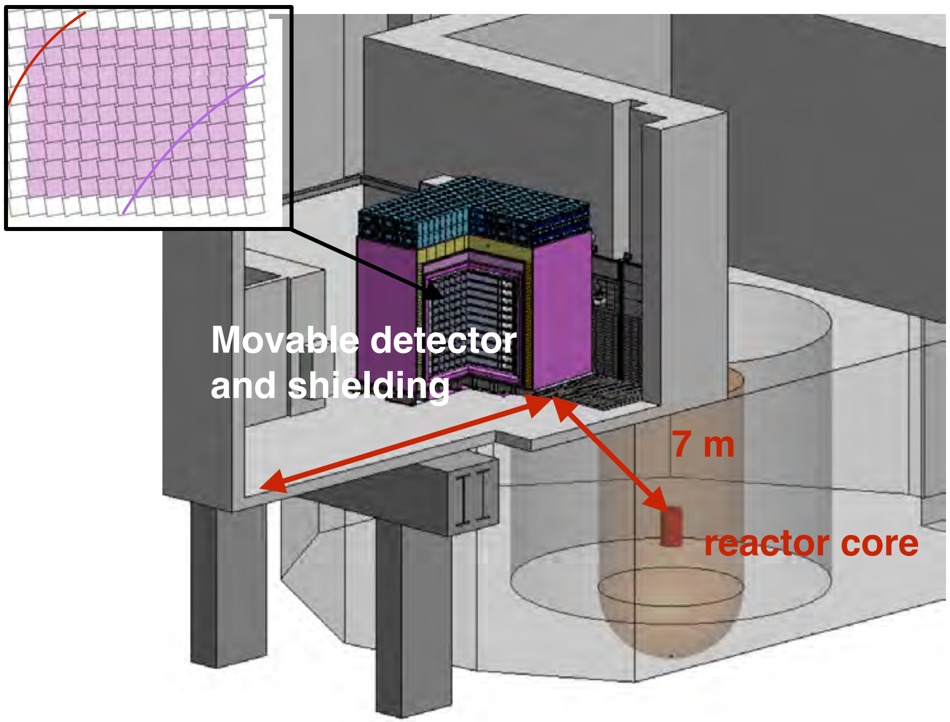
Relative Spectrum Measurement

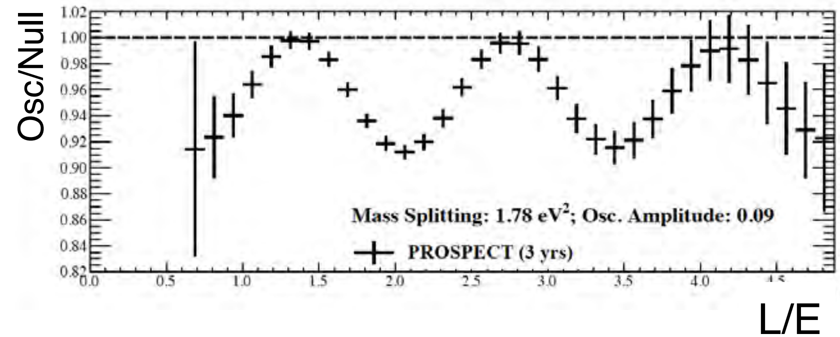
relative measurement of L/E and spectral shape distortions

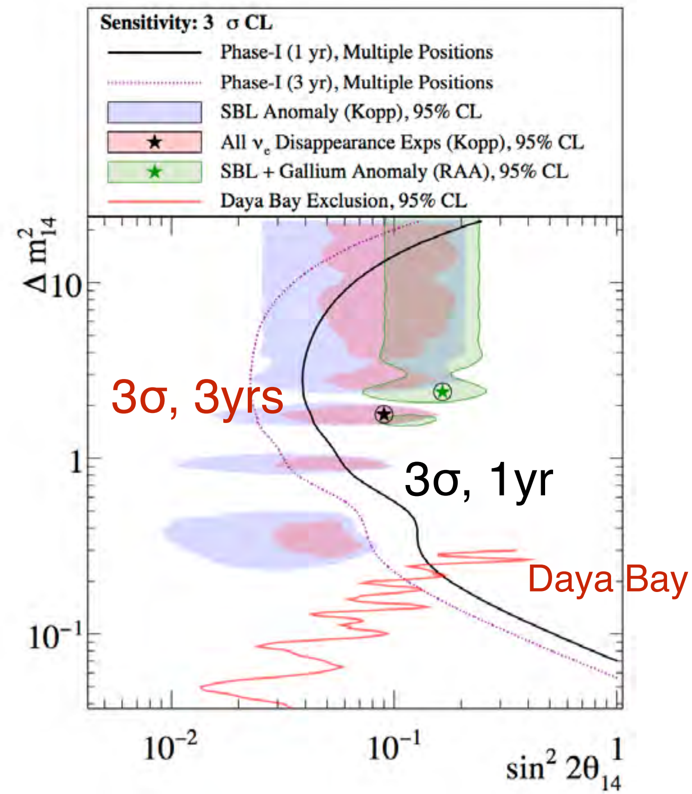
PROSPECT Physics

A Precision Oscillation Experiment

Model-independent test of oscillation of eV-scale neutrinos







Objectives

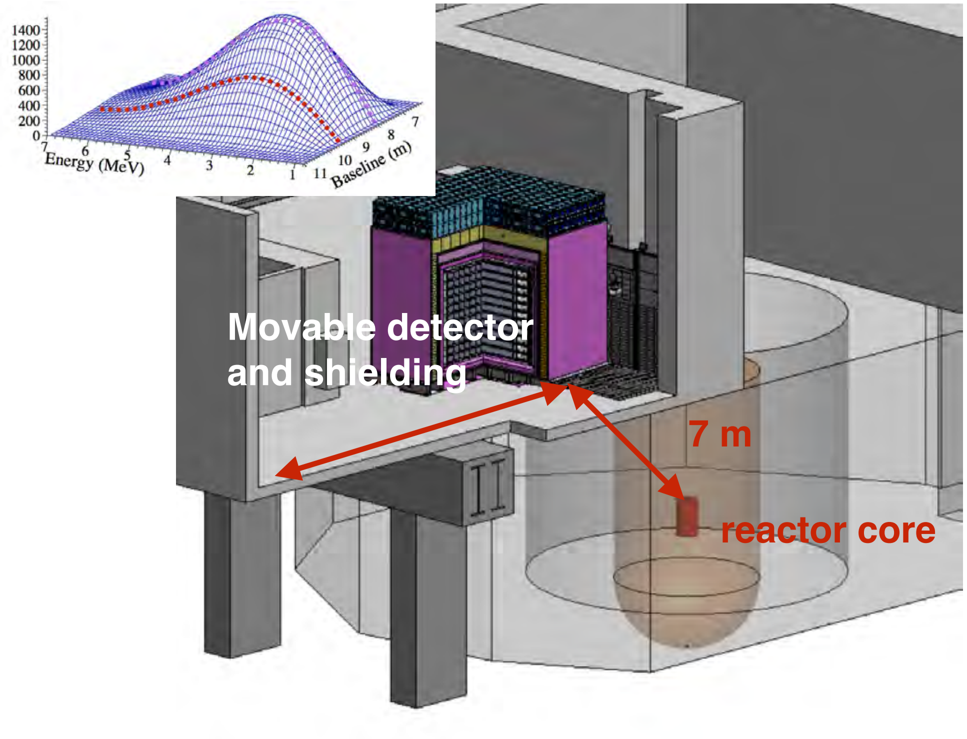
4σ test of best fit after 1 year

>3σ test of favored region after 3 years

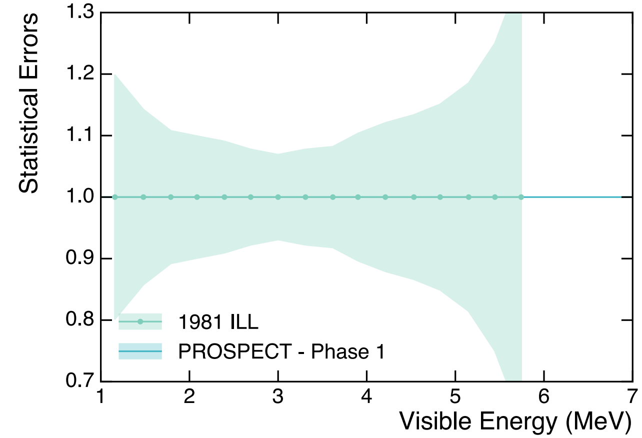
PROSPECT Physics

A Precision Spectrum Experiment

A precision measurement of spectrum



Improvement on ILL

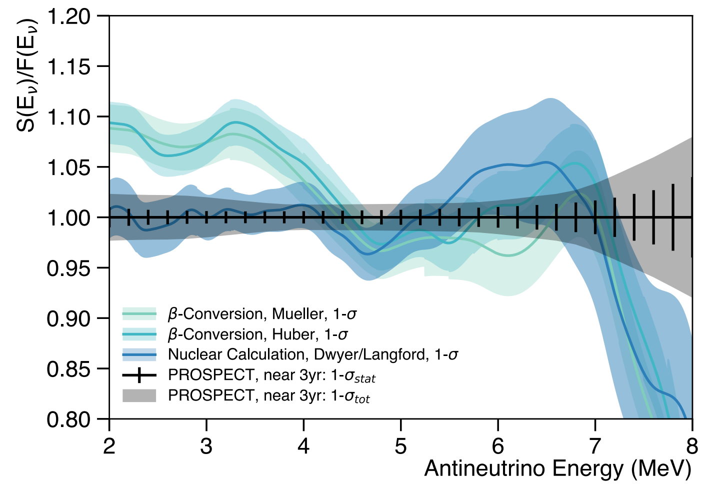


~160k events per year

~4.5%/√E

1981 ILL: ~5000 events

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



Objectives

Measurement of ^{235}U spectrum

Compare different reactor models

Antineutrinos from Reactors

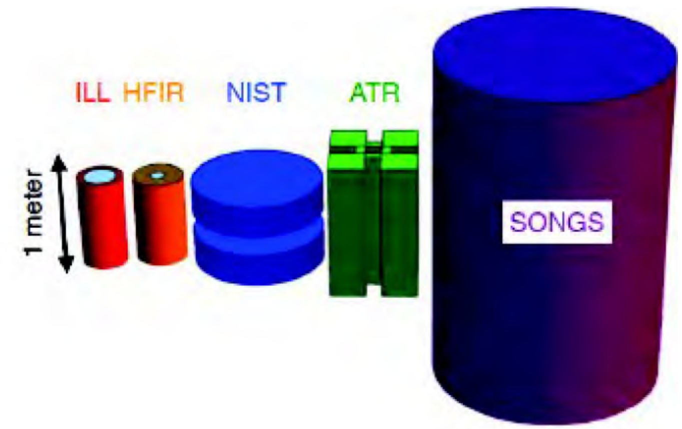
High-powered research reactors

highly-enriched (HEU):
mainly ^{235}U, ~10-100 MW_{th},

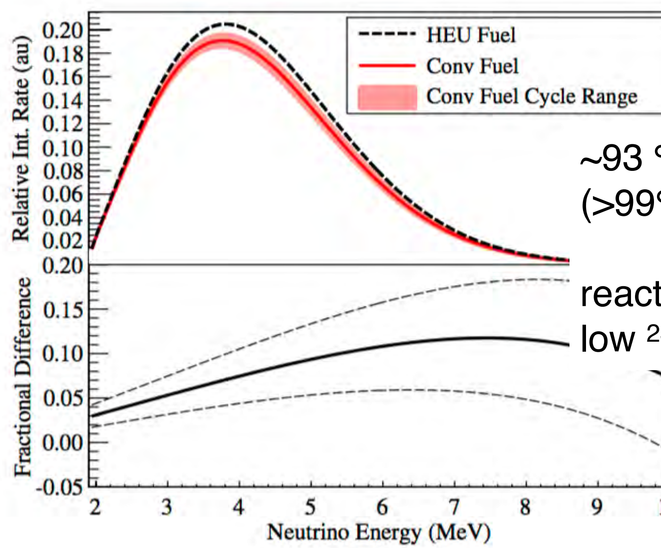
Commercial power reactors

low-enriched (LEU):
many fission isotopes, ~GW_{th}

“Point Source” vs Extended Core



HEU core provides static spectrum of ^{235}U



~93 % ^{235}U enrichment
(>99% $\bar{\nu}_e$ from ^{235}U)

reactor cycles: ~25 days,
low ^{239}P buildup (< 0.5%)

Experimental Site

Access Established on-site operation
User facility, easy 24/7 access

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

PROSPECT Detector and Shielding Development

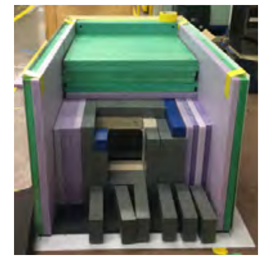
PROSPECT-0.1
Characterize LS
Aug 2014-Spring 2015

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

PROSPECT-2
Background studies
Dec 2014 - Aug 2015

12.5 cm length
1.7 liters
^{6}LiLS

multi-layer shielding

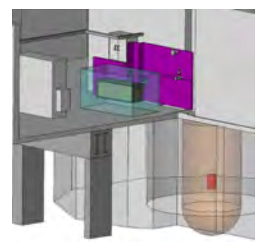


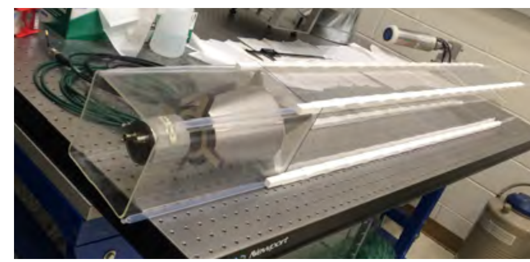
PROSPECT-20
Segment characterization
Scintillator studies
Background studies
Spring/Summer 2015

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

PROSPECT-50
Baseline design prototype
Winter 2015

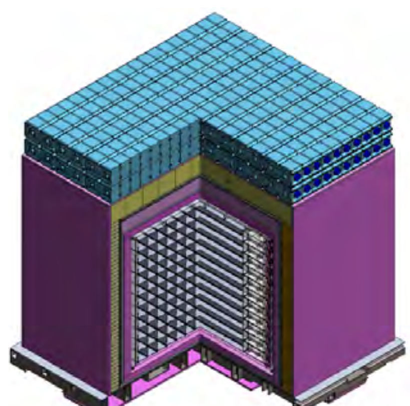
1x2 segments
1.2m length
50 liters
^{6}LiLS

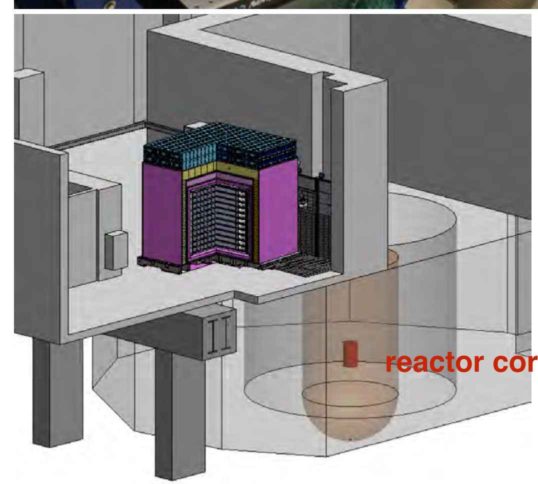




PROSPECT

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

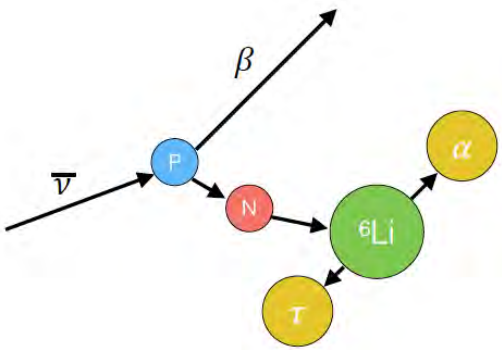




Antineutrino Event Identification with ^{6}Li

PROSPECT

Inverse Beta Decay



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

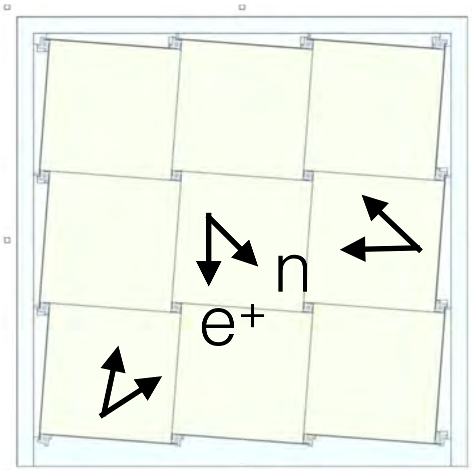
Delay signal: ~0.5 MeV signal from neutron capture on ^{6}Li

40µs delayed n capture

Background Reduction

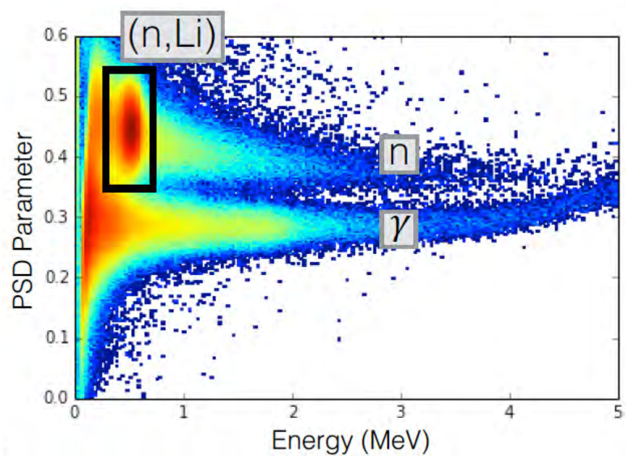
detector design & fiducialization

IBD event in segmented ^{6}LiLS detector



signal	inverse beta decay (IBD) γ-like prompt, n-like delay
backgrounds	fast neutron n-like prompt, n-like delay
	accidental gamma γ-like prompt, γ-like delay

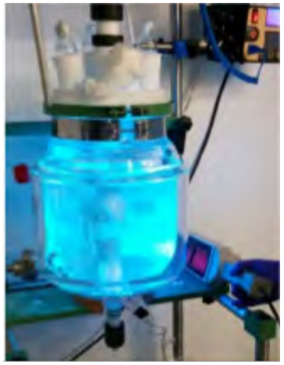
Pulse Shape Discrimination



Background reduction is key challenge

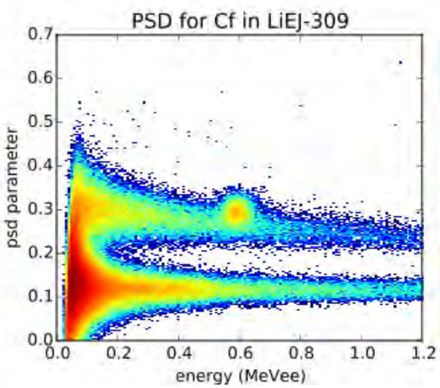
Inner Detector Components

^{6}Li-Loaded Liquid Scintillator



Developed non-toxic, non-flammable formulation based on EJ-309

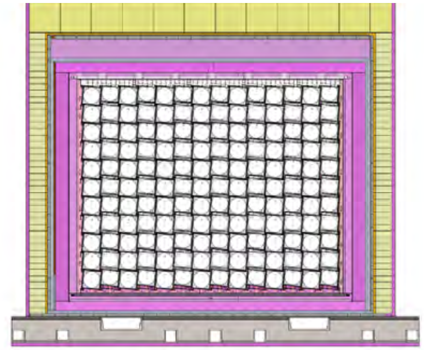
Light Yield
- EJ-309 base: 11500 ph/MeV
- LiLS: 8200 ph/MeV



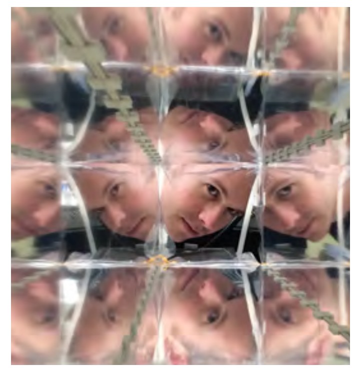
Excellent PSD performance for neutron capture & heavy recoils

0.1% ^{6}Li loading

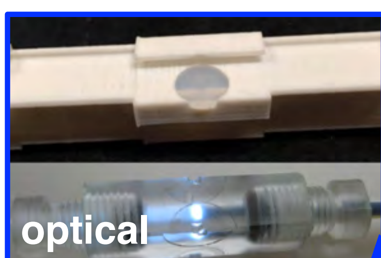
Low-Mass Optical Separators

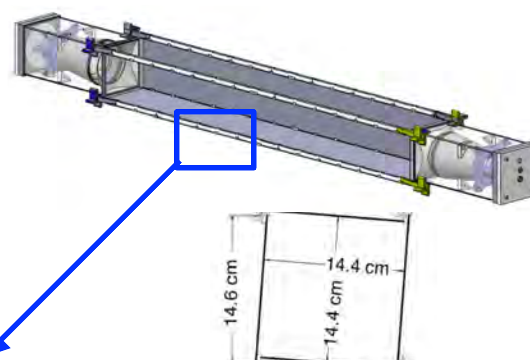


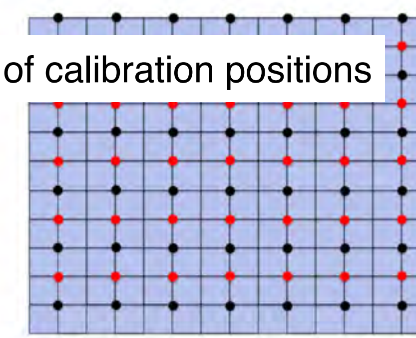
High reflectivity, high-rigidity, low mass reflector system developed



Calibration







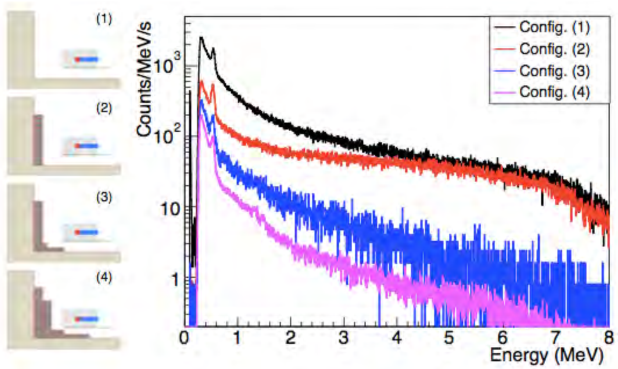
Backgrounds & Shield Design

On-site Measurements

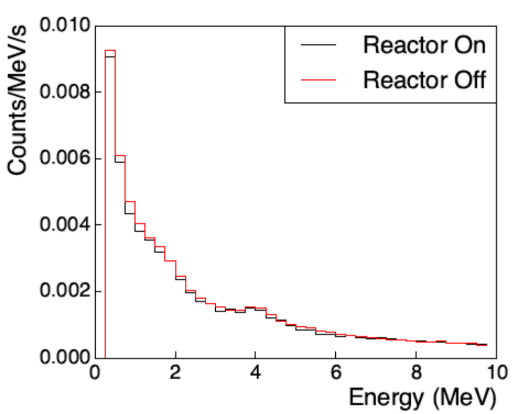
Characterize background field at HFIR, develop localized shielding requirements

PROSPECT Collaboration Nucl. Instrum. Meth. A806 (2016) 401–419

Localized shielding studies



Reactor On/Off Studies



PROSPECT Shielding

local shielding next to reactor wall

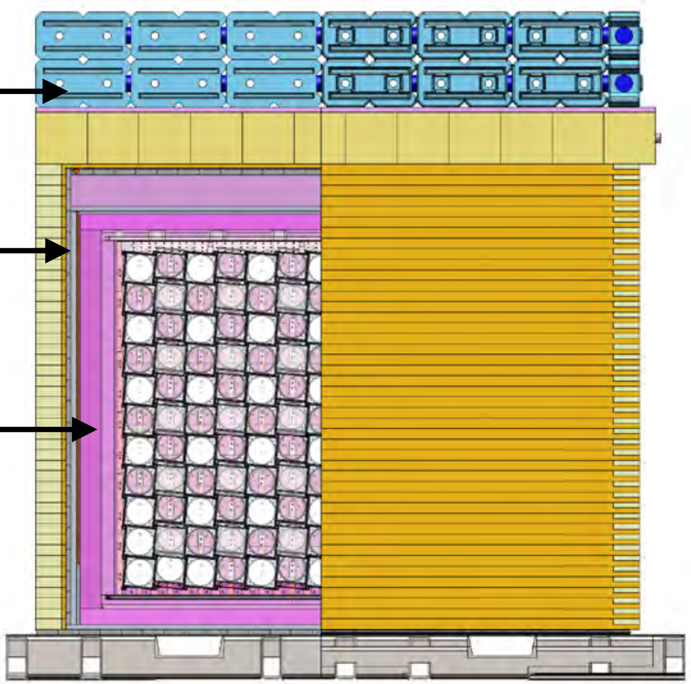
multi-layer passive shield:

- water bricks, HDPE, borated HDPE, lead

Water bricks
Polyethylene
Outer neutron shielding for neutron moderation

Lead
High Z shielding

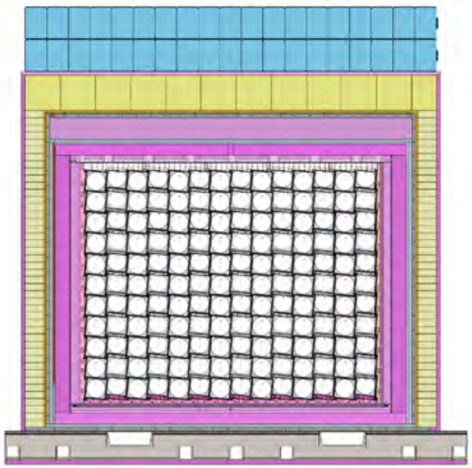
Inner Neutron Shielding
Suppress neutrons produced from spallation on lead



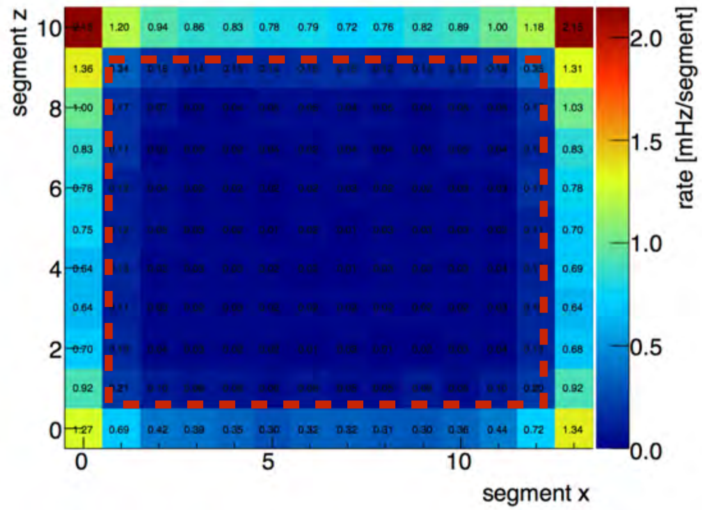
Background Rejection via Segmentation

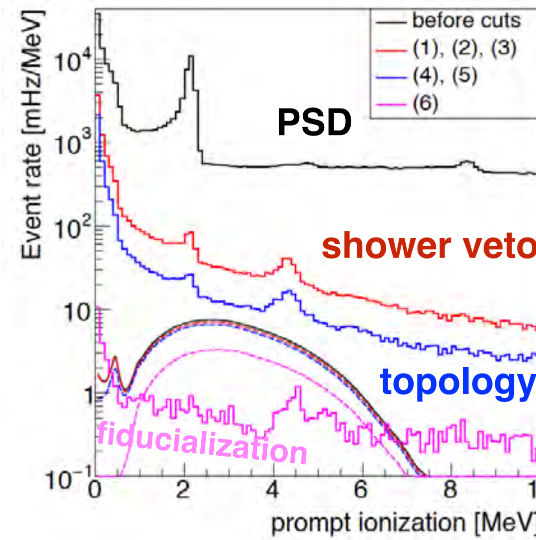
PROSPECT

Segmentation



Fiducialization





Background Reduction Steps

Efficient PSD and neutron tagging

Identification of multiple particle interactions

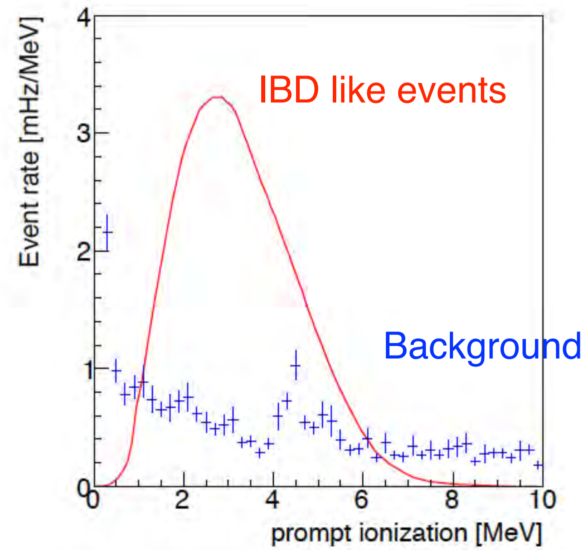
Fiducialization: Active suppression by >3 orders of magnitude

Prompt Spectrum

~940 IBD events/day

Rate and shape of residual IBD-like background measured during reactor-off periods.

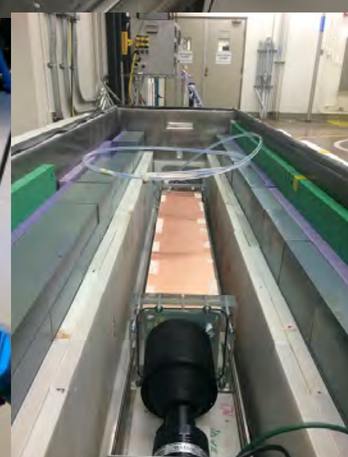
projected S:B is 3:1



Prototyping and Detector Assembly

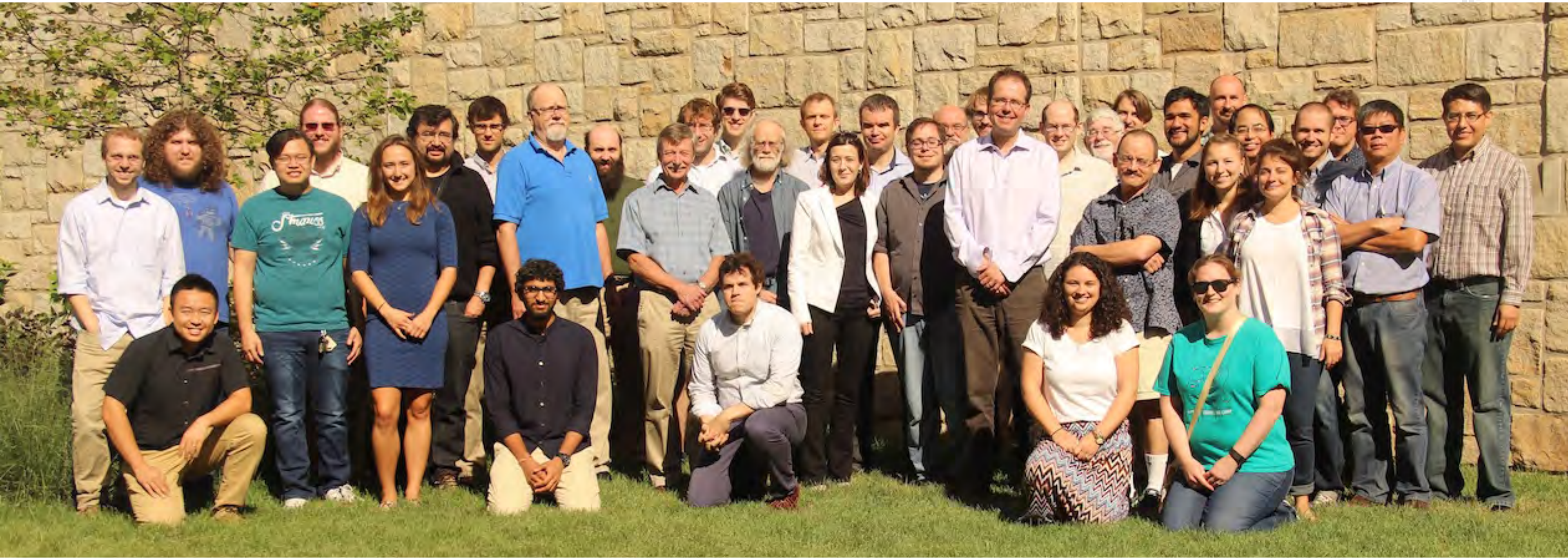




Preparing Detector Assembly

PROSPECT Collaboration



4 national laboratories
10 universities
68 collaborators

prospect.yale.edu

Summary & Outlook

PROSPECT aims to resolve current reactor anomalies
- probe favored region for eV-scale sterile neutrinos at >3σ within 3 years
- measure the ^{235}U $\overline{\nu}_e$ spectrum, complementary to LEU measurements

New data from HEU reactors are required to address the reactor rate and spectrum anomalies.

PROSPECT R&D program
- developed LiLS detector technology that can mitigate reactor- and cosmogenic related backgrounds
- deployed multiple detectors at HFIR to validate models and prepare for full-size system deployment

PROSPECT proceeding with detector construction. Installation in 2017.

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