PROSPECT: A Precision Reactor Oscillation and Spectrum Experiment

Xianyi Zhang
Illinois Institute of Technology
On behalf of the PROSPECT Collaboration

TIPP, May 22, 2017

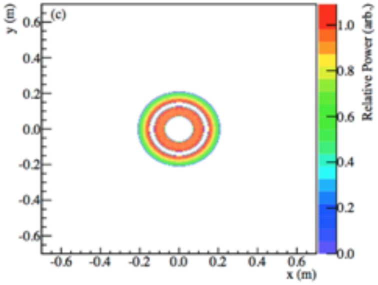
PROSPECT Experiment

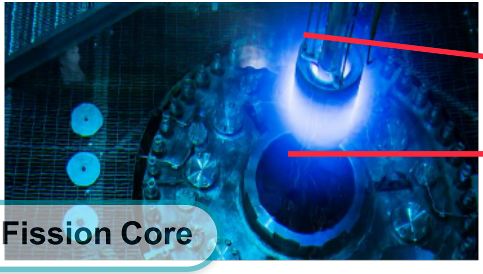
A short baseline reactor antineutrino experiment. We aim to:

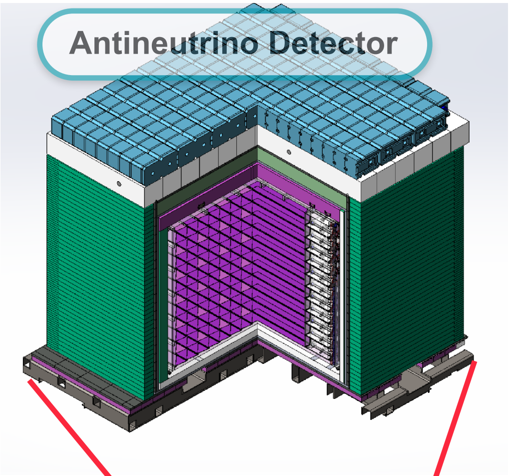
- Measure the spectrum of antineutrinos from a Highly Enriched U-235 reactor (HEU).
- Probe the oscillation of a light sterile neutrino, independent from the reactor models.

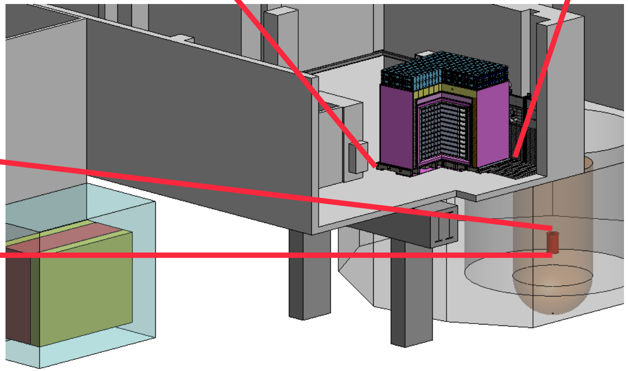
Reactor:

- High Flux Isotope Reactor (HFIR), at Oak Ridge Nation Laboratory.
- Size: d x h = 40cm x 50cm.
- Power: 85 MW.
- U-235 enrichment > 93%.
- Antineutrino generated from U-235 > 99%.
- Duty cycle: 47%.

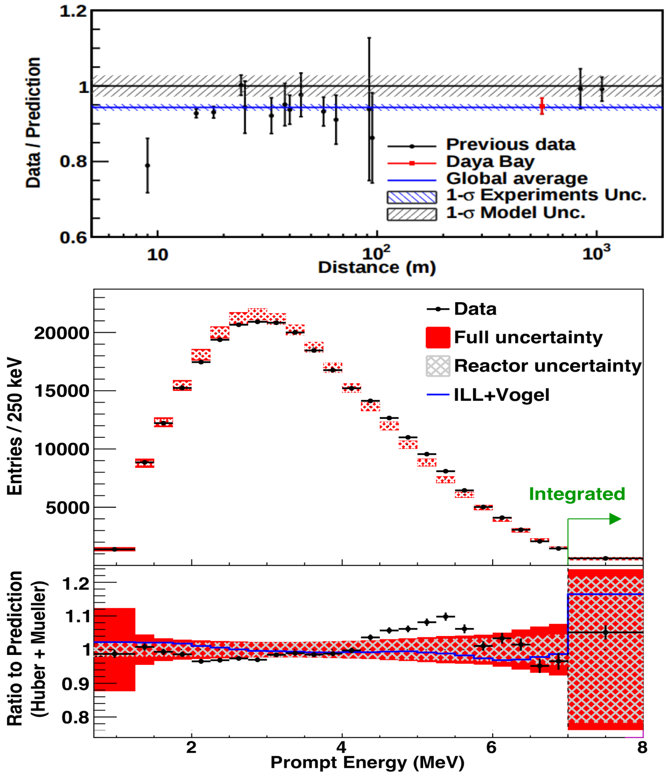






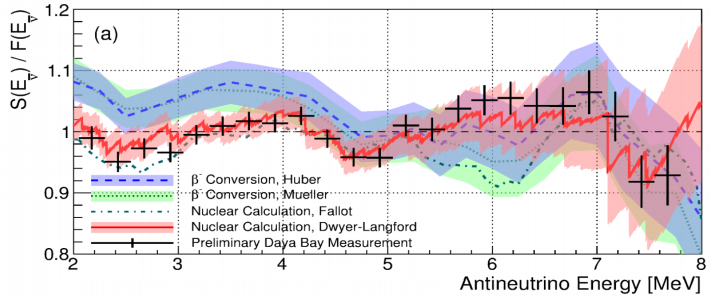


Motivation



Daya Bay Antineutrino Flux and Spectrum,
Phys. Rev. Lett. 116, 061801, 2016

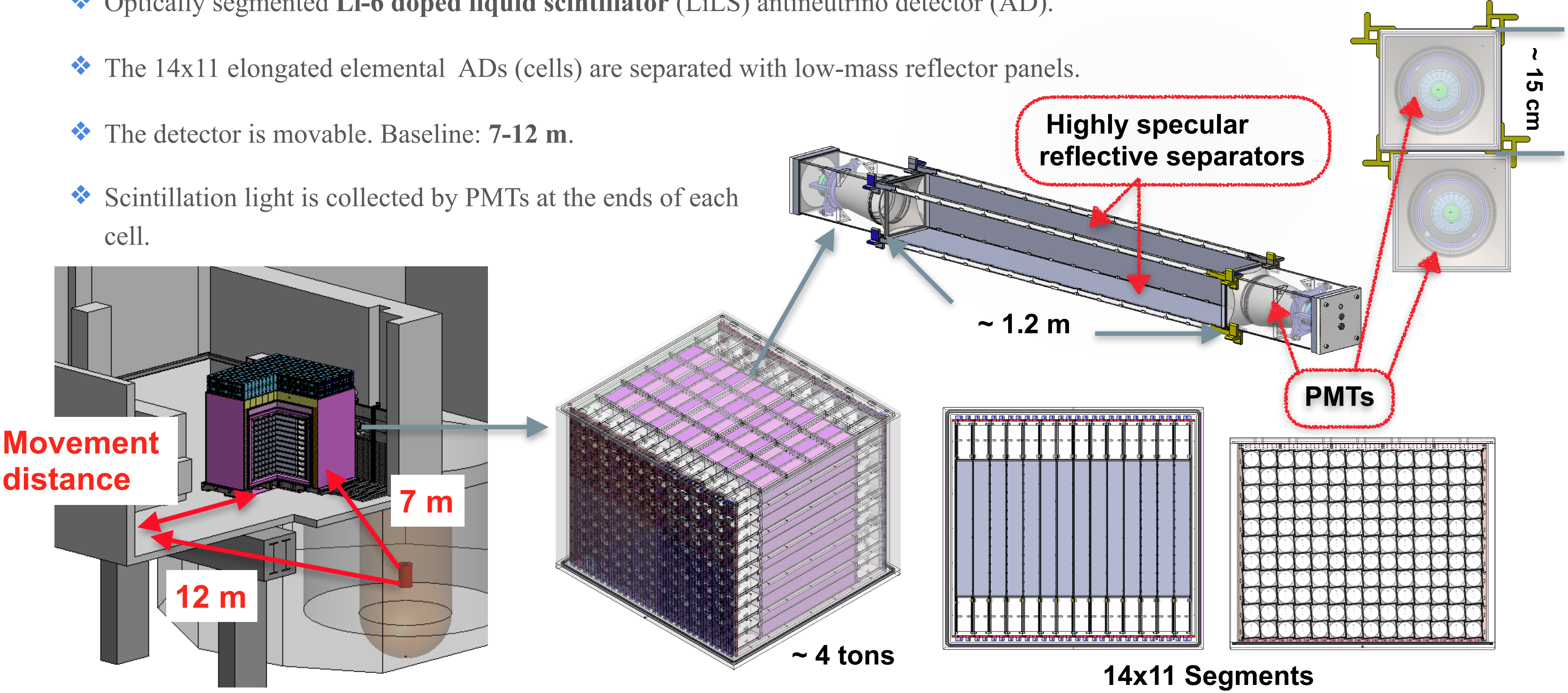
- The antineutrino flux measured by θ_{13} experiments shows ~6% global deficit from prediction. This deficit can be a hint of the sterile neutrino oscillation or incomplete data of reactor fission branches.
- The reactor antineutrino spectral measurement contains 8-10% excess at 5-7 MeV compared with the prediction.
- The spectral prediction models of reactor antineutrino are different.



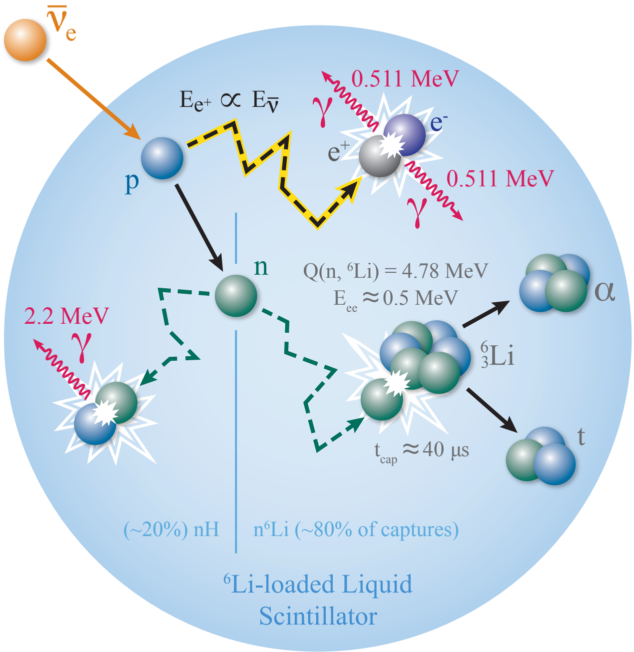
Comparison between *ab-initio* and β conversion prediction,
Phys. Rev. Lett. 114, 012502, 2015

Detector Design

- Optically segmented **Li-6 doped liquid scintillator** (LiLS) antineutrino detector (AD).
- The 14x11 elongated elemental ADs (cells) are separated with low-mass reflector panels.
- The detector is movable. Baseline: **7-12 m**.
- Scintillation light is collected by PMTs at the ends of each cell.

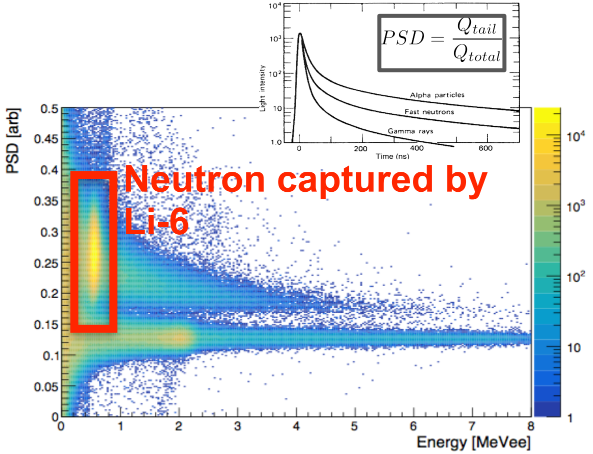


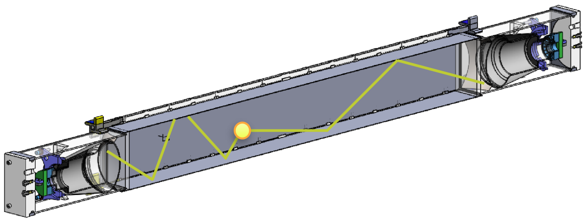
Event Detection



IBD Detection on LiLS

- Detect Inverse Beta Decay (IBD) process of antineutrinos.
- The **β⁺** event (prompt event) and ***n*-capture** event (~40μs delayed event) of LiLS generated scintillation light.
- The Pulse Shape Discrimination (PSD) of scintillator distinguishes the **β⁺-like** event and ***n*-like** events.

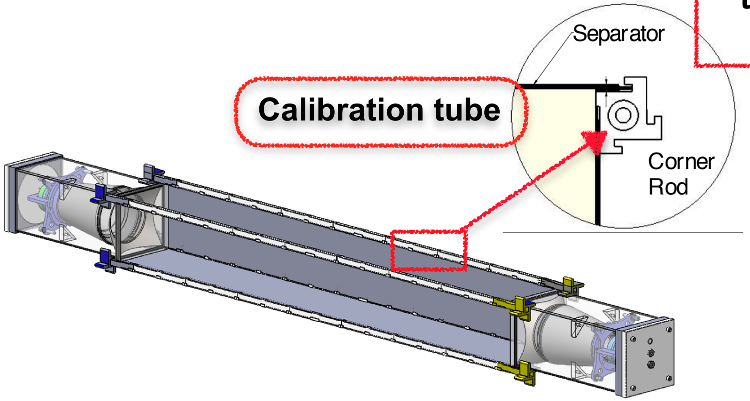




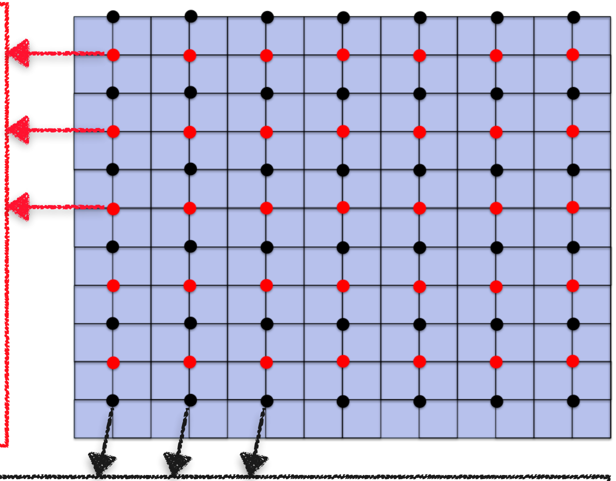
The scintillation light generate is constrained in the cell and detected by the PMTs, which enables event position reconstruction by timing and light difference.

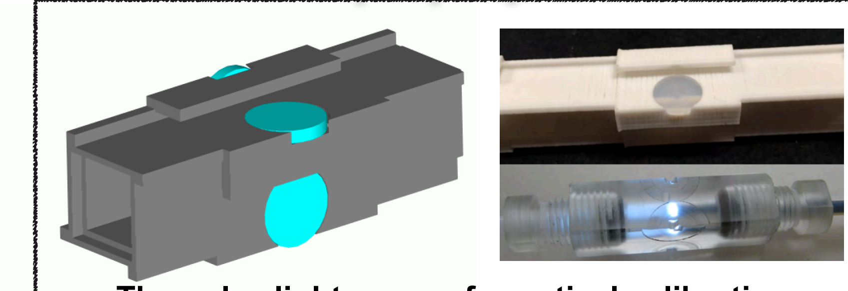
Calibration

- The calibration sources are transported through teflon guide tubes.
- The calibration tubes are inside the 3-D printed rods.
- Each cell is adjacent to a radioactive calibration source and an optical calibration source.



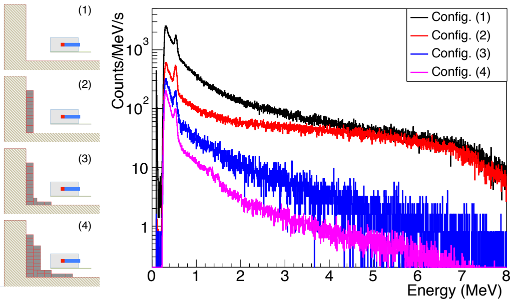
Radioactive source transported by timing belt.



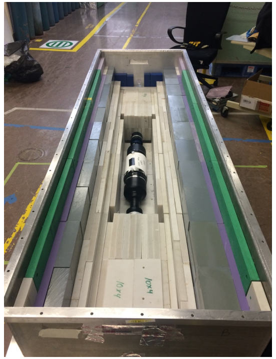


The pulse light source for optical calibration

Background Characterization and Shielding

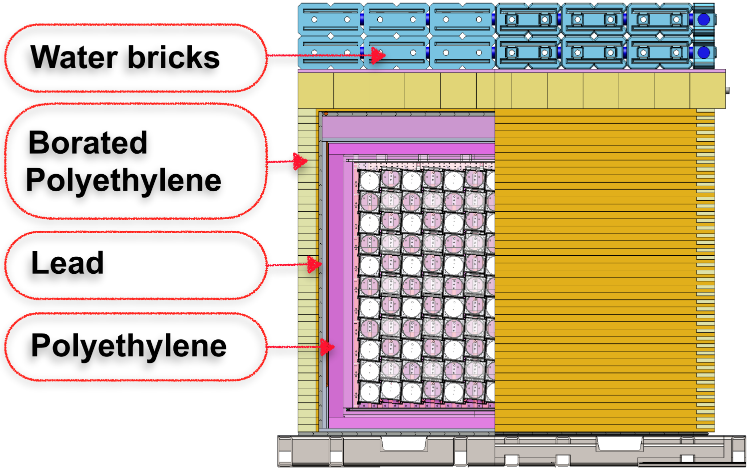


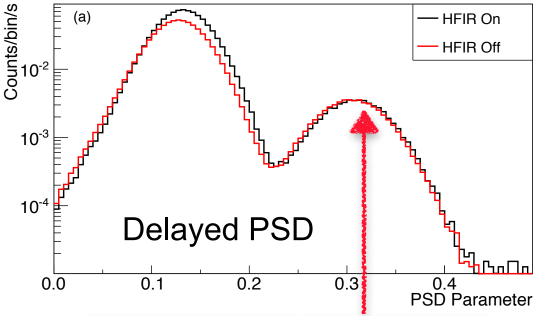
Background rate vs shielding
arXiv: 1506.03547



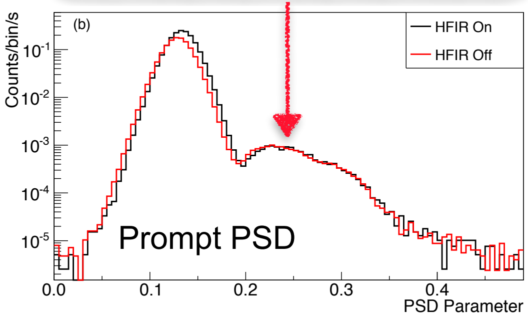
Shielded 2L prototype measuring the background

- The main sources of background: **gammas**, **thermal** and **fast neutrons** and **muons**.
- We developed the shielding configurations based on onsite background measurement and prototyping.



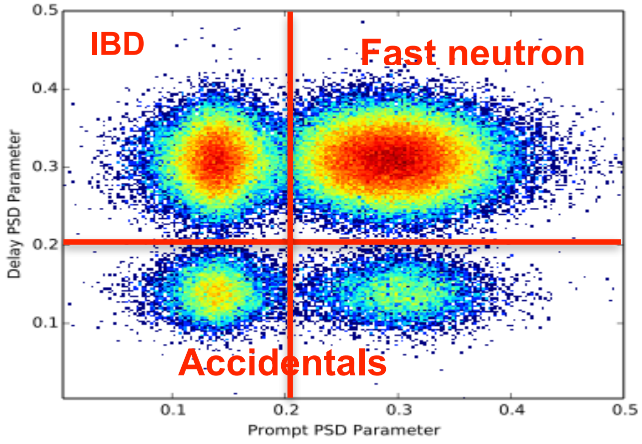


The neutron event rate between reactor on/off shows reactor correlated neutron is eliminated.

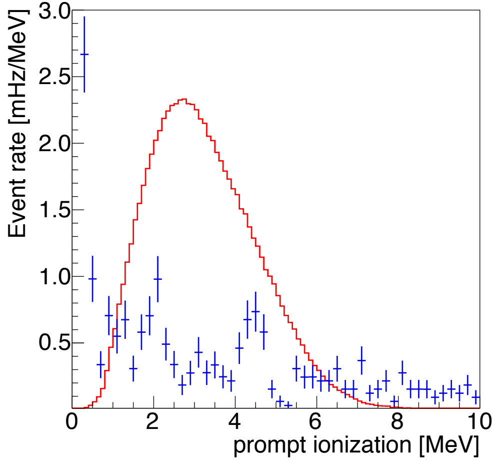


Event Selection

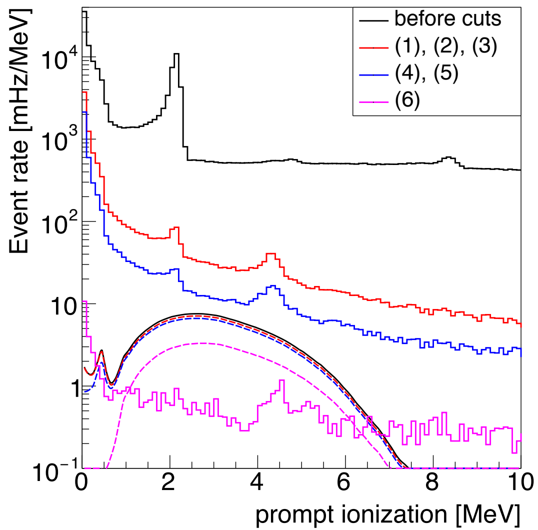
- The PSD selection, reduce the rate of accidentals.
- We apply 6 cuts during data analysis.
- The main background is **cosmogenic neutron.**
- **S:B is 3:1**.
- **IBD like event rate after background subtraction: ~160,000 events/year.**



PSD selection



Simulated signal to background
arXiv: 1512.02202



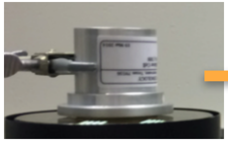
(1), (2), (3) - time coincidence cut,
(4), (5) - spacial topology cut,
(6) - detector outer volume cut.

Signal compared with subtracted background,
arXiv: 1512.02202

Prototypes and Timeline

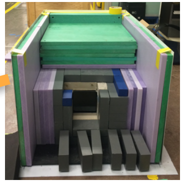
Run DAQ. Remote data taking. See n-Li and PSD

PROSPECT 0.1
Aug. 2014



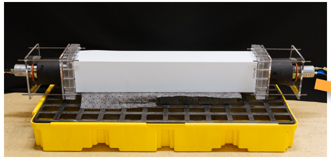
Demonstrate shielded background rate.

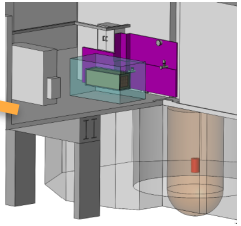
PROSPECT 2
Dec. 2014 - Mar. 2015



Demonstrate timing based event reconstruction and light collection performance.

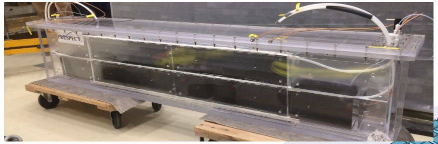
PROSPECT 20
Mar. 2015 - Summer 2016





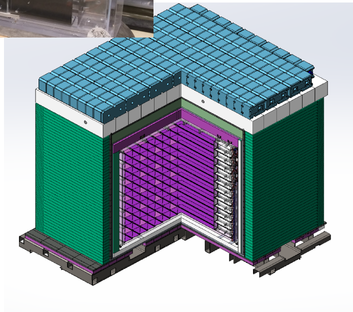
Test the configurations for final design with two cells. Observe relative segments' response on calibrations.

PROSPECT 50
Jan. 2016 - Now



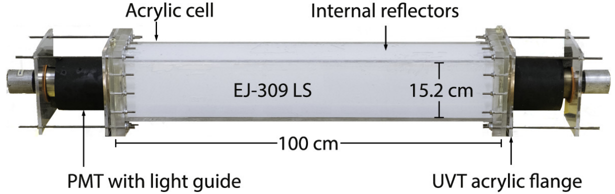
See antineutrinos, probe oscillation and measure spectrum from HEU.

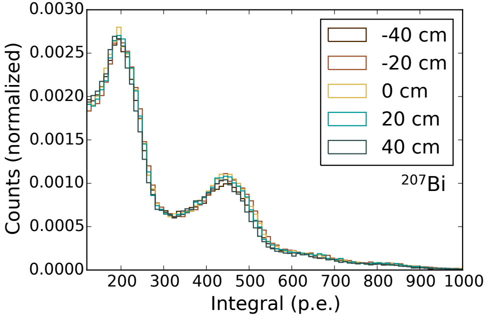
PROSPECT AD-I
on the way in 2017



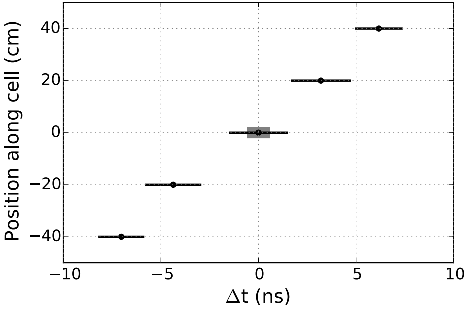
Highlights from the Prototype Detectors

- PROSPECT-20 is a 20 liter prototype that validates the background shielding and detector performance.



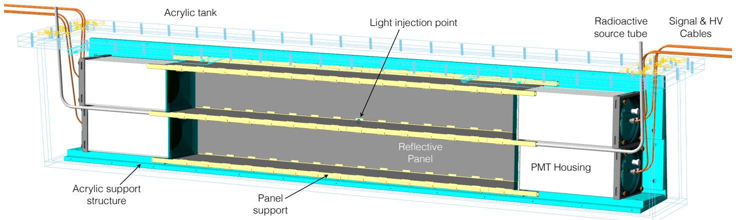


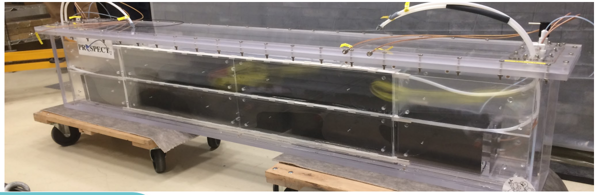
Spectrum uniformity along the cell, *arXiv:1508.06575*



The position reconstruction precision, *arXiv:1508.06575*

- PROSPECT-50 is a 50 liter prototype to demonstrate event detection of the segmented detector, test the configurations and exercise the detector construction. The configuration has shown good light collection stability.

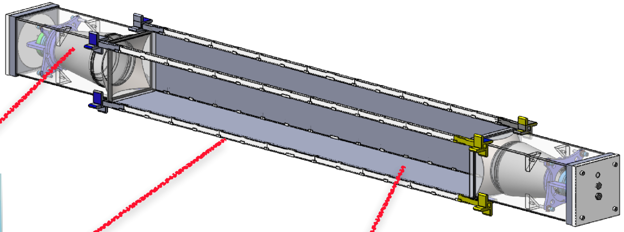


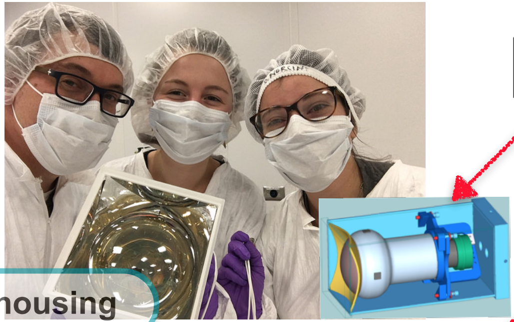


Constructing P-50

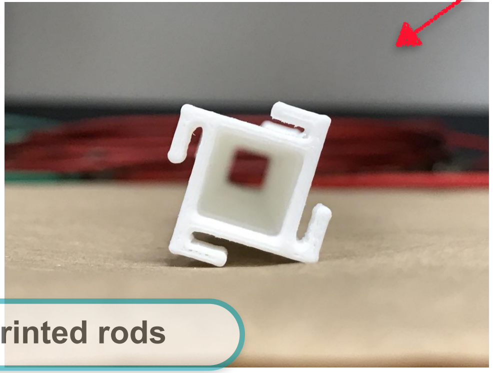
Detector Construction

❖ The fabrication of the parts of PROSPECT is ongoing. All of the components are designed and made to be compatible with LiLS.





PMT housing



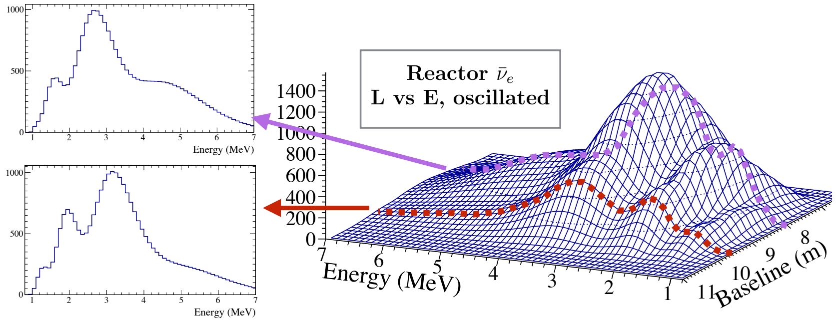
3-D printed rods

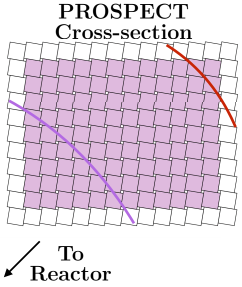
Multilayer reflector laminating

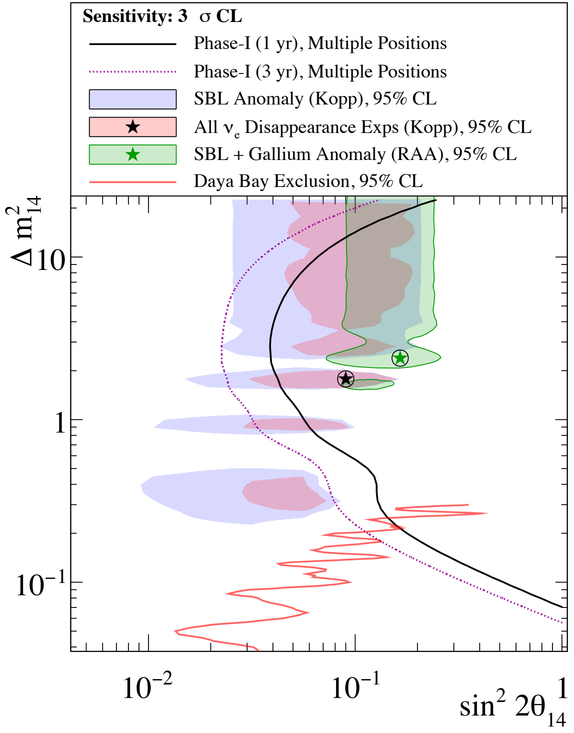
Making LiLS

Probe a Sterile Neutrino

- Test the oscillation of sterile neutrino by observing the electron antineutrino disappearance.
- We are able to test sterile neutrino hypothesis in $\Delta m^2 \sim 1\ \mathrm{eV}^2$ range by probing the oscillation.
- The segmented AD enables cell-to-cell spectrum and flux comparison. Providing antineutrino spectra based on baseline. So by moving the detector and comparing the spectra bin-to-bin, we can tune **L** and **E** to achieve different mass splittings.



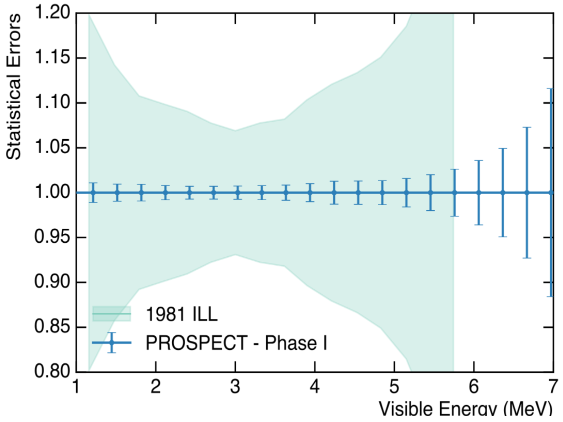




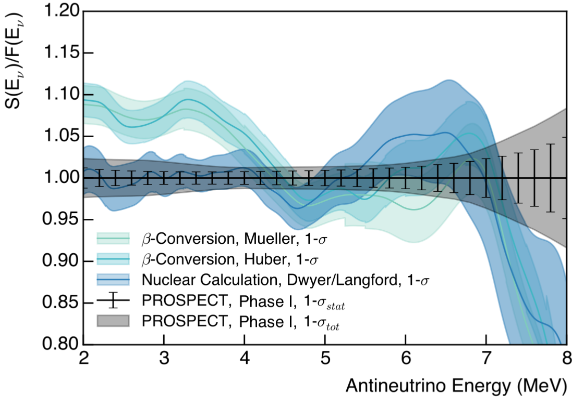
Spectral Measurement

Direct spectral measurement to the HEU reactor:

- Energy resolution: σ=4.5%/√E.
- The statistical uncertainty < 1.5% per energy bin in interested range (with expected 0.2 MeV energy bins).
- We will compare our measurement with other experiments and models. These comparisons can help us understand the cause of the excess at 5-7 MeV.
- Provide a reference U-235 spectrum for future reactor antineutrino experiments.



Statistical uncertainty of PROSPECT compared with the former spectrum by ILL , ***Arxiv: 1512.02202***



Statistical and total uncertainty (in 3 years) compared with theoretical models, ***Arxiv: 1512.02202***

Summary

- There are deviations from current reactor antineutrino models that could indicate possible new physics and/or incomplete data within the reactor models.
- The PROSPECT aims to measure the spectrum and flux of antineutrinos from HFIR at short baseline to reactor model independently search a sterile neutrino oscillation and explain the ‘bump’ with the spectrum model.
- Prototypes of PROSPECT have been deployed to study in-situ backgrounds, light collection performance and detector configurations.
- We have started the fabrication of detector parts. The commissioning of PROSPECT will begin in 2017.
- To observe the oscillation of sterile neutrino, we will test the best-fit at 4σ C.L. within one year of data taking.
- We will measure the spectrum of U-235 with high energy resolution and statistics.

Thank you!

HEISING-SIMONS FOUNDATION

Lawrence Livermore National Laboratory

NIST

BROOKHAVEN NATIONAL LABORATORY

OAK RIDGE National Laboratory

Drexel UNIVERSITY

ILLINOIS INSTITUTE OF TECHNOLOGY

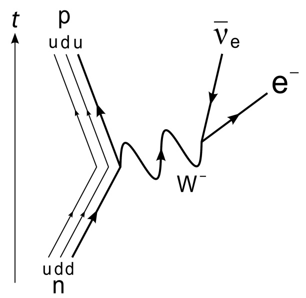
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Yale

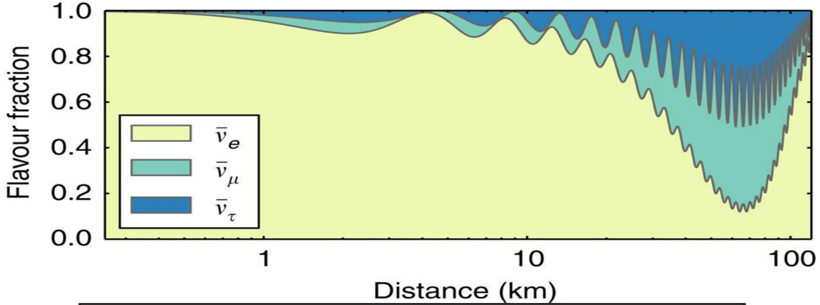
W&M

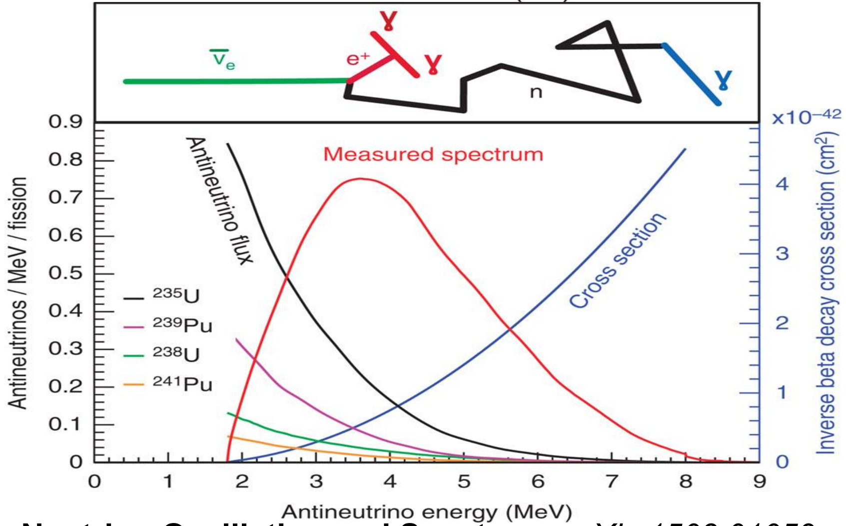
Backup - The Reactor Antineutrino

- Fission reactors generate antineutrinos through β-decay.



- Mainly 4 fission source isotopes of reactor antineutrino.
- Reactor antineutrino experiments:
  - ➢ Antineutrino spectrum of fission reactor.
  - ➢ Oscillation of reactor antineutrino.





Neutrino Oscillation and Spectrum, ***arXiv:1503.01059***

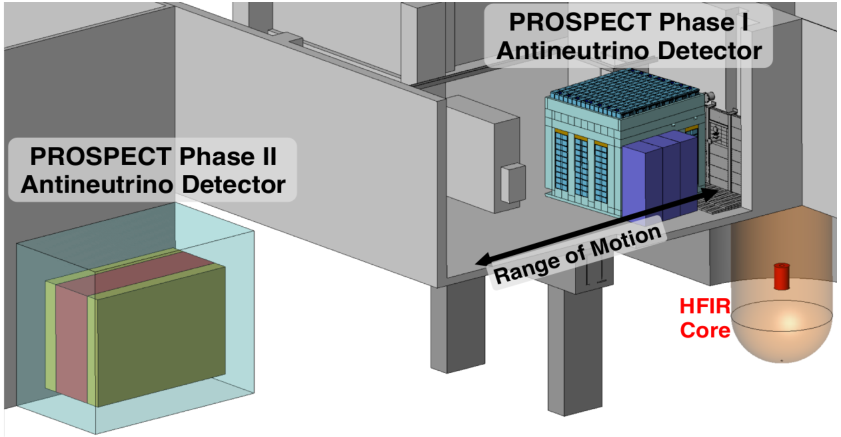
Backup - Phase II (in plan)

Motivation:

- Measurement covers more oscillation cycles.
- Increase the statistical uncertainty.

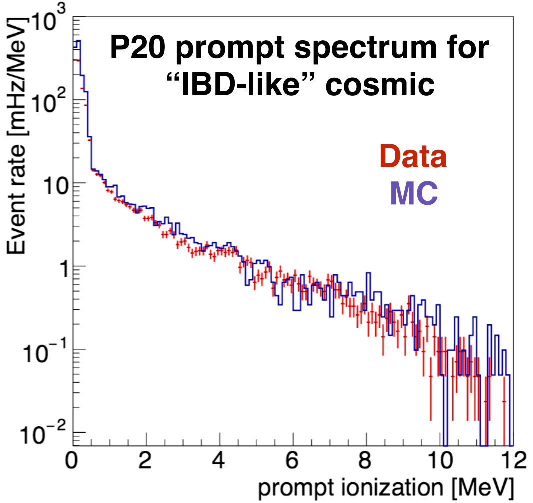
Parameters:

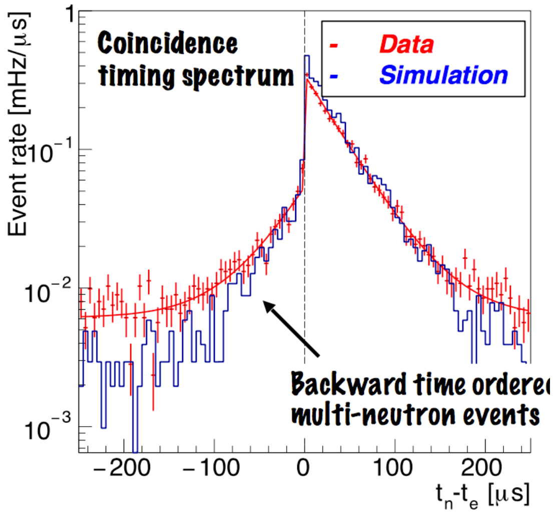
- Baseline: 16 - 20 m.
- Target mass: ~10 t.
- Segmented IBD detector.



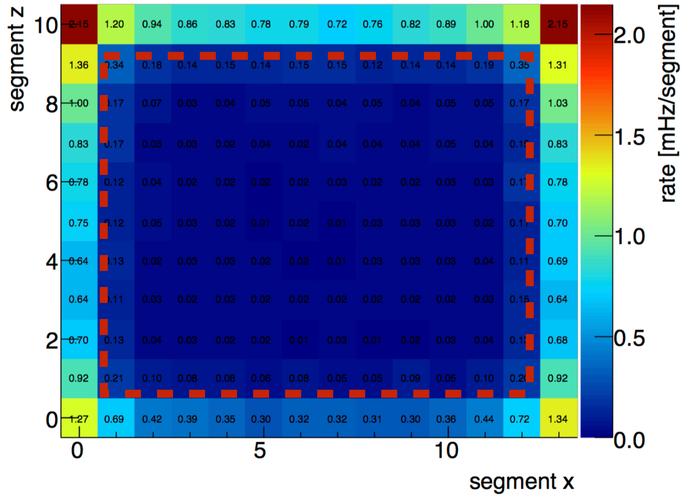
Backup - Simulation

- We wrote Geant4 MC package specifically for PROSPECT AD-1 and prototypes.
- The simulations helped us determine the detecter response correctly and make decisions for calibration and shielding strategies.





Data and MC agreement,
arXiv:1508.06575



The event rate comparison between the outer and inner volume.