PROSPECT – The Precision Reactor Oscillation and Spectrum Experiment

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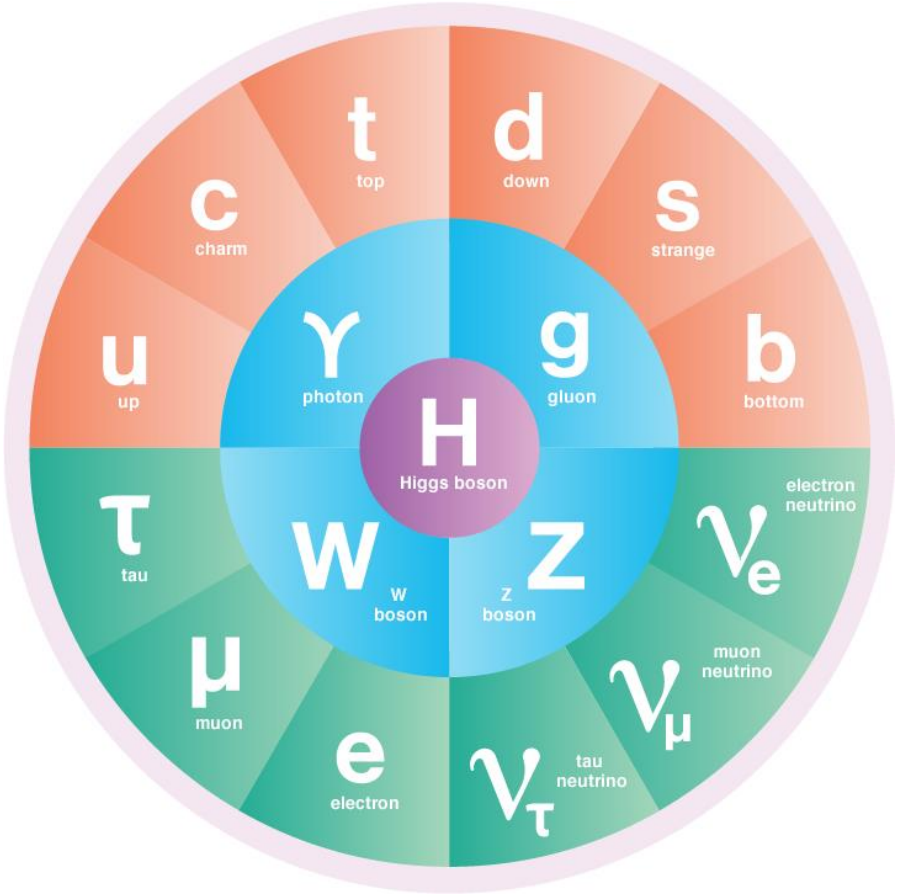
What are neutrinos?

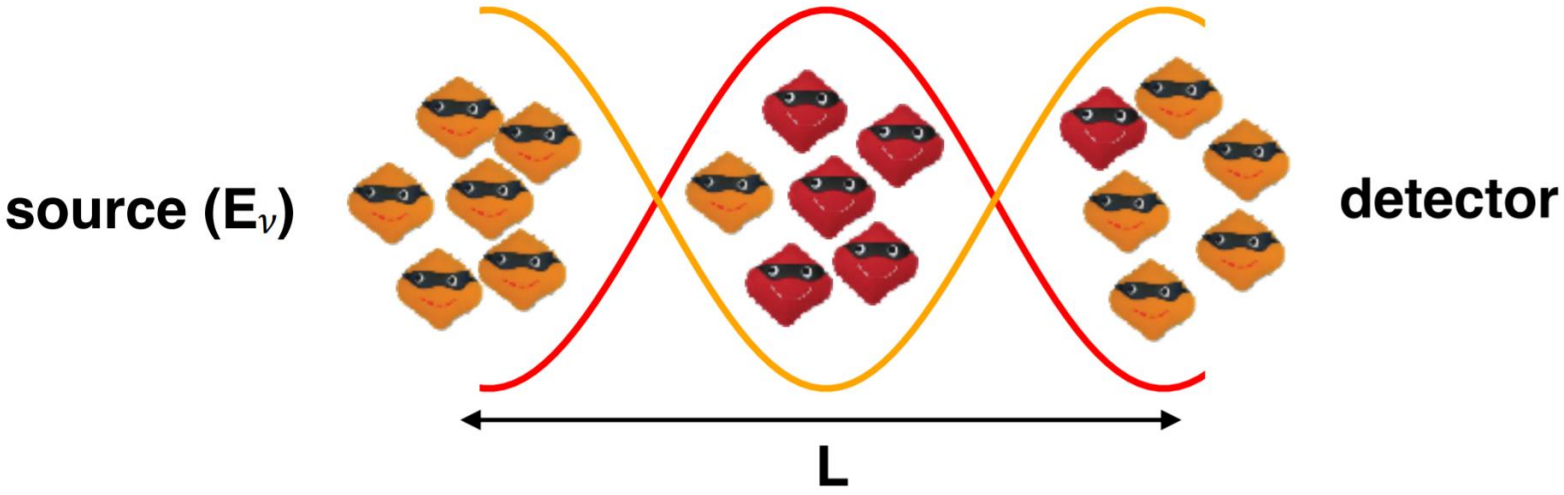


- Neutral, nearly massless fundamental particles that come in 3 flavors:

  ν_e , ν_μ , and ν_τ
- Interact weakly, and are produced in nuclear decay.
- Sources include the Sun, nuclear reactors, cosmic rays, and astrophysical events, such as supernovae.

Neutrino Oscillation

- Neutrinos have been observed to change flavors from solar, reactor, and accelerator experiments
- This is quantum mechanical effect: a neutrino is a quantum superposition of mass and flavor states



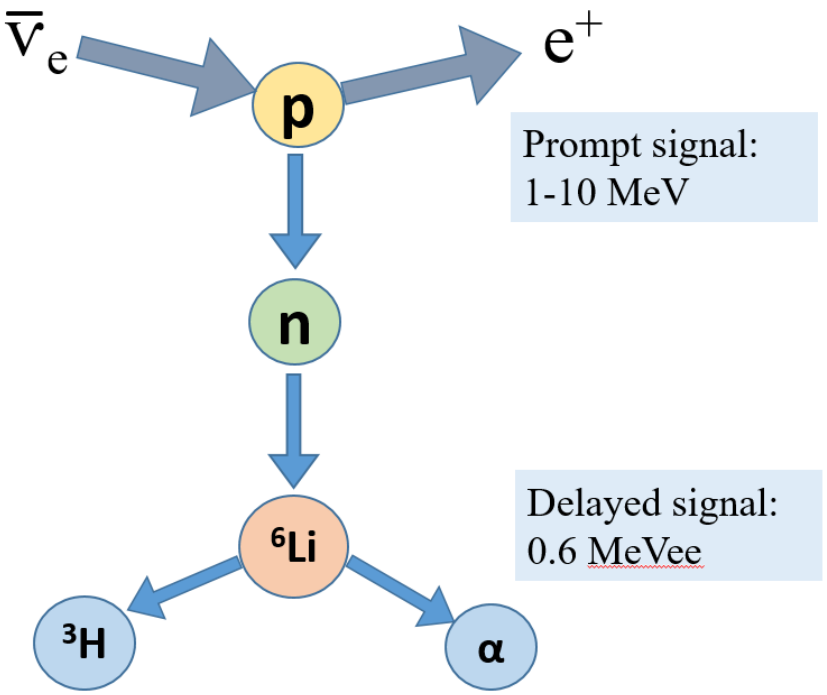
Detecting Reactor Neutrinos

- Nuclear reactors produce a copious amount of antineutrinos via nuclear decay (beta minus decay).
- These neutrinos are detected via inverse beta decay:

$$\bar{\nu}_e + p \rightarrow e^+ + n^0$$

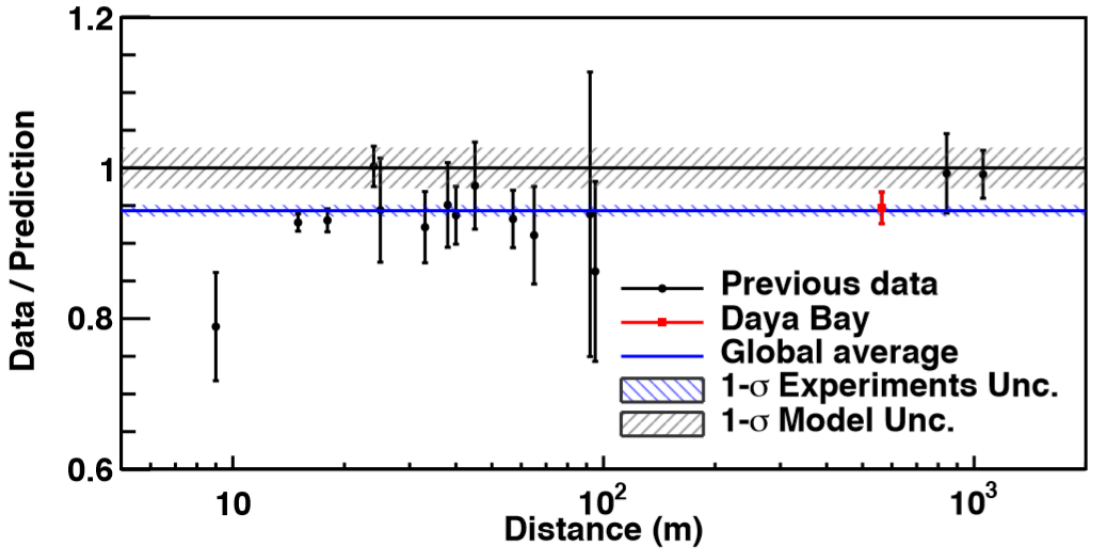
- Recent experiments have found oscillation parameters, and raised new questions

Antineutrino signature:
Inverse Beta Decay

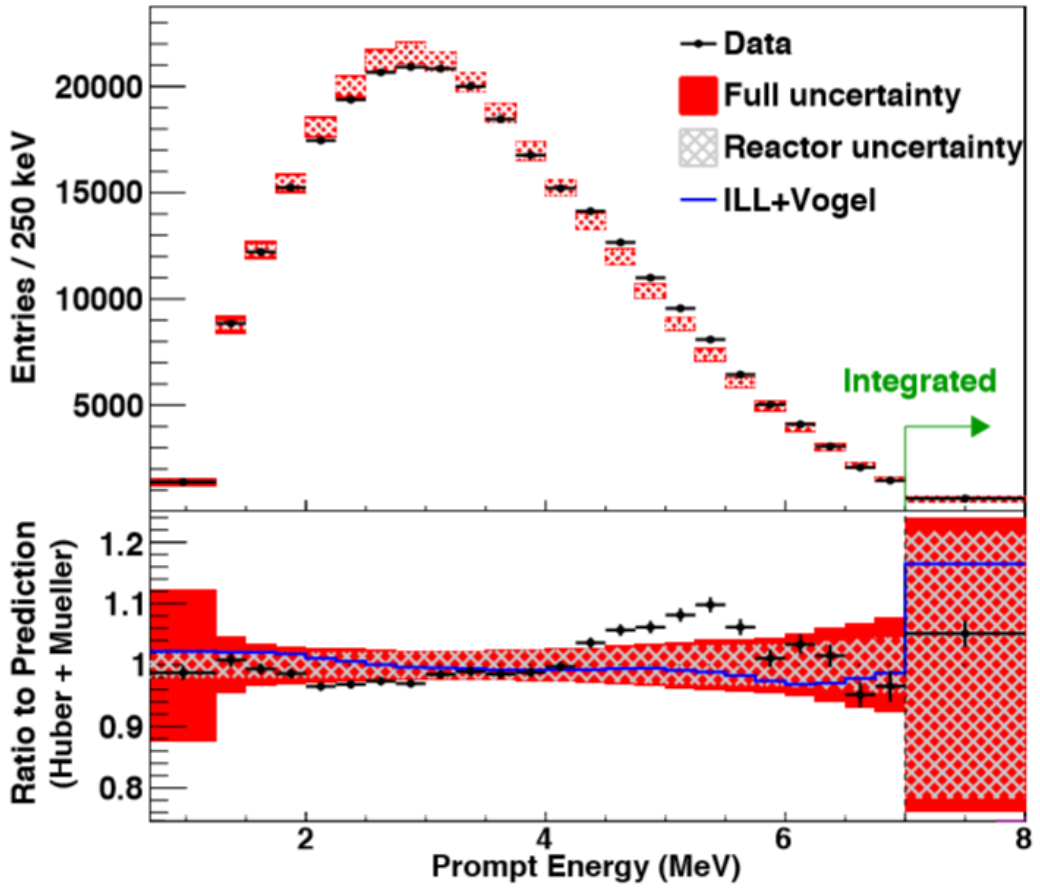


Reactor Neutrino Anomalies

1. Neutrino flux deficit -> fewer neutrinos observed than expected
2. Spectral deviation -> more neutrinos in one energy range than expected



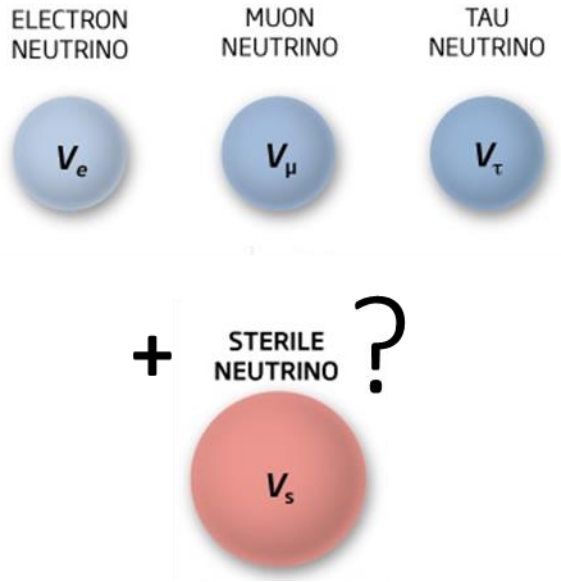
Antineutrino flux observed vs model. (Phys. Rev. Lett. 116, 061801)



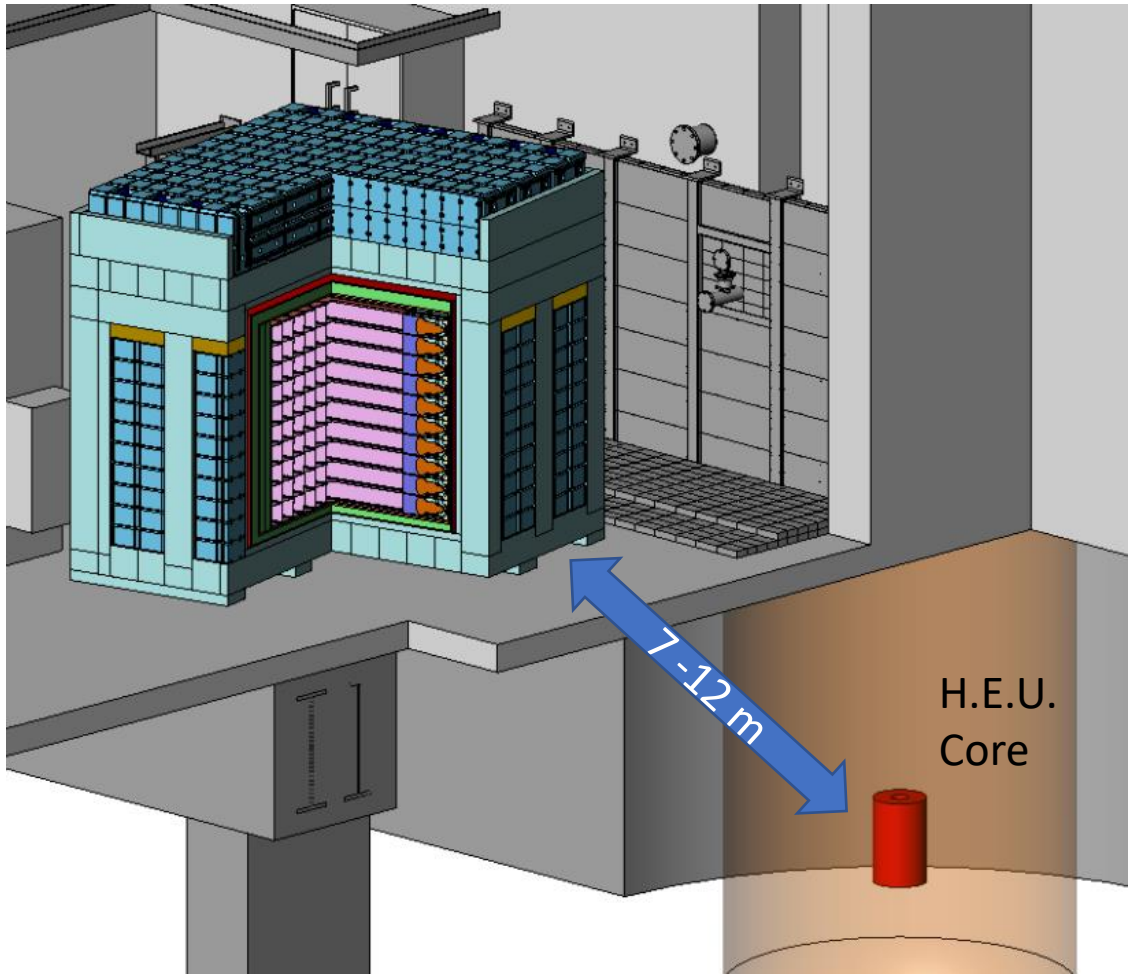
Predicted and measured prompt energy spectra. Spectrum normalized to prediction (Phys. Rev. Lett. 116, 061801)

Goals of the PROSPECT Experiment

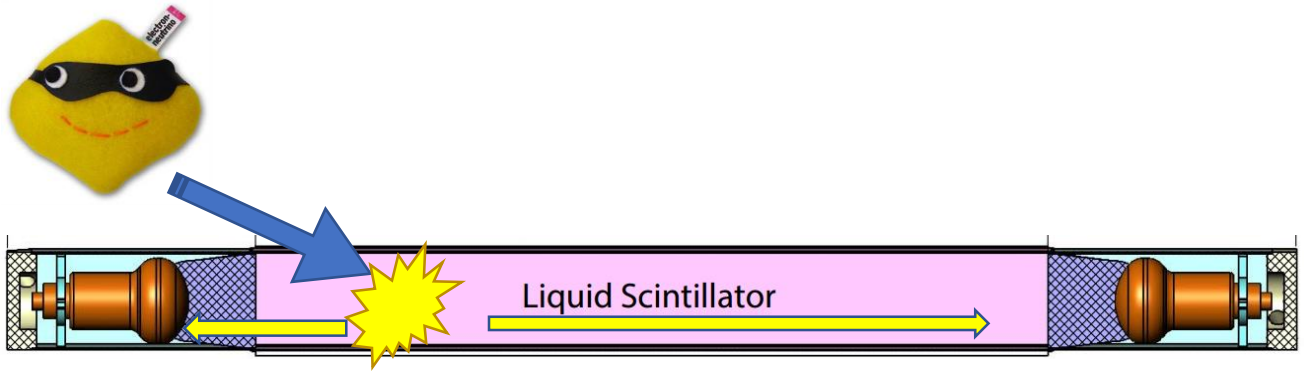
1. To search for oscillations into a new neutrino flavor – an eV-scale **sterile neutrino:**
    - Address the flux deficit anomaly
    - Probe physics beyond Standard Model
2. To **precisely** measure the **antineutrino spectrum** from a highly-enriched ^{235}U core
    - Address spectral deviation



PROSPECT Detector Design



- Location: Oak Ridge National Laboratory's High Flux Isotope Reactor
- 11x14 array of optical segments, ~4-ton
- Target/detection medium: ^{6}Li-loaded liquid scintillator
- Double-ended photomultiplier readout



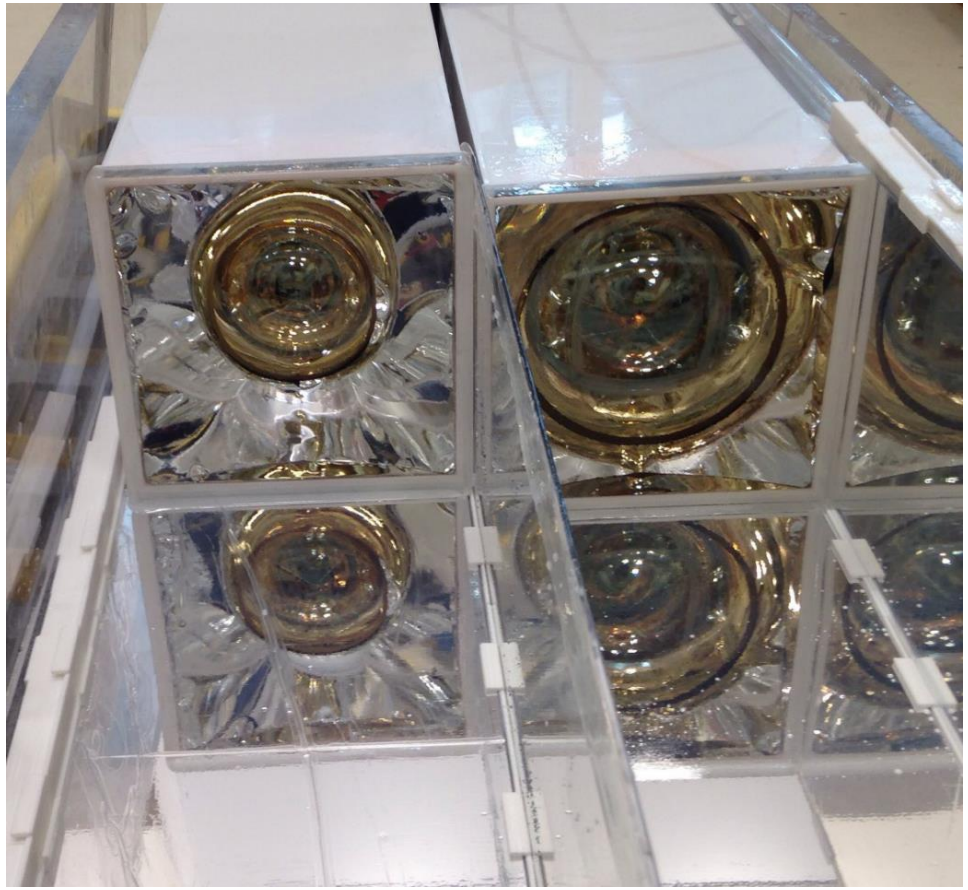
Detector calibration

Goals:

- To benchmark energy response
- To reconstruct position information

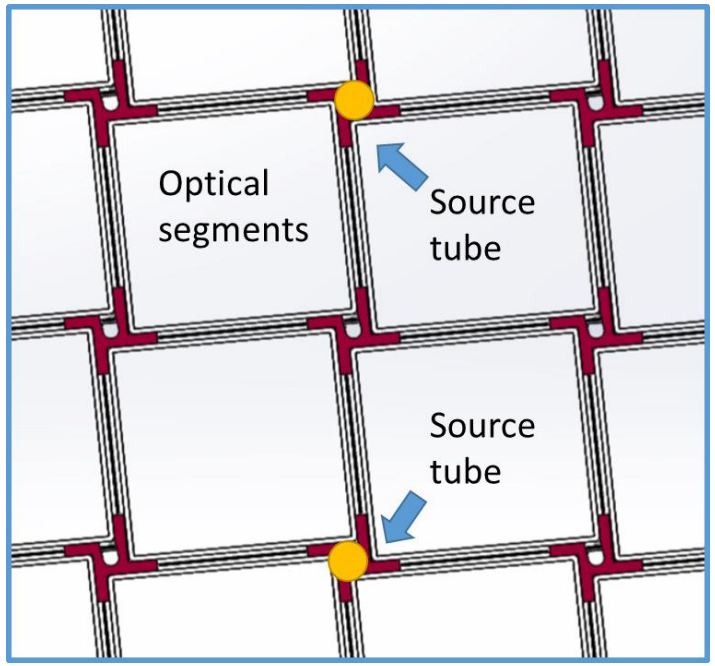
Requirements:

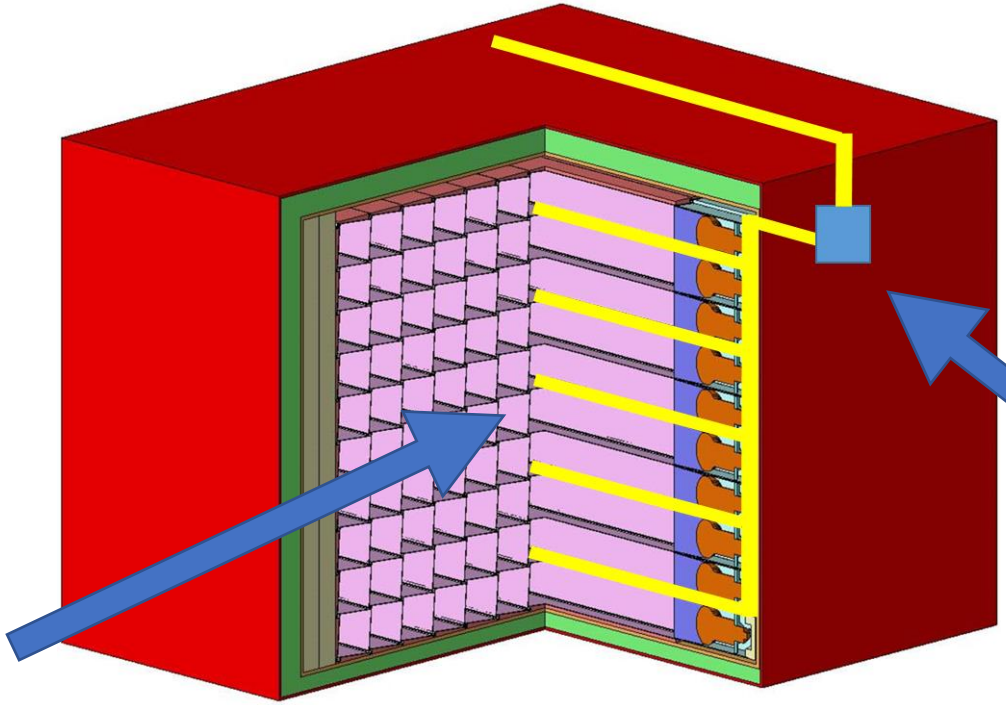
- Retractable radioactive source, movable inside the detector
- Precise positioning



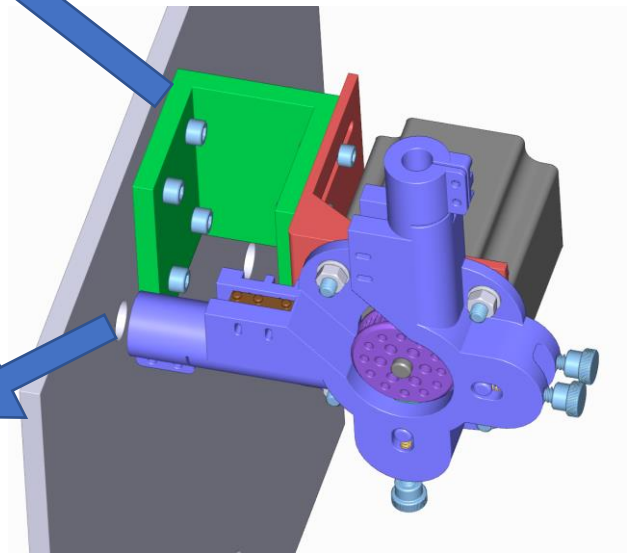
PROSPECT Source Calibration System Design

Sources deployed through guide tubes along segment length:

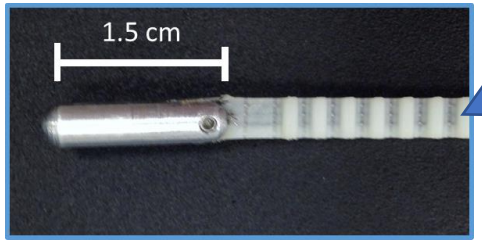




Driven by stepper motor, controlled remotely:



Source in capsule, on timing belt:



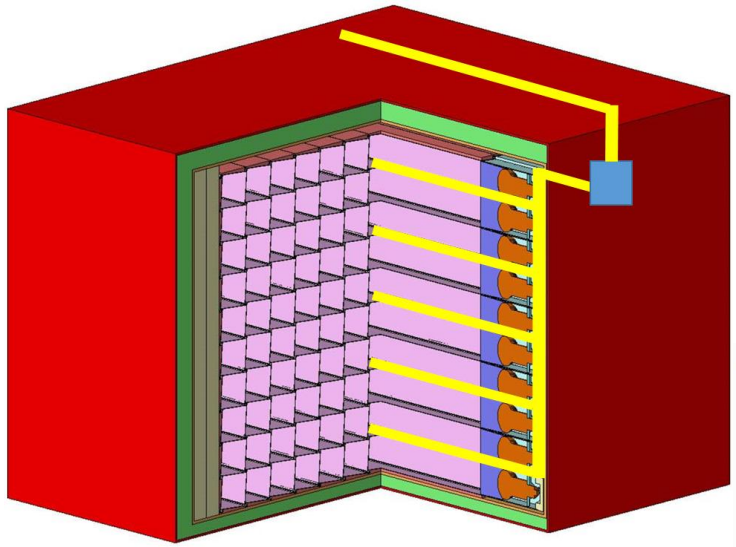
Development of Deployment System

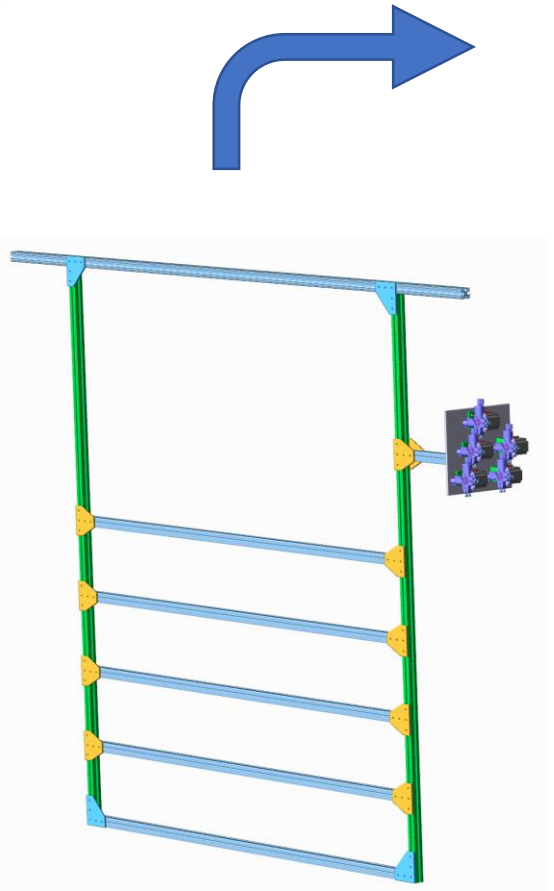
Prototype motor system developed:

- 3D printed timing belt pulley: **precise positioning** along segment
- Teflon guide and storage tubing: **low friction** deployment
- Arduino motor control: **remote operation** of calibration

Result: passed precision and longevity tests for one calibration path.

Current Work: Full Calibration Column Test

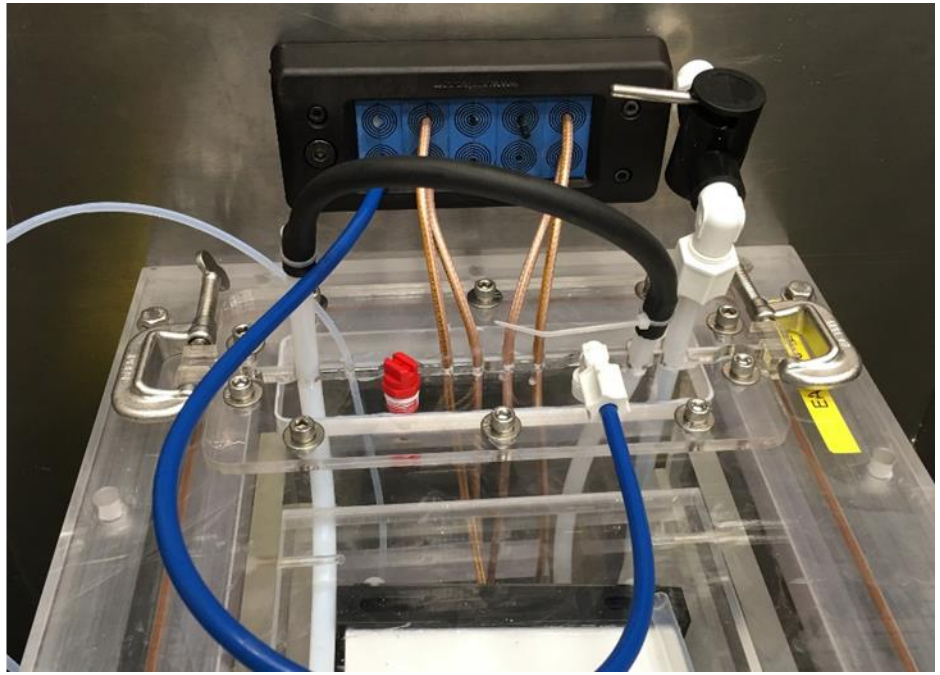




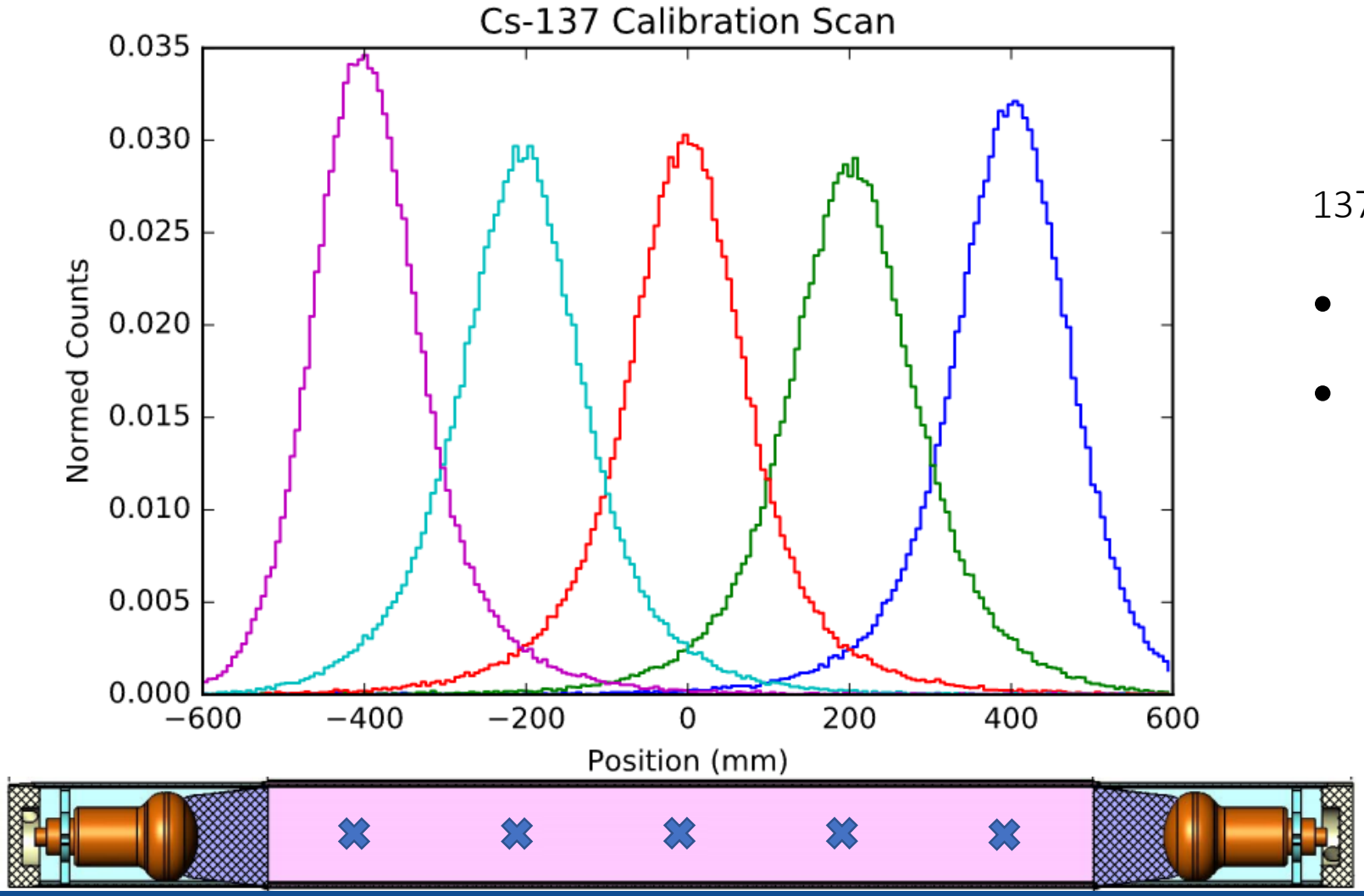
PROSPECT-50 and Calibration Testing

PROSPECT-50 (P50): a prototype 50 L, 2-segment detector.

- Source calibration installed, with string-deployed system
- Used to test hardware and conduct calibration analysis



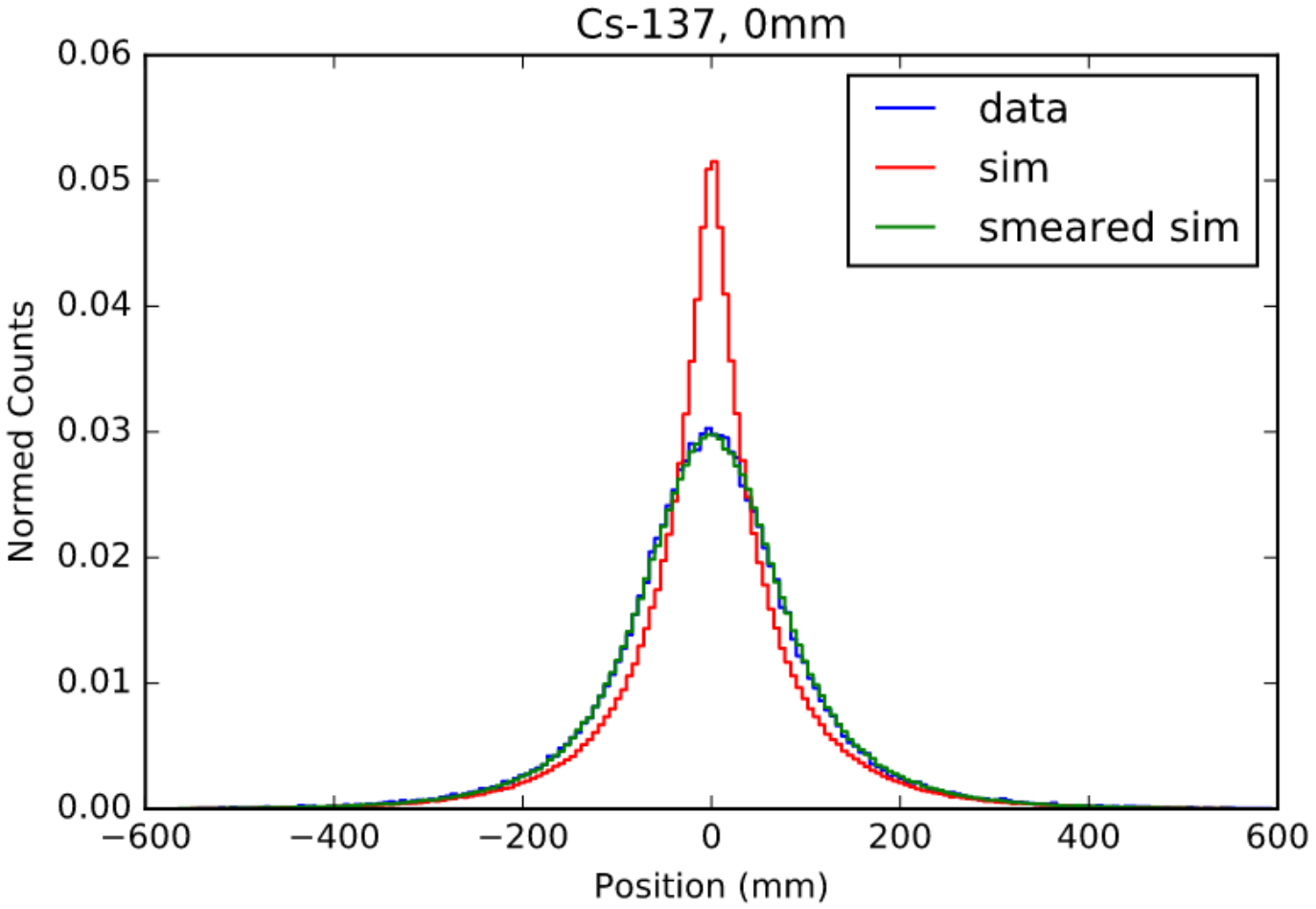
Position Reconstruction Analysis in P50



^{137}Cs: 662 KeV gamma decay

- Internal ^{137}Cs source
- Placed along the length of lower P50 cell, in 20 cm increments.

Position Reconstruction Analysis in P50



Simulation: the position distribution of gamma rays in P50, assuming perfect resolution.

"Smeared" simulation: simulated event convolved with normal distribution, done for an array of standard deviations (possible resolutions).

χ^2 minimization to data yields:

Position Resolution: 4.65 cm

Summary

- Neutrino investigations at reactors allow us to explore new physics!
- PROSPECT goals: sterile neutrino search & spectrum measurement
- PROSPECT Progress:
  - Antineutrino detector under construction
  - Installation at ORNL in summer 2017
  - First data in 2017

The PROSPECT Collaboration – prospect.yale.edu

Back-up

Neutrino Oscillation

- Neutrinos are generated in weak eigenstates (flavors), which are each composed of a specific mixture of mass eigenstates.
- Neutrinos propagate in mass states, which travel at different speeds.
- Thus the mass fractions change, differing from the initial neutrino state.
- The resulting change of flavor states is called neutrino oscillation.