Working Towards an **Absolute Reactor Antineutrino Flux Measurement** using PROSPECT-I Data

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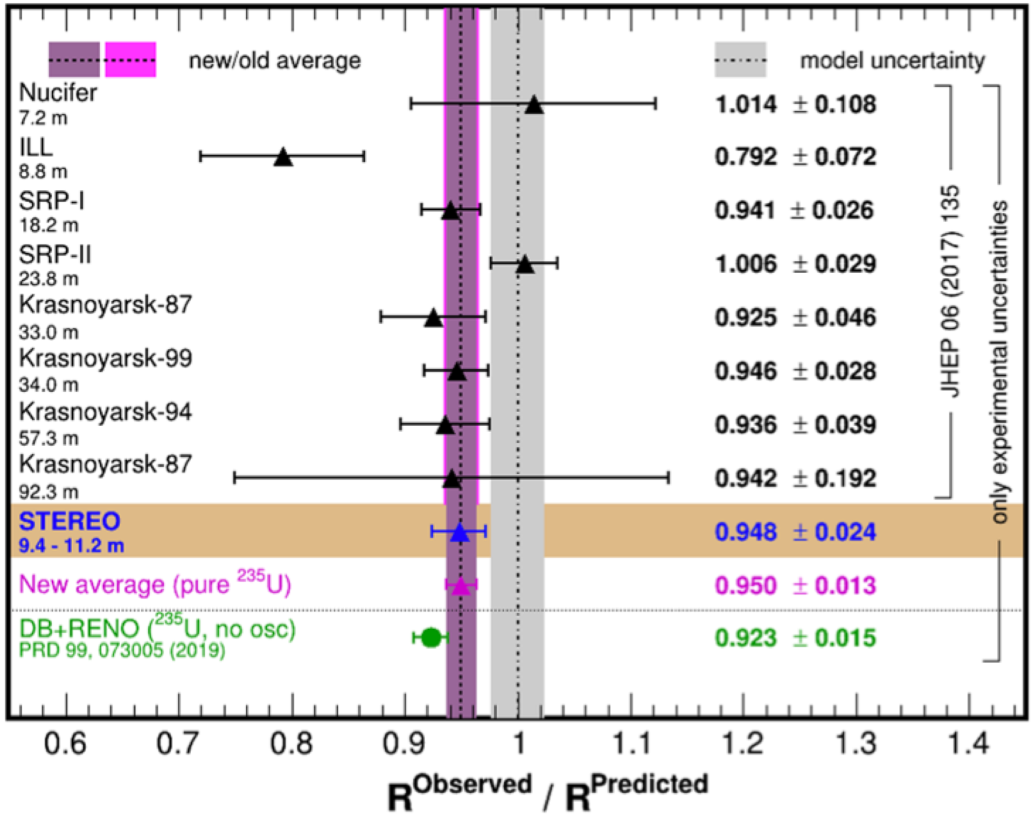
Motivation for absolute flux analysis

- Two flux prediction methods
  - *Ab-initio* method
    - Summation of decay rates convolved with branching fractions of β-decays from isotopes in core to final nuclear states
  - β^- spectrum conversion
    - Conversion of electron spectrum of fission isotopes into an $\bar{\nu}_e$ spectrum using nuclear decay theory and branching fractions

- Measured flux and predicted flux do not agree: Observed flux deficit
  - Are reactor neutrinos oscillating to sterile neutrinos?
  - Are the flux predictions overestimated?

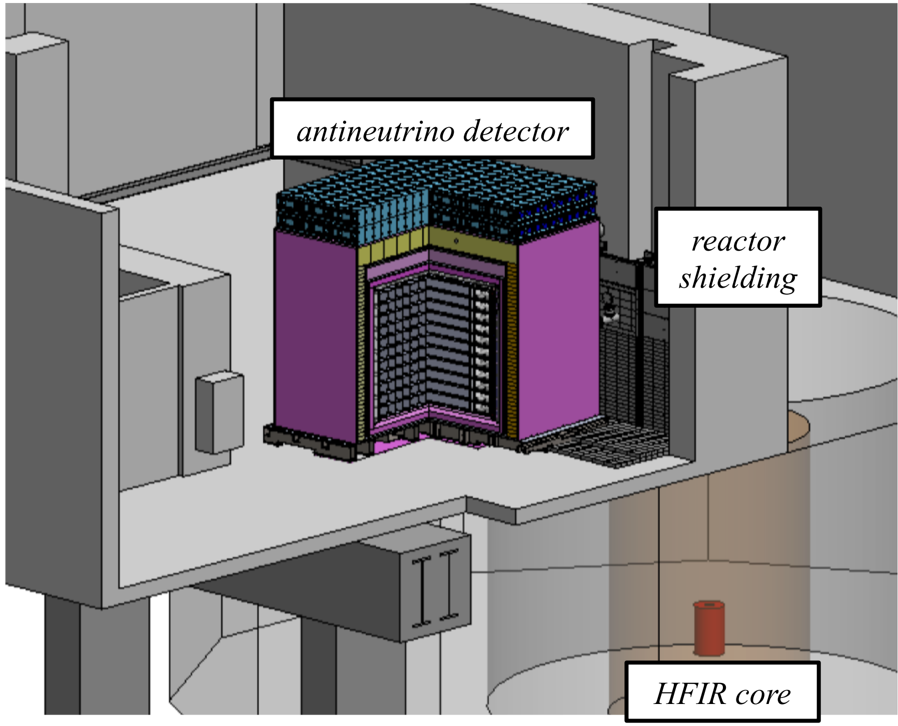
Phys. Rev. Lett. 125, 201801 (2020)



Precision Oscillation and Spectrum Experiment

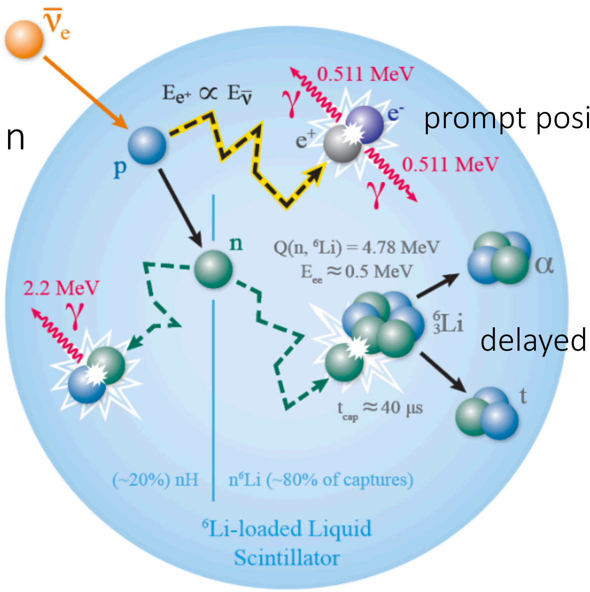
PROSPECT

- 4-ton ^{6}Li-doped liquid scintillator (LiLS) in segmented detector located ~8 m from the HEU core of the High Flux Isotope Reactor (HFIR) at ORNL
  - Pulse-shape discrimination (PSD) for particle ID
  - Event topology
  - Fiducialization
- Double PMT readout with light concentrators
- Layered shielding and segmentation suppress cosmogenic backgrounds



154 segments, each loaded to 25 L of LiLS

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



- Inverse beta decay (IBD) event signature
  - ~few MeV prompt positron signal
  - ~0.5MeV delayed neutron capture on ^{6}Li (nLi)

PROSPECT-1 prompt energy spectrum measurement

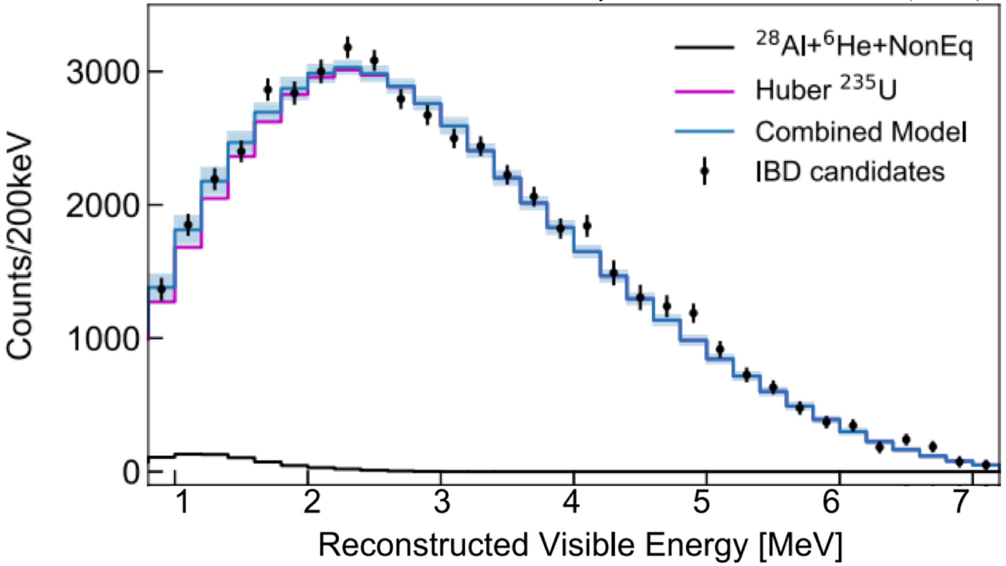
- After 7 month run (95 days reactor-on, 72 days reactor-off), PROSPECT-I demonstrated:
  - High statistics and precise spectrum shape
  - Precise measurement of daily neutrino rate

    (~530 $\bar{\nu}_e$ events/day)

➡ Possible to do absolute measurement of ^{235}U IBD event yield

- PROSPECT-I has completed one phase of measurements and is currently being upgraded to do second phase of measurements as PROSPECT-II
  - P-I studies can inform P-II analysis

Phys. Rev. D 103, 032001 (2021)



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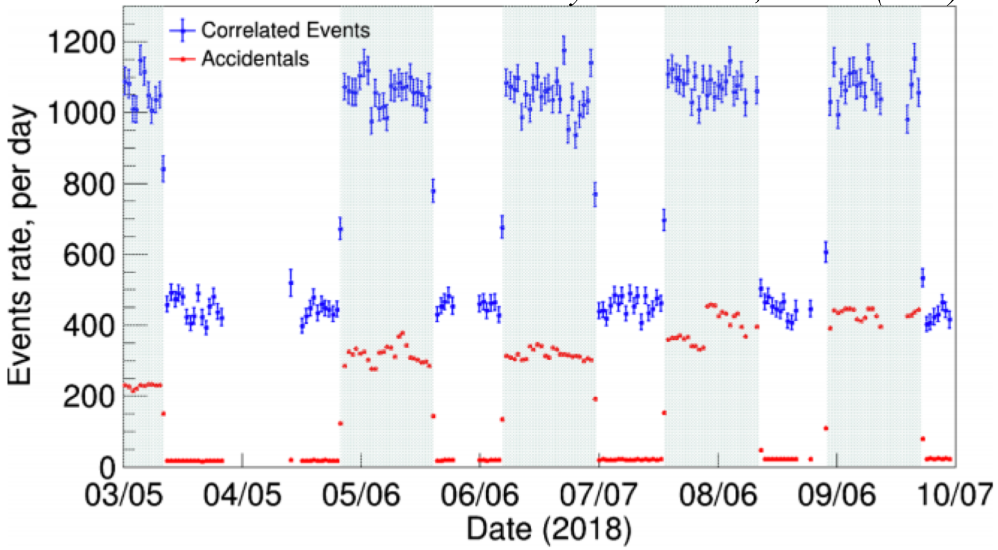


Working towards an absolute flux measurement with PROSPECT

- Measurement of reactor $\bar{\nu}_e$ flux
  - Can determine $\bar{\nu}_e$ production in a nuclear reactor core per second at time t in terms of neutrinos per unit energy:
    - Thermal power output of reactor core
    - Fission fraction and $\bar{\nu}_e$ flux from fission isotope i
    - Average energy release per fission

$$\frac{d\phi(E_\upsilon,t)}{dE_\upsilon} = \frac{W_{th}(t)}{\bar{E}(t)} \sum_{i=1}^{4} f_i(t) s_i(E_\upsilon) + s_{nf}(E_\upsilon,t)$$

Reactor $\bar{\nu}_e$ flux from nonfuel sources (negligible for PROSPECT)

- Due to high statistics and strong background rejection, uncertainties are largely systematic

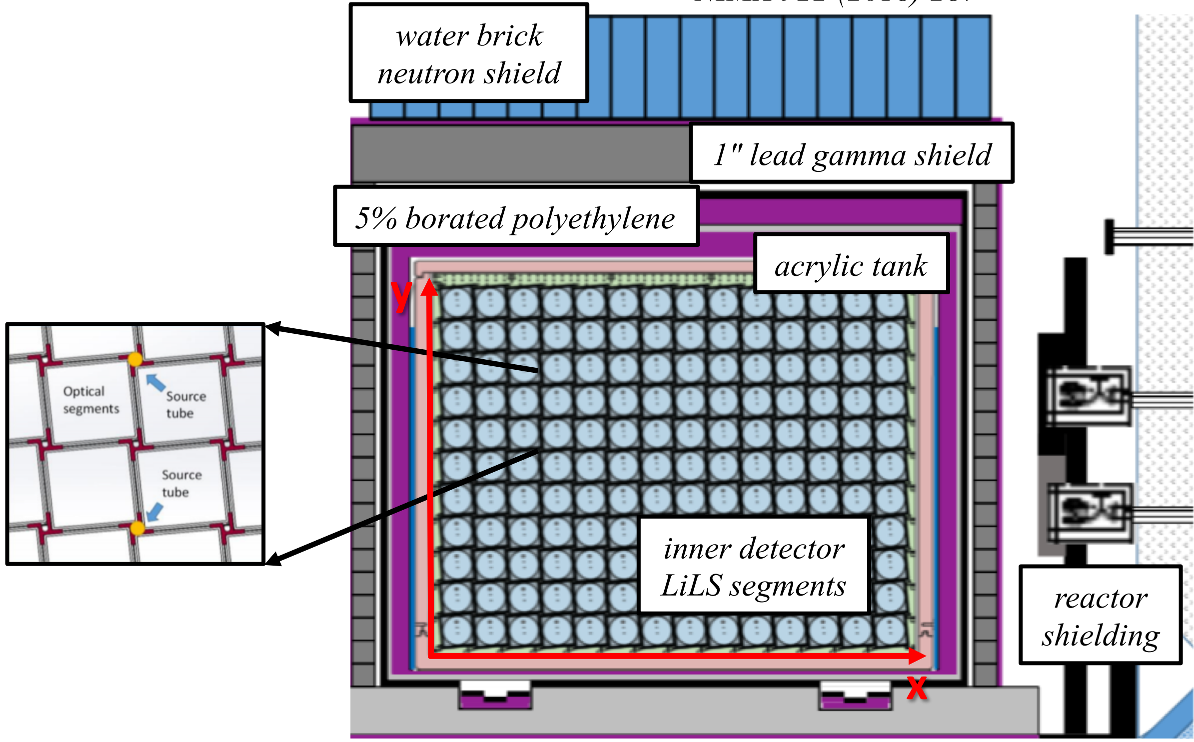
- Applications:
  - Updated and more precise measurement relative to flux predictions
  - Reactor antineutrino anomaly and sterile neutrino oscillation[1, 2]
  - Contribution to global fit of reactor neutrino fluxes
  - Reactor power monitoring for verification and safeguards

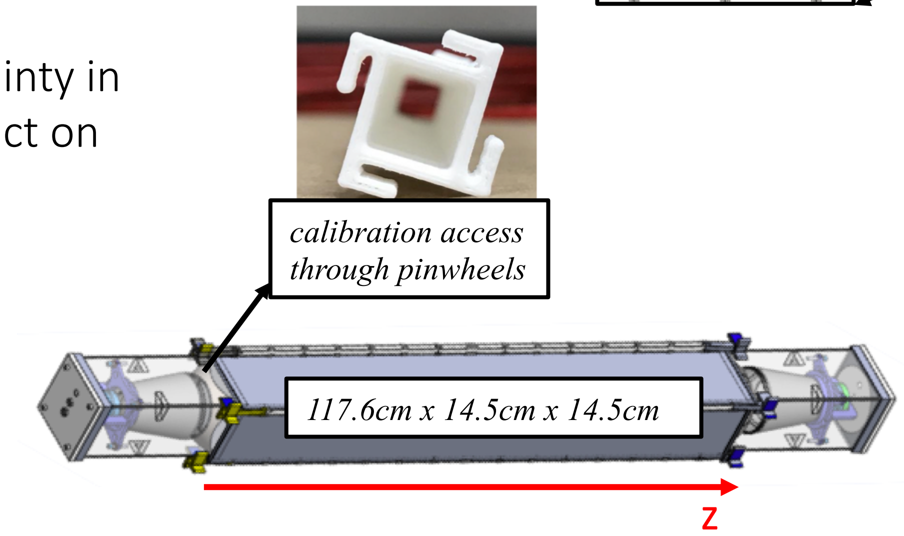
[1] Mueller T et al. 2011 Phys. Rev. C83 054615
[2] Mention G et al. 2011 Phys. Rev. D83 073006

Position reconstruction studies with P-I data to support absolute flux measurement

- Constraining systematic uncertainties is important part of understanding the absolute flux measurement
- Gather information on z position of IBD positron event
  - Uncertainty in z cut will contribute to uncertainty in entire absolute flux measurement
  - Planned fiducial cut z = $\pm$30 cm
- Characterize systematic uncertainty in fiducial z cut to determine impact on flux measurement

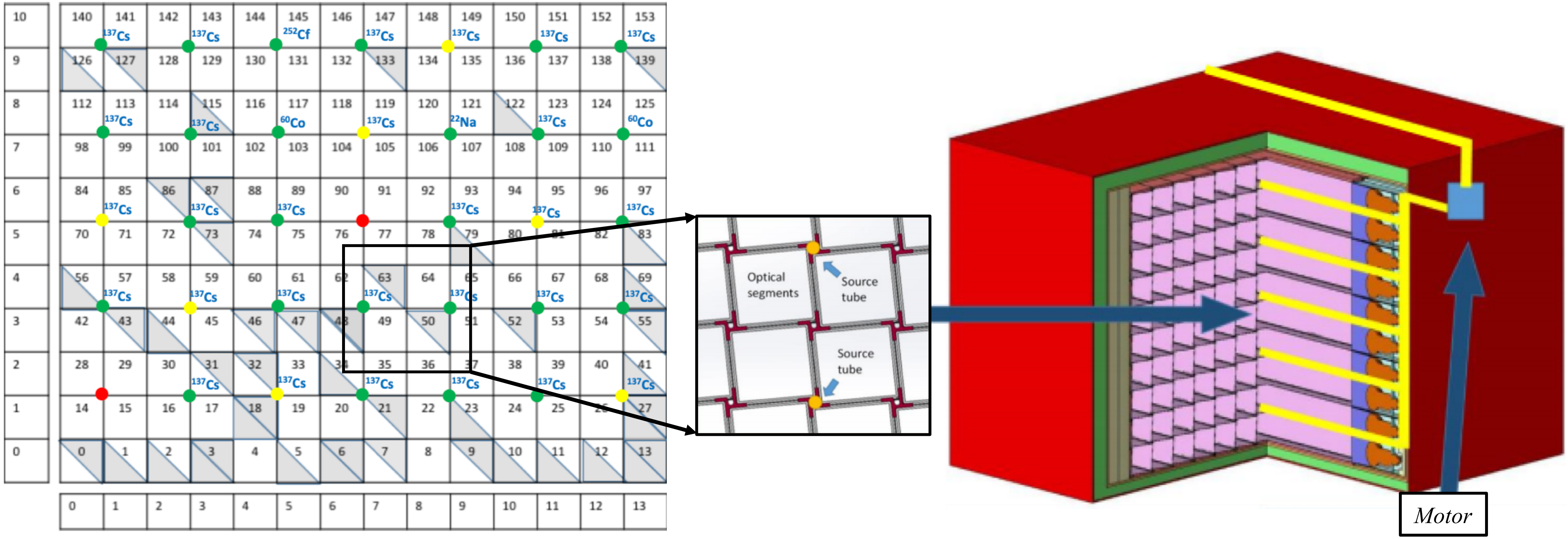
NIMA 922 (2018) 287





Calibration sources used to determine z position reconstruction ability

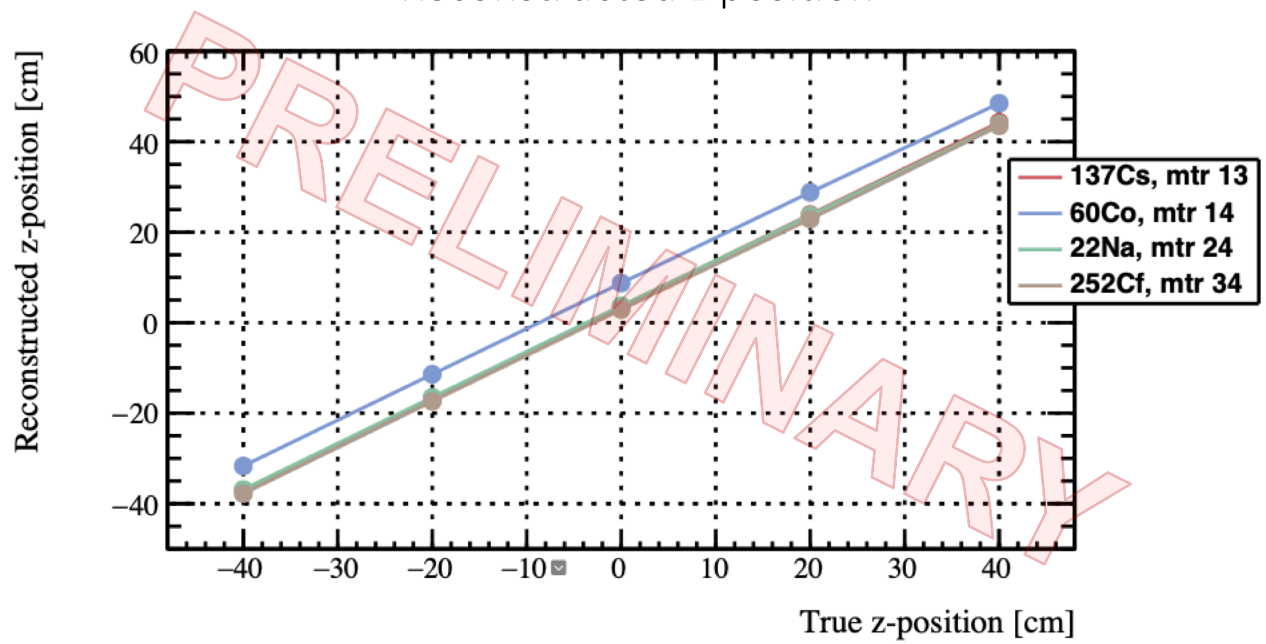
- Procedure for scans taken over several month period:
  - Calibration sources attached to timing belt driven by motor along segments
  - Scans taken with calibration sources at 5-7 predetermined z-positions along segment



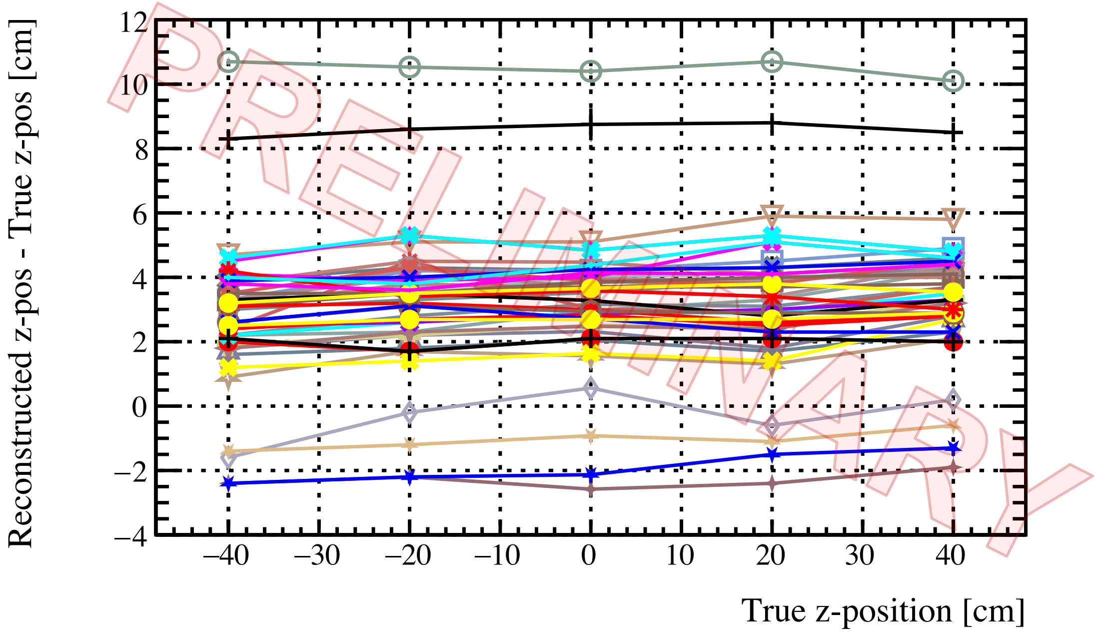
^{137}Cs, ^{60}Co, ^{22}Na, ^{252}Cf, AmBe

Preliminary z position reconstruction studies

Reconstructed z position



Reconstructed z position – Expected z position

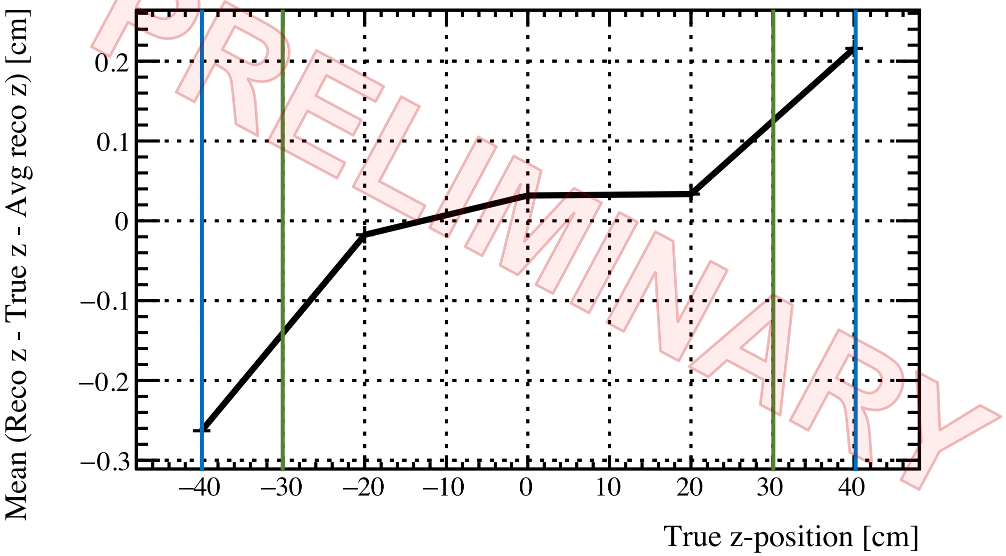


- Subtraction of expected z-positions from reconstructed z-positions over multiple scans yields a set of nontrivial z offsets
  - Causes stretching of fiducial volume

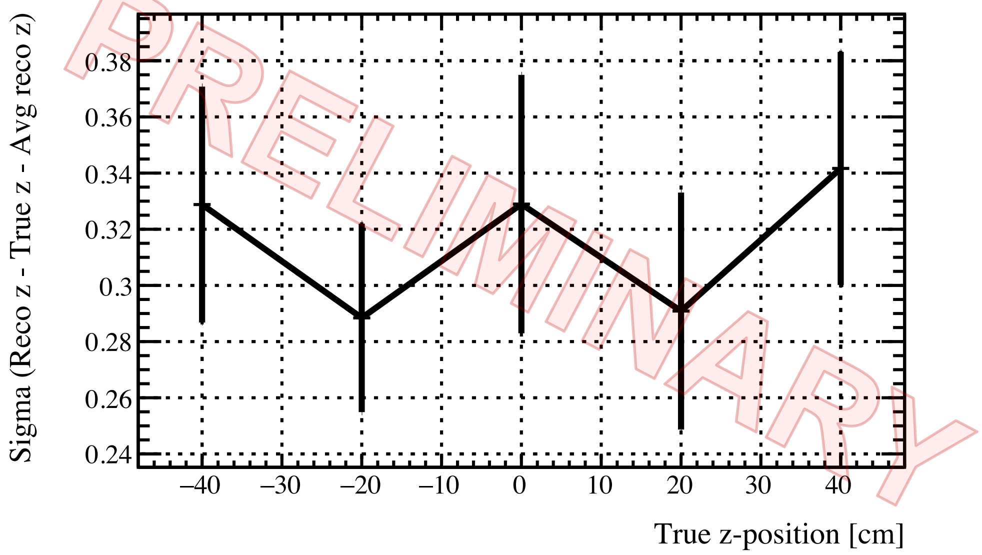
This study can inform the choice of fiducial z cut length for future absolute flux analysis.

Characterizing systematic error in fiducial z cut

Mean $\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$



Standard Deviation $\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$



$1\sigma = 0.342 \pm 0.0415$ cm from mean z offset

➡ Based on the stretching we see aggregated over scans of many different calibration source axes it appears uncertainty in z measurement is of order 0.5 cm, which corresponds to around order 1% uncertainty.

Closing thoughts and next steps

- Promising results for absolute flux analysis in P-I
  - **For a ~3% measure of absolute flux, we are on track with order ~1% systematic uncertainty in fiducial z length**
  - Increasing fiducial volume leads to lower fractional uncertainty and better statistics

- Working towards flux measurement with P-I and P-II
  - Measurement is systematics limited, first step in constraining uncertainty in fiducial cut
  - PROSPECT-II will have improved statistics, background reduction, and systematic uncertainties to get down to 1% measure of absolute flux
  - Potential deployment at LEU location could provide measurement of IBD event yield with precision comparable to existing theoretical predictions for the fission isotopes in the reactor core

Stay tuned for absolute flux results from PROSPECT-I in the near future!