# PROSPECT-II calibration strategy

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On behalf of the PROSPECT Collaboration

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

***Past(Tue):***
FK.00005: Precise Measurement of Reactor Antineutrino Spectra from Joint Analyses of PROSPECT, STEREO, and Daya Bay
Benjamin T Foust
FK.00006: PROSPECT-II: Physics goals with an upgraded precision reactor oscillation and spectrum neutrino experiment
Thomas J Langford
FK.00007: Working Towards an Absolute Reactor Antineutrino Flux Measurement using PROSPECT-I Data
Paige Kunkle
FK.00008: Reactor Background Measurements at HFIR in Support of the PROSPECT-II Experiment
BLAINE HEFFRON
***Poster Session:***
HA.00031: Directional Neutrino Detection with PROSPECT
Manjinder Oueslati

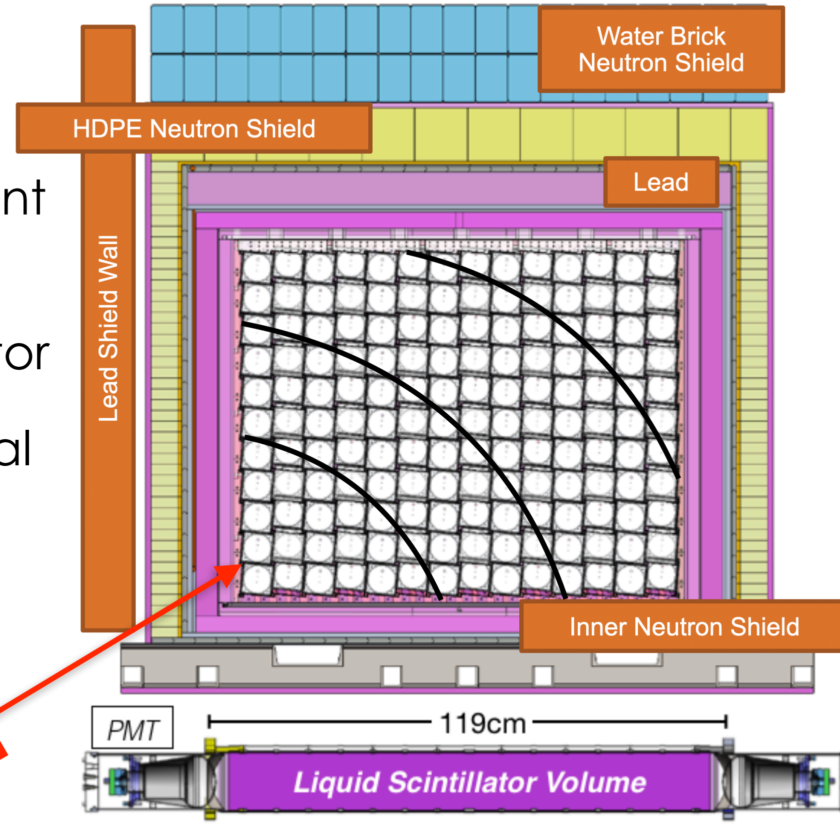
# Outline

- PROSPECT-I introduction
- PROSPECT-I calibration
- Changes in PROSPECT-II upgrades
- Results of R&D study on P-II calibration
- Summary

# PROSPECT experiment

PROSPECT detector:

- Short baseline reactor neutrino experiment located at HFIR, ORNL
- ~4 ton $^{6}$Li-loaded liquid scintillator detector
- Optically segmented into 14 x 11 identical detectors
- In-situ internal calibration access
- Less than ~1m w.e. overburden

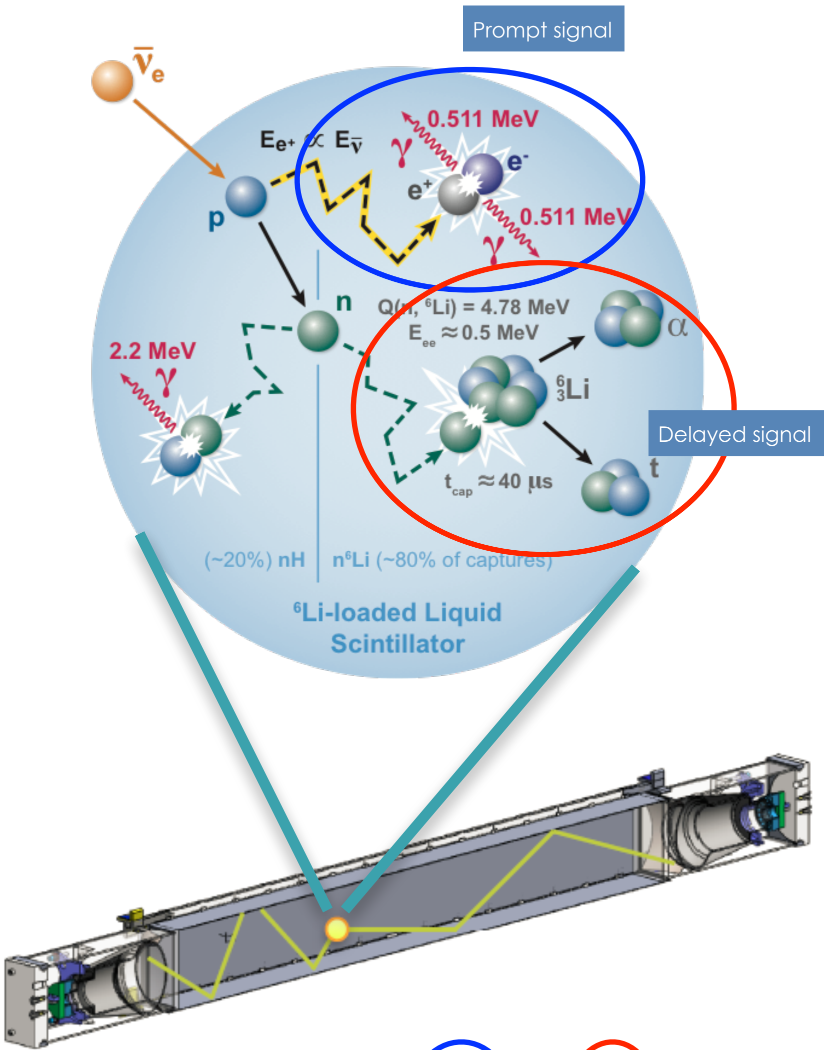


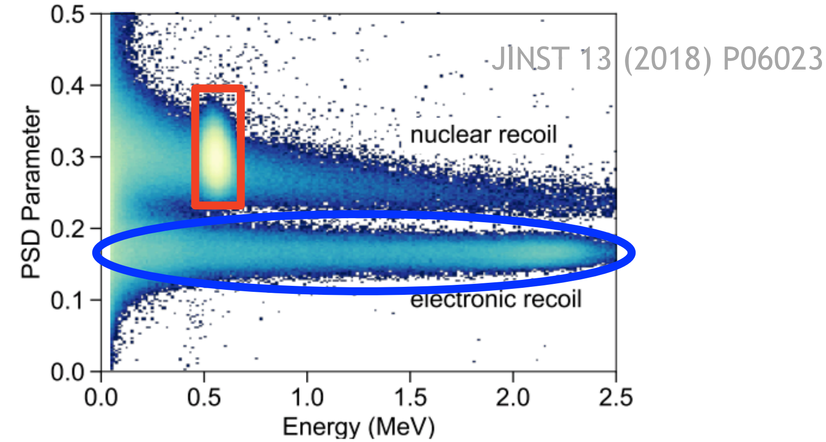

HFIR reactor core


High Flux Isotope Reactor: HFIR

- 85 MW research reactor
- Compact core
- Fresh highly-enriched $^{235}$U fuel

# Inverse Beta Decay as neutrino signal



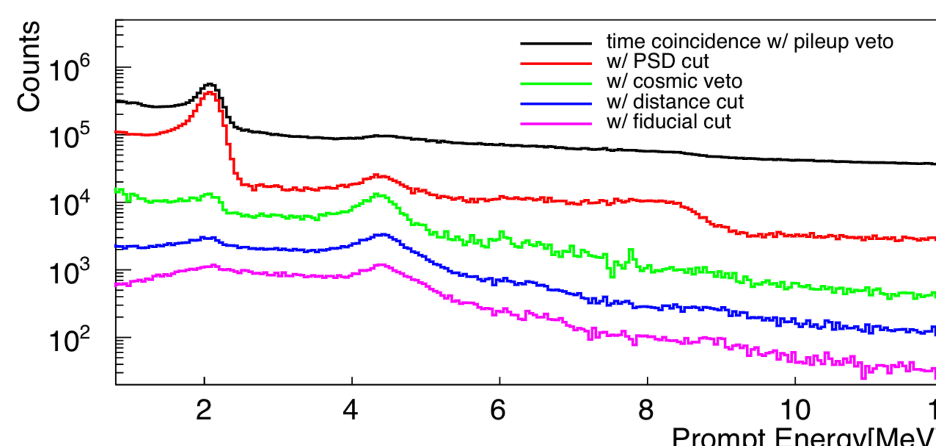




- Distinctive spatial/temporal correlation
- Particle ID capable LS via PSD
- Segment fiducialization, veto cuts, etc

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

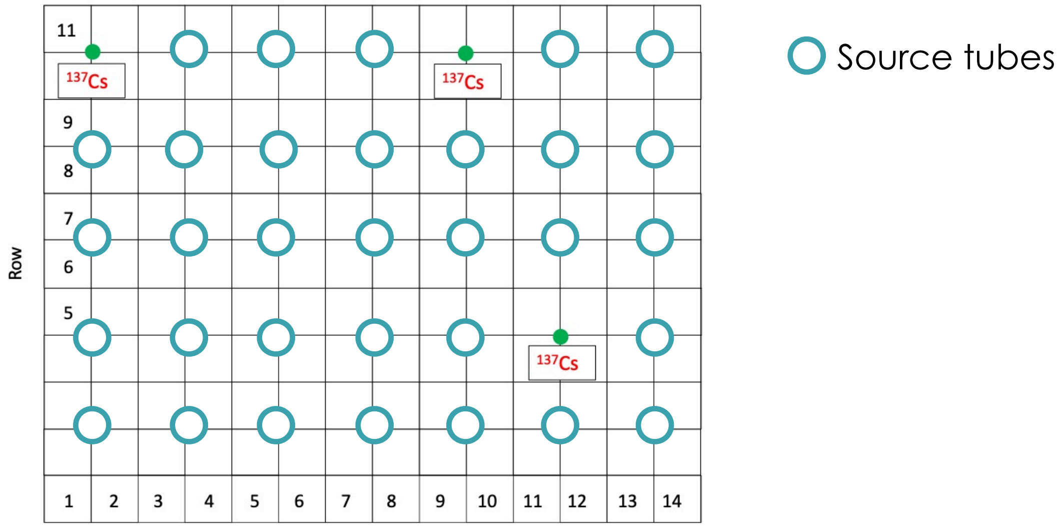
Prompt signal Delayed signal

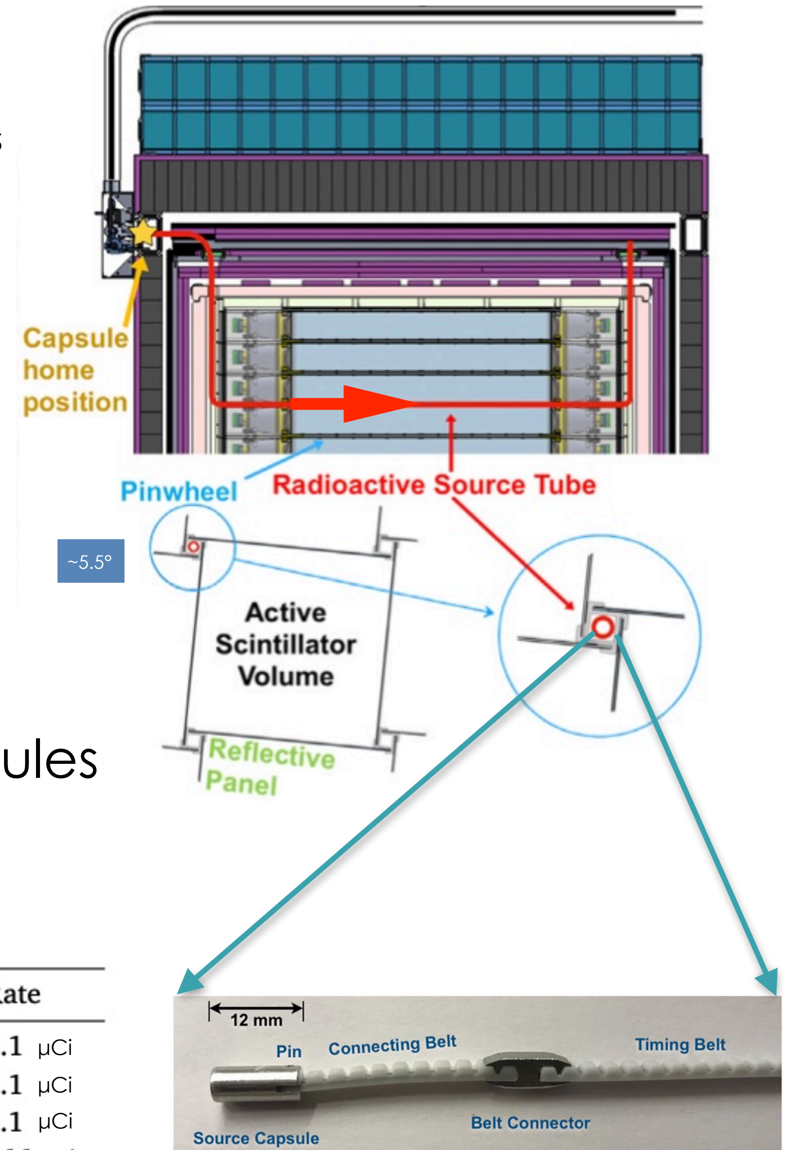
Sequential application of event selection




PRD103, 032001(2020)

# P-I Calibration system




- 14x11 segments and 5x7 source tubes
- ~5° tilted pinwheels house source capsules transported by stepper motor

**Table 1**
Calibration sources and their uses.

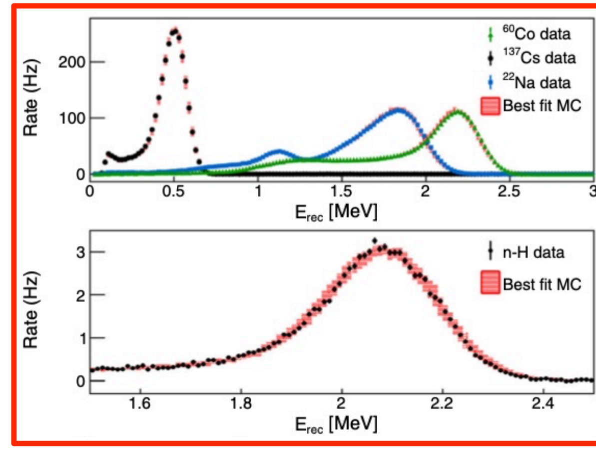
| Source | Type | $\gamma$ Energy (MeV) | Primary purpose | Rate |
|---|---|---|---|---|
| $^{137}$Cs | Gamma | 0.662 | Segment comparison | 0.1 μCi |
| $^{22}$Na | Gamma | 2×0.511, 1.275 | Positron, edge effects | 0.1 μCi |
| $^{60}$Co | Gamma | 1.173, 1.332 | Energy scale | 0.1 μCi |
| $^{252}$Cf | Neutron | 2.223 (n-H capture) | Neutron response | 866 n/s |
| AmBe | Neutron | – | Neutron response | 70 n/s |

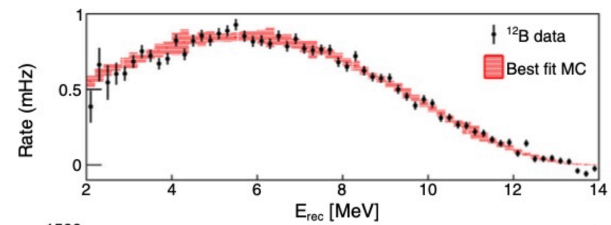
PROSPECT collaboration, NIMA 944 (2019) 162465

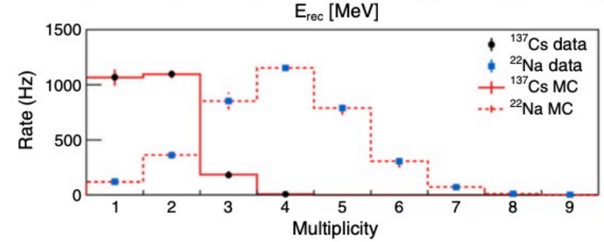
Internal sources

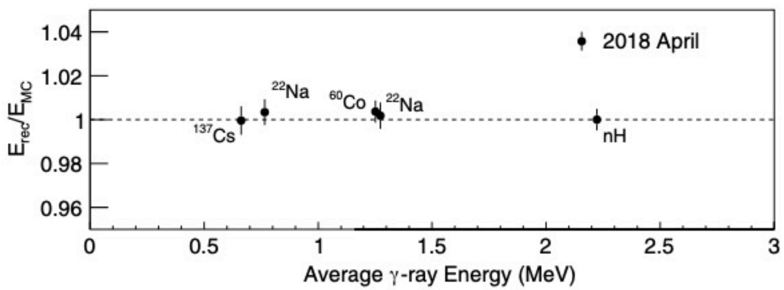
# P-I Calibration result

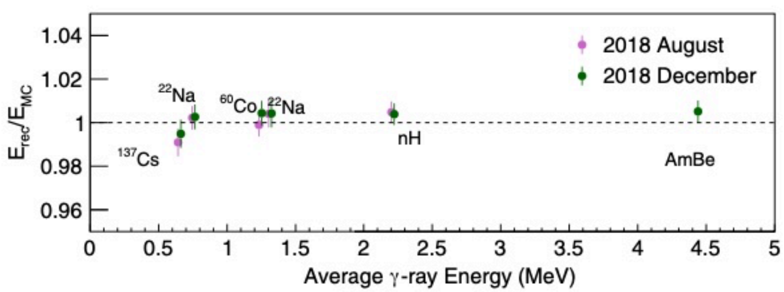
- Internal radioactive sources + cosmogenic $^{12}B$ events for energy calibration
- Detector energy non-linearity model is best fitted to data in both spectrum and event multiplicity



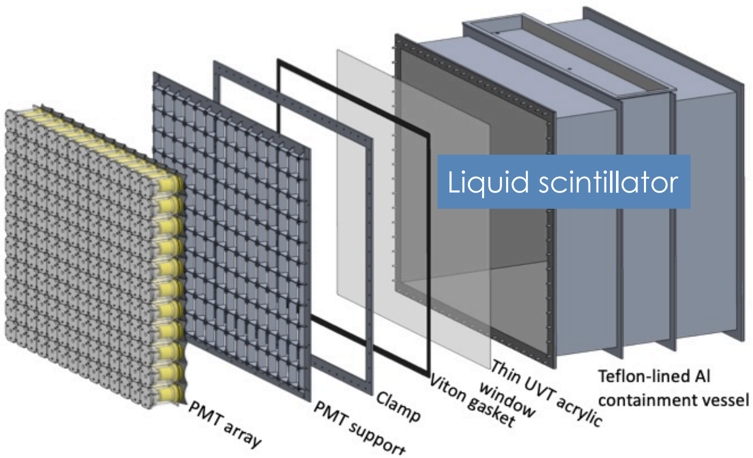

- Energy scale calibration ensures the energy reconstruction within +/-1% uncertainty and consistent across the data-taking period



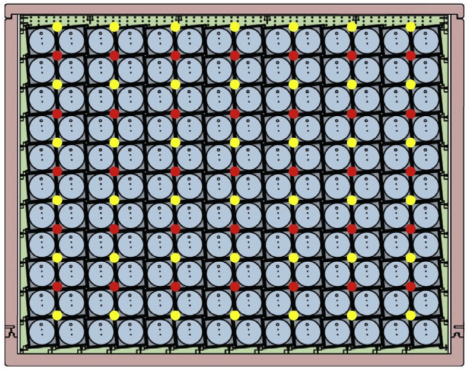

PROSPECT collaboration, PRD**103**, 032001(2020)

# Preliminary detector design for PROSPECT-II

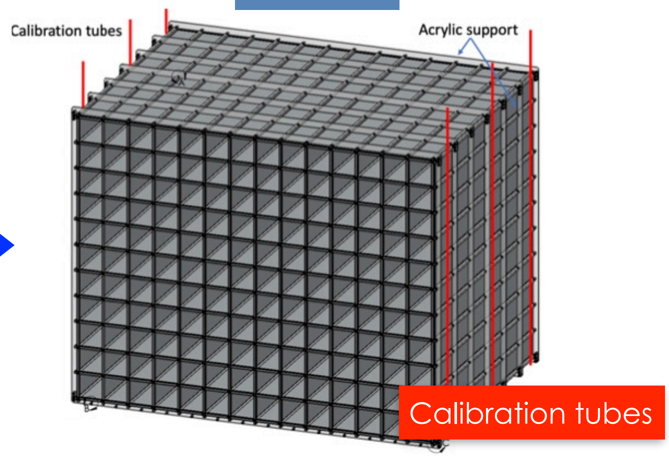
- Several PROSPECT PMTs showed current instability
- Separate PMTs from liquid scintillator volume to improve long term stability
- Simple and robust to be redeployed at other reactor sites
- External calibration source




P-I design



P-II design



# External calibration performance simulation

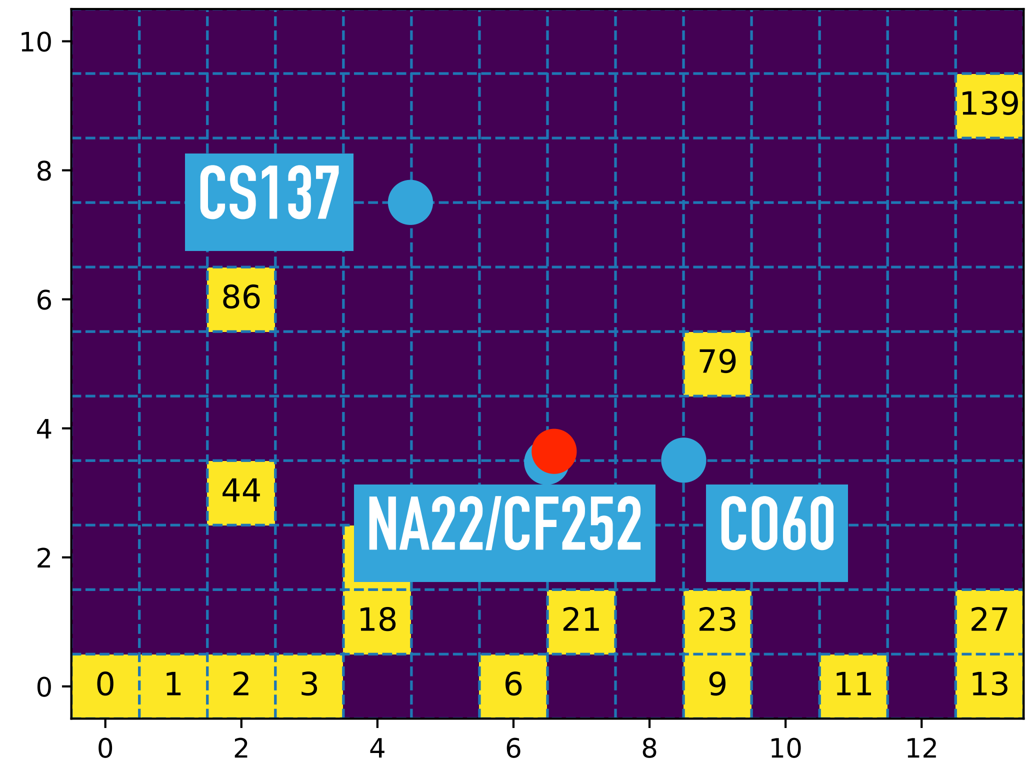
- Can external calibration perform as well as we had in PROSPECT?
- What is level of degradation in calibration parameter precision?

Validation R&D study based P-I simulation/data

Internal calibration used in PROSPECT-I

Fiducial volume

Inactive segments



# External calibration performance simulation

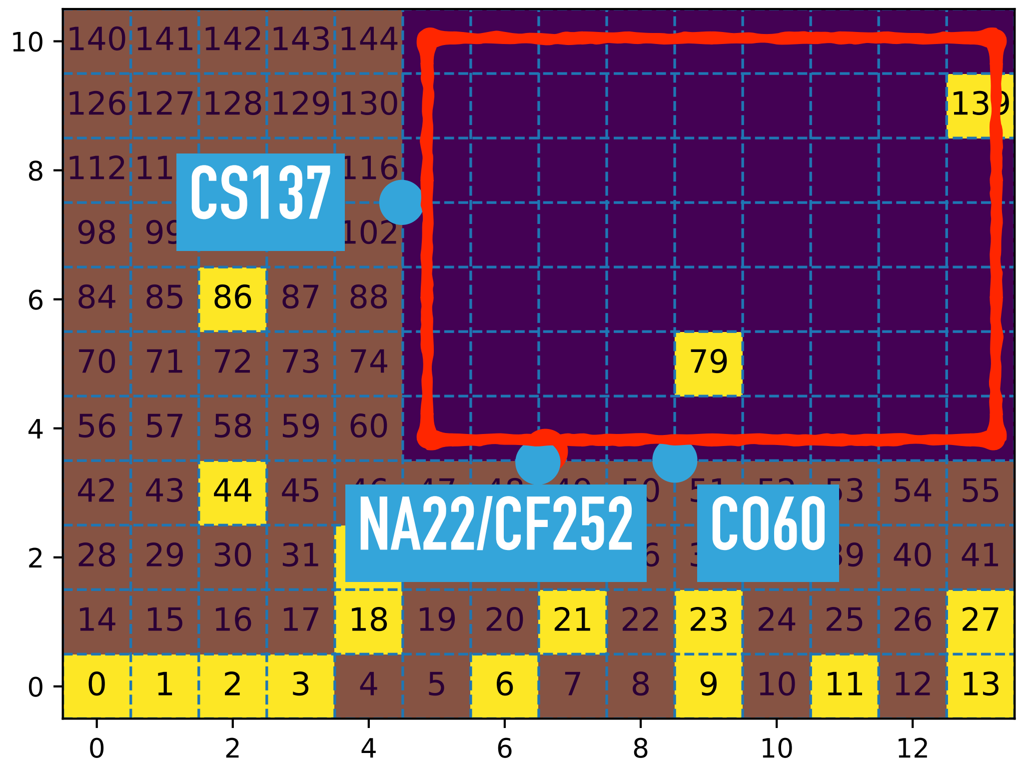
- Manually switch off certain segments in the analysis
- Calibration sources are effectively <1cm outside the fiducial volume

External calibration

Fiducial volume

Inactive segments

Manual turned off



# Methodology

- The non-linearity detector response model is not directly simulated via the computational-resource-heavy process of optical photon production and propagation.
- Instead, fractional conversion of true deposited energy to scintillation light is calculated step-by-step during GEANT4 propagation of the particle using parametrization of these physics processes:

$$E_{\mathrm{MC}} = A \sum_i (E_{\mathrm{scint},i}(k_{B2}, k_{B2}) + E_{c,i}(k_C)).$$

Birks' empirical law

$$\frac{dE_{scint}}{dx} = \frac{\frac{dE}{dx}}{1 + k_{B1}\frac{dE}{dx}}$$

Cherenkov light production

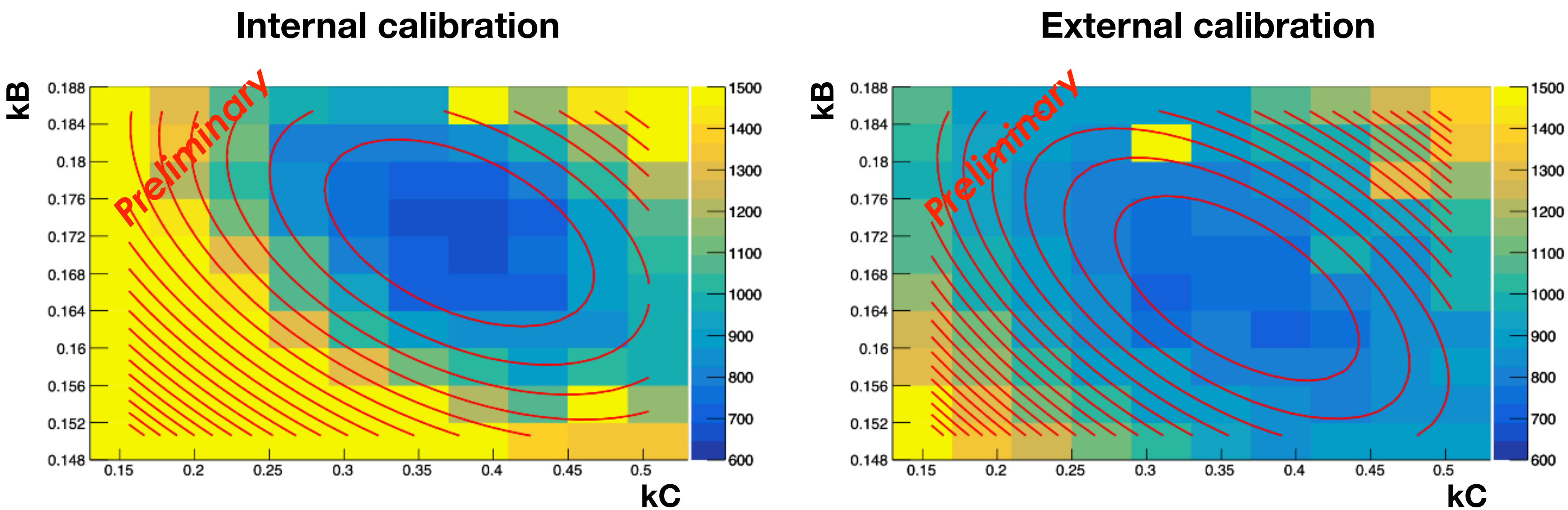
$$E_c = k_c \sum_\lambda N_\lambda E_\lambda$$

- Best fit response model is determined by minimizing data-MC chi2 for both spectrums and event multiplicity in parameter space (kB,kC)

$$\chi^2_{\mathrm{data-MC}} = \sum_\gamma \chi^2_\gamma + \sum_{\mathrm{multi}} \chi^2_{\mathrm{multi}} + \chi^2_{^{12}\mathrm{B}},$$

# Preliminary results

- Chi2 map in parameter space (kB,kC)

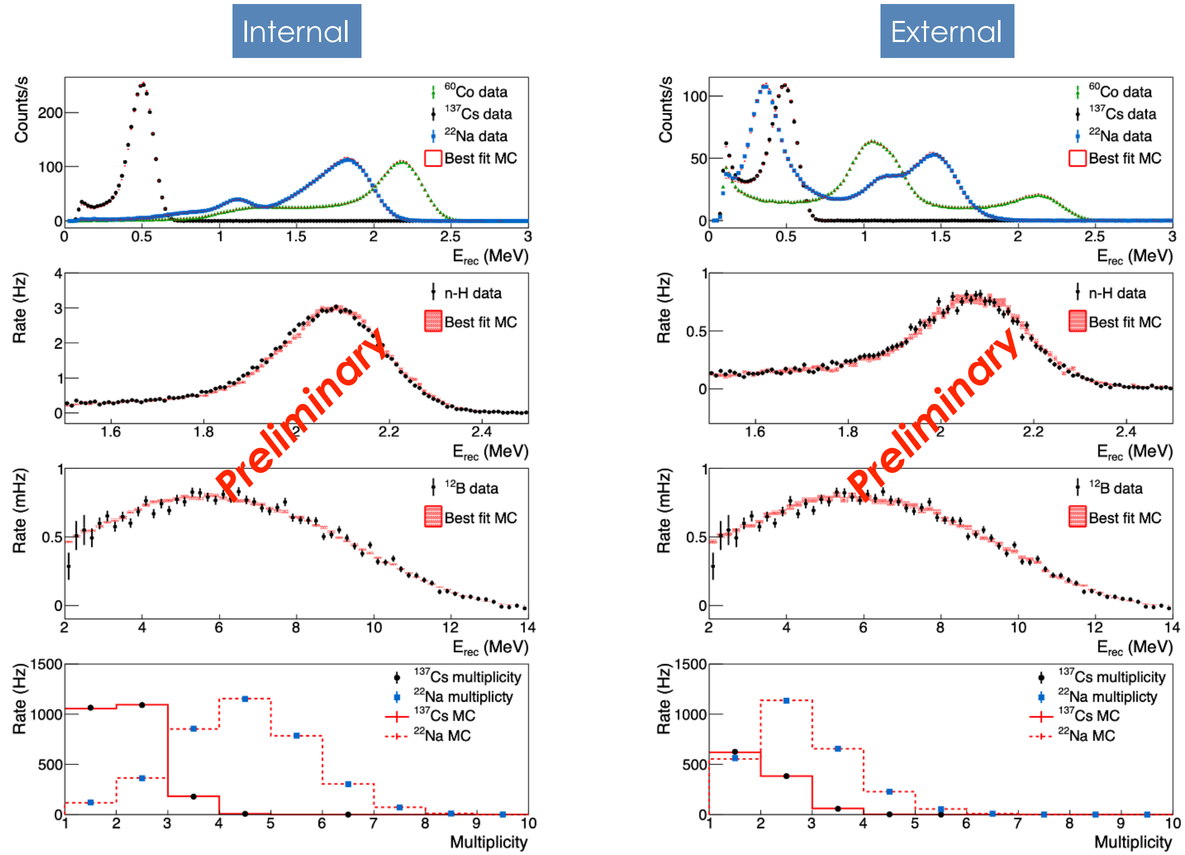



- The best fit response models are compatible with each other.
- Quantify how well the model parameters are constrained.

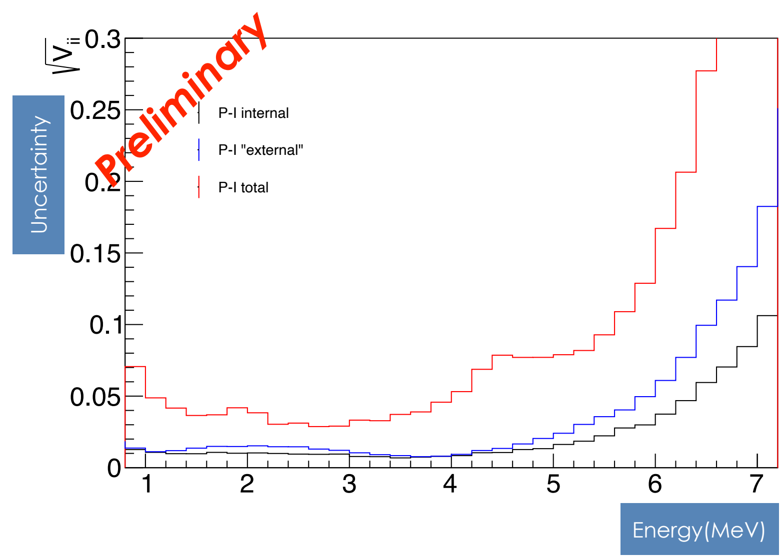
| Configuration | A | kB1 | kC |
|---|---|---|---|
| Internal | $1.008 \pm 0.002$ | $0.172 \pm 0.003$ | $0.377 \pm 0.034$ |
| External | $1.006 \pm 0.003$ | $0.167 \pm 0.007$ | $0.361 \pm 0.058$ |

# Preliminary results

- Both calibration setups show great agreement in spectrum and event multiplicity.




- Toy-model generated covariance matrix and compare energy model uncertainty, still dominated P-I statistics





OAK RIDGE National Laboratory

# Summary

- PROSPECT-I collected over ~50k IBD events in less than a year and updated oscillation and spectrum analysis on the way(next speakers).
- PROSPECT-I deploys internal calibration campaign that allows event reconstruction at sub-percent level precision.
- PROSPECT-II detector aims to improve long term stability with simpler and more rigid design.
- This R&D study evaluate the external-source-only performance for PROSPECT-II calibration.
- External calibration demonstrates promising performance with simplified P-II geometry and will improve in actual P-II detector.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PROSPECT
Thank you!
Funding provided by:
HEISING-SIMONS FOUNDATION
U.S. DEPARTMENT OF ENERGY
GRFP
14 Institutions, 70 collaborators
BROOKHAVEN NATIONAL LABORATORY
NIST
LE MOYNE COLLEGE A·D·1946
UNIVERSITY OF WATERLOO
W&M
Lawrence Livermore National Laboratory
OAK RIDGE National Laboratory
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## Poster Session:

HA.00031: Directional Neutrino Detection with PROSPECT
Manjinder Oueslati

## Today(Wed):

LK.00006: PROSPECT-II calibration strategy
Xiaobin Lu
LK.00007: Improved Event Reconstruction and Spectrum Analysis using PROSPECT Antineutrino Data
Christian Roca Catala
LK.00008: Improved Inverse Beta Decay event selection and its impact on the PROSPECT oscillation analysis
Diego C Venegas Vargas