OSIRIS' results on radioactive background levels in the JUNO scintillator

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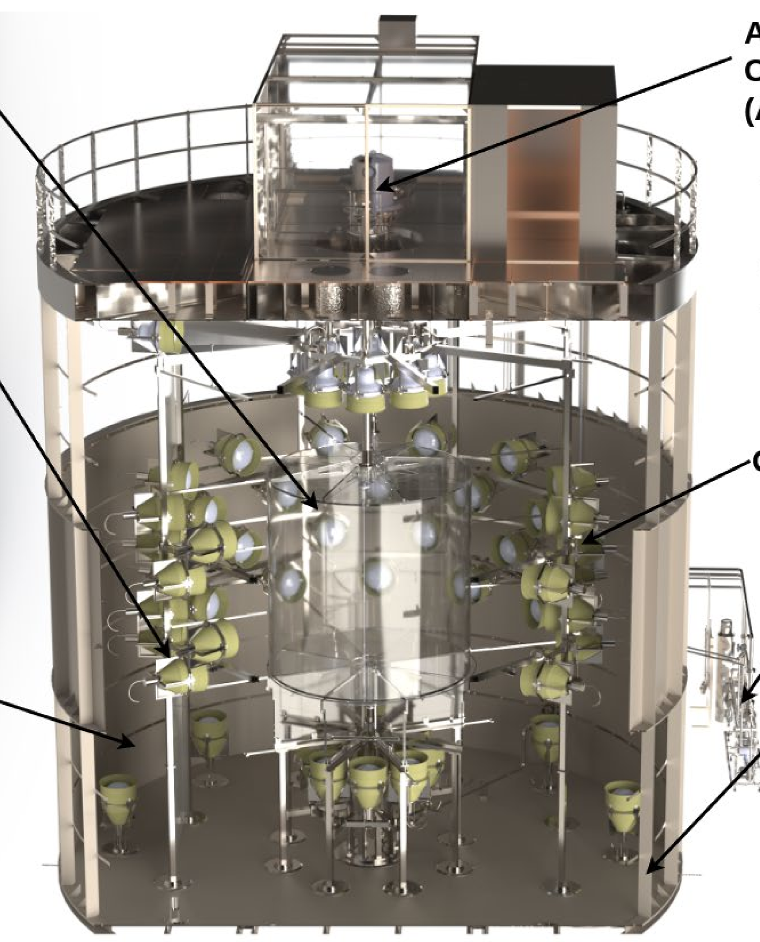
Motivation

The **Jiangmen Underground Neutrino Observatory** (JUNO) requires ultra-pure liquid scintillator to achieve its physics goals. The **Online Scintillator Internal Radioactivity Investigation System** (OSIRIS) monitored the radiopurity of the scintillator during detector filling by identifying characteristic Bi–Po coincidence signals from the uranium and thorium decay chains.

Liquid scintillator **requirements** for neutrino mass ordering analysis based on inverse beta decay signals:

$$c(^{238}U) < 10^{-15}\ g/g \text{ and } c(^{232}Th) < 10^{-15}\ g/g$$

Detector Overview



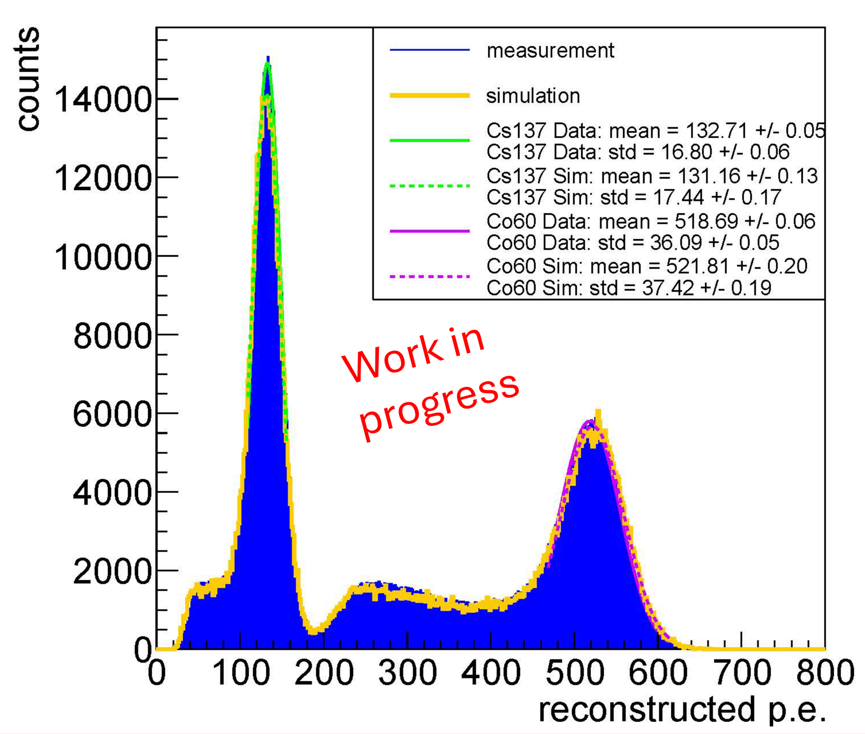
Simulation Framework

A comprehensive simulation framework has been developed for OSIRIS:

- **Detector simulation:** based on Geant4 (11.3.2), it incorporates the detailed detector geometry, a custom scintillation and Cherenkov process, and an optical model considering absorption and re-emission
- **Electronics simulation:** models the PMT response in terms of charge and timing effects, and reproduces the detector trigger logic

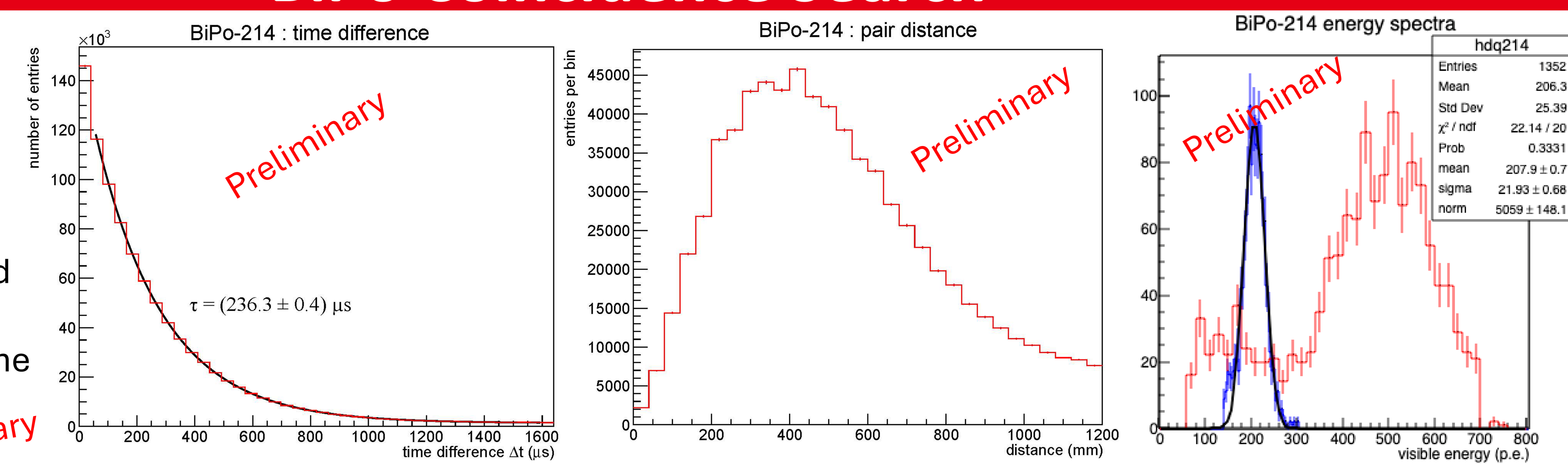
Simulation reproduces the detector response in terms of peak positions of calibration spectra within ~3.5% accuracy across the calibration axis.

Comparison between simulated and measured calibration data at $z = 0$ m



^{214}BiPo Coincidence Search

The β-α coincidence of ^{214}Bi and ^{214}Po (τ_{214} = 164 μs) is exploited to monitor the ^{238}U contamination. A selection of cuts in time, position and energy is chosen to suppress background. The result is:

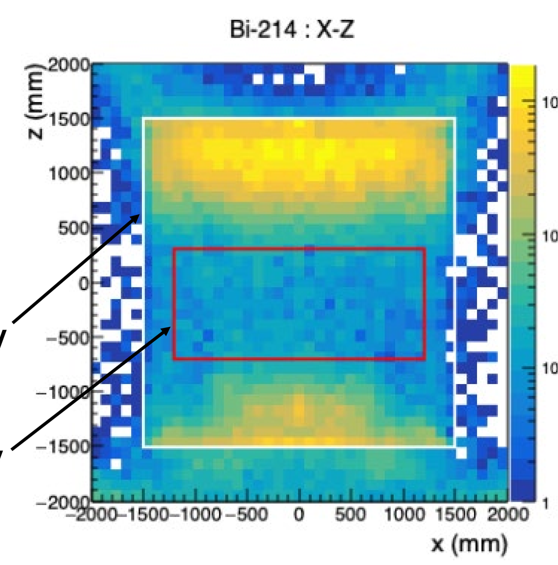


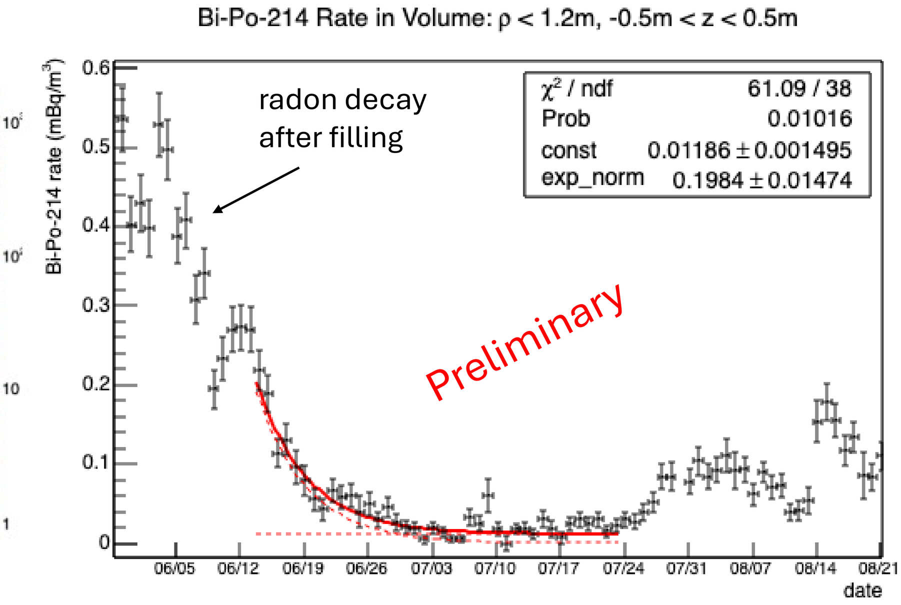
Preliminary

$$c(^{238}U) < (1.10 \pm 0.14) \times 10^{-15}\ g/g$$

Result is dominated by residual radon background from LS diffusion and convection.
JUNO: $(7.5 \pm 0.9) \times 10^{-17}$ g/g [1]

Cut	Value	Efficiency
Time	$< 5\,\tau_{214}$	99.2 %
Distance	< 1 m	76.6 %
Prompt Energy	> 50 p.e.	99.2 %
Delayed Energy	> 150 p.e.	99.9 %
Total		74.1 %





^{212}BiPo Coincidence Search

The β-α coincidence of ^{212}Bi and ^{212}Po (τ_{212} = 431ns) is used to probe the ^{232}Th concentration. Two-window and in-window coincidence searches are performed, the latter based on dip-test event identification. The Feldman–Cousins upper limit (**90% C.L.**) is:

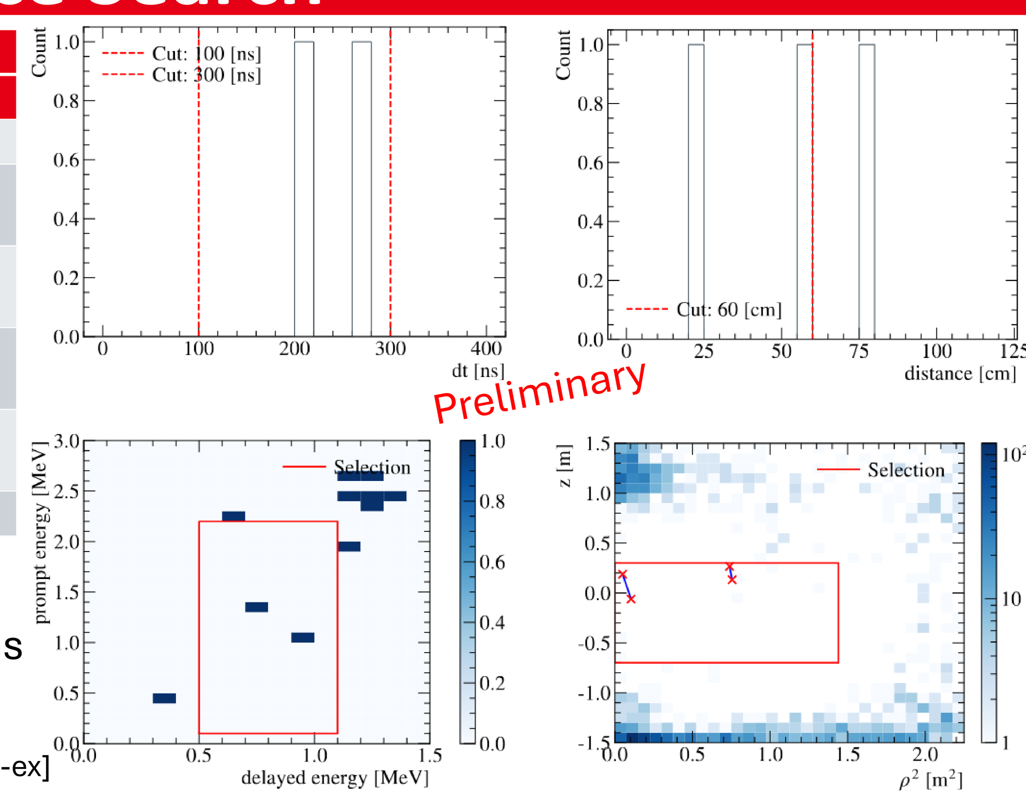
Preliminary

$$c(^{232}Th) < 4.0 \times 10^{-16}\ g/g$$

JUNO: $(8.2 \pm 0.7) \times 10^{-17}$ g/g [1]

		Efficiency	
Cut	Value	In-window	Two-window
Dip p-value	<0.01	94.3 %	-
Time		29.4 % at [100, 300] ns	22.3 % at [600, $3\tau_{212}$]
Position (ρ, z)	< 0.6 m	89.0 %	79.0 %
Prompt Energy	> 0.1 MeV	82.1 %	98.2 %
Delayed Energy	> [0.5, 1.1] MeV	97.6 %	98.4 %
Total		21.4 %	17.0 %

Two selected in-window candidates in 607.5 h

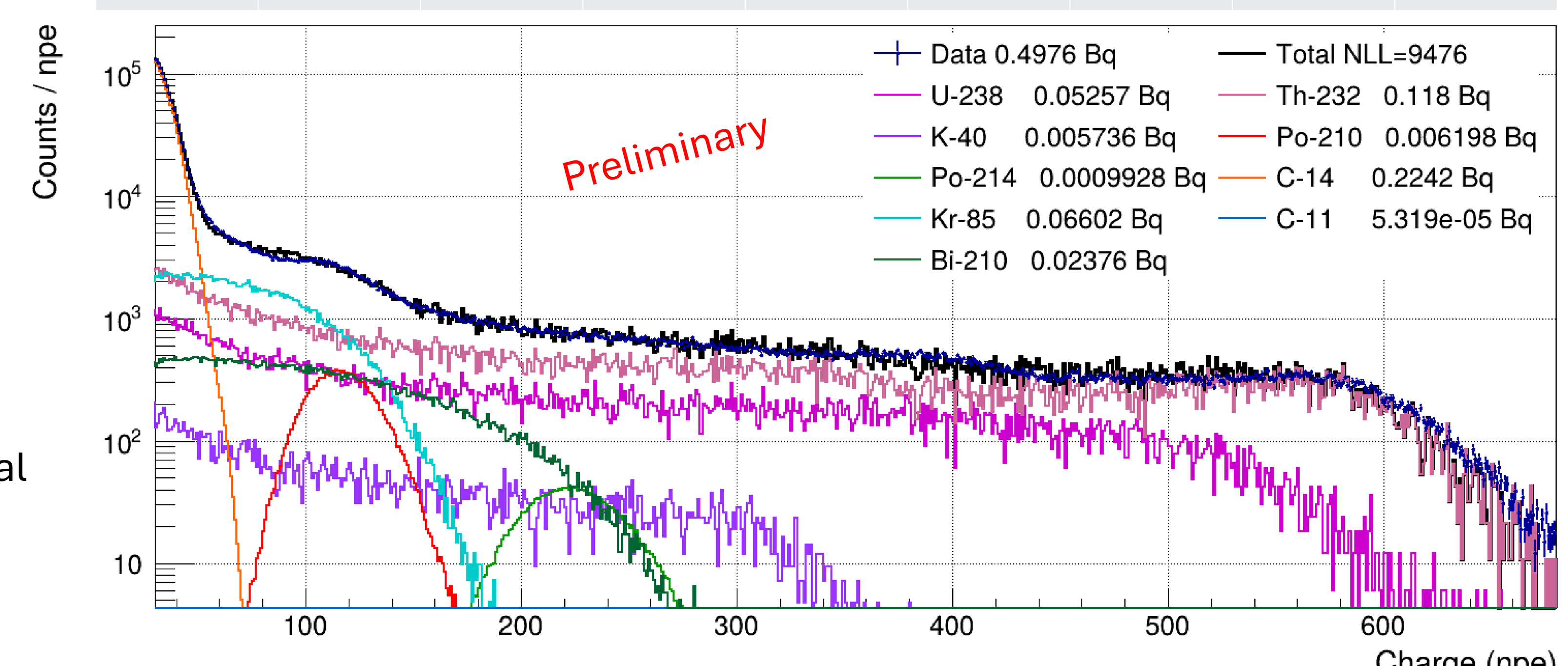


[1] JUNO collaboration, "Initial Performance Results of the JUNO Detector," arXiv:2511.14590 [hep-ex]

Singles Analysis

A binned likelihood fit is performed on the OSIRIS charge spectrum after BiPo cleaning and muon veto, using independent templates for the internal β/α- radioisotopes and external gamma backgrounds.
External gammas are simulated using a geometrical biasing method for computing efficiency and then normalized and scaled according to the branching ratio and expected activity in the rock volume around the experimental hall.
^{11}C is constrained by a cosmogenic estimate based on [arXiv:0907.0066].

Fit components								
Internal contaminants					External Gamma			Cosmo
^{14}C	^{85}Kr	^{210}Bi	^{210}Po	^{214}Po	^{40}K	^{232}Th	^{238}U	^{11}C



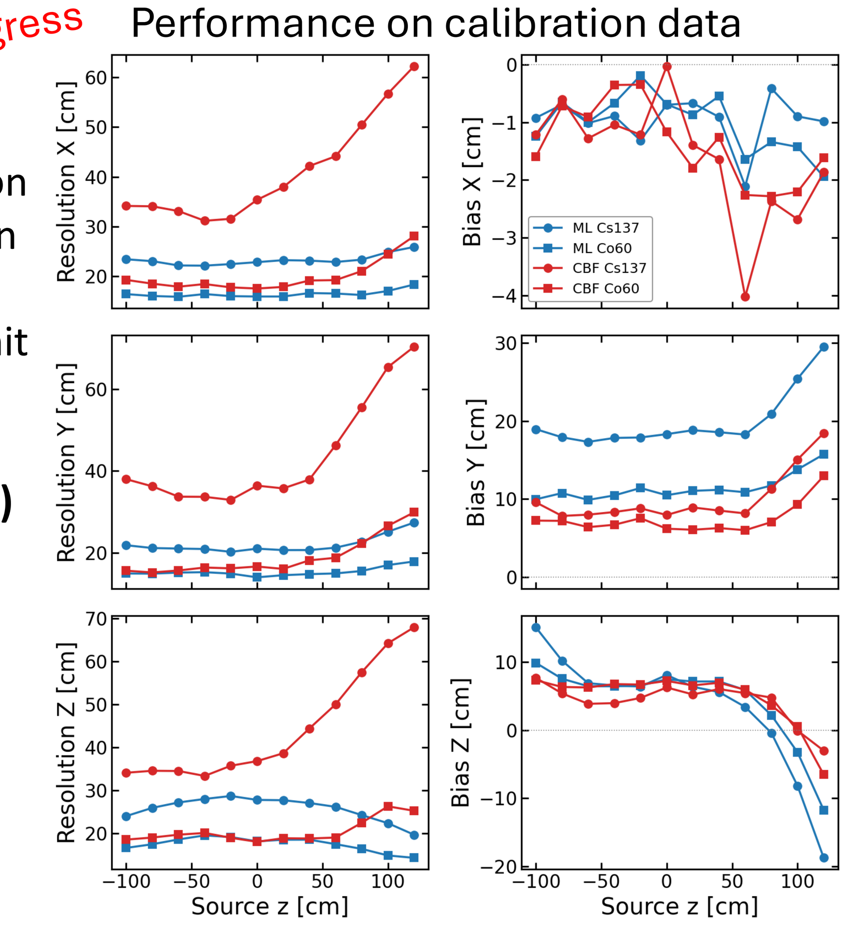
Vertex Reconstruction

Work in progress

Likelihood fit (CBF) based on MC simulation templates of PMT charge hit patterns

Network (ML) using PMT charge hit pattern to predict event vertex

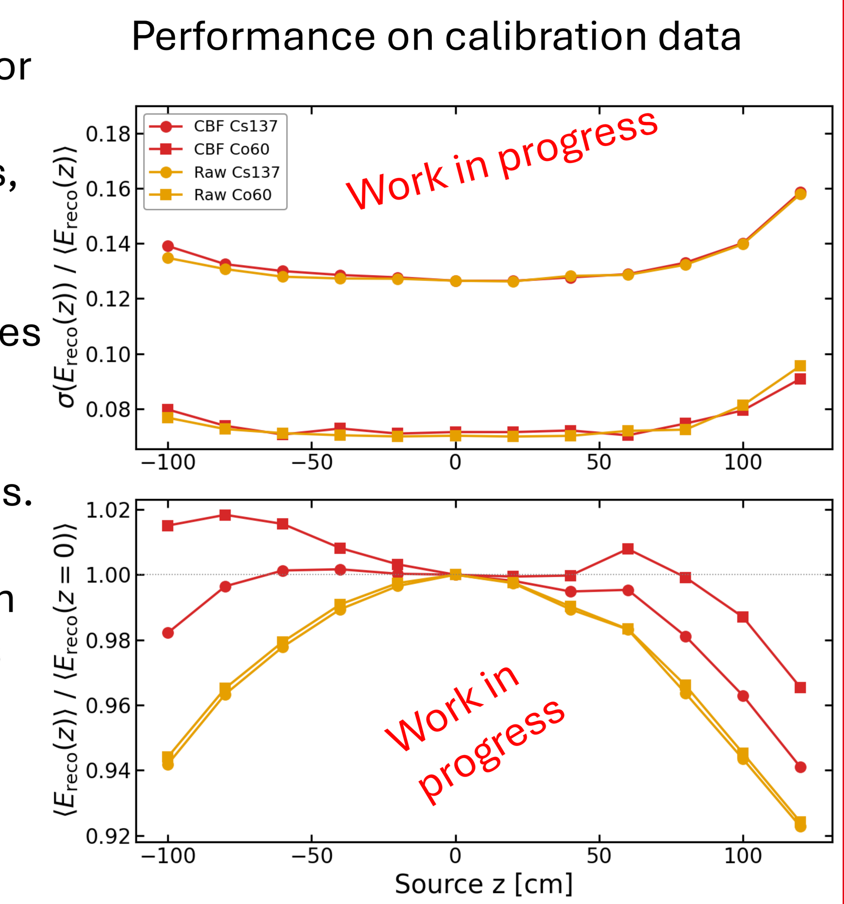
Performance on calibration data



Energy Reconstruction

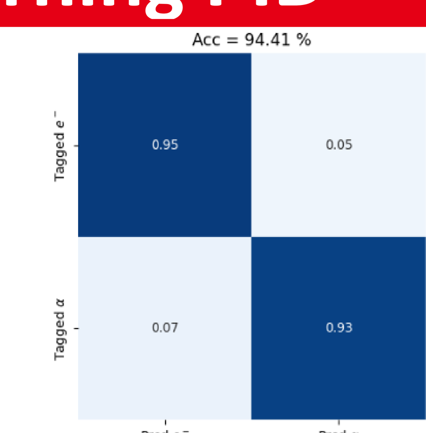
Due to detector geometry and optical effects, the light collection efficiency varies by up to 8% across the calibration axis. An energy reconstruction mitigating this effect is therefore applied.

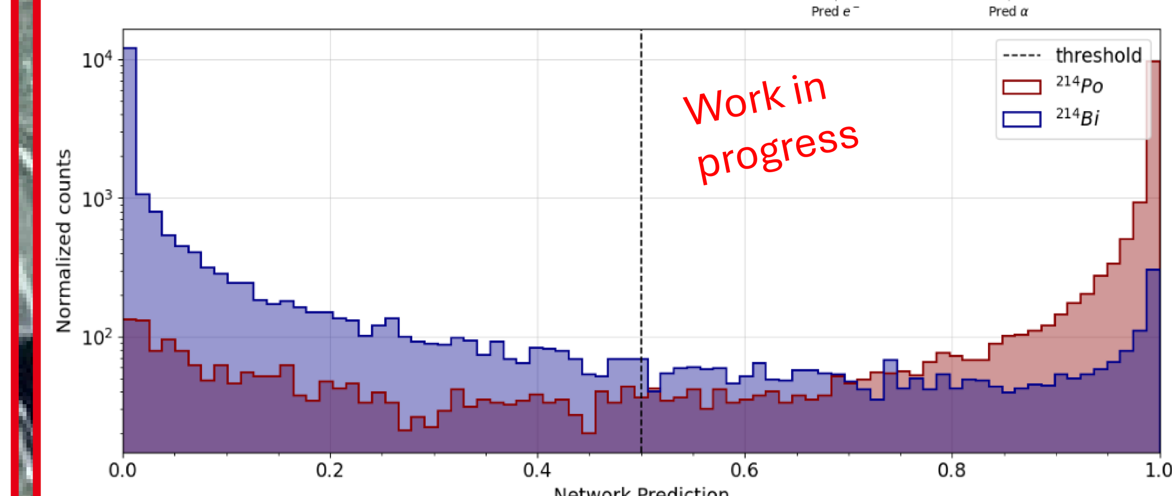
Performance on calibration data



Machine Learning PID

A transformer-based architecture using the first four hit times on a PMT is used to discriminate between α- and β-events.





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