Tagging Correlated Events in a Small-Scale Liquid Scintillator Detector

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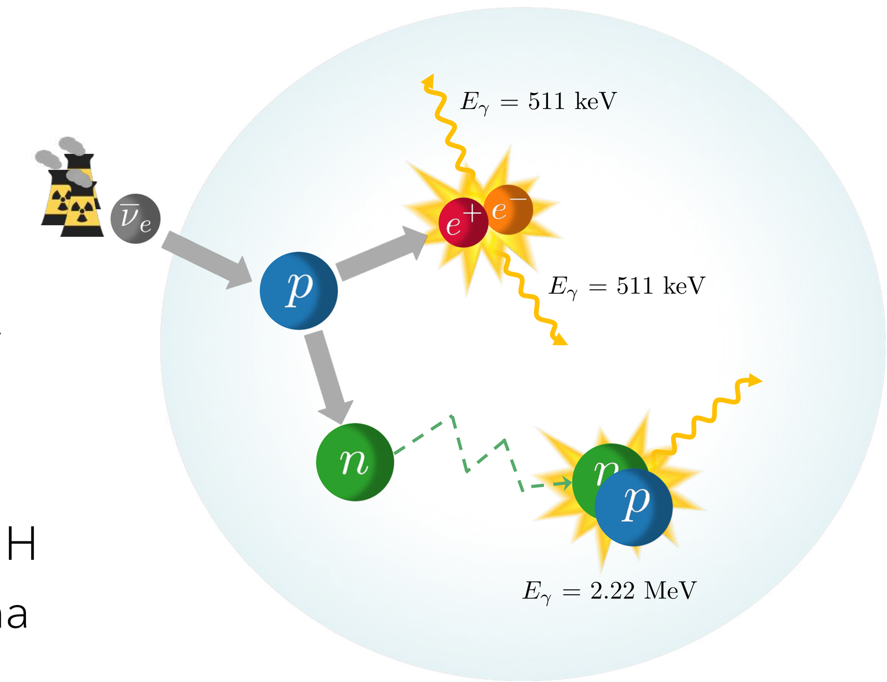
IBD reaction

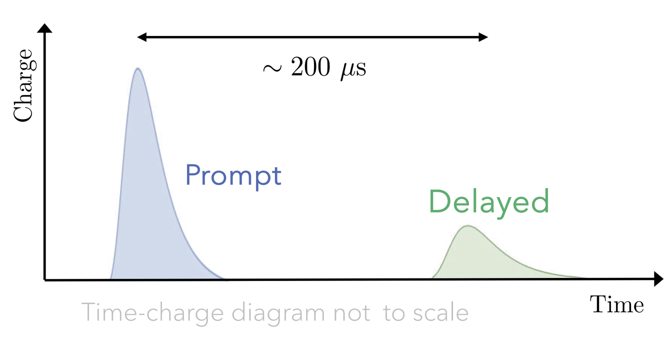
The detection of reactor antineutrinos widely relies on the Inverse Beta Decay (IBD) reaction:

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



Prompt signal: energy deposited by positron in liquid scintillator (LS), including annihilation energy

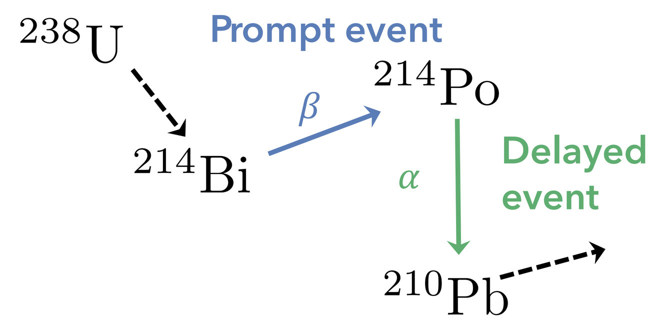
Delayed signal: neutron capture on H (or ^{12}C): 2.22 MeV (4.95 MeV) gamma emission, $\tau \approx 200\ \mu s$



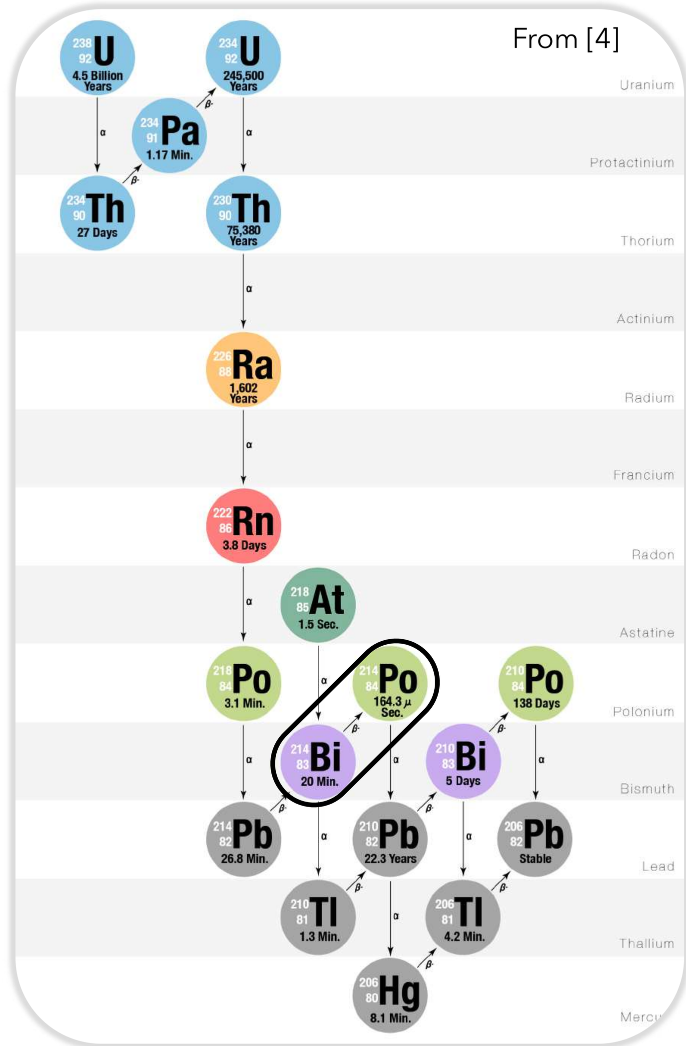
Time delay between the prompt signal and the delayed signal allows for **efficient background suppression** and **event tagging**.

The Jiangmen Underground Neutrino Observatory (**JUNO**) will use the IBD reaction as its primary channel to study the disappearance of reactor electron antineutrinos. JUNO is a medium baseline experiment under construction in South China [1] with the main goal of neutrino mass ordering determination and precisely measuring three oscillation parameters [2].

Why ^{214}Bi-^{214}Po?



The decay of Bismuth-214 (^{214}Bi) to Polonium-214 (^{214}Po) is part of the **Uranium-238** decay chain.



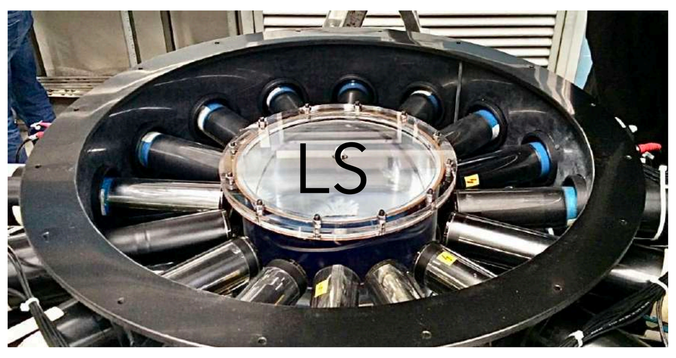
- The ^{214}**Bi** to ^{214}**Po** decay is analogous to the IBD process, where two correlated events occur within a short time window
- Provides a β-α coincidence "easy" to tag
- The Δ*t* is exponential and close to the IBD one ($\tau \approx 236\ \mu s$)

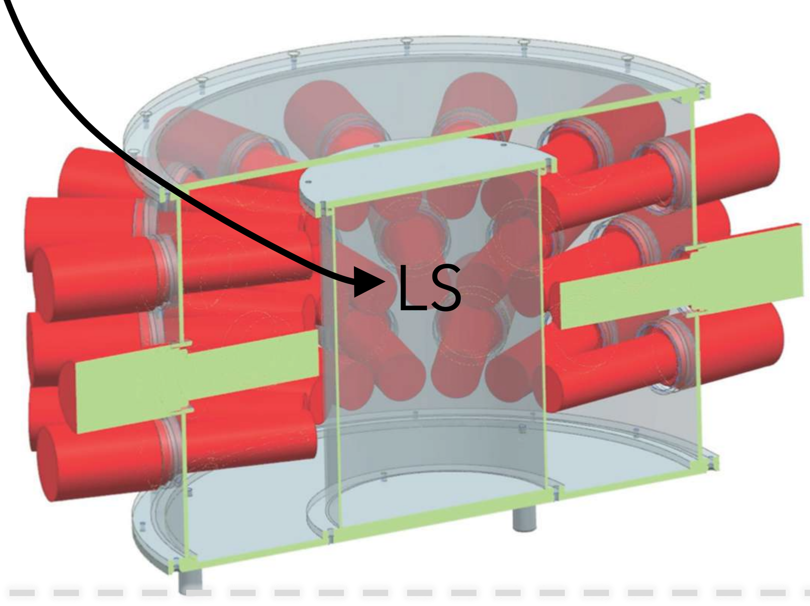
The similar time pattern provides a benchmark to **test selection strategies on real data**

Tagging correlated events in liquid scintillator

Setup

- Small-scale LS detector as a test-setup for JUNO [3]
- 20 l liquid scintillator (**LS**)
- 16 readout boards
- 48 channels with 2-inches XP2020 PMTs
- 3 plastic scintillator bars (1 on top, 2 on the bottom) to trigger on cosmic muons



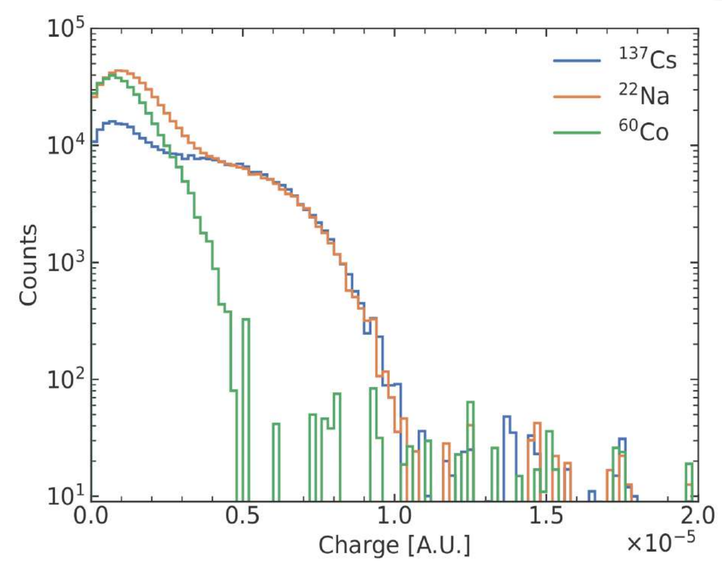


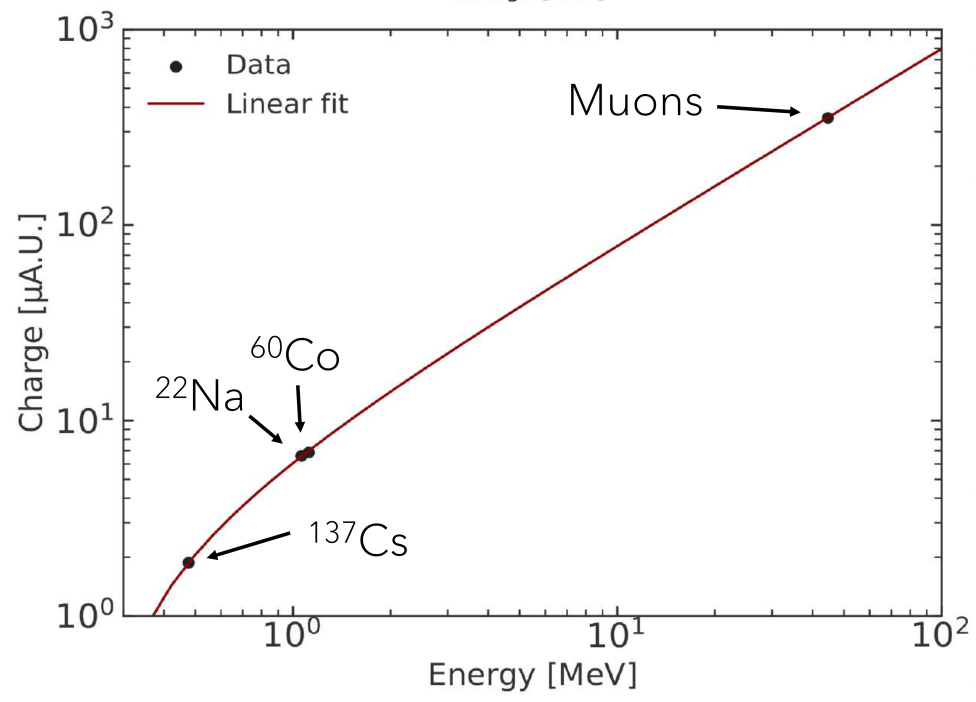
Same **electronics**, **readout system**, and **LS formula** as the JUNO experiment

Test bench for various experimental components

Energy calibration

- Preliminary analysis of PMTs single photo-electron response to equalize their gain
- Calibration of the energy response with three radioactive sources ^{137}Cs, ^{22}Na, and ^{60}Co
- Runs without sources are taken to characterize the background spectrum
- Additional calibration point with cosmic muons





Only the Compton continuum is visible and not the full energy peak. This is due to both the low Z of the liquid scintillator material and the small size of the detector.

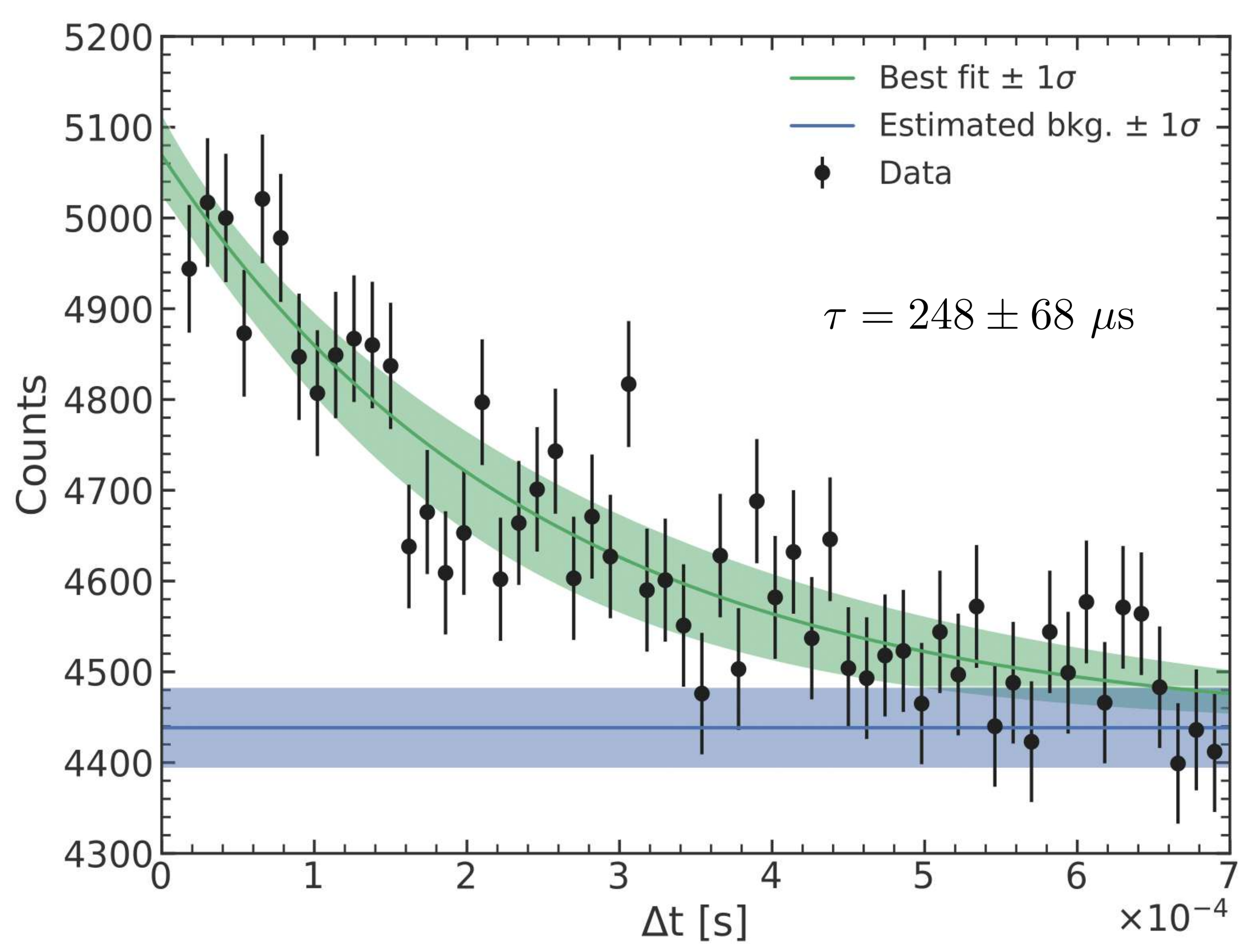
$E_{e,\max}$ of Compton edge is related to the expected full gamma energy E_γ

$$E_{e,\max} = \frac{2E_\gamma^2}{2E_\gamma + m_e}$$

Event selection and results

Different selection criteria are applied to distinguish ^{214}**Bi**-^{214}**Po** pairs from accidental radioactivity background.

- Time cut:
  - $\Delta t < 0.7$ ms
- Energy cut:
  - $E_{\text{prompt}} \in (1.4, 3.5)$ MeV
  - $E_{\text{delayed}} \in (0.7, 1.1)$ MeV
- Multiplicity trigger condition: at least 5 fired PMTs



15 hours of data-taking

250k ^{214}Bi-^{214}Po **candidates** after selection

10k events **estimated to be** ^{214}Bi-^{214}Po events

The best fit value of τ is **consistent with expectation**

The full electronics, readout, and event selection chain has been tested

References

[1] JUNO Collaboration. "JUNO physics and detector". PPNP 123 (2022): 103927.
[2] JUNO Collaboration. "Potential to Identify the Neutrino Mass Ordering with Reactor Antineutrinos in JUNO". arXiv:2405.18008 (2024).
[3] V. Cerrone, et al. "Validation and integration tests of the JUNO 20-inch PMT readout electronics". NIMA 1053 (2023): 168322.
[4] https://www.nachi.org/gallery/radon/uranium-238-decay-chain

Acknowledgements

Arsenii Gavrikov is supported by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant Agreement No.101034319 and from the European Union – NextGenerationEU.