Measurement of the Carbon-14 Activity in JUNO Liquid Scintillator

Jiahui WEI[1], **Shishen XIAN**[2] on behalf of the JUNO Collaboration

[1]Institute of High Energy Physics, Chinese Academy of Sciences

[2]Tsung-Dao Lee Institute, Shanghai Jiao Tong University

Introduction

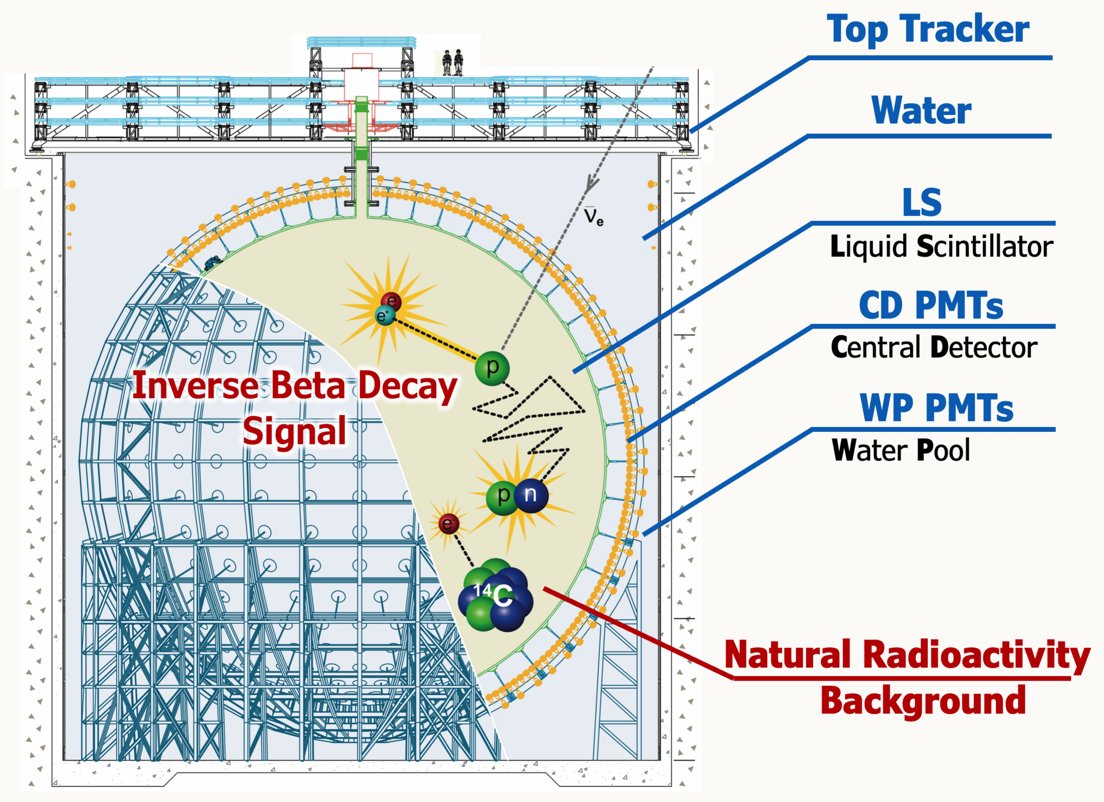

Figure 1: Schematic of the JUNO detector.

- **The Jiangmen Underground Neutrino Observatory (JUNO)** is a 20-kton liquid scintillator detector designed for precision neutrino measurements.
- **^{14}C** is the dominant intrinsic radioactive background below 1 MeV, and can produce overlapping scintillation signals (pile-up) [1].
- **Goal:** measure the ^{14}C activity with early JUNO data.

Method I: MM-Trigger Hit Spectrum

- **The Multi-Messenger (MM) trigger** is a dedicated low-threshold trigger developed for transient astrophysical neutrino searches and other low-energy signals.
- **The PMT hit-count spectrum** is sensitive to ^{14}C pile-up activity.
- ^{14}C pile-up produces a characteristic high-hit tail.
- The tail shape is sensitive to the total ^{14}C activity.
- Activity is extracted through a **Bayesian MCMC fit** [2].

$$A_{14}^{\mathrm{MM}} = 134^{+17}_{-18}\ \mathrm{kBq}. \quad \text{(Preliminary result)}$$

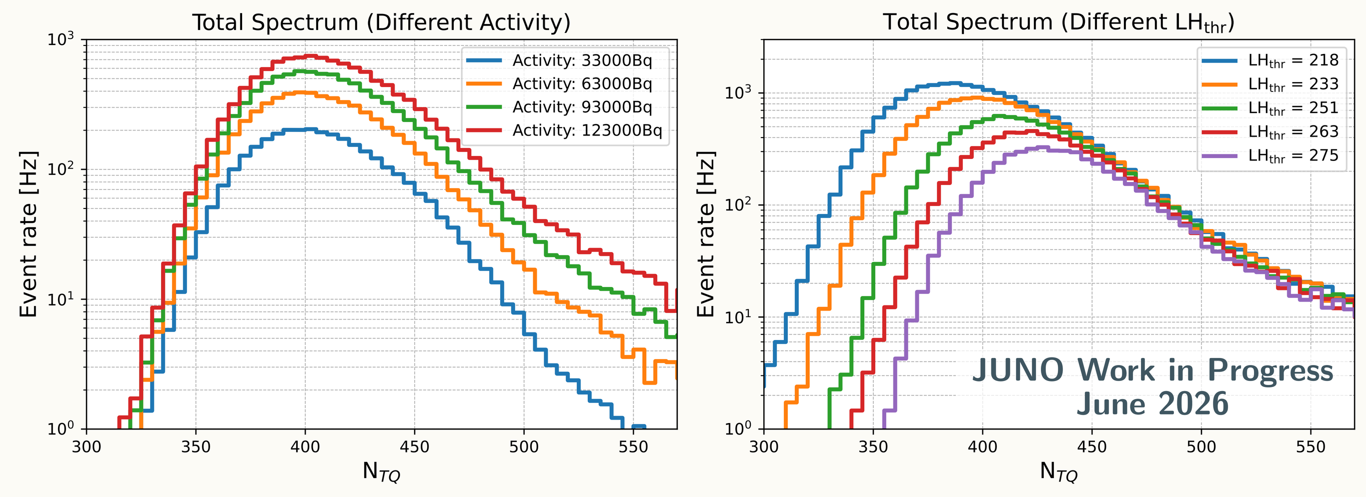

Figure 2: MM-trigger spectra versus the number of hits N_{TQ} for different ^{14}C activities and trigger thresholds. Above 420 hits, the slope is sensitive to the ^{14}C activity.

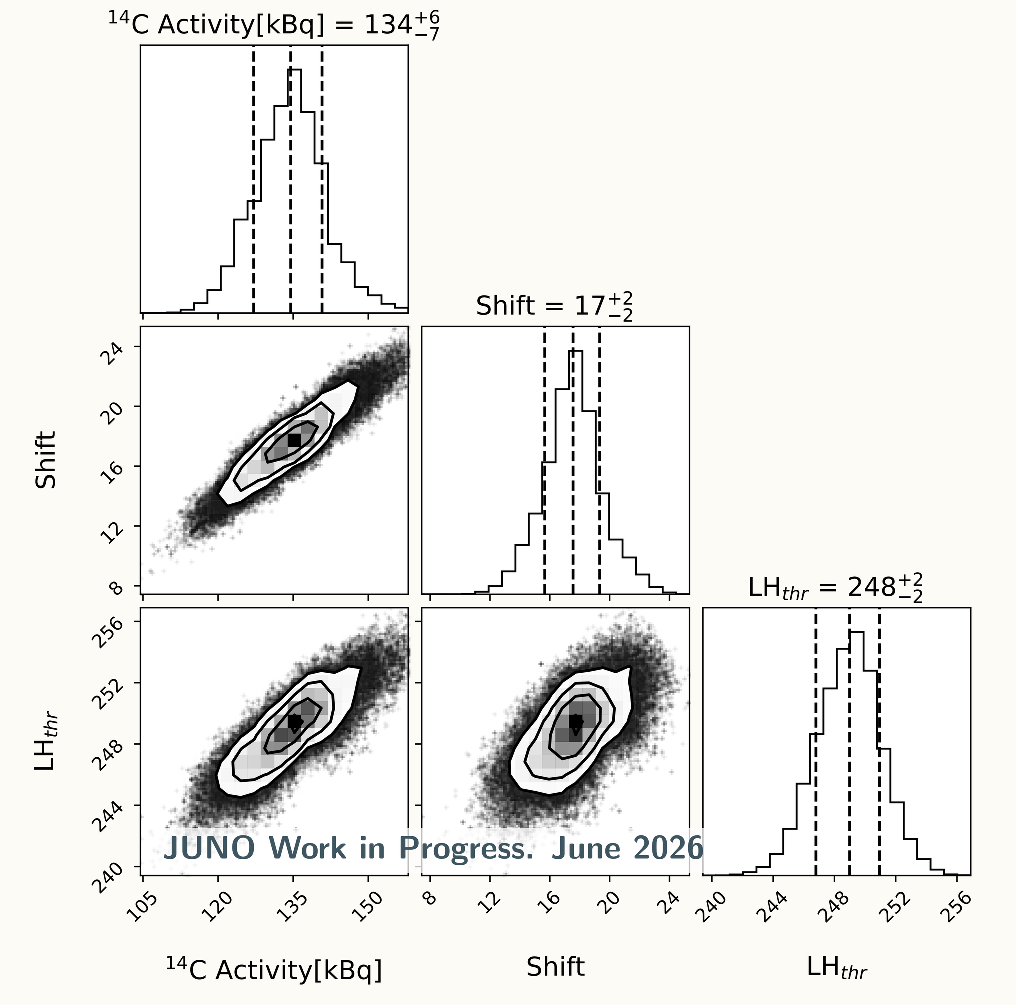

Figure 3: Posterior distributions and correlations of the fit parameters, including the ^{14}C activity, PMT hit number shift, and trigger threshold LH_{thr}.

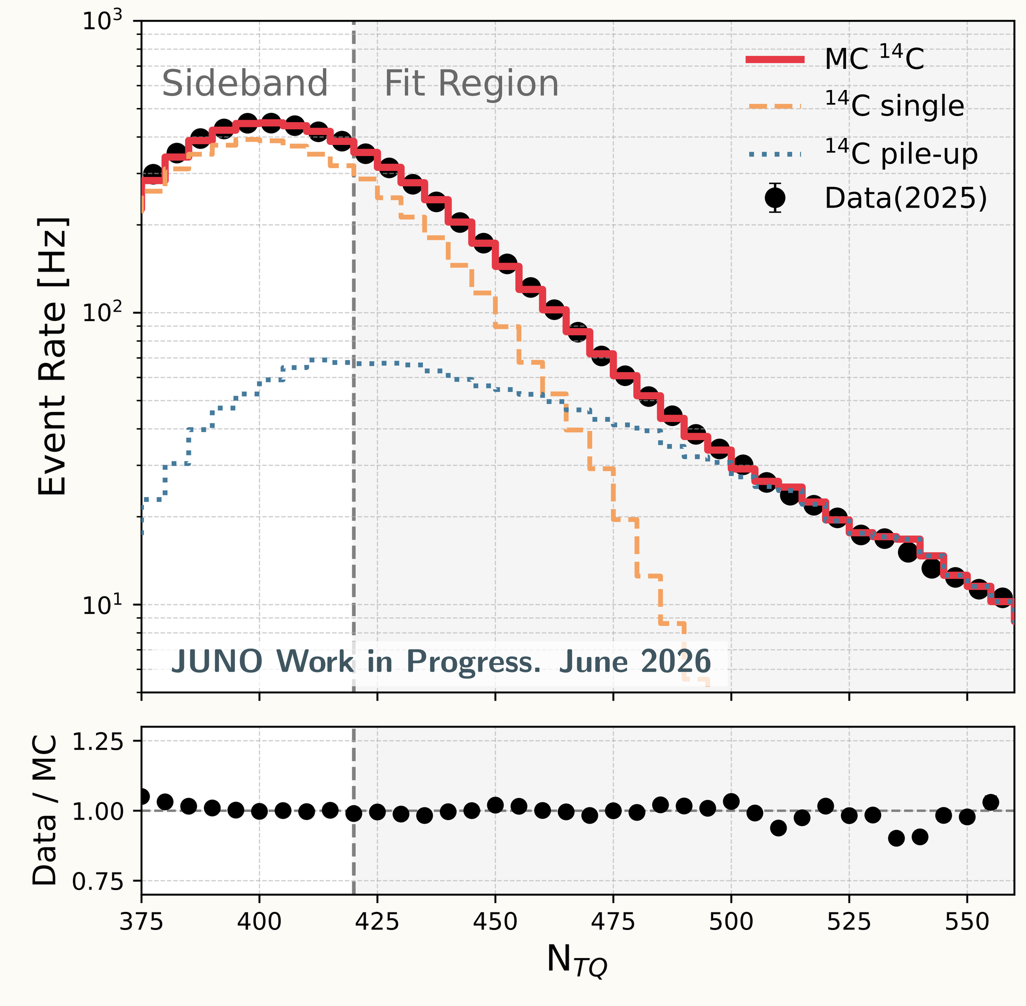

Figure 4: Best-fit comparison between data and the Monte Carlo prediction. The contributions from single and pile-up 14 C components are shown separately.

Method II: Periodic-Trigger Timing Analysis

- **The periodic trigger** records a 1008 ns detector readout window at 50 Hz, independent of physics events.
- **Pure dark noise (DN)** produces approximately uniform hit times.
- **^{14}C decays** generate correlated scintillation photons and non-uniform timing structures.
- **Low Kuiper-test p-values** define a ^{14}C-enriched sample [3].
- **Boundary truncated pulses** are accounted for using fully contained ^{14}C pulses with artificial readout boundaries.
- **Template fit** is used to obtain ^{14}C activity from the fractional contributions.

$$A_{14}^{\mathrm{periodic}} = (130 \pm 18)\ \mathrm{kBq}. \quad \text{(Preliminary result)}$$

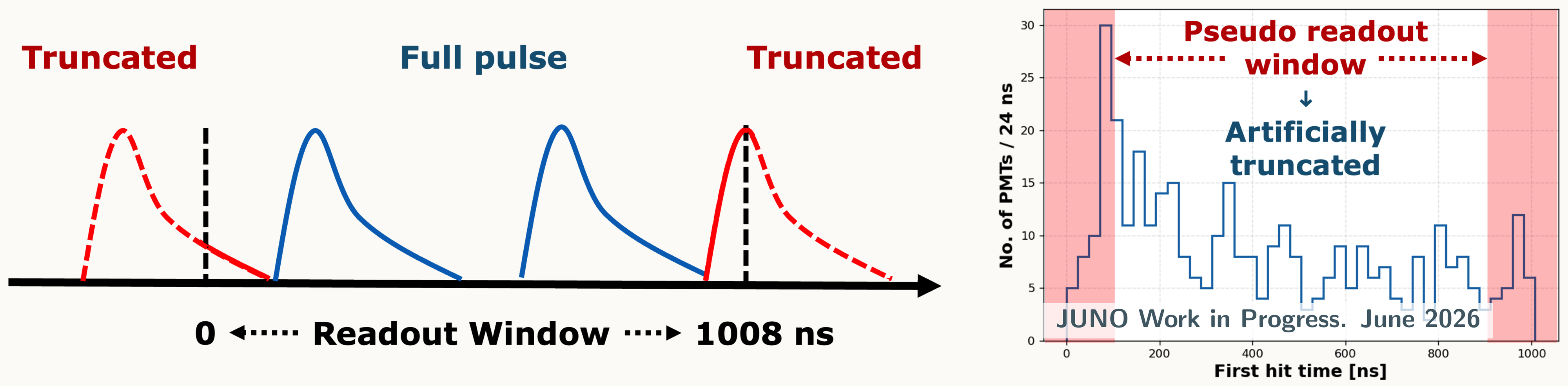

Figure 5: Pulse truncation occurs when a ^{14}C decay is only partially contained within the readout window. Fully contained pulses are re-windowed to construct data-driven truncated templates.

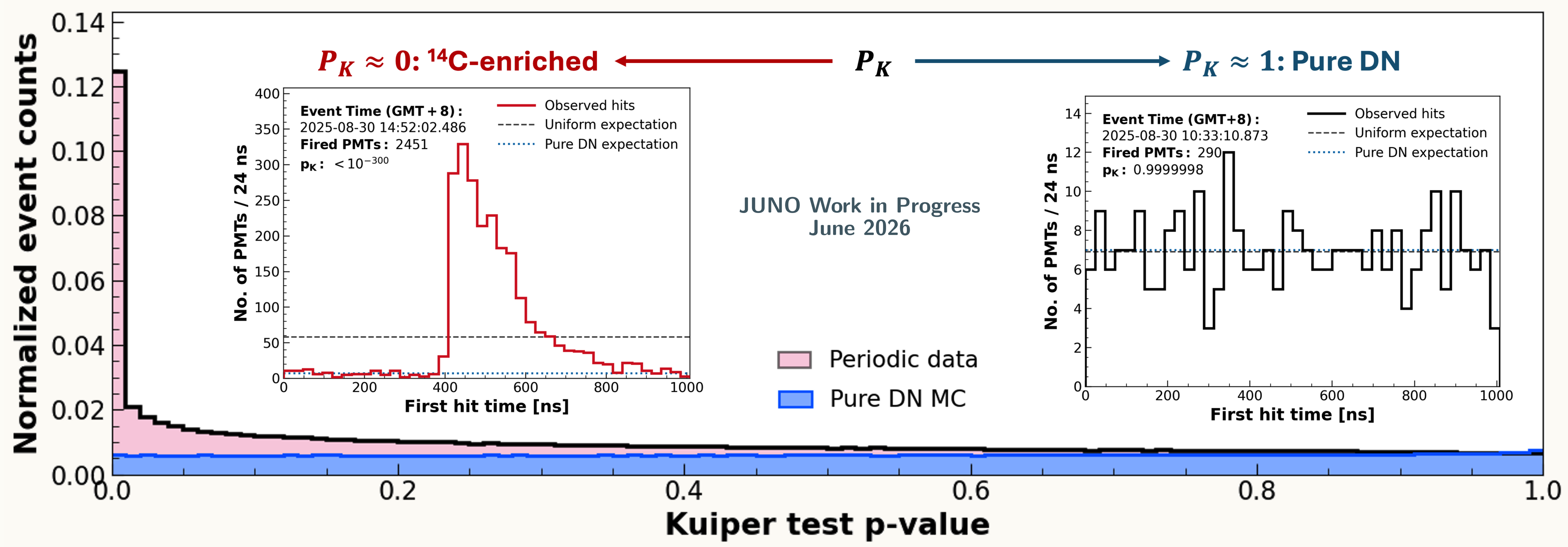

Figure 6: Kuiper-test p-value distribution, P_K, for periodic-trigger events with two representative first hit time distributions from events with different P_K. The excess at low p-values indicates non-uniform timing consistent with ^{14}C decays.

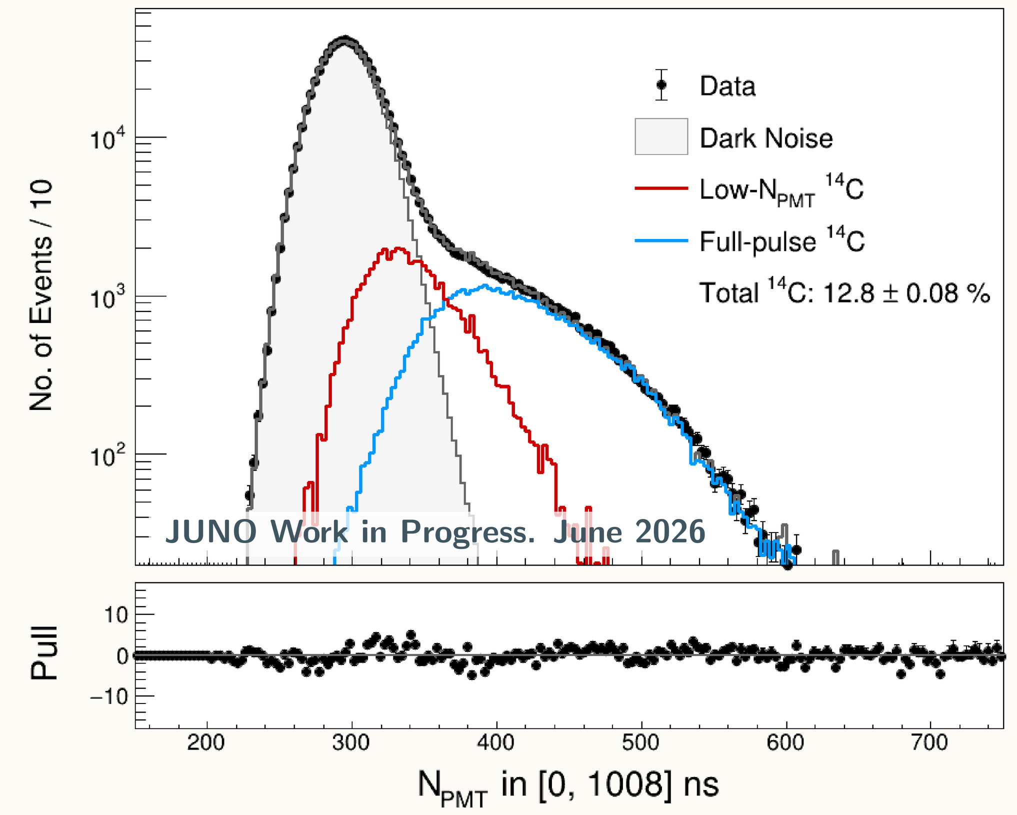

Figure 7: Template fit to the number of fired PMTs (N_{PMT}) in periodic-trigger data to extract the ^{14}C fraction.

Results

- The two methods give **consistent ^{14}C activities.**
- **Dominant uncertainties**
  - MM trigger: PMT-hit response and trigger-threshold uncertainty.
  - Periodic trigger: template construction, finite window acceptance and residual non-^{14}C radioactive backgrounds.
- **Preliminary result:**

$$\frac{^{14}\mathrm{C}}{^{12}\mathrm{C}} = \frac{A_{14}\,\tau\, M_{14}}{N_A\, f_{\mathrm{C}}\, m_{\mathrm{LS}}} \simeq (4-5)\times 10^{-17}\ \mathrm{g/g}.$$

(Preliminary result, uncertainty under evaluation)

  - N_A: Avogadro's constant
  - M_{14}: molar mass of ^{14}C
  - τ: mean lifetime of ^{14}C
  - m_{LS}: LS mass
  - f_{C}: carbon mass fraction in the LS
- **Impact:** provides an essential input for
  - low-energy background and ^{14}C pile-up modeling
  - detector response studies and reconstruction
  - MM-trigger performance evaluation.

References

[1] Abusleme, Angel, et al. "Initial performance results of the JUNO detector." *Chinese Physics C* 50.4 (2026): 043001.

[2] Foreman-Mackey, Daniel, et al. "emcee: the MCMC hammer." *Publications of the Astronomical Society of the Pacific* 125.925 (2013): 306-312.

[3] Kuiper, Nicolaas H. "Tests concerning random points on a circle." *Nederl. Akad. Wetensch. Proc. Ser. A.* Vol. 63. No. 1. 1960.