Channel-level SiPM Calibration at JUNO-TAO

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Introduction

TAO (satellite experiment of **JUNO**): a ton-scale liquid-scintillator detector for high-precision reactor neutrino measurements.

- The central detector (CD) features **8,048 SiPM readout channels** with ∼83% optical coverage.
- After quality selections, **7,260 channels** (∼90.2%) are retained for physics analysis. The remaining channels include those with missing ADC cards (to be installed) and high noise levels (to be mitigated during summer maintenance).
- Precise channel-level calibration of gain, timing, and DCR is essential for achieving the target energy resolution.

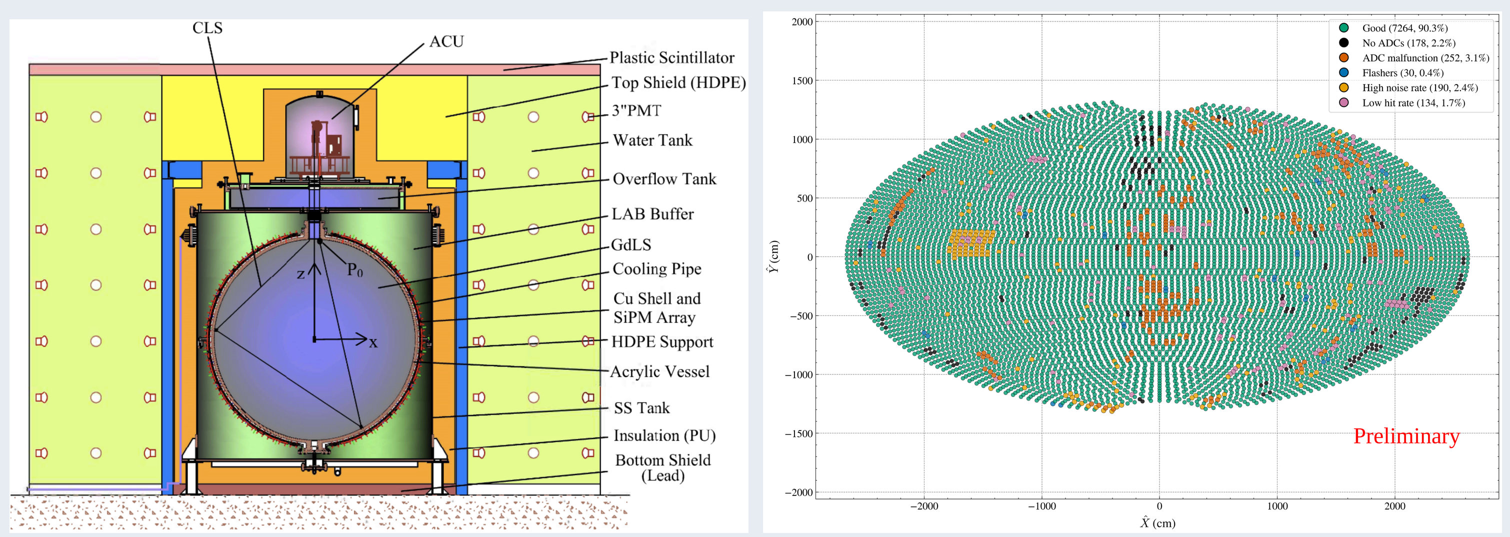

Figure 1:(Left) Schematic of the TAO detector. (Right) Distribution of malfunctioning channels on the copper shells.

SiPM Dark-count Rate (DCR)

The DCR is evaluated using background events in the energy range of 1–3 MeV within $\Delta T = 104$ ns pre-signal time window.

- **Average DCR:** ∼ 73 kHz per channel (63 Hz/mm^2).
- The increase around April 10: from a 1.5°C temperature increase.
- Approximately **24%** of this rate is attributed to **external optical cross-talk**.

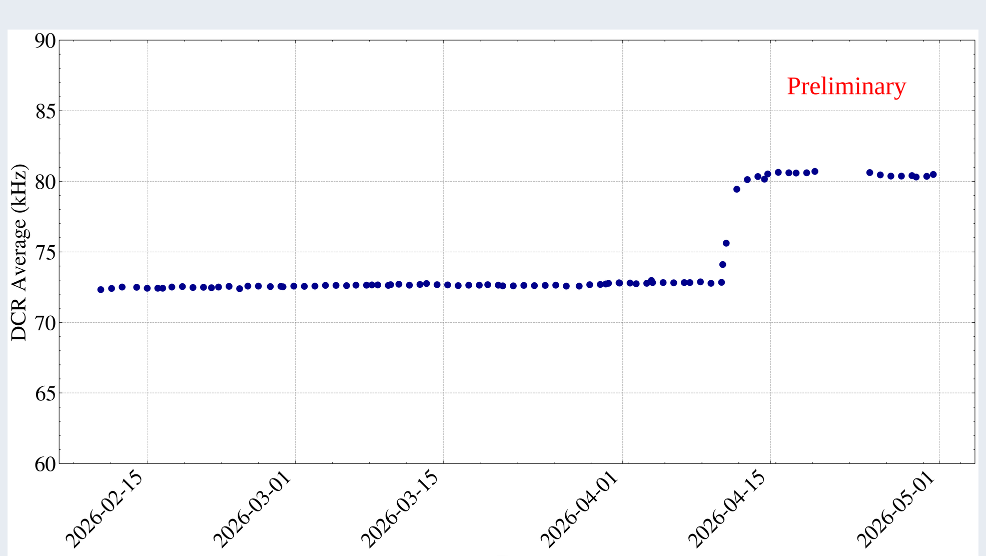

Figure 2:Stability of the average DCR over time.

Gain of the SiPMs

The SiPM gain is extracted from the ADC spectrum using a multi-component fit. The fit function describes the pedestal, single-photoelectron (SPE) peak, and higher-order peaks with after-pulse contributions:

$$F(x) = A_1 \cdot \mathrm{erf}(x;\mu_0,\sigma_0)\cdot N(x;1,\sigma_1) + \sum_{n=2}^{N} A_n \sum_{i=0}^{l} G(i;n,\alpha)\cdot N(x;n,i,\sigma_n)\,, \quad (1)$$

where the gain is extracted from the spacing between successive photoelectron peaks.

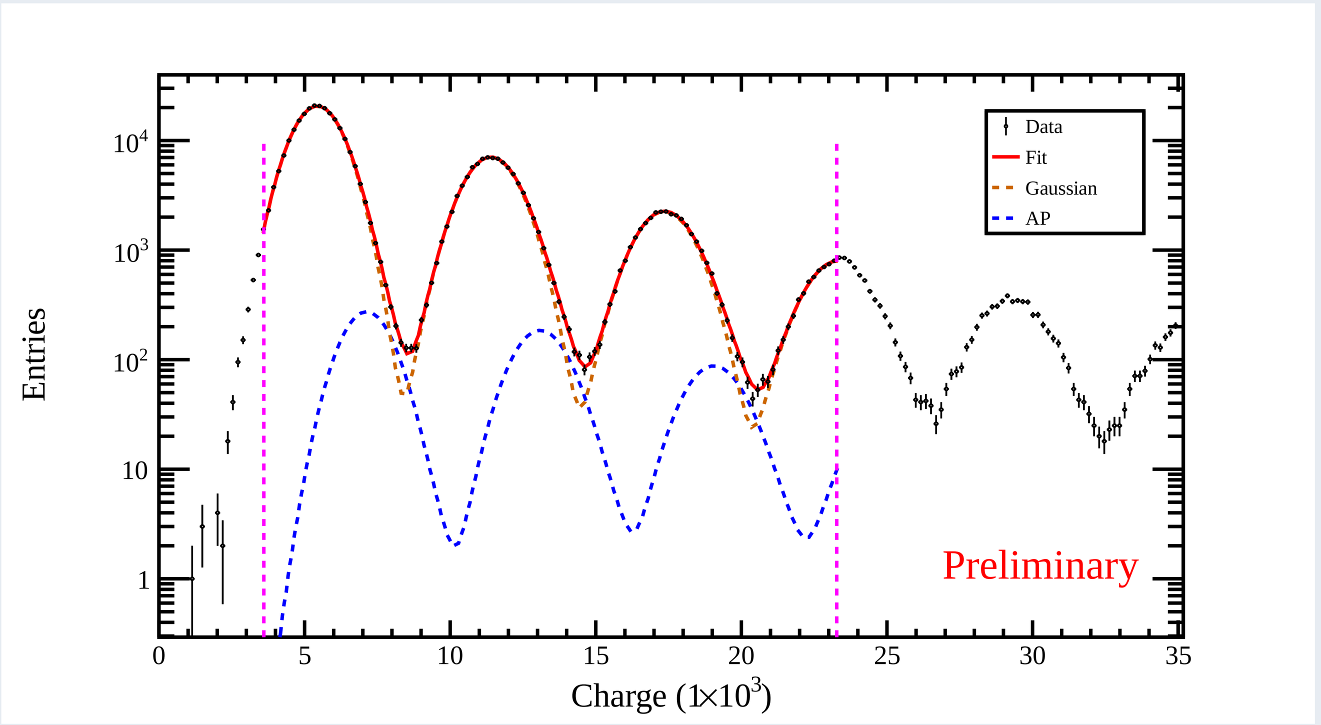

Figure 3:ADC spectrum fit showing photoelectron and after-pulse components.

SPE Resolution & Gain Stability

The SPE resolution, defined as σ_1/Gain, characterizes the ability to resolve individual photoelectrons.

- The average SPE resolution is **13.9%**, meeting the TAO requirement of <15%.
- The gain stability is monitored run-by-run, with a relative variation of <0.2% under stable conditions.
- The decrease around April 10: from a 1.5°C temperature increase.

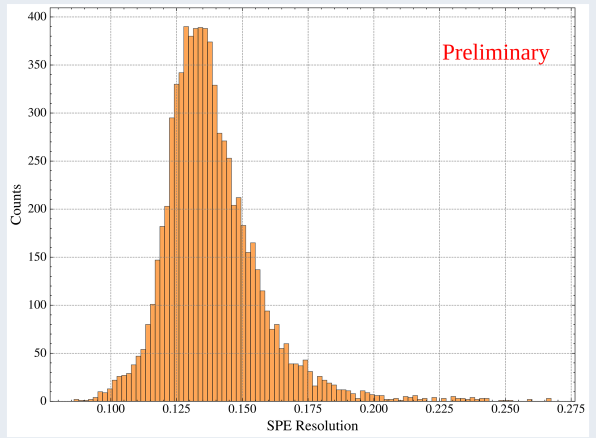

Figure 4:SPE resolution.

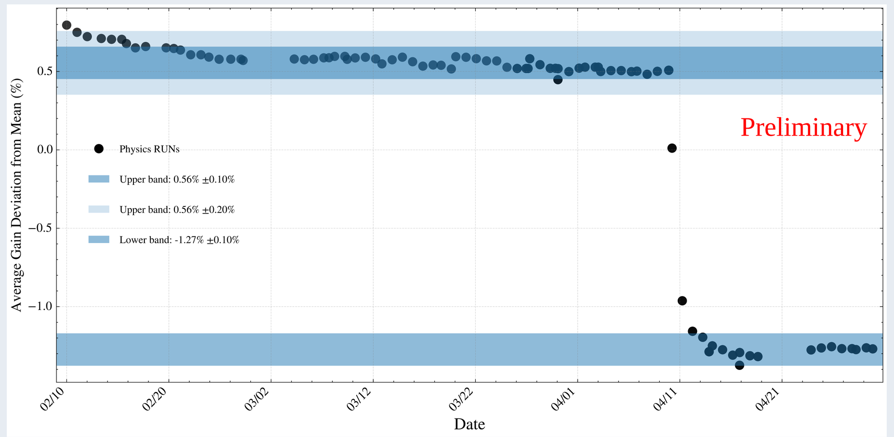

Figure 5:Average SiPM gain stability.

Time Offset

Time offsets arise from cable-length differences and ADC latency.

- Calibration uses selected events (0.7–3 MeV) around the center.
- Peak time determined by fitting with a double-sided Crystal Ball function.

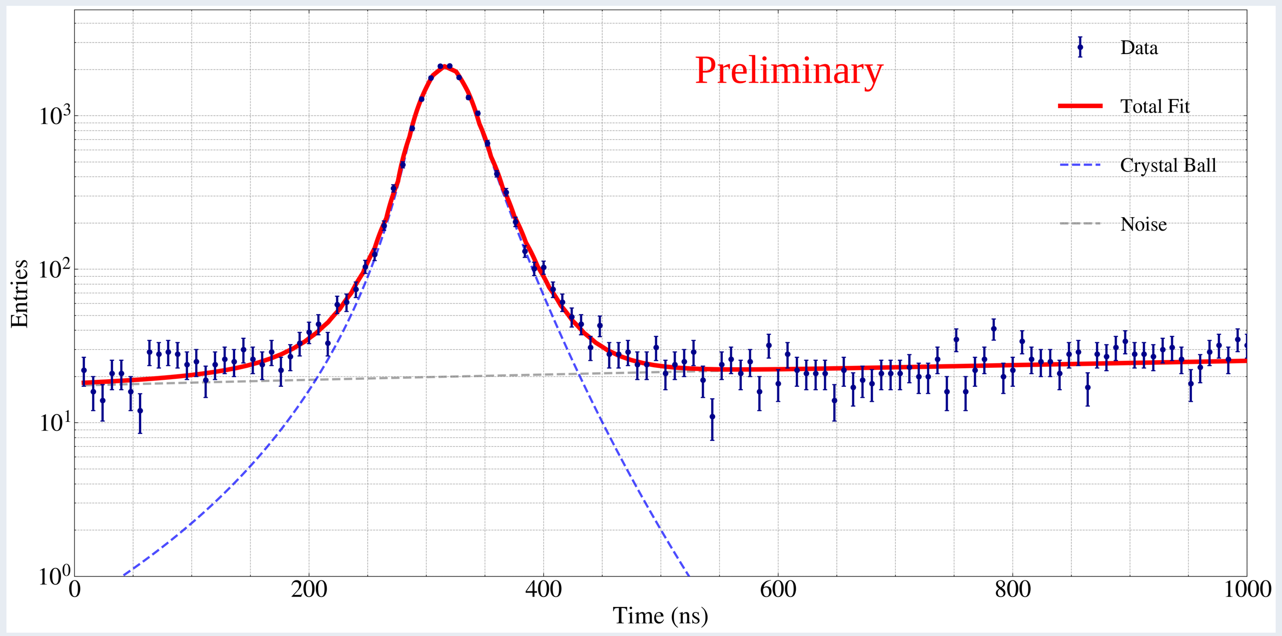

Figure 6:Time distribution fit with a double-sided Crystal Ball function.

- Offline correction applied run-by-run.
- **Median timing uncertainty: 0.68 ns**, primarily limited by timestamp assignment and electronic noise.

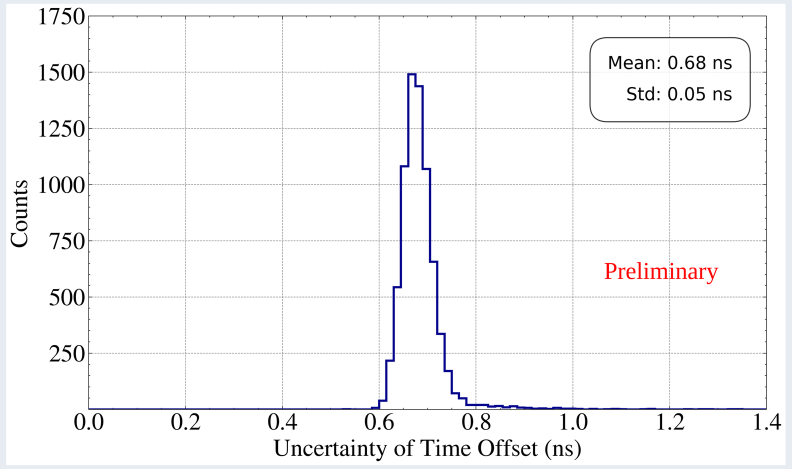

Figure 7:Uncertainty of channel time offsets.

Summary

- Excellent channel-level performance achieved with 7,260 good channels.
- Average SPE resolution: **13.9%** (requirement: <15%).
- Average DCR: **68.4 kHz** per channel, including ∼24% external optical cross-talk contribution, with long-term stability.
- Gain and DCR variations are well-correlated with temperature.

References

[Abusleme et al.(2025)] A. Abusleme et al. (JUNO), Chin. Phys. C **49**, 033104 (2025), `2405.18008`.

[Abusleme et al.(2020)] A. Abusleme et al. (JUNO) (2020), `2005.08745`.