Time Calibration of the 1-ton Prototype Detector & Preliminary Study of Energy Calibration Using Wakefield Acceleration

Yapeng Wang, Haoyang Fu

Department of Engineering Physics & Center for High Energy Physics,
Tsinghua University

July 3, 2026

Outline

Motivation

Why Time Calibration?

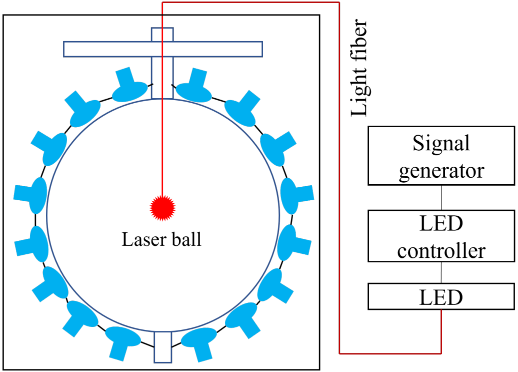
- Precise time calibration is essential for vertex and direction reconstruction

Why Wakefield Acceleration?

- Conventional radioactive sources have limited energy range and are isotropic
- LWFA provides a directional, tunable MeV electrons
- Potential for precise in-situ energy calibration and angular resolution estimation of large detectors.

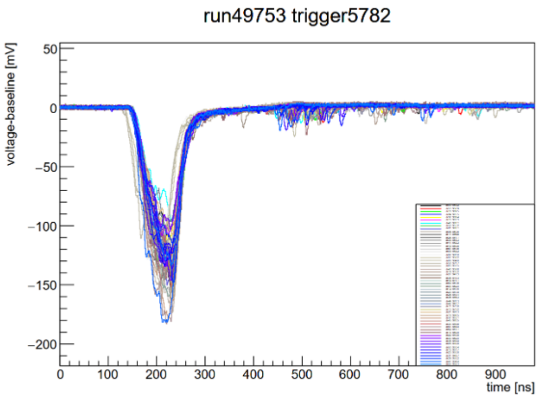
Time Calibration —Detector Setup

- A 415 nm LED light source driven by a signal generator is placed at the detector center
- The LED is coupled through an optical fiber to a PTFE laser ball
- PMTs, signal cables, and electronic circuits introduce inherent time offsets among channels
- Uncontrolled drift of these offsets will deteriorate time resolution and event reconstruction accuracy
- LED pulse width: ~ 100 ns; light intensity sufficient for all PMTs to receive synchronous



LED Light Source & Detector Schematic

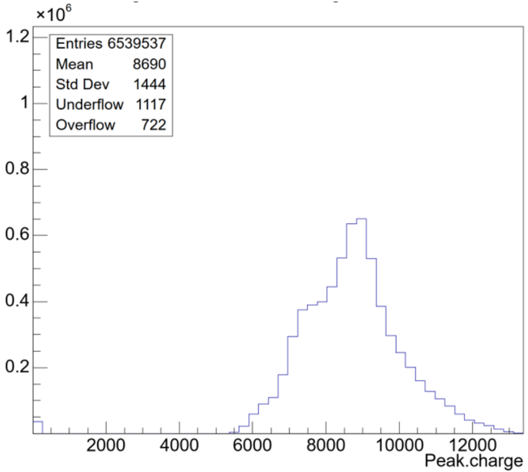
The waveform of 60 PMTs for LED events.



Time Calibration —Method

Signal arrival time of each channel is determined by:

1. Rise time: the position where the waveform first reaches 20% of the first peak height
2. Data with first-peak integrated charge $< 5000\,\mathrm{ADC}\cdot\mathrm{ns}$ are excluded to reject dark noise



first-peak charge integration distribution

Time Calibration —Mathematical Model

At the m-th LED flash, the photon arrival time recorded by the i-th PMT:

$$T_{mi} = t_m + TOF_{mi} + T_i + \tau_{mi}. \quad (1)$$

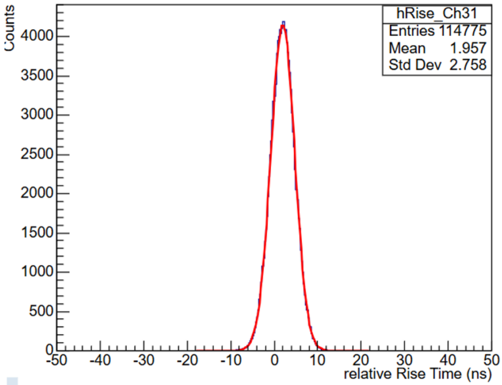
- t_m: time of the event relative to the signal-recording reference
- TOF_{mi}: photon time-of-flight within the detector
- T_i: PMT transit time and signal propagation time
- τ_{mi}: random fluctuations including TTS of the PMT and LED emission time instability

Time Calibration —Inter-Channel Time Difference

To suppress the statistical fluctuation of t_m, the difference between two channels is taken:

$$T_{mi} - T_{mj} = TOF_{mi} - TOF_{mj} + T_i - T_j + \tau_{m,i} - \tau_{m,j}. \tag{2}$$

- For light from the central LED, $TOF_{mi} = TOF_{mj}$ for all channels
- $\tau_{m,i} - \tau_{m,j}$ follows a Gaussian centered at zero
- $\Delta\hat{T}_{ij}$: mean of the rise-time difference distribution for channel pair (i, j)



Time Calibration —Decentralization Method

To avoid over-reliance on any single channel, the time differences are decentralized:

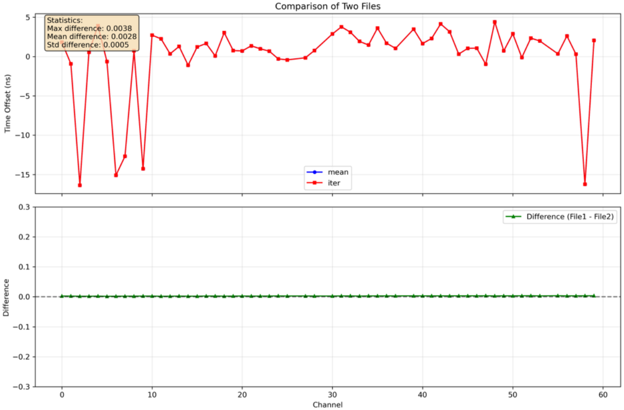
$$\bar{T}_i = \frac{1}{N} \sum_{j=0}^{N} \Delta \hat{T}_{ij}, \tag{3}$$

where N is the total number of live channels, and $\bar{T}_i$ is the time offset of channel i relative to the array mean.

Time Calibration —Results: LED Data

compared this method(mean) with the iterative method [a].

- For LED calibration data, the two methods yield consistent results



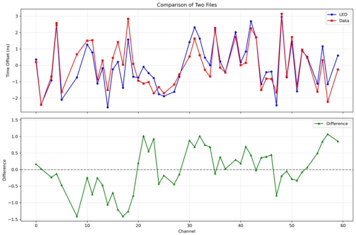
---

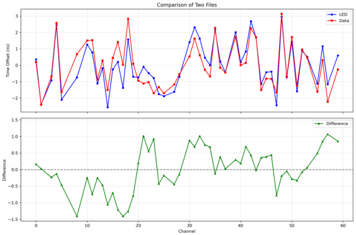
[a] Zhaolin:R&D of the Jinping Neutrino Experiment,2021.

Time Calibration —Results: Radioactive Source vs. LED

Radioactive background data were also used to cross-check the feasibility of time calibration.

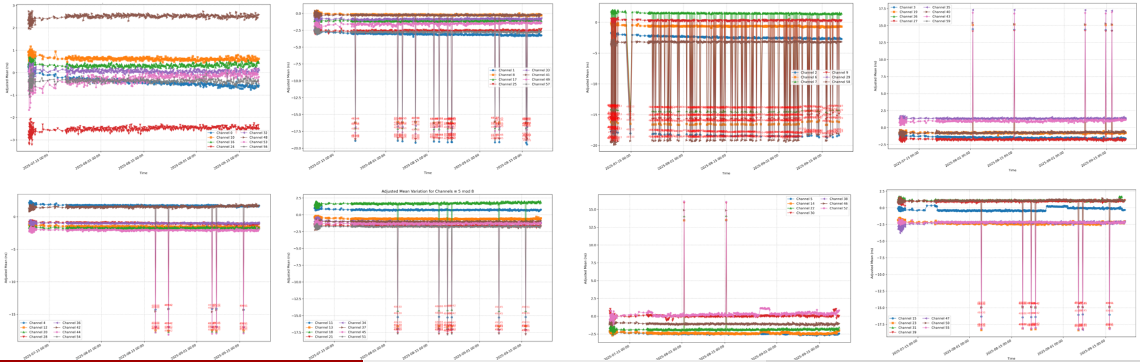
- Mean method: $\sim 1\,\text{ns}$ deviation from LED results
- Iterative method: $\sim 2\,\text{ns}$ deviation from LED results





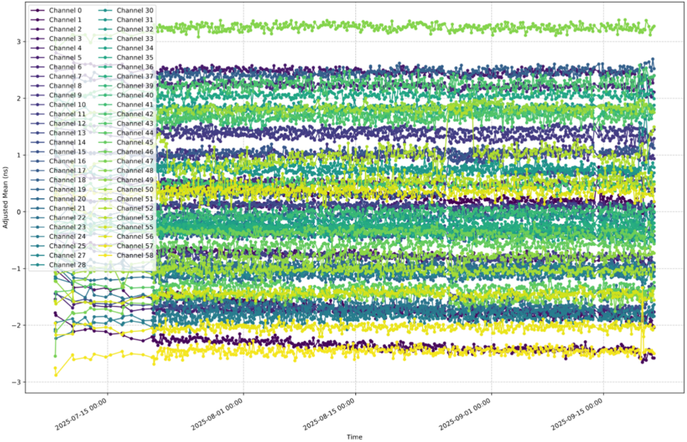
Time Calibration —Results: Clock Drift

- Examining calibration results across runs, a 16 ns clock drift between electronics boards was identified



Time Calibration —Results: Clock Drift (Corrected)

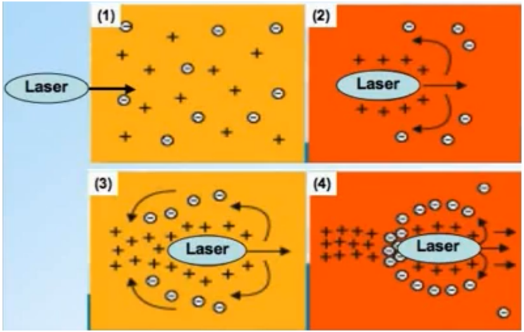
- After correcting for the drift, calibration results became stable



Energy Calibration —Wakefield Electron Source

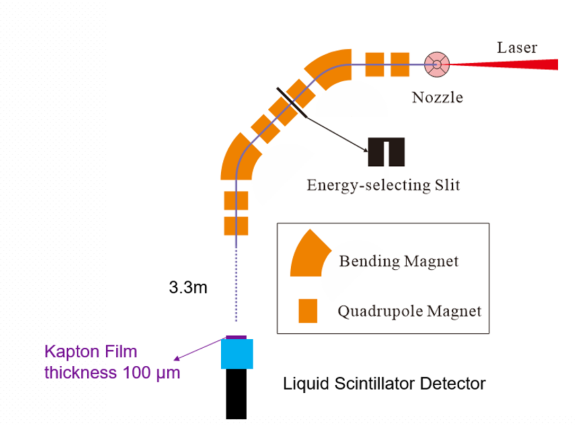
Principle of Laser Wakefield Acceleration (LWFA):

- An intense laser pulse propagates through an underdense plasma
- Ponderomotive force expels plasma electrons, creating a trailing wakefield
- The wakefield sustains extremely high accelerating gradients ($\sim$ GV/m)
- Witness electrons injected into the wakefield are trapped and accelerated

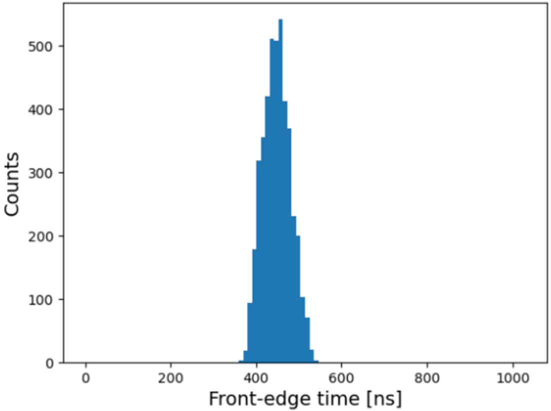


This produces a directional electron beam with

Energy Calibration —Experimental Method



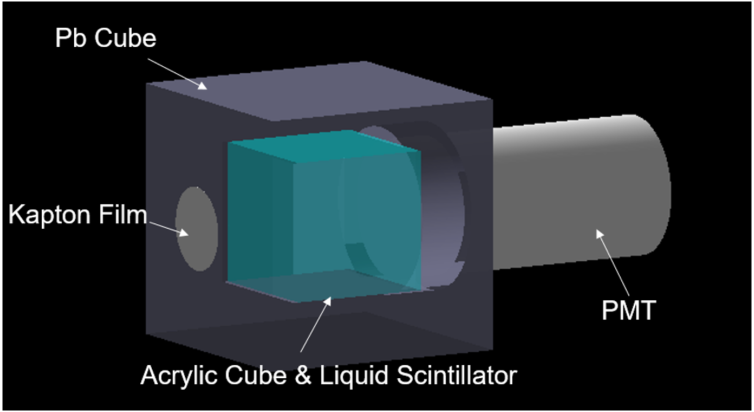
Schematic: small liquid-scintillator detector + electron beam



External trigger synchronized with electron emission

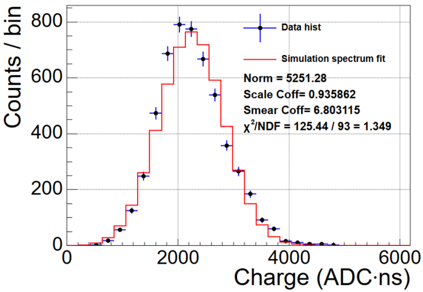
GEANT4 Simulation

- GEANT4 simulation of 4.5 MeV electrons depositing energy in the liquid-scintillator detector

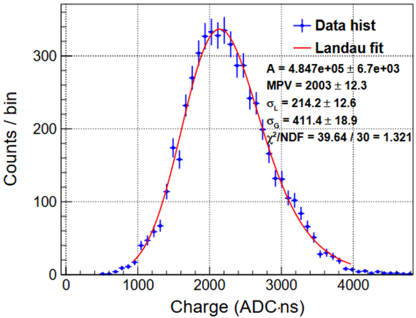


Energy Calibration —Simulation & Fitting Results

- Simulated energy spectrum is consistent with experimental data



- Fitted with a Landau-convoluted Gaussian function. Experimental data agree well with the model



Summary & Outlook

Time Calibration:

- Established a stable method for time calibration.
- This method also can be used with radioactive background with uncertainty 1 ns.
- Identified and corrected a 16 ns clock drift between different runs.

Energy Calibration Study:

- Wakefield acceleration provides a stable MeV-level electron source.
- Electron quantities and energy require further precise measurements.

Thank you!