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PMT gain calibration for the JSNS² Experiment

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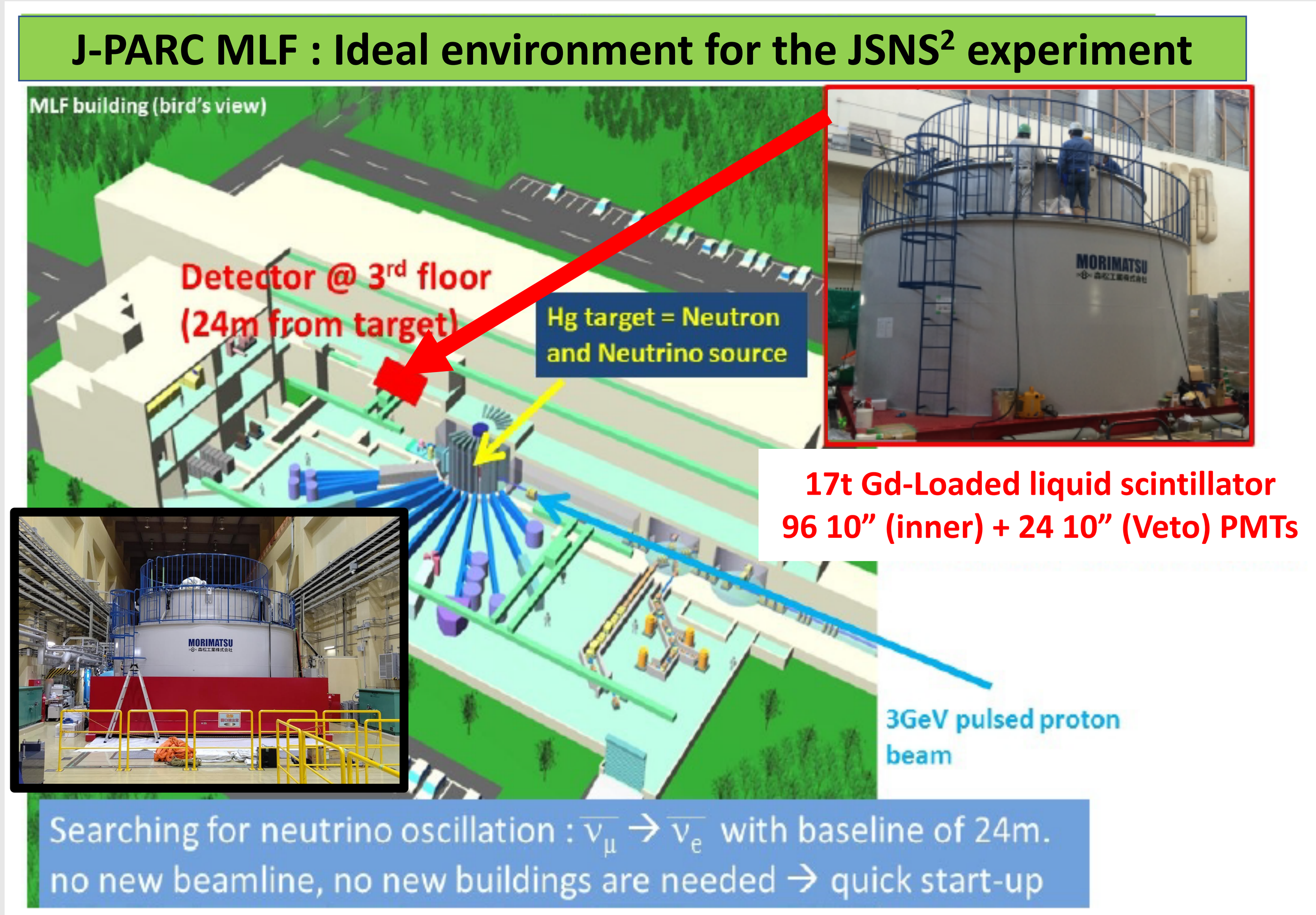
Poster #353

Introduction

The JSNS² experiment will search for neutrino oscillations with Δm^2 near 1 eV² from $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, detected via the IBD and tagged via gammas from neutron capture on Gadolinium. A 1 MW beam of 3 GeV protons beam incident on a mercury target at the MLF at J-PARC produces an intense neutrino flux from μ-DAR. The JSNS² experiment consists of a 50 tons liquid scintillator(LS) detector, that is already completed and located at a distance of 24 m from the neutrino source. JSNS² is the only experiment that can directly test the LSND anomaly without having to rely on theoretical scaling assumptions. The commissioning of the detector has started already using LEDs with nanosecond-pulse width, and the data taking started in June 2020 after filling the detector with LS. In this poster we will introduce the results of the calibrations runs including PMT gain adjustment.

Introduction of the JSNS² experiment & LED Run



PMTs in our experiment are essential device for reconstruction and energy measurement. It is necessary to characterize individual PMTs performance and to operate them at the right gain and optimized dynamic range.

Using a series of dry runs with a total of 14 LEDs with nanosecond-pulse width and 96 10-inch inner PMTs [1], we validated the individual PMT performance against benchtop gain measurements. The waveforms from the PMTs were taken by a DAQ system which consists of 28 FADCs with a 500 MHz sampling rate and 8 Bits of resolution and 16 FEE modules.[2] The maximum sampling rate of these FADCs is 500 MHz, meaning pulse-height measurements are made every 2 ns. LED data was taken over a 5μs time window. A total of 50,000 events were used for this study.

Hit Occupancy

In order to measure the gain we focused on Single Photoelectron(SPE) hits, since the Multi-PE part may introduce a bias when determining the gain by fitting to the SPE region. In order to have SPE hit dominant data, we used only events with restricted hit occupancy.

- The fraction of SPE hits is calculated via Poisson-distribution for hit probability.

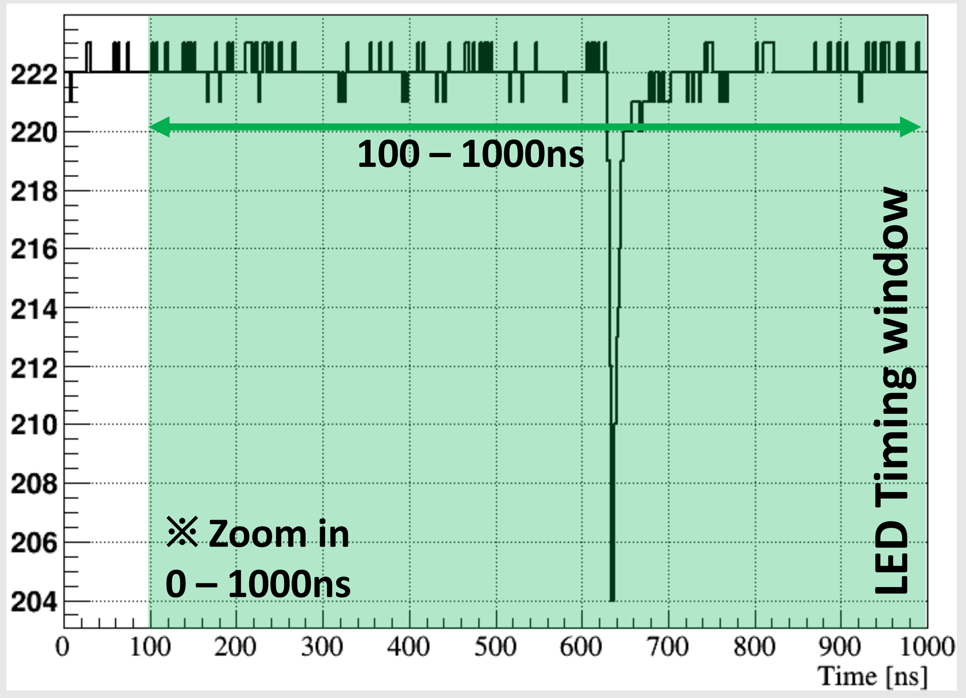
$$F_{SPE} = \frac{P(n=1;\mu_i)}{P_h(\mu_i)} = \frac{\mu_i e^{-\mu_i}}{1-e^{-\mu_i}} \underset{\mu_i \ll 1}{\Longrightarrow} F_{SPE} \approx 1 - \frac{\mu_i}{2} \approx 1 - \frac{O_i}{2}$$

- If the occupancy(O_i) was restricted to less than 5%, 97.5% of hits are SPE hits according to calculation with the formula above.
- Because we used an LED which has limited coverage, more than one LEDs are needed to achieve coverage for 96 inner PMTs.
- Matching LED-PMT pairs, corresponding to 5% occupancy, were found by varying LED intensities.

LED Timing Selections

Besides the hit occupancy scheme, another event selection method was applied called LED timing selection. This LED timing selection method can reduce un-related LED events (dart hits, hardware noise, etc…) significantly.

- Estimate the normal peak region for LED related events.
- Select the LED timing window between 100ns and 1000ns in the entire waveform window of 5μs.
- If a signal is found this region it is accepted.
- Other signals will be rejected.



Pedestal calculation method

We calculate the pedestal of the waveform on an event by event basis. In order to calculate the charge from these waveforms, a suitable pedestal is calculated for each waveform. The recreated waveform, referred to as '0', is the baseline waveform consistent with each PMT respectively.

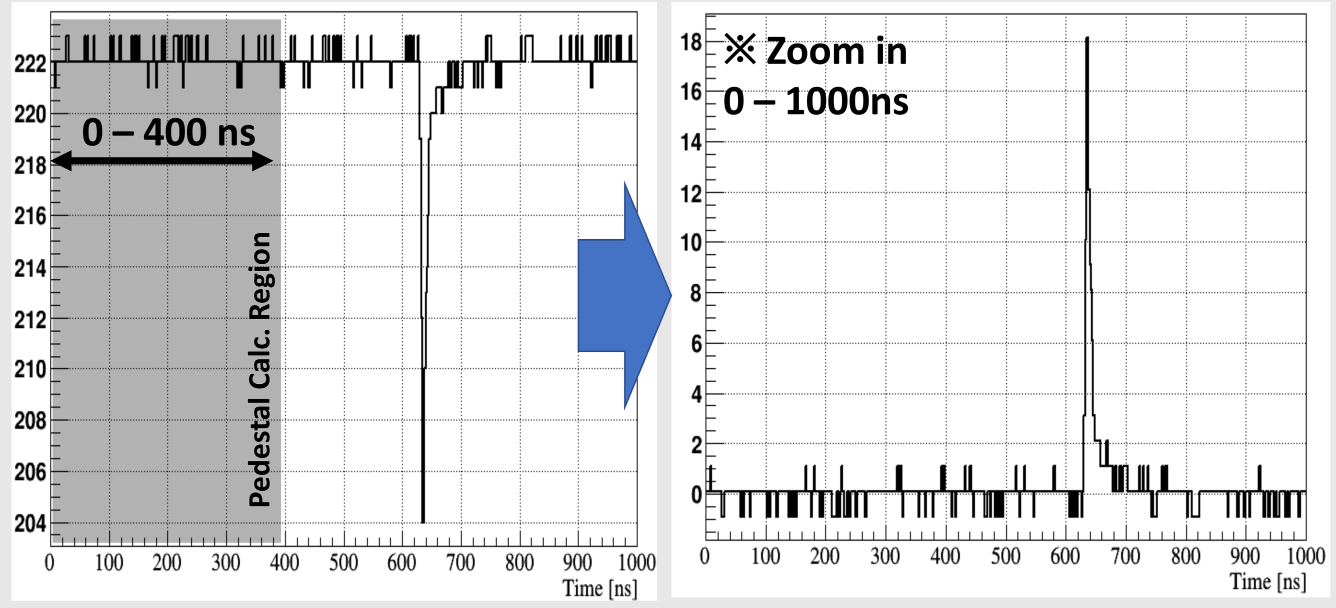
The pedestal calculation process is simple for this study.

- Calculate the average of pedestal region (e.g. 0 to 400ns in the left figure)

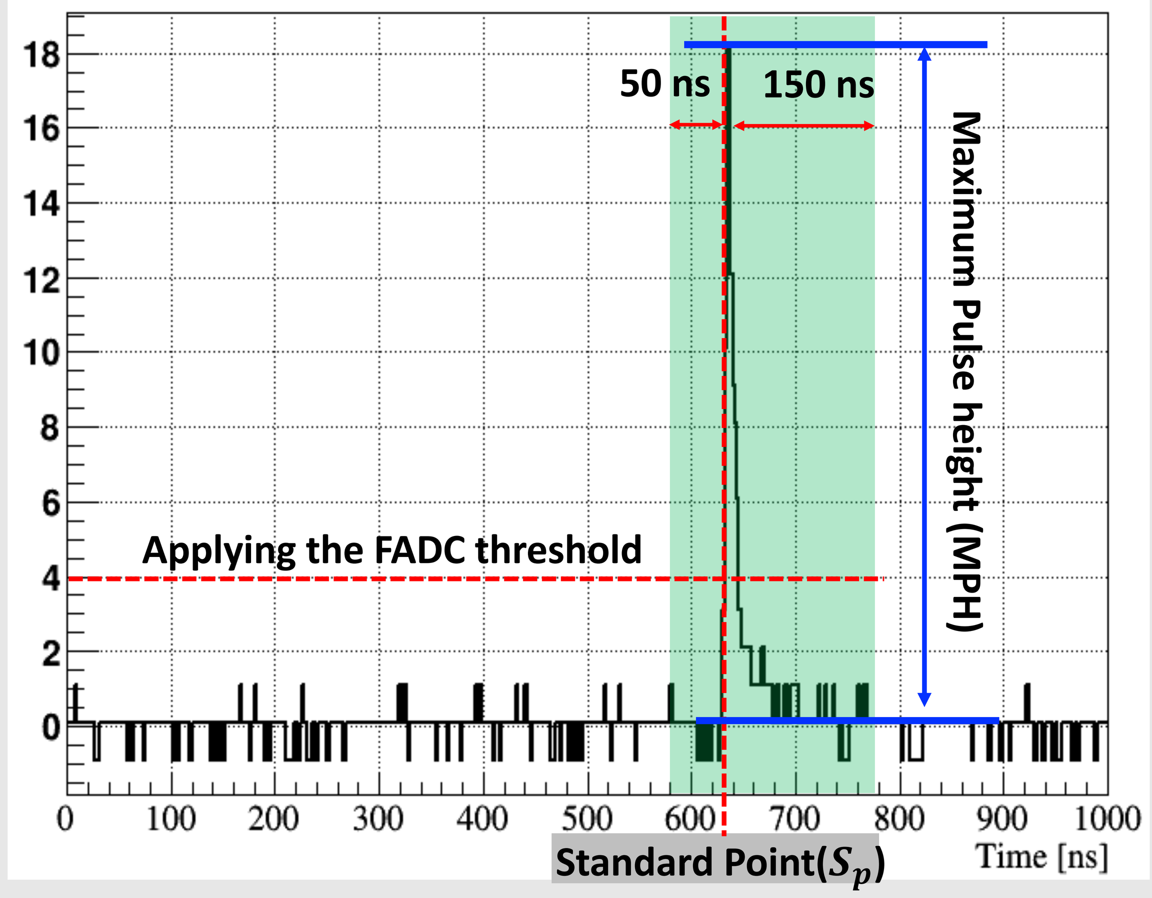
$$P_{Avg} = \frac{1}{N}\sum_{n=0}^{N} f_n$$

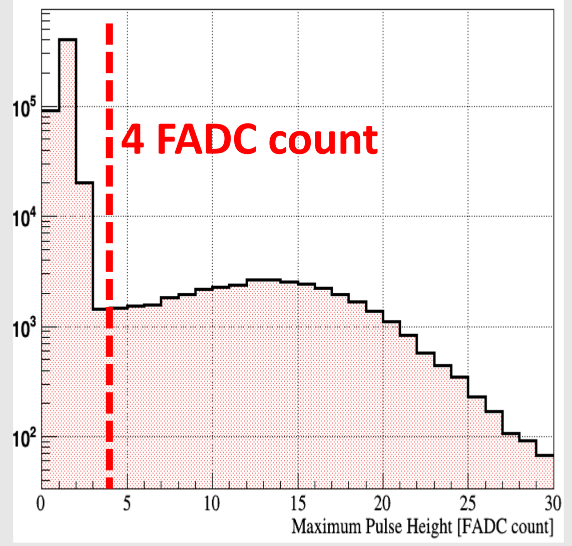
- P_{Avg} : Average pedestal
- N : Entry of the data sample
- f_n: n^{th} FADC data sample

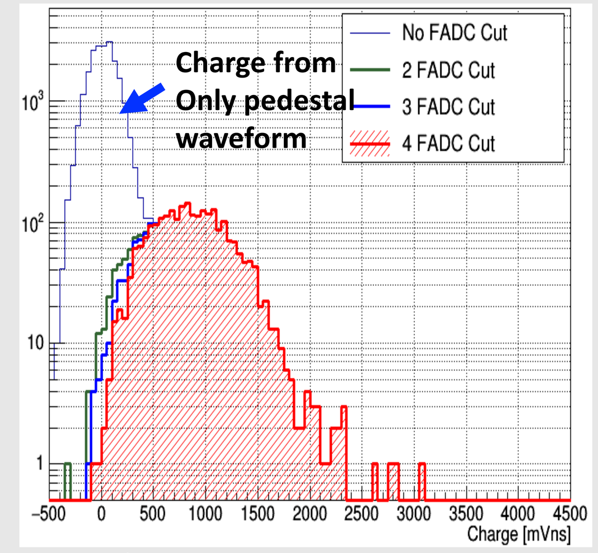
- Subtract the calculated pedestal from all waveform data points.



Charge Calculation







$$Q_{SPE}\,[mVns] = \sum_{n=S_p-50\,ns}^{S_p+150\,ns} \alpha F_p(n)$$

- S_p : standard point
- F_p : Data point of waveform
- α : conversion factor $\frac{1000}{2^8} \approx 3.9\, mV/bit$

In order to obtain the charge from the waveforms, a FADC threshold algorithm that extracts the calculated charge between SPE signal and the pedestal was applied.

- Investigated the threshold using MPH distribution.
- Obtained optimized FADC threshold from MPH tendency.
- Measured the S_p at which the FADC threshold was crossed, and integrated over a 200ns region with: $-50ns < S_p < +150ns$
- If not crossed to FADC threshold, Integration region was done by fixed region : 600 ns to 800 ns

Measuring the gain

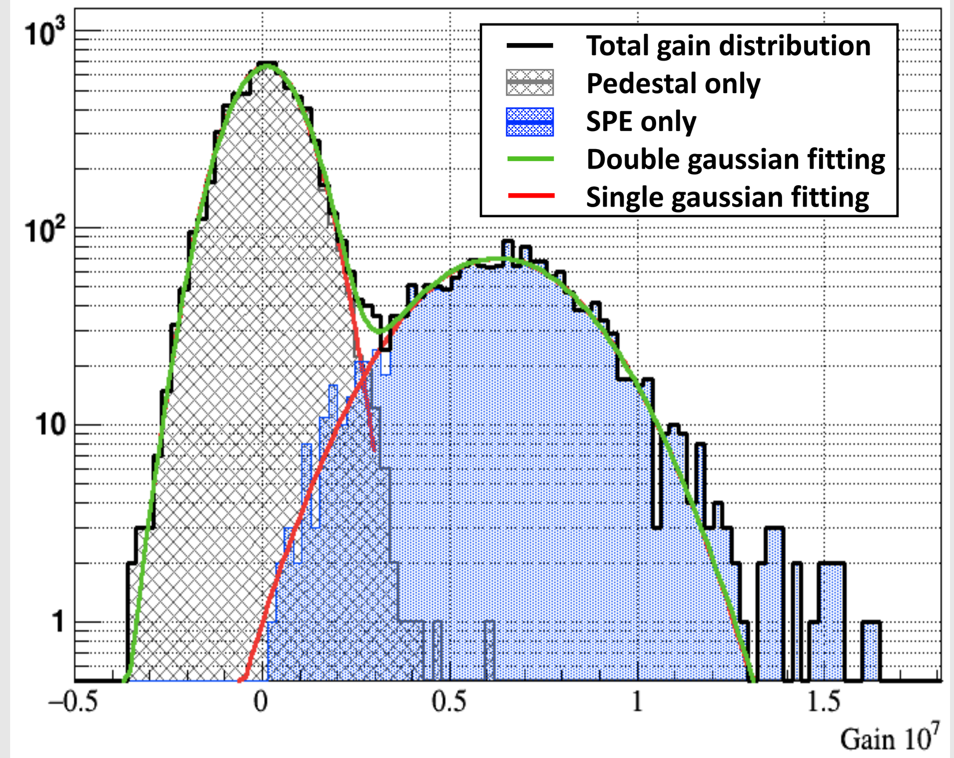
By using correction factors, the calculated charge can be converted into a gain.

- Calculating the charge by integrating the waveform.
- Applying a unit correction factor to the calculated charge.

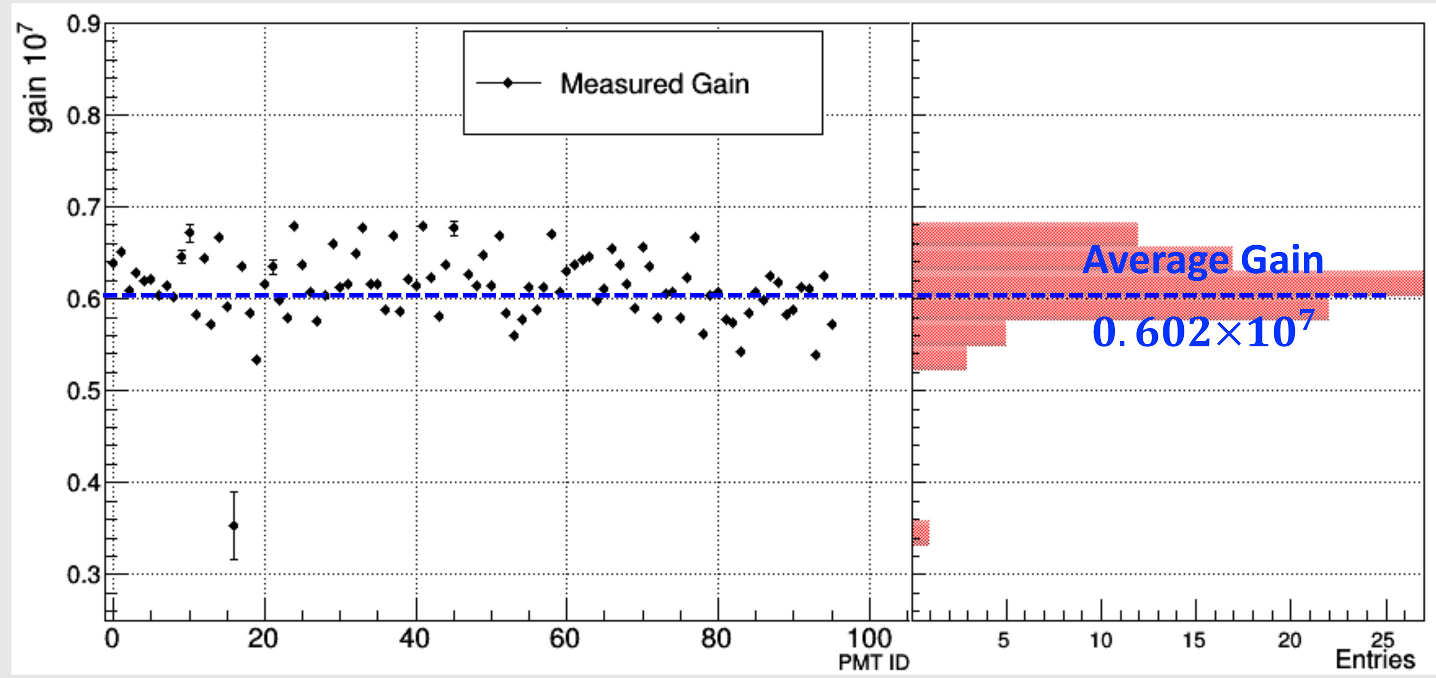
Item		Contents
FEE high-gain factor [2]	F_{FEE}	16.0
Resistance	R [Ω]	50.0
Electric charge	Q [C]	1.6×10^{-19}

$$G_{SPE} = \frac{Q_{SPE}}{F_{FEE}\times R\times q}\ \left[\,Units: \frac{mV\cdot ns}{V\cdot s\cdot 10^{-19}} = O(10^7)\,\right]$$

- Make a distribution using converted gain.
- Result gain measured by double gaussian fitting via pedestal peak and SPE peak fitting results.
- The mean value of second gaussian will be used for the gain of SPE events.



Conclusion



- Average Gain = **0.602×10^7** [target gain **0.6×10^7**]
- RMS [σ] of the gain distribution is **0.03** (PMT Pre-calibration : **0.07**)

Reference

- [1] Technical Design Report(TDR), T.Maruyama et al arXiv:1705.08692
- [2] The JSNS² data acquisition system , J.S.Park et al arXiv:2006.00670

See Other Posters

- [#322] Measurement of beam related gamma background using plastic scintillator at JSNS²
- [#352] Signal Timing Analysis from the Dry Run in the JSNS² Experiment
- [#355] Efforts for Launching JSNS² Experiment at J-PARC
- [#367] The Design and Development of the JSNS² DAQ Upgrade
- [#482] KDAR Neutrino Measurements with JSNS²