Signal Timing Analysis from the Dry Run in the JSNS² Experiment

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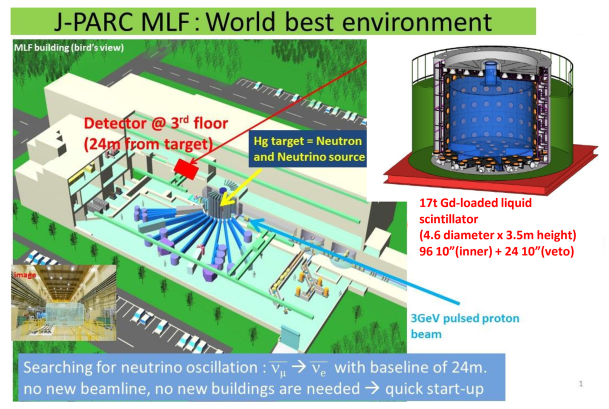
NEUTRINO 2020

Sanghoon Jeon for the JSNS² Collaboration
Sungkyunkwan University

J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source

JSNS²

- J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source
- The main purpose is searching for the existence of sterile neutrino with Δm^2 near 1 eV^2 at the J-PARC Material and Life Science Experimental Facility (MLF) and offering the ultimate direct test of the LSND anomaly.
- A 1 MW beam of 3 GeV protons incident on a spallation neutron target produces an intense neutrino beam from muon decay at rest.
- The experiment will search for $\bar{\nu}_\mu$ to $\bar{\nu}_e$ oscillations which are detected by the inverse beta decay interaction $\bar{\nu}_e + p \rightarrow e^+ + n$, followed by gammas from neutron capture on Gd.
- The detector has a fiducial volume of 17 tons and is located 24 meters away from the mercury target.



Event Reconstruction

JSNS² uses a reconstruction tool, named JADE, which reconstructs the energy and the event vertex. Accordingly, JADE requires timing information for each PMT channel in order to reconstruct the event variables.

$$-\ln L_{Event} = \sum_{i=1}^{N_{PMTs}} -\ln L_q(q_i, \vec{\alpha}) + \sum_{i=1}^{N_{PMTs}} -\ln L_t(\omega_i(t), \vec{\alpha})$$

Consequently, timing resolution of PMT hits affect the resolution of neutrino energy and event vertex. To estimate the resolution and the availability into JADE of timing information, analysis for signal timing was performed by using the dry runs which were done on Mar. & Apr. in 2020 in MLF.

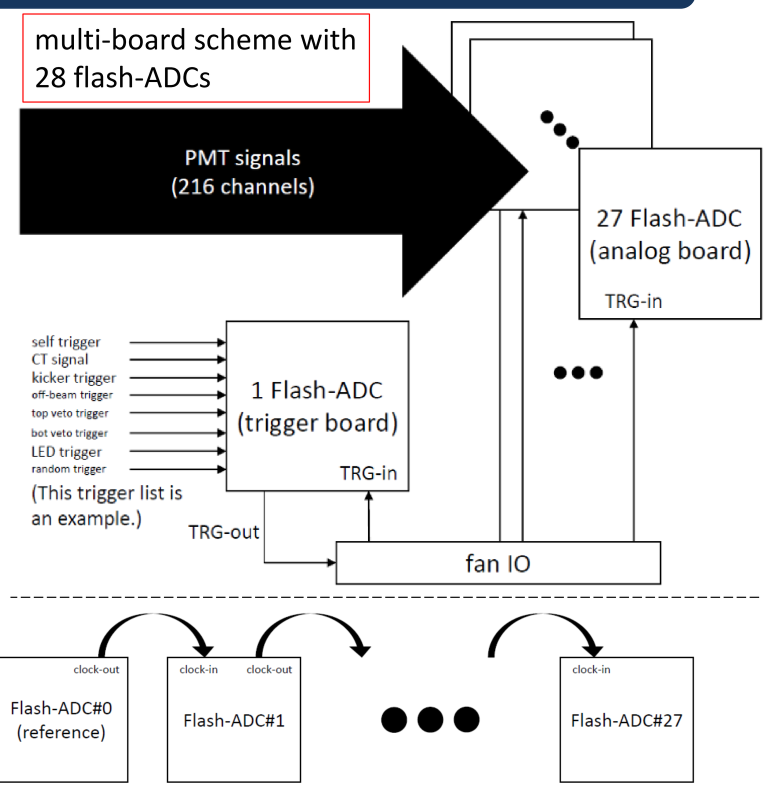
DAQ System

- Multi-Board Scheme

JSNS² uses 96 PMTs for the inner detector and 24 PMTs for the veto detector. For the inner channels, 2 channels are assigned per a PMT which are a high gain channel and a low gain channel. Therefore, 96*2+24=216 channels are taken in total. To take the data with CAEN V1721 which is 8bit flash-ADC with 8 input analog channels, at least 27 boards are required. In addition, 1 board was added for a trigger board.

- Time Synchronization

To use a common time flow, the flash-ADCs have to use a time synchronization scheme so that only one clock should be referred by all the flash-ADCs. By using a daisy chain with synchronization cables, the reference clock is propagated to al the others.



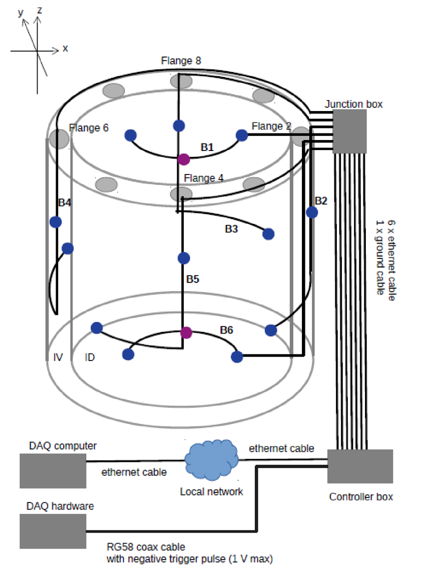
time synchronization of the flash-ADCs with a daisy chain

LED System & Dry Run

It is well known that a LED run is very useful for a detector calibration, such as PMT gain and signal timing. JSNS² also uses an LED system with the following configurations.

- less than 1ns rising time and less than 2ns falling time (very good performance for calibrating timing information)
- a trigger pulse that can be delayed, with negative amplitude, to be read-out with one channel of flash-ADC read-out system.
- 12 pulserheads (420nm), 2 pulserheaders (355nm)
- installed on the inner surface of the inner detector

In the Mar. & Apr. dry runs, LED runs were also performed with various LED configurations, such as LED channels and LED intensity. By using the samples, several analyses are being performed to understand the detector and to prepare physics runs.



Time Variance of Signals

There are several components which lead to variation of signal timing. Their effects can be summarized as the following formula.

$$t(ch\#, event\#) = t_{TOF}(vertex, ch\#) + t_{cable}(ch\#) + t_{ch}(ch\#) + t_{TD}(LED\#)$$

$t(ch\#, event\#)$	: visible timing of signals from raw waveforms
$t_{TOF}(vertex, ch\#)$	: timing delay by TOF of optical photons. (time interval between LED and each PMT)
$t_{cable}(ch\#)$	: timing delay by PMT cable length difference (JSNS2 has PMTs with various cable length.)
$t_{ch}(ch\#)$	: timing delay by the characteristics of electronics channels.
$t_{TD}(LED\#)$	: timing delay by the trigger delay of LED channels. (only for LED runs)

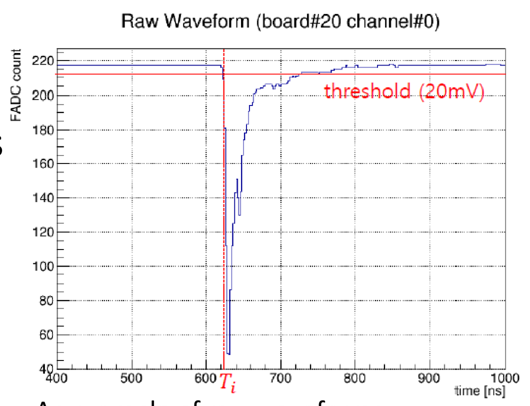
Definition of $t(ch\#, event\#)$

$t(ch\#, event\#)$ means visible signal timing with respect to the trigger signal from the LED module, which is defined as the following.

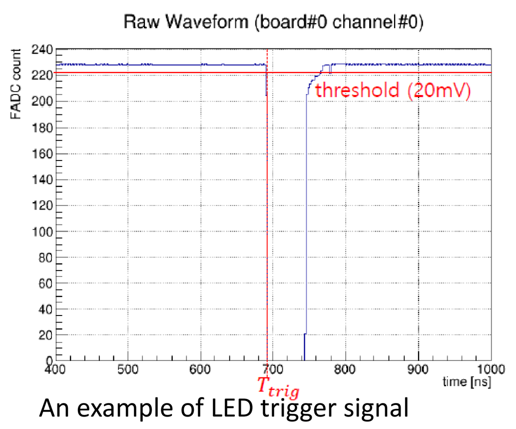
$$t(ch\# = i, event\#) = T_i - T_{trig}$$

T_i : bin# when the raw waveform of ith channel gets over the threshold (20mV here)

T_{trig} : T_i for the trigger channel in the trigger board



An example of raw waveforms and the definition of T_i

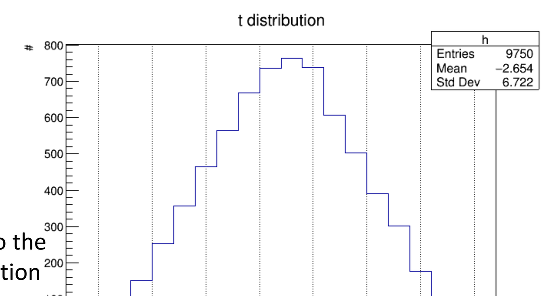


An example of LED trigger signal and the definition of T_{trig}

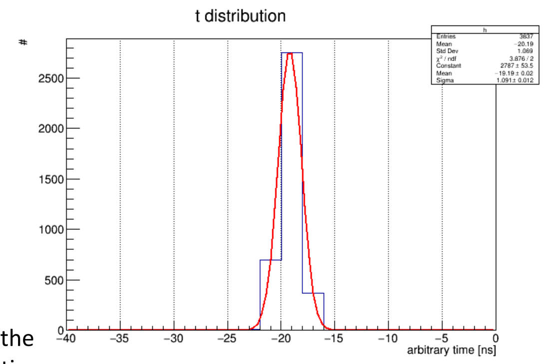
Time Synchronization of Flash-ADCs

The right 2 plots show an effect of the time synchronization shown in the Chapter "DAQ System".

- By implementing the time synchronization, t resolution gets much better.
- The gaussian fitting to t distribution with the time synchronization shows 1.09[ns] of sigma for this example.
- The gaussian fitting is performed for all PMT channels and all LED configurations. Most PMT channels show t resolution with less than 2[ns] of sigma.
- The following analysis is done by using the mean values from this t measurement.



t distribution w/o the time synchronization



t distribution w/ the time synchronization

Summary

- JSNS² is an experiment proposed to search for the existence of sterile neutrino with $\Delta m^2 \sim 1eV^2$ using intense $\bar{\nu}_\mu$ beam from the J-PARC (MLF) at Japan.
- The event reconstruction requires precise timing information.
- Dry runs were performed on Mar. and Apr. in 2020. And, many good samples were taken by using a LED system. By using the samples, the timing resolution for the current JSNS² detector was estimated.
- An analysis was done to understand and to measure the effects of the components which can affect signal timing.
- A few nanosecond of signal timing resolution was achieved.
- This analysis will be the first step for analyses of physics runs in near future.

Time of Flight, $t_{TOF}(vertex, ch\#)$

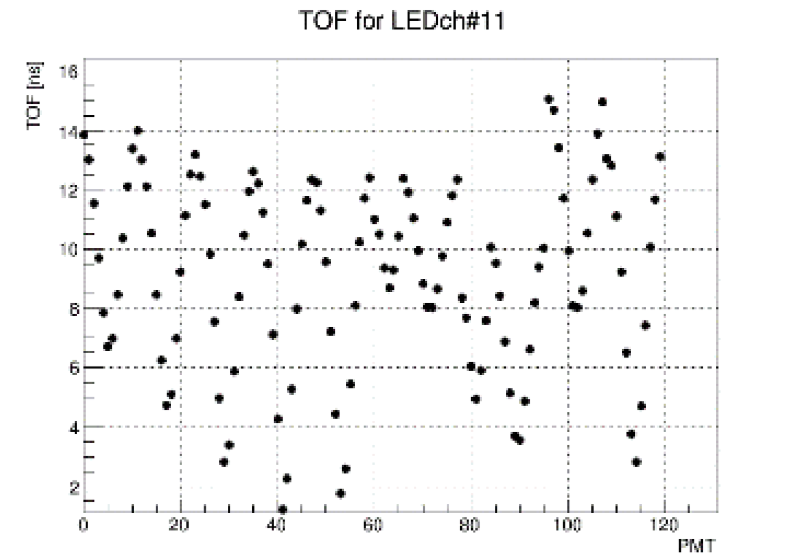
Event vertex reconstruction is based on the vertex dependence of the signal timing for each PMT channel. Indeed, t_{TOF} is the key for the reconstruction tool for physics run. That is why all the other components, $t_{cable}, t_{ch}, t_{Syn}, t_{TD}$ should be understood and measured.

For LED runs, coordinates of the pulserheads are given, so that t_{TOF} is specified and can be used as a correction factor in order to measure the other components.

$$t_{TOF}(LED\#, ch\#) = \frac{n}{c} \times |\vec{r}_{LED\#} - \vec{r}_{ch\#}|$$

$\vec{r}_{LED\#}$: coordinates of a LED pulserhead
$\vec{r}_{ch\#}$: coordinates of a PMT
c : speed of light
n : refractive index of medium in the detector : For the dry run, the index for air can be used.

For physics runs, the detector will be filled with liquid scintillator. Considering the refractive index for liquid scintillator is larger than 1, the effect of t_{TOF} will get increased. It is useful to see the effect by comparing the results between the dry runs and the physics runs.



branch	pulserhead	r [mm]	phi [degree]	z [mm]	pulserhead	r [mm]	phi [degree]	z [mm]	pulserhead	r [mm]	phi [degree]	z [mm]
1	1	945.3	53.9	1500	2	945.3	126.1	1500	3	945.3	233.9	1500
2	4	1857.6	47.3	785	5	1857.6	92.3	-785				
3	6	1857.6	317.3	785	7	1857.6	2.3	-785				
4	8	1857.6	227.3	785	9	1857.6	272.3	-785				
5	10	1857.6	137.3	785	11	1857.6	182.3	-785				
6	12	945.3	53.9	-1500	13	945.3	306.1	-1500	14	945.3	233.9	-1500

Table for the coordinates of the LED pulserheads

Trigger Delay, $t_{TD}(LED\#)$

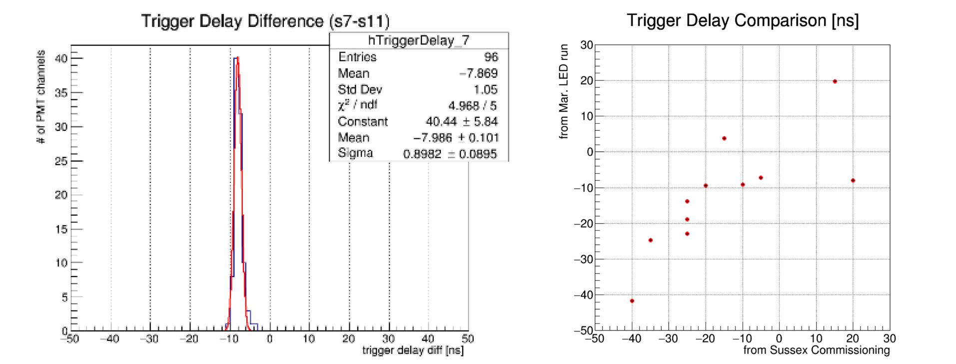
The JSNS² LED system has 14 LED channels which are located on the inner surface of the inner detector. To use them, it is important to estimate the characteristics for each channel, such as trigger delay which is a time difference between generation of the trigger signal and photon emission from the LED pulserhead.

In this analysis, the relative trigger delay with respect to LED#11 was measured.

By subtracting the 2 formulae for each LED channel,

$$t_{TD}(LED\#i) - t_{TD}(LED\#j)$$
$$= [\text{mean}(t) - t_{TOF}(ch\#)](LED\#i)$$
$$- [\text{mean}(t) - t_{TOF}(ch\#)](LED\#j)$$

, the relative trigger delay can be obtained.



relative trigger delay of LED#9 with respect to LED#11
By fitting a gaussian function, mean value can be obtained.

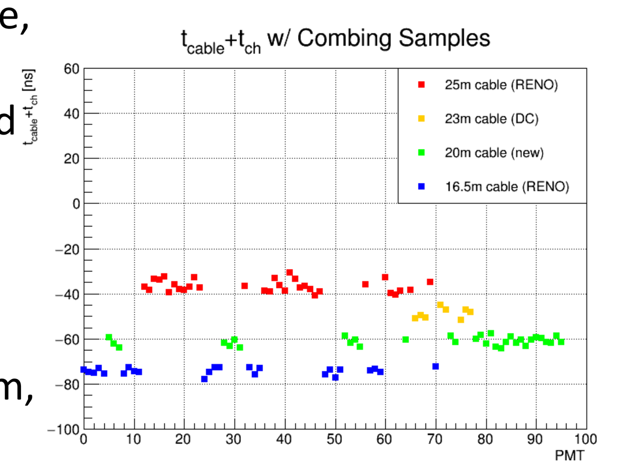
comparison of the relative trigger delay with the commissioning from Sussex University

PMT Cable Length and Characteristics of Channels, $t_{cable}(ch\#) + t_{ch}(ch\#)$

Finally, all the necessary components were given. Therefore, the effects of the PMT cable length difference and characteristics of the electronics channels can be measured according to the following formula.

$$t_{cable}(ch\#) + t_{ch}(ch\#)$$
$$= \text{mean}(t) - t_{TOF}(LED\#, ch\#) - t_{TD}(LED\#)$$

Considering the cable length difference is 10m in maximum, ~50ns of timing difference is very reasonable. Also, the channel characteristics with 5ns fluctuation is well seen.



Reference

[1] T. Maruyama et al., arXiv:1705.08629 (physics)
[2] J. S. Park et al, arXiv:2005.01599 (physics)
[3] Mod. V1721/V1731 8 Channel 8bit – 500MS/s Digitizer, http://www.caen-group.com/servlet/checkCaenManualFile?Id=9207

Other presentations for JSNS²

- Measurement of beam related gamma background using plastic scintillator at JSNS² (#332)
- PMT gain calibration for the JSNS² Experiment (#353)
- Efforts for Launching JSNS² Experiment at J-PARC (#355)
- The Design and Development of the JSNS² DAQ Upgrade (#367)
- KDAR Neutrino Measurements with JSNS² (#482)