Measurements on the afterpulse of the 20-inch Photomultiplier Tubes for the JUNO experiment

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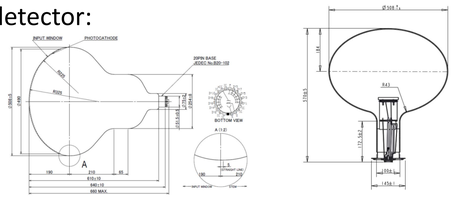
Introduction

The afterpulse is one of the main characterizations of the photomultiplier tubes (PMTs) which can introduce undesired background noise signals, thus its detailed rate, time and charge distributions are important. Two types of **20-inch PMTs** to be used in the Jiangmen Unverground Neutrino Observatory (JUNO) [1] central detector:

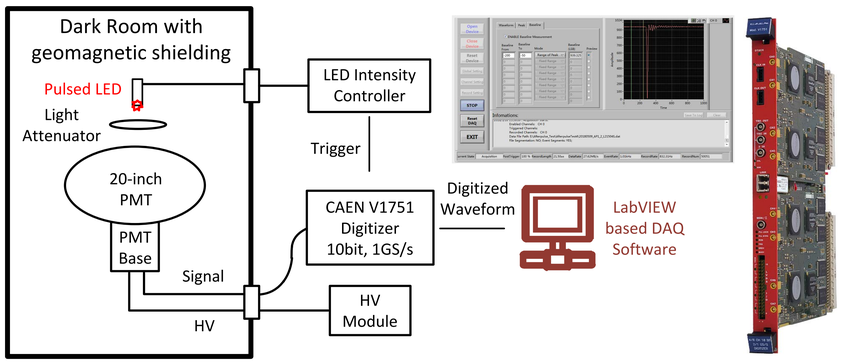
- R12860-50 dynode PMTs by Hamamatsu
- Microchannel plate (MCP) PMTs by North Night Vision Technology.



Test Platform

Measurement platform was set up in the scanning station system[2][3] with geomagnetic shielding.

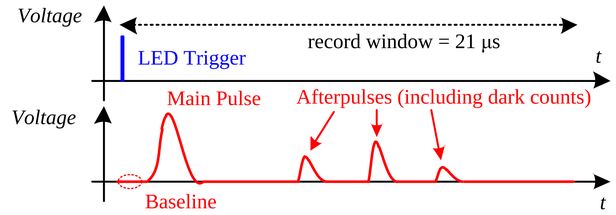
- **A stablized, pulsed LED** was fixed on top of the PMT's photon cathode with a **fixed light intensity** where the average measured main pulse of each tested PMT was less than 100 photons.
- High voltage has been calibrated to achieve **a gain of 10^7** for the tested PMT, which has been selected as an optimal high voltage for the JUNO experiment[2].



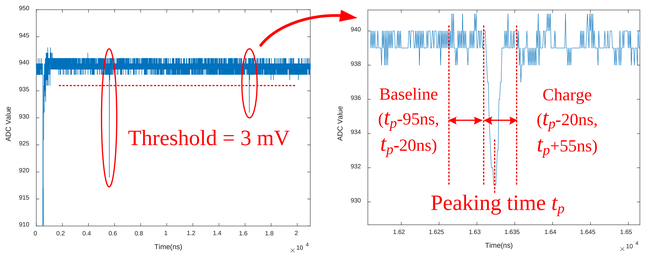
- PMT output waveforms were captured and digitized by a 10-bit fast ADC. The record window is 21 μs after the LED trigger, covering the **measurements on the baseline, main pulse and the afterpulses**.
- **Waveforms of the dark counts** were measured with LED off and the same condition as the afterpulse measurements. Dark counts' contribution to the total charge within the record window would be deducted.

Parameters	Test setup
Analog Bandwidth	500 MHz
Sampling Rate	1GS/s
Record Length	21 μs after trigger
Trigger Rate	1 kHz, provided by LED controller.

Data Analysis



Both the **charge Q_{ap}** and **peaking time t_p** of **each afterpulse** were measured from the waveform.



- Afterpulses were picked off with a threshold of 3mV above the baseline of the main pulse, corresponding to a total charge 1/4 of the single photoelectron signal.
- **Peaking time t_p** is measured related to the main pulse.
- **Baseline of each afterpulse** was calculated from the 75 ns window ranging from 95 ns to 25 ns before t_p. **Charge Q_{ap}** was calculated by the integration of the waveform with 75 ns window ranging from 25 ns before t_p to 55 ns after t_p. The selected time windows are the same as those for acceptance tests for the JUNO PMTs[3].
- Total afterpulse charge were considered within a **afterpulse time window T_w from 0.5 μs to 20 μs after the main pulse**, where the waveform is not influenced by the ringing at the tail of main pulse. Total charge ratio to the main pulse is calculated by the summation of all Q_{ap} and reduction of the average charge from the dark counts' charge Q_{dark} locating in the afterpulse time window :

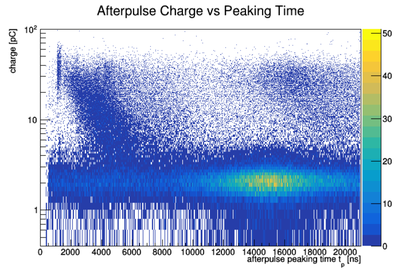
For each PMT, a number of 50,000 main pulses (N_{main}) were captured.

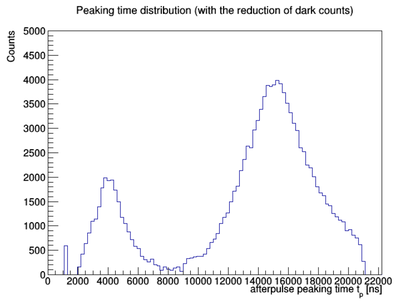
$$Ratio = \frac{\sum_{i=1}^{N_{ap}} Q_{ap,i} - N_{main} Q_{dark}}{\sum_{i=1}^{N_{main}} Q_{main,i}}$$

Results

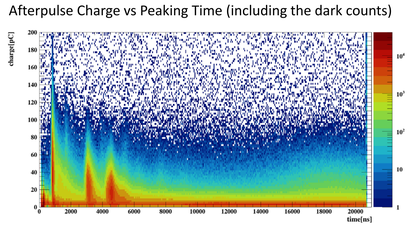
For Hamamatsu PMTs, **two afterpulses at around 3~5 μs and 15 μs** respectively were observed, consistent with vendor's measurements.

- Large pulses up to 100 pC exist for the first group of afterpulses.
- Afterpulses around 15 μs after the main pulse are **almost of single photoelectron charge**.

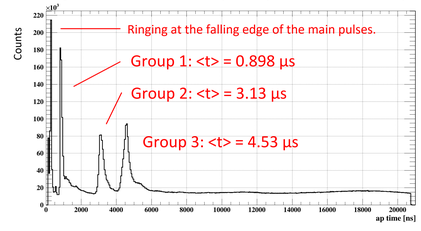




For MCP PMTs, current tests give out three probable groups of afterpulses centered at **898 ns, 3.13 μs and 4.53 μs.**



Peaking time distribution of the picked pulses after the main pulses



- The t_p central value of three groups decreases as the PMT high voltage increases.
- A relatively smaller afterpulse ratio was observed for MCP-PMTs compared to Dynode -PMTs.

	Current number of tested PMTs	Average Afterpulse Ratio (with main pulse charge 130~150 pC)
Hamamatsu	7	11.91%
MCP PMTs	140	6.74%

References:
[1] F. An et al. Neutrino Physics with JUNO. J. Phys. G, 43(3):030401, 2016.
[2] Anfimov, N. (2017). Large photocathode 20-inch PMT testing methods for the JUNO experiment. Journal of Instrumentation, 12(06), C06017.
[3] Zhang, H., Wang, Z., Wang, W., Qin, Z., Olshevskiy, A., Anfimov, N., ... & Tietzsch, A. (2020). Tested Performance of JUNO 20" PMTs. In Journal of Physics: Conference Series (Vol. 1468, p. 012197).