Proc. 5th Int. Workshop New Photon-Detectors (PD18)
JPS Conf. Proc. **27**, 011007 (2019)
https://doi.org/10.7566/JPSCP.27.011007

Development of TPC Trigger Hodoscope for J-PARC E42/E45 hadron experiment

Wooseung Jung[1], Jung keun Ahn[1], Shoichi Hasegawa[2], Kenneth Hicks[3], Sanghoon Hwang[4], Yudai Ichikawa[2], Shinhyung Kim[1], Hiroyuki Sako[2], Susumu Sato[2], Kiyoshi Tanida[2]

[1]*Department of Physics, Korea University, Seoul 136-713, Korea*
[2]*ASRC, JAEA, Tokai, Ibaraki 319-1195, Japan*
[3]*Ohio University, Athens, Ohio 45701, USA*
[4]*Korea Research Institute of Standards and Science (KRISS), Daejeon 305-600, Korea*

E-mail: aswe11@korea.ac.kr

(Received March 25, 2019)

We have developed HypTPC consists of TPC and the trigger hodoscope for the J-PARC hadron experiments. The TPC Hodoscope has large scintillators of 80 x 7 x 1 cm^3 to cover the TPC. Especially, we have developed a readout circuit for multiple MPPCs to detect photons generated over a large area of the scintillator. A general methods of applying voltage to multiple MPPCs are parallel and series connections. In the case of parallel connections, a signal has a long tail due to the large sensor capacitance. MEG collaboration used four MPPC segments as a serial connection. However, in the case of a series connection, the requiring bias voltage is very high, and the gain is low. To avoid this problem, we have developed a new individual biasing method with a summing amplifier for stable multiple MPPC readouts.
We also made prototype detectors and performed a cosmic-ray test. Brief descriptions of our prototypes and preliminary results of the cosmic-ray test are presented in this article.

KEYWORDS: Scintillator counter, MPPC, J-PARC

1. Introduction

A Hyperon spectrometer, which is designed for the hadron experiments at J-PARC, consists of superconducting dipole magnet and a time projection chamber (HypTPC). One of the hadron experiments using the Hyperon spectrometer is the E42 experiment searching the H-dibaryon via ^{12}C(K^-, K^+) reaction [1]. Another is the E45 baryon spectroscopy experiment with (π, 2π) reactions [3].

A TPC trigger hodoscope is enclosing the HypTPC with 32 segments of long scintillators. This TPC Trigger hodoscope has a role of multiplicity trigger. For the E45 experiment, generated a N^* with π beam on a liquid hydrogen target decays to a three-body final state with two charged particles. By requiring coincidence trigger of π^+ and p in $\pi^+ p \rightarrow \pi^0 \pi^+ p$ reaction with $P_{\pi^+} = 1.235$ GeV/c with the current setup, we can suppress 30 % of background events. And also, β vs p/q information is available for particle identification of proton, π.

The TPC trigger hodoscope is located in a narrow gap between the TPC and the superconducting Helmholtz coil magnet. And a magnetic field intensity of magnet is 1.0 to 1.5 T. So, we use the Multi-Pixel-Photon-Counter(MPPC) of the model number S13360-3050PE [5], which occupies a small space and can be operated within a strong magnetic field. Size of the segment is 80 cm with 1 x 7 cm^2 cross-section which is large enough to cover the TPC. In order to detect more photons efficiently, we have developed a way to operate a large number of MPPCs at the same time and attached 8 MPPCs of 3 x 3mm^2 size on each side of the scintillator.

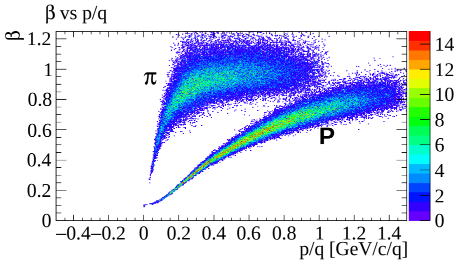


Fig. 1. Simulation result of P/π separation in $\pi^+ p \rightarrow \pi^0\pi^+ p$ reaction with $P_{\pi^+} = 1.235$ GeV/c by assuming that the resolution of the TPC trigger hodoscope is 150 ps

2. Development of the TPC trigger Hodoscope

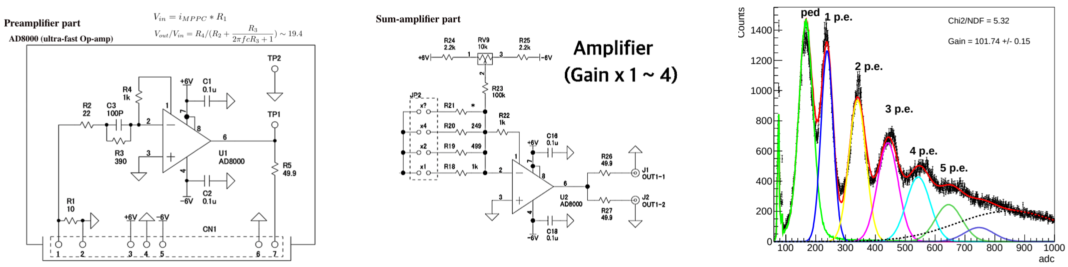
The most important point of using multiple MPPCs is a method of applying voltage for MPPCs. Typically, MPPCs are biased in series or parallel connection. However, there are advantages and also disadvantages to each method. The MEG collaboration directly compared the signal characteristics of four 6 x 6mm^2 MPPCs connected in series and parallel. [4].

Depending on the biasing method, the sensor capacitance value which is proportional to the decay constant changes. For parallel connections, the signal's pile-up problem occur due to large decay constant. On the other hands, for serial connections, the signal has a short tail but the gain decreases and a required bias voltage is very high. So, we devised a new method called individual biasing with a summing amplifier. Each MPPC is biased separately and each signal is fed to a differential amplifier. The amplified signals from 8 MPPCs are then summed up through a unity-gain amplifier. Prototypes were fabricated using four 3x3 mm2 MPPCs, S13360-3050CS, and size of 15^L x 7^W x 1^T cm^3 of the EJ-232 plastic scintillator supplied by ELJEN Technology [6]. In the prototype test, we used a differentiator preamplifier. For the summing amplifier, we used the Ortec AN308/NL NIM mixer module [7]. The cosmic ray test results showed a resolution of 196, 273, and 170 ps for serial, parallel, and individual biasing methods, respectively. According to the prototype test, we developed the preamplifier by selecting the individual biasing method.

The newly developed multiple MPPC signal readout circuit for TPC trigger hodoscope has a summing amplifier, and eight preamplifiers with eight S13360-3050CS MPPCs arranged in 3.35 mm in a row. Each MPPC corresponds to a preamplifier and the applied voltage can be individually adjusted for gain matching within MPPCs. A signal generated by MPPC is amplified in the differentiator preamplifier, and the signal is integrated and amplified in the summing amplifier at the end of the circuit. The summing amplifier and all preamplifiers use the AD8000 ultra-fast Opamp [8]. Each Opamp has few mV levels of intrinsic offsets. So after amplification, each preamplifier has various DC offset. To sum eight of preamplifier's signals, we put coupling capacitors at the end of preamplifiers for reducing DC offsets. Also, there is a part of a resistor chain for baseline adjustment of summed output. Moreover, the summing amplifier's gain can be changed from 1 to 4 times by changing a feedback resistance. The readout circuit has a jumper pin that selects whether or not each MPPC is enabled. We did a LED test to check the photo-electron counting ability of readout circuit. Set the readout circuit's gain as 4 times, we measured the signal that was amplified 10 times with a NIM amplifier. We obtained a gain of single photo-electron by fitting a charge distribution with a multi-gaussian function. The pedestal position slightly shifted from the origin because only the negative part of the baseline fluctuation was amplified in the NIM amplifier.

The TPC trigger hodoscope's segment compose of multiple MPPC signal readout circuits on both sides of a 15^L x 7^W x 1^T cm^3 scintillator. Five kinds of candidates were made to confirm the best condition of time resolution depending on the type of scintillator and light guide. The scintillators were

ELJEN technology's EJ-200 [10]., general purpose, and the EJ-230/EJ-232 for fast timing counter. The scintillators were wrapped in Al mylar and black sheet for a light block. For the EJ-230 and EJ-232 scintillators, a version with light guides is manufactured separately. Generally, when making a scintillator counter, light guides were attached to the scintillator. However, we made a light guide structure by cutting the edge of EJ-232 and EJ-230 scintillators, rather than attaching. Size of the light guide structure is 10 cm in length, and the MPPC side is 4 x 35 mm^2, which corresponds to the size of eight MPPCs.



(a) (b) (c)

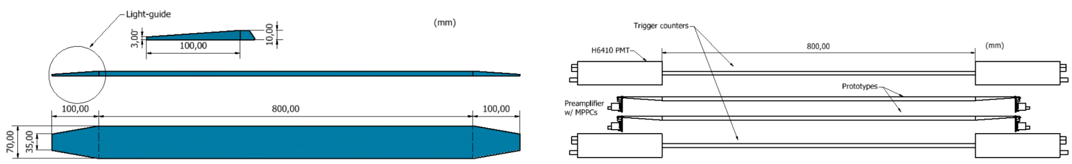
Fig. 2. (a) (b) Schematic drawings of the readout circuit (c) Charge distribution of current readout circuit for weak light of the LED.

3. Test with a cosmic ray

3.1 Test setup

The cosmic test was performed to measure the time resolution at JAEA. For the cosmic test, we made two trigger counters with the EJ-232 scintillator which has the same size as the segment of TPC Trigger hodoscope and the H6410 2-inch PMTs [9].

We did three tests in total. In each test, we placed one or two TPC trigger hodoscope candidates between two trigger counters to trigger events which cosmic ray was passing all the counters. In the first two tests, the difference in time resolution according to the type of scintillator was measured. The first time, we measured the time resolution of a candidate of EJ-232 without light-guide structures. Also in the second test, we did the same way for the candidates of EJ-200 and EJ-230 without light-guide structures. In the third test, to confirm the effect of the light-guide structure on the time resolution improvement, we measured the time resolutions of the candidates of EJ-230 and EJ-232 with light-guide structures.



(a) (b)

Fig. 3. (a) Schematic drawing of the scintillator with light-guide structures. (b) Schematic drawing of the cosmic test bench.

3.2 Analysis and the test result

To select the MIP cosmic ray events that passed vertically through all counters, we provided cut conditions corresponding to 8 cm in the center of the two trigger counters from its hit position distributions. The hit position distributions of each counter can be drawn according to the time difference on both sides of the trigger counter. The total distributions corresponds to the total counter length of 80 cm. And we selected events in the center of the hit position distributions of trigger counters. After the centered event selection, the time-walk due to the threshold of the leading edge discriminator is corrected. Among counters, We corrected a tof of two counters through the following parameterization.

$$tof^c = tof - \frac{a}{\sqrt{q - q_0}} - b, \tag{1}$$

where tof is the measured time-of-flight. And q and q_0 represent QDC which is the integrated charge of the pulse and its offset. a and b are best-fit parameters for correction, and tof^c is corrected tof. In all tof, four QDCs which are corresponding to on both sides of the two counters were used to sequentially time-walk correction.

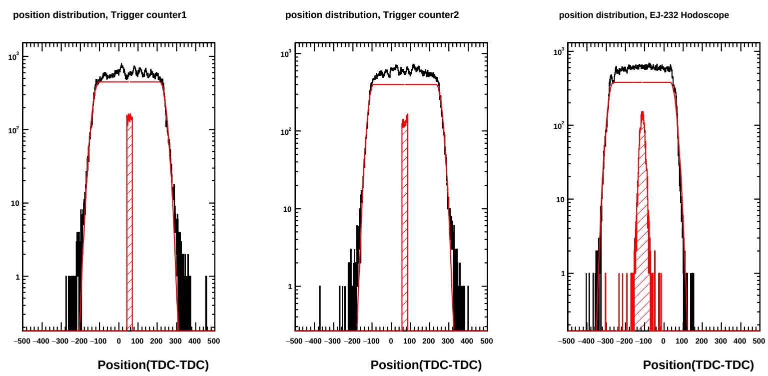


Fig. 4. Position distributions of the up, down trigger counters and the testing counter. Red histograms represent the selected event.

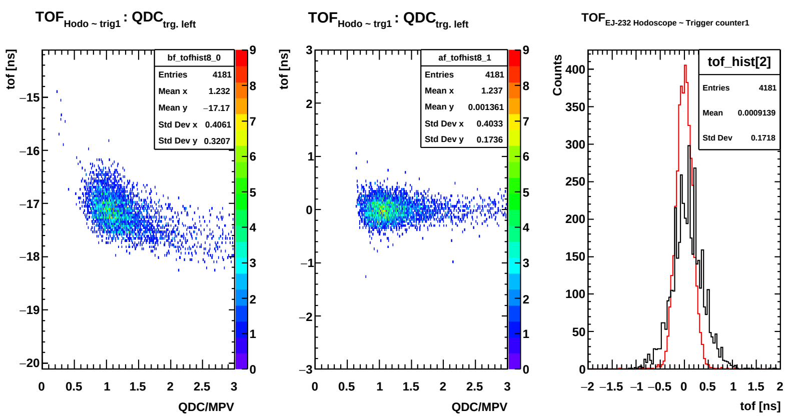


Fig. 5. The two left figures show the tof vs $Charge$ distributions before and after the time-walk correction. The right histogram shows the change in tof distribution before and after correction (black to red)

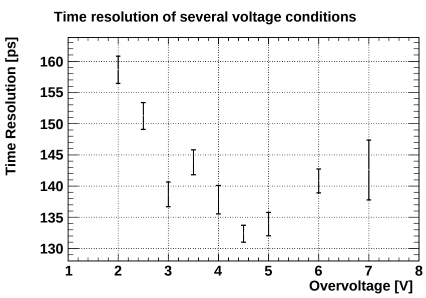
From the standard deviations(σ) of tof, Gaussian distributions, intrinsic time resolutions of each counter were obtained through uncertainty propagation. The candidates with the EJ-230/EJ-232 scintillators for the fast timing counter has better time resolution than that of the general purpose EJ-200, especially the EJ-232 with a rise time of 0.35 ns was the best. By the effect of the light guide, about twice as many photons as are detected, and the time resolutions were also improved. The best time resolution is 117 ± 1 ps of EJ-232 counter with the light-guide condition.

Table I. Scintillator comparison

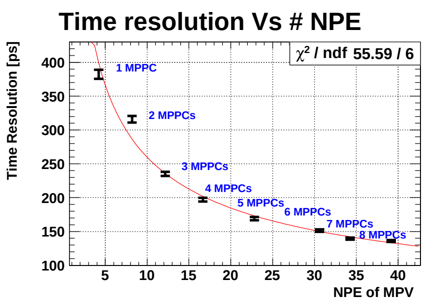
	Scintillators		
Properties	EJ-200	EJ-230	EJ-232
Scintillation Efficiency (photons/1 MeV e^-)	10,000	9,700	8,400
Wavelength of Maximum Emission (nm)	425	391	370
Light Attenuation Length[a](cm)	380	120	
Rise Time (ns)	0.9	0.5	0.35
Decay Time (ns)	2.1	1.5	1.6
Time resolution[b](ps)			
Without Light-guides	174 ± 1	156 ± 1	132 ± 1
With Light-guides		125 ± 1	117 ± 1

[a] The typical 1/e attenuation length of a 2x20x300cm size scintillator
[b] Measured value. Errors are statistical only.

Moreover, based on the EJ-232 scintillator counter which has the best result, an optimization study was carried out to confirm the time resolution changes according to the over-voltage condition and the number of MPPCs. Based on Hamamatsu's data sheet, a +3 V over-voltage condition is recommended. Experimental results show that at the region of 1 ~ 2 V higher than +3 V was better. Especially at +4.5 V overvoltage condition was the best. And, as the number of MPPC increases from 1 to 8, the time resolution is improved. When N represent the detected number of photons, the time resolution follows a function of $\sqrt{a + b/N}$ where a and b are constants.



(a)



(b)

Fig. 6. This is the preliminary result of optimization studies. The time resolution relationship with (a) the applied voltage and (b) the number of MPPCs(npe)

4. Summary

We have developed 80 cm long plastic scintillator counters with Multiple-MPPCs for the trigger purpose. The prototypes made up of EJ-200, EJ-230, EJ-232 plastic scintillators. The best timing resolution was measured to be 117 ps using cosmic-ray tests. And also optimization studies were carried out to obtain the optimal applied voltage condition and to get the time resolution information according to the number of MPPC in the current system. We confirmed that as the number of MPPCs increases, the time resolution increases as the number of detected photons increases.

References

[1] J.K.Ahn and K.Imai, J-PARC Proposal E42, Search for the H-dibaryon with a Large Acceptance Hyperon Spectrometer ; J. K. Ahn, Few-Body Sys. **54**, (2013) pp 387- 390.
[2] J.K. Ahn *et al.* (E42 collaboration): Search for H-dibaryon with a Large Acceptance Hyperon Spectrometer, Proposal for 50 GeV proton synchrotron.
`http://j-parc.jp/researcher/Hadron/en/pac_1201/pdf/KEK_J-PARC-PAC2011-06.pdf`
[3] K. Hicks *et al.* (E45 collaboration): 3-body hadronic reactions for new aspects of baryon spectroscopy, Proposal for J-PARC 50 GeV Proton Synchrotron.
`http://j-parc.jp/researcher/Hadron/en/pac_1207/pdf/P45_2012-3.pdf`
[4] Kaneko D *et al.*, Performance of UV-sensitive MPPC for liquid xenon detector in MEG experiment, DOI:10.1109/NSSMIC.2013.6829484
[5] `https://www.hamamatsu.com/resources/pdf/ssd/s13360_series_kapd1052e.pdf`
[6] `https://eljentechnology.com/products/plastic-scintillators/ej-232-ej-232q`
[7] `https://siliconpr0n.org/media/camac/CAMAC3/an308-spec.htm`
[8] `https://www.analog.com/media/en/technical-documentation/data-sheets/ad8000.pdf`
[9] `https://www.hamamatsu.com/jp/en/product/type/H6410/index.html`
[10] `https://eljentechnology.com/products/plastic-scintillators/ej-200-ej-204-ej-208-ej-212`