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A beam position fiber counter with scintillation fibers and multi-pixel photon counter for high intensity beam operation

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ABSTRACT

A beam position fiber counter consisting of the scintillation fiber (Kuraray SCSF-78 M) and a multi-pixel photon counter (HPK S10362-11-100P) was developed in order to handle a 10 MHz secondary pion beam in the J-PARC E40 experiment. This counter was installed at the entrance of the beam line spectrometer at the K1.8 experimental area in J-PARC and used for the momentum reconstruction. In order to suppress the accidental background and reconstruct the beam momentum, a good timing resolution better than 0.8 ns (σ) and a good position resolution better than 200 μm were simultaneously required for the counter. These requirements were well achieved by reading the 320 fibers with a diameter of 1 mm, which were arranged in a staggered position, with MPPC fiber by fiber. The signal induced from each MPPC was handled with an Extended Analogue SiPM Integrated ReadOut Chip (EASIROC) developed by Omega/IN2P3 in France. In addition, the timing of the discriminated signals from EASIROC was measured by a FPGA-based multi-hit TDC implemented into Spartan-6. Finally, we obtained the timing resolution of 0.68 ns (σ) and the position resolution of 190 μm (σ) under the 9 MHz beam condition using a pion beam.

1. Introduction

A beam position fiber counter (BFC) is an equipment in the K1.8 beam line spectrometer [1] to reconstruct a beam momentum for the J-PARC E40 experiment [2], which aims to measure the differential cross-sections of the $\Sigma^{\pm}$p scatterings. In this experiment, the double-scattering processes, namely, $\Sigma^{\pm}$ production via $\pi^{\pm}p \rightarrow K^{+}\Sigma^{\pm}$ followed by $\Sigma^{\pm}p \rightarrow \Sigma^{\pm}p$ or $\Sigma^{-}p \rightarrow \Lambda n$ in a liquid hydrogen target are identified by the spectrometer systems and the surrounding detector [3] as shown in Fig. 1. The purpose of the experiment is to investigate the Baryon–Baryon interaction in the flavor SU(3) symmetry by measuring the differential cross-sections of Σp scatterings with a large statistics ($\sim 10^4$ events). Thus, a high intensity secondary pion beam of up to 10 MHz was necessary to attain a significant $\Sigma-$production yield.

In general, a beam momentum distribution of a secondary beam line is spreading due to the momentum bite of the beam line. Therefore, the momentum of each beam particle should be measured with a beam line spectrometer by using the position information at the entrance and the exit of the spectrometer magnets. BFC was used to measure the horizontal position at the entrance of the spectrometer. Since a time interval between two beam particles becomes shorter under the high intensity beam condition of 10 MHz, multitracks will be detected within a selected time gate. In order to identify the beam particle causing a reaction from the accidental hits, the timing resolution of BFC is quite important because a narrower time gate is able to be applied with a better timing resolution. The timing resolution better than 0.8 ns (σ) is required in order to suppress the accidental background to less than 5%. The beam momentum is calculated from the hit positions of BFC and drift chambers locating at the exit of the spectrometer using a third-order transfer matrix. In order to achieve the momentum resolution of $dp/p = 3.3 \times 10^{-4}$ (FWHM), the position resolution better than 200 μm is required. Then, BFC has been designed as a fine segmented hodoscope system comprised scintillation fibers, Pixelated Photon Detector (PPD), and the readout electronics to meet such requirements. The recent progress of Pixelated Photon Detector (PPD) enables us to readout the scintillation fibers with PPD fiber by fiber in order to meet such requirements. In addition, electronics dedicated to readout multi-PPD are essential to operate a large number of PPDs. Owing to Extended Analogue Silicon Photomultiplier Integrated ReadOut Chip (EASIROC), which was developed by Omega/IN2P3 [4], the multi-PPD readout electronics were successfully developed [5]. In this paper, we will report the structure of BFC, the readout electronics, and the detector performances.

2. Beam position fiber counter (BFC)

The beam position fiber counter was comprised the scintillation fibers with a diameter of 1 mm (Kuraray SCSF-78 M [6]) and

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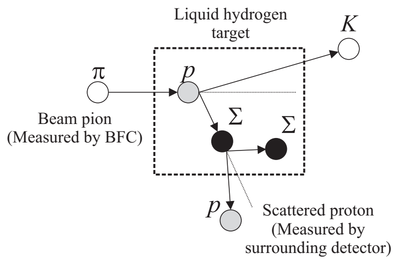

Fig. 1. The scheme of the double-scattering process identified in the J-PARC E40 experiment. The pion beam is measured by BFC.

Table 1
The specification of Kuraray SCSF-78 M.

Diameter	Emission peak	Decay time	Att. length
1 mm	450 nm	2.8 ns	> 4.0 m

Multi-Pixel Photon Counter (MPPC, HPK S10362-11-100P [7]). The sensor and cell sizes of MPPC were 1×1 mm^2 and 100 μm, respectively. The MPPC which had the highest Photo Detection Efficiency (PDE) in the Hamamatsu products was selected to measure the Minimum Ionizing Particle (MIP). In addition, the surface mount type MPPC was adopted to make the readout frame as compact as possible. As for the scintillation fiber, the specifications of SCSF-78 M are summarized in Table 1 [6]. The photo of BFC is shown in Fig. 2. The sensitive region was made from 320 scintillation fibers, which were arranged into a staggered relation with an overlap of 0.5 mm in order to reduce the insensitive region. Its size of 160 (Horizontal) $\times$ 80 (Vertical) mm^2 fully covers the beam size. Since these fibers were fixed by the fixing frame, no adhesive is pasted on the surfaces of fibers in the sensitive region.

To make a contact with a MPPC sensor, one end of each fiber was inserted into holes drilled in the readout frame as shown in Fig. 2. Scintillation light from these ends was collected by MPPC soldered on to the MPPC card. Owing to the same arrangement of the holes on the frame and the MPPCs on the card, the sensors were coupled to the readout ends of fibers by air contact just by attaching the MPPC card with screws. Since the diameter of the fiber and the sensor size were the same, the precise positioning of MPPC was quite important to obtain the uniform light yield. Thus, precision of placing each MPPC better than 100 μm was ensured by the special tool used in the soldering process. On the other hand, the other end of the fiber was fixed at the fixing frame position. These non-readout ends were open and not mirrored.

BFC has only one plane with the size of 160×80 mm^2 and measures the x position of the beam particle.

3. Readout electronics

The multi-PPD readout electronics [5] using EASIROC [4] has been developed for the MPPC readout. EASIROC is an ASIC dedicated for the multi-PPD operation; it has all the essential functions to operate PPD such as the bias adjustment, pre-amplification, shaping, and discrimination. The readout scheme is shown in Fig. 3. A common voltage from a power supply was applied to all the cathodes while the bias voltage of each MPPC was adjusted by DAC in EASIROC channel by channel. Signals from MPPCs were shaped by the slow shaper for the charge measurement and by the fast shaper for the timing measurement after amplification. The fast shaped signals were discriminated by the update type discriminator and were output in parallel. On the other hand, the slow shaper line for the charge measurement was turned off during the beam measurement due to the signal pileup at

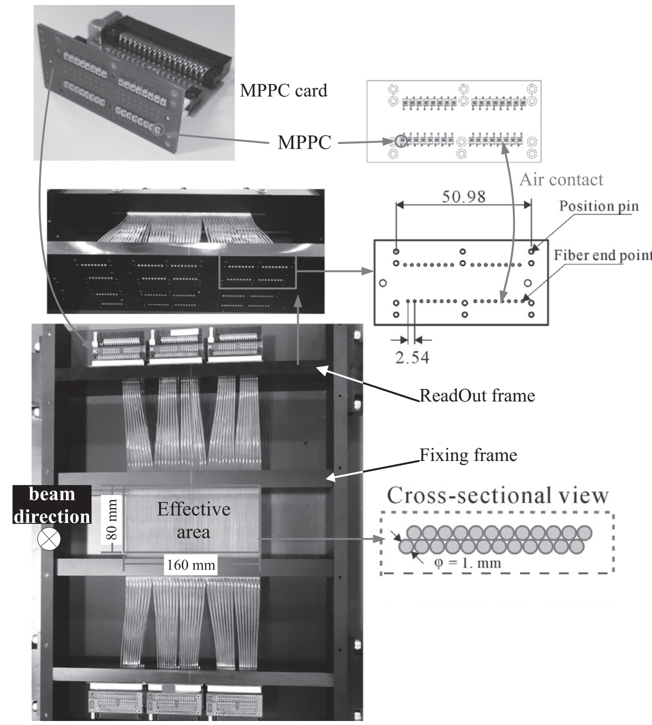

Fig. 2. The picture of the beam position fiber counter and the MPPC card.

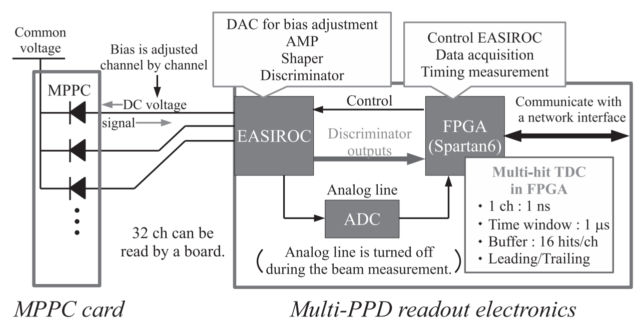

Fig. 3. The scheme of the readout method and the electronic for the multi-PPD readout using EASIROC.

the shaper. Then, the time walk was corrected by the Time-Over-Threshold information of the discriminated signals instead of ADC information. The discriminated signals were connected to FPGA (SPARTAN6) to measure its timing and TOT using FPGA-based multi-hit TDC (MHTDC). This MHTDC can measure the timing of leading/trailing edges of signals with a timing precision of 1 ns. The size of the time window and the buffer are 1 μs and 16 hits/ch, respectively. Furthermore, this FPGA built an event packet and communicated with the network interface. Finally, the event packet was transmitted via TCP/Ethernet through the network interface.

4. Performances

We evaluated the performances of BFC, namely, the uniformity of the light yield, the position resolution, the timing resolution, and the efficiency by using a β-ray source and the pion beam. In the measurement, the over voltage of each MPPC was adjusted to around 0.9 V.

For β ray: In order to evaluate the light yield for MIP, we measured the response of BFC to a β ray with ADC on the multi-

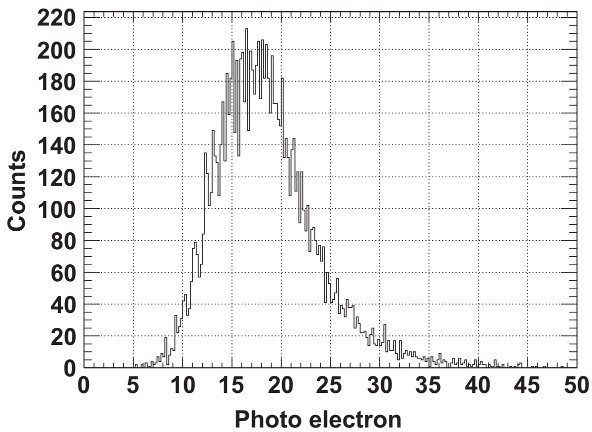

Fig. 4. The photo-electron distribution of one fiber for β ray obtained using a ^{90}Sr source.

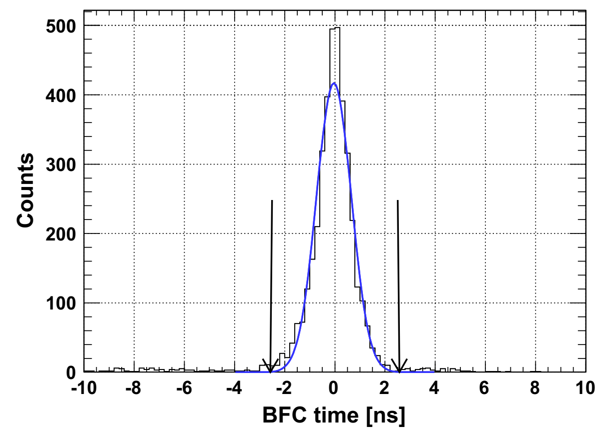

Fig. 6. The timing distribution under 9 MHz. Arrows show the timing gate of ± 2.5 ns.

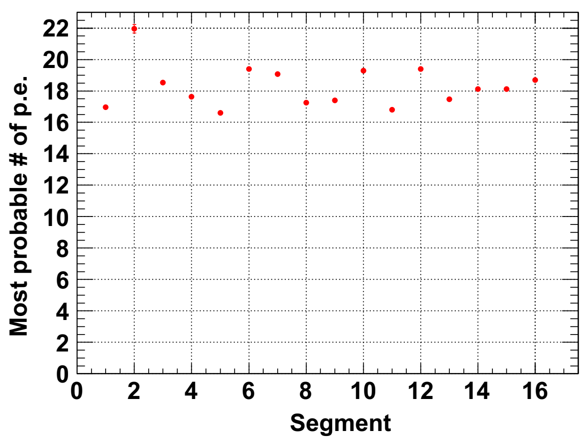

Fig. 5. The distribution of the most probable values of the photo-electron distribution for β ray.

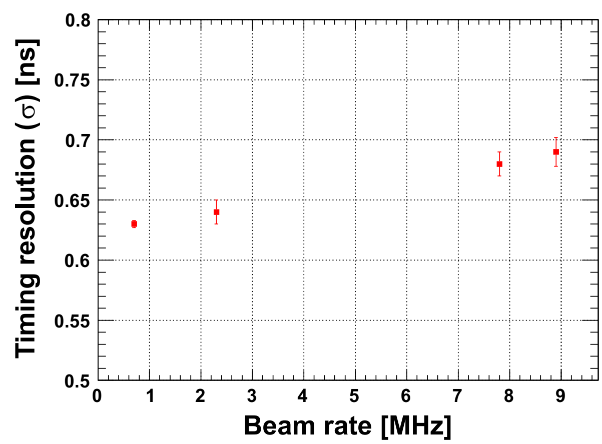

Fig. 7. The rate dependence of the timing resolution.

PPD readout electronics with EASIROC using the ^{90}Sr source, which was placed on BFC. To trigger a β ray passing through BFC, the plastic scintillator with PMT was placed below BFC. The typical photo-electron distribution for the β ray is shown in Fig. 4 for one fiber. In order to assure that the β ray passed through the target fiber segment, we required that the ADC value of the segment was maximum among all the fiber segments. It is clear that the obtained light yield is enough to detect MIP. In addition, its uniformity is shown in Fig. 5. Owing to the good position precision of MPPC, an excellent uniformity was obtained.

For pion beam: BFC was installed at the entrance of the K1.8 beam line to evaluate the performances for the pion beam. In the present measurement, the threshold of discriminators in EASIROC was set to 3.5 p.e. based on the previous result. For the beam measurement, we introduced the clustering method to improve the position resolution and the timing resolution. Since the fibers were arranged in the staggered relation, the beam pions hit two fibers at the same time. In such a case, these fibers were treated as a single cluster. The averaged position was adopted as the position of the cluster while the mean timing was not used. The timing of each fiber hit was calculated using the another timing counter (BH2) located in the same beam line spectrometer, whose timing resolution was ~90 ps (σ), it was located in the same spectrometer. In a cluster, the time difference between BFC and BH2 which was the most close to "zero" was selected from hits participating in the cluster as its timing in order to improve the timing resolution because the purpose of BFC was not to measure the time-of-flight but to identify the pion causing a reaction with a good signal-to-noise ratio. Finally, the timing distribution of BFC under the 9 MHz condition was obtained as shown in Fig. 6. The distribution was gated with the timing gate of ± 2.5 ns as shown with arrows in the figure.

The position resolution was measured by using two sets of MultiWire Proportional Chambers (MWPC), which had six layers (*xuvxuv*). A position resolution of each layer was 200 μm. BFC was installed between them in order to evaluate a position resolution of BFC. By reconstructing π beam tracks using these 12 layers, we were able to measure the x position at the BFC point with the position resolution of $200/\sqrt{12}$ μm. The residual between the beam track reconstructed by MWPCs and the hit on BFC was 190 μm. Although the position resolution of the beam track was not subtracted, its contribution was negligible. Thus, the position resolution better than the requirement was achieved.

The rate dependencies of the timing resolution and the detection efficiency were also evaluated by changing the beam rate. The timing resolution was defined as σ of a single Gaussian. The rate dependence of the timing resolution is shown in Fig. 7. The better resolution than the requirement of 0.68 ns (σ) was obtained even under the 9 MHz condition. Furthermore, the rate dependence of the detection efficiency is shown in Fig. 8, where the timing gate of ± 2.5 ns was applied. BFC keeps the efficiency of 97% under the 9 MHz condition.

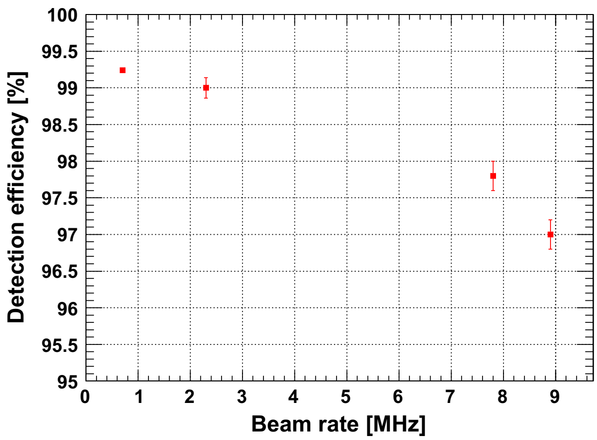

Fig. 8. The rate dependence of the detection efficiency when applying the time gate of ± 2.5 ns.

As the result of the evaluation, it has been confirmed that the sufficient performances are achieved.

5. Summary

We are planing to perform the J-PARC E40 experiment on $\Sigma^{\pm}p$ scatterings using the high intensity pion beam (10 MHz). In order to handle such a high intensity secondary beam, the beam position fiber counter was made from the scintillation fibers (Kuraray SCSF-78 M) and MPPC (HPK S10362-11-100P). The multi-PPD readout electronics with EASIROC processed signals from MPPC and measured its timing by FPGA-based MHTDC with the timing precision of 1 ns. As the result of the performance evaluations using β ray, a sufficient light yield and its uniformity were confirmed. The position resolution and the rate dependencies of the timing and efficiency were evaluated using the pion beam. The position resolution was 190 μm. The timing resolution and the detection efficiency were 0.68 ns (σ) and 97% under the 9 MHz condition, respectively. Since these values are better than those of requirements, we conclude that BFC has been successfully developed and ready for the J-PARC E40 experiment.

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