Development of a scintillation fiber tracker for measuring high-intensity beams

K. Shirotori[1], T. Akaishi[2], T. Aramaki[3], H. Asano[4], C.-Y. Chang[5], W.-C. Chang[5], R. Honda[3], Y. Igarashi[6], T. Ishikawa[7], S. Kajikawa[3], S. Koyano[8], Y. Ma[4] K. Nagai[5], Y. Nagasaki[8], K. Nishiura[8], H. Noumi[1], H. Sako[9], T.N. Takahashi[1] and for the J-PARC E50 collaboration

[1]*Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan*

[2]*Department of Physics, Osaka University, Toyonaka 560-0043, Japan*

[3]*Department of Physics, Tohoku University, Sendai 980-8578, Japan*

[4]*RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*

[5]*Institute of Physics, Academia Sinica, Taipei 11529, Taiwan*

[6]*Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, Japan*

[7]*Research Center for Electron Photon Science (ELPH), Tohoku University, Sendai, 982-0826, Japan*

[8]*Moderation-Line Co.,Ltd, Hamamatsu 432-8006, Japan*

[9]*Advanced Science Research Center (ASRC), Japan Atomic Energy Agency (JAEA), Tokai, Ibaraki 319-1195, Japan*

We plan charmed baryon spectroscopy experiment (J-PARC E50 [1]) at the high-momentum beam line of the J-PARC hadron experimental facility. In the experiment, the excited states of charmed baryons are produced via the $p(\pi^-, D^{*-})Y_c^{*+}$ reaction using the π^- beam of 20 GeV/c. Production rates and decay branching ratios of the excited states are measured in a wide mass region by the missing mass method. The diquark correlation which is expected to appear in the properties of the excited state of charmed baryon can be clarified by the systematic measurements of production rates and decay branching ratios. For measuring the missing mass and decay events of charmed baryons, we are constructing the spectrometer system [2].

The intense π^- beam of 6.0×10^7/spill (30 MHz for the 2 sec extraction) is planned to be used in the experiment. For measuring the beam tracks, it is necessary for tracking detectors to be satisfied under the operation by assuming the beam with size of 100 mm(horizontal)$\times$100 mm(vertical) and expecting total counting rate of 30 MHz. The beam intensity is over the limit of the wire chamber operation so that a high-rate counters such as a scintillation fiber tracker are needed to handle the high-intensity beam. The beam of 100 mm(H)$\times$100 mm(V) is measured by the fiber tracker with a multi-layer configuration. The counting rate per 1-mm segment is expected to 0.3$-$1 MHz in the case of the total intensity of 30 MHz. In the high-rate beam condition of 1MHz/1mm, it is necessary for the fiber tracker to satisfy the layer efficiency of 97%, the position resolution of less than 200 μm and the time resolution of 1 ns(rms).

The proto-type scintillation fiber tracker in order to proof the feasibility by a test experiment was produced. The fiber tracker consisted of a 1-mm diameter scintillation fiber (SCSF-78M, Kuraray Co.,Ltd) with a stagger configuration for constructing one layer. Fibers were placed by using an Epoxy type glue for a precise position resolution. Three layers having tilted angles of 0°, +30° and $-$30°, respectively, were combined to one unit, called XUV unit. For constructing the fiber tracker, 4 XUV units were installed so that there were 12 layers in total. Each fiber is attached to the 1.3-mm size MPPC (s13360-1350PE) with air contact. The picture and drawing of the fiber tracker were shown in Fig. 1.

We evaluated the performances of the fiber tracker in the high-counting rate environment. The experiment was performed in the second experimental room in the the Research Center for Electron Photon Science(ELPH). Detectors were installed at the downstream of the beam extraction points of the Stretcher Booster Ring to the GeV-γ building. For the experiment, the electron and positron beams converted from the extracted γ rays by the 1-mm thick Aluminum cover of the beam pile flange were used. The counting rate per fiber was estimated from a 1-mm width timing counter installed at the upstream of the fiber tracker. Beam rates were adjusted from the beam current of the accelerator to more than 1 MHz/1 mm fiber conditions. In the analysis, the event-by-event scaler values measured by the HUL module [3] were used for obtaining the counting rate of the fiber tracker. The hit rate (counts/sec.) was calculated by the running mean in every 200 mseconds to avoid fluctuation of the beam intensity. From the counting rates of the timing counter, we selected three counting rate regions of average rates of 300 kHz (200$-$400 kHz), 800 kHz (600$-$1200 KHz) and 2 MHz (1.2$-$2.5 MHz) per 1-mm fiber. The NIM-EASIROC module [4] was used for reading out signals from MPPC. For evaluating performances in the high-rate conditions. several signal thresholds of 1.5$-$5.5 p.e. of the pulse height of the minimum ionization signal and the over voltage of MPPC(V_{over}) of 6V were used. The number of photoelectrons was $\sim$25 in this over voltage condition.

Figure 2 shows the average layer efficiency of the fiber tracker by changing the counting rate conditions. The definition of layer efficiency was that (1) track was found, (2) neighbor layers had hit and (3) the layer which was evaluated to the efficiency was not included to the tracking. The result shows that the layer efficiency achieved $97.5 \pm 0.5\%$ up to 2 MHz. Figure 3 shows the width of the residual distribution of the linear tracking

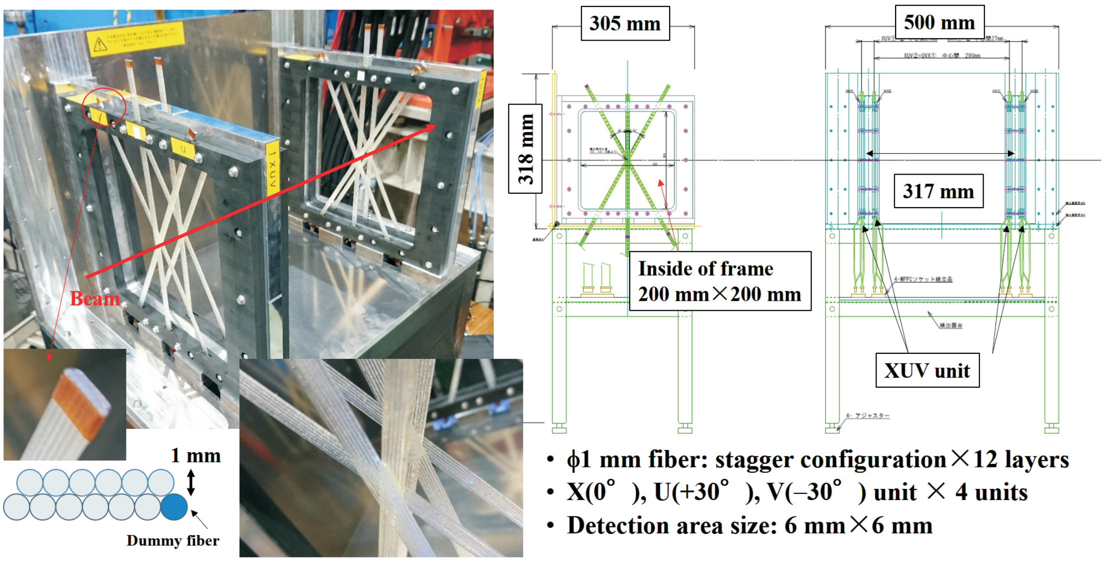

Figure 1: The picture and drawing of the proto-type scintillation fiber tracker.

by using the least squares method. For evaluating the position resolution from the residual distribution, we compared the residual distribution between the data and the simulation results. In the simulation, actual material thicknesses, beam momenta and each layer efficiency were input. In the case of the average rate per fiber of 300 kHz, the residual distribution was simulated with the results by inputing a position resolution of 140 μm(rms). It consisted with the expected position resolution by using the clustering of fiber with the stagger configuration of 1-mm diameter fibers. In the case of the average rate per fiber of 800 kHz, the position resolution was estimated to be 160 μm(rms). The accidental hits and gain drop by the NIM-EASIROC module affected to the clustering so that the position resolution became worse that that of the lower rate condition. The time resolution of 0.9 ± 0.1 ns was obtained in the case of the average rate per fiber of 800 kHz. On the other hand, we found that the NIM-EASIROC module showed the performance drop in the high-rate condition. For the actual fiber tracker, it is necessary to develop a new readout module by using a latest ASIC chip such as PETIROC2 [5].

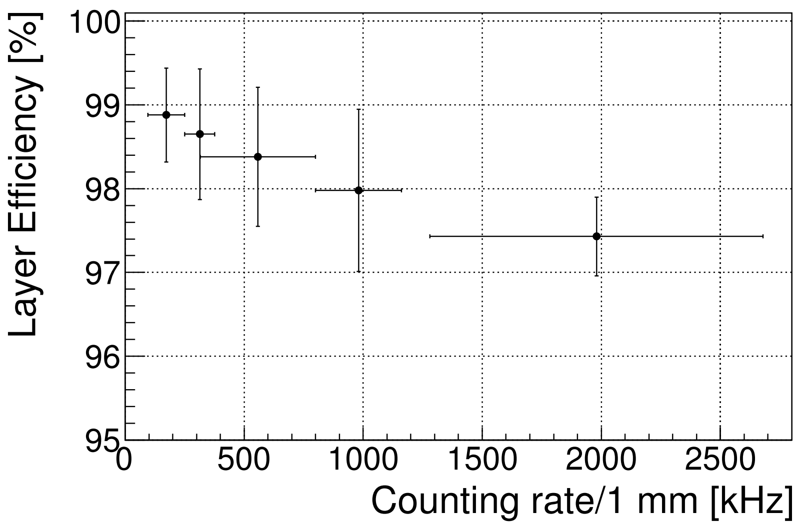

Figure 2: The average layer efficiency by changing the counting rate conditions. Horizontal and vertical error bars show the range of the counting rate by selecting event-by-event scaler counts and efficiency differences of each layer, respectively.

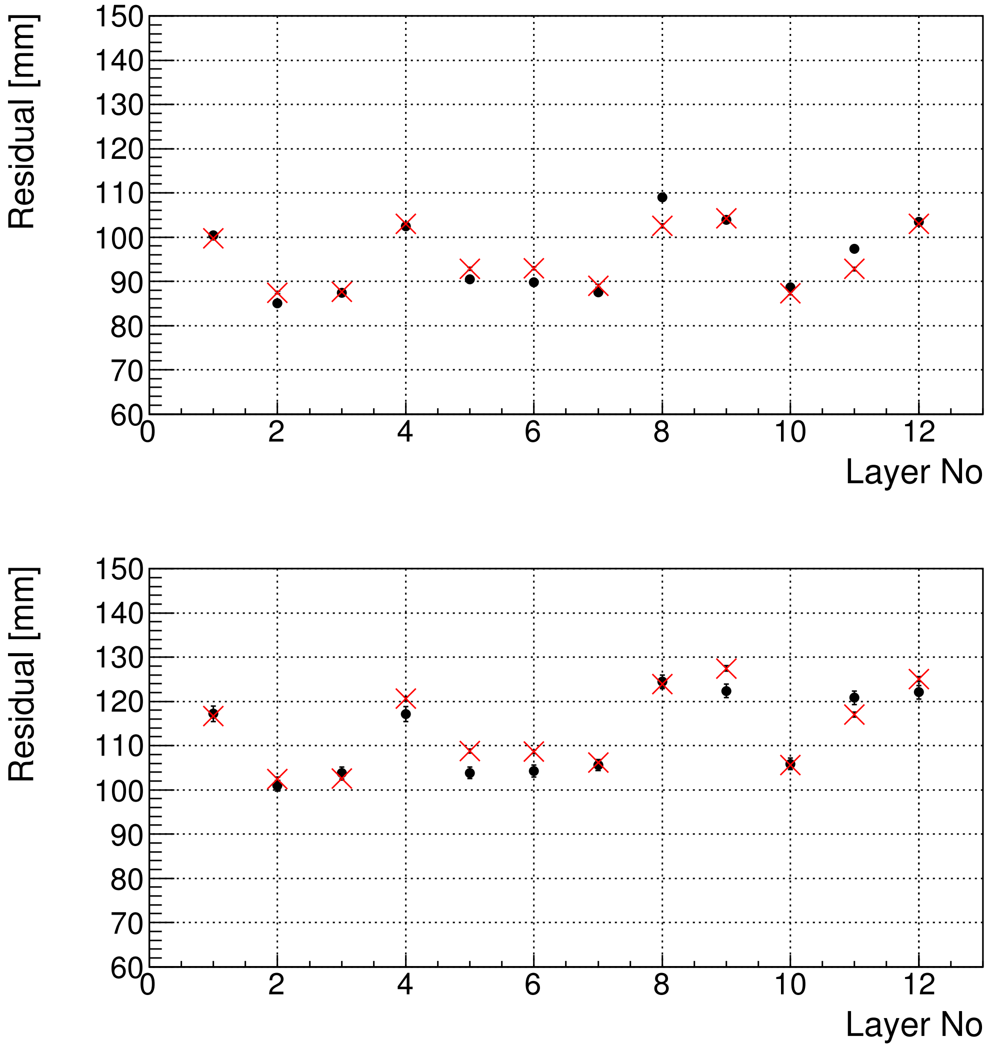

Figure 3: Width of the residual distribution of each layer estimated from data and simulation. Black points and red crosses show width of the residual distributions of data and simulation, respectively. Top and bottom figure show the residual distribution in the average counting rates of 300 kHz and 800 kHz, respectively. Input position resolutions of conditions of top and bottom figure are 140 μm(rms) and 160μm(rms), respectively.

The fiber tracker achieved the goal of required performances of the layer efficiency of more than 97%, the position resolution of 160 μm(rms) and the time resolution of 0.9 ± 0.1 ns(rms) at the countign rate condition of 1 MHz/1 mm fiber. From the results by the high-rate test of the proto-type fiber tracker with MPPC, we have proofed the feasibility in the counting rate condition of 1 MHz/1 mm fiber. For the next step, we are producing the actual scintillation fiber trackers and developing a new readout module for the E50 experiment.

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