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Test experiment for a performance evaluation of a scattered proton detector system for the Σp scattering experiment E40

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Abstract

We are going to measure differential cross sections of Σp scatterings in the J-PARC E40 experiment. In E40, we will utilize a Cylindrical Fiber Tracker (CFT), which surrounds a liquid hydrogen target, and a BGO calorimeter which is placed at the outer side of CFT in order to measure a trajectory and kinetic energy of a scattered proton, respectively. We are now developing a CFT prototype detector, which has an effective area of 40 cm along the beam direction. It consists of three layers, that is, two layers of "ϕ" layer and one layer of "U" layer. In the "ϕ" layer configuration, the fibers are placed in a straight line along the beam direction. On the other hand, in the "U" layer configuration, the fibers are placed with a tilt angle. By combining these ϕ and U configurations, a three dimensional tracking becomes possible. This prototype detector consists of about 1,200 channels of fibers whose diameter is 0.75 mm. In order to readout this large numbers of fibers, we use a MPPC and EASIROC readout board, which is a dedicated board to operate multichannel MPPCs. This technique has been already established through a development of beamline fiber trackers in the K1.8 beamline. As for the BGO calorimeter, we have started a test of a large size BGO calorimeter which size is $400 \times 25 \times 35$ mm^3 and has the same effective length with the CFT detector.

In the later part of June beam time, we would like to perform a test experiment at the K1.1BR beamline in order to evaluate the performance of this CFT prototype and BGO calorimeter, which is a "scattered proton detector system". We will check the response of the CFT prototype detector and BGO for proton and $\pi^{\pm}$ particles which momentum ranges are $300 \sim 550$ MeV/c and $130 \sim 300$ MeV/c, respectively. These momentum ranges are expected in the E40 experiment. In the E40 experiment, the particle identification is done by using the ΔE-E relation where ΔE is the energy deposit at CFT and E is the total energy at BGO calorimeter. The most important issue in this test experiment is to evaluate this particle identification performance. Therefore we would like to request a test experiment at the K1.1BR beamline. We request a beam time of 58 hours including the detector commissioning, beam tuning and data taking with several experimental conditions.

In this proposal, we also summarize the development of the beamline fiber trackers, which had been developed by E40 group and had enabled us to operate a high intensity beam of 12 M/spill in the last E10 beam time, because it is closely related with the development of the CFT detector and the E40 experimental condition.

1 Summary of experimental condition

- Beamline : K1.1BR beamline
- Date : Beam time in RUN50a (15th June - 26the June)
  Many members of this experiment are also E13 collaborator. At the beginning of the E13 beam time, it is expected that we have many tasks to start up the E13 experiment. Therefore, we request the later part of this run period, because at that time, the E13 experiment becomes stable and this test experiment member can concentrate on this experiment.
- Requested beam time : 58 hours
- Beam momentum : p beam , 550 MeV/c, 500 MeV/c^*, 400 MeV/c, 300 MeV/c^*
  π beam : 300 MeV/c^*, 170 MeV/c
  The beam momenta with * can be adjusted from higher beam momentum by installing a degrader, when it is difficult to change the beam momentum frequently.
- Electric separator : Used to separate π and p
- Beam intensity : less than 30 k/spill
- Necessary space : 5 × 2 m^2
- Main detector size : 0.5 × 0.6 m^2
- Necessary number of Rack : Two, one for EASIROC board, one for NIM bin for trigger and so on
- Necessary electricity power : 2000 W
- Necessary setup time : 1 day
- Necessary set down time : 0.5 day

Contents

2 Introduction

We had proposed a Σ proton scattering experiment at the K1.8 beam line, which is named as the E40 experiment[1]. In the E40 experiment we aim to measure the differential cross sections of Σ^+p and Σ^-p elastic scatterings and $\Sigma^-p \rightarrow \Lambda n$ inelastic scattering by detecting more than 10,000 scattering events. Through this experiment, we will reveal the following two physics topics. One purpose is to verify a large repulsive core which is expected in the Σ^+p channel due to the Pauli repulsive principle in the quark level[2][3]. The other one is to investigate the ΣN interaction systematically by measuring three isospin separating channels. Experimentally, we use a new experimental technique to resolve an experimental difficulty of a hyperon proton scattering experiment. A liquid hydrogen (LH_2) target is used as both Σ production and Σp scattering targets. Figure 1 shows the experimental setup around the target. The LH_2 target is surrounded by a cylindrical fiber tracker (CFT) and a BGO calorimeter and charged particles from the target are detected by these detectors. Because both the Σ production reaction ($\pi^{\pm}p \rightarrow K^+\Sigma^{\pm}$) and the Σp scattering reaction ($\Sigma p \rightarrow \Sigma p$) are "two-body reaction", the Σp scattering events can be identified kinematically by measuring four vectors of $\pi^{\pm}$ beam, K^+ and scattered proton.

In the E40 experiment, there are two challenging points which are essential to accomplish the experiment.

- In order to have a large number of Σ beam, high intensity π beam of 20 M/spill should be used.
- In order to have a large acceptance for the scattered proton, the scattered proton detector system by CFT and BGO should have a large acceptance.

For the first point, we have developed beamline fiber trackers, which can operate stably under the high intensity beam. We already have installed two fiber trackers (BFT and SFT) at the upstream of the beam spectrometer magnet and at the downstream of the target, respectively, as shown in Figure 2. Thanks to the good time resolution of $\sim$1 ns, triggered

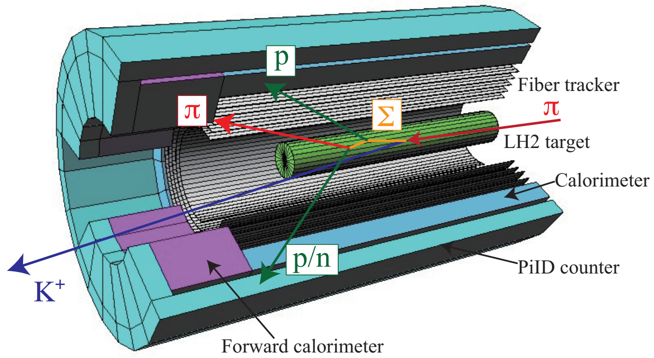

Figure 1: Experimental setup around the LH_2 target. The LH_2 target is used as both the Σ production target and Σp scattering target. The target is surrounded by a cylindrical fiber tracker (CFT) and a BGO calorimeter and charged particles from the target are detected by these detectors.

event can be separated from accidental background events. At the E10 experimental beam time, high intensity π beam of 12 M/spill could be used.

For the second point, we are now designing and developing a prototype of Cylindrical Fiber Tracker (CFT) and BGO calorimeter. The CFT prototype detector has a long effective area of 40 cm along the beam direction and consists of three layers of fibers. The BGO calorimeter has the same effective length of 40 cm with the CFT prototype. By combining the CFT prototype and the BGO calorimeter, we have to evaluate the performance of this detector system. Therefore, in this proposal, we would like to request a beam time of a test experiment at the K1.1BR beamline to evaluate the performance of the scattered proton detector system of CFT and BGO. We will irradiate proton and $\pi^{\pm}$ beams on the CFT prototype and the BGO calorimeter. The detector response such as photon yield of the CFT fibers and the BGO calorimeter should be studied. In the E40 experiment, the particle identification is done by using the ΔE-E relation where ΔE is the energy deposit at CFT and E is the total energy deposit at the BGO calorimeter. The most important issue in this test experiment is to evaluate this particle identification performance.

In the following sections, we will summarize the performance of the beamline fiber trackers which was developed by the E40 group. The design of the CFT prototype and BGO calorimeter will also summarized. Then, we will mention the test experiment including the purpose of the test experiment, experimental setup and request of the beam time.

3 E40 experiment preparation status

We summarize the development status of the essential detectors for E40.

3.1 Beamline Fiber Trackers

In the E40 experiment, a high intensity π beam of 20 M/spill (10^7 Hz) will be used in order to have an enough Σ beam intensity. However, the present accelerator condition is quite severe to use such a high intensity beam because the time structure of the slow extraction is quite

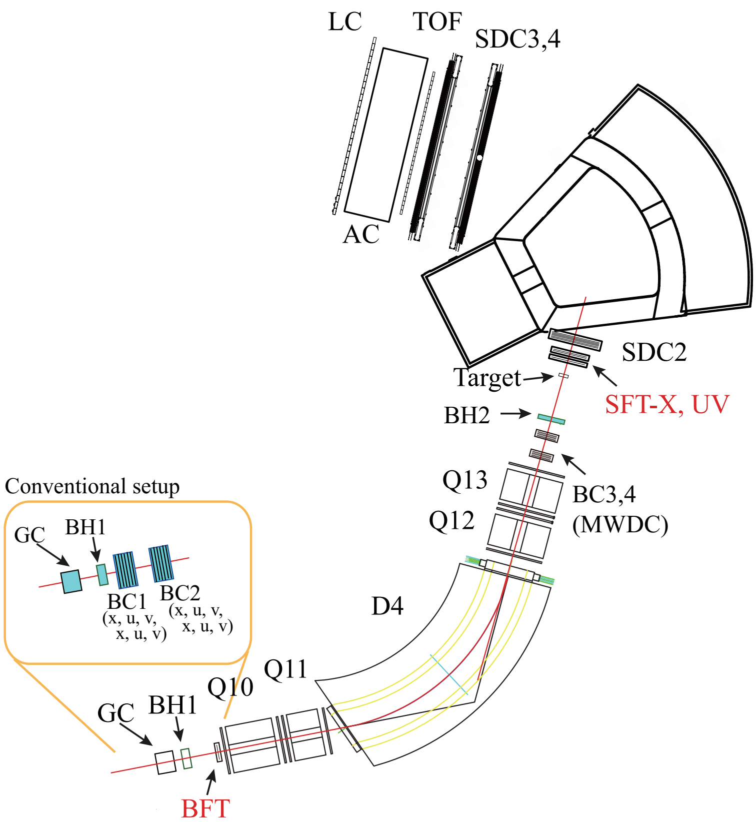

Figure 2: Experimental setup in the K1.8 beamline with beamline fiber trackers. The BFT detector which measures horizontal postion was installed at the upstream of the beamline spectrometer magnet instead of MWPCs (BC1,2). The SFT detector which has three layers (X, U, V) was installed at the downstream of the target.

worse. The instant beam intensity fluctuates very much and about 20 times larger beam particles than the average beam intensity come instantaneously. The original setup of the beamline spectrometer at the K1.8 beamline consists of MWPCs with a wire pitch of 1 mm and MWDCs which drift length is 1.5 mm. Especially, the MWPC detectors were unstable under the present beam condition and the wire was sometimes broken. The operation of the MWDC detectors was possible. However, it was difficult to separate the triggered events from the accidental background using the TDC information because the time response was slow due to its drift time. In order to resolve these problems, we had replaced MWPC to Beamline Fiber Tracker (BFT) and also replaced MWDC (SDC1) which is located at the downstream of the target to Scattered particle Fiber Tracker (SFT) as shown in Figure 2. In the E10 experimental beam time, it became possible to handle a high intensity π beam of 12 M/spill by using these fiber trackers. Here we summarize BFT and SFT detectors.

Figure 3 shows the picture and the drawing of BFT. BFT consists of 320 fibers whose diameter is 1 mm. We placed two layers of 160 fibers in a staggered relation each other in order to remove the ineffective region. Because the enough momentum resolution of $\Delta p/p = 4 \times 10^{-4}$ (FWHM) can be obtained by measuring the horizontal position at the BFT position with a position resolution better than 250 μm, BFT has only one staggered layer in order to decrease the effect of the multiple scattering at BFT. For the photon sensor

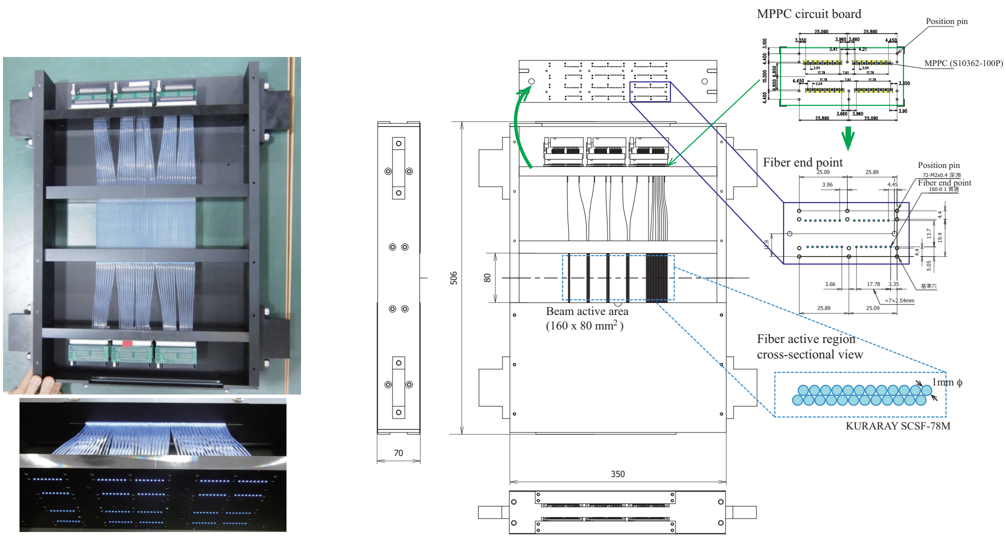

Figure 3: Photograph and drawing of BFT. BFT fibers are placed vertically to measure the horizontal position and effective area is 160 × 80 mm^2. Two layers of 160 fibers of 1 mm diameter are placed in a staggered relation each other. The readout edge of the fibers are fixed into the holes on the detector frames where the hole position is consistent with the MPPC position on the MPPC PCB board.

of the fibers, MPPCs were used. We made a compact MPPC PCB board where 32 channels of MPPCs were mounted in 2.54 mm pitch as shown in Figure 4. In order to assure the good contact between the fibers and the MPPCs, the MPPCs are placed with a good precision better than 100 μm. The readout edges of the fibers are fixed into the holes on the detector frame where the hole position is consistent with the MPPC position on the MPPC PCB. By fixing the MPPC PCB by precision pins to the detector frame at the readout edge, the contact between fibers and MPPCs are assured. Many channels of MPPCs are read with EASIROC board which is a dedicated board for operation and readout of multichannel MPPCs. Figure 5 shows the photograph of the EASIROC board. This EASIROC board enables us to operate 32 ch of MPPCs. The EASIROC chip, which is the ASIC on this board, has preamplifier, shaping amplifier and discriminator for each 32 ch inputs. The operation voltages for each 32 ch inputs can be adjusted with a precision of 20 mV. Charge and timing information can be obtained by ADC and multi hit TDC with a precision of 1 ns on this board. By combining fiber detector, MPPC and EASIROC board, fiber trackers with multi channel MPPCs readout can be operated quite easily. Through the development of BFT, we could establish the technique to handle multi channel MPPCs. This technique will be also applied to SFT and CFT which is described later.

Second fiber tracker was SFT which was installed at the downstream of the target. Because hit information on SFT together with SDC2 information were used to find the track from the target, SFT consists of three layers which are X plane to measure the horizontal position and U and V planes with tilt anges of $\pm 45^{\circ}$ to obtain the vertical information. SFT X plane has the same structure with BFT. Fibers of 1 mm diameter are used and SFT X plane has a larger effective area of 256 × 160 mm^2. On the other hand, for SFT U, V planes,

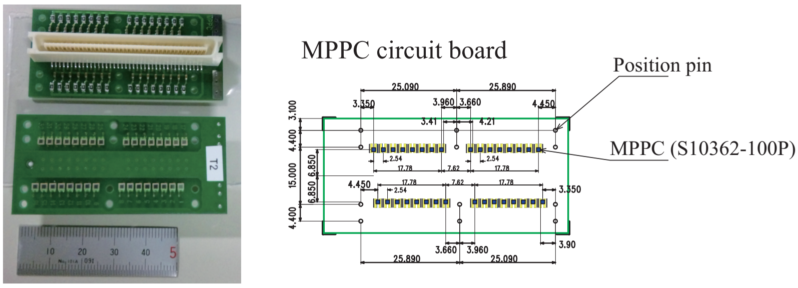

Figure 4: Photograh and drawing of MWPC PCB board. 32 MPPCs are mounted in 2.54 mm pitch. This MPPC PCB is fixed on the detector frame at the fiber readout edge with the position pin.

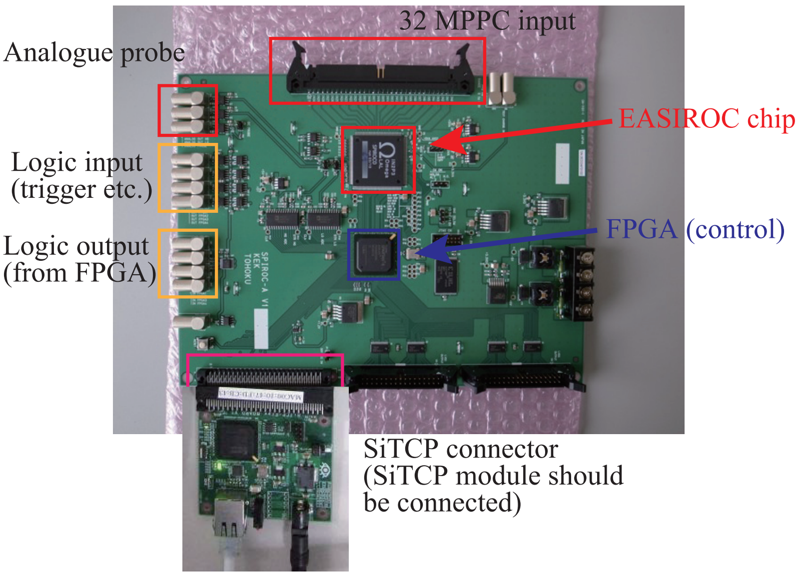

Figure 5: Photograph of EASIROC board. The EASIROC chip, which is an ASIC dedicated for MPPC readout, has 32 channel inputs of MPPC and each channel has a preamplifier, slow shaper for an energy measurement, and fast shaper and discriminator for a time measurement. The operation voltages for each 32 ch inputs can be adjusted with a precision of 20 mV. Charge and timing information can be obtained by ADC and multi hit TDC with a precision of 1 ns on this board.

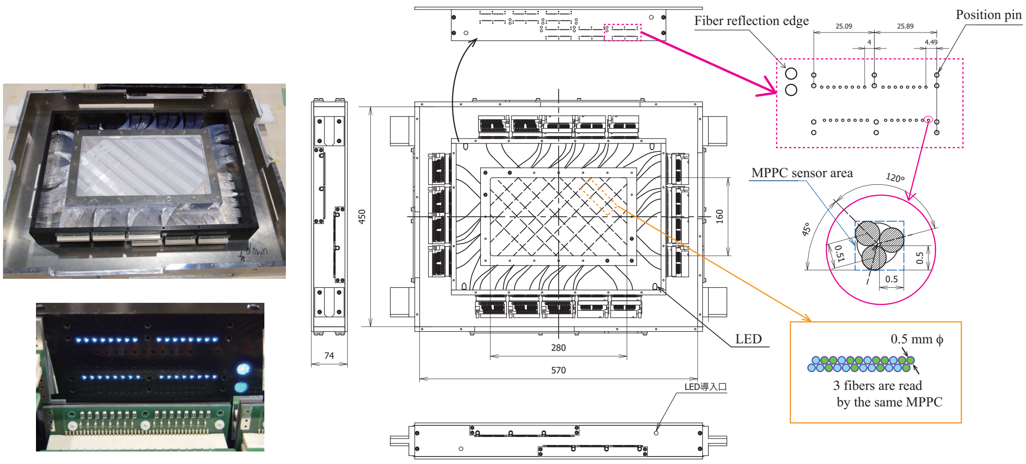

Figure 6: Photograph and drawing of SFT U, V planes. The fibers of 0.5 mm diameter were placed with tilt angels of ±45° to obtain the vertical information. The neighboring three fibers were read by one MPPC.

fibers of 0.5 mm diameter were used to reduce the effect of the multiple scattering at SFT U, V planes. Figure 6 shows the photograph and drawing of SFT U, V planes. In order to reduce the number of readout MPPC with keeping a reasonable position resolution, three fibers were read by one MPPC as shown in Figure 6. In order to keep a good contact between 3 fibers and MPPC, mechanically three neighboring holes were made and the three fibers were fixed into the holes as shown in Figure 6. Because 0.5 mm diameter fibers were used for SFT U, V planes, the light yield is expected to be not sufficient to obtain the enough efficiency. In order to collect many photons as much as possible, we put the ESR reflector on the fiber edge which was the opposite side of readout edge.

Presently about 1,500 channels of MPPCs are operated for BFT and SFT. These multi channel MPPCs can be operated easily and stably by using the EASIROC board. Figure 7 shows the beam profiles at BFT and SFT positions, respectively, and these detectors cover the beam particle sizes. Figure 8 shows the comparison of TDC distribuions between SFT X and BC3 (MWDC with 1.5 mm drift length) at the beam intensity of 10 M/spill. The signal to noise ratio for BC3 is quite worse due to the slow time response during the drift time. On the other hand, for SFT X, the signal to noise ratio is quite improved thanks to its good time resolution of 1 ns. The efficiencies of BFT, SFT were studied by changing the beam intensity up to 15 M/spill. The enough efficiency of more than 98 % could be obtained under the such high intensity. The position resolution was obtained to be 190 μm for BFT. This resolution is enough to have the good momentum resolution of the K1.8 beamline spectrometer.

Figure 9 shows the beam intensity history at the K1.8 beamline. BFT and SFT were installed at the E27 and E10 beam times, respectively. By utilizing these detectors, we could handle 12 M/spill π beam at the E10 beam time. These detectors contributed to increase the beam intensity under the present beam time structure. In the E40 experiment, π beam of 20 M/spill will be used. We believe this beam intensity is accesible by using these fiber trackers and upgrading the present detectors.

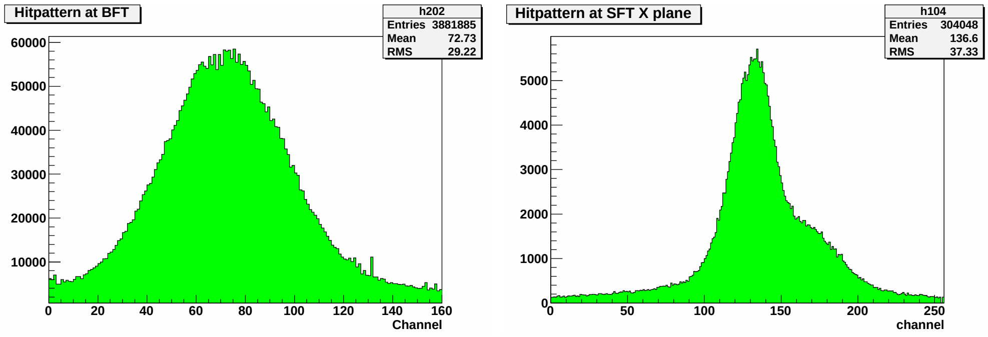

Figure 7: Hit pattern distributions for BFT (left) and SFT X (right).

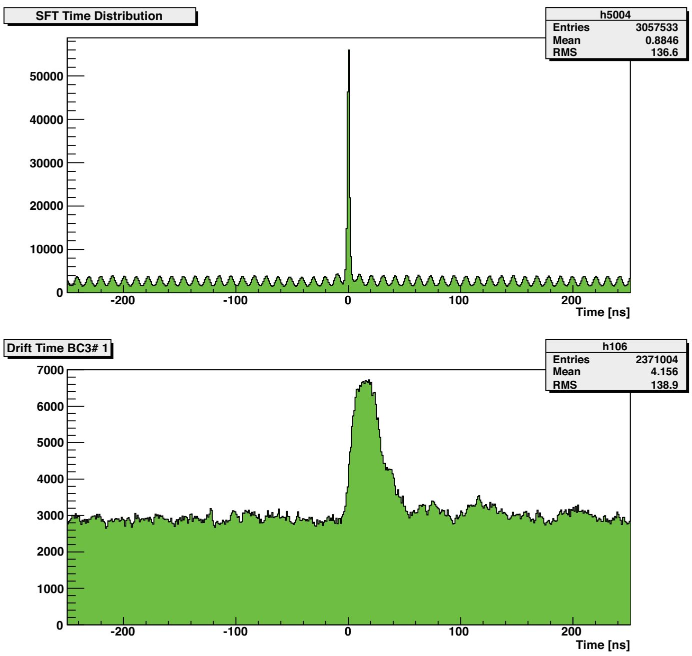

Figure 8: TDC distributions of SFT X plane (top) and BC3 (bottom). The signal to noise ratio for SFT X plane is quite improved than that of BC3 thanks to the good time resolution of 1 ns.

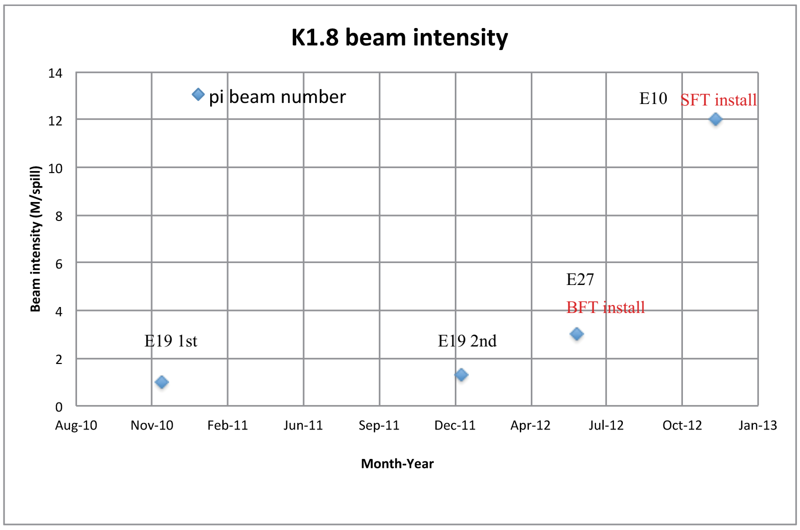

Figure 9: Beam intensity history at the K1.8 beamline. BFT and SFT were installed at the E27 and E10 beam times, respectively.

3.2 Cylindrical Fiber Tracker

Now we are designing and developing a Cylindrical Fiber Tracker (CFT) based on the experience cultivated at the developments of BFT and SFT. CFT surrounds the LH_2 target and detects charged particles from the target. CFT has two different fiber configurations, that is, the "ϕ" configuration and the "U" configuration. In the "ϕ" configuration, the fibers are placed in a straight line along the beam direction as shown in Figure 10. On the other hand, in the "U" configuration, the fibers are placed with a tilt angle as shown in Figure 11. By combining these two layer configurations, three dimensional tracking can be possible by CFT. Now, we are developing a prototype of CFT, which consists of three layers of "ϕ" ("ϕ1"), "U" and "ϕ" ("ϕ2") configurations. The radii for the "ϕ1", "U" and "ϕ2" layers are 4 cm, 5 cm and 6 cm from the center, respectively. For the beam direction, these layers have an effective length of 40 cm. As for the fiber size, diameter of 0.75 μm is used by considering both the light yield for minimum ionization particles and the thickness of the fiber material. For the readout of CFT, we also use the MPPC PCBs and EASIROC boards like other fiber detectors. However, different type of MPPCs whose pixel size is 400 are used considering the wide dynamic range for the energy deposit by MIP and protons at CFT.

Figure 10 shows the structure of the ϕ1 layer. In order to place and fix the fibers, we apply a new method for CFT. For BFT and SFT, we made a fiber sheet where fibers contacted with the neighboring fibers then piled up the two sheets in a staggered relation each other. However, for CFT we make fiber fix frames at both sides of the active region, where there are two rows of holes for positioning and fixing the fibers as shown in Figure 10. In each row, there is space between neighboring fibers. However, by place two rows in a zigzag relation, there is no ineffective area from the center of the cylinder. The spacing between the neighboring fibers in the same row is determined by considering the uniformity of the fiber material thickness and efficiency for MIP. In this CFT prototype detector, we prepare two different spacings between fibers as shown as (A) and (B) in Figure 10. In the fiber configuration (A), spacing between two fibers is smaller in order to have an enough photon number at the overlapped fiber region, while in the fiber configuration (B) the spacing is determined to obtain a uniform material thickness. By irradiating π and p beams to the both points, we will study the effect of the fiber spacing to the efficiency for MIP and the uniformity of the energy deposit.

Figure 11 shows the structure of the U layer. Its structure is quite challenging. The fibers are placed with a tilt angle of 38.15° along the surface of the cylinder. In order to succeed in this challenge, we decided to introduce several pillars along the beam direction which had position pins to fix the fiber position as shown in the bottom part in Figure 11. The pillar is made by an acrylic bar of 1 mm thickness in order to reduce material thickness. The fibers are sandwiched by two acrylic bars with position pins and have a zigzag configuration as shown in Figure 11 in order to reduce the ineffective area. The most important aim of the prototype of U configuration is to establish the method to produce this fiber configuration and to confirm that sufficient efficiency and position resolution expected from the geometrical configuration are obtained.

Each layer of CFT prototype is made up respectively. After finishing the construction of each layer, these fiber layers will be combined together. In order to evaluate the performance, we will irradiate π and p beams to this prototype detector so as for the beam particles to penetrate the both sides of 3 layers, that is, 6 layers. Then tracking with prototype detector becomes possible. We would like to study the following topics by using this prototype detector.

- We confirm that CFT can be constructed with the expected position resolution.
- We check that CFT has sufficient light yield for MIP and has enough dynamic range for a large energy deposit by low energy protons.
- We check that particle identification between π and proton can be done by using the information of ΔE-E relation where ΔE is the energy deposit at fibers and E is the total energy deposit at BGO calorimeter which is installed at the outer part of CFT.

3.3 BGO Calorimeter

BGO calorimeter will be placed at the outer side of CFT to measure the total energy of the scattered protons. Now we are testing a large BGO calorimeter which has the same effective length of 40 cm with that of CFT. The size of the BGO calorimeter is $400 \times 25 \times 35$ mm^3 (Figure 12 (a)). The following performances are required for the BGO calorimeter.

- BGO calorimeter has a stopping power up to 140 MeV proton.
- Its energy resolution is required to be better than $\sigma/E = 3\%$ for 70 MeV proton.

Figure 12 (b) shows the energy spectrum for 661 keV γ ray from a ^{137}Cs source. From this measurement, energy resolution of 11 % was obtained for 661 keV. Therefore the BGO calorimeter is expected to have the required resolution at higher energy. The detailed study for high energy proton will be performed by irradiating a proton beam of 80 MeV at a cyclotron facility (CYRIC) at Tohoku university. This test experiment at CYRIC will be performed in May.

At the test experiment at J-PARC, we also have to evaluate the particle identification power by using ΔE-E method as mentioned above. Therefore, by irradiating π and p beams to CFT and the BGO calorimeter we would like to check this point.

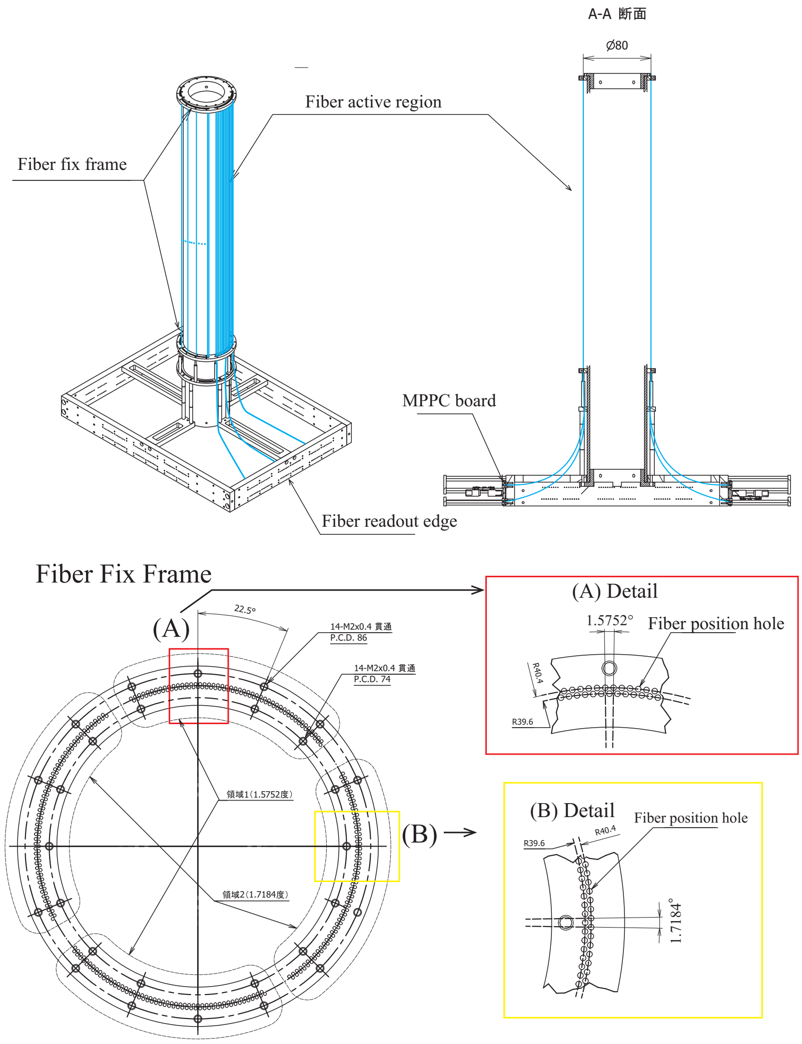

Figure 10: Drawings of CFT prototype ϕ1 layer. The top figures show the whole picture and its cross sectional view. The fiber active region has a 40 cm length along the beam direction. The fibers are fixed into the position holes at the fiber fix frame as shown in the bottom part. Two different fiber spacings, that is, (A) and (B) regions are prepared to study the effect of the fiber spacing to the efficiency and the uniformity of the energy deposit.

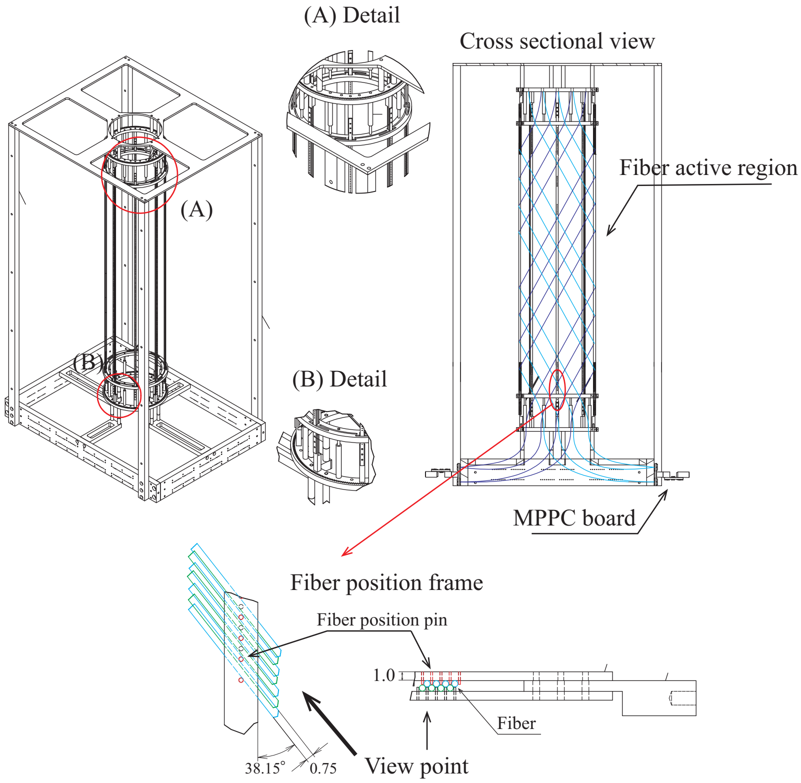

Figure 11: Drawings of CFT prototype U layer. The top figures show the whole picture and its cross sectional view. The fibers are placed with a tilt angle of 38.15° along the surface of the cylinder. In order to assure the position of the fibers, we introduce several pillers along the beam direction which have position pins to fix the fiber position as shown in the bottom part. The fibers are sandwiched by two acrylic bars with position pins and have a zigzag configuration in order to reduce the ineffective area.

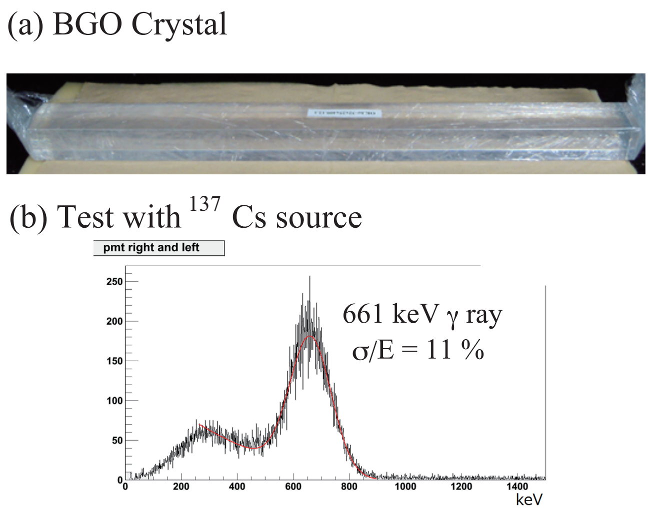

Figure 12: (a) Photograph of a BGO calorimeter which is almost the same size with the actual equipment. The size is $400 \times 25 \times 35$ mm^3. (b) Energy spectrum obtained for γ ray of 661 keV from a ^{137}Cs source. Energy resolution of $\sigma/E = 11\%$ was obtained for 661 keV.

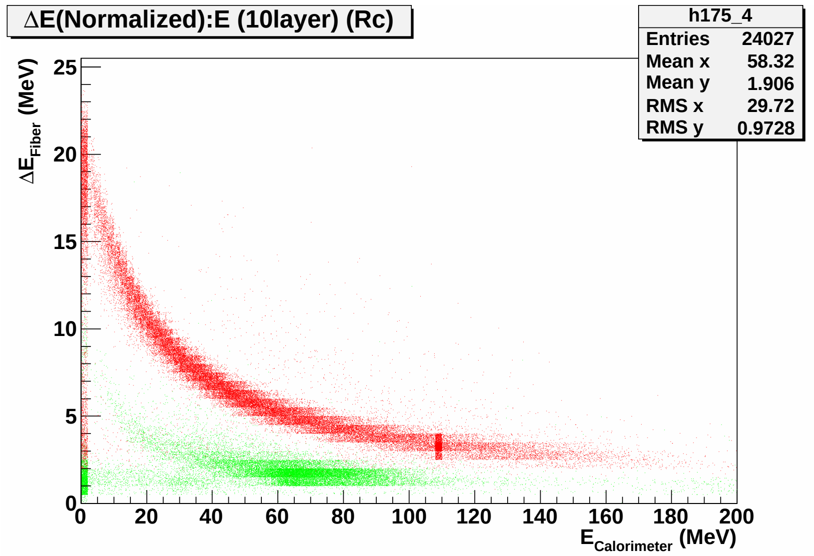

Figure 13: ΔE-E relation where ΔE is the energy deposit at fibers and E is the total energy deposit at BGO calorimeter. The red band corresponds to proton and the green one corresponds to π.

4 Test expriment for CFT and BGO calorimeter

We would like to perform a test experiment to evaluate the performance of the scattered proton detector system which consists of CFT prototype and the BGO calorimeter by irradiating π and p beams at the K1.1BR beamline.

4.1 Purpose

In order to evaluate the performance of the CFT prototype and the BGO calorimeter, we would like to perform a test experiment to irradiate p and π beam with momentum ranges from 300 MeV/c to 550 MeV/c and from 130 MeV/c to 300 MeV/c, respectively. In the E40 experiment, the LH_2 target is surrounded by CFT and BGO calorimeter and proton and π particles emitted from the target are detected by these detectors. The momentum of proton ranges from 0 MeV/c to 600 MeV/c depending on the scattering angle of the elastic scattering. On the other hand, π particles, which originated from the decay of hyperon, have mainly momentum from 100 MeV/c to 300 MeV/c. Therefore we would like to irradiate π and p beams with these momentum ranges and then study the following topics. At first, we will check that CFT has sufficiency light yield for MIP and has enough dynamic range for a large energy deposit by low energy proton. For CFT "ϕ" layers, we will study the effect of the fiber spacing on the efficiency for MIP and the uniformity of the energy deposit by changing the irradiation position to the CFT prototype. We check that particle identification between π and proton can be done by using the information of ΔE-E relation where ΔE is the energy deposit at the CFT fibers and E is the total energy deposit at the BGO calorimeter which is installed at the outer part of CFT. Figure 13 shows the expected spectrum of ΔE-E relation in the E40 experiment. In this test experiment, by changing the beam momentum we will check this relation for proton and π particles.

4.2 Experimental setup

Figure 14 shows the experimental setup. In the beamline, two scintillation counters (S1, S2) are placed with the length of 4 m in order to identify the beam particle (π and p) from the time of flight measurement. Electrons in beam particles are rejected by a Gas Cherenkov (GC) counter. In order to identify π and p at the online level, a Lucite Cherenkov (LC) counter is also installed. The triggers for p and π beams are defined as follows,

$$Proton = S1 \times S2 \times \bar{GC} \times \bar{LC}, Pi = S1 \times S2 \times \bar{GC} \times LC. \quad (1)$$

At the downstream of the S2 counter, the CFT prototype is placed perpendicularly to the beamline. In this setup, beam particles penetrate 6 fibers, that is, ϕ2 layer, U layer, ϕ1 layer, ϕ1 layer, U layer and ϕ2 layer. We will perform the tracking by using the 6 hit points and obtain the ΔE information from the ADC measurement. At the downstream of the CFT prototype, the BGO calorimeter is placed in order to stop the particle (especially proton) and measure the total energy. Because it is expected that the beam size is wider than BGO calorimeter, the BGO calorimeter is surrounded by plastic scintillators in order to veto the events where a particle grazes or penetrates the BGO calorimeter. For the BGO calorimeter, we will test the readout by PMT and MPPC-array which has a sensitive area of 12×12 mm^2. Therefore, PMT and MPPC-array are attached to the different edge of the BGO crystal.

In the E40 experiment, charged particles enter CFT with various incident angles. In order to test the incident angle effect, the CFT and BGO detectors will be put on a turn table and rotated. Then we study the angle effect to the ΔE-E relation and the tracking.

As for the beam condition, proton beam of 550, 500, 400, 300 MeV/c momenta and $\pi^{\pm}$ of 300 and 170 MeV/c will be used. The beam intensity is supposed to be less than 30 k/spill in order to prevent a pile-up event for BGO counter. We will adjust the beam intensity by changing the opening size of the beamline slit. In order to remove the unwanted particle from the beam, the electric separator should be used to separate π and p particles. Table 1 shows the summary of the used beam for p and π beams and ΔE_{fiber} and E_{BGO}. For p beam, we can cover the expected energy region. By installing some degraders additionally, the response for intermediate and lower beam momenta can also be studied. Because proton are stopped in the BGO calorimeter, the banana curve in the ΔE-E relation can be checked. For the π beam, most of π particles with the momentum higher than 150 MeV/c penetrate the BGO calorimeter. The π particles with the momentum lower than 150 MeV/c are stopped in the BGO calorimeter. Such π particles make a banana curve in the ΔE-E relation. We want to study both these momentum ranges. For higher momentum, 300 MeV/c π beam will be used. For lower momentum, 170 MeV/c beam will be used and its momentum will be degraded to about 150 and 130 MeV/c by installing a graphite degrader. Because π^+ particles stopped at the BGO calorimeter decay without a nuclear capture, such π^+ makes a banana curve in the ΔE-E relation. On the other hand, the stopped π^- is absorbed by the nucleus and causes a nuclear reaction. Therefore, such π^- has different relation in the ΔE-E spectrum. We have to check whether such nuclear captured π^- makes the contamination at the proton region or not. Therefore, we want to study both π^+ and π^- particles. We will frequently change the beam momentum. If it is difficult to change the beam momentum frequently by the confliction with the other beamlines, the beam momentum will be adjusted by installing degraders. Table 2 shows the relation between momentum of beam particles and the thickness of the graphite degrader whose density is 2.2 g/cm^3. At least, we want to use 550 MeV/c and 400 MeV/c proton beams and 170 MeV/c for $\pi^{\pm}$ beams.

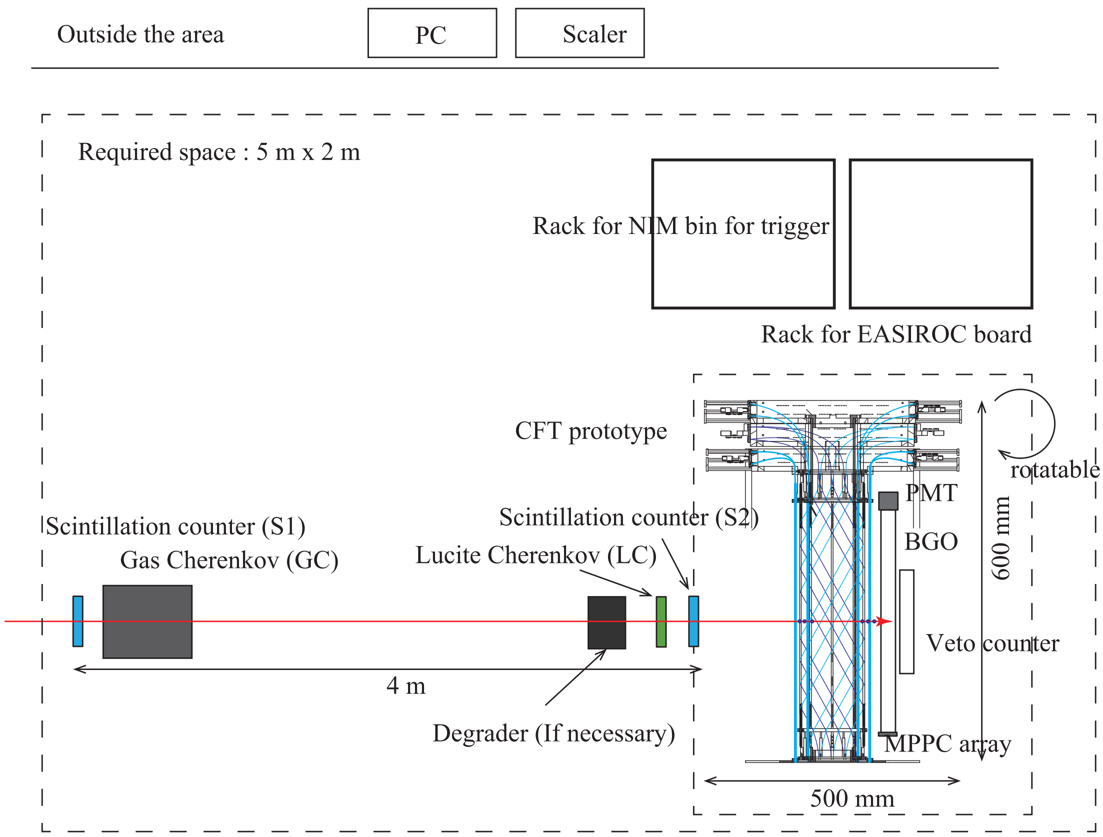

Figure 14: Experimental setup. In the beamline, two scintillation counters (S1, S2) are placed in order to identify the beam particle (π and p) from the time of flight measurement. Electrons in beam particles are rejected by a Gas Cherenkov (GC) counter. In order to identify π and p at the online level, a Lucite Cherenkov (LC) counter is also installed. At the downstream of the S2 counter, the CFT prototype and the BGO calorimeter are placed.

In the Figure 14, required space including the electronics are written. We will place 2 racks to mount EASIROC boards and NIM bins for trigger making. Almost all electronics will be installed inside the experimental area. The whole necessary space is 5×2 m^2. For the electricity power, we expect 2000 W, where 500 W is for EASIROC boards and 1500 W for NIM bins and other detectors. We estimated that the setup time and the setdown time are 24 hours and 12 hours, respectively.

4.3 Beam time schedule and request time

The beam time plan is summarized as follows.

1. Detector commissioning and timing adjustment (4 hours)
2. Beam adjustment (6 hours)
   We will adjust the magnet current values for each momentum range. The correction magnet values for π and p are also adjusted. The beam intensity is also checked by adjusting slit opening size.

Table 1: Summary of the beam momentum to be studied and other informations. ΔE_{fiber} is the estimated sum of the energy loss at 6 layers. The π momenta of 150 and 130 MeV/c are degraded from the 170 MeV/c beam.

p (MeV/c)	E_{kin} (MeV)	β	ΔE_{fiber} (MeV)	E_{BGO} (MeV)	Range in BGO (cm)
			proton		
550	150	0.505	2.4	143	3.8
500	125	0.470	2.77	118	2.78
400	81	0.392	3.83	75.6	1.28
300	46	0.304	6.16	36	0.41
			π		
300	192	0.907	0.937	32.7 (dE in 3.5 cm)	
170	80	0.774	1.18	47.1 (dE in 3.5 cm)	
150	65	0.733	1.29	62	3.3
130	51	0.683	1.46	48	2.2

Table 2: Relation between the momentum and the thickness of graphite degrader whose density is 2.2 g/cm^3.

Graphite thickness (cm)	p (MeV/c)	E_{kin} (MeV)
Degrade 550 MeV/c p beam		
2.0	500	125
3.5	460	106
4.5	425	91
5.0	400	82
5.5	380	73
6.0	350	64
6.5	320	53
6.8	295	45
7.0	276	40
Degrade 170 MeV/c π beam		
2.0	155	69
3.0	147	63
4.0	138	57
5.0	130	51

3. Data acquisition with p beam of 550 MeV/c (3 hours)
   We will change the angel of the CFT prototype from 0 degree to 20 and 40 degrees. At each detector angle, 100,000 events will be accumulated. If the trigger rate is assumed to be 500 /spill, it takes 20 minites for one setup. Then, we install a thin degrader to study the intermediate beam momentum. These studies are also continued for the different beam momenta.

4. Data acquisition with p beam of 500 MeV/c (3 hours)

5. Data acquisition with p beam of 400 MeV/c (3 hours)

6. Data acquisition with p beam of 300 MeV/c (3 hours)

7. Data acquisition with π^+ beam of 300 MeV/c (3 hours)

8. Data acquisition with π^+ beam of 170 MeV/c (4 hours)
   We will adjust beam momentum to 150 MeV/c and 130 MeV/c by adjusting the thickness of the degrader. Therefore we need longer times than other measurements.

9. Data acquisition with π^- beam of 170 MeV/c (4 hours)

10. We change the beam irradiating point of the CFT detector. (2 hours)
    Until now, the beam is irradiated to the (B) region in Figure 10. In order to irradiated to the (A) region, the CFT prototype detector will be rotated 90 degrees on the center axis of the cylinder.

11. Continue the same studies from 3 to 9 (23 hours)

We would like to request 58 hours in total.

5 Summary

We are planning the Σp scattering experiment, E40. In order to perform this experiment, we are developing the following two topics; (1) acceptability of the high intensity beam, (2) development of the scattered proton detector around the LH_2 target. In order to realize these issues, we have established the fiber detector system with MPPC and the EASIROC readout board. For the first topic, we had developed and installed beamline fiber trackers at the K1.8 beamline (BFT, SFT) which were stable under the high intensity beam of 12 M/spill and had a good timing resolution (σ=1 ns). These fiber detectors enable us to select a triggered event from a large accidental background thanks to its good time resolution. For the second point, we are now designing and developing a prototype of Cylindrical Fiber Tracker (CFT) and BGO calorimeter. The CFT prototype detector has a long effective area of 40 cm along the beam direction and consists of three layers of fibers. The fiber channel number of the CFT prototype is about 1,200. Such multi channel fibers are read by the MPPC and the EASIROC board. The BGO calorimeter has the same effective length of 40 cm with the CFT prototype. By combining the CFT prototype and the BGO calorimeter, we have to evaluate the performance of this detector system. For this purpose, we propose a test experiment at the K1.1BR beamline by using p and π beams. We will check the response of the CFT prototype detector and the BGO calorimeter for p and $\pi^{\pm}$ particles which momentum ranges are 300 $\sim$ 550 MeV/c and 130 MeV/c to 300 MeV/c, respectively. These momentum ranges are expected in the E40 experiment. We also evaluate the particle identification power with the information of ΔE-E relation at the CFT prototype and the BGO calorimeter. For this test experiment, we would like to request a beam time of 58 hours.

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