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Cosmic-ray test of a time-of-flight detector for double-strangeness experiments at J-PARC

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ABSTRACT

We have developed a time-of-flight (ToF) array consisting of 24 plastic scintillators for triggering and timing measurements in a series of planned experiments to study double-strangeness hadronic and nuclear systems at the K1.8 beamline of J-PARC. Each ToF scintillator is 180 cm long with a cross-section of 8×3 cm^2, and is read out by H1949-50 photomultiplier tubes at both ends. The timing and attenuation properties of the scintillators are measured using cosmic-ray muons and β rays from ^{90}Sr. The cosmic-ray muon events are triggered by three pairs of 120-cm-long plastic scintillators, sandwiching the ToF array. The intrinsic time resolutions of the scintillators are estimated to be in the range 60–100 ps, which is adequate for reliable separation between π and K at 1.2 GeV/c. The attenuation length is measured to be approximately 210 cm, which is half that for a bulk scintillator.

1. Introduction

A new time-of-flight (ToF) system of the KURAMA K^+ spectrometer has been developed for double-strangeness experiments [1–3] carried out at the Hadron Hall of J-PARC. This ToF system was designed to reliably separate π, K and p from (K^-, K^+) reactions in the momentum range 1.6–2.0 GeV/c. Scattered particles from a target travel 4–5 m through the KURAMA dipole magnet with a solid angle of 160 msr. The start signal for the ToF measurement is provided by a plastic scintillator counter BH2, placed 1.2 m upstream from the target.

The masses of reconstructed charged particles can be calculated from the relation $m^2=p^2(1-\beta^2)/\beta^2$, where β is the speed of the charged particle, given by $\beta=L/(c\cdot \mathrm{ToF})$ with L and c being the flight length and speed of light in vacuum, respectively. Using the parameterization $\sigma_p^{MS}/p=a_1/\beta$ for multiple Coulomb scattering, $\sigma_p/p=a_2p$ for momentum resolution and $\sigma_t\equiv a_3$ for ToF resolution, the mass resolution can be expressed as

$$\sigma^2(m^2)=4m^4\left(1+\frac{m^2}{p^2}\right)a_1^2+4m^4p^2a_2^2 +4p^2(p^2+m^2)\frac{c^2}{L^2}a_3^2. \quad (1)$$

The derivation of the above equation is described in detail in Appendix.

We assume that the momentum resolution of the KURAMA spectrometer is 0.63% at 1.2 GeV/c with $a_1=0.00458$ and $a_2=0.00323$. The momentum distribution of K^+ particles in the $p(K^-, K^+)\Xi^-$ reaction peaks at 1.2 GeV/c for a K^- beam momentum of 1.8 GeV/c. The ToF resolution can be obtained from the quadratic sum of intrinsic time resolutions σ_{BH2} and σ_{ToF} for the BH2 start counter and ToF system, respectively:

$$\sigma_t^2=\sigma_{BH2}^2+\sigma_{ToF}^2 \quad (2)$$

where σ_{BH2} was measured to be 80 ps by using a 500-MeV positron beam at ELPH, Tohoku University. Fig. 1 shows simulated distributions of momentum versus reconstructed mass for charged particles generated using an event generator JAM [4], assuming the combined ToF resolution $\sigma_t=150$ ps for a ToF system located at a distance of 5 m from the BH2 start counter. Since K^+ decays in

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flight, it is necessary to make the flight length as short as possible to obtain a large acceptance for high-statistics measurements. Moreover, a good ToF resolution should be simultaneously guaranteed for reliable particle identification. Therefore, we built a ToF system and tested its performance using cosmic-ray muons.

In this paper, we report the results of a cosmic-ray test carried out on the newly developed ToF system at J-PARC. The design considerations for the ToF system are presented in Section 2, and the cosmic-ray test setup is presented in Section 3. Time-resolution measurement results for the ToF system are discussed in Section 4. The measurement of the attenuation length of scintillation light in the ToF scintillator is described in details in Section 5.

2. Time-of-flight system

Our ToF system is composed of 24 plastic scintillator (Eljen EJ-200 [5]) slats. They are placed in an alternative back and forth manner with two neighboring slats overlapping by 5 mm on both sides, as shown in Fig. 2. Each slat is 180 cm long, 8 cm wide, and 3 cm thick. The maximum vertical angular coverage is 20° at the exit window of the KURAMA dipole magnet when an experimental target is placed 800 mm from the magnet center. The KURAMA magnet is a normal conducting magnet with a pole gap of 800 mm. The magnetic field integral $\int B\,dl$ is 0.7 T m. The slat length is chosen so as to cover the full vertical angular range ($\pm 10°$) at a maximum distance of 5 m downstream of the target.

The plastic scintillator is wrapped with a double-layer aluminized mylar and light-tight black sheets. Each scintillator is coupled to two high-gain photomultiplier tubes (H1949-50 [6]) through fish-tail-shaped acrylic light guides at both ends, as shown in Fig. 3. The photomultiplier tubes (diameter: 2 in) are operated at -2 kV with a typical gain of 2×10^7. The light guide and plastic scintillator are glued by irradiating them with UV-light. The whole system is supported by a movable Al structure. The scintillators are attached to the two horizontal bars of the support structure.

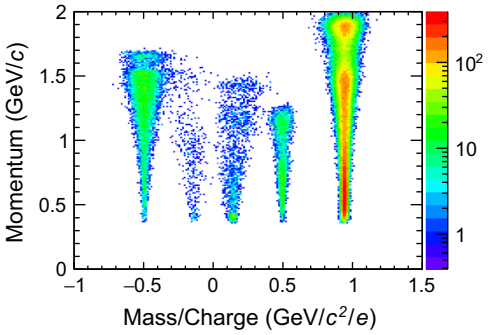

Fig. 1. Simulated correlation between momentum and reconstructed mass for charged particles in the KURAMA spectrometer.

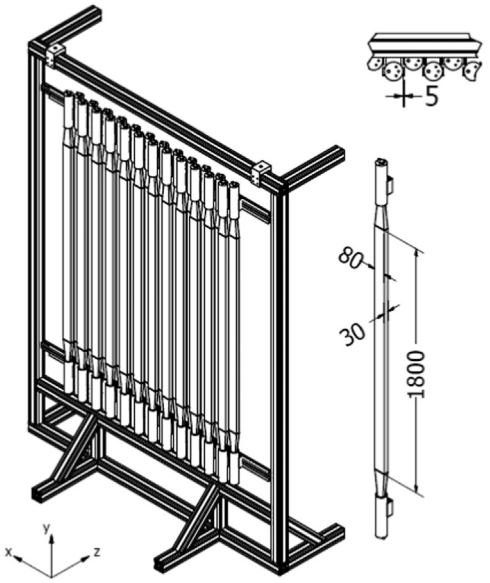

Fig. 2. Schematic view of the ToF system. All units are mm.

3. Cosmic ray test

For triggering cosmic rays, three pairs of long scintillators are constructed. In each pair, the front and rear trigger counters are positioned at distances of 41.5 cm and 63.0 cm, respectively, from the surfaces of the even-numbered ToF slats and at distances of 45.5 cm and 59.0 cm, respectively, from those of the odd-numbered ones. The trigger counters are placed horizontally at heights of $y=-80$, 0, and $+80$ cm, as shown in Fig. 4. Each trigger scintillator is 120 cm long, 8 cm wide, and 3 cm thick. The two photomultiplier tubes are coupled directly to each scintillator at both ends with silicon optical grease.

The cosmic-ray trigger is provided by the coincidence of ORed signals emitted from trigger scintillators in both the front and rear planes. The trigger rate is approximately 1 Hz. A minimum-ionizing particle (MIP) traversing a 3-cm-thick plastic scintillator would yield a signal of about -400 mV at each end, which corresponds to

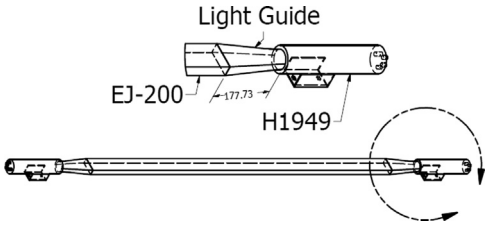

Fig. 3. Schematic view of coupling sections between a photomultiplier tube and a scintillator slat. All units are mm.

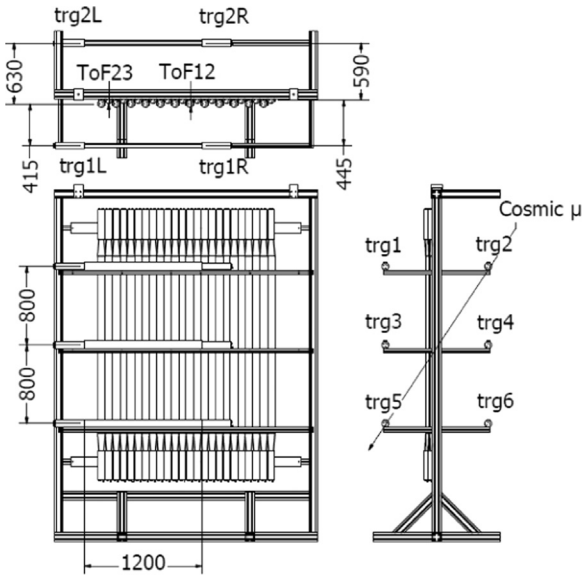

Fig. 4. Schematic view of the cosmic-ray test setup for the ToF system. The ToF system and trigger counters are labeled with numbers. All units are mm.