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π/p separation at 1.2 GeV/c by an emulsion cloud chamber

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Abstract

We have performed an experimental study of π/p separation at a momentum of 1.2 GeV/c using an Emulsion Cloud Chamber (ECC) detector with secondary beam produced by the proton synchrotron at KEK. The separation is greater than 3 standard deviations using $\mathrm{d}E/\mathrm{d}x$ measurements of 2.6 mm long tracks with an automatic emulsion read-out system.

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1. Introduction

The Emulsion Cloud Chamber (ECC) is a modular structure made of a sandwich of passive material plates such as lead interleaved with emulsion layers. Minimum Ionizing Particles (MIPs) are observed as thin tracks having grain densities of ~ 30 grains/100 μm in typical nuclear emulsion. It is known that the grain density is almost proportional to the electronic energy loss, and its mean rate ($\mathrm{d}E/\mathrm{d}x$) is given by the Bethe–Bloch equation [1]. According to the Bethe–Bloch equation, $\mathrm{d}E/\mathrm{d}x$ in a given material is a function of only its velocity (β). So if the momentum is known, measurement of $\mathrm{d}E/\mathrm{d}x$ along the particle trajectory allows particle identification. Here, we report an experimental test that studied the ability to distinguish between protons and charged pions in the momentum-tagged secondary beam of positive charged particles with momenta (p) of 1.2 GeV/c using an ECC detector. The β of $\pi^+(p)$ is 0.99(0.79) and $\mathrm{d}E/\mathrm{d}x$ for $\pi^+(p)$ is 1.08(1.23) times larger than an MIP.

2. Set up, beam exposure and readout of ECC

A schematic diagram of ECC is shown in Fig. 1. Its structure is obtained by interleaving 28 1 mm thick lead plates with thin emulsion sheets. These emulsion sheets are mass-produced for the future long baseline neutrino experiment, OPERA [2]. Each sheet had a 44 μm thick emulsion layer on both sides of a 200 μm thick plastic base. There were two extra emulsion sheets in front of the first

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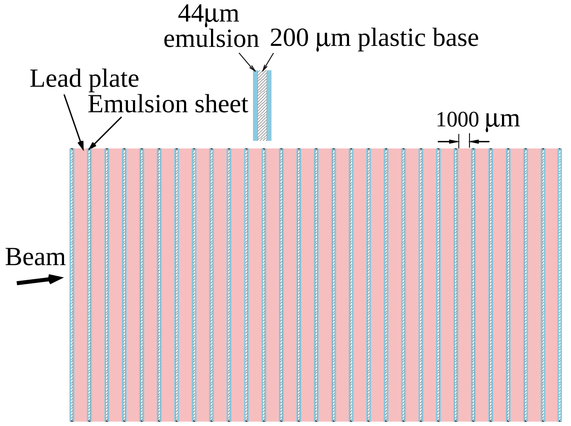

Fig. 1. ECC structure.

lead plate and the back of the last lead plate. The transverse size of the emulsion sheets was 102 × 127 mm^2. These were packed by thermo-sealing under vacuum in an aluminum-coated film. The total thickness of the ECC corresponded to 0.16 interaction lengths and 5 radiation lengths. On November 16th 2002, an ECC was exposed to a positive charged secondary beam produced at the KEK PS Internal Target $\pi 2$ beam line [3]. The momentum of the beam was selected as 1.2 GeV/c with the relative spread of momentum ($\Delta p/p$) of $\pm 1\%$ as defined by the magnetic spectrometer. Around $1 \sim 2$ GeV/c, the main beam components were protons and π^+'s, and contamination from positrons and μ^+'s were one order of magnitude smaller. Here, the z-axis is defined in the perpendicular direction with respect to the ECC surface. The ECC surface was oriented so that the beam direction with respect to the z-axis was shifted by 50 mrad. The density of the beam was 10^4 tracks/cm^2. The development and readout of the ECC was carried out at the scanning laboratory of Nagoya University, Japan. Twenty-nine emulsion sheets from an ECC were developed immediately to achieve good homogeneity. The Ultra Track Selector (UTS) [4] read out 16 tomographic CCD images from a microscope in 44 µm thick emulsion layers, and tracks in these images were recognized in three dimensions by an image processor. The angles and positions of recognized tracks were recorded and treated as track segments. Also, the pulse height for each track segment was recorded. Pulse height was defined as the number of tomographic CCD images having pixels associated with each recognized track. For minimum-ionizing tracks, the average gap between grains was ~3 µm, which is also the depth of the field and distance between two subsequent tomographic CCD images. Therefore, the pulse height measured the number of grains along track segments, and was useful for dE/dx analysis. The efficiency of detecting track segments was 98%. The area of 5 × 5 mm^2 was scanned on both sides of the emulsion layers from the first sheet to the 29th sheet along the z-axis.

3. Analysis

First, track segments in both sides of emulsion were connected across the base. Connected tracks were defined as base tracks. For each base track, pulse height was calculated by adding the pulse heights on both sides of the emulsion, with a maximum value of 32. Next the beam tracks were reconstructed through the ECC by connecting base tracks found in each sheet. A schematic diagram of pulse height analysis is shown in Fig. 2. In total, 552 beam tracks were reconstructed. Fig. 3(a) shows the distribution of pulse height on the first sheet (PH$_1$). Its average and root-mean-square are 25.4 and 2.8, respectively. In order to maximize the statistics of grains used for the analysis, the average pulse height through 29

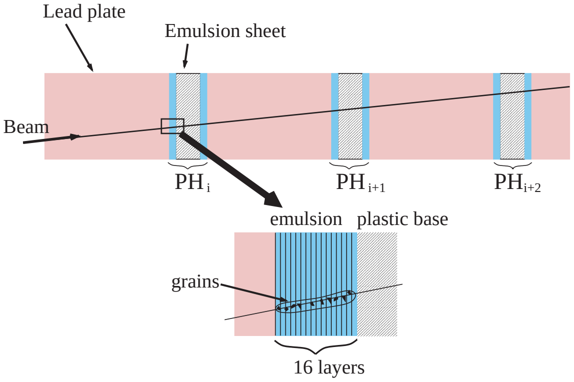

Fig. 2. Schematic view of pulse height measurement.

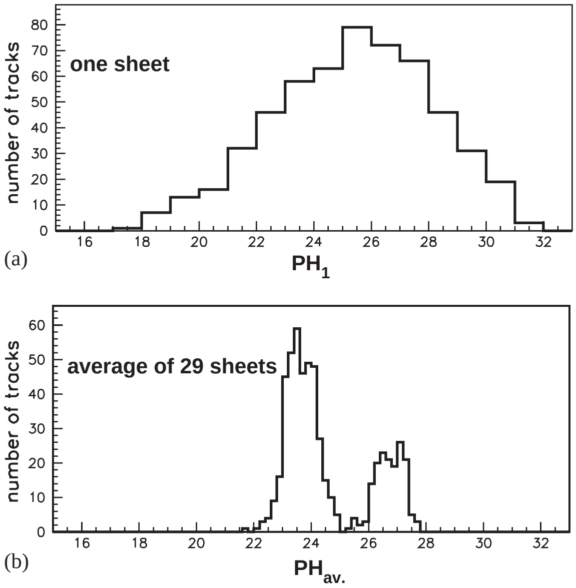

Fig. 3. Pulse height distribution for one sheet measurement (a), and after taking the average of 29 sheets (b).

sheets (the total length in emulsion is 2.6 mm for each track) was calculated as

$$\mathrm{PH}_{\mathrm{av.}} \equiv \frac{\sum_{i=1}^{N} \mathrm{PH}_i}{N},$$

where PH_i is the pulse height on sheet (i) N is the number of sheets on which track are detected (maximum 29). Fig. 3 (b) shows the distribution of $\mathrm{PH}_{\mathrm{av.}}$. There are two distinct peaks corresponding to π^+ ($\mathrm{PH}_{\mathrm{av.}} = 22$–$25$) and proton ($\mathrm{PH}_{\mathrm{av.}} = 25$–$28$). The central value and width of a Gaussian fit are 23.7(26.8) and 0.53(0.48) for the π (proton) peak, respectively. The width of each peak is smaller by a factor of $\sim 1/\sqrt{29}$ compared to the first sheet by the gain in statistics. The ratio of the central value of $\mathrm{PH}_{\mathrm{av.}}$ for π^+ to proton is in good agreement with the expected ratio of $\mathrm{d}E/\mathrm{d}x$. The difference between π and proton is also shown in the measurement of Multiple Coulumb Scattering (MCS). $p\beta$ can be determined by the measurement of deflections caused by MCS along the trajectory

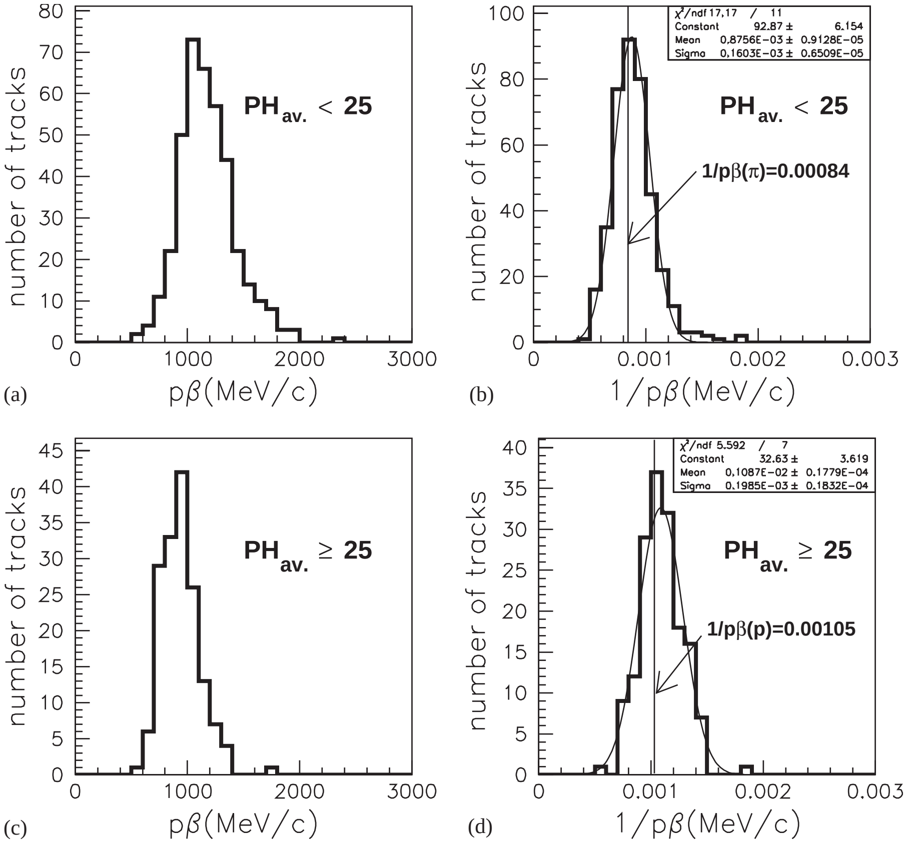

Fig. 4. (a) $p\beta$ and (b) $1/p\beta$ distribution for $\mathrm{PH}_{\mathrm{av.}} < 25$, (c) $p\beta$ and (d) $1/p\beta$ distribution for $\mathrm{PH}_{\mathrm{av.}} \geqslant 25$. In (b) and (d) the expected central value is indicated.

of a track. Since the beam momentum was fixed at 1.2 GeV/c, the expected β for a proton is 25% smaller than for a π. Fig. 4(a) shows the distribution of the measured $p\beta$ by MCS in ECC for the tracks assumed to be π ($PH_{av.} < 25$). The same distribution for protons ($PH_{av.} \geqslant 25$) is shown in Fig. 4(c). Fig. 4(b and d) shows the distribution of inverse $p\beta$, with the vertical line indicating the expected central value. The central value of $1/p\beta$ between the data and the expected value agrees well.

4. Conclusion

In this study a π/p separation greater than 3 sigma was achieved at a momentum of 1.2 GeV/c by detecting the 14% difference in ionization energy loss. This result demonstrates that the UTS automatic emulsion read-out system works as an ideal grain counter for relativistic singly charged particles in emulsion. This method will be widely applicable for particle identification in ECC detectors.

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