CHARACTERISTICS OF A LOW-ENERGY ANTIPROTON BEAM K4

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Abstract

The beam K4 is designed to transport high-intensity, high-purity antiprotons in the momentum range between 0.4 to 0.8 GeV/c. Antiprotons are separated from unwanted particles (pions, muons and electrons) by double-stage mass separation. The solid-angle momentum acceptance of the beam is 34.1 msr%ΔP/P and the beam length is 28.5 m. The measured intensities of antiprotons at 450, 500, 580 and 650 MeV/c are 100, 210, 510 and 1100 per 10^{12} ppp; the corresponding $\pi^-\mu^-e^-/\bar{p}$ ratios are 13.1, 7.7, 8.8 and 22.5, respectively.

Introduction

In recent years there has been increasing need for high-intensity, high-purity, low-energy antiproton beams for the investigation on antiproton physics below 1 GeV/c.[1] At such a low energy, the yield of antiprotons is 10^{-3} to 10^{-5} times as small as that of pions; therefore, efficient mass separation is necessary to reduce the enormous pion background.

At KEK, we have constructed a low-energy antiproton beam K4 using double-stage mass separation technique. Single-stage mass separation reduces the number of unwanted particles to 1/50 to 1/500. Addition of the second mass separator will square this reduction factor.

To reduce the construction cost and to save space in the counter experiment hall, we have decided that the beam should share its first half with the existing K3 beam; K3 is a single-stage electrostatically separated kaon and antiproton beam with the maximum momentum of 1.1 GeV/c.[2]

The construction of the elements of the beam began in the winter of 1979; the commissioning of the beam was in October 1983 and the first physics experiment[3] started immediately after it.

Beam design

Figure 1 shows the schematic layout of the beam and Table I summarizes the parameters of the beam. Primary protons are incident on

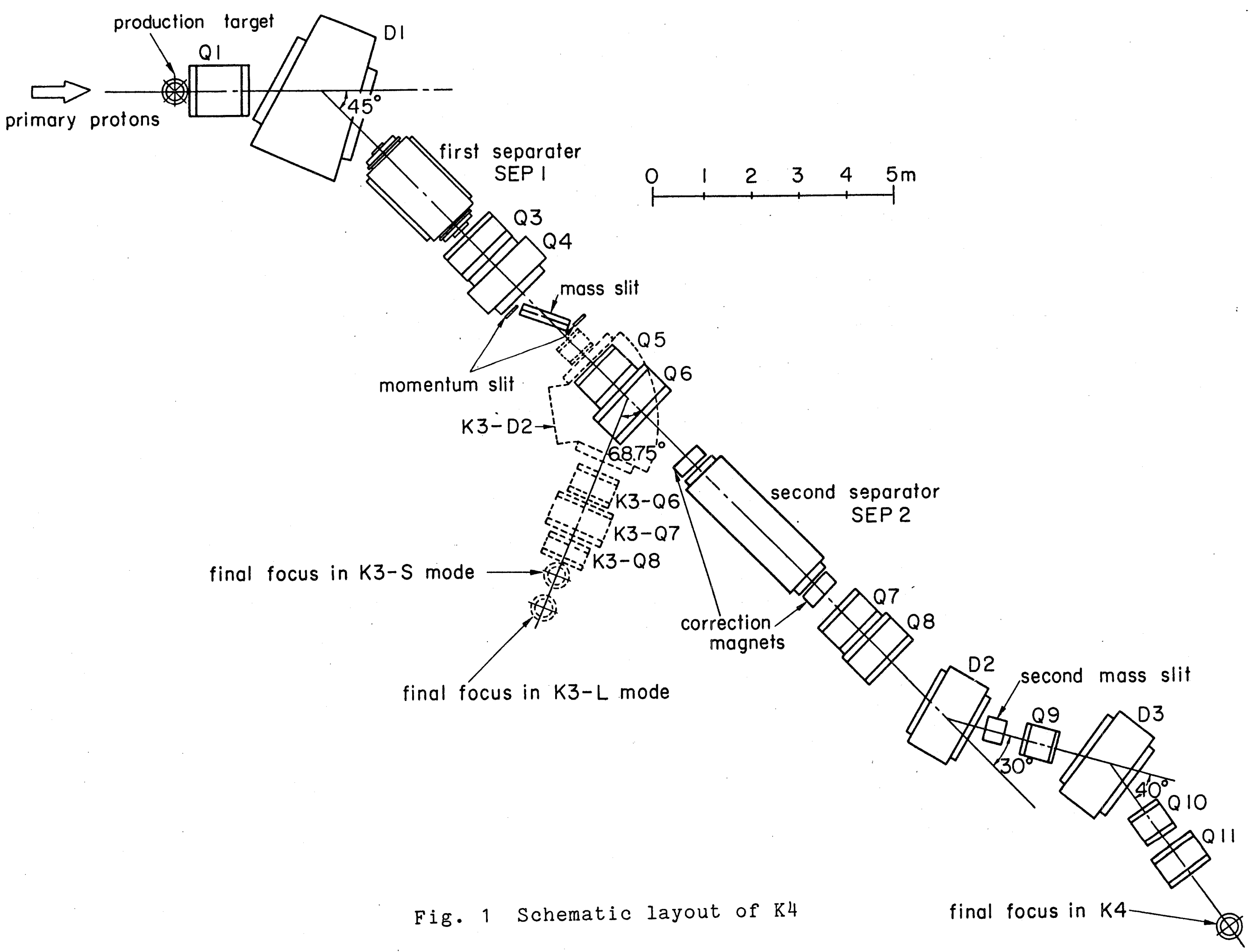

Fig. 1 Schematic layout of K4

a platinum target placed 33.5 cm upstream of the first quadrupole magnet Q1, which focuses the beam horizontally. The 30 cm bore of Q1 limits the horizontal acceptance of the beam to ±220 mr. The central production angle is chosen to be zero degree.

Table I Parameters of K4

Momentum range	0.4∿0.8 GeV/c
Target	5x10x60 mm^3Pt
Central production angle	0°
Beam length	28.51 m
Solid-angle acceptance	7 msr
Horizontal acceptance	±200 mr
Vertical acceptance	±11 mr
Momentum bite	±3.0%ΔP/P
Solid-angle momentum acceptance	34.1 msr%ΔP/P

The first dipole magnet D1 is placed symmetrical with respect to the incoming and outgoing central trajectory. It bends the secondary particles through 45° to separate them from the primary protons. This bending action also gives a necessary dispersion to the secondary particles. The pole-face rotations of 28° at the entrance and exit of the magnet focus the beam vertically and made the beam nearly parallel in the first separator.

The first stage of the mass separation is done by a 1.88-m electrostatic separator SEP1 with a crossed magnetic field. The electric field of 40 kV/cm is applied between the electrodes across a 15 cm gap. The crossed magnetic field cancels the bending force of the electric field on wanted particles to keep their trajectories unchanged in the separator.

A quadrupole doublet Q3 - Q4 focuses the beam onto the first focus F1. The first mass slit located at F1 stops unwanted particles and a momentum slit defines the momentum bite of the beam.

Quadrupole magnets Q5 and Q6 focus the beam horizontally onto F2 located near the center of the second separator. They also make the beam slightly divergent vertically in the separator. Quadrupole magnets Q7 and Q8 focus the beam onto F3 in both directions, where the second mass slit is placed. A dipole magnet D2 placed downstream of Q8 bends the beam through 30° and partially momentum-recombines the beam.

The second electrostatic separator SEP2 has 3 m electrodes. The electric field of 50 kV/cm is applied across the 12 cm gap. Two dipole magnets placed upstream and downstream of the separator compensate the bend of the antiproton trajectory due to the electric field of the separator.

The last stage of the beam is a momentum-recombination section that consists of a dipole and three quadrupole magnets. The dipole magnet D3 bends the beam through 40°. Quadrupole magnets Q9, Q10 and Q11 focus the beam both horizontally and vertically onto the final focus F4 placed 1.5 m downstream of the exit face of Q11.

The beam is simulated with the program DECAY TURTLE[4] to the second order. The calculated solid-angle momentum acceptance is 34.1 msr%ΔP/P, which is 90% of K3.

The first mass slit makes an angle of 30° with respect to the central trajectory. The main second-order chromatic aberration term <Y|Y'ΔP/P> is zero along the jaws of the mass slit. At the second mass slit the corresponding angle is very close to zero degree; therefore, it is not practical to tilt the mass slit.

Measurement of the beam performance

Set-up The beam tuning of K4 and its performance measurement was done during the first stage of the experiment E68 using the same setup. Figure 2 shows schematically the setup used.

Two TOF counters S1 and S2, S1 being placed in front of the third focus F3 and S2 placed 60 cm downstream of Q11, select antiprotons from background pions, muons and electrons. Five multiwire proportional chambers W1 to W5 determine the trajectory of the incoming beam. The $\bar{p}$ beam is slowed down in a carbon degrader. The dE/dx signal of the slow $\bar{p}$ is measured by a 10-mm thick scintillation counter S4 and by a 3-mm thick Si SSD. The trajectory of the slowed down $\bar{p}$ is measured by MWPC's W6 and W7. The beam stops in liquid hydrogen contained in a target cell with the dimension of 140 mm in diameter and 230 mm in length.

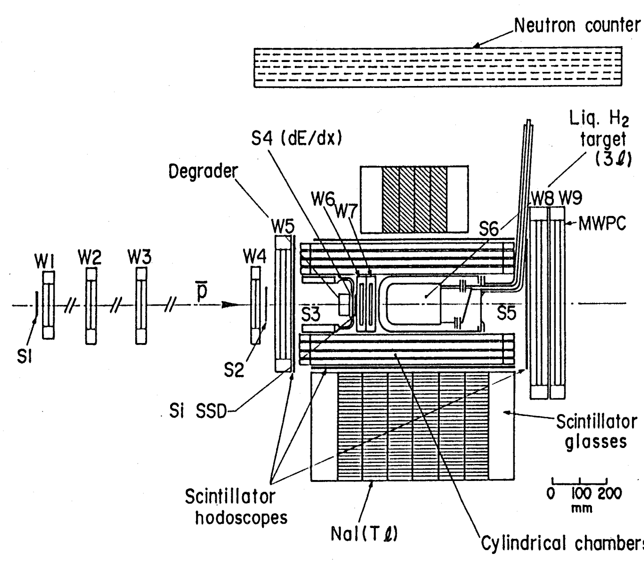

Fig. 2 Setup for E68 experiment.

Measurement The performance of the beam was measured at 450, 500, 580 and 650 MeV/c. Figure 3 shows a typical two-dimentional profile of the $\bar{p}$ at 580 MeV/c at the center of the hydrogen target. It is calculated by extrapolating the antiproton trajectory measured by W3 and W4 onto the target center. The shape is nearly round; the width is 3 cm at FWHM in both directions.

Figure 4 and 5 show the typical separation curves of the beam. In Fig. 4 the crossed magnetic field of SEP1 is varied, while the currents of the correction magnets for SEP2 are set to transport 580 MeV/c antiprotons. It shows clear separation between

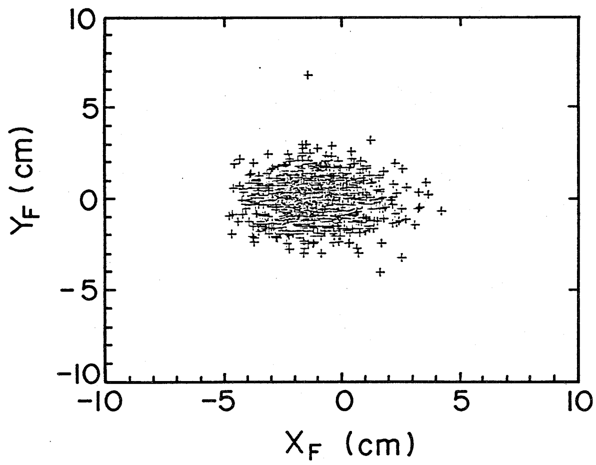

Fig. 3 Beam profile at the center of the hydrogen target.

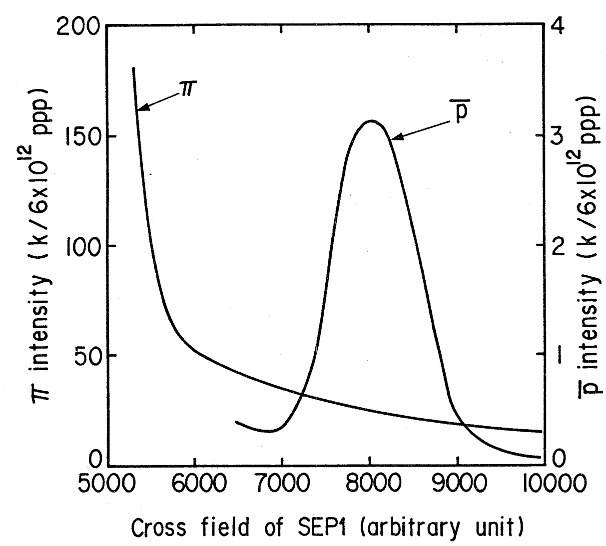

Fig. 4 Separation curve of SEP1 at 580 MeV/c; SEP2 is tuned for antiprotons.

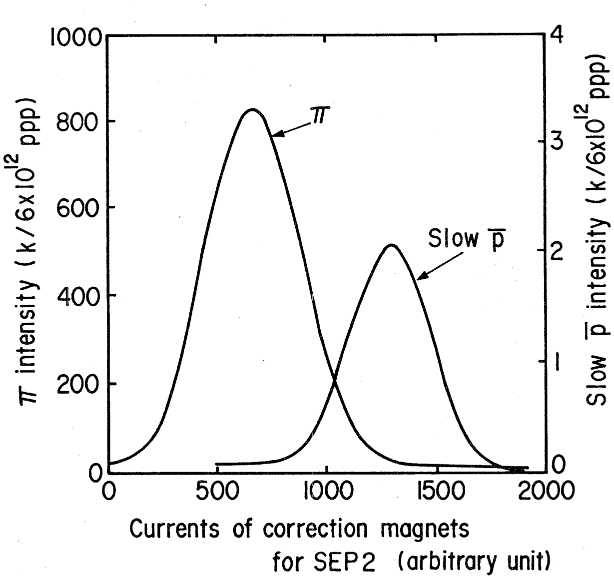

Fig. 5 Separation curve of SEP2 at 580 MeV/c; SEP1 is tuned for antiprotons.

pions and antiprotons.

Figure 5 shows the variation of intensities of pions and antiprotons when the crossed field of SEP1 is tuned for 580 MeV/c antiprotons and the currents of the correction magnets for SEP2 are varied. It shows that the reduction of the pion background due to the second separator is 1/80.

Figure 6 shows measured antiproton intensities and background-to-antiproton ratios with a function of the beam momentum.

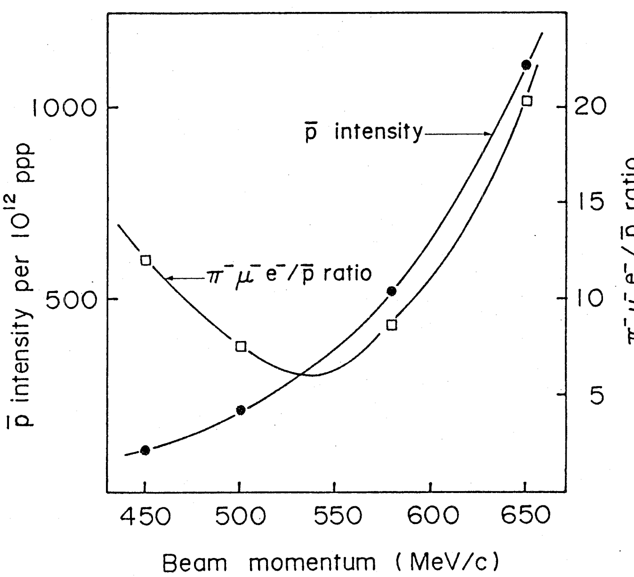

Fig. 6 Intensity of antiprotons and $\pi^-\mu^-e^-/\bar{p}$ ratio versus beam momentum.

Discussion

To estimate the effectiveness of the double-stage separation, we compare our results with the performance of the K3 beam. From reference 5, the $\pi^-\mu^-e^-/\bar{p}$ ratios at K3 between 500 and 600 MeV/c are 200 - 300. This means that the additional reduction of 1/20 - 1/40 is achieved in K4 compared with K3.

Acknowledgments

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