CERN/EP/0050R/MFL/mk
24 June 1980

A MEASUREMENT OF $\bar{p}$ PRODUCTION AT 5 AND 6 GeV/c BY 250 GeV PROTONS INCIDENT ON Be TARGETS

I.F. Corbett, Max Ferro-Luzzi and D.E. Plane

Using the well understood S1 beam [1] in the West Hall in the unseparated mode, three sets of measurements were made:

(a) Total fluxes 150 m from the production target T1.

(b) e/π ratios at the CEDAR [2] Cerenkov counter 214 m from T1.

(c) $\bar{p}$/total flux ratios with threshold Cerenkov counters $\sim$ 192 m from T1.

With these measurements and some assumptions about the loss of particles down the beam line it is possible to obtain the $\bar{p}$ production rates with an error of $\sim \pm$ 20%, mostly coming from uncertainty in the incident proton flux.

TOTAL FLUX MEASUREMENTS

These were made under well controlled beam conditions at -5 GeV/c only, using carefully prepared counters efficient at high rates. The acceptance of the beam for the two different collimator settings used was calculated using the program TURTLE [3]. The measured fluxes at these two settings, when normalized to the same acceptance, agree to ± 5%. Table 1 below gives the results.

TABLE 1

Target head[a]	Total flux at -5 GeV/c Particles/incident proton/μsr/%
#2 3 x 2 x 300 Be	$2.0 \cdot 10^{-6}$
#3 2 x 1 x 100 Be	$3.8 \cdot 10^{-7}$
#4 2 x 1.5 x 40 Be	$1.0 \cdot 10^{-7}$
#5 3 x 2 x 10 Be	$2.5 \cdot 10^{-8}$

(a) Transverse and longitudinal dimensions in mm.

The incident proton beam intensity was measured with an uncertainty of ∿ ± 20% by secondary emission foils.

CEDAR MEASUREMENTS OF e/π RATIOS

A pressure scan at -5 GeV/c showed clean well separated peaks for π, μ and e. The CEDAR was then set alternately at the pressures corresponding to the π or e peaks and different production targets were used. The pressure curves were repeated with the beam retuned to -6 GeV/c and the measurements with different target heads made as at -5 GeV/c. The results are given in tables 2 and 3 below.

To save time the μ/π ratio was only measured once, at -5 GeV/c. It is assumed that the μ/π ratio is the same for all targets and is the same for 5 and 6 GeV/c. Because the μ content of the beam is so small any error in this assumption will have a negligible effect. The p ratios are taken from the subsequent measurements with the threshold counters. The K^- content was measured at less than 0.1% and is ignored.

TABLE 2

Target head	% of total at -5 GeV/c e^-	π^-	μ^-	$\bar{p}$
#1 2 x 1 x 300	89.01	10.39	0.36	0.25
#3 2 x 1 x 100	73.44	25.19	0.86	0.51
#4 2 x 1.5 x 40	55.75	41.95	1.44	0.86
#5 3 x 2 x 10	38.60	58.23	1.96	1.19

TABLE 3

Target head	% of total at -6 GeV/c e^-	π^-	μ^-	$\bar{p}$
#1	85.09	14.05	0.48	0.38
#3	65.13	32.95	1.12	0.79
#4	46.30	50.77	1.72	1.21
#5	29.66	66.41	2.26	1.67

With the beam tuned to -6 GeV/c sheets of lead 1 mm thick were put into the beam about 50 m upstream of the CEDAR. The lead was between a horizontal and a vertical focus, and there were three bending magnets between the lead and the CEDAR. The results are given below in table 4.

TABLE 4

Pb thickness[a]	% e^-	$e^-/(\mu+\pi+\bar{p})$	$\mu+\pi+\bar{p}$ flux relative to no Pb
0 mm	46.3%	0.86	1.00
1 mm	36.9%	0.59	0.82
2 mm	26.8%	0.37	0.74
4 mm	13.6%	0.16	0.61

(a) Radiation length of Pb is 5.6 mm.

It should be remarked that the angular acceptance of the S1 beam is very small and the multiple Coulomb scattering in 4 mm lead is ∿ 2 mrad, so much of the reduction in flux could be due to particles being scattered out of the beam.

MEASUREMENT OF $\bar{p}$ FLUXES

The experimental layout used is shown in fig. 1. Scintillation counters S1, S2 and S3, all larger than the beam size, defined a transmission telescope. C2, the standard EA Cerenkov counter in the S1 beam, was filled with CO_2 to 1.2 bar (absolute) throughout the measurements. It detected e, μ and π; when in coincidence with the scintillator telescope it appeared to have an inefficiency of $\ll 0.1\%$. C1 was filled with ethane (C_2H_6) at various pressures to detect the anti protons. A $\bar{p}$ (or K^-) was identified by a count in C1 with no count in C2, each Cerenkov signal being strobed by the triple coincidence of the counter telescope. Random coincidences and veto inefficiencies were measured to be compatible with the beam rate of 100 - 500 kHz and electronic logic resolution times of 10 - 20 ns. Within the limits of the SPS stability all measurements were done at the same total flux rate, to keep electronic rate effects constant.

The C1 pressure curve at -6 GeV/c with target #4 is shown in fig. 2 and that at -5 GeV/c is shown in fig. 3.

The results of these measurements are given below in table 5.

TABLE 5

Target head	$\bar{p}$/all (in %) 5 GeV/c	6 GeV/c
#1	0.25 ± 0.02	0.38 ± 0.02
#3	-	0.79 ± 0.02
#4	0.86 ± 0.02	1.21 ± 0.02
#5	1.19 ± 0.02	-

Apart from electronic uncertanties of the order of 0.1 - 0.5% of the $\bar{p}$ signal, the main source of error comes from:

(a) $\bar{p}$ interacting in C1, producing pion(s) which traverse C2 and hence veto the $\bar{p}$, and

(b) $\bar{p}$ producing δ-rays in C2 and hence self-vetoing.

The effect of $\bar{p}$ interactions should show up as a slope on the plateau region of the pressure curve, since the interaction probability and hence loss of $\bar{p}$'s will increase as the pressure increases. No such slope can be seen. A calculation using the total inelastic cross section suggests that $\sim$ 3% of $\bar{p}$ should be lost by this mechanism. The effect of δ rays can be calculated explicitly to give a correction of $\sim$ +1%. A combined correction factor of 1.04 has therefore been applied to the measured $\bar{p}$ fluxes.

A single K^- measurement (fig. 2) was made at -6 GeV/c with target head #4, giving K^-/all = (0.065 ± 0.015)%

FLUXES AT PRODUCTION TARGET

To obtain the $\bar{p}$, π^- and e^- yields at the production target it is necessary to correct for π decays between the different measurement positions, and also estimate the loss of particles due to scattering, interactions etc. The beam optics design is such that no particles should be lost by beam acceptance cuts in the region of the measurements. To make these corrections it was assumed:

(a) that material in the beam had the same proportional effect on all particles. This is not unreasonable since most of the materials were light, with radiation lengths of the same order as interaction lengths.

(b) that changes in the (already small) μ and K^- composition of the beam could be ignored.

With these assumptions the production fluxes can be obtained in particles per incident proton/μsr/%, as given in table 6, with an uncertainty of ± 20% from the incident proton flux measurement.

TABLE 6

Particles per μsr per % per incident proton at -5 GeV/c

Target head	e^-	π^-	$\bar{p}$	$\bar{p}/\pi$ (%)
#1 2 x 1 x 300 Be	$1.21\ 10^{-6}$	$3.04\ 10^{-7}$	$3.50\ 10^{-9}$	1.15
#3 2 x 1 x 100 Be[(a)]	$2.62\ 10^{-7}$	$1.80\ 10^{-7}$	$1.86\ 10^{-9}$	1.03
#4 2 x 1.5 x 40 Be	$5.03\ 10^{-8}$	$8.14\ 10^{-8}$	$8.00\ 10^{-10}$	0.98
#5 3 x 2 x 10 Be	$8.39\ 10^{-9}$	$2.72\ 10^{-8}$	$2.70\ 10^{-10}$	0.99

(a) $\bar{p}$ results obtained by interpolation.

Similar yields at 6 GeV/c, where total flux measurements were not made, are obtained by using the observation that during the CEDAR measurements the total flux at -6 GeV/c was ∿ 25% greater than at -5 GeV/c with the same collimator settings.

TABLE 7

Particles per μsr per % per incident proton at -6 GeV/c

Target head	e^-	π^-	$\bar{p}$	$\bar{p}/\pi$ (%)
#1 2 x 1 x 300 Be	$1.29\ 10^{-6}$	$4.59\ 10^{-7}$	$6.65\ 10^{-9}$	1.44
#3 2 x 1 x 100 Be	$2.27\ 10^{-7}$	$2.48\ 10^{-7}$	$3.18\ 10^{-9}$	1.28
#4 2 x 1.5 x 40 Be	$3.72\ 10^{-8}$	$8.78\ 10^{-9}$	$1.13\ 10^{-9}$	1.28
#5 3 x 2 x 10 Be(a)	$5.38\ 10^{-9}$	$2.69\ 10^{-8}$	$3.44\ 10^{-10}$	1.27

(a) $\bar{p}$ results obtained by interpolation.

The results for both -5 and -6 GeV/c are shown in figs 4 and 5.

These results can be compared with the predictions of the thermodynamic model(*), see table 8.

TABLE 8

momentum	Target	$\bar{p}$ production measured	$\bar{p}$ production predicted	$\bar{p}/\pi^-$ (in %) measured	$\bar{p}/\pi^-$ (in %) predicted
-5 GeV/c	300 mm	$(3.5 \pm 0.7)10^{-9}$	$1.8\ 10^{-9}$	1.1 ± 0.1	1.17
	40 mm	$(8.0 \pm 1.6)10^{-10}$	$4.2\ 10^{-10}$		
-6 GeV/c	300 mm	$(6.6 \pm 1.6)10^{-9}$	$2.6\ 10^{-9}$	1.3 ± 0.1	1.18
	40 mm	$(1.1 \pm 0.2)10^{-9}$	$6.0\ 10^{-10}$		

The $\bar{p}/\pi^-$ ratios clearly agree very well; the observed increase of a factor 2 in production rates could well be due to tertiary and higher order production.

(*) A version of the thermodynamic model used by the SPS EA group predicted the intensities. Target efficiencies were calculated using a proton absorption length of 400 mm and an absorption length for secondaries of 550 mm, assuming no sideways escape of secondaries. This model predicts secondary particle production in pp collisions: to account for the Be target, scaling factors of 0.45 for π and 0.64 for K^- and $\bar{p}$ were used. These factors were measured experimentally between 60 and 340 GeV/c in the North Area (to be published as CERN yellow report).

The corresponding figures for K^- at 6 GeV/c with the 40 mm long target are:

K^-		$K^-/\pi(\%)$	
measured	predicted	measured	predicted
$(5.0 \pm 1.6)10^{-9}$	$6.7\ 10^{-9}$	5.7 ± 1.8	13.0

An earlier measurement of the $\bar{p} : K^- : \pi$ ratios at 6 GeV/c by Bozzoli et al. (4), with 200 GeV/c protons on the 40 mm Be target, gave the results

$$\bar{p} : K^- : \pi = (1.5 \pm 0.4) : (5.2 \pm 0.9) : 100$$

which compare well with our results

$$\bar{p} : K^- : \pi = (1.3 \pm 0.1) : (5.7 \pm 1.4) : 100.$$

REFERENCES

[1] S1 beam:
West Area surface beams, DE Plane, March 1978, CERN/SPS/EA/78-7.

[2] CEDAR Cerenkov Counters:
C. Boret, R. Maleyran, A. Placci and M. Placidi, September 1977, CERN/SPS/EBP/77-19.

[3] TURTLE:
K.L. Brown and Ch. Iselin, CERN/74-2, February 1974.

[4] W. Bozzoli et al. Nucl. Phys. B140 (1978) 271.

FIGURE CAPTIONS

Fig. 1 Experimental set up to measure the $\bar{p}$ flux. C1 is the high-pressure Cherenkov counter, filled with ethane ($C_2 H_6$). C2 is the EA Cherenkov counter filled with CO_2 at 1.2 bar (absolute). S1, S2 and S3 are scintillation counters; S1 with size 150 x 100 mm^2, S2 and S3 with size 100 mm in diameter. The CEDAR was ∿ 18 m downstream of S3. S1 was ∿ 192 m from the target head T1.

Fig. 2 Pressure curve at -6 GeV/c with the C1 Cherenkov. The counter telescope was S1.S2.S3. The counting rate, normalized to the telescope, was S1.S2.S3.C1.$\overline{C2}$. The two steps appearing in the graph are due to the antiprotons and to the K^-. The target head was # 4.

Fig. 3 Pressure curve at -5 GeV/c with the C1 Cherenkov for the same conditions as in fig. 2. The K^- flux was not measured at this momentum.

Fig. 4 Antiproton production rates as a function of the beryllium target length at 5 and 6 GeV/c.

Fig. 5 Negative pion production rate as a function of the beryllium target length at 5 and 6 GeV/c.

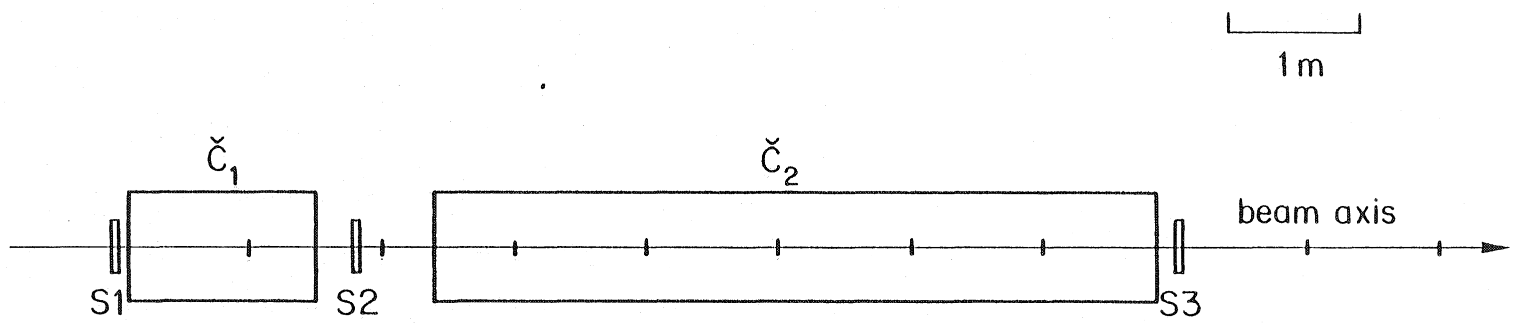
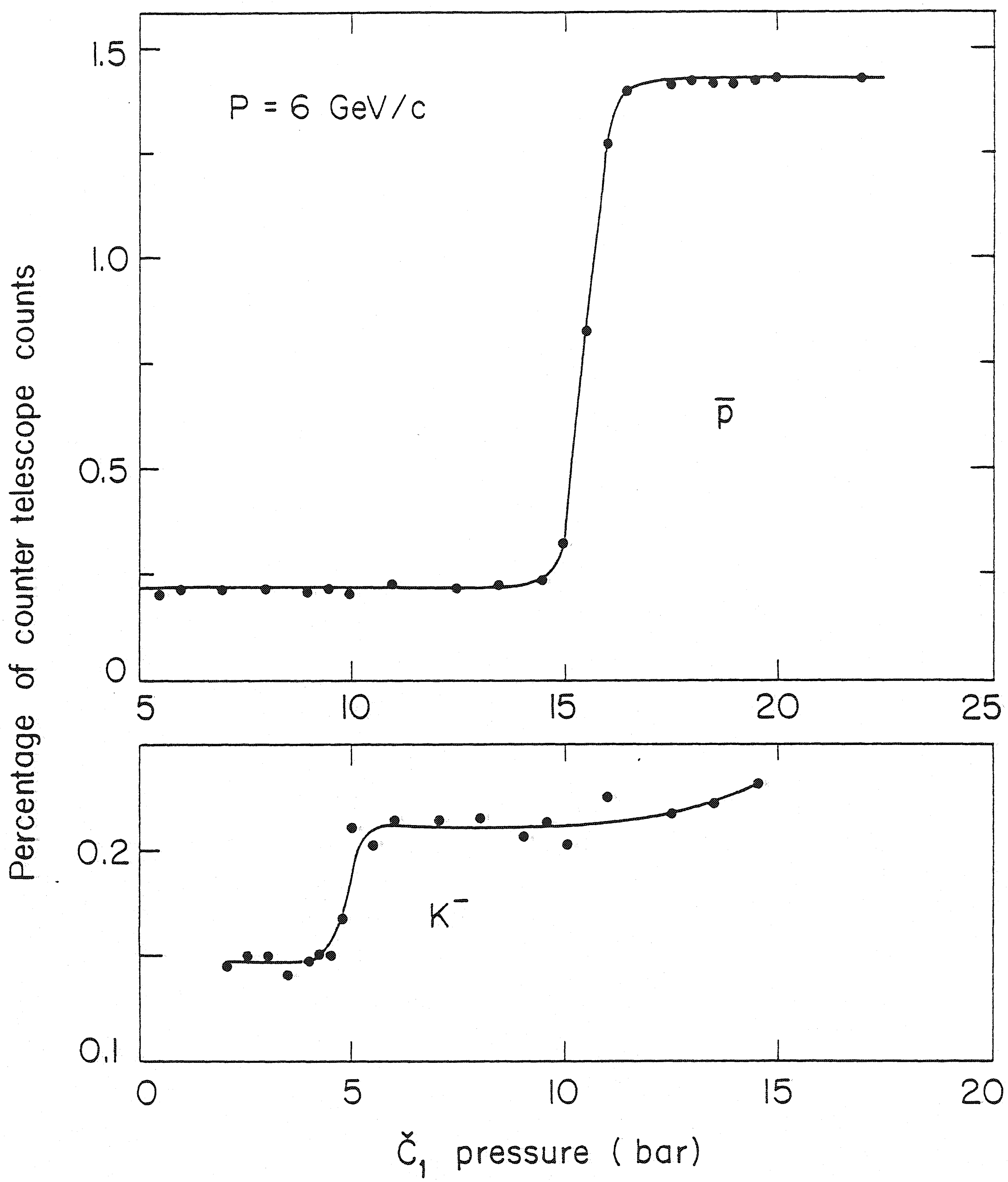
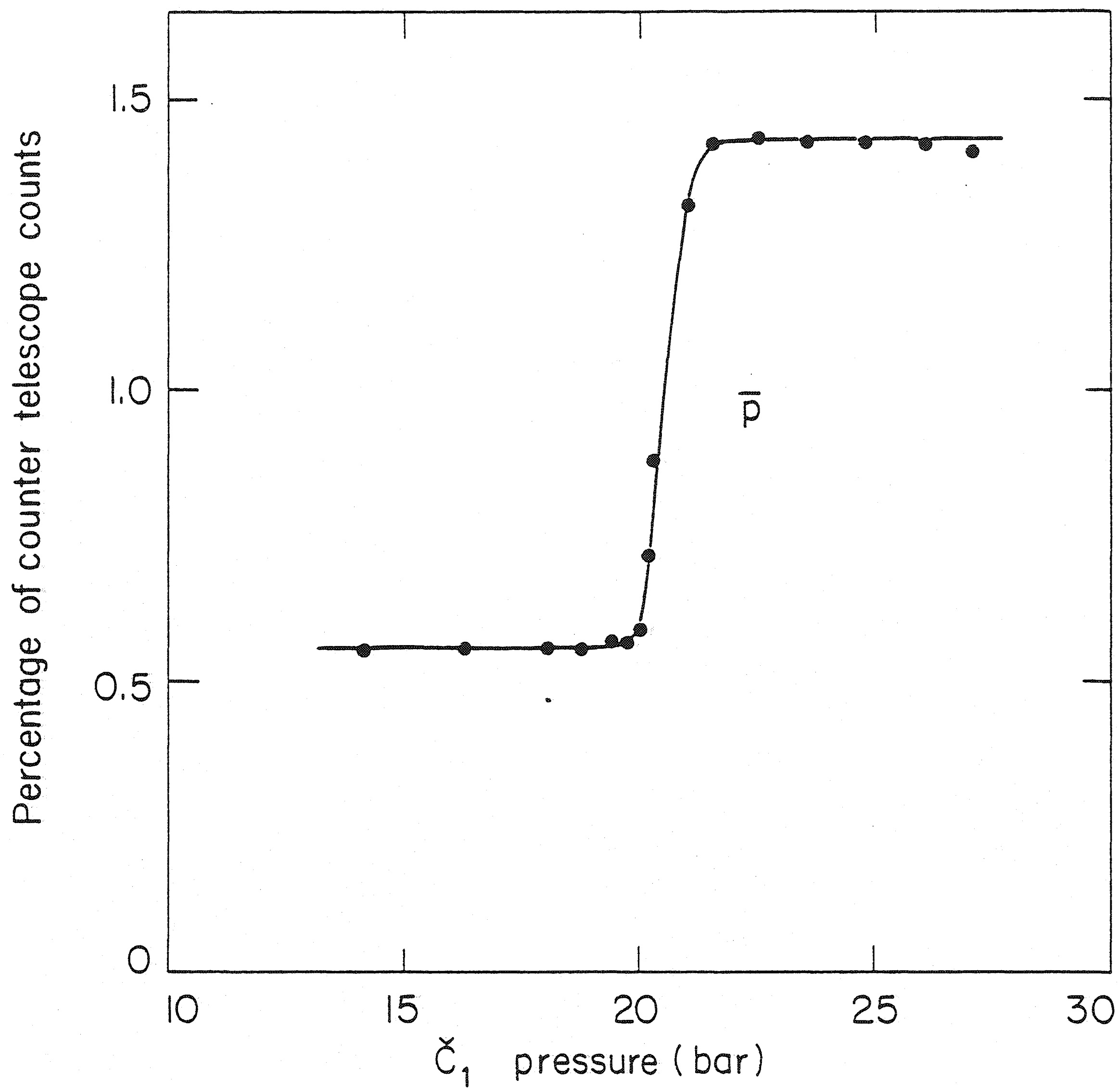


Fig. 1



Percentage of counter telescope counts
P = 6 GeV/c
p̄
K⁻
Č₁ pressure (bar)
1.5
1.0
0.5
0
5
10
15
20
25
0.2
0.1
0
5
10
15
20

Fig. 2



Percentage of counter telescope counts
1.5
1.0
0.5
0
10
15
20
25
30
$\check{C}_1$ pressure (bar)
$\bar{p}$

Fig. 3

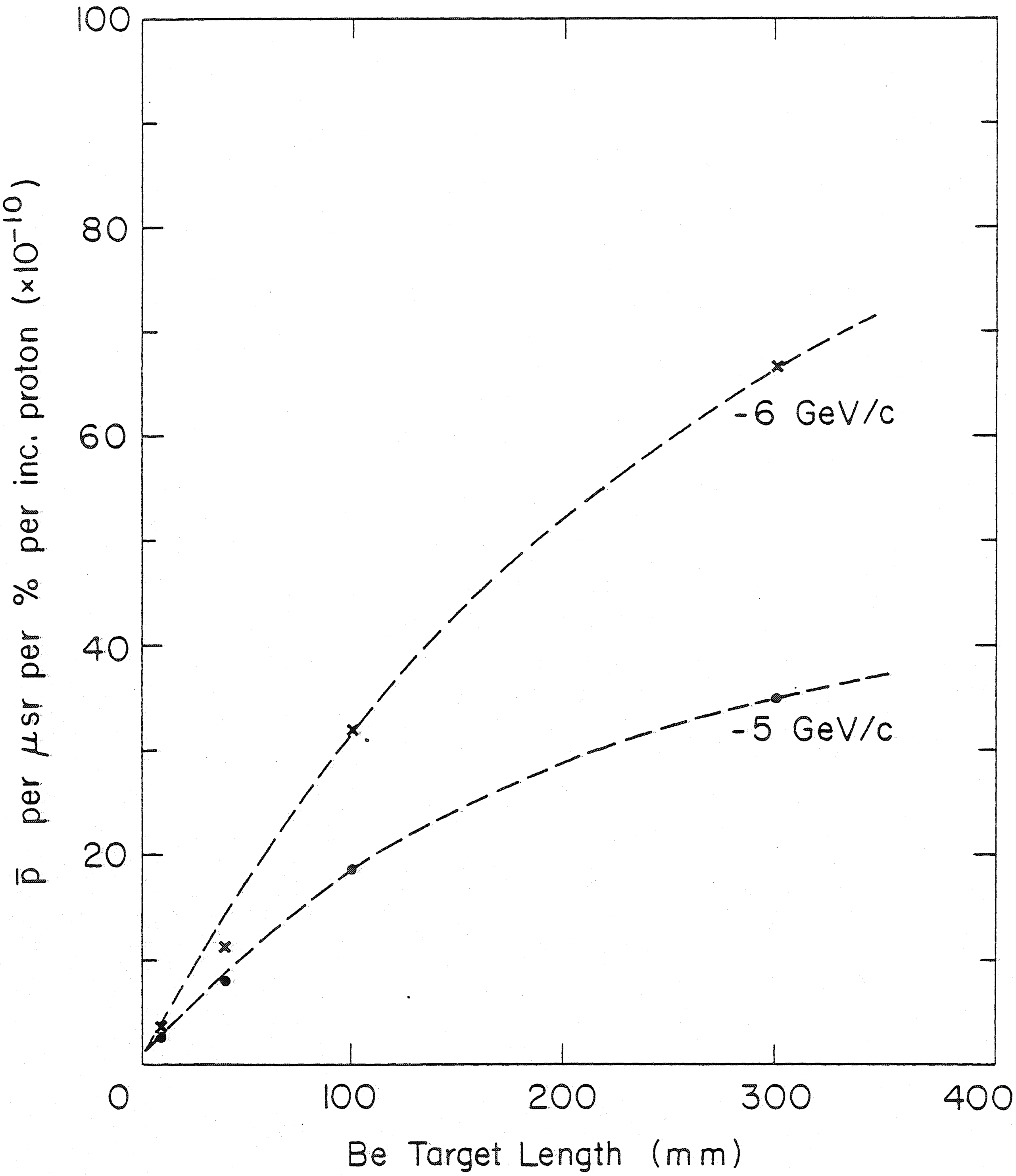

100
80
60
40
20
0
100
200
300
400
p̄ per μsr per % per inc. proton (×10⁻¹⁰)
Be Target Length (mm)
-6 GeV/c
-5 GeV/c

Fig. 4

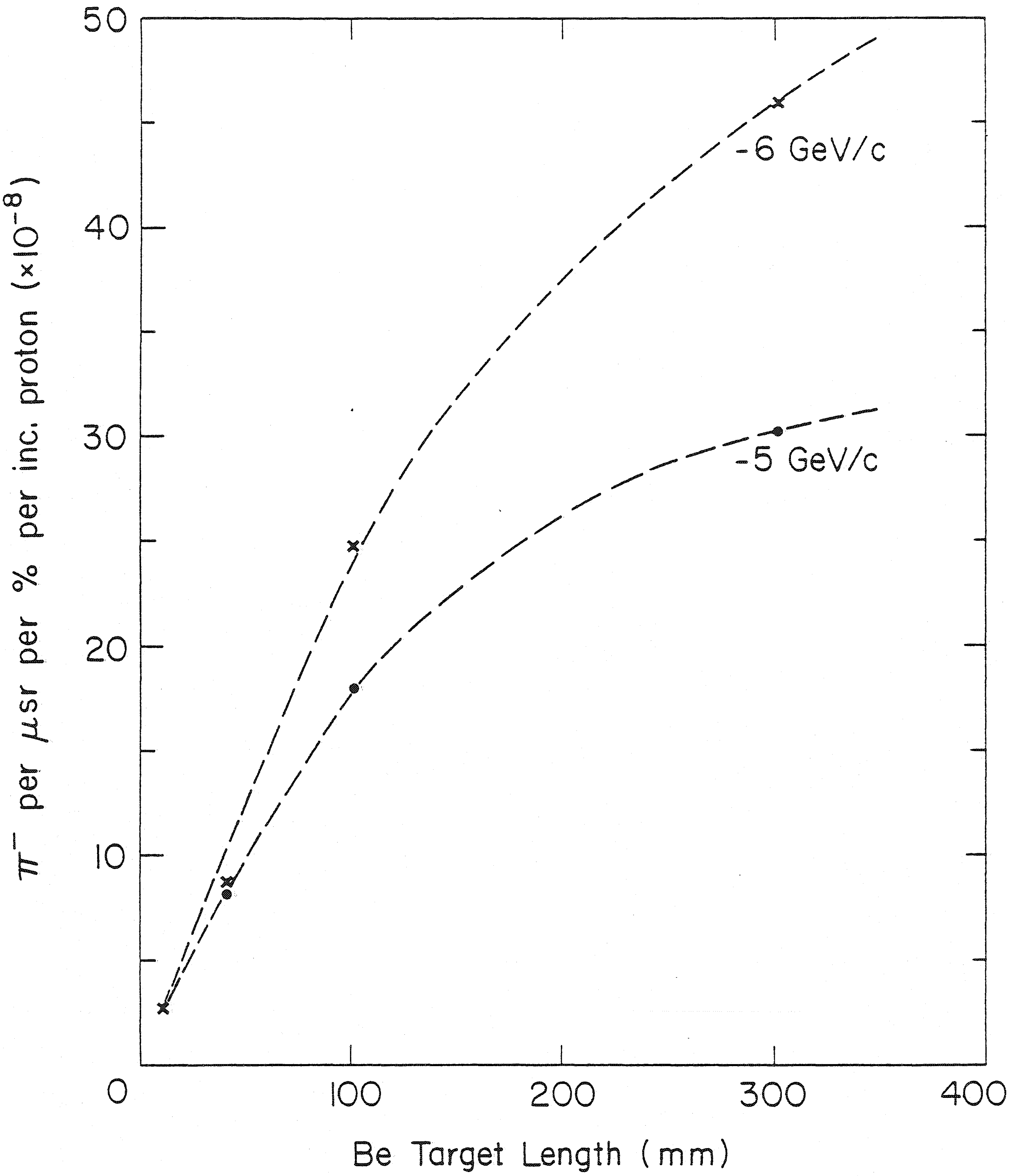

50
40
30
20
10
0
100
200
300
400
-6 GeV/c
-5 GeV/c
π⁻ per μsr per % per inc. proton (×10⁻⁸)
Be Target Length (mm)

Fig. 5