FERMILAB PROPOSAL No. 324

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A PROPOSAL TO STUDY SINGLE PARTICLE INCLUSIVE SPECTRA IN HIGH ENERGY HADRON-HADRON COLLISIONS

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March 1974

REQUEST FOR RECONSIDERATION OF NAL PROPOSAL 52

(SINGLE PARTICLE INCLUSIVE SPECTRA IN $\begin{Bmatrix}\pi^{\pm}\\ k^{\pm}\\ p^{\pm}\end{Bmatrix} + p \rightarrow \begin{Bmatrix}\pi^{\pm}\\ k^{\pm}\\ p^{\pm}\end{Bmatrix}$ + anything)

<u>Experimenters</u>: E. W. Beier, H. Brody, K. Raychaudhuri, H. Takeda
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<u>Date:</u> March 1974

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Request for Reconsideration of NAL Proposal 52

(Single Particle Inclusive Spectra in $\begin{Bmatrix} \pi^{\pm} \\ k^{\pm} \\ p^{\pm} \end{Bmatrix} + p \rightarrow \begin{Bmatrix} \pi^{\pm} \\ k^{\pm} \\ p^{\pm} \end{Bmatrix} +$ anything)

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ABSTRACT

We resubmit our proposal to measure the differential cross section for the production of particle c in the single-particle inclusive reaction a + b → c + anything, where a and c are any combination of $\pi^{\pm}$, $k^{\pm}$ and $p^{\pm}$. Spectra will be measured with incident momenta P_a = 40, 80 and 160 Gev/c over a range of secondary momenta P_c = 0.3 - 2.5 Gev/c and angle θ_c = 5 - 180°, covering the target fragmentation region and part of the central region. In addition we will make precision measurements of the s-dependence of the inclusive cross-sections integrated over the fixed range P_c = 0.3 - 0.6 Gev/c and θ_c = 53 - 57°, for six incident momenta extending to the highest available in the Meson Area. The cross-sections will be measured with the U. of Pa. Single Particle Spectrometer, which is presently being used at the Brookhaven A.G.S. Preliminary A.G.S. results are presented to document the performance of this spectrometer.

INTRODUCTION

There are three principal reasons for reconsideration of this proposal:
(1) We have now completed the 0.25 - 2.5 Gev/c secondary momentum phase ("short arm") of our BNL running and can document the quality of our spectrometer with actual data.
(2) Based on our running experience at BNL, we have modified our proposal somewhat. First, we have added a series of precision s-dependence measurements with fixed spectrometer momentum and angle and variable beam momentum. These will extend our A.G.S. s-dependence measurements, preliminary results of which are presented below. Second, we have decided to measure spectra with the short arm only. This still gives complete coverage of the target fragmentation kinematic region, but it gives only partial coverage of the central region. The kinematic region from 2.5 Gev/c, where the short arm coverage stops, to 20 Gev/c, where the SAS facility begins its coverage, can be studied with our "long arm" configuration. We leave this for a future proposal.
(3) We understand that the University of Washington group has shifted its interest from inclusive scattering to hadron jets, and that their inclusive scattering experiment has been taken off the schedule. These is now a large gap in the physics of the NAL program: specifically, there is no precision measurement of inclusive spectra in the target fragmentation and central region, with incident particles other than protons.

Part I of this document is an updated summary of our proposal. Part II is a preliminary report on our inclusive scattering results at BNL. Part II is in response to Prof. Wilson's letter at the time our proposal was initally deferred. That letter stated that action on our proposal would be deferred until preliminary results from our work at Brookhaven became available.

I. SUMMARY OF PROPOSAL

Physics

With the construction of the CERN ISR and the NAL 400 GeV synchrotron, an understanding of multiparticle production processes in hadronic interactions has assumed a role of fundamental importance. Although the general features of these processes has emerged, the data are, in many cases, meager, and experiments performed at different energies with different techniques are often difficult to compare because of restricted kinematic coverage, relative normalization errors, etc. Thus, there exists no set of measurements which fully test the content of models such as the Mueller-Regge phenomenology; for example, factorization, the approach to scaling, production by π's and k's, and so forth. We believe the measurements we propose are as important as measurements of total and elastic cross sections and should be performed at NAL early in the accelerator program.

We propose to extend our systematic study of single particle production, begun at the Brookhaven AGS, to NAL energies. Specifically we propose to measure the differential cross section for the production of particle c in the single particle inclusive reaction:

$$a + p \rightarrow c + \text{anything}$$

where a and c are any of the charged hadrons $\pi^{\pm}$, $k^{\pm}$ and $p^{\pm}$. We sometimes shall abbreviate this reaction as " a $\rightarrow$ c".

The measurements we propose are of two types. The first type is a measurement of the spectrum of particle c for

$$x = \frac{P_{11}^{cm}}{P_{11}^{cm}(MAX)}$$

in the interval $-1.0 < x \leq 0.0$ at incident laboratory momenta P_a = 40, 80, and 160 GeV/c. Our spectrometer provides continuous coverage in secondary lab momentum and lab angle and therefore does not prejudice the measurement in favor of any particular set of variables. Together with our existing AGS measurements at 8, 12, and 20 GeV/c, these higher energy measurements will provide a consistent set of cross sections over a large range of center mass energy.

The second type of measurement is a precision determination of the s-dependence of the inclusive cross-section integrated over the fixed range P_c = 0.3 - 0.6 Gev/c, θ_c = 53 - 57^o, i.e at a single fixed spectrometer setting. These s-dependence measurements will be made with six incident momenta ranging from 20 Gev/c up to the highest available at the Meson Lab. They will supplement our AGS measurements at 4, 6, 8, 10, 12, 15 and 20 Gev/c.

Spectrometer

The University of Pennsylvania Single Particle Spectrometer (Fig. 1) is fully operational at the AGS and requires no further development. The spectrometer is constructed on a steel arm which rotates about a pivot beneath a liquid hydrogen target. A small C-magnet (12C24 with 4" gap) is used in conjunction with multiwire proportional counters (MWPC) and trigger scintillation counters to measure the differential cross section for production of charged particles in a given momentum interval. Immediately behind these detectors is a set of threshold Cerenkov counters, scintillation counters, and another MWPC which are used to measure the ratios of the particle types.

The spectrometer angle is varied in steps corresponding to about one third of the spectrometer's angular acceptance so that the cross section at each production angle is measured in different parts of the spectrometer. A "run" at fixed angle lasts about five minutes. A PDP-9 computer ends the run at a preset count, moves the spectrometer to the next angle, and begins the next run. Incrementing the spectrometer angle takes about six seconds and is accurate to one percent of the increment (the absolute angle is recorded).

The momentum acceptance is $\frac{P(MAX)}{P(MIN)} = 2$, and the momentum range 0.3 - 2.5 GeV/c is covered in three "configurations" of the spectrometer. The configurations have different particle identification detectors, magnet current, and MWPC transverse position. Changing between configurations is a simple procedure; each change is performed only once during the experiment.

The momentum resolution is typically $\frac{\delta P}{P} = .01$ rms. It is limited at low momentum by multiple scattering and at high momentum by the 2 mm wire spacing of the MWPC's.

Particle identification is achieved by the use of threshold Cerenkov counters, and, at low momentum, time of flight and energy loss. Typically, three Cerenkov counters are used. They identify π's, high momentum K's, and low momentum K's respectively. Although construction of counters with the specifications of some of the counters is non-trivial, the counters have been developed and used successfully at the AGS.

Running time and Schedule

The running time required is based on our experience at BNL and is:

1)	Measurement of spectrum		750 hours
2)	Measurement of s-dependence		250 hours
		Total	1000 hours

The equipment is constructed and running at BNL. We will be able to set up at NAL beginning Fall 1974.

We propose to perform the experiment in the west branch of the M1 beam. The entire spectrometer will fit in the alcove presently occupied by the target for Experiment #104 (Total Cross Section).

II. PRELIMINARY A.G.S. RESULTS

Normalization Accuracy

We have strived for absolute normalization accuracy at the few percent level. To search for rate dependent effects, we studied, as a function of incident intensity, the ratio R = (reconstructed secondaries)/(incident beam particles). The measured cross-section is directly proportional to this ratio. The data, Fig. 2, show no significant rate dependence.

In an analogous way we studied the dependence of R on horizontal beam steering. The data are shown in Fig. 3. When the beam is grossly mis-steered, the target full ratio increases because part of the beam hits the target walls, but the full-empty difference remains constant.

.To test the absolute normalization accuracy, we measured $\frac{d\sigma}{dt}$ for elastic scattering of π^+, π^- and p on protons at energies where prior measurements exist. A typical result is shown in Fig. 4. These measurements give us good confidence in our overall normalization.

Particle Identification

The spectrometer is designed for good secondary particle identification not only for $\pi^{\pm}$ and p, but also for $k^{\pm}$ and $\bar{p}$. Figures 5 a-b illustrate the mass separation for positive secondaries in the range $P_c = 1.2 - 2.5$ Gev/c, $\theta_c = 9\text{-}25°$, which is near x = 0 for π's and k's. Fig. 5a is the pulse height spectrum for all secondaries going thru $\check{C}_1$, which separates π's from heavier particles. Fig. 5b is the pulse height spectrum in $\check{C}_3$, which separates low momentum k's from p's. Entries are made in this distribution only for particles with $P_c = 1.2 - 1.88$ Gev/c and $\check{C}_1$ pulse height below 160, i.e. low momentum k's and p's.

In general it appears that uncertainties due to $\pi/k/p$ misidentification are small throughout our data.

Spectra

We have measured inelastic spectra at P_a = 8, 12 and 20 Gev/c, P_c = 0.3 - 2.5 Gev/c, and θ_c = 5 - 180°, with all four polarity combinations. These data have not yet been reduced, but the systematic checks described above give us good confidence in our measurements. Approximately 5×10^6 good events have been recorded.

s-Dependence

We have also measured the s-dependence of the inclusive cross-sections at a fixed secondary momentum in the lab corresponding to the target fragmentation region. These data have been analyzed up to an overall normalization constant, and preliminary results are presented in Fig. 6. The points plotted give values of the inclusive cross-section, integrated over the fixed spectrometer acceptance, in arbitrary units, for various beam momenta (s values). Relative normalization is all that is needed to study the s-dependence of these data; absolute normalization will be obtained later.

There are several aspects of these data that suggest that extension to NAL energies will be particularly profitable.

(1) Accuracy

For the nine copious reactions $\{\pi^{\pm}, p\} \rightarrow \{\pi^{\pm}, p\}$, statistical accuracies approaching 1% are obtained and there appear not to be any s-dependent normalization problems. This is to be compared with normalization discrepencies of ~10% which are encountered in comparing inclusive scattering measurements with bubble chambers.

(2) Limiting Behavior and Pomeron Factorization

It is widely believed that:

(a) inclusive cross-sections of the type we have measured approach a high-energy limit;

(b) the approach to the limit has the form $A + Bs^{-1/2}$;

(c) the high-energy limit is the same for particle and antiparticle in the beam;

(d) the limits of the cross section at $s = \infty$ for different beam particle types are in the same ratio as the corresponding total cross-sections (Pomeron factorization)

Our data are roughly (to within a factor of ≤ 1.5) compatible with these features. However we are unable to fit our data in detail with models satisfying (a) - (d). For example in the simple Mueller-Regge pole model Pomeron factorization requires the intercepts for $\{p \to \pi^-\}$ and $\{\pi \to \pi^-\}$ at $s = \infty$ to have the same ratio as the total pp cross section and the total πp cross section at $s = \infty$. Our data suggest violation of Pomeron factorization by 20% in $\{\pi^\pm, p\} \to \pi^+$ and 40% in $\{\pi^\pm, p\} \to \pi^-$. These results are suggestive but not definitive. Clearly, measurements at higher energies are needed to provide a definitive answer. The question of Pomeron factorization is of fundamental importance to an understanding of high energy hadronic interactions; our kind of measurement is one of the few experimentally feasible direct tests.

(3) The Approach to Scaling

There is a type of information which can come essentially from our AGS data alone: by assuming that the high energy behavior is at least crudely given by (2a-d) above, we obtain information about the rate of approach to scaling. The results are in the form of B values in $A + Bs^{-1/2}$ for the fifteen reactions $\{\pi^\pm, k^\pm, p^\pm\} \to \pi^\pm$ and $\{\pi^\pm, p\} \to k^+$.

The values obtained are insensitive to the details of the high energy behavior assumed. We find clear contradictions with certain of the predictions which have been made about the approach to the scaling limit using duality. For example note the strong s-dependence of $p \to \pi^{\pm}$ (Figs. 6 a,b) which according to common folklore scales early.

It is obvious that the approach to scaling needs further study at NAL. The extended s interval will give a better lever arm for the slope determinations. Because of the favorable $\bar{p}$ and k fraction in the NAL beam, we will be able to study k^+ and k^- induced reactions with good statistics, and $\bar{p}$ induced reactions with moderate statistics. Finally, we should be able to study proton production in the Regge region (our AGS proton production data correspond to missing masses in the resonance region; Regge behavior may be setting in at our highest s-values (Figs. 6 i-k).

(4) Analogy with Total Cross-Section Measurements

The physics of our s-dependence measurements is similar to that of total cross-section measurements. Therefore, one of the exciting possibilities is that there may be unexpected deviations from simple extrapolations, analogous to those seen in total cross section measurements at Serpukhov and, more recently at the ISR.

FIGURE CAPTIONS

Fig. 1. Plan view of the "short arm" spectrometer, which measures angle, momentum and particle type from 0.3 to 2.5 Gev/c. Mounted on the rotary carriage are a 12C24 magnet, trigger counter T_{1-3}, proportional wire chambers PC_{1-5} and threshold Čerenkov Counters $\check{C}_{1-3}$.

Fig. 2. Rate dependence of the measured cross-section. The normal operating beam rate ranges from 0.1×10^6 particles/pulse at the smallest spectrometer angles to 1.5×10^6 at large angles.

Fig. 3. Beam steering dependence of the measured cross-section. In normal operation the magnet is kept within the limits marked "DVM Tolerance".

Fig. 4. Elastic calibration. The cross-section $\frac{d\sigma}{dt}$ for $\pi^- p$ elastic scattering as measured in this experiment is compared with previous measurements.

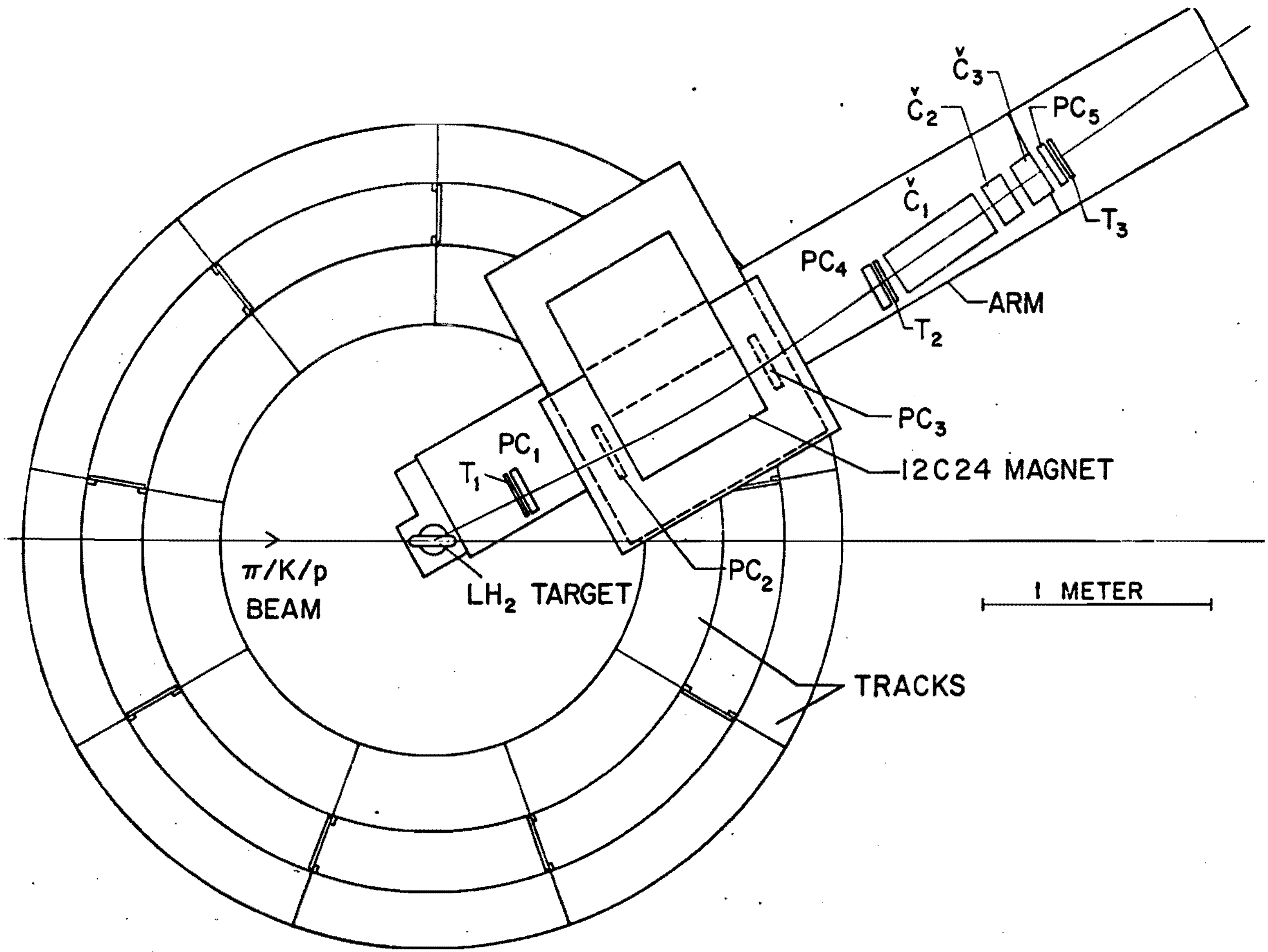
Fig. 5. Spectrometer Čerenkov counter pulse height distribution for a sample of 50% of the data for 20 Gev/c positive beam and 1.2 - 2.5 Gev/c, 9-25 degree positive secondaries.

(a) Spectrum for $\check{C}_1$, which operates at an index of refraction n = 1.019 in order to count π's but not k's and p's.

(b) Spectrum in $\check{C}_3$, which operates at n = 1.117. Only particles of momentum 1.2 - 1.88 Gev/c and pulse height below 160 in $\check{C}_1$ are entered in this distribution, which therefore contains essentially p's and k's only.

Fig. 6. Preliminary s-dependence results. These are raw data on the number of events detected in fixed spectrometer acceptance near P_c = 0.3-0.6, θ_c = 53° - 57°, per 10^8 beam particles. The following important corrections

have not been applied: π and K decay and interactions; spectrometer acceptance variation; lepton contamination in the beam. All but the last of these corrections are expected to be roughly s-independent. Lepton contamination may be important at low s, but has not been measured yet.



$\check{C}_3$
$\check{C}_2$
PC_5
$\check{C}_1$
T_3
PC_4
ARM
T_2
PC_3
PC_1
T_1
12C24 MAGNET
$\pi/K/p$
BEAM
LH_2 TARGET
PC_2
1 METER
TRACKS

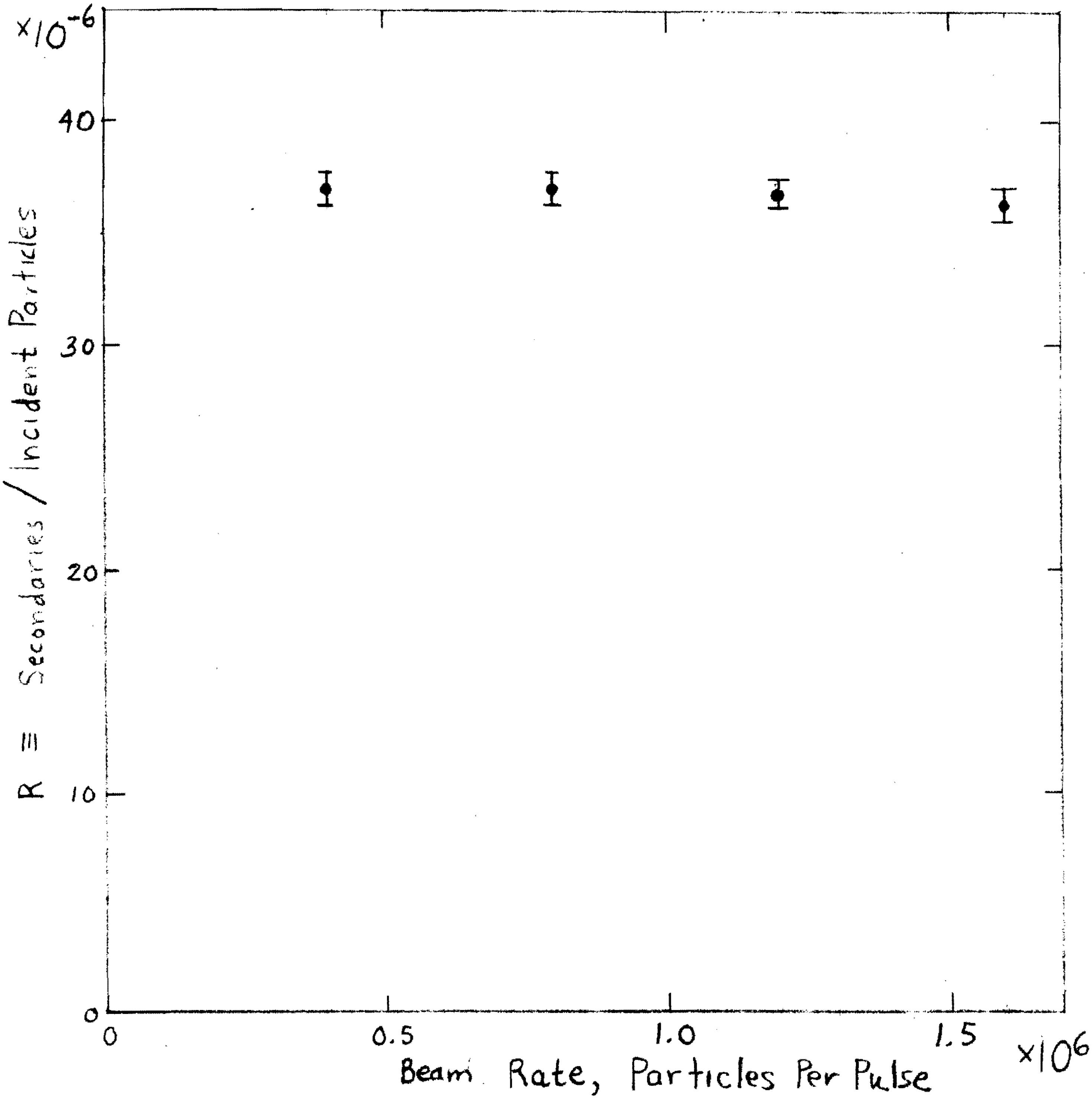
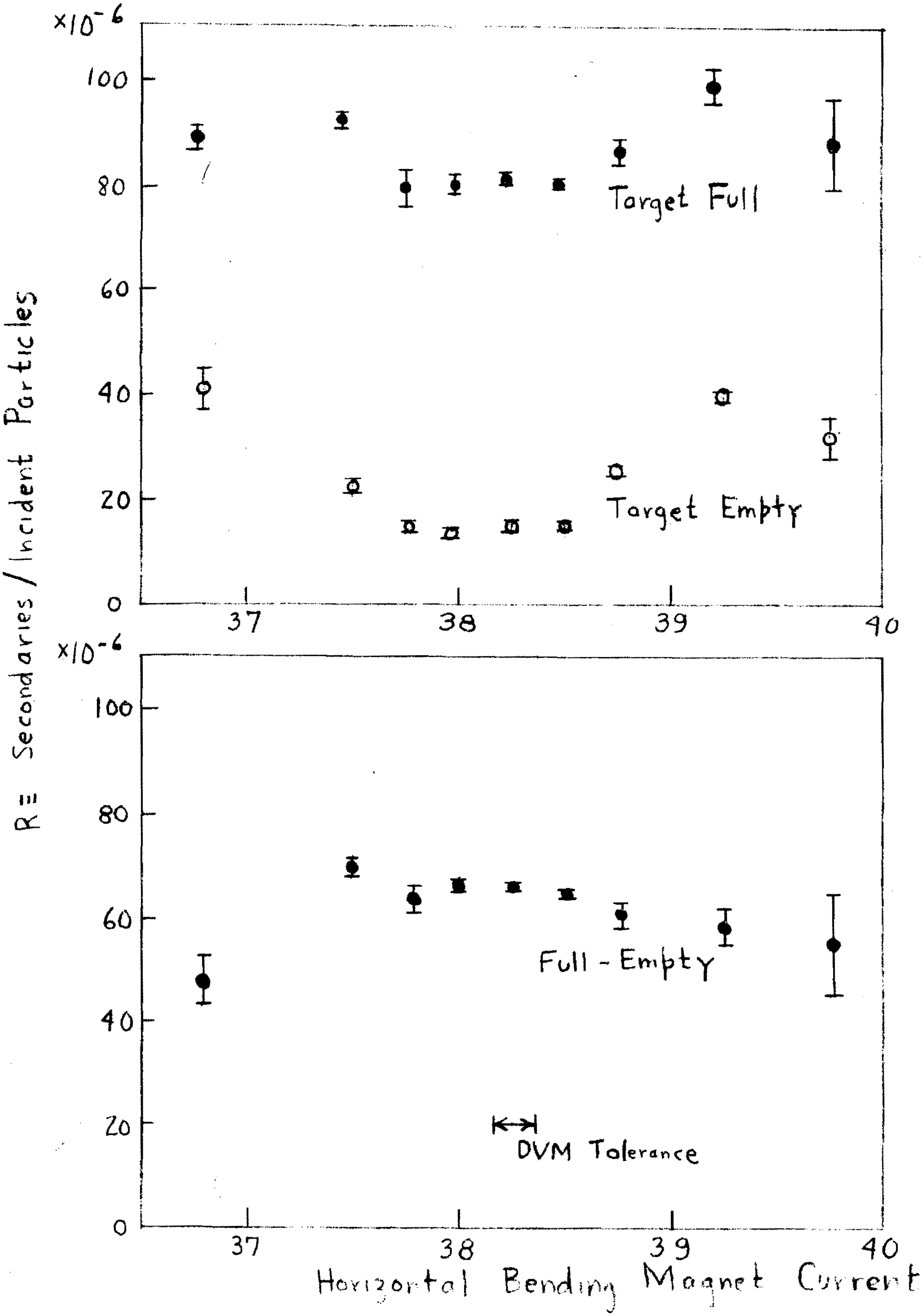

×10^-6
40
30
20
10
0
R ≡ Secondaries / Incident Particles
0
0.5
1.0
1.5
×10^6
Beam Rate, Particles Per Pulse

Figure 2



x10^-6
100
80
60
40
20
0
Target Full
Target Empty
37
38
39
40
R= Secondaries / Incident Particles
x10^-6
100
80
60
40
20
0
Full - Empty
DVM Tolerance
37
38
39
40
Horizontal Bending Magnet Current

Figure 3

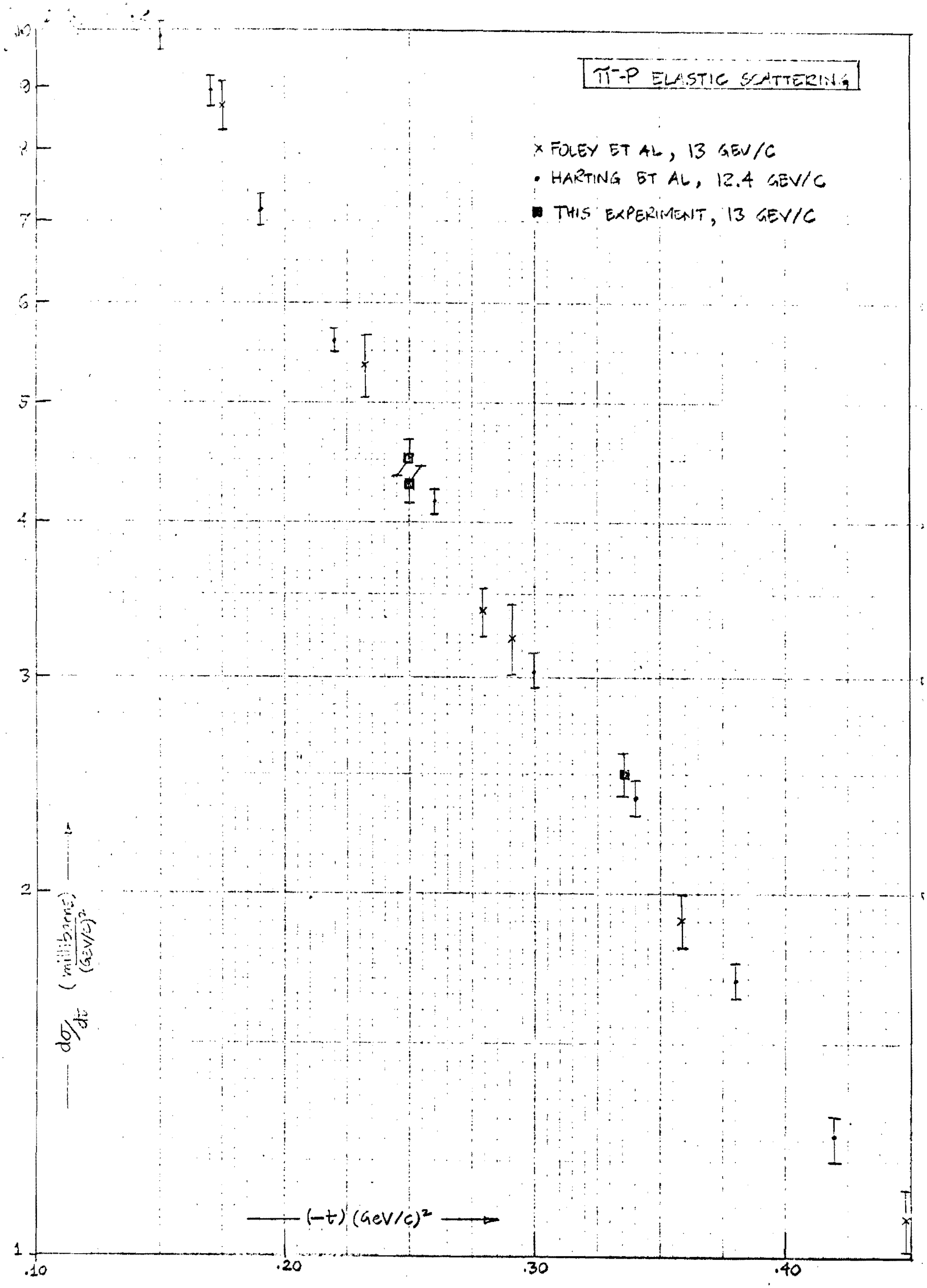

π⁻-P ELASTIC SCATTERING
× FOLEY ET AL, 13 GEV/C
• HARTING ET AL, 12.4 GEV/C
■ THIS EXPERIMENT, 13 GEV/C
dσ/dt (millibarns/(GeV/c)²)
(−t) (GeV/c)²
10
9
8
7
6
5
4
3
2
1
.10
.20
.30
.40

Figure 4

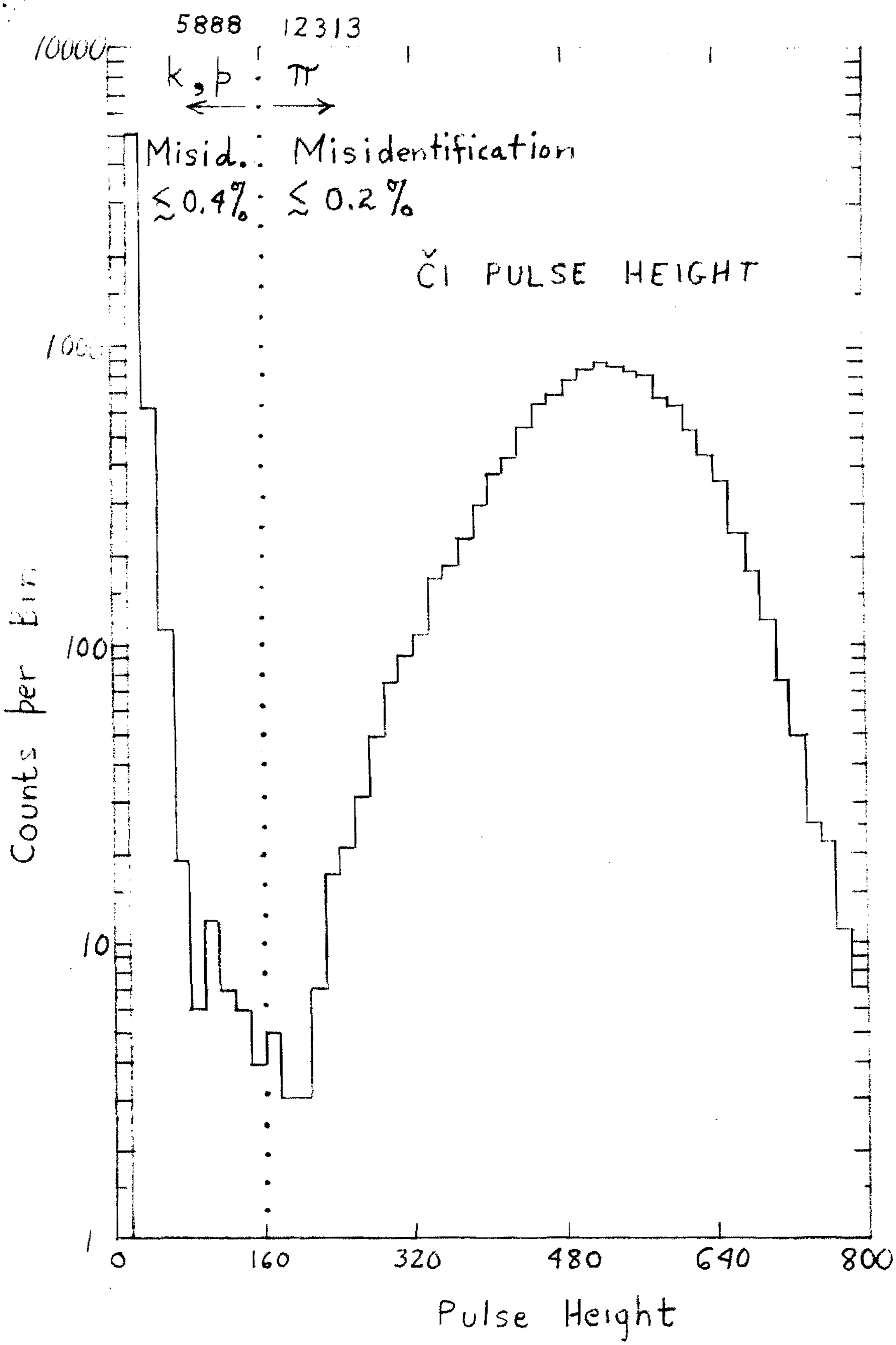
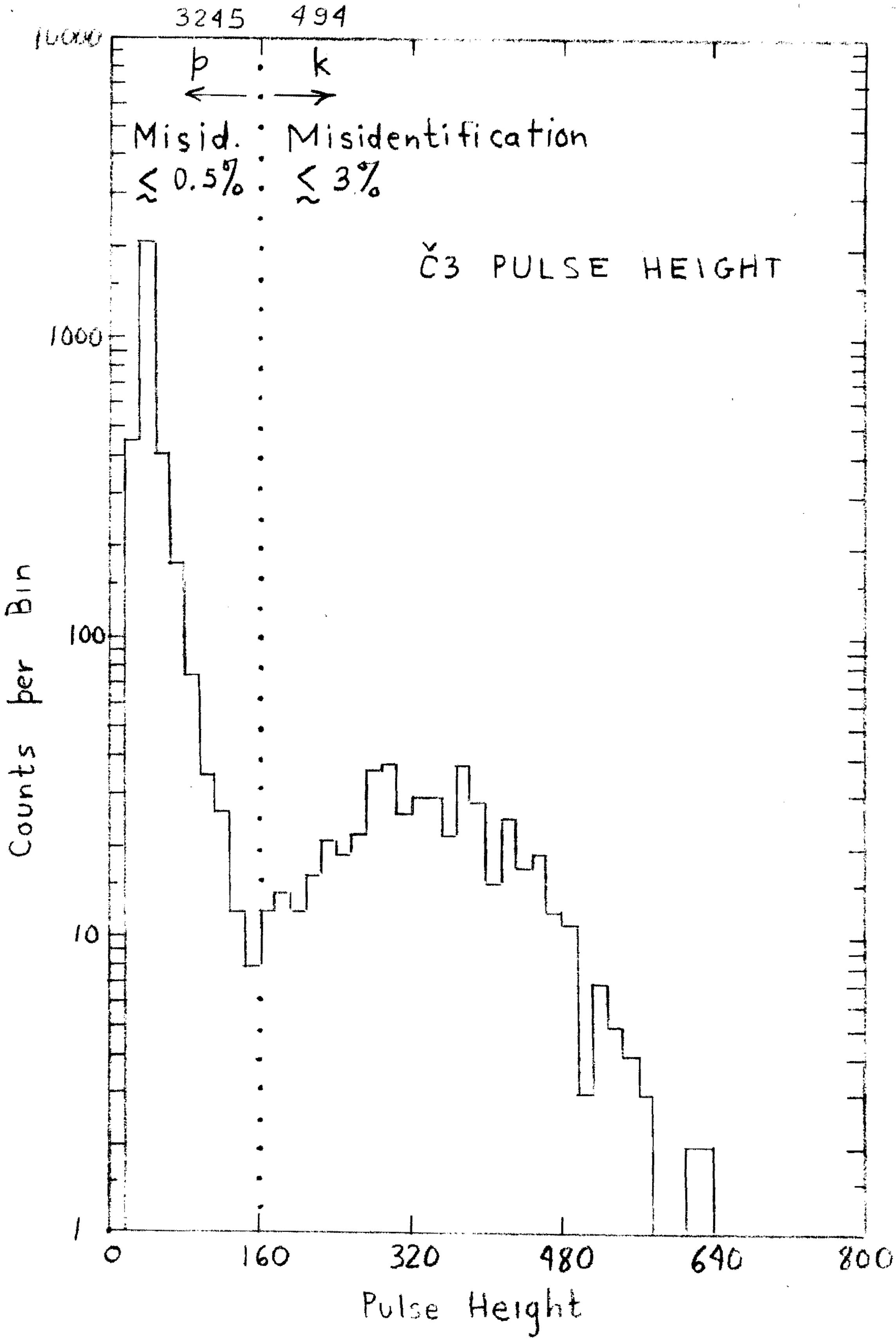
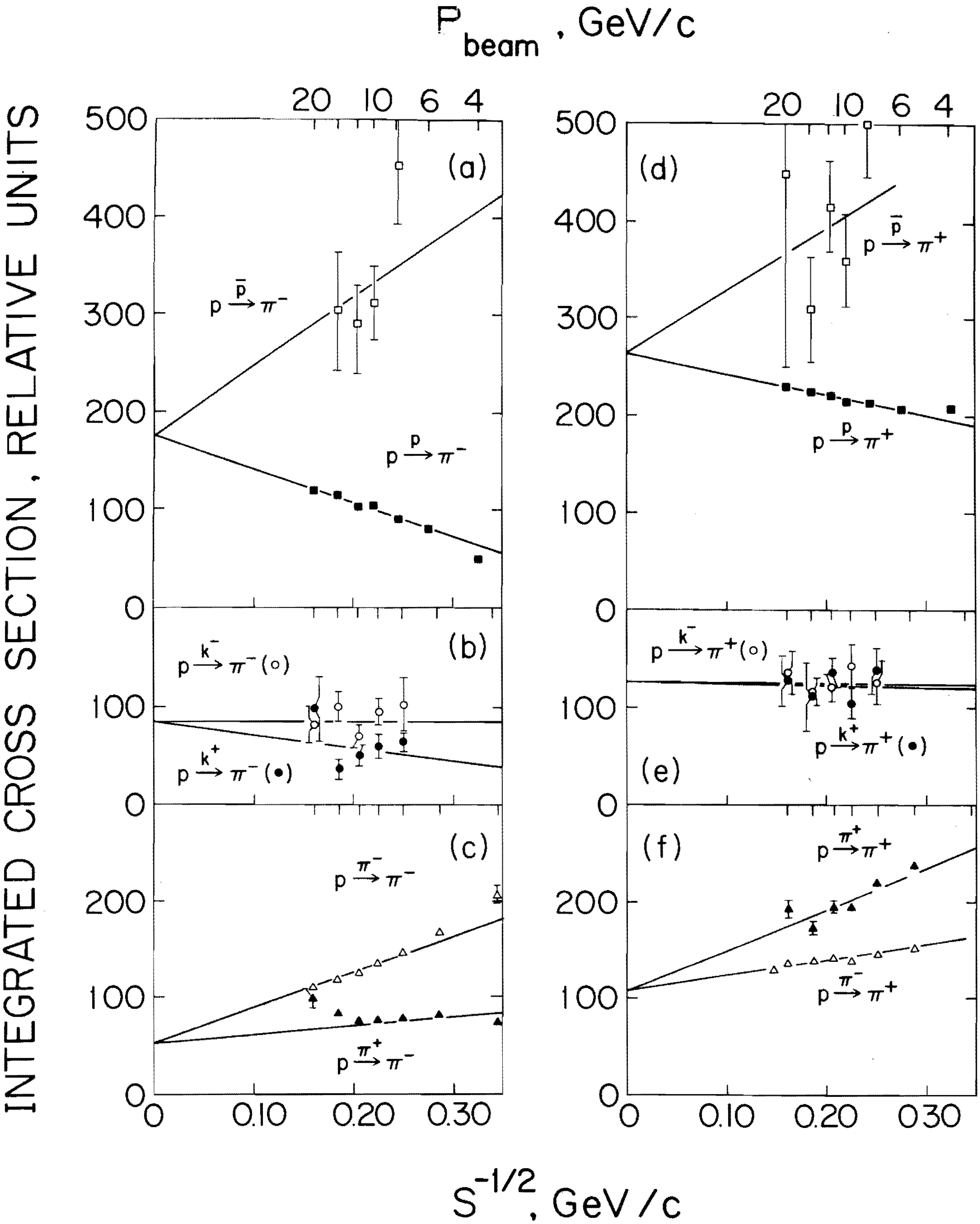

5888
12313
k, p
π
Misid.
≲0.4%
Misidentification
≲ 0.2 %
Č1 PULSE HEIGHT
Counts per Bin
10000
1000
100
10
1
0
160
320
480
640
800
Pulse Height

Figure 5a



3245
494
p
k
Misid.
≲ 0.5%
Misidentification
≲ 3%
Č3 PULSE HEIGHT
Counts per Bin
10000
1000
100
10
1
0
160
320
480
640
800
Pulse Height

Figure 5b



P beam , GeV/c
20
10
6
4
500
400
300
200
100
0
(a)
(b)
(c)
(d)
(e)
(f)
INTEGRATED CROSS SECTION , RELATIVE UNITS
p $\xrightarrow{\bar{p}}$ π^-
p $\xrightarrow{p}$ π^-
p $\xrightarrow{k^-}$ π^- (○)
p $\xrightarrow{k^+}$ π^- (●)
p $\xrightarrow{\pi^-}$ π^-
p $\xrightarrow{\pi^+}$ π^-
p $\xrightarrow{\bar{p}}$ π^+
p $\xrightarrow{p}$ π^+
p $\xrightarrow{k^-}$ π^+ (○)
p $\xrightarrow{k^+}$ π^+ (●)
p $\xrightarrow{\pi^+}$ π^+
p $\xrightarrow{\pi^-}$ π^+
0
0.10
0.20
0.30
$S^{-1/2}$, GeV/c

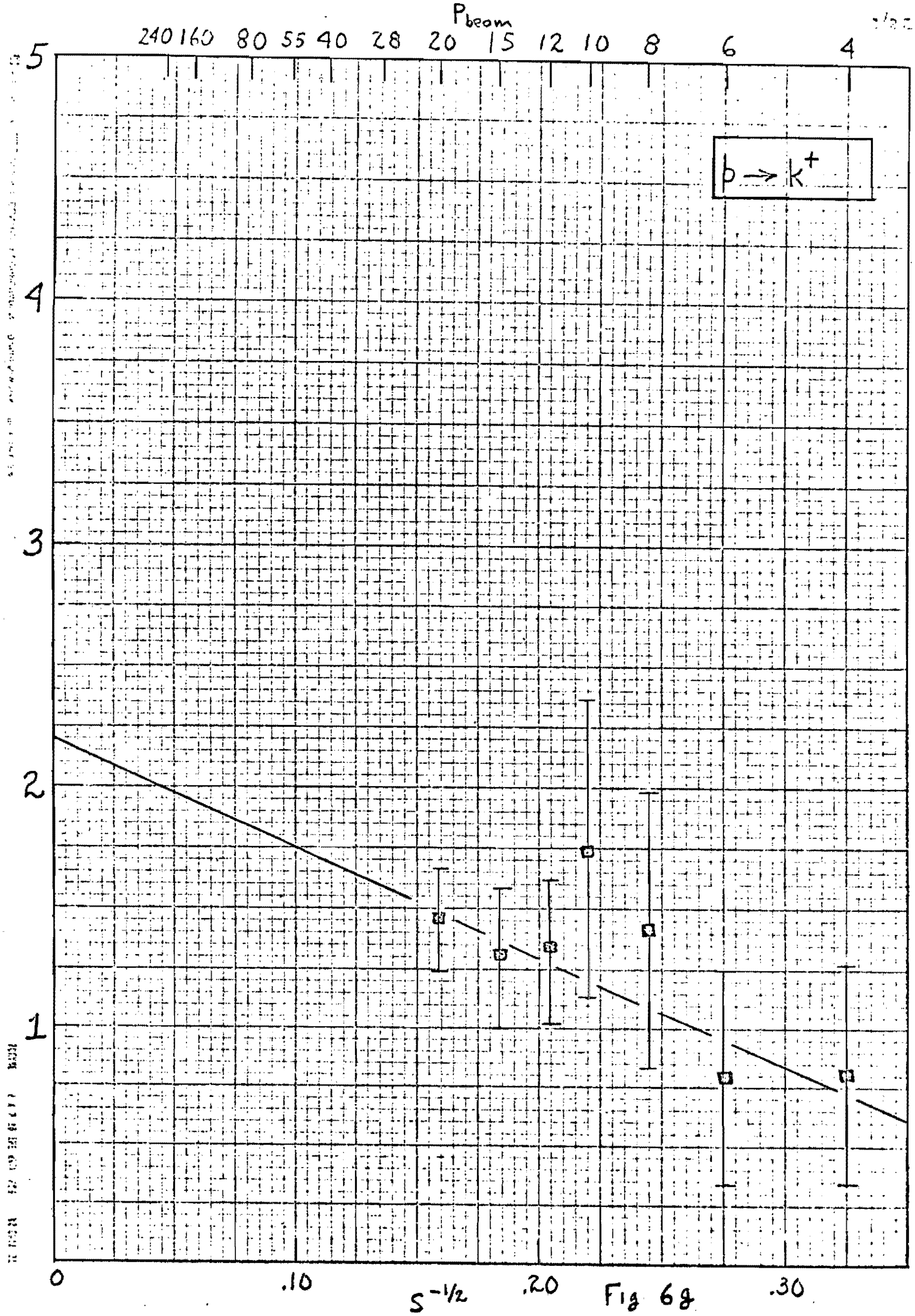
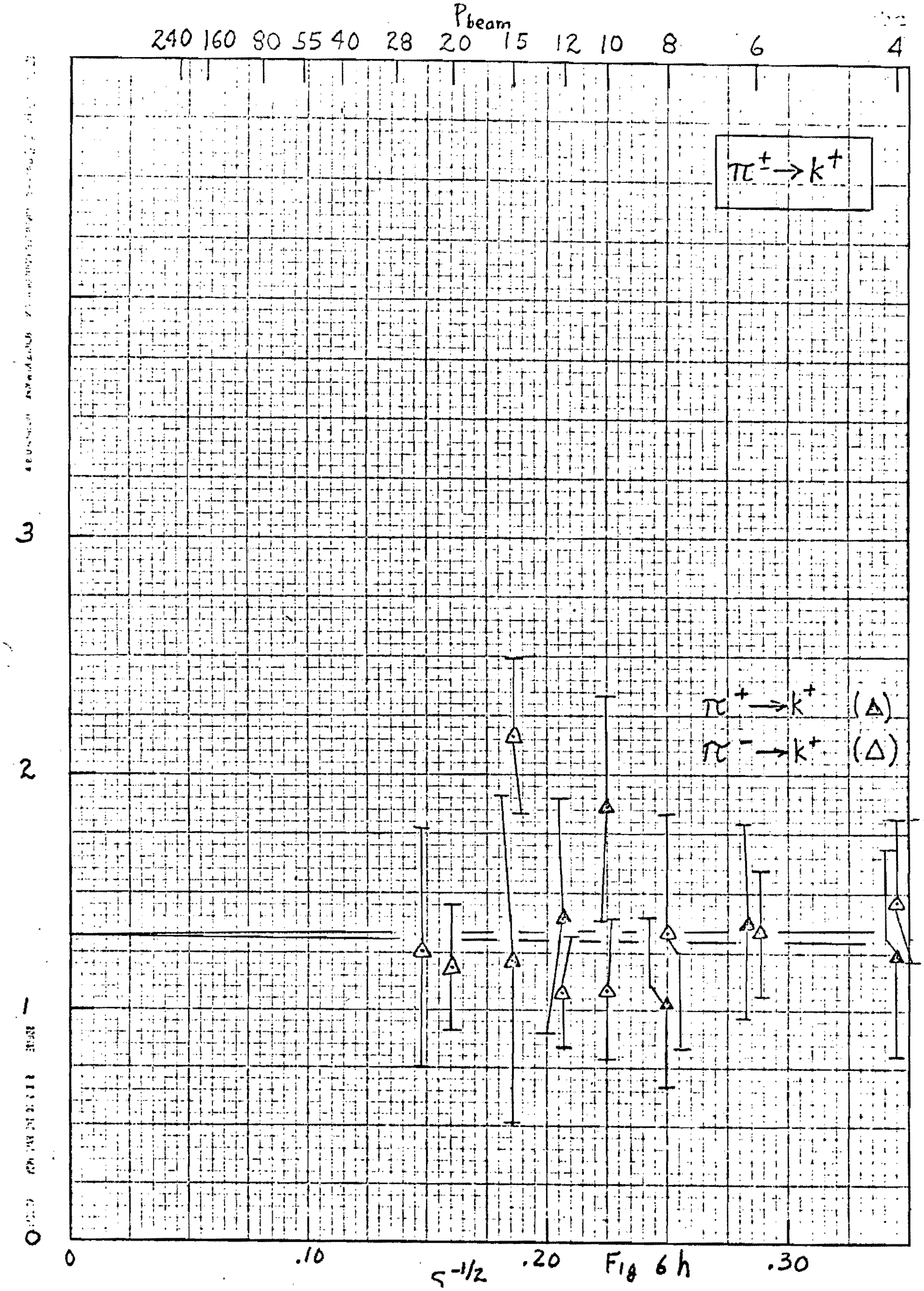
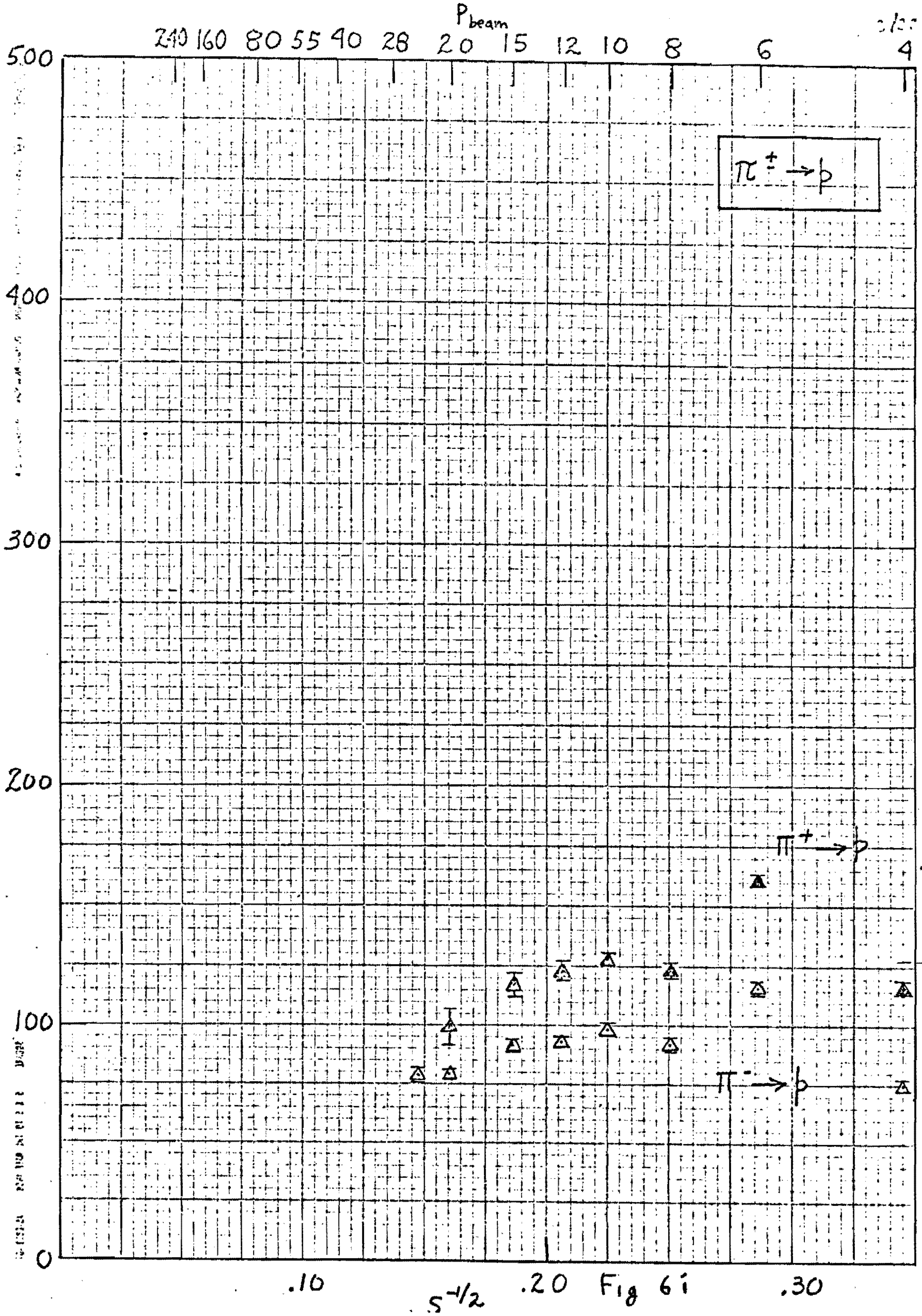


Fig 6g



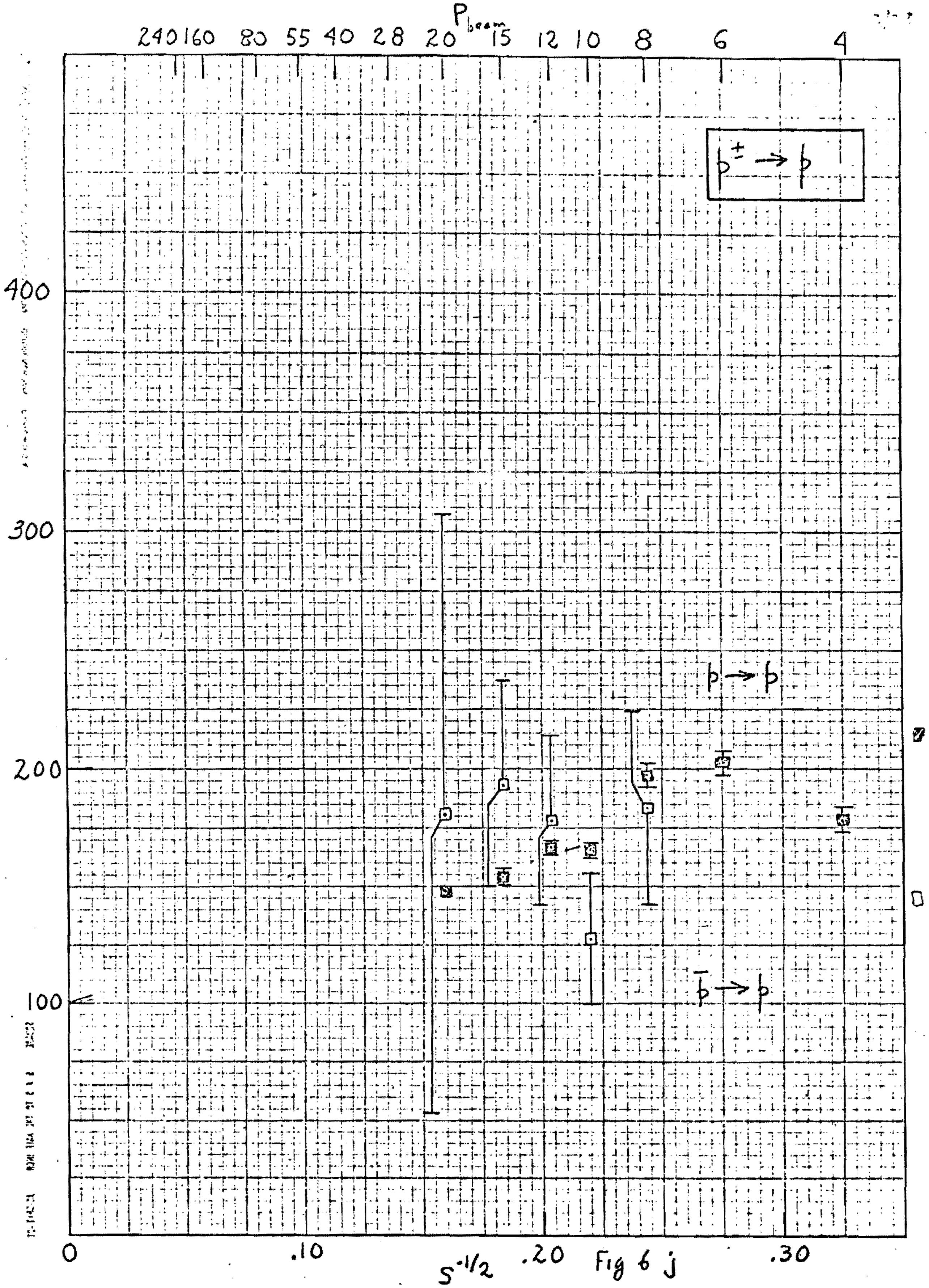
Pbeam
240 160 80 55 40 28 20 15 12 10 8 6 4
π± → k+
π+ → k+ (▲)
π− → k+ (Δ)
3
2
1
0
0
.10
.20
.30
s^-1/2

Fig 6 h



P beam
240 160 80 55 40 28 20 15 12 10 8 6 4
500
400
300
200
100
0
$\pi^{\pm} \to p$
$\pi^{+} \to p$
$\pi^{-} \to p$
.10
$s^{-1/2}$
.20
.30

Fig 6i



P beam
240 160 80 55 40 28 20 15 12 10 8 6 4
p± → p
400
300
200
100
p → p
p̄ → p
0
.10
.20
.30
S^-1/2

Fig 6 j

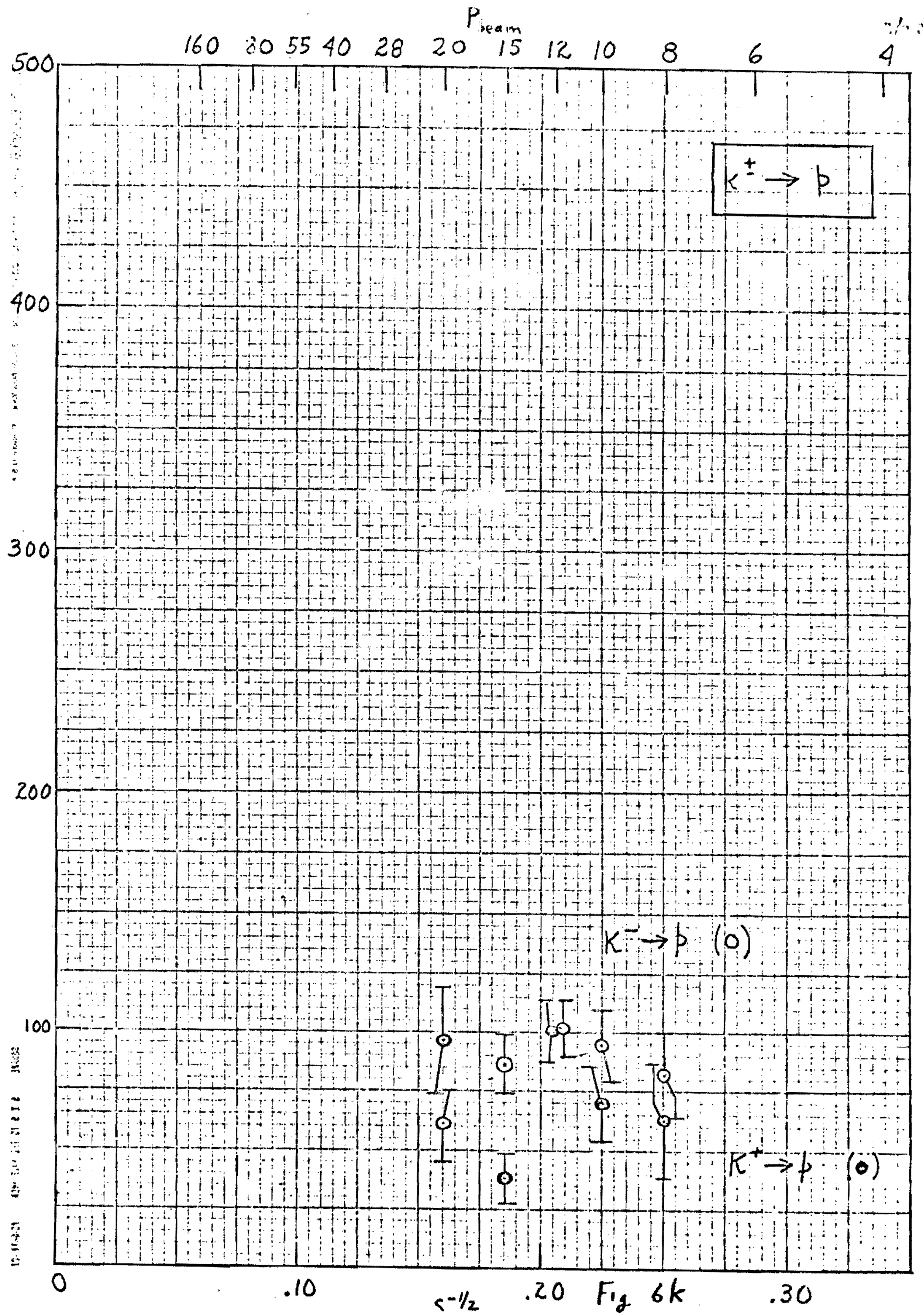

P beam
160
80
55
40
28
20
15
12
10
8
6
4
500
400
300
200
100
0
.10
.20
.30
$s^{-1/2}$
$K^{\pm} \to p$
$K^{-} \to p$ (o)
$K^{+} \to p$ (•)

Fig 6k