Fermi National Accelerator Laboratory

FERMILAB-Pub-77/99-EXP
7100.284

(Submitted to Phys. Rev. Lett.)

INCLUSIVE PRODUCTION OF $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$ IN HIGH ENERGY p-p COLLISIONS

J. R. Johnson, R. Kammerud, T. Ohsugi, D. J. Ritchie,
R. Shafer, D. Theriot, and J. K. Walker
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

F. E. Taylor
Physics Department, Northern Illinois University
DeKalb, Illinois 60115

October 1977

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

INCLUSIVE PRODUCTION OF $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$ IN HIGH ENERGY p-p COLLISIONS

J. R. Johnson*, R. Kammerud+, T. Ohsugi, D. J. Ritchie,
R. Shafer, D. Theriot and J. K. Walker
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

and

F. E. Taylor
Physics Department, Northern Illinois University
DeKalb, Illinois 60115

ABSTRACT

The single particle inclusive cross sections for $p + p \rightarrow \pi^{\pm}, K^{\pm}, p, \bar{p} + X$ have been measured in the low $p_{\perp}$ region $\lesssim 1.5$ GeV/c as a function of the radial scaling variable X_R in p-p collisions at 100, 200 and 400 GeV at Fermilab. The measured π^+/π^- and K^+/K^- ratios are shown to be remarkably similar to the same ratios which have recently been measured at large $p_{\perp}$ at 90° in the center of mass system.

*Present address: SLAC, Stanford, California 94305

+Present address: Lawrence Berkeley Laboratory, Berkeley, California 94720

Measurements of inclusive hadron production in high energy p-p collisions may be used to probe the constituent structure of the nucleon and to study the short range interactions of these constituents. Many of the models for inclusive hadron production are limited to the large $p_\perp$ region where the hard scattering of the constituents of the initial projectiles is supposed to reveal a simple underlying structure.[1] A complete understanding of these inclusive reactions must however cover the entire kinematic region, and hence must include the low $p_\perp$ region as well as the large $p_\perp$ region. It is therefore of interest to examine the inclusive production of hadrons in the low $p_\perp$ region in light of what is known about these reactions at large $p_\perp$.

We have made measurements[2] of π^o production at both large and small transverse momentum from 15^o to 110^o in the c.m. frame. These data were most compactly described in terms of a radial scaling variable X_R ($X_R = E^*/E^*_{max}$ where E^* = total energy of detected particle in the c.m. frame and E^*_{max} = maximum energy available to the particle). This scaling variable led to a simple scaling behavior of single particle inclusive cross sections in p-p collisions over a wide kinematic range.[3] Recently, results have been reported[4] at Fermilab energies for particle production ratios in the reaction

$$\begin{aligned} p + p &\to \pi^\pm + X \\ &\to K^\pm + X \end{aligned}$$

at 90^o in the c.m. frame. It is therefore of interest to measure these ratios at small ($\sim 0^{\circ}$) angles and investigate the similarities, if any, with the data at 90°. In this letter we report the results of these measurements, make a comparison with the 90° data, and comment on the remarkable similarity of the two sets of data.

The data presented here have been taken with a 2.4 GeV/c double half quadrupole spectrometer in the P-West area of Fermilab. An over view of the apparatus is shown in Fig. 1. By the forward - backward symmetry of p-p collisions in the c.m. frame, a modest low-momentum spectrometer can cover a large kinematic range by detecting "slow" particles produced in the backwards hemisphere. A well collimated proton beam was allowed to interact with a 12.7 cm long liquid hydrogen target. The produced particles were detected and their species determined by a system of Cerenkov counters and scintillation counters inside the 2.4 GeV/c spectrometer. Nine proportional wire chambers allowed the detected hadron momentum to be determined to $\Delta p/p \lesssim 2\%$ over a momentum acceptance of $\pm 10\%$. The angle of the spectrometer could be remotely adjusted from 5° to 125° in the lab. The solid angle acceptance was roughly 0.2 milli-steradian and was defined by the proportional wire chambers.

The absolute normalizations of the particle yields were determined by a Monte Carlo calculation of the spectrometer acceptance and by a measurement of the proton incident flux with two secondary emission monitors which were calibrated by two beam toroids. The data have been corrected for nuclear absorption and decay in flight.[5]

Data were taken at fixed $p_\perp$ as a function of X_R in the region $0.05 \leq X_R \leq 1.0$. The $p_\perp$ values measured were 0.25 GeV/c to 1.5 GeV/c in 0.25 GeV/c steps at 100, 200, and 400 GeV incident proton energy. Fig. 2 shows the invariant cross sections $E\frac{d\sigma}{dp^3}$ at constant $p_\perp = 0.75$ GeV/c versus X_R for $p + p \rightarrow \pi^+, \pi^-, K^+, K^-, p, \bar{p}$ + anything. (The limitation of space precludes plotting the data at the 5 other $p_\perp$ values.) Only statistical errors are shown. The systematic normalization errors are estimated to be ±10% based on the reproduciability of the data. The values of the invariant cross sections are consistent with other data[3] which overlap for the same value of $p_\perp$ and X_R and s. It is evident from Fig. 2 that the invariant cross sections scale from 100 to 400 GeV for fixed $p_\perp$ and X_R. Furthermore, this scaling behavior is observed over the entire $p_\perp$ range of this experiment.[5]

This data provides the first opportunity to make a direct comparison of the particle ratios π^+/π^- and K^+/K^- versus X_R for both small $p_\perp$ and large $p_\perp$ data over the same range of center of mass energy. Generally it has been assumed that these two kinematic regions are characterized by long range interactions described by Regge or diffractive scattering and short range interactions described by the quark-parton model, and are therefore not related in an obvious way. Recently, however, there have been theoretical attempts[6] to provide a unified theoretical treatment of the two regions. In Fig. 3 we have plotted these invariant cross section ratios as a function X_R for both the data of this experiment for small $p_\perp$ ($0.25 \leq p_\perp \leq 1.5$ GeV/c are averaged together) in the fragmentation region and the data of Antreasyan et al.[4] at large $p_\perp$ ($0.77 \leq p_\perp \leq 7.67$ GeV/c) at 90° in the c.m. system. It is evident from Fig. 3 that the particle ratios in these two different kinematic regions are in remarkable agreement. This suggests that the ratios are uniquely dependent on the quantum number requirements for particle production. The predictions of Field and Feynman[1] for the 90° region are shown in Fig. 3 to be in good agreement with both the 90° and 0° data. For $X_R \geq 0.6$ the present data tend to lie below the theoretical prediction for π^+/π^-. In fact, the π^+/π^- ratios appears to be approaching 5 for $X_R \to 1$. Field and Feynman[1] speculate on the possibility that the ratio $\pi^+/\pi^- \to 5$ as $X_R \to 1$. Farrar and Jackson[7] have discussed a quark-vector gluon model in which the helicity of a fast quark ($X_R \sim 1$) is the same as that of the proton which implies the u/d quark ratio approaches 5 as $X_R \to 1$. This leads to the π^+/π^- ratio $\to 5$, since it is determined by this quark ratio.

The theoretical predictions of Field and Feynman[1], and Farrar and Jackson[7] are claimed to be valid for short distance behavior. On the other hand, the data indicate that the particle ratios π^+/π^- are remarkably insensitive to angle and to transverse momentum. The particle ratios are therefore insensitive to the range of the interaction. It is therefore tempting to infer from the data that the alignment of the spin of the proton and the spin of the leading valence quark at large X_R is a general phenomenon of hadron interactions. This would imply that the K^+/K^- ratio would tend to ∞ as $X_R \to 1$ in agreement with the data of Fig. 3.

In conclusion, the single particle inclusive cross sections for fixed $p_{\perp}$ ($\lesssim$ 1.5 GeV/c) and X_R scale from 100 to 400 GeV incident proton energy. The particle ratios π^+/π^- and K^+/K^- versus X_R are independent of transverse momentum and angle. In particular the π^+/π^- ratio is approaching 5 and the K^+/K^- tends to infinity as X_R approaches 1.

We would like to thank M. Atac, D. C. Carey, T. Collins, A. Roberts, and J. Sauer for their help in the early phases of the experiment; R. Brock and P. Neeson for their help in the data taking and preliminary data analysis; and D. Burandt, R. Olsen, B. Cox, C. T. Murphy and the personnel of the Proton Laboratory for their excellent technical support. Conversations with D. W. Duke are acknowledged.

REFERENCES

[1] For example: R. D. Field and R. P. Feynman, Phys. Rev. D15, 2590 (1977).

[2] D. C. Carey et al. Phys. Rev. Lett. 33, 327 (1974); and Phys. Rev. Lett. 33, 330 (1974); and Phys. Rev. D14, 1196 (1976).

[3] F. E. Taylor et al., Phys. Rev. D14, 1217 (1976).

[4] D. Antreasyan et al., Phys. Rev. Lett. 38, 112 and 115 (1977).

[5] A more detailed description of the apparatus and the data will follow in a later publication.

[6] Wolfgang Ochs, Nuc. Phys. B118, 397 (1977); Stanley J. Brodsky and John F. Gunion, UCD-77-9 and SLAC-PUB-1939 (1977); K. P. Das and Rudolph C. Hwa OTIS-73 (Jan. 1977).

[7] Glennys R. Farrar and Darrel R. Jackson, Phys. Rev. Lett. 35, 1416 (1975).

FIGURE CAPTIONS

Figure 1: The 2.4 GeV/c spectrometer. Shown are the two half quadrupole magnets Q_1 and Q_2, and the locations of the scintillation and Cerenkov counters and the multiwire proportional chambers (MWPC).

Figure 2: The invariant cross sections $E\frac{d\sigma}{dp^3}$ $(p + p \rightarrow h + X)$ for $h = \pi^{\pm}, K^{\pm}, p, \bar{p}$ at constant $p_{\perp} = 0.75$ GeV/c are plotted versus X_R. Data are shown for three incident proton energies: 100, 200, 400 GeV. The lines through the data are the fits: $E\frac{d\sigma}{dp^3} = B_h(1 - X_R)^{n_h}$ given in Ref. 5. The dotted line through the proton data is to guide the eye.

Figure 3: The particle ratio: a) π^+/π^- and b) K^+/K^- from this experiment and that of Antreasyan et al. (Ref. 4) plotted versus X_R. The K^+/K^- ratio data at $X_R \geq 0.55$ from Ref. 4 have not been plotted since their error bars are very large.

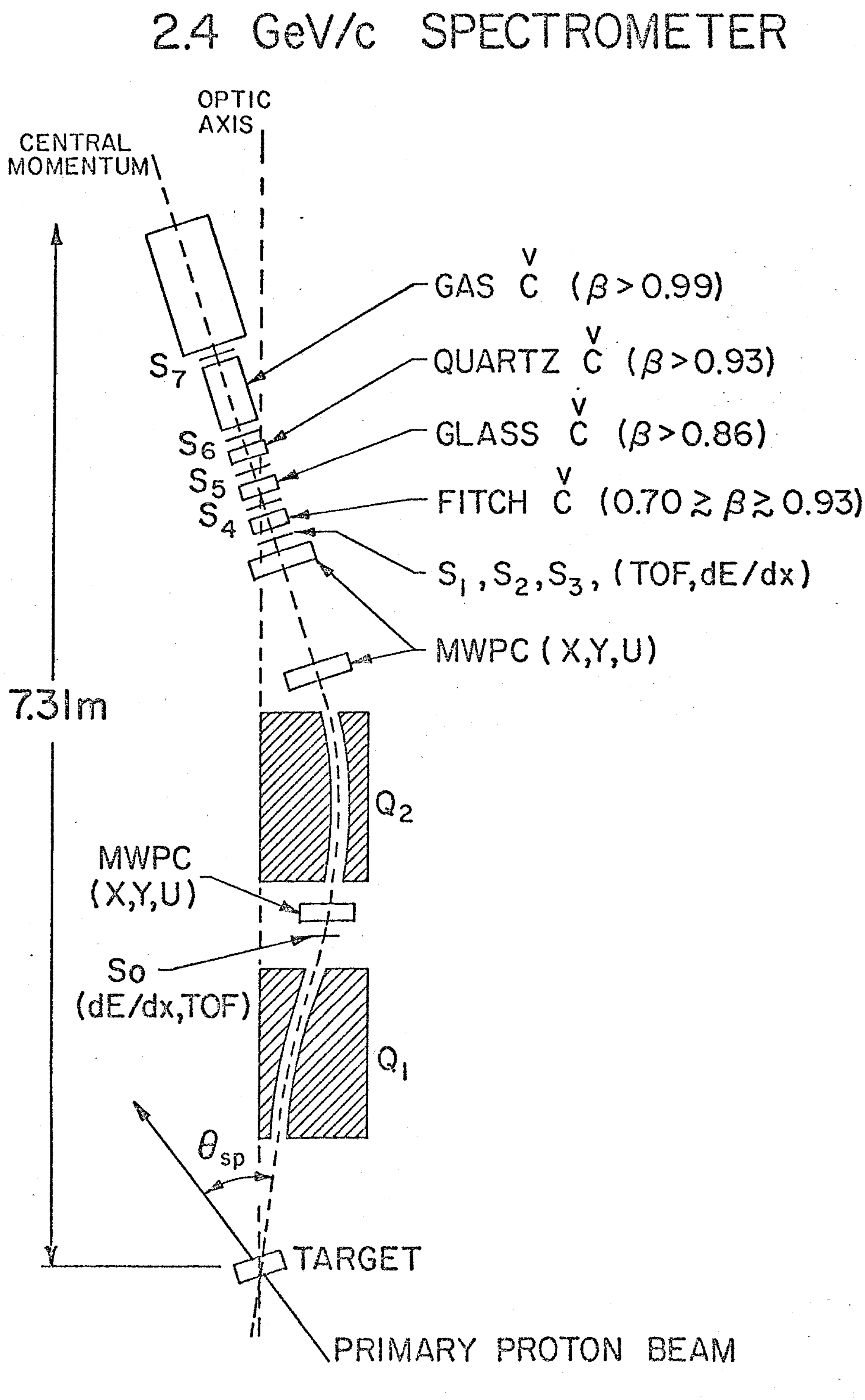
2.4 GeV/c SPECTROMETER
OPTIC AXIS
CENTRAL MOMENTUM
GAS Č (β > 0.99)
QUARTZ Č (β > 0.93)
GLASS Č (β > 0.86)
FITCH Č (0.70 ≳ β ≳ 0.93)
S1, S2, S3, (TOF, dE/dx)
MWPC (X,Y,U)
S7
S6
S5
S4
7.31m
Q2
MWPC (X,Y,U)
So (dE/dx,TOF)
Q1
θsp
TARGET
PRIMARY PROTON BEAM

Fig. 1

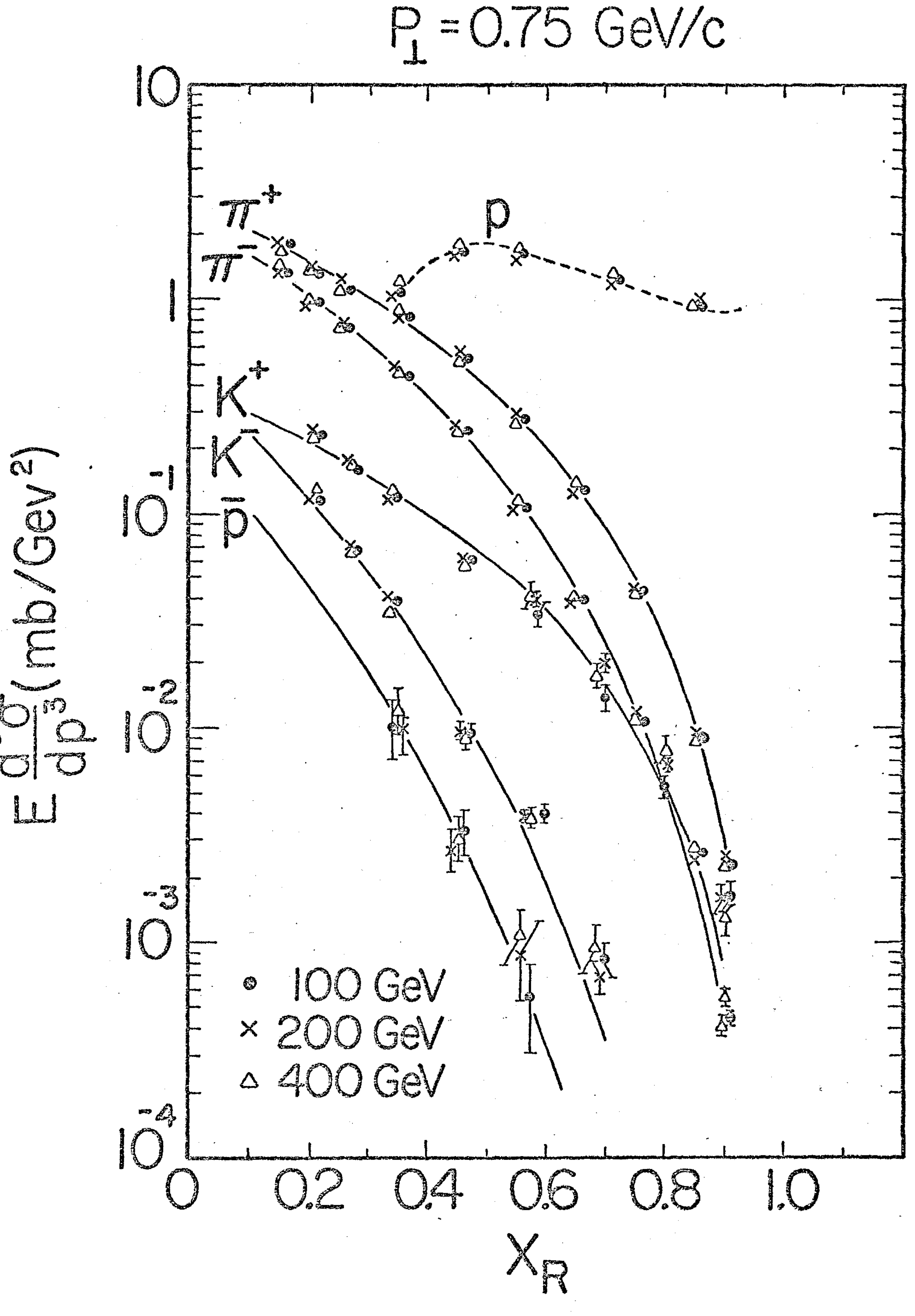
P⊥ = 0.75 GeV/c
π+
π−
p
K+
K−
p̄
100 GeV
200 GeV
400 GeV
E d³σ/dp³ (mb/GeV²)
X_R
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
0
0.2
0.4
0.6
0.8
1.0

Fig. 2

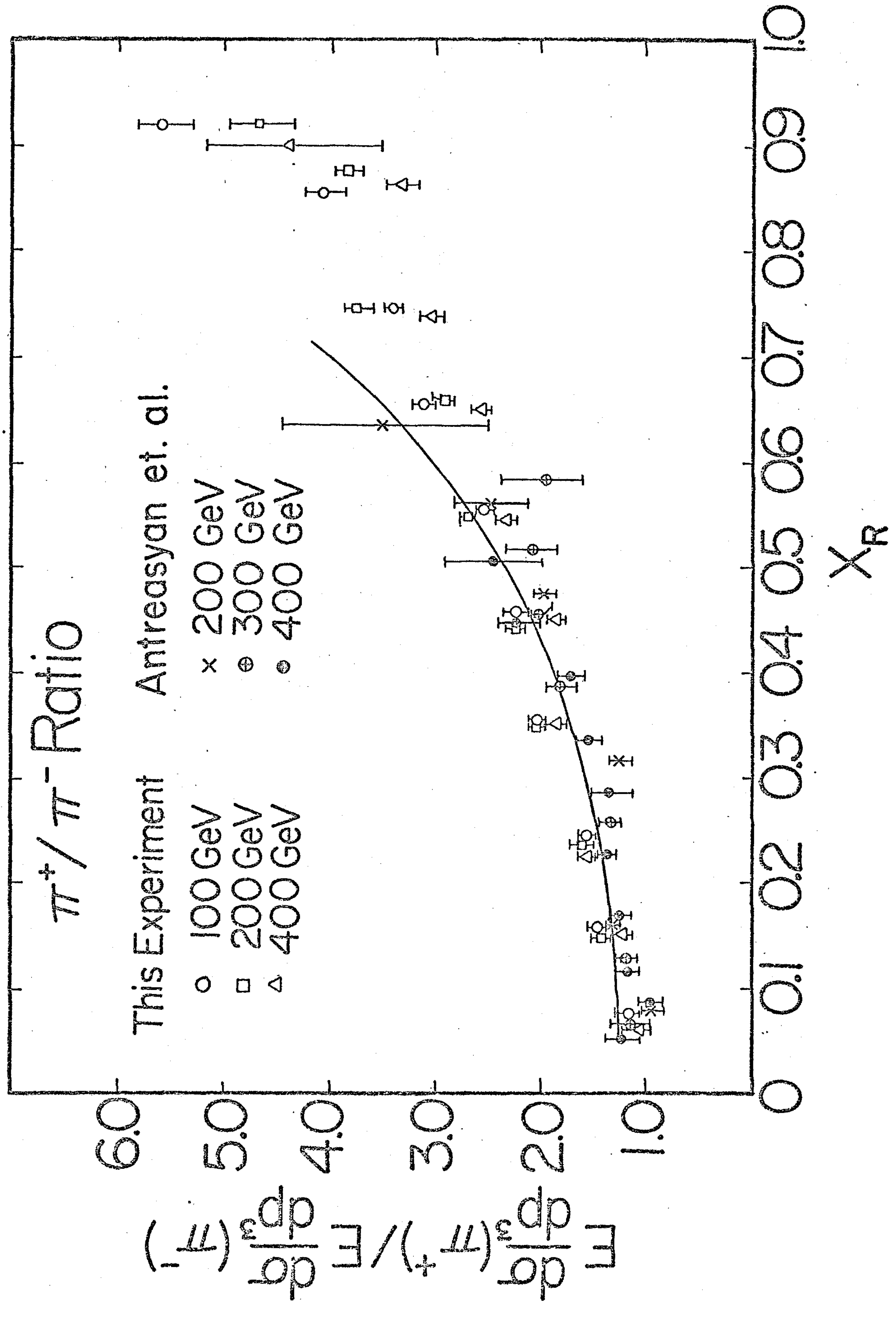
π^+/π^- Ratio
This Experiment
100 GeV
200 GeV
400 GeV
Antreasyan et. al.
200 GeV
300 GeV
400 GeV
$E\frac{d\sigma}{dp^3}(\pi^+)/E\frac{d\sigma}{dp^3}(\pi^-)$
6.0
5.0
4.0
3.0
2.0
1.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
X_R

Fig. 3-a

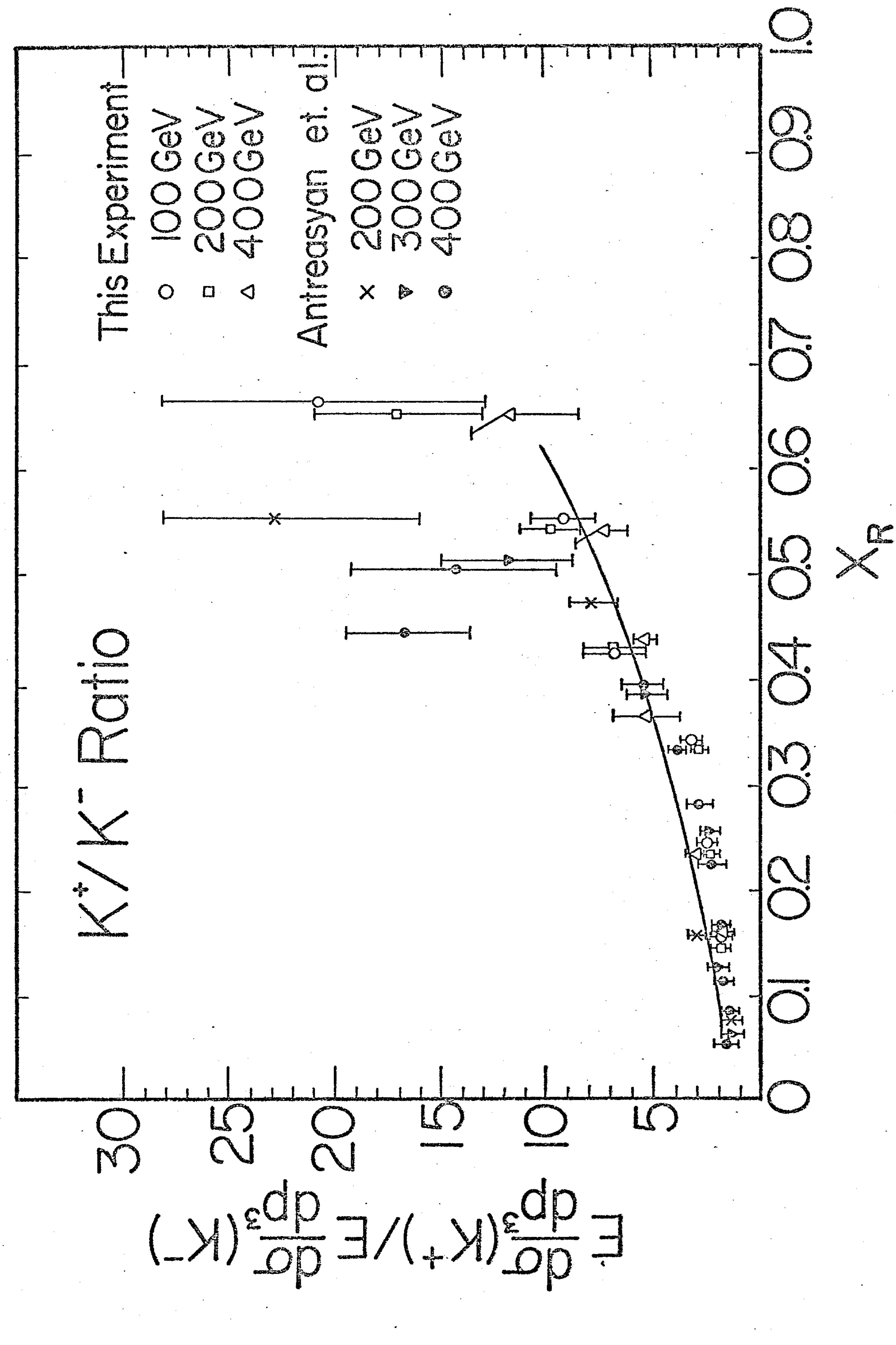
K+/K- Ratio
This Experiment
100GeV
200GeV
400GeV
Antreasyan et. al.
200GeV
300GeV
400GeV
X_R
$E\frac{d\sigma}{dp^3}(K^+)/E\frac{d\sigma}{dp^3}(K^-)$
0
5
10
15
20
25
30
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Fig. 3-b