SLAC-PUB-1640
August 1975
(T/E)

HIGH-MOMENTUM HADRONS FROM e^+e^- REACTIONS: SPECTRA, PARTICLE RATIOS, AND MULTIPLICITIES*

T. L. Atwood**, B. A. Barnett**, M. Cavalli-Sforza†, D. G. Coyne#, G. Goggi†, G. C. Mantovani†, G. K. O'Neill#, A. Piazzoli†, B. Rossini†, H.F.W. Sadrozinski#, D. Scannicchio†, L. V. Trasatti**§, G. T. Zorn**

** University of Maryland, College Park, Maryland

† Istituto di Fisica Nucleare, Università di Pavia and Istituto Nazionale di Fisica Nucleare, Sezione di Pavia, 27100 Pavia, Italy

Princeton University, Princeton, New Jersey

ABSTRACT

We present results from a study of high-momentum inclusive hadron production in electron-positron interactions at $\sqrt{S} = 3.8$ and 4.8 GeV. Comparison of the momentum spectra at these energies shows no scaling violation in the region $x \; (=E/E_{beam}) > 0.7$. At $\sqrt{S} = 4.8$ GeV the K/π ratio for hadrons with momenta > 1.1 GeV/c is $.27 \pm .08$, and the average number of charged hadrons is $3.6 \pm .3$ for those events which have at least one charged hadron with momentum greater than 1.1 GeV/c.

(Submitted to Phys. Rev. Letters)

This paper presents results from an experiment which measured the inclusive cross section for hadron production in e^+e^- interactions. Measurements were made at e^+e^- center of mass energies of 3.8, 4.8, 5.0, and 5.1 GeV at the SPEAR facility of SLAC. The experiment occurred prior to the discovery[1] of the ψ(J) particles, so the data does not add direct information about these particles. It has been observed that R, the ratio of the cross section for "$e^+e^- \rightarrow$ hadrons" relative to "$e^+e^- \rightarrow \mu^+\mu^-$", increases[2] from $\sim$ 2.5 to $\sim$ 5 around 4 GeV, and we present data below and above this energy. This report will deal with events having a particle with a momentum greater than 1.1 GeV/c, where our particle identification is best and our backgrounds least. Data for lower particle momenta will be presented later. The data samples at $\sqrt{S}$ = 5.0 and 5.1 GeV together were only about 15% of that at $\sqrt{S}$ = 4.8 GeV. These have all been combined and will be referred to as $\sqrt{S}$ = 4.8 GeV.

The main element of the apparatus (Fig. 1) was a single arm magnetic spectrometer set at 90° to the e^+e^- beams and subtending about 1% of 4π steradians. The magnetic field was vertical and rather uniform at $\sim$ 4.2 kgauss; the total $\int B\, d\ell$ was $\sim$ 11.8 kgauss-meters. Particle positions were measured by proportional wire chambers[3] or scintillation counters. The event trigger required a charged particle passing through the spectrometer in coincidence with the passage of the e^+e^- bunches through the interaction region.

The experiment achieved $e/\mu/\pi/K/p$ identification of the spectrometer particle by a combination of a threshold Cerenkov counter, shower counters, range measurement, and time of flight. The Cerenkov counter was filled with 90 psig. of propane. Its pion threshold was 1.05 GeV/c, and it unambiguously separated $e/\mu/\pi$ from K/p above 1.2 GeV/c. This particle identification was aided by time-of-flight measurements between 1.1 GeV/c and 1.2 GeV/c. The Cerenkov pulse height was also helpful in distinguishing electrons from pions above 1.05 GeV/c, but electrons were identified primarily by a five layer lead-scintillator shower counter. The total thickness of that counter was 7.2 radiation lengths; the average electron pulse was about 6 times that of a minimum ionizing muon. Muons were identified by their passage through a 26 inch thick iron "hadron filter." Scintillation counters were located at three depths in this filter to measure particle ranges. Protons were distinguished from kaons by a time-of-flight measurement. A scintillation counter (S1) near the interaction region and the scintillation counters in the first two layers of the shower counter formed the time-of-flight link. The total flight path was $\approx$ 5 meters. During data taking the TOF system was monitored every few hours by pulsing light emitting diodes mounted on each counter and recording the results on the data tape.

A central detector ("polymeter") surrounded the SPEAR beam pipe and covered 99% of the solid angle. It consisted of four units of three proportional wire chambers each. These sat above, below, and on each side of the interaction region, with wires running parallel to the e^+e^- beams. It measured the charged particle multiplicity and helped in the reconstruction of the event vertices.

Three proportional wire chambers, a shower counter and a hadron filter similar to those in the spectrometer were placed on the side of the e^+e^- beams opposite to the spectrometer. This system measured particle directions and identified electrons and muons. It greatly improved our identification of event types $e^+e^- \rightarrow e^+e^-$ and $e^+e^- \rightarrow \mu^+\mu^-$, the main backgrounds. Studies of these events showed that the cosmic ray background was negligible and that our vertex reconstruction had a spatial precision of ±3 mm and collinearity precision of ±.5°.

We measured the ratio of hadron events to $e^+e^- \to \mu^+\mu^-$ events, assuming the validity of QED for the muon events. Several experiments[4] have shown that $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to e^+e^-$ events with small noncollinearity agree with QED. We therefore imposed a 10° noncollinearity cut upon our $\mu^+\mu^-$ data, although we can identify μ pairs with noncollinearities up to $\stackrel{\sim}{\sim}$ 40°. No multiplicity requirement was imposed in the event selection criteria. However, of the 288 $\mu^+\mu^-$ events only 9 had a multiplicity other than two. Each of the 9 had a multiplicity of three or four, and could be due to the conversion of a radiated γ-ray. They give an upper limit of approximately 3% for an accidental particle in the polymeter. We used the computer program of Berends, Gaemers, and Gastmans[5] to calculate the $e^+e^- \to \mu^+\mu^-$ inclusive cross section (twice the normal cross section) to order α^3 for noncollinearity $\leq$ 10° averaged over our geometrical acceptance. We found $\frac{d\sigma}{d\Omega}$ = .44 nb/ster at $\sqrt{S}$ = 4.8 GeV and $\frac{d\sigma}{d\Omega}$ = .69 nb/ster at $\sqrt{S}$ = 3.8 GeV. The cross sections quoted later in this report have a normalization uncertainty of ±7% at $\sqrt{S}$ = 4.8 GeV and ±11% at $\sqrt{S}$ = 3.8 GeV due to the $\mu^+\mu^-$ statistics.

Backgrounds in the experiment were determined by two different means. We made separated and single-beam runs during the experiment, scanning these for events containing a high momentum hadron satisfying our normal selection criteria. Though none was found, the running times involved only limited our background to < 5%. We used e^+e^- and $\mu^+\mu^-$ events to locate the beam interaction region. Comparison of the vertex regions for high momentum hadron events and for e^+e^- and $\mu^+\mu^-$ events showed that a 2% reduction in cross sections was needed to account for hadronic backgrounds from gas scatters and beam pipe interactions.

The time-of-flight measurements were used to separate protons from kaons. There were 21 nonpionic events, but no valid measurement could be made on 3 of them because of shower counter system contamination. Of the 18 events with TOF measurements, 15 were kaons and 3 were antiprotons. The 3 unanalyzable events were weighted as proton or kaon in the same ratio as unambiguous events.

Corrections from our Monte Carlo program were applied to find the original production ratios. This gave K/π ratios of .27 ± .08 (78 π's and 14 K's observed) and .8 ± .5 (7 π's and 4 K's observed) at $\sqrt{S}$ = 4.8 and 3.8 GeV respectively. The p/π ratio is .04 ± .02 (3 $\bar{p}$'s and 78 π's observed) at $\sqrt{S}$ = 4.8 GeV. These ratios are for particles produced at 90° with momenta greater than 1.1 GeV/c. The K/π ratios are larger than those reported at lower momenta[6] in e^+e^- or at similar momenta in pp interactions.[7] No p's or $\bar{p}$'s were found at $\sqrt{S}$ = 3.8 GeV.

Figure 2 shows a scatter plot of the charged multiplicity measured by the polymeter versus the momentum of the spectrometer hadron. The few events which have an odd number are due predominately to γ-ray conversions in the .04 radiation lengths of material in the beam pipe and first proportional wire chamber and, to a lesser extent, to inefficiencies in the PWC's. The figure shows that the multiplicity does not depend dramatically upon particle type or S, but clearly decreases as the energy of the one particle increases, the tendency one might expect from energy conservation. The average charged multiplicities for all of these events, selected to have at least one charged hadron with momentum greater than 1.1 GeV/c, are 3.6 ± .3 and 3.8 ±.5 at $\sqrt{S}$ = 4.8 and 3.8 GeV respectively. Note that event types which have two charged hadrons with momentum greater than 1.1 GeV/c contribute to the average with double weighting since they have twice the detection probability, while event types with no high momentum particles don't contribute at all.

Figure 3 shows the inclusive invariant cross section at 90°, differential in momentum, for π's and K's above 1.1 GeV/c, at $\sqrt{S}$ = 4.8 GeV. This figure shows that below 1.6 GeV the π cross sections are distinctly larger than the K cross sections, but may become similar at higher particle energy. It also shows that the statistics are such that the K/π ratio quoted earlier is dominated by the lower energy data. Figure 4 shows the quantity $S\, d\sigma/d\Omega dx|_{90°}$ vs. $x(\equiv E\ \text{hadron}/E\ \text{beam})$ for all hadrons at $\sqrt{S}$ = 3.8 GeV and at $\sqrt{S}$ = 4.8 GeV. No significant scaling violation is observed in the region above $x = 0.7$. Below $x = 0.7$ there is one point at $x = 0.65$ which is suggestive of scaling breakdown, but the data does not permit an extrapolation into this region.

No $e^+e^- \to \pi^+\pi^-, K^+K^-, p\bar{p}$ events were seen at either S value. With 95% confidence the normal (not inclusive) differential cross sections for these processes at 90° are below 16., 22., and 15. pb/ster respectively at $\sqrt{S}$ = 3.8 and are below 3.8, 4.9 and 3.7 pb/ster respectively at $\sqrt{S}$ = 4.8 Gev.

ACKNOWLEDGEMENTS

We gratefully acknowledge the large contributions of the staffs at SLAC, Princeton, Pavia, and Maryland without whom this experiment would not have been possible. We also thank Dr. K. J. F. Gaemers for installing the QED corrections program of ref. 5 in the Maryland computer.

REFERENCES

*Work supported by Energy Research and Development Administration, Istituto Nazionale di Fisica Nucleare, and National Science Foundation Grant GP27974.

**§Present address: Laboratori Nazionali di Frascati - Casella Postale 70, Frascati, Rome.

[1] J. J. Anbert et al., Phys. Rev. Lett. 33, 1404 (1974).
J. E. Augustin et al., Phys. Rev. Lett. 33, 1406 (1974).
C. Bacci et al., Phys. Rev. Lett. 33, 1408 (1974).
G. S. Abrams et al., Phys. Rev. Lett. 33, 1453 (1974).

[2] J. E. Augustin et al., SLAC Pub. 1520, L86-3621, Jan. 1975. Submitted to Phys. Rev. Lett.

[3] M. Cavalli-Sforza, G. Goggi, B. Rossini, A. Piazzoli, D. Scannicchio, Nucl. Instr. and Meth. 124, 73 (1975).

[4] J. E. Augustin et al., Phys. Rev. Lett. 34, 233 (1974).
H. Newman et al., Phys. Rev. Lett. 32, 483 (1974).
R. Madaras et al., Phys. Rev. Lett. 30, 507 (1973).
B. L. Baron et al., Phys. Rev. Lett. 33, 663 (1974).
B. Borgia et al., Lettere al Nuovo Cimento 3, 115 (1972).

[5] F. A. Berends, K. J. F. Gaemers, and R. Gastmans, Nucl. Phys. B57, 381 (1973).

[6] B. Richter, XVII International Conf. on High Energy Physics, London, IV-37 (1974) and private communication.

[7] B. Alper et al., Phys. Lett. 47B, 275 (1973).
J. W. Cronin et al., Phys. Rev. Lett. 31, 1426 (1973).

LIST OF FIGURES

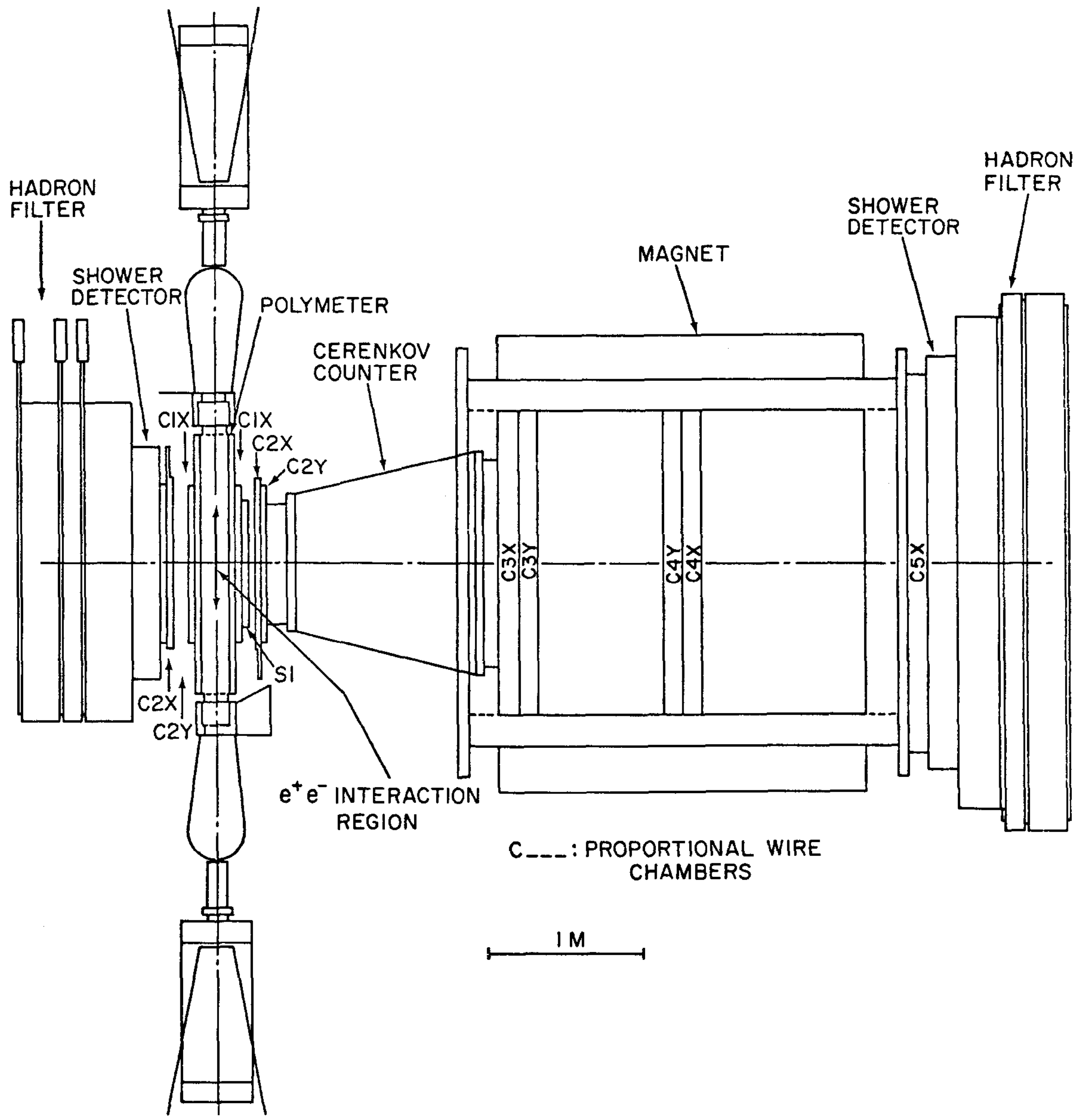
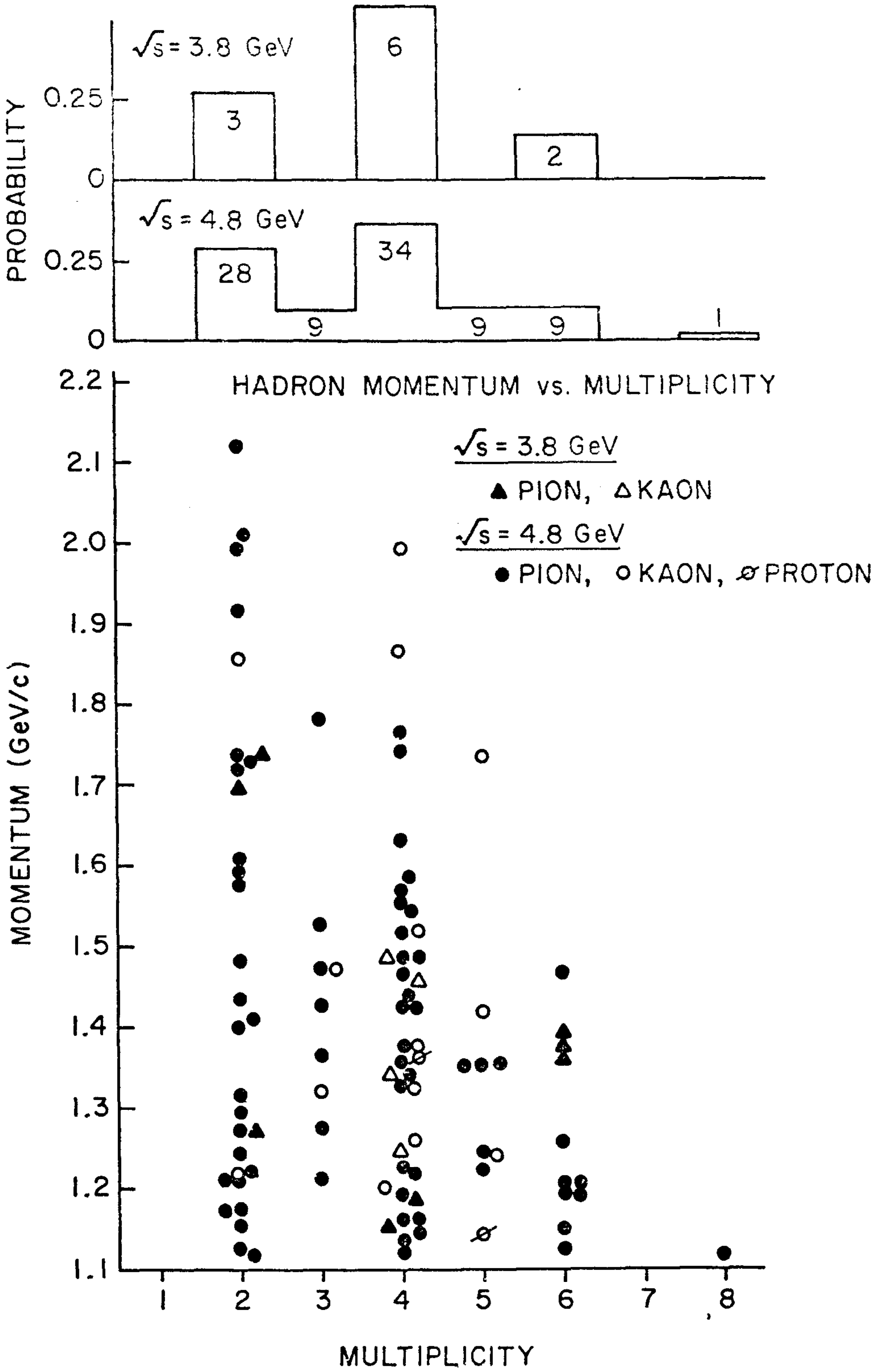

HADRON FILTER
SHOWER DETECTOR
POLYMETER
CERENKOV COUNTER
MAGNET
SHOWER DETECTOR
HADRON FILTER
C1X
C1X
C2X
C2Y
C3X
C3Y
C4Y
C4X
C5X
S1
C2X
C2Y
e+e- INTERACTION REGION
C___: PROPORTIONAL WIRE CHAMBERS
1 M

Fig. 1



√s = 3.8 GeV
PROBABILITY
0.25
0
3
6
2
√s = 4.8 GeV
0.25
0
28
9
34
9
9
1
HADRON MOMENTUM vs. MULTIPLICITY
√s = 3.8 GeV
▲ PION, △ KAON
√s = 4.8 GeV
● PION, ○ KAON, ⌀ PROTON
MOMENTUM (GeV/c)
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
2
3
4
5
6
7
8
MULTIPLICITY

Fig. 2

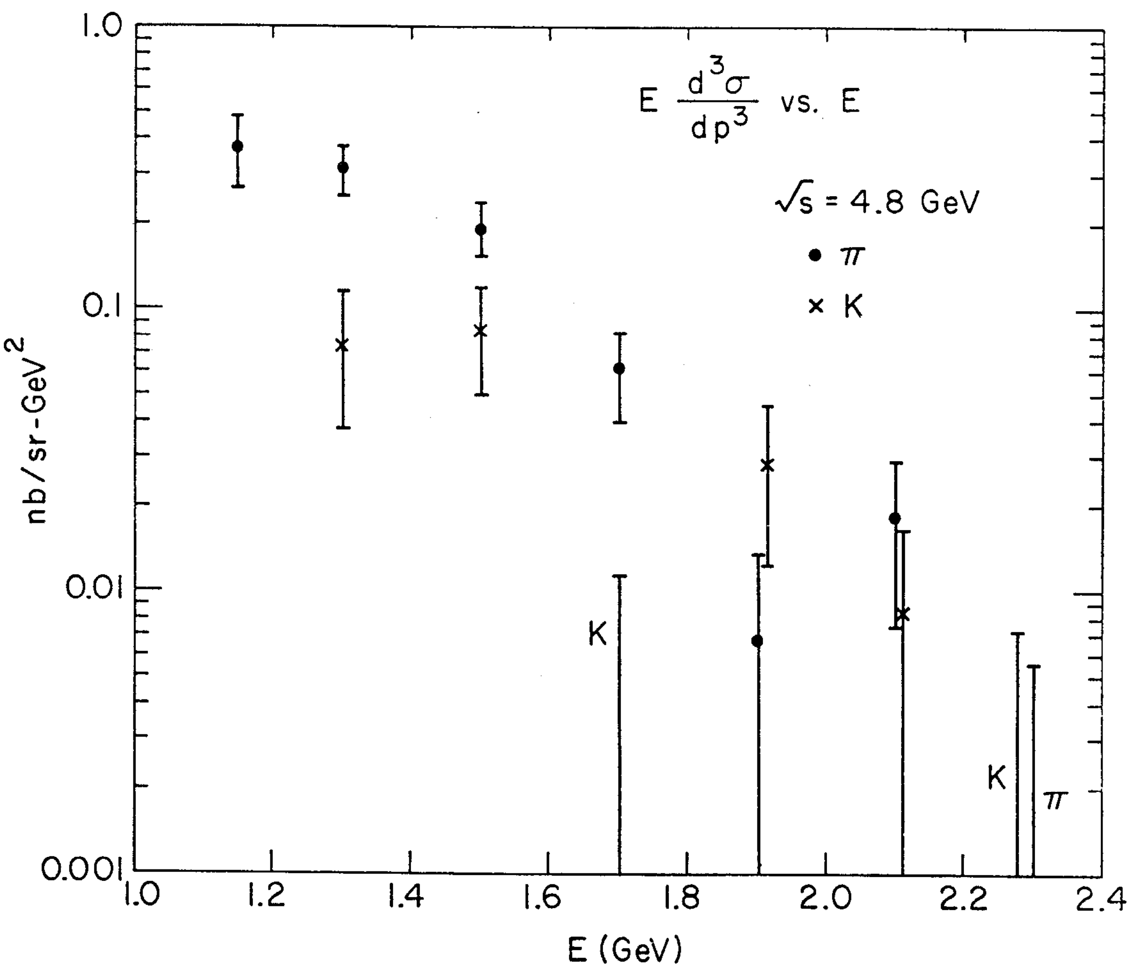
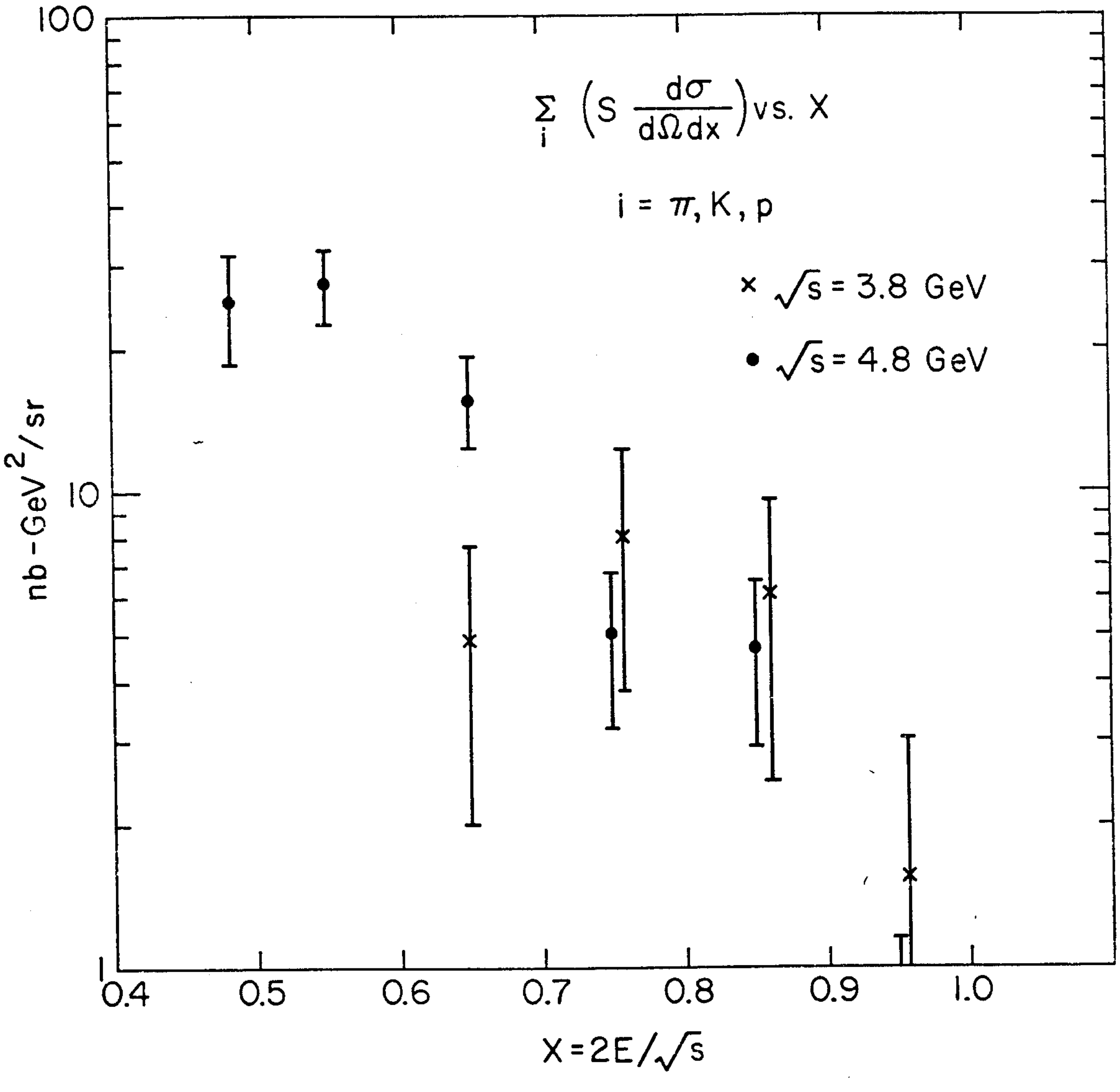

$E \frac{d^3\sigma}{dp^3}$ vs. E
$\sqrt{s}$ = 4.8 GeV
• π
× K
K
K
π
nb/sr-GeV^2
1.0
0.1
0.01
0.001
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
E (GeV)

Fig. 3



$\sum_i \left(S \frac{d\sigma}{d\Omega dx}\right)$ vs. X
i = π, K, p
× $\sqrt{s}$ = 3.8 GeV
• $\sqrt{s}$ = 4.8 GeV
100
10
1
nb - GeV^2/sr
0.4
0.5
0.6
0.7
0.8
0.9
1.0
X = 2E/$\sqrt{s}$

Fig. 4