Comparison of the Production of Charged Hadrons at Large Transverse Momentum in $\pi^- p$ and pp Collisions

N. D. Giokaris, J. M. Green,[(a)] H. J. Frisch, C. Grosso-Pilcher, M. D. Mestayer, L. Schachinger,[(b)] M. J. Shochet, and M. L. Swartz
Enrico Fermi Institute and Department of Physics, The University of Chicago, Chicago, Illinois 60637

and

P. A. Piroué, B. G. Pope, and R. L. Sumner
Department of Physics, Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
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Measurements of the production cross sections at large values of transverse momentum (P_T) for $\pi^\pm$, $K^\pm$, p, and $\bar{p}$ in 200- and 300-GeV/c $\pi^- p$ collisions are presented. The dependences of the cross section on P_T, the transverse scaling variable $x_T = 2P_T/\sqrt{s}$, and the production angle are discussed. The cross sections are compared with those from pp collisions and with theoretical predictions. While the $\pi^- p$ and pp data are quite different, both agree qualitatively with hard-scattering calculations.

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We report cross sections for inclusive charged-hadron production at values of P_T up to 6 GeV/c in $\pi^- p$ and pp collisions. The experiment is the latest in a series of Chicago-Princeton experiments[1] which use a small-acceptance single-arm spectrometer to detect and identify hadrons. A specific aim of this experiment was to measure the dependence on P_T, $x_T \equiv 2P_T/\sqrt{s}$, and angle of the production of different particle types for π^- beams, and to compare the cross sections for pion and proton beams. If valence-quark scattering plays a large role in high-P_T particle production, then the valence antiquark in the π^- should produce marked differences between pion and proton interactions, especially for the production of particles such as π^-, K^-, and $\bar{p}$ which contain the same valence antiquark as the π^-. We do see large differences between pion and proton collisions. The data are compared to current theoretical calculations as well as to relevant results of previous experiments on π^0 production[2,3] and charged-particle production.[4] The calculations match the trends of our data; simple quark-counting schemes also roughly describe our results.

The spectrometer has been described in a previous Letter.[5] Briefly, the equipment consisted of a magnetic spectrometer with an acceptance $(\Delta p/p)\Delta\Omega$ of 420 μsr·%, instrumented with two Cherenkov counters for identification of pions, kaons, and protons, a calorimeter for muon

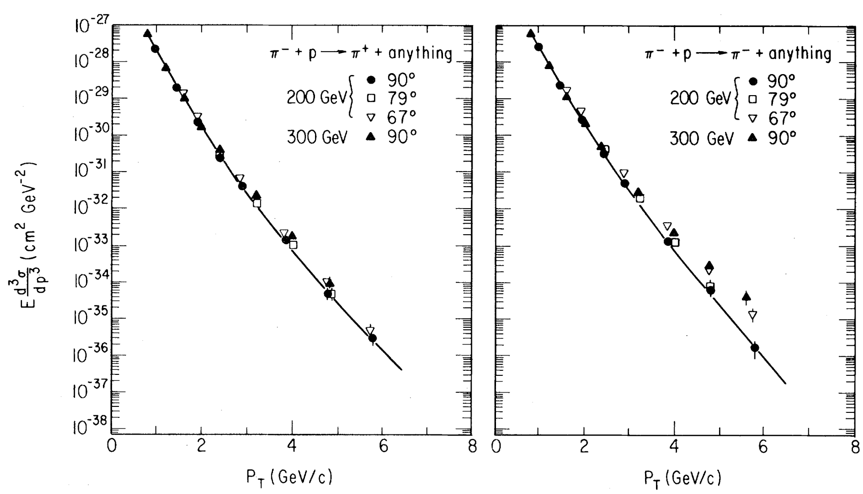

FIG. 1. The inclusive cross sections vs P_T for the production of π^+ and π^-. The angles refer to the $\pi^- p$ c.m. frame. The solid lines are hand drawn through the 90° points.

TABLE I. The results of fits of the 200- and 300-GeV data to a form $E\,d^3\sigma/dp^3 = (A/P_T^n)(1-x_T)^b$. The values for a proton beam from Ref. 1 are also given for comparison.

	$\pi^- p$			pp	
	n	b	χ^2/DOF	n	b
π^+	8.6 ± 0.5	7.0 ± 0.6	6.6/4	8.2 ± 0.5	9.0 ± 0.5
π^-	7.5 ± 0.5	8.9 ± 0.7	2.2/5	8.5 ± 0.5	9.9 ± 0.5
K^+	7.3 ± 0.6	8.6 ± 1.1	1.1/4	8.4 ± 0.7	8.3 ± 0.6
K^-	8.4 ± 0.5	8.2 ± 0.5	9.3/4	10.1 ± 1.5	11.5 ± 1.3
p	9.9 ± 0.8	6.4 ± 1.5	1.8/4	11.8 ± 1.6	7.3 ± 1.1
$\bar{p}$	9.8 ± 1.2	8.1 ± 0.8	0.96/1	8.8 ± 1.8	14.2 ± 2.0

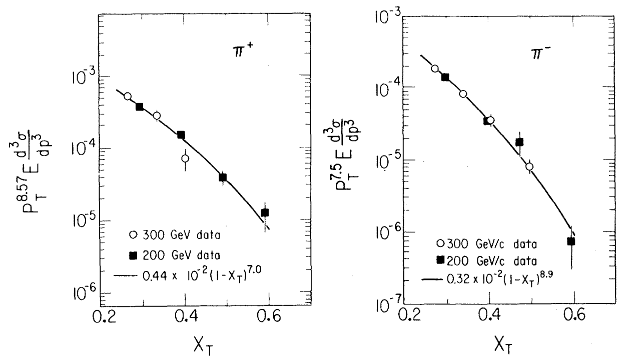

FIG. 2. The results of the fits of the 200- and 300-GeV data for pion production to the form $(1/P_T^n)(1-x_T)^b$. The fitted power of n has been multiplied by the cross section to produce a curve which depends only on x_T if the data scale. The units of the ordinate are cm^2 (GeV$/c)^{n-2}$; x_T is of course dimensionless.

identification, and drift chambers for track reconstruction. The spectrometer viewed the target at an angle of 80 mrad from the beam, which corresponds to 90° in the c.m. frame for 300-GeV beams and 79° for 200-GeV incident beams. Additional 200-GeV pion-beam runs were taken with four dipoles in the beam line to change the targeting angle by ±16 mrad, allowing data collection at c.m. angles of 90° and 67°. The transverse momenta studied ranged from 0.8 to 6.0 GeV/c.

The drift-chamber information was used to reconstruct particle trajectories with an efficiency of 95%. The reconstructed tracks were required to project back through the magnet apertures and to intersect the target. The yields were corrected for the contribution of the empty target (10% to 15%), decay in flight (4% for pions at $P_T = 3$ GeV/c), absorption in the target and in the spectrometer (15%), and particle misidentification (8%). At each value of P_T the acceptance was corrected for the effect of the rapidly falling spectrum over the spectrometer aperture. Two ionization chambers upstream of the target and two scintillator telescopes, one on each side of the target, measured the beam flux incident on the hydrogen target.

The cross sections for $\pi^- p \to \pi^+ + X$ and $\pi^- p \to \pi^- + X$ are shown in Fig. 1 for the three angles at which data were taken with the 200-GeV beam, and for the 90° c.m. angle with the 300-GeV π^- beam. The errors shown include both statistical and systematic uncertainties. The uncertainty

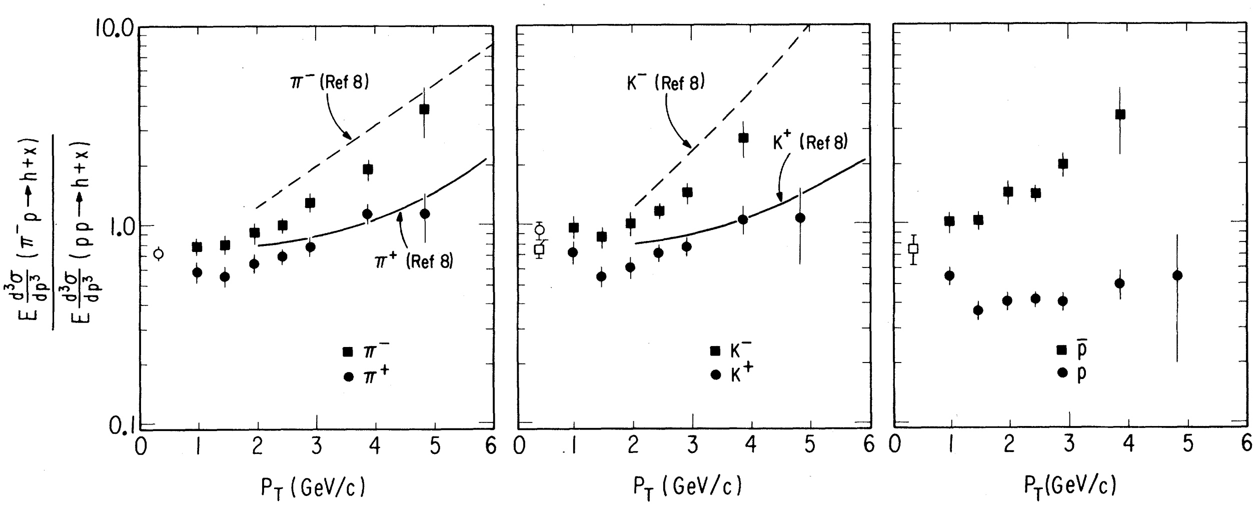

FIG. 3. The relative particle production vs P_T for a π beam vs a proton beam. The data are for 200-GeV beams, at 90° in the c.m. The lines are predictions of Ref. 8. The π^+, $K^\pm$, and $\bar{p}$ points at $P_T = 0.3$ GeV/c (open circles and squares) are from Ref. 9.

in the overall normalization is less than 10%.

The two sets of data taken at 90° at 200 and 300 GeV allow us to test for scaling of the form predicted by naive dimensional counting,[6] $E\,d^3\sigma/dp^3 = (A/P_T{}^n)(1-x_T)^b$. A transverse-momentum cut at 2.6 GeV/c is made to exclude the low-P_T region where soft scattering dominates the cross sections. The results of the fit for each particle type are given in Table I. These fitted parameters are stable with respect to increases in the P_T cutoff value. Figure 2 shows the scaled cross sections versus x_T for negative and positive pion production.

For $\pi^\pm$ and $K^\pm$ high-P_T production the fitted values for n (the power of $1/P_T$) are consistent with a value of 8, which is the value observed for these reactions in p-p collisions at these energies.[7] This value is less than the value of 10 observed previously for π^0 production in 100- and 200-GeV $\pi^- p$ collisions.[2] The values of n for p and $\bar{p}$ production are both about 10, and are more alike than in the pp case. The values of b tend to be lower (especially for K^- and $\bar{p}$'s) than in the p-p case, presumably because fewer quarks share the momentum in the initial state.

The existence of an initial valence antiquark would suggest that at large x_T incident π^-'s should produce more π^-, K^-, and $\bar{p}$'s than incident protons at the same energy. Figure 3 shows this to be so, with an enhancement factor of about 4 at $P_T \sim 5$ GeV/c. At this same P_T, however, π^- are as effective as incident protons at producing π^+ and K^+, in spite of starting with a neutral rather than a charge-two state. The production of protons in $\pi^- p$ collisions is approximately half that in pp collisions, reinforcing the naive belief that the copious production of protons in p-p collisions at these energies is due to the initial protons themselves.

In Fig. 4 we present a comparison of the relative production of charged pions by the 200-GeV π^- beam and the 200-GeV proton beam. We have plotted the average of the π^+ and π^- cross sections, so that one can compare with previous measurements.[2] The slope agrees with a $1/(1-x_T)^2$ dependence, as expected from dimensional counting.

The angular dependence of the particle ratios was presented in our earlier Letter.[5] In Fig. 5, we show results for the ratios of the π^- to π^+ cross sections versus c.m. angle at a value of transverse momentum of 4 GeV/c. The solid line is the prediction of a quantum chromodynamics calculation from Feynman, Field, and Fox.[8] The dashed line, which comes closer to the data is a similar recent calculation with a gluon frag-

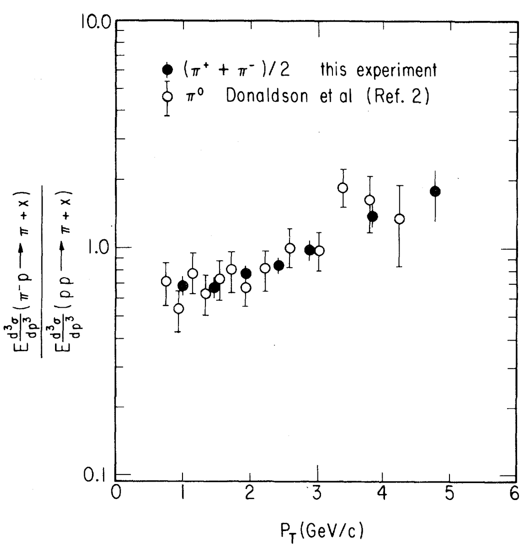

FIG. 4. A comparison of the relative production of pions for the π^- beam and the proton beam, at 90° in the c.m. The circles are the average of π^+ and π^- for the 200-GeV beams. Also shown are the data of Donaldson *et al*. (Ref. 2).

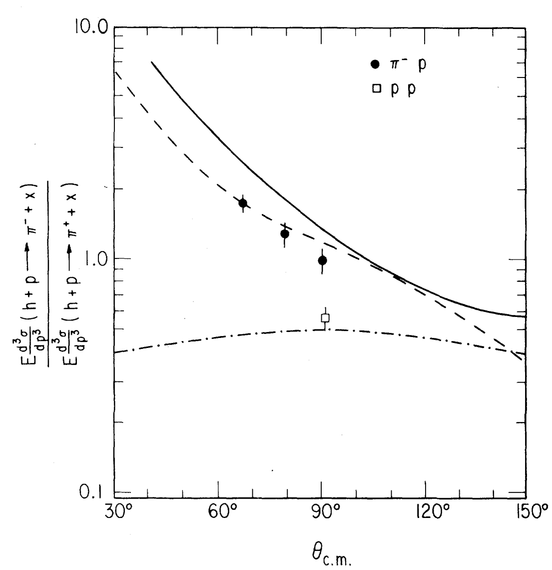

FIG. 5. The angular dependence of the trigger ratio π^-/π^+ at $P_T = 4$ GeV/c for the π^- beam. The solid curve is the prediction from Ref. 8: The dashed curve is the same model with a harder gluon fragmentation (Ref. 10). The proton datum at 90° and the corresponding prediction of Ref. 8 are shown for comparison.

mentation function which produces more hard particles[10] (i.e., more particles with a larger fraction of the gluon momentum). On the same plot are shown our measured point for the p-p case at 90° and the p-p prediction of Ref. 8. The difference in valence-quark content of the target and projectile produces an asymmetry in the π^-/π^+ ratio with angle which is quite unlike the flat behavior in p-p collisions.[11]

In conclusion, we have measured the cross section in $\pi^- p$ and pp collisions for the production of identified charged hadrons over the P_T range $0.8 < P_T < 6.0$ GeV/c. The data scale with P_T and x_T; the fitted parameters are tabulated and compared to the pp case. The comparisons agree well both with hard-scattering calculations and with simple quark counting rules.

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[a]Present address: Department of Physics and Astronomy, Rutgers University, P. O. Box 849, Piscataway, N. J. 08854.

[b]Present address: Bell Laboratories, 600 Mountain Avenue, Murray Hill, N. J. 07974.

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[7]The data presented in Table I on the fitted powers for proton-proton interactions are from Ref. 1. The comparisons shown in Figs. 4 and 5 are new proton-proton data taken with our present spectrometer. The two sets of data agree well.

[8]R. P. Feynman, R. D. Field, and G. C. Fox, Phys. Rev. D 18, 3320 (1978).

[9]G. Brandenburg, private communication, to be published. The open points in Fig. 3 are extrapolated to $x = 0$ from data in the region $x \geqslant 0.2$ in 175-GeV πp and pp collisions. The data for $\pi^- p \to \pi^-$ and $pp \to p$ are not as easily extrapolated to $x = 0$ and hence no points are shown.

[10]R. D. Field, private communication.

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