SOME RESULTS ON INCLUSIVE REACTIONS OBTAINED IN BUBBLE CHAMBER EXPERIMENTS

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During the past year a rather strange phenomenon could be observed, namely, that the number of papers giving reviews of experimental data on inclusive reactions was greater than the number of experimental papers presenting those data. I am going to increase their ratio, keeping in mind, however, the old principle of psychology that : "The probability of remembering increases with increasing number of repetitions".

In this talk I am going to present some results of the study of inclusive reactions only in meson-proton collisions below 30 GeV. This subject has become so broad, that it is impossible to discuss all the problems which are now of interest, therefore, I will concentrate on few arbitrarily selected topics. To illustrate them I shall use the data obtained by the Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-London-Vienna-Warsaw Collaboration for π^+p at 8 GeV/c, $\pi^{\pm}p$ at 16 GeV/c and K^-p at 10 GeV/c.

1. Let me start with the hypothesis of limiting fragmentation proposed by Benecke et al., [1]. This asserts that when two particles collide each of them breaks into fragments and that the momentum spectra of the target fragments approach, as the energy increases, a limiting (energy independent) distribution in the laboratory frame, while for the fragments of the projectile a limiting distribution is to be expected in the projectile rest frame (mirror system). This hypothesis, as presented in ref. [1], does not specify how quickly the limit should be approached, suggesting, however, that in general this will occur "slowly".

There exist a number of different predictions [2-7] concerning the requirements which are necessary and/or sufficient for "early" limiting fragmentation. Chan et al., [2] have suggested in the framework of Regge-pole models, that limiting distribution for the reaction

$$A + B \to C + \text{anything} \qquad (1)$$

should be obtained already at present accelerators energies (below 30 GeV), when the system $(AB\bar{C})$ has exotic quantum numbers, otherwise the limit be approached approximately a $s^{-1/2}$. Ellis et al. [3] have suggested that, in addition to $(AB\bar{C})$, also the system (AB) must be exotic in order to obtain early limiting fragmentation.

In fig. 1 are presented [8] the $p^{\parallel}_{LAB}$ distributions for the reactions

$$\pi^+ p \rightarrow \pi^- + \text{anything} \qquad \text{at 8 and 16 GeV/c} \tag{2}$$

$$\text{and } \pi^+ p \rightarrow \pi^+ + \text{anything} \qquad \text{at 8 and 16 GeV/c} \tag{3}$$

For both reactions the system $(AB) \equiv (p\pi^+)$ is non-exotic, while the system $(AB\bar{C})$ is exotic for reaction (2) and non-exotic for reaction (3). The agreement between the $p^{\parallel}_{LAB}$ distribution at the two energies for reaction (2), indicating that limiting fragmentation occurs, does not support the suggestion of Ellis et al.

The longitudinal momentum distributions in the projectile rest frame for reactions (2) and (3), shown in fig. 2, present the same features. In this case, however, for reaction (2) both the system $(AB\bar{C})$ and the system $(A\bar{C}) \equiv (\pi^+\pi^+)$ are exotic. Unfortunately at present, the data available do not allow to distinguish among other predictions for early limiting, larger statistics being needed. One of the interesting tests would be to study the reaction

$$K^- p \rightarrow \pi^+ + \text{anything} \tag{4}$$

at different energies, for which the system $(AB\bar{C})$ and (AB) are both non-exotic, and the system $(A\bar{C}) \equiv (K^-\pi^-)$ has exotic quantum numbers.

I would like at this moment to make a general remark concerning comparison of two or more experimental distributions. The errors on experimental distributions as given by the authors, usually are statistical errors plus corrections for the experimental biases found during the analysis of the data. There are, however, systematic errors, which nobody knows how to determine, which in bubble chamber experiments hopefully amounts to some percent. Therefore, it is always dangerous to compare absolute values of results obtained in different experiments. For the experimental data reported above, the authors hope, that since the results for the various reactions come from experiments performed by the same group using the same methods and equipment, the influence of systematic errors is indeed small.

2. The second topic I will discuss concerns scaling in inclusive reactions as proposed by Feynman [9]. The hypothesis of scaling predicts that the invariant distribution

$$f(x, p_\perp, s) = \frac{E}{\pi\, p^*_{MAX}} \frac{d^2\sigma}{dx\, dp^2_\perp},$$

where $x = p^*_\parallel / p^*_{MAX}$, becomes independent of s as $s \to \infty$. This hypothesis corresponds to the hypothesis of limiting fragmentation in the regions of x near ±1. It is, however, more general since it also gives a definite prediction for the central region near x = 0. In fig. 3a is shown the invariant distribution of x integrated over transverse momentum for reaction (2) at 8 and 16 GeV/c.

Near x = ±1 the distribution presents the same features as seen in figs. 1 and 2, namely that limiting fragmentation occurs. However, in the central region near x = 0, the absolute value of the f(x, s) function is larger at the higher energy. This effect may be even better seen in fig. 3b in which is presented the reduced rapidity distribution for the same reaction. This may be taken as evidence that at our accelerator energies scaling does not occur. This result was confirmed in other experiments [10] thus for the answer to the problem of scaling one has probably to wait for results of experiments in the energy range of the ISR.

Fig. 4 presents the invariant distribution of x integrated over $p_\perp$ for reaction (3). Here the situation is very different: the f(x, s) distributions at different energies do not present limiting behaviour, i.e. scaling in the regions of x = ±1, but are in excellent agreement for x = 0. This behaviour was also observed [11] for another reaction in which "C" = "A", namely

$$\pi^- p \rightarrow \pi^- + \text{anything} \quad \text{at 8 and 18.5 GeV/c} \qquad (4)$$

and until now has not been predicted by any existing model.

The exponential slopes of the $d\sigma/dx$ distribution of π^- mesons produced backwards in the different experiments presented in fig. 5 seem to increase with increasing energy of the incoming particle. This excludes the possibility that the distributions of pions present "naive" scaling, as proposed by Michejda [12] for protons at intermediate energies.

The results presented above concerned production of pions in meson-proton collision. The pions produced at accelerators energies have an average multiplicity ob about 5. A somewhat special case at our energies are the inclusi reactions in which only one particle of the type "C" is produced per event. Such reactions may be called "undeveloped" inclusive reaction [13]. An example of this is

$$K^- p \rightarrow \Lambda + \text{anything} \qquad (5)$$

where at our energies the cross sections for $(\Lambda\bar{\Lambda})$ and (ΛK) pair production are very small. The cross section for the hypercharge annihilation reaction

$$K^- p \rightarrow \Lambda + \text{pions} \qquad (6)$$

which dominates reaction (5), falls rapidly with increasing energy, so it is not surprising that the $d\sigma/dx$ and invariant $f(x, s)$ distributions of lambdas shown in fig. 6 do not present scaling. It is not, however, inconsistent with possible scaling at much higher energies, since this hypothesis is proposed for asymptotic situation when pair production will probably dominate reaction (5).

A large amount of data available on the study of single particle distributions were recently reviewed by Deutschmann [10].

3. The ABBCCHW Collaboration [14] has reported a comparison of the momentum spectra of pions produced in π^+p and π^-p collisions both at same energy of 16 GeV/c. The reactions studied were

$$\pi^+ p \rightarrow \pi^+ + \text{anything} \qquad (7)$$

$$\pi^+ p \rightarrow \pi^- + \text{anything} \qquad (8)$$

$$\pi^- p \rightarrow \pi^- + \text{anything} \qquad (9)$$

and $$\pi^- p \rightarrow \pi^+ + \text{anything} \qquad (10)$$

The invariant x distributions for these four reactions are presented in fig. 7. One notices a similarity of the distributions in the forward direction for the pairs of reactions (7) and (9) and (8) and (10) respectively. Especially the strong "leading" particle effect seems to be the same for the first pair. All four distributions are, however, significantly different in the backward direction ($x < 0$).

The corresponding rapidity distributions for reactions (7) - (10) shown in fig. 8 present practically the same features. The broad shoulder in the region of $1.5 \lesssim y \lesssim 3.0$ for reactions (7) and (9) corresponds to the "leading" particle effect well observed in the distributions of f(x, s). This is due to the very strong kinematical restrictions put by transverse momentum on the rapidity distribution as can be seen in fig. 9. One notices that the range of rapidity corresponding to the rather sharp peak of "leading" effect is relatively large. In order to study the leading particle effect in more detail the rapidity and invariant x distributions in the reactions (9) and (10) were plotted in fig. 10 for different values of transverse momenta. It is interesting to note that the leading particle effect persists for all values of $p_\perp$ in the reaction (9), but it disappears with increasing transverse momentum for reaction (10). This is probably due to the fact that the leading effect for the pions of charge opposite to the incoming one comes from the decay of mesonic resonances. The change of the position of the peak in the rapidity plots for different values of $p_\perp$ is again due to kinematic constraints.

4. Finally, I would like to concentrate on the problem of asymmetry in the production of pions in meson-proton collisions. As can be seen in fig. 11, the longitudinal momentum distributions of produced pions [15] are quite well described by an exponential function

$$\frac{d\sigma}{dp_L} \sim e^{-A|p_L|}$$

at least in the central region. They are, however, strongly asymmetric with respect to $p_L = 0$, more pions being produced forward than backward or in other words $A_{backward} > A_{forward}$. This is not due to the leading particle effect since it is observed very strongly near $p_L^* = 0$. It is, therefore, of great interest to study pion emission in the central region as the basis for different models and in particular the question of whether a reference frame exists in which the pions produced are emitted symmetrically is of importance to all phenomenological descriptions. The search for the symmetry system in pion emission originally follows from the idea of Elbert et al. [16], who observed symmetry of produced pion distribution in the system corresponding in the simple quark model to the quark-quark collision centre-of-mass. The proposed method consisted of transforming the distribution of pions along the beam axis until they become symmetric around $p_L = 0$. The new reference frame may be characterised by the ratio of incoming momenta

$$R = p(\text{proton}) \;/\; p(\text{meson}).$$

The idea of simple quark model, as was already noticed in original paper and confirmed later in several experiments [17, 18, 19] has basic difficulty of explaining the fact that the symmetry system depends very strongly on the multiplicity of the final state. In the recent work of ABBCCHLVW Collaboration [15] several different methods of searching for symmetry system were used and in addition it was checked by studying transverse momentum distributions, that the system in which the longitudinal momentum is symmetric, indeed corresponds to the symmetry system of pions emission. The compilation of the values of parameter R for different experiments shown in fig. 12 indicates that it is not strongly dependent on energy but is slightly different for different incoming particles. The values of R equal to about 1.5 for Kp collisions and to about 1.75 for πp collisions (1.0 for pp interactions) may indicate the dependence of R on the mass of incoming particle. It is not clear, however, whether the effect will persist at higher energies when the products of the fragmentation of target and projectile will be better separated from possible pionisation products.

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FIGURE CAPTIONS

1. Longitudinal momentum distribution in the laboratory frame for π^- and π^+ produced in π^+p collisions at 8 and 16 GeV/c.

2. Longitudinal momentum distribution in the projectile rest frame for π^- and π^+ produced in π^+p collisions at 8 and 16 GeV/c.

3. Distributions of

   a) invariant f(x, s) distribution

   b) reduced rapidity distribution

   for reaction (2) at 8 and 16 GeV/c.

4. The invariant x distribution for reaction (3) at 8 and 16 GeV/c.

5. Exponential slopes of $d\sigma/dx$ distributions for π^- mesons produced backward in the c.m. system as a function of incoming momentum.

6. Distribution of the functions

   a) f(x, s), b) $d\sigma/dx$ and c) $1/\sigma(\Lambda) \cdot d\sigma/dx$

   for the reaction (6) at 4.2 and 10.1 GeV/c.

7. The invariant x distributions for reactions (7) - (10) at 16 GeV/c.

8. Rapidity distributions for reactions (7) - (10) at 16 GeV/c.

9 Lines of equal rapidity on the Peyrou-plot.

10. Rapidity and invariant x distributions for different values of $p_\perp^2$ for the reactions (9) and (10) at 16 GeV/c.

11. Longitudinal momentum distributions for the reactions

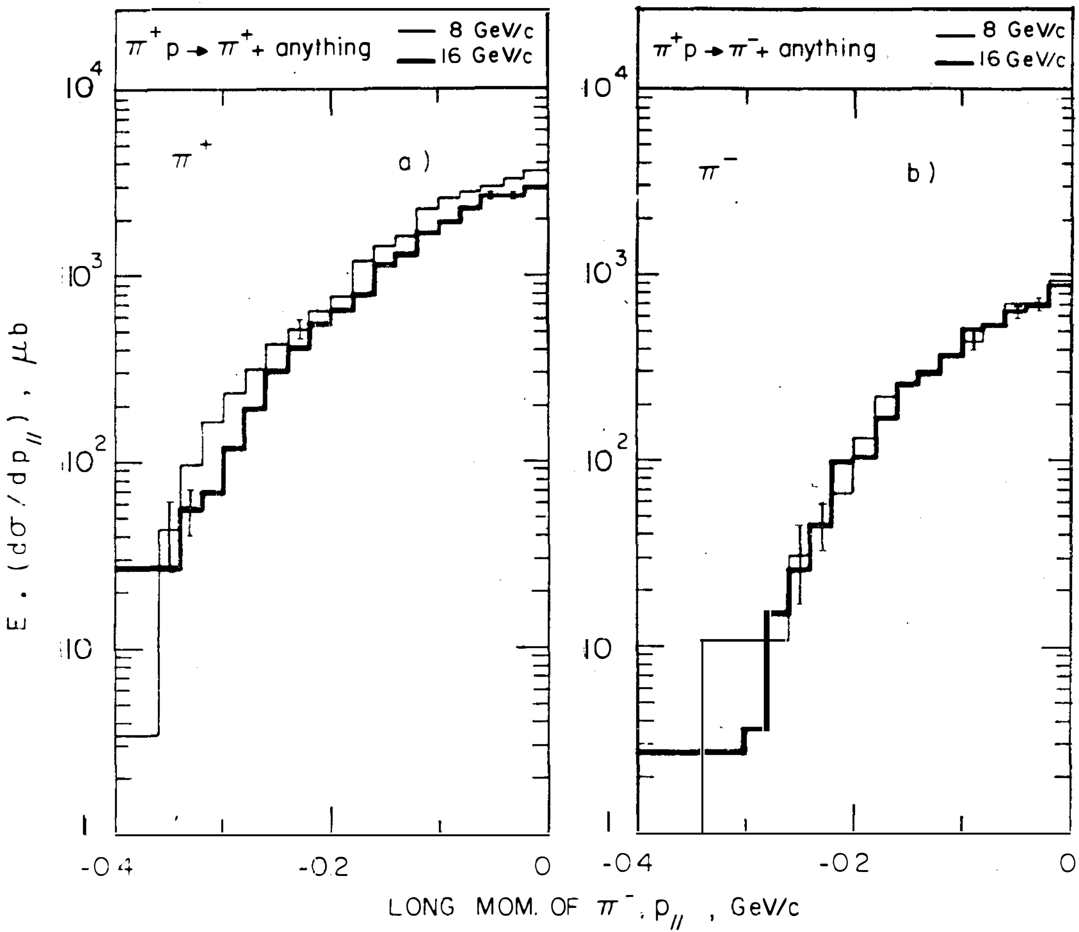
   a) $\pi^+p \rightarrow \pi^-$ + anything at 8 GeV/c

   b) $\pi^+p \rightarrow \pi^-$ + anything at 16 GeV/c

   c) $K^-p \rightarrow \pi^\pm$ + anything at 10 GeV/c

   d) $\pi^-p \rightarrow \pi^\pm$ + anything at 16 GeV/c

12. Values of parameter R as the function of incoming momentum.



π⁺p → π⁺ + anything
8 GeV/c
16 GeV/c
π⁺
a)
π⁺p → π⁻ + anything
8 GeV/c
16 GeV/c
π⁻
b)
E · (dσ / dp//) , μb
LONG MOM. OF π⁻ , p// , GeV/c

Fig. 1

Fig. 2

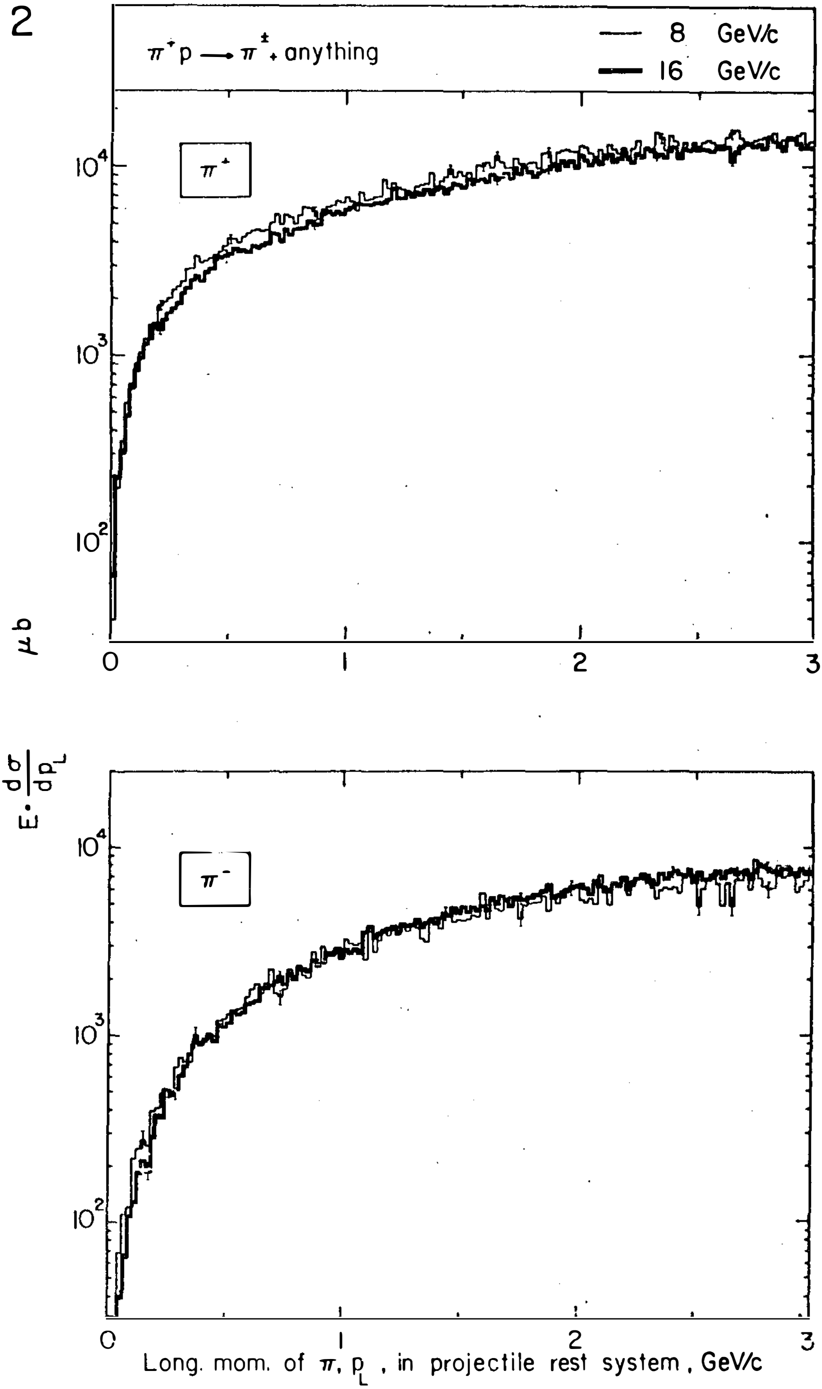
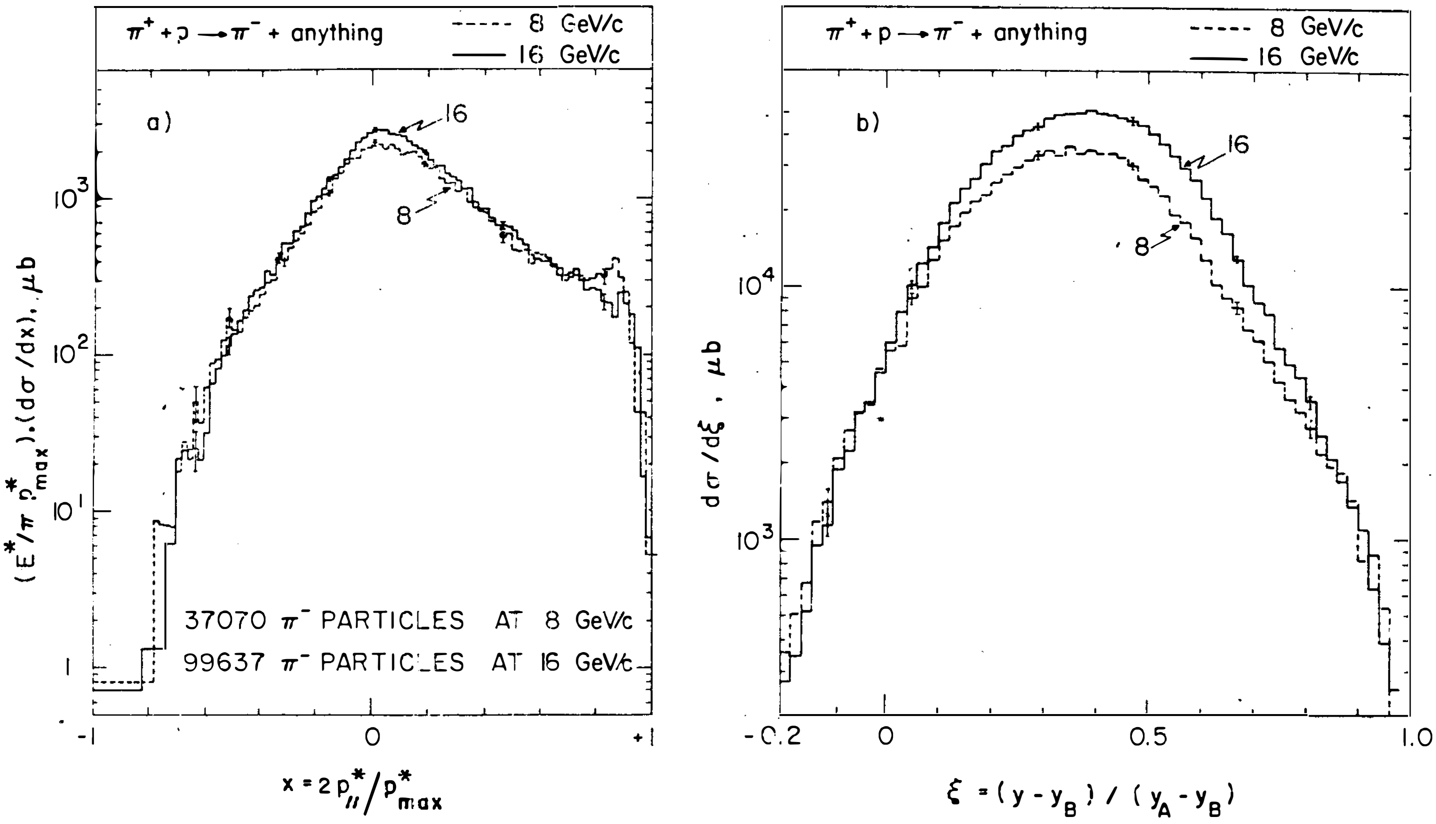
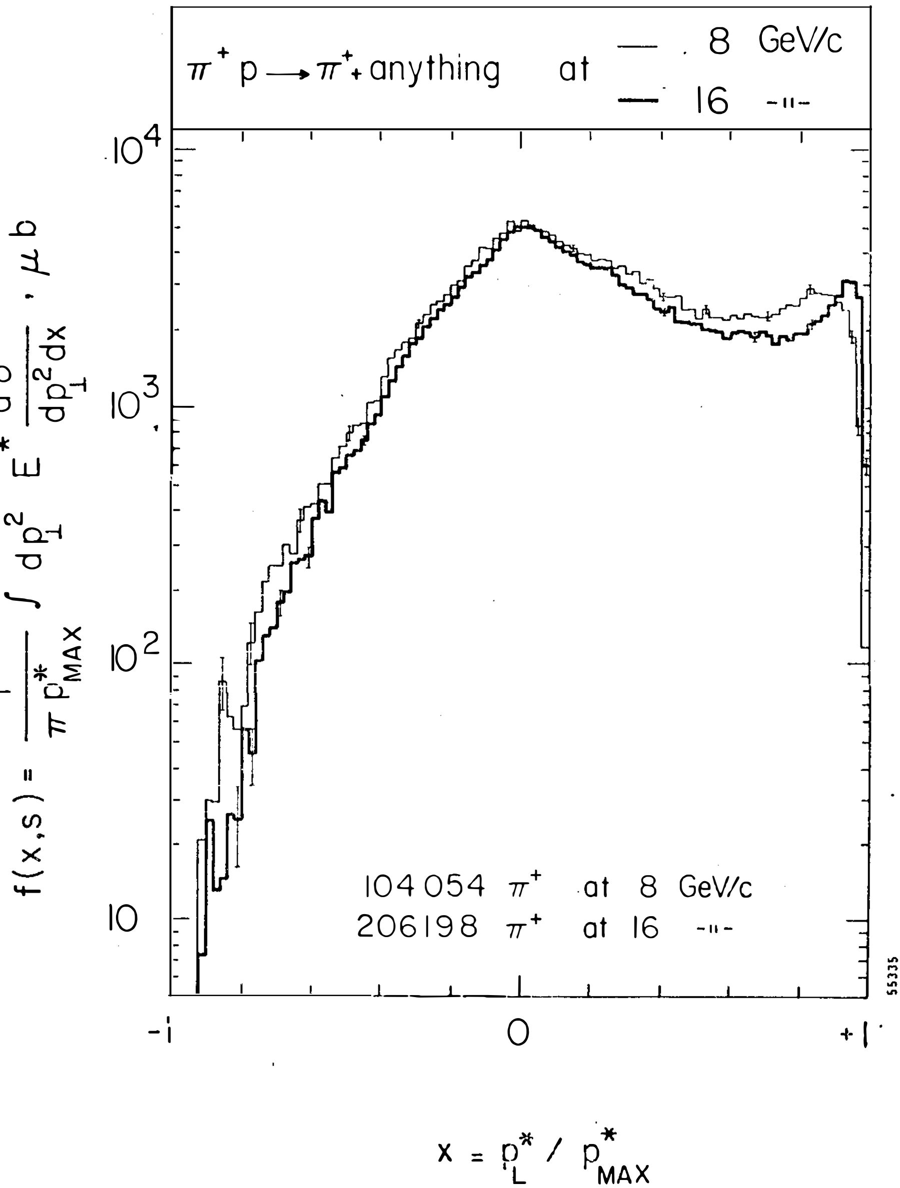

$\pi^+ p \longrightarrow \pi^\pm$ + anything
8 GeV/c
16 GeV/c
π^+
π^-
10^4
10^3
10^2
$E \cdot \frac{d\sigma}{dp_L}$ μb
0
1
2
3
Long. mom. of π, p_L, in projectile rest system, GeV/c

Fig. 3



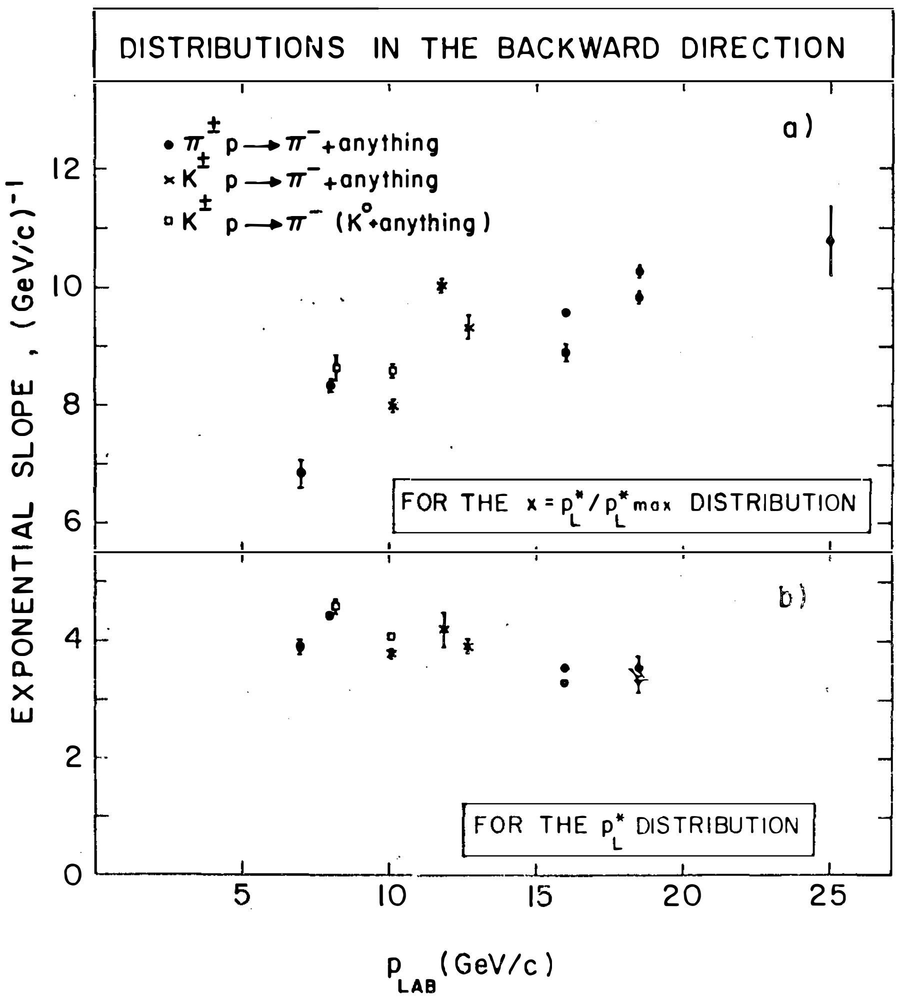
$\pi^+ + p \rightarrow \pi^- +$ anything
8 GeV/c
16 GeV/c
a)
16
8
$(E^*/\pi p^*_{max}) \cdot (d\sigma/dx)$, μb
10^3
10^2
10^1
1
37070 π^- PARTICLES AT 8 GeV/c
99637 π^- PARTICLES AT 16 GeV/c
-1
0
+1
$x = 2p^*_{//}/p^*_{max}$
b)
10^4
10^3
$d\sigma/d\xi$, μb
-0.2
0
0.5
1.0
$\xi = (y - y_B)/(y_A - y_B)$

Fig. 4



π⁺ p ⟶ π⁺ + anything at
— 8 GeV/c
— 16 -"-
10⁴
10³
10²
10
f(x,s) = 1/(π p*MAX) ∫ dp⊥² E* d²σ/(dp⊥² dx) , μb
104 054 π⁺ at 8 GeV/c
206198 π⁺ at 16 -"-
-1
0
+1
x = p*L / p*MAX
55335

Fig. 5



DISTRIBUTIONS IN THE BACKWARD DIRECTION
a)
• $\pi^{\pm}$ p → π^{-} + anything
× $K^{\pm}$ p → π^{-} + anything
▫ $K^{\pm}$ p → π^{-} (K^{o} + anything)
FOR THE $x = p_L^* / p_L^*{}_{max}$ DISTRIBUTION
b)
FOR THE p_L^* DISTRIBUTION
EXPONENTIAL SLOPE, $(GeV/c)^{-1}$
p_{LAB} (GeV/c)
0
2
4
6
8
10
12
5
10
15
20
25

Fig. 6

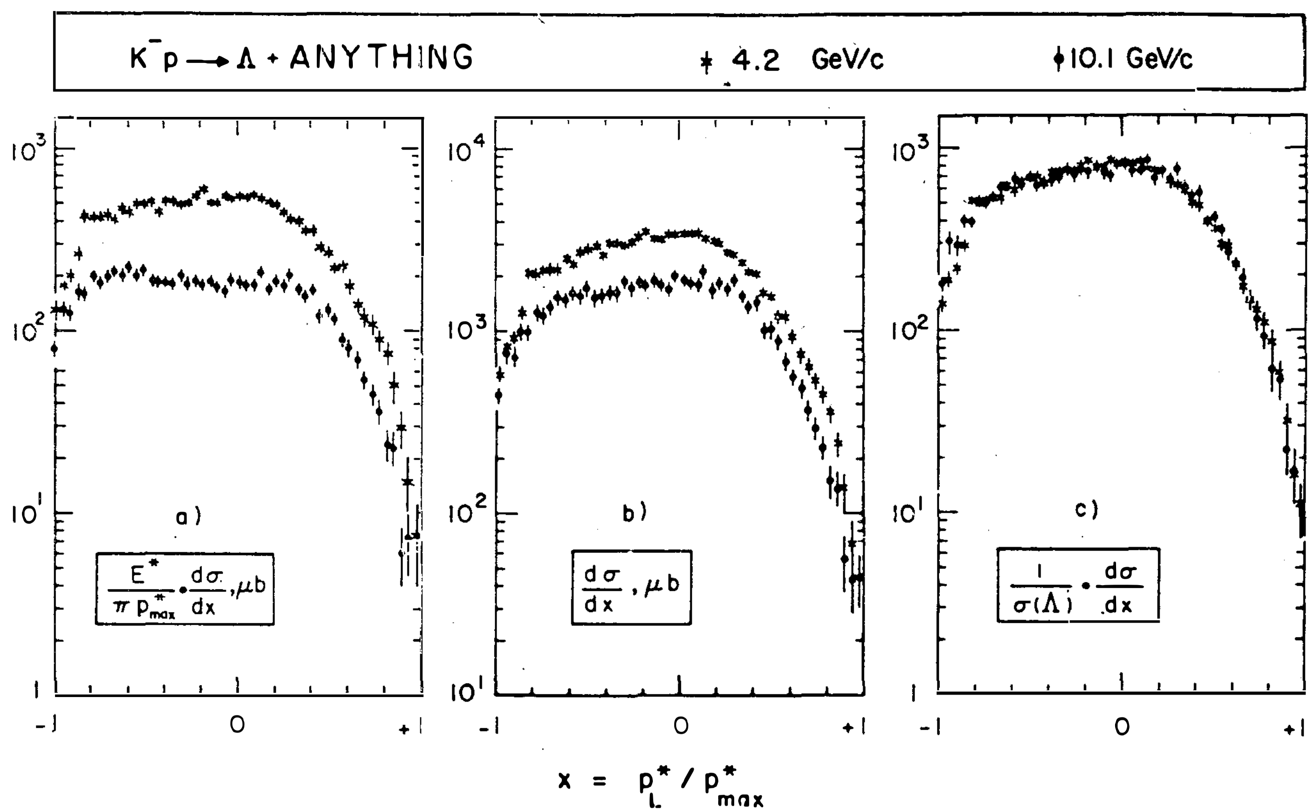
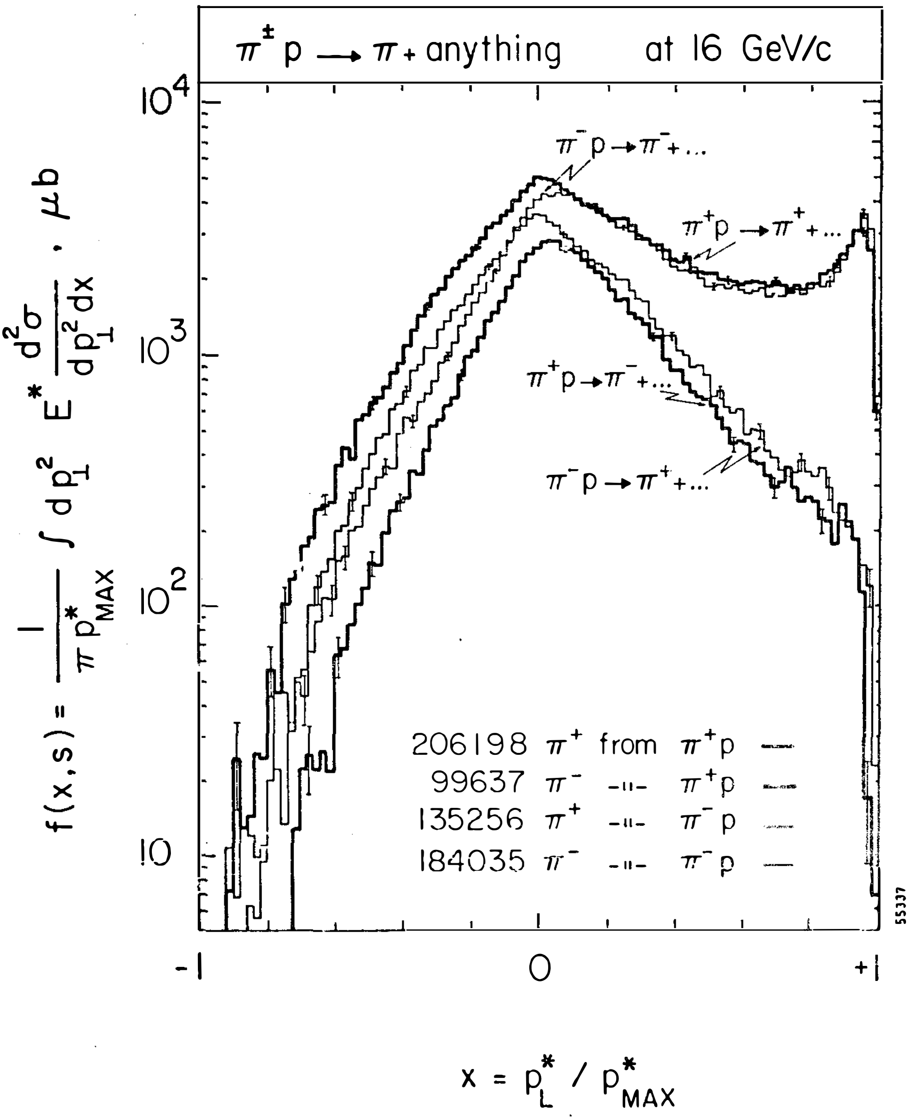
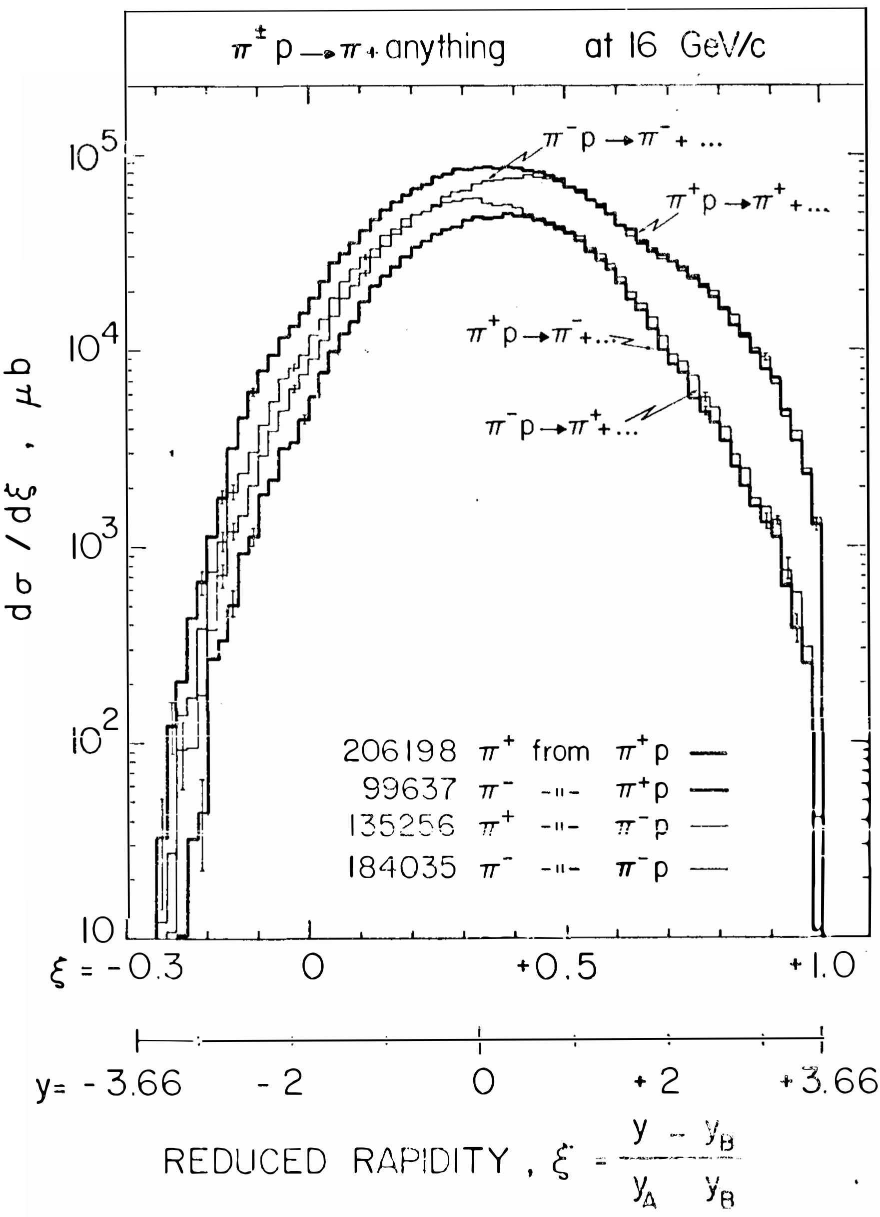

K⁻p → Λ + ANYTHING
4.2 GeV/c
10.1 GeV/c
a)
b)
c)
$\frac{E^*}{\pi p^*_{max}} \cdot \frac{d\sigma}{dx}, \mu b$
$\frac{d\sigma}{dx}, \mu b$
$\frac{1}{\sigma(\Lambda)} \cdot \frac{d\sigma}{dx}$
10^3
10^2
10^1
1
10^4
-1
0
+1
$x = p^*_L / p^*_{max}$

Fig. 7



$\pi^{\pm}p \longrightarrow \pi$ + anything at 16 GeV/c
10^4
10^3
10^2
10
$\pi^-p \to \pi^- + \ldots$
$\pi^+p \to \pi^+ + \ldots$
$\pi^+p \to \pi^- + \ldots$
$\pi^-p \to \pi^+ + \ldots$
206198 π^+ from π^+p
99637 π^- -"- π^+p
135256 π^+ -"- π^-p
184035 π^- -"- π^-p
-1
0
+1
$f(x,s) = \frac{1}{\pi p^*_{MAX}} \int dp_\perp^2 \; E^* \frac{d^2\sigma}{dp_\perp^2 dx}$, μb
$x = p^*_L \,/\, p^*_{MAX}$
55337

Fig. 8



π± p → π + anything at 16 GeV/c
π⁻p → π⁻ + ...
π⁺p → π⁺ + ...
π⁺p → π⁻ + ...
π⁻p → π⁺ + ...
206198 π⁺ from π⁺p
99637 π⁻ -"- π⁺p
135256 π⁺ -"- π⁻p
184035 π⁻ -"- π⁻p
dσ / dξ , μb
10⁵
10⁴
10³
10²
10
ξ = -0.3
0
+0.5
+1.0
y= -3.66
-2
0
+2
+3.66
REDUCED RAPIDITY , ξ = (y − y_B)/(y_A − y_B)
55332

LINES OF EQUAL RAPIDITY FOR PIONS IN πp INTERACTIONS
AT 16 GeV/c

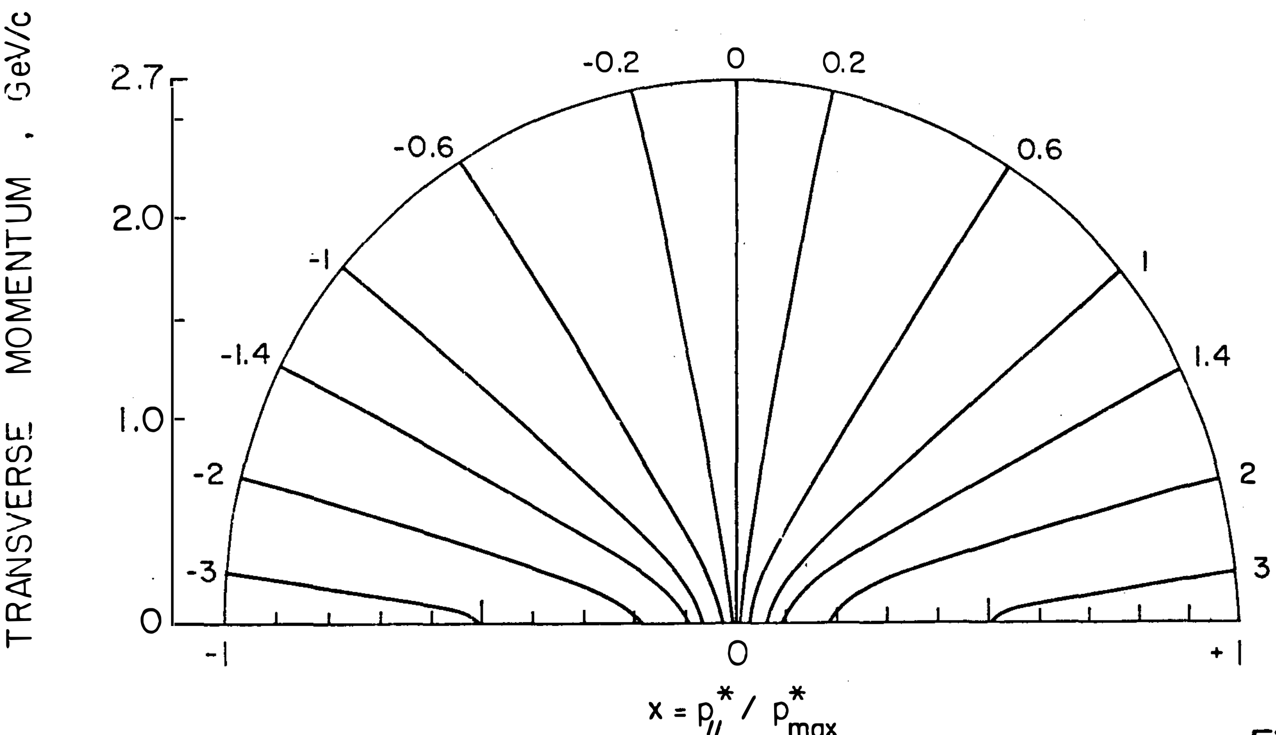
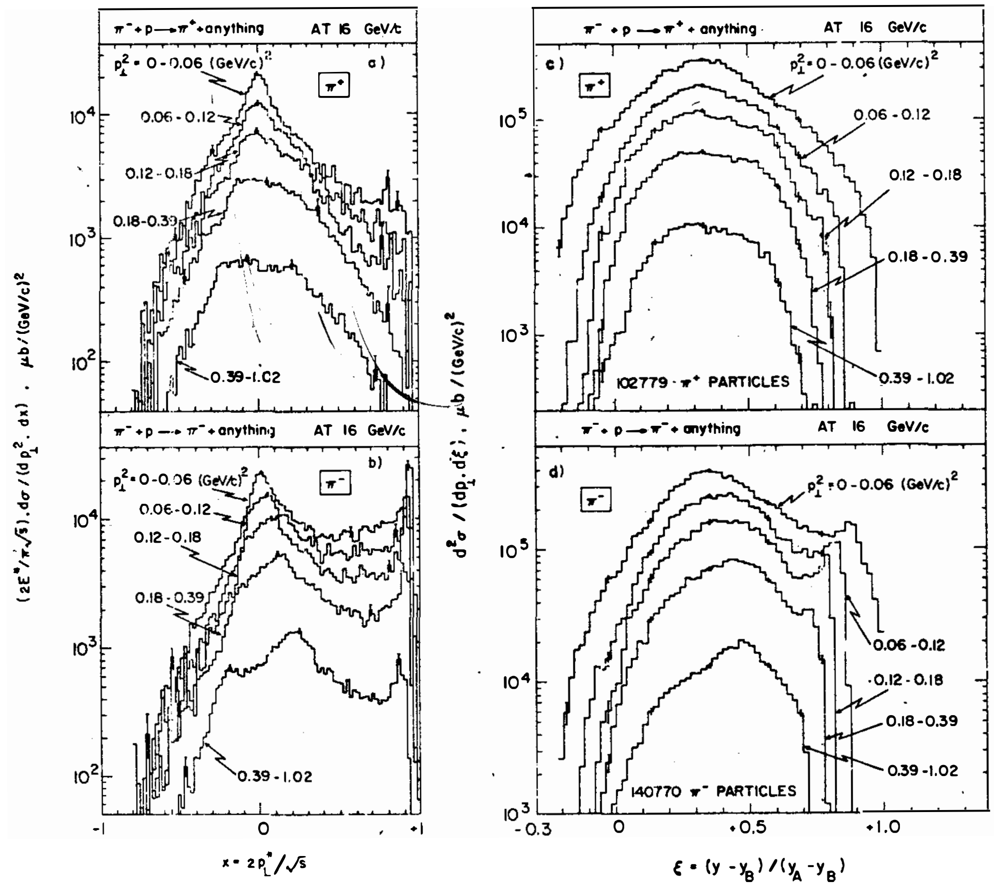


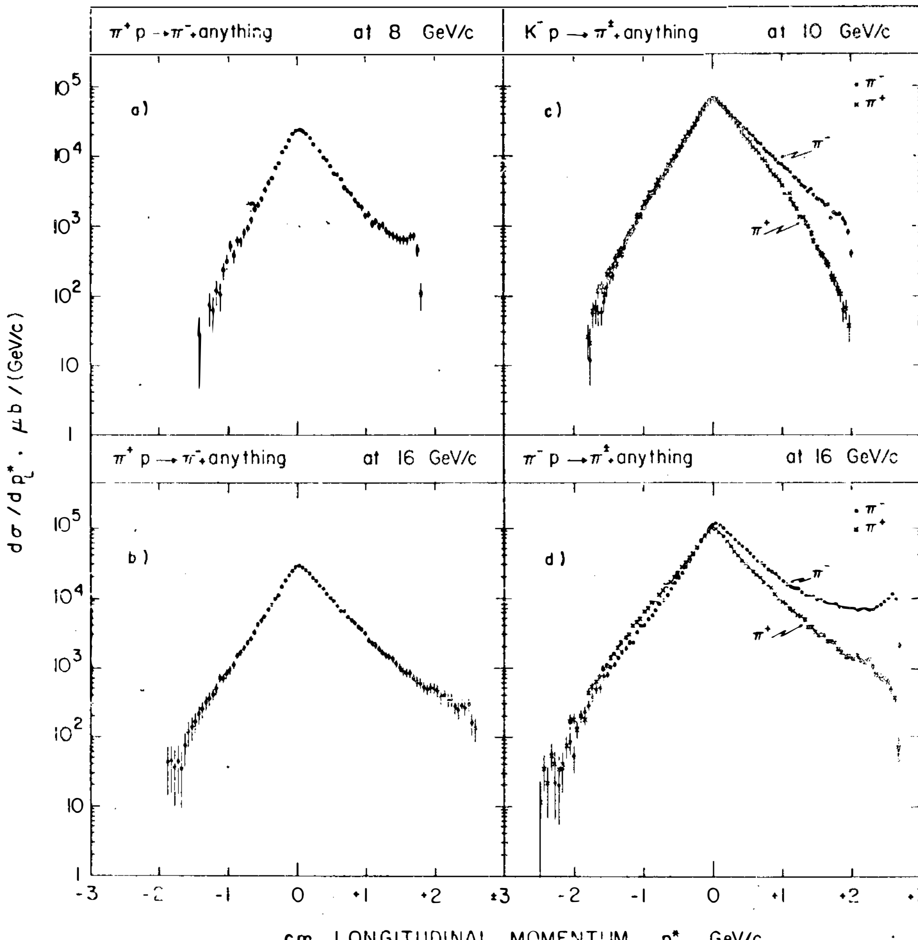
Fig. 9

Fig. 10



π⁻ + p → π⁺ + anything AT 16 GeV/c
a)
π⁺
p⊥² = 0 - 0.06 (GeV/c)²
0.06 - 0.12
0.12 - 0.18
0.18 - 0.39
0.39 - 1.02
10⁴
10³
10²
π⁻ + p → π⁻ + anything AT 16 GeV/c
b)
π⁻
p⊥² = 0 - 0.06 (GeV/c)²
0.06 - 0.12
0.12 - 0.18
0.18 - 0.39
0.39 - 1.02
10⁴
10³
10²
-1
0
+1
(2E*/π√s) . dσ / (dp⊥² . dx) , μb / (GeV/c)²
x = 2p_L*/√s
π⁻ + p → π⁺ + anything AT 16 GeV/c
c)
π⁺
p⊥² = 0 - 0.06 (GeV/c)²
0.06 - 0.12
0.12 - 0.18
0.18 - 0.39
0.39 - 1.02
102779 π⁺ PARTICLES
10⁵
10⁴
10³
π⁻ + p → π⁻ + anything AT 16 GeV/c
d)
π⁻
p⊥² = 0 - 0.06 (GeV/c)²
0.06 - 0.12
0.12 - 0.18
0.18 - 0.39
0.39 - 1.02
140770 π⁻ PARTICLES
10⁵
10⁴
10³
-0.3
0
+0.5
+1.0
d²σ / (dp⊥ . dξ) , μb / (GeV/c)²
ξ = (y - y_B) / (y_A - y_B)

Fig. 11


π⁺ p → π⁻ + anything at 8 GeV/c
K⁻ p → π± + anything at 10 GeV/c
π⁺ p → π⁻ + anything at 16 GeV/c
π⁻ p → π± + anything at 16 GeV/c
a)
b)
c)
d)
• π⁻
× π⁺
π⁻
π⁺
dσ / dp*_L , μb / (GeV/c)
c.m. LONGITUDINAL MOMENTUM , p*_L , GeV/c
10⁵
10⁴
10³
10²
10
1
-3
-2
-1
0
+1
+2
±3
+3

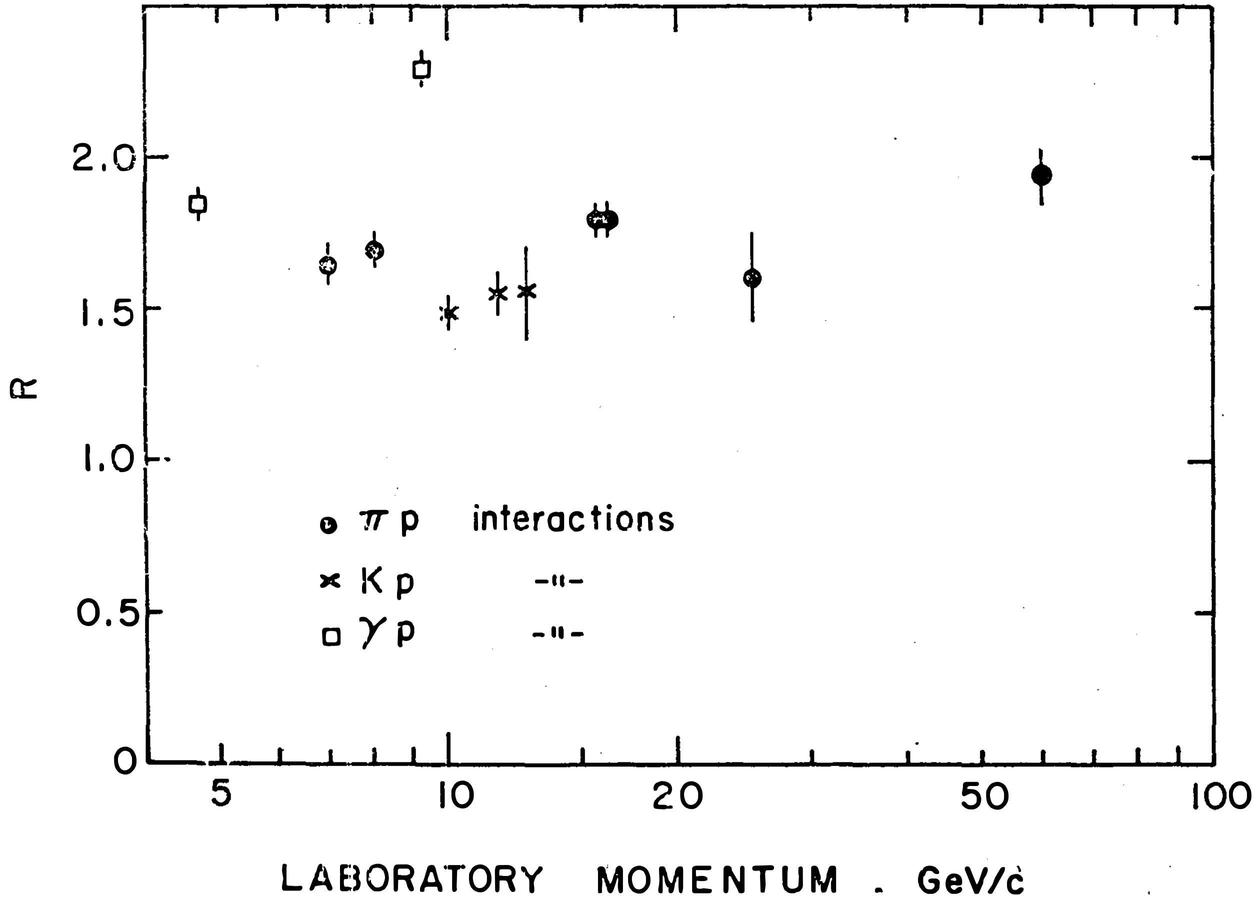

R
2.0
1.5
1.0
0.5
0
5
10
20
50
100
LABORATORY MOMENTUM . GeV/c
π p interactions
K p -"-
γ p -"-

Fig. 12