PUB-76-143-E
PRL
E154



# The Average Charged Multiplicity in $\pi^- + p \to \pi^-_{fast} + X$ at 147 GeV/c and Comparison with Other Reactions*

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Abstract

The average charged multiplicity, $\langle n_x \rangle$, has been determined for $\pi^- + p \to \pi^-_{fast} + X$ at 147 GeV/c and is found to increase linearly with $|t|$ as well as $\ln M_x^2$. The coefficient of the $\ln M_x^2$ term is approximately equal to that for other reactions, but the absolute value of $\langle n_x \rangle$ is significantly smaller even when analyzed in terms of available energy. This result is discussed in terms of a simple model.

In this paper we present for the first time data on the dependence of the average charged multiplicity, $\langle n_x \rangle$, of the system X in the inclusive reaction

$$\pi^- + p \to \pi^-_{fast} + X \qquad (1)$$

on the square of the invariant mass of X, $M_x^2$, and on the square of the four momentum transfer, t, between the incoming and fast outgoing $\pi^-$. We have observed a statistically significant linear increase of $\langle n_x \rangle$ with $|t|$ as well as with $\ln M_x^2$. The coefficient of the $\ln M_x^2$ term is approximately equal to that for other reactions. However, differences are observed between the absolute values of the average charged multiplicity for different reactions even when the comparison is made in terms of available energy. This result is discussed in terms of a simple model.

The dependence of $\langle n_x \rangle$ on $M_x^2$ in inclusive reactions of the type $a + b \to c + X$

has previously been studied both theoretically and experimentally. A linear dependence of $\langle n_x \rangle$ on $\ln M_x^2$ has been predicted by several theoretical models[1, 2]. The slope of this dependence is expected to be independent of s, t, and the type of the incident particle, and to be identical to the slope of the linear increase with ln s of the average total charged multiplicity, $\langle n_c \rangle$, in hadron-hadron reactions[2]. These predictions have previously been verified for the reactions

$$p + p \rightarrow p + X \qquad (2)$$

at Fermilab[3] and ISR energies[4], and for the reaction

$$\pi^- + p \rightarrow p + X \qquad (3)$$

at 205 GeV/c[5]. It is not possible to fit $\langle n_c \rangle$ for

$$p + p \rightarrow X \qquad (4)$$

by a ln s term alone over the whole range of s including ISR energies, but $\langle n_c \rangle$ for

$$\pi^- + p \rightarrow X \qquad (5)$$

can be fit by a ln s dependence from s = 20 GeV$^2$ through Fermilab energies[5, 6]. The various models also suggest a dependence of $\langle n_x \rangle$ on t but do not predict a unique functional form[1, 2]. Studies of reaction (2) at 205 GeV/c and ISR energies and of reaction (3) at 205 GeV/c indicated that $\langle n_x \rangle$ has a weak or no t-dependence in these reactions[4, 7]. It has been previously pointed out that when $\langle n_c \rangle$ for $pp \rightarrow X$, $\pi^{\pm}p \rightarrow X$, and $K^{\pm}p \rightarrow X$ is plotted as a function of the available energy, $Q = \sqrt{s} - m_a - m_b$, for the reaction $a + b \rightarrow X$, all values lie approximately on a universal curve[8]. Whitmore and Derrick[9] have extended this idea to inclusive reactions of the type $a + b \rightarrow c + X$, where c is produced in the fragmentation region of the incoming particle a, and have plotted $\langle n_x \rangle$ as a function of $Q = M_x - m_b$. A roughly universal dependence of $\langle n \rangle$ on $\ln Q^2$ has been obtained for reactions (2) - (5)[9].

This experiment consisted of an exposure of 105,000 pictures with a beam of 147 GeV/c $\pi^-$ mesons in the Fermilab 30-inch bubble chamber proportional wire

chamber hybrid spectrometer. Details of the experimental arrangement and of the data reduction in this experiment have already been published [6,10]. From the total sample of 7218 inelastic events we have obtained a sample of 1867 inelastic events with a fast $\pi^-$, for which $x(\pi^-)$[11] is greater than 0.5. This study was possible be-because of the momentum resolution ($\Delta p/p \leq 0.09$) of the hybrid system for fast forward particles. The details of the analysis will be presented in a later publication.

In fig. 1 we present $\langle n_x \rangle$ as a function of $|t|$ for various $M_x^2$ intervals, and significant increases in $\langle n_x \rangle$ as a function of $|t|$ are observed in all $M_x^2$ regions. The data for $M_x^2 > 20$ GeV$^2$ can all be fit by a linear dependence on $|t|$ and within our uncertainties the slopes of this dependence are independent of $M_x^2$. The dependence of $\langle n_x \rangle$ on $\ln M_x^2$ for various t-intervals is shown in fig. 2 and is consistent with the linear behavior that was found previously in reactions (2) and (3)[3,4,5] and predicted theoretically[1,2]. Within our uncertainties the slope of the dependence on $\ln M_x^2$ is independent of t. We have therefore carried out a two-dimensional fit to all the data for reaction (1) in the kinematical region $|t| < 2$ GeV$^2$ and $20 < M_x^2 < 140$ GeV$^2$ of the expression $\langle n_x \rangle = A + B \ln M_x^2 + C\,|t|$. The best fit yielded the parameters $A = -1.77 \pm 0.61$, $B = 1.43 \pm 0.15$, and $C = 1.06 \pm 0.19$ with a chi-square probability of 26%. The solid lines in figs. 1 and 2 are plotted from the fitted function and, as one can see, all the data in figs. 1-2 are satisfactorily described by this parametrization.

We have also carried out a two-dimensional fit to the data for reaction (3) from this experiment and obtained the preliminary result, $B = 1.47 \pm 0.15$. Our results for B in reactions (1) and (3) may be compared with the values of the coefficient of the $\ln M_x^2$ or $\ln s$ term from previous fits to $\langle n \rangle$ ($\langle n_x \rangle$ or $\langle n_c \rangle$, respectively) for reactions (2)-(5), and the agreement is good[7-9, 12]. The preliminary value of C we have obtained for reaction (3) indicates that there is little dependence of $\langle n_x \rangle$ on t

for this reaction in agreement with previous results[7] and contrasting with the significant t-dependence obtained for reaction (1).

When we compare our results for $\langle n \rangle$ as a function of $\ln Q^2$ for reactions (1) and (3) with published results for reactions (2) and (3) at 205 GeV/c[3,5] and reactions (4) and (5) at energies corresponding to $Q^2 \leq 180$ GeV$^2$[8], there are significant differences in the absolute values of $\langle n \rangle$. The data for these three pairs of reactions are shown in figs. 3(a) - 3(c), together with the results of fits of the expression, $\langle n \rangle = A' + B' \ln Q'^2$, to the data for each reaction in the region of $Q^2$ shown. These fits were done in terms of the shifted variable, $Q'^2 = Q^2/Q_M^2$, where $Q_M^2$ is the value of $Q^2$ at the center of the region fit, so that $A'$ is equal to $\langle n \rangle$ at that point for each reaction. The systematic displacements between the fits for each of the three pairs of reactions, $\delta'(j)$, are thus given by the differences between the values of $A'$ for each pair, and the values obtained are $\delta$ (i) = 0.27 ± 0.06, $\delta$ (ii) = 0.30 ± 0.10, and $\delta$ (iii) = 0.55 ± 0.12 for (i) reactions 5 and 4, (ii) reactions 3 and 2, and (iii) reactions 3 and 1, respectively[13].

We have attempted to explain these differences by a simple model which assumes that for any given reaction $a + b \rightarrow X$, the outgoing particles can originate from three distinct regions (fig. 3g): a central region, which is independent of particles a and b and where the average multiplicity $n_0$ increases with energy as $B \ln s$, and the fragmentation regions of particles a and b, where the average multiplicities $n_a$ and $n_b$ are presumably energy independent, but may depend on the nature of the fragmented particle[14]. Based on this description one obtains for the average charged multiplicity:

$$\langle n \rangle = n_a + n_0 + n_b = n_a + B \ln s + n_b. \qquad (6)$$

$\langle n_x \rangle$ for the single inclusive reaction, $a + b \rightarrow c + X$, may be described analogously

where the process $E_{ac} + b \to X$ ($E_{ac}$ is the exchanged particle) replaces $a + b \to X$ (see fig. 3h). Thus:

$$\langle n_x \rangle = n_{Eac} + n_0 + n_b = n_{Eac} + B \ln M_x^2 + n_b \,. \quad (7)$$

Due to the virtual nature of $E_{ac}$, $n_{Eac}$ (unlike $n_a$ or $n_b$) may depend on the kinematic variables s, $M_x^2$, and t[14]. Using eq. (6) for reactions (4) and (5) and eq. (7) for reactions (1) - (3), the differences of the average multiplicities for the three pairs of reactions are predicted to be:

$$\delta\,(i) = \delta\,(ii) = n_\pi - n_p \quad (8)$$

$$\delta\,(iii) = (n_\pi - n_p) + (n_{Epp} - n_{E\pi\pi}). \quad (9)$$

Figures 3d-f show the data for $\langle n \rangle$ as a function of ln s or ln $M_x^2$ for the six reactions together with the results of fits of the expression $\langle n \rangle = A + B \ln E_x'^2$ to the data. Here again the fit has been done in terms of a shifted variable $E_x'^2 = s/s_M$ [or $E_x'^2 = M_x^2 / (M_x^2)_M$] where $s_M$ [or $(M_x^2)_M$] is the value of s [or $M_x^2$] at the center of the region fit, so that A is equal to $\langle n \rangle$ at that point for each reaction. The systematic displacements between the fits for each of the three pairs of reactions, $\delta\,(j)$, are thus the differences between the values of A for each pair, and the values obtained are $\delta\,(i) = 0.53 \pm 0.05$, $\delta\,(ii) = 0.57 \pm 0.09$, and $\delta\,(iii) = 0.89 \pm 0.12$. Thus, we find that within errors $\delta\,(i) = \delta\,(ii)$, in agreement with the prediction of (8). The average of their two values gives $n_\pi - n_p = 0.55 \pm 0.05$. A similar result may be obtained from a study[15] of the reactions $\pi^+ + p \to \Delta^{++} + X$ and $p + p \to \Delta^{++} + X$ at 100 GeV/c. According to our picture, the difference between $\langle n_x \rangle$ for these reactions should also be equal to $n_\pi - n_p$. The experimental result is $\sim 0.6$, in good agreement with our value. From $n_\pi - n_p$ and the experimental value for $\delta\,(iii)$, we obtain from expression (9), $n_{Epp} - n_{E\pi\pi} = 0.34 \pm 0.13$.

We conclude that the average charged multiplicity $\langle n_x \rangle$ in the reaction

$\pi^- + p \rightarrow \pi^-_{fast} + X$ at 147 GeV/c can be parametrized as a linear function of $|t|$ and $\ln M_x^2$. The slope of the $\ln M_x^2$ dependence is very similar to those found for reactions (2) - (5), but systematic differences are observed between the absolute values of the average charged multiplicities which persist when the data are analyzed in terms of available energy. Comparison with the simple model described above indicates that the experimental results can be explained in terms of two differences: (1) a pion fragments on the average into more charged particles than a proton; (2) a virtual exchanged object coupled to two protons fragments on the average into more charged particles than a virtual exchanged object coupled to two pions.

We gratefully acknowledge several stimulating discussions with C. DeTar. We wish to express our sincere thanks to Fermilab and especially to the members of the Neutrino Section whose dedicated efforts made this experiment possible. We also wish to thank the scanning and measuring groups of our institutions for their competent execution of a new and difficult task.

Footnotes and References

* This work supported in part by the U. S. Energy Research and Development Administration and the National Science Foundation.

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## Figure Captions

Fig. 1: The average charged multiplicity of the system X for reaction (1) as a function of $|t|$ for (a) $0 < M_x^2 < 20$ GeV$^2$, (b) $20 < M_x^2 < 140$ GeV$^2$, and (c) - (h) various $M_x^2$ ($> 20$ GeV$^2$) intervals. The straight lines are plotted from the two-dimensional function described in the text.

Fig. 2: The average charged multiplicity of the system X for reaction (1) as a function of $M_x^2$ for (a) $|t| < 2$ GeV$^2$ and (b) - (e) various $|t|$ intervals. The straight lines are plotted from the two-dimensional function described in the text.

Fig. 3: a) The average charged multiplicity as a function of $\ln Q^2$ for reactions (4) and (5) [8]. The solid lines are calculated from the best fits of the expression $A' + B' \ln Q'^2$ to the data. The arrows labeled $\delta'$ (i) indicate the point at which the difference between the average multiplicities for this pair of reactions (i) was calculated; (b) Same as (a) for the pair (ii) of reactions (2) and (3) at 205 GeV/c [3, 5]; (c) Same as (a) for the pair (iii) of reactions (1) and (3) at 147 GeV/c; (d) The average charged multiplicity as a function of s for reactions (4) and (5) [8]. The solid lines are calculated from the best fits of the expression $A + B \ln E_x'^2$ to the data (see text). The arrows labeled $\delta$ (i) indicate the point at which the difference between the average multiplicities for this pair of reactions (i) was calculated; (e) Same as (d) with s replaced by $M_x^2$ for the pair (ii) of reactions (2) and (3) at 205 GeV/c [3, 5]; (f) Same as (d) with s replaced by $M_x^2$ for the pair (iii) of reactions (1) and (3) at 147 GeV/c; (g) Diagram for the total inelastic reaction $a + b \to X$ (see text); (h) Diagram for the inclusive reaction $a + b \to c + X$ (see text).

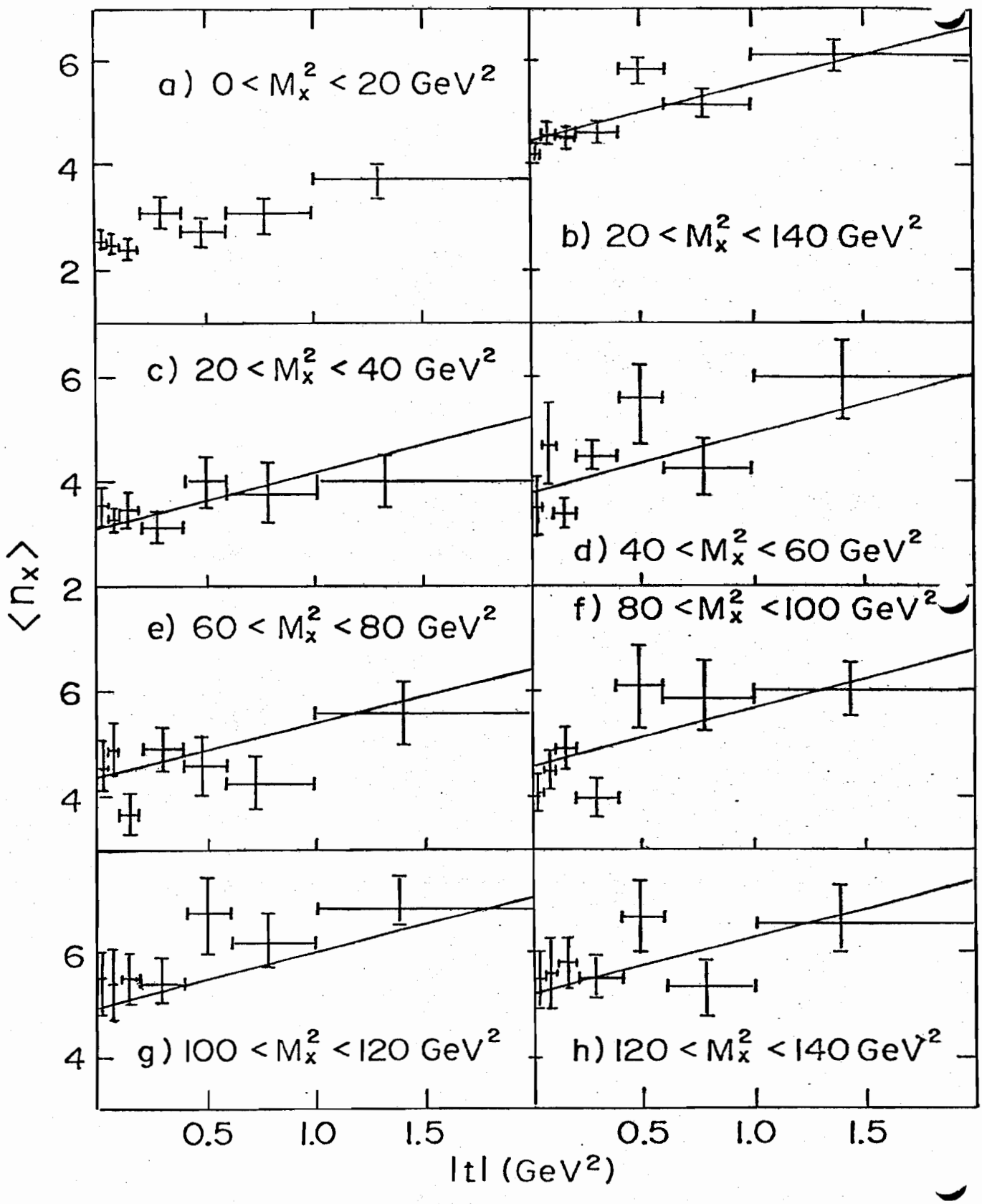
a) 0 < $M_x^2$ < 20 GeV$^2$
b) 20 < $M_x^2$ < 140 GeV$^2$
c) 20 < $M_x^2$ < 40 GeV$^2$
d) 40 < $M_x^2$ < 60 GeV$^2$
e) 60 < $M_x^2$ < 80 GeV$^2$
f) 80 < $M_x^2$ < 100 GeV$^2$
g) 100 < $M_x^2$ < 120 GeV$^2$
h) 120 < $M_x^2$ < 140 GeV$^2$
$\langle n_x \rangle$
|t| (GeV$^2$)
0.5
1.0
1.5
2
4
6

Figure 1

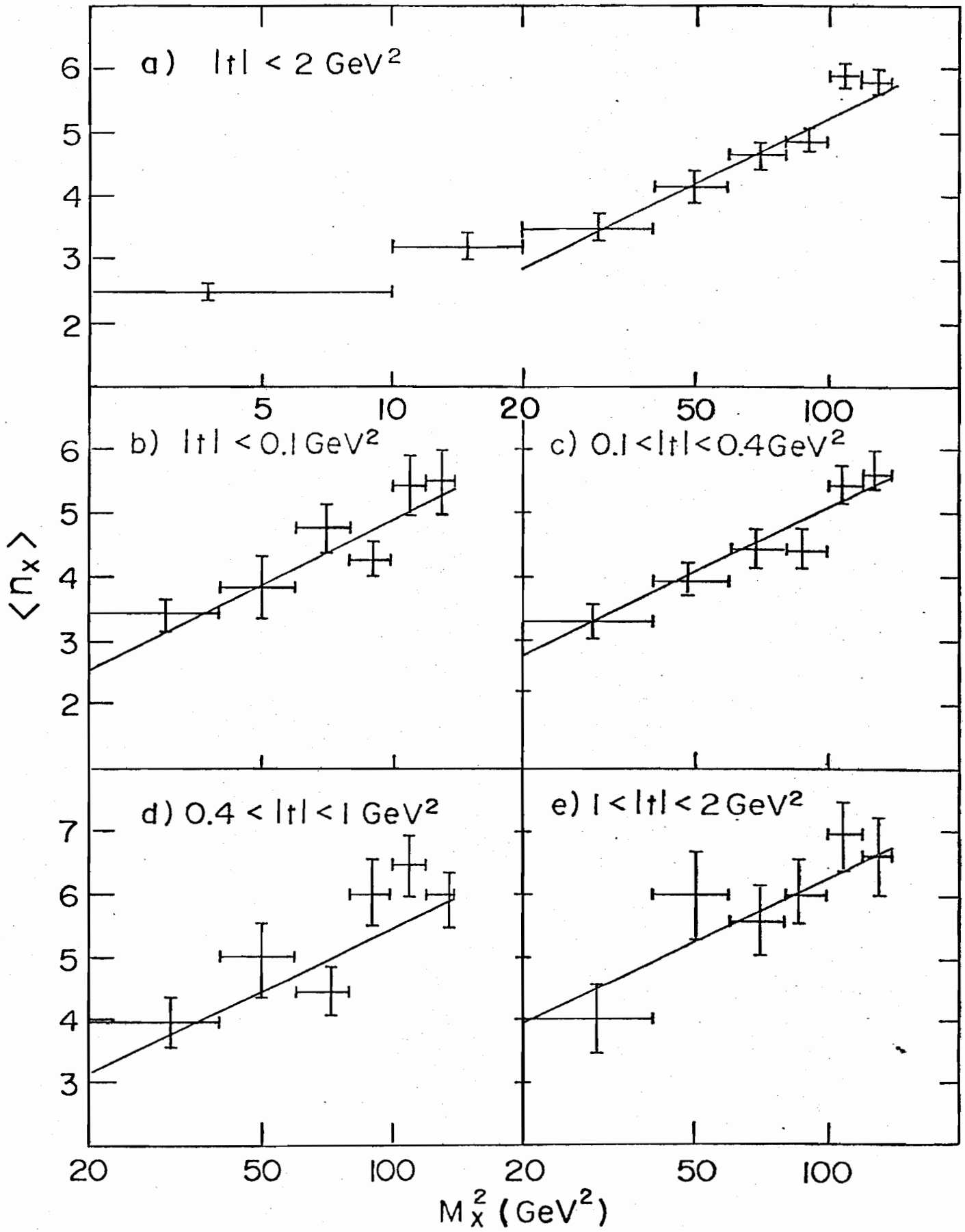
a) |t| < 2 GeV²
b) |t| < 0.1 GeV²
c) 0.1 < |t| < 0.4 GeV²
d) 0.4 < |t| < 1 GeV²
e) 1 < |t| < 2 GeV²
⟨n_x⟩
M_x² (GeV²)

Figure 2

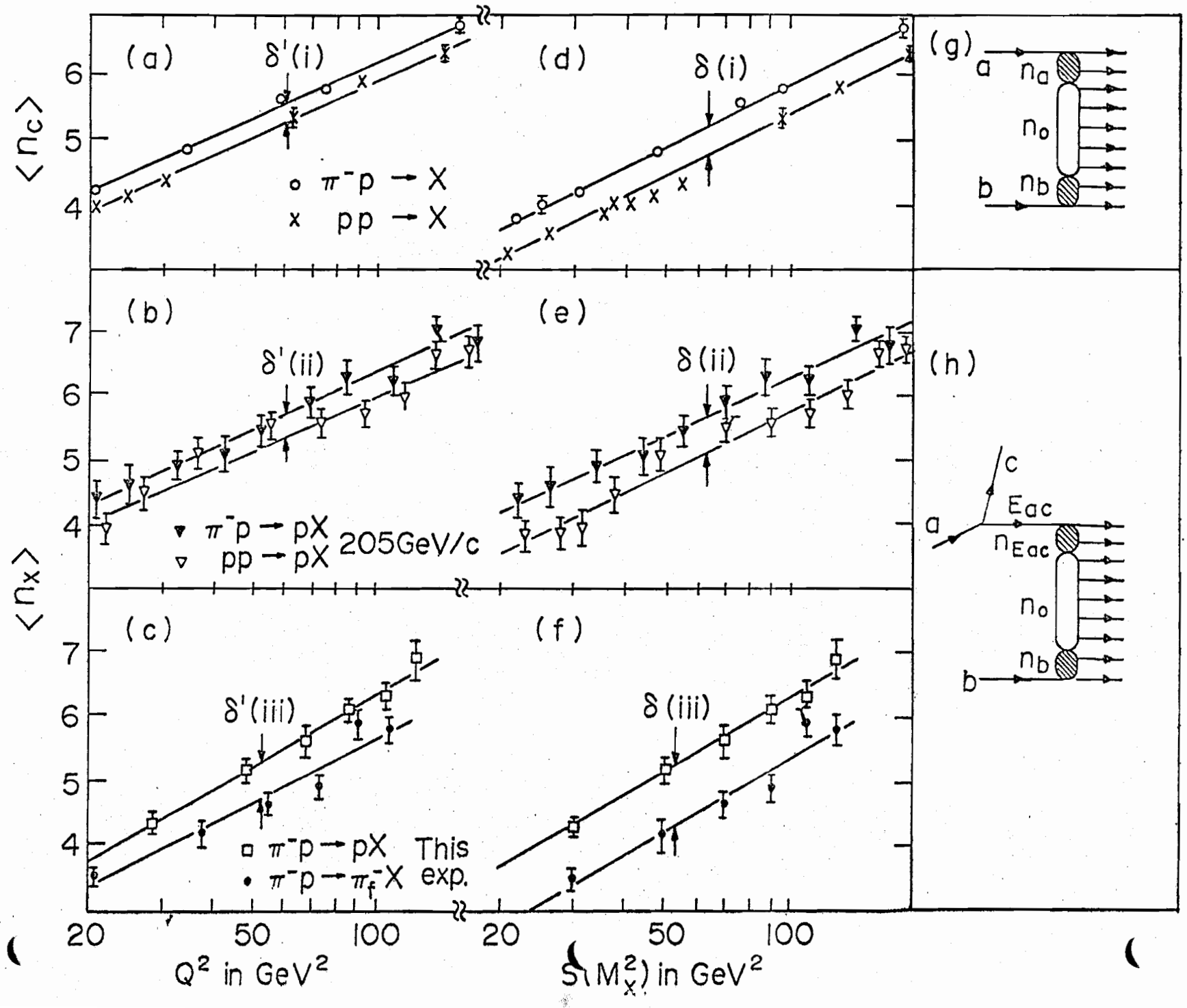
(a)
δ'(i)
(d)
δ(i)
(g)
a
$n_a$
$n_o$
b
$n_b$
$\langle n_c \rangle$
$\pi^- p \to X$
$pp \to X$
(b)
δ'(ii)
(e)
δ(ii)
(h)
c
$E_{ac}$
a
$n_{E_{ac}}$
$n_o$
$n_b$
b
$\langle n_x \rangle$
$\pi^- p \to pX$
$pp \to pX$
205GeV/c
(c)
δ'(iii)
(f)
δ(iii)
$\pi^- p \to pX$
$\pi^- p \to \pi_f^- X$
This exp.
$Q^2$ in GeV$^2$
$S(M_X^2)$ in GeV$^2$

Figure 3