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MULTIPLICITY DISTRIBUTIONS IN THE REACTION $p + p \rightarrow p$ + ANYTHING

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ABSTRACT

It is shown that, for fixed mass of the system X, the charged particle multiplicity distribution in the reaction $p + p \to p + X$ is remarkably similar to the shape of the multiplicity distribution for the reaction $p + p \to$ anything observed at an equivalent fixed center of mass energy.

The dependence of the charged-particle multiplicity on missing mass for the diffractive excitation of a beam proton (or pion) has been studied in several experiments[1-4] performed with the 30-in. bubble chamber at the National Accelerator Laboratory (NAL). The results of the studies of the inclusive reactions

$$p + p \rightarrow \text{slow proton} + \text{anything} \qquad (1)$$

and

$$\pi^- + p \rightarrow \text{slow proton} + \text{anything}, \qquad (2)$$

have shown[2] that the average charged-particle multiplicity, $\langle n \rangle$, of the system of mass M recoiling from the slow proton shows little dependence on the energy of the incident beam hadron. Furthermore, both the average value and the second moment of the multiplicity distribution were seen[2,4] to depend on M^2 in much the same way as the corresponding quantities in the reactions

$$p + p \rightarrow \text{anything} \qquad (3)$$

and

$$\pi^- + p \rightarrow \text{anything} \qquad (4)$$

depend on s, the square of the center of mass energy. This letter demonstrates that, for fixed energy, not only are the average multiplicity and second moment similar in reactions (1) and (3) but that in fact the entire charged particle multiplicity distribution for reaction (1) is remarkably similar to that found at fixed $\sqrt{s}$ for the process (3).

Figure 1 (a) shows a comparison[5] between the average charged-particle multiplicities observed in reaction (1), at 205 GeV/c, and in reaction (3) at different s values. A similar comparison[4] between reaction (2) also at 205 GeV/c, and the process (4) is shown in Fig. 1 (b). In these plots, the energy scale has been chosen to be the available energy, E_a, defined as

$$E_a = M - m_p, \; M - m_\pi, \tag{5}$$

for reactions (1) and (2), and as

$$E_a = \sqrt{s} - 2\, m_p, \; \sqrt{s} - (m_p + m_\pi) \tag{6}$$

for reactions (3) and (4).

One observes that excellent agreement is found between reactions (1) and (3) and between (2) and (4). Furthermore, the average multiplicities in the inclusive processes (1) and (2) are strikingly similar (as shown by the dashed curves in Fig. 1) considering that one is studying proton diffraction in one case and pion diffraction in the other. The most striking feature of Fig. 1 is the lack of any abrupt transition in going from the diffractive excitation region ($M^2 \lesssim 25$ GeV^2 at 205 GeV/c), where the cross section is strongly M^2 dependent,[5] to the region ($M^2 \gtrsim 40$ GeV^2) in which $d\sigma/dM^2$ for reactions (1) and (2) show[5] little dependence on M^2.

In view of the similarities in $\langle n \rangle$, it is of interest to examine the higher moments of the distributions. An equivalent, and more graphical, way of doing this is to compare the entire distributions at a fixed energy E_a. In order to remove the normalization differences for reactions (1) and (3), we use the probability P_n, for producing n charged particles in an inelastic collision. P_n is defined as:

$$P_n = \sigma_n / \sigma_{inel},$$

when σ_n is the cross section for producing n charged particles and σ_{inel} is the total inelastic cross section.

Figure 2 shows the values of P_n for reaction (1), at 205 GeV/c, and for reaction (3) at different values of E_a. Note that for the inclusive reaction (1) n must be odd, while for process (3) n is always even. The following features are clear:

(a) Within the errors the data show a smooth energy dependence even for $E_a \approx 0$;

(b) The P_n for odd n show an energy dependence very similar to that observed[5] in pp, $\pi^{\pm}p$, $K^{\pm}p \rightarrow$ anything: namely, the high multiplicity cross sections show a rapid rise followed by a broad maximum, whereas the low multiplicity cross sections show a slow decrease. These trends yield multiplicity distributions which get broader as the energy increases;

(c) For $n \geq 3$, the even and odd n probabilities alternate in magnitude at a fixed E_a; and,

(d) $P_2 > P_1$ for all values of E_a.

As a result of the features observed in Fig. 2, one concludes that at fixed E_a the multiplicity distributions for (1) and (3) will have similar shapes, with the even- and odd-prong probabilities alternating but perhaps consistent with a single curve.[6] This may be seen in more detail in Fig. 3 which shows P_n as a function of n for different values of M^2. The data for reaction (1) are from the 205 GeV/c pp experiment[2] and those for reaction (3) are chosen to be at similar values of E_a. Since these curves peak at $n > 2$, P_2 must always be greater than P_1, as observed in Fig. 2. It is interesting to note that if one chose to plot against n_-, the number of negative particles, the two sets of points would be displaced sideways by one unit relative to each other. In this case the agreement between the different sets of data would not be so striking. It is not clear which variable (n or n_-) is more fundamental.

The smooth dependence of P_n on n, for both even and odd values of n, implies immediately that, for fixed available energy, $\langle n \rangle$, $f_2^{cc} = \langle n^2 \rangle - \langle n \rangle^2$, and all higher moments of the multiplicity distributions for the two processes will be the same.

This remarkable similarity in the shapes of the charged particle multiplicity distributions is suggestive of a certain universality of multiparticle production in hadronic collisions. Thus, if one supposes that the reaction $p + p \rightarrow p + X$ proceeds by the exchange of a single particle (R), then we observe that the off-mass-shell Rp and on-mass-shell pp collisions yield similar distributions.

However, there are no compelling reasons to suppose that single-particle exchange dominates these reactions and such a mechanism is almost certainly both model and energy dependent. For example, for small M^2 ($\leq 25\ GeV^2$) one is studying diffractive fragmentation of the beam hadron and one might expect to be observing only Pomeron exchange. On the other hand, for large M^2 ($M^2 \gtrsim 50\ GeV^2$) no single-particle exchange is likely to dominate. However, as already noted, there is no distinctive change in the multiplicity data as M^2 increases from the diffractive region to the higher mass (nondiffractive ?) region. In addition, we cannot rule out the possibility that the recoil proton itself is the decay product of an excited state produced at the lower (target) vertex.

It would be interesting to continue such studies when more extensive data become available and to compare the single particle inclusive distributions and multiparticle correlations in reactions (1-4).

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[5] J. Whitmore, NAL preprint, NAL-Pub-73/70-EXP, submitted to Physics Reports (1973).

[6] It is interesting to note that the same consistency with a single curve for the even and odd prong cross sections is indicated by the 40 GeV/c $\pi^- p$, $\pi^- n$ data of O. Balea et al, Nucl. Phys. B52, 414 (1973) and by the 67 GeV/c pp, pn data of M. G. Antonova et al, Phys. Letters 39B, 282 (1972).

FIGURE CAPTIONS

Fig. 1 Comparison of the average charged particle multiplicities for (a) $pp \to$ anything with $pp \to p$ + anything at 205 GeV/c, and (b) $\pi^- p \to$ anything with $\pi^- p \to p$ + anything at 205 GeV/c as a function of the square of the available energy. The same dashed line has been drawn in (a) and (b) to guide the eye.

Fig. 2 The probability for producing n charged particles in $pp \to$ anything (even n) and $pp \to p$ + anything (odd n) interactions as a function of the available energy, E_a. The curves are only drawn to guide the eye.

Fig. 3 The probability for producing n charged particles in $pp \to$ anything (even n) and $pp \to p$ + anything (odd n) interactions at fixed available energy as a function of n.

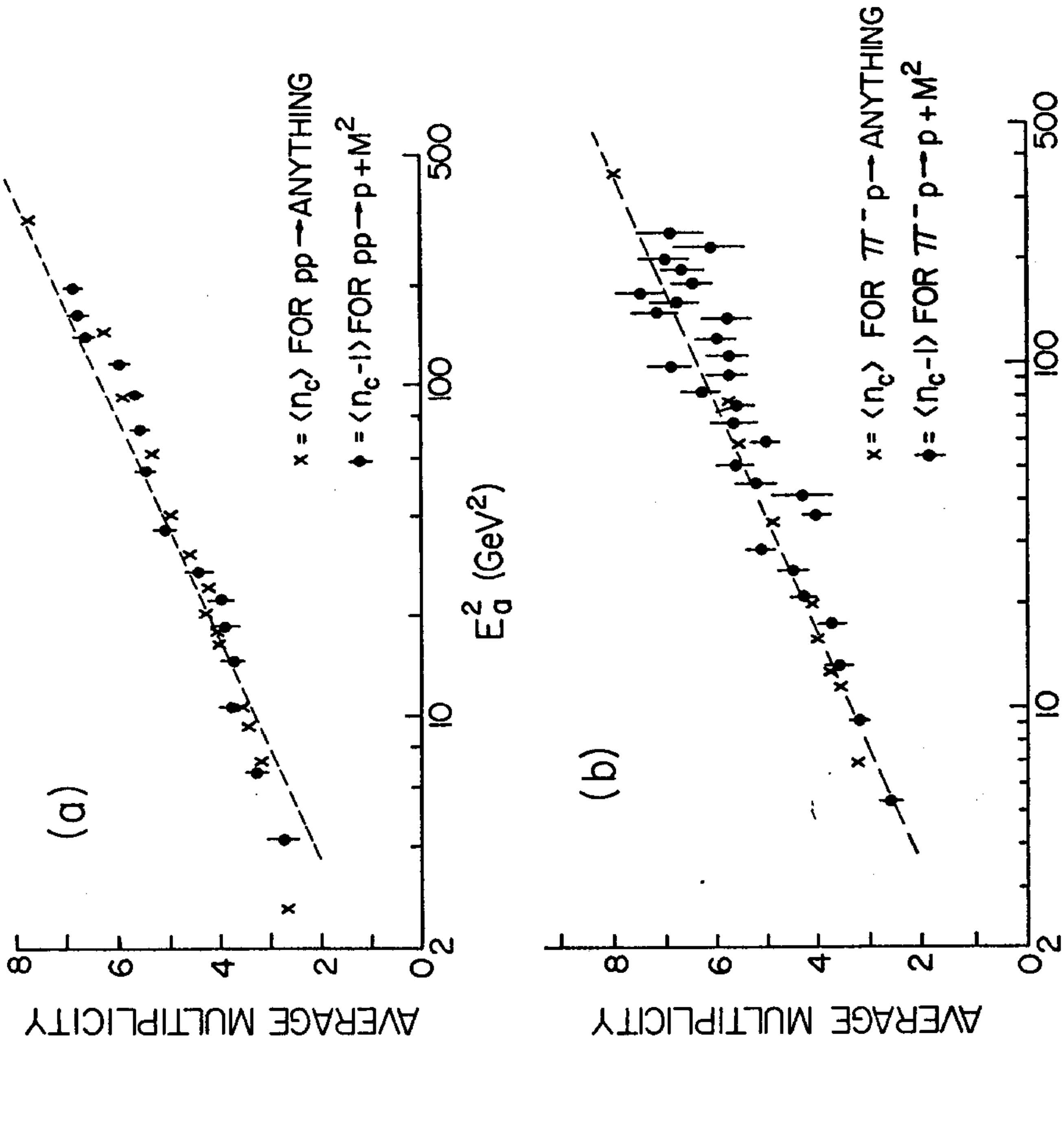
(a)
AVERAGE MULTIPLICITY
E_a^2 (GeV^2)
x = ⟨n_c⟩ FOR pp → ANYTHING
= ⟨n_c-1⟩ FOR pp → p + M^2
(b)
AVERAGE MULTIPLICITY
E_a^2 (GeV)^2
x = ⟨n_c⟩ FOR π^-p → ANYTHING
= ⟨n_c-1⟩ FOR π^-p → p + M^2

Fig. 1

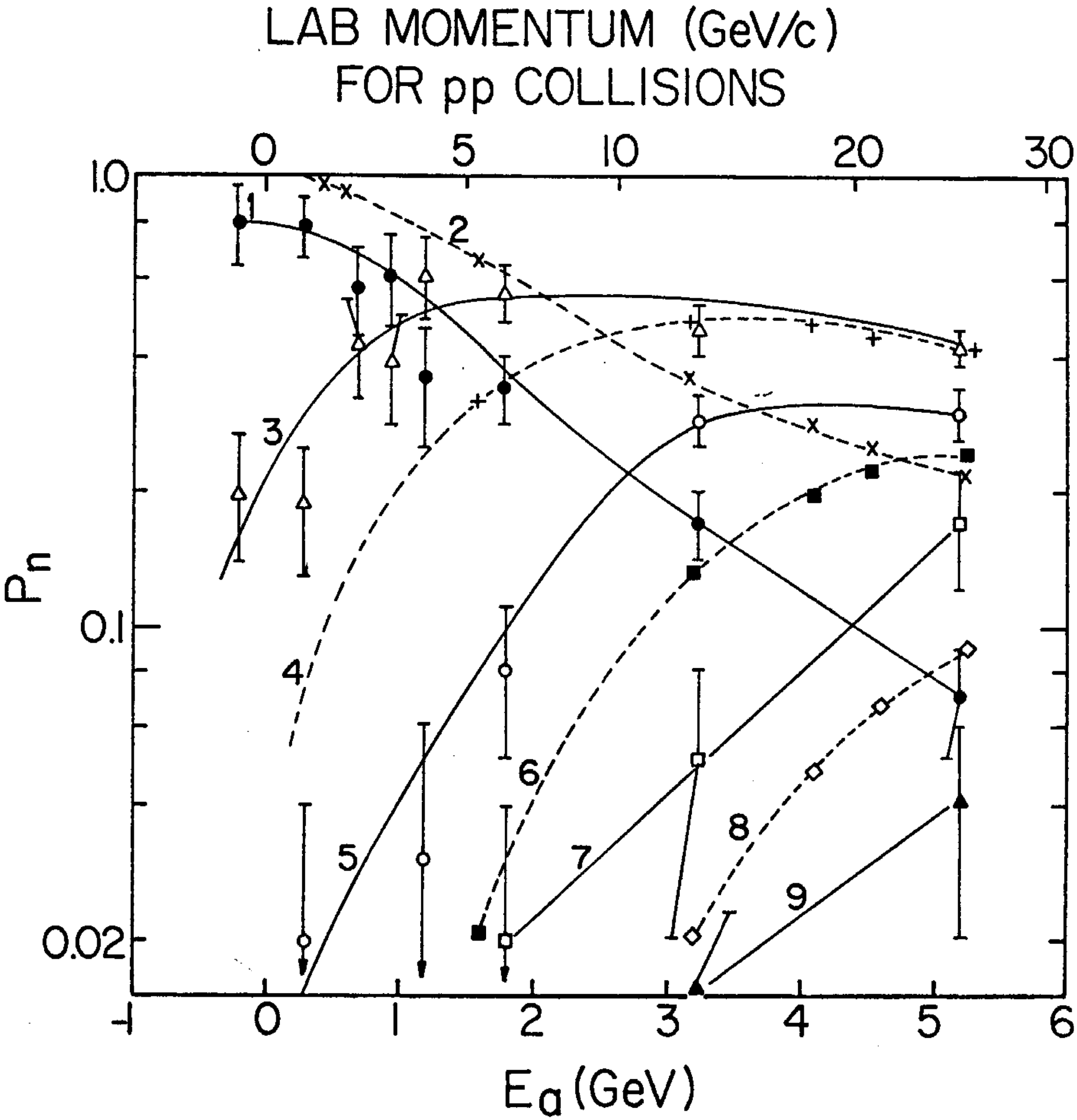
LAB MOMENTUM (GeV/c)
FOR pp COLLISIONS
0
5
10
20
30
1.0
0.1
0.02
P_n
1
2
3
4
5
6
7
8
9
-1
0
1
2
3
4
5
6
E_a (GeV)

Fig. 2

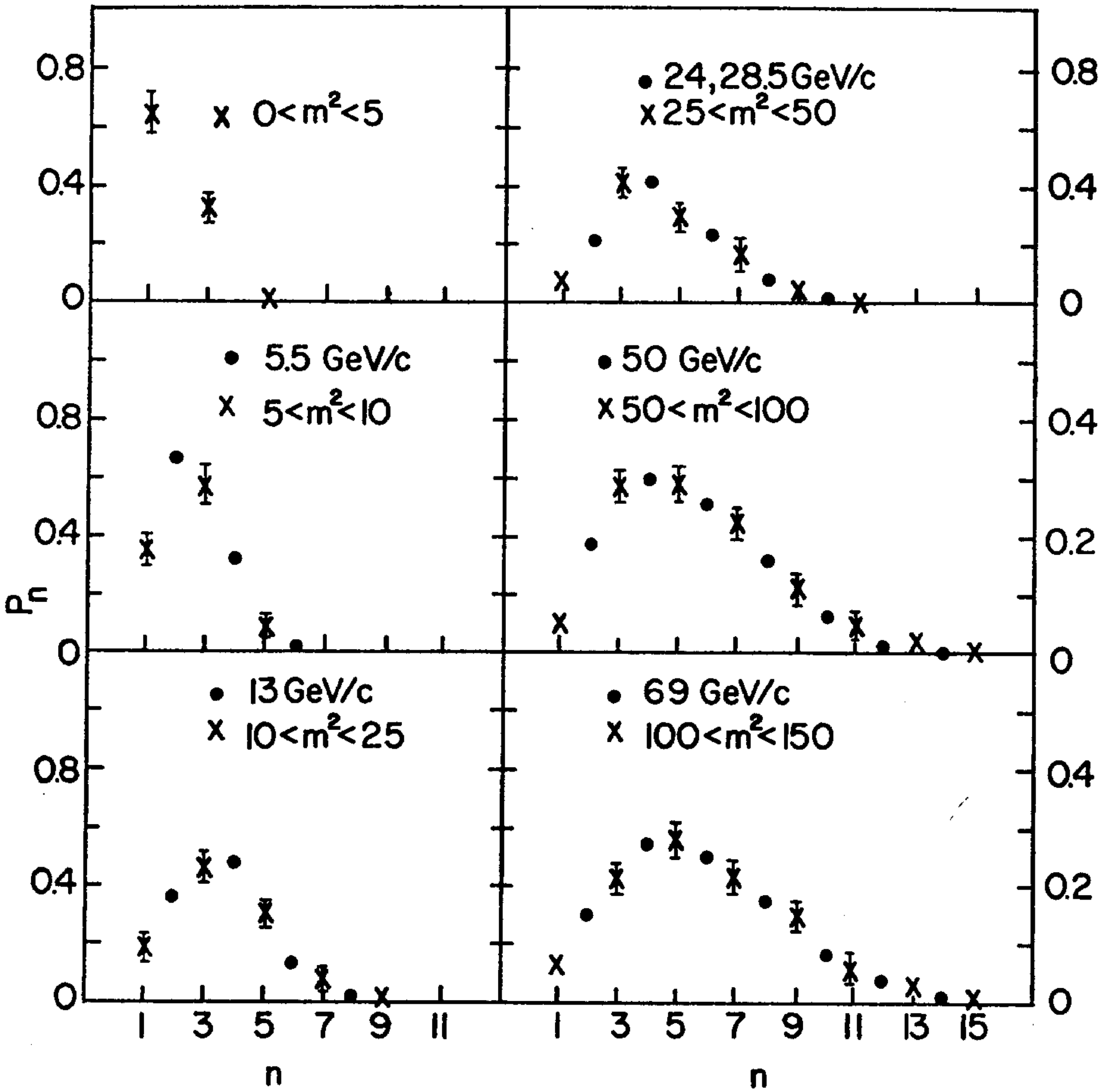
0<m²<5
• 5.5 GeV/c
X 5<m²<10
• 13 GeV/c
X 10<m²<25
• 24, 28.5 GeV/c
X 25<m²<50
• 50 GeV/c
X 50<m²<100
• 69 GeV/c
X 100<m²<150
P_n
n
n
0.8
0.4
0
1 3 5 7 9 11
1 3 5 7 9 11 13 15
0.8
0.4
0.2
0

Fig. 3