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A COMPARISON OF Δ^{++} PRODUCTION IN $\pi^\pm$ p AND pp

INTERACTIONS AT 147 GeV/c[*]

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ABSTRACT

The inclusive total and partial cross sections for Δ^{++} production in the target region are presented for π^+p and pp interactions. These distributions are compared to Δ^{++} distributions from our previous π^-p experiment. The fact that these three experiments are at the same energy and have been analysed in the same manner and with the same systematics means that the comparison is sensitive to small differences in shape or cross section. The results indicate that the shapes of the distributions in y, x, p_T^2 and t' are independent of the incident beam particle, and that the cross section ratios agree with the predictions of a triple-Regge model.

I. INTRODUCTION

The study of inclusive production of resonances has concentrated mainly on the ρ^0[1] and the Δ^{++}[2-5]. The investigation of the inclusive ρ^0 production is complicated by the considerable background in the ρ^0 region. In the case of the Δ^{++}, the background is much lower and is usually reduced even further by various techniques, resulting in a relatively clean measurement of inclusive Δ^{++}.

Inclusive Δ^{++} production has been studied at energies up to ~15 GeV/c in $\pi^{\pm}p$, pp, and $K^{\pm}p$[2]. At Fermilab energies, its production was investigated mainly in the reactions [3-5]

$$pp \rightarrow \Delta^{++} X^0 \tag{1}$$

$$\pi^+ p \rightarrow \Delta^{++} X^0 \tag{2}$$

and

$$\pi^- p \rightarrow \Delta^{++} X^{--} \tag{3}.$$

Two properties of inclusive Δ^{++} production appeared in all three reactions : (1) the inclusive cross section of Δ^{++} production seemed to be almost constant in the energy range of 10 GeV/c to the highest Fermilab energies at which reactions (1) - (3) have been measured; (2) (a) the distribution of the four-momentum transfer squared between the target proton and the Δ^{++}, $t_{p\Delta}$, and that of the transverse momentum squared, p_T^2 , are exponentials with steep slopes; (b) the Feynman-x distribution of the Δ^{++} has a broad maximum near -0.85 and falls rapidly at -1.0. All these features led to two apparently different description of the production mechanism: one pion exchange at the lower vertex and resonance formation at that vertex, which then decays into

$\Delta^{++}\pi^-$ (see Fig. 1). In the comparative study of Δ^{++} production in reactions (1) - (3) we will assume the one-particle exchange point of view, although the same conclusions may be reached in the resonance picture.

When performing a comparison of Δ^{++} production in reactions (1) - (3) it is very important that all three reactions are treated in the same manner. In fact, earlier attempts of such a comparison[5] all lacked this fact and therefore could not reach definite conclusions. The present experiment is the first to have all three reactions (1) - (3) performed at exactly the same energy, with the same apparatus and with the same systematics. We use this unique feature to compare in this paper the production of Δ^{++} in pp, π^+p and π^-p reactions at 147 GeV/c. In Section II we present the experimental details. Results of reactions (1) and (2) are given in Section III and in Section IV the comparison between reactions (1), (2) and (3) is discussed. A summary of the results appears in Section V.

II. EXPERIMENTAL DETAILS

The data used in the present study come from two exposures in the Fermilab 30-inch hybrid spectrometer :one with a negative beam, mainly π^-, and one with a positive beam composed of π^+, K^+ and p. In both exposures the beam momentum was 147 GeV/c. 105,000 pictures of $\pi^- p$ interactions have been taken, results of which have already been published[6,7]. The positive beam exposure was of 500,000 pictures and consistent of two parts; one in which the beam content was mainly π^+ and p with a very small number of K^+'s and another with the ratio of $\pi^+/K^+/p$ of 6/1/3. The second part of the positive exposure had an addition of a lead glass Forward Gamma Detector(FGD). General details of the experimental arrangement and of the data reduction have already been published[6].

For this study we use all of the $\pi^- p$ data, consisting of about 7,000 successful events, and about 10 percent of the positive exposure yielding about 2,000 events. This is a preliminary report of the comparative study, however we believe that the conclusions will not change with the much bigger sample which the complete analysis will present. We hope then also to add to the present comparison the reaction

$$K^+ p \rightarrow \Delta^{++} X^0 \tag{4}$$

We stress again the important fact that all three reactions (1) - (3) have been analysed exactly in the same manner. All negative outgoing particles were considered to be π^-'s. A positive particle was considered to be a π^+ meson, unless it had a lab momentum below 1.4 GeV/c and was identified by ionization to be a proton. Because of this cut at 1.4 GeV/c we had to require in

certain cases the additional cut of $|t_{p\Delta}| \leq 1.0$ $(GeV/c)^2$, so as not to distort the distributions. Further details of the data handling and the various corrections, most of which are topology dependent, can be found in reference 7.

One should note that since we are mainly interested here in a comparative study, we use for the pp interactions only Δ^{++} produced in a single c.m. - system hemisphere.

II. RESULTS

The invariant mass distribution of the $p\pi^+$ system is given for all topologies in Fig. 2(a) for reaction (1). A strong Δ^{++} signal is seen on top of a smooth background, and no other statistical significant structure is apparent. Much of the background underneath the Δ^{++} resonance comes from combinational effect of high multiplicity events. This background can be significantly reduced by selecting the $p\pi^+$ combination having the smallest value of the rapidity y^* (shaded part of Fig. 2 (a)). This selection is in fact justified by the distribution shown in Fig. 3 (a). In this figure one sees the center of mass rapidity distribution of all $p\pi^+$ combinations y^* $(p\pi^+)$ and the shaded part has the additional requirement that the $p\pi^+$ combinations are in the Δ^{++} region, $1.14 < M(p\pi^+) < 1.30$ GeV. This graph shows that the Δ^{++} tend to be produced at the lowest kinematically - allowed rapidity. Figures 2(b) and 3(b) show the same results for reaction (2).

In order to obtain cross sections for reactions (1) and (2) one can either fit the mass plot to the sum of a Breit-Wigner resonance shape and a polynomial background over an appropriate mass range, or use the number of events in a given $p\pi^+$ mass interval, say $1.14 - 1.30$ GeV. Both methods have been shown to give the same results[5],[7]. In Table I we present the cross section values for reactions (1) and (2), with the contribution of each of the different topologies, n, to the total value. In Figs. 4(a) and 4(b) we plot these values of $d\sigma/dn$ for reactions (1) and (2) respectively. It is interesting to note that the Δ^{++} is being produced even in high multiplicity reactions.

The Feynaman x distribution of the Δ^{++}, which is defined as the $p\pi^+$ combination with the lowest rapidity in the event and with an effective mass in the range 1.14 to 1.30 GeV, is shown in Fig. 5. In both cases we also require the additional restriction that $|t_{p\Delta}| \leq 1.0$ (GeV/c)^2. One observes a steep rise near $x = -1$ and a broad maximum near -0.85. The $t_{p\Delta}$ distribution for the Δ^{++} region is almost flat (not shown) because of the large t_{min} values associated with high masses recoiling against the Δ^{++}. In contrast, the distribution in $t' = |t - t_{min}|$ shown in Fig. 6 has a steep exponential decrease. Such an exponential decrease is also observed in Fig. 7, where we show the distribution of p_T^2 for the Δ^{++} region.

IV. COMPARATIVE STUDY

We use now the fact that we have analysed all three reactions (1) -(3) at the same energy and exactly in the same manner, to perform a comparison of Δ^{++} inclusive production in pp, π^+p and π^-p interactions. To this end we compare the $p\pi^+$ mass distribution (Fig. 2), the rapidity distribution (Fig.3), the Δ^{++} cross section dependence on topology n (Fig.4), the Feynman - x distribution (Fig.5), $d\sigma/dt'$ (Fig.6) and $d\sigma/dp_T^2$ (Fig.7) of the Δ^{++} events produced in reactions (1), (2) and (3). A comparison of reaction (2) and reaction (3) ((b) and (c) in all the figures, respectively), shows that the distributions are very much alike both in shape and in magnitude. This statement is true for each of the variables mentioned above. The distribution of reaction (1) ((a) in all figures) resembles those of reaction (2) and (3) in shape, but are about 60% higher in magnitude. A comparison of the total Δ^{++} cross section values for the three reactions yields (see Table I) :

$$R_1 = \frac{\sigma(\pi^+p \to \Delta^{++}X^0)}{\sigma(\pi^-p \to \Delta^{++}X^-)} = 1.05 \pm 0.09 \tag{5}$$

and

$$R_2 = \frac{\sigma(\pi^-p \to \Delta^{++}X^{--})}{\sigma(pp \to \Delta^{++}X^0)} = 0.61 \pm 0.07 \tag{6}$$

The similarity of the distributions and the ratios R_1 and R_2 can in fact be expected if one assumes a π- exchange triple - Regge diagram [8] with a Pomeron - $\pi\pi$ coupling (Fig. 8). The fact that the cross section values of reactions (1) - (3) remain almost constant over a wide range of energies [3-6],

justifies the fact that we use a Pomeron at the beam vertex in the triple Regge diagram. Also studies of the production and decay of the Δ^{++} showed indeed that the one-pion exchange model with absorption[8] gives a good description of the data. Therefore using the diagram shown in Fig. 8 one obtains the predictions :

$$R_1 = \frac{g^2_{P\pi\pi}}{g^2_{P\pi\pi}} = 1 \tag{7}$$

$$R_2 = \frac{g^2_{P\pi\pi}}{g^2_{Ppp}} \approx 0.63 \tag{8}$$

where g^2_{abc} is the triple Regge coupling at the vertex connecting particles a, b and c. These predictions are in excellent agreement with the measured ratios (5) and (6). This model also predicts that the distributions should be similar in all three reactions, a prediction which is very well borne out by this experiment.

V. SUMMARY AND CONCLUSIONS

We have presented preliminary results of Δ^{++} production in pp and $\pi^+ p$ interactions at 147 GeV/c and compared with its production in $\pi^- p$ interactions at the same energy. We have made use of the fact that all three experiments have been done with the same apparatus and have been analysed in exactly the same manner. We find that the shapes of the inclusive distributions are independent of the incoming beam particle. The magnitude of Δ^{++} inclusive production in $\pi^+ p$ and $\pi^- p$ reactions are equal within errors both for the total and the differential cross section. These cross sections are about 40% lower than that of Δ^{++} production in pp reactions. Our results are in excellent agreement with the predictions of a triple Regge model.

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T A B L E   1

Topological distribution of the $\overline{\text{cross section}}$ values for Δ^{++} production in pp, π^+p and π^-p interactions at 147 GeV/c.

n \ beam	1.14 < M (p π^+) < 1.30 GeV			
	p	π^+	π^-	π^- (fit)
4	0.68 ±0.10	0.39 ±0.06	0.31 ±0.03	0.38 ±0.13
6	0.68 ±0.10	0.42 ±0.06	0.36 ±0.03	0.40 ±0.09
8	0.59 ±0.10	0.38 ±0.06	0.45 ±0.04	0.41 ±0.12
10	0.45 ±0.08	0.22 ±0.05	0.29 ±0.03	0.26 ±0.10
12-16	0.29 ±0.07	0.30 ±0.06	0.22 ±0.04	0.02 ±0.12
Total	2.69 ±0.20	1.91 ±0.13	1.63 ±0.08	1.56 ±0.23

F I G U R E   C A P T I O N S

Fig. 1   Diagrams describing Δ^{++} production via (a) single-exchange (b) double-exchange mechanism.

Fig. 2   Invariant mass of $p\pi^+$ combinations for all combinations in all events (unshaded histogram) and for the lowest rapidity $p\pi^+$ combination in each event (shaded histogram) for the reactions (a) pp, (b) π^+p and (c) π^-p.

Fig. 3   Center-of-mass rapidity for $p\pi^+$ combinations. The unshaded histogram is for all $p\pi^+$ combinations and the shaded histogram is for $p\pi^+$ combinations in the Δ^{++} region, for the reactions (a) pp, (b) π^+p and (c) π^-p.

Fig. 4   Production cross section of Δ^{++} as a function of n for (a) pp, (b) π^+p and (c) π^-p interactions.

Fig. 5   Feynman-x distribution for the lowest rapidity $p\pi^+$ combination in the Δ^{++} region in which $|t_{p\Delta}| \leq 1.0$ (Gev/c)^2 for the reactions (a) pp, (b) π^+p and (c) π^-p.

Fig. 6 $a\sigma/dt'$ for the lowest rapidity $p\pi^+$ combination in the Δ^{++} region for (a) pp (b) π^+p and (c) π^-p interactions.

Fig. 7   The p_T^2 distribution for inclusive Δ^{++} production in (a) pp, (b) π^+p and (c) π^-p interactions.

Fig. 8   Triple-Regge diagramatic representation of Δ^{++} production in reactions (1) - (3).
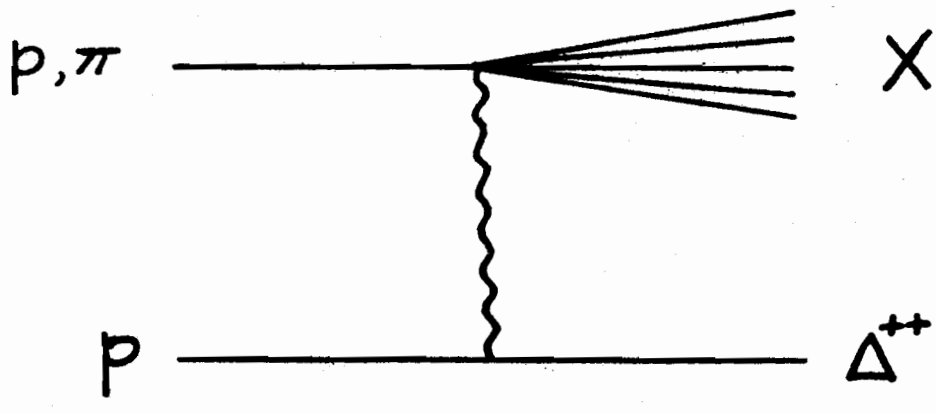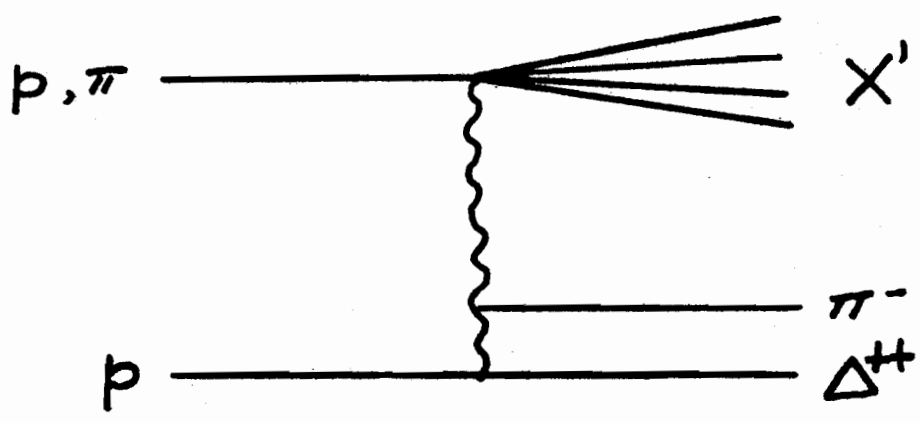
Fig. 1

Fig. 2 a

Fig. 2b

Fig.2c

Fig. 3 a

(b)   center of mass rapidity
□   of all $p\pi^+$ combinations
▨   of $p\pi^+$ such that
     $1.14 < M(p\pi^+) < 1.3\,GeV$

$d\sigma/dy^*$, in mb

$y^*(p\pi^+)$

Fig. 3b

(c) center of mass rapidity
□ of all $p\pi^+$ combinations
▨ of $p\pi^+$ such that
$1.14 < M(p\pi^+) < 1.3\,GeV$

$d\sigma/dy^*$, in mb

$y^*(p\pi^+)$

Fig. 3c

(a)

$p\,p \rightarrow \Delta^{++} X$

$\sigma\,(\Delta^{++})$ (mb)
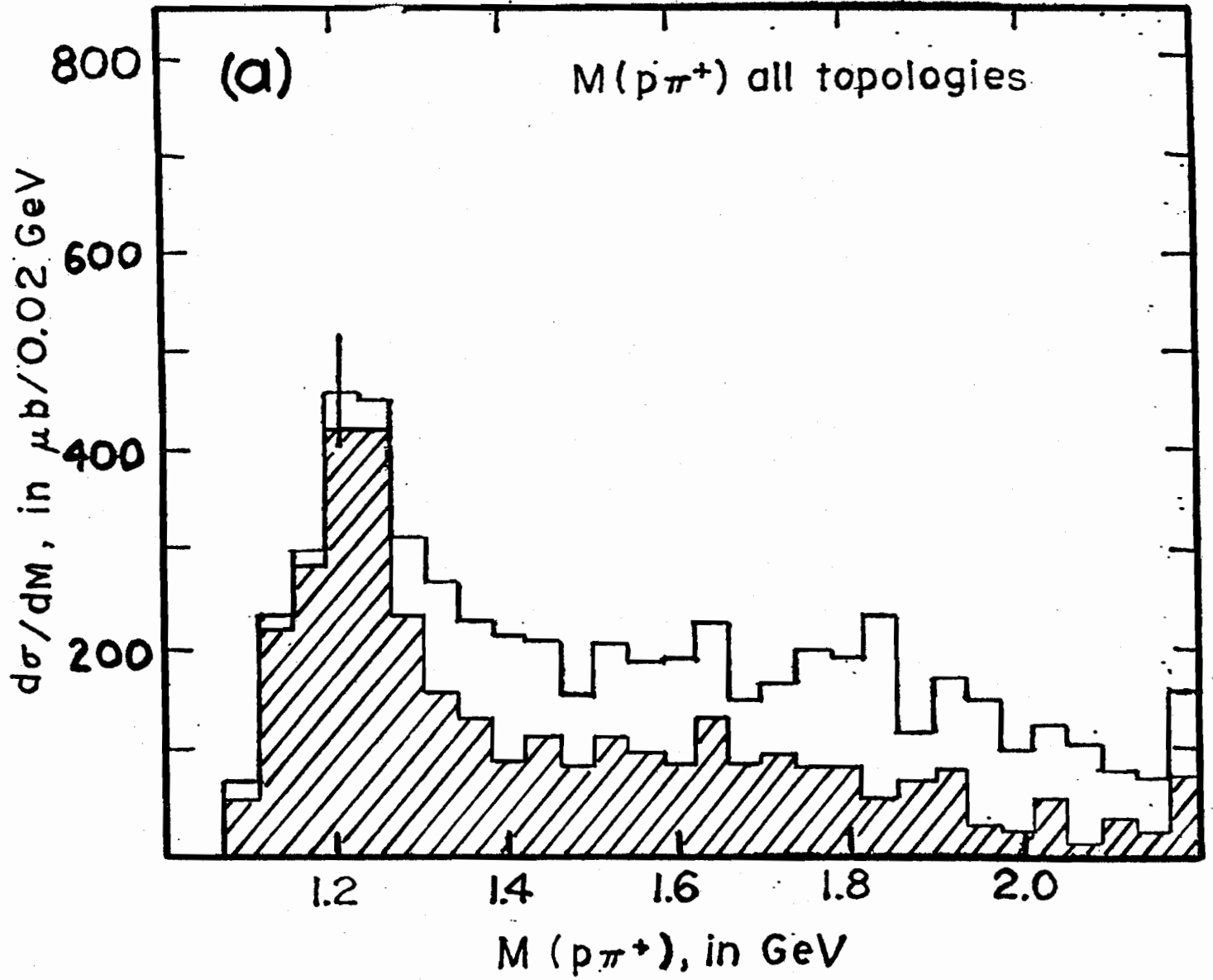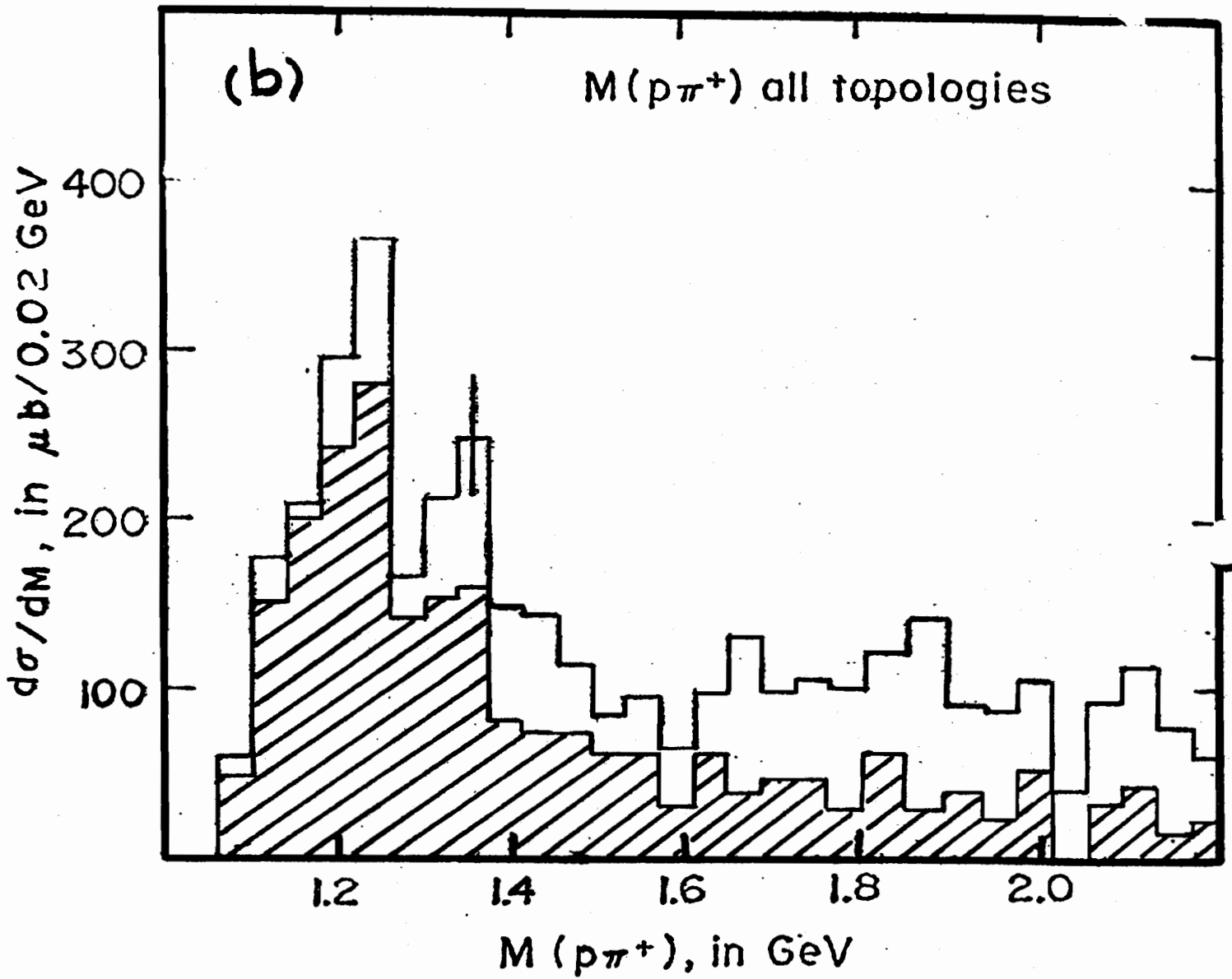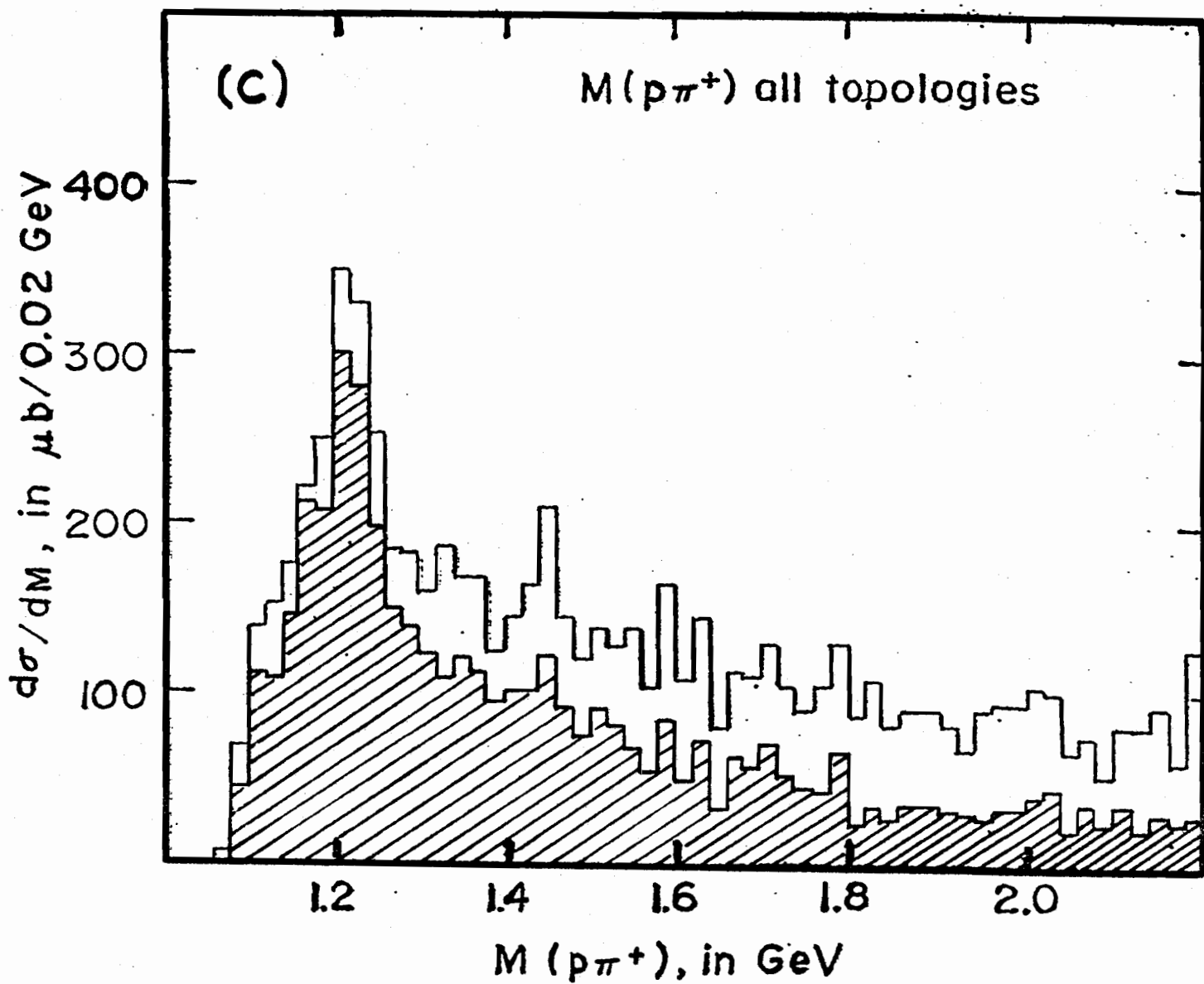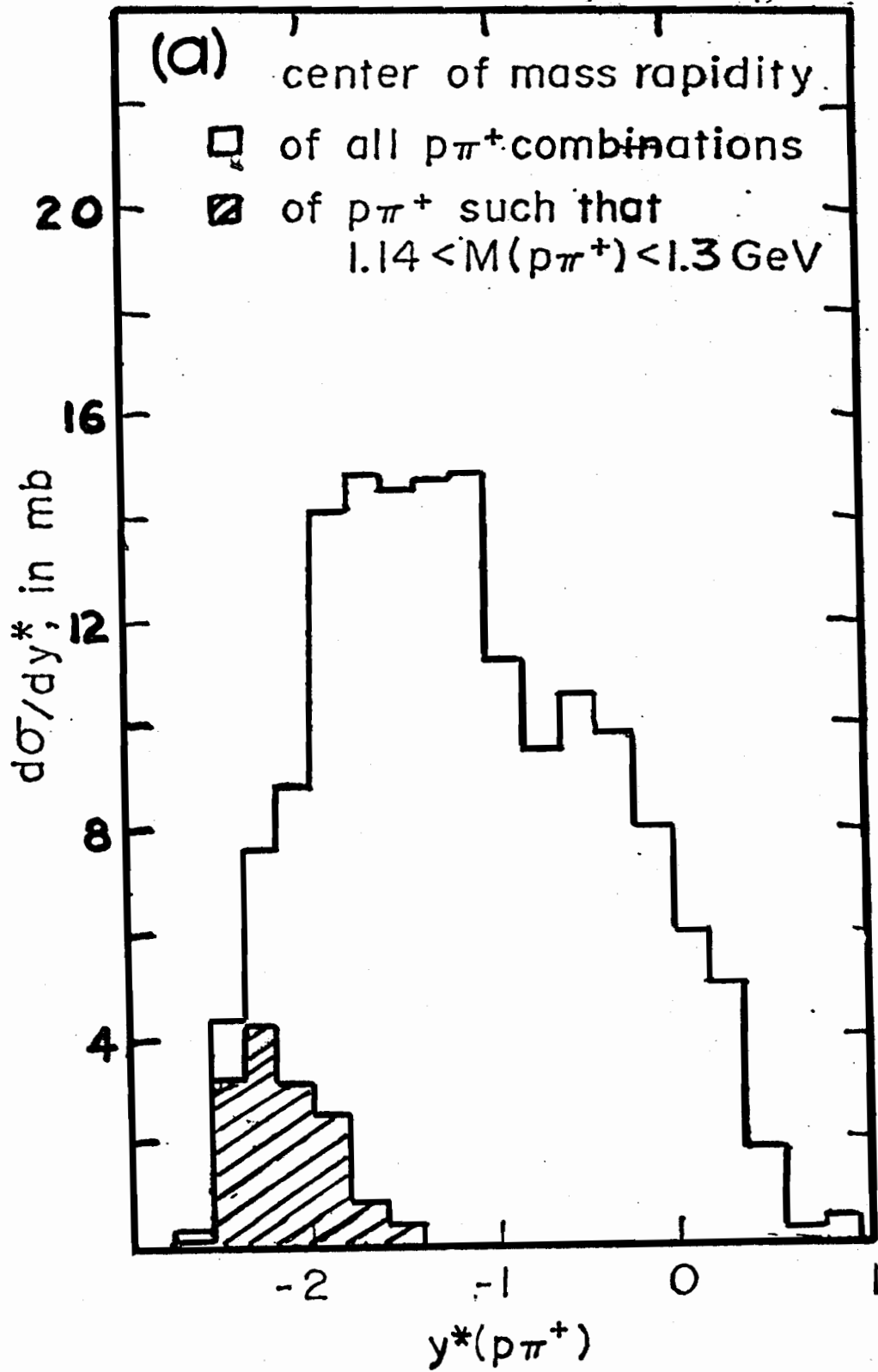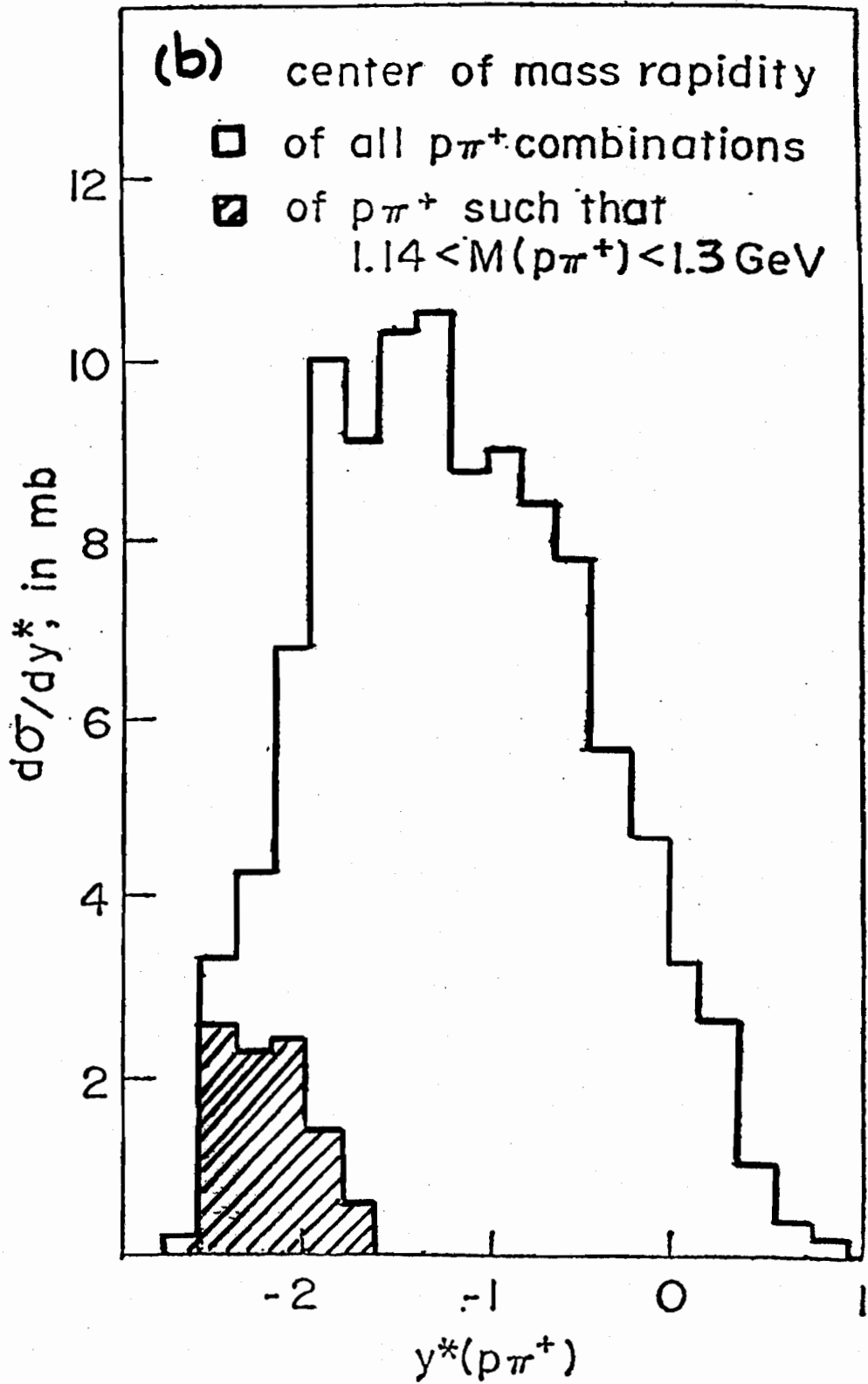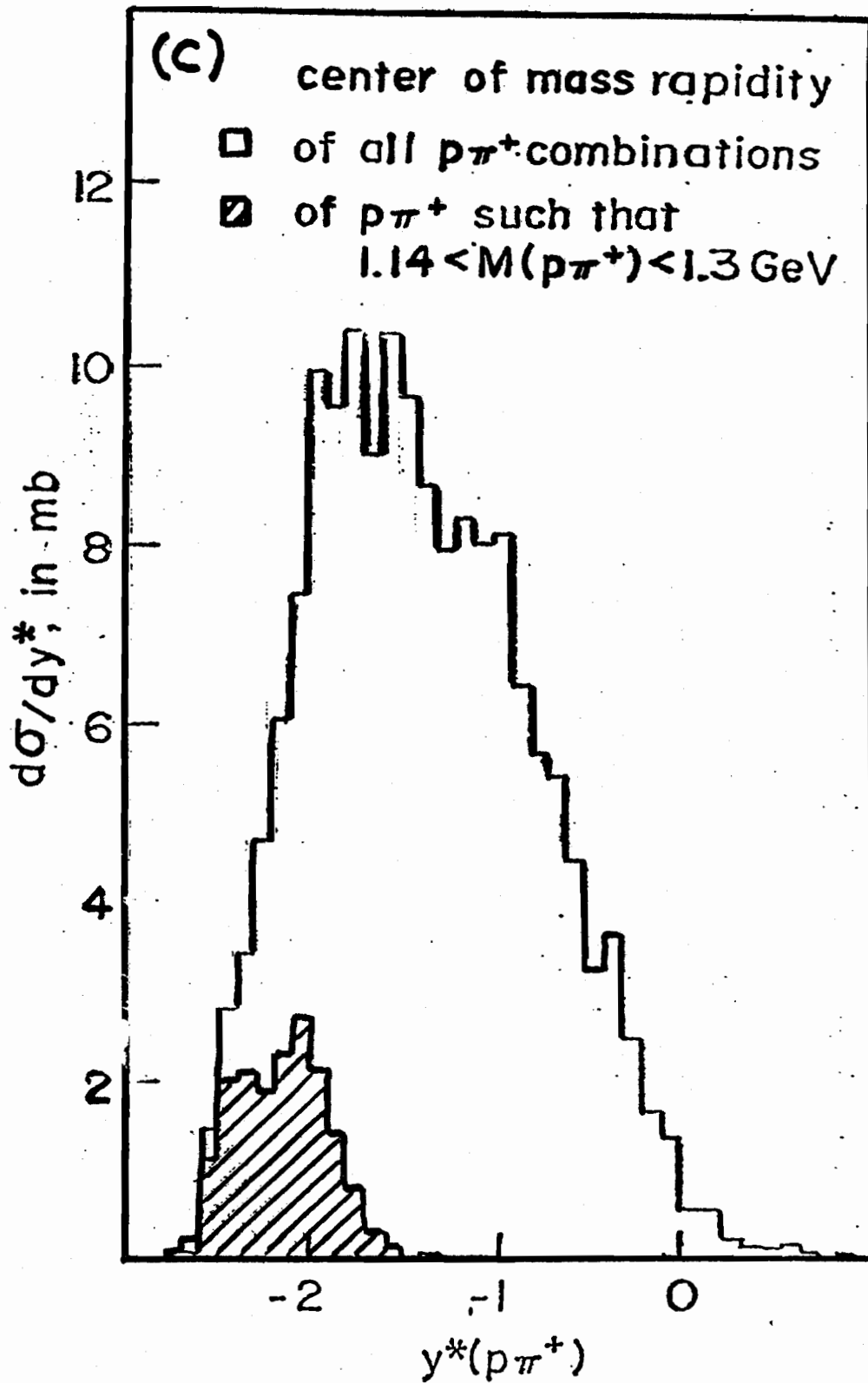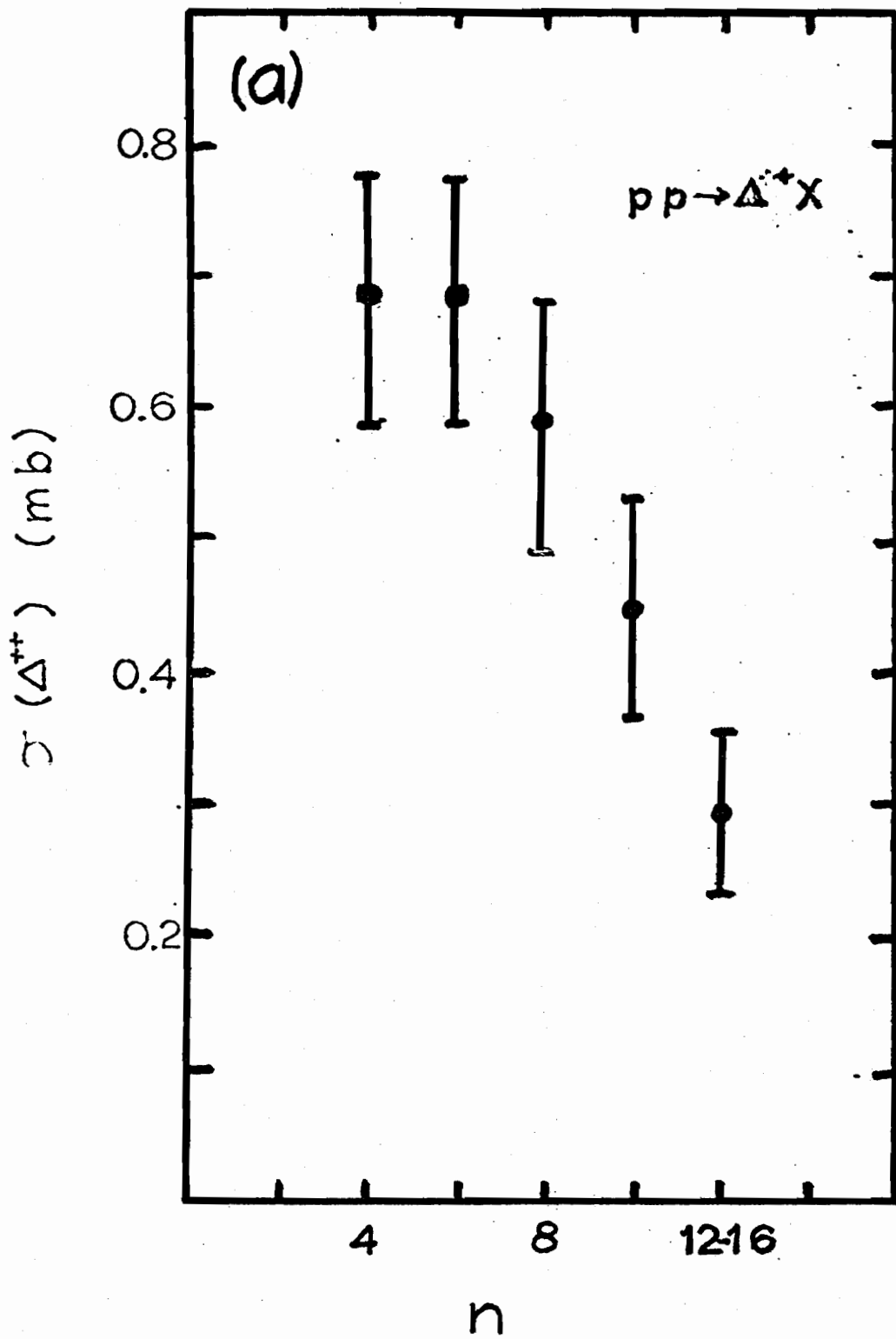
Fig 4a
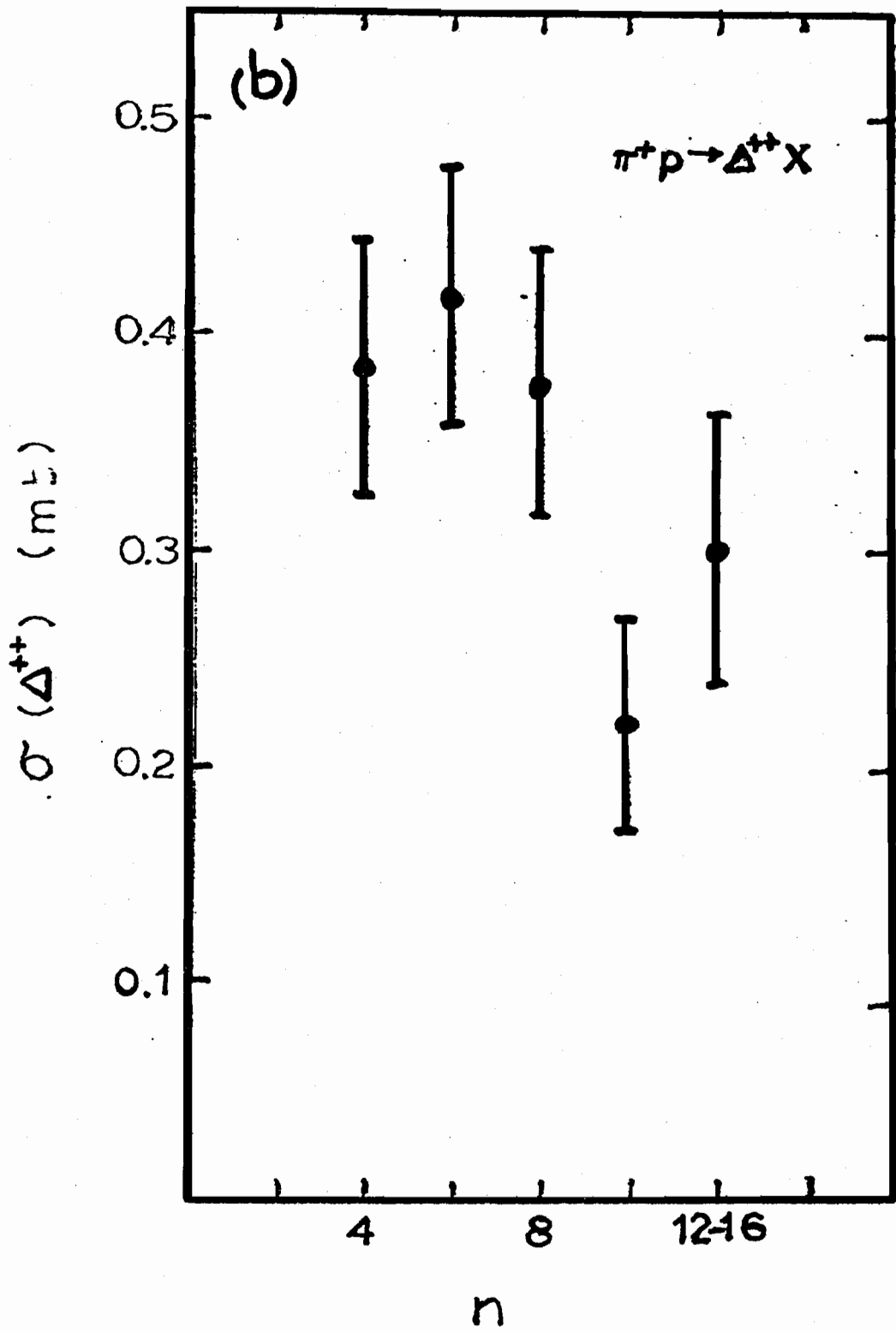
Fig. 4b

Fig. 4c

Fig. 5a

Fig. 5b

Feynman x (Δ^{++}) (c)

$|t_{p\Delta}| < 1.$

dσ/dx, in mb

x (Δ^{++})
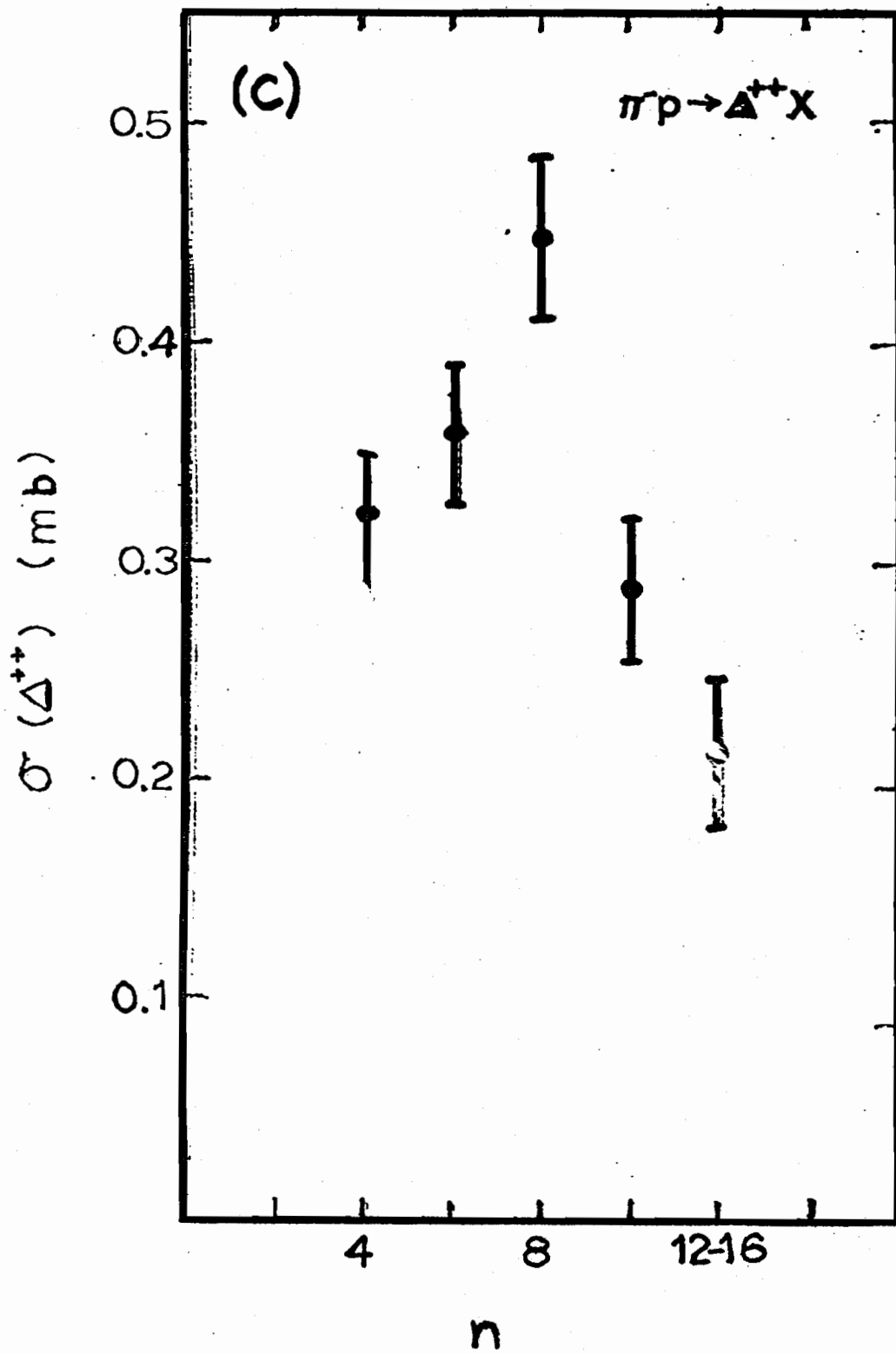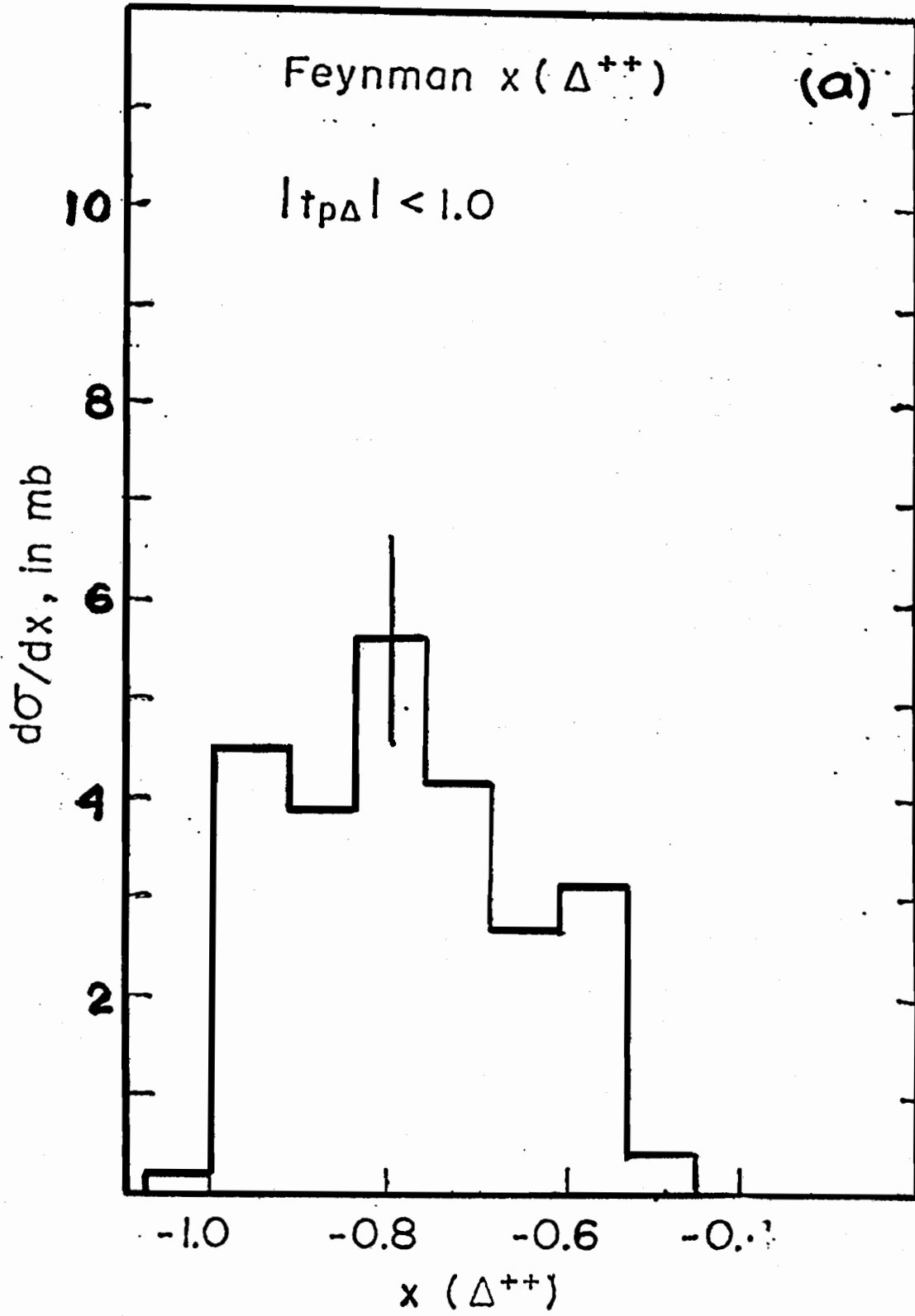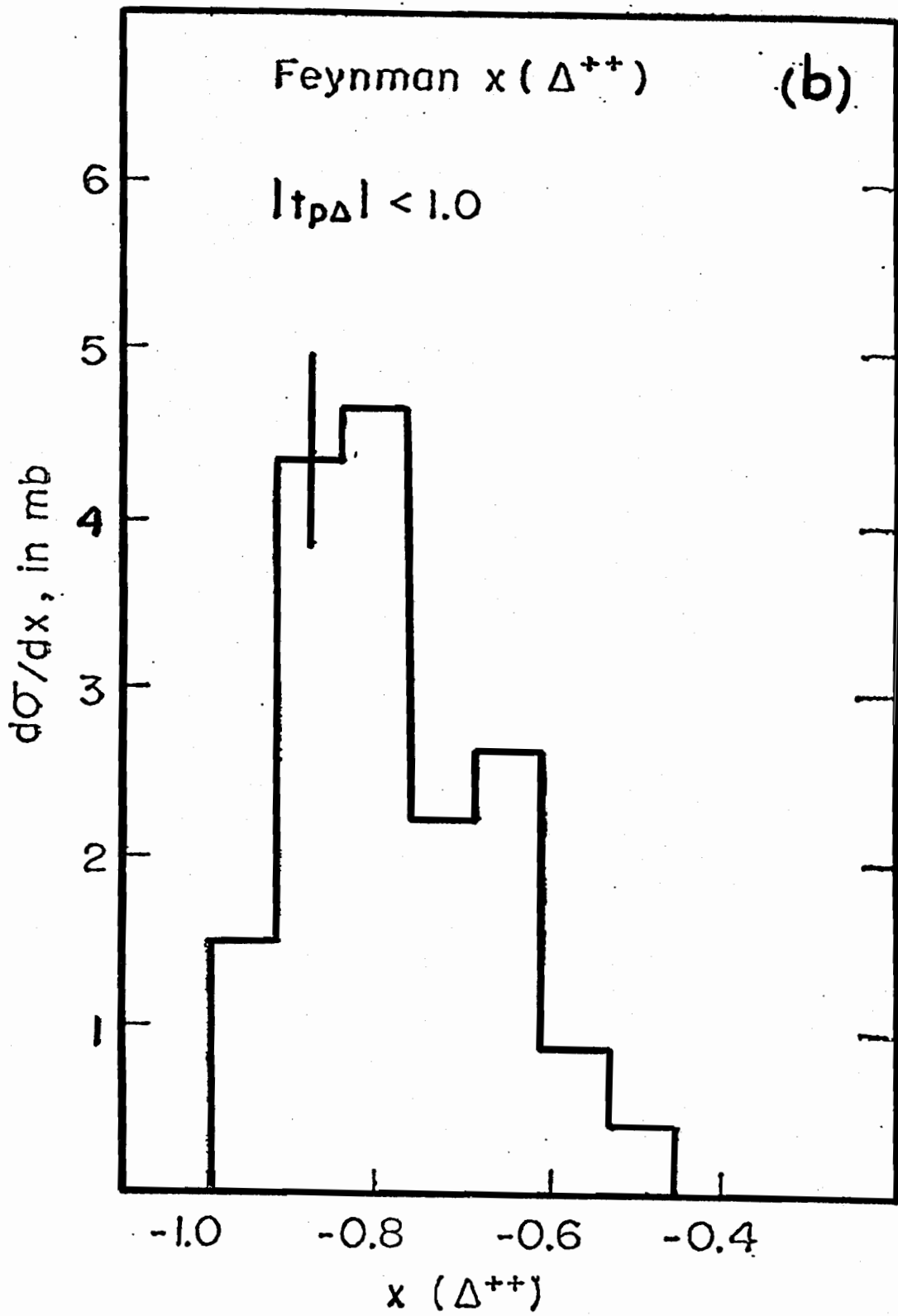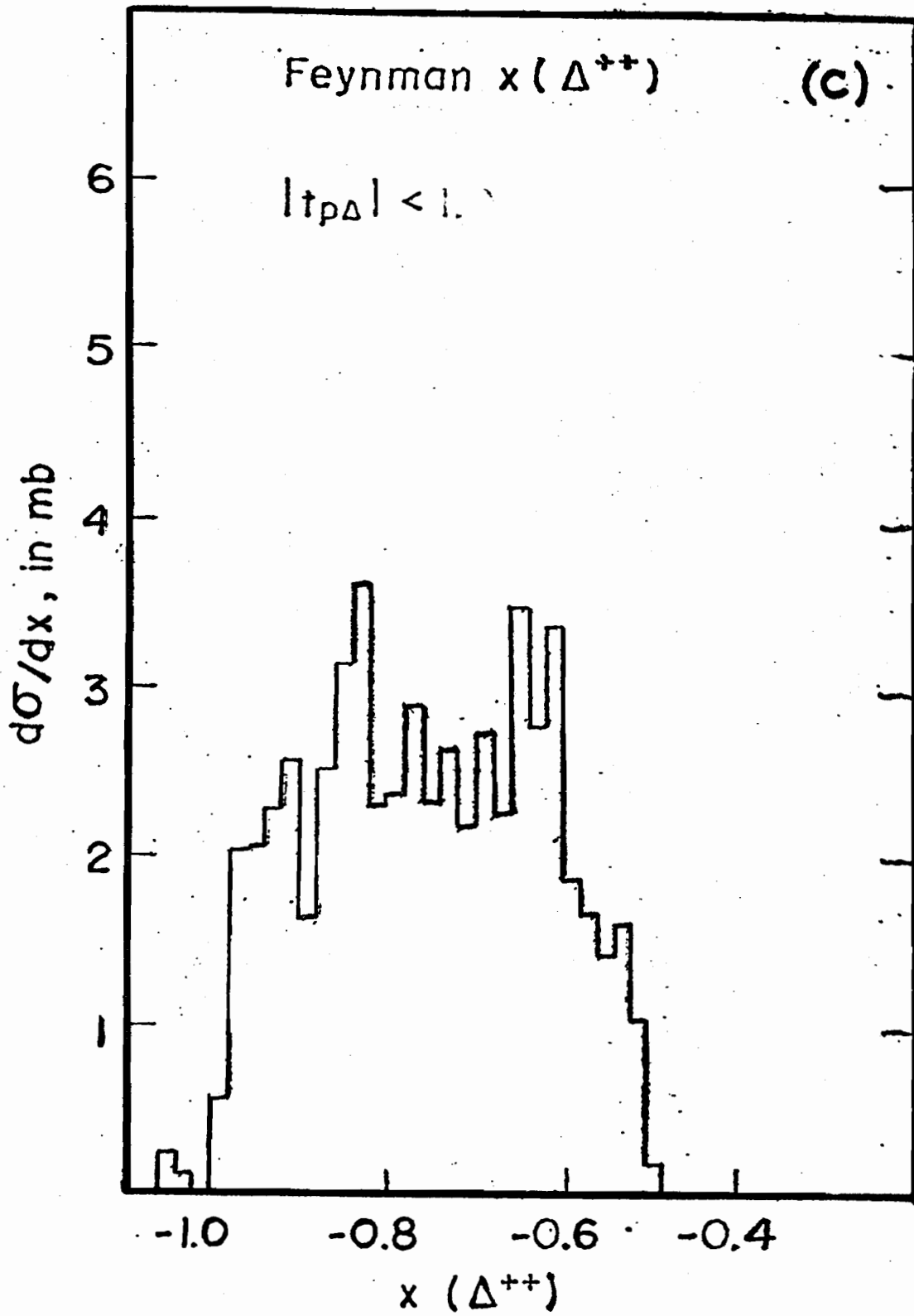
Fig. 5c
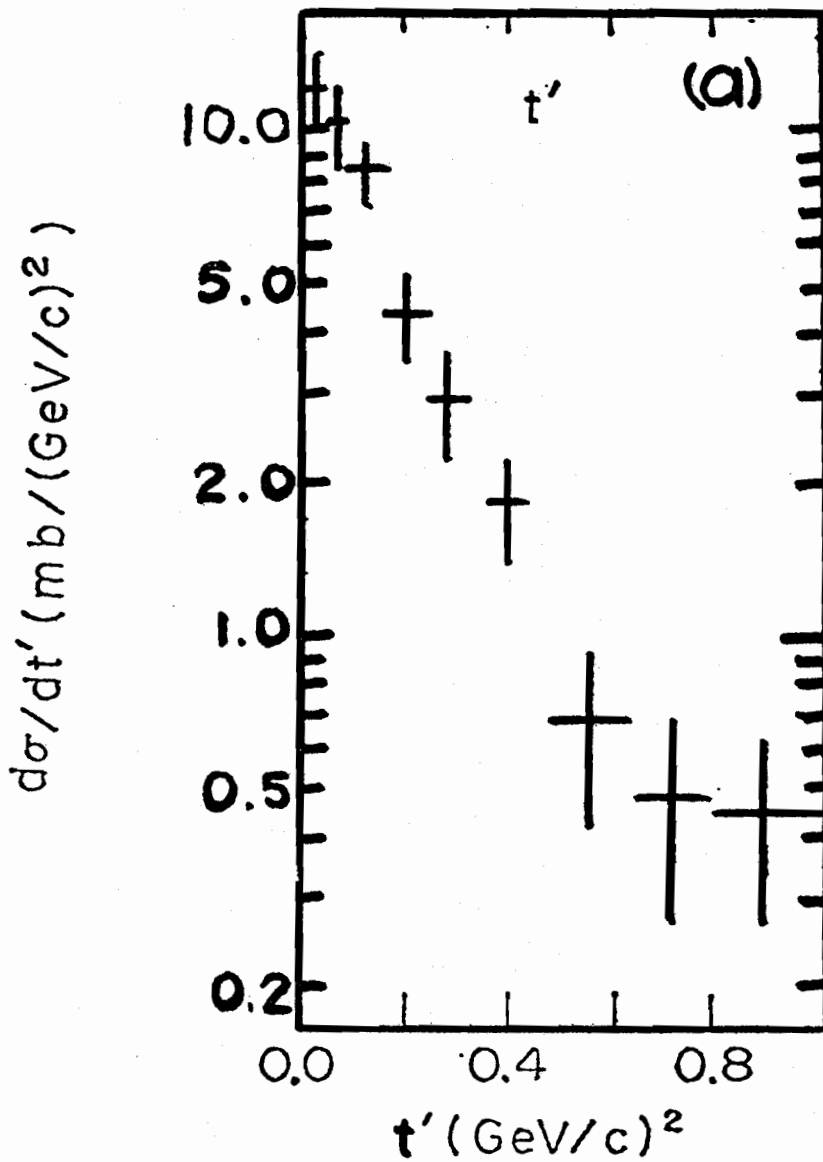
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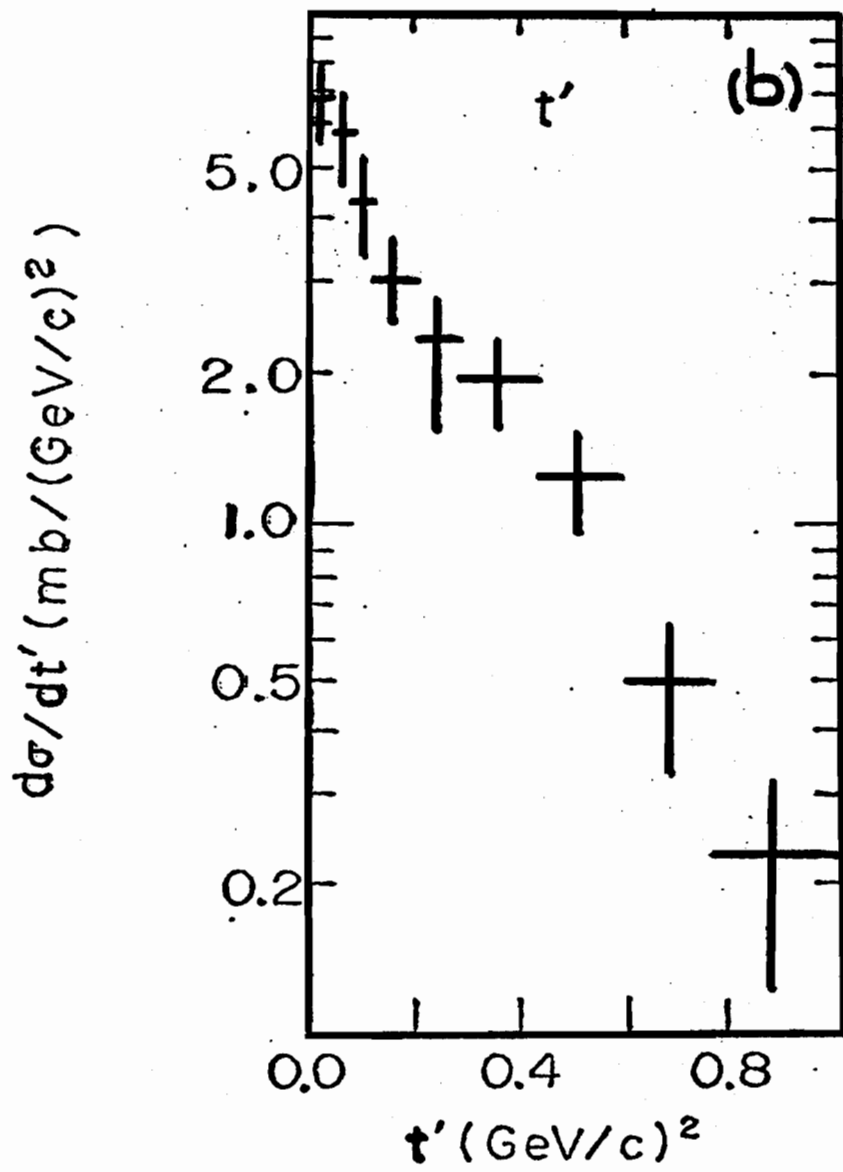
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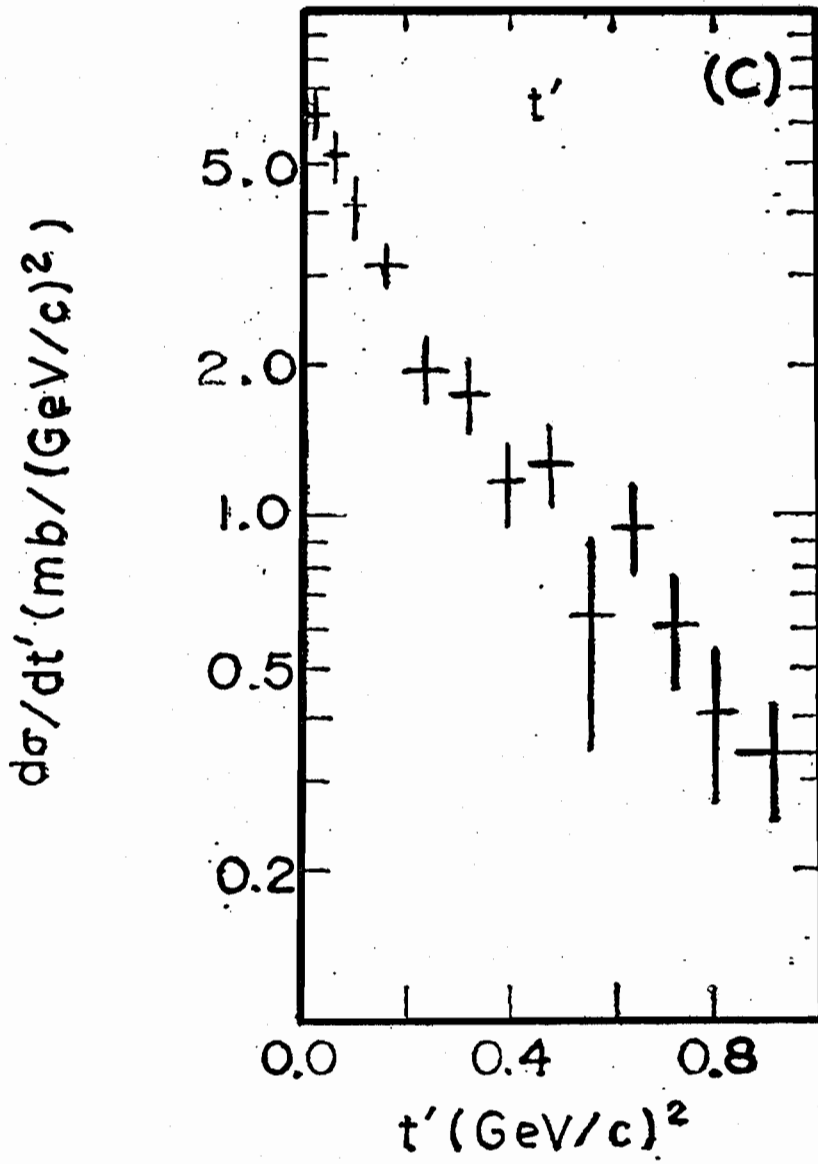
Fig. 6c

Fig. 7a

Fig. 7b

Fig. 7c

Fig. 8