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ELASTIC AND TWO-PRONG INELASTIC INTERACTIONS OF 8 GeV/c POSITIVE PIONS WITH PROTONS

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A study of the interactions of 8 GeV/c positive pions in hydrogen is of interest as it provides information on high-energy collisions.
At the same time the momentum is sufficiently low that resonance production can be studied. One of the main results of this experiment is that resonance and isobars are produced abundantly at this energy.

On 50,000 photographs taken in the 81cm Saclay hydrogen bubble chamber with a beam of 8.04 $\pm$ 0.06 GeV/c positive pions from the CERN proton synchrotron, some 3,000 two-prong events were measured and analysed using the THRESH-GRIND-BAKE-SLICE-SUMX or similar system.

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CROSS-SECTIONS

Assuming a total cross-section of 25.8 mb from the work of von Dardel et al[1], the following partial cross-sections for two-prong interactions were calculated :

For $\pi^+ + p \rightarrow \pi^+ + p$, $\sigma = 4.84 \pm 0.20$ mb

$\rightarrow \pi^+ + p + \pi^0$, $\sigma = 0.97 \pm 0.10$

$\rightarrow \pi^+ + \pi^+ + n$, $\sigma = 0.65 \pm 0.08$

$\rightarrow \pi^+ + p + (m\ \pi^0)$, $\sigma = 2.17 \pm 0.2$ where $m \geqslant 2$

$\rightarrow \pi^+ + \pi^+ + (n + m\pi^0)$, $\sigma = 2.12 \pm 0.2$ where $m \geqslant 1$.

ELASTIC SCATTERING

1,228 events were found to be elastic scatters. The slope of the differential cross-section, $\frac{d\sigma}{d(-t)}$ as a function of the squared four-momentum transfer, is consistent with the results of Foley et al[2], for $-t$ less than 0.4 $(GeV/c)^2$.

From the C.M. angular distribution shown in Figure 1, it may be seen that there are 1,398 events (corrected for losses at small angles) in the range $+1.0 < \cos\theta^*_\pi < +0.76$, no events in the range -0.76 to $+0.99$ and two events with a $\cos\theta^*_\pi$ between -0.99 and -1.00. Both these backward elastic scattering events have been measured twice and are good fits to elastic scattering only. These two events correspond to a cross-section of about 7 μb. This result can be compared with the results of the Aachen-Berlin-Birmingham-Bonn-Hamburg-London (Imperial College) and München Collaboration[3], who found with 4 GeV/c π^+, a backward peak of about 40 μb. It is interesting to note that with negative pions at 4.0[4] and at 10.0 GeV/c[5], no backwards elastic events were found whereas, if one had been found, it would have corresponded to about 6 μb and $2\frac{1}{2}$ microbarns, respectively.

SINGLE PION PRODUCTION

Single pion production occurs in the two reactions

$$\pi^+ p \rightarrow p\ \pi^+\ \pi^0 \qquad (1)$$

$$\pi^+ p \rightarrow n\ \pi^+\ \pi^+ \qquad (2)$$

In Figure 2, the Peyrou plot (transverse momentum against C.M. longitudinal momentum) for neutrons for reaction (2) shows a strong backwards grouping and indicates the peripheral nature of the reaction. This can also be seen in Figure 3 where the Peyrou plot for the π^+ from the same reaction shows two distant groups, one very forwards and the other, broader, slightly backwards in the C.M. Similar results are found for the protons and pions of reaction (1).

The Dalitz plot, Figure 4, for reaction (1), shows three bands corresponding to the production of the three excited states $(p\pi^+)$ and $(p\pi^0)$ in the (3/2, 3/2) states $(\pi^+\pi^0)$ as $\rho^\pm$ mesons. What is unusual about this plot is the absence of events in middle region. The peripheral nature of these high-energy reactions is probably responsible for the separation of the events into bands along the edges of the plot.

It is interesting to compare Figure 4 with Figure 5, which is the Dalitz plot for reaction (2). Here there are fewer events along the plot boundary, which would correspond to the peripheral production of a $(\pi\pi)$ state, probably because of the fact that since both pions are positive, the ρ-meson cannot be formed. This can also be seen in Figure 6 where the $(\pi^+\pi^0)$ and $(\pi^+\pi^+)$ effective mass distributions are presented.

From the Dalitz plot of Figure 4, the reaction appears to go mainly through the three channels :

$$\pi^+ p \to N^{*++} \pi^0 \qquad (4)$$

$$\to N^{*+} \pi^+ \qquad (5)$$

$$\to p\, \rho^+ \qquad (6).$$

If we compare this Dalitz plot with that obtained by the German-British Collaboration[3], we note two important differences :

i) at 4 GeV/c there is no absence of events in the central region

ii) while there are bands corresponding to reactions (4) and (6), there is no appreciable production of N^{*+}.

At 8 GeV/c, the production of N^{*+} which decays to $(p\pi^0)$ is very pronounced and is more frequent than production of the doubly charged N^{*++} which is perhaps a surprising result. As the N^{*+} can and does decay into $(n\pi^+)$ in reaction (2), this effect is enhanced.

The peripheral nature of the production of ρ-mesons and of the N^{*++} in reaction (1) can be seen in Figure 7. Since this is a two-body process, the points on this Peyrou plot must lie on a circle.

The two-prong events with identified proton, in which no kinematic fit was obtained (i.e. there were two or more missing neutrals), can be written as

$$\pi^+ p \rightarrow p\pi^+ X \qquad (6)$$

where X is the effective mass of all the neutrals. If it is required that the proton has a Δ^2 (four-momentum transfer) of less than -0.6 $(\mathrm{GeV/c})^2$, then the effective mass distribution of the $(\pi^+ X)$ combination which is given in Figure 8, shows a peak near 1250 MeV. If this peak were due to the B-meson which decays into $\pi^+\omega$ and then the ω-meson decayed in the neutral mode, then the number of events expected in the reaction $\pi^+ p \rightarrow p\pi^+\pi^+\pi^-\pi^0$ giving B-mesons, with the ω-meson decaying in the $(\pi^+\pi^+\pi^0)$ mode which is favoured by a factor of about 6, would be an order of magnitude greater than is observed. It is possible that this peak is the A_2 meson decaying into $(\pi^+\pi^0\pi^0)$ with one of the $\pi^+\pi^0$ combinations being a rho-meson. Then, from kinematic considerations one would expect the $(\pi^0\pi^0)$ effective mass to give a broad peak centered near the rho mass of 750 MeV as is in fact found. If the isotopic spin of A_2 is one or two, then it can decay with equal probability into $(\rho^0\pi^+)$ and $(\rho^+\pi^0)$. From the number of four prong reactions of the type

$$\pi^+ + p \rightarrow p + A_2 \longrightarrow p + \rho^0 + \pi^+ \longrightarrow p + \pi^+ + \pi^+ + \pi^-$$

it is found that the ratio of the decay modes is consistent with one indicating that A_2 is in a pure isotopic spin state.

Nauenberg, Pais and Peierls have predicted that a ρπ resonance should exist with the property that the decay mode $\rho^+\pi^0$ is forbidden. As this is in disagreement with the assignment of the peak in Fig. 8 to the A_2 meson, it may be concluded that the A_2 meson is not the (ρπ) resonance predicted by Nauenberg, Pais and Peierls.

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REFERENCES

1) von Dardel et al., Phys. Rev. Lett., 8, 173 (1962).

2) Foley et al., Phys.Rev.Lett., 10, 543 (1963).

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5) S. Brandt et al., Phys.Rev.Lett., 10, 413 (1964)

FIGURE CAPTIONS

Fig. 1 C.M. angular distribution of the scattered π^+ in elastic events, $\pi^+ p \longrightarrow \pi^+ p$. The two observed events of backward scattering correspond to $-t = 14.3$ (GeV/c)^2.

Fig. 2 Plot of transverse momentum vs. c.m. longitudinal momentum for neutrons in reaction $\pi^+ p \longrightarrow \pi^+ \pi^+ n$.

Fig. 3 Plot of transverse momentum vs. c.m. longitudinal momentum for π^+ in reaction $\pi^+ p \longrightarrow \pi^+ \pi^+ n$.

Fig. 4 Plot of $(p\pi^o)$ effective mass squared vs. $(p\pi^+)$ effective mass squared for reaction $\pi^+ p \longrightarrow p\, \pi^+ \pi^o$.

Fig. 5 Plot of $(\pi^+_a\, n)$ effective mass squared vs. $(\pi^+_b n)$ for reaction $\pi^+ p \longrightarrow \pi^+_a\, \pi^+_b\, n$.

Fig. 6 $(\pi^+\pi^o)$ and $(\pi^+\pi^+)$ effective mass distributions for reactions $\pi^+ p \longrightarrow p\, \pi^+\, \pi^o$ and $\pi^+ p \longrightarrow \pi^+ \pi^+ n$, respectively. The solid lines are the phase space distributions normalized to the same area.

Fig. 7 Peyrou plots (transverse momentum vs. c.m. longitudinal momentum) of:

a) N^{*++}, for the events of the type $\pi^+ p \longrightarrow p\pi^+\pi^o$ in which no N^{*+} and no ρ^+ were found.

b) ρ^+, for the events of the type $\pi^+ p \longrightarrow p\pi^+\pi^o$ in which no N^{*++} and no N^{*+} were formed.

Fig. 8 Effective mass distribution of the combination $\pi^+ X$ for the reaction $\pi^+ p \longrightarrow p\pi^+ X$, where X is the effective mass of all the neutral particles, $m\pi^o$.

The events chosen are those in which no N^{*++} was formed and the squared four-momentum transferred to the proton is less than 0.3 (GeV/c)^2.

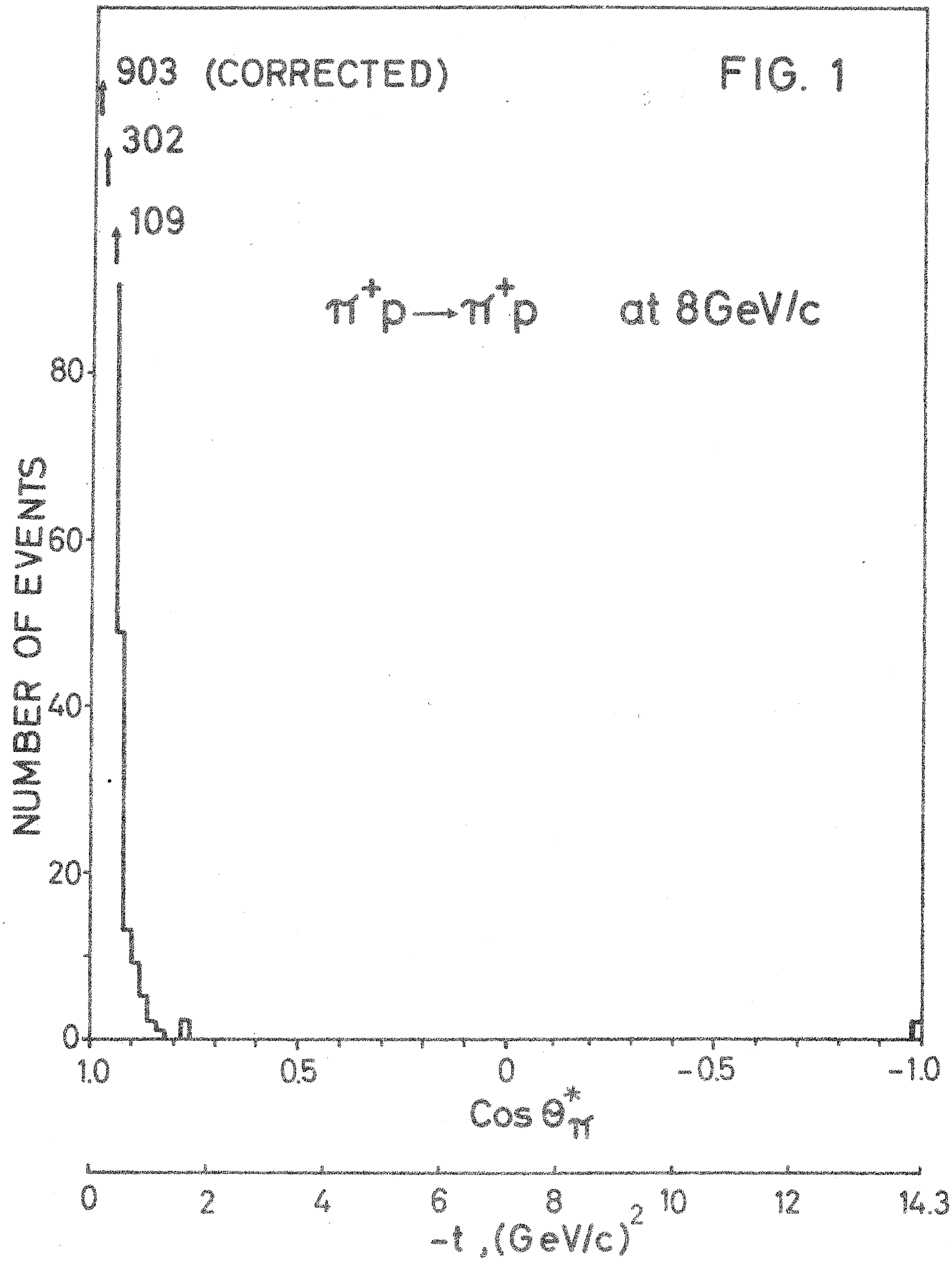

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FIG. 2

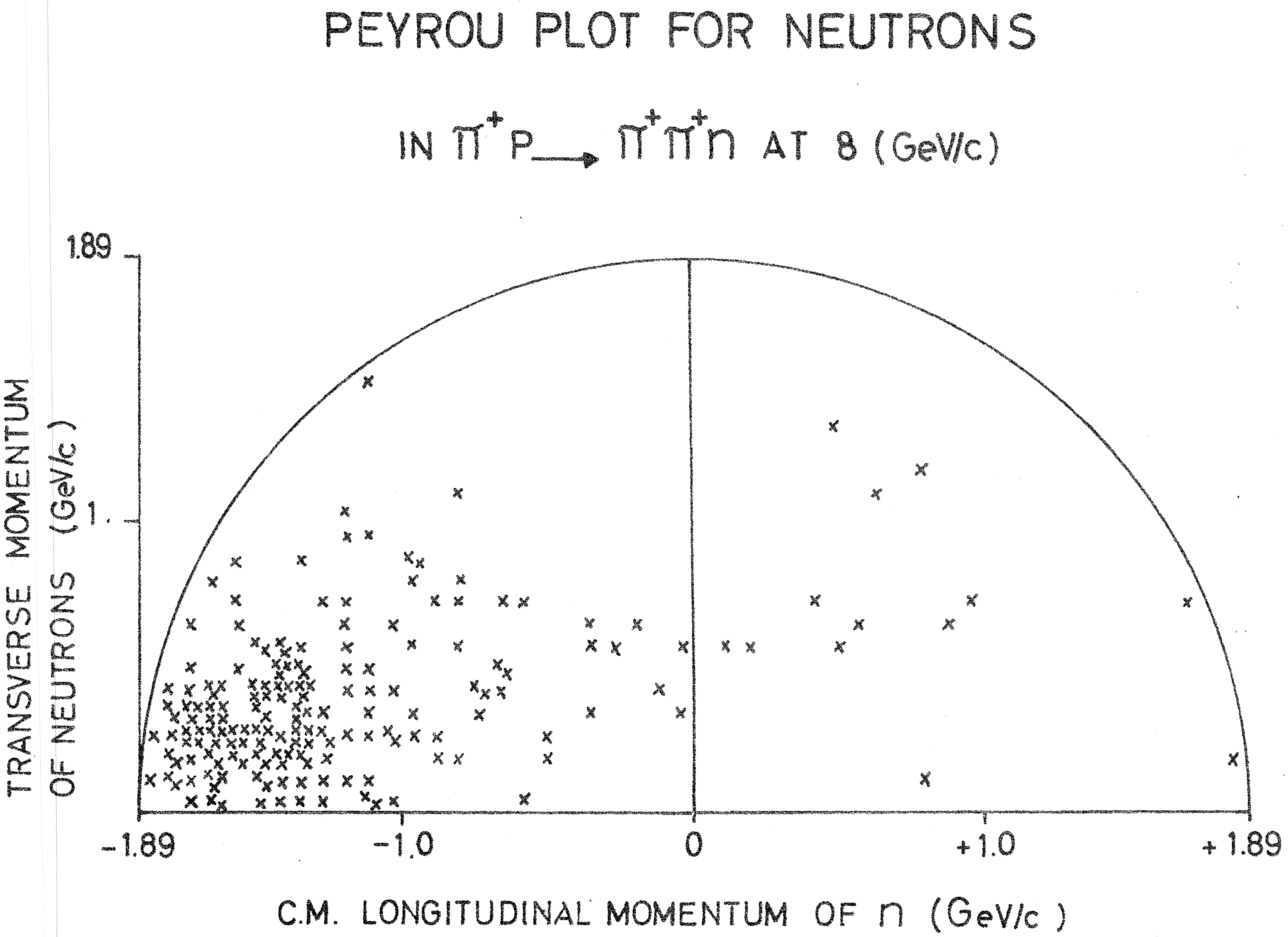

PEYROU PLOT FOR NEUTRONS
IN $\pi^+ p \longrightarrow \pi^+\pi^+ n$ AT 8 (GeV/c)
1.89
1.
TRANSVERSE MOMENTUM OF NEUTRONS (GeV/c)
-1.89
-1.0
0
+1.0
+1.89
C.M. LONGITUDINAL MOMENTUM OF n (GeV/c)

FIG. 3

PEYROU PLOT FOR π^+.

IN $\pi^+ P \rightarrow \pi^+\pi^+ n$ AT 8 (GeV/c)

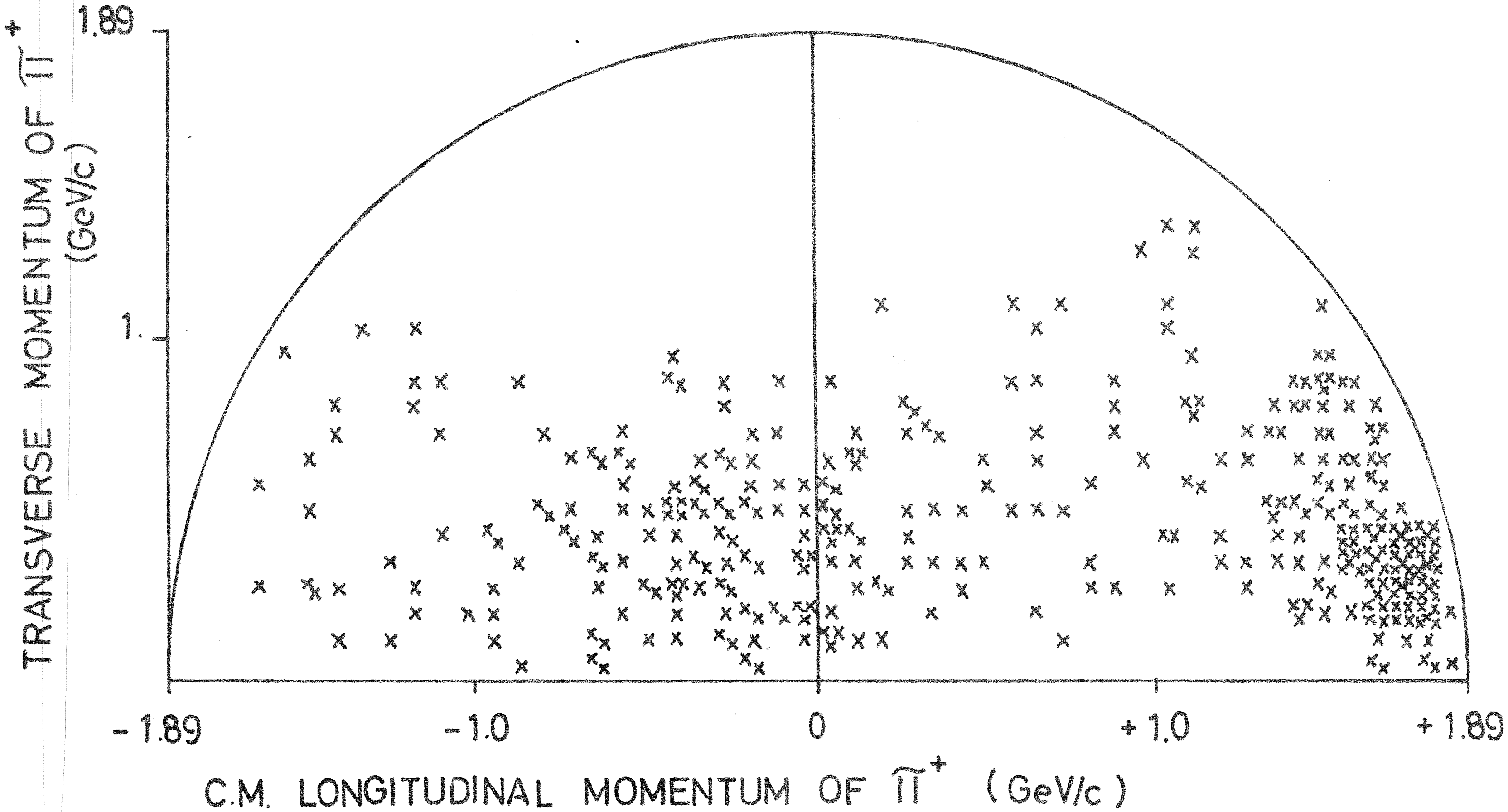
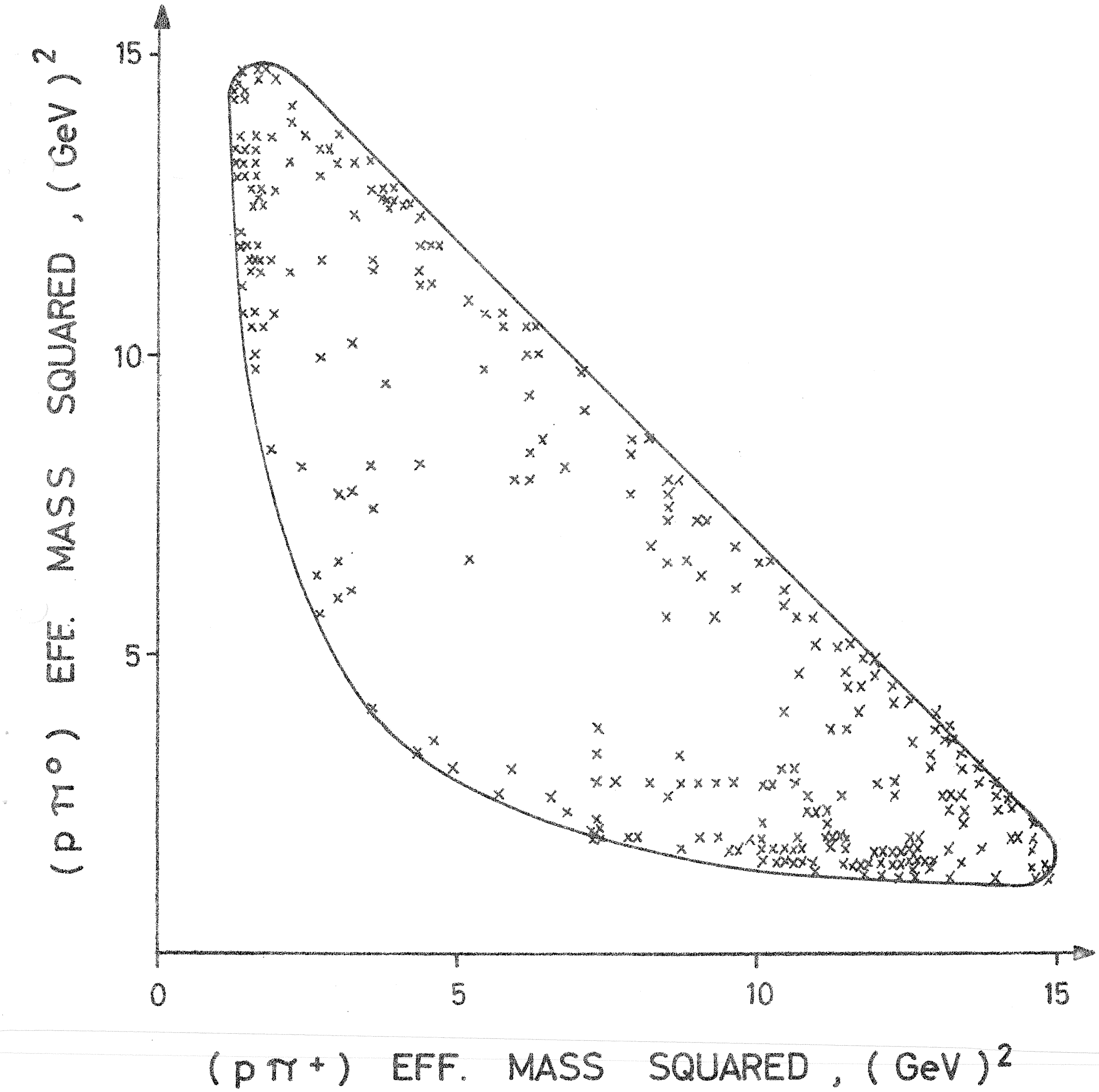


FIG. 4

$\pi^+ p \rightarrow p \pi^+ \pi^0$ AT 8 GeV/c.



$\pi^+ p \longrightarrow n \pi^+ \pi^+$ at 8 GeV/c

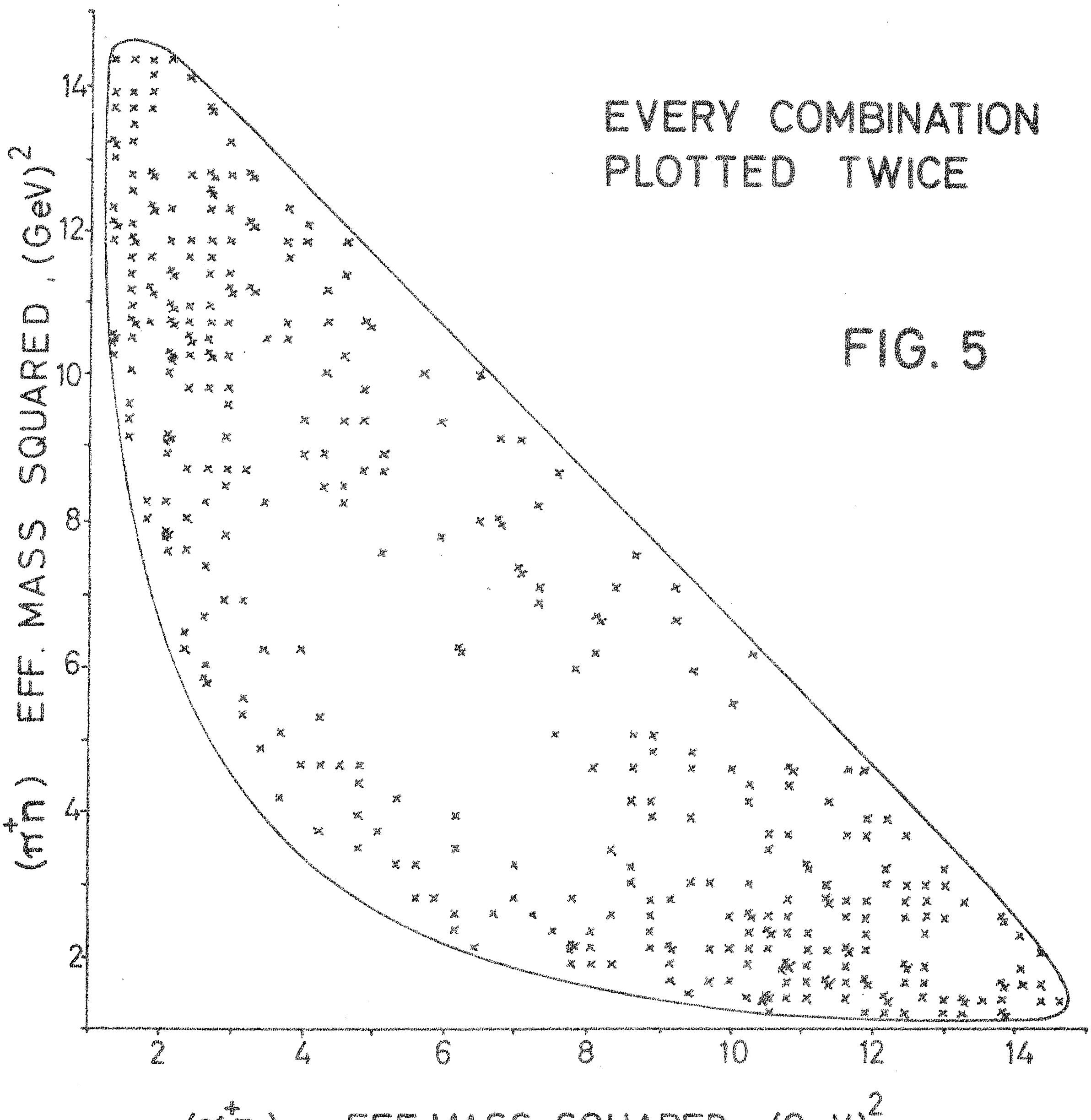


FIG. 5

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$\pi^+ p \rightarrow p \pi^+ X$ AT 8 GeV/c

EVENTS GIVING N^{*++} EXCLUDED, Δ^2 LESS THAN 0.3 $(GeV/c)^2$

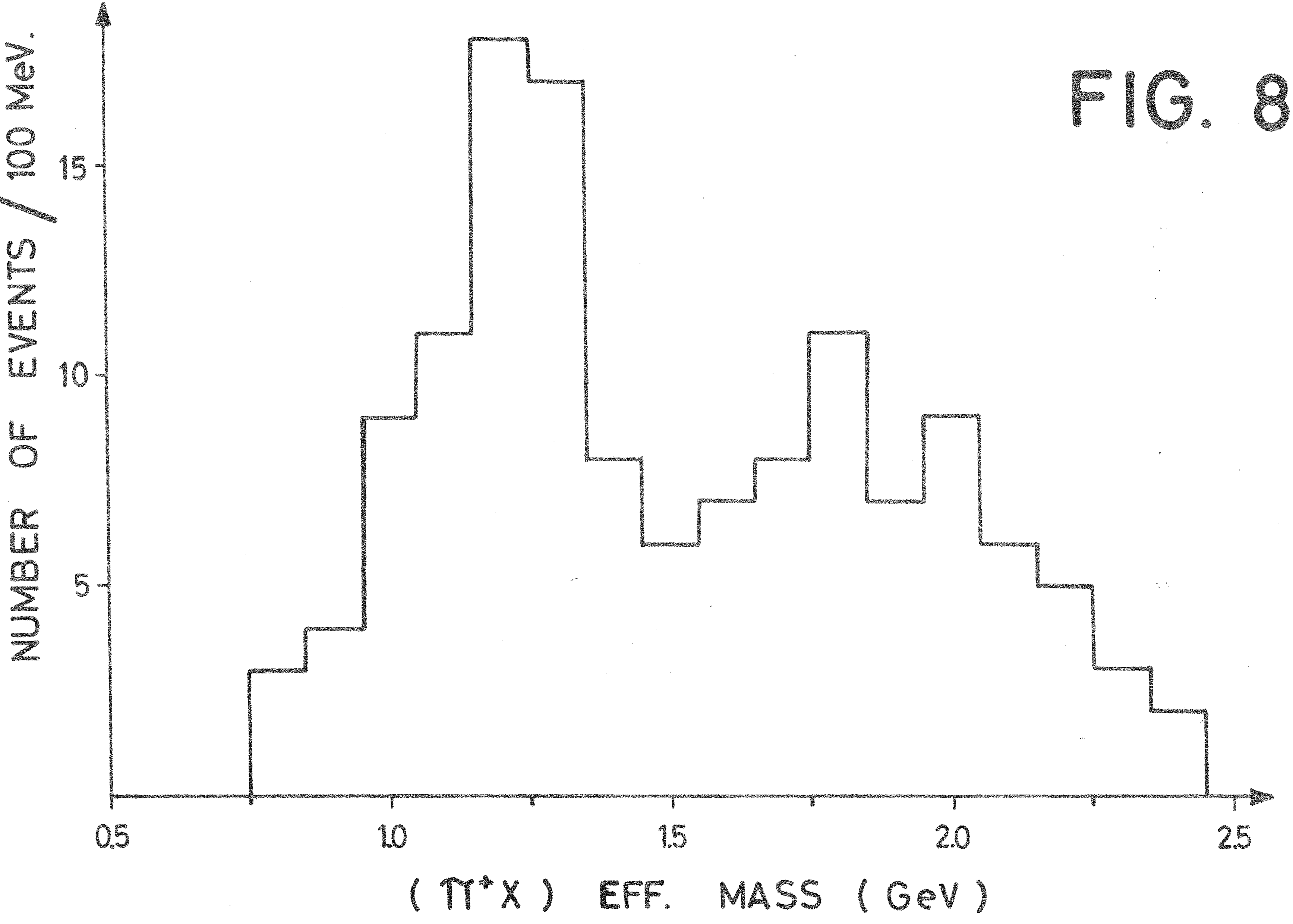

FIG. 8