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RESONANCE PRODUCTION BY 8 GeV/c POSITIVE PIONS ON PROTONS

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There has been little information published on the production of resonances (other than the ρ and N^{*++}) at high energies (above 6 GeV/c). Here are presented results[1] indicating that in 2 - and 4 - prong interactions of 8 GeV/c positive pions in hydrogen resonances are produced abundantly, often making the reaction a two-body process, e.g.: $\pi^{+} + p \longrightarrow N^{*} + \omega$. These reactions are found to be of a peripheral nature, which makes the separation of resonances from background cleaner than at lower energies.

On 60,000 photographs taken in the Saclay 81cm hydrogen bubble chamber with a beam of 8.04 ± 0.06 GeV/c positive pions from the CERN proton synchrotron, approximately 7000 two - and four - prong events were measured and analysed using the THRESH - GRIND - BAKE - SLICE - SUMX or similar program system. To distinguish protons from pions, ionizations measurements were make on tracks of up to 2 GeV/c, using the mean gap length method.

Assuming the total cross section of 25.8 mb obtained by von Dardel et al[2], the cross sections for the various channels were calculated (after corrections for scanning losses and small angle scatters) and are shown in Table I. About 60 o/o of the two prong, and 50 o/o of the four prong events had kinematic fits, i.e., corresponded to reaction channels in which no more than one neutral particle is produced.

The Dalitz plot for the two prong reactions

$$\pi^{+} p \longrightarrow p \pi^{+} \pi^{o} \qquad (1)$$

and

$$\pi^{+} p \longrightarrow n \pi^{+} \pi^{+} \qquad (2)$$

are shown in Fig. 1. Their characteristic feature is that the points are grouped round the edge of the plot, with few in the centre. In the plot for reaction (1) three bands can be seen corresponding to production of ρ^{o}, N^{*++} and N^{*+}, so that the reaction proceeds mainly through the two-body channels

$$\pi^{+} p \longrightarrow N^{*++} \pi^{o} \qquad (3)$$

$$\longrightarrow p \rho^{+} \qquad (4)$$

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

The Dalitz plot for reaction (2) is somewhat different as, with the charge states involved, neither the ρ-meson nor the N^{*++} isobaric state can be formed.

The peripheral nature of the production of the N^{*++} isobar and of the ρ-meson in reaction (1), via channels (3) and (4), can be seen in the two plots of transverse momentum vs. c.m. longitudinal momentum, in Fig. 2a. Since these are two-body processes, the points must lie on a circle.

In Fig. 3 is plotted the distribution of the c.m. momentum of the pions produced in reaction (2). The occurence of the large group of pions with momentum close to the kinematic maximum indicates the importance of two body and quasi-two body channels.

Consider now the four-prong events. For the reaction

$$\pi^+ p \longrightarrow p \pi_A^+ \pi_B^+ \pi^- \qquad (6)$$

the $(p \pi_A^+)$ effective mass is plotted against the $(\pi_B^+ \pi^-)$ effective mass in Fig. 4a. The distribution of the $(p \pi^+)$ effective mass projected in Fig. 4b shows that the N^{*++} isobar is frequently produced. If it is required that one of the π^+ is in the N^{*++} isobar, then the plot in Fig. 4c of the effective mass of the π^- with the other π^+, shows that ρ^o and f^o mesons are produced. Almost half the events of reaction (6) correspond, in fact, to one or other of the two-body reactions

$$\pi^+ + p \longrightarrow N^{*++} + \rho^o \qquad (7)$$

$$\longrightarrow N^{*++} + f^o \,. \qquad (8)$$

In the $p_T - p_L^*$ plots of Fig. 2b, it can be seen that the N^* and most of the ρ^o- mesons are produced peripherally.

In the reaction

$$\pi^+ p \longrightarrow p \pi^+ \pi^+ \pi^- \pi^o \qquad (9)$$

it is found that N^{*++} isobars and ω^o-mesons are produced. In Fig. 5, the $(\pi^+ \pi^- \pi^o)$ effective mass is plotted for all events in which the other π^+ is in the N^{*++} isobar. It may be seen that the ω-meson is observed, indicating that the two-body reaction

$$\pi^+ + p \longrightarrow N^{*++} + \omega \,. \qquad (10)$$

occurs. The width of the ω-meson peak gives some indication of the experimental resolution obtained with 8 GeV/c incident particles.

In the range from 1150 to 1275 MeV of the $(\pi^+ \omega)$ effective mass, which corresponds to the B-meson, only seven events were found, this number being consistent with number of background events expected. The corresponding cross section for the B-meson production is then less than or equal to 21 μb, indicating that this cross section decreases with increasing incident momentum, as observed by Hess et al[3] for 3.2 and 4.2 GeV/c negative pions.

In the plot of the $(\pi^+ \pi^- \pi^o)$ effective mass, where any two of the pions are consistent with a ρ-meson, no evidence was found for the production of the H-meson $(\rho^\pm \pi^\mp$ or $\rho^o \pi^o)$ at 970 MeV, reported[4] for 4 GeV/c $\pi^+ p$ - interactions.

The production of the $(\rho^o\ \pi^+)$ resonances corresponding to the A-mesons[5,6,7] was studied in the reaction $\pi^+ p \longrightarrow p\ \pi^+\ \pi^+\ \pi^-$. Fig. 6 shows the $(\pi^+\ \pi^+\ \pi^-)$ effective mass distribution obtained by excluding events with an N^{*++} and requiring at least one $(\pi^+\ \pi^-)$ combination to be consistent with the ρ-meson mass. It can be seen that there are two distinct peaks with relatively little background. The reduction of background compared with that obtained with 3 to 4 GeV/c incident pions is probably due to the peripheral nature of the interactions at 8 GeV/c, which facilitates the assignment of pions to the baryonic or mesonic vertex.

We assume that these two peaks in the $(\rho^o\ \pi^+)$ effective mass are the A_1 and A_2 mesons. For the A_1 mass we find a value of 1.04 GeV. The probability of the previously reported value, 1.09 GeV, is in our data, 5 o/o; for the A_2 peak, the mass found, 1.29 GeV, is consistent with the values obtained previously.

It has been reported[8] that the A_2 meson decays in 60 o/o of the cases into ρ π, in 20 o/o into $K\ \bar{K}$ and in 20 o/o into η π.

Since about 80 events corresponding to the A_2-meson were observed to decay into $\rho^o\ \pi^+$ and the same number must decay into $\rho^+\ \pi^o$, we would expect 160/3 = 53 events in which the A_2 decays into the η π. From the branching ratios of the η decay modes, 36 of these should appear in the two-prong channel $\pi^+ p \longrightarrow p\ \pi^+$ + neutrals, where the mass of the neutral is required to be consistent with the η-mass, and 14 should be found in the $p\ \pi^+\ \pi^+\ \pi^-\ \pi^o$ channel, where the requirements are made that the $(\pi^+\ \pi^+\ \pi^-\ \pi^o)$ mass is in the A_2-range, and the $(\pi^+\ \pi^-\ \pi^o)$ is consistent with the η-mass. Only 8 events of the first type, which could all be background, and 1 event of the second type are observed. These results therefore give a branching ratio for the η π decay mode of the A_2-meson of 0 ± 3 o/o.

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TABLE I

Channel	corrected no. of events	cross sections (mb)
$\pi^+ p$	1591	$4.8 \pm .3$
$\pi^+ p \pi^0$	319	$1.0 \pm .1$
$n \pi^+ \pi^+$	214	$0.7 \pm .1$
$\pi^+ p (m \pi^0)\ m > 1$	712	$2.2 \pm .2$
$n \pi^+ \pi^+ (m \pi^0)\ m > 0$	698	$2.1 \pm .2$
$p \pi^+ \pi^+ \pi^-$	694	$2.1 \pm .2$
$p \pi^+ \pi^+ \pi^- \pi^0$	684	$2.1 \pm .2$
$n \pi^+ \pi^+ \pi^+ \pi^-$	283	$0.9 \pm .1$
$p \pi^+ \pi^+ \pi^- (m \pi^0)\ m > 1$	754	$2.5 \pm .2$
$n \pi^+ \pi^+ \pi^+ \pi^- (m \pi^0)\ m > 0$	756	$2.5 \pm .2$

TABLE CAPTION

Cross sections for various reaction channels in $\pi^+ p$ interactions at 8 GeV/c.

FIGURE CAPTIONS

Fig. 1 Dalitz plots for the reactions $\pi^+ p \to p \pi^+ \pi^o$ and $\pi^+ p \to n \pi^+ \pi^+$.

Fig. 2 Plots of transverse momentum vs. c.m. longitudinal momentum for (a) N^{*++} and ρ^+ resonances produced in the reaction $\pi^+ p \to p \pi^+ \pi^o$, (b) N^{*++} and ρ^o resonances produced in the reaction $\pi^+ p \to p \pi^+ \pi^+ \pi^-$. It must be noted that about half of the ρ^o-mesons in this diagram are produced not in the 2-body reaction (7) but in the decay of the A-mesons.

Fig. 3 c.m. momentum distribution of positive pions produced in the reaction $\pi^+ p \to n \pi^+ \pi^+$.

Fig. 4 For the reaction $\pi^+ p \to p \pi^+_A \pi^+_B \pi^-$ (a) Scatter diagram of $(p \pi^+_A)$ effective mass vs $(\pi^+_B \pi^-)$ effective mass. (b) $(p \pi^+)$ effective mass distribution. (c) $(\pi^+_A \pi^-)$ effective mass distribution when $(\pi^+_B p)$ effective mass is in the N^{*++} region. The solid line is the phase space distribution for the reaction $\pi^+ p \to \pi^+ \pi^- N^{*++}$, normalised to the total area.

Fig. 5 $(\pi^+_A \pi^- \pi^o)$ effective mass distribution in the reaction $\pi^+ p \to p \pi^+_A \pi^+_B \pi^- \pi^o$ when $(p \pi^+_B)$ is in the N^{*++} region.

Fig. 6 $(\rho^o \pi^+)$ effective mass distribution in the reaction $\pi^+ p \to p \pi^+ \pi^+ \pi^-$, when neither $(\pi^+ p)$ combination is in the N^* mass band from 1.12 to 1.34 GeV.

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FIGURE 1

SINGLE PION PRODUCTION BY 8 GeV/c π^+

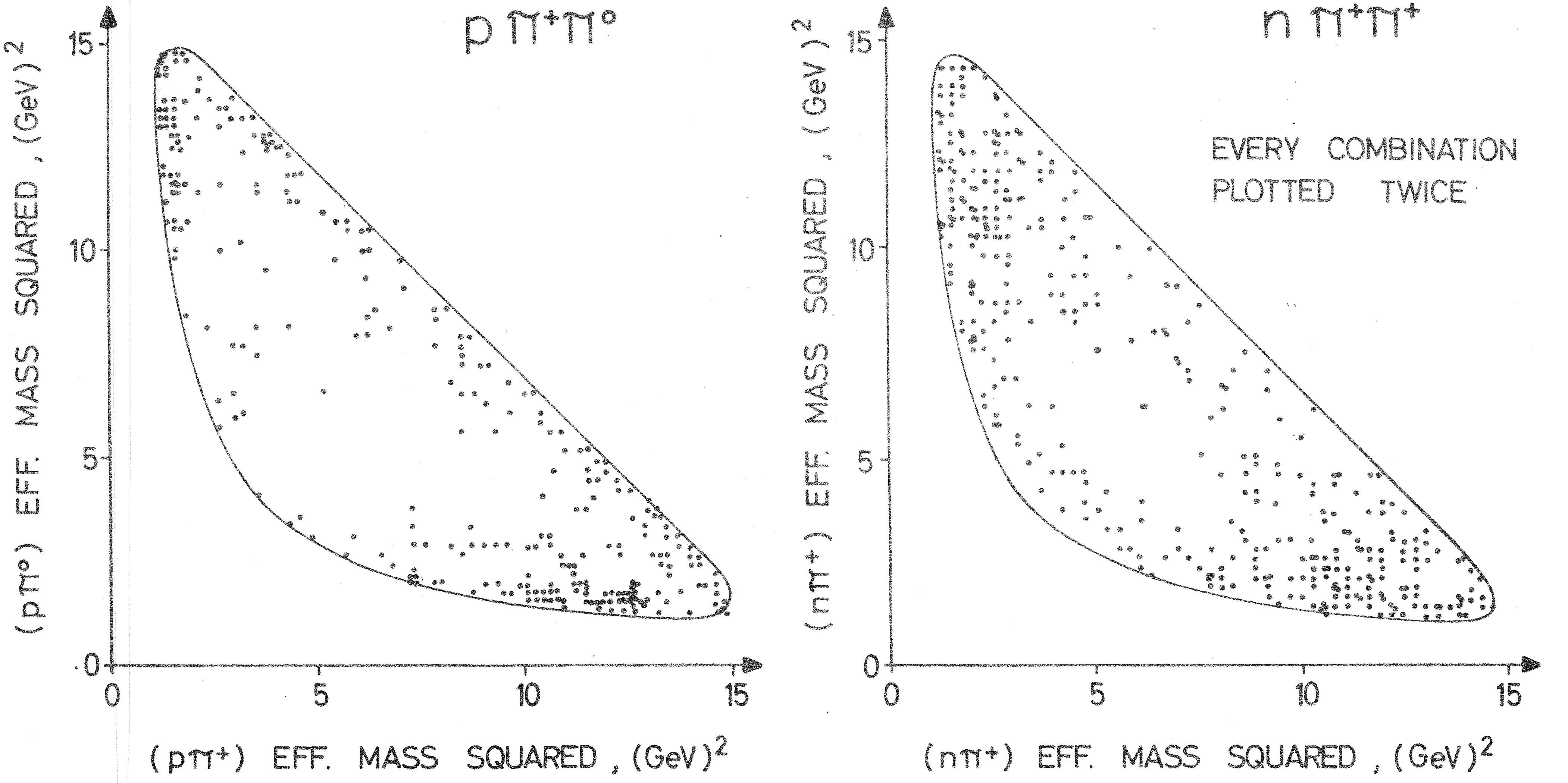


FIGURE 2

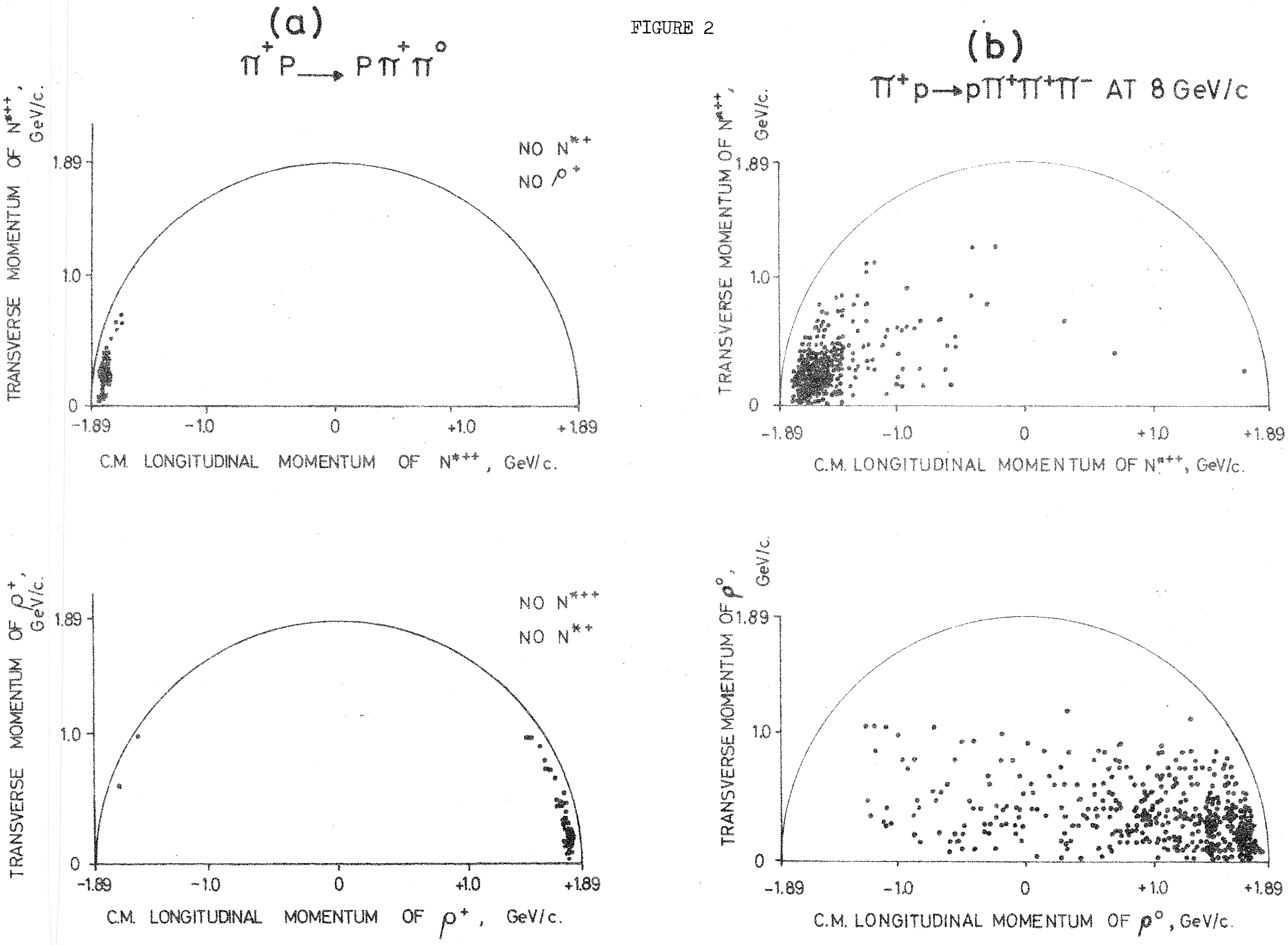
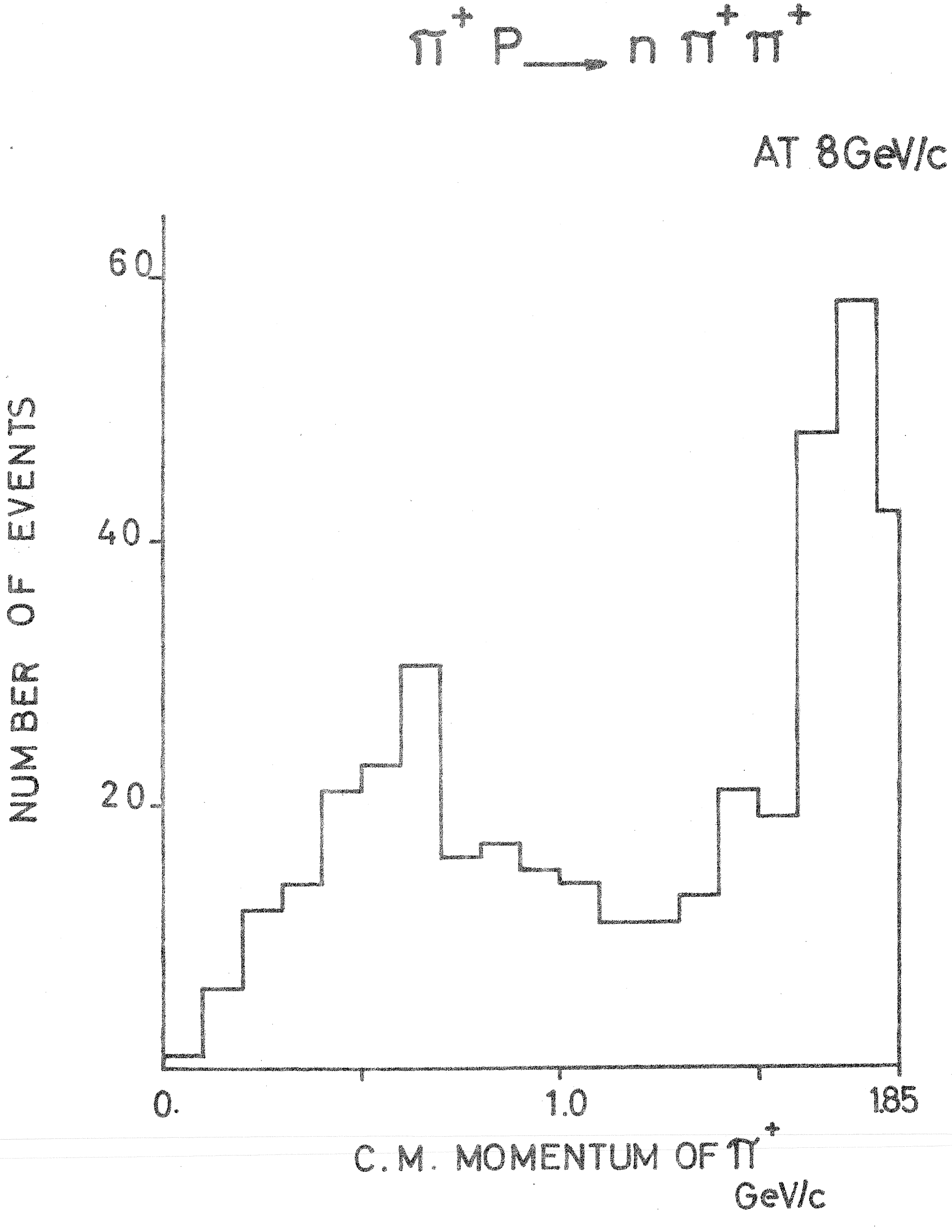
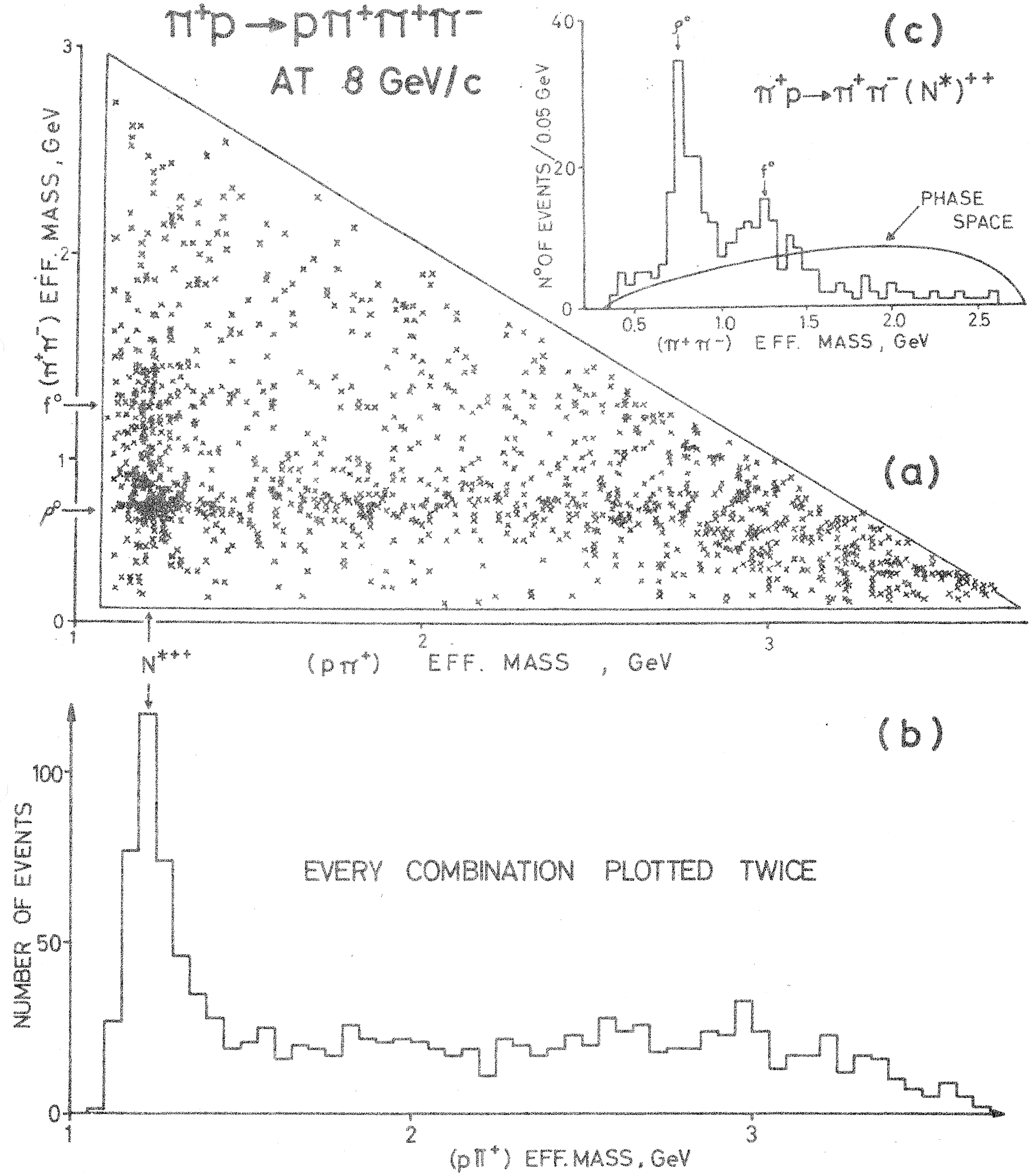

(a)
π⁺P ⟶ Pπ⁺π°
TRANSVERSE MOMENTUM OF N*++, GeV/c.
NO N*+
NO ρ+
1.89
1.0
0
-1.89
-1.0
0
+1.0
+1.89
C.M. LONGITUDINAL MOMENTUM OF N*++, GeV/c.
TRANSVERSE MOMENTUM OF ρ+, GeV/c.
NO N*++
NO N*+
C.M. LONGITUDINAL MOMENTUM OF ρ+, GeV/c.
(b)
π⁺p→pπ⁺π⁺π⁻ AT 8 GeV/c
TRANSVERSE MOMENTUM OF N*++, GeV/c
C.M. LONGITUDINAL MOMENTUM OF N*++, GeV/c.
TRANSVERSE MOMENTUM OF ρ°, GeV/c.
C.M. LONGITUDINAL MOMENTUM OF ρ°, GeV/c.

FIGURE 3

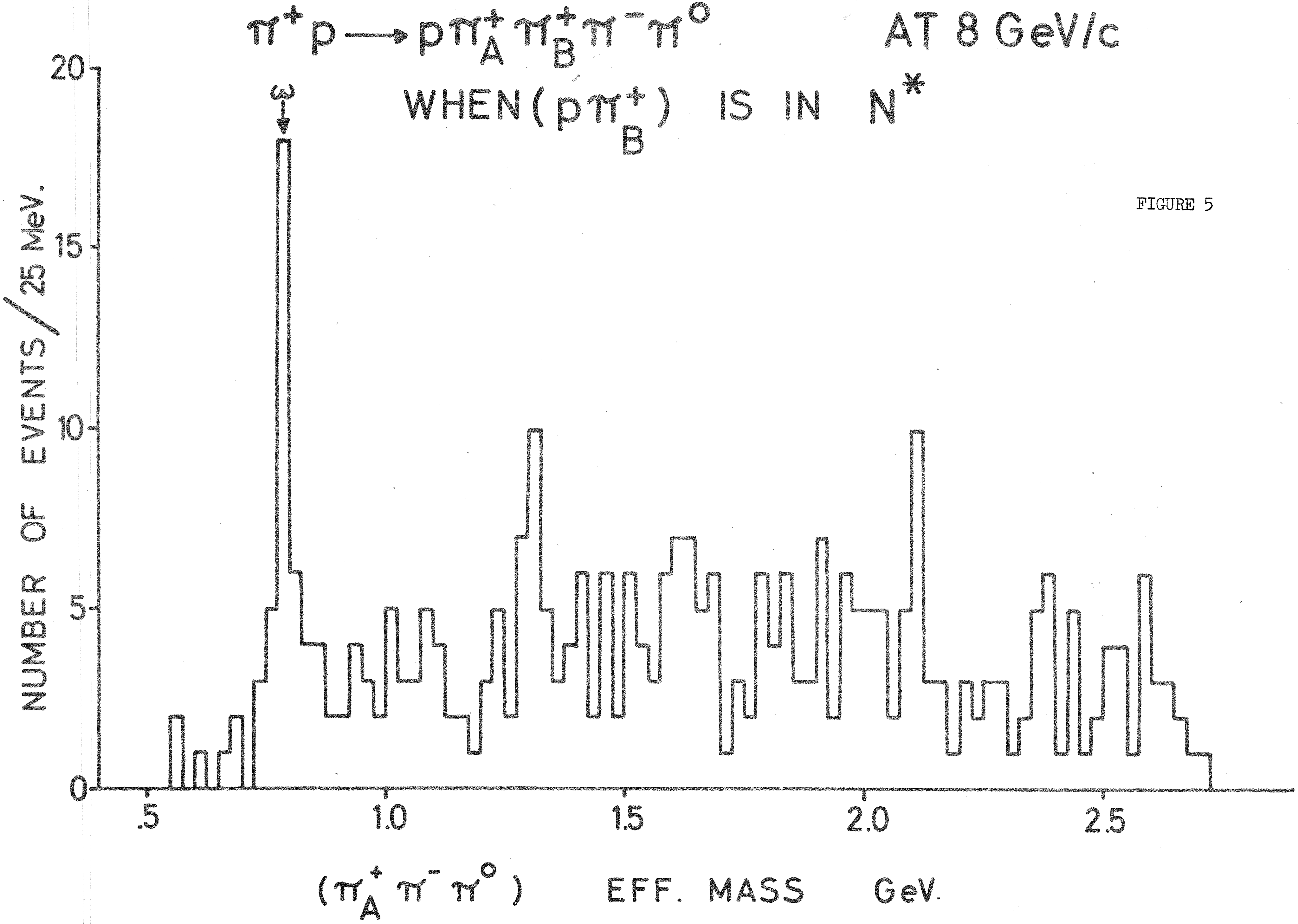


$\pi^+ P \longrightarrow n \pi^+ \pi^+$
AT 8GeV/c
NUMBER OF EVENTS
60
40
20
0.
1.0
1.85
C.M. MOMENTUM OF π^+
GeV/c

FIGURE 4



π⁺p → pπ⁺π⁺π⁻
AT 8 GeV/c
(π⁺π⁻) EFF. MASS, GeV
f°
ρ°
(a)
(pπ⁺) EFF. MASS, GeV
N*⁺⁺
(c)
π⁺p → π⁺π⁻(N*)⁺⁺
N° OF EVENTS/0.05 GeV
ρ°
f°
PHASE SPACE
(π⁺π⁻) EFF. MASS, GeV
(b)
NUMBER OF EVENTS
EVERY COMBINATION PLOTTED TWICE
(pπ⁺) EFF. MASS, GeV



$\pi^+ p \longrightarrow p\pi_A^+\pi_B^+\pi^-\pi^o$ AT 8 GeV/c
WHEN $(p\pi_B^+)$ IS IN N^*
ω
NUMBER OF EVENTS / 25 MeV.
20
15
10
5
0
.5
1.0
1.5
2.0
2.5
$(\pi_A^+\pi^-\pi^o)$ EFF. MASS GeV.

FIGURE 5