3ème Version - corrigée

To be submitted to
Physics Letters

CERN/TC/PHYSICS 65-13
8.6.1965

SINGLE π^0 PRODUCTION BY 8 GeV/c POSITIVE PIONS AND POSSIBLE ENHANCEMENTS IN THE $(\pi^+\pi^0)$ SYSTEM

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The reaction $\pi^+ + p \longrightarrow p + \pi^+ + \pi^0$ produced by 8 GeV/c positive pions, is shown to be of a peripheral nature with frequent production of $N^{*++}_{3,3}$, $N^{*+}_{3,3}$ and ρ^+. Absorption model calculations are shown to be in agreement with the results for the reaction $\pi^+p \longrightarrow p\rho^+$ which can be interpreted in terms of pion exchange, but are found to be in disagreement for the reactions $\pi^+p \longrightarrow N^*\pi$ which require vector-meson exchange. Possible enhancements in the $(\pi^+\pi^0)$ system at 1620 and 1910 MeV are discussed.

On 140,000 photographs of the 81 cm Saclay hydrogen bubble chamber exposed to a beam of 8 GeV/c positive pions from the CERN proton synchrotron, 9173 two-prong events were measured. Preliminary results

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have been reported [1]. Using THRESH - GRIND - BAKE - SLICE - SUMX or similar systems, 738 events were found to fit the reaction

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

The Dalitz plot for the reaction (1) is shown in Fig. 1. The striking features are the concentration of events in three bands along the edges of the plot and the scarsity of events in the middle. The bands correspond to $(\pi^+\pi^0)$ enhancement as ρ^+ resonance, $(p\pi^+)$ enhancement as $N^{*++}_{3,3}$ and $(p\,\pi^0)$ enhancements in $T = \frac{3}{2}$ and $\frac{1}{2}$ isobars.

Possible biases and contaminations of the sample of events fitting the reaction (1) have been studied in detail. None of the main features of the reaction changed significantly when severe requirements were imposed on the probability of the kinematic fit, on the value of the missing mass or on the error of the missing mass. Contamination of the sample may be expected from (a) elastic events and (b) double π^0 production, that is the reaction $\pi^+ p \longrightarrow p\,\pi^+\pi^0\pi^0$.

When the outgoing pion of an elastic event suffers a small angle scatter, its momentum may be measured too low to fit the elastic reaction. The event is then fitted kinematically by introducing a π^0 lying in almost in the same direction as the π^+. Consequently, the elastic contamination must reveal itself as an excess of events in the $(\pi^+\pi^0)$ effective mass region of 300 - 400 MeV. In our data, an excess of 30 events in that region is present. This corresponds to the wrong assignment of less than 1% of the observed elastic events.

The contamination of double π^0 events has been investigated by taking events from the reaction $\pi^+ p \longrightarrow p\,\pi^+\pi^+\pi^-$ and, considering only the proton and one of the π^+'s, by trying to produce with them a fit to $\pi^+ p \longrightarrow p\,\pi^+\pi^0$; in other words, replacing a $\pi^+\pi^-$ combination with a simple π^0. A sample of 250 such artificial events have thus been produced and used to study the background caused by double π^0 events. It was found that the ρ^+ resonance and the N^{*++} enhancement were practically uncontaminated, while the N^{*+} enhancement observed included events in which two π^0 had been produced. A correction for this contamination can

be applied assuming that the ratio ($N^{*++}\ \pi^0 \longrightarrow p\ \pi^+\pi^0$) to ($N^{*+}\pi^+ \longrightarrow p\ \pi^+\pi^0$) is 9 : 4.

The corrected total cross section for the reaction $\pi^+ p \longrightarrow p\ \pi^+\pi^0$ is found to be 0.58 ± 0.04 mb. The partial cross sections for the two-body reactions $\pi^+ p \longrightarrow N^{*++}\ \pi^0$ and $\pi^+ p \longrightarrow p\ \rho^+$ are 0.11 ± 0.01 and 0.17 ± 0.04 mb, respectively. Therefore, the reaction $\pi^+ + p \longrightarrow p + \pi^+ + \pi^0$ proceeds through two-body channels in about 60 °/o of the cases.

The experimental values of the cross sections for $N^{*++} + \pi^0$ and $p\ \rho^+$ have been compared with the predictions of the absorption model [2] which are 0.72 and 0.14 mb, respectively. Thus good agreement is obtained for the reaction $\pi^+ p \longrightarrow p\ \rho^+$, where pion exchange is assumed, and disagreement is found for the reaction $\pi^+ p \longrightarrow N^{*++}\ \pi^0$, where vector meson exchange is required.

In Fig.2 are presented the differential cross sections $d\sigma/dt$, as a function of the squared four-momentum transfer, for the reaction $\pi^+ p \longrightarrow p\ \rho^+$ and $\pi^+ p \longrightarrow N^*_{3,3}\ \pi$. The results of calculations using the absorption model are also shown. It can be seen that good agreement is obtained for π-meson exchange, but when vector meson exchange is required, the experimental results and the theory disagree.

The $(\pi^+\pi^0)$ effective mass distribution is shown in Fig. 3. Apart from the peak at the rho mass, two peaks are seen near 1600 and 1900 MeV. Since phase space is not applicable to high energy interactions because of their peripheral nature, a background has been drawn by hand in Fig. 3. The enhancements represent $3\frac{1}{2}$ and 5 standard deviations, respectively, relative to this background. Fitting of Breit-Wigner curves plus background in the mass range 1225 to 3025 MeV gives peak values of 1620 ± 20 and 1910 ± 20 MeV and full widths of 80 ± 40 and 90 ± 40 MeV, respectively.

As stated above, cuts in the probability, missing mass and error on the missing mass do not alter the structure observed. The artificial events produced from the reaction $\pi^+ p \longrightarrow p\ \pi^+\pi^+\pi^-$ showed no enhancement in the 1500 - 2000 MeV region.

It can be seen from the Dalitz plot of Fig. 1, that the largest contribution to the 1600 and 1900 MeV peaks come from events lying in the N^{*++} and N^{*+} bands. Since there must be a correlation between the angular distribution of the N^{*} decay and the mass spectrum of the $(\pi^{+}\pi^{o})$ system, it might be asked whether the observed effect is not due to a peculiarity of the N^{*} angular distribution. The histogram of this angular distribution shows markedly less structure than the $(\pi^{+}\pi^{o})$ mass spectrum. Therefore, if the peaks at 1600 and 1900 MeV represent a physical effect, this effect is more likely to be a $(\pi\ \pi)$ interaction than an unusual decomposition of the N^{*}. However, to test whether the observed peaks are only statistical fluctuations of a smooth $(\pi^{+}\pi^{o})$ mass spectrum resulting from a smooth angular distribution of the decay of the N^{*}, the following procedure has been applied. The N^{*} experimental angular distribution for the 207 events lying in the N^{*} bands was fitted by a polynomial of the form $(a + b \cos\theta + c \cos^{2}\theta)$. Assuming this fit, the expected $(\pi^{+}\pi^{o})$ mass distribution was calculated. The result is shown in Fig. 4 as a solid line normalised to the same area as the experimental histogram. The peaks at 1620 and 1910 MeV appear as 2.7 and 3.5 standard deviation effects. This procedure is a very stringent one for the significance of resonances as it is not an independent background calculation but contains some reflection of the existence of the peaks. We must admit therefore that the experimental $(\pi^{+}\pi^{o})$ mass histogram differs significantly from a smooth curve in the region from 1600 to 1900 MeV. Since about 60°/o of the events in the peaks lie in the N^{*} bands, their interpretation as $(\pi\ \pi)$ resonances is more difficult than if there were no possible interference; also, it is not possible at present to study their spin and parity.

An enhancement in the $(\pi^{+}\pi^{-})$ system has been reported by Goldberg et al. [3] at a mass of 1675 ± 30 MeV. The angular distribution is flat outside the forward peak, whereas in the $(\pi^{+}\pi^{o})$ enhancement near 1620 MeV reported here, there are few events outside the forward and backward peaks.

We are deeply indebted to the operating crews of the CERN proton synchrotron, of the 81cm Saclay bubble chamber and of the 02 beam. We would like to thank the scanning, measuring and computing staffs at each of our laboratories. We are pleased to acknowledge helpful discussions with Professor L. Van Hove, Professor Ch. Peyrou and Dr. B.E.Y. Svensson.

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FIGURE CAPTIONS

Fig. 1. Dalitz plot for the reaction $\pi^+ p \longrightarrow p \pi^+ \pi^o$.

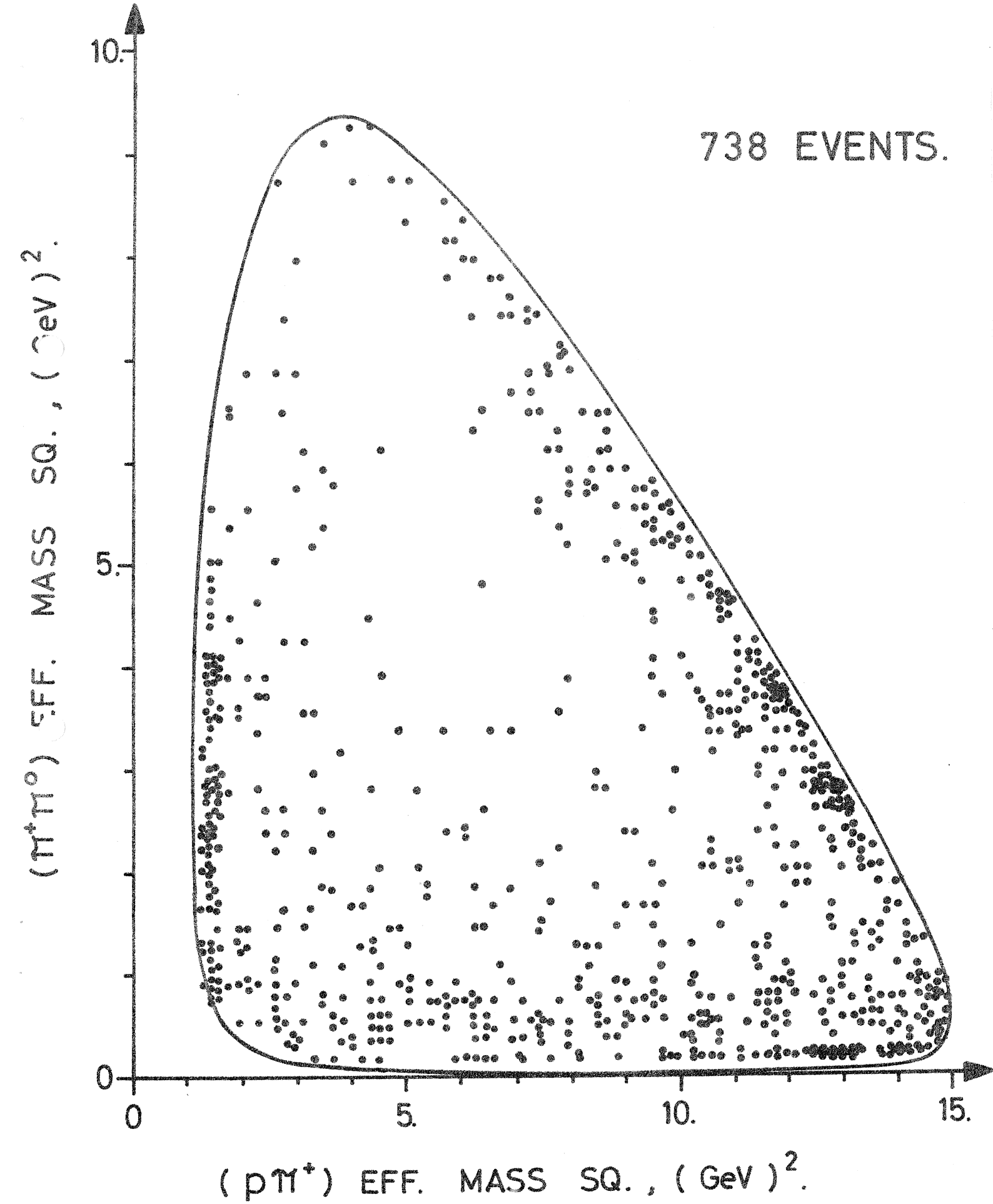
Fig. 2. Distributions of $d\sigma/dt$, plotted on a log scale against $-t$, for the reactions $\pi^+ p \longrightarrow p \rho^+$ and $\pi^+ p \longrightarrow N^* \pi$, where N^* may be N^{*++} or N^{*++}. The curves are calculations using the absorption model[2].

Fig. 3. $(\pi^+ \pi^o)$ effective mass distribution. The curve is drawn by hand to fit the regions outside possible $(\pi^+ \pi^o)$ enhancements.

Fig. 4. $(\pi^+ \pi^o)$ effective mass distribution when $(p \pi^+)$ or $(p \pi^o)$ masses lie in the $N^*_{3,3}$ mass range 1.12 to 1.34 GeV. For explanation of curve, see text.

FIG. 1

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



23323 PS/4931

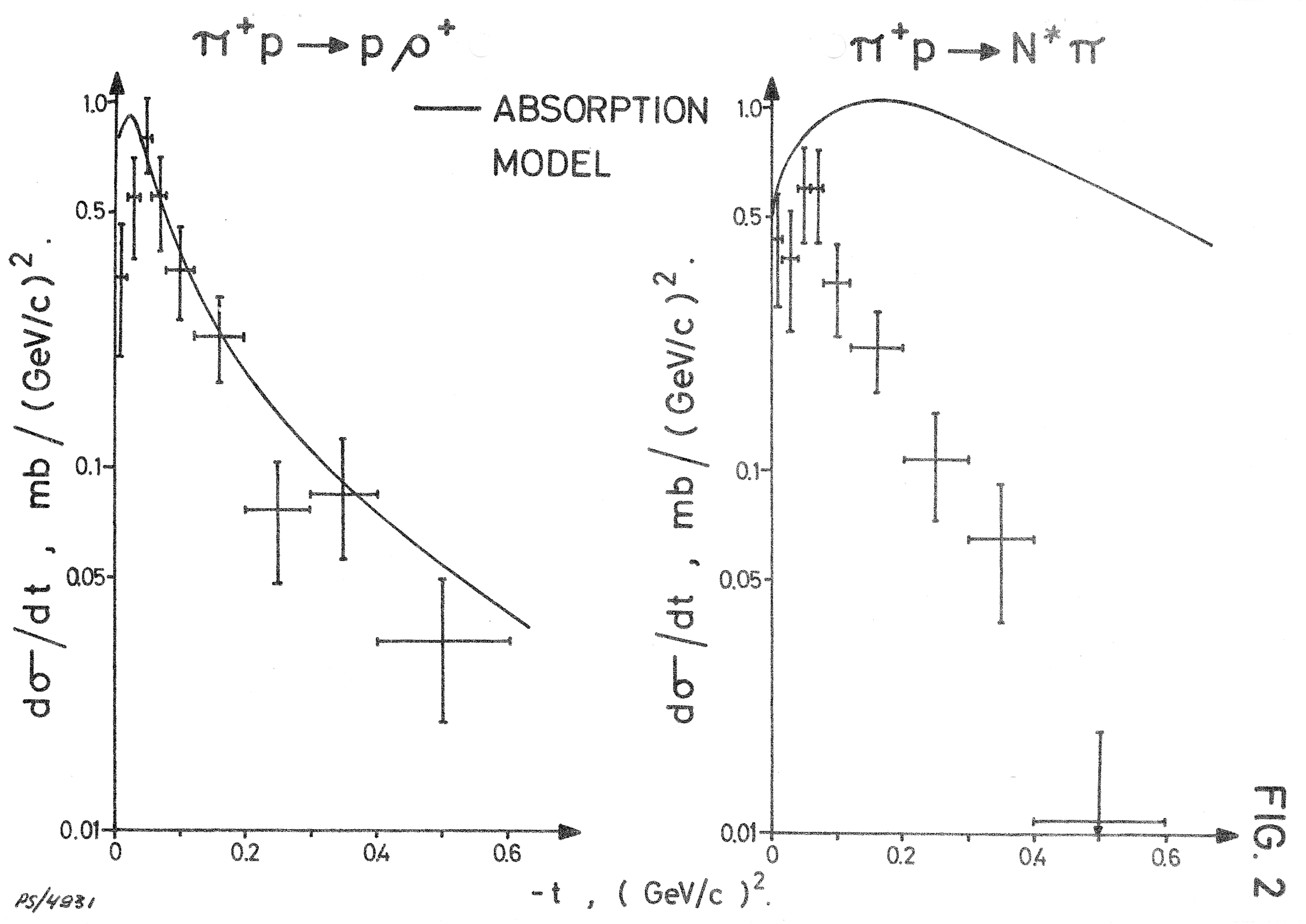

$\pi^+ p \rightarrow p \rho^+$
ABSORPTION MODEL
$d\sigma/dt$, mb / (GeV/c)^2.
1.0
0.5
0.1
0.05
0.01
0
0.2
0.4
0.6
$\pi^+ p \rightarrow N^* \pi$
$d\sigma/dt$, mb / (GeV/c)^2.
1.0
0.5
0.1
0.05
0.01
0
0.2
0.4
0.6
$-t$, (GeV/c)^2.

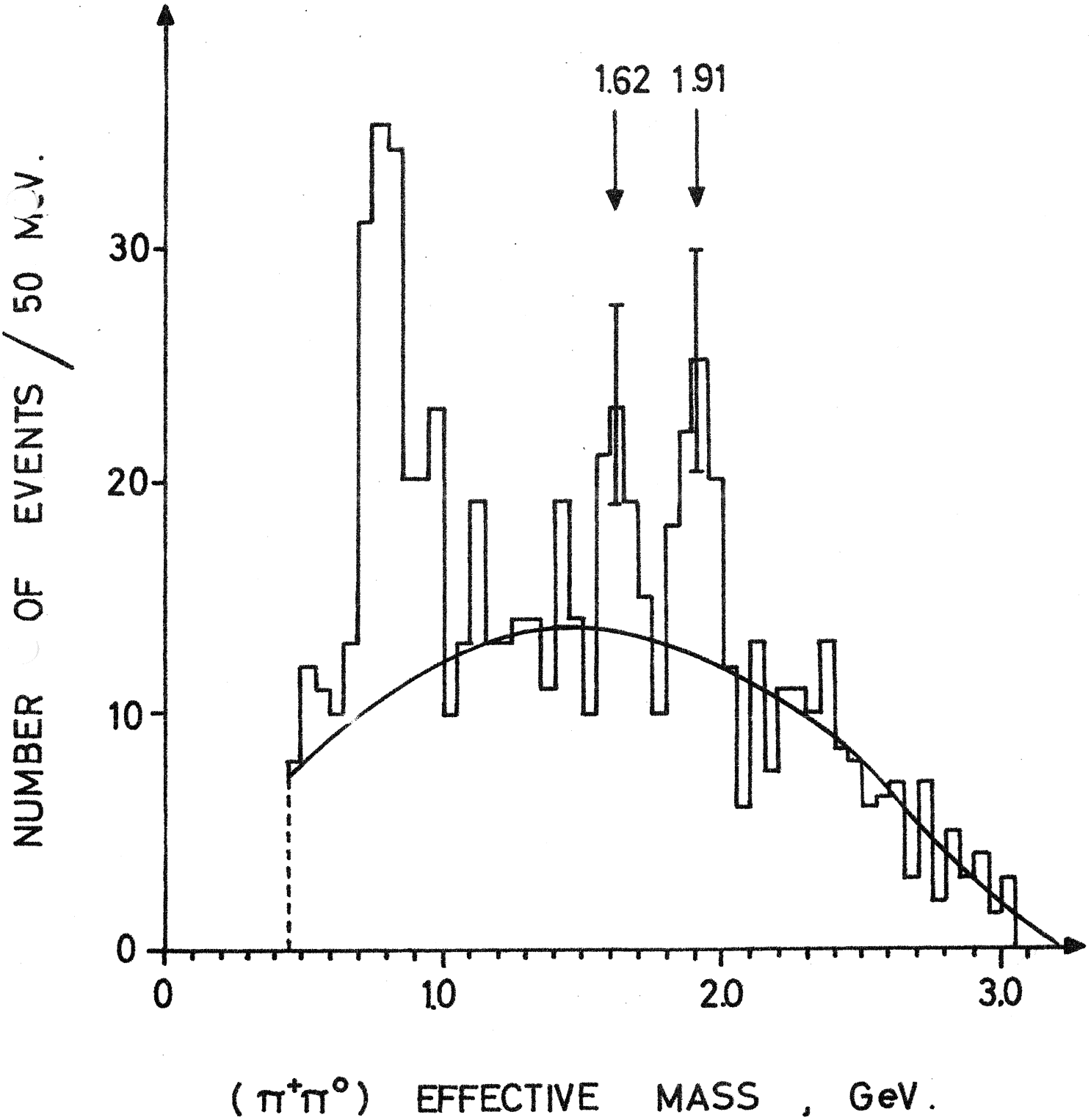
FIG. 2

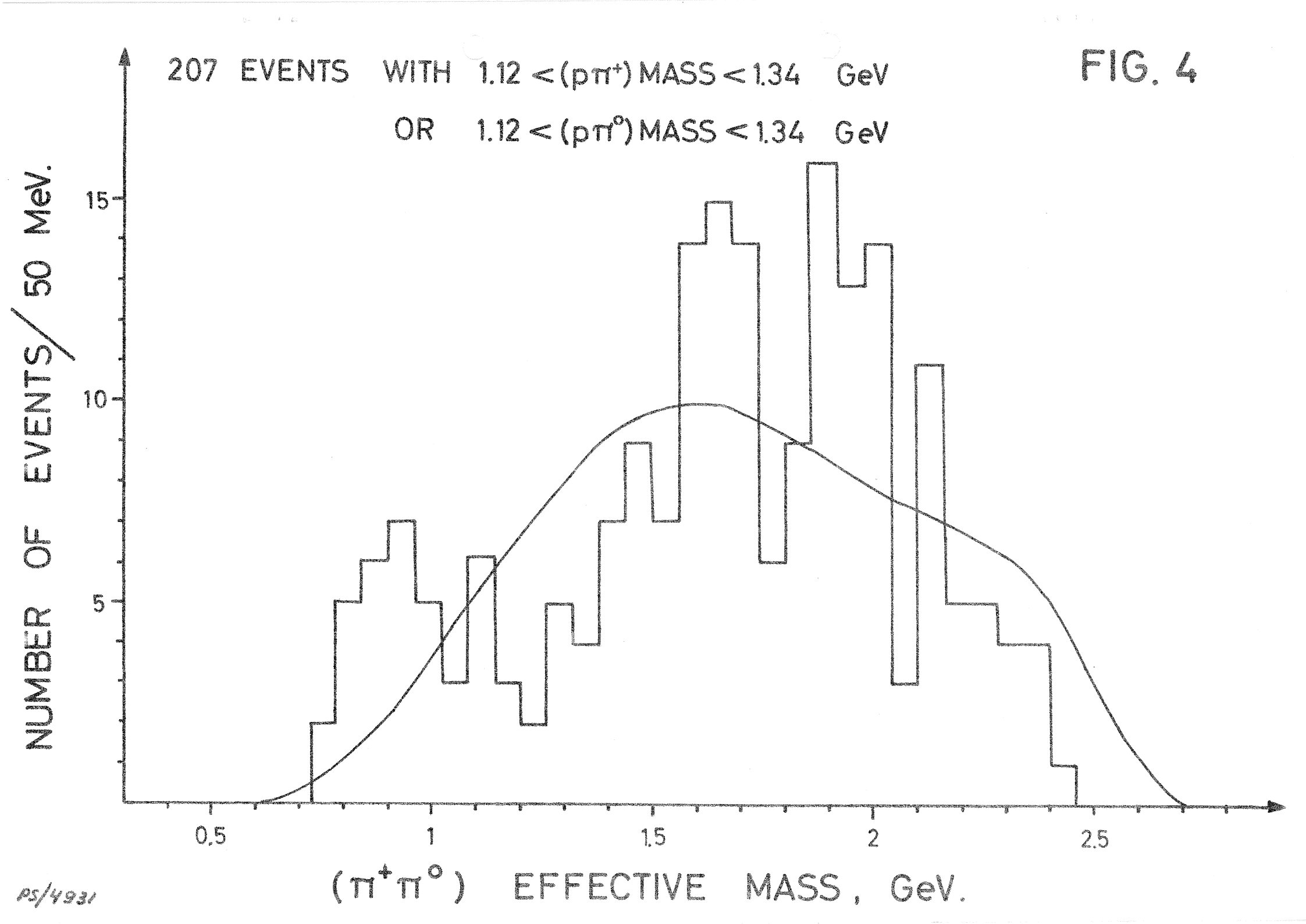
PS/4931

FIG. 3

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

688 EVENTS




207 EVENTS WITH 1.12 < (pπ+) MASS < 1.34 GeV
OR 1.12 < (pπ°) MASS < 1.34 GeV
FIG. 4
NUMBER OF EVENTS / 50 MeV.
15
10
5
0.5
1
1.5
2
2.5
(π+π°) EFFECTIVE MASS, GeV.
PS/4931