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ANNIHILATIONS OF 5.7 GEV/C $\bar{p}$ IN HYDROGEN INTO FOUR CHARGED PIONS

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Four-prong events produced in the 81 cm Saclay hydrogen bubble chamber by a 5.7 GeV/c separated antiproton beam from the CERN proton synchrotron were measured with the CERN HPD system. After a single remeasurement of events which failed on the first pass through the system, 19,093 events (89 % of all attempted) were successfully reconstructed. An analysis of the HPD measurements consisting of a comparison with a sample of events measured in the conventional manner and a study of the events for which measurements did not satisfy the acceptance criteria will be published separately [1]. This study has shown that no significant difference exists between the two methods.

Only 191 events fitted the reaction

$$\bar{p}\,p \longrightarrow \pi^+\pi^+\pi^-\pi^-$$

giving a cross-section of 173 $\pm$ 16 μb. A study of the χ^2, missing mass and missing momentum distributions shows that the background of the other channels is negligible and only a few events could have been lost. The error of the cross-section includes an estimated 5 % uncertainty in separating the 4-pion channel from the total sample.

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The angular distributions of pions in the c.m. system show very strong asymmetry and anisotropy, as one can see in Fig.1. Within the statistical errors they are reflections of each other as is expected from C conservation. After reflecting the π^+ distribution and summing it up with the π^- distribution, we calculated 2 ratios: the forward to backward $F/B = 1.33 \pm 0.10$ and the polar to equatorial $P/E = 2.33 \pm 0.18$. The forward excess corresponds to 0.56 pions per event. The backward peak (i.e. for example for π^- a peak in the direction of a target proton) was already observed by Baltay et al.[2] at 3.25 GeV/c. Their F/B ratio is 1.29 ± 0.16 and that of P/E 1.95 ± 0.22. It should be noted that neutral $\pi^+\pi^-$ resonances which are produced with strong collimation, as will be shown later, contribute equally to the peaking in both the forward and the backward directions.

The influence of Bose-Einstein statistics seems to play a negligible role in the interactions under study as there is no difference between the distributions of c.m. opening angle for like ($\pi^\pm\pi^\pm$) and unlike ($\pi^+\pi^-$) pairs. The ratio of the number of pairs having this angle larger than 90° to the number of pairs having it smaller than 90° is equal to 2.27 ± 0.17 for like pairs and 2.14 ± 0.17 for unlike pairs in agreement with the ordinary phase space prediction, which is 2.2 [3].

The two-pion mass ditributions are shown in Fig.2. The $\pi^+\pi^-$ mass distribution (2a) exhibits two peaks at 770 MeV and 1240 MeV which we attribute to ρ^o and f^o meson production. Fitting this distribution, using a least squares method, with a curve which is the sum of a phase space curve and two Breit-Wigner curves together with appropriate phase spaces for pion pairs in which both or only one of the pions in the pair were not in the resonant combination, we obtained the following parameters: masses $M_{\rho^o} = 768 \pm 14$ MeV, $M_{f^o} = 1240 \pm 20$ MeV, widths $\Gamma_{\rho^o} = 72 \pm 30$ MeV, $\Gamma_{f^o} = 102 \pm 46$ MeV and frequencies of resonance production $f_{\rho^o} = 0.24 \pm 0.07$, $f_{f^o} = 0.25 \pm 0.07$. When compared with the data from the same reaction at 3.25 GeV/c [2], we notice that the percentage of ρ^o events has not changed, while the absolute cross-section for $4\pi^\pm$ annihilations has decreased by a factor of 4.

In the same histogram (2a), we notice a third bump around 1550 MeV. If we look at the mass distribution of the doubly charged combinations (Fig.2b) we notice a bump of 2.9 standard deviations above phase space in a mass region corresponding to that of the bump at 1550 MeV in the $\pi^+\pi^-$ mass histogram. Adding these two histograms in Fig.2c (which one can do if one is looking for an object with isospin I = 2), we obtain 3.4 standard deviations from the phase space curve which includes reflection of ρ^0 (24 %) and f^0 (25 %) production. In terms of number of events we observe, in the mass interval 1.45 - 1.64 GeV, 152 events whereas the expected number is 116 events. When we try to fit the $\pi^+\pi^-$ distribution including a third Breit-Wigner curve to account for the bump, we obtain for the ρ^0 a larger width (138 MeV) and a higher frequency of about 40%. The curve gives then a better fit in the region between the ρ^0 and the f^0 peaks. We think it is justified to neglect the Bose-symmetrization effect in the mass distributions because of the similarity of the angular distributions of the opening angle for like and unlike pairs, which has been discussed previously. This is especially true for the combined $\pi\,\pi$ mass distribution where possible small deviations present in the $\pi^\pm\pi^\pm$ and $\pi^+\pi^-$ mass spectra should cancel.

If a resonance with I = 2 corresponding to the bump exists, it would have a mass M = 1540 $\pm$ 30 MeV, and a width Γ = 156 $\pm$ 80 MeV. We find, however, no supporting evidence in our data from a comparison of production and decay angles for the peak region and the adjacent regions of $\pi\,\pi$ spectra. The only other explanation for this bump which we could find is the possibility of a statistical fluctuation.

A search for associated production of ρ^0 and f^0 mesons gave a negative result. The upper limit for any of the following 2-body reactions:

$$\bar{p}\,p \longrightarrow \rho^0\rho^0,\ f^0f^0,\ \rho^0f^0$$

is 15 μb with a confidence level of 95%.

The 3π mass distribution follows closely the phase space curve. The upper limits for

$$\bar{p}\,p \longrightarrow \pi^\pm A_1^\mp \quad \text{and} \quad \bar{p}\,p \longrightarrow \pi^\pm A_2^\mp$$

are equal to 5 μb, again with a 95% confidence level.

Therefore, when neglecting possible small contributions from the 2-body processes, we find that single ρ^o and single f^o production contribute as genuine 3-body reactions to about 50% of the cross-section for the analysed channel :

$$\bar{p}\,p \longrightarrow \rho^o\pi^+\pi^- \qquad \sigma = 42 \pm 13\ \mu b$$
$$\bar{p}\,p \longrightarrow f^o\pi^+\pi^- \qquad \sigma = 43 \pm 12\ \mu b,$$

where we use the results of the fit with two Breit-Wigner curves. The ρ^o's and f^o's are produced in these reactions strongly collimated in the forward-backward directions, as is shown in Fig.3. The peak region has been defined to be between 650 - 850 MeV for the ρ^o and 1100 - 1300 MeV for the f^o. Background events have been subtracted using $\pi^+\pi^-$ combinations in adjacent regions and the resulting distributions folded. It should be noted that the non-resonant $\pi^+\pi^-$ pairs are also rather collimated although not as strongly as ρ's and f's.

Another way of looking at the forward-backward collimation of ρ^o and f^o mesons is a Chew-Low plot presented in Fig.4. For each $\pi^+\pi^-$ mass combination (there are 4 x 191 of them) the four-momentum transfers to beam antiproton and target proton were plotted. One sees two groups of points having small t-values and $\pi^+\pi^-$ masses corresponding to the ρ^o and f^o mesons.

In Fig.5 we have plotted the absolute values of the cosine of the angle between the π^+ coming from ρ^o decay and the normal to the ρ^o production plane in the rest frame of the ρ^o meson. This distribution is significantly different from the background and shows that ρ^o mesons are produced with their spin lying preferentially in the production plane. From this distribution we have determined the spin density matrix element $\rho_{oo} = 0.67 \pm 0.25$, which is equal to the probability of having a spin projection equal to zero, where the quantization axis is along the normal. On the other hand the decay distribution of π^- mesons relative to the incident antiproton momentum (for ρ^o's emitted forwards) and the one of π^+ mesons relative to the target proton momentum (for ρ^o's emitted backwards) calculated in the ρ^o rest frame is not only symmetric but also consistent with isotropy.

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(see also A. Accensi, V. Alles-Borelli, B. French, Å. Frisk, J.M. Howie, L. Michejda, W.G. Moorhead, B.W. Powell, P. Villemoes, to be published in the Proceedings of the Conference on Programming for Flying Spot Devices at Columbia University, October 1965)

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FIGURE CAPTIONS :

Fig. 1. Angular distribution of negative and positive pions in the centre of mass system.

Fig. 2. Mass distributions of $\pi\ \pi$ systems

a) $\pi^+\pi^-$ mass distribution. The curve is the best fit to the data of the following form: phase space + two Breit-Wigner curves for ρ^0 and f^0 + their reflections normalized to the total number of $\pi^+\pi^-$ pairs.

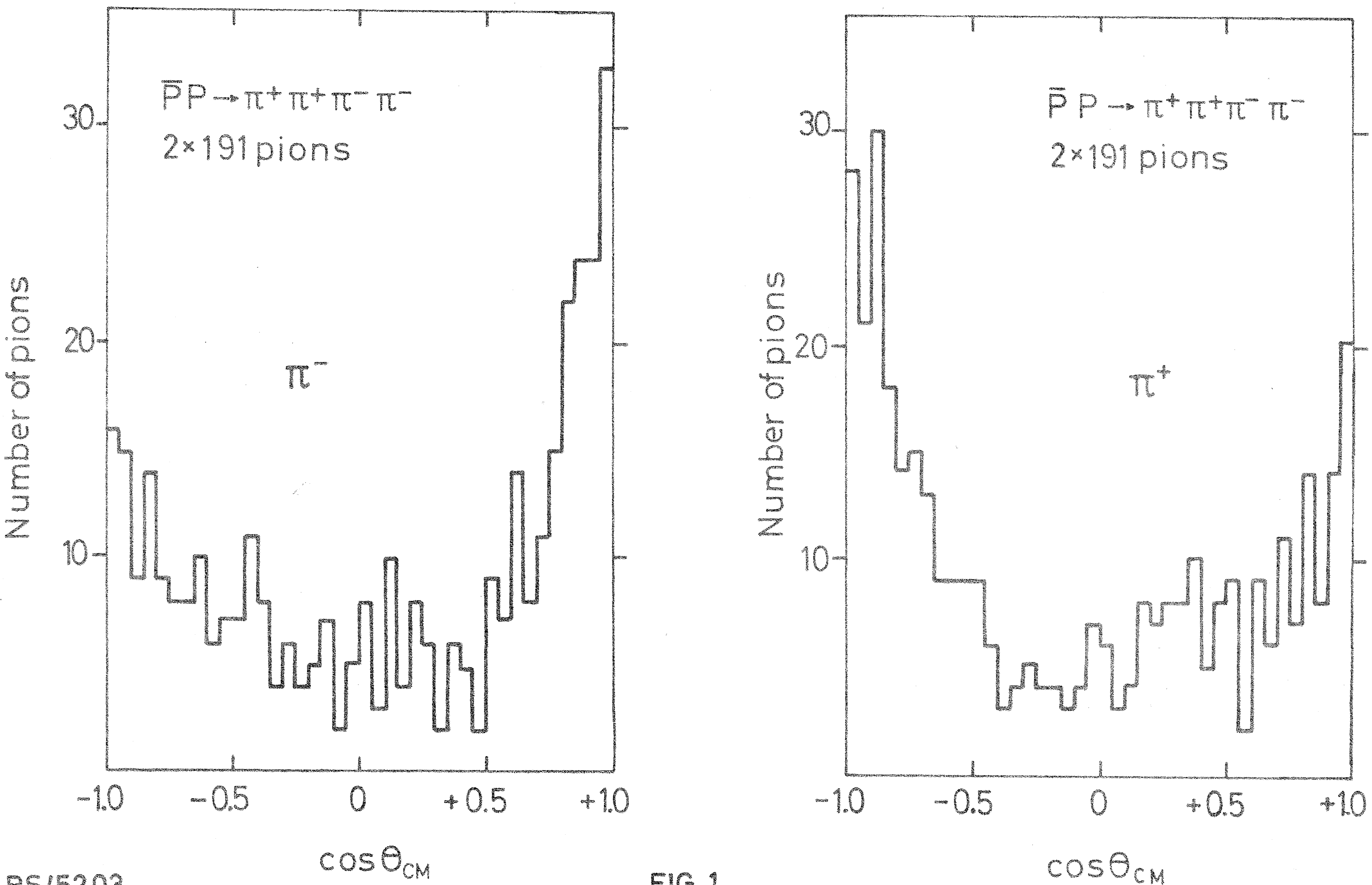
b) $\pi^+\pi^+$ and $\pi^-\pi^-$ mass distribution. The curve is a phase space curve normalized to all events.

c) Mass spectrum of all $\pi\ \pi$ pairs compared with a curve which is the sum of the curves shown in Figs. 2 a) and b).

Fig. 3. Folded production angular distributions of f^0 and ρ^0 in the centre of mass system. Dashed right-hand parts are reflections relative to the $\cos\theta = 0$ axis.

Fig. 4. Chew-Low plot of the $\pi^+\pi^-$ combinations.

Fig. 5. Distribution of the absolute values of the cosine of the angle between the π^+ coming from ρ^0-decay and the normal to the production plane in the rest frame of the ρ^0-meson.



$\bar{P}P \rightarrow \pi^+\pi^+\pi^-\pi^-$
2×191 pions
π^-
Number of pions
30
20
10
-1.0
-0.5
0
+0.5
+1.0
$\cos\Theta_{CM}$
$\bar{P}P \rightarrow \pi^+\pi^+\pi^-\pi^-$
2×191 pions
π^+
Number of pions
30
20
10
-1.0
-0.5
0
+0.5
+1.0
$\cos\Theta_{CM}$

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FIG. 1.

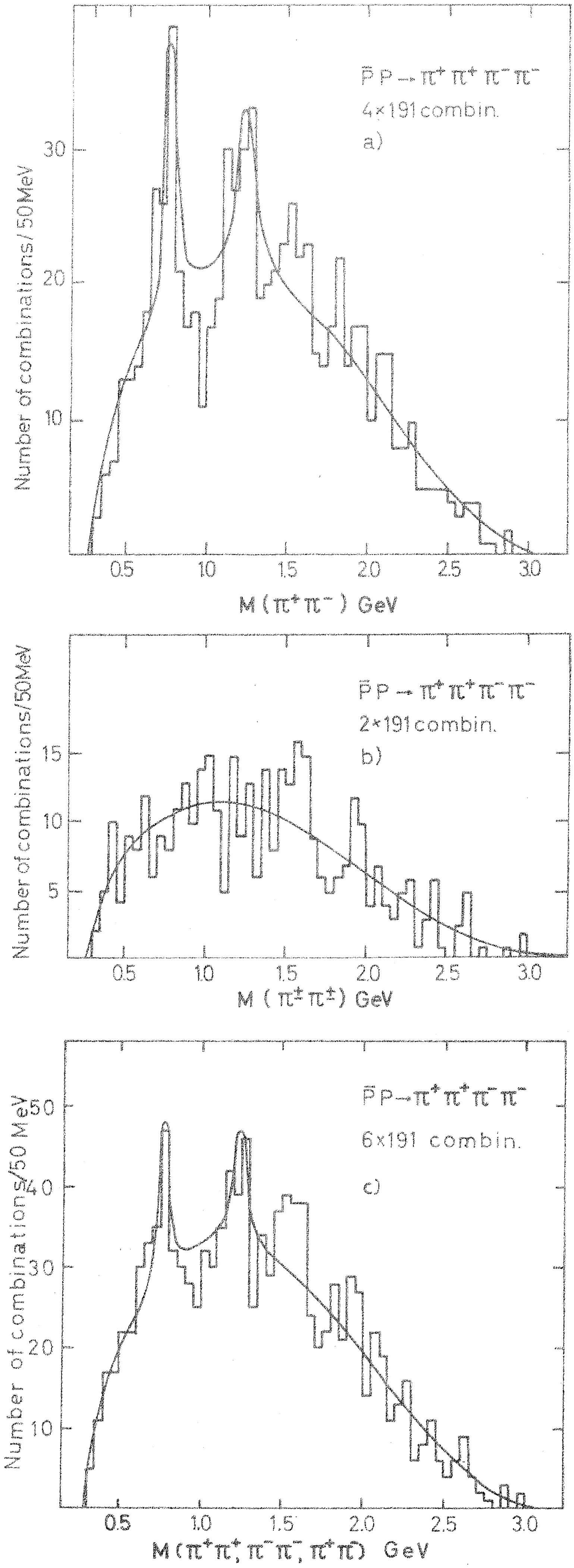
$\bar{p}p \to \pi^+\pi^+\pi^-\pi^-$
4×191 combin.
a)
Number of combinations / 50 MeV
$M(\pi^+\pi^-)$ GeV
$\bar{p}p \to \pi^+\pi^+\pi^-\pi^-$
2×191 combin.
b)
Number of combinations/50MeV
$M(\pi^\pm\pi^\pm)$ GeV
$\bar{p}p \to \pi^+\pi^+\pi^-\pi^-$
6×191 combin.
c)
Number of combinations/50 MeV
$M(\pi^+\pi^+, \pi^-\pi^-, \pi^+\pi^-)$ GeV

FIG. 2.

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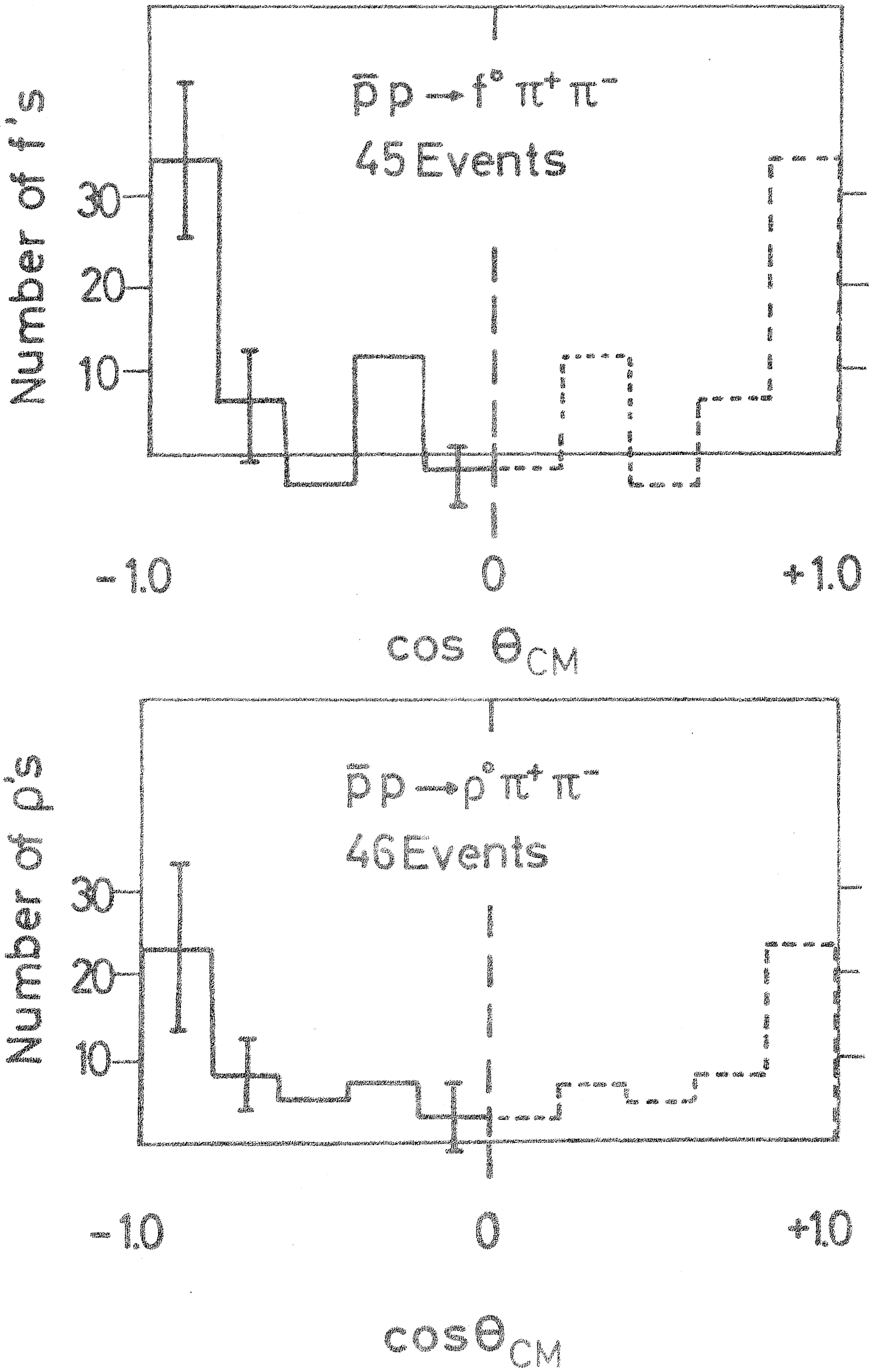
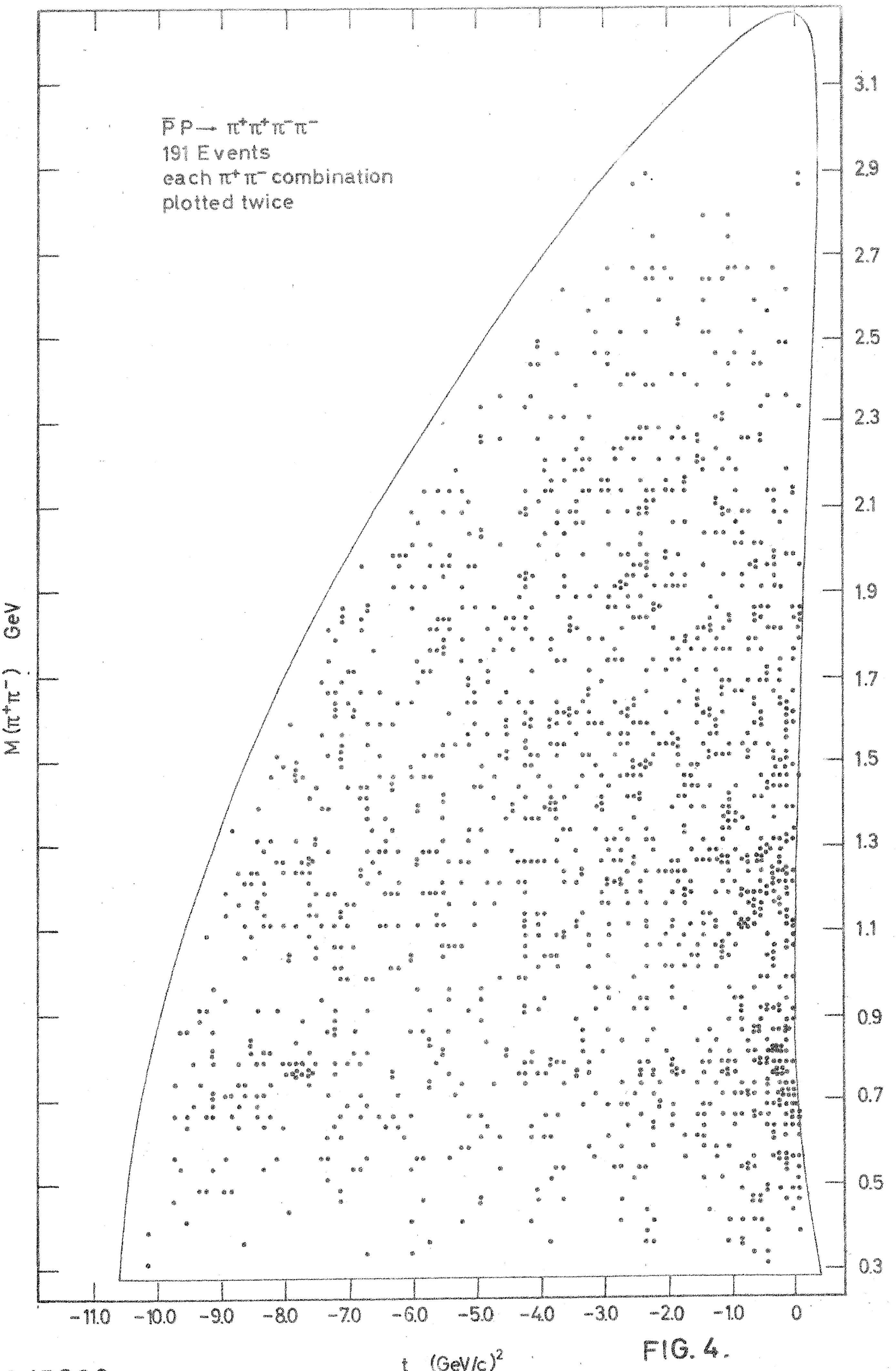


$\bar{p}p \to f^0 \pi^+ \pi^-$
45 Events
Number of f's
30
20
10
-1.0
0
+1.0
$\cos \Theta_{CM}$
$\bar{p}p \to \rho^0 \pi^+ \pi^-$
46 Events
Number of ρ's
30
20
10
-1.0
0
+1.0
$\cos \Theta_{CM}$

FIG. 3.

PS/5203



$\bar{P}P \rightarrow \pi^+\pi^+\pi^-\pi^-$
191 Events
each $\pi^+\pi^-$ combination
plotted twice
$M(\pi^+\pi^-)$ GeV
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0.3
-11.0 -10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -1.0 0
t $(GeV/c)^2$

FIG. 4.

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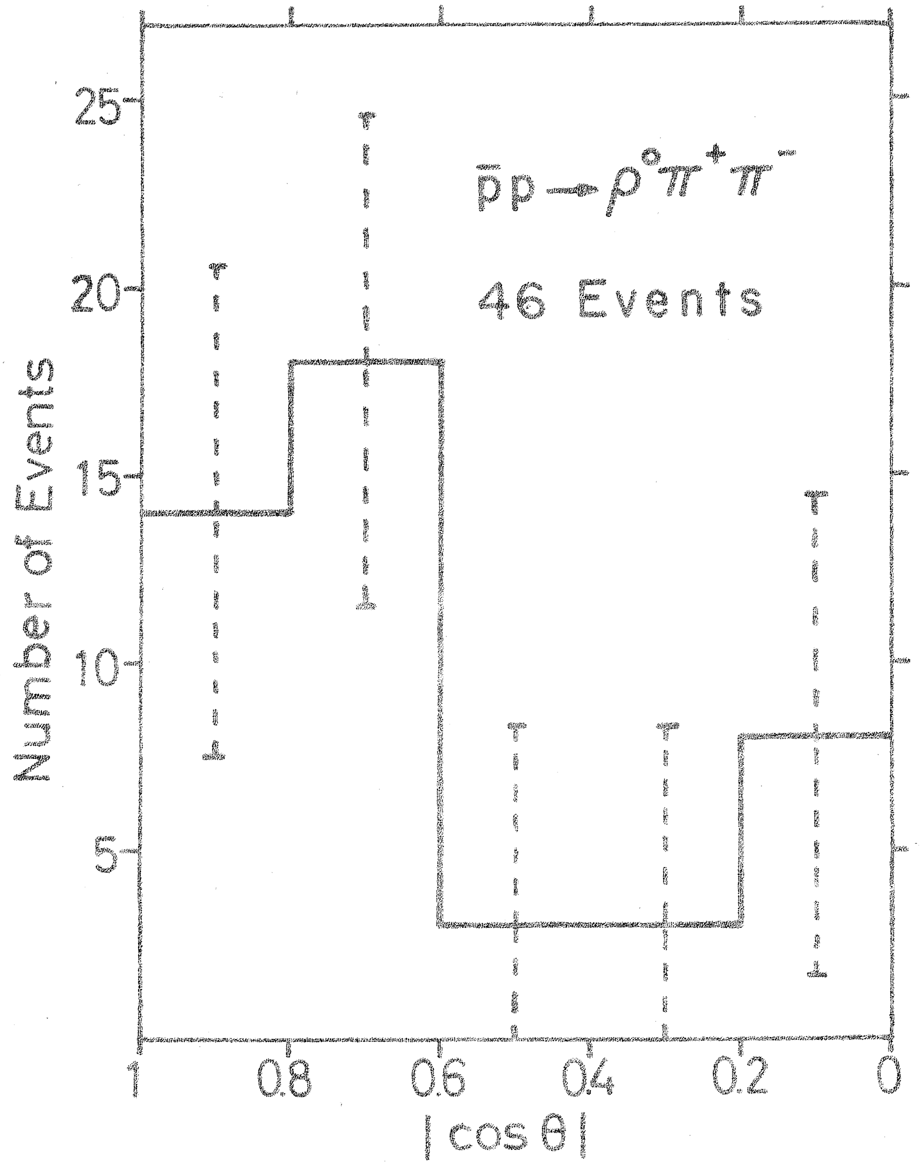
25
20
15
10
5
Number of Events
p̄p → ρ°π⁺π⁻
46 Events
1
0.8
0.6
0.4
0.2
0
|cos θ|

FIG. 5.

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