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Abstract

Six prong events produced in $\pi^+ p$ interactions at 4 GeV/c have been analysed. The cross sections for the various reactions and for the production of resonances are given. Resonance production is found to be rather strong. The only quasi-two body process clearly identified is $\pi^+ p \longrightarrow N^{*++} X^o$. Simultaneous production of N^{*++} and ρ^o, N^{*++} and ω, and of η and ρ^o is also observed. The $\pi^+\pi^-$ mass distribution in reaction $\pi^+ p \longrightarrow p\pi^+\pi^+\pi^+\pi^-\pi^-$ shows a peak of about 4 standard deviations above background at 670 MeV with a full width at half-maximum of about 60 MeV.

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1. Introduction

Interactions of 4 GeV/c π^+ mesons with protons have been studied in the Saclay 81 cm hydrogen bubble chamber at CERN. Results on two- and four prong events[1] and on events with strange particles[2] have already been published. This paper completes the study by giving results for events with six outgoing charged particles.

2. Cross sections

In table I the cross sections are given for the various reactions. These values were determined in the same way as described in ref.1.

Table I: Cross sections

reaction $\pi^+ p \longrightarrow$	number of events	cross section (μb)
(1) $p\pi^+\pi^+\pi^+\pi^-\pi^-$	176	249 ± 36
(2) $p\pi^+\pi^+\pi^+\pi^-\pi^-\pi^o$	179	253 ± 36
(3) $n\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-$	28	40 ± 9
(4) $p\pi^+\pi^+\pi^+\pi^-\pi^-(m\pi^o)$ $m \geqslant 2$	55	78 ± 14
(5) $n\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-(m\pi^o)$ $m \geqslant 1$	14	20 ± 6
total	451	640 ± 83

The reactions (1) and (2) are dominated by the production of resonances as is found in a similar study with 5 GeV/c π^+ mesons[3]. In the following we study the resonance production in these reactions and give an attempt to separate the various channels which contribute. When studying the production of resonances in six prong events one has to keep in mind the large background which is frequently present because of the large number of possible particle combinations. As an example the ρ^o production in reaction (1) is seen only as a small enhancement in the

$\pi^+\pi^-$ effective mass distribution, although this enhancement is compatible with the assumption that in about 40% of all events a ρ^o is produced (fig.1b).

3. Resonance production in reaction (1)

The $p\pi^+$ effective mass distribution shows strong $N^{*++}(1238)$ production as can be seen from fig.1a. The curve labeled P.S. gives the prediction of pure phase space. The amount of N^{*++} production was estimated by fitting the $p\pi^+$ mass distribution by a sum of phase space distributions for the final states $p\pi^+\pi^+\pi^-\pi^-$ and $N^{*++}\pi^+\pi^+\pi^-\pi^-$, the latter being weighted by a Breit-Wigner distribution for the N^* decay. The result of the fit is also shown in fig.1a. According to the fit the fraction of N^{*++} production of reaction (1) amounts to 82 ± 10% corresponding to a cross section of 204 ± 39 μb.

Fig.1b shows the effective mass distribution for the $\pi^+\pi^-$ system. A statistically significant and narrow peak is observed at about 670 MeV. This peak is not a kinematical effect due to the strong N^{*++} production. This can be seen from the shaded histogram of fig.1b where only those $\pi^+\pi^-$ masses are shown for which the same π^+ together with the proton gives a $p\pi^+$ mass outside the N^* region. The peak persits in this distribution. Further study of this peak is difficult because of the large background. It could be connected with the conjectures J = o, T = o $\pi\pi$ resonance (ϵ meson)[4]. Above 700 MeV there is a shoulder which we attribute to the production of ρ^o mesons.

4. Resonance production in reaction (2)

Reaction (2) is rather involved. The figs.2a,2b and 3a show the effective mass distributions of the combinations $p\pi^+$, $\pi^+\pi^-\pi^o$ and $\pi^+\pi^+\pi^-\pi^-\pi^o$ respectively. The curves labeled P.S. give the prediction of pure phase space. Strong production of N^{*++} (fig.2a) and ω (fig.2b) is observed as well as the η meson (fig.2b) and the X^o meson (fig.3a).

4.1 X^o production

The most clean channel is that of X^o production. We checked that all 9 $\pi^+\pi^+\pi^-\pi^-\pi^o$ mass combinations in the X^o region belong indeed to different events. Each of the $\pi^+\pi^+\pi^-\pi^-\pi^o$ combinations in the X^o region has at least one $\pi^+\pi^-\pi^o$ combination in the η region in agreement with the dominant decay mode $X^o \rightarrow \pi\pi\eta$. Fig.3b shows a scatter diagram of $M_{p\pi_a^+}$ versus $M_{\pi_b^+\pi_c^+\pi^-\pi^-\pi^o}$. Six of the nine $\pi^+\pi^+\pi^-\pi^-\pi^o$ combinations in the X^o region are associated with a $p\pi^+$ combination in the N^* region. We therefore attribute these events to the channel $\pi^+p \rightarrow N^{*++}X^o$. This channel is strongly peripheral since the cosine of the X^o production angle in the cm. system is larger than 0.8 for all events. Similar investigations of the X^o were recently described in ref.3 and in a paper of Trilling et al[5] where also references to earlier work on the X^o can be found.

4.2 N^{*++} and ω production

The production of N^{*++} and ω is the predominant feature of reaction (2)(fig.2). The amount of N^{*++} and ω production was determined by fitting the $p\pi^+$ and $\pi^+\pi^-\pi^o$ mass distributions simultaneously by a sum of phase space distributions for the final states $N^{*++}\omega\pi^+\pi^-$, $N^{*++}\pi^+\pi^+\pi^-\pi^-\pi^o$, $p\,\pi^+\pi^+\pi^-$ and $p\pi^+\pi^+\pi^+\pi^-\pi^-\pi^o$. The N^{*++} channels have been weighted by a Breit-Wigner distribution for the N^*, and those with an ω meson by the appropriate Gaussian distribution. The combinations in the η peak were excluded from the fit. The result of the fit is given in table II and is also shown by the curves in figs.2a and 2b. As can be seen from table II N^{*++} and ω are produced to a large extent via $\pi^+p \rightarrow N^{*++}\omega\pi^+\pi^-$.

The events with a $p\pi_a^+$ combination in the N^* region and a $\pi_b^+\pi_b^-\pi^o$ combination in the ω region were investigated further: Fig.4 shows the distribution of $M_{p\pi_a^+\pi_a^-}$ for these events. For comparison the prediction of the fit described above is shown by the curve. A prominent peak is observed around 1470 MeV. Evidence for a higher nucleon isobar at about the same mass

value has been reported by various authors[6]. We might interpret this peak as being due to the inelastic decay of this isobar. Within our statistics we cannot determine whether the decay proceeds via $N^{*++}\pi^-$ or directly via $p\pi^+\pi^-$, as the $N\pi$ mass of a $N\pi\pi$ system of 1470 MeV is kinematically constrained to lie in the N^* region. The peak could also be due to a displacement of the phasespace distribution due to the peripheral production of N^{*++}.

4.3 η production

In order to study the production of η mesons (not coming from X^o decay) we have removed all events from the sample which had a $\pi^+\pi^+\pi^-\pi^-\pi^o$ combination in the X^o region. This should not lead to a loss of η events, since the X^o is observed practically without background (fig.3a). We are left with about 20 events having a $\pi^+\pi^-\pi^o$ mass in the η region (background subtracted). Fig.5 shows further details of the η production. If the mass of a $\pi^+\pi^-$ combination is constrained to lie in the ρ region one observes a pronounced η peak in the invariant mass distribution of the remaining two $\pi^+\pi^-\pi^o$ combinations. This peak contains practically all η events (fig.5a). Similarly, if a $\pi^+\pi^-\pi^o$ combination is constrained to lie in the η region, the remaining two $\pi^+\pi^-$ combinations show a bump at the ρ mass (fig.5b). No such bump is observed if the $\pi^+\pi^-\pi^o$ mass is constrained to lie in a control region adjacent to the η region (fig.5c). Thus our data suggest that η and ρ^o in reaction (2) are produced simultaneously via $\pi^+p \rightarrow p\pi^+\eta\rho^o$. The $p\pi^+$ mass distribution for this channel peaks at the N^* mass. However, as phase space predicts also a maximum in this region it was not possible to determine the amount of N^* production in this channel.

Table II gives the number of events in the various resonance channels of reaction (2) and the corresponding cross section. In these cross sections the neutral decay modes of η, ω and X^o are included[7].

Table II: Partial cross sections for reaction (2)

	number of events	fraction of reaction (2)	cross section (μb) (corr. for neutral decay[7])
N^{*++}, total	141	78 ± 9	197 ± 35
ω total	111	62 ± 4	178 ± 26
$N^{*++}\omega\pi^+\pi^-$	94	52 ± 9	150 ± 33
$N^{*++}\pi^+\pi^+\pi^-\pi^-\pi^o$	41	23 ± 4	58 ± 13
$p\omega\pi^+\pi^+\pi^-$	17	10 ± 10	28 ± 28
$p\pi^+\pi^+\pi^+\pi^-\pi^-\pi^o$	-	0 ± 5	0 ± 13
η total (without X^o)	19	11 ± 3	106 ± 35
N^{*++} X^o	6	3.4 ± 1.4	71 ± 32
$p\pi^+$ X^o	3	1.7 ± 1	35 ± 20

5. Acknowledgments

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$$\frac{\eta \longrightarrow \pi^+\pi^-\pi^0}{\text{all } \eta \text{ decays}} = (25 \pm 1.6)\% \qquad \frac{\omega \longrightarrow \pi^+\pi^-\pi^0}{\text{all } \omega \text{ decays}} = 88\ \%$$

$$\frac{X^0 \longrightarrow \pi^+\pi^+\pi^-\pi^-\pi^0}{\text{all } X^0 \text{ decays}} = (12 \pm 2)\ \%$$

Captions to figures

Fig. 1 Effective mass distributions of (a) $p\pi^+$ and (b) $\pi^+\pi^-$ for reaction $\pi^+p \longrightarrow p\pi^+\pi^+\pi^+\pi^-\pi^-$. The curves labeled P.S. give the normalized prediction of pure phase space. The curve labeled FIT in fig.1a is the result of the fit (see text). The shaded histogram in fig.1b is obtained from those $\pi^+\pi^-$ mass combinations for which the π^+ together with the proton has a mass outside the $N^*(1238)$ region.

Fig. 2 Effective mass distributions for reactior $\pi^+p \longrightarrow p\pi^+\pi^+\pi^+\pi^-\pi^-\pi^o$. The curves labeled P.S. give the normalized prediction of pure phase space. The curves labeled FIT show the result of the fit (see text).

Fig. 3 $\pi^+\pi^+\pi^-\pi^-\pi^o$ effective mass distribution (a) and scatter diagram of $M_{p\pi_a^+}$ versus $M_{\pi_b^+\pi_c^+\pi^-\pi^-\pi^o}$ (b) for reaction $\pi^+p \longrightarrow p\pi^+\pi^+\pi^+\pi^-\pi^-\pi^o$.
The prediction of pure phase space is shown by the curve labeled P.S.

Fig. 4 Effective mass distribution of $p\pi_a^+\pi_a^-$ for reaction $\pi^+p \longrightarrow p\pi^+\pi^+\pi^+\pi^-\pi^-\pi^o$ with $M_{p\pi_a^+}$ in the $N^*(1238)$ region and $M_{\pi_b^+\pi_b^-\pi^o}$ in the ω region. The curve shows the prediction of the fit (see text).

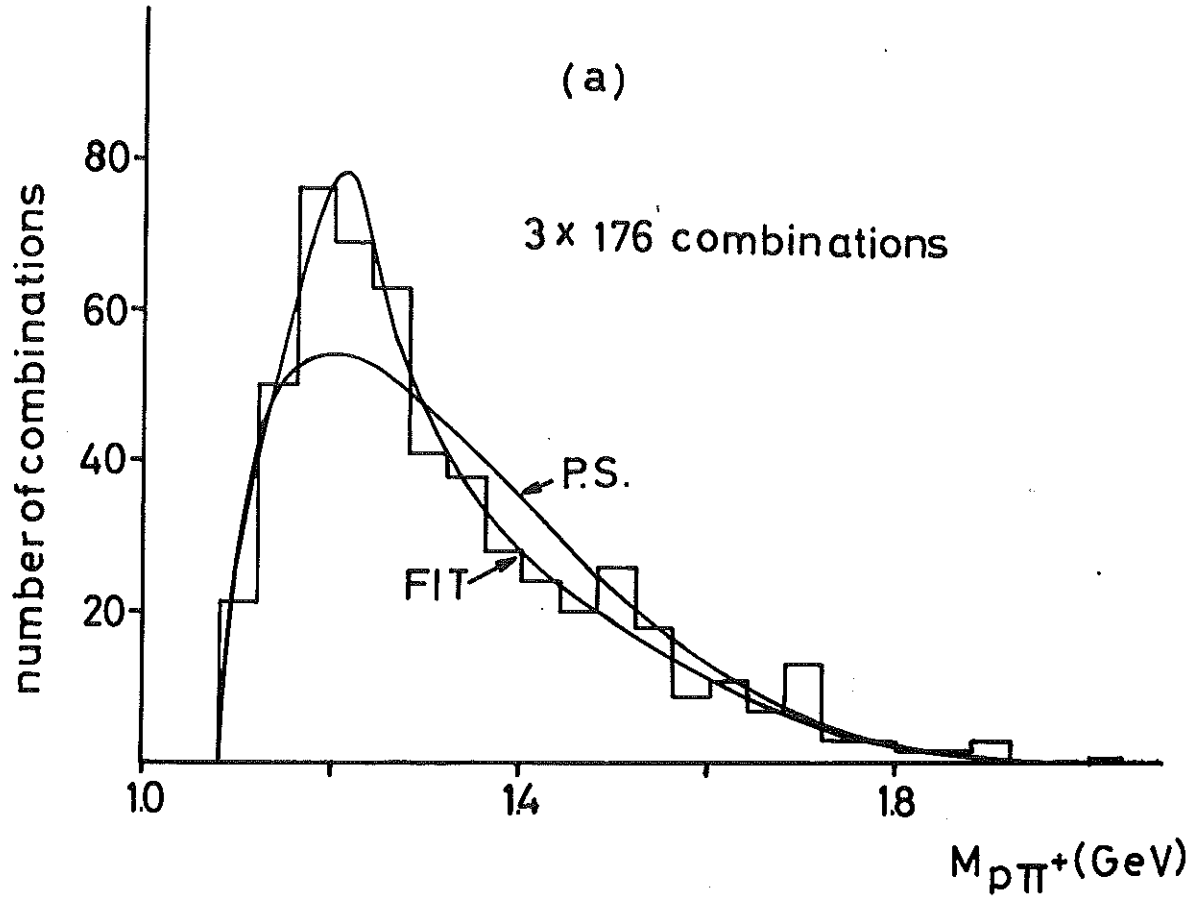
Fig. 5 Effective mass distributions for reaction $\pi^+p \longrightarrow p\pi^+\pi^+\pi^+\pi^-\pi^-\pi^o$.

a) $M_{\pi_a^+\pi_a^-\pi^o}$ and $M_{\pi_b^+\pi_a^-\pi^o}$ for events with $M_{\pi_c^+\pi_b^-}$ in the ρ region

b) $M_{\pi_b^+\pi_b^-}$ and $M_{\pi_c^+\pi_b^-}$ for events with $M_{\pi_a^+\pi_a^-\pi^o}$ in the η region

c) $M_{\pi_b^+\pi_b^-}$ and $M_{\pi_c^+\pi_b^-}$ for events with $M_{\pi_a^+\pi_a^-\pi^o}$ in a control region adjacent to the η region.

The solid histograms are obtained after removal of the X^o events.
The curves show the prediction of the fit (see text).


(a)
3 x 176 combinations
P.S.
FIT
number of combinations
80
60
40
20
1.0
1.4
1.8
M pπ+ (GeV)

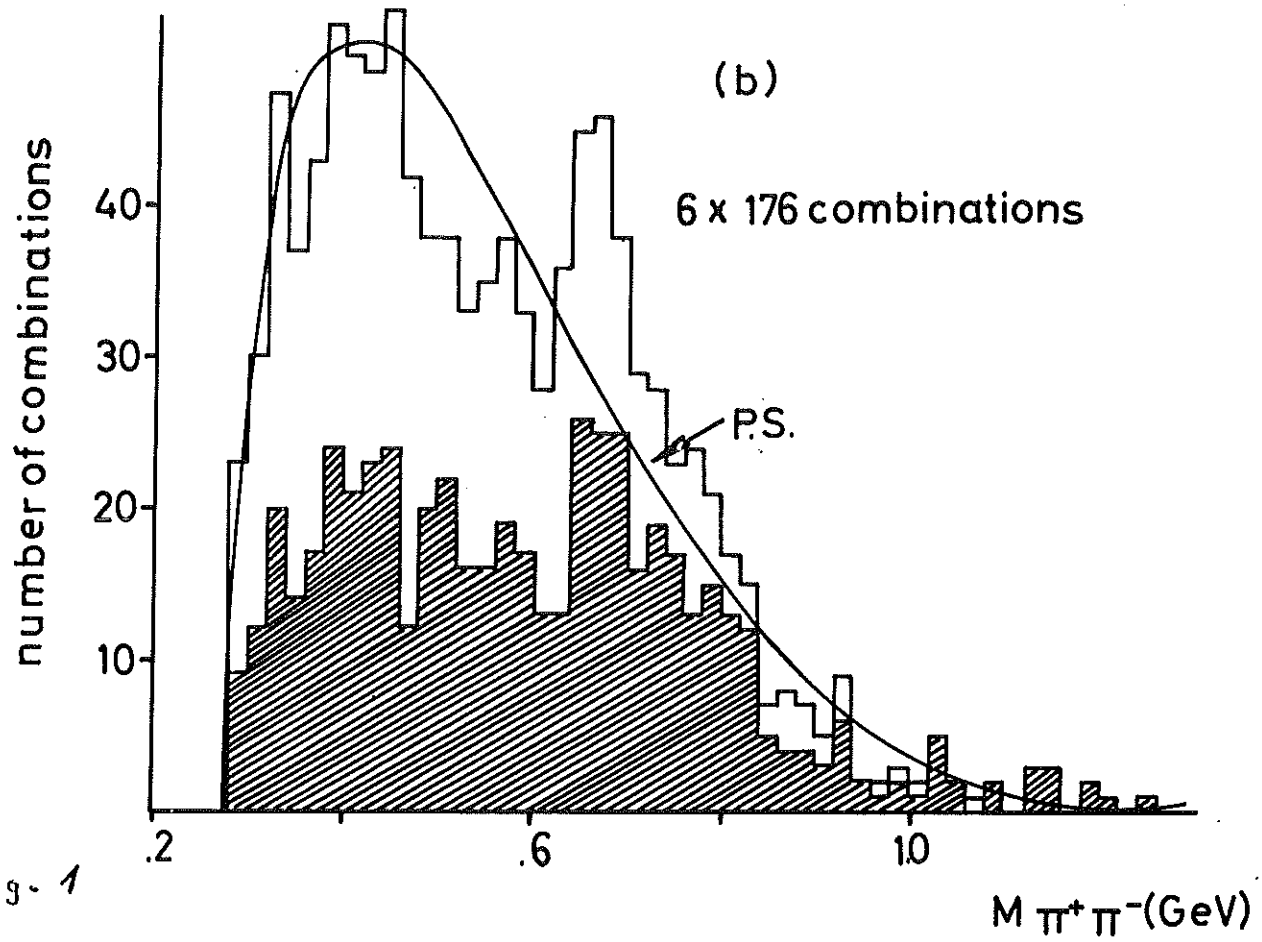

(b)
6 x 176 combinations
P.S.
number of combinations
40
30
20
10
.2
.6
1.0
M π+ π− (GeV)

fig. 1

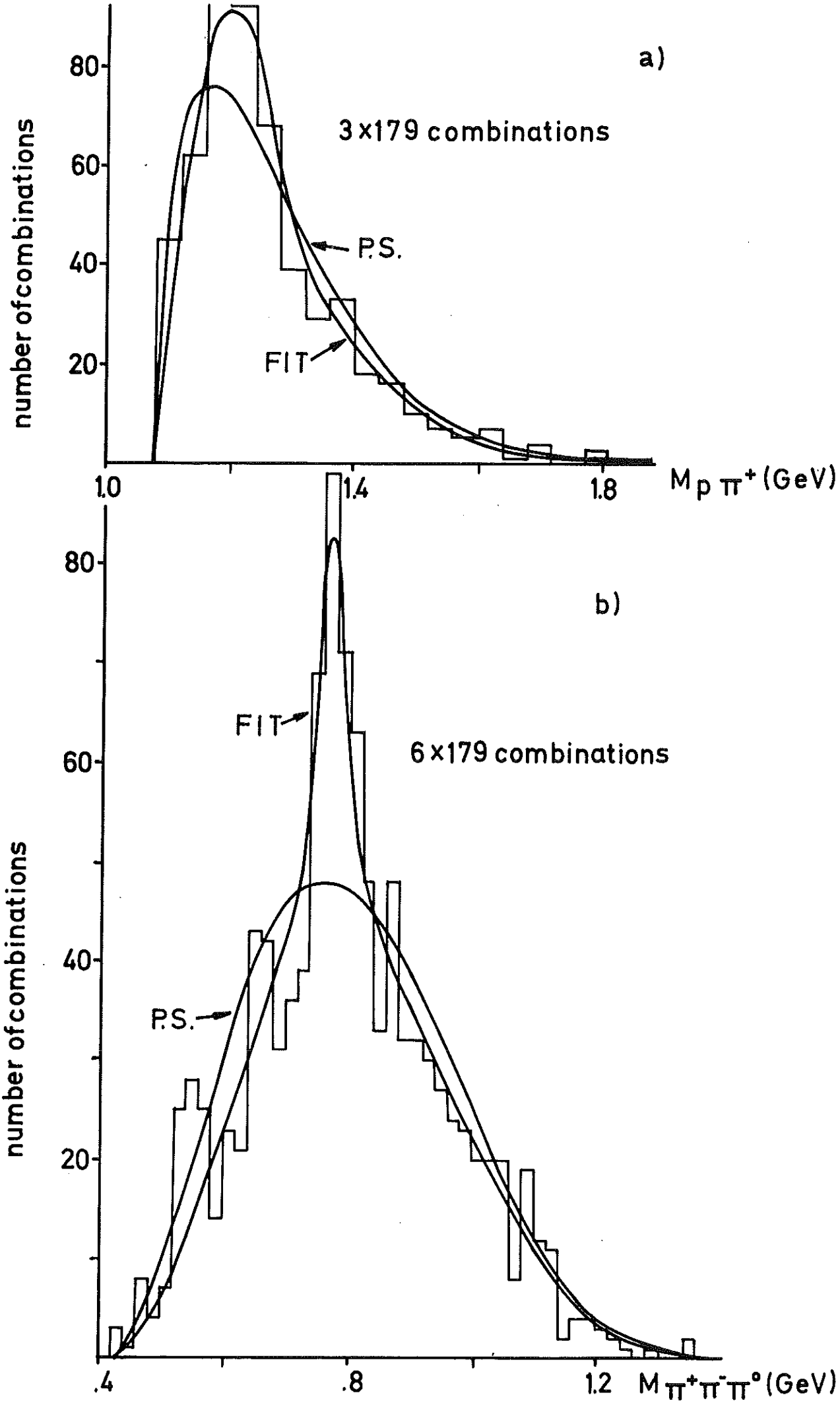

a)
3x179 combinations
P.S.
FIT
number of combinations
80
60
40
20
1.0
1.4
1.8
M p π+ (GeV)
b)
FIT
6x179 combinations
P.S.
number of combinations
80
60
40
20
.4
.8
1.2
M π+π-π° (GeV)

fig 2

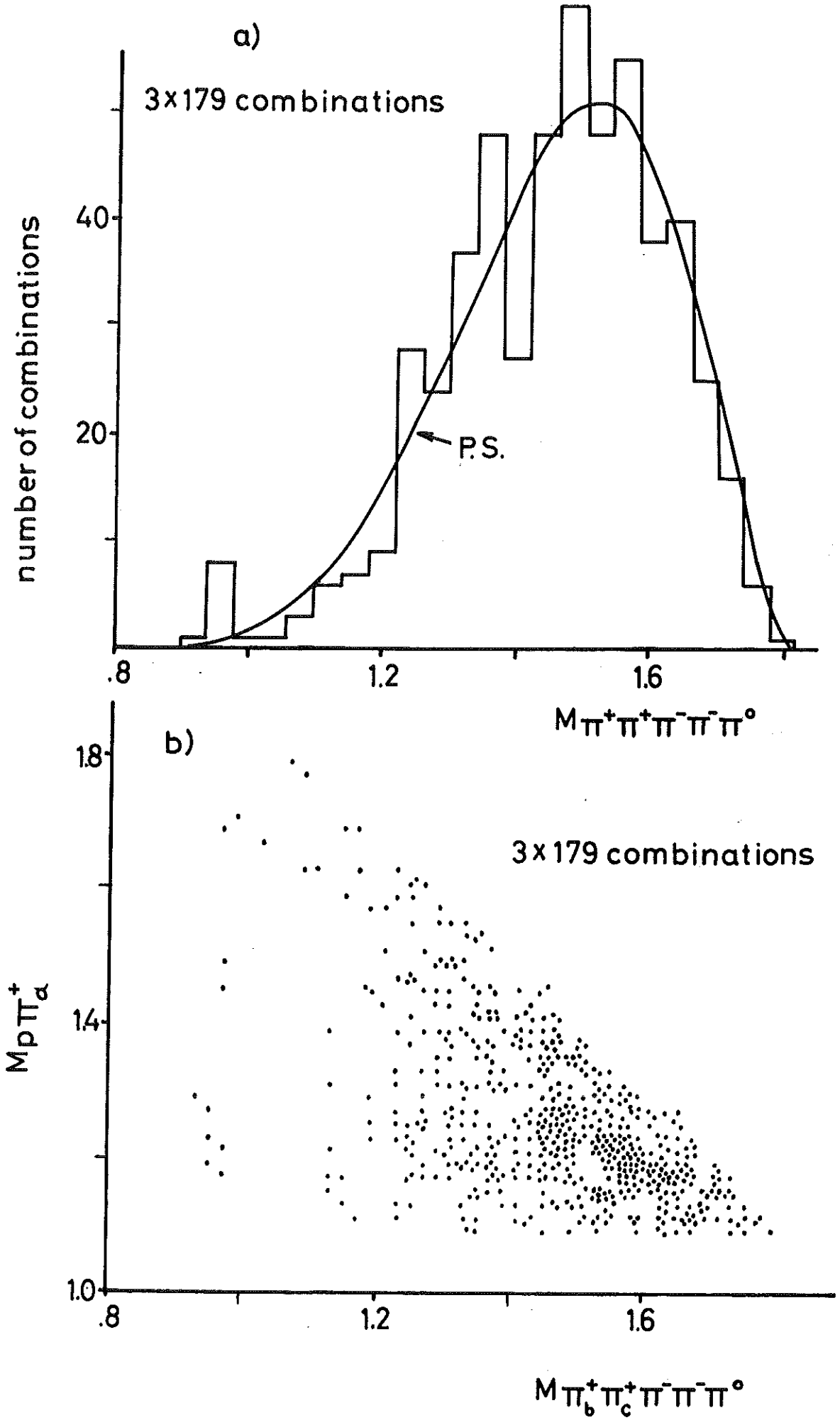

a)
3x179 combinations
number of combinations
40
20
P.S.
.8
1.2
1.6
$M\pi^+\pi^+\pi^-\pi^-\pi^\circ$
b)
3x179 combinations
$M p\pi^+_a$
1.8
1.4
1.0
.8
1.2
1.6
$M\pi^+_b\pi^+_c\pi^-\pi^-\pi^\circ$

fig 3

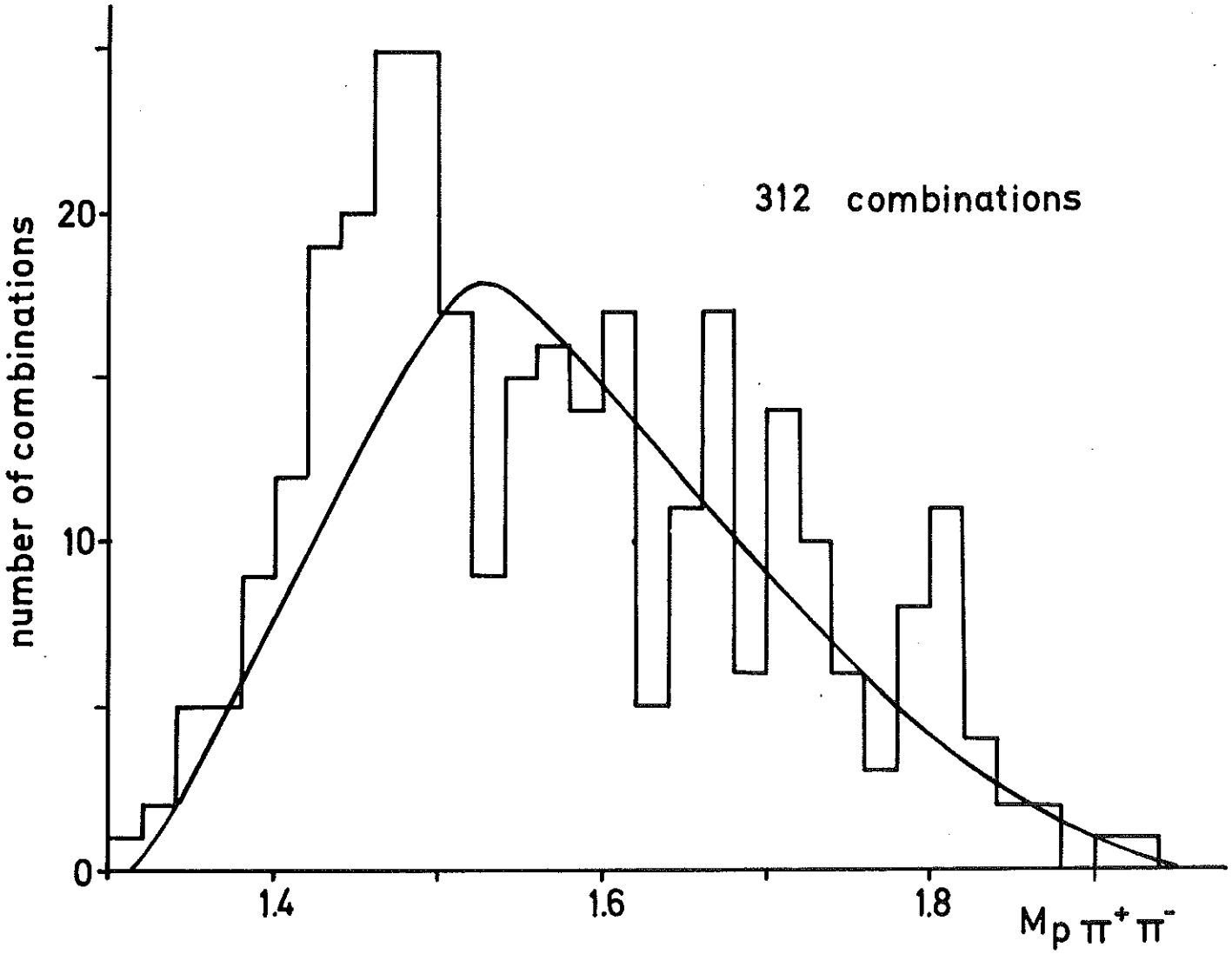

312 combinations
number of combinations
20
10
0
1.4
1.6
1.8
$M_{p\,\pi^+\pi^-}$

fig 4

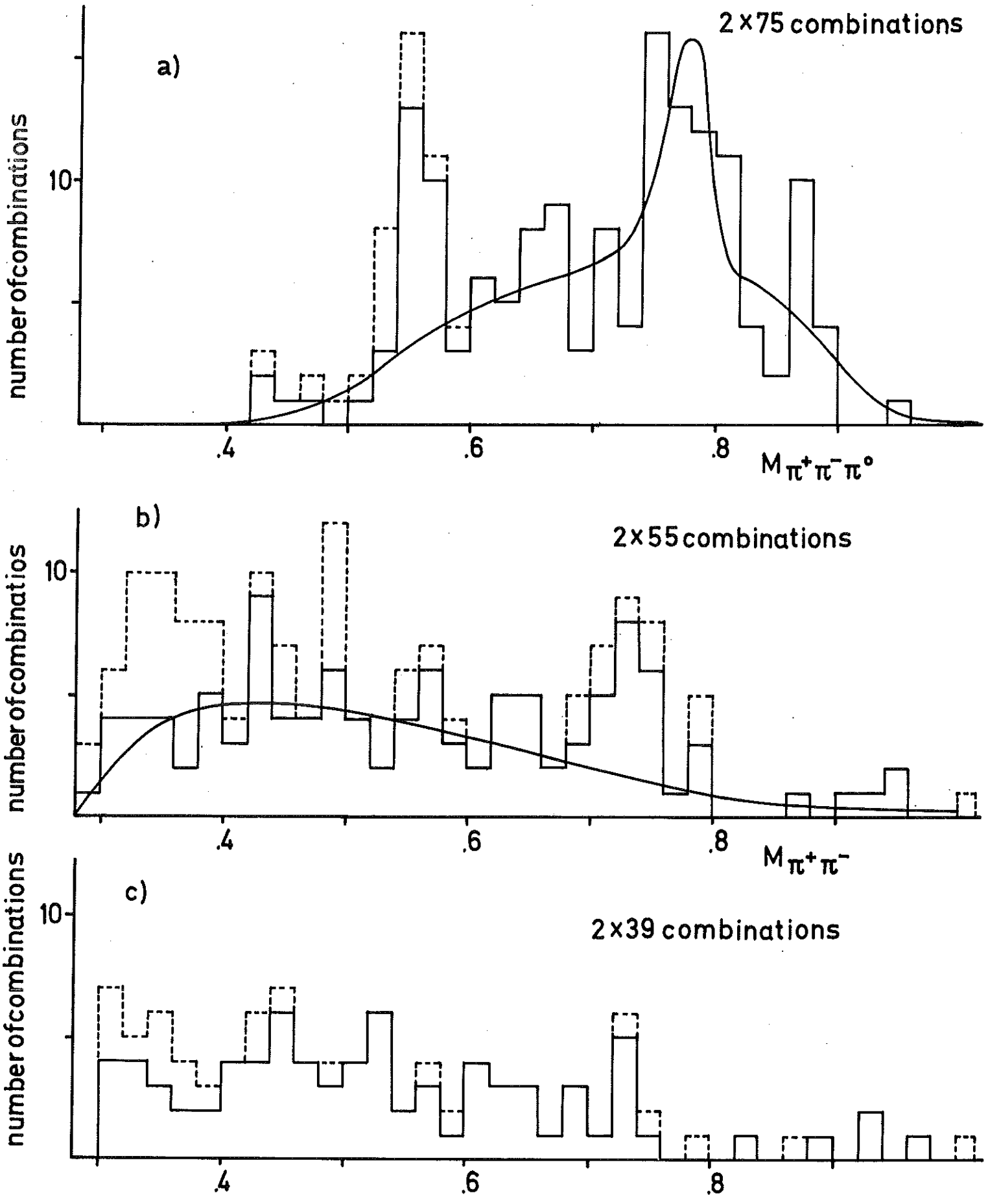

a)
2×75 combinations
number of combinations
10
.4
.6
.8
$M_{\pi^+\pi^-\pi^\circ}$
b)
2×55 combinations
number of combinatios
10
.4
.6
.8
$M_{\pi^+\pi^-}$
c)
2×39 combinations
number of combinations
10
.4
.6
.8

fig 5