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RARE DECAY MODES OF ρ, A_1 AND A_2 MESONS

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In a study [1,2,3] of the interactions produced by 8 GeV/c positive pions in the Saclay 81cm hydrogen bubble chamber, the possible decay modes of the ρ-meson into 4π and into $\pi\eta$, and of the A_1 and A_2-mesons into 3π, $\pi\eta$, πX^0 and $K\bar{K}$ have been investigated. The C-violating $\pi\eta$ decay mode of the ρ is not observed. For the A_1 and A_2-mesons, it is found that the $\pi\rho$ decay mode is by far the dominant mode. The modes $\pi\eta$ of A_1 and A_2, and $K\bar{K}$ of A_2, occur in a few percent of the cases at most, hence there is no serious violation of the conservation of the Bronzan-Low quantum number [4]. The results, summarized in Table I, have been obtained as described below.

Out of the 18,000 events of 2 and 4-prong interactions which have been analyzed, here we have considered the events in the following channels :

(1)	$\pi^+ p \longrightarrow p\pi^+\pi^0$	738 events
(2)	$\pi^+ p \longrightarrow p\pi^+\pi^+\pi^-$	1711 events
(3)	$\pi^+ p \longrightarrow p\pi^+\pi^+\pi^-\pi^0$	1710 events
(4)	$\pi^+ p \longrightarrow p\pi^+\pi^+\pi^-$ + neutrals	2192 events.

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In channel (1), 89 events have been attributed to the quasi two-body process $\pi^+ p \rightarrow p\rho^+ \rightarrow p\pi^+\pi^0$. To look for a possible decay of the ρ^+ into four pions, we have plotted the $(\pi^+\pi^+\pi^-\pi^0)$-effective mass distribution for the events in channel (3). The result is shown in Fig. 1. No events lie in the ρ-meson mass region (0.62 to 0.88 GeV); this sets an upper limit of 1°/o for the branching ratio $(\rho \rightarrow 4\pi)/(\rho \rightarrow 2\pi)$[5].

From Fig. 1 a limit can be derived also for the existence of the decay mode $\rho^+ \rightarrow \pi^+\eta \rightarrow \pi^+\pi^+\pi^-\pi^0$, which would constitute a violation of charge conjugation in strong interactions. Allowing for the neutral decay of the eta, one obtains $(\rho \rightarrow \pi\eta)/(\rho \rightarrow 2\pi) < 3°/o$.

Among the 1711 events of reaction (2), 543 events fulfilled the double condition that no $p\pi^+$ combination has an effective mass in the region of the N^*_{1238} isobar (1.12 to 1.34 GeV) and at least one of the $\pi^+\pi^-$ combinations has an effective mass lying in the ρ-region. For these latter events, the $\pi^+\rho^0$ mass distribution is plotted in Fig. 2a. Two clearly resolved peaks are seen corresponding to the A_1 and A_2-mesons [6]. We assume that the background under the peaks is represented by the curve (see figure), which is the result of an OPE-type calculation by Wolf [7]. After subtraction of the background, one obtains 95 events in the A_1 mass region (0.95 to 1.125 GeV) and 88 events in the A_2 mass region (1.22 to 1.34 GeV). With the assumption that both A-mesons have isospin I = 1, and therefore that the decays $\pi^+\rho^0$ and $\pi^0\rho^+$ are equally probable, which is not inconsistent with our results, there are then 190 A_1-mesons and 176 A_2-mesons lying outside the N^* band and decaying into $\pi\rho$.

Fig. 2b shows for comparison the $(\pi^+\pi^+\pi^-)$ mass distribution of the 263 events of reaction (2) satisfying the condition that no $(\pi^+\pi^-)$ combination has an effective mass in the ρ-band, still with N^{*++} excluded. No evidence of A_1 or A_2 is found, the total number of events observed in the A_1 and A_2-bands, 12 and 10 respectively, being consistent with background. The branching ratios $(A_1^+ \rightarrow \pi^+\pi^+\pi^-)/(A_1^+ \rightarrow \pi^+\rho^0)$ and $(A_2^+ \rightarrow \pi^+\pi^+\pi^-)/(A_2^+ \rightarrow \pi^+\rho^0)$ are both less than 3.5°/o.

Evidence has been published [8] for the existence of a $\pi\eta$ decay mode for A_2, and possibly also for A_1, using incident pions of 2.7, 3.65 and 4.0 GeV/c. For A_2, Trilling et al. [9] reported for the $\pi\eta$ decay a rate of 28°/o of the $\pi\rho$ mode. Such a large $\pi\eta$ decay rate of A_2 would constitute a serious

violation of the conservation of the quantum number A proposed by Bronzan and Low, whereas a decay rate of a few percent would be acceptable. Our data concerning such a decay mode are presented in Fig. 2c. Among the 1710 events of channel (3), the events were chosen for which no $(p\pi^+)$ combination lies in the N^*_{1238} band and at least one of the $(\pi^+\pi^-\pi^o)$ combinations has an effective mass in the region of the eta-meson (0.5 to 0.6 GeV). In the $\pi^+\eta$ effective mass distribution of Fig. 2c, there are 1 and 3 events, respectively, in the A_1 and A_2 bands, all being consistent with a uniform background. After correction for the other decay modes of the eta, one obtains $(A_1 \longrightarrow \pi\eta)/(A_1 \longrightarrow \pi\rho) < 1.5^o/o$ and $(A_2 \longrightarrow \pi\eta)/(A_2 \longrightarrow \pi\rho) < 3^o/o$. This result, previously reported in reference (1), is inconsistent with the results of references (8, 9), but is in good agreement with a recent value of $3 \pm 3^o/o$ for the A_2 reported by Chung et al.[10] at 3.2 GeV/c. Glashow and Socolow[11] have predicted on the basis of SU(3) symmetry a ratio $(A_2 \longrightarrow \pi\eta)/(A_2 \longrightarrow \pi\rho) = 11/70$ with no mixing between the members of the 2^+ nonet. Our result is incompatible with this value, but mixing can reduce the theoretical estimate.

The A_1 and A_2 decay mode into $\pi^+X^o \longrightarrow \pi^+(\pi^+\pi^-\eta) \longrightarrow \pi^+\pi^+\pi^-$ + neutrals has been investigated using the 2192 events of the reaction (4). It was required that a) no $p\pi^+$ combination has an effective mass in the N^*_{1238} region, b) the missing mass be in the eta-region, and c) the $(\pi^+\pi^-$ + neutrals) effective mass be in the X^o region (0.92 to 1.00 GeV). The resulting (π^+X^o) mass distribution is shown in Fig. 2d. No event lies in the A_1 region and one event is in the A_2 region. Correcting for other decay modes[12], an upper limit of $1.5^o/o$ is obtained for both $(A_1 \longrightarrow \pi X^o)/(A_1 \longrightarrow \pi\rho)$ and $(A_2 \longrightarrow \pi X^o)/(A_2 \longrightarrow \pi\rho)$.

At lower energies of the incident pions, an enhancement has been observed[13,14] in the effective mass distribution of the $K\bar{K}$ system, with position and width similar to those of the A_2-meson. The assumption was then made[13] that this enhancement represents an alternate decay mode of the A_2-mesons. Originally, this decay mode was considered frequent enough to constitute a serious violation of the conservation of the Bronzan-Low quantum number. In the course of the systematic study of 8 GeV/c π^+p interactions, a sample 2.4 times larger than that used for collecting 2 and 4-prong events was used to select 2-prong events associated with one neutral strange particle with visible decay. These events were studied by the groups at CERN and in Warsaw and Cracow. The reaction

$$\pi^+p \longrightarrow pK^{+-}K^o \qquad (5)$$

was used to investigate the $K\bar{K}$ enhancement possibly corresponding to an A_2 decay mode. In about 800 events analyzed, 16 were found that could be assigned to reaction (5). The $K^{\pm}\bar{K}^{o}$ effective mass distribution, corrected for K^{o} decays outside the chamber, is plotted in Fig. 2e. No events are observed in the A_1 mass region, which establishes the upper limit of $1^{o}/o$ for the branching ratio $(A_1 \longrightarrow K\bar{K})/(A_1 \longrightarrow \pi\rho)$. A total of 5 events are observed in the A_2 mass region, of which about 1 event is consistent with a uniform background. After correcting for the neutral decay modes of the K^{o}, and if one assumes that the enhancement observed is indeed the A_2, one obtains $(A_2 \longrightarrow K\bar{K})/(A_2 \longrightarrow \pi\rho) = 3 \pm 2^{o}/o$ [15]. This result is consistent with the result recently deduced by Chung et al. [10].

As a conclusion, the $\pi\eta$ decay mode of the A-mesons is not important enough, if it exists at all, to constitute a serious violation of the Bronzan-Low quantum number. The same is true for the $K\bar{K}$ decay mode, if the peak observed in several experiments indeed represents the decay of the A_2-meson. The $\pi\eta$ decay rate of the A_2-meson is less than that predicted by Glashow and Socolow from SU(3).

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5) For the determination of the branching ratios, the following criteria have been used :

   a) If no event is observed in the mass region of the resonance in question, then the branching ratio is quoted as $< X^{o}/o$, where X is the value that would be calculated if one event had been observed.

   b) If there are events, N, say, in the mass region of the resonance in question, but there is no peak above the estimated phase space background, then the branching ratio has been quoted as $< Y^{o}/o$, where Y is the branching ratio that would have been obtained if a peak of $N^{1/2}$ events has been observed.

6) Here we assume that the A_1-enhancement is a resonant state and not a kinematic effect.

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15) As no N^{*} can be formed in reaction (5), here we take 208 and 197 events for A_1 and A_2, respectively, which includes corrections for those events with a $p\pi^+$ combination lying in the N^{*} mass region.

CAPTION FOR FIGURES

Fig. 1 Effective mass distribution of the $(\pi^+\pi^+\pi^-\pi^o)$ system in the channel $\pi^+ p \longrightarrow p\pi^+\pi^+\pi^-\pi^o$.

Fig. 2 Decay modes of the A_1 and A_2-mesons.

a) $(\pi^+\pi^+\pi^-)$ effective mass distribution for the events in channel $\pi^+ p \longrightarrow p\pi^+\pi^+\pi^-$, when no $p\pi^+$ combination has a mass in the N^{*}_{1238} region (1.12 to 1.34 GeV) and at least one $\pi^+\pi^-$ combination has a mass in the ρ-region (0.62 to 0.88 GeV). The solid line represents the background resulting from an OPE calculation[7].

b) The same distribution when no $\pi^+\pi^-$ combination is in the ρ-region.

c) $\pi^+\eta$ effective mass distribution for the events in the channel $\pi^+ p \longrightarrow p\pi^+\pi^+\pi^-\pi^o$ satisfying the conditions that no $p\pi^+$ combination lies in the N^{*}_{1238} region and at least one of the $\pi^+\pi^-\pi^o$ combinations has effective mass in the eta region (0.5 to 0.6 GeV).

d) Effective mass distribution for the combination π^+X^o in the channel $\pi^+ p \longrightarrow p\pi^+\pi^+\pi^-$ + neutrals, for the events satisfying the conditions that no $p\pi^+$ combination is in the N^{*}_{1238} region, the mass of the missing neutrals is in the eta region and the $(\pi^+\pi^-$ + neutrals) mass is in the X^o region (0.92 to 1.0 GeV).

e) $K^{+-}K^o$ effective mass distribution for the events of the reaction $\pi^+ p \longrightarrow pK^{+-}K^o$.

CAPTION FOR TABLE

TABLE I : Branching ratios for rare decay modes of the ρ, A_1 and A_2-mesons, assuming as standards (100°/o) the decay modes ππ for the ρ-meson and πρ for the A-mesons.

TABLE I

Decay modes	ρ-meson	Decay modes	A_1-meson	A_2-meson
$\pi^+\pi^o$	100°/o (STD)	$\pi\ \rho$	100°/o (STD)	100°/o (STD)
$\pi^+\pi^+\pi^-\pi^o$	<1°/o	$\pi^+\pi^+\pi^-$	< 3.5°/o	< 3.5°/o
$\pi^+\eta$	<3°/o	$\pi^+\eta$	< 1.5°/o	< 3°/o
		π^+X^o	< 1.5°/o	< 1.5°/o
		$K^+\bar{K}^o$	< 1°/o	3°/o ± 2°/o

PS/ 5137/mhg

$\pi^+ p \longrightarrow p\ \pi^+\pi^+\pi^-\pi^\circ$ AT 8 GeV/c

1710 EVENTS

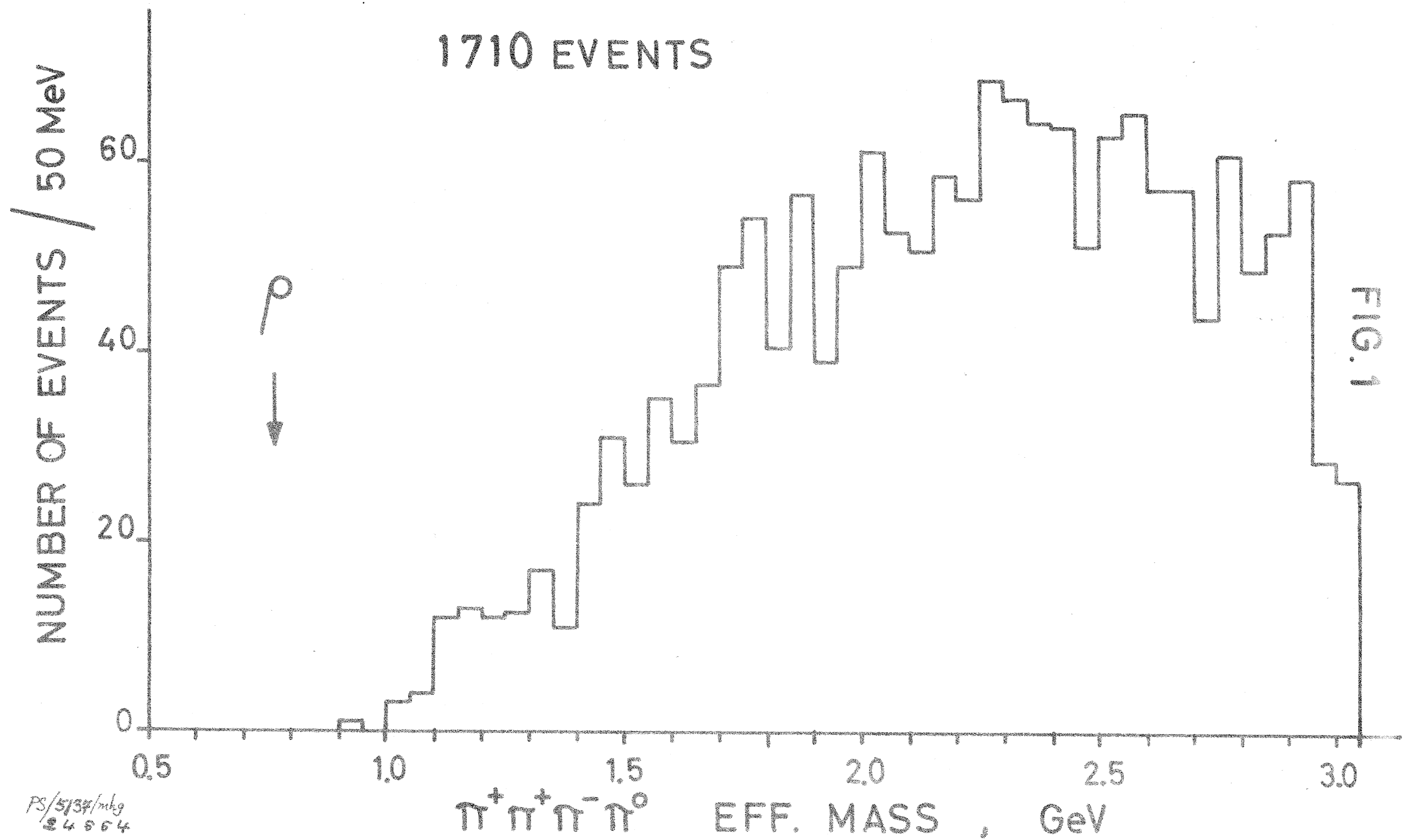

FIG. 1

DECAY MODES OF A1 AND A2

8 GeV/c π^+

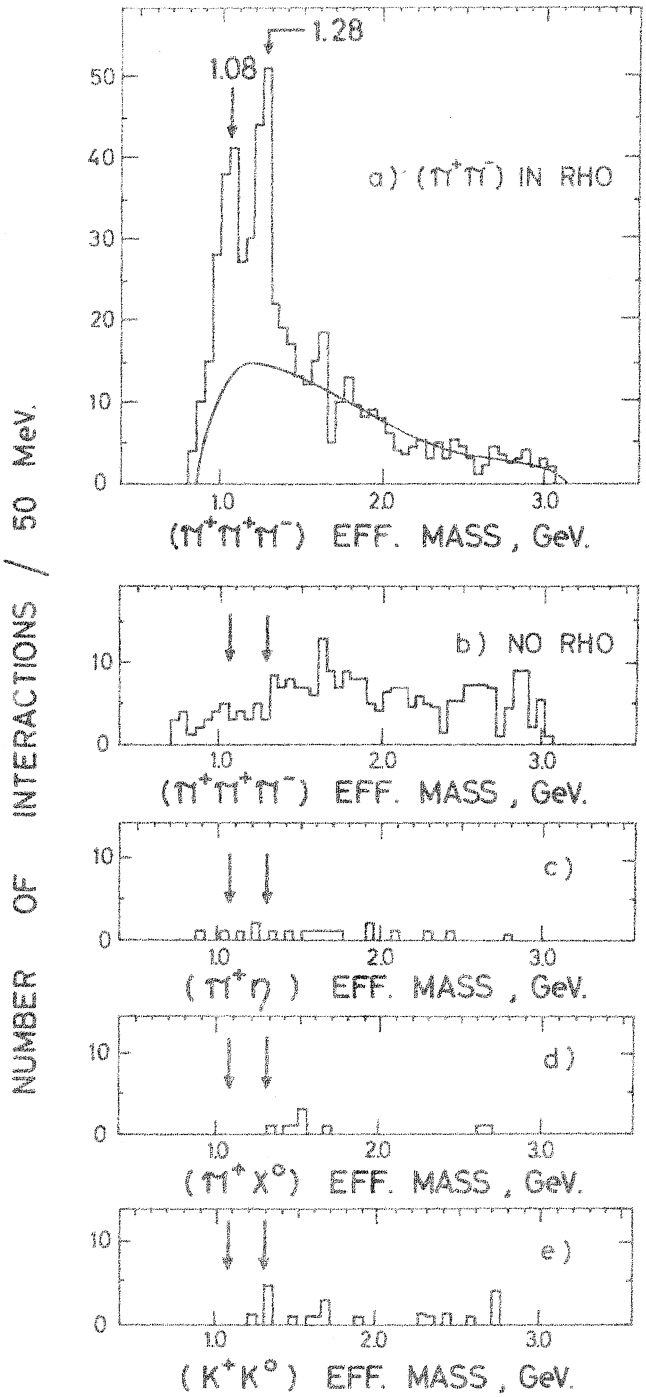

FIG. 2

PS/5137/mhg
DIA 25296