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EVIDENCE AGAINST THE INTERPRETATION OF THE A_1 ENHANCEMENT AS A KINEMATIC EFFECT

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ABSTRACT

The mechanisms proposed to explain the $\pi\rho$ enhancement at 1.1 GeV (A_1 meson) as a kinematic effect are discussed and results are presented, derived from a study of 8 GeV/c π^+p interactions, which are inconsistent with the interpretation of the A_1 as a kinematic effect, and hence favour its interpretation as a resonant state.

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In the $\pi\rho$ mass distribution of the reaction $\pi^{\pm}p \rightarrow p\pi^{\pm}\pi^{+}\pi^{-}$, peaks have been observed[1] near 1.10 and 1.30 GeV, which have been called the A_1 and A_2 mesons, respectively. It has been suggested by a number of authors that the A_1 enhancement may be due, not to a resonant state, but to a kinematic effect, since processes can be conceived which would produce a peak at around 1.1 GeV in the $\pi\rho$ mass distribution. The fact that no alternate decay mode is observed for the A_1[2], while a $K\bar{K}$ enhancement at 1300 MeV can be assumed to be evidence for another decay mode of the A_2, gives additional weight to such an interpretation.

It is the purpose of this letter to present results from a study of 8 GeV/c $\pi^{+}p$ interactions which are not compatible with the interpretation of A_1 as a kinematic effect.

In the analysis of about 9000 four-prong events produced by (8.04 ± 0.06) GeV/c positive pions in the 81 cm Saclay hydrogen bubble chamber produced from an extracted beam of the CERN proton-synchrotron, 1711 events were found to fit the reaction

$$\pi^{+}p \rightarrow p\,\pi_A^{+}\pi_B^{+}\pi^{-}. \qquad (1)$$

This channel is dominated by N^{*++}_{1238} and rho-production. Since the A-mesons are observed as enhancements in the $\pi\rho$ system, and since the formation of the N^{*++}_{1238} isobar is competitive with the formation of the A-mesons, a further selection of events was made by requiring that :

a) no $p\pi^{+}$ combination had an effective mass in the region of the N^{*++}_{1238} (1.12 to 1.34 GeV).

b) at least one of the $\pi^{+}\pi^{-}$ combinations had an effective mass in the region of the rho-meson (0.62 to 0.88 GeV).

Both conditions were fulfilled by 543 events. This selection of events could be biassed by interference effects between the N^{*} and the $\pi\rho$ system. However, the Dalitz plot for the reaction $\pi^{+}p \rightarrow p\,\pi^{+}\rho^{o}$ shown in Fig. 1, indicates that the overlap between the N^{*} and the $\pi^{+}\rho^{o}$ bands involves, at this energy, a relatively small number of events, and hence interference effects must be unimportant. The projection of the selected events on the $(\pi\rho)$ axis is shown in Fig. 2, where two well resolved-peaks can be seen at 1.08 and 1.28 GeV, corresponding to the A_1 and A_2 mesons.

The basic difficulty in analysing these peaks is the lack of knowledge of the shape of the non-resonant background. At these energies, in fact, the statistical phase-space distribution, peaked at high masses, does not represent the physical situation (see the dotted curve in Fig. 2).

A mechanism suggested by Peierls[3] to interpret nucleon isobars led Nauenberg and Pais[4] to predict an enhancement in the $\pi\rho$ system near 1.1 GeV, even before the A_1 peak was discovered. However, this was later shown to be incorrect both theoretically[5] and experimentally[6].

Chang[7] suggested that interference between the two possible rho's ($\pi_A^+\pi^-$ and $\pi_B^+\pi^-$) in reaction (1) could produce a $\pi\rho$ enhancement near 1.1 GeV. This would be too small to emerge from the general background, but could become important when the background is reduced by requiring that no N^* is present. However, more detailed calculations by Sweig[8] have shown that this prediction was incorrect.

An improvement over the phase-space calculation of the background was made by Deck[9], who pointed out that a large contribution to the background must arise from peripheral processes that can be described with the formalism of the OPE model. In particular, Deck's calculation considered the case in which a rho-meson is produced at the mesonic vertex, while the virtual pion exchanged undergoes diffraction scattering on the proton at the baryonic vertex. Describing the squared amplitude at this latter vertex, for πp masses greater than 1.6 GeV, by the expression $d\sigma/dt$ = const. exp $(-At)$, where t is the four-momentum transfer squared and $A = 6\ (\mathrm{GeV}/c)^{-2}$, is the slope of the πp elastic differential cross section, Deck found, at 3.65 GeV/c incident momentum, that the $(\pi\rho)$ effective mass distribution was indeed very different from the statistical distribution, being peaked at 1.08 GeV. The full width at half height, G, of the distribution obtained was about 350 MeV, and the cross section about 1/30 of the experimental one. However, by combining conveniently this distribution with phase-space, Deck could satisfactorily fit the small peak observed for the A_1 at 3.65 GeV/c. Maor and O'Halloran[10] improved Deck's calculation, by substituting the exp(-At) parametrization of (π^+p) elastic scattering with the experimental cross section and angular distribution. Their result, again at 3.65 GeV/c, is similar to that of Deck, but the peak is somewhat wider ($G \approx$ 400 MeV).

We have performed two series of Deck-type calculations, for three values of the incoming pion momentum, i.e., for 3.65, 8.0 and 16.0 GeV/c, using the values of the slope A indicated in Table I,

(a) making the same assumptions and approximations as Deck,

(b) removing an approximation introduced in the original Deck calculation(11).

It is found that our calculations of type (b) produce somewhat broader peaks at the higher momenta than calculations of type (a), that the position of the peak is always at about 1100 MeV independently of incoming energy and A-value chosen, but that the width of the peak increases with increasing energy, being at 16 GeV/c about twice that at 3.65 GeV/c. In Table I, the results obtained from the calculations of type (b) are summarized.

TABLE I

P	A	M	G
3.65 GeV/c	$6(\text{GeV/c})^{-2}$	1100 MeV	350 MeV
8.00 "	9 "	1100 "	500 "
16.00 "	9 "	1100 "	700 "

The consequence on this is that, at 8 GeV/c, the calculated distribution has too broad a maximum to account for the rather narrow A_1 peak which we observe. If a fit to our data is made with this background, the enhancement at the A_1 mass emerges by more than 3 standard deviation above the background.

The conclusion that the Deck mechanism cannot explain the peak at 1.1 GeV, is confirmed and strengthened by the result of a more complete calculation recently performed by Wolf(12), for 8 GeV/c incident pions.

The assumption is made, here, that at the mesonic vertex two pions are produced, instead of a rho of fixed mass, and that the squared amplitude at this vertex is described by the $\pi^+\pi^-$ cross section, as derived from experiment. The diffraction of the virtual pion at the baryonic vertex is described by the experimental π^+p cross section as in Ref. (10), symmetrisation with respect to the two positive pions is introduced and form factors of the Ferrari-Selleri type[13] are used. Events of reaction (1) are generated by a Monte Carlo method, then weighted according to the matrix elements, and finally the desired distributions are produced in the same way as the experimental distributions are produced from the data. The distributions thus obtained should adequately describe the behaviour of reaction (1), in the absence of the A_1 and A_2 resonances.

Wolf's distribution for the effective mass of the $(\pi^+\pi^+\pi^-)$ system when no π^+p combination is in the mass region of the N^* isobar, and when at least one of the $\pi^+\pi^-$ combinations is in the rho-mass region[14] is drawn in Fig. 2 (dashed line). It can be seen that this background still has a maximum at ~1100 MeV, but much broader than that of the corresponding Deck-type calculations.

The experimental distribution of Fig. 2 was fitted (solid line) with two Breit-Wigner curves[15] for the two enhancements and with the "background" shape as calculated by Wolf. The peak observed at 1076 $\pm$ 14 MeV with $\Gamma = 130^{+50}_{-40}$ MeV contains 60% of the events in the A_1 region $(0.95 < M(\pi\rho) < 1.125$ GeV). The presence of this peak above background is consistent with the description of A_1 as a resonance.

It should be noted that the results reported here are obtained for a higher incident pion energy than in previous experiments, and that this might be the reason for the discrepancies in the results. It has been recently shown by Shen et al.[16] that at 3.65 GeV/c several results on angular distributions are consistent with the assumption that the peak observed at around 1.1 GeV is a kinematic effect due to the Deck mechanism described above, though the existence of a very small contribution of a resonant state cannot be ruled out. In our opinion this represents the fact that the production of the A_1 resonance at that energy is weak. In fact, in the $\pi\rho$ mass distribution for 3 to 4 GeV/c incident pions, only about 25% of the events in the mass band considered for A_1 are above the estimated background[17]. It is therefore not surprising that the observed distributions are not strongly influenced by the presence of the A_1 events. The angular distributions obtained at 8 GeV/c are all consistent with the assumption that 60% of the events in the A_1 band derive from a resonance and 40% from a non-resonant background, as calculated by Wolf.

In conclusion, the mechanism suggested to interpret the $\pi\rho$-enhancement at 1.1 GeV as a kinematic effect cannot account for the peak observed at that mass in π^+p interactions at 8 GeV/c. It seems therefore probable that the A_1 peak observed at $M = 1076 \pm 14$ MeV with $\Gamma = 130 {}^{+50}_{-40}$ Mev does correspond to a resonant state, with dominant, if not unique, decay mode into $\pi\rho$[2].

We are deeply indebted to the operating crews of the CERN proton synchrotron, of the 81 cm 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 Dr. R. Armenteros and Prof. Ch. Peyrou.

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FIGURE CAPTIONS

1. Dalitz plot for the reactions $\pi^+ p \rightarrow p\,\pi^+\rho^o$ at 8 GeV/c. The rho-band is between 0.62 and 0.88 GeV.

2. Effective mass distribution for the system $\pi^+\rho^o \rightarrow \pi^+\pi^+\pi^-$, with N^{*++} excluded, at 8 GeV/c.
   The solid line is the result of fitting the experimental distribution with two Breit-Wigner curves and the background shape calculated by Wolf in the frame work of the OPE model, and shown by the dashed line. The dotted curve is the statistical phase-space distribution normalized to the same area as the OPE background.

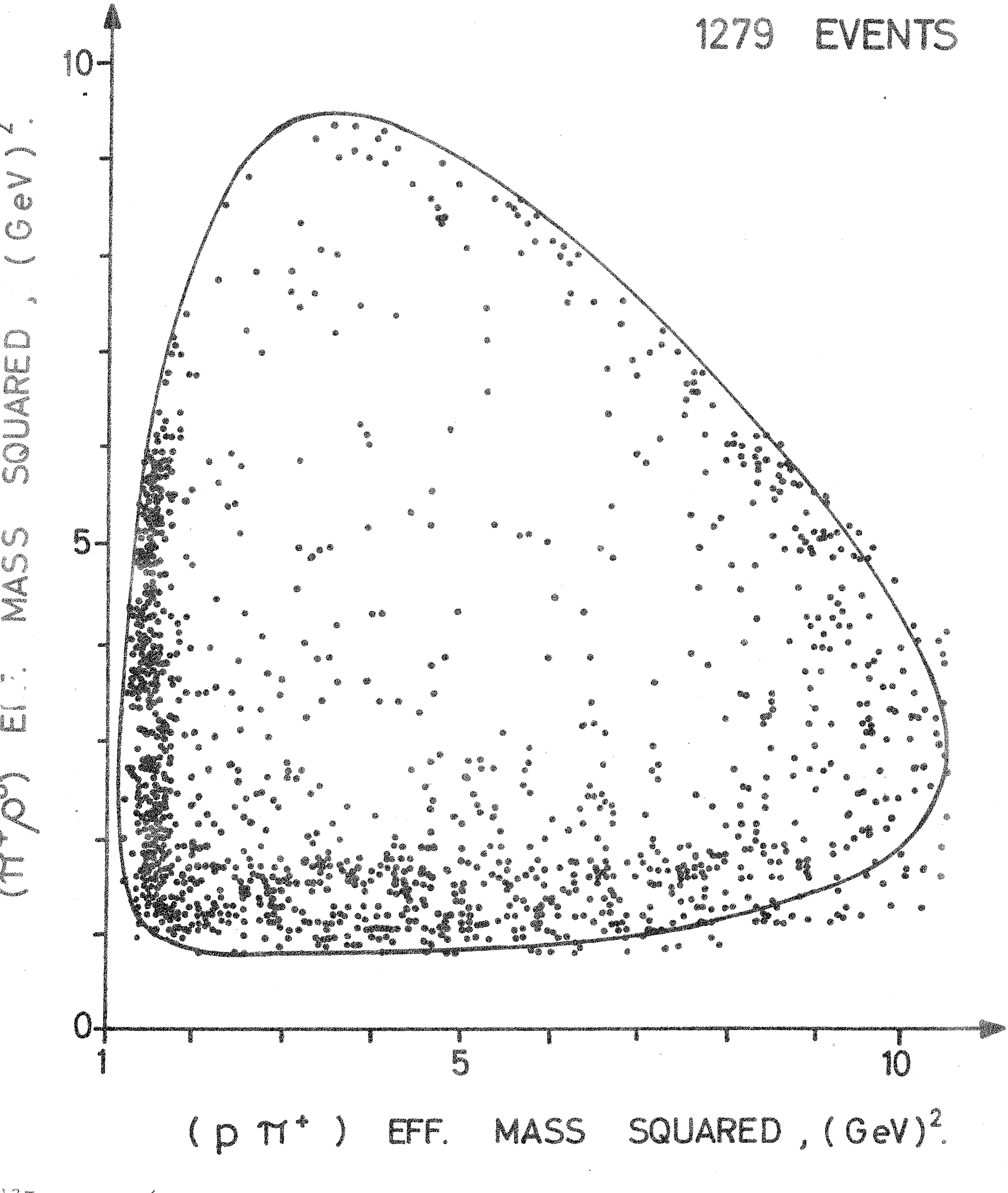
TABLE CAPTION

1. Results of Deck-type calculations (type (b)) of the $M(\pi\rho)$ distribution for incident pions of momentum p = 3.65, 8.0 and 16.0 GeV/c.
   The constant A is the slope of the elastic differential $\pi^+ p$ cross section introduced in the calculations. M is the mass and G is the full width at half-height of the peak obtained.

FIG. 1

$\pi^+ p \to p\pi^+\rho^0 \to p\pi^+\pi^+\pi^-$ AT 8 GeV/c.

DALITZ PLOT FOR $p\pi^+\rho^0$



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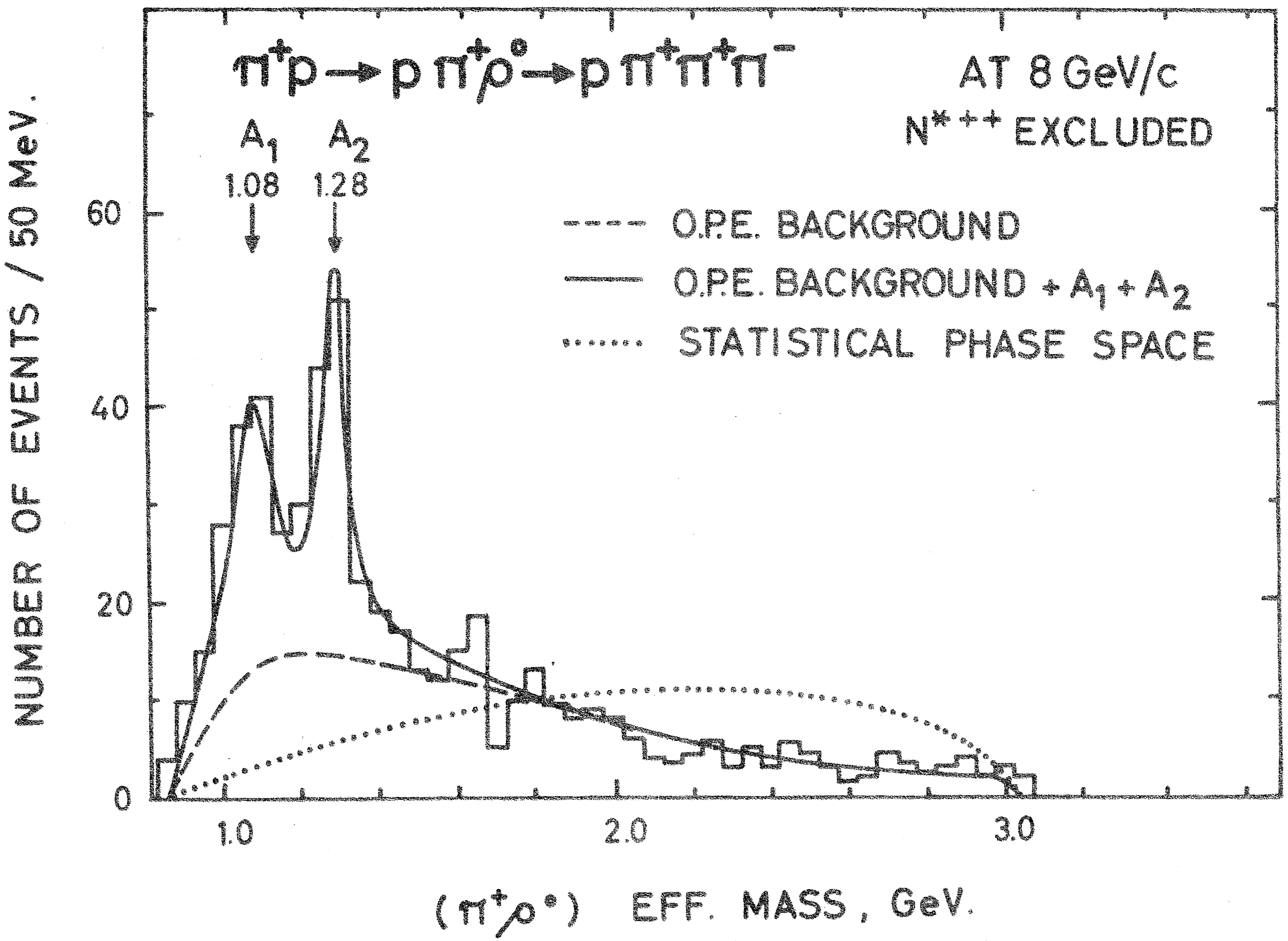
$\pi^+p \rightarrow p\pi^+\rho^\circ \rightarrow p\pi^+\pi^+\pi^-$
AT 8 GeV/c
N^{*++} EXCLUDED
A_1
1.08
A_2
1.28
O.P.E. BACKGROUND
O.P.E. BACKGROUND + A_1 + A_2
STATISTICAL PHASE SPACE
NUMBER OF EVENTS / 50 MeV.
0
20
40
60
1.0
2.0
3.0
$(\pi^+\rho^\circ)$ EFF. MASS, GeV.

Fig. 2