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Decay Angular Distributions of Resonances in Two-body Reactions Produced by 8 GeV/c Positive Pions on Protons

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Abstract : The decay angular distributions of resonances produced in 8 GeV/c π^+p interactions have been analysed in terms of density-matrix elements and, in a case of double resonance production, in terms of angular correlations between the decay of the two resonances. The results are compared with the predictions of the absorption model. In general, fair agreement is found, although discrepancies are observed in some cases.

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In this letter we report on a further study of the production mechanism of processes with two-body intermediate states in π^+p collisions of 8 GeV/c primary momentum. In a previous letter[1] concerning the same reactions we presented momentum transfer distributions and absolute cross-sections. In comparing these results with predictions of the absorption model we found fair agreement in the case of reactions which can proceed through one-pion exchange, whereas serious disagreement was encountered for processes requiring vector meson exchange.

The present letter is concerned with decay angular distributions of resonances analysed in terms of spin density matrix elements and, in a case of double resonance production, $\pi^+p \rightarrow N^{*++}\rho^o$, in terms of angular correlations between the two decay processes.

The following reactions were studied :

$$\pi^+p \rightarrow p\,\rho^+ \quad (1)$$
$$\rightarrow N^{*++}\rho^o \quad (2)$$
$$\rightarrow N^{*++}\pi^o \quad (3)$$
$$\rightarrow N^{*++}\omega^o \quad (4)$$
$$\rightarrow N^{*++}f^o \quad (5)$$

The decay angles of resonances, used here, are those defined by Gottfried and Jackson[2], i.e. θ and φ are the polar and azimuthal angles in the rest system of the resonance. For two body decays, the angles are defined with respect to the direction of the outgoing π^+, and for the three body decay of the ω the direction of the normal to the decay plane is used. Following the method of Ref. (2), the spin density matrix elements were calculated from the experimental decay angles by means of a maximum likelihood method. The results for reactions (1) to (4) are presented in Table I, which shows the matrix elements $\rho_{m,n}$ together with the predictions[3] from the absorption model, and the experimental results reported[4] for the same reactions at 4 GeV/c. It is interesting to note that the matrix elements obtained at 8 GeV/c are similar to those obtained at 4 GeV/c.

For the two reactions, (1) and (2), proceeding via pion exchange, fair agreement is found between the experimental data and the theoretical predictions. In particular, the matrix elements $\rho_{o,o}$ which would be equal to unity if absorption were not present, are different from one and in good agreement with the calculated values. For reaction (2), which has the largest cross section, also the variation of the density matrix elements with the squared four-momentum transfer, $|t|$, has been studied and the results are shown in Fig. 1. For the diagonal elements $\rho_{0,0}$ and $\rho_{3,3}$, which are the most important elements, the absorption model predicts the $|t|$ dependence fairly well. For the off-diagonal elements, however, poor agreement or disagreement is obtained.

For the two reactions, (3) and (4), proceeding via vector meson exchange, the data in Table I indicate that reasonable agreement is obtained for reaction (3), $\pi^+ p \to N^{*++}\pi^o$, but disagreement is found for reaction (4), $\pi^+ p \to N^{*++}\omega$, particularly concerning the diagonal element $\rho_{0,0}$. This element, that would be zero if there were no absorption, is predicted by the model to be 0.54, while its experimental value is 0.26 ± 0.10. It is an interesting fact that in the similar experiment[4] at 4 GeV/c, significant deviations again occurred for $N^{*++}\omega$, in the same direction and approximately of the same size as found here at 8 GeV/c.

For reaction (5), $\pi^+ p \to N^{*++} f^o$, the results are given in Table II. Since f^o is a spin 2 particle, there are three diagonal elements defining its angular distribution in terms of spherical harmonics.

$$W(\cos \Theta_{f^o}) \approx \rho_{0,0} |Y_2^0|^2 + 2\rho_{1,1} |Y_2^1|^2 + 2\rho_{2,2} |Y_2^2|^2 \qquad (6)$$

where $\rho_{0,0}$, $\rho_{1,1}$ and $\rho_{2,2}$ are positive numbers which are related through the condition that the trace of the density matrix must be 1. It can be seen that $\rho_{2,2}$ is negative, contrary to what would be expected for a pure resonance. The diagonal density matrix elements have been calculated also for the published results [5,6] for $\pi^- p \to nf^o$ at 3.7 and 4.0 GeV/c and are shown in Table II, where it can be seen that the $\rho_{2,2}$ values are again negative. A negative value of $\rho_{2,2}$ corresponds to the observation of fewer events near cos Θ = 0, than predicted from equation (6). That the height of the maximum at the centre of the decay angular distribution of the f^o is smaller than expected, has been noted before [5,6]. Lee et al. [5] suggested that this could be due either to interference with an S-wave background or to the exchange of a particle other than a pion. However, since a negative value of $\rho_{2,2}$ cannot be produced by the exchange of a spin two particle, but can be caused by an S-wave interference, this latter possibility seems a reasonable explanation of the effect observed.

Goldhaber et al.[7] first demonstrated the existence of correlations in the decay angles of resonances in case of double resonance production. Such correlations which should not occur if these processes were dominated by single pion exchange without absorption, are predicted by the absorption model [8]. For reaction (2), $\pi^+p \rightarrow N^{*++}\rho^0$, the correlation between the decay polar angle of the N^*-isobar, θ_{N^*}, and of the rho-meson θ_ρ, is shown by the scatter diagram of Fig. 2a. It may be seen that the cos θ distribution for the mesonic (baryonic) resonance becomes flatter as the angle of the baryonic (mesonic) resonance is restricted to the equatorial region ($|\cos\theta| \leqslant 0.4$). In Fig. 2a, the experimental data indicate a large forward-backward asymmetry in the decay of the rho-meson, asymmetry that is not contained in the absorption model. Projections of the scatter diagram of Fig. 2a are presented in Fig. 2b, c, d and e, folded along the cos $\theta = 0$ axes in order to compensate for the above mentioned asymmetry, and are then compared with the predictions of the absorption model (solid lines in the figures). The curves are normalized only to the total cross section, i.e., to the sum of the events in the distributions 2b and 2c (for ρ^0), and 2d and 2e (for N^{*++}). Assuming that the folding of the projections is justifiable, the agreement between theory and experiment is very good.

In conclusion, with the assumption made that the presence of background in the resonance mass region has negligible effect, the results concerning the angular distributions in quasi-two-body reactions studied in 8 GeV/c π^+p interactions can be summarized as follows :

(a) the density matrix elements calculated from the experimental decay angular distributions of the resonances are similar at 8 GeV/c and at lower energies, and show final state absorption effects.

(b) In cases of double resonance production, correlations in the decay angles of the renances, discovered at lower energies, are observed also at 8 GeV/c.

(c) For reactions that can proceed via the exchange of a single pion, the absorption model, beside predicting correctly the total and differential cross sections, also describes reasonably well the main features of the polarization phenomena. The discrepancies observed are on points of detail. The correlation phenomena are properly described by the model.

(d) For reactions that require the exchange of a vector meson, the absorption model fails in its predictions for total and differential cross sections. As far as the polarization phenomena are concerned, fair agreement is found for reaction $\pi^+p \rightarrow N^{*++}\pi^o$, disagreement for $\pi^+p \rightarrow N^{*++}\omega$.

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The numerical calculations were kindly done by Prof. J.D. Jackson and Dr. B.E.Y. Svensson.

Figure Captions

Fig. 1. Density matrix elements of reaction $\pi^+ p \rightarrow N^{*++}\rho^o$ as functions of t . The curves are the predictions of the absorption model.

Fig. 2. a) Scatter diagram of $\cos \Theta_{N^*}$, the decay polar angle of the N^{*++} isobar in reaction $\pi^+ p \rightarrow N^{*++}\rho^o$, versus $\cos \Theta_\rho$, the decay polar angle of the rho-meson.

b) and c) Distributions of $\cos \Theta_{N^*}$ for $|\cos \Theta_\rho| \leqslant 0.4$ and $|\cos \Theta_\rho| > 0.4$, respectively, folded about the line $\cos \Theta_{N^*} = 0$.

d) and e) Same for $\cos \Theta_\rho$.

The solid lines are the predictions of the absorption model, normalized only to the total cross section. The events used here are selected with the condition $|t| < 0.3$ $(GeV/c)^2$.

Table Captions

Table I Density matrix elements for reaction (1) to (4) at 8 GeV/c compared with values found at 4 GeV/c and with absorption model predictions. The values are averaged over $|t|$ values up to 0.3 $(GeV/c)^2$ for reactions (1) to (3) and up to 0.6 $(GeV/c)^2$ for reaction (4).

Table II Density matrix elements for reaction (5) at 8 GeV/c compared with the results obtained for the reaction $\pi^- p \rightarrow nf^o$ at 3.7 and 4.0 GeV/c.

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TABLE I

Density Matrix Elements

$\pi^+ p$ Interactions

Reaction	Particle assumed exchanged	Matrix Element	Experiment at 8 GeV/c	Theory at 8 GeV/c	Experiment at 4 GeV/c Ref.(4)	Reaction	Particle assumed exchanged	Matrix Element	Experiment at 8 GeV/c	Theory at 8 GeV/c	Experiment at 4 GeV/c Ref.(4)
$p\,\rho^+$	π	$\rho_{0,0}$	0.54 ± 0.07	0.54	0.70 ± 0.08	$N^{*++}\pi^0$	ρ	$\rho_{3,3}$	0.22 ± 0.06	0.14	0.40 ± 0.06
		$\rho_{1,-1}$	0.075 ± 0.062	0.17	0.17 ± 0.08			Re $\rho_{3,-1}$	0.132 ± 0.067	0.21	0.21 ± 0.08
		Re $\rho_{1,0}$	-0.08 ± 0.05	-0.10	-0.07 ± 0.07			Re $\rho_{3,1}$	0.066 ± 0.057	-0.06	-0.03 ± 0.07
$N^{*++}\rho^0$	π	$\rho_{3,3}$	0.05 ± 0.03	0.05	0.08 ± 0.03	$N^{*++}\omega^0$	ρ	$\rho_{3,3}$	0.24 ± 0.08	0.17	0.15 ± 0.04
		Re $\rho_{3,-1}$	0.015 ± 0.028	0.00	0.01 ± 0.03			Re $\rho_{3,-1}$	0.017 ± 0.035	0.02	0.04 ± 0.04
		Re $\rho_{3,1}$	-0.076 ± 0.033	-0.01	-0.01 ± 0.03			Re $\rho_{3,1}$	-0.113 ± 0.083	0.06	-0.05 ± 0.04
		$\rho_{0,0}$	0.77 ± 0.04	0.82	0.77 ± 0.04			$\rho_{0,0}$	0.26 ± 0.10	0.54	0.47 ± 0.05
		$\rho_{1,-1}$	-0.035 ± 0.024	0.01	-0.04 ± 0.03			$\rho_{1,-1}$	0.17 ± 0.03	0.02	0.13 ± 0.05
		Re $\rho_{1,0}$	-0.119 ± 0.025	-0.04	-0.06 ± 0.03			Re $\rho_{1,0}$	-0.03 ± 0.06	0.14	-0.10 ± 0.03

TABLE II

Density Matrix Elements

Matrix Element	$\pi^+ p \to N^{*++} f^0$ at 8 GeV/c $\lvert t \rvert \leq 0.6$ (GeV/c)^2	$\pi^- p \to n f^0$ at 4 GeV/c $\lvert t \rvert < 0.3$ (GeV/c)^2	$\pi^- p \to n f^0$ at 3.7 GeV/c $\lvert t \rvert < 0.4$ (GeV/c)^2
$\rho_{3,3}$	0.04 ± 0.04		
Re $\rho_{3,-1}$	-0.03 ± 0.04		
Re $\rho_{3,1}$	-0.07 ± 0.05		
$\rho_{0,0}$	0.85 ± 0.10	1.01 ± 0.20	0.64 ± 0.07
$\rho_{1,1}$	0.19 ± 0.04	0.21 ± 0.09	0.29 ± 0.06
$\rho_{2,2}$	-0.12 ± 0.06	-0.22 ± 0.09	-0.11 ± 0.06
$\rho_{1,-1}$	-0.04 ± 0.06		
$\rho_{2,-2}$	0.0 ± 0.06		
Re $\rho_{1,0}$	-0.06 ± 0.04		
Re $\rho_{2,0}$	0.04 ± 0.06		
Re $\rho_{2,1}$	-0.06 ± 0.04		
Re $\rho_{2,-1}$	-0.02 ± 0.04		

SPIN DENSITY MATRIX ELEMENTS $\pi^+ + p \rightarrow N^{*++} + \rho^0$ AT 8 GeV/c

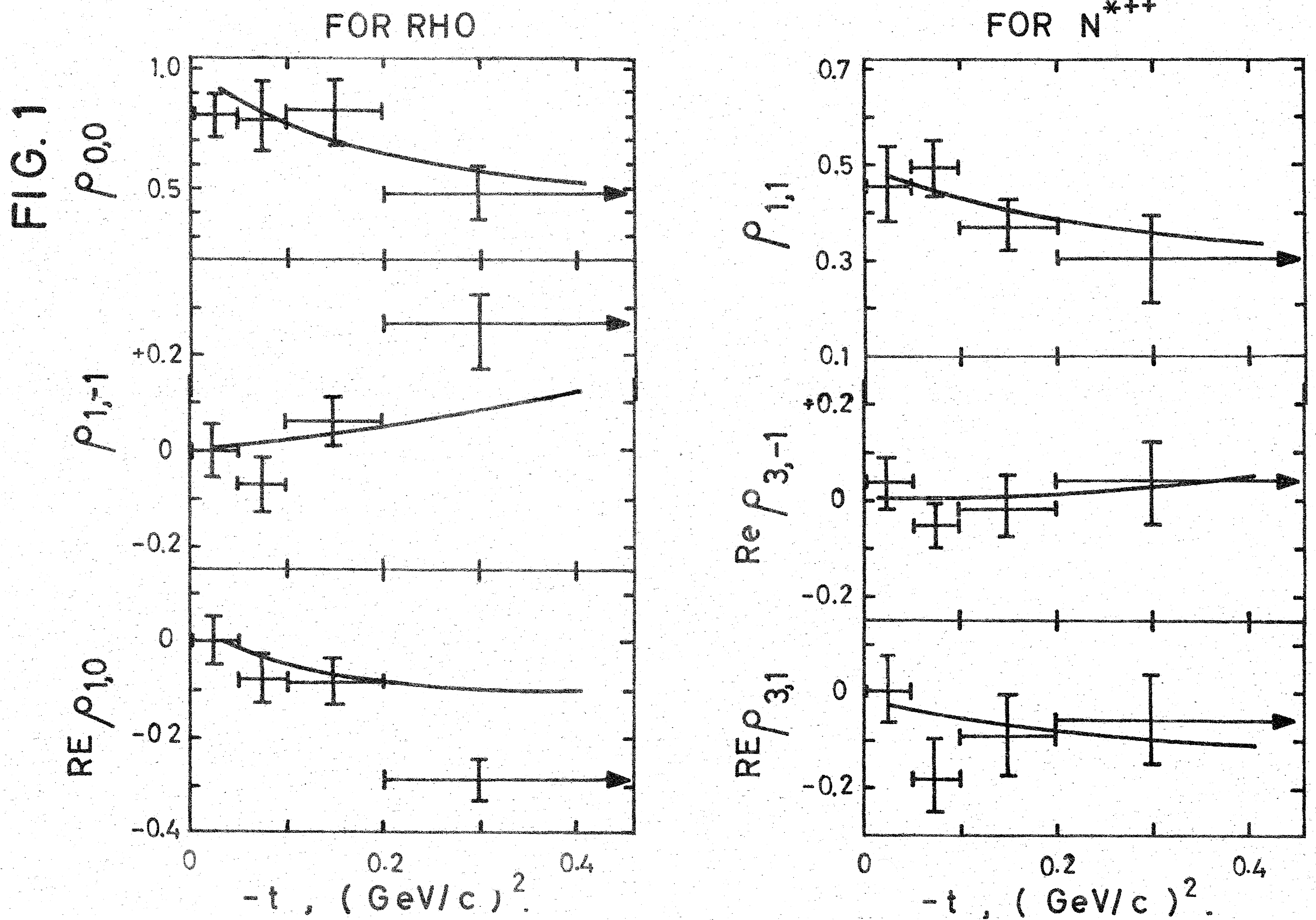

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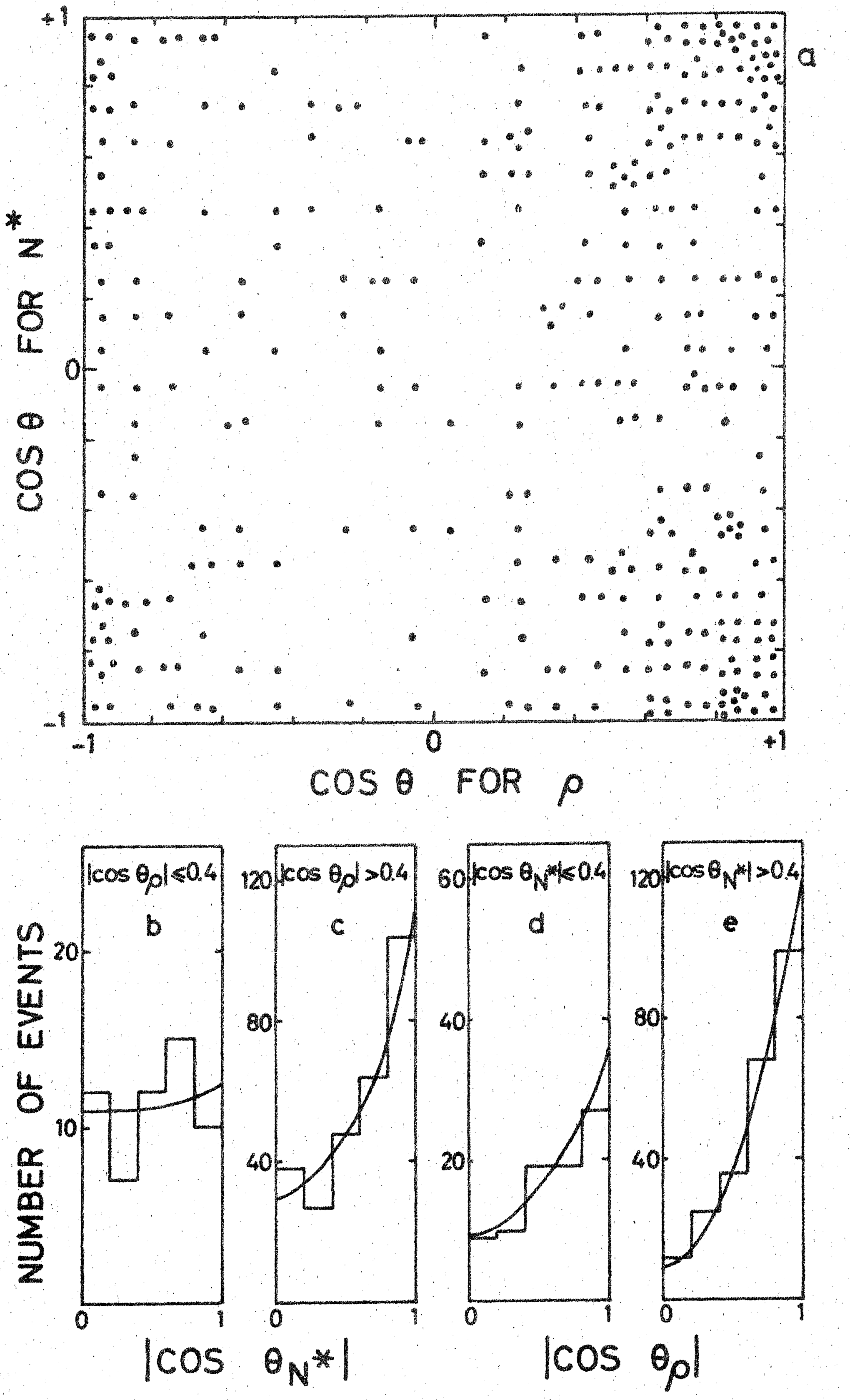
FIG. 2

$\pi^+ p \rightarrow N^{*++} \rho^0 \longrightarrow p \pi^+ \pi^+ \pi^-$ AT 8 GeV/c



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