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INTERFERENCE EFFECTS IN THE PROCESS $\pi^+ p \rightarrow \rho^+ p$ †

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ABSTRACT

It is shown from an analysis of experimental data on the reaction $\pi^+ p \rightarrow \pi^+ \pi^o p$ that asymmetries in $\pi^+ \pi^o$ decay angular distributions have a natural interpretation in terms of interference between $\rho^+ p$ production and diffractive dissociation of the proton.

The $\pi\pi$ systems produced in reactions of the form $\pi N \rightarrow \pi\pi N$ have been the subject of intensive study particularly in the region of invariant mass near the ρ resonance.[1] For the reactions $\pi^\pm p \rightarrow \pi^\pm \pi^o p$, the $\pi\pi$ decay angular distributions, measured in the Jackson frame, exhibit asymmetries which go from a backward maximum to a forward one as the $\pi\pi$ mass is increased from below to above the central value of the ρ resonance. This behavior has generally been interpreted in the context of the one-pion-exchange (OPE) model in terms of an S-wave $I = 2$ $\pi\pi$ elastic amplitude interfering with the resonant $I = 1$ P-wave state. A slowly varying $\pi\pi$ S-wave phase shift of approximately -15^o accounts adequately for the observed angular asymmetry.[2] The purpose of this letter is to provide a different interpretation for the asymmetry which leads to a clearer understanding of some related features of the $p\pi^\pm\pi^o$ production process. Specifically we show that data on the reaction $\pi^+ p \rightarrow \pi^+ \pi^o p$ obtained

in a bubble chamber study of $\pi^+ p$ interactions at 3.7 GeV/c can be well understood in terms of a model in which ρ^+ production and diffractive dissociation of the proton have amplitudes which are coherent and interfere destructively for $\pi\pi$ masses below the ρ mass and constructively above it. This new interpretation may well be equivalent to the OPE approach at the pion pole and hence does not necessarily invalidate the determination of $\pi\pi$ phase shifts, provided that this determination involves extrapolation from a small enough region of momentum transfer.

The experimental data consist of 4717 events in the channel $\pi^+\pi^o p$ obtained from an exposure of the 72-inch LRL bubble chamber to a 3.7 GeV/c π^+ beam.[3] The main peripheral contributions, clearly shown in the Chew-Low plots of Figs. 1a-c, are,

$$\pi^+ p \rightarrow \pi^o \Delta^{++} \quad , \tag{1a}$$

$$\pi^+ p \rightarrow \pi^+ [p\pi^o]^+ \quad , \tag{1b}$$

$$\pi^+ p \rightarrow \rho^+ p \quad . \tag{1c}$$

The process (1b), which denotes the observed production of a highly peripheral enhancement in the $p\pi^o$ mass region from threshold to about 1800 MeV, is interpreted as diffractive dissociation of the incident proton into the final $p\pi^o$ state. Although the reaction $\pi^+ p \rightarrow \pi^+ \Delta^+$ makes some contribution to the peripheral events seen in Fig. 1b, this contribution is only a small part of the enhancement actually observed. Presumably this enhancement contains contributions from many of the $N^*_{1/2}$ resonances although these are not well resolved. Furthermore as already pointed out by Boesebeck et al.,[4] there are contributions from the mass region below 1400 MeV where no $N^*_{1/2}$ resonances have been established in pion-nucleon phase shift analyses.

To exhibit most clearly the existence of interference between diffractive dissociation and ρ^+ production in their region of overlap, we show in Figs.

2a-e scatter plots of $\pi\pi$ mass-squared versus four-momentum-transfer-squared between incident and outgoing proton, and in Figs. 3a-e the $\pi\pi$ mass projections within the momentum-transfer interval $-t_p < 0.5$ $(\text{GeV/c})^2$. These plots and projections are shown for various regions of cos α where α is the polar decay angle of the $\pi\pi$ system in the Jackson frame. In interpreting these figures, it should be remembered that cos α is closely related to the value of t_π, the squared four-momentum-transfer between incident and outgoing π^+. Forward values of α correspond to small values of $-t_\pi$, i.e., the region in which diffractive dissociation is important (Fig. 1b). Indeed the range $1 \geq \cos\alpha \geq 0.8$ roughly corresponds to $0 > t_\pi > -0.07$ $(\text{GeV/c})^2$ near the ρ region.

In Figs. 2a and 3a the large populations for $\pi\pi$ masses above the ρ mass arise from proton diffractive dissociation [(1b) above], and are seen principally in the bin $1 \geq \cos\alpha \geq 0.8$ because of their peripheral behavior. The striking feature in these two figures is the very sharp cutoff in event population for $\pi\pi$ mass just below 700 MeV. Indeed this population is lower than what one would expect from either the ρ alone or the background alone and is therefore easily understood only in terms of an interference effect. The large magnitude of this effect can be gauged from the fact that the $\pi\pi$ mass peak in the histogram of Fig. 3a is shifted upward by about 60 MeV. A fit of the mass spectrum of Fig. 3a to phase space plus a ρ resonance of adjustable mass leads for this forward interval of cos α to a fitted ρ central value of 838 ± 15 MeV. The absence of similar interference effects in other ranges of cos α including the backward region (not shown in Figs. 2 or 3) suggests interference between ρ production and the only process concentrated at forward values of α (small t_π), namely, the diffractive dissociation.

To make a more quantitative test of this idea, we have represented the populations of Fig. 3 by an amplitude of the form

$$A = A_\rho + A_d \qquad (2)$$

where the ρ amplitude was approximated by,

$$A_\rho \propto \frac{1}{(m_\rho^2 - m^2) - i\Gamma m_\rho} [a \cos\alpha + b(\sin\alpha\, e^{i\varphi} + \sin\alpha\, e^{-i\varphi})] \qquad (3a)$$

and the diffractive amplitude by,

$$A_d \propto e^{(\gamma/2)t_\pi} e^{i\delta} . \qquad (3b)$$

In Eq. (3) m is the $\pi\pi$ mass, φ is the Treiman-Yang angle, δ is a constant phase to be adjusted by fitting to the data and γ represents an average slope for the angular distribution of the diffractive process. The value of γ is taken from the data to be 5.5 $(\text{GeV/c})^{-2}$, and the value of t_π is expressed in terms of cos α. The φ dependence of the interference terms is assumed to average to zero, and therefore only the angular coefficient a, taken to be $\sqrt{\rho_{00}}$, appears in the interference term.[5] The ρ production density matrix element ρ_{00} has a measured average value of 0.46 in the range of t_p under consideration. From a separate fit to the $\pi\pi$ mass spectrum between $-0.5 \leq \cos\alpha \leq 0.5$, which is almost pure ρ, the values $m_\rho = 765 \pm 8$ MeV and $\Gamma = 170 \pm 30$ MeV are obtained. With this input, the $\pi\pi$ mass spectrum, calculated from the absolute square of the amplitude (2) multiplied by an appropriate phase space factor, was fitted to the experimental data in Figs. 3a-e. The resulting fit gives $\delta = 170^\circ \pm 6^\circ$ with $\chi^2 = 61$ for 49 degrees of freedom. The corresponding $\pi\pi$ mass spectra are given by the curves shown in Figs. 3a-e. Both the χ^2 and the curves of Fig. 3 indicate remarkably good agreement between the data and the model, especially when account is taken of its very

approximate nature. It is worth noting that removal of the interference term in the absolute square of the amplitude (2) leads to only a very poor fit of the data ($\chi^2 = 101$).

It is interesting to see if these results are compatible with the simplest Regge exchange diagrams that one might choose to represent ρ production and diffractive dissociation. We assume ρ production to be represented by Reggeized pion exchange and diffractive dissociation by Pomeranchukon exchange. We further suppose that in the diffractive process, the final $p\pi^o$ state, spanning numerous resonances, on the average contributes an imaginary phase. Since the $\pi^+\pi^o$ phase is automatically incorporated in the Breit-Wigner part of (3a), the angle δ contains the 90^o average contribution of the $p\pi^o$ final state interaction plus the phase difference between the Pomeranchukon and pion propagators, which is also about 90^o. Thus δ is expected to be zero or 180^o in good agreement with the experimental value of 170 ± 6^o.[6]

It is easily seen that the interference effects just discussed lead to distributions of cos α with asymmetries which depend upon $\pi^+\text{-}\pi^o$ mass in just the manner described at the beginning of this paper; and, in this sense, our model also provides an interpretation of these asymmetries. However the converse procedure of interpreting the ππ angular distributions over the relatively large momentum transfer range under study ($-t_p \leq 0.5$ (GeV/c)^2) as representing $\pi^+\text{-}\pi^o$ elastic scattering dominated by a resonant P-wave interfering with an I = 2 S-wave having a phase shift of roughly -15^o does <u>not</u> lead in a natural way to the mass distributions of Fig. 3. Indeed if we assume that $\pi^+\text{-}\pi^o$ mass distributions at a given value of cos α are roughly proportional to $\frac{d\sigma(\pi^+\pi^o)}{d\Omega}$, the upward mass shift calculated for Fig. 3a is less than 10 MeV instead of the much larger value actually observed. Thus the model presented here gives a much better description of the data

than a one-pion-exchange amplitude applied to the rather large momentum transfer range covered. It is essential however to emphasize that our description is not in any sense incompatible with an OPE model at the pion pole. Indeed this compatibility is in accord with the duality arguments made by Chew and Pignotti.[7]

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REFERENCES

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1. See, for example, P. E. Schlein, Review of Some Experimental Results on the $\pi\pi$ and $K\pi$ Interactions, Lecture Notes for the International School of Subnuclear Physics, Erice, Sicily (1970).

2. J. P. Baton, G. Laurens, and J. Reignier, Phys. Letters 33B, 528 (1970).

3. Further details are given in the thesis of J. MacNaughton, Lawrence Radiation Laboratory Report UCRL-20178 (1971), unpublished.

4. K. Boesebeck et al., Nucl. Phys. B28, 381 (1971).

5. The amplitude (3a) actually represents a pure state producible by exchange of an unnatural spin-parity system. In the real ρ production process, the effective value of the angular coefficient a in the interference term is $\leq \sqrt{\rho_{00}}$.

6. We have neglected in this discussion any interference between $\pi^+\Delta^+$ and ρ^+p final states. In fact we have observed very little interference between $\pi^o\Delta^{++}$ and ρ^+p. From this we conclude that the $\pi^+\Delta^+$ state makes very little contribution to the observed effects.

7. G. F. Chew and A. Pignotti, Phys. Rev. Letters 20, 1078 (1968).

FIGURE CAPTIONS

Fig. 1. Chew-Low plots for the reaction $\pi^+ p \rightarrow \pi^+ \pi^o p$.

Fig. 2. Scatter plots of $-t'_p$ vs $\pi^+\pi^o$ mass squared. The value of $-t'_p$ is the momentum transfer squared between incident and final proton minus the kinematic minimum corresponding to each particular value of $\pi^+\pi^o$ mass. These plots correspond to various ranges of cos α, where α is the $\pi\pi$ decay angle in the Jackson frame, as follows: (a) $1 \geq \cos \alpha \geq 0.8$, (b) $0.8 \geq \cos \alpha \geq 0.6$, (c) $0.6 \geq \cos \alpha \geq 0.4$, (d) $0.4 \geq \cos \alpha \geq 0.2$, (e) $0.2 \geq \cos \alpha \geq 0$.

Fig. 3. $\pi^+\pi^o$ mass spectra for $-t_p < 0.5$ $(\text{GeV}/c)^2$ for the same angular ranges as in Fig. 2. The curves are from the fit described in the text. Although the bins shown are the ones used in the fit and are not all the same size, the ordinates do give events per unit bin width. The vertical lines denote $m_{\pi\pi} = 765$ MeV, the expected ρ central value.

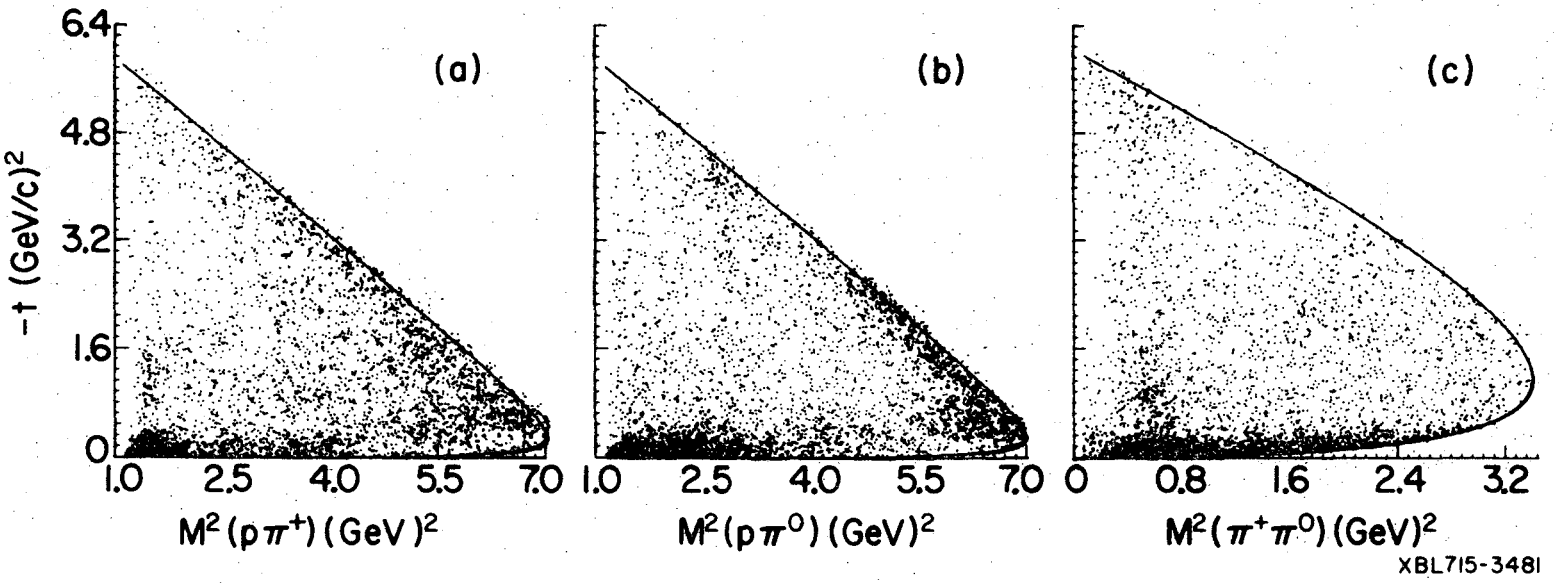
6.4
4.8
3.2
1.6
0
-t (GeV/c)²
(a)
(b)
(c)
1.0
2.5
4.0
5.5
7.0
0
0.8
1.6
2.4
3.2
M²(pπ⁺) (GeV)²
M²(pπ⁰) (GeV)²
M²(π⁺π⁰) (GeV)²
XBL715-3481

Fig. 1

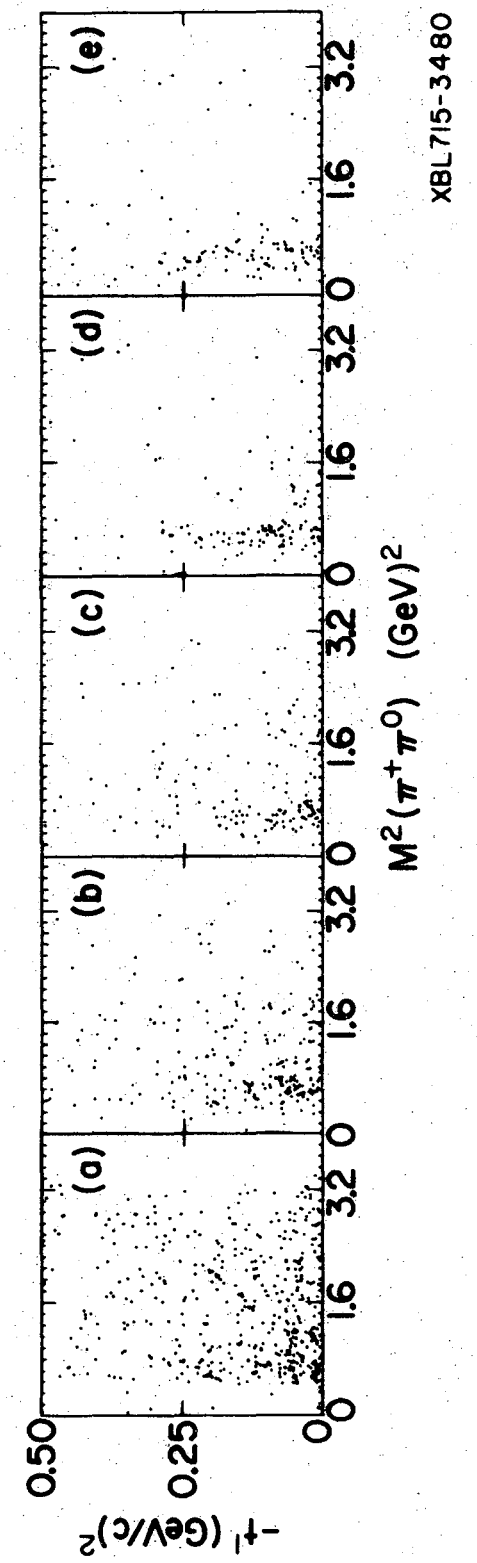

Fig. 2

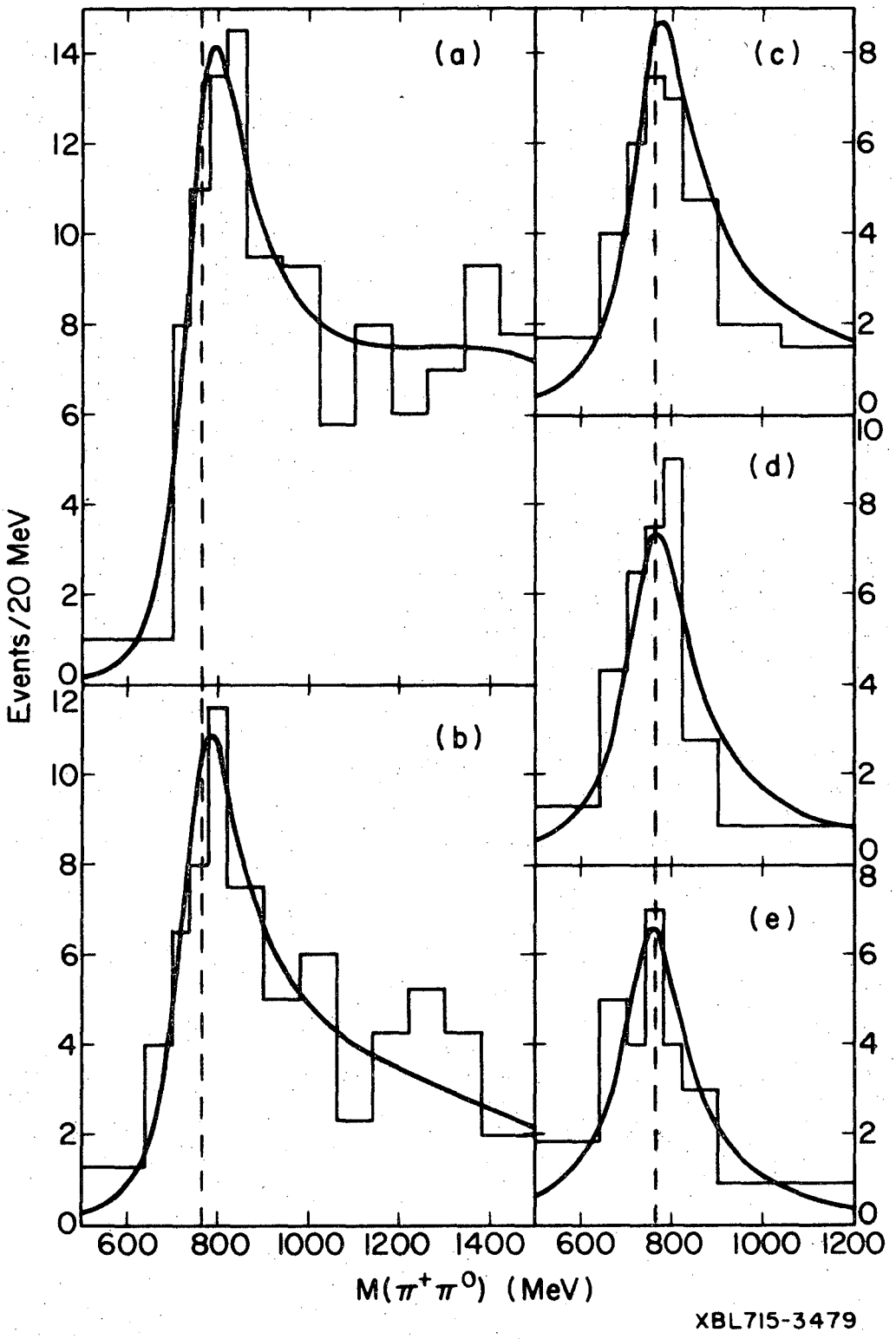
(a)
(b)
(c)
(d)
(e)
Events/20 MeV
M(π⁺π⁰) (MeV)
600
800
1000
1200
1400
XBL715-3479

Fig. 3

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