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TWO VARIATIONS ON A RHO-PRIME THEME: DATA FROM LASS AND MARK III*

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ABSTRACT

A brief summary is presented of results pertaining to excited states of the $\rho(770)$ obtained from analyses of LASS and MARK III data. The interpretation of these states in the context of the quark model is discussed.

Introduction

This paper provides a brief summary of an analysis of the dipion system produced in the reaction

$$K^- p \rightarrow \pi^- \pi^+ \Lambda \quad (\sim 26000 \text{ events}) \qquad (1)$$

at 11 GeV/c incident momentum, and of a quasi-two-body $\rho\pi$ description of the decay

$$J/\psi \rightarrow \pi^- \pi^+ \pi^0 \quad (\sim 28000 \text{ events}) \qquad (2)$$

in the full dimensionality of the three-pion final state. The data on reaction (1) were obtained using the LASS spectrometer at SLAC; the event selection criteria, analysis procedures and results are described in detail in ref.1. Reaction (2) was studied using the MARK III spectrometer at the SPEAR storage ring facility at SLAC; the data sample corresponds to 5.8×10^6 produced J/ψ events. Experimental and analysis procedures are described in ref.2, which also contains a detailed discussion of the preliminary results.

Reaction (1) yields evidence for an excited state of the $\rho(770)$, the $\rho_1(1300)$, while the analysis of reaction (2) requires the existence of a second such excited state, the $\rho_1(1600)$. These results are summarized and discussed in the context of the quark model in the following sections.

$\rho_1(1300)$ Production in Reaction (1).

The Dalitz plot for reaction (1) is shown in Fig.1. The $\pi^-\pi^+$ system exhibits strong production of the $\rho(770)$, a clear band at the $f_2(1270)$ and faint evidence for the $\rho_3(1690)$. In order to amplitude analyse the dipion system, events corresponding to the strong production of $\Sigma^+(1385)$ and higher mass Σ states (cf. Fig.1) are removed. After correction for this loss of acceptance, the mass dependence of the resulting P_+ dipion amplitude and phase (relative to D_+) are as shown in Fig.2; the sub-script "+" indicates that the dipion system is produced via natural parity exchange in the t-channel. The structure at the ρ peak is due to $\rho-\omega$ interference, and is well-described in the standard manner.[1] A description of the observed mass dependence in terms of the $\rho(770)$ alone is inadequate (cf. the dashed curves in Fig.2), while the inclusion of a second P-wave Breit-Wigner resonance yields an excellent description of the data (cf. the

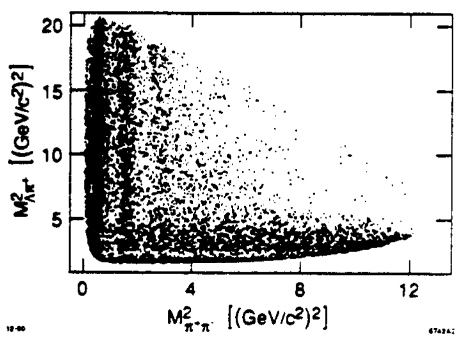

Figure 1. The Dalitz plot for reaction (1) (26462 events).

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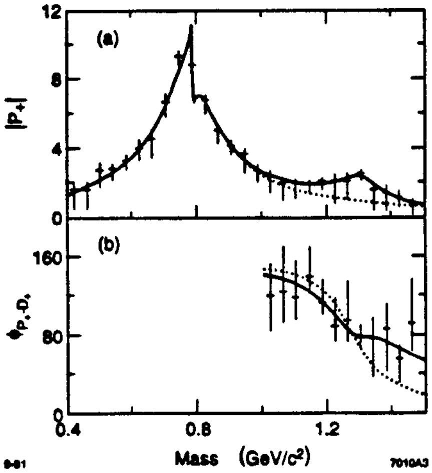

Figure 2. The mass dependence of (a) the P_+ amplitude, and (b) the P_+-D_+ phase resulting from the amplitude analysis of the dipion system produced in reaction (1); the curves are described in the text.

solid curves of Fig.2). This excited state of the $\rho(770)$ has mass (1302 $^{+28}_{-25}$) MeV/c^2, width (140 $^{+48}_{-40}$) MeV/c^2, and an estimated elasticity $\sim$ 5%; it is designated the $\rho_1(1300)$.

Evidence for $\rho_1(1600)$ from Reaction (2).

The Dalitz plot for reaction (2) is shown in Fig. 3; its main features are the bands associated with the three charge configurations of the $\rho(770)$, and the almost complete absence of events near the center of the plot. It is natural to attempt to represent the amplitude describing reaction (2) in terms of the sequential two-body decay processes $J/\psi \to \rho\pi$ and $\rho \to \pi\pi$. A maximum likelihood fit to the data using a properly-symmetrized amplitude of this kind is able to reproduce the data distributions in the vicinity of the ρ bands reasonably well; however, the Dalitz plot corresponding to the fitted intensity distribution shows no depletion near the center.[2]

The reason for this failure is shown in Fig.4. For each dipion, the events for which the helicity cosine ($\cos\theta_1$) of each of the daughter pions satisfies $|\cos\theta_1| \leq 0.2$ are selected; this eliminates reflections due to $\rho(770)$ production in the other dipion combinations. The resulting dipion mass distributions are combined and shown as the data points in Fig.4. The curve in Fig.4 corresponds to the $\rho(770)$ line-shape. In the mass range $\sim$ 0.9-1.3 GeV/c^2 the data points are significantly above the extrapolated ρ line-shape, while in the region above $\sim$ 1.4 GeV/c^2 they exhibit a dramatic drop below the curve; the rise in the data above $\sim$ 1.9 GeV/c^2 is due to residual reflection from the other ρ bands.

The conclusion to be drawn from Fig.4 is that a parametrization in terms of the $\rho(770)$ alone is incapable of reproducing the dipion mass dependence of the data on reaction (2).

The mass dependence of Fig.4 is very similar to that of the pion form factor for mass values up to $\sim$ 1.6 GeV/c^2;[3,4] however, the data of ref.4 have a peak in the region 1.7-1.8 GeV/c^2 which is not present in Fig.4. The data of ref.3 are well-described by including the $\rho(770)$ and significant coherent contributions from two $J^{PC}=1^{--}$ excited

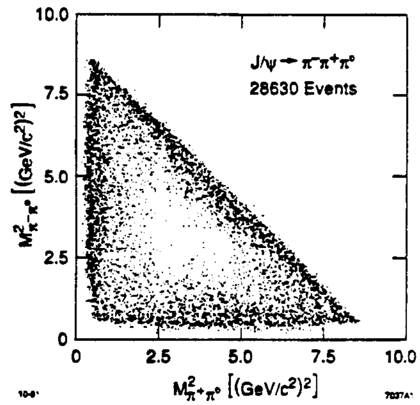

Figure 3. The Dalitz plot for reaction (2) (28630 events).

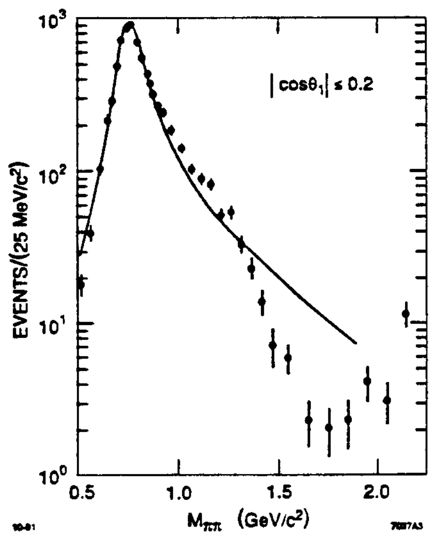

Figure 4. The $\pi\pi$ mass distribution from reaction (2) for $|\cos\theta_1| \leq 0.2$; the distributions for the different dipion charge configurations have been combined; the curve corresponds to the ρ line-shape, as described in the text.

states of mass $\sim$ 1.3 GeV/c^2 and $\sim$ 1.6 GeV/c^2. Motivated by this, the data on reaction (2) were re-fit using a dipion mass dependence, $F(\mathrm{m})$, given by

$$F(\mathrm{m}) = B(\mathrm{m}, \rho(770)) + c_1 e^{i\beta_1} B(\mathrm{m}, \rho_1(1300)) + c_2 e^{i\beta_2} B(\mathrm{m}, \rho_1(1600)), \quad (3)$$

where the functions B represent Breit-Wigner amplitudes, and m is the mass of the dipion system in question. In this expression, c_1, c_2, β_1 and β_2 are taken to be constants whose values are the same for all three dipion charge configurations, and which are to be determined by the likelihood fit. The results of the fit indicate that the contribution due to the $\rho_1(1300)$ is small; consequently, the mass and width of this state are fixed at the values obtained in the LASS analysis,[1] namely 1302 and 140 MeV/c^2, respectively. The contribution due to the $\rho_1(1600)$ proves to be large, and so the mass and width of this state are left free in the fit.

The fit yields the mass and width of the $\rho(770)$ as (776.2 $\pm$ 1.3) MeV/c^2 and (150.6 $\pm$ 2.4) MeV/c^2 respectively; the corresponding values for the $\rho_1(1600)$ are (1600 $\pm$ 28) MeV/c^2 and (383 $\pm$ 25) MeV/c^2, where the errors are purely statistical. In addition, it is estimated that the elasticities of the ρ states are given by

$$\sqrt{x_\rho(770)} : \sqrt{x_\rho(1300)} : \sqrt{x_\rho(1600)} = 1 : 0.031 \pm 0.016 : 0.508 \pm 0.017$$

where x denotes the elasticity i.e. the elasticities are approximately in the ratio 1: 10^{-3} :0.25.

Discussion of the Fit to Reaction (2).

The fit to the data on reaction (2) is of very good quality; in particular, the non-$\rho(770)$ structure of Fig.4 is well-reproduced as is the observed depopulation at the center of the Dalitz plot.[2] This is illustrated in Fig.5, where the data points are the result of applying the same selection criteria as for Fig.4 to the data sample used in the fit, and the histogram corresponds to the resulting fitted intensity distribution.

The fitted value of the $\rho(770)$ width is consistent with the PDG value,[5] however the mass value differs significantly from the PDG value, namely (768.7 $\pm$ 0.7) MeV/c^2. It should be noted that the value obtained in the present analysis agrees very well with the high statistics results of Barkov et al.[3] ((775.9 $\pm$ 1.1) MeV/c^2) and Hyams et al.[6] ((778 $\pm$ 2) MeV/c^2).

The mass, width and elasticity estimate for the $\rho_1(1600)$ are in good agreement with the results

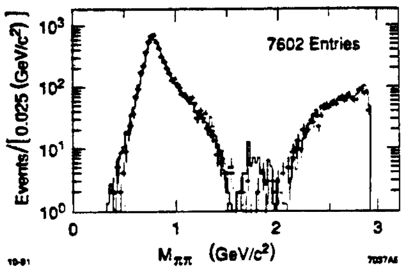

Figure 5. The $\pi\pi$ mass distribution from reaction (2) for those events in the analysis sample satisfying $|\cos\theta_1| \leq 0.2$ (data points); the distributions for the different dipion charge configurations have been combined; the histogram corresponds to the fit described in the text.

from $\pi\pi$ scattering phase shift analyses.[7] In ref.7 it is concluded that the preferred P-wave solution contains a resonance of mass $\sim$ 1575 MeV/c^2, width $\sim$ 340 MeV/c^2 and elasticity in the range 15-30%, all of which are in accord with the results from the fit to reaction (2). However, the estimate of the elasticity of the $\rho_1(1300)$ is much lower than the value $\sim$ 5% obtained in the LASS analysis.[1] This suggests that the coupling of the J/ψ to this state may be much weaker than that to the $\rho(770)$ or to the $\rho_1(1600)$.

The data of Bisello et al.[4] on the pion form factor seem to require a fourth ρ state of mass $\sim$ 1720 MeV/c^2. Preliminary indications are that the inclusion of such a state in the fit to reaction (2) leads to an improved fit to the dip in Fig. 4, and to a better description of the central region of the Dalitz plot. This result, together with the values of all relevant branching fractions, will appear in a future publication containing the final results of the analysis.

Conclusion.

In the context of the quark model, the most likely interpretation of the $\rho_1(1600)$ is that it is a partner of the $\rho_3(1690)$ in the D-wave ground state triplet i.e. it is the 1^3D_1 state. The much lower mass and small elasticity of the $\rho_1(1300)$ observed in reaction (1) suggest that this state may be the first radial excitation of the $\rho(770)$ i.e. it is the 2^3S_1 state. Similarly, if there is indeed a fourth state at $\sim$ 1.7 GeV/c^2, its mass and weak coupling to J/ψ suggest that it might be the second radial excitation of the $\rho(770)$ i.e. the 3^3S_1 state. However, these assignments may constitute an over-simplification in the sense that the $^3S_1$ and $^3D_1$ states can mix in principle, so that the observed states may not be in one-to-one correspondence with the pure quark model states.

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