PHOTOPRODUCTION OF $\rho\rho$ and ρf SYSTEMS

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ABSTRACT

A study is made of photoproduction of $\rho\rho$, ρf , $\rho\omega$ and $\omega\omega$ systems, produced with masses > 1.8 GeV at high Feynman x_F by photons of energy 20-70 GeV. There is evidence for a peak at a mass of ~ 2.3 GeV with a width of ~ 0.25 GeV in $\rho^0 f^0$ and $\rho^\pm f^0$ combinations. Angular distributions, in the 4π c.m. system, are found to be isotropic for these states, in sharp contrast to the strongly peaked angular distribution found for $\rho^0 \rho^0$ combinations at the same mass.

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1. INTRODUCTION

Photoproduction has been studied of meson systems, M , by diffractive dissociation of the photon in the reaction

$$\gamma + p \rightarrow M + p \quad (1)$$

(for examples, see Refs. 1-3). Such diffractive dissociation has the merit of selecting particular meson systems for study, especially vector mesons. This paper reports on another procedure which selects an alternative set of meson systems, M' , produced inclusively in the reaction

$$\gamma + p \rightarrow M' + X \quad (2)$$

with a small degree of inelasticity.

Meson systems, M' , are selected when produced with large Feynman x_F , so that the recoiling baryon systems, X , have relatively small masses. Such mildly inelastic production should have important contributions from triple-Regge processes (see Fig. 1, and for a review see Ref. 4), and in particular from the exchange of the highest trajectories: the degenerate ρ , ω , A_2 and f trajectories. Hence one would expect to see, at large Feynman x_F , production of meson states which couple relatively strongly to a photon and one of the mesons on these trajectories. A particular example [5] is photoproduction by a triple-Regge process involving ρ^0 or ω^0 exchange, which should produce the same meson states as are produced in $\gamma\gamma$ collisions with related cross-sections.

A search has been made for photoproduction of $\rho\rho$, $\rho\omega$ and $\omega\omega$ states with $x_F \geq 0.7$. This search has used data sets with $M' = \pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^0\pi^0$, $\pi^+\pi^-\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$.

Particular results are a strong anisotropy in the $\rho^0\rho^0$ angular distribution, which indicates $\rho^0\rho^0$ elastic scattering, and a peak at a mass ~ 2.3 GeV, with a width ~ 0.25 GeV, in production of $\rho^0(\pi^+\pi^-)$ and of $\rho^+(\pi^+\pi^-)$ with, in both cases, a peak in the $(\pi^+\pi^-)$ mass spectrum which is consistent with decay of the f^0 -meson or possibly of the $\epsilon(1300)$.

2. EXPERIMENTAL PROCEDURE

The data-sets used result from two photoproduction experiments in the Omega spectrometer at the CERN SPS (WA4 and WA57) in which a tagged photon

beam [6], with photons of energies 20-70 GeV, interacted in a 60 cm hydrogen target. The resulting charged particles were detected in the Omega spectrometer and gamma-rays were detected in the large photon detector. The two experiments had different trigger requirements:

i) The WA4 experiment required 4-9 charged particles to be detected in a forward MWPC. The $\pi^+ \pi^- \pi^+ \pi^-$ data-set was taken from the results of this experiment.

ii) The WA57 experiment required 2-5 charged particles to be detected in a forward MWPC and at least one gamma-ray to be detected in the photon detector. The $\pi^+ \pi^+ \pi^- \pi^0$, $\pi^+ \pi^- \pi^0 \pi^0$, $\pi^+ \pi^- \pi^+ \pi^- \pi^0$ and $\pi^+ \pi^- \pi^+ \pi^- \pi^0 \pi^0$ data-sets were taken from the results of this experiment.

The data-sets were first selected by requiring events with the appropriate charge combination of π mesons plus any number (including zero) of other detected particles. The most forward π mesons in the event were then selected, in order to reduce the very considerable combinatorial background while accepting systems with large x_F . 4π systems were selected if the four π mesons had the four largest momenta and the four smallest angles with respect to the incident photon beam. Events in which the same four π mesons satisfied both these criteria and in which those four π mesons had the required charge combination were then selected if x_F of the 4π system was greater than 0.7 ^{*)}. The 5π and 6π systems were selected if the four charged mesons had the four smallest angles with respect to the incident photon direction in the γp c.m. system of the charged particles in the event and these angles were less than 90° . When there were more π^0 mesons detected than the number needed to complete the required system, the one or two at smallest angles to the incident photon were selected. Finally the event was accepted if x_F of the 5π or 6π system was greater than 0.7.

The procedure for studying these selected events is described by reference to Fig. 2, which shows the application of the analysis procedure to a particular example; that of $\pi^+ \pi^- \pi^+ \pi^-$ systems with mass 2.0-2.6 GeV.

^{*)} x_F was calculated for each event by taking $x_F = 1$ to correspond to a meson system, M' , of the same mass recoiling against a proton mass.

Figure 2a shows the $\pi^+\pi^-$ mass spectrum (4 entries/event), which has a prominent peak due to the ρ^0 meson, indicating $\sim 0.35 \rho^0$ meson/event. To find what is in coincidence with these ρ^0 mesons the mass spectrum is studied of those $\pi^+\pi^-$ pairs which are in coincidence with a $\pi^+\pi^-$ pair with a mass in the range 0.6-0.9 GeV. This mass spectrum is referred to as the "opposite ρ peak spectrum" and is shown in Fig. 2b. The effect of the background under the ρ meson peak in Fig. 2a is then estimated as the mass spectrum of $\pi^+\pi^-$ pairs in coincidence with a $\pi^+\pi^-$ pair in either of the mass ranges 0.45-0.6 GeV or 0.9-1.05 GeV. The resulting estimate is referred to as the "opposite ρ wings" spectrum and is shown in Fig. 2c. The difference between these latter spectra, which is referred to as the "opposite peak-wings" spectrum, is an estimate of those $\pi^+\pi^-$ pairs which are in coincidence with ρ^0 mesons. This spectrum is shown in Fig. 2d. The results in Fig. 2 indicate that there are, in coincidence with ρ^0 mesons, two peaks at masses 0.76 and 1.25 GeV.

This peak-wings procedure was tested by applying it to Monte Carlo simulation of various models of 4π systems, assuming, respectively, $\rho\rho$, $\rho\pi\pi$ phase space and 4π phase space. Where ρ mesons are involved in these models, the events were generated with a probability which takes into account the fact that more than one $\pi\pi$ pair can be identified as a ρ meson. Calculation of this probability has been described [3] in detail previously so only a brief summary will be given here. For each possible ρ meson identification in an event a probability amplitude was written representing the ρ meson by a Watson final state interaction [7,8]. The amplitudes for all ρ meson identifications in one event were then added, and the sum squared to give the probability for the event. These sets of events were then passed through the same peak-wings analysis procedure. It was found that, primarily due to the interference between amplitudes from different identifications, events generated as $\rho\pi\pi$ for 4π masses less than 1.8 GeV could produce a ρ meson peak in the "opposite peak-wings" spectrum and so could give a false indication of $\rho\rho$ coincidence. For 4π masses greater than 1.8 GeV no such false indication was found, so we have restricted attention to masses > 1.8 GeV in the present work.

A further possible cause of false effects due to the peak-wings selection is a shoulder in the "opposite peak-wings" spectrum, which moved to

higher masses as 4π mass increases. [An example of this shoulder is seen in Fig. 4d, where it is at $M(\pi\pi) \sim 0.985$ GeV.] This shoulder complicates the analysis of the 1.25 GeV peak. However, both in experiment and in simulation, the shoulder was found to change position with 4π mass while the experimental peak did not. We therefore conclude that the 1.25 GeV peaks in Figs. 2d, 3a, 3b and 4h, is indication of a genuine peak produced in coincidence with a ρ meson.

Further evidence that these indications of coincidences are not due to kinematical artefacts is derived from the experimental observation that coincidence rates vary, with ρ -meson angle and with 4π mass, in a different way from the single ρ -meson rates. For example, with the selection to be shown in Fig. 3, the single ρ^0 -meson rate decreases by a factor of 2.3 on changing from polar angles to equatorial angles, while the number of coincidences with the 0.76 GeV peak changes by a larger factor and the number of coincidences with the 1.25 GeV peak does not change within errors.

Searches were made for $\omega\rho$ coincidences in the 5π data-set and for $\omega\omega$ coincidences in the 6π data-set by studying mass spectra opposite the ω -meson peak and wings in an analogous way. Simulations of $\omega\rho$ and $\omega\omega$ systems showed that there such kinematical problems were less severe, due to the narrower ω -meson peak.

The above simulations of the meson system, M' , were extended to a full simulation of reaction (2) by assuming the baryon system, X , to break up to p_T -limited phase space with a multiplicity chosen to correspond to reactions with a c.m. energy equal to the mass of X . Events generated according to this prescription were passed through a full simulation of the experimental apparatus, including a simulation of showering in the photon detector. These events accepted by the apparatus were then passed through the data analysis procedure to give an estimate of the acceptance, which was used to calculate cross-sections. For data-sets including π^0 mesons the acceptance was found to be very poor for events where the π^0 meson was going backward in the $n\pi$ c.m. system. In particular, acceptance was very poor for $\cos \theta(\rho^\pm) < -0.75$, where $\theta(\rho^\pm)$ is the angle of the $\rho^\pm$ meson with respect to the direction

of the incident photon in the 4π c.m. system. Hence for the $\pi^+\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\pi^0\pi^0$ data-sets events were only accepted if $|\cos \theta(\rho^\pm)| < 0.75$ to remove this range of angle in a symmetric way. Similarly for the 5π and 6π data-sets events were only accepted for $|\cos \theta(\omega)| < 0.75$. One uncertainty should be noted: the acceptance of the software cut used to select forward meson systems, which is calculated to be $\sim 1/2$, can depend on the model assumed for the break up of X. Changing the model of X to isotropic decay, which is a relatively extreme change, changed the calculated acceptance by $\sim 15\%$ for $\rho\rho$ states and by $\sim 25\%$ for $\omega\omega$ states.

In these simulations it was shown that the effects of experimental acceptance did not cause false indication of coincidences.

3. RESULTS

In the previous section features of inclusive production of coincidences of ρ^0 mesons with 0.76 and 1.25 GeV peaks have been shown for the example of $\pi^+\pi^-\pi^+\pi^-$ with masses of 2.0-2.6 GeV. No statistically significant observations of such coincidences in the $\pi^+\pi^-\pi^+\pi^-$ data-set could be made at lower 4π masses due to the considerable combinatorial background resulting from single ρ^0 -meson production.

Further detail is shown in Fig. 3 which shows "opposite peak-wings" spectra, for the same $\pi^+\pi^-\pi^+\pi^-$ mass range, where the first $\pi^+\pi^-$ pair is selected to be in either of two ranges of θ_ρ (the angle between the direction of the incident photon and the direction of the selected $\pi^+\pi^-$ pair in the 4π c.m. system)

- i) polar angles ($|\cos \theta_\rho| > 0.5$) : Fig. 3a
- ii) equatorial angles ($|\cos \theta_\rho| < 0.5$) : Fig. 3b

Figure 3 shows that ρ mesons are coincident with the 1.25 GeV peak with roughly equal probability in both ranges of angle, but that coincidences with the 0.76 GeV peak are essentially confined to polar angles.

The main features of coincidences with $\rho^\pm$ mesons deduced from the $\pi^+\pi^+\pi^-\pi^0$ data-set are shown in Fig. 4. Figures 4a and 4e show $\pi\pi$ mass spectra, for those cases where the $\pi\pi$ pair is neutral or singly

charged. Figures 4b and 4f show the mass spectra opposite the ρ (neutral or single charged) peak, while Figs. 4c and 4g show the corresponding "opposite ρ wings" spectra and Figs. 4d and 4h show the "opposite ρ peak-wings spectra". Figures 4f-h, for $M(4\pi) = 2.2-2.4$ GeV, show definite evidence for coincidences with peaks at 0.76 and 1.25 GeV, while Figs. 4b-d, for $M(4\pi) = 1.8-2.2$ GeV, show that such coincidences are not seen at that lower mass. The absence of coincidences with the 1.25 GeV peak at the lower mass can be due to the threshold, but the variation in production of coincidences with the 0.76 GeV peak indicates a dynamical effect. Further study of the data for $M(4\pi) = 2.2-2.4$ GeV, selecting the initial $\pi\pi$ pair to be either charged or neutral, shows that there is a 1.25 GeV peak in the "opposite $\rho^\pm$ peak-wings" spectrum while there is no significant 1.25 GeV peak in the "opposite ρ^0 peak-wings" spectrum. This result is consistent with the 1.25 GeV peak being due to an $I = 0$ meson.

Fits have been made to many "opposite ρ peak", "opposite ρ wings", and "opposite ρ peak-wings" spectra with two Breit-Wigner formulas, with fixed widths, and a cubic polynomial background. Examples of such fits are shown in Figs. 3a, 3b, and 4h. Assuming $M = 0.76$ GeV, $\Gamma = 0.14$ GeV for the lower peak gave fits with good χ^2 so a good identification can be made with the ρ meson. Fits to the 1.25 GeV peak are more of a problem due to the kinematical shoulder noted in the previous section. Better fits are obtained for relatively wide bins of 4π mass where the shoulder is more smeared out, but there is still some uncertainty in the results: good fits were obtained with $\Gamma \approx 0.22$ GeV and M in the range 1.22-1.30 GeV. These results are consistent with this peak being due to the f^0 meson, but one cannot rule out the possibility of it being due to a relatively narrow $\epsilon(1300)$, noting the wide range of positions and widths which can result from that state (as summarized by the Particle Data Group [9]). Both of these candidates for the peak have $I = 0$, in accord with the observation of the peak only in the neutral state. We refer to this peak as the f^0 meson hereafter.

Cross-sections have been deduced from the numbers of $\rho\rho$ and ρf coincidences derived from such fits. The numbers of ρf coincidences deduced depend on the mass and width assumed for the f meson. To obtain a reliable

estimate of the variation of ρf intensity, with 4π mass and ρ meson angle, fits were made assuming a fixed mass and width for the f meson.

The resulting cross-sections for production of $\rho^0 \rho^0$, $\rho^\pm \rho^0$, $\rho^+ \rho^-$, $\rho^0 f^0$ and $\rho^\pm f^0$ coincidences as a function of 4π mass are shown in Fig. 5. The errors shown indicate relative uncertainties, and do not include overall systematic errors such as are due to the uncertainty in target fragmentation or to the uncertainty in the fits to the f peak.

No significant signal for $\rho^0 \omega^0$ or $\omega^0 \omega^0$ coincidences was observed. Cross-sections for $|\cos \theta(\omega)| < 0.75$ have been calculated from intensities deduced from the "opposite ω peak-wings" spectra for total mass in the range 2.0-2.6 GeV. These cross-sections, though not significantly different from zero, are reported as indications of limits:

$$\begin{aligned} \rho^0 \omega^0 \text{ coincidences} &: 4.7 \pm 3.3 \text{ nb/0.2 GeV} \\ \omega^0 \omega^0 \text{ coincidences} &: 2.7 \pm 2.2 \text{ nb/0.2 GeV} \end{aligned}$$

(The units are chosen to be directly comparable with the cross-sections shown in Fig. 5.)

The dependences of yields of coincidences on the angle, θ_ρ , of the ρ meson, measured with respect to the incident gamma-ray direction in the 4π c.m. system, have been studied. For $\rho^0 \rho^0$ for $M(4\pi) = 2.0-2.6$ GeV:

$ \cos \theta_\rho $	Relative yield of $\rho^0 \rho^0$
0.5 $\rightarrow$ 1.0	1.00 ± 0.34
0.0 $\rightarrow$ 0.5	0.18 ± 0.23

and for $\rho^0 f^0$, for the same mass range,

$\cos \theta_\rho$	Relative yields of $\rho^0 f^0$
0.5 $\rightarrow$ 1.0	1.00 ± 0.26
0.0 $\rightarrow$ 0.5	0.88 ± 0.21
-0.5 $\rightarrow$ 0.0	0.83 ± 0.22
-1.0 $\rightarrow$ -0.5	0.97 ± 0.28

These results show a relatively isotropic angular distribution for $\rho^0 f^0$, but a peaked angular distribution for $\rho^0 \rho^0$, as was already demonstrated in Fig. 3. More detailed study of the $\rho^0 \rho^0$ angular distribution, in smaller bins of θ_ρ , shows that essentially all the $\rho^0 \rho^0$ coincidences are confined to $|\cos \theta_\rho| > 0.75$. For $\rho^+ \rho^-$ coincidences in the mass range 1.8-2.8 GeV relative ratios found were:

$$\begin{array}{lll} |\cos \theta(\rho^+)| < 0.5 & : & 1.01 \pm 0.36 \\ 0.5 < |\cos \theta(\rho^+)| < 0.75 & : & 0.99 \pm 0.25 \\ \cos \theta(\rho^+) < 0.0 & : & 1.06 \pm 0.29 \\ \cos \theta(\rho^+) > 0.0 & : & 0.94 \pm 0.34 \end{array}$$

These results indicate that any anisotropy in the $\rho^+ \rho^-$ angular distribution is smaller than that for $\rho^0 \rho^0$. A similar analysis was made for $\rho^\pm \rho^0$ and $\rho^\pm f^0$ in the mass range 2.2-2.4 GeV, which showed no significant departure from isotropy, but the statistical accuracy was poor.

The probability of these coincidences can be considered in terms of a degree of correlation, namely whether the number of coincidences is more (positive correlation) or less (negative correlation) than the random coincidence rate deduced from the observed production of single mesons. For example, for $2.0 < M(\pi^+ \pi^- \pi^+ \pi^-) < 2.6$ GeV, the number of ρ^0 mesons per event is ~ 0.35 while the number of $\rho^0 \rho^0$ coincidences/event is ~ 0.01 . For this case, of identical charges for the ρ mesons, there are various ways to estimate a random coincidence rate, but for any of them the result is distinctly larger than that observed. Hence the ρ^0 mesons have high probability of being produced singly, and the correlation is negative. As the number of coincidences observed is much smaller than the random rate, it could be thought that the observed coincidence rate is some small residue which has no particular dynamical significance.. However, the strong peaking observed in the $\rho^0 \rho^0$ angular distribution argues against this view. Similarly the $\omega^0 \omega^0$ coincidence rate is distinctly smaller than estimates of the random coincidence rate from the observed single ω^0 -meson rate. For $\rho^\pm \rho^0$, $\rho^0 f^0$ and $\rho^\pm f^0$ the correlations are positive, with the observed $\rho^\pm \rho^0$ rate being $\sim 3 \times$ random rate, and the number of ρf^0 coincidences being, in each case, consistent with all the f^0 mesons being in coincidence with a ρ meson.

4. DISCUSSION OF RESULTS

This paper reports inclusive production of pairs of meson resonances, with total mass > 1.8 GeV, in 4π , 5π and 6π systems with Feynman $x_F > 0.7$. In particular $\rho\rho$ and ρf coincidences are observed. [An alternative interpretation replacing the f with the $\epsilon(1300)$ has been noted.] The yields of these coincidences are reported as functions of mass and angle, showing significant peaks in mass for the ρf states and in angle for the $\rho^0\rho^0$ state.

A possible interpretation of the results is presented in terms of three contributions:

i) Production of a peak at a mass ~ 2.3 GeV, with a width ~ 0.25 GeV, in the $\rho^0 f^0$ and $\rho^\pm f^0$ states. These peaks could be due to a threshold effect or to a resonance.

ii) Elastic scattering of the ρ^0 component of the initial photon on an exchanged ρ^0 meson is observed in the $\rho^0\rho^0$ state, with this scattering having a typical p_T limited distribution with $\langle p_T \rangle \sim 0.35$ GeV/c. This scattering would be expected to be largely diffractive, so that any corresponding contribution to the $\rho^+\rho^-$ state from this process should be small.

iii) Production of a $\rho^+\rho^-$ state, with a slow fall of cross-section with increasing 4π mass. There is a stronger contribution in the central angular region than is observed for the $\rho^0\rho^0$ signal, which indicates a different mechanism.

The production of the peak in the ρf states is discussed first. As these states have $I^G = 1+$, production of the neutral state by a triple-Regge process involving the dominant ρ^0 meson component of the photon should be by f^0 exchange, which is in accord with the large production of $\rho^0 f^0$. Corresponding production of the charged state should be by $\rho^\pm$ exchange, so that the different coupling involved allows a possible explanation of the different cross-sections for production of the different charge states.

Assuming production by the mechanism in the preceding paragraph and decoupling between the production vertex and decay vertex, it is predicted that final state intensities should be related as

$$\frac{\rho^{\pm} f^0}{\rho^0 f^0} = \frac{\rho^+ \rho^-}{\rho^0 f^0} = \frac{\rho^{\pm} \rho^0}{\rho^{\pm} f^0} . \quad (3)$$

(Further detailed assumptions are equality of coupling of Reggeon and corresponding particle, and equality of ρp and $f p$ total cross-sections.) To compare these ratios for the present experiment one has to correct for the different angular ranges of the measurements. Assuming isotropic angular distributions they predict, from the observed peaks in $\rho^0 f^0$ and $\rho^{\pm} f^0$, a peak in $\rho^+ \rho^-$ of height ~ 40 nb/0.2 GeV and a peak in $\rho^{\pm} \rho^0$ of height ~ 6 nb/0.2 GeV. Within the systematic uncertainties this suggests an appreciable fraction of the $\rho^+ \rho^-$ cross-section for mass > 2.2 GeV could be due to this process. However, for production of $\rho^{\pm} \rho^0$ there must be a further large contribution to explain the experimental results.

Such a further contribution to production of $\rho^{\pm} \rho^0$ would be expected, due to elastic scattering of the ρ^0 meson component of the incident photon on an exchanged $\rho^{\pm}$. If this elastic scattering were diffractive and thus due to exchange of an $I = 0$ system, the expected $\rho^{\pm} \rho^0$ production should be twice as large as for $\rho^0 \rho^0$ in (ii) above. However, the diffractive $\rho^{\pm} \rho^0$ angular distribution should peak strongly at $\cos \theta (\rho^0) > 0.75$, for which range of angles the acceptance of the present experiment is poor. Hence with the present quality of data, there is no discrepancy with the predictions in Eq. (3). It is possible that there could be interference in $\rho^{\pm} \rho^0$ production between the elastic scattering and the 2.3 GeV peak.

Although most of the $\rho^+ \rho^-$ cross-section for mass > 2.2 GeV is consistent with the process just described, production of $\rho^+ \rho^-$ at lower masses must be explained otherwise. An $I = 0$ state is such a possible explanation, and would be consistent with a peak at lower masses such as, for example, that reported [10,11] in the reaction

$$\gamma + \gamma \rightarrow \rho^0 + \rho^0$$

or, for example, that reported [12] in the decay

$$J/\psi \rightarrow \gamma \rho^0 \rho^0 .$$

An $I^G = 1+$ state cannot decay to $\rho^0 \omega^0$ or to $\omega^0 \omega^0$, which explains the failure to observe the 2.3 GeV peak in these states. For $\rho^0 \omega^0$ and $\omega^0 \omega^0$ one would expect similar elastic scattering to that observed in $\rho^0 \rho^0$, but observation of this is inhibited by the lower ω^0 -meson component of the incident photon or by the very low acceptance for a backward-going ω^0 meson, or both. Hence it is reasonable that significant production of these states has not been observed in this experiment.

In conclusion, we report production of $\rho\rho$ and ρf systems at $x_F > 0.7$. That the largest cross-sections are for production of $\rho^0 \rho^0$ and $\rho^0 f^0$ systems is consistent with expectation from the predicted exchanges and the dominant ρ^0 meson component of the incident photon.

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Figure captions

- Fig. 1 : a) Diagram involved in triple-Regge process: the lower vertex involves the total collision of the exchanged Reggeon, R, with the incident proton.
b) Result of squaring the amplitude for (a) and summing over X, the products of the Rp collision. As this collision is represented by the exchange of the Pomeron, P, the inclusive production of M' should not fall with increasing photon energy.
- Fig. 2 : $\pi^+\pi^-$ mass spectra for forward $\pi^+\pi^-\pi^+\pi^-$ systems.
a) Total $\pi^+\pi^-$ mass spectrum.
b) "Opposite ρ peak" spectrum: mass spectrum of $\pi^+\pi^-$ pairs in coincidence with $\pi^+\pi^-$ with a mass in the range 0.6-0.9 GeV.
c) "Opposite ρ wings" spectrum: mass spectrum of $\pi^+\pi^-$ pairs in coincidence with $\pi^+\pi^-$ with a mass in one of the ranges 0.45-0.6 GeV or 0.9-1.05 GeV.
d) "Opposite ρ peak-wings" spectrum: the result of subtracting (c) from (b). This spectrum is taken to be an estimate of the $\pi^+\pi^-$ mass spectrum in coincidence with a ρ^0 meson.
- Fig. 3 : Opposite ρ peak-wings" spectra for forward $\pi^+\pi^-\pi^+\pi^-$ systems with a mass in the range 2.0-2.6 GeV, for two ranges of angle, θ_ρ , between the directions of the ρ^0 meson and the incident photon in the 4π c.m. system:
a) $|\cos \theta_\rho| > 0.5$
b) $|\cos \theta_\rho| < 0.5$
The curves shown are the results of fits assuming Breit-Wigner formulas for the ρ and f plus a cubic polynomial background.
- Fig. 4 : $(\pi\pi)^{+/-/0}$ mass spectra for forward $\pi^+\pi^-\pi^+\pi^-$ systems for $|\cos \theta_\rho| < 0.75$. Figures 4a-d are for 4π masses in the range 1.8-2.2 GeV; Figs. 4e-h are for 4π masses in the range 2.2-2.4 GeV.
a) and e) Total $(\pi\pi)^{+/-/0}$ mass spectra
b) and f) "Opposite $\rho^{+/-/0}$ peak" spectra
c) and g) "Opposite $\rho^{+/-/0}$ wings" spectra
d) and h) "Opposite $\rho^{+/-/0}$ peak-wings" spectra.

The curve shown on (h) is the result of a fit assuming Breit-Wigner formulas for the ρ and f , plus a cubic polynomial background.

Fig. 5 : Cross-sections, as a function of 4π mass, for production of

- a) $\rho^0 \rho^0$
- b) $\rho^0 f^0$
- c) $\rho^\pm \rho^0$
- d) $\rho^\pm f^0$
- e) $\rho^+ \rho^-$.

(a)

(b)

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5