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# A study of the $f_0(1370)$ , $f_0(1500)$ , $f_0(2000)$ and $f_2(1950)$ observed in the centrally produced $4\pi$ final states

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## Abstract

The production and decay properties of the  $f_0(1370)$ ,  $f_0(1500)$ ,  $f_0(2000)$  and  $f_2(1950)$  have been studied in central pp interactions at 450 GeV/c. The  $dP_T$ ,  $\phi$  and  $|t|$  distributions of these resonances are presented. For the  $J = 0$  states, the  $f_0(1370)$  and  $f_0(2000)$  have similar  $dP_T$  and  $\phi$  dependences. These are different to the  $dP_T$  and  $\phi$  dependences of the  $f_0(980)$ ,  $f_0(1500)$  and  $f_0(1710)$ . For the  $J = 2$  states the  $f_2(1950)$  has different dependences to the  $f_2(1270)$  and  $f_2'(1520)$ . This shows that the  $dP_T$  and  $\phi$  dependences are not just  $J$  phenomena.

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The WA102 collaboration has recently published a study of the centrally produced  $4\pi$  final states [1]. In this paper the production and decay properties of the resonances observed in these channels will be presented. In previous publications the properties of the  $f_1(1285)$  [2],  $\eta_2(1645)$  and  $\eta_2(1870)$  [3] have already been presented. In this paper the properties of the  $f_0(1370)$ ,  $f_0(1500)$ ,  $f_0(2000)$  and  $f_2(1950)$  will be discussed.

In previous analyses it has been observed that when the centrally produced system has been analysed as a function of the parameter  $dP_T$ , which is the difference in the transverse momentum vectors of the two exchange particles [4, 5], all the undisputed  $q\bar{q}$  states (i.e.  $\eta$ ,  $\eta'$ ,  $f_1(1285)$  etc.) are suppressed at small  $dP_T$  relative to large  $dP_T$ , whereas the glueball candidates  $f_0(1500)$ ,  $f_0(1710)$  and  $f_2(1950)$  are prominent [6].

In addition, an interesting effect has been observed in the azimuthal angle  $\phi$  which is defined as the angle between the  $p_T$  vectors of the two outgoing protons. For the resonances studied to date which are compatible with being produced by DPE, the data [7] are consistent with the Pomeron transforming like a non-conserved vector current [8]. In order to determine the  $\phi$  dependence for the resonances observed, a spin analysis has been performed on the  $\pi^+\pi^-\pi^+\pi^-$  and  $\pi^+\pi^-\pi^0\pi^0$  channels in four different  $\phi$  intervals each of 45 degrees. As an example, fig. 1 shows the  $J^{PC} = 0^{++} \rho\rho$  wave from the  $\pi^+\pi^-\pi^+\pi^-$  channel in the four intervals. The waves have been fitted in each interval with the parameters of the resonances fixed to those obtained from the fits to the total data as described in ref [1]. The distributions found are consistent for the two channels and the fraction of each resonance as a function of  $\phi$  from the  $\pi^+\pi^-\pi^+\pi^-$  channel is plotted in fig. 2. The distributions observed for the  $f_0(1370)$  and  $f_0(1500)$  are similar to what was found in the analysis of the  $\pi^+\pi^-$  final state [9].

In order to calculate the contribution of each resonance as a function of  $dP_T$ , the waves have been fitted in three  $dP_T$  intervals with the parameters of the resonances fixed to those obtained from the fits to the total data as described in ref [1]. Table 1 gives the percentage of each resonance in three  $dP_T$  intervals together with the ratio of the number of events for  $dP_T < 0.2$  GeV to the number of events for  $dP_T > 0.5$  GeV for each resonance considered. The dependences found for the  $f_0(1370)$  and  $f_0(1500)$  are similar to what was found in the analysis of the  $\pi^+\pi^-$  final state [9].

The fact that the  $f_0(1370)$  and  $f_0(1500)$  have different  $\phi$  and  $dP_T$  dependences confirms that these are not simply  $J$  dependent phenomena. This is also true for the  $J = 2$  states, where the  $f_2(1950)$  has different dependences to the  $f_2(1270)$  and  $f_2'(1520)$  [9].

In order to determine the four momentum transfer dependence ( $|t|$ ) of the resonances observed in the  $\pi^+\pi^-\pi^+\pi^-$  channel the waves have been fitted in  $0.1 \text{ GeV}^2$  bins of  $|t|$  with the parameters of the resonances fixed to those obtained from the fits to the total data as described in ref [1]. Fig. 2 shows the four momentum transfer from one of the proton vertices for these resonances. The distributions have been fitted with a single exponential of the form  $\exp(-b|t|)$  and the values of  $b$  found are given in table 2. The values of  $b$  for the  $f_0(1370)$  and  $f_0(1500)$  are similar to what was found in the analysis of the  $\pi^+\pi^-$  final state [9].

The  $\phi$  distribution, the  $dP_T$  and  $t$  dependence of the  $f_2(1950)$  are different to what has been observed for other  $J^{PC} = 2^{++}$  resonances [9] but are similar to what was observed for the  $\phi\phi$  [10] and  $K^*(892)\bar{K}^*(892)$  [11] final states which were both found to have  $J^{PC} = 2^{++}$ . In order to see if the  $\phi\phi$  and  $K^*(892)\bar{K}^*(892)$  final states could be due to the  $f_2(1950)$ , the

parameters of the  $f_2(1950)$  have been used as input to a Breit-Wigner function which has been modified to take into account the different thresholds.

Superimposed on the  $\phi\phi$  mass spectrum in fig. 3a) is the distribution that could be due to the  $f_2(1950)$ . As can be seen, although the  $f_2(1950)$  can describe most of the spectrum, there is an excess of events in the 2.3 GeV mass region. Including a Breit-Wigner to describe the  $f_2(2340)$ , which has previously been observed decaying to  $\phi\phi$  [12], with  $M = 2330 \pm 15$  MeV and  $\Gamma = 130 \pm 20$  MeV gives the distribution in fig. 3b). Assuming that the  $f_2(1950)$  has a  $\phi\phi$  decay mode then correcting for the unseen decay modes the branching ratio of the  $f_2(1950)$  to  $f_2(1270)\pi\pi/\phi\phi$  was found to be  $72 \pm 9$ .

Superimposed on the  $K^{*0}\bar{K}^{*0}$  mass spectrum in fig. 3c) is the distribution that could be due to the  $f_2(1950)$ . As can be seen the  $f_2(1950)$  can describe all the  $K^{*0}\bar{K}^{*0}$  mass spectrum. Assuming that the  $f_2(1950)$  has a  $K^{*0}\bar{K}^{*0}$  decay mode then correcting for the unseen decay modes the branching ratio of the  $f_2(1950)$  to  $f_2(1270)\pi\pi/K^{*0}\bar{K}^{*0}$  was found to be  $33 \pm 4$ . In addition, the branching ratio of the  $f_2(1950)$  to  $\phi\phi/K^{*0}\bar{K}^{*0}$  above the  $\phi\phi$  threshold is  $0.8 \pm 0.14$ .

We have previously published a paper describing the decays of the  $f_0(1370)$  and  $f_0(1500)$  to  $\pi\pi$  and  $K\bar{K}$  [9]. In ref. [1] a fit has been performed to the  $\rho\rho$  and  $\sigma\sigma$  final states and the contributions of the  $f_0(1370)$  and  $f_0(1500)$  has been determined. After correcting for the unseen decay modes and the  $\sigma\sigma$  decay mode the branching ratio of the  $f_0(1500)$  to  $4\pi/\pi\pi$  is found to be  $1.37 \pm 0.16$ . In the initial Crystal Barrel publication this value was  $3.4 \pm 0.8$  [13]. In the latest preliminary analysis [14] of the Crystal Barrel data the value is  $1.54 \pm 0.6$ . Hence although the experiments disagree about the relative amount of  $\rho\rho$  and  $\sigma\sigma$  in the  $4\pi$  decay mode [1], the overall measured branching ratio is consistent.

After correcting for the unseen decay modes and taking into account the above uncertainties the branching ratio of the  $f_0(1370)$  to  $4\pi/\pi\pi$  is found to be  $34^{+22}_{-9}$ . The large error is due to the fact that there is considerable uncertainty in the amount of  $f_0(1370)$  in the  $\pi\pi$  final state due to the possible contribution from the high mass side of the  $f_0(1000)$ . In the latest preliminary analysis [14] of the Crystal Barrel data the value is  $12.2 \pm 5.4$ . A coupled channel fit of the  $\pi\pi$ ,  $K\bar{K}$ ,  $4\pi$ ,  $\eta\eta$  and  $\eta\eta'$  final states is in progress and will be reported in a future publication.

In summary, the  $dP_T$ ,  $\phi$  and  $|t|$  distributions for the  $f_0(1370)$ ,  $f_0(1500)$ ,  $f_0(2000)$  and  $f_2(1950)$  have been presented. For the  $J = 0$  states the  $f_0(1370)$  and  $f_0(2000)$  have similar  $dP_T$  and  $\phi$  dependences. These are different to the  $dP_T$  and  $\phi$  dependences of the  $f_0(980)$ ,  $f_0(1500)$  and  $f_0(1710)$ . For the  $J = 2$  states the  $f_2(1950)$  has different dependences to the  $f_2(1270)$  and  $f_2'(1520)$ . This shows that the  $dP_T$  and  $\phi$  dependences are not just  $J$  phenomena.

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Table 1: Production of the resonances as a function of  $dP_T$  expressed as a percentage of their total contribution and the ratio (R) of events produced at  $dP_T \leq 0.2$  GeV to the events produced at  $dP_T \geq 0.5$  GeV.

	$dP_T \leq 0.2$ GeV	$0.2 \leq dP_T \leq 0.5$ GeV	$dP_T \geq 0.5$ GeV	$R = \frac{dP_T \leq 0.2 \text{ GeV}}{dP_T \geq 0.5 \text{ GeV}}$
$f_0(1370)$	$11.0 \pm 2.0$	$32.9 \pm 3.0$	$56.1 \pm 4.9$	$0.19 \pm 0.04$
$f_0(1500)$	$23.8 \pm 2.5$	$47.3 \pm 4.5$	$28.8 \pm 2.9$	$0.83 \pm 0.12$
$f_0(2000)$	$11.9 \pm 1.3$	$37.7 \pm 3.2$	$50.2 \pm 4.1$	$0.23 \pm 0.03$
$f_2(1950)$	$27.4 \pm 2.4$	$45.5 \pm 5.1$	$27.1 \pm 2.4$	$1.01 \pm 0.12$

Table 2: The slope parameter  $b$  from a single exponential fit to the  $|t|$  distributions.

	$f_0(1370)$	$f_0(1500)$	$f_0(2000)$	$f_2(1950)$
$b/\text{GeV}^{-2}$	$5.8 \pm 0.5$	$5.1 \pm 0.4$	$5.6 \pm 0.4$	$5.9 \pm 0.4$

## Figures

Figure 1: The  $J^{PC} = 0^{++}$   $\rho\rho$  wave from the  $\pi^+\pi^-\pi^+\pi^-$  channel as a function of  $\phi$ . a)  $\phi < 45$  degrees, b)  $45 < \phi < 90$  degrees, c)  $90 < \phi < 135$  degrees and d)  $135 < \phi < 180$  degrees. The superimposed curves are the resonance contributions coming from the fits described in the text.

Figure 2: The  $\phi$  and four momentum transfer squared ( $|t|$ ) distributions for a), b) the  $f_0(1370)$ , c), d) the  $f_0(1500)$ , e), f) the  $f_0(2000)$  and g), h) the  $f_2(1950)$ .

Figure 3: a) and b) The  $\phi\phi$  and c) the  $K^*\overline{K}^*$  mass spectra with fits described in the text.

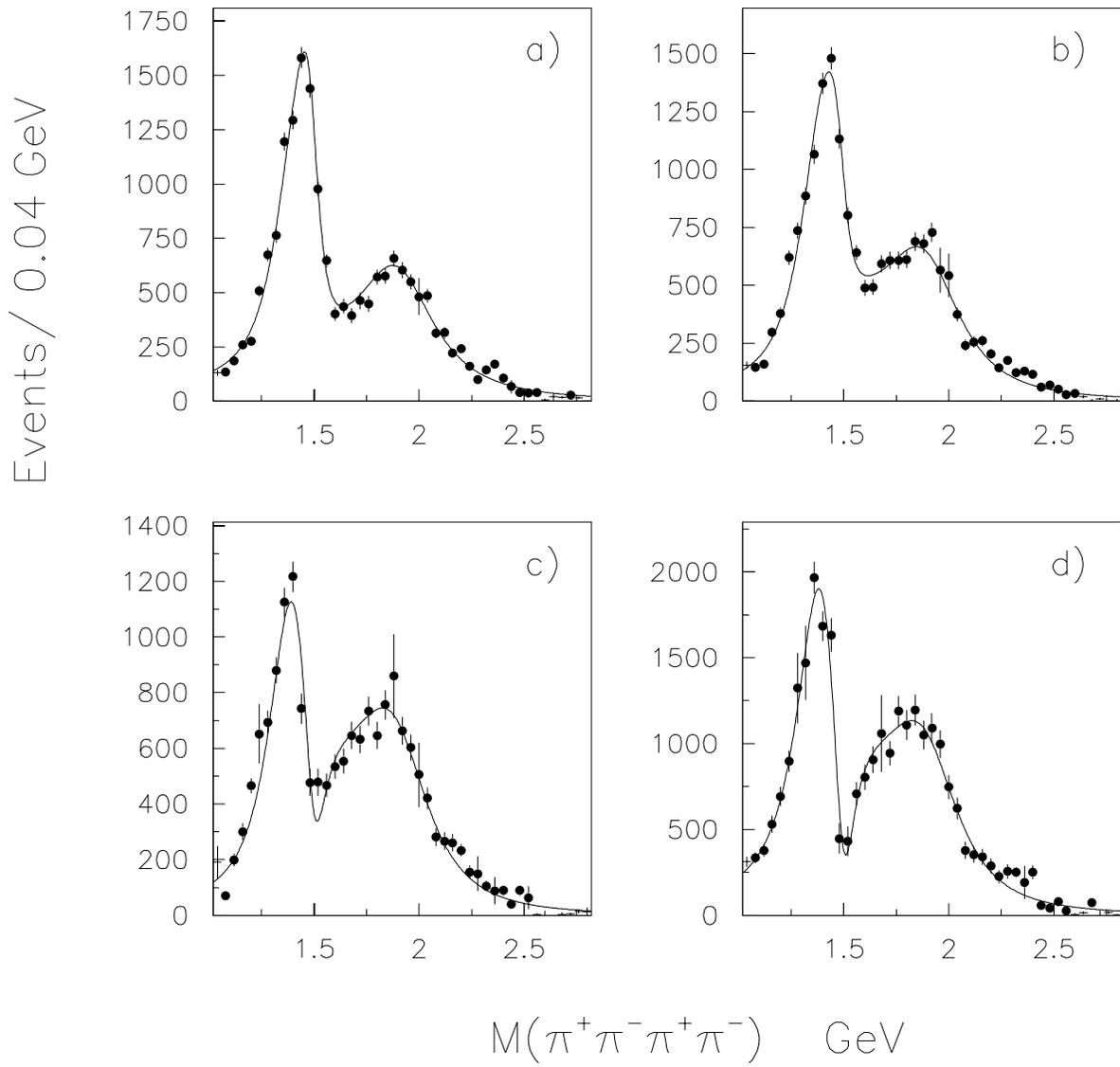


Figure 1

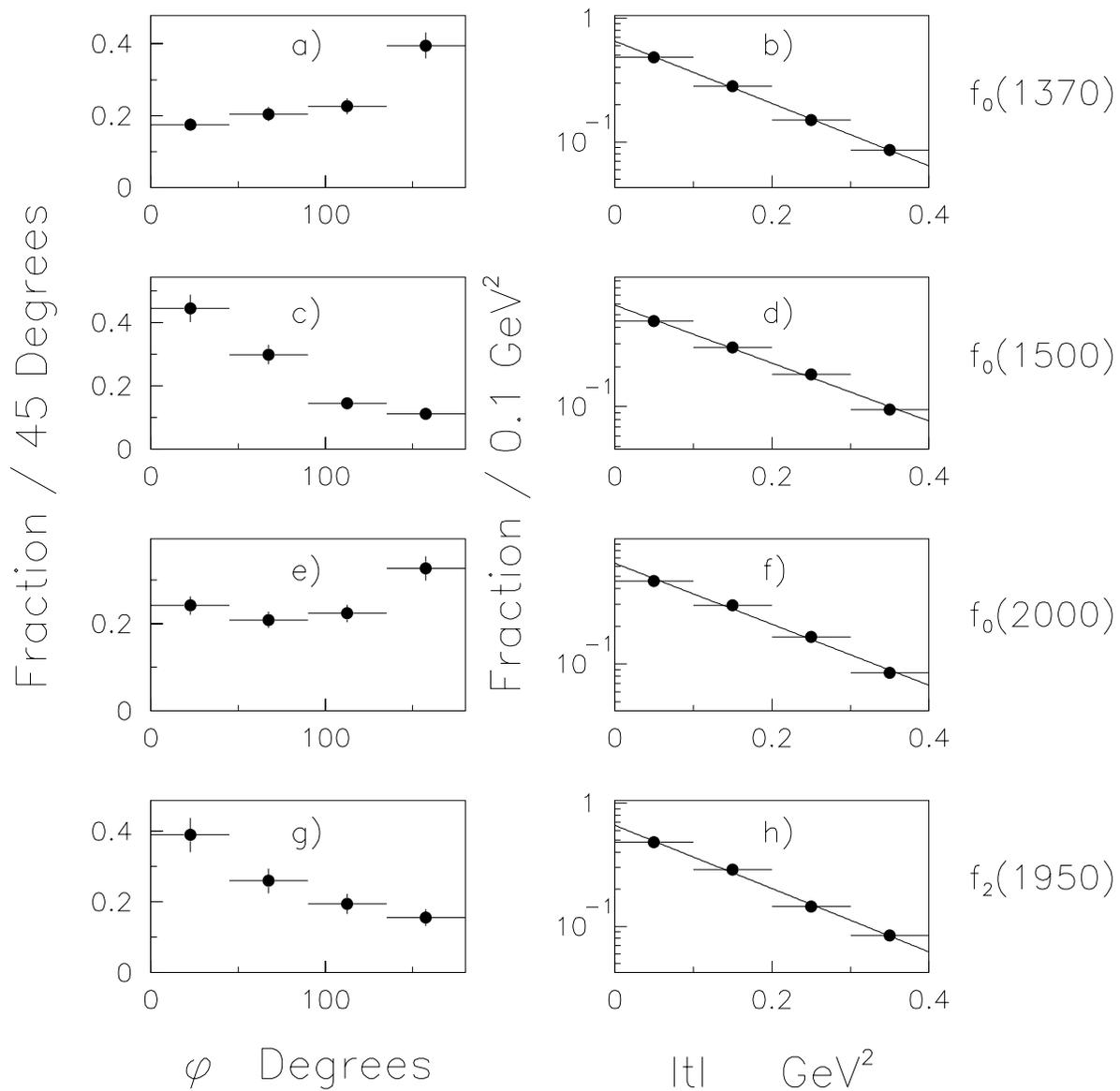


Figure 2

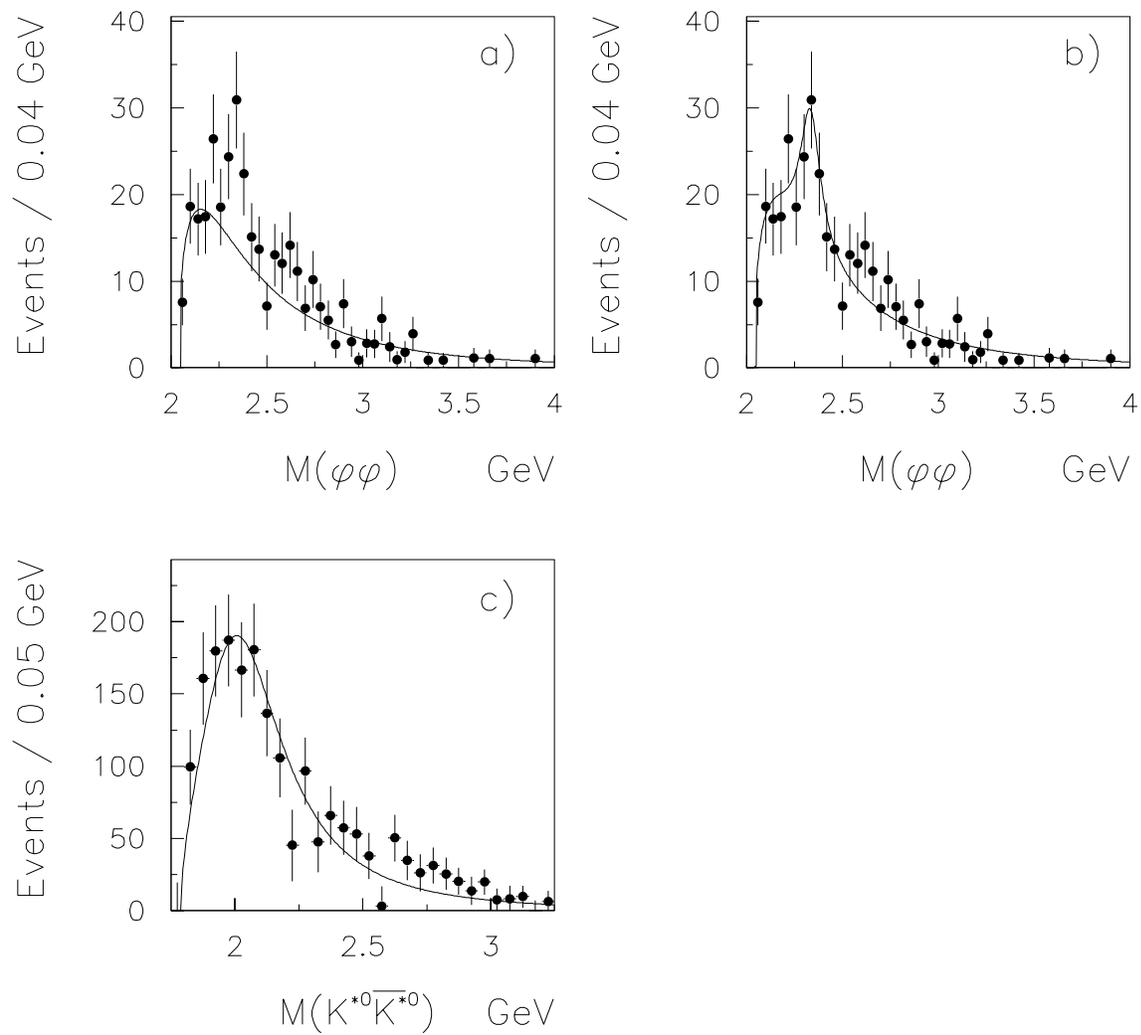


Figure 3