Shape distortions of meson resonances produced
in hadron interactions at $p_T \geq 2 \text{ GeV}/c$

The WA77 Collaboration

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Abstract : We study the shape of the invariant mass spectra of several resonances produced at $p_T \geq 2. \text{ GeV}/c$ and observed through two-particle final states, namely the $f_2(1270)$, $K^*(892)$, $\bar{K}^*(892)$, $K^*(1430)$, and $\bar{K}^*(1430)$ mesons. The data sample comes from π^-Be interactions at $p_{lab} = 150 \text{ GeV}/c$ and $300 \text{ GeV}/c$ which have been collected using the OMEGA spectrometer at CERN. We find that although these meson resonances have their masses and widths consistent with the corresponding world average values, their shapes are all subject to the same kind of distortion : their low-mass tail is enhanced while their high-mass tail is sharply cut. This observation indicates that meson resonances produced in the fragmentation of quarks and gluons are distorted by the same damping factor in a way which preserves their masses and lifetimes.

1 Introduction

It is a known property of resonances that their observed mass distributions can vary from one experiment to another, depending on the production mechanism[1][2]. The main origin of this effect is the unknown mass dependence of resonance production cross sections. These are generally subject to more or less arbitrary assumptions which affect the decay amplitude $\Gamma_{res}(m)$ of the resonance in the fitting procedures[2].

In exclusive experiments effects due to the production mechanism can be superposed with interference effects associated with processes involving the same final state. Interference effects thus produce an important skewing of the ρ^0 lineshape in photoproduction experiments (see ref.[3] for instance). Large distortions of the $S^*/f_0(975)$ meson have also been reported by many experiments (see ref.[4] for instance). Phase space effects can also produce large changes of the resonance shape. For instance, in the decay $\eta \rightarrow \pi^+\pi^-\gamma$ which is dominated by $\eta \rightarrow \rho^0\gamma$, the $\pi^+\pi^-$ mass spectrum is cut at the η mass in such a way that the ρ^0 peak is completely outside the available phase space[5]. In summary, several mechanisms can produce distortions of the invariant mass distributions of broad resonances, sometimes in a predictable way.

In high- p_T physics, we deal with another kind of production mechanism: the fragmentation of coloured strings into hadrons[6]. With this respect, O. Podobrin[7] has recently shown that Bose-Einstein correlation effects between resonance decay products and nearby (in phase space) stable pions can produce a large shift of the resonance masses. On the other hand, A. Lindner[8] has shown that the Lund Monte Carlo provides distortions of the ρ meson mass spectrum. These results illustrate that internal properties of the colour string fragmentation process can result in observable modifications of resonance mass spectra.

The ARGUS collaboration has looked for this kind of shape distortions for the ρ meson but could not reach any firm conclusion[9] because of lack of statistics. They have nevertheless taken this effect into account in recent works[10]. Studies involving light flavour mesons are also available from LEP experiments[11][12][13][14]. Some indication of ρ^0 lineshape distortion has been already reported by the OPAL collaboration[12].

Here in the WA77 experiment, we study the shape of five resonances for which the influence of reflections can be essentially removed and the background is well under control. These meson resonances ($f_2(1270)$, $K^{*0}(892)$, $\bar{K}^{*0}(892)$, $K^{*0}(1430)$ and $\bar{K}^{*0}(1430)$) have a large branching fraction to two-body channels ($\pi^+\pi^-$, $K^\pm\pi^\mp$). Moreover these resonances are rarely decay products of higher resonances and the feed down of $K^{*0}(892)$ mesons from $K^{*0}(1430)$ decays is removed by our trigger at the 98% level.

The mass spectra also reveal a significant ϕ signal[15] in K^+K^- , however we are not sensitive to possible distortions of this signal because of our mass resolution. There is in addition a large ρ^0 signal[15]; this signal is not studied in the present work because it is produced by several mechanisms (parton fragmentation[6], prompt production[16], η' decay[19]) and then its shape cannot follow from a single phenomenon.

We first give a brief description of the experiment and of the data samples (section 2). Then we study (section 3) the $f_2(1270)$ meson in the full samples of data collected at 300 and 150 GeV/c; due to its statistical importance, this signal allows a detailed study of systematic effects. Section 4 deals with the analysis of the $K^+\pi^-$ mass spectrum with an identified K^+ ; for this purpose we only use our 300 GeV/c data sample and study the $K^{*0}(892)$ and $K^{*0}(1430)$ meson invariant mass distributions. Section 5 is devoted to the study of the $K^-\pi^+$ mass spectrum with an identified K^- ; here also we only use our 300 GeV/c data sample and study the $\bar{K}^{*0}(892)$ and $\bar{K}^{*0}(1430)$ meson invariant mass distributions. In section 6, we discuss

the results obtained for the various mesons and examine some *a priori* possible explanations. Finally section 7 is devoted to a summary of our conclusions.

2 The data samples

The basic idea of the WA77 trigger is to obtain a sample of events with three particles at large p_T where a pair of them (of opposite charges) is supposed to come from the decay of a neutral resonance, while the third track (p , $\bar{p}$, $K^\pm$, $\pi^\pm$) is assumed to be the leading particle of an opposite jet. Details about the trigger and setup have been given elsewhere [15][18–22]. This trigger favours the observation of meson resonances decaying into two bodies which are leading particles of a high- p_T jet. We have verified this property on a Lund Monte Carlo sample of events tracked through the simulation of our setup and fulfilling our trigger conditions. We have thus found that 99.5% of the Monte Carlo events accepted by our trigger have no more than three tracks at $p_T \geq 1$ GeV/c.

The WA77 experiment has performed two runs of data taking on $\pi^- N$ interactions, the first at 300 GeV/c, the second at 150 GeV/c. In the 300 GeV/c setup two multicell Cerenkov counters were used for identification of particle species. We selected events in the rapidity range :

$$2.80 \leq Y_{lab}^{pair} \leq 3.70 \quad , \quad (1)$$

and with transverse momenta :

$$\begin{cases} p_T^{trig.part.} \geq 1 \text{ GeV/c} \\ p_T^{pair} \geq 2 \text{ GeV/c} \end{cases} . \quad (2)$$

At 300 GeV/c, this corresponds to a center of mass rapidity window $(-0.43, +0.47)$, while at 150 GeV/c it corresponds to the window $(-0.08, +0.90)$. The total number of events is 209 654 in the 300 GeV/c sample and 238 749 in the 150 GeV/c sample.

3 Study of the $f_2(1270)$ meson

We consider here the mass spectra obtained assuming both particles in the pair to be pions. We do not use in this case the information provided by the Cerenkov counters since we know[21] that the pion assignment in our experiment is widely contaminated by kaons and protons. The $f_2(1270)$ region suffers only little from $K^{*0}(1430)$ contamination because its reflection produces a tiny signal which does not affect the properties of the $f_2(1270)$ meson (see section 3.3) and therefore it has not been considered in the final fit. No other source of contamination has been found in this mass region.

3.1 Fitting method

In order to perform our fits we have taken into account besides the resonances ($\rho^0(770)$, $f_2(1270)$, $S^*/f_0(975)$) the reflections due to the large signals[22] of the $\phi(1020)$, $K^{*0}(892)$ and $\bar{K}^{*0}(892)$ mesons. These last signals appear shifted due to the wrong mass assignment given to

their decay products. The invariant mass histogram of the pairs with the $\pi^+\pi^-$ mass assignment is shown in figure (1) for the 300 GeV/c data. It has been fitted using the following expression :

$$\begin{aligned} \frac{dN}{dm} = & [f_{bckg}(m) + a_\rho BW(\rho^0, m) + a_{S^*} BW(S^*, m) + a_{f_2} BW(f_2, m)] \\ & + a_\phi REF(\phi, m) + a_{K^*} REF(K^*, m) \quad . \end{aligned} \quad (3)$$

In this expression $f_{bckg}(m)$ is a function of the invariant mass of the pair (m) which describes the background[13][15]. It has been parametrized as :

$$f_{bckg}(m) = a(m - m_{th})^\alpha \exp[bm + cm^2 + dm^3] \quad , \quad (4)$$

where $m_{th} = 2m_\pi$ is the threshold mass of the system. We have checked on a Lund Monte Carlo sample that this expression describes correctly the mass histogram of the non-resonant pairs. BW and REF in expression (3) stand respectively for Breit-Wigner distributions and reflections of resonances when a wrong mass assignment is applied. We take as Breit-Wigner distribution of a resonance R :

$$BW(R, m) = \frac{m m_R \Gamma_{\pi\pi}(m)}{|m_R^2 - m^2 - im_R \Gamma(m)|^2} \quad , \quad (5)$$

where $\Gamma_{\pi\pi}(m)$ is the $\pi\pi$ partial width and $\Gamma(m)$ is the full width of the resonance R . The denominator in rel. (5) coincides with the usual $(m_R^2 - m^2)^2 + m_R^2 \Gamma^2(m)$ when the mass m is above all thresholds[1]. However, between the $\pi\pi$ and $K\bar{K}$ thresholds the partial width (see rel. (6) below) $\Gamma_{K\bar{K}}$ becomes purely imaginary and thus contributes to the real part of the Breit-Wigner denominator in rel.(5) ; this effect has been taken into account in our fits. Therefore, rel. (5) is the standard expression established in [1], assuming the production cross section of the resonance R to be constant. With this definition of a Breit-Wigner distribution, each a in rel. [3] is precisely the production cross-section of the corresponding resonance, in agreement with ref. [1].

The reflections of $K^{*0}(892)$ and $\bar{K}^{*0}(892)$ are superposed when using the $\pi^+\pi^-$ mass assignment, and not distinguishable. The shapes of all reflections have been computed by generating samples of events using a standard Breit-Wigner[1], following the tracks in the full simulation of our setup[17][21] and finally changing the correct mass assignment to $\pi^+\pi^-$. Our simulation takes into account the acceptance effects and the accuracy of the reconstruction program TRI-DENT. Therefore by this procedure we take into account acceptance and resolution effects on these mass distributions.

The parametrization of the $S^*/f_0(975)$ has been done following ref. [23] ; a large sample of events has been generated, tracked through the simulation of our detector and reconstructed to account for acceptance and resolution effects. We considered this precaution as necessary because this meson is close to the $f_2(1270)$ meson mass. We have chosen a heuristic parametrization¹ for the ρ^0 meson (a Breit-Wigner with a width larger by 20 MeV than nominal). In this way expression (3) describes correctly the mass region below 1 GeV.

To describe the $f_2(1270)$ meson, we have not used the standard way[1] to write a relativistic Breit-Wigner expression, but rather followed the suggestion of ref.[5] by using a more general expression. Assuming the world average values[24] for the various branching fractions, the $f_2(1270)$ decay amplitude is written :

¹The ρ^0 meson in our experiment is expected to be produced through many mechanisms, including the η' decay ; a precise study of this region is presently under way.

$$\Gamma_{f_2}(m) = \gamma_{f_2} \left[r_0 + r_K \left[\frac{q_K(m)}{q_K(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_K} + r_\pi \left[\frac{q_\pi(m)}{q_\pi(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_\pi} \right] + \gamma_{res} \quad , \quad (6)$$

where $q_K = 1/2\sqrt{m^2 - 4m_K^2}$, $q_\pi = 1/2\sqrt{m^2 - 4m_\pi^2}$ and $r_\pi = 0.849$, $r_K = 0.046$ and $r_0 = 0.105$ are respectively the branching fractions to $\pi\pi$, $K\overline{K}$ and the remaining channels. The constant part of the width accounts mainly for the decay modes into four bodies. λ_K and λ_π are parameters to be fitted. These two parameters are actually fixed to 1 in the standard approach[1] ; it has been shown [5] that the equivalent expression for the ρ^0 distribution with the exponent λ allowed to vary is able to give a good and simple description of the $e^+e^- \rightarrow \pi^+\pi^-$ data while it is not possible to obtain a good fit with λ fixed to one.

The parameter γ_{f_2} is the $f_2(1270)$ natural width and γ_{res} is the mass resolution at the resonance peak (20 MeV). This is the usual approach to account for resolution effects[26] ; we have checked with our simulation that this describes correctly the resolution effects in our experiment.

In the expression of the f_2 Breit–Wigner (rels. (3) and (5)), the denominator contains the full expression (6), but the numerator contains only the $\pi\pi$ part (last term in rel. (6)) together with the resolution contribution :

$$\Gamma_{\pi\pi} = r_\pi \gamma_{f_2} \left[\frac{q_\pi(m)}{q_\pi(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_\pi} + \gamma_{res} \quad , \quad (7)$$

The parameters α , a , b , c , d , a_ρ , a_{S^*} , a_{f_2} , a_ϕ , a_{K^*} are constants to be fitted with the constraint that the integral of the right–hand side of rel. (3) must be equal to the experimental number of events N . All resonance parameters (masses and widths) are fixed to their world average values[24], except for those for the f_2 which are fitted.

It should be noted that we have chosen to describe the resonance contributions assuming that their production cross sections are constant. Traditionally, these are assumed to have a phase–space distribution and this phase–space distribution is identified with the background in order to lessen the number of free parameters[25]. We have also used this method in previous publications[15][20][22]. Here we describe the resonance contributions assuming a constant production cross section after having checked that both constant and phase space cross sections give results consistent within errors for both resonance yields and functional shapes. Other attempts have been tried which will be described in section 3.3. Let us also mention that the two methods sketched above have been recently compared by the DELPHI collaboration[13] which have reached the same conclusion as ours.

Finally, we have chosen a binning (20 MeV) which matches our mass resolution at the $f_2(1270)$ mass in order to minimize the loss of information about the shape of the mass spectra.

3.2 Fitting the $\pi^+\pi^-$ spectra

As a general remark, we have found no sensitivity of our data to the precise value of λ_K ; varying it between 1 and 14 does not produce any change above the one σ level. Therefore we have decided to fix definitely $\lambda_K = 1$ in the $f_2(1270)$ analysis.

Let us first discuss the 300 GeV/c data. As a first attempt, we have tried fitting our spectrum assuming $\lambda_\pi = 1$ and fixing m_{f_2} and γ_{f_2} at their world average values[24]. This fit

corresponds to $\chi^2/dof = 210/139$ and is shown in fig. (1) ; it clearly goes too much above background on the f_2 high-mass tail region. Leaving free m_{f_2} and γ_{f_2} , the quality of the fit improves ($\chi^2/dof = 177/137$) and provides :

$$\begin{cases} m_{f_2} = 1240 \pm 6 \text{ MeV} \\ \gamma_{f_2} = 102^{+21}_{-18} \text{ MeV} \end{cases} . \quad (8)$$

Finally, leaving free m_{f_2} , γ_{f_2} , λ_π , we obtain a good fit (see figure (2)) corresponding to $\chi^2/dof = 141/136$ with the following parameters :

$$\begin{cases} m_{f_2} = 1227^{+10}_{-14} \text{ MeV} \\ \gamma_{f_2} = 219^{+75}_{-46} \text{ MeV} \\ \lambda_\pi = 12.13^{+2.11}_{-1.94} \end{cases} . \quad (9)$$

Turning now to our 150 GeV/c data, we have also first performed the fit after fixing $\lambda_\pi = 1$ and using the world average values for m_{f_2} and γ_{f_2} . The fit obtained is shown in figure (3) and corresponds to $\chi^2/dof = 222/139$. It also clearly goes too much above background on the $f_2(1270)$ high-mass tail. Setting $\lambda_\pi = 1$, but allowing m_{f_2} and γ_{f_2} to vary, we find :

$$\begin{cases} m_{f_2} = 1259 \pm 6 \text{ MeV} \\ \gamma_{f_2} = 72 \pm 12 \text{ MeV} \end{cases} , \quad (10)$$

corresponding to $\chi^2/dof = 179/137$. Finally, leaving free λ_π , m_{f_2} and γ_{f_2} , we find :

$$\begin{cases} m_{f_2} = 1254^{+7}_{-9} \text{ MeV} \\ \gamma_{f_2} = 148^{+45}_{-29} \text{ MeV} \\ \lambda_\pi = 13.44^{+3.22}_{-2.52} \end{cases} , \quad (11)$$

with a good quality of the fit ($\chi^2/dof = 144/136$) ; the corresponding fit is shown in figure (4).

3.3 Discussion of the results

As a general conclusion, assuming $\lambda_\pi = 1$ and fixing the $f_2(1270)$ parameters at their world average values ($m_{f_2} = 1275 \text{ MeV}$, $\gamma_{f_2} = 185 \text{ MeV}$) does not provide a satisfactory description of the data. Figures (1) and (3) clearly show that the $f_2(1270)$ high-mass tail extends too much and exhibits large systematic effects (see the insets in fig. (1) and (3)). Leaving free the mass and width slightly improves the quality of the fits but they are both significantly below their commonly accepted values[24].

However, we always obtain a good fit if we leave free λ_π . In this case, the $f_2(1270)$ natural width is in agreement with the accepted value[24], but the mass is systematically lower.

In this respect, we have studied the effects of systematic errors. The first source is our neglecting of the $K^{*0}(1430)$ reflection which occurs nearly at the $f_2(1270)$ mass with a width of about 300 MeV. Assuming[27] the ratio $K^{*0}(1430)/K^{*0}(892) = 0.2$, we have redone our fits

using expression (3) including a $K^{*0}(1430)$ reflection ; this increases the $f_2(1270)$ mass value by 6 MeV at both energies but has little effect on the $f_2(1270)$ width and λ_π . This is surely an upper bound since examining our samples with the $\pi^\pm K^\mp$ mass assignment clearly shows that the $K^{*0}(1430)$ contribution does not exceed 10% of the $f_2(1270)$ signals :

$$\begin{cases} n_{f_2} = 5051^{+1443}_{-977} & (300 \text{ GeV/c}) \\ n_{f_2} = 4339^{+985}_{-736} & (150 \text{ GeV/c}) \end{cases}, \quad (12)$$

and stays well inside the level of errors.

Another possible source of systematic effects is our assumption that a_{f_2} in expression (3) is constant. In this respect, we have replaced the term $a_{f_2} BW(f_2, m)$ in rel. (3) by $a_{f_2} f_{\pi\pi}(m) BW(f_2, m)$, where $f_{\pi\pi}(m)$ is the invariant mass distribution of non-resonant $\pi^+\pi^-$ pairs determined from a sample of Lund events accepted by our setup. The idea is that this function simulates the two-pion phase space distribution in our experiment. The results coincide with the above ones within errors. We have also tried fitting our spectra assuming $f_{\pi\pi}(m)$ to be of the form² $[m_{f_2}/m]^\mu$. The improvement is small at both energies (the χ^2 decreases by only 4 units) and gives values consistent with that in rels (9) and (11) for γ_{f_2} and λ_π , while we find :

$$\begin{cases} m_{f_2} = 1245^{+12}_{-16} \text{ MeV} & \mu = 3.39^{+2.88}_{-1.64} & (300 \text{ GeV/c}) \\ m_{f_2} = 1266 \pm 8 \text{ MeV} & \mu = 2.87^{+1.54}_{-1.34} & (150 \text{ GeV/c}) \end{cases}, \quad (13)$$

in good agreement with the result of EHS[26].

We have also considered the influence of the background shape. Changing the threshold behaviour or adding a m^4 term in the exponential (see rel. (4)) does not remove the effect observed in the $f_2(1270)$ mass region. Another way to test the effect of background is to change the p_T cut ; in this respect we have reanalyzed our data requiring $p_T^{pair} \geq 2.2 \text{ GeV/c}$ instead of $p_T^{pair} \geq 2.0 \text{ GeV/c}$. At 300 GeV/c this produces a reduction of $\simeq 20\%$ for both the background and the $f_2(1270)$ signal, and the fit gives $\lambda_\pi = 18.8^{+3.5}_{-2.9}$. At 150 GeV/c this new p_T cut produces a reduction of $\simeq 50\%$ for the background and $\simeq 35\%$ for the $f_2(1270)$ signal ; in this case the fit provides $\lambda_\pi = 13.6^{+8.3}_{-4.8}$. Therefore the sharpening of the $f_2(1270)$ mass distribution cannot be attributed to the size of the background or to some given value of the signal to background ratio.

Finally we have checked by simulation studies that the acceptance function of $\pi\pi$ pairs is a slowly decreasing function of m nearly flat in the f_2 mass region. Therefore its effect can be neglected in expression (3) without affecting the results of the fit.

To conclude, the systematic effects which have been investigated tend to leave the values of γ_{f_2} and λ_π unchanged while they can produce a downward shift of the f_2 mass up to $\simeq 15$ MeV. Systematic effects due to the background shape or size have not been detected. Therefore, we can rely on the width and λ_π estimates in our data which correspond to one of the best available statistics (compare rels. (12) with the statistics reported in ref. [24]).

We can summarize our results on the $f_2(1270)$ meson by performing a weighted mean of rels. (9) and (11) :

²Indeed, since we are dominated by parton fragmentation, it is not clear that using a $\pi\pi$ phase space distribution is justified.

$$\begin{cases} \lambda_\pi = 12.6^{+1.8}_{-1.5} \\ \gamma_{f_2} = 167^{+39}_{-25} \text{ MeV} \end{cases} \quad (14)$$

Our estimate of the $f_2(1270)$ width is in agreement with the world average value[24] (185 ± 20 MeV) at the 1σ level; our estimate of the damping power λ_π ($\simeq 12$) gives a number considerably larger than what is usually expected[1]. For instance, the power obtained for the ρ^0 meson in the $e^+e^- \rightarrow \pi^+\pi^-$ process ranges[5] from $\simeq 0.66$ to $\simeq 1.75$.

Since there is no theory of this damping power[5], a question arises as to whether such a value ($\lambda_\pi \simeq 12$) looks normal or if it points towards a distortion of the $f_2(1270)$ invariant mass distribution when this meson is produced at large p_T as a leading fragment of a (high- p_T) jet. We note that most of spectroscopic experiments (see refs. [4] and [28] for instance) accomodate³ to $\lambda_\pi = 1$. In ref. [29] the $f_2(1270)$ coupling to $\pi^+\pi^-$ is considered yielding the following expression for the width :

$$\begin{cases} \Gamma(m) &= \Gamma_{f_2} \frac{q_\pi(m)}{q_\pi(m_{f_2})} \frac{D_2[q_\pi(m_{f_2})R]}{D_2[q_\pi(m)R]} \\ D_2[q_\pi(m)R] &= 9 + 3[q_\pi(m)R]^2 + [q_\pi(m)R]^4 \end{cases} \quad (15)$$

where the range parameter[2] R is found[29] to be $R \geq 3 \text{ GeV}^{-1}$ or $R \geq 9 \text{ GeV}^{-1}$, depending on the fit hypotheses. It follows from these lower bounds that only the last term in the second expression (15) plays a significant role. Therefore, in this experiment at least, the result corresponds to an effective value $\lambda_\pi = 4$. Comparing this result with rel. (14), clearly shows that in parton fragmentation, we get an additional damping power of $\simeq 8$. The skewing effect is shown in figure (5) ; here we have plotted the same Breit–Wigner expression (5) using $\lambda_\pi = 1$ and $\lambda_\pi = 12.5$, leaving unchanched γ_R and m_R . It should be noticed that the resulting skewing effect plays in such a way that the physical parameters of the $f_2(1270)$ meson, mass and width (or lifetime), can be considered as unchanged⁴ at the level of accuracy of our data.

4 Study of the $K^+\pi^-$ spectrum

In the data taken at 300 GeV/c, we have used the Cerenkov information to single out a sample of 16266 events with an identified K^+ meson ; no constraint has been placed on the negative particle. We have shown in ref.[21] that the probability for a particle identified as a kaon to be a pion is consistent with zero, while the probability of the converse is $\simeq 30\%$. Therefore, requesting a pion signature for the negative particle would have much more reduced our sample without a useful gain in the signal over background ratio. A significant fraction ($\simeq 30\%$) of the protons survive the condition of identified K^+ ; these will essentially

³CELLO collaboration [28] has not succeeded in determining the shape of the $f_2(1270)$ resonance because of the interplay in the $\gamma\gamma \rightarrow \pi^+\pi^-$ reaction of non-resonant terms which contribute to the D -wave together with the (main) $f_2(1270)$ resonant term.

⁴One should also notice that the values which are unchanged are the zero of the real part of the inverse propagator (*i.e.* m_R) in rel. (5) and the value of the imaginary part of this function at $m = m_R$ (*i.e.* γ_R) ; of course real and imaginary parts refer to the case when m is above all thresholds. It is these definitions of mass and width which appear to be stable.

contribute to the background as no Δ^0 contribution has been found in our data. A departure from pure phase space distribution in the threshold region is in any case expected because of anticorrelation phenomena in pair production[21] and therefore it is difficult to single out a possible Δ^0 contribution here. The data taken at 150 GeV/c are not used since there is no available Cerenkov information ; in this case, the K^* signals are widely mixed with the $\rho^0(770)$ and $f_2(1270)$ reflections and our conclusions would hardly be model dependent. Requiring one K mass assignment from the Cerenkov counters reduces the signals considerably but removes the $\rho^0(770)$ and $f_2(1270)$ signals completely.

The $K^+\pi^-$ spectrum is given in figure (6). We observe a clear signal of the $K^{*0}(892)$ (hereafter denoted K_V^*) and a small $K^{*0}(1430)$ signal (hereafter denoted K_T^*) ; the relatively broad bump between the $K\pi$ threshold and the K_V^* peak is the $\phi(1020)$ meson reflection in the $K\pi$ mass assignment. No other obvious structure can be seen⁵. Other K^* mesons fall in the 1400 MeV region[24][30] (as well as the reflection of the $f'(1515)$ signal) and could contribute to shadow somehow the K_T^* signal and shape. Therefore we need to check that the 1.43 GeV structure is indeed dominated by the K_T^* signal.

We have performed our fits using :

$$\frac{dN}{dm} = f_{acc}(m) [f_{bckg}(m) + a_V BW(K_V^*, m) + a_T BW(K_T^*, m)] + a_\phi REF(\phi, m) \quad . \quad (16)$$

In this expression $f_{bckg}(m)$ is a function of the invariant mass of the pair (m) which describes the background. It has been parametrized as :

$$f_{bckg}(m) = a(m - m_{th})^\alpha \exp[bm + cm^2 + dm^3 + em^4] \quad , \quad (17)$$

where m_{th} is the relevant two-particle threshold mass. We have generated a large sample of events using the Lund Monte Carlo program PYTHIA[8] and followed the tracks through a complete simulation of our setup. Using the pairs obtained by requiring that both particles do not come from the decay of the same resonance we have checked that expression (17) above was able to describe correctly the $K\pi$ spectra. We have especially checked that the third and fourth order terms in the exponential were needed to get a satisfactory description of the mass spectrum over our full mass range.

$f_{acc}(m)$ is the acceptance function of $K\pi$ pairs. It has also been directly computed from our simulation. As it can be seen from figure (7), this function peaks near the $K^*(892)$ mass and is flat around the $K^*(1430)$ mass. Unlike the case of the $\pi^+\pi^-$ spectrum, it is not possible to neglect its effect. There are also[21] non-resonant $p\pi^-$ pairs which give a slightly harder threshold behaviour. This phenomenon plays a role on the first 100 MeV of the invariant mass histogram and the corresponding bins have been removed from the fits.

The resonance contributions have been represented by the standard relativistic Breit-Wigner expression (5). Following ref. [5], the width of the meson K_V^* has been parametrized as :

$$\Gamma_V(m) = \gamma_V \left[\frac{q_{K\pi}(m)}{q_{K\pi}(m_V)} \right]^3 \left[\frac{m_V}{m} \right]^{\lambda_V} + \gamma_{res} \quad , \quad (18)$$

where γ_V is the natural width of the K_V^* resonance and γ_{res} is the resolution at the K_V^* peak (9 MeV) estimated from simulation. $q_{K\pi}(m)$ is the momentum of each decay product of the

⁵It must be noticed that the K_T^* signal in the original sample is overwhelmed by the background.

K_V^* resonance in its rest frame, and m_V is the resonance mass. Therefore we treat the K_V^* as a purely elastic resonance. In the standard treatment[1] followed by most experiments λ_V is set to 1 ; here we allow it to vary.

The K_T^* meson has been treated in the same way as the $f_2(1270)$ meson (see rel. (6) above) : the main decay modes into two bodies ($K\pi$, $K^*(892)\pi$) have been explicitly accounted for, while we have accounted for the rest by means of a constant width :

$$\gamma_T(1 - Br(K\pi) - Br(K_V^*\pi)) = 0.251\gamma_T \quad , \quad (19)$$

where γ_T is the K_T^* full width. The branching fractions of the K_T^* meson have been taken at their world average values[24]. Therefore, we have used :

$$\Gamma_T(m) = \gamma_T \left[0.251 + 0.252 \left[\frac{q_{K_V^*\pi}(m)}{q_{K_V^*\pi}(m_T)} \right]^5 \left[\frac{m_T}{m} \right] + 0.497 \left[\frac{q_{K\pi}(m)}{q_{K\pi}(m_T)} \right]^5 \left[\frac{m_T}{m} \right]^{\lambda_T} \right] + \gamma_{res} \quad , \quad (20)$$

where $q_{K_V^*\pi}$ and $q_{K\pi}$ are the 3-momenta of the K_T^* decay products for the corresponding decay modes⁶. We have fixed $\lambda = 1$ for the $K_V^*\pi$ channel after having checked that our data are not sensitive to this channel⁷. γ_T is the K_T^* natural width and γ_{res} is the mass resolution of our setup at the K_T^* peak mass (14 MeV).

The numerators of the BW functions in rel. (16), are always the partial widths to $K^+\pi^-$ increased by the resolution at the corresponding resonance peak.

$REF(\phi, m)$ in rel. (16) is the reflection of the ϕ meson. It has been computed directly by generating a sample of ϕ mesons from a Breit-Wigner law (see rel. (5)) and tracking the K^+ and K^- particles through our simulation. The reflected spectrum has been simply obtained by changing the true particle assignment to $K^+\pi^-$.

Our free parameters are those in rel. (17) and a_V , a_T and a_ϕ which give the number of mesons in our spectrum for K_V^* , K_T^* and ϕ resonances respectively. Here again there is a constraint among these parameters which requires that the integral of the right-hand side of rel. (16) gives the number of experimental events in the same interval.

We shall also denote m_V and m_T the masses of the K_V^* and K_T^* mesons respectively. They will be fixed or fitted as well as the natural widths γ_V and γ_T .

As a first attempt we have fixed the masses and widths of the K_V^* and K_T^* mesons at their world average values[24], requiring in addition $\lambda_V = \lambda_T = 1$. The first five bins (*i.e.* 100 MeV) are removed from the fit. The best fit is shown in figure (6) and corresponds to $\chi^2/dof = 145/112$. Looking at the inset, where the background and the ϕ contribution have been subtracted, it is clear that the high-mass tail of K_V^* extends too much above the background. The K_T^* signal is too small to allow any eye estimate. Leaving free m_V , Γ_V , λ_V and m_T , Γ_T , λ_T , the quality of the fit improves ($\chi^2/dof = 128/106$). The fitted values of interest are :

⁶What has been said concerning the $f_2(1270)$ Breit-Wigner denominator in rel. (5) when m is between the $\pi\pi$ and $K\bar{K}$ threshold applies fully for the K_T^* Breit-Wigner between the πK and $K_V^*\pi$ thresholds ; we have accounted for this effect in precisely the same way.

⁷Varying this λ from 1 to 14 does not produce any significant change in the results.

$$\left\{ \begin{array}{l} m_V = 892 \pm 3 \text{ MeV}, \quad \gamma_V = 39 \pm 11 \text{ MeV} \quad \lambda_V = 13.53^{+3.42}_{-3.00} \\ m_T = 1435 \pm 13 \text{ MeV}, \quad \gamma_T = 100 \pm 49 \text{ MeV} \quad \lambda_T = 5.56 \pm 3.31 \end{array} \right. \quad (21)$$

The errors are large because of correlations between each γ and its corresponding λ . The resulting fit is given in figure (8) and the inset clearly shows that the resonance tails are now more realistically described. Moreover, the number of ϕ mesons obtained from this fit and that obtained using the K^+K^- mass assignment in the same sample are consistent within errors ; this indicates that the background is correctly estimated and that threshold effects do not affect the mass region of interest. The mass and width obtained from fit for the K_V^* meson are consistent with the world average values[24] (896.1 MeV and 50.5 MeV respectively). This is also true for the K_T^* meson mass and width obtained from the fit (ref. [24] gives 1432.4 MeV and 109 MeV respectively). This indicates that identifying the small structure located around 1.43 GeV with the $K^{*0}(1430)$ meson is reasonable. One should notice the large value found for λ_V (consistent with that of the $f_2(1270)$ meson) ; the value found for λ_T is inconclusive but still consistent with a large value.

Since the K^* mesons in our data have parameters consistent with their world average values, it is reasonable to fix m_V , m_T , γ_V and γ_T at their average values[24] ; in this case, we get $\chi^2/dof = 133/110$ and :

$$\left\{ \begin{array}{l} \lambda_V = 12.9^{+2.2}_{-2.7} \\ \lambda_T = 4.9^{+4.4}_{-1.8} \end{array} \right. \quad (22)$$

In our data there are 839 ± 99 K_V^* events and 420 ± 71 K_T^* events.

5 Study of the $K^-\pi^+$ spectrum

Using the data taken at 300 GeV/c and requiring from Cerenkov information an identified K^- , we get a sample of 10 157 events. We have not required any identification of the positive particle for the reason already mentioned (see section 4 above). Here we have to deal with a contamination of K^- by $\bar{p}$; the situation is fortunately not symmetrical to the contamination by protons in the previous sample since the ratio $\bar{p}/p$ is more favourable[21] ($0.41 \div 0.46$) in the present case. Since this contamination is significant only near threshold we remove the first five bins (100 MeV) from the fit. The formulae and arguments given in the previous section are still valid in the present case.

The $K^-\pi^+$ mass spectrum is shown in figure (9), apart from the ϕ reflection, one sees a clear signal of the $\bar{K}_V^*$ meson and a broad structure which will be identified with the $\bar{K}_T^*$ meson⁸. The mass distributions of these mesons are expected identical to that of their antiparticles (see section 4).

We have first performed a fit by setting the masses and widths of the $\bar{K}^*$ mesons at their world average values[24], assuming $\lambda_V = \lambda_T = 1$. The result of the fit is shown in figure (9)

⁸We shall consider this identification correct if the parameters obtained by fit are consistent with that of the $\bar{K}^{*0}(1430)$ meson.

($\chi^2/dof = 143/112$). As before, the inset shows that the $\overline{K}_V^*$ high-mass tail extends too much and nothing firm can be asserted about the $\overline{K}_T^*$ meson.

We have then released m_V , Γ_V , λ_V and m_T , Γ_T , λ_T . In this case, the fit (shown in figure (10)) gives a better description of the data ($\chi^2/dof = 108/106$) with better resonance tails. The fitted parameters are

$$\begin{cases} m_V = 892 \pm 3 \text{ MeV}, & \gamma_V = 34^{+16}_{-13} \text{ MeV} & \lambda_V = 14.0 \pm 4.9 \\ m_T = 1401^{+14}_{-29} \text{ MeV}, & \gamma_T = 91^{+80}_{-43} \text{ MeV} & \lambda_T = 10.5^{+4.1}_{-5.4} \end{cases} \quad (23)$$

As a result of the large correlations between γ s and λ s parameters and of the relatively small statistics, there are large uncertainties on most of these parameters (especially for the widths). However these results allow us to check that the $\overline{K}_V^*$ and $\overline{K}_T^*$ mass and width values are in agreement with the corresponding world average values[24]. The values found for the λ s are both large and consistent with that found for K_V^* and K_T^* (see rels. (21)) as can be expected from charge conjugation symmetry.

Since the parameters of $\overline{K}_V^*$ and $\overline{K}_T^*$ are in good agreement with their accepted values, we have done a final fit by fixing m_V , γ_V and m_T , γ_T to their usual values[24]. We thus obtained a good fit ($\chi^2/dof = 129/110$) with the following values :

$$\begin{cases} \lambda_V = 12.7^{+3.6}_{-4.3} \\ \lambda_T = 12.1^{+2.3}_{-4.8} \end{cases} \quad (24)$$

The numbers of mesons are 543 ± 80 ($\overline{K}_V^*$) and 262 ± 63 ($\overline{K}_T^*$) ; we have also checked that the ϕ signal is in agreement with that obtained using the K^+K^- mass assignment, where the signal occurs in a single (20 MeV) bin.

Instead of performing algebraically the weighted mean of rel. (22) and (24) between charge conjugate partners, we have preferred performing a global fit of the sample obtained by merging the $K^+\pi^-$ and $K^-\pi^+$ mass spectra. Thus we get a good fit ($\chi^2/dof = 135/106$) and meson yields in agreement with the results given above⁹. The 'mean values' of the damping powers are :

$$\begin{cases} \lambda_V = 13.4^{+2.4}_{-2.7} \\ \lambda_T = 9.1^{+4.5}_{-6.0} \end{cases} \quad (25)$$

These values are consistent with those obtained for $f_2(1270)$ at the 1. σ level.

We could expect λ_V to be of the order[5] of λ_ρ (*i.e.* $0.66 \div 1.75$) since they are both vector mesons. On the other hand, ref.[30] has tried a fit of the kind (15) and obtained a result consistent with a behaviour like m^{-2} or m^{-3} . The LASS collaboration[30] also quotes a result for the K_T^* meson which is at most of the order m^{-5} . Thus, the results of sections 4 and 5 point towards a distortion of the K_V^* mass spectrum by an additional damping power of $\simeq 10$; the K_T^* mass distribution is consistent with the same distortion than the K_V^* and with no

⁹We obtain 1310 ± 205 for $K^{*0}(892) + \overline{K}^{*0}(892)$ while we expect 1382 ± 127 and 491 ± 150 for $K^{*0}(1430) + \overline{K}^{*0}(1430)$ while we expect 682 ± 95 .

distortion as well because of the large value of the errors. As for the $f_2(1270)$, this distortion preserves the fundamental parameters of these mesons (masses and widths). Indeed the same global fit provides :

$$\begin{cases} m_V = 892 \pm 2 \text{ MeV} & \gamma_V = 40^{+10}_{-9} \text{ MeV} \\ m_T = 1424 \pm 10 \text{ MeV} & \gamma_T = 73^{+37}_{-24} \text{ MeV} \end{cases} . \quad (26)$$

Consequences of systematic effects have been examined in both the $K^+\pi^-$ and $K^-\pi^+$ spectra. We have checked that changing the a_V and a_T to the distributions of non-resonant πK pairs does not affect our results. Assuming a production cross section which varies like m^{-3} (see rel. (13)) leads to the same conclusion. In this case, moreover, because the mesons K_V^* and K_T^* are much sharper than the $f_2(1270)$ meson, their masses are not affected by more than 3 MeV. Finally the feed-down of K_V^* mesons by K_V^* coming from K_T^* decay is negligible because mainly of our p_T cut (see rel. (2)). Therefore, our conclusions are stable and especially the sharp fall-off of the invariant mass distributions summarized by rels. (22), (24), (25).

6 General discussion of the results

Our results are summarized in table (1), apart from the value of the damping power λ , we also consider our estimate of the $f_2(1270)$ width as reliably measured and reasonably free from systematic errors. This result is in good agreement with the recent high statistics result¹⁰ of the DM2 collaboration[31] (169.0 ± 7.5 MeV) and with that of the EHS collaboration[26] (180 ± 24). The damping powers obtained using the $f_2(1270)$ and $K^{*0}(892)$ mesons are remarkably similar ; the damping power associated with the $K^{*0}(1430)$ mesons is lower but consistent with those of the previous mesons at the 1σ level.

The first conclusion of sections 3 to 5 is that the meson mass distributions are all distorted in the same way. The second conclusion is that this distortion preserves the values of the mesons masses and widths¹¹. This result looks general since the same properties are observed for mesons having different spins ($J = 1, 2$) and different strangeness content (f_2 and K^*).

In principle, our results could be compared with that obtained by the SFM collaboration which has measured the rates of $f_2(1270)$ and $K^{*0}(892)$ mesons at large p_T at ISR energies[32]. Unfortunately, this comparison is not possible because they have accounted for the background by the event mixing technics which produces distortions of the resonance signals and the authors of ref. [32] have corrected the subtracted spectra for these distortions. These corrections may have washed out the effect we observe in our experiment.

Another possibility would be that the observed distortions are produced by interference effects. We consider this assumption as unlikely since we are dealing with large multiplicity events ($\simeq 10$) and varying species of final state particles. In this case, we expect interference contributions to cancel out. As an illustration, ref.[23] has examined the inclusive $\pi^+\pi^-$ production in J/ψ decays and reached the conclusion that their data were consistent with no ρ^0 - ω interference. Our mass histogram for pairs with $\pi^+\pi^-$ mass assignment (see fig. (1) for

¹⁰Ref. [31] uses a Breit-Wigner curve but does not provide further information about its precise shape ; this should mean that they use the standard shape[1].

¹¹Technically, the resonance mass which appears stable is defined as the zero (m_R) of the real part of the inverse propagator $D^{-1}(m) = (m_R^2 - m^2) - im_R\Gamma(m)$, while the width is defined by $\gamma_R = \Gamma(m_R)$. This property has been already noted in section 3.3.

instance) is also consistent with no ρ^0 - ω interference. Moreover, it is hard to imagine that interference effects would give the same distortion for all cases and that they would leave nearly unchanged the masses and widths of broad objects.

Resonance	mass our result	mass P.D.G.	width our result	width P.D.G.	λ	χ^2/dof
$f_2(1270) (300)$	1227^{+10}_{-14}	1275 ± 5	236^{+75}_{-46}	185 ± 20	$12.1^{+2.1}_{-1.9}$	141/136
$f_2(1270) (150)$	1254^{+7}_{-9}		165^{+45}_{-29}		$13.4^{+3.2}_{-2.5}$	144/136
$K^{*0}(892)$	892 ± 3	896.1 ± 0.3	39 ± 11	50.5 ± 0.6	$13.5^{+3.4}_{-3.0}$	128/106
$\overline{K}^{*0}(892)$	892 ± 3		34^{+16}_{-13}		14.0 ± 4.9	108/106
$K^{*0} + \overline{K}^{*0}$	892 ± 2		40^{+10}_{-9}		$13.4^{+2.4}_{-2.7}$	135/106
$K^{*0}(1430)$	1435 ± 13	1432.4 ± 1.3	100 ± 49	109 ± 5	5.6 ± 3.3	128/106
$\overline{K}^{*0}(1430)$	1401^{+14}_{-29}		91^{+80}_{-43}		$10.5^{+4.1}_{-5.4}$	108/106
$K^{*0} + \overline{K}^{*0}$	1424 ± 10		73^{+37}_{-24}		$9.1^{+4.5}_{-6.0}$	135/106

Table 1 : Summary of the results concerning all the fitted mesons.

We are thus left with the conclusion that the observed distortions are due to the production mechanism at work in our experiment : the hadronization process of colored quarks and gluons. This process enhances the probability to produce a given meson at low mass and suppresses its production at large mass. More surprising is that these distortions leave unchanged the resonance physical parameters. These properties are in qualitative agreement with what has been seen recently from a Lund Monte Carlo sample by A. Lindner[8] when examining the shape of the ρ^0 mass spectrum. Since resonance mass spectra in the Lund Monte Carlo are simply fixed width Breit–Wigner expressions the agreement cannot be otherwise than qualitative.

These properties illustrate the specificity of color string fragmentation as a production mechanism of resonances, at least as leading fragments. Of course, resonances produced in resonance decays are affected differently, and sometimes not affected at all¹².

On the other hand, resonances decaying to more than two particles are surely affected, but our experiment does not allow any precise study of this effect. For instance, there is some indication that $a_2(1320)$ is observed in its three pion decay mode, but the combinatorial three particle background is so large that no study can be performed.

Our main result can be sketched in the following way : when produced at large p_T , any given resonance R of spin l having two-particle decay modes can be described by a Breit–Wigner distribution, the shape of which remains formally the usual one[1], with the usual mass and width (m_R and γ_R) ; however, its decay amplitude to a given decay mode X written[5] :

¹²For instance, the ρ^0 produced in the η' decay is surely affected by phase space effects due essentially to the η' mass but not to the η' production mechanism since this meson is too sharp to feel any damping factor.

$$\Gamma_X(m) = \gamma_R \left[\frac{q_X(m)}{q_X(m_R)} \right]^{(2l+1)} \left[\frac{m_R}{m} \right]^\lambda ,$$

always gives a good description of the data and $\lambda \simeq 12.5$ looks like a universal parameter. This power is large enough to suggest an actual exponential damping. The present theoretical knowledge does not provide however any motivated guideline to a suitable parametrization of meson shape distortions in high- p_T processes.

7 Conclusions

We have analyzed the invariant mass distributions of five mesons ($f_2(1270)$, $K^{*0}(892)$, $\overline{K}^{*0}(892)$, $K^{*0}(1430)$, $\overline{K}^{*0}(1430)$) produced at $p_T \geq 2.0$ GeV/c, under conditions where they are likely to be leading fragments of high- p_T jets. We have found that these mass distributions are sharply distorted ; these distributions are affected by a large damping power ($\simeq m^{-12}$), far above the usual one. At the level of accuracy allowed by our data, we have also shown that this distortion does not affect the mass and width of any of the resonances examined sofar. We have also shown that the distortions look alike for the mesons studied, without any respect to their spin or quark content. It has to be expected that this phenomenon affects all resonances primarily produced in the parton fragmentation mechanism, for instance the ρ meson. Our conclusions apply to two-body decay channels of resonances. The meson shape distortions observed in our data give experimental support to the existence of phase space effects in the process of quark fragmentation into hadrons.

References

- [1] J.D. Jackson, Nuovo Cimento XXXIV (1964) 1644.
- [2] J. Pisut and M. Roos, Nucl. Phys. **B6** (1968) 325.
- [3] J. Ballam *et al.*, Phys. Rev. **5** (1972) 545.
- [4] T.A. Armstrong *et al.* Zeit. für Phys. **C51** (1991) 351.
- [5] M. Benayoun *et al.* Zeit. für Phys. **C 58** (1993) 31.
- [6] B. Andersson *et al.* Phys. Rep. **97** (1983) 31 ;
H. Bengtsson and G. Ingelman Comput. Phys. Comm. **34** (1985) 251 ;
“The Lund Monte Carlo Programs”, CERN long writeups W5035, W5045, W5046, W5047, W5048, nov. 1989.
- [7] O. Podobrin, Ph. D. Thesis, DESY report FCE-92-03, Hamburg 1992.
- [8] A. Lindner, Ph. D. Thesis, Dortmund 1992.
- [9] H. Albrecht *et al.*, DESY preprint 93-084, Hamburg 1993.
- [10] H. Albrecht *et al.* Zeit. für Phys. **C58** (1993) 199.
- [11] ALEPH collaboration, preprint CERN-PPE/92-74, Geneva 1992.
- [12] OPAL collaboration, preprint CERN-PPE/92-116, Geneva 1992.
- [13] P. Abreu *et al.*, DELPHI collaboration, Phys. Lett. **B298** (1993) 236.
- [14] P.D. Acton *et al.*, OPAL collaboration, Zeit. für Phys. **C56** (1992) 521.
- [15] M. Benayoun *et al.* Phys. Lett. **B183** (1987) 412.
- [16] M. Benayoun *et al.* Nucl. Phys. **B282** (1987) 653.
- [17] M. Benayoun *et al.* Phys. Lett. **B192** (1987) 447.
- [18] M. Benayoun *et al.* Phys. Lett. **B198** (1987) 281.
- [19] W. Beusch *et al.* Nucl. Instrum. Methods **A249** (1986) 391.
- [20] M.T. Trainor, “Direct meson production at $p_T \geq 2$. GeV/c in 300 GeV/c $\pi^- Be$ interactions”, PhD thesis, University of Birmingham, March 1988 ;
R. Fini, “Produzione inclusiva di risonanze a medio-alto momento trasverso”, Tesi di Dottorato, Università degli studi di Bari, january 1990, National library of Rome and Florence.
- [21] A. Bellogianni *et al.*, Zeit. für Phys. **C54** (1992) 535.
- [22] A. Bellogianni *et al.*, Zeit. für Phys. **C59** (1993) 35.
- [23] G. Gidal *et al.*, Phys. Lett. **B107** (1981) 153.
- [24] Review of Particle Properties, Phys. Rev **D45** (1992).
- [25] P. Granet *et al.* Nucl. Phys. **B140** (1978) 389.
- [26] M. Aguilar-Benitez *et al.* Zeit für Phys. **C50** (1991) 405.
- [27] S. Abachi *et al.*, Phys. Rev. Lett. **57** (1986) 1990.
- [28] H.-J. Behrend *et al.* Zeit für Phys. **C56** (1992) 381 ;
J. Harjes, Thesis, preprint DESY-FCE-91-01, Hamburg 1991.
- [29] V. Chabaud *et al.* Nucl. Phys. **B223** (1983) 1.
- [30] D. Aston *et al.* Nucl. Phys. **B296** (1988) 493.
- [31] J.E. Augustin *et al.* Nucl. Phys. **B320** (1989) 1.
- [32] A. Breakstone *et al.* Zeit für Phys. **C43** (1989) 185.

Figure Captions

- Figure 1 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 300 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming the world average values for the $f_2(1270)$ parameters, $\lambda_K = 1$, $\lambda_\pi = 1$. In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the large high-mass tail of the $f_2(1270)$.
- Figure 2 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 300 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming $\lambda_K = 1$, but leaving free the mass, width of the $f_2(1270)$ meson and λ_π . In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice how the high-mass tail of the $f_2(1270)$ is reduced.
- Figure 3 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 150 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming the world average values for the $f_2(1270)$ parameters, $\lambda_K = 1$, $\lambda_\pi = 1$. In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the large high-mass tail of the $f_2(1270)$.
- Figure 4 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 150 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming $\lambda_K = 1$, but leaving free the mass, width of the $f_2(1270)$ meson and λ_π . In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the reduction in the high-mass tail of the $f_2(1270)$.

- Figure 5 : Effect of the damping power λ_π on the shape of a Breit–Wigner contribution to the cross section. In full line we have represented the case $\lambda_\pi = 1$, in dashed dotted line the case $\lambda_\pi = 12.5$.
- Figure 6 : Invariant mass plot of trigger pairs with an identified K^+ ; the data are extracted from our 300 GeV/c sample. The fit represented has been obtained assuming the world average values for the masses and widths of both K^* mesons and both damping powers $\lambda = 1$.
- Figure 7 : Acceptance function of $K\pi$ trigger pairs as a function of their (true) invariant mass.
- Figure 8 : Invariant mass plot of trigger pairs with an identified K^+ ; the data are extracted from our 300 GeV/c sample. The fit shown has been obtained leaving free the masses and widths of both K^* mesons and both damping powers λ .
- Figure 9 : Invariant mass plot of trigger pairs with an identified K^- ; the data are extracted from our 300 GeV/c sample. The fit represented has been obtained assuming the world average values for the masses and widths of both K^* mesons and both damping powers $\lambda = 1$.
- Figure 10 : Invariant mass plot of trigger pairs with an identified K^- ; the data are extracted from our 300 GeV/c sample. The fit represented is obtained, leaving free the masses and widths of both K^* mesons and both damping powers λ .

8 Introduction

It is a known property of resonances that their observed mass distributions can vary from one experiment to another, depending on the production mechanism[1][2]. The main origin of this effect is the unknown mass dependence of resonance production cross sections. These are generally subject to more or less arbitrary assumptions which affect the decay amplitude $\Gamma_{res}(m)$ of the resonance in the fitting procedures[2].

In exclusive experiments effects due to the production mechanism can be superposed with interference effects associated with processes involving the same final state. Interference effects thus produce an important skewing of the ρ^0 lineshape in photoproduction experiments (see ref.[3] for instance). Large distortions of the $S^*/f_0(975)$ meson have also been reported by many experiments (see ref.[4] for instance). Phase space effects can also produce large changes of the resonance shape. For instance, in the decay $\eta \rightarrow \pi^+\pi^-\gamma$ which is dominated by $\eta \rightarrow \rho^0\gamma$, the $\pi^+\pi^-$ mass spectrum is cut at the η mass in such a way that the ρ^0 peak is completely outside the available phase space[5]. In summary, several mechanisms can produce distortions of the invariant mass distributions of broad resonances, sometimes in a predictable way.

In high- p_T physics, we deal with another kind of production mechanism: the fragmentation of coloured strings into hadrons[6]. With this respect, O. Podobrin[7] has recently shown that Bose–Einstein correlation effects between resonance decay products and nearby (in phase space) stable pions can produce a large shift of the resonance masses. On the other hand, A. Lindner[8] has shown that the Lund Monte Carlo provides distortions of the ρ meson mass spectrum. These results illustrate that internal properties of the colour string fragmentation process can result in observable modifications of resonance mass spectra.

The ARGUS collaboration has looked for this kind of shape distortions for the ρ meson but could not reach any firm conclusion[9] because of lack of statistics. They have nevertheless taken this effect into account in recent works[10]. Studies involving light flavour mesons are also available from LEP experiments[11][12][13][14]. Some indication of ρ^0 lineshape distortion has been already reported by the OPAL collaboration[12].

Here in the WA77 experiment, we study the shape of five resonances for which the influence of reflections can be essentially removed and the background is well under control. These meson resonances ($f_2(1270)$, $K^{*0}(892)$, $\bar{K}^{*0}(892)$, $K^{*0}(1430)$ and $\bar{K}^{*0}(1430)$) have a large branching fraction to two-body channels ($\pi^+\pi^-$, $K^\pm\pi^\mp$). Moreover these resonances are rarely decay products of higher resonances and the feed down of $K^{*0}(892)$ mesons from $K^{*0}(1430)$ decays is removed by our trigger at the 98% level.

The mass spectra also reveal a significant ϕ signal[15] in K^+K^- , however we are not sensitive to possible distortions of this signal because of our mass resolution. There is in addition a large ρ^0 signal[15]; this signal is not studied in the present work because it is produced by several mechanisms (parton fragmentation[6], prompt production[16], η' decay[19]) and then its shape cannot follow from a single phenomenon.

We first give a brief description of the experiment and of the data samples (section 2). Then we study (section 3) the $f_2(1270)$ meson in the full samples of data collected at 300 and 150 GeV/c; due to its statistical importance, this signal allows a detailed study of systematic effects. Section 4 deals with the analysis of the $K^+\pi^-$ mass spectrum with an identified K^+ ; for this purpose we only use our 300 GeV/c data sample and study the $K^{*0}(892)$ and $K^{*0}(1430)$ meson invariant mass distributions. Section 5 is devoted to the study of the $K^-\pi^+$ mass spectrum with an identified K^- ; here also we only use our 300 GeV/c data sample and study the $\bar{K}^{*0}(892)$ and $\bar{K}^{*0}(1430)$ meson invariant mass distributions. In section 6, we discuss

the results obtained for the various mesons and examine some *a priori* possible explanations. Finally section 7 is devoted to a summary of our conclusions.

9 The data samples

The basic idea of the WA77 trigger is to obtain a sample of events with three particles at large p_T where a pair of them (of opposite charges) is supposed to come from the decay of a neutral resonance, while the third track (p , $\bar{p}$, $K^\pm$, $\pi^\pm$) is assumed to be the leading particle of an opposite jet. Details about the trigger and setup have been given elsewhere [15][18–22]. This trigger favours the observation of meson resonances decaying into two bodies which are leading particles of a high- p_T jet. We have verified this property on a Lund Monte Carlo sample of events tracked through the simulation of our setup and fulfilling our trigger conditions. We have thus found that 99.5% of the Monte Carlo events accepted by our trigger have no more than three tracks at $p_T \geq 1$ GeV/c.

The WA77 experiment has performed two runs of data taking on $\pi^- N$ interactions, the first at 300 GeV/c, the second at 150 GeV/c. In the 300 GeV/c setup two multicell Cerenkov counters were used for identification of particle species. We selected events in the rapidity range :

$$2.80 \leq Y_{lab}^{pair} \leq 3.70 \quad , \quad (27)$$

and with transverse momenta :

$$\begin{cases} p_T^{trig.part.} \geq 1 \text{ GeV/c} \\ p_T^{pair} \geq 2 \text{ GeV/c} \end{cases} \quad . \quad (28)$$

At 300 GeV/c, this corresponds to a center of mass rapidity window $(-0.43, +0.47)$, while at 150 GeV/c it corresponds to the window $(-0.08, +0.90)$. The total number of events is 209 654 in the 300 GeV/c sample and 238 749 in the 150 GeV/c sample.

10 Study of the $f_2(1270)$ meson

We consider here the mass spectra obtained assuming both particles in the pair to be pions. We do not use in this case the information provided by the Cerenkov counters since we know[21] that the pion assignment in our experiment is widely contaminated by kaons and protons. The $f_2(1270)$ region suffers only little from $K^{*0}(1430)$ contamination because its reflection produces a tiny signal which does not affect the properties of the $f_2(1270)$ meson (see section 3.3) and therefore it has not been considered in the final fit. No other source of contamination has been found in this mass region.

10.1 Fitting method

In order to perform our fits we have taken into account besides the resonances ($\rho^0(770)$, $f_2(1270)$, $S^*/f_0(975)$) the reflections due to the large signals[22] of the $\phi(1020)$, $K^{*0}(892)$ and $\bar{K}^{*0}(892)$ mesons. These last signals appear shifted due to the wrong mass assignment given to

their decay products. The invariant mass histogram of the pairs with the $\pi^+\pi^-$ mass assignment is shown in figure (1) for the 300 GeV/c data. It has been fitted using the following expression :

$$\begin{aligned} \frac{dN}{dm} = & [f_{bckg}(m) + a_\rho BW(\rho^0, m) + a_{S^*} BW(S^*, m) + a_{f_2} BW(f_2, m)] \\ & + a_\phi REF(\phi, m) + a_{K^*} REF(K^*, m) \end{aligned} \quad (29)$$

In this expression $f_{bckg}(m)$ is a function of the invariant mass of the pair (m) which describes the background[13][15]. It has been parametrized as :

$$f_{bckg}(m) = a(m - m_{th})^\alpha \exp[bm + cm^2 + dm^3] \quad , \quad (30)$$

where $m_{th} = 2m_\pi$ is the threshold mass of the system. We have checked on a Lund Monte Carlo sample that this expression describes correctly the mass histogram of the non-resonant pairs. BW and REF in expression (3) stand respectively for Breit-Wigner distributions and reflections of resonances when a wrong mass assignment is applied. We take as Breit-Wigner distribution of a resonance R :

$$BW(R, m) = \frac{m m_R \Gamma_{\pi\pi}(m)}{|m_R^2 - m^2 - im_R \Gamma(m)|^2} \quad , \quad (31)$$

where $\Gamma_{\pi\pi}(m)$ is the $\pi\pi$ partial width and $\Gamma(m)$ is the full width of the resonance R . The denominator in rel. (5) coincides with the usual $(m_R^2 - m^2)^2 + m_R^2 \Gamma^2(m)$ when the mass m is above all thresholds[1]. However, between the $\pi\pi$ and $K\bar{K}$ thresholds the partial width (see rel. (6) below) $\Gamma_{K\bar{K}}$ becomes purely imaginary and thus contributes to the real part of the Breit-Wigner denominator in rel.(5) ; this effect has been taken into account in our fits. Therefore, rel. (5) is the standard expression established in [1], assuming the production cross section of the resonance R to be constant. With this definition of a Breit-Wigner distribution, each a in rel. [3] is precisely the production cross-section of the corresponding resonance, in agreement with ref. [1].

The reflections of $K^{*0}(892)$ and $\bar{K}^{*0}(892)$ are superposed when using the $\pi^+\pi^-$ mass assignment, and not distinguishable. The shapes of all reflections have been computed by generating samples of events using a standard Breit-Wigner[1], following the tracks in the full simulation of our setup[17][21] and finally changing the correct mass assignment to $\pi^+\pi^-$. Our simulation takes into account the acceptance effects and the accuracy of the reconstruction program TRI-DENT. Therefore by this procedure we take into account acceptance and resolution effects on these mass distributions.

The parametrization of the $S^*/f_0(975)$ has been done following ref. [23] ; a large sample of events has been generated, tracked through the simulation of our detector and reconstructed to account for acceptance and resolution effects. We considered this precaution as necessary because this meson is close to the $f_2(1270)$ meson mass. We have chosen a heuristic parametrization¹³ for the ρ^0 meson (a Breit-Wigner with a width larger by 20 MeV than nominal). In this way expression (3) describes correctly the mass region below 1 GeV.

To describe the $f_2(1270)$ meson, we have not used the standard way[1] to write a relativistic Breit-Wigner expression, but rather followed the suggestion of ref.[5] by using a more general expression. Assuming the world average values[24] for the various branching fractions, the $f_2(1270)$ decay amplitude is written :

¹³The ρ^0 meson in our experiment is expected to be produced through many mechanisms, including the η' decay ; a precise study of this region is presently under way.

$$\Gamma_{f_2}(m) = \gamma_{f_2} \left[r_0 + r_K \left[\frac{q_K(m)}{q_K(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_K} + r_\pi \left[\frac{q_\pi(m)}{q_\pi(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_\pi} \right] + \gamma_{res} \quad , \quad (32)$$

where $q_K = 1/2\sqrt{m^2 - 4m_K^2}$, $q_\pi = 1/2\sqrt{m^2 - 4m_\pi^2}$ and $r_\pi = 0.849$, $r_K = 0.046$ and $r_0 = 0.105$ are respectively the branching fractions to $\pi\pi$, $K\overline{K}$ and the remaining channels. The constant part of the width accounts mainly for the decay modes into four bodies. λ_K and λ_π are parameters to be fitted. These two parameters are actually fixed to 1 in the standard approach[1] ; it has been shown [5] that the equivalent expression for the ρ^0 distribution with the exponent λ allowed to vary is able to give a good and simple description of the $e^+e^- \rightarrow \pi^+\pi^-$ data while it is not possible to obtain a good fit with λ fixed to one.

The parameter γ_{f_2} is the $f_2(1270)$ natural width and γ_{res} is the mass resolution at the resonance peak (20 MeV). This is the usual approach to account for resolution effects[26] ; we have checked with our simulation that this describes correctly the resolution effects in our experiment.

In the expression of the f_2 Breit–Wigner (rels. (3) and (5)), the denominator contains the full expression (6), but the numerator contains only the $\pi\pi$ part (last term in rel. (6)) together with the resolution contribution :

$$\Gamma_{\pi\pi} = r_\pi \gamma_{f_2} \left[\frac{q_\pi(m)}{q_\pi(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_\pi} + \gamma_{res} \quad , \quad (33)$$

The parameters α , a , b , c , d , a_ρ , a_{S^*} , a_{f_2} , a_ϕ , a_{K^*} are constants to be fitted with the constraint that the integral of the right–hand side of rel. (3) must be equal to the experimental number of events N . All resonance parameters (masses and widths) are fixed to their world average values[24], except for those for the f_2 which are fitted.

It should be noted that we have chosen to describe the resonance contributions assuming that their production cross sections are constant. Traditionally, these are assumed to have a phase–space distribution and this phase–space distribution is identified with the background in order to lessen the number of free parameters[25]. We have also used this method in previous publications[15][20][22]. Here we describe the resonance contributions assuming a constant production cross section after having checked that both constant and phase space cross sections give results consistent within errors for both resonance yields and functional shapes. Other attempts have been tried which will be described in section 3.3. Let us also mention that the two methods sketched above have been recently compared by the DELPHI collaboration[13] which have reached the same conclusion as ours.

Finally, we have chosen a binning (20 MeV) which matches our mass resolution at the $f_2(1270)$ mass in order to minimize the loss of information about the shape of the mass spectra.

10.2 Fitting the $\pi^+\pi^-$ spectra

As a general remark, we have found no sensitivity of our data to the precise value of λ_K ; varying it between 1 and 14 does not produce any change above the one σ level. Therefore we have decided to fix definitely $\lambda_K = 1$ in the $f_2(1270)$ analysis.

Let us first discuss the 300 GeV/c data. As a first attempt, we have tried fitting our spectrum assuming $\lambda_\pi = 1$ and fixing m_{f_2} and γ_{f_2} at their world average values[24]. This fit

corresponds to $\chi^2/dof = 210/139$ and is shown in fig. (1) ; it clearly goes too much above background on the f_2 high-mass tail region. Leaving free m_{f_2} and γ_{f_2} , the quality of the fit improves ($\chi^2/dof = 177/137$) and provides :

$$\begin{cases} m_{f_2} = 1240 \pm 6 \text{ MeV} \\ \gamma_{f_2} = 102^{+21}_{-18} \text{ MeV} \end{cases} . \quad (34)$$

Finally, leaving free m_{f_2} , γ_{f_2} , λ_π , we obtain a good fit (see figure (2)) corresponding to $\chi^2/dof = 141/136$ with the following parameters :

$$\begin{cases} m_{f_2} = 1227^{+10}_{-14} \text{ MeV} \\ \gamma_{f_2} = 219^{+75}_{-46} \text{ MeV} \\ \lambda_\pi = 12.13^{+2.11}_{-1.94} \end{cases} . \quad (35)$$

Turning now to our 150 GeV/c data, we have also first performed the fit after fixing $\lambda_\pi = 1$ and using the world average values for m_{f_2} and γ_{f_2} . The fit obtained is shown in figure (3) and corresponds to $\chi^2/dof = 222/139$. It also clearly goes too much above background on the $f_2(1270)$ high-mass tail. Setting $\lambda_\pi = 1$, but allowing m_{f_2} and γ_{f_2} to vary, we find :

$$\begin{cases} m_{f_2} = 1259 \pm 6 \text{ MeV} \\ \gamma_{f_2} = 72 \pm 12 \text{ MeV} \end{cases} , \quad (36)$$

corresponding to $\chi^2/dof = 179/137$. Finally, leaving free λ_π , m_{f_2} and γ_{f_2} , we find :

$$\begin{cases} m_{f_2} = 1254^{+7}_{-9} \text{ MeV} \\ \gamma_{f_2} = 148^{+45}_{-29} \text{ MeV} \\ \lambda_\pi = 13.44^{+3.22}_{-2.52} \end{cases} , \quad (37)$$

with a good quality of the fit ($\chi^2/dof = 144/136$) ; the corresponding fit is shown in figure (4).

10.3 Discussion of the results

As a general conclusion, assuming $\lambda_\pi = 1$ and fixing the $f_2(1270)$ parameters at their world average values ($m_{f_2} = 1275 \text{ MeV}$, $\gamma_{f_2} = 185 \text{ MeV}$) does not provide a satisfactory description of the data. Figures (1) and (3) clearly show that the $f_2(1270)$ high-mass tail extends too much and exhibits large systematic effects (see the insets in fig. (1) and (3)). Leaving free the mass and width slightly improves the quality of the fits but they are both significantly below their commonly accepted values[24].

However, we always obtain a good fit if we leave free λ_π . In this case, the $f_2(1270)$ natural width is in agreement with the accepted value[24], but the mass is systematically lower.

In this respect, we have studied the effects of systematic errors. The first source is our neglecting of the $K^{*0}(1430)$ reflection which occurs nearly at the $f_2(1270)$ mass with a width of about 300 MeV. Assuming[27] the ratio $K^{*0}(1430)/K^{*0}(892) = 0.2$, we have redone our fits

using expression (3) including a $K^{*0}(1430)$ reflection ; this increases the $f_2(1270)$ mass value by 6 MeV at both energies but has little effect on the $f_2(1270)$ width and λ_π . This is surely an upper bound since examining our samples with the $\pi^\pm K^\mp$ mass assignment clearly shows that the $K^{*0}(1430)$ contribution does not exceed 10% of the $f_2(1270)$ signals :

$$\begin{cases} n_{f_2} = 5051^{+1443}_{-977} & (300 \text{ GeV/c}) \\ n_{f_2} = 4339^{+985}_{-736} & (150 \text{ GeV/c}) \end{cases}, \quad (38)$$

and stays well inside the level of errors.

Another possible source of systematic effects is our assumption that a_{f_2} in expression (3) is constant. In this respect, we have replaced the term $a_{f_2} BW(f_2, m)$ in rel. (3) by $a_{f_2} f_{\pi\pi}(m) BW(f_2, m)$, where $f_{\pi\pi}(m)$ is the invariant mass distribution of non-resonant $\pi^+\pi^-$ pairs determined from a sample of Lund events accepted by our setup. The idea is that this function simulates the two-pion phase space distribution in our experiment. The results coincide with the above ones within errors. We have also tried fitting our spectra assuming $f_{\pi\pi}(m)$ to be of the form¹⁴ $[m_{f_2}/m]^\mu$. The improvement is small at both energies (the χ^2 decreases by only 4 units) and gives values consistent with that in rels (9) and (11) for γ_{f_2} and λ_π , while we find :

$$\begin{cases} m_{f_2} = 1245^{+12}_{-16} \text{ MeV} & \mu = 3.39^{+2.88}_{-1.64} & (300 \text{ GeV/c}) \\ m_{f_2} = 1266 \pm 8 \text{ MeV} & \mu = 2.87^{+1.54}_{-1.34} & (150 \text{ GeV/c}) \end{cases}, \quad (39)$$

in good agreement with the result of EHS[26].

We have also considered the influence of the background shape. Changing the threshold behaviour or adding a m^4 term in the exponential (see rel. (4)) does not remove the effect observed in the $f_2(1270)$ mass region. Another way to test the effect of background is to change the p_T cut ; in this respect we have reanalyzed our data requiring $p_T^{pair} \geq 2.2 \text{ GeV/c}$ instead of $p_T^{pair} \geq 2.0 \text{ GeV/c}$. At 300 GeV/c this produces a reduction of $\simeq 20\%$ for both the background and the $f_2(1270)$ signal, and the fit gives $\lambda_\pi = 18.8^{+3.5}_{-2.9}$. At 150 GeV/c this new p_T cut produces a reduction of $\simeq 50\%$ for the background and $\simeq 35\%$ for the $f_2(1270)$ signal ; in this case the fit provides $\lambda_\pi = 13.6^{+8.3}_{-4.8}$. Therefore the sharpening of the $f_2(1270)$ mass distribution cannot be attributed to the size of the background or to some given value of the signal to background ratio.

Finally we have checked by simulation studies that the acceptance function of $\pi\pi$ pairs is a slowly decreasing function of m nearly flat in the f_2 mass region. Therefore its effect can be neglected in expression (3) without affecting the results of the fit.

To conclude, the systematic effects which have been investigated tend to leave the values of γ_{f_2} and λ_π unchanged while they can produce a downward shift of the f_2 mass up to $\simeq 15$ MeV. Systematic effects due to the background shape or size have not been detected. Therefore, we can rely on the width and λ_π estimates in our data which correspond to one of the best available statistics (compare rels. (12) with the statistics reported in ref. [24]).

We can summarize our results on the $f_2(1270)$ meson by performing a weighted mean of rels. (9) and (11) :

¹⁴Indeed, since we are dominated by parton fragmentation, it is not clear that using a $\pi\pi$ phase space distribution is justified.

$$\begin{cases} \lambda_\pi = 12.6^{+1.8}_{-1.5} \\ \gamma_{f_2} = 167^{+39}_{-25} \text{ MeV} \end{cases} \quad (40)$$

Our estimate of the $f_2(1270)$ width is in agreement with the world average value[24] (185 ± 20 MeV) at the 1σ level; our estimate of the damping power λ_π ($\simeq 12$) gives a number considerably larger than what is usually expected[1]. For instance, the power obtained for the ρ^0 meson in the $e^+e^- \rightarrow \pi^+\pi^-$ process ranges[5] from $\simeq 0.66$ to $\simeq 1.75$.

Since there is no theory of this damping power[5], a question arises as to whether such a value ($\lambda_\pi \simeq 12$) looks normal or if it points towards a distortion of the $f_2(1270)$ invariant mass distribution when this meson is produced at large p_T as a leading fragment of a (high- p_T) jet. We note that most of spectroscopic experiments (see refs. [4] and [28] for instance) accomodate¹⁵ to $\lambda_\pi = 1$. In ref. [29] the $f_2(1270)$ coupling to $\pi^+\pi^-$ is considered yielding the following expression for the width :

$$\begin{cases} \Gamma(m) &= \Gamma_{f_2} \frac{q_\pi(m)}{q_\pi(m_{f_2})} \frac{D_2[q_\pi(m_{f_2})R]}{D_2[q_\pi(m)R]} \\ D_2[(q_\pi(m)R)] &= 9 + 3[q_\pi(m)R]^2 + [q_\pi(m)R]^4 \end{cases} \quad (41)$$

where the range parameter[2] R is found[29] to be $R \geq 3 \text{ GeV}^{-1}$ or $R \geq 9 \text{ GeV}^{-1}$, depending on the fit hypotheses. It follows from these lower bounds that only the last term in the second expression (15) plays a significant role. Therefore, in this experiment at least, the result corresponds to an effective value $\lambda_\pi = 4$. Comparing this result with rel. (14), clearly shows that in parton fragmentation, we get an additional damping power of $\simeq 8$. The skewing effect is shown in figure (5) ; here we have plotted the same Breit–Wigner expression (5) using $\lambda_\pi = 1$ and $\lambda_\pi = 12.5$, leaving unchanched γ_R and m_R . It should be noticed that the resulting skewing effect plays in such a way that the physical parameters of the $f_2(1270)$ meson, mass and width (or lifetime), can be considered as unchanged¹⁶ at the level of accuracy of our data.

11 Study of the $K^+\pi^-$ spectrum

In the data taken at 300 GeV/c, we have used the Cerenkov information to single out a sample of 16266 events with an identified K^+ meson ; no constraint has been placed on the negative particle. We have shown in ref.[21] that the probability for a particle identified as a kaon to be a pion is consistent with zero, while the probability of the converse is $\simeq 30\%$. Therefore, requesting a pion signature for the negative particle would have much more reduced our sample without a useful gain in the signal over background ratio. A significant fraction ($\simeq 30\%$) of the protons survive the condition of identified K^+ ; these will essentially

¹⁵CELLO collaboration [28] has not succeeded in determining the shape of the $f_2(1270)$ resonance because of the interplay in the $\gamma\gamma \rightarrow \pi^+\pi^-$ reaction of non-resonant terms which contribute to the D -wave together with the (main) $f_2(1270)$ resonant term.

¹⁶One should also notice that the values which are unchanged are the zero of the real part of the inverse propagator (*i.e.* m_R) in rel. (5) and the value of the imaginary part of this function at $m = m_R$ (*i.e.* γ_R) ; of course real and imaginary parts refer to the case when m is above all thresholds. It is these definitions of mass and width which appear to be stable.

contribute to the background as no Δ^0 contribution has been found in our data. A departure from pure phase space distribution in the threshold region is in any case expected because of anticorrelation phenomena in pair production[21] and therefore it is difficult to single out a possible Δ^0 contribution here. The data taken at 150 GeV/c are not used since there is no available Cerenkov information ; in this case, the K^* signals are widely mixed with the $\rho^0(770)$ and $f_2(1270)$ reflections and our conclusions would hardly be model dependent. Requiring one K mass assignment from the Cerenkov counters reduces the signals considerably but removes the $\rho^0(770)$ and $f_2(1270)$ signals completely.

The $K^+\pi^-$ spectrum is given in figure (6). We observe a clear signal of the $K^{*0}(892)$ (hereafter denoted K_V^*) and a small $K^{*0}(1430)$ signal (hereafter denoted K_T^*) ; the relatively broad bump between the $K\pi$ threshold and the K_V^* peak is the $\phi(1020)$ meson reflection in the $K\pi$ mass assignment. No other obvious structure can be seen¹⁷. Other K^* mesons fall in the 1400 MeV region[24][30] (as well as the reflection of the $f'(1515)$ signal) and could contribute to shadow somehow the K_T^* signal and shape. Therefore we need to check that the 1.43 GeV structure is indeed dominated by the K_T^* signal.

We have performed our fits using :

$$\frac{dN}{dm} = f_{acc}(m) [f_{bckg}(m) + a_V BW(K_V^*, m) + a_T BW(K_T^*, m)] + a_\phi REF(\phi, m) \quad . \quad (42)$$

In this expression $f_{bckg}(m)$ is a function of the invariant mass of the pair (m) which describes the background. It has been parametrized as :

$$f_{bckg}(m) = a(m - m_{th})^\alpha \exp[bm + cm^2 + dm^3 + em^4] \quad , \quad (43)$$

where m_{th} is the relevant two-particle threshold mass. We have generated a large sample of events using the Lund Monte Carlo program PYTHIA[8] and followed the tracks through a complete simulation of our setup. Using the pairs obtained by requiring that both particles do not come from the decay of the same resonance we have checked that expression (17) above was able to describe correctly the $K\pi$ spectra. We have especially checked that the third and fourth order terms in the exponential were needed to get a satisfactory description of the mass spectrum over our full mass range.

$f_{acc}(m)$ is the acceptance function of $K\pi$ pairs. It has also been directly computed from our simulation. As it can be seen from figure (7), this function peaks near the $K^*(892)$ mass and is flat around the $K^*(1430)$ mass. Unlike the case of the $\pi^+\pi^-$ spectrum, it is not possible to neglect its effect. There are also[21] non-resonant $p\pi^-$ pairs which give a slightly harder threshold behaviour. This phenomenon plays a role on the first 100 MeV of the invariant mass histogram and the corresponding bins have been removed from the fits.

The resonance contributions have been represented by the standard relativistic Breit-Wigner expression (5). Following ref. [5], the width of the meson K_V^* has been parametrized as :

$$\Gamma_V(m) = \gamma_V \left[\frac{q_{K\pi}(m)}{q_{K\pi}(m_V)} \right]^3 \left[\frac{m_V}{m} \right]^{\lambda_V} + \gamma_{res} \quad , \quad (44)$$

where γ_V is the natural width of the K_V^* resonance and γ_{res} is the resolution at the K_V^* peak (9 MeV) estimated from simulation. $q_{K\pi}(m)$ is the momentum of each decay product of the

¹⁷It must be noticed that the K_T^* signal in the original sample is overwhelmed by the background.

K_V^* resonance in its rest frame, and m_V is the resonance mass. Therefore we treat the K_V^* as a purely elastic resonance. In the standard treatment[1] followed by most experiments λ_V is set to 1 ; here we allow it to vary.

The K_T^* meson has been treated in the same way as the $f_2(1270)$ meson (see rel. (6) above) : the main decay modes into two bodies ($K\pi$, $K^*(892)\pi$) have been explicitly accounted for, while we have accounted for the rest by means of a constant width :

$$\gamma_T(1 - Br(K\pi) - Br(K_V^*\pi)) = 0.251\gamma_T \quad , \quad (45)$$

where γ_T is the K_T^* full width. The branching fractions of the K_T^* meson have been taken at their world average values[24]. Therefore, we have used :

$$\Gamma_T(m) = \gamma_T \left[0.251 + 0.252 \left[\frac{q_{K_V^*\pi}(m)}{q_{K_V^*\pi}(m_T)} \right]^5 \left[\frac{m_T}{m} \right] + 0.497 \left[\frac{q_{K\pi}(m)}{q_{K\pi}(m_T)} \right]^5 \left[\frac{m_T}{m} \right]^{\lambda_T} \right] + \gamma_{res} \quad , \quad (46)$$

where $q_{K_V^*\pi}$ and $q_{K\pi}$ are the 3-momenta of the K_T^* decay products for the corresponding decay modes¹⁸. We have fixed $\lambda = 1$ for the $K_V^*\pi$ channel after having checked that our data are not sensitive to this channel¹⁹. γ_T is the K_T^* natural width and γ_{res} is the mass resolution of our setup at the K_T^* peak mass (14 MeV).

The numerators of the BW functions in rel. (16), are always the partial widths to $K^+\pi^-$ increased by the resolution at the corresponding resonance peak.

$REF(\phi, m)$ in rel. (16) is the reflection of the ϕ meson. It has been computed directly by generating a sample of ϕ mesons from a Breit-Wigner law (see rel. (5)) and tracking the K^+ and K^- particles through our simulation. The reflected spectrum has been simply obtained by changing the true particle assignment to $K^+\pi^-$.

Our free parameters are those in rel. (17) and a_V , a_T and a_ϕ which give the number of mesons in our spectrum for K_V^* , K_T^* and ϕ resonances respectively. Here again there is a constraint among these parameters which requires that the integral of the right-hand side of rel. (16) gives the number of experimental events in the same interval.

We shall also denote m_V and m_T the masses of the K_V^* and K_T^* mesons respectively. They will be fixed or fitted as well as the natural widths γ_V and γ_T .

As a first attempt we have fixed the masses and widths of the K_V^* and K_T^* mesons at their world average values[24], requiring in addition $\lambda_V = \lambda_T = 1$. The first five bins (*i.e.* 100 MeV) are removed from the fit. The best fit is shown in figure (6) and corresponds to $\chi^2/dof = 145/112$. Looking at the inset, where the background and the ϕ contribution have been subtracted, it is clear that the high-mass tail of K_V^* extends too much above the background. The K_T^* signal is too small to allow any eye estimate. Leaving free m_V , Γ_V , λ_V and m_T , Γ_T , λ_T , the quality of the fit improves ($\chi^2/dof = 128/106$). The fitted values of interest are :

¹⁸What has been said concerning the $f_2(1270)$ Breit-Wigner denominator in rel. (5) when m is between the $\pi\pi$ and $K\bar{K}$ threshold applies fully for the K_T^* Breit-Wigner between the πK and $K_V^*\pi$ thresholds ; we have accounted for this effect in precisely the same way.

¹⁹Varying this λ from 1 to 14 does not produce any significant change in the results.

$$\left\{ \begin{array}{l} m_V = 892 \pm 3 \text{ MeV}, \quad \gamma_V = 39 \pm 11 \text{ MeV} \quad \lambda_V = 13.53^{+3.42}_{-3.00} \\ m_T = 1435 \pm 13 \text{ MeV}, \quad \gamma_T = 100 \pm 49 \text{ MeV} \quad \lambda_T = 5.56 \pm 3.31 \end{array} \right. . \quad (47)$$

The errors are large because of correlations between each γ and its corresponding λ . The resulting fit is given in figure (8) and the inset clearly shows that the resonance tails are now more realistically described. Moreover, the number of ϕ mesons obtained from this fit and that obtained using the K^+K^- mass assignment in the same sample are consistent within errors ; this indicates that the background is correctly estimated and that threshold effects do not affect the mass region of interest. The mass and width obtained from fit for the K_V^* meson are consistent with the world average values[24] (896.1 MeV and 50.5 MeV respectively). This is also true for the K_T^* meson mass and width obtained from the fit (ref. [24] gives 1432.4 MeV and 109 MeV respectively). This indicates that identifying the small structure located around 1.43 GeV with the $K^{*0}(1430)$ meson is reasonable. One should notice the large value found for λ_V (consistent with that of the $f_2(1270)$ meson) ; the value found for λ_T is inconclusive but still consistent with a large value.

Since the K^* mesons in our data have parameters consistent with their world average values, it is reasonable to fix m_V , m_T , γ_V and γ_T at their average values[24] ; in this case, we get $\chi^2/dof = 133/110$ and :

$$\left\{ \begin{array}{l} \lambda_V = 12.9^{+2.2}_{-2.7} \\ \lambda_T = 4.9^{+4.4}_{-1.8} \end{array} \right. . \quad (48)$$

In our data there are 839 ± 99 K_V^* events and 420 ± 71 K_T^* events.

12 Study of the $K^-\pi^+$ spectrum

Using the data taken at 300 GeV/c and requiring from Cerenkov information an identified K^- , we get a sample of 10 157 events. We have not required any identification of the positive particle for the reason already mentioned (see section 4 above). Here we have to deal with a contamination of K^- by $\bar{p}$; the situation is fortunately not symmetrical to the contamination by protons in the previous sample since the ratio $\bar{p}/p$ is more favourable[21] ($0.41 \div 0.46$) in the present case. Since this contamination is significant only near threshold we remove the first five bins (100 MeV) from the fit. The formulae and arguments given in the previous section are still valid in the present case.

The $K^-\pi^+$ mass spectrum is shown in figure (9), apart from the ϕ reflection, one sees a clear signal of the $\bar{K}_V^*$ meson and a broad structure which will be identified with the $\bar{K}_T^*$ meson²⁰. The mass distributions of these mesons are expected identical to that of their antiparticles (see section 4).

We have first performed a fit by setting the masses and widths of the $\bar{K}^*$ mesons at their world average values[24], assuming $\lambda_V = \lambda_T = 1$. The result of the fit is shown in figure (9)

²⁰We shall consider this identification correct if the parameters obtained by fit are consistent with that of the $\bar{K}^{*0}(1430)$ meson.

($\chi^2/dof = 143/112$). As before, the inset shows that the $\overline{K}_V^*$ high-mass tail extends too much and nothing firm can be asserted about the $\overline{K}_T^*$ meson.

We have then released m_V , Γ_V , λ_V and m_T , Γ_T , λ_T . In this case, the fit (shown in figure (10)) gives a better description of the data ($\chi^2/dof = 108/106$) with better resonance tails. The fitted parameters are

$$\begin{cases} m_V = 892 \pm 3 \text{ MeV}, & \gamma_V = 34^{+16}_{-13} \text{ MeV} & \lambda_V = 14.0 \pm 4.9 \\ m_T = 1401^{+14}_{-29} \text{ MeV}, & \gamma_T = 91^{+80}_{-43} \text{ MeV} & \lambda_T = 10.5^{+4.1}_{-5.4} \end{cases} \quad (49)$$

As a result of the large correlations between γ s and λ s parameters and of the relatively small statistics, there are large uncertainties on most of these parameters (especially for the widths). However these results allow us to check that the $\overline{K}_V^*$ and $\overline{K}_T^*$ mass and width values are in agreement with the corresponding world average values[24]. The values found for the λ s are both large and consistent with that found for K_V^* and K_T^* (see rels. (21)) as can be expected from charge conjugation symmetry.

Since the parameters of $\overline{K}_V^*$ and $\overline{K}_T^*$ are in good agreement with their accepted values, we have done a final fit by fixing m_V , γ_V and m_T , γ_T to their usual values[24]. We thus obtained a good fit ($\chi^2/dof = 129/110$) with the following values :

$$\begin{cases} \lambda_V = 12.7^{+3.6}_{-4.3} \\ \lambda_T = 12.1^{+2.3}_{-4.8} \end{cases} \quad (50)$$

The numbers of mesons are 543 ± 80 ($\overline{K}_V^*$) and 262 ± 63 ($\overline{K}_T^*$) ; we have also checked that the ϕ signal is in agreement with that obtained using the K^+K^- mass assignment, where the signal occurs in a single (20 MeV) bin.

Instead of performing algebraically the weighted mean of rel. (22) and (24) between charge conjugate partners, we have preferred performing a global fit of the sample obtained by merging the $K^+\pi^-$ and $K^-\pi^+$ mass spectra. Thus we get a good fit ($\chi^2/dof = 135/106$) and meson yields in agreement with the results given above²¹. The 'mean values' of the damping powers are :

$$\begin{cases} \lambda_V = 13.4^{+2.4}_{-2.7} \\ \lambda_T = 9.1^{+4.5}_{-6.0} \end{cases} \quad (51)$$

These values are consistent with those obtained for $f_2(1270)$ at the 1. σ level.

We could expect λ_V to be of the order[5] of λ_ρ (*i.e.* $0.66 \div 1.75$) since they are both vector mesons. On the other hand, ref.[30] has tried a fit of the kind (15) and obtained a result consistent with a behaviour like m^{-2} or m^{-3} . The LASS collaboration[30] also quotes a result for the K_T^* meson which is at most of the order m^{-5} . Thus, the results of sections 4 and 5 point towards a distortion of the K_V^* mass spectrum by an additional damping power of $\simeq 10$; the K_T^* mass distribution is consistent with the same distortion than the K_V^* and with no

²¹We obtain 1310 ± 205 for $K^{*0}(892) + \overline{K}^{*0}(892)$ while we expect 1382 ± 127 and 491 ± 150 for $K^{*0}(1430) + \overline{K}^{*0}(1430)$ while we expect 682 ± 95 .

distortion as well because of the large value of the errors. As for the $f_2(1270)$, this distortion preserves the fundamental parameters of these mesons (masses and widths). Indeed the same global fit provides :

$$\begin{cases} m_V = 892 \pm 2 \text{ MeV} & \gamma_V = 40^{+10}_{-9} \text{ MeV} \\ m_T = 1424 \pm 10 \text{ MeV} & \gamma_T = 73^{+37}_{-24} \text{ MeV} \end{cases} . \quad (52)$$

Consequences of systematic effects have been examined in both the $K^+\pi^-$ and $K^-\pi^+$ spectra. We have checked that changing the a_V and a_T to the distributions of non-resonant πK pairs does not affect our results. Assuming a production cross section which varies like m^{-3} (see rel. (13)) leads to the same conclusion. In this case, moreover, because the mesons K_V^* and K_T^* are much sharper than the $f_2(1270)$ meson, their masses are not affected by more than 3 MeV. Finally the feed-down of K_V^* mesons by K_V^* coming from K_T^* decay is negligible because mainly of our p_T cut (see rel. (2)). Therefore, our conclusions are stable and especially the sharp fall-off of the invariant mass distributions summarized by rels. (22), (24), (25).

13 General discussion of the results

Our results are summarized in table (1), apart from the value of the damping power λ , we also consider our estimate of the $f_2(1270)$ width as reliably measured and reasonably free from systematic errors. This result is in good agreement with the recent high statistics result²² of the DM2 collaboration[31] (169.0 ± 7.5 MeV) and with that of the EHS collaboration[26] (180 ± 24). The damping powers obtained using the $f_2(1270)$ and $K^{*0}(892)$ mesons are remarkably similar ; the damping power associated with the $K^{*0}(1430)$ mesons is lower but consistent with those of the previous mesons at the 1σ level.

The first conclusion of sections 3 to 5 is that the meson mass distributions are all distorted in the same way. The second conclusion is that this distortion preserves the values of the mesons masses and widths²³. This result looks general since the same properties are observed for mesons having different spins ($J = 1, 2$) and different strangeness content (f_2 and K^*).

In principle, our results could be compared with that obtained by the SFM collaboration which has measured the rates of $f_2(1270)$ and $K^{*0}(892)$ mesons at large p_T at ISR energies[32]. Unfortunately, this comparison is not possible because they have accounted for the background by the event mixing technics which produces distortions of the resonance signals and the authors of ref. [32] have corrected the subtracted spectra for these distortions. These corrections may have washed out the effect we observe in our experiment.

Another possibility would be that the observed distortions are produced by interference effects. We consider this assumption as unlikely since we are dealing with large multiplicity events ($\simeq 10$) and varying species of final state particles. In this case, we expect interference contributions to cancel out. As an illustration, ref.[23] has examined the inclusive $\pi^+\pi^-$ production in J/ψ decays and reached the conclusion that their data were consistent with no ρ^0 - ω interference. Our mass histogram for pairs with $\pi^+\pi^-$ mass assignment (see fig. (1) for

²²Ref. [31] uses a Breit-Wigner curve but does not provide further information about its precise shape ; this should mean that they use the standard shape[1].

²³Technically, the resonance mass which appears stable is defined as the zero (m_R) of the real part of the inverse propagator $D^{-1}(m) = (m_R^2 - m^2) - im_R\Gamma(m)$, while the width is defined by $\gamma_R = \Gamma(m_R)$. This property has been already noted in section 3.3.

instance) is also consistent with no ρ^0 - ω interference. Moreover, it is hard to imagine that interference effects would give the same distortion for all cases and that they would leave nearly unchanged the masses and widths of broad objects.

Resonance	mass our result	mass P.D.G.	width our result	width P.D.G.	λ	χ^2/dof
$f_2(1270) (300)$	1227^{+10}_{-14}	1275 ± 5	236^{+75}_{-46}	185 ± 20	$12.1^{+2.1}_{-1.9}$	141/136
$f_2(1270) (150)$	1254^{+7}_{-9}		165^{+45}_{-29}		$13.4^{+3.2}_{-2.5}$	144/136
$K^{*0}(892)$	892 ± 3	896.1 ± 0.3	39 ± 11	50.5 ± 0.6	$13.5^{+3.4}_{-3.0}$	128/106
$\overline{K}^{*0}(892)$	892 ± 3		34^{+16}_{-13}		14.0 ± 4.9	108/106
$K^{*0} + \overline{K}^{*0}$	892 ± 2		40^{+10}_{-9}		$13.4^{+2.4}_{-2.7}$	135/106
$K^{*0}(1430)$	1435 ± 13	1432.4 ± 1.3	100 ± 49	109 ± 5	5.6 ± 3.3	128/106
$\overline{K}^{*0}(1430)$	1401^{+14}_{-29}		91^{+80}_{-43}		$10.5^{+4.1}_{-5.4}$	108/106
$K^{*0} + \overline{K}^{*0}$	1424 ± 10		73^{+37}_{-24}		$9.1^{+4.5}_{-6.0}$	135/106

Table 1 : Summary of the results concerning all the fitted mesons.

We are thus left with the conclusion that the observed distortions are due to the production mechanism at work in our experiment : the hadronization process of colored quarks and gluons. This process enhances the probability to produce a given meson at low mass and suppresses its production at large mass. More surprising is that these distortions leave unchanged the resonance physical parameters. These properties are in qualitative agreement with what has been seen recently from a Lund Monte Carlo sample by A. Lindner[8] when examining the shape of the ρ^0 mass spectrum. Since resonance mass spectra in the Lund Monte Carlo are simply fixed width Breit–Wigner expressions the agreement cannot be otherwise than qualitative.

These properties illustrate the specificity of color string fragmentation as a production mechanism of resonances, at least as leading fragments. Of course, resonances produced in resonance decays are affected differently, and sometimes not affected at all²⁴.

On the other hand, resonances decaying to more than two particles are surely affected, but our experiment does not allow any precise study of this effect. For instance, there is some indication that $a_2(1320)$ is observed in its three pion decay mode, but the combinatorial three particle background is so large that no study can be performed.

Our main result can be sketched in the following way : when produced at large p_T , any given resonance R of spin l having two-particle decay modes can be described by a Breit–Wigner distribution, the shape of which remains formally the usual one[1], with the usual mass and width (m_R and γ_R) ; however, its decay amplitude to a given decay mode X written[5] :

²⁴For instance, the ρ^0 produced in the η' decay is surely affected by phase space effects due essentially to the η' mass but not to the η' production mechanism since this meson is too sharp to feel any damping factor.

$$\Gamma_X(m) = \gamma_R \left[\frac{q_X(m)}{q_X(m_R)} \right]^{(2l+1)} \left[\frac{m_R}{m} \right]^\lambda ,$$

always gives a good description of the data and $\lambda \simeq 12.5$ looks like a universal parameter. This power is large enough to suggest an actual exponential damping. The present theoretical knowledge does not provide however any motivated guideline to a suitable parametrization of meson shape distortions in high- p_T processes.

14 Conclusions

We have analyzed the invariant mass distributions of five mesons ($f_2(1270)$, $K^{*0}(892)$, $\overline{K}^{*0}(892)$, $K^{*0}(1430)$, $\overline{K}^{*0}(1430)$) produced at $p_T \geq 2.0$ GeV/c, under conditions where they are likely to be leading fragments of high- p_T jets. We have found that these mass distributions are sharply distorted ; these distributions are affected by a large damping power ($\simeq m^{-12}$), far above the usual one. At the level of accuracy allowed by our data, we have also shown that this distortion does not affect the mass and width of any of the resonances examined sofar. We have also shown that the distortions look alike for the mesons studied, without any respect to their spin or quark content. It has to be expected that this phenomenon affects all resonances primarily produced in the parton fragmentation mechanism, for instance the ρ meson. Our conclusions apply to two-body decay channels of resonances. The meson shape distortions observed in our data give experimental support to the existence of phase space effects in the process of quark fragmentation into hadrons.

References

- [1] J.D. Jackson, Nuovo Cimento XXXIV (1964) 1644.
- [2] J. Pisut and M. Roos, Nucl. Phys. **B6** (1968) 325.
- [3] J. Ballam *et al.*, Phys. Rev. **5** (1972) 545.
- [4] T.A. Armstrong *et al.* Zeit. für Phys. **C51** (1991) 351.
- [5] M. Benayoun *et al.* Zeit. für Phys. **C 58** (1993) 31.
- [6] B. Andersson *et al.* Phys. Rep. **97** (1983) 31 ;
H. Bengtsson and G. Ingelman Comput. Phys. Comm. **34** (1985) 251 ;
“The Lund Monte Carlo Programs”, CERN long writeups W5035, W5045, W5046, W5047, W5048, nov. 1989.
- [7] O. Podobrin, Ph. D. Thesis, DESY report FCE-92-03, Hamburg 1992.
- [8] A. Lindner, Ph. D. Thesis, Dortmund 1992.
- [9] H. Albrecht *et al.*, DESY preprint 93-084, Hamburg 1993.
- [10] H. Albrecht *et al.* Zeit. für Phys. **C58** (1993) 199.
- [11] ALEPH collaboration, preprint CERN-PPE/92-74, Geneva 1992.
- [12] OPAL collaboration, preprint CERN-PPE/92-116, Geneva 1992.
- [13] P. Abreu *et al.*, DELPHI collaboration, Phys. Lett. **B298** (1993) 236.
- [14] P.D. Acton *et al.*, OPAL collaboration, Zeit. für Phys. **C56** (1992) 521.
- [15] M. Benayoun *et al.* Phys. Lett. **B183** (1987) 412.
- [16] M. Benayoun *et al.* Nucl. Phys. **B282** (1987) 653.
- [17] M. Benayoun *et al.* Phys. Lett. **B192** (1987) 447.
- [18] M. Benayoun *et al.* Phys. Lett. **B198** (1987) 281.
- [19] W. Beusch *et al.* Nucl. Instrum. Methods **A249** (1986) 391.
- [20] M.T. Trainor, “Direct meson production at $p_T \geq 2$. GeV/c in 300 GeV/c $\pi^- Be$ interactions”, PhD thesis, University of Birmingham, March 1988 ;
R. Fini, “Produzione inclusiva di risonanze a medio-alto momento trasverso”, Tesi di Dottorato, Università degli studi di Bari, january 1990, National library of Rome and Florence.
- [21] A. Bellogianni *et al.*, Zeit. für Phys. **C54** (1992) 535.
- [22] A. Bellogianni *et al.*, Zeit. für Phys. **C59** (1993) 35.
- [23] G. Gidal *et al.*, Phys. Lett. **B107** (1981) 153.
- [24] Review of Particle Properties, Phys. Rev **D45** (1992).
- [25] P. Granet *et al.* Nucl. Phys. **B140** (1978) 389.
- [26] M. Aguilar-Benitez *et al.* Zeit für Phys. **C50** (1991) 405.
- [27] S. Abachi *et al.*, Phys. Rev. Lett. **57** (1986) 1990.
- [28] H.-J. Behrend *et al.* Zeit für Phys. **C56** (1992) 381 ;
J. Harjes, Thesis, preprint DESY-FCE-91-01, Hamburg 1991.
- [29] V. Chabaud *et al.* Nucl. Phys. **B223** (1983) 1.
- [30] D. Aston *et al.* Nucl. Phys. **B296** (1988) 493.
- [31] J.E. Augustin *et al.* Nucl. Phys. **B320** (1989) 1.
- [32] A. Breakstone *et al.* Zeit für Phys. **C43** (1989) 185.

Figure Captions

- Figure 1 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 300 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming the world average values for the $f_2(1270)$ parameters, $\lambda_K = 1$, $\lambda_\pi = 1$. In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the large high-mass tail of the $f_2(1270)$.
- Figure 2 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 300 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming $\lambda_K = 1$, but leaving free the mass, width of the $f_2(1270)$ meson and λ_π . In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice how the high-mass tail of the $f_2(1270)$ is reduced.
- Figure 3 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 150 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming the world average values for the $f_2(1270)$ parameters, $\lambda_K = 1$, $\lambda_\pi = 1$. In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the large high-mass tail of the $f_2(1270)$.
- Figure 4 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 150 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming $\lambda_K = 1$, but leaving free the mass, width of the $f_2(1270)$ meson and λ_π . In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the reduction in the high-mass tail of the $f_2(1270)$.

- Figure 5 : Effect of the damping power λ_π on the shape of a Breit–Wigner contribution to the cross section. In full line we have represented the case $\lambda_\pi = 1$, in dashed dotted line the case $\lambda_\pi = 12.5$.
- Figure 6 : Invariant mass plot of trigger pairs with an identified K^+ ; the data are extracted from our 300 GeV/c sample. The fit represented has been obtained assuming the world average values for the masses and widths of both K^* mesons and both damping powers $\lambda = 1$.
- Figure 7 : Acceptance function of $K\pi$ trigger pairs as a function of their (true) invariant mass.
- Figure 8 : Invariant mass plot of trigger pairs with an identified K^+ ; the data are extracted from our 300 GeV/c sample. The fit shown has been obtained leaving free the masses and widths of both K^* mesons and both damping powers λ .
- Figure 9 : Invariant mass plot of trigger pairs with an identified K^- ; the data are extracted from our 300 GeV/c sample. The fit represented has been obtained assuming the world average values for the masses and widths of both K^* mesons and both damping powers $\lambda = 1$.
- Figure 10 : Invariant mass plot of trigger pairs with an identified K^- ; the data are extracted from our 300 GeV/c sample. The fit represented is obtained, leaving free the masses and widths of both K^* mesons and both damping powers λ .

15 Introduction

It is a known property of resonances that their observed mass distributions can vary from one experiment to another, depending on the production mechanism[1][2]. The main origin of this effect is the unknown mass dependence of resonance production cross sections. These are generally subject to more or less arbitrary assumptions which affect the decay amplitude $\Gamma_{res}(m)$ of the resonance in the fitting procedures[2].

In exclusive experiments effects due to the production mechanism can be superposed with interference effects associated with processes involving the same final state. Interference effects thus produce an important skewing of the ρ^0 lineshape in photoproduction experiments (see ref.[3] for instance). Large distortions of the $S^*/f_0(975)$ meson have also been reported by many experiments (see ref.[4] for instance). Phase space effects can also produce large changes of the resonance shape. For instance, in the decay $\eta \rightarrow \pi^+\pi^-\gamma$ which is dominated by $\eta \rightarrow \rho^0\gamma$, the $\pi^+\pi^-$ mass spectrum is cut at the η mass in such a way that the ρ^0 peak is completely outside the available phase space[5]. In summary, several mechanisms can produce distortions of the invariant mass distributions of broad resonances, sometimes in a predictable way.

In high- p_T physics, we deal with another kind of production mechanism: the fragmentation of coloured strings into hadrons[6]. With this respect, O. Podobrin[7] has recently shown that Bose–Einstein correlation effects between resonance decay products and nearby (in phase space) stable pions can produce a large shift of the resonance masses. On the other hand, A. Lindner[8] has shown that the Lund Monte Carlo provides distortions of the ρ meson mass spectrum. These results illustrate that internal properties of the colour string fragmentation process can result in observable modifications of resonance mass spectra.

The ARGUS collaboration has looked for this kind of shape distortions for the ρ meson but could not reach any firm conclusion[9] because of lack of statistics. They have nevertheless taken this effect into account in recent works[10]. Studies involving light flavour mesons are also available from LEP experiments[11][12][13][14]. Some indication of ρ^0 lineshape distortion has been already reported by the OPAL collaboration[12].

Here in the WA77 experiment, we study the shape of five resonances for which the influence of reflections can be essentially removed and the background is well under control. These meson resonances ($f_2(1270)$, $K^{*0}(892)$, $\bar{K}^{*0}(892)$, $K^{*0}(1430)$ and $\bar{K}^{*0}(1430)$) have a large branching fraction to two-body channels ($\pi^+\pi^-$, $K^\pm\pi^\mp$). Moreover these resonances are rarely decay products of higher resonances and the feed down of $K^{*0}(892)$ mesons from $K^{*0}(1430)$ decays is removed by our trigger at the 98% level.

The mass spectra also reveal a significant ϕ signal[15] in K^+K^- , however we are not sensitive to possible distortions of this signal because of our mass resolution. There is in addition a large ρ^0 signal[15]; this signal is not studied in the present work because it is produced by several mechanisms (parton fragmentation[6], prompt production[16], η' decay[19]) and then its shape cannot follow from a single phenomenon.

We first give a brief description of the experiment and of the data samples (section 2). Then we study (section 3) the $f_2(1270)$ meson in the full samples of data collected at 300 and 150 GeV/c; due to its statistical importance, this signal allows a detailed study of systematic effects. Section 4 deals with the analysis of the $K^+\pi^-$ mass spectrum with an identified K^+ ; for this purpose we only use our 300 GeV/c data sample and study the $K^{*0}(892)$ and $K^{*0}(1430)$ meson invariant mass distributions. Section 5 is devoted to the study of the $K^-\pi^+$ mass spectrum with an identified K^- ; here also we only use our 300 GeV/c data sample and study the $\bar{K}^{*0}(892)$ and $\bar{K}^{*0}(1430)$ meson invariant mass distributions. In section 6, we discuss

the results obtained for the various mesons and examine some *a priori* possible explanations. Finally section 7 is devoted to a summary of our conclusions.

16 The data samples

The basic idea of the WA77 trigger is to obtain a sample of events with three particles at large p_T where a pair of them (of opposite charges) is supposed to come from the decay of a neutral resonance, while the third track (p , $\bar{p}$, $K^\pm$, $\pi^\pm$) is assumed to be the leading particle of an opposite jet. Details about the trigger and setup have been given elsewhere [15][18–22]. This trigger favours the observation of meson resonances decaying into two bodies which are leading particles of a high- p_T jet. We have verified this property on a Lund Monte Carlo sample of events tracked through the simulation of our setup and fulfilling our trigger conditions. We have thus found that 99.5% of the Monte Carlo events accepted by our trigger have no more than three tracks at $p_T \geq 1$ GeV/c.

The WA77 experiment has performed two runs of data taking on $\pi^- N$ interactions, the first at 300 GeV/c, the second at 150 GeV/c. In the 300 GeV/c setup two multicell Cerenkov counters were used for identification of particle species. We selected events in the rapidity range :

$$2.80 \leq Y_{lab}^{pair} \leq 3.70 \quad , \quad (53)$$

and with transverse momenta :

$$\begin{cases} p_T^{trig.part.} \geq 1 \text{ GeV/c} \\ p_T^{pair} \geq 2 \text{ GeV/c} \end{cases} . \quad (54)$$

At 300 GeV/c, this corresponds to a center of mass rapidity window $(-0.43, +0.47)$, while at 150 GeV/c it corresponds to the window $(-0.08, +0.90)$. The total number of events is 209 654 in the 300 GeV/c sample and 238 749 in the 150 GeV/c sample.

17 Study of the $f_2(1270)$ meson

We consider here the mass spectra obtained assuming both particles in the pair to be pions. We do not use in this case the information provided by the Cerenkov counters since we know[21] that the pion assignment in our experiment is widely contaminated by kaons and protons. The $f_2(1270)$ region suffers only little from $K^{*0}(1430)$ contamination because its reflection produces a tiny signal which does not affect the properties of the $f_2(1270)$ meson (see section 3.3) and therefore it has not been considered in the final fit. No other source of contamination has been found in this mass region.

17.1 Fitting method

In order to perform our fits we have taken into account besides the resonances ($\rho^0(770)$, $f_2(1270)$, $S^*/f_0(975)$) the reflections due to the large signals[22] of the $\phi(1020)$, $K^{*0}(892)$ and $\bar{K}^{*0}(892)$ mesons. These last signals appear shifted due to the wrong mass assignment given to

their decay products. The invariant mass histogram of the pairs with the $\pi^+\pi^-$ mass assignment is shown in figure (1) for the 300 GeV/c data. It has been fitted using the following expression :

$$\begin{aligned} \frac{dN}{dm} = & [f_{bckg}(m) + a_\rho BW(\rho^0, m) + a_{S^*} BW(S^*, m) + a_{f_2} BW(f_2, m)] \\ & + a_\phi REF(\phi, m) + a_{K^*} REF(K^*, m) \end{aligned} \quad (55)$$

In this expression $f_{bckg}(m)$ is a function of the invariant mass of the pair (m) which describes the background[13][15]. It has been parametrized as :

$$f_{bckg}(m) = a(m - m_{th})^\alpha \exp[bm + cm^2 + dm^3] \quad , \quad (56)$$

where $m_{th} = 2m_\pi$ is the threshold mass of the system. We have checked on a Lund Monte Carlo sample that this expression describes correctly the mass histogram of the non-resonant pairs. BW and REF in expression (3) stand respectively for Breit-Wigner distributions and reflections of resonances when a wrong mass assignment is applied. We take as Breit-Wigner distribution of a resonance R :

$$BW(R, m) = \frac{m m_R \Gamma_{\pi\pi}(m)}{|m_R^2 - m^2 - im_R \Gamma(m)|^2} \quad , \quad (57)$$

where $\Gamma_{\pi\pi}(m)$ is the $\pi\pi$ partial width and $\Gamma(m)$ is the full width of the resonance R . The denominator in rel. (5) coincides with the usual $(m_R^2 - m^2)^2 + m_R^2 \Gamma^2(m)$ when the mass m is above all thresholds[1]. However, between the $\pi\pi$ and $K\bar{K}$ thresholds the partial width (see rel. (6) below) $\Gamma_{K\bar{K}}$ becomes purely imaginary and thus contributes to the real part of the Breit-Wigner denominator in rel.(5) ; this effect has been taken into account in our fits. Therefore, rel. (5) is the standard expression established in [1], assuming the production cross section of the resonance R to be constant. With this definition of a Breit-Wigner distribution, each a in rel. [3] is precisely the production cross-section of the corresponding resonance, in agreement with ref. [1].

The reflections of $K^{*0}(892)$ and $\bar{K}^{*0}(892)$ are superposed when using the $\pi^+\pi^-$ mass assignment, and not distinguishable. The shapes of all reflections have been computed by generating samples of events using a standard Breit-Wigner[1], following the tracks in the full simulation of our setup[17][21] and finally changing the correct mass assignment to $\pi^+\pi^-$. Our simulation takes into account the acceptance effects and the accuracy of the reconstruction program TRI-DENT. Therefore by this procedure we take into account acceptance and resolution effects on these mass distributions.

The parametrization of the $S^*/f_0(975)$ has been done following ref. [23] ; a large sample of events has been generated, tracked through the simulation of our detector and reconstructed to account for acceptance and resolution effects. We considered this precaution as necessary because this meson is close to the $f_2(1270)$ meson mass. We have chosen a heuristic parametrization²⁵ for the ρ^0 meson (a Breit-Wigner with a width larger by 20 MeV than nominal). In this way expression (3) describes correctly the mass region below 1 GeV.

To describe the $f_2(1270)$ meson, we have not used the standard way[1] to write a relativistic Breit-Wigner expression, but rather followed the suggestion of ref.[5] by using a more general expression. Assuming the world average values[24] for the various branching fractions, the $f_2(1270)$ decay amplitude is written :

²⁵The ρ^0 meson in our experiment is expected to be produced through many mechanisms, including the η' decay ; a precise study of this region is presently under way.

$$\Gamma_{f_2}(m) = \gamma_{f_2} \left[r_0 + r_K \left[\frac{q_K(m)}{q_K(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_K} + r_\pi \left[\frac{q_\pi(m)}{q_\pi(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_\pi} \right] + \gamma_{res} \quad , \quad (58)$$

where $q_K = 1/2\sqrt{m^2 - 4m_K^2}$, $q_\pi = 1/2\sqrt{m^2 - 4m_\pi^2}$ and $r_\pi = 0.849$, $r_K = 0.046$ and $r_0 = 0.105$ are respectively the branching fractions to $\pi\pi$, $K\overline{K}$ and the remaining channels. The constant part of the width accounts mainly for the decay modes into four bodies. λ_K and λ_π are parameters to be fitted. These two parameters are actually fixed to 1 in the standard approach[1] ; it has been shown [5] that the equivalent expression for the ρ^0 distribution with the exponent λ allowed to vary is able to give a good and simple description of the $e^+e^- \rightarrow \pi^+\pi^-$ data while it is not possible to obtain a good fit with λ fixed to one.

The parameter γ_{f_2} is the $f_2(1270)$ natural width and γ_{res} is the mass resolution at the resonance peak (20 MeV). This is the usual approach to account for resolution effects[26] ; we have checked with our simulation that this describes correctly the resolution effects in our experiment.

In the expression of the f_2 Breit–Wigner (rels. (3) and (5)), the denominator contains the full expression (6), but the numerator contains only the $\pi\pi$ part (last term in rel. (6)) together with the resolution contribution :

$$\Gamma_{\pi\pi} = r_\pi \gamma_{f_2} \left[\frac{q_\pi(m)}{q_\pi(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_\pi} + \gamma_{res} \quad , \quad (59)$$

The parameters α , a , b , c , d , a_ρ , a_{S^*} , a_{f_2} , a_ϕ , a_{K^*} are constants to be fitted with the constraint that the integral of the right–hand side of rel. (3) must be equal to the experimental number of events N . All resonance parameters (masses and widths) are fixed to their world average values[24], except for those for the f_2 which are fitted.

It should be noted that we have chosen to describe the resonance contributions assuming that their production cross sections are constant. Traditionally, these are assumed to have a phase–space distribution and this phase–space distribution is identified with the background in order to lessen the number of free parameters[25]. We have also used this method in previous publications[15][20][22]. Here we describe the resonance contributions assuming a constant production cross section after having checked that both constant and phase space cross sections give results consistent within errors for both resonance yields and functional shapes. Other attempts have been tried which will be described in section 3.3. Let us also mention that the two methods sketched above have been recently compared by the DELPHI collaboration[13] which have reached the same conclusion as ours.

Finally, we have chosen a binning (20 MeV) which matches our mass resolution at the $f_2(1270)$ mass in order to minimize the loss of information about the shape of the mass spectra.

17.2 Fitting the $\pi^+\pi^-$ spectra

As a general remark, we have found no sensitivity of our data to the precise value of λ_K ; varying it between 1 and 14 does not produce any change above the one σ level. Therefore we have decided to fix definitely $\lambda_K = 1$ in the $f_2(1270)$ analysis.

Let us first discuss the 300 GeV/c data. As a first attempt, we have tried fitting our spectrum assuming $\lambda_\pi = 1$ and fixing m_{f_2} and γ_{f_2} at their world average values[24]. This fit

corresponds to $\chi^2/dof = 210/139$ and is shown in fig. (1) ; it clearly goes too much above background on the f_2 high-mass tail region. Leaving free m_{f_2} and γ_{f_2} , the quality of the fit improves ($\chi^2/dof = 177/137$) and provides :

$$\begin{cases} m_{f_2} = 1240 \pm 6 \text{ MeV} \\ \gamma_{f_2} = 102^{+21}_{-18} \text{ MeV} \end{cases} . \quad (60)$$

Finally, leaving free m_{f_2} , γ_{f_2} , λ_π , we obtain a good fit (see figure (2)) corresponding to $\chi^2/dof = 141/136$ with the following parameters :

$$\begin{cases} m_{f_2} = 1227^{+10}_{-14} \text{ MeV} \\ \gamma_{f_2} = 219^{+75}_{-46} \text{ MeV} \\ \lambda_\pi = 12.13^{+2.11}_{-1.94} \end{cases} . \quad (61)$$

Turning now to our 150 GeV/c data, we have also first performed the fit after fixing $\lambda_\pi = 1$ and using the world average values for m_{f_2} and γ_{f_2} . The fit obtained is shown in figure (3) and corresponds to $\chi^2/dof = 222/139$. It also clearly goes too much above background on the $f_2(1270)$ high-mass tail. Setting $\lambda_\pi = 1$, but allowing m_{f_2} and γ_{f_2} to vary, we find :

$$\begin{cases} m_{f_2} = 1259 \pm 6 \text{ MeV} \\ \gamma_{f_2} = 72 \pm 12 \text{ MeV} \end{cases} , \quad (62)$$

corresponding to $\chi^2/dof = 179/137$. Finally, leaving free λ_π , m_{f_2} and γ_{f_2} , we find :

$$\begin{cases} m_{f_2} = 1254^{+7}_{-9} \text{ MeV} \\ \gamma_{f_2} = 148^{+45}_{-29} \text{ MeV} \\ \lambda_\pi = 13.44^{+3.22}_{-2.52} \end{cases} , \quad (63)$$

with a good quality of the fit ($\chi^2/dof = 144/136$) ; the corresponding fit is shown in figure (4).

17.3 Discussion of the results

As a general conclusion, assuming $\lambda_\pi = 1$ and fixing the $f_2(1270)$ parameters at their world average values ($m_{f_2} = 1275 \text{ MeV}$, $\gamma_{f_2} = 185 \text{ MeV}$) does not provide a satisfactory description of the data. Figures (1) and (3) clearly show that the $f_2(1270)$ high-mass tail extends too much and exhibits large systematic effects (see the insets in fig. (1) and (3)). Leaving free the mass and width slightly improves the quality of the fits but they are both significantly below their commonly accepted values[24].

However, we always obtain a good fit if we leave free λ_π . In this case, the $f_2(1270)$ natural width is in agreement with the accepted value[24], but the mass is systematically lower.

In this respect, we have studied the effects of systematic errors. The first source is our neglecting of the $K^{*0}(1430)$ reflection which occurs nearly at the $f_2(1270)$ mass with a width of about 300 MeV. Assuming[27] the ratio $K^{*0}(1430)/K^{*0}(892) = 0.2$, we have redone our fits

using expression (3) including a $K^{*0}(1430)$ reflection ; this increases the $f_2(1270)$ mass value by 6 MeV at both energies but has little effect on the $f_2(1270)$ width and λ_π . This is surely an upper bound since examining our samples with the $\pi^\pm K^\mp$ mass assignment clearly shows that the $K^{*0}(1430)$ contribution does not exceed 10% of the $f_2(1270)$ signals :

$$\begin{cases} n_{f_2} = 5051^{+1443}_{-977} & (300 \text{ GeV/c}) \\ n_{f_2} = 4339^{+985}_{-736} & (150 \text{ GeV/c}) \end{cases}, \quad (64)$$

and stays well inside the level of errors.

Another possible source of systematic effects is our assumption that a_{f_2} in expression (3) is constant. In this respect, we have replaced the term $a_{f_2} BW(f_2, m)$ in rel. (3) by $a_{f_2} f_{\pi\pi}(m) BW(f_2, m)$, where $f_{\pi\pi}(m)$ is the invariant mass distribution of non-resonant $\pi^+\pi^-$ pairs determined from a sample of Lund events accepted by our setup. The idea is that this function simulates the two-pion phase space distribution in our experiment. The results coincide with the above ones within errors. We have also tried fitting our spectra assuming $f_{\pi\pi}(m)$ to be of the form²⁶ $[m_{f_2}/m]^\mu$. The improvement is small at both energies (the χ^2 decreases by only 4 units) and gives values consistent with that in rels (9) and (11) for γ_{f_2} and λ_π , while we find :

$$\begin{cases} m_{f_2} = 1245^{+12}_{-16} \text{ MeV} & \mu = 3.39^{+2.88}_{-1.64} & (300 \text{ GeV/c}) \\ m_{f_2} = 1266 \pm 8 \text{ MeV} & \mu = 2.87^{+1.54}_{-1.34} & (150 \text{ GeV/c}) \end{cases}, \quad (65)$$

in good agreement with the result of EHS[26].

We have also considered the influence of the background shape. Changing the threshold behaviour or adding a m^4 term in the exponential (see rel. (4)) does not remove the effect observed in the $f_2(1270)$ mass region. Another way to test the effect of background is to change the p_T cut ; in this respect we have reanalyzed our data requiring $p_T^{pair} \geq 2.2 \text{ GeV/c}$ instead of $p_T^{pair} \geq 2.0 \text{ GeV/c}$. At 300 GeV/c this produces a reduction of $\simeq 20\%$ for both the background and the $f_2(1270)$ signal, and the fit gives $\lambda_\pi = 18.8^{+3.5}_{-2.9}$. At 150 GeV/c this new p_T cut produces a reduction of $\simeq 50\%$ for the background and $\simeq 35\%$ for the $f_2(1270)$ signal ; in this case the fit provides $\lambda_\pi = 13.6^{+8.3}_{-4.8}$. Therefore the sharpening of the $f_2(1270)$ mass distribution cannot be attributed to the size of the background or to some given value of the signal to background ratio.

Finally we have checked by simulation studies that the acceptance function of $\pi\pi$ pairs is a slowly decreasing function of m nearly flat in the f_2 mass region. Therefore its effect can be neglected in expression (3) without affecting the results of the fit.

To conclude, the systematic effects which have been investigated tend to leave the values of γ_{f_2} and λ_π unchanged while they can produce a downward shift of the f_2 mass up to $\simeq 15$ MeV. Systematic effects due to the background shape or size have not been detected. Therefore, we can rely on the width and λ_π estimates in our data which correspond to one of the best available statistics (compare rels. (12) with the statistics reported in ref. [24]).

We can summarize our results on the $f_2(1270)$ meson by performing a weighted mean of rels. (9) and (11) :

²⁶Indeed, since we are dominated by parton fragmentation, it is not clear that using a $\pi\pi$ phase space distribution is justified.

$$\begin{cases} \lambda_\pi = 12.6^{+1.8}_{-1.5} \\ \gamma_{f_2} = 167^{+39}_{-25} \text{ MeV} \end{cases} \quad (66)$$

Our estimate of the $f_2(1270)$ width is in agreement with the world average value[24] (185 ± 20 MeV) at the 1σ level; our estimate of the damping power λ_π ($\simeq 12$) gives a number considerably larger than what is usually expected[1]. For instance, the power obtained for the ρ^0 meson in the $e^+e^- \rightarrow \pi^+\pi^-$ process ranges[5] from $\simeq 0.66$ to $\simeq 1.75$.

Since there is no theory of this damping power[5], a question arises as to whether such a value ($\lambda_\pi \simeq 12$) looks normal or if it points towards a distortion of the $f_2(1270)$ invariant mass distribution when this meson is produced at large p_T as a leading fragment of a (high- p_T) jet. We note that most of spectroscopic experiments (see refs. [4] and [28] for instance) accomodate²⁷ to $\lambda_\pi = 1$. In ref. [29] the $f_2(1270)$ coupling to $\pi^+\pi^-$ is considered yielding the following expression for the width :

$$\begin{cases} \Gamma(m) &= \Gamma_{f_2} \frac{q_\pi(m)}{q_\pi(m_{f_2})} \frac{D_2[q_\pi(m_{f_2})R]}{D_2[q_\pi(m)R]} \\ D_2[q_\pi(m)R] &= 9 + 3[q_\pi(m)R]^2 + [q_\pi(m)R]^4 \end{cases} \quad (67)$$

where the range parameter[2] R is found[29] to be $R \geq 3 \text{ GeV}^{-1}$ or $R \geq 9 \text{ GeV}^{-1}$, depending on the fit hypotheses. It follows from these lower bounds that only the last term in the second expression (15) plays a significant role. Therefore, in this experiment at least, the result corresponds to an effective value $\lambda_\pi = 4$. Comparing this result with rel. (14), clearly shows that in parton fragmentation, we get an additional damping power of $\simeq 8$. The skewing effect is shown in figure (5) ; here we have plotted the same Breit–Wigner expression (5) using $\lambda_\pi = 1$ and $\lambda_\pi = 12.5$, leaving unchanched γ_R and m_R . It should be noticed that the resulting skewing effect plays in such a way that the physical parameters of the $f_2(1270)$ meson, mass and width (or lifetime), can be considered as unchanged²⁸ at the level of accuracy of our data.

18 Study of the $K^+\pi^-$ spectrum

In the data taken at 300 GeV/c, we have used the Cerenkov information to single out a sample of 16266 events with an identified K^+ meson ; no constraint has been placed on the negative particle. We have shown in ref.[21] that the probability for a particle identified as a kaon to be a pion is consistent with zero, while the probability of the converse is $\simeq 30\%$. Therefore, requesting a pion signature for the negative particle would have much more reduced our sample without a useful gain in the signal over background ratio. A significant fraction ($\simeq 30\%$) of the protons survive the condition of identified K^+ ; these will essentially

²⁷CELLO collaboration [28] has not succeeded in determining the shape of the $f_2(1270)$ resonance because of the interplay in the $\gamma\gamma \rightarrow \pi^+\pi^-$ reaction of non-resonant terms which contribute to the D -wave together with the (main) $f_2(1270)$ resonant term.

²⁸One should also notice that the values which are unchanged are the zero of the real part of the inverse propagator (*i.e.* m_R) in rel. (5) and the value of the imaginary part of this function at $m = m_R$ (*i.e.* γ_R) ; of course real and imaginary parts refer to the case when m is above all thresholds. It is these definitions of mass and width which appear to be stable.

contribute to the background as no Δ^0 contribution has been found in our data. A departure from pure phase space distribution in the threshold region is in any case expected because of anticorrelation phenomena in pair production[21] and therefore it is difficult to single out a possible Δ^0 contribution here. The data taken at 150 GeV/c are not used since there is no available Cerenkov information ; in this case, the K^* signals are widely mixed with the $\rho^0(770)$ and $f_2(1270)$ reflections and our conclusions would hardly be model dependent. Requiring one K mass assignment from the Cerenkov counters reduces the signals considerably but removes the $\rho^0(770)$ and $f_2(1270)$ signals completely.

The $K^+\pi^-$ spectrum is given in figure (6). We observe a clear signal of the $K^{*0}(892)$ (hereafter denoted K_V^*) and a small $K^{*0}(1430)$ signal (hereafter denoted K_T^*) ; the relatively broad bump between the $K\pi$ threshold and the K_V^* peak is the $\phi(1020)$ meson reflection in the $K\pi$ mass assignment. No other obvious structure can be seen²⁹. Other K^* mesons fall in the 1400 MeV region[24][30] (as well as the reflection of the $f'(1515)$ signal) and could contribute to shadow somehow the K_T^* signal and shape. Therefore we need to check that the 1.43 GeV structure is indeed dominated by the K_T^* signal.

We have performed our fits using :

$$\frac{dN}{dm} = f_{acc}(m) [f_{bckg}(m) + a_V BW(K_V^*, m) + a_T BW(K_T^*, m)] + a_\phi REF(\phi, m) \quad . \quad (68)$$

In this expression $f_{bckg}(m)$ is a function of the invariant mass of the pair (m) which describes the background. It has been parametrized as :

$$f_{bckg}(m) = a(m - m_{th})^\alpha \exp[bm + cm^2 + dm^3 + em^4] \quad , \quad (69)$$

where m_{th} is the relevant two-particle threshold mass. We have generated a large sample of events using the Lund Monte Carlo program PYTHIA[8] and followed the tracks through a complete simulation of our setup. Using the pairs obtained by requiring that both particles do not come from the decay of the same resonance we have checked that expression (17) above was able to describe correctly the $K\pi$ spectra. We have especially checked that the third and fourth order terms in the exponential were needed to get a satisfactory description of the mass spectrum over our full mass range.

$f_{acc}(m)$ is the acceptance function of $K\pi$ pairs. It has also been directly computed from our simulation. As it can be seen from figure (7), this function peaks near the $K^*(892)$ mass and is flat around the $K^*(1430)$ mass. Unlike the case of the $\pi^+\pi^-$ spectrum, it is not possible to neglect its effect. There are also[21] non-resonant $p\pi^-$ pairs which give a slightly harder threshold behaviour. This phenomenon plays a role on the first 100 MeV of the invariant mass histogram and the corresponding bins have been removed from the fits.

The resonance contributions have been represented by the standard relativistic Breit-Wigner expression (5). Following ref. [5], the width of the meson K_V^* has been parametrized as :

$$\Gamma_V(m) = \gamma_V \left[\frac{q_{K\pi}(m)}{q_{K\pi}(m_V)} \right]^3 \left[\frac{m_V}{m} \right]^{\lambda_V} + \gamma_{res} \quad , \quad (70)$$

where γ_V is the natural width of the K_V^* resonance and γ_{res} is the resolution at the K_V^* peak (9 MeV) estimated from simulation. $q_{K\pi}(m)$ is the momentum of each decay product of the

²⁹It must be noticed that the K_T^* signal in the original sample is overwhelmed by the background.

K_V^* resonance in its rest frame, and m_V is the resonance mass. Therefore we treat the K_V^* as a purely elastic resonance. In the standard treatment[1] followed by most experiments λ_V is set to 1 ; here we allow it to vary.

The K_T^* meson has been treated in the same way as the $f_2(1270)$ meson (see rel. (6) above) : the main decay modes into two bodies ($K\pi$, $K^*(892)\pi$) have been explicitly accounted for, while we have accounted for the rest by means of a constant width :

$$\gamma_T(1 - Br(K\pi) - Br(K_V^*\pi)) = 0.251\gamma_T \quad , \quad (71)$$

where γ_T is the K_T^* full width. The branching fractions of the K_T^* meson have been taken at their world average values[24]. Therefore, we have used :

$$\Gamma_T(m) = \gamma_T \left[0.251 + 0.252 \left[\frac{q_{K_V^*\pi}(m)}{q_{K_V^*\pi}(m_T)} \right]^5 \left[\frac{m_T}{m} \right] + 0.497 \left[\frac{q_{K\pi}(m)}{q_{K\pi}(m_T)} \right]^5 \left[\frac{m_T}{m} \right]^{\lambda_T} \right] + \gamma_{res} \quad , \quad (72)$$

where $q_{K_V^*\pi}$ and $q_{K\pi}$ are the 3-momenta of the K_T^* decay products for the corresponding decay modes³⁰. We have fixed $\lambda = 1$ for the $K_V^*\pi$ channel after having checked that our data are not sensitive to this channel³¹. γ_T is the K_T^* natural width and γ_{res} is the mass resolution of our setup at the K_T^* peak mass (14 MeV).

The numerators of the BW functions in rel. (16), are always the partial widths to $K^+\pi^-$ increased by the resolution at the corresponding resonance peak.

$REF(\phi, m)$ in rel. (16) is the reflection of the ϕ meson. It has been computed directly by generating a sample of ϕ mesons from a Breit-Wigner law (see rel. (5)) and tracking the K^+ and K^- particles through our simulation. The reflected spectrum has been simply obtained by changing the true particle assignment to $K^+\pi^-$.

Our free parameters are those in rel. (17) and a_V , a_T and a_ϕ which give the number of mesons in our spectrum for K_V^* , K_T^* and ϕ resonances respectively. Here again there is a constraint among these parameters which requires that the integral of the right-hand side of rel. (16) gives the number of experimental events in the same interval.

We shall also denote m_V and m_T the masses of the K_V^* and K_T^* mesons respectively. They will be fixed or fitted as well as the natural widths γ_V and γ_T .

As a first attempt we have fixed the masses and widths of the K_V^* and K_T^* mesons at their world average values[24], requiring in addition $\lambda_V = \lambda_T = 1$. The first five bins (*i.e.* 100 MeV) are removed from the fit. The best fit is shown in figure (6) and corresponds to $\chi^2/dof = 145/112$. Looking at the inset, where the background and the ϕ contribution have been subtracted, it is clear that the high-mass tail of K_V^* extends too much above the background. The K_T^* signal is too small to allow any eye estimate. Leaving free m_V , Γ_V , λ_V and m_T , Γ_T , λ_T , the quality of the fit improves ($\chi^2/dof = 128/106$). The fitted values of interest are :

³⁰What has been said concerning the $f_2(1270)$ Breit-Wigner denominator in rel. (5) when m is between the $\pi\pi$ and $K\bar{K}$ threshold applies fully for the K_T^* Breit-Wigner between the πK and $K_V^*\pi$ thresholds ; we have accounted for this effect in precisely the same way.

³¹Varying this λ from 1 to 14 does not produce any significant change in the results.

$$\left\{ \begin{array}{l} m_V = 892 \pm 3 \text{ MeV}, \quad \gamma_V = 39 \pm 11 \text{ MeV} \quad \lambda_V = 13.53^{+3.42}_{-3.00} \\ m_T = 1435 \pm 13 \text{ MeV}, \quad \gamma_T = 100 \pm 49 \text{ MeV} \quad \lambda_T = 5.56 \pm 3.31 \end{array} \right. \quad (73)$$

The errors are large because of correlations between each γ and its corresponding λ . The resulting fit is given in figure (8) and the inset clearly shows that the resonance tails are now more realistically described. Moreover, the number of ϕ mesons obtained from this fit and that obtained using the K^+K^- mass assignment in the same sample are consistent within errors ; this indicates that the background is correctly estimated and that threshold effects do not affect the mass region of interest. The mass and width obtained from fit for the K_V^* meson are consistent with the world average values[24] (896.1 MeV and 50.5 MeV respectively). This is also true for the K_T^* meson mass and width obtained from the fit (ref. [24] gives 1432.4 MeV and 109 MeV respectively). This indicates that identifying the small structure located around 1.43 GeV with the $K^{*0}(1430)$ meson is reasonable. One should notice the large value found for λ_V (consistent with that of the $f_2(1270)$ meson) ; the value found for λ_T is inconclusive but still consistent with a large value.

Since the K^* mesons in our data have parameters consistent with their world average values, it is reasonable to fix m_V , m_T , γ_V and γ_T at their average values[24] ; in this case, we get $\chi^2/dof = 133/110$ and :

$$\left\{ \begin{array}{l} \lambda_V = 12.9^{+2.2}_{-2.7} \\ \lambda_T = 4.9^{+4.4}_{-1.8} \end{array} \right. \quad (74)$$

In our data there are 839 ± 99 K_V^* events and 420 ± 71 K_T^* events.

19 Study of the $K^-\pi^+$ spectrum

Using the data taken at 300 GeV/c and requiring from Cerenkov information an identified K^- , we get a sample of 10 157 events. We have not required any identification of the positive particle for the reason already mentioned (see section 4 above). Here we have to deal with a contamination of K^- by $\bar{p}$; the situation is fortunately not symmetrical to the contamination by protons in the previous sample since the ratio $\bar{p}/p$ is more favourable[21] ($0.41 \div 0.46$) in the present case. Since this contamination is significant only near threshold we remove the first five bins (100 MeV) from the fit. The formulae and arguments given in the previous section are still valid in the present case.

The $K^-\pi^+$ mass spectrum is shown in figure (9), apart from the ϕ reflection, one sees a clear signal of the $\bar{K}_V^*$ meson and a broad structure which will be identified with the $\bar{K}_T^*$ meson³². The mass distributions of these mesons are expected identical to that of their antiparticles (see section 4).

We have first performed a fit by setting the masses and widths of the $\bar{K}^*$ mesons at their world average values[24], assuming $\lambda_V = \lambda_T = 1$. The result of the fit is shown in figure (9)

³²We shall consider this identification correct if the parameters obtained by fit are consistent with that of the $\bar{K}^{*0}(1430)$ meson.

($\chi^2/dof = 143/112$). As before, the inset shows that the $\overline{K}_V^*$ high-mass tail extends too much and nothing firm can be asserted about the $\overline{K}_T^*$ meson.

We have then released m_V , Γ_V , λ_V and m_T , Γ_T , λ_T . In this case, the fit (shown in figure (10)) gives a better description of the data ($\chi^2/dof = 108/106$) with better resonance tails. The fitted parameters are

$$\begin{cases} m_V = 892 \pm 3 \text{ MeV}, & \gamma_V = 34^{+16}_{-13} \text{ MeV} & \lambda_V = 14.0 \pm 4.9 \\ m_T = 1401^{+14}_{-29} \text{ MeV}, & \gamma_T = 91^{+80}_{-43} \text{ MeV} & \lambda_T = 10.5^{+4.1}_{-5.4} \end{cases} \quad (75)$$

As a result of the large correlations between γ s and λ s parameters and of the relatively small statistics, there are large uncertainties on most of these parameters (especially for the widths). However these results allow us to check that the $\overline{K}_V^*$ and $\overline{K}_T^*$ mass and width values are in agreement with the corresponding world average values[24]. The values found for the λ s are both large and consistent with that found for K_V^* and K_T^* (see rels. (21)) as can be expected from charge conjugation symmetry.

Since the parameters of $\overline{K}_V^*$ and $\overline{K}_T^*$ are in good agreement with their accepted values, we have done a final fit by fixing m_V , γ_V and m_T , γ_T to their usual values[24]. We thus obtained a good fit ($\chi^2/dof = 129/110$) with the following values :

$$\begin{cases} \lambda_V = 12.7^{+3.6}_{-4.3} \\ \lambda_T = 12.1^{+2.3}_{-4.8} \end{cases} \quad (76)$$

The numbers of mesons are 543 ± 80 ($\overline{K}_V^*$) and 262 ± 63 ($\overline{K}_T^*$) ; we have also checked that the ϕ signal is in agreement with that obtained using the K^+K^- mass assignment, where the signal occurs in a single (20 MeV) bin.

Instead of performing algebraically the weighted mean of rel. (22) and (24) between charge conjugate partners, we have preferred performing a global fit of the sample obtained by merging the $K^+\pi^-$ and $K^-\pi^+$ mass spectra. Thus we get a good fit ($\chi^2/dof = 135/106$) and meson yields in agreement with the results given above³³. The 'mean values' of the damping powers are :

$$\begin{cases} \lambda_V = 13.4^{+2.4}_{-2.7} \\ \lambda_T = 9.1^{+4.5}_{-6.0} \end{cases} \quad (77)$$

These values are consistent with those obtained for $f_2(1270)$ at the 1. σ level.

We could expect λ_V to be of the order[5] of λ_ρ (*i.e.* $0.66 \div 1.75$) since they are both vector mesons. On the other hand, ref.[30] has tried a fit of the kind (15) and obtained a result consistent with a behaviour like m^{-2} or m^{-3} . The LASS collaboration[30] also quotes a result for the K_T^* meson which is at most of the order m^{-5} . Thus, the results of sections 4 and 5 point towards a distortion of the K_V^* mass spectrum by an additional damping power of $\simeq 10$; the K_T^* mass distribution is consistent with the same distortion than the K_V^* and with no

³³We obtain 1310 ± 205 for $K^{*0}(892) + \overline{K}^{*0}(892)$ while we expect 1382 ± 127 and 491 ± 150 for $K^{*0}(1430) + \overline{K}^{*0}(1430)$ while we expect 682 ± 95 .

distortion as well because of the large value of the errors. As for the $f_2(1270)$, this distortion preserves the fundamental parameters of these mesons (masses and widths). Indeed the same global fit provides :

$$\begin{cases} m_V = 892 \pm 2 \text{ MeV} & \gamma_V = 40^{+10}_{-9} \text{ MeV} \\ m_T = 1424 \pm 10 \text{ MeV} & \gamma_T = 73^{+37}_{-24} \text{ MeV} \end{cases} . \quad (78)$$

Consequences of systematic effects have been examined in both the $K^+\pi^-$ and $K^-\pi^+$ spectra. We have checked that changing the a_V and a_T to the distributions of non-resonant πK pairs does not affect our results. Assuming a production cross section which varies like m^{-3} (see rel. (13)) leads to the same conclusion. In this case, moreover, because the mesons K_V^* and K_T^* are much sharper than the $f_2(1270)$ meson, their masses are not affected by more than 3 MeV. Finally the feed-down of K_V^* mesons by K_V^* coming from K_T^* decay is negligible because mainly of our p_T cut (see rel. (2)). Therefore, our conclusions are stable and especially the sharp fall-off of the invariant mass distributions summarized by rels. (22), (24), (25).

20 General discussion of the results

Our results are summarized in table (1), apart from the value of the damping power λ , we also consider our estimate of the $f_2(1270)$ width as reliably measured and reasonably free from systematic errors. This result is in good agreement with the recent high statistics result³⁴ of the DM2 collaboration[31] (169.0 ± 7.5 MeV) and with that of the EHS collaboration[26] (180 ± 24). The damping powers obtained using the $f_2(1270)$ and $K^{*0}(892)$ mesons are remarkably similar ; the damping power associated with the $K^{*0}(1430)$ mesons is lower but consistent with those of the previous mesons at the 1σ level.

The first conclusion of sections 3 to 5 is that the meson mass distributions are all distorted in the same way. The second conclusion is that this distortion preserves the values of the mesons masses and widths³⁵. This result looks general since the same properties are observed for mesons having different spins ($J = 1, 2$) and different strangeness content (f_2 and K^*).

In principle, our results could be compared with that obtained by the SFM collaboration which has measured the rates of $f_2(1270)$ and $K^{*0}(892)$ mesons at large p_T at ISR energies[32]. Unfortunately, this comparison is not possible because they have accounted for the background by the event mixing technics which produces distortions of the resonance signals and the authors of ref. [32] have corrected the subtracted spectra for these distortions. These corrections may have washed out the effect we observe in our experiment.

Another possibility would be that the observed distortions are produced by interference effects. We consider this assumption as unlikely since we are dealing with large multiplicity events ($\simeq 10$) and varying species of final state particles. In this case, we expect interference contributions to cancel out. As an illustration, ref.[23] has examined the inclusive $\pi^+\pi^-$ production in J/ψ decays and reached the conclusion that their data were consistent with no ρ^0 - ω interference. Our mass histogram for pairs with $\pi^+\pi^-$ mass assignment (see fig. (1) for

³⁴Ref. [31] uses a Breit-Wigner curve but does not provide further information about its precise shape ; this should mean that they use the standard shape[1].

³⁵Technically, the resonance mass which appears stable is defined as the zero (m_R) of the real part of the inverse propagator $D^{-1}(m) = (m_R^2 - m^2) - im_R\Gamma(m)$, while the width is defined by $\gamma_R = \Gamma(m_R)$. This property has been already noted in section 3.3.

instance) is also consistent with no ρ^0 - ω interference. Moreover, it is hard to imagine that interference effects would give the same distortion for all cases and that they would leave nearly unchanged the masses and widths of broad objects.

Resonance	mass our result	mass P.D.G.	width our result	width P.D.G.	λ	χ^2/dof
$f_2(1270) (300)$	1227^{+10}_{-14}	1275 ± 5	236^{+75}_{-46}	185 ± 20	$12.1^{+2.1}_{-1.9}$	141/136
$f_2(1270) (150)$	1254^{+7}_{-9}		165^{+45}_{-29}		$13.4^{+3.2}_{-2.5}$	144/136
$K^{*0}(892)$	892 ± 3	896.1 ± 0.3	39 ± 11	50.5 ± 0.6	$13.5^{+3.4}_{-3.0}$	128/106
$\overline{K}^{*0}(892)$	892 ± 3		34^{+16}_{-13}		14.0 ± 4.9	108/106
$K^{*0} + \overline{K}^{*0}$	892 ± 2		40^{+10}_{-9}		$13.4^{+2.4}_{-2.7}$	135/106
$K^{*0}(1430)$	1435 ± 13	1432.4 ± 1.3	100 ± 49	109 ± 5	5.6 ± 3.3	128/106
$\overline{K}^{*0}(1430)$	1401^{+14}_{-29}		91^{+80}_{-43}		$10.5^{+4.1}_{-5.4}$	108/106
$K^{*0} + \overline{K}^{*0}$	1424 ± 10		73^{+37}_{-24}		$9.1^{+4.5}_{-6.0}$	135/106

Table 1 : Summary of the results concerning all the fitted mesons.

We are thus left with the conclusion that the observed distortions are due to the production mechanism at work in our experiment : the hadronization process of colored quarks and gluons. This process enhances the probability to produce a given meson at low mass and suppresses its production at large mass. More surprising is that these distortions leave unchanged the resonance physical parameters. These properties are in qualitative agreement with what has been seen recently from a Lund Monte Carlo sample by A. Lindner[8] when examining the shape of the ρ^0 mass spectrum. Since resonance mass spectra in the Lund Monte Carlo are simply fixed width Breit–Wigner expressions the agreement cannot be otherwise than qualitative.

These properties illustrate the specificity of color string fragmentation as a production mechanism of resonances, at least as leading fragments. Of course, resonances produced in resonance decays are affected differently, and sometimes not affected at all³⁶.

On the other hand, resonances decaying to more than two particles are surely affected, but our experiment does not allow any precise study of this effect. For instance, there is some indication that $a_2(1320)$ is observed in its three pion decay mode, but the combinatorial three particle background is so large that no study can be performed.

Our main result can be sketched in the following way : when produced at large p_T , any given resonance R of spin l having two-particle decay modes can be described by a Breit–Wigner distribution, the shape of which remains formally the usual one[1], with the usual mass and width (m_R and γ_R) ; however, its decay amplitude to a given decay mode X written[5] :

³⁶For instance, the ρ^0 produced in the η' decay is surely affected by phase space effects due essentially to the η' mass but not to the η' production mechanism since this meson is too sharp to feel any damping factor.

$$\Gamma_X(m) = \gamma_R \left[\frac{q_X(m)}{q_X(m_R)} \right]^{(2l+1)} \left[\frac{m_R}{m} \right]^\lambda ,$$

always gives a good description of the data and $\lambda \simeq 12.5$ looks like a universal parameter. This power is large enough to suggest an actual exponential damping. The present theoretical knowledge does not provide however any motivated guideline to a suitable parametrization of meson shape distortions in high- p_T processes.

21 Conclusions

We have analyzed the invariant mass distributions of five mesons ($f_2(1270)$, $K^{*0}(892)$, $\overline{K}^{*0}(892)$, $K^{*0}(1430)$, $\overline{K}^{*0}(1430)$) produced at $p_T \geq 2.0$ GeV/c, under conditions where they are likely to be leading fragments of high- p_T jets. We have found that these mass distributions are sharply distorted ; these distributions are affected by a large damping power ($\simeq m^{-12}$), far above the usual one. At the level of accuracy allowed by our data, we have also shown that this distortion does not affect the mass and width of any of the resonances examined sofar. We have also shown that the distortions look alike for the mesons studied, without any respect to their spin or quark content. It has to be expected that this phenomenon affects all resonances primarily produced in the parton fragmentation mechanism, for instance the ρ meson. Our conclusions apply to two-body decay channels of resonances. The meson shape distortions observed in our data give experimental support to the existence of phase space effects in the process of quark fragmentation into hadrons.

References

- [1] J.D. Jackson, Nuovo Cimento XXXIV (1964) 1644.
- [2] J. Pisut and M. Roos, Nucl. Phys. **B6** (1968) 325.
- [3] J. Ballam *et al.*, Phys. Rev. **5** (1972) 545.
- [4] T.A. Armstrong *et al.* Zeit. für Phys. **C51** (1991) 351.
- [5] M. Benayoun *et al.* Zeit. für Phys. **C 58** (1993) 31.
- [6] B. Andersson *et al.* Phys. Rep. **97** (1983) 31 ;
H. Bengtsson and G. Ingelman Comput. Phys. Comm. **34** (1985) 251 ;
“The Lund Monte Carlo Programs”, CERN long writeups W5035, W5045, W5046, W5047, W5048, nov. 1989.
- [7] O. Podobrin, Ph. D. Thesis, DESY report FCE-92-03, Hamburg 1992.
- [8] A. Lindner, Ph. D. Thesis, Dortmund 1992.
- [9] H. Albrecht *et al.*, DESY preprint 93-084, Hamburg 1993.
- [10] H. Albrecht *et al.* Zeit. für Phys. **C58** (1993) 199.
- [11] ALEPH collaboration, preprint CERN-PPE/92-74, Geneva 1992.
- [12] OPAL collaboration, preprint CERN-PPE/92-116, Geneva 1992.
- [13] P. Abreu *et al.*, DELPHI collaboration, Phys. Lett. **B298** (1993) 236.
- [14] P.D. Acton *et al.*, OPAL collaboration, Zeit. für Phys. **C56** (1992) 521.
- [15] M. Benayoun *et al.* Phys. Lett. **B183** (1987) 412.
- [16] M. Benayoun *et al.* Nucl. Phys. **B282** (1987) 653.
- [17] M. Benayoun *et al.* Phys. Lett. **B192** (1987) 447.
- [18] M. Benayoun *et al.* Phys. Lett. **B198** (1987) 281.
- [19] W. Beusch *et al.* Nucl. Instrum. Methods **A249** (1986) 391.
- [20] M.T. Trainor, “Direct meson production at $p_T \geq 2$. GeV/c in 300 GeV/c $\pi^- Be$ interactions”, PhD thesis, University of Birmingham, March 1988 ;
R. Fini, “Produzione inclusiva di risonanze a medio-alto momento trasverso”, Tesi di Dottorato, Università degli studi di Bari, january 1990, National library of Rome and Florence.
- [21] A. Bellogianni *et al.*, Zeit. für Phys. **C54** (1992) 535.
- [22] A. Bellogianni *et al.*, Zeit. für Phys. **C59** (1993) 35.
- [23] G. Gidal *et al.*, Phys. Lett. **B107** (1981) 153.
- [24] Review of Particle Properties, Phys. Rev **D45** (1992).
- [25] P. Granet *et al.* Nucl. Phys. **B140** (1978) 389.
- [26] M. Aguilar-Benitez *et al.* Zeit für Phys. **C50** (1991) 405.
- [27] S. Abachi *et al.*, Phys. Rev. Lett. **57** (1986) 1990.
- [28] H.-J. Behrend *et al.* Zeit für Phys. **C56** (1992) 381 ;
J. Harjes, Thesis, preprint DESY-FCE-91-01, Hamburg 1991.
- [29] V. Chabaud *et al.* Nucl. Phys. **B223** (1983) 1.
- [30] D. Aston *et al.* Nucl. Phys. **B296** (1988) 493.
- [31] J.E. Augustin *et al.* Nucl. Phys. **B320** (1989) 1.
- [32] A. Breakstone *et al.* Zeit für Phys. **C43** (1989) 185.

Figure Captions

- Figure 1 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 300 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming the world average values for the $f_2(1270)$ parameters, $\lambda_K = 1$, $\lambda_\pi = 1$. In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the large high-mass tail of the $f_2(1270)$.
- Figure 2 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 300 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming $\lambda_K = 1$, but leaving free the mass, width of the $f_2(1270)$ meson and λ_π . In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice how the high-mass tail of the $f_2(1270)$ is reduced.
- Figure 3 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 150 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming the world average values for the $f_2(1270)$ parameters, $\lambda_K = 1$, $\lambda_\pi = 1$. In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the large high-mass tail of the $f_2(1270)$.
- Figure 4 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 150 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming $\lambda_K = 1$, but leaving free the mass, width of the $f_2(1270)$ meson and λ_π . In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the reduction in the high-mass tail of the $f_2(1270)$.

- Figure 5 : Effect of the damping power λ_π on the shape of a Breit–Wigner contribution to the cross section. In full line we have represented the case $\lambda_\pi = 1$, in dashed dotted line the case $\lambda_\pi = 12.5$.
- Figure 6 : Invariant mass plot of trigger pairs with an identified K^+ ; the data are extracted from our 300 GeV/c sample. The fit represented has been obtained assuming the world average values for the masses and widths of both K^* mesons and both damping powers $\lambda = 1$.
- Figure 7 : Acceptance function of $K\pi$ trigger pairs as a function of their (true) invariant mass.
- Figure 8 : Invariant mass plot of trigger pairs with an identified K^+ ; the data are extracted from our 300 GeV/c sample. The fit shown has been obtained leaving free the masses and widths of both K^* mesons and both damping powers λ .
- Figure 9 : Invariant mass plot of trigger pairs with an identified K^- ; the data are extracted from our 300 GeV/c sample. The fit represented has been obtained assuming the world average values for the masses and widths of both K^* mesons and both damping powers $\lambda = 1$.
- Figure 10 : Invariant mass plot of trigger pairs with an identified K^- ; the data are extracted from our 300 GeV/c sample. The fit represented is obtained, leaving free the masses and widths of both K^* mesons and both damping powers λ .

22 Introduction

It is a known property of resonances that their observed mass distributions can vary from one experiment to another, depending on the production mechanism[1][2]. The main origin of this effect is the unknown mass dependence of resonance production cross sections. These are generally subject to more or less arbitrary assumptions which affect the decay amplitude $\Gamma_{res}(m)$ of the resonance in the fitting procedures[2].

In exclusive experiments effects due to the production mechanism can be superposed with interference effects associated with processes involving the same final state. Interference effects thus produce an important skewing of the ρ^0 lineshape in photoproduction experiments (see ref.[3] for instance). Large distortions of the $S^*/f_0(975)$ meson have also been reported by many experiments (see ref.[4] for instance). Phase space effects can also produce large changes of the resonance shape. For instance, in the decay $\eta \rightarrow \pi^+\pi^-\gamma$ which is dominated by $\eta \rightarrow \rho^0\gamma$, the $\pi^+\pi^-$ mass spectrum is cut at the η mass in such a way that the ρ^0 peak is completely outside the available phase space[5]. In summary, several mechanisms can produce distortions of the invariant mass distributions of broad resonances, sometimes in a predictable way.

In high- p_T physics, we deal with another kind of production mechanism: the fragmentation of coloured strings into hadrons[6]. With this respect, O. Podobrin[7] has recently shown that Bose–Einstein correlation effects between resonance decay products and nearby (in phase space) stable pions can produce a large shift of the resonance masses. On the other hand, A. Lindner[8] has shown that the Lund Monte Carlo provides distortions of the ρ meson mass spectrum. These results illustrate that internal properties of the colour string fragmentation process can result in observable modifications of resonance mass spectra.

The ARGUS collaboration has looked for this kind of shape distortions for the ρ meson but could not reach any firm conclusion[9] because of lack of statistics. They have nevertheless taken this effect into account in recent works[10]. Studies involving light flavour mesons are also available from LEP experiments[11][12][13][14]. Some indication of ρ^0 lineshape distortion has been already reported by the OPAL collaboration[12].

Here in the WA77 experiment, we study the shape of five resonances for which the influence of reflections can be essentially removed and the background is well under control. These meson resonances ($f_2(1270)$, $K^{*0}(892)$, $\bar{K}^{*0}(892)$, $K^{*0}(1430)$ and $\bar{K}^{*0}(1430)$) have a large branching fraction to two-body channels ($\pi^+\pi^-$, $K^\pm\pi^\mp$). Moreover these resonances are rarely decay products of higher resonances and the feed down of $K^{*0}(892)$ mesons from $K^{*0}(1430)$ decays is removed by our trigger at the 98% level.

The mass spectra also reveal a significant ϕ signal[15] in K^+K^- , however we are not sensitive to possible distortions of this signal because of our mass resolution. There is in addition a large ρ^0 signal[15]; this signal is not studied in the present work because it is produced by several mechanisms (parton fragmentation[6], prompt production[16], η' decay[19]) and then its shape cannot follow from a single phenomenon.

We first give a brief description of the experiment and of the data samples (section 2). Then we study (section 3) the $f_2(1270)$ meson in the full samples of data collected at 300 and 150 GeV/c; due to its statistical importance, this signal allows a detailed study of systematic effects. Section 4 deals with the analysis of the $K^+\pi^-$ mass spectrum with an identified K^+ ; for this purpose we only use our 300 GeV/c data sample and study the $K^{*0}(892)$ and $K^{*0}(1430)$ meson invariant mass distributions. Section 5 is devoted to the study of the $K^-\pi^+$ mass spectrum with an identified K^- ; here also we only use our 300 GeV/c data sample and study the $\bar{K}^{*0}(892)$ and $\bar{K}^{*0}(1430)$ meson invariant mass distributions. In section 6, we discuss

the results obtained for the various mesons and examine some *a priori* possible explanations. Finally section 7 is devoted to a summary of our conclusions.

23 The data samples

The basic idea of the WA77 trigger is to obtain a sample of events with three particles at large p_T where a pair of them (of opposite charges) is supposed to come from the decay of a neutral resonance, while the third track (p , $\bar{p}$, $K^\pm$, $\pi^\pm$) is assumed to be the leading particle of an opposite jet. Details about the trigger and setup have been given elsewhere [15][18–22]. This trigger favours the observation of meson resonances decaying into two bodies which are leading particles of a high- p_T jet. We have verified this property on a Lund Monte Carlo sample of events tracked through the simulation of our setup and fulfilling our trigger conditions. We have thus found that 99.5% of the Monte Carlo events accepted by our trigger have no more than three tracks at $p_T \geq 1$ GeV/c.

The WA77 experiment has performed two runs of data taking on $\pi^- N$ interactions, the first at 300 GeV/c, the second at 150 GeV/c. In the 300 GeV/c setup two multicell Cerenkov counters were used for identification of particle species. We selected events in the rapidity range :

$$2.80 \leq Y_{lab}^{pair} \leq 3.70 \quad , \quad (79)$$

and with transverse momenta :

$$\begin{cases} p_T^{trig.part.} \geq 1 \text{ GeV/c} \\ p_T^{pair} \geq 2 \text{ GeV/c} \end{cases} \quad . \quad (80)$$

At 300 GeV/c, this corresponds to a center of mass rapidity window $(-0.43, +0.47)$, while at 150 GeV/c it corresponds to the window $(-0.08, +0.90)$. The total number of events is 209 654 in the 300 GeV/c sample and 238 749 in the 150 GeV/c sample.

24 Study of the $f_2(1270)$ meson

We consider here the mass spectra obtained assuming both particles in the pair to be pions. We do not use in this case the information provided by the Cerenkov counters since we know[21] that the pion assignment in our experiment is widely contaminated by kaons and protons. The $f_2(1270)$ region suffers only little from $K^{*0}(1430)$ contamination because its reflection produces a tiny signal which does not affect the properties of the $f_2(1270)$ meson (see section 3.3) and therefore it has not been considered in the final fit. No other source of contamination has been found in this mass region.

24.1 Fitting method

In order to perform our fits we have taken into account besides the resonances ($\rho^0(770)$, $f_2(1270)$, $S^*/f_0(975)$) the reflections due to the large signals[22] of the $\phi(1020)$, $K^{*0}(892)$ and $\bar{K}^{*0}(892)$ mesons. These last signals appear shifted due to the wrong mass assignment given to

their decay products. The invariant mass histogram of the pairs with the $\pi^+\pi^-$ mass assignment is shown in figure (1) for the 300 GeV/c data. It has been fitted using the following expression :

$$\begin{aligned} \frac{dN}{dm} = & [f_{bckg}(m) + a_\rho BW(\rho^0, m) + a_{S^*} BW(S^*, m) + a_{f_2} BW(f_2, m)] \\ & + a_\phi REF(\phi, m) + a_{K^*} REF(K^*, m) \end{aligned} \quad (81)$$

In this expression $f_{bckg}(m)$ is a function of the invariant mass of the pair (m) which describes the background[13][15]. It has been parametrized as :

$$f_{bckg}(m) = a(m - m_{th})^\alpha \exp[bm + cm^2 + dm^3] \quad , \quad (82)$$

where $m_{th} = 2m_\pi$ is the threshold mass of the system. We have checked on a Lund Monte Carlo sample that this expression describes correctly the mass histogram of the non-resonant pairs. BW and REF in expression (3) stand respectively for Breit-Wigner distributions and reflections of resonances when a wrong mass assignment is applied. We take as Breit-Wigner distribution of a resonance R :

$$BW(R, m) = \frac{m m_R \Gamma_{\pi\pi}(m)}{|m_R^2 - m^2 - im_R \Gamma(m)|^2} \quad , \quad (83)$$

where $\Gamma_{\pi\pi}(m)$ is the $\pi\pi$ partial width and $\Gamma(m)$ is the full width of the resonance R . The denominator in rel. (5) coincides with the usual $(m_R^2 - m^2)^2 + m_R^2 \Gamma^2(m)$ when the mass m is above all thresholds[1]. However, between the $\pi\pi$ and $K\bar{K}$ thresholds the partial width (see rel. (6) below) $\Gamma_{K\bar{K}}$ becomes purely imaginary and thus contributes to the real part of the Breit-Wigner denominator in rel.(5) ; this effect has been taken into account in our fits. Therefore, rel. (5) is the standard expression established in [1], assuming the production cross section of the resonance R to be constant. With this definition of a Breit-Wigner distribution, each a in rel. [3] is precisely the production cross-section of the corresponding resonance, in agreement with ref. [1].

The reflections of $K^{*0}(892)$ and $\bar{K}^{*0}(892)$ are superposed when using the $\pi^+\pi^-$ mass assignment, and not distinguishable. The shapes of all reflections have been computed by generating samples of events using a standard Breit-Wigner[1], following the tracks in the full simulation of our setup[17][21] and finally changing the correct mass assignment to $\pi^+\pi^-$. Our simulation takes into account the acceptance effects and the accuracy of the reconstruction program TRI-DENT. Therefore by this procedure we take into account acceptance and resolution effects on these mass distributions.

The parametrization of the $S^*/f_0(975)$ has been done following ref. [23] ; a large sample of events has been generated, tracked through the simulation of our detector and reconstructed to account for acceptance and resolution effects. We considered this precaution as necessary because this meson is close to the $f_2(1270)$ meson mass. We have chosen a heuristic parametrization³⁷ for the ρ^0 meson (a Breit-Wigner with a width larger by 20 MeV than nominal). In this way expression (3) describes correctly the mass region below 1 GeV.

To describe the $f_2(1270)$ meson, we have not used the standard way[1] to write a relativistic Breit-Wigner expression, but rather followed the suggestion of ref.[5] by using a more general expression. Assuming the world average values[24] for the various branching fractions, the $f_2(1270)$ decay amplitude is written :

³⁷The ρ^0 meson in our experiment is expected to be produced through many mechanisms, including the η' decay ; a precise study of this region is presently under way.

$$\Gamma_{f_2}(m) = \gamma_{f_2} \left[r_0 + r_K \left[\frac{q_K(m)}{q_K(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_K} + r_\pi \left[\frac{q_\pi(m)}{q_\pi(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_\pi} \right] + \gamma_{res} \quad , \quad (84)$$

where $q_K = 1/2\sqrt{m^2 - 4m_K^2}$, $q_\pi = 1/2\sqrt{m^2 - 4m_\pi^2}$ and $r_\pi = 0.849$, $r_K = 0.046$ and $r_0 = 0.105$ are respectively the branching fractions to $\pi\pi$, $K\overline{K}$ and the remaining channels. The constant part of the width accounts mainly for the decay modes into four bodies. λ_K and λ_π are parameters to be fitted. These two parameters are actually fixed to 1 in the standard approach[1] ; it has been shown [5] that the equivalent expression for the ρ^0 distribution with the exponent λ allowed to vary is able to give a good and simple description of the $e^+e^- \rightarrow \pi^+\pi^-$ data while it is not possible to obtain a good fit with λ fixed to one.

The parameter γ_{f_2} is the $f_2(1270)$ natural width and γ_{res} is the mass resolution at the resonance peak (20 MeV). This is the usual approach to account for resolution effects[26] ; we have checked with our simulation that this describes correctly the resolution effects in our experiment.

In the expression of the f_2 Breit–Wigner (rels. (3) and (5)), the denominator contains the full expression (6), but the numerator contains only the $\pi\pi$ part (last term in rel. (6)) together with the resolution contribution :

$$\Gamma_{\pi\pi} = r_\pi \gamma_{f_2} \left[\frac{q_\pi(m)}{q_\pi(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_\pi} + \gamma_{res} \quad , \quad (85)$$

The parameters α , a , b , c , d , a_ρ , a_{S^*} , a_{f_2} , a_ϕ , a_{K^*} are constants to be fitted with the constraint that the integral of the right–hand side of rel. (3) must be equal to the experimental number of events N . All resonance parameters (masses and widths) are fixed to their world average values[24], except for those for the f_2 which are fitted.

It should be noted that we have chosen to describe the resonance contributions assuming that their production cross sections are constant. Traditionally, these are assumed to have a phase–space distribution and this phase–space distribution is identified with the background in order to lessen the number of free parameters[25]. We have also used this method in previous publications[15][20][22]. Here we describe the resonance contributions assuming a constant production cross section after having checked that both constant and phase space cross sections give results consistent within errors for both resonance yields and functional shapes. Other attempts have been tried which will be described in section 3.3. Let us also mention that the two methods sketched above have been recently compared by the DELPHI collaboration[13] which have reached the same conclusion as ours.

Finally, we have chosen a binning (20 MeV) which matches our mass resolution at the $f_2(1270)$ mass in order to minimize the loss of information about the shape of the mass spectra.

24.2 Fitting the $\pi^+\pi^-$ spectra

As a general remark, we have found no sensitivity of our data to the precise value of λ_K ; varying it between 1 and 14 does not produce any change above the one σ level. Therefore we have decided to fix definitely $\lambda_K = 1$ in the $f_2(1270)$ analysis.

Let us first discuss the 300 GeV/c data. As a first attempt, we have tried fitting our spectrum assuming $\lambda_\pi = 1$ and fixing m_{f_2} and γ_{f_2} at their world average values[24]. This fit

corresponds to $\chi^2/dof = 210/139$ and is shown in fig. (1) ; it clearly goes too much above background on the f_2 high-mass tail region. Leaving free m_{f_2} and γ_{f_2} , the quality of the fit improves ($\chi^2/dof = 177/137$) and provides :

$$\begin{cases} m_{f_2} = 1240 \pm 6 \text{ MeV} \\ \gamma_{f_2} = 102^{+21}_{-18} \text{ MeV} \end{cases} . \quad (86)$$

Finally, leaving free m_{f_2} , γ_{f_2} , λ_π , we obtain a good fit (see figure (2)) corresponding to $\chi^2/dof = 141/136$ with the following parameters :

$$\begin{cases} m_{f_2} = 1227^{+10}_{-14} \text{ MeV} \\ \gamma_{f_2} = 219^{+75}_{-46} \text{ MeV} \\ \lambda_\pi = 12.13^{+2.11}_{-1.94} \end{cases} . \quad (87)$$

Turning now to our 150 GeV/c data, we have also first performed the fit after fixing $\lambda_\pi = 1$ and using the world average values for m_{f_2} and γ_{f_2} . The fit obtained is shown in figure (3) and corresponds to $\chi^2/dof = 222/139$. It also clearly goes too much above background on the $f_2(1270)$ high-mass tail. Setting $\lambda_\pi = 1$, but allowing m_{f_2} and γ_{f_2} to vary, we find :

$$\begin{cases} m_{f_2} = 1259 \pm 6 \text{ MeV} \\ \gamma_{f_2} = 72 \pm 12 \text{ MeV} \end{cases} , \quad (88)$$

corresponding to $\chi^2/dof = 179/137$. Finally, leaving free λ_π , m_{f_2} and γ_{f_2} , we find :

$$\begin{cases} m_{f_2} = 1254^{+7}_{-9} \text{ MeV} \\ \gamma_{f_2} = 148^{+45}_{-29} \text{ MeV} \\ \lambda_\pi = 13.44^{+3.22}_{-2.52} \end{cases} , \quad (89)$$

with a good quality of the fit ($\chi^2/dof = 144/136$) ; the corresponding fit is shown in figure (4).

24.3 Discussion of the results

As a general conclusion, assuming $\lambda_\pi = 1$ and fixing the $f_2(1270)$ parameters at their world average values ($m_{f_2} = 1275 \text{ MeV}$, $\gamma_{f_2} = 185 \text{ MeV}$) does not provide a satisfactory description of the data. Figures (1) and (3) clearly show that the $f_2(1270)$ high-mass tail extends too much and exhibits large systematic effects (see the insets in fig. (1) and (3)). Leaving free the mass and width slightly improves the quality of the fits but they are both significantly below their commonly accepted values[24].

However, we always obtain a good fit if we leave free λ_π . In this case, the $f_2(1270)$ natural width is in agreement with the accepted value[24], but the mass is systematically lower.

In this respect, we have studied the effects of systematic errors. The first source is our neglecting of the $K^{*0}(1430)$ reflection which occurs nearly at the $f_2(1270)$ mass with a width of about 300 MeV. Assuming[27] the ratio $K^{*0}(1430)/K^{*0}(892) = 0.2$, we have redone our fits

using expression (3) including a $K^{*0}(1430)$ reflection ; this increases the $f_2(1270)$ mass value by 6 MeV at both energies but has little effect on the $f_2(1270)$ width and λ_π . This is surely an upper bound since examining our samples with the $\pi^\pm K^\mp$ mass assignment clearly shows that the $K^{*0}(1430)$ contribution does not exceed 10% of the $f_2(1270)$ signals :

$$\begin{cases} n_{f_2} = 5051^{+1443}_{-977} & (300 \text{ GeV/c}) \\ n_{f_2} = 4339^{+985}_{-736} & (150 \text{ GeV/c}) \end{cases}, \quad (90)$$

and stays well inside the level of errors.

Another possible source of systematic effects is our assumption that a_{f_2} in expression (3) is constant. In this respect, we have replaced the term $a_{f_2} BW(f_2, m)$ in rel. (3) by $a_{f_2} f_{\pi\pi}(m) BW(f_2, m)$, where $f_{\pi\pi}(m)$ is the invariant mass distribution of non-resonant $\pi^+\pi^-$ pairs determined from a sample of Lund events accepted by our setup. The idea is that this function simulates the two-pion phase space distribution in our experiment. The results coincide with the above ones within errors. We have also tried fitting our spectra assuming $f_{\pi\pi}(m)$ to be of the form³⁸ $[m_{f_2}/m]^\mu$. The improvement is small at both energies (the χ^2 decreases by only 4 units) and gives values consistent with that in rels (9) and (11) for γ_{f_2} and λ_π , while we find :

$$\begin{cases} m_{f_2} = 1245^{+12}_{-16} \text{ MeV} & \mu = 3.39^{+2.88}_{-1.64} & (300 \text{ GeV/c}) \\ m_{f_2} = 1266 \pm 8 \text{ MeV} & \mu = 2.87^{+1.54}_{-1.34} & (150 \text{ GeV/c}) \end{cases}, \quad (91)$$

in good agreement with the result of EHS[26].

We have also considered the influence of the background shape. Changing the threshold behaviour or adding a m^4 term in the exponential (see rel. (4)) does not remove the effect observed in the $f_2(1270)$ mass region. Another way to test the effect of background is to change the p_T cut ; in this respect we have reanalyzed our data requiring $p_T^{pair} \geq 2.2 \text{ GeV/c}$ instead of $p_T^{pair} \geq 2.0 \text{ GeV/c}$. At 300 GeV/c this produces a reduction of $\simeq 20\%$ for both the background and the $f_2(1270)$ signal, and the fit gives $\lambda_\pi = 18.8^{+3.5}_{-2.9}$. At 150 GeV/c this new p_T cut produces a reduction of $\simeq 50\%$ for the background and $\simeq 35\%$ for the $f_2(1270)$ signal ; in this case the fit provides $\lambda_\pi = 13.6^{+8.3}_{-4.8}$. Therefore the sharpening of the $f_2(1270)$ mass distribution cannot be attributed to the size of the background or to some given value of the signal to background ratio.

Finally we have checked by simulation studies that the acceptance function of $\pi\pi$ pairs is a slowly decreasing function of m nearly flat in the f_2 mass region. Therefore its effect can be neglected in expression (3) without affecting the results of the fit.

To conclude, the systematic effects which have been investigated tend to leave the values of γ_{f_2} and λ_π unchanged while they can produce a downward shift of the f_2 mass up to $\simeq 15$ MeV. Systematic effects due to the background shape or size have not been detected. Therefore, we can rely on the width and λ_π estimates in our data which correspond to one of the best available statistics (compare rels. (12) with the statistics reported in ref. [24]).

We can summarize our results on the $f_2(1270)$ meson by performing a weighted mean of rels. (9) and (11) :

³⁸Indeed, since we are dominated by parton fragmentation, it is not clear that using a $\pi\pi$ phase space distribution is justified.

$$\begin{cases} \lambda_\pi = 12.6^{+1.8}_{-1.5} \\ \gamma_{f_2} = 167^{+39}_{-25} \text{ MeV} \end{cases} \quad (92)$$

Our estimate of the $f_2(1270)$ width is in agreement with the world average value[24] (185 ± 20 MeV) at the 1σ level; our estimate of the damping power λ_π ($\simeq 12$) gives a number considerably larger than what is usually expected[1]. For instance, the power obtained for the ρ^0 meson in the $e^+e^- \rightarrow \pi^+\pi^-$ process ranges[5] from $\simeq 0.66$ to $\simeq 1.75$.

Since there is no theory of this damping power[5], a question arises as to whether such a value ($\lambda_\pi \simeq 12$) looks normal or if it points towards a distortion of the $f_2(1270)$ invariant mass distribution when this meson is produced at large p_T as a leading fragment of a (high- p_T) jet. We note that most of spectroscopic experiments (see refs. [4] and [28] for instance) accomodate³⁹ to $\lambda_\pi = 1$. In ref. [29] the $f_2(1270)$ coupling to $\pi^+\pi^-$ is considered yielding the following expression for the width :

$$\begin{cases} \Gamma(m) &= \Gamma_{f_2} \frac{q_\pi(m)}{q_\pi(m_{f_2})} \frac{D_2[q_\pi(m_{f_2})R]}{D_2[q_\pi(m)R]} \\ D_2[q_\pi(m)R] &= 9 + 3[q_\pi(m)R]^2 + [q_\pi(m)R]^4 \end{cases} \quad (93)$$

where the range parameter[2] R is found[29] to be $R \geq 3 \text{ GeV}^{-1}$ or $R \geq 9 \text{ GeV}^{-1}$, depending on the fit hypotheses. It follows from these lower bounds that only the last term in the second expression (15) plays a significant role. Therefore, in this experiment at least, the result corresponds to an effective value $\lambda_\pi = 4$. Comparing this result with rel. (14), clearly shows that in parton fragmentation, we get an additional damping power of $\simeq 8$. The skewing effect is shown in figure (5) ; here we have plotted the same Breit–Wigner expression (5) using $\lambda_\pi = 1$ and $\lambda_\pi = 12.5$, leaving unchanched γ_R and m_R . It should be noticed that the resulting skewing effect plays in such a way that the physical parameters of the $f_2(1270)$ meson, mass and width (or lifetime), can be considered as unchanged⁴⁰ at the level of accuracy of our data.

25 Study of the $K^+\pi^-$ spectrum

In the data taken at 300 GeV/c, we have used the Cerenkov information to single out a sample of 16266 events with an identified K^+ meson ; no constraint has been placed on the negative particle. We have shown in ref.[21] that the probability for a particle identified as a kaon to be a pion is consistent with zero, while the probability of the converse is $\simeq 30\%$. Therefore, requesting a pion signature for the negative particle would have much more reduced our sample without a useful gain in the signal over background ratio. A significant fraction ($\simeq 30\%$) of the protons survive the condition of identified K^+ ; these will essentially

³⁹CELLO collaboration [28] has not succeeded in determining the shape of the $f_2(1270)$ resonance because of the interplay in the $\gamma\gamma \rightarrow \pi^+\pi^-$ reaction of non-resonant terms which contribute to the D -wave together with the (main) $f_2(1270)$ resonant term.

⁴⁰One should also notice that the values which are unchanged are the zero of the real part of the inverse propagator (*i.e.* m_R) in rel. (5) and the value of the imaginary part of this function at $m = m_R$ (*i.e.* γ_R) ; of course real and imaginary parts refer to the case when m is above all thresholds. It is these definitions of mass and width which appear to be stable.

contribute to the background as no Δ^0 contribution has been found in our data. A departure from pure phase space distribution in the threshold region is in any case expected because of anticorrelation phenomena in pair production[21] and therefore it is difficult to single out a possible Δ^0 contribution here. The data taken at 150 GeV/c are not used since there is no available Cerenkov information ; in this case, the K^* signals are widely mixed with the $\rho^0(770)$ and $f_2(1270)$ reflections and our conclusions would hardly be model dependent. Requiring one K mass assignment from the Cerenkov counters reduces the signals considerably but removes the $\rho^0(770)$ and $f_2(1270)$ signals completely.

The $K^+\pi^-$ spectrum is given in figure (6). We observe a clear signal of the $K^{*0}(892)$ (hereafter denoted K_V^*) and a small $K^{*0}(1430)$ signal (hereafter denoted K_T^*) ; the relatively broad bump between the $K\pi$ threshold and the K_V^* peak is the $\phi(1020)$ meson reflection in the $K\pi$ mass assignment. No other obvious structure can be seen⁴¹. Other K^* mesons fall in the 1400 MeV region[24][30] (as well as the reflection of the $f'(1515)$ signal) and could contribute to shadow somehow the K_T^* signal and shape. Therefore we need to check that the 1.43 GeV structure is indeed dominated by the K_T^* signal.

We have performed our fits using :

$$\frac{dN}{dm} = f_{acc}(m) [f_{bckg}(m) + a_V BW(K_V^*, m) + a_T BW(K_T^*, m)] + a_\phi REF(\phi, m) \quad . \quad (94)$$

In this expression $f_{bckg}(m)$ is a function of the invariant mass of the pair (m) which describes the background. It has been parametrized as :

$$f_{bckg}(m) = a(m - m_{th})^\alpha \exp[bm + cm^2 + dm^3 + em^4] \quad , \quad (95)$$

where m_{th} is the relevant two-particle threshold mass. We have generated a large sample of events using the Lund Monte Carlo program PYTHIA[8] and followed the tracks through a complete simulation of our setup. Using the pairs obtained by requiring that both particles do not come from the decay of the same resonance we have checked that expression (17) above was able to describe correctly the $K\pi$ spectra. We have especially checked that the third and fourth order terms in the exponential were needed to get a satisfactory description of the mass spectrum over our full mass range.

$f_{acc}(m)$ is the acceptance function of $K\pi$ pairs. It has also been directly computed from our simulation. As it can be seen from figure (7), this function peaks near the $K^*(892)$ mass and is flat around the $K^*(1430)$ mass. Unlike the case of the $\pi^+\pi^-$ spectrum, it is not possible to neglect its effect. There are also[21] non-resonant $p\pi^-$ pairs which give a slightly harder threshold behaviour. This phenomenon plays a role on the first 100 MeV of the invariant mass histogram and the corresponding bins have been removed from the fits.

The resonance contributions have been represented by the standard relativistic Breit-Wigner expression (5). Following ref. [5], the width of the meson K_V^* has been parametrized as :

$$\Gamma_V(m) = \gamma_V \left[\frac{q_{K\pi}(m)}{q_{K\pi}(m_V)} \right]^3 \left[\frac{m_V}{m} \right]^{\lambda_V} + \gamma_{res} \quad , \quad (96)$$

where γ_V is the natural width of the K_V^* resonance and γ_{res} is the resolution at the K_V^* peak (9 MeV) estimated from simulation. $q_{K\pi}(m)$ is the momentum of each decay product of the

⁴¹It must be noticed that the K_T^* signal in the original sample is overwhelmed by the background.

K_V^* resonance in its rest frame, and m_V is the resonance mass. Therefore we treat the K_V^* as a purely elastic resonance. In the standard treatment[1] followed by most experiments λ_V is set to 1 ; here we allow it to vary.

The K_T^* meson has been treated in the same way as the $f_2(1270)$ meson (see rel. (6) above) : the main decay modes into two bodies ($K\pi$, $K^*(892)\pi$) have been explicitly accounted for, while we have accounted for the rest by means of a constant width :

$$\gamma_T(1 - Br(K\pi) - Br(K_V^*\pi)) = 0.251\gamma_T \quad , \quad (97)$$

where γ_T is the K_T^* full width. The branching fractions of the K_T^* meson have been taken at their world average values[24]. Therefore, we have used :

$$\Gamma_T(m) = \gamma_T \left[0.251 + 0.252 \left[\frac{q_{K_V^*\pi}(m)}{q_{K_V^*\pi}(m_T)} \right]^5 \left[\frac{m_T}{m} \right] + 0.497 \left[\frac{q_{K\pi}(m)}{q_{K\pi}(m_T)} \right]^5 \left[\frac{m_T}{m} \right]^{\lambda_T} \right] + \gamma_{res} \quad , \quad (98)$$

where $q_{K_V^*\pi}$ and $q_{K\pi}$ are the 3-momenta of the K_T^* decay products for the corresponding decay modes⁴². We have fixed $\lambda = 1$ for the $K_V^*\pi$ channel after having checked that our data are not sensitive to this channel⁴³. γ_T is the K_T^* natural width and γ_{res} is the mass resolution of our setup at the K_T^* peak mass (14 MeV).

The numerators of the BW functions in rel. (16), are always the partial widths to $K^+\pi^-$ increased by the resolution at the corresponding resonance peak.

$REF(\phi, m)$ in rel. (16) is the reflection of the ϕ meson. It has been computed directly by generating a sample of ϕ mesons from a Breit-Wigner law (see rel. (5)) and tracking the K^+ and K^- particles through our simulation. The reflected spectrum has been simply obtained by changing the true particle assignment to $K^+\pi^-$.

Our free parameters are those in rel. (17) and a_V , a_T and a_ϕ which give the number of mesons in our spectrum for K_V^* , K_T^* and ϕ resonances respectively. Here again there is a constraint among these parameters which requires that the integral of the right-hand side of rel. (16) gives the number of experimental events in the same interval.

We shall also denote m_V and m_T the masses of the K_V^* and K_T^* mesons respectively. They will be fixed or fitted as well as the natural widths γ_V and γ_T .

As a first attempt we have fixed the masses and widths of the K_V^* and K_T^* mesons at their world average values[24], requiring in addition $\lambda_V = \lambda_T = 1$. The first five bins (*i.e.* 100 MeV) are removed from the fit. The best fit is shown in figure (6) and corresponds to $\chi^2/dof = 145/112$. Looking at the inset, where the background and the ϕ contribution have been subtracted, it is clear that the high-mass tail of K_V^* extends too much above the background. The K_T^* signal is too small to allow any eye estimate. Leaving free m_V , Γ_V , λ_V and m_T , Γ_T , λ_T , the quality of the fit improves ($\chi^2/dof = 128/106$). The fitted values of interest are :

⁴²What has been said concerning the $f_2(1270)$ Breit-Wigner denominator in rel. (5) when m is between the $\pi\pi$ and $K\bar{K}$ threshold applies fully for the K_T^* Breit-Wigner between the πK and $K_V^*\pi$ thresholds ; we have accounted for this effect in precisely the same way.

⁴³Varying this λ from 1 to 14 does not produce any significant change in the results.

$$\left\{ \begin{array}{l} m_V = 892 \pm 3 \text{ MeV}, \quad \gamma_V = 39 \pm 11 \text{ MeV} \quad \lambda_V = 13.53^{+3.42}_{-3.00} \\ m_T = 1435 \pm 13 \text{ MeV}, \quad \gamma_T = 100 \pm 49 \text{ MeV} \quad \lambda_T = 5.56 \pm 3.31 \end{array} \right. \quad (99)$$

The errors are large because of correlations between each γ and its corresponding λ . The resulting fit is given in figure (8) and the inset clearly shows that the resonance tails are now more realistically described. Moreover, the number of ϕ mesons obtained from this fit and that obtained using the K^+K^- mass assignment in the same sample are consistent within errors ; this indicates that the background is correctly estimated and that threshold effects do not affect the mass region of interest. The mass and width obtained from fit for the K_V^* meson are consistent with the world average values[24] (896.1 MeV and 50.5 MeV respectively). This is also true for the K_T^* meson mass and width obtained from the fit (ref. [24] gives 1432.4 MeV and 109 MeV respectively). This indicates that identifying the small structure located around 1.43 GeV with the $K^{*0}(1430)$ meson is reasonable. One should notice the large value found for λ_V (consistent with that of the $f_2(1270)$ meson) ; the value found for λ_T is inconclusive but still consistent with a large value.

Since the K^* mesons in our data have parameters consistent with their world average values, it is reasonable to fix m_V , m_T , γ_V and γ_T at their average values[24] ; in this case, we get $\chi^2/dof = 133/110$ and :

$$\left\{ \begin{array}{l} \lambda_V = 12.9^{+2.2}_{-2.7} \\ \lambda_T = 4.9^{+4.4}_{-1.8} \end{array} \right. \quad (100)$$

In our data there are 839 ± 99 K_V^* events and 420 ± 71 K_T^* events.

26 Study of the $K^-\pi^+$ spectrum

Using the data taken at 300 GeV/c and requiring from Cerenkov information an identified K^- , we get a sample of 10 157 events. We have not required any identification of the positive particle for the reason already mentioned (see section 4 above). Here we have to deal with a contamination of K^- by $\bar{p}$; the situation is fortunately not symmetrical to the contamination by protons in the previous sample since the ratio $\bar{p}/p$ is more favourable[21] ($0.41 \div 0.46$) in the present case. Since this contamination is significant only near threshold we remove the first five bins (100 MeV) from the fit. The formulae and arguments given in the previous section are still valid in the present case.

The $K^-\pi^+$ mass spectrum is shown in figure (9), apart from the ϕ reflection, one sees a clear signal of the $\bar{K}_V^*$ meson and a broad structure which will be identified with the $\bar{K}_T^*$ meson⁴⁴. The mass distributions of these mesons are expected identical to that of their antiparticles (see section 4).

We have first performed a fit by setting the masses and widths of the $\bar{K}^*$ mesons at their world average values[24], assuming $\lambda_V = \lambda_T = 1$. The result of the fit is shown in figure (9)

⁴⁴We shall consider this identification correct if the parameters obtained by fit are consistent with that of the $\bar{K}^{*0}(1430)$ meson.

($\chi^2/dof = 143/112$). As before, the inset shows that the $\overline{K}_V^*$ high-mass tail extends too much and nothing firm can be asserted about the $\overline{K}_T^*$ meson.

We have then released m_V , Γ_V , λ_V and m_T , Γ_T , λ_T . In this case, the fit (shown in figure (10)) gives a better description of the data ($\chi^2/dof = 108/106$) with better resonance tails. The fitted parameters are

$$\begin{cases} m_V = 892 \pm 3 \text{ MeV}, & \gamma_V = 34^{+16}_{-13} \text{ MeV} & \lambda_V = 14.0 \pm 4.9 \\ m_T = 1401^{+14}_{-29} \text{ MeV}, & \gamma_T = 91^{+80}_{-43} \text{ MeV} & \lambda_T = 10.5^{+4.1}_{-5.4} \end{cases} \quad (101)$$

As a result of the large correlations between γ s and λ s parameters and of the relatively small statistics, there are large uncertainties on most of these parameters (especially for the widths). However these results allow us to check that the $\overline{K}_V^*$ and $\overline{K}_T^*$ mass and width values are in agreement with the corresponding world average values[24]. The values found for the λ s are both large and consistent with that found for K_V^* and K_T^* (see rels. (21)) as can be expected from charge conjugation symmetry.

Since the parameters of $\overline{K}_V^*$ and $\overline{K}_T^*$ are in good agreement with their accepted values, we have done a final fit by fixing m_V , γ_V and m_T , γ_T to their usual values[24]. We thus obtained a good fit ($\chi^2/dof = 129/110$) with the following values :

$$\begin{cases} \lambda_V = 12.7^{+3.6}_{-4.3} \\ \lambda_T = 12.1^{+2.3}_{-4.8} \end{cases} \quad (102)$$

The numbers of mesons are 543 ± 80 ($\overline{K}_V^*$) and 262 ± 63 ($\overline{K}_T^*$) ; we have also checked that the ϕ signal is in agreement with that obtained using the K^+K^- mass assignment, where the signal occurs in a single (20 MeV) bin.

Instead of performing algebraically the weighted mean of rel. (22) and (24) between charge conjugate partners, we have preferred performing a global fit of the sample obtained by merging the $K^+\pi^-$ and $K^-\pi^+$ mass spectra. Thus we get a good fit ($\chi^2/dof = 135/106$) and meson yields in agreement with the results given above⁴⁵. The 'mean values' of the damping powers are :

$$\begin{cases} \lambda_V = 13.4^{+2.4}_{-2.7} \\ \lambda_T = 9.1^{+4.5}_{-6.0} \end{cases} \quad (103)$$

These values are consistent with those obtained for $f_2(1270)$ at the 1. σ level.

We could expect λ_V to be of the order[5] of λ_ρ (*i.e.* $0.66 \div 1.75$) since they are both vector mesons. On the other hand, ref.[30] has tried a fit of the kind (15) and obtained a result consistent with a behaviour like m^{-2} or m^{-3} . The LASS collaboration[30] also quotes a result for the K_T^* meson which is at most of the order m^{-5} . Thus, the results of sections 4 and 5 point towards a distortion of the K_V^* mass spectrum by an additional damping power of $\simeq 10$; the K_T^* mass distribution is consistent with the same distortion than the K_V^* and with no

⁴⁵We obtain 1310 ± 205 for $K^{*0}(892) + \overline{K}^{*0}(892)$ while we expect 1382 ± 127 and 491 ± 150 for $K^{*0}(1430) + \overline{K}^{*0}(1430)$ while we expect 682 ± 95 .

distortion as well because of the large value of the errors. As for the $f_2(1270)$, this distortion preserves the fundamental parameters of these mesons (masses and widths). Indeed the same global fit provides :

$$\begin{cases} m_V = 892 \pm 2 \text{ MeV} & \gamma_V = 40^{+10}_{-9} \text{ MeV} \\ m_T = 1424 \pm 10 \text{ MeV} & \gamma_T = 73^{+37}_{-24} \text{ MeV} \end{cases} . \quad (104)$$

Consequences of systematic effects have been examined in both the $K^+\pi^-$ and $K^-\pi^+$ spectra. We have checked that changing the a_V and a_T to the distributions of non-resonant πK pairs does not affect our results. Assuming a production cross section which varies like m^{-3} (see rel. (13)) leads to the same conclusion. In this case, moreover, because the mesons K_V^* and K_T^* are much sharper than the $f_2(1270)$ meson, their masses are not affected by more than 3 MeV. Finally the feed-down of K_V^* mesons by K_V^* coming from K_T^* decay is negligible because mainly of our p_T cut (see rel. (2)). Therefore, our conclusions are stable and especially the sharp fall-off of the invariant mass distributions summarized by rels. (22), (24), (25).

27 General discussion of the results

Our results are summarized in table (1), apart from the value of the damping power λ , we also consider our estimate of the $f_2(1270)$ width as reliably measured and reasonably free from systematic errors. This result is in good agreement with the recent high statistics result⁴⁶ of the DM2 collaboration[31] (169.0 ± 7.5 MeV) and with that of the EHS collaboration[26] (180 ± 24). The damping powers obtained using the $f_2(1270)$ and $K^{*0}(892)$ mesons are remarkably similar ; the damping power associated with the $K^{*0}(1430)$ mesons is lower but consistent with those of the previous mesons at the 1σ level.

The first conclusion of sections 3 to 5 is that the meson mass distributions are all distorted in the same way. The second conclusion is that this distortion preserves the values of the mesons masses and widths⁴⁷. This result looks general since the same properties are observed for mesons having different spins ($J = 1, 2$) and different strangeness content (f_2 and K^*).

In principle, our results could be compared with that obtained by the SFM collaboration which has measured the rates of $f_2(1270)$ and $K^{*0}(892)$ mesons at large p_T at ISR energies[32]. Unfortunately, this comparison is not possible because they have accounted for the background by the event mixing technics which produces distortions of the resonance signals and the authors of ref. [32] have corrected the subtracted spectra for these distortions. These corrections may have washed out the effect we observe in our experiment.

Another possibility would be that the observed distortions are produced by interference effects. We consider this assumption as unlikely since we are dealing with large multiplicity events ($\simeq 10$) and varying species of final state particles. In this case, we expect interference contributions to cancel out. As an illustration, ref.[23] has examined the inclusive $\pi^+\pi^-$ production in J/ψ decays and reached the conclusion that their data were consistent with no ρ^0 - ω interference. Our mass histogram for pairs with $\pi^+\pi^-$ mass assignment (see fig. (1) for

⁴⁶Ref. [31] uses a Breit-Wigner curve but does not provide further information about its precise shape ; this should mean that they use the standard shape[1].

⁴⁷Technically, the resonance mass which appears stable is defined as the zero (m_R) of the real part of the inverse propagator $D^{-1}(m) = (m_R^2 - m^2) - im_R\Gamma(m)$, while the width is defined by $\gamma_R = \Gamma(m_R)$. This property has been already noted in section 3.3.

instance) is also consistent with no ρ^0 - ω interference. Moreover, it is hard to imagine that interference effects would give the same distortion for all cases and that they would leave nearly unchanged the masses and widths of broad objects.

Resonance	mass our result	mass P.D.G.	width our result	width P.D.G.	λ	χ^2/dof
$f_2(1270) (300)$	1227^{+10}_{-14}	1275 ± 5	236^{+75}_{-46}	185 ± 20	$12.1^{+2.1}_{-1.9}$	141/136
$f_2(1270) (150)$	1254^{+7}_{-9}		165^{+45}_{-29}		$13.4^{+3.2}_{-2.5}$	144/136
$K^{*0}(892)$	892 ± 3	896.1 ± 0.3	39 ± 11	50.5 ± 0.6	$13.5^{+3.4}_{-3.0}$	128/106
$\overline{K}^{*0}(892)$	892 ± 3		34^{+16}_{-13}		14.0 ± 4.9	108/106
$K^{*0} + \overline{K}^{*0}$	892 ± 2		40^{+10}_{-9}		$13.4^{+2.4}_{-2.7}$	135/106
$K^{*0}(1430)$	1435 ± 13	1432.4 ± 1.3	100 ± 49	109 ± 5	5.6 ± 3.3	128/106
$\overline{K}^{*0}(1430)$	1401^{+14}_{-29}		91^{+80}_{-43}		$10.5^{+4.1}_{-5.4}$	108/106
$K^{*0} + \overline{K}^{*0}$	1424 ± 10		73^{+37}_{-24}		$9.1^{+4.5}_{-6.0}$	135/106

Table 1 : Summary of the results concerning all the fitted mesons.

We are thus left with the conclusion that the observed distortions are due to the production mechanism at work in our experiment : the hadronization process of colored quarks and gluons. This process enhances the probability to produce a given meson at low mass and suppresses its production at large mass. More surprising is that these distortions leave unchanged the resonance physical parameters. These properties are in qualitative agreement with what has been seen recently from a Lund Monte Carlo sample by A. Lindner[8] when examining the shape of the ρ^0 mass spectrum. Since resonance mass spectra in the Lund Monte Carlo are simply fixed width Breit–Wigner expressions the agreement cannot be otherwise than qualitative.

These properties illustrate the specificity of color string fragmentation as a production mechanism of resonances, at least as leading fragments. Of course, resonances produced in resonance decays are affected differently, and sometimes not affected at all⁴⁸.

On the other hand, resonances decaying to more than two particles are surely affected, but our experiment does not allow any precise study of this effect. For instance, there is some indication that $a_2(1320)$ is observed in its three pion decay mode, but the combinatorial three particle background is so large that no study can be performed.

Our main result can be sketched in the following way : when produced at large p_T , any given resonance R of spin l having two-particle decay modes can be described by a Breit–Wigner distribution, the shape of which remains formally the usual one[1], with the usual mass and width (m_R and γ_R) ; however, its decay amplitude to a given decay mode X written[5] :

⁴⁸For instance, the ρ^0 produced in the η' decay is surely affected by phase space effects due essentially to the η' mass but not to the η' production mechanism since this meson is too sharp to feel any damping factor.

$$\Gamma_X(m) = \gamma_R \left[\frac{q_X(m)}{q_X(m_R)} \right]^{(2l+1)} \left[\frac{m_R}{m} \right]^\lambda ,$$

always gives a good description of the data and $\lambda \simeq 12.5$ looks like a universal parameter. This power is large enough to suggest an actual exponential damping. The present theoretical knowledge does not provide however any motivated guideline to a suitable parametrization of meson shape distortions in high- p_T processes.

28 Conclusions

We have analyzed the invariant mass distributions of five mesons ($f_2(1270)$, $K^{*0}(892)$, $\overline{K}^{*0}(892)$, $K^{*0}(1430)$, $\overline{K}^{*0}(1430)$) produced at $p_T \geq 2.0$ GeV/c, under conditions where they are likely to be leading fragments of high- p_T jets. We have found that these mass distributions are sharply distorted ; these distributions are affected by a large damping power ($\simeq m^{-12}$), far above the usual one. At the level of accuracy allowed by our data, we have also shown that this distortion does not affect the mass and width of any of the resonances examined sofar. We have also shown that the distortions look alike for the mesons studied, without any respect to their spin or quark content. It has to be expected that this phenomenon affects all resonances primarily produced in the parton fragmentation mechanism, for instance the ρ meson. Our conclusions apply to two-body decay channels of resonances. The meson shape distortions observed in our data give experimental support to the existence of phase space effects in the process of quark fragmentation into hadrons.

References

- [1] J.D. Jackson, Nuovo Cimento XXXIV (1964) 1644.
- [2] J. Pisut and M. Roos, Nucl. Phys. **B6** (1968) 325.
- [3] J. Ballam *et al.*, Phys. Rev. **5** (1972) 545.
- [4] T.A. Armstrong *et al.* Zeit. für Phys. **C51** (1991) 351.
- [5] M. Benayoun *et al.* Zeit. für Phys. **C 58** (1993) 31.
- [6] B. Andersson *et al.* Phys. Rep. **97** (1983) 31 ;
H. Bengtsson and G. Ingelman Comput. Phys. Comm. **34** (1985) 251 ;
“The Lund Monte Carlo Programs”, CERN long writeups W5035, W5045, W5046, W5047, W5048, nov. 1989.
- [7] O. Podobrin, Ph. D. Thesis, DESY report FCE-92-03, Hamburg 1992.
- [8] A. Lindner, Ph. D. Thesis, Dortmund 1992.
- [9] H. Albrecht *et al.*, DESY preprint 93-084, Hamburg 1993.
- [10] H. Albrecht *et al.* Zeit. für Phys. **C58** (1993) 199.
- [11] ALEPH collaboration, preprint CERN-PPE/92-74, Geneva 1992.
- [12] OPAL collaboration, preprint CERN-PPE/92-116, Geneva 1992.
- [13] P. Abreu *et al.*, DELPHI collaboration, Phys. Lett. **B298** (1993) 236.
- [14] P.D. Acton *et al.*, OPAL collaboration, Zeit. für Phys. **C56** (1992) 521.
- [15] M. Benayoun *et al.* Phys. Lett. **B183** (1987) 412.
- [16] M. Benayoun *et al.* Nucl. Phys. **B282** (1987) 653.
- [17] M. Benayoun *et al.* Phys. Lett. **B192** (1987) 447.
- [18] M. Benayoun *et al.* Phys. Lett. **B198** (1987) 281.
- [19] W. Beusch *et al.* Nucl. Instrum. Methods **A249** (1986) 391.
- [20] M.T. Trainor, “Direct meson production at $p_T \geq 2$. GeV/c in 300 GeV/c $\pi^- Be$ interactions”, PhD thesis, University of Birmingham, March 1988 ;
R. Fini, “Produzione inclusiva di risonanze a medio-alto momento trasverso”, Tesi di Dottorato, Università degli studi di Bari, january 1990, National library of Rome and Florence.
- [21] A. Bellogianni *et al.*, Zeit. für Phys. **C54** (1992) 535.
- [22] A. Bellogianni *et al.*, Zeit. für Phys. **C59** (1993) 35.
- [23] G. Gidal *et al.*, Phys. Lett. **B107** (1981) 153.
- [24] Review of Particle Properties, Phys. Rev **D45** (1992).
- [25] P. Granet *et al.* Nucl. Phys. **B140** (1978) 389.
- [26] M. Aguilar-Benitez *et al.* Zeit für Phys. **C50** (1991) 405.
- [27] S. Abachi *et al.*, Phys. Rev. Lett. **57** (1986) 1990.
- [28] H.-J. Behrend *et al.* Zeit für Phys. **C56** (1992) 381 ;
J. Harjes, Thesis, preprint DESY-FCE-91-01, Hamburg 1991.
- [29] V. Chabaud *et al.* Nucl. Phys. **B223** (1983) 1.
- [30] D. Aston *et al.* Nucl. Phys. **B296** (1988) 493.
- [31] J.E. Augustin *et al.* Nucl. Phys. **B320** (1989) 1.
- [32] A. Breakstone *et al.* Zeit für Phys. **C43** (1989) 185.

Figure Captions

- Figure 1 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 300 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming the world average values for the $f_2(1270)$ parameters, $\lambda_K = 1$, $\lambda_\pi = 1$. In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the large high-mass tail of the $f_2(1270)$.
- Figure 2 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 300 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming $\lambda_K = 1$, but leaving free the mass, width of the $f_2(1270)$ meson and λ_π . In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice how the high-mass tail of the $f_2(1270)$ is reduced.
- Figure 3 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 150 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming the world average values for the $f_2(1270)$ parameters, $\lambda_K = 1$, $\lambda_\pi = 1$. In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the large high-mass tail of the $f_2(1270)$.
- Figure 4 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 150 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming $\lambda_K = 1$, but leaving free the mass, width of the $f_2(1270)$ meson and λ_π . In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the reduction in the high-mass tail of the $f_2(1270)$.

- Figure 5 : Effect of the damping power λ_π on the shape of a Breit–Wigner contribution to the cross section. In full line we have represented the case $\lambda_\pi = 1$, in dashed dotted line the case $\lambda_\pi = 12.5$.
- Figure 6 : Invariant mass plot of trigger pairs with an identified K^+ ; the data are extracted from our 300 GeV/c sample. The fit represented has been obtained assuming the world average values for the masses and widths of both K^* mesons and both damping powers $\lambda = 1$.
- Figure 7 : Acceptance function of $K\pi$ trigger pairs as a function of their (true) invariant mass.
- Figure 8 : Invariant mass plot of trigger pairs with an identified K^+ ; the data are extracted from our 300 GeV/c sample. The fit shown has been obtained leaving free the masses and widths of both K^* mesons and both damping powers λ .
- Figure 9 : Invariant mass plot of trigger pairs with an identified K^- ; the data are extracted from our 300 GeV/c sample. The fit represented has been obtained assuming the world average values for the masses and widths of both K^* mesons and both damping powers $\lambda = 1$.
- Figure 10 : Invariant mass plot of trigger pairs with an identified K^- ; the data are extracted from our 300 GeV/c sample. The fit represented is obtained, leaving free the masses and widths of both K^* mesons and both damping powers λ .

29 Introduction

It is a known property of resonances that their observed mass distributions can vary from one experiment to another, depending on the production mechanism[1][2]. The main origin of this effect is the unknown mass dependence of resonance production cross sections. These are generally subject to more or less arbitrary assumptions which affect the decay amplitude $\Gamma_{res}(m)$ of the resonance in the fitting procedures[2].

In exclusive experiments effects due to the production mechanism can be superposed with interference effects associated with processes involving the same final state. Interference effects thus produce an important skewing of the ρ^0 lineshape in photoproduction experiments (see ref.[3] for instance). Large distortions of the $S^*/f_0(975)$ meson have also been reported by many experiments (see ref.[4] for instance). Phase space effects can also produce large changes of the resonance shape. For instance, in the decay $\eta \rightarrow \pi^+\pi^-\gamma$ which is dominated by $\eta \rightarrow \rho^0\gamma$, the $\pi^+\pi^-$ mass spectrum is cut at the η mass in such a way that the ρ^0 peak is completely outside the available phase space[5]. In summary, several mechanisms can produce distortions of the invariant mass distributions of broad resonances, sometimes in a predictable way.

In high- p_T physics, we deal with another kind of production mechanism: the fragmentation of coloured strings into hadrons[6]. With this respect, O. Podobrin[7] has recently shown that Bose–Einstein correlation effects between resonance decay products and nearby (in phase space) stable pions can produce a large shift of the resonance masses. On the other hand, A. Lindner[8] has shown that the Lund Monte Carlo provides distortions of the ρ meson mass spectrum. These results illustrate that internal properties of the colour string fragmentation process can result in observable modifications of resonance mass spectra.

The ARGUS collaboration has looked for this kind of shape distortions for the ρ meson but could not reach any firm conclusion[9] because of lack of statistics. They have nevertheless taken this effect into account in recent works[10]. Studies involving light flavour mesons are also available from LEP experiments[11][12][13][14]. Some indication of ρ^0 lineshape distortion has been already reported by the OPAL collaboration[12].

Here in the WA77 experiment, we study the shape of five resonances for which the influence of reflections can be essentially removed and the background is well under control. These meson resonances ($f_2(1270)$, $K^{*0}(892)$, $\bar{K}^{*0}(892)$, $K^{*0}(1430)$ and $\bar{K}^{*0}(1430)$) have a large branching fraction to two-body channels ($\pi^+\pi^-$, $K^\pm\pi^\mp$). Moreover these resonances are rarely decay products of higher resonances and the feed down of $K^{*0}(892)$ mesons from $K^{*0}(1430)$ decays is removed by our trigger at the 98% level.

The mass spectra also reveal a significant ϕ signal[15] in K^+K^- , however we are not sensitive to possible distortions of this signal because of our mass resolution. There is in addition a large ρ^0 signal[15]; this signal is not studied in the present work because it is produced by several mechanisms (parton fragmentation[6], prompt production[16], η' decay[19]) and then its shape cannot follow from a single phenomenon.

We first give a brief description of the experiment and of the data samples (section 2). Then we study (section 3) the $f_2(1270)$ meson in the full samples of data collected at 300 and 150 GeV/c; due to its statistical importance, this signal allows a detailed study of systematic effects. Section 4 deals with the analysis of the $K^+\pi^-$ mass spectrum with an identified K^+ ; for this purpose we only use our 300 GeV/c data sample and study the $K^{*0}(892)$ and $K^{*0}(1430)$ meson invariant mass distributions. Section 5 is devoted to the study of the $K^-\pi^+$ mass spectrum with an identified K^- ; here also we only use our 300 GeV/c data sample and study the $\bar{K}^{*0}(892)$ and $\bar{K}^{*0}(1430)$ meson invariant mass distributions. In section 6, we discuss

the results obtained for the various mesons and examine some *a priori* possible explanations. Finally section 7 is devoted to a summary of our conclusions.

30 The data samples

The basic idea of the WA77 trigger is to obtain a sample of events with three particles at large p_T where a pair of them (of opposite charges) is supposed to come from the decay of a neutral resonance, while the third track (p , $\bar{p}$, $K^\pm$, $\pi^\pm$) is assumed to be the leading particle of an opposite jet. Details about the trigger and setup have been given elsewhere [15][18–22]. This trigger favours the observation of meson resonances decaying into two bodies which are leading particles of a high- p_T jet. We have verified this property on a Lund Monte Carlo sample of events tracked through the simulation of our setup and fulfilling our trigger conditions. We have thus found that 99.5% of the Monte Carlo events accepted by our trigger have no more than three tracks at $p_T \geq 1$ GeV/c.

The WA77 experiment has performed two runs of data taking on $\pi^- N$ interactions, the first at 300 GeV/c, the second at 150 GeV/c. In the 300 GeV/c setup two multicell Cerenkov counters were used for identification of particle species. We selected events in the rapidity range :

$$2.80 \leq Y_{lab}^{pair} \leq 3.70 \quad , \quad (105)$$

and with transverse momenta :

$$\begin{cases} p_T^{trig.part.} \geq 1 \text{ GeV/c} \\ p_T^{pair} \geq 2 \text{ GeV/c} \end{cases} \quad . \quad (106)$$

At 300 GeV/c, this corresponds to a center of mass rapidity window $(-0.43, +0.47)$, while at 150 GeV/c it corresponds to the window $(-0.08, +0.90)$. The total number of events is 209 654 in the 300 GeV/c sample and 238 749 in the 150 GeV/c sample.

31 Study of the $f_2(1270)$ meson

We consider here the mass spectra obtained assuming both particles in the pair to be pions. We do not use in this case the information provided by the Cerenkov counters since we know[21] that the pion assignment in our experiment is widely contaminated by kaons and protons. The $f_2(1270)$ region suffers only little from $K^{*0}(1430)$ contamination because its reflection produces a tiny signal which does not affect the properties of the $f_2(1270)$ meson (see section 3.3) and therefore it has not been considered in the final fit. No other source of contamination has been found in this mass region.

31.1 Fitting method

In order to perform our fits we have taken into account besides the resonances ($\rho^0(770)$, $f_2(1270)$, $S^*/f_0(975)$) the reflections due to the large signals[22] of the $\phi(1020)$, $K^{*0}(892)$ and $\bar{K}^{*0}(892)$ mesons. These last signals appear shifted due to the wrong mass assignment given to

their decay products. The invariant mass histogram of the pairs with the $\pi^+\pi^-$ mass assignment is shown in figure (1) for the 300 GeV/c data. It has been fitted using the following expression :

$$\begin{aligned} \frac{dN}{dm} = & [f_{bckg}(m) + a_\rho BW(\rho^0, m) + a_{S^*} BW(S^*, m) + a_{f_2} BW(f_2, m)] \\ & + a_\phi REF(\phi, m) + a_{K^*} REF(K^*, m) \end{aligned} \quad (107)$$

In this expression $f_{bckg}(m)$ is a function of the invariant mass of the pair (m) which describes the background[13][15]. It has been parametrized as :

$$f_{bckg}(m) = a(m - m_{th})^\alpha \exp[bm + cm^2 + dm^3] \quad , \quad (108)$$

where $m_{th} = 2m_\pi$ is the threshold mass of the system. We have checked on a Lund Monte Carlo sample that this expression describes correctly the mass histogram of the non-resonant pairs. BW and REF in expression (3) stand respectively for Breit-Wigner distributions and reflections of resonances when a wrong mass assignment is applied. We take as Breit-Wigner distribution of a resonance R :

$$BW(R, m) = \frac{m m_R \Gamma_{\pi\pi}(m)}{|m_R^2 - m^2 - im_R \Gamma(m)|^2} \quad , \quad (109)$$

where $\Gamma_{\pi\pi}(m)$ is the $\pi\pi$ partial width and $\Gamma(m)$ is the full width of the resonance R . The denominator in rel. (5) coincides with the usual $(m_R^2 - m^2)^2 + m_R^2 \Gamma^2(m)$ when the mass m is above all thresholds[1]. However, between the $\pi\pi$ and $K\bar{K}$ thresholds the partial width (see rel. (6) below) $\Gamma_{K\bar{K}}$ becomes purely imaginary and thus contributes to the real part of the Breit-Wigner denominator in rel.(5) ; this effect has been taken into account in our fits. Therefore, rel. (5) is the standard expression established in [1], assuming the production cross section of the resonance R to be constant. With this definition of a Breit-Wigner distribution, each a in rel. [3] is precisely the production cross-section of the corresponding resonance, in agreement with ref. [1].

The reflections of $K^{*0}(892)$ and $\bar{K}^{*0}(892)$ are superposed when using the $\pi^+\pi^-$ mass assignment, and not distinguishable. The shapes of all reflections have been computed by generating samples of events using a standard Breit-Wigner[1], following the tracks in the full simulation of our setup[17][21] and finally changing the correct mass assignment to $\pi^+\pi^-$. Our simulation takes into account the acceptance effects and the accuracy of the reconstruction program TRI-DENT. Therefore by this procedure we take into account acceptance and resolution effects on these mass distributions.

The parametrization of the $S^*/f_0(975)$ has been done following ref. [23] ; a large sample of events has been generated, tracked through the simulation of our detector and reconstructed to account for acceptance and resolution effects. We considered this precaution as necessary because this meson is close to the $f_2(1270)$ meson mass. We have chosen a heuristic parametrization⁴⁹ for the ρ^0 meson (a Breit-Wigner with a width larger by 20 MeV than nominal). In this way expression (3) describes correctly the mass region below 1 GeV.

To describe the $f_2(1270)$ meson, we have not used the standard way[1] to write a relativistic Breit-Wigner expression, but rather followed the suggestion of ref.[5] by using a more general expression. Assuming the world average values[24] for the various branching fractions, the $f_2(1270)$ decay amplitude is written :

⁴⁹The ρ^0 meson in our experiment is expected to be produced through many mechanisms, including the η' decay ; a precise study of this region is presently under way.

$$\Gamma_{f_2}(m) = \gamma_{f_2} \left[r_0 + r_K \left[\frac{q_K(m)}{q_K(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_K} + r_\pi \left[\frac{q_\pi(m)}{q_\pi(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_\pi} \right] + \gamma_{res} \quad , \quad (110)$$

where $q_K = 1/2\sqrt{m^2 - 4m_K^2}$, $q_\pi = 1/2\sqrt{m^2 - 4m_\pi^2}$ and $r_\pi = 0.849$, $r_K = 0.046$ and $r_0 = 0.105$ are respectively the branching fractions to $\pi\pi$, $K\overline{K}$ and the remaining channels. The constant part of the width accounts mainly for the decay modes into four bodies. λ_K and λ_π are parameters to be fitted. These two parameters are actually fixed to 1 in the standard approach[1] ; it has been shown [5] that the equivalent expression for the ρ^0 distribution with the exponent λ allowed to vary is able to give a good and simple description of the $e^+e^- \rightarrow \pi^+\pi^-$ data while it is not possible to obtain a good fit with λ fixed to one.

The parameter γ_{f_2} is the $f_2(1270)$ natural width and γ_{res} is the mass resolution at the resonance peak (20 MeV). This is the usual approach to account for resolution effects[26] ; we have checked with our simulation that this describes correctly the resolution effects in our experiment.

In the expression of the f_2 Breit–Wigner (rels. (3) and (5)), the denominator contains the full expression (6), but the numerator contains only the $\pi\pi$ part (last term in rel. (6)) together with the resolution contribution :

$$\Gamma_{\pi\pi} = r_\pi \gamma_{f_2} \left[\frac{q_\pi(m)}{q_\pi(m_{f_2})} \right]^5 \left[\frac{m_{f_2}}{m} \right]^{\lambda_\pi} + \gamma_{res} \quad , \quad (111)$$

The parameters α , a , b , c , d , a_ρ , a_{S^*} , a_{f_2} , a_ϕ , a_{K^*} are constants to be fitted with the constraint that the integral of the right–hand side of rel. (3) must be equal to the experimental number of events N . All resonance parameters (masses and widths) are fixed to their world average values[24], except for those for the f_2 which are fitted.

It should be noted that we have chosen to describe the resonance contributions assuming that their production cross sections are constant. Traditionally, these are assumed to have a phase–space distribution and this phase–space distribution is identified with the background in order to lessen the number of free parameters[25]. We have also used this method in previous publications[15][20][22]. Here we describe the resonance contributions assuming a constant production cross section after having checked that both constant and phase space cross sections give results consistent within errors for both resonance yields and functional shapes. Other attempts have been tried which will be described in section 3.3. Let us also mention that the two methods sketched above have been recently compared by the DELPHI collaboration[13] which have reached the same conclusion as ours.

Finally, we have chosen a binning (20 MeV) which matches our mass resolution at the $f_2(1270)$ mass in order to minimize the loss of information about the shape of the mass spectra.

31.2 Fitting the $\pi^+\pi^-$ spectra

As a general remark, we have found no sensitivity of our data to the precise value of λ_K ; varying it between 1 and 14 does not produce any change above the one σ level. Therefore we have decided to fix definitely $\lambda_K = 1$ in the $f_2(1270)$ analysis.

Let us first discuss the 300 GeV/c data. As a first attempt, we have tried fitting our spectrum assuming $\lambda_\pi = 1$ and fixing m_{f_2} and γ_{f_2} at their world average values[24]. This fit

corresponds to $\chi^2/dof = 210/139$ and is shown in fig. (1) ; it clearly goes too much above background on the f_2 high-mass tail region. Leaving free m_{f_2} and γ_{f_2} , the quality of the fit improves ($\chi^2/dof = 177/137$) and provides :

$$\begin{cases} m_{f_2} = 1240 \pm 6 \text{ MeV} \\ \gamma_{f_2} = 102^{+21}_{-18} \text{ MeV} \end{cases} . \quad (112)$$

Finally, leaving free m_{f_2} , γ_{f_2} , λ_π , we obtain a good fit (see figure (2)) corresponding to $\chi^2/dof = 141/136$ with the following parameters :

$$\begin{cases} m_{f_2} = 1227^{+10}_{-14} \text{ MeV} \\ \gamma_{f_2} = 219^{+75}_{-46} \text{ MeV} \\ \lambda_\pi = 12.13^{+2.11}_{-1.94} \end{cases} . \quad (113)$$

Turning now to our 150 GeV/c data, we have also first performed the fit after fixing $\lambda_\pi = 1$ and using the world average values for m_{f_2} and γ_{f_2} . The fit obtained is shown in figure (3) and corresponds to $\chi^2/dof = 222/139$. It also clearly goes too much above background on the $f_2(1270)$ high-mass tail. Setting $\lambda_\pi = 1$, but allowing m_{f_2} and γ_{f_2} to vary, we find :

$$\begin{cases} m_{f_2} = 1259 \pm 6 \text{ MeV} \\ \gamma_{f_2} = 72 \pm 12 \text{ MeV} \end{cases} , \quad (114)$$

corresponding to $\chi^2/dof = 179/137$. Finally, leaving free λ_π , m_{f_2} and γ_{f_2} , we find :

$$\begin{cases} m_{f_2} = 1254^{+7}_{-9} \text{ MeV} \\ \gamma_{f_2} = 148^{+45}_{-29} \text{ MeV} \\ \lambda_\pi = 13.44^{+3.22}_{-2.52} \end{cases} , \quad (115)$$

with a good quality of the fit ($\chi^2/dof = 144/136$) ; the corresponding fit is shown in figure (4).

31.3 Discussion of the results

As a general conclusion, assuming $\lambda_\pi = 1$ and fixing the $f_2(1270)$ parameters at their world average values ($m_{f_2} = 1275 \text{ MeV}$, $\gamma_{f_2} = 185 \text{ MeV}$) does not provide a satisfactory description of the data. Figures (1) and (3) clearly show that the $f_2(1270)$ high-mass tail extends too much and exhibits large systematic effects (see the insets in fig. (1) and (3)). Leaving free the mass and width slightly improves the quality of the fits but they are both significantly below their commonly accepted values[24].

However, we always obtain a good fit if we leave free λ_π . In this case, the $f_2(1270)$ natural width is in agreement with the accepted value[24], but the mass is systematically lower.

In this respect, we have studied the effects of systematic errors. The first source is our neglecting of the $K^{*0}(1430)$ reflection which occurs nearly at the $f_2(1270)$ mass with a width of about 300 MeV. Assuming[27] the ratio $K^{*0}(1430)/K^{*0}(892) = 0.2$, we have redone our fits

using expression (3) including a $K^{*0}(1430)$ reflection ; this increases the $f_2(1270)$ mass value by 6 MeV at both energies but has little effect on the $f_2(1270)$ width and λ_π . This is surely an upper bound since examining our samples with the $\pi^\pm K^\mp$ mass assignment clearly shows that the $K^{*0}(1430)$ contribution does not exceed 10% of the $f_2(1270)$ signals :

$$\begin{cases} n_{f_2} = 5051^{+1443}_{-977} & (300 \text{ GeV/c}) \\ n_{f_2} = 4339^{+985}_{-736} & (150 \text{ GeV/c}) \end{cases}, \quad (116)$$

and stays well inside the level of errors.

Another possible source of systematic effects is our assumption that a_{f_2} in expression (3) is constant. In this respect, we have replaced the term $a_{f_2} BW(f_2, m)$ in rel. (3) by $a_{f_2} f_{\pi\pi}(m) BW(f_2, m)$, where $f_{\pi\pi}(m)$ is the invariant mass distribution of non-resonant $\pi^+\pi^-$ pairs determined from a sample of Lund events accepted by our setup. The idea is that this function simulates the two-pion phase space distribution in our experiment. The results coincide with the above ones within errors. We have also tried fitting our spectra assuming $f_{\pi\pi}(m)$ to be of the form⁵⁰ $[m_{f_2}/m]^\mu$. The improvement is small at both energies (the χ^2 decreases by only 4 units) and gives values consistent with that in rels (9) and (11) for γ_{f_2} and λ_π , while we find :

$$\begin{cases} m_{f_2} = 1245^{+12}_{-16} \text{ MeV} & \mu = 3.39^{+2.88}_{-1.64} & (300 \text{ GeV/c}) \\ m_{f_2} = 1266 \pm 8 \text{ MeV} & \mu = 2.87^{+1.54}_{-1.34} & (150 \text{ GeV/c}) \end{cases}, \quad (117)$$

in good agreement with the result of EHS[26].

We have also considered the influence of the background shape. Changing the threshold behaviour or adding a m^4 term in the exponential (see rel. (4)) does not remove the effect observed in the $f_2(1270)$ mass region. Another way to test the effect of background is to change the p_T cut ; in this respect we have reanalyzed our data requiring $p_T^{pair} \geq 2.2 \text{ GeV/c}$ instead of $p_T^{pair} \geq 2.0 \text{ GeV/c}$. At 300 GeV/c this produces a reduction of $\simeq 20\%$ for both the background and the $f_2(1270)$ signal, and the fit gives $\lambda_\pi = 18.8^{+3.5}_{-2.9}$. At 150 GeV/c this new p_T cut produces a reduction of $\simeq 50\%$ for the background and $\simeq 35\%$ for the $f_2(1270)$ signal ; in this case the fit provides $\lambda_\pi = 13.6^{+8.3}_{-4.8}$. Therefore the sharpening of the $f_2(1270)$ mass distribution cannot be attributed to the size of the background or to some given value of the signal to background ratio.

Finally we have checked by simulation studies that the acceptance function of $\pi\pi$ pairs is a slowly decreasing function of m nearly flat in the f_2 mass region. Therefore its effect can be neglected in expression (3) without affecting the results of the fit.

To conclude, the systematic effects which have been investigated tend to leave the values of γ_{f_2} and λ_π unchanged while they can produce a downward shift of the f_2 mass up to $\simeq 15$ MeV. Systematic effects due to the background shape or size have not been detected. Therefore, we can rely on the width and λ_π estimates in our data which correspond to one of the best available statistics (compare rels. (12) with the statistics reported in ref. [24]).

We can summarize our results on the $f_2(1270)$ meson by performing a weighted mean of rels. (9) and (11) :

⁵⁰Indeed, since we are dominated by parton fragmentation, it is not clear that using a $\pi\pi$ phase space distribution is justified.

$$\begin{cases} \lambda_\pi = 12.6^{+1.8}_{-1.5} \\ \gamma_{f_2} = 167^{+39}_{-25} \text{ MeV} \end{cases} \quad (118)$$

Our estimate of the $f_2(1270)$ width is in agreement with the world average value[24] (185 ± 20 MeV) at the 1σ level; our estimate of the damping power λ_π ($\simeq 12$) gives a number considerably larger than what is usually expected[1]. For instance, the power obtained for the ρ^0 meson in the $e^+e^- \rightarrow \pi^+\pi^-$ process ranges[5] from $\simeq 0.66$ to $\simeq 1.75$.

Since there is no theory of this damping power[5], a question arises as to whether such a value ($\lambda_\pi \simeq 12$) looks normal or if it points towards a distortion of the $f_2(1270)$ invariant mass distribution when this meson is produced at large p_T as a leading fragment of a (high- p_T) jet. We note that most of spectroscopic experiments (see refs. [4] and [28] for instance) accomodate⁵¹ to $\lambda_\pi = 1$. In ref. [29] the $f_2(1270)$ coupling to $\pi^+\pi^-$ is considered yielding the following expression for the width :

$$\begin{cases} \Gamma(m) &= \Gamma_{f_2} \frac{q_\pi(m)}{q_\pi(m_{f_2})} \frac{D_2[q_\pi(m_{f_2})R]}{D_2[q_\pi(m)R]} \\ D_2[(q_\pi(m)R)] &= 9 + 3[q_\pi(m)R]^2 + [q_\pi(m)R]^4 \end{cases} \quad (119)$$

where the range parameter[2] R is found[29] to be $R \geq 3 \text{ GeV}^{-1}$ or $R \geq 9 \text{ GeV}^{-1}$, depending on the fit hypotheses. It follows from these lower bounds that only the last term in the second expression (15) plays a significant role. Therefore, in this experiment at least, the result corresponds to an effective value $\lambda_\pi = 4$. Comparing this result with rel. (14), clearly shows that in parton fragmentation, we get an additional damping power of $\simeq 8$. The skewing effect is shown in figure (5) ; here we have plotted the same Breit–Wigner expression (5) using $\lambda_\pi = 1$ and $\lambda_\pi = 12.5$, leaving unchanched γ_R and m_R . It should be noticed that the resulting skewing effect plays in such a way that the physical parameters of the $f_2(1270)$ meson, mass and width (or lifetime), can be considered as unchanged⁵² at the level of accuracy of our data.

32 Study of the $K^+\pi^-$ spectrum

In the data taken at 300 GeV/c, we have used the Cerenkov information to single out a sample of 16266 events with an identified K^+ meson ; no constraint has been placed on the negative particle. We have shown in ref.[21] that the probability for a particle identified as a kaon to be a pion is consistent with zero, while the probability of the converse is $\simeq 30\%$. Therefore, requesting a pion signature for the negative particle would have much more reduced our sample without a useful gain in the signal over background ratio. A significant fraction ($\simeq 30\%$) of the protons survive the condition of identified K^+ ; these will essentially

⁵¹CELLO collaboration [28] has not succeeded in determining the shape of the $f_2(1270)$ resonance because of the interplay in the $\gamma\gamma \rightarrow \pi^+\pi^-$ reaction of non-resonant terms which contribute to the D -wave together with the (main) $f_2(1270)$ resonant term.

⁵²One should also notice that the values which are unchanged are the zero of the real part of the inverse propagator (*i.e.* m_R) in rel. (5) and the value of the imaginary part of this function at $m = m_R$ (*i.e.* γ_R) ; of course real and imaginary parts refer to the case when m is above all thresholds. It is these definitions of mass and width which appear to be stable.

contribute to the background as no Δ^0 contribution has been found in our data. A departure from pure phase space distribution in the threshold region is in any case expected because of anticorrelation phenomena in pair production[21] and therefore it is difficult to single out a possible Δ^0 contribution here. The data taken at 150 GeV/c are not used since there is no available Cerenkov information ; in this case, the K^* signals are widely mixed with the $\rho^0(770)$ and $f_2(1270)$ reflections and our conclusions would hardly be model dependent. Requiring one K mass assignment from the Cerenkov counters reduces the signals considerably but removes the $\rho^0(770)$ and $f_2(1270)$ signals completely.

The $K^+\pi^-$ spectrum is given in figure (6). We observe a clear signal of the $K^{*0}(892)$ (hereafter denoted K_V^*) and a small $K^{*0}(1430)$ signal (hereafter denoted K_T^*) ; the relatively broad bump between the $K\pi$ threshold and the K_V^* peak is the $\phi(1020)$ meson reflection in the $K\pi$ mass assignment. No other obvious structure can be seen⁵³. Other K^* mesons fall in the 1400 MeV region[24][30] (as well as the reflection of the $f'(1515)$ signal) and could contribute to shadow somehow the K_T^* signal and shape. Therefore we need to check that the 1.43 GeV structure is indeed dominated by the K_T^* signal.

We have performed our fits using :

$$\frac{dN}{dm} = f_{acc}(m)[f_{bckg}(m) + a_V BW(K_V^*, m) + a_T BW(K_T^*, m)] + a_\phi REF(\phi, m) \quad . \quad (120)$$

In this expression $f_{bckg}(m)$ is a function of the invariant mass of the pair (m) which describes the background. It has been parametrized as :

$$f_{bckg}(m) = a(m - m_{th})^\alpha \exp[bm + cm^2 + dm^3 + em^4] \quad , \quad (121)$$

where m_{th} is the relevant two-particle threshold mass. We have generated a large sample of events using the Lund Monte Carlo program PYTHIA[8] and followed the tracks through a complete simulation of our setup. Using the pairs obtained by requiring that both particles do not come from the decay of the same resonance we have checked that expression (17) above was able to describe correctly the $K\pi$ spectra. We have especially checked that the third and fourth order terms in the exponential were needed to get a satisfactory description of the mass spectrum over our full mass range.

$f_{acc}(m)$ is the acceptance function of $K\pi$ pairs. It has also been directly computed from our simulation. As it can be seen from figure (7), this function peaks near the $K^*(892)$ mass and is flat around the $K^*(1430)$ mass. Unlike the case of the $\pi^+\pi^-$ spectrum, it is not possible to neglect its effect. There are also[21] non-resonant $p\pi^-$ pairs which give a slightly harder threshold behaviour. This phenomenon plays a role on the first 100 MeV of the invariant mass histogram and the corresponding bins have been removed from the fits.

The resonance contributions have been represented by the standard relativistic Breit-Wigner expression (5). Following ref. [5], the width of the meson K_V^* has been parametrized as :

$$\Gamma_V(m) = \gamma_V \left[\frac{q_{K\pi}(m)}{q_{K\pi}(m_V)} \right]^3 \left[\frac{m_V}{m} \right]^{\lambda_V} + \gamma_{res} \quad , \quad (122)$$

where γ_V is the natural width of the K_V^* resonance and γ_{res} is the resolution at the K_V^* peak (9 MeV) estimated from simulation. $q_{K\pi}(m)$ is the momentum of each decay product of the

⁵³It must be noticed that the K_T^* signal in the original sample is overwhelmed by the background.

K_V^* resonance in its rest frame, and m_V is the resonance mass. Therefore we treat the K_V^* as a purely elastic resonance. In the standard treatment[1] followed by most experiments λ_V is set to 1 ; here we allow it to vary.

The K_T^* meson has been treated in the same way as the $f_2(1270)$ meson (see rel. (6) above) : the main decay modes into two bodies ($K\pi$, $K^*(892)\pi$) have been explicitly accounted for, while we have accounted for the rest by means of a constant width :

$$\gamma_T(1 - Br(K\pi) - Br(K_V^*\pi)) = 0.251\gamma_T \quad , \quad (123)$$

where γ_T is the K_T^* full width. The branching fractions of the K_T^* meson have been taken at their world average values[24]. Therefore, we have used :

$$\Gamma_T(m) = \gamma_T \left[0.251 + 0.252 \left[\frac{q_{K_V^*\pi}(m)}{q_{K_V^*\pi}(m_T)} \right]^5 \left[\frac{m_T}{m} \right] + 0.497 \left[\frac{q_{K\pi}(m)}{q_{K\pi}(m_T)} \right]^5 \left[\frac{m_T}{m} \right]^{\lambda_T} \right] + \gamma_{res} \quad , \quad (124)$$

where $q_{K_V^*\pi}$ and $q_{K\pi}$ are the 3-momenta of the K_T^* decay products for the corresponding decay modes⁵⁴. We have fixed $\lambda = 1$ for the $K_V^*\pi$ channel after having checked that our data are not sensitive to this channel⁵⁵. γ_T is the K_T^* natural width and γ_{res} is the mass resolution of our setup at the K_T^* peak mass (14 MeV).

The numerators of the BW functions in rel. (16), are always the partial widths to $K^+\pi^-$ increased by the resolution at the corresponding resonance peak.

$REF(\phi, m)$ in rel. (16) is the reflection of the ϕ meson. It has been computed directly by generating a sample of ϕ mesons from a Breit-Wigner law (see rel. (5)) and tracking the K^+ and K^- particles through our simulation. The reflected spectrum has been simply obtained by changing the true particle assignment to $K^+\pi^-$.

Our free parameters are those in rel. (17) and a_V , a_T and a_ϕ which give the number of mesons in our spectrum for K_V^* , K_T^* and ϕ resonances respectively. Here again there is a constraint among these parameters which requires that the integral of the right-hand side of rel. (16) gives the number of experimental events in the same interval.

We shall also denote m_V and m_T the masses of the K_V^* and K_T^* mesons respectively. They will be fixed or fitted as well as the natural widths γ_V and γ_T .

As a first attempt we have fixed the masses and widths of the K_V^* and K_T^* mesons at their world average values[24], requiring in addition $\lambda_V = \lambda_T = 1$. The first five bins (*i.e.* 100 MeV) are removed from the fit. The best fit is shown in figure (6) and corresponds to $\chi^2/dof = 145/112$. Looking at the inset, where the background and the ϕ contribution have been subtracted, it is clear that the high-mass tail of K_V^* extends too much above the background. The K_T^* signal is too small to allow any eye estimate. Leaving free m_V , Γ_V , λ_V and m_T , Γ_T , λ_T , the quality of the fit improves ($\chi^2/dof = 128/106$). The fitted values of interest are :

⁵⁴What has been said concerning the $f_2(1270)$ Breit-Wigner denominator in rel. (5) when m is between the $\pi\pi$ and $K\bar{K}$ threshold applies fully for the K_T^* Breit-Wigner between the πK and $K_V^*\pi$ thresholds ; we have accounted for this effect in precisely the same way.

⁵⁵Varying this λ from 1 to 14 does not produce any significant change in the results.

$$\left\{ \begin{array}{l} m_V = 892 \pm 3 \text{ MeV}, \quad \gamma_V = 39 \pm 11 \text{ MeV} \quad \lambda_V = 13.53^{+3.42}_{-3.00} \\ m_T = 1435 \pm 13 \text{ MeV}, \quad \gamma_T = 100 \pm 49 \text{ MeV} \quad \lambda_T = 5.56 \pm 3.31 \end{array} \right. . \quad (125)$$

The errors are large because of correlations between each γ and its corresponding λ . The resulting fit is given in figure (8) and the inset clearly shows that the resonance tails are now more realistically described. Moreover, the number of ϕ mesons obtained from this fit and that obtained using the K^+K^- mass assignment in the same sample are consistent within errors ; this indicates that the background is correctly estimated and that threshold effects do not affect the mass region of interest. The mass and width obtained from fit for the K_V^* meson are consistent with the world average values[24] (896.1 MeV and 50.5 MeV respectively). This is also true for the K_T^* meson mass and width obtained from the fit (ref. [24] gives 1432.4 MeV and 109 MeV respectively). This indicates that identifying the small structure located around 1.43 GeV with the $K^{*0}(1430)$ meson is reasonable. One should notice the large value found for λ_V (consistent with that of the $f_2(1270)$ meson) ; the value found for λ_T is inconclusive but still consistent with a large value.

Since the K^* mesons in our data have parameters consistent with their world average values, it is reasonable to fix m_V , m_T , γ_V and γ_T at their average values[24] ; in this case, we get $\chi^2/dof = 133/110$ and :

$$\left\{ \begin{array}{l} \lambda_V = 12.9^{+2.2}_{-2.7} \\ \lambda_T = 4.9^{+4.4}_{-1.8} \end{array} \right. . \quad (126)$$

In our data there are 839 ± 99 K_V^* events and 420 ± 71 K_T^* events.

33 Study of the $K^-\pi^+$ spectrum

Using the data taken at 300 GeV/c and requiring from Cerenkov information an identified K^- , we get a sample of 10 157 events. We have not required any identification of the positive particle for the reason already mentioned (see section 4 above). Here we have to deal with a contamination of K^- by $\bar{p}$; the situation is fortunately not symmetrical to the contamination by protons in the previous sample since the ratio $\bar{p}/p$ is more favourable[21] ($0.41 \div 0.46$) in the present case. Since this contamination is significant only near threshold we remove the first five bins (100 MeV) from the fit. The formulae and arguments given in the previous section are still valid in the present case.

The $K^-\pi^+$ mass spectrum is shown in figure (9), apart from the ϕ reflection, one sees a clear signal of the $\bar{K}_V^*$ meson and a broad structure which will be identified with the $\bar{K}_T^*$ meson⁵⁶. The mass distributions of these mesons are expected identical to that of their antiparticles (see section 4).

We have first performed a fit by setting the masses and widths of the $\bar{K}^*$ mesons at their world average values[24], assuming $\lambda_V = \lambda_T = 1$. The result of the fit is shown in figure (9)

⁵⁶We shall consider this identification correct if the parameters obtained by fit are consistent with that of the $\bar{K}^{*0}(1430)$ meson.

($\chi^2/dof = 143/112$). As before, the inset shows that the $\overline{K}_V^*$ high-mass tail extends too much and nothing firm can be asserted about the $\overline{K}_T^*$ meson.

We have then released m_V , Γ_V , λ_V and m_T , Γ_T , λ_T . In this case, the fit (shown in figure (10)) gives a better description of the data ($\chi^2/dof = 108/106$) with better resonance tails. The fitted parameters are

$$\begin{cases} m_V = 892 \pm 3 \text{ MeV}, & \gamma_V = 34^{+16}_{-13} \text{ MeV} & \lambda_V = 14.0 \pm 4.9 \\ m_T = 1401^{+14}_{-29} \text{ MeV}, & \gamma_T = 91^{+80}_{-43} \text{ MeV} & \lambda_T = 10.5^{+4.1}_{-5.4} \end{cases} \quad (127)$$

As a result of the large correlations between γ s and λ s parameters and of the relatively small statistics, there are large uncertainties on most of these parameters (especially for the widths). However these results allow us to check that the $\overline{K}_V^*$ and $\overline{K}_T^*$ mass and width values are in agreement with the corresponding world average values[24]. The values found for the λ s are both large and consistent with that found for K_V^* and K_T^* (see rels. (21)) as can be expected from charge conjugation symmetry.

Since the parameters of $\overline{K}_V^*$ and $\overline{K}_T^*$ are in good agreement with their accepted values, we have done a final fit by fixing m_V , γ_V and m_T , γ_T to their usual values[24]. We thus obtained a good fit ($\chi^2/dof = 129/110$) with the following values :

$$\begin{cases} \lambda_V = 12.7^{+3.6}_{-4.3} \\ \lambda_T = 12.1^{+2.3}_{-4.8} \end{cases} \quad (128)$$

The numbers of mesons are 543 ± 80 ($\overline{K}_V^*$) and 262 ± 63 ($\overline{K}_T^*$) ; we have also checked that the ϕ signal is in agreement with that obtained using the K^+K^- mass assignment, where the signal occurs in a single (20 MeV) bin.

Instead of performing algebraically the weighted mean of rel. (22) and (24) between charge conjugate partners, we have preferred performing a global fit of the sample obtained by merging the $K^+\pi^-$ and $K^-\pi^+$ mass spectra. Thus we get a good fit ($\chi^2/dof = 135/106$) and meson yields in agreement with the results given above⁵⁷. The 'mean values' of the damping powers are :

$$\begin{cases} \lambda_V = 13.4^{+2.4}_{-2.7} \\ \lambda_T = 9.1^{+4.5}_{-6.0} \end{cases} \quad (129)$$

These values are consistent with those obtained for $f_2(1270)$ at the 1. σ level.

We could expect λ_V to be of the order[5] of λ_ρ (*i.e.* $0.66 \div 1.75$) since they are both vector mesons. On the other hand, ref.[30] has tried a fit of the kind (15) and obtained a result consistent with a behaviour like m^{-2} or m^{-3} . The LASS collaboration[30] also quotes a result for the K_T^* meson which is at most of the order m^{-5} . Thus, the results of sections 4 and 5 point towards a distortion of the K_V^* mass spectrum by an additional damping power of $\simeq 10$; the K_T^* mass distribution is consistent with the same distortion than the K_V^* and with no

⁵⁷We obtain 1310 ± 205 for $K^{*0}(892) + \overline{K}^{*0}(892)$ while we expect 1382 ± 127 and 491 ± 150 for $K^{*0}(1430) + \overline{K}^{*0}(1430)$ while we expect 682 ± 95 .

distortion as well because of the large value of the errors. As for the $f_2(1270)$, this distortion preserves the fundamental parameters of these mesons (masses and widths). Indeed the same global fit provides :

$$\begin{cases} m_V = 892 \pm 2 \text{ MeV} & \gamma_V = 40^{+10}_{-9} \text{ MeV} \\ m_T = 1424 \pm 10 \text{ MeV} & \gamma_T = 73^{+37}_{-24} \text{ MeV} \end{cases} . \quad (130)$$

Consequences of systematic effects have been examined in both the $K^+\pi^-$ and $K^-\pi^+$ spectra. We have checked that changing the a_V and a_T to the distributions of non-resonant πK pairs does not affect our results. Assuming a production cross section which varies like m^{-3} (see rel. (13)) leads to the same conclusion. In this case, moreover, because the mesons K_V^* and K_T^* are much sharper than the $f_2(1270)$ meson, their masses are not affected by more than 3 MeV. Finally the feed-down of K_V^* mesons by K_V^* coming from K_T^* decay is negligible because mainly of our p_T cut (see rel. (2)). Therefore, our conclusions are stable and especially the sharp fall-off of the invariant mass distributions summarized by rels. (22), (24), (25).

34 General discussion of the results

Our results are summarized in table (1), apart from the value of the damping power λ , we also consider our estimate of the $f_2(1270)$ width as reliably measured and reasonably free from systematic errors. This result is in good agreement with the recent high statistics result⁵⁸ of the DM2 collaboration[31] (169.0 ± 7.5 MeV) and with that of the EHS collaboration[26] (180 ± 24). The damping powers obtained using the $f_2(1270)$ and $K^{*0}(892)$ mesons are remarkably similar ; the damping power associated with the $K^{*0}(1430)$ mesons is lower but consistent with those of the previous mesons at the 1σ level.

The first conclusion of sections 3 to 5 is that the meson mass distributions are all distorted in the same way. The second conclusion is that this distortion preserves the values of the mesons masses and widths⁵⁹. This result looks general since the same properties are observed for mesons having different spins ($J = 1, 2$) and different strangeness content (f_2 and K^*).

In principle, our results could be compared with that obtained by the SFM collaboration which has measured the rates of $f_2(1270)$ and $K^{*0}(892)$ mesons at large p_T at ISR energies[32]. Unfortunately, this comparison is not possible because they have accounted for the background by the event mixing technics which produces distortions of the resonance signals and the authors of ref. [32] have corrected the subtracted spectra for these distortions. These corrections may have washed out the effect we observe in our experiment.

Another possibility would be that the observed distortions are produced by interference effects. We consider this assumption as unlikely since we are dealing with large multiplicity events ($\simeq 10$) and varying species of final state particles. In this case, we expect interference contributions to cancel out. As an illustration, ref.[23] has examined the inclusive $\pi^+\pi^-$ production in J/ψ decays and reached the conclusion that their data were consistent with no ρ^0 - ω interference. Our mass histogram for pairs with $\pi^+\pi^-$ mass assignment (see fig. (1) for

⁵⁸Ref. [31] uses a Breit-Wigner curve but does not provide further information about its precise shape ; this should mean that they use the standard shape[1].

⁵⁹Technically, the resonance mass which appears stable is defined as the zero (m_R) of the real part of the inverse propagator $D^{-1}(m) = (m_R^2 - m^2) - im_R\Gamma(m)$, while the width is defined by $\gamma_R = \Gamma(m_R)$. This property has been already noted in section 3.3.

instance) is also consistent with no ρ^0 - ω interference. Moreover, it is hard to imagine that interference effects would give the same distortion for all cases and that they would leave nearly unchanged the masses and widths of broad objects.

Resonance	mass our result	mass P.D.G.	width our result	width P.D.G.	λ	χ^2/dof
$f_2(1270) (300)$	1227^{+10}_{-14}	1275 ± 5	236^{+75}_{-46}	185 ± 20	$12.1^{+2.1}_{-1.9}$	141/136
$f_2(1270) (150)$	1254^{+7}_{-9}		165^{+45}_{-29}		$13.4^{+3.2}_{-2.5}$	144/136
$K^{*0}(892)$	892 ± 3	896.1 ± 0.3	39 ± 11	50.5 ± 0.6	$13.5^{+3.4}_{-3.0}$	128/106
$\overline{K}^{*0}(892)$	892 ± 3		34^{+16}_{-13}		14.0 ± 4.9	108/106
$K^{*0} + \overline{K}^{*0}$	892 ± 2		40^{+10}_{-9}		$13.4^{+2.4}_{-2.7}$	135/106
$K^{*0}(1430)$	1435 ± 13	1432.4 ± 1.3	100 ± 49	109 ± 5	5.6 ± 3.3	128/106
$\overline{K}^{*0}(1430)$	1401^{+14}_{-29}		91^{+80}_{-43}		$10.5^{+4.1}_{-5.4}$	108/106
$K^{*0} + \overline{K}^{*0}$	1424 ± 10		73^{+37}_{-24}		$9.1^{+4.5}_{-6.0}$	135/106

Table 1 : Summary of the results concerning all the fitted mesons.

We are thus left with the conclusion that the observed distortions are due to the production mechanism at work in our experiment : the hadronization process of colored quarks and gluons. This process enhances the probability to produce a given meson at low mass and suppresses its production at large mass. More surprising is that these distortions leave unchanged the resonance physical parameters. These properties are in qualitative agreement with what has been seen recently from a Lund Monte Carlo sample by A. Lindner[8] when examining the shape of the ρ^0 mass spectrum. Since resonance mass spectra in the Lund Monte Carlo are simply fixed width Breit–Wigner expressions the agreement cannot be otherwise than qualitative.

These properties illustrate the specificity of color string fragmentation as a production mechanism of resonances, at least as leading fragments. Of course, resonances produced in resonance decays are affected differently, and sometimes not affected at all⁶⁰.

On the other hand, resonances decaying to more than two particles are surely affected, but our experiment does not allow any precise study of this effect. For instance, there is some indication that $a_2(1320)$ is observed in its three pion decay mode, but the combinatorial three particle background is so large that no study can be performed.

Our main result can be sketched in the following way : when produced at large p_T , any given resonance R of spin l having two-particle decay modes can be described by a Breit–Wigner distribution, the shape of which remains formally the usual one[1], with the usual mass and width (m_R and γ_R) ; however, its decay amplitude to a given decay mode X written[5] :

⁶⁰For instance, the ρ^0 produced in the η' decay is surely affected by phase space effects due essentially to the η' mass but not to the η' production mechanism since this meson is too sharp to feel any damping factor.

$$\Gamma_X(m) = \gamma_R \left[\frac{q_X(m)}{q_X(m_R)} \right]^{(2l+1)} \left[\frac{m_R}{m} \right]^\lambda ,$$

always gives a good description of the data and $\lambda \simeq 12.5$ looks like a universal parameter. This power is large enough to suggest an actual exponential damping. The present theoretical knowledge does not provide however any motivated guideline to a suitable parametrization of meson shape distortions in high- p_T processes.

35 Conclusions

We have analyzed the invariant mass distributions of five mesons ($f_2(1270)$, $K^{*0}(892)$, $\overline{K}^{*0}(892)$, $K^{*0}(1430)$, $\overline{K}^{*0}(1430)$) produced at $p_T \geq 2.0$ GeV/c, under conditions where they are likely to be leading fragments of high- p_T jets. We have found that these mass distributions are sharply distorted ; these distributions are affected by a large damping power ($\simeq m^{-12}$), far above the usual one. At the level of accuracy allowed by our data, we have also shown that this distortion does not affect the mass and width of any of the resonances examined sofar. We have also shown that the distortions look alike for the mesons studied, without any respect to their spin or quark content. It has to be expected that this phenomenon affects all resonances primarily produced in the parton fragmentation mechanism, for instance the ρ meson. Our conclusions apply to two-body decay channels of resonances. The meson shape distortions observed in our data give experimental support to the existence of phase space effects in the process of quark fragmentation into hadrons.

References

- [1] J.D. Jackson, Nuovo Cimento XXXIV (1964) 1644.
- [2] J. Pisut and M. Roos, Nucl. Phys. **B6** (1968) 325.
- [3] J. Ballam *et al.*, Phys. Rev. **5** (1972) 545.
- [4] T.A. Armstrong *et al.* Zeit. für Phys. **C51** (1991) 351.
- [5] M. Benayoun *et al.* Zeit. für Phys. **C 58** (1993) 31.
- [6] B. Andersson *et al.* Phys. Rep. **97** (1983) 31 ;
H. Bengtsson and G. Ingelman Comput. Phys. Comm. **34** (1985) 251 ;
“The Lund Monte Carlo Programs”, CERN long writeups W5035, W5045, W5046, W5047, W5048, nov. 1989.
- [7] O. Podobrin, Ph. D. Thesis, DESY report FCE-92-03, Hamburg 1992.
- [8] A. Lindner, Ph. D. Thesis, Dortmund 1992.
- [9] H. Albrecht *et al.*, DESY preprint 93-084, Hamburg 1993.
- [10] H. Albrecht *et al.* Zeit. für Phys. **C58** (1993) 199.
- [11] ALEPH collaboration, preprint CERN-PPE/92-74, Geneva 1992.
- [12] OPAL collaboration, preprint CERN-PPE/92-116, Geneva 1992.
- [13] P. Abreu *et al.*, DELPHI collaboration, Phys. Lett. **B298** (1993) 236.
- [14] P.D. Acton *et al.*, OPAL collaboration, Zeit. für Phys. **C56** (1992) 521.
- [15] M. Benayoun *et al.* Phys. Lett. **B183** (1987) 412.
- [16] M. Benayoun *et al.* Nucl. Phys. **B282** (1987) 653.
- [17] M. Benayoun *et al.* Phys. Lett. **B192** (1987) 447.
- [18] M. Benayoun *et al.* Phys. Lett. **B198** (1987) 281.
- [19] W. Beusch *et al.* Nucl. Instrum. Methods **A249** (1986) 391.
- [20] M.T. Trainor, “Direct meson production at $p_T \geq 2$. GeV/c in 300 GeV/c $\pi^- Be$ interactions”, PhD thesis, University of Birmingham, March 1988 ;
R. Fini, “Produzione inclusiva di risonanze a medio-alto momento trasverso”, Tesi di Dottorato, Università degli studi di Bari, january 1990, National library of Rome and Florence.
- [21] A. Bellogianni *et al.*, Zeit. für Phys. **C54** (1992) 535.
- [22] A. Bellogianni *et al.*, Zeit. für Phys. **C59** (1993) 35.
- [23] G. Gidal *et al.*, Phys. Lett. **B107** (1981) 153.
- [24] Review of Particle Properties, Phys. Rev **D45** (1992).
- [25] P. Granet *et al.* Nucl. Phys. **B140** (1978) 389.
- [26] M. Aguilar-Benitez *et al.* Zeit für Phys. **C50** (1991) 405.
- [27] S. Abachi *et al.*, Phys. Rev. Lett. **57** (1986) 1990.
- [28] H.-J. Behrend *et al.* Zeit für Phys. **C56** (1992) 381 ;
J. Harjes, Thesis, preprint DESY-FCE-91-01, Hamburg 1991.
- [29] V. Chabaud *et al.* Nucl. Phys. **B223** (1983) 1.
- [30] D. Aston *et al.* Nucl. Phys. **B296** (1988) 493.
- [31] J.E. Augustin *et al.* Nucl. Phys. **B320** (1989) 1.
- [32] A. Breakstone *et al.* Zeit für Phys. **C43** (1989) 185.

Figure Captions

- Figure 1 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 300 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming the world average values for the $f_2(1270)$ parameters, $\lambda_K = 1$, $\lambda_\pi = 1$. In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the large high-mass tail of the $f_2(1270)$.
- Figure 2 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 300 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming $\lambda_K = 1$, but leaving free the mass, width of the $f_2(1270)$ meson and λ_π . In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice how the high-mass tail of the $f_2(1270)$ is reduced.
- Figure 3 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 150 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming the world average values for the $f_2(1270)$ parameters, $\lambda_K = 1$, $\lambda_\pi = 1$. In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the large high-mass tail of the $f_2(1270)$.
- Figure 4 : Invariant mass plot with $\pi^+\pi^-$ mass assignment of the data taken at 150 GeV/c. The curve is the fit done with rels. (3) , (5) and (6), assuming $\lambda_K = 1$, but leaving free the mass, width of the $f_2(1270)$ meson and λ_π . In the inset, we have subtracted the background and all resonances apart from $f_2(1270)$; notice the reduction in the high-mass tail of the $f_2(1270)$.

- Figure 5 : Effect of the damping power λ_π on the shape of a Breit–Wigner contribution to the cross section. In full line we have represented the case $\lambda_\pi = 1$, in dashed dotted line the case $\lambda_\pi = 12.5$.
- Figure 6 : Invariant mass plot of trigger pairs with an identified K^+ ; the data are extracted from our 300 GeV/c sample. The fit represented has been obtained assuming the world average values for the masses and widths of both K^* mesons and both damping powers $\lambda = 1$.
- Figure 7 : Acceptance function of $K\pi$ trigger pairs as a function of their (true) invariant mass.
- Figure 8 : Invariant mass plot of trigger pairs with an identified K^+ ; the data are extracted from our 300 GeV/c sample. The fit shown has been obtained leaving free the masses and widths of both K^* mesons and both damping powers λ .
- Figure 9 : Invariant mass plot of trigger pairs with an identified K^- ; the data are extracted from our 300 GeV/c sample. The fit represented has been obtained assuming the world average values for the masses and widths of both K^* mesons and both damping powers $\lambda = 1$.
- Figure 10 : Invariant mass plot of trigger pairs with an identified K^- ; the data are extracted from our 300 GeV/c sample. The fit represented is obtained, leaving free the masses and widths of both K^* mesons and both damping powers λ .