RESONANCE PRODUCTION IN e^+e^- COLLISIONS *

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Abstract

Two processes which give rise to light meson resonances in e^+e^- collisions are $\gamma\gamma$ reactions and inclusive production in jets from e^+e^- annihilation. New results are presented from $\gamma\gamma$ collisions at ARGUS and from hadronic Z^0 decays in DELPHI and OPAL.

INTRODUCTION

Studies of meson resonance production in e^+e^- reactions have been pursued for many years in two main areas. In $\gamma\gamma$ reactions, $e^+e^- \rightarrow e^+e^-X$, the system X, when produced via two almost real photons, has a restricted set of possible quantum numbers. This enables rather complete analyses of the properties of the final states, and the reactions allow tests of Vector Meson Dominance. However the numbers of events available have been somewhat low and there are many channels still to be studied in detail. The second area, inclusive resonance production in e^+e^- annihilation, enables the testing of QCD-inspired models of parton fragmentation since the resonances arise in hadronization of $q\overline{q}$, $q\overline{q}g$ etc. states from intermediate virtual photons or real Z^0's. Many physics measurements at LEP are now limited by systematic errors arising from incomplete knowledge of the structure of multihadronic events, so that measurements of inclusive particle and resonance rates are vital to improve the physics simulations and reduce these systematic errors.

RESONANCES IN $\gamma\gamma$ REACTIONS

The reaction $\gamma\gamma \rightarrow$ two vector mesons

Although an unexpectedly large cross section has been measured for the reaction $\gamma\gamma \rightarrow \rho^0\rho^0$, probably due to interference of isospin 0 and isospin 2 states, rates for other vector meson pairs are much lower. ARGUS[1] have now made a partial wave analysis of their $\gamma\gamma \rightarrow 5\pi$ data including the $\rho^0\omega$ channel, and have in addition made the first observations of $\rho^0\phi$ and $\omega\phi$ production.

In $\gamma\gamma \rightarrow \rho^0\omega$, which accounts for 7.8% of the total 5π cross section, the main contribution is found to come from the $(J^P,J_Z)=(2^+,2)$ partial wave. In $\gamma\gamma \rightarrow \pi^+\pi^-K^+K^-$ there is a clear correlation between the ρ^0 signal in $\pi^+\pi^-$ and the ϕ in K^+K^- as is shown in figure 1. The measured cross section for $\rho^0\phi$ is compatible with the previous upper limit, and rises sharply at threshold, falling slowly with

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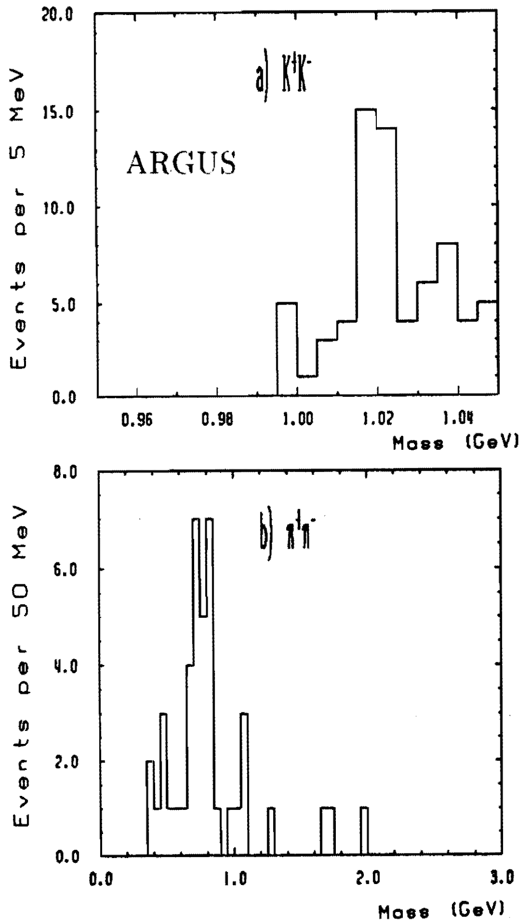

Figure 1. (a) Mass of K^+K^-; and (b) mass of $\pi^+\pi^-$ for K^+K^- mass within 10 MeV of the ϕ mass (ARGUS).

mass. Evidence for $\gamma\gamma \to \omega\phi$ is seen in the $\pi^+\pi^-\pi^0K^+K^-$ state, with a cross section of 0.72 ± 0.38 nb for the mass range 1.9–2.3 GeV. Above 2.3 GeV a new upper limit of 0.3 nb has been set.

The reaction $\gamma\gamma \to \pi^+\pi^-\pi^0$

The channel $\gamma\gamma \to \pi^+\pi^-\pi^0$ is known to be dominated by a_2 production in the helicity 2 state; additionally there has been evidence for $\pi_2(1670)$. The intensity of the helicity zero contribution to a_2 is of interest since relativistic corrections could allow as much as 6%. The ARGUS data[2] have been analysed using a maximum likelihood partial wave analysis employing a full set of possible contributions. The mass region 0.8–1.5 GeV is dominated by the $(J^P,J_Z)=(2^+,\pm2)$ $\rho^\pm\pi^\mp$ wave due to a_2, with a $J_Z = 0$ contribution of only about 1%. The partial width was measured to be $\Gamma_{\gamma\gamma}(a_2) = 0.90 \pm 0.15$ keV. For the $\pi(1300)$, the PWA gave an upper limit $\Gamma_{\gamma\gamma}(\pi(1300))\mathrm{Br}(\pi(1300) \to \rho^\pm\pi^\mp) < 0.01$ keV. The data also show a peak at higher mass, identified with the π_2, and evidence for an additional peak at 1.8 GeV which cannot be identified with a known resonance. A similar peak was already seen by ARGUS in $K^+K^-\pi^0$.

RESONANCES IN HADRONIC Z^0 DECAY

Vector Mesons: $\rho(770)$, $K^*(892)$ and $\phi(1020)$

Both DELPHI[3] and OPAL[4] have data on the inclusive production of the $\rho(770)^0$, $K^*(892)^0$ and $\phi(1020)$ vector mesons in Z^0 decay. All three states are identified in the corresponding two-particle mass spectra: $\pi^+\pi^-$, $K^\pm\pi^\mp$ and K^+K^- respectively. OPAL makes use of dE/dx measurements of the charged tracks in order to separate pions from kaons with good efficiency over a large momentum range. Like-charge particle combinations are used as a measure of the backgrounds in the unlike-charge mass spectra which contain the resonances. The result is that the resonances are cleanly identified in the appropriate mass spectra on rather low effective backgrounds. As an illustration, figure 2 shows the OPAL data for $K^\pm\pi^\mp$ (points with error bars) compared to an absolute prediction of the Jetset72 Monte Carlo with its default parameter set. It is clear that the Monte Carlo model overestimates the K^* rate. OPAL then use fits, in bins of the scaled momentum variable x_p, to appropriate contributions as deduced from Monte Carlo simulations in order to measure for the resonances the fragmentation functions, $1/\sigma.\mathrm{d}\sigma/\mathrm{d}x_p$, and the overall

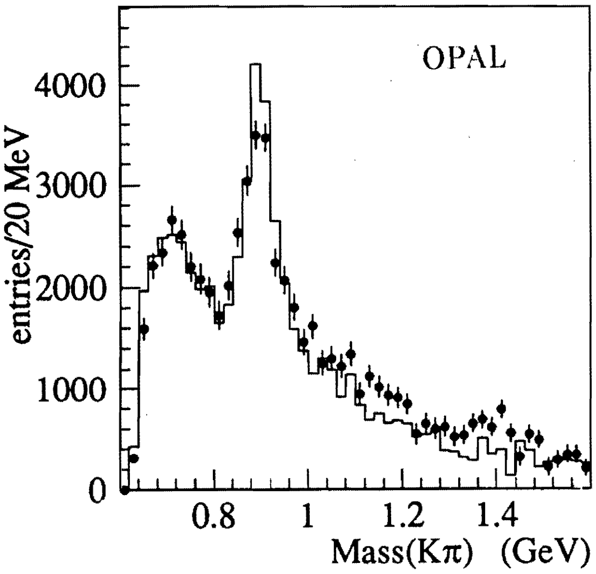

Figure 2. Mass of inclusive $K^{\pm}\pi^{\mp}$ combinations (OPAL).

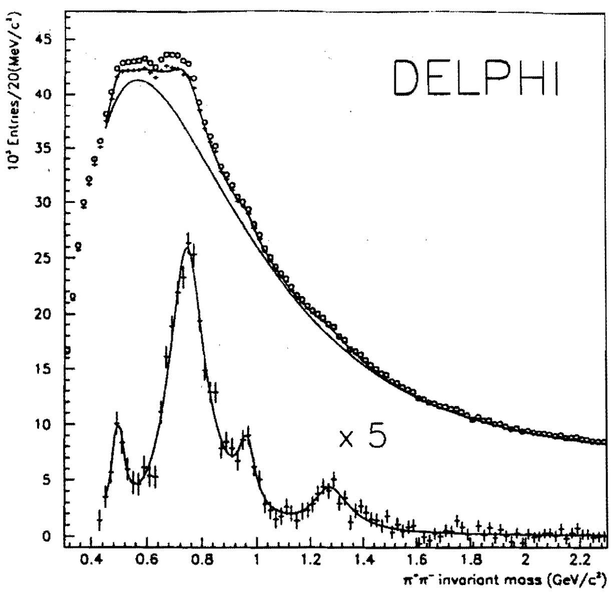

Figure 3. Mass of inclusive $\pi^{\pm}\pi^{\mp}$ combinations (DELPHI) for $x_p > 0.1$. Open dots show raw data while crosses are data corrected for reflections.

mean multiplicities per Z^0 decay.

DELPHI make no use of particle identification but instead form the mass spectra using assumed particle types. The spectra are then fitted, again for ranges of x_p, using analytical functions to represent resonance line shapes and background contributions. Problems due to reflections, arising from lack of particle identification, are treated using a weighting technique and iterating the fits. Because of this lack of particle identification, the resulting measurement errors are considerably larger than those obtained by OPAL.

Both groups report problems with the $\rho(770)^0$. The fitted mass quoted by DELPHI, 757±2 MeV, is well below the particle data group value and is inconsistent with it. Nevertheless DELPHI extract rates for the ρ^0 from their fits. OPAL however point out that the lineshape of the ρ^0 appears to be significantly distorted, especially at low momentum, and that a lack of proper understanding at present prohibits reliable measurement of the intensity. They find that a better representation of the observed line shape is obtained in the Jetset simulations if use is made of the option to generate Bose-Einstein effects. OPAL state that good measurements of the inclusive ρ^0 will have to await better understanding of these effects.

Table 1 gives a summary of the measured vector meson multiplicities per hadronic Z^0 decay (note that the two ϕ measurements are over different x_p ranges). For completeness the table also contains a measurement of $K^*(892)^{\pm}$ previously published by DELPHI[5], and a recent result from OPAL[6] which is significantly lower than the DELPHI result but in good agreement with the OPAL K^{*0} measurement. The $K^{*\pm}$ results are based on analyses of inclusive $K^0_S\pi^{\pm}$ spectra and are independent of the neutral vector meson analyses.

Scalar and tensor mesons: $f_0(975)$, $f_2(1270)$ *and* $K^*_2(1430)$

In their fits to the $\pi^+\pi^-$ spectra, DELPHI allow, in addition to contributions from backgrounds and ρ^0, terms due to the $f_0(975)$ and $f_2(1270)$ mesons, both of which have large

Table 1. Mean multiplicities of resonances per multihadronic Z^0 decay

Resonance	Multiplicity	Experiment	x_p Range	Jetset	Herwig
$\rho(770)^0$	$1.43 \pm 0.12 \pm 0.22$	DELPHI	$x_p > 0$	1.55	1.40
$K^*(892)^0$	$0.76 \pm 0.07 \pm 0.06$	OPAL	$x_p > 0$	1.06	0.77
	$0.97 \pm 0.18 \pm 0.31$	DELPHI	$x_p > 0$	1.04	0.84
$K^*(892)^\pm$	$0.72 \pm 0.02 \pm 0.08$	OPAL	$x_p > 0$	1.10	0.82
	$1.33 \pm 0.11 \pm 0.24$	DELPHI	$x_p > 0$		
$\phi(1020)$	$0.086 \pm 0.015 \pm 0.010$	OPAL	$x_p > 0$	0.189	0.113
	$0.077 \pm 0.019 \pm 0.033$	DELPHI	$x_p > 0.2$	0.060	0.078
$f_0(975)$	$0.10 \pm 0.03 \pm 0.019$	DELPHI	$x_p > 0.05$		
$f_2(1270)$	$0.11 \pm 0.04 \pm 0.03$	DELPHI	$x_p > 0.1$		0.24

branching ratios to $\pi\pi$. Figure 3 shows the inclusive $\pi^+\pi^-$ mass spectrum with the fitted curves; the lower data are after subtraction of the fitted background and clearly show the resonance contributions from ρ^0, f_0 and f_2 (as well as a peak due to K^0_S). As with the ρ^0, the fitted f_0 mass, at 961±4 MeV, is somewhat below the PDG value. The measured multiplicities are given in table 1.

Both groups report evidence for $K^*_2(1430)$ production in the inclusive $K^\pm\pi^\mp$ spectra (see for example figure 2), but neither has sufficient statistical accuracy in the data analysed so far to present a useful measurement.

Discussion

As mentioned previously, measurements of inclusive resonance yields serve two main functions: as tests of models based on QCD, such as Jetset and Herwig, and as a means of improving the physics simulations of multihadronic Z^0 decays. Both DELPHI and OPAL have compared their vector meson measurements with the predictions of Jetset (with parton showers) and Herwig using parameter sets found to describe well the particle yields at PEP and Petra energies and with modifications to some parameters needed to reproduce global event properties at LEP. Table 1 lists the predictions of the models; the two groups use different program versions but the resonance yields are not strongly affected. The ρ^0 yield is in agreement with both models within the rather large errors, and with the caveat that there still appear to be some poorly understood systematic effects in the resonance line shape in the data. The K^* measurements are in good agreement with Herwig, while the Jetset predictions are considerably higher. Similarly the ϕ rate is in better agreement with Herwig than with Jetset. Thus it appears that, for these mesons at least, the variation of yield with energy is better simulated by Herwig.

The fragmentation functions, $1/\sigma.d\sigma/dx_p$, have also been compared with the behaviours predicted by the models. In general there is good agreement in the shapes although the OPAL data for the K^{*0} and ϕ, figure 4, indicate that the momentum spectra may be too hard in the Monte Carlo simulations. Figure 5 shows the fragmentation functions from DELPHI for ρ^0, f_0 and f_2. The f_0 is simulated by neither program, and the f_2 by default only in Herwig. It can be seen that although the rate for f_2 is high in the simulation, the shape is similar to that for the f_0 and is reproduced

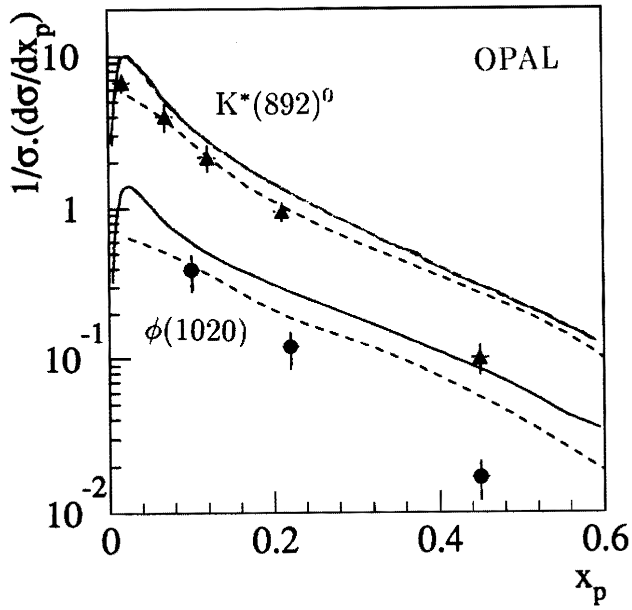

Figure 4. Fragmentation function for K* (triangles) and ϕ (circles) (OPAL). The curves show predictions of Jetset (solid) and Herwig (dashed).

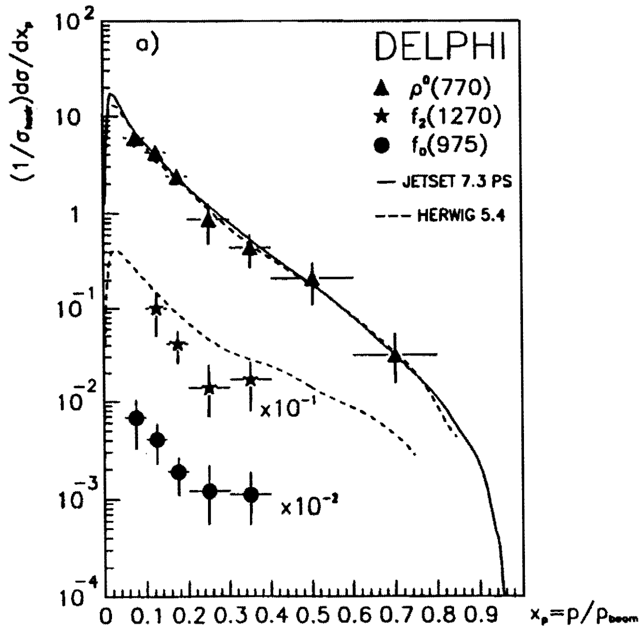

Figure 5. Fragmentation function for ρ^0, f_0 and f_2 (DELPHI). The curves show predictions of Jetset (solid) and Herwig (dashed).

by Herwig. The DELPHI result indicates that f_2 production is an important feature of inclusive mass spectra in Z^0 decay and should be included in Jetset simulations of LEP physics. For work of high precision, the f_0 may also be important.

Studies of meson resonances in Z^0 decays are only just beginning, and significantly more knowledge of rates for identified stable particles and resonances will be needed before a consistent picture emerges. Then it may be possible to gain a much better understanding of the details of quark and gluon hadronization.

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