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Measurement of Inclusive $f_1(1285)$ and $f_1(1420)$ Production in Z Decays with the DELPHI Detector

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ABSTRACT: Inclusive production of two $(K\bar{K}\pi)^0$ states in the mass region 1.22–1.56 GeV in Z decay at LEP I has been observed by the DELPHI Collaboration. The measured masses and widths are 1274 ± 4 and 29 ± 12 MeV for the first peak and 1426 ± 4 and 51 ± 14 MeV for the second. A partial-wave analysis has been performed on the $(K\bar{K}\pi)^0$ spectrum in the mass range; the first peak is consistent with the quantum numbers $I^G(J^{PC}) = 0^+(0^{-+}/1^{++})$ and the second with $I^G(J^{PC}) = 0^+(1^{++})$. These measurements, as well as their total hadronic production rates per hadronic Z decay, are consistent with the mesons of the type $n\bar{n}$, where $n = \{u, d\}$. They are very likely to be the $f_1(1285)$ and the $f_1(1420)$, respectively.

1. Introduction

The inclusive production of mesons has been a subject of long-standing study at LEP[1][2], as it provides an insight into the nature of fragmentation of quarks and gluons to hadrons. So far the studies have been done on the S-wave mesons (both $^1S_0$ and $^3S_1$) such as π and ρ, as well as certain P-wave mesons $f_2(1270)$ and $K_2^*(1430)$ (i.e. $^3P_2$) and $f_0(980)$ and $a_0(980)$ ($^3P_0$). Very little is known about the production of mesons belonging to other P-wave (i.e. $^3P_1$ and $^1P_1$). For the first time, we present in this work a study of the inclusive production of $J^{PC} = 1^{++}$ mesons $f_1(1285)$ and $f_1(1420)$ (i.e. $^3P_1$).

2. Experimental Procedure

The analysis presented here is based on a data sample of about 3.3 million hadronic Z decays collected from 1992 to 1995 with the DELPHI detector. Detailed description of the DELPHI detector and its performance can be found elsewhere[4][5].

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Hadronic events are selected by requiring at least 5 charged particles, with at least 3-GeV energy in each hemisphere of the event—defined with respect to the beam direction—and total energy at least 12% of the center-of-mass energy. The contamination from events due to beam-gas scattering and to γ-γ interactions is estimated to be less than 0.1% and the background from $\tau^+\tau^-$ events less than 0.2% of the accepted events.

$K^\pm$ identification has been provided by the RICH detectors for particles with momenta above 700 MeV/c, while the ionization loss measured in the TPC has been used for momenta above 100 MeV/*c*. A more detailed description of the identification tags can be found in Ref. [1]. The K_S candidates are detected by their decay in flight into $\pi^+\pi^-$. The details of the method and the various cuts applied are described in Ref. [6].

After all the above cuts, only events with at least one $K_S K^+\pi^-$ or $K_S K^-\pi^+$ combination have been kept in the present analysis, corresponding to a sample of 705 688 events.

3. $K_S K^\pm\pi^\mp$ Mass Spectra

Because of big combinatorial background there is no visible enhancement in the mass region between 1.25 to 1.45 GeV both in total $K_S K^\pm\pi^\mp$ mass spectrum and in that with the K^* cut $0.822 < M(K\pi) < 0.962$ GeV. The key to a successful study of the $f_1(1285)$ and $f_1(1420)$ is to make a mass cut $M(K_S K^\pm) \leq 1.04$ GeV, as shown in Fig. 1, where two clear peaks are seen. There are two reasons for this: (1) the decay mode $a_0(980)^\pm\pi^\mp$ is selected by the mass cut, while the general background for the $K\bar{K}\pi$ system is reduced by a factor of $\simeq 7$ at 1.42 GeV or more at higher masses; (2) the interference effect of the two $K^*(892)$ bands on the Dalitz plot at $M(K\bar{K}\pi) \sim 1.4$ GeV is enhanced, if the G-parity is positive[9]. The results of the fit with smooth background and two S-wave Breit-Wigner forms are shown in Fig. 1. The fitted parameters for mass and width are (1274 ± 4) MeV and (29 ± 12) MeV for the first peak and (1426 ± 4) MeV and (51 ± 14) MeV for the second one.

The main sources of systematic errors come from the various cuts and selection criteria applied for the V^0 reconstruction plus the charged K identification—on the one hand—and the conditions of the mass-fit procedure—on the other. The first type of error is estimated to be 7% of a given cross section., in the low $K_S K^\pm$ mass region. To estimate the second type of error, we have performed a series of fits, varying the mass range of the fit, thereby allowing the background level to fluctuate. In this way we estimate the fit uncertainty to be 15% for the $f_1(1285)$ and 14% for the $f_1(1420)$. The systematic errors have been added quadratically. It should be emphasized that the quoted masses and the widths are not intended to be new experimental measurements; rather, they are merely given as an indication that our peaks are consistent with the known parameters.

4. Partial-wave Analysis

We have chosen to employ the so-called Dalitz plot analysis, integrating over the three Euler angles. This entails an essential simplification in the number of parameters required in the

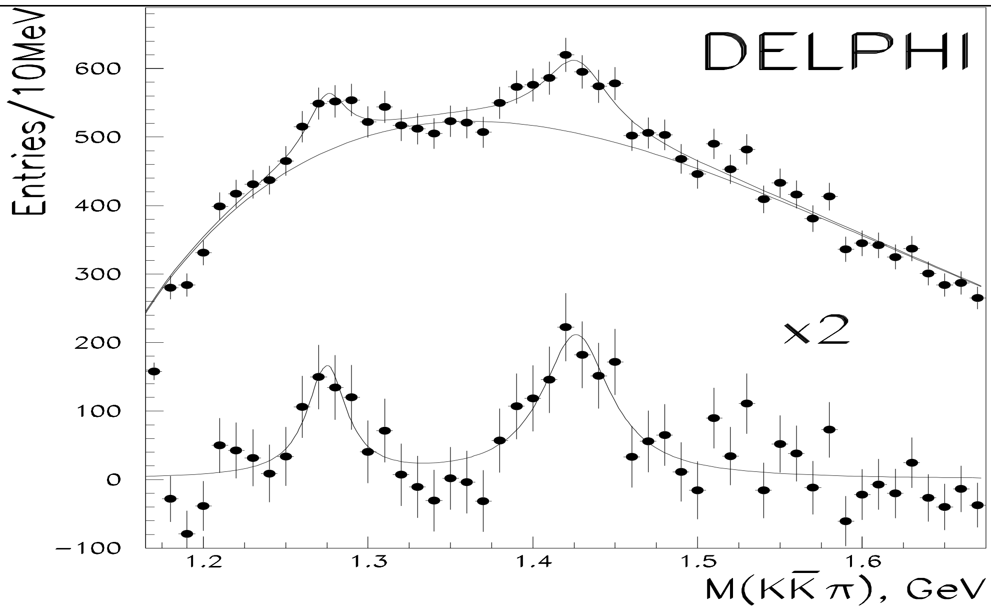

Figure 1: $M(K_s\,K^{\pm}\,\pi^{\mp})$ distribution with a mass cut $M(K_s\,K^{\pm}) < 1.04$ GeV. The two solid curves in the upper part of the histogram describe Breit-Wigner fits over a smooth background (see text). The lower histogram and the solid curve give the same fits with the background subtracted and amplified by a factor of two.

analysis, as the decay amplitudes involving the D-functions defined over the three Euler angles and their appropriate decay-coupling constants, are orthogonal for different spins and parities[7]. The actual fitting of the data is done by using the maximum-likelihood method, in which the normalization integrals are evaluated with the accepted Monte Carlo events[8], thus taking into account the finite acceptance of the detector and the event selection.

We assume that the background does not interfere with signals and that it is a non-interfering superposition of a flat distribution (on the Dalitz plot) and the partial waves $I^G(J^{PC}) = 0^+(1^{++})\,a_0(980)\pi$, $0^+(1^{++})\,(K^*(892)\bar{K} + c.c.)$ and $0^-(1^{+-})\,(K^*(892)\bar{K} + c.c.)$.

The signal regions, for $M(K\bar{K}\pi)$ in $1.26 \to 1.30$ and $1.38 \to 1.48$ GeV, have been fitted with a non-interfering superposition of the partial waves $I^G(J^{PC}) = 0^+(1^{++})$, $0^+(1^{+-})$ and $0^-(0^{-+})$, where the decay channels $a_0(980)\pi$ and $K^*(892)\bar{K} + c.c.$ are allowed to interfere within a given J^{PC}. All other possible partial waves have been found to be negligible in the signal regions. Because of a lack of phase space, the two isobars $a_0(980)$ and $K^*(892)$ cannot be distinguished for $M(K\bar{K}\pi)$ below 1.30 GeV, so we have kept the $a_0(980)\pi$ decay mode only. The fit results can be summarized as follows: (1) the maximum likelihood is found to be the same for $I^G(J^{PC}) = 0^+(1^{++})\,a_0(980)\pi$ and for $0^-(0^{-+})\,a_0(980)\pi$, i.e. the 1.28- GeV region is equally likely to be the $f_1(1285)$ or the $\eta(1295)$; (2) in the 1.4-GeV region, the maximum likelihood is marginally better (by about 3 for $\Delta \ln \mathcal{L}$) for $I^G(J^{PC}) = 0^+(1^{++})$ $f_1(1420)$ than $I^G(J^{PC}) = 0^+(0^{-+})$ $\eta(1440)$; the $I^G(J^{PC}) = 0^+(1^{+-})$ $h_1(1380)$ is excluded in this analysis (by about 13 for $\Delta \ln \mathcal{L}$). These results are also shown in Fig. 2.

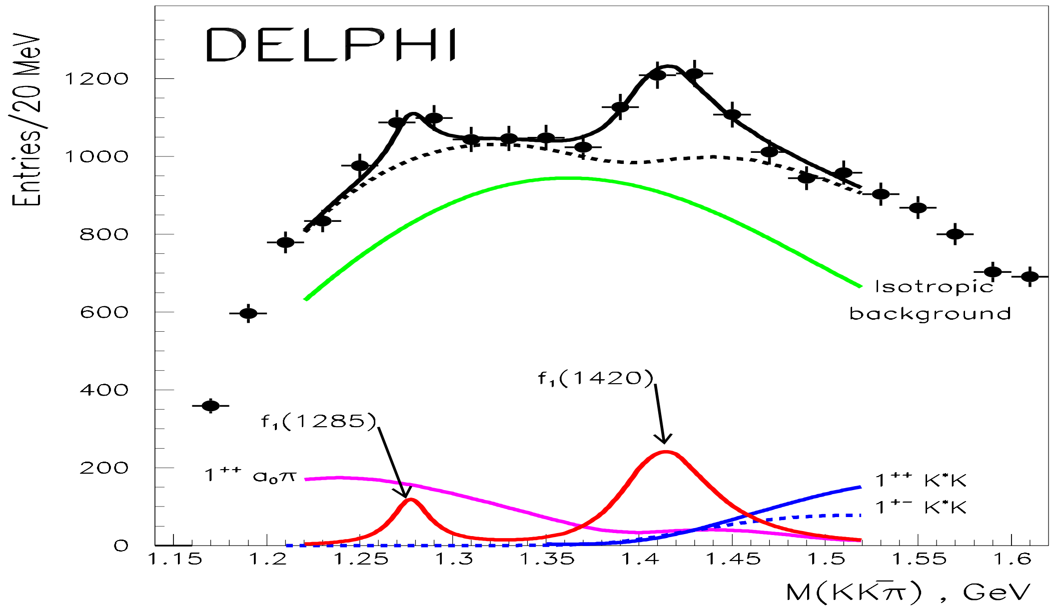

Figure 2: $M(K_S K^{\pm} \pi^{\mp})$ distributions per 20 MeV with a breakdown into the partial-waves for the signals and the background. The signals consist of 1^{++} $a_0(980)\pi$ for the first peak and 1^{++} $K^*(892)\bar{K}$ for the second peak. The background consists of non-interfering superposition of isotropic distribution (1), 1^{++} $a_0(980)\pi$ (2), 1^{++} $K^*(892)\bar{K}$ (3) and 1^{+-} $K^*(892)\bar{K}$ (4).

5. Discussion and Conclusions

We have measured the production rate $\langle n \rangle$ per hadronic Z decay for $f_1(1285)/\eta(1295)$ and $f_1(1420)$. We assume for this study that *both have spin 1.* The results are

$$\begin{aligned} \langle n \rangle &= 0.132 \pm 0.034 \quad \text{for} \quad f_1(1285) \\ \langle n \rangle &= 0.0512 \pm 0.0078 \quad \text{for} \quad f_1(1420) \end{aligned} \tag{5.1}$$

taking a $K\bar{K}\pi$ branching ratio of $(9.0\pm0.4)\%$ for the $f_1(1285)$ and 100% for the $f_1(1420)$[3]. The production rate per spin state [i.e. divided by $(2J+1)$] has been studied in Ref. [2]; in Fig. 3 is given all the available data for those mesons with a 'triplet' $q\bar{q}$ structure, i.e. $S = 1$ in the spectroscopic notation $^{2S+1}L_J$. To this figure we have added our two mesons for comparison. It is seen that both $f_1(1285)$ and $f_1(1420)$ come very close to the line corresponding to other mesons whose constituents are thought to be of the type $n\bar{n}$. This is suggestive of two salient facts: (1)the first peak at 1.28 GeV is very likely to be the $f_1(1285)$; (2) both $f_1(1285)$ and $f_1(1420)$ have little $s\bar{s}$ content. Indeed, the two states which are thought to be pure $s\bar{s}$ mesons, the ϕ and the $f_2'(1525)$, are down by a factor $\gamma^k \approx 1/4$ ($\gamma = 0.50 \pm 0.02$ and $k = 2$), as shown in Fig. 3. This is highly unlikely given the production rate (5.1).

We have studied the inclusive production of $f_1(1285)/\eta(1295)$ and $f_1(1420)$ in Z decays at LEP I. The measured masses and widths are 1274 ± 4 and 29 ± 12 MeV for the first peak and 1426 ± 4 and 51 ± 14 MeV for the second one. For the first time, a partial-wave analysis has been carried out on the $(K\bar{K}\pi)^0$ system. The results show that the first peak is equally likely to be the $f_1(1285)$ or the $\eta(1295)$, while the second peak is consistent with the $f_1(1420)$. However, the hadronic production rate of these two states suggests that their quantum numbers are very probably $I^G(J^{PC}) = 0^+(1^{++})$ and that their quark constituents are mainly of the type $n\bar{n}$, where $n = \{u, d\}$.

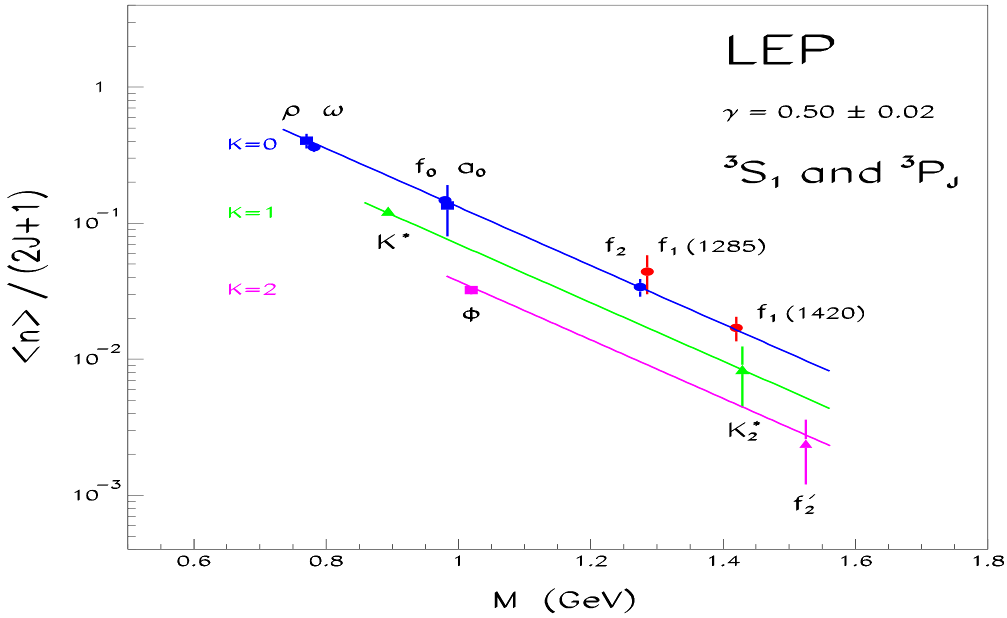

Figure 3: Total production rate per spin state and isospin for scalar, vector and tensor mesons as a function of the mass (open symbols). The two solid circles correspond to the $f_1(1285)$ and the $f_1(1420)$.

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