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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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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 $1274\pm4$ and $29\pm12$ MeV for the first peak and $1426\pm4$ and $51\pm14$ MeV for the second. A partial-wave analysis has been performed on the $(K\bar{K}\pi)^0$ spectrum in this 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 insight into the nature of fragmentation of quarks and gluons to hadrons. For the first time, we present in this paper a study of the inclusive production of two $J^{PC} = 1^{++}$ mesons, the $f_1(1285)$ and the $f_1(1420)$ (i.e. $^3P_1$).

There are at least four nonstrange isoscalar mesons,[3] $I^G(J^{PC}) = 0^+(1^{++})$ and $I^G(J^{PC}) = 0^+(0^{-+})$, known in the mass region between 1.2 and 1.5 GeV, which couple strongly to the decay channel $(K\bar{K}\pi)^0$. They are $f_1(1285)$, $\eta(1295)$, $f_1(1420)$ and $\eta(1440)$, which are mostly $n\bar{n}$ states, where $n = \{u, d\}$. There exist possibly two additional states, $I^G(J^{PC}) = 0^-?(1^{+-})$ $h_1(1380)$ and $I^G(J^{PC}) = 0^+(1^{++})$ $f_1(1510)$, which may harbor a large $s\bar{s}$ content.[3] Given this complexity in the $(K\bar{K}\pi)^0$ systems, it is important that one seek answers as to which resonances among these are readily excited in inclusive hadron $Z$ decays.

The DELPHI data for this study is based on the neutral $K\bar{K}\pi$ channel in the reaction $Z \rightarrow (K_S K^\pm\pi^\mp) + X^0$.

## 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.[4,5]

The charged particle tracks have been measured in the 1.2-T magnetic field by a set of tracking detectors. The average momentum resolution for charged particles in hadronic final states, $\Delta p/p$, is usually between 0.001 and 0.01.

A charged particle has been accepted in this analysis—if its momentum $p$ is greater than 100 MeV/$c$; its momentum error $\Delta p$ is less than $p$; and its impact parameter with respect to the nominal crossing point is within 4 cm in the transverse ($xy$) plane and 4 cm/$\sin\theta$ along the beam direction ($z$-axis), $\theta$ being the polar angle of the track.

Hadronic events are then 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.

After the event selection, in order to ensure a better signal-to-background ratio for the resonances in the $K_S K^{\pm}\pi^{\mp}$ invariant mass spectra, tighter requirements have been imposed on the track impact parameters, i.e. they have to be within 0.2 cm in the transverse plane and 0.4 cm/$\sin\theta$ along the beam direction.

$K^{\pm}$ 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/$c$. Its efficiency has been estimated by comparing the experimental data with simulated events generated with JETSET[6] tuned with the DELPHI parameters[7] and passed through the detector simulation program DELSIM.[8]

The $K_S$ candidates are detected by their decay in flight into $\pi^+\pi^-$. Our selection process consists of taking the $V^0$'s passing certain criteria[9] for quality of the reconstruction plus a mass cut given by $0.45 < M(K_S) < 0.55$ GeV.

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

The key to a successful study of the $f_1(1285)$ and $f_1(1420)$—given the enormous background in the $K_S\, K^{\pm}\, \pi^{\mp}$ mass spectrum in this mass region—is to make a mass cut $M(K_S\, K^{\pm}) \leq 1.04$ GeV, as shown in Fig. 1. Two clear peaks are seen in this mass region. 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.[10]

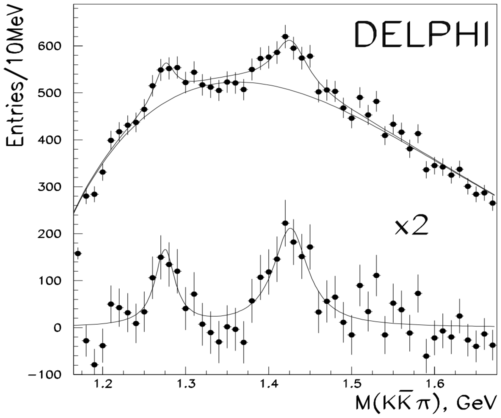

Figure 1. $M(K_S\,K^{\pm}\,\pi^{\mp})$ distributions from the $Z$ decays with the DELPHI detector at LEP I—with a mass cut $M(K_S\,K^{\pm}) < 1.04$ GeV. The two solid curves in the upper part of the histogram describe Breit-Wigner fits over a smooth background (see text). The lower histogram and the solid curve give the same fits with the background subtracted and amplified by a factor of two.

In order to measure the resonance parameters for these two states, we have first generated a Monte Carlo sample, deleting—from the existing MC package—all mesons with a major decay mode into $(K\bar{K}\pi)^0$ in the mass region 1.25 to 1.45 GeV, i.e. $f_1(1285)$, $h_1(1380)$ and $f_1(1420)$, which is then passed through the standard detector simulation program. The smooth curve shown in Fig. 1 has been obtained by fitting the mass spectrum of the aforementioned MC sample between 1.15 to 1.65 GeV with a background function

$$f_b(M) = (M - M_0)^{\alpha_1}\,\exp(\alpha_2\,M + \alpha_3\,M^2) \qquad (1)$$

where $M$ and $M_0$ are the effective masses of the $(K\bar{K}\pi)^0$ system and its threshold, respectively, and $\alpha_i$ are the experimental parameters. We have fitted the $(K\bar{K}\pi)^0$ spectrum adding two $S$-wave Breit-Wigner forms to the background $f_b(M)$, given by

$$f_r(M) = \Gamma_r^2 \Big/ \left[(M - M_r)^2 + (\Gamma_r/2)^2\right] \qquad (2)$$

where $M_r$ and $\Gamma_r$ are the mass and the width to be determined experimentally. The results are shown in Fig. 1 and also in Table I.

Table I. Fitted parameters and numbers of events

| Mass (MeV) | Width (MeV) | Events |
|---|---|---|
| $1274 \pm 4$ | $29 \pm 12$ | $345 \pm 88$ (stat) $\pm$ 69 (sys) |
| $1426 \pm 4$ | $51 \pm 14$ | $790 \pm 119$ (stat) $\pm$ 110 (sys) |

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 (7%)—on the one hand—and the conditions of the mass-fit procedure—on the other (15%). The systematic errors have been added quadratically and are shown in Table 1.

## 4 Partial-wave Analysis

There exists a long list of 3-body partial-wave analyses; the reader may consult PDG[3] for earlier references, for example, on $a_1(1260)$, $a_2(1320)$, $K_1(1270/1400)$ or $K_2(1770)$. For the first time, we apply the same technique to a study of the $(K\bar{K}\pi)^0$ system from the inclusive decay of the $Z$ at LEP.

We have chosen to employ the so-called Dalitz plot analysis, integrating over the three Euler angles.[11] 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,[12] thus taking into account the finite acceptance of the detector and the event selection.

The background under the two $f_1$'s is very large, some $\sim$ 80%. It is assumed that this represents essentially different processes with, for example, different overall multiplicities—so that the background does not interfere with the signals. We assume further that the background itself 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 $0^-(1^{+-})\,(K^*(892)\bar{K} + c.c.)$. We have verified that these amplitudes give a good description of the three background regions for $M(K\bar{K}\pi)$ in $1.22 \to 1.26$, $1.30 \to 1.38$ and $1.48 \to 1.56$ GeV, respectively.

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. 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 better (by about 14 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 23 for $\Delta \ln \mathcal{L}$).

It should be emphasized that both the mass-dependent (per 20 MeV) and the mass-independent global fits give compatible results.

## 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

$$\begin{aligned} \langle n \rangle &= 0.132 \pm 0.034 \quad \text{for} \quad f_1(1285) \\ \langle n \rangle &= 0.0512 \pm 0.0078 \quad \text{for} \quad f_1(1420) \end{aligned} \tag{3}$$

taking a $K\bar{K}\pi$ branching ratio of $(9.0 \pm 0.4)\%$ 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;[2] in Fig. 2 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.

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 $1274 \pm 4$ and $29 \pm 12$ MeV for the first peak and $1426 \pm 4$ and $51 \pm 14$ 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 $n = \{u, d\}$. Finally, we conclude that the mesons $\eta(1295)$, $\eta(1440)$ and $h_1(1380)$ are less likely to be produced in the inclusive $Z$ decays compared to $f_1(1285)$ and $f_1(1420)$.

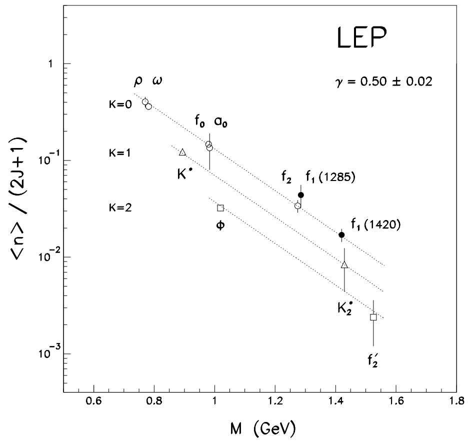

Figure 2. Total production rate per spin state and isospin for scalar, vector and tensor mesons as a function of the mass (open symbols). The two solid circles correspond to the $f_1(1285)$ and the $f_1(1420)$.

## References

1. P. Abreu *et al.*, DELPHI Collab., Phys. Lett. **B449** (1999) 364.
2. V. Uvarov, Phys.Lett. B511 (2001) 136.
3. Review of Particle Physics, Eur. Phys. J. C**15**, (2000) 1.
4. P. Aarnio *et al.*, DELPHI Collab., Nucl. Inst. Meth. **A303** (1991) 233.
5. P. Abreu *et al.*, DELPHI Collab., Nucl. Inst. Meth. **A378** (1996) 57.
6. T. Sjöstrand, Comput. Phys. Comm. **82** (1994) 74.
7. P. Abreu *et al.*, DELPHI Collab., Z.Phys. C 73 (1996) 11.
8. P.Aarnio *et al.*, DELPHI Collab., Nucl. Instr. Meth. A 378 (1996) 57.
9. P. Abreu *et al.*, DELPHI Collab., Z.Phys. C 65 (1995) 587.
10. See S. U. Chung, 'Analysis of $K\bar{K}\pi$ systems (Version I),' BNL-QGS-98-901 (1998), http://cern.ch/suchung/.
11. See S. U. Chung, 'Spin Formalisms,' CERN preprint 71-8 (1971).
12. S. U. Chung *et al.*, Phys. Rev. **D60** (1999) 092001.