OBSERVATION OF F MESON PRODUCTION IN HIGH ENERGY e^+e^- ANNIHILATION

TASSO Collaboration

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Production of the F meson by e^+e^- annihilation at high energies has been observed in the $\varphi\pi$ final state with a mass of 1.975 ± 0.009 ± 0.010 GeV and a width consistent with the mass resolution. The yield of F production times branching ratio relative to μ pair production is $R_F(x \geqslant 0.3)\, B(F^\pm \to \varphi\pi^\pm) = 0.061 \pm 0.012 \pm 0.018$.

Nonstrange charmed mesons have been extensively studied [‡1] [2–5], while little is known about those carrying strangeness [6–8]. Recently the CLEO group [9] has reported the observation of the F meson produced by e^+e^- annihilation at a CM energy of W = 10.5 GeV. The F meson has been detected in the $\varphi\pi$ decay mode with a mass of 1.970 ± 0.005 ± 0.005 GeV. While this value is not in disagreement with that obtained in the first measurement [6] of the F, m_F = 2.03 ± 0.06 GeV, it is at variance with the photoproduction results of the F which, averaged over all their measured decay modes, yield m_F = 2.02 ± 0.01 GeV [7,8]. We present in this letter data on F production in e^+e^- annihilation which confirm the CLEO result at high energies.

The experiment was performed with the TASSO detector [10] at the storage ring PETRA at DESY. Data were taken at CM energies W = 14, 22 and 25 GeV with an integrated luminosity of 5.4 pb^{-1} and between 30 and 42 GeV with an average $\bar{W}$ = 34.7 GeV and an integrated luminosity of 77.6 pb^{-1}. A total number of 29 166 hadronic events were selected using the same cuts as in ref. [11]. A momentum resolution for charged particles of $\sigma_p/p = 0.01 \cdot (2.9 + p^2)^{1/2}$ was obtained by using the average beam position as a constraint in the track reconstruction [4].

F production was searched for in the decay mode $F^\pm \to \varphi\pi^\pm \to K^+K^-\pi^\pm$. Particle identification was used to reduce the number of wrong mass assignments. For $|\cos\vartheta| \leqslant 0.8$, where ϑ is the angle with respect to the beam direction, particle identification was done by time-of-flight (TOF) counters [12] placed between the central drift chamber and the solenoid at a radius of 1.32 m. The π/K separation with the TOF counters is possible for momenta $p \leqslant 1.0$ GeV/c. Since most of the φ's coming from high momentum F mesons are expected to be energetic, the kaons were not required to be positively identified by the TOF counters.

Candidates for φ mesons are searched for by looking at invariant mass combinations of oppositely charged tracks interpreted as kaons. However, particles positively identified as pions or protons by the TOF counters were not considered as kaons [‡2]. The K^+K^- mass spectrum is shown in fig. 1 for all mass combinations and for the combinations with a fractional energy $x_{KK} = 2E_{KK}/W \geqslant 0.4$ (shaded histogram). The latter shows a clear φ signal. A background (parametrized in

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‡1 For a review of low energy charm production see ref. [1].

‡2 For each particle type i ($i = \pi$, k, p) the probabilities W_i were calculated according to $W_i = Cf_i(p)\exp[-(\tau_m - \tau_i)^2/2\sigma_\tau^2]$ where τ_m is the measured TOF, τ_i the expected TOF for hypothesis i, σ_τ being the resolution for the time measurement, $f_i(p)$ the momentum dependent particle fraction for the hypothesis according to ref. [12] and C a normalization constant such that $\Sigma W_i = 1.0$. Using,this, we called a particle a sure pion, if $W_\pi \geqslant 0.9$ for $0.3 \leqslant p_\pi \leqslant 1.0$ GeV/c a sure kaon, if $W_K \geqslant 0.6$ and $0.1 \leqslant M^2 \leqslant 0.6$ GeV^2 for $0.3 \leqslant p_K \leqslant 1.0$ GeV/c; a sure proton, if $W_p \geqslant 0.6$ and 0.6 GeV$^2 \leqslant M^2$ for $0.4 \leqslant p_p \leqslant 1.4$ GeV/c; where M is the mass of the particle as calculated from the momentum and TOF measurements.

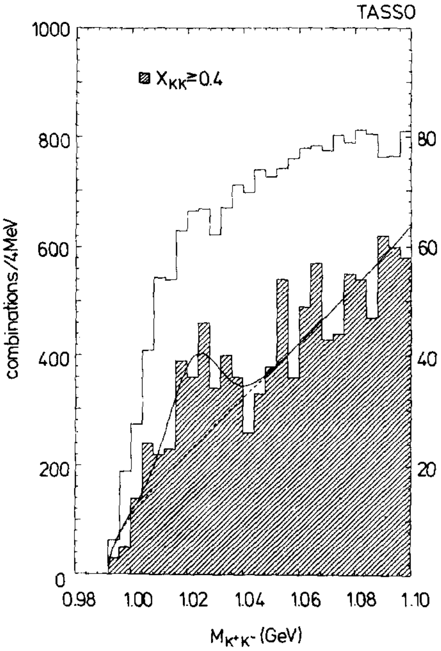

Fig. 1. Invariant mass distribution of oppositely charged particles (interpreted as kaons). Data from all CM energies are included. The shaded histogram (note different scale at the right hand side) is for all combinations with $x_{KK} \geqslant 0.4$. The curve shows the fit of a gaussian plus a background term (see text).

terms of the K^+ momentum in the K^+K^- rest frame multiplying a polynomial) plus a gaussian shape for the φ was fitted to the shaded histogram, yielding a mass of 1023 ± 2 MeV in agreement with the standard φ mass, $m_\varphi = 1.020$ GeV [13], and a width (FWHM) of 21 ± 7 MeV, which is consistent with the width expected from our detector resolution. We define as φ-candidates all K^+K^- mass combinations within ±15 MeV of the nominal φ mass.

The φ candidates were combined with any of the other charged tracks in the event interpreted as a pion (particles identified as sure kaons or protons in the TOF system were not taken). The resulting $K^+K^-\pi^\pm$ mass spectrum is shown in fig. 2a for combinations with a fractional energy $x_{KK\pi} = 2E_{KK\pi}/W > 0.4$. A clear enhancement is seen at a mass around 1.97 GeV. No signal is observed when K^+K^- combinations in the φ control region ($1.05 \leqslant M_{KK} \leqslant 1.10$ GeV) are selected (fig. 2b). From this and the fact that the φ control region is close to the φ mass we conclude that the 1.97 GeV signal observed in fig. 2a is associated with the $\varphi\pi$ channel. The same conclusion can be drawn from a comparison of the K^+K^- mass distribution for the $K^+K^-\pi^\pm$ mass combination in the 1.97 GeV region and in a control region.

In order to determine the mass and width of the observed signal, a gaussian plus a background term of the form $dn/dM = a_0 + a_1M + a_2M^2$ were fitted to the $KK\pi$ mass spectrum shown in fig. 2a. The fit yielded a signal of 49 ± 14 events and a mass of 1.975 ± 0.009 GeV. The systematic uncertainty of the mass calibration in this range was found to be less than 10 MeV. This was determined from $K_S^0 \to \pi^+\pi^-$ decays, from the position of the φ peak, and from a measurement of the total CM energy with $\mu^+\mu^-$ pairs. The

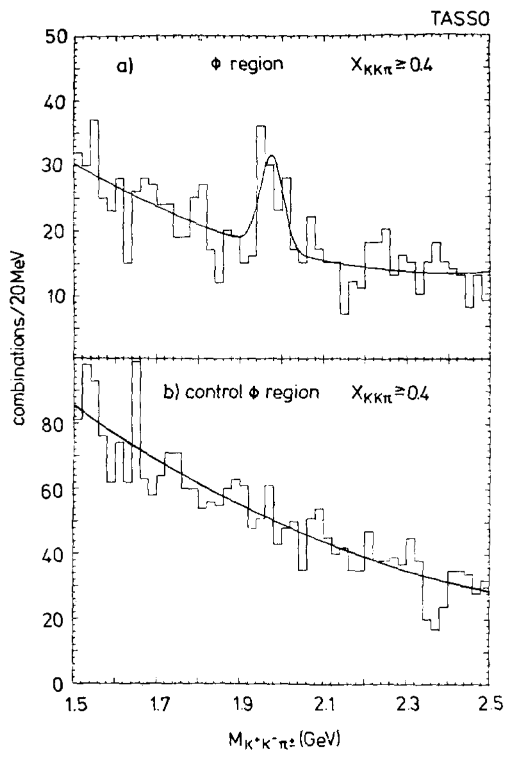

Fig. 2. Distributions of the $K^+K^-\pi^\pm$ mass with $x_{KK\pi} \geqslant 0.4$. Data from all CM energies are included. The curves show the result of the fits as described in the text. (a) For K^+K^- combinations in the φ region ($1.005 < M(K^+K^-) < 1.035$ GeV). The curve shows the fit of a gaussian plus a background term (see text). (b) For K^+K^- combinations in the φ control region ($1.05 < M(K^+K^-) < 1.10$ GeV). The curve is a fit to a smooth background.

width of the gaussian (0.064 ± 0.021 GeV FWHM) is consistent with the expected mass resolution and hence with a small natural width. The properties of the 1.97 GeV signal (mass, width and $\varphi\pi$ decay mode) agree with those of the F(1.97) observed by the CLEO group [9].

We now consider F production at $W > 30$ GeV ($\bar{W} = 34.7$ GeV). For the determination of the cross sections, the number of F mesons was found from the $K^+K^-\pi^\pm$ mass distributions for $x_{KK\pi}$ intervals between 0.3 and 1.0 using fits with a polynomial background plus a gaussian for the F. Monte Carlo events of the type $e^+e^- \to c\bar{c}$ including gluon emission and radiative effects and leading to $F^\pm \to \varphi\pi^\pm$ were generated [‡3] and passed through the detector and the event selection criteria [11]. These events were used to compute the detector acceptance and efficiency. The overall detection efficiency for the chain $F^\pm \to \varphi\pi^\pm$; $\varphi \to K^+K^-$ was found to be 0.46 at $x_{KK\pi} = 0.30$ and to decrease to 0.26 at $x_{KK\pi} = 0.9$, the average being 0.31. The data were also corrected for the other decay modes of the φ, assuming a branching ratio $B(\varphi \to K^+K^-) = 0.49 \pm 0.01$ [13].

In fig. 3 we present the $F^\pm$ scaled cross section multiplied by the branching ratio, $s/\beta\, d\sigma/dx\, B(F^\pm \to \varphi\pi^\pm)$, ($s = W^2$, $\beta = p_F/E_F$) as a function of the scaled F energy $x = 2E_F/W$. The errors shown include only the statistical uncertainties. There is an overall systematic error of ±30% due to uncertainties in the detection efficiency and in the background determination. The shape of the distribution is similar to our D* cross section [4] and can be described well by the parametrization of ref. [14]:

$$\frac{s}{\beta}\frac{d\sigma}{dx} \sim \frac{1}{x[1 - 1/x - \epsilon/(1-x)]^2} . \qquad (1)$$

A fit to the data of fig. 3 yielded $\epsilon = 0.45 \pm 0.25$, which can be compared with our value of $\epsilon = 0.18 \pm 0.07$ obtained for D* production [4].

The integrated measured $F^\pm$ cross section for $x \geqslant 0.3$ yielded, relative to the μ pair cross section ($\sigma_{\mu\mu} = 4\pi\alpha^2/3s = 0.072$ nb at 34.7 GeV), $R_F(x \geqslant 0.3)B(F^\pm \to \varphi\pi^\pm) = \sigma_F(x > 0.3)B(F^\pm \to \varphi\pi^\pm)/\sigma_{\mu\mu} = 0.061 \pm 0.012 \pm 0.018$. Using the parametrization given in eq. (1) to extrapolate to $x \leqslant 0.3$, the total $F^\pm \to \varphi\pi^\pm$ production was found to be $R_F\, B(F^\pm \to \varphi\pi^\pm) = 0.064 \pm 0.013 \pm 0.019$. This can be compared with the expected total yield for primary strange charmed meson production, $R(c\bar{s} + \bar{c}s) = 2 \cdot \frac{4}{12} \cdot 4.01 \cdot 0.167 = 0.486$, where $\frac{4}{11}$ is the relative contribution of the c quark to the total cross section, 4.01 is our measured R value [11] and 0.167 is the assumed probability to pick up an $s\bar{s}$ pair from the sea [15]. From the observed $F^\pm \to \varphi\pi^\pm$ yield and under the above assumptions we then find for the branching ratio $B(F^\pm \to \varphi\pi^\pm) = 0.13 \pm 0.03 \pm 0.04$, where the systematic error includes only the uncertainties in the measured cross section. This value is larger than the value of $B(F^\pm \to \varphi\pi^\pm) \approx 0.044$ obtained in ref. [9] in a similar way. Note, however, that our result for $B(F^\pm \to \varphi\pi^\pm)$ may be reduced by as much as 25% due to possible F's originating from primary bottom quarks at low x.

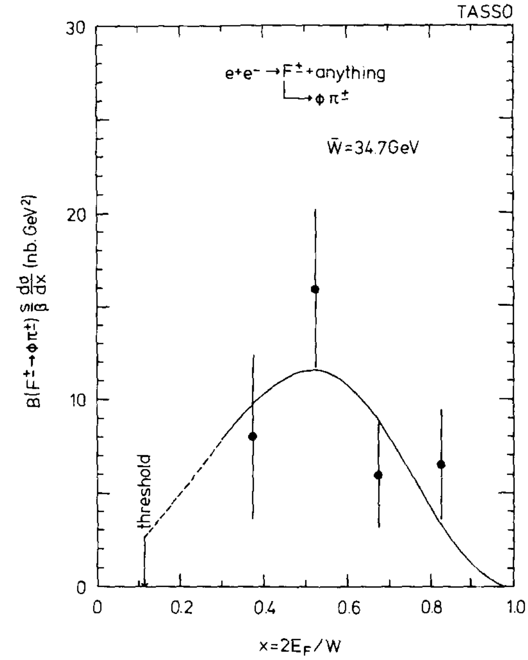

Fig. 3. The scaled cross sections $s/\beta \cdot d\sigma/dx \cdot B(F^\pm \to \varphi\pi^\pm)$ for F meson production at $\bar{W} = 34.7$ GeV. The curve shown is the result of the fit according to eq. (1).

‡3 From the spin properties of the F and the φ, an isotopic distribution was assumed for the $\pi^\pm$ in the $\varphi\pi$ rest frame. The decay $\varphi \to K^+K^-$ was generated with a $\cos^2\vartheta_K$ distribution, where ϑ_K is the angle between the K^+ in the φ rest frame and the φ direction in the $\rho\pi$ rest frame.

In summary we have observed F meson production in the $\varphi\pi^{\pm}$ final state with a mass of $1.975 \pm 0.009 \pm 0.010$ GeV [‡4] and a width consistent with our mass resolution. The F production yield times the branching ratio was found to be $R_F(x \geqslant 0.3) \cdot B(F^{\pm} \to \varphi\pi^{\pm}) = 0.061 \pm 0.012 \pm 0.018$.

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[‡4] This result is also in agreement with preliminary data of the ARGUS Collaboration (unpublished).

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