# EVIDENCE FOR F* MESON PRODUCTION IN $e^+e^-$ ANNIHILATION AT 10 GeV CENTER-OF-MASS ENERGY

ARGUS Collaboration

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Using the ARGUS detector at DORIS we have obtained evidence for a resonance which decays into an F meson and a photon. The observed mass is 2109 ± 9 ± 7 MeV, which is 144 ± 9 ± 7 MeV greater than the F meson mass. Its properties are consistent with those of the F* meson with $J^P = 1^-$.

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In analogy with the D* meson an excited F meson, the $J^P = 1^-, I = 0$ F* meson is predicted by the quark model [1]. Unlike the D* meson the F* is forbidden by isospin conservation to decay strongly into $\pi^0$F. This leaves the radiative decay as the dominant mode. Searches for the F* meson have been made previously [2].

In this letter we report evidence for a stat of mass 2109 MeV decaying into an $F^\pm$ meson and a photon, where the $F^\pm$ meson is identified by its decay into $\Phi\pi^\pm$ [3,4]. From its production and decay properties we interpret this state to be the F* meson.

The data presented here have been collected using the ARGUS detector at the DORIS II $e^+e^-$ storage ring at DESY. The CM energy range was from 9.4 to 10.6 GeV. A short description of the detector and its trigger has been given in ref. [5], and its particle identification capabilities are described in ref. [6]. The event sample used for this analysis consists of 43.7 events/pb, comprising 8.7/pb on the $\Upsilon$(1S) resonance, 25.1/pb on the $\Upsilon$(2S), 5.4/pb on the $\Upsilon$(4S) and 4.5/pb in the continuum.

Events corresponding to $e^+e^-$ annihilation into multihadron final states were selected, as in ref. [5], by requiring that $\geqslant$4 tracks be reconstructed in the drift chamber and that they be associated with the primary interaction point. For charged particle identification we have used both the specific ionisation in the drift chamber ($\mathrm{d}E/\mathrm{d}x$) and the time-of-flight (TOF) information. For each track in an event the probability for each mass hypothesis is

$$P_i[\chi^2(\mathrm{d}E/\mathrm{d}x)_i + \chi^2(\mathrm{TOF})_i] , \quad i = \pi, \mathrm{K}, \mathrm{p} .$$

In forming effective mass combinations a track is entered with unity weight for each mass hypothesis for which the particle identification gives a probability larger than 3%. Almost all tracks having momenta below 700 MeV/$c$ are uniquely identified. As the momentum increases beyond 700 MeV/$c$ the proportion of ambigious tracks also increases steadily.

For the photon detection we use the 1760 lead-scintillator-sandwich counters which have an energy resolution of $\sigma/E = (0.07^2 + 0.08^2\ \mathrm{GeV}/E)^{1/2}$. All counters have been calibrated using Bhabba events and are systematically monitored with a laser-pulse system. To illustrate the photon reconstruction we show in fig. 1 the background-subtracted $\pi^0$ mass distribution. Fitting a gaussian gives a mass value

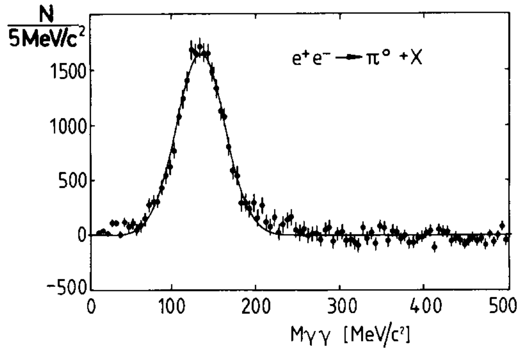


Fig. 1. The background-subtracted $\gamma\gamma$ mass distribution. The curve is a gaussian fit to the data.

136.0 ± 0.6 ± 5 MeV and a width of 26 ± 1 MeV, in agreement with an expected width of 24 MeV.

F meson candidates were obtained by forming all combinations of $K^+K^-\pi^\pm$ in the selected multihadronic events with the restriction that the invariant mass of the $K^+K^-$ pair be in the range 1.014–1.025 GeV. In addition the momentum of the pion was required to be larger than 0.3 GeV as in our study of the F meson [4]. All such candidates were subsequently paired with all possible photons but under the restriction that the photon laboratory energy $E_\gamma$ be larger than 110 MeV and that the momentum of the $\Phi\pi\gamma$-system be larger than 1.8 GeV/$c$.

For the accepted $\Phi\pi\gamma$-combinations we show in figs. 2a–2c the $\Phi\pi$ invariant mass distribution for three intervals in $M(\Phi\pi\gamma)$. There is a clear F signal correlated with a $\gamma$ from the F* interval with $M(\Phi\pi\gamma)$ = 2.08 to 2.17 GeV while for the side bands there is little signal above background. Further evidence comes from a comparison of figs. 3a and 3b. Here the momentum of the $\Phi\pi$ system is selected to be larger than 1.65 GeV/$c$. In fig. 3a no extra photon was required, whereas in fig. 3b a photon from the F* interval was asked for. Obviously this requirement leads to a substantial improvement of the F signal to background ratio. To show that the observed enhancement is due to F* production and not artificially caused by a steeply falling photon spectrum and the $E_\gamma$ cut chosen, we display in fig. 4 the invariant mass of the $\Phi\pi\gamma$ system as a function of the $E_\gamma$ cut. Here we have required the $\Phi\pi$ system to be in a 20 MeV wide band around the F peak. As can be seen from fig. 4 there is a signal for all $E_\gamma$ cuts between

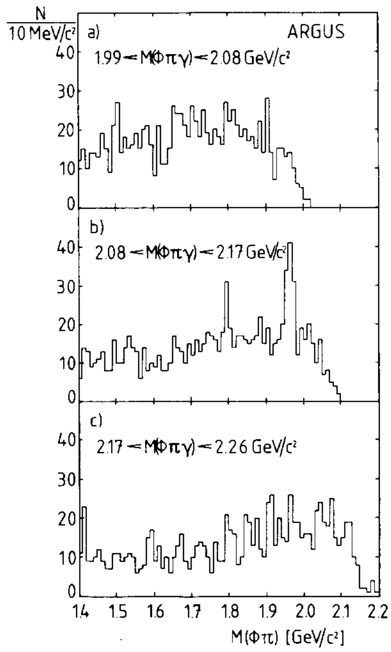


Fig. 2. (a)–(c) The invariant mass $M(\Phi\pi)$ for various intervals of the invariant mass $M(\Phi\pi\gamma)$. The momentum $P(\Phi\pi\gamma)$ of the $\Phi\pi\gamma$ system is required to be larger than 1.8 GeV/$c$.

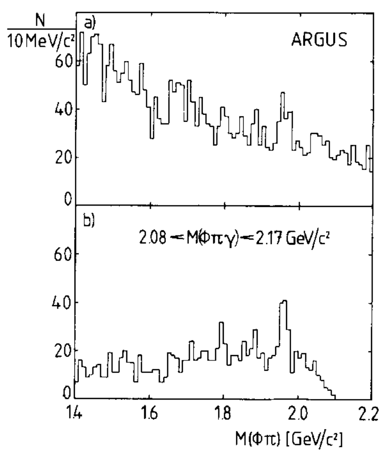


Fig. 3. (a) the number of $\Phi\pi$ combinations as a function of the invariant mass $M(\Phi\pi)$ without any requirement of an extra photon, but with the restriction $P(\Phi\pi) > 1.65$ GeV/$c$. (b) as (a) but requiring the invariant mass $M(\Phi\pi\gamma)$ to be in the F* peak region.

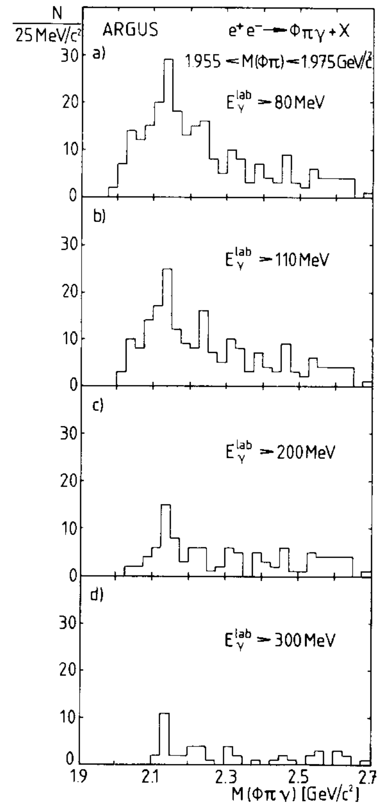


Fig. 4. The invariant mass $M(\Phi\pi\gamma)$ distributions as a function of the photon energy cut off. The mass of the $\Phi\pi$ system is required to be in a 20 MeV wide band around the F-peak.

80 and 300 MeV at the same $\Phi\pi\gamma$ mass of about 2.1 GeV.

The enhancement of the F signal in fig. 2b and the lack of it in the sidebands (figs. 2a,2c) as well as the observed reduction of the signal in fig. 4 with the increasing $E_\gamma$ cut agrees well with a Monte Carlo simulation of F* production. The simulation uses events generated according to the Field–Feynman model [7] where the fragmentation of the charmed quarks is adjusted to reproduce the fragmentation functions for D and F mesons in refs. [6,4]. The events are processed through a detector simulation program and subsequently reconstructed with our data analysis program. In addition we have undertaken a number of studies in order to exclude the possibility that the peak in fig. 2 is an artefact. We have used various event mixing methods, the method of cutting outside the Φ and F peaks, as well as Monte Carlo simulations

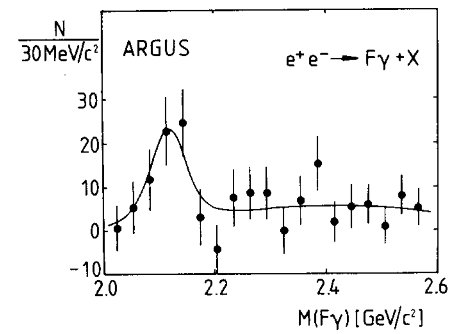


Fig. 5. The $M(\Phi\pi\gamma)$ background subtracted distribution showing the number of F mesons found in each 30 MeV wide $M(\Phi\pi\gamma)$ slice. The curve is the result of a fit as explained in the text.

of possible reflections from other charmed mesons produced. In none of these studies do we find effects such as the one in figs. 2 and 4. We therefore interpret the observed peak as the F* meson. Further supporting evidence is given by the decay angular distribution of the photon in the F* rest frame with respect to the F* direction which is consistent with being flat.

To determine the mass of the F*, the $M(\Phi\pi\gamma)$ mass distribution was subdivided into slices. For each slice a fit was made to the $M(\Phi\pi)$ spectrum, using a third order polynomial plus a gaussian of fixed mass (1965 MeV) and fixed width (15 MeV). The number of F's was extracted from each fit and plotted as function of the $M(F\gamma)$ mass as shown in fig. 5. The distribution in fig. 5 was fitted by a gaussian plus a background with a shape as given by the Monte Carlo simulation. The resulting width is 29 ± 8 MeV in agreement with the 30 MeV width determined from the Monte Carlo simulation. We have repeated the fit with a fixed width of 30 MeV, yielding an uncorrected mass value of 2121 ± 9 MeV, and 45 ± 11 events in the peak.

The fitted mass value has to be corrected for the fact that, due to the limited photon energy resolution, the photon energy cut off suppresses the lower tail of the F* peak and effectively shifts the peak upwards in mass. From the Monte Carlo simulation we obtain a correction of −12 MeV to $M(F^*)$ resulting in an F* mass of 2109 ± 9 ± 7 MeV. The last error is systematic and includes a 5 MeV error from the photon energy calibration, a 4 MeV error for the uncertainty in the mass correction and a 3 MeV error in the magnetic field calibration, all added in quadrature. Using the F mass value of 1965 ± 3 MeV obtained from a fit to fig. 2b, this corresponds to a mass difference $\Delta M = M(F^*) - M(F)$ of 144 ± 9 ± 7 MeV.

Correcting the observed number of events for the detection efficiency, 0.70 ± 0.10, for photons coming from an F* with momentum larger than 1.8 GeV/$c$, gives 64 ± 18 events. Together with the total observed number of F's corresponding to an F* momentum cut off of 1.8 GeV, 58 ± 14, we find that on the average more than 66% (84% CL) of the observed F mesons are produced from F* mesons.

In summary we have observed a peak in the Fγ ($F \to \Phi\pi$) invariant mass distribution which we associate with the $J^P = 1^-$, $I = 0$ F* meson. Its production and decay characteristics support such an interpretation. The mass of the F* is determined to be 2109 ± 9 ± 7 MeV corresponding to a mass difference $\Delta M = M(F^*) - M(F)$ of 144 ± 9 ± 7 MeV.

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## *References*

[1] M.K. Gaillard, B.W. Lee and J.L. Rosner, Rev. Mod. Phys. 47 (1975) 277.

[2] R. Brandelik et al., Phys. Lett. 70B (1977) 132; 80B (1979) 412;

B. Partridge et al., Phys. Rev. Lett. 47 (1981) 760;
H.P. Horisberger, SLAC-Report 266 (1984);
W. Hofmann, LBL-17845 (1984).

[3] CLEO Collab., A. Chen et al., Phys. Rev. Lett. 51 (1983) 634;
TASSO Collab., M. Althoff et al., Phys. Lett. 136B (1984) 130;
ACCMOR Collab., R. Bailey et al., Phys. Lett. 139B (1984) 320.

[4] ARGUS Collab., H. Albrecht et al., Production and decay of F mesons in $e^+e^-$-annihilation at 10 GeV centre-of-mass energy submitted to Phys. Lett. B.

[5] ARGUS Collab., H. Albrecht et al., Phys. Lett. 134B (1984) 137.

[6] ARGUS Collab., H. Albrecht et al., Production and decay of charged $D^*$ mesons in $e^+e^-$ annihilation at $\sqrt{s} = 10$ GeV, submitted to Phys. Lett. B.

[7] R.D. Field and R.P. Feynman, Nucl. Phys. B136 (1978) 1.