OBSERVATION OF F DECAYS INTO $\bar{K}^*K$

The ARGUS collaboration

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Using the ARGUS detector at DORIS II, the decay of $F^+ \to \bar{K}^{*0}K^+$, and the ratio $BR(F^+ \to \bar{K}^{*0}K^+)/BR(F^+ \to \phi\pi^+)$ is found to be 1.44 ± 0.37. This is a substantial rate for a decay channel which cannot proceed via a colour-favoured diagram

We have earlier reported [1] evidence for the production of F mesons in e^+e^- annihilation at $\sqrt{s} = 10$ GeV, by reconstructing decays into the $\phi\pi$ and $\phi(3\pi)$ channels. Observations of $F \to \phi\pi$ have also been reported by other e^+e^- experiments [2]. The F-decay branching ratios and the fragmentation of c quarks into $c\bar{s}$ states are of considerable interest. In particular, measurement of the branching ratios of weak F decays provides insight into the interplay of the various possible decay mechanisms. The spectator model can account for the observed $\phi\pi$ and $\phi(3\pi)$ decays of the F meson. Although such a picture of heavy-quark decays [3] describes the broad features of these decays, its shortcomings have already been demonstrated by results on the D^0, D^+ and F^+ lifetimes [4]. Recently, it has been shown that colour suppression is inoperative in D^+ decays [5]. Also, we have observed the decay $D^0 \to \bar{K}^0 \phi$ [6], which indicates a contribution of W-exchange diagrams to heavy-meson decays. Therefore, if quark-annihilation and colour-suppressed spectator mechanisms [7] (fig. 1) are important for heavy-meson decay, then one expects the F meson to decay with a substantial branching ratio into the $\bar{K}^{*0}K^+$ channel.

In this letter, we report the observation of the decay $F^+ \to \bar{K}^{*0}K^+$ [‡1] and present a measurement of the ratio $BR(F^+ \to \bar{K}^{*0}K^+)/BR(F^+ \to \phi\pi^+)$. The data sample used for this analysis was collected with the ARGUS detector, operating in the e^+e^- storage ring DORIS II at DESY. It correponds to a total luminosity of 149.1 pb^{-1}, of which 21.7 pb^{-1}, 32.9 pb^{-1}, 59.2 pb^{-1} and 35.3 pb^{-1} were obtained on the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(4S)$ and in the continuum or during scanning, respectively. The detector is a 4π spectrometer, described in more detail elsewhere [8]. The charged particle momenta and mean dE/dx loss were determined using the central drift chamber. Particles were identified on the basis of measurements of both dE/dx and of time of flight. For a given track, all mass hypotheses were accepted for which the likehood ratio [9] constructed from these measurements exceeded 5%. The efficiency has been checked by investigating the dependence on identification of the number of reconstructed K^0_S's, ϕ's and Λ's in the $\pi^+\pi^-$, K^+K^- and $p\pi^-$ mass distributions, respectively.

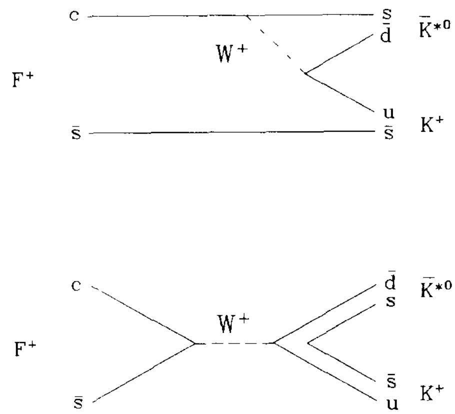

Fig. 1. Colour-suppressed spectator and annihilation diagrams for the decay $F^+ \to \bar{K}^{*+}$.

Multihadron final states were selected by requiring $\geqslant 3$ tracks reconstructed in the drift chamber and associated with the primary interaction point. All K^- and π^+ originating within 6σ of the primary vertex were combined, and those for which the invariant mass was within ± 50 MeV/c^2 of the nominal $\bar{K}^{*0}$ mass were taken as $\bar{K}^{*0}$ candidates. In addition, a

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[‡1] References in this paper to a specific charged state are to be interpreted as also implying the charge conjugate state.

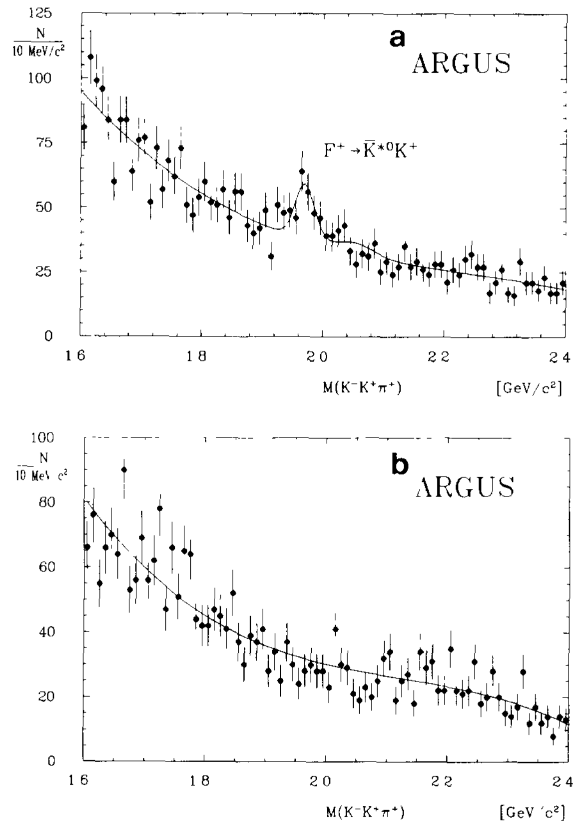

Fig 2(a) $K^-\pi^+K^+$ invariant-mass distribution with $M(K^-\pi^+)$ in the $\bar{K}^{*0}$ region, $p(K^-\pi^+K^+) \geqslant 2.5$ GeV/c, $\cos\theta_{K^{*0}} \geqslant 0.2$ and $|\cos\theta_H[K^-]| \geqslant 0.5$ The fit includes the contribution of the D^+ reflection (b) The same as (a), except $M(K^-\pi^+)$ lies within the sideband intervals 0.75–0.80 MeV/c^2 and 1.00–1.05 MeV/c^2, outside the $\bar{K}^{*0}$ mass region

momentum cut on the $\bar{K}^{*0}K^+$ system was applied:

$$p(\bar{K}^{*0}K^+) \geqslant 2.5\ \text{GeV}/c\,.$$

The invariant-mass distribution of $\bar{K}^{*0}K^+$ combinations shows an enhancement near 1970 MeV/c^2 (fig. 2a). For this figure, two additional cuts have been made. First, it was required that $\cos\theta_{\bar{K}^{*0}} \geqslant 0.2$, where $\theta_{\bar{K}^{*0}}$ is the angle of the $\bar{K}^{*0}$ in the F rest frame with respect to the F boost direction. This cut eliminates reflections from $D^+ \to \bar{K}^{*0}\pi^+$ in the signal region by forcing the K^+ to be in the backward hemisphere of the F decay, and therefore slow and well identified by dE/dx and time-of-flight measurements. Second, we demanded that the helicity angle of the K^- with respect to the K^+ in the $\bar{K}^{*0}$ rest frame satisfy the condition $|\cos\theta_H[K^-]| \geqslant 0.5$. In the decay $F^+ \to \bar{K}^{*0}K^+$, this angular distribution should be of the form $\cos^2\theta_H[K^-]$, since the $\bar{K}^{*0}$ must have helicity zero in the F rest frame. This helicity-angle cut removes 50% of the uniformly distributed combinatorial background, while retaining 87.5% of the F signal.

Figs. 2a and 2b show respectively the invariant-mass distributions of $\bar{K}^{*0}K^+$ for the $\bar{K}^{*0}$ mass band and for sidebands outside the $\bar{K}^{*0}$ mass, defined by the mass regions 0.75 GeV/c^2 to 0.80 GeV/c^2 and 1.0 GeV/c^2 to 1.05 GeV/c^2. The distribution in fig. 2a shows an enhancement near 1970 MeV/c^2, while the distribution in fig. 2b does not. The fitted number of F mesons are $87.2^{+19.1}_{-21.0}$ and <18 (90% confidence level), respectively, where the F mass was taken to be 1970 MeV/c^2 from the $\phi\pi^+$ channel and the RMS width was fixed from the detector Monte Carlo to be 16.0 MeV/c^2.

One possible difficulty with this channel is contamination by reflections from the decay $D^+ \to \bar{K}^{*0}\pi^+$, which peak around 1970 MeV/c^2, due to misidentification of the π^+ as a K^+. We have studied this problem with a detector Monte Carlo, and with the decay $D^0 \to K^{*-}\pi^+$, where $K^{*-} \to K^0_S\pi^-$ The virtue of this technique is that no F signal can complicate the study of reflections from the D^0.

A K^0_S defined as a $\pi^+\pi^-$ pair, which forms a secondary vertex where at least one of the two tracks is separated from the primary vertex by more than 7σ. Furthermore, the invariant mass of the pair must lie within ± 50 MeV/c^2 of the K^0_S mass, and the χ^2 for a constrained fit to that mass must be less than 36

In the $K^0_S\pi^-\pi^+$ invariant-mass distribution a clear peak is observed at the D^0 mass (fig. 3) Reflections from this signal, arising from misidentification of the π^+, can be studied by examining the $K^0_S\pi^-K^+$ mass distribution. The number of $K^0_S\pi^-K^+$ events fitted at the F mass with a width of 16 MeV/c^2 is shown in fig. 4 as a function of $\cos\theta_{K^*}$. The mass distributions in each angular bin were fitted with a gaussian of the same fixed mass and width plus a third-order polynomial background. For the interval, $\cos\theta_{K^*} \geqslant 0.2$, no signal is seen in the F region: reflection contributions fom D^0 decays are confined to the interval $\cos\theta_{K^*} < 0.2$. This demonstrates the effectiveness of the cut $\cos\theta_{\bar{K}^{*0}} \geqslant 0.2$, made in the F study, in removing practically all of the reflection

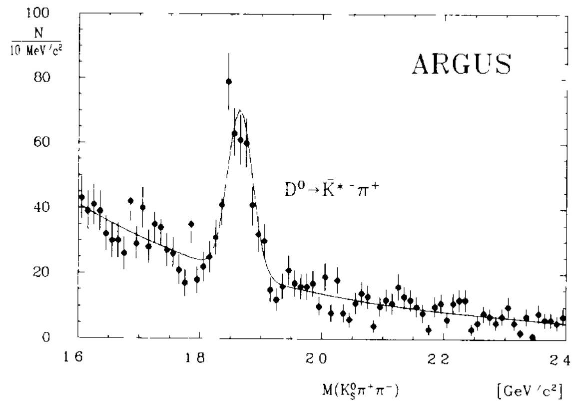

Fig 3 $K^0_S\pi^-\pi^+$ invariant-mass distribution with $M(K^0_S\pi^-)$ in the K^* mass region, $p(K^0_S\pi^-\pi^-) \geqslant 2.5$ GeV/c and $-1 \leqslant \cos\theta_{K^*} \leqslant 0.8$

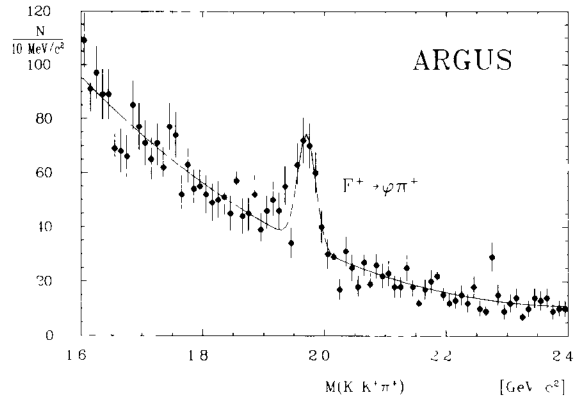

Fig 5 $K^-K^+\pi^+$ invariant-mass distribution with $M(K^-K^+)$ in the ϕ mass region, $p(K^-K^+\pi^+) \geqslant 2.5$ GeV/c and $-1 \leqslant \cos\theta_\phi \leqslant 0.8$

from D^+ decays. We have also studied with the detector Monte Carlo possible reflection contributions from the decay $\Lambda_C \to K^- p\pi^+$, where the proton is misidentified as a K^+. The cut $\cos\theta_{\bar{K}^{*0}} \geqslant 0.2$ is found to be effective in removing this reflection as well. In fig. 2a, the fit includes the fixed contribution from the D^+ reflection. The position, width and amplitude of this contribution were determined from the D^+ Monte Carlo and the data. The systematic error on the size of the F signal due to the Monte Carlo uncertainty and the statistical error from the D^+ data is ± 2 events.

Since the $\phi\pi$ decay mode of the F meson has been well established [1,2], it is convenient to find the

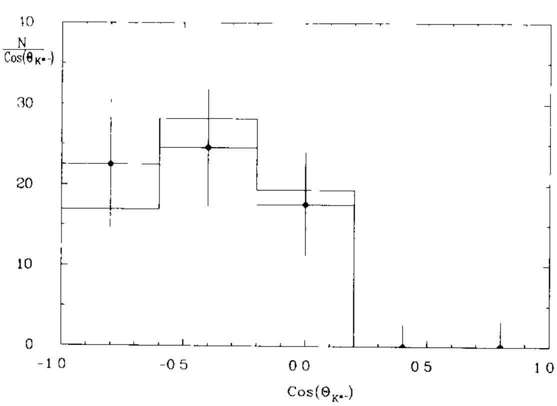

Fig 4 Number of $K^0_S\pi^+K^-$ events fitted at the mass in five $\cos\theta_{K^*}$ angular bins, where $M(F) = 1970$ MeV/c^2 and $\sigma(F) = 16.0$ MeV/c^2. The open histogram is the Monte Carlo prediction for reflection from D^0

ratio of the branching ratios for the $\bar{K}^{*0}K^+$ and $\phi\pi$ channels. The virtue of such a procedure is that the two channels have similar detector acceptance, and so, if the same data set is used in detecting both, common uncertainties largely cancel. The ratio of branching ratios is given by

$$\frac{BR(F^+ \to \bar{K}^{*0}K^+)}{BR(F^+ \to \phi\pi^+)} = \epsilon \frac{N(F^+ \to \bar{K}^{*0}K^+)}{N(F^+ \to \phi\pi^+)},$$

where ϵ is the ratio of the efficiencies for the two processes, and N is the number of events obtained with the same F momentum cut. In order to determine the number of $\phi\pi$ decays, we have processed the data with the same cuts as were applied to this channel in our earlier work [1]: namely, $1.005 \leqslant M(\phi) \leqslant 1.035$ GeV/c^2, $-1 \leqslant \cos\theta_\phi \leqslant 0.8$, where θ_ϕ is the corresponding angle to $\theta_{\bar{K}^{*0}}$, and $p(\phi\pi) \geqslant 2.5$ GeV/c. The resulting invariant-mass distribution is shown in fig. 5, and the number of $F^+ \to \phi\pi^+$ decays is found to be 152.3 ± 19.7. For this fit, the width was fixed to 15 MeV/c^2 from the detector Monte Carlo, and the mass was determined to be $1970.4 \pm 2.3 \pm 3.0$ MeV/c^2. The ratio of efficiencies, ϵ, was likewise determined from the Monte Carlo to be 3.41 ± 0.17, mainly due to the difference between the $\cos\theta_{\bar{K}^{*0}}$ and $\cos\theta_\phi$ cuts. Finally, accounting for the known branching ratios for $\phi \to K^+K^-$ of (49.3 ± 1.0)% and for $\bar{K}^{*0} \to K^-\pi^+$ of 2/3, we find

$$\frac{BR(F^+ \to \bar{K}^{*0}K^+)}{BR(F^+ \to \phi\pi^+)} = 1.44 \pm 0.37 .$$

The F-production cross section times branching ratio, σ_F BR, for the $\phi\pi$ channel is found to be $(14.7 \pm 1.9 \pm 1.9)$ pb, in good agreement with our previously reported [1] value of $(12.7 \pm 2.8 \pm 1.7)$ pb. In both cases the acceptance correction for the momentum cut is based on the Peterson [10] form of the fragmentation function, with the free parameter epsilon taken to be $0.50^{+0.22}_{-0.14}$ from our earlier publication. The corresponding result for the $\bar{K}^{*0}K^+$ channel is $(21.2 \pm 4.7 \pm 2.7)$ pb.

To conclude, we have observed the decay $F^+ \to \bar{K}^{*0}K^+$. The branching ratio to this channel is found to be 1.44 ± 0.37 times that for $F^+ \to \phi\pi^+$. Thus, the $\bar{K}^{*0}K^+$ decay mode of the F meson, which proceeds only through annihilation and colour-suppressed spectator diagrams, occurs at a rate comparable with that for the colour-favoured spectator decay $F \to \phi\pi$.

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References

[1] ARGUS Collab., H. Albrecht et al., Phys. Lett. 153 B (1985) 343.

[2] CLEO Collab., A. Chen et al., Phys. Lett. 51 (1983) 634; HRS Collab., M. Derrick et al., Phys. Rev. Lett. 54 (1985) 256, 2568.

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

[4] N. Ushida et al., Phys. Rev. Lett. 45 (1980) 1049, 1053; N.W. Reay, Proc. 1983 Intern. Lepton/photon Symp. (Cornell, 1983) p. 244; N. Ushida et al., Phys. Rev. Lett. 51 (1983) 2362; K. Abe et al., Phys. Rev. D 30 (1984) 1; M.I. Adamovich et al., Phys. Lett. B 140 (1984) 119, 123; M. Aguilar-Benitez et al., Phys. Lett. B 146 (1984) 266; MARK II Collab., J.M. Yelton et al., Phys. Rev. Lett. 52 (1984) 2019.

[5] MARK III Collab., R.M. Baltrusaitis et al., Phys. Rev. Lett. 55 (1985) 150.

[6] ARGUS Collab., H. Albrecht et al., Phys. Lett. B 158 (1985) 525.

[7] W. Bernreuther, B. Stech and O. Nachtmann, Z. Phys. C 4 (1980) 257.

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

[9] ARGUS Collab., H. Albrecht et al., Phys. Lett. B 150 (1985) 235.

[10] C. Peterson et al., Phys. Rev. D 27 (1983) 105.