MEASUREMENT OF MASS AND LIFETIME
OF HADRONICALLY PRODUCED CHARMED F MESONS

ACCMOR Collaboration

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ABSTRACT

We have observed three unique decays of F mesons into $KK\pi$ and five unique decays of D mesons into $KK\pi$, using the NALL spectrometer together with a telescope of high-resolution silicon microstrip detectors. The mass value obtained for the F meson is (1975 ± 4) MeV, the lifetime $(3.2^{+3.0}_{-1.3}) \times 10^{-13}$ s.

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1. INTRODUCTION

Evidence for charmed F-meson production has been reported in several experiments; for a summary of the results we refer the reader to review talks [1-3]. At this moment there are two conflicting measurements for the mass of the F meson. Most of the experiments report a mass value around 2020 MeV, while a recent result obtained in an e^+e^- experiment by the CLEO group at Cornell [4] shows a significant narrow enhancement in the $\phi\pi^\pm$ mass spectrum at 1970 MeV. This result is confirmed by the ARGUS [5] and TASSO [6] Collaborations at DESY.

In this paper we give supporting evidence for the CLEO result. Using high resolution silicon microstrip detectors, we have observed a total of six events which we interpret as the $KK\pi$ decay of the F meson; three events have an ambiguous solution with the $pK\pi$ decay mode of the Λ_c .

2. THE EXPERIMENT

The experiment was performed at the CERN SPS, using the ACCMOR spectrometer in a 200 GeV unseparated hadron beam. A schematic layout of the spectrometer is shown in fig.1. The beam is focused ($FWHM_{hor} = 12$ mm, $FWHM_{vert} = 0.3$ mm) onto a Be target of 20 mm length, 0.5 mm height, and 20 mm width.

The data have been taken under two different trigger conditions:

The single electron trigger (A) selects interactions containing an electron from the reaction

$$\text{hadron} + \text{Be} \rightarrow C + \bar{C} + X' \quad \text{or cc.} \\ \quad \quad \quad \downarrow \\ \quad \quad \quad e+X$$

(C represents any charmed particle), with the multicellular Cherenkov counter Q (π threshold of 12 GeV) and the lead scintillator calorimeter E-CAL (e threshold 2.8 GeV). A second-stage trigger uses the information from the multiwire proportional chambers P2 and calorimeter E-CAL in order to reduce background in the single electron trigger from hadrons, photons, and conversion pairs [7].

The inclusive ϕ trigger (B) selects interactions containing at least two oppositely charged kaon candidates from the reaction

$$\text{hadron} + \text{Be} \rightarrow K^+ K^- + \text{anything}$$

with multicellular Cherenkov counters C2 and C3, and the scintillator arrays MA and MB. A second-stage trigger [8] uses the information of the multiwire proportional chambers P3 and the Cherenkov counters to reconstruct the momenta of the kaon candidates on line; these momenta are required to lie between the π and K thresholds in C2 or C3, i.e. in the range 6.5–44 GeV; subsequently the invariant mass of the K pair is calculated and required to be below 1.15 GeV, in order to select mainly ϕ mesons.

The parts of the spectrometer used for the off-line reconstruction of the events are:

- Six silicon microstrip detectors (MSD) to measure the incident beam at the Be target with a precision $\sigma_{\text{hor}} = 25 \mu\text{m}$ and $\sigma_{\text{vert}} = 6 \mu\text{m}$.
- Six MSDs, arranged in three pairs with strips at an angle of $\pm 14^\circ$ to the horizontal plane, to measure the charged particles produced in the reaction. Each detector has an area of 24 mm $\times$ 36 mm and a spatial resolution of 4.5 μm (7.8 μm) in the central (outer) region. The measurement accuracy of tracks extrapolated to the primary vertex is 10 μm perpendicular to the beam, typically allowing a reconstruction of the position of the primary vertex along the beam with a precision of 150 μm . The spatial resolution decreases to approximately 20 μm (40 μm) in the central (outside) region of the detector, if the distance between two particle tracks is smaller than $\sim 120 \mu\text{m}$ (240 μm) within one projection. Further details on the detectors can be found in ref. [9].
- Forty-eight planes of large-area drift chambers (DC) and two spectrometer magnets (M1, M2) to measure the momenta of the charged particles.
- Three multicellular Cherenkov counters C1, C2, C3 to identify π , K, and p, in the momentum range 4–80 GeV.

The mass resolution and calibration of the spectrometer have been carefully checked using known particles such as K^0 , Λ^0 , K^{*} , ϕ , and D mesons [10]. Depending on the kinematics, the resolution for the decay $F(D) \rightarrow KK\pi$ varies between 5 and 20 MeV.

3. DATA ANALYSIS

Table 1 gives a summary of the number of events at different stages during the off-line analysis for both triggers A and B. For trigger A we have used only data obtained with incident negative beam, while for trigger B data obtained with both beam polarities have been analysed.

All events are fully reconstructed in the spectrometer with the help of the drift chamber information. Three Cherenkov counters allow us to identify a large fraction of the secondary produced particles. The numbers quoted in table 2 under the column "particle identification" represent a measure of the probability that the assigned particle type produced the observed Cherenkov signals taking into account photoelectron statistics and position dependence of light collection in the optical system. Particles without identification are indicated by dashes in the table. Any particle which has an ambiguous kaon/proton solution is accepted as a kaon candidate, while any ambiguous kaon/pion solution is rejected as a kaon candidate.

The analysis of the information provided by the microstrip detectors is restricted to those events which have the invariant mass of the K pair with any secondary pion in the interval $1.8 \text{ GeV} < M(K^+K^-\pi) < 2.2 \text{ GeV}$. For the data from trigger B we have restricted the mass of the K pair to the interval $1.01 \text{ GeV} < M(K^+K^-) < 1.03 \text{ GeV}$, i.e. selected the ϕ meson. Figure 2 shows the $\phi\pi$ mass spectrum for these data.

As shown in table 1, we are left with about 90,000 events to be analysed with the MSDs. The method of track reconstruction in the vertex telescope is described elsewhere [11]. Here we give a short summary of the strategy applied for event selection.

The main sources of background in reconstructing charm decays are:

- i) Errors in track reconstruction due to a wrong combination of measured coordinates with a physical track (as measured by the drift chamber system).
- ii) Secondary interactions.
- iii) Real charm events (partly with undetected neutrals) in which wrong track combinations have been selected for a vertex (i.e. by taking a track out of the primary vertex and attaching it to the $KK\pi$ vertex).

We have applied the following selection criteria to select clean charm decays:

- i) Events where all tracks form a single vertex are rejected.
- ii) If an individual vertex is formed by the $KK\pi$ tracks with a probability $\geq 10\%$, a search for the primary vertex is done by considering all other tracks (excluding the electron for the data of trigger A). The highest multiplicity vertex with probability $\geq 0.1\%$, which includes the beam and the momentum sum vector of the $KK\pi$ system, is taken as the primary vertex.
- iii) If more than one track is not assigned to either of the two vertices a search for an additional third vertex using these tracks is performed (this vertex should contain the electron for the data of trigger A). The event is rejected if this vertex does not include all remaining tracks, or if this vertex and the $KK\pi$ vertex are compatible with a single vertex.
- iv) The $KK\pi$ vertex and the primary vertex must be separated by more than 3 standard deviations in the beam direction.
- v) All three decay tracks have to miss the primary vertex (1 standard deviation for the closest, 3 standard deviations for all other tracks).

4. RESULTS

By applying the selection criteria mentioned in the previous paragraph we are left with a total of fourteen events, six belonging to sample A and eight to sample B. Five out of the six events in sample A have the charge of the electron opposite to the charge of the $(KK\pi)$ combination, as required for the decay of a charm-anticharm pair of particles, under the assumption that the electron originates from a semileptonic decay of one of the charmed particles. The sixth event has the wrong electron signature and is not considered for further analysis. A visual scan of the event reveals that the trigger electron probably originates from a very asymmetric photon conversion undetected in the prompt electron selection procedure. In every other respect this event fulfils all criteria of a good F-meson decay. The probability of finding such an F decay in the "wrong sign electron" data sample is estimated to be about 15%. Figure 3 shows one of the events. The coordinates in the MSDs reconstructed from the analogue information are indicated with a cross (x); the lines are the tracks reconstructed with the MSDs and DCs; one projection of the MSD reconstruction is shown together with a very much enlarged view of the vertex region, where the decay vertex is clearly visible.

Table 2 summarizes various properties of the fourteen events. Given are charge, momenta, and the probabilities for the particle assignments, and, independent of the identification probabilities, the effective mass for alternative interpretations of the decay particles. We only considered the decay modes $F(D) \rightarrow KK\pi$, $\Lambda_c^+ \rightarrow pK^-\pi^+$, $\Lambda_c^- \rightarrow \bar{p}K^+\pi^-$, and $D^\pm \rightarrow K^\mp\pi^\pm\pi^\pm$. None of the events however has a $K\pi\pi$ mass close to the D mass. Also given are the Feynman x_F for the decay, the measured proper lifetime (τ), and the corrected lifetime (τ_c) obtained after subtracting the minimum detectable decay distance due to the selection cuts.

Figure 4 shows the $KK\pi$ mass spectrum for the selected data sample. Events which have an approximately equal or bigger probability for a proton than a kaon assignment and have a $K\pi\pi$ mass value within 2 standard deviations of the Λ_c mass ($m = 2282$ MeV) [12] are shown hatched. The events are clustered at the D mass ($m = 1865$ MeV), and at $m = (1975 \pm 4)$ MeV, the mass found for the F meson by the CLEO group.

One event which has $m = (1830 \pm 5)$ MeV is considered as background, as its mass is incompatible with known charmed particle masses, as long as no additional unseen particles are allowed in the decay. The average of the measured lifetimes of the three unique F decays is 6.2×10^{-13} s. If we correct for the cuts needed for the selection of the events we obtain a corrected lifetime of $(3.2 \pm_{1.3}^{3.0}) \times 10^{-13}$ s.

The five events at the D-meson mass we interpret as the yet unobserved Cabibbo forbidden decay $D \rightarrow K^+ K^- \pi$. Comparing the two events found with trigger A with the sample of $D \rightarrow K \pi \pi$ from the same experiment [13] yields a branching ratio $KK\pi/K\pi\pi$ equal to (0.25 ± 0.20) . The average corrected lifetime for these events is $(13.3 \pm_{5.5}^{15.0}) \times 10^{-13}$ s (including corrections for long decays), in agreement with the value $(8.8 \pm 2.7) \times 10^{-13}$ s found from $K\pi\pi$ decays of the charged D meson [13]. The four events, which are ambiguous between F^- and $\bar{\Lambda}_c^-$ or D^+ and Λ_c^+ , have a corrected average lifetime of $(3.0 \pm_{1.1}^{2.1}) \times 10^{-13}$ s if interpreted as Λ_c .

Of the two unique F decays of sample A, for which the $K^+ K^-$ mass has not been constrained to the ϕ mass, none of the $K^+ K^-$ pairs originate from a ϕ meson decay. One of the two $D \rightarrow KK\pi$ decays from the same data sample is compatible with a $\phi\pi$ decay.

5. CONCLUSIONS

We have measured the mass and the lifetime of the F meson in the decay mode $F \rightarrow KK\pi$, using a magnetic spectrometer and a telescope of high-resolution silicon strip detectors. Our mass value of (1975 ± 4) MeV confirms the results obtained in recent $e^+ e^-$ experiments. The lifetime for the F of $(3.2 \pm_{1.3}^{3.0}) \times 10^{-13}$ s is similar to the lifetime of the neutral D meson and Λ_c baryon and smaller than the value found for the charged D meson. We also have found five D mesons decaying into $KK\pi$ and four $\bar{\Lambda}_c^-$ decays into $\bar{p} K\pi$; three of the $\bar{\Lambda}_c^-$ decays can be interpreted as the decay of an F meson and one as the decay of a D meson owing to ambiguous particle identification.

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Table 1 Data reductions.

	TRIGGER A	TRIGGER B	
selection stage	-200 GeV	-200 GeV	+200 GeV
Fast + second stage trigger	4.4×10^6	4×10^5	4×10^5
Selection of electron	1.2×10^6		
After rejecting electron pairs	260×10^3		
Select at least one K^+ and one K^-	22×10^3	1.7×10^5	1.8×10^5
Select			
$M(KK\pi): 1.8-2.2$	19×10^3		
and			
$M(KK): 1.01-1.03$		35×10^3	35×10^3

Table 2 Summary of properties of fourteen events. The values given for x_F and $\tau(\tau_c)$ are assuming a $KK\pi$ decay mode. If a particle cannot be identified (for example, it does not traverse the Cherenkov counters) the identification probability for π , K , and p is indicated by - ; if no light is found and no light expected for K and p , the identification probability for both K and p is 1.0. Events 12 to 14 have an incident positive beam.

EVENT TRIG.	MOMEN- TUM	PARTICLE IDENTIFICATION PROBABILITIES			M(KK π)	M(KK)	M(pK π)	x_F	$\tau(\times 10^{13})$	$\tau_c(\times 10^{13})$	
		π	K	p							for KK π interpretation
1. D $^-$	A	+30.3 -32.6 -56.6	0 0 0.20	0.17 0.13 0.18	0 0 0	1874 $\pm$ 5	1016 $\pm$ 2		0.59	6.5 $\pm$ 0.3	5.3 $\pm$ 0.3
2. F $^-$	A	+12.8 -46.6 -18.0	0.01 0 -	1.0 0.15 -	1.0 0.04 -	1969 $\pm$ 17	1234 $\pm$ 4	2222 $\pm$ 16	0.32	6.9 $\pm$ 0.3	4.8 $\pm$ 0.3
3. D $^+$	A	-19.5 +25.6 +5.8	0 0 -	0.34 0.15 -	0.68 0.68 -	1857 $\pm$ 10	1220 $\pm$ 7	2171 $\pm$ 9	0.22	3.1 $\pm$ 0.3	1.2 $\pm$ 0.3
4. F $^+$	A	-3.6 +26.7 +5.1	0.37 0.02 -	1.0 1.0 -	1.0 1.0 -	1984 $\pm$ 6	1627 $\pm$ 5	2187 $\pm$ 6	0.11	6.8 $\pm$ 0.6	2.0 $\pm$ 0.6
5. (F/A $_c$) $^-$	A	+19.2 -21.0 -4.9	0.01 0 0.79	0.93 0.05 0	0.36 0.38 0	1969 $\pm$ 5	1500 $\pm$ 4	2291 $\pm$ 5	0.18	5.1 $\pm$ 0.3	3.5 $\pm$ 0.3
Wrong sig- 6. nature electron	A	-19.5 +16.5 +15.0	0 0 0.16	1.0 1.0 0	1.0 1.0 0	1970 $\pm$ 5	1279 $\pm$ 4	2418 $\pm$ 5	0.21	7.6 $\pm$ 0.4	1.1 $\pm$ 0.4
7. D $^+$	B	-20.2 +19.3 +3.3	0 0 -	0.57 0.83 -	0.55 0.14 -	1869 $\pm$ 7	1023 $\pm$ 2	2215 $\pm$ 6	0.17	25.5 $\pm$ 0.3	22.9 $\pm$ 0.3
8. D $^+$	B	-22.8 +17.8 +12.6	0 0 -	0.63 0.88 -	0.28 0.17 -	1874 $\pm$ 15	1017 $\pm$ 2	2326 $\pm$ 14	0.23	28.0 $\pm$ 0.3	26.3 $\pm$ 0.3
9. F $^+$	B	-11.8 +17.3 +25.0	0.01 0 0.44	0.94 0.09 0	0 0.09 0	1970 $\pm$ 5	1011 $\pm$ 1	2423 $\pm$ 5	0.22	4.8 $\pm$ 0.3	2.8 $\pm$ 0.3
10 (F/A $_c$) $^-$	B	+17.1 -17.8 -3.2	0 0 0.37	0.68 0.57 0.20	0.13 1.0 0.20	1969 $\pm$ 6	1020 $\pm$ 2	2289 $\pm$ 5	0.14	6.0 $\pm$ 0.4	0.8 $\pm$ 0.4
11 (F/A $_c$) $^-$	B	+15.0 -18.7 -7.8	0.01 0 -	1.0 0.25 -	1.0 1.0 -	1955 $\pm$ 12	1024 $\pm$ 2	2288 $\pm$ 11	0.15	3.0 $\pm$ 0.5	0.4 $\pm$ 0.5
12. D $^+$	B	-16.3 +10.7 +40.1	0 0 -	0.19 0.81 -	0 0 -	1861 $\pm$ 32	1019 $\pm$ 2		0.31	2.5 $\pm$ 0.5	0.5 $\pm$ 0.5
13. -	B	-29.5 +37.6 +14.3	0 0 0.08	0.98 0.90 0	0 0 0	1830 $\pm$ 5	1020 $\pm$ 1		0.38	2.5 $\pm$ 0.6	0.2 $\pm$ 0.6
14 (D/A $_c$) $^+$	B	-19.0 +18.0 +15.2	0 0 -	0.90 1.0 -	0.10 1.0 -	1838 $\pm$ 16	1017 $\pm$ 2	2285 $\pm$ 17	0.23	10.9 $\pm$ 1.2	5.0 $\pm$ 1.2

Figure captions

- Fig. 1 : Top view of Nall spectrometer, showing target (Be), silicon microstrip detectors (MSD), magnets (M), drift chambers (DC), Cherenkovs (Q,C), multiwire proportional chambers (P), scintillator arrays (MA,MB), and electron (photon) calorimeters (E-CAL,G).
- Fig. 2 : Mass spectrum of all $\phi\pi$ combinations for data belonging to trigger B.
- Fig. 3 : a) Display of event No. 9 with the decay $F \rightarrow KK\pi$. The full lines are tracks reconstructed in MSDs and in DCs. The dash-dotted lines represent tracks only seen in MSDs.
b) Enlarged view of the vertex region.
- Fig. 4 : $M(KK\pi)$ for thirteen selected events (event No. 6 is not included). The hatched events are ambiguous with the interpretation $\Lambda_c \rightarrow pK\pi$.

Fig. 1

$M_{\phi\pi}$ [GeV]

Fig. 2

Fig. 3

Fig. 4