New results on charm decays and lifetimes from Fermilab experiment FOCUS

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ABSTRACT: FOCUS is a very high statistics charm experiment, run at Fermilab in 1996-1997, which reconstructed over 1,000,000 charm events). In this paper some of the latest results in the decays of charm mesons and baryons will be reported : new decay channels, singly and doubly Cabibbo suppressed decays, lifetimes, 3-body Dalitz analysis.

1. The FOCUS experiment

The fixed target experiment FOCUS (E831) took data in 1996-1997[1]. A γ beam impinged on a segmented 10% interaction length BeO target. A large aperture, forward spectrometer, with excellent vertex capabilities and particle identification, allowed the detection of the decay products of charmed mesons and baryons. The average γ energy was $\simeq 180$ GeV for events that satisfied the trigger. Charged particles from the target were detected in four planes of microstrips interleaved with the segments of the target. More downstream, 12

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planes of silicon microstrips were arranged in four stations with three views each. The whole microstrip detector provided an average resolution of $\sim 300~\mu$m in the direction along the beam and $\sim 6~\mu$m in the transverse directions. The momentum of the charged particles was detected by measuring the deflection in two analysing magnets and 20 planes of multiwire proportional chambers. Particle identification was provided by three threshold multicell Čerenkov counters for electrons, pions, kaons and protons while the muon identification was provided by scintillation counters and Resistive Plate Counters located behind large concrete and/or iron shieldings. Two electromagnetic calorimeters (a lead-glass calorimeter at small angles, a lead-scintillator sampling calorimeter at large angles) and a hadron calorimeter (a sampling iron-scintillator with tiles read out by WLS plastic fibers) where used to detect showers and provide signals to form the fast first level trigger.

2. Results shown at this conference

Presently FOCUS has the largest charm sample consisting of over a million reconstructed charm events. Here only some of the physics results will be mentioned : a) high statistics and/or new decay channels and relative branching ratios (BR) of charm mesons and baryons; b) lifetime measurements; c) Dalitz analysis of 3-body decays. Throughout this paper, whenever a decay is indicated, also the charge conjugate decay is implied.

3. High statistics and/or new decay channels and relative branching ratios of charm mesons and baryons

For almost all charm mesons new decay channels have been discovered or statistics has greatly improved compared to previous experiments.

1) $D^+ \to K^+ K^+ K^-$ and $D_s^+ \to K^+ K^+ K^-$. These doubly Cabibbo suppressed (DCSD) and singly Cabibbo suppressed decays (SCSD) have never been observed before. They are particularly interesting since they cannot occur via simple spectator diagrams. Preliminary results of relative BR are $\frac{\Gamma(D^+ \to K^+ K^+ K^-)}{\Gamma(D^+ \to K^- \pi^+ \pi^+)} = (0.14 \pm 0.02)\%$ and $\frac{\Gamma(D_s^+ \to K^+ K^+ K^-)}{\Gamma(D_s^+ \to K^- \pi^+ \pi^+)} = (0.87 \pm 0.25)\%$ (no systematic errors yet).

2) $D^+ \to K^+ \pi^+ \pi^-$ and $D_s^+ \to K^+ \pi^+ \pi^-$; these decays are DCS and SCS respectively. The FOCUS signal consists of 433 ± 48 events for the D^+ and 844 ± 43 events for the D_s, approximately 10 times the statistics of previous experiments E687 and E791. The BR relative to $K^+ \pi^+ \pi^-$ is under study and soon the result will be available.

3) $D^0 \to \pi^+ \pi^- \pi^+ \pi^-$; a very clean signal of 7609 ± 104 evts and $S/N = 12.6$ (largest statistics in the world) will allow the measurement of the relative BR $\frac{\Gamma(D^0 \to \pi^+ \pi^- \pi^+ \pi^-)}{\Gamma(D^0 \to K^- \pi^+ \pi^+ \pi^-)}$ with a precision of $\sim 3\%$.

4) $D^\pm \to K_s \pi^\pm$ and $D^\pm \to K_s K^\pm$; the statistics in this channels allows to measure the relative BR $\frac{\Gamma(D \to K_s \pi)}{\Gamma(D \to K\pi\pi\pi)}$ and $\frac{\Gamma(D \to K_s K)}{\Gamma(D \to K\pi\pi\pi)}$ with an unprecedented precision of $\sim 2\%$, and the first measure of $A_{CP} \equiv [\frac{\Gamma(D^+ \to K_s K^+)}{\Gamma(D^+ \to K^- \pi^+ \pi^+ \pi^-)} - \frac{\Gamma(D^- \to K_s K^-)}{\Gamma(D^- \to K^+ \pi^+ \pi^- \pi^-)}]/[\frac{\Gamma(D^+ \to K_s K^+)}{\Gamma(D^+ \to K^- \pi^+ \pi^+ \pi^-)} + \frac{\Gamma(D^- \to K_s K^-)}{\Gamma(D^- \to K^+ \pi^+ \pi^- \pi^-)}]$. These results have been submitted to PRL recently.

5) $D^+ \to K_s K^+ \pi^+ \pi^-$ and $D_s^+ \to K_s K^+ \pi^+ \pi^-$; these SCSD and Cabibbo favoured

decays respectively, have never been observed before. The FOCUS relative BR result is $\frac{\Gamma(D^+\to K_s K^+\pi^+\pi^-)}{\Gamma(D^+\to K_s\pi^+\pi^+\pi^-)} = (5.62 \pm 0.39 \pm 0.40)\%$.

6) $D^+ \to K_s K^+ K^- \pi^+$; this decay has also never been observed before. A raw yield of 35 ± 7 events gives a relative BR of $\frac{\Gamma(D^+\to K_s K^+ K^-\pi^+)}{\Gamma(D^+\to K_s\pi^+\pi^+\pi^-)} = (0.77 \pm 0.15 \pm 0.09)\%$.

7) Λ_c^+ decay channels. FOCUS could collect the highest statistics in the world not only in the golden mode $pK\pi$ but also in the following decay channels : a) $\Lambda_c \to \Lambda^0\pi^+\pi^+\pi^-$; the raw yield of this signal is 1101 ± 5 events with $\frac{S}{N} = 1.1$; b) $\Lambda_c \to pK_s$; the raw yield is 2822 ± 127 events with $\frac{S}{N} = 0.5$; c) $\Lambda_c \to \Sigma^+\pi^+\pi^-$; the raw yield is 1418 ± 63; d) $\Lambda_c \to \Sigma^-\pi^+\pi^+$; the raw yield is 472 ± 35 events; e) $\Lambda_c \to \Sigma^+ K^+ K^-$; the raw yield is 111 ± 16 events with a large component of $\Lambda_c \to \Sigma^+\phi$ (about 56% of the raw signal). This decay are particularly interesting since they cannot be described by simple spectator diagrams

8) Ξ_c^+ decay channels. The FOCUS large samples of Ξ_c^+ consist, among the others, of : a) $\Xi_c^+ \to pK^-\pi^+$; The raw yield is 202 ± 35 events. This is the only SCS decay channel of the Ξ_c^+ known up to day and the only other observation is by experiment SELEX in 2000. The relative BR $\frac{\Gamma(\Xi_c^+\to pK^-\pi^+)}{\Gamma(\Xi_c^+\to\Sigma^-\pi^+\pi^+)} = 0.234 \pm 0.047 \pm 0.022$ and it is in agreement with the Selex result. b) $\Xi_c^+ \to \Omega^- K^+\pi^+$; this is a new decay according to PDG[2]. The raw yield is 25 ± 7 events and $\frac{S}{N} = 1.8$; c) $\Xi_c^+ \to \Lambda^0 K^-\pi^+\pi^+$; this channel has a raw yield of 137 ± 25 events; d) $\Xi_c^+ \to \Sigma^+ K^-\pi^+$; this signal consists of 181 ± 18 raw events.

9) Ξ_c^0 decay channels. FOCUS presently has two relatively high statistics channels : a) $\Xi_c^0 \to \Xi^-\pi^+$; (94 ± 14 events) and b) $\Xi_c^0 \to \Omega^- K^+$; this decay cannot be described at the tree level by a spectator diagram, but by an exchange diagram. The signal consists of 42 ± 11 events.

4. Lifetime measurements

The FOCUS collaboration is analysing the lifetime of all the singly charmed mesons and the Λ_c, Ξ_c^+ and Ξ_c^0 baryons and, in the future, the lifetime of the Ω_c^0. In this way it will be possible to determine better the lifetime hierarchy of the singly charmed particles, which is very important from the theoretical point of view.

1) D^0 and D^+ lifetime;
preliminary results from this analysis show that the statistical errors are already better than the PDG[2] errors (which are 13 fs for the D^+ and 2.8 fs for the D^0).The systematic errors are still being evaluated;

2) D_s^+ lifetime;
the preliminary result, obtained with 50% of the total sample in the decay channel $D_s^+ \to \Phi\pi^+$ is $\tau = 506 \pm 8$ fs, where the error is statistical only. This is in agreement with the present PDG average of 496^{+10}_{-9} fs; the statistical error is already comparable.

3) Λ_c lifetime;
the preliminary result obtained using 80 % of the whole data set is $\tau = 204.5 \pm 3.4(stat.)$ fs and it is in agreement with and has better error than the present PDG[2] world average of $\tau = 206 \pm 12(stat.)$

4) Ξ_c^+ lifetime;

Table 1: *Preliminary fit results for $D^+ \to K^+K^-\pi^+$ Dalitz analysis.*

	fit fraction	phase (Degrees)
$\overline{K^{0*}}(890)$	0.30 ± 0.01	0 (fixed)
$\overline{K^{0*}}(1430)$	0.38 ± 0.01	65 ± 3
$\phi(1020)$	0.28 ± 0.01	-179 ± 4

Table 2: *Preliminary fit results for the $D_s^+ \to K^+K^-\pi^+$ Dalitz analysis.*

	fit fraction	phase (Degrees)
$\overline{K^{0*}}(890)$	0.44 ± 0.01	0 (fixed)
$\overline{K^{0*}}(1430)$	0.06 ± 0.01	114 ± 5
$\phi(1020)$	0.45 ± 0.01	148 ± 4
$f_0(980)$	0.16 ± 0.01	135 ± 4
$f_1(1710)$	0.04 ± 0.01	106 ± 8

the decay channels used in this analysis are $\Xi_c^+ \to \Xi^-\pi^+\pi^+$, $\Xi_c^+ \to \Sigma^+K^-\pi^+$, $\Xi_c^+ \to \Lambda K^-\pi^+\pi^+$ and $\Xi_c^+ \to pK^-\pi^-$. We measure $\tau = 0.439 \pm 0.022(stat.) \pm 0.009(sys.)$ ps. The PDG[2] world average is presently 330^{+60}_{-40} fs which is compatible within 2 σ with FOCUS result;

5) Ξ_c^0 lifetime;

a preliminary result obtained using only the decay channel $\Xi_c^0 \to \Xi^-\pi^+$ is $\tau = 124 \pm 10(stat.)$ fs, in agreement with the PDG[2] average of $\tau = 98^{+23}_{-15}$ fs.

5. Dalitz analysis

FOCUS has presently the largest statistics in the world for all 3-body decay channels of the D mesons. Here preliminary results from $D^+ \to K^+K^-\pi^+$, $D_s^+ \to K^+K^-\pi^+$, $D^0 \to K_sK^+K^-$, $D^+ \to \pi^+\pi^+\pi^-$ and $D_s^+ \to \pi^+\pi^+\pi^-$ are presented.

1) Dalitz analysis of $D^+ \to K^+K^-\pi^+$. The Dalitz plot consists of ~ 6600 events. Preliminary results are summarized in table 1. Three resonances dominate, the $\overline{K^{0*}}(890)$, the ϕ and the $\overline{K^{0*}}(1430)$. The absence of the non-resonant component in the fit fraction indicates that this is essentially a two-body decay. This preliminary results are in agreement with the previous experimental results by E687.

2) Dalitz analysis of $D_s^+ \to K^+K^-\pi^+$. The Dalitz plot consists of ~ 7500 events. The preliminary fit results are summarized in table 2. Also this decay is strongly dominated by the $\overline{K^{0*}}(890)$ and ϕ. The fit fraction of $\overline{K^{0*}}(1430)$ in this case is small and a sizeable fit fraction od $f_0(980)$ is present. This result is in agreement with the most recent experimental published result (E687).

3) Dalitz analysis of $D^0 \to K_sK^+K^-$. In this channel the D^0 is tagged with D^* to determine its charm content. This decay channel cannot be described by a simple spectator diagram and diagrams in which intermediate states couple both to K^+K^- and $\pi^+\pi^-$ (like $f_0(980)$ or $a_0^0(980)$) could play an important role. In fact in table 3 (preliminary results),

Table 3: *Preliminary fit results for $D^0 \to K_s K^+ K^-$ Dalitz analysis.*

	fit fraction	phase (Degrees)
$f_0(980)$ or $a_0^0(980)$	$0.692 \pm 0.044 \pm 0.02$	0 (fixed)
$\phi(1020)$	$0.462 \pm 0.036 \pm 0.02$	$-87 \pm 11 \pm 7$
$a_0^+(980)$	$0.124 \pm 0.034 \pm 0.02$	$140 \pm 19 \pm 6$

Table 4: *Preliminary fit results for the $D_s \to \pi^+ \pi^+ \pi^-$ Dalitz analysis.*

	fit fraction	phase (Degrees)
NR	0.2345 ± 0.0484	244 ± 6
$\rho^0(770)$	0.0058 ± 0.0076	229 ± 60
$f_0(980)$	0.9057 ± 0.0432	0 (fixed)
$f_2(1270)$	0.1020 ± 0.0143	141 ± 8
$S_0(1475)$	0.1922 ± 0.0351	70 ± 6
$\rho^0(1450)$	0.0354 ± 0.0088	200 ± 23

Table 5: *Preliminary fit results for the $D^+ \to \pi^+ \pi^+ \pi^-$ Dalitz analysis.*

	fit fraction	phase (Degrees)
NR	0.098 ± 0.043	0 (fixed)
$\rho^0(770)$	0.328 ± 0.038	63 ± 17
$f_0(400)$	0.189 ± 0.052	-97 ± 31
$f_0(980)$	0.067 ± 0.015	-146 ± 18
$f_2(1270)$	0.123 ± 0.021	-213 ± 18
$S_0(1475)$	0.018 ± 0.012	242 ± 26

beside the strong presence of ϕ one can actually see a large fit fraction for a $f_0(980)$ and/or $a_0^0(980)$ resonance and the presence of $a_0^+(980)$.

4) Dalitz analysis of $D_s^+ \to \pi^+ \pi^+ \pi^-$. The Dalitz plot consists of 1475 events. In this channel one expects the presence of resonances coupling to both $K\overline{K}$ and $\pi\pi$ to account for the absence of strange quarks in the final state (3π). As one can see from the preliminary results shown in table 4 one can actually note a large fit fraction for a $f_0(980)$ and conversely a very low fit fraction of $\rho^0(770)$.

5) Dalitz analysis of $D^+ \to \pi^+ \pi^+ \pi^-$. The Dalitz plot consists of 1527 events and presently it is the largest sample in the world. It is a CSD and the preliminary results are summarized in table 5. As one might have excpect, here the situation is somewhat reversed with respect to the previous Dalitz plot and there is a large fit fraction for the $\rho^0(770)$.

References

[1] The FOCUS spectrometer is an upgraded version of the Fermilab E687 spectrometer which is described in P.L.Frabetti et al., Nucl. Instrum. Meth. **A320**, 519 (1992).

[2] Review of Particle Physics, The European Physical Journal C **15**, 1 (2000).