Preliminary Results from FOCUS

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ABSTRACT: Fermilab's FOCUS experiment obtained a very high statistics sample of charmed particle decays. Preliminary results on spectroscopy, doubly Cabibbo suppressed decays and lifetimes are presented.

1. Introduction

The main goal of Fermilab's FOCUS (Photoproduction of Charm with an Upgraded Spectrometer) experiment was a tenfold increase in the number of charm events detected by an upgraded E687 spectrometer [1]. Among the many improvements for FOCUS, the changes to the target region were very significant. FOCUS used a segmented target in order to increase the percentage of charm decay vertices occurring outside the material which are free from backgrounds from secondary interactions. The addition of silicon detector planes interleaved with the target pieces improved the typical lifetime resolution for charmed decays from an initial 50fs down to 30fs.

FOCUS exceeded its goal by reconstructing more than 10^6 charm particle decays from a sample of more than 6.3x10^9 triggers collected during Fermilab's 1996-97 fixed target run. The results presented here are based on the preliminary analysis of partial data sets.

Among the many interesting topics in charm physics to be studied by FOCUS are spectroscopy, lifetimes, doubly Cabibbo suppressed decays, CP violation, mixing, rare decays, resonance structure (Dalitz plots), semileptonic decays and photoproduction dynamics. Only the first three topics will be discussed here.

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2. Charm Spectroscopy

A rich spectrum of charmed meson and baryon states is predicted from SU(4) together with heavy quark effective theory (HQET). Many of the predictions of the latter are borne out to a higher degree than expected even though the charm mass is really not that heavy. All of the meson ground states have been observed but there are several baryon ground states still missing including the doubly and triply charmed states. FOCUS has preliminary signals for most of the known ground and excited states.

As an example, Figure 1 presents the mass difference histograms used to determine the D^{*+}, D^{*0} mass splitting with roughly 25% of the total FOCUS sample. The decay channels involved ($D^{*+} \to D^+\pi^0$ and $D^{*0} \to D^0\pi^0$) require the use of the EM calorimeters which were upgraded for FOCUS. The right-hand plot shows the stability of the results as the vertex detachment cut is varied. For the $D^{*+} - D^+$ mass difference, we measure 140.64$\pm$0.10MeV (statistical error only), while the number for the $D^{*0} - D^0$ mass difference is 142.12$\pm$0.07(stat)Mev.

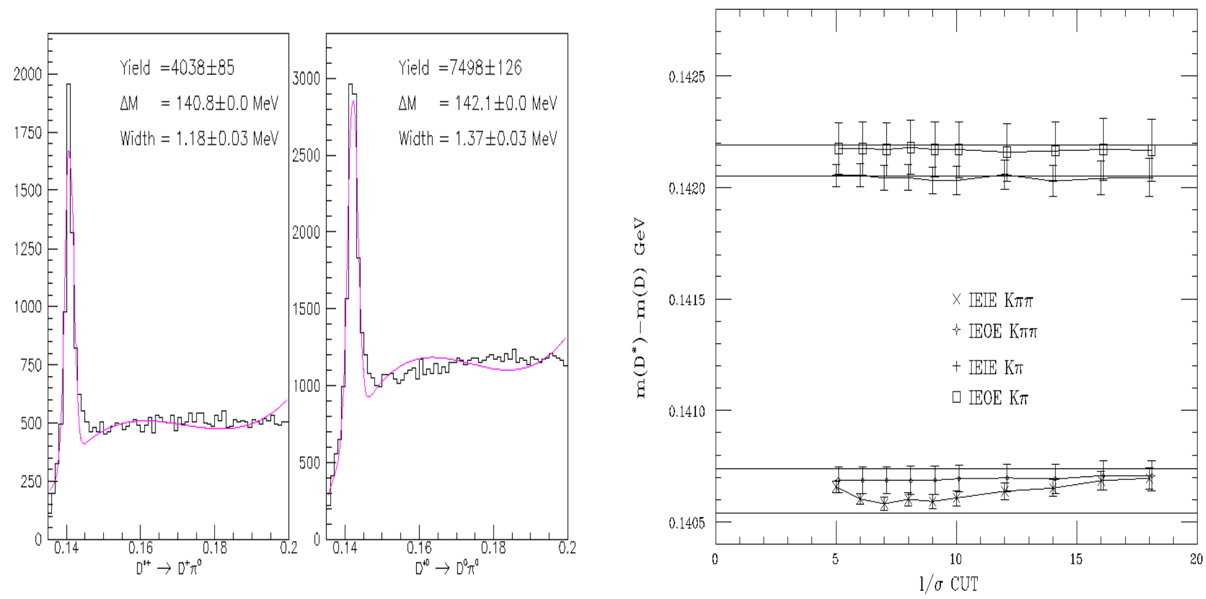

Figure 1. $D^* - D$ mass difference histograms for $D^{*+} \to D^+\pi^0$ (left) and $D^{*0} \to D^0\pi^0$ (center). On the right is a plot of the results as a function of the vertex detachment cut. The results are also divided according to the EM calorimeters used to identify the γs.

One of E687's EM calorimeters was replaced with a lead-glass array in FOCUS which has greatly improved our ability to study γ and π^0 channels. We project a total sample of over 25000 $D^{*0} \to D^0\pi^0$ events while the best existing measurement [2] was based on 1200 events. Further proof of our capability to study π^0 channels is provided in Figure 2 which shows a variety of D decays involving π^0s. With over 10^5 $D^{*+} \to D^0\pi^+$ events reconstructed in its total sample, FOCUS will be able to study the excited charmed

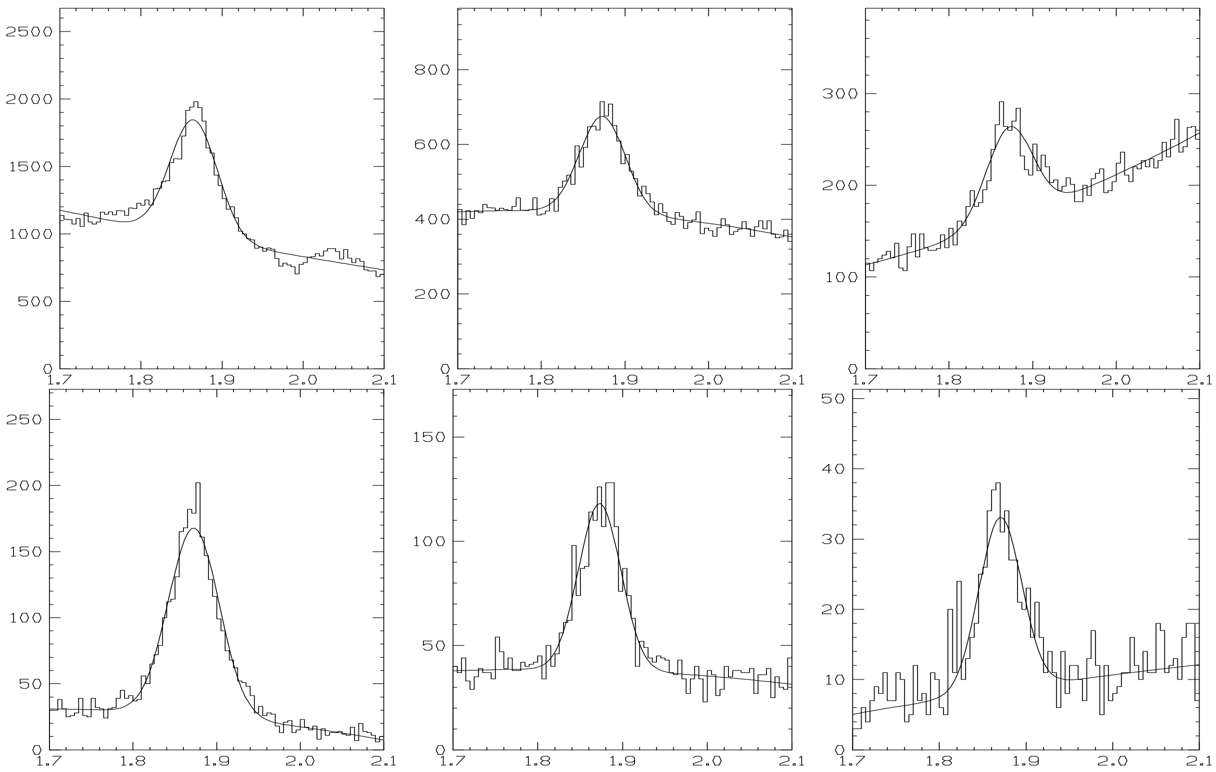

Figure 2. D decays involving $\pi^0 s$ from 20% of the FOCUS data. The top row from the left consists of $D^0 \to K^-\pi^+\pi^0$ (yield=12713), $D^+ \to K^-\pi^+\pi^+\pi^0$ (y=3545) and $D^0 \to K^-\pi^+\pi^+\pi^-\pi^0$ (y=1396). The bottom row shows the same channels with harder π^0cuts. The yields become 2150, 996 and 303.

meson states. Preliminary signals have already been found for $D_2^{*+}(2460) \to D^0\pi^+$, $D_2^{*0}(2460) \to D^+\pi^-$, $D_2^{*0}(2460) \to D^{*+}\pi^-$, $D_1^0(2420) \to D^{*+}\pi^-$, and $D_{sJ}^{*+}(2573) \to D^0 K^+$.

Precision studies of the charmed baryon states are made possible by a large and very clean Λ_c^+ sample (Figure 3). Besides the $pK^-\pi^+$ channel shown in Figure 3, many other Λ_c^+ decay channels are seen: $pK_s^0\pi^-\pi^+$, $\Lambda^0\pi^-\pi^+\pi^+$, pK_s^0, $\Lambda^0\pi^+$, $\Sigma^+\pi^+\pi^-$, $\Sigma^-\pi^+\pi^+$ and $\Xi^-K^+\pi^+$. These allow us to increase the statistics in the charmed baryon studies. FOCUS observes thirteen charmed baryon states. For example, several exclusive Ξ_c^+ decay channels give us a projected total sample of 860 events which is roughly six times the existing world sample. Some of the channels observed are $\Xi^-\pi^+\pi^+, \Lambda^0 K^-\pi^+\pi^+$, and $\Sigma^+K^-\pi^+$. We also confirm the Cabibbo suppressed (CS) channel $pK^-\pi^+$.

Among the early FOCUS baryon results, there is a preliminary measurement of the $\Sigma_c^{++} - \Sigma_c^0$ mass difference. This is of interest since the PDG98 value ($+0.57 \pm 0.23$MeV/c^2) would place it as the only known case where the isopartner containing the u quark (in this case two u quarks) has a higher mass than the one containing the d quark (at the 2σ level). We measure the $\Sigma_c^{++} - \Lambda_c^+$ mass difference in a sample of 362 $\Sigma_c^{++} \to \Lambda_c^+\pi^+$ events as $167.59 \pm 0.20 \pm 0.27$ MeV/c^2. The sample of $\Sigma_c^0 \to \Lambda_c^+\pi^-$ contains 487 events with a $\Sigma_c^0 - \Lambda_c^+$ mass difference of $167.54 \pm 0.19 \pm 0.34$ MeV/c^2. The result for the $\Sigma_c^{++} - \Sigma_c^0$ mass

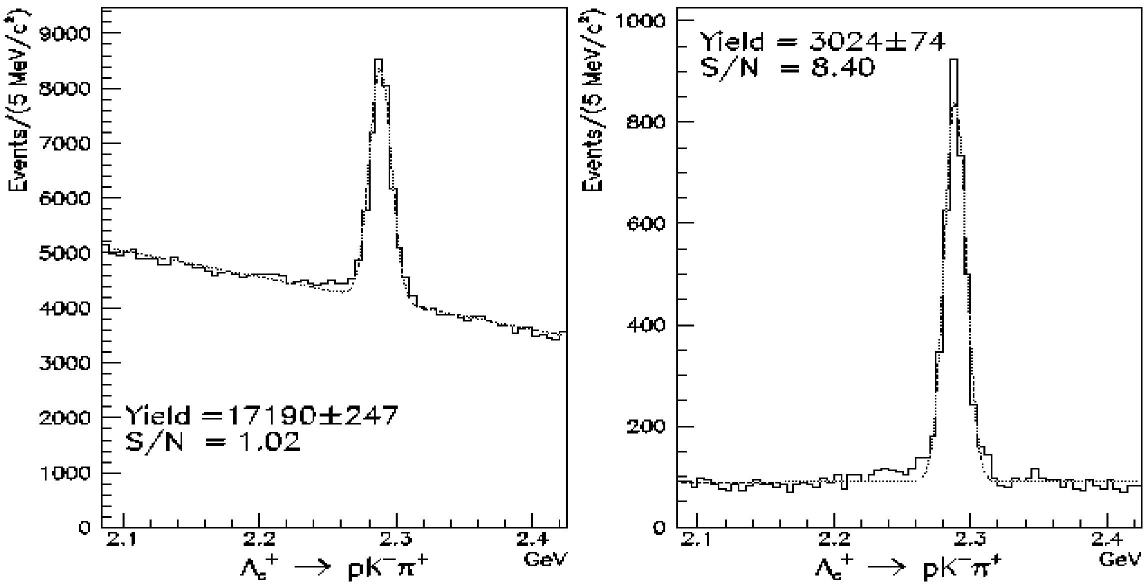

Figure 3. $\Lambda_c^+ \to pK^-\pi^+$ signal with loose and tight cuts.

difference is $+0.05\pm0.28 \pm 0.09$ MeV/c^2.

3. Doubly Cabibbo Suppressed Decays

FOCUS will make important contributions to the study of doubly Cabibbo suppressed (DCS) decays which are interesting due to the possibility of interference with mixing as well as for the unique insight into hadronic decay mechanisms. To zeroeth order, one expects the ratio to the Cabibbo favored (CF) decay to be $tan^4\theta_C \simeq 0.2\%$. Deviations from this are due to final state interactions, interference between diagrams, etc.

Figure 4 presents preliminary signals ($\backsim$ 50% of the total) for two DCS D^+ decays, $K^+\pi^+\pi^-$ and $K^+K^+K^-$. The singly Cabibbo suppressed (CS) decays of the D_s^+ to the same final states are also present. The DCS $K^+\pi^+\pi^-$ decay was first seen by E687 but the FOCUS statistical errors are much smaller. The preliminary result is:

$\Gamma(\ D^+ \to K^+\pi^+\pi^-)/\Gamma(D^+ \to K^-\pi^+\pi^+) = 0.72\pm0.09(stat)\%$.

The triple K decay of the D^+ is seen for the first time by FOCUS. This decay cannot occur via a spectator diagram because the $\overline{d}$ in the initial state does not appear in the final state. This is the rarest DCS decay yet observed. The preliminary result is:

$\Gamma(\ D^+ \to K^+K^+K^-)/\Gamma(\ D^+ \to K^-\pi^+\pi^+) = 0.13\pm0.023(stat)\%$.

4. Lifetimes

Comparisons of precise lifetime measurements of the different charm species shed light on the contributions of different non-leptonic diagrams to the decay processes. Typically, the rate for the fully leptonic decays is small due to helicity suppression and the semileptonic rates are approximately equal. Thus, for instance, the large difference between the

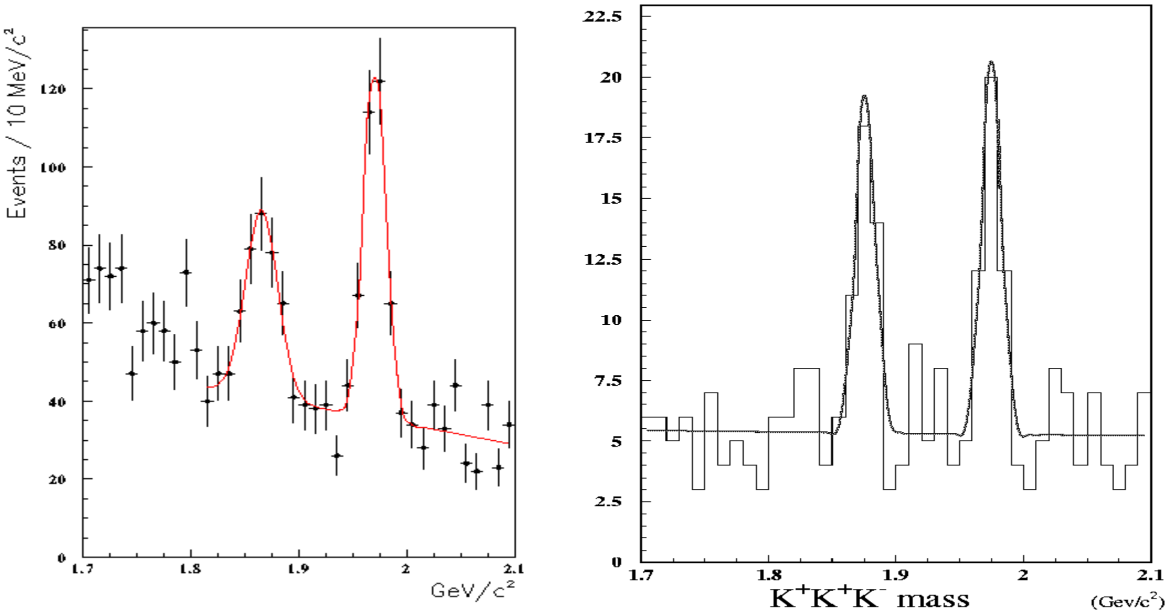

Figure 4. DCS D^+ decays. $K^+\pi^+\pi^-$ (left) and $K^+K^+K^-$ (right).

D^+ and D^0 lifetimes must be due to the non-leptonic processes. A systematic program of precise lifetime measurements will be important in understanding non-perturbative QCD.

E687 has been the only experiment to measure all the charmed particle lifetimes and FOCUS promises to improve these measurements based on its superior statistics and vertexing. As its first results, FOCUS has made preliminary measurements of the D_s^+ and Λ_c^+ lifetimes. The ratio of the D_s^+ to the D^0 lifetime is of great interest because any significant difference between them may be related to the presence of W-annihilation (WA) in the D_s^+ decay and W-exchange (WX) in the case of the D^0. In PDG98 the D_s^+ lifetime appeared to be 12% higher than the D^0's but only at the 3σ level. The implication of this result to the question of the size of the WA/WX contributions was further clouded by the fact that differences as large as 7% could be explained by other effects without any WX/WA contribution [3].

Figure 5 presents the main signal selection cuts and the reduced proper time histogram for the D_s^+ measurement which is based on approximately 50% of the total FOCUS data. The $\phi\pi^+$ channel was used. The $KK\pi$ mass cut is applied after a KK mass cut has selected the ϕ candidates. A cut is also made on the helicity angle of the decay. Angular momentum conservation dictates that the ϕ and π^+ must be in an orbital momentum L=1 state. The distribution of the angle between the π^+ and one of the kaons in the ϕ center-of-mass will be proportional to the cos^2 of the angle. The cut on this angle shown in the Figure is very effective at reducing background. The background-subtracted reduced proper time histogram has been corrected for acceptance as determined by Monte Carlo and the result of the fit is shown as the line in Figure 5. The actual fitting procedure involves a binned maximum likelihood technique where the lifetime distribution for the background events is determined from the mass sidebands and the amount of background

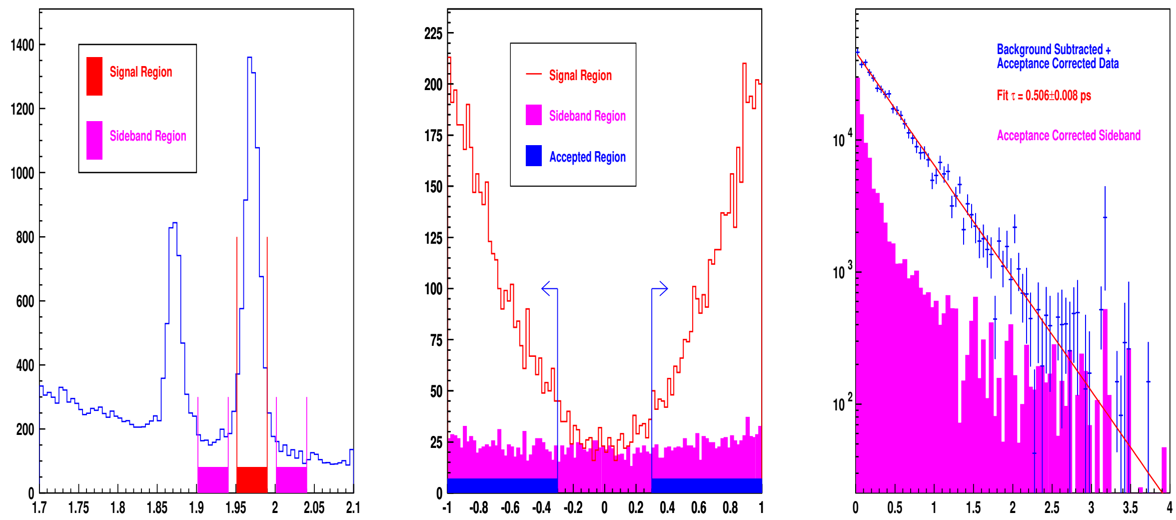

Figure 5. $D_s^+ \rightarrow \phi\pi^+$ signal (left), helicity angle distribution (center) and lifetime fit (right).

under the signal region is allowed to vary. The fitted lifetime is 0.506±0.008ps where the error is only statistical. The result for the lifetime ratio is 1.22±0.02(stat) establishing without question the significance of the non-spectator diagrams. However, given the possibility of destructive or constructive interference between these diagrams and the spectator diagrams, more experimental input is needed to sort out the size and sign of the contributions [4].

A similar procedure was used to measure the Λ_c^+ lifetime using approximately 80% of the FOCUS data. The $pK^-\pi^+$ mode is used for this analysis There are $\backsim$ 8500 decays in the signal peak. The preliminary result is 0.2045±0.0034(stat)ps.

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