$D^0$-$\bar{D}^0$ MIXING AND CP VIOLATION FROM FOCUS EXPERIMENT

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Measurement results on $D^0$-$\bar{D}^0$ mixing and CP violation are presented. FOCUS, a fixed target experiment at Fermilab, collected a high statistics photo-produced charm sample during the 96-97 run. We reconstructed more than 1 million charmed particles and compared the lifetimes of two $D^0$ meson decays to $K^-\pi^+$ and $K^-K^+$. The mixing parameter, $y_{CP}$, we obtained is $(3.42\pm1.39\pm0.74)\%$.

We also searched CP asymmetries in $D^+ \rightarrow K^- K^+ \pi^+$, $D^0 \rightarrow K^- K^+$ and $D^0 \rightarrow \pi^- \pi^+$ decay modes. We did not see any evidence of CP violation by comparing the decay rates for particle and antiparticle.

1 Introduction

FOCUS (Photoproduction of Charm with an Upgraded Spectrometer) is the successor of the E687 experiment with a significantly upgraded spectrometer, and it is designed to study charm physics. Charm particles are produced by the interaction of roughly 180 GeV high energy photons with a segmented beryllium oxide target.

During the 96–97 fixed target run at Fermilab, we collected more than 6.3 billion events and reconstructed more than 1 million charm particles in $D \rightarrow K\pi, K2\pi$ and $K3\pi$ decay modes. From this sample, we measured the lifetime differences in the $D^0$ meson system and searched for CP violation in singly Cabibbo suppressed $D$ meson decays. Since the Standard Model predictions for these processes are extremely small, any observation of a signal could be a clear indication of physics beyond the Standard Model.

2 $D^0$–$\bar{D}^0$ mixing

In hadronic decays of the neutral charm meson there is an interference term between the mixing and the doubly Cabibbo suppressed paths. By direct comparison of a lifetime difference between weak eigenstates we can search for charm mixing. Assuming both CP is conserved, and $D^0 \rightarrow K^- \pi^+$ is an equal mixture state of CP even and odd, then

$$y_{CP} = \frac{\tau(D \rightarrow K\pi)}{\tau(D \rightarrow K\bar{K})} - 1 \quad (1)$$

where $D^0 \rightarrow K^- K^+$ is a CP even eigenstate.

For analysis the sample was selected by requiring either $D^*$ tagging (tagged sample),
which satisfy the mass difference between $D^*$ and $D$ is within $3$ MeV/$c^2$ of the nominal value, or requiring more stringent cuts on particle identification for kaons and pions, momentum asymmetry $(|P_1 - P_2|/P_1 + P_2)$ between two daughter tracks, the resolution in decay proper time and requirement of primary vertex inside the target material (inclusive sample). The cuts are chosen not to bias the reduced proper time distribution. The tagged sample has clean signals while the inclusive sample gives a larger sample of events. After all of cuts applied, we have 119738 signal events in $K\pi$ and 10331 in $KK$ from the combination of two samples. The mass plots for the $K\pi$ and $KK$ candidates used in this analysis are shown in Figure 1. The reflection background coming from $K\pi$ decays in the $KK$ mass distribution is clearly seen and the amount of the reflection is obtained by a mass fit to the signal sample. The reflection mass shape is obtained from a high statistics Monte Carlo sample. We assume that time evolution of the reflection is described by the lifetime of $K\pi$ and fit the reduced proper time distribution of the $K\pi$ and $KK$ samples at the same time. There are four fit parameters: $K\pi$ lifetime, the lifetime difference between $K\pi$ and $KK$ and two background levels for the $K\pi$ and $KK$. The signal contributions for the $K^-\pi^+$, $K^-K^+$ and the reflection from misidentified $D^0 \rightarrow K^-\pi^+$ in the reduced proper time histograms are described by $f(t')\exp(-t'/\tau)$ in the fit likelihood. $f(t')$ is a function for any deviation from a pure exponential signal due to acceptance and absorption variation. The background number parameters are either floated or fixed to the number of events in mass sidebands using a Poisson term, which ties the background level to that observed in the sidebands, in the fit likelihood. The bin width of the reduced proper time is 200 fs. The fit results to the observed proper time distribution for $K\pi$.
and KK are shown in Figure 2. By changing the selection cuts and trying different fitting methods the systematic errors are estimated. We tested the particle identification hypothesis for kaon candidates and the minimum detachment required between primary and secondary vertices. The former affects the level of reflection backgrounds and the latter affects the amount of non-charm backgrounds. Since the results could be affected by various charm reflections which produce curved mass distributions and are therefore not properly subtracted from symmetrically placed sidebands, we check this effect by reducing sideband width by half. We also tried two different options of background handling as stated in the previous paragraph. The differences in fitted $y_{cp}$ are added quadratically. We tried other variations of selection and fitting and found that results are nearly identical to standard fits. We obtained

$$y_{cp} = (3.42 \pm 1.39 \pm 0.74)\%$$

(2)

Our result is consistent with that of E791 measurement but the sign of our measurement is opposite to that of CLEO. The theoretical expectation for the strong phase involved in this process varies and caution is needed in combining the $y_{cp}$ and the $y'$ (which is a rotational transformation of mixing parameters $x$ and $y$ that depends on a strong phase shift) into one mixing parameter, $y$.

3 CP violation

It is well known that CP violating effects occur in a decay process only if the decay amplitude is the sum of two different parts, whose phases are made of a weak and a strong contribution. The expected asymmetries are around $10^{-3}$. We look at the Cabibbo suppressed decay modes which have the largest branching fractions and select decay modes, $D^+ \rightarrow K^- K^+ \pi^+$, $D^0 \rightarrow K^- K^+$ and $D^0 \rightarrow \pi^- \pi^+$. We use the sign of the bachelor pion in the $D^{*\pm}$ decay to tag the neutral D as either a $D^0$ or a $\bar{D}^0$. In photoproduction fixed target experiment we must account for the different production rates of charm particles and antiparticles. This is done using Cabibbo favored modes $D^0 \rightarrow K^- \pi^+$ and $D^+ \rightarrow K^- \pi^+ \pi^+$. This way also has the advantage that most of the corrections due to inefficiencies cancel out by dividing the rate of singly Cabibbo suppressed decays by Cabibbo favored decay modes. We assume that there is no measurable CP violation in the Cabibbo favored decays. The CP asymmetry can be written as

$$A_{cp} = \frac{\eta(D) - \eta(\bar{D})}{\eta(D) + \eta(\bar{D})}$$

(3)

where $\eta$ (considering for example the decay mode $D^0 \rightarrow K^- K^+$)

$$\eta(D) = \frac{N(D^0 \rightarrow K^- K^+)}{N(D^0 \rightarrow K^- \pi^+)}$$

(4)

and $N(D^0 \rightarrow K^- K^+)$ is the efficiency corrected number of candidate decays. To tag the flavor of the neutral D meson $D^*$ tagging is required. As a result the statistical error in the neutral decay modes are larger than those of charged decay mode. Our measurements are summarized in the Table and results from E791 experiment are also presented. The FOCUS measurement is 2–3 times better than the the previous measurements by E791. We found no evidence for CP violation in the singly Cabibbo suppressed decay modes.

References

1. P.L. Frabetti et al., Nucl. Instr. Meth. A320, 519 (1992).
2. J.M. Link et al., Phys. Lett. B485, 62 (2000).
3. E.M. Aitala et al., Phys. Rev. Lett. 83, 32 (1999).
4. R. Godang et al., Phys. Rev. Lett. 84, 5038 (2000).
Table 1. CP asymmetry in D decays.

|        | $D^+ \rightarrow K^- K^+\pi^+$ | $D^0 \rightarrow K^- K^+$ | $D^0 \rightarrow \pi^-\pi^+$ |
|--------|--------------------------------|--------------------------|-----------------------------|
| FOCUS  | $+0.006 \pm 0.011 \pm 0.005$  | $-0.001 \pm 0.022 \pm 0.015$ | $+0.048 \pm 0.039 \pm 0.025$ |
| E791   | $-0.014 \pm 0.029$            | $-0.010 \pm 0.049 \pm 0.012$ | $-0.049 \pm 0.078 \pm 0.025$ |

5. S. Bergmann, Y. Grossman, Z. Ligeti, Y. Nir and A.A. Petrov, [hep-ph/0005181].
6. J.M. Link et al., [hep-ex/0005073].
7. E.M. Aitala et al., Phys. Lett. B403, 377 (1997); Phys. Lett. B83, 32 (1999).