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Flavor Changing Neutral Current Charm Decays

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The DØ collider experiment at Fermilab have studied flavor changing neutral current process $c \to u\mu^+\mu^-$ using a 508 pb^{-1} data sample of $p\,\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV. We observe the $D_s^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-$ final state with a significance above background greater than 7 standard deviations. We also measure $13.2^{+5.6}_{-4.9}$ of $D^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-$ events with a significance of 2.7 standard deviations above background and set a limit on the ratio of branching fractions of $\mathscr{B}(D^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-)/\mathscr{B}(D_s^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-) < 0.28$ at the 90% confidence level. Using the previously measured values of the $D_s^\pm \to \phi\pi^\pm$ and $\phi \to \mu^+\mu^-$ branching fractions we convert this to a limit on the branching fraction of $\mathscr{B}(D^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-) < 3.1 \times 10^{-6}$ at the 90% confidence level.

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1. Introduction

Flavor changing neutral current (FCNC) decays are forbidden at tree level in the standard model (SM) and proceed via higher order penguin or box diagrams. Many extensions of the SM (such as R-parity violating Supersymmetry [1]) allow for significant enhancement of FCNC decay rates with respect to SM expectations. Just as the decay $B^{\pm} \to J/\psi K^{\pm} \to K^{\pm} l^{+} l^{-}$ played a crucial role in benchmarking the studies of $b \to s l^{+} l^{-}$ transitions, the observation of the decay $D_s^{\pm} \to \phi \pi^{\pm} \to \pi^{\pm} l^{+} l^{-}$ is an essential first step in the study of $c \to u l^{+} l^{-}$ transitions. At this conference we report on a study of FCNC charm decays (of $D_s^{\pm}$ and $D^{\pm}$ mesons) including the observation of $D_s^{\pm} \to \phi \pi^{\pm} \to \pi^{\pm} \mu^{+} \mu^{-}$ decay. Our study is based on 508 pb^{-1} of Run II data delivered in 2002-2004 and recorded by the Tevatron's[1] DØ experiment [2].

2. Production and Reconstruction of $D_s^{\pm}$ and $D^{\pm}$

At the Tevatron, the D mesons are either directly produced in the $p\bar{p}$ collisions, or are created as the decay products of directly produced mesons, e.g. B. We take advantage of the excellent muon coverage of the DØ detector as we focus on the dimuon D decays. In this analysis, data taken with the dimuon triggers (with recording rate of ≈2Hz) have been used. We require two muons with transverse momentum $p_T > 2$ GeV$/c$. The dimuon system is formed by combining two oppositely charged muon candidates that are associated with the same jet [3] and the same primary vertex, form a well reconstructed vertex, and have an invariant mass $0.96 < m(\mu^{+}\mu^{-}) < 1.06$ GeV$/c^2$. The dimuon mass distribution in the region of the ϕ, ω, and ρ resonances is shown in Fig. 1.

Candidate $D_{(s)}^{\pm}$ mesons are formed by combining the dimuon system with a track ($p_T > 0.18$ GeV$/c$) that is associated with the same jet and primary vertex as the dimuon system. The invariant mass of the three body system must be in the range 1.3 GeV$/c^2 < m(\mu^{+}\mu^{-}\pi^{\pm}) < 2.5$ GeV$/c^2$. The three particles must form a well reconstructed vertex and the flight direction must be consistent with a particle originating from the primary vertex.

The above selection criteria yields on average more than three $D_{(s)}^{\pm}$ candidates/event in events where at least one candidate is reconstructed. We choose the candidate with the minimum value of $\mathscr{M} = \chi^2_{\rm vtx} + (1/p_T(\pi))^2 + \Delta R^2_{\pi}$, where $\chi^2_{\rm vtx}$ is the three particle vertex χ^2, ΔR_{π} is the distance in η, ϕ space between the π and the $\mu^{+}\mu^{-}$ system, and the π transverse momentum is in units of GeV$/c$. This selects the correct candidate in 90% of MC events. Events found outside of the 1.75 GeV$/c^2 < m(\mu^{+}\mu^{-}\pi^{\pm}) < 2.15$ GeV$/c^2$ region (sideband data) are used to model the background.

3. Background Suppression

Backgrounds are reduced by using likelihood functions of four variables: $\mathscr{I}_D, \mathscr{S}_D, \Theta_D$ and $\mathscr{R}_{\mathscr{S}}$. The isolation is defined as $\mathscr{I}_D = p(D)/\sum p_{\rm cone}$, where the sum is over tracks in a cone of $\Delta R < 1$ centered on the D meson; the transverse flight length significance $\mathscr{S}_D$ defined as the transverse distance of the reconstructed D vertex from the primary vertex normalized to the error

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[1] $p\bar{p}$ collider at $\sqrt{s}$ = 1.96 TeV located at Fermilab in the vicinity of Chicago in the USA. It expects to deliver ≈ 5000 pb^{-1} of Run II data until the end of 2009. The Tevatron hosts two collider experiments: the Collider Detector at Fermilab (CDF) and the DØexperiment.

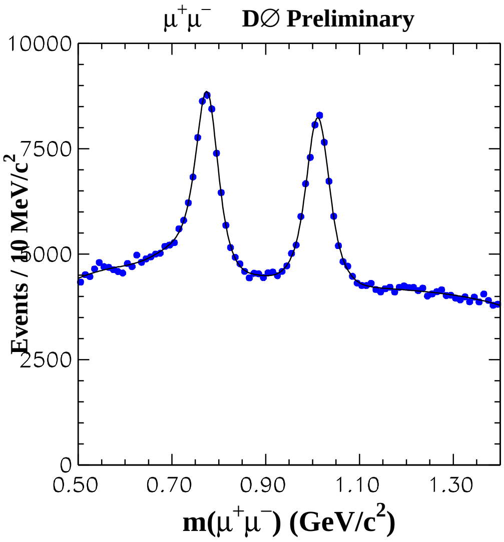

Figure 1: The inclusive $m(\mu^+\mu^-)$ invariant mass spectrum for the 508 pb^{-1} DØ data sample. The solid line is a fit to the distribution that includes components for $\phi \to \mu^+\mu^-$, $\omega \to \mu^+\mu^-$, and $\rho \to \mu^+\mu^-$ as well as combinatoric background.

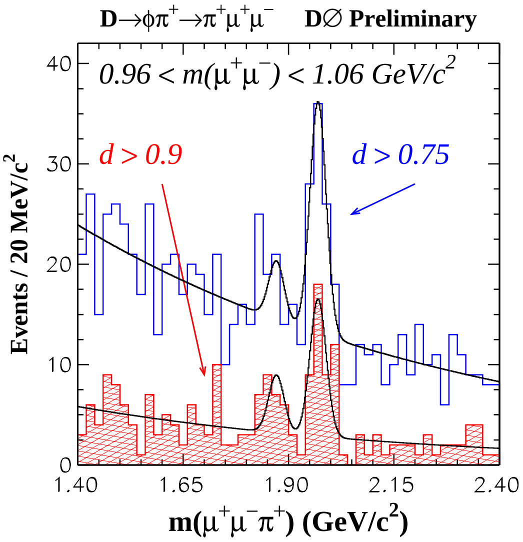

Figure 2: The $m(\pi^\pm\mu^+\mu^-)$ mass spectrum for events with the likelihood ratio $d > 0.75$ (blue) and $d > 0.9$ (red hatched). The results of binned likelihood fits to the distributions including contributions for $D_s^\pm$, $D^\pm$, and combinatoric background are overlaid on the histograms.

in the primary and D vertex measurements; the collinearity angle Θ_D defined as the angle between the D momentum vector and the position vector pointing from the primary to the secondary vertex; the significance ratio $\mathscr{R}_{\mathscr{S}}$ defined as the ratio of the $\pi^\pm$ impact parameter significance to $\mathscr{S}_D$.

For signal MC (S) and sideband data (B) events, we form combined likelihood variables ($\mathscr{L}$) reflecting correlations. We then select events, whose likelihood ratio $d = \mathscr{L}(\mathrm{S})/(\mathscr{L}(\mathrm{S}) + \mathscr{L}(\mathrm{B}))$ is greater than 0.9.

4. Results

Figure 2 shows the $m(\pi^\pm\mu^+\mu^-)$ mass spectrum for events passing all above described requirements. We observe 51 events in the $D_s^\pm$ signal region 1.91 GeV$/c^2 < m(\pi^\pm\mu^+\mu^-) < 2.03$ GeV$/c^2$ with an expected background of 18 events determined from extrapolating the event yields in the sidebands. This gives an excess of 33 events with a significance above background of 7.8 standard deviations.

The $D^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-$ signal is extracted from a binned likelihood fit to the data sample with $d > 0.9$ shown in Fig. 2 assuming possible contributions from $D_s^\pm$ and $D^\pm$ initial states as signal and combinatoric background. The signal distributions are modeled as Gaussians. The fit parameters are determined by relaxing the requirement on d to $d > 0.75$ and floating the mean and sigma of the $D_s^\pm$ Gaussian. The difference in the means of the $D_s^\pm$ and $D^\pm$ Gaussians are constrained to the known value [4] and the sigmas are constrained by $\sigma(D^\pm) = (m(D^\pm)/m(D_s^\pm)) \times \sigma(D_s^\pm)$.

The background is modeled as an exponential. The resulting fit is displayed in Fig 2. The fit yields 56^{+12}_{-11} of $D_s^\pm$ candidates in the region $d > 0.75$. Using the Gaussian parameters determined above, we search for an excess of $D^\pm$ events in the $d > 0.9$ data sample. The fit parameterization is identical to the fit above with the exception that the $D_s^\pm$ mean and sigma are now fixed to the values determined in the fit to the $d > 0.75$ region. The fit yields $13.2^{+5.6}_{-4.9}$ $D^\pm$ candidates in the region $d > 0.9$. This is consistent with a 2.7σ fluctuation in the background. We employ the following identity to measure or set a limit on $\mathscr{B}(D^\pm)$:

$$\frac{\mathscr{B}(D^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-)}{\mathscr{B}(D_s^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-)} = \frac{f(D_s^\pm)}{f(D^\pm)} \times \frac{\varepsilon(D_s^\pm; d > 0.75)}{\varepsilon(D^\pm; d > 0.9)} \times \frac{N(D^\pm; d > 0.9)}{N(D_s^\pm; d > 0.75)},$$

where the production fractions are $f(D_s^\pm) = 0.101 \pm 0.027$ and $f(D^\pm) = 0.232 \pm 0.018$ [5]. The efficiency ratio was determined from MC to be 1.6 ± 0.3, the uncertainty on the ratio of $D_s^\pm$ and $D^\pm$ yields was found to be +14%, -24%. The $D_s^\pm$ and ϕ branching fractions are taken from [4]. The statistical uncertainties were +47%, -43%. Combining the above quantities yields:
$\frac{\mathscr{B}(D^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-)}{\mathscr{B}(D_s^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-)} = 0.17^{+0.08}_{-0.07}{}^{+0.06}_{-0.07}$ and $\mathscr{B}(D^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-) = (1.70^{+0.79}_{-0.73}{}^{+0.76}_{-0.82}) \times 10^{-6}$.
We also determine the upper limit on these quantities at 90% C.L.:
$\frac{\mathscr{B}(D^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-)}{\mathscr{B}(D_s^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-)} < 0.28$ and $\mathscr{B}(D^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-) < 3.14 \times 10^{-6}$.

5. Conclusions

In conclusion, we have clearly observed the $D_s^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-$ process indicating that we have achieved better sensitivity to three body FCNC charm meson decays than any previous experiment that has reported results on these modes. Our SM limit on the $D^\pm \to \phi\pi^\pm \to \pi^\pm\mu^+\mu^-$ is almost a factor of 3 below the previous best limit set by the FOCUS collaboration [6].

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