Recent Charm Physics Results from the Tevatron

Paul E. Karchin[a] *

[a]Wayne State University, Department of Physics and Astronomy
666 W. Hancock St., Detroit Michigan 48201, United States of America

Three recent results on charm physics are presented based on Run II data using the Fermilab Tevatron Collider. The DØ collaboration reports preliminary results on the first observation of the rare decay $D_s^\pm \to \pi^\pm\phi$, $\phi \to \mu^+\mu^-$, a measurement of the branching fraction for $D^\pm$ to the same final state, and an upper limit for the non-resonant decay $D^\pm \to \pi^\pm\mu^+\mu^-$. The CDF collaboration reports a preliminary measurement of the angular distribution for $X(3872) \to J/\psi\pi^+\pi^-$ and restricts the $X(3872)$ quantum numbers to $J^{PC} = 1^{++}$ or 2^{-+}. Also, CDF reports a measurement of the ratio of branching fractions of the rare (doubly Cabibbo-suppressed) decay $D^0 \to K^+\pi^-$ and the Cabibbo-favored decay $D^0 \to K^-\pi^+$ (and charge conjugate decays).

1. Preliminary DØ Measurement of $D^\pm$ and $D_s^\pm \to \pi^\pm\mu^+\mu^-$

These decays are highly suppressed in the standard model (SM) and hence are sensitive to new physics. The only SM process for $D_s^\pm \to \pi^\pm\mu^+\mu^-$ occurs when the charm quark has a Cabibbo-favored weak transition leading to a virtual ϕ intermediate state, as shown in Fig. 1(A). For the $D^\pm$, the $\pi^\pm\mu^+\mu^-$ final state can be reached through a Cabibbo-suppressed transition of the charm quark leading to a virtual ϕ intermediate state (Fig. 1(B)), or through second-order, short-distance weak interactions, as shown in Fig. 1(C) and (D). The SM predictions for the branching fractions for the decays through the ϕ resonance are simply the product of the well-measured branching ratios $\mathcal{B}(D^\pm, D_s^\pm \to \pi^\pm\phi) \times \mathcal{B}(\phi \to \mu^+\mu^-)$. For $\mathcal{B}(D_s^\pm \to \pi^\pm\phi,\ \phi \to \mu^+\mu^-)$, the SM prediction is 10.3×10^{-6} and the best upper limit, from the FOCUS experiment, is 29×10^{-6} at 90% C.L. For $\mathcal{B}(D^\pm \to \pi^\pm\phi,\ \phi \to \mu^+\mu^-)$, the SM prediction is 1.77×10^{-6}. The SM prediction for non-resonant $\mathcal{B}(D^\pm \to \pi^\pm\mu^+\mu^-) = 9.4 \times 10^{-9}$. The best experimental upper limit, also from FOCUS, is $\mathcal{B}(D^\pm \to \pi^\pm\mu^+\mu^-) < 8.8 \times 10^{-6}$ at 90% C.L.

Rare decays of heavy flavor particles via flavor-changing neutral-current processes are sensitive to new physics. For down-type quarks, the transition $s \to d$ is studied in K meson decay and $b \to s$ is studied in B meson decay. However, in some new physics scenarios, the exotic signal appears only in up-type quark transitions, studied via $c \to u$ in D meson decays. Examples are an R-parity violating supersymmetry model [1] and a "little higgs" model with a new up-type vector quark [2]. The former model predicts a branching ratio for the non-resonant decay $D^\pm \to \pi^\pm\mu^+\mu^-$ significantly above the SM prediction.

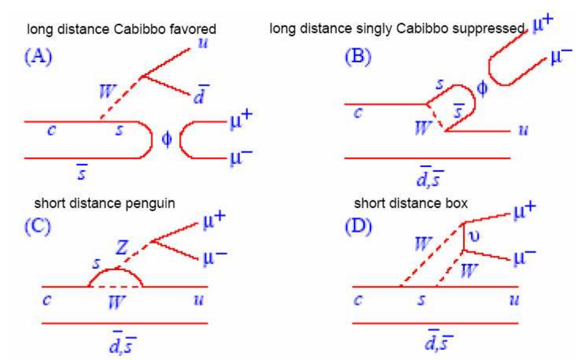

Figure 1. Standard model Feynman diagrams leading to $\pi^\pm\mu^+\mu^-$ final states from decay of $D_s^\pm$ (A) and $D^\pm$ (B), (C) and (D).

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The preliminary results from DØ [3] are based on an integrated luminosity of approximately 1 fb^{-1}. The data is recorded using a di-muon trigger. With cuts optimized for the decay $D_s^\pm \to \pi^\pm\phi$, $\phi \to \mu^+\mu^-$, a signal of 65 ± 11 is obtained for that decay and a signal of 26 ± 9 is observed for $D^\pm \to \pi^\pm\phi$, $\phi \to \mu^+\mu^-$, as shown in Fig. 2. This is the first observation of the $D_s^\pm$ decay mode. With cuts optimized for the $D^\pm$ decay mode, there are 6 candidates in the D^+ signal region and this is used to measure $\mathcal{B}(D^\pm \to \pi^\pm\phi, \phi \to \mu^+\mu^-) = 1.75 \pm 0.7(\text{stat}) \pm 0.5(\text{syst}) \times 10^{-6}$. The normalization is based on the signal and predicted branching fraction for the corresponding $D_s^\pm$ decay. The measurement of $\mathcal{B}(D^\pm \to \pi^\pm\phi, \phi \to \mu^+\mu^-)$ is consistent with the SM prediction. Using the same normalization technique mentioned previously, the resulting limit for the non-resonant decay is $\mathcal{B}(D^\pm \to \pi^\pm\mu^+\mu^-) < 4.7\times10^{-6}$ at 90% C.L. This limit is improved over the previous one, but well above the SM prediction and hence leaving open the possibility for new physics signals from more sensitive measurements.

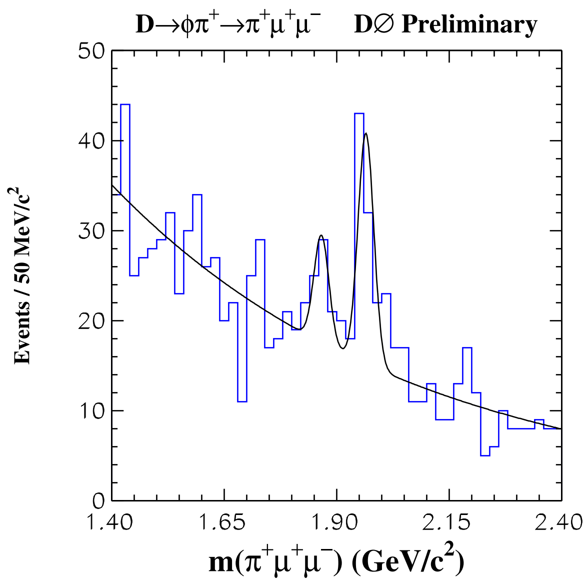

Figure 2. Invariant mass distribution showing signals for $D^\pm$ and $D_s^\pm \to \pi^\pm\phi$, $\phi \to \mu^+\mu^-$.

2. Preliminary CDF Measurement of $X(3872)$ Angular Distribution and Analysis of Quantum Numbers

The $X(3872)$ is a narrow resonance with a well established decay to the final state $J/\psi\pi^+\pi^-$. The fundamental composition of this state is unclear. Possibilities include charmonium (a $c\bar{c}$ resonance), a D^0 and $\overline{D}^{*0}$ bound into a "molecule" or an extended 4-valence-quark state with quark content $c\bar{c}d\bar{d}$. Determination of the spin J, parity P and charge-conjugation C quantum numbers can help identify the underlying nature of this state. The CDF collaboration reports a preliminary measurement [4] of the angular distributions of the $X(3872)$ decay products in the $J/\psi\pi^+\pi^-$ final state and resulting constraints on the J^{PC} quantum numbers.

In this analysis, the X is considered to decay into a J/ψ and an intermediate $(\pi^+\pi^-)$ resonant state. The $(\pi^+\pi^-)$ can be in an s-wave ($L_{\pi\pi} = 0$) or p-wave ($\rho, L_{\pi\pi} = 1$) state. The J^{PC} quantum numbers of the X affect the distributions of three angles: $\theta_{J/\psi}$ is measured between the μ^+ and its parent J/ψ direction, $\theta_{\pi\pi}$ is measured between the π^+ and its parent $(\pi^+\pi^-)$ direction, and $\Delta\Phi$ is measured between the μ-μ and π-π decay planes. The measured angular distributions are compared with simulated ones generated with a variety of possible J^{PC} values. The simulation uses a decay generator based on a helicity amplitude method and a parametric model for detector acceptance and efficiency.

The data correspond to an integrated luminosity of 0.78 fb^{-1} and were recorded using a dimuon trigger. An $X(3872)$ signal of 2292 ± 98 is obtained as seen in Fig. 3. The $\theta_{J/\psi}$-$\theta_{\pi\pi}$-$\Delta\Phi$ angular space is divided into $2 \times 2 \times 3 = 12$ bins. The signal yield, determined in each bin, is shown in Fig. 4. Expected distributions for 13 different J^{PC} hypotheses were determined and 4 of these are shown in Fig. 4. Based on a χ^2 comparison between data and prediction, only 2 of the 13 J^{PC} hypotheses have significant probabilities; these are 1^{++} (27.8%) and 2^{-+} (25.8%). All the other hypotheses lead to probabilities $< 0.02\%$.

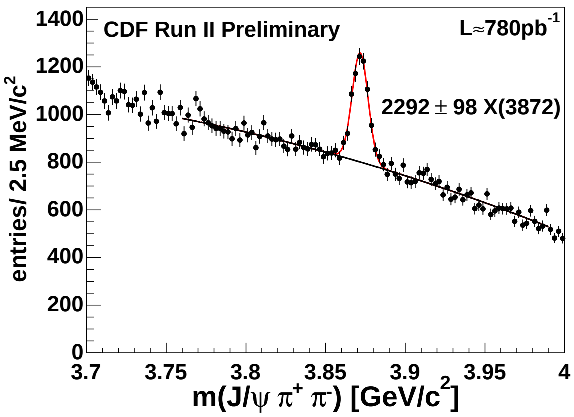

Figure 3. Invariant mass distribution showing the $X(3872)$ signal.

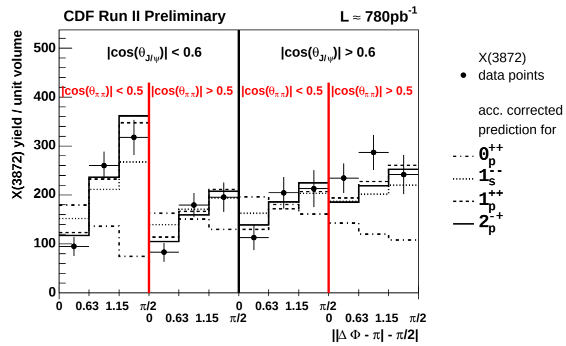

Figure 4. Angular distribution for $X(3872)$ decay products compared with expectations for different J^{PC} hypotheses.

Both of the probable J^{PC} hypotheses are consistent with charmonium states: χ'_{c1} (1^{++}) and 1^1D_2 (2^{-+}). However, the masses of these states predicted from charmonium models are not compatible with 3872 MeV/c^2. Furthermore, the decay of a charmonium state to $J/\psi\rho$ violates conservation of isospin. One of the probable states, 1^{++}, is compatible with a charm meson molecular state. As theoretical models of charmonium and exotic states improve, it may be possible to further restrict the interpretation of the $X(3872)$.

3. CDF Measurement of the Doubly Cabibbo Suppressed Charm Decay $D^0 \to K^+\pi^-$

In the SM, the decay $D^0 \to K^+\pi^-$ proceeds through a doubly Cabibbo-suppressed (DCS) tree diagram and possibly through a "mixing" process in which the D^0 changes into a $\overline{D}^0$. (In this section, discussion of a decay reaction implicitly includes the charge conjugate process.) The DCS decay rate depends on CKM factors as well as the magnitude of SU(3) flavor symmetry violation. Mixing may occur through two distinct types of second-order weak processes. In the first, the D^0 decays into a virtual ("long-range") intermediate state such as $\pi^+\pi^-$, which subsequently decays into a $\overline{D}^0$. The second type is a short range process, with either a "box" or "penguin" topology. It is not established whether long range mixing occurs. Its strength depends on SU(3) flavor symmetry violation. Short range mixing is negligible in the SM. However, exotic weakly interacting particles could enhance the short range mixing and provide a signature of new physics.

The ratio of branching fractions $R_{\mathcal{B}} = \mathcal{B}(D^0 \to K^+\pi^-)/\mathcal{B}(D^0 \to K^-\pi^+)$ is related to the parameters describing the underlying processes by $R_{\mathcal{B}} = R_D + \sqrt{R_D}y' + (x'^2 + y'^2)/2$, where R_D is the squared modulus of the ratio of DCS to Cabibbo-favored (CF) amplitudes, and x' and y' are parameters describing the mixing. In the limit of SU(3) flavor symmetry and without exotic physics, the charm-describing parameter R_D is equal to $\tan^4\theta_C$, where θ_C is the Cabibbo angle measured in kaon decays. The world average values, $R_D = (3.62 \pm 0.29) \times 10^{-3}$ and $\tan^4\theta_C = (2.88 \pm 0.27) \times 10^{-3}$, are equal within their uncertainties, consistent with SU(3) flavor symmetry. More accurate measurements are needed to test the relation further and search for charm mixing.

The CDF collaboration reports a measurement [5] of $R_{\mathcal{B}}$ based on an integrated luminosity of 0.35 fb^{-1} using data recorded with a secondary vertex trigger. The decay chain $D^{*+} \to \pi^+ D^0$,

$D^0 \to K^+\pi^-$ is reconstructed, where the charge of the π^+ from D^{*+} decay distinguishes the D^0 from $\bar{D}^0$. The large CF background is suppressed mainly by removing DCS candidates consistent with CF decays when the K and π assignments are interchanged for the D^0 decay products. The invariant $K^+\pi^-$ mass distribution, shown in Fig. 5, includes contributions from signal and backgrounds from pions randomly associated with D^* decay, misidentified CF decays because of interchanged K and π assignment, and random combinations of K and π.

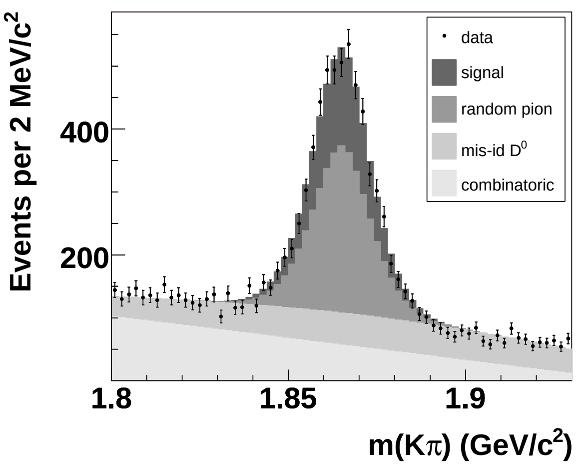

Figure 5. CDF data for $K^+\pi^-$ invariant mass with estimated contributions from DCS signal and backgrounds.

To determine the DCS signal, candidates are divided into 60 slices of Δm, each slice of width 0.5 MeV$/c^2$, where $\Delta m = m(K^+\pi^-\pi^+) - m(K^+\pi^-) - m(\pi^+)$. The D^0 signal yield is determined from the $K\pi$ mass distribution for each slice. The signal yields for all the slices are shown in Fig. 6. The total DCS signal is 2005 ± 104, which combined with the CF signal of 495172 ± 907 gives $R_{\mathcal{B}} = 4.05 \pm 0.21(\text{stat}) \pm 0.11(\text{syst}) \times 10^{-3}$. This result is consistent with measurements from the B factories, the most accurate of which is from Belle [6]. However, the difference between the CDF value and the world average for $\tan^4\theta_C$ has a significance of 3.4 σ. This difference could be due to a statistical fluctuation, a modest SU(3) flavor violation or a signal for mixing. Additional data from CDF with an analysis of $R_{\mathcal{B}}$ versus time should help sort out the effects of DCS decay, SU(3) flavor violation, and mixing.

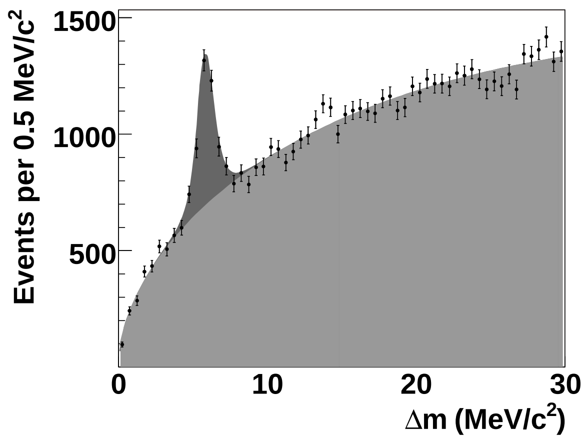

Figure 6. CDF data for $\Delta m = m(K^+\pi^-\pi^+) - m(K^+\pi^-) - m(\pi^+)$ and fit results for DCS signal and background.

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