



NEW CHARM(ONIUM) RESULTS FROM CDF

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After many upgrades to the CDF detector and to the accelerator complex, Run II began in April 2001. The new detector has improved capabilities for charm physics, and first results from the analysis of early Tevatron Run II data are reported here.

1 Introduction

After the very successful Tevatron Run I (1992-1995), colliding protons and antiprotons with a center of mass energy of $\sqrt{s} = 1.8$ TeV, the accelerator and the colliding beam experiments CDF and DØ were upgraded for Run II. On the accelerator side, the beam energy has been increased from 900 GeV to 980 GeV. A new proton storage ring, the “Main Injector”, has been built, and the same tunnel houses the “Recycler” storage ring, which will improve the rate at which antiprotons can be accumulated, and may also be utilized to reuse antiprotons after recovering them from the Tevatron. The bunch spacing in the Tevatron has been reduced from 3.5 μ s to 396 ns. The results shown below are based on early Run II data corresponding to an integrated luminosity of up to 69 pb^{-1} , i.e. comparable to the Run I data set ($\int \mathcal{L} dt \simeq 110 \text{pb}^{-1}$).

The CDF detector [1] is designed for general purpose use, with a large tracking system inside a uniform 1.4T solenoidal magnetic field, 4π calorimetry, and a muon detection system. The entire tracking system has been replaced for Run II, consisting of a Silicon tracking system with typically seven layers at radii of 1.5cm to 28cm, and the Central Outer Tracker (COT), an open cell drift chamber for the precise momentum measurement of charged tracks, using up to 96 space points. Between the COT and the solenoid is the new Time-of-Flight detector (TOF), which together with the momentum measurement provides particle identification by determining a particle’s mass. The three-level trigger system and the data acquisition system [2] have been significantly enhanced for Run II. Traditionally triggering on heavy flavor physics at hadron colliders relies on a lepton signature; examples are the decay of the J/ψ into $\mu^+ \mu^-$ or semileptonic b decays. With the Silicon Vertex Tracker (SVT) [3] at the second trigger level CDF has introduced a novel method to obtain heavy flavor

decays. The SVT uses COT tracks as seeds to a parallelized pattern recognition in the Silicon vertex detector. The following linearized track fit returns track parameters with nearly offline resolution on a time scale of $15 \mu\text{s}$. Originally designed to select hadronic B decays the SVT also collects a large sample of charm hadrons. All of the measurements shown here, with the exception of the J/ψ cross section, are based on data samples collected with the SVT.

2 Prompt D Meson Cross Sections

There is no published measurement of the charm cross section from the Tevatron. With the advent of the SVT this measurement is possible in Run II, and it is of theoretical interest due to the larger than expected beauty cross sections compared to next-to-leading order QCD calculations. The measurement shown here, based on the analysis of 5.8 pb^{-1} of data, makes use of four fully reconstructed decay modes: $D^0 \rightarrow K^-\pi^+$, $D^{*+} \rightarrow D^0\pi^+$ with $D^0 \rightarrow K^-\pi^+$, $D^+ \rightarrow K^-\pi^+\pi^+$, and $D_s^+ \rightarrow \phi\pi^+$ with $\phi \rightarrow K^+K^-$.

The contributions from prompt and secondary charm are separated by utilizing the impact parameter distribution of the reconstructed D meson samples. Mesons originating from B decays exhibit a large impact parameter. A fit to the impact parameter distribution yields prompt production fractions of $88.6 \pm 0.4(\text{stat}) \pm 3.5(\text{sys})\%$, $88.1 \pm 1.1 \pm 3.9\%$, $89.1 \pm 0.4 \pm 2.8\%$, and $77.3 \pm 3.8 \pm 2.1\%$ for D^0 , D^+ , D^+ , and D_s^+ , respectively, averaged over the full analyzed p_T range. The measured prompt differential cross sections are shown in Fig. 1. They are compared to a next-to-leading order QCD calculation [4], and a fixed order next-to-leading log calculation [5]. The calculations are lower than, but compatible with the data.

3 $m_{D_s^+} - m_{D^+}$ Mass Difference

The measurement of the $m_{D_s^+} - m_{D^+}$ mass difference provides a test for Heavy Quark Effective Theory and lattice QCD. While many precision measurements of meson masses can be expected from Run II, the analysis shown here could already be carried out with a modest amount of luminosity.

The mass difference measurement relies on D_s^+ and D^+ decays into $\phi\pi^+$ with $\phi \rightarrow K^+K^-$, as shown in Fig. 2. Using the same decay mode has the advantage of cancelling systematic uncertainties. The unbinned likelihood fit of the mass spectrum results in $m_{D_s^+} - m_{D^+} = 99.41 \pm 0.38(\text{stat}) \pm 0.21(\text{sys})\text{MeV}$, with uncertainties comparable to the world average [6]. This measurement constitutes the first published Run II result from CDF [7].

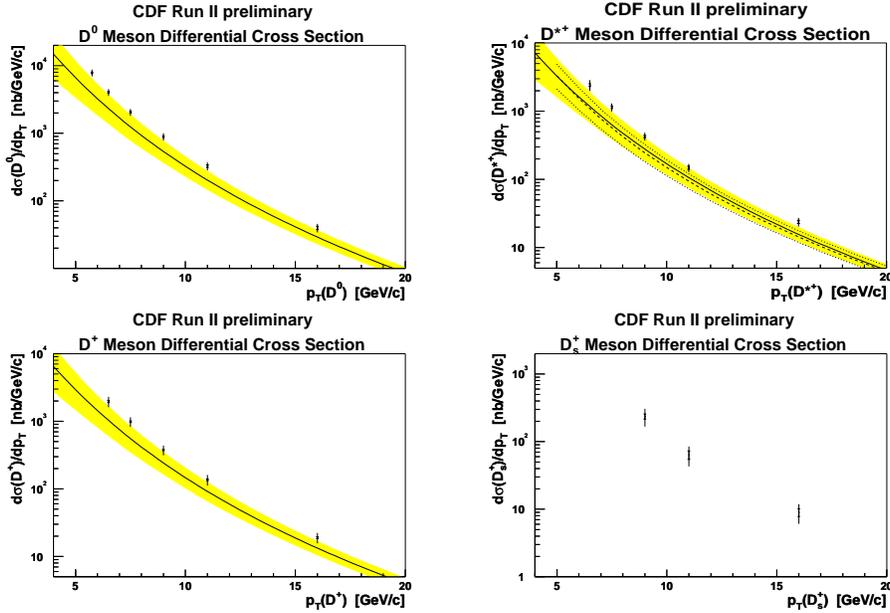


Figure 1: Differential cross section for the four reconstructed D mesons. Theoretical predictions from Kniehl *et al.* (dashed line with dotted line indicating uncertainty) and Cacciari *et al.* (full line with shaded band as uncertainty) are compared to the data. The theoretical uncertainties are based on varying the renormalization and factorization scales independently by factors of 0.5 to 2.

4 Cabibbo Suppressed Decays and CP Violation

Utilizing the large sample of D^0 mesons in 65 pb^{-1} integrated luminosity collected with the secondary vertex trigger, relative branching fractions are measured, $\frac{\Gamma(D^0 \rightarrow K^+ K^-)}{\Gamma(D^0 \rightarrow K^+ \pi^-)} = 9.38 \pm 0.18(\text{stat}) \pm 0.10(\text{sys})\%$ and $\frac{\Gamma(D^0 \rightarrow \pi^+ \pi^-)}{\Gamma(D^0 \rightarrow K^+ \pi^-)} = 3.686 \pm 0.076(\text{stat}) \pm 0.036(\text{sys})\%$, comparing favorably with the current best measurement [8]. In the analysis, the D^0 candidate is combined with a charged slow pion to form a D^* meson; in this way, backgrounds are reduced, and the charge of the slow pion from the D^* decay serves as an unbiased tag of the D^0 flavor. Examples of the reconstructed decays are shown in Fig. 3.

The CP violating decay rate asymmetries $A = \frac{\Gamma(D^0 \rightarrow f) - \Gamma(\bar{D}^0 \rightarrow f)}{\Gamma(D^0 \rightarrow f) + \Gamma(\bar{D}^0 \rightarrow f)}$ are also measured. It is found that $A(D^0 \rightarrow K^+ K^-) = 2.0 \pm 1.7(\text{stat}) \pm 0.6(\text{sys})\%$ and $A(D^0 \rightarrow \pi^+ \pi^-) = 3.0 \pm 1.9(\text{stat}) \pm 0.6(\text{sys})\%$, comparable to previous

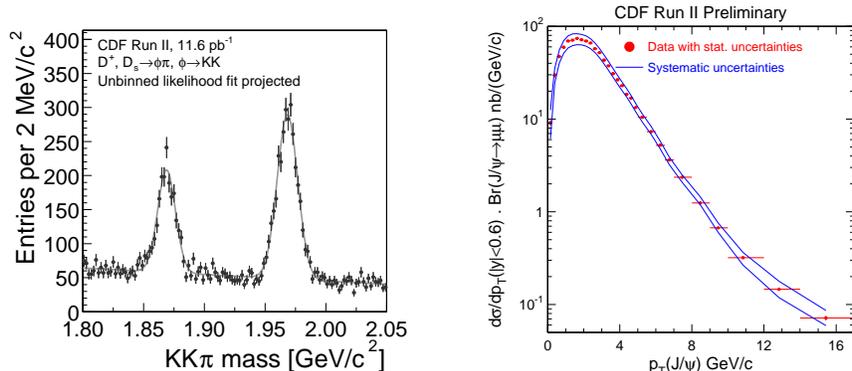


Figure 2: *Left:* The reconstructed $D^+ \rightarrow \phi\pi^+$ and $D_s^+ \rightarrow \phi\pi^+$ mass distribution. *Right:* The inclusive J/ψ cross section differential in p_T for $|y(J/\psi)| < 0.6$.

measurements [9].

5 Search for the FCNC Decay $D^0 \rightarrow \mu^+\mu^-$

The search for the flavor changing neutral current (FCNC) decay $D^0 \rightarrow \mu^+\mu^-$ is another example of an analysis that greatly benefits from the SVT trigger, by providing the well measured normalization mode $D^0 \rightarrow \pi^+\pi^-$. The branching ratio is $\mathcal{O}(10^{-13})$ in the Standard Model, but can be enhanced up to $\mathcal{B}(D^0 \rightarrow \mu^+\mu^-) \simeq 3.5 \cdot 10^{-6}$ in R-parity violating models of Supersymmetry. In a data sample corresponding to an integrated luminosity of 69pb^{-1} no candidate event is observed (Fig. 4) with 1.7 ± 0.7 background events expected. After correcting for relative acceptance an upper limit of $\mathcal{B}(D^0 \rightarrow \mu^+\mu^-) \leq 2.4 \cdot 10^{-6}$ at 90% CL is set, improving the current best limit [10] of $4.1 \cdot 10^{-6}$.

6 Measurement of the J/ψ Cross Section

One of the surprises of Run I was the direct production cross section for J/ψ and $\psi(2S)$ mesons [11], which turned out to be orders of magnitude larger than the theoretical expectation in the Color Singlet Model. While later calculations within the framework of non-relativistic QCD, including intermediate color octet states, are in broad agreement with the data, there is continued interest in the subject; in particular measurements of the J/ψ and $\psi(2S)$ polarization appear to be in conflict with the theory, albeit not with convincing statistical significance.

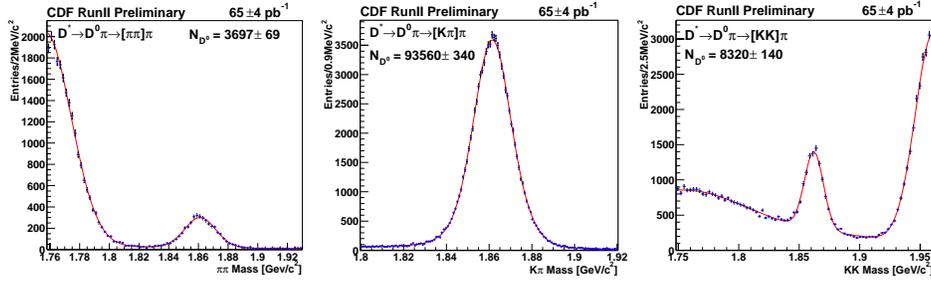


Figure 3: Reconstructed D^0 decay modes for branching ratio and CP asymmetry measurements. Note that in the KK (right) and $\pi\pi$ (left) modes the reflections are well separated.

For Run II the muon trigger momentum thresholds at CDF were lowered to $\geq 1.4 \text{ GeV}$, thus allowing to trigger on J/ψ 's at rest for the first time. Using a data sample of 39.7 pb^{-1} the inclusive differential cross section in bins of the J/ψ transverse momentum has been measured for J/ψ rapidities $|y(J/\psi)| < 0.6$ (Fig. 2). The region $p_T < 5 \text{ GeV}$ is covered for the first time. The total cross section has been determined to be $\sigma(p\bar{p} \rightarrow J/\psi X, |y(J/\psi)| < 0.6) \cdot \mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-) = 240 \pm 1(\text{stat})_{-28}^{+35}(\text{sys}) \text{ nb}$. In the future, the determination of the prompt production cross section, more precise data at large p_T , polarization measurements, and similar measurements of $\psi(2S)$, $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ production will shed further light on the production mechanisms for heavy vector mesons.

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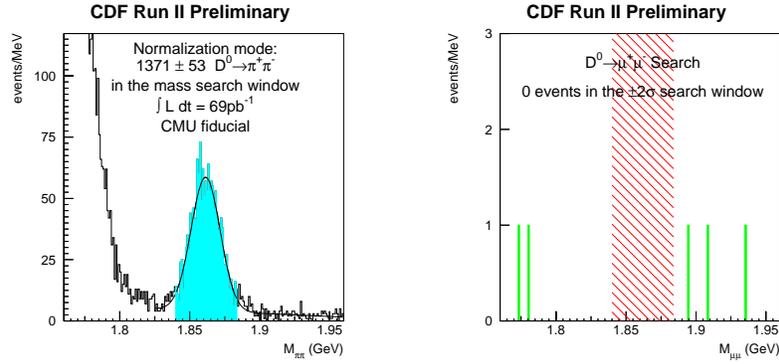


Figure 4: Search for $D^0 \rightarrow \mu^+ \mu^-$. *Left*: Mass spectrum for the normalization mode $D^0 \rightarrow \pi^+ \pi^-$; the search window is indicated by the shaded area. *Right*: Dimuon candidate events; the search window is indicated by the hatched area.

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