Charm Physics at the Tevatron

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First charm physics results from the CDF and D∅ experiments at the Tevatron Run II are presented. With the addition of the Secondary Vertex Trigger CDF has become a competitive charm experiment.

1 Introduction

The cross section of $p\bar{p}$ into charm is very high compared to $e^+e^-$-machines, but it is orders of magnitude smaller than the total cross section of $\sim 100\text{mb}$. This explains the need for a good trigger mechanism. Traditionally charm physics at hadron colliders relies on a lepton signature. For example, the decay of the $J/\psi$ into two leptons or semi-leptonic decays of $D$-mesons.

Both detectors at the Tevatron, CDF and D∅ have undergone substantial upgrades for RUN II. CDF now exploits a new trigger technique selecting more abundant hadronic decays.

2 $J/\psi$ Cross Section

D∅ measures the differential $J/\psi$ cross section in bins of rapidity using $4.74\text{pb}^{-1}$ of data. Using a data sample with an integrated luminosity of $39.7\text{pb}^{-1}$ CDF measures the differential cross section in bins of $p_T$. The resulting distributions are shown in Fig. 1.

For RUN II the muon trigger momentum thresholds at CDF were lowered to $\geq 1.4\text{GeV}$, allowing one to trigger on $J/\psi$'s at rest for the first time. The total inclusive cross section has been measured to $\sigma(p\bar{p} \rightarrow J/\psi X, |y(J/\psi)| < 0.6) \cdot B(J/\psi \rightarrow \mu\mu) = 240 \pm 1(\text{stat})^{+35}_{-28}(\text{sys})\text{nb}$. 
3 Secondary Vertex Trigger

With the Silicon Vertex Tracker (SVT)\(^2\) the CDF experiment has introduced a novel method to obtain heavy flavor decays.

The SVT uses tracks from the Central Outer Tracking chamber as seeds to a parallelized pattern recognition in the Silicon Vertex Detector. The following linearized track fit returns track parameters with nearly offline resolution. The precise measurement of the track impact parameter allows one to trigger on displaced tracks from long-lived hadrons containing heavy flavor.

Originally designed to select hadronic B-decays the SVT also collected a large sample of charm mesons.

4 Prompt D-meson Cross Section

The cross section is measured in four fully reconstructed decay modes: \(D^0 \rightarrow K^-\pi^+, D^{*+} \rightarrow D^0\pi^+, D^+ \rightarrow K^-\pi^+\pi^+\) and \(D^{*+}_s \rightarrow \phi\pi^+\) using 5.8pb\(^{-1}\) of CDF data.

In order to separate prompt and secondary charm, the impact parameter distribution of the reconstructed D-meson samples is used. Mesons originating from B-decay exhibit a large impact parameter. A fit to the impact parameter distribution yields prompt production fractions of 88.6\(\pm\)3.5\% for \(D^0\), 88.1\(\pm\)1.1\(\pm\)3.9\% for \(D^{*+}\), 89.1\(\pm\)0.4\(\pm\)2.8\% for \(D^+\) and 77.3\(\pm\)3.8\(\pm\)2.1\% for \(D^{*+}_s\)-mesons averaged over all \(p_T\) bins.

The measured prompt differential cross section is shown in Fig. 2. The total cross sections are found to be: \(\sigma(D^0, p_T \geq 5.5 GeV_c) = 13.3\pm0.2\pm1.5\mu b\), \(\sigma(D^{*+}, p_T \geq 6.0 GeV_c) = 5.4\pm0.1\pm0.8\mu b\), \(\sigma(D^+, p_T \geq 6.0 GeV_c) = 4.3\pm0.1\pm0.7\mu b\), \(\sigma(D^{*+}_s, p_T \geq 8.0 GeV_c) = 0.75\pm0.05\pm0.22\mu b\).

5 \(m_{D^{*+}_s} - m_{D^+}\) Mass Difference

The \(m_{D^{*+}_s} - m_{D^+}\) mass difference provides a test for HQET and lattice QCD. This measurement\(^4\), using only an integrated luminosity of 11.6pb\(^{-1}\), relies on \(D^{*+}_s\) and \(D^+ \rightarrow \phi\pi^+\) decays into \(\phi\pi^+\) as shown in Fig. 3. Using the same decay mode has the advantage of canceling systematics.

For a mass measurement a calibrated momentum scale is the key issue. A large \(J/\psi\) sample was used to calibrated energy loss and magnetic field. Slopes in the momentum dependence of the \(J/\psi\) are attributed to uncorrected energy loss. The corrections are adjusted to account for missing material. The overall mass shift with respect to the well measured world average \(J/\psi\) mass is used to fine tune the magnetic field. This is illustrated in Fig. 3.
It is found that the competitive measurement results in $m_{D_s^+} - m_{D^+} = 99.41 \pm 0.38_{\text{stat}} \pm 0.21_{\text{sys}} \text{MeV}/c^2$. 

### 6 Cabbibo Suppressed Decays and CP Violation

Utilizing the huge sample of $D^0$-mesons in 65pb$^{-1}$ integrated luminosity collected with the secondary vertex trigger CDF measures the relative branching fractions:

$$\frac{\Gamma(D^0 \rightarrow K^+K^-)}{\Gamma(D^0 \rightarrow K^+\pi^-)} = 9.38 \pm 0.18_{\text{stat}} \pm 0.10_{\text{sys}}\%$$

$$\frac{\Gamma(D^0 \rightarrow \pi^+\pi^-)}{\Gamma(D^0 \rightarrow K^+\pi^-)} = 3.68 \pm 0.07_{\text{stat}} \pm 0.036_{\text{sys}}\%$$

This result compares favorably with the current best measurement$^5$. The reconstructed decays are shown in Fig. 4. The CP violating decay rate asymmetries $A = \frac{\Gamma(D^0 \rightarrow f) - \Gamma(D^0 \rightarrow \bar{f})}{\Gamma(D^0 \rightarrow f) + \Gamma(D^0 \rightarrow \bar{f})}$ 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 measurements$^6$. 

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**Figure 2:** Differential cross section for the four reconstructed D-mesons. A theoretical prediction from a Fixed Order Next-to-Leading-Log calculation is overlaid$^3$. 

**Figure 3:** Left: Calibration of the momentum scale using the momentum dependence of the $J/\psi$ mass. Right: The reconstructed $D_s^+ \rightarrow \phi\pi$ and $D^+ \rightarrow \phi\pi$ mass distribution.
Figure 4: The reconstructed $D^0$ decay modes. It can be seen that the reflections are well separated. In order to determine the flavor of the $D^0$-mesons, they are reconstructed from $D^*$ decays.

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

A search for the flavor changing neutral current (FCNC) decay $D^0 \rightarrow \mu^+\mu^-$ has been conducted at CDF based on 69pb$^{-1}$ of data. This branching ratio is $O(10^{-13})$ in the standard model, but can be enhanced up to $B(D^0 \rightarrow \mu^+\mu^-) \sim 3.5 \times 10^{-6}$ in R-parity violating SUSY models. No signal is observed with 1.7 background events expected. Using the data sample from the secondary vertex trigger provides a well measured normalization mode $D^0 \rightarrow \pi^+\pi^-$. After correcting for relative acceptance an upper limit of:

$$B(D^0 \rightarrow \mu^+\mu^-) \leq 2.4 \times 10^{-6} \text{ at 90\% CL}$$

is found. This measurement improves the current world best limit \(^7\) of $4.1 \times 10^{-6}$.

8 Conclusion

A variety of competitive measurements have been performed, establishing that the experiments at the Tevatron are back online for physics. The ability to trigger on displaced vertices opens new and exciting possibilities for charm physics at hadron colliders.

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References

1. DØ Collaboration, FERMILAB-Pub96/357-E
   CDF II Collaboration, FERMILAB-Pub96/390-E (1996)
2. W. Ashmanskas et al, Nucl. Instrum. Methods A447, 218 (2000)
3. Priv. comm. by Cacciari and Nason, using M. Cacciari, M. Greco and P. Nason, JHEP 9805, 007 (1998) and M. Cacciari and P. Nason, Phys. Rev. Lett. 89, 122003 (2002)
4. CDF II Collaboration, Measurement of the Mass Difference $m(D^+_s) - m(D^+)$ at CDF II, FERMILAB-Pub03/048-E (2003), submitted to PRD.
5. FOCUS Collaboration, Phys. Lett. B 555, 167-173 (2003), preprint: hep-ex/0212058
6. CLEOII Collaboration, Phys. Rev. D 65, 092001 (2002), preprint: hep-ex/0111024.
7. BEATRICE Collaboration, Phys. Lett. B 408, 469 (1997).
   E771 Collaboration, Phys. Rev. Lett. 77, 2380-2383 (1996).