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Charm and Beauty at the Tevatron

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Abstract. The large heavy quark production cross section in $p\bar{p}$ collisions makes the Tevatron an excellent place to study charm and bottom physics. This allows for a rich program of spectroscopy, CP parameter measurements, and searches for new physics.

INTRODUCTION

The Tevatron is a $p\bar{p}$ collider at the Fermi National Accelerator Laboratory near Chicago Illinois. It operates at a center of mass energy of $\sqrt{s}$ = 1.96 TeV and is currently the highest energy hadron collider in the world. Two detectors, the Collider Detector at Fermilab (CDF) and D0, are operated at the Tevatron.

The Tevatron is an excellent place to study bottom and charm quark physics for two main reasons reasons: the large cross section ($\sim 100\mu b$) relative to e^+e^- colliders (few *nb*), and the production of a full spectrum of mesons and baryons with *b* and *c* quarks. Studies of the D^0, B^0_d and B^0_s systems give access to various CP parameters. Studies of rare decays give access to various CP effects as well as new physics[1]. In 2001, Fermilab began collider operations (Run 2) with a set of physics goals with a large emphasis on heavy quark (*c*,*b*,*t*) physics. The program in charm and and bottom physics has started with an emphasis on spectroscopy, and is starting to move on to searches for new physics and CP violation.

CDF and D0 Detectors

In order to pursue the previously described physics agenda after Run 1 the detectors at the Tevatron, CDF and D0, underwent extensive upgrades during the period 1996-2001. For the *B* physics programs at the two experiments, the upgrades addressed the following needs.

- Excellent tracking and vertexing.
- Ability to trigger on displaced vertices.
- Particle ID for flavor tagging.
- Efficient use of trigger bandwidth.

The upgraded CDF and D0 detectors have been described in more detail elsewhere[2].

Triggers and Datasets

Both D0 and CDF use three types of triggers for charm and beauty physics which roughly correspond to three different types of final states: di-lepton decays, semileptonic decays, and multi-hadron decays. The di-lepton triggers were used in Run 1 as well, but the single lepton trigger p_T thresholds have been lowered and the rapidity range extended. Semileptonic decays were measurable in Run 1 only by using single lepton triggers which had a low signal purity. The signal purity has been improved in Run 2 by adding a displaced vertex requirement which became possible due to the addition to the trigger of a programmable module which uses information from the silicon tracker to detect displaced vertices. This trigger has been in regular use at CDF, and is being commissioned at D0. The ability to trigger on displaced vertices also allows us to implement a trigger for charm and bottom decays to fully hadronic final states.

The Tevatron luminosity has been gradually improving since the beginning of 2002, and is approaching its initial design goals for instantaneous luminosity (5×10^{31} cm^{-2} s^{-1}). Since the end of commissioning in Spring 2002 this has allowed both experiments to accumulate over 150 pb^{-1} of integrated luminosity on tape. Due to data quality and ongoing detector studies the results presented here are based on up to 115 pb^{-1} for both CDF and D0.

RUN 2 RESULTS

Charm Spectroscopy

The displaced vertex trigger has opened up a large area of charm physics at the Tevatron which can be measured with relatively low levels of integrated luminosity. Figure 1 shows the ratio of the measured cross sections $d\sigma/p_T$ for $D^0 \to K^+\pi^-$, $D^+ \to K^\pm\pi^\mp\pi^\pm$, and $D^{*+} \to D^0\pi^+$ to theoretical calculations[3] as a function of p_T. As the figure shows, all of the ratios are systematically above 1.0.

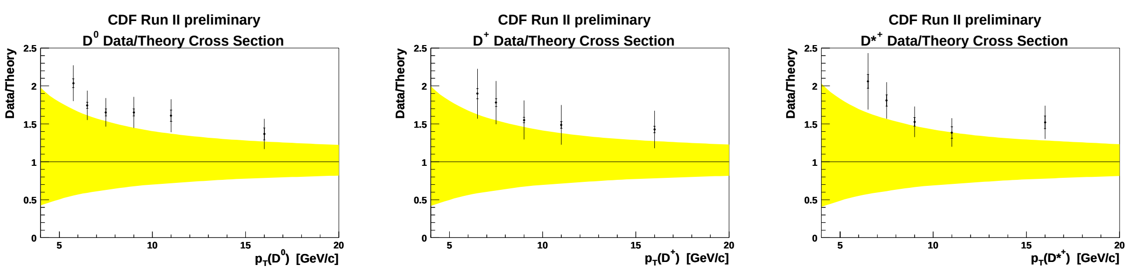

FIGURE 1. Ratio of Data to Theory for the exclusive charmed meson decays: $D^0 \to K^\pm\pi^\mp$, $D^\pm \to K^\pm\pi^\mp\pi^\pm$, and $D^{*\pm} \to D^0\pi^\pm$.

Using the lower p_T thresholds for muons available in early running at CDF, they measured the J/ψ inclusive cross section in $p\bar{p}$ collisions down to $p_T^{J/\psi} = 0$. This is the first time this has been done at a hadron collider.

Bottom Spectroscopy

A variety of bottom mesons and baryons have been reconstructed at the Tevatron using all three datasets: dilepton, semileptonic, and hadronic. Other than extended kinematic coverage the dilepton dataset is similar to what was available in Run 1, so analyses using this dataset are the most advanced. So far all results use only the dimuon channel. The results for B meson and b baryon masses and lifetimes for decays to a final state with a J/ψ are summarized in table 1. For the B_s^0 and Λ_b^0 mass measurements, these are already the best available measurements. Currently the Tevatron is the only place that b baryons can be studied, and we have already collected the world's largest number of observed Λ_b^0 decays using all three datasets as shown in figure 2.

TABLE 1. Masses and Lifetimes of bottom mesons and baryons. Unless otherwise indicated, where multiple uncertainties are quoted, the first uncertainty is statistical and the second is systematic.

Decay		CDF	D0
J/ψ inclusive	life	$1.526 \pm 0.034 \pm 0.035$	$1.552 \pm 0.013 \pm 0.028$
$B_u^+ \to J/\psi K^+$	mass	$5279.32 \pm 0.68 \pm 0.94$	5271.2 ± 1.7(stat)
	life	$1.63 \pm 0.05 \pm 0.04$	$1.65 \pm 0.083 \, ^{+0.096}_{-.1233}$
$B_d^0 \to J/\psi K^{*0}$	mass	$5280.30 \pm 0.92 \pm 0.96$	5264.8 ± 2.6(stat)
	life	$1.51 \pm 0.06 \pm 0.02$	$1.51 \, ^{+.19}_{-.17} \pm 0.20$
$B_s^0 \to J/\psi \phi$	mass	$5365.50 \pm 1.29 \pm 0.94$	5359.4 ± 3.8(stat)
	life	$1.33 \pm 0.14 \pm 0.02$	$1.19 \, ^{+.19}_{-.16} \pm 0.14$
$\Lambda_b^0 \to J/\psi \Lambda$	mass	$5620.4 \pm 1.6 \pm 1.2$	5600 ± 25(stat)
	life	$1.25 \pm 0.26 \pm 0.10$	$1.05 \, ^{+.21}_{-.18} \pm 0.12$

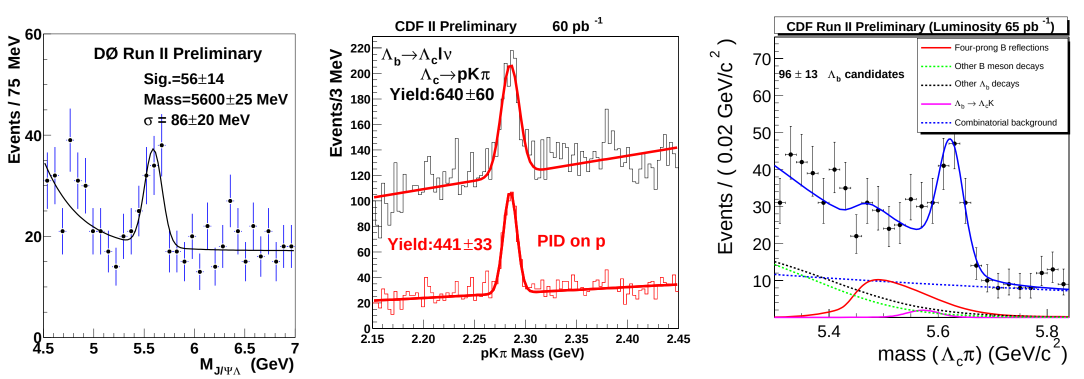

FIGURE 2. Reconstructed Λ_b^0 decays using the dimuon dataset, the semileptonic dataset, and the hadronic dataset.

Of particular interest for bottom physics at the Tevatron is the study of the properties of the B_s^0 meson. In a general sense it is less well measured than the B_d^0[4], and it also undergoes mixing in a similar way. In fact, there are a variety of CP measurements which benefit from a combined analysis of B_d^0 and B_s^0 decays which are possible at the Tevatron[5]. Figure 3 shows plots for the highest yield fully reconstructed B_s decay and an analogous B_d decay used for normalization and systematic studies.

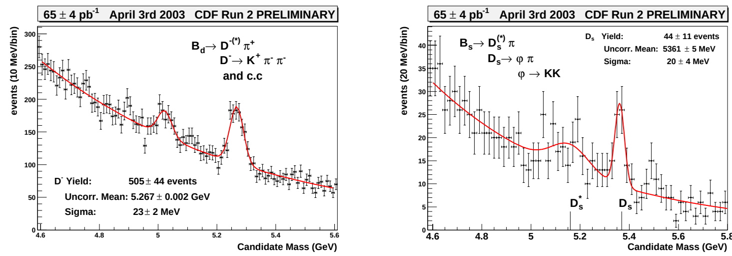

FIGURE 3. Reconstructed $B_d \to D^+\pi^-$ and $B_s \to D_s^+\pi^-$ decays.

Rare Decays

The large charm/bottom production rate has also produced results for the first rare decay searches from Run 2 at the Tevatron. The decays $D^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$ are highly suppressed in the Standard Model $\sim 10^{-9}$[6], but can be enhanced by various types of new physics[7]. Figure 4 shows the result for searches for these two decays which gives values of $BR(D^0 \to \mu^+\mu^-) < 2.4 \times 10^{-6}$ at the 90% confidence level and $BR(B_s^0 \to \mu^+\mu^-) < 9.5 \times 10^{-7}$ at the 90% confidence level. Both of these measurements are significant improvements on the current limits[4].

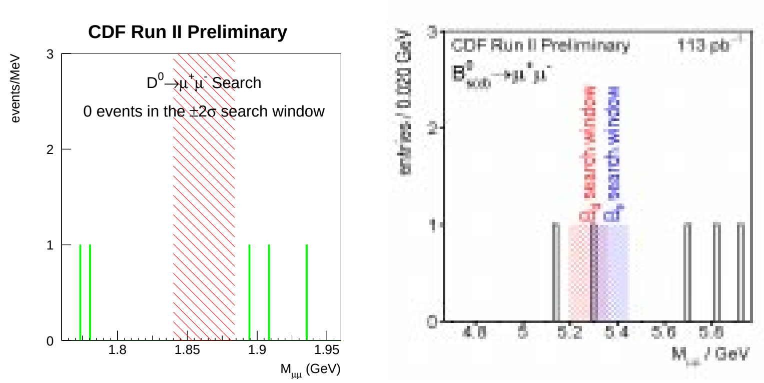

FIGURE 4. Search results for the rare decay $D^0 \to \mu^+\mu^-$ for a luminosity of 69 pb^{-1} and for the rare decay $B_s^0 \to \mu^+\mu^-$ for a luminosity of 113 pb^{-1}.

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