BOTTOM PRODUCTION AT THE TEVATRON

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Bottom production in hadronic collisions is studied with the CDF and DØ detectors at the Fermilab Tevatron $p\bar{p}$ collider at $\sqrt{s} = 1.8$ TeV. From CDF, a new measurement of the production cross section for B^+ mesons is extracted from the $B^+ \to J/\psi K^+$ decay channel. The CDF observed production rates as a function of B meson transverse momentum are significantly above next-to-leading order QCD predictions. DØ presents the production cross section for jets containing b quarks. This differential cross section as a function of jet transverse energy is obtained from a sample of muon tagged jets. By requiring jets above 20 GeV, the DØ measurement probes a higher $p_T(b)$ momentum region. Within experimental and theoretical uncertainties, DØ results are found to be higher than but compatible with next-to-leading order QCD predictions. Both measurements are performed in the central rapidity region.

1 Introduction

Measurements of bottom production cross sections in $\overline{p}p$ colliders provide an important quantitative test for perturbative quantum chromodynamics (QCD). The b quark mass is considered large enough ($m_b >> \Lambda_{QCD}$) to justify matrix element expansions in the strong coupling constant α_s, and b production calculations exist at next-to-leading order (NLO) in α_s. [1,2]

Past measurements of single b production in the central rapidity region, at $\sqrt{s} = 0.63$ TeV [3,4] and $\sqrt{s} = 1.8$ TeV [5,6,7] indicate a broad agreement with the shape of the theoretical p_T spectrum, but have been systematically higher than the NLO QCD predictions[1,2] by roughly a factor of 2.5. More recently, similar measurements with high rapidity muons [8] ($2.4 < |y^\mu| < 3.2$) indicate an even greater excess of observation over theory for forward b production. Single differential B meson cross section measurements [9] are also systematically higher than the NLO QCD prediction.

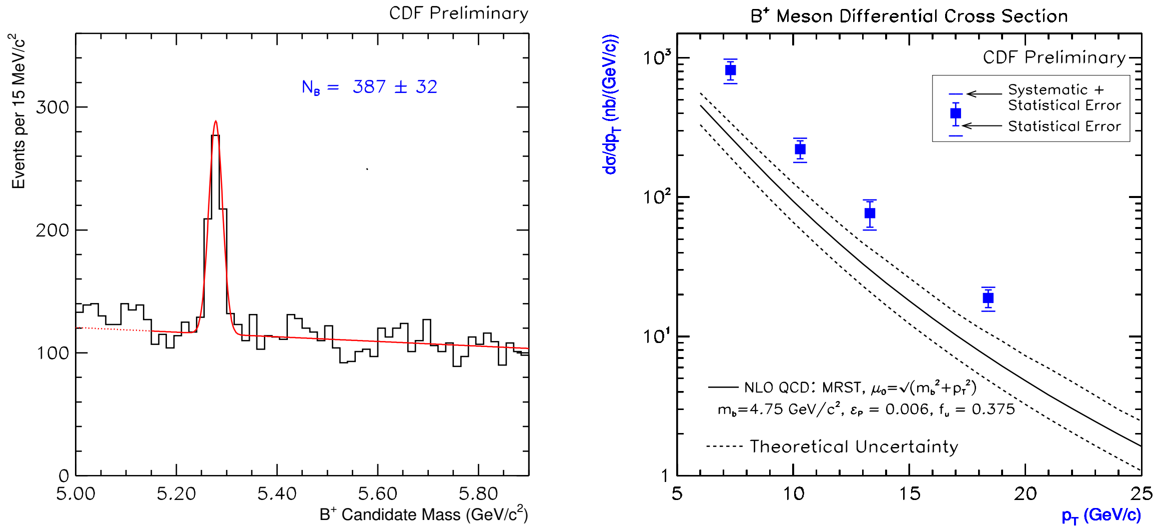

Figure 1: B^+ meson signal and differential(P_T) cross section from CDF.

Interestingly enough, results on $b\bar{b}$ photoproduction at HERA were reported [10] at this conference with significant excess of events over theory predictions. Measurements on QCD produced $b\bar{b}$ at LEP and SLD [11] are in better agreement with theory expectations, but again systematically higher.

Calculations of higher order corrections [12,13] have shown that cross section enhancements can be obtained. Such enhancements however fall short of accounting for the observed discrepancy between theory and data. This longstanding mismatch has motivated continuous theoretical and experimental effort dedicated to reduce uncertainties in general, and to broaden the scope of observable quantities [14,15]. It is in this spirit that we report two new results on b production at the Fermilab Tevatron collider.

Section 2 describes CDF's new measurement of B meson production in the central rapidity region. Section 3 presents the just completed DØ measurement of the production cross section for jets containing b quarks (b jets). In section 4, the DØ b jets data sample is used to revisit and extend previous b quark production results.

2 CDF Cross Section for B^+ Production

This new analysis of B meson production in the $B^+ \to J/\psi K^+$ ($J/\psi \to \mu^+\mu^-$) decay channel uses the full Run-I data sample, with five times more integrated luminosity than the CDF previous measurement.[9] From a dimuon trigger, $(98 \pm 4)pb^{-1}$ of data are collected, and offline selection is such that both muons, constrained to the J/ψ mass, must be well measured in the Silicon Vertex Detector (SVX), with a secondary vertex satisfying a proper lifetime cut $c\tau(J/\psi) > 100\mu m$.

A p_T cut of 1.25 (6.0) GeV is imposed on the K (B) candidates. The number of B mesons, determined from a maximum likelihood fit to a gaussian plus a linear background (figure 1), is 387 ± 32. The B mass is refitted in four separate p_T bins (6-9-12-15-25 GeV/c) and normalized to a differential cross section in the central rapidity region ($|y^B| < 1$). The result is shown in figure 1, together with the NLO QCD expectations. The integrated cross section is $3.52 \pm 0.42(stat) \pm 0.53(sys)\mu b$, about 2.5 times higher than the central theory prediction. Theory values stem from a NLO QCD Monte Carlo event generator with MRST structure functions. The quarks are fragmented according to the Peterson parameterization with $\epsilon = 0.006$. The b quark mass is set to 4.75 GeV and the QCD renormalization scale is chosen to be $\mu_o = (P_T^2 + M_b^2)^{1/2}$. The produced B mesons are decayed using the CLEO decay tables (QQ package).

3 DØ Cross Section for b Jet Production

Previous studies of b production by the DØ collaboration have concentrated on the b quarks themselves, through their inclusive $b \to$ muon decays. The kinematic relationship between b quarks and daughter muons was used to extract integrated b quark production rates as a function of $p_T(b)$ threshold [6], or the azimuthal correlations between the $b\bar{b}$ pair [15]. Such studies relied primarily on the muon spectrometer.

DØ now presents a complementary measurement of b production, based primarily on calorimetry (muons as taggers only), with main focus on b jets rather than b quarks. b jets are defined as hadronic jets carrying b flavor. As opposed to b quarks, b jets are directly observable and therefore reduce model dependence when the connection between observation and theory is made.

This measurement is in straight correspondence with a NLO QCD calculation by S. Frixione and M. Mangano[16], who highlight the theoretical advantages of considering jets rather than open quarks. For instance, large logarithms that appear at all orders in the open quark calculation (due to hard collinear gluons) are naturally avoided when all fragmentation modes are integrated and it nolonger matters what proportion of the jet energy is carried by b quarks or by radiation.

The analysis uses (5.2 ± 0.3) pb^{-1} of Tevatron Run I data from a muon plus jet trigger, from which an inclusive sample of muon tagged jets is extracted. Event selection is such that tagged jets must have hadronic transverse energy (E_T) above 25 GeV, pseudorapidity $|\eta| < 0.6$, and carry within their reconstruction cone ($\Delta R = 0.7$) a muon track with p_T above 6 GeV and $|\eta| < 0.8$. About 30000 events are thus selected, and less than 0.4% of them have either a second tagged jet or a doubly tagged one. This is due to the relatively high muon p_T cut, which also helps to enrich the b flavor content of the sample.

After detection efficiencies and resolution corrections are applied to the inclusive spectrum, the background from light flavors decaying to muons needs to be removed. This is done on a statistical basis, through fits of the distribution of muon transverse momentum with respect to the associated jet axis (P_T^{rel}). Monte Carlo templates representing light and heavy quark decay patterns are floated such as to fit the observed P_T^{rel} spectra in four different transverse energy ranges. Such fits determine the fraction of muons from b decays as a function of tagged jet E_T.

Corrections for acceptance losses stem from (i) the flavor tagging with muons (muon p_T threshold, pseudorapidity range and the muon-jet association criterion) (ii) the restricted pseudorapidity range for jets (theory[16] considers jets with $|\eta| < 1$) (iii) the unseen lepton energy inside the jet, which needs to be added (statistically) to the hadronic E_T registered in the calorimeter. The final cross section normalization is achieved by dividing the b jets spectrum by the $b \to \mu + X$ inclusive branching ratio, the integrated luminosity, and a factor of two to remove the $\bar{b}$ content.

The resulting b jets differential cross section ($|\eta| < 1$) is shown in figure 2, together with the associated NLO QCD calculation[16]. The theory uncertainty band is dominated by the QCD renormalization scale dependence, with central value chosen as $\mu_o = (E_T^2 + M_b^2)^{1/2}$, and floated between $2\mu_0$ and $\mu_0/2$. The b quark mass is set to 4.75 GeV. The measurement uncertainties are driven by the P_T^{rel} fits for the b fraction, seconded by the tagging acceptance losses, and calorimeter energy scale calibration at lower E_T. The uncertainties are highly correlated.

Figure 2 repeats a general pattern of the past b production studies (*e.g.* section 2, and figure 3 for $p_T^{min} < 20$ GeV) where data points lie well above the central values of the theory prediction. But in the present case, figure 2 also suggests a trend towards convergence between theory and observation at higher transverse energies. This issue is revisited in the next section.

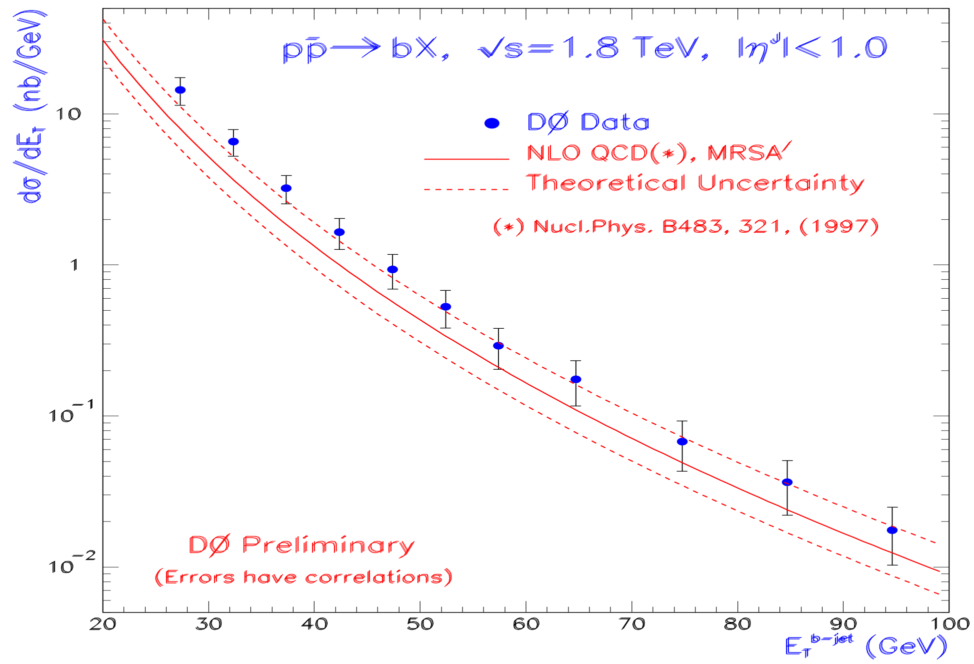

Figure 2: b Jets differential(E_T) cross section from DØ.

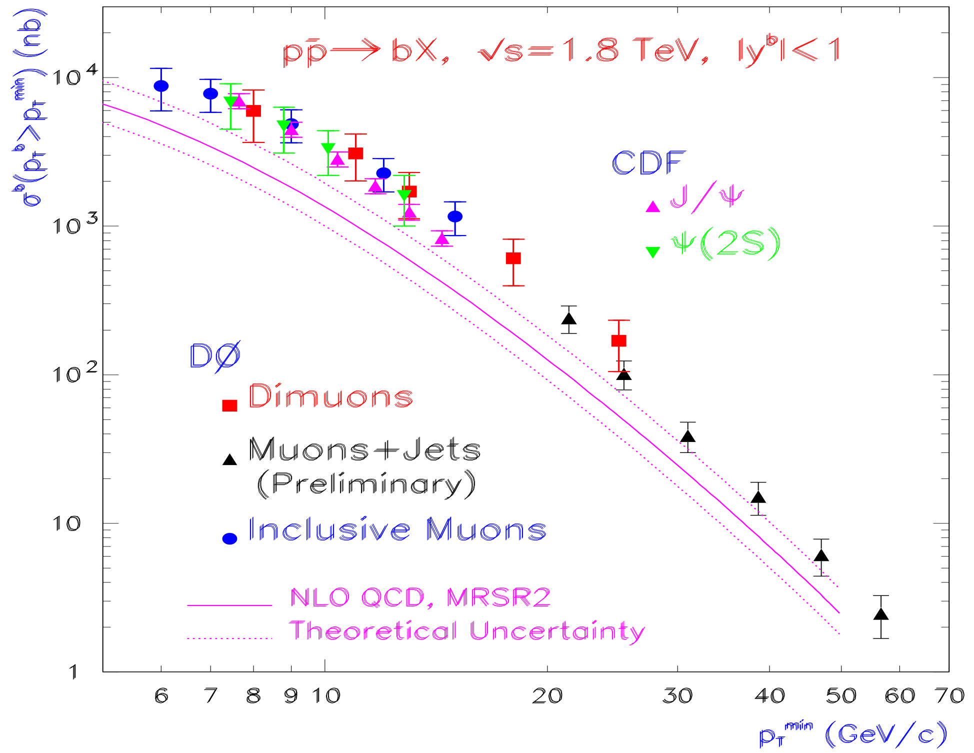

Figure 3: Integrated b quark cross section as a function of p_T threshold.

4 DØ Cross Section for b Quark Production

A natural extension to the b jets study presented above is to use the same data sample and analyze it from the perspective of b quarks rather than b jets. This affords not only a consistency check against previous measurements, but also an opportunity to extend their kinematic range. The analysis is a straightforward repetition of the steps carried out in reference 6 for a sample of inclusive muons. The kinematic relationship between the observed muon spectrum and the parent b quark spectrum is used to extract the integrated b quark production cross section as a function of minimum $p_T(b)$ (integrated from p_T^{min} to infinity, and over the rapidity range $|y^b| < 1$). The main difference from reference 6 is the requirement of a jet in association with the muon, which naturally forces the sample into a higher $p_T(b)$ region.

The results are shown in figure 3 (black triangles, $p_T^{min} > 20$ GeV), together with previous measurements from DØ [6,15] CDF [7] and the current theory expectation.[2] Consistency among all measurements is very satisfactory. As with b jets, uncertainties are dominated by systematics rather than statistics. Because the b signal increases with muon p_T, b tagging with P_T^{rel} as a function of muon p_T is more precise than with jet E_T. It is the model dependence, introduced in the access to the parent b quark integrated spectrum as a function of the daughter muon spectrum, that completely dominates the uncertainties in this type of measurement.

It is seen that the present analysis doubles the $p_T(b)$ reach of the previous measurements. This is due to the requirement of jets in the trigger and offline selection, as opposed to muon only triggers in the previous cases. A general trend can also be extracted from figure 3: the agreement between data and theory is improving as one moves towards harder transverse momenta. Of course this trend should be confirmed with extended and improved measurements in the upcoming Tevatron Run II, when various triggering and offline selection handles, as well as an order of magnitude increase in luminosity, will comfortably extend the $p_T(b)$ reach.

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