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Inclusive Muon and b Quark Production Cross Sections in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.8 TeV

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Inclusive Muon and b Quark Production Cross Sections in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

The DØ Collaboration[1]

(July 1995)

We report on the measurement of inclusive muon and b quark production by the DØ collaboration in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron Collider. The results represent a refined analysis of the previously published 1992-93 data. We measure the muon cross section due to b quark decays over the kinematic range $4 < p_T^\mu < 30$ GeV/c and $|y^\mu| < 0.8$. The extracted b quark production cross section is consistent with next to leading order QCD predictions within theoretical and experimental errors. The improved inclusive b quark production cross section is $6.9 \pm 0.1(\text{stat}) \pm 2.2(\text{syst})$ μb for $p_T^b > 6$ GeV/c and $|y^b| < 1.0$.

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INTRODUCTION

The study of b quark production in high energy hadronic interactions plays a crucial role in the testing of the perturbative quantum chromodynamics (QCD) description of heavy quark production (1–3). The cross section for b quark production measured at $\sqrt{s} = 0.63$ TeV by UA1 (4) is in agreement with the NLO theoretical predictions (1). However, the CDF (5) published data at $\sqrt{s} = 1.8$ TeV are generally higher than these predictions.

In this paper we present a summary of a completed analysis of inclusive muon and b quark cross sections. The results have been recently published in Physical Review Letters (6). However, more accurate luminosity measurements have become available since the publication (7). The improved cross sections presented in this report are lower by 3% and their uncertainties are reduced by 10%. We compare the b quark cross sections extracted from single muon production with preliminary new results from DØ taken from dimuon and J/ψ production.

DØ DETECTOR

DØ is a large multi-purpose detector operating at the Tevatron $p\bar{p}$ Collider, located at Fermi National Accelerator Laboratory. It features a non-magnetic inner tracking system, a compact and hermetic calorimeter and an extensive muon system. The DØ detector

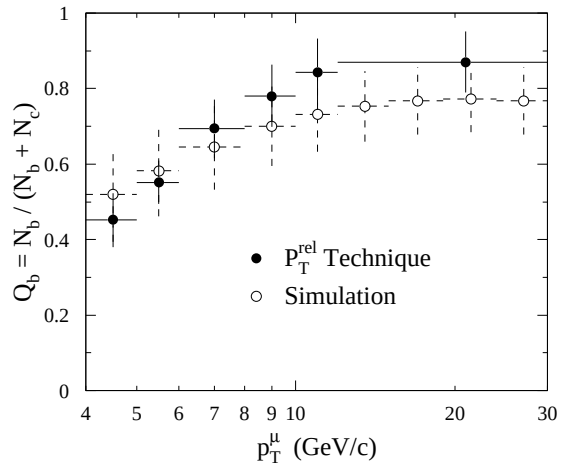

FIG. 1. The measured b fraction (Q_b) using p_T^{rel} technique, compared to the result of a simulation using ISAJET Monte Carlo, as a function of the muon p_T.

has been described in detail elsewhere (8) and only the features relevant for the analyses described here will be discussed briefly.

The inner tracking system covers a cylindrical region of radius 75 cm with wire drift chambers for the detection of charged tracks. The relatively small radius translates to a short decay path which makes muon contamination from in-flight decays of π/K minimal. The outermost tracking detector is a central drift chamber with a resolution in the transverse plane of 180 μm. Tracks in the central chamber are used to determine the primary interaction vertices and to refine muon tracks.

The calorimeter is a uranium–liquid argon sampling detector, with a fractional electromagnetic energy resolution of $15\%/\sqrt{E}$, where E is in GeV, and a fractional hadronic energy resolution for pions of $50\%/\sqrt{E}$ (9). The measured fractional resolution for jets is $75\%/\sqrt{E}$. Muon identification is enhanced by measuring the minimum ionizing energy deposition in the calorimeter.

The muon system consists of three layers of chambers, with magnetized iron toroids located between the first and second layers. The magnetic field in the iron toroids is 1.9 T and provides a momentum measurement with a resolution, $\sigma(1/p)/(1/p) = 0.18\,(p-2)/p \oplus 0.008p$, with p in GeV/c. The thickness of the calorimeter plus iron toroids varies from 14 λ in the central region to 19 λ in the forward region. This reduces the hadronic punchthrough background to a negligible level ($< 0.5\%$) and allows a good identification of muons in jets.

μ AND b CROSS SECTIONS

Tagging b quarks through their semi-leptonic decays into muons has been standard in the study of b production. For moderately high p_T, muons come primarily from b quark decays. The standard technique for extracting a b cross section from inclusive muon data is to measure the muon cross section, determine the fraction of events coming from b decays, associate muon p_T with b quark p_T, and then correct for acceptance, branching ratio and fragmentation effects. The following is the analysis of inclusive muon data.

This analysis was based on data corresponding to a total integrated luminosity of $\int \mathcal{L}\, dt =$

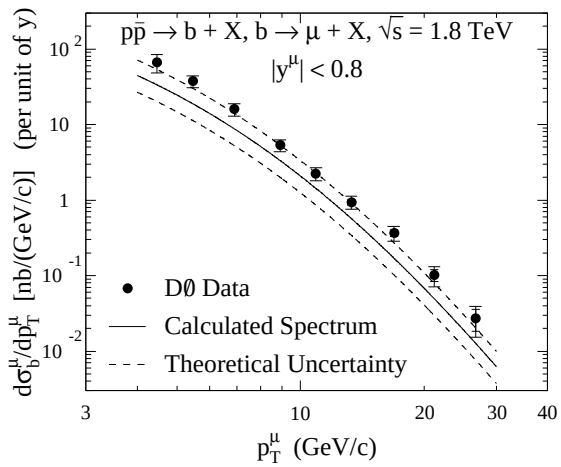

FIG. 2. The unfolded muon cross section corresponding to inclusive b decays compared to the expected spectrum (see text for details). Inner error bars are statistical and outer statistical and systematic added in quadrature.

75.6 ± 4.1 nb^{-1} [2]. The data sample was obtained by filtering the interactions through a multi-level trigger. At the level 1 hardware trigger at least one muon candidate was required and the level 2 software trigger required at least one reconstructed muon track with transverse momentum $p_T^\mu > 3$ GeV/c. Events were fully reconstructed off-line and retained for further analysis if they contained at least one muon track with rapidity $|y^\mu| < 0.8$ and $p_T^\mu > 3.5$ GeV/c. Candidate muons had to deposit $>$ 1 GeV of energy in the calorimeter; the mean energy loss for a single muon is about 2.5 GeV. A match was required with a good track in the central tracking detector pointing back to the primary interaction vertex. To minimize cosmic ray background, the reconstructed time of passage (t_0) through the muon chambers had to be within 100 ns of the beam crossing. A total of 15995 muons passed all selections. Using ISAJET (10) Monte Carlo and data the total detection efficiency was estimated to be 0.28 ± 0.03 for $p_T^\mu \geq 6$ GeV/c.

b Fraction in Inclusive μ Events

Possible sources of backgrounds to muons from heavy flavor decays consist of cosmic rays, muons from Drell-Yan and J/ψ decays, and from π/K and W/Z decays. The residual cosmic ray contamination was estimated from the observed t_0 distribution to be $(9 \pm 3)\%$ and was subtracted from the data. Muons from Drell-Yan and J/ψ decays were estimated to contribute less than 2% of the data.

In obtaining the b quark cross section we restricted our analysis to muons in the p_T^μ range 4–30 GeV/c. We estimated and subtracted the expected W/Z background using ISAJET for the p_T distributions, with cross sections and systematic errors determined from our data (11). The remainder is expected to come mainly from b and c quark decays. To

[2] In computing the cross sections of Ref. (6) we used $\int \mathcal{L}\, dt = 73.3 \pm 8.8$ nb^{-1} instead of the more accurate luminosity measurement used in this report (7). Therefore, the improved cross sections presented in this report are lower by 3% and their uncertainties are reduced by 10%.

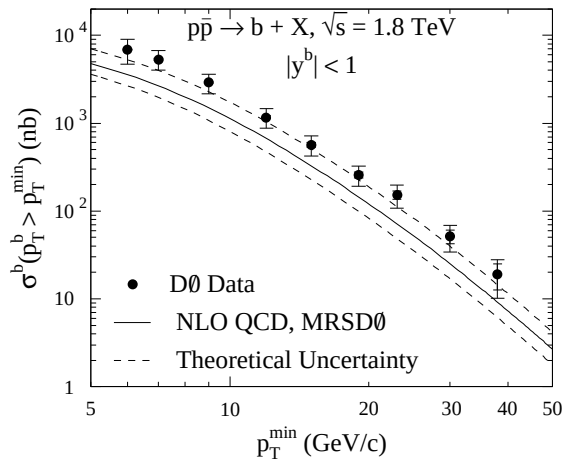

FIG. 3. The b quark production cross section compared to NLO QCD predictions (see text for details). Inner error bars are statistical and outer statistical and systematic added in quadrature.

determine the fraction of muons from b quark decays, f_b, we used the transverse momentum of the muon with respect to the associated jet axis (p_T^{rel}). Jets are reconstructed for $E_T^{jet} >$ 8 GeV, using a cone algorithm with radius $R = 0.7$, where $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. The p_T^{rel} distributions for b quark, c quark, and π/K decays were modeled with ISAJET.

Another interesting quantity in the study of heavy flavor production is the b fraction of all b and c decays, $Q_b = N_b/(N_b + N_c)$, which can be obtained by subtracting the π/K contribution (6). The relation between Q_b and f_b is simply $Q_b = f_b/(1 - f_{\pi/K})$, and at large p_T the π/K contribution is negligible and $Q_b \simeq f_b$. The measured Q_b distribution, compared to the result of ISAJET Monte Carlo simulation, is displayed in Fig. 1. The two results are consistent within errors but are slightly different in shape.

μ Cross Section

The muon cross section due to inclusive b quark decays was obtained by correcting for the total muon detection efficiency and for the measured fraction due to b decays. The spectrum was also corrected for the muon momentum resolution using the technique of Reference (12). The size of this correction varies from 1 at low p_T to 0.7 at $p_T = 20$ GeV/c with an uncertainty of (6%). The results, including the statistical and systematic errors are summarized in Table 1. The spectrum shown in Fig. 2, with systematic errors of 18%, is extracted without assumptions concerning heavy flavor production cross sections, and represents our experimental result. The theoretical spectrum was calculated using ISAJET for b quark production, fragmentation and decay, with the cross section normalized to the NLO QCD calculation (1). We used the Peterson fragmentation function with $\epsilon_b = 0.006 \pm 0.003$ (13) and the average LEP inclusive branching ratio $\mathrm{Br}(B \to \mu) = 0.110 \pm 0.005$ (14).

TABLE 1. A summary of the unfolded b produced muon cross section, the statistical and systematic uncertainties as a function of the muon transverse momentum p_T^μ. p_T^μ is computed using the algorithm of reference (15).

p_T^μ bin (GeV/c)	p_T^μ (GeV/c)	$\frac{d\sigma_b^\mu}{dp_T^\mu}$ [nb/(GeV/c)]	Statistical [nb/(GeV/c)]	Systematic [nb/(GeV/c)]
4-5	4.5	66.192	0.861	17.872
5-6	5.5	37.251	0.671	6.705
6-8	6.9	15.888	0.318	2.860
8-10	8.9	5.312	0.197	0.956
10-12	10.9	2.237	0.132	0.403
12-15	13.3	0.938	0.075	0.169
15-19	16.9	0.366	0.039	0.073
19-24	21.2	0.102	0.018	0.024
24-30	26.7	0.027	0.009	0.008

TABLE 2. A summary of the inclusive b quark production cross section integrated above a certain p_T^{min}, the statistical and systematic uncertainties as a function of the b quark p_T.

p_T^{min} (GeV/c)	$\sigma^b(p_T^b > p_T^{min})$ (nb)	Statistical (nb)	Systematic (nb)
6	6884.0	89.5	2202.9
7	5362.0	96.5	1340.5
9	2895.2	57.9	723.8
12	1167.1	43.2	291.8
15	566.9	33.5	141.7
19	258.0	20.6	64.5
23	152.3	16.3	41.1
30	51.4	9.1	14.9
38	18.9	6.2	6.2

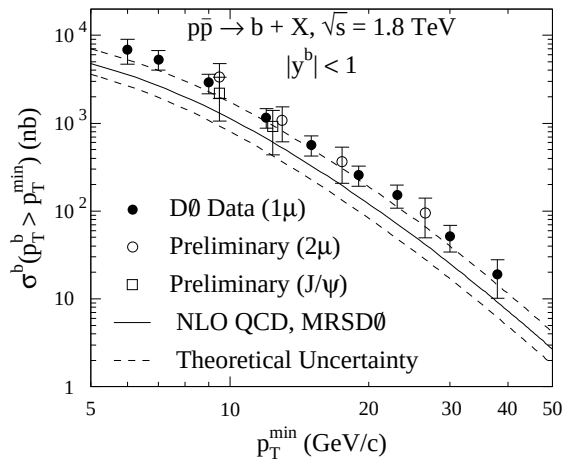

FIG. 4. The combined DØ b quark production cross section measurements compared to NLO QCD predictions (see text for details). Error bars are statistical and systematic uncertainties added in quadrature.

b Quark Production Cross Section

We extracted the b quark production cross section from the muon spectrum following the method described in Reference (6). The resulting cross section as a function of p_T^{min}, for $|y^b| < 1.0$, is shown in Fig. 3. p_T^{min} is calculated for each muon p_T bin and refers to the b quark p_T above which 90% of the muons in the interval originate from b quarks with $p_T > p_T^{min}$. The results including the statistical and systematic errors are summarized in Table 2. In addition to the uncertainties due to the muon spectrum, the total systematic uncertainties 25% include (12%) due to the assumed p_T shape and 13% due to the branching ratio and fragmentation. The curves represent the NLO QCD predictions (1) using MRSDØ parton distribution functions (16). The QCD mass scale $\Lambda^{(5)}_{\overline{MS}} = 140$ MeV and the renormalization and factorization scale $\mu = \mu_0$ (with $\mu_0^2 = m_b^2 + (p_T^b)^2$, and $m_b = 4.75$ GeV/c^2) were used for the solid curve, and customary variations of these parameters for the dashed curves: 187 MeV and $\mu_0/2$ (upper), and 100 MeV and $2\mu_0$ (lower).

The DØ Collaboration has also measured the b quark production cross section using two other independent data samples: non-resonant dimuons (17) and J/ψ's due to b quark fragmentation (18). Results of these measurements, also submitted to this conference, are combined with the inclusive single muon data presented in this report in Fig. 4. A good overall consistency of results employing different triggers and analysis techniques is observed.

CONCLUSIONS

The DØ experiment has measured b production cross section in $p\bar{p}$ collisions. We measured the muon cross section due to b quark decays over the kinematic range $4 < p_T^\mu < 30$ GeV/c and $|y^\mu| < 0.8$. The improved inclusive b quark production cross section is $6.9 \pm 0.1(\text{stat}) \pm 2.2(\text{syst})$ μb for $p_T^b > 6$ GeV/c and $|y^b| < 1.0$. Our results indicate that

NLO QCD calculations describe heavy flavor production within the experimental and theoretical errors. Although there is a residual discrepancy of $\sim 50\%$ in magnitude between the central values, the p_T shapes are in good agreement over the entire p_T range. A precise agreement of the theory and data can be obtained with extreme values for Λ_{QCD} and the renormalization scale μ.

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