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Small Angle Muon and b-Quark Production in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.8 TeV

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Small Angle Muon and b-Quark Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

The DØ Collaboration[1]

(D0NOTE 3022)

We report on a measurement of small angle muon production ($2.4 < |y^{\mu}| < 3.2$) in $p\bar{p}$ collisions at $\sqrt{s}$ =1.8 TeV with the DØ detector at Fermilab. We have determined the fraction of the inclusive μ cross section in this region due to b-quark production and decay. Combining this measurement with our previously measured cross section in the central region, we calculate $d\sigma/dy$ for muons from b decay with $p_T^{\mu} > 5$ GeV/c and $p_T^{\mu} > 8$ GeV/c. These measurements are compared to next-to-leading order QCD calculations.

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INTRODUCTION

The study of b-quark production in hadronic interactions plays a crucial role in the testing of the perturbative quantum chromodynamics (pQCD) description of heavy quark production (1–3). Next-to-leading order (NLO) predictions are consistent with b-quark cross section measurements at the Tevatron in the central rapidity region (4,5), although the measurements are at the upper edge of the theoretical uncertainty band.

This paper describes measurements with the DØ detector that extend the rapidity range to the forward region and compares these results to the NLO pQCD predictions. We present the first measurement of the differential muon cross section due to b production and decay in the forward rapidity region $2.4 < |y^{\mu}| < 3.2$ as a function of p_T^{μ}, and combine this result with our previous central rapidity range measurement to determine the differential cross section as a function of rapidity.

THE DØ DETECTOR

DØ is a large multi-purpose detector operating at the Tevatron $p\bar{p}$ Collider, located at Fermi National Accelerator Laboratory. The DØ detector has been described in detail elsewhere (6). It features a non-magnetic inner tracking system, a compact and hermetic calorimeter, and an extensive muon system.

The measurements reported in this paper use the small angle muon system (SAMUS). It consists of six stations (A, B, and C; north and south) with exterior dimensions 312 cm $\times$

312 cm in the transverse plane. Each station has three doublets of 29 mm interior diameter cylindrical proportional drift tubes, which are oriented in the x, y, and u directions (u is at 45° from x and y). The momentum resolution of this system varies from $\approx 19\%$ at 20 GeV/c to $\approx 25\%$ at 100 GeV/c. Muons reaching the SAMUS chambers traverse approximately 20 interaction lengths of material. This reduces the hadronic punch-through background to a negligible level. The SAMUS region does, however, face a large combinatoric background corresponding to low energy "spray" from showers initiated by small angle particles from the primary collision. There are an average of 6 to 14 hits per doublet, per bunch crossing, and the inner SAMUS drift tubes have an approximate 5% occupancy rate on average.

The trigger is done in four levels. The first corresponds to a scintillator hodoscope that requires an inelastic collision within 1 m of the center of the DØ detector. Then a hardware trigger searches (x,y,u) coarse triplet space points in each of the three stations, and then searches for x and y roads 12 cm wide corresponding to these triplets. To improve background rejection, this trigger also includes hit multiplicity cuts. The search roads are narrowed to 4.5 cm wide at the next level. The final level is a software filter run on a computer farm that reconstructs the tracks without using the drift times and requires energy deposited in the calorimeter consistent with a minimum ionizing particle. The offline reconstruction uses the drift times and the vertex of the event as determined by the central drift chamber, and requires hits in all three SAMUS stations.

INCLUSIVE MUON CROSS SECTION

The data used in this analysis were collected in special runs during the 1994-95 collider run. The integrated luminosity for these runs is 104.1 ± 5.6 nb^{-1}. Muons were selected in the rapidity range $2.4 < |y^\mu| < 3.2$, subject to the following offline cuts. Events with single interactions only were accepted, leaving an effective integrated luminosity of $L = (59.8 \pm 4.8)$ nb^{-1}. Muon tracks were required to have at least 16 out of a possible 18 hits. An energy deposition of at least 1.5 GeV, consistent with a minimum ionizing particle, was required in the hadronic calorimeter near the muon track. The transverse momentum kick to the muon from the SAMUS toroid had to be greater than 1.5 GeV/c to ensure good momentum resolution and to avoid the edges of the toroid where the magnetic field map is less accurate. And, finally, events with a trigger and reconstruction efficiency less than a threshold $\epsilon_{min} = 0.05$, determined by Monte Carlo, were rejected to avoid low efficiency tails which are poorly understood. The number of surviving muon candidates is 3224.

The inclusive muon cross section was calculated as follows:

$$\frac{d\sigma^\mu}{dp_T^\mu} = \frac{1}{L\Delta y}\frac{N^\mu f_p}{\epsilon}, \tag{1}$$

where f_p is a correction factor that accounts for momentum smearing. Because of high correlations between variables and cuts, this correction and that of the detection efficiency (ϵ) were determined by:

$$\frac{N^\mu f_p}{\epsilon} = \frac{H(data)H(MCgen)}{H(MCreco)}, \tag{2}$$

where the H's are elements of of 2-dimensional histograms in the (p_T, y) plane. $H(data)$ is the data distribution with all offline cuts, $H(MCgen)$ is the generated Monte Carlo distribution, and $H(MCreco)$ is the reconstructed Monte Carlo distribution with full detector simulation and the same cuts as the data. The Monte Carlo events were weighted in an

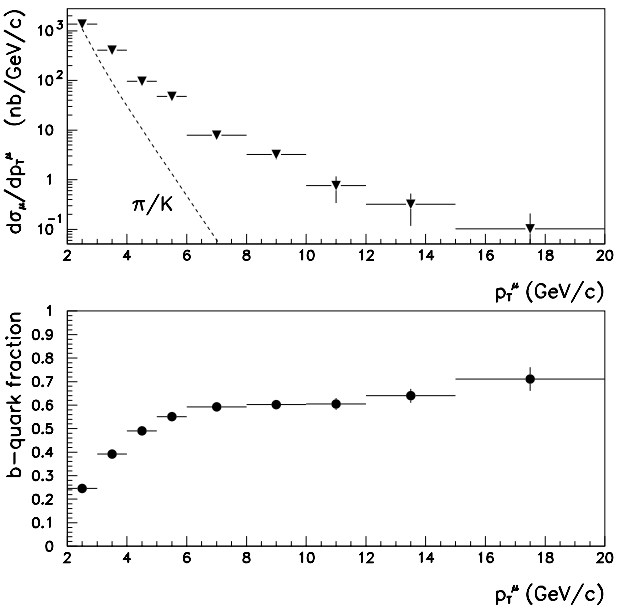

FIG. 1. (a) The inclusive muon cross section, per unit of rapidity, in the forward region as a function of p_T^μ (errors are statistical only). The dashed line shows the expected contributions from π/K decays. (b) The fraction of b events after π/K subtraction as a function of p_T^μ using MNR (3) predictions for b and c production cross sections.

iterative procedure to match the p_T and y spectra of the data. The Monte Carlo momentum resolution was tested against the J/ψ signal in the data's dimuon mass spectrum (7).

The inclusive muon cross section, which includes both μ^+ and μ^-, is shown in Fig. 1(a). The contributions to this cross section from cosmic rays and hadronic punch-through are estimated to be negligible (both less than 1%). The W and Z decay contribution is also negligible as determined by both DØ data and ISAJET Monte Carlo simulations (8). The pion and kaon decay spectrum (also shown in Fig.1(a)) was obtained using ISAJET, which was found to be in agreement with the charged particle spectrum measured by the CDF collaboration (9) in the central region $|\eta| < 1$. The ISAJET π/K spectrum also matches our data in the first p_T^μ bin (2-3 GeV/c), which should be dominated by these decays. The excess of the cross section above the π/K contribution is attributed to b- and c-quark decay.

MUON CROSS SECTION FROM b DECAYS

The fraction of muons from b decays to those from both b and c decays was determined in a Monte Carlo simulation. ISAJET events were used for b/c production, fragmentation, and decay, with cross sections normalized to NLO pQCD calculations (3). The b fraction as a function of p_T^μ is shown in Fig. 1(b). Subtracting the π/K contribution from the inclusive muon cross section, and multiplying the resulting spectrum by the b fraction as a function of p_T^μ gives the differential muon cross section from b production and decay.

The main sources of the 31% systematic uncertainty in this cross section are due to the detection efficiency correction (20%), the π/K subtraction (14%), and the b fraction (10%). The uncertainty in the detection efficiency was determined by varying the offline cuts and

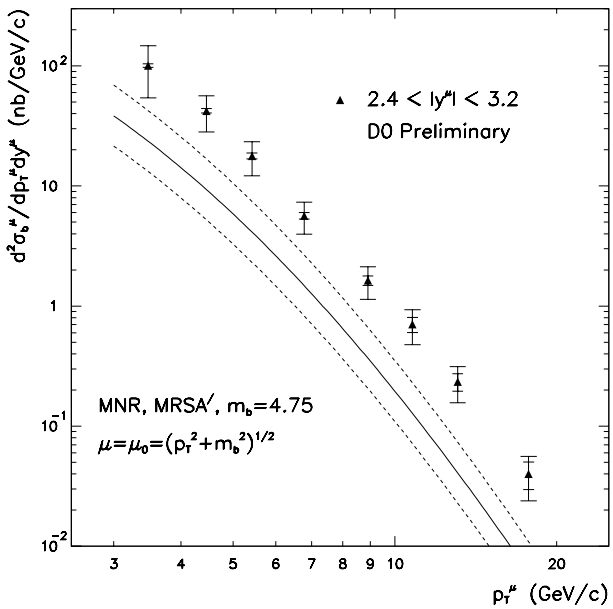

FIG. 2. The measured differential muon cross section, per unit of rapidity, in the forward region from b production and decay as a function of p_T^μ. Triangles are DØ data; inner error bars are statistical and outer are statistical and systematic added in quadrature. The Solid curve is a NLO pQCD predictions with dashed curves representing the theoretical uncertainties (see text).

the ϵ_{min} threshold. The normalization of the muon cross section from π/K decay affects mainly the first p_T bin from 2 to 3 GeV. Comparing with the data in this bin, we determine that the ISAJET normalization is correct to a factor of ≈ 1.3. This normalization factor was used to determine the uncertainty due to the π/K subtraction. The uncertainty due to the b-fraction correction was estimated by using fractions determined using ISAJET cross sections and a data measurement in the central region (4).

The cross section for muons from b production and decay is shown in Fig. 2., along with a NLO pQCD theoretical prediction (3) using MRSA´ parton distribution functions (10), $\mu = \mu_0 = \sqrt{m_b^2 + p_T^2}$, and $m_b = 4.75$ GeV/c^2. The theoretical uncertainty was determined by using MRSD0 pdf's, and by varying the parameters m_b and μ from 4.5 to 5.0 GeV/c^2 and $\mu_0/2$ to $2\mu_0$, respectively. The corresponding muon spectrum was obtained using the weighted ISAJET technique described previously. The theoretical predictions match the shape of the cross section, but are approximately a factor of four lower than the data.

RAPIDITY DEPENDENCE

By combining the forward muon cross section from b decays with that of a previous DØ measurement in the central rapidity range ($|y^\mu| < 0.8$) (4) we obtain the differential cross section as a function of rapidity $d\sigma_b^\mu/d|y^\mu|$. The differential cross sections as a function of p_T^μ are shown in Fig. 3 for both regions.

The differential cross section as a function of rapidity is shown in Figs. 4(a) and 4(b) for $p_T^\mu > 5$ GeV/c and $p_T^\mu > 8$ GeV/c, respectively. The NLO pQCD predictions also shown

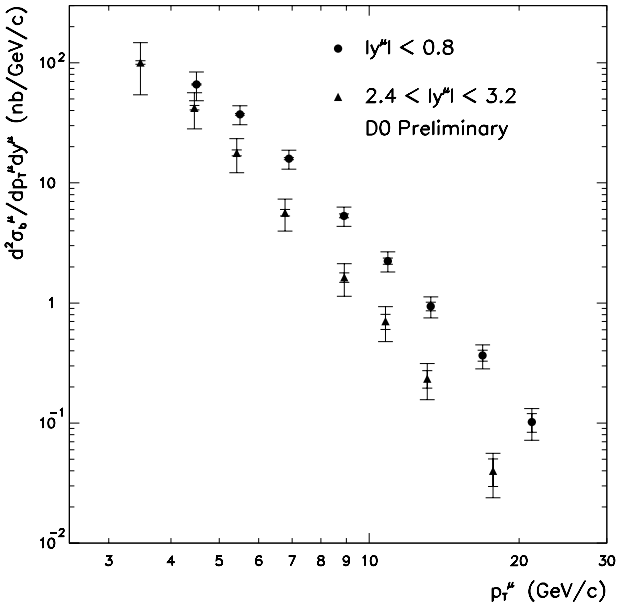

FIG. 3. The measured differential muon cross sections from b production and decay, per unit of rapidity, as a function of p_T^μ in both the forward (triangles) and central (circles) rapidity regions.

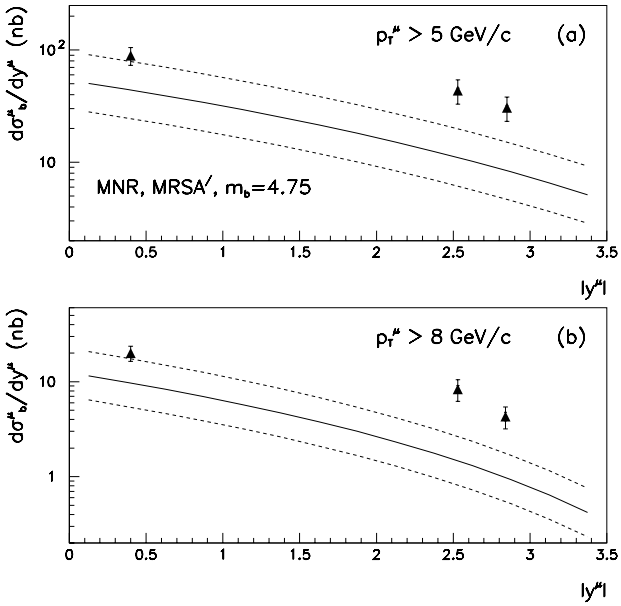

FIG. 4. The measured differential muon cross sections from b production and decay as a function of y^μ for (a) $p_T^\mu > 5$ GeV/c, and (b) $p_T^\mu > 8$ GeV/c. The Solid curve is a NLO pQCD prediction with dashed curves representing the theoretical uncertainties (see text).

in the figures do not match the data. They are a factor of two lower than data in the central region (but consistent within errors), but are a factor of four lower in the forward region.

CONCLUSIONS

The DØ experiment has made the first measurement of the inclusive muon cross section in the forward rapidity region $2.4 < |y^{\mu}| < 3.2$ at $\sqrt{s} = 1.8$ TeV. We have determined the b contribution to this cross section, and have extracted differential cross sections for muons from b decay as a function of p_T and rapidity. The predictions of NLO pQCD do not describe the data in the forward region well.

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