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

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

The DØ Collaboration¹
(July 1995)

We report on a preliminary measurement of the inclusive dimuon cross section in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV using the DØ detector at the Fermilab Tevatron. From these results, we extract the inclusive b -quark production cross section for the kinematic range $|y^b| < 1.0$ and $9 \text{ GeV}/c < p_T^{\text{min}} < 25 \text{ GeV}/c$. The difference in azimuthal angle in the transverse plane for dimuon pairs from $b\bar{b}$ production is also shown.

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INTRODUCTION

An important test of perturbative QCD is its ability to describe the inclusive heavy quark cross sections. The inclusive b -quark cross section at $\sqrt{s} = 1.8$ TeV as measured by DØ (1), (2), and CDF (3), (4), (5), (6), agrees within theoretical and experimental errors with the next-to-leading order (NLO) QCD predictions (7) however the central values of the data systematically lie at the upper end of the theoretical predictions. We have used dimuon events to extract an additional, independent measurement of the b -quark cross section. All results presented in this paper are to be considered preliminary.

DATA SELECTION CUTS AND EFFICIENCIES

The data were collected with the DØ detector (8) from $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV during the 1992-1993 Fermilab Tevatron run. A hardware (Level 1) and software (Level 2) dimuon trigger selected events with two muon candidates having $p_T^\mu > 3$ GeV/c and $|\eta^\mu| < 1.7$. The trigger efficiency (including muon chamber efficiencies) was determined by complete Monte Carlo simulation of the detector and trigger and cross-checked with appropriate data samples. Taking as our denominator dimuon events from $b\bar{b}$ decay with an invariant mass between 6 and 35 GeV/c², $|\eta_\mu| < 0.8$, and dimuon opening angle $< 165^\circ$, the combined Level 1 and Level 2 trigger efficiency rises from 16% to 26% over the p_T^μ range considered (50% of the plateau value is reached at 6 GeV/c).

Offline cuts were applied to select two high quality muons. Each muon was required to have a good track fit and impact parameter in the bend and non-bend views. Additionally each track needed to have a good match to a central tracking chamber track. At least 1 GeV of energy in the hit calorimeter cells plus their first nearest neighbors was required for each muon as well. Kinematic cuts of $|\eta^\mu| < 0.8$ and $p_T^\mu > 4.0$ GeV/c were also applied. A fiducial cut removing muons in the region $80^\circ < \phi_\mu < 110^\circ$ was employed as the muon proportional chamber efficiencies in that region were very low due to radiation damage effects from the main ring accelerator.

Additional cuts were applied in order to decrease certain backgrounds. The dimuon mass was restricted to be in the region $6 \text{ GeV}/c^2 < M_{\mu\mu} < 35 \text{ GeV}/c^2$ thus eliminating low mass, sequential decays of heavy quarks, J/ψ decays, and Z decays. Each muon was also required to have an associated jet with $E_T^{jet} > 12 \text{ GeV}$ within $\Delta R = \sqrt{d\phi^2 + d\eta^2} = 0.8$. The jet requirement reduced backgrounds from Υ and Drell-Yan production to negligible levels. To further reduce cosmic ray background, the opening angle between the two muons was required to be less than 165° . The total efficiency, including trigger and muon chamber efficiency after all cuts and using the denominator stated above, rises from 1% to 12% over the p_T^μ range considered. After all cuts a total of 197 events remain corresponding to an integrated luminosity of $\int \mathcal{L} dt$ of $6.6 \pm 0.4 \text{ pb}^{-1}$.

INCLUSIVE DIMUON AND B -QUARK CROSS SECTIONS

The inclusive dimuon cross section as a function of p_T of the leading muon was obtained via:

$$\frac{d\sigma}{dp_T^\mu} = \frac{(N - N_{cosmic})}{\Delta p_T^\mu} \cdot \frac{1}{\epsilon \cdot \int \mathcal{L} dt} \quad (1)$$

where p_T^μ is the transverse momentum of the leading muon, N is the total number of events, N_{cosmic} is the cosmic ray background, Δp_T^μ is the p_T bin width, ϵ is the total efficiency, and $\int \mathcal{L} dt$ is the integrated luminosity. The overall efficiency (including trigger, muon chamber, offline selection, and jet efficiencies) was determined from complete Monte Carlo simulation of the detector and trigger. The Monte Carlo events were then analyzed in an identical manner to the data. Cosmic ray background was estimated by fitting the crossing time distribution in the muon chambers to known distributions for beam produced and cosmic ray events. The resulting p_T distribution was then unfolded to account for the p_T resolution of the detector ($\delta(1/p)/(1/p) = [(\frac{0.18(p-2)}{p})^2 + (0.008p)^2]^{1/2}$), (p in GeV/c). This was carried out using a method based on Bayes' Theorem (10). The resulting inclusive dimuon cross section is shown in Fig. 1.

The fraction of dimuons from $b\bar{b}$ decay was determined by performing a maximum likelihood fit to the data using the distributions of the transverse momentum of the leading and trailing (in p_T) muons relative to the associated jet axis (p_T^{rel}). Here the jet axis was defined by vector addition of the jet and muon momenta and is corrected for the muon energy loss in the calorimeter. Besides signal dimuons from $b\bar{b}$ decay, background dimuons from $c\bar{c}$ decay, heavy flavor plus π/K decay, and cosmic rays were also considered. The input distributions to the fit were determined by Monte Carlo except for the p_T^{rel} distribution for cosmic rays which was taken from data. Results of the fit are shown in Figs. 2 and 3.

The resulting b -quark fraction of dimuon events is shown in Fig. 4 along with a prediction obtained by using ISAJET generated signal and background Monte Carlo events.

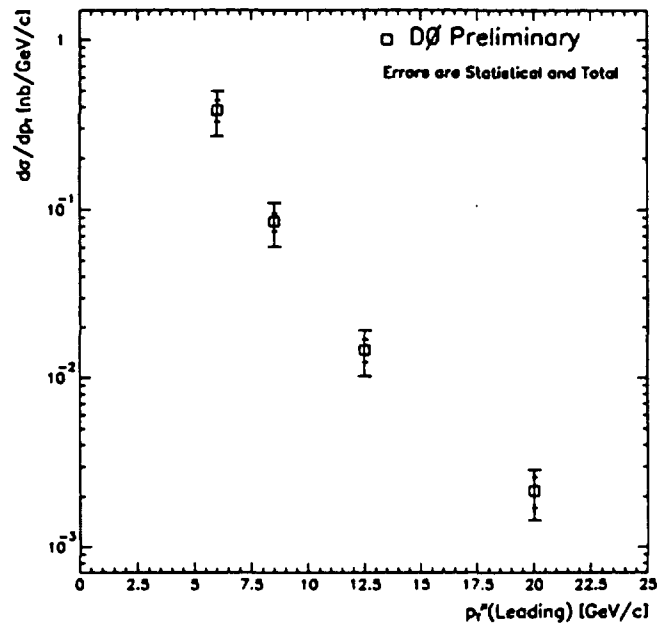


FIG. 1. Dimuon cross section $d\sigma/dp_T^{\mu}$ as a function of the highest p_T muon of the pair. This cross section is for dimuons with $|\eta^{\mu}| < 0.8$, $p_T^{\mu} > 4$ GeV/c, $6 \text{ GeV}/c^2 < M_{\mu\mu} < 35 \text{ GeV}/c^2$, and dimuon opening angle $< 165^{\circ}$.

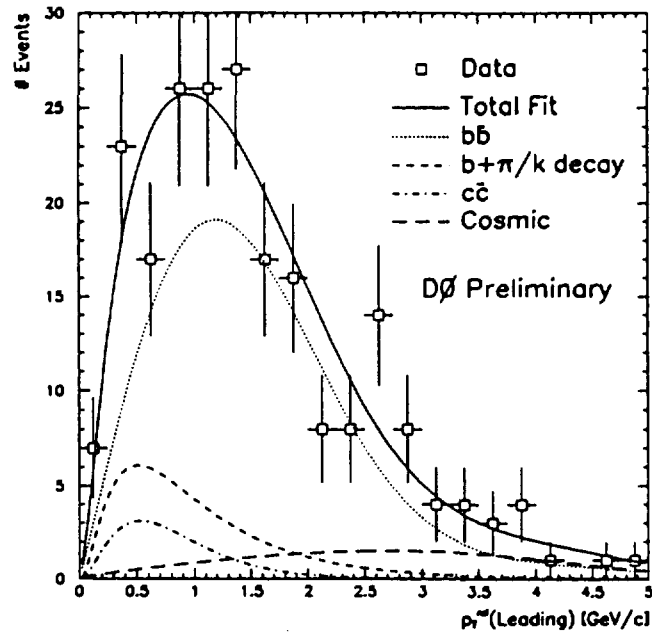


FIG. 2. p_T^{rel} distribution for the leading muon in p_T .

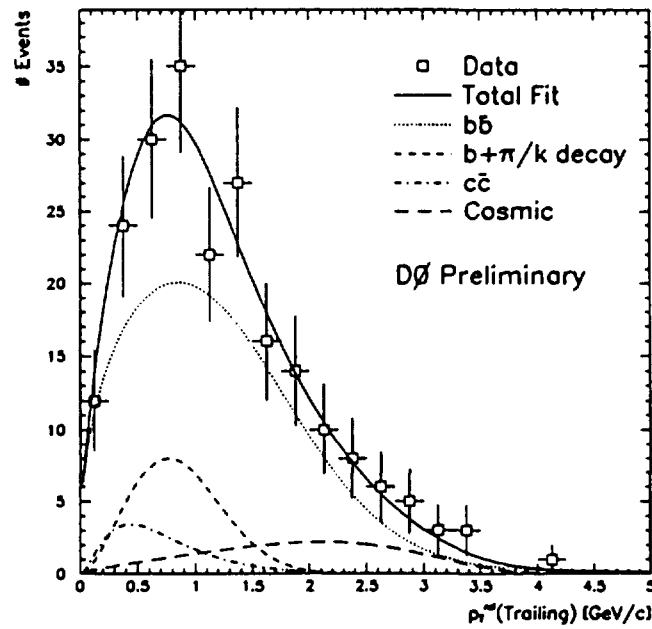


FIG. 3. p_T^{rel} distribution for the trailing muon in p_T .

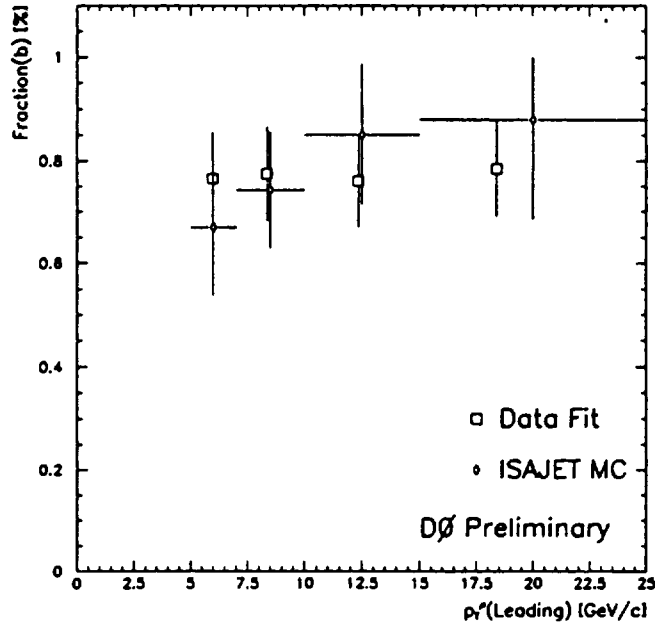


FIG. 4. b -quark fraction as a function of p_T of the leading muon for a dimuon sample with $|\eta^\mu| < 0.8$, $p_T^\mu > 4$ GeV/c, 6 GeV/c² $< M_{\mu\mu} < 35$ GeV/c², and dimuon opening angle $< 165^\circ$.

Reasonable agreement between the two methods is noted and the difference is taken as the systematic error in the b -quark fraction. For inclusive single muons, the b -quark fraction determined using a fit to the $p_T^{\mu el}$ distribution was also found to be in good agreement with the ISAJET prediction (1).

Once the b -quark fraction of dimuon events is determined the integrated inclusive b -quark cross section can be extracted following the method of UA1 (9). The resulting b -quark cross section as a function of p_T^{min} is plotted in Fig. 5. Here p_T^{min} refers to the b -quark p_T above which 90% of the muons satisfying all cuts originate from b quarks with $p_T > p_T^{min}$. One set of systematic errors is associated with the inclusive dimuon cross section and includes uncertainties in the trigger and offline cut efficiencies (25%), luminosity (5%), and cosmic ray subtraction (5%). A second set of systematic errors is associated with determination of the b -quark cross section and includes uncertainties in the b -quark fraction (15%), b -quark fragmentation (21%), p_T^μ spectrum in b -quark decay (14%), b -quark p_T spectrum (13%), and the branching ratio for $b \rightarrow \mu$ (7%). Plotted in Fig. 5 are the statistical and total (statistical plus systematic) errors.

Also shown in Fig. 5 is the b -quark cross section from the DØ inclusive single muon data (1) and the NLO QCD prediction of Nason, Dawson and Ellis (7). This prediction is based on use of MRSDO structure functions with $\Lambda_5^{\overline{MS}} = 140$ MeV, and $m_b = 4.75$ GeV/c². The theoretical uncertainty results from choosing $100 < \Lambda_5^{\overline{MS}} < 187$ MeV, and the factorization-renormalization scale μ in the range $\mu_0/2 < \mu < 2\mu_0$, where $\mu_0 = \sqrt{m_b^2 + (p_T^b)^2}$. There is good agreement among the b -quark cross sections deter-

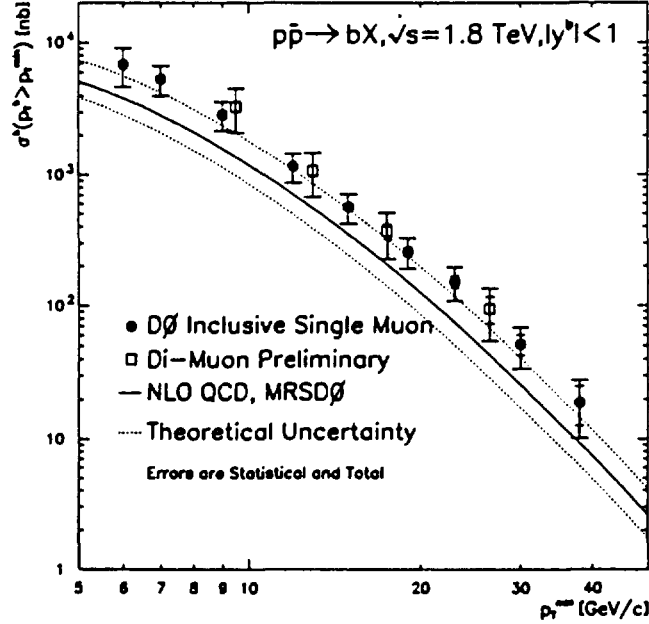


FIG. 5. The inclusive b -quark production cross section for $|y^b| < 1$ integrated above p_T^{min} extracted using the dimuon sample. p_T^{min} is the b -quark p_T above which 90% of the muons satisfying all cuts originate from b quarks with $p_T > p_T^{min}$. Also shown is the b -quark cross section as measured using the inclusive single muon sample. The figure also contains the NLO QCD predictions of Nason, Dawson, and Ellis with theoretical uncertainties described in the text.

mined from inclusive single muons, dimuons, and J/ψ production (2). Within experimental and theoretical uncertainties the b -quark cross section from data agrees with the NLO QCD prediction.

Using the same Monte Carlo technique as described above, one can equally well determine a set of trigger and offline efficiencies as a function of $\Delta\phi^{\mu\mu}$, the difference in azimuthal angle between the dimuons in the transverse plane. The b -quark fraction as a function of $\Delta\phi^{\mu\mu}$ can be determined using the p_T^{rel} method also described above. In Fig. 6 the resulting cross section $d\sigma/d\Delta\phi^{\mu\mu}$ for dimuons from $b\bar{b}$ production is shown. Sequential decays and low mass gluon splitting type processes are suppressed because of the invariant mass cut used in the analysis. In the context of ISAJET production mechanisms and with our kinematic cuts one expects the flavor creation subprocess to show a relatively narrow peak at $\Delta\phi^{\mu\mu} = 180^\circ$, the flavor excitation subprocess to give a broader peak at $\Delta\phi^{\mu\mu} = 180^\circ$, and the gluon splitting subprocess to be peaked around $\Delta\phi^{\mu\mu} = 70^\circ$. Work on producing the NLO QCD predictions for $\Delta\phi^{\mu\mu}$ as well as fitting this data distribution to the individual production mechanisms used by ISAJET is in progress.

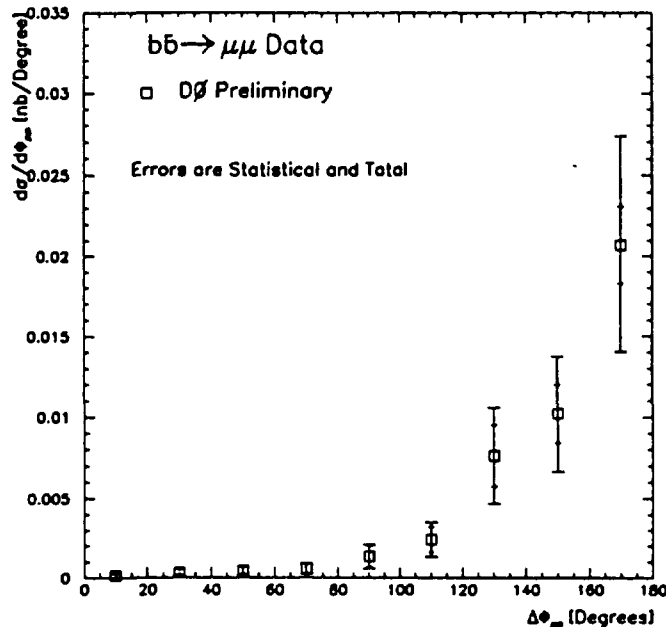


FIG. 6. Dimuon cross section $d\sigma/d\Delta\phi^{\mu\mu}$. This cross section is for dimuons with $|\eta^\mu| < 0.8$, $p_T^\mu > 4$ GeV/c, 6 GeV/c² $< M_{\mu\mu} < 35$ GeV/c², and dimuon opening angle $< 165^\circ$.

CONCLUSIONS

We have measured the inclusive dimuon cross section and subsequently extracted the b -quark cross section in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV using the DØ detector at Fermilab. The extracted b -quark cross section agrees with that derived from the inclusive single muon data. The measured b -quark cross section also agrees within errors with the NLO QCD prediction of Nason, Dawson, and Ellis (7). We have presented the $\Delta\phi^{\mu\mu}$ distribution for dimuons from $b\bar{b}$ production which can be compared to the NLO QCD prediction.

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