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B-Physics Results from DØ

MARC M. BAARMAND

(representing the DØ Collaboration)

Department of Physics and Astronomy,
State University of New York,
Stony Brook, NY 11794-3800, USA

Abstract

A number of B-physics results from the DØ experiment at the Fermilab Tevatron Collider is reported. Measurements of $b\bar{b}$ production in $p\bar{p}$ interactions at $\sqrt{s} = 1800$ GeV and 630 GeV are used to evaluate, for the first time with the same detector, the center-of-mass energy and rapidity dependence of b-quark production cross section. A measurement of the $b\bar{b}$ angular correlations using dimuon triggers is also presented. Preliminary results from these measurements are compared with the next-to-leading order QCD predictions. Finally, dimuon data samples are used to study p_T and rapidity dependence of b-produced and direct charmonium production.

1. Introduction

In the past decade, measurements of b-quark production in high energy hadronic interactions have played a crucial role in testing the perturbative quantum chromodynamics (pQCD) description of heavy quark production [1,2]. The cross section for b-quark production in $p\bar{p}$ collisions has been measured by the DØ and CDF experiments [3,4] at $\sqrt{s} = 1800$ GeV using various single and dimuon triggers, where muons come from semi-leptonic b-quark decays. These results agree in the shape of the p_T^b distribution with the next-to-leading order (NLO) QCD predictions but are generally higher than their central values. The disagreement is particularly large in the forward rapidity region ($2.4 <\mid y^\mu \mid< 3.2$), where measurements were recently made by DØ for the first time.

At the end of 1995, the Tevatron was operating at a center-of-mass energy of 630 GeV, the energy at which the b-quark cross section was previously measured by the UA1 experiment [5]. These data offer an unique opportunity to measure the b-quark production cross section at two different energies using the same apparatus and to compare their ratio with the NLO QCD expectations. The predicted ratio is less sensitive to the specific choice of the parameters in theory than the individual cross sections. Furthermore, most of the systematic uncertainties affecting the cross section measurements should cancel in the ratio.

As a further test of QCD, one can study correlated $b\bar{b}$ production. Dimuon data samples allow a direct measurement of $b\bar{b}$ correlations, such as the difference in azimuthal angle between the b and $\bar{b}$ quarks, which examines the relative amounts of different b-quark production mechanisms. A relatively large contribution from the NLO gluon splitting processes, which give rise to 3-body topologies, is expected [1].

Finally, a significant portion of charmonium production in high energy hadron collisions is expected to come through b-hadron decays. The large rapidity coverage of the DØ muon system is utilized to measure the inclusive $J/\Psi \to \mu^+\mu^-$ in the forward rapidity region and compare with the predictions for direct and b-produced production.

2. b-Quark Cross Sections at 630 and 1800 GeV

The analyses of the $\sqrt{s} = 1800$ GeV data are described in detail in [3]. They are based on inclusive muon, single muon and dimuon plus jets triggers, and the J/Ψ data sample. The results for the b-quark production cross section as a function of p_T^{min} (see below), for $|y^b| < 1.0$, are shown in Fig. 1. The NLO QCD prediction, shown by the solid line, is based on the MNR calculation [2] using the MRSA' parton distribution function [8] with $\Lambda^{(5)}_{\overline{MS}} = 152$ MeV, $m_b = 4.75$ GeV/c^2 and $\mu = \mu_0$. The dashed curves show the theoretical uncertainties obtained by varying m_b between 4.5 and 5 GeV$/c^2$, and μ between $\mu_0/2$ and $2\mu_0$. Note that there is good agreement between the measurements from different processes, however, the predictions underestimate the data by about a factor of two.

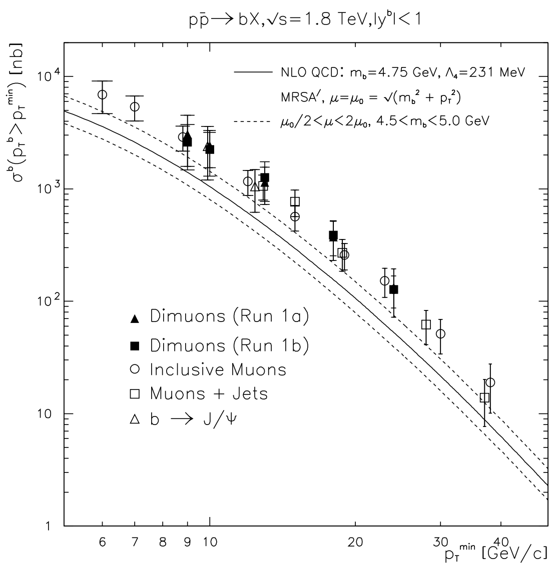

Fig. 1. The b-quark production cross section measured by DØ at 1800 GeV compared with the NLO QCD predictions. The error bars represent the total of statistical and systematic errors.

The analysis of the $\sqrt{s} = 630$ GeV data is based on single-muon events. Using $342 \pm 41\ nb^{-1}$ of data recorded with a single muon trigger in the central part of the detector, events containing a muon candidate with a pseudorapidity within ± 0.8 and a transverse momentum $4 < p_T^\mu < 10$ GeV$/c$ are retained for further analysis. The muon scintillators are used to reduce the cosmic rays background. The fraction of remaining cosmic rays, f_{bgd}, exhibits a strong dependence with p_T^μ: it is less than 5% for $p_T^\mu < 5$ GeV$/c$ but becomes larger than 80% when $p_T^\mu > 10$ GeV$/c$.

The inclusive muon cross section is obtained by the relation:

$$\frac{d\sigma^\mu}{dp_T^\mu} = \frac{N_\mu \cdot (1 - f_{bgd})}{\int \mathcal{L}dt \cdot \epsilon_\mu} \cdot f_{\rm unfold} \ , \qquad (1)$$

where N_μ is the number of selected muons, $\int \mathcal{L}dt$ is the integrated luminosity and $f_{\rm unfold}$ is a correction factor that accounts for the smearing due to the muon momentum resolution. The muon detection efficiency, ϵ_μ, is obtained using events generated with the ISAJET Monte Carlo [6], simulated with GEANT and reconstructed in the same way as real data. This efficiency, which is cross-checked with data when possible, is of the order of 10% with some p_T^μ dependence. The relative systematic errors on the inclusive muon cross section are about 16 to 22%.

The muon cross section for inclusive b-quark decays is extracted as follows:

$$\frac{d\sigma_b^\mu}{dp_T^\mu} = \left(\frac{d\sigma^\mu}{dp_T^\mu} - \frac{d\sigma^\mu_{\pi/K}}{dp_T^\mu} \right) \cdot f_b \ , \qquad (2)$$

where $\frac{d\sigma^\mu_{\pi/K}}{dp_T^\mu}$ represents the differential cross section for pions and kaons decaying in flight into muons, and f_b is the fraction of muons from b-quark decays among b and c quark semileptonic decays. These two quantities are obtained using ISAJET.

To extract an inclusive b-quark production cross section from the experimental muon spectrum, the following relation is used:

$$\sigma^b(p_T^b > p_T^{\rm min}) = \frac{1}{2}\, \sigma_b^\mu(p_T^{\mu 1}, p_T^{\mu 2})\, \frac{\sigma^b_{MC}}{\sigma^\mu_{MC}} \ , \qquad (3)$$

where $\sigma_b^\mu(p_T^{\mu 1}, p_T^{\mu 2})$ is the b-produced muon cross section integrated over the interval $p_T^{\mu 1} < p_T^\mu < p_T^{\mu 2}$, σ^b_{MC} is the total inclusive b-quark cross section for $p_T^b > p_T^{\rm min}$, and σ^μ_{MC} is the cross section for production of b quarks that decay to muons within the p_T^μ interval and with $p_T^b > p_T^{\rm min}$. The factor $\frac{1}{2}$ yields the cross section average for b and $\bar{b}$ production from the measurement of μ^+ and μ^- data. The $\sigma^b_{MC}/\sigma^\mu_{MC}$ conversion factors are evaluated using the HVQJET Monte Carlo event generator [7], which is a direct implementation of the MNR calculation [2] for $b\bar{b}$ parton generation. HVQJET combines the positive and negative weighted "partonic events", when the event topologies are similar, to cancel the infra-red and collinear divergences in the cross sections. A modified version of ISAJET is then used for hadronization, fragmentation, particle decay and modeling of the underlying event. The computation uses the MRSA' parton distribution function, together with the parameters $\Lambda^{(5)}_{\overline{MS}} = 152$ MeV, $m_b = 4.75$ GeV$/c^2$,

$\mu = \mu_0 \equiv \sqrt{m_b^2 + (p_T^b)^2}$ and $Br(b \to \mu) = 0.105$. The systematic uncertainties of the b-quark cross section vary between 54 to 33 % as a function of p_T.

The obtained b-quark production cross section is shown in Fig. 2. Also shown are the results from CDF [9,10] and UA1 [5]. The CDF cross section is a single measurement determined from the $b \to J/\psi X$ cross section measured at $\sqrt{s} = 1800$ GeV and the measured ratio of 630 and 1800 GeV b cross sections. The NLO QCD predictions are obtained using the MNR calculation and the same parameters described above for the 1800 GeV analysis. The ratio of the measured cross sections to the theoretical expectations is shown in Fig. 3. As in the case of 1800 GeV measurements, the predictions underestimate the data by about a factor of two.

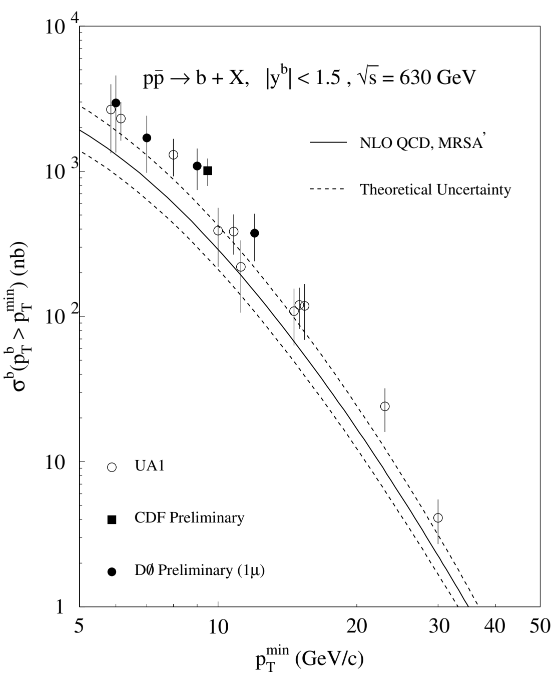

Fig. 2. The b-quark production cross sections measured by CDF, DØ and UA1 at 630 GeV compared with the NLO QCD predictions. The error bars represent the total error.

The ratio of the cross sections obtained at 630

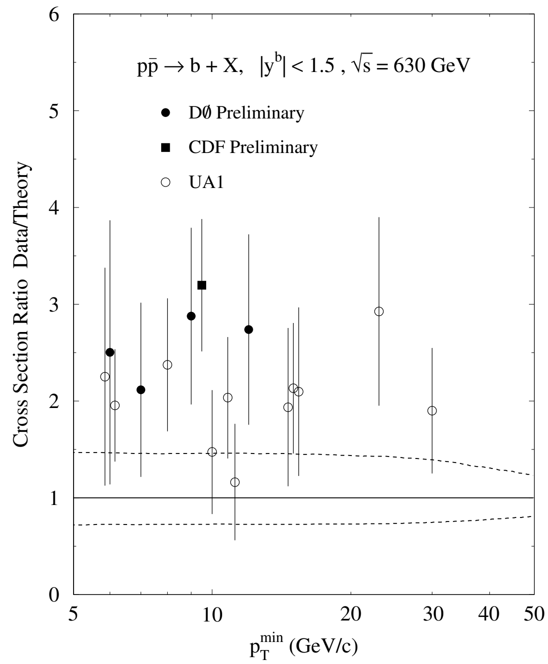

Fig. 3. The ratio of the measured b-quark production cross sections to the NLO QCD predictions.

and 1800 GeV is presented in Fig. 4. The inner and outer bars show the statistical and the total errors affecting this ratio, respectively. These results are in agreement with the NLO QCD predictions, computed in the same way as in Fig. 2. The total errors on the DØ ratios are large because the ratios are obtained by dividing the absolute cross sections independently measured at 630 GeV and 1800 GeV [3], with the assumption that only the systematic errors on the integrated luminosity and the $\sigma^b_{MC}/\sigma^\mu_{MC}$ conversion factors are correlated between both measurements. Work is in progress to reduce these errors.

3. *b*-Quark Cross Section versus Rapidity

Using the Small Angle Muon Spectrometer (SAMUS) [11], DØ has measured the muon cross section in the previously unexplored forward rapidity region, $2.4 < |y^\mu| < 3.2$. The data were collected at $\sqrt{s} = 1800$ GeV for a total integrated luminosity of 104 nb^{-1} during the 1994-95 Tevatron run. The differential muon cross section in

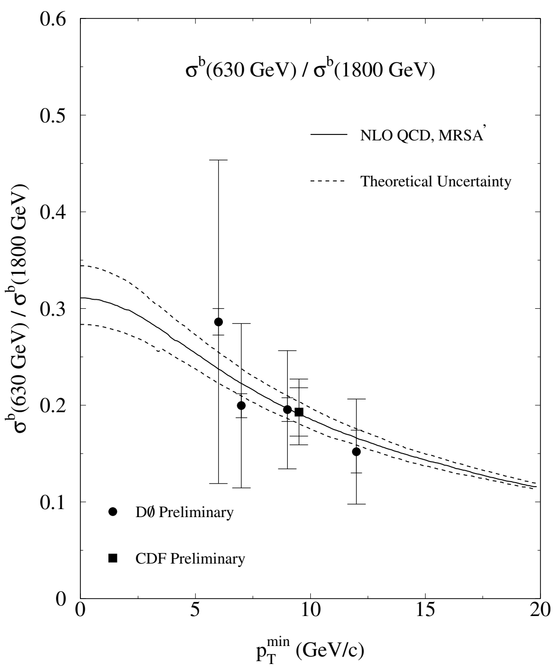

Fig. 4. Ratio of b-quark production cross sections at 630 GeV to 1800 GeV.

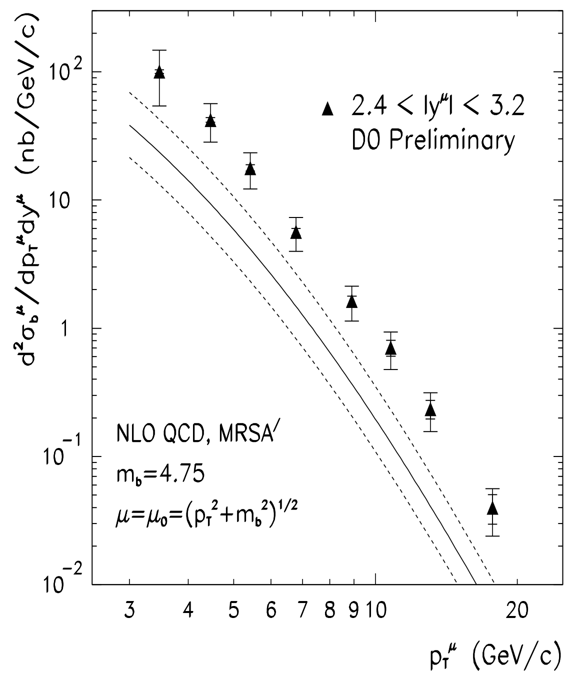

Fig. 5. Differential muon cross section, per unit of rapidity, in the forward region from b quark production and decay as a function of p_T^μ. The inner error bars are statistical and the outer ones are statistical and systematic added in quadrature. The solid curve is the NLO QCD predictions with the dashed curves representing the theoretical uncertainties.

the forward region from b production and decay is obtained from the inclusive muon cross section, following the same steps described in Section 2. The pion and kaon decay spectrum and the fraction of muons from b decays are calculated using ISAJET. The result is shown in Fig. 5. The NLO QCD predictions match the shape of the cross section, but are approximately a factor of four lower than the data.

The differential muon cross section as a function of rapidity, $d\sigma_b^\mu/d|y^\mu|$, is obtained by combining the DØ forward and central ($|y^\mu| < 0.8$) muon cross sections. Figure 6 shows the results for $p_T^\mu > 5$ and 8 GeV/c. The NLO QCD predictions do not match the data; they are a factor of two lower in the central region (although consistent within errors) and a factor of four lower in the forward region.

4. $b\bar{b}$ Angular Correlation Measurements

The differential $b\bar{b}$ cross section, $d\sigma_{b\bar{b}}^{\mu\mu}/d\Delta\phi^{\mu\mu}$, gives further information on the underlying QCD production mechanisms by studying the topological correlation between the two b-quarks. The difference between the azimuthal angle between the b and $\bar{b}$ quarks (or nearly equivalently, between the decay muons), allows us to differentiate between the contributing QCD production mechanisms, which are the leading order (LO) process (flavor creation) and the next-to-leading order processes (gluon splitting, flavor excitation and gluon radiation). A sizeable contribution from the higher order processes is expected in the region of $\Delta\phi^{\mu\mu} < 140$ degrees, where the leading order contribution is small.

For this analysis, the 1800 GeV dimuon data sample is used. Kinematical and topological requirements are imposed to reduce backgrounds: two muons with $|\eta^\mu| < 0.8$, $4 < p_T^\mu < 25$ GeV/c, and $6 < M^{\mu\mu} < 35$ GeV/c^2. The lower mass limit removes dimuons resulting from the low

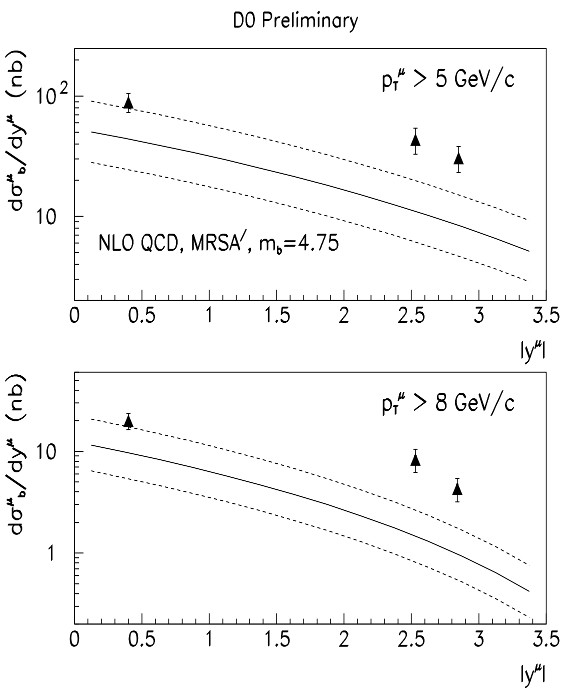

Fig. 6. Differential muon cross sections from b production and decay as a function of $|y^\mu|$ for p_T^μ > 5 and 8 GeV/c. The solid curve is the NLO QCD predictions with the dashed curves representing the theoretical uncertainties.

mass vector mesons, cascade decay of single b-quarks and through J/ψ decays, while the upper limit removes dimuon decays of the Z boson. Each muon is also required to have an associated jet with $E_T > 12$ GeV within a cone of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.8$. A total of 397 events passed all selection criteria, corresponding to a total integrated luminosity $\int \mathcal{L}dt = 6.5\, pb^{-1}$. In addition to $b\bar{b}$ pairs, these dimuon events can also arise from $c\bar{c}$ pairs, events in which one or both of the muons are produced by in-flight decays of π or K mesons, Drell-Yan production, Υ decays, and cosmic rays. To extract the fraction of the dimuons coming from b-quark decays, we use a maximum likelihood fit [12] based on p_T^{rel} (the transverse momentum of the muon with respect to the associated jet axis) for both the leading and trailing muons.

Figure 7 shows the measured $\Delta\phi^{\mu\mu}$ distribution. It is compared with the LO and NLO QCD predictions determined using the HVQJET Monte Carlo. All three gluon-gluon, gluon-quark/-antiquark and quark-antiquark initiated subprocesses are included. The data show a clear excess above the HVQJET predictions and the agreement with the overall shape is only fair. Nevertheless, the measured distribution clearly indicates the presence of the higher order processes, which produce event topologies with b and $\bar{b}$ not back-to-back. From our HVQJET studies, we have learned that the dimuon selection requirements, particularly the mass cuts, strongly favor the LO $b\bar{b}$ events - the calculated K-factor is 1.2 instead of the expected factor of two. Also, inclusion of the gluon-quark/-antiquark subprocess lowers the sum of the cross sections for the large values of $\Delta\phi^{\mu\mu}$ (> 160 degrees) because of the large negative divergent behavior of gluon-quark/-antiquark cross section in that region.

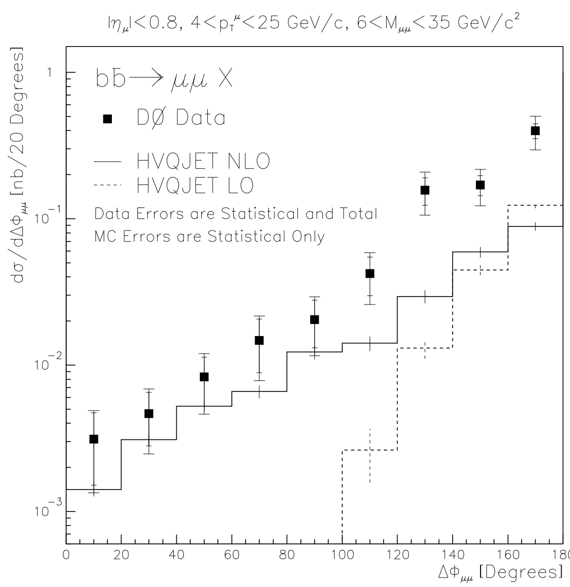

Fig. 7. The measured $\Delta\phi^{\mu\mu}$ spectrum from $b\bar{b}$ production at 1800 GeV, compared to the HVQJET predictions (see text). The LO histogram includes the leading-order gg and $q\bar{q}$ processes, and the NLO histogram includes the leading-order plus next-to-leading order gg, $q\bar{q}$, gq and $g\bar{q}$ processes.

5. Charmonium Production

Previous measurements from UA1 [5] at $\sqrt{s} =$ 630 GeV, from CDF [4,10] and DØ [3] at $\sqrt{s} =$ 1800 GeV show that the inclusive J/Ψ transverse momentum distribution is not in agreement with b-hadron decay plus prompt production as predicted by the color-singlet model [13]. Using the SAMUS detectors, the inclusive $J/\Psi \rightarrow \mu^+\mu^-$ cross section has been measured in the forward rapidity region for the first time. The data were collected at $\sqrt{s} = 1800$ GeV for a total integrated luminosity of 9.8 pb^{-1} during the 1994-96 Tevatron runs.

Figure 8 shows the J/Ψ production cross section for $2.5 < |\eta^{J/\Psi}| < 3.7$ as a function of its transverse momentum. The data are compared with the theoretical predictions of the color-singlet and color-octet [14] models plus J/Ψ from b-quark decays. The parameters of the color-octet model are obtained from the CDF measurements of J/Ψ production at $|\eta| < 0.6$ [14]. Note that the color-octet plus b-produced predictions are in good agreement with the measurements, while the color-singlet plus b-produced model significantly underestimates the data. Also, the prompt J/Ψ production makes the main contribution to the total cross section in the forward region.

In Fig. 9, we use the central and forward DØ and CDF data to examine the pseudorapidity dependence of J/Ψ production cross section for the two kinematic regions of $p_T > 5$ GeV/c and $p_T > 8$ GeV/c. Again, the color-octet model, combined with b-produced J/Ψ, gives reasonable agreement with the experimental measurements.

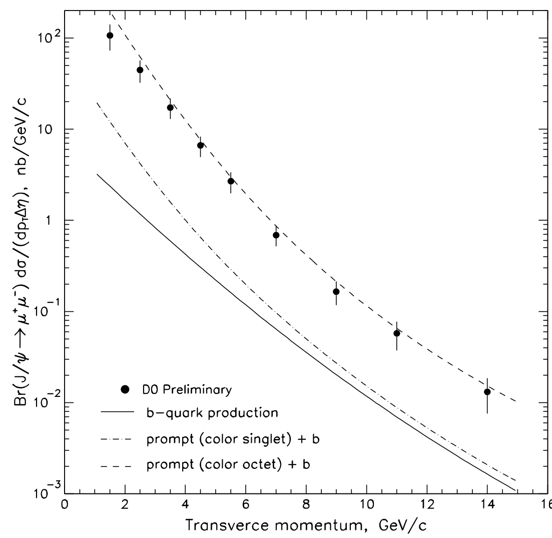

Fig. 8. The J/Ψ production cross section for $2.5 < |\eta^{J/\Psi}| < 3.7$ as a function of its transverse momentum, compared with predictions of the color-singlet and color-octet models plus J/Ψ from b-quark decays.

6. Conclusions

We have presented preliminary measurements of b-quark production cross section in $p\bar{p}$ collisions performed by the DØ experiment at the Tevatron. The measured cross sections, using central muons ($|y^\mu| < 0.8$), agree in the shape of the p_T^b distribution with the NLO QCD predictions but are a factor of two larger than their central values. This trend is observed both at 630 and 1800 GeV, however, the ratio of the cross sections at these two center-of-mass energies is compatible with the NLO expectations. Preliminary results on $b\bar{b}$ angular correlations show a similar comparison in normalization with NLO QCD. The shape of $d\sigma/d\Delta\phi^{\mu\mu}$, although only in fair agreement with NLO QCD, clearly indicates a sizeable contribution from the higher order processes. The DØ experiment has also measured the b-produced muon cross section in the forward rapidity region ($2.4 < |y^\mu| < 3.2$). These measurements, although agree in the p_T shape, are a factor of four higher than predictions. The measured cross section as a function of rapidity is not reproduced by the NLO QCD calculations. The charmonium studies in the forward rapidity region indicate that the data are reasonably well described by a combination of the b-produced plus the color-octet prompt production of J/Ψ.

7. Acknowledgments

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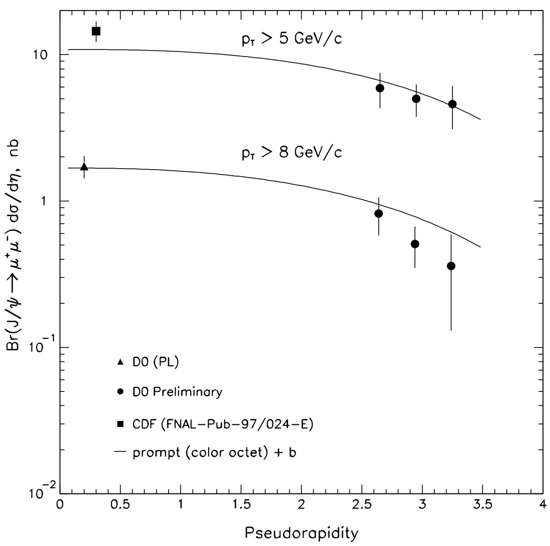

Fig. 9. The pseudorapidity dependence of J/Ψ production cross section for $p_T > 5$ GeV/c and $p_T > 8$ GeV/c.

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