Fermi National Accelerator Laboratory

FERMILAB-Conf-96/176-E
CDF

Measurement of the Ratio of b-Quark Production Cross Sections at $\sqrt{s}$ = 630 GeV and $\sqrt{s}$ = 1800 GeV

Jonathan Lewis
For the CDF Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

July 1996

Contributed Paper at the *28th International Conference on High Energy Physics (ICHEP96)*, Warsaw, Poland, July 25-31, 1996

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Disclaimer

ICHEP96/pa04-59a
FERMILAB-CONF-96/176-E
CDF/PUB/BOTTOM/PUBLIC/3733
July 11, 1996

Measurement of the Ratio of b-Quark Production Cross Sections at $\sqrt{s} = 630\,\mathrm{GeV}$ and $\sqrt{s} = 1800\,\mathrm{GeV}$

The CDF Collaboration

Abstract

We report on a measurement of the ratio of b-quark production cross section in $p\overline{p}$ collisions at $\sqrt{s} = 630\,\mathrm{GeV}$ and $\sqrt{s} = 1800\,\mathrm{GeV}$ collected by the Collider Detector at Fermilab. Results are compared to the predictions of next-to-leading order QCD calculations.

Next-to-leading-order (NLO) QCD has been applied to describe the production of heavy quarks in $p\overline{p}$ interactions[1, 2]. Although the theory can make precise descriptions of the shapes of single and double differential cross sections, the absolute normalization is not well-determined due to large uncertainties in the b-quark mass, the QCD factorization and renormalization scales, and the value of Λ_{QCD}. Measurements of single b production as a function of momentum from CDF at $\sqrt{s} = 1800\,\mathrm{GeV}$ [3] and from UA1 at $\sqrt{s} = 630\,\mathrm{GeV}$ [4, 5] show good agreement with NLO QCD up to this choice of scale[6]. Although the renormalization scale is subject to large experimental uncertainties, the choice of scale should be insensitive to the energy of the incident hadrons, and the ratio of the production cross sections at the two beam energies as a function of b momentum should be insensitive to the scale. Because there are large systematic uncertainties in making comparisons between measurements from the two detectors and from different experimental signatures, we seek to measure the relative b production as a function of beam energy using a common signature in one experiment and compare to the predictions of NLO QCD.

Two properties of b hadron decays yield important experimental signatures: a large branching ratio of semileptonic decays and a long lifetime. Leptons are readily identified in an experimental trigger. However, inclusive lepton samples also include large backgrounds. Associating the lepton with a reconstructed secondary vertex significantly suppresses backgrounds and yields a highly enriched sample of B events. Furthermore, those events with vertices found opposite the B-candidate momentum provide a natural measure of the residual background in the forward displaced events.

This paper describes a measurement of the energy dependence of b production using events containing muons associated with secondary vertices in a sample of $1.89 \pm 0.06\,\mathrm{pb}^{-1}$ of $\overline{p}p$ collisions at $\sqrt{s} = 1800\,\mathrm{GeV}$ collected with the CDF detector in early 1993 and and a sample of $0.46 \pm 0.04\,\mathrm{pb}^{-1}$ at $\sqrt{s} = 630\,\mathrm{GeV}$ collected in December 1995. The CDF detector is described in detail elsewhere[7]. We describe briefly below the detector subsystems crucial to the reconstruction of B decays: the Silicon Vertex detector (SVX), the Central Tracking Chamber (CTC), the muon detectors, and the muon trigger. The SVX is a four-layer silicon microstrip detector. The strips run parallel to the beam axis (z) and have a pitch of 60 μm in the inner three layers and 55 μm in the outermost layer. The detector covers the range $|z| < 30$ cm, where z is measured from the center of the detector. The spatial resolution of the device is 13 μm with an impact parameter resolution of $(13+40/p_T)$ μm, where p_T is the component of a particle's momentum transverse to the beam axis measured in GeV/c. The transverse profile of the beam is approximately circular with an r.m.s. width of approximately 40 μm. The longitudinal r.m.s. length of the luminous region within the CDF detector is about 30 cm. The CTC[8] is an 84-layer open-cell drift chamber. It contains five 12-layer superlayers of axial wires and four interleaved 6-layer superlayers with $\pm 3°$ stereo angle. The momentum resolution of the combined CTC-SVX system is $\delta p_T/p_T = \sqrt{(0.0009 p_T)^2 + (0.0066)^2}$, where p_T is measured in GeV/c.

Two sets of detectors are used to identify high-momentum muons. The Central Muon system (CMU) includes four layers of drift chambers forming a cylinder outside the central calorimeter. The calorimeter includes about 4 interaction lengths of material. The CMU covers the pseudorapidity range $|\eta| < 0.6$ and 85% of azimuth, where $\eta \equiv -\ln(\tan\frac{\theta}{2})$ and θ is the polar angle relative to the proton beam. Four layers of central muon upgrade (CMP) drift chambers lie in four planes around the central detector behind an additional 60 cm of steel and cover approximately 65% of the solid angle of the CMU system. The combined efficiency for muons in the geometric acceptance of the detector is $> 95\%$. Identification of muons requires matching charged particle tracks found in the CTC to track segments reconstructed in the drift tubes of both muon systems.

CDF employs a three level triggering scheme. Muons are identified at the first level by coincidences between radially aligned wires in both muon detectors. The temporal separation of the hits in two layers of CMU is required to be consistent with a muon of $p_T > 5$ GeV/c. If the first level of trigger is satisfied, detector input is disabled while the second level of the trigger evaluates the event. Muon events are required to have at least one of the first level coincidences matched to a track found by the CFT online track processor[9]. Events that pass the second level requirements are digitized and passed to the Level 3 CPU farm that performs a software reconstruction analysis. Events that contain a high-momentum reconstructed muon candidate are included in a muon data sample for further analysis. Muon candidates are required to have a CTC track projecting to a track segment in the muon chambers within 3 standard deviations of the prediction in the azimuthal view in both muon detectors and within 4 standard deviations in z view in the CMU system.

In events with muon candidates with $p_T > 6.2\,\mathrm{GeV}/c$, we find the highest-$p_T$ track in a cone of $R^2 = (\Delta\eta)^2 + (\Delta\phi)^2 < 1.0$ around the muon such that the mass of the combination is less than $5.3\,\mathrm{GeV}/c^2$, consistent with two particles from a single b-hadron decay, where the second particle is assigned the pion mass. Because fragmentation particles tend to be soft, we require the second particle to have $p_T > 1\mathrm{GeV}/c$. To reject background events from charm-particle decays, we require that the mass of the combination be greater than $1.5\,\mathrm{GeV}/c^2$. We constrain the two tracks to a common decay vertex, and require the χ^2 probability of the fit to be greater than 1%. We define the transverse decay length $L_{xy} = \vec{d} \cdot \hat{p}_T^{\mu h}$, where $\vec{d}$ is the displacement of the decay vertex from the beamline, and $\hat{p}_T^{\mu h}$ is the unit vector of the transverse momentum of the μ-track combination. To reject muons from pion and kaon decays, we require $L_{xy} < 2\,\mathrm{cm}$. Background events in which tracks are randomly associated will equally populate positive and negative regions of L_{xy}. So the number of b candidates is the number of events with positive L_{xy} less the number with negative L_{xy} in each of the two samples. Because there are still large backgrounds from prompt events, to limit the effect of large subtractions, we restrict the signal region to $L_{xy} > 0.25\,\mathrm{mm}$ and estimate the background from the number of events with $L_{xy} < -0.25\,\mathrm{mm}$. This cut also eliminates the need to correct for b events in which L_{xy} is found to be negative as a result of limited position resolution. We find 305 (141) events in the signal (background) region in the 630 GeV sample and 11679 (6062) in the 1800 GeV sample for net yields of 164 ± 21 and 5617 ± 133, respectively. Figures 1 and 2 show the L_{xy} distributions in the two data samples.

In order to determine the ratio of cross sections we must correct for the different acceptance for b events at the two energies. The difference in acceptance arises from two sources. First, because the Tevatron operating conditions were different at the two energies, the r.m.s. length of the luminous region was different in the two running periods, giving different acceptances for charged particle tracks to be observed in the SVX. Secondly, NLO QCD predicts that the b momentum spectrum is more steeply falling with momentum at 630 GeV than at 1800 GeV, giving different acceptances to the kinematic cuts in the analysis. We determine the relative acceptance using Monte Carlo simulation of one million semileptonic b-hadron decays at each energy. We generate events with single b quarks with momentum $p_T > 9.5\,\mathrm{GeV}/c$ and rapidity $|y_b| < 1$ according to NLO QCD using the MRSA$'$ [10] parton distributions ($\Lambda_4 = 231\,\mathrm{MeV}$), a b-quark mass $m_b = 4.75\,\mathrm{GeV}/c^2$, and renormalization scale $\mu = \mu_0$ where $\mu_0^2 = m_b^2 + {p_T}^2$. b quarks are fragmented using the Peterson parameterization with $\epsilon = 0.006$ [11, 12] and relative populations of B^+:B^0:B_s:Λ_b=0.375:0.375:0.150:0.100. Hadron decays are simulated with the CLEO Monte Carlo program[13]. We find the relative acceptance to be $A_{630}/A_{1800} = 0.62 \pm 0.04$. Thus the ratio of cross sections is

$$\frac{\sigma_b(p_T > 9.5, |y_b| < 1, \sqrt{s} = 630\,\mathrm{GeV})}{\sigma_b(p_T > 9.5, |y_b| < 1, \sqrt{s} = 1800\,\mathrm{GeV})} = 0.193 \pm 0.025 \pm 0.023$$

where the uncertainties are statistical and systematic respectively. The systematic uncertainty is dominated by the uncertainty in the integrated luminosity at 630 GeV. The theoretical prediction for the ratio of cross sections is 0.189 ± 0.012 using MRSA$'$ parton distributions where for the central value we use $\mu = \mu_0$ and $m_b = 4.75\,\mathrm{GeV}/c^2$ and the error is derived varying μ between $2\mu_0$ and $\mu_0/2$ and m_b between 4.5 and $5.0\,\mathrm{GeV}/c^2$. The minimum b-quark p_T is determined from Monte Carlo simulations where it is found that 99% of b events with a muon of $p_T > 6.2\,\mathrm{GeV}/c$ and another charged particle of $p_T > 1\,\mathrm{GeV}/c$ descend from a b quark with a p_T of at least $9.5\,\mathrm{GeV}/c$. Figure 3 shows the measured ratio and with the theoretical predictions as a function of minimum b momentum.

In ISAJET [14] Monte Carlo simulations, we have looked for possible sources of displaced secondary vertices other than single b quarks. We find

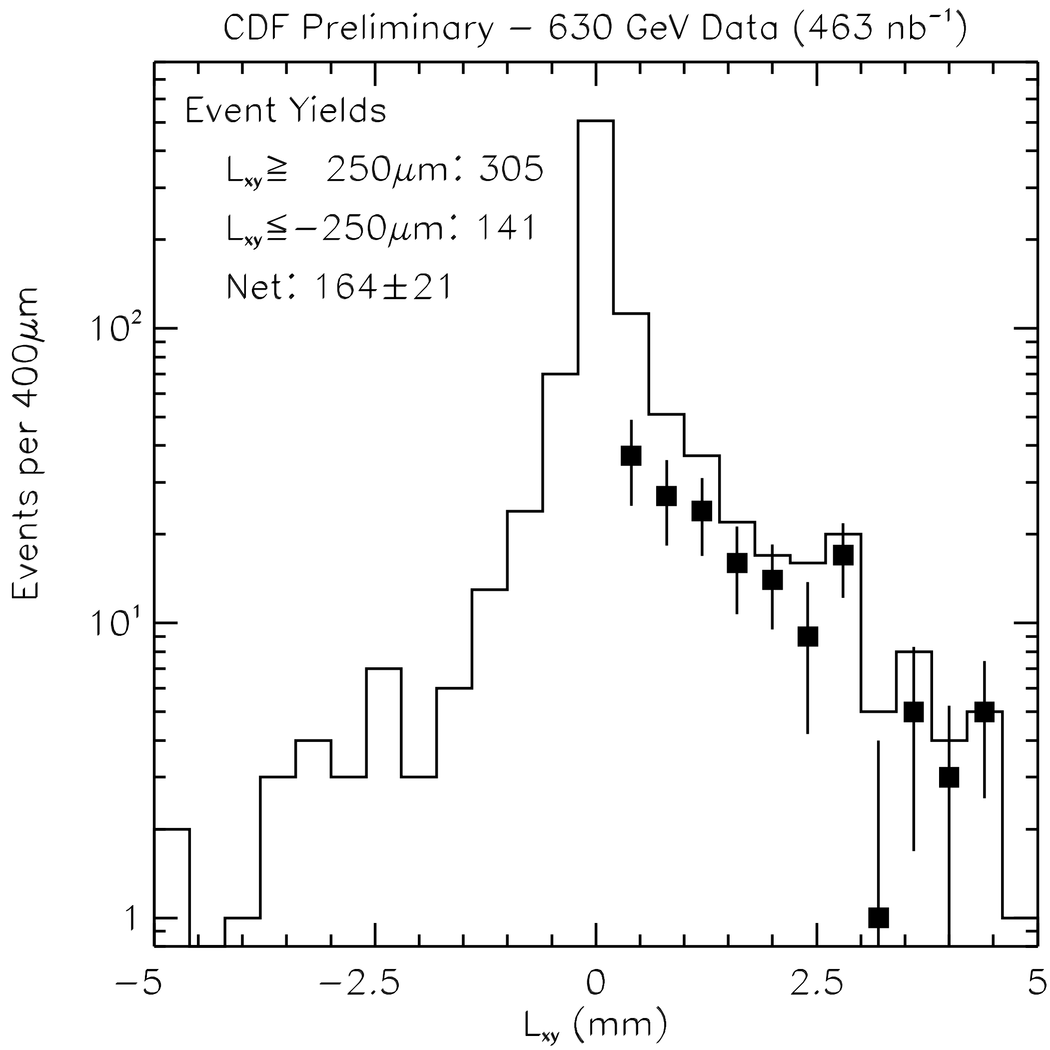

Figure 1: Transverse flight distance between the μ-track vertex and the primary vertex in 630 GeV data. The points show the number of b candidates determined from the excess of events in each positive flight-distance bin compared to the corresponding negative flight-distance bin.

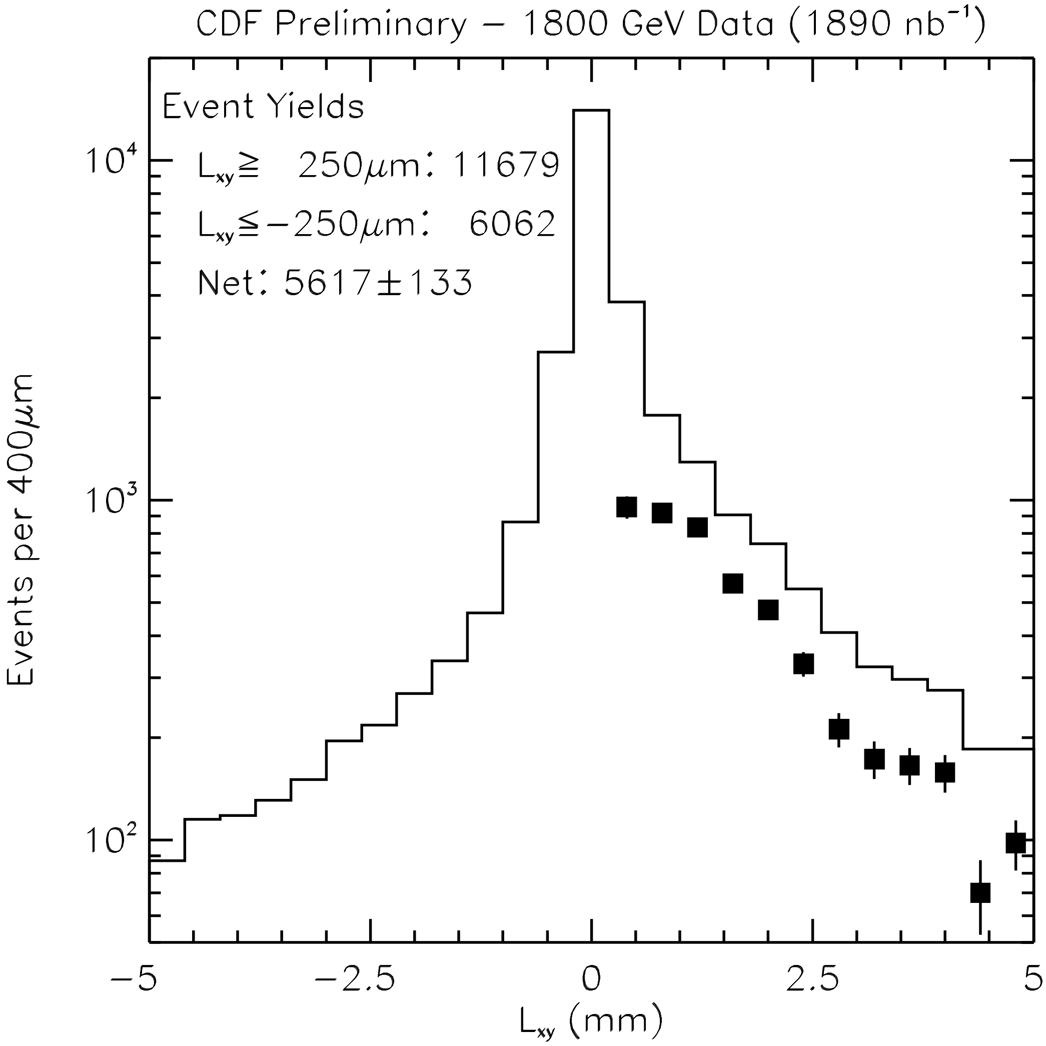

Figure 2: Transverse flight distance between the μ-track vertex and the primary vertex in 1800 GeV data. The points show the number of b candidates determined from the excess of events in each positive flight-distance bin compared to the corresponding negative flight-distance bin.

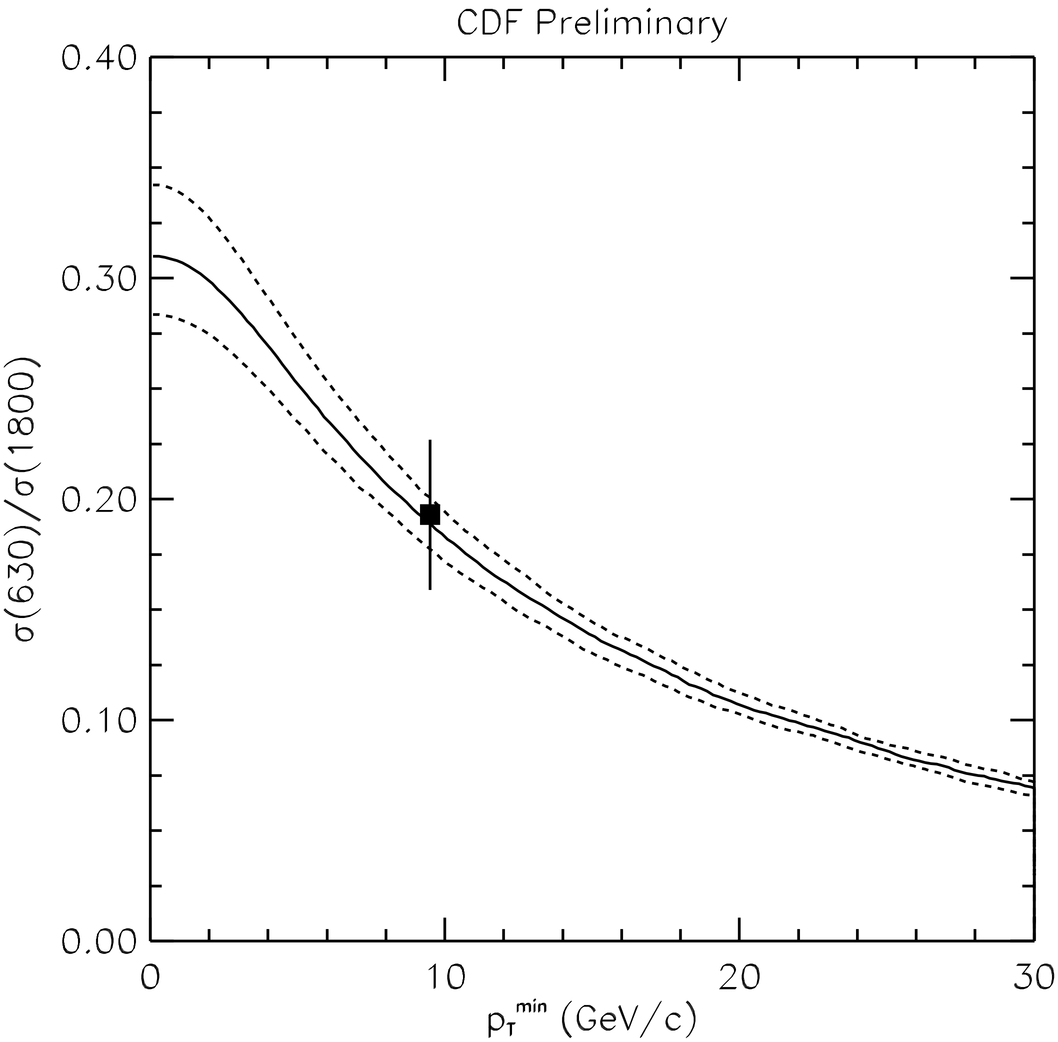

Figure 3: Theoretical predictions using MRSA$'$ parton distribution functions on the ratio of b quark cross sections (integrated above a minimum p_T) at 630 GeV to 1800 GeV. The solid line is for choice of scale μ_0 and a b mass of 4.75 GeV; the dashed lines show the theoretical variation with scale and b mass. The data point is this measurement. Uncertainties are combined statistical and systematic.

that the acceptance to b quarks created via a "gluon splitting" mechanism is consistent with the acceptance in our single-b simulation. Further, we find that the 90% upper limit on the acceptance to $c\bar{c}$ pairs created either directly or via gluon splitting is 5% of the acceptance to b quarks. Also, as a check that the observed events are consistent with coming entirely from B decays, we fit the background-subtracted L_{xy} distributions to an exponential and compare with the NLO QCD Monte Carlo simulations. We find an effective decay length of $1.57 \pm 0.07\,\mathrm{mm}$ compared with an expected value of $1.49 \pm 0.04\,\mathrm{mm}$ in the 1800 GeV sample and $1.50 \pm 0.24\,\mathrm{mm}$ compared with 1.34 ± 0.04 in the 630 GeV sample.

Finally, we use the measured cross section ratio to determine the total b quark cross section at 630 GeV for $p_T > 9.5\,\mathrm{GeV}/c$. The b-quark cross section for $\sqrt{s} = 1800\,\mathrm{GeV}$, $p_T > 9.5\,\mathrm{GeV}/c$ and $|y_b| < 1$ is determined by logarithmic interpolation of the two nearest points measured by CDF in the $b \to J/\psi X$ channel [15] to be $3.81 \pm 0.36\,\mu\mathrm{b}$. UA1 b cross section measurements at 630 GeV are quoted for the rapidity interval $|y_b| < 1.5$, so to make a direct comparison, we multiply this cross section by the measured ratio and by a correction factor of 1.37 for different rapidity range determined from NLO QCD using the central values of μ and m_b, yielding

$$\sigma_b(p_T > 9.5, |y_b| < 1.5, \sqrt{s} = 630\,\mathrm{GeV}) = 1.01 \pm 0.12 \pm 0.18\,\mu b$$

where the uncertainties are statistical and systematic. Figure 4 shows this result and the UA1 measurements [4, 5] compared to the prediction of NLO QCD with the MRSA$'$ parton distributions for $\mu = \mu_0$ and $m_b = 4.75\,\mathrm{GeV}/c^2$. We also include the prediction using the older DFLM parton distributions [16] which were used for the comparison to theoretical predictions in the UA1 papers. Although, the CDF measurement does lie somewhat above UA1 points, the experimental results are consistently higher than the prediction using the MRSA$'$ parton distributions using the central values of μ and m_b as is the case in the 1800 GeV cross section measurements[3].

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministy of Education, Science and Culture of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; and the A.P. Sloan Foundation.

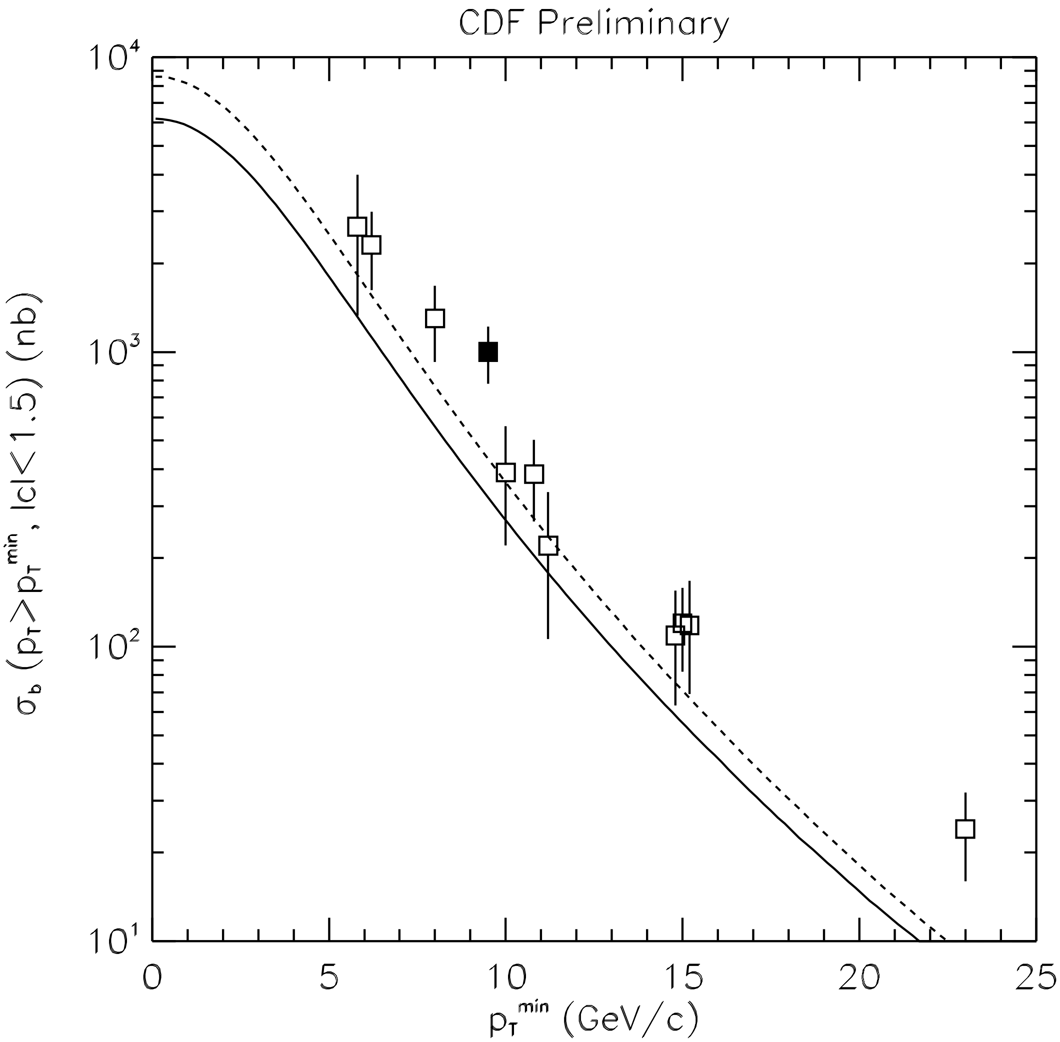

Figure 4: The CDF measurement of b-quark cross section at 630 GeV derived from measured ratio and cross sections measured in the $b \rightarrow J/\psi X$ channel [15] is shown by the solid square. Open squares show the UA1 measurements from [4] and [5]. The solid curve is the theoretical prediction of the b quark cross section integrated above a minimum p_T using MRSA$'$ parton distributions for choice of scale μ_0 and a b mass of 4.75 GeV$/c^2$. The dashed curve shows the prediction using the DFLM parton distributions. Uncertainties are combined statistical and systematic.

References

[1] P. Nason, S. Dawson, and R.K. Ellis, *Nucl. Phys.* **B303,** 607; (1988);, , B327;49 (1988).

[2] M.L. Mangano, P. Nason, and G. Ridolfi, *Nucl. Phys.* **B373,** 295 (1992).

[3] F. Abe *et al.*, *Phys. Rev. Lett.* **75,** 1451 (1995).

[4] C. Albajar *et al.*, *Phys. Lett.* **B256,** 121 (1991).

[5] C. Albajar *et al.*, *Z. Phys.* **C61,** 41 (1994).

[6] S. Frixione, M.L. Mangano, P. Nason, and G. Ridolfi, *Nucl.Phys.* **B431,** 453 (1994).

[7] F. Abe, *et al.*, *Nucl. Inst. Meth.* **A271,** 387 (1988).

[8] F. Bedeschi *et al.*, *Nucl. Inst. Meth.* **A268,** 50 (1988).

[9] G.W. Foster *et al.*, *Nucl. Inst. Meth.* **A269,** 93 (1988).

[10] A.D. Martin, W.J. Stirling, R.G. Roberts, *Phys.Lett.* **B354,** 155 (1995).

[11] C. Peterson *et al.*, *Phys. Rev.* **D27,** 105 (1983).

[12] J. Chrin, *Z. Phys.* **C36,** 163 (1987).

[13] P. Avery, K. Read and G. Trahern, Cornell Internal Note CSN-212, unpublished (1985).

[14] F. Paige and S.D. Protopopescu, BNL Report No. 38034, unpublished (1986).

[15] "J/ψ and ψ' Production at CDF," CDF Collaboration, FERMILAB-CONF-96/156-E, contributed to this conference.

[16] M. Diemoz, F. Ferroni, E. Longo and G. Martinelli, *Z. Phys.* **C39,** 21 (1988); J.V. Allaby *et al.*, *Phys. Let.* **B197,** 281 (1987).