Fermi National Accelerator Laboratory

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CDF

b Quark Production Cross Sections and the b - $\bar{b}$ Correlated Production Cross Section at CDF

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Abstract

Recent results on b quark and B meson production cross sections have been obtained at $\sqrt{s} = 1.8$ TeV proton-antiproton collisions using the Collider Detector Facility (CDF) at Fermilab, using the exclusive decay modes $B^{\pm} \rightarrow J/\Psi\, K^{\pm}$ and $B^{0} \rightarrow J/\Psi\, K^{*}$. Another measurement made using data from the 1988-89 run on the correlated $b+\overline{b}$ cross section is also presented.

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1 The Correlated $b-\bar{b}$ Cross Section

Data from the 1988-89 run at Fermilab using an electron-muon trigger was used to measure the production cross section of bottom quark-antiquark pairs. Electron-muon pairs have no background from Drell-Yan, Z boson decays, or cosmic rays making this a particularly clean signal of correlated heavy quark decays.

The CDF detector is described elsewhere [1]. The trigger required a cluster in the electromagnetic calorimeter of greater than 5 GeV and a stiff track pointing to that cluster. An additional requirement that the associated muon have greater than 3 GeV/c of transverse momentum (P_T) was imposed by the trigger. The events were also required to have a missing transverse energy ($\not{E}_T$) less than 2.4σ from zero and a displacement along the beam-line < 60 cm from the detector center.

Additional cuts were placed on the electron and muon candidates to improve the purity of the sample. For the electrons $E_T > 5.0$ GeV and $\frac{E}{p} < 2.0$. The shower had to be consistent with an electron both in the strip chamber located at shower maximum and in the lateral shower development profile. Finally the electron candidate track in the central tracking chamber (CTC) had to match the shower profile in the strip chamber to within 2.0 cm in ϕ and 3.5 cm in z.

Muon candidates were required to have deposited less than 2.0 GeV of energy in the electromagnetic calorimeter and less than 4.0 GeV in the hadron calorimeter. The intercepts of candidates in the central muon chambers (CMU) had to match extrapolated CTC tracks to within 15 cm in ϕ and 20 cm in z. The impact parameter of the CTC tracks had to be within 0.5 cm of the known beam position, and the displacement of the tracks along the beam line less than 5.0 cm from the event vertex. The efficiencies of these cuts were measured from the data using an independent sample and were $\simeq 0.5 \pm 0.2$ for all the lepton P_T thresholds. This represented the largest contribution to the systematic uncertainty.

After imposing the analysis cuts, the quantity $\Delta_{e\mu}$ is formed by subtracting the number of same sign (N_{ss}) electron-muon pairs from the number of opposite sign (N_{os}) pairs. This removes background from decays-in-flight and fake muons (due to punch-through) which have no os or ss preference. There will be some background to the correlated $b-\bar{b}$ cross section due to direct charm quark production so one must multiply $\Delta_{e\mu}$ by $f_{b\bar{b}}$, the fraction of opposite sign minus same sign pairs that come from b quarks. The equation used to generate the correlated

Table 1: The acceptance (A) for b quark decays into muons and electrons for the different thresholds used in this analysis. α shows the relative acceptance of cascade decays to direct semileptonic decays of B mesons.

P_T^{thresh} GeV/c	P_T^{min} GeV/c	$A(b\to\mu)$	$\alpha(b\to c\to\mu)$
3.0	6.50	0.157 ± 0.001	0.182 ± 0.006
4.0	7.50	0.122 ± 0.001	0.130 ± 0.006
5.0	8.75	0.097 ± 0.001	0.126 ± 0.006
E_T^{thresh} GeV/c	P_T^{min} GeV/c	$A(b\to e)$	$\alpha(b\to c\to e)$
5.0	8.75	0.144 ± 0.003	0.099 ± 0.004

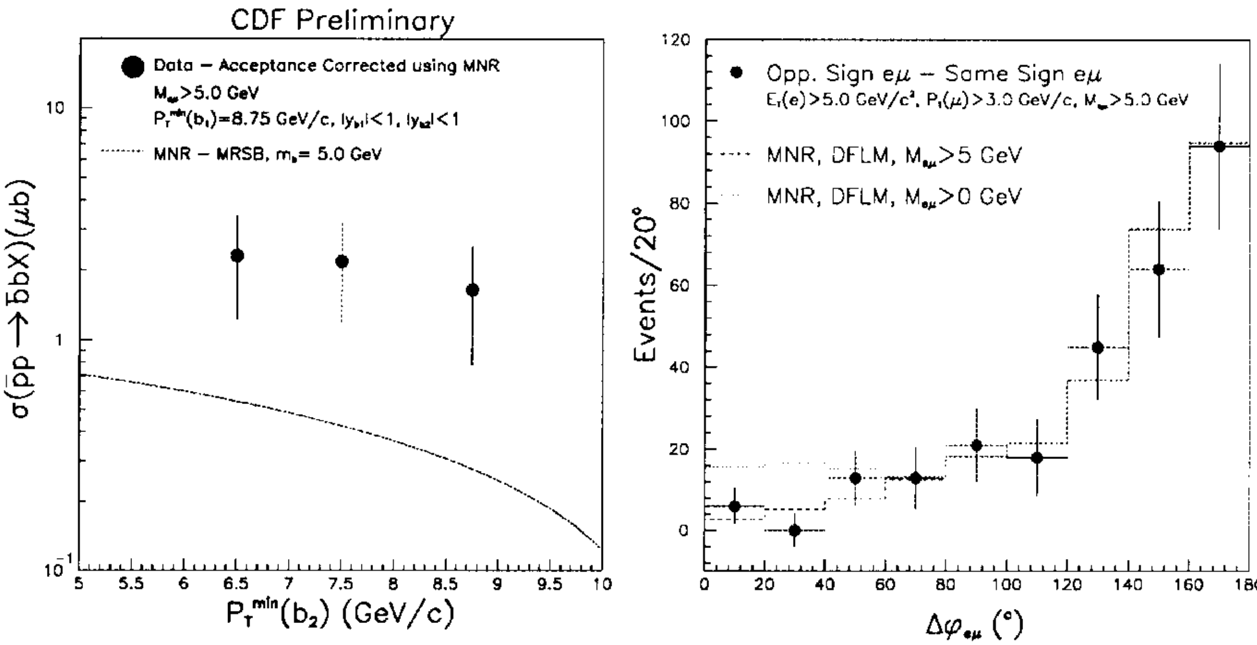

Figure 1: The left figure shows correlated $b\bar{b}$ cross section for P_T^{min} =6.5, 7.5, and 8.75 GeV/c on the b quark yielding the muon and P_T^{min} = 8.75 GeV/c of the b quark yielding the electron. The figure on the right shows the difference in ϕ between the electron and muon in the data compared to the Monte Carlo model.

cross section is given by:

$$\sigma(p\bar{p} \to b\bar{b}\ X) \simeq \frac{f_{b\bar{b}}\Delta_{e\mu}}{L(1-2\chi)^2 2\epsilon_{CUTS}\epsilon_{trig}A(be)A(b\mu)\Gamma_{be}\Gamma_{b\mu}} \tag{1}$$

where L is the integrated luminosity (L = 2.94 pb^{-1}), ϵ_{CUTS} is the efficiency of the offline cuts, ϵ_{trig} is the trigger efficiency, $A(be,\ b\mu)$ are the electron and muon acceptances, and $\Gamma_{be,\, b\mu}$ represent the b quark branching rations to electrons and muons respectively. The parameter χ accounts for the probability of mixing of the neutral B mesons ($\chi = .16 \pm .04$ was used here). The equation is only approximately equal to the cross section because there are additional corrections for the cascade decays to leptons from $b \to c \to \mu,\ e$. Table 1 shows the contribution of the cascade decays as well as the acceptances for the thresholds used in this analysis. These acceptances were obtained using a correlated cross section calculation by Mangano, Nason, and Ridolfi [2] with MRSB [3] structure functions and a detector simulation. The correlated cross sections obtained are shown in Figure 1. P_T^{min} is defined as the transverse momentum possessed by 90% of the b quarks that produced events in the data. The final results are $2.31 \pm 0.42 \pm 1.00$, $2.18 \pm 0.28 \pm 0.96$, and $1.65 \pm 0.26 \pm 0.83$ μb for P_T^{min} of 6.5, 7.5, and 8.75 GeV/c respectively. P_T^{min} is fixed at 8.75 for the other b quark.

2 Measurements using Exclusive Decays to $J/\psi + K$

The 1992 collider run was completed in June 1993. The new run allows the preliminary confirmation of the 1989 results in some of the exclusive decay modes of the B meson. The integrated cross section of b quarks with $P_T > P_T^{min}$ in the channel $B^0 \to J/\psi + K^{*0}$ was measured, and enough statistics were collected in the exclusive decay mode $B^{\pm} \to J/\psi + K^{\pm}$ for the measurement of the differential B meson cross section as a function of P_T. This analysis represents 14.3 ± 1.0 pb^{-1} from the 1992 run.

Large samples of these exclusive decay channels are obtained by collecting events where the J/ψ decayed to two muons. The CDF dimuon trigger uses a three-level trigger system [4]. The efficiency to find a muon at Level 1 rises from 50% at $P_T = 1.6$ GeV/c to 90% at $P_T = 3.1$ GeV and reaches a plateau of 94%. The tracks must be separated by at least 0.09 radians in ϕ. Level 2 requires that at least one of the muon tracks match a charged track in the CTC found by the Central Fast Track (CFT) processor [5]. The efficiency to find a track in the CFT rises from 50% at $P_T = 2.65$ GeV/c to 90% at $P_T = 3.1$ GeV/c and reaches a plateau of 93%. At Level 3 [6] the trigger (using online track reconstruction software) requires a pair of oppositely signed muons with an invariant mass between 2.8 and 3.4 GeV/c^2.

To reduce the background from random tracks associated with direct J/ψ production, P_T cuts are placed on the K^+ (>2.0 GeV/c) and the kaon(pion) candidates from the K^* ($>$ 1.5(0.5) GeV/c). Due to high background, the K^* mass peak is not seen, but since the detector resolution is much better than the natural width of the K^* (49.8 MeV/c^2) the requirement 846 MeV/c^2 $\leq m(K\pi) \leq$ 946 MeV/c^2 was imposed. In the case of particle exchanges still landing within the invariant mass window of the K^*, the closest combination to the world average mass was chosen. Finally, the P_T of the reconstructed B mesons was constrained to be greater than 6.0 GeV/c in the charge case and 7.0 GeV/c in the neutral case.

A Monte Carlo model of the quark fragmentation and decay and a detector simulation was used to determine the cut efficiencies and detector acceptance. b quarks were generated using the next-to-leading order calculation [7, 2] and the MRSD0 [8] structure functions. The quark was fragmented according to Peterson [9] with $\epsilon_b = 0.006 \pm 0.001 \pm 0.002$ [10]. The events thus generated were passed through a full detector simulation and trigger parameterization. Varying the value of μ_0 in the production calculation and ϵ_b in fragmentation yielded estimated systematic errors of 5% and 7% respectively. The analysis cuts were applied to the simulated data to determine the detector acceptance and cut efficiencies for the charged and neutral decay channels. These acceptances are shown in Table 2 for both the integrated and binned cross sections. The number of reconstructed B mesons above background is also shown.

The combined tracking efficiency for the muon pair is 97% and the tracking efficiency for the other decay products is 92% [11]. Simulated tracks were embedded in real data samples

Table 2: The acceptance after cuts to charged and neutral B mesons. Also shown are the numbers of signal events and statistical error after fitting to a gaussian plus background.

	$P_T^{min}(B)$, GeV/c	Acceptance (%)	# of B mesons
B^+	>6 GeV/c	2.59	104 ± 21
	>9 GeV/c	5.24	56 ± 12
	>12 GeV/c	7.65	32 ± 8
	6–9 GeV/c	0.917	48 ± 14
	9–12 GeV/c	3.36	24 ± 9
	12–15 GeV/c	5.78	13 ± 6
B^0	>7 GeV/c	1.75	24 ± 12

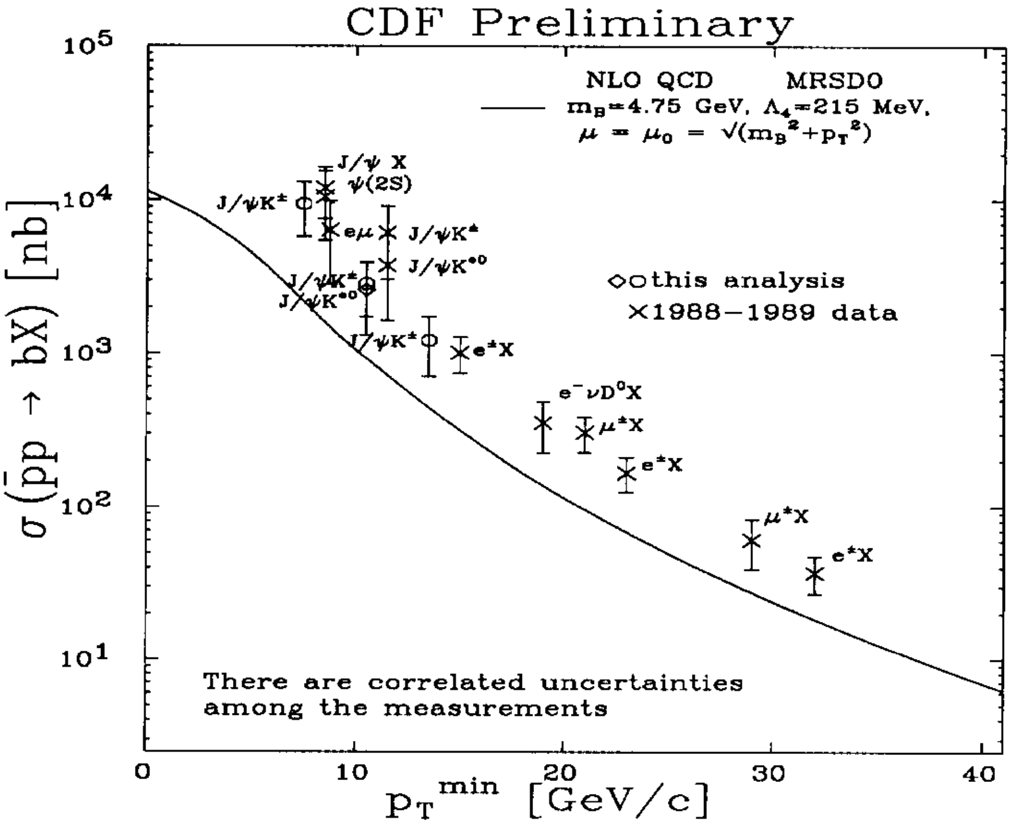

Figure 2: The total b quark cross section integrated above quark momentum P_T^{min}. The results of this analysis are shown with filled symbols along with previous CDF results from 1988.

allowing for determination of a $\pm 5\%$ systematic uncertainty on these efficiencies.

The systematic uncertainty in the trigger efficiency was estimated by varying the slope of the simulated trigger turn on by $\pm 50\%$ yielding an 8% systematic uncertainty. Other effects simulated included the reconstruction of kaon or pion decays-in-flight and the reconstruction efficiency of the K^{*0}. When combined in quadrature all the detector and acceptance uncertainties amount to $\pm 19\%$ for $B^{\pm} \rightarrow J/\psi\, K^{\pm}$ and $\pm 23\%$ for $B^0 \rightarrow J/\psi\, K^{*0}$. The largest systematic comes from the world average Branching ratio of the two decay modes which adds $\pm 26\%$ and $\pm 31\%$ to the previous systematics for the charged and neutral modes respectively.

Using the b quark Monte Carlo described previously values of P_T^{min} are obtained at 7.5, 10.5, and 13.5 GeV/c for charged B meson decays and at 10.5 GeV/c for the neutral mode. The resulting integrated b quark cross sections are shown in Figure 2 along with previous CDF measurements from the 1988-89 collider run.

The sample contained enough statistics in the charged decay channel to allow for measurement of $d\sigma/dP_T$ over 3 bins of 3 GeV/c in P_T. The P_T distribution for the events under the mass peak was plotted and the average P_T for each bin used. The number of B mesons reconstructed in each bin is shown in Table 2. An exponential function was fit to the distributions in each bin to correct for the integration over 3 GeV/c. This was 8% different than simply dividing by the bin width and so this was added in quadrature as an additional systematic uncertainty. Figure 3 shows the differential B meson cross section compared to the Monte Carlo described in this section. A systematic uncertainty of 32% common to all three points has been removed.

In both the integrated and differential cross section, the measurement using 1992 data confirms the results obtained in 1989 of approximately a factor of 2 greater b quark produc-

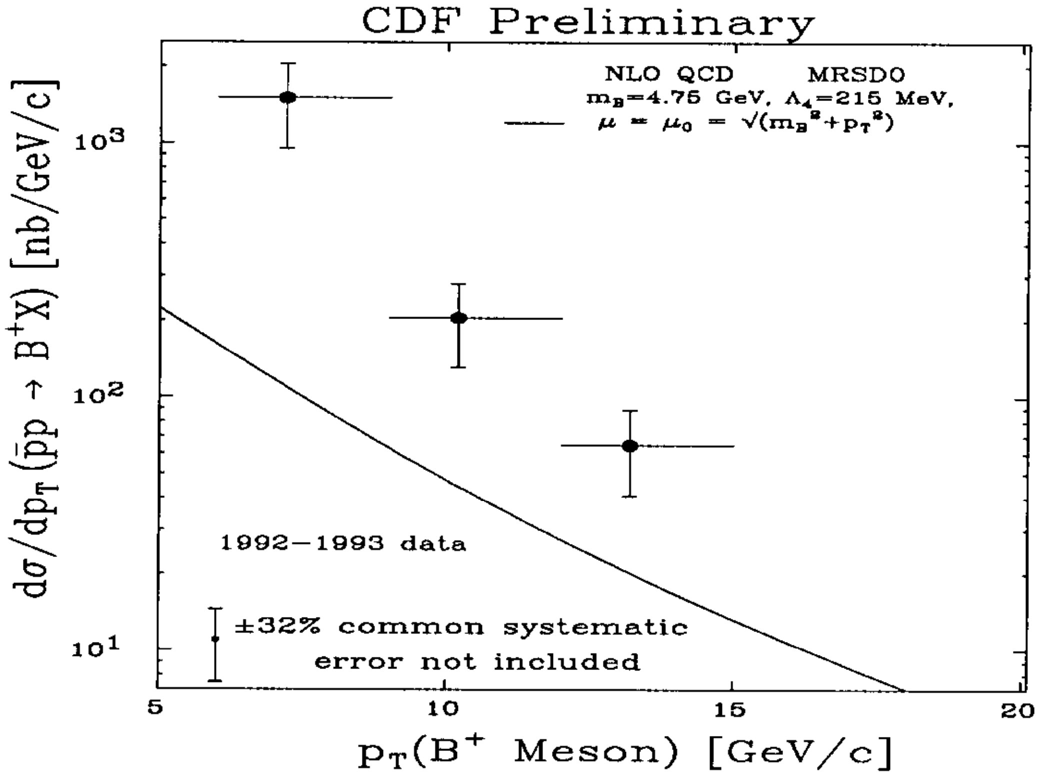

Figure 3: $d\sigma/dP_T$ of B mesons is compared with the predicted B meson cross section using NDE [7] with MRSD0 [8] structure functions and Peterson fragmentation [9].

tion at the Tevatron than the theory predicts. The differential cross section also points to disagreement with the predicted shape at low P_T as well.

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