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# MEASUREMENT OF CORRELATED $b$ QUARK CROSS SECTIONS AT CDF

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## ABSTRACT

Using data collected during the 1992-93 collider run at Fermilab, CDF has made measurements of correlated $b$ quark cross section where one $b$ is detected from a muon from semileptonic decay and the second $b$ is detected with secondary vertex techniques. We report on measurements of the cross section as a function of the momentum of the second $b$ and as a function of the azimuthal separation of the two $b$ quarks, for transverse momentum of the initial $b$ quark greater than 15 GeV. Results are compared to QCD predictions.

Studies of $b$ production in $p\bar{p}$ collisions provide quantitative tests of perturbative QCD. Measurements of the cross section for $p\bar{p} \rightarrow bX$ have been made at CDF[1] and UA1.[2] In this analysis we extend the range of comparisons between theory and experiment by performing a measurement of $b$-$\bar{b}$ correlations in the process $p\bar{p} \rightarrow b\bar{b}X$. We identify the first $b$ via its semileptonic decay to a muon, and the other $b$ (referred to for simplicity as the $\bar{b}$, though we do not perform explicit flavor identification for either $b$) by using precision track reconstruction to measure the displaced tracks from $\bar{b}$ decay. Identification of the $b$ and $\bar{b}$ permits a measurement of the cross section as a function of the transverse momentum of the $\bar{b}$, $\frac{d\sigma_{\bar{b}}}{dE_T}$, and as a function of the azimuthal separation of the two $b$ quarks, $\frac{d\sigma_{\bar{b}}}{d\delta\phi}$, for transverse momentum of the initial $b$ quark greater than 15 GeV. The data used here were collected by the Collider Detector at Fermilab (CDF) during the 1992-93 Tevatron collider run, and correspond to an integrated luminosity of $15.1 \pm 0.5$ pb$^{-1}$.

The CDF has been described in detail elsewhere.[3] The tracking systems used for this analysis are the silicon vertex detector[4] (SVX), the central tracking chamber (CTC), and the muon system. The central muon system consists of two detector elements. The Central Muon chambers (CMU) provide muon identification over 85% of $\phi$ in the pseudorapidity range $|\eta| \leq 0.6$, where $\eta = -\ln[\tan(\theta/2)]$. This $\eta$ region is further instrumented by the Central Muon Upgrade chambers (CMP), located behind the CMU after an additional $\approx 3$ absorption lengths. The calorimeter systems used for this analysis are the central and plug systems, which give $2\pi$ azimuthal coverage in the range $|\eta| < 1.1$ and $1.1 < |\eta| < 2.4$ respectively.

*Presented by David Gerdes, representing the CDF Collaboration.

From events that pass an inclusive muon trigger, we select good-quality CMU muons with $P_T > 9$ GeV that have an associated track segment in the CMP. We further require the muon track to fall within the fiducial region of the SVX. This sample contains 145,784 events. An independent analysis has measured the fraction of muons from $b$-decay in this sample to be $36.0 \pm 2.4 \pm 2.5\%$,[5] making this an excellent sample to look for the presence of additional $\bar{b}$ jets.

The long lifetime of $b$ quarks causes the tracks from $b$-decay to be displaced relative to the primary $p\bar{p}$ interaction point. The high-precision track reconstruction made possible by the SVX allows us to identify these tracks with good efficiency. We use the "jet-probability" algorithm,[6] which compares the impact parameters of the tracks in a jet to the measured resolution of the SVX and determines an overall probability that the jet is primary. This probability is flat between 0 and 1 for jets from zero-lifetime particles, and has a peak at low values for jets from $b$ and $c$ decays.

To identify the $\bar{b}$ jets in the inclusive muon sample, we require that the event contain at least one jet with $E_T > 10$ GeV, $|\eta| < 1.5$, and at least 2 good tracks. The jet is required to be separated from the muon in $\eta - \phi$ space by $\Delta R \geq 1.0$, so that the tracks clustered around the jet axis are separated from the $\mu$ direction. There are 17810 events in this sample. We then fit the jet probability distribution of these jets to a sum of Monte Carlo templates for $b$, $c$, and primary jets, thereby obtaining the fraction of $\bar{b}$ jets in the sample.

The Monte Carlo samples for $b$ and $c$ jets are produced using the ISAJET event generator[7] and a full detector simulation. The CLEO Monte Carlo program[8] is used to model the decay of $B$ mesons, using an average $b$ lifetime of $c\tau = 420$ $\mu$m. The input jet probability templates for $b$, $c$, and zero-lifetime jets are shown in Figure 1a. The fit is actually done using the variable $\log_{10}$(jet probability), which magnifies the interesting region of low jet probability. Tests of the fitter in Monte Carlo samples with known admixtures of $b$, $c$, and primary jets show that the fitter returns the correct number of jets of each type to within the uncertainties. The data are shown in Figure 1b together with the results of the fit. The fit agrees very well with the data over ten orders of magnitude in jet probability, and predicts $2620 \pm 97$ $\bar{b}$ jets, $2085 \pm 180$ $c$ jets, and $13103 \pm 161$ primary jets for a total of 17808.

To convert the results of the above fit into a measurement of the cross section, we calculate the acceptance for both $b \rightarrow \mu$ and $\bar{b}$ jets. The $\mu$ acceptance and efficiency has three parts: (1) the fiducial acceptance for muons coming from $b$'s with $|\eta| < 1$, (2) the fraction of $b$'s, $P_T^b > P_T^{min}$, that decay to muons with $P_T > 9$ GeV, and (3) the trigger and identification efficiencies for 9 GeV muons. The first two factors are studied using the Monte Carlo sample described above. The $P_T^{min}$ value, chosen such that 90% of muons with $P_T > 9$ GeV come from $b$ quarks with $P_T > P_T^{min}$, is 15 GeV. The trigger and identification efficiencies for muons are determined from $J/\psi$ and $Z^\circ$ samples. The overall acceptance for $b \rightarrow \mu(P_T^\mu > 9\text{GeV}, P_T^b > 15 \text{ GeV}, |y^b| < 1)$, including the semileptonic branching ratio,[10] is $0.239^{+0.030}_{-0.018}\%$.

The $\bar{b}$ jet acceptance represents the fraction of $\bar{b}$ quarks that produce jets with $E_T > 10$ GeV, $|\eta| < 1.5$ and at least 2 good tracks inside a cone of 0.4 around the jet axis, in events where there is also a $b$ quark which decays to a $\mu$ with $P_T > 9$ GeV within the CMU-CMP acceptance. The $\bar{b}$ jet acceptance is calculated separately as a

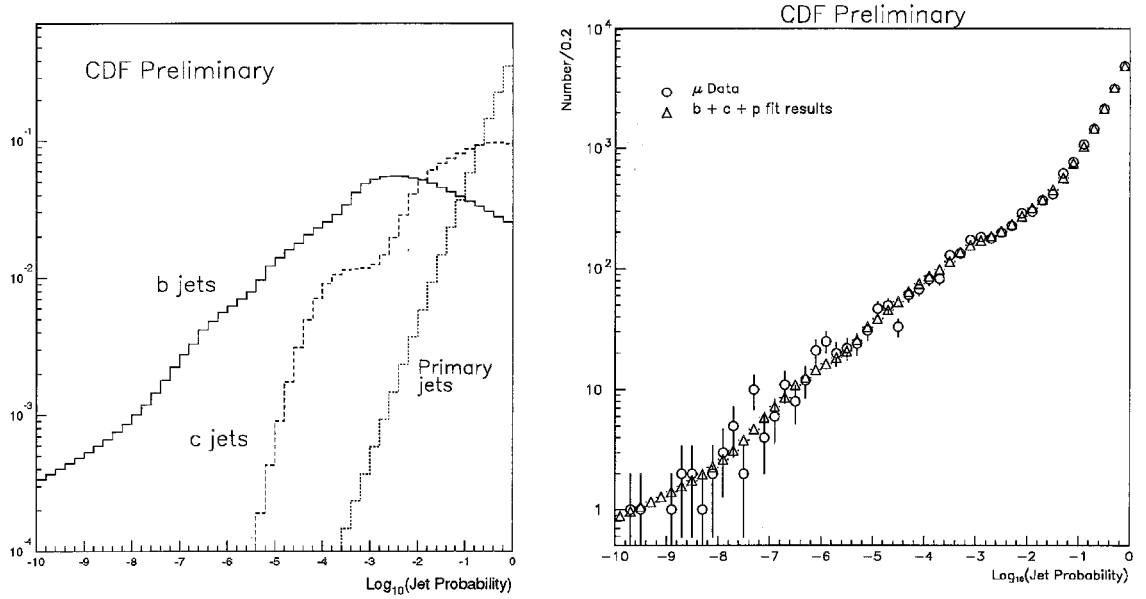


Fig. 1. (a) Jet probability distributions for $b$, $c$, and primary jets. (b) Observed jet probability distribution for jets in the inclusive muon sample, together with the results of the fit.

function of the jet $E_T$ and azimuthal opening angle between the two quarks, using the Monte Carlo sample described above. The average acceptance for the $\bar{b}$ is $\approx 40\%$, and ranges from $32.9 \pm 1.9\%$ (statistical error only) for $10 < E_T < 15$ GeV to $49.8 \pm 7.3\%$ for $40 < E_T < 50$ GeV. For $\delta\phi < \frac{\pi}{8}$ radians, the acceptance is $7.3 \pm 2.2\%$, while for $\frac{7\pi}{8} < \delta\phi < \pi$, the acceptance is $51.4 \pm 0.8\%$.

We have compared the values for the $\bar{b}$ jet acceptance from ISAJET samples to the acceptance from HERWIG samples. The acceptance agrees within the statistical error in the samples as a function of $E_T$, differing at the 5% level. We take this as an additional systematic uncertainty on the acceptance. In combination with a 10% uncertainty due to the vertex distribution for events in the SVX fiducial volume, we have a common 11.2% systematic uncertainty in all the jet acceptance numbers.

We use the jet probability fit to determine the number of $\bar{b}$ jets as a function of (1) the azimuthal separation $\delta\phi$ between the jet and the muon, and (2) the $E_T$ of the jet, and convert these numbers into the differential cross section using the aceptances calculated above. Figure 2a shows the measured distribution of $d\sigma_{\bar{b}}/d(\delta\phi)$, together with a prediction from the Mangano-Nason-Ridolfi (MNR) calculation.[11] There is a large change in the acceptance for $\delta\phi < \frac{3\pi}{8}$ due to the $\Delta$R separation requirement on the $\mu$–jet system. The shapes of the theoretical prediction and the experimental data agree well, especially for $\delta\phi > \frac{\pi}{2}$, but the overall normalization of the data is about a factor of 1.3 higher than predicted.

We also divide the jets into six $E_T$ bins between 10 and 50 GeV, and fit the jet probability distribution for each bin to determine $d\sigma_{\bar{b}}/dE_T$. This cross section is shown in Figure 2b. Work to compare this measurement to the MNR prediction, which requires a bin-by-bin understanding of the detector response, is in progess.

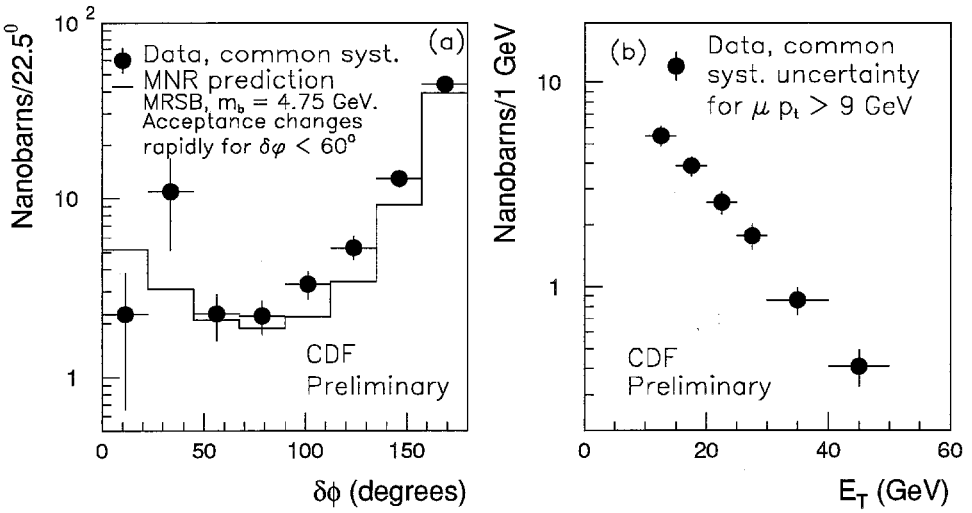


Fig. 2. Measured differential cross section as a function of (a) the azimuthal angle between the $\bar{b}$ jet and the muon, for jets with $E_T > 10$ GeV and $|\eta| < 1.5$, and (b) the $E_T$ of the $\bar{b}$ jet. There is a common systematic uncertainty of $^{+18.3}_{-15.4}\%$ not shown in the experimental points. Also shown in (a) is the prediction from the MNR calculation.

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