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Dimuon Production and $B^0 - \bar{B}^0$ Mixing at DØ

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Abstract

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 collider. From these results, we extract the cross section for b-quark production for the kinematic range of $|y^b| < 1.0$ and 9 GeV/c $< P_T^{bmin} <$ 25 GeV/c. We also report a measurement of the time and flavor averaged $B^0 - \bar{B}^0$ mixing probability (χ). We have determined χ to be $0.09 \pm 0.04(stat) \pm 0.03(sys)$ in good agreement with the world average.

Introduction

Important tests of QCD include its ability to describe the inclusive light and heavy quark production cross sections. The b-quark cross section measured by CDF [1] and DØ [2, 3] tends to be higher than the next-to-leading order (NLO) predictions. We have used dimuon events to extract an additional independent measurement of the b-quark cross section. The same dimuon event sample has been used to measure the time and flavor averaged $B^0 - \bar{B}^0$ mixing probability. This new measurement can be combined with the previous measurements [4, 5, 6, 7, 8, 9] to improve the world average, used to constrain elements of the Cabibbo-Kobayashi-Maskawa [10] matrix.

The data were taken at the Fermi National Accelerator Laboratory with the DØ detector using $p\bar{p}$ interactions at $\sqrt{s}$ = 1.8 TeV. The DØ detector [11] is a multi-purpose colliding beam detector, which consists of a central tracking system surrounded by a hermetic, finely-segmented liquid-argon calorimeter enclosed by the magnetized iron toroids and chambers of the muon system. The data sample used in this analysis was collected in the 1992 - 1993 run, with an integrated luminosity of 6.6 pb^{-1}

Data selection

The data selection used a multi-level trigger system. The first level employs scintillating counters which determine the number of interactions and the vertex position of an event, reject beam-gas events and provide luminosity measurements. The muon hardware trigger used 60 cm wide hodoscopic elements formed from the muon drift chambers, and required hits from these elements to be consistent with a muon produced in the interaction region. The software based muon event filter required two reconstructed muons with transverse momentum $p_T^\mu > 3$ GeV/c. In order to enhance the statistics the mixing analysis used an additional jet-muon combined trigger and filter. The jet trigger is a calorimeter hardware trigger which forms trigger towers by adding together the calorimeter signal from cells in η, ϕ, and depth. The transverse segmentation of trigger towers is $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$. The trigger passes events with transverse energy (E_T) in a trigger tower greater than a pre-set value which in our case was 3 GeV. The calorimeter jet filter uses a cone algorithm with a cone size $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.7$. The jet E_T was required to be greater than 10 GeV.

In the off-line reconstruction good muons were selected by requiring tracks with hits in at least two out of three layers of the muon chambers. Candidate muons were required to deposit at least 1 GeV energy in the calorimeter and to possess a matching track in the central tracking detector pointing back to the primary interaction vertex in the bend and non-bend views. Further, muon tracks were restricted to $|\eta^\mu| < 0.8$ and 4 GeV/c $< P_T^\mu <$ 25 GeV/c. In the dimuon cross section analysis each muon was associated with a jet by requiring the muon and a jet to be within $\Delta R < 0.8$. The $B^0 - \bar{B}^0$ mixing analysis only required one associated jet. The jet transverse energy had to be greater than 12 GeV. To eliminate dimuons coming from J/Ψ decays and same-side sequential decays as well as Z decays, the dimuon invariant mass had to be within a mass range of 6 - 35 GeV/c^2. To eliminate most of the cosmic ray background the dimuon opening angle was required to be less than 165 degrees.

After imposing the above cuts, the data sample of the dimuon cross section analysis had 216 events. The $B^0 - \bar{B}^0$ mixing analysis used an additional cut: all muons with associated jets were required to have the transverse component of the μ relative to the jet (axis) direction (p_T^{rel}) be more than 1.2 GeV/c; 172 events remained.

Muon and b-quark cross sections

The differential dimuon cross section as a function of the leading muon (highest p_T muon in the event) was obtained by using the following formula:

$$\frac{d\sigma}{dp_T^\mu} = \frac{N - N_C}{\Delta p_T^\mu} \cdot \frac{1}{\varepsilon \cdot \int Ldt} \tag{1}$$

where p_T^μ is the transverse momentum of the leading muon, N is the total number of events, N_C is cosmic ray background, ε is the combined trigger, off-line reconstruction and quality cut efficiencies including the geometrical acceptance and $\int Ldt$ is the integrated luminosity. The efficiency ε was determined by passing Monte Carlo events through the DØ detector, trigger and filter simulations, and off-line reconstruction packages. In all

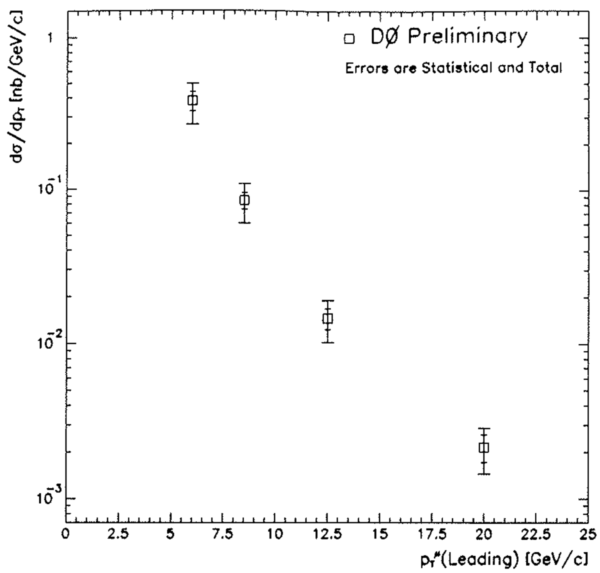

Figure 1: Dimuon cross section measurement.

cases the efficiencies were cross-checked using appropriate data samples. Cosmic ray contamination was estimated by fitting the crossing time distribution in the muon chambers to known distributions for beam produced muons and cosmic rays. The resulting dimuon cross section plotted as a function of the leading muon p_T is shown in Fig. 1.

In order to estimate the b fraction we used the p_T^{rel} technique. Monte Carlo studies showed that different dimuon processes have different p_T^{rel} distributions. We simultaneously fitted to the data the leading and trailing (second highest p_T muon in the event) muon p_T^{rel} distributions to estimate contributions from different processes to the dimuon data sample. The data and the result of the fit are shown in Figs. 2 and 3. The b-quark fraction determined by this technique is in reasonable agreement with Monte Carlo predictions, as shown in Fig. 4.

Once the fraction of the dimuon inclusive cross section coming from b-quark decay is determined, the integrated inclusive b-quark cross section can be extracted following the method of UA1 [12]. The resulting b-quark cross section is plotted in Fig. 5 from the inclusive dimuon cross section data. The major sources of the systematic errors are the trigger and off-line cut efficiences ($\sim 25\%$) and uncertainty in the b-quark fragmentation ($\sim 21\%$). In Fig. 5 the inclusive b-quark cross section from the inclusive single muons is also shown. The b-quark cross sections from inclusive single muon [2, 3] and dimuon data samples are in good agreement with each other. They also agree with the next-to-leading order QCD calculation of Nason Dawson and Ellis [13] within theoretical and experimental uncertainties.

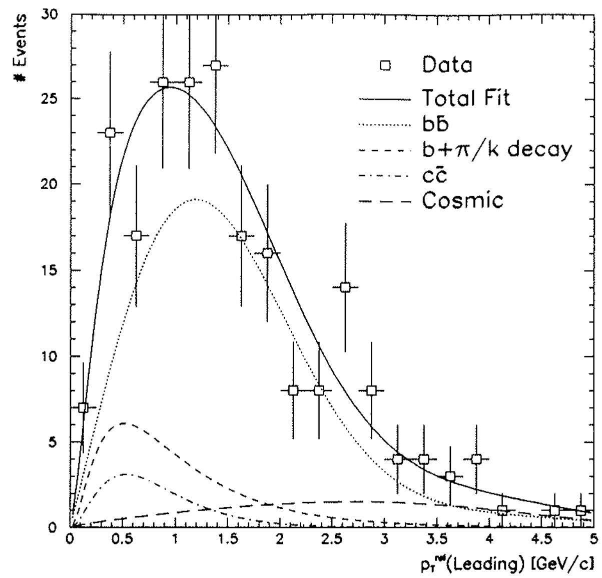

Figure 2: p_T^{rel} distribution for the leading muon.

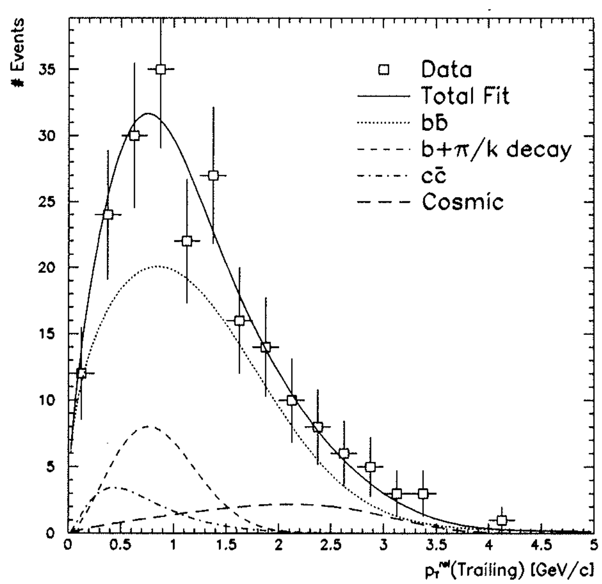

Figure 3: p_T^{rel} distribution for the trailing muon.

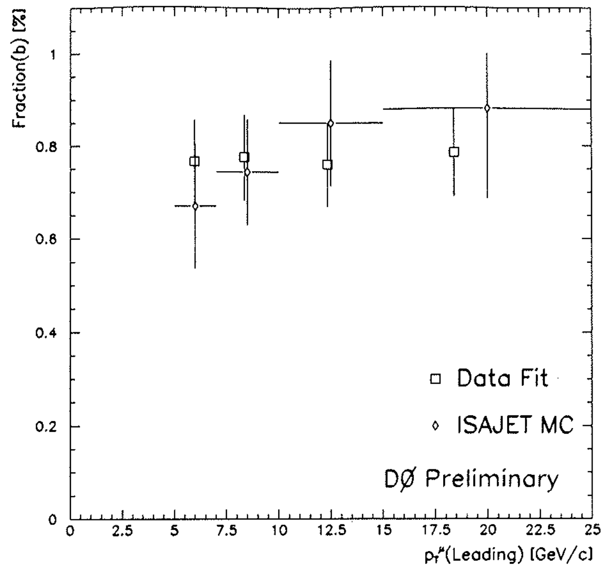

Figure 4: b fraction as a function of p_T of the leading muon.

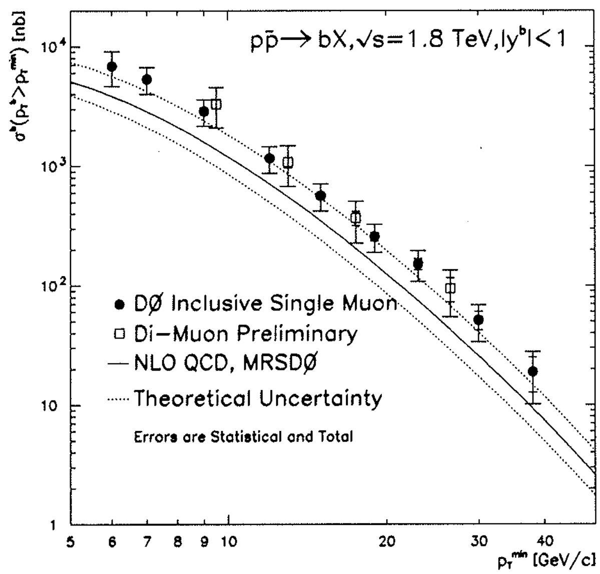

Figure 5: The inclusive b-quark production cross section, integrated above p_T^{min}, comparing to NLO QCD predictions. This cross section is the measured cross section for producing b and $\bar{b}$ divided by 2. The inner error bars are statistical only and outer statistical and systematic added in quadrature. This prediction is based on use of MRSDO structure functions with $\Lambda_5^{\overline{MS}} = 140\ MeV$, and $m_b = 4.75\ GeV/c^2$. 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 $\mu_0 = \sqrt{m_b^2 + \langle p_T^b \rangle^2}$.

$B^0 - \bar{B}^0$ Mixing

The time averaged mixing probability χ is given in terms of the mixing parameter x as

$$\chi = \frac{P(B^0 \rightarrow \bar{B}^0)}{P(B^0 \rightarrow B^0) + P(B^0 \rightarrow \bar{B}^0)} \approx \frac{x^2}{2 + 2x^2} \qquad (2)$$

Table 1: Probability of like-and unlike-sign dimuons from contributing processes, and their fractional contributions to dimuon events.

Process Type	Like-sign	Unlike-sign	Fraction	Total error
$b \to \mu^-, \bar{b} \to \mu^+$	$2\chi(1-\chi)$	$(1-\chi)^2+\chi^2$	.69	.06
$b \to c \to \mu^+, \bar{b} \to \mu^+$	$(1-\chi)^2+\chi^2$	$2\chi(1-\chi)$	.16	.03
$b \to c \to \mu^+, \bar{b} \to \bar{c} \to \mu^-$	$2\chi(1-\chi)$	$(1-\chi)^2+\chi^2$	.02	.01
$c \to \mu^+, \bar{c} \to \mu^-$	0%	100%	.03	.01
$\pi, K \to \mu$ background	50%	50%	.10	.04

where x is the mass difference of the mass eigenstates divided by their average decay width. The mixing probability is redefined as

$$\chi = \frac{BR(b \to B^0 \to \bar{B}^0 \to \mu^+)}{BR(b \to \mu^\pm)} \tag{3}$$

The sign of the muon produced via the semi-leptonic decay of the B^0 or $\bar{B}^0$ can be used to tag events in which mixing has occurred.

The ratio R, of like-to unlike-sign dimuons, is an experimentally measurable quantity and it is directly related to the mixing probability. The data sample contains a total of 59 like-sign and 113 unlike-sign dimuon events. Correcting for the estimated cosmic ray background (described in the previous section), one finds that the ratio of like-to unlike-sign dimuons to be

$$R = \frac{\text{like} - \text{sign}}{\text{unlike} - \text{sign}} = 0.43 \pm 0.07(stat) \pm 0.05(sys) \tag{4}$$

where the systematic error reflects the uncertainties associated with the fits used to estimate the background fraction of cosmic rays.

In order to extract χ from R it is necessary to model the relative contributions of all processes which contribute to dimuon production. The probabilities of like-and unlike-sign dimuons in the presence of mixing are given in Table 1 for the different production processes.

The relative contributions of the different dimuon production processes were modeled and determined using ISAJET Monte Carlo plus the full DØ detector and trigger simulations. These are also given in Table 1. The most significant contributions to the systematic error are due to uncertainties in the production cross sections, fragmentation functions, muon decay spectrum shape, and muon branching ratios.

Assuming these relative fractions of contributing processes, χ was extracted from R as the solution to a quadratic equation

$$\chi = 0.09 \pm 0.04(stat) \pm 0.03(sys) \qquad \text{(Preliminary)} \tag{5}$$

where the systematic error is dominated by the uncertainties in the estimation of the fractions of contributing processes. The measured value of χ is in good agreement with other recent experimental results [4, 5, 6, 7, 8, 9] as shown in Fig. 6.

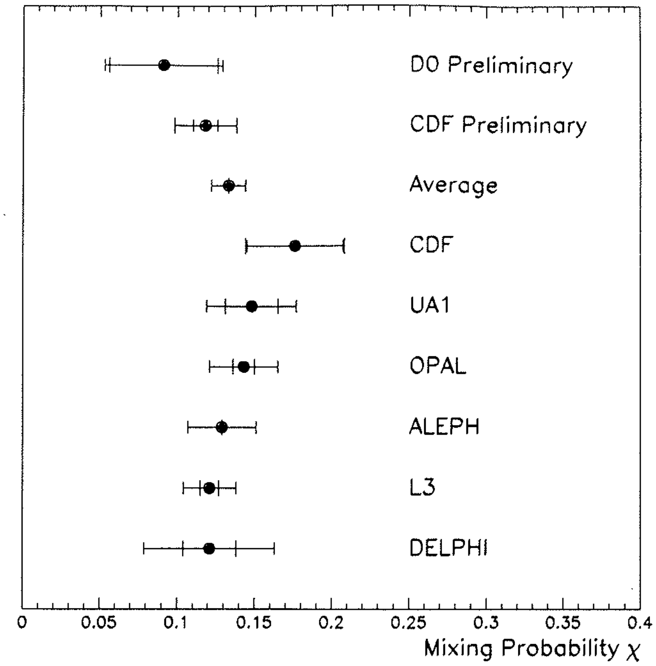

Figure 6: Mixing probability measurements. The average does not include preliminary DØ and CDF (14) results.

Conclusions

The b-quark cross section from dimuons measured by the DØ in the region $|y^b| < 1.0$ is in agreement with b-quark cross section from single muons and it is also in good agreement, within the range of experimental error and theoretical uncertainty, with the next-to-leading order predictions. The measured value of χ is in good agreement with the world average.

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