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via B Semileptonic Decays

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MEASUREMENT OF THE B CROSS SECTION AT CDF VIA B SEMILEPTONIC DECAYS

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ABSTRACT

Using data collected during the 1992-1993 collider run at Fermilab, CDF has reconstructed several hundred charmed mesons (D^0 , D^+ , D^{*+} and D_s) in association with leptons from B semileptonic decays. We report on a measurement of the cross section of B and B_s mesons as a function of transverse momentum using this sample. The observation of a charmed meson eliminates many systematic uncertainties in the background subtraction inherent in previous measurements from inclusive lepton samples, and allows the backgrounds to be measured from the data. The B meson p_T range probed by the lepton+charm technique is 18 GeV and above, and thus these measurements complement similar measurements at lower p_T in the fully exclusive channels $B \rightarrow J/\psi K$ and $B \rightarrow J/\psi K^*$. Results are compared to other Tevatron measurements and Next-To-Leading-Order QCD predictions.

1. Introduction

One source of leptons in $\bar{p}p$ interactions is semileptonic B decays. The requirement of an identified charm particle in the final state provides a narrow peak signature for B 's and low backgrounds. Further, backgrounds can be constrained from particle combinations inconsistent with coming from a B decay. This paper describes a measurement of B and B_s production using $17.9 \pm 0.6 \text{ pb}^{-1}$ of $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV collected with the CDF detector between August 1992 and May 1993. The B cross section is measured from the number of D^0 's[†] and D^{*+} 's reconstructed in the inclusive muon sample. The B_s fraction is measured from the ratio of D_s to D^+ events in a combined electron and muon sample. The CDF detector is described in detail elsewhere.¹ Muons are identified² as central tracking chamber (CTC) tracks that extrapolate to track segments in both the central muon detector (CMU) located behind the central calorimeter the central muon upgrade chambers (CMP) behind an additional 60 cm of steel. The combined efficiency for muons in the geometric acceptance of the detector is $> 95\%$. The electrons are identified by CTC tracks that extrapolate to electromagnetic showers in the central calorimeter. They must pass requirements on shower shape and

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[†]Reference to any particular state implies the charge conjugate state as well.

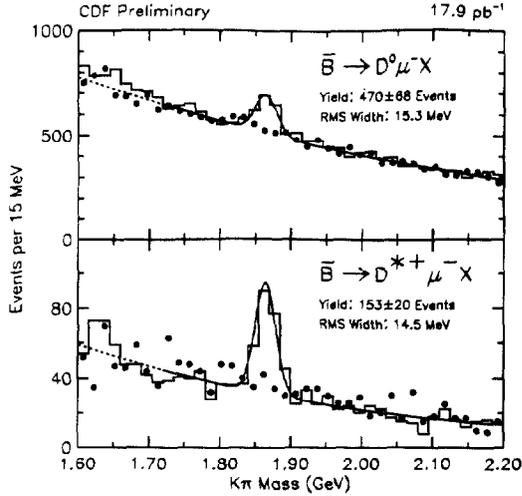


Figure 1: The solid histogram shows $K^-\pi^+$ mass for $D^0\mu^-$ and $D^{*+}\mu^-$ candidates. The dotted histograms are the background distributions described in the text. The curve indicates the results of the fit.

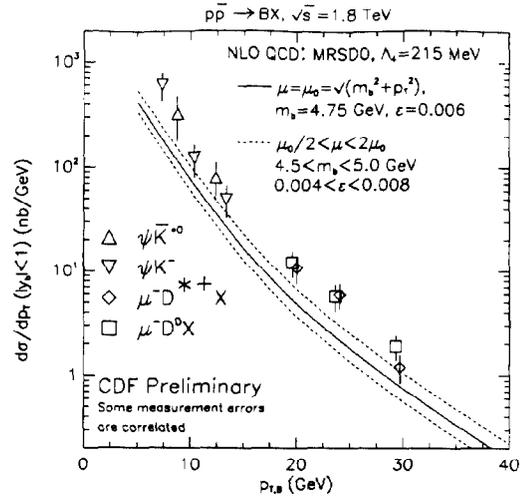


Figure 2: B meson cross sections determined from $D\mu$ and $J/\psi K$ yields. Curves show predictions of next-to-leading-order QCD.

depth profile and on the matching of CTC tracks to clusters in the wire chambers located near shower maximum in the calorimeter.³

2. B Cross section with $\mu + D^0$ and $\mu + D^{*+}$

In events with identified muons with $p_T > 7.5$ GeV, we assign to charged particle tracks the kaon and pion masses and compute $(K^-\pi^+)$ and $(K^-\pi^+\pi^+)$ invariant masses. A combination with a $K\pi$ mass between 1.55 and 2.25 GeV and a $K\pi\mu$ mass less than 5.3 GeV is considered a D^0 candidate, and the mass is recalculated applying the constraint that the K and π originate from a common point. If difference in mass of the $(K^-\pi^+\pi^+)$ and $(K^-\pi^+)$ systems is less than 153 MeV, the event is identified as containing a D^{*+} candidate as well.

To obtain a $B \rightarrow \mu D^0$ sample, we make the following requirements on the $K\pi$ combination: the charge is consistent with B decay; $\min(p_T(K), p_T(\pi)) \geq 1.5$ GeV; $\max(p_T(K), p_T(\pi)) \geq 3.0$ GeV; $m(\mu K\pi) \leq 5.3$ GeV; and $|\cos\theta^*| \leq 0.8$, where θ^* is the angle between the kaon and the muon in the $K\pi$ rest frame. In the μD^0 search, we do not reject identified D^{*+} 's: this is a measurement of the B cross section via the inclusive decay $B \rightarrow \mu D^0 X$.

We make a separate search for $B \rightarrow \mu D^{*+} X$, where $D^{*+} \rightarrow D^0\pi^+$, applying the D^{*+} pion tag. The $K\pi$ signal to noise ratio is much larger, resulting in comparable statistical uncertainties despite the smaller number of events. We apply the same requirements to the $K\pi$ combination as above with the $\cos\theta^*$ cut removed and the additional requirement that $p_T \geq 450$ MeV for the soft pion from the D^{*+} decay. This sample is not statistically independent of the D^0 sample: 80% of the events in the D^{*+}

sample are also included in the D^0 sample. The D^0 mass distributions with the cuts applied are shown in Fig. 1.

Because $B \rightarrow \mu D$ decays always include an undetected particles, we must estimate the B meson p_T from kinematic properties of detected particles. We parameterize this correction in terms of m_{visible} and $p_{T,\text{visible}}$, the mass and transverse momentum of the lepton+ D^0 or D^* system. The correction is applied in two steps. We multiply $p_{T,\text{visible}}$ by a fourth-order polynomial in the missing mass fraction, $(m_B - m_{\text{visible}})/m_B$. We correct the intermediate value, p'_T , to arrive at the estimate of the B momentum: $p_T = b_1 p'_T / (1 - b_2 p'_T)$. The parameters of the correction functions are obtained by comparing the reconstructed m_{visible} and $p_{T,\text{visible}}$ from a sample of two million Monte Carlo events with the generated B meson p_T . Because we can determine the B meson momentum only to about 15% on an event-by-event basis, the acceptance has some sensitivity to the generated B meson spectrum. Replacing the generated spectrum with one that is a factor two smaller for every 4 GeV increase in p_T changes the measured cross section changes by less than 4% per bin. We also use the Monte Carlo sample to calculate the reconstruction efficiency and geometric acceptance.

We fit the $K\pi$ mass spectra in the D^0 and D^* searches separately to a Gaussian on a quadratic background. The mean of the Gaussian is fixed to the known D^0 mass.⁴ A background $K\pi$ sample is simultaneously fitted. For the D^0 search the wrong lepton charge is chosen, and for the D^* search wrong-charge leptons and soft pions are used so that both signal and background distributions are for neutral objects. The backgrounds from the right- and wrong-charge distributions are constrained to be the same, and the width of the peak in the wrong sign distribution is determined from width of the D^0 in the Monte Carlo sample when the K and π assignments are reversed. We exclude the region below 1.72 GeV to avoid the D^0 decay to $K^-\pi^+\pi^0$. We then divide the sample into three bins of B -meson p_T and repeat the process with the widths of the Gaussians constrained to the value returned by the Monte Carlo, scaled by the ratio of the inclusive D^0 width to the Monte Carlo prediction.

The sources of systematic uncertainty are listed in Table 1. The numbers of reconstructed D^0 's and the single-species B cross sections derived from these numbers are shown in Table 2. We assume that $\sigma(B^0) = \sigma(B^+)$. We reduce the number of D^* tagged D^0 's by $6 \pm 6\%$ to account for the possibility of accidental tags: finding a π that is not from a D^* that happens to pass all the D^* tagging requirements. This value comes from counting the number of D^* tags in a different mass difference window, one that has the same number of pions as in the D^* mass window.

| Source of Uncertainty | $D^0\mu^-$ | $D^{*+}\mu^-$ |
|-----------------------------------------|------------|---------------|
| Luminosity | 4 % | 4 % |
| Acceptance | 6 % | 6 % |
| Tracking efficiency | 2 % | 7 % |
| Trigger efficiency | 3 % | 3 % |
| K, π decays in flight | 2 % | 2 % |
| B p_T resolution | 4 % | 4 % |
| Fitting method and background shape | 8 % | 8 % |
| $\text{Br}(B \rightarrow \mu X)$ | 10 % | 10 % |
| $\text{Br}(B \rightarrow \mu D^{**})$ | 2 % | 2 % |
| $\text{Br}(D^{*+} \rightarrow \pi^+ D)$ | | 2 % |
| $\text{Br}(D \rightarrow K\pi)$ | 6 % | 6 % |
| Total | 17 % | 18 % |

Table 1: Systematic errors in measurement of B cross section.

The results are compared in Fig. 2 to the lower p_T CDF measurements from $B^+ \rightarrow J/\psi K^+$ and $B^0 \rightarrow J\psi K^{*0}$ decays as well as the Next-to-Leading Order QCD prediction⁵ using the MRSD0 parton distribution functions⁶ and Peterson fragmentation⁷ using $\epsilon = 0.006 \pm 0.002$ ⁸.

3. B_s Fraction

The same technique could be used to measure the B_s cross section by reconstructing D_s mesons produced in association with muons. Because the B_s production rate is smaller than the non-strange B production rate, and because the combined branching ratio $\text{Br}(D_s \rightarrow \phi\pi) \times \text{Br}(\phi \rightarrow K^+K^-)$ is smaller than $\text{Br}(D^0 \rightarrow K\pi)$, there are not nearly as many reconstructed μD_s events as μD^0 events. We expand the sample to include electrons as well and apply rather tight isolation cuts on the lepton to improve the signal to noise ratio. In the $\phi\pi$ spectrum, the D_s and D^+ peaks are visible. By measuring the ratio of observed D_s 's (coming predominantly from B_s decays) to D^+ 's (coming predominantly from B^- or \bar{B}^0 decays), we can extract the ratio of produced B_s 's relative to B^0 or B^+ 's.

We relax the lepton p_T cut to 6 GeV and require that the leptons originate within 30 cm of the center of the detector along the beamline. We consider tracks within a cone of $R(\equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}) < 0.8$ around the lepton. Two tracks from oppositely charged particles are assigned the kaon mass, and if their invariant mass is within ± 8 MeV of the ϕ mass of 1019 MeV, the combination is classified as a ϕ candidate and is combined with another track that is assigned the pion mass. The three-track combination is fitted with the constraint that all three tracks intersect at a common point, requiring the probability $P(\chi^2) \geq 1\%$. We require candidates to satisfy the following conditions: $p_T(K) \geq 1$ GeV; $p_T(\pi) \geq 800$ MeV; $p_T(\phi) \geq 2$ GeV; the lepton is isolated such that the transverse energy in a cone of $R \leq 0.4$ around the lepton does not exceed the $\phi\pi$ transverse momentum by more than 20%; and the displacement of the $\phi\pi$ vertex projected along the momentum direction is positive. Figure 3 shows the $\phi\pi$ mass distribution where the associated lepton had a charge consistent with B decay, (i.e. $B_s^0 \rightarrow D_s^{(*)-}\ell^+\nu$). Peaks from both $D_s^+ \rightarrow \phi\pi^+$ and $D^+ \rightarrow \phi\pi^+$ are visible. We fit the ratio of the number of D_s mesons observed to the number of D^+ 's and find it to be $3.5^{+2.3}_{-1.1}$ for the combined muons and electron sample, where the ratio of the widths of the two peaks has been determined in Monte Carlo simulations.

| p_T range | D^0 | | D^{*+} | |
|-------------|------------------|---------------------------------------|------------------|---------------------------------------|
| | Number of Events | $d\sigma/dp_T$ ($ y < 1$) (nb/GeV) | Number of Events | $d\sigma/dp_T$ ($ y < 1$) (nb/GeV) |
| All | 459 ± 69 | | 153 ± 20 | |
| 18-22 GeV | 112 ± 26 | $12.1 \pm 2.8 \pm 2.0$ | 39 ± 9 | $10.8 \pm 2.6 \pm 1.9$ |
| 22-26 GeV | 98 ± 22 | $5.7 \pm 1.3 \pm 1.0$ | 43 ± 8 | $5.9 \pm 1.2 \pm 1.1$ |
| 26-34 GeV | 98 ± 23 | $2.0 \pm 0.5 \pm 0.3$ | 27 ± 7 | $1.2 \pm 0.3 \pm 0.2$ |

Table 2: $D\mu$ yields and B cross sections.

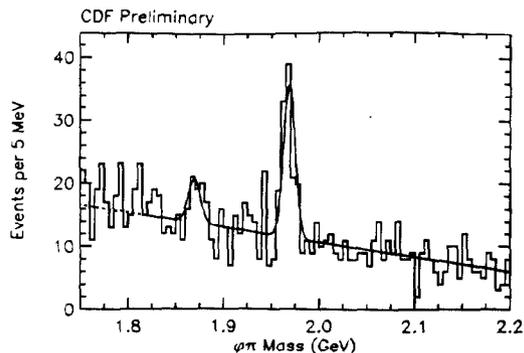


Figure 3: The solid histogram shows $\phi\pi^+$ mass for $D^+\mu^-$ and $D_s^+\mu^-$ candidates. The curve indicates the results of the fit.

| Source of Uncertainty | Value |
|----------------------------------------------------------|-------------|
| $\text{Br}(\bar{B} \rightarrow D, D^* l^- X)$ | 10 % |
| $\text{Br}(\bar{B} \rightarrow D^{**} l^- X)$ | 10 % |
| $\text{Br}(D_s^+ \rightarrow \phi\pi^+)$ | 18 % |
| $\text{Br}(D^+ \rightarrow \phi\pi^+)$ | 13 % |
| Relative acceptance and efficiency for D_s^+ and D^+ | 10 % |
| $\tau(B_s)/\tau(B_{u,d})$ | 12 % |
| Total | 31 % |

Table 3: Fractional uncertainties in B_s^0 production fraction.

The relationship between the cross section and the number of reconstructed D^+ and D_s^+ mesons is given by:

$$\frac{\sigma(B_s)}{\sigma(B_{u,d})} = \frac{\Gamma(B_{u,d} \rightarrow D^+ l X) \tau(B_{u,d}) \text{BR}(D^+ \rightarrow \phi\pi) N(D_s \rightarrow \phi\pi)}{\Gamma(B_s \rightarrow D_s l X) \tau(B_s) \text{BR}(D_s \rightarrow \phi\pi) N(D^+ \rightarrow \phi\pi)}$$

where the B semileptonic branching fractions have been replaced by partial widths and lifetimes. The acceptance and reconstruction efficiency of the two states is equal to within 10%. We assume that the semileptonic partial widths for all B mesons are the same and that the lifetimes are equal to within 12%. Additionally, we assume that the D^{**} fraction is the same ($20 \pm 10\%$) in all decays and that all D_s^{**} 's decay to DK . From these assumptions and the branching fractions $D^+ \rightarrow \phi\pi^+$ of $0.57 \pm 0.11\%$ ⁴ and $D_s \rightarrow \phi\pi^+$ of $5.1 \pm 0.9\%$ ⁹, we can calculate the relative fraction of B_s mesons: $\sigma(B_s)/(\sigma(B_u) + \sigma(B_d)) = .26_{.08}^{+.17} \pm .08$. The systematic uncertainties are dominated by branching ratios and are enumerated in the Table 3. This measurement is consistent with the common assumption that 15% of b 's fragment into B_s and 75% into B_u or B_d . It is slightly larger than the LEP average¹⁰ of $.112 \pm .024 \pm .020$ when one includes the new CLEO $D_s^+ \rightarrow \phi\pi^+$ branching ratio.

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