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We report on the status of b quark and b hadron production using $110\,\mathrm{pb}^{-1}$ of data collected by the CDF detector between 1992 and 1995. We present the first direct measurement of the ratio of b quark cross sections at $\sqrt{s} = 630$ GeV and $\sqrt{s} = 1800$ GeV, and an update on the measurement of the B meson differential cross section. We also present measurements of the branching fraction for $\Lambda_b \to J/\psi\Lambda$, and the product of fragmentation fraction and branching fractions for the semileptonic decay $\Lambda_b \to \Lambda_c^+ e^- \bar{\nu} X$.

The production and decay of b hadrons provides a convenient laboratory for the quantitative study of QCD. The large muonic branching fraction (10%) and long lifetime ($c\tau \sim 450\,\mu$m) of the b quark facilitate the accumulation of large inclusive muon datasets while controlling the background by identifying the b hadron decay vertex. In addition, many of the b hadron decay modes contain the narrow J/ψ resonance, providing a trigger (via $J/\psi \to \mu\mu$) and excellent reconstruction efficiency (75% for $B^\pm \to J/\psi K^\pm$) for the study of exclusive decays. We use all of these techniques to exploit the $110\,\mathrm{pb}^{-1}$ of data collected during Tevatron Run 1.

1 Ratio of $\sigma_b(630\,\mathrm{GeV})$ to $\sigma_b(1800\,\mathrm{GeV})$

Previous measurements of single inclusive b production by UA1 at $\sqrt{s} = 630$ GeV, and by CDF and D0 at $\sqrt{s} = 1800$ GeV, agree with next-to-leading-order (NLO) QCD [1] within large theoretical uncertainties, although with a significant spread in the different experimental results [2]. Using $0.46 \pm 0.04\,\mathrm{pb}^{-1}$ of data collected at $\sqrt{s} = 630$ GeV, and $1.89 \pm 0.06\,\mathrm{pb}^{-1}$ of data at $\sqrt{s} = 1800$ GeV, we measure the ratio of the b quark cross section at the two center-of-mass energies. This ratio is less sensitive to the specific choice of theory parameters.

The technique uses a sample of inclusive muons having transverse momentum, p_t, greater than $6.2\,\mathrm{GeV}/c$. The b decay vertex is identified by constraining the muon and the highest p_t track ($> 1.0\,\mathrm{GeV/c}$) in a cone of radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 1.0$ around the muon direction, to originate from a common point. The non-muon track is assigned the pion mass and the invariant mass of the μ-track combination is required to fall between 1.5 and $5.3\,\mathrm{GeV}/c^2$. The background is further reduced by requiring the transverse decay length in the μ-track momentum direction, L_{xy}, be greater than 0.25mm

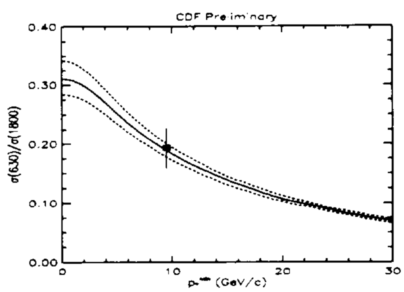

Figure 1: The CDF measurement (data point) and theoretical prediction for the ratio of b cross sections at 630 and 1800 GeV. The dashed curves show the variation in the theory with scale and b mass.

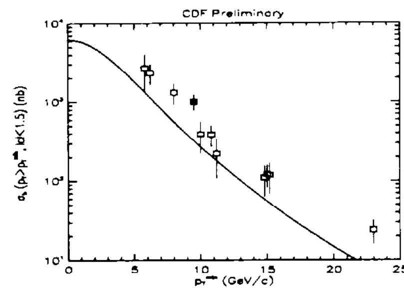

Figure 2: The CDF measured b cross section at 630 GeV (solid square) compared to the UA1 measurements and theoretical prediction using MRSA$'$ parton distributions.

and less than 2cm. We estimate the signal content as the number of events with $L_{xy} > 0$ minus the number with $L_{xy} < 0$. There are 305(141) events with $L_{xy} > 0 (L_{xy} < 0)$ in the 630 GeV sample, and 11679(6062) events in the 1800 GeV sample, giving net yields of 164$\pm$21 and 5617$\pm$133 respectively. The ratio of the acceptances at the two energies was found to be $A^{630}/A^{1800} = 0.62 \pm 0.04$ from Monte Carlo, giving a cross section ratio of

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

where the minimum b quark p_t was determined from Monte Carlo by requiring that 99% of b events passing the analysis cuts originate from b quarks with $p_t > p_t^{min}$. The measured ratio is in excellent agreement with the theoretical result of 0.189 ± 0.012, using MRSA$'$ [3] parton densities, $m_b = 4.75\,\mathrm{GeV}/c^2$, and $\mu = \mu_0 = \sqrt{m_b^2 + p_t^2}$.

Figure 1 shows the experimental ratio and theoretical prediction as a function of p_t^{min}. Figure 2 shows a comparison between CDF and UA1 data at $\sqrt{s} = 630$ GeV compared to theory using the MRSA$'$ parton densities, where we have used the measured ratio, the CDF cross section at $\sqrt{s} = 1800$ GeV [4], and a scale factor of 1.37 to account for the different rapidity range of the two detectors. We obtain the result

$$\sigma_b(p_t > 9.5, |y| < 1.5, \sqrt{s} = 630\,\mathrm{GeV}) = 1.01 \pm 0.12(stat) \pm 0.18(syst)\mu\mathrm{b}. \quad (2)$$

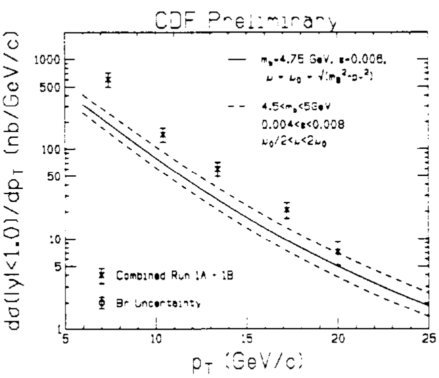

Figure 3: Combined Run 1A + 1B B meson cross section as a function of $p_t(B)$, compared to the theoretical prediction.

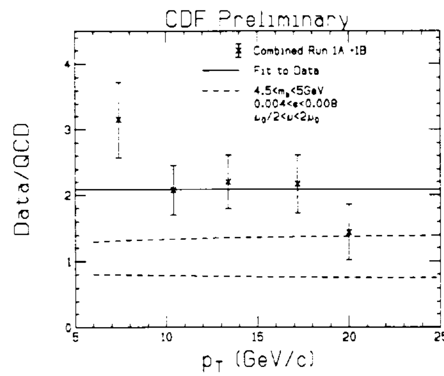

Figure 4: Data relative to the theoretical prediction. The solid line is a fit to the data, dashed lines show the theoretical uncretainty.

The original UA1 publication[5] compared data to theory using the older DFLM parton distributions and found good agreement. From Figure 2 we see that the CDF and UA1 results are in reasonable agreement, and both experimental measurements are higher than theory when using a modern set of parton distribution functions.

2 B Meson Differential Cross Section

A previous measurement of the B meson differential cross section based on $19\,\mathrm{pb}^{-1}$ of Run 1A (1992-1993) data using the exlusive decays $B^{\pm} \to J/\psi K^{\pm}$ and $B^0 \to J/\psi K^{*0}$, found $\frac{DATA}{QCD} = 1.9 \pm 0.3$ [6]. In this section we present preliminary results using $B^{\pm} \to J/\psi K^{\pm}$ in $55\,\mathrm{pb}^{-1}$ of Run 1B data.

Reconstruction of the decay $B^{\pm} \to J/\psi K^{\pm}$ begins with a sample of $J/\psi \to \mu\mu$ decays where both muons have $p_t > 2.0\,\mathrm{GeV}/c$ and an invariant mass within 3σ of the Particle Data Group (PDG) J/ψ mass, where σ is the uncertainty on the mass[7]. The J/ψ and a kaon track candidate ($p_t > 1.25\,\mathrm{GeV}/c$) are fit to a common vertex, while constraining $m(\mu\mu) = m(J/\psi)$. Valid B candidates must satisfy $5.2 < m(\mu\mu K) < 5.6\,\mathrm{GeV}/c^2$, $p_t > 6.0\,\mathrm{GeV}/c$, and $c\tau > 100\,\mu\mathrm{m}$. The cross section is calculated independently for each p_t bin using the equation

$$\frac{d\sigma_B}{dp_t} = \frac{N/2}{\Delta p_t \mathcal{L} A \epsilon Br(B \to J/\psi K)} \tag{3}$$

where N is the number of fitted B mesons per bin, Δp_t is the bin width, $\mathcal{L}$ is the integrated luminosity, A is the acceptance, ϵ is the reconstruction efficiency, and the factor of 2 comes from defining the cross section for B^+ only. We find $\sigma(p_t > 6.0\,\mathrm{GeV}/c) = 2667 \pm 297(stat) \pm 610(syst)$nb, in good agreement with the Run 1A result of $\sigma = 2390 \pm 320(stat) \pm 440(syst)$nb. Figure 3 shows the results compared to NLO theory as a function of $p_t(B)$, where the first three bins are combined 1A + 1B, the fourth bin is 1B only, and the last bin is 1A only. Figure 4 shows the data divided by theory as a function of $p_t(B)$, we find $\frac{DATA}{QCD} = 2.1 \pm 0.2$.

3 Λ_b Production

The UA1 collaboration was the first to claim observation of the exclusive decay $\Lambda_b \to J/\psi\Lambda$, with a measured branching fraction of $(1.8 \pm 1.0)\%$ [8]. However, this result was subsequently challenged by the inability of CDF and the LEP experiments to observe the decay at the claimed rate. Using $110\,\mathrm{pb}^{-1}$ of data, we present measurements of the branching fraction for the exclusive decay $\Lambda_b \to J/\psi\Lambda$, and the product of fragmentation fraction $f(b \to \Lambda_b)$ and branching fraction for the semileptonic decay $\Lambda_b \to \Lambda_c^+ e^- \bar{\nu} X$.

Reconstruction of the decay $\Lambda_b \to J/\psi\Lambda$ starts with a J/ψ sample similar to the one described in Sec. 2. Candidate Λ baryons are identified via their decay to $p\pi$ by vertex constraining pairs of oppositely charged tracks, where the proton mass is assigned to the higher momentum track, and requiring the invariant mass to be within $4\,\mathrm{MeV}/c^2$ of the PDG value. The Λ candidate must have $p_t > 1.5\,\mathrm{GeV}/c$, and a displacement greater than 1.0 cm in the direction of its transverse momentum. Finally, a fit is performed on the $J/\psi\Lambda$ system, constraining $m(\mu\mu) = m(J/\psi)$, and the Λ momentum to point to the dimuon vertex. Λ_b candidates are required to have $p_t > 6.0\,\mathrm{GeV}/c$ and $|\eta| < 1.0$.

Figure 5 shows the invariant mass distribution for the $J/\psi\Lambda$ combination along with a fit to a gaussian plus a linear background, resulting in a signal of 38 events on a background of 18.1 ± 1.6, and a mass of $5621 \pm 4(stat) \pm 3(syst)\,\mathrm{MeV}/c^2$. For the rate measurement, additional tracking quality cuts are applied to reduce the systematic uncertainty, resulting in a final sample of 7.8 ± 3.4 Λ_b candidates. We measure the ratio of production cross section times branching fraction for the Λ_b relative to the topologically similar decay $B^0 \to J/\psi K_s^0$, $K_s^0 \to \pi^+\pi^-$, as many of the systematic uncertainties cancel. Using a sample of 57.6 ± 8.7 fully reconstructed B^0 decays we find

$$\frac{\sigma(\bar{p}p \to \Lambda_b X) Br(\Lambda_b \to J/\psi\Lambda)}{\sigma(\bar{p}p \to B^0 X) Br(B^0 \to J/\psi K_s^0)} = 0.27 \pm 0.12(stat) \pm 0.05(syst) \tag{4}$$

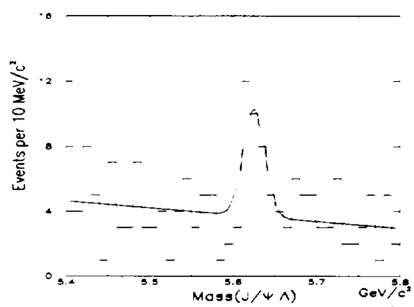

Figure 5: The $J/\psi\Lambda$ invariant mass for the decay $\Lambda_b \to J/\psi\Lambda$. For the 5 bins in the mass range $5.6 - 5.65\,\mathrm{GeV}/c^2$ we observe 38 events on a background of 18.1 ± 1.6.

where the relative efficiency times branching fraction $\epsilon_{B^0} Br(K_s \to \pi\pi)/\epsilon_{\Lambda_b} Br(\Lambda \to p\pi) = 2.02 \pm 0.05$. Using this result, and assuming $\sigma_{\Lambda_b}/\sigma_{B^0} = 0.1/0.375$ and $Br(B^0 \to J/\psi K^0_s) = 3.7 \times 10^{-4}$, we find

$$Br(\Lambda_b \to J/\psi\Lambda) = [3.7 \pm 1.7(stat) \pm 0.7(syst)] \times 10^{-4} \tag{5}$$

which agrees with previous limits from CDF [9] and the LEP [10] experiments, but is inconsistent with the original UA1 claim.

We use $19\,\mathrm{pb}^{-1}$ of Run 1A data to search for the decay $\Lambda_b \to \Lambda_c^+ e^- \bar{\nu} X$, in events containing a high $p_t (> 8\,\mathrm{GeV}/c)$ electron. The Λ_c is fully reconstructed via its decay to $pK\pi$. Proton, kaon, and pion candidates are required to have $p_t > 2.0, 1.0, \mathrm{and} 0.45\,\mathrm{GeV}/c$ respectively, where the proton track is identified by energy loss measurements in the central tracking chamber. A vertex constrained fit is performed on the $pK\pi$ system, requiring fit probability $> 1\%$, $2.1 < m(pK\pi) < 2.5\,\mathrm{GeV}/c^2$, and transverse decay length along the Λ_c momentum $> 500\mu\mathrm{m}$. The Λ_b sample consists of right-sign (RS) correlated $e^- \Lambda_c^+$ combinations with $3.5 < m(epK\pi) < 6.0\,\mathrm{GeV}/c^2$. Fitting the mass distribution to the sum of a gaussian plus a linear background yields 33.7 ± 9.0 events in the RS sample, and no events in the wrong-sign sample. The product of production cross section times branching fraction is calculated from the equation

$$\begin{aligned} \sigma_b f(b \to \Lambda_b) Br(\Lambda_b \to \Lambda_c^+ e^- \bar{\nu} X) Br(\Lambda_c^+ \to pK^-\pi^+) \\ = N(e\Lambda_c)/2\mathcal{L}\epsilon \end{aligned} \tag{6}$$

where $N(e\Lambda_c)$ is the number of RS combinations, $\epsilon = (4.7 \pm 0.5) \times 10^{-4}$ is the total efficiency as determined by data and Monte Carlo, and the factor of two accounts for the presence of both charge combinations in the data. We find $\sigma_b f(b \to \Lambda_b)Br = 1.9 \pm 0.5^{+0.80}_{-0.66}$ nb, which, if we use the CDF measured b quark cross section $\sigma_b(p_t > 10.5\,\mathrm{GeV}/c) = 1.99 \pm 0.48$, implies

$$\begin{aligned} f(b \to \Lambda_b)Br(\Lambda_b \to \Lambda_c^+ e^- \bar{\nu} X)Br(\Lambda_c^+ \to pK^-\pi^+) \\ = (9.3 \pm 2.5^{+4.6}_{-4.0}) \times 10^{-4}, \end{aligned} \tag{7}$$

which agrees with previous results from the LEP experiments [11].

Acknowledgments

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