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INCLUSIVE J/ψ, $\psi(2S)$ AND b-QUARK PRODUCTION IN $\bar{p}p$ COLLISIONS AT $\sqrt{s} = 1.8$ TEV *

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Abstract

Inclusive J/ψ and $\psi(2S)$ production has been studied in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV with the Collider Detector at Fermilab. The products of production cross section times the branching fraction of $J/\psi(\psi(2S))$ to $\mu^+\mu^-$ are reported as functions of the $J/\psi(\psi(2S))$ P_T in the kinematic range $P_T > 6$ GeV/c and $|\eta| \leq 0.5$. The products of the integrated cross section times branching fraction and the b-quark production cross section calculated from these values are also reported.

INTRODUCTION

This paper presents a study of the reactions $\bar{p}p \rightarrow J/\psi(\psi(2S))$ X $\rightarrow \mu^+\mu^-$X at $\sqrt{s} = 1.8$ TeV using 2.6 ± 0.2 pb^{-1} of data collected during the 1988-1989 running period of the Fermilab $\bar{p}p$ collider. This study is important for the investigation of charmonium production mechanisms in $\bar{p}p$ collisions[1], and it is the first measurement of J/ψ and $\psi(2S)$ cross sections at Tevatron energies. The J/ψ and $\psi(2S)$ signals are also important for the study of the production of b quarks at low P_T;[2,3] this paper reports the inclusive b-quark production cross section.

J/ψ, $\psi(2S)$ SIGNALS

The components of the Collider Detector at Fermilab (CDF) relevant for this analysis are the central tracking chamber (CTC) which is in a 1.4116–T axial magnetic field and the central muon chambers that provide muon identification in the pseudorapidity region $|\eta^\mu| < 0.61$. The data sample used for the analysis was collected with a multi-level central dimuon trigger. From events passing this trigger, a sample of opposite sign dimuons was selected with the following cuts: $P_T^\mu > 3.0$ GeV/c for each muon; less than a 3σ difference in position between each muon chamber track and its associated, extrapolated CTC track, where σ is the calculated uncertainty due to multiple scattering, energy loss, and measurement uncertainties; a common vertex along the beam axis for the two muons; $|\eta| \leq 0.5$ and $6.0 < P_T < 14.0$ GeV/c for the muon pair. The resulting mass distributions after all cuts are shown in Fig. 1. The J/ψ and $\psi(2S)$ peaks were each fit to a Gaussian line shape plus a linear background. The

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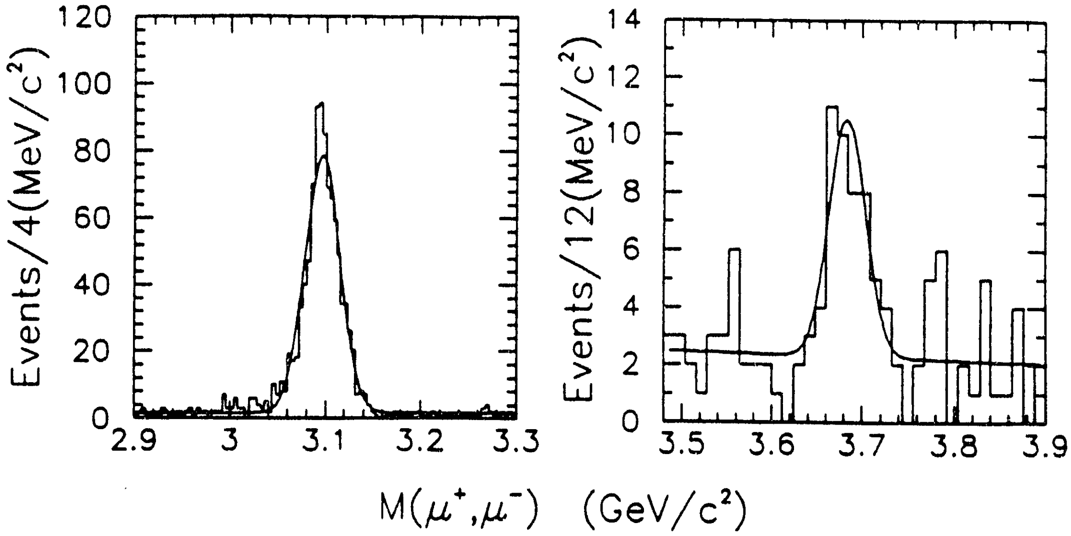

Figure 1. $\mu^+\mu^-$ mass distribution for (a) J/ψ and (b) $\psi(2S)$. The histogram corresponds to the data and the solid curve is a fit to a Gaussian plus a linear background.

number of J/ψ candidates above background within a $\pm 2.5\sigma$ mass signal region, $3.05 < m_{\mu^+\mu^-} < 3.15$ GeV/c^2, is 889±30 and the resulting J/ψ mass is (3.0965±0.0007) GeV/c^2 with σ = (18.5±0.6) MeV/c^2. The number of $\psi(2S)$ candidates above background within a $\pm 2.5\sigma$ mass signal region, $3.63 < m_{\mu^+\mu^-} < 3.73$ GeV/c^2, is 35 ± 8 and the $\psi(2S)$ mass is (3.683±0.005) GeV/c^2 with σ = (20±4) MeV/c^2.

J/ψ, $\psi(2S)$ CROSS SECTIONS

After correcting the J/ψ and $\psi(2S)$ signals for trigger efficiency, kinematic and geometric acceptance and all other experimental efficiencies as a function of P_T, we obtain the J/ψ and $\psi(2S)$ differential cross sections which are displayed in Fig. 2 as functions of P_T. The circles correspond to the data. The vertical error bars are from statistical fluctuations and the P_T-dependent systematic uncertainties added in quadrature. Theoretical predictions for the two types of processes expected to dominate J/ψ and $\psi(2S)$ production are also plotted.

The solid curve in Fig. 2a (2b) is a next-

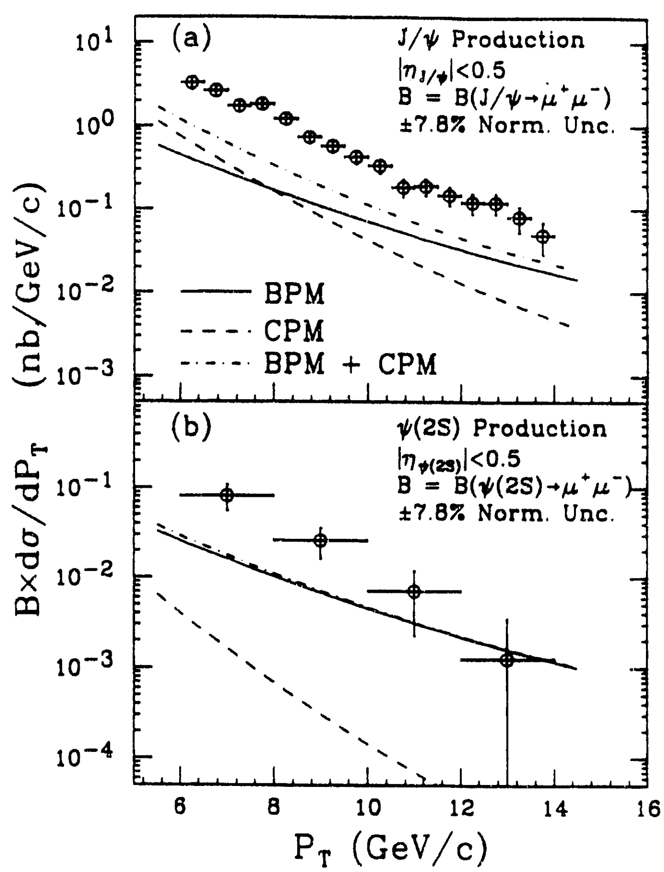

Figure 2. The product $B \times \left(\frac{d\sigma}{dP_T}\right)$ vs. P_T for (a) $J/\psi \rightarrow \mu^+\mu^-$ and (b) $\psi(2S) \rightarrow \mu^+\mu^-$.

to-leading-order calculation by Nason, Dawson and Ellis (NDE)[4] of the production of b-quarks, leading to B-mesons by modeling the energy sharing between the quark and the meson with the Peterson fragmentation function[5] and using $\epsilon_P = 0.006 \pm 0.002$. The B mesons subsequently decay to J/ψ ($\psi(2S)$) whose momentum spectra are given by ARGUS(CLEO)[6,7]. We refer to this overall calculation as B-production model (BPM). Uncertainties in this prediction arise because the b mass is comparable to the P_T of this experiment and in a range where neglected higher order terms may be significant. Further, the strongest leading-order processes for b production are gluon fusion at low x where the structure functions are not well known.

The dashed curve in Fig. 2a (2b) corresponds to J/ψ's ($\psi(2S)$'s) from direct charmonium production[1,8]. We refer to this overall calculation as the charmonium production model (CPM). The direct $\psi(2S)$ production was found[8] to be very small, $\sim$ 25 times smaller in magnitude than the data.

The sum of these two contributions (BPM and CPM) is also plotted in Fig. 2. In Fig. 2a we fit the theory to the data by summing the two theoretical contributions with independent normalization factors. With no normalization constraints a good fit is obtained with $\sim$69% J/ψ production from CPM and $\sim$31% J/ψ production from BPM. However, a previous CDF study[3] of $B^\pm \to J/\psi K^\pm$ showed that the BPM calculation underestimates the b-quark cross section by a factor of 5.5 ± 2.8 which indicates that (75^{+25}_{-40})% of our J/ψ's come from B decays. Using this information we find that the 90% C.L. upper limit on the BPM contribution is $\sim$60%. If future measurements exceed this value, then one must conclude that not only the normalization of BPM, but also the P_T-dependence of at least one of the models is wrong.

The products of the inclusive production cross section times branching fraction in the kinematic range $P_T > 6$ GeV/c and $|\eta| \leq 0.5$ are:

$$\sigma(\bar{p}p \to J/\psi\ X) \times B(J/\psi \to \mu^+\mu^-) =$$

$$6.88 \pm 0.23(stat)\ {}^{+0.93}_{-1.08}\ (syst)\ \text{nb} \quad \text{and}$$

$$\sigma(\bar{p}p \to \psi(2S)X) \times B(\psi(2S) \to \mu^+\mu^-) =$$

$$0.232 \pm 0.051(stat)\ {}^{+0.029}_{-0.032}\ (syst)\ \text{nb},$$

where an extrapolation of the cross sections for values of $P_T > 14$ GeV/c was carried out. The central values of the $J/\psi(\psi(2S))$ production cross sections are given for zero polarization, and the systematic uncertainties due to unknown polarizations are ${}^{+6.5\ (4.4)\%}_{-11.2(7.3)\%}$.

The other major systematic uncertainty in both the J/ψ and $\psi(2S)$ production cross sections is due to the trigger efficiency and was estimated to be $\pm$9%.

b-QUARK CROSS SECTION

In order to determine the b-quark cross section, we use the measurement of the $J/\psi(\psi(2S))$ inclusive production cross sections, the ratio of $J/\psi(\psi(2S))$ to b-quark cross sections as determined by a Monte Carlo technique[9,4,5,6,7], the combined branching ratios[10,11] $B(B \to J/\psi(\psi(2S))\ X) \times B(J/\psi(\psi(2S)) \to \mu^+\mu^-)$, Br_2, and the fraction f_B of $J/\psi(\psi(2S))$'s from B meson decays:

$$\sigma^b_{exp}(P^b_T > P^{min}_T, |y^b| < 1) =$$

$$\frac{\text{Br}_1 \times \sigma^c_{exp}(P^c_T > 6\text{GeV/c}, |\eta^c| < 0.5) \times \text{R} \times \text{f}_B}{2 \times \text{Br}_2}, \quad (1)$$

where

$$R = \frac{\sigma^b_{BPM}(P^b_T > P^{min}_T, |y^b| < 1.0)}{\sigma^c_{BPM}(P^c_T > 6\text{GeV/c}, |\eta^c| < 0.5)},$$

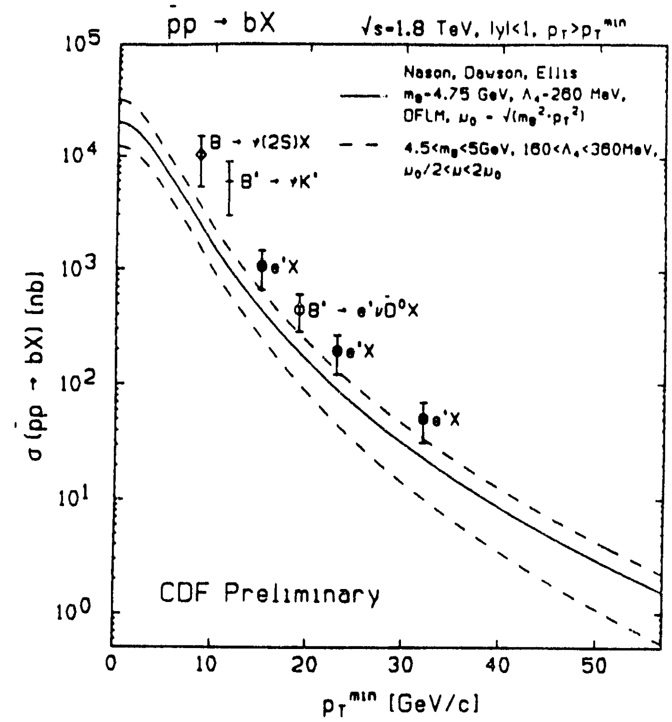

Figure 3. The b-quark production cross section.

$\mathrm{Br}_1 = \mathrm{B}(J/\psi(\psi(2S)) \rightarrow \mu^+\mu^-)$ and the index "c" stands for "$J/\psi(\psi(2S))$". P_T^{min} is determined by the Monte Carlo program and is chosen such that approximately 90% of the produced $J/\psi(\psi(2S))$ have $P_T^b > P_T^{min}$; we have set P_T^{min} = 8.5 GeV/c for this analysis. Assuming the fraction f_B to be unity, we get:

$$\sigma^b(P_T^b > 8.5\mathrm{GeV/c}, |y^b| < 1) = 18.9 \begin{array}{c} +4.7 \\ -5.0 \end{array} \mu\mathrm{b}$$

using J/ψ's and

$$\sigma^b(P_T^b > 8.5\mathrm{GeV/c}, |y^b| < 1) = 10.5 \begin{array}{c} +5.0 \\ -5.1 \end{array} \mu\mathrm{b}$$

using $\psi(2S)$'s. The fraction is believed to be close to one for $\psi(2S)$'s[1,8,12] but not for J/ψ's. In Fig. 3 we display the b-quark cross section derived by using $\psi(2S)$'s together with b-quark cross sections derived from other CDF analyses. The b-quark cross section we get using $\psi(2S)$'s is approximately 1.5 standard deviations higher than the theoretical calculation[4], in reasonable agreement with Ref. 3.

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