Fermi National Accelerator Laboratory

FERMILAB-Conf-96/235-E
CDF

Charmonium and Bottomonium Production in $p\bar{p}$ Collisions at CDF

Mark W. Bailey
Representing the CDF Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

University of New Mexico
Albuquerque, New Mexico 87131

August 1996

Published Proceedings of the *1996 Divisional Meeting of Division of Particles and Fields, American Physical Society*, Minneapolis, Minnesota, August 10-15, 1996

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

CHARMONIUM AND BOTTOMONIUM PRODUCTION IN $p\bar{p}$ COLLISIONS AT CDF

MARK W. BAILEY [a]
The University of New Mexico, Albuquerque, NM 87131

We present measurements of charmonium and bottomonium production using a data sample collected by CDF during the 1992-93 $p\bar{p}$ collider run at the Fermilab Tevatron.

1 Introduction

We present measurements of charmonium and bottomonium production using a data sample collected by CDF during the 1992-93 $p\bar{p}$ collider run at the Fermilab Tevatron.

Previous CDF measurements of J/ψ and $\psi(2S)$ production during the 1988-89 collider run showed production cross sections considerably larger than contemporary theory predicted. This drew theoretical interest, but at the time the question of whether or not the excess could be attributed to a large prompt component was not addressed.

In these analyses, differential cross-sections for J/ψ, $\psi(2S)$ and three Υ states have been measured using the $\mu^+\mu^-$ decay channel. Using a silicon vertex detector, we separate the J/ψ and $\psi(2S)$ samples into their components arising from b decay and from prompt production by analyzing the proper decay length distributions. Additionally, by reconstruction of the decay $\chi_c \to J/\psi\gamma$, we determine the fraction of the prompt J/ψ sample coming from χ_c decay, compared to that from direct charm and gluon fragmentation.

We also briefly summarize recent proposed improvements in the theoretical description of the observed production rates.[1]

2 Charmonium total cross sections

$\psi(2S)$ and J/ψ candidates are reconstructed via their dimuon decay modes. Each muon is required to be detected in the CDF central muon chambers, which cover the pseudorapidity range $|\eta| < 0.6$, and to have transverse momentum, p_T, greater than 2.0 GeV/c. Additionally, at least one muon is required to have $p_T > 2.8$ GeV/c, and the J/ψ or $\psi(2S)$ candidate must have $p_T > 5.0$ GeV/c. About 22,000 J/ψ and 800 $\psi(2S)$ are reconstructed in data samples of 15.4 pb^{-1} and 17.8 pb^{-1}, respectively. The product of dimuon branching

[a] Representing the CDF Collaboration

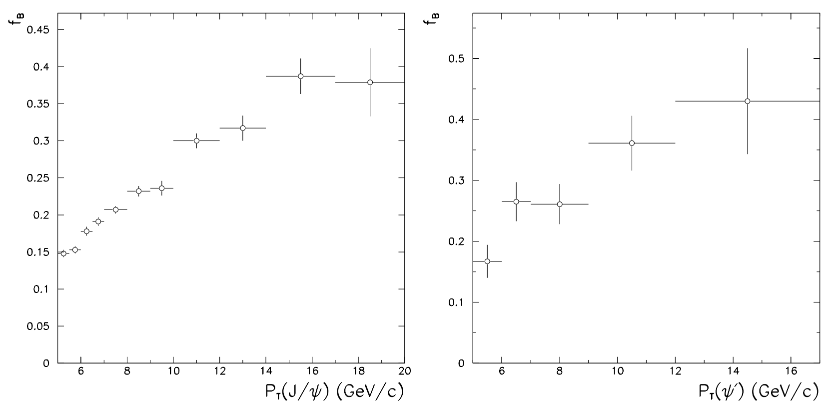

Figure 1: Fraction of J/ψ (left) and $\psi(2S)$ (right) from b decay as a function of p_T.

ratio times integrated cross section is found to be $17.35 \pm 0.14 \pm 2.79$ nb for J/ψ and $0.57 \pm 0.04 \pm 0.09$ nb for $\psi(2S)$.

3 Charmonium from b Decay

The fraction of $\psi(2S)$ and J/ψ resulting from the decay of b hadrons is determined by an analysis of the proper decay length ($c\tau$) distributions. The $c\tau$ distribution is fitted to three components: an exponential convoluted with a Gaussian resolution function for the b hadron decay component, a Gaussian function centered at 0 for prompt production, and a Gaussian function with positive and negative exponential tails to described the background, both combinatorial as well as from, e.g., sequential $b \to \mu^- c \to \mu^+ s$ decays. The samples are subdivided into ranges of $p_T(\mu^+\mu^-)$ and fitted separately for each range. Figure 1 shows the fraction from b decay as a function of p_T for J/ψ and $\psi(2S)$. These fractions are then convoluted with the charmonia p_T spectra to give the b cross section, as shown in figure 2. The results are within a factor of 2-3 of the NLO QCD prediction,[2] using a central value of the input parameters, and are consistent with other CDF b cross section results.[3]

4 Prompt Charmonium Production

The large fraction of prompt charmonium production is in disagreement with theoretical predictions based on color singlet production of $c\bar{c}$ bound states.[4]

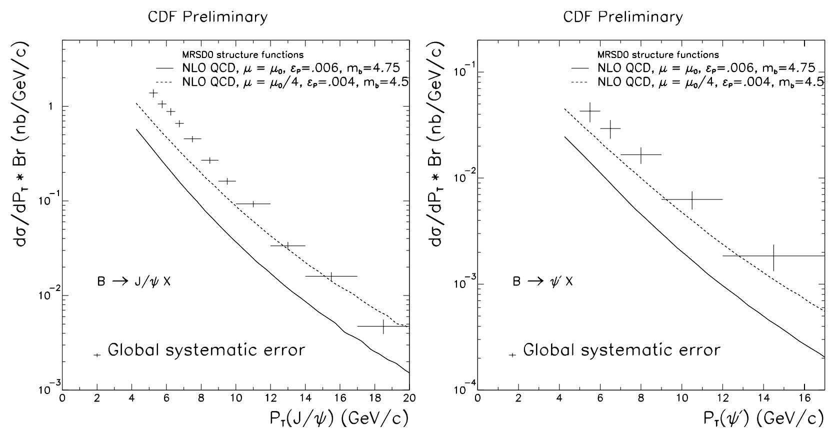

Figure 2: b quark cross section determined from the J/ψ (left) and $\psi(2S)$ (right) samples.

The rate of prompt $\psi(2S)$ production is about a factor of 50 larger than predictions based on such a model. All prompt $\psi(2S)$ are believed to be directly produced, since χ_c states with sufficient mass to decay to $\psi(2S)$ lie above the threshold for strong decays to $D\overline{D}$ meson pairs. However, prompt J/ψ are produced not only directly, but also via radiative decays $\chi_c \to J/\psi\gamma$.

To determine the fraction of prompt *direct* J/ψ produced, we fully reconstruct χ_c states. Photon candidates detected in the central electromagnetic calorimeter with energy greater than 1 GeV and having no charged track pointing to the same calorimeter tower are combined with $\mu^+\mu^-$, and a peak containing 1230 ± 72 χ_c candidates is observed in the mass difference distribution $M(\mu^+\mu^-\gamma) - M(\mu^+\mu^-)$. The background under the peak has been modelled by embedding simulated π^0 and η^0 decay photons in real J/ψ events. The fraction of J/ψ coming from prompt χ_c decay, measured for 4 different p_T bins, ranges from about 32% for 4-6 GeV/c to 28% for > 10 GeV/c. Multiplying the total prompt J/ψ cross section by the χ_c fraction shows that the rate of J/ψ production from χ_c is within a factor of 2-3 of the theoretical prediction, but, as with the $\psi(2S)$, the remaining direct J/ψ cross section is about a factor of 50 larger than the color singlet prediction.

One proposal to explain the prompt charmonium production rates observed is to include $c\bar{c}$ pairs produced in a color octet state.[5] The initial production can be calculated perturbatively and can be used to predict the p_T dependence of the cross section. The transition to a color singlet state needed to form a bound $c\bar{c}$ particle proceeds via soft gluon emission. This latter process

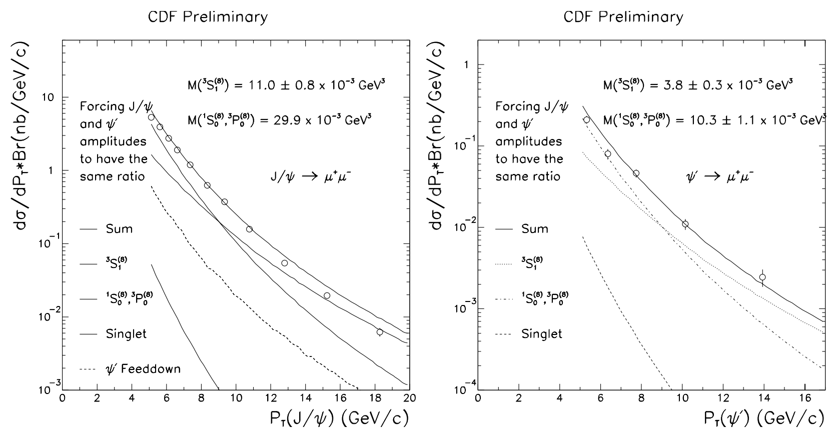

Figure 3: Prompt direct J/ψ (left) and $\psi(2S)$ (right) cross-sections, compared to the theoretical prediction, with color octet components fitted simultaneously to the J/ψ and $\psi(2S)$ distributions.

cannot be calculated perturbatively, so the normalization is found by fitting the theory to the data. Figure 3 shows the prompt J/ψ and $\psi(2S)$ cross sections and the corresponding theoretical predictions when the fitted color octet contributions are included.[6] Further cross-checks in hadro- and photo-production experiments are desirable, as is a measurement CDF hopes to make of the $\psi(2S)$ polarization, which is predicted to be transversely polarized in this model.

5 Bottomium Production

CDF has also published production cross sections for $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ based on a data sample of 16 pb^{-1}.[7] All three states combined yield a total of about 1800 candidates reconstructed in the $\mu^+\mu^-$ decay channel.

Recently, a theoretical prediction including color octet contributions was fitted to the $\Upsilon(1S)$ and $\Upsilon(2S)$ differential distributions.[6] Figures 4 and 5 show the fit results, which provide good descriptions of the shapes of the distributions.

Increased statistics using CDF's full 110-pb^{-1} data sample will allow finer binning in p_T, improving the experimental description of the shape. Reconstruction of the χ_b states via $\Upsilon\gamma$ decay — while difficult due to the small mass difference between χ_b and Υ — would provide an additional probe of the underlying production mechanisms.

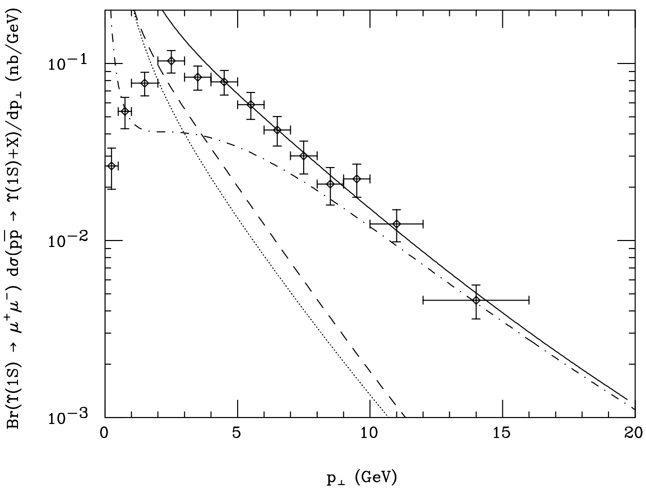

Figure 4: $\Upsilon(1S)$ differential cross section, compared to the theoretical prediction. The dotted line shows the color singlet contribution, while the dashed lines are the color octet components fitted to the data. The solid line is the sum of all contributions.

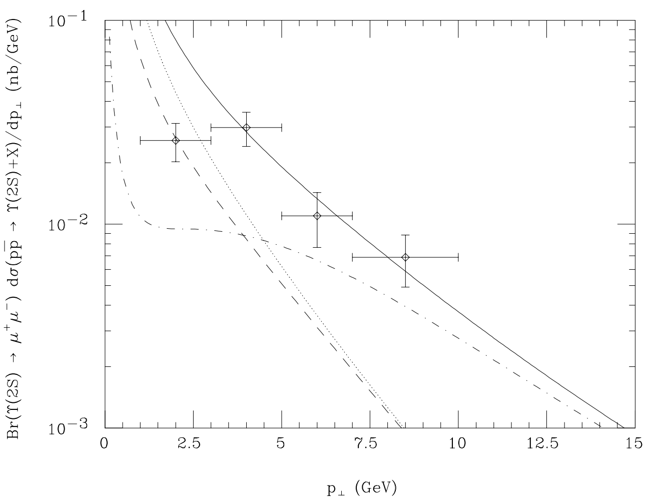

Figure 5: $\Upsilon(2S)$ differential cross section, compared to the theoretical prediction. The dotted line shows the color singlet contribution, while the dashed lines are the color octet components fitted to the data. The solid line is the sum of all contributions.

6 Conclusion

CDF has measured the differential production cross sections for J/ψ, $\psi(2S)$, and three Υ states. The prompt and b-decay parts of both charmonium states have been extracted. The J/ψ prompt cross section has been further subdivided into its direct and χ_c components.

These measurements provided the impetus for improved theoretical models, such as the color octet model, which show potential to explain charmonium production in $p\overline{p}$ collisions. Additional experimental results, such as measurement of the $\psi(2S)$ polarization and reconstruction of χ_b states — both possible with CDF's existing dataset — may provide additional insight into the underlying production mechanisms.

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Science and Culture of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the A. P. Sloan Foundation; and the Alexander von Humboldt-Stiftung.

References

1. A comprehensive review from E. Braaten, S. Fleming, and T. Yuan, Ohio St. Univ. Tech. Report # OHSTPY-HEP-T-96-001.
2. P. Dawson *et al.*, *Nucl. Phys.* B **327**, 49 (1988); M. Mangano *et al.*, *Nucl. Phys.* B **373**, 295 (1992).
3. F. Abe,*et al.*, *Phys. Rev. Lett.* **75**, 1451 (1995); F. Abe, *et al.*, *Phys. Rev.* D **53**, 1051 (1996).
4. E.W.N. Glover, A.D. Martin, and W.J. Stirling, *Z. Phys.* C **38**, 473 (1988).
5. E. Braaten and S. Fleming, *Phys. Rev. Lett.* **74**, 3327 (1995).
6. P. Cho and A. Leibovich, *Phys. Rev.* D **53**, 6203 (1996).
7. F. Abe, *et al.*, *Phys. Rev. Lett.* **75**, 4358 (1995).