J/ψ pair production at the Tevatron with $\sqrt{s}$=1.96 TeV *

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Abstract: We study the J/ψ pair production issue at the Fermilab Tevatron Run II with a center-of-mass energy of $\sqrt{s}$=1.96 TeV. Both the color-singlet and color-octet production mechanisms are considered. Our results show that the transverse momentum (p_T) scaling behaviors of the double J/ψ differential cross-sections in the color-singlets and color-octets deviate distinctively from each other while p_T is larger than 8 GeV, and with a luminosity of 5 fb^{-1}, the J/ψ pair events from the color-singlet scheme are substantially measurable in the Tevatron experiments, even with a certain lower transverse momentum cut. Hence the Tevatron is still a possible platform to check the heavy quarkonium production mechanism.

Key words: color-singlet scheme, color-octet scheme, polarization

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1 Introduction

The Tevatron [1, 2] Run II with a center-of-mass energy of $\sqrt{s}$ = 1.96 TeV is a good platform for the study of heavy quark mesons. In this brief report, we reevaluate the J/ψ pair production rate at the Tevatron in the framework of non-relativistic chromodynamics (NRQCD) [3]. In the color-singlet model, the partonic subprocesses start at order α_s^4, which include g+g → J/ψ+J/ψ and q+$\bar{q}$ → J/ψ+J/ψ. Intuitively, the latter, the quark-antiquark annihilation process, contributes less than the former at the Tevatron, and hence in the following analysis we mainly focus on the gluon-gluon process as shown in Fig. 1.

2 Calculation formula and numerical results

The differential cross-section for J/ψ pair hadroproduction reads

$$\frac{d\sigma}{dp_T}(pp\to 2J/\psi+X)$$
$$=\sum_{a,b}\int dy_1 dy_2 f_{a/p}(x_a)$$
$$\times f_{b/p}(x_b)2p_T x_a x_b \frac{d\hat{\sigma}}{dt}(a+b\to 2J/\psi), \qquad (1)$$

where $f_{a/p}$ and $f_{b/p}$ denote the parton densities in the proton or antiproton, and y_1, y_2 are the rapidity of the two produced J/ψs. x_a, x_b are the momentum fractions carried by partons with the relations:

$$x_a=\frac{\sqrt{p_T^2+m^2}}{\sqrt{s}}[\exp(y_1)+\exp(y_2)],$$

$$x_b=\frac{\sqrt{p_T^2+m^2}}{\sqrt{s}}[\exp(-y_1)+\exp(-y_2)].$$

The partonic scattering process, the gluon-gluon to polarized and unpolarized J/ψ pair differential cross-section $\frac{d\hat{\sigma}}{dt}$, can be calculated in the standard method, which has been performed previously in Refs. [4, 5], and we confirm the analytic result.

In NRQCD, the color-octet scheme is guaranteed [6]. For the J/ψ pair production process, the typical Feynman diagrams are shown in Fig. 1. Part of it, the lower two ones in the CO mechanism in the figure, the fragmentation processes, was evaluated in Ref. [7]. In this work, we consider not only the J/ψ pair in the configuration of $|c\bar{c}[^3S_1^{(8)}]gg\rangle|c\bar{c}[^3S_1^{(8)}]gg\rangle$, but also in the configuration of $|c\bar{c}[^3S_1]\rangle|c\bar{c}[^3S_1^{(8)}]gg\rangle$, though the latter contributes less in the end.

The perturbative calculations of the Feynman diagrams for both CS and CO are similar, except for the difference in the CO and CS non-perturbative matrix

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element projections. In the numerical calculation we enforce the Tevatron experimental conditions, the pseudo-rapidity cut $|\eta(\mathrm{J}/\psi)|<2.0$, and the center-of-mass energy $\sqrt{s}$=1.96 TeV for Tevatron Run II. The input parameters take the values [2]

$$m_c=1.5\ \mathrm{GeV},\ |R(0)|^2=0.8\ \mathrm{GeV}^3,$$
$$\langle\mathcal{O}_8^{\mathrm{J}/\psi}(^3S_1)\rangle=0.012\ \mathrm{GeV}^3. \tag{2}$$

With the above formulas and inputs, one can readily obtain the polarized J/ψ pair production cross-section at the Tevatron. In the numerical calculation, the parton distribution of CTEQ5L [8] is used. The integrated cross-section $\sigma(\mathrm{p\,p} \to \mathrm{J}/\psi\mathrm{J}/\psi)$ with various p_{T} lower bounds is presented in Table 1 for the CS and CO production schemes, respectively, where the branching fraction of $B(\mathrm{J}/\psi\to\mu^+\mu^-)=0.0597$ is taken into account.

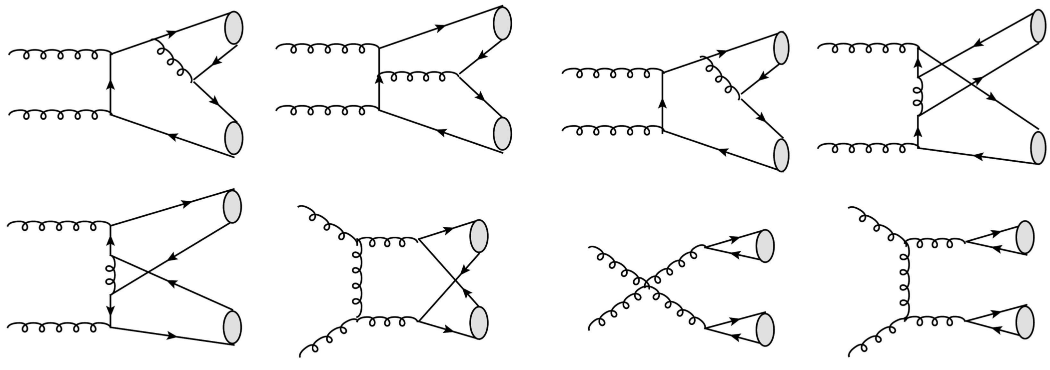

Fig. 1. Typical Feynman diagrams of J/ψ pair production at leading order: (a) belongs to the CS scheme, while (b) is the CO case.

Table 1. The integrated cross-sections of J/ψ pair production under various low transverse momentum cuts. Here, ⊥⊥ represents the situation in which both J/ψs are transversely polarized, ‖‖ shows that both J/ψs are longitudinally polarized, ‖⊥ represents the fact that one J/ψ is longitudinally polarized and the other is transversely polarized. The tot_{18} in the last row represents the double J/ψ yields from the CS + CO production scheme for reference.

	CS model					CO model				
$\sigma\backslash p_{\mathrm{Tcut}}$	3 GeV	4 GeV	5 GeV	6 GeV	7 GeV	3 GeV	4 GeV	5 GeV	6 GeV	7 GeV
⊥⊥	0.520 pb	0.145 pb	0.044 pb	0.015 pb	5.408 fb	0.047 pb	0.033 pb	0.021 pb	0.014 pb	8.869 fb
‖‖	0.214pb	0.074pb	0.025 pb	8.927 fb	3.411 fb	0.345 fb	0.102 fb	0.032 fb	0.011 fb	0.004 fb
‖⊥	0.547 pb	0.131 pb	0.032 pb	8.424 fb	2.466 fb	5.303 fb	2.640 fb	1.289 fb	0.636 fb	0.323 fb
tot	1.278 pb	0.348 pb	0.101 pb	0.032 pb	0.011 pb	0.053 pb	0.035 pb	0.023 pb	0.014 pb	9.195 fb
tot_{18}	–	–	–	–	–	0.040 pb	0.011 pb	3.384 fb	1.107 fb	0.400 fb

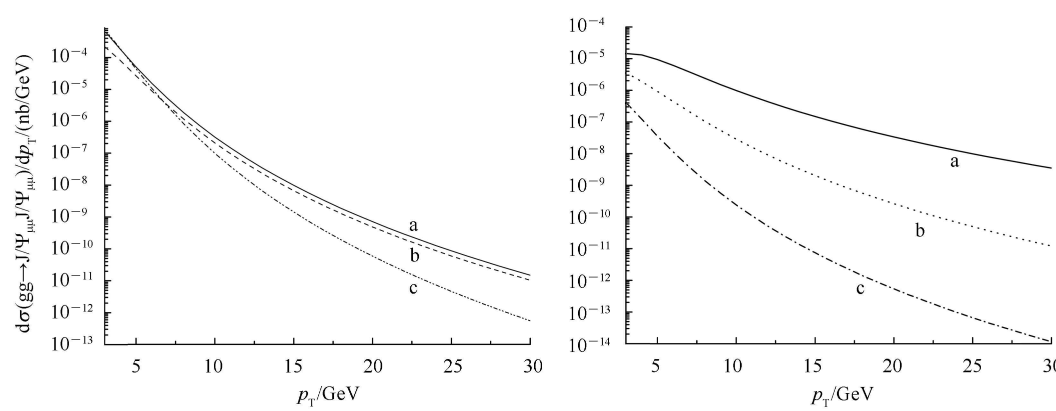

Fig. 2. The differential cross-section of J/ψ pair production versus p_{T} at the Tevatron. The left figure represents the color-singlet yields, and the lines from top to bottom, i.e. a ,b and c, denote the ⊥⊥, ‖‖ and ‖⊥ cases, respectively. The right figure represents the color-octet yields, with the lines from top to bottom, i.e. a, b and c, denoting the ⊥⊥, ‖⊥ and ‖‖ cases, respectively.

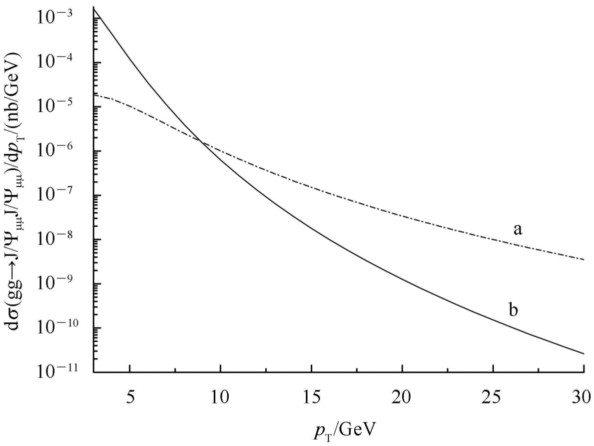

Fig. 3. The differential cross-section of J/ψ pair production versus $p_{\rm T}$ at the Tevatron. Lines a and b represent the color-octet and color-singlet yields in the unpolarized case, respectively.

The spectra of double-J/ψ exclusive production as a function of transverse momentum $p_{\rm T}$ are illustrated in Figs. 2 and 3. Fig. 2 shows that at large $p_{\rm T}$, in the CS scheme the contribution from the $\perp\perp$ case dominates the process, while in the CO case, the $\perp\perp$ dominates the process in all $p_{\rm T}$ regions. Fig. 3 indicates that the conventional CS production scheme dominates over the CO one in the relatively low-$p_{\rm T}$ region, while $p_{\rm T}<8$ GeV.

3 Conclusion

In conclusion, we evaluated J/ψ pair production at Fermilab Tevatron Run II energy. With a luminosity of $\sim$5 fb^{-1}, we found that there are a large number of J/ψ pair events produced there. Imposing a low transverse momentum cut of 7 GeV, the observed data should only come from the CO mechanism, and the detection efficiency should be 10% or lower. In all, this shows hope that we can observe the J/ψ pair production process in Tevatron II experiments, and even check the charmonium production mechanism through it.

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