

Diffractive production of $\chi_c(0^+, 1^+, 2^+)$ mesons at LHC, Tevatron and RHIC

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We consider exclusive double diffractive production of scalar $\chi_c(0^+)$, axial-vector $\chi_c(1^+)$ and tensor $\chi_c(2^+)$ charmonia in proton-(anti)proton collisions at different energies. The corresponding amplitudes for these processes are derived within the k_t -factorisation approach and the corresponding cross section is calculated with different unintegrated gluon distribution functions (UGDFs) known from the literature. We compare exclusive production of all charmonium states $\chi_c(0^+)$, $\chi_c(1^+)$ and $\chi_c(2^+)$ including branching fraction for radiative $J/\Psi + \gamma$ decay channel. Corresponding experimental consequences are discussed.

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The QCD mechanism for the diffractive production of heavy central system has been proposed recently by Kaidalov, Khoze, Martin and Ryskin (Durham group, KKMR) for Higgs production at the LHC (see Refs. [1, 2, 3]). In the framework of this approach the amplitude of the exclusive $pp \rightarrow pXp$ process is considered to be a convolution of the hard subprocess amplitude describing the fusion of two off-shell gluons into a heavy system $g^*g^* \rightarrow X$, and the soft part represented in terms of the off-diagonal unintegrated gluon distributions (UGDFs) (see Fig. 1).

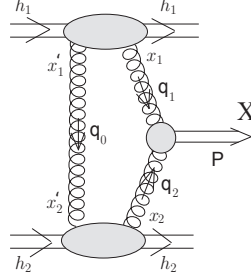


Figure 1: The QCD mechanism of diffractive production of the heavy central system X .

In order to check the underlying production mechanism it is worth to replace Higgs boson by a lighter (but still heavy enough to provide the factorisation) meson which is easier to measure. In this respect the exclusive production of heavy quarkonia is under special interest from both experimental and theoretical points of view [4]. Testing the KKMR approach against various data on exclusive meson production at high energies is a good probe of nonperturbative dynamics of partons described by UGDFs.

Recently, the signal from the diffractive $\chi_c(0^+, 1^+, 2^+)$ charmonia production in the radiative $J/\psi + \gamma$ decay channel has been measured by the CDF Collaboration [5]: $d\sigma/dy|_{y=0}(pp \rightarrow pp(J/\psi + \gamma)) \simeq 0.97 \pm 0.26$. In the very forward limit the contributions from $\chi_c(1^+, 2^+)$ vanish due to the $J_z = 0$ selection rule, however, for general kinematics this might not be true [6]. In particular, it was shown in Ref. [7] that the axial-vector $\chi_c(1^+)$ production, due a relatively large branching fraction of its radiative decay, may not be negligible and gives a noticeable contribution to the total signal measured by the CDF Collaboration. As shown below, the same holds also for the tensor $\chi_c(2^+)$ meson contribution.

The production of the axial-vector $\chi_c(1^+)$ meson has an additional suppression w.r.t. $\chi_c(0^+, 2^+)$ in the limit of on-shell fusing gluons due to the Landau-Yang theorem [7]. Such an extra suppression may lead to the dominance of the $\chi_c(2^+)$ contribution in the radiative decay channel. Off-shell effects play a significant role also for the scalar $\chi_c(0^+)$ production reducing the total cross section by a factor of 2 – 5 depending on UGDFs [8].

According to the KKMR approach the amplitude of the exclusive double diffractive color singlet production $pp \rightarrow pp\chi_{cJ}$ is [9, 8]

$$\mathcal{M}_{J,\lambda} = \text{const} \cdot \delta_{c_1 c_2} \mathfrak{S} \int d^2 q_{0,t} V_{J,\lambda}^{c_1 c_2}(q_1, q_2, P) \frac{f_{g,1}^{\text{off}}(x_1, x'_1, q_{0,t}^2, q_{1,t}^2, t_1) f_{g,2}^{\text{off}}(x_2, x'_2, q_{0,t}^2, q_{2,t}^2, t_2)}{q_{0,t}^2 q_{1,t}^2 q_{2,t}^2}, \quad (1)$$

where $t_{1,2}$ are the momentum transfers along the proton lines, q_0 is the momentum of the screening gluon, $q_{1,2}$ are the momenta of fusing gluons, and $f_{g,i}^{\text{off}}(x_i, x'_i, q_{0,t}^2, q_{i,t}^2, t_i)$ are the off-diagonal UGDFs.

The prescription for the off-diagonal UGDFs through their diagonal counterparts, inspired by the positivity constraints [10], reads [11, 8]

$$\begin{aligned} f_{g,1}^{\text{off}} &= \sqrt{f_g^{(1)}(x'_1, q_{0,t}^2, \mu_0^2) \cdot f_g^{(1)}(x_1, q_{1,t}^2, \mu^2)} \cdot F_1(t_1), \\ f_{g,2}^{\text{off}} &= \sqrt{f_g^{(2)}(x'_2, q_{0,t}^2, \mu_0^2) \cdot f_g^{(2)}(x_2, q_{2,t}^2, \mu^2)} \cdot F_1(t_2), \quad x'_1 = x'_2 = \xi \cdot q_{0,t} / \sqrt{s}, \end{aligned} \quad (2)$$

where $F_1(t_1)$ and $F_1(t_2)$ are the isoscalar nucleon form factors and ξ is auxiliary parameter.

The hard vertex function $V_{J,\lambda}^{c_1 c_2}(q_1, q_2, P)$ describes the coupling of two virtual gluons to χ_{cJ} meson. It can be found by using the next-to-leading-logarithmic-approximation (NLLA) BFKL $g^* g^*(q\bar{q})$ -vertex in quasi-multi-Regge kinematics (QMRK) and projecting it out to the colour singlet bound state χ_{cJ} employing the pNRQCD technique (for scalar and axial-vector case, see Refs. [8, 7]). We do not take into account the NLO QCD corrections here, $K_{NLO} = 1$.

Results for the total cross section of diffractive $\chi_c(0^+, 1^+, 2^+)$ meson production at Tevatron energy $W = 1960$ GeV are shown in Table 1. As have been pointed out in Ref. [6] the absorptive corrections are quite sensitive to the meson spin-parity. This was studied before in the context of scalar and pseudoscalar Higgs production in Ref. [2]. In the last column we adopt the following effective gap survival factors (for $\langle p_t \rangle \simeq 0.5$ GeV), calculated for different spins in Ref. [6]: $\langle S_{\text{eff}}^2(\chi_c(0^+)) \rangle \simeq 0.02$, $\langle S_{\text{eff}}^2(\chi_c(1^+)) \rangle \simeq 0.05$ and $\langle S_{\text{eff}}^2(\chi_c(2^+)) \rangle \simeq 0.05$. Having in mind that the total cross section σ_{χ_c} is less than the differential one $d\sigma_{\chi_c}/dy|_{y=0}$ by a factor of 4 – 5, we conclude that the calculated signal in the $J/\psi + \gamma$ channel turns out to be quite below the CDF data for off-diagonal UGDFs calculated as in Eq. (2) with $\xi = 1$. This provides an argument that x' should be smaller than used, i.e. $\xi < 1$. The dependence of the results on ξ will be reported elsewhere.

Table 1: Integrated cross section σ_{χ_c} (in nb) of the exclusive diffractive production of $\chi_c(0^+, 1^+, 2^+)$ mesons and their signals in radiative decay channel for different UGDFs at Tevatron. First three lines correspond to Eq. (2) with $\xi = 1$, forth line is calculated in the KMR prescription [1] with $R_g = 1$. In the last column we took into account the NLO corrections with $K_{NLO} \simeq 1.5$.

UGDF	$\chi_c(0^+)$		$\chi_c(1^+)$		$\chi_c(2^+)$		ratio	expected signal
	σ_{χ_c}	$\sigma_{J/\psi\gamma}$	σ_{χ_c}	$\sigma_{J/\psi\gamma}$	σ_{χ_c}	$\sigma_{J/\psi\gamma}$	$\frac{\chi_c(2^+) \rightarrow J/\psi\gamma}{\chi_c(0^+) \rightarrow J/\psi\gamma}$	$K_{NLO}^2 \sum_{\chi_c} \langle S_{\text{eff}}^2 \rangle \sigma_{J/\psi\gamma}$
KL [12]	55.2	0.6	0.5	0.2	6.7	1.3	2.2	0.2
GBW [13]	160	1.8	4.2	1.4	50.2	9.7	5.4	1.3
KS [14]	443.6	5.1	3.0	1.0	50.8	9.9	1.9	1.5
KMR [1]	1127	12.8	8.1	2.8	74.2	14.4	1.1	2.5

The relative contributions of different charmonium states in $J/\psi + \gamma$ channel are found to be:

$$\sigma(0^+ \rightarrow J/\psi + \gamma) : \sigma(1^+ \rightarrow J/\psi + \gamma) : \sigma(2^+ \rightarrow J/\psi + \gamma) = \begin{cases} 1 : 0.71 : 4.64, & \text{KL} \\ 1 : 1.94 : 13.47, & \text{GBW} \\ 1 : 0.49 : 4.85, & \text{KS} \\ 1 : 0.55 : 2.81, & \text{KMR} \end{cases}$$

We see that the contribution of the tensor $\chi_c(2^+)$ meson dominates over $\chi_c(0^+, 1^+)$ for all UGDFs.

It is also interesting to consider the diffractive production of χ_c states at different energies. As an example, in Table 2 we present the integrated cross sections of $\chi_c(1^+)$ production at RHIC,

Tevatron and LHC energies [7]. The results show similar energy behavior of the diffractive cross section for different UGDFs except KMR UGDF giving more strong growth of the cross section with energy. The same is true for other χ_c states.

Table 2: Integrated cross section σ_{tot} (in nb) for exclusive $\chi_c(1^+)$ production at different energies. No absorption effects are included here.

UGDF	RHIC	Tevatron	LHC
KL	0.05	0.5	1.7
GBW	0.04	4.2	73.1
KS	0.05	3.0	44.8
KMR, $R_g = 1$	0.1	8.1	510.5

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