Inclusive production of J/ψ and ψ' mesons at the LHC

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Abstract. We discuss the prompt production of J/ψ mesons in proton-proton collisions at the LHC within a NRQCD k_t-factorization approach using Kimber-Martin-Ryskin (KMR) unintegrated gluon distributions (UGDF). We include both direct color-singlet production ($gg \to J/\psi$g) as well as a feed-down from $\chi_c \to J/\psi\gamma$ and $\psi' \to J/\psi X$. The production of the decaying mesons (χ_c or ψ')is also calculated within NRQCD k_t-factorization. The corresponding matrix elements for $gg \to J/\psi$, $gg \to \psi'$ and $gg \to \chi_c$ include parameters of the nonrelativistic spatial wave functions of quarkonia at $r = 0$, which are taken from potential models from the literature. We get the ratio of the corresponding of the cross sections for $\chi_c(2)$-to-$\chi_c(1)$ much closer to experimental data than obtained in recent analyses. Differential distributions in rapidity of J/ψ and ψ' are calculated and compared to experimental data of the ALICE and LHCb collaborations. We discuss possible onset of gluon saturation effects at forward/backward rapidities. One can describe the experimental data for J/ψ production within model uncertainties with color-singlet component only. Therefore our theoretical results leave only a relatively small room for the color-octet contributions.

1 Introduction

For a long time there are discrepancies among authors about the production mechanism of J/ψ quarkonia in proton-proton and proton-antiproton collisions. Some authors think that the cross section is dominated by the color-octet contribution. Some authors believe that the color-singlet contribution dominates. The color-octet contribution cannot be calculated from first principle and is rather fitted to the experimental data. Different fits from the literature give different magnitudes of the color-octet contributions. Therefore we concentrate on the color-singlet contribution. In the present paper we wish to calculate the color-singlet contribution as well as possible in the NRQCD k_t-factorization and see how much room is left for the more difficult color-octet contribution. In the present approach we concentrate rather on small transverse momenta of J/ψ or ψ' relevant for ALICE and LHCb data [1–5]. We expect that color-singlet contributions may dominate in this region of the phase space. Finally ψ' quarkonium also has a sizable branching fraction into $J/\psi X$ [6]. Fortunately this contribution is much smaller than the direct one as will be discussed in [8]. It was considered recently in an almost identical approach in [9].

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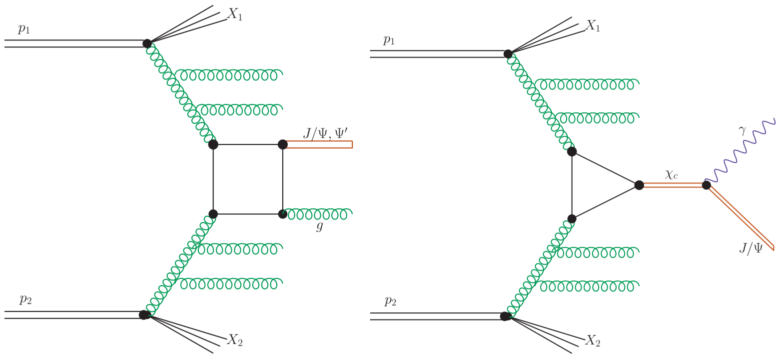

Figure 1. The leading-order diagram for prompt J/ψ (ψ') meson production in the k_t-factorization approach.

2 Inclusive production of J/ψ and ψ' mesons in the NRQCD k_t-factorization approach

The main color-singlet mechanism for the production of J/ψ and ψ' mesons is shown in Fig.1 (left panel). We restrict ourselves to the gluon-gluon fusion mechanism. In the NLO the differential cross section in the k_t-factorization can be written as:

$$\frac{d\sigma(pp \to J/\psi g X)}{dy_{J/\psi} dy_g d^2p_{J/\psi,t} d^2p_{g,t}} = \frac{1}{16\pi^2 \hat{s}^2} \int \frac{d^2q_{1t}}{\pi} \frac{d^2q_{2t}}{\pi} \overline{|\mathcal{M}^{off-shell}_{g^*g^* \to J/\psi g}|^2} \times \delta^2\left(\vec{q}_{1t} + \vec{q}_{2t} - \vec{p}_{H,t} - \vec{p}_{g,t}\right) \mathcal{F}_g(x_1, q_{1t}^2, \mu_F^2) \mathcal{F}_g(x_2, q_{2t}^2, \mu_F^2) . \quad (1)$$

We calculate the dominant color-single $gg \to J/\psi g$ contribution taking into account transverse momenta of initial gluons. The corresponding matrix element squared for the $gg \to J/\psi g$ is

$$|\mathcal{M}_{gg\to J/\psi g}|^2 \propto \alpha_s^3 |R(0)|^2 . \quad (2)$$

The matrix element is taken from [10]. In our calculation we choose the scale of the running coupling constant as:

$$\alpha_s^3 \to \alpha_s(\mu_1^2)\alpha_s(\mu_2^2)\alpha_s(\mu_3^2) , \quad (3)$$

where $\mu_1^2 = max(q_{1t}^2, m_t^2)$, $\mu_2^2 = max(q_{2t}^2, m_t^2)$ and $\mu_3^2 = m_t^2$, where here m_t is the J/ψ transverse mass. The factorization scale in the calculation was taken as $\mu_F^2 = (m_t^2 + p_{t,g}^2)/2$.

Similarly we calculate the P-wave χ_c meson production. Here the lowest-order subprocess $gg \to \chi_c$ is allowed by positive C-parity of χ_c mesons.

In the k_t-factorization approach the leading-order cross section for the χ_c meson production can be written as:

$$\sigma_{pp\to\chi_c} = \int dy d^2p_t d^2q_t \frac{1}{s x_1 x_2} \frac{1}{m_{t,\chi_c}^2} \overline{|\mathcal{M}_{g^*g^*\to\chi_c}|^2} \mathcal{F}_g(x_1, q_{1t}^2, \mu_F^2) \mathcal{F}_g(x_2, q_{2t}^2, \mu_F^2)/4 , \quad (4)$$

which can also be used to calculate rapidity and transverse momentum distributions of the χ_c mesons. In the last equation $\mathcal{F}_g$ are unintegrated gluon distributions and $\sigma_{gg\to\chi_c}$ is $gg \to \chi_c$ (off-shell) cross section. The situation is illustrated diagrammatically in Fig.1 (right panel).

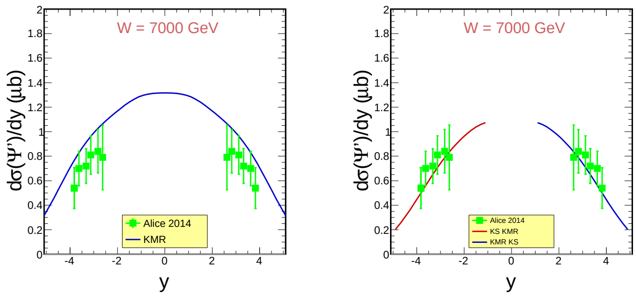

Figure 2. Rapidity distribution of ψ' meson with KMR (left plots) and mixed UGDFs (KS and KMR, right plots). The ALICE data [4] are shown for comparison.

The matrix element squared for the $gg \to \chi_c$ subprocess is

$$|\mathcal{M}_{gg\to\chi_c}|^2 \propto \alpha_s^2 |R'(0)|^2 \ . \tag{5}$$

We used the matrix element taken from the Kniehl, Vasin and Saleev paper [7].

For this subprocess the best choice for running coupling constant is:

$$\alpha_s^2 \to \alpha_s(\mu_1^2)\alpha_s(\mu_2^2) \ , \tag{6}$$

where $\mu_1^2 = max(q_{1t}^2, m_t^2)$ and $\mu_2^2 = max(q_{2t}^2, m_t^2)$. Above m_t is transverse mass of the χ_c meson.

The factorization scale for the χ_c meson production is fixed as $\mu_F^2 = m_t^2$.

3 Results

In Fig.2 we show differential cross section in rapidity for ψ' production at 7 TeV. Our results are compared with ALICE experimental data [4]. In the left panel we present results for Kimber-Martin-Ryskin (KMR) UGDF and in the right panel for mixed Kimber-Martin-Ryskin (KMR) and Kutak-Stasto (KS) UGDFs. Because KMR alone overshoot experimental data for rapidity distribution the best solution is to take the KMR distribution for large x and KS for small x. For ψ' meson we have to include only the direct diagram so it's easy to compare our result with experimental data.

For J/ψ meson we have to include both diagrams. Below we present results for these two subprocesses. In Fig.3 we show rapidity distribution for direct J/ψ meson production. We present results for three different values of energy: W = 2.76 TeV (left), W = 7 TeV (middle) and W = 13 TeV (right). Our results are compared with ALICE and LHCb experimental data [1–5].

In Fig.4 we present results for three different values of energy: W = 2.76 TeV (left), W = 7 TeV (middle) and W = 13 TeV (right) panel. The dotted lines are for χ_{c1} meson contribution, the dot-dashed lines are for χ_{c2} meson contributions ant the solid lines are sum of these two components. The presented here results are calculated with mixed UGDFs (KMR and KS).

4 Conclusion

We have calculated the color-singlet contribution in the NRQCD k_t-factorization and compared our results with ALICE and LHCb data. Our results in rapidity are almost consistent or even exceed

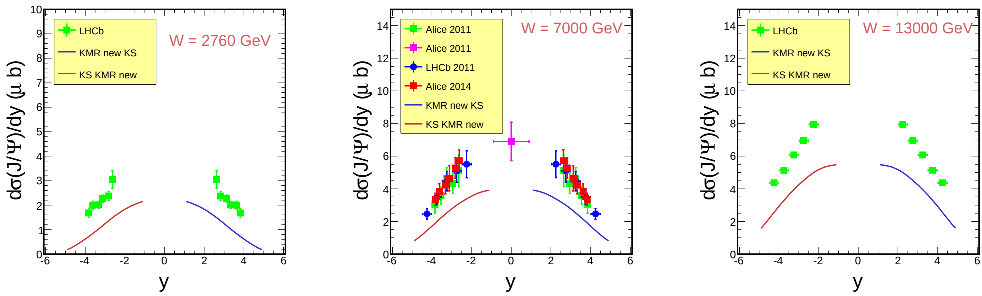

Figure 3. Rapidity distribution of J/ψ meson with KMR (upper plots) and mixed UGDFs (Kutak-Stasto and KMR). The ALICE and LHCb data points [1–5] are shown for comparison.

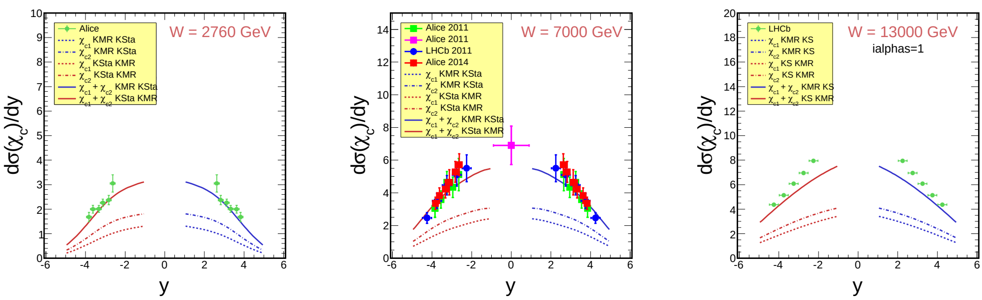

Figure 4. Rapidity distribution of χ_c meson with mixed UGDFs (Kutak-Stasto and KMR). The ALICE and LHCb data points [1–5] for J/ψ are shown for comparison.

experimental data. Cross section strongly depends on UGDF and we think the best solution is to use mixed UGDFs (KMR-KS). In our approach only small room is left for color-octet contribution.

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