Production of two J/ψ mesons in proton-proton collisions at the LHC

ANTONI SZCZUREK[1]

Institute of Nuclear Physics, Polish Academy of Sciences, PL-31-342 Kraków, Poland

Faculty of Mathematics and Natural Sciences, University of PL-35-310 Rzeszów, Poland

ANNA CISEK

Faculty of Mathematics and Natural Sciences, University of PL-35-310 Rzeszów, Poland

WOLFGANG SCHÄFER

Institute of Nuclear Physics, Polish Academy of Sciences, PL-31-342 Kraków, Poland

We discuss inclusive production of pairs of J/ψ quarkonia. Both leading-order single parton (box) contribution and double-parton contributions are included. In addition we discuss a contribution of higher-order two-gluon exchange and a feed down from double χ_c production. The second two contributions are important for large rapidity distance between the two J/ψ mesons and for relatively large cut-offs on quarkonia transverse momenta. A relation to current experiments is discussed.

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1 Introduction

The production of single J/ψ mesons in proton-proton collsions was a vivid topic for more than three decades [1]. Several differential distributions were measured. The nonrelativistic perturbative QCD is the standard theoretical approach in this context. There is no agreement and comonly accepted explanation of the many experimental data collected for years.

Recently there are several experimental results also for double J/ψ production [2, 3, 5, 4, 6]. Also here there are puzzles that require dedicated studies. The leading-order result of the order of $\mathcal{O}(\alpha_s^4)$ is well known for some time [7]. Also double-parton mechanism was discussed in this context.

Here we discuss several mechanisms relevant for understanding current measurements. In addition to the leading-order contribution we include also double-parton scattering mechanism. The normalization parameter of the corresponding cross section, the so-called σ_{eff}, is unknown. $\sigma_{\text{eff}} \approx 15$ mb was obtained for other double parton scattering processes [8]. The σ_{eff} parameter adjusted to some of the recent double J/ψ measurements were found to be much lower. How this result can be understood?

Here we discuss two more mechanisms of double J/ψ production not included in theoretical analyses. We will discuss their main characteristics and possible consequence for the value of σ_{eff} extracted from the experimental studies.

2 Discussed mechanisms

The mechanisms considered in our analysis are shown in Fig.1.

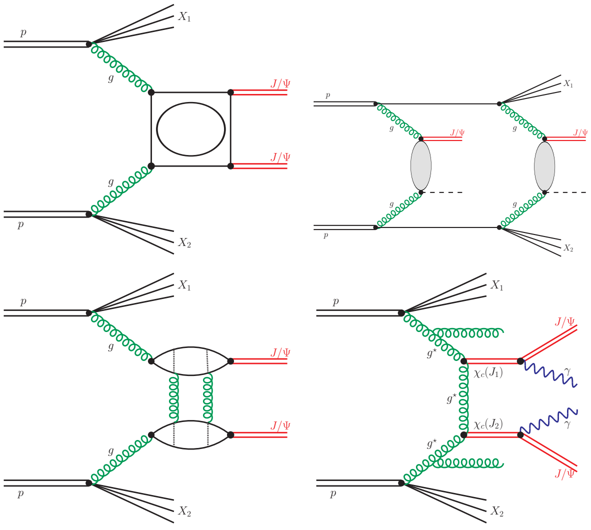

Figure 1: The mechanisms considered in our analysis.

The leading-order contribution is represented here in a bit symbolic representation (the inserted circle). The circle represent extra gluon. Some explicit Feynman diagrams were presented e.g.in our previous paper [9].

The double-scattering diagram is presented here also in a bit generic form. The blobs shown in the figure represent several mechanisms of single J/ψ production discussed e.g. by A. Cisek [13] at this workshop.

The two-gluon exchange mechanisms was already considered in our previous paper [9]. It was shown there that it contributes to the region of large rapidity distances between the two produced J/ψ mesons.

The last mechanism was not considered in regular papers, but was already discussed recently in some conference talks by the present speaker. Here we only sketch main features of the mechanism. The details will be presented elsewhere [14].

The contribution of the first mechanism is calculated here in the k_t factorization approach. In the k_t-factorization approach the corresponding differential cross section can be written as:

$$\begin{aligned}\frac{d\sigma(pp \to J/\psi J/\psi X)}{dy_1 dy_2 d^2p_{1t} d^2p_{2t}} &= \frac{1}{16\pi^2 (x_1 x_2 s)^2} \int \frac{d^2q_{1t}}{\pi} \frac{d^2q_{2t}}{\pi} \overline{|\mathcal{M}^{\mathrm{off-shell}}_{g^* g^* \to J/\psi J/\psi}|^2} \\ &\times\; \delta^2\left(\vec{q}_{1t} + \vec{q}_{2t} - \vec{p}_{1t} - \vec{p}_{2t}\right) \mathcal{F}_g(x_1, q_{1t}^2, \mu_F^2) \mathcal{F}_g(x_2, q_{2t}^2, \mu_F^2) \; . \end{aligned} \tag{1}$$

The relevant off-shell matrix elements were obtained first in [10]. The Kimber-Martin-Ryskin unintegrated distributions were used in practical calculations.

In the present analysis we assume a simple factorized ansatz for the double scattering cross section. The the differential cross section for double J/ψ production can be writen as:

$$\frac{d\sigma(pp \to J/\psi J/\psi)}{dy_1 d^2p_{1t} dy_2 d^2p_{2t}} = \frac{1}{2\sigma_{\mathrm{eff}}} \cdot \frac{d\sigma(pp \to J/\psi X)}{dy_1 d^2p_{1t}} \cdot \frac{d\sigma(pp \to J/\psi X)}{dy_2 d^2p_{2t}} \; . \tag{2}$$

σ_{eff} is responsible for the overlap of partonic densities of colliding protons. It is often treated as a free parameter to be fitted to experimental data. How to use single J/ψ cross section is to some extent an open issue. One possibility is to calculate it in some approach (k_t-factorization for instance). Another possibility is to parametrize experimental data. Here we follow [11, 12] and write cross section in terms of a ficticious matrix element with free parameters fitted to experimental data. Quite nice fits to experimental data can be obtained. This will be shown elsewhere [16].

The double χ_c contribution is calculated in the k_t-factorization approach with a formula similar as that for the double J/ψ production. The matrix element for the $g^* g^* \to \chi_c(J_i)\chi_c(J_j)$ subprocess can be written in a somewhat simplified (omitting spins of χ_c mesons) way as

$$\begin{aligned}\mathcal{M}^{ab}_{\mu\nu} &= V^{ac}_{\mu\alpha}(q_1, p_1 - q_1) \frac{-g^{\alpha\beta}\delta_{cd}}{\hat{t}} V^{db}_{\beta\nu}(p_2 - q_2, q_2) \\ &+\; V^{ac}_{\mu\alpha}(q_1, p_2 - q_1) \frac{-g^{\alpha\beta}\delta_{cd}}{\hat{u}} V^{db}_{\beta\nu}(p_1 - q_2, q_1) \; . \end{aligned} \tag{3}$$

To obtain the k_t-factorization amplitude one should contract the above tensorial amplitude with the polarization vectors of the off-shell gluons [14].

There are several combinations of the $\chi_c(J_i)\chi_c(J_j)$ final states:

$$
\begin{array}{ll}
(a) & \chi_c(0)\chi_c(0), \\
(b) & \chi_c(0)\chi_c(1), \\
(c) & \chi_c(0)\chi_c(2), \\
(d) & \chi_c(1)\chi_c(1), \\
(e) & \chi_c(1)\chi_c(2), \\
(f) & \chi_c(2)\chi_c(2).
\end{array}
$$

The branching fractions in the $\chi_c \to J/\psi + \gamma$ decays [15] cause that only (d),(e) and (f) cases are of practical meaning.

More details will be discussed in our original papers [14, 16].

3 Selected results

Here we wish to show only some selected results. In Fig.2 we show result obtained in [9] for the LHCb cuts. There leading order, DPS and two-gluon exchange contributions were considered. Clearly for the LHCb kinematics the leading order (box) contribution dominates. However, when going to large rapidity distances between the two J/ψ mesons one has to include also the DPS contribution (dash-dotted line) and even two-gluon exchange contribution (dashed line) multiplied by an extra factor [9].

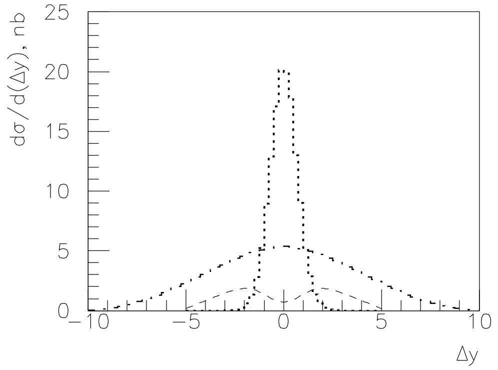

Figure 2: Distribution in rapidity difference of the two J/ψ mesons for the LHCb kinematics.

Recently we have considered also the situation relevant for a recent ATLAS experiment [5]. Here -2.1 $< y <$ 2.1 and $p_t >$ 8.5 GeV (and some other cuts on muons) conditions are imposed experimentally. The situation at the large transverse momenta ($p_t > 8.5$ GeV) is slightly different than for the LHCb experiment where relatively low transverse momenta were measured. In Fig.3 we show distribution in the rapidity difference for the ATLAS kinematics. We show all four discussed here contributions. In this preliminary calculation only one combination of $\chi_c(J_i)\chi_c(J_j)$ for $J_i = 1$ and $J_j = 1$ was included. All combinations will be shown in Ref.[16]. As for the LHCb experiment the dominant box contribution is concentrated at low rapidity distances. Both two-gluon exchange and double-χ_c contributions have a similar shape as the double scattering one. This may, at least partially, explain why the ATLAS collaboration obtained small σ_{eff} parameter when omitting the higher-order two-gluon exchange mechanism and feed down for double χ_c production. Clearly more studies are needed.

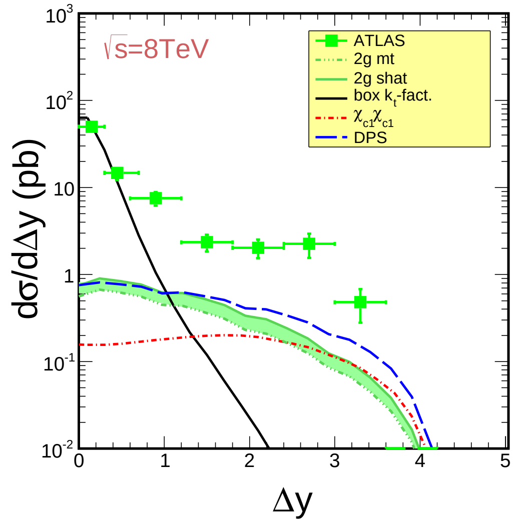

Figure 3: Distribution in rapidity difference of the two J/Ψ mesons for the ATLAS kinematics.

4 Conclusions

In this talk a discussion on mechanisms relevant for double J/ψ production was presented. Several mechanisms were discussed. In addition to the commonly recognized leading-order (box) contribution and discussed recently by different authors double-scattering mechanism we included also two-gluon exchange mechanism and a feed down from double χ_c channel. The two-gluon exchange mechanism, formally three loop type, was calculated in the high-energy approximation. It turned out to be important at high rapidity distance between two J/ψ mesons. The two-χ_c production was considered recently only by our group. The amplitudes for off-shell gluons $g^*g^* \to \chi_c(J_i)\chi_c(J_j)$ were calculated using $g^*g^* \to \chi_c(J_k)$ vertices calculated within nonrelativistic pQCD approach. The details of the matrix element will be shown elsewhere [14]. The *t*- or *u*-channel gluon exchange mechanisms lead to a population of two χ_c mesons at large rapidity distance.

Both two-gluon exchange and the double feed down mechanisms have characteristics similar to the double-scattering mechanism. This may potentially explain why fits to experimental data, where only leading-order (box) and double scattering mechanisms were included, found very small value of σ_{eff}. Our preliminary calculation strongly suggests that the missing single parton scattering mechanisms should be included in trials to understand experimental data. This will be discussed elsewhere [16].

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