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Double parton interactions in double J/ψ production at LHC

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The problem of disentangling the single (SPS) and double (DPS) parton scattering modes at the LHC conditions is discussed. Our analysis is based on comparing the shapes of the differential cross sections and on studing their behavior under imposing kinematical cuts.

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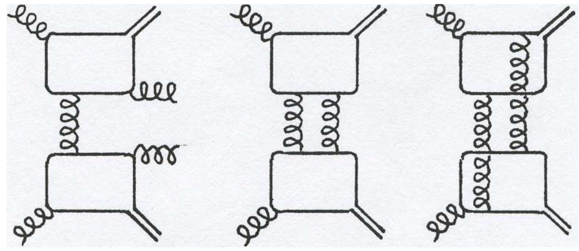

Figure 1: Examples of Feynman diagrams representing the J/ψ pair production in pseudo-diffraction gluon-gluon scarreting.

1. Introduction

In the last years, the production of J/ψ pairs has attracted a significant renewal attention in the context of searches for double parton scattering processes [1]. A number of discussions has been stimulated by the recent measurement [2] of the double J/ψ production cross section at the LHCb experiment at CERN. Theoretical estimates based on both collinear [3, 4] and k_t-factorization [5] approaches show that the single (SPS) and double (DPS) parton scattering contributions are comparable in size and, taken together, can perfectly describe the measured cross section.

However to disentangle the SPS and DPS mechanisms one needs to clearly understand the production kinematics. Naive expectations that the SPS mechanism should result in the back-to-back event configuration received no support from the later calculations. Including the initial state radiation effects (either in the form of k_t-dependent gluon distributions [6] or by means of simulating the parton showers in a phenomenological way [4]) washes out the original azimuthal correlations. On the other hand, it has been suggested [4] that the DPS production is characterized by a much larger rapidity difference between the two J/ψ mesons.

The goal of the present study is to carefully examine the J/ψ pair production properties in the different kinematical domains paying attention to the different contributing processes [7]. On the SPS side, we consider the leading-order $\mathscr{O}(\alpha_s^4)$ subprocess and the subleading $\mathscr{O}(\alpha_s^6)$ contribution from pseudo-diffractive gluon-gluon scattering represented by one-gluon exchange and two-gluon exchange mechanisms.

2. Theoretical framework

At the leading order, $\mathscr{O}(\alpha_s^4)$, the SPS subprocess $g+g \to J/\psi + J/\psi$ is represented by a set of 31 "box" diagrams. Our approach is based on perturbative QCD, nonrelativistic bound state formalism [8], and the k_t-factorization ansatz [9] in the parton model. The calculation of this subprocess is identical to that describedin Ref. [6]. Only the color singlet channels are taken into consideration in the present study since this approach was found to be fully sufficient [10] to describe all of the known LHC data on J/ψ production.

We also consider the pseudo-diffractive gluon-gluon scattering subprocesses represented by the diagrams of Fig. 1.

Despite the latter are of formally higher order in α_s, they contribute to the events with large rapidity difference between the two J/ψmesons and in that region can take over the leading-order

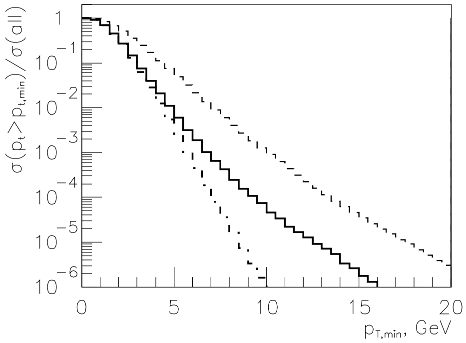

Figure 2: Fraction of the production cross section left after inposing cuts on the J/ψ transverse momsentum.

’box’ subprocess. The pseudo-diffractive subprocesses are of our special interest as they potentially can mimic the DPS mechanism having very similar kinematics.

The evaluation of the one-gluon exchange diagrams $g(k_1)+g(k_2) \to J/\psi(p_1)+J/\psi(p_2)+g(k_3)+g(k_4)$ is straightforward, but the number of diagrams is rather large. Note that the matrix element is free from infrared singularities. This is due to the specific property of the quark loop amplitude which vanishes when any of the three attached gluons becomes soft. These calculations have also been performed in the k_t-factorization approach .

The elementary $g+g \to J/\psi + J/\psi$ cross section can be easily calculated in the high-energy approximation similarly to how it was done for the $\gamma+\gamma \to J/\psi + J/\psi$ reaction [12]. The corresponding cross section is proportional to $\alpha_s^6(\mu_r^2)$, and therefore depends strongly on the choice of the renormalization scale. In the calculation presented here we take $\mu_r^2 = m_t^2$, where m_t is the J/ψ transverse mass.

The cross section for the two-gluon exchange contribution to the $p+p \to J/\psi + J/\psi + X$ reaction (see Fig. 1) is calculated in the collinear approximation with MSTW2008(NLO) gluon distribution function [11] and the factorization scale $\mu_f^2 = m_t^2$. We neglect here the possible interference between the box diagram and the two-gluon exchange mechanism, which is formally of lower order than the square of the two-gluon amplitude. As it will become obvious from the numerical results the two gluon mechanism is exceedingly small in the region of invariant masses dominated by the box mechanism.

The inclusive DPS cross section is calculated using standard factorization assumptions. Under the hypothesis of having two independent hard partonic subprocesses A and B in a single pp collision, and under the further assumption that the longitudinal and transverse components of generalized parton distributions factorize from each other, the inclusive DPS cross section reads

$$\sigma_{\rm DPS}^{\rm AB} = \frac{m}{2}\frac{\sigma_{\rm SPS}^{A}\sigma_{\rm SPS}^{B}}{\sigma_{\rm eff}}, \qquad (2.1)$$

The inclusive SPS cross sections $\sigma_{\rm SPS}^{A}$ and $\sigma_{\rm SPS}^{B}$ for the individual partonic subrocesses A and B can be calculated in a usual way using the single parton distribution functions. The symmetry factor m equals to 1 for identical subprocesses and 2 for the differing ones.

These simplifying factorization assumptions, though rather customary in the literature and quite convenient from the computational point of view, are not sufficiently justified and are cur-

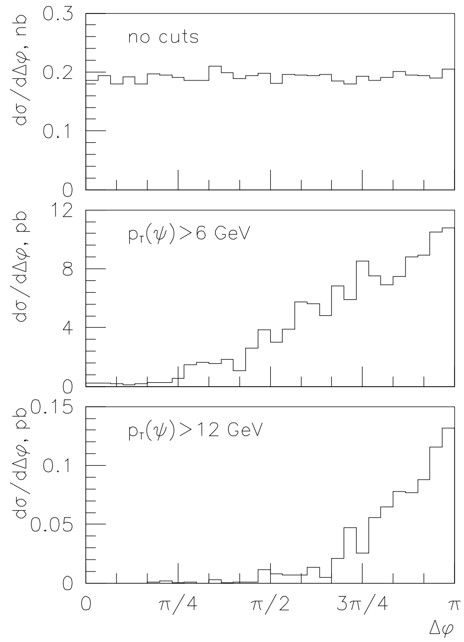

Figure 3: Azimuthal angle difference distributions of the J/ψ mesons.

rently under revision [1]. Nevertheless, we restrict ourselves to this simple form (2.1) regarding it as the first estimate for the DPS contribution. In fact, we obtain the lower bound estimate for the contribution under consideration. The CDF and D0 measurements [13] give $\sigma_{\text{eff}} \simeq 15$ mb, that constitutes roughly 20% of the total (elastic + inelastic) $p\bar{p}$ cross section at the Tevatron energy. We used this value in our analysis.

3. Results and discussion

We start with discussing the role of kinematic restrictions on the J/ψ transverse momentum. Shown in Fig. 2 are the fractions of SPS events surviving after imposing cuts on $p_T(\psi)$. The dashed line corresponds to the true SPS mode under the requiremnt that at least one (arbitrarily chosen) J/ψ meson has $p_T(\psi)>p_{T,min}$. The dash-dotted line corresponds tothe cuts on both J/ψ's produced independently (the DPS mode).The explic it calculation (solid curve) lies between the two idealistic extreme cases related to the fully independent (dash-dotted curve) and fully back-to-back correlated (dashed curve) production of J/ψ pairs.

Another illustration of this property is given by the distributionsin the azimuthal angle difference $d\sigma(\psi\psi)/d\Delta\varphi$ exhibited in Fig. 3. The distribution tends to concentrate around $\Delta\varphi \simeq \pi$ when the cuts on $p_T(\psi)$ become tighter (the middle and the lower plots in Fig. 3.) In principle, one could get rid of the SPS contribution by imposing cuts like $p_T(\psi) > 6$ GeV, $\Delta\varphi < \pi/4$, but the DPS cross section would then fall from tens of nanobarns to few picobarns.

Now we turn to rapidity correlations explained in Fig. 4. In the case of independent production (the DPS mode), the distribution over Δy is rather flat (dash-dotted curve in Fig. 4), while in the case of SPS 'box' contribution (dotted curve in Fig. 4) it is concentrated around $\Delta y \simeq 0$ and does

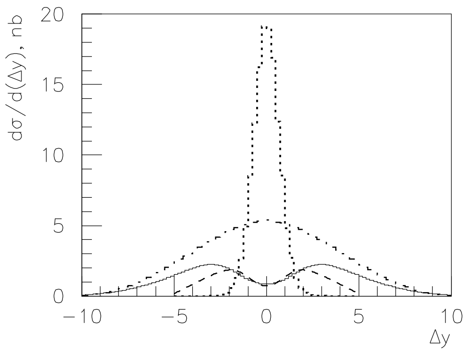

Figure 4: Distribution over the rapidity difference between J/ψ mesons.

not extend beyond the interval $|\Delta y| < 2$. In Fig. 4 we also show pseudo-diffractive contributions from the one- and two-gluon exchange processes of Fig. 1. As it was expected, these processes lead to relatively large Δy and even show maxima at $\Delta y \simeq \pm 2$. At the same time, the absolute size of the one-gluon exchange cross section is found to be remarkably small.

In summary we find it rather difficult to disentangle the SPS and DPS modes on the basis of azimuthal or transverse momentum correlations. Selecting large rapidity difference events looks more promising. The leading order SPS contribution is localized inside the interval $|\Delta y| \leq 2$.

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