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Vector Meson Production in Photon - induced Interactions at the LHC

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In this contribution we analyse double vector meson production in photon – hadron (γh) interactions at $pp/pA/AA$ collisions and present predictions for $\rho\rho$, $J/\Psi J/\Psi$ and $\rho J/\Psi$ production considering the double scattering mechanism. We estimate the total cross sections and compare our results with the predictions for double vector meson production in $\gamma\gamma$ interactions at hadronic c olliders. Our results demonstrate that the $\rho\rho$ and $J/\Psi J/\Psi$ production in $PbPb$ collisions is dominated by the double scattering mechanism, while the two - photon mechanism dominates in pp collisions. Moreover, our results indicate that the analysis of the $\rho J/\Psi$ production at LHC can be useful to constrain the double scattering mechanism.

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1. Introduction

Recent theoretical and experimental studies have demonstrated that hadronic colliders can also be considered photon – hadron and photon – photon colliders [1]. This allows to study photon – induced interactions in a new kinematical range and probe, e.g. the nuclear gluon distribution [2, 3], the dynamics of the strong interactions [4, 5, 6, 7], the Odderon [8, 9], the mechanism of quarkonium production [10, 11, 6, 7] and the photon flux of the proton [12, 13]. In particular, the installation of forward detectors in the LHC [14, 15] should allow to isolate more easily the exclusive processes, where the incident hadrons remain intact, permitting, for example, a detailed study of the exclusive production of two vector mesons. Recent results from the LHCb Collaboration on exclusive double J/Ψ production [16] have demonstrated that the experimental analysis of this process is feasible, motivating the improvement of its theoretical description [17, 18, 19, 20, 22]. In particular, in Ref. [22] we have revisited the double vector production in $\gamma\gamma$ interactions, proposed originally in Refs. [23], taking into account recent improvements in the description of the $\gamma\gamma \rightarrow VV$ ($V = \rho, J/\Psi$) cross section at low [19, 20] and high [21] energies. The results presented in Ref. [22] have demonstrated that the analysis of this process is feasible in hadronic collisions, mainly in pp collisions, and that its study may be useful to constrain the QCD dynamics at high energies, as proposed originally in Ref. [23]. However, pairs of vector mesons can also be produced in photon – hadron (γh) interactions if a double scattering occurs in the same event. The treatment of this double scattering mechanism (DSM) for γh interactions in heavy ion collisions was proposed originally in Ref. [24] and the double ρ production was recently discussed in detail in Ref. [25]. Such results demonstrated that the contribution of the double scattering mechanism is important for high energies, which motivates a more detailed analysis of this process. In this contribution we review our recent results on double J/Ψ and $\rho J/\Psi$ production in $pp/pA/AA$ collisions presented in Ref. [26]. Additionally, we compare our results for double vector meson production in γh interactions with those obtained in Ref. [22] for $\gamma\gamma$ interactions. As we will demonstrate below, the $\rho\rho$ and $J/\Psi J/\Psi$ production in $PbPb$ collisions is dominated by the double scattering mechanism, while the two - photon mechanism dominates in pp collisions. Moreover, our results indicate that the analysis of the $\rho J/\Psi$ production at LHC can be useful to constrain the double scattering mechanism.

2. Formalism

Let us start our analysis presenting a brief review of the main concepts and formulas to describe single and double vector meson production in γh interactions at hadronic colliders. The basic idea in the photon-induced processes is that an ultra-relativistic charged hadron (proton or nucleus) generates a strong electromagnetic field. A photon stemming from the electromagnetic field of one of the two colliding hadrons can interact with one photon emitted by the other hadron (photon - photon process) or can interact directly with the other hadron (photon - hadron process) [1, 27]. In these processes the total cross section can be factorized in terms of the equivalent flux of photons (emitted by the projectile) and the photon-photon or photon-target production cross section. In this paper our main focus will be the diffractive vector meson production in photon – hadron interactions in hadronic collisions. The differential cross sections for the production of a single vector meson V at rapidity y at fixed impact parameter b can be expressed as follows:

$$\frac{d\sigma\left[h_1+h_2\rightarrow h_1\otimes V\otimes h_2\right]}{d^2bdy}=\left[\omega N_{h_1}(\omega,b)\,\sigma_{\gamma h_2\rightarrow V\otimes h_2}(\omega)\right]_{\omega_L}+\left[\omega N_{h_2}(\omega,b)\,\sigma_{\gamma h_1\rightarrow V\otimes h_1}(\omega)\right]_{\omega_R}$$

where the rapidity (y) of the vector meson in the final state is determined by the photon energy ω in the collider frame and by the mass M_V of the vector meson [$y\propto\ln(\omega/M_V)$]. Moreover, $\sigma_{\gamma h_i\rightarrow V\otimes h_i}$ is the total cross section for the diffractive vector meson photoproduction, with the symbol $\otimes$ representing the presence of a rapidity gap in the final state and $\omega_L\,(\propto e^{-y})$ and $\omega_R\,(\propto e^{y})$ denoting photons from the h_1 and h_2 hadrons, respectively. Eq. (2.1) takes into account that both incident hadrons can be the source of photons which will interact with the other hadron.

The double vector meson production can occur if two γh interactions are present in the same event. In order to treat this double - scattering mechanism we will follow the approach from Refs. [24, 25], where it was s proposed that the double differential cross section for the production of a vector meson V_1 at rapidity y_1 and a second vector meson V_2 at rapidity y_2 is given by:

$$\frac{d^2\sigma_{h_1h_2\rightarrow h_1V_1V_2h_2}}{dy_1dy_2}=\mathscr{C}\int_{b_{min}}\frac{d\sigma\left[h_1+h_2\rightarrow h_1V_1h_2\right]}{d^2bdy_1}\times\frac{d\sigma\left[h_1+h_2\rightarrow h_1V_2h_2\right]}{d^2bdy_2}\,d^2b\,, \qquad (2.1)$$

where $\mathscr{C}$ is equal to 1 (1/2) for $V_1\neq V_2$ ($V_1=V_2$) and $b_{min}=R_{h_1}+R_{h_2}$ excludes the overlap between the colliding hadrons and allows to take into account only ultra-peripheral collisions. Consequently, the double vector meson production can be easily estimated in terms of the cross sections of single vector meson production, which are determined by the photon flux and the $\gamma h\rightarrow Vh$ cross section.

In order to describe diffractive vector meson photoproduction we will consider the color dipole formalism, which successfully describes the HERA data and the recent LHC data [28, 6, 7]. In this approach the description of single vector meson production can be factorized as follows: i) a photon is emitted by one of the incident hadrons, ii) the photon fluctuates into a quark-antiquark pair (the dipole), iii) this color dipole interacts with the other hadron by the exchange of a color single state, denoted Pomeron ($I\!P$) and, iv) the pair is converted into the vector meson final state. In Ref. [26] we have assumed that the vector meson is predominantly a quark-antiquark state and that its spin and polarization structure is the same as in the photon and can be described by the Gauss-LC model, as in Ref. [7]. Finally, in order to estimate the photon - hadron cross section we must specify the dipole - target scattering amplitude $\mathscr{N}^h$. In Ref. [26] we assumed that the dipole proton scattering amplitude $\mathscr{N}^p$ is given by the bCGC model [29], which is based on the CGC formalism [30] and takes into account the impact parameter dependence of the dipole - proton scattering amplitude. In the nuclear case, we have considered the Glauber model, which allows to express the dipole - nucleus scattering amplitude in terms of the dipole - proton one.

3. Results

In what follows we present our predictions for the energy dependence of the total cross sections for the $\rho\rho$, $\rho J/\Psi$ and $J/\Psi J/\Psi$ production in γh interactions in $pp/pPb/PbPb$ collisions (For other distributions see Ref. [26]). We will denote the predictions associated to the double scattering mechanics by DSM hereafter. Following Ref. [25] we will estimate the equivalent photon spectra for $A=Pb$ assuming the nucleus as a point - like object, i.e. $F(q^2)=1$. We have verified that using

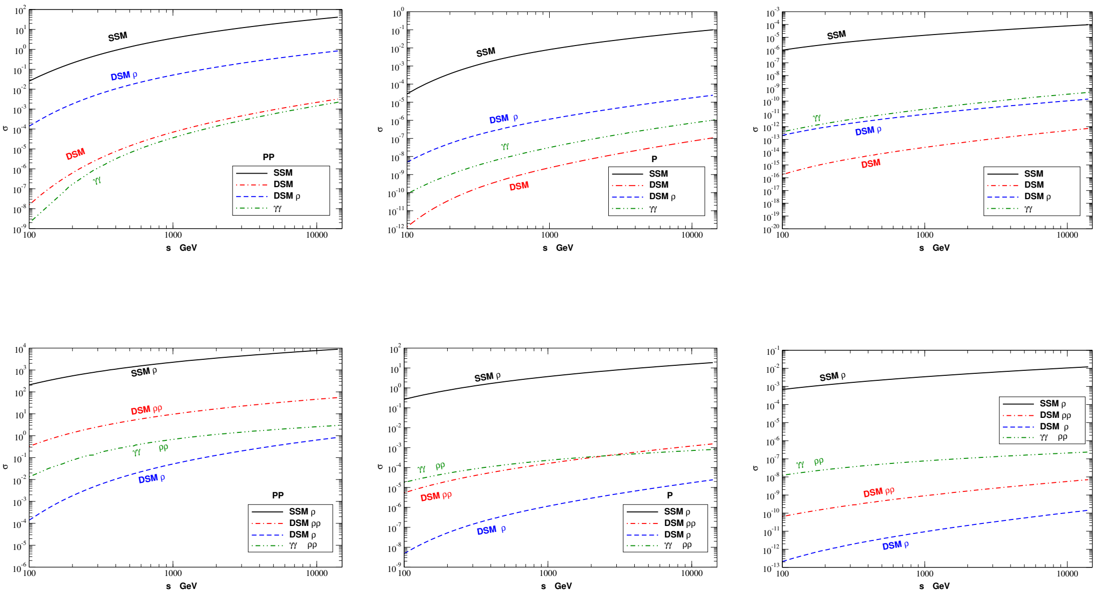

Figure 1: Energy dependence of the $J/\Psi J/\Psi$ (upper panels) and $\rho\rho$ (lower panels) production cross sections in γh and $\gamma\gamma$ interactions in $PbPb$ (left panels), pPb (middle panels) and pp (right panels) collisions. The predictions associated to the double scattering mechanism are denoted DSM. For comparison the predictions for single vector meson production, denoted SSM, are also shown.

a more realistic form factor for the nucleus, the impact in the predictions for the total cross sections is smaller than 5%. In the proton case, we will take $F(q^2) = 1/[1+q^2/(0.71\text{GeV}^2)]^2$ and $R_p = 0.7$ fm as in Ref. [22]. Moreover, we will compare our predictions for the $J/\Psi J/\Psi$ and $\rho\rho$ production with the results obtained in Ref. [22] for the production of these final states in $\gamma\gamma$ interactions. In Fig. 1 we present our predictions for the energy dependence of the total cross sections for double vector meson production in γh and $\gamma\gamma$ interactions. For the double J/Ψ production (upper panels), the double scattering mechanism becomes competitive with the two - photon one only in $PbPb$ collisions, being a factor 10 (100) smaller in pPb (pp) collisions. In particular, for pp collisions, the DSM contribution is negligible. On the other hand, our results demonstrate that the associated production of a J/Ψ and a ρ meson by the double scattering mechanism is important in the LHC energy range. It is important to emphasize that this final state can also be produced by $\gamma\gamma$ interactions. However, as its contribution in hadronic collisions is still an open question due to the large uncertainty in the normalization of the $\gamma\gamma \to \rho J\Psi$ cross section (For a detailed discussion see Ref. [21]), we do not present the corresponding predictions. In the case of the double ρ production (lower panels), the double scattering mechanism is dominant in $PbPb$ collisions, in agreement with the results presented in Ref. [25]. On the other hand, the contributions of the double scattering and two - photon mechanisms are similar in pPb collisions, while the $\gamma\gamma$ dominates in the pp collisions. These results demonstrate that the analysis of this final state in $PbPb/pPb/pp$ can be useful to disentangle the different mechanisms of $\rho\rho$ production.

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