

Photoproduction of J/ψ with dissociation of protons

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We present the cross sections for both electromagnetic and diffractive dissociation of protons for semiexclusive production of J/ψ mesons in proton-proton collisions at the LHC. Differential distributions in missing mass (M_X), as well as distributions in rapidity and transverse momentum of the J/ψ are calculated for $\sqrt{s} = 7$ TeV and 13 TeV proton proton collisions. We compare the distributions for purely electromagnetic and purely diffractive proton excitations/dissociation. We predict cross sections for electromagnetic and diffractive excitations of similar order of magnitude.

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1 Introduction

The exclusive vector meson $V = J/\psi, \psi', \Upsilon$ production in proton-proton collisions as measured by the LHCb collaboration [1] has recently attracted a lot of attention.

Indeed, it turns out, that at LHC-energies the exclusive production cross section probes the $\gamma p \rightarrow Vp$ amplitude at higher energies than were previously available, e.g. at HERA.

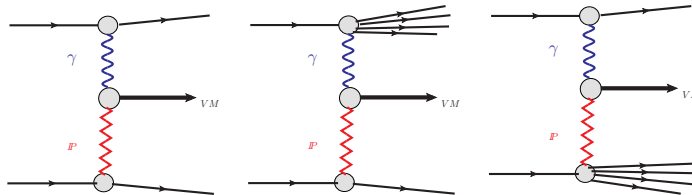


Figure 1: Born diagrams for three vector meson production mechanisms. Left panel: exclusive production through the $\gamma\mathbf{P}$ -fusion, middle panel: semiexclusive production with electromagnetic excitation of one of the protons, right panel: semiexclusive production with diffractive dissociation of one of the incoming protons.

For heavy vector mesons, the diffractive photoproduction amplitude in turn is a sensitive probe of the proton's (unintegrated) gluon distribution (see e.g. the review [2] and references therein). A number of subtleties have to be taken into account, even in the case of fully exclusive production, such as the interference of contributions where different protons emitted the photon and absorptive corrections, all treated in [3].

Here we are concerned with a different complication: due to the fact that up to now there are no measurements with tagged protons, there is always a contribution with dissociation, which needs to be modelled. As shown in fig.1, the dissociation can be induced by electromagnetic as well as strong interactions (diffractive dissociation). More details can be found in [4].

2 Diffractive photoproduction with electromagnetic dissociation

The electromagnetic dissociation processes have a nice property, that they can be calculated in an entirely data-driven way [6, 7]. In fact the $\gamma^*p \rightarrow X$ vertices can after summing over states X be related to the nucleon deep-inelastic structure function. The cross section for semiexclusive vector meson production then is given as

$$\frac{d\sigma(pp \rightarrow XVp; s)}{dyd^2\mathbf{p}} = \int \frac{d^2\mathbf{q}}{\pi\mathbf{q}^2} \mathcal{F}_{\gamma/p}^{(\text{inel})}(z_+, \mathbf{q}^2) \frac{1}{\pi} \frac{d\sigma^{\gamma^*p \rightarrow Vp}}{dt}(z_+, s, t = -(\mathbf{q} - \mathbf{p})^2) + (z_+ \leftrightarrow z_-). \quad (1)$$

Photons carry a longitudinal momentum fraction $z_{\pm} = e^{\pm y} \sqrt{\mathbf{p}^2 + m_V^2} / \sqrt{s}$ and transverse momentum \mathbf{q} . The effective photon flux in dissociative events is

$$\mathcal{F}_{\gamma/p}^{(\text{inel})}(z, \mathbf{q}^2) = \frac{\alpha_{\text{em}}}{\pi} (1-z) \int_{M_{\text{thr}}^2}^{\infty} \frac{dM_X^2 F_2(x_{\text{Bj}}, Q^2)}{M_X^2 + Q^2 - m_p^2} \left[\frac{\mathbf{q}^2}{\mathbf{q}^2 + z(M_X^2 - m_p^2) + z^2 m_p^2} \right]^2, \quad (2)$$

with

$$Q^2 = \frac{1}{1-z} \left[\mathbf{q}^2 + z(M_X^2 - m_p^2) + z^2 m_p^2 \right], x_{\text{Bj}} = \frac{Q^2}{Q^2 + M_X^2 - m_p^2}. \quad (3)$$

In practical calculations, fits of F_2 from refs.[8, 9] have been useful.

3 Diffractive photoproduction with strong dissociation

For the description of diffractive dissociation, unfortunately we do not have much data to guide our calculations. We take two types of mechanisms into account. At low transverse momentum transfers, the excitation of resonances dominates. Due to the vacuum quantum numbers of the Pomeron these resonances must be isospin 1/2. Their spin and parity can however differ from the nucleon quantum numbers. A model of [5] includes resonances on the nucleon trajectory, $N^*(1680)$, $J^P = \frac{5}{2}^+$, $N^*(2220)$, $J^P = \frac{9}{2}^+$, and $N^*(2700)$, $J^P = \frac{13}{2}^+$. The lowest-lying positive parity excitation, the Roper resonance $N^*(1440)$ is also included but does not play a very important role. It should be pointed out, that negative parity resonances like $N^*(1520)$, $J^P = \frac{3}{2}^-$ can also be diffractively excited, but are up to now not included in the model.

Large mass continuum dissociation at large p_T is treated in a similar fashion as incoherent diffraction on a nucleus: we simply assume that the diffractive production takes place on a constituent of the target (a quark or gluon parton) and sum incoherently over partons, at a hard scale which corresponds to $p_T^2 + M_{J/\psi}^2$. See [4] for more information.

4 Results and summary

Let us present some numerical results [4] obtained from the approach described above. In fig.2 we show the ratio of dissociative over exclusive J/ψ production

$$R(y) = \frac{d\sigma_{pp \rightarrow pJ/\psi X}(M_X < M_{X,\text{max}})/dy}{d\sigma_{pp \rightarrow pJ/\psi p}/dy}.$$

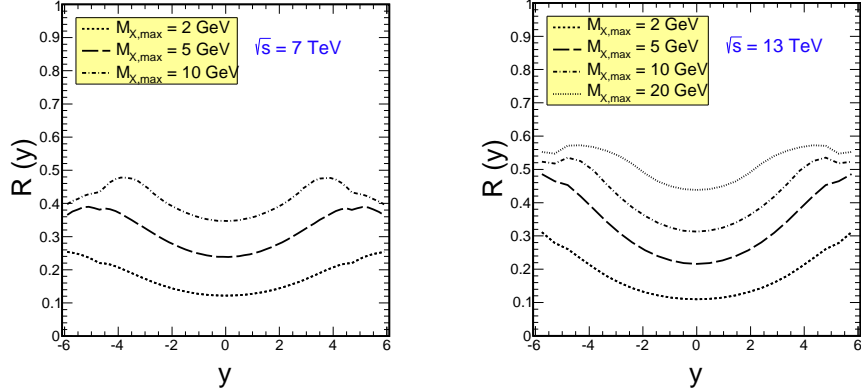


Figure 2: The ratio $R(y)$ of dissociative to exclusive production of J/ψ as a function of rapidity of the meson.

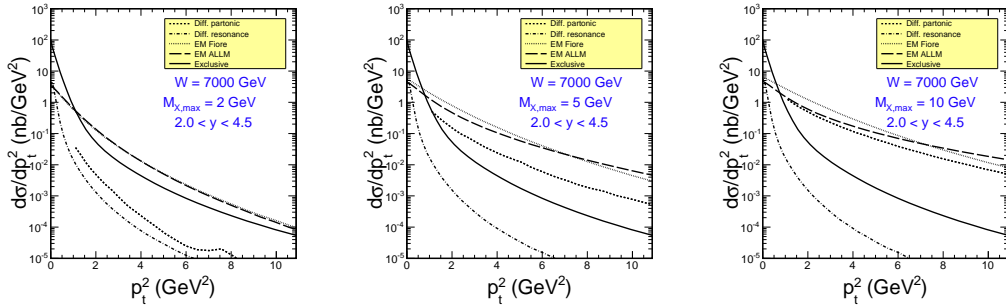


Figure 3: The differential p_T^2 -distribution of J/ψ -mesons for different production mechanisms. The cuts in rapidity correspond to the range of the LHCb experiment. From left to right, the upper limit on the M_X integration is changed.

Here the dissociative cross section has been integrated up to $M_{X,\max}$, and results for several values of the upper limit are shown. We also show two different pp cms-energies.

In fig.3 we show the distribution of the J/ψ in p_T^2 for different production mechanisms. We imposed cuts in rapidity that correspond to the ones of the LHCb experiment. Exclusive production shows the typical coherent peak, while inelastic processes give rise to a much smaller slope of the p_T^2 spectrum at larger p_T^2 . We also observe, that electromagnetic dissociation is as important, or, depending on the cuts on M_X , even more important than diffractive dissociation.

Finally, it should be mentioned that a measurement of the J/ψ photoproduction at large p_T , but at the same time with large rapidity gaps between the vector meson and other particles is interesting in its own right. Similarly to the gap-jet-gap cross

section it can contain useful information on the perturbative QCD Pomeron.

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References

- [1] R. Aaij *et al.* [LHCb Collaboration], J. Phys. G **40** (2013) 045001 [arXiv:1301.7084 [hep-ex]]; J. Phys. G **41** (2014) 055002 [arXiv:1401.3288 [hep-ex]]; JHEP **1509** (2015) 084 [arXiv:1505.08139 [hep-ex]].
- [2] I. P. Ivanov, N. N. Nikolaev and A. A. Savin, Phys. Part. Nucl. **37** (2006) 1 [hep-ph/0501034].
- [3] W. Schäfer and A. Szczurek, Phys. Rev. D **76** (2007) 094014 [arXiv:0705.2887 [hep-ph]]; A. Cisek, W. Schäfer and A. Szczurek, JHEP **1504** (2015) 159 [arXiv:1405.2253 [hep-ph]].
- [4] A. Cisek, W. Schäfer and A. Szczurek, Phys. Lett. B **769** (2017) 176 [arXiv:1611.08210 [hep-ph]].
- [5] L.L. Jenkovszky, O.E. Kuprash, J.W. Låmsa, V.K. Magas and R. Orava, Phys. Rev. **D83** (2011) 056014.
- [6] G. G. da Silveira, L. Forthomme, K. Piotrkowski, W. Schäfer and A. Szczurek, JHEP **1502** (2015) 159 [arXiv:1409.1541 [hep-ph]].
- [7] M. Łuszczak, W. Schäfer and A. Szczurek, Phys. Rev. D **93** (2016) no.7, 074018 [arXiv:1510.00294 [hep-ph]].
- [8] R. Fiore, A. Flachi, L. L. Jenkovszky, A. I. Lengyel and V. K. Magas, Eur. Phys. J. A **15** (2002) 505 [hep-ph/0206027].
- [9] H. Abramowicz, E. M. Levin, A. Levy and U. Maor, Phys. Lett. B **269**, 465 (1991); H. Abramowicz and A. Levy, hep-ph/9712415.