Study on the PDF comparisons for quarkonium + γ production at the LHC and FCC energies

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Abstract: *The quarkonium plus photon production in coherent hadron-hadron interactions at LHC is studied using the non-relativistic QCD (NRQCD) factorization formalism. We investigate a set of kinematic distributions and compute the total cross sections for M + γ (M = J/Ψ and Y) production. Our results demonstrate the feasibility of such process in the LHC kinematic regime and explore the possibilities for the Future Circular Collider, where higher event yields can be achieved.*

Introduction

In the last years, quarkonium production has become the subject of intense theoretical and experimental investigation. This has been motivated by the observation of gross discrepancies between experimental measurements of J/Ψ production at the Collider Detector at Fermilab (CDF) [1], and theoretical calculations based on the color-singlet model (CSM). Attempts to understand this discrepancy focus on new production mechanisms which allow the charm-anticharm to be produced in a color-octet state and evolve non-perturbatively into charmonium, since that its large mass provides a natural hard scale that allows the application of perturbative QCD. There are several mechanisms proposed for the quarkonium production in hadron colliders [2], as the color singlet model, the color octet model and the color evaporation model. Also, the diffractive quarkonium production is sensitive to the gluon content of the Pomeron at small-x and may be particularly useful in studying the different mechanisms for quarkonium production.

Theoretical approach

Here, the photoproduction of associated J=Ψ+γ is analized within the nonrelativistic QCD (NRQCD) factorization formalism. We focus on the inclusive processes

$$p + p \rightarrow p + J/\psi + \gamma + X$$

at the 13-TeV LHC and 100-TeV Future Circular Collider (FCC) energies and predict their cross sections as a function of the momentum distribution (p_T). Such processes are interesting since the produced large p_T quarkonia are relatively easy to detect through their leptonic decay modes and their transverse momenta are balanced by the associated high energy photon.

The differential cross section for the process γ+g → quarkonium + photon, including both color-singlet and color-octet contributions, is expressed as [3]

$$\frac{d\sigma}{dt}(\gamma + g \rightarrow J/\psi + \gamma) = \frac{64\pi^2}{3}\frac{e_c^4\alpha^2\alpha_s m_c}{s^2}\left(\frac{s^2s_1^2 + t^2t_1^2 + u^2u_1^2}{s_1^2t_1^2u_1^2}\right)\langle O_8^{J/\psi}(^3S_1)\rangle$$

$$s = \frac{p_\perp^2 + (2m_c)^2(1-z)}{z(1-z)}, \quad t = -\frac{p_\perp^2 + (2m_c)^2(1-z)}{z}, \quad u = -\frac{p_\perp^2}{1-z}.$$

The total cross sections is obtained by convolving the differential cross section with the gluon distribution of the proton,

$$\sigma_{\text{tot}} = \int dx dt f_{g/p}(x)\frac{d\sigma}{dt} = \int dz dp_\perp^2 \frac{x f_{g/p}(x)}{z(1-z)}\frac{d\sigma}{dt}.$$

References
[1] CDF Collaboration, A. Sansoni, *et al*, **Nucl. Phys. A 610**, 373c (1996)
[2] J. P. Lansberg, **Int. J. Mod. Phys. A21**, 3857 (2006)
[3] T. Mehen, **PRD 55** (1997) 4338
[4] M. Cacciari, M. Kramer, PRL 76 (1996) 4128
[5] M. Butenschoen and B. Kniehl, **PRL 106** (2011) 022003
[6] K. T. Chao *et al*, **PRL 108** (2012) 242004 (2012)

Finally, the momentum fraction of the gluon x is related to *z* and p_T

$$x = \frac{s}{s_{\gamma p}} = \frac{p_\perp^2 + (2m_c)^2(1-z)}{s_{\gamma p}z(1-z)}$$

where $s_{\gamma p}$ is the photon-proton center-of-mass energy squared.

Results

Figure 1 show the comparison between four values of NRQCD Matrix Elements (see references) at LHC energy of 13 TeV provided by Mehen [3], Cacciari & Kramer [4], the BK fit [5] and Chao et al [6].

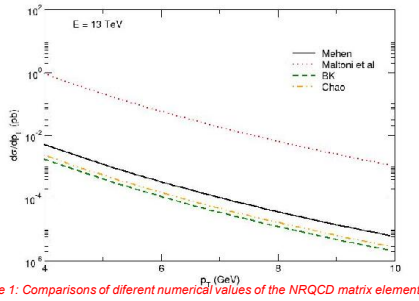

Figure 1: Comparisons of diferent numerical values of the NRQCD matrix elements

The predictions considering the value from Ref. [5] are higher than those considering other matrix elements, off by a factor off 2. In Figure 2, we show our results of J/Ψ cross section comparing different PDFs parametrizations at the LHC energy (14 TeV) and FCC energy (100 TeV). The different parametrizations show similar results in p_T, however the rapidity distributions show a clear discrepancy between them (Figure 3), showing the need for more constraints from data.

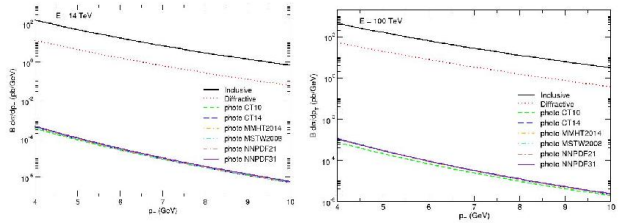

Figure 2: Comparisons of diferent PDFs for p_T distributions at 14 and 100 TeV

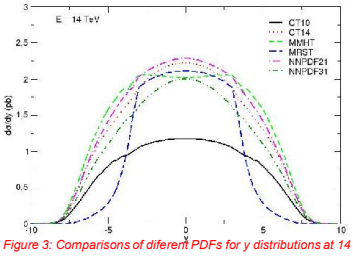

Figure 3: Comparisons of diferent PDFs for y distributions at 14 TeV

Summary

Our results demonstrate that the p_T and Y distributions are strongly dependent on the NRQCD matrix elements and the PDFs parametrization. A detailed data analysis could provide sensible results to constraint the proton PDF parametrizations and NRQCD models.