Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics B 917 (2017) 234–240

NUCLEAR PHYSICS B

www.elsevier.com/locate/nuclphysb

Charmonium production in ultra-peripheral heavy ion collisions with two-photon processes

Gong-Ming Yu [a,*], Yue-Chao Yu [a,b], Yun-De Li [b], Jian-Song Wang [a,*]

[a] *Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[b] *Department of Physics, Yunnan University, Kunming 650091, China*

Received 25 December 2016; received in revised form 8 February 2017; accepted 17 February 2017
Available online 24 February 2017
Editor: Tommy Ohlsson

Abstract

We calculate the production of large-p_T charmonium and narrow resonance state (exotic charmonium) in proton–proton, proton–nucleus, and nucleus–nucleus collisions with the semi-coherent two-photon interactions at Relativistic Heavy Ion Collider (RHIC), Large Hadron Collider (LHC), and Future Circular Collider (FCC) energies. Using the large quasi-real photon fluxes, we present the $\gamma\gamma \to H$ differential cross section for charmonium and narrow resonance state production at large transverse momentum in ultra-peripheral heavy ion collisions. The numerical results demonstrate that the experimental study of ultra-peripheral collisions is feasible at RHIC, LHC, and FCC energies.

1. Introduction

The two-photon interactions [1–6] at unprecedentedly high energies can be studied in ultra-peripheral heavy ion collisions. Recently, the measurement for ultra-peripheral collisions was performed by PHENIX Collaboration [7] and STAR Collaboration [8,9] at Relativistic Heavy Ion Collider (RHIC) energies, as well as ALICE Collaboration [10–15] and CMS Collaboration [16–18] at Large Hadron Collider (LHC) energies. Moreover, the equivalent photon flux present

* Corresponding author.
E-mail addresses: ygmanan@163.com (G.-M. Yu), jswang@impcas.ac.cn (J.-S. Wang).

http://dx.doi.org/10.1016/j.nuclphysb.2017.02.009
0550-3213/

in high energy nuclear collisions is very high, and has been found many useful applications in photon production [19–23], dilepton production [24–30], jet production [31,32], double vector meson production [33–36], (exotic) charmonium production [37–42], decuplet-baryon pair production [43], doubly heavy baryon production [44], graviton production [45], W/Z boson production [46,47], and Higgs boson production [48–50] in the ultra-peripheral heavy ion collisions. The most existing calculations concentrated on the total cross section and also of the rapidity or the two-photon energy distributions, an interesting theoretical quantity, which may not be measured easily in ultra-peripheral collisions at Relativistic Heavy Ion Collider (RHIC), Large Hadron Collider (LHC), and Future Circular Collider (FCC), since the experiments running at RHIC, LHC, and those planned at FCC demand the distributions of transverse momenta and rapidity.

In the present work, we investigate the semi-coherent two-photon processes for large-p_T charmonium and narrow resonance state (exotic charmonium) production in proton–proton, proton–nucleus, and nucleus–nucleus collisions at RHIC, LHC, and FCC energies. If the transverse momenta of both photons are the same large (non-coherent) or small (coherent), the total transverse momentum would have a very small value, then the charmonium and narrow resonance state (exotic charmonium) could not obtain large transverse momentum in the $\gamma\gamma \to H$ interaction, where H is the (exotic) charmonium. Indeed, the single track condition [28,29] leads to the weak contribution of non-coherent and coherent photon–photon processes for large-p_T charmonium and narrow resonance state (exotic charmonium) production compared with the semi-coherent processes. Hence we work in the semi-coherent two-photon approach, in which one photon is relatively hard and is incoherently emitted by participating projectile, while another can be soft enough to be in a coherent domain. In the equivalent photon approximation that the effect of the electromagnetic field for an ultrarelativistic proton or nucleus is replaced by a flux of photons, we present the differential cross section as a function of the transverse momenta for the large-p_T charmonium, as well as the narrow resonance state (exotic charmonium) [51–54] that has been firmly established in ultra-peripheral collisions at RHIC, LHC, and FCC energies in the recent years.

The paper is organized as following. In Section 2, we present the production of large-p_T charmonium and narrow resonance state (exotic charmonium) from the semi-coherent two-photon interactions in ultra-peripheral heavy ion collisions. The numerical results for proton–proton, proton–nucleus, and nucleus–nucleus collisions at RHIC, LHC, and FCC energies are plotted in Section 3. Finally, the conclusion is given in Section 4.

2. General formalism

The differential cross-section for the charmonium and narrow resonance state (exotic charmonium) production from the semi-coherent two-photon interaction in ultra-peripheral heavy ion collisions can be written as

$$d\sigma = \hat{\sigma}_{\gamma\gamma\to H}(W) dN_1 dN_2, \tag{1}$$

where the total cross section $\hat{\sigma}_{\gamma\gamma\to H}(W)$ for the charmonium and narrow resonance state (exotic charmonium) production from the two-photon fusion interaction can be written in terms of the two-photon decay width of the corresponding state as [39–41,55]

$$\hat{\sigma}_{\gamma\gamma\to H}(W) = 8\pi^2(2J+1)\frac{\Gamma_{H\to\gamma\gamma}}{M_H}\delta(W^2 - M_H^2), \tag{2}$$