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Inelastic electromagnetic production of J/ψ in p–p ultra-peripheral collisions

Jia-Qing Zhu, Yun-De Li *

Department of Physics, Yunnan University, Kunming 650091, People's Republic of China

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Abstract

J/ψ production in p–p ultra-peripheral collisions through the inelastic electromagnetic process, where the virtual photons emitted from the incoming nucleon interact with the partons in the target nucleon, is studied. The comparisons between the results of the equivalent photon approximation approach and the exact treatment ones are presented. Based on the method of Martin and Ryskin, the coherent and incoherent contributions are considered simultaneously. The distributions of Q^2 (virtuality of the photon) and the total cross sections are calculated. The numerical results show that, the equivalent photon approximation approach is only effective in the $Q^2 \to \infty$ region where Q^2_{max} is small enough. It can be seen that an improper choice of Q^2_{max} will cause obvious errors in the equivalent photon approximation approach (the total cross sections are more than twice larger than the exact ones), and the exact treatment needs to be adopted to dealing with the widely kinematics region of Q^2.

1. Introduction

It is well known that, the electromagnetic processes in ultra-peripheral collisions (UPCs) can be studied by using the equivalent photon approximation (EPA) approach [1–4]. Based on the method of Fermi [5], Weizsäcker [6] and Williams [7], many topics are studied such as the determining of the nuclear parton distributions, small x physics, and heavy quarkonium produc-

* Corresponding author.
E-mail address: yndxlyd@163.com (Y.-D. Li).

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tion [4]. The precision of the EPA approach can be represented by the dynamical cut off Λ_γ^2 of the virtuality of photon Q^2 [8]. When $Q^2 > \Lambda_\gamma^2$, the virtual photo-absorption cross sections quickly decrease comparing with their values on the mass shell. The EPA approach could be a good approximation of the exact treatment only in the kinematics region of $Q^2 < \Lambda_\gamma^2$ (some detailed comparisons of the EPA approach with the exact analysis can be found in Refs. [9–14]). However, this kinematics restriction is not always considered in the previous works, where $Q^2_{\max}$ is set to be the order of $\hat{s}$ (the centre-of-mass (CM) frame energy square of the photo-absorption process) or even infinity [12,13]. Although the final results as the function of Q^2 fall off rapidly along with the increasing Q^2, errors from the $Q^2 > \Lambda_\gamma^2$ region can not be always neglected.

In this work, we consider the inelastic photoproduction of J/ψ in p–p UPCs, which has received many researches in the EPA approach. We present the comparisons between the EPA approach with the exact treatment which recovers the EPA approach in the limit $Q^2 \to 0$ and can be considered as the generalization of Leptoproduction [15–17]. Two types of the photons emission processes are considered: coherent emission and incoherent emission [18]. In the first type, virtual photons coherently radiated by the whole proton which remains intact after the photon emitted. In the second type, photon incoherently radiated by the individual constituents (quarks) inside the proton, and the proton will dissociate or excite after the photon radiated. Since the two types should be considered simultaneously, a method developed by Martin and Ryskin [19], which introduced weighting factors for both coherent and incoherent parts in order to avoid the double counting problem, is used.

This paper is organized as follow. Section 2 presents the formulism for the calculations. The coherent and incoherent cross sections are introduced by using the Martin–Ryskin method. Taking the limit $Q^2 \to 0$, the equivalent photons approximation approach is also introduced. A preliminary discussion about the comparison between the equivalent photons approximation approach and the photon parton distribution function approach is presented. Section 3 illustrates the numerical results with the distribution of Q^2. The total cross sections are also presented. In Section 4, we present the conclusions. To avoid confusion, the terminology "coherent" or "incoherent" is always used to describe the photon emission types in this paper, which is different in many literatures where the "coherent" and "incoherent" usually refer to the case that the photons interact with the whole target nucleus or the constituents in it. Finally, the "inelastic electromagnetic process" in our work is only refer to the process that the virtual photons emitted from the incoming nucleon interact with the partons in the target nucleon, which corresponding to the inelastic photoproduction process in the EPA framework.

2. Formulism

Heavy quarkonium production processes [20–22] can be calculated by using the non-relativistic quantum chromodynamics (NRQCD) factorization formulism [24]. However, the NRQCD prediction is breakdown and the color-octet channels exhibit collinear singularities in the region of $z = 1$, where diffractive production takes place. In order to screen the collinear singularities and exclude the elastic production which is due to the diffractive processes, we only consider the processes that the J/ψ is produced in association with an addition final particle (quark or gluon). It can be seen from the next section that, if the transverse momentum p_T of J/ψ has a nonzero minimum value, the maximum value of z will less than 1. In fact, the processes above naturally have the nonzero minimum values of p_T in the corresponding CM frame when the virtuality of photon has a nonzero value [17]. In this work, we choose the cutoff that $p_T > m_{J/\psi}$ for the practical calculations.