Isolated pair photon production in the Parton Reggeization Approach
Парное рождение изолированных фотонов в подходе реджезации партонов

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В статье мы провели расчеты дифференциальных сечений парного рождения изолированных фотонов в рамках подхода реджезации партонов (ПРП) при энергиях коллайдеров Tevatron и LHC. Расчёты проводились с использованием генератора событий партонного уровня KaTie и улучшенной модели KMRW для неинтегрированных функций распределения партонов. Получено хорошее согласие с экспериментальными данными коллабораций ATLAS и CDF, сделана оценка сечения рождения дифотонов на коллайдере NICA.

In the article, we calculate differential cross sections for pair production of isolated photons within the parton Reggeization approach (PRA) at energies of Tevatron and LHC colliders. The calculations were performed within the KaTie parton-level event generator and improved KMRW model for unintegrated parton distribution functions. The satisfactory agreement with experimental data from ATLAS and CDF collaborations was obtained, and the estimation for photon pair production cross section at the NICA collider was performed.

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Introduction

Nowadays, isolated high-p_T photon pair production is the subject of active experimental and theoretical studies. This process has a number of unique features that make them an important tool to test the high-energy chromodynamics (QCD). There are theoretical calculations in the fixed order formalism of the collinear parton model up to next-to-next-to-leading order (NNLO) accuracy as well as in the high-energy factorization (or k_T-factorization) in which the resummation of large real high-order corrections in the hard partonic cross sections is applied using the formalism of unintegrated parton distribution functions (unPDFs).

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In the article, we consider diphoton production processes within the PRA [1], which is based on the collinear factorization in the high-energy limit (so-called, Regge limit), gauge invariant Lipatov's effective field theories of Reggeized gluons and Reggeized quarks [2], and improved Kimber-Martin-Ryskin-Watt (KMRW) [3] model for unintegrated parton distribution functions (unPDFs). Unlike previous studies of diphoton prodection in the PRA [4], we perform calculations applying Monter-Carlo event generator KaTie [5] and using the new unPDFs [6], which allows for a more careful analysis and avoids double counting.

Parton Reggeization Approach

In the PRA, the modified multi-Regge-Kinematic approximation is used [6], which is accurate both the multi-Regge and collinear limits of the QCD amplitudes. Thanks to the t-channel factorization, this allows us to represent the cross-section in the factorized form:

$$d\sigma = \sum_{i,j} \int \frac{dx_1}{x_1} \int \frac{d^2\mathbf{q}_{T1}}{\pi} \Phi_i(x_1, t_1, \mu^2) \int \frac{dx_2}{x_2} \int \frac{d^2\mathbf{q}_{T2}}{\pi} \Phi_j(x_2, t_2, \mu^2) \, d\hat{\sigma}_{ij}, \quad (1)$$

where $t_i = |\mathbf{q}_{Ti}|$ and $d\hat{\sigma}_{ij}$ is the partonic cross section, which is calculated using Reggeized amplitudes obtained by the Feynman rules of the Lipatov's effective theory [2]. To calculate unPDFs, we use the improved KMRW model [3], taking into account the exact normalization condition of the BFKL type,

$$\int_0^{\mu^2} d\mathbf{q}_T^2 \, \Phi_q(x, \mathbf{q}_T^2, \mu^2) = F_q(x, \mu^2).$$

The normalization condition can be achieved by the function $T_q(x, \mathbf{q}_T^2, \mu^2)$ usually refereed as a Sudakov formfactor

$$\Phi_q(x, \mathbf{q}_T^2, \mu^2) = \frac{d}{d\mathbf{q}_T^2} \left[T_q(x, \mathbf{q}_T^2, \mu^2) \, F_q(x, \mathbf{q}_T^2) \right],$$

with the boundary conditions $T_i(t = 0, \mu^2, x) = 0$ and $T_i(t \geq \mu^2, \mu^2, x) = 1$. Such a way we resolve the problem of infra-red divergence at the $\mathbf{q}_T^2 \to 0$ and improved unPDF can be written as follows

$$\Phi_i(x, t, \mu^2) = \frac{\alpha_S(\mu)}{2\pi} \frac{T_i(t, \mu^2, x)}{t} \times \sum_j \int_x^1 dz \, P_{ij}(z) \, F_j\left(\frac{x}{z}, t\right) \times \theta\left(\Delta(t, \mu^2) - z\right), \quad (2)$$

where $\Delta(t, \mu^2) = \mu/(\mu + \sqrt{t})$. The Sudakov formfactor is calculated as it was obtained in Ref. [6]

$$T_i(t, \mu^2, x) = \exp\left[- \int_t^{\mu^2} \frac{dt'}{t'} \frac{\alpha_S(t')}{2\pi} \left(\tau_i(t', \mu^2) + \Delta\tau_i(t', \mu^2, x) \right) \right],$$

where

$$\tau_i(t,\mu^2) = \sum_j \int_0^1 dz\ zP_{ji}(z)\theta(\Delta(t,\mu^2)-z),$$

$$\Delta\tau_i(t,\mu,x) = \sum_j \int_0^1 dz\ \theta(z-\Delta(t,\mu^2))\left[zP_{ji}(z) - \frac{F_j\left(\frac{x}{z},t\right)}{F_i(x,t)}P_{ij}(z)\theta(z-x)\right].$$

Pair photon production in the PRA

The leading order (LO) subprocesse of pair photon production in the PRA is quark-antiquark annihilation:

$$Q + \bar{Q} \to \gamma + \gamma \tag{3}$$

In the next-to-leading order (NLO) approximation in strong coupling constant there are two subprocesses

$$Q + R \to \gamma + \gamma + q \tag{4}$$

$$Q + \bar{Q} \to \gamma + \gamma + g \tag{5}$$

In Ref. [1], a problem related to double counting between LO and NLO subprocesses was studied. Under the k_T-factorization formalism, the final state radiation strongly decoupled in rapidity is included in the unPDFs, while radiation close in rapidity to the final diphoton is included in the hard scattering coefficient. To avoid double counting, which is being due to the integration for all rapidity region, the subtracted term must be added. The last one correspond the asymptotic limit of the NLO amplitudes. We have found in Ref. [1] that contribution of the NLO subprocess (5) must be very small and may be omitted due to the three reasons: the amplitude of (5) is NLO correction in α_s to the LO subprocess (3), the subtraction term for (5) is large at all rapidities, and quark (antiquark) unPDFs are small to the gluon ones.

Results

In Fig. 1 (left panels), our predictions of the spectra on the invariant mass, azimuthal angle difference, and diphoton transverse momentum are compared with the CDF data [7] at the energy $\sqrt{s} = 1.96$ TeV, and photon transverse momenta $p_{T3,4} \geq 15, 17 (3 = \gamma_1, 4 = \gamma_2)$ GeV in the central rapidity range: $|y_{3,4}| < 0.1$. The curve legend is given in the figure caption. Compared with the previous calculations in the PRA [4], our calculations, used improved unPDFs, provide a better description both at the small and large invariant diphoton masses and transverse momenta.

In Fig. 1 (right panels) the comparison of theoretical predictions and experimental data from ATLAS collaboration [8] is presented at the $\sqrt{s} = 13$ TeV, $p_{T3,4} \geqslant 30, 40$ GeV, $|y_{3,4}| \leqslant 2.37$, $1.37 \leqslant |y_{3,4}| \leqslant 1.52$. Satisfactory agreement between the data and theory was obtained with the same accuracy as in the full NLO calculations of the collinear parton model.

In addition to the calculations for the LHC, we predictict the total cross section for the production of a isolated pair of photons at the energy of NICA collider $\sqrt{s} = 27$ GeV for photon transverse momenta and rapidities $p_{T3,4} \geqslant 2$ GeV, $|y_{3,4}| \leqslant 3$. We used two different values of isolation cone radius R and obtained $\sigma(pp \to \gamma\gamma X) = (16.82\,^{+167.45}_{-3.70})$ nb for $R = 0.1$ and $\sigma(pp \to \gamma\gamma X) = (94.35\,^{+183.86}_{-25.83})$ nb for $R = 0.4$.

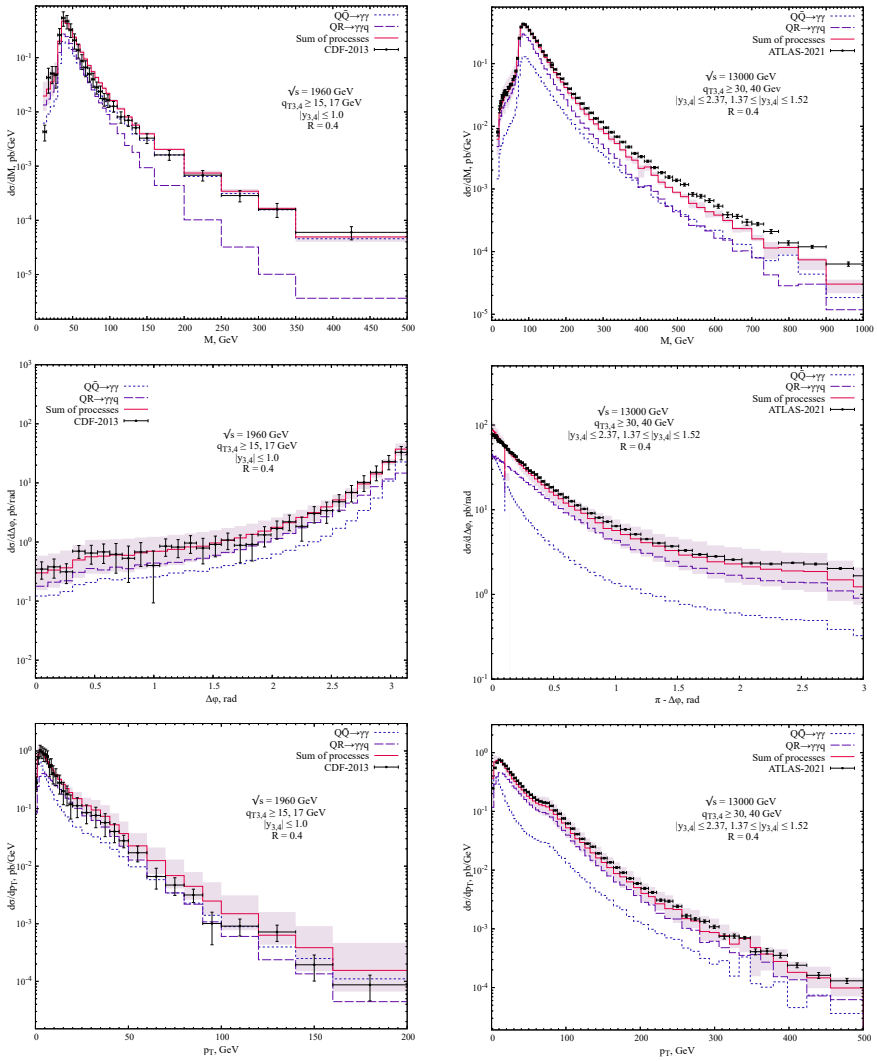

Fig. 1. Differential cross section for diphoton production as a function of diphoton invariant mass (M), azimuthal angle difference ($\Delta\phi$) and transverse momentum (p_T) the data are from the CDF [7] (left panels) and ATLAS collaborations [8](right panels).

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Conflict of interest

The authors of this work declare that they have no conflicts of interest.

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