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Prompt photon and Drell-Yan lepton pair production in the $\mathbf{k_T}$-factorization approach at modern colliders

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We present the results of the numerical calculations of prompt photon and Drell-Yan lepton pair production at Tevatron and LHC in the framework of the k_T-factorization approach. Our predictions are compared with the D0, CDF, CMS and ATLAS experimental data.

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Our study is motivated by recent measurements of the inclusive prompt photon and Drell-Yan lepton pair production performed by the CMS and ATLAS collaborations at LHC [1 – 3], taken at $\sqrt{s} = 7$ TeV.

Previously the k_T-factorization approach was used for the prompt photon production at Tevatron [4 – 6]. A good description of the results of the D0 and CDF collaborations was achieved. Also in [7] the process of the prompt photon production with associated heavy (c, b) quarks was investigated and a reasonable agreement of the experimental data with the theoretical results was obtained. Here we expand the analysis to the LHC energies.

According to the k_T-factorization theorem, to calculate the cross section of the prompt photon or Drell-Yan lepton pair production one should convolute the off-shell partonic cross sections with the relevant unintegrated quark and/or gluon distributions in a proton:

$$\sigma = \sum_{i,j=q,g} \int \hat{\sigma}^*_{ij}(x_1, x_2, \mathbf{k}^2_{1T}, \mathbf{k}^2_{2T})\, f_i(x_1, \mathbf{k}^2_{1T}, \mu^2)\, f_j(x_2, \mathbf{k}^2_{2T}, \mu^2)\, dx_1 dx_2\, d\mathbf{k}^2_{1T} d\mathbf{k}^2_{2T},$$

where $\hat{\sigma}^*_{ij}(x_1, x_2, \mathbf{k}^2_{1T}, \mathbf{k}^2_{2T})$ is the relevant partonic cross section. The initial off-shell partons have fractions x_1 and x_2 of initial protons longitudinal momenta and non-zero transverse momenta $\mathbf{k}_{1T}$ and $\mathbf{k}_{2T}$.

Concerning the unintegrated parton distributions we use two different sets. First is the KMR set [8, 9]. The KMR approach represents an approximate treatment of the parton evolution mainly based on the DGLAP equation and incorpotating the BFKL effects at the last step of the parton ladder only, in the form of the properly defined Sudakov formfactors $T_q(\mathbf{k}^2_T, \mu^2)$ and $T_q(\mathbf{k}^2_T, \mu^2)$, including logarithmic loops. In this approach both gluons and quarks densities can be obtained.

For prompt photon production we also use another set of unintegrated parton distributions, obtained as a numerical solution of the CCFM evolution equation [10], namely the CCFM A0 set. However, as a result of the solution we have only gluon distribution. In order to calculate the quarks distribution, we follow the scheme, proposed in [5, 6]. The unintegrated quark distribution are presented as

$$f_q(x, \mathbf{k}^2_T, \mu^2) = f_q^{(v)}(x, \mathbf{k}^2_T, \mu^2) + f_q^{(g)}(x, \mathbf{k}^2_T, \mu^2) + f_q^{(s)}(x, \mathbf{k}^2_T, \mu^2), \tag{1}$$

where $f_q^{(v)}$ is the unintegrated valence quarks distribution and $f_q^{(g)}$ and $f_q^{(s)}$ – the contributions of the sea quarks arising from the last and earlier steps of the parton evolution respectively. $f_q^{(v)}(x, \mathbf{k}^2_T, \mu^2)$ was calculated in [11]. The contribution from the sea quarks coming from the last evolution step, $f_q^{(g)}(x, \mathbf{k}^2_T, \mu^2)$, can be taken into account with the gluon fusion subprocess, $g^*g^* \to \gamma q\bar{q}$ [6]. The contribution of the sea quarks coming from the earlier evolution steps, $f_q^{(s)}(x, \mathbf{k}^2_T, \mu^2)$, can be estimated via some change of the KMR scheme, and this contribution turns out to be rather significant (see discussion later). However, we don't add it to the CCFM predictions, since it may yield double counting in this case. In the KMR approach this contribution is easily taken into account.

We have calculated the off-shell $\mathscr{O}(\alpha_{em}\alpha_S)$ matrix elements for $q^*\bar{q}^* \to \gamma g$, $q^*g^* \to \gamma q$ and $\mathscr{O}(\alpha_{em}\alpha_S^2)$ matrix element for $g^*g^* \to \gamma q\bar{q}$ for prompt photon production. For Drell-Yan lepton pair production we take into account the off-shell matrix element for $qg^* \to \gamma/Z + q \to l^+l^-q$ and the on-shell matrix element for $q\bar{q} \to \gamma/Z \to l^+l^-$. In the k_T-factorization approach the contribution from another subprocess, $q\bar{q} \to \gamma/Z + g \to l^+l^-g$ is already taken into account by the quark-antiquark annihilation due to the initial state radiation. So this subprocess has been taken out of our consideration in order to avoid double counting, which is in contrast with the collinear QCD factorization.

The calculation implies a modification of the gluon polarization density matrix. It takes so called BFKL form: $\sum \varepsilon^{\mu} \varepsilon^{*\nu} = k_T^{\mu} k_T^{\nu} / \mathbf{k}_T^2$. For prompt photon production we also modified the quark polarization density matrix. For the off-shell quark it takes the form [12]: $\sum u^s(k) \bar{u}^s(k) = x\hat{P}$, where P is the momentum of the incoming proton. For Drell-Yan lepton pair production we used the standard rule for quark polarization sum, since the difference between the contributions of the on-shell and off-shell quark matrix elements is insignificant and much smaller than the uncertainty, connected with the choice of the factorization scale. In all other respects the evaluation follows the standard QCD Feynman rules.

To take into account the non-logarithmic loop corrections in Drell-Yan lepton pair production we use the approach proposed in [13]. It was demonstrated that main part of the non-logarithmic loop corrections to the quark-antiquark annihilation cross section can be absorbed in the effective K-factor:

$$K = \exp\left(C_F \frac{\alpha_S(\mu^2)}{2\pi} \pi^2 \right) \tag{2}$$

where the color factor C_F = 4/3. A particular choice $\mu^2 = \mathbf{p}_T^{4/3} M^{2/3}$ has been proposed [13, 14] to eliminate sub-leading logarithmic terms. We choose this scale to evaluate the strong coupling constant in (2).

In KMR unintegrated parton distributions we used the standard MSTW'2008 (LO) set [15] as an input. We took the renormalization and factorization scales $\mu_R^2 = \mu_F^2 = \xi^2 p_T^2$. In order to evaluate theoretical uncertainties, we varied ξ between 1/2 and 2 about the default value $\xi = 1$. Following to [16], we set $M_Z = 91.1876$ GeV, $\Gamma_Z = 2.4952$ GeV, $\sin^2 \theta_W = 0.23122$. We used the LO formula for the strong coupling constant $\alpha_s(\mu^2)$ with $n_f = 4$ active quark flavours at $\Lambda_{QCD} =$ 200 MeV, so that $\alpha_S(M_Z) = 0.1232$.

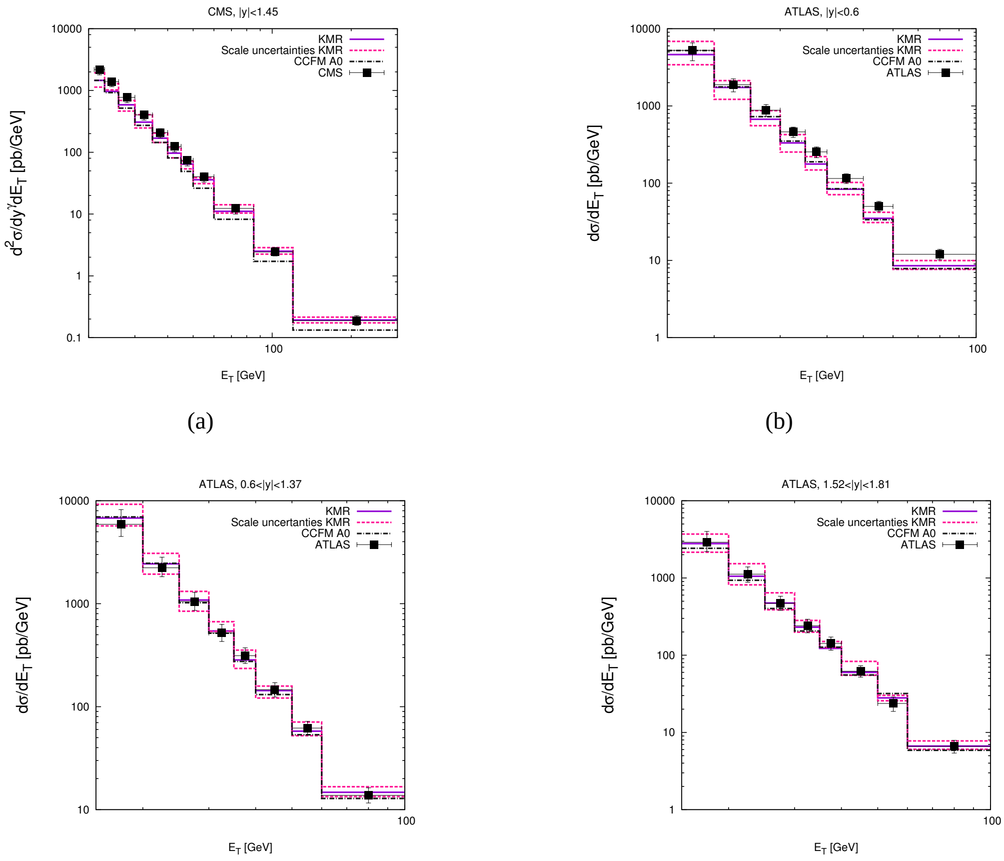
Considering prompt photon production, in order to reduce the huge background from the secondary photons produced by the decays of π^0 and η mesons we have used the isolation criterion as it is introduced in the experimental analyses:

$$E_T^{had} \leq E^{max}, \quad (\eta^{had} - \eta)^2 + (\varphi^{had} - \varphi)^2 \leq R^2,$$

where E_T^{had} is the hadronic transeverse energy deposited inside a cone with with aperture R centered around the photon direction in the pseudo-rapidity and azimuthal angle plane.

On Fig. 1 we present the results of our numerical simulations. The figure represents the simulated cross-sections of the inclusive prompt photon production in comparison with the data, obtained by the CMS and ATLAS collaborations. The notations are shown on the figure. One can see a reasonable agreement of the theoretical results with the data. However, the CCFM predictions tend to underestimate the data. It may be connected with the ignoring of the sea quarks, coming from the earlier evolution. For more detailes see [17].

The results of our calculations [18] for Drell-Yan lepton pair production are presented in Fig. 2, 3 in comparison with the D0 [19], CDF [20 – 22] and CMS [3] data. Solid histograms are obtained by fixing both the factorization and renormalization scales at the default value $\mu = M_{ll}$, whereas the



(a) (b)

(c) (d)

Figure 1: *The differential cross sections of the inclusive prompt photon production in pp collisions as a function of p_T calculated at $\sqrt{s}$ =7 TeV.*

upper and lower dashed histograms correspond to the scale variation as it was described above for the case of prompt photon production. One can see that the Tevatron and LHC experimental data are reasonably well described by the k_T-factorization approach in the whole range of invariant masses. Specially we point out a good description of dilepton transverse momentum distributions measured by the CDF collaboration (Fig. 3) since this observable strongly depends on the unintegrated parton density used.

In summary, we have studied the processes of the inclusive prompt photon production and Drell-Yan lepton pair production in the k_T-factorization QCD approach at LHC energies. A reasonably good description of D0, CDF, CMS and ATLAS data for the inclusive prompt photon and Drell-Yan lepton pair production at Tevatron and LHC has been obtained. A theoretical uncertainties investigation has been studied and a predictive power of the used approach has been shown.

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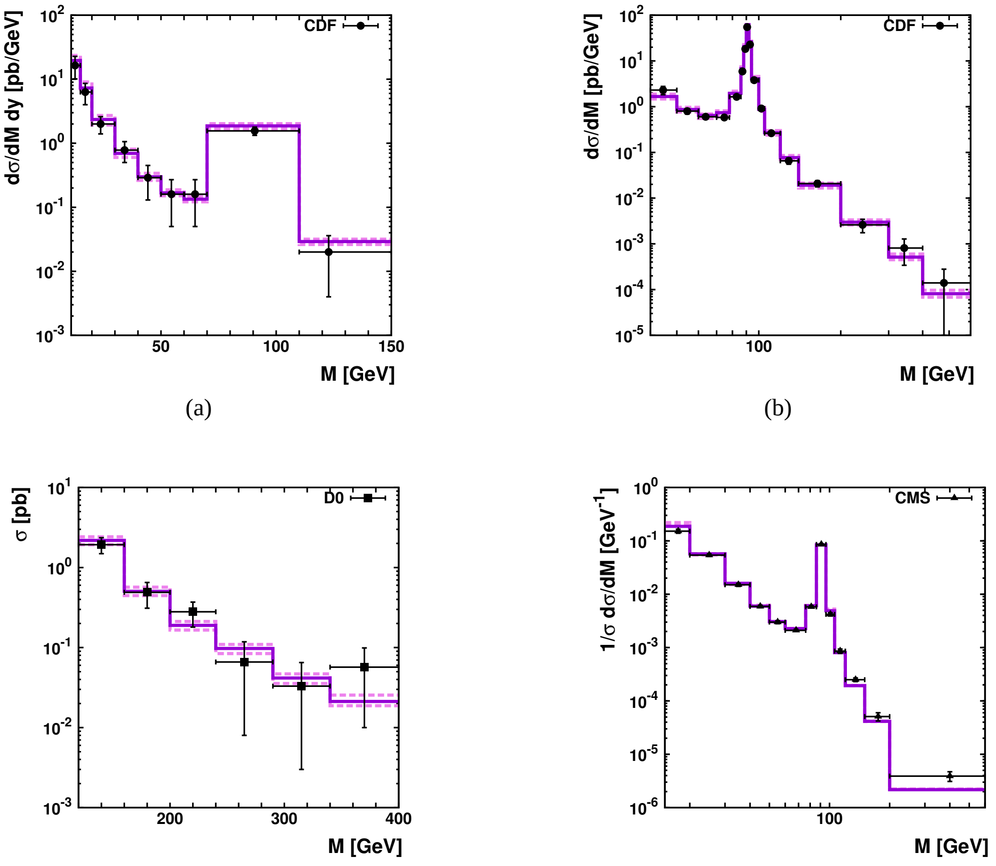
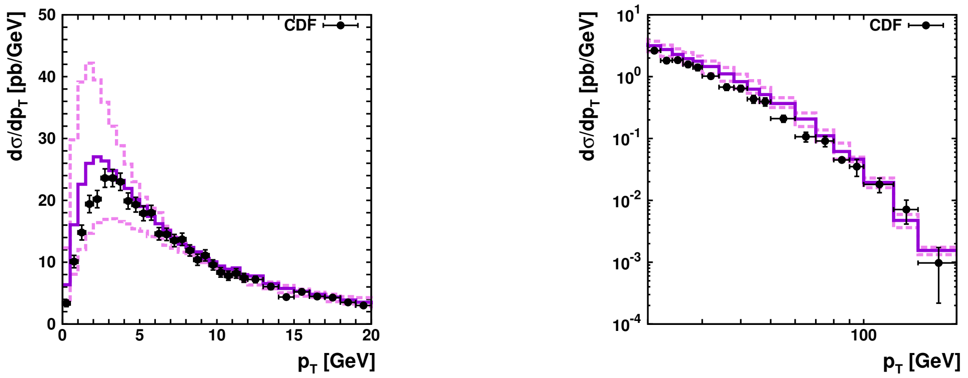


(a) (b)

(c) (d)

Figure 2: *The differential cross sections of the Drell-Yan lepton pair production in hadron collisions as a function of* M_{ll} *calculated at* $\sqrt{s}$ *=1.8 TeV (a—c) and 7 TeV (d). The experimental data are from D0, CDF and CMS [3].*



(a) (b)

Figure 3: *The differential cross sections of the Drell-Yan lepton pair production in hadron collisions as a function of* p_T *calculated at* $\sqrt{s}$ *=1.8 TeV. The experimental data are from CDF.*

count of the off-shell quarks contribution. The authors were supported by RF FASI grant NS-4142.2010.2, RF FASI state contract 02.740.11.0244 and RFBR grant 11-02-01454-a. A.L. and M.M. were supported by the grant of President of Russian Federation (MK-3977.2011.2). A.L. and N.Z. also were supported by DESY Directorate in the framework of Moscow — DESY project on Monte-Carlo implementation for HERA — LHC and the RMES (grant the Scientific Research on High Energy Physics).

References

[1] CMS Collaboration, *Measurement of the Isolated Prompt Photon Production Cross Section in pp Collisions at $\sqrt{s} = 7$ TeV*, *Phys. Rev. Lett.* **106** (2011) 082001 [`1012.0799 [hep-ex]`].

[2] ATLAS Collaboration, *Measurement of the inclusive isolated prompt photon cross section in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, *Phys. Rev. D* **83** (2011) 052005 [`1012.4389 [hep-ex]`].

[3] CMS Collaboration, *Measurement of the Drell-Yan Cross Section in pp Collisions at $\sqrt{s} = 7$ TeV*, *JHEP* **1101** (2011) 007 [`1108.0566 [hep-ex]`].

[4] A.V. Lipatov and N.P. Zotov, *Prompt photon hadroproduction at high energies in the k_T-factorization approach*, *J. Phys. G* **34** (2007) 219 [`hep-ph/0507243`].

[5] S.P. Baranov, A.V. Lipatov and N.P. Zotov, *Prompt photon hadroproduction at high energies in off-shell gluon-gluon fusion*, *Phys. Rev. D* **77** (2008) 074024 [`0708.3560 [hep-ph]`].

[6] A.V. Lipatov and N.P. Zotov, *Relevance of the quark component in prompt photon and electroweak gauge boson production at high energies*, *J. Phys. G* **36** (2009) 125008 [`0811.2575 [hep-ph]`].

[7] S.P. Baranov, A.V. Lipatov and N.P. Zotov, *Associated production of prompt photons and heavy quarks in off-shell gluon-gluon fusion*, *Eur. Phys. J. C* **56** (2008) 371 [`0805.2650 [hep-ph]`].

[8] M.A. Kimber, A.D. Martin and M.G. Ryskin, *Unintegrated parton distributions*, *Phys. Rev. D* **63** (2001) 114027 [`hep-ph/0101348`].

[9] G. Watt, A.D. Martin and M.G. Ryskin, *Unintegrated parton distributions and inclusive jet production at HERA*, *Eur. Phys. J. C* **31** (2003) 73 [`hep-ph/0306169`].

[10] H. Jung, *Un-integrated PDFs in CCFM, Preprint* [`hep-ph/0306169`].

[11] M. Deak, H. Jung, K. Kutak, *Valence quarks and k_T factorisation, Preprint* [`hep-ph/0306169`].

[12] S.P. Baranov, A.V. Lipatov, N.P. Zotov, *Deep inelastic prompt photon production at HERA in the kt-factorization approach*, *Phys. Rev. D* **81** (2010) 094034 [`1001.4782 [hep-ph]`].

[13] G. Watt, A.D. Martin and M.G. Ryskin, *Unintegrated parton distributions and electroweak boson production at hadron colliders*, *Phys. Rev. D* **70** (2004) 014012 [`hep-ph/0309096`].

[14] A. Kulesza and W.J. Stirling, *Sudakov logarithm resummation in transverse momentum space for electroweak boson production at hadron colliders, Nucl. Phys. B* **555** (1999) 279 [`hep-ph/9902234`].

[15] A.D. Martin, W.J. Stirling, R.S. Thorne and G. Watt, *Parton distributions for the LHC, Eur. Phys. J. C* **63** (2009) 189 [`0901.0002 [hep-ph]`].

[16] C. Amster *et al*. (PDG Collaboration), *Review of Particle Physics*, *Phys. Lett. B* **667** (2008) 1.

[17] A.V. Lipatov, M.A. Malyshev and N.P. Zotov, *Testing for k_T-factorization with inclusive prompt photon production at LHC*, *Phys. Lett. B* **699** (2011) 93 [`1102.1134 [hep-ph]`].

[18] A.V. Lipatov, M.A. Malyshev and N.P. Zotov, *Drell-Yan lepton pair production at high energies in the k_T-factorization approach*, *DESY-11-216*, [`1110.6582 [hep-ph]`].

[19] B. Abbott *et al*. (D0 Collaboration), *Measurement of the high mass Drell-Yan cross-section and limits on quark electron compositeness scales*, *Phys. Rev. Lett* **82** (1999) 4769 [`hep-ex/9812010`].

[20] F. Abe *et al*. (CDF Collaboration), *Measurement of Drell-Yan electron and muon pair differential cross-sections in $\bar{p}p$ collisions at $\sqrt{s}$=1.8 TeV*, *Phys. Rev. D* **49** (1994) 1.

[21] T. Affolder *et al*. (CDF Collaboration), *The transverse momentum and total cross section of e^+e^- pairs in the Z boson region from $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV*, *Phys. Rev. Lett.* **84** (2000) 845 [`hep-ex/0001021`].

[22] T. Affolder *et al*. (CDF Collaboration), *Measurement of $d(\sigma)/dM$ and forward-backward charge asymmetry for high mass Drell-Yan e^+e^- pairs from $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV*, *Phys. Rev. Lett.* **87** (2001) 131802 [`hep-ex/0106047`].