Prompt photon and associated b,c-tagged jet production within the k_T-factorization approach

A.V. Lipatov[1], *M.A. Malyshev*[1,2], *N.P. Zotov*[1]

[1]Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University,
[2]Faculty of Physics, Lomonosov Moscow State University,
Leninskie Gory 1 (2), 119991 Moscow, Russia

We present the results of the numerical calculations of prompt photon and associated b- or c-quark tagged jet production at Tevatron in the framework of the k_T-factorization approach. Our predictions are compared with the D∅ and CDF experimental data.

Prompt photon and associated jet production has been intensively investigated both theoretically and experimentally up to now since it is highly sensitive to parton distribution in the hadron (so it provides a test of hard subprocess dynamics) and contributes significantly to the background for the physics beyound the Standard Model processes.

Recently an attempt of the description of the newest ZEUS data on the prompt photon and associated non-tagged jet photoproduction at HERA has been made in the framework of the k_T-factorization approach [1]. The consideration was based on $2 \to 3$ matrix elements with the addition of box-diagrams contribution. However, the difficulties in the description of the data still remain. For instance, there is qualitative disagreement in jet rapidities distributions.

In this light it is interesting to look at the results, obtained with the tagged jets. Such investigation was made by the D∅ and CDF collaborations for the prompt photon and associated heavy quark production at the Tevatron [2, 3, 4, 5, 6, 7, 8].

The k_T-factorization approach was used to describe the production of prompt photons associated with the charm or beauty quark in paper [9]. The consideration was based on the $\mathcal{O}(\alpha\alpha_s^2)$ amplitude for the gluon fusion subprocess $g^*g^* \to \gamma Q\bar{Q}$. Reasonably good agreement between the numerical predictions and the Tevatron data [5, 6] was obtained in the region of relatively low p_T^γ where the off-shell gluon fusion dominates. However, the quark-induced subprocesses become more important at moderate and large p^γ and therefore should be taken into account. In work [10] the analysis was extended by including into the consideration two additional $\mathcal{O}(\alpha\alpha_s^2)$ subprocesses: $q\bar{q} \to \gamma Q\bar{Q}$ and $qQ \to \gamma qQ$. The presented proceedings paper is based on this study.

According to the k_T-factorization theorem, the cross section of the prompt photon and associated heavy quark production is obtained by convoluting the off-shell partonic cross sections with the relevant unintegrated quark and/or gluon distributions in a proton:

$$\sigma = \sum_{a,b=q,\,g} \int \hat{\sigma}^*_{ab}(x_1, x_2, \mathbf{k}_{1T}^2, \mathbf{k}_{2T}^2)\, f_a(x_1, \mathbf{k}_{1T}^2, \mu^2) f_b(x_2, \mathbf{k}_{2T}^2, \mu^2)\, dx_1 dx_2\, d\mathbf{k}_{1T}^2 d\mathbf{k}_{2T}^2 \frac{d\phi_1}{2\pi}\frac{d\phi_2}{2\pi},$$

where $\hat{\sigma}^*_{ab}(x_1, x_2, \mathbf{k}_{1T}^2, \mathbf{k}_{2T}^2)$ is the relevant partonic cross section. The initial off-shell partons have fractions x_1 and x_2 of initial protons longitudinal momenta, non-zero transverse momenta $\mathbf{k}_{1T}$ and $\mathbf{k}_{2T}$ and azimuthal angles ϕ_1 and ϕ_2.

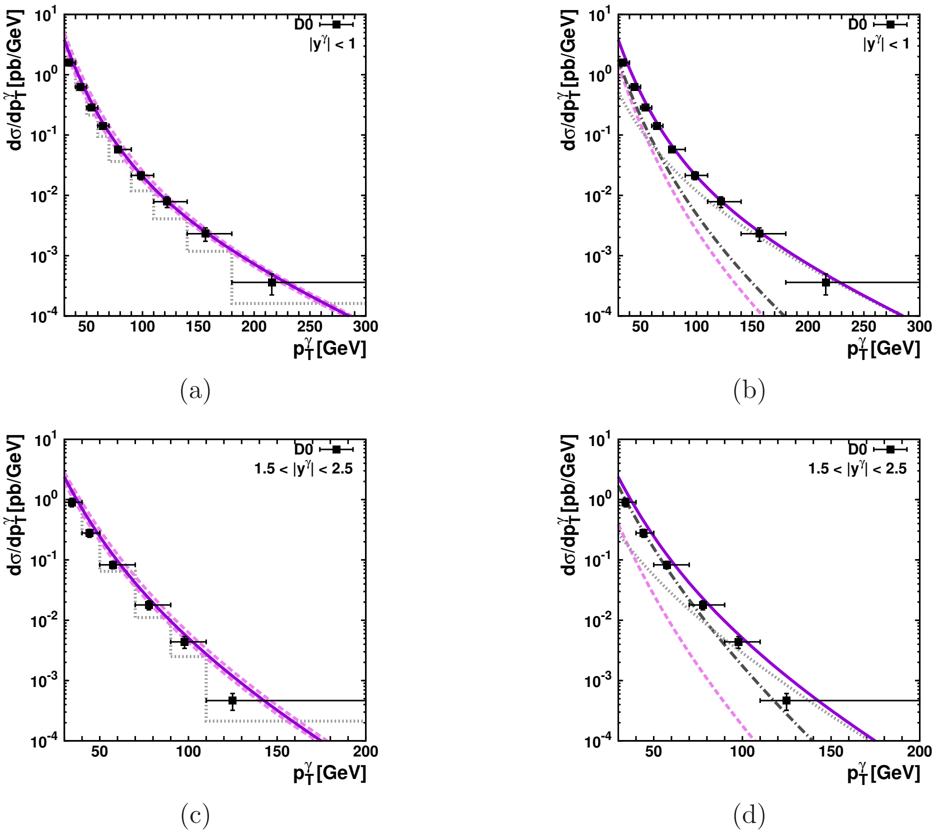
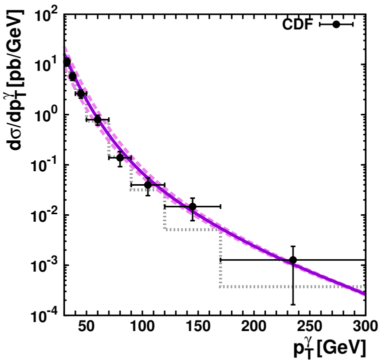
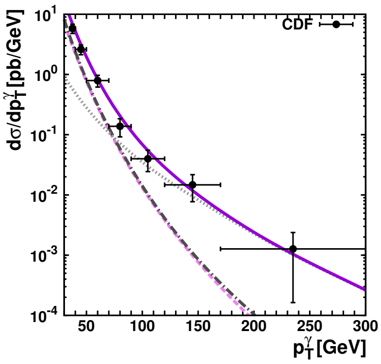


Figure 1: The associated $\gamma + b$-jet cross section as a function of photon transverse momentum p_T^γ in the kinematical region of $|y^{jet}| < 1.5$, $p_T^{jet} > 15$ GeV at $\sqrt{s} = 1960$ GeV. Left panels: the solid curve corresponds to the KMR predictions at the default scale $\mu = E_T$; the upper and lower dashed curves correspond to scale variations described in the text. The dotted histogram represents the NLO pQCD predictions [16] listed in [3]. Right panels: the different contributions to the $\gamma + b$-jet cross section. The dashed, dotted and dash-dotted curves correspond to the contributions from the $g^* g^* \to \gamma Q\bar{Q}$, $q^* \bar{q}^* \to \gamma Q\bar{Q}$ and $q^* Q \to \gamma q Q$ subprocesses, respectively. The solid curve represents their sum. The experimental data are from DØ [3].



(a)



(b)

Figure 2: The associated $\gamma + c$-jet cross section as a function of photon transverse momentum p_T^γ in the kinematical region of $|y^\gamma| < 1.0$, $|y^{jet}| < 1.5$ and $p_T^{jet} > 20$ GeV at $\sqrt{s} = 1960$ GeV. The notations are the same as for Fig. 1. The experimental data are from CDF [8].

In this work we use the KMR uPDFs [11, 12]. The KMR approach is the formalism to construct the unintegrated parton distributions from the known conventional parton distributions[1].

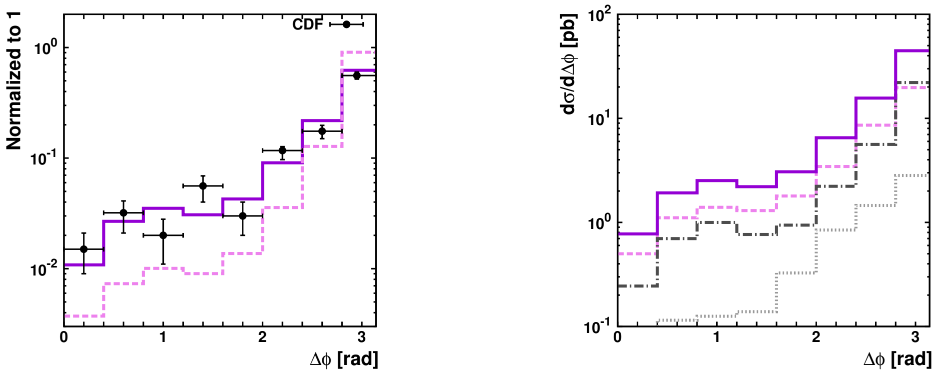
The calcuation of the matrix elements generally follows the standard Feynman rules. The only difference comes from the modification of the polarization sum rules. In the k_T-factorization approach the gluon polarization density matrix takes so called BFKL form: $\sum \epsilon^\mu \epsilon^{*\nu} = k_T^\mu k_T^\nu / \mathbf{k}_T^2$. The spin density matrix for the off-shell quark with the momentum $k = xP + k_T$ in massless limit is [14] $\sum_s u^s(k)\bar{u}^s(k) = x\hat{P}$, where P is the momentum of the incoming proton (or antiproton). Since the expression was obtained in the massless approximation, we neglected the light quarks masses.

In our numerical calculations 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 $\xi = 1$. 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 $\alpha_S(M_Z) = 0.1232$. We set the charm and beauty quark masses to $m_c = 1.5$ GeV and $m_b = 4.75$ GeV.

In order to reduce the huge background from the secondary photons produced by the decays of π^0 and η mesons the isolation criterion is introduced in the experimental analyses. The isolation not only reduces the background but also significantly reduces the so called fragmentation components, connected with collinear photon radiation (10%)[2]. The same isolation cuts were introduced into our calculations.

Some selected results of our calculation [10] for the production of the prompt photon with the associated heavy quark are shown in Figs. 1, 2. The results are compared with the data taken by the D∅ and CDF collaborations at $\sqrt{s} = 1960$ GeV [3, 8]. For comparison we also plot the NLO QCD predictions [16]. We find that the full set of experimental data is reasonably well described by the k_T-factorization approach: the shape and absolute normalization of measured cross sections are adequately reproduced (for more details see [10]).

[1] Numerically, as the input we used the MSTW2008 collinear parton distributions [13].
[2] For details see [15]



(a) (b)

Figure 3: The associated $\gamma + \mu$ cross section as a function of the azimuthal angle difference between the photon and muon in the kinematical region of $|\eta^\gamma| < 0.9$, $|\eta^\mu| < 1.0$ and $p_T^\mu > 4$ GeV at $\sqrt{s} = 1800$ GeV. Panel (a): the solid and dashed lines correspond to the k_T-factorization and collinear QCD factorization calculations, respectively. The notations on the panel (b) are the same as for Fig. 1. The experimental data are from CDF [5].

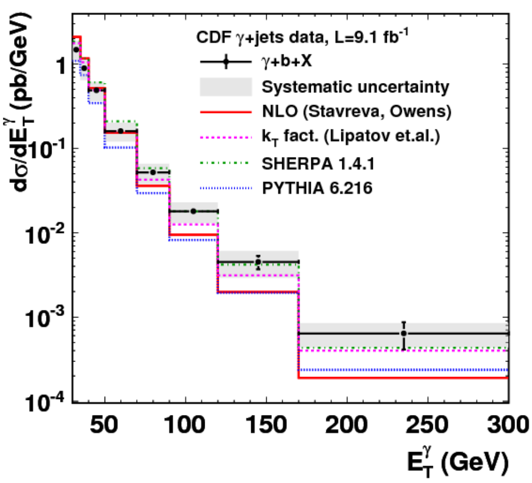


Figure 4: The associated $\gamma + b$-jet cross section as a function of photon transverse momentum p_T^γ in the kinematical region of $|y^\gamma| < 1.04$, $|y^{jet}| < 1.5$ and $p_T^{jet} > 20$ GeV at $\sqrt{s} = 1960$ GeV. The graph is taken from [8].

The results of the calculation for associated production of the prompt photon and the muon originated from the semileptonic decays of charm or beauty quarks are presented in Fig. 3. The experimental data are from CDF [5]. To produce muons from charmed and beauty quarks, we first convert them into D or B hadrons using the Peterson fragmentation function [17] and then simulate their semileptonic decay according to the standard electroweak theory. Additionally, the cascade decays $b \to c \to \mu$ have been taken into account. We set the fragmentation parameters $\epsilon_c = 0.06$ and $\epsilon_b = 0.006$ and corresponding branching fractions to $f(c \to \mu) = 0.0969$, $f(b \to \mu) = 0.1071$ and $f(b \to c \to \mu) = 0.0802$ [18]. We find that the k_T-factorization predictions describe the data very well. One can see that the CDF data clearly favor the k_T-factorization results.

Finally, on the Fig. 4 for an illustration we show the comparison of the $\gamma + b$ CDF data with different numerical calculations (including the k_T-factorization results), which was taken from the experimental paper [8]. In that paper the good description of the data by our simulation was specially pointed by the collaboration.

In summary, we have studied the process of the prompt photon production with the associated heavy (b, c) quark in the k_T-factorization QCD approach at Tevatron energies. A reasonably good description of D∅ and CDF data for the associated prompt photon and heavy quark production has been obtained. Also the associated prompt photon and μ-meson production has been studied. A theoretical uncertainties investigation has been made and a predictive power of the used approach has been shown. Compared to the associated prompt photon and non-tagged jet production at HERA [1], the obtained good agreement is notable. It shows, that the reliability of the predictions may be significantly improved if in the analyses the produced jets are tagged as in the case of the prompt photon and associated heavy quark production at Tevatron.

This research was supported by the FASI of Russian Federation (grant NS-3920.2012.2), RFBR grant 13-02-01060 and the grant of the Ministry of education and sciences of Russia (agreement 8412). A.L. and M.M. were also supported by RFBR grant 12-02-31030. A.L. and N.Z. would like to thank DESY Directorate for the support in the framework of Moscow—DESY project on Monte-Carlo implementation for HERA—LHC. M.M. is very grateful to the Organizing Committee for the financial support.

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