Prompt photon and electroweak gauge boson production in off-shell gluon fusion

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S.P. Baranov, A.V. Lipatov, N.P. Zotov, Phys. Rev. D **77**, 074024 (2008)
S.P. Baranov, A.V. Lipatov, N.P. Zotov, Phys. Rev. D **78**, 014025 (2008)
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Introduction

Studying of the prompt photon and electroweak gauge boson production at high energies is of interest:

- one of most important “standard candles” in high energy physics
- W/Z data are used to validate detector and trigger performance and stability
- the cross sections are sensitive to the proton PDF
- there is no effects of final-state hadronization
- starting point for investigation of Higgs or top production

Fixed-order QCD calculations

- in the LO QCD, the main production mechansims are quark-gluon Compton scattering and/or quark-antiquark annihilation
- known up to NLO (γ) and NNLO (W, Z) level
- these calculations are reliable at high transverse momenta only, since diverge at low transverse momenta due to soft and collinear gluon emission
- the soft-gluon resummation technique should be used at low transverse momenta
- in the case of prompt photon production, the intrinsic transverse momentum of incoming partons (~3 GeV) should be taken into account to reproduce the Tevatron data

kt-factorization approach of QCD

- based on the BFKL or CCFM equations
- formulated in the terms of unintegrated parton densities
- transverse momentum of incoming partons is generated during the evolution cascade under control of relevant equations
- large logarithms ~ ln 1/*x* are summed
- already incorporates the soft-gluon resummation formulas
- has been applied already to number of QCD processes

J. Andersen et al. (Small-x Collaboration), Eur. Phys. J. C **48**, 53 (2006)
J. Andersen et al. (Small-x Collaboration), Eur. Phys. J. C **35**, 77 (2004)
B. Andersson et al. (Small-x Collaboration), Eur. Phys. J. C **25**, 77 (2002)

First calculations of $\gamma/W/Z$ production

- were based on the quark-gluon Compton scattering and/or quark-antiquark annihilation

  M.A. Kimber, A.D. Martin, M.G. Ryskin, Eur. Phys. J. C **12**, 655 (2000)
  G. Watt, A.D. Martin, M.G. Ryskin, Phys. Rev. D **70**, 014012 (2004)

- an important part of these calculations is the unintegrated quark densities (u.q.d.) in a proton
- at moment, u.q.d. are available in the Kimber-Martin-Ryskin (KMR) formalism only
- so, in this way there is no possibility to investigate the dependence of calculated cross sections on the evolution scheme

Approach

The cental part of our approach is the $g^* + g^* \to \gamma$ /W/Z + q + q subprocess

- since the sea quark can only appear as a result of gluon splitting, at the price of absorbing the last gluon splitting into the hard subprocess (i.e., considering the $2 \to 3$ rather than $2 \to 2$ and/or $2 \to 1$ matrix elements) the problem of poorly unknown u.q.d. can be reduced to the problem of gluon ones
- the contribution from the valence quarks (described well by the DGLAP equations) should be calculated separately

Approach

- this way enables us with making comparisons between the different parton evolution schemes and parametrizations of parton densities
- by considering the higher order matrix elements we take into account the terms not containing large logarithms, i.e. terms not included in the evolution equations
- within this scheme we can get a numerical estimate of corresponding contributions

Approach

- however, this idea can only work well if the sea quarks mainly appear from the last step of gluon evolution: then we can absorb this last step of gluon ladder into hard matrix element
- so, the contribution from the quarks coming from the earlier steps (i.e. second-to-last, third-to-last, etc) is not taken into account
- it is not evident in advance, whether the last gluon splitting dominates or not. One of our goal is to clarify this point
- another our goal is to study, to what extent the quark conributions can be reexpressed in terms of the gluon ones

KMR model

enables us to discriminate between the various component of the u.q.d. Within this model, the uPDFs are given by

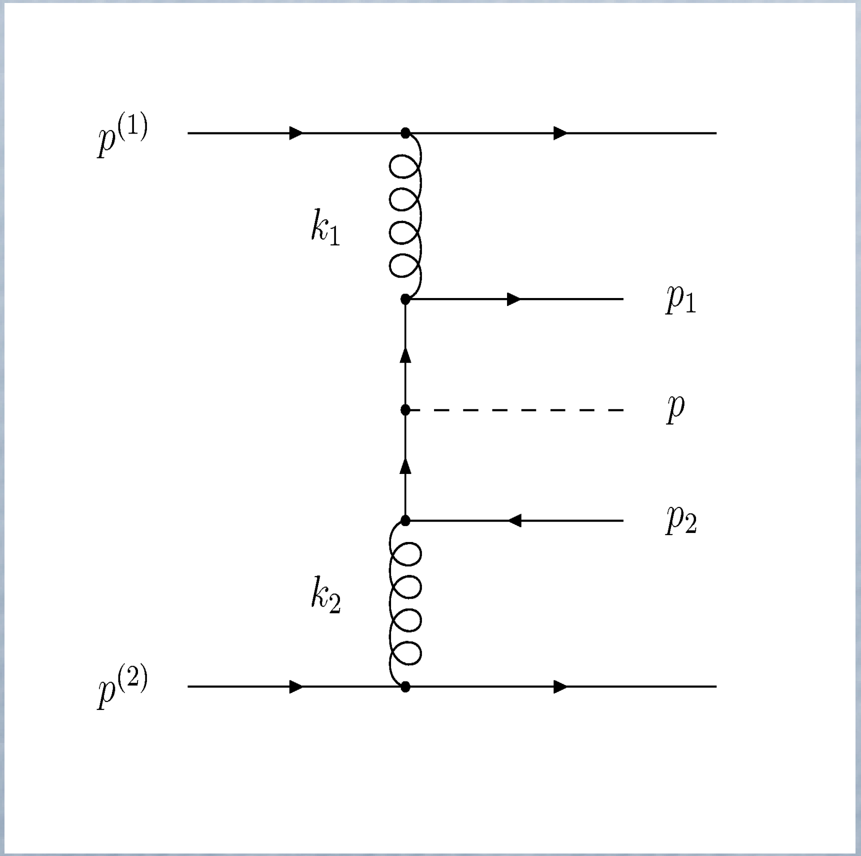
$$f_q \sim P_{qq} \times q + P_{qg} \times g$$
$$f_g \sim P_{gq} \times q + P_g \times g$$

We can modify the KMR scheme as follows:

- if only first term is kept and the second term omitted, we switch the last gluon splitting off, thus excluding the q_g component
- keeping only sea quark in first term, we remove the valence quarks from the evolution ladder. In this way only the q_s contributions to the unintegrated quark density are taken into account

Subprocesses under consideration

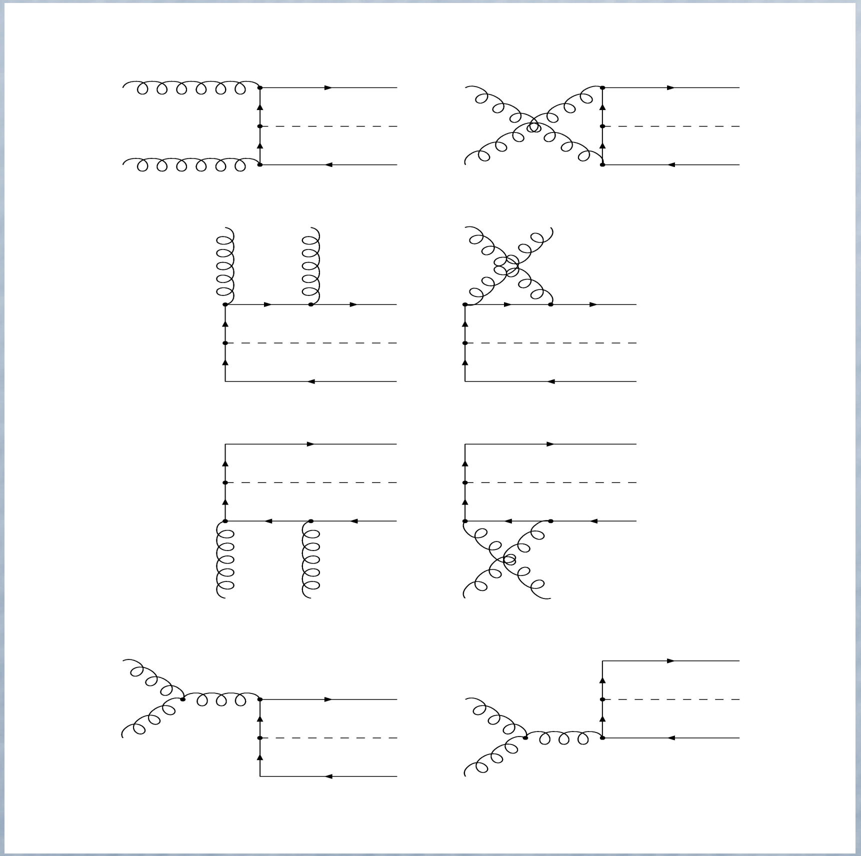
- $g^* + g^* \to \gamma/W/Z + q + q$
- $q(v,s) + g^* \to \gamma/W/Z + q$
- $q(v,s) + q(v,s) \to \gamma + g$
- $q(v,s) + q(v,s) \to W/Z$



Last three of them are rather straightforward

Off-shell gluon-gluon fusion

- there are eight Feynman diagrams describing this subprocess
- both incoming gluons are off-shell
- gauge invariance has been tested
- cross check with M. Deak and F. Schwennsen has been made



arXiv:0805.3763 [hep-ph]

Default set of parameters

- quark masses: 4.5 MeV (u), 8.5 MeV (d), 155 MeV (s), 1.5 GeV (c) and 4.75 GeV (b)
- gauge boson masses: 80.403 GeV (W) and 91.1876 GeV (Z)
- scale: transverse mass of electroweak boson or transverse energy of produced prompt photon
- usual cone isolation condition in the case of prompt photon production
- $\sin^2\theta_W = 0.23122$, $\Lambda_{QCD} = 200\ MeV$

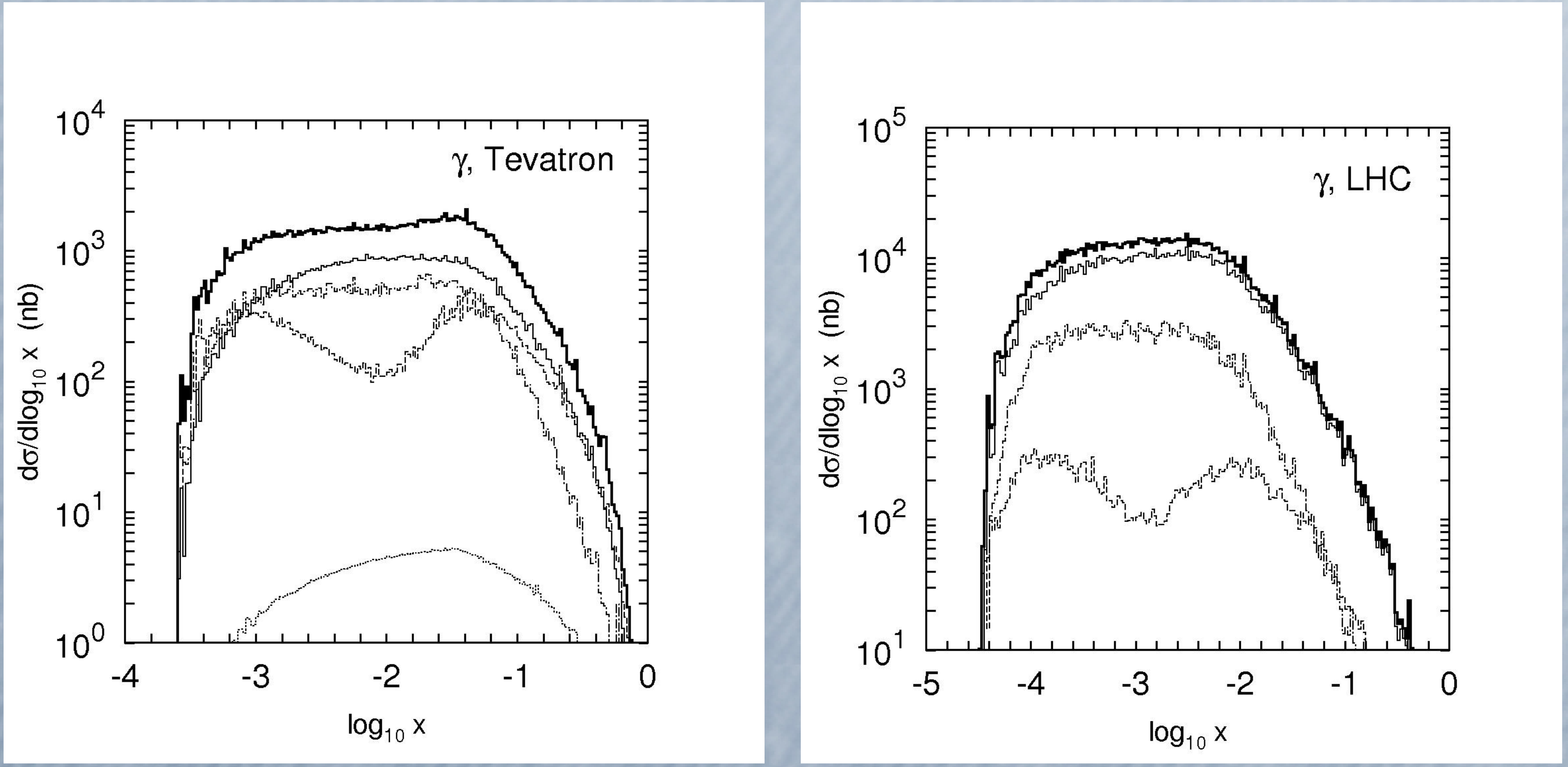
High order corrections

- it is well-known that the leading-order kt-factorization approach naturally includes part of high-order corrections arising from the real parton emissions
- also the logarithmic loop corrections are included in the Sudakov form factors which appear in the KMR formulas
- the non-logarithmic loop corrections can be taken into account by the K-factor:

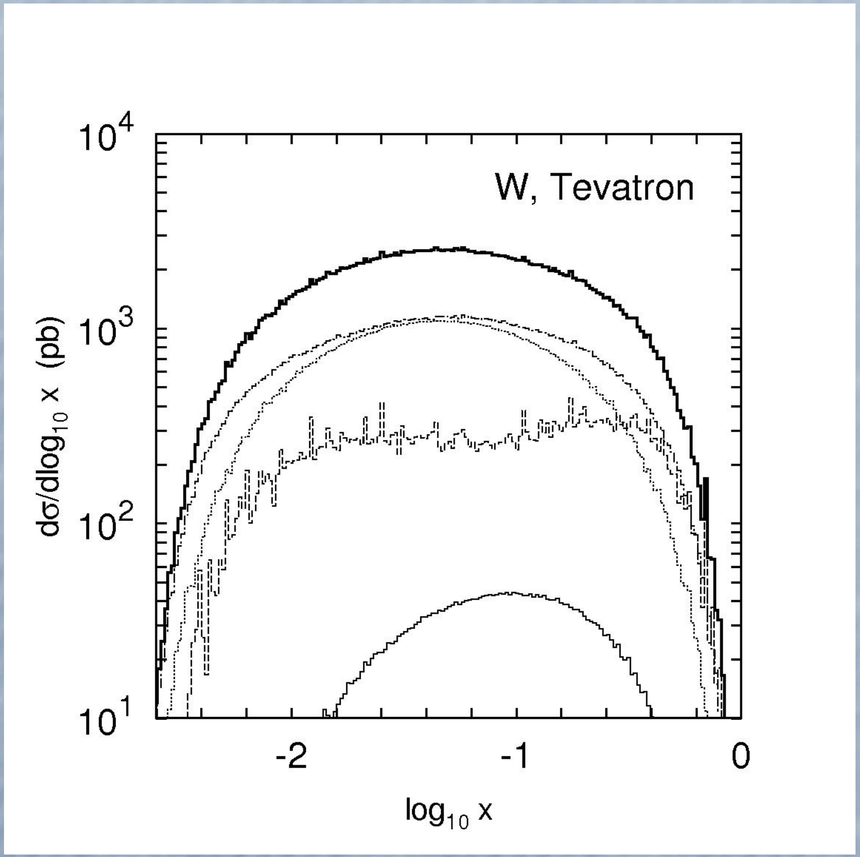
$$K\,(q + q \to W/Z) = \exp\left[C_F\, \alpha_s\,(\mu^2)\, \pi^2/2\,\pi\right]$$

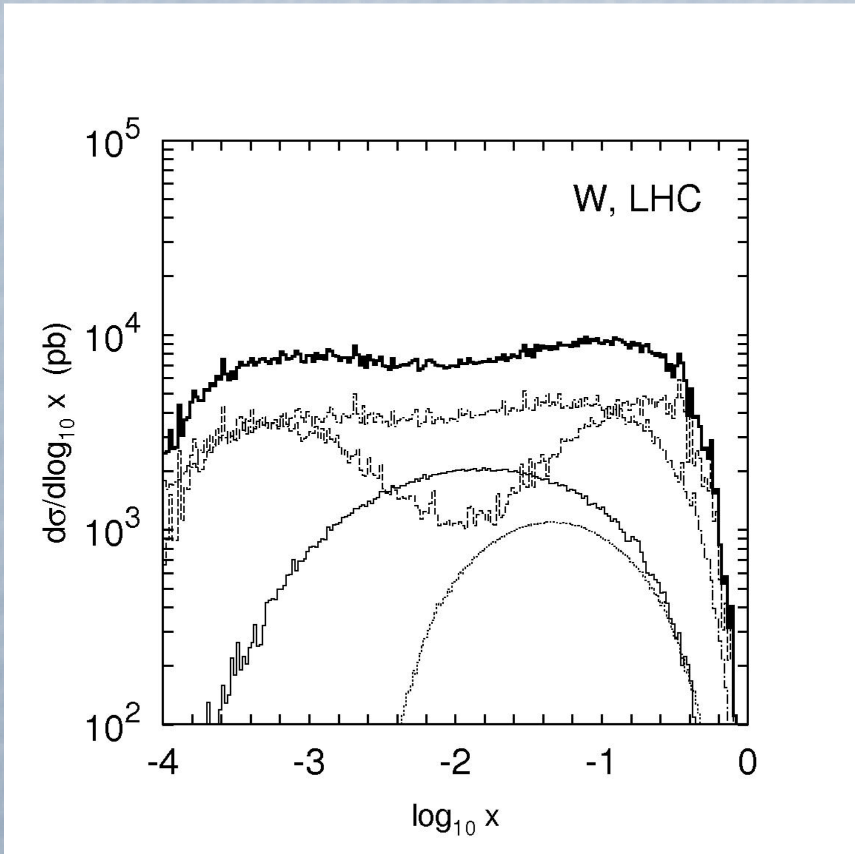
G. Watt, A.D. Martin, M.G. Ryskin, Phys. Rev. D **70**, 014012 (2004)

x-distributions (prompt photon production)

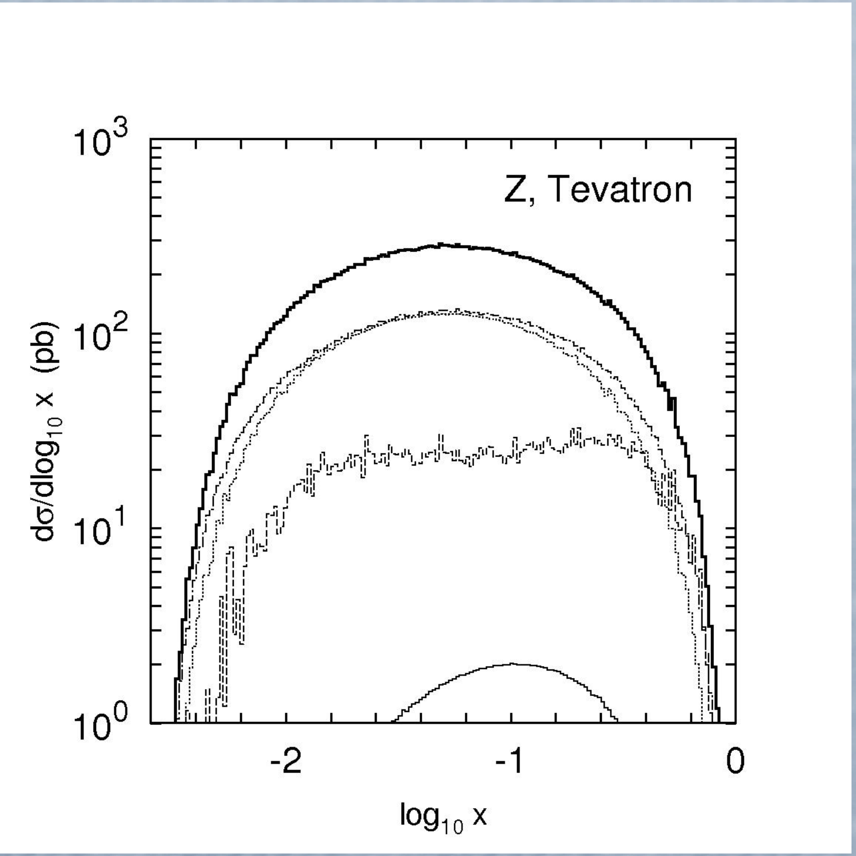


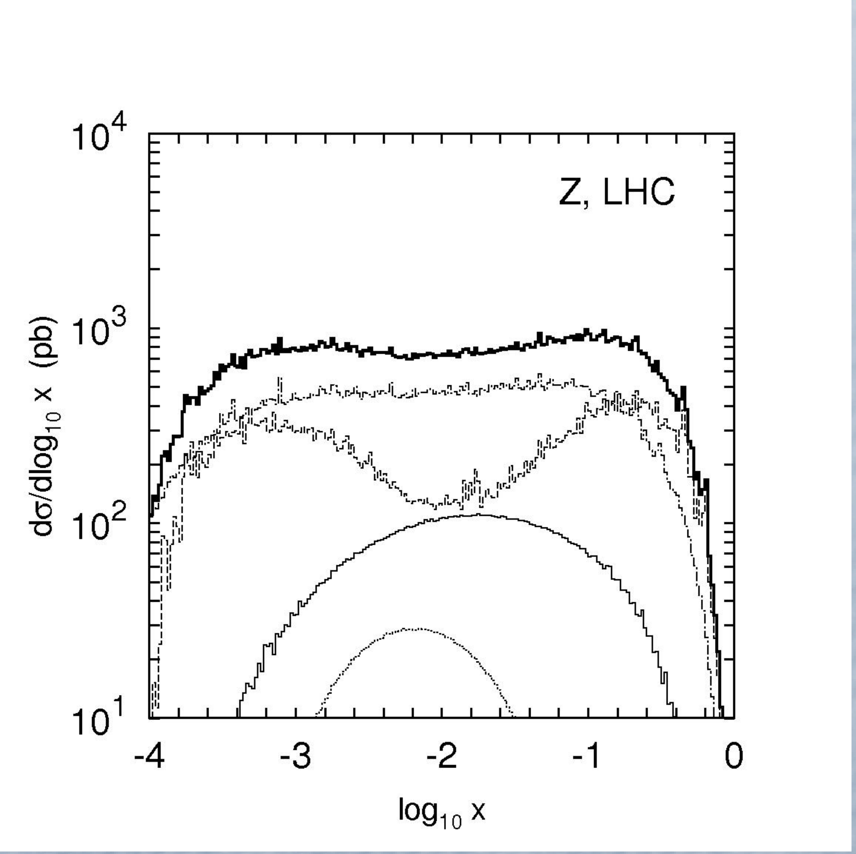
x-distributions (W production)



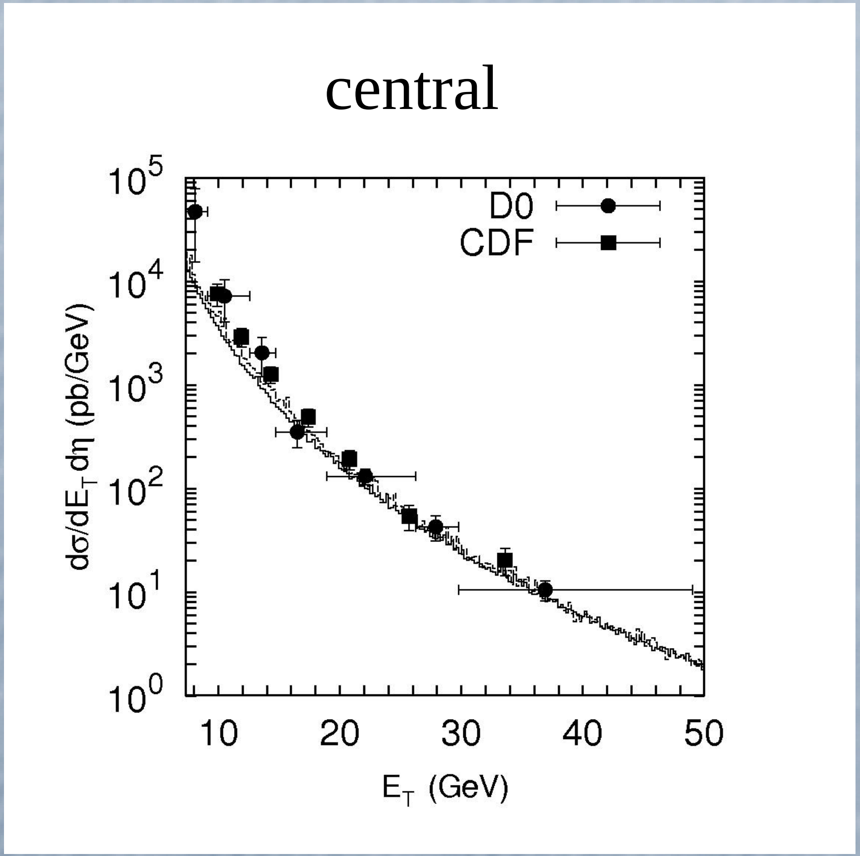


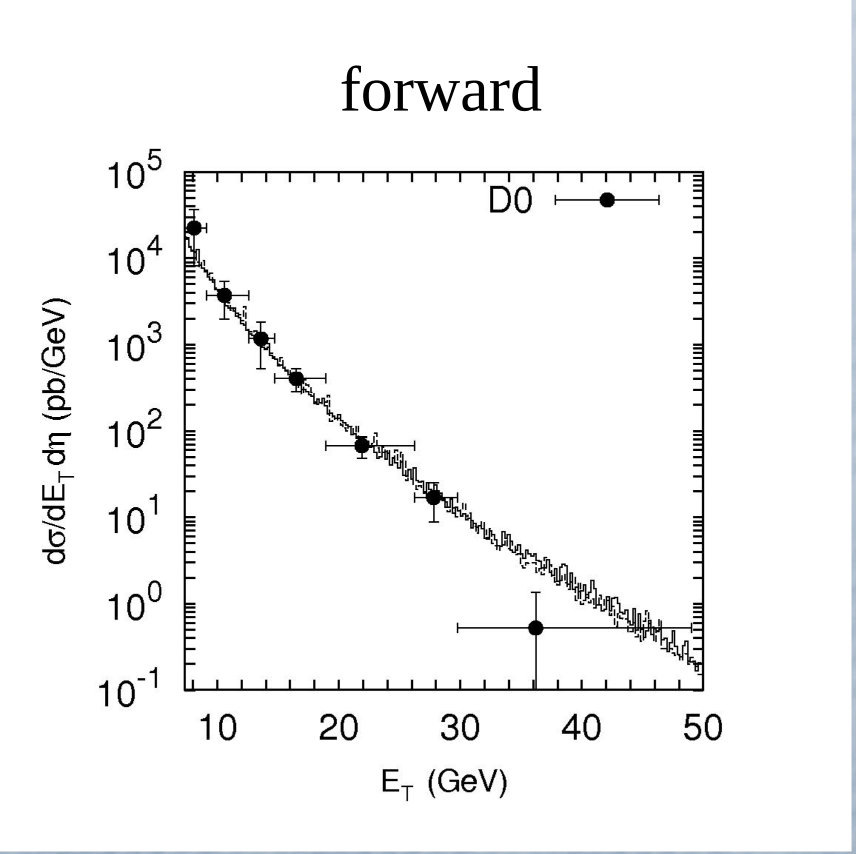
x-distributions (Z production)



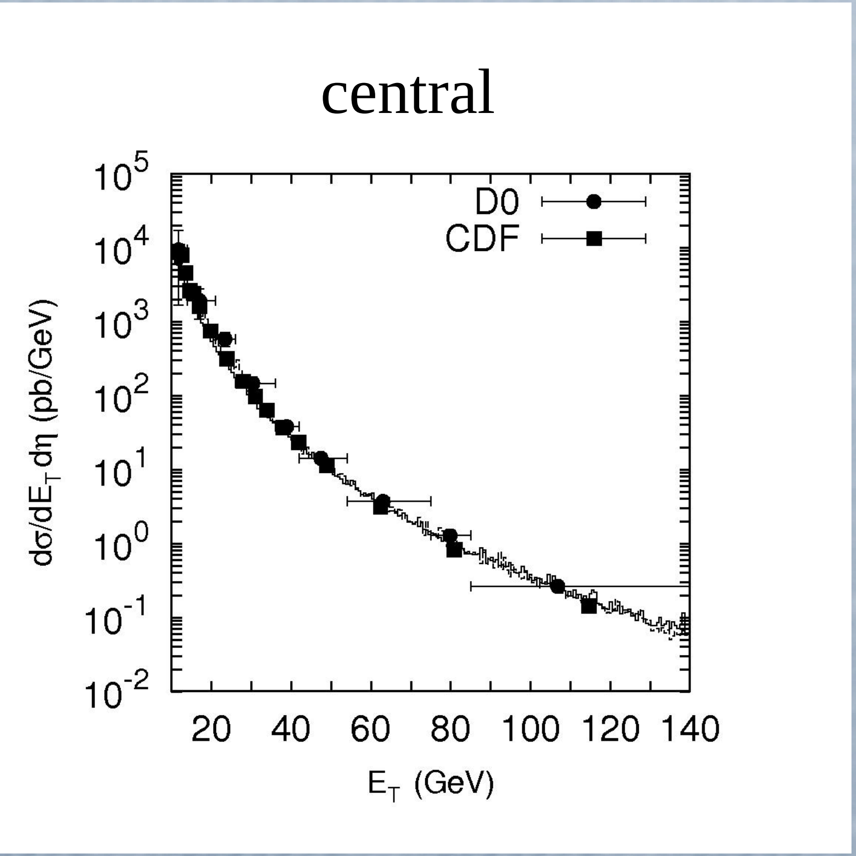


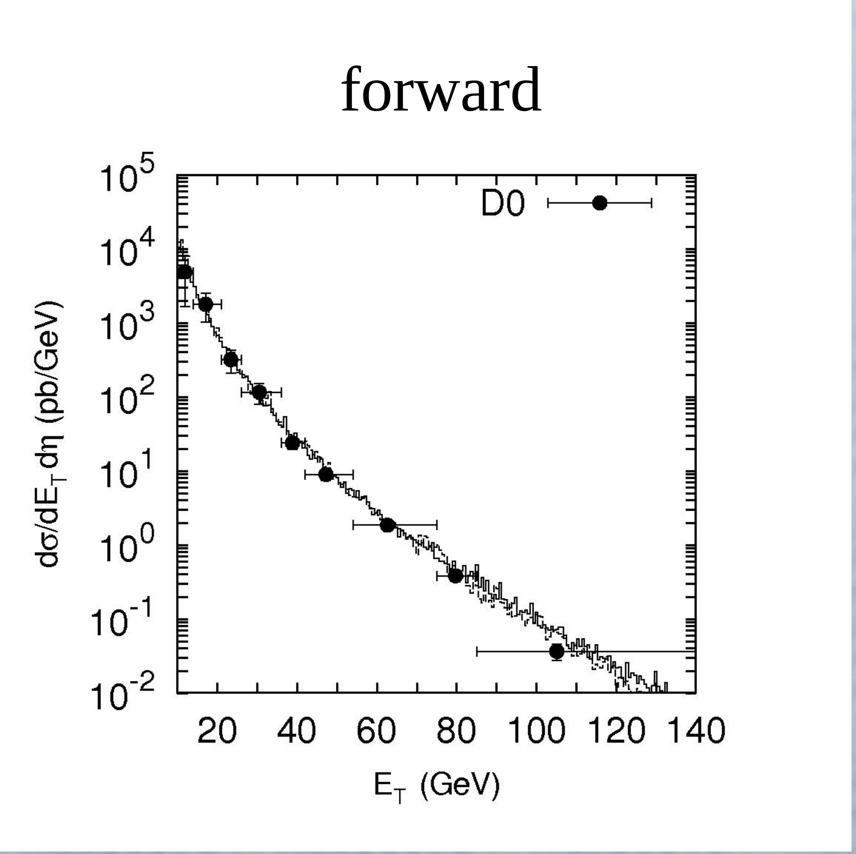
Prompt photon production (630 GeV)



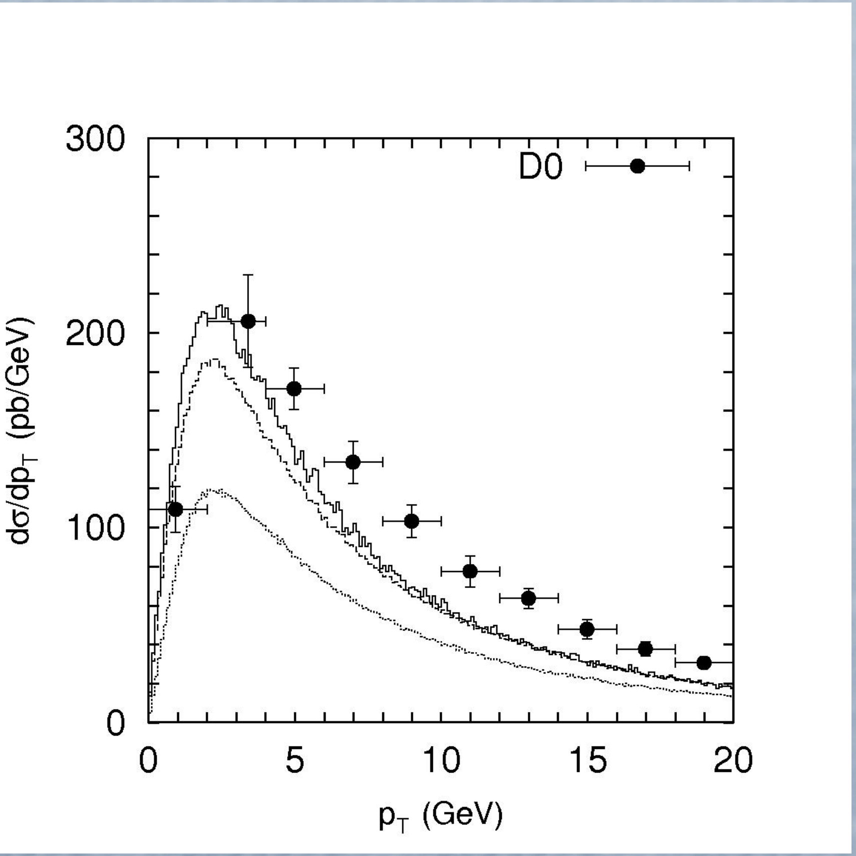


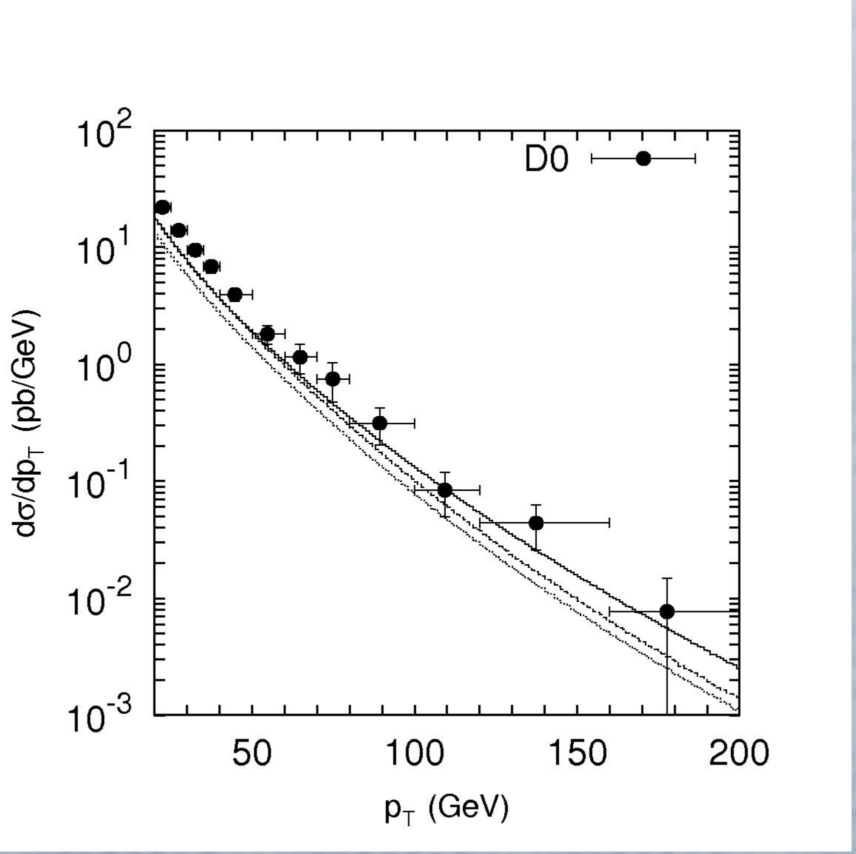
Prompt photon production (1800 GeV)



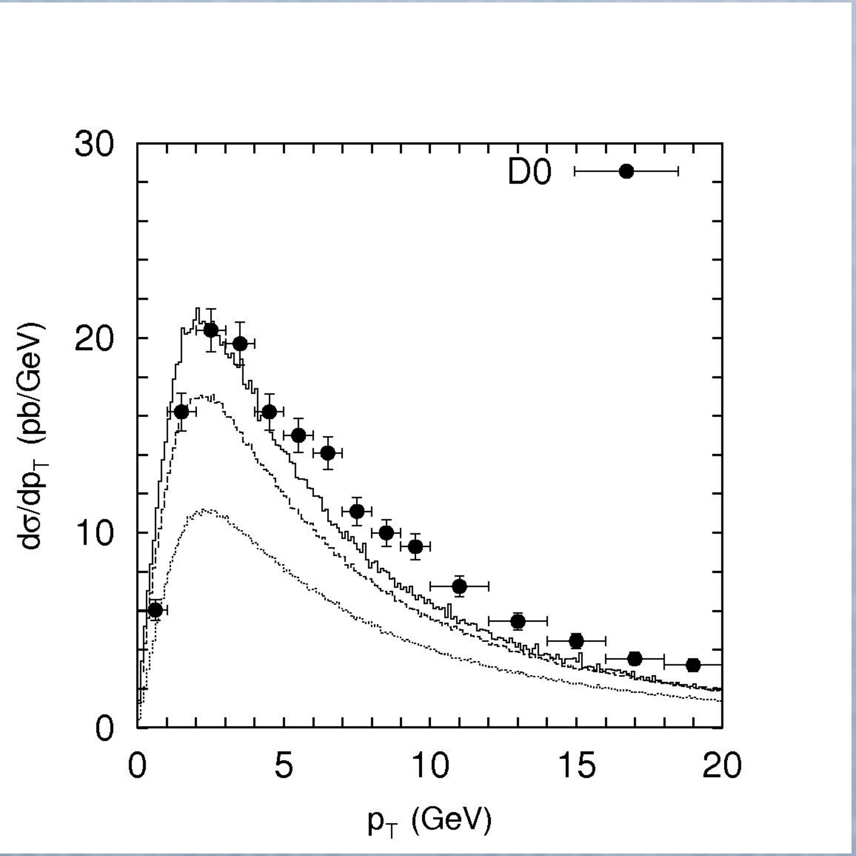


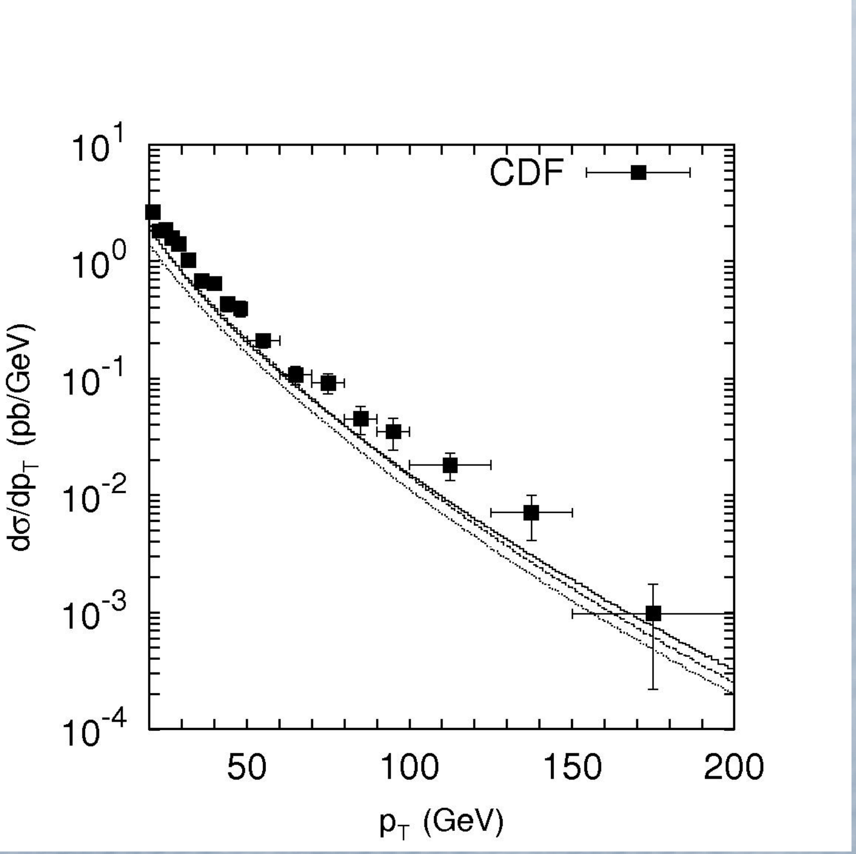
W production (1800 GeV)



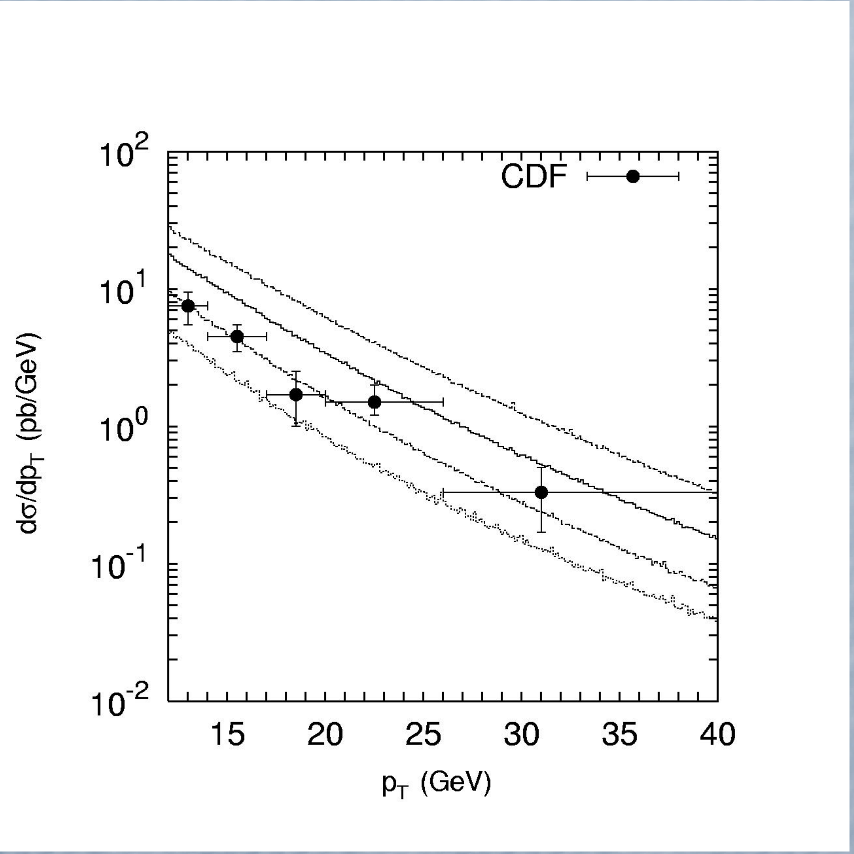


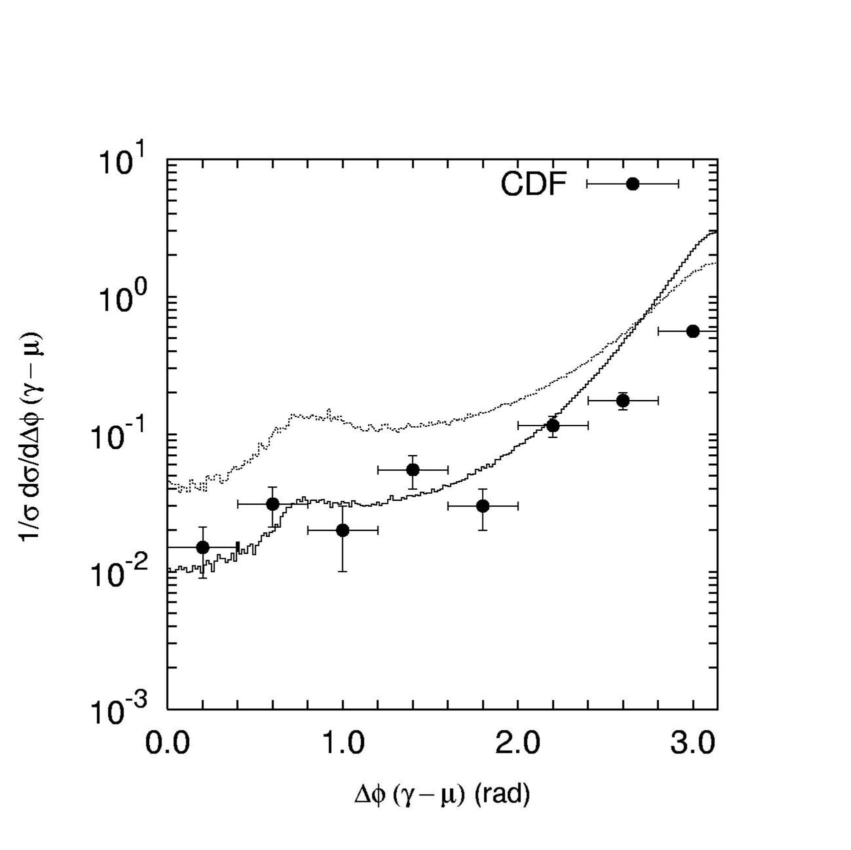
Z production (1800 GeV)





Photon + heavy quark production





Summary

- using the kt-factorization approach, we have studied the production of prompt photon and electroweak gauge bosons in the hadronic collisions at high energies
- central part of our derivation is the off-shell gluon-gluon fusion subprocess $g^* + g^* \to \gamma/W/Z + q + q$
- in contrast with the previous calculations, in our approach the problem of unknown unintegrated quark distributions has been reduced to the problem of gluon ones
- valence quark contributions have been taken into account separately

Summary

- we find that the gluon-gluon fusion is an important mechanism of the prompt photon production at both the Tevatron and LHC
- in the case of W/Z production, off-shell gluon-gluon fusion contributes only several percent at the Tevatron and up to 25% at the LHC
- we demonstrate that the significant contribution also comes from the sea quarks emerging from the earlier steps of the parton evolution rather than from the last gluon splitting
- quarks need to be directly included in the evolution equations for consistency and completeness of later