Prompt photon production at HERA in the kt-factorization approach

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Content

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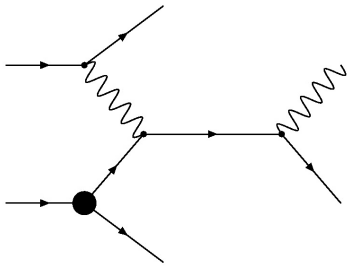
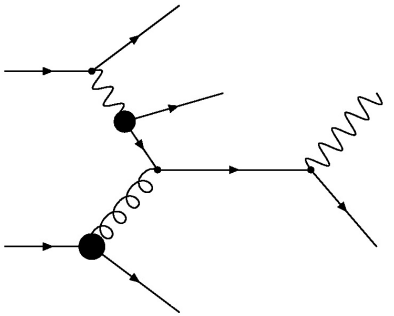
- Phenomenology of kt-factorization
- Some calculation details
- Numerical results
  - photoproduction regime
  - DIS
- Summary

Motivation I

- Prompt photons are directly coupled to the interacted quarks
- At HERA, they can be produced via direct and resolved photon events
- They directly probe the proton and photon PDFs
- They not affected by the subsequent fragmentation and hadronization



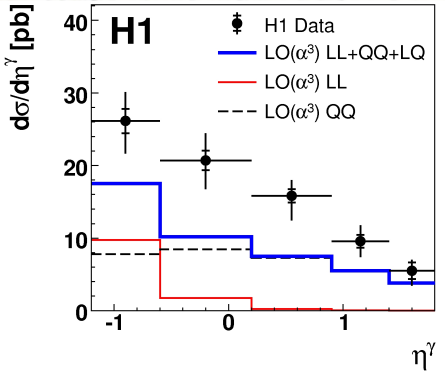


Motivation II

- The NLO QCD predictions are typically 30 — 40% below the photoproduction data

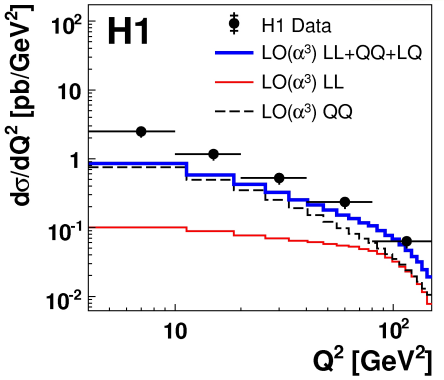
  A. Zembrzuski, M. Krawczyk,
  PRD 64, 114017 (2001)

  M. Fontannaz, J.Ph. Guillet, G. Heinrich,
  EPJ C 21, 303 (2001)



- At DIS, there is substantial underestimation of the data at low Q^2

  A. Gehrmann-De Rider, G. Kramer,
  H. Spiesberger, PRL 96, 132006 (2006)



Motivation III

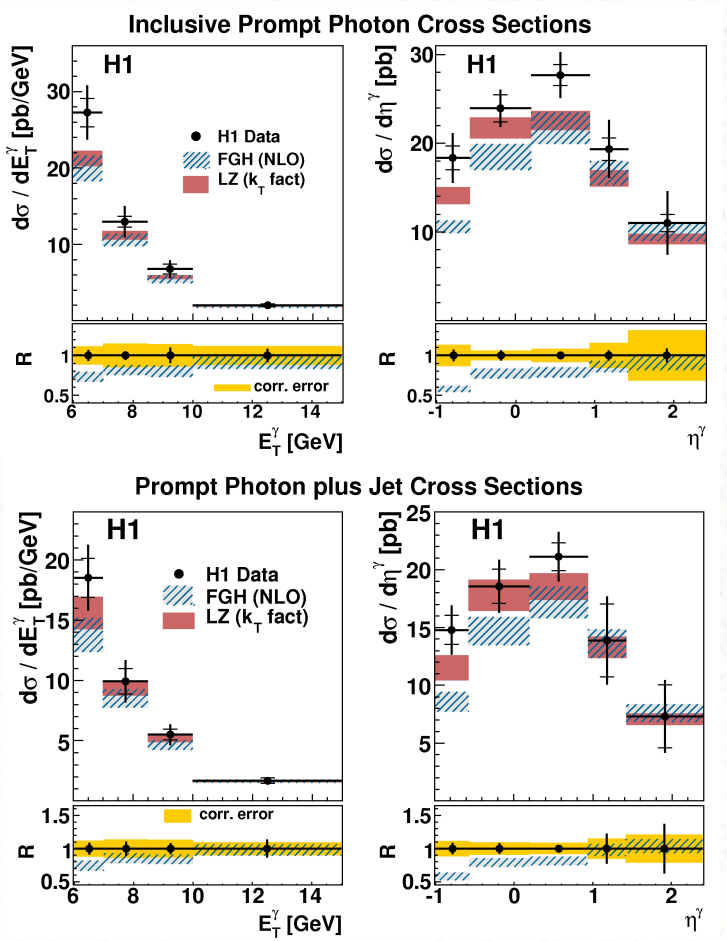
- The visible disagreement in NLO calculations can be reduced by the introducing «by hands» of some intrinsic partonic transverse momentum kt ~ 2 GeV. However, such large kt should have a significant QCD component

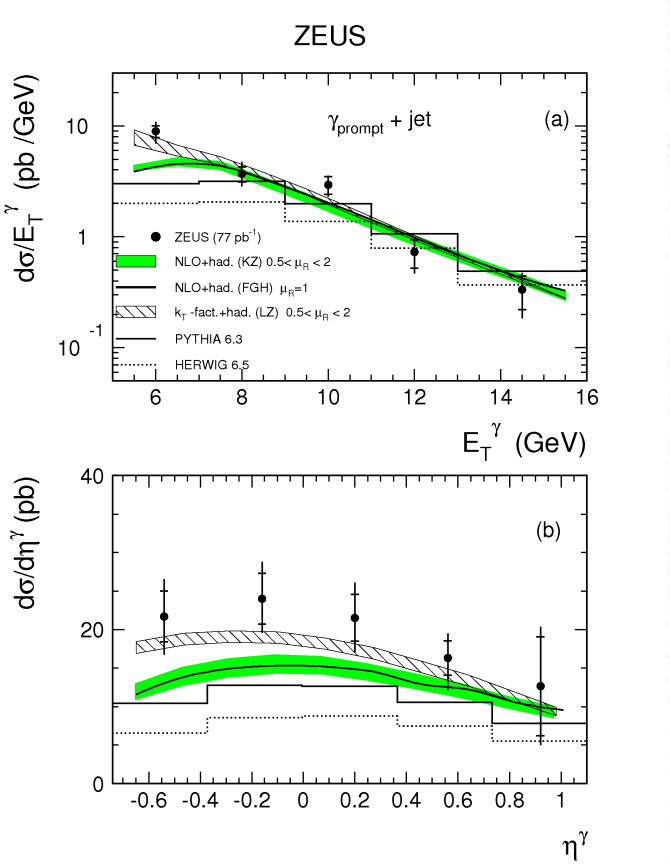
- The non-zero partonic kt is naturally occurs in the ***kt-factorization approach of QCD***, where it is controlled by the non-collinear (BFKL-like) evolution equations

- First applications of the kt-factorization approach to the prompt photon photo-production have been made

  A.V. Lipatov, N.P. Zotov, PRD 72, 054002 (2005)

Motivation IV





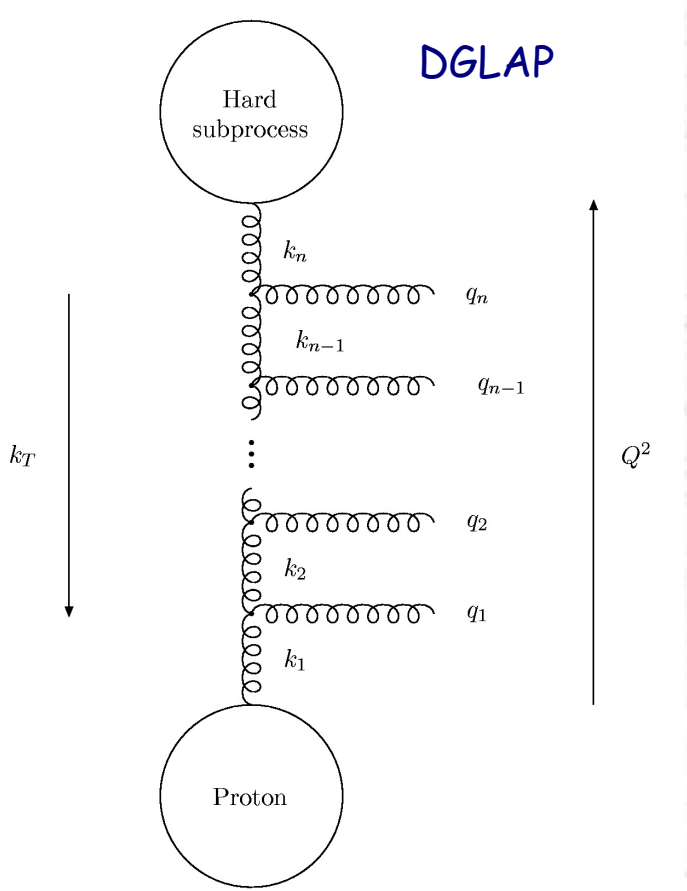
kt-factorization approach II

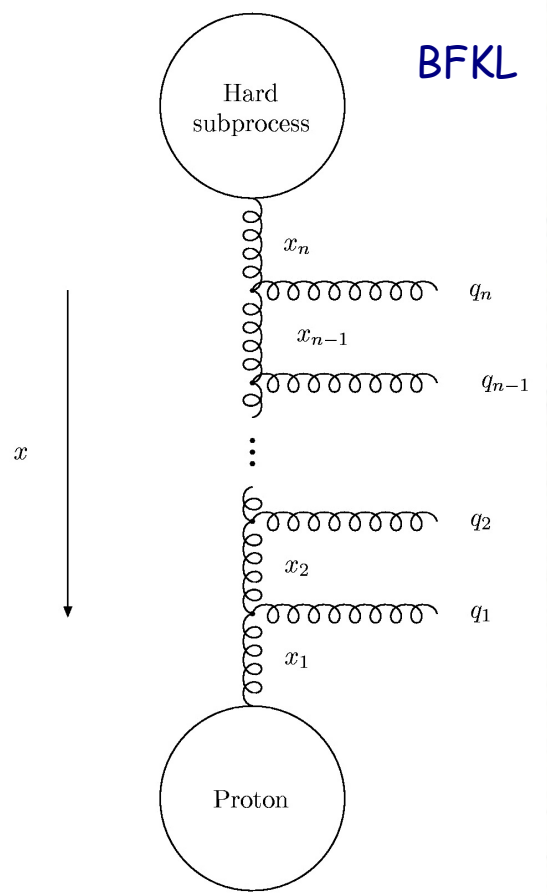
- The large logarithms ~1/x are summed up via BFKL or CCFM equations
- Matrix elements of partonic subprocesses should be off-shell
- Partonic PDFs should be unintegrated (i.e. kt-dependent)
- Any observable can be calculated by the convolution of off-shell matrix elements with the unintegrated PDFs in both x and kt

See more details in

Small-x Collaboration, EPJ C 48, 53 (2006); EPJ C 35, 67 (2004); EPJ C 25, 77 (2002)

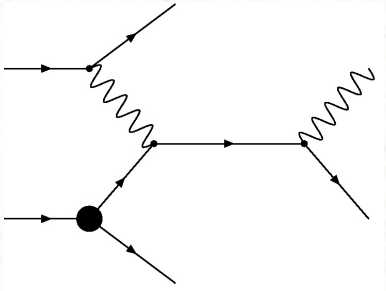
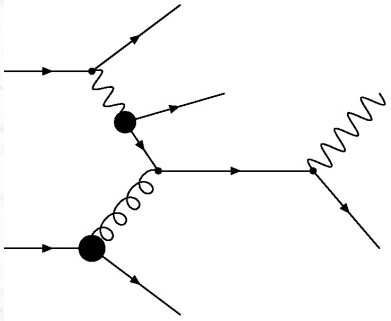
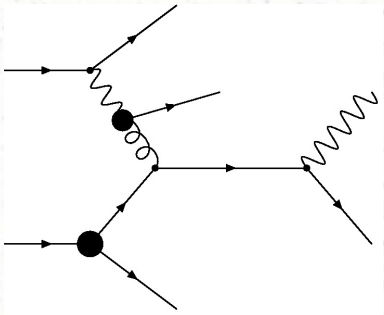
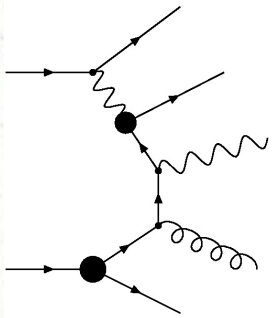
kt-factorization approach I



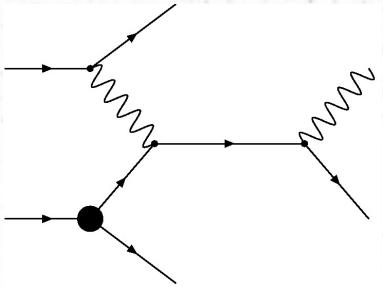
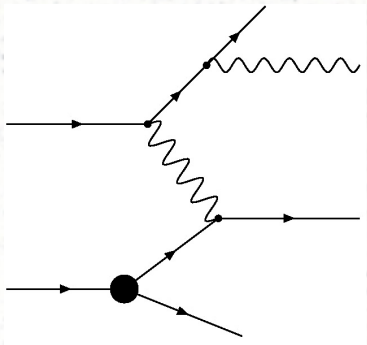


Calculations I

Photoproduction

DIS

Calculations II

In off-shell matrix elements:

- Polarization tensor for off-shell gluons: $\sum e^{\mu} e^{\nu} = \frac{k_T^{\mu} k_T^{\nu}}{k_T^2}$
- To calculate the spin density matrix for off-shell quarks, we extend the original diagram and consider the off-shell quark line as internal line in the extended diagram.
- In the small-x approximation: $\sum u \bar{u} = x \hat{p}_p$ (neglecting also the quark masses)

Calculations III

- KMR unintegrated PDFs

  M.A. Kimber, A.D. Martin, M.G. Ryskin, PRD 63, 114027 (2001)

$$f_q(x,k_T^2,\mu^2) \sim T_q(k_T^2,\mu^2)[P_{qq}\times q(x,k_T^2)+P_{qg}\times g(x,k_T^2)]$$
$$f_g(x,k_T^2,\mu^2) \sim T_g(k_T^2,\mu^2)[P_{gq}\times q(x,k_T^2)+P_{g}\times g(x,k_T^2)]$$

- CCFM unintegrated PDFs

  gluon density has been fitted on DIS data — H. Jung, arXiv:hep-ph/0411287

  valence quark density has been proposed — M. Deak, H. Jung, K. Kutak, DIS'08

  sea quark density is approximated by the last gluon splitting, i.e.

$$f_q^{(s)}(x,k_T^2,\mu^2) \sim P_{qg}\times f_g(x,k_T^2,\mu^2)$$

Calculations IV

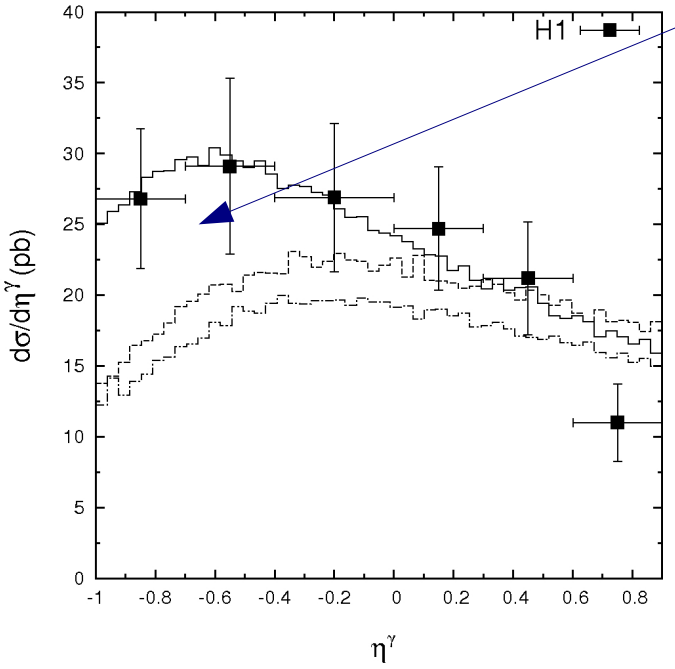
Numerical parameters:

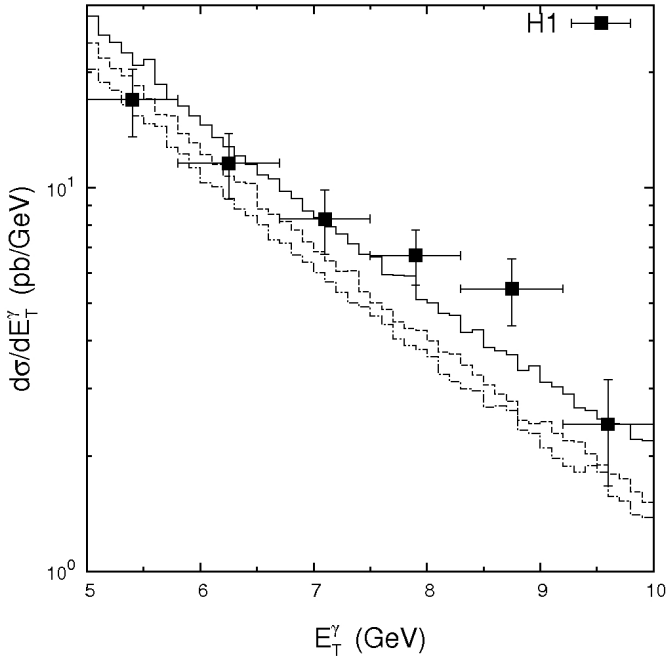
- Massless approximation for all quark flavours
- Isolation criterion (also removes the fragmentation photons)
- $N_f = 4, \ \Lambda_{QCD} = 200$ MeV
- Hard scale $\mu^2 = E_T^2$

Numerical results: incl. photoproduction

Soild histograms — KMR uPDFs
Dashed (dash-dotted) — CCFM set A0 (B0)

Missing sea quarks component in CCFM





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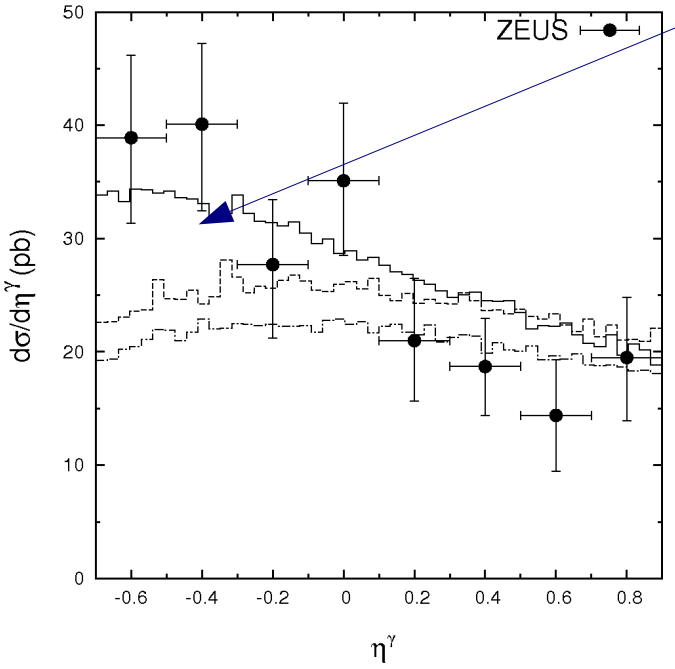
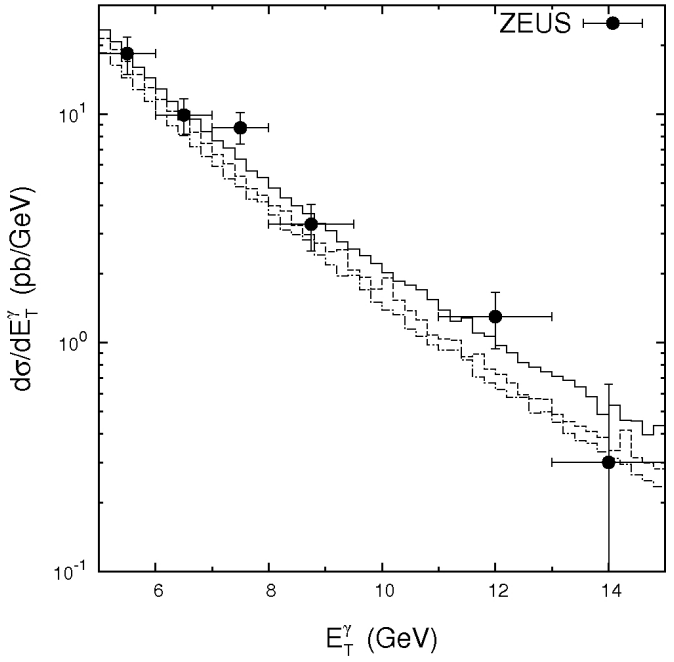
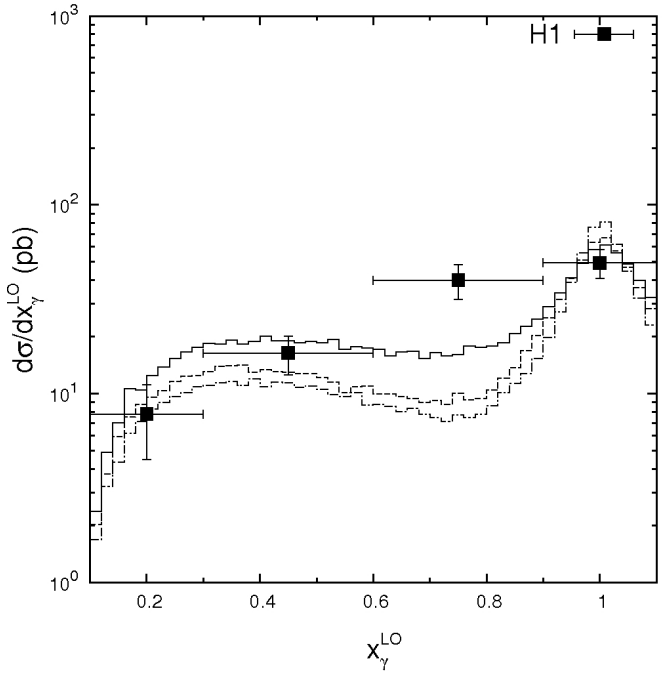
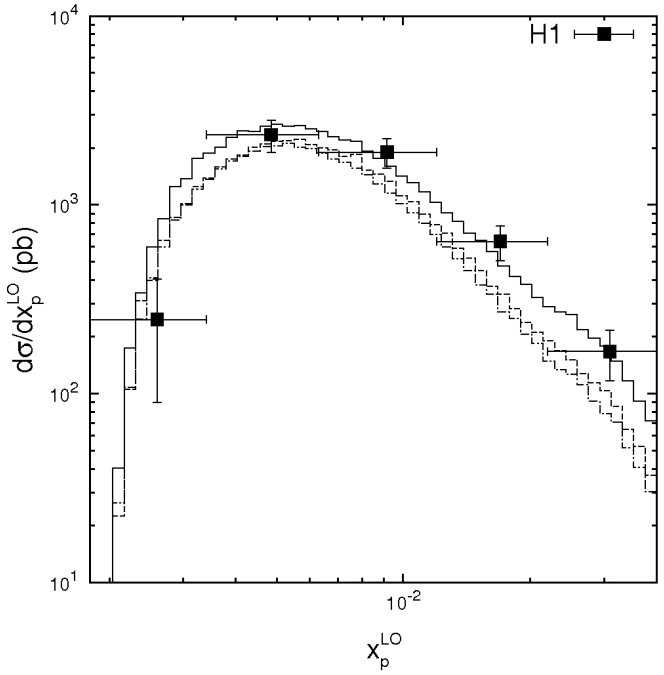




Numerical results: excl. photoproduction

Soild histograms — KMR uPDFs
Dashed (dash-dotted) — CCFM set A0 (B0)





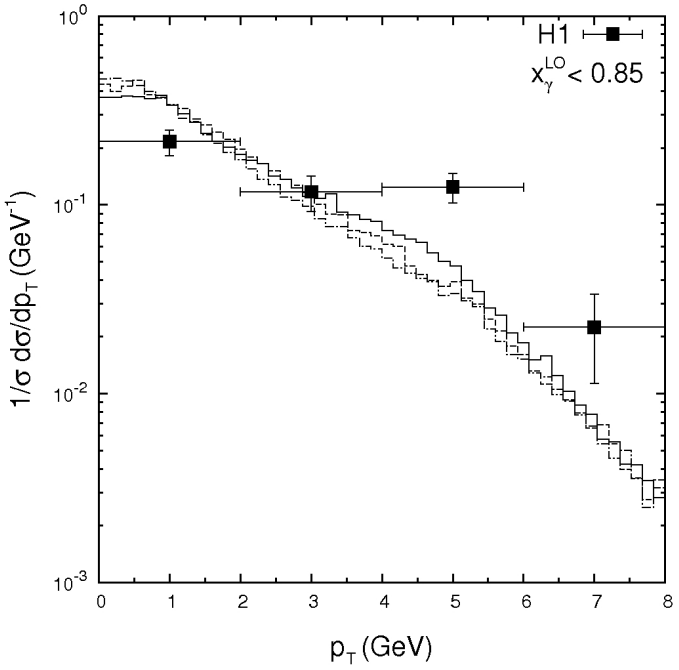
Numerical results: excl. photoproduction

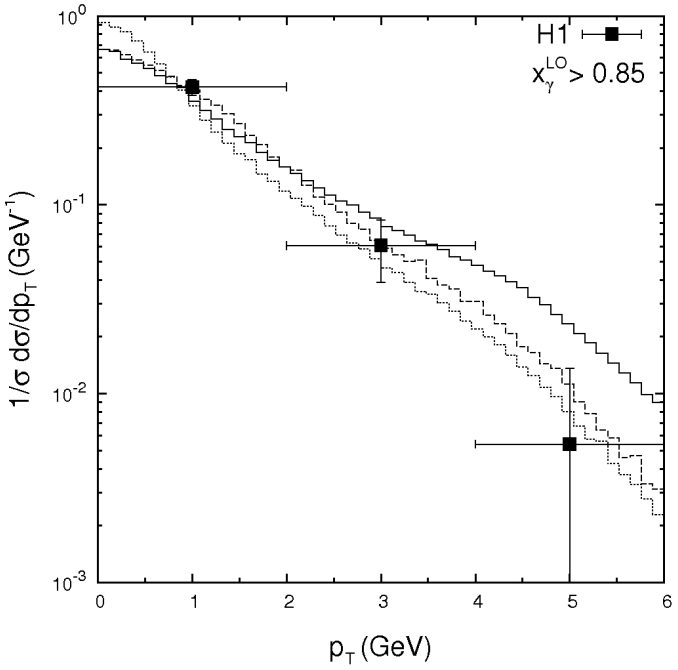
$p_T = E_T^{\gamma} \sin \Delta\varphi$

Sensitive to the high-order contributions

Soild histograms — KMR

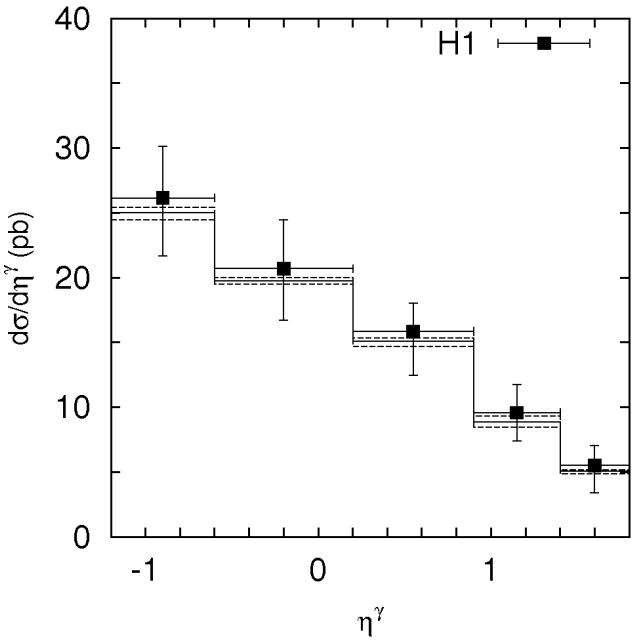
Dashed (dash-dotted) — CCFM

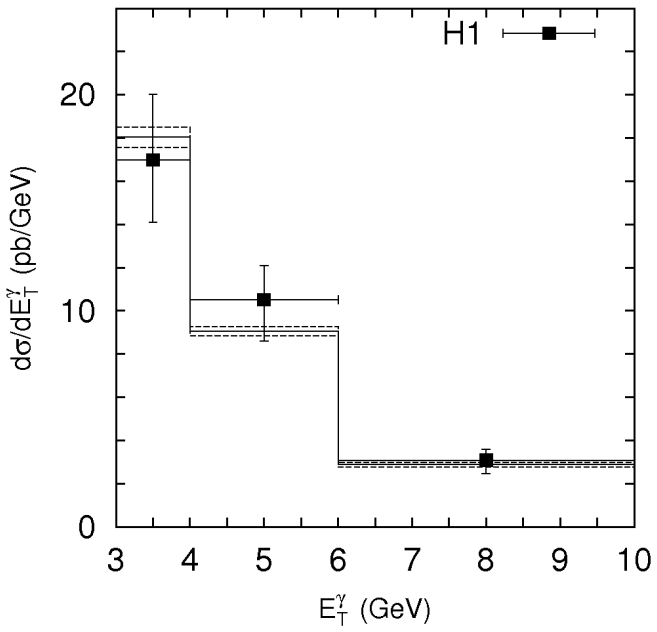




Numerical results: DIS

Soild histograms — KMR uPDFs
Upper and lower dashed histograms — scale variations in KMR





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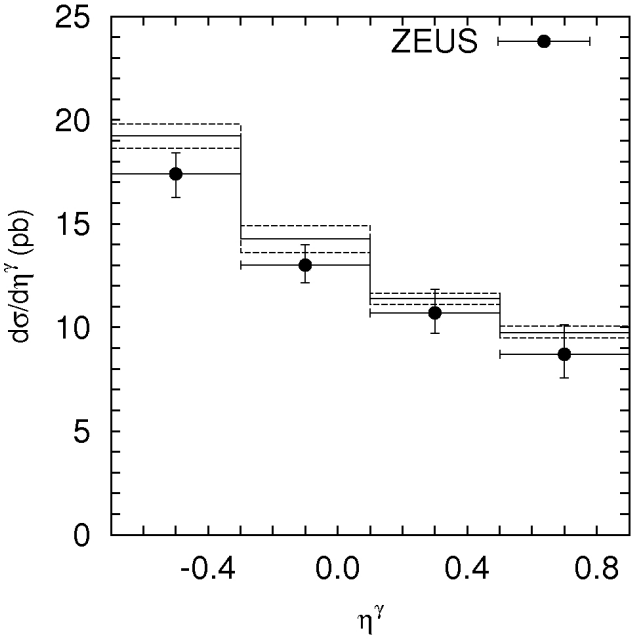

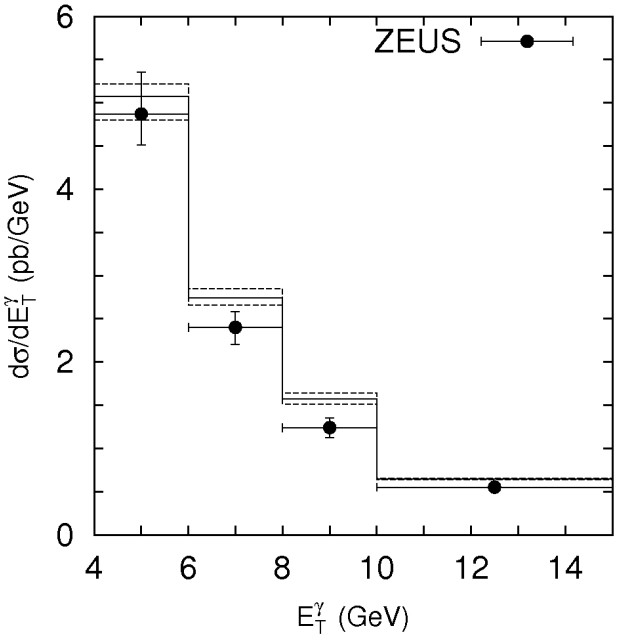

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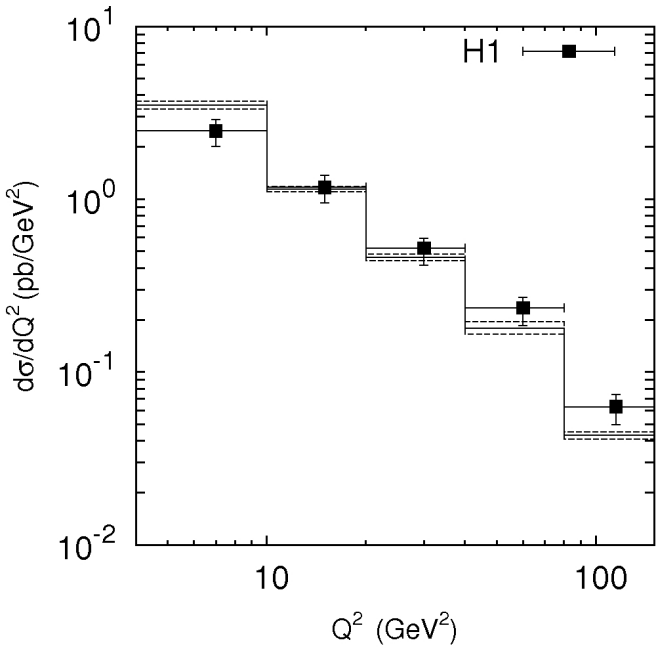
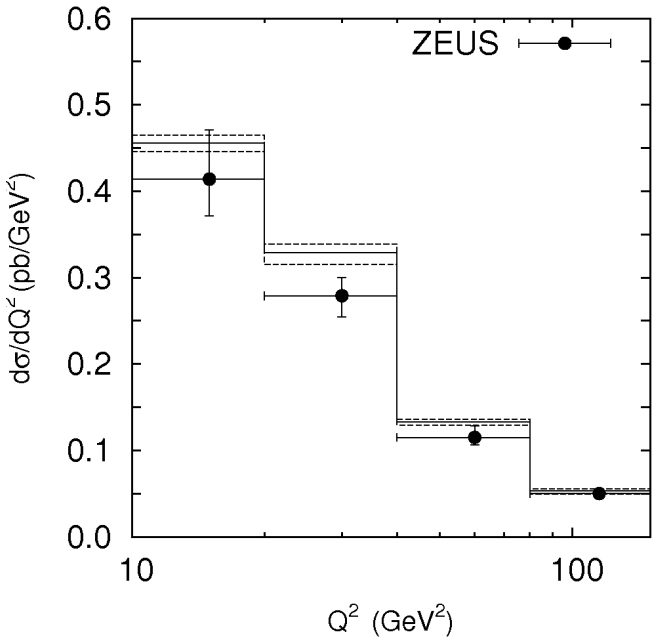
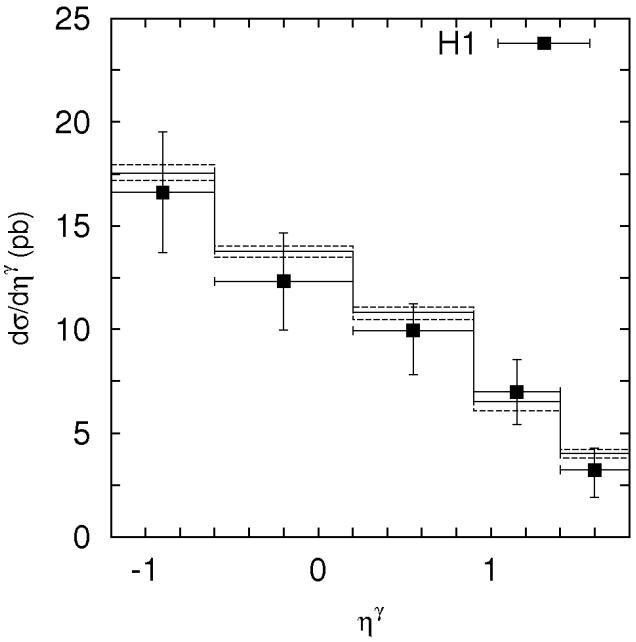
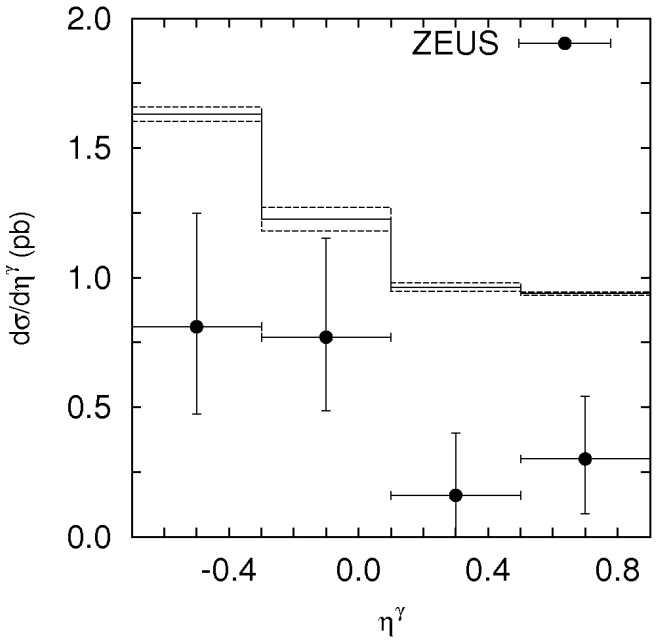




Numerical results: DIS

Different description of the H1 and ZEUS data
in the exclusive production case





Summary

- We presented the numerical calculations for the prompt photon production at HERA (both photo-production and DIS)
- We find a good agreement with the HERA data
- The transverse momentum of initial partons is important for description of the HERA data
- The higher-order QCD contributions are effectively simulated in the kt-factorization approach at LO level
- The contribution from the quarks are important and should be included into the non-collinear evolution cascade