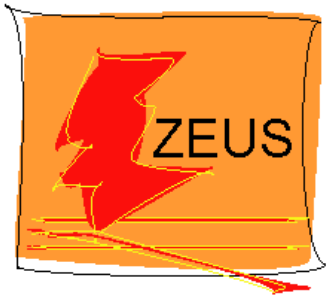


Further studies of Isolated photon production in Deep Inelastic Scattering at HERA

Speaker:
Olena Hlushchenko
(For the ZEUS collaboration)

Physics Institute III B

RWTH AACHEN UNIVERSITY

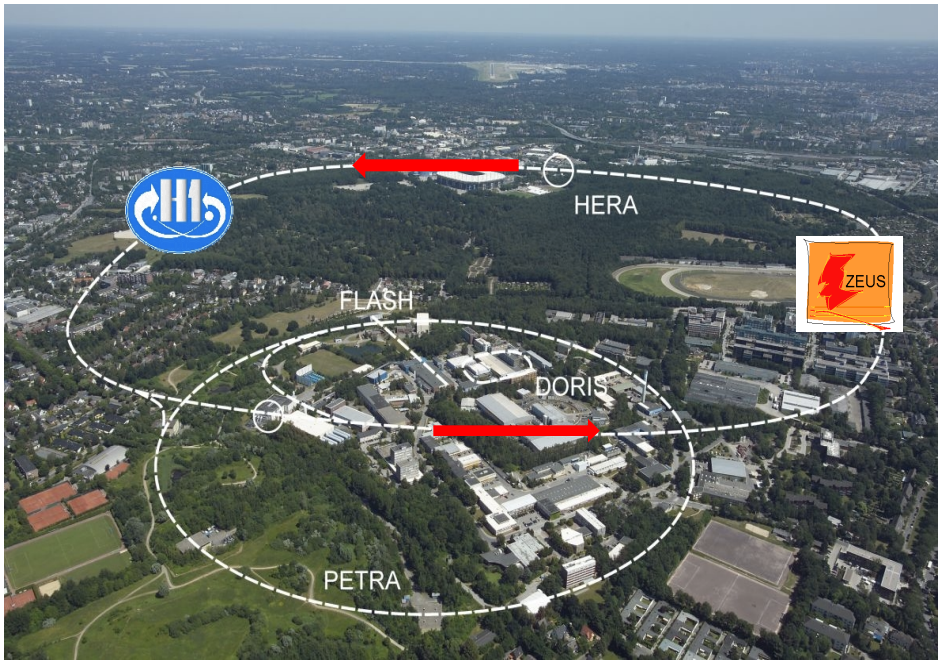
April 2017
Birmingham

ZEUS-prel-16-001

The ZEUS Detector at HERA

- Protons: 920 GeV
- Electron/Positrons: 27.5 GeV

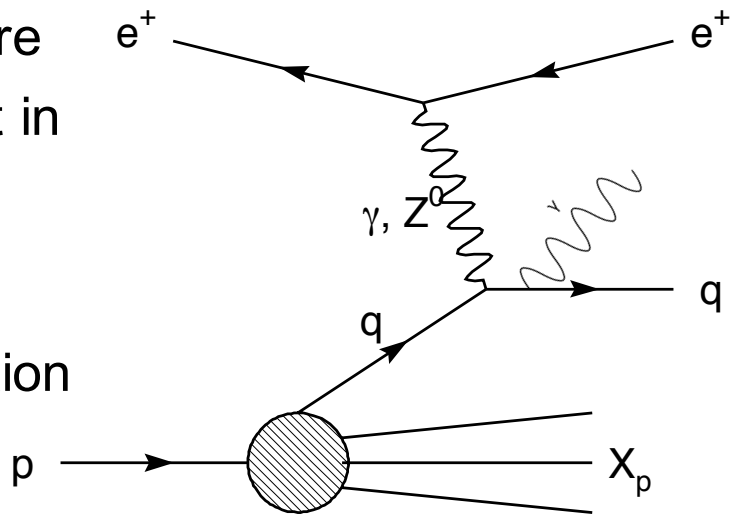
- Data
- HERA II period (2004-2007)
- Integrated luminosity: 326 pb^{-1}



Deep inelastic scattering

- Kinematics:
  - → $Q^2 = -q^2$ – virtuality 4-momentum transfer
  - → $y = \frac{P \cdot q}{P \cdot k}$ – inelasticity measure fraction of the lepton energy lost in the interaction
  - → $x = \frac{Q^2}{2P \cdot q}$ – Bjorken scaling variable. QPM: momentum fraction carried by the incoming parton
- DIS:
  - → $Q^2 > 1$ GeV²
  - → electron found

Neutral current



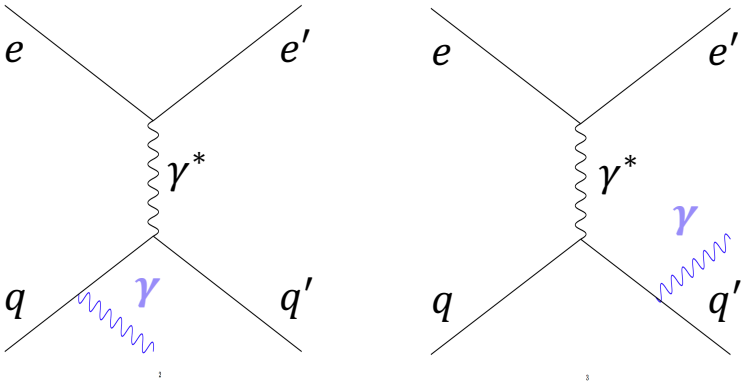
$$Q^2 = sxy$$

$$\sqrt{s} = 318 \text{ GeV}$$

Prompt photons

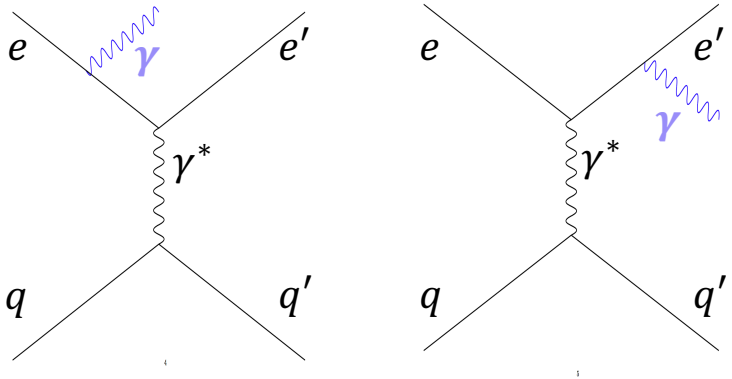
- Photons which are produced promptly in the collision - **before quarks and gluons form hadrons**

QQ - photons



prompt photons are emitted from a quark as part of hard process

LL - photons



photon is radiated from an incoming or outgoing lepton

Motivation

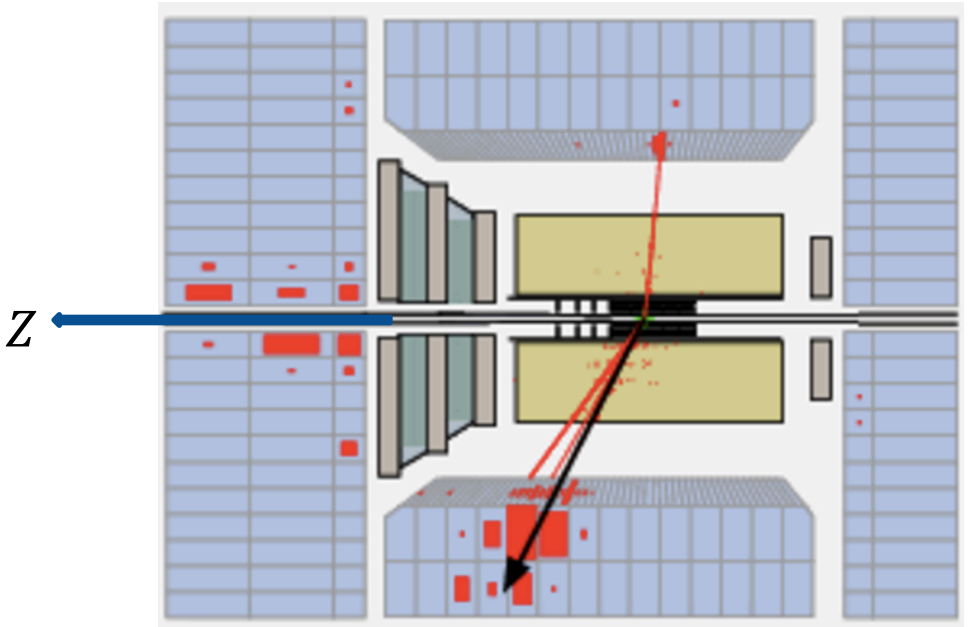
- A study of the dynamics of prompt photon emission can be used to probe different theoretical models such as the k_T-factorisation model and pQCD approaches
- It is interesting to know whether dynamics changes with virtuality scale
- A study of prompt photons can give a check of the proton's parton distribution functions
- Photons are a possible background to new physics processes: their production should be well understood
- Complements previous ZEUS publication of prompt photons in DIS *Physics Letters B 715 (2012) 88–97*

Event selection

- Prompt photon selection
  - → $4 < E_T^{\gamma} < 15\ \ GeV$
  - → $-0.7 < \eta_{\gamma} < 0.9$ – in BCAL
  - → $E_{EMC} / (E_{EMC} + E_{HAD}) > 0.9$
  - → $\Delta R(\eta, \varphi) < 0.2$
  - → $E_{\gamma} / E_{jet\ with\ \gamma} > 0.9$

Isolation In CAL

- Jet selection
  - → $E_T^{jet} > 2.5\ \ GeV$
  - → $-1.5 < \eta_{jet} < 1.8$
  - → Jet with $E_{T,max}^{jet}$
- Some Kinematics:
  - → $10 < Q_{el}^2 < 350\ GeV^2$
  - → $E_{e,corr} > 10\ GeV$
  - → $140^o < \theta_{el} < 180^o$
  - → $35 < E - p_z < 65, GeV$

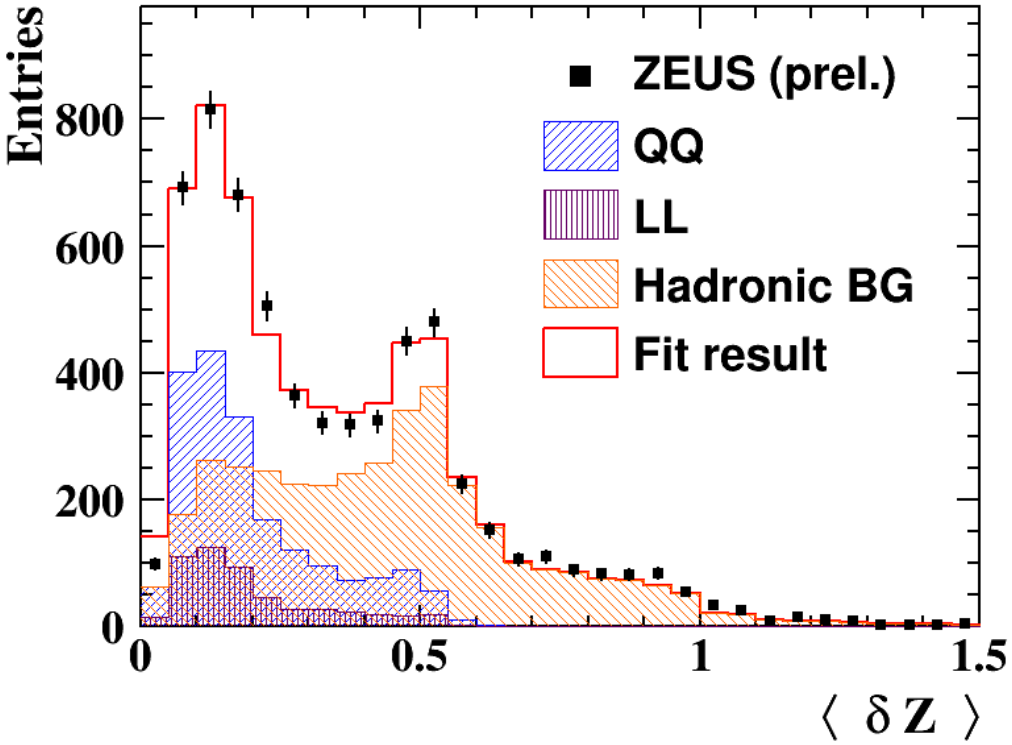


BCAL is finely segmented in the Z direction

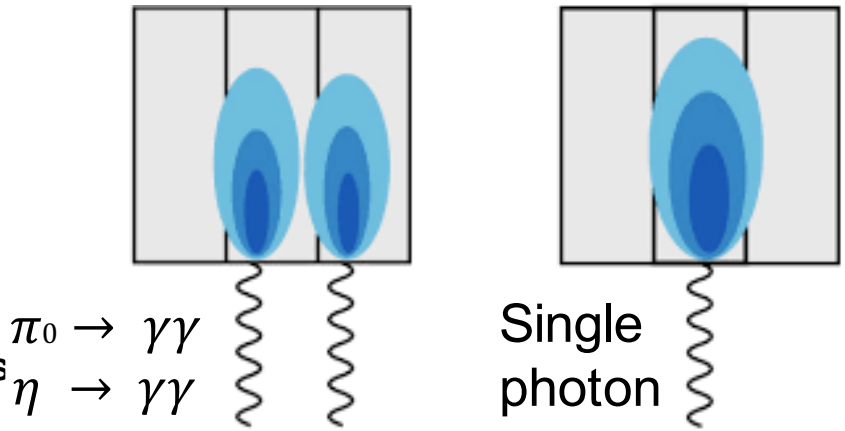
- $x_{\gamma} = \frac{\sum_{jet,\gamma}(E - p_z)}{2 y_{JB} E_e}$
- $x_p = \frac{\sum_{jet,\gamma}(E + p_z)}{2 E_p}$
- $\Delta\eta = \eta_{jet} - \eta_{\gamma}$
- $\Delta\varphi = \varphi_{jet} - \varphi_{\gamma}$
- $\Delta\varphi_{e,\gamma} = \varphi_e - \varphi_{\gamma}$
- $\Delta\eta_{e,\gamma} = \eta_e - \eta_{\gamma}$

Signal extraction

ZEUS Preliminary 16-001



Energy-weighted mean width of the electromagnetic shower (cluster) in calorimeter relative to its centroid



Summary of uncertainties

- Typical statistical uncertainty is **13%**
  - ΔAcc – acceptance uncertainty, **~3-4%** effect
- Typical systematic uncertainty is **10%**
  - Dominated by the energy scale
- Fit of fraction of QQ in data
  - Δa – uncertainty of fit parameter, **~1%** effect
- $\Delta \mathcal{L}$ – 2%, but not included in the following plots

Cross Sections

- For a given observable Y , the production cross section:

$$\frac{d\sigma}{dY} = \frac{N(\gamma_{QQ})}{A_{QQ} \cdot \mathcal{L} \cdot \Delta Y} + \frac{d\sigma_{LL}^{MC}}{dY}$$

$N(\gamma_{QQ})$ - number of QQ photons extracted from the fit,

ΔY - bin width,

$\mathcal{L}$ - total integrated luminosity,

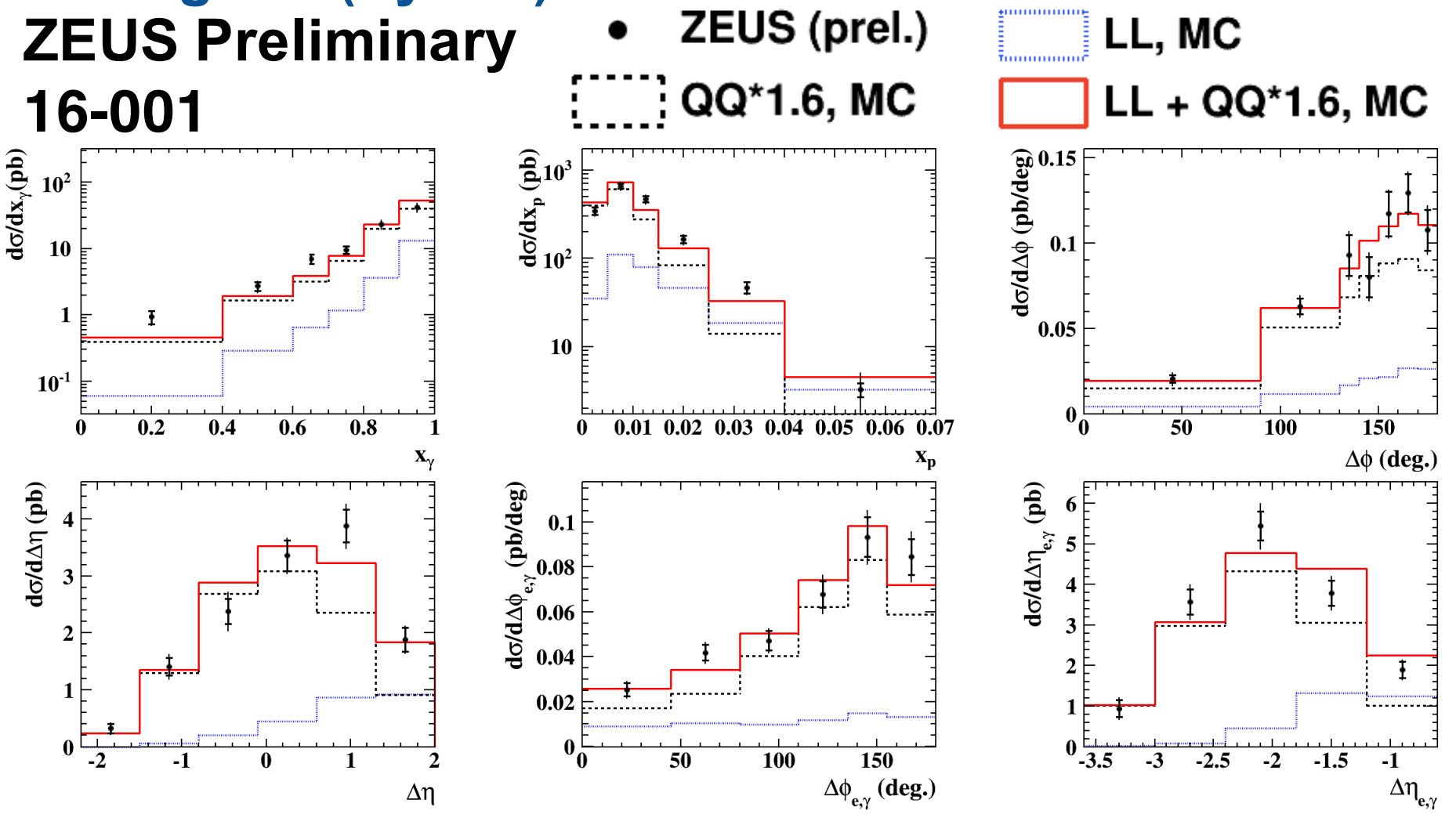
$\frac{d\sigma_{LL}^{MC}}{dY}$ - cross section for LL photons

A_{QQ} - ratio of the number of events reconstructed to those generated in a given bin

Cross Sections compared to LO + Leading Log QQ (Pythia) and LL (Ariadne) MC

ZEUS Preliminary

16-001

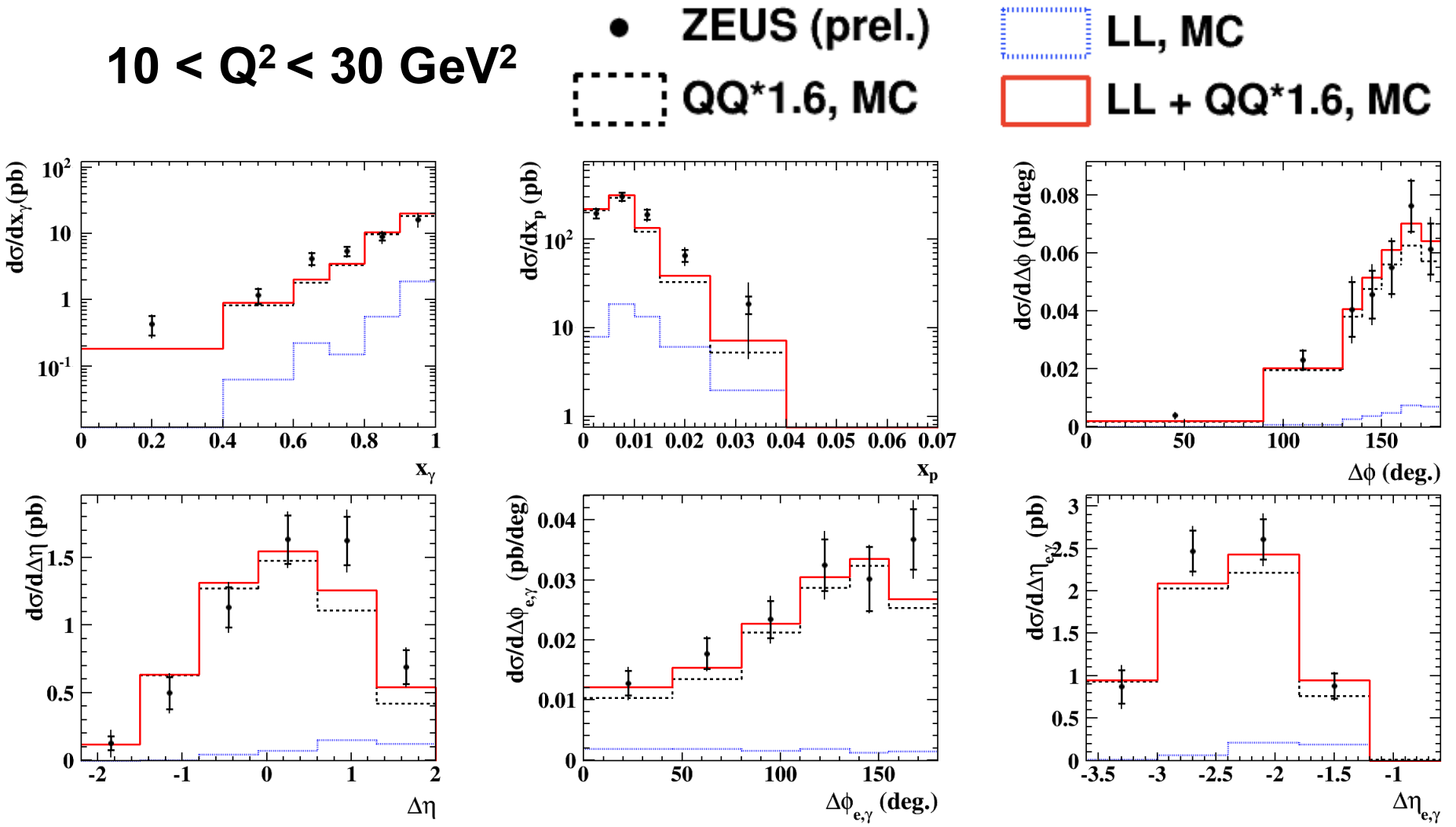


Two Q^2 kinematical regions on full statistics

- Cross sections for two separate kinematic regions: $10 < Q^2 < 30$ GeV^2 and $30 < Q^2 < 350$ GeV^2 were also calculated
- $Q^2 = 30$ GeV^2 was chosen to divide available data sample into 2 with similar numbers of events

ZEUS Preliminary 16-001

$10 < Q^2 < 30\ \mathrm{GeV}^2$



ZEUS Preliminary 16-001

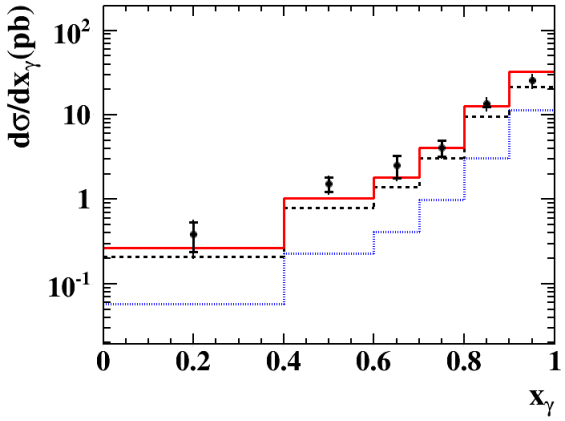
$30 < Q^2 < 350\ \mathrm{GeV}^2$

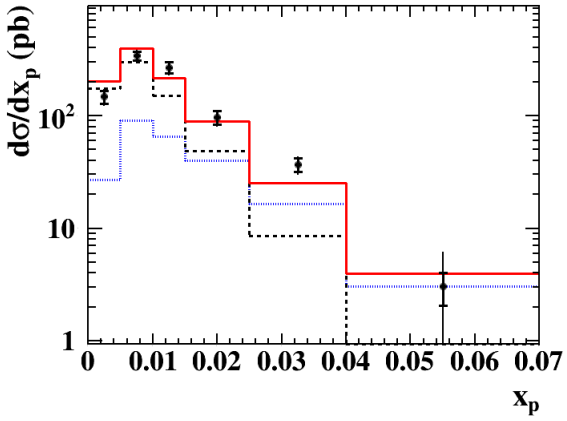
ZEUS (prel.)

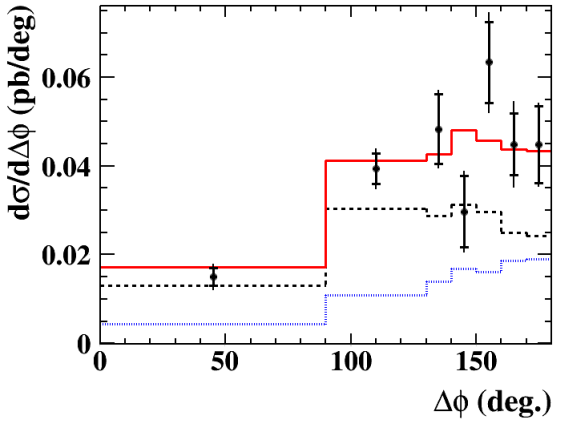
QQ*1.6, MC

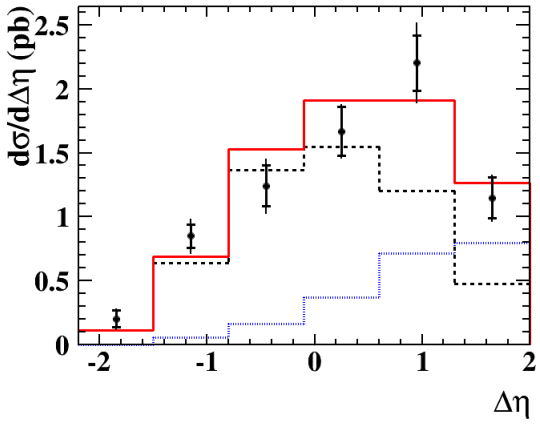
LL, MC

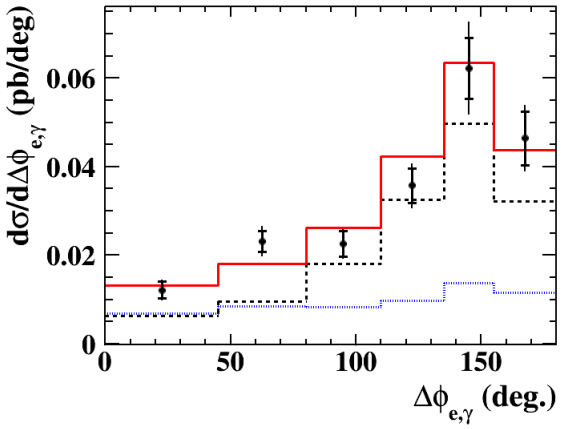
LL + QQ*1.6, MC

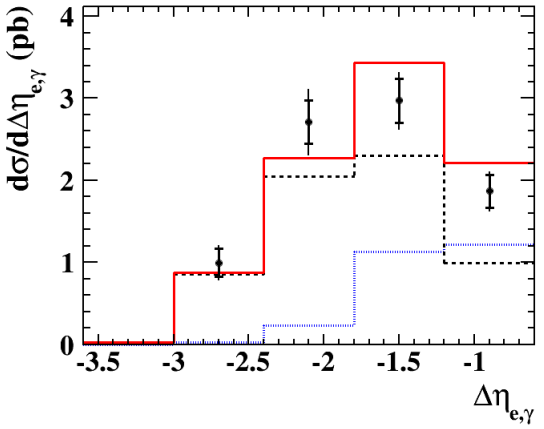






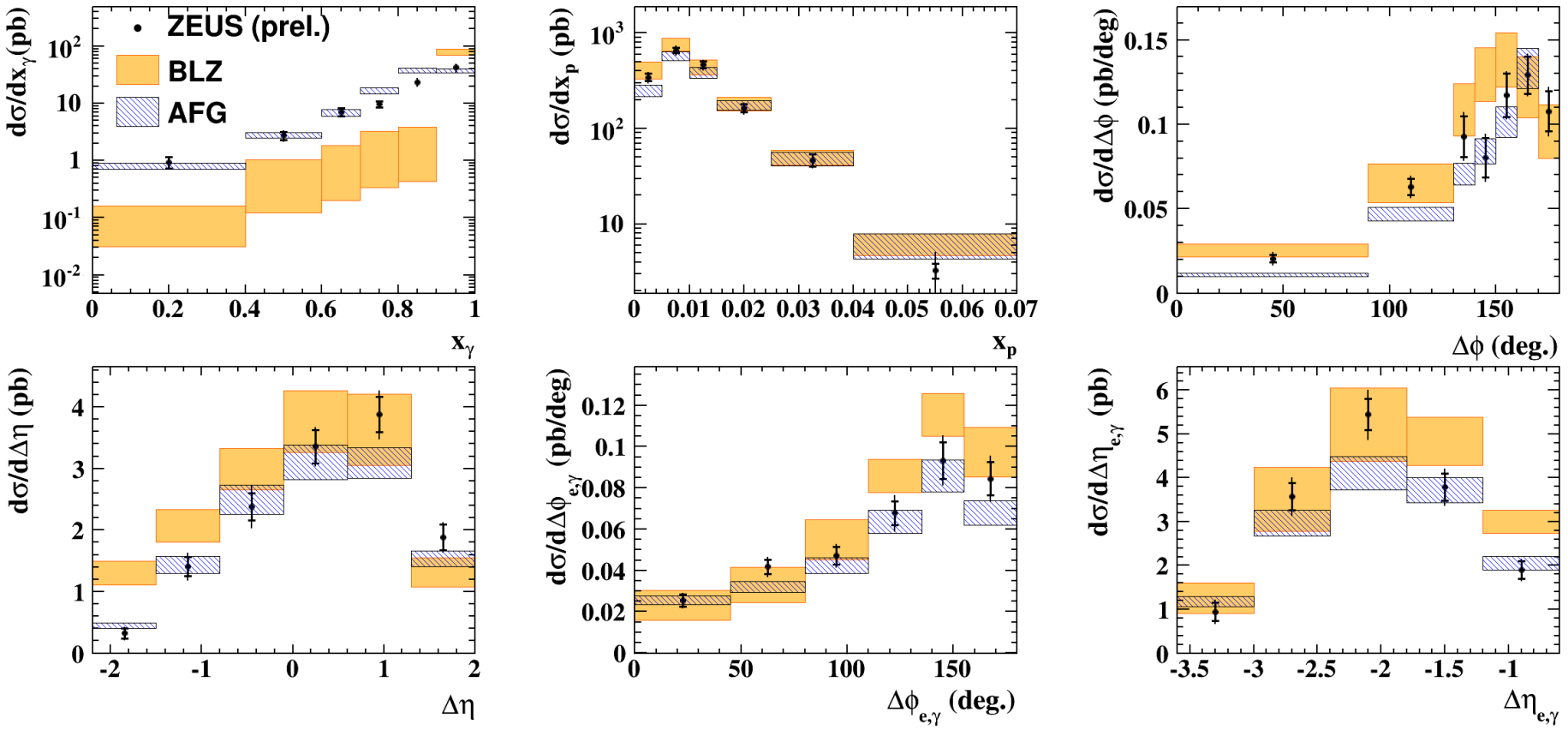






Comparison with theory

ZEUS Preliminary 16-001



Aurenche, Fontannaz and Guillet : LAPTH-005/17 LPT-Orsay 16-88

Baranov, Lipatov and Zotov: PRD81, 094034 (2010)

Conclusion

- Experimental differential cross sections have been obtained for x_γ, x_p, $\Delta\eta$, $\Delta\varphi$, $\Delta\eta_{e,\gamma}$, $\Delta\varphi_{e,\gamma}$ correlated observables
- Pythia describes the shape of the data reasonably well in both Q^2 ranges separately when rescaled by a factor 1.6, as in the previous ZEUS DIS publication
- AFG (NLO) calculations show an overall good agreement to the data
- k_t-factorisation (BLZ) predictions show a fair agreement with the data with the exception of x_γ and $\Delta\eta$

  → However x_γ and $\Delta\eta$ - variables sensitive to the gluon radiation - are reasonably well described by Pythia

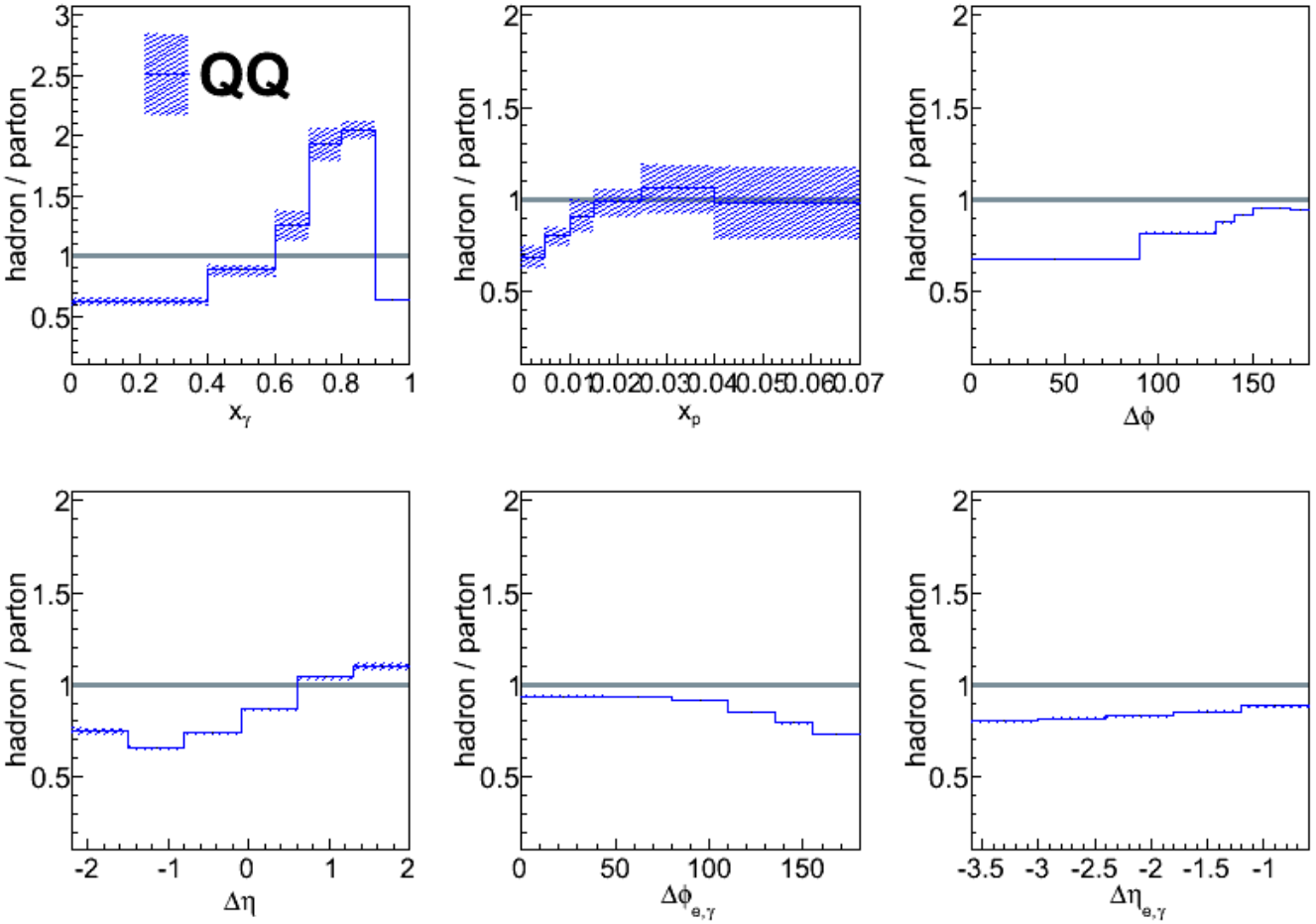
Appendix

Systematics uncertainties

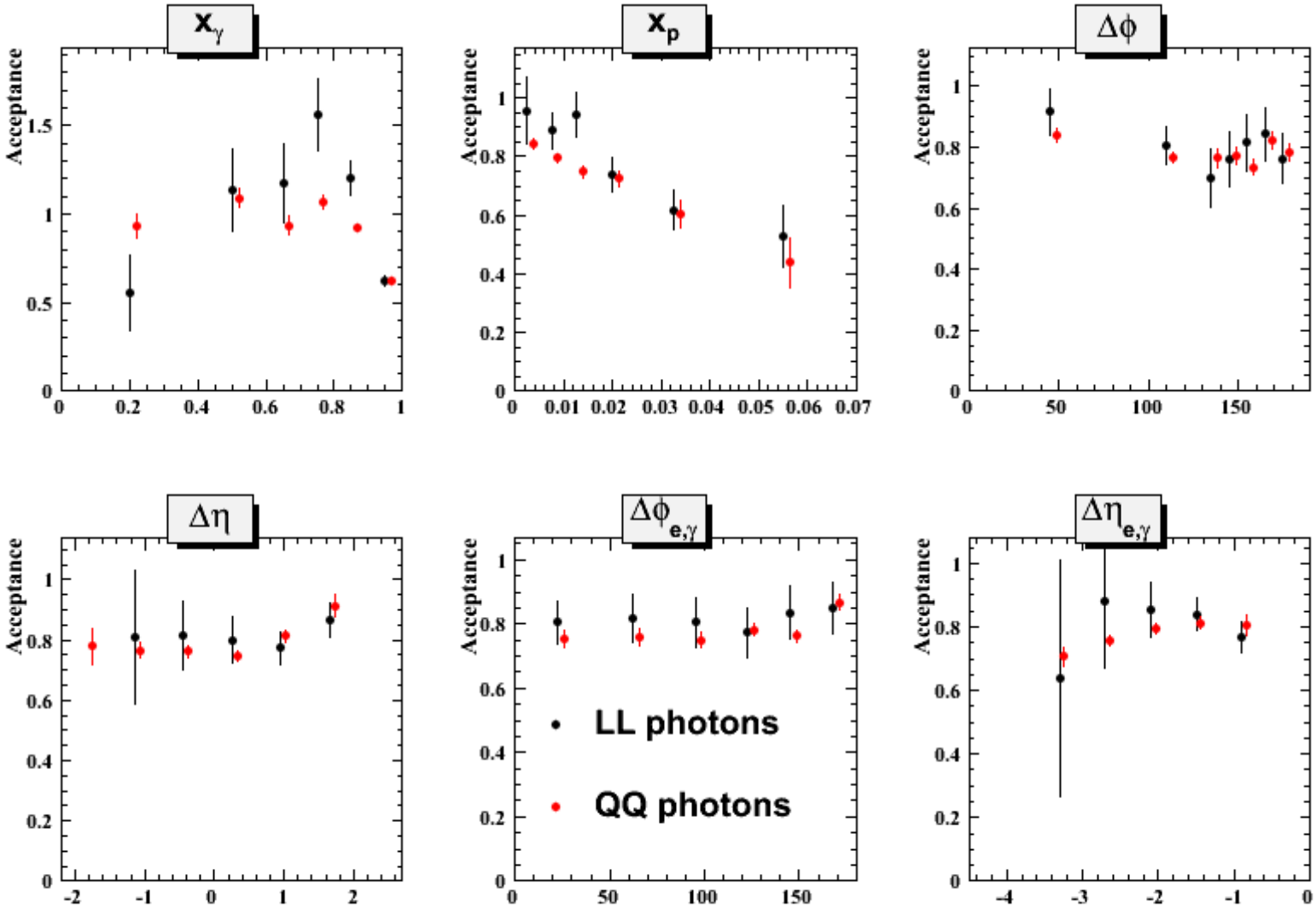
- Before applying cuts for the event selection the values of such variables as:
  - → E_γ - energy of the photon varied by $\pm 2\%$ (~6% effect)
  - → E_{jet}- energy of the jet varied by
    $\pm 1.5\%$ for $E_{jet} > 10$ GeV,
    $\pm 2.5\%$ for $6 < E_{jet} < 10$ GeV,
    $\pm 4\%$ for $E_{jet} < 6$ GeV
    (7% effect)
  - → E_e- energy of the electron varied by $\pm 2\%$ (~1% effect)
- The dependence on the modelling of hadronic background by Ariadne was investigated by changing the upper fit limit in range [0.6, 1.0] (~5% effect)
- Uncerrtainty on the acceptance due to Pythia model is taking as half of the change attributable to the reweighting (~1% effect)

Hadronization corrections

- $\kappa = \dfrac{had\ level}{part\ level}$ $\qquad \delta\kappa = \sqrt{\dfrac{C^2(D+E)+ D^2(C+E)+E^2(C+D)+2CDE}{(C+E)^4}}$
- Here: $C = had\ \&\ part$, $D = had\ \&\ not\ part$, $E = not\ had\ \&\ part$



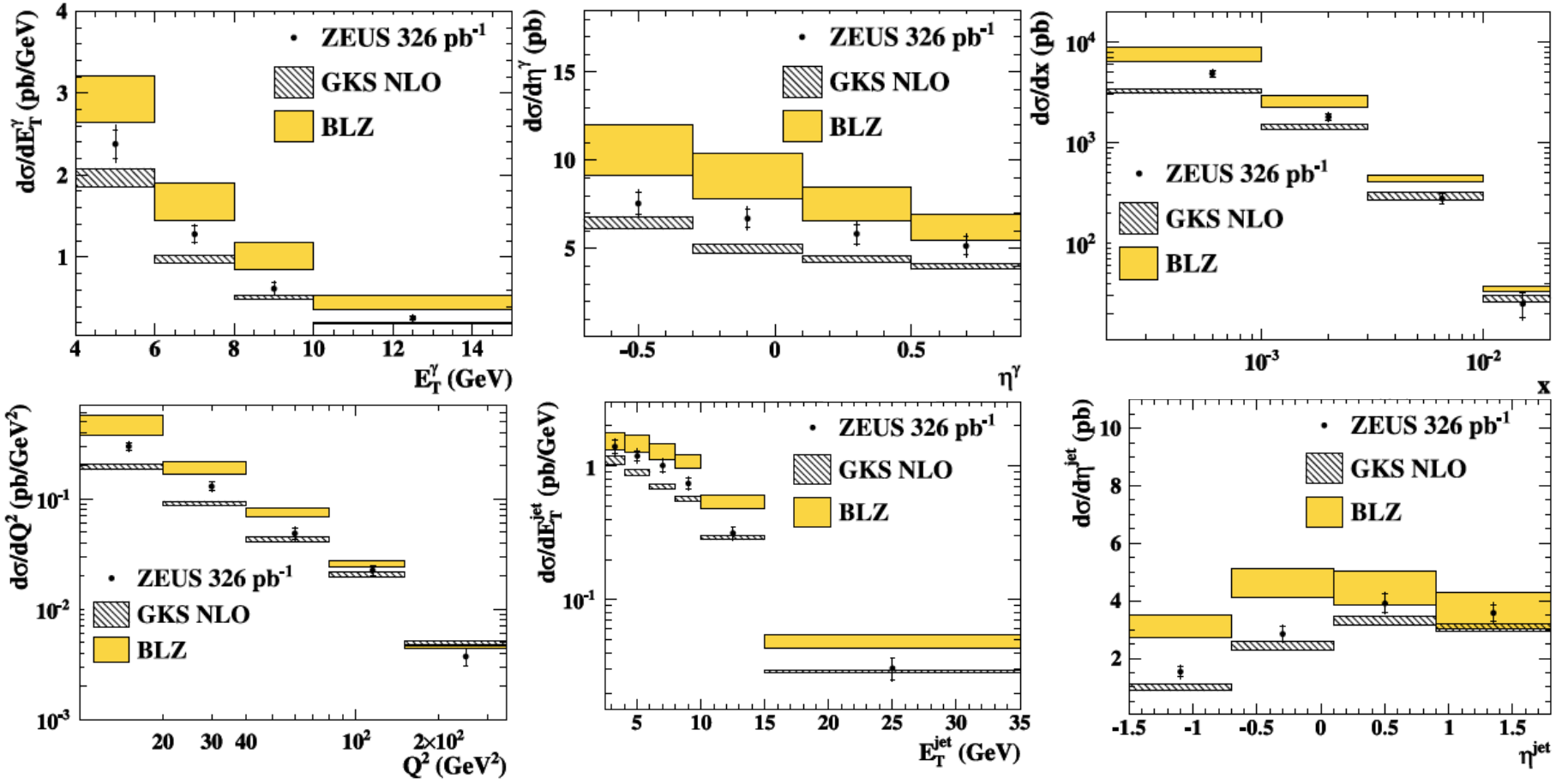
Acceptance


x_γ
x_p
$\Delta\phi$
$\Delta\eta$
$\Delta\phi_{e,\gamma}$
$\Delta\eta_{e,\gamma}$
Acceptance
LL photons
QQ photons

Theoretical models

- Baranov, Lipatov and Zotov (BLZ) : Rev. D 81 (2010) 094034
  - → approach is based on the calculation of the CS using the convolution of the off-shell matrix element and unintegrated quark-distribution (therefore the kt-factorisation).
  - → In the kt-factorization theory some part of final state jets can originate not only from hard subprocess, but also from the parton evolution cascade in initial state.
  - → To determine the 4-momenta of these jets (in particular, their rapidities) model approximation was used
  - → Lambda_QCD = 200 MeV, number of flavours Nf = 4, scale muR^2 = muF^2 = Q^2; MSTW'2008 pdfs as an input for the KMR partons
- Aurenche, Fontannaz and Guillet (AFG) : Rev. D 81 (2010) 094034 – **NLO theory with conventional PDFs**
  - → Predictions are available as CS with pt cut betwen pT_cut in center-of-mass frame 2.5 GeV/c and .5 GeV/c

Previous study



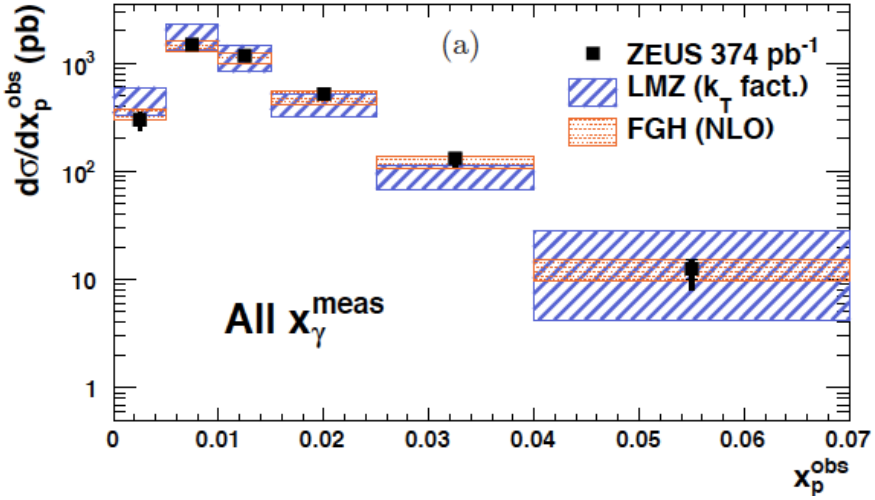
The previous ZEUS DIS publication measured x, Q^2, E_T^{γ}, η_{γ}, E_T^{jet} and η_{jet}.

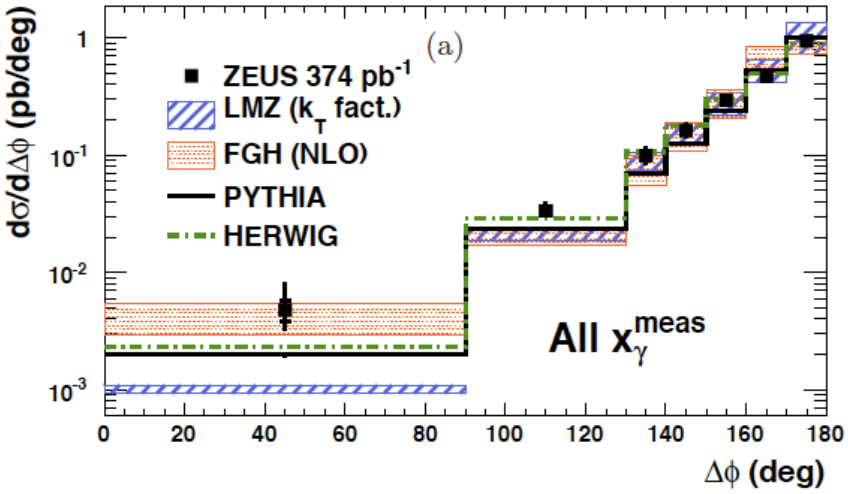
(*Physics Letters B 715 (2012) 88–97*)

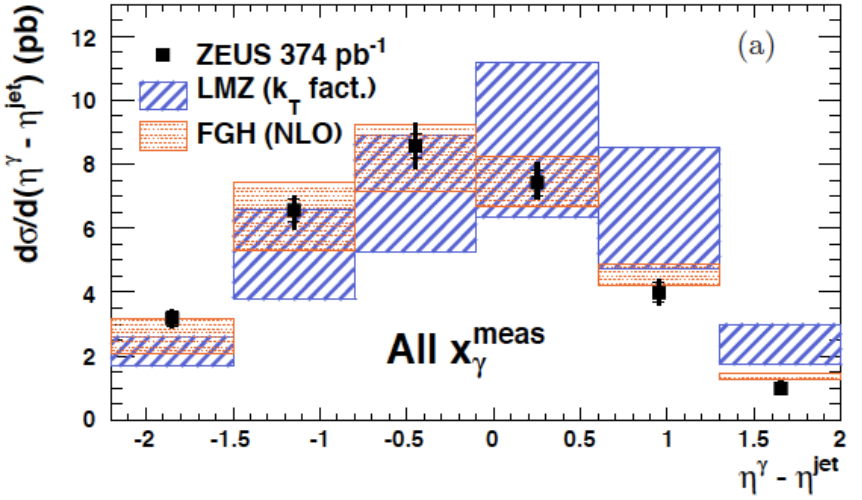
Study of photon-jet and photon-electron variables

- $x_\gamma = \frac{\sum_{jet,\gamma}(E - p_Z)}{2 y_{JB} E_e}$
- $x_p = \frac{\sum_{jet,\gamma}(E + p_Z)}{2 E_p}$
- $\Delta\eta = \eta_{jet} - \eta_\gamma$
- $\Delta\varphi = \varphi_{jet} - \varphi_\gamma$
- $\Delta\varphi_{e,\gamma} = \varphi_e - \varphi_\gamma$
- $\Delta\eta_{e,\gamma} = \eta_e - \eta_\gamma$

A similar kind of analysis was previously done for photoproduction ($Q^2 < 1$ GeV^2)







arXiv:1405.7127v2 [hep-ex]