


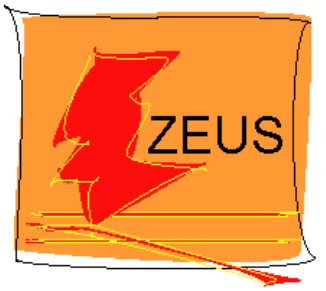

Measurement of isolated photons with and without accompanying jets at HERA

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DESY / National Technical University of Ukraine “Kyiv Polytechnic Institute”
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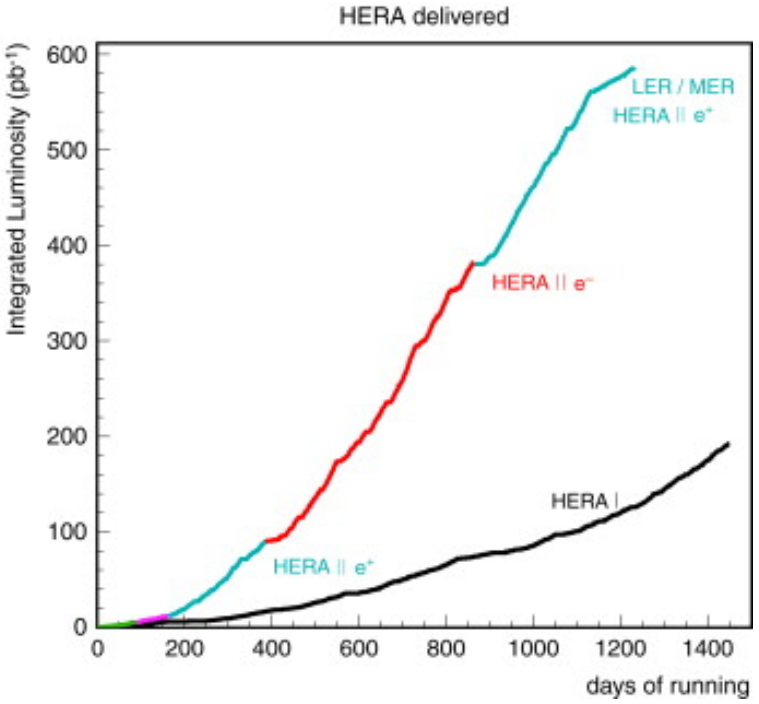
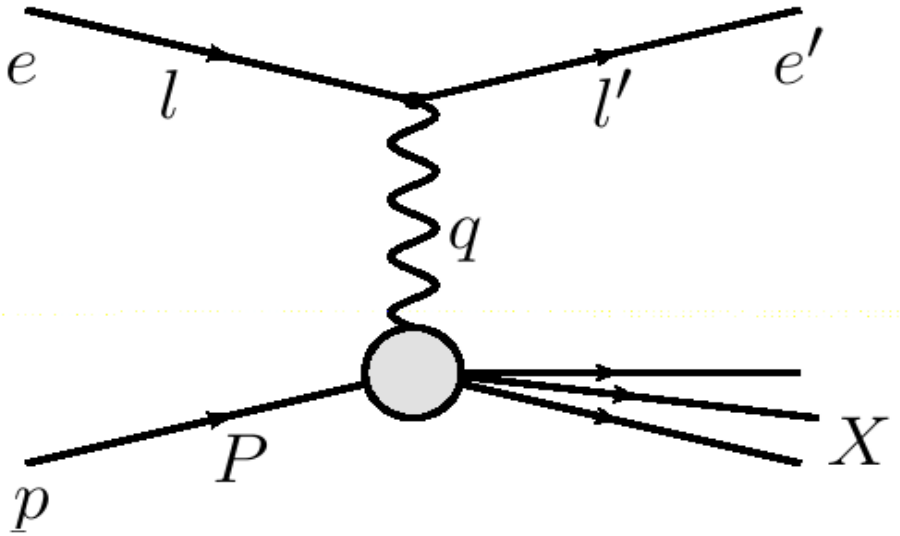
PHP: ZEUS-prel-13-001
DIS: Phys. Lett. B 715 (2012) 88-97

On behalf of the ZEUS collaboration

HERA collider





– **Electrons** / **Positrons** : 27.5 GeV

– **Protons**: 920 GeV

$\sqrt{s} = 318$ GeV

Kinematics:

$Q^2 = -q^2 = -(l - l')^2$

$$y = \frac{P.q}{P.l}$$

$$x_{Bj} = \frac{Q^2}{2P.q}$$

$Q^2 = x_{Bj} y s$

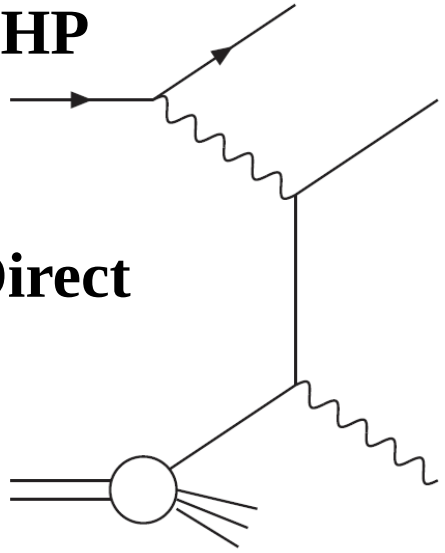
$Q^2 \leq 1$ GeV^2 : photoproduction (PHP)

$Q^2 \geq 1$ GeV^2 : DIS

Isolated photons

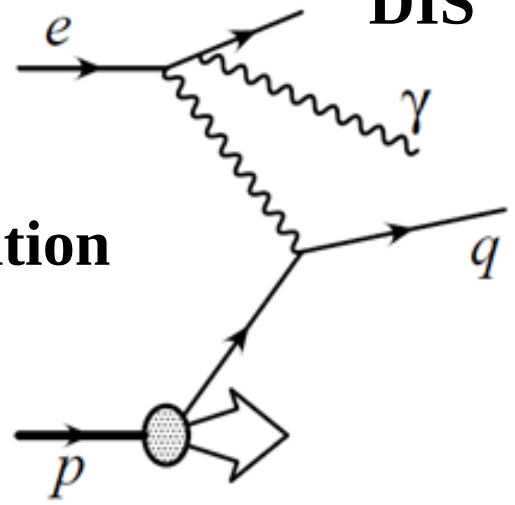
PHP

Direct



DIS

LL-radiation



Prompt photon: one that emerges directly from a pQCD process. It is useful to reduce fragmentation component by isolation requirement.

- A useful tool to test QCD model to order α^3
- Can be used to measure and constrain the parton densities of proton and photon

- Photoproduction (PHP): a quasi-real exchanged photon (Q^2 ~~ 0 GeV^2)
- DIS processes: photons also radiated from incoming and outgoing leptons

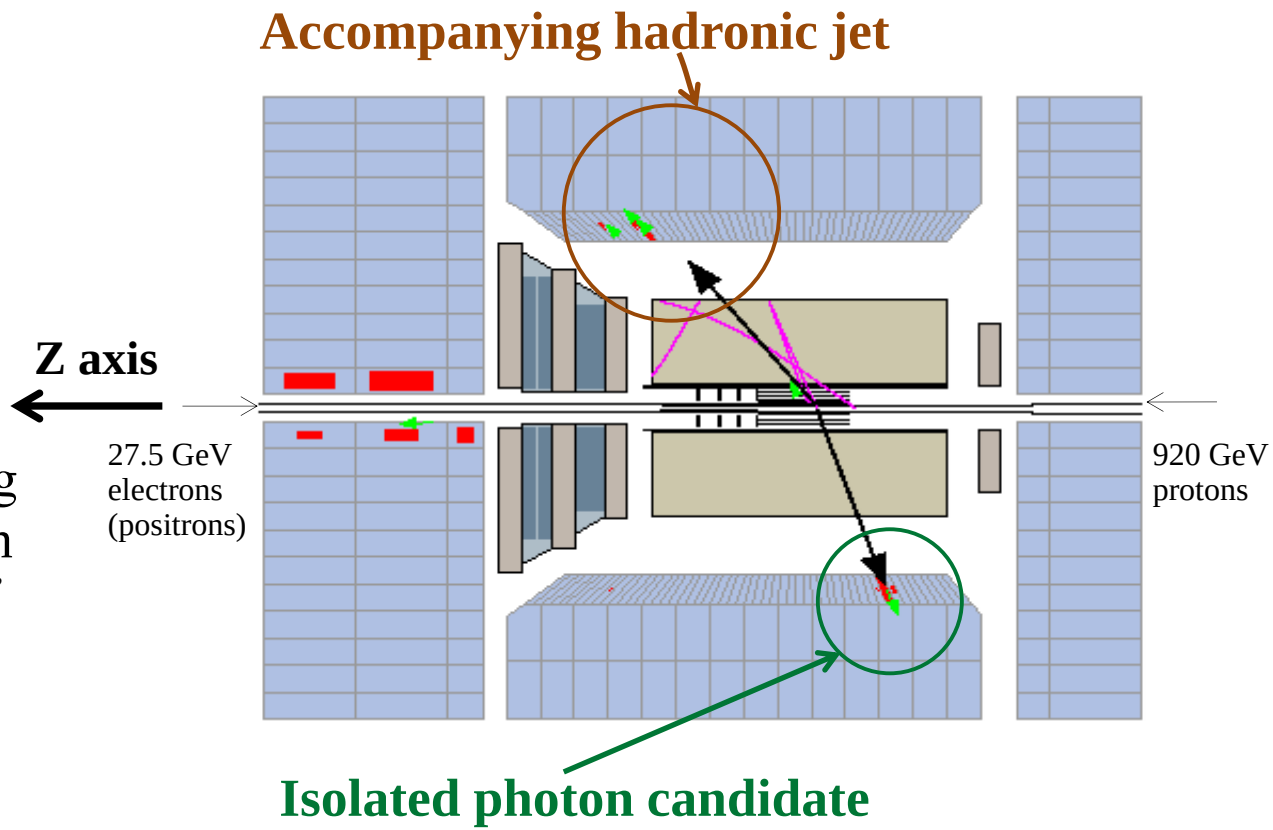
Isolated photons with and without jet requirement in photoproduction

Data samples. Event selection

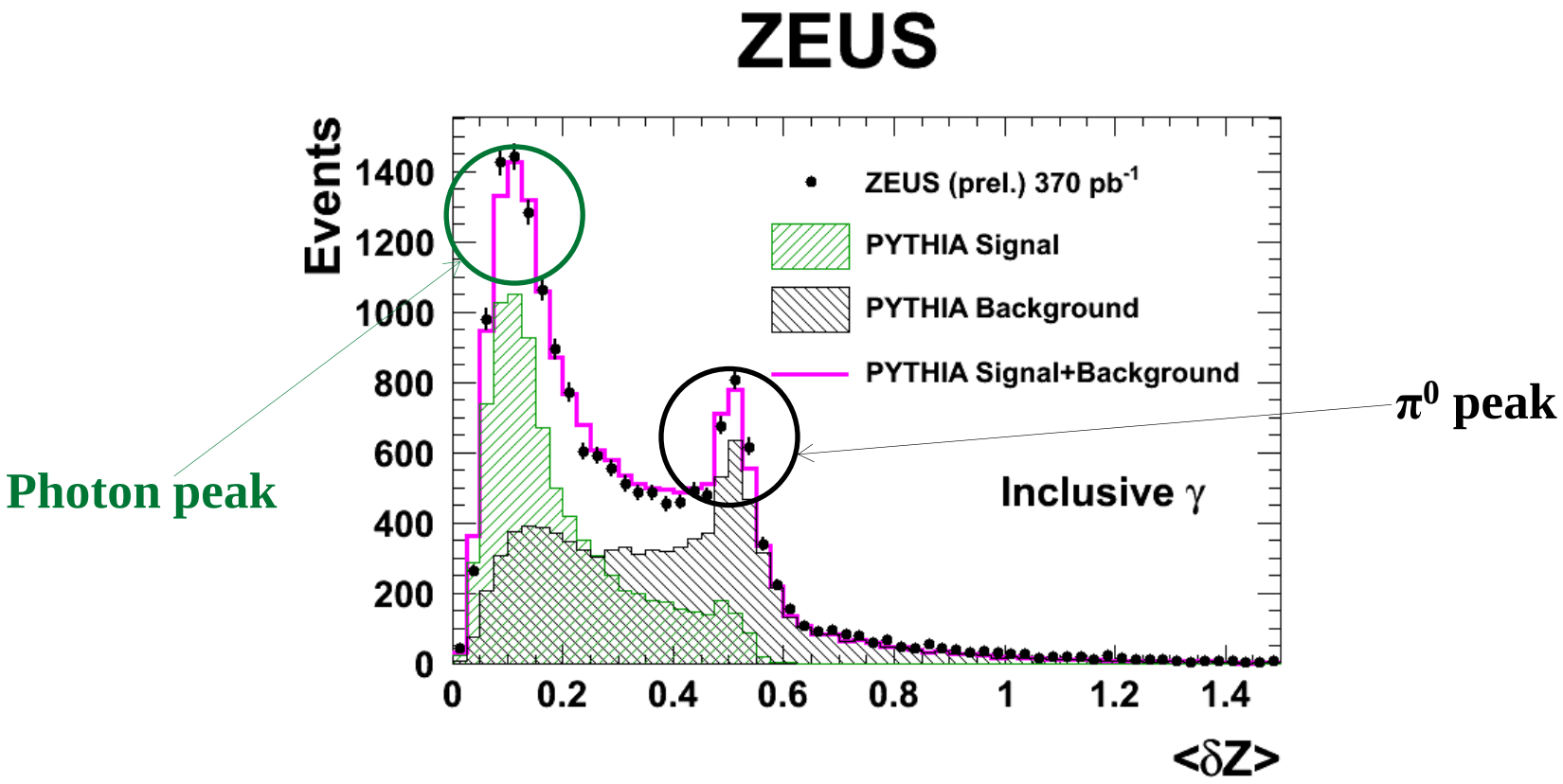
- ZEUS HERA II 2004-2007: 370 pb^{-1} positron and electron data
- Monte Carlo Signal: PYTHIA
- Monte Carlo Background: PYTHIA (photons from: $\pi^0 \rightarrow \gamma\gamma$, $\eta \rightarrow \gamma\gamma$, $\eta \rightarrow \pi^0\pi^0\pi^0$)

- **Photon:**
- $Q^2 < 1\ GeV^2$
- $6 < E_T^{\gamma} < 15$ GeV
- $-0.7 < \eta^{\gamma} < 0.9$
- Isolation: In any "jet" containing the photon candidate, the photon must contain at least 0.9 of $E^{\text{"jet"}}$
- No tracks in cone 0.2 about γ

- **Accompanying jet:**
- $4 < E_T^{jet} < 35$ GeV
- $-1.5 < \eta^{jet} < 1.8$



Photon identification

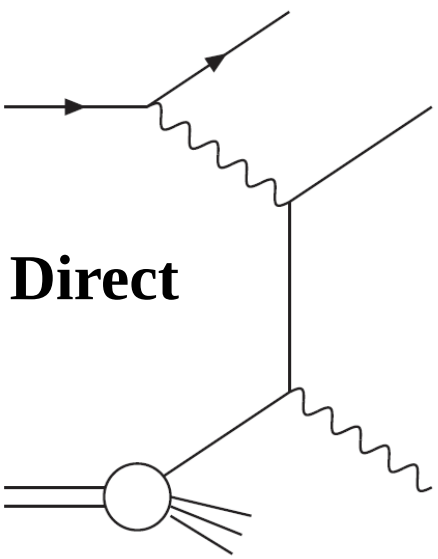


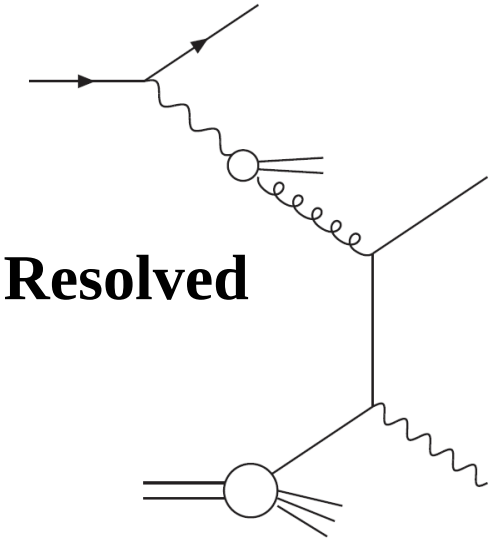
The photon signal is distinguished from the background

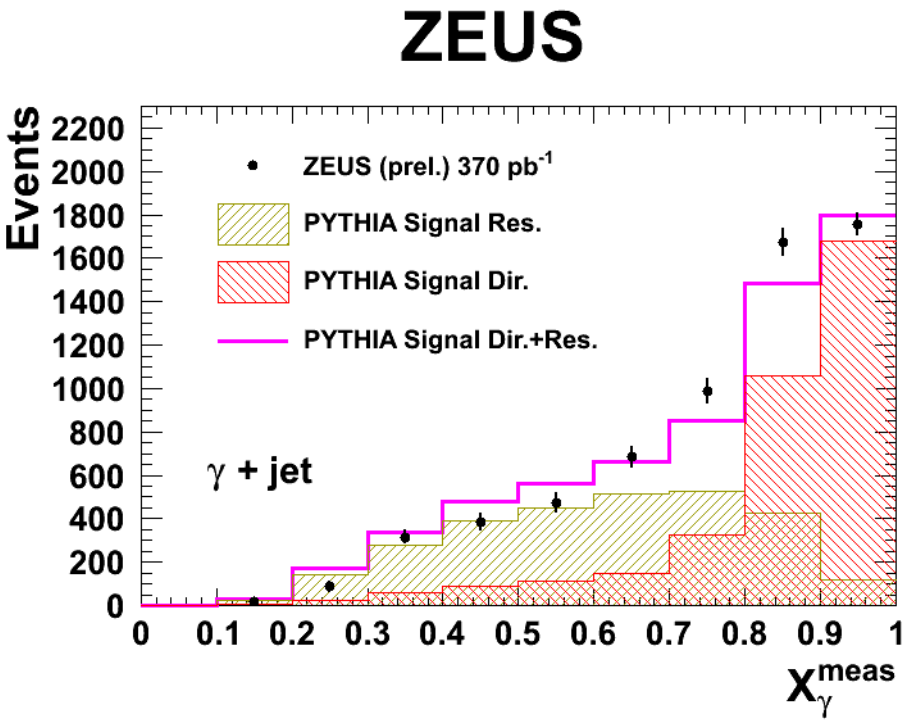
using the <δZ> = the energy weighted mean width of the electromagnetic cluster in the Z direction

$$< \delta Z > = \frac{\sum_i E_i |Z_i - Z_{cluster}|}{w_{cell} \sum_i E_i}$$

Definition of direct/resolved mix







X_γ^{meas} = fraction of the incoming photon energy given to the final state photon and jet to lowest-order approximation

$$X_\gamma^{meas} = \frac{E^\gamma + E^{jet} - p_Z^\gamma - p_Z^{jet}}{E^{all} - p_Z^{all}}$$

Each measured cross-section point has a <dZ> fit.

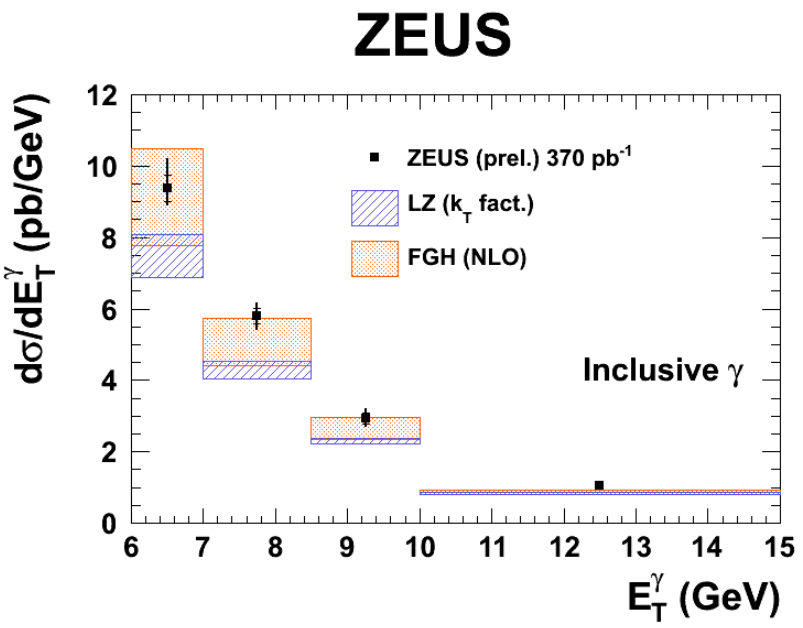
Theoretical predictions

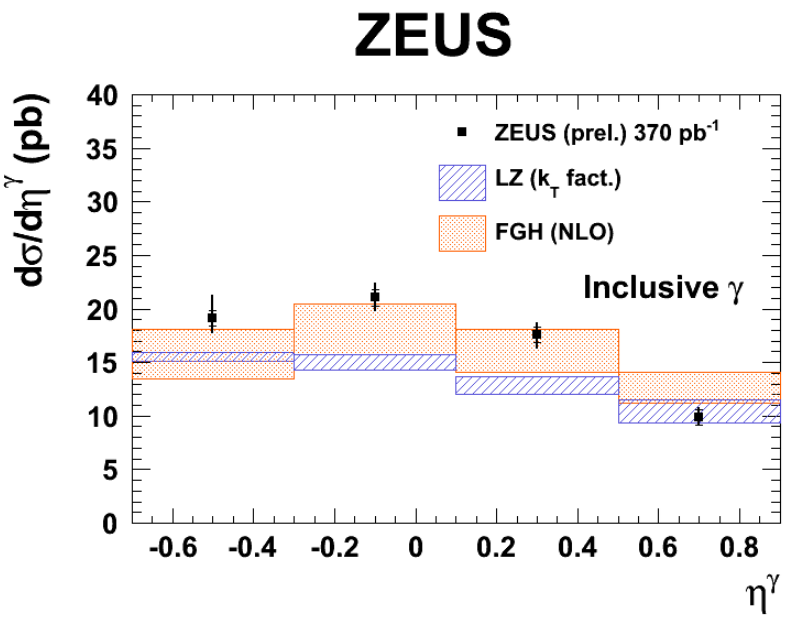
Comparison is made to predictions by

- **M. Fontannaz, J.-P. Guillet, G. Heinrich (FGH)**
- LO and NLO and the box diagram term calculated explicitly.
- Fragmentation processes calculated in terms of a fragmentation function.
- Renormalisation scale gives an uncertainty.

- **A. V. Lipatov, N. P. Zotov (LZ)**
- the k_T factorisation method.
- use of unintegrated proton and photon parton densities at LO.
- Uncertainties come from renormalisation and factorisation scales varied by factors 0.5 and 2 simultaneously.

Inclusive photon cross sections

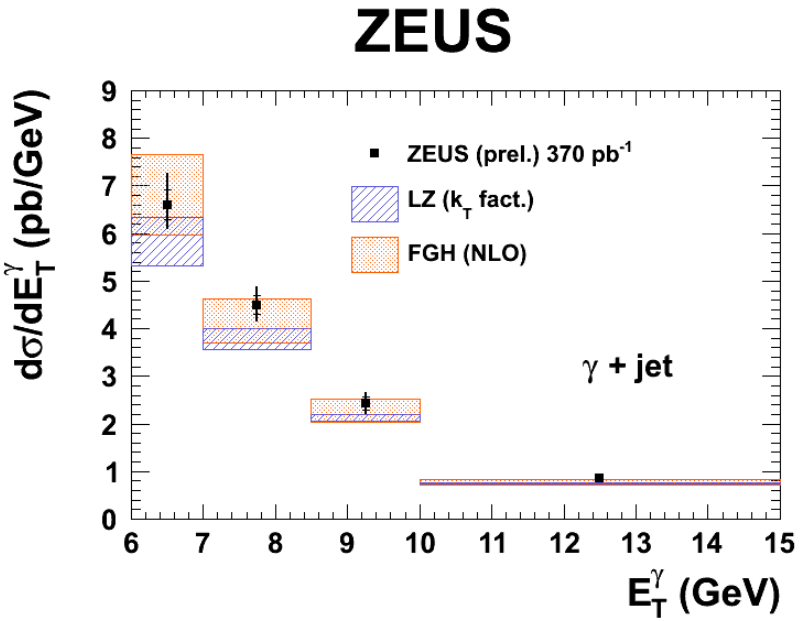


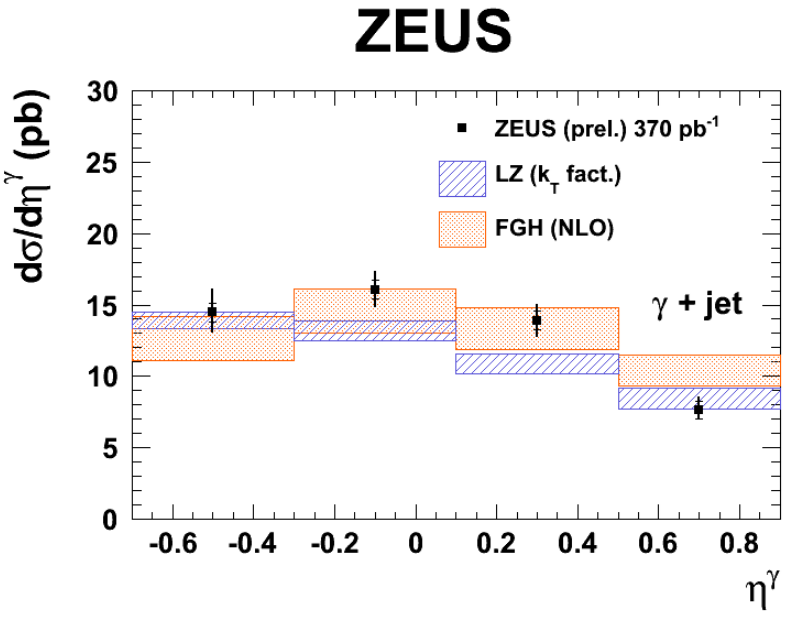


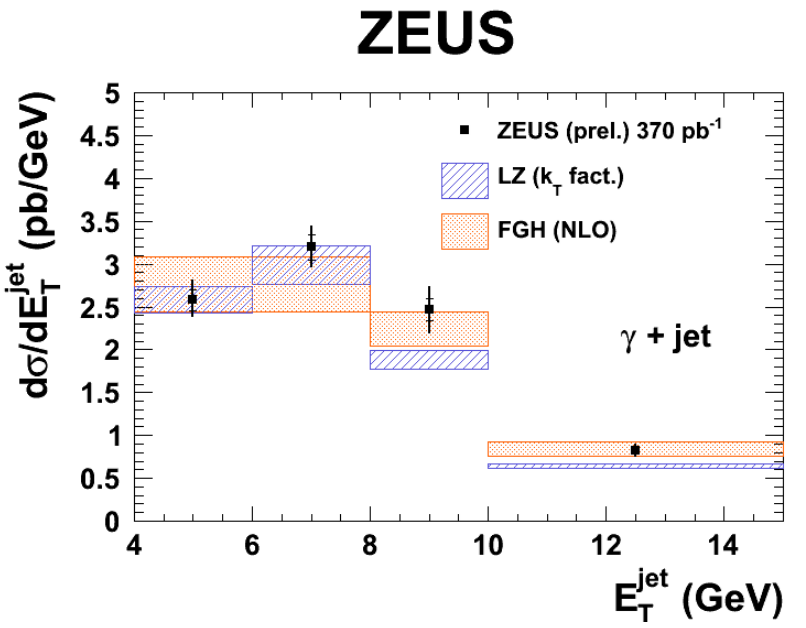
- Main source of data systematics is due to photon and jet energy scale uncertainties.

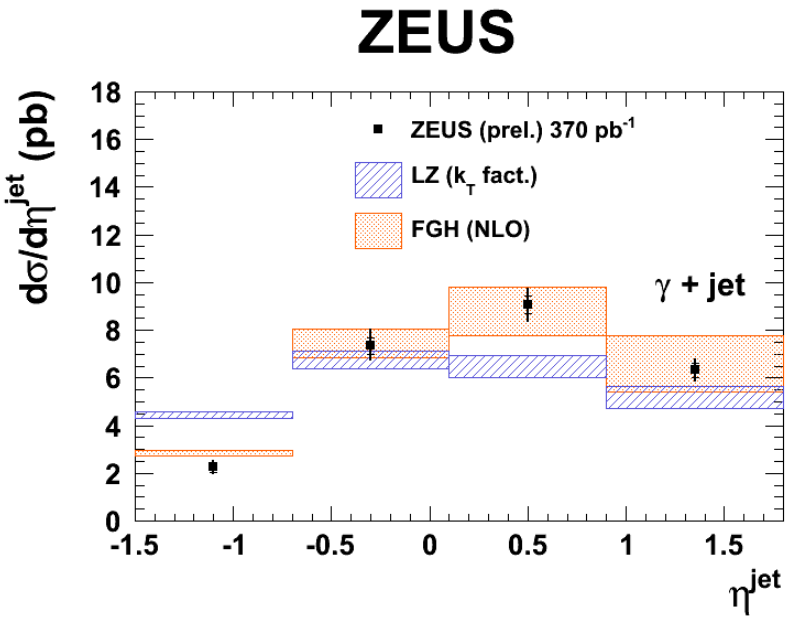
- LZ tends to underestimate data.
- Within errors there is a good description of data by FGH.

Cross sections for photon plus jet



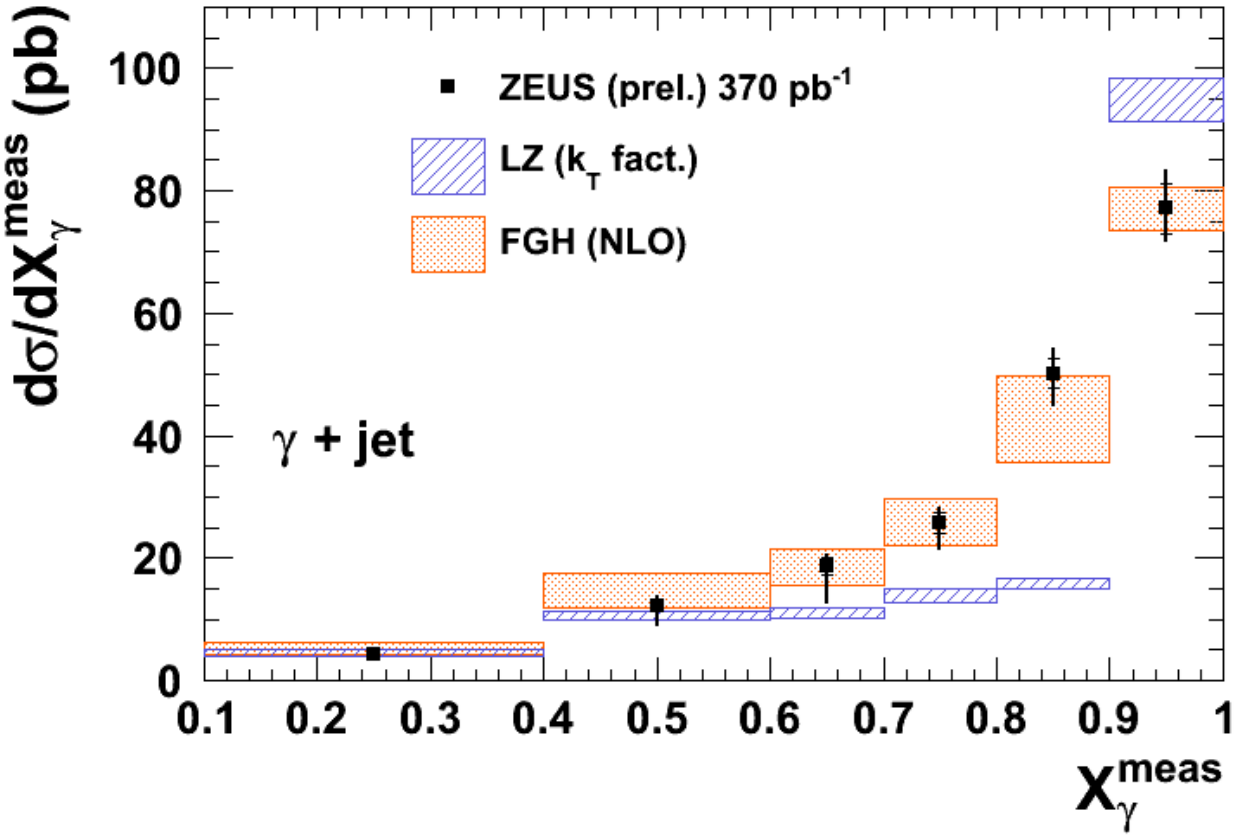






- Within uncertainties FGH describes data better than LZ.

Cross sections for photon plus jet

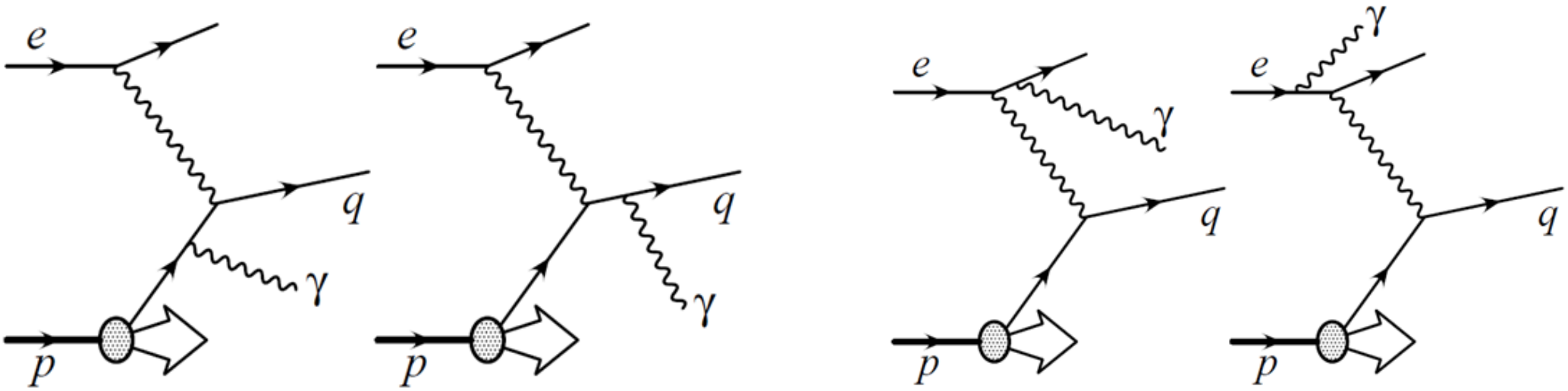


- Good description of full distribution by FGH.

Isolated photons plus jets in DIS

Isolated photons plus jets in DIS

QQ **LL**



Isolated photons from:

- QQ-radiation (incoming or outgoing quark)
- LL-radiation (ISR, FSR)

Photons + jets expected to be more sensitive to the underlying partonic process, compared to inclusive photons (P.L.B 687 (2010) 16-25)

Data samples. Event selection

• ZEUS HERA II integrated luminosity ≈ 330 pb^{-1}

Monte Carlo:

• PYTHIA for QQ processes

• ARIADNE for LL processes and for background (neutral mesons from jets)

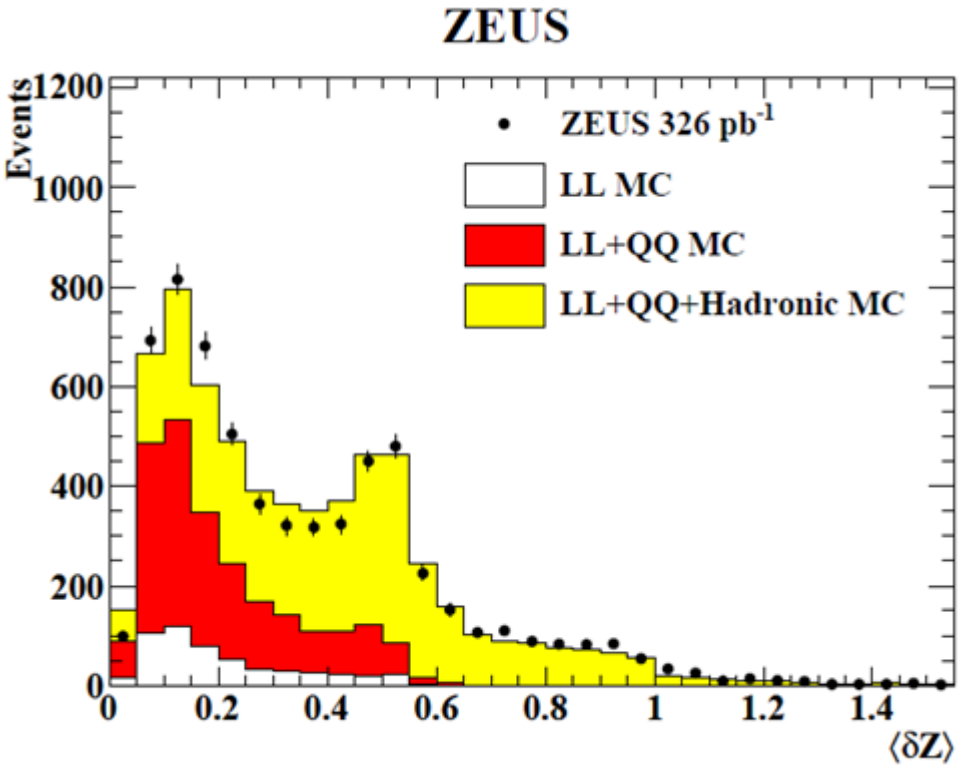
Photon isolation:

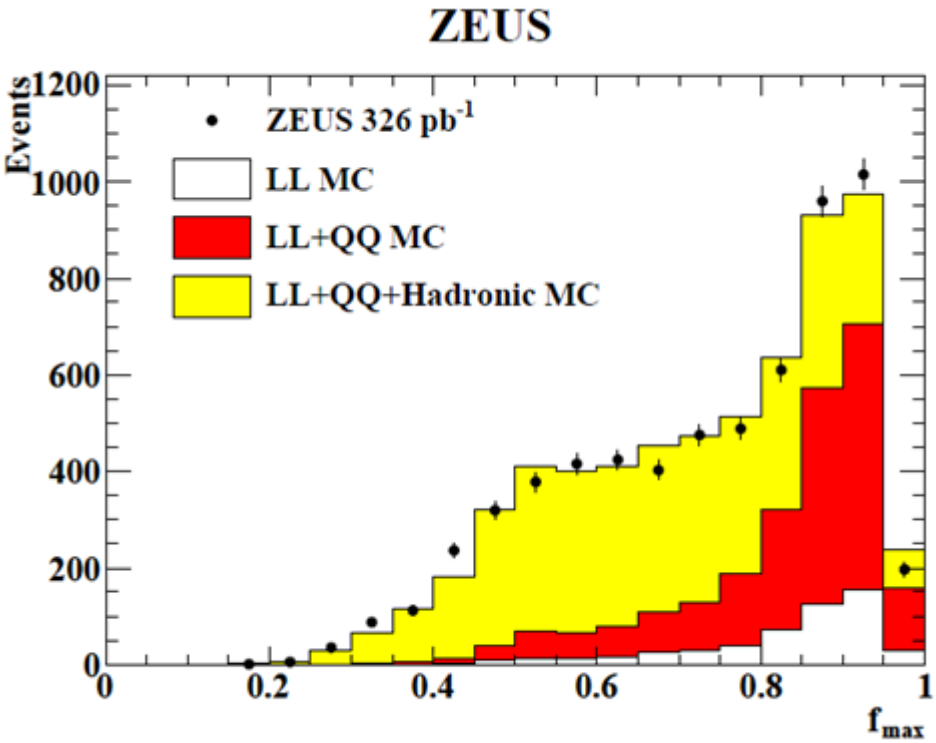
• In any “jet” containing the photon candidate, the photon must contain at least 0.9 of $E^{\text{“jet”}}$

• No tracks in cone 0.2 about γ

- **Electron:**
  - $E'_{elec} > 10$ GeV
  - $140 < \theta_{elec} < 180^{o}$
- **Photon:**
  - $10 < Q^2 < 350$ GeV^2
  - $4 < E_T^{\gamma} < 15$ GeV
  - $-0.7 < \eta^{\gamma} < 0.9$
- **Accompanying jet:**
  - $E_T^{jet} > 2.5$ GeV
  - $-1.5 < \eta^{jet} < 1.8$

Photon identification



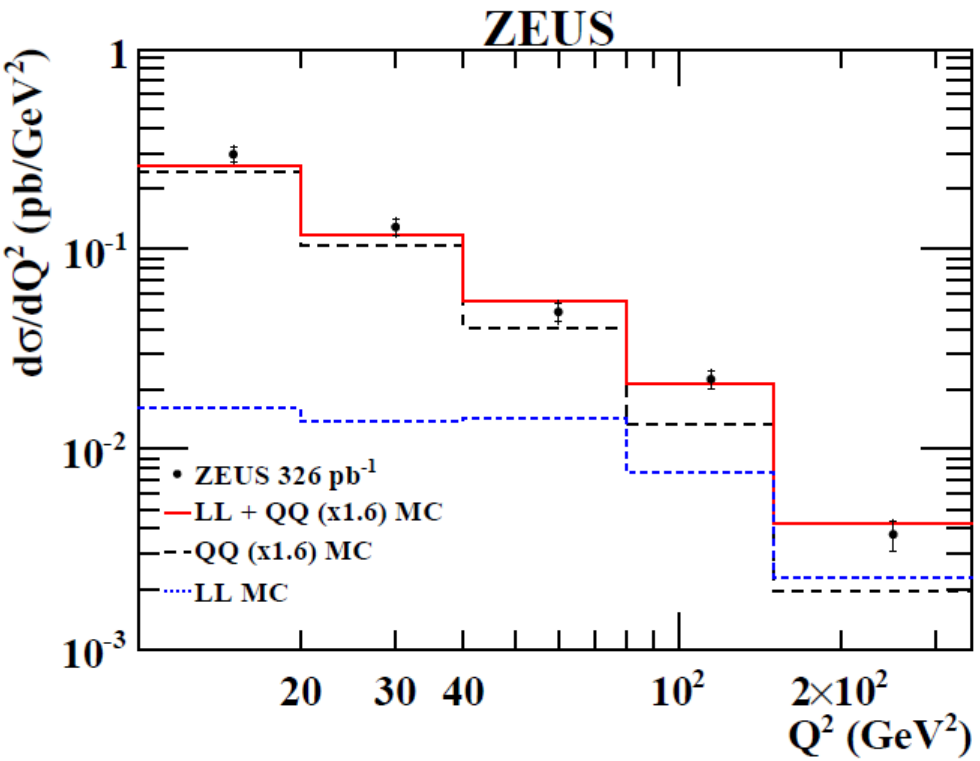


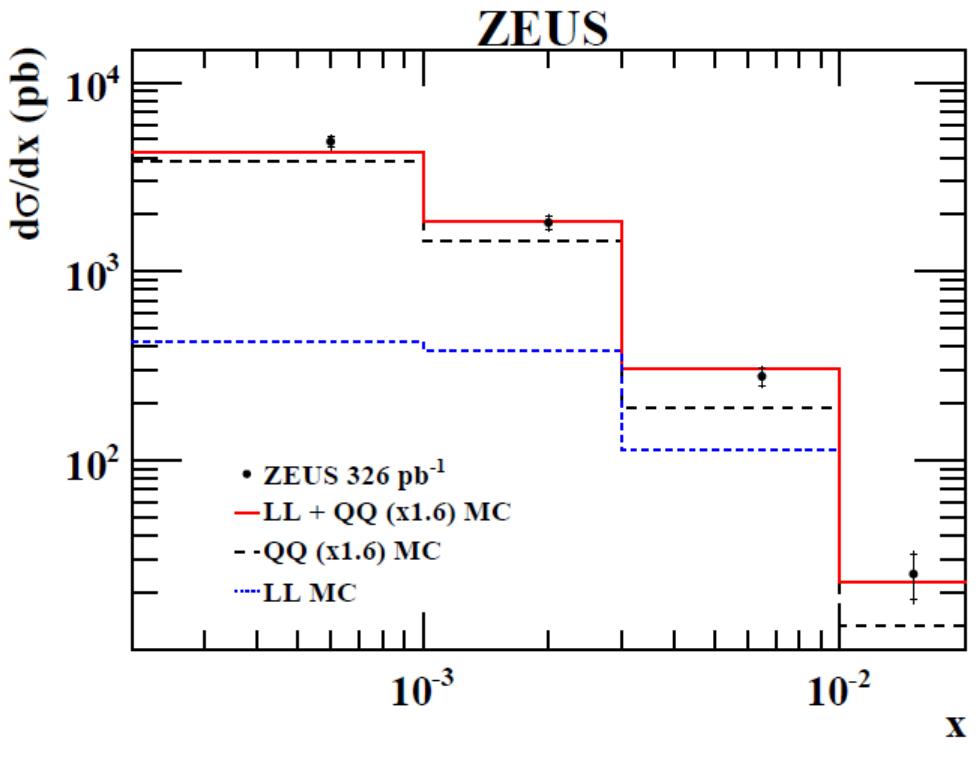
<δZ> = weighted mean width of the electromagnetic cluster in the Z direction

Cross-check from f_{max} = fraction of photon-candidate shower contained in electromagnetic calorimeter cell with largest signal.

Results were consistent with <dZ> method

Cross sections for DIS photon plus jet

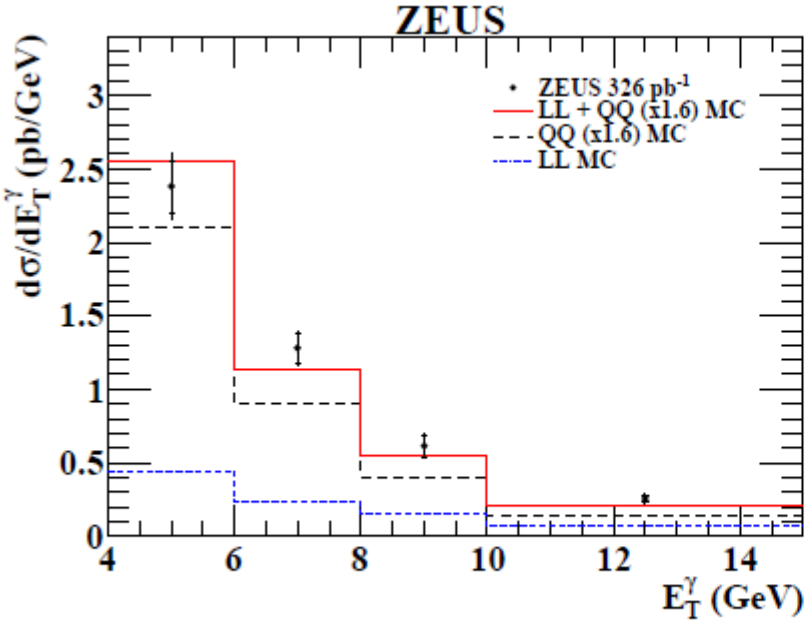


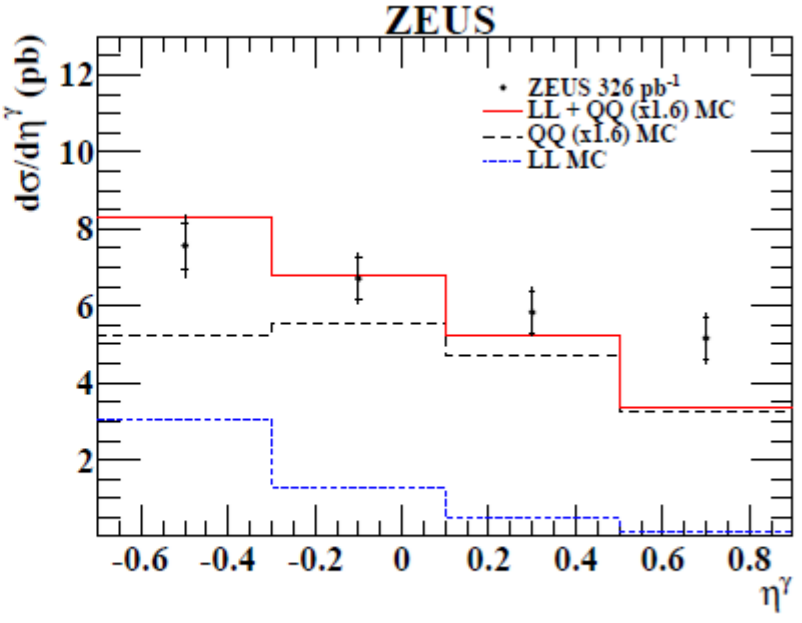


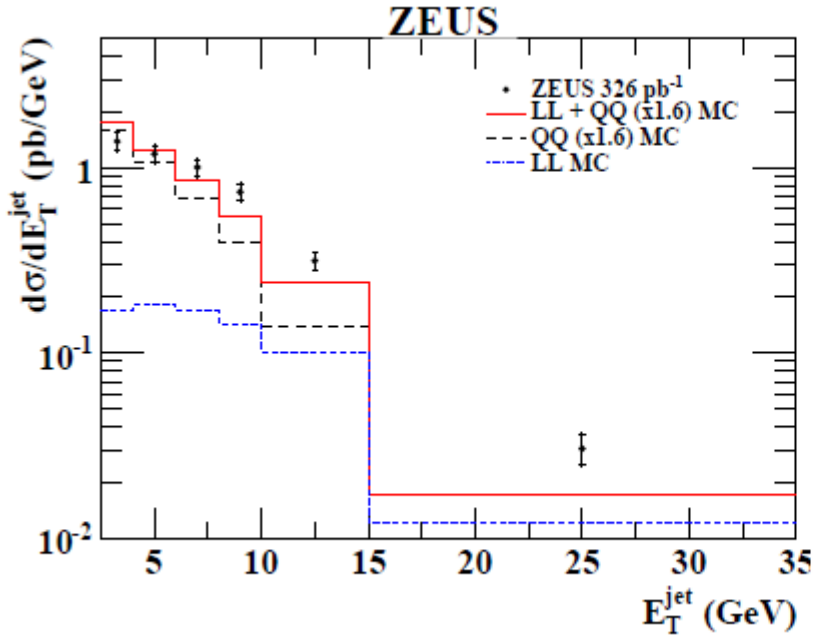
Compare data with PYTHIA and ARIADNE

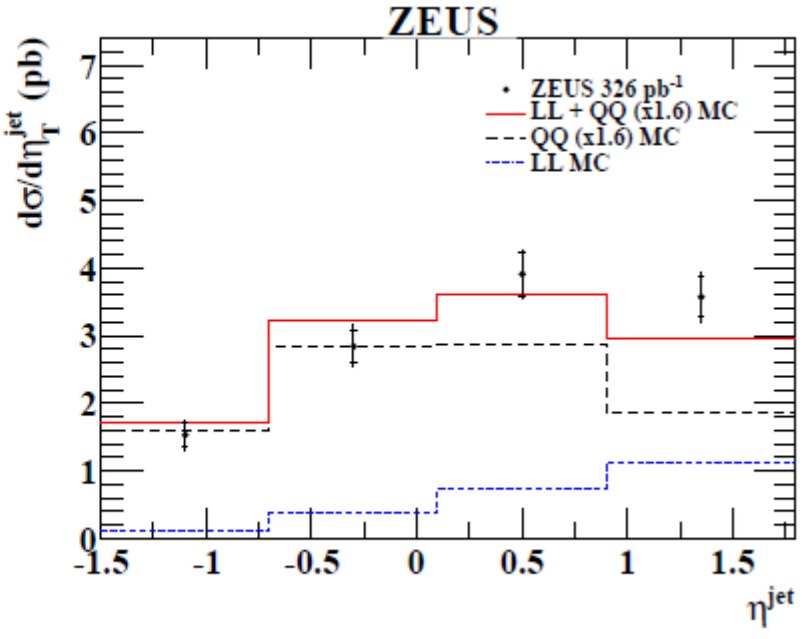
- Good agreement between MC model and experimental data.

Cross sections for DIS photon plus jet









Theoretical predictions

Comparison made to predictions by

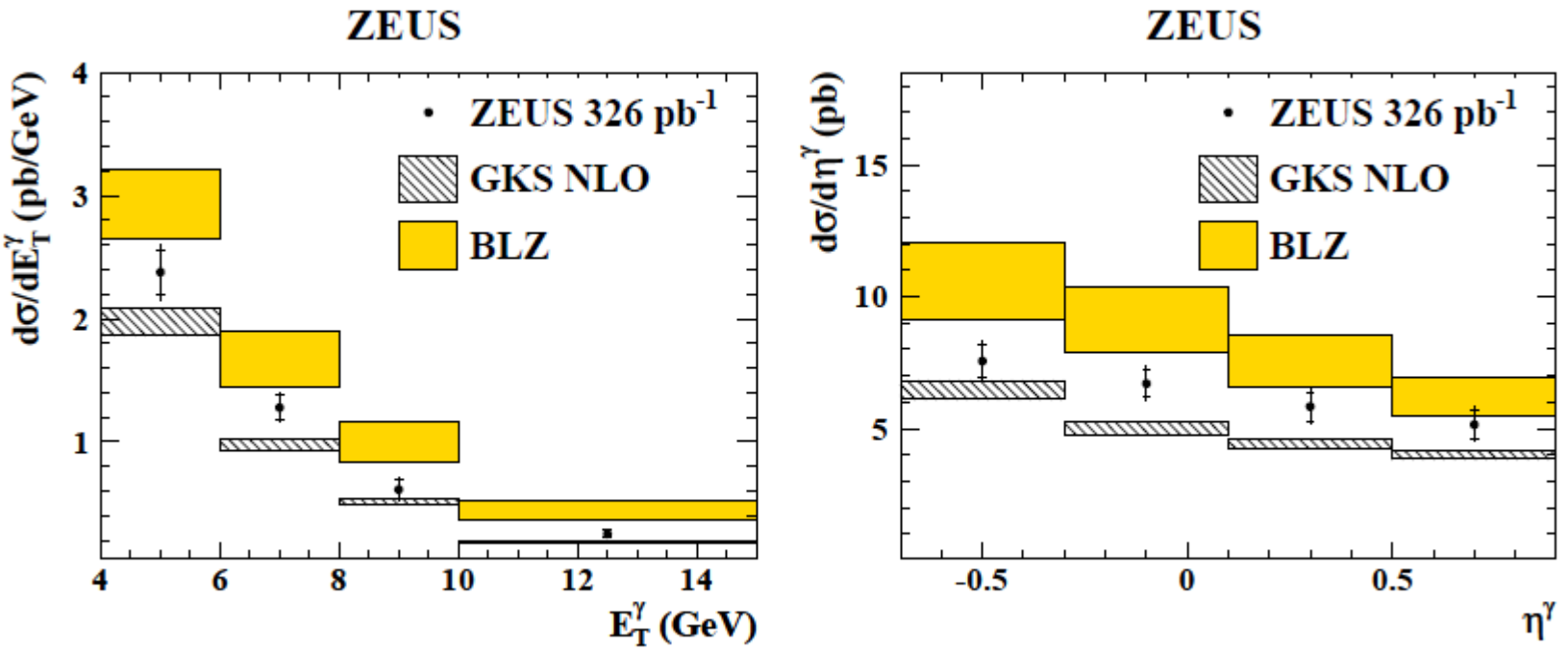
- A. Gehrmann-De Ridder, G. Kramer and H. Spiesberger (GKS):

- LO (α^3) and NLO ($\alpha^3\ \alpha_s$) approach
- Contributions come from radiation of a photon from quark line (QQ), lepton line (LL) and interference term LQ.

- S. P. Baranov, A. V. Lipatov, N. P. Zotov (BLZ):

- k_T-factorisation QCD approach
- based on off-shell partonic amplitude $eq^* \rightarrow e\gamma q$
- unintegrated proton parton densities are used

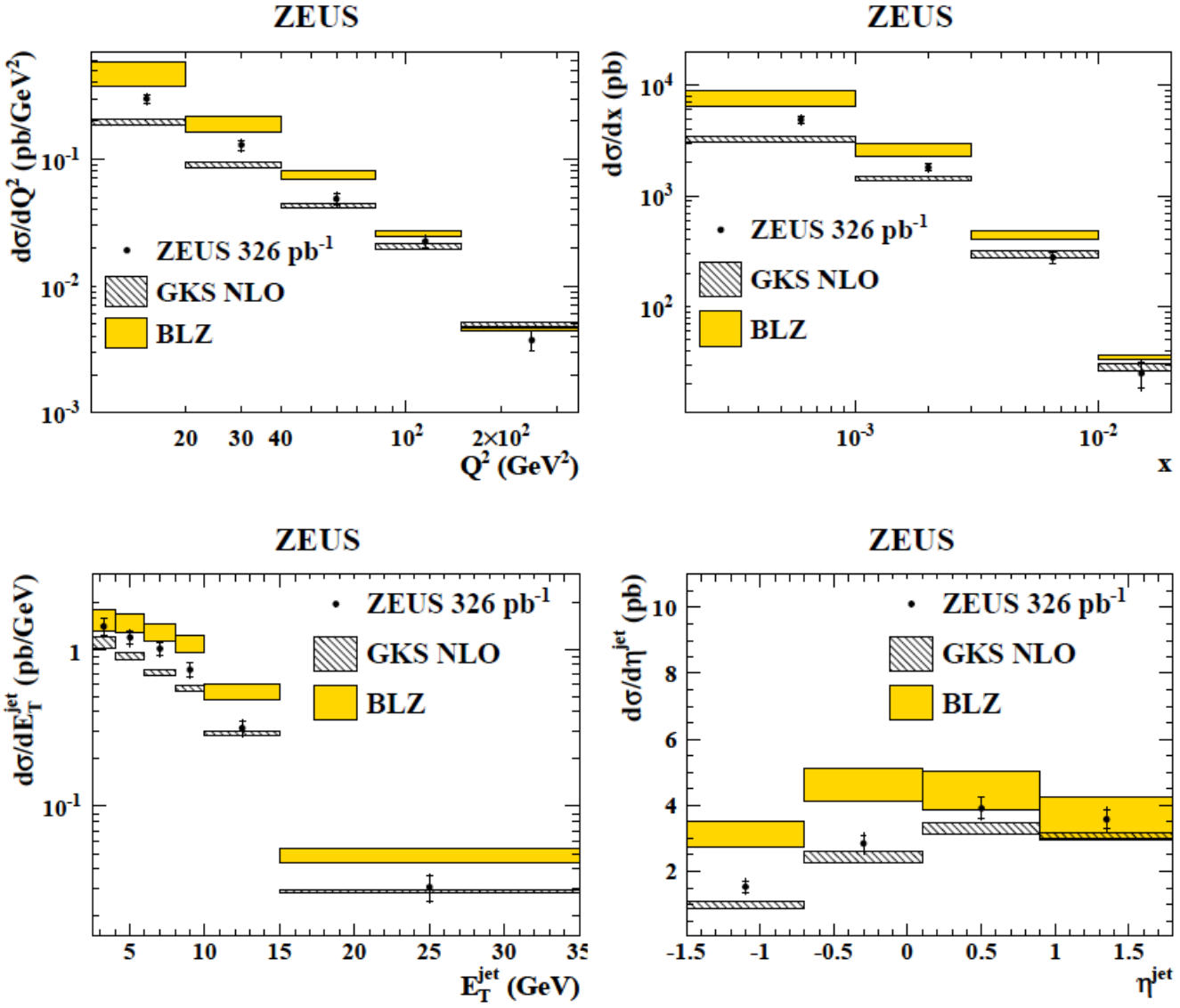
Cross sections for DIS photon plus jet



Theoretical uncertainties due to factorisation and renormalisation scales, varied by factor 2 up and down

GKS predictions systematically underestimate data and BLZ overestimate them

Cross sections for DIS photon plus jet



In most bins GKS predictions underestimate and BLZ overestimate data.

Summary

• Isolated photons have been measured by ZEUS at HERA, with and without a jet requirement.

Photoproduction:

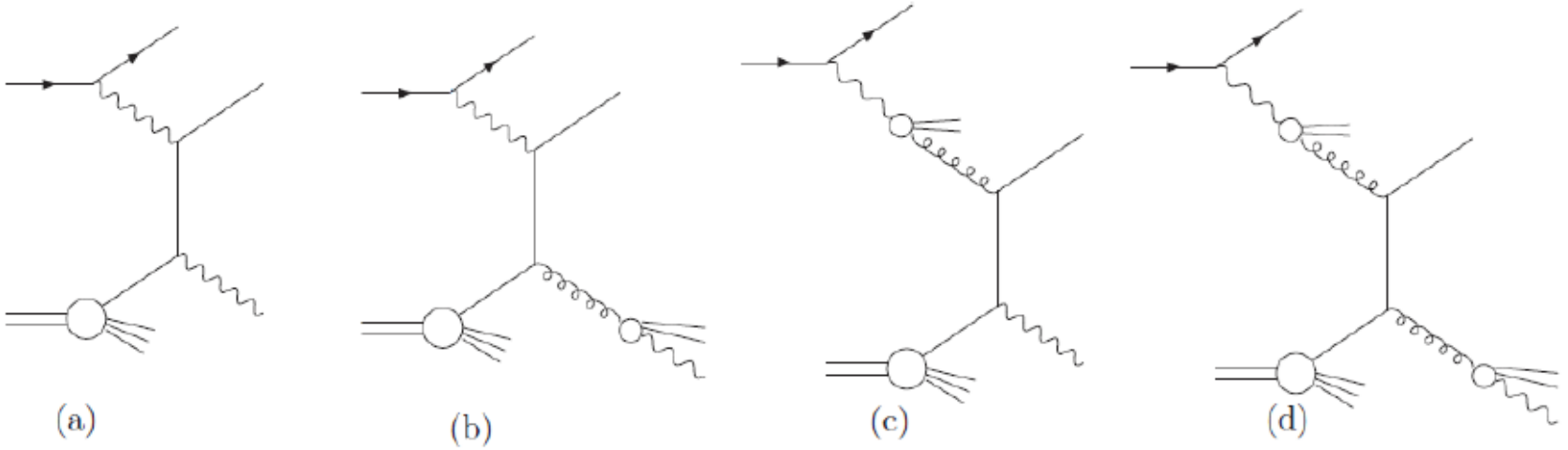
- Within errors, the NLO predictions of FGH describe well the experimental data.
- A reasonable description is also provided by the k_T factorisation model of Lipatov and Zotov.

DIS:

- Predictions give a fair description of the data but systematically overestimate (for k_T factorisation approach) or underestimate (for fixed order NLO calculations) them.
- Results indicate the desirability of further QCD calculations.
- Hopefully, results can be utilised to constrain PDF.

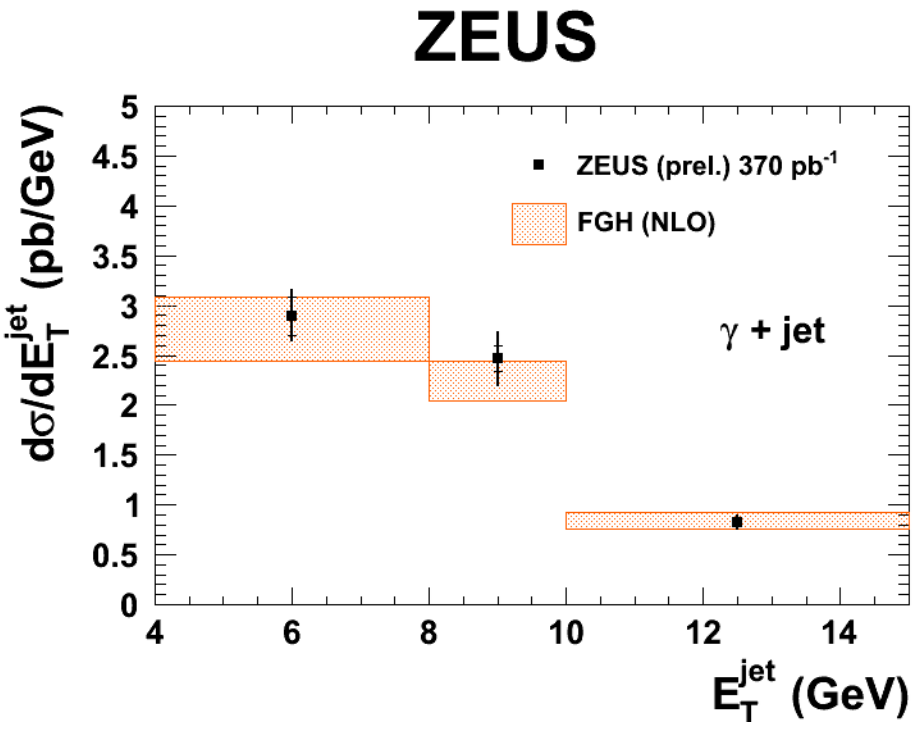
Backup slides

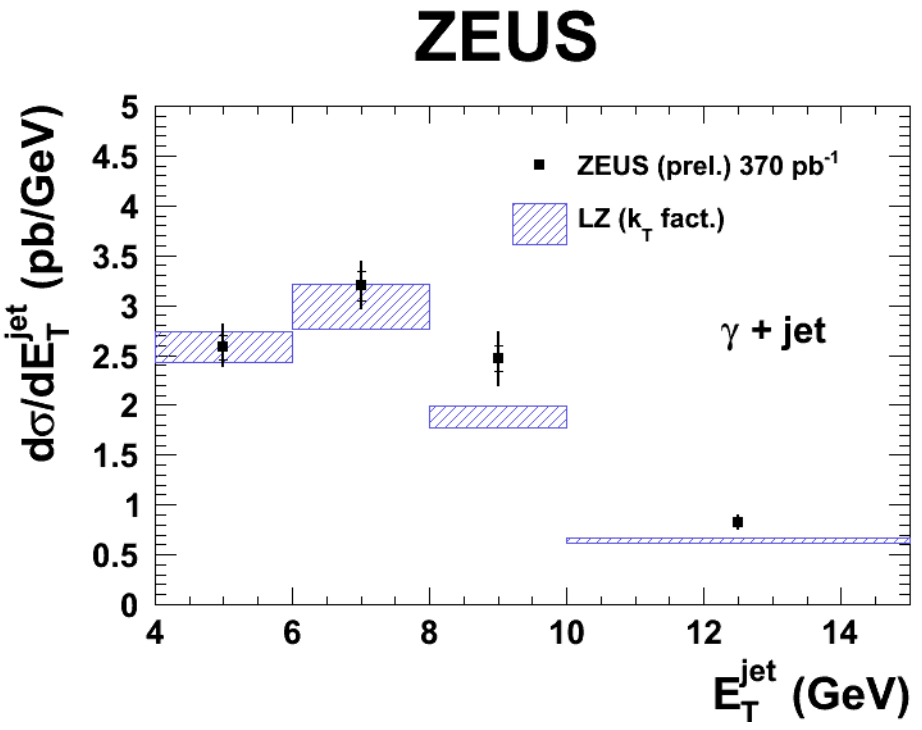
Isolated photons in photoproduction



(a) direct, in which the entire incoming photon interacts,
(c) resolved, in which a parton from the photon interacts.
Higher order pQCD processes occur and also “fragmentation” processes (b, d).

Isolated photons in photoproduction





Comparison with FGH and LZ plotted separately.
To compare with FGH first two bins in experimental data are combined.