Prompt Photon + Jet Production in Neutral Current DIS at HERA

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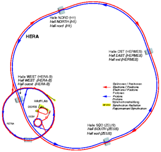
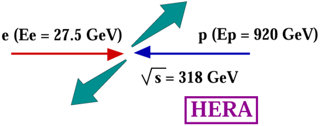
On behalf of ZEUS Collaboration

ZEUS Collaboration





Motivation of prompt photons studying:

• Prompt photons are high transverse energy final state photons which are emitted directly during the hard scattering process

• Prompt photons do not undergo the hadronization process, therefore theoretical calculations can be done with better precision

• The final state photon is a particle which arrives in the detector after participating in the actual hard scattering process and so it can provide direct information of the process and the proton structure

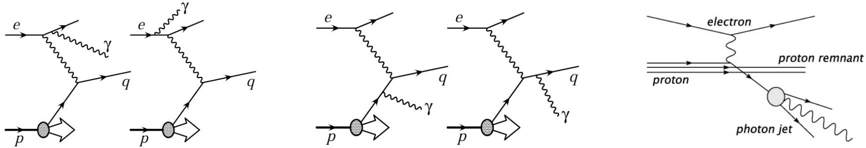
• DIS processes provide a defined set of kinematic conditions that allow prompt photon production to be studied, and theoretical predictions to be tested

• Prompt photons are a background at hadron colliders to any searches involving final state photons ($H \to \gamma\gamma$)

• It is expected for prompt photons + jets to be more sensitive to underlying parton process

Prompt photons in DIS: approach

- Theoretical prediction of A. Gehrmann-De Ridder, T. Gehrmann and E. Poulsen (Phys.Rev.Lett.96:132002,2006)
- LO(α^3) with three components:



- (LEFT) photon radiated from incoming or outgoing lepton (**LL** radiation)
- (MIDDLE) photon radiated from a quark (**QQ** radiation)
- (RIGHT) photon from jet fragmentation (photon carries fraction z of quark momentum) ($D_{q\rightarrow\gamma}(z)$) (it is suppressed in our analysis)
- LQ interference small and neglected here
- Prediction: Total = LL + QQ + $D_{q\rightarrow\gamma}(z)$

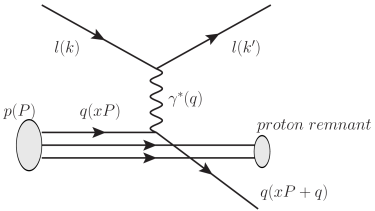
Phase Space

- $332pb^{-1}$ of HERA data were used
- PYTHIA (signal)
- ARIADNE (background)

- $E_{e,corr} > 10$ GeV
- $140^\circ < \theta_{el} < 180^\circ$
- $10 < Q^2 < 350\mathrm{GeV}^2$
- $4 < E_{T,\gamma}/\mathrm{GeV} < 15$
- $-0.7 < \eta_\gamma < 0.9$
- $\frac{\mathrm{E}_\gamma}{\mathrm{E}_{\text{jet containing } \gamma}} > 0.9$
- $E_{T,jet} > 2.5\mathrm{GeV}$
- $-1.5 < \eta_{jet} < 1.8$

- jet reconstruction done with $k_T$clus algorithm
- take highest $E_{T,jet}$ jet within η range in the event

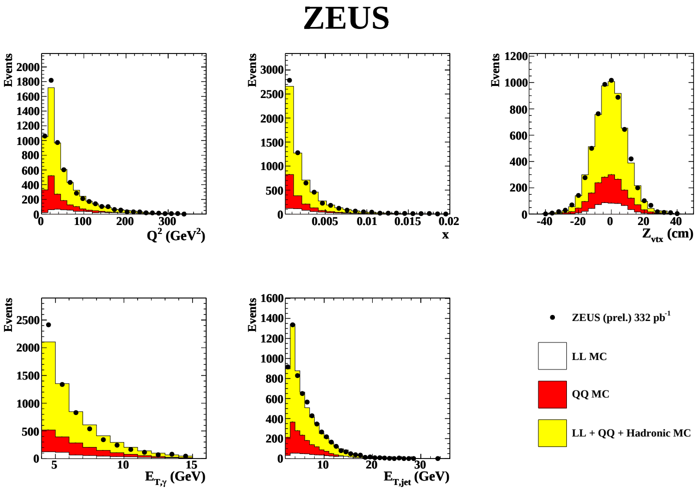
Kinematic variables



- Q^2 defined by:
  $Q^2 = -q^2 = -(k - k')^2$
- k - 4-momentum of incoming electron
- k' - 4-momentum of outgoing electron

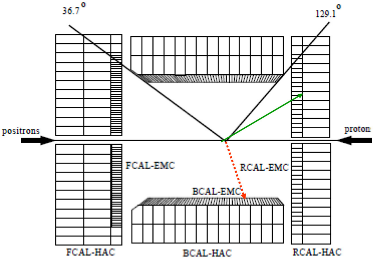
- x defined by:
  $x = \frac{q^2}{2P(k-k`)}$
- P - 4-momentum of the incoming proton

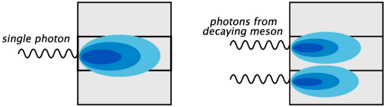
Control Plot



- MC describes data reasonably

Signal Extraction





Objective

- We have to differentiate photon signal from a background of neutral mesons in the ZEUS Barrel Calorimeter (BCAL)
- The energy is deposited in cells of the BCAL
- ZEUS BCAL cells are 5 cm in the Z-direction (beam direction)
- Mainly a single photon is containing in one cell

- Neutral mesons (π^0 and η mainly) decay to photons with small opening angle
- Meson EM shower is wider than single photon EM

Shower Shape Variables

- We have to identify photon candidate as a cluster of calorimeter cells
- The energy of the photon should be nearly all contained in the BCAL-EMC

- To quantify transverse shower width we implement two shower shape variables:

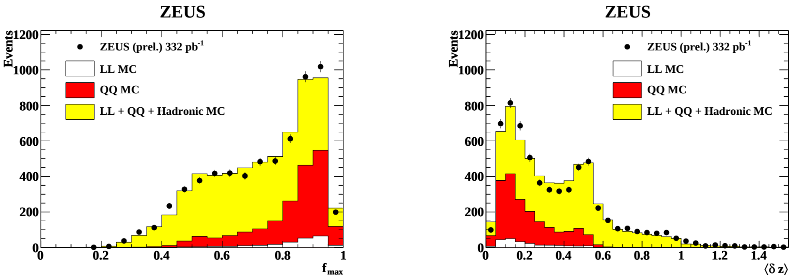
f_{max} - ratio of the energy in the highest energy cell of a cluster to the total energy of a cluster

$\langle \delta z \rangle$ - energy weighted mean width of the electromagnetic cluster in Z direction:

$$\langle \delta z \rangle = \frac{\sum_i |Z_i - Z_{cluster}| * E_i}{W_{cell} \sum_i E_i}$$

- We fit our distributions using PYTHIA prediction of the QQ photons for the QQ part of cross section and ARIADNE prediction of the LL photons for LL part, and ARIADNE for the neutral Hadronic background

Shower Shape Variables



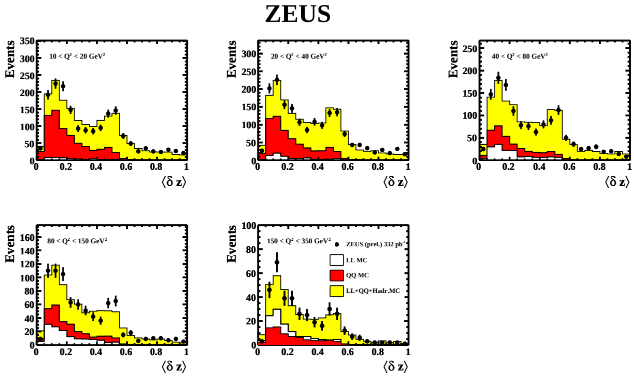
- f_{max}: photon signal peaks close to 1 as expected
- Hadronic background generally lays at low f_{max} values
- Good agreement with MC

- $\langle \delta z \rangle$: photon signal gives a narrow peak at 0.1
- π^0 signal peak can be visible at 0.5
- Good agreement with MC

- The $\langle \delta z \rangle$ distribution has the more detailed structure and was chosen to define the prompt photon fraction in data and to extract signal

fits: $\langle \delta z \rangle / Q^2$

In every bin of a measured quantity, we do a fit to the signal and background using the events in that bin. Here are some examples:



- The LL contribution increases with increasing Q^2
- Good MC agreement with data

Studying of systematic effects

Systematic effects for the following variables have been checked and summed in quadrature:

$\star$ Photon energy in data scaled $\pm 2\%$:
$\Rightarrow$ resulting deviation is less then 3-4$\%$ in most bins

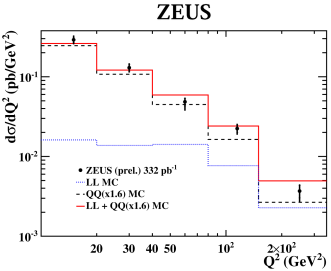
$\star$ Electron energy in data scaled $\pm 2\%$
$\Rightarrow$ resulting deviation is 5-10$\%$

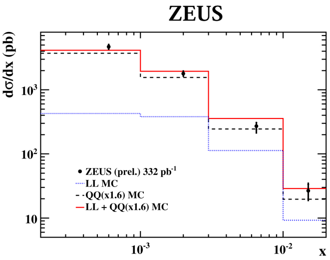
$\star$ $\langle \delta z \rangle$ fit range has been changed to [0, 0.6] and [0, 1.]
$\Rightarrow$ resulting deviation in most of bins is less then 8$\%$

$\star$ Jet energy in data scaled $\pm 10\%$ for $E_{T,jet}^{corr} < 10\mathrm{GeV}$ and $\pm 3\%$ in other cases
$\Rightarrow$ resulting deviation is about 10$\%$

Previous analysis of prompt photons in DIS showed that varying other parameters make an effect about 1$\%$

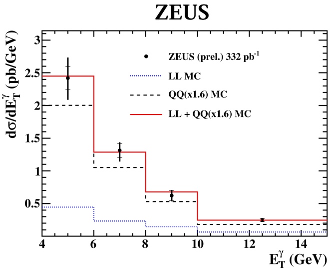
Prompt photons + jets differential cross sections vs. Q^2 and x

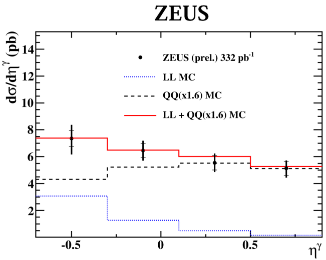




- LL contribution held fixed at the predicted value
- The QQ contribution is scaled by factor of 1.6 to give good agreement to the data
- MC describes data well

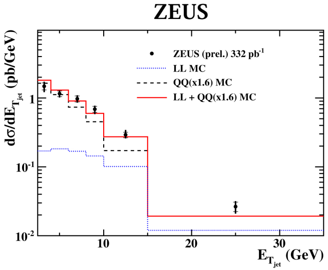
Prompt photons + jets differential cross sections vs. $E_{T,\gamma}$ and η_γ

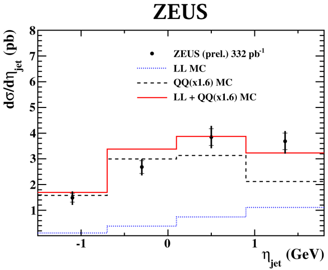




- MC gives a reasonable description of the data

Prompt photons + jets cross differential sections vs. $E_{T,jet}$ and η_{jet}





- The MC gives a reasonable description of the data

Summary

- Prompt photon + jets cross sections in DIS have been measured differentially in η_γ, $E_{T,\gamma}$, x, Q^2, η_{jet} and $E_{T,jet}$ at HERA using ZEUS detector in restricted phase spase

- MC model describes data well after scaling the QQ component

- We are now in a position to test theory predictions

Back-up slides

Event Selection Cuts

Phase Space

- $10 < Q^2 < 350\mathrm{GeV}^2$

Cleaning Cuts

- $-40 < Z_{\mathrm{vtx}}/cm < 40$
- $35\ \mathrm{GeV} < \mathrm{E} - \mathrm{p_z} < 65\ \mathrm{GeV}$

Electron Cuts

- $E_{e,corr} > 10\ \mathrm{GeV}$
- $140^\circ < \theta_{el} < 180^\circ$
- $-14.8 < e_x/\mathrm{cm} < 14.8$
- $-14.6 < e_y/\mathrm{cm} < 12.5$

Triggers

- SPP02 trigger for 0405e
- SPP09 trigger for 06e, 0607p

Prompt Photon Phase Space

- $4 < E_{T,\gamma}/\mathrm{GeV} < 15$
- $-0.7 < \eta_\gamma < 0.9$

Prompt Photon Cleaning Cuts

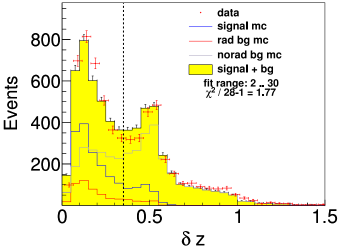
- $\Delta r < 0.2$
- $\frac{\mathrm{E_{EMC}}}{\mathrm{E_{HAC}+E_{EMC}}} > 0.9$
- $\frac{\mathrm{E}_\gamma}{\mathrm{E}_{\text{jet containing }\gamma}} > 0.9$
- $f_{max} > 0.05$

Jet Selection

- based on zufos
- $E^{corr}_{T,jet} > 2.5\mathrm{GeV}$
- $-1.5 < \eta_{jet} < 1.8$
- take highest $E_{T,jet}$ jet within η range in the event

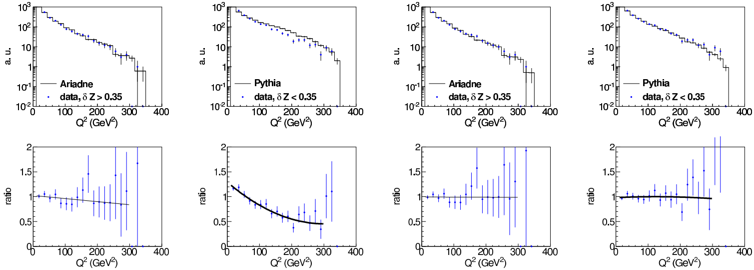
Q^2-reweighting

- Q^2-reweighting procedure has been improved since last meeting, instead of reweighting MC after inclusive DIS selection to inclusive DIS Data
- Split data events after full event selection into two parts: with $\langle \delta z \rangle > 0.35$ (more background events) and with $\langle \delta z \rangle < 0.35$ (more signal events)



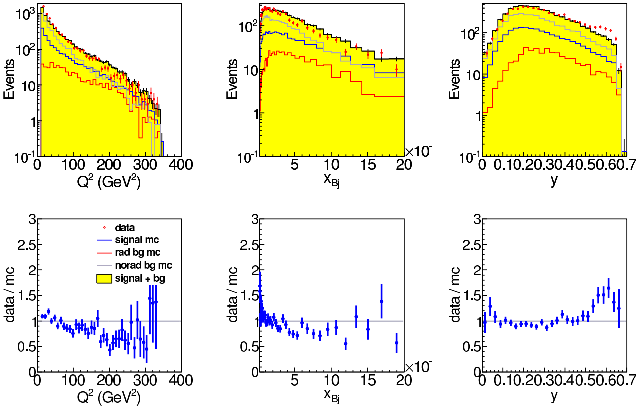
- reweight non-radiative Ariadne background to the part of data with $\langle \delta z \rangle > 0.35$
- reweight signal Pythia MC to the part with $\langle \delta z \rangle < 0.35$
- do not reweight LL Ariadne at all, since it is well theoretically understood

Q^2-reweighting



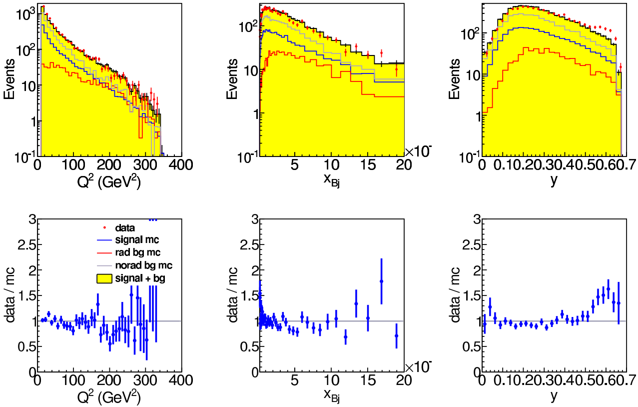
- Left four plots are before reweighting
- Right four plots are after reweighting
- Linear fit for Pythia and polynomial of order two for Ariadne
- Compared hadronic level of MC with Data corrected for acceptance effects
- Data and MC summed over periods

Q^2-reweighting



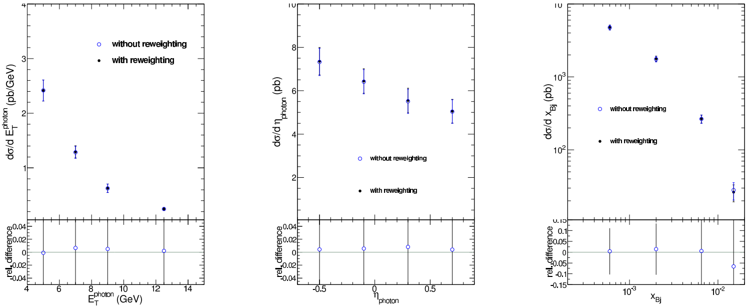
- Control plots before Q^2-reweighting

Q^2-reweighting



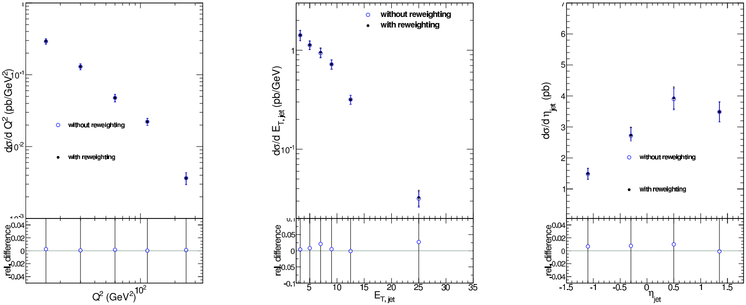
- Control plots after Q^2-reweighting: better description of Data by MC for Q^2 and x

Cross-section comparison with/without Q^2 reweighting (1/2)



- Discrepancy is typically less then 1%

Cross-section comparison with/without Q^2 reweighting (2/2)



- Influence on Q^2 cross-section is tiny