Prompt Photon Production in NC DIS at ZEUS

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On behalf of the ZEUS collaboration

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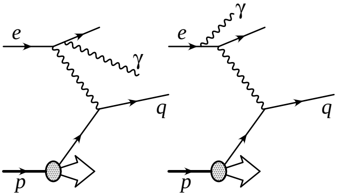
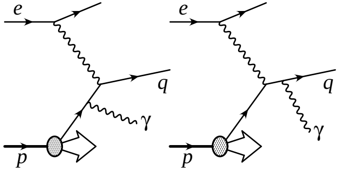
Motivation

The term 'prompt photon' refers to isolated, high-pT photon in the final state.

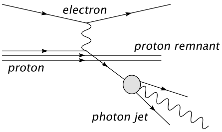
LL - hard radiation from leptons



QQ - hard radiation from quarks



$D_{q\to\gamma}(z)$ - quark to photon fragmentation



Photon carries fraction z of quark momentum.

QL interference term

small and neglected here.

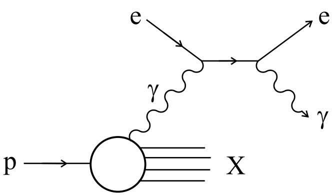
Prediction: LL + QQ + $D_{q\to\gamma}(z)$

LO(α^3) from A. Gehrmann-De Ridder, T. Gehrmann and E. Poulson.
(Phys.Rev.Lett.96:132002,2006)

Motivation

$$\gamma^p \otimes \hat{\sigma}(e\gamma \to e\gamma)$$

where γ^p is photon content of proton



Calculated by MRST group

Sensitive to photon content of proton. (Eur.Phys.J.C39:155-161,2005)

Phase space and selection needs to be re-optimised to enrich and properly study this process.

Prompt-photon measurements can offer:

- Tests of QCD whilst themselves being largely insensitive to hadronization (unlike jets).
- Probes of the photon/parton content of the proton.

In addition they are a background to any searches involving final state photons ($H \to \gamma\gamma$).

Phase Space

Phase Space

- $E_e > 10$ GeV
- $140^\circ < \theta_e < 172^\circ$
- $10 < Q^{2*} < 350\,\mathrm{GeV}^2$
- $4 < E_T^\gamma < 15$ GeV
- $-0.7 < \eta^\gamma < 0.9$
- $\frac{E_\gamma}{E_{\mathrm{jet\ containing\ }\gamma}} > 0.9$

  jet reconstruction done with $k_T$clus algorithm

$^*Q^2$ defined by,

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

k = 4-momentum of incoming electron
k' = 4-momentum of outgoing electron

x defined by,

$$x = \frac{q^2}{2P.(k-k')}$$

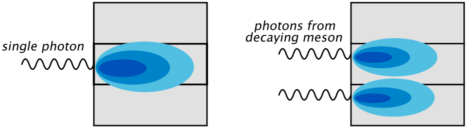
P = 4-momentum of the incoming proton

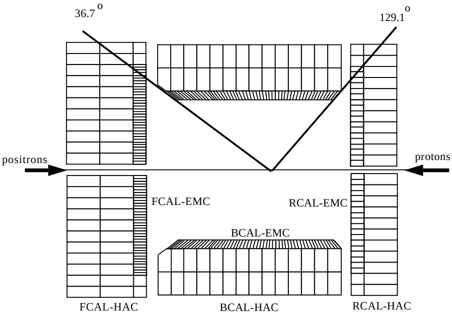
$320\mathrm{pb}^{-1}$ of HERA data were used.

Signal Extraction

Background is neutral mesons (mainly π^0 and η) which decay to photons with small opening angle.

Meson EM showers wider than single photon EM.





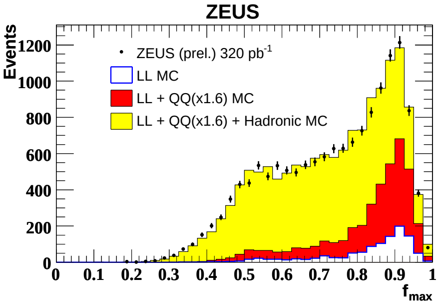
ZEUS Barrel Electromagnetic Calorimeter (BCAL-EMC) granularity of 5 cm in the Z-direction (beam direction).

Quantify transverse shower width using 'shower shape variables' $f_{\max}$ and $\langle \delta z \rangle$.

Shower Shape Variable - $f_{\max}$

$f_{\max}$

$$\frac{\text{Energy in most energetic electromagnetic calorimeter cell}}{\text{Total energy of cluster}}$$



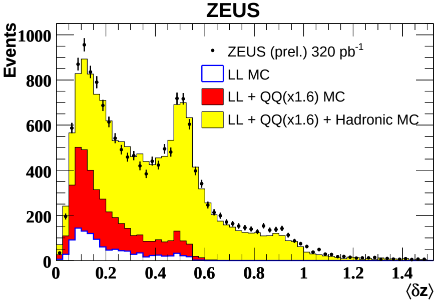
LL MC: ARIADNE prediction of LL photons.
QQ MC: PYTHIA prediction of QQ photons.
Hadronic MC: Hadronic background from ARIADNE.

- Photon signal peaks close to 1 as expected.
- Hadronic background generally at much lower $f_{\max}$
- Well modelled by MC.

Shower Shape Variable - $\langle \delta z \rangle$

$$\langle \delta Z \rangle = \frac{\sum_i E_i |Z_i - Z_{\rm cluster}|}{W_{\rm cell} \sum_i E_i} =$$ the energy-weighted mean modulus of width in the z-direction.

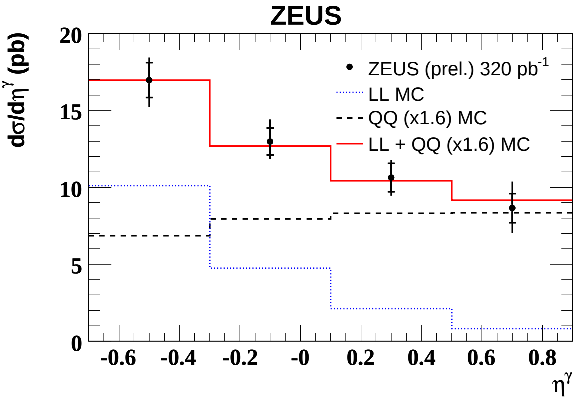
[$W_{\rm cell}$ = cell width in Z , $Z_{\rm cluster}$ = centre of gravity of cluster, for the ith cell in the cluster, $Z_i = Z$ position, E_i = energy]



LL MC: ARIADNE prediction of LL photons.
QQ MC: PYTHIA prediction of QQ photons.
Hadronic MC: Hadronic background from ARIADNE.

- Photon signal peaks sharply at narrow widths (low $\langle \delta z \rangle$).
- Background peak at ~ 0.5 from two photon decay.
- Fit region $\langle \delta z \rangle < 0.8$ to extract signal.

Differential prompt-photon cross section: $\frac{d\sigma}{d\eta^\gamma}$



Phase Space

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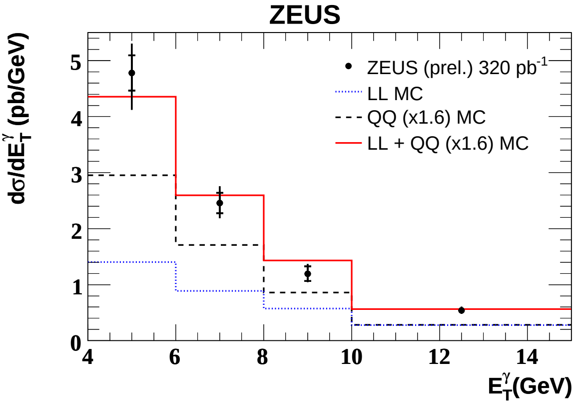
- $\frac{E_\gamma}{E_{\text{jet containing } \gamma}} > 0.9$

- LL contribution is held fixed at the predicted value.
- QQ contribution from PYTHIA scaled factor of 1.6
- Full model description gives excellent description of shape.

Differential prompt-photon cross section: $\frac{d\sigma}{dE_T^\gamma}$



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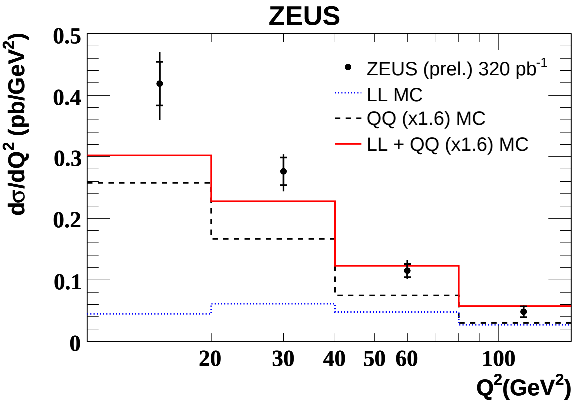
- $\frac{E_\gamma}{E_{\mathrm{jet\ containing}\ \gamma}} > 0.9$

- Again good description by MC after scaling PYTHIA QQ.

Differential prompt-photon cross section: $\frac{d\sigma}{dQ^2}$

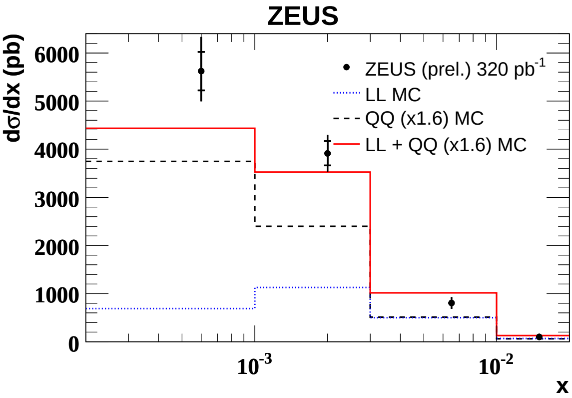


Phase Space

- $E_e > 10$ GeV
- $140^\circ < \theta_e < 172^\circ$
- $10 < Q^2 < 150$ GeV^2
- $4 < E_T^\gamma < 15$ GeV
- $-0.7 < \eta^\gamma < 0.9$
- $\frac{E_\gamma}{E_{\text{jet containing }\gamma}} > 0.9$

- MC describes data well at high Q^2.

Differential prompt-photon cross section: $\frac{d\sigma}{dx}$



Phase Space

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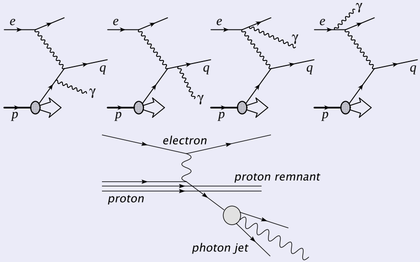
- $\frac{E_\gamma}{E_{\text{jet containing } \gamma}} > 0.9$

- First differential measurement in x at HERA!
- Reasonable description by MC at high x.

Theory Reminder

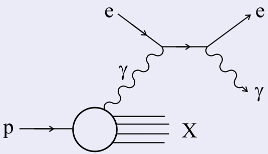
The following theoretical predictions are compared to ZEUS data,

LL + QQ incl. $D_{q\to\gamma}(z)$



LO(α^3) from A. Gehrmann-De Ridder, T. Gehrmann and E. Poulson.
(Phys.Rev.Lett.96:132002,2006)

LL $\gamma^p \otimes \hat{\sigma}(e\gamma \to e\gamma)$ enhanced

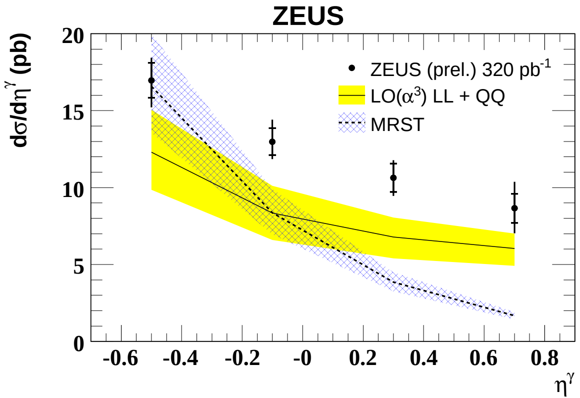


LO(α^2) from MRST.
(Eur.Phys.J.C39:155-161,2005)
Note: Selection not optimised for this process.

The quoted theoretical uncertainty band results from changing the factorisation scale, μ_F to $0.5\mu_F$ and $2\mu_F$.

No hadronisation corrections have been applied.

Differential prompt-photon cross section: $\frac{d\sigma}{d\eta^{\gamma}}$

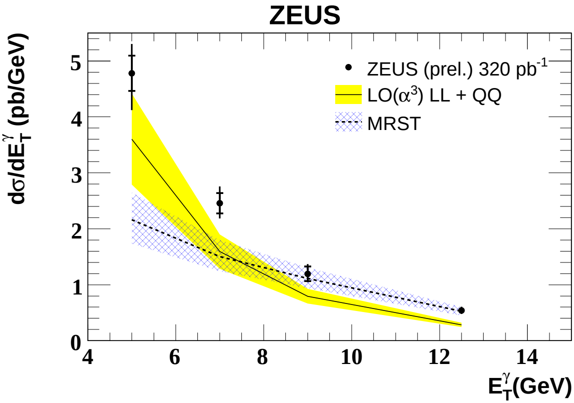


Phase Space

- $E_e > 10$ GeV
- $140^\circ < \theta_e < 172^\circ$
- $10 < Q^2 < 350\,\text{GeV}^2$
- $4 < E_T^{\gamma} < 15$ GeV
- $-0.7 < \eta^{\gamma} < 0.9$
- $\frac{E_{\gamma}}{E_{\text{jet containing }\gamma}} > 0.9$

- LL + QQ normalisation is low (as maybe be expected for LO calculation) but shape reasonable.
- MRST falls steeply with η^{γ} as expected for a lepton initiated process.

Differential prompt-photon cross section: $\frac{d\sigma}{dE_T^\gamma}$



Phase Space

- $E_e > 10$ GeV
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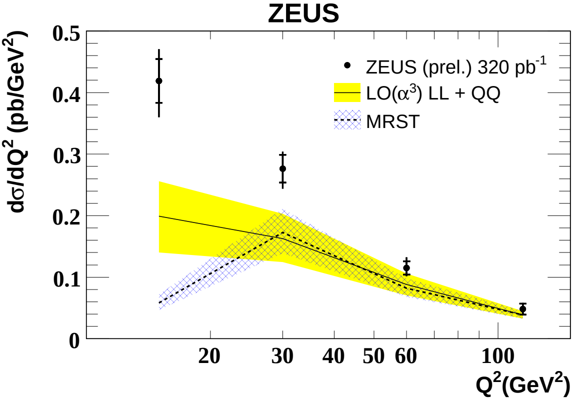
- $\frac{E_\gamma}{E_{\text{jet containing }\gamma}} > 0.9$

- Again LL + QQ normalisation is low but shape reasonable.
- MRST shows flatter E_T^γ cross section and describes high E_T^γ well.

Differential prompt-photon cross section: $\frac{d\sigma}{dQ^2}$

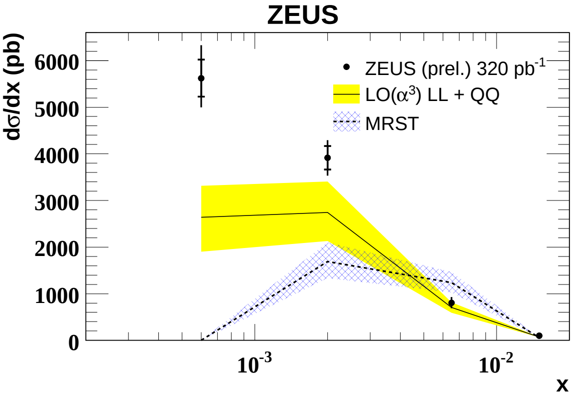


Phase Space

- $E_e > 10$ GeV
- $140^\circ < \theta_e < 172^\circ$
- $10 < Q^2 < 150$ GeV^2
- $4 < E_T^\gamma < 15$ GeV
- $-0.7 < \eta^\gamma < 0.9$
- $\frac{E_\gamma}{E_{\text{jet containing } \gamma}} > 0.9$

- Both predictions describe the data reasonably well at high Q^2.
- Both underestimate low Q^2, especially MRST.

Differential prompt-photon cross section: $\frac{d\sigma}{dx}$



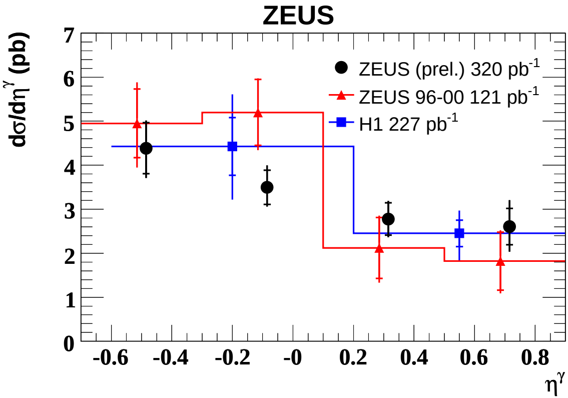
Phase Space

- $E_e > 10$ GeV
- $140^\circ < \theta_e < 172^\circ$
- $10 < Q^2 < 350$ GeV^2
- $4 < E_T^\gamma < 15$ GeV
- $-0.7 < \eta^\gamma < 0.9$
- $\frac{E_\gamma}{E_{\text{jet containing } \gamma}} > 0.9$

- Similarly to Q^2, both predictions describe data reasonably well at high x but fail at low x.

Comparison to previous HERA results

NOTE: Not full phase space: $Q^2 > 35\,\mathrm{GeV}^2, 5\,\mathrm{GeV} < E_T^\gamma < 10\,\mathrm{GeV}$



Restricted Phase Space

- $E_e > 10$ GeV
- $140^\circ < \theta_e < 172^\circ$
- $35 < Q^2 < 350\,\mathrm{GeV}^2$
- $5 < E_T^\gamma < 10$ GeV
- $-0.7 < \eta^\gamma < 0.9$
- $\frac{E_\gamma}{E_{\mathrm{jet\ containing}\ \gamma}} > 0.9$

Both ZEUS results use same binning, points offset for clarity.

- All HERA measurements are in agreement.

Conclusions

- Inclusive prompt photon cross section in DIS have been measured differentially in η^{γ}, E_T^{γ}, Q^2 and x at HERA using the ZEUS detector in a restricted phase space.
- Measurement is consistent with previous HERA results and of higher precision.
- Monte Carlo simulation describes the η^{γ}, E_T^{γ} cross sections well after scaling the QQ component, the simulations underestimate the cross sections at low Q^2 and x.
- A LO prediction including both the LL and QQ contributions has been compared to the data and found to underestimate the cross section, particularly at low Q^2 and x.
- A prediction for the LL component enhanced by the photon-in-proton contribution has also been compared and found to be of similar size to the data. It also underestimates the cross section at low Q^2 and x.

Candidate Selection

To select NC DIS we require,

DIS electron selection

- $E'_e > 10$ GeV
- Electron is in RCAL
- Box Cut :
  $|x| < 14.8$ cm,
  -14.6 cm $< y < 12.5$ cm

DIS event selection

- $35 \text{ GeV} < E - P_z < 65 \text{ GeV}$
- $|Z_{vertex}| < 40$ cm
- $\#$ vertex tracks NOT in RCAL ≥ 1
- $10 \text{ GeV}^2 < Q^2_{electron} < 350 \text{ GeV}^2$

Photon candidates are trackless Energy Flow Objects satisfying,

Photon candidate selection

- $4 < E_T^\gamma < 15$ GeV
- $-0.7 < \eta^\gamma < 0.9$
- No track within 0.2 in (η, ϕ)
- $\frac{\text{candidate EMC Energy}}{\text{Total candiate Energy}} > 0.9$
- $\frac{\text{candidate energy}}{\text{energy of jet containing cand.}} > 0.9$*

* - for this isolation criteria, jet is k_T $R = 1.0$, mode 3211.
(E recombination scheme, recommended arXiv:0803.0678v1)

Systematic Uncertainties

The following were checked and summed in quadrature.

- Signal extraction fit performed using f_{max} instead of $\langle \delta z \rangle$
  $\rightarrow$ typically 5%, at worst comparable to statistical uncertainty
- $\langle \delta z \rangle$ fit range changed to [0,0.65], [0,1.0]
  $\rightarrow$ typically 5%, at worst comparable to statistical uncertainty
- The energy scale of the EMC was varied by $\pm 2\%$
  $\rightarrow$ typically less than 2%
- The EMC energy fraction cut was varied by $\pm 5\%$
  $\rightarrow$ always less than 2%

In addition the following were found to be around 1%.

- Varying $E - p_z$ upper and lower cuts $\pm 3\mathrm{GeV}$.
- Varying $|Z_{vertex}|$ by 5cm.
- Varying track isolation distance from 0.2 to 0.1 and 0.3.
- Varying minimum track momentum $\pm 100\mathrm{MeV}$.
- Varying LL signal fraction $\pm 5\%$.