

Prompt Photon Production in Deep Inelastic Scattering and Photoproduction at HERA



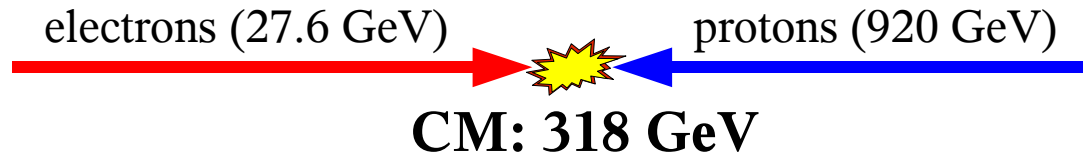
- ✓ ***Prompt Photons at HERA***
- ✓ ***Prompt Photons in DIS***
 - ✓ *H1 [Eur. Phys. J. C 54, p371, (2008)]*
 - ✓ *ZEUS [preliminary]*
- ✓ ***Prompt Photons in Photoproduction***
 - ✓ *H1 [preliminary]*

*Krzysztof Nowak, University of Zurich
on behalf of the H1 and ZEUS Collaborations*



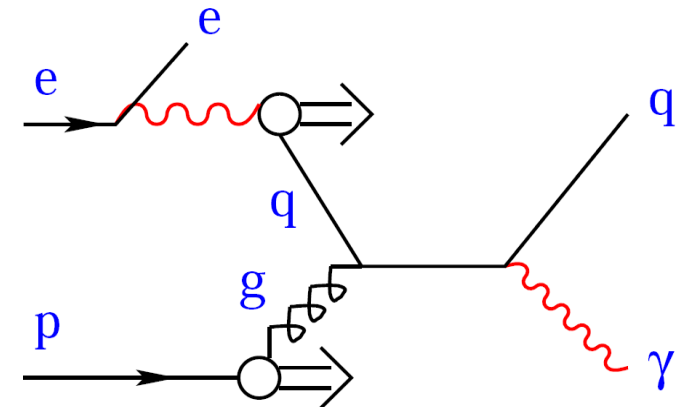
Prompt photons at HERA

- ✓ **HERA:**

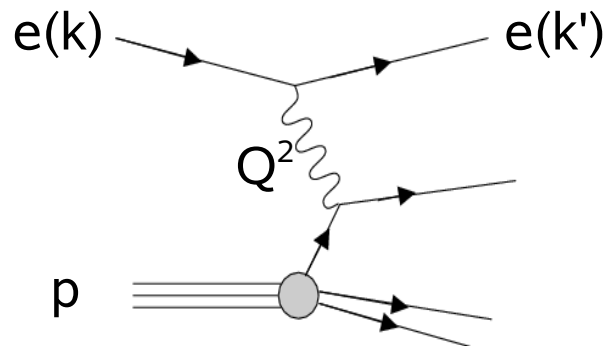


- ✓ **Prompt Photons (PP):**

- ✓ Sensitivity to quark and gluon pdfs of both photon and proton
- ✓ Test different QCD models
- ✓ PP being background for Higgs discovery ($H \rightarrow \gamma\gamma$)



- ✓ **ep kinematics:**

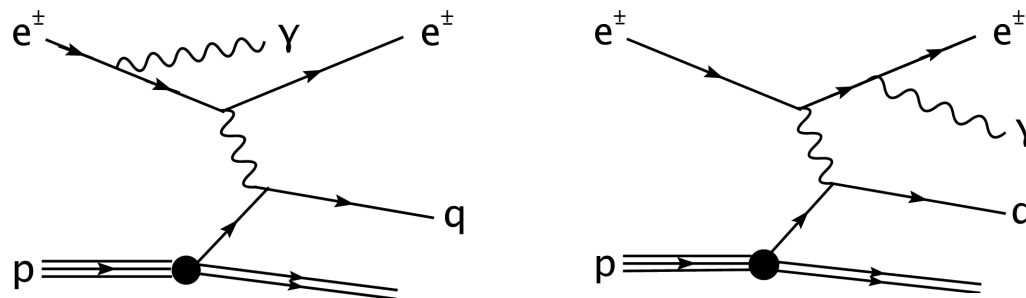


- ✓ Important variable – the virtuality of the mediating photon $Q^2 = -(k - k')^2$
- ✓ $Q^2 > 0$ – Deep Inelastic Scattering (DIS)
- ✓ $Q^2 \approx 0$ – Photoproduction (PhP)

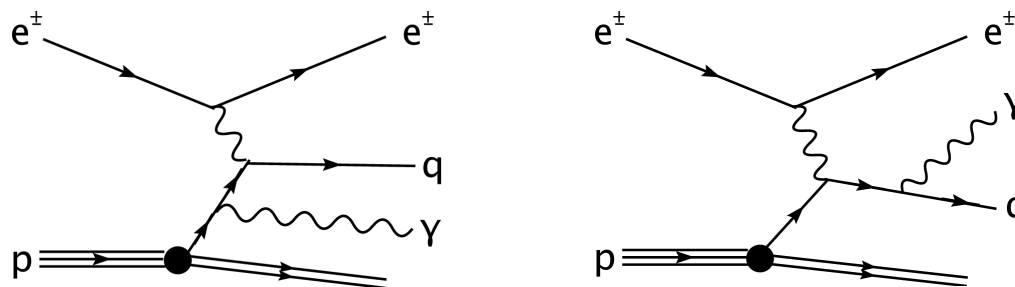
Prompt (Isolated) photons in DIS

- ✓ *Contributions from:*

- ✓ *Hard radiation from the lepton line (LL)*



- ✓ *Hard radiation from the quark line (QQ)*



- ✓ *Interference term (LQ) usually small*

Isolated Photon Production in DIS

Eur. Phys. J. C 54, p371, (2008)



✓ $\int L = 227 \text{ pb}^{-1}$

✓ Photon phase space

✓ $3 < E_T^\gamma < 10 \text{ GeV}$

✓ $-1.2 < \eta^\gamma < 1.8$

✓ $z = E_T^\gamma / E_T^{\gamma \text{ jet}} > 0.9$

✓ DIS phase space

✓ $4 < Q^2 < 150 \text{ GeV}^2$

✓ $E_{e'} > 10 \text{ GeV}$

✓ $153^\circ < \theta_{e'} < 177^\circ$

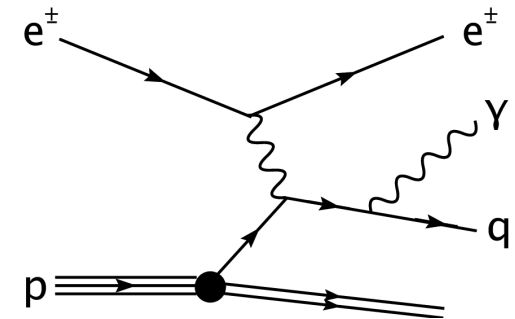
✓ $W_X > 50 \text{ GeV}$

✓ $y > 0.05$

✓ Jet definition (k_T algorithm)

✓ $p_T^{\text{jet}} > 2.5 \text{ GeV}$

✓ $-1.0 < \eta^{\text{jet}} < 2.1$

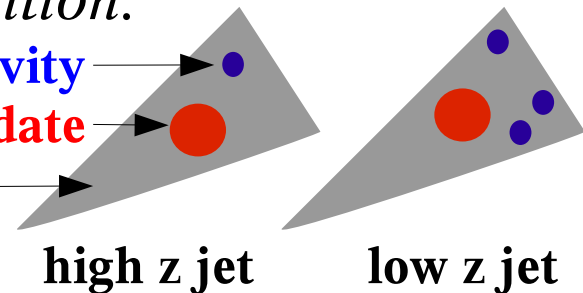


Isolation definition:

Hadronic activity

Photon candidate

Photon jet



Prompt Photon Production in DIS

preliminary results (DIS 2009)



✓ $\int L = 320 \text{ pb}^{-1}$

✓ **Photon phase space**

✓ $4 < E_T^\gamma < 15 \text{ GeV}$

Higher photon energies accessible thanks to the ZEUS preshower detector

✓ $-0.7 < \eta^\gamma < 0.9$

✓ $z = E_T^\gamma / E_T^{\gamma \text{ jet}} > 0.9$

*Concentration on the central part of the detector
(H1: $-1.2 < \eta^\gamma < 1.8$)*

✓ **DIS phase space**

✓ $10 < Q^2 < 350 \text{ GeV}^2$

Higher Q^2 (H1: $4 < Q^2 < 150 \text{ GeV}^2$)

✓ $E_{e'} > 10 \text{ GeV}$

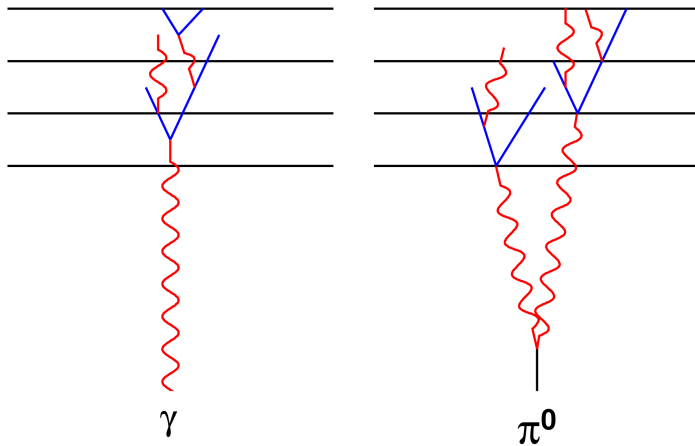
✓ $140^\circ < \theta_{e'} < 172^\circ$

Prompt Photon Production in DIS

background discrimination



- ✓ *Main background – neutral hadrons decaying into photons*

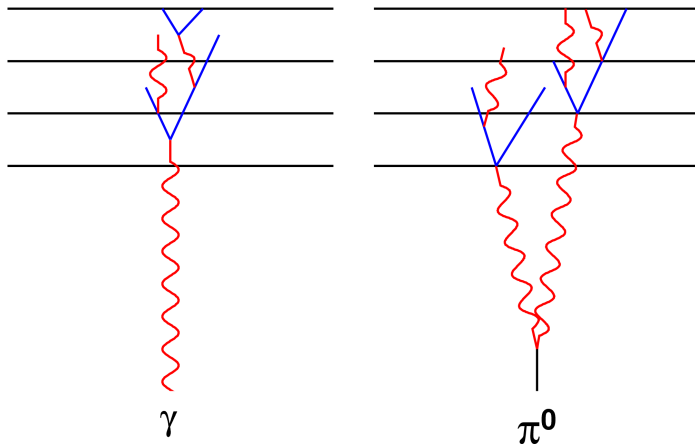


Prompt Photon Production in DIS

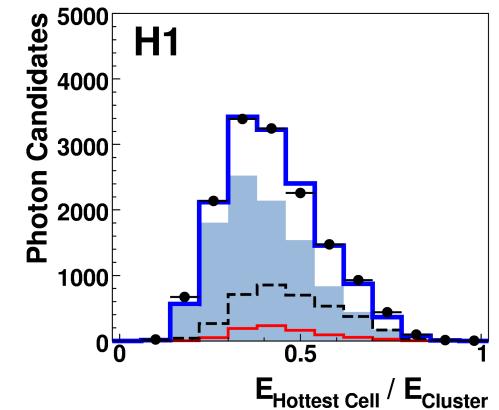
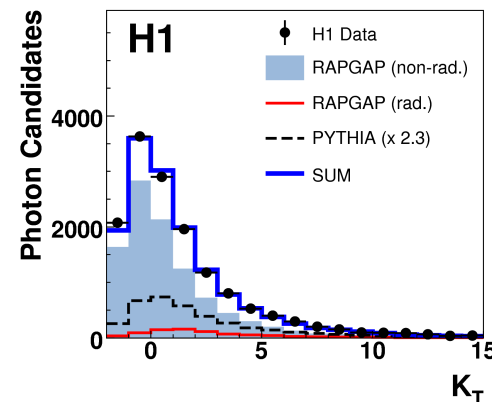
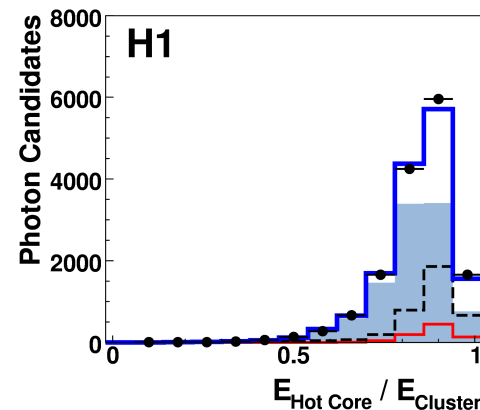
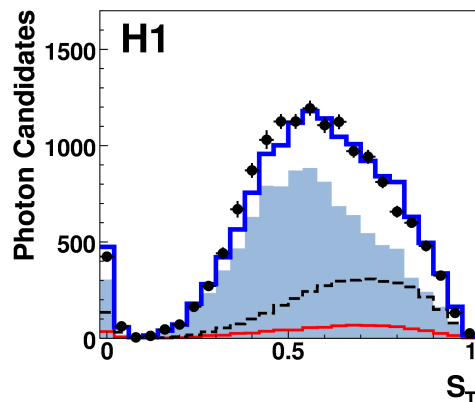
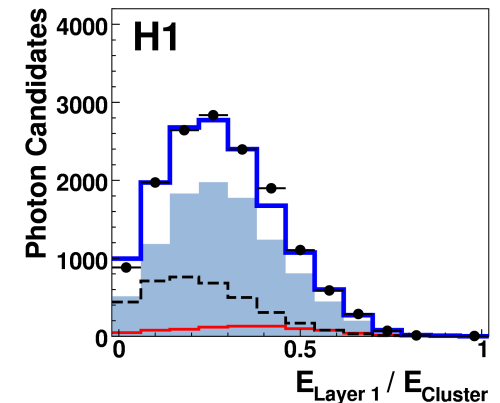
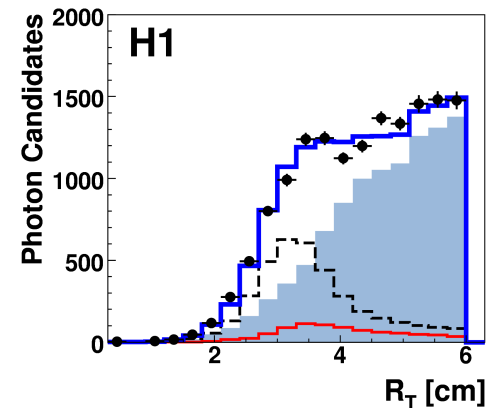
background discrimination



- ✓ Main background – neutral hadrons decaying into photons



- ✓ Six shower shape variables used to extract photon signal

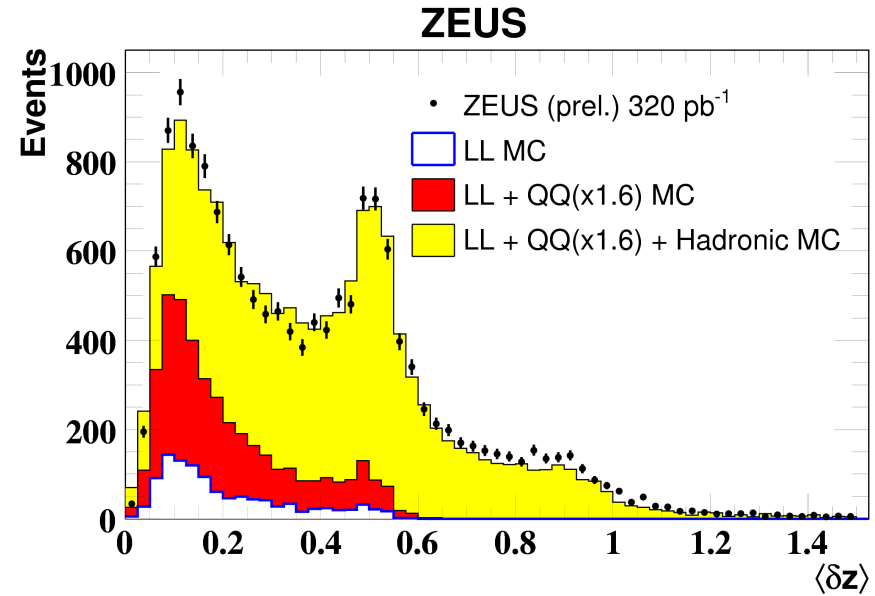
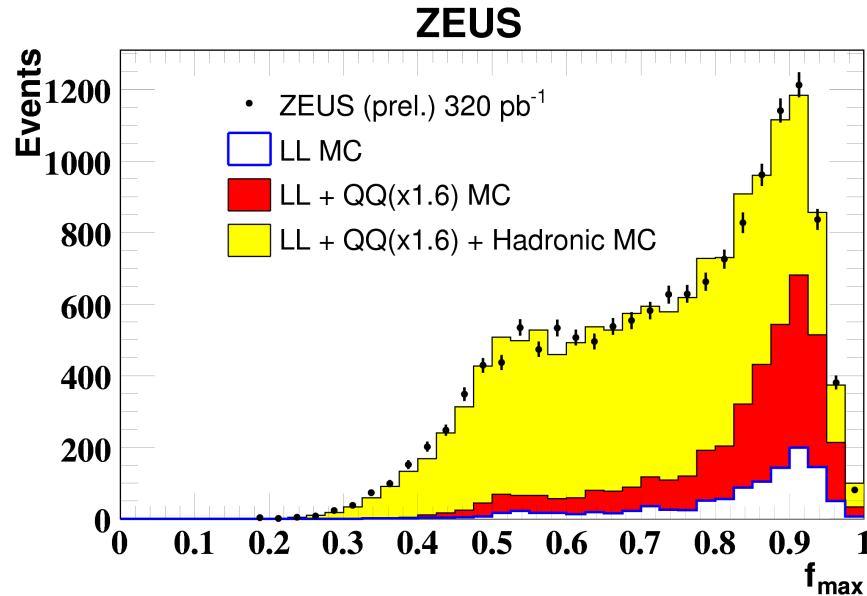


Prompt Photon Production in DIS

background discrimination

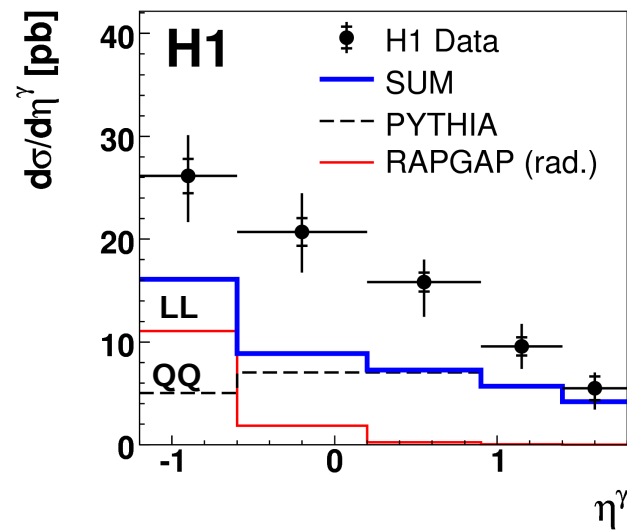
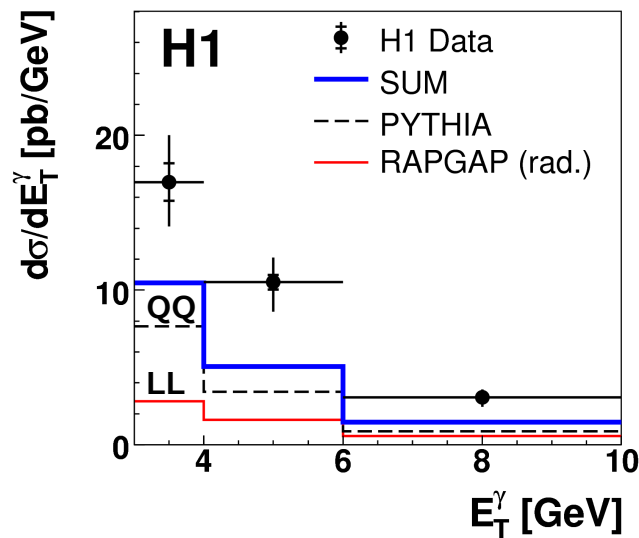


- ✓ Similar approach
- ✓ Two variables are used
 - ✓ Energy fraction in the most energetic cell f_{\max}
 - ✓ Energy weighted mean modulus of width in z-direction $\langle \delta z \rangle$



Prompt Photon Production in DIS

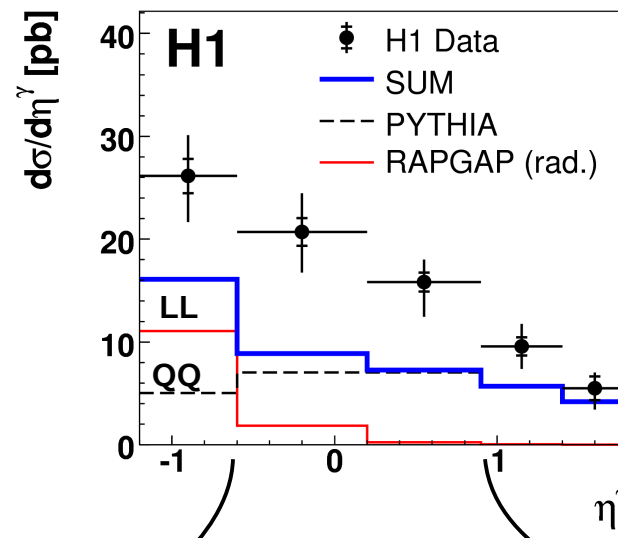
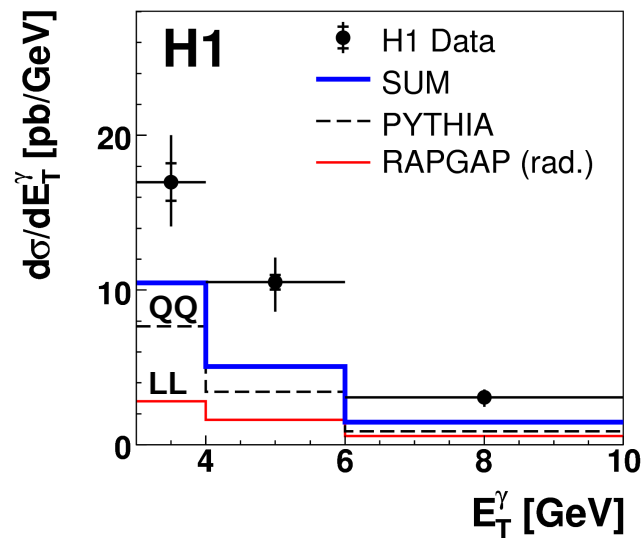
comparison to MC prediction



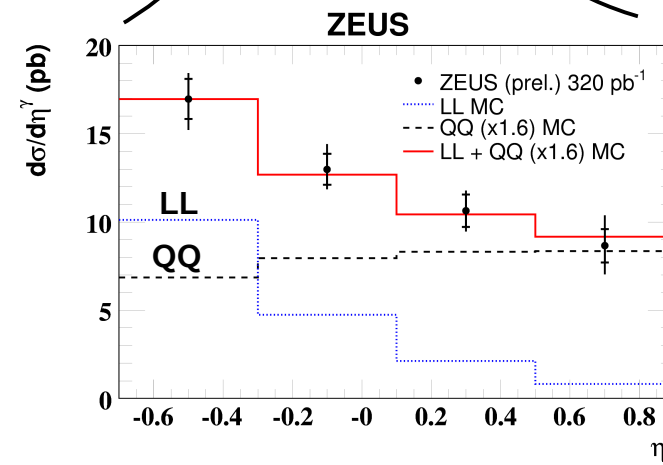
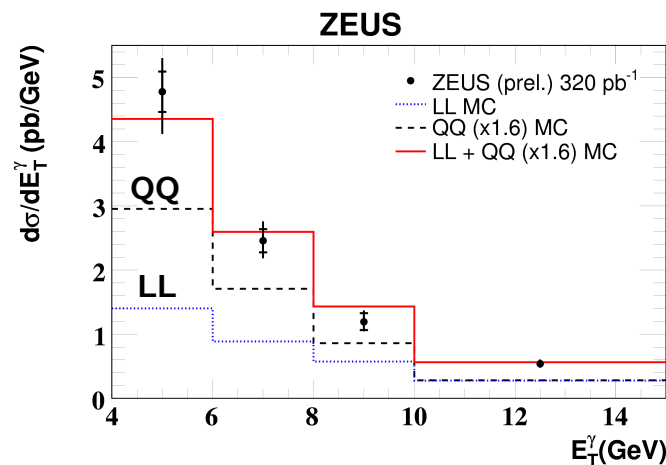
✓ *H1: PYTHIA used for QQ*
RAPGAP used for LL

Prompt Photon Production in DIS

comparison to MC prediction



✓ **H1:** PYTHIA used for QQ
RAPGAP used for LL

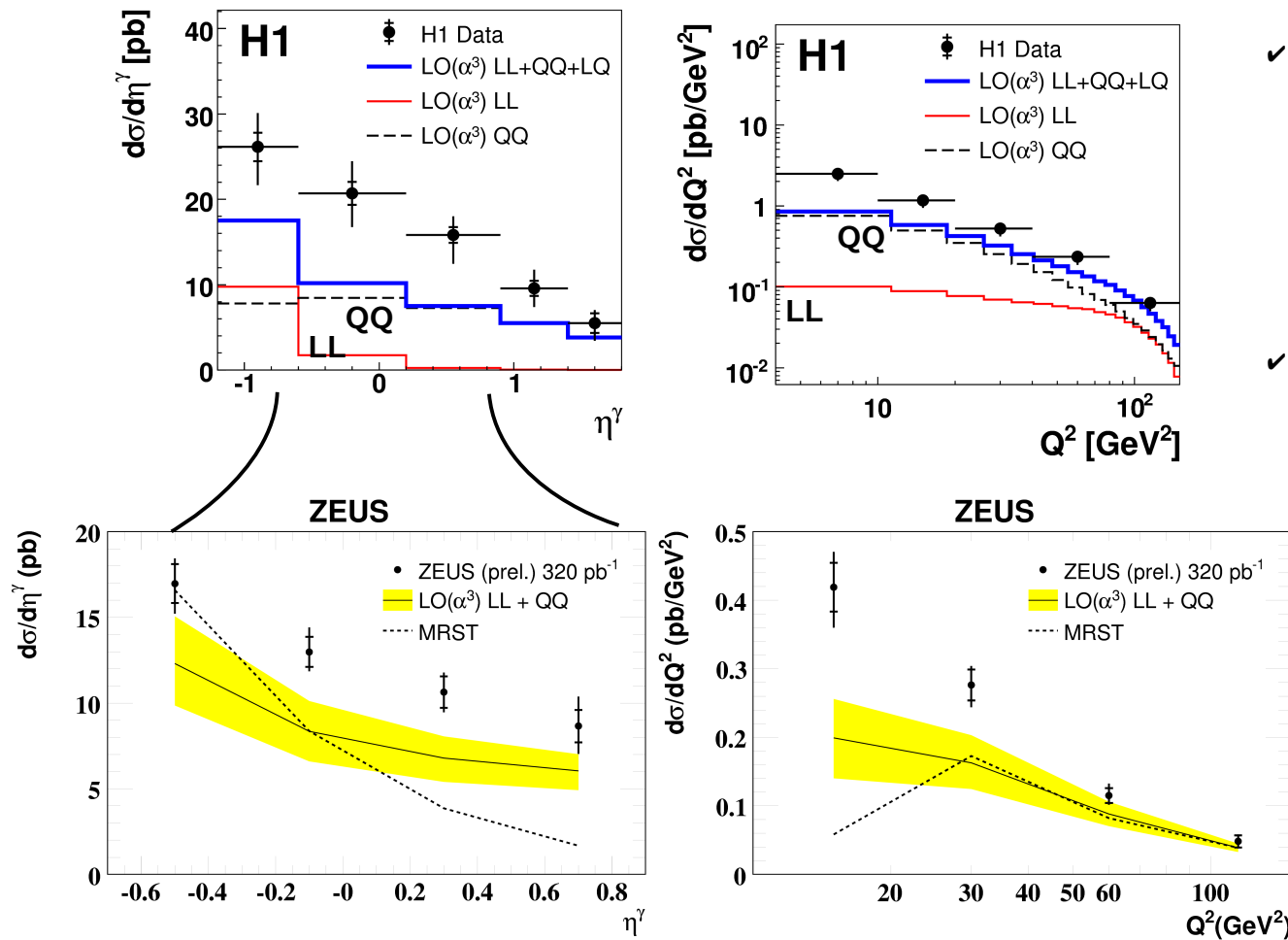


✓ **ZEUS:**
QQ (PYTHIA) $\times 1.6$
LL (DJANGO)

✓ Both measurement
consistent: MC needs
scaling

Prompt Photon Production in DIS

comparison to QCD calculations



✓ **A. Gehrmann-De Ridder et al.** [$O(\alpha^3 \alpha_s^0)$]

✓ **A.D. Martin et al.**
(MRST - ZEUS only)

✓ enhanced LL component including QED Compton scattering ($\gamma e \rightarrow \gamma e$)

✓ QQ part neglected
(limited validity)

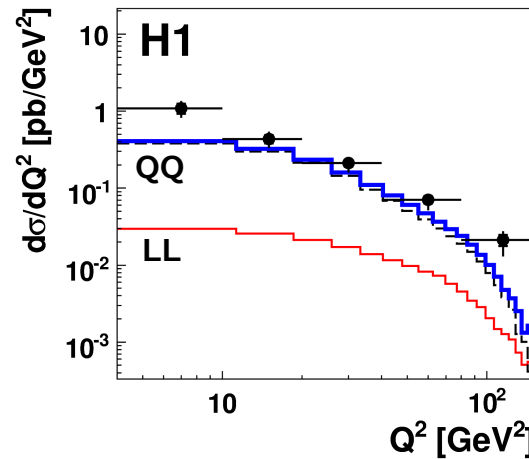
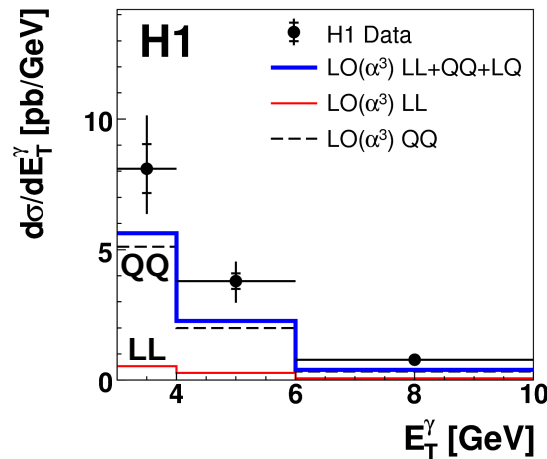
✓ Still interesting
(high Q^2 , low E_T^γ , low η^γ)

Prompt Photon Production in DIS

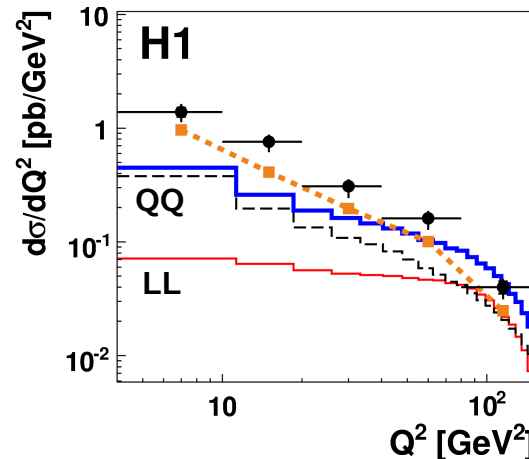
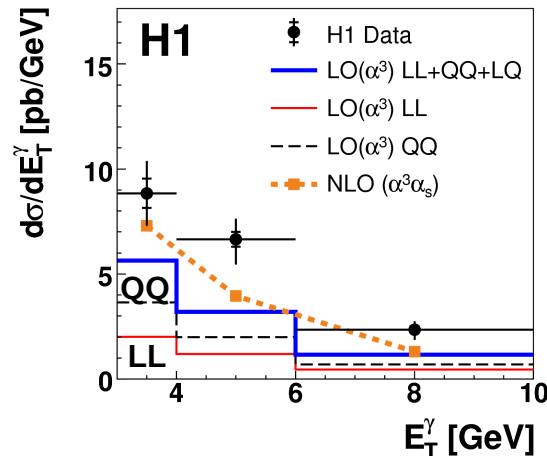
comparison to QCD calculations

- ✓ Photon plus no-jet and photon plus jet cross sections
- ✓ NLO calculation (Kramer et al.) [$O(\alpha^3 \alpha_s^1)$] available for photon + jet cross sections

Photon + no jet



Photon + jet



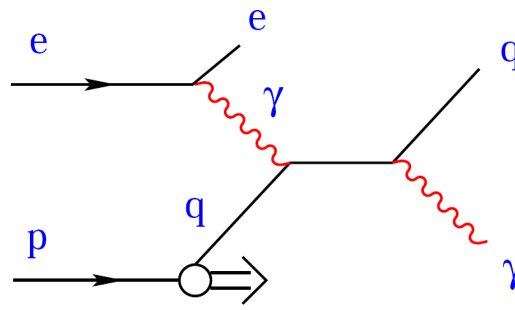
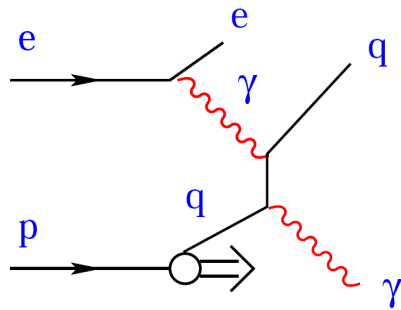
- ✓ Normalization problem for LO calculation
- ✓ NLO calculation increases low Q^2 prompt photon rates by 35% - closer to data

Prompt Photon Production in PhP

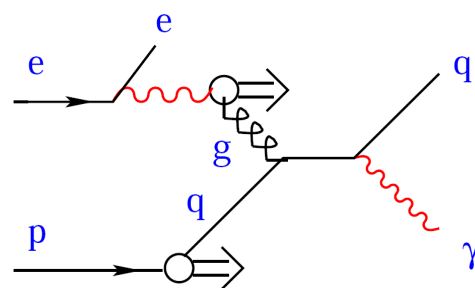
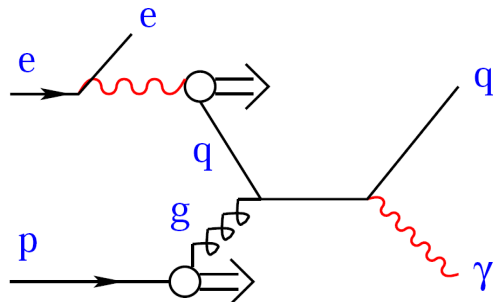
- ✓ In photoproduction lepton line radiation (LL) contribution can be neglected
- ✓ Resolved events become more important – sensitivity to photon pdf!

LO Feynman diagrams:

Direct



Resolved



- ✓ Often used x_γ :
longitudinal photon
energy fraction entering
hard interaction
- ✓ Separates both classes
 - ✓ Direct: $x_\gamma \equiv 1$
 - ✓ Resolved: $x_\gamma < 1$

Prompt Photon Production in PhP

preliminary results (DIS 2009)



- ✓ $\int L = 340 \text{ pb}^{-1}$
- ✓ ***Inclusive phase space***
 - ✓ $6 < E_T^\gamma < 15 \text{ GeV}$
 - ✓ $-1.0 < \eta^\gamma < 2.43$
 - ✓ $z = E_T^\gamma / E_T^{\gamma \text{ jet}} > 0.9$
 - ✓ $Q^2 < 1 \text{ GeV}^2$
 - ✓ $0.1 < y < 0.7$
- ✓ ***Photon + jet phase space***
 - ✓ *Inclusive phase space*
 - ✓ $p_T^{\text{jet}} > 4.5 \text{ GeV}$
 - ✓ $-1.3 < \eta^{\text{jet}} < 2.3$

Prompt Photon Production in PhP

preliminary results (DIS 2009)



✓ $\int L = 340 \text{ pb}^{-1}$

✓ Inclusive phase space

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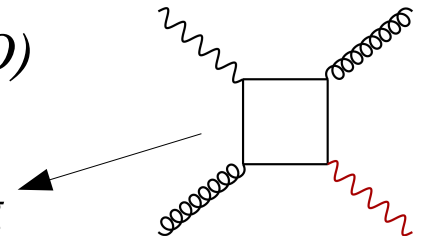
✓ Photon + jet phase space

- ✓ Inclusive phase space
- ✓ $p_T^{\text{jet}} > 4.5 \text{ GeV}$
- ✓ $-1.3 < \eta^{\text{jet}} < 2.3$

Results compared to calculation by:

✓ **M. Fontannaz, J. P. Guillet,
G. Heinrich (FGH)**

- ✓ collinear approach (NLO)
- ✓ includes
 - ✓ box diagram $\gamma g \rightarrow \gamma g$
 - ✓ quark-to-photon fragmentation



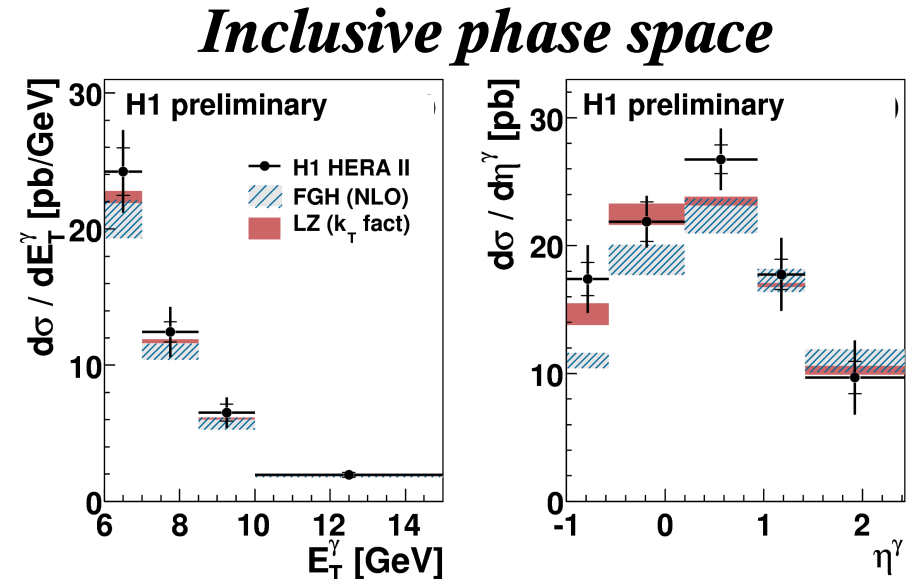
✓ **A. V. Lipatov, N. P. Zotov (LZ)**

- ✓ k_T -factorisation approach (unintegrated pdfs)
- ✓ using Kimber-Martin-Ryskin prescription
- ✓ fragmentation contribution and box diagram neglected

Prompt Photon Production in PhP

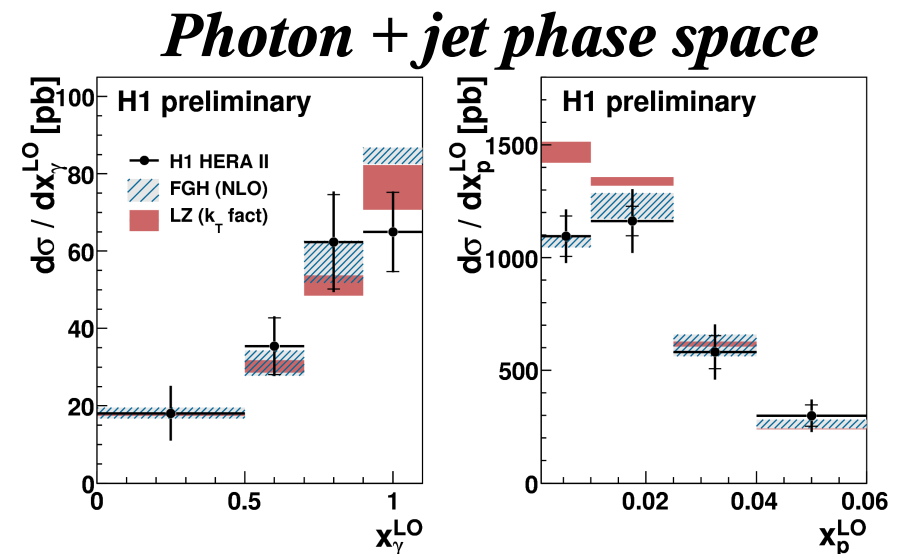
Cross sections

- ✓ **Inclusive cross sections:**
reasonable agreement
(except low η^γ)



- ✓ **Exclusive cross section:**
may construct observables with
more insight into the underlying
partonic process

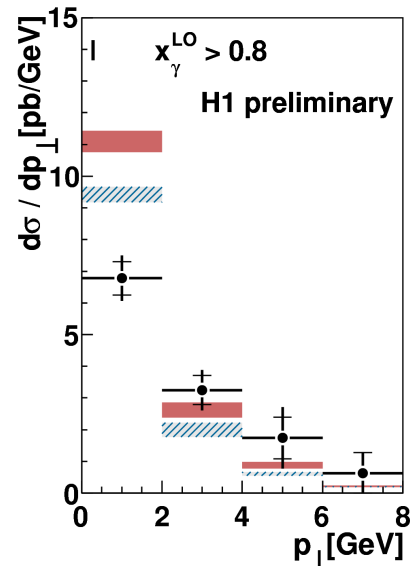
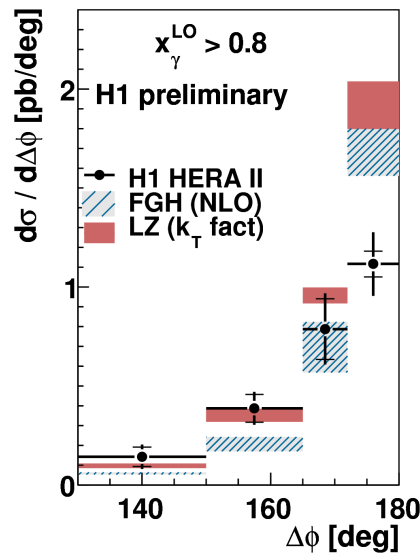
$$x_y^{LO} = E_T^\gamma \frac{e^{-\eta^{jet}} + e^{-\eta^\gamma}}{2yE_e} \quad x_p^{LO} = E_T^\gamma \frac{e^{\eta^{jet}} + e^{\eta^\gamma}}{2E_p}$$



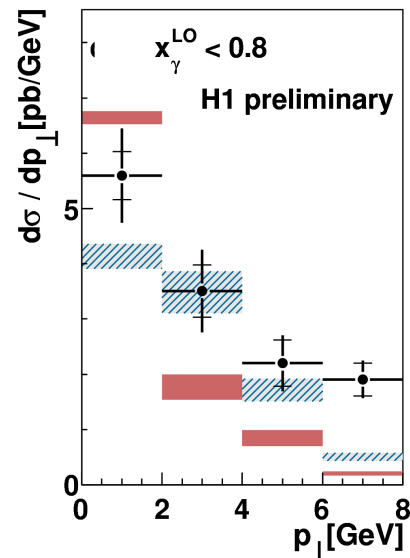
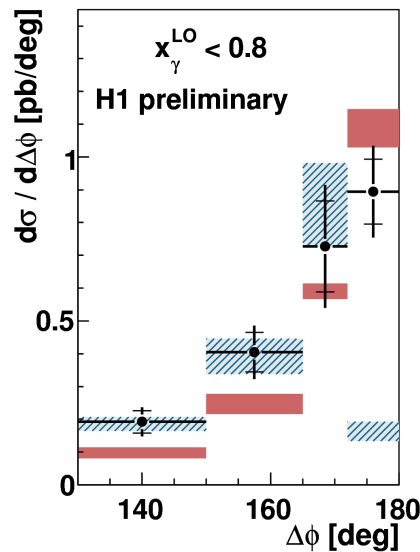
Prompt Photon Production in PhP

Photon – jet correlations

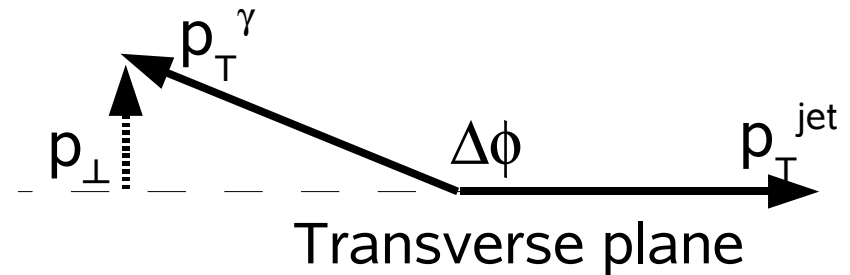
Direct enhanced



Resolved enhanced



- ✓ Photon – jet correlations in direct (resolved) enhanced phase space



- ✓ Direct process more back-to-back
- ✓ Sensitivity to soft gluon emission in the highest $\Delta\phi$ bin in the resolved case
 - ✓ fixed order FGH calculation not reliable
 - ✓ k_T factorisation absorbs soft gluons in pdf
- ✓ LZ missing diagrams are expected in tails of resolved cross sections

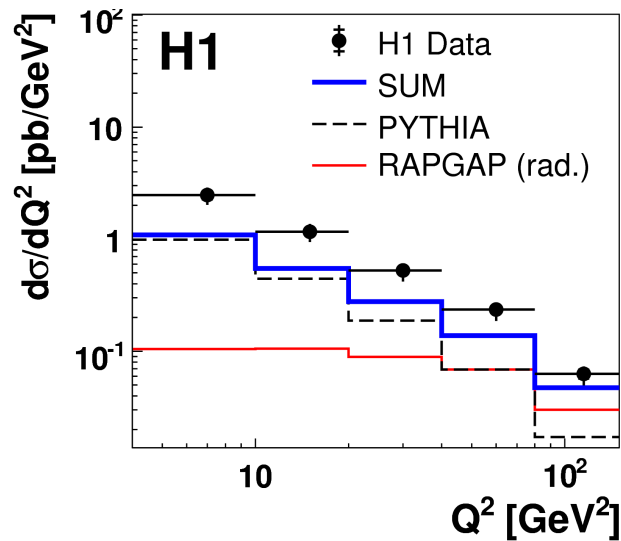
Summary

- ✓ ***New H1 and ZEUS results on prompt photon production in DIS presented***
 - ✓ *Compatible observations*
 - ✓ *MC and LO calculations underestimate prompt photon production in DIS*
 - ✓ *NLO calculations (γ +jet) closer but still below data*
- ✓ ***New preliminary H1 results on prompt photons in photoproduction presented***
 - ✓ *NLO and k_T factorisation based calculations slightly underestimate measurements*
 - ✓ *Largest disagreement visible in γ -jet correlation studies*

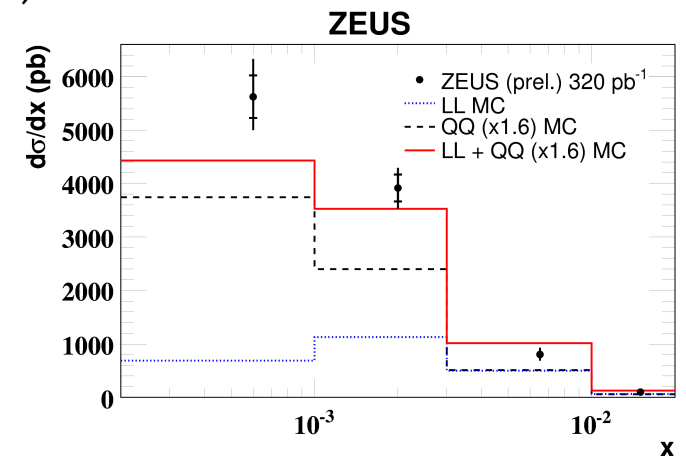
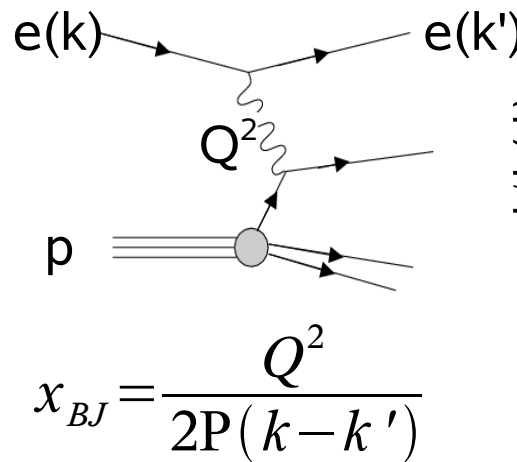
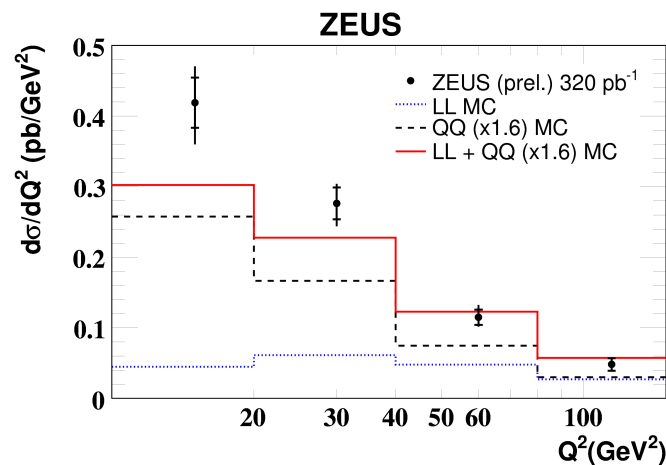
Backup

Prompt Photon Production in DIS

comparison to MC prediction

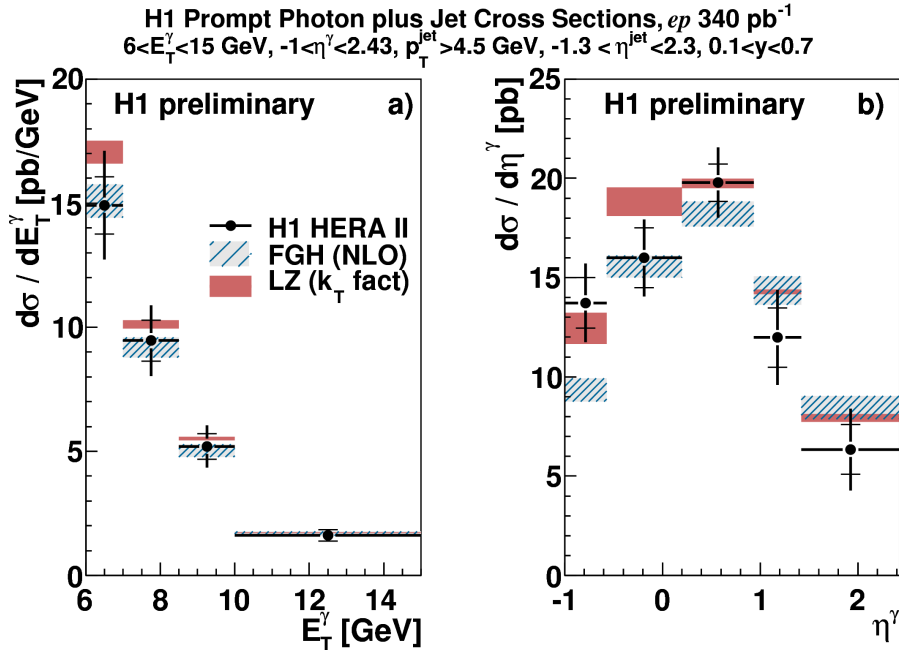


- ✓ Cross sections in bins of Q^2
 - ✓ Different shape in MC
- ✓ The first prompt photon HERA measurement of x_{BJ}

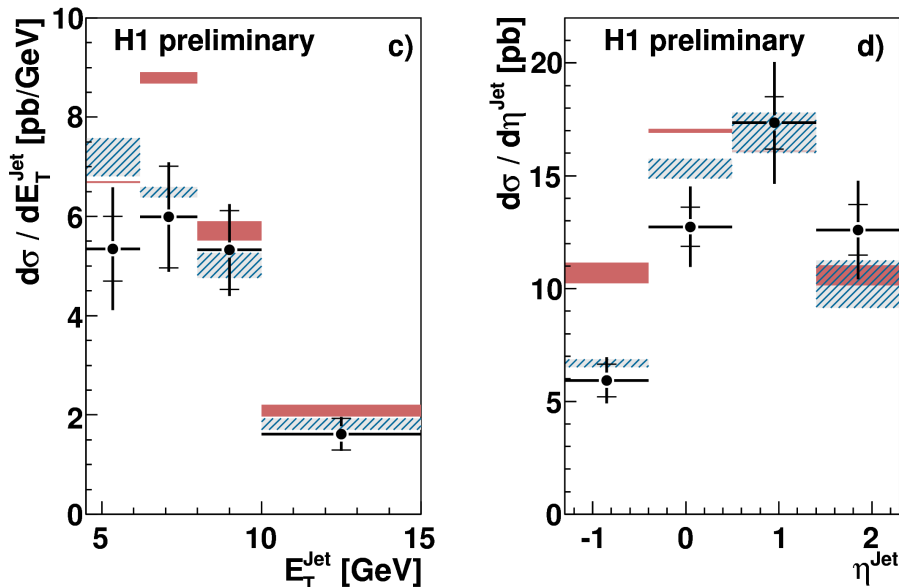


Prompt photon + jet cross sections

Photon



Jet



- ✓ Photons $\eta^\gamma > 1.0$ not studied before at HERA
- ✓ **Observation 1:** Cross sections in bins of photon variables better described by LZ
- ✓ **Observation 2:** On contrary, jet properties better described by FGH