Prompt Photon Production
in Deep Inelastic Scattering and Photoproduction at HERA

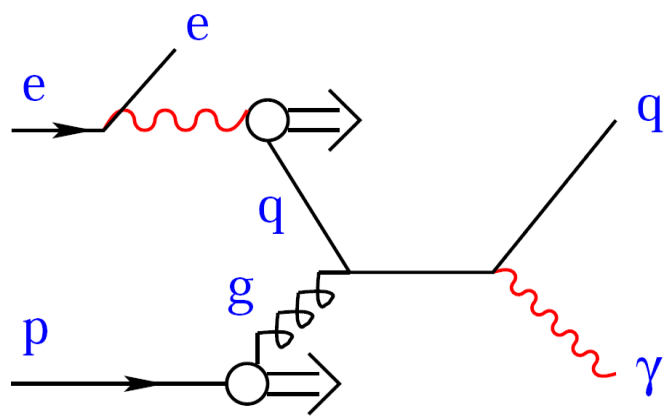
- ***Prompt Photons at HERA***
- ***Prompt Photons in DIS***
  - *H1 [Eur. Phys. J. C **54**, p371, (2008)]*
  - *ZEUS [preliminary]*
- ***Prompt Photons in Photoproduction***
  - *H1 [preliminary]*

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

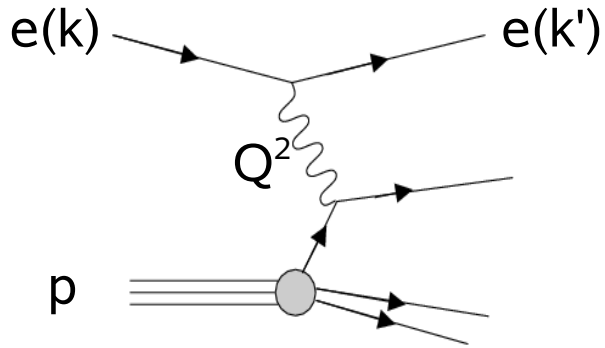
Prompt photons at HERA

- ***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 ($H \to \gamma\gamma$)*



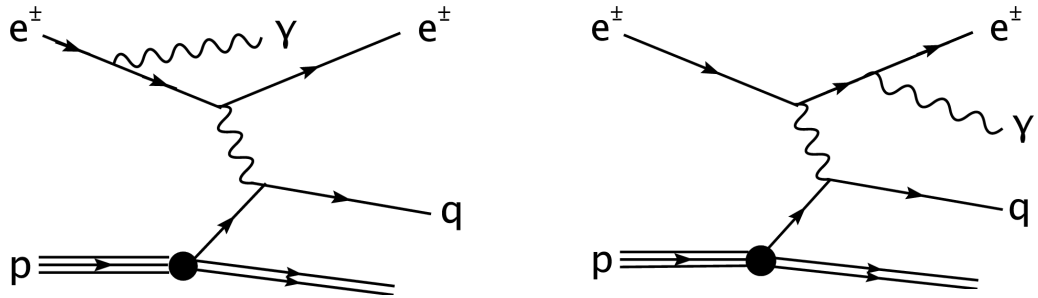
- ***ep kinematics:***



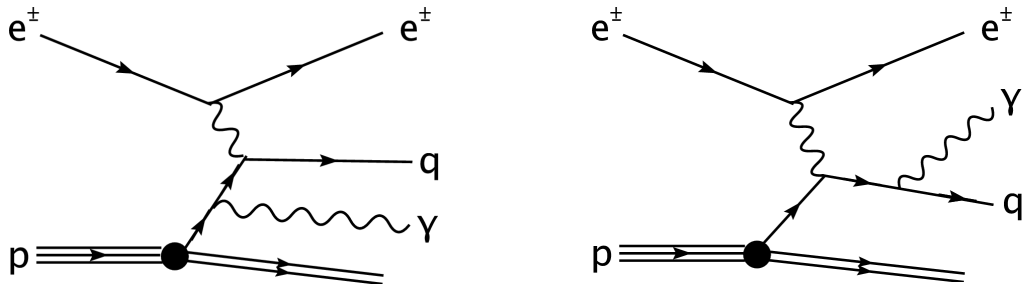
  - *Important variable – the virtuality of the mediating photon* $Q^2 = -(k - k')^2$
  - $Q^2 > 0$ – *Deep Inelastic Scattering (DIS)*
  - $Q^2 \approx 0$ – *Photoproduction (PhP)*

Prompt (Isolated) photons in DIS

- ***Contributions from:***
  - *Hard radiation from the lepton line (**LL**)*



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



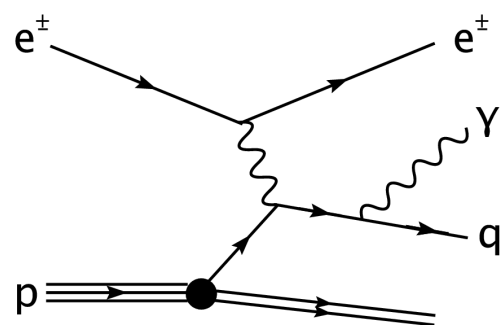
  - *Interference term (**LQ**) usually small*

Isolated Photon Production in DIS

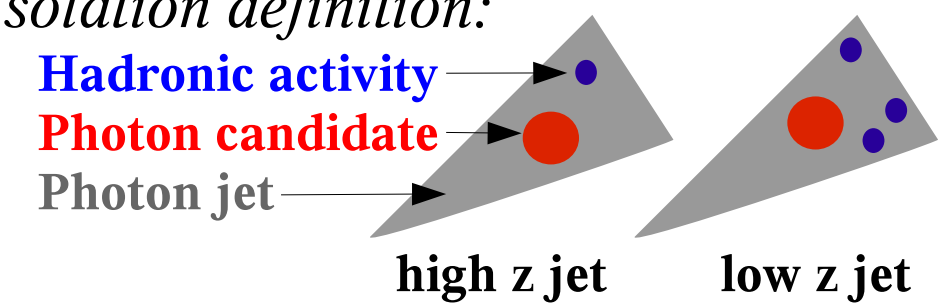
Eur. Phys. J. C 54, p371, (2008)

- $\int L = 227\ pb^{-1}$
- **Photon phase space**
  - $3 < E_T^{\gamma} < 10\ GeV$
  - $-1.2 < \eta^{\gamma} < 1.8$
  - $z = E_T^{\gamma} / E_T^{\gamma\ jet} > 0.9$
- **DIS phase space**
  - $4 < Q^2 < 150\ GeV^2$
  - $E_{e'} > 10\ GeV$
  - $153^{\circ} < \theta_{e'} < 177^{\circ}$
  - $W_X > 50\ GeV$
  - $y > 0.05$

- **Jet definition** (k_T algorithm)
  - $p_T^{jet} > 2.5\ GeV$
  - $-1.0 < \eta^{jet} < 2.1$



Isolation definition:



Prompt Photon Production in DIS

preliminary results (DIS 2009)

- $\int L = 320\ pb^{-1}$
- ***Photon phase space***
  - $4 < E_T^{\gamma} < 15\ GeV$
  - $-0.7 < \eta^{\gamma} < 0.9$
  - $z = E_T^{\gamma} / E_T^{\gamma\ jet} > 0.9$
- ***DIS phase space***
  - $10 < Q^2 < 350\ GeV^2$
  - $E_{e'} > 10\ GeV$
  - $140^{o} < \theta_{e'} < 172^{o}$

Higher photon energies accessible thanks to the ZEUS preshower detector

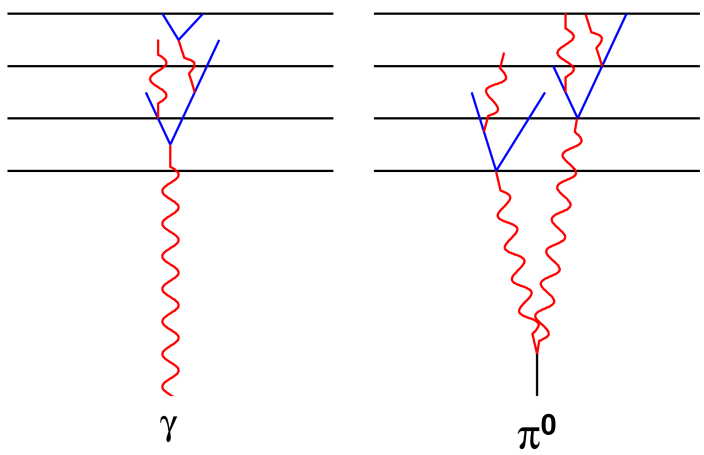
*Concentration on the central part of the detector (**H1**: $-1.2 < \eta^{\gamma} < 1.8$)*

*Higher Q^2 (**H1**: $4 < Q^2 < 150\ GeV^2$)*

Prompt Photon Production in DIS

background discrimination

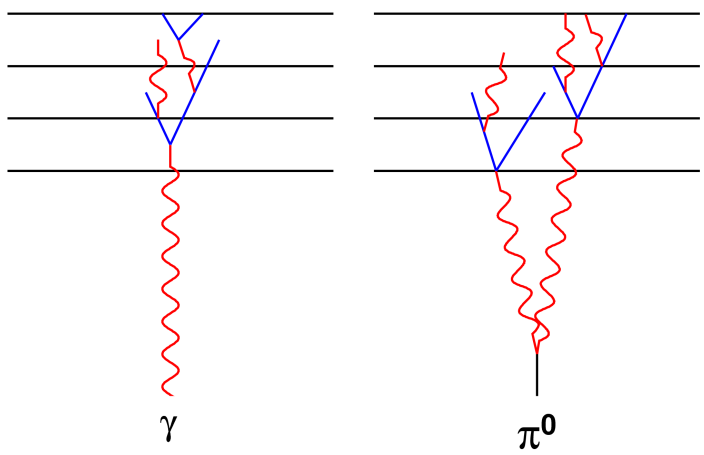
- *Main background – neutral hadrons decaying into photons*



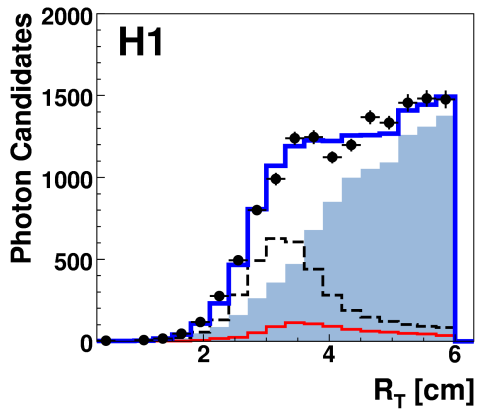
Prompt Photon Production in DIS

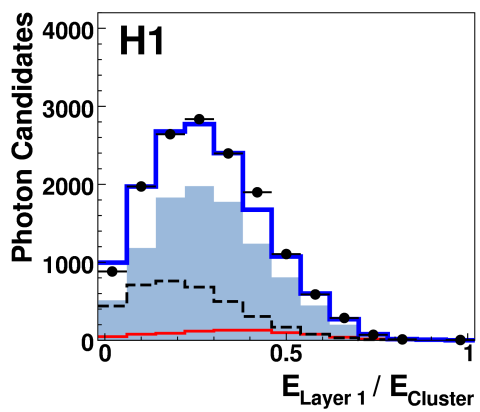
background discrimination

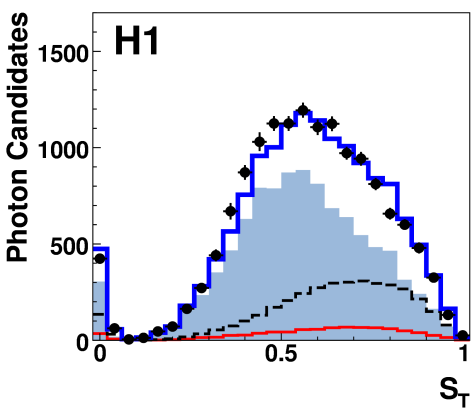
- *Main background – neutral hadrons decaying into photons*

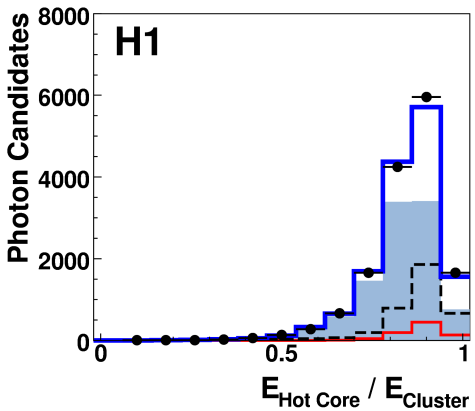


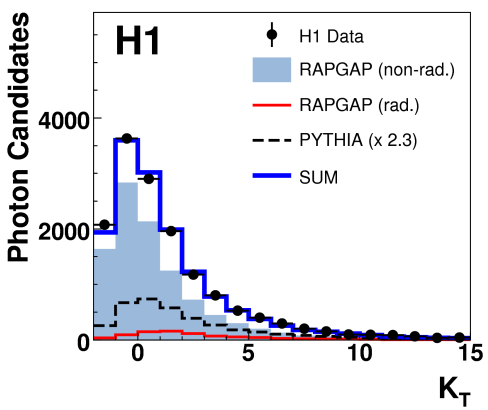
- *Six shower shape variables used to extract photon signal*

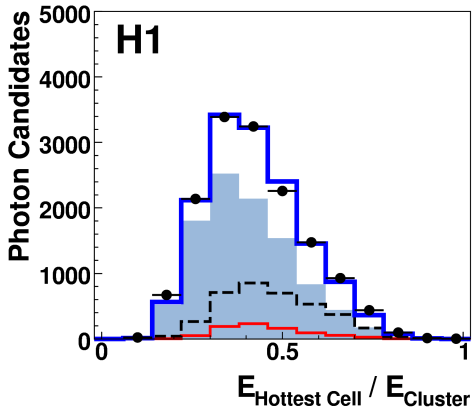








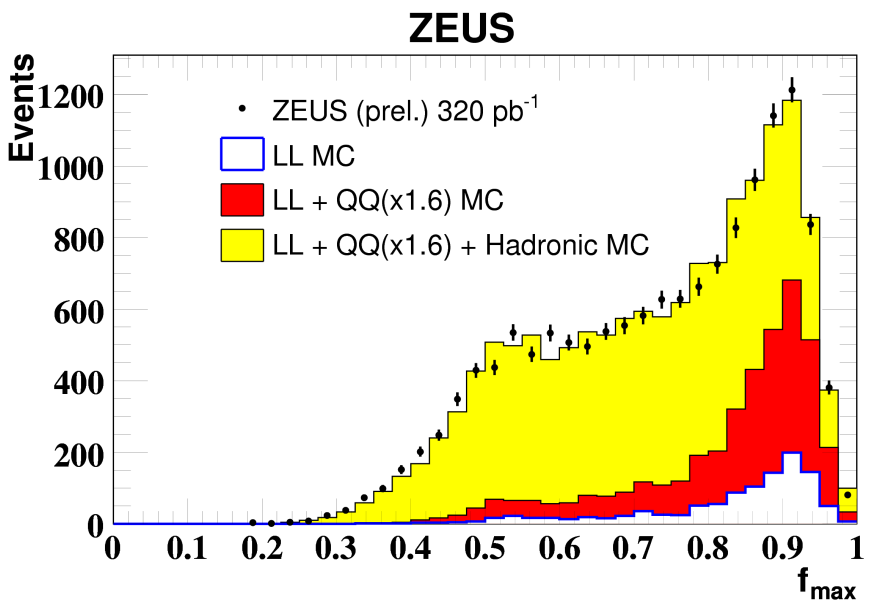


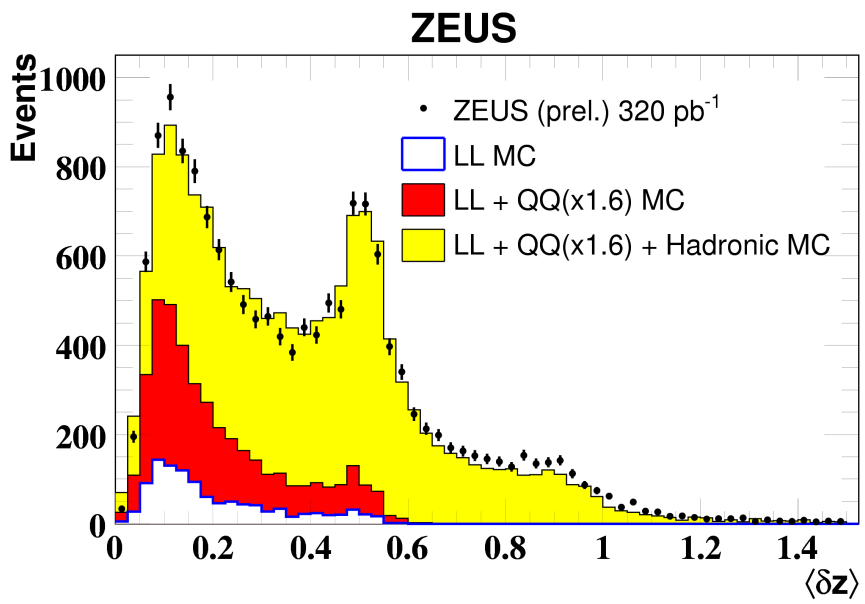


Prompt Photon Production in DIS

background discrimination

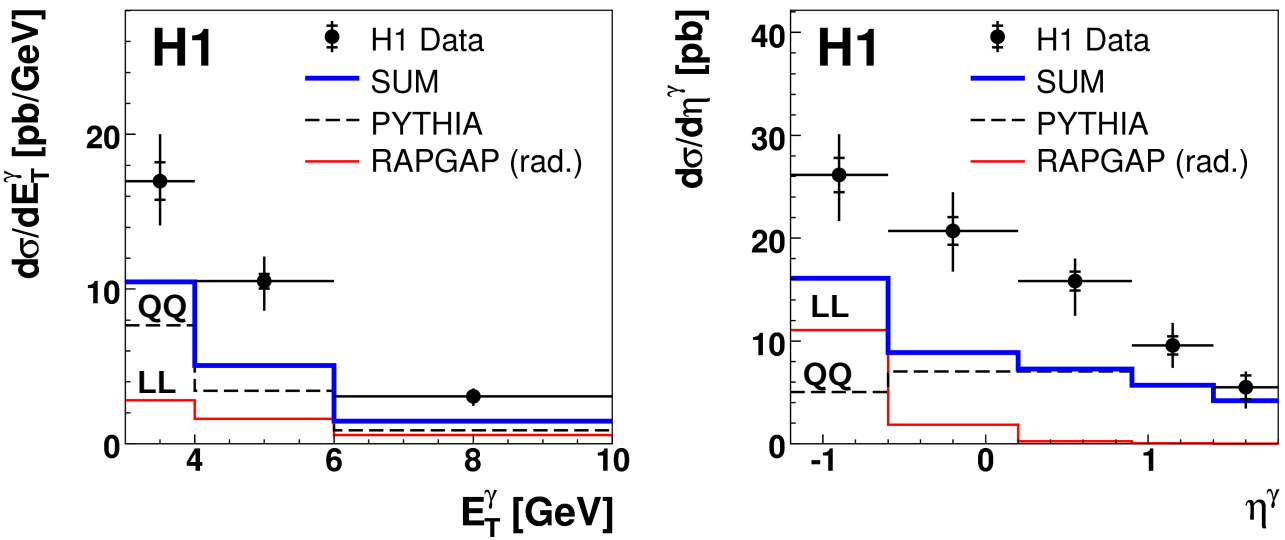
- *Similar approach*
- *Two variables are used*
  - *Energy fraction in the most energetic cell* $\mathbf{f_{max}}$
  - *Energy weighted mean modulus of width in z-direction* $\langle\delta z\rangle$





Prompt Photon Production in DIS

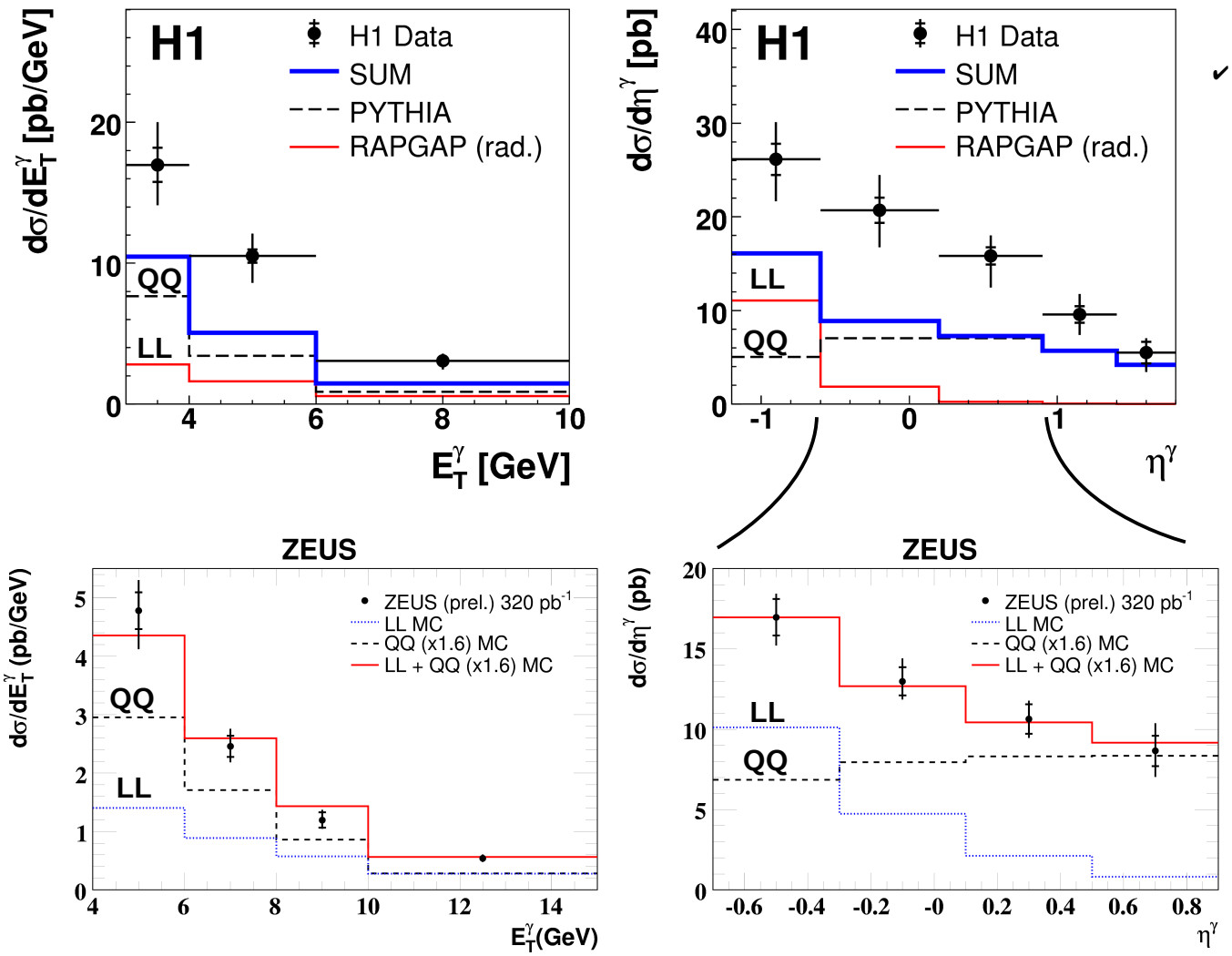
comparison to MC prediction



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

Prompt Photon Production in DIS

comparison to MC prediction

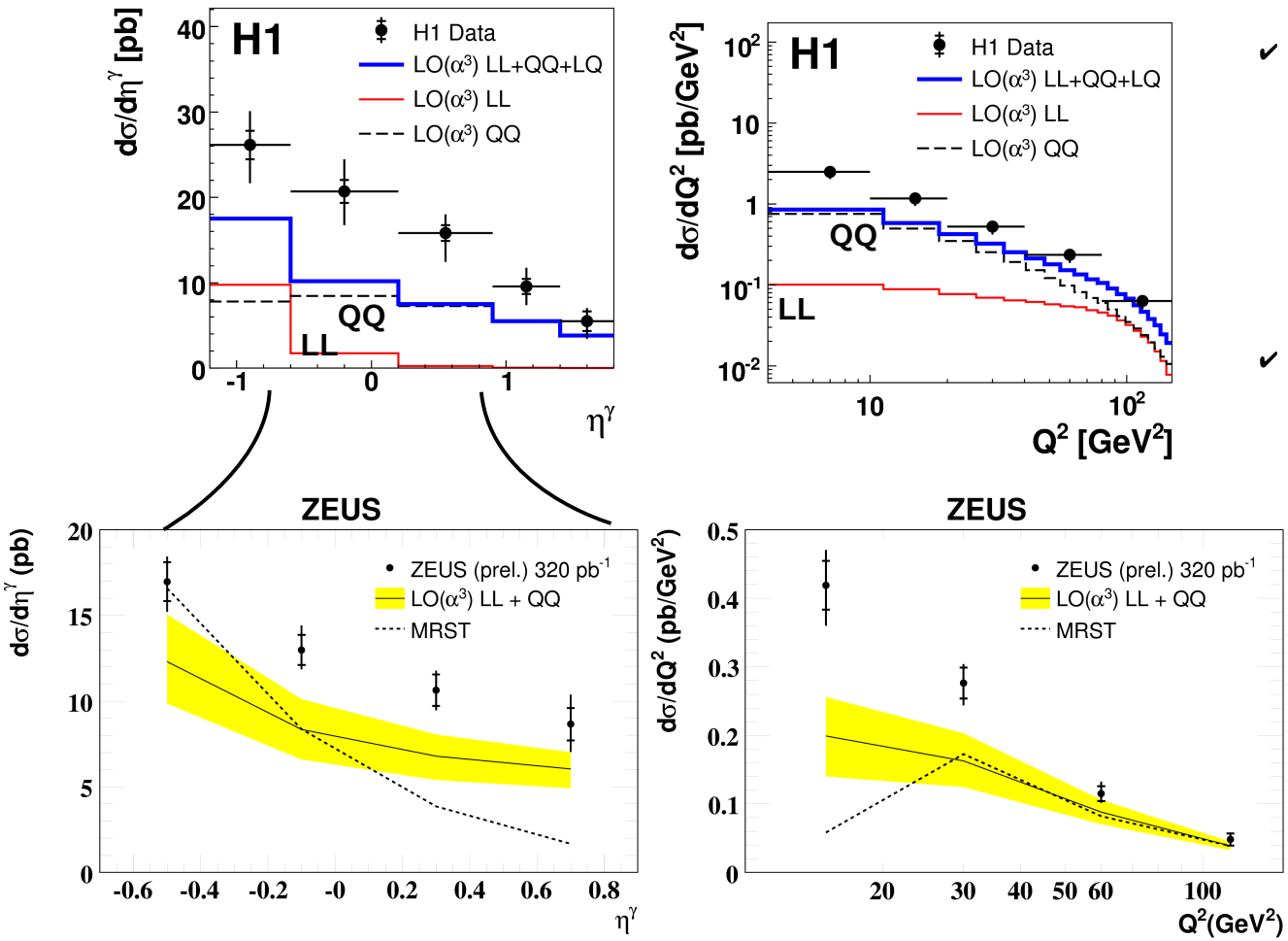


- ***H1:*** PYTHIA *used for* QQ
  RAPGAP *used for* LL

- ***ZEUS:***
  QQ (PYTHIA) *x 1.6*
  LL (DJANGOH)

- *Both measurement consistent: MC needs scaling*

Prompt Photon Production in DIS
comparison to QCD calculations



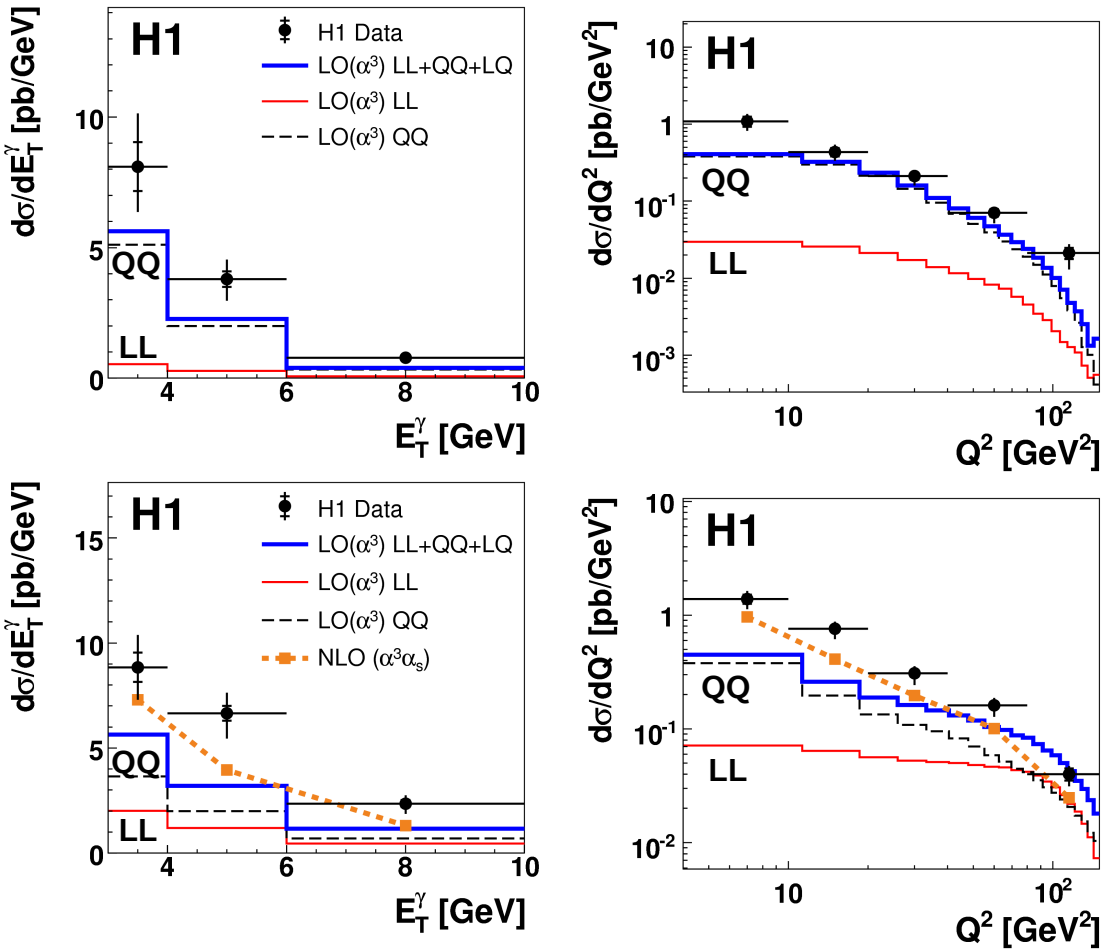
- ***A.Gehrmann-De Ridder et al.*** *[$O(\alpha^3 \alpha_S^0)$]*
- ***A.D.Martin et al.*** *(**MRST** - ZEUS only)*
  - *enhanced* LL *component including QED Compton scattering* ($\gamma_p e \rightarrow \gamma e$)
  - QQ *part neglected (limited validity)*
  - *Still interesting (high* Q^2*, low* E_T^γ*, 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*

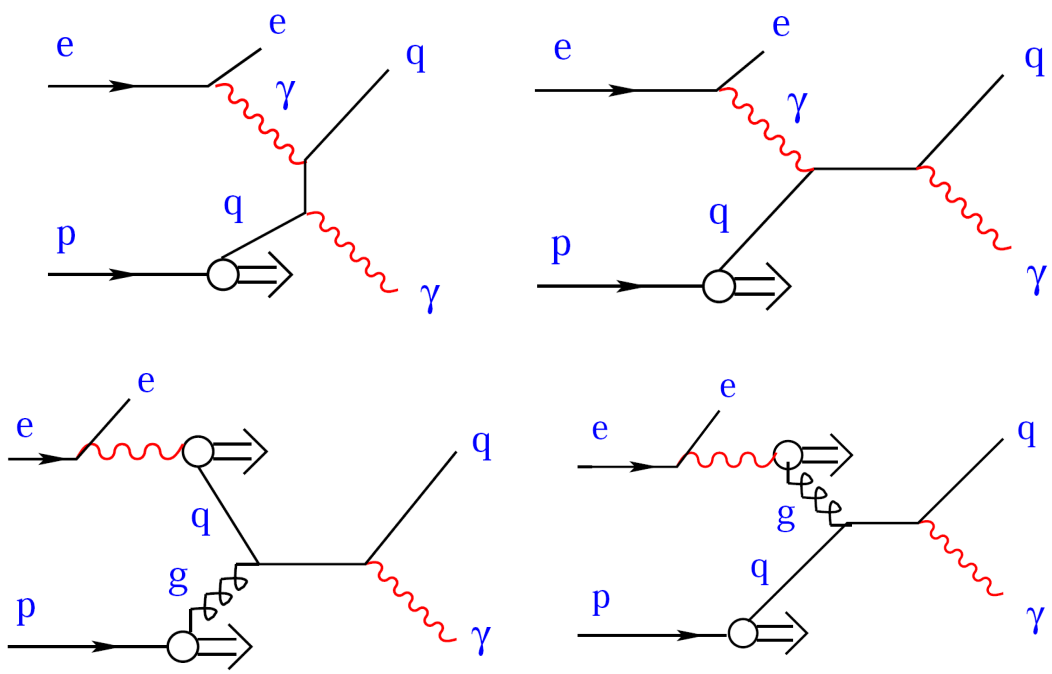
Prompt Photon Production in PhP

- *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)

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

Prompt Photon Production in PhP

preliminary results (DIS 2009)

- $\int L = 340\ pb^{-1}$
- **Inclusive phase space**
  - $6 < E_T^{\gamma} < 15\ GeV$
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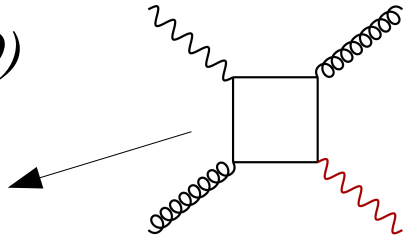
- **Photon + jet phase space**
  - Inclusive phase space
  - $p_T^{jet} > 4.5\ GeV$
  - $-1.3 < \eta^{jet} < 2.3$

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

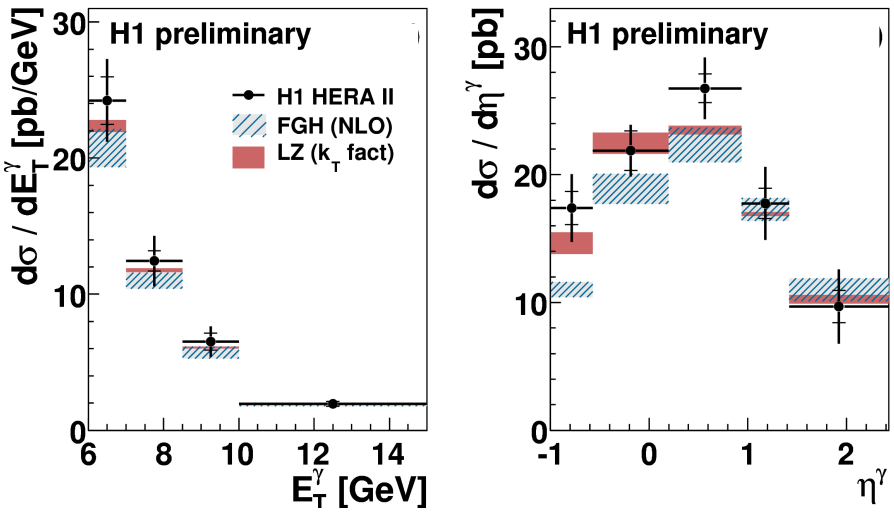
- ***Inclusive cross sections:***
  reasonable agreement
  (except low η^{γ})

- ***Exclusive cross section:***

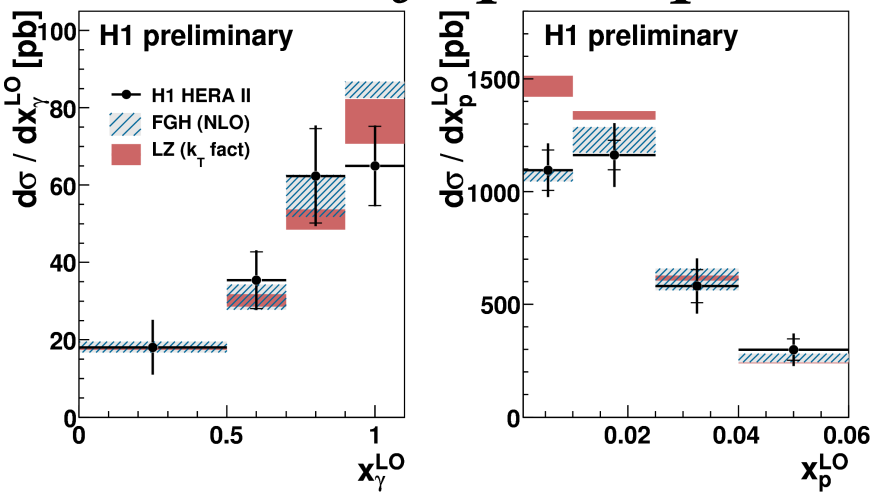
  may construct observables with more insight into the underlying partonic process

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

Inclusive phase space

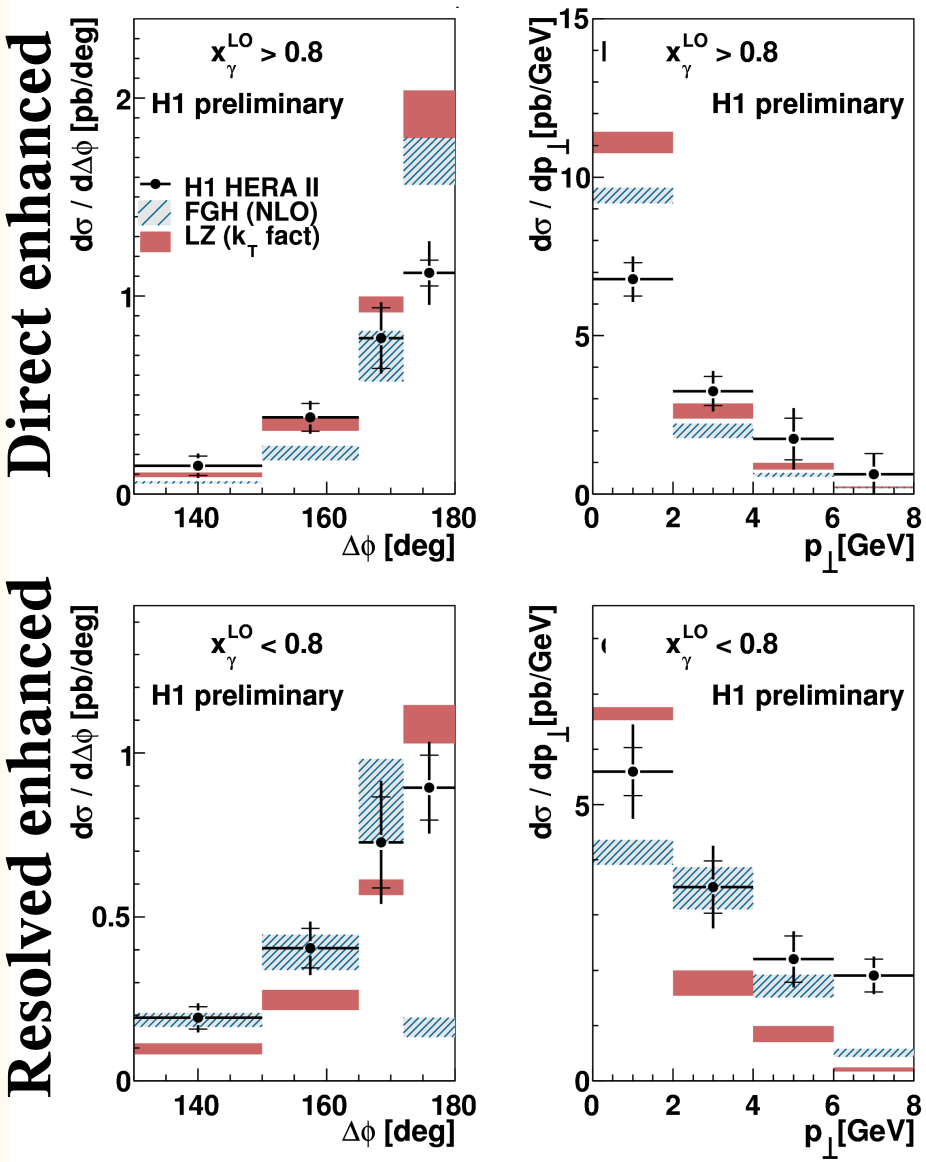


Photon + jet phase space

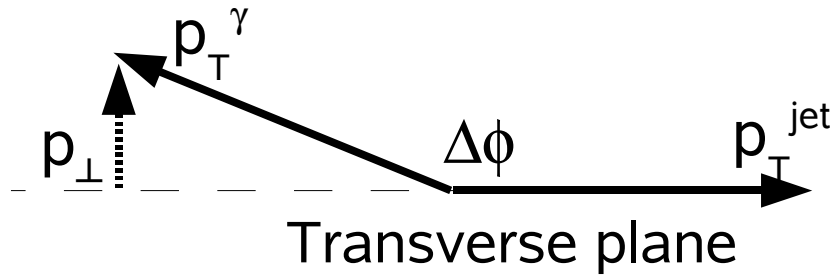


Prompt Photon Production in PhP

Photon – jet correlations



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



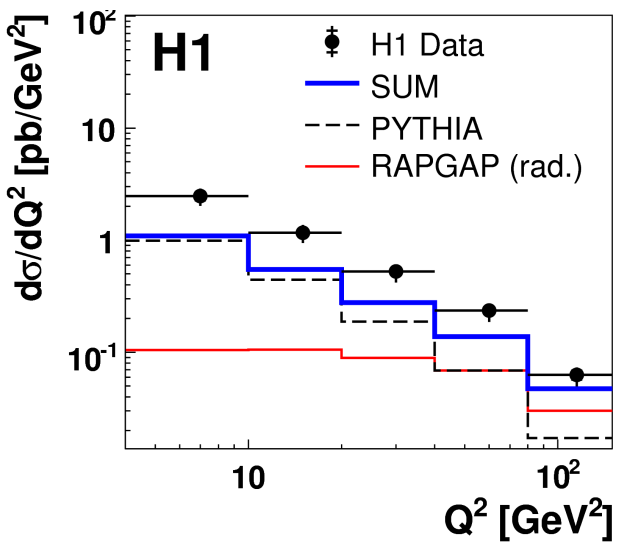
- *Direct process more back-to-back*
- *Sensitivity to soft gluon emission in the highest $\Delta\phi$ bin in the resolved case*
  - *fixed order FGH calculation not reliable*
  - *k_T factorisation absorbs soft gluons in pdf*
- *LZ missing diagrams are expected in tails of resolved cross sections*

Summary

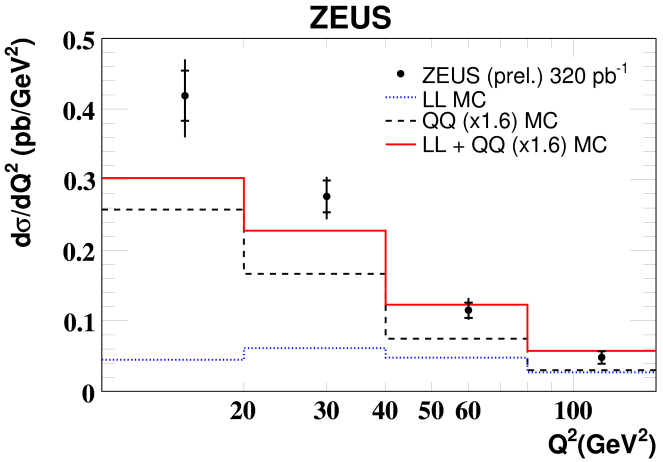
- ***New H1 and ZEUS results on prompt photon production in DIS presented***
  - *Compatible observations*
  - *MC and LO calculations underestimate prompt photon production in DIS*
  - *NLO calculations (γ+jet) closer but still below data*
- ***New preliminary H1 results on prompt photons in photoproduction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

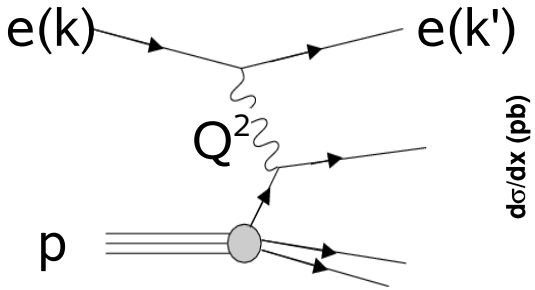
Backup

Prompt Photon Production in DIS
comparison to MC prediction

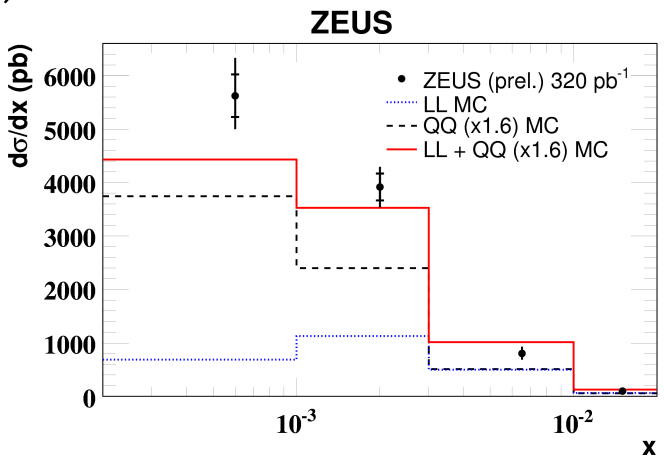


- *Cross sections in bins of Q^2*
  - *Different shape in MC*
- *The first prompt photon HERA measurement of x_{BJ}*

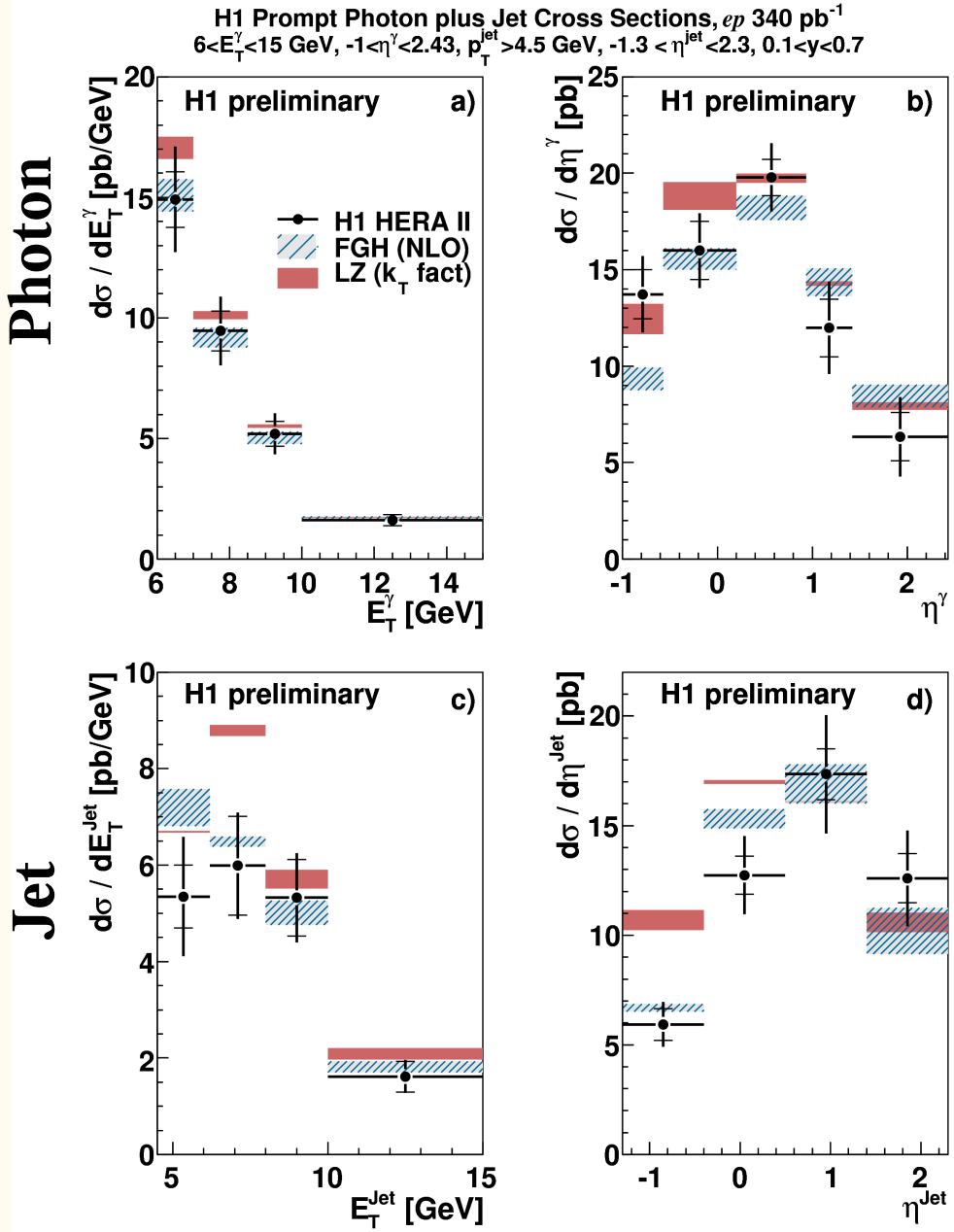




$$x_{BJ} = \frac{Q^2}{2P(k-k')}$$



Prompt photon + jet cross sections



- ✔ *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*