Prompt Photons in Photoproduction and Deep Inelastic Scattering at HERA

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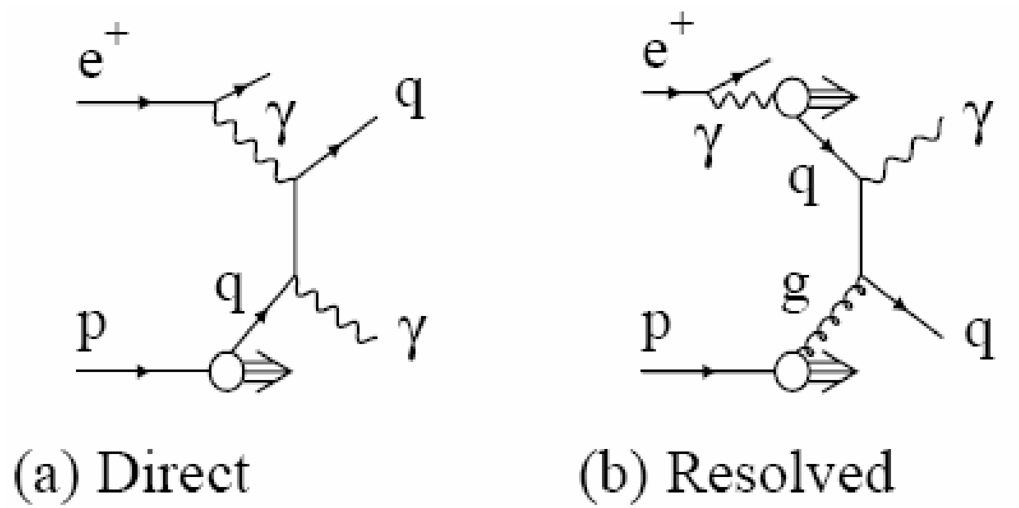
On behalf of the ZEUS & H1 Collaborations

Photon 2007 Paris, France

Prompt Photons



Prompt Photon:

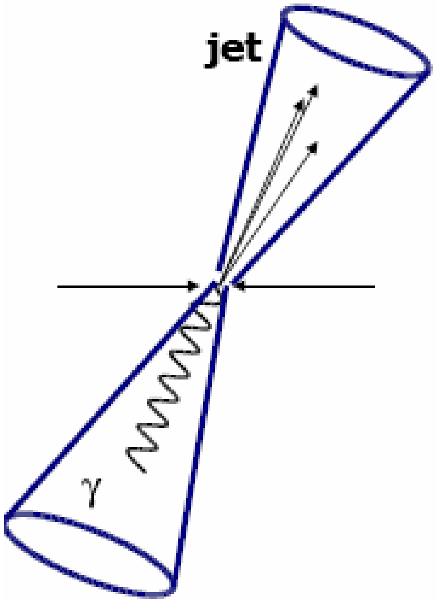
- γ is produced in the hard scatter
  - → Carries information about the struck parton
  - → No Hadronisation correction
  - → Sensitive to both quark and gluon densities

Non-Prompt Background:

- ISR/FSR: Photon is radiated from the Lepton
- Radiative events: Photon is radiated after the interaction
- Neutral mesons: Photon originates from a decay of a hadron

$$\pi^0 \rightarrow 2\gamma$$

Prompt Photons + Jet in Photoproduction



Presence of a jet:

- More sensitivity to underlying partonic processes
- Introduces some hadronisation
  - Smaller hadronisation correction than dijets

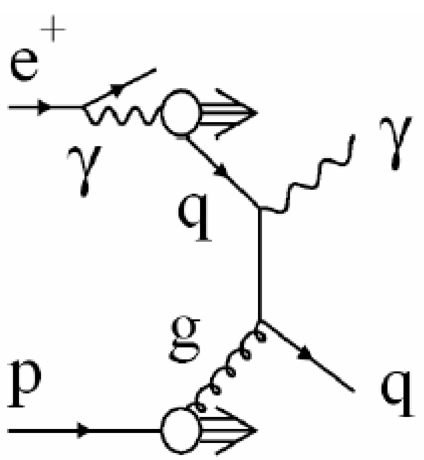
Photoproduction ($Q^2 \approx 0$):

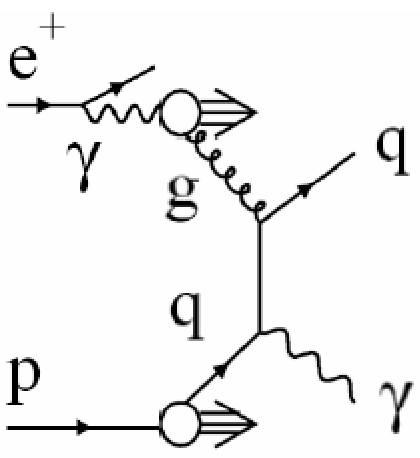
- Exchange photon is real
- No additional P_t given to the γ+jet system by $e^{\pm}$
- The γ+jet will be back to back → Well separated

Resolved contribution:

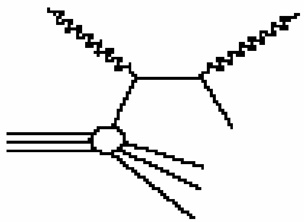
- γ hadronic structure
- Constrain gluon distribution

NLO calculation available:

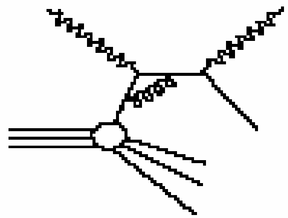




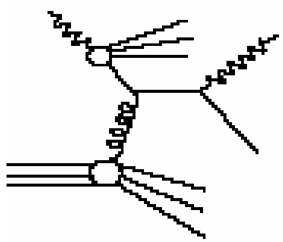
NLO Calculations



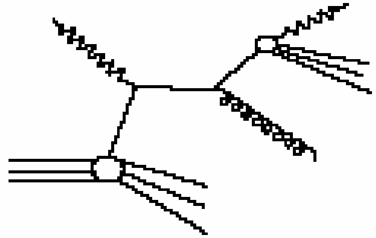
Compton Process α_{em}^2



$\alpha_s \alpha_{em}^2$



Resolved initial photon
$\alpha_s \alpha_{em}$



Resolved final photon
$\alpha_s \alpha_{em}$

K.Krawczyk & A.Zembrzuski (KZ):

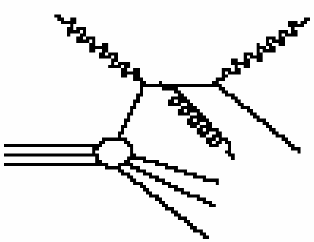
- **GRV parametrisation:**
  - **photon structure function**
  - **proton structure function**
  - **fragmentation function**

Fontanaz, Guillet & Heinrich (FGH):

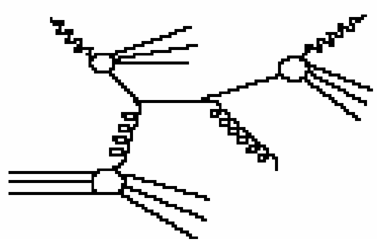
- **MRST proton structure function**
- **AFG photon structure function**

A.Lipatov & N.Zotov (LZ):

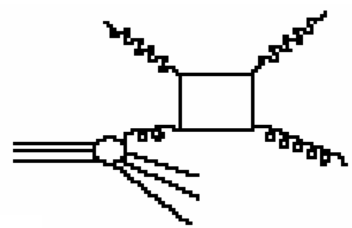
- **K_t-factorization approach**
  - **Unintegrated quark/gluon densities using Kimber-Martin-Ryskin prescription**



$\alpha_s \alpha_{em}^2$



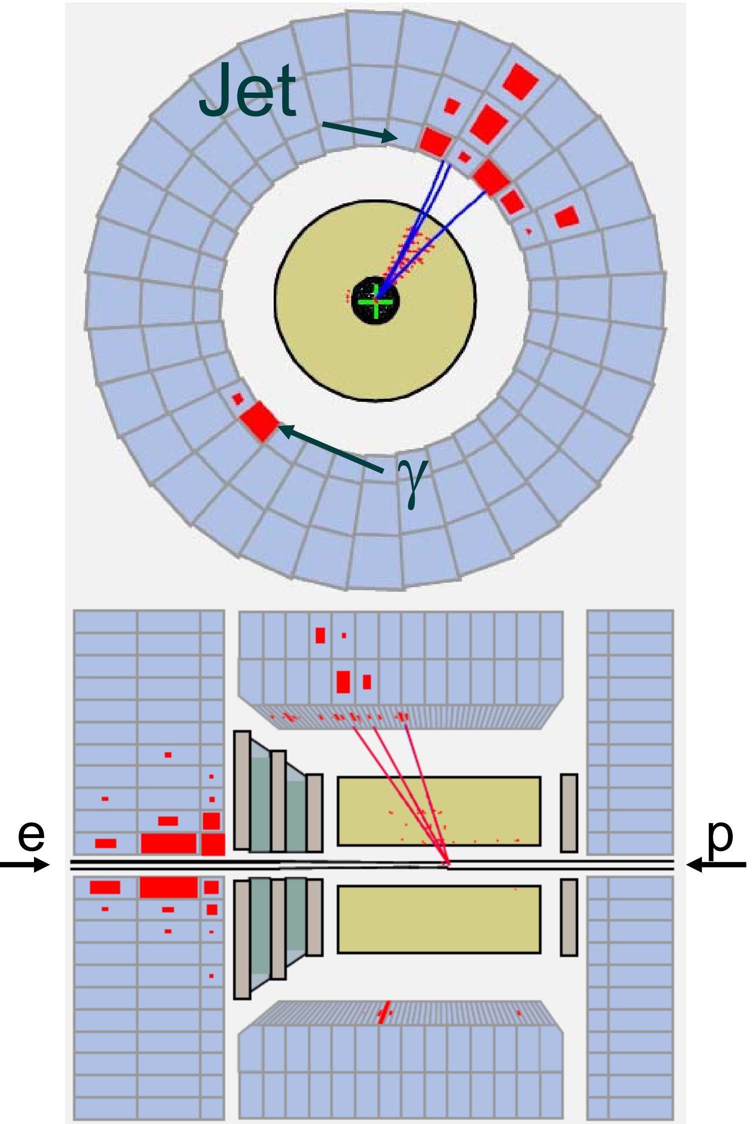
Double resolved $\alpha_s^2 \alpha_{em}^2$



Box diagram $\alpha_s^2 \alpha_{em}^2$

Need hadronic corrections from MC

Prompt Photons in Photoproduction



ZEUS:

99-00 Data, 77.1 pb^{-1}

Photoproduction Sample:

- $0.2 \leq Y_{JB} \leq 0.8$
- $Q^2 < 1\ GeV^2$

2 or more jets from the K_t algorithm:

- Photon candidate:
  - $E_{EMC}/E_{Total} \geq 0.9$
  - $-0.7 \leq \eta^{\gamma} \leq 1.1$ (BCAL region)
  - $5.0 \leq E_t^{\gamma} \leq 16.0$ GeV
  - No associated track
  - Low multiplicity: # of energy flow objects
- Associated jet:
  - $E_{EMC}/E_{Total} \leq 0.9$
  - $-1.6 \leq \eta^{jet} \leq 2.4$
  - $6.0 \leq E_t^{jet} \leq 17.0$ GeV
- (Note the asymmetric E_t cuts)

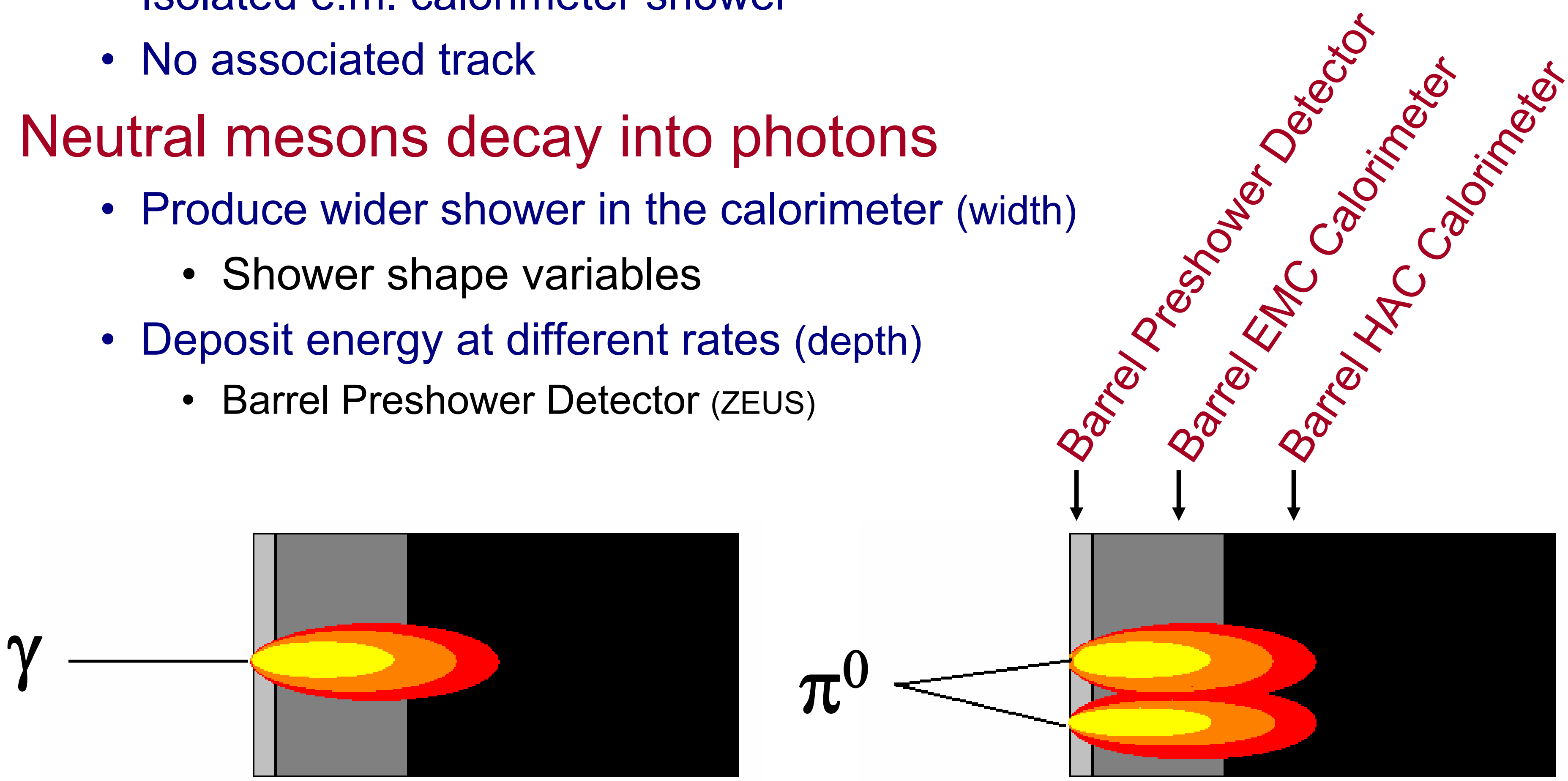
Isolated γ Identification

Photons

- Isolated e.m. calorimeter shower
- No associated track

Neutral mesons decay into photons

- Produce wider shower in the calorimeter (width)
  - Shower shape variables
- Deposit energy at different rates (depth)
  - Barrel Preshower Detector (ZEUS)



Photoproduction background

ZEUS:

Fit sum of prompt γ MC & background MC to Barrel Preshower Detector (BPRE)

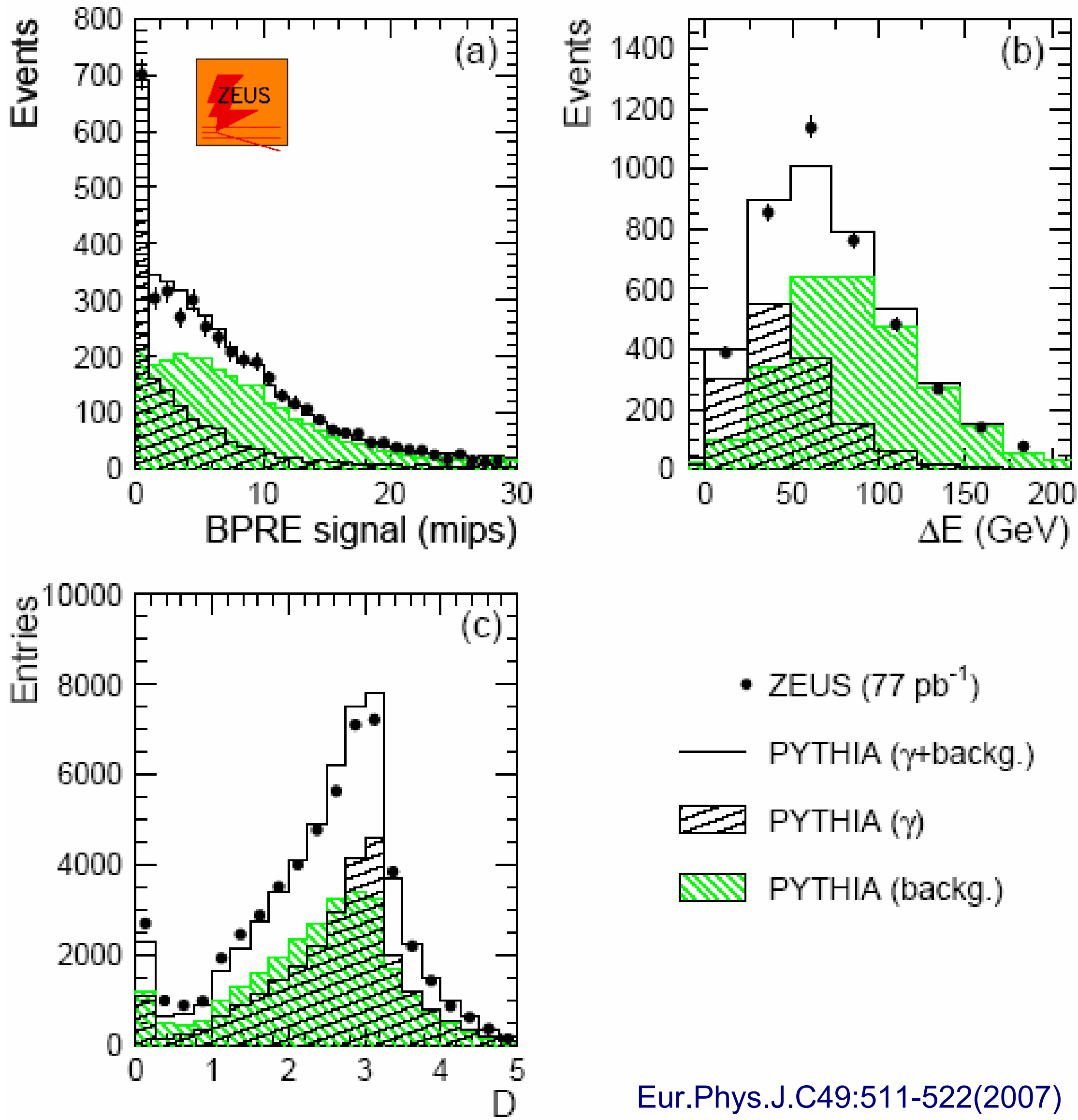
- Determine relative amounts
- Done bin-by-bin for E_t's, η's and $X\gamma$ distributions

• Large fraction of events with < 1 MIP → high purity

• Examine calorimeter based variables

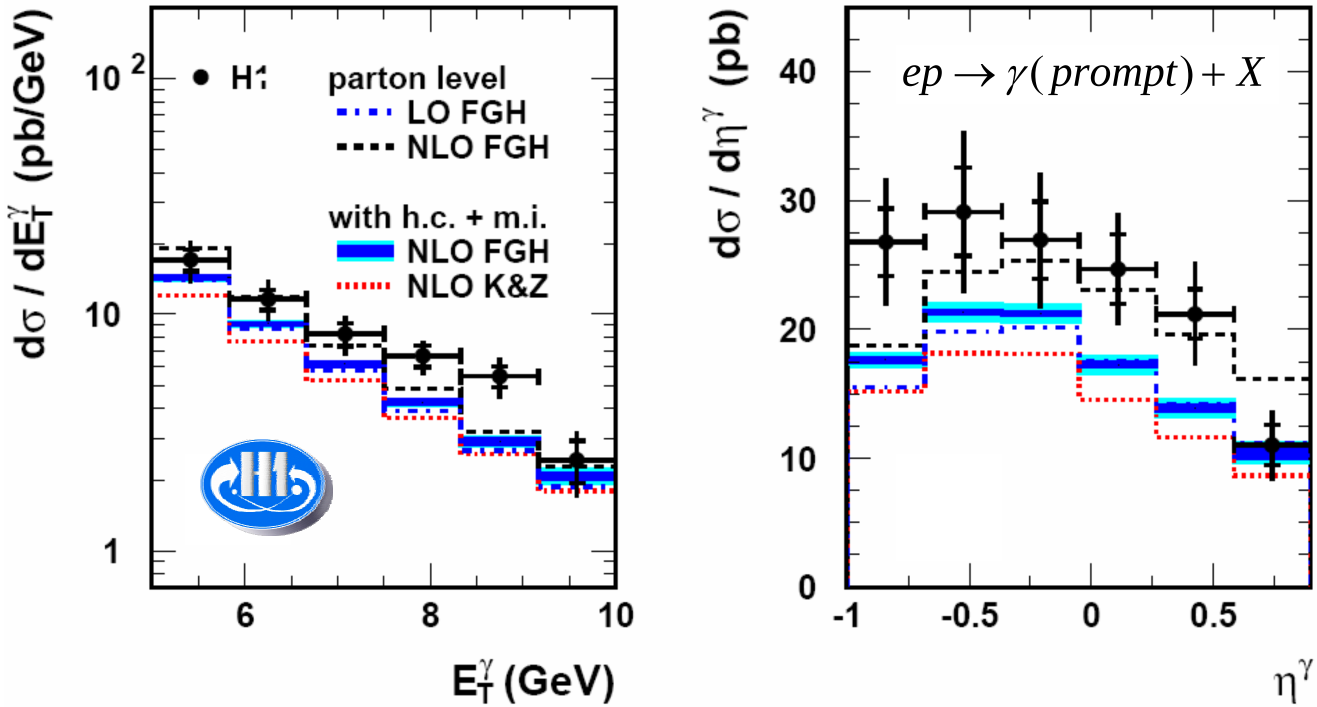
- $\Delta E = E_{Total} - E_{(\gamma + jet)}$
- D = Distance (in $\eta\phi$) from γ to energy flow objects
- Both are well reproduced by the sum of MCs

• Verified via DVCS sample



Eur.Phys.J.C49:511-522(2007)

Inclusive Prompt γ



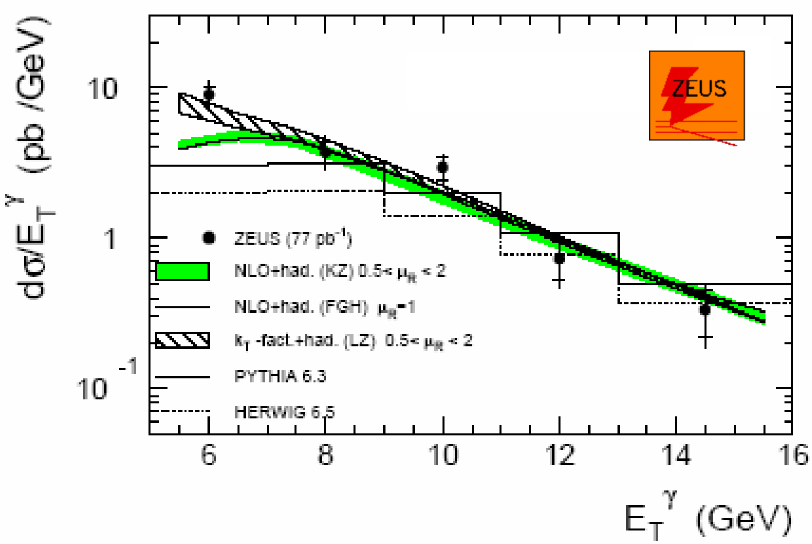
QCD Calculations:

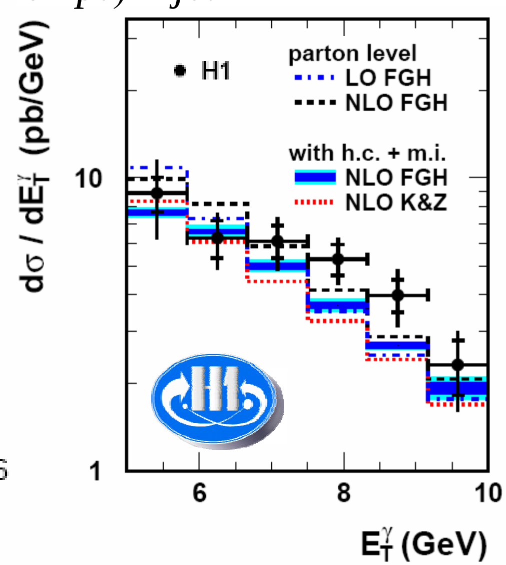
- NLO/LO ratio increasing with η^γ from 1.2 to 1.4
- Shown with & without corrections for hadronisation and multiple interactions
- Largest correction factors at high η^γ

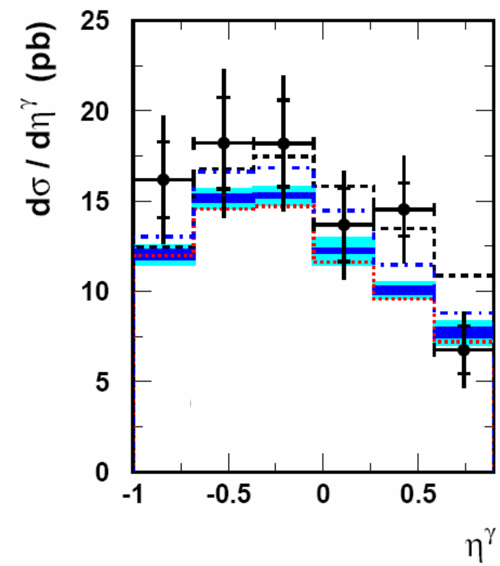
Eur.Phys.J.C38:437-445(2005)

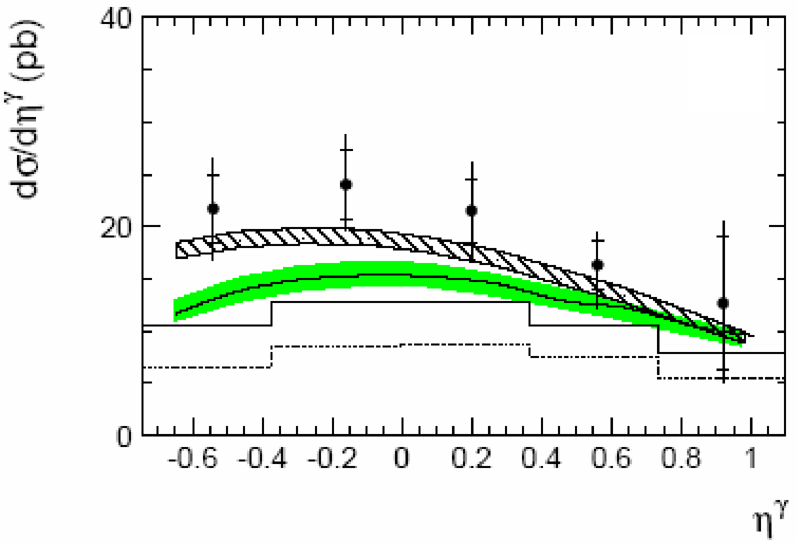
Prompt γ + Jet

$$ep \to \gamma(prompt) + jet + X$$









HERWIG & PYTHIA:

- Underestimate the measured cross section, particularly at low E_t^γ

KZ & FGH:

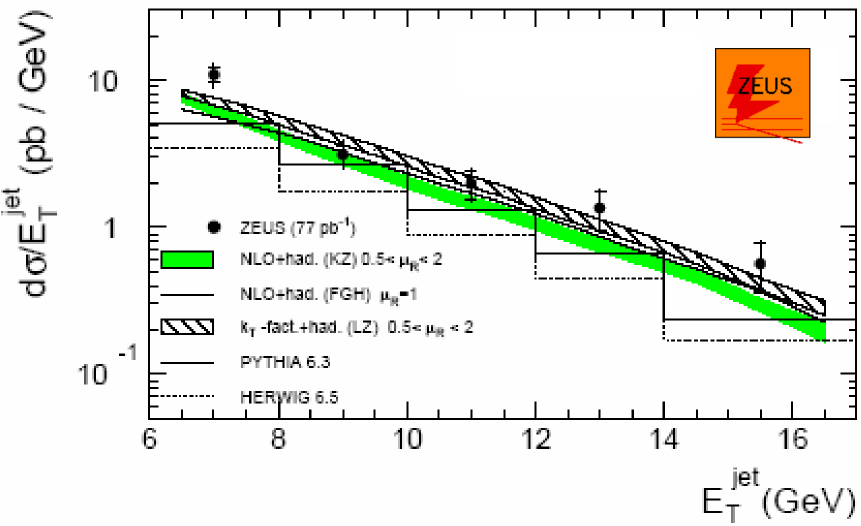
- Improved agreement with the measured cross section
- Hadronic corrections are necessary

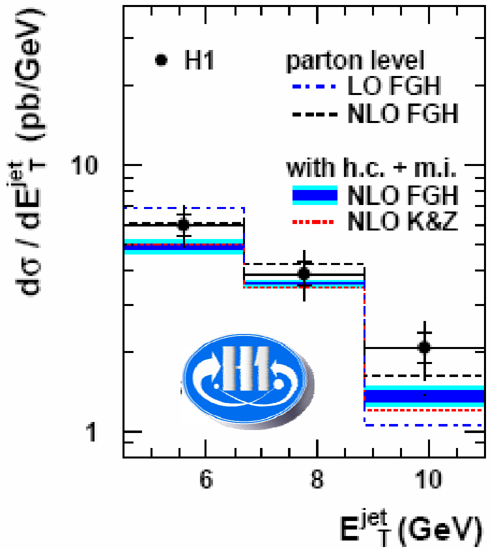
LZ:

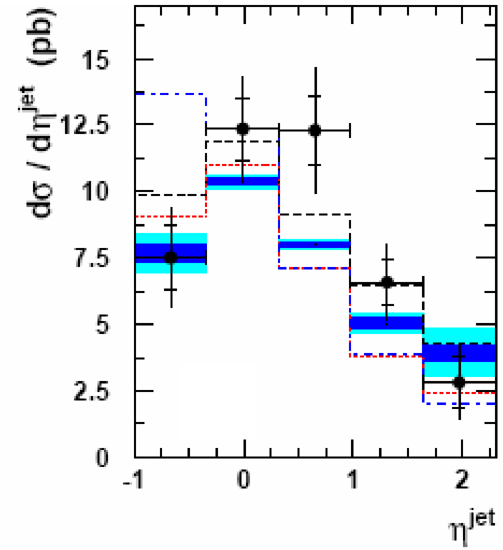
- Improves description for E_t^γ and low η^γ

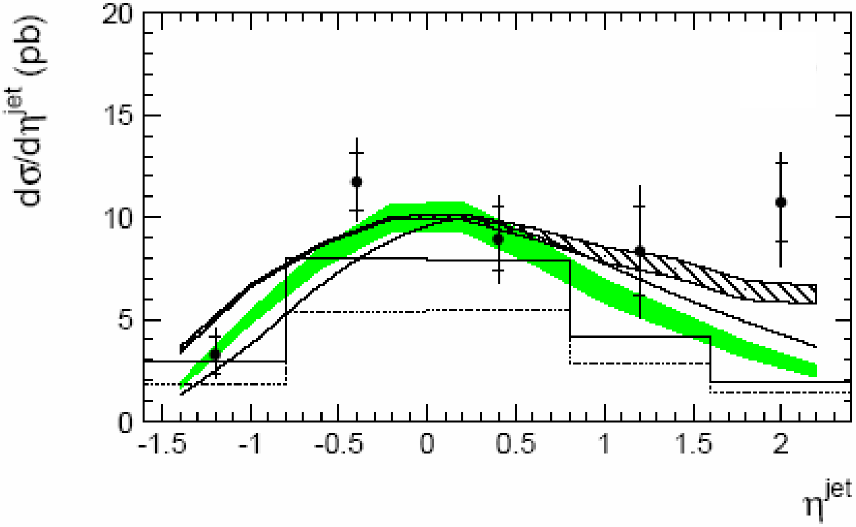
Prompt γ + Jet

$$ep \rightarrow \gamma(prompt) + jet + X$$









HERWIG & PYTHIA:

- Underestimate the measured cross section, particularly at high η^{jet}

KZ & FGH:

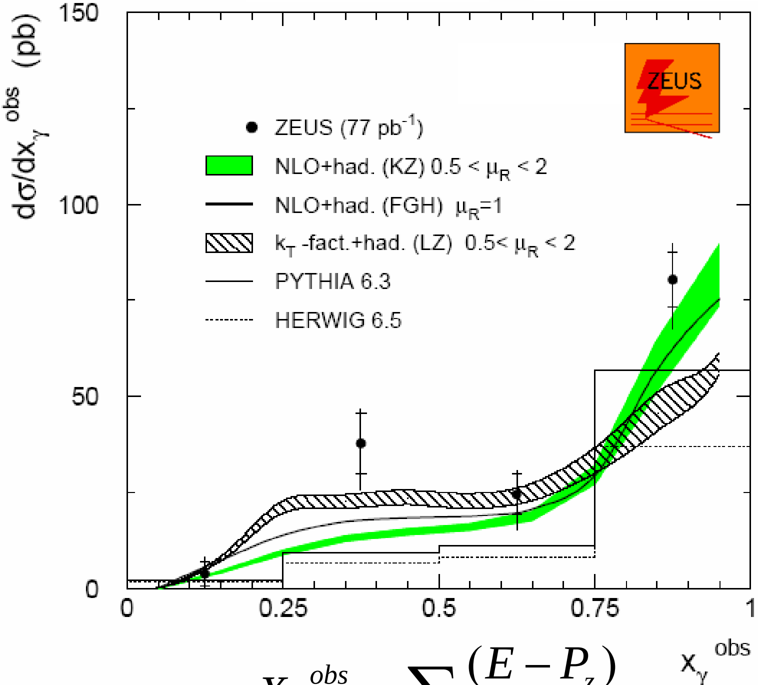
- Improved agreement with the measured cross section
- Hadronic corrections are necessary

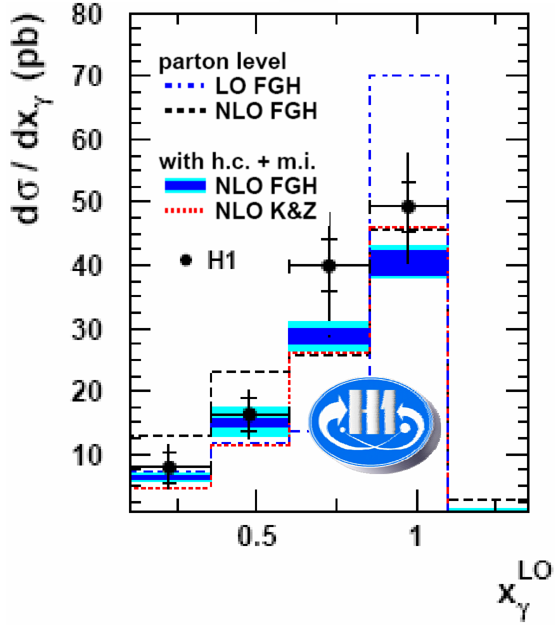
LZ:

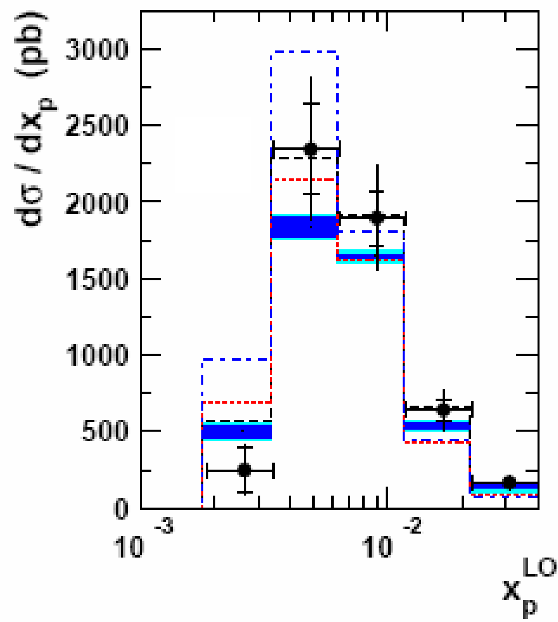
- Improves description of high η^{jet}

Momentum Fractions

$$ep \to \gamma(prompt) + jet + X$$







$$X_\gamma^{\ obs} = \sum_{\gamma,jet} \frac{(E - P_z)}{2E_e y}$$

$$X_\gamma^{\ LO} = \frac{E_T^\gamma (e^{-\eta^{jet}} + e^{-\eta^\gamma})}{2yE_e}$$

$$X_P^{\ LO} = \frac{E_T^\gamma (e^{\eta^{jet}} + e^{\eta^\gamma})}{2E_P}$$

KZ & FGH:

- Improvement compared to LO MC, particularly at high X_γ (Direct contribution)
- h.c. & m.i. corrections improve agreement in $x_\gamma^{LO} < 0.6$

LZ:

- Improvement for low X_γ (Resolved contribution)

$\mathbf{P_\perp}$

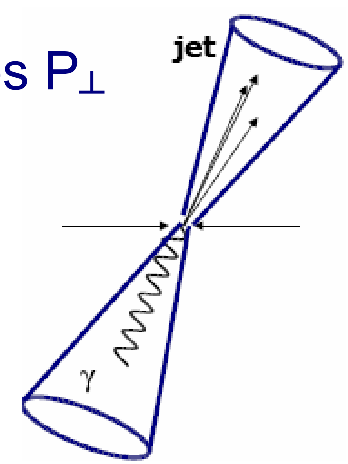
$$p_\perp \equiv \frac{|\vec{p}_T^{\,\gamma} \times \vec{p}_T^{\,jet}|}{|\vec{p}_T^{\,jet}|} = E_T^\gamma \cdot \sin(\Delta\phi)$$

HERWIG & PYTHIA:

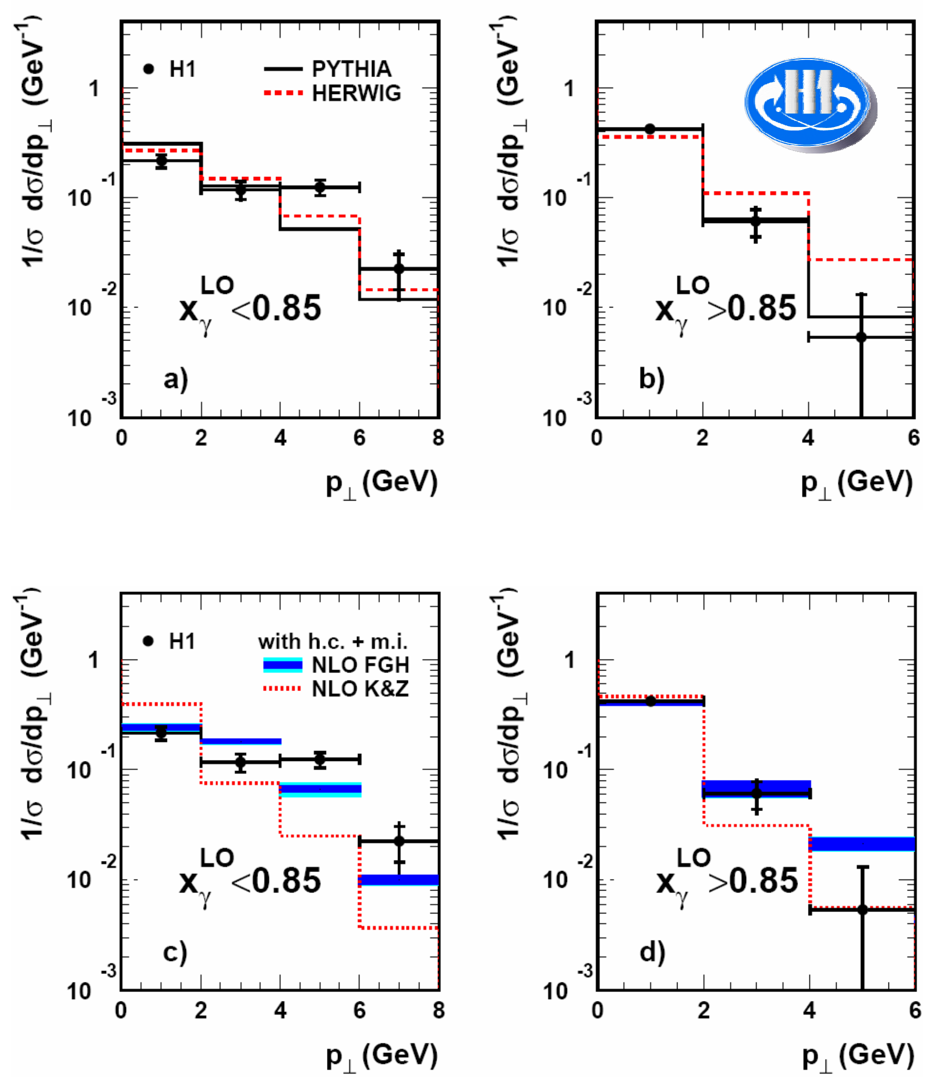
- Agree with data for x_γ^{LO}<0.85
- PYTHIA best describes $x_\gamma^{LO} > 0.85$

KZ & FGH:

- Consistent with data in most bins
- FGH best describes $P_\perp$ distributions



$$ep \rightarrow \gamma(prompt) + jet + X$$

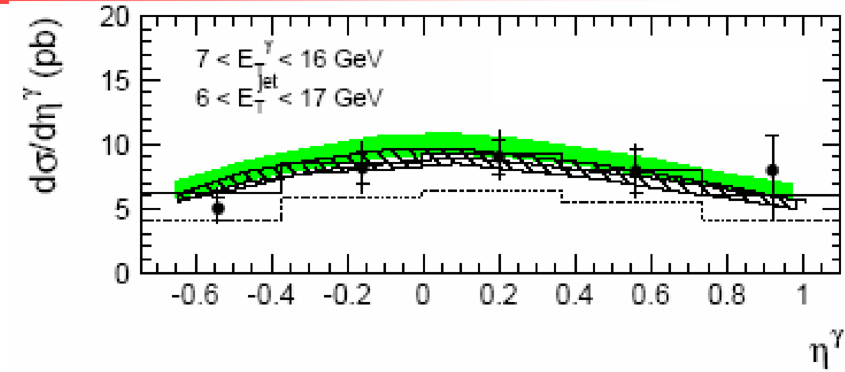


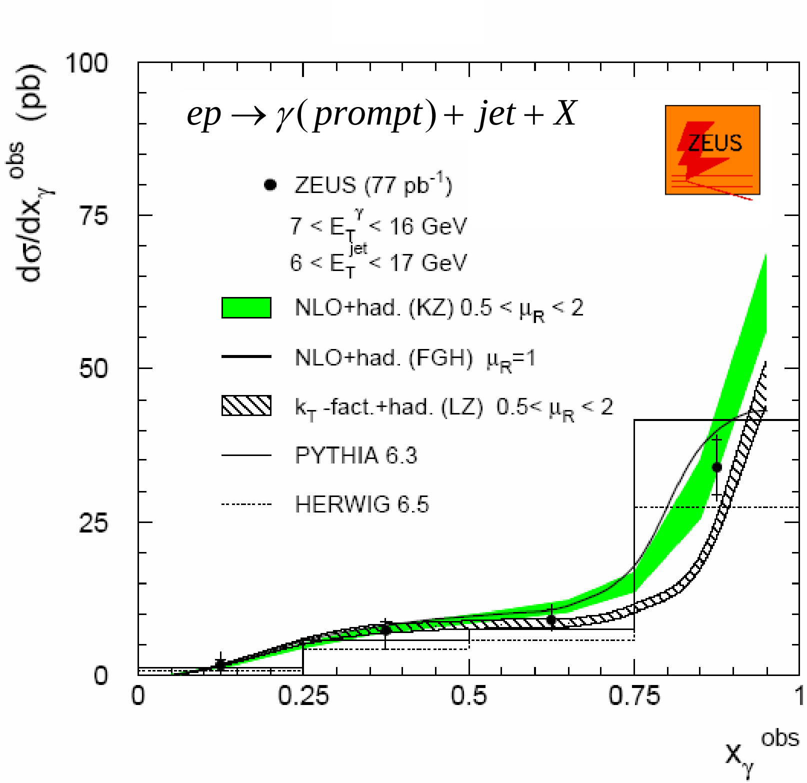
Minimum E_T^{Jet}<Minimum E_T^{γ}

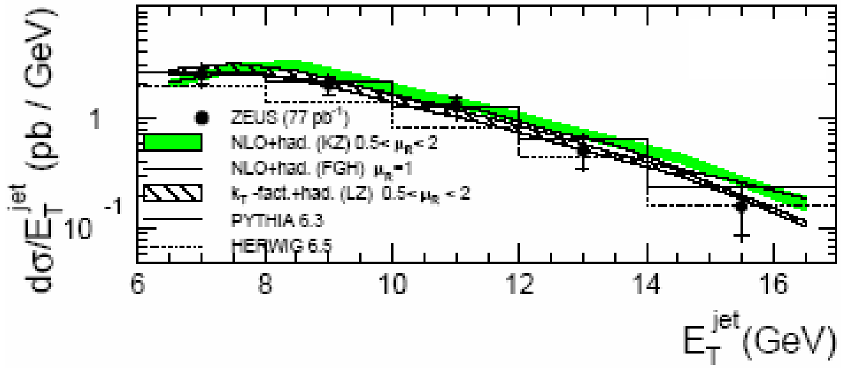
$5.0 \leq E_t^{\gamma} \leq 16.0$ GeV → $7.0 \leq E_t^{\gamma} \leq 16.0$ GeV

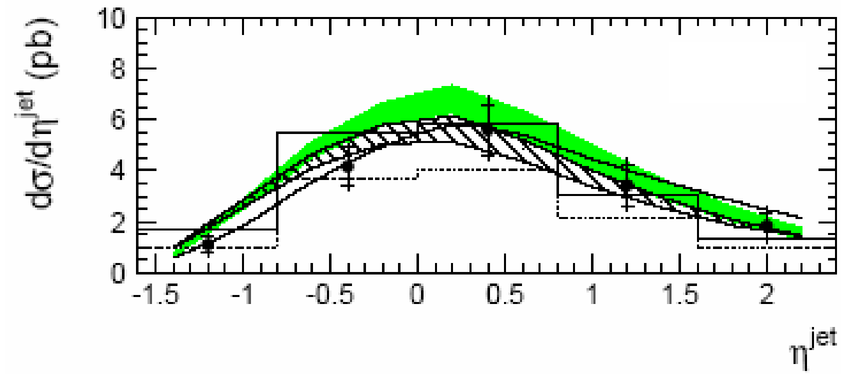
$6.0 \leq E_t^{jet} \leq 17.0$ GeV → $6.0 \leq E_t^{jet} \leq 17.0$ GeV

Improved agreement between data & all Theories

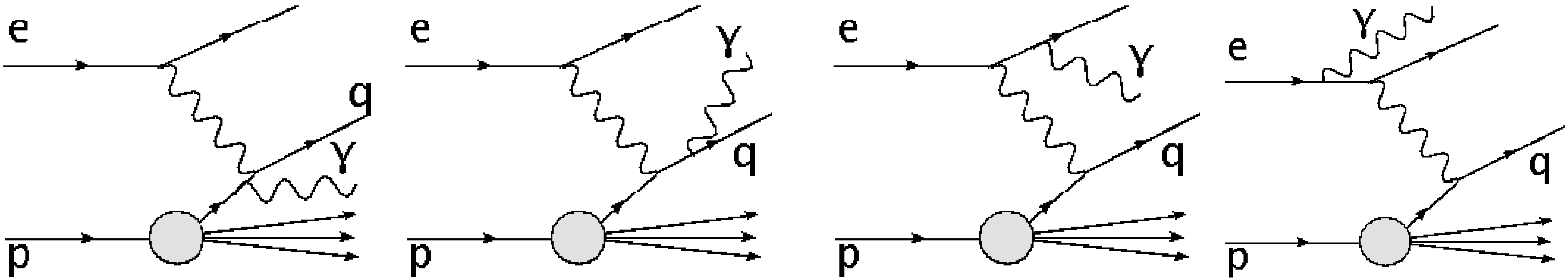








Prompt Photons in DIS

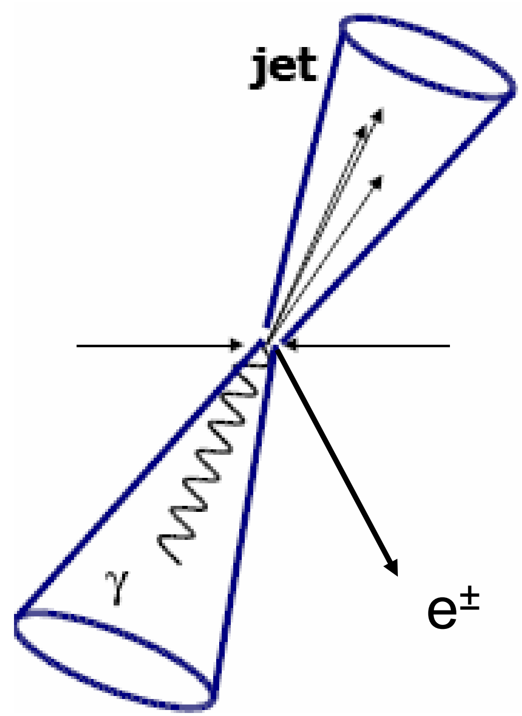


Same as photoproduction:

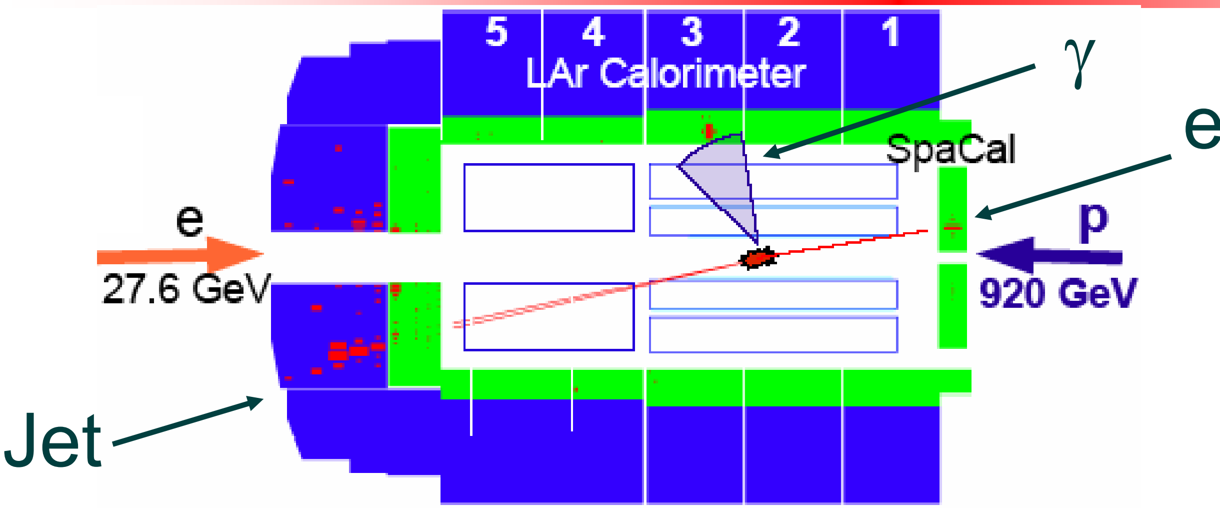
- Isolated photon
- Hadronic activity
- Separation from background (neutral hadrons)
    - Shower shape analysis

New for deep inelastic scattering:

- Scattered electron
- γ & Jet won't be back to back
- No resolved contribution
- Large contribution from ISR & FSR from $e^{\pm}$



Prompt Photons in DIS



- Scattered Electron
- γ & Jet won't be back to back

99-05 Data, 227 pb^{-1}

DIS Sample:

- $\geq$ 1 track not from $e^{\pm\prime}$
- $E_e' > 10$ GeV
- $153 < \theta_e' < 177°$
- $35 < \Sigma(E-p_z) < 70$ GeV
- $|Z_{vertex}| < 40$ cm
- $0.05 \leq Y$
- $4 < Q^2 < 150$ GeV^2
- $W_X^2 > 2500$ GeV^2

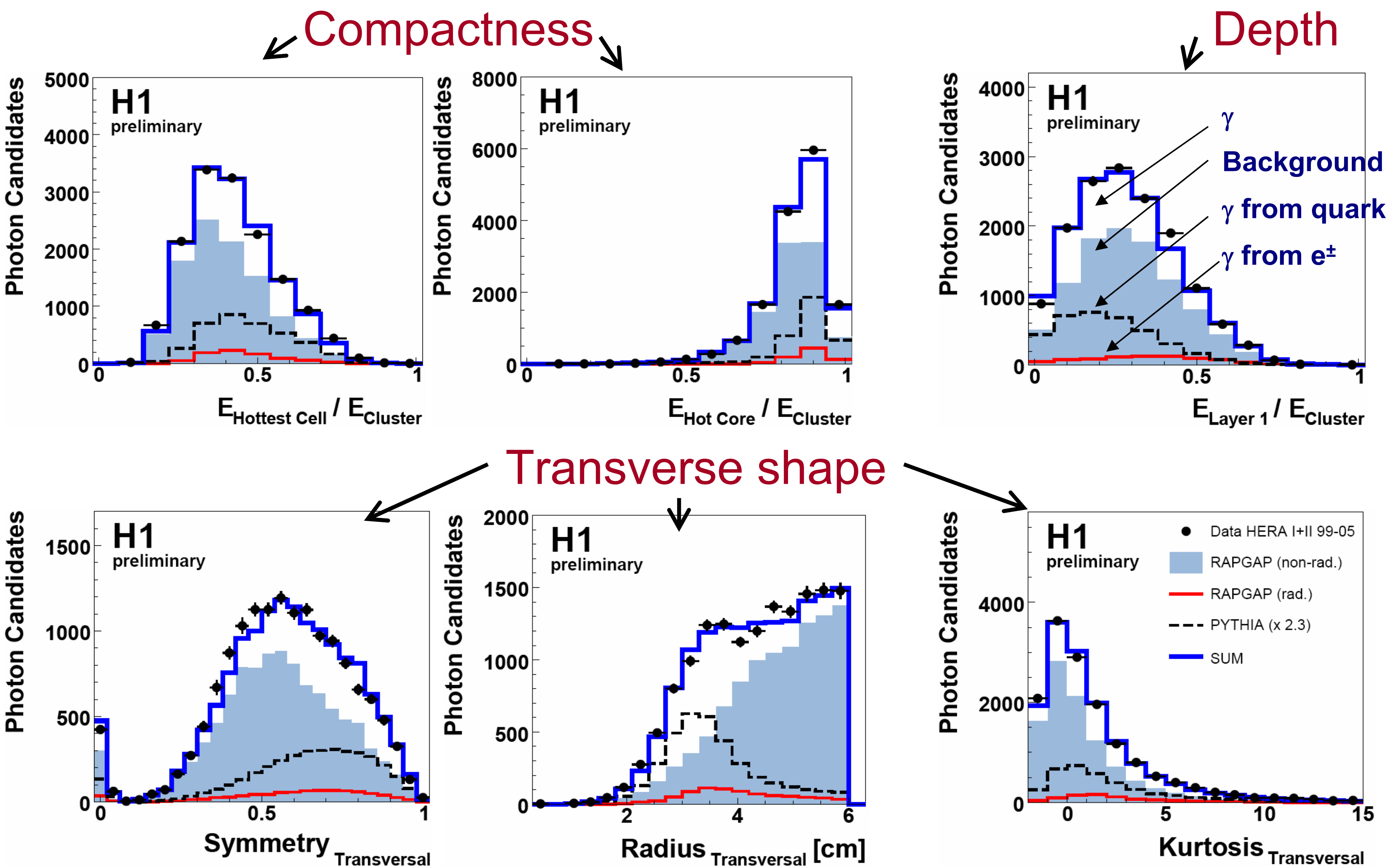
Photon candidate:

- $-1.2 \leq \eta^\gamma \leq 1.8$
- $3.0 \leq E_t^\gamma \leq 10$ GeV
- No associated track
- $E_t^\gamma / E_t^{\gamma\text{'s kt-jet}} > 0.9$

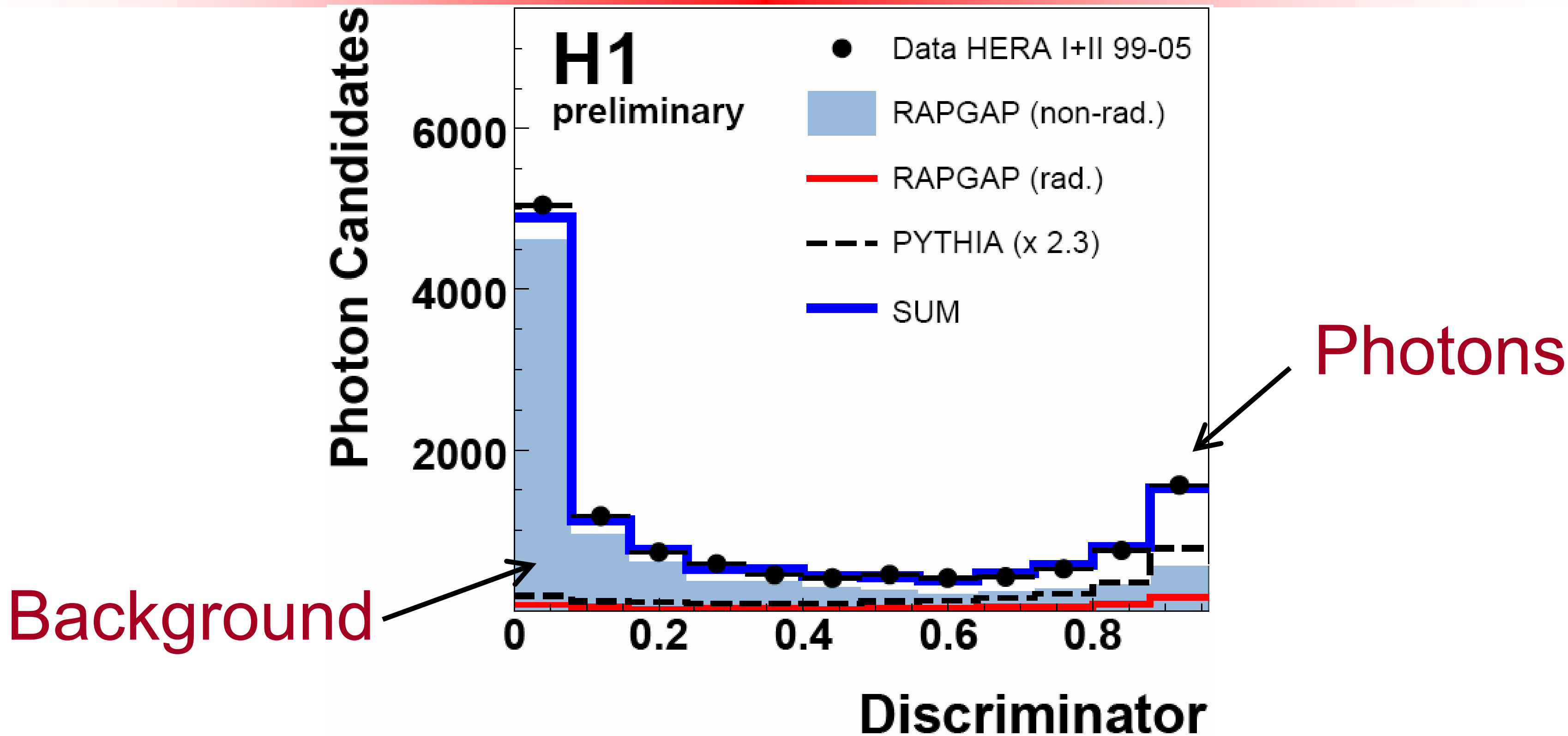
Associated jet:

- $-1.0 \leq \eta^{jet} \leq 2.1$
- $2.5 \text{ GeV} \leq E_t^{jet}$

Shower Shape Variables



Shower Likelihood

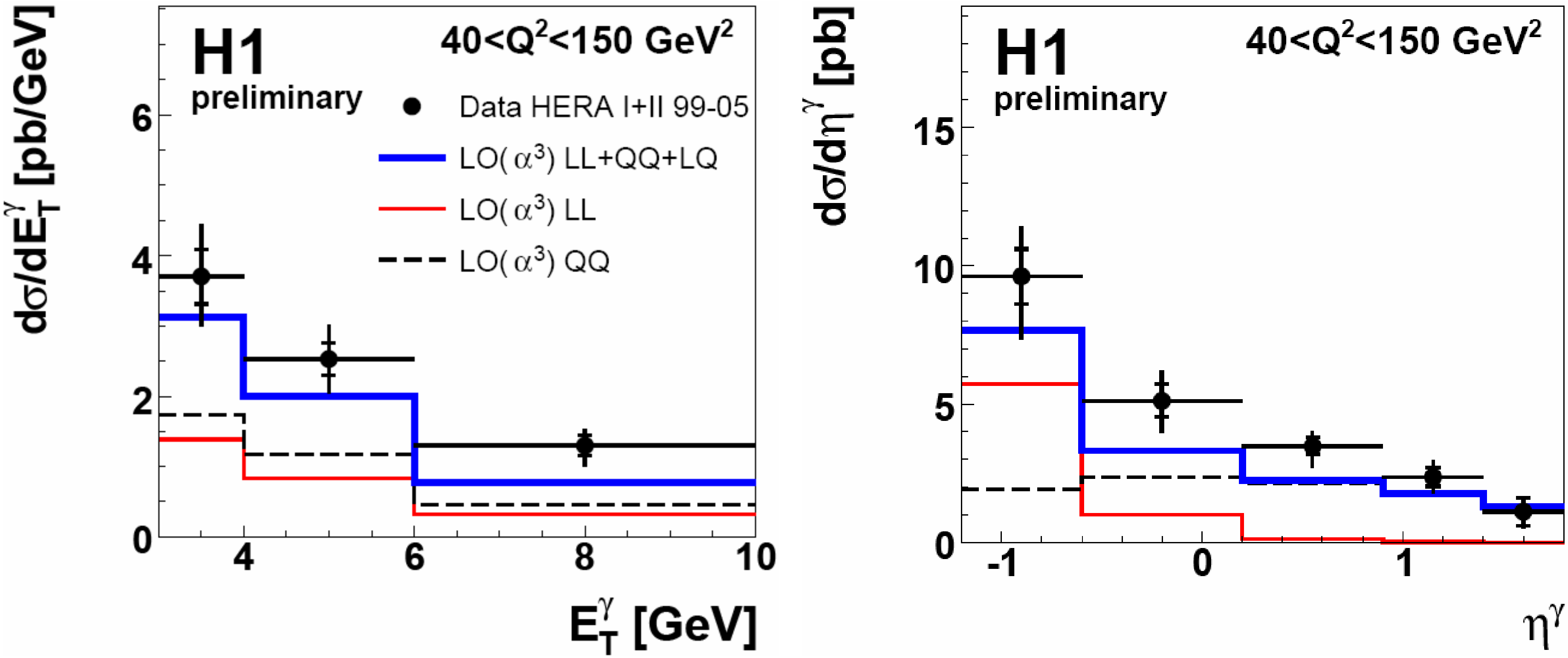


Discriminator:

- Likelihood function from shower shape variables determined via single particle MC simulations
- Fit γ & background MCs to describe data
- Done in bins of E_t & η

DIS Cross Section

$$ep \rightarrow \gamma(prompt) + X$$



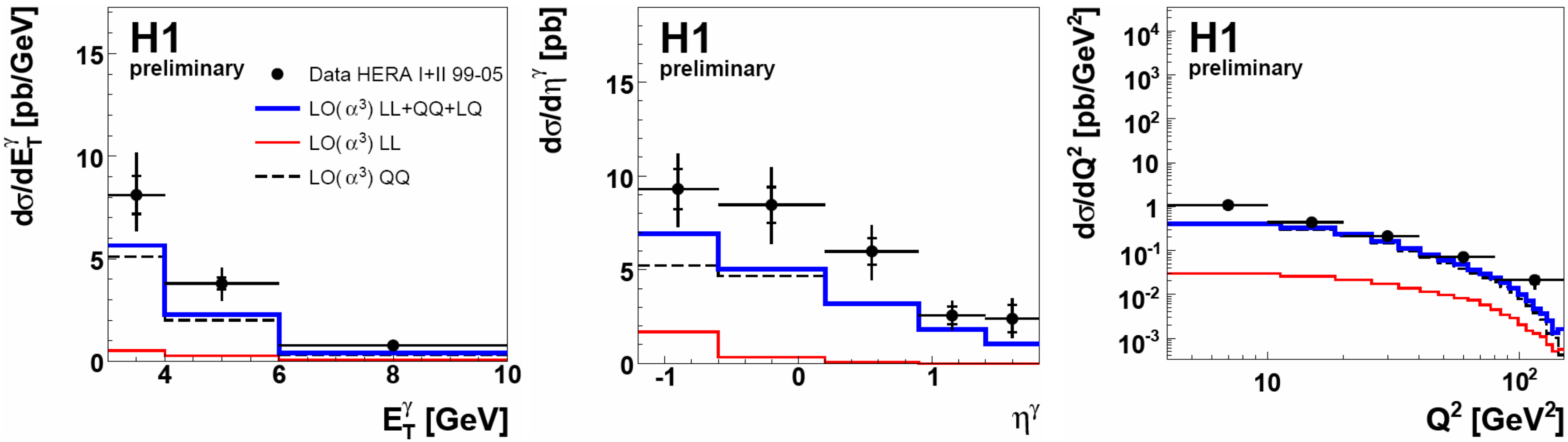
- Shapes well described
- Radiation from electron negligible in forward region ($\eta^\gamma > 0$)

$$\sigma(e^{\pm} p \rightarrow e^{\pm} + \gamma_{prompt} + X) = 14.0 \pm 0.8(\text{stat.}) {}^{+2.1}_{-2.1} (\text{syst.})\,\text{pb}$$

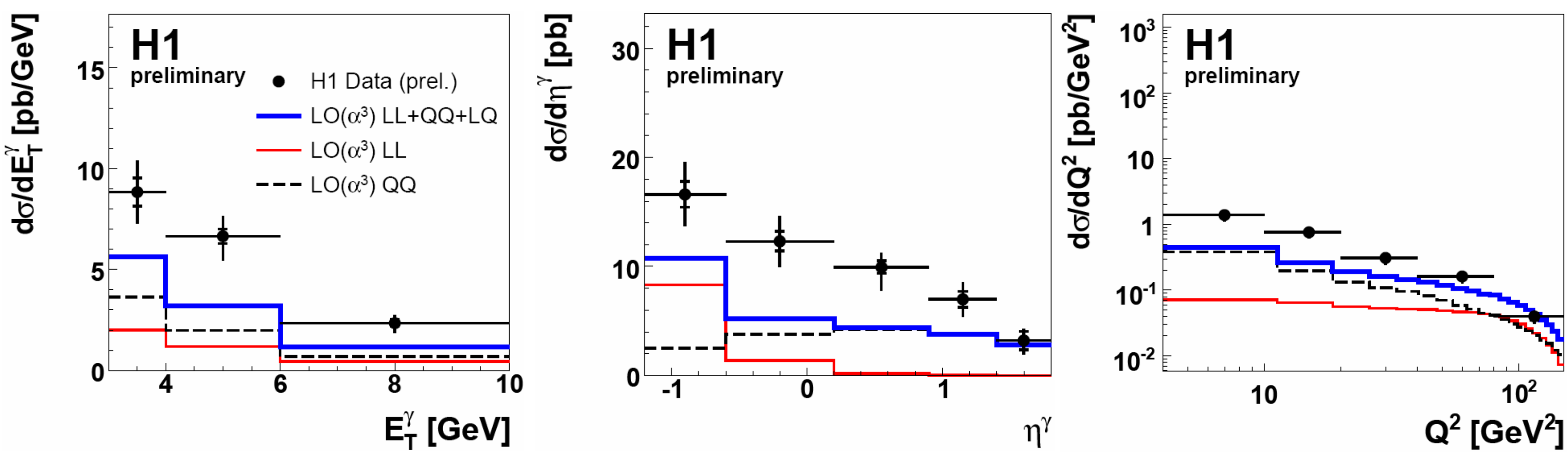
LO	10.3 pb
MC	8.8 pb

γ with & without a Jet

γ + no jet (no hadronic jet E_T^{Jet} > 2.5 GeV -1.0 < η^{Jet} <2.1): LL suppressed



γ + jet: cross section comparable size to photon plus no-jets



Summary

Photoproduction:

- MC significantly lower than the data (50%)
- NLO QCD calculations describe data reasonably well (80% of data)
  - Differences in the forward jet and low E_T^{γ} regions
  - h.c. & m.i. corrections are necessary
  - Minimum E_T^{Jet} < Minimum E_T^{γ} allows better description from theories
- $P_{\perp}$ described by PYTHIA but not HERWIG
  - HERWIG predicts too hard a $P_{\perp}$ distribution at large x_{γ}^{LO}

DIS:

- LO and MC significantly lower than the data (50%)
  - Most prominent at low Q^2
  - High Q^2: LO and MC lower, but only by 30%, shapes described
- Exclusive measurement: Photon plus no-jets & photon plus jets
  - Photon plus jets cross section roughly twice the photon plus no-jets cross section
  - Photon plus no-jets: radiation from electron suppressed