Prompt Photon Production at HERA

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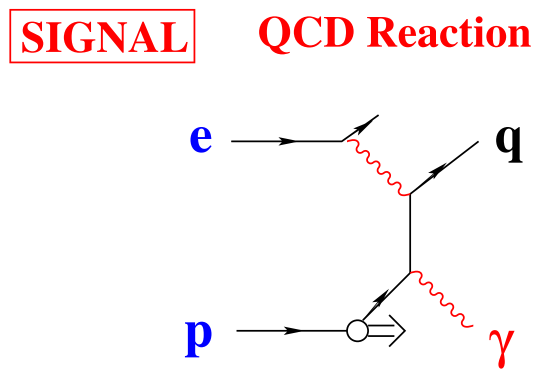
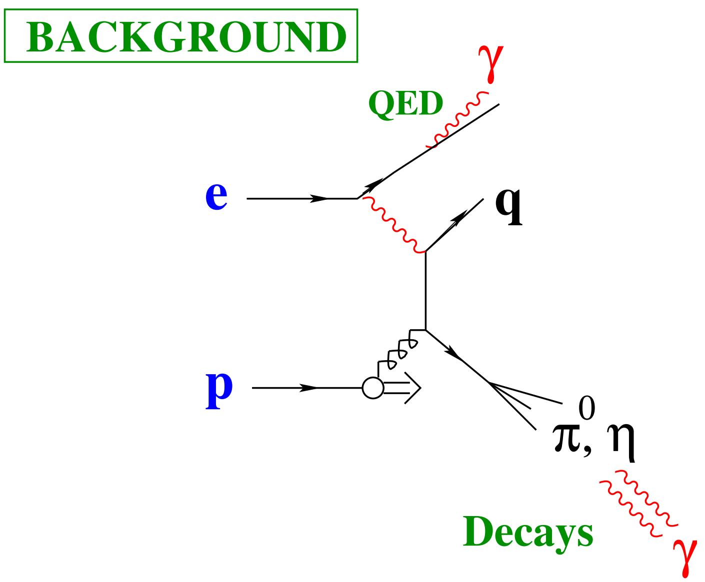
- Photo-production
  - Inclusive prompt-photons
  - Prompt-photons with associated jets
- Prompt photons in Deep Inelastic Scattering
- Conclusion

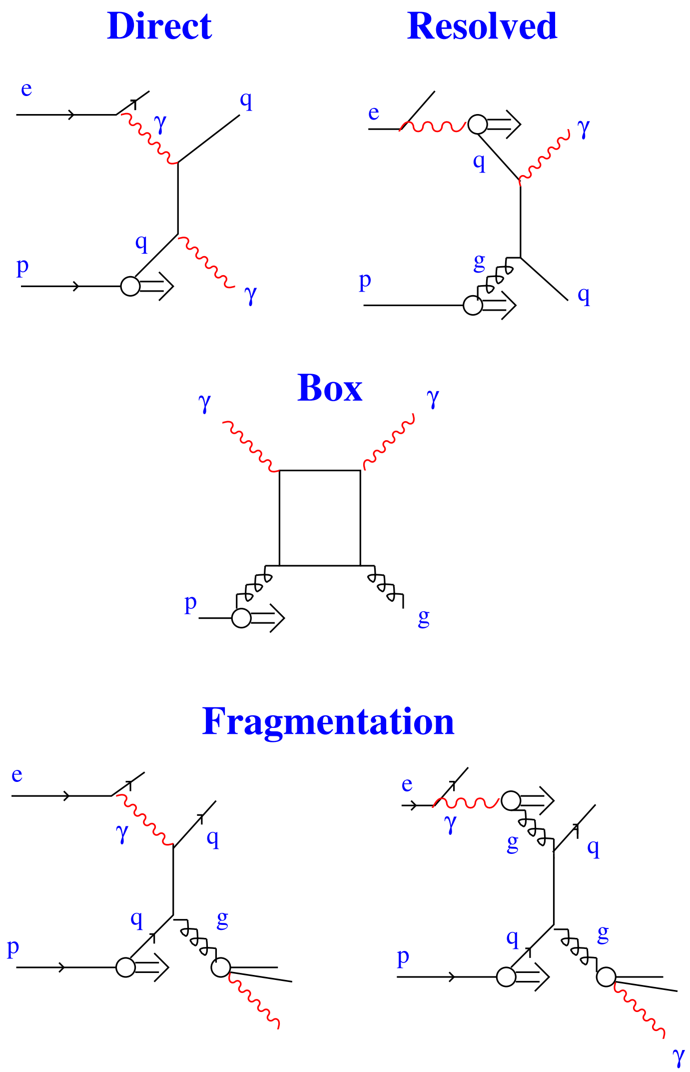
Prompt photons in ep scattering





- prompt photon events have a photon in the final state with substantial E_T
- advantage compared to jet analysis:
  - direct access by γ to hard interaction (no hadronisation)
  - good energy measurement
- but:
  - small cross section
  - π^0, η background difficult to suppress

Prompt photons in pQCD



- **prompt photons produced in direct and resolved processes and in fragmentation**

⇒ **test pQCD calculations :**
  - **NLO matrix elements**
  - **PDFs of the photon and the proton**

- **NLO for comparison with data**

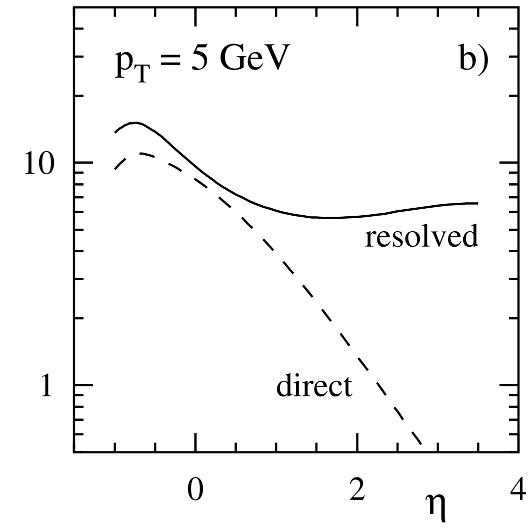
(Fontannaz, Guillet and Heinrich [hep-ph/0105121])

PDFs **AFG for photon**
MRST2 for proton
Bourhis fragmentation functions.

other calculations:

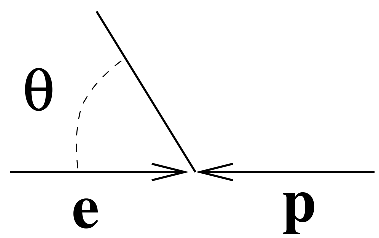
Gordon, Vogelsang [hep-ph/9606457]
Krawczyk, Zembrzuski [hep-ph/9810253]
DIS: Gehrmann-De Ridder, Kramer and Spiesberger [hep-ph/0003082]

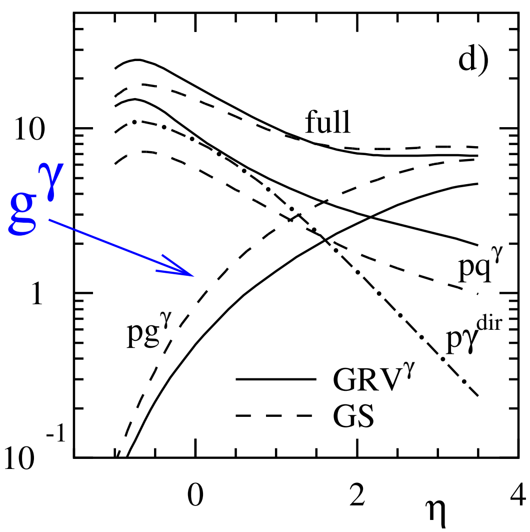
Contributions to the total cross section



NLO calculation by Gordon, Vogelsang (hep-ph/9606457)

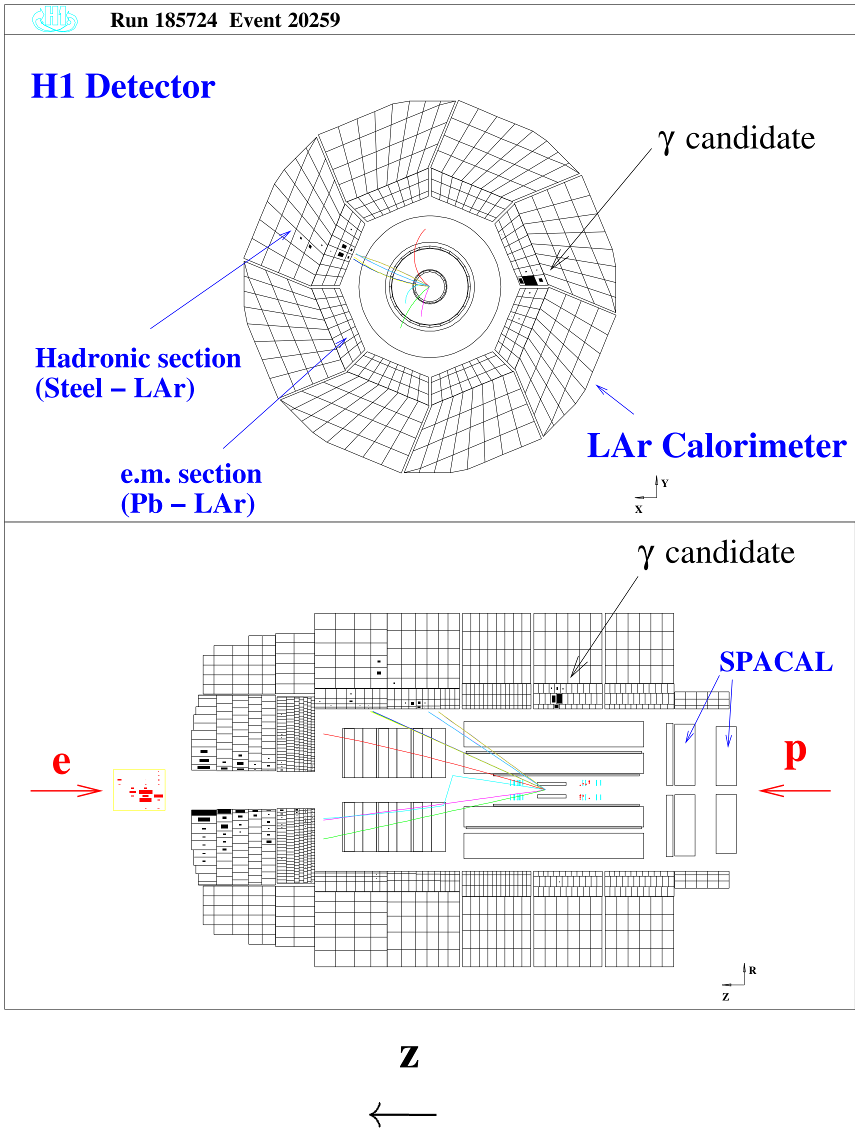
⇒ **Resolved contribution dominant at large pseudorapidity** $\eta = -\log\left(\tan\left(\frac{\theta}{2}\right)\right)$





⇒ **Basically no sensitivity to the gluon density in the photon for** $\eta < 1$

Prompt photons in the H1 detector



⇒ Signature: Well isolated compact shower in the Liquid Argon Calorimeter + track veto

⇒ Good granularity to separate γ's from π^0's and η's up to $E_T \approx 10$ GeV

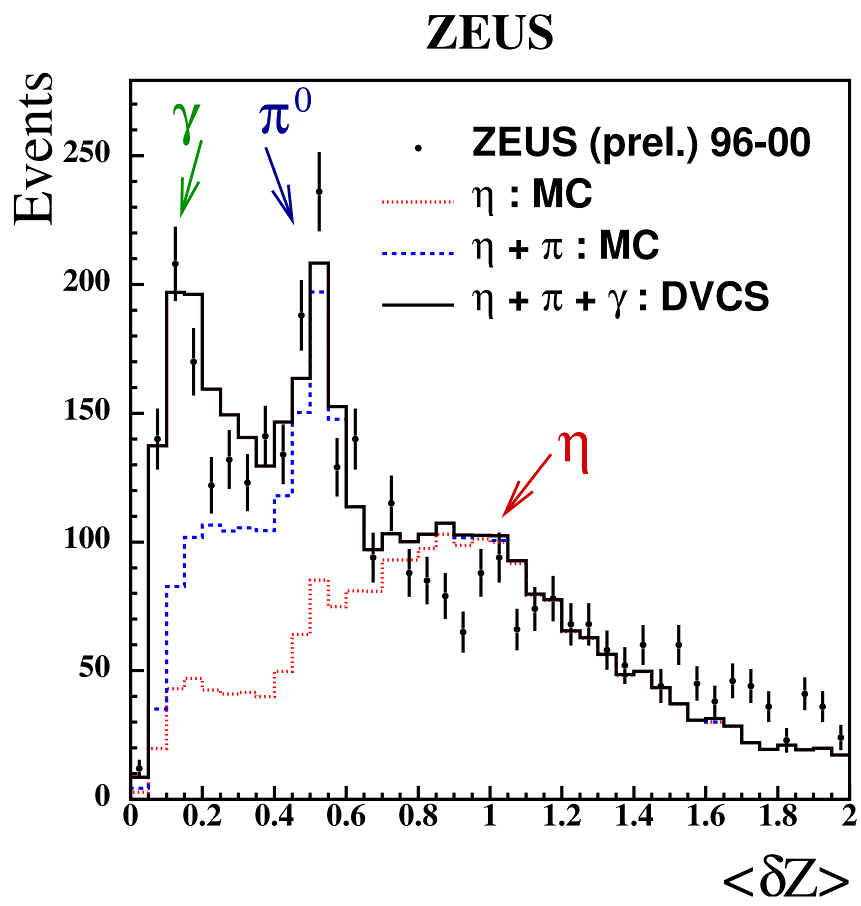
Kinematic region

H1 photo-production	ZEUS photo-production	ZEUS DIS
1996-2000 data: 105 pb^{-1}	1996-97 data: 38.4 pb^{-1}	1996-2000 data: 121 pb^{-1}
$Q^2 < 1\ \mathrm{GeV}^2$		$Q^2 > 35\ \mathrm{GeV}^2$
$5 < E_T^\gamma < 10$ GeV ($E_T^\gamma < 15$ GeV for $d\sigma/dE_T^\gamma$)		
$-1 < \eta^\gamma < 0.9$	$-0.7 < \eta^\gamma < 0.9$	
$122 < W < 266$ GeV	$134 < W < 285$ GeV	
Isolation: hadronic $E_T^{cone} < 0.1\ E_T^\gamma$ (in cone with $R = \sqrt{\Delta\Phi^2 + \Delta\eta^2} = 1$)		

Prompt photon + jet

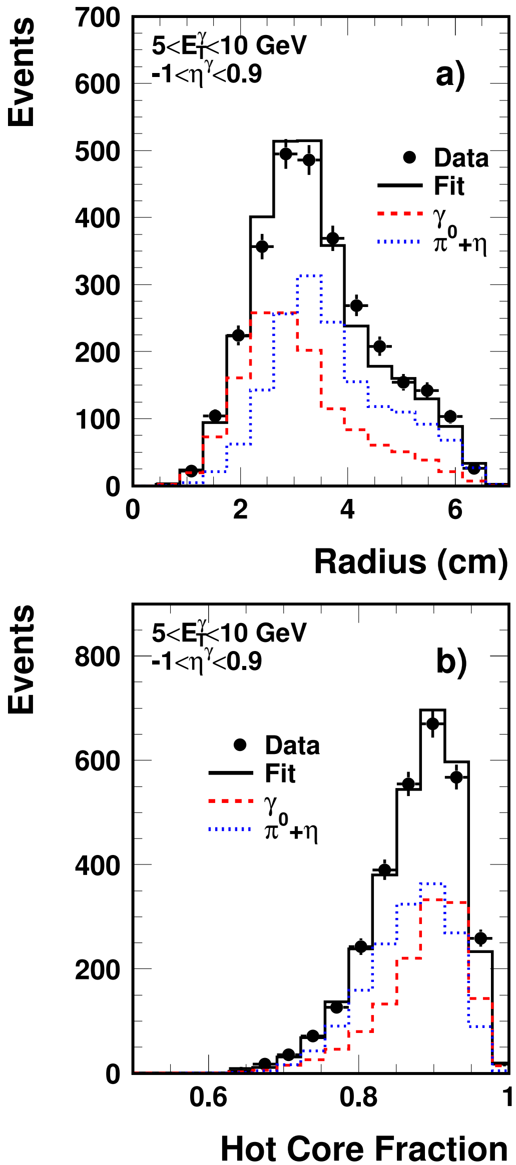
inclusive k_T		cone algorithm $R = 0.7$
$E_T^{jet} > 4.5$ GeV	$E_T^{jet} > 5$ GeV	$E_T^{jet} > 6$ GeV
$-1. < \eta^{jet} < 2.3$	$-1.5 < \eta^{jet} < 1.8$	

γ, π^0, η separation at ZEUS



- **use shower shape variables**
  for γ's, π^0's and η's
  - $< \delta Z >$ $= \sum E_{cell} \cdot |Z_{cell} - < Z > | / \sum E_{cell}$
  - f_{max} = **fraction of energy of γ in the most energetic calorimeter cell**
- **η fraction from high $< \delta Z >$ range**
- **cut at 0.65 in $< \delta Z >$**
- **signal extracted by a fit**

γ signal extraction at H1



- **use shower shape variables** for γ's, π^0's and η's
  - **Radius** = $\frac{\Sigma_{cells}\, w_i\, r_i}{\Sigma_{cells}\, w_i}$
  - **Hot Core Fraction** = $\frac{\text{Energy in shower core}}{\text{Total Energy}}$

define a likelihood discriminator

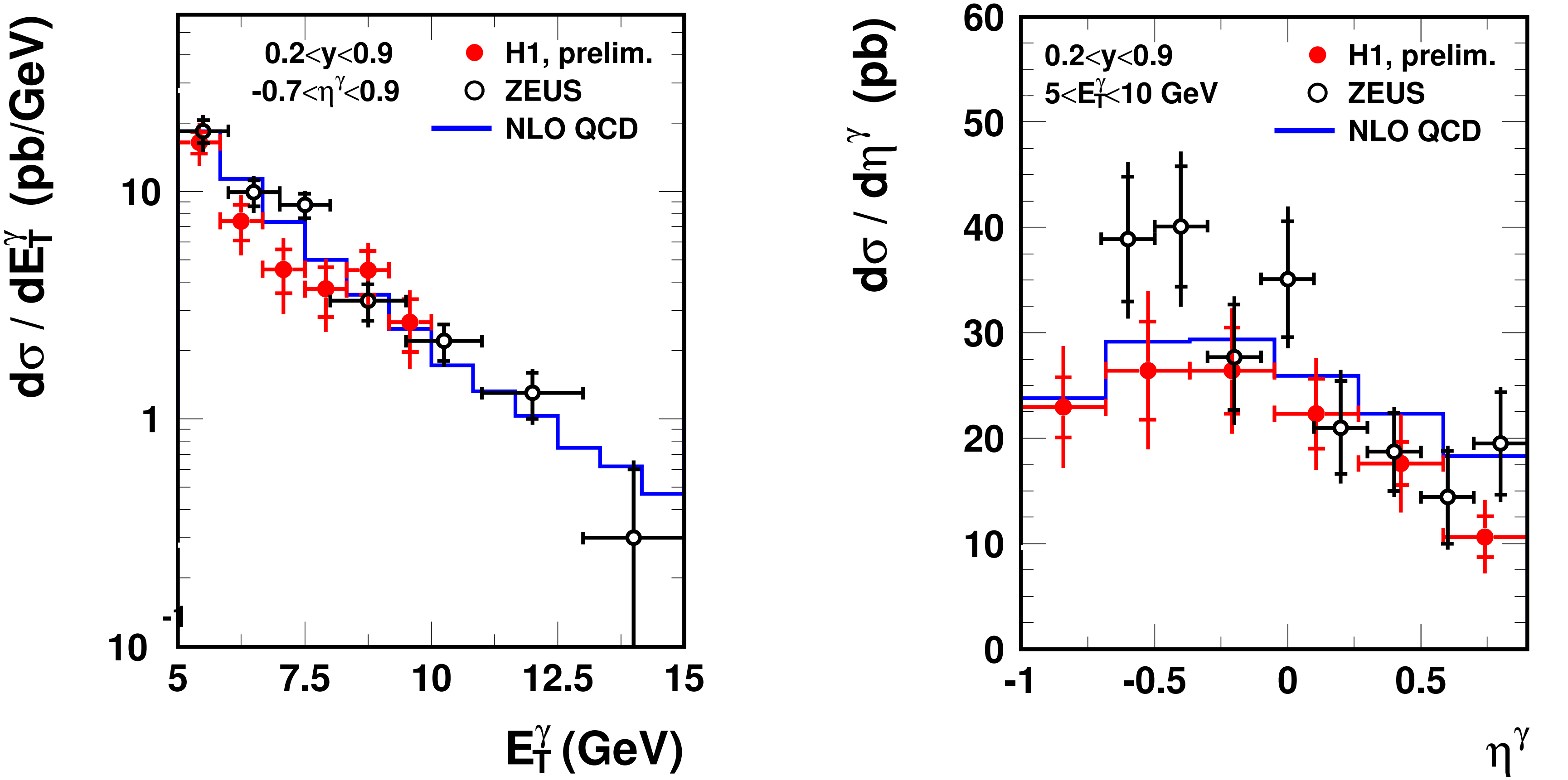
- **fit discriminator in (E_T, η) bins**

(energy dependence and changing calo granularity)

$\longleftarrow$ summed distributions shown

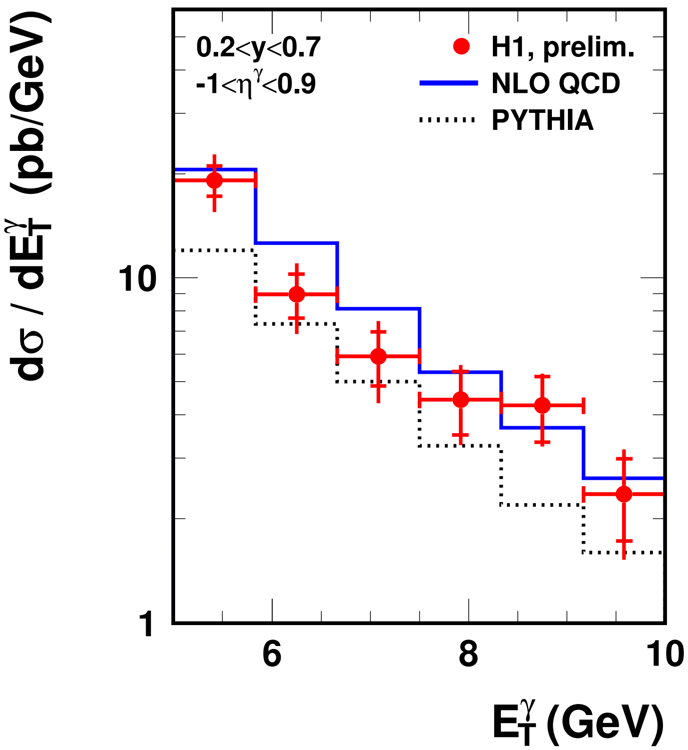
$\Rightarrow$ **Shower shape variables well described by the fit.**

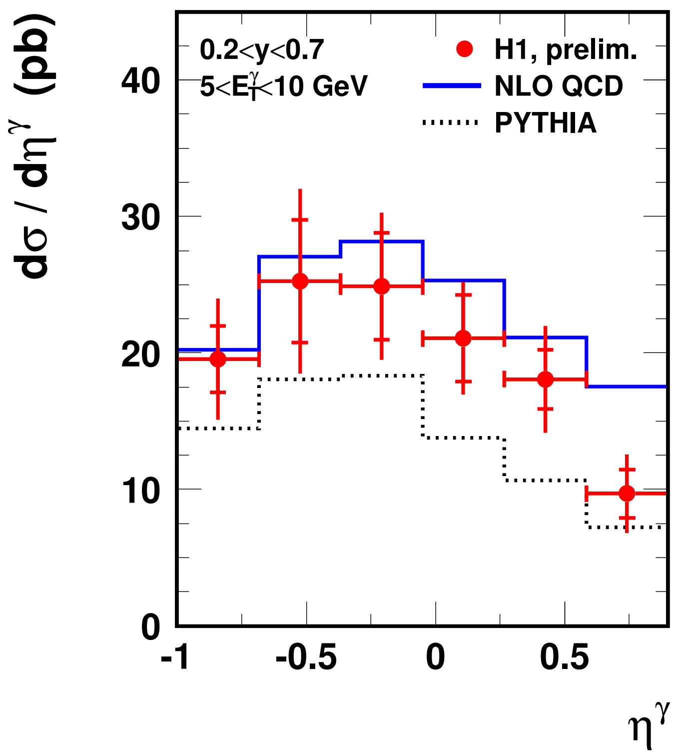
Inclusive Prompt Photons cross section



- **ZEUS above H1 at low η^{γ}, but data consistent within errors**

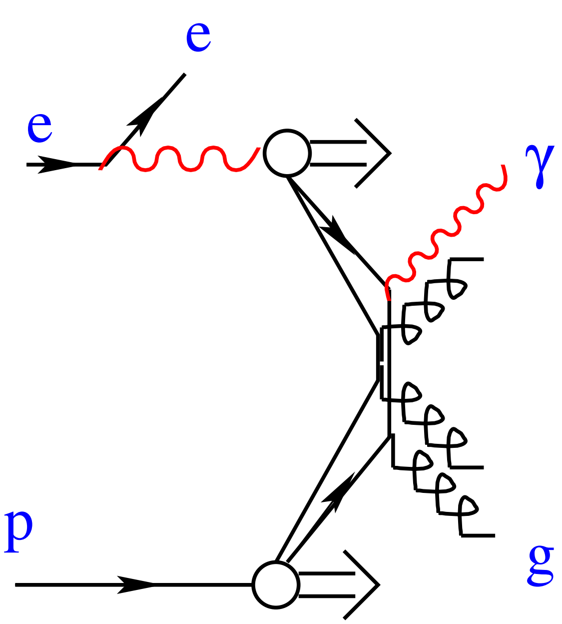
Comparison with NLO and PYTHIA

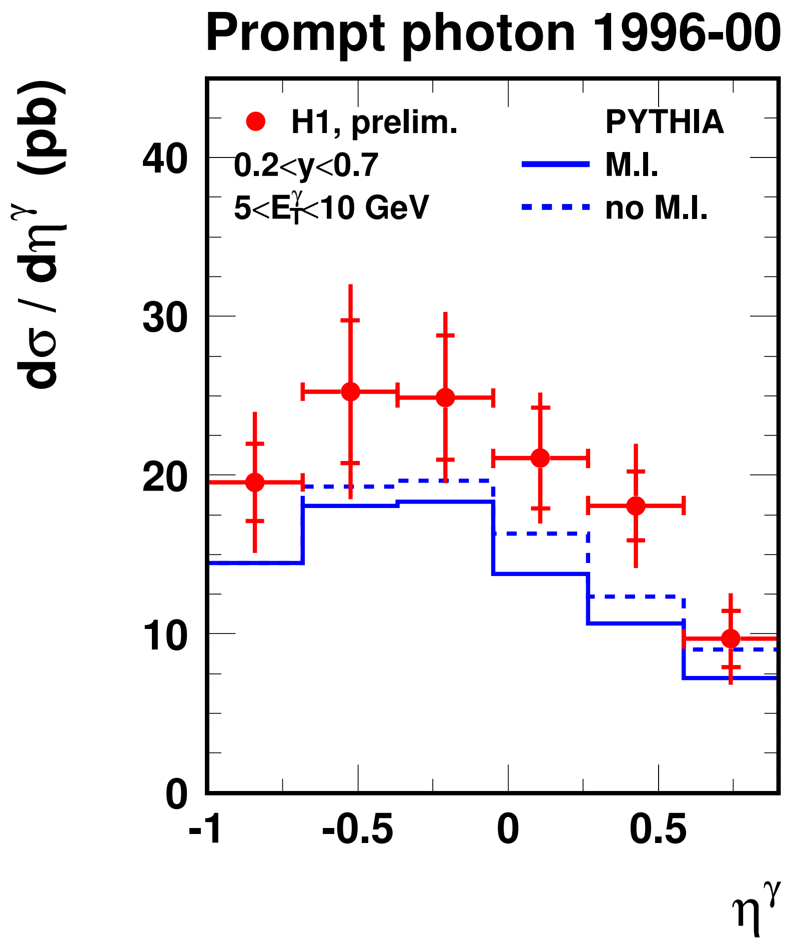




- pQCD (NLO, Fontannaz et al.) describes the data within errors
- PYTHIA: describes shapes,   but too low

Effect of multiple interactions





⇒ **Underlying event activity**

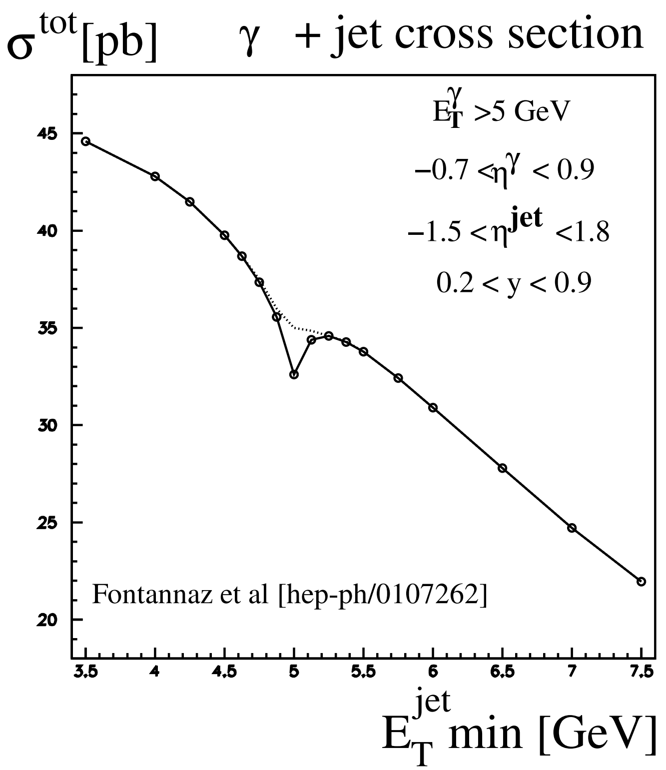
⇒ **Hadronic energy in the isolation cone**

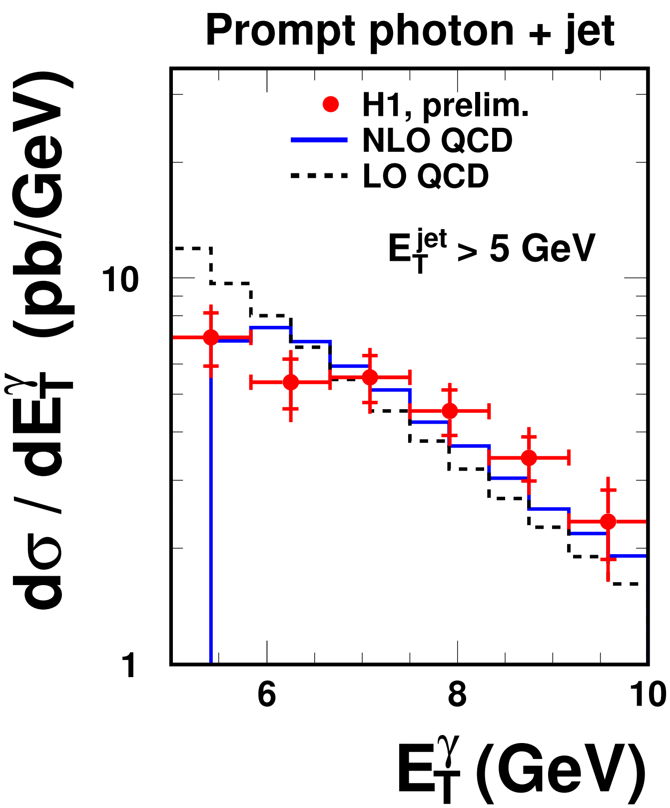
⇒ **Effect about 25% for positive η according to PYTHIA**

Jet requirement

Infrared instabilities discussed by Fontannaz et al., problem of symmetric cuts

e.g. $\mathbf{E_{T,min}^{jet}} = \mathbf{E_{T,min}^{\gamma}} = \mathbf{5}$ GeV



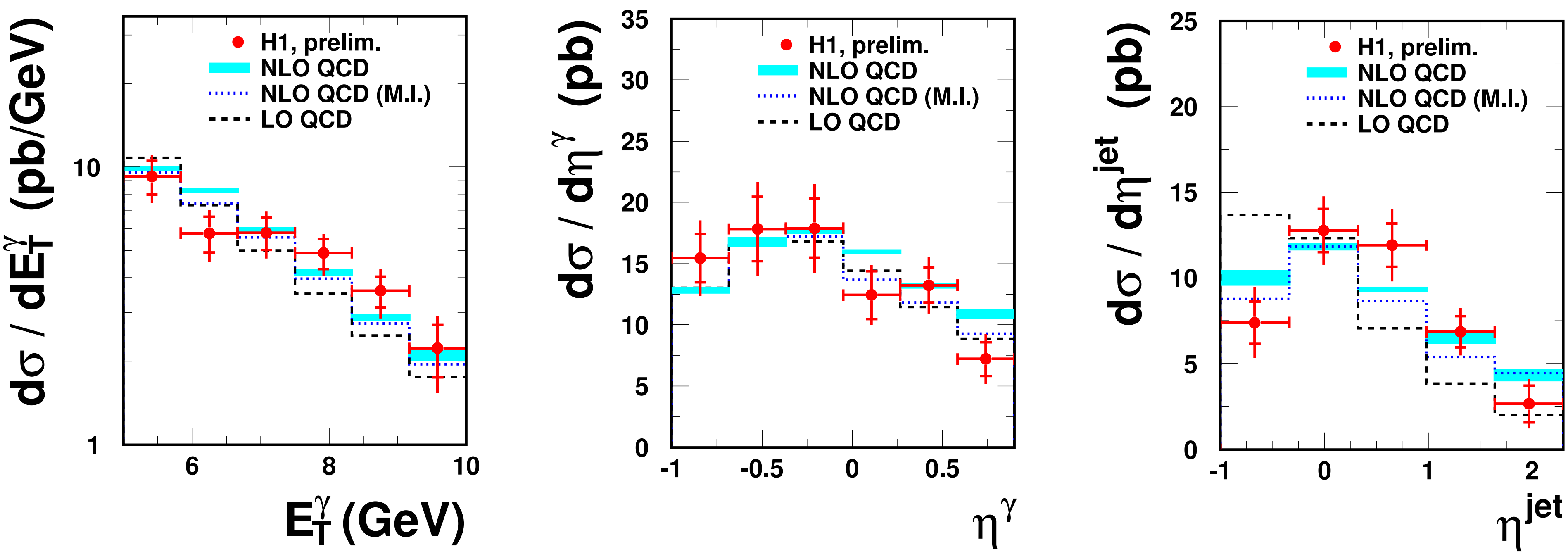


⇒ **NLO calculations lose their predictive power** **(same effect in di-jets)**

⇒ **Avoid symmetric cuts,** **for following results, H1 uses $E_T^{jet} > 4.5$ GeV**

Prompt photon + jet cross section vs E_T^{γ}, η^{γ} and η^{jet}

Comparison with LO and NLO (for NLO scale variation 0.5 E_T^{γ} to 2 E_T^{γ})



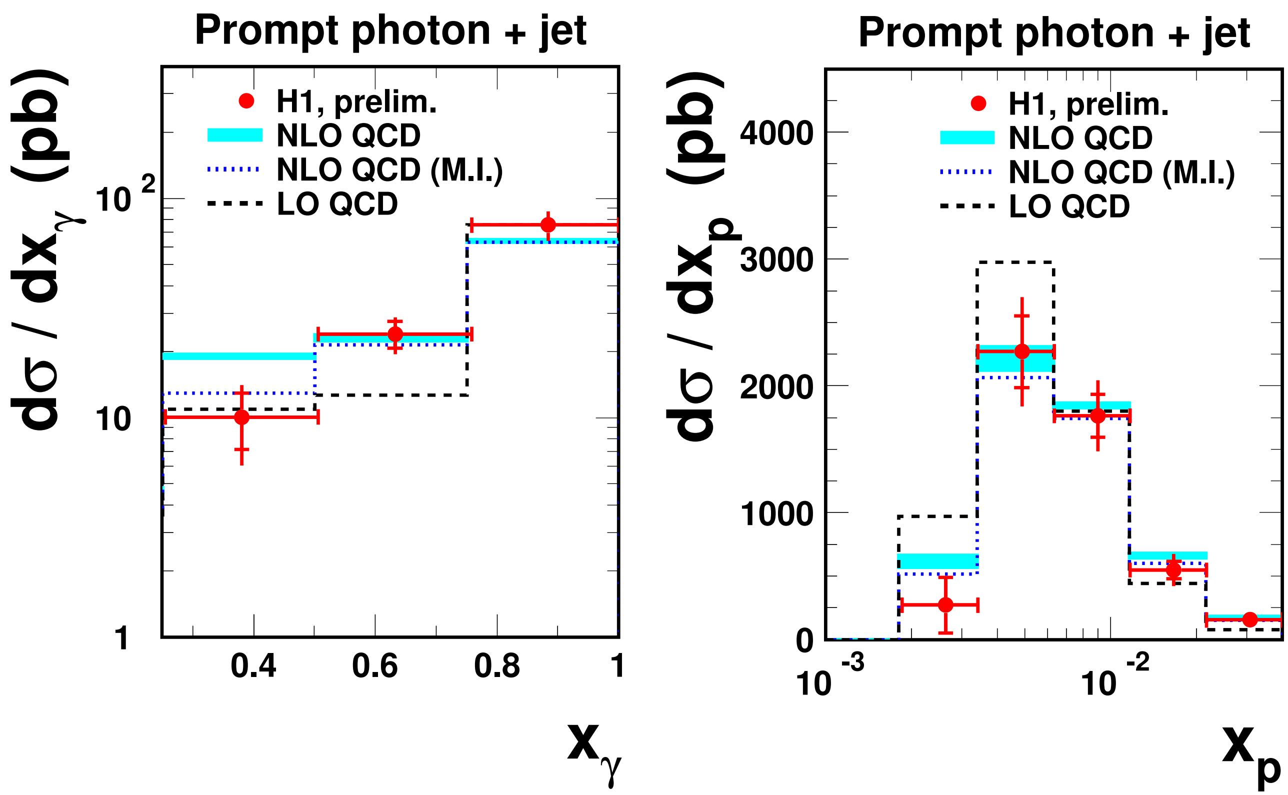
– Correction to NLO for multiple interactions applied by PYTHIA

→ improves description at large η^{γ}

– substantial and negative NLO corrections at $\eta^{jet} < 0$

⇒ **NLO describes the data within errors**

Prompt photon + jet cross section vs x_γ, x_p



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

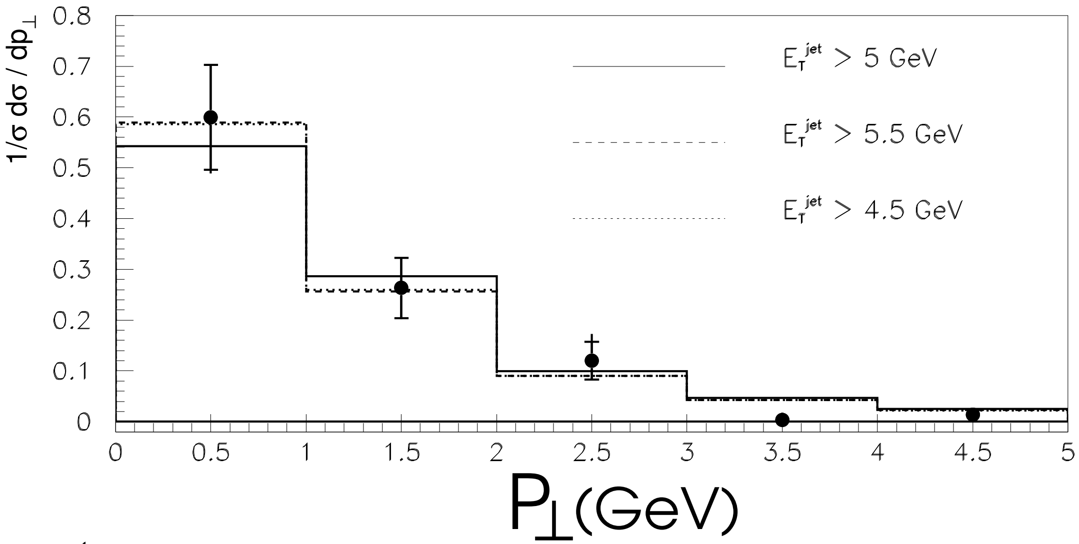
- $x_p = \frac{E_T^{jet} e^{\eta^{jet}} + E_T^{\gamma} e^{\eta^{\gamma}}}{2E_p}$

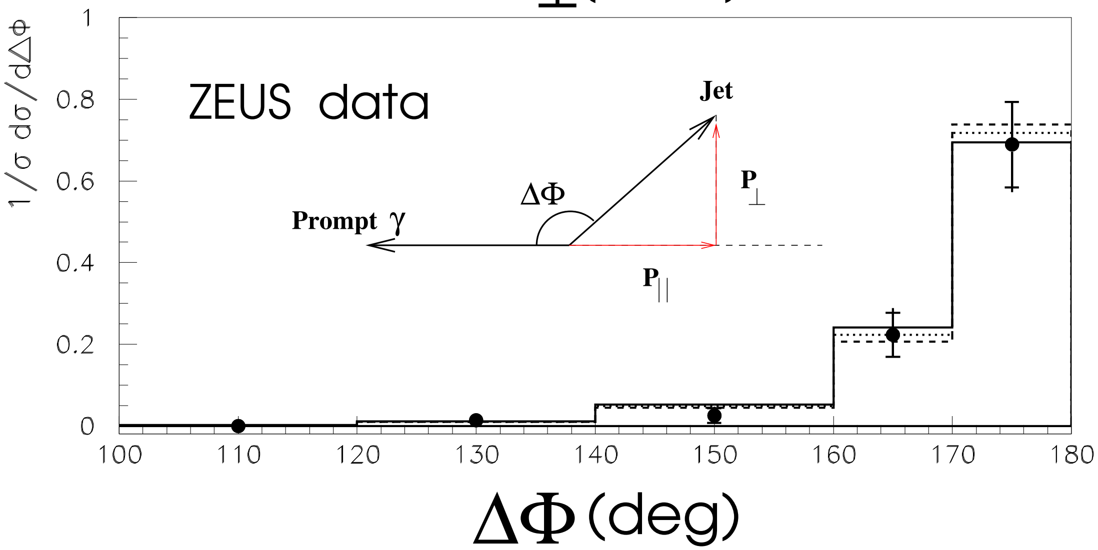
- **Infrared instability at $x_\gamma = 1$ smoothed by large binning**
- **Multiple Interactions effect at $x_\gamma < 0.5$ where resolved contributions dominate**

$\Rightarrow$ **NLO describes the data**

P_T balance of prompt photon and jet

Fontannaz et al [hep-ph/0107262]



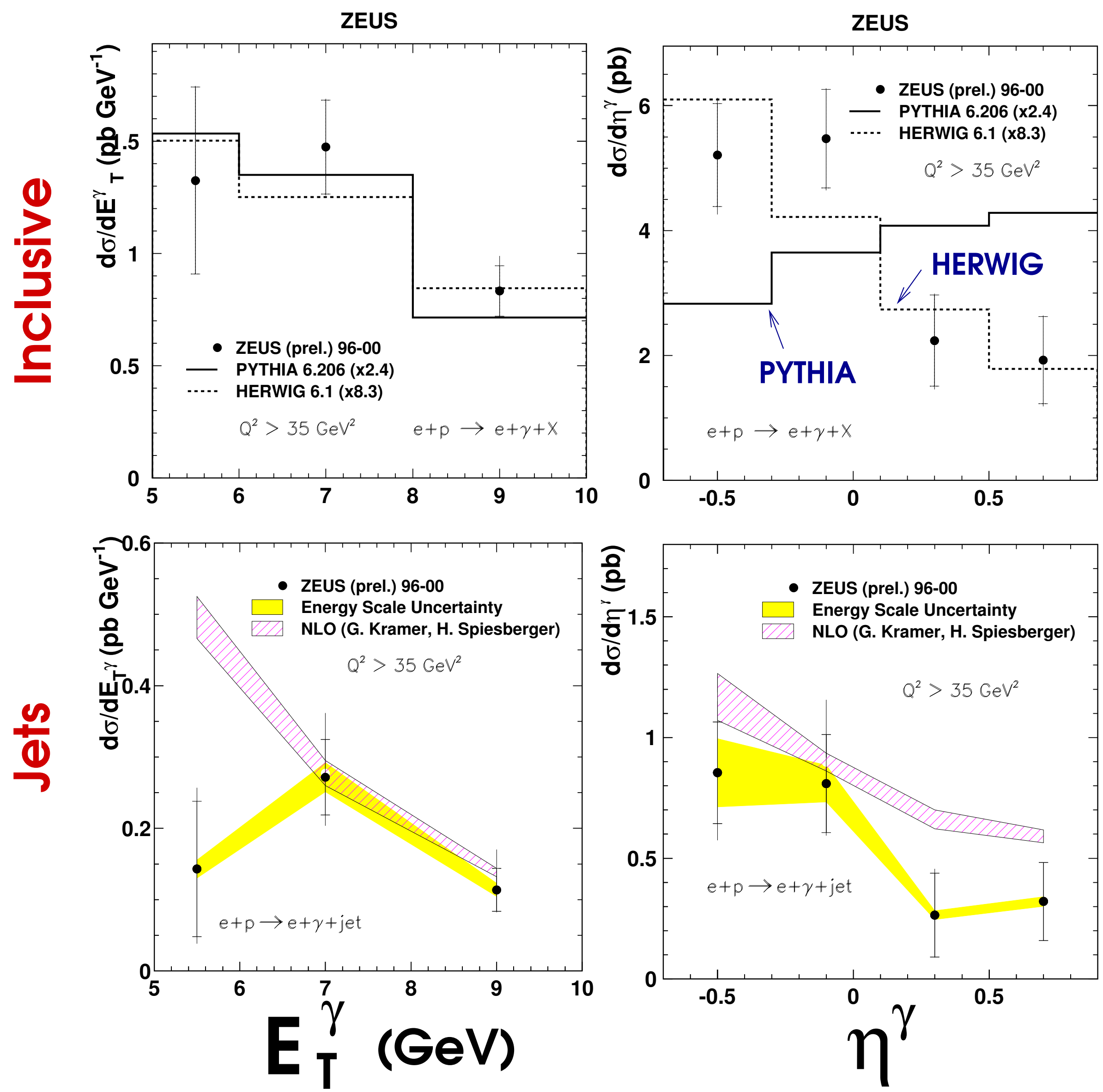


- **ZEUS** (hep-ex/0104001) **analysed $p_\perp$ and ΔΦ distributions in terms of effective intrinsic k_T ($\approx$ 1.7GeV) of partons in the proton, using PYTHIA**

- **$x_\gamma > 0.9$, to minimise effect of photon structure**

⇒ Now data well described by NLO without additional k_T

Prompt photons in DIS



- in DIS resolved contribution suppressed
- up quark contribution more dominant than in F_2
- large normalisation factors applied to PYTHIA (x 2.4) and HERWIG (x 8.3)

⇒ **reasonable normalisation within large errors of NLO** (Kramer, Spiesberger)

Conclusions

Photo-production

- **Inclusive prompt γ cross sections as a function of E_T^{γ} and η^{γ}**
  well described by pQCD in NLO

  PYTHIA event generator describes data in shape

- **prompt γ + Jet cross sections well described by NLO**
  (especially if multiple interactions corrections, based on PYTHIA, are applied)

DIS

- **First data reasonably well described by NLO within large errors**