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for the
ZEUS and H1
collaborations



**UNIVERSITY
of
GLASGOW**

Prompt Photon Production at ZEUS and H1

**Workshop on Low- x Physics,
Prague, 2004**

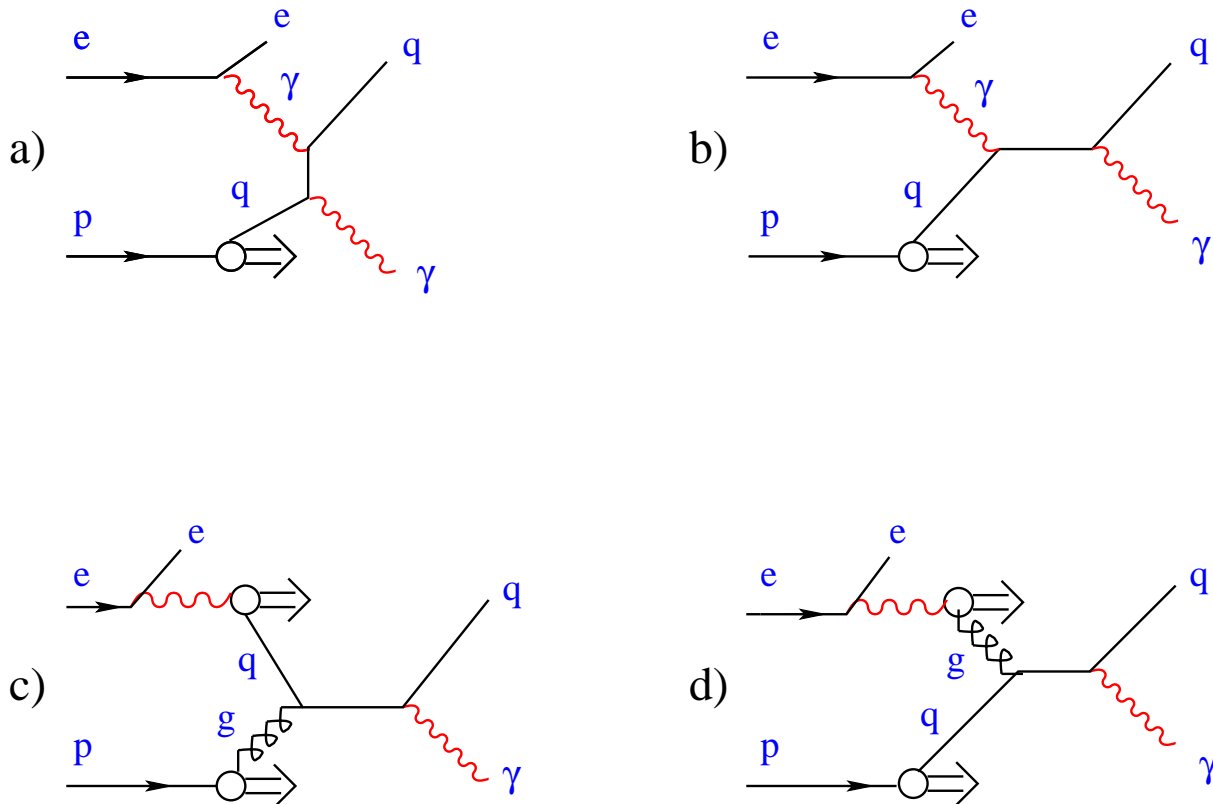
Outline

- Overview of prompt photons and the QCD processes
- Outline of ZEUS method
- ZEUS results: photoproduction
- ZEUS results in DIS
- Outline of the H1 method
- H1 results
- Comparison between ZEUS and H1 Inclusive photoproduction results
- Conclusion

Prompt photon overview

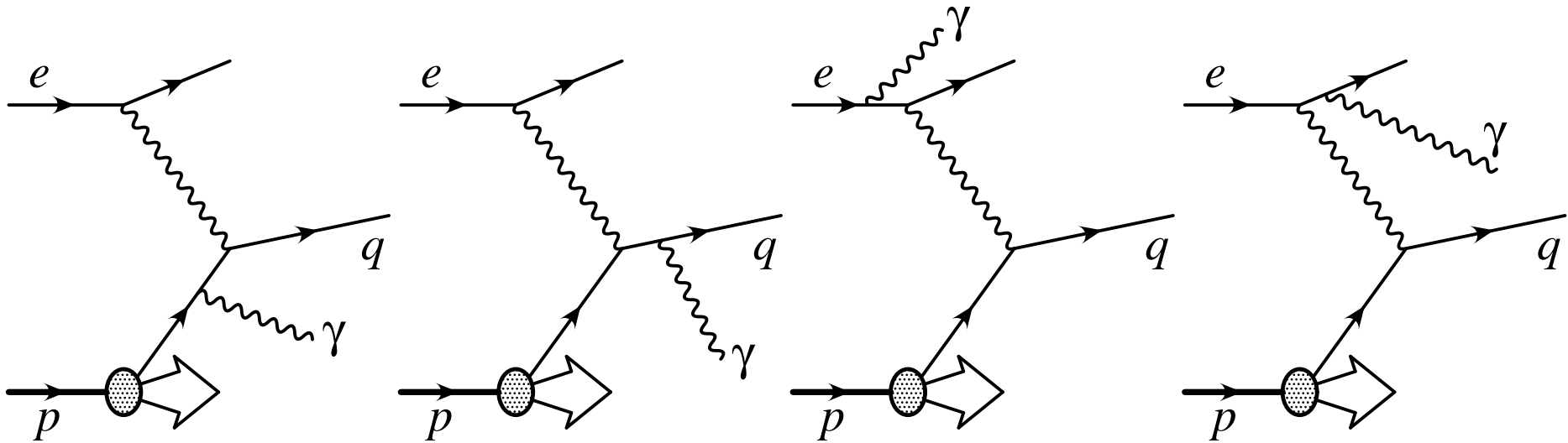
- A ‘prompt’ photon is a high- E_T , isolated photon.
- These arise as part of the pQCD process, rather than fragmentation or decay.
- Prompt photon processes are a clean probe of QCD:
 - ▶ Emerge from the interaction without intermediate hadronisation.
- At HERA, two neutral current processes have been studied:
 - $e^\pm p \rightarrow \gamma + X$: the *inclusive* process
 - $e^\pm p \rightarrow \gamma + \text{jet} + X$: the *photon plus jet* process.
- The jet requirement constrains the measurement, however it also introduces hadronic corrections.
- ZEUS has studied prompt photons in both the photoproduction and the DIS regimes.
- H1 has recently published results in the photoproduction regime.

Prompt photon processes: PHP



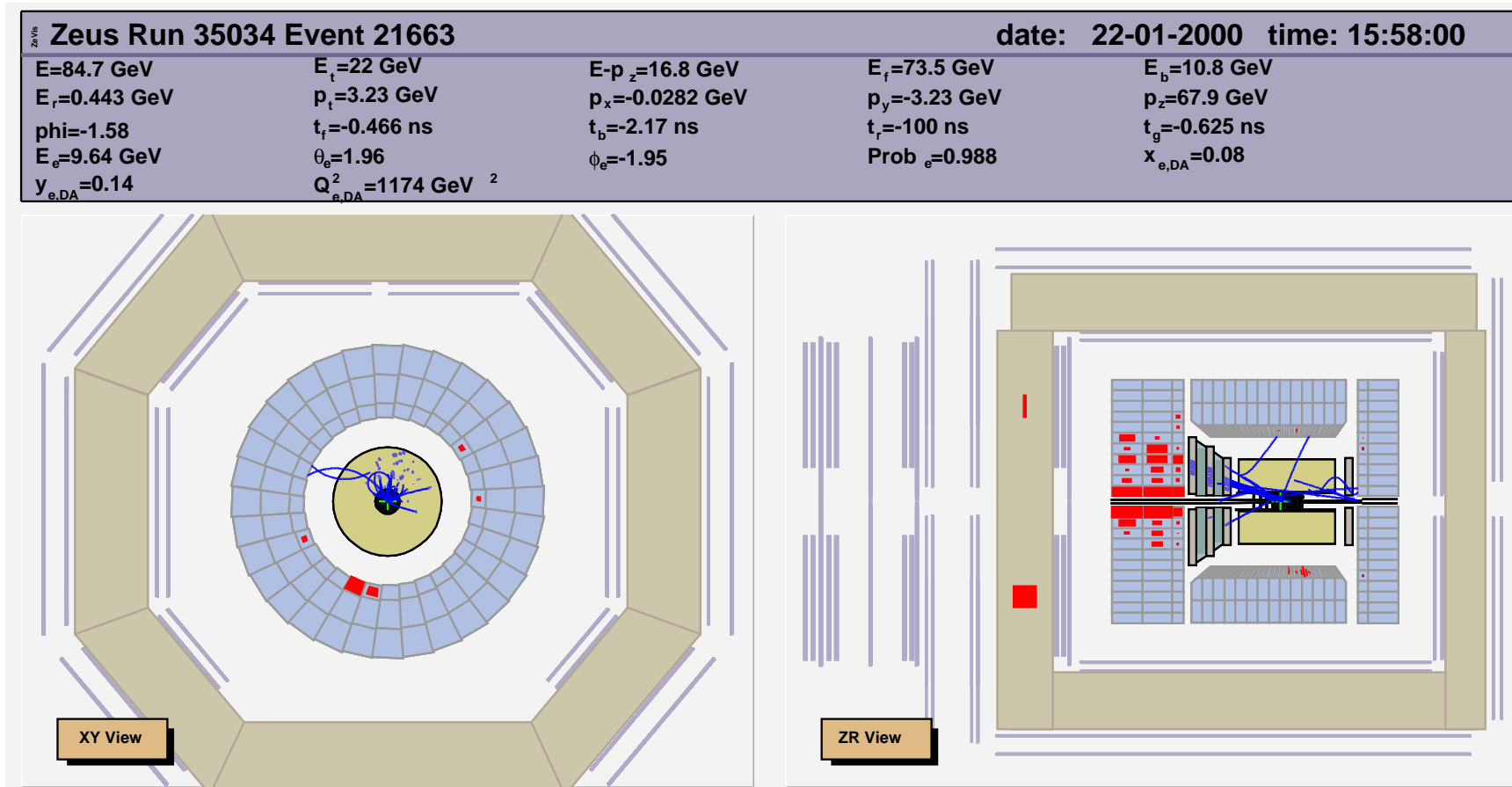
- The LO processes contributing to cross-section in PHP.
- ‘Radiative’ events occur when a high- E_T γ is radiated from a final state quark.
 - ▶ These form an irreducible background and must also be modelled.

Prompt photon processes: DIS



- The LO processes contributing to cross-section in DIS are 0th order in α_s
- The right hand diagrams show final-state photon emission from the lepton line.
- In DIS the interplay between the diagrams is rather more complex.

Sample ZEUS prompt photon event



- A sample ZEUS prompt photon event with balancing jet

ZEUS Selection

- Outline of method

- ▶ Locate a cluster of electromagnetic energy in the BCAL
- ▶ Remove clusters with nearby tracks
- ▶ Apply isolation criterion:

In unit cone around photon: $\sum \mathbf{E}_T < 0.1 \mathbf{E}_T^\gamma$

- Photoproduction Selection:

- ▶ $0.2 < y < 0.9$
- ▶ $-0.7 < \eta^\gamma < 0.9$
- ▶ $5 < \mathbf{E}_T^\gamma < 15$ GeV for the E_T^γ distributions.

Distribution is restricted to < 10 GeV in η^γ .

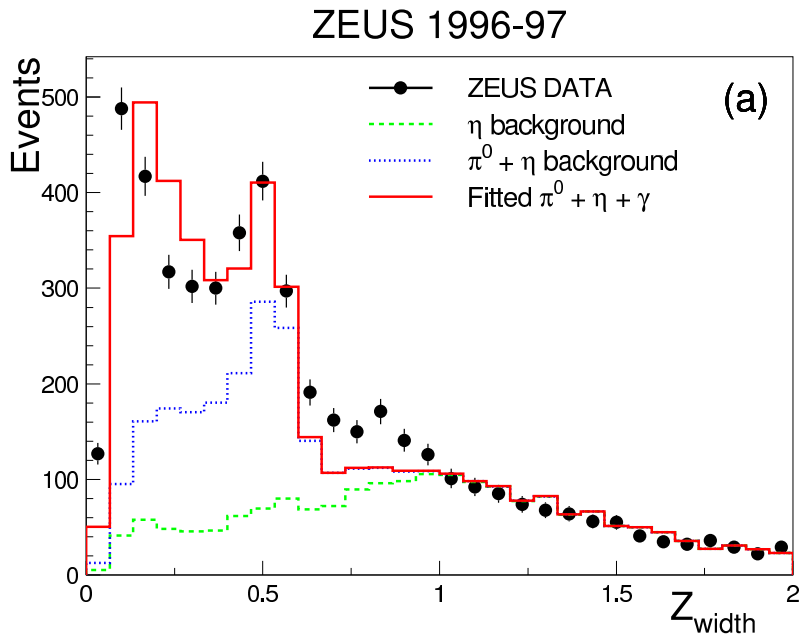
- DIS Selection:

- ▶ $Q^2 > 35$ GeV², $E_e > 10$ GeV, $139.8^\circ < \theta_e < 171.8^\circ$
- ▶ $-0.7 < \eta^\gamma < 0.9$ and $5 < \mathbf{E}_T^\gamma < 10$ GeV
- ▶ Where jets are required: $\mathbf{E}_T^{\text{jet}} > 6$ GeV and $-1.5 < \eta^{\text{jet}} < 1.8$.

- Still contribution from neutral mesons, which mimic photon signal in the CAL.

- ▶ These decay to multiple photons, providing a different cluster shape.
- ▶ Use this to perform a statistics-based background subtraction.

The Neutral Meson Background Subtraction



- $\langle \delta Z \rangle = \frac{\sum (\mathbf{E}_{\text{cell}} |z_{\text{cell}} - \bar{z}|)}{\sum \mathbf{E}_{\text{cell}}}$

- Measures the cluster width in z
- A cut at 0.65 removes the η -meson tail

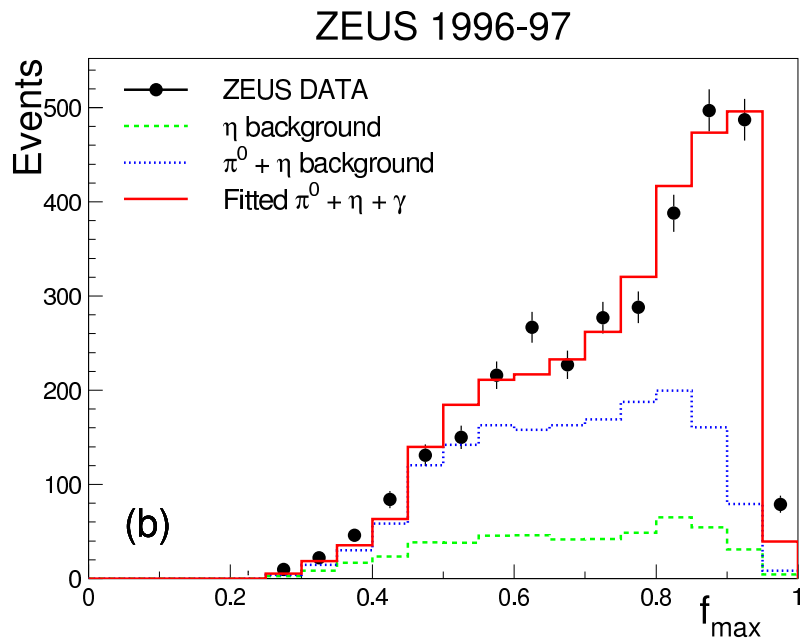
- $f_{\text{max}} = \frac{\text{Energy in most energetic cell}}{\text{Total energy in cluster}}$

- We define two regions:

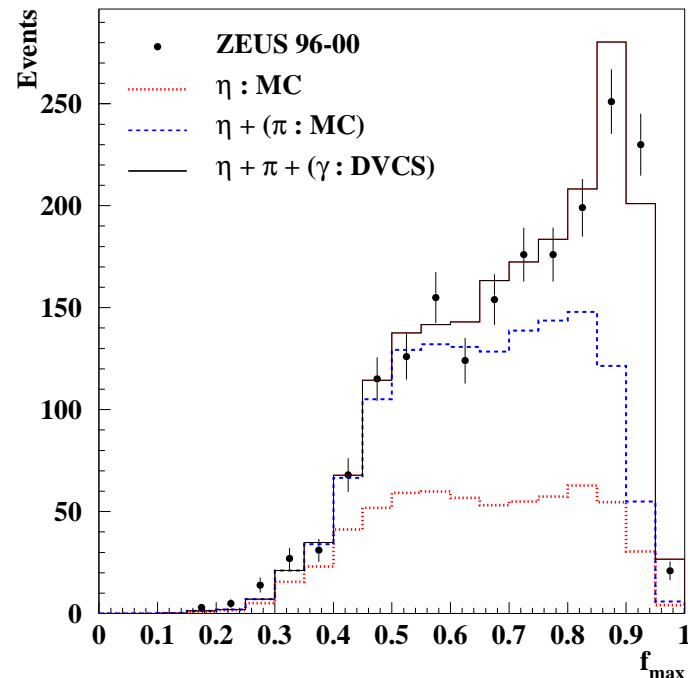
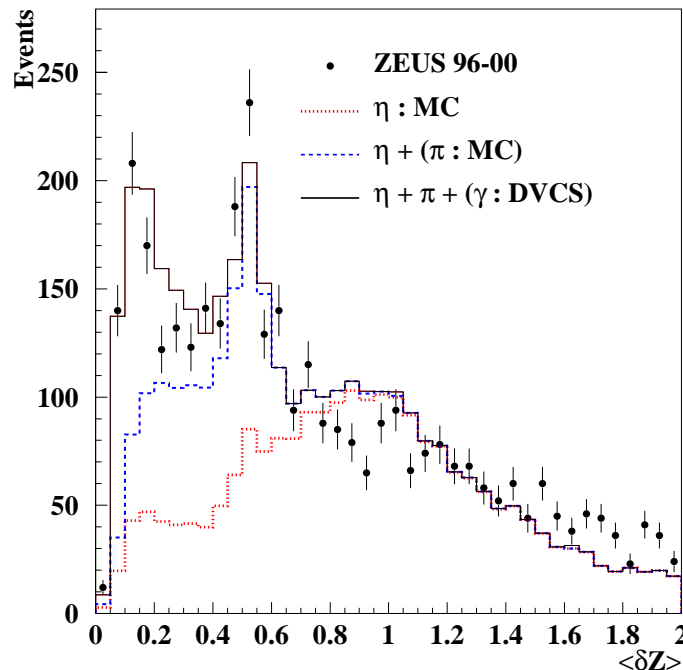
- ▷ ‘good’: $f_{\text{max}} > 0.75$ and

- ▷ ‘poor’: $f_{\text{max}} < 0.75$.

- Use a statistical signal extraction.

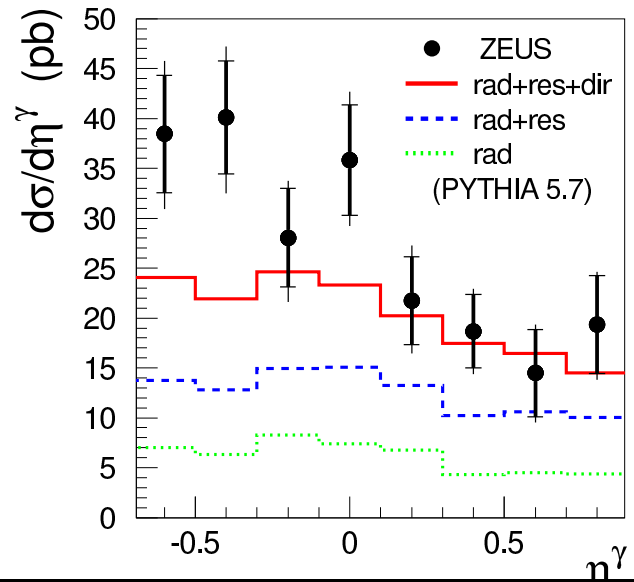
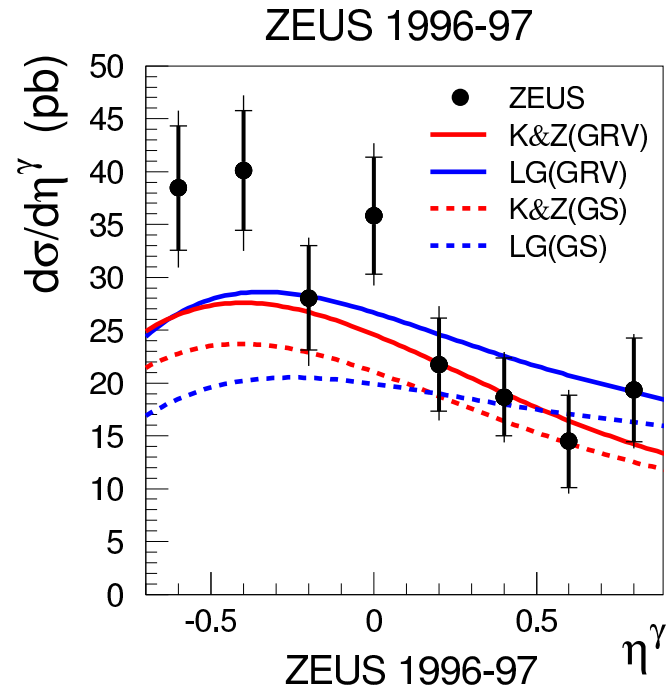
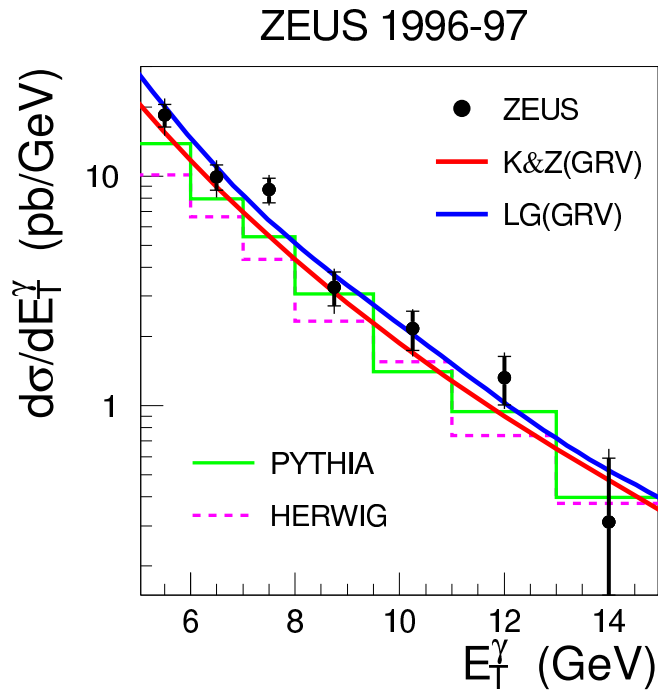


Prompt photons in DIS at ZEUS: DVCS background subtraction



- Single particle Monte Carlo does not well model the data
- For the DIS analysis: use DVCS photons instead of simulated single photons.
 - ▶ DVCS: Deeply Virtual Compton Scattering
 - ▶ *Diffraction* process: no hadronic activity in the detector
 - No contamination from neutral mesons
- These photons make for a much improved fit to the prompt photon data.

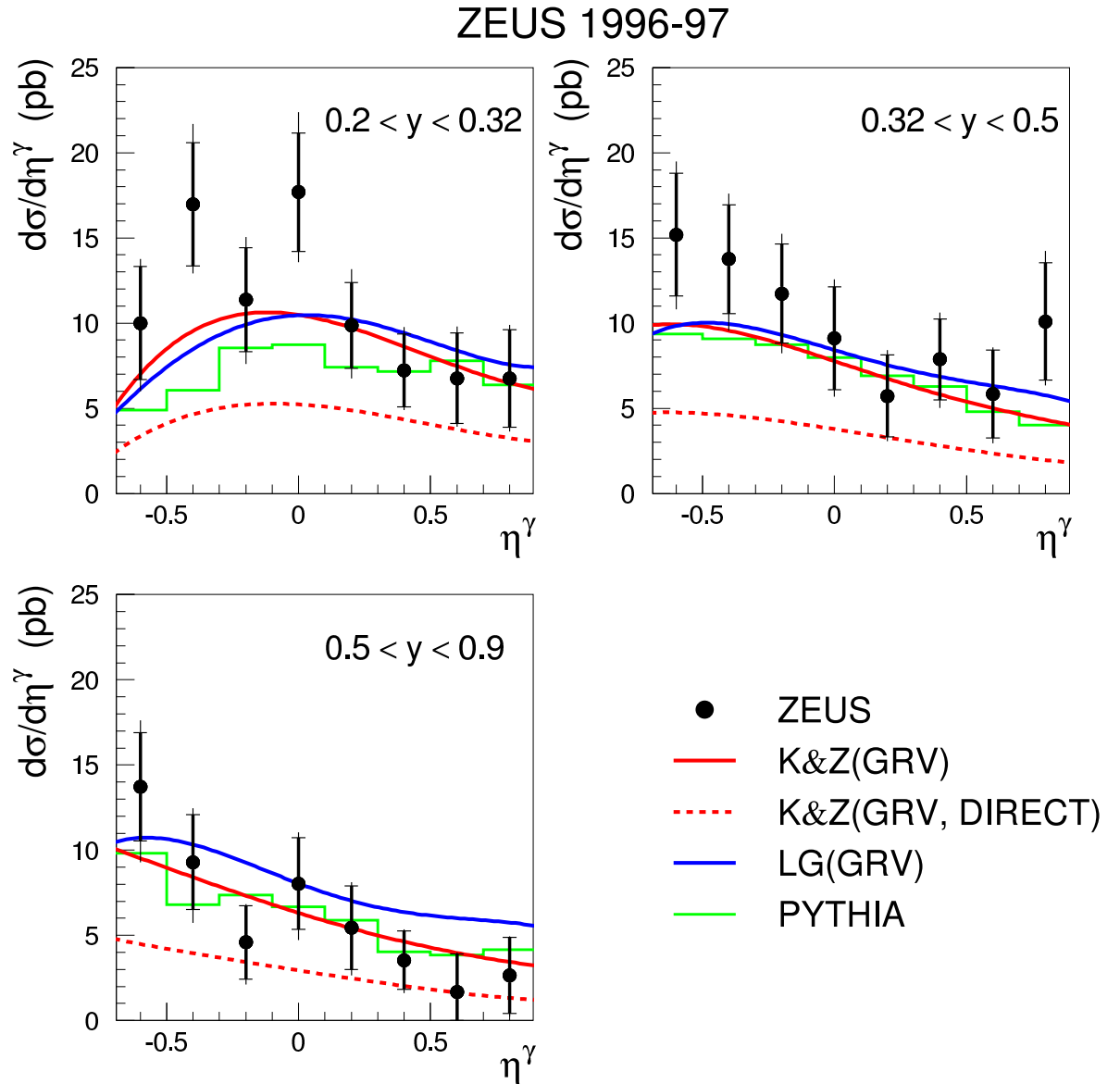
Inclusive photon results in PHP: ZEUS



- 96-97 ZEUS data
- Measured cross section
 - ▶ Compared to Pythia 5.7
 - ▶ NLO from Gordon (LG) and Krawczyk and Zembrzuski(K&Z)

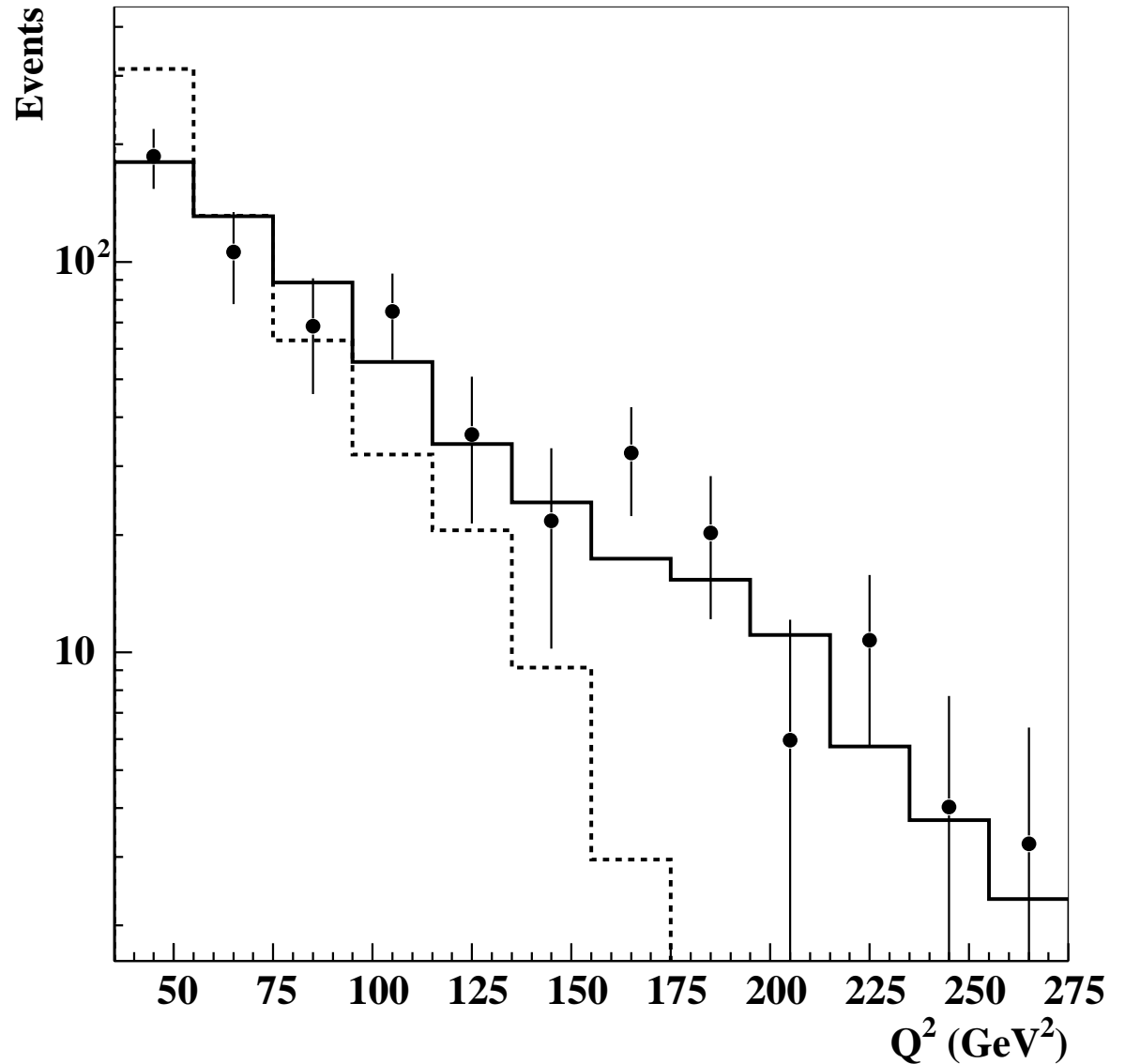
The η cross section in y sections

- Examining the excess in η^γ in slices of y
- Most notable for $y < 0.5$
- The peak is seen in simulations
 - ▶ More prominent for data

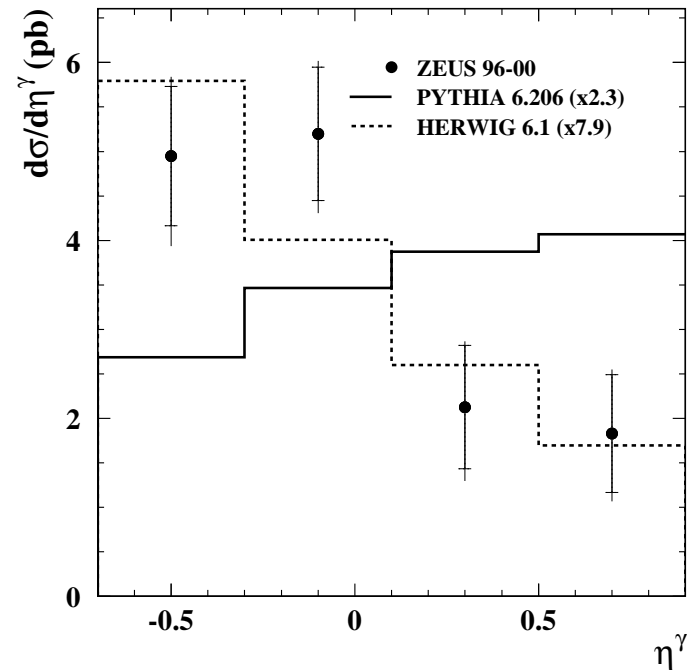
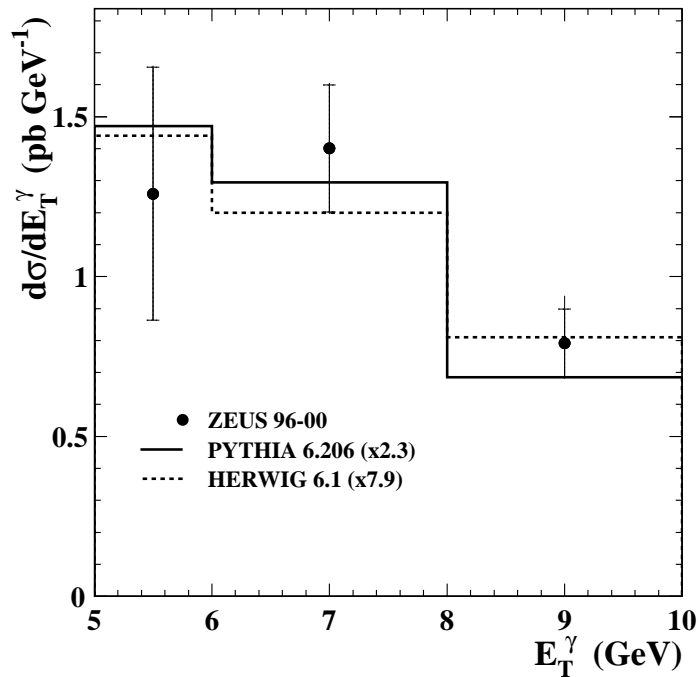


The ZEUS DIS measurement

- Q^2 distribution in DIS
- ZEUS data 96-00
- Histograms: PYTHIA (solid) and HERWIG (dashed)
- PYTHIA models the data reasonably well



Inclusive prompt photons in DIS at ZEUS



- Cross Sections shown for the inclusive process in DIS
- Comparisons to PYTHIA and HERWIG shown
 - ▷ Neither MC fits the data well
 - ▷ Both require normalisation
- $Q^2 > 35 \text{ GeV}^2$

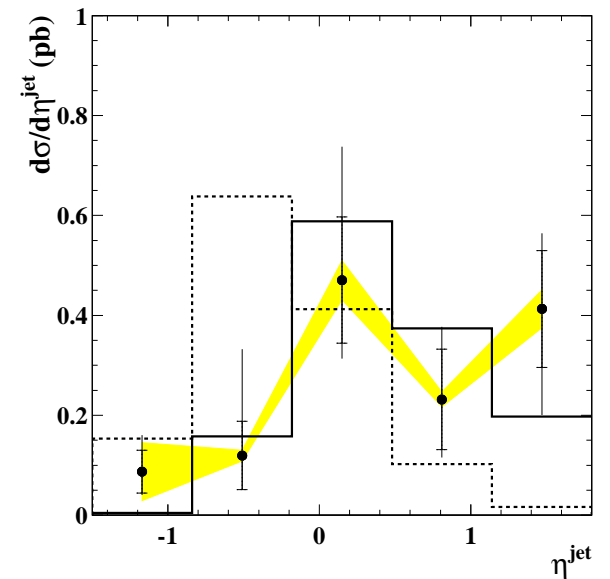
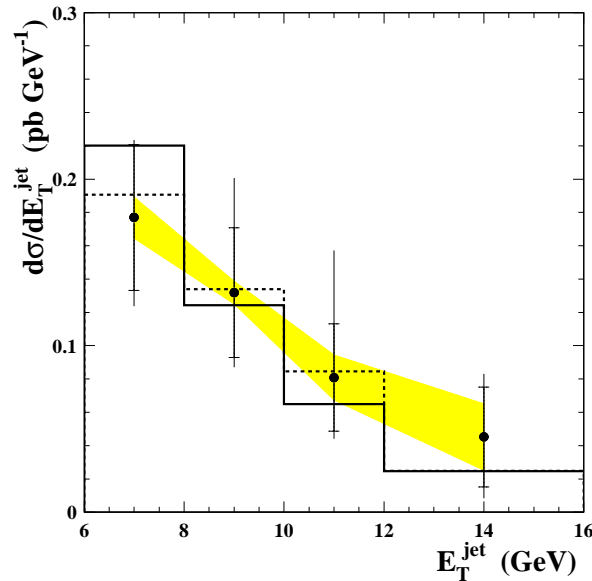
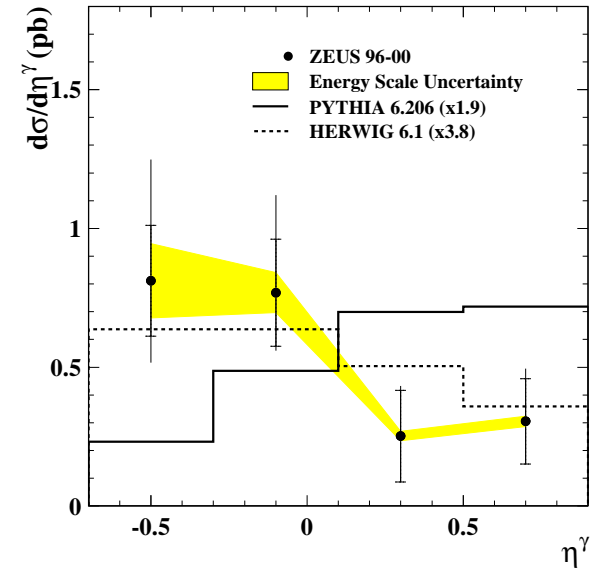
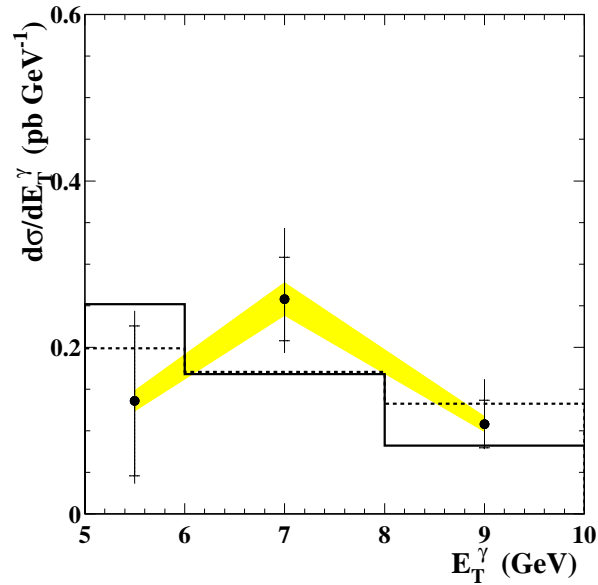
Prompt photons with jet in DIS at ZEUS

- 96-00 ZEUS DIS data

- The histograms show PYTHIA and HERWIG predictions

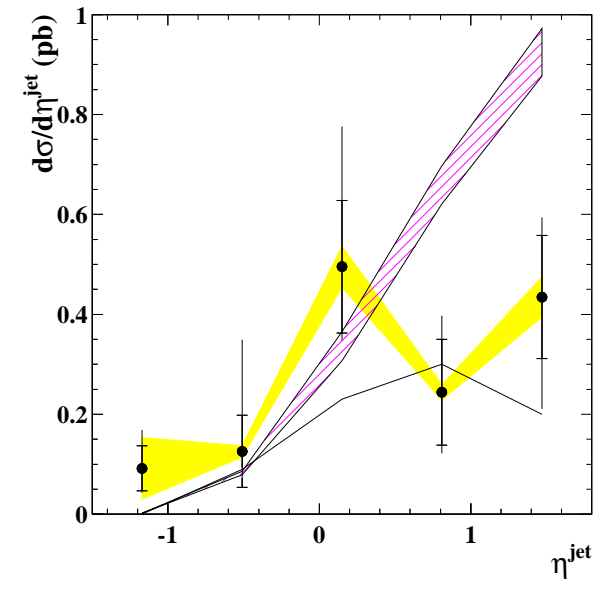
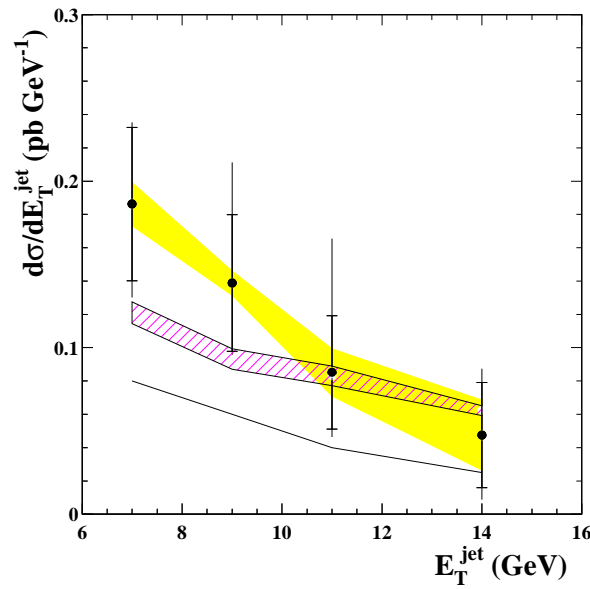
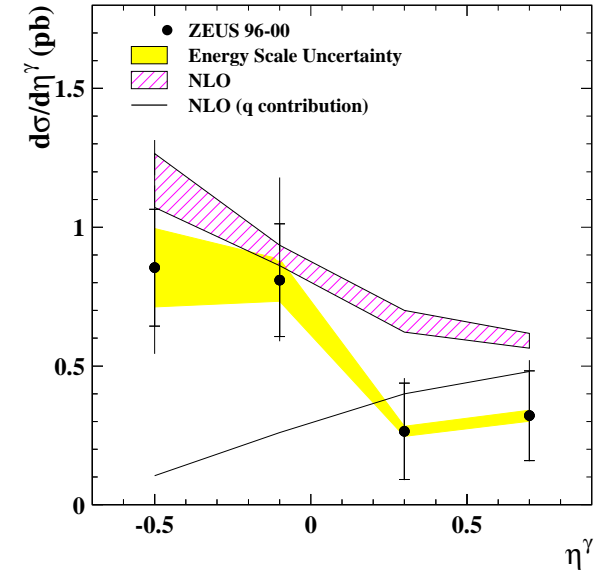
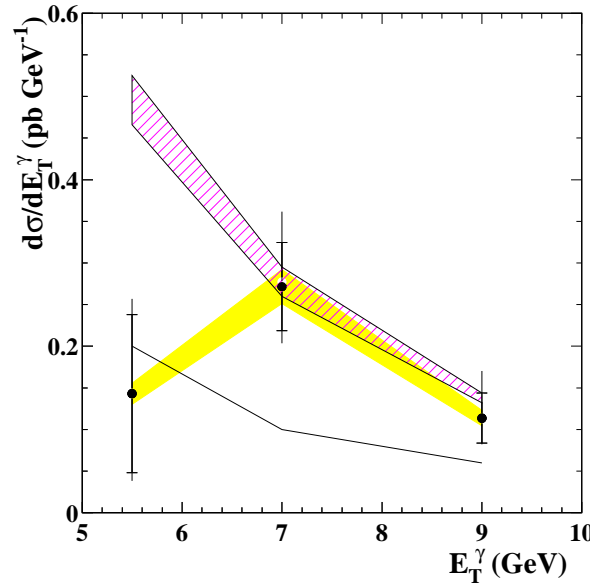
▶ Scaling required in both cases.

- $Q^2 > 35 \text{ GeV}^2$



Prompt photons with jet in DIS at ZEUS: NLO

- 96-00 ZEUS DIS data
- Compared to NLO predictions from Kramer and Spiesberger
- Black line shows the quark-line contribution.
- $Q^2 > 35 \text{ GeV}^2$



The H1 measurement

- The H1 method is similar to the ZEUS method

- ▷ An electromagnetic shower in the LAr Calorimeter is required where:

- ◇ $-1 < \eta^\gamma < 0.9$ and $E_T^\gamma > 5 \text{ GeV}$

- ▷ Candidates with tracks within 25cm are removed

- ▷ The isolation criterion is enforced as in the ZEUS analysis

- ▷ Jets, for the photon plus jet process, must fulfill

- ◇ $E_T^{\text{jet}} > 4.5 \text{ GeV}$

- ◇ $-1 < \eta^{\text{jet}} < 2.3$

- The cross sections are presented for the kinematic region:

$$\sqrt{s} = 319 \text{ GeV}, 0.2 < y < 0.7, Q^2 < 1 \text{ GeV}^2$$

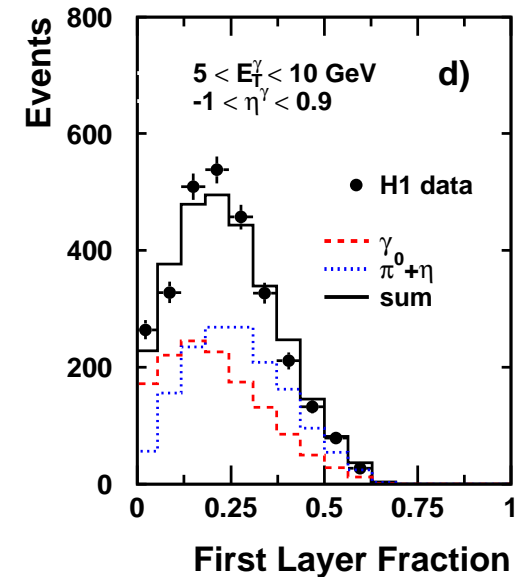
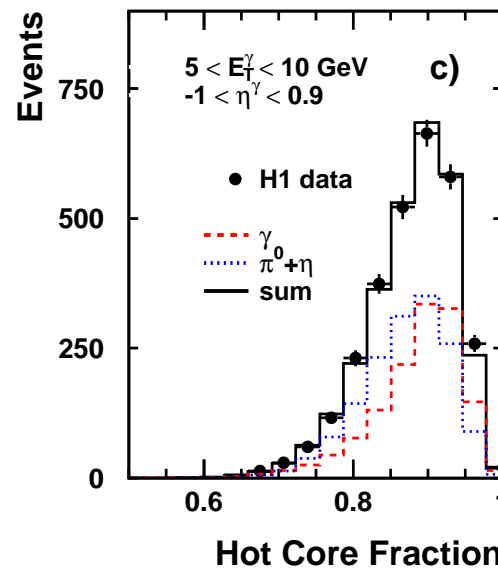
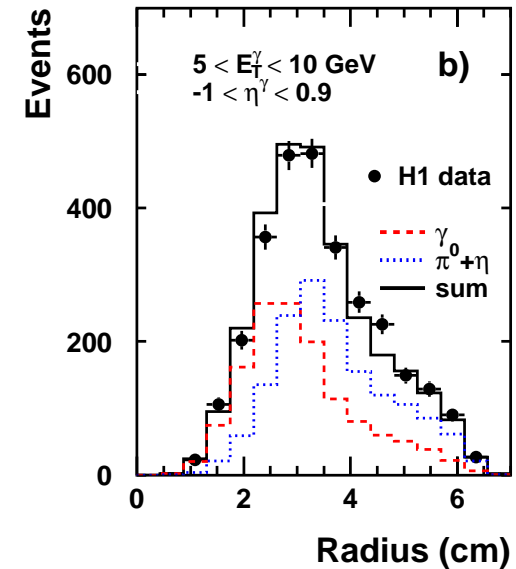
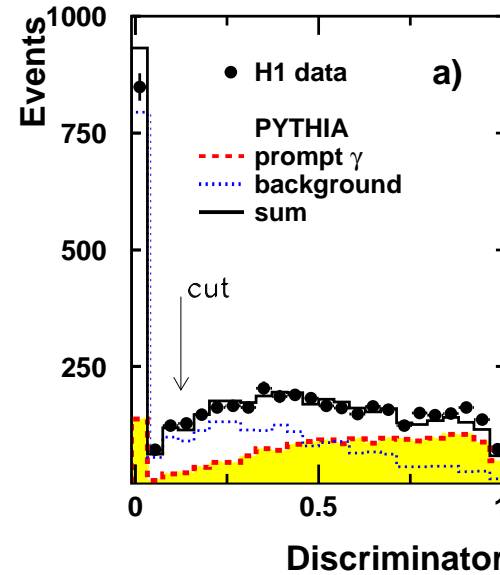
$$5 < E_T^\gamma < 10 \text{ GeV}, -1 < \eta^\gamma < 0.9, E_T^{\text{cone}} < 0.1 E_T^\gamma$$

- As in the ZEUS case, background from neutral mesons of the order of the prompt photon signal still exists.

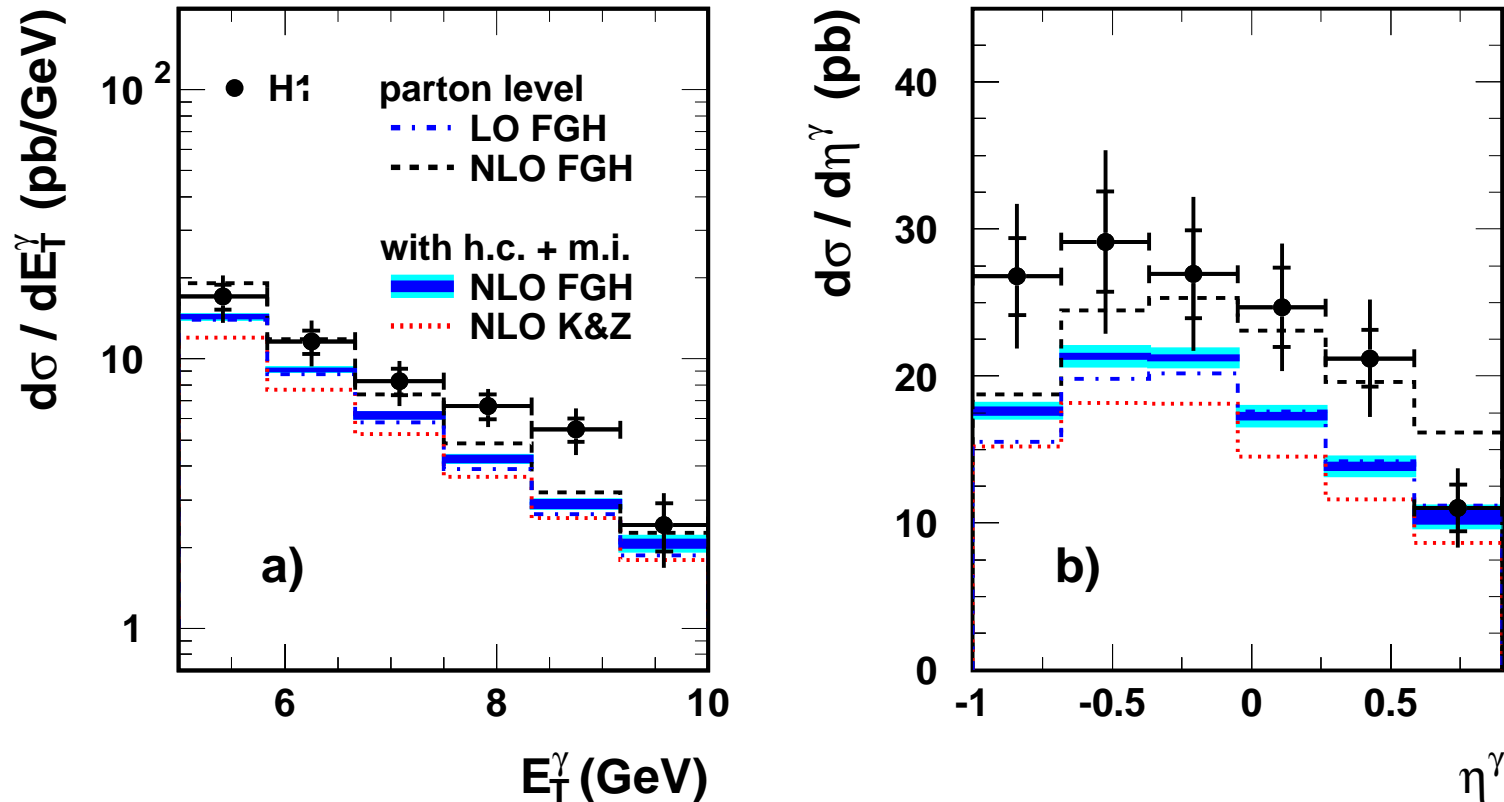
- ▷ These are removed by a discriminator function.

The H1 background subtraction

- The discriminator depends on
 - ▶ radius of the shower (R).
 - ▶ fraction in the highest energy cell (HCF),
 - ▶ depth the photon penetrates (FLF),
- Use R , HCF and FLF to generate a likelihood function based on photon, π^0 and η -meson simulation.
- Discriminator d is formed by $\text{likelihood}(\gamma)/\text{likelihood}(\gamma + \pi^0)$
- Place a cut: $d > 0.125$



H1 results: Inclusive prompt photon production

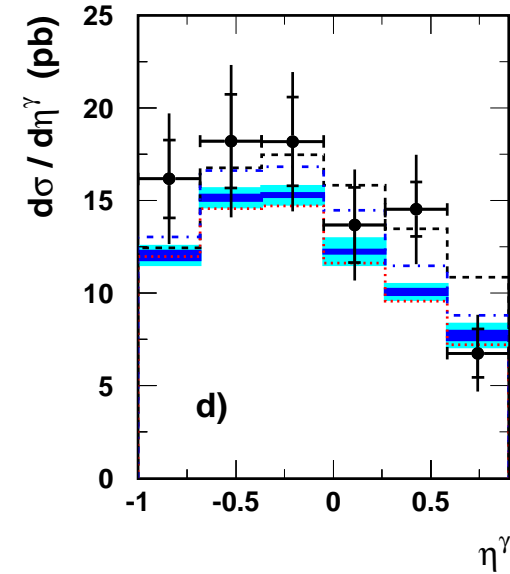
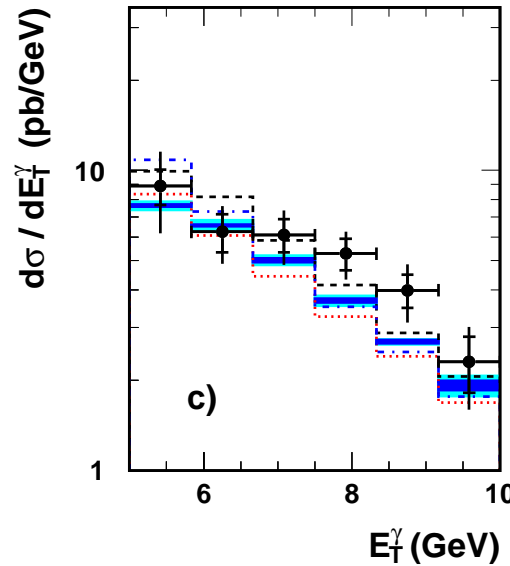


- Cross Sections shown for the inclusive process in photoproduction
- Compared to LO and NLO predictions:
 - ▷ Calculations by Fontannaz, Guillet and Heinrich (FGK)
 - ▷ Also by Krawczyk and Zembrzuski (red)

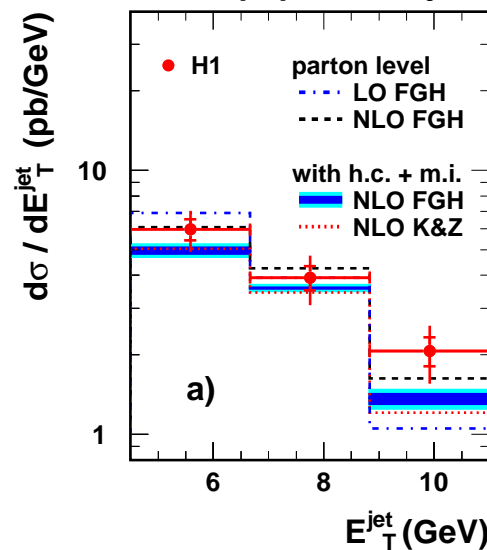
H1 results: Prompt photon with jet

- Cross Sections shown for the γ + jet process
- Compared to LO and NLO predictions:
- Calculations by
 - ▶ Fontannaz, Guillet and Heinrich
 - ▶ Krawczyk and Zembrzuski (red)

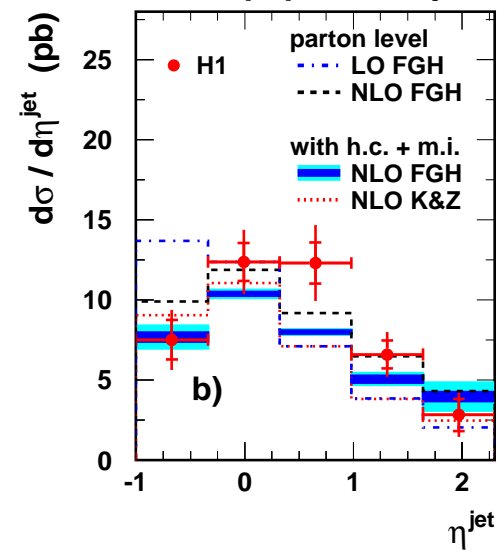
Prompt photon + jet



Prompt photon + jet

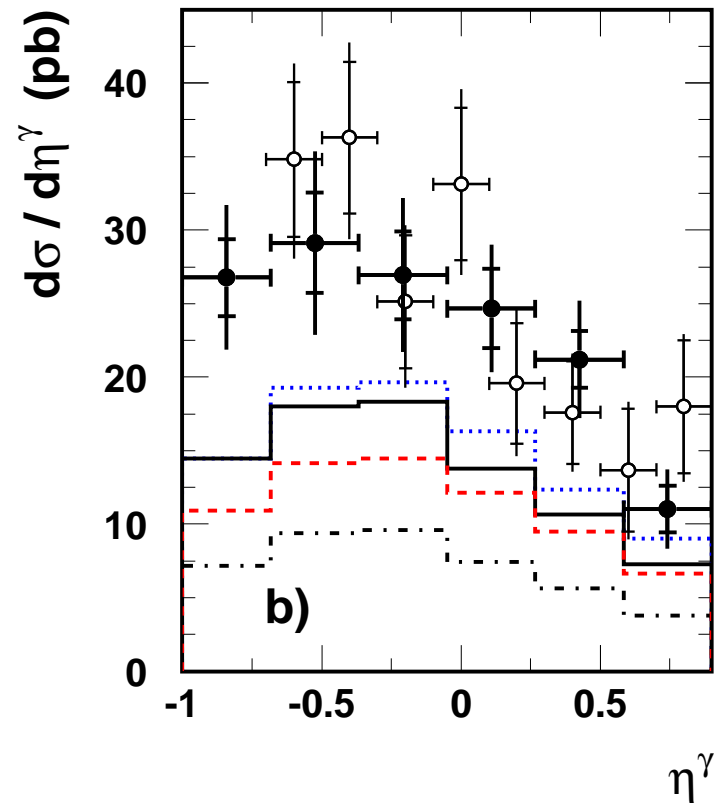
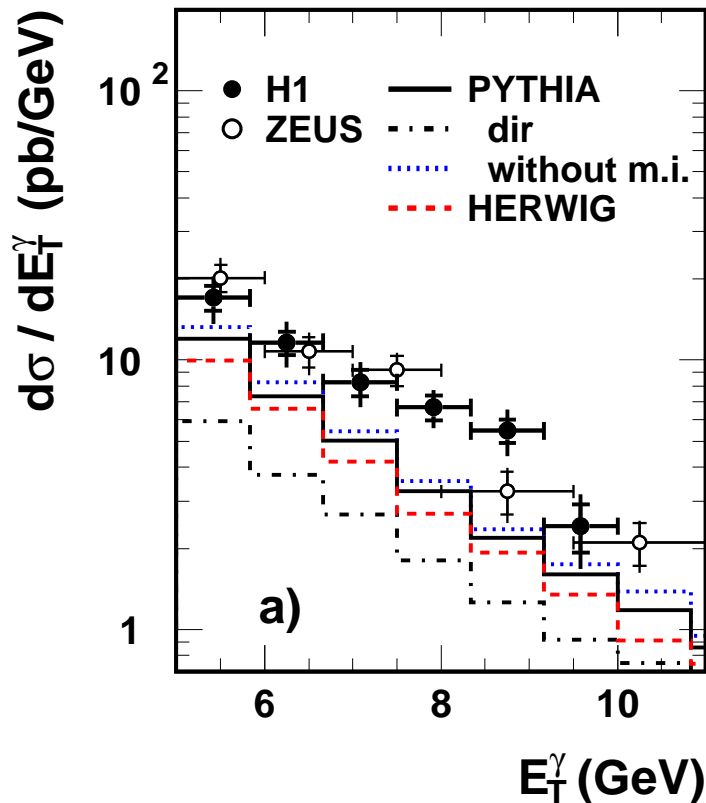


Prompt photon + jet



Comparing ZEUS and H1

Inclusive prompt photon



- Open circles - ZEUS 96-97 data
- Closed circles - H1 96-2000 data
- Compared to PYTHIA, HERWIG (histograms)
 - ▶ Red dashed histogram is HERWIG, black solid histogram is PYTHIA

Summary

- Prompt photon results have been presented from ZEUS and H1.
- From ZEUS:
 - ▷ Inclusive results from the photoproduction regime
 - ▷ Inclusive results in DIS
 - ▷ Photon + jet results in DIS
- From H1:
 - ▷ Inclusive results in photoproduction
 - ▷ Photon + jet results from photoproduction
- Comparisons between H1 and ZEUS show reasonable agreement
- NLO calculations describe the data rather better than PYTHIA or HERWIG
- Progress in understanding the background:
 - ▷ Use of discriminator by H1
 - ▷ Use of DVCS data photons by ZEUS
- The topic continues to be a fruitful one.