

# Prompt Photons at HERA

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Inclusive prompt photon production in DIS  
signal-background separation with shower shape analysis  
significantly extend phasespace of former measurement by ZEUS  
comparison to new LO calculation  
([hep-ph/0601073](#), [hep-ph/0604030](#))



Photon plus jet cross section in Photoproduction  
new method of signal-background separation  
access to high photon energies  
comparison to NLO and  $k_t$  factorisation approach



# Prompt Photons: Motivation

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Crucial to understand the production of photons in association with hadrons

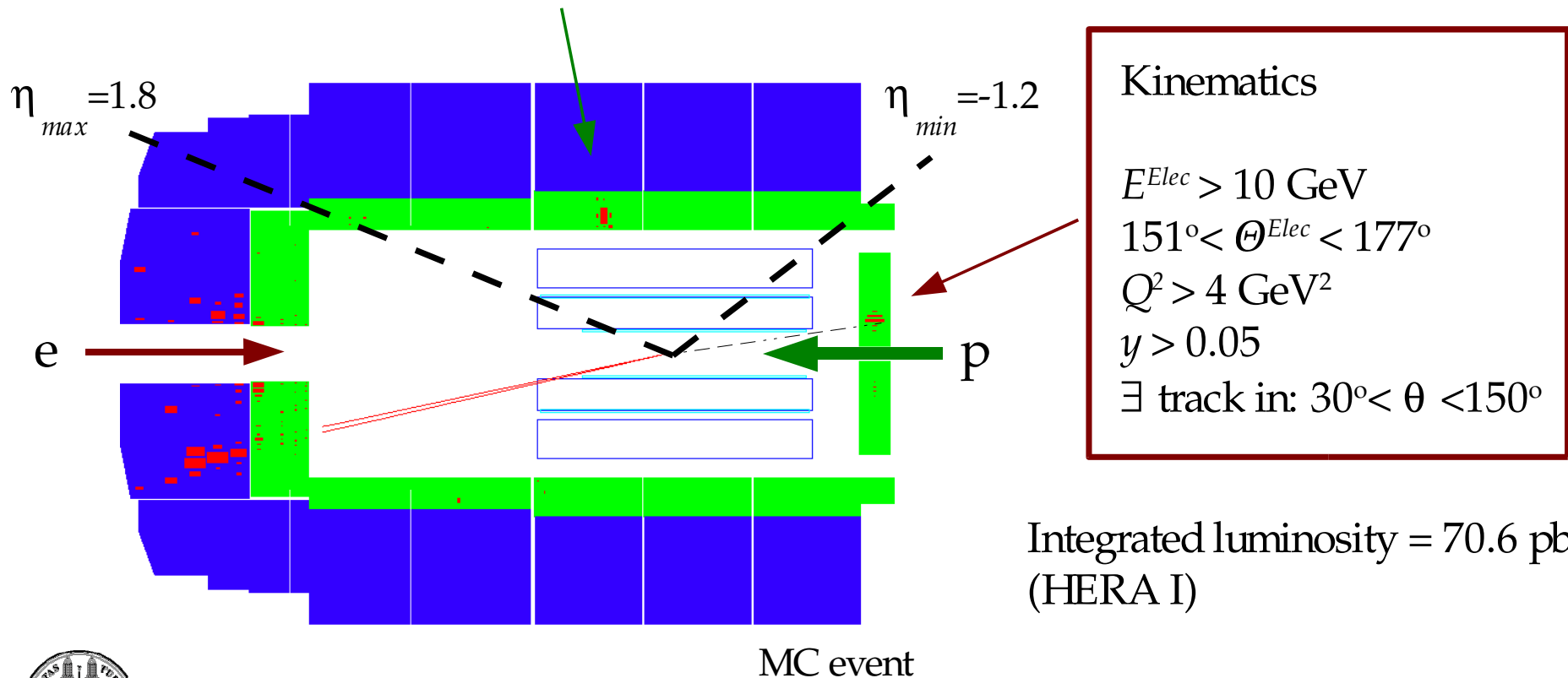
- possible signature for new physics
  - important background for the search for Higgs:  $H \rightarrow \gamma\gamma$   
LHC:  $m_H < 130 \text{ GeV}$  most promising channel  $H \rightarrow \gamma\gamma X$
- Prompt photon cross section
- Quark-to-photon fragmentation function  $D_{q \rightarrow \gamma}$  so far only measured at ALEPH  
is it possible to measure it at HERA?





# Prompt Photons in DIS: Selection

Photon: cluster in electromagnetic calorimeter  $3 < E_t^\gamma < 10 \text{ GeV}$   
 no track  $-1.2 < \eta^\gamma < 1.8$   
 Isolation:  $z = E_\gamma/E^{\text{PhotonJet}} > 0.9$   
 (democratic clustering approach)



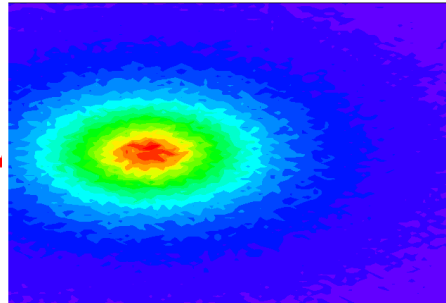
Integrated luminosity =  $70.6 \text{ pb}^{-1}$   
 (HERA I)





# Background: neutral mesons

Photon signal

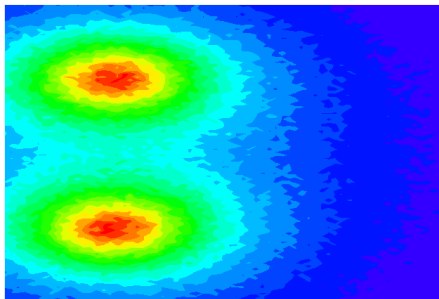
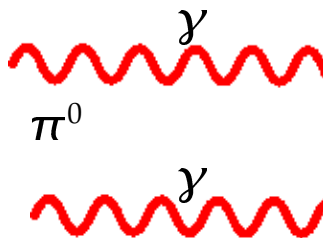


Compact electromagnetic cluster  
no track pointing to it

Background: neutral mesons decaying into multiple photons

$\pi^0, \eta, \eta', \rho, \omega, K^0, K^*, K_L, K_S, n$

decay photons form a single cluster at high energies



Identify multi photon clusters by analysis of shower shapes:

- transverse radius
- compactness
- symmetry
- energy fraction in first layer
- energy fraction of hottest cell
- transverse kurtosis



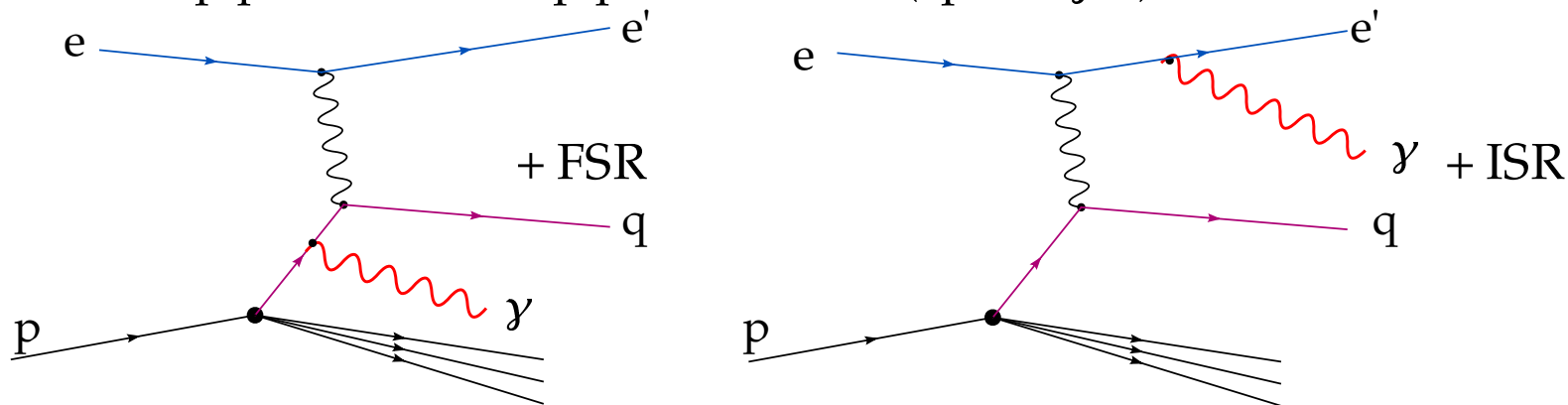


# MC Generators and LO calculation

## MC Generators

- 1) PYTHIA 6.2, HERWIG 6.5  $\gamma+q \rightarrow \gamma+q$   
Flux of incoming photons is approximated in DIS mode
- 2) ISR and FSR radiation off the electron RAPGAP 3.1

LO( $\alpha^3$ ) calculation by Gehrmann et al. for prompt photon crosssection in DIS  
hep-ph/0601073, hep-ph/0604030  $\sigma(ep \rightarrow e\gamma X)$



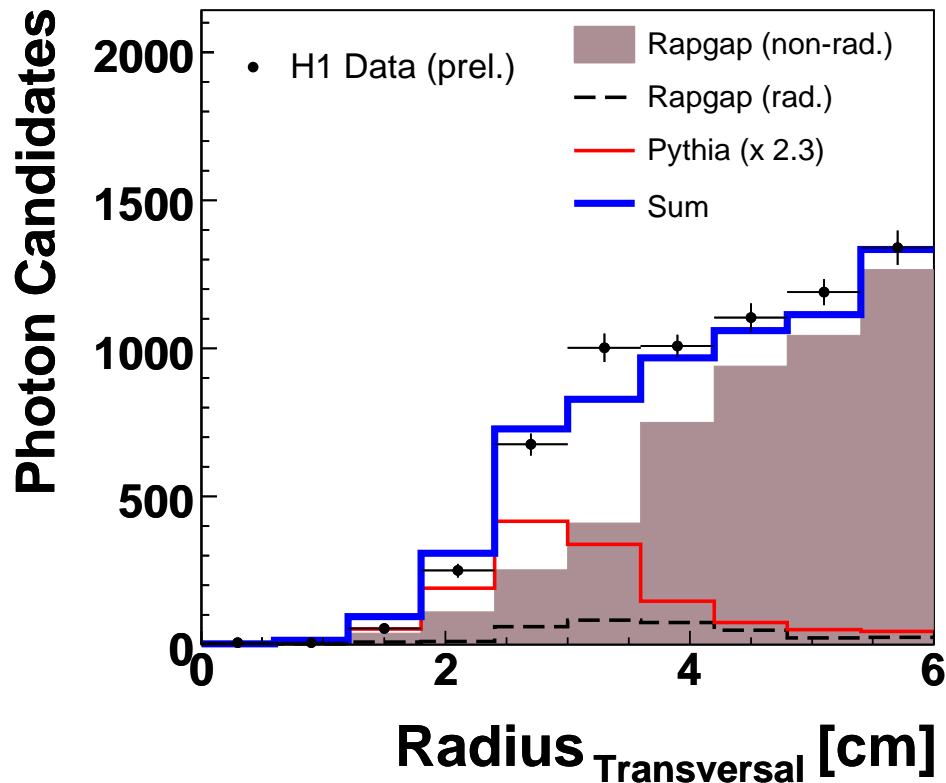
Contributions: QQ radiation off the quark  
(including large angle radiation and photon fragmentation)  
LL radiation off the electron  
QL interference (negligible)





# Signal-Background separation

Transverse radius of the cluster



Background:

neutral mesons RAPGAP(non rad)  
without radiated photons

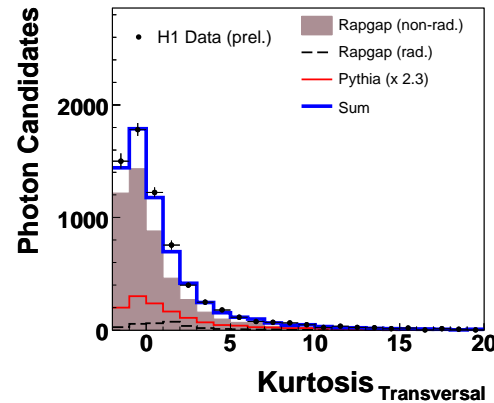
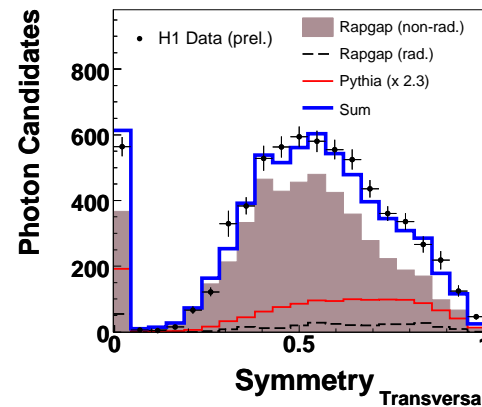
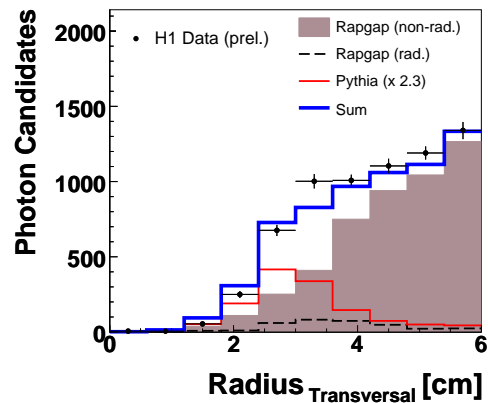
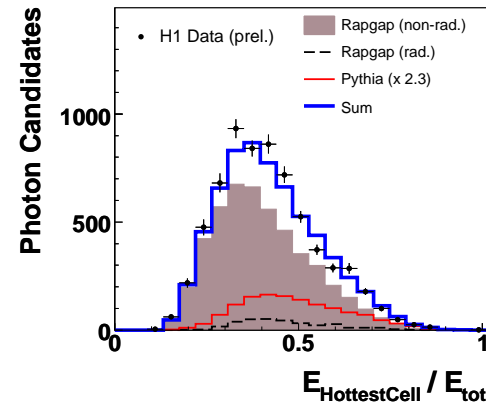
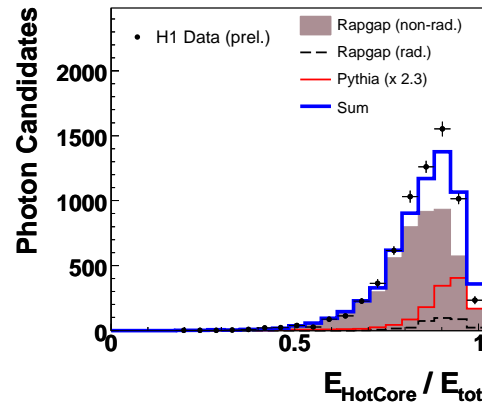
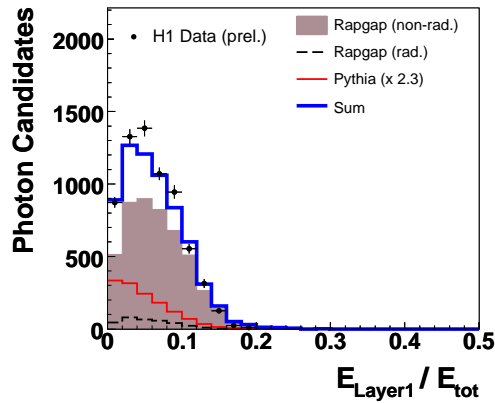
Signal:

- 1) Photons from quark line  
PYTHIA (scaled by 2.3)
- 2) Photons from electron line  
RAPGAP (rad)





# Discrimination by shower shapes



All six Cluster shapes well described by sum of MC

Extraction of the signal with single particles, ratio of neutral mesons from RAPGAP



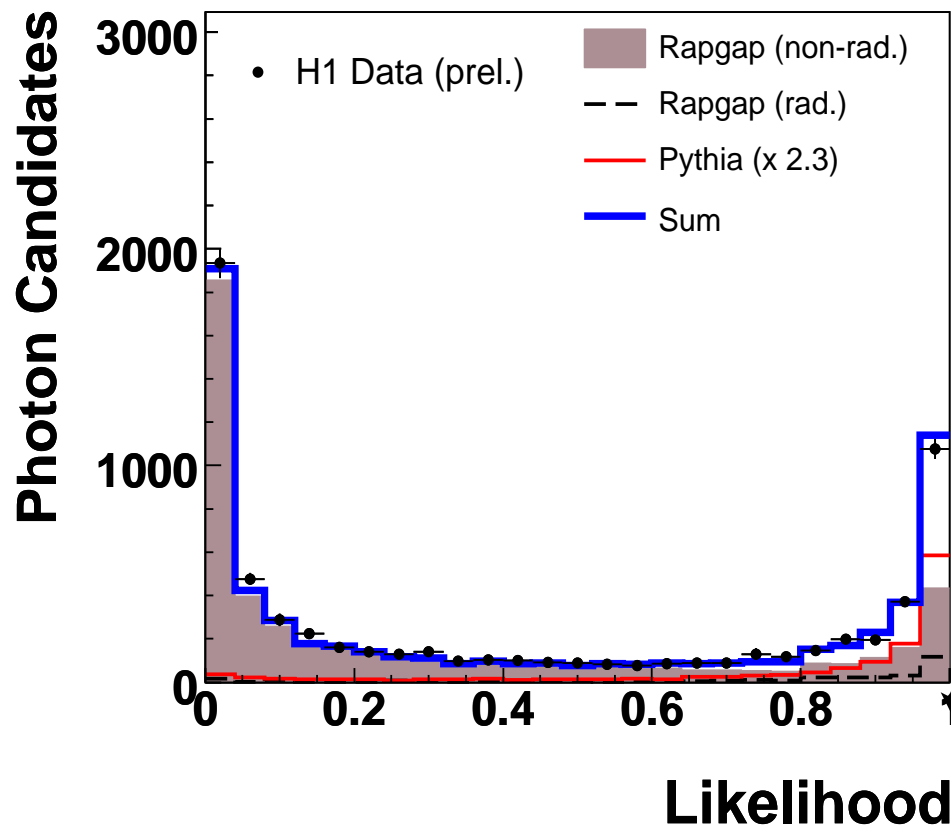


# Extraction of photon signal

All six variables combined in a Likelihood method (naive Bayes)

Prob. density functions defined by single particles samples – high statistics

Signal: Photons, Background 10 types of neutral mesons



Number of Photons  
 $\chi^2$  fit to Likelihood  
in bins in  $E_T^\gamma$  and  $\eta^\gamma$

MC describes the fraction of neutral mesons very well

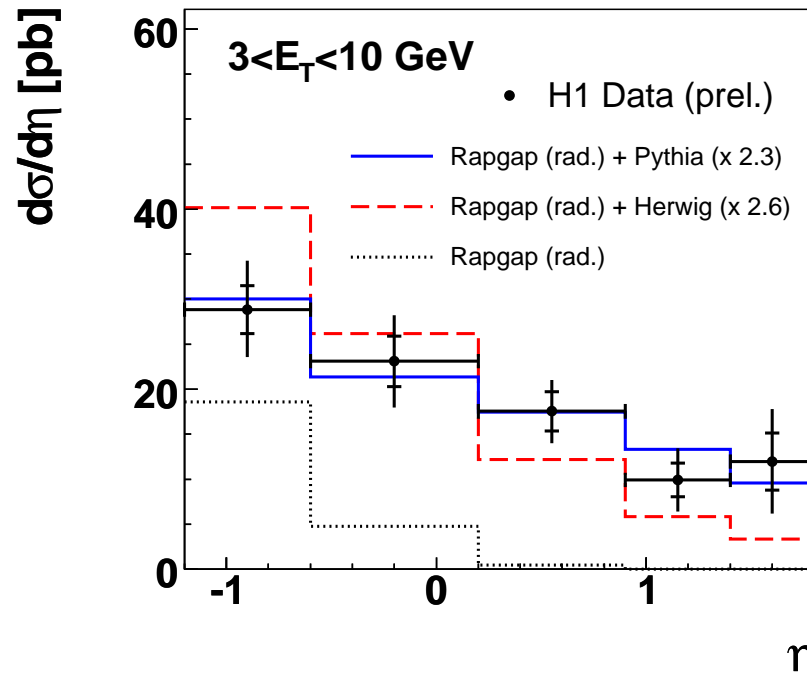
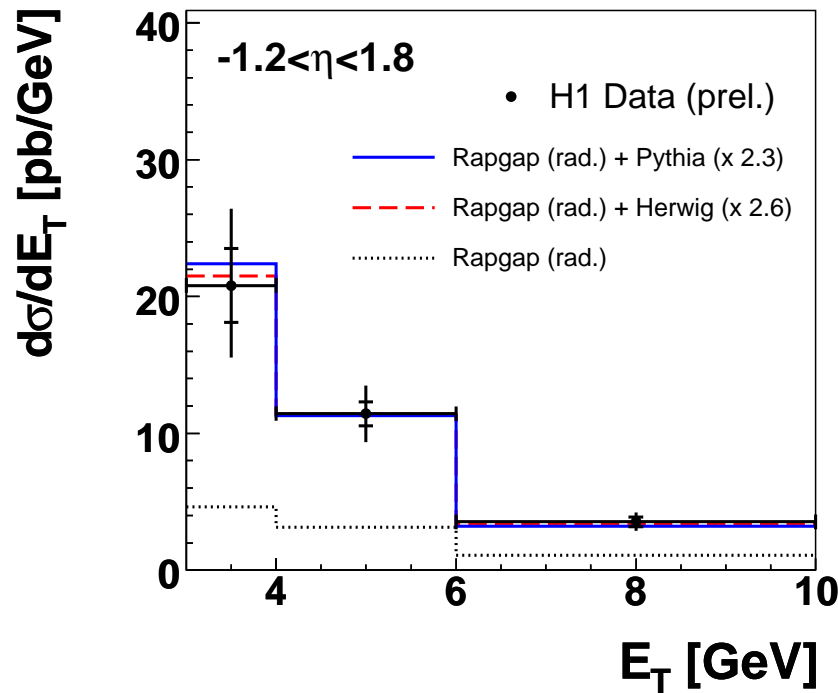
Inseparable background







# Cross Sections and Generators

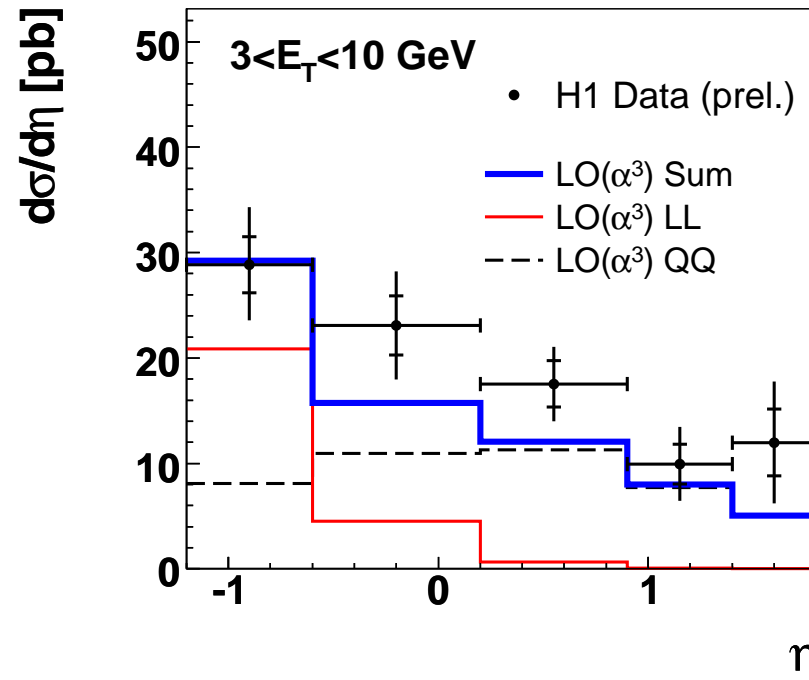
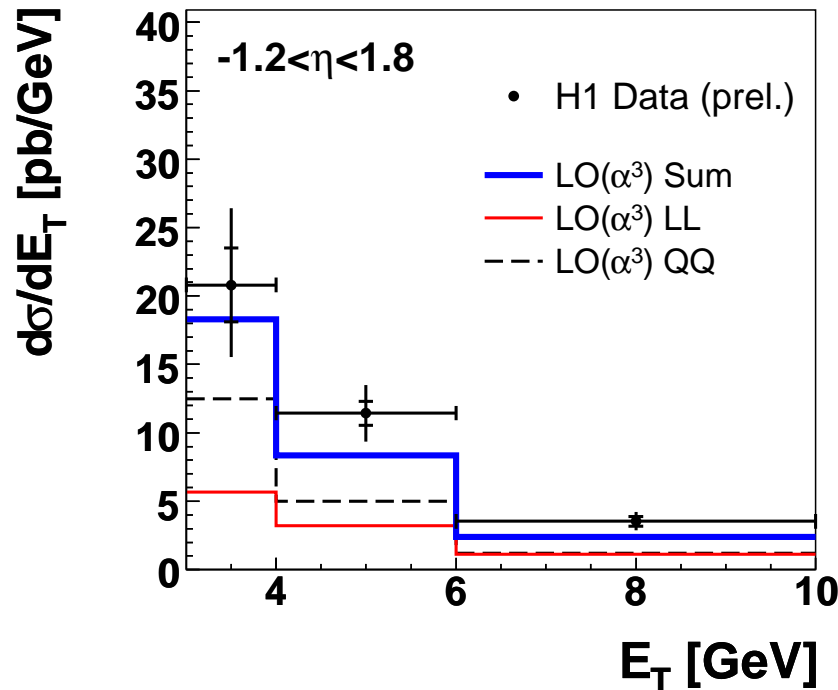


- Both generators need scaling to match total cross section  
PYTHIA: factor 2.3, HERWIG 2.6
- Backward region: radiation off the electron line dominates
- PYTHIA gives a better description of the  $\eta$  distribution





# Cross Sections and LO calculation

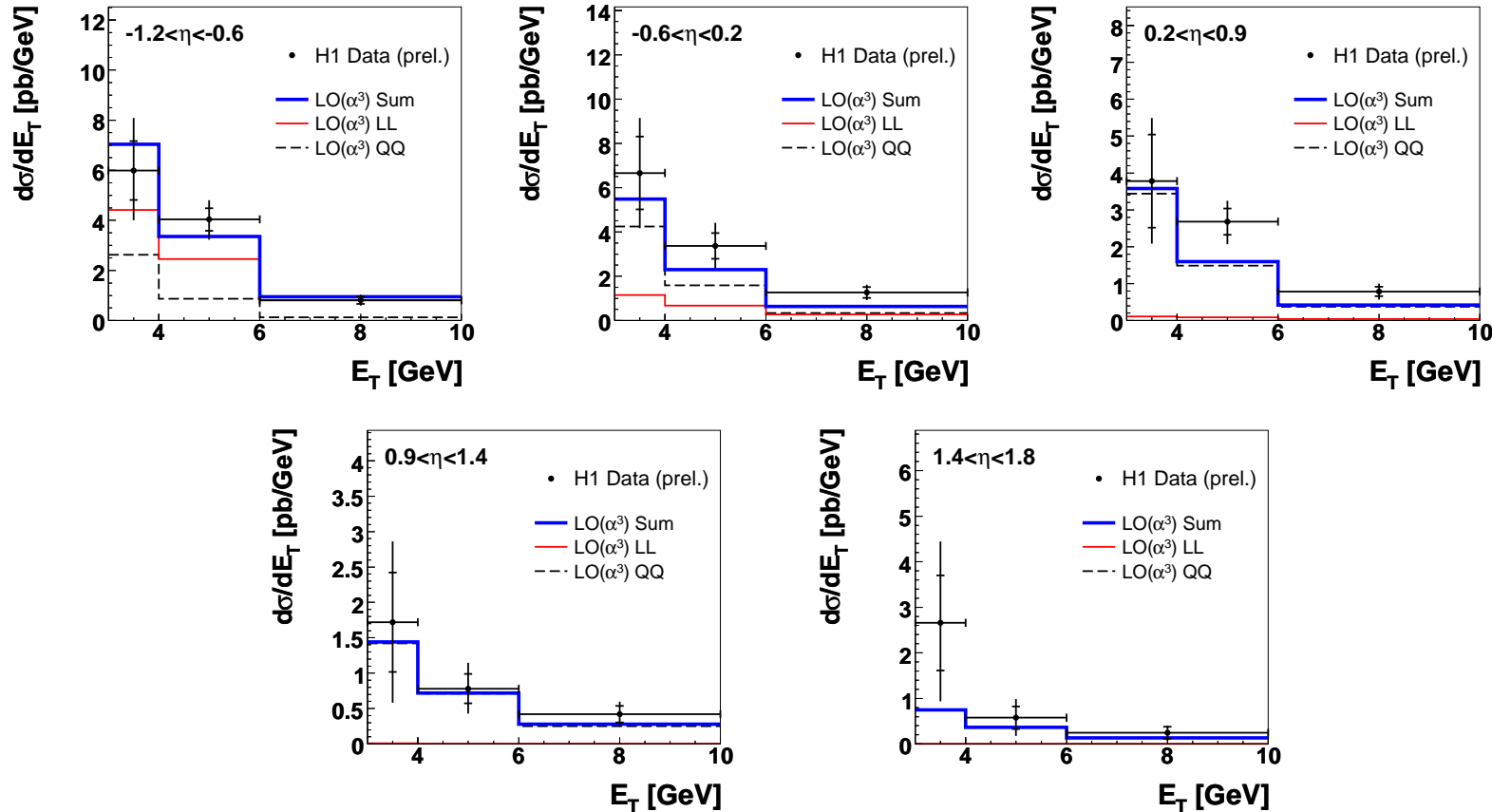


- LO calculation by Gehrmann et al. (hep-ph/0601073, hep-ph/0604030)
- Good description of data, normalization and shapes reproduced
- Data slightly higher
- Large  $\eta$ : QQ term dominates





# Cross Sections in $\eta$ -bins



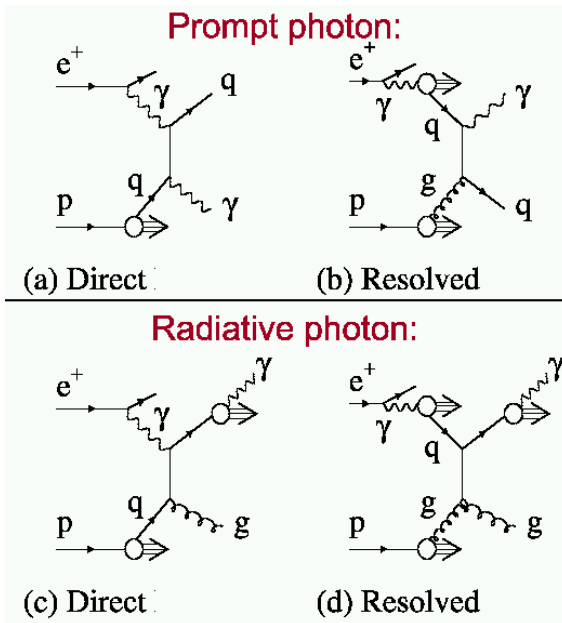
Bins in  $\eta$  correspond to wheels in calorimeter

LO calculation by Gehrmann et al. (hep-ph/0601073, hep-ph/0604030)





# Prompt photons plus jet in $\gamma p$



- Sensitivity to quark and gluon densities in proton and photon
- less corrections for hadronisation and fragmentation than with di-jets

- Photon plus jet  $\rightarrow x_y$
- theoretical predictions more reliable  
NLO calculation available
- Photoproduction: photon and jet well separated

## Theoretical Predictions

- KZ: M. Krawczyk and A. Zembrzuski (NLO with GRV)
- FGH: Fontanaz, Guillet and Heinrich (NLO with MRST01, AFG02)
- LZ: A. Lipatov and N. Zotov ( $k_t$  factorization approach)  
unintegrated quark gluon densities using Kimber-Martin-Ryskin prescription





# Event selection

Integrated luminosity:  $77.1 \text{ pb}^{-1}$

Kinematics:  $Q^2 < 1 \text{ GeV}^2$ ,  $0.2 \leq y_{jb} \leq 0.8$

Jets: 2 or more jets ( $K_t$  algorithm)

Photoncandidate  $E_{\text{EMC}}/E \geq 0.9$

$E_T/E_T^{\text{Photonjet}} > 0.9$  (Isolation)

$5 \leq E_t^\gamma \leq 16 \text{ GeV}$

$-0.7 \leq \eta^\gamma \leq 1.1$

no track

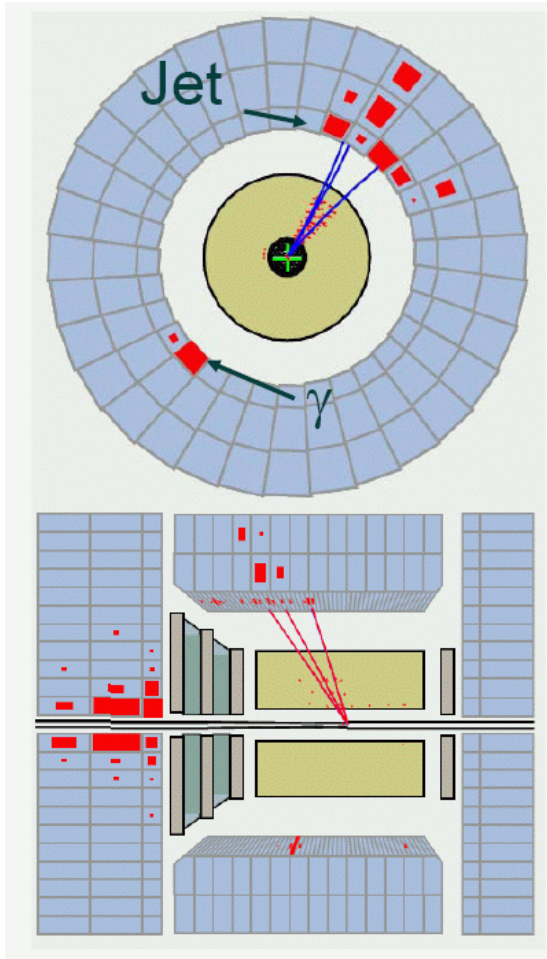
Associated jet:  $E_{\text{EMC}}/E \leq 0.9$

$6 \leq E_t^{\text{Jet}} \leq 17 \text{ GeV}$

$-1.6 \leq \eta^{\text{Jet}} \leq 2.4$

Separation photon-neutral mesons with preshower detector

Monte Carlo: PYTHIA6.3, HERWIG 6.5



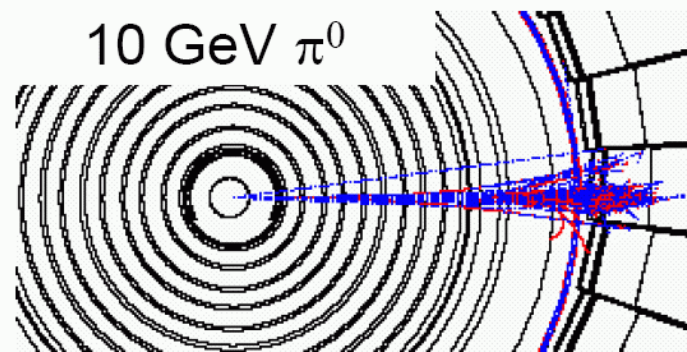
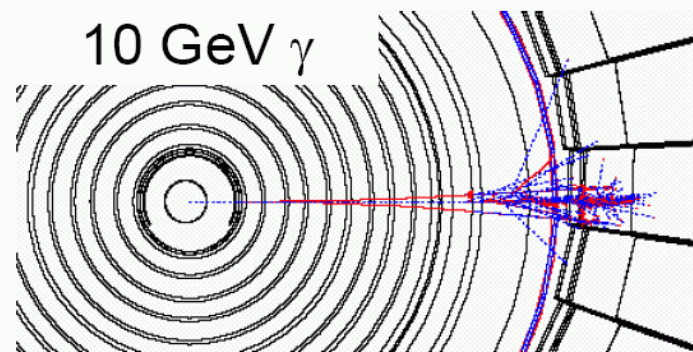
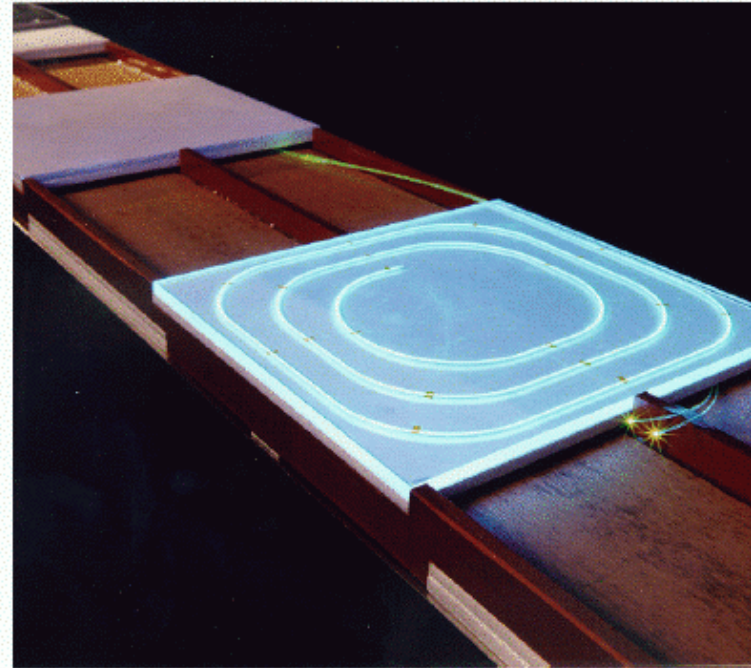


# Barrel Preshower detector

Scintillator tiles in front of calorimeter

Energy in BCAL presampler is proportional to number of photons

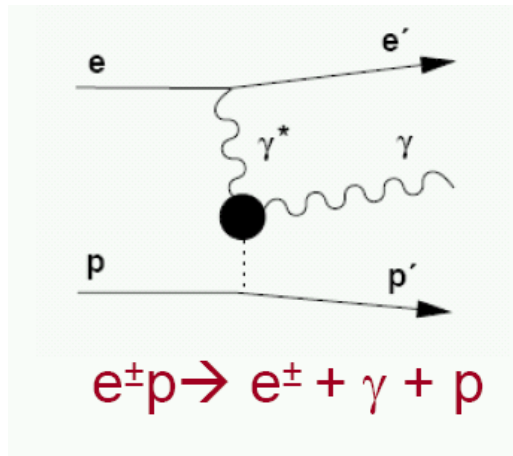
→ Allows separation also for high energies



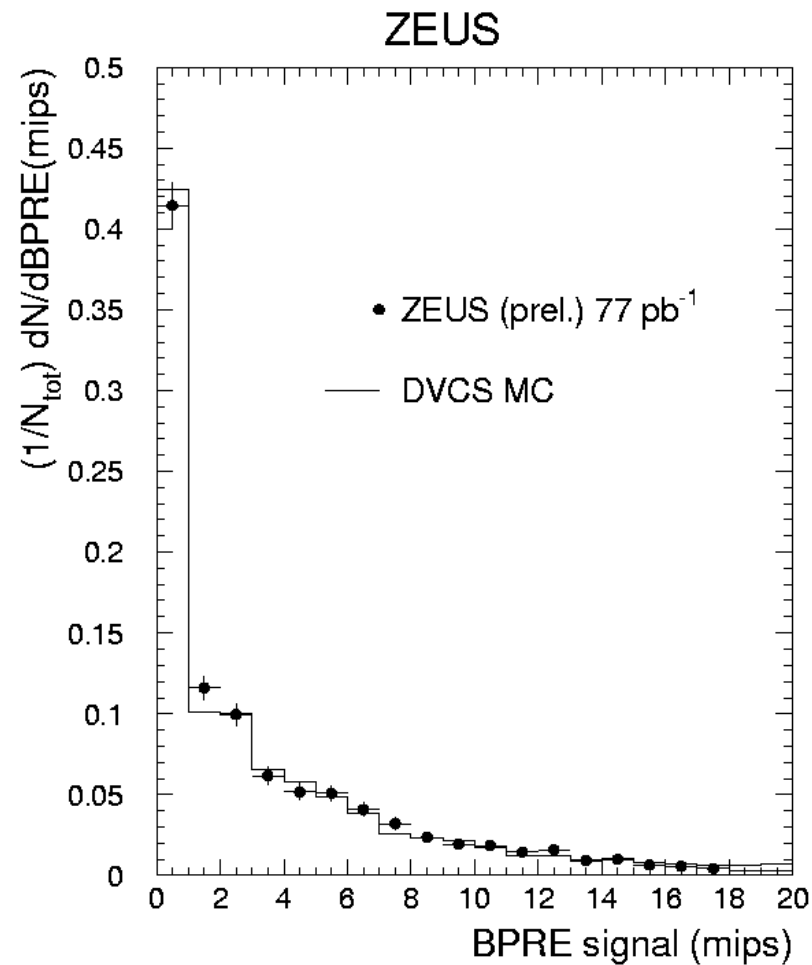


# Preshower signal: DVCS sample

Study with DVCS sample:  
events with one track  
two isolated elmgn. clusters



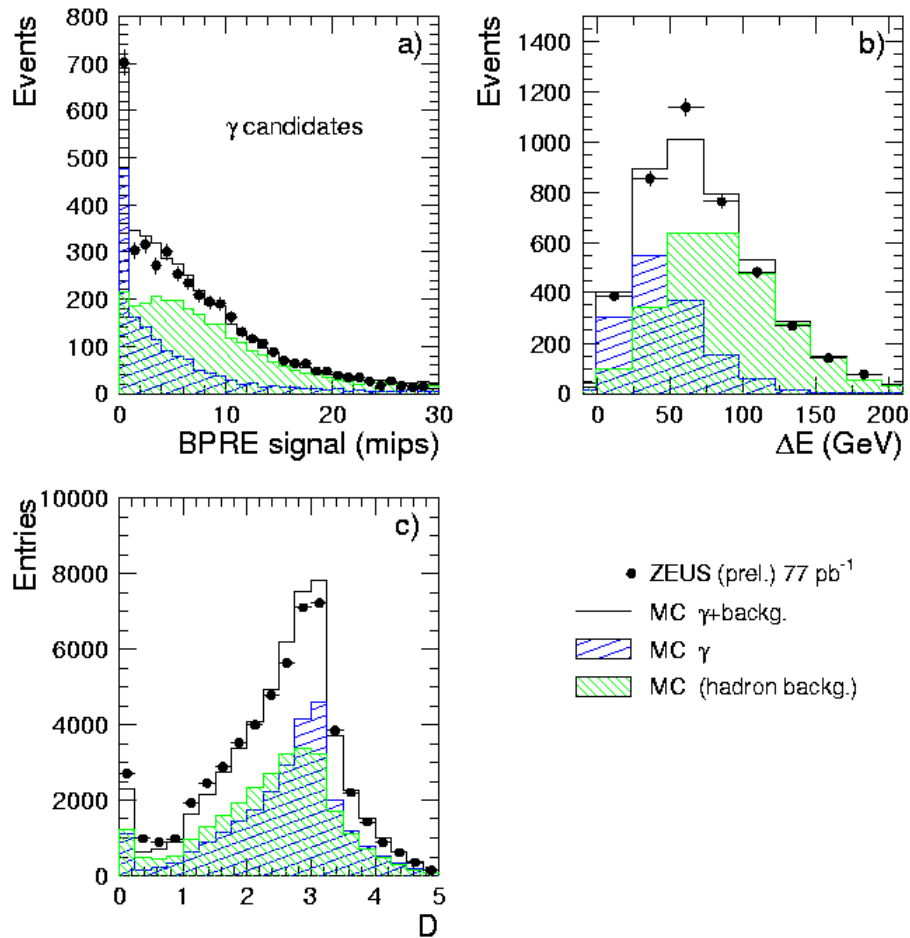
Agreement between data and MC  
with additional dead material





# Extraction of photon signal

## ZEUS



Fit sum of prompt  $\gamma$  and background MC to BPRE signal in bins of  $E_t$ ,  $\eta$  of photon and jet and  $x_\gamma$

Control distributions

- $\Delta E = E_{\text{Total}} - E_{(\gamma+\text{Jet})}$
- D: Distance in  $\eta\phi$  from Photon to energy flow objects

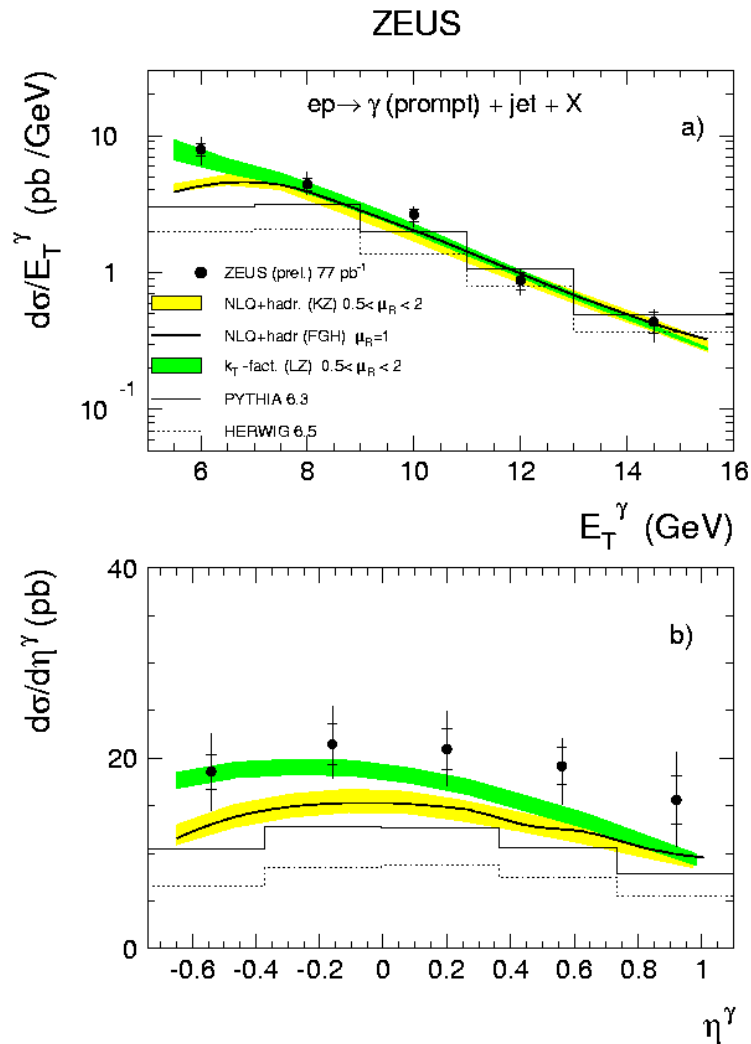
well described by signal+background MC







# Cross sections: Photon $E_t^\gamma$ , $\eta^\gamma$



HERWIG and PYTHIA :  
significantly lower at low  $E_t^\gamma$

KZ and FGH:  
low in lowest  $E_t^\gamma$  bin

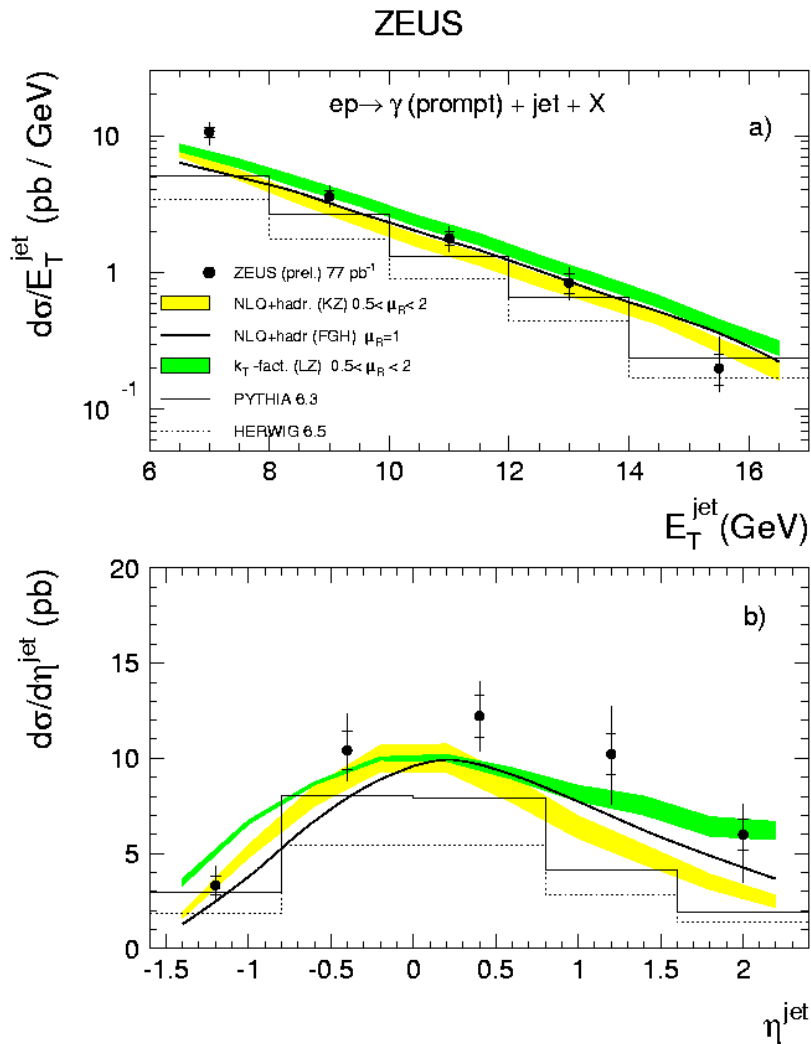
LZ describes shapes and normalization

$E_T > 10$  GeV: new measurement at HERA  
not accessible with shower shape analysis!  
H1 measurement  $E_T \leq 10$  GeV (hep-ex/0407018)





# Cross sections: Jets $E_t^{Jet}$ , $\eta^{Jet}$



HERWIG and PYTHIA :

forward jets not well described

measured cross section underestimated

Theoretical predictions describe the data

forward region best described by LZ



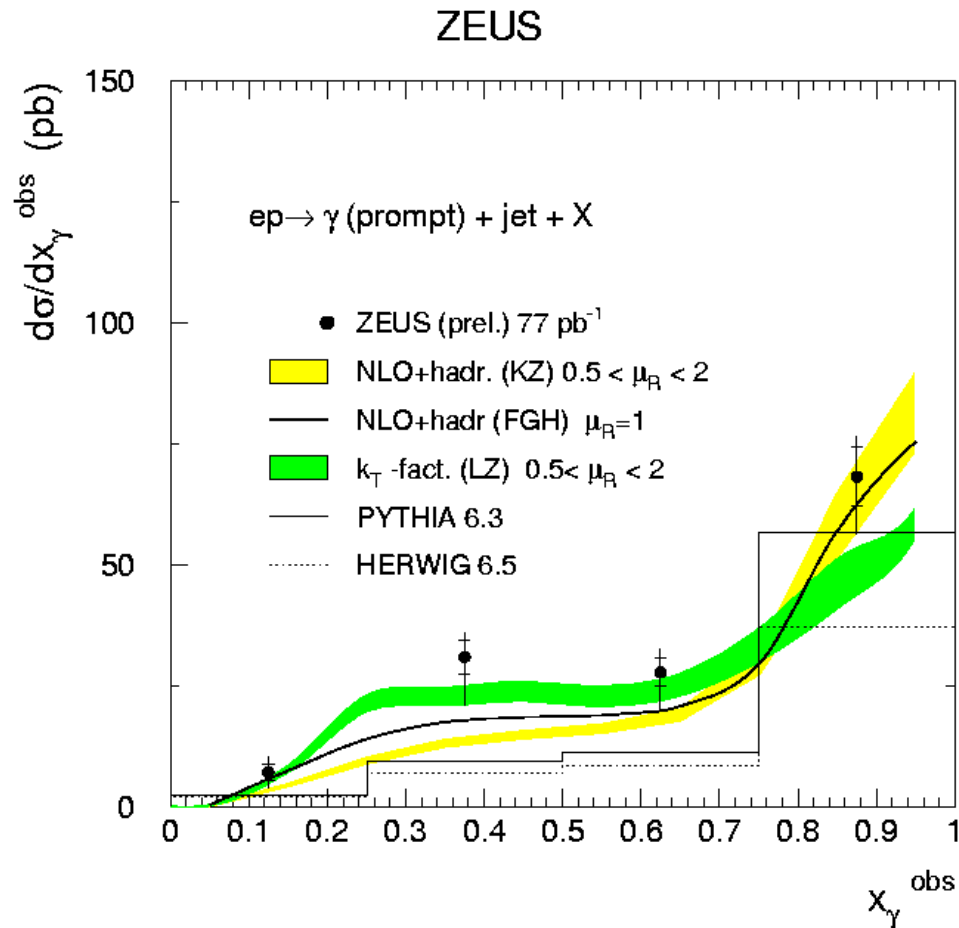


# Cross sections: $x_\gamma$

NLO calculations (KZ FGH)  
describe direct component

LZ describe resolved component

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





## Summary: prompt photons in $\gamma p$

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Prompt Photon plus Jet cross section in photoproduction

- new technique for photon-neutral meson separation, based on the signal in the preshower detector
- PYTHIA and HERWIG have problems describing the data in shape and are low in normalization
- Theoretical calculations describe the data reasonably





# Summary: prompt photons in DIS

## Inclusive Prompt Photons in DIS

- new analysis, extending the phasespace of the previous measurement by ZEUS (he-ex/0402019) significantly ( $E_t^\gamma$ ,  $\eta^\gamma$ ,  $Q^2$ )  
10x higher cross section
- Data well described by new LO( $\alpha^3$ ) calculation (Gehrmann et al)
- PYTHIA and HERWIG plus radiation off the electron line describe the shape but are low in normalization

Outlook: more statistics with HERA II (expected: 220 pb<sup>-1</sup>)

Photon plus jet(s)

Quark-to-photon fragmentation function at lower z





# H1-ZEUS: Photon + jet in $\gamma p$



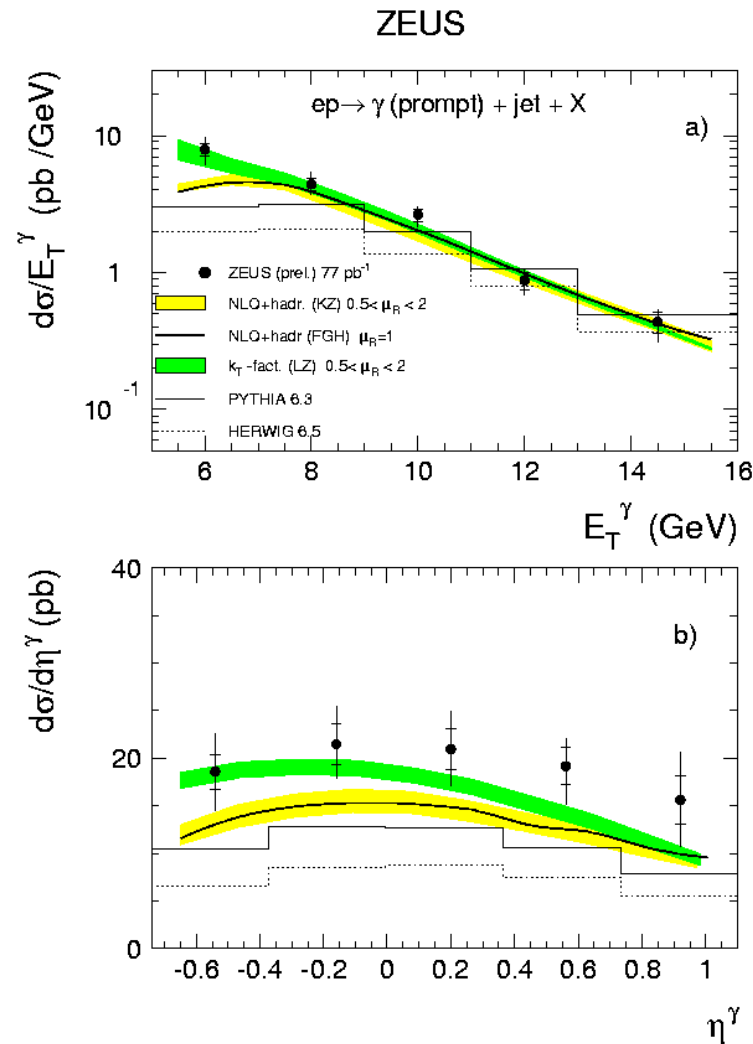
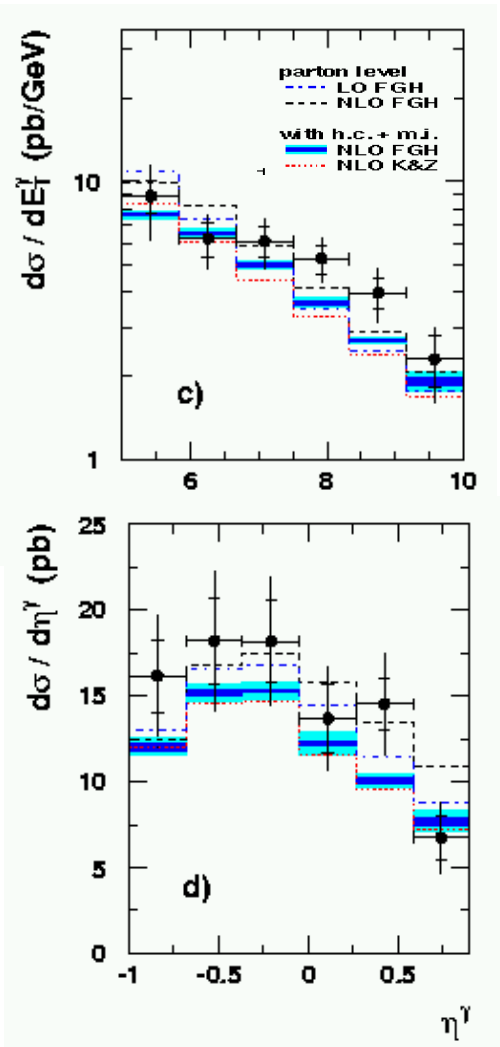
Published in 04:

hep-ex/0407018

note:

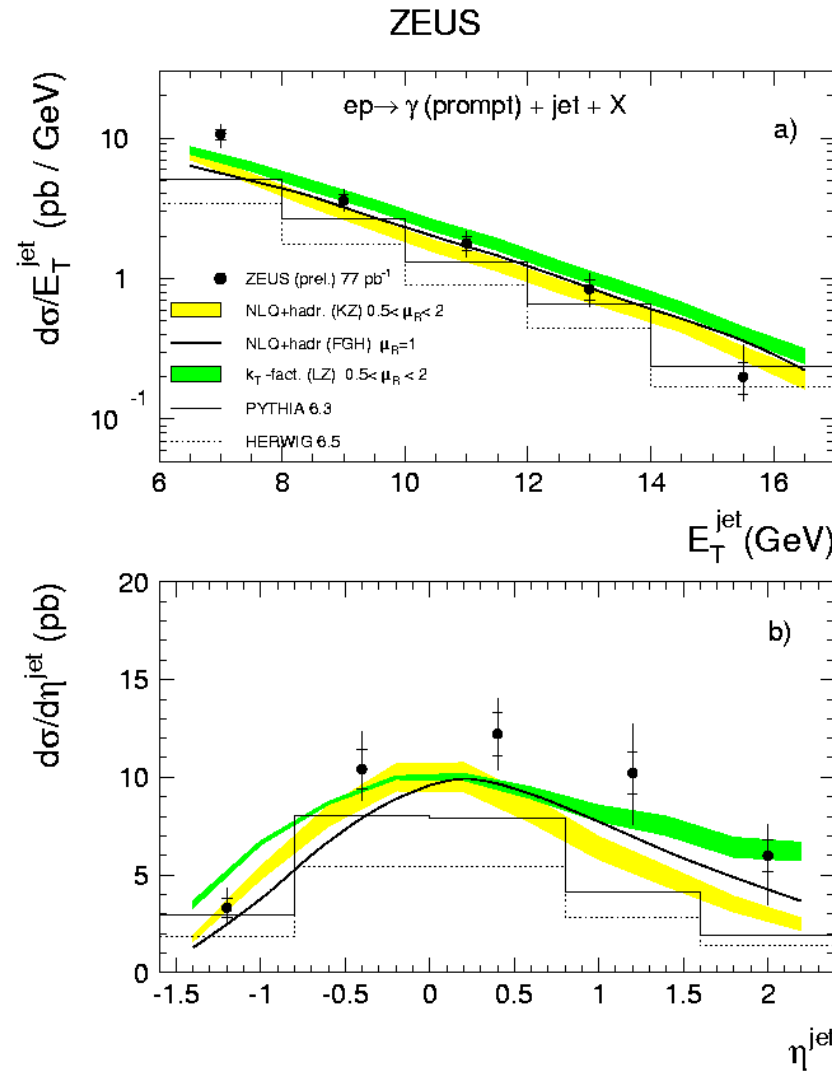
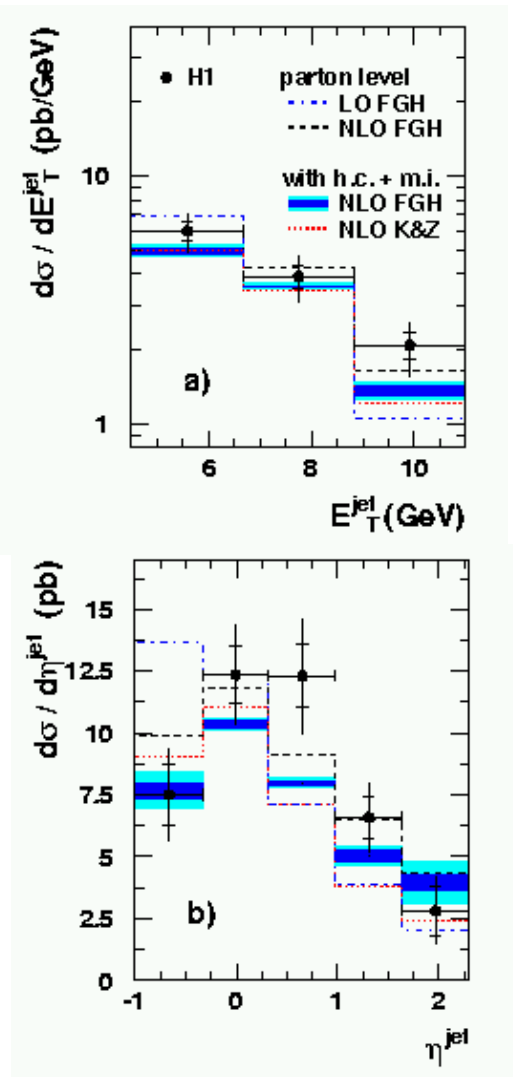
different range

$E_T^\gamma$ ,  $\eta^\gamma$  and  $y!$





# H1-ZEUS : Photon + jet in $\gamma p$



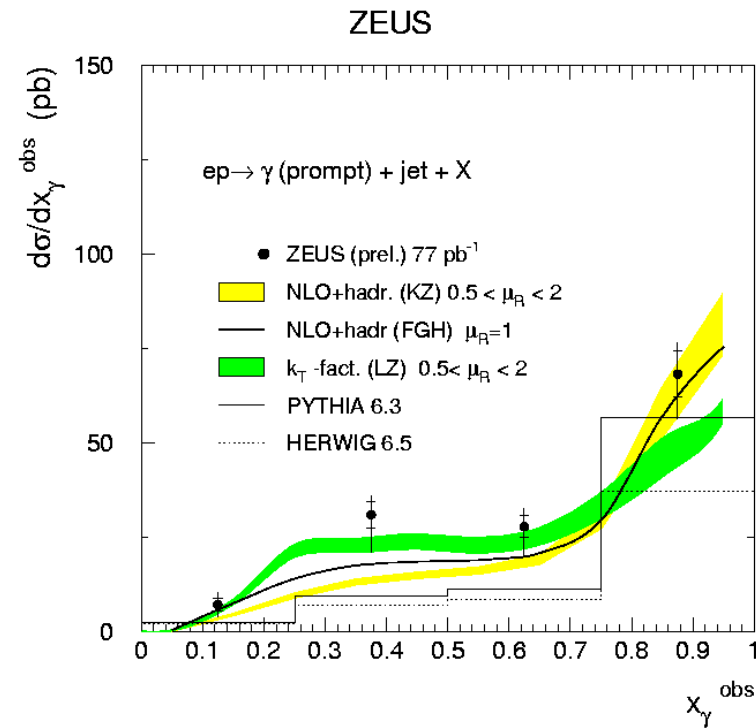
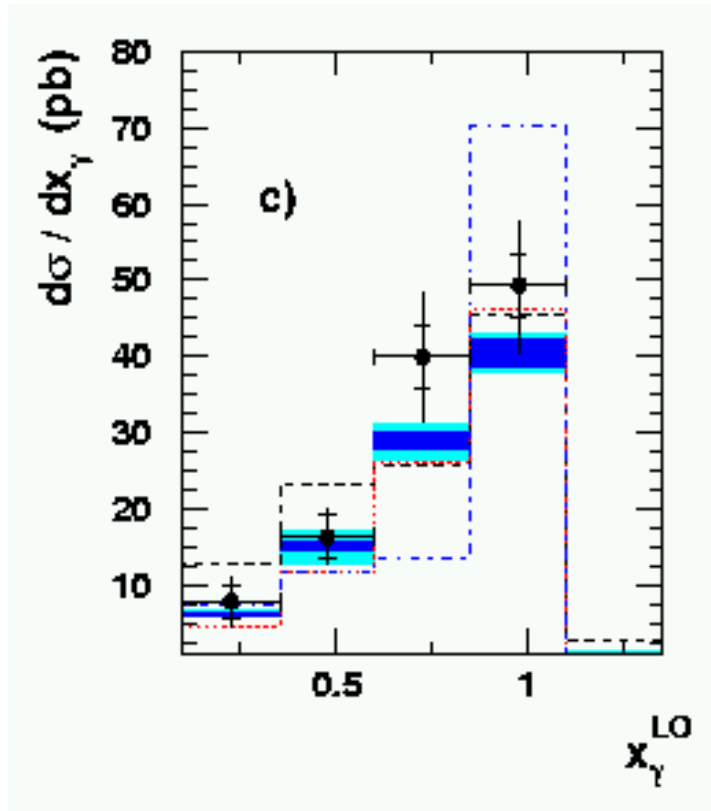


# H1-ZEUS: Photon + jet in $\gamma p$



H1 Published in 04: hep-ex/0407018

Note different kinematical regions







# H1 and ZEUS: prompt $\gamma$ in DIS



ZEUS published in 04:

hep-ex/0402019

$E_t^\gamma$

ZEUS: 5-10 GeV

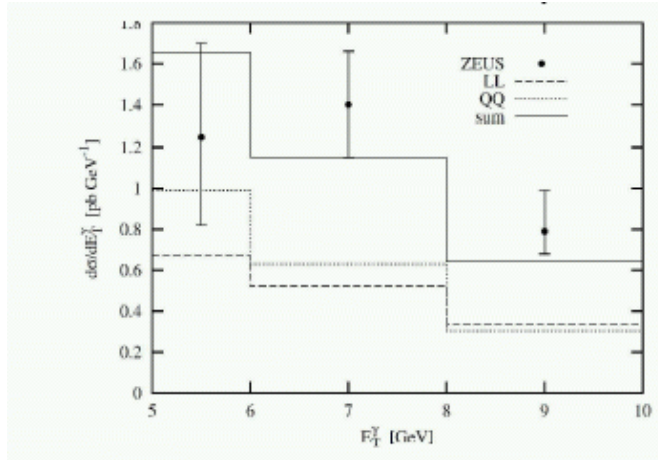
H1: 3-10 GeV

$\eta^\gamma$

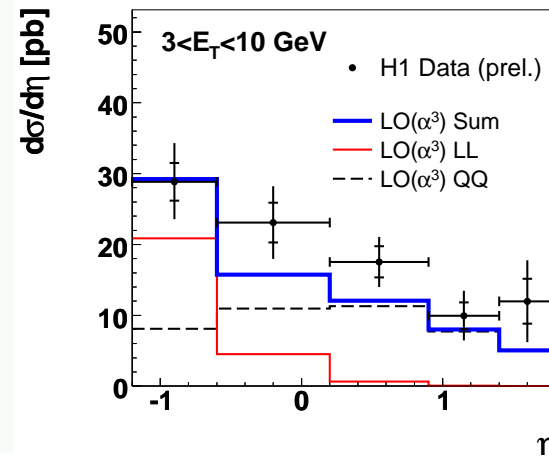
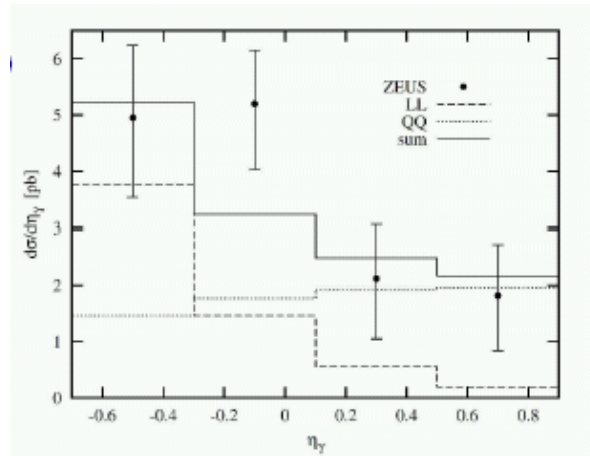
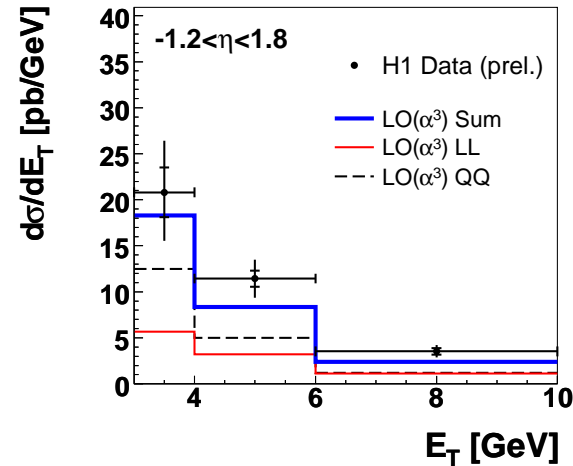
ZEUS -0.7-0.9

H1 -1.2-1.8

ZEUS:  $Q^2 > 35 \text{ GeV}^2$



H1:  $Q^2 > 4 \text{ GeV}^2$





# H1 and ZEUS: prompt $\gamma$ in DIS



ZEUS published in 04:

hep-ex/0402019

$E_t^\gamma$

ZEUS: 5-10 GeV

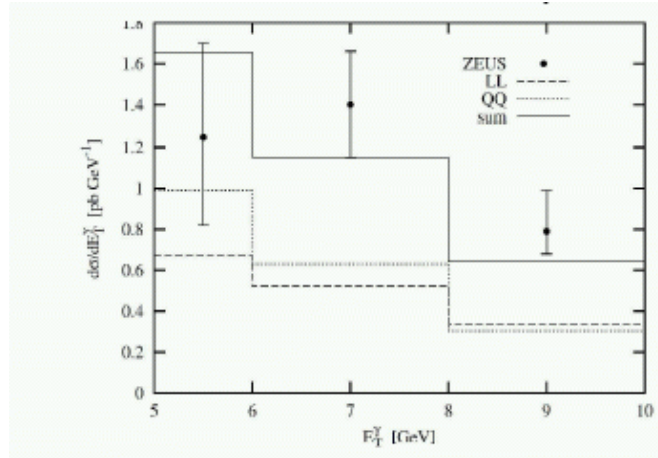
H1: 3-10 GeV

$\eta^\gamma$

ZEUS -0.5-0.8

H1 -1.2-1.8

ZEUS:  $Q^2 > 35 \text{ GeV}^2$



H1:  $Q^2 > 4 \text{ GeV}^2$

