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On behalf of H1 and ZEUS Collaborations

Deeply virtual Compton scattering and prompt photon production at ZEUS and H1 experiments

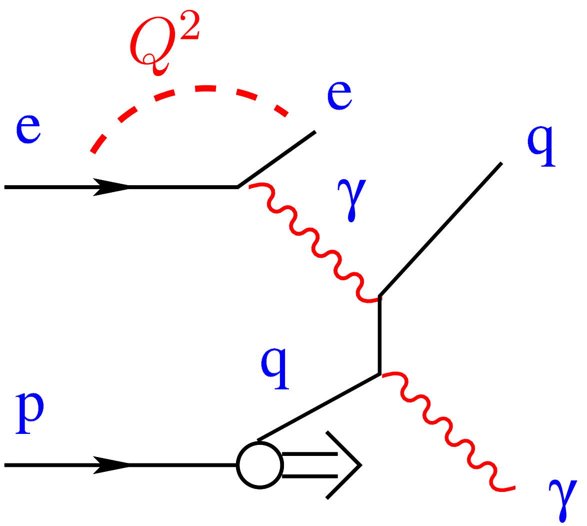
International Conference on the Structure and Interactions of the Photon

Warsaw, Poland, 31 August - 4 September, 2005

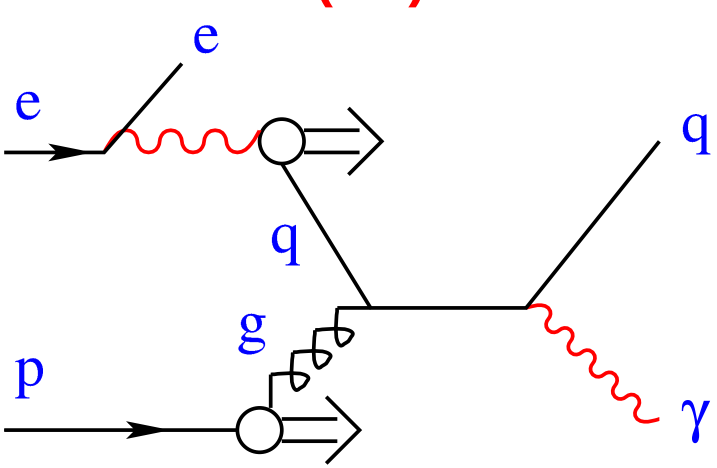
Prompt Photon Production at HERA

$$e + p \longrightarrow e + \gamma + X$$

DIRECT (LO)



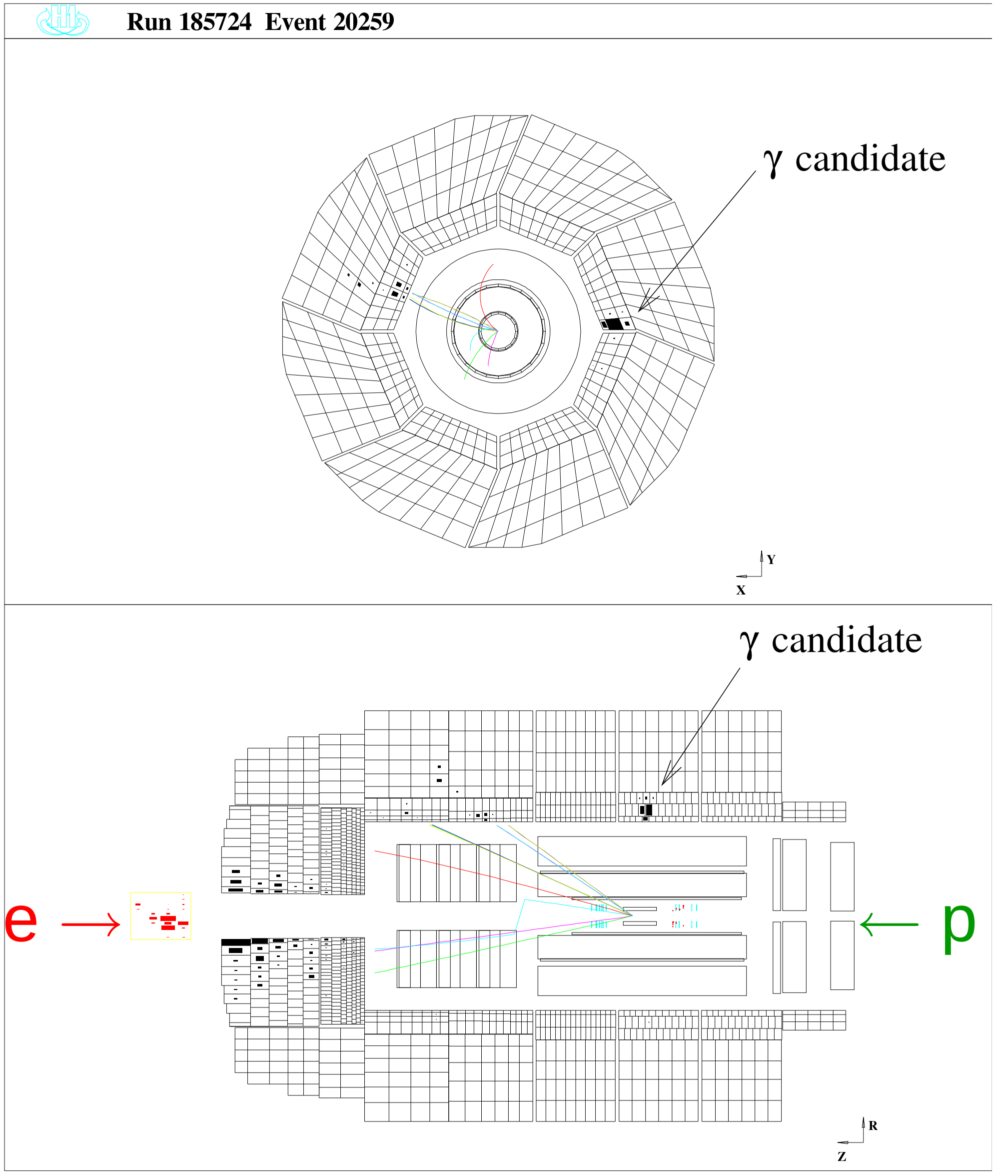
RESOLVED (LO)



- Point like coupling to quark
  - $\longrightarrow$ Direct probe of hard process
  - $\longrightarrow$ Test of QCD
- Small (No) hadronization effects (In contrast to jet production)
- ($\sim$) Sensitivity to proton and photon PDFs.
- Two signatures:
  - Inclusive prompt photon
  - Prompt photon + jet

Prompt γ - Data Selection

Photoproduction: H1 + ZEUS $Q^2 < 1\ \mathrm{GeV}^2$ **DIS: ZEUS** $Q^2 > 35\ \mathrm{GeV}^2$

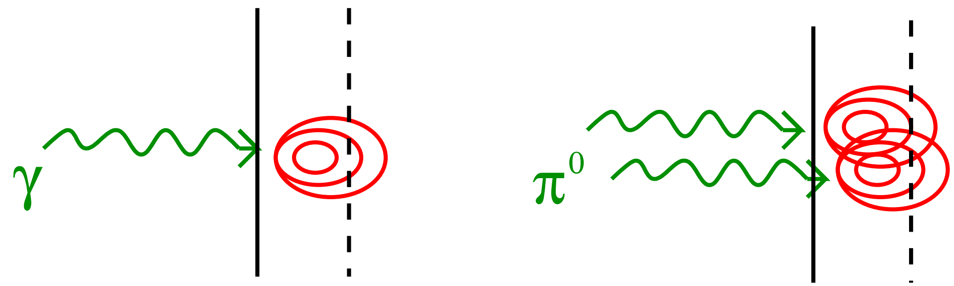


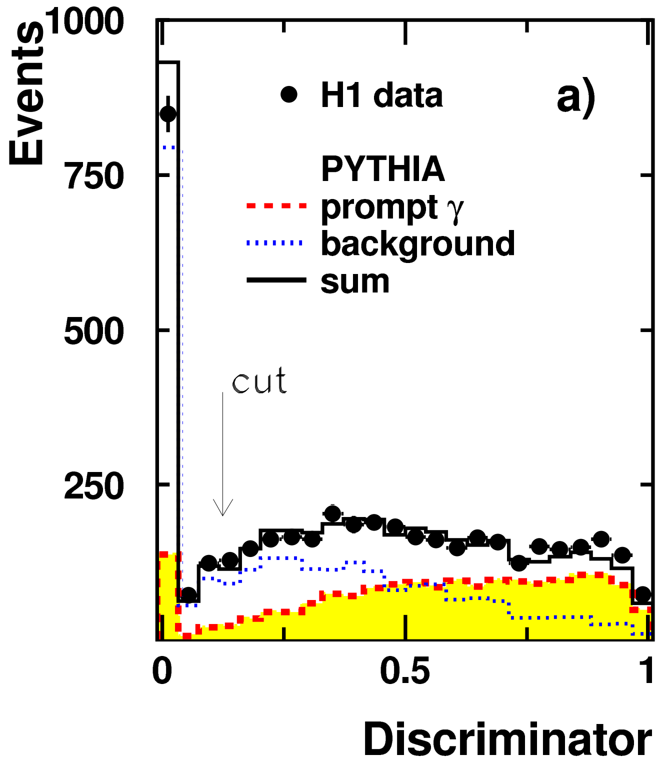
- Isolated photon candidate:
  - $E_T^\gamma > 5$ GeV
  - -1 (-0.7) < η^γ <0.9 — H1 (ZEUS)
  - no associated track
  - cone $R = \sqrt{\Delta\Phi^2 + \Delta\eta^2} = 1$ with $E_T^\gamma / E_T^{\mathrm{cone}} > 0.9$
- At least 2 tracks:
  $\rightarrow$ remove DVCS+Bethe-Heitler
  $\rightarrow$ reduce fragmentation proc.
- For prompt γ + Jet sample:
  - $E_T^{\mathrm{jet}} > 4.5\ (6)$ GeV
  - -1 < η^{jet} < 2.3 H1; -1.5 < η^{jet} < 1.8 ZEUS

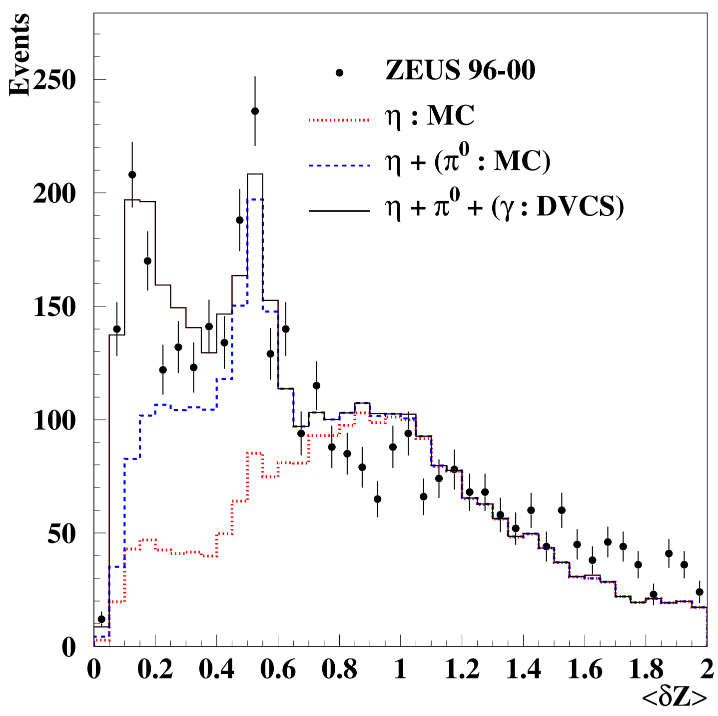
Prompt γ - Signal Extraction

Experimental difficulty: photons from hadronic background (π^0, ...)

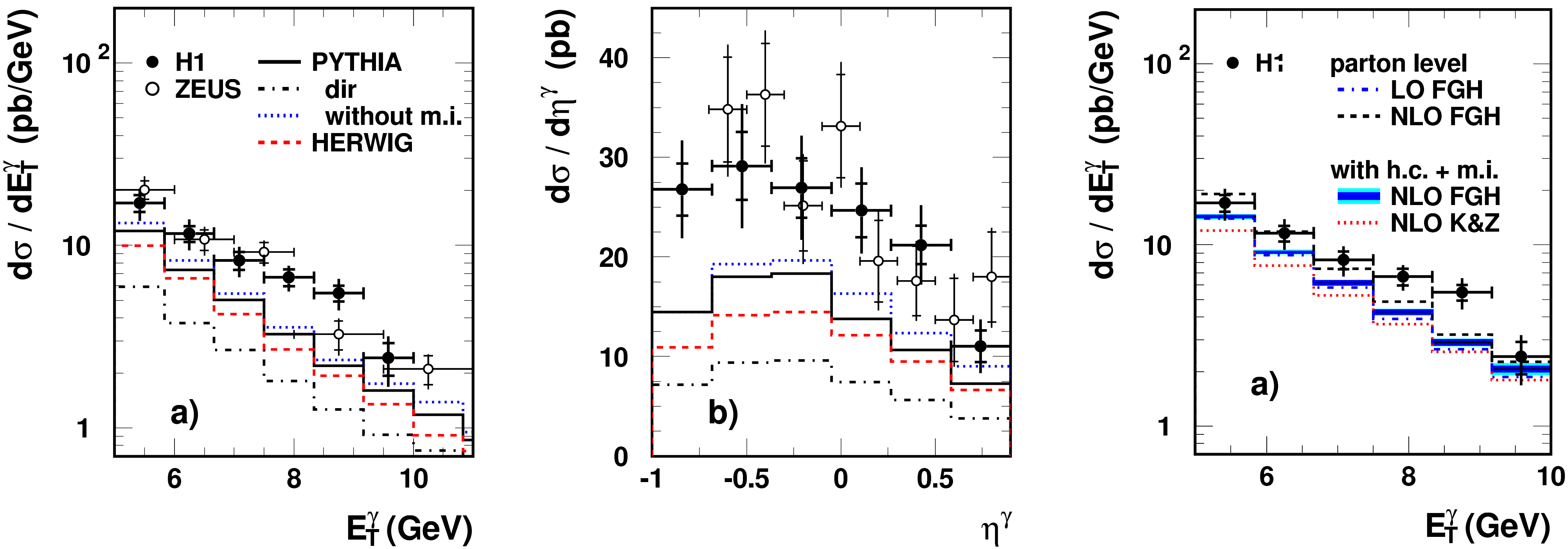
$\longrightarrow$ Signal extraction on basis of shower shape in calorimeters





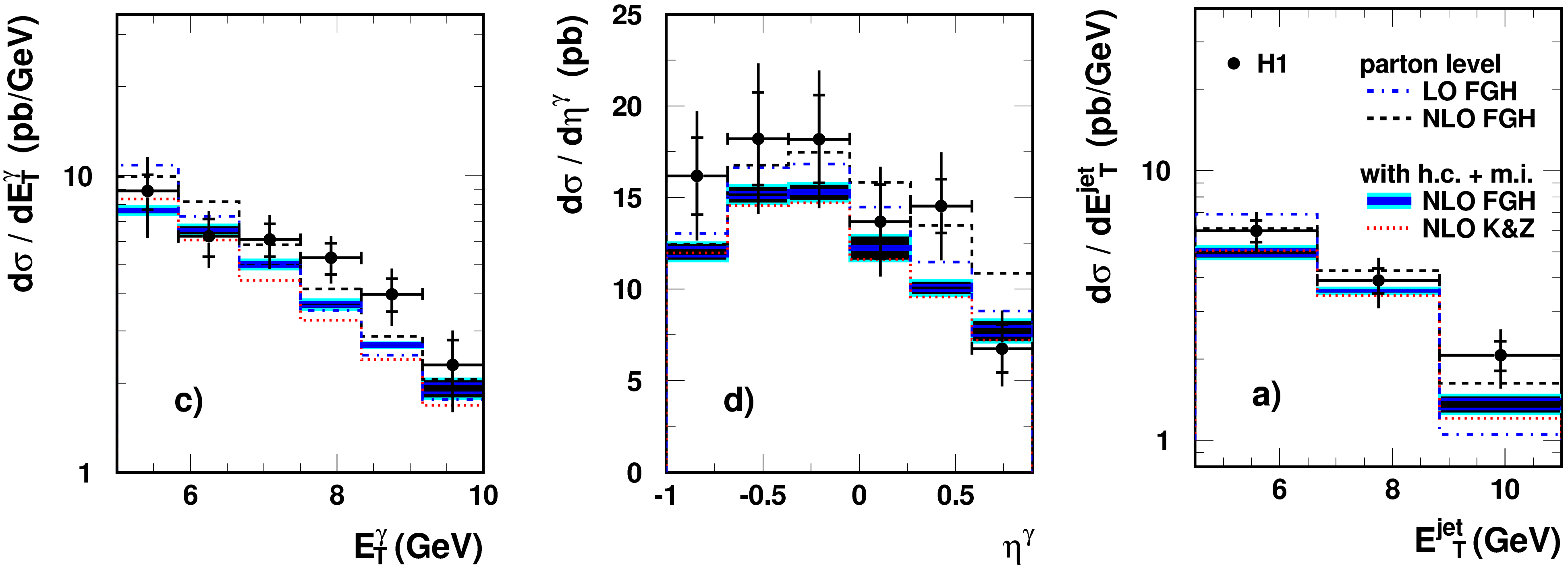


Prompt γ - Inclusive Photoproduction



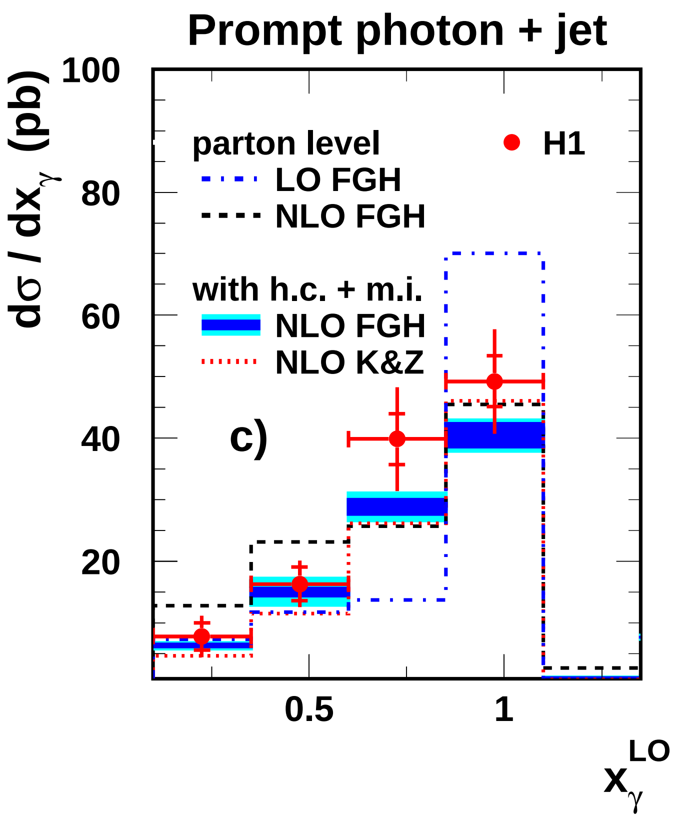
- Agreement between H1 and ZEUS
- MC: **PYTHIA (HERWIG):** shape OK but 30 (40) % too low
  Multiple interactions and hadronization corr. reduce σ
  (cf Isolation cut)
- NLO pQCD: **Fontannaz, Guillet & Heinrich / Krawczyk & Zembrzuski**
  $\longrightarrow$ good shape description but too low by 30 %

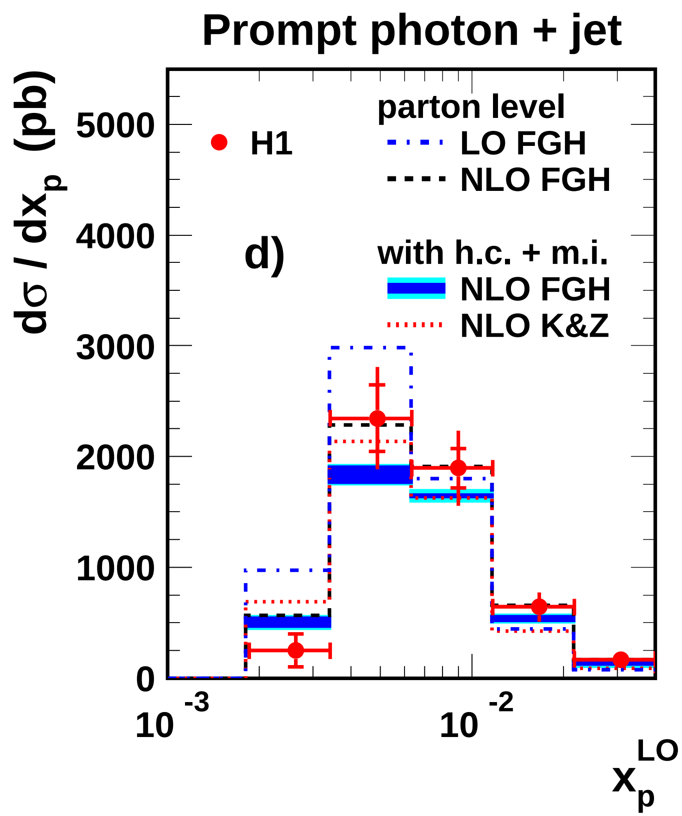
Prompt γ + Jet - Photoproduction



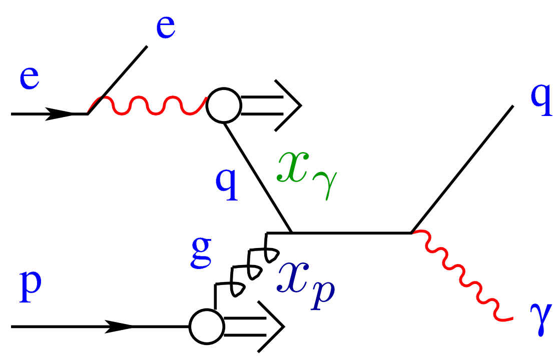
- NLO pQCD:
  - Good description of shapes and normalisation
  - Jet requirement result in a better description and smaller LO/NLO difference than in inclusive case
- Multiple interactions and hadronizaton corr. Smaller effect than in inclusive case

Prompt γ + Jet - Photoproduction





x_γ Fractional part of incoming photon energy taking part in interaction

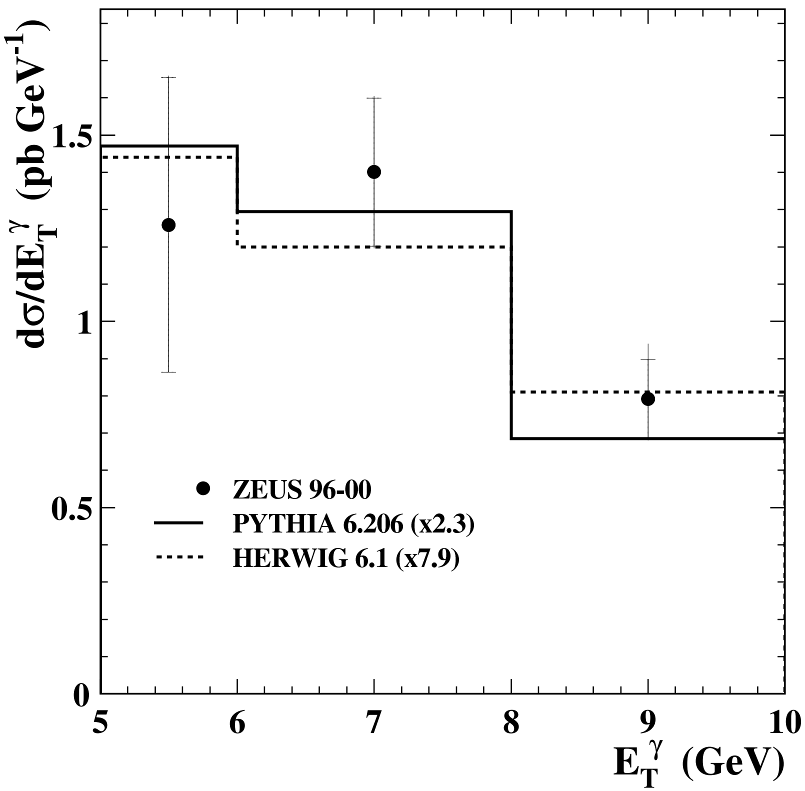


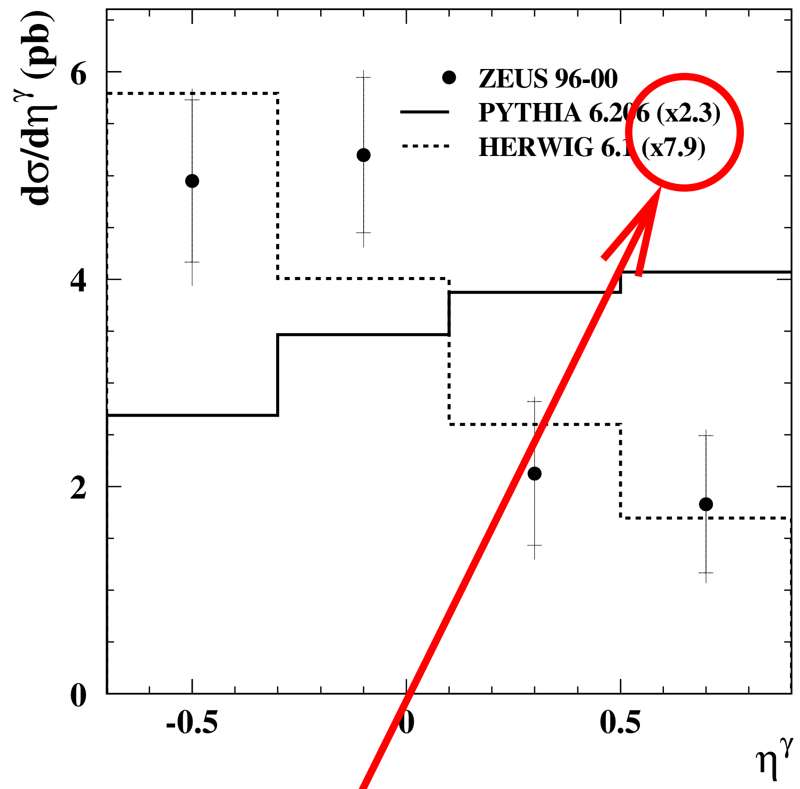
x_p Fraction of proton's momentum involved in hard scaterring

- NLO pQCD + Multiple interactions describe the data
- MI and h.c. matter for resolved γ contribution ($x_\gamma < 0.5$)

Prompt γ - Inclusive DIS

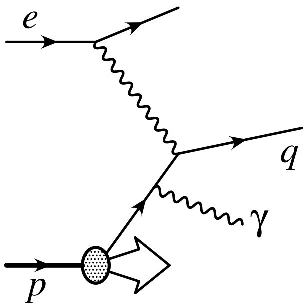
$Q^2 > 35\ \mathrm{GeV}^2$



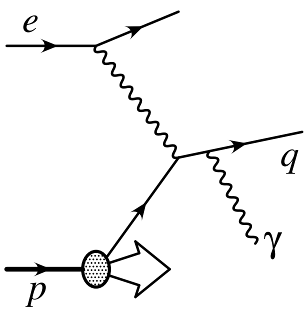


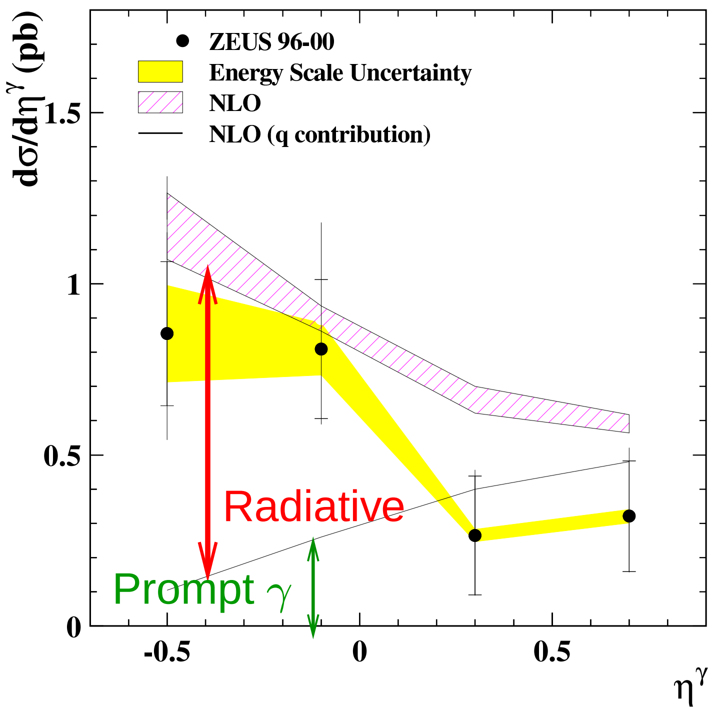
- PYTHIA (HERWIG): factor 2 (8) too low
- E_T^γ well described by PYTHIA and PYTHIA
- Poor description of η^γ by PYTHIA
- Wide angle QED bremsstrahlung not included in MCs

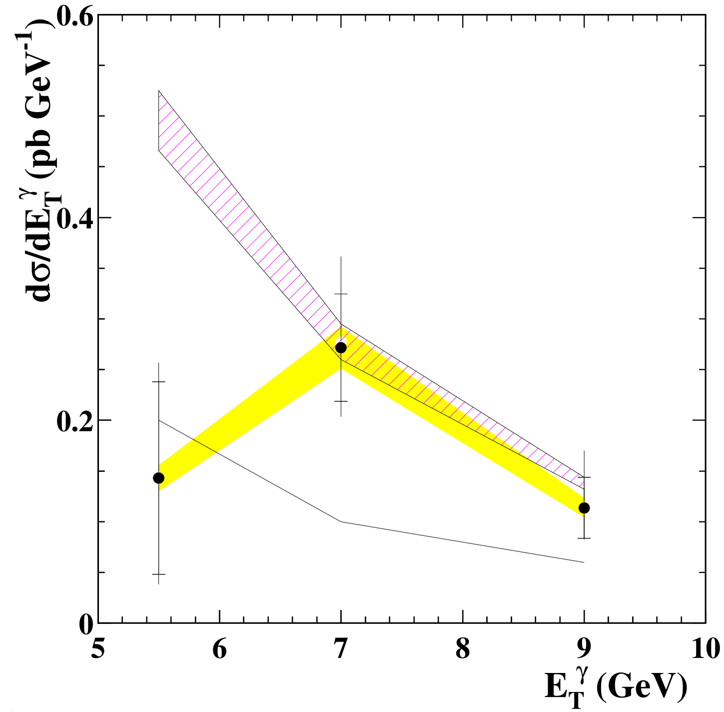
Prompt γ + Jet - DIS

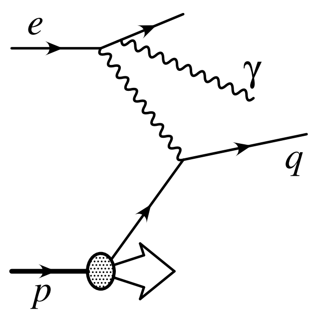


Prompt γ

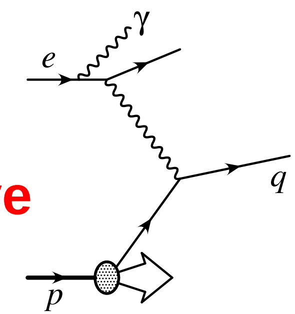








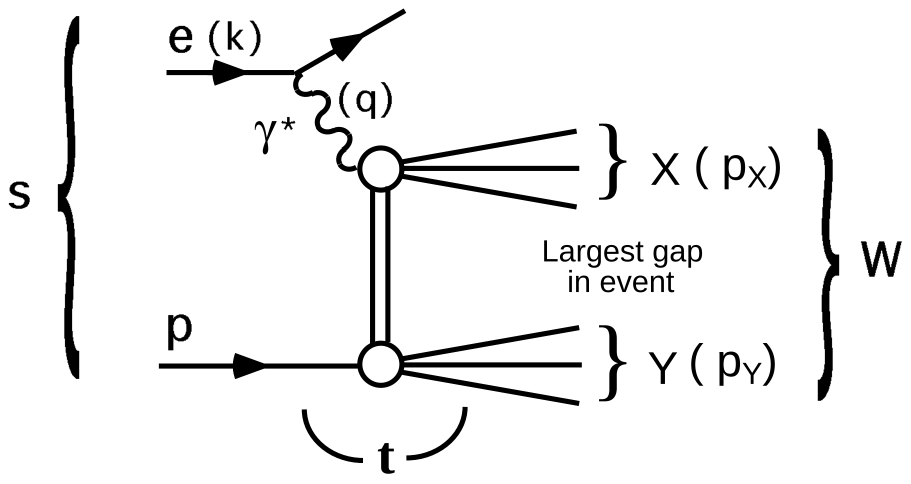
Radiative



- **NLO pQCD** (Kramer-Spiesberger): provides good description except maybe at low E_T^γ (but large errors)
- Large contribution from wide angle bremsstrahlung needed

Deeply Virtual Compton Scattering

$$e + p \longrightarrow e + \gamma + p$$



Diffraction: $e + p \rightarrow e + X + Y$

- Factorization theorem:

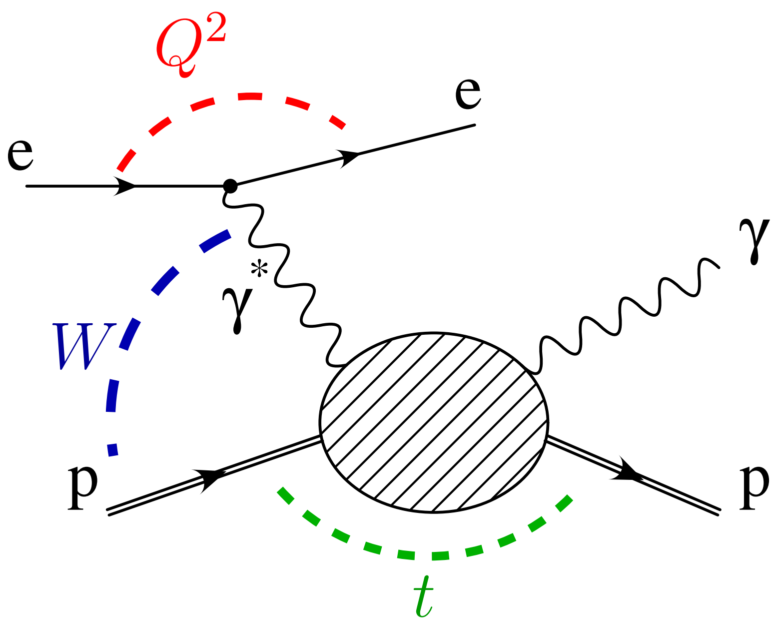
  $\longrightarrow$ First Diffractive process fully calculable in QCD

- No VM wave function uncertainty

- Access to Generalized Parton Distributions (GPDs)

Deeply Virtual Compton Scattering

$$\mathrm{e + p \longrightarrow e + \gamma + p}$$



- Factorization theorem:
  $\longrightarrow$ First Diffractive process fully calculable in QCD
- No VM wave function uncertainty
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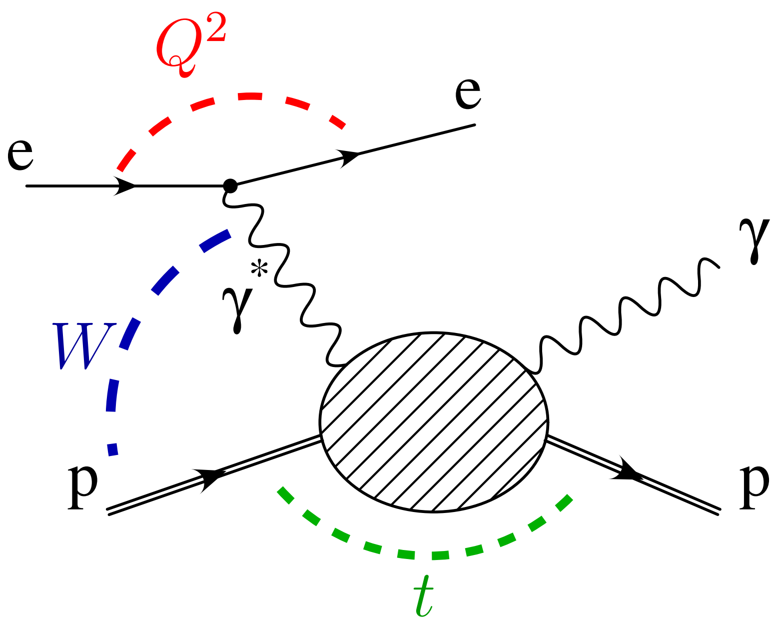
Deeply Virtual Compton Scattering

$$\mathrm{e} + \mathrm{p} \longrightarrow \mathrm{e} + \gamma + \mathrm{p}$$



- Factorization theorem:

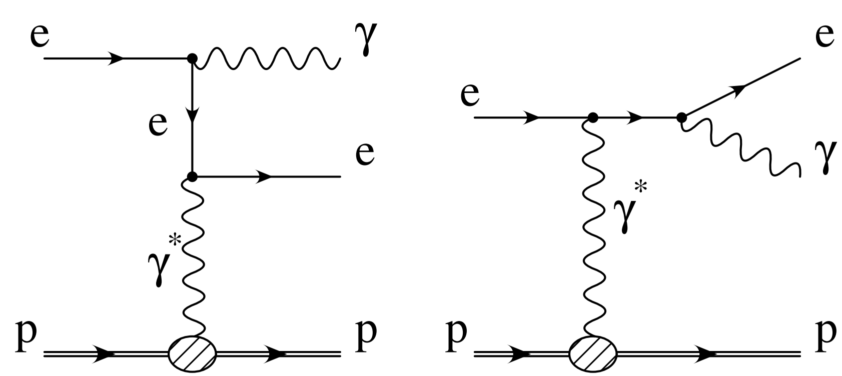
  $\longrightarrow$ First Diffractive process fully calculable in QCD

- No VM wave function uncertainty

- Access to Generalized Parton Distributions (GPDs)

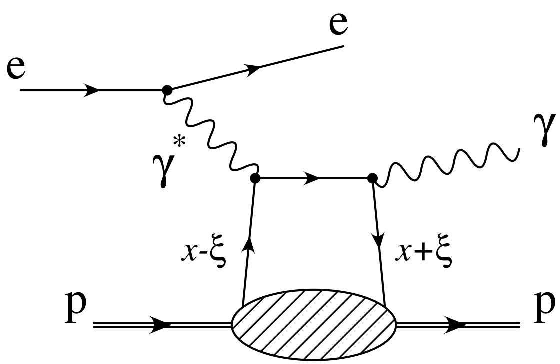
- Interference with Bethe-Heitler which is a pure QED process.

  ($\longrightarrow$ Access to Amplitudes in Asymmetries)

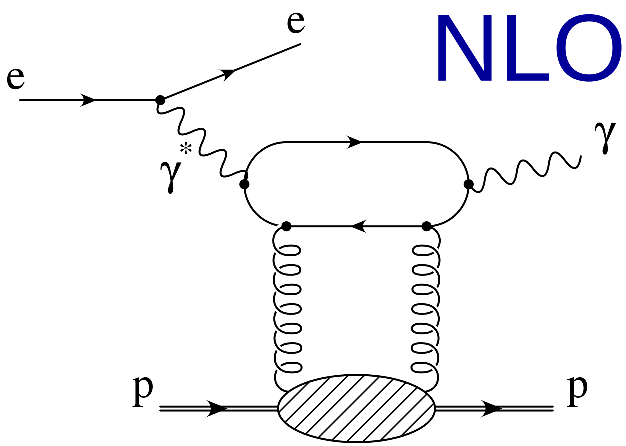


DVCS - QCD predictions

LO



NLO



ξ - “Skewedness", i.e. momemtum difference between emitted and absorbed parton

$\longrightarrow$ GPDs: $H^{q,g}(x,\xi,t) \xrightarrow[t\to 0]{\xi\to 0} q(x), g(x)$

$\tilde{H}^{q,g}(x,\xi,t) \xrightarrow[t\to 0]{\xi\to 0} \Delta q(x), \Delta g(x)$

+ E, $\tilde{E}$: no PDF equivalent

GPDs encodes info about transverse motion of partons and about their correlations

At low x, DVCS is mainly sensitive to $H^g(x,\xi,t)$

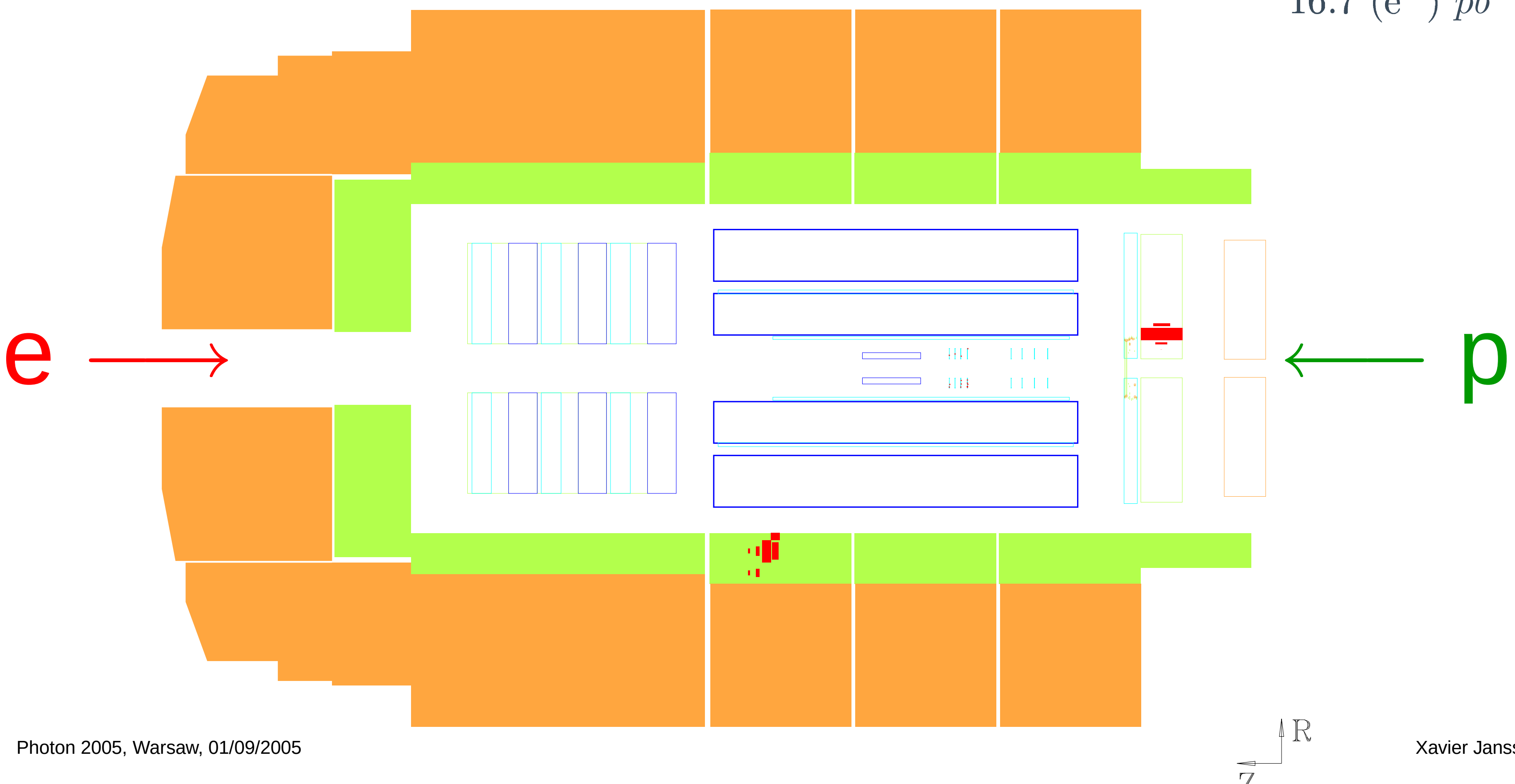
NLO leading twist calcl. by A. Freund and M. McDermott
Eur. Phys. J. C23 (2002) 651

DVCS - Data Selection

γ sample

DVCS + Bethe-Heitler

	H1	ZEUS
$E_1 >$	15 GeV	10 GeV
$p_{T_2} >$	1 GeV	
$E_2 >$		3 GeV
$E_3 <$	0.5 GeV	0.2 GeV
elast.	no track, Fwd	no track
Lumi	46.5 pb^{-1} (e^+)	95 (e^+) pb^{-1}
		16.7 (e^-) pb^{-1}

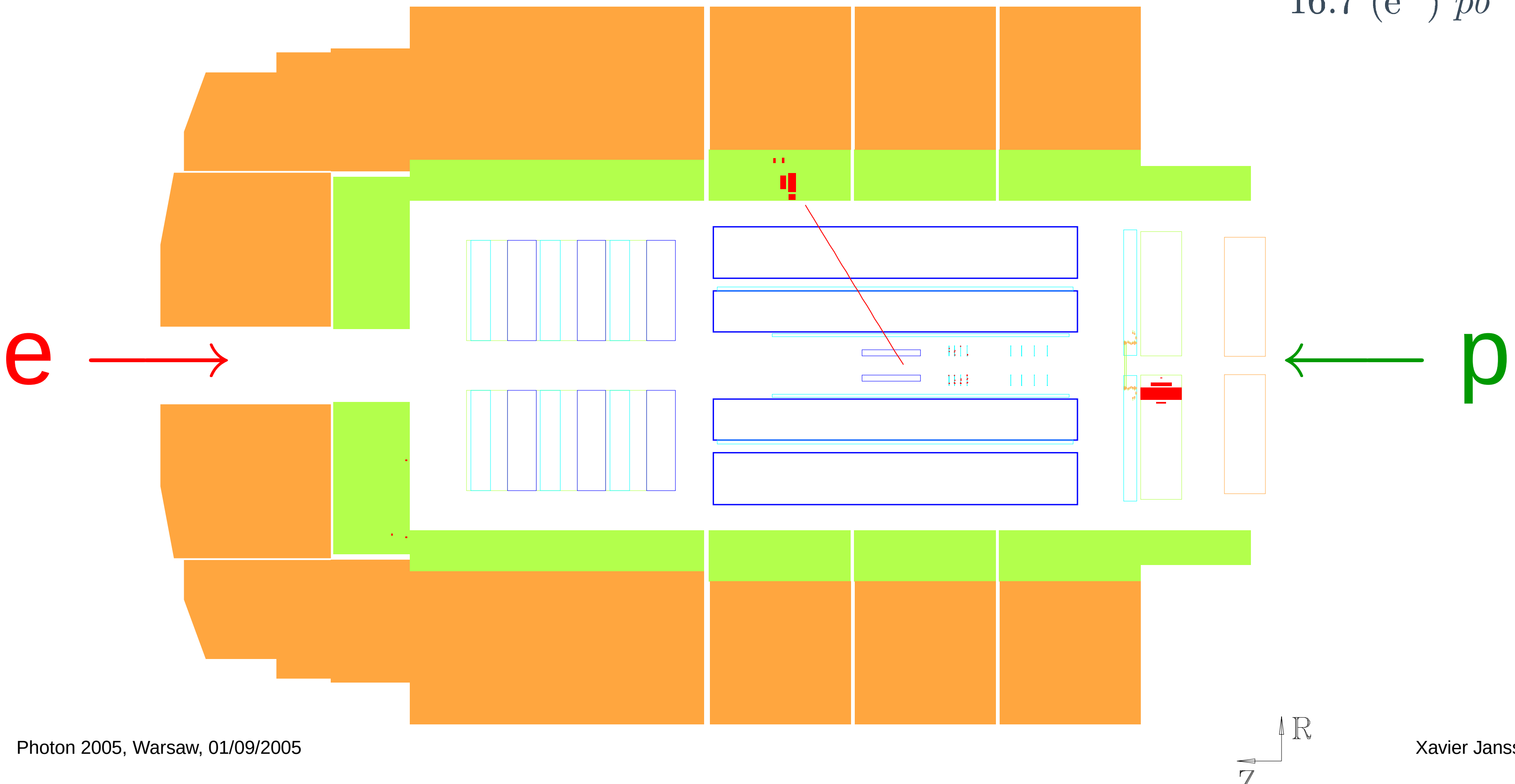


DVCS - *Data Selection*

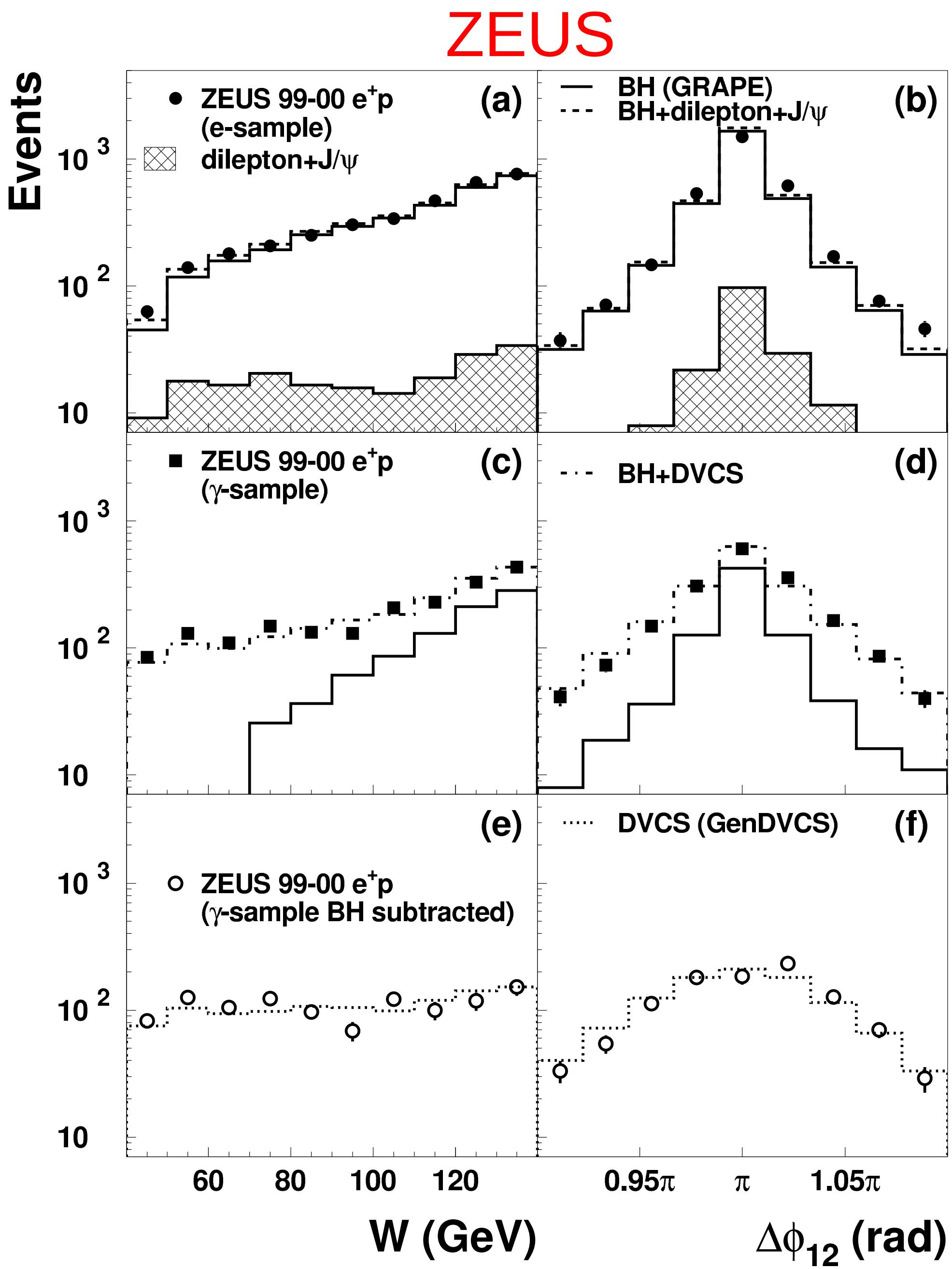
Control sample

Mainly Bethe-Heitler

	H1	ZEUS
$E_1 >$	15 GeV	10 GeV
$p_{T_2} >$	1 GeV	
$E_2 >$		3 GeV
$E_3 <$	0.5 GeV	0.2 GeV
elast.	no track, Fwd	no track
Lumi	46.5 pb^{-1} (e^+)	95 (e^+) pb^{-1} 16.7 (e^-) pb^{-1}



DVCS - *Control Plots*



- Control sample:

  Well described by MC

  $\Longrightarrow$ Detector understood

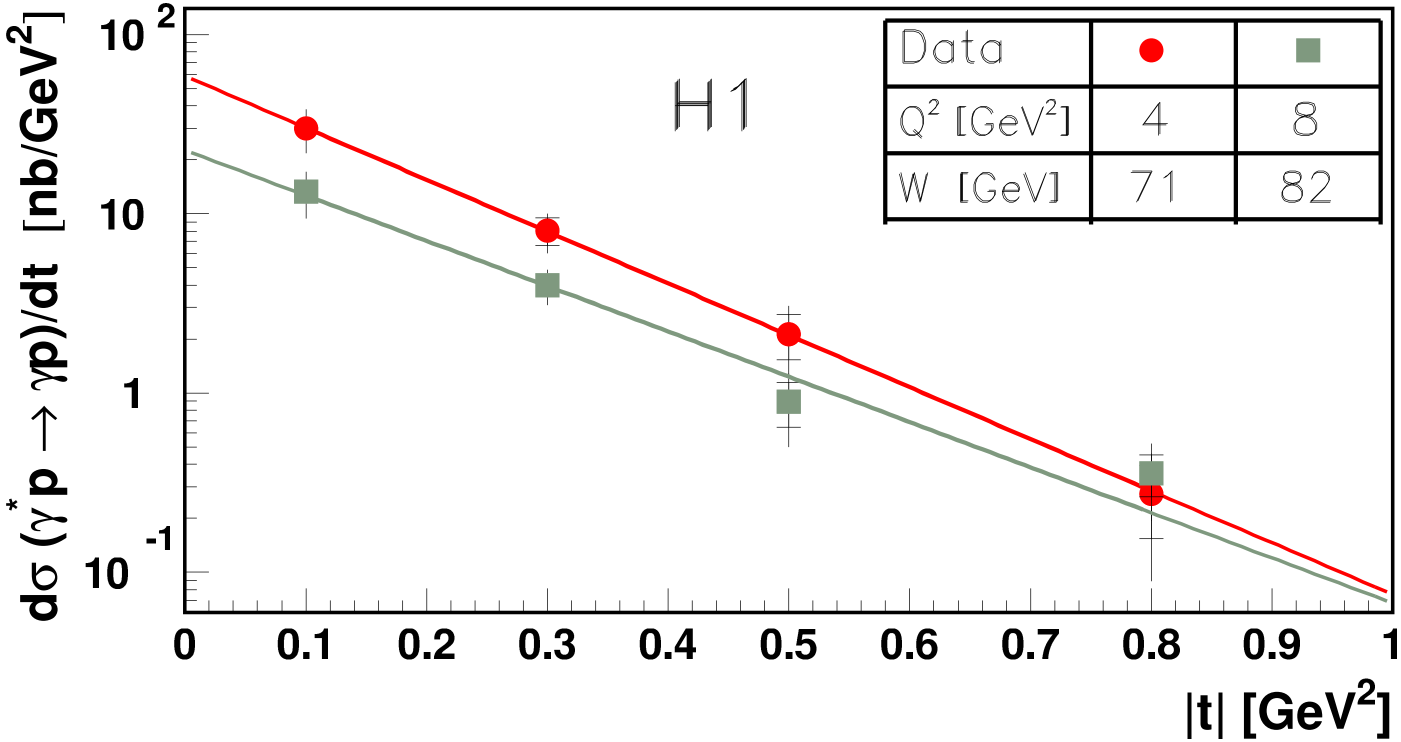
- γ sample:

  Good description by BH + DVCS MC

$\Longrightarrow$DVCS cross section:

1. Subtract Bethe-Heitler ($\int d\phi$ Interf. = 0)
2. $\sigma_{ep} \longrightarrow \sigma_{\gamma^* p}$ (/ flux factor)

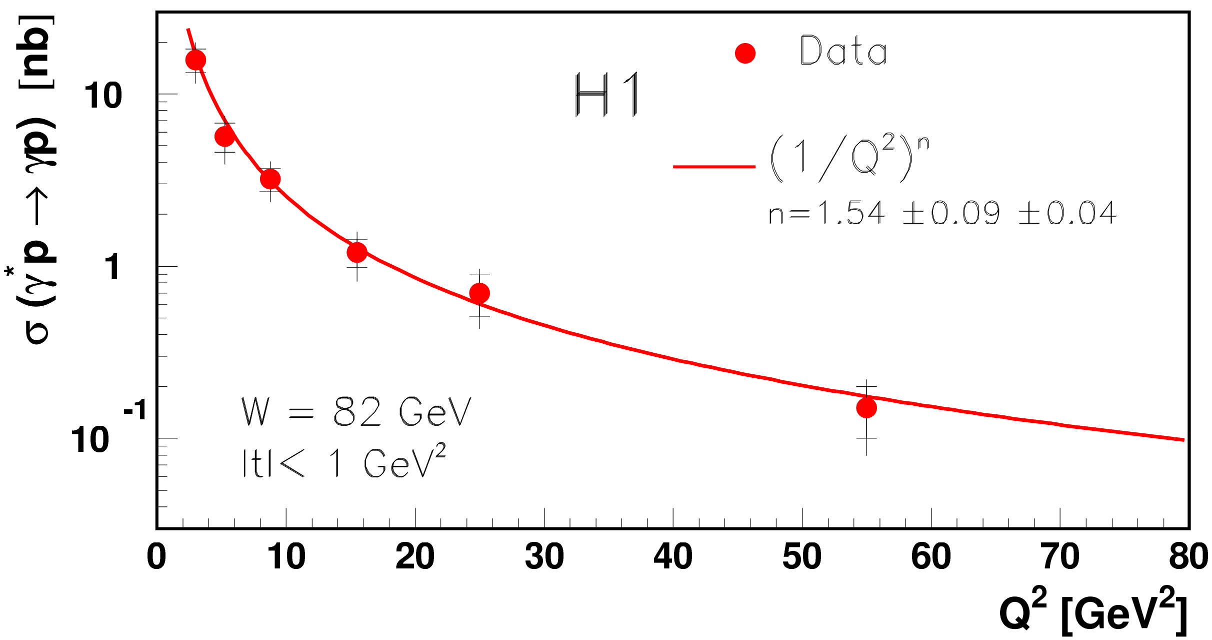
DVCS - t *dependence*



- First measurement of t-dependence
- Exponential fit in t: $\mathrm{d}\sigma/\mathrm{d}t \;\propto\; \exp(-bt)$

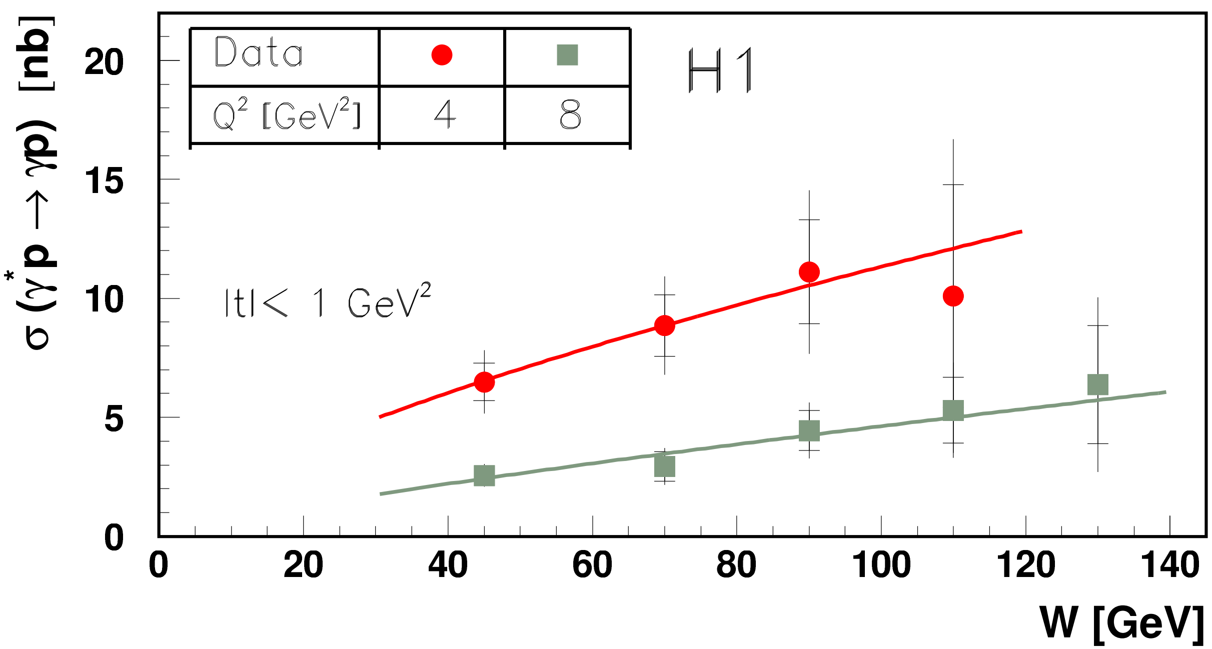
  $\longrightarrow b = 6.02 \pm 0.35 \pm 0.39\ \mathrm{GeV}^{-2}$ at $Q^2 = 8\ \mathrm{GeV}^2$
- No Q^2 dependence observed within errors

DVCS - Q^2 *and* W *dependences*



Fit in Q^2: $\propto (Q^2)^{-n}$

$n = 1.54 \pm 0.09 \pm 0.04$



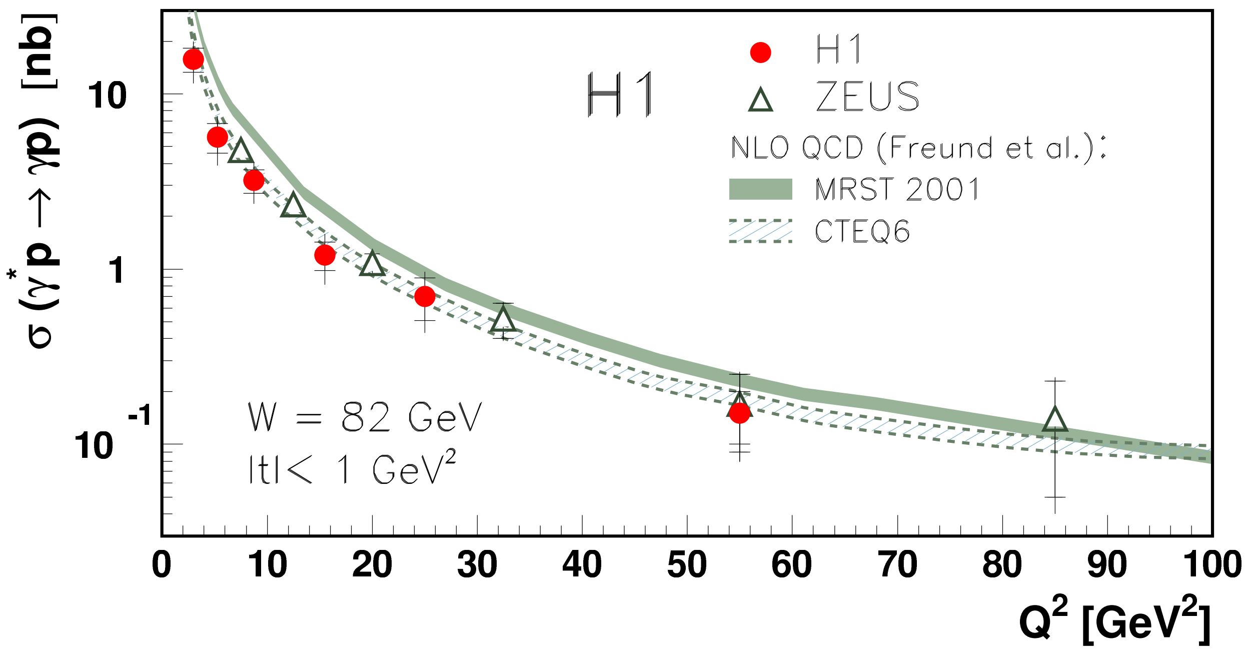
W dependence for
2 Q^2 values

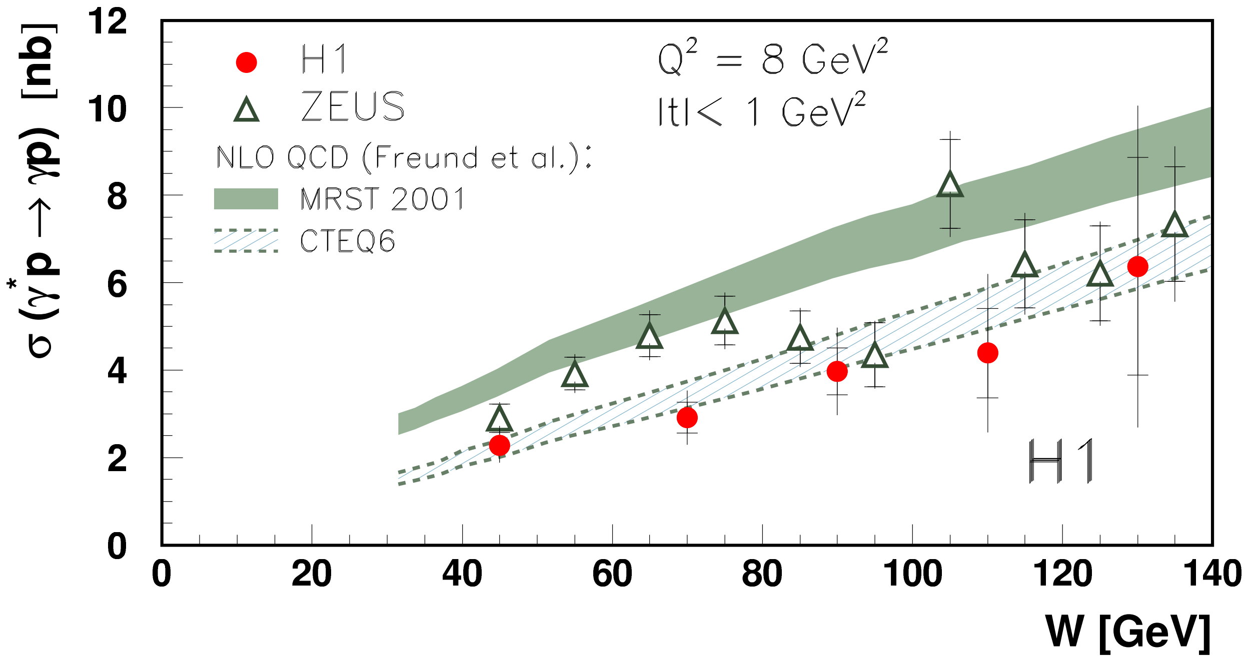
Fit: $\propto W^{\delta}$

$\delta = 0.77 \pm 0.23 \pm 0.19$

$\rightarrow$ indicates hard regime
cf. J/ψ production

DVCS - *Comparison to QCD predictions*





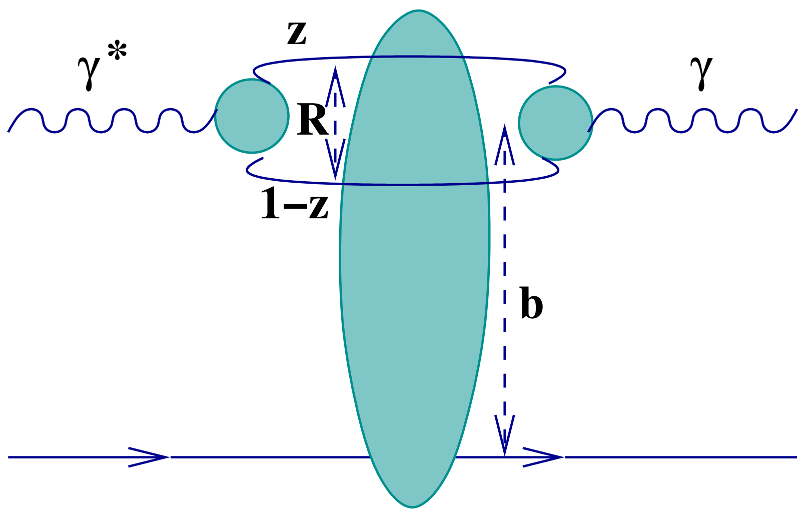
H1 and ZEUS data are in agreement

Comparison to NLO QCD:

- **Band width reduced by b slope measurement**
- **Good description by NLO QCD calculations.**
- **Sensitivity to GPDs parametrization ?**

DVCS - ... and to Color Dipole Models

In proton rest frame:



- γ^* fluctuates in $q\bar{q}$ + $q\bar{q}g$ + ...

$$\mathcal{A} = \int dR^2\, dz\; \Psi^{in}\; \sigma_{dipole}\; \Psi^{out}$$

- Ψ^{in} and Ψ^{out} calculable
- σ_{dipole} modeled

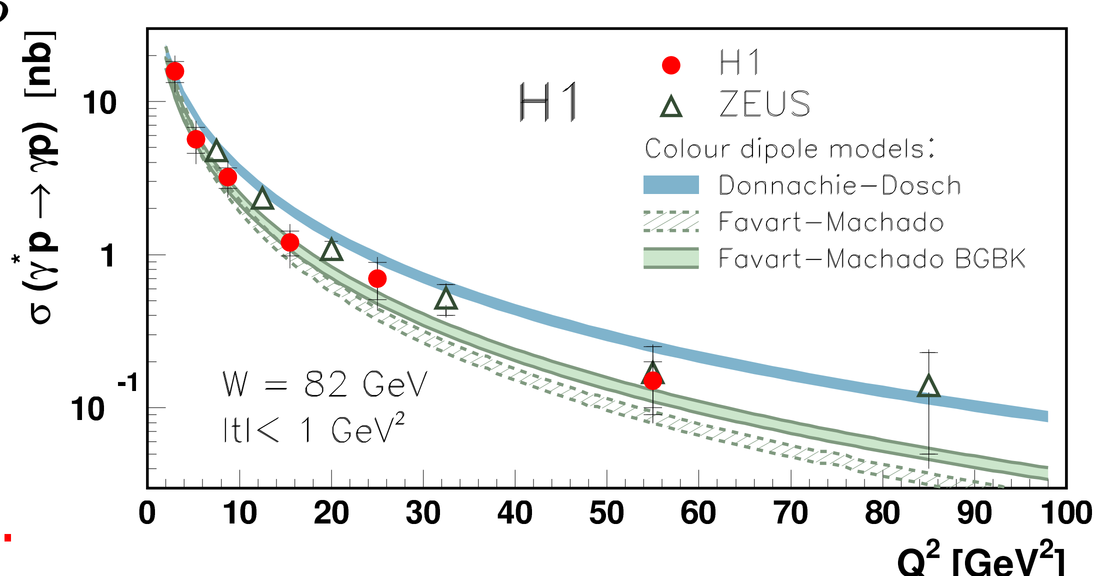
Donnachie-Dosch: hard + soft $I\!\!P$

Phys. Lett. B502 (2001) 74

Favart-Machado:

GBW Saturation model

Eur. Phys. J. C29 (2003) 365



$\longrightarrow$ Describe shape and norm.

$\longrightarrow$ F-M sligthly better (when including DGLAP)

CONCLUSION

DVCS cross sections measurements versus Q^2, W and t:

- First t slope measurement $\longrightarrow$ Constraint theory normalisation
- NLO QCD predictions based on GPDs in agreement with data
- Sensitivity to different GPD models
- Color Dipole models also in agreement with data

Prompt photon production

- Small hadronisation effects $\longrightarrow$ Alternative to Jets to study QCD
- PYTHIA and HERWIG undershoot all measurements
- NLO pQCD undershoot inclusive Prompt γ photoproduction
- (Prompt γ + Jet) data are better described by NLO pQCD