Deeply virtual Compton Scattering at HERA

Alice Valkárová
Institute of Particle and Nuclear Physics,
Charles University of Prague

representing H1 Collaboration

Symmetries and Spin
Praha, 14–27 July , 2002

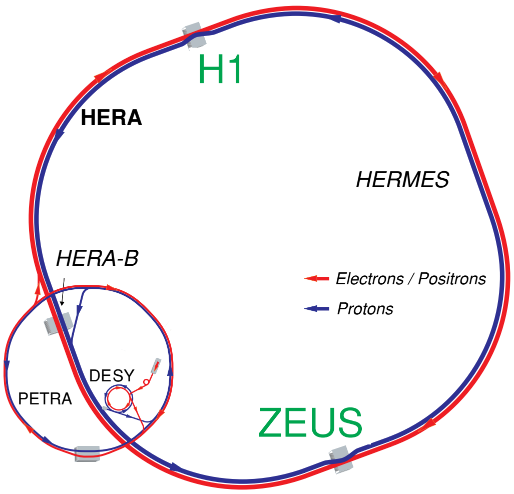
The HERA ep collider

HERA I

$e^{\pm} \quad \Longrightarrow \quad \Longleftarrow \quad p$

27.5 GeV **820 – 920 GeV**

$\sqrt{s} = 300 - 319$ GeV



1993-1994

e^-p **at** $\sqrt{s} = 300$ **GeV**

H1 (ZEUS) 0.92 (0.82) pb^{-1}

1994-1997

e^+p **at** $\sqrt{s} = 300$ **GeV**

H1 (ZEUS) 36.6 (47.7) pb^{-1}

1998-1999

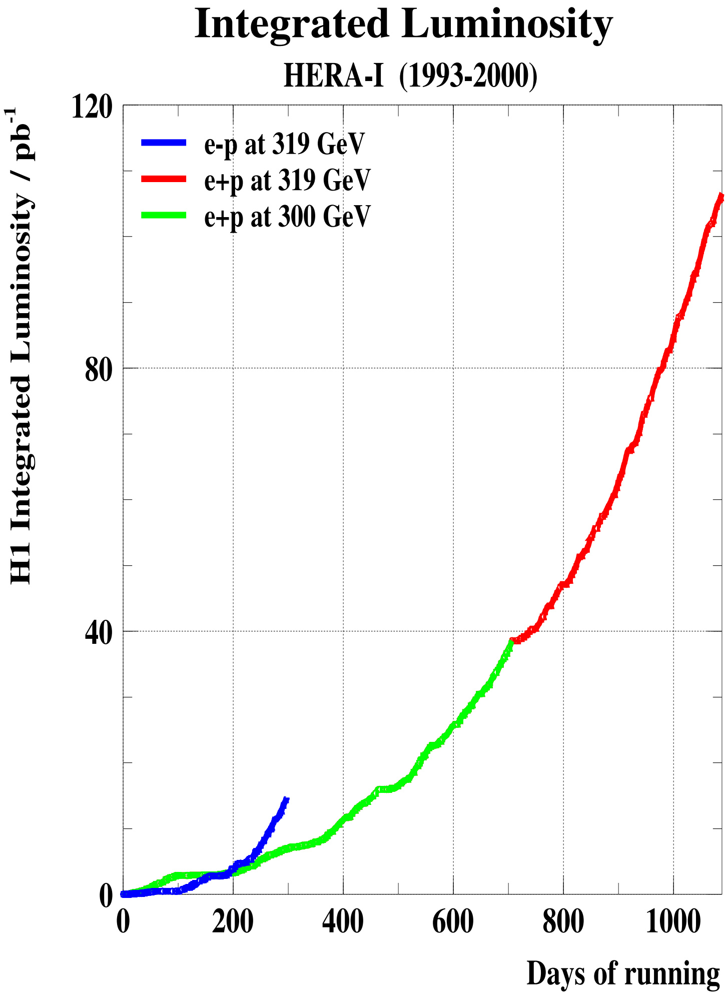
e^-p **at** $\sqrt{s} = 319$ **GeV**

H1 (ZEUS) 16.4 (17) pb^{-1}

1999-2000

e^+p **at** $\sqrt{s} = 319$ **GeV**

H1 (ZEUS) 65 (70) pb^{-1}



Integrated Luminosity

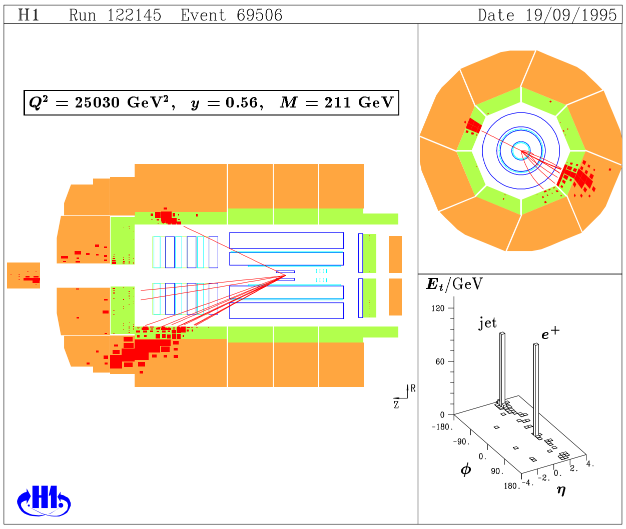
HERA-I (1993-2000)

The H1 and ZEUS experiments

Omni-purpose experiments, similar to LEP or Tevatron detectors

the H1 detector

$e^{\pm} \rightarrow$

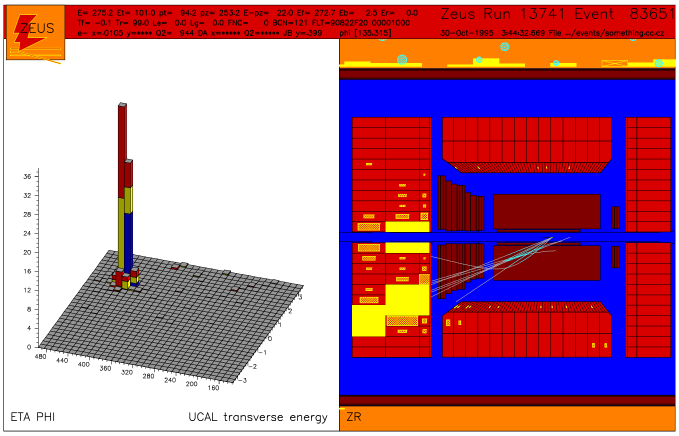


$\leftarrow p$

LAr calorimeter with high granularity

the ZEUS detector

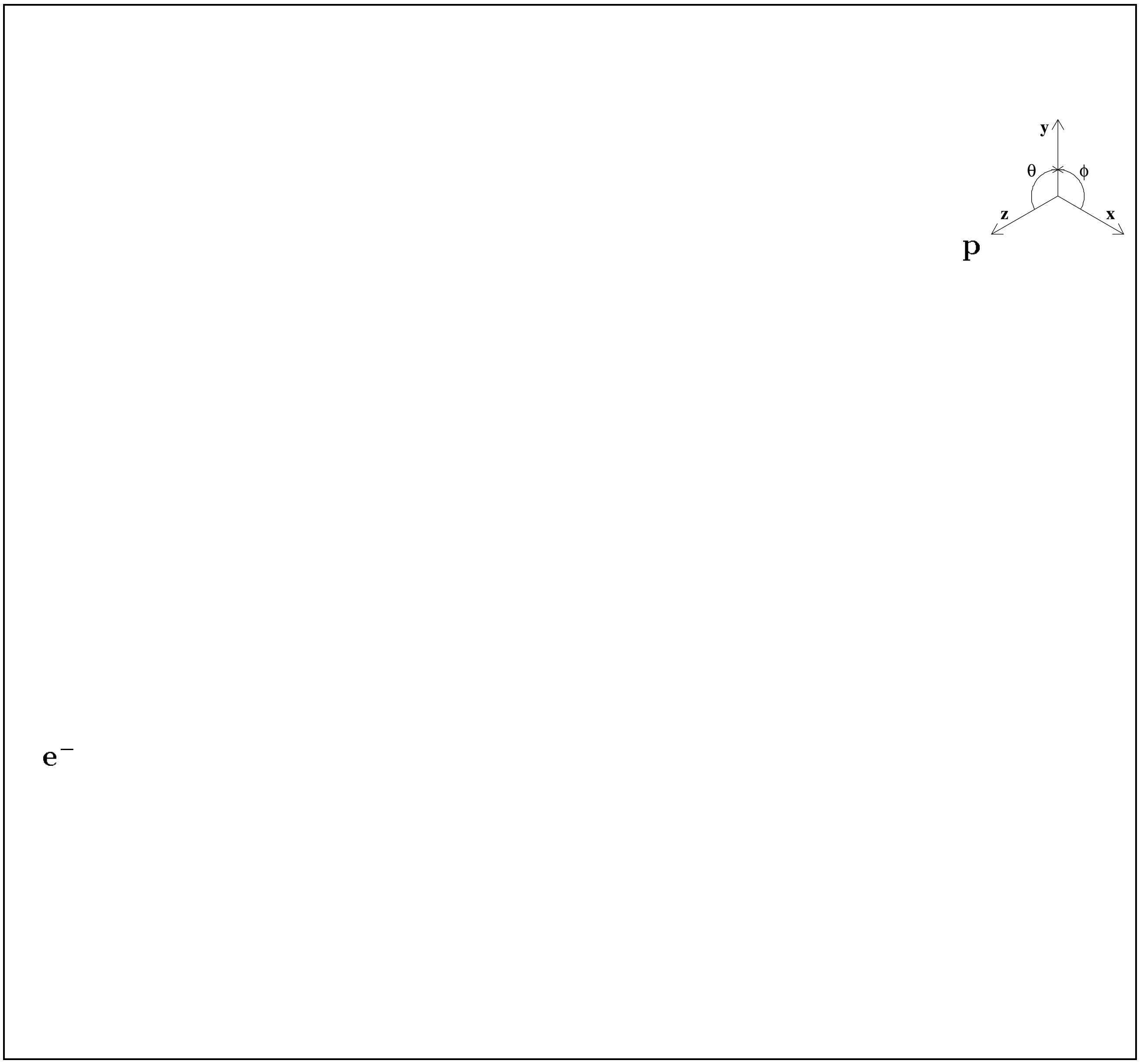
$e^{\pm} \rightarrow$



$\leftarrow p$

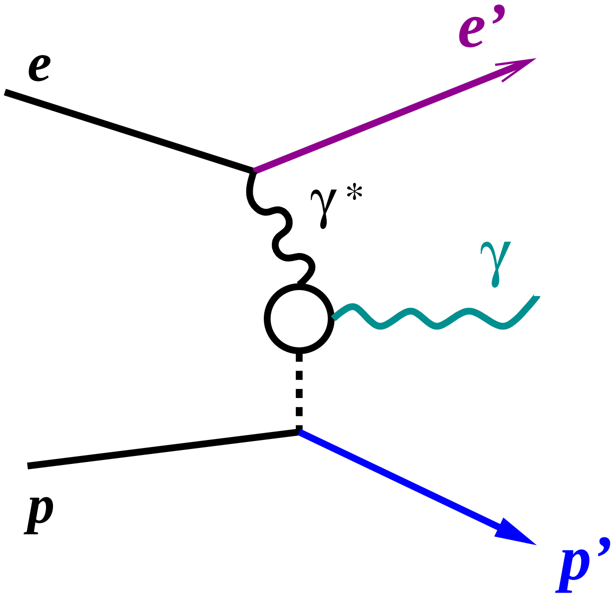
Compensating high resolution uranium calorimeter

H1 DETECTOR



- $\boxed{1}$ Beam pipe and beam magnets
- $\boxed{2}$ Central tracking device
- $\boxed{3}$ Forward tracking device
- $\boxed{4}$ Electromagnetic LAr calorimeter
- $\boxed{5}$ Hadronic LAr calorimeter
- $\boxed{6}$ Superconducting coil (1.15 T)
- $\boxed{7}$ Compensating magnet
- $\boxed{8}$ Helium supply for $\boxed{7}$
- $\boxed{9}$ Muon chambers
- $\boxed{10}$ Instrumented iron yoke
- $\boxed{11}$ Forward muon toroid
- $\boxed{12}$ Backw. calorimeter (SpaCal)
- $\boxed{13}$ PLUG calorimeter
- $\boxed{14}$ Concrete shielding
- $\boxed{15}$ Liquid argon cryostat

Deeply virtual Compton scattering



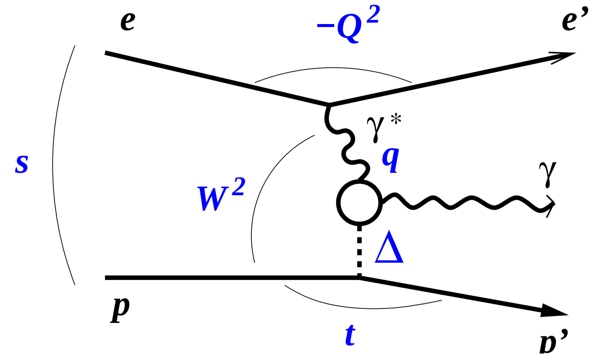
diffractive scattering of a virtual photon off a proton

$$\boxed{e^+ + p \longrightarrow e^+ + \gamma + p}$$

DVCS competes with purely electromagnetic Bethe–Heitler process (completely calculable)

$$\sigma^{DVCS} << \sigma^{QED}$$

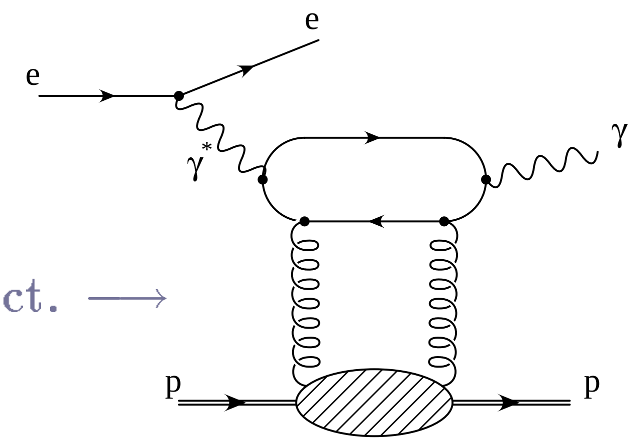
DVCS diagram:



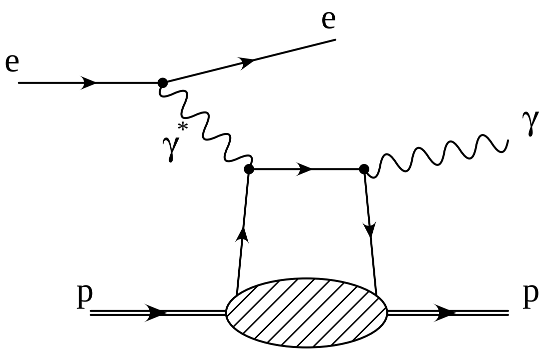
$$s = (e+p)^2$$
$$W^2 = (q+p)^2$$
$$Q^2 = -q^2 = -(e-e')^2 = sxy$$
$$x = Q^2/2p\cdot q$$
$$y = p\cdot q/p\cdot e$$
$$t = \Delta^2 = (p-p')^2 \approx -p_T'^2$$

modeled as

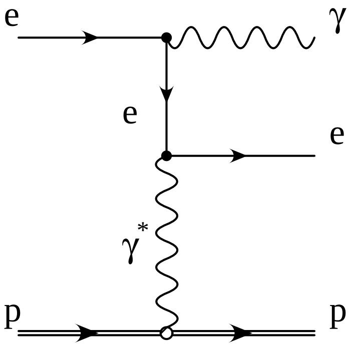
fact. ⟶

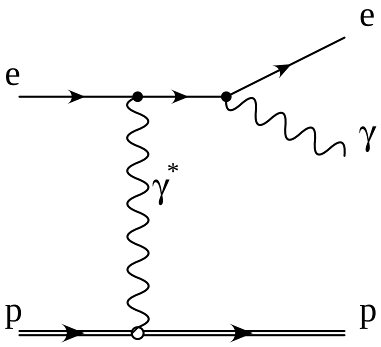


$G(x_1, x_2, Q^2)$



- Bethe-Heitler process





Investigating DVCS is challenging

- **e^+ typically scatters at low angles**
  → no tracks in the event (no vertex!)
  → kinematics poorly reconstructed
- **low γ energy in central region, 1< E_γ <5 GeV**
  → energy resolution is poor
- **scattered proton is not observed**
  → only e^+ and γ in the final state
- $\sigma^{DVCS} << \sigma^{QED}$

- **large Q^2, large W and small t**
- **HERA: wide range in Q^2 and W accessible**

Why is DVCS interesting?

Generalised (Skewed) Parton Distributions

- Generalisations of the usual pdf's for non-forward scattering
- A probe for correlations in the parton distributions

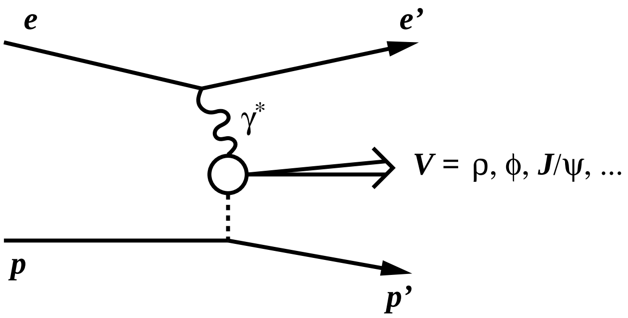
Interference Term

- Interference of QCD amplitude with QED amplitude
- Allows for measurement of real part of a QCD amplitude

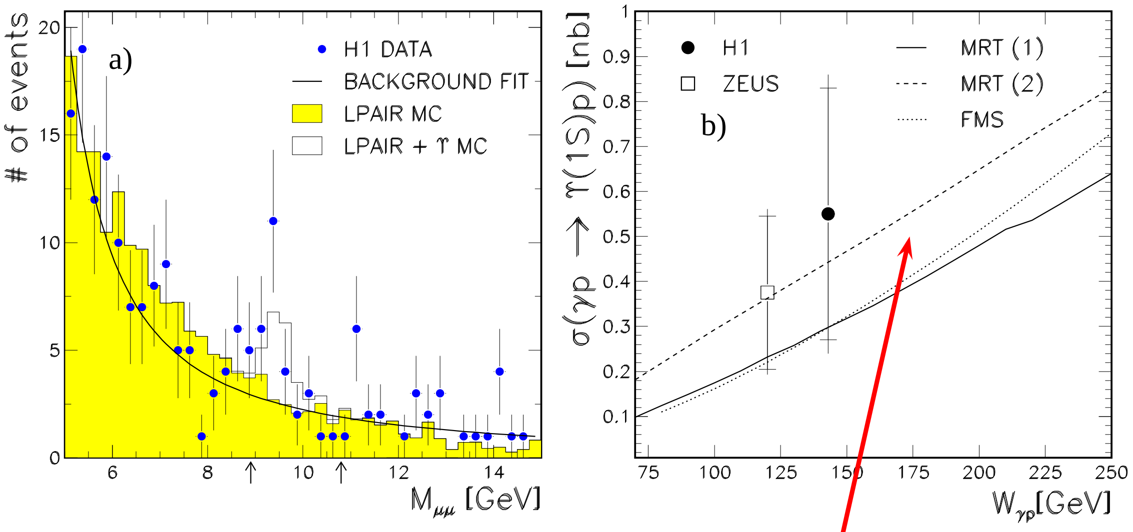
Vector meson production at HERA

For calculation of cross sections → skewed (generalised) parton distributions GPD (see talk of Oleg Terayev).

Important for high Q^2 or high vector meson masses!!!



ϒ production at HERA



Predictions MRT and FMS use the generalised parton distributions (GPD).

Predictions without GPD are too low.

DVCS and vector meson production

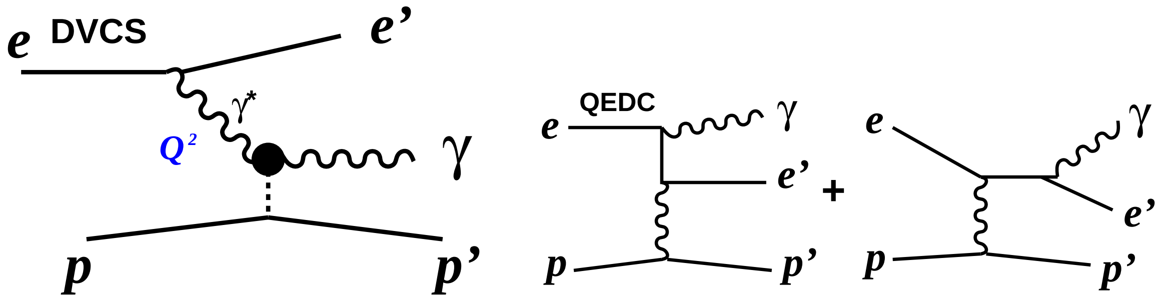
Vector meson production:

- → VM wave function
- GPDs appear quadratically in the cross section – no possibility to extract them

DVCS:

- → point–like coupling of the final state photon to the quark
- GPDs appear linearly in the interference term with BH – possible to extract them

QCD – based model predictions at low –x



not predicted by models

⇓

$$\frac{d\sigma^{\mathrm{DVCS}}}{dx\,dy\,dt\,d\phi_r} \sim \frac{1}{Q^6} e^{-B|t|} (1+\eta^2)$$

$$\eta = \frac{Re(A(\gamma^* p \to \gamma p))}{Im(A(\gamma^* p \to \gamma p))}$$

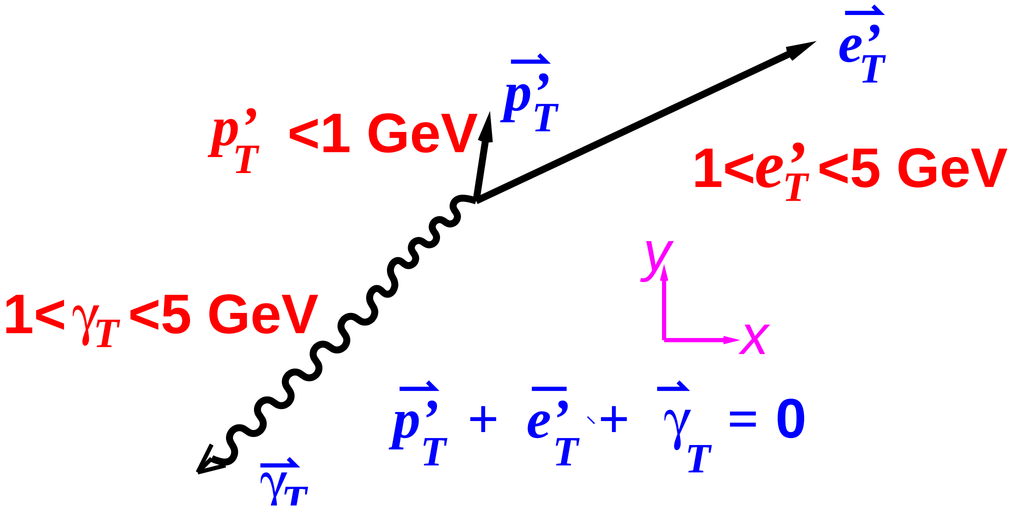
$$\frac{d\sigma^{\mathrm{INT}}}{dx\,dy\,dt\,d\phi_r} \sim \pm \frac{1}{Q^5} \eta \frac{e^{-B|t|/2}}{\sqrt{|t|}} \cos\phi_r$$

$$\phi_r = \phi'_e - \phi'_p$$

$$\frac{d\sigma^{\mathrm{QEDC}}}{dx\,dy\,dt\,d\phi_r} \sim \frac{1}{Q^4} \frac{1}{|t|}$$

Predictions of Frankfurt,Freund and Strikman (Phys.Rev.D58 (1998) 114001) used as input to MC generator and Donnachie and Dosch (Phys.Lett.B502 (2001) 74)

ϕ_r and t are difficult to measure!!



$\phi_r = \phi_e^{'} - \phi_p^{'}$ Scattered proton is not observed.

t=$(p - p^{'})^2 \sim -p_T^{'2}$

Resolution on $e_T^{'}$ and $\gamma_T^{'}$ is poor

⟶ difficult to measure p'_T well, thus $\phi_p^{'}$

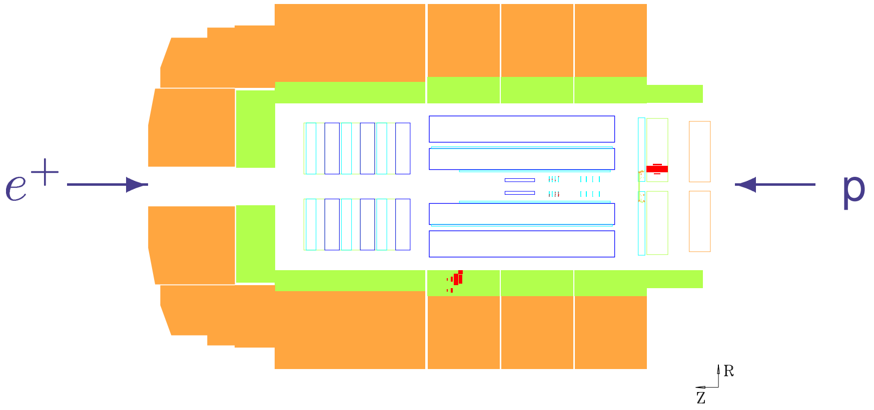
⟶ measurement of ϕ_r and GPD is longer term goal

So far, focus has been on detecting DVCS in data.

cos ϕ_r term integrates to zero since scattered proton is not observed, so need only consider DVCS+QEDC (no interference term).

DVCS: H1 ANALYSIS

DVCS



$E_{back} > 15$ GeV

$p_T > 1$ GeV in LAr cal

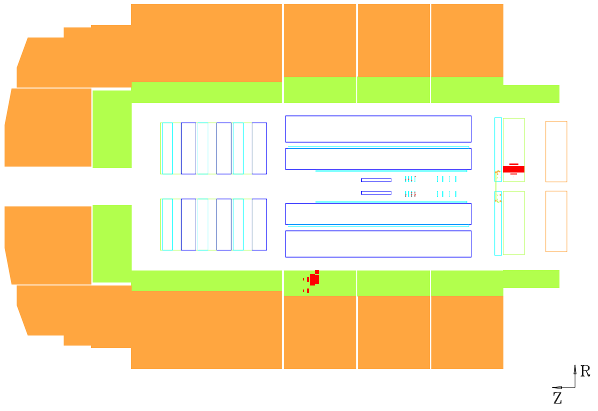
No other clusters > 0.5 GeV

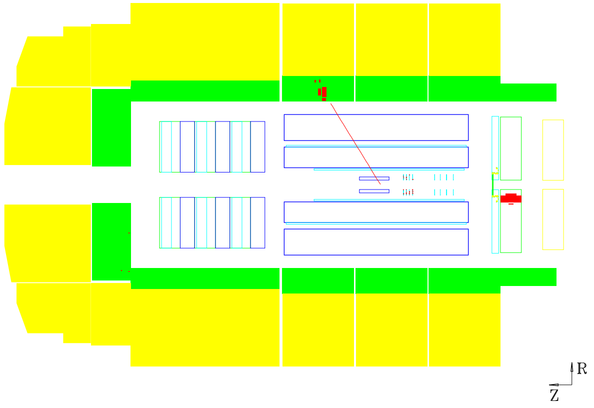
Empty forward detectors

γ-sample

e^+-sample (control)

Bethe-Heitler





Main selection requirements

- One electromagn.cluster in LAr with $p_T > 1$ GeV
- One electromagn.cluster in SpaCAL with $E > 15$ GeV
- No other cluster with E >0.5 GeV
- No track or one track must point to cluster
- $2 < Q^2 < 20\ GeV^2$
- 30< W <120 GeV
- (-1.15< η_{LAr} <1.5)

- **Control sample: – Dominated by Bethe–Heitler events – reference sample to monitor the detector performance and its simulation.**
  Photon candidate in SpaCAL calorimeter and positron candidate (track!) in LAr calorimeter.
  DVCS is negligible!
- **Enriched DVCS sample: Photon candidate in LAr and the positron candidate in SpaCAL.**
  Cross sections DVCS and BH have similar magnitude.

’97 e^+p data, 8 pb^{-1}

- **338 e^+ candidates (control sample)**
- **172 γ candidates (enriched DVCS sample)**

Monte Carlo samples

- DVCS Monte Carlo model – Frankfurt,Freund and Strikman (Phys.Rev.D58 (1998) 114001) contains DVCS, BH and their interference.

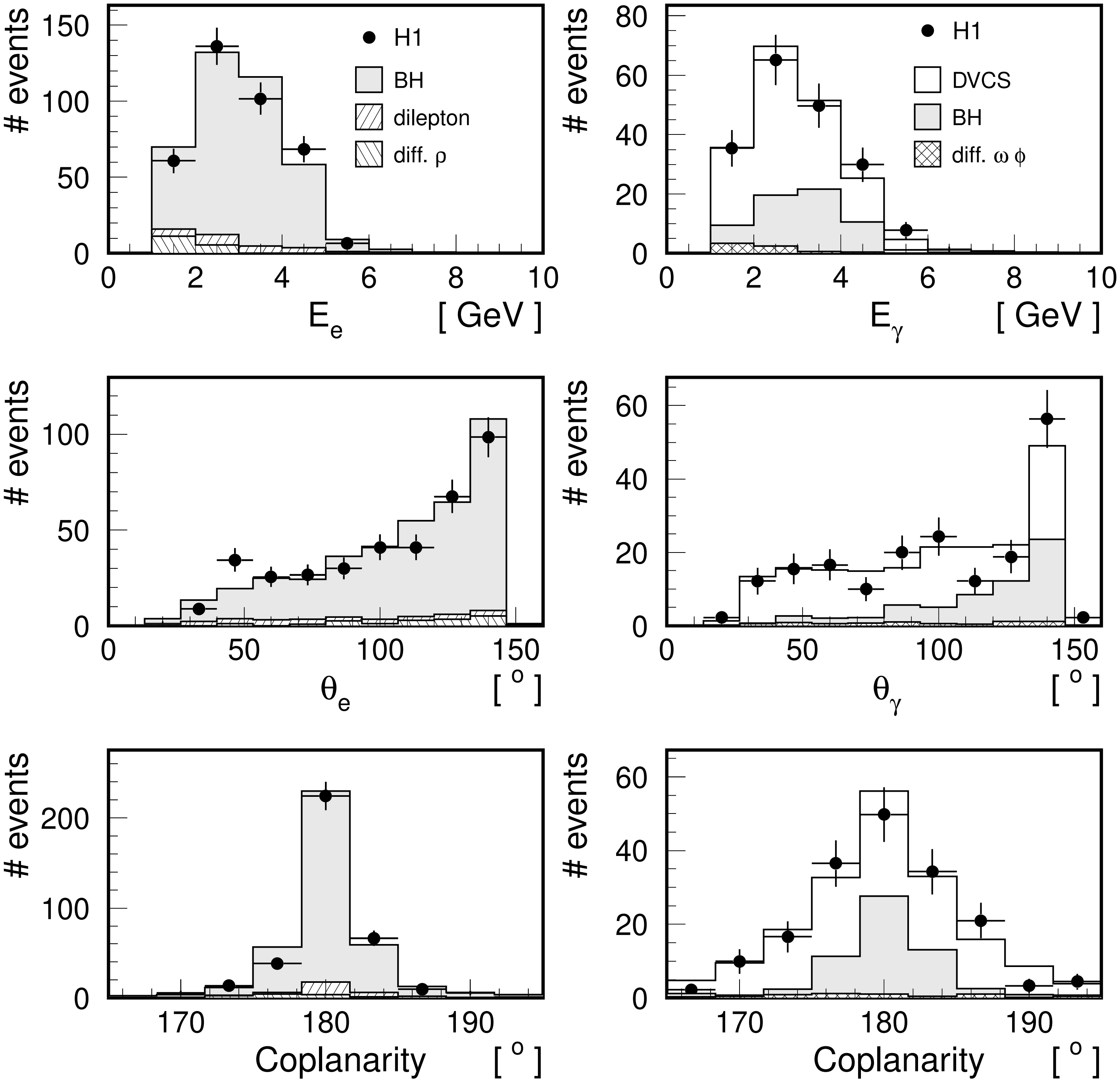
- COMPTON – Bethe–Heitler events for background

- DIFFVM – background, diffractive vector meson events ($\rho \rightarrow \pi^+\pi^-,\ \omega \rightarrow \pi^0\gamma,\ \phi \rightarrow K^0_S K^0_L,\ K^0_S \rightarrow \pi^0\pi^0$)
- GRAPE – di–lepton production, ($e^+p \rightarrow e^+e^-e^+p$) background

Cross section definition:
$2 < Q^2 < 20\ GeV^2$
30$<W<$120 GeV
$|t| < 1\ GeV^2$

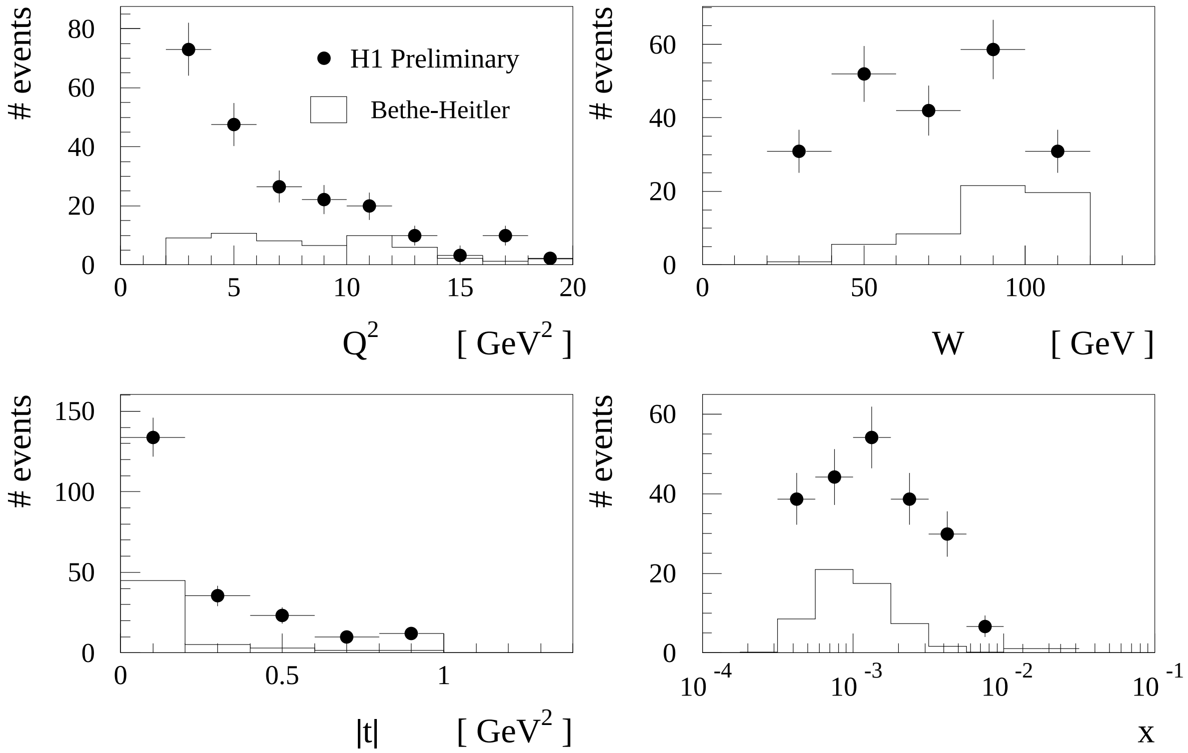
Control sample

Enriched DVCS sample



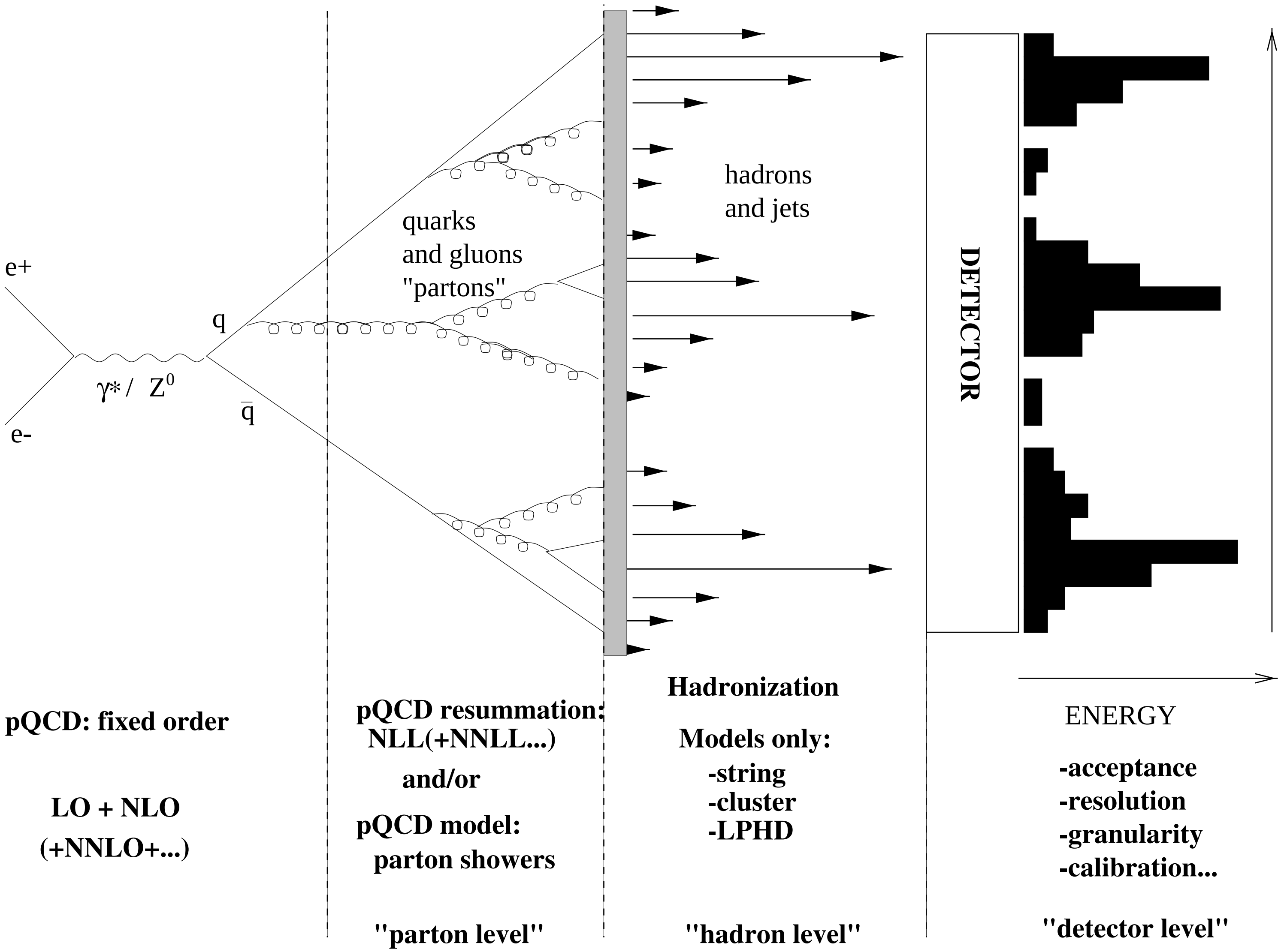
H1 - DVCS observation (Cont.)

- kinematic distributions (uncorrected)



⇒ differences in shape and in normalisation can be observed

Corrections for detector effects



pQCD: fixed order

LO + NLO
(+NNLO+...)

pQCD resummation:
NLL(+NNLL...)
and/or
pQCD model:
parton showers

"parton level"

Hadronization

Models only:
- **string**
- **cluster**
- **LPHD**

"hadron level"

- **acceptance**
- **resolution**
- **granularity**
- **calibration...**

"detector level"

H1 - Cross section measurement

- kinematics is reconstructed by using the double angle method

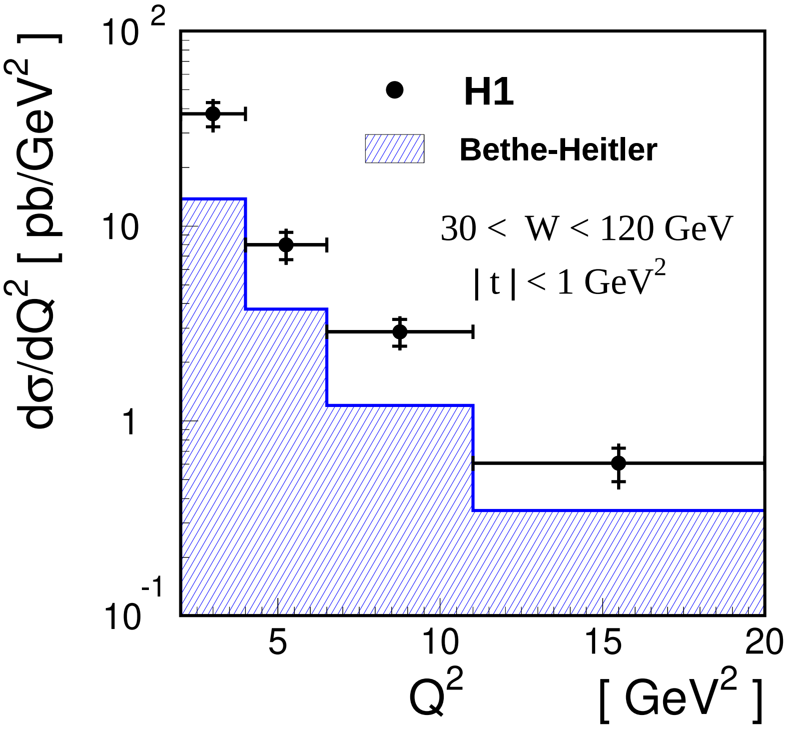
- data are corrected for
  - detector effects
  - acceptance (using DVCS MC)
  - QED ISR
  - proton dissociative background (10%)

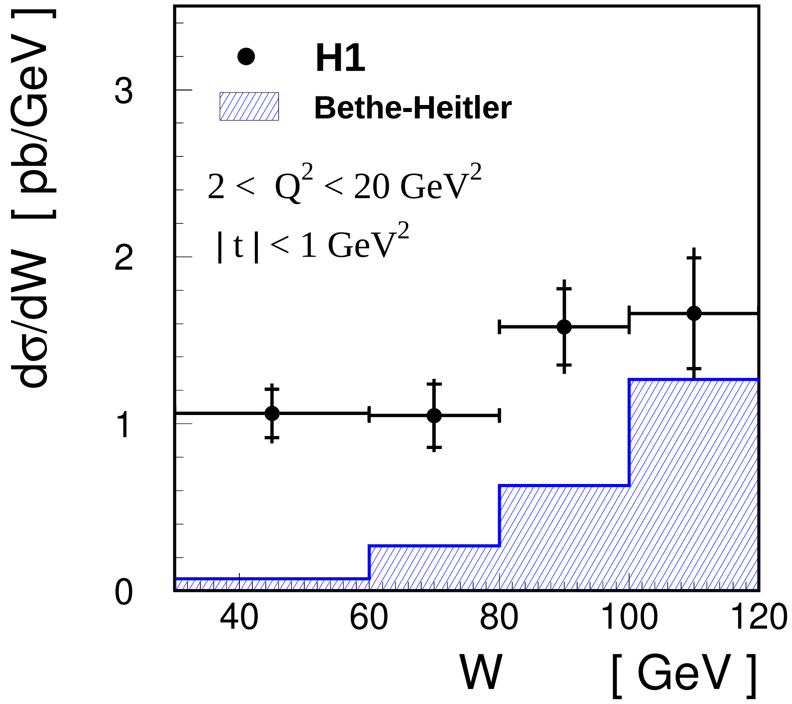
⇒ elastic cross section

- main systematic errors
  - measurement of angle 5 - 10 %
  - dissociative background subtraction 5 %
  - acceptance corrections 10 %

- MC : t–slope $7 - 10\,\mathrm{GeV}^{-2}$

H1 cross section measurement





Clear excess above QED Compton prediction

DVCS model calculations

Frankfurt, Freund and Strikman - FFS
(Phys.Rev.D58 (1998) 114001)
Donnachie and Dosch – DD
(Phys.Lett.B502 (2001) 74).

Both contain soft and hard contributions and exponential t–dependence: $e^{-b|t|}$

FFS

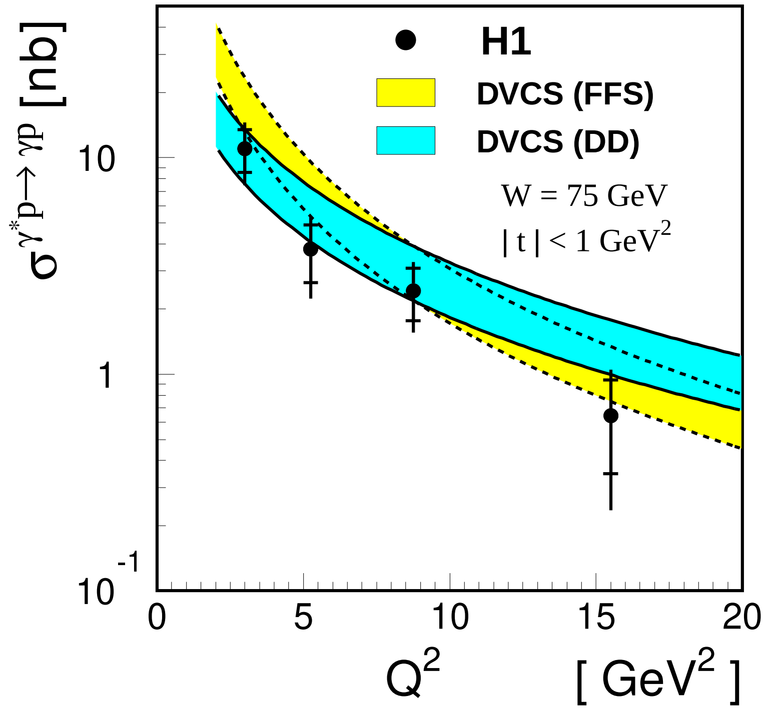
- soft contribution: aligned jet model
- hard contribution: perturbative QCD

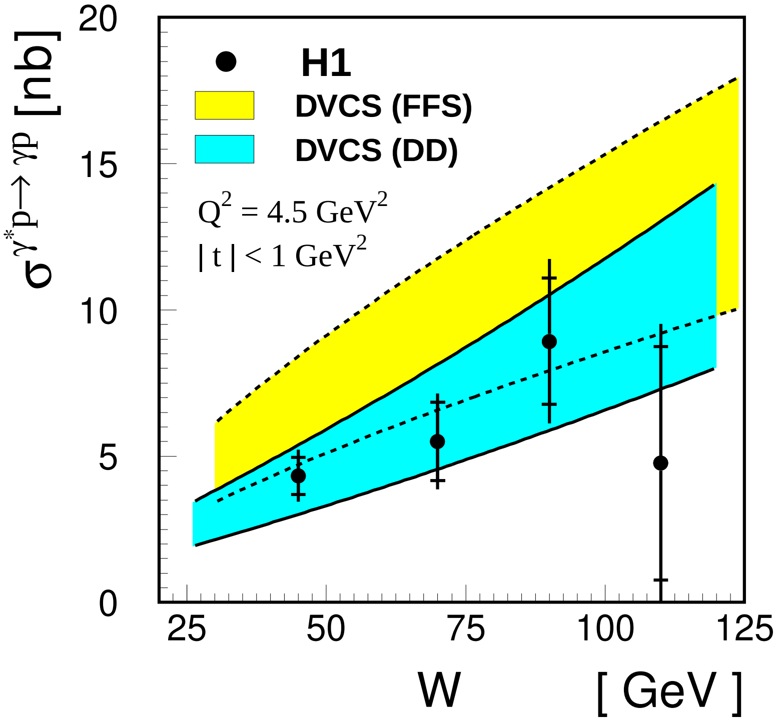
DD

- soft contribution: reggeon and soft pomeron exchange
- hard contribution: dipole model, parameters from pp and $\gamma^* p$ measurements

H1 cross section measurement

bands → model variation of t–slope $5 < b < 9\ GeV^{-2}$.





Cross sections in general agreement with QCD prediction

PROSPECTS FOR THE FUTURE

Increase of Luminosity: 1 fb^{-1}

so far:

H1: $\sim 8\ pb^{-1}$

ZEUS: $\sim 40\ pb^{-1}$

for HERA II polarized beams of electrons (positrons)

New and upgraded detectors:

VFPS (Very Forward Proton Spectrometer) :

t measured at small W

The upgraded BST:

precise measurement of θ_e, ϕ_e

$$z_{vertex} \longrightarrow \theta_\gamma$$

Improvement of systematic errors!!

SUMMARY AND OUTLOOK

- **Excess of photons over the QED Compton expectation clearly established**
- **Event distributions of excess are inconsistent with QED Compton but generally consistent with deeply virtual Compton scattering**
- **QED background subtracted and DVCS cross section measured**
- **DVCS theoretical predictions generally reproduce measurement**
- **DVCS analysis is just beginning. HERA II promises $\sim 1\ fb^{-1}$ in 5 years, H1 – new forward proton spectrometer**
- **Future measurements will focus on t–distribution, interference term and generalised parton distributions**