Measurement of Deeply Virtual Compton Scattering in ep collisions at HERA

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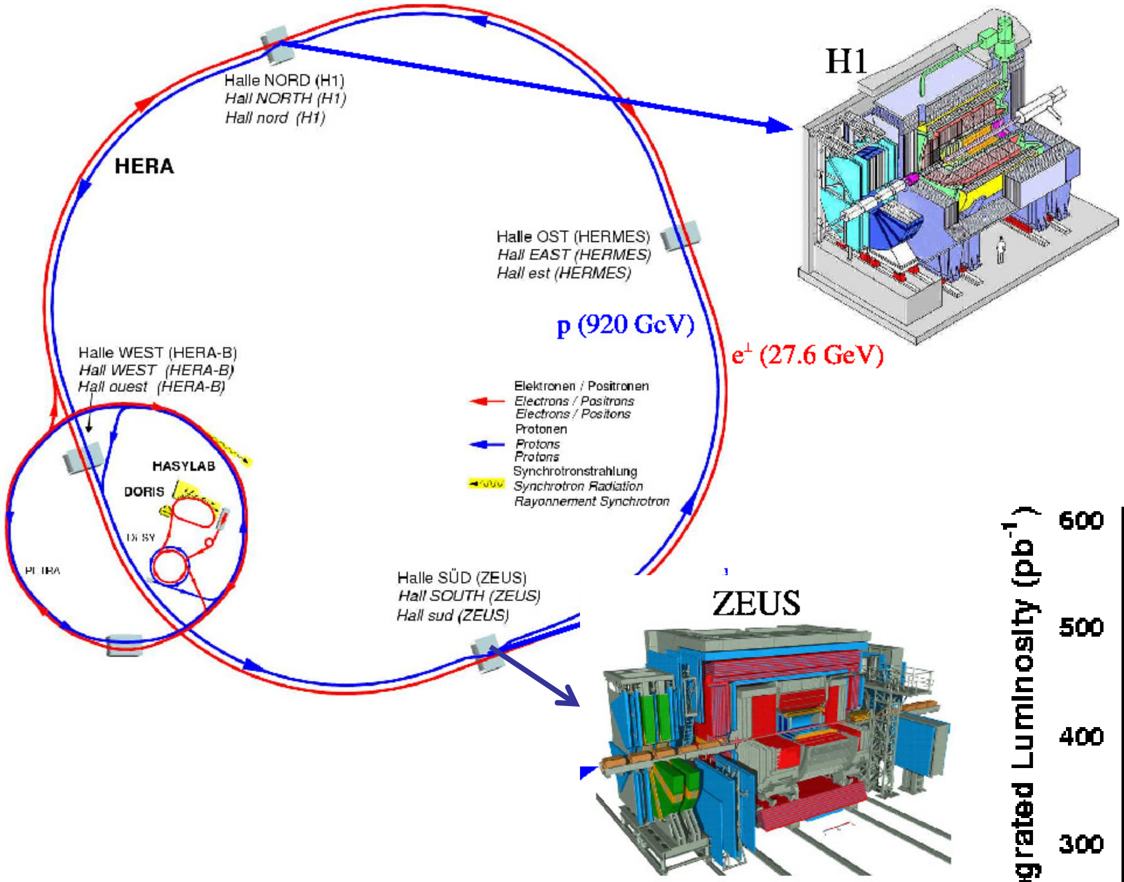
On behalf of the H1 and ZEUS Collaborations

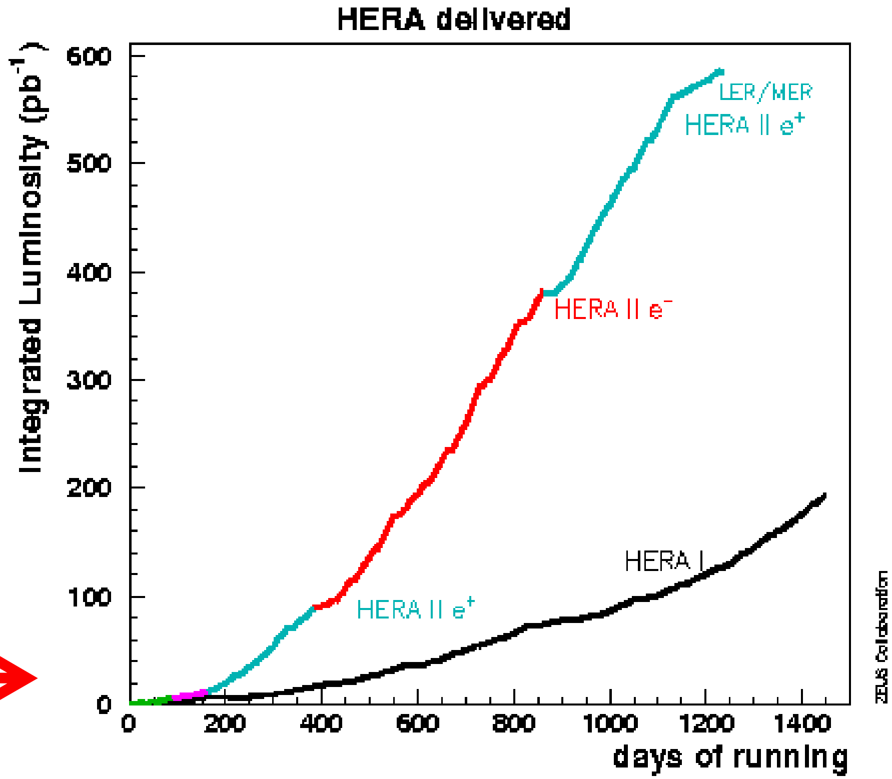
HERA colliding experiments overview



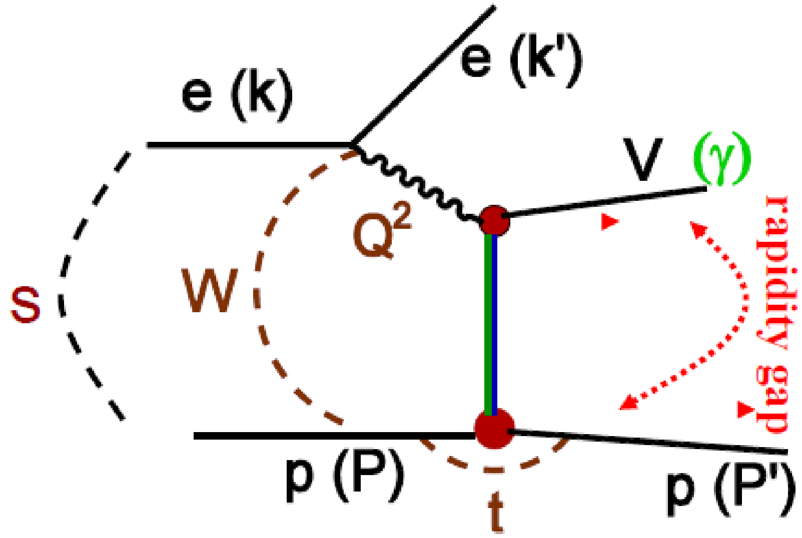
Detectors not originally designed for diffractive physics

Lots of results achieved in diffraction at HERA

HERA I + HERA II ~0.5 fb^{-1}



DVCS at HERA



Main kinematic variables

photon virtuality:

$$Q^2 = -q^2 = -(k-k')^2 \approx 4 E_e E'_e \sin^2\frac{\theta}{2}$$

photon-proton centre-of-mass energy:

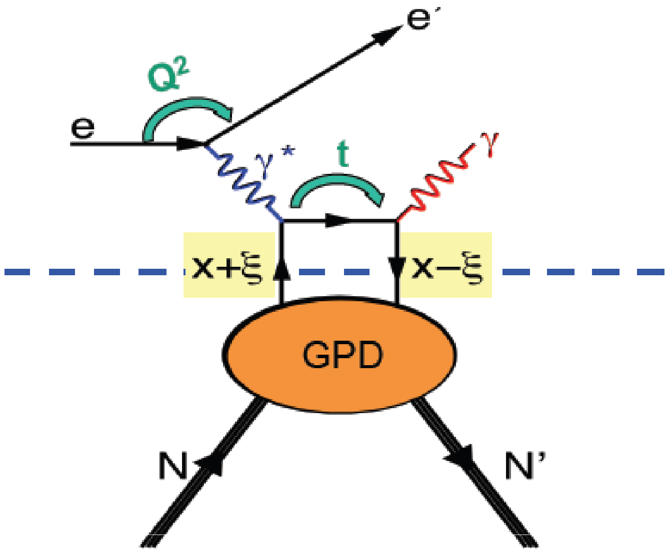
$$W^2 = (q+p)^2, \text{ where: } m_p < W < \sqrt{s}$$

square 4-momentum at the p vertex:

$$t = (p' - p)^2$$

- **Together with VMs measurements to investigate the transition from soft to hard regime is possible at HERA**
- **DVCS is the cleanest way to access Generalized Parton Distribution (GPD)**
- **GPSs are an ingredient for estimating diffractive cross sections at LHC**

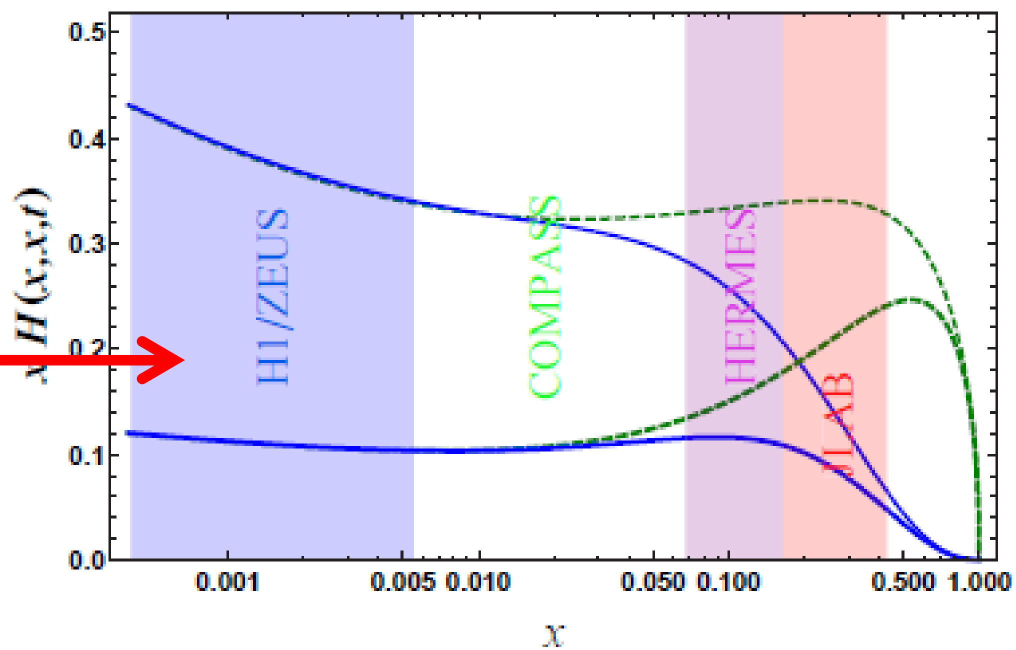
GPD



GPD, probability amplitude for a nucleon to emit a parton with momentum fraction x+ξ and to absorb it with momentum x- ξ

$\xi \sim x_{Bj}/(2-x_{Bj})$

Small-x range constrained by HERA



(K. Kumerickia and D. Mueller arXiv:0904.0458v2 ,2010)

DVCS processes studied in a wide kinematic range at HERA

ZEUS – HERA I

Phys. Lett. B 573 (2003)

$5<Q^2<100$ GeV^2

$40<W<140$ GeV

(95.0+16.7pb^{-1})

JHEP05(2009)108

$1.5<Q^2<100$ GeV^2

$40<W<170$ GeV

(61.1pb^{-1})

$0.08<|t|<0.53$ GeV^2

(31.3 pb^{-1})

H1- HERA I

Eur. Phys. J. C 44 (2005)

$2<Q^2<80$ GeV^2

$30<W<140$ GeV (46.5 pb^{-1})

H1 – HERA II

Phys.Lett.B659 (2008) (145 pb^{-1})

Phys.Lett.B681 (2009) (306 pb^{-1})

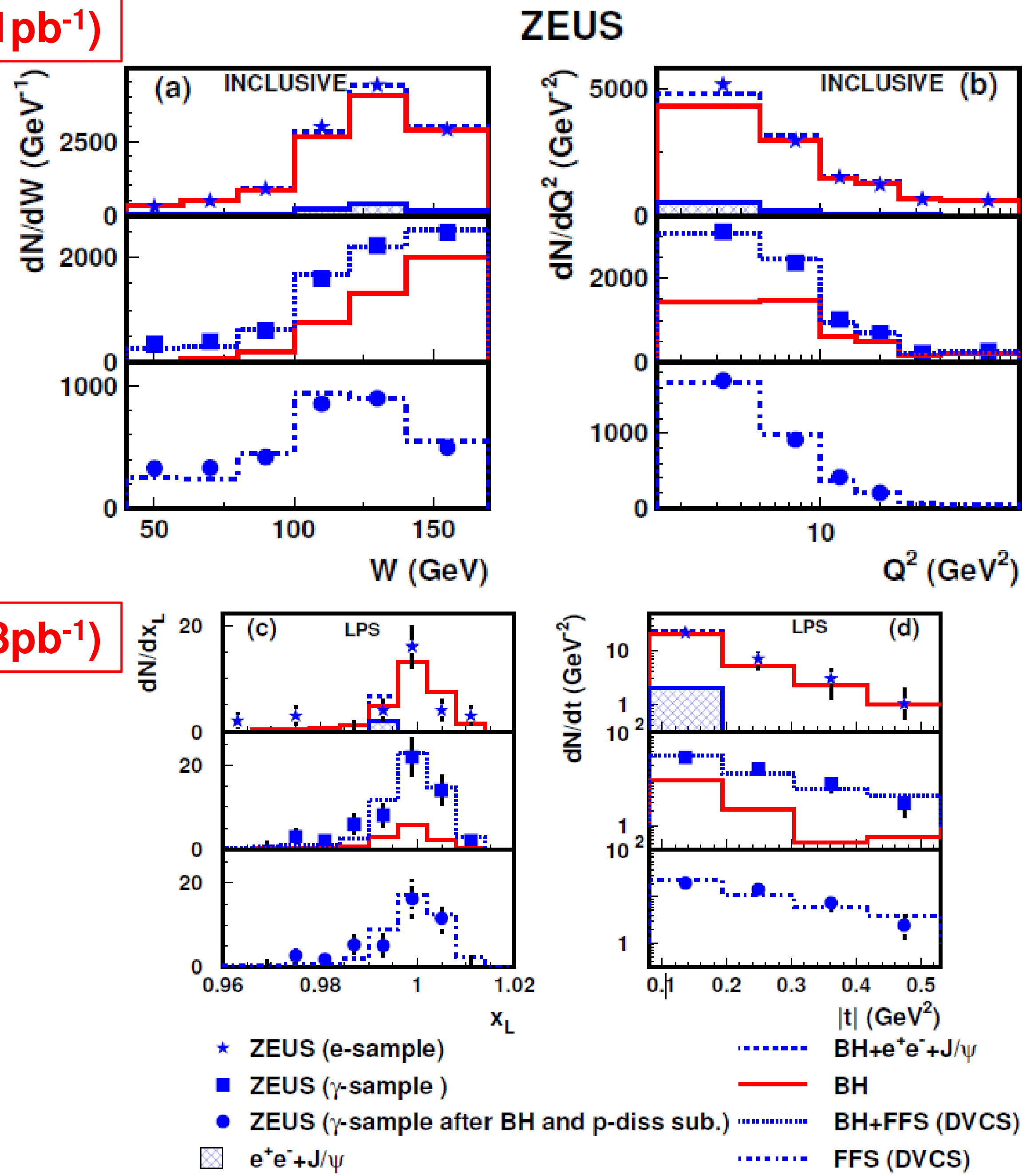
$6.5<Q^2<180$ GeV^2

$30<W<140$ GeV

$|t|<1.0$ GeV^2

ZEUS

(61.1pb^{-1})



(31.3pb^{-1})

e$^+$-sample compared with BH+background MC (dilep. and J/ψ)

γ-sample compared with BH + DVCS MC

DVCS sample compared with DVCS MC

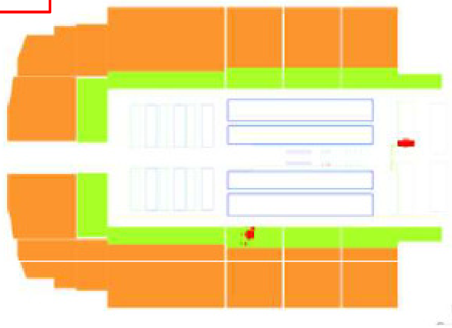
The estimated fraction of BH events in the γ-sample is: ~ 60 %

$1.5<Q^2<100$ GeV^2
$40<W<170$ GeV
$0.08<|t|<0.53$ GeV^2

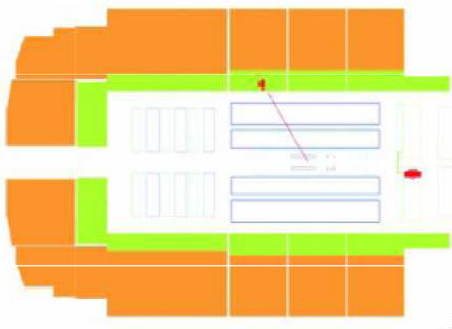
H1

306 pb^{-1}

- DVCS enriched sample



- BH control sample



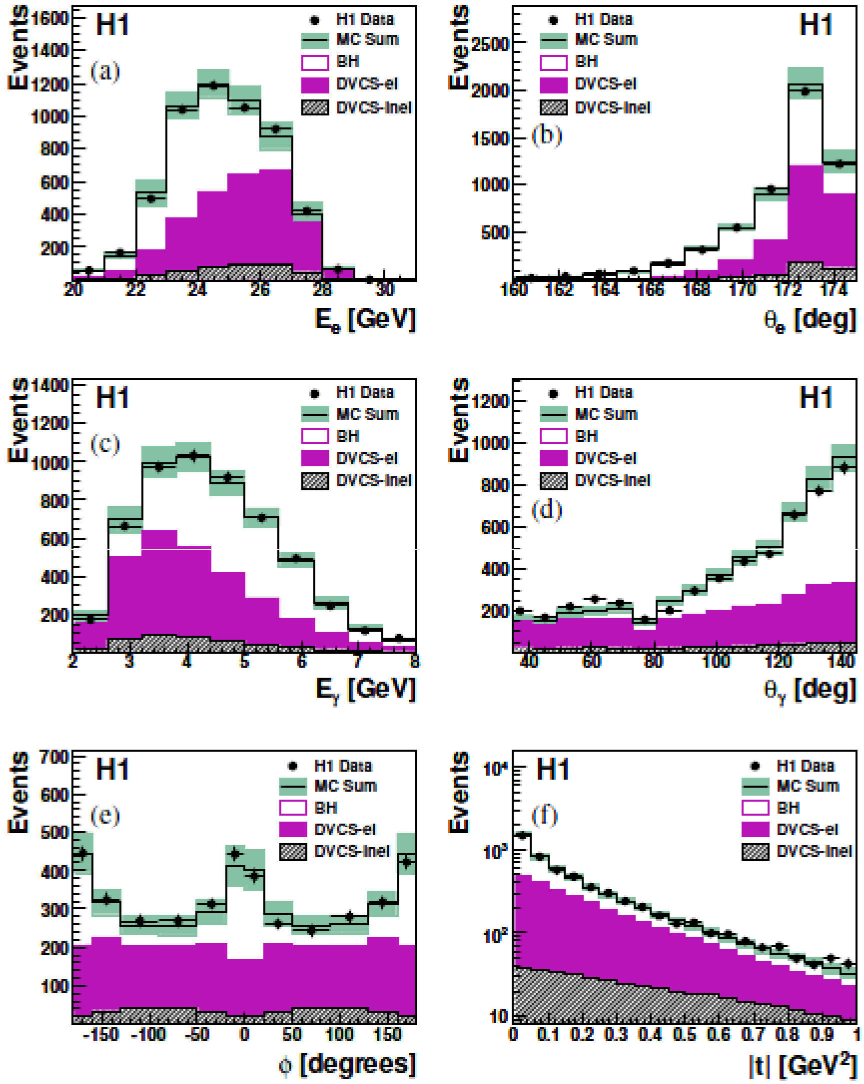
HERA II 2004-2007

e$^{\pm}$ beam charge available

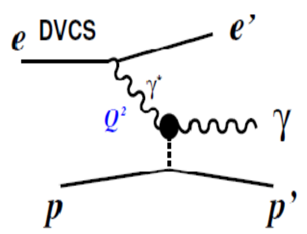
$6.5<Q^2<180$ GeV^2

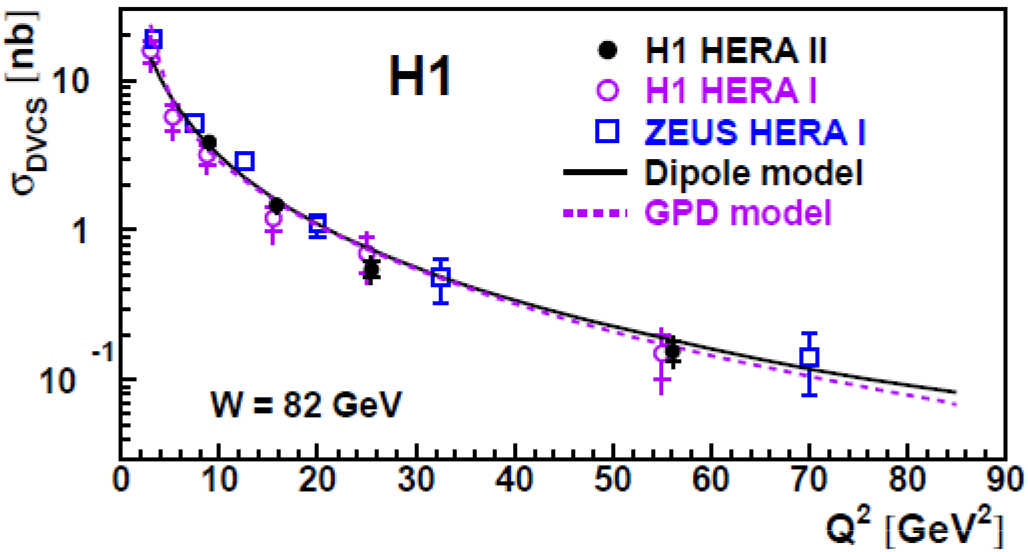
$30<W<140$ GeV

$|t|<1.0$ GeV^2

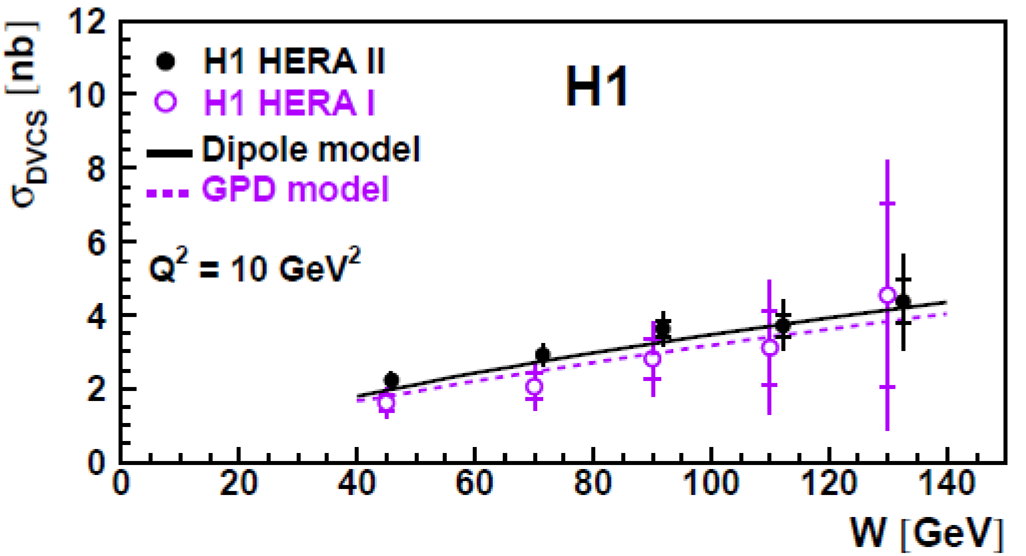


H1 DVCS cross section measurements



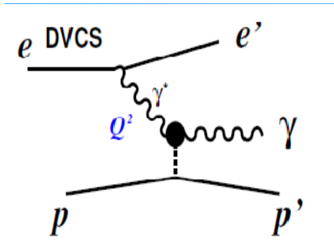


Phys.Lett.B681 (2009)

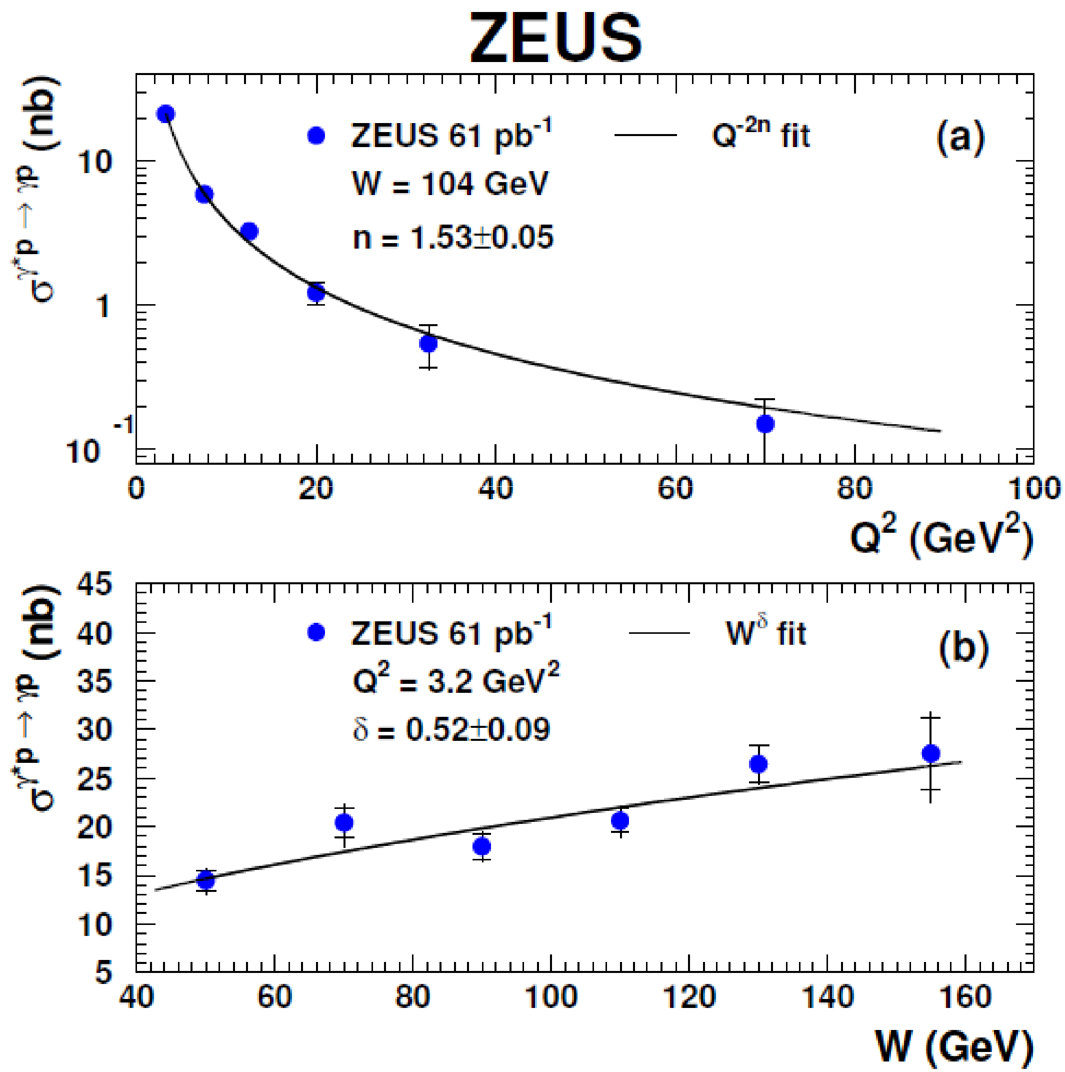


HERA I and II :
- results in agreement
- precision improved

Data compared with:
- dipole model
- GPD model
(see later)

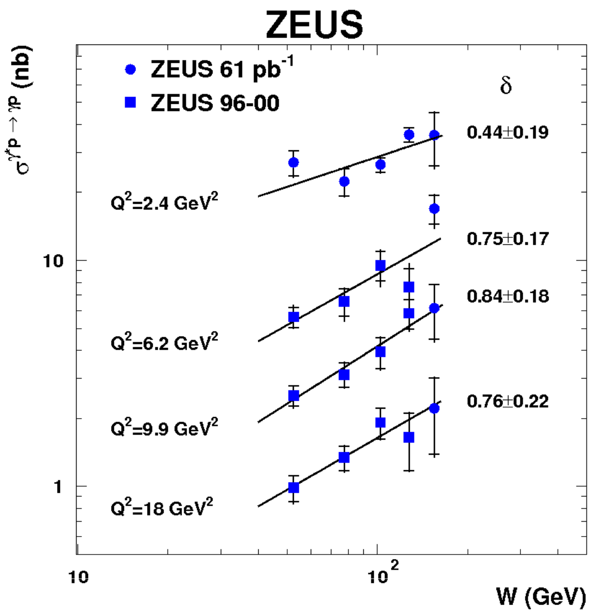


ZEUS DVCS cross section measurements

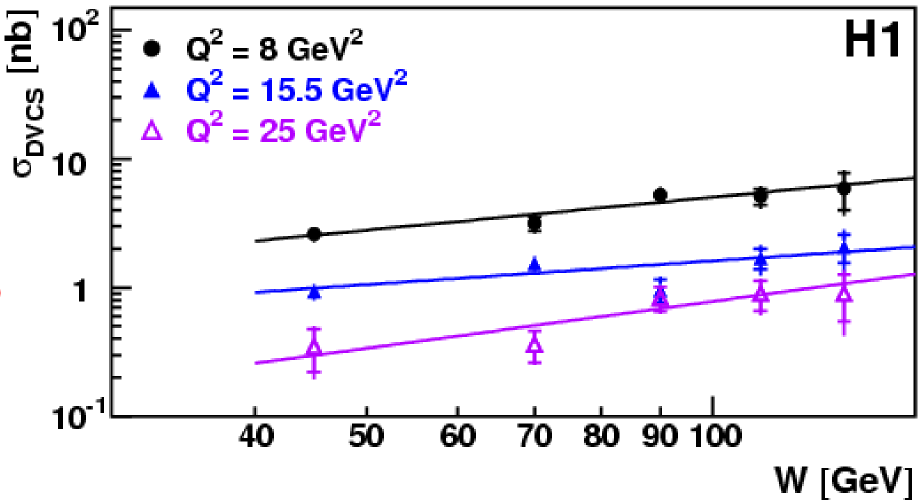


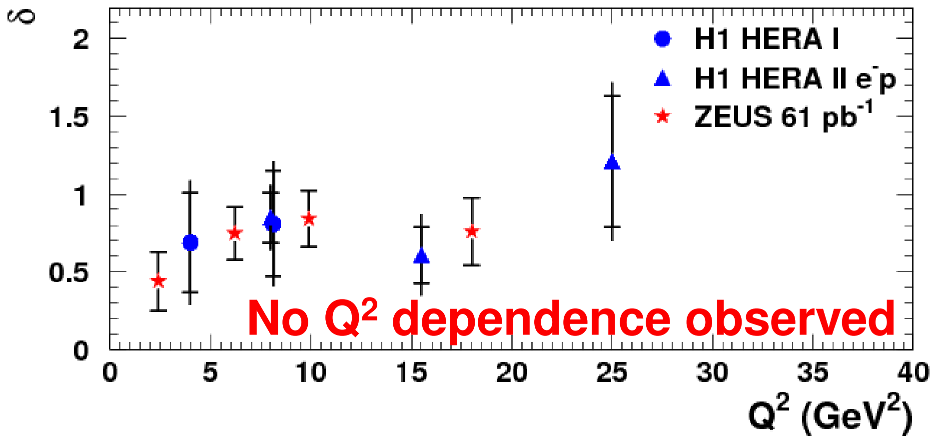
ZEUS: JHEP05 108 (2009)

DVCS W-dependence vs Q^2



Fit: $\sigma \sim W^{\delta}$



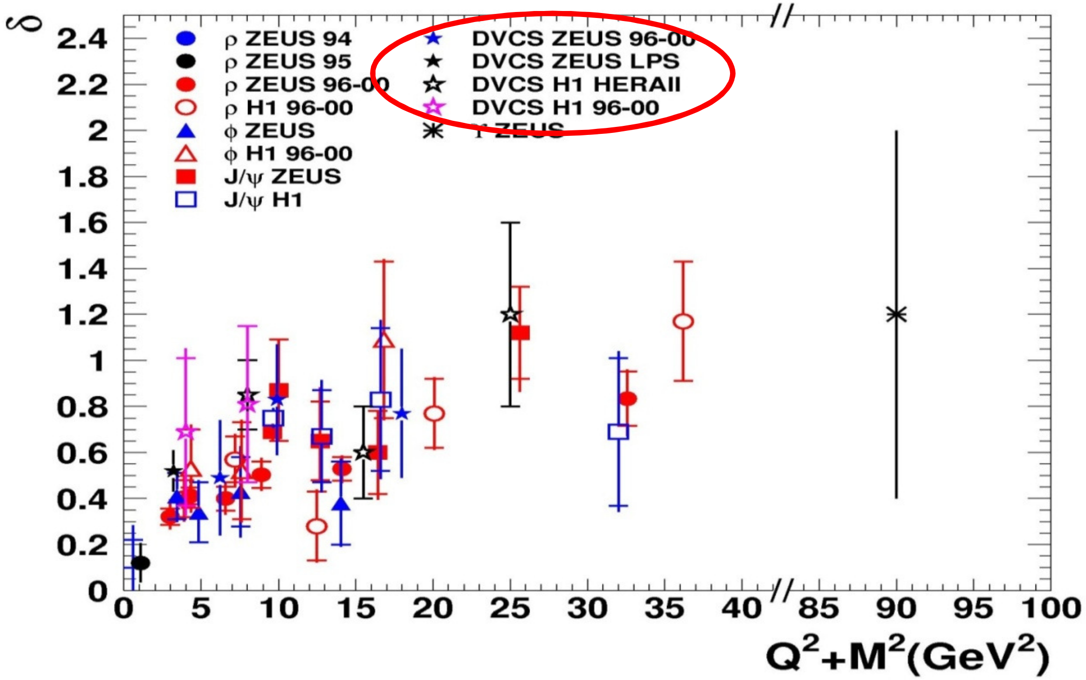


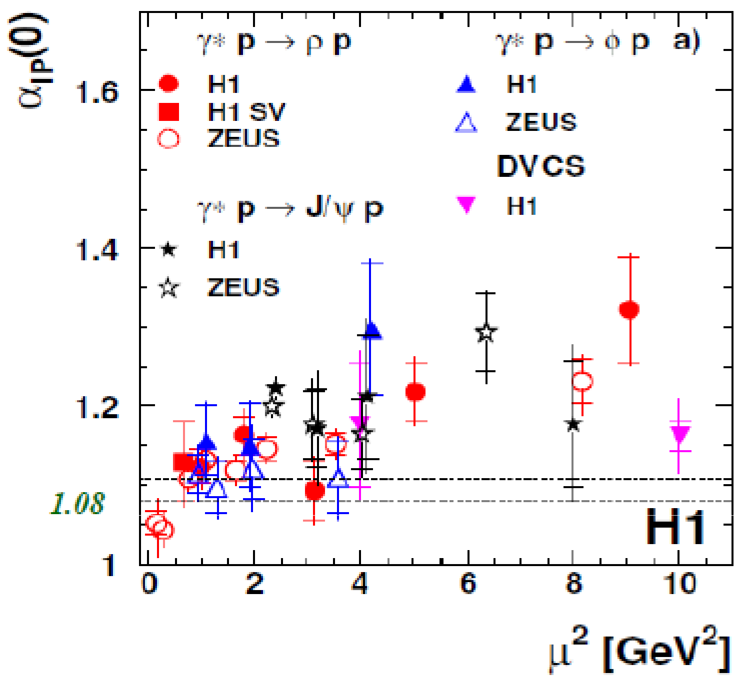
H1 average:
δ=0.63±0.08±0.14

ZEUS (Q^2=3.2 GeV^2):
δ=0.52±0.09

DVCS W-dependence shows a hard regime even at low Q^2 similar to heavy VMs

W-dependence summary





$$\begin{cases} \sigma(W) \propto W^{\delta} \\ \delta(t) = 4(\alpha_{IP}(t) - 1) \end{cases} \Rightarrow \begin{cases} \alpha_{IP}(0) = 1 + \delta/4 + \alpha'_{IP}/\langle |t| \rangle \\ \mu^2 = (Q^2 + M^2)/4 \\ \mu^2 = Q^2 \end{cases}$$

$\mu^2 = (Q^2 + M^2)/4$ → **for VMs**

$\mu^2 = Q^2$ → **for DVCS**

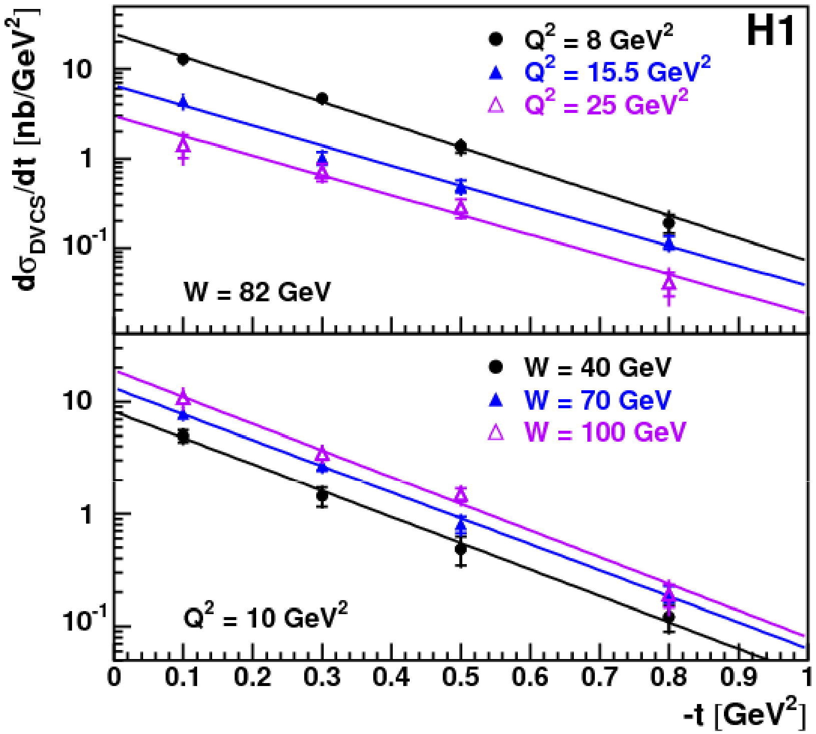
Common hardening of $\alpha_{IP}(0)$ with μ^2

δ increases with μ^2 (from soft to hard)

DVCS - t dependence

145 pb^{-1}

Phys.Lett.B659:796-806,2008

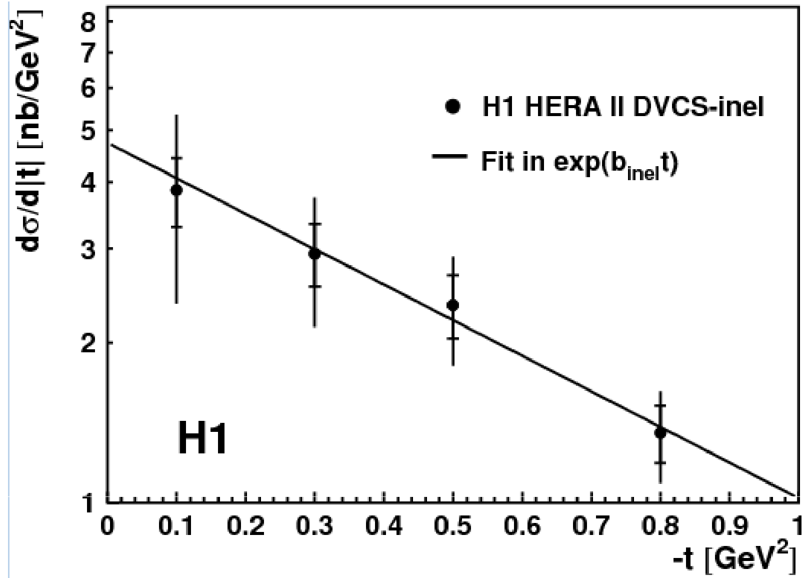


$$t = -\left|\vec{P}_{T_\gamma} + \vec{P}_{T_e}\right|^2$$

$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

b_{el}=5.45 ±0.19 ± 0.34 GeV^{-2}
(Q^2= 8 GeV^2
W= 82 GeV)

Phys.Lett.B681 (2009)

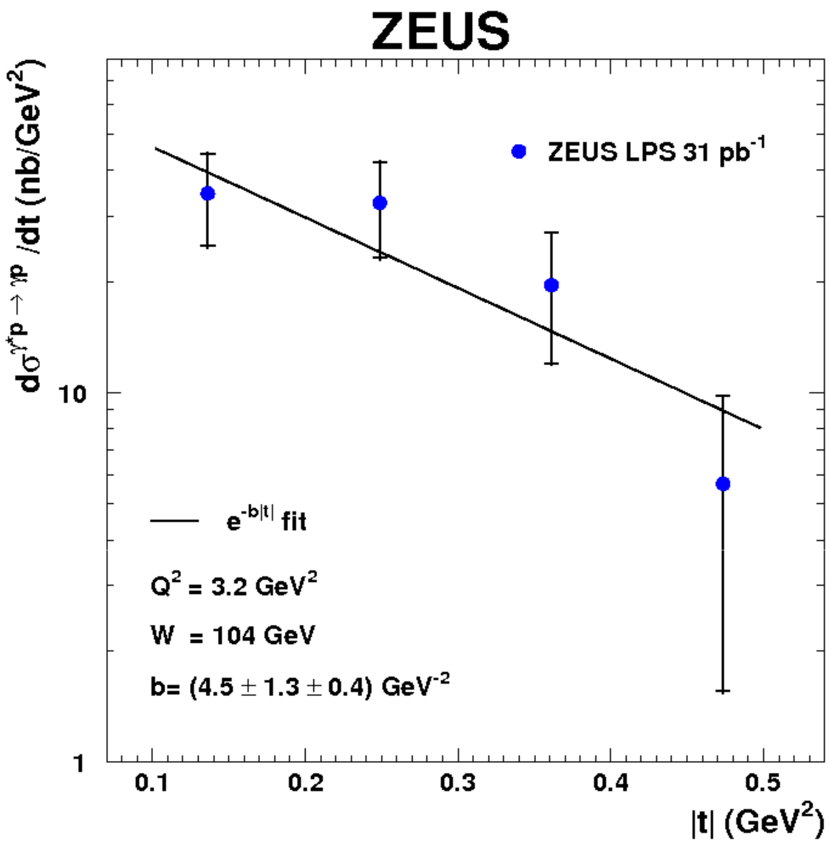


First measurement:
b_{inel}=1.53 ±0.26 ± 0.44 GeV^{-2}
Q^2= 10 GeV^2
W= 82 GeV

mass of the p diss system:
1.4<M_Y<10GeV

306 pb^{-1}

DVCS - t dependence



JHEP05(2009)108

$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

b_{el} = 4.5 ± 1.3 ± 0.4 GeV^{-2}
(Q^2= 3.2 GeV^2)

31.3 pb^{-1}

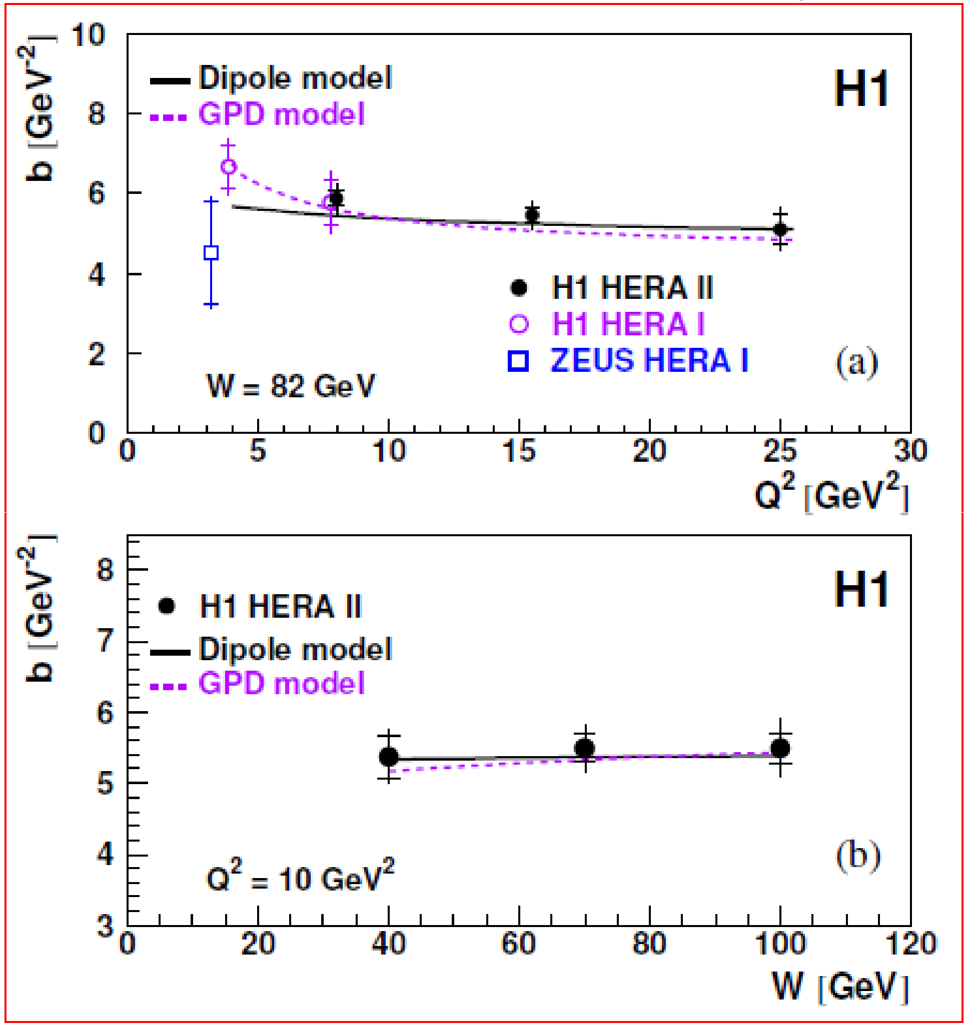
At ZEUS dσ/dt measured for the first time by a direct measurement of the outgoing proton 4-momentum using the LPS spectrometer

No p dissociation background → Clean measurement

Low detector acceptance → low statistics

DVCS - b dependence

H1: Phys.Lett.B681 (2009)



no strong Q^2 dependence

$$b(Q^2) = A(1 - B\log(Q^2/2))$$

(Phys.Rev. D68 (2003) 096006)

$b(Q^2)$ used for GPD model
(Eur. Phys. J. C 58, 2008)

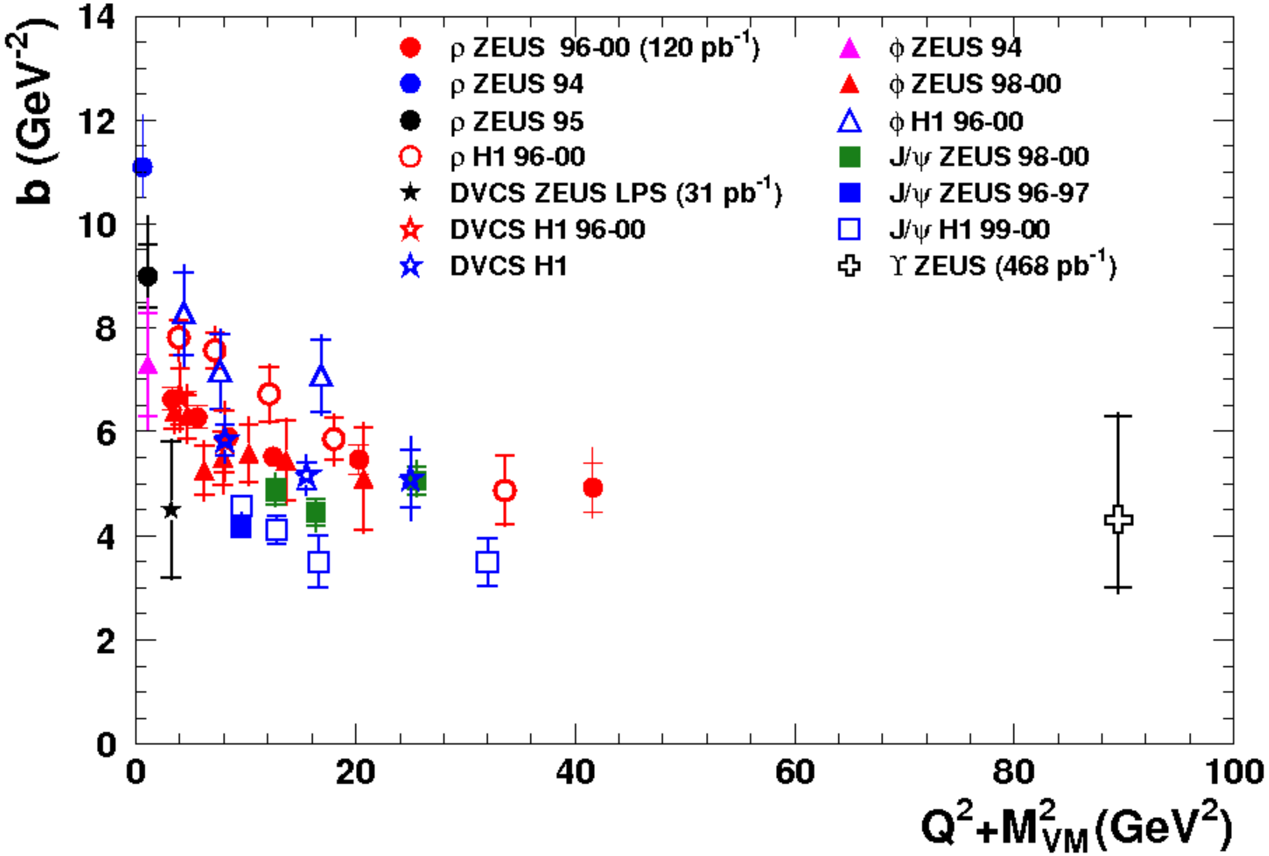
No DVCS data enter for
dipole model parameters
(Marquet, Peschanski,Soyez,
Phys. Rev. D 76, 2007)

no W dependence

$b_{el} = 5.41 \pm 0.14 \pm 0.31$ GeV^{-2}
(Q^2= 10 GeV^2 W=82GeV)

t dependence

Similar slope for all VM vs scale



- b characterize the transversal size of interaction ($b=b_V+b_p$), large dipole for light VM, the size became smaller with scale, where:
  $b_V=1/(Q^2+M^2)$
  $b_p \sim 5$ GeV^{-2}

- b decreases with increasing scale (from soft to hard)

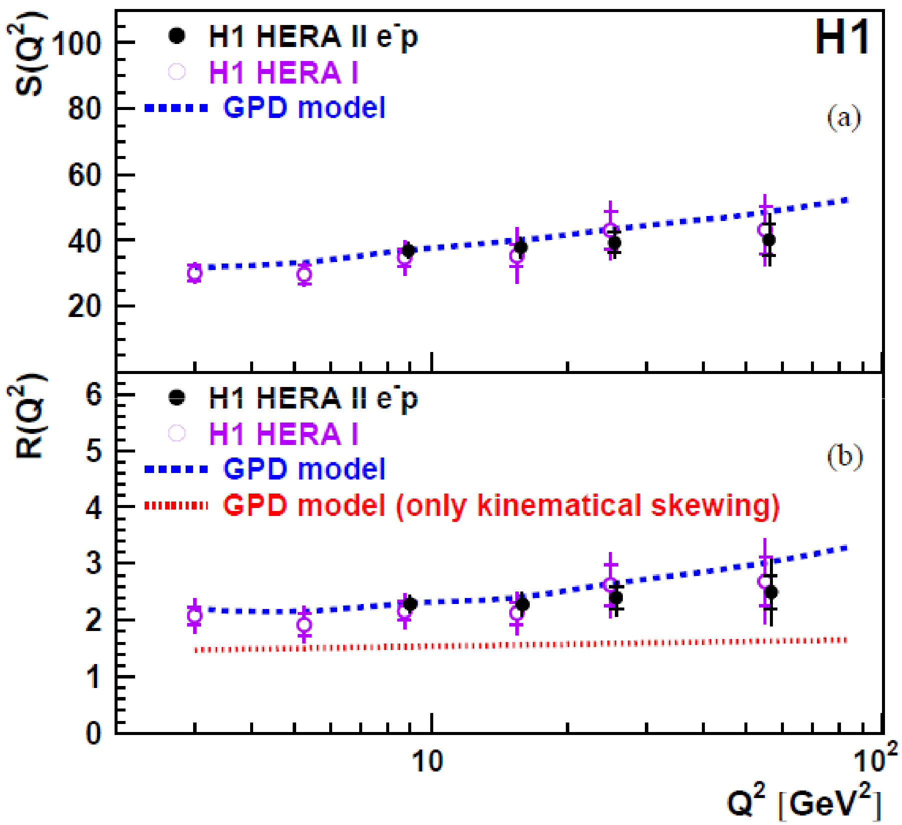
QCD interpretation

H1: Phys.Lett.B659:796-806,2008

S, Q^2 evolution of GPDs
(removing $b(Q^2)$ dependence)

$$S = \sqrt{\frac{\sigma_{DVCS}\, Q^4\, b(Q^2)}{(1+\rho^2)}}$$

compared with GPD model including a pQCD skewed evolution provide a reasonable description



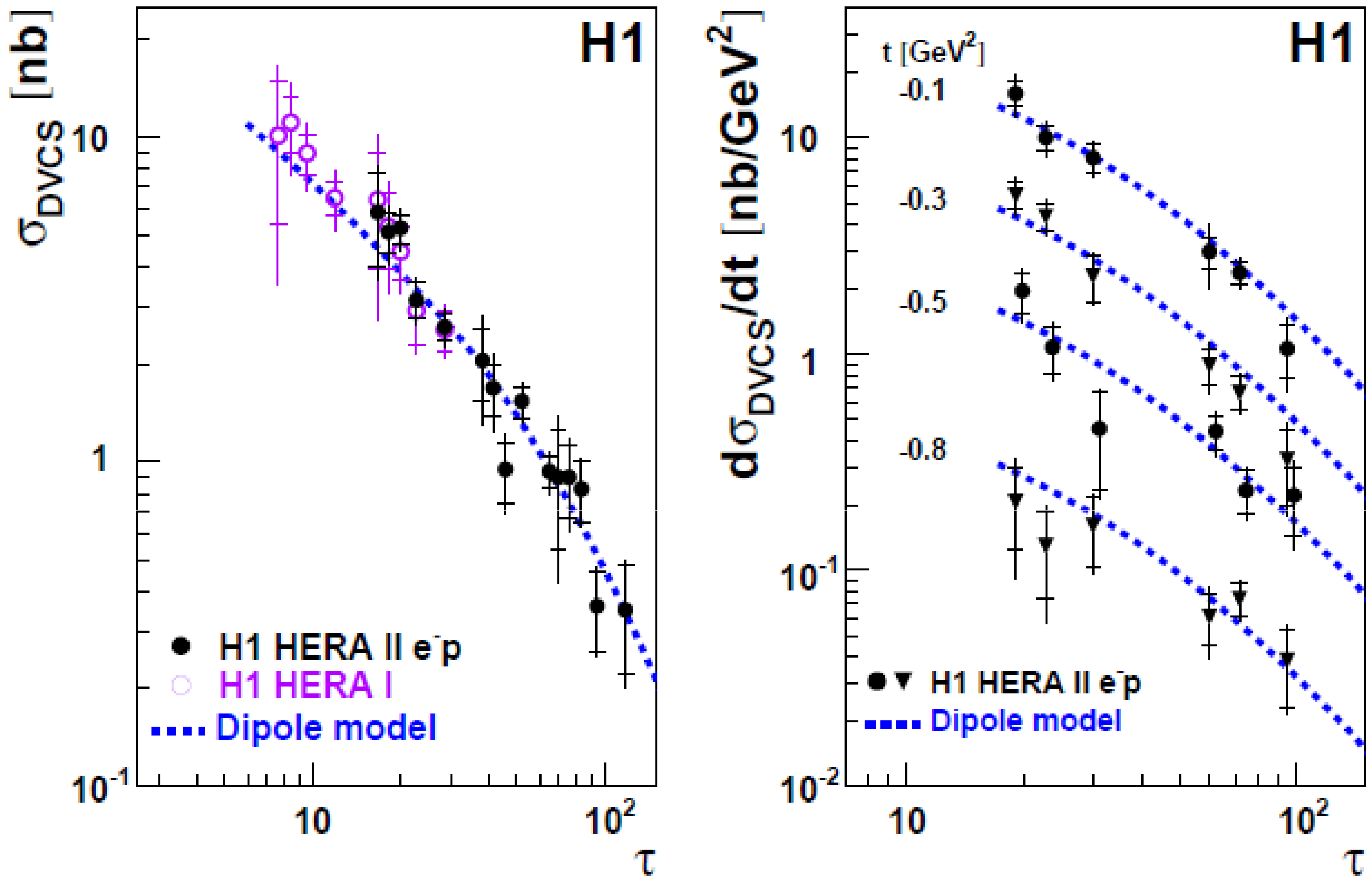
R, the magnitude of the skewing effect:

$$R = \frac{4\sqrt{\pi\, \sigma_{DVCS}\, b(Q^2)}}{\sigma_T(\gamma^* p \to X)\sqrt{(1+\rho^2)}}$$

ratio of the imaginary parts of the DVCS and DIS amplitudes → GPDs/PDFs
The skewing factor is close to 2

Dipole model approach to describe DVCS

H1: Phys.Lett.B659:796-806,2008



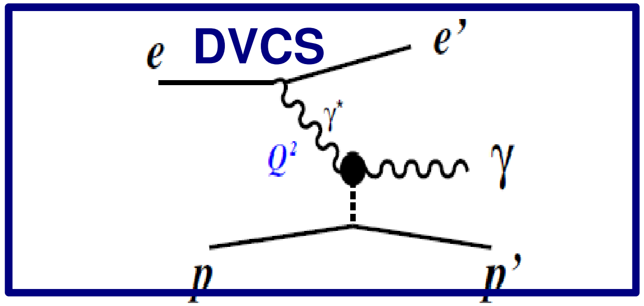
Geometrical scaling:

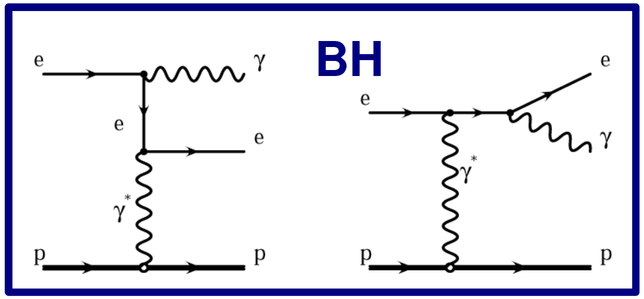
$$\tau = \frac{Q^2}{Q_s^2(x)}$$

Describe reasonably DVCS data

(Marquet, Peschanski,Soyez, Phys. Rev. D 76, 2007)

BCA measured at HERA

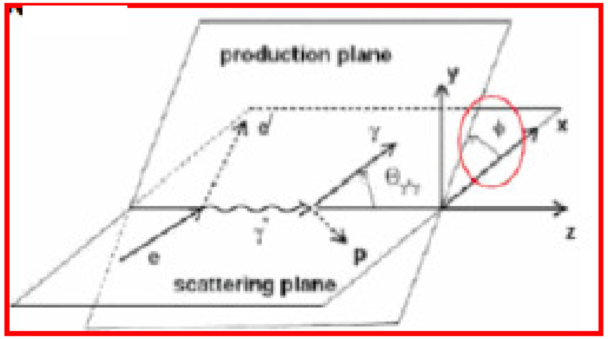




DVCS and BH: identical final state → Interfere

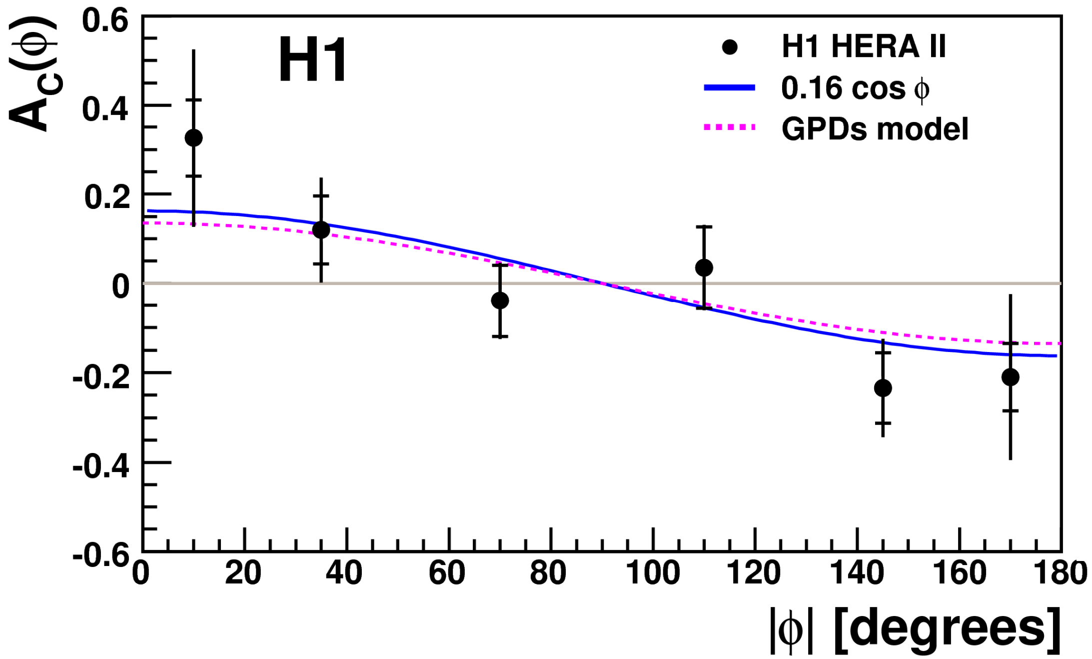
Photon production amplitude: $|A|^2 = |A_{DVCS}|^2 + |A_{BH}|^2 + |A_I|^2$

Beam charge asymmetry: $A_C = \frac{d\sigma^{+.} - d\sigma^{-.}}{d\sigma^{+.} + d\sigma^{-.}} = p_1 \cos\phi \propto Re(A_{DVCS})\cos\phi$



(Belitsky, Mueller, Kirchner convension
hep-ph/0112108)

BCA measured at HERA



$$p_1 = 0.16 \pm 0.04 \pm 0.06$$

$\rho = \mathrm{Re}\, A_{DVCS} / \mathrm{Im}\, A_{DVCS} = 0.20 \pm 0.05 \pm 0.08$

At low x the real part of DVCS amplitude is positive

GPDs based model compatible with data

Summary

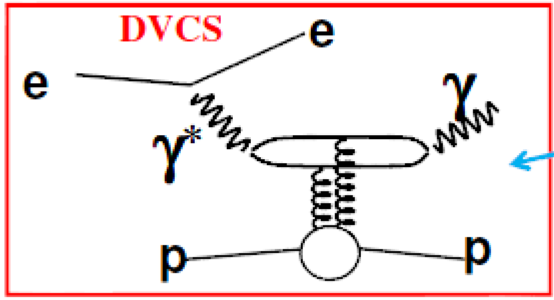
DVCS studied at HERA and new measurements are coming

DVCS measurements contributes to the understanding of the transition from the soft to the hard regime

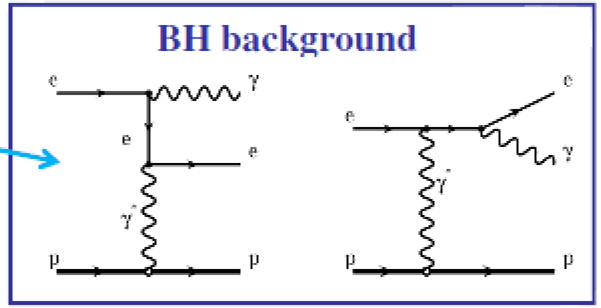
HERA represents a powerful ‘instrument’ to understand diffraction in perturbative regime and to complete the mapping of the proton structure

Very important impact on GPD determination at low x

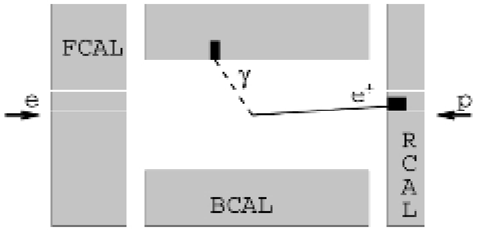
DVCS strategy at HERA

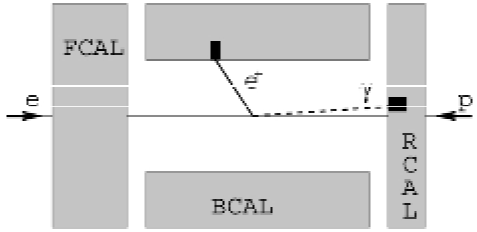


- ✓ two em clusters
- ✓ less the 2 tracks
- ✓ nothing more!



Real photon emitted from the lepton





γ-Sample: no tracks matching to the second candidate: DVCS+BH

e-Sample: a track match to the second candidate: BH+ Dilepton+J/Ψ

Wrong sign e-Sample: a negative track match to the forward candidate (Dilepton+J/Ψ)