Deeply Virtual Compton Scattering

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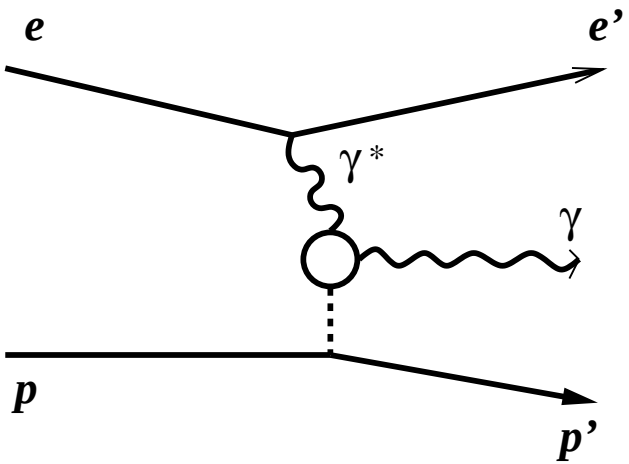
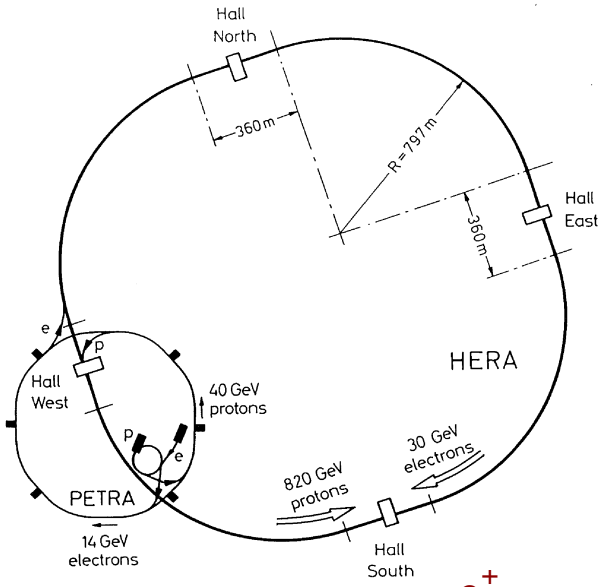
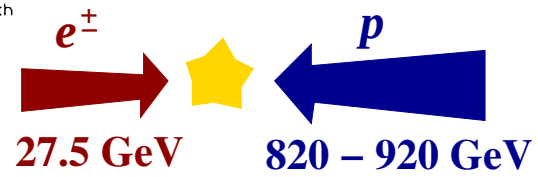
on behalf of the H1 and ZEUS Collaborations



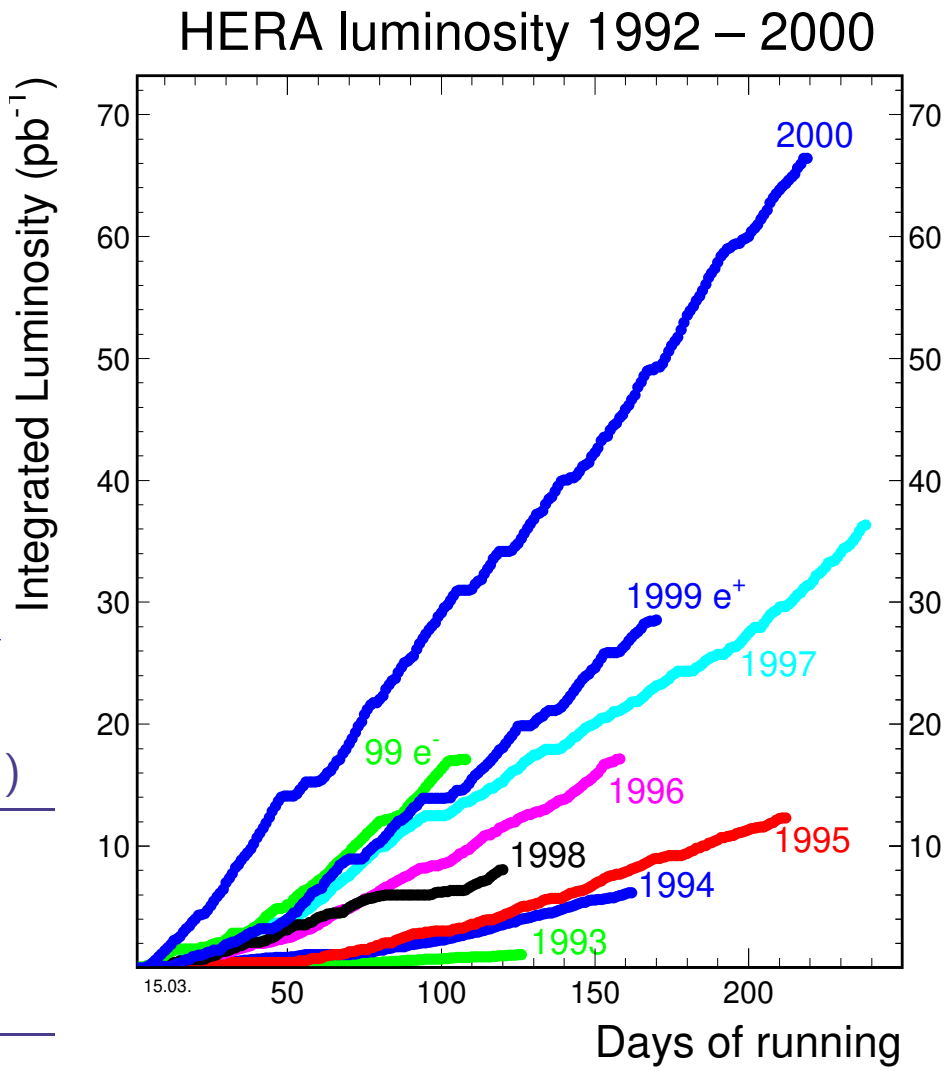
- **Introduction**
- **Strategy for measuring DVCS**
- **H1 cross sections**
- **ZEUS cross sections**
- **Summary**
- **Outlook**

HERA - A Unique Collider



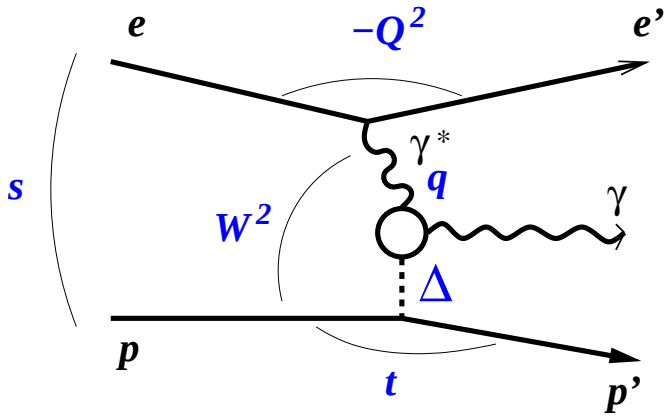


Year	Beam	$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})
1996 - 1997	e^+p	300	50
1998 - 1999	e^-p	320	25
1999 - 2000	e^+p	320	95



DVCS

DVCS diagram:



$s = (e+p)^2$ $(\sqrt{s} = 300 \text{ GeV})$

$W^2 = (q+p)^2$ $(30 < W < 140 \text{ GeV})$

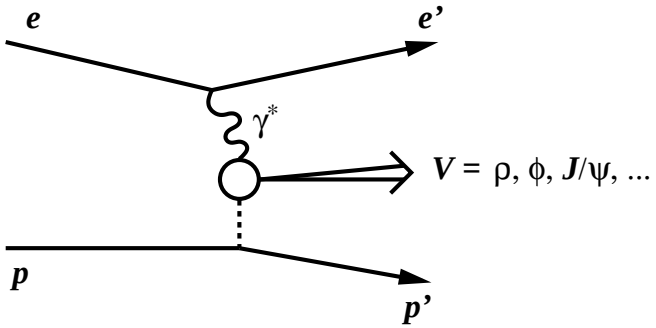
$Q^2 = -q^2 = -(e-e')^2 = sxy$ $(Q^2 > 2 \text{ GeV}^2)$

$x = Q^2/2p \cdot q$

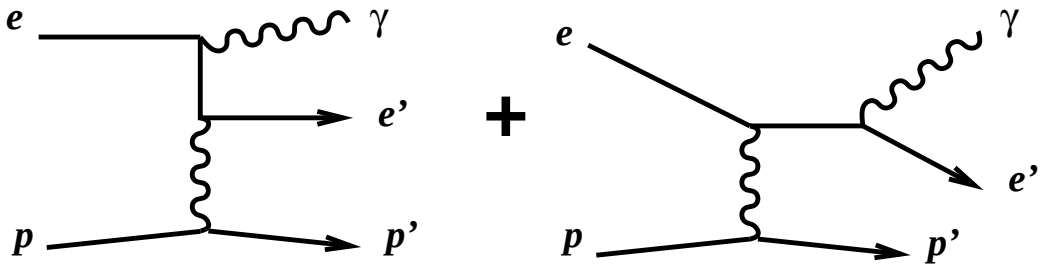
$y = p \cdot q/p \cdot e$

$t = \Delta^2 = (p-p')^2 \approx -p_T'^2$

Compare Vector Meson prodn.



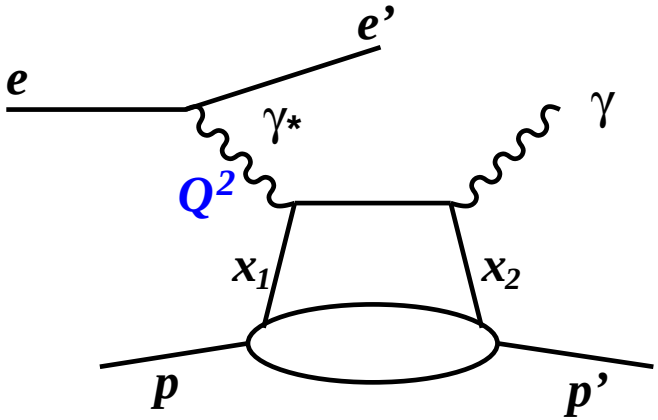
Note: DVCS competes with QED Compton (completely calculable)



DVCS Process in QCD

Handbag diagram at high-x:

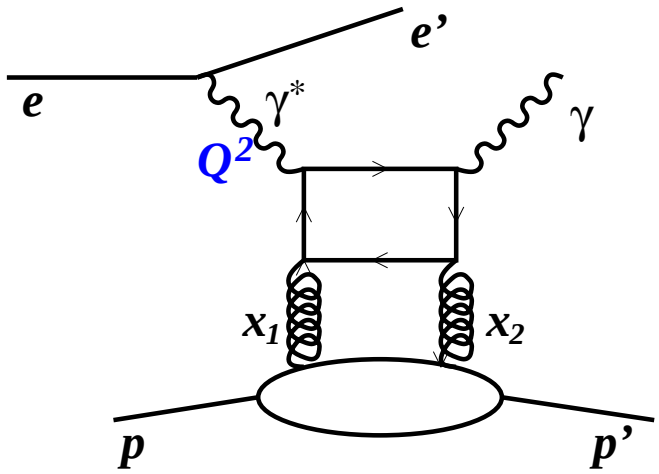
(HERMES and JLAB)



$x_1 \neq x_2$

Dominant contribution at low-x?

(ZEUS and H1)



Why is DVCS Interesting?

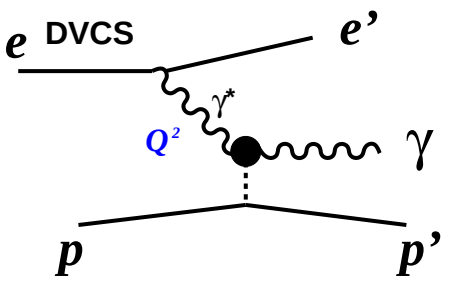
Skewed Parton Distributions.

- Generalisations of the usual pdfs 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.

QCD-based model predictions at low-x



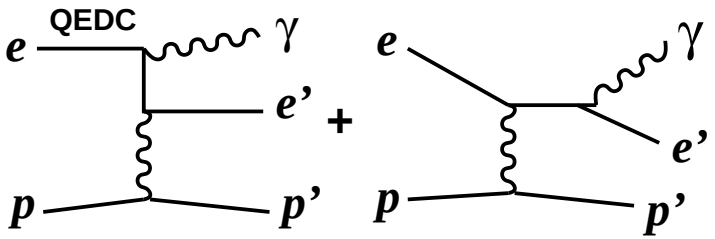
not predicted by models

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

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

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

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

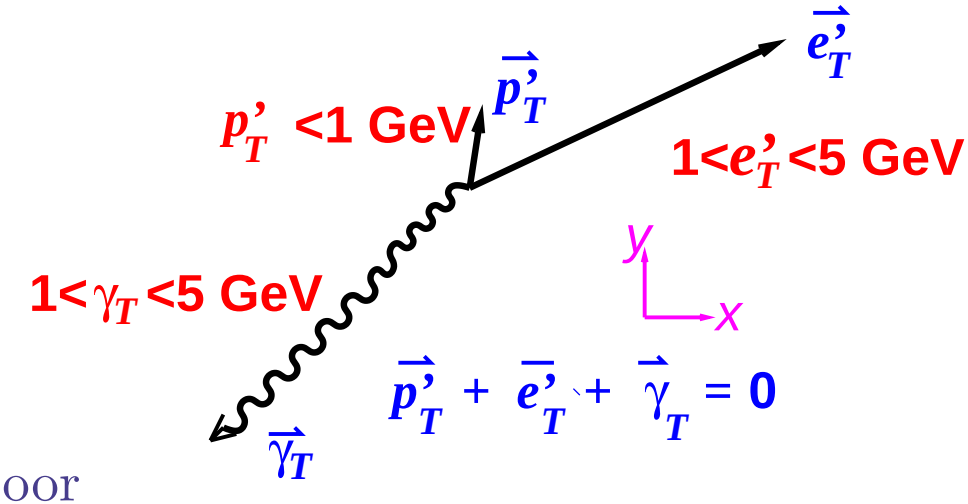


$$\frac{d\sigma^{\mathrm{QEDC}}}{dxdydtd\phi_r} \sim \frac{1}{Q^4}\frac{1}{|t|}$$

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

ϕ_r AND t ARE DIFFICULT TO MEASURE!

$\phi_r = \phi_{e'} - \phi_{p'}$
$t = (p - p')^2 \approx -p_T^{'2}$



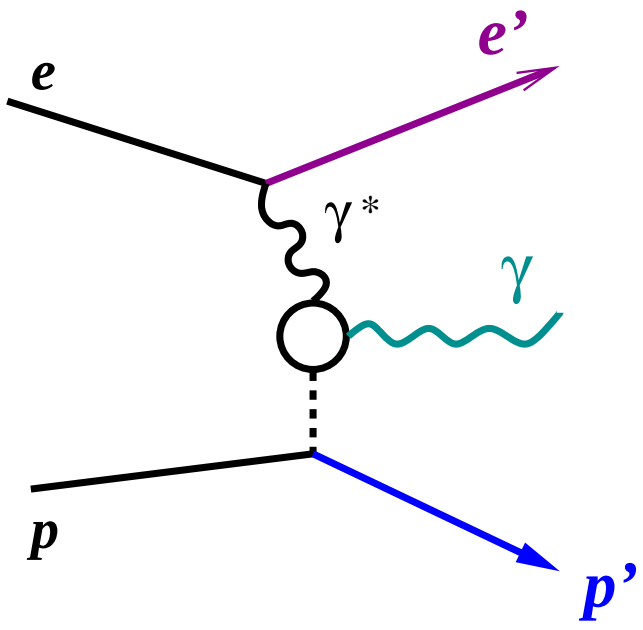
Scattered proton is not observed
$\Rightarrow$ must infer its $\vec{p'}_T$ from e' and γ:

However, resolution on e'_T and γ'_T is poor
$\Rightarrow$ difficult to measure $\vec{p'}_T$ well, thus ϕ'_p
$\Rightarrow$ measurement of ϕ_r (and SPDs) is longer term goal

So far, focus has been on detecting DVCS in data

Note: $\cos\phi_r$ term integrates to zero since scattered proton is not observed, so need only consider DVCS+QEDC (no interference term)

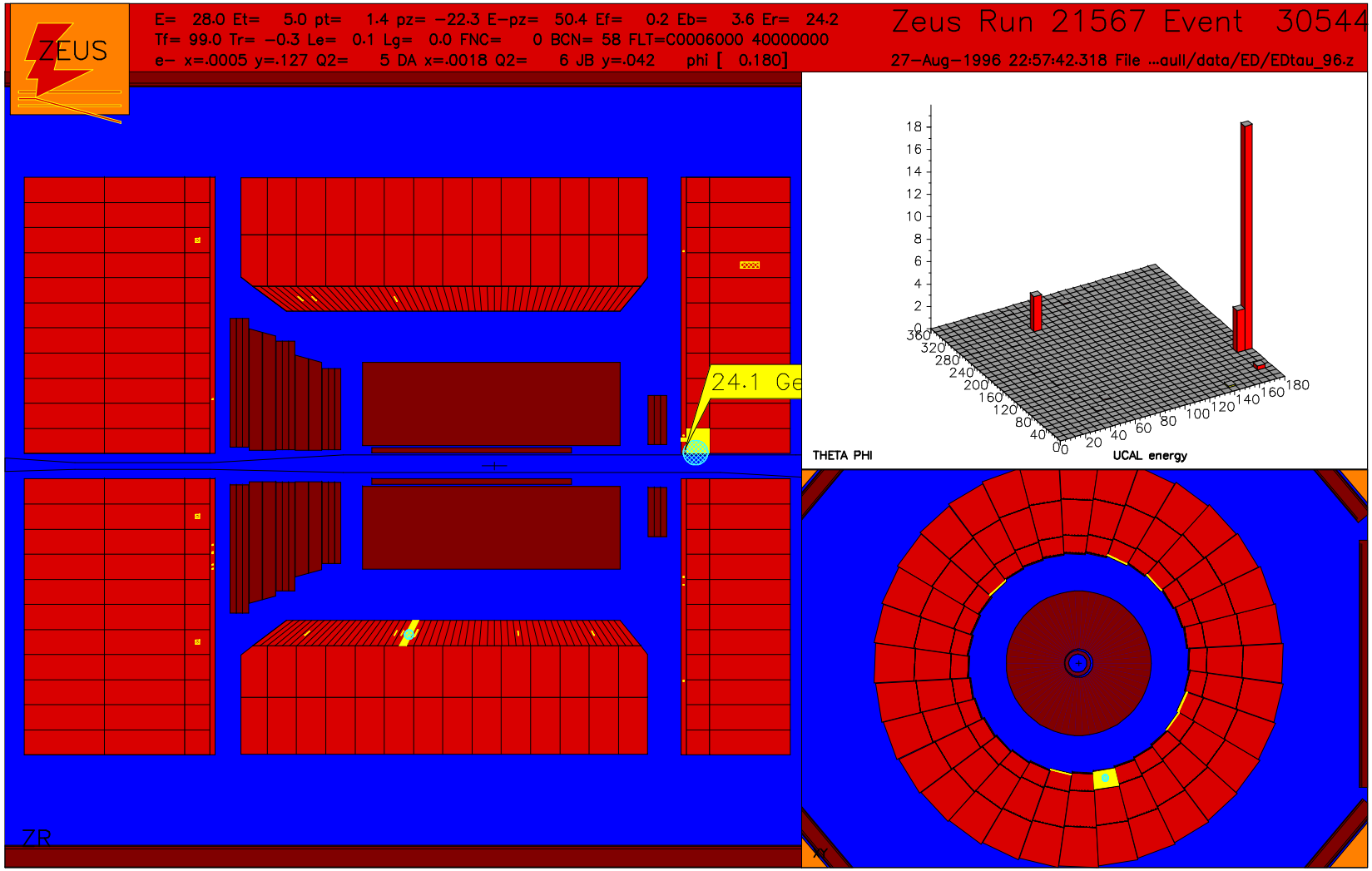
Investigating DVCS at HERA is challenging



- e typically scatters at low angles
  $\rightarrow$ no tracks in the event (no vertex)
  $\rightarrow$ kinematics poorly reconstructed
- unlike vector meson case (e.g. $\rho \rightarrow \pi^+\pi^-$)
  there is no mass constraint from which to profit
  $\rightarrow$ is it really a γ? (could be π^0, η)
- scattered proton is not observed
  $\rightarrow$ only e and γ in final state
- $\sigma^{\text{DVCS}} \ll \sigma^{\text{QEDC}}$

Nevertheless, DVCS has been observed at HERA
$\Rightarrow$ First observation by ZEUS presented at Tampere in 1999 [hep-ex/0003030]

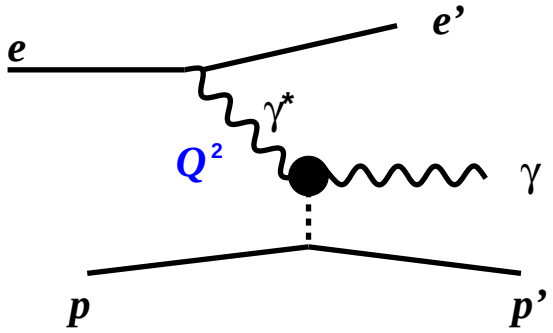
DVCS Candidate Event in the ZEUS Detector



Strategy for Detecting DVCS

DVCS

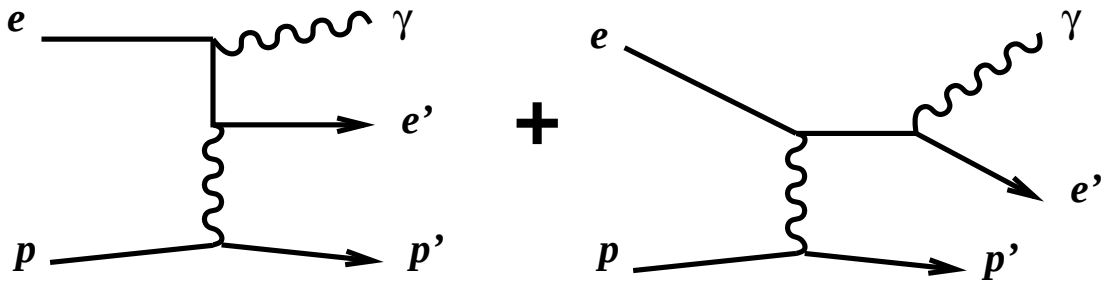
– e scatters at low angles



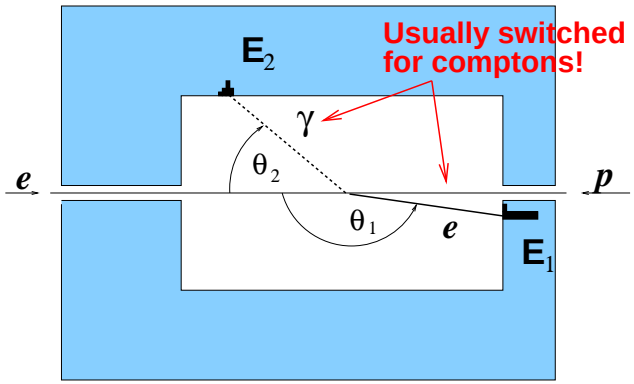
QEDC

– γ scatters at low angles

– suppress with cuts on θ_1, θ_2



Typical DVCS topology:

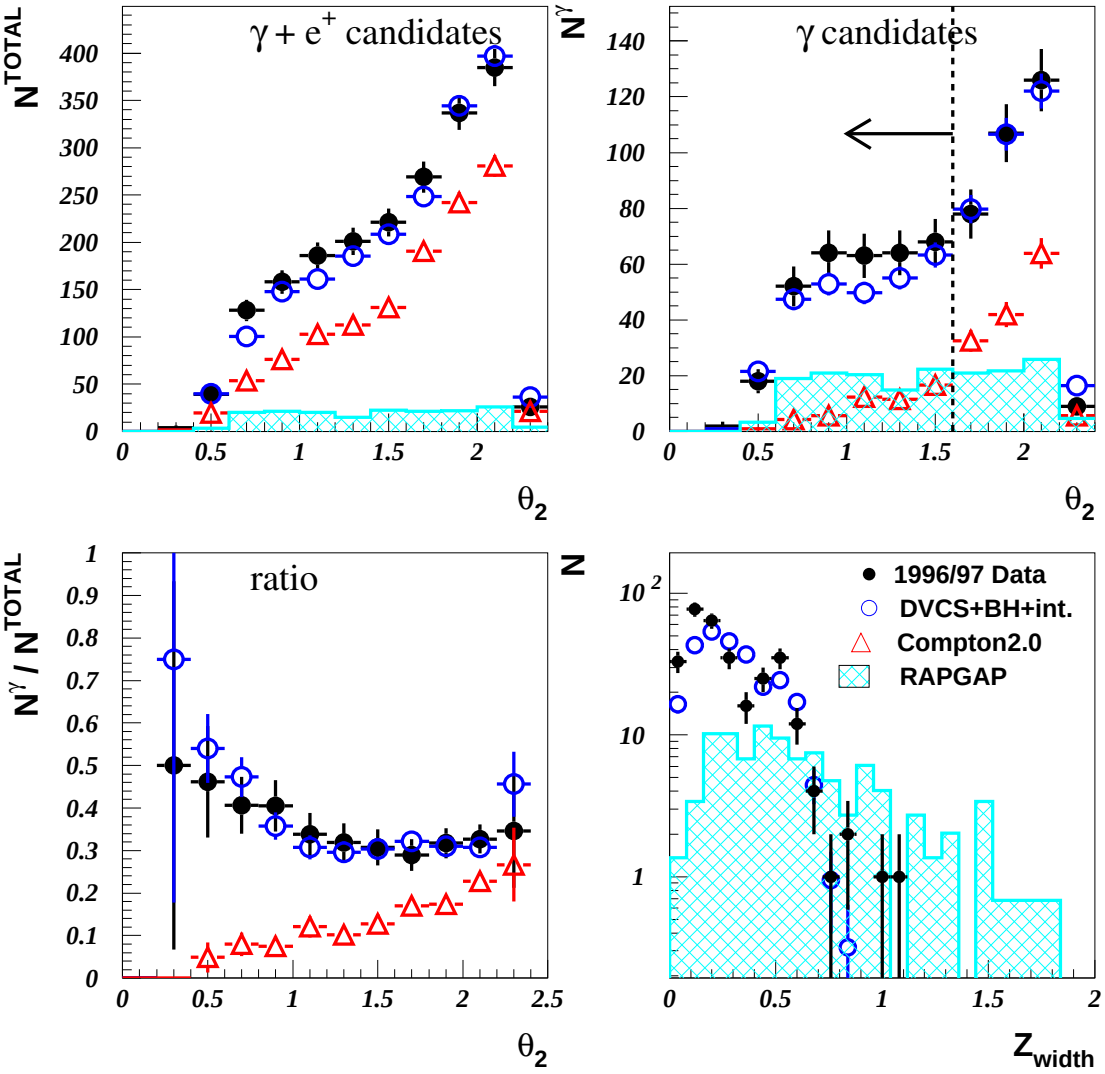


Main selection requirements:

- 2 EM clusters in detector and nothing else
- 0 or 1 track; if 1, must be matched to a cluster
- $\theta_1 > 2.8$ rad (DVCS e^+ scatters at low angle)
- $\theta_2 < 2.4$ rad (DVCS γ prominant at low y)
- $|\theta_1 - \theta_2| > 0.8$ rad (Compton suppression)
- $E_2 > 2$ GeV, $Q^2 > 6$ GeV^2, $M_{12} < 30$ GeV

First observation of DVCS at HERA

ZEUS 1996/97 Preliminary



Excess of events in good agreement with FFS QCD–based prediction.

⇒ First observation of DVCS at HERA.

(presented at EPS99 in Tampere)

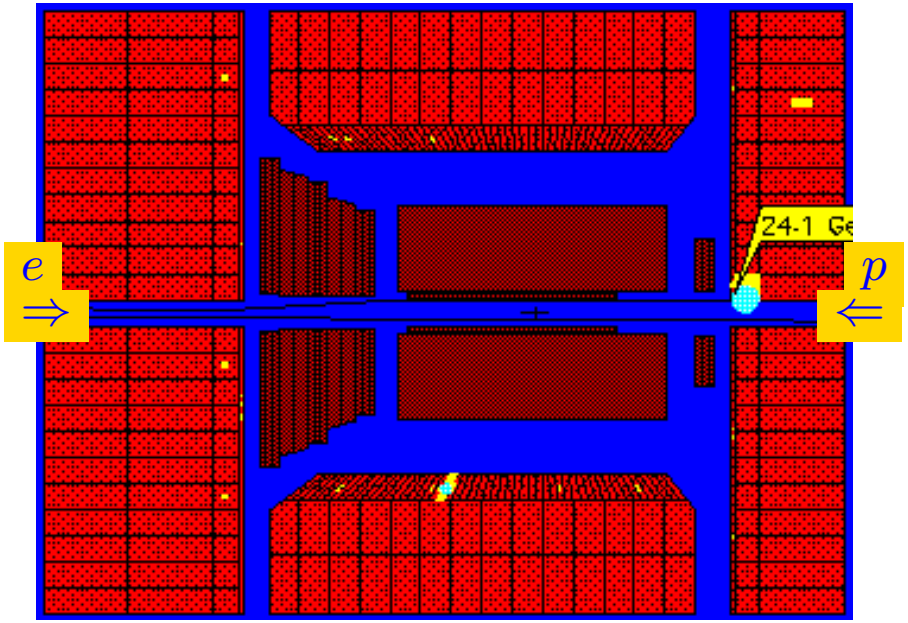
$$Z_{\text{width}} = \frac{\sum |Z_{\text{cell}} - \overline{Z}| \times E_{\text{cell}}}{\sum E_{\text{cell}}}$$

⇒ π^o / η hypothesis cannot account for shower shapes

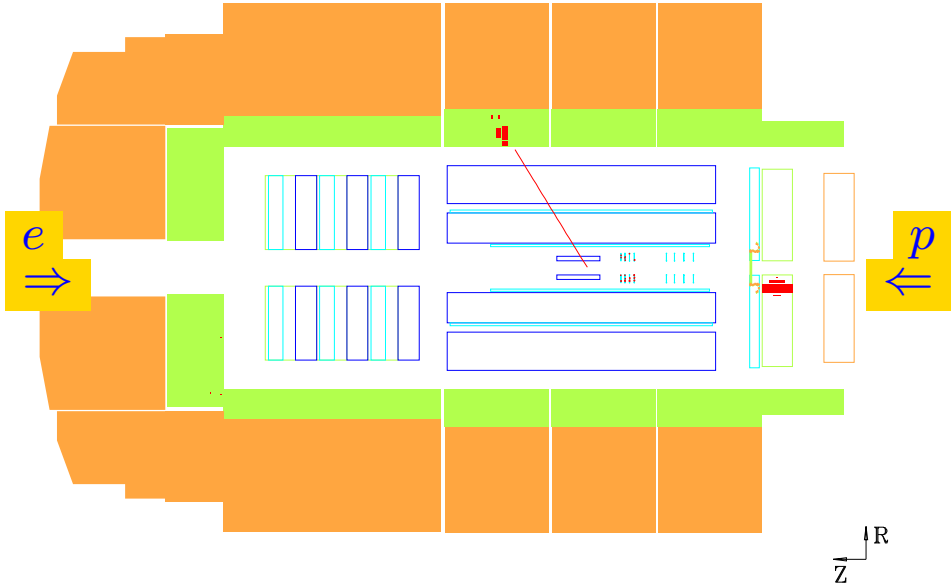
Strategy for extracting cross section

Topology studied and analysis strategy is same for both ZEUS and H1:

case 1: γ sample (enriched DVCS)
Both DVCS and QEDC contribute



case 2: e^+ sample (control)
QEDC alone contributes



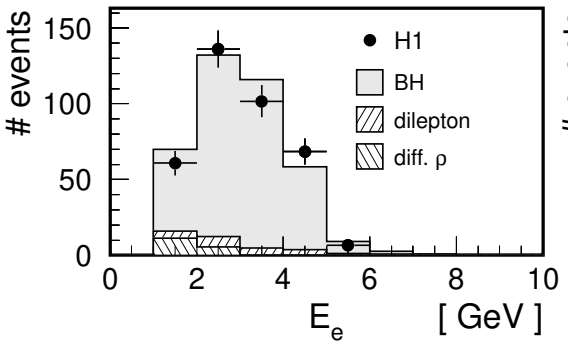
If QEDC MC describes case 2, use it to subtract QEDC contribution in case 1

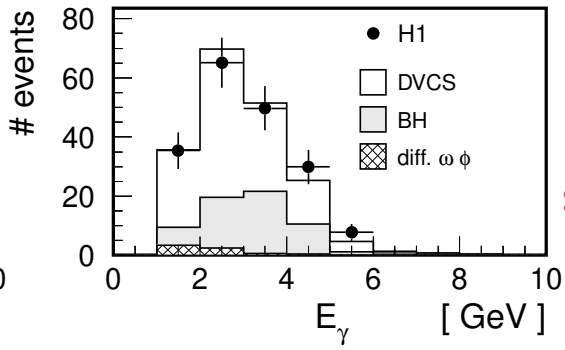
Comparison of ZEUS and H1 analyses

H1	**ZEUS**
Main selection requirements:	
1 EM cluster in Lar with $p_T > 1$ GeV	1 EM cluster in BCAL with $E_T^{\mathrm{BCAL}} > 3$ GeV
1 EM cluster in SpaCAL with $E > 15$ GeV	1 EM cluster in RCAL with $E^{\mathrm{RCAL}} > 10$ GeV
No other cluster with $E > 0.5$ GeV	Remaining CAL energy < 0.2 GeV
0 or 1 tracks, must point to cluster	0 or 1 tracks, must point to cluster
$2 < Q_e^2 < 20$ GeV^2	$5 < Q_e^2 < 100$ GeV^2
$30 < W_{\mathrm{DA}} < 120$ GeV	$40 < W_{\mathrm{DA}} < 140$ GeV
$(-1.15 < \eta_{\mathrm{Lar}} < 1.5)$	$-0.6 < \eta_{\mathrm{BCAL}} < 1.0$
Events satisfying selection cuts:	
$338(e) + 172(\gamma)$	$1059(e) + 537(\gamma)$
from $8\mathrm{pb}^{-1}$ of '97 e^+p data	from $37\mathrm{pb}^{-1}$ of '96-'97 e^+p data
Cross section definitions:	
$2 < Q^2 < 20$ GeV^2	$5 < Q^2 < 100$ GeV^2
$30 < W < 120$ GeV	$40 < W < 140$ GeV
$\lvert t \rvert < 1$ GeV^2	$E_T^\gamma > 3$ GeV
	$-0.6 < \eta_\gamma < 1.0$

H1 CONTROL PLOTS

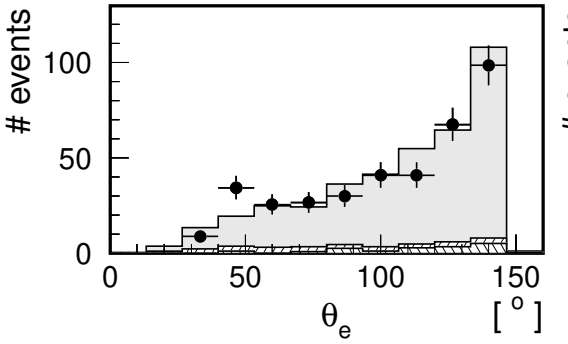
Control sample→
(primarily QEDC)

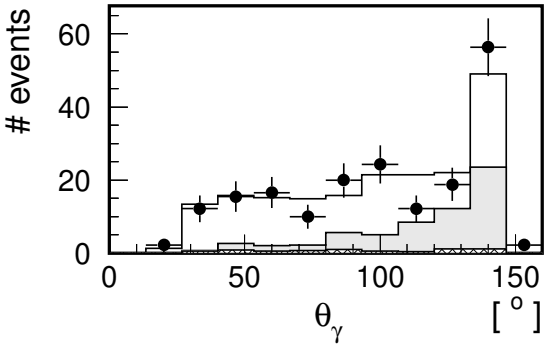




← Enriched DVCS sample (primarily DVCS)

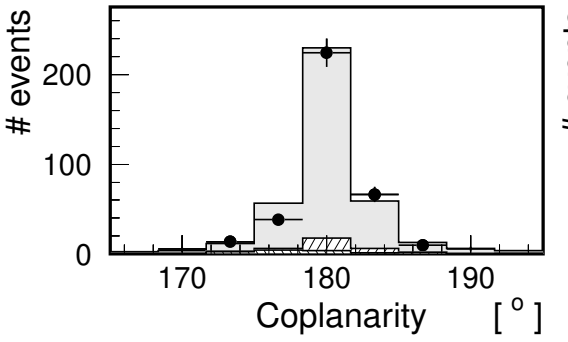
Good agreement between data and MC

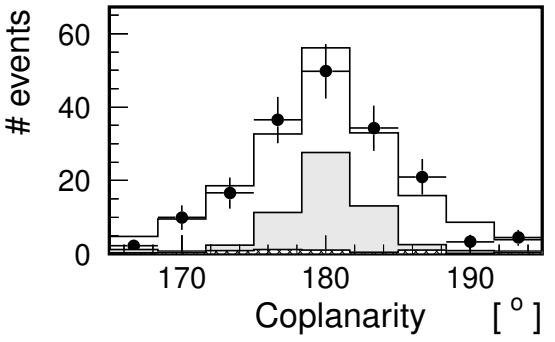




DVCS MC scaled to agree with data

Detector well understood

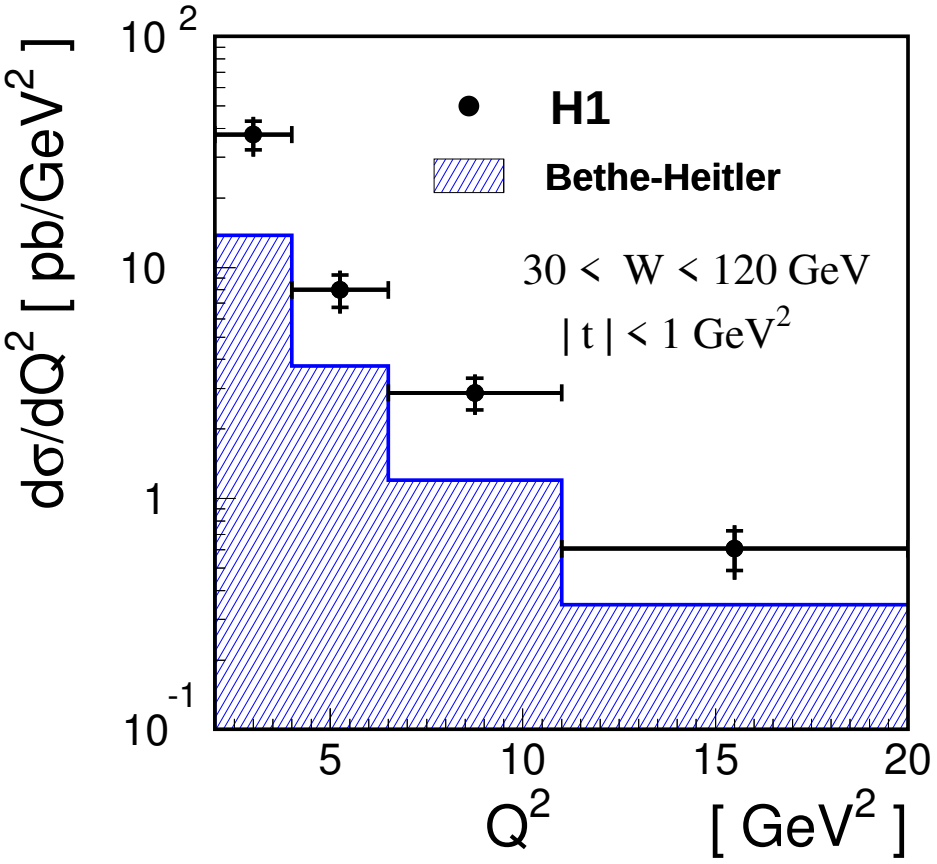


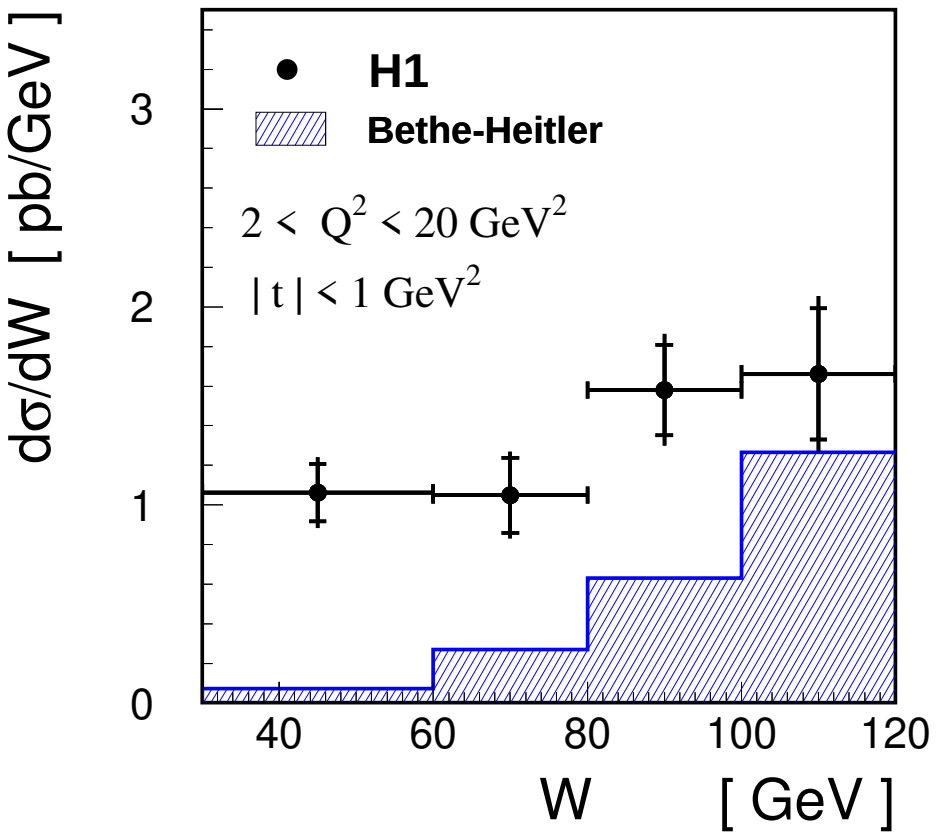


Good agreement between data and MC

H1 $e^+p \to e^+p\gamma$ cross sections

Differential cross sections $d\sigma/dQ^2$ and $d\sigma/dW$





Clear excess above QED Compton prediction

H1 DVCS cross sections

Cross sections for elastic DVCS process $\sigma^{\gamma^* p \to \gamma p}$