Deeply Virtual Compton Scattering

and

Light Cone Wave Function of the Photon

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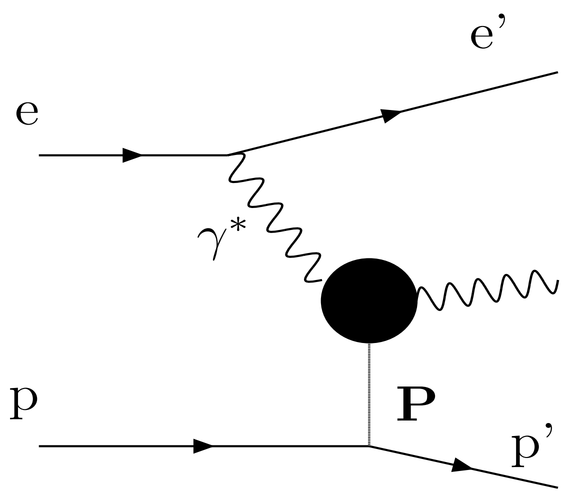
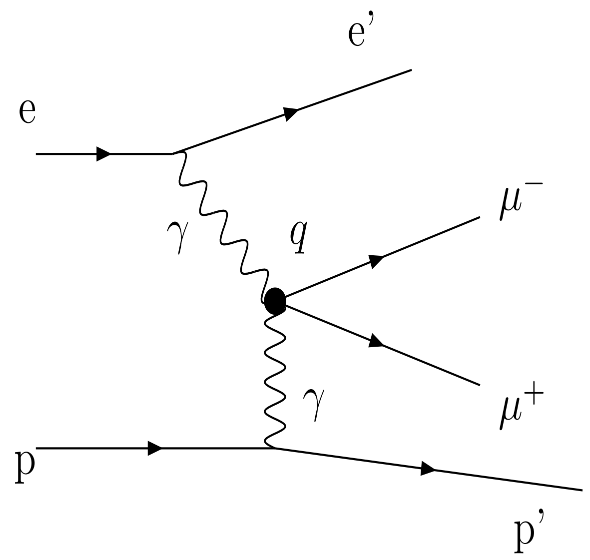
for the ZEUS Collaboration



DVCS



LCWF

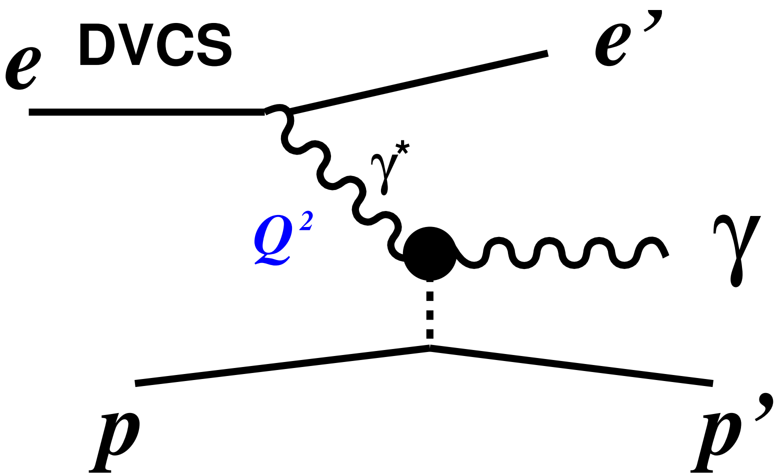
Deeply Virtual Compton Scattering

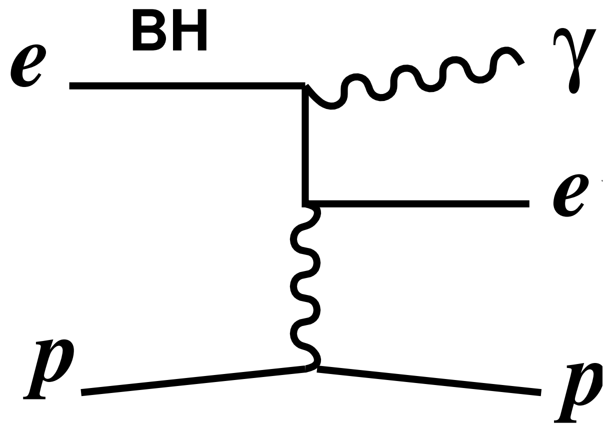
Deeply Virtual Compton Scattering (DVCS)

$\longrightarrow$ diffractive scattering of the virtual photon

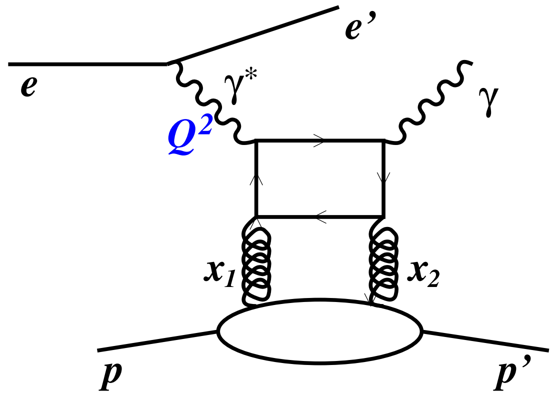
- Interference between QCD with QED (BH) amplitudes $\longrightarrow$ rich structure in ϕ, angle between the hadronic and leptonic planes $\longrightarrow$ asymmetries (angular,charge)

  $\longrightarrow$ gives access to the Generalized Parton Distributions GPDs





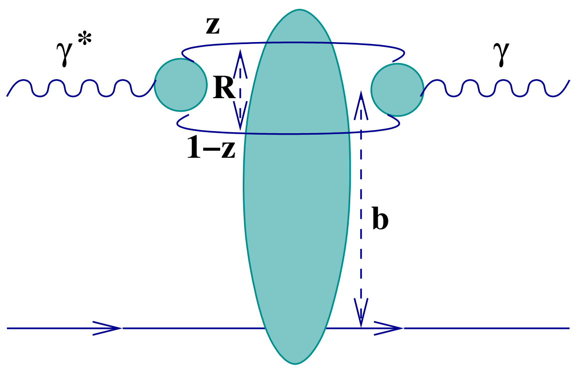
QCD Models for DVCS



QCD-based Model - Frankfurt, Freund and Strikman (FFS):

$$\frac{d^3\sigma_{\rm DVCS}}{dx dQ^2 dt} = \frac{\pi^2\alpha^3}{2xR^2Q^6}[1+(1-y)^2]e^{bt}F_2^2(x,Q^2)(1+\rho^2)$$

NLO calculation Freund, McDermott



Colour Dipole Model - Donnachie and Dosch (DD), Forshaw,Kerley and Shaw (FKS), McDermott,Frankfurt,Guzey and Strikman (MFGS)

$$\mathcal{A} \sim \int_{R,z} \psi_{in}^{\gamma^*}\sigma_D\psi_{out}^{\gamma}$$

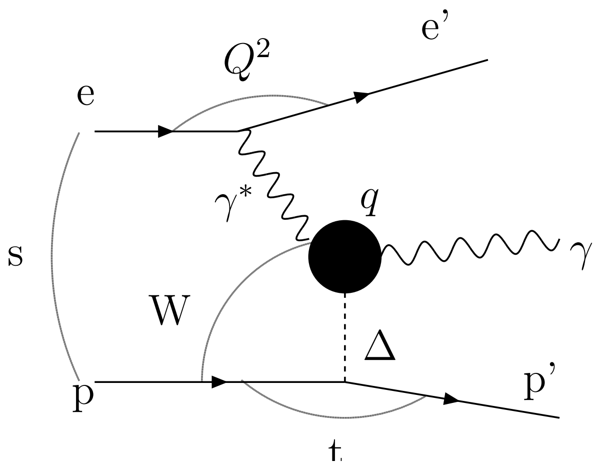
σ_D - dipole-p cross section

$\psi_{in}^{\gamma^*}$ - light-cone wave function of the incoming photon

ψ_{out}^{γ} - light-cone wave function of the outgoing photon

DVCS - event selection

ZEUS: e^+p sample, $95\,pb^{-1}$, e^-p sample $17\,pb^{-1}$



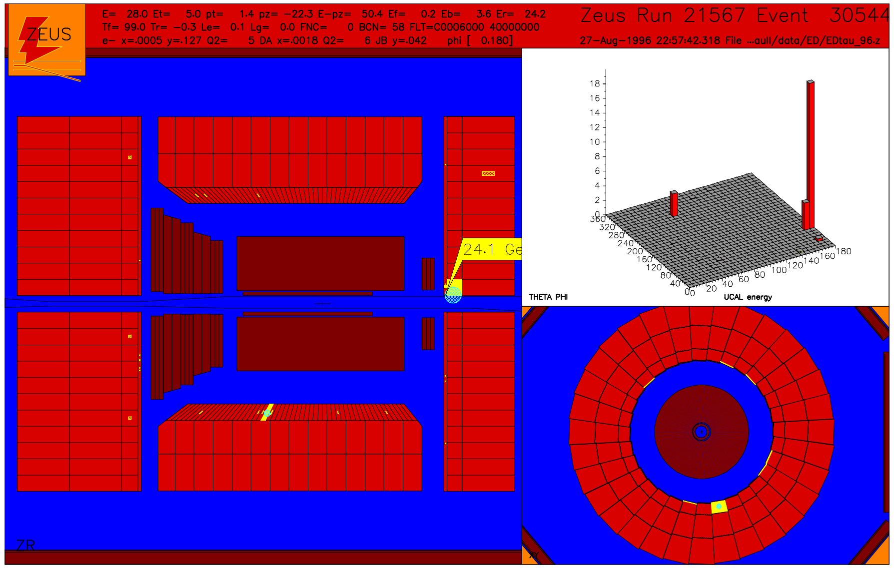
HERA

$$\sqrt{s} = 300, 320\,\text{GeV}$$

$$5 < Q^2 < 100\,\text{GeV}^2$$

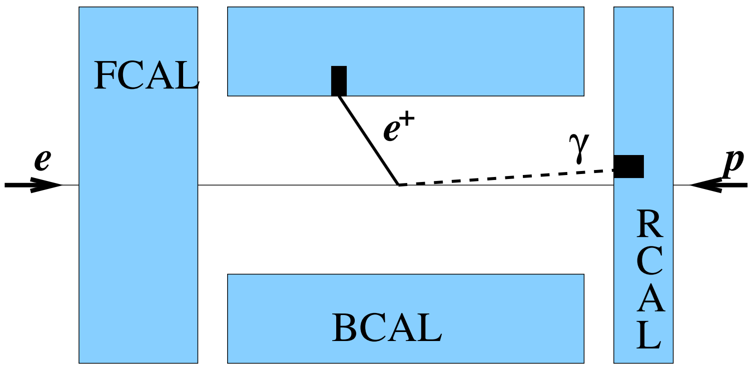
$$40 < W < 140\,\text{GeV}$$

$$10^{-4} < x < 10^{-2}$$



- 2 EM clusters
- 0 or 1 Track; if 1, must be matched to EM cluster
- No other activity above noise level to reject events where the proton dissociates

DVCS - event topology

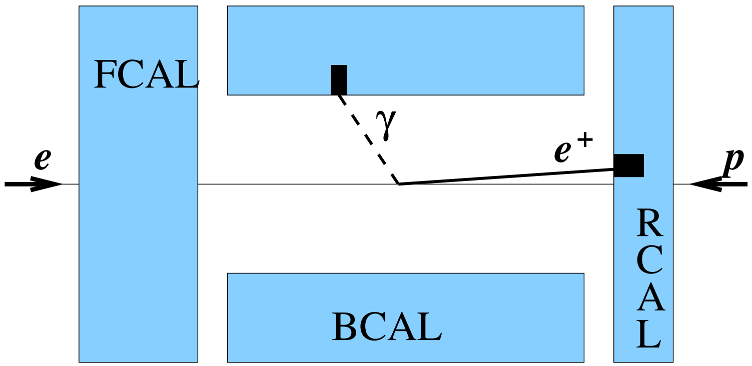


γ from QED bremsstrahlung emitted

in e-beam direction

e^+ sample CONTROL SAMPLE

only BH contributes, 7000 events



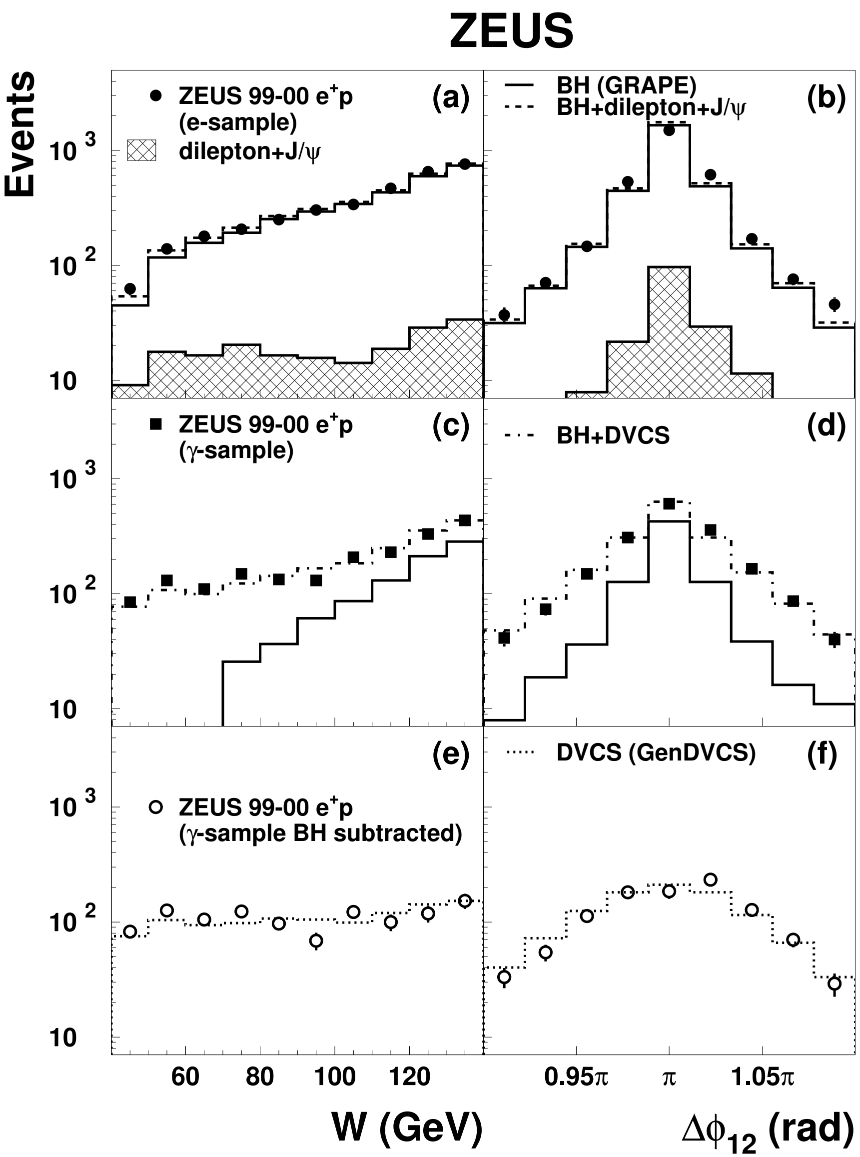
γ sample ENRICHED WITH DVCS

both BH and DVCS contribute, 4000 events

BH MC describes data in control sample

$\longrightarrow$ use MC to subtract BH in enriched DVCS sample

DVCS - control plots

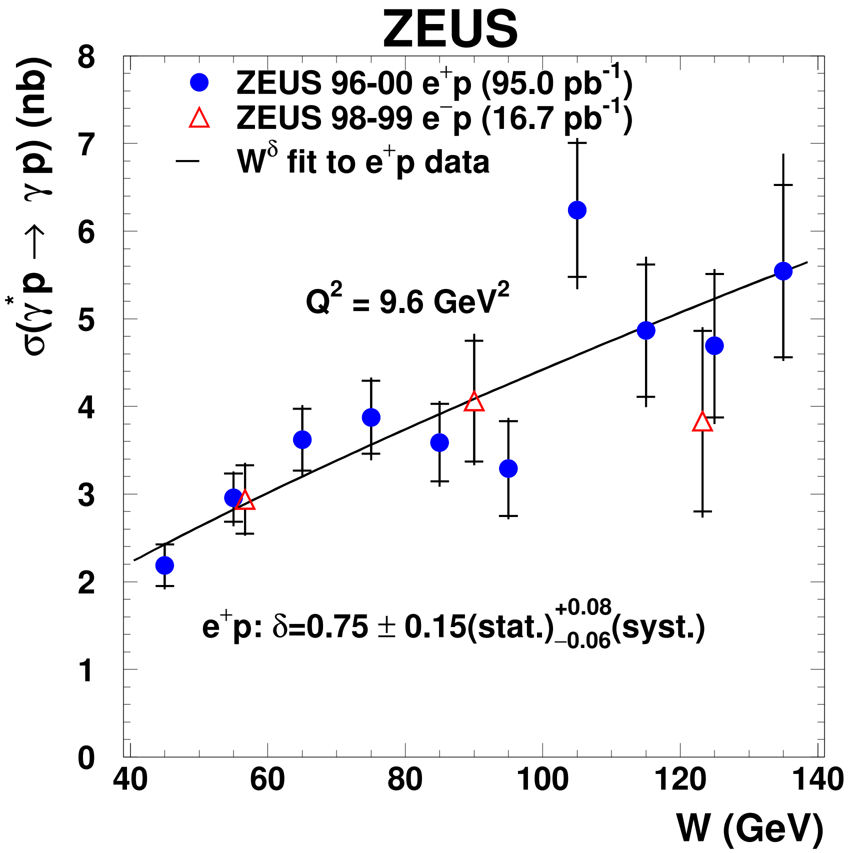


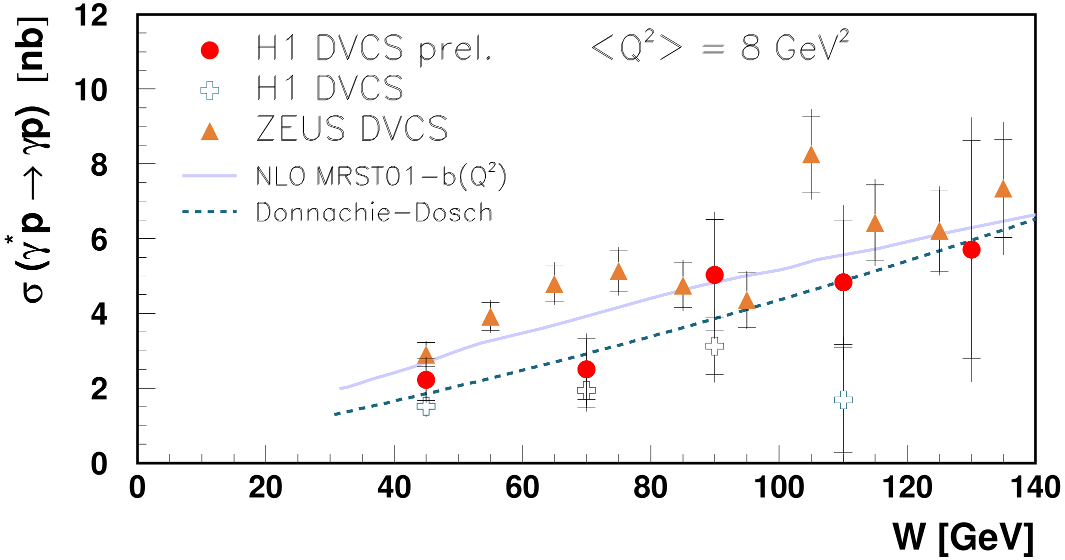
e^+ sample BH control sample

γ sample DVCS + BH

γ sample after BH subtraction DVCS

DVCS - W dependence

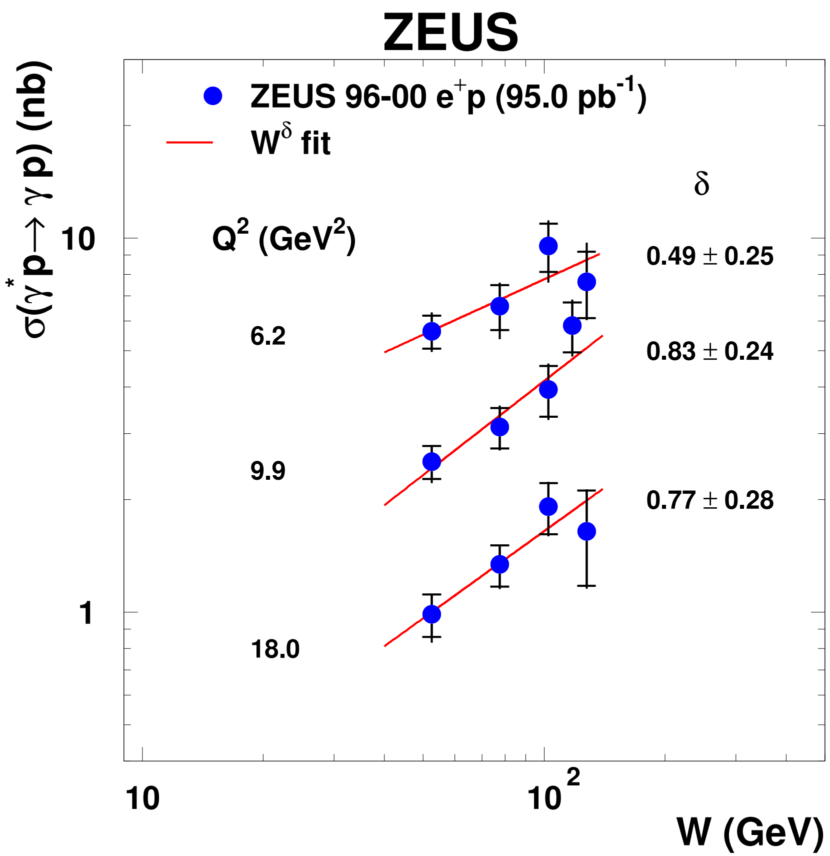


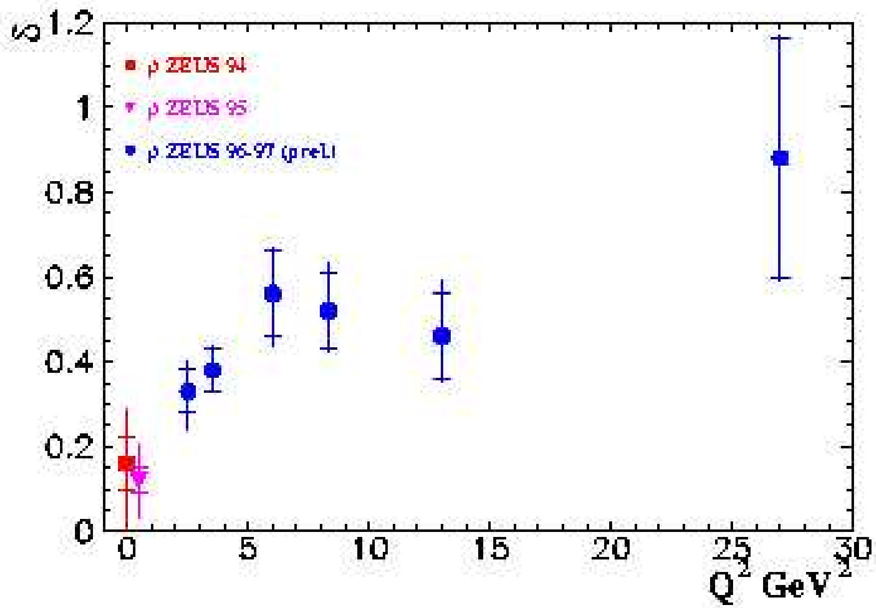


No differences between e^+p and e^-p samples

steep rise of σ with W
$\longrightarrow$ DVCS is a hard process

DVCS - W dependence

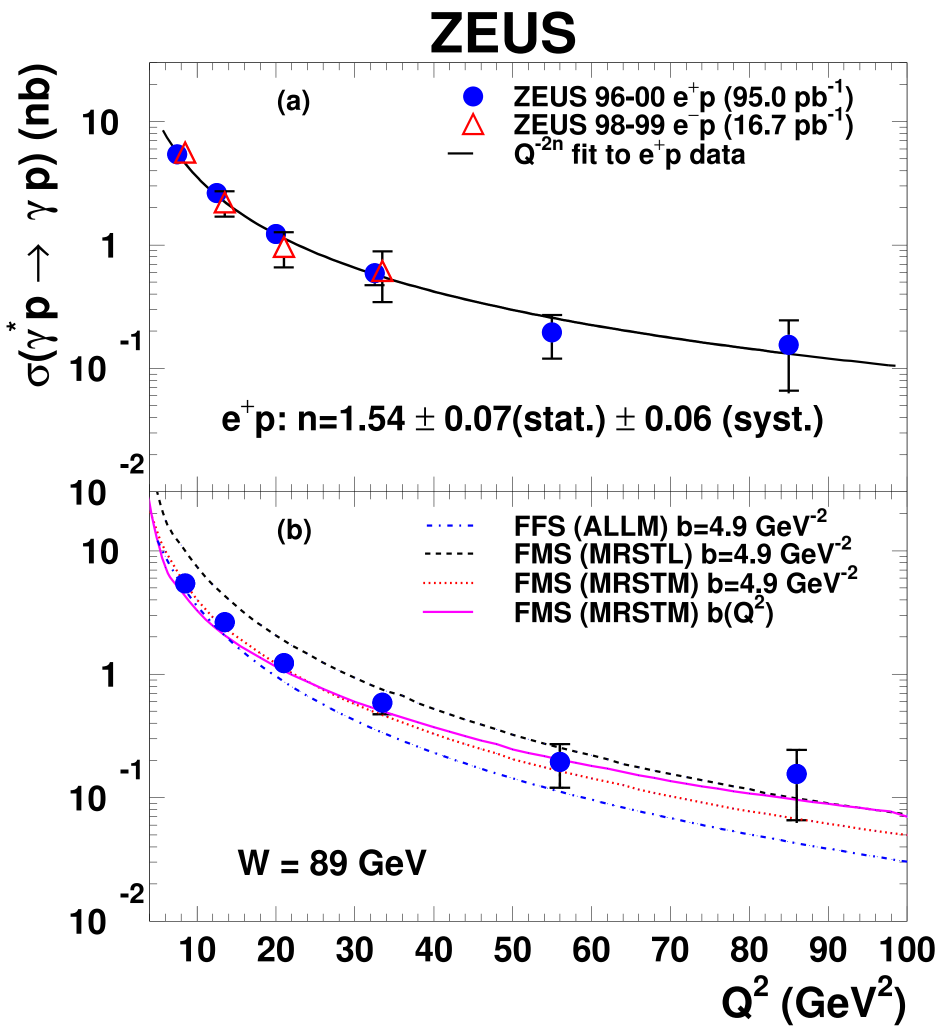




Data compatible with δ increasing with Q^2
steep rise of σ with W $\rightarrow$ DVCS is a hard process

Dependence similar as for
vector mesons

Q^2 dependence



- $\sigma(\gamma^* p \rightarrow \gamma p) \sim Q^{-3}$

Freund,McDermott and Strikman

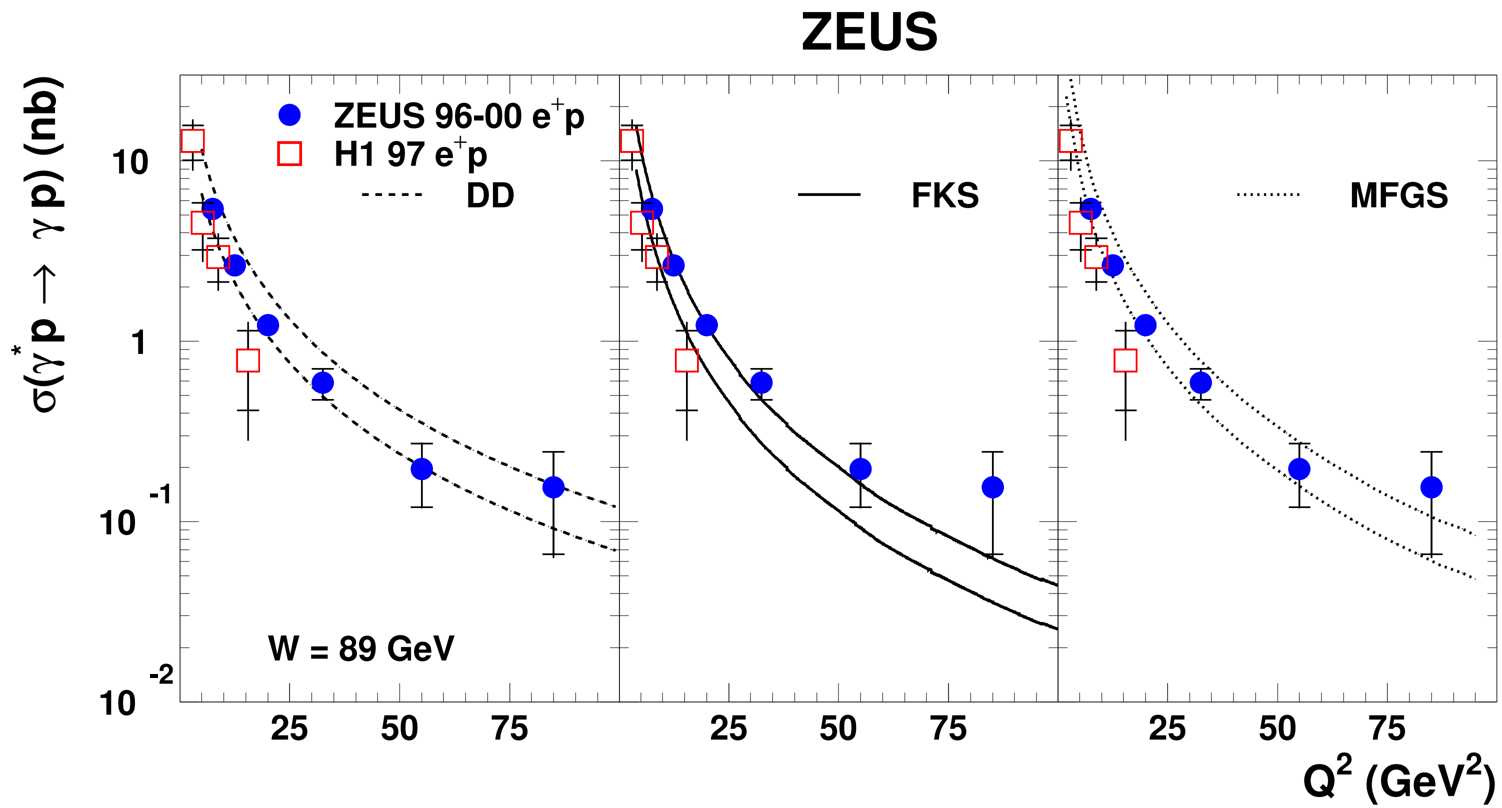
NLO calculation

$b(Q^2) = 8[1 - 0.15 ln(Q^2/2)]\text{GeV}^{-2}$

The best description

is given by NLO calculation

Comparison with Colour Dipole Models



upper curves $b = 4\,\mathrm{GeV}^{-2}$

lower curves $b = 7\,\mathrm{GeV}^{-2}$

DD (Donnachie and Dosh) - perturbative + Regge

FKS (Forshaw,Kerley and Shaw) - Regge approach

MFGS(McDermott,Frankfurt,Guzey and Strikman)- QCD colour transparency

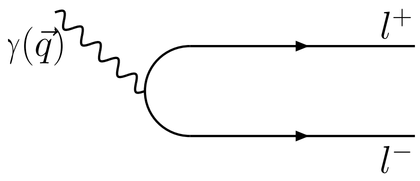
Very different models give similar predictions in the measured kinematical region

Summary for DVCS

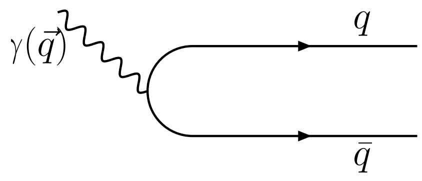
- $\sigma(\gamma^* p \rightarrow \gamma p)$ measured in the range $4 < Q^2 < 100\,\mathrm{GeV}^2$ and $40 < W < 140\,\mathrm{GeV}$
- No significant difference between e^+p and e^-p
- $\sigma(\gamma^* p \rightarrow \gamma p)$ rises steeply with $W \rightarrow$ hard process
- $\sigma(\gamma^* p \rightarrow \gamma p) \sim Q^{-3}$
- $\frac{d\sigma}{dt} = \frac{d\sigma}{dt}|_{t=0} e^{-b(Q^2)|t|}$
  Q^2 dependence of b-slope may be crucial in extracting GPDs, however
  t dependence still not measured

Photon light-cone wave function - introduction

Light-Cone Wave Functions (LCWF)



$$\rightarrow \psi_\gamma = a|\gamma_p\rangle + b|l^+l^-\rangle + (other\ e.m.)$$
$$+ c|q\bar{q}\rangle + (other\ hadronic) + ...$$



$\longrightarrow$ are the probability amplitudes to find a component with a given momentum in the momentum space

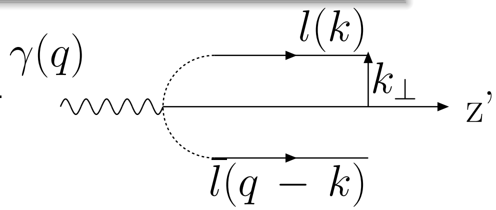
$\longrightarrow$ are the solutions of LC Hamiltonian: $H_{LC}^{QCD}\,|\psi_\gamma\rangle = M_h^2\,|\psi_\gamma\rangle$ ($H_{LC}^{QCD} = P^+P^- - P_\perp^2$)

$\longrightarrow$ are usually tested through measurements of form factors

$\longrightarrow$ are the best descriptions of the composite system

Photon light-cone wave function - QED and QCD

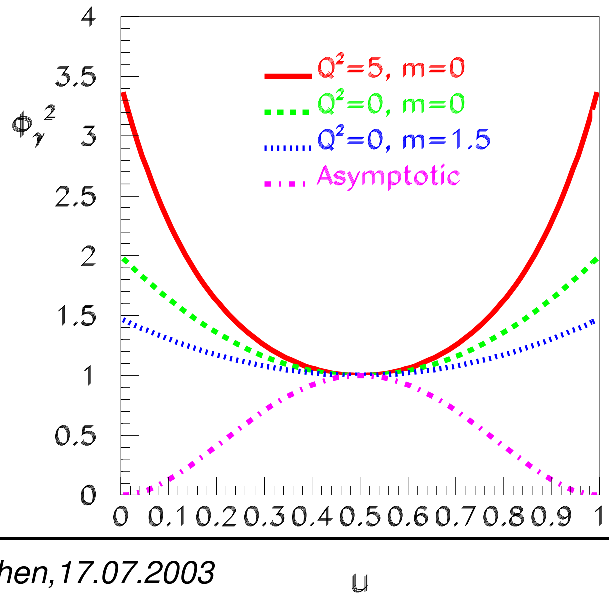
The LCWF for the lowest Fock states: $\psi^{\gamma}_{\lambda_1\lambda_2} = -ee_l \frac{\bar{l}_{\lambda_1}(k)\lambda\cdot\epsilon^{\gamma} l_{\lambda_2}(q-k)}{\sqrt{u(1-u)}(Q^2+\frac{k_\perp^2+m^2}{u(1-u)})}$



- longitudinal light-cone momentum fraction: $u = \frac{k_i^+}{p^+} = \frac{k_i^0+k_i^z}{p^0+p^z}$ $\qquad \sum_{i=1}^{n} u_i = 1$
- transverse momenta: $\vec{k}_{\perp i}$ $\qquad \sum_{i=1}^{n} \vec{k}_{\perp i} = \vec{0}_\perp$

The hadronic $|q\bar{q}\rangle$ LCWF is expected by pQCD to be the same as for electromagnetic $|l^+l^-\rangle$ for $k_\perp^2 >> \Lambda^2_{QCD}$:

S.J.Brodsky, L.Frankfurt, J.F.Gunion, A.H.Mueller and M.Strikman, Phys.Rev.**D50**,3134(1994)



- for the transversely polarised photons:

$$\Phi^2_{f\bar{f}/\gamma^*_T} \sim \sum_{\mu=1}^{2} \frac{1}{4} Tr\psi^2 = \frac{m^2+k_\perp^2[u^2+(1-u)^2]}{[k_\perp^2+a^2]^2}$$

$$a^2 = m^2 + Q^2 u(1-u)$$

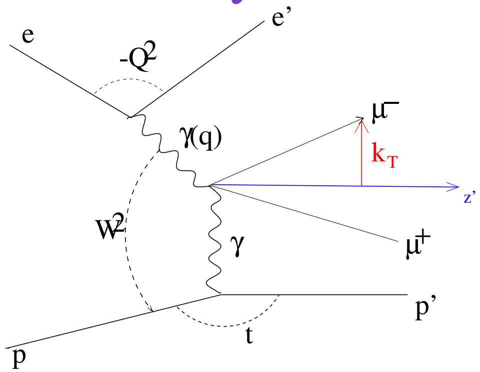
- for the longitudinally polarised photons:

$$\Phi^2_{f\bar{f}/\gamma^*_L} \sim \frac{Q^2[u^2(1-u)^2]}{[k_\perp^2+a^2]^2}$$

LCWF - measurement of QED component

ZEUS e^+p sample 55.4 pb^{-1}

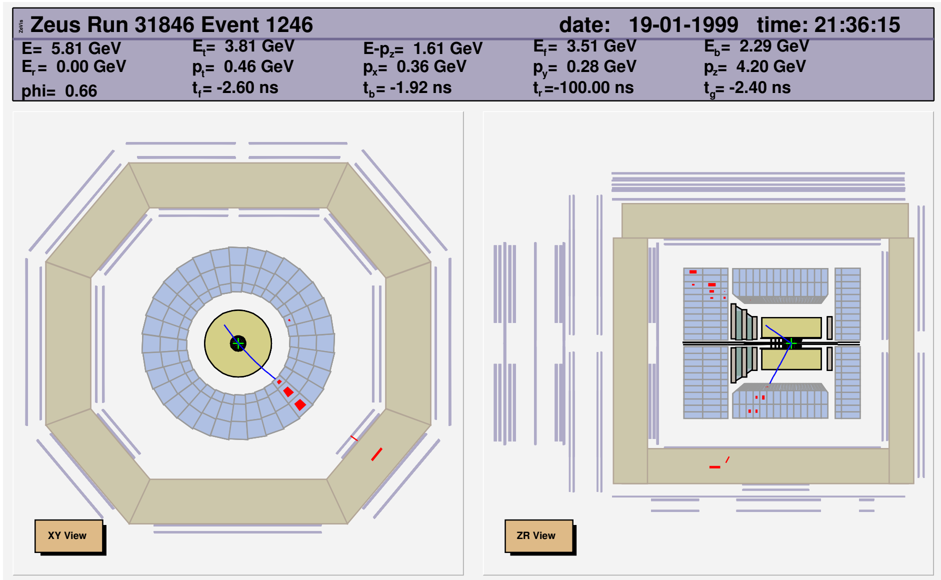
$30 < W < 170\,GeV, Q^2 \sim 0$



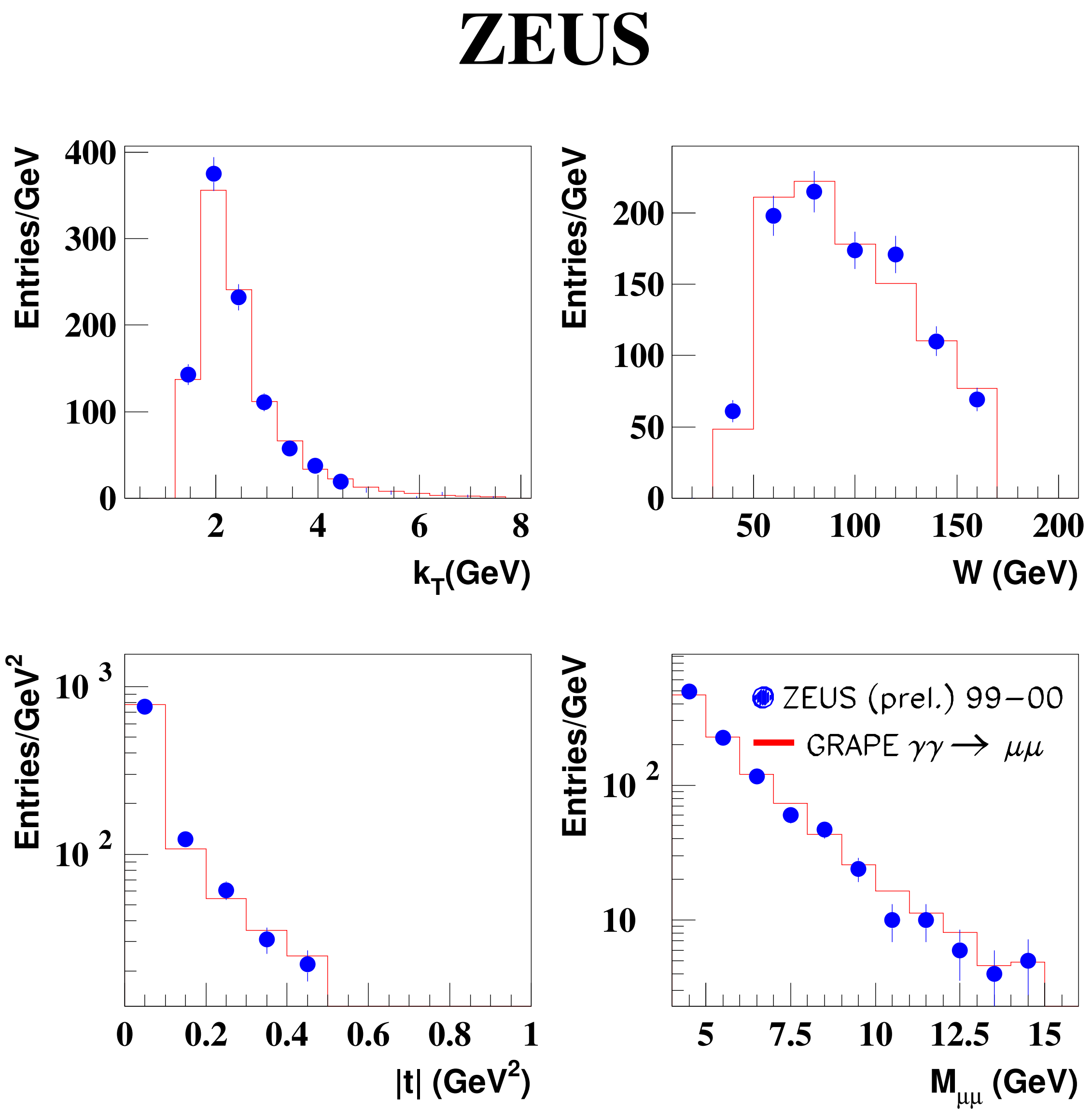
$\gamma\gamma \to \mu^+\mu^-$

- Proton and electron undetected
- Only 2 μ in detector
- Diffractive (small t)
- $4 < M_{\mu\mu} < 15\,\mathrm{GeV}$

* $u = \frac{E_1 + p_{z'_1}}{E_1 + E_2 + p_{z'_1} + p_{z'_2}}$ $\quad 0 < u < 1$
* $\vec{k_{T_1}} + \vec{k_{T_2}} = \vec{0}$
* $W^2 = (q + P)^2 \approx 2E_p \sum_i (E_i - p_{zi})$
* $t = (P - P')^2 \approx -p^2_{T\mu\mu}$
* $M^2_{\mu\mu} = (p_1 + p_2)^2$



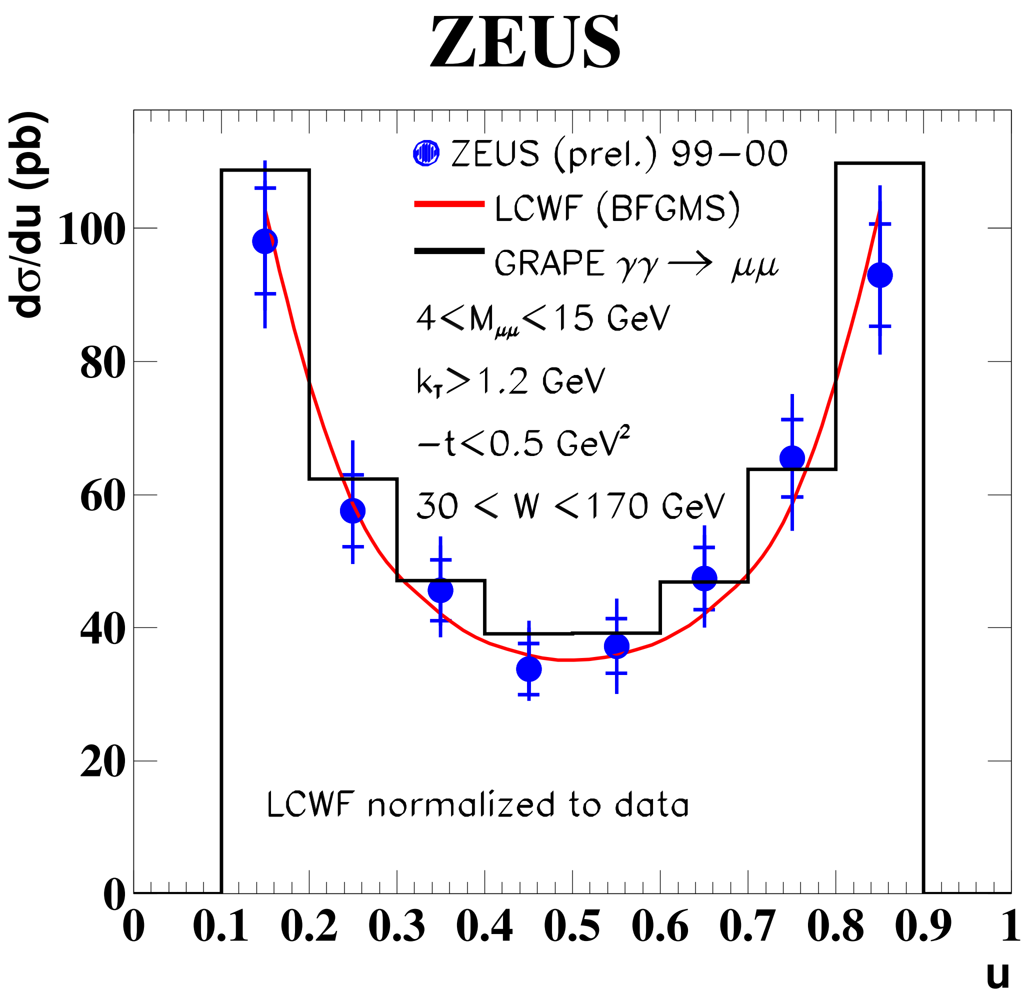
Kinematical variable distributions for the LCWF



DATA and MC

in good agreement

LCWF - measurement of QED component



Calculations: Brodsky, Frankfurt, Gunion, Müller, Strikman (BFGMS)

- Electromagnetic LCWF of the photon is measured
- BFGMS is in agreement with QED and data
- Results demonstrate the first proof that diffractive dissociation of particles can be reliably used to measure their LCWF

Summary for Light Cone Wave Function

- Photon electromagnetic LCWF is measured and is in agreement with QED
- This demonstrate the first proof that diffractive dissociation of particles can be reliably used to measure their LCWF
- Measured EM LCWF gives support for the method used in previous measurements of the pion LCWF and possible future applications