Vector Meson production and DVCS at HERA

On behalf of the H1 and ZEUS Collaborations

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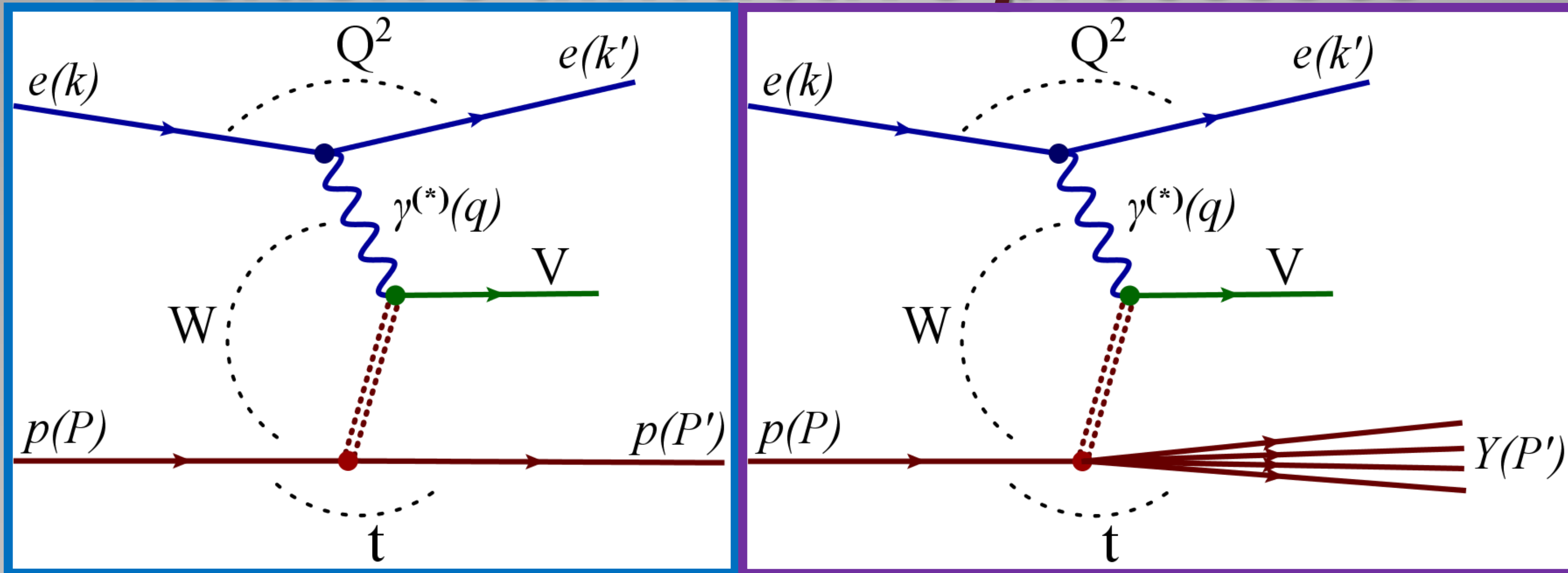
Exclusive diffractive processes



Diffraction - no quantum numbers are exchanged in the interaction btw γ and p $\rightarrow$ no colour flux $\rightarrow$ large rapidity gap

V - Vector Meson (ρ, ω, ϕ, J/ψ, ψ', Υ) photon (γ)

Q^2 - photon virtuality $Q^2=-q^2=-(k-k')^2$

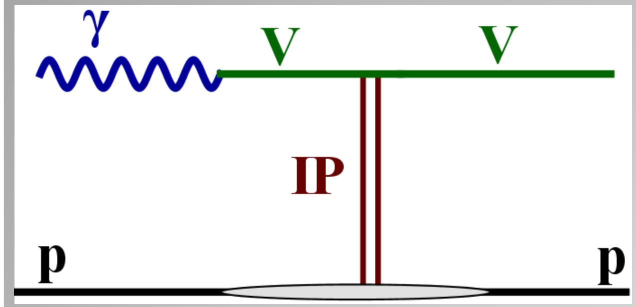
($Q^2 \approx 0$ – photoproduction, $Q^2 > 0$ – electroproduction)

W - c.m. energy of γp system $W^2=(q+p)^2$

t - (4-mom. transfer)^2 at p-vertex $t = (P - P')^2$

The proton can stay intact p(P′) or dissociate Y(P′)

VDM & Regge theory (Soft physics)



Vector Dominace Model (VDM):

• The photon fluctuates into a vector meson, V, which carries the same quantum numbers as the photon ($\gamma p \rightarrow Vp$)

• The vector meson scatters elastically off the incoming proton ($Vp \rightarrow Vp$)

Predictions:

$$\frac{d\sigma(\gamma p \to Vp)}{dt} \propto e^{-b_0 t}\left(\frac{W^2}{W_0^2}\right)^{2(\alpha(t)-1)}$$

Experimental observations:

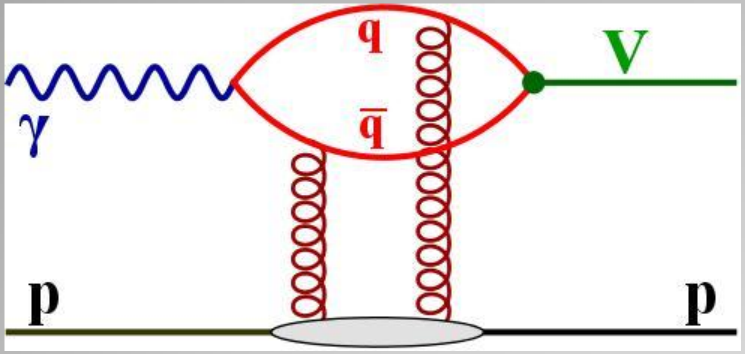
• $\alpha(t) = \alpha(0) + \alpha' t$, $\alpha(0) = 1.08$, $\alpha' = 0.25$; (Donnachie-Landschof)

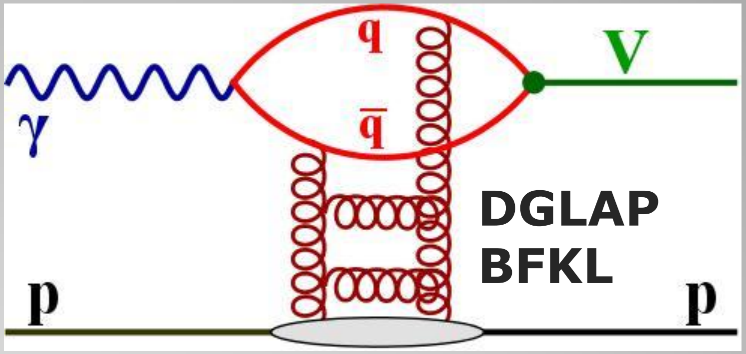
• Shrinkage of the diffractive peak $b(W) = b_0 + 4\alpha' ln\left(\frac{W}{W_0}\right)$

• Weak energy dependence of cross section

$\sigma \propto W^{\delta}$, $\delta \approx 4\left[\alpha(0) - \frac{\alpha'}{b_0} - 1\right]$, $\delta \sim 0.2$;

pQCD models (Hard physics)





- the photon fluctuates into a $q\bar{q}$ state
- the $q\bar{q}$ pair scatters off the proton target
- the scattered $q\bar{q}$ pair turns into a vector meson

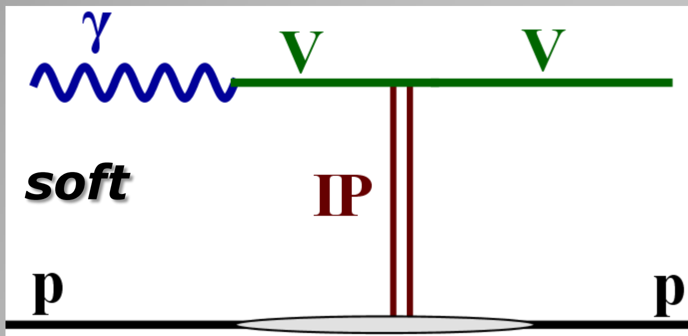
Predictions:

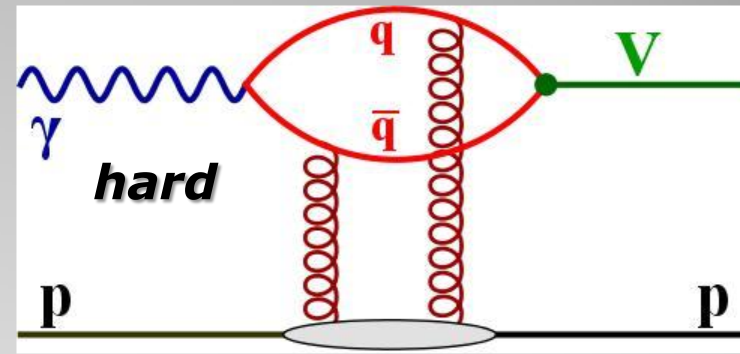
- $\sigma \propto [xg(x,\mu^2)]^2$ where $\mu^2 = f(Q^2, M_V^2, t)$
- Increasing W corresponds to going to small x

$$x \approx \frac{Q^2}{W^2} \text{ at low } x$$

- fast increase of the $\gamma^* p \to Vp$ cross section with energy W
- universal exponential t dependence
- $b \sim 4 - 5 GeV^{-2} \Rightarrow \alpha' \approx 0$

Transition from soft to hard physics

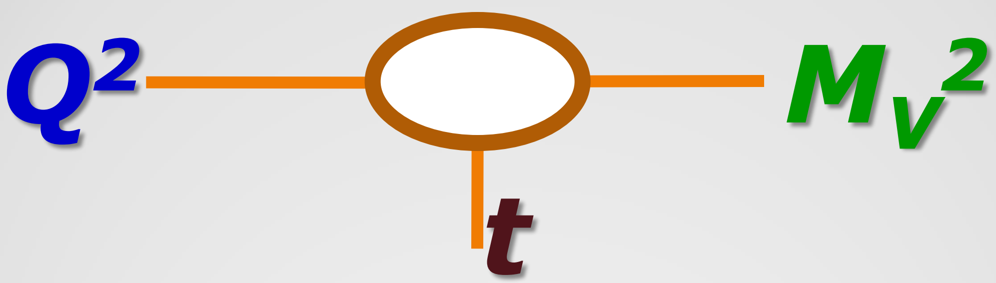




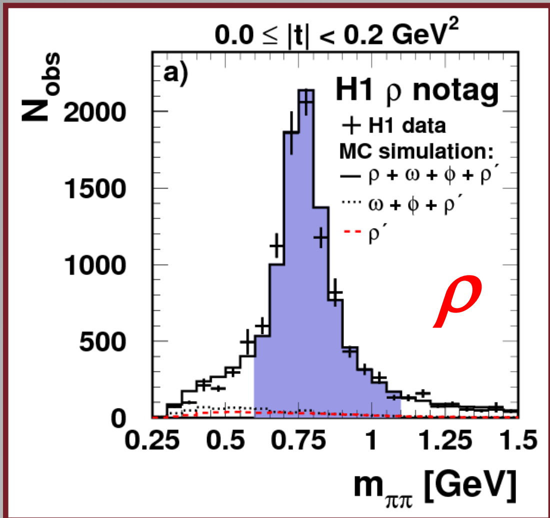
$\delta \approx 0.2$ $\sigma \propto W^{\delta}$ $\delta \le 0.7$

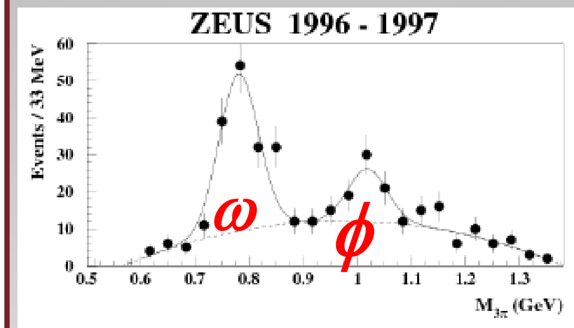
$b \approx 10 GeV^{-2}$ $\frac{d\sigma}{d|t|} \propto e^{-b|t|}$ $b \approx 4\text{-}5 GeV^{-2}$

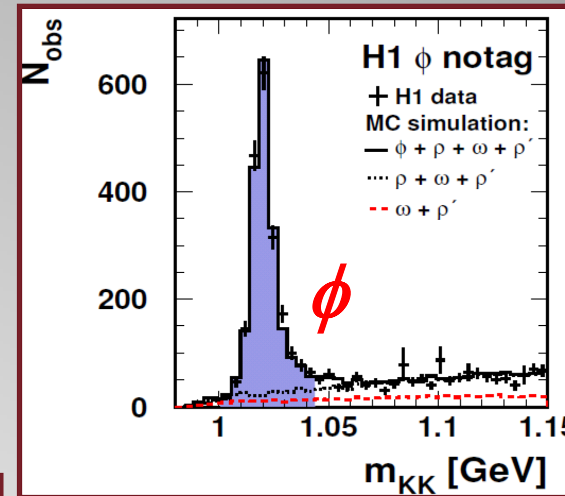
$\alpha' \approx 0.25 GeV^{-2}$ $\alpha(t), b(W)$ $\alpha' \approx 0$

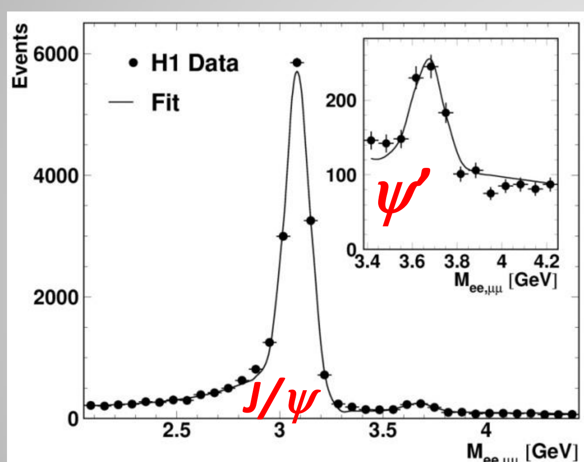


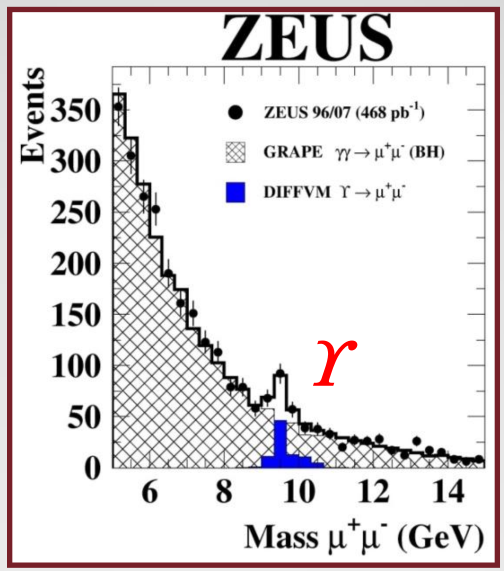
Vector mesons mass distributions





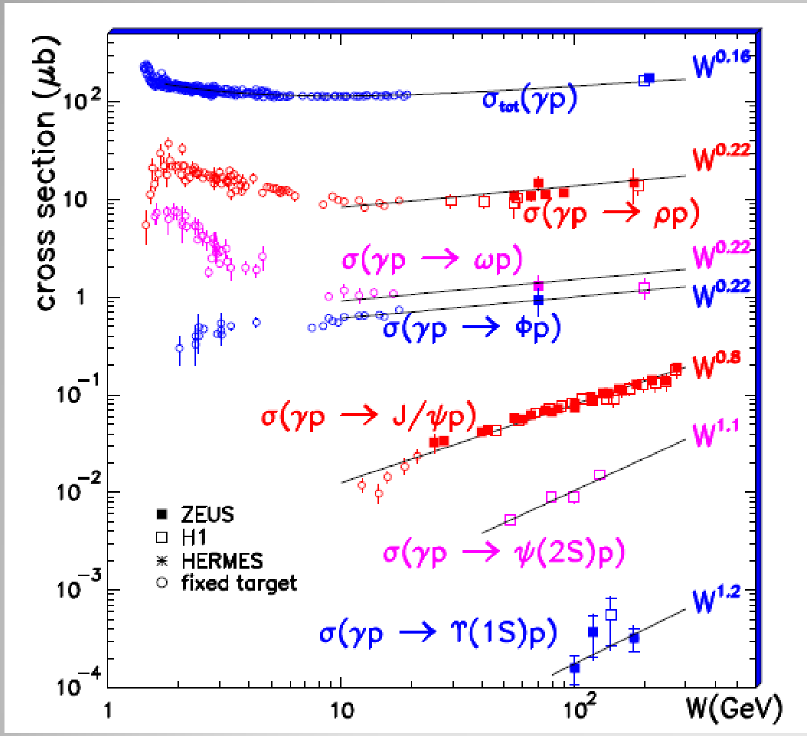






W dependence of the photoproduction of VM

The parameterisation of the cross section: $\sigma \propto W^{\delta}$



Process becomes hard (steeper W dependence) as mass of VM becomes larger → **Apply pQCD models**

W dependence of the photoproduction of VM

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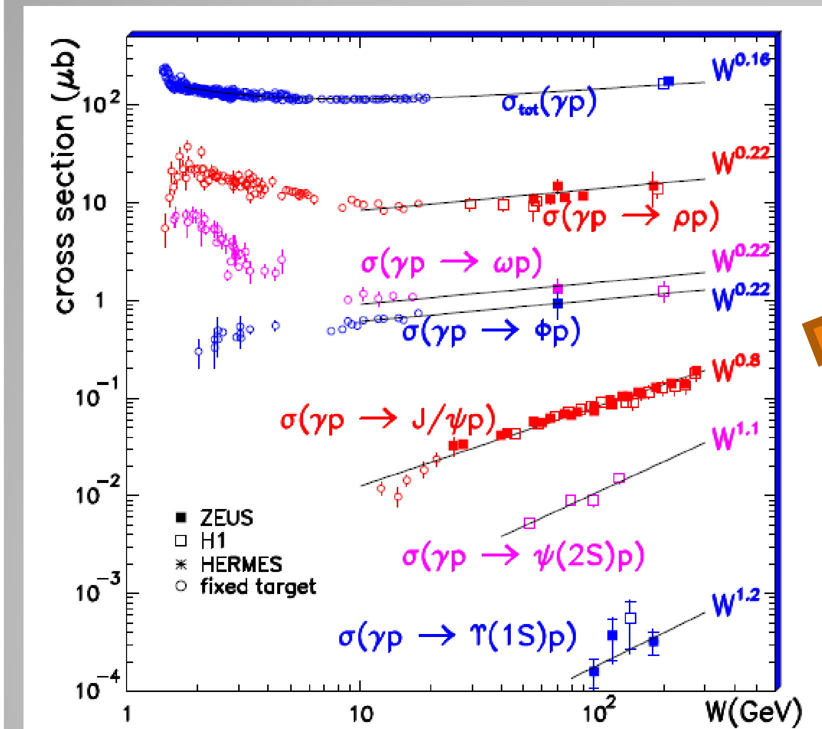
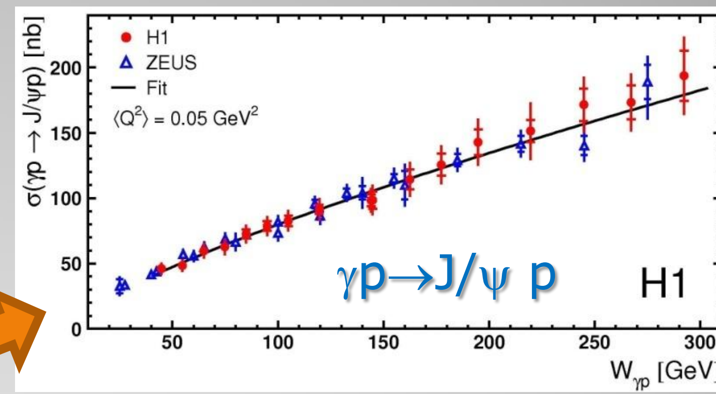
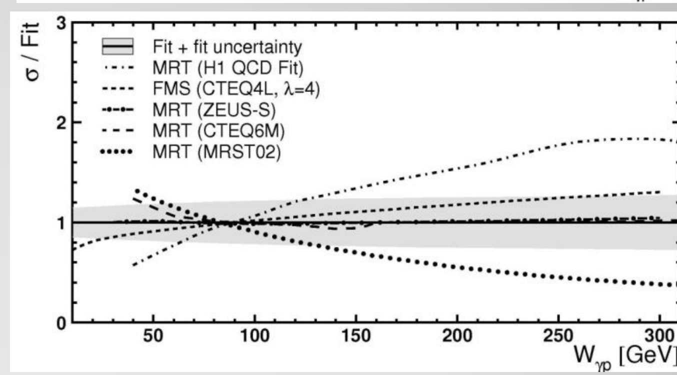




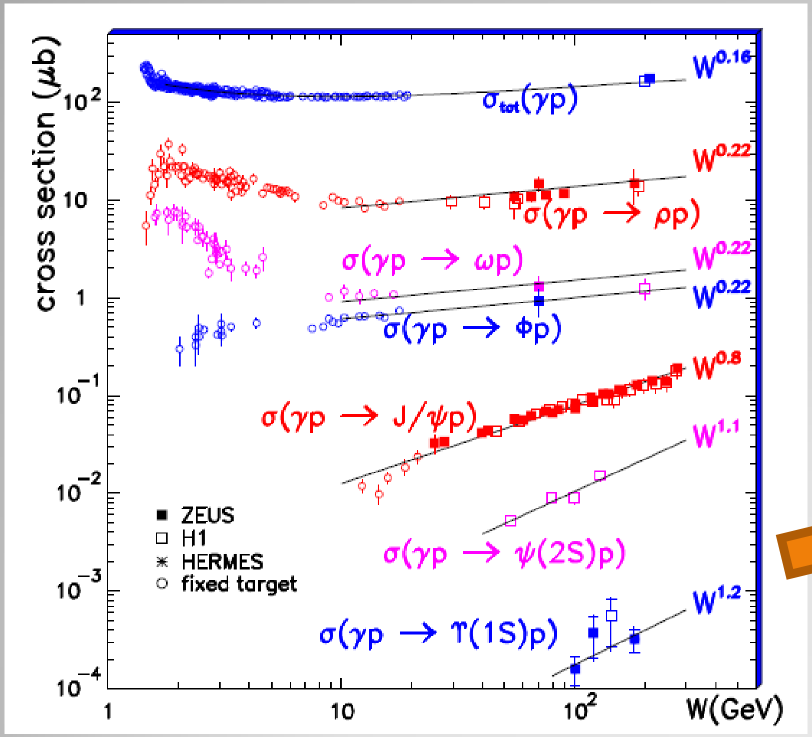


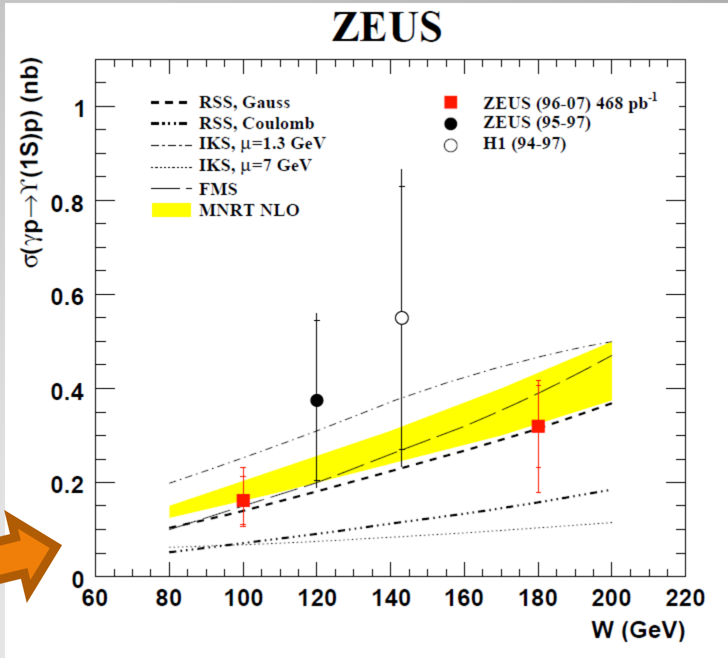
FMS – L. **Frankfurt**, M. **McDermott** and M. **Strikman**, JHEP **0103 (2001)**
MRT – A. D. **Martin**, M. G. **Ryskin** and T. **Teubner**, Phys. Rev. D **62 (2000)** 014022

Sensitivity to gluon density

W dependence of the photoproduction of VM

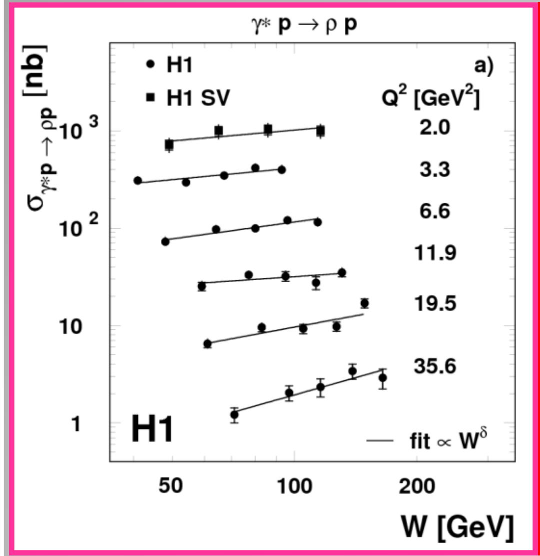
The parametrisation of the cross section: $\sigma \propto W^{\delta}$

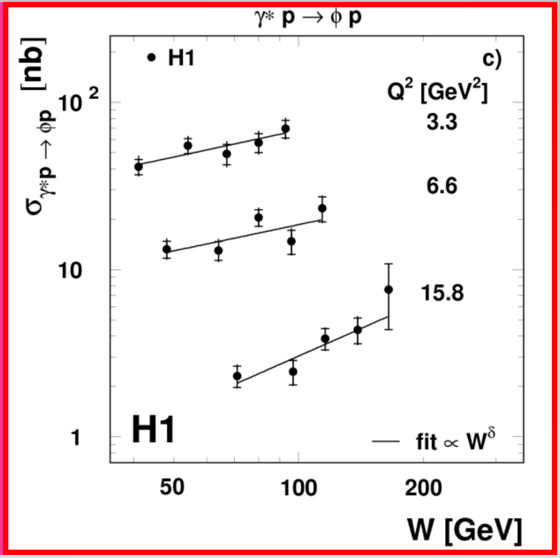




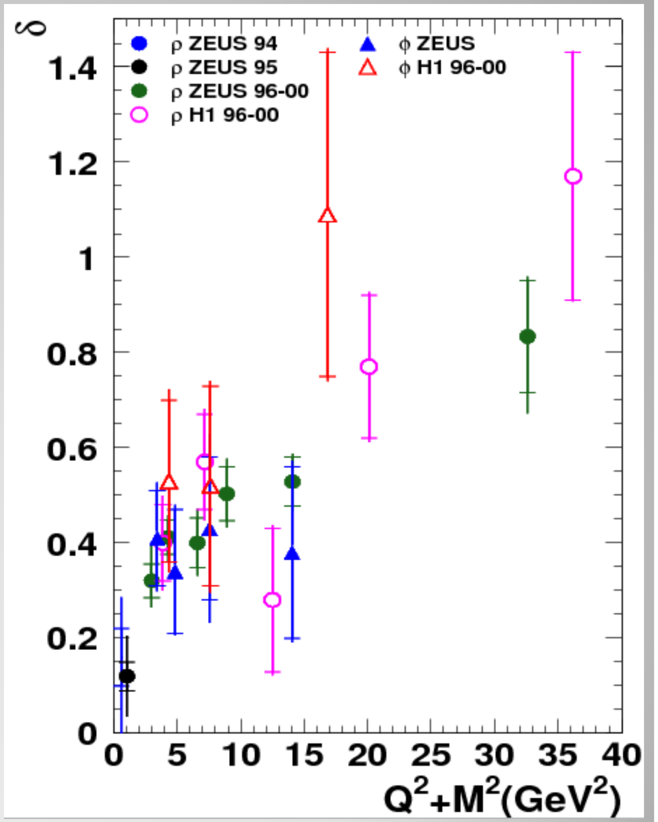
RSS (k_T) – A. **Rybarska**, W. **Schäfer** , A. **Szczurek**, Phys. Lett. B 668 (2008), p. 126.
IKS(NLO)– D.Yu. **Ivanov**, G. **Krasnikov** , L. **Szymanowski**, Nucl. Phys. B (Proc. Suppl.) 146 (2005), p. 134.
FMS(CTEQ4L) – L.L. **Frankfurt**, M.F. **McDermott** , M. **Strikman**, JHEP 9902 (1999), p. 002.
MNRT(HERA J/ψ) – A.D. **Martin**, C. **Nockles**, M. **Ryskin**, T. **Teubner**, Phys. Lett.B 662 (2008), p. 252.

VM electroproduction (W dependence)



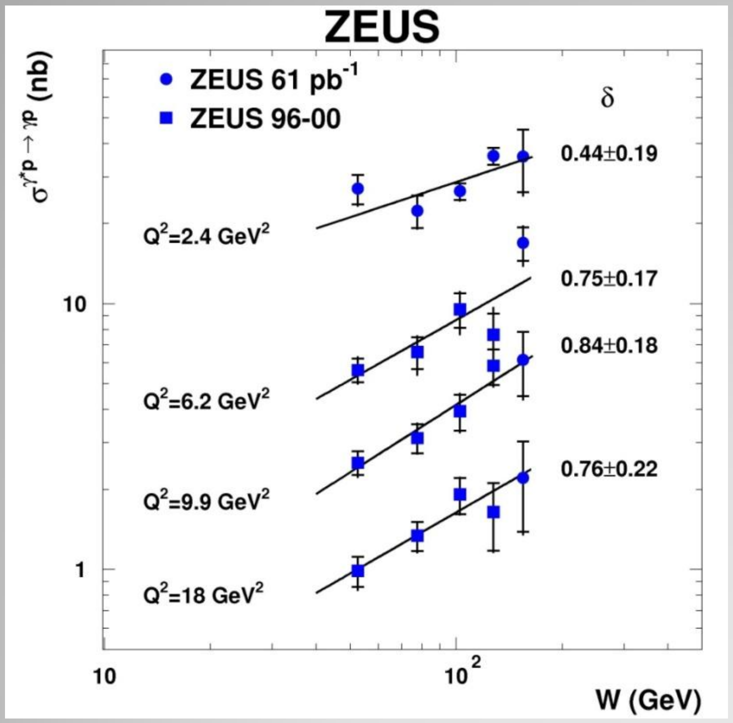


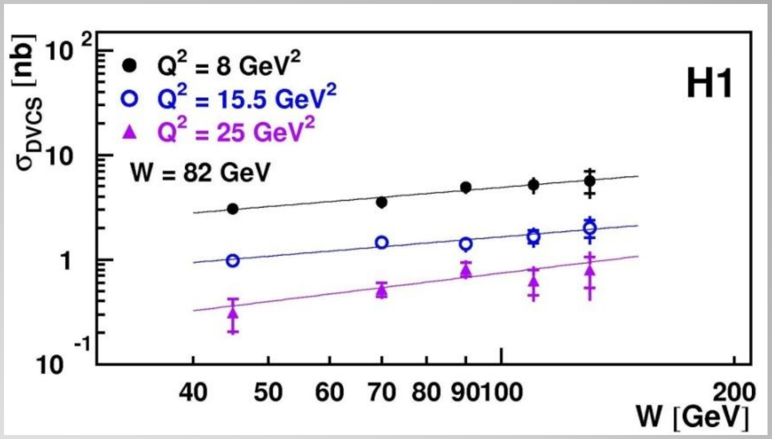
fit: $\sigma \sim W^{\delta}$

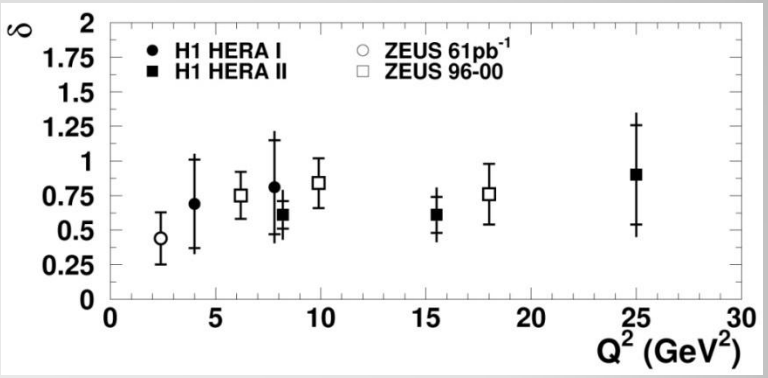


cross section W dependence becomes steeper at high Q^2 for ρ, ϕ from soft to hard regime

Deeply Virtual Compton Scattering (W dependence)

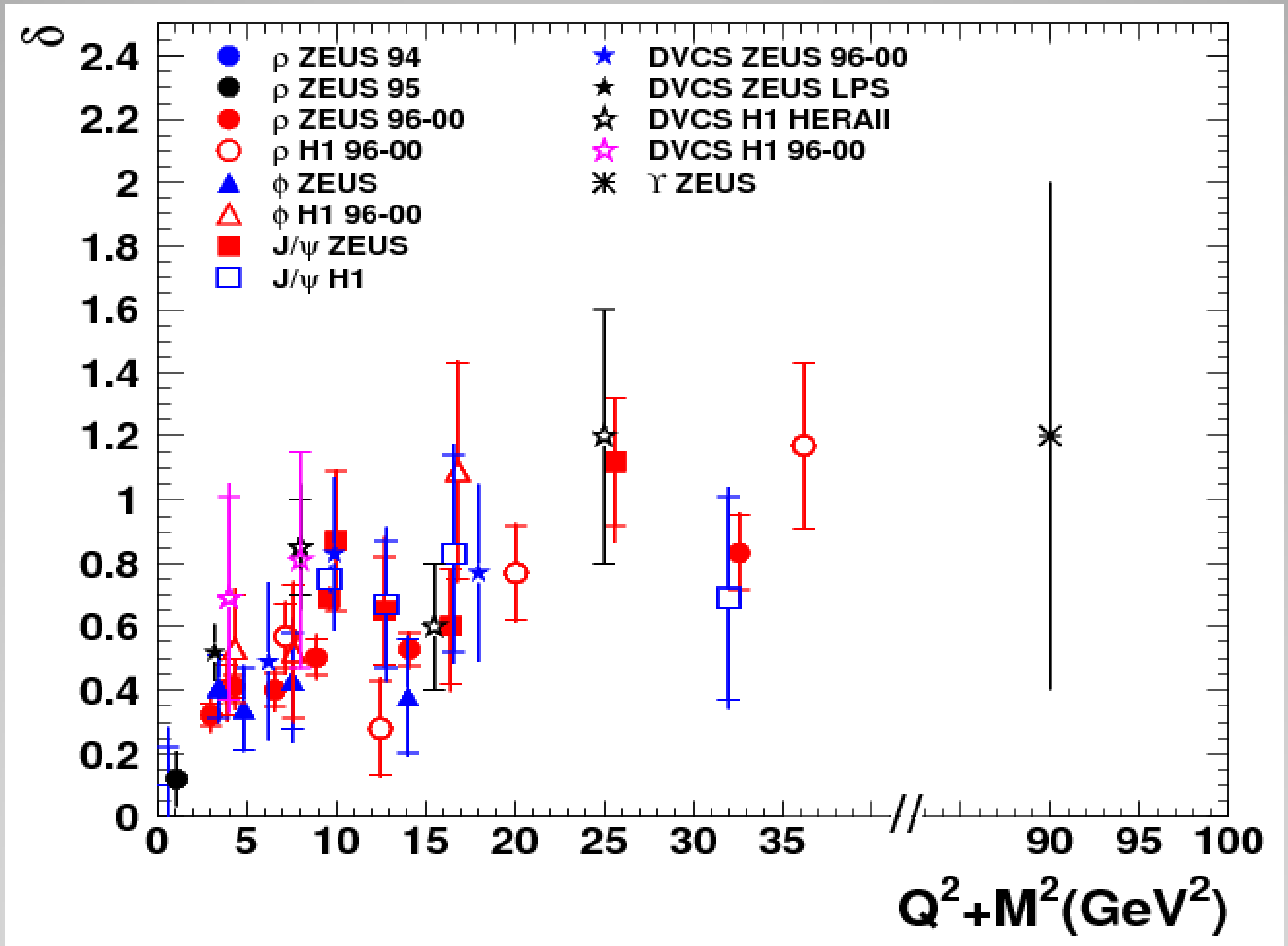






- fit: $\sigma \sim W^{\delta}$
- No δ dependence on Q^2 is observed
- Hard regime

Summary (W dependence)

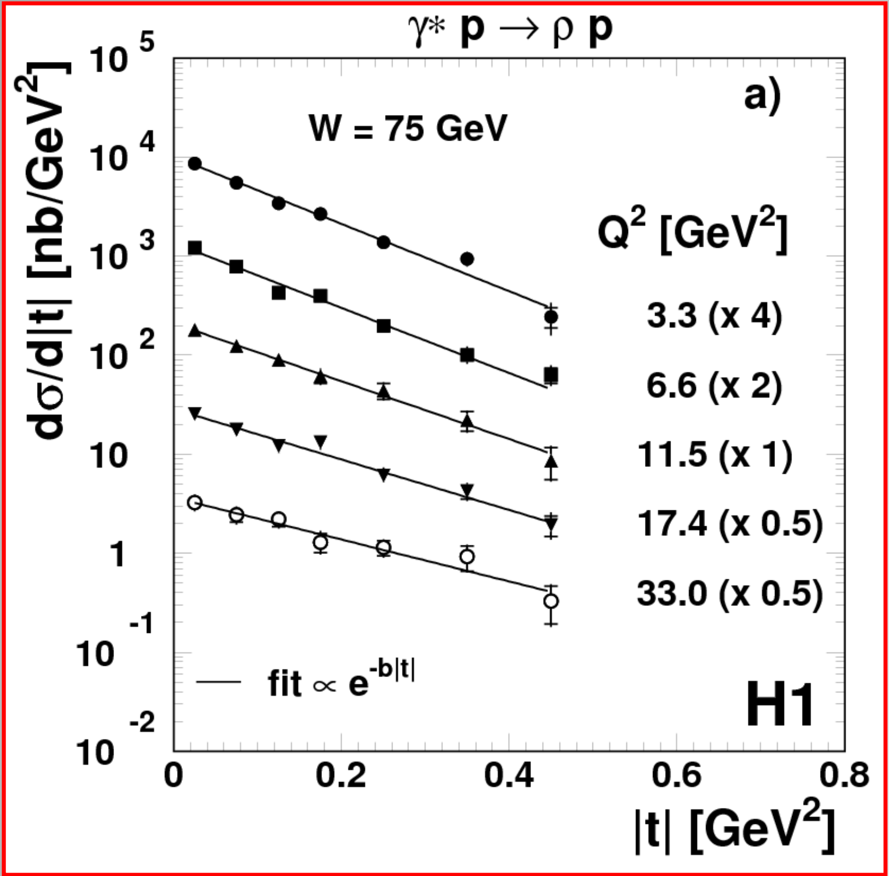


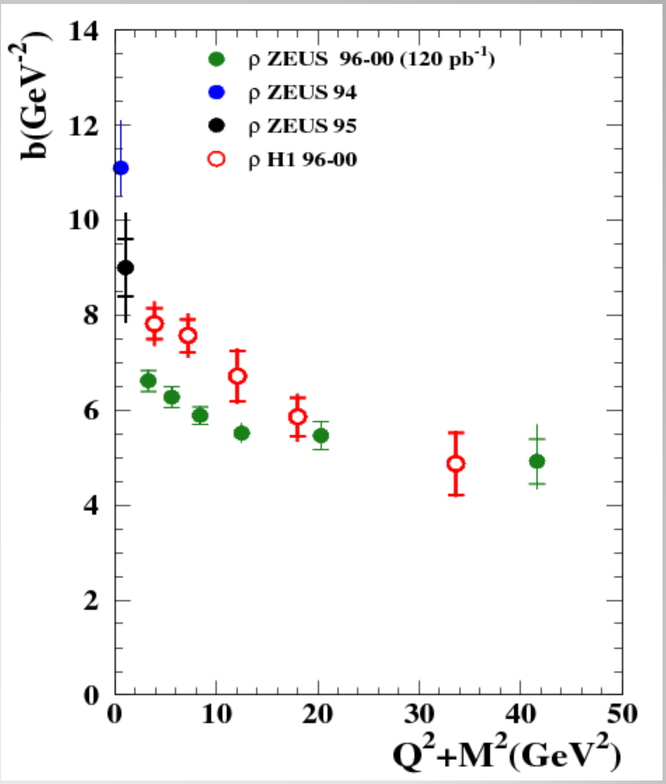
- process becomes hard as scale (Q^2+M^2) becomes larger

|t| dependence (ρ)

$d\sigma/d|t| \sim \exp(-b|t|)$ in bins of Q^2

b describes the transverse size of the interaction region $b \propto R^2$

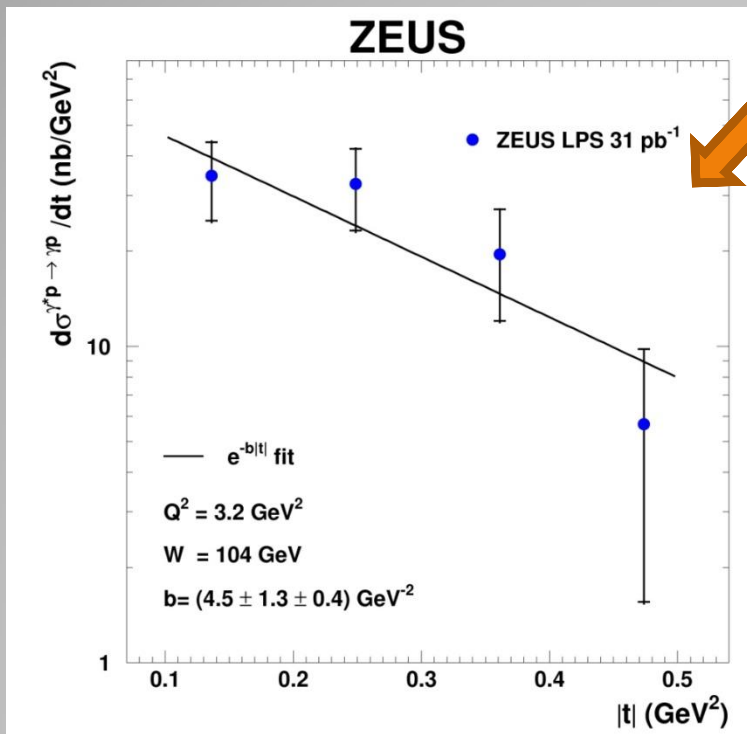




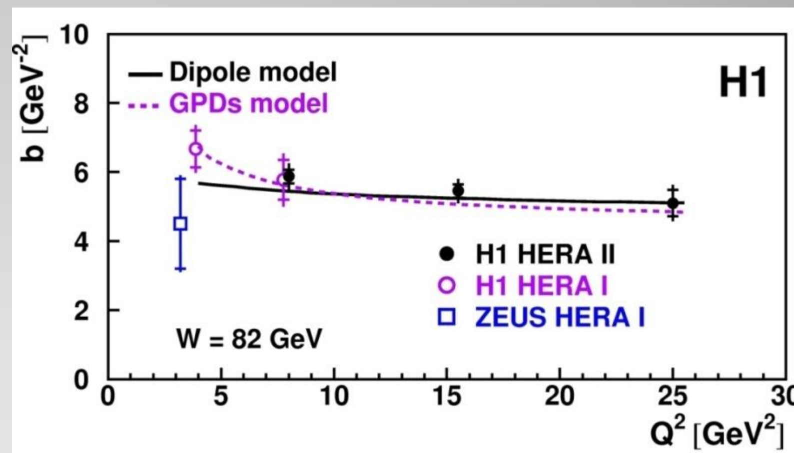
Transverse size of dipole decreases with Q^2

b decreases from soft values to pQCD expected values (~4-5 GeV^{-2})

|t| dependence (DVCS)



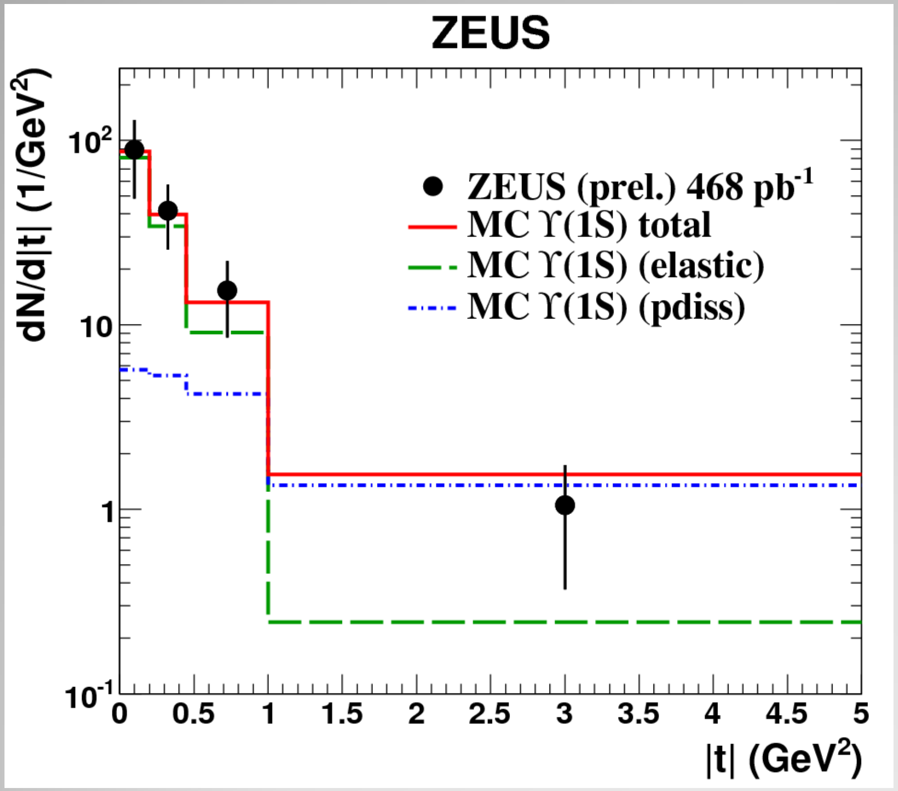
direct t measurement using Leading Proton Spectrometer



H1: $b = 5.41 \pm 0.14 \pm 0.31$ GeV^{-2}
ZEUS: $b = 4.5 \pm 1.3 \pm 0.4$ GeV^{-2}

- DVCS point don’t show Q^2 dependence

|*t*| *dependence (Upsilon)* photoproducion



2 times far from present results at $Q^2 + M^2 = 89.5\ GeV^2$

Elastic: $b = 4.3^{+1.7}_{-1.1}\ {}^{+0.5}_{-0.5} [GeV^{-2}]$

|t| dependence

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

transverse size:

$$b = b_V + b_p$$

Vector Meson transverse size

$$b_V \sim \frac{1}{Q^2+M_V^2}$$

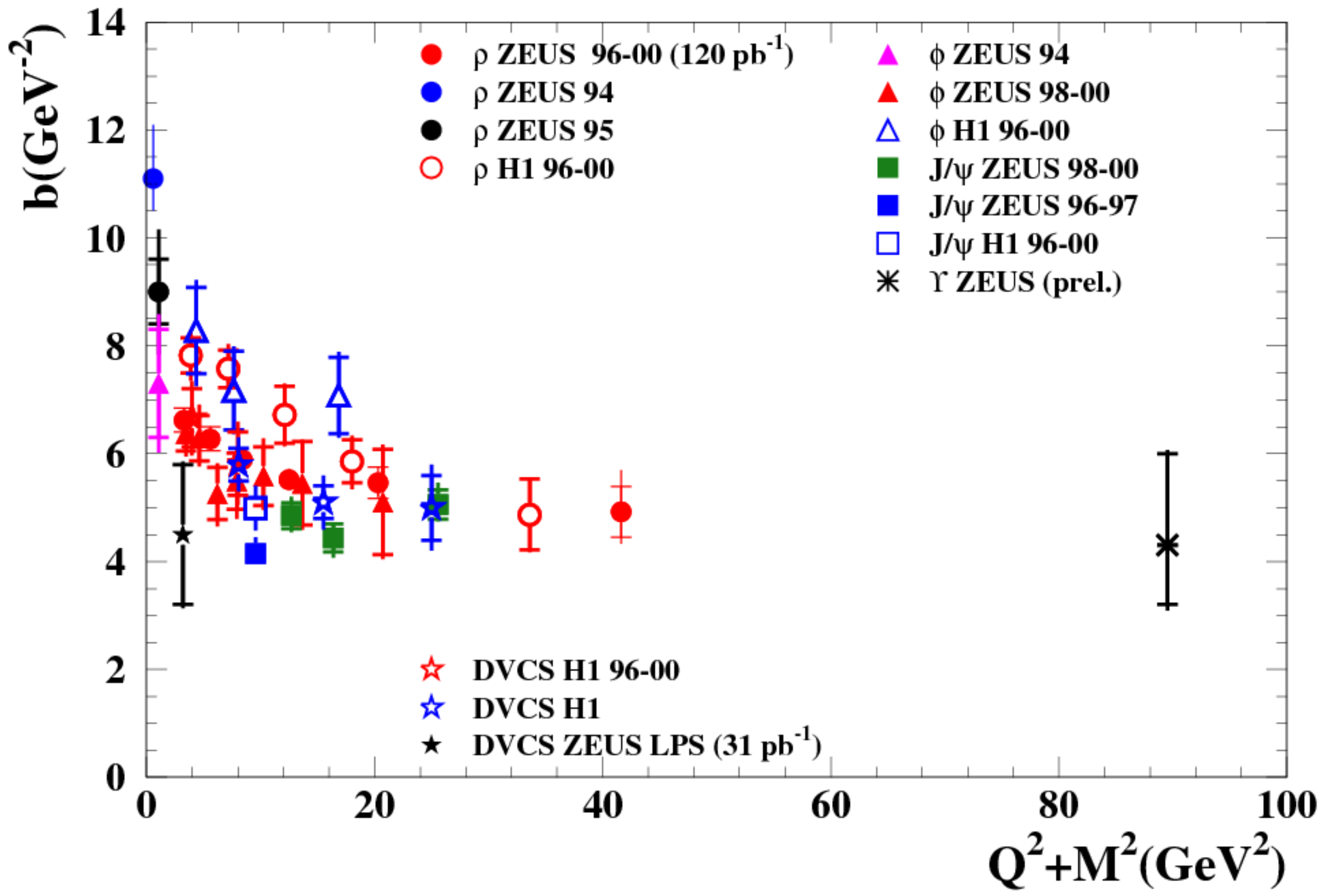
Target size:

$$b_p \approx 5 GeV^{-2}$$

corresponds to

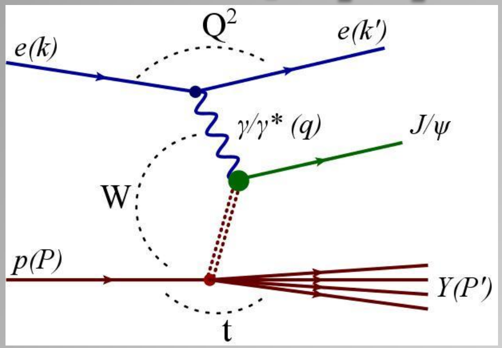
$$r_{gluons} \approx 0.5 \text{ fm}$$

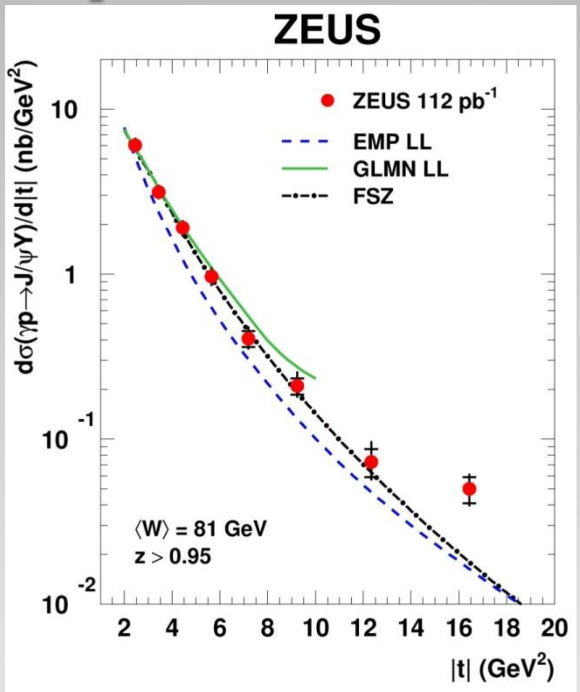
$$r_{em} \approx 0.8 \text{ fm}$$

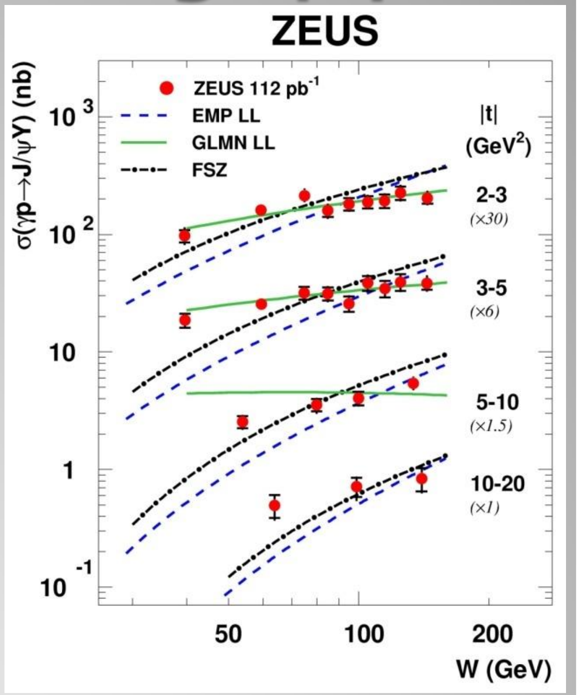


b decreases with from ~ 10 GeV^{-2} (soft) to ~5 GeV^{-2} (hard)
size of scattered VM getting smaller with scale

J/ψ photoproduction at high|t|







Hard scale provided by |t| and mass
t dependence no longer exponential

$$\frac{d\sigma}{d|t|} \propto t^n$$

n=-1.9±0.1, 2<|t|<4 GeV^2
n=-3.0±0.1, 4<|t|<16 GeV^2

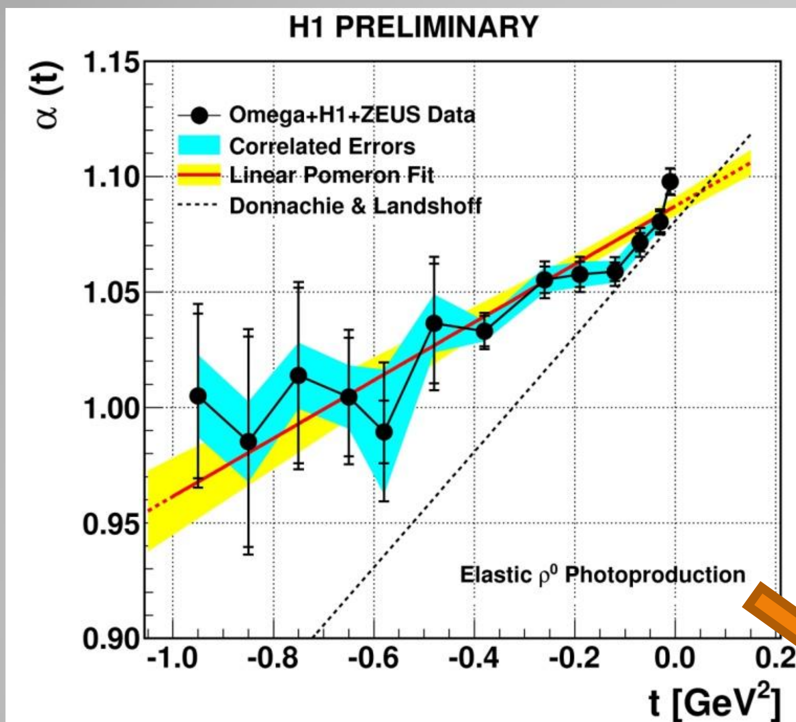
σvsW in t ranges: data rise with W for all t
EMP (BFKL)below data
GLMN (DGLAP)fails at |t|>5GeV^2
FSZ gives good description up |t|=12 GeV^2
BFKL LL and FSZ are too steep (W dependence)

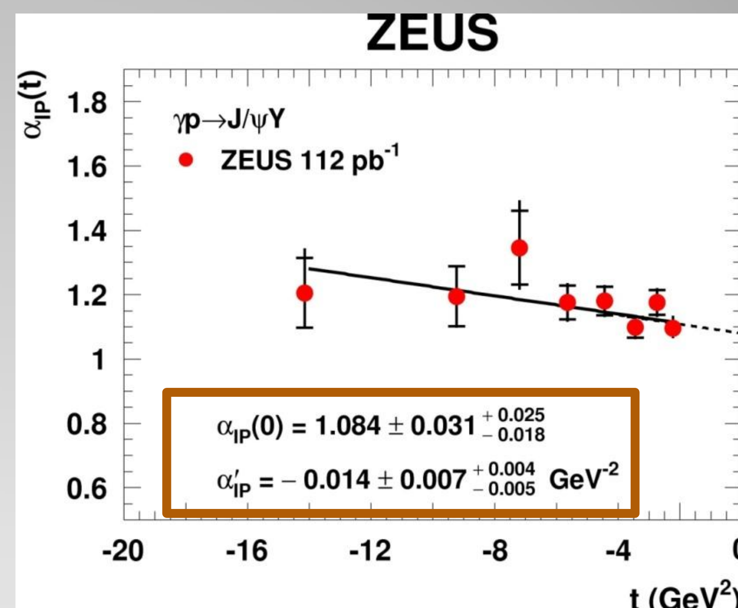
None of the models describes the data over the full phase space

effective Pomeron trajectory

$$\frac{d\sigma}{d|t|} \propto \left(\frac{W}{W_0}\right)^{4(\alpha(t)-1)}$$

$$\alpha(t) = \alpha(0) + \alpha' t$$





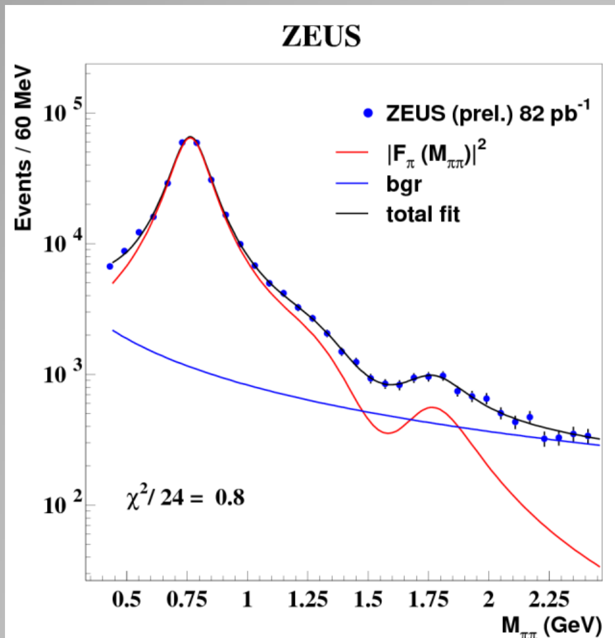
$$DL: \alpha(t) = 1.08 + 0.25t$$

$$\alpha(0) = 1.0871 \pm 0.0026 \pm 0.0030$$

$$\alpha' = 0.126 \pm 0.013 \pm 0.012 GeV^{-2}$$

$\alpha(0)$ consistent with 1.08 from soft pp scattering
α' ~twice smaller than 0.25 GeV^{-2}

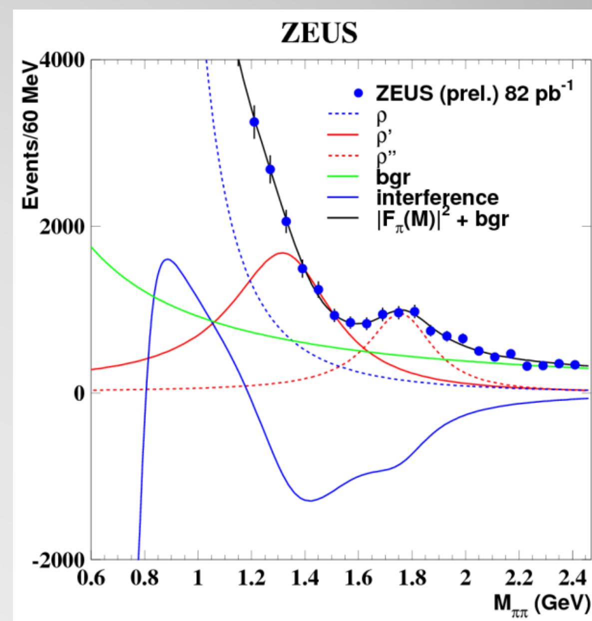
Two pion diffractive electroproduction



Measure two pion mass distribution $0.4<M_{\pi\pi}<2.4$ GeV in $2<Q^2<80$ GeV^2

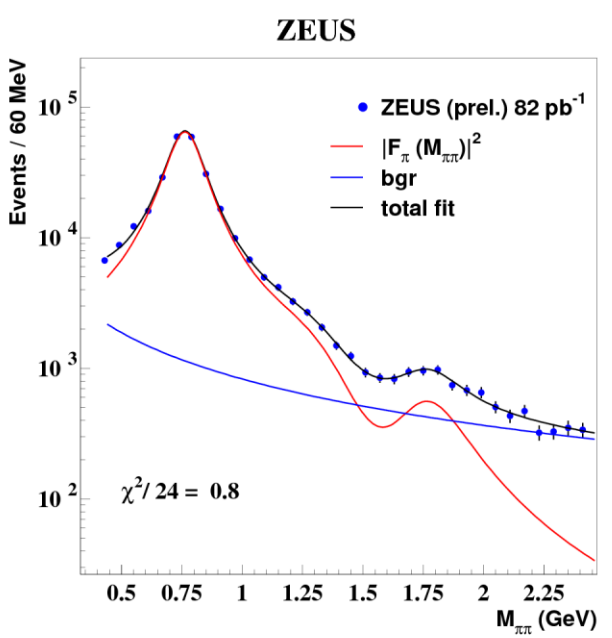
$$\frac{dN(M_{\pi\pi})}{dM_{\pi\pi}} = N\left[|F_\pi(M_{\pi\pi})|^2 + \frac{B}{M_{\pi\pi}^n}\right]$$

$$F_\pi(M_{\pi\pi}) = \frac{BW(\rho)+\beta BW(\rho')+\gamma BW(\rho'')}{1+\beta+\gamma}$$



11 parameters fit:
N, B, n, M(ρ), Γ(ρ), M(ρ'), Γ(ρ'), M(ρ''), Γ(ρ''), β, γ,
where N - total normalization factor, B, n - described background, M, Γ - masses and widths of vector mesons and β, γ - relative amplitudes

Two pion diffractive electroproduction



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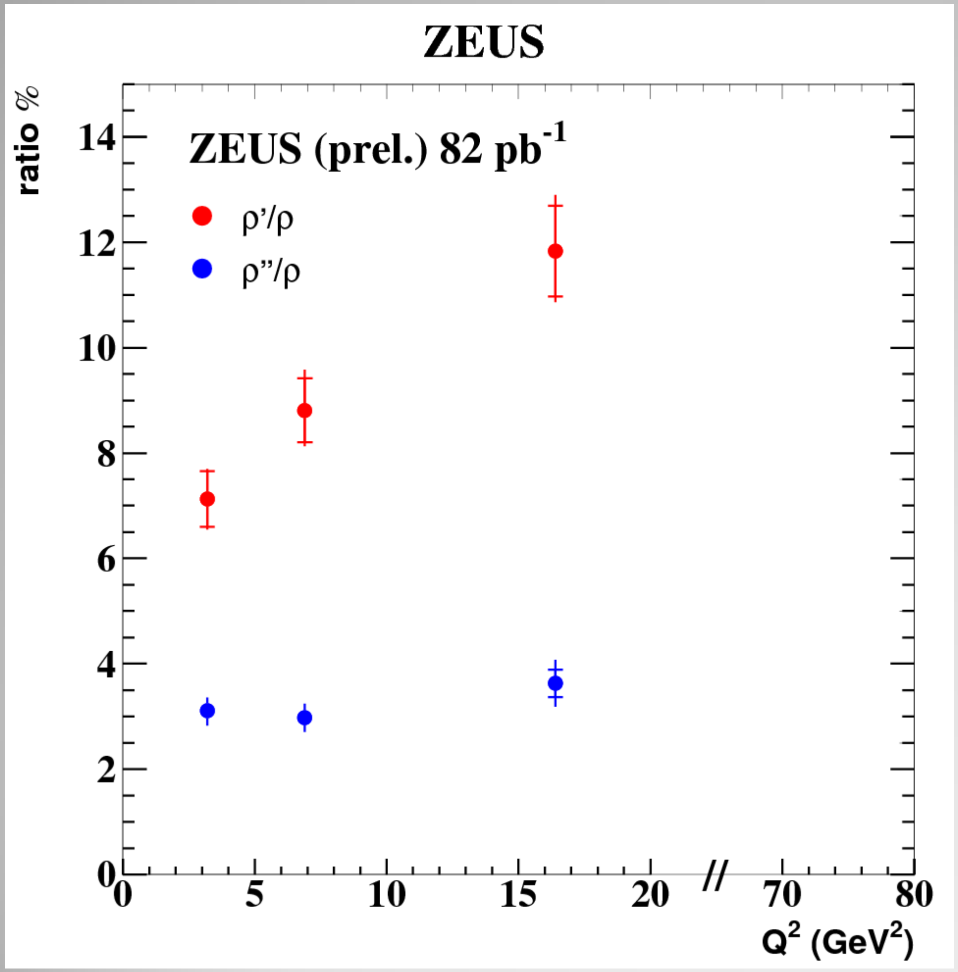
Par.	ZEUS (prel.)	PDG
M_ρ	$772 \pm 2^{+2}_{-1}$	775.49 ± 0.34
Γ_ρ	$155 \pm 5 \pm 2$	149.4 ± 1
$M_{\rho'}$	$1360 \pm 20^{+20}_{-30}$	1465 ± 25
$\Gamma_{\rho'}$	$460 \pm 30^{+40}_{-45}$	400 ± 60
β	$-0.27 \pm 0.02 \pm 0.02$	
$M_{\rho''}$	$1770 \pm 20^{+15}_{-20}$	1720 ± 20
$\Gamma_{\rho''}$	$310 \pm 30^{+25}_{-35}$	250 ± 100
γ	$0.10 \pm 0.02^{+0.02}_{-0.01}$	

11 parameters fit:
N, B, n, M(ρ), Γ(ρ), M(ρ′), Γ(ρ′), M(ρ′′), Γ(ρ′′), β, γ, where N - total normalization factor, B, n - described background, M, Γ - masses and widths of vector mesons and β, γ - relative amplitudes

ρ,ρ′,ρ′′electroproduction (cross section ratios)



ρ′/ρ–increases with Q^2

the **anomalous behaviour of ρ′/ρ *production*** ratio with Q^2 *was predicted in works of* J. Nemchik,B. Kopeliovich, N.Nikolaev, B.Zakharov, (see hep-ph/9605208)

ρ′′/ρ–constant with Q^2

Summary

New measurements of ρ, ϕ and Υ at HERA.

The measurements allow us to study the transition from the soft to hard regime.

Effective Pomeron trajectory has smaller slope than that extracted from soft hadron-hadron scattering.

DVCS asymmetries and |t| slope measurements provide access to GPDs.

Measurement of ρ, ρ', ρ'' production shows anomalous behaviour of ρ'/ρ cross section ratio

pQCD expectations are in general compatible with the data, but still a lot to be understood.

Backup

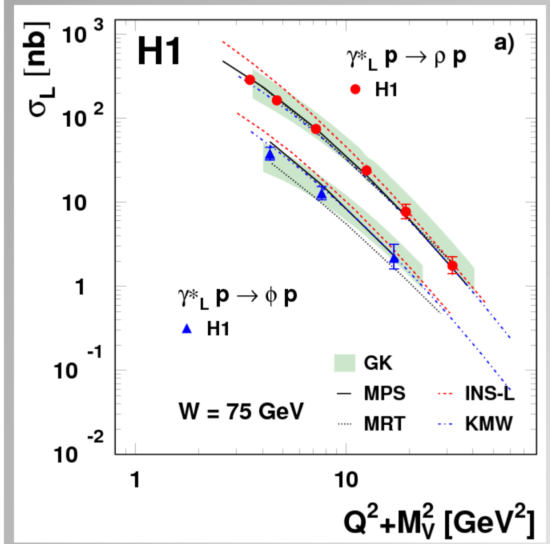
HERA experiments

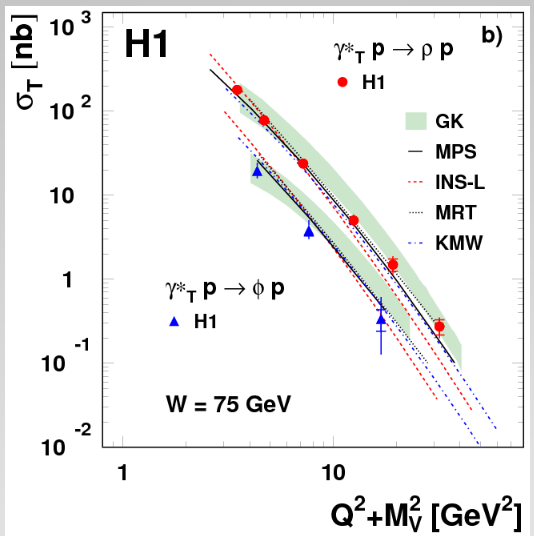
27.5 GeV electrons/positrons with 920 GeV protons beam

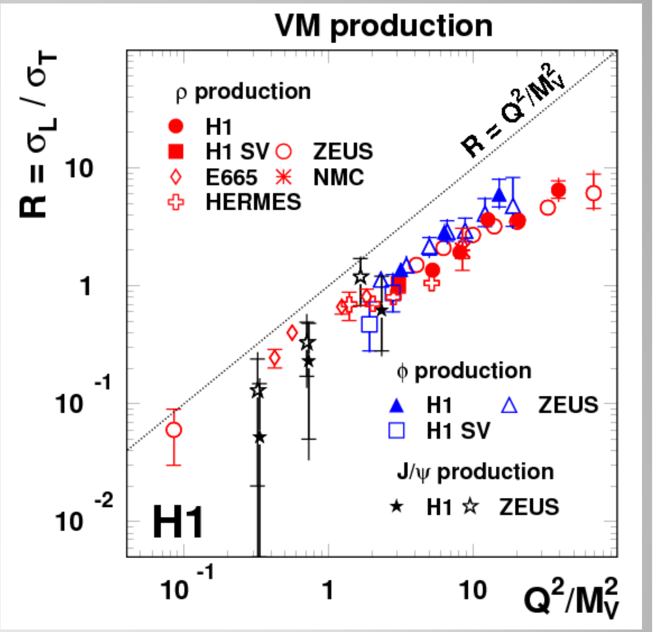
CMS energy = 318 GeV

σ_L , σ_T *cross sections*

- Unique opportunity to extract **R** = σ_L / σ_T $\sigma = \sigma_T + \varepsilon\,\sigma_L$ $\varepsilon \approx 0.996$
- **R** measured from angular distributions f(*cos* θ_h, r^{04}_{00}), in SCHC approximation







expectation: $R=\sigma_L/\sigma_T \sim Q^2/M^2$
as the scale gets harder σ_L dominates

σ_L and σ_T have different Q^2+M^2 dependence
Models based on pQCD describe well σ_L , but not σ_T

INS - I.P. **Ivanov**, N.N. **Nikolaev** and A.A. **Savin**, Phys.Part.Nucl. 37 (2006) 1
GK - S.V. **Goloskokov** and P**. Kroll**, arXiv:hep-ph/0708.3569 (2007)
MPS -C. **Marquet**, R. **Peschanski** and G. **Soyez**, Phys. Rev. D76 (2007) 034011

effective Pomeron trajectory

$$\frac{d\sigma}{d|t|} \propto \left(\frac{W}{W_0}\right)^{4(\alpha(t)-1)}$$

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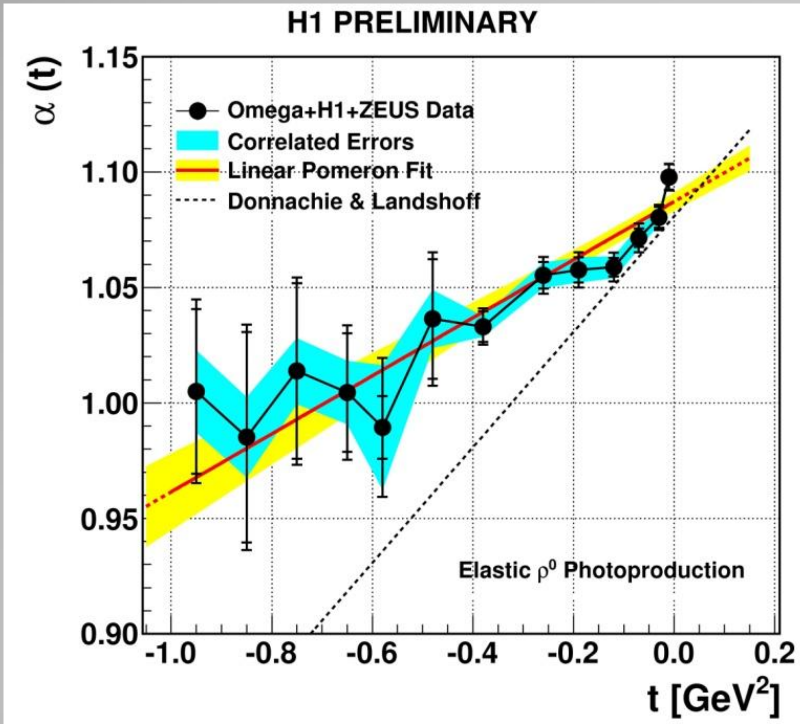

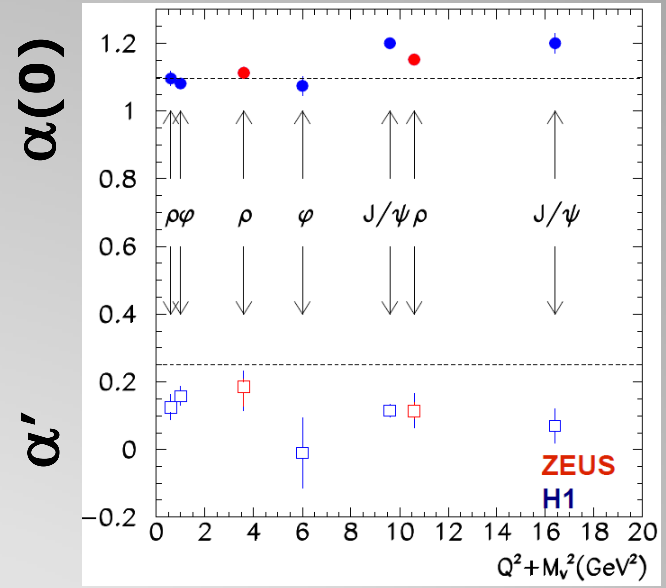

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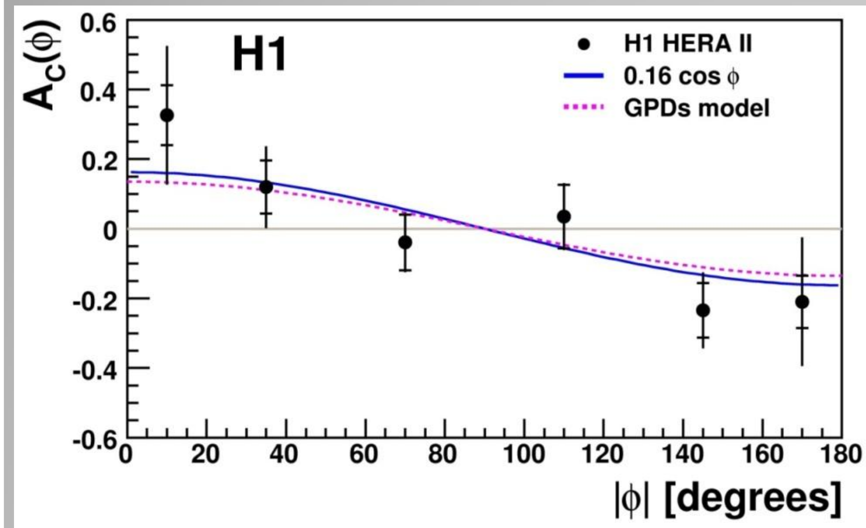
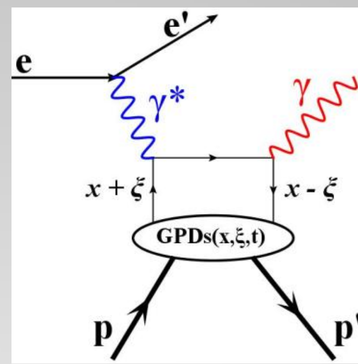
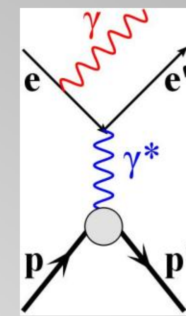
DVCS – Beam Charge Asymmetry

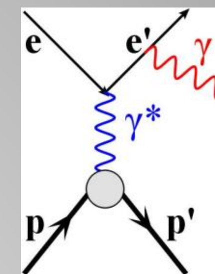
DVCS and Bethe-Heitler have the same initial and final states and they are indistinguishable. The QCD-QED interference term is sensitive to the real part of the QCD amplitude. It changes sign with lepton beam charge:

$$\sigma = \sigma_{DVCS} + \sigma_{BH} \pm \sigma_{interf.}$$









$x_{1,2} = x \pm \xi$ – parton longitudinal momentum fraction, ξ – fraction of the momentum transfer

$$A_C = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = p_1 \cos(\phi) + \cdots$$

DVCS gives access to Generalized Parton Distributions (GPD), which describe the correlations between two partons(x_1,x_2) which differ by longitudinal ($x_1 \neq x_2$) and transverse (t) momentum at given Q^2

$p_1 = 0.16 \pm 0.04 \pm 0.06$

ϕ is the angle between two planes defined by incoming and outgoing electron and γ^* and outgoing proton

GPD's based model compatible with data