Exclusive Diffraction at HERA

Outline:

- **Vector mesons**
- **Deeply Virtual Compton Scattering**

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on behalf of the H1 and ZEUS Collaborations
New Trends in HERA Physics 2011
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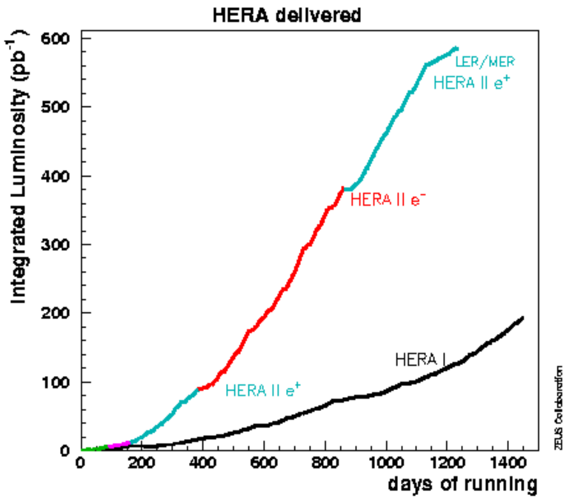
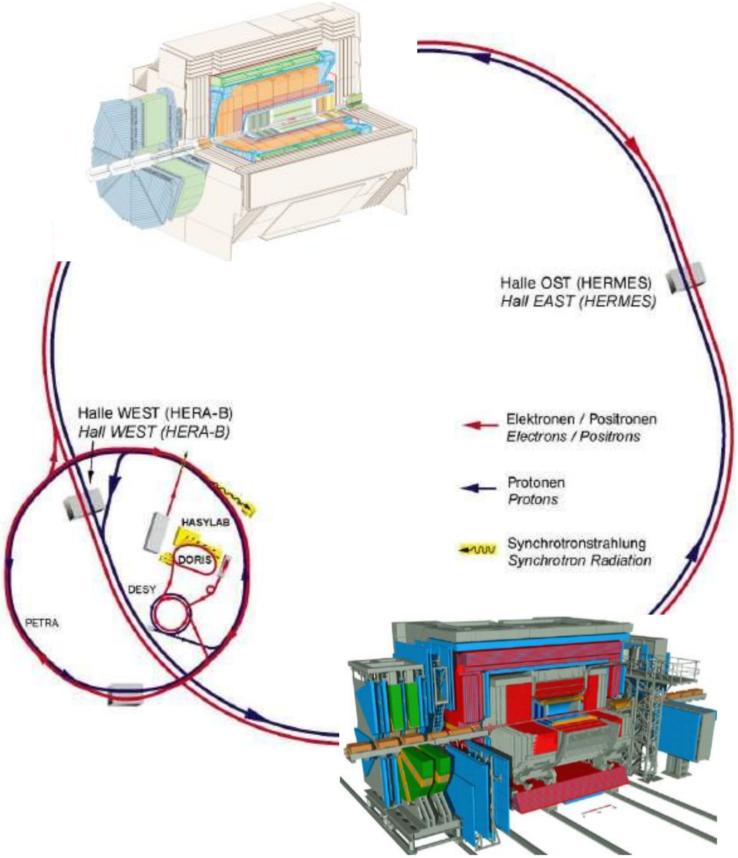
HELMHOLTZ | ASSOCIATION

DESY

HERA

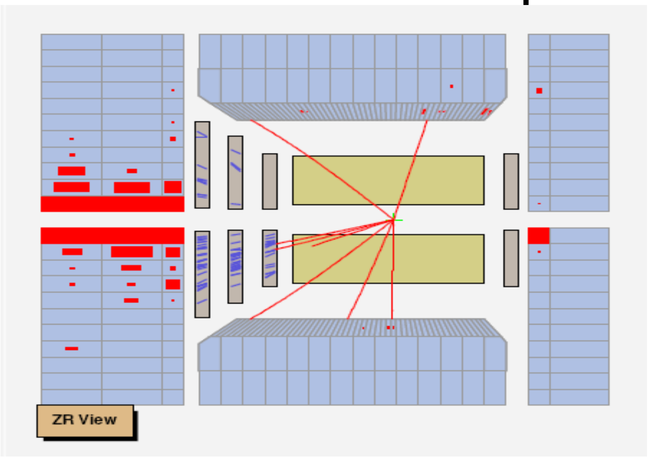
Hadron Elektron Ring Anlage at DESY
electron proton interactions
collected luminosity 0.5fb $^{-1}$/experiment



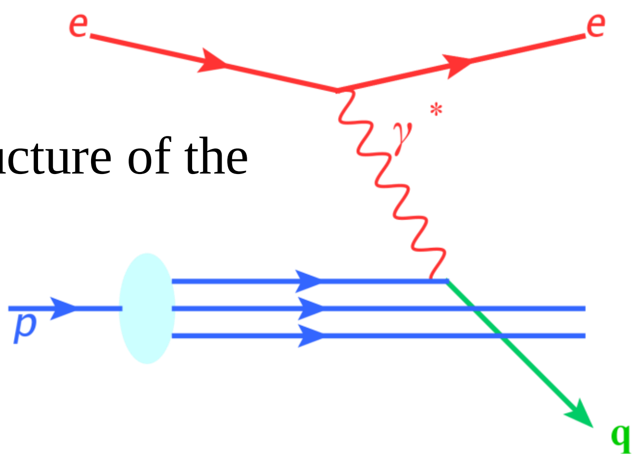


Diffraction in ep collision at HERA

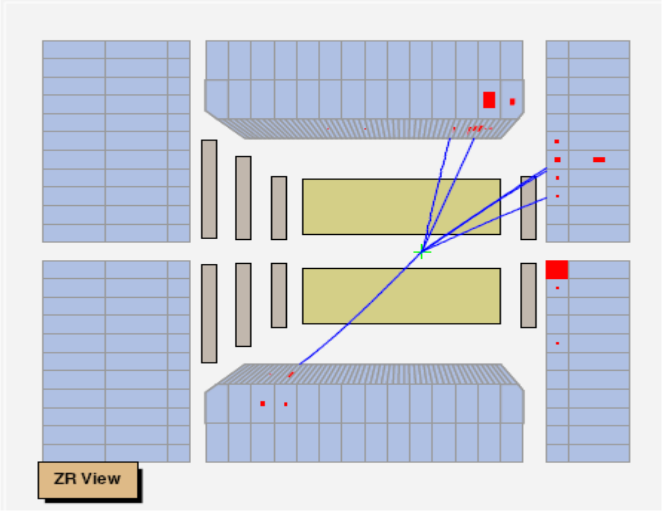
Non – diffractive ep



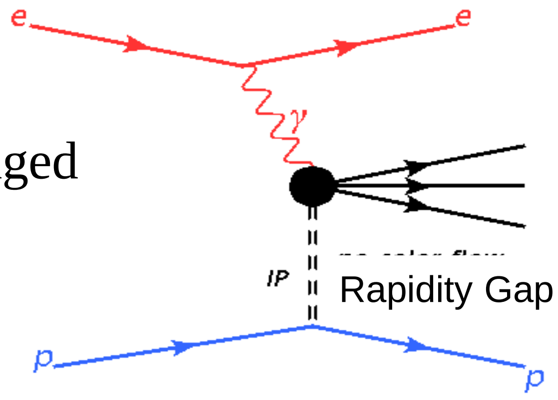
photon probes internal structure of the proton



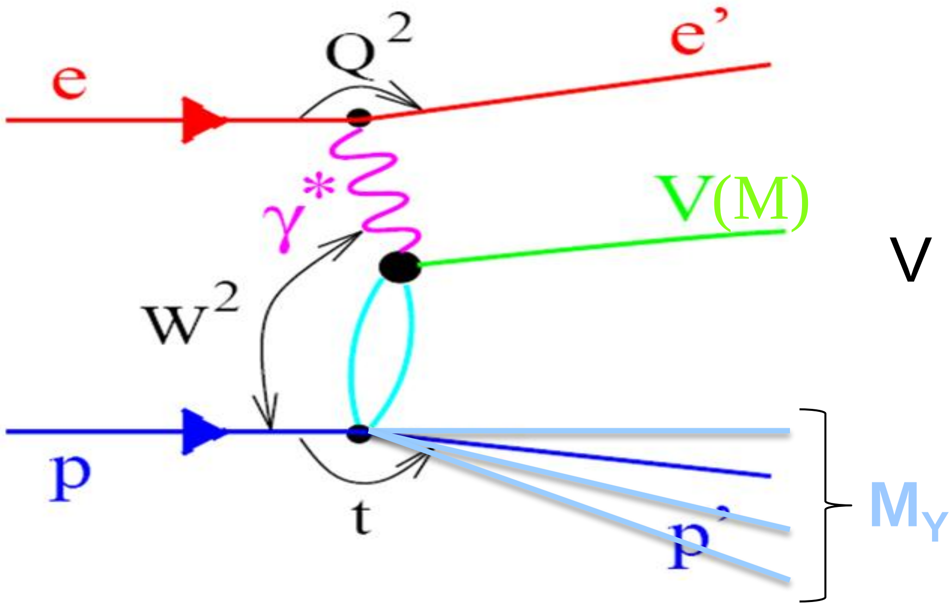
Diffractive ep



no quantum numbers exchanged



Diffractive Production



V = ρ, ρ', ρ'', ϖ, ϕ, J/ψ, ϒ, γ

Proton dissociation

M – invariant mass of the vector meson

W – center-of-mass energy of the photon proton system

Q^2 – virtuallity of the photon

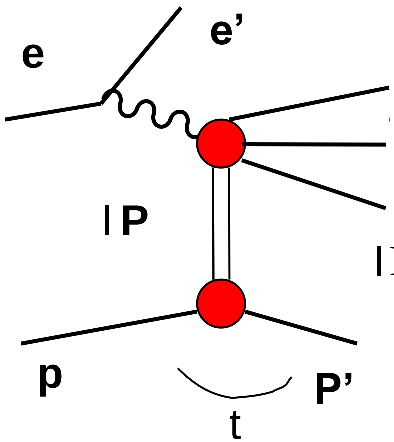
t – the square of the momentum transfer between hadrons

M_Y – mass of the proton dissociation system

Regge Phenomenology vs. pQCD

Regge Phenomenology

(soft diffraction)



X

IP =Pomeron trajectory

$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha' \cdot t$

$$\frac{d\sigma}{dt} \propto e^{b(W)\cdot t}\left(\frac{W}{W_0}\right)^{4(\alpha_{IP}(t)-1)}$$

$$\sigma_{tot} \propto \left(\frac{W}{W_0}\right)^{2(\alpha_{IP}(0)-1)}$$

$$b(W) = b_0 + 4\alpha' \cdot \ln\left(\frac{W}{W_0}\right)$$

⇨ shrinkage

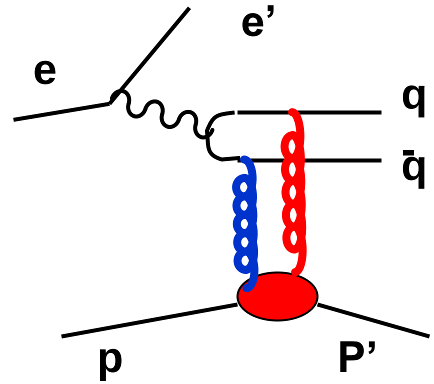
From fit to hadronic data :

$$\alpha_{IP}(t) = 1.08 + 0.25 \cdot t$$

(Donnachie, Landshoff)

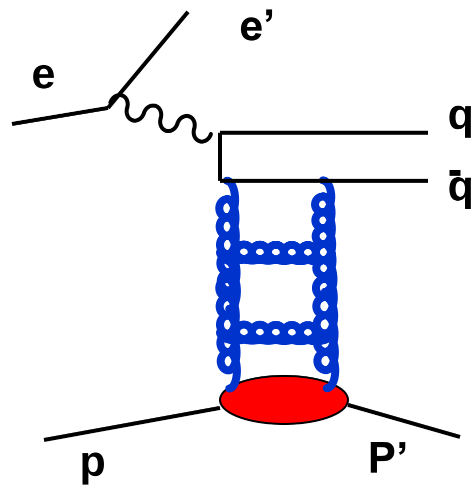
Perturbative QCD

(hard diffraction)



X

simplest approach:
colorless 2 gluon exchange



BFKL-type
gluon ladder exchange

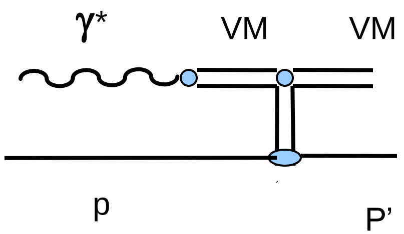
Various pQCD inspired models exist

⇨ little or no shrinkage

DESY

Exclusive Vector Meson Production

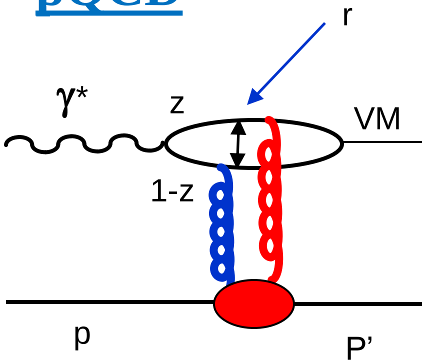
VDM+Regge



$$\frac{d\sigma}{dt} = e^{b\cdot t}\left(\frac{W}{W_0}\right)^{4(\alpha_{IP}(t)-1)} \Longrightarrow \sigma(W) \propto W^{\delta} \;;\; \delta \approx 0.22$$

$$b(W) = b_0 + 4\alpha' \cdot \ln\frac{W}{W_0} \Longrightarrow$$ Shrinkage ; $b \propto r^2$

pQCD



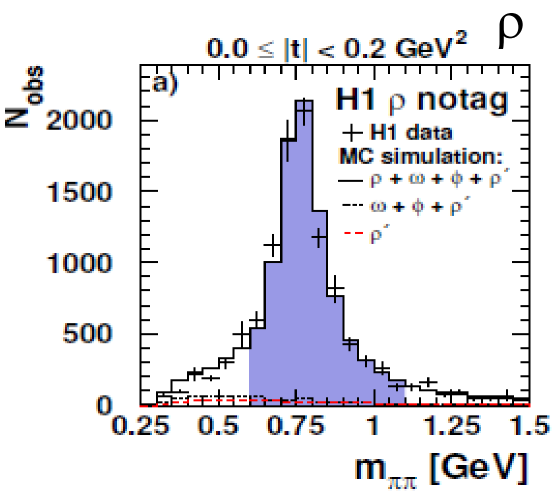
$$r^2 = \left[z(1-z)Q^2 + m_q^2\right]^{-1} \Longrightarrow$$ r^2 small if Q^2 large or M_V large

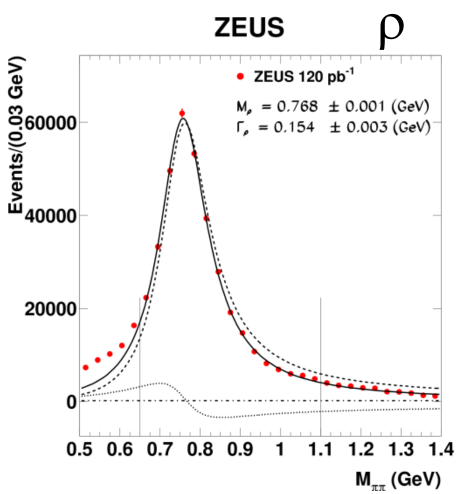
$$\sigma_L \propto \alpha_s^2(Q_{eff}^2)\cdot|x \cdot g(x, Q_{eff}^2)|^2$$ Ryskin : $Q_{eff}^2 = \frac{1}{4}\left(Q^2 + M_V^2 + |t|\right)$

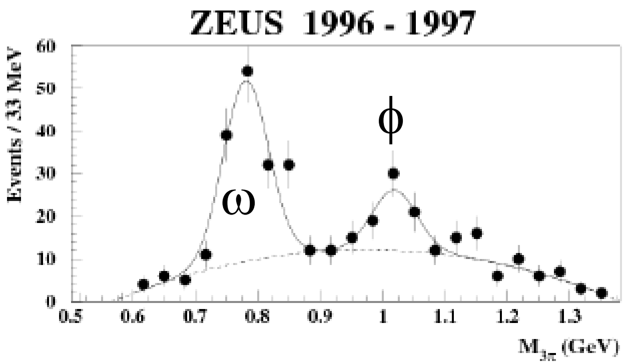
$\Longrightarrow$ $\sigma(w) \propto W^{\delta}$; $\delta \approx 0.8$ fast rise with W

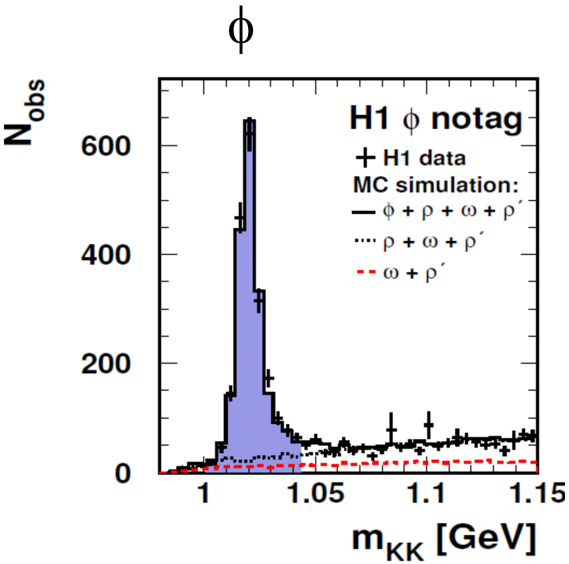
$b \approx 4\ GeV^2$ and $\alpha' \approx 0$ no or little shrinkage

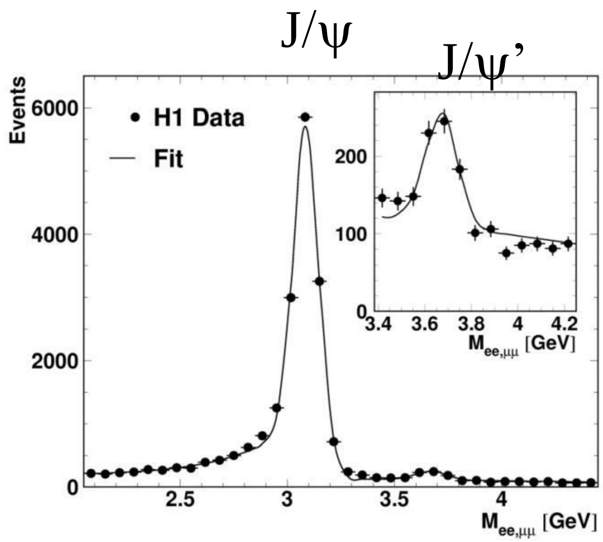
Vector mesons at HERA

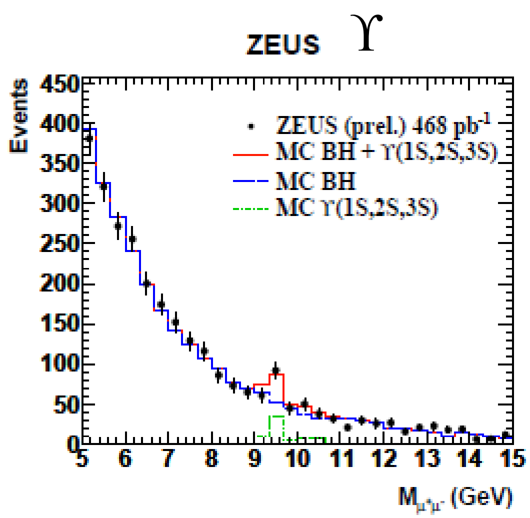






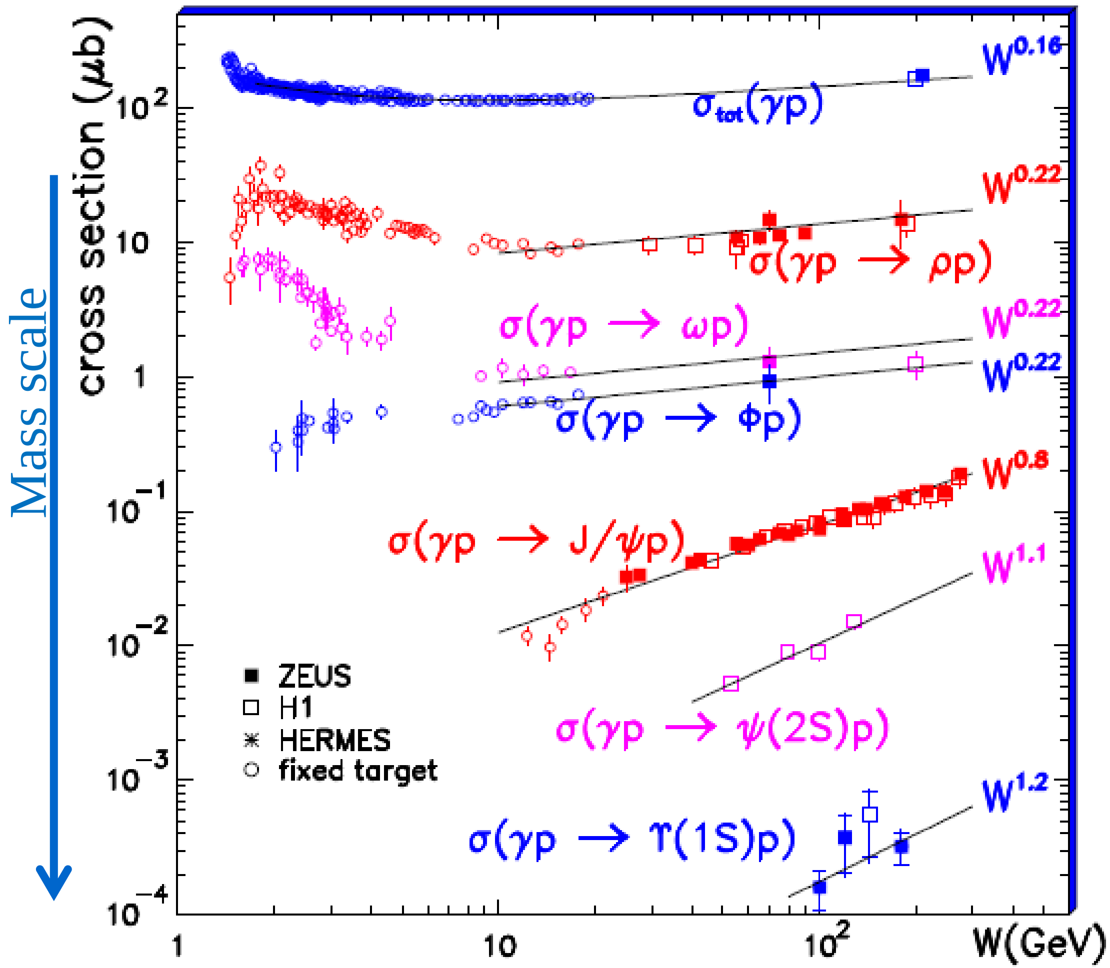






Mass scale

Photoproduction $Q^2 \approx 0$



ρ, ω, φ, ψ, ψ(2s), Υ

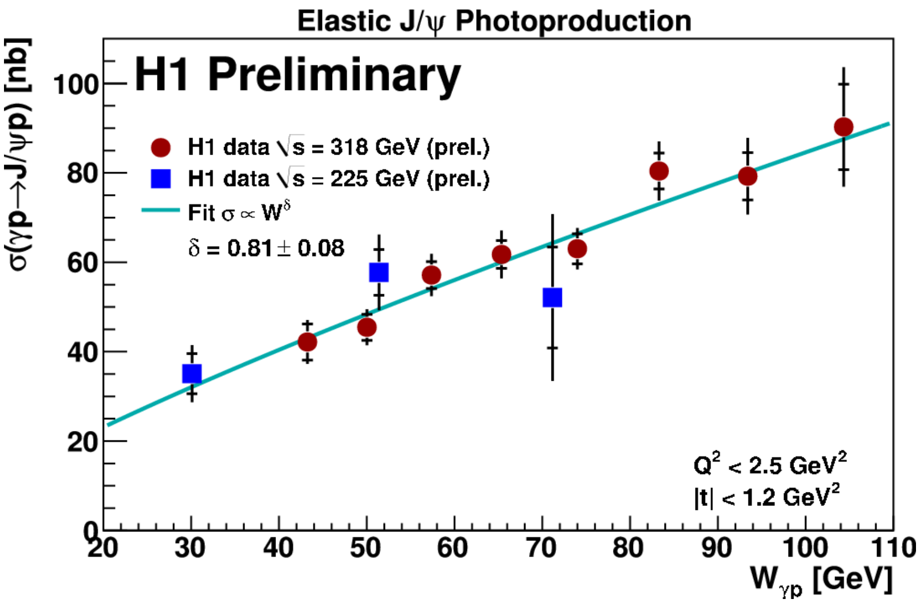
The W-dependence of the "light" vector-meson (ρ, ω, ϕ) production is described by Regge phenomenology

$\delta \approx 0.22$

For higher mass vector mesons the rise of the production cross section with W gets steeper.

This indicates the on set of hard diffractive scattering

W dependence

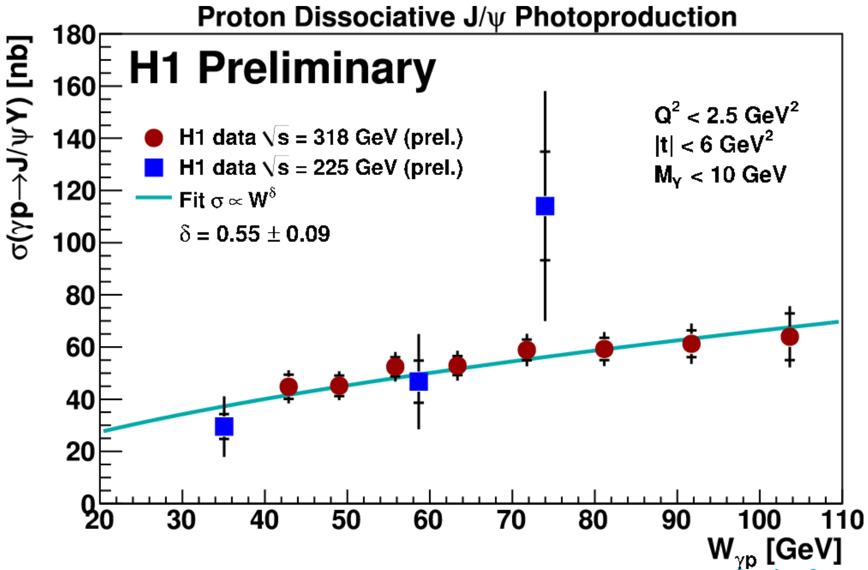


H1prel11-011

$\sqrt{s} = 318\ GeV$ – nominal energy run

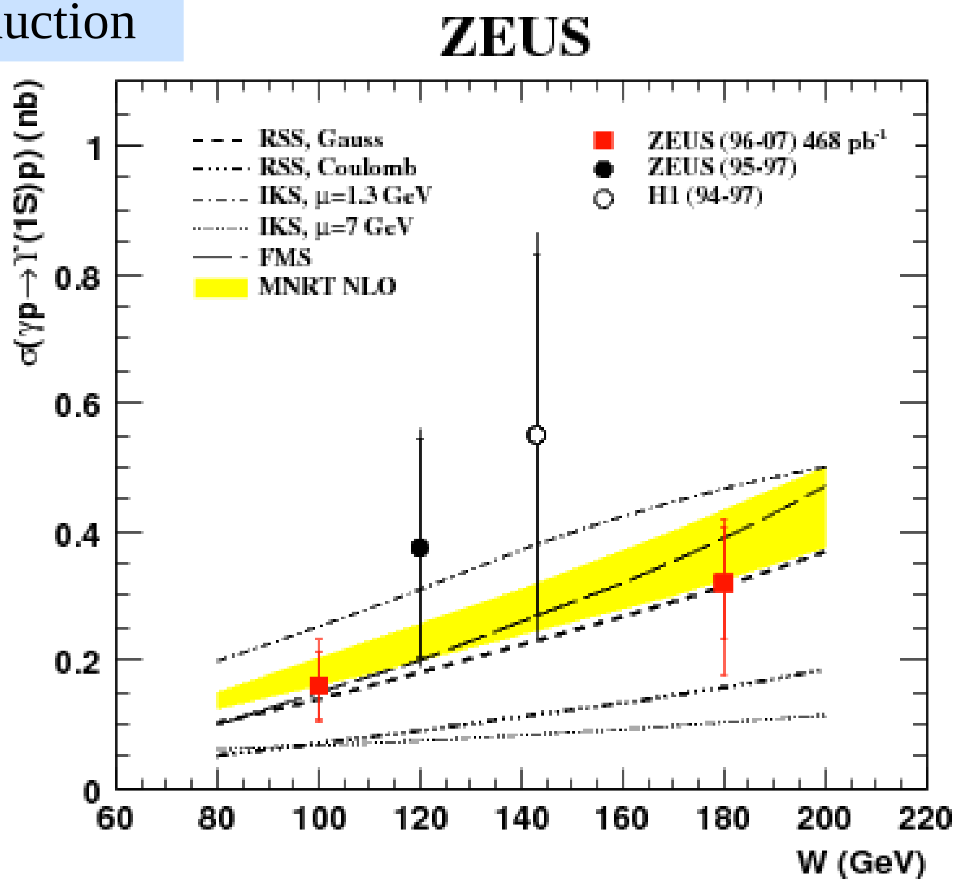
Reduced energy run
→ allow to extend the phase-space towards lower W.

Simultaneous extraction of the exclusive and proton-diffractive components from the data.



W dependence

Photoproduction

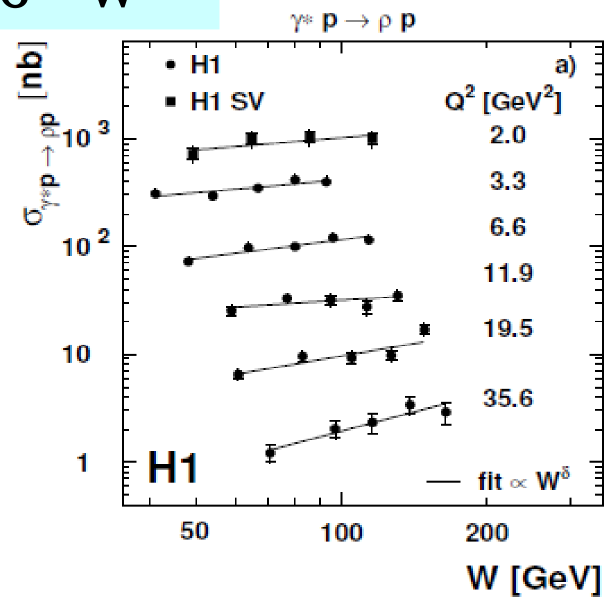


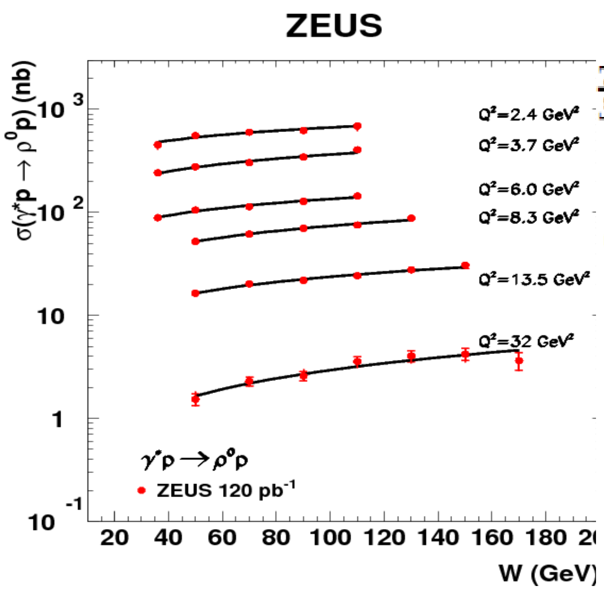
$\delta = 1.2 \pm 0.8$

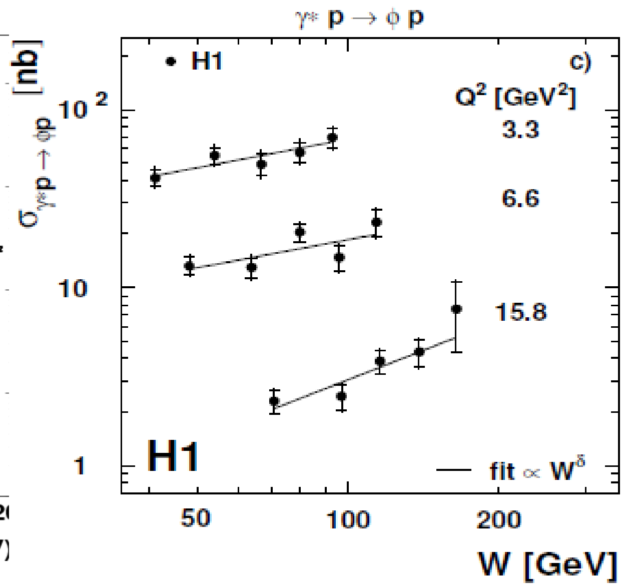
- cross section W dependence, $\sigma \sim W^{\delta}$:
- two measured points $\delta = 1.2 \pm 0.8$
- consistent with theoretical prediction, $\delta \sim 1.7$

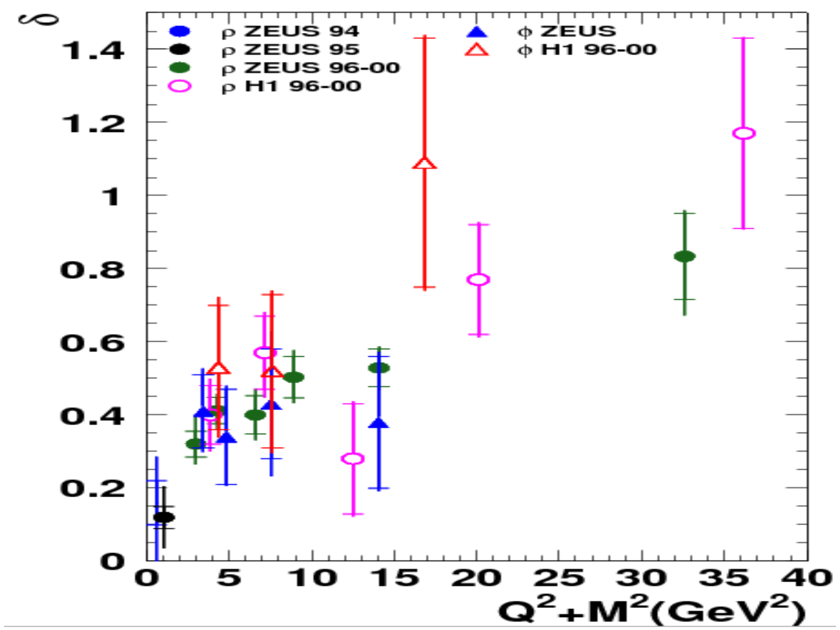
W dependence as a function of Q^2

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







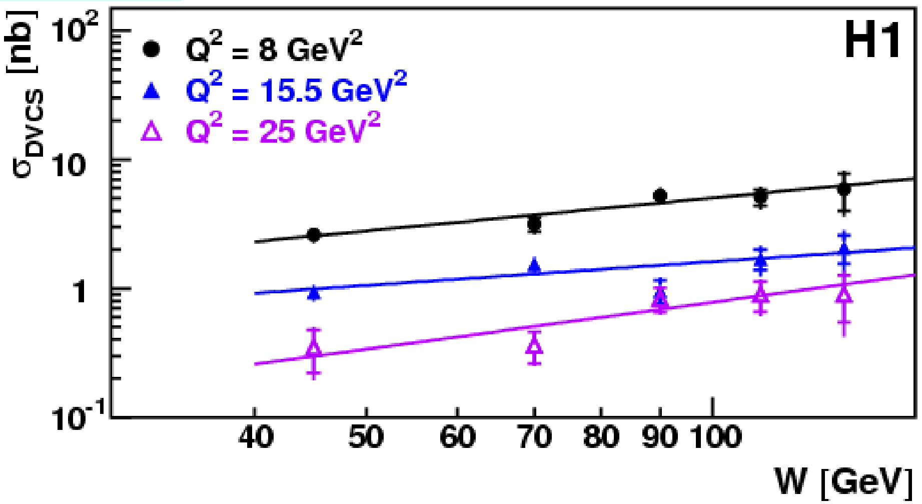


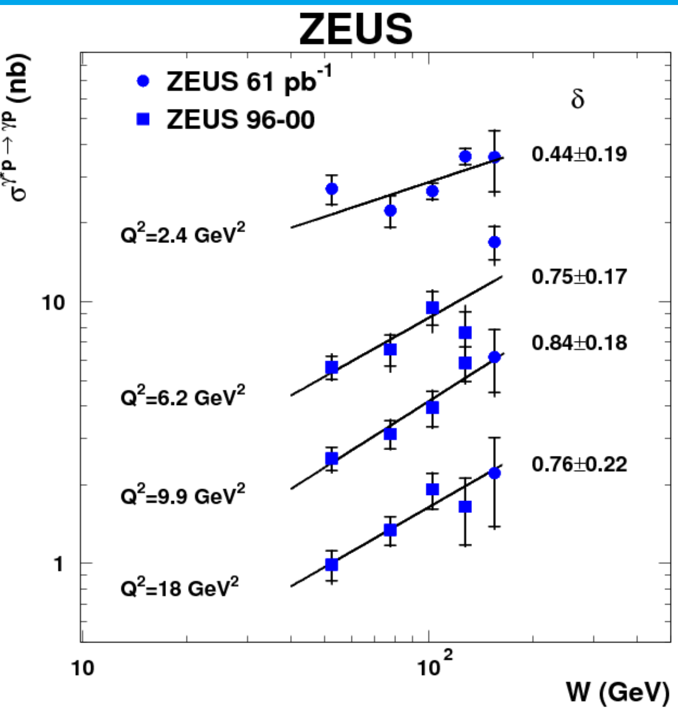
H1 Collab., JHEP05 (2010) 032 , 10/09
ZEUS Collb, PMC Physics A 1, 6

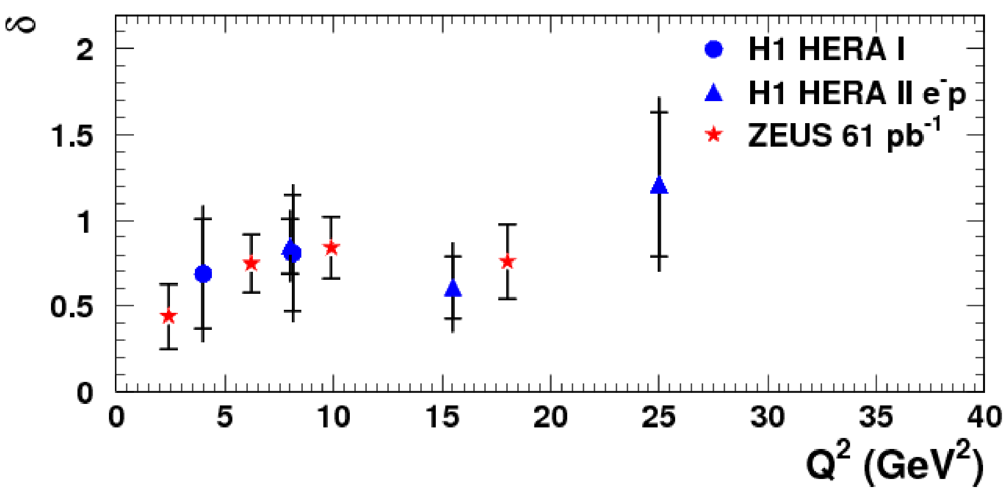
- δ~0.2 for very low Q^2
- Cross section depends on Q^2 (steeper with increasing Q^2)

DVCS - W dependence as a function of Q^2

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



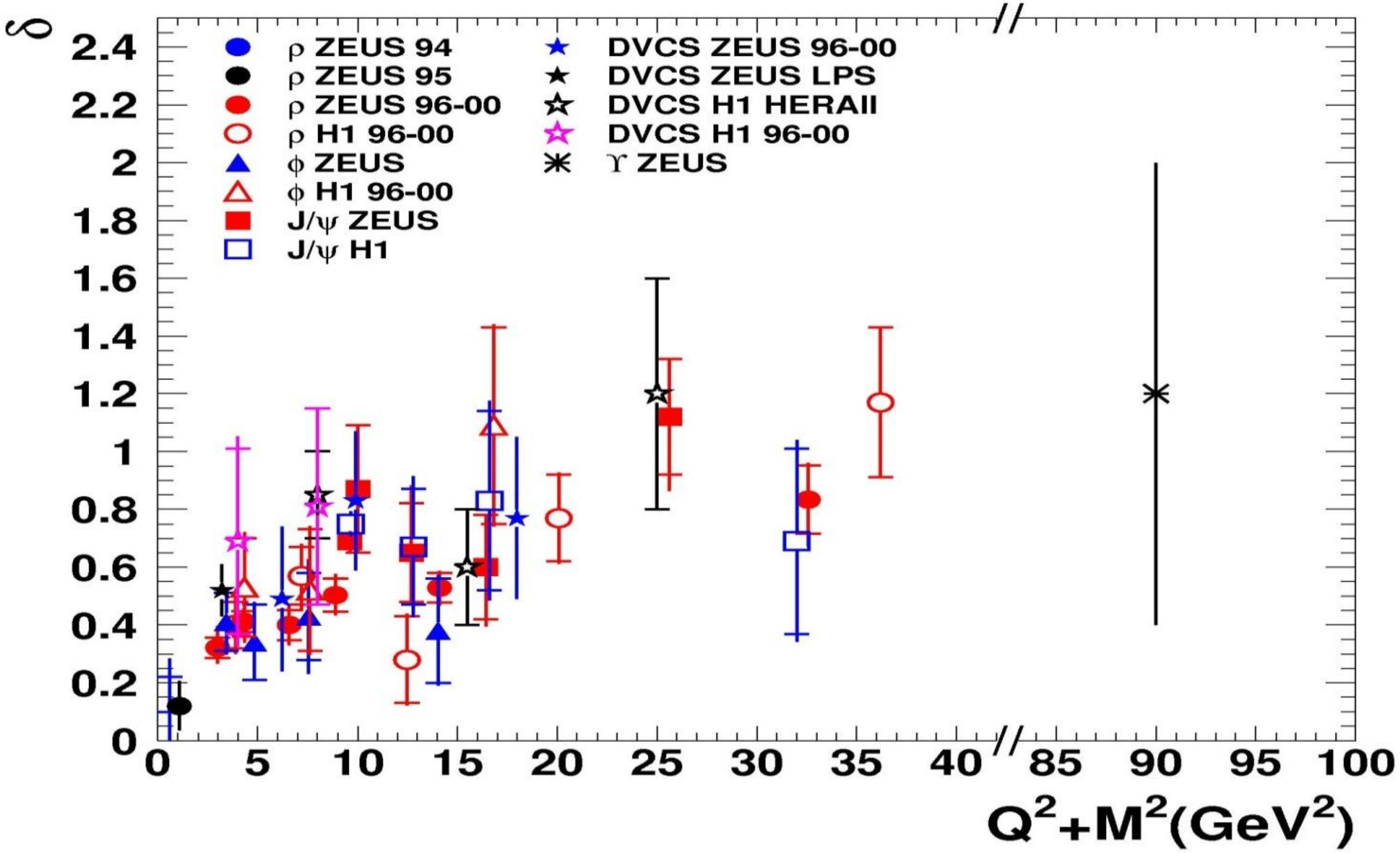




- no δ dependence on Q^2 is observed
- hard regime

ZEUS: JHEP05(2009)108
H1: Phys.Lett.B659:796-806,2008

δ dependence as a function of scale Q^2+M^2



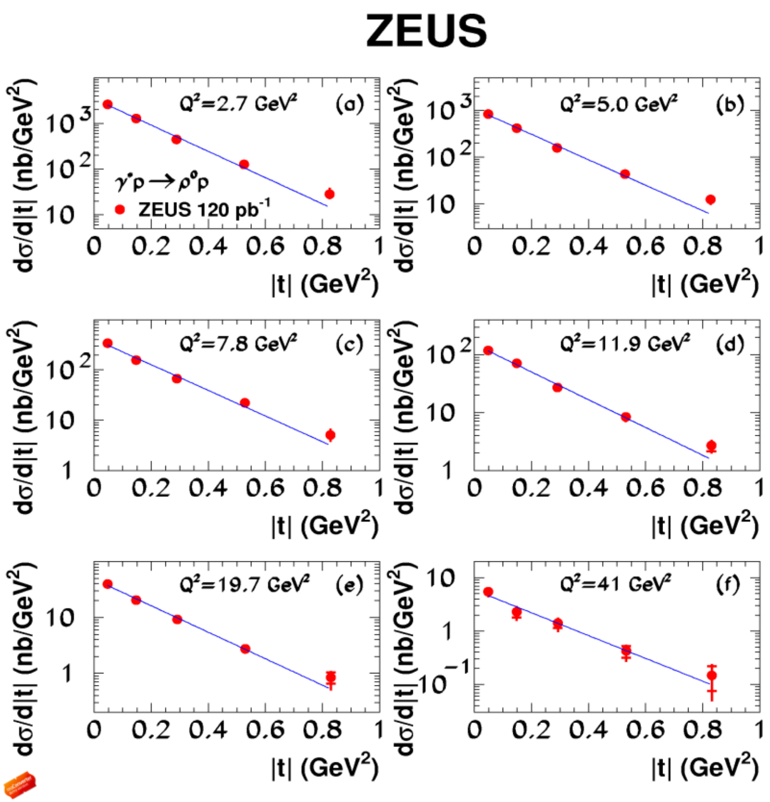
Process becomes hard as scale (Q^2+M^2) be comes larger

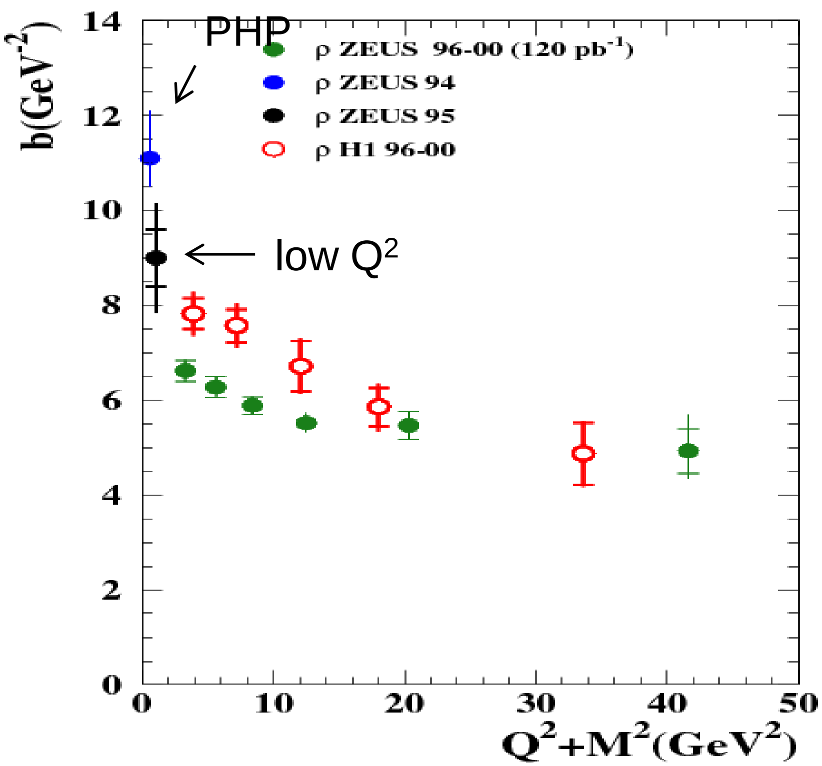
t dependence

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

Transverse size of interaction region: $b = b_{v(\gamma)} + b_p$

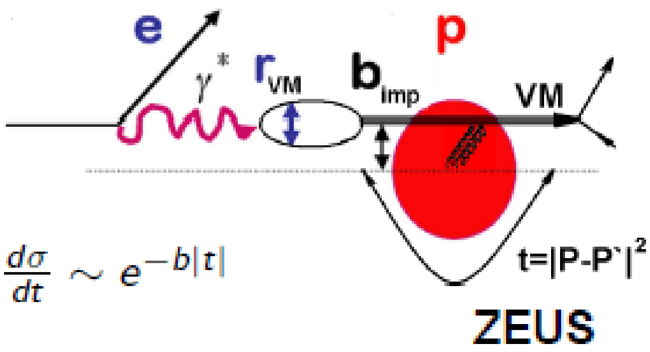
Transverse size vector meson (gama) and target (proton)

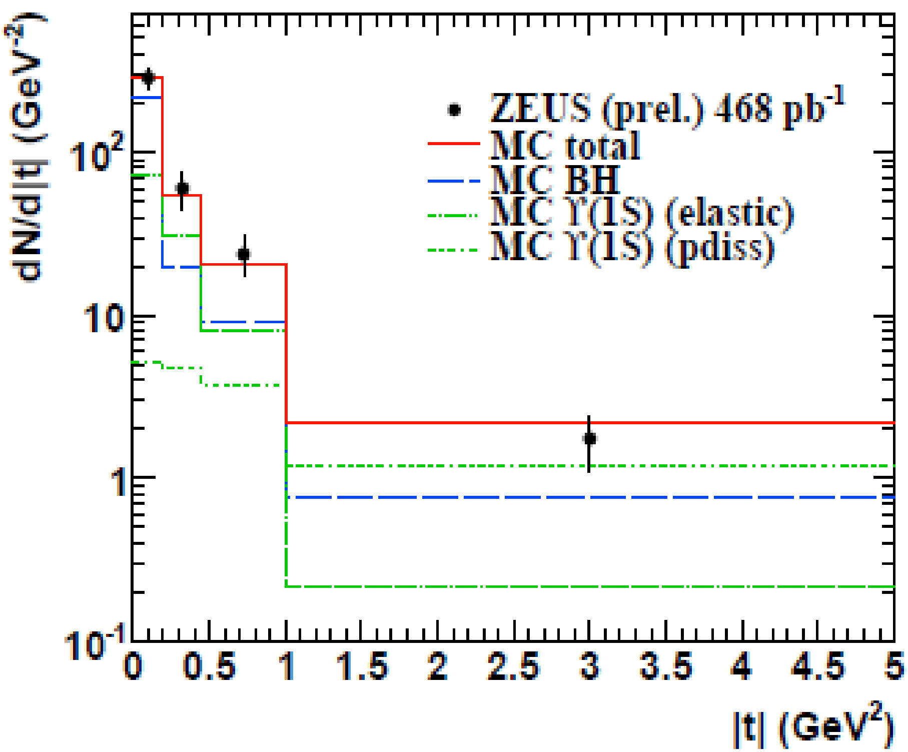




The b-slope of ρ-production decreases with Q^2.

b slope





Transverse size of interaction region:

$$b = b_{v(\gamma)} + b_p$$

vector meson (gama) target (proton)

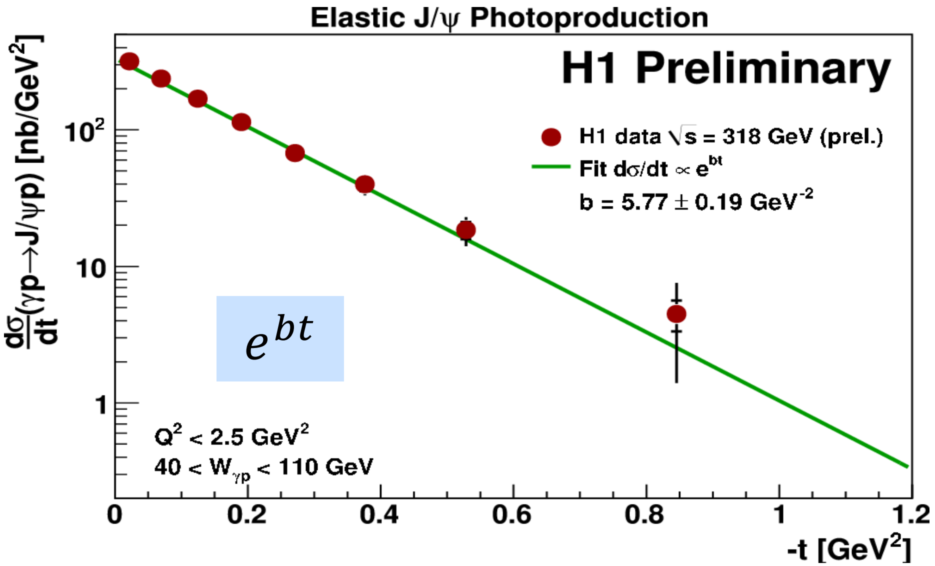
$$b = 4.3^{+1.7}_{-1.1}\ ^{+0.5}_{-0.5}\,[GeV^{-2}]$$

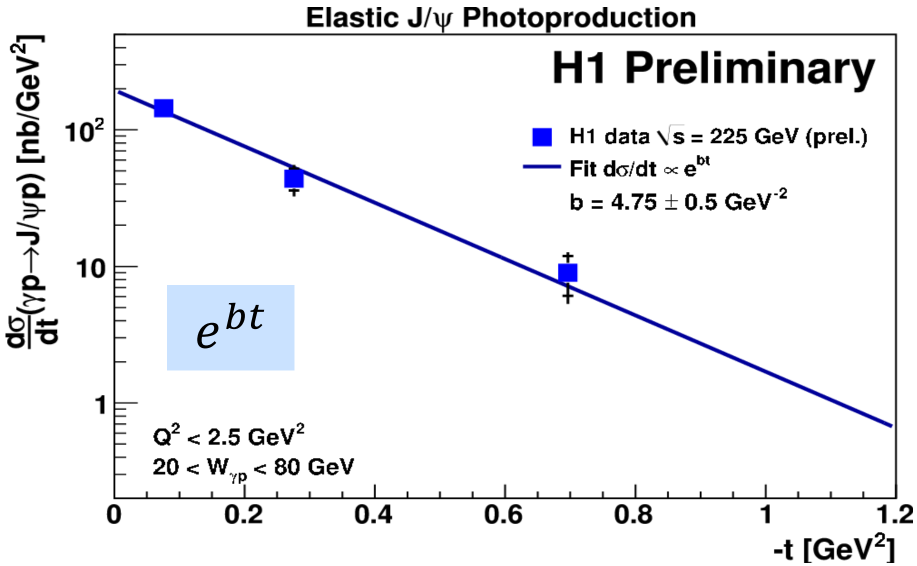
High |t| proton dissociation change dependence of t

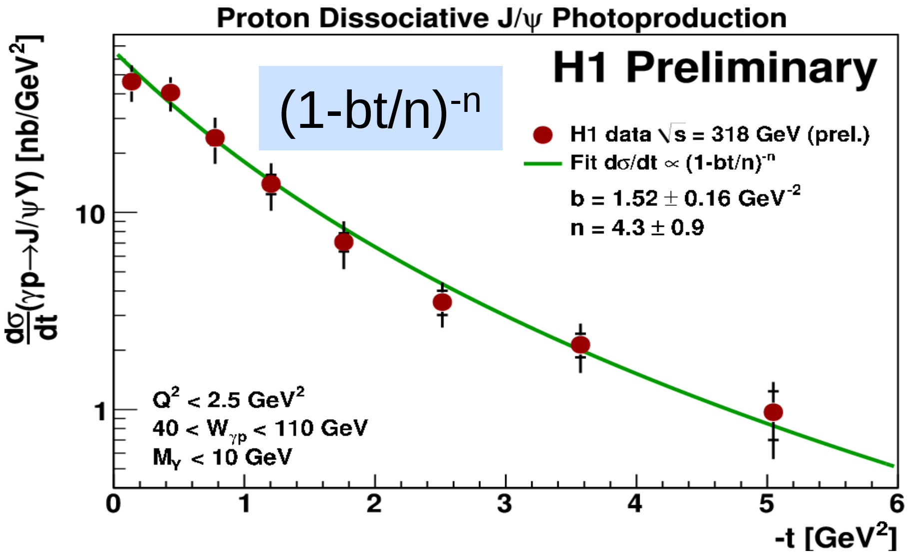
b slope

$\sqrt{s} = 318$ GeV – nominal energy run

$\sqrt{s} = 225$ GeV – reduced energy run

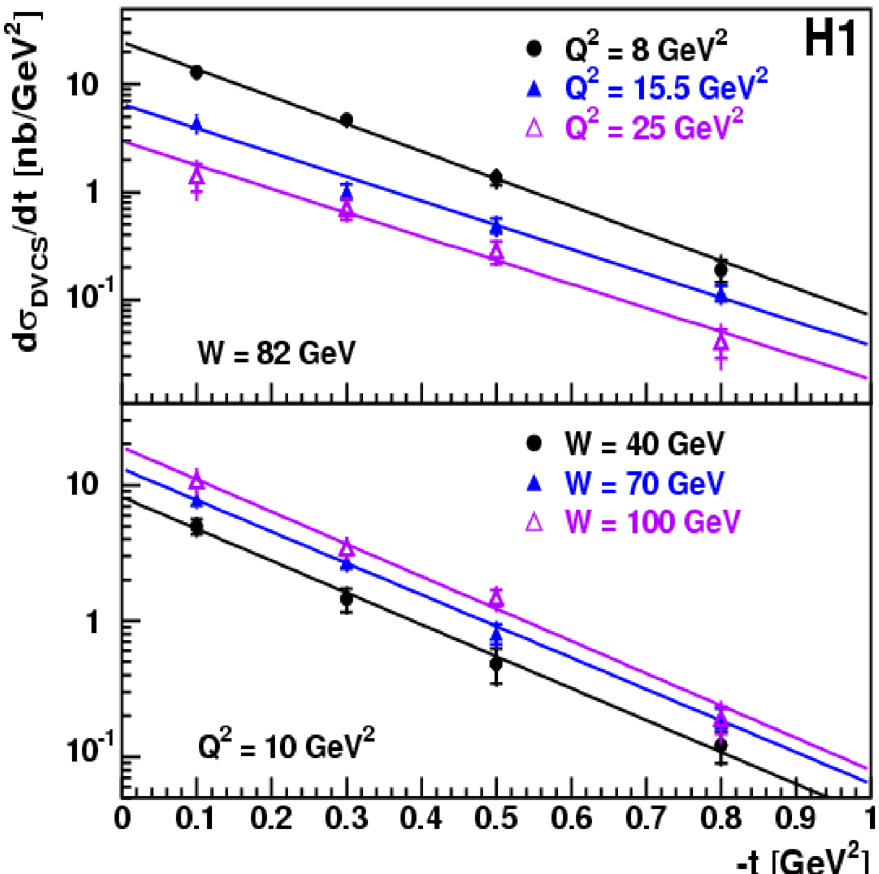






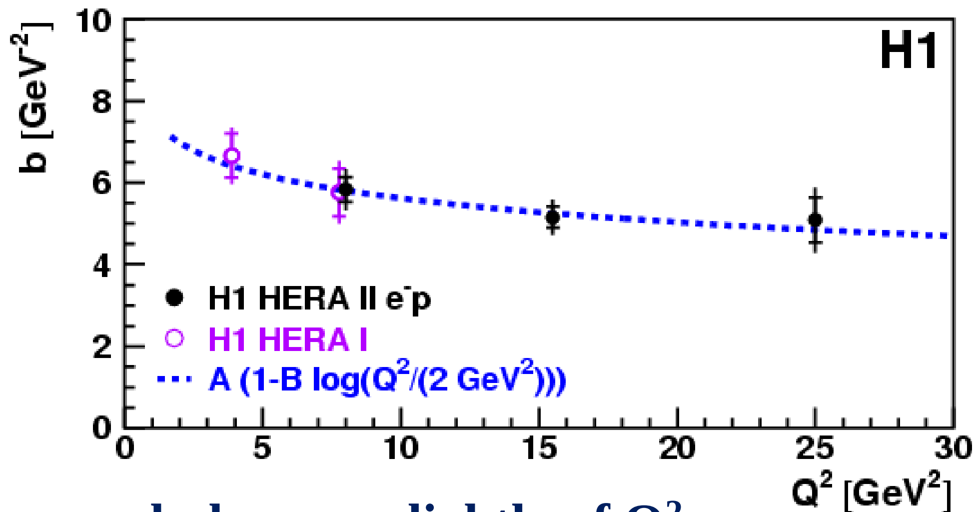
- Slight dependence slope of W
- Differential proton dissociative cross section fitted with function behaving as an exponential at low |t| and and follows a power law at larger |t|.

DVCS t dependence

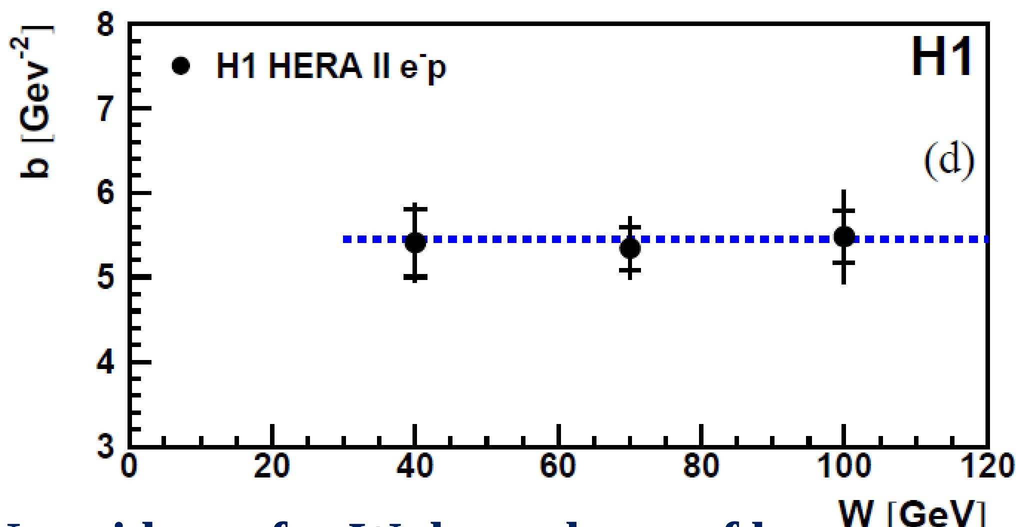


$b = 5.45 \pm 0.19 \pm 0.34\ \text{GeV}^{-2}$

for $\langle Q^2 \rangle = 8\ \text{GeV}^2$



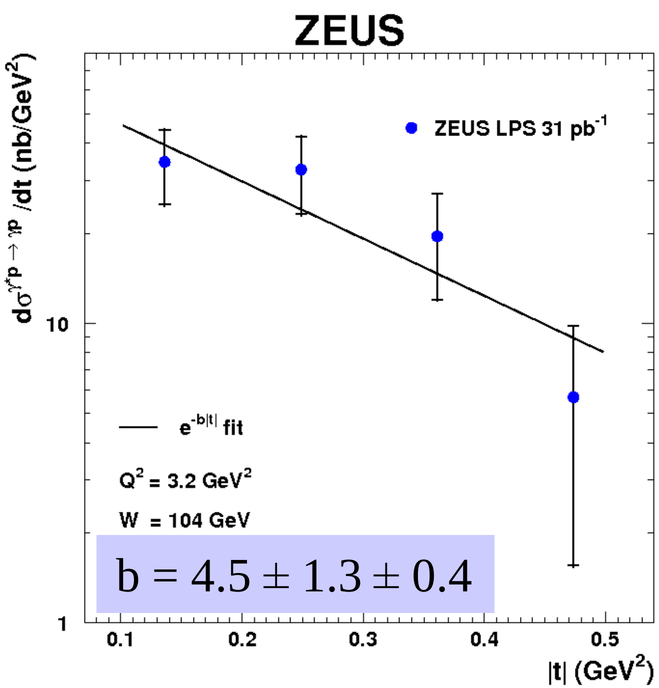
b deepens slightly of Q^2



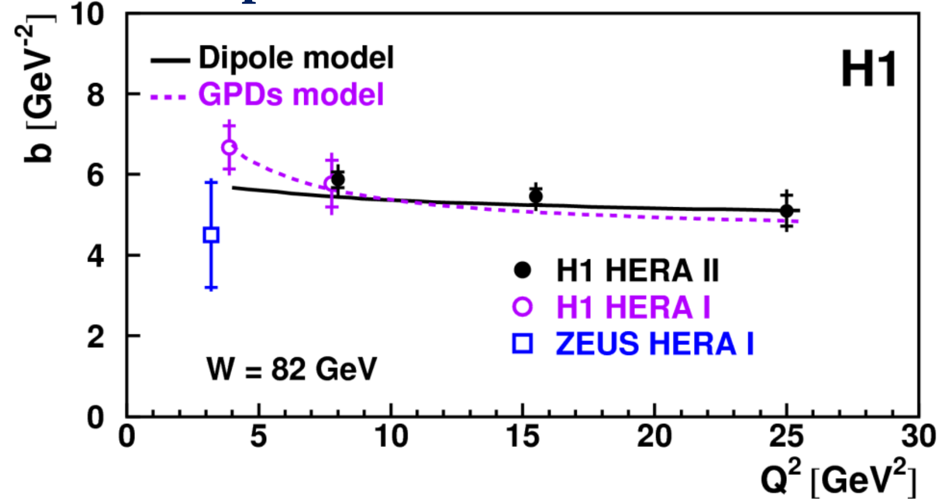
No evidence for W dependence of b

H1. Physics Letters B, 659(4):796-806.

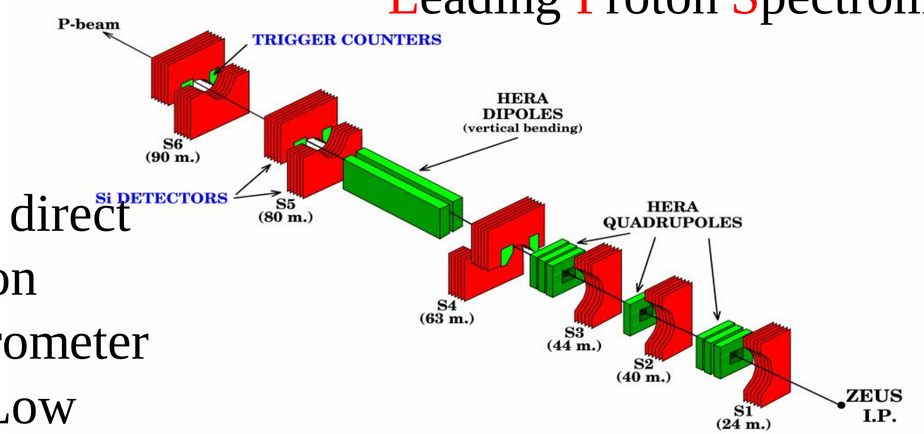
t dependence of DVCS at ZEUS



Comparison ZEUS and H1 results

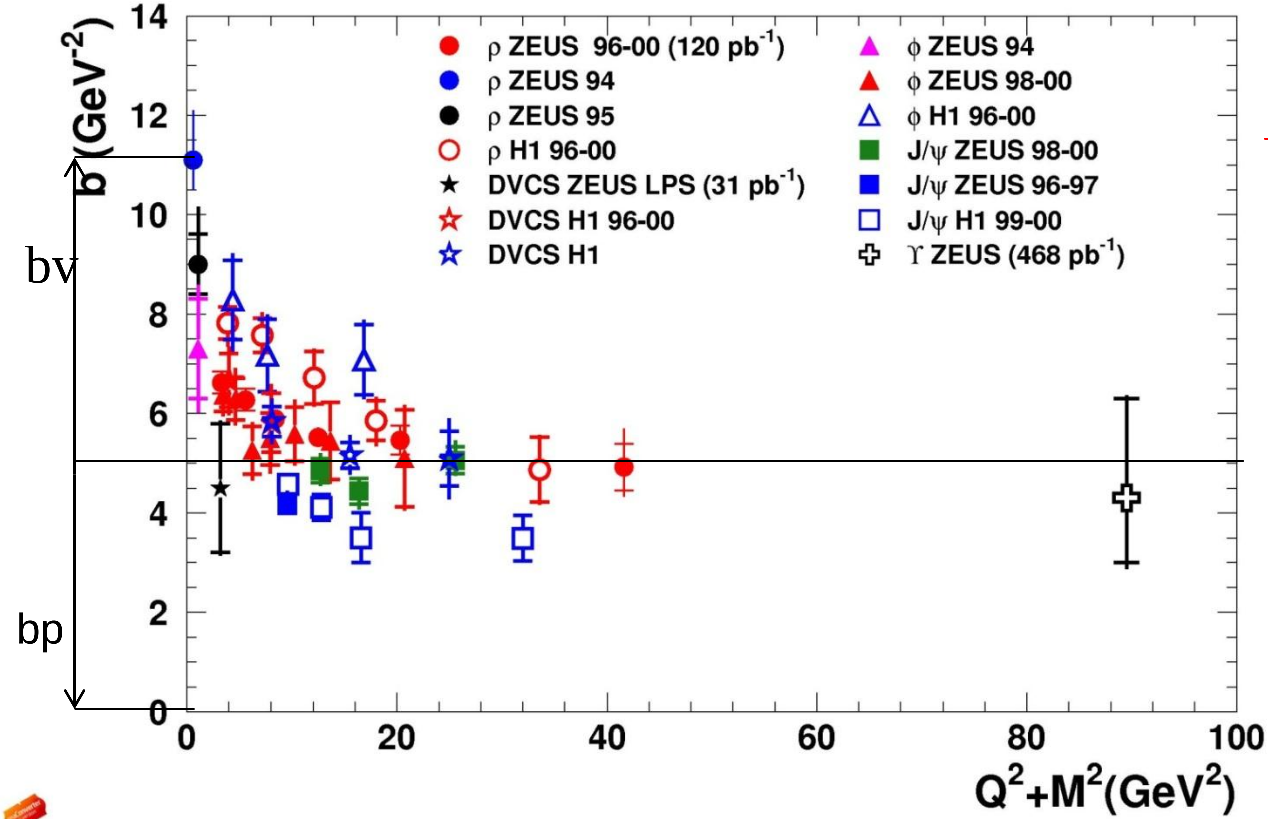


Leading Proton Spectrometer



- ZEUS measures DVCS by using a direct measurement of the outgoing proton 4-momentum using the LPS spectrometer
- No p dissociation background → Low detector acceptance → low statistics → Clean measurement

t dependence



Geometrical transverse size:

$b = b_{v(\gamma)} + b_p$

Vector meson $b_v = \frac{1}{Q^2 + M^2}$

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

b_p can be interpreted as:

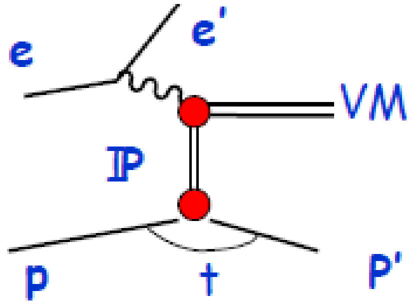
$r_{gluons} \sim 0.5$ fm

Charge radius of the proton

$r_{em} \sim 0.8$ fm

The slope b decreasing with increasing scale, to asymptotic value 5 GeV^{-2}

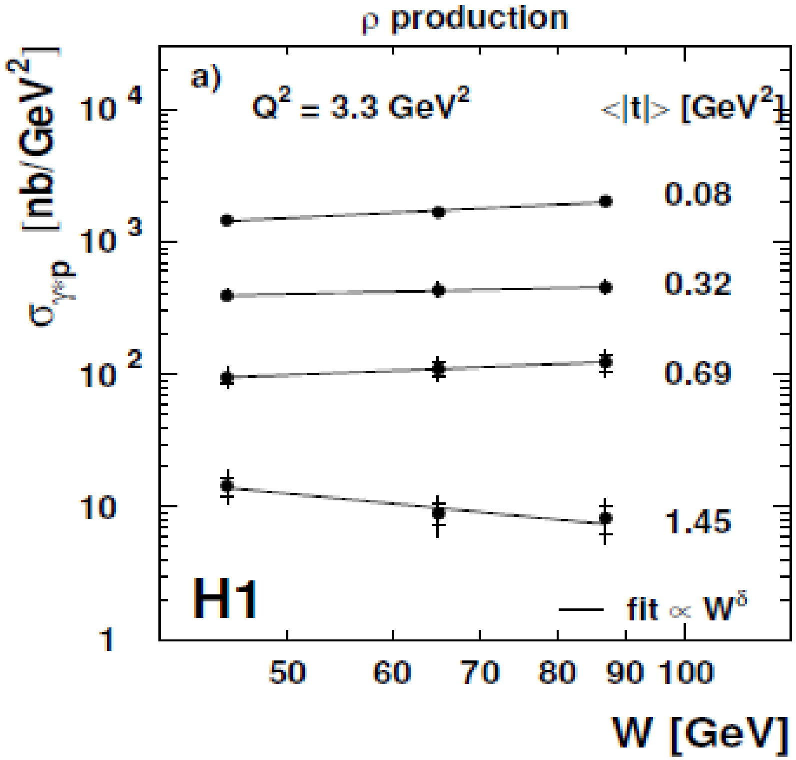
Pomeron trajectory

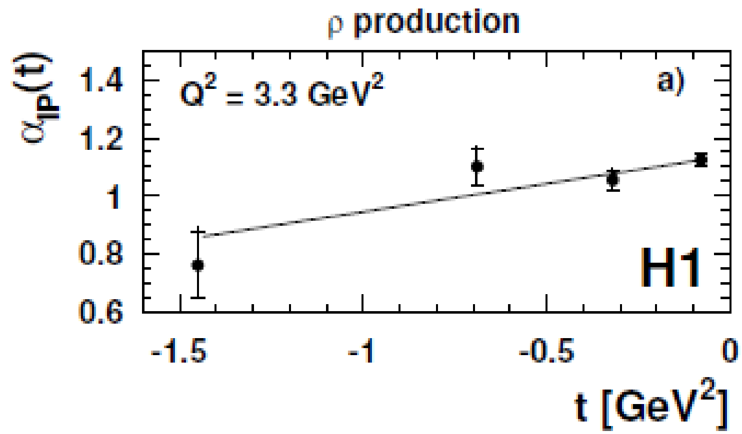


$$\frac{d\sigma}{dt} \propto e^{b(W)\cdot t}\left(\frac{W}{W_0}\right)^{4(\alpha_{IP}(t)-1)}$$

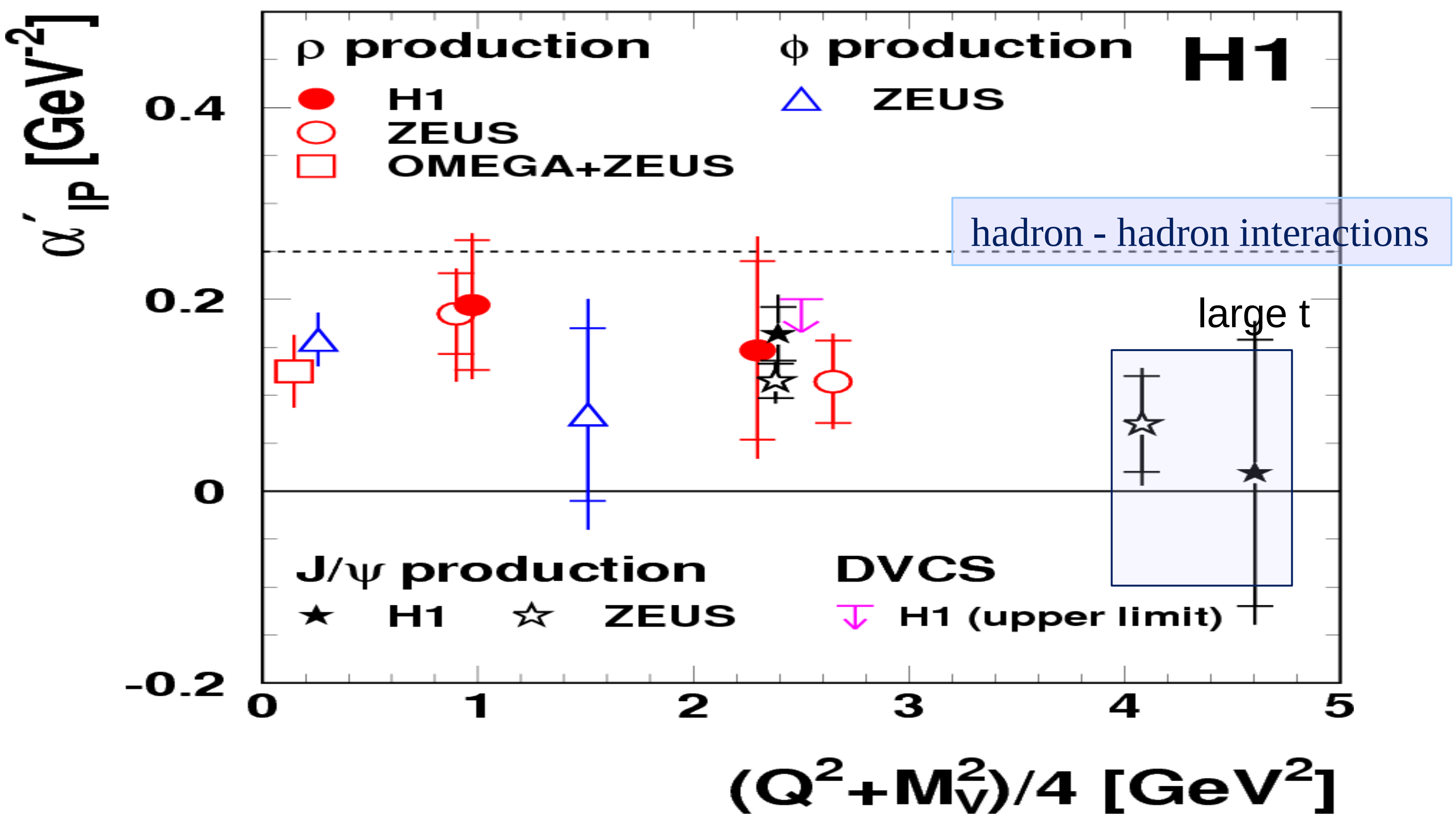
Measure W-dependence separately for different t-bins Pomeron trajectory

$$\alpha_{IP}(t)=\alpha_{IP}(0)+\alpha'\bullet t$$





Pomeron trajectory



α'_{IP} depends on t —However→ for high |t| , proton diffractive processes dominate.

Exclusive dipion production

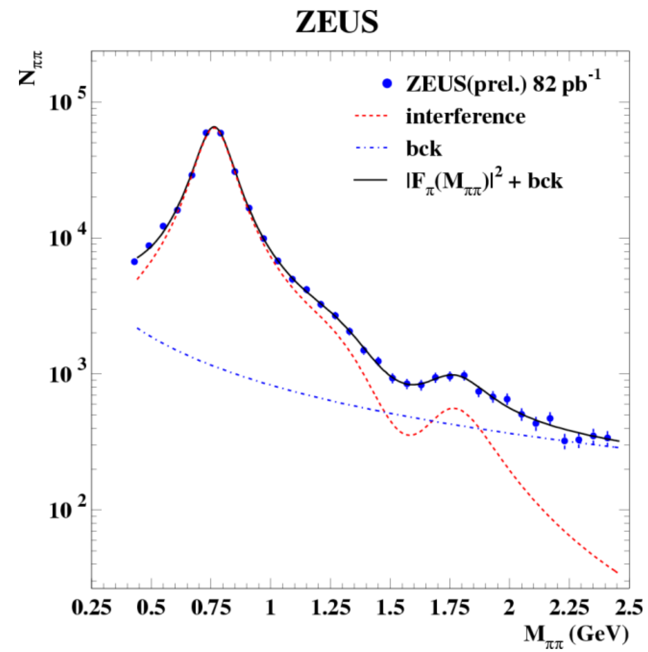
The two pion invariant mass is fitted as:

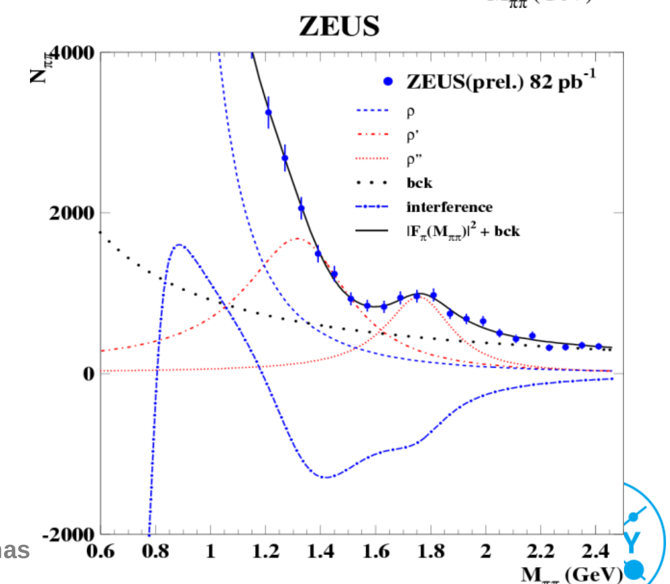
$$\frac{dN}{dM_{\pi\pi}} = N\left[|F_{\pi\pi}|^2 + B\left(\frac{M_\rho}{M_{\pi\pi}}\right)^n\right]$$

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

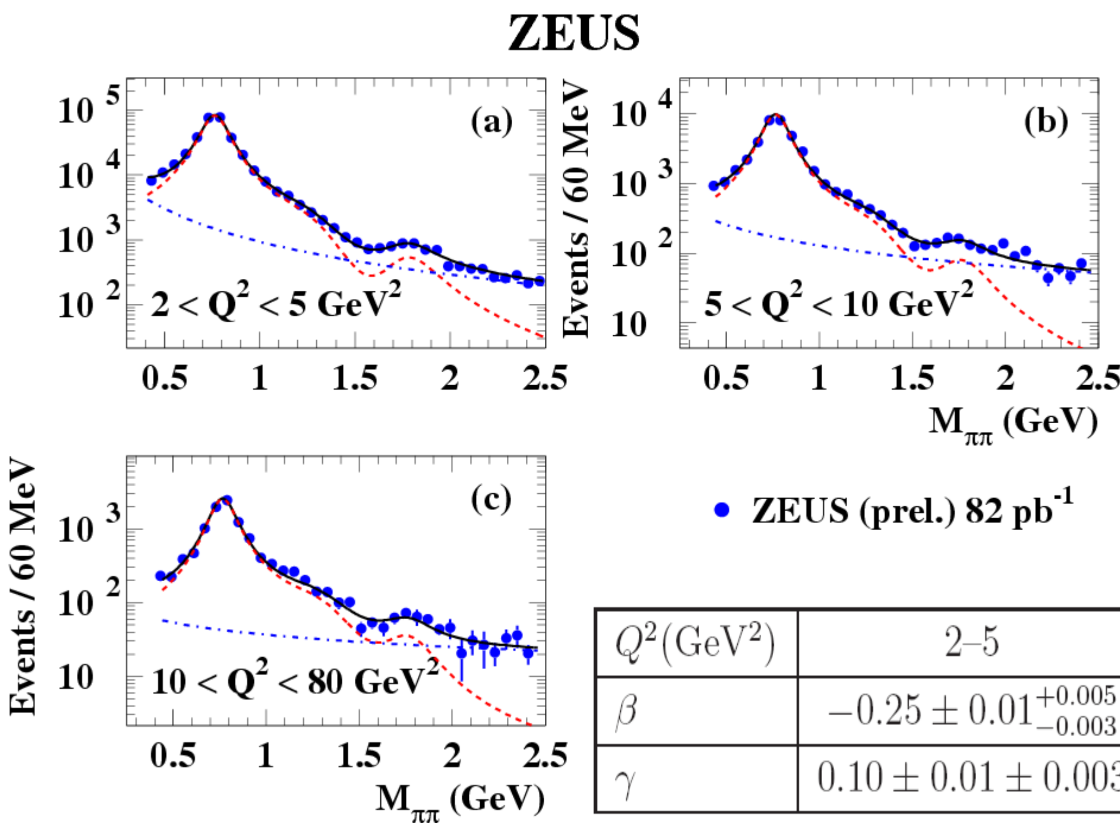
- β,γ are relative amplitudes
- BW . Breit Wigner amplitude

- ρ (770) and ρ"(1700) are clearly visible, ρ'(1450) - a mere shoulder
- the masses and the widths of the ρ (770) and ρ"(1700) as well as the width of ρ'(1450) agree with PDG





Q^2 dependence of relative amplitude



Fit: the masses and the widths of the three resonances were fixed to the values found in overall fit.

$Q^2(\mathrm{GeV}^2)$	2–5	5–10	10–80
β	$-0.25 \pm 0.01^{+0.005}_{-0.003}$	$-0.28 \pm 0.01^{+0.005}_{-0.008}$	$-0.35 \pm 0.02 \pm 0.01$
γ	$0.10 \pm 0.01 \pm 0.003$	$0.10 \pm 0.01^{+0.005}_{-0.003}$	$0.12 \pm 0.02^{+0.008}_{-0.006}$

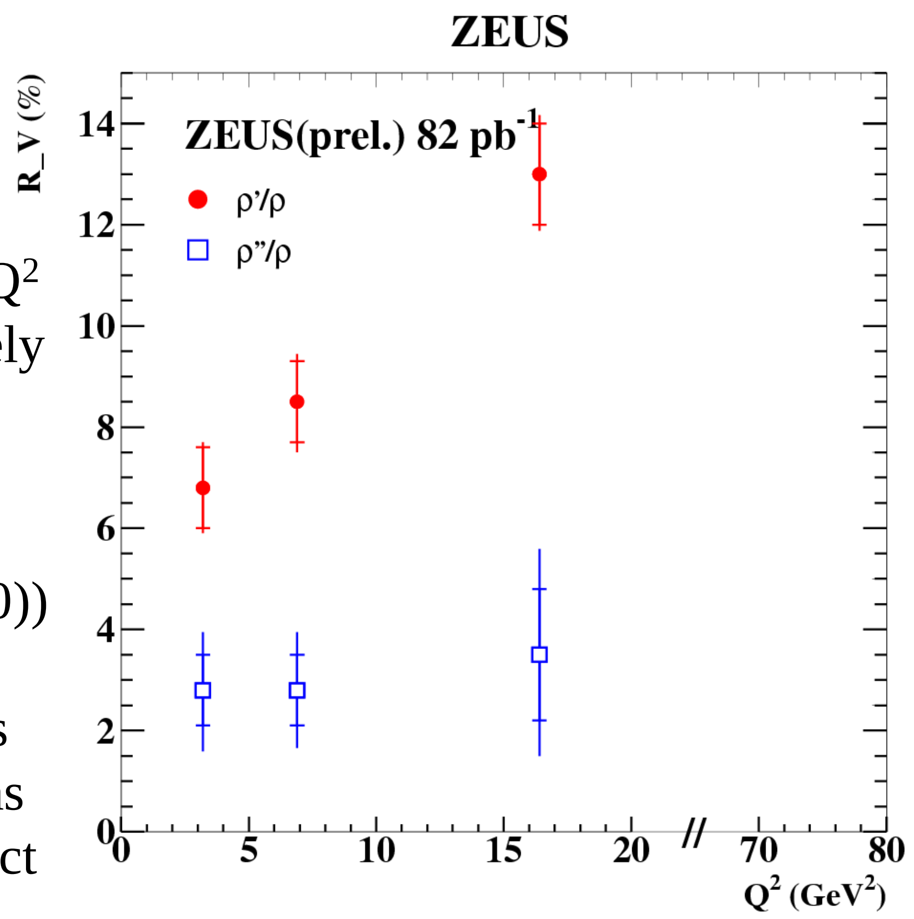
- reasonable description of data in three Q^2 regions
- the absolute value of β increases with Q^2
- γ remains Q^2 independent within the uncertainties

Ratio as a function of Q^2

Ratio is defined as:

$$R_V = \frac{\sigma(V \rightarrow \pi\pi)}{\sigma(\rho(770))}$$

- the value of $R\rho'(1450)$ increases with Q^2
- the value of $R\rho''(1700)$ is approximately constant or slightly increases
- this behavior is predicted by several models
- the suppression of the 2S state ($\rho'(1450)$) is connected to a node effect which results in cancellations of contributions from different impact parameter regions at lower Q^2, while at higher Q^2 the effect of cancellation vanishes
- the D state ($\rho''(1700)$) suppression is connected to the spinorial structure of the $q\bar{q}$ state into which the photon fluctuates.



Summary

- A large variety of Vector Mesons as well as Deeply Virtual Compton Scattering has been studied in wide kinematics range
- The measurements allow the study the transition from the soft to the hard regime as a function of scale
- Two pion mass distribution, $0.4<M_{\pi\pi}<2.5$GeV is well described by the pion electromagnetic form factor, which includes three resonances ρ, ρ', ρ''

BACKUP

Upsilon reference

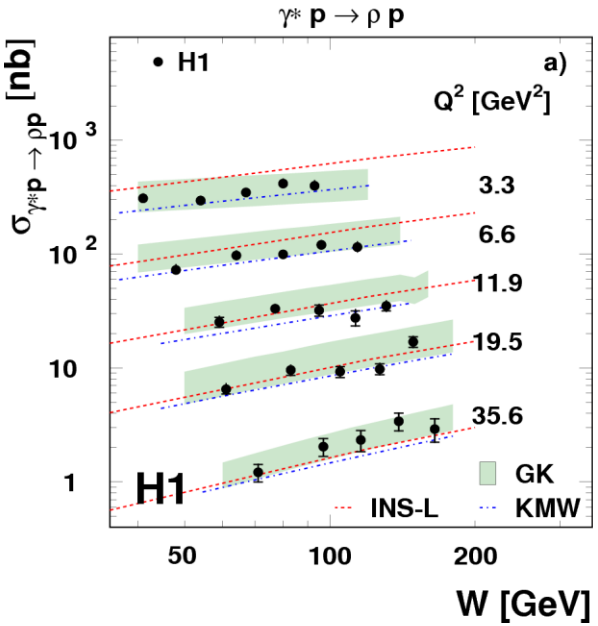
RSS (kT) - A. Rybarska, W. Schafer, A. Szczurek, Phys. Lett. B668(2008), p. 126.

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,JHEP9902(1999), p. 002.

MNRT(HERA J/psi)-A.D. Martin, C. Nockles, M. Ryskin, T. Teubner,Phys. Lett.B662(2008), p. 252.

W dependence as a function of Q^2



INS-L Ivanov, Nikolev, Sawin with kt-unintegrated model

Goloskov, Kroll Generalised Parton Distributions

Kowalski, Motyka, Watt with Golec-Biernat Wuesthoff Saturation

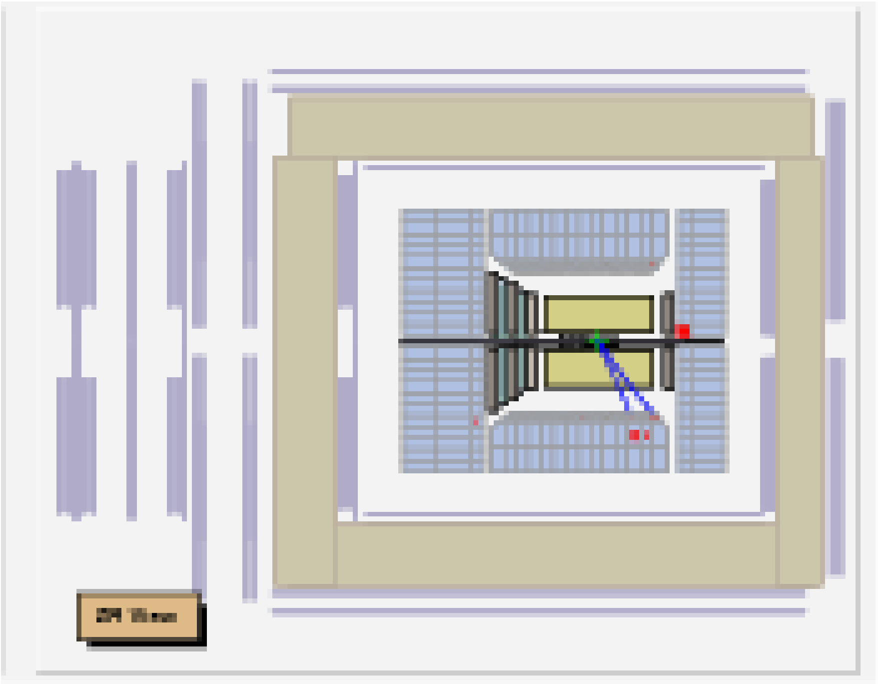
H1 Collab., JHEP05 (2010) 032 , 10/09

Data Selection

- data collected by the ZEUS Detector 1998-2000 (82 pb^{-1})
- two pions and electron are measured in the detector
- no additional activity above noise level

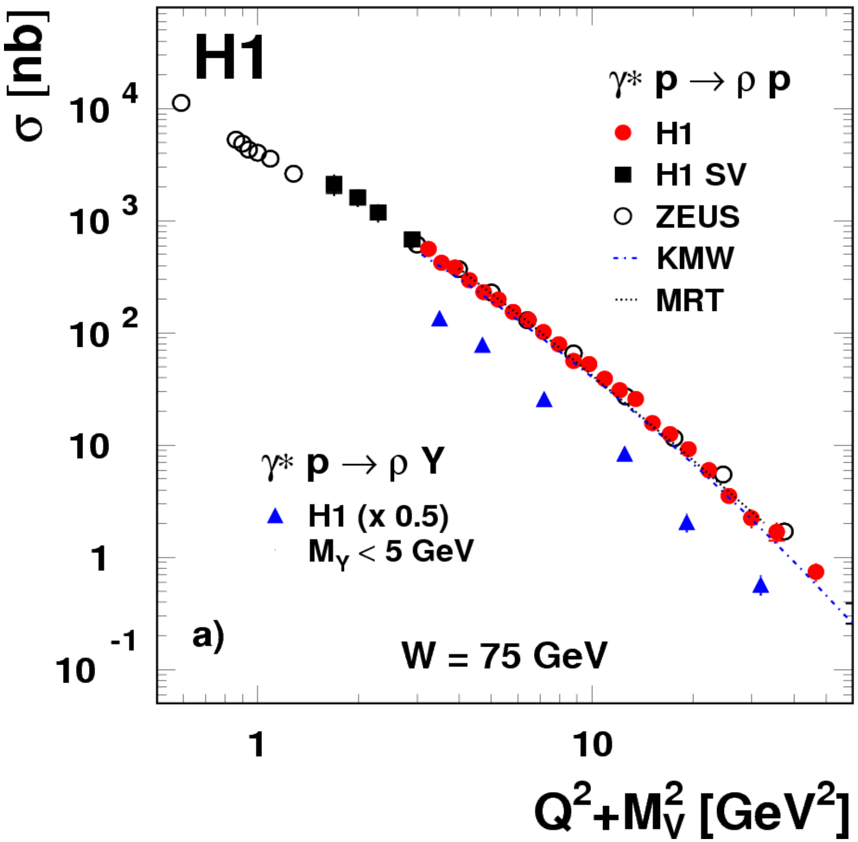
Kinematical range:

- $0.4 < M_{\pi\pi} < 2.5$ GeV
- $2 < Q^2 < 80$ GeV^2
- $32 < W < 180$ GeV
- $|t| < 0.6$ GeV^2



Number of events ~63k

Q^2 dependence of Vector Mesons



Kowalski, Motyka, Watt with Golec-Biernat Wuesthoff Saturation

Marin, Ryskin, Teubner model: does not provide normalisation (uncertainty on the quark invariant mass corresponding to the meson recombination)

Very good agreement between both experiments

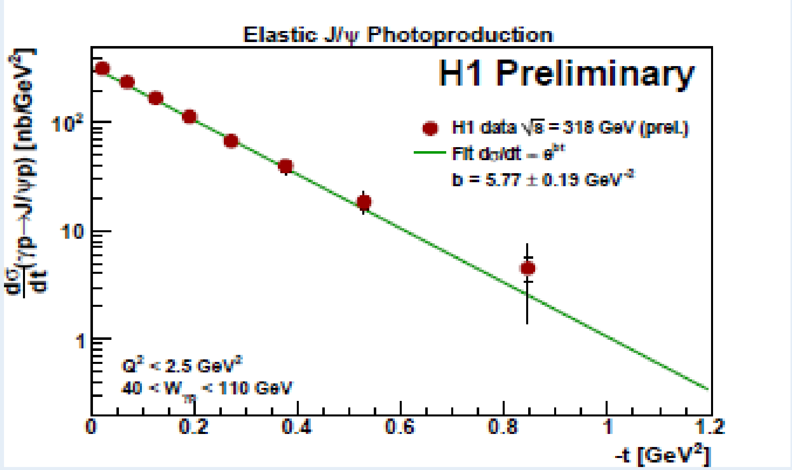
KMW: the shape of ρ and ϕ elastics cross sections are well described

Normalisation of predictions is low by 10% for ρ and higher 25% for ϕ

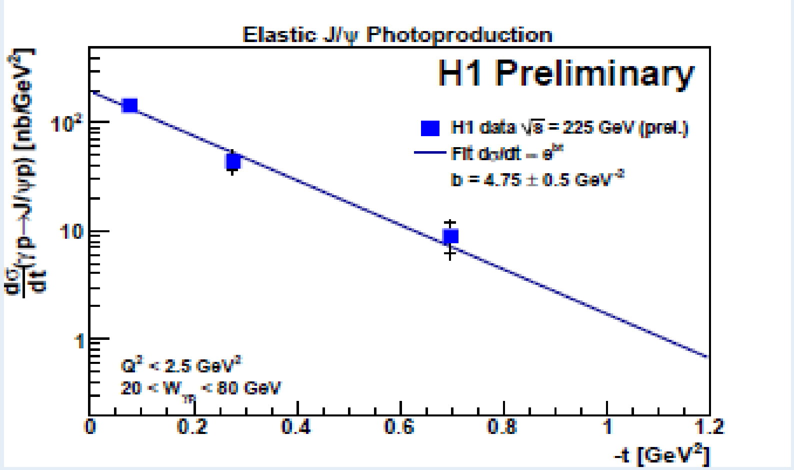
MRT: good description of Q^2 dependence

Differential Elastic Cross Section as Function of t

High Energy Period



Low Energy Period



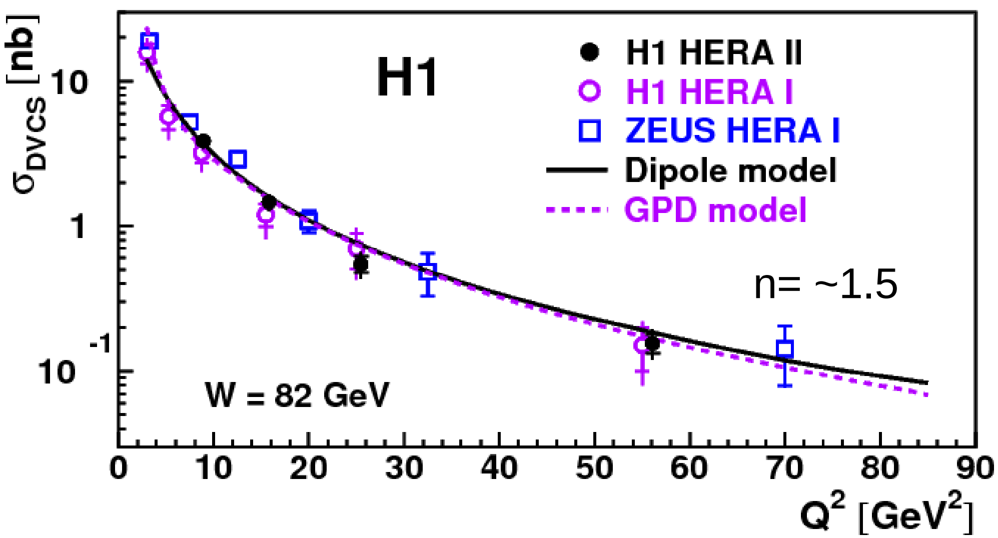
- Differential elastic cross section fitted with an exponential.
  b-slope for (error includes statistical and systematic uncertainty)
  - high energy period $(5.77 \pm 0.19)\,\mathrm{GeV}^{-2}$
  - low energy period $(4.75 \pm 0.5)\,\mathrm{GeV}^{-2}$
- Shallower b-slope for low energy period expected because of lower $W_{\gamma p}$ region and positive shrinkage of pomeron trajectory.
- b-slopes cannot directly be compared to published H1 values because cross section were measured as function of $p_{t,\psi}^2$.

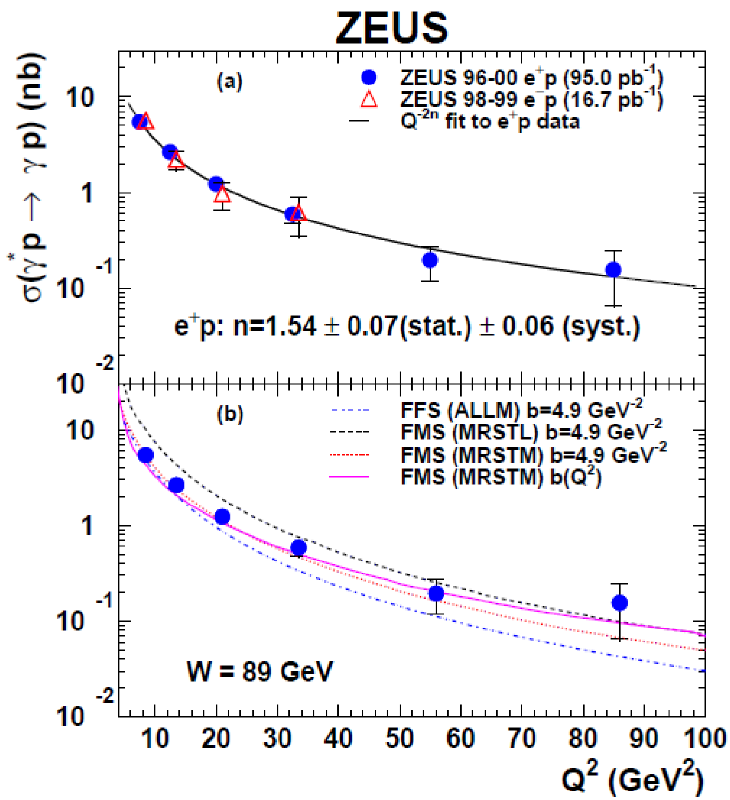
Remark: The normalisation uncertainty of 9 % is not included in the error bars of the data points, but was taken into account for the fit. (This is the same for all cross sections.)

Q^2 dependence of DVCS

$\sigma \propto (Q^2 + M^2)^n$

H1. Physics Letters B, 659(4):796-806.





ZEUS Collaboration, Phys. Lett. B 573 (2003) 46

Results in agreement with previous measurements
as well as with General Parton Model and Dipole Model

Par.	ZEUS(prel)	PDG
M_ρ	$771 \pm 2^{+2}_{-1}$	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	$0.10 \pm 0.02^{+0.02}_{-0.01}$	