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Diffractive Vector Meson Production and DVCS at HERA

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on behalf of the ZEUS and H1 Collaborations

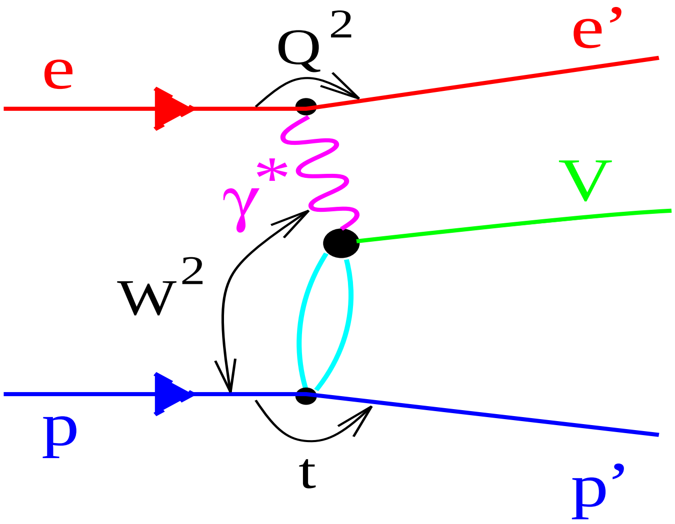
Outline:

- Introduction
- DVCS
- Photoproduction of Vector Mesons
- Electroproduction of Vector Mesons
- Pomeron trajectory
- Proton Dissociative Production of Vector Mesons
- Summary

Vector Meson Production

HERA collides positrons(electrons) and protons

27.5 GeV e $\Longrightarrow$ $\sqrt{s}$ **= 300 (320) GeV** $\Longleftarrow$ **p 820 (920) GeV**

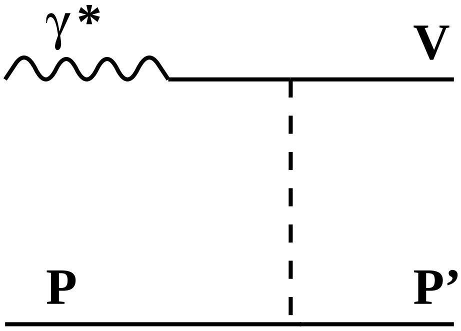


$V = (\rho^o, \omega, \phi, J/\psi, \Upsilon)$

$V = \gamma\,(DVCS)$

- $Q^2 = -(k - k')^2$ photon virtuality
- W is $\gamma^* p$ center of mass (CM) energy
- $t = (p - p')^2$ momentum transfer squared at the proton vertex

VDM and Regge theory



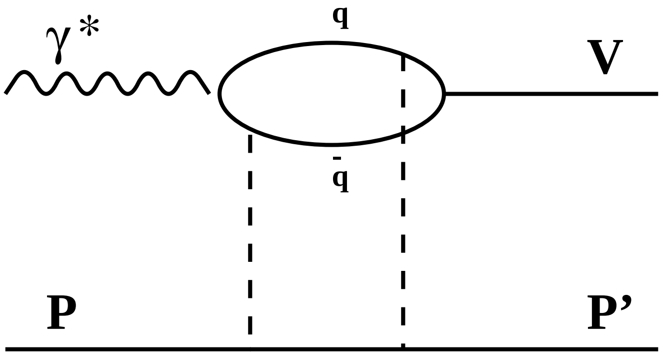
- The photon fluctuates into a light vector meson, V, which carries the same quantum numbers as the photon ($\gamma p \to$ Vp)
- The vector meson scatters elastically off the incoming proton (Vp $\to$ Vp)

Predictions :

- $\frac{d\sigma(\gamma p \to Vp)}{dt} \propto e^{-b_0|t|}(W^2/W_0^2)^{2(\alpha(t)-1)}$
- $\alpha(t) = 1.08 + 0.25t$ (DL parametrization), (Soft Pomeron)
- $\alpha(t) = 1.4 + 0.1t$ (DL parametrization), (Hard Pomeron)
- Shrinkage of the diffractive peak
  $b(W) = b_0 + 2\alpha' \ln{(W^2/W_o^2)}$
- Weak energy dependence of cross section
  $d\sigma/dt \propto W^\delta, \qquad \delta \simeq 0.2$

J. J. Sakurai
A. Donnachie and P. V. Landshoff
D. Schildknecht et al. ...

QCD models



- 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 :

- $\sigma_L \propto \frac{\alpha_S^2(Q)}{Q^6}|xG(x,Q^2)|^2$
- A fast increase of the $\gamma^* p \to Vp$ cross section with energy W (longitudinal cross section dominates at large Q^2)
- SU(4) restoration, possibly modified by VM wave functions effects $\rho : \omega : \phi : J/\psi = 9 : 1 : 2 : 8$
- Universal exponential t dependence, $b \sim 4 - 5\,\mathrm{GeV}^{-2} \quad \Longrightarrow \quad \alpha' \to 0\,?$

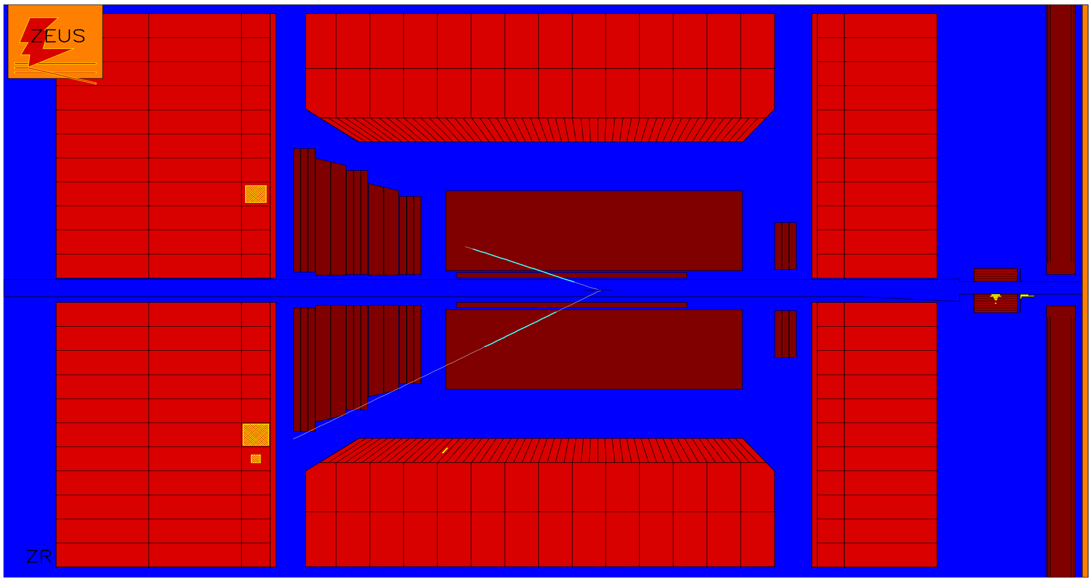
S. J. Brodsky et al.
L. Frankfurt et al.
M. Ryskin et al.
A. D. Martin et al. ...

$\boxed{\text{Exclusive production } \gamma^* p \to V^o p}$

Kinematic range

$$
\begin{array}{ccc}
Q^2 & \to & 0 \div 70\,\mathrm{GeV}^2 \\
W & \to & 20 \div 280\,\mathrm{GeV} \\
|t| & \to & 0 \div 10\,\mathrm{GeV}^2
\end{array}
$$

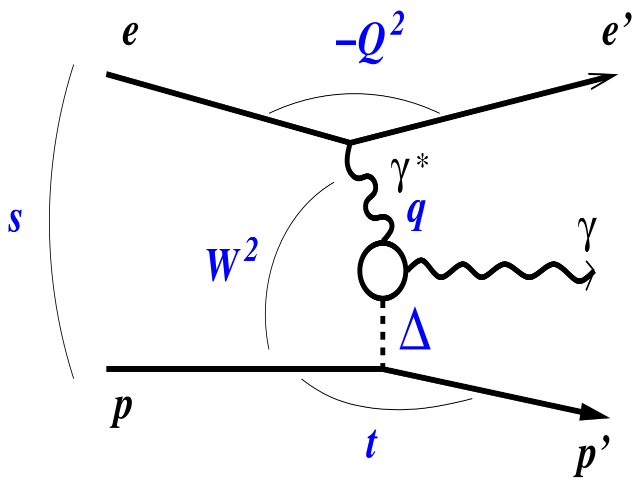
- Photoproduction: $Q^2 \approx 0$
  (do not observe the scattered e in Calorimeter)
- Electroproduction, Q^2 range : $0.25 < Q^2 < 70$ GeV^2
  (observe the scattered e in the main Calorimeter or in special taggers)



- tracks reconstructed by tracking detector
- no energy deposits not associated with tracks or the positron

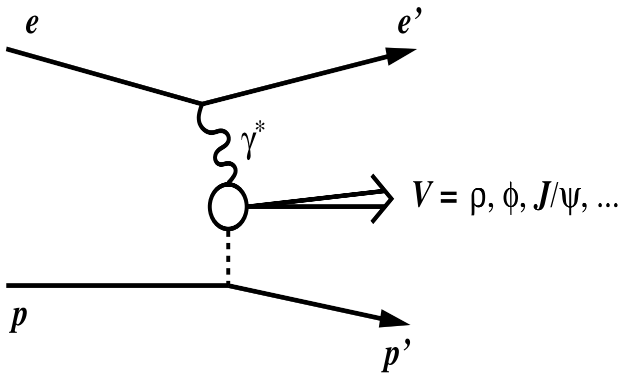
DVCS

DVCS diagram:

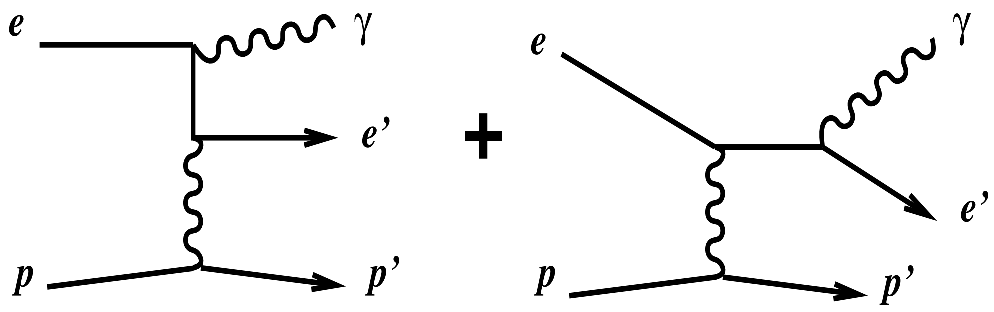


$$s = (e+p)^2$$
$$W^2 = (q+p)^2$$
$$Q^2 = -q^2 = -(e-e')^2 = sxy$$
$$x = Q^2/2p\cdot q$$
$$y = p\cdot q/p\cdot e$$
$$t = \Delta^2 = (p-p')^2 \approx -p_T'^2$$

Compare Vector Meson prodn.

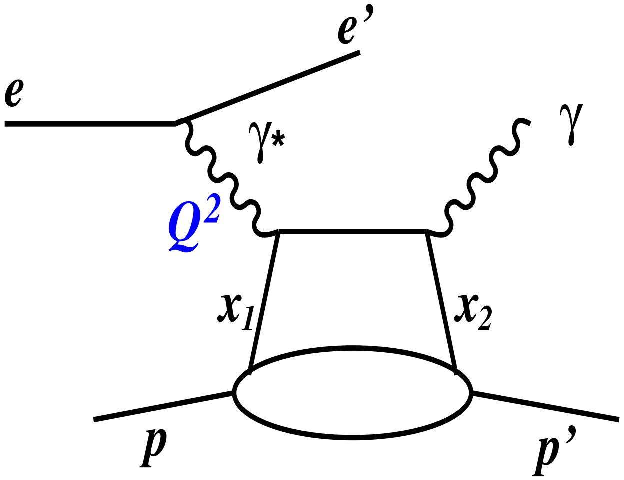


Note: DVCS competes with QED Compton (completely calculable)



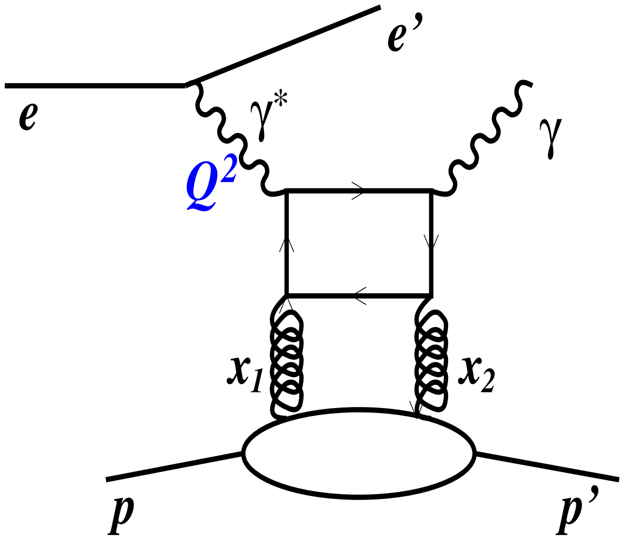
DVCS Process in QCD

Handbag diagram (high-x):



$x_1 \neq x_2$

Dominant contribution at low-x (ZEUS+H1):



Why is DVCS Interesting?

Skewed Parton Distributions.

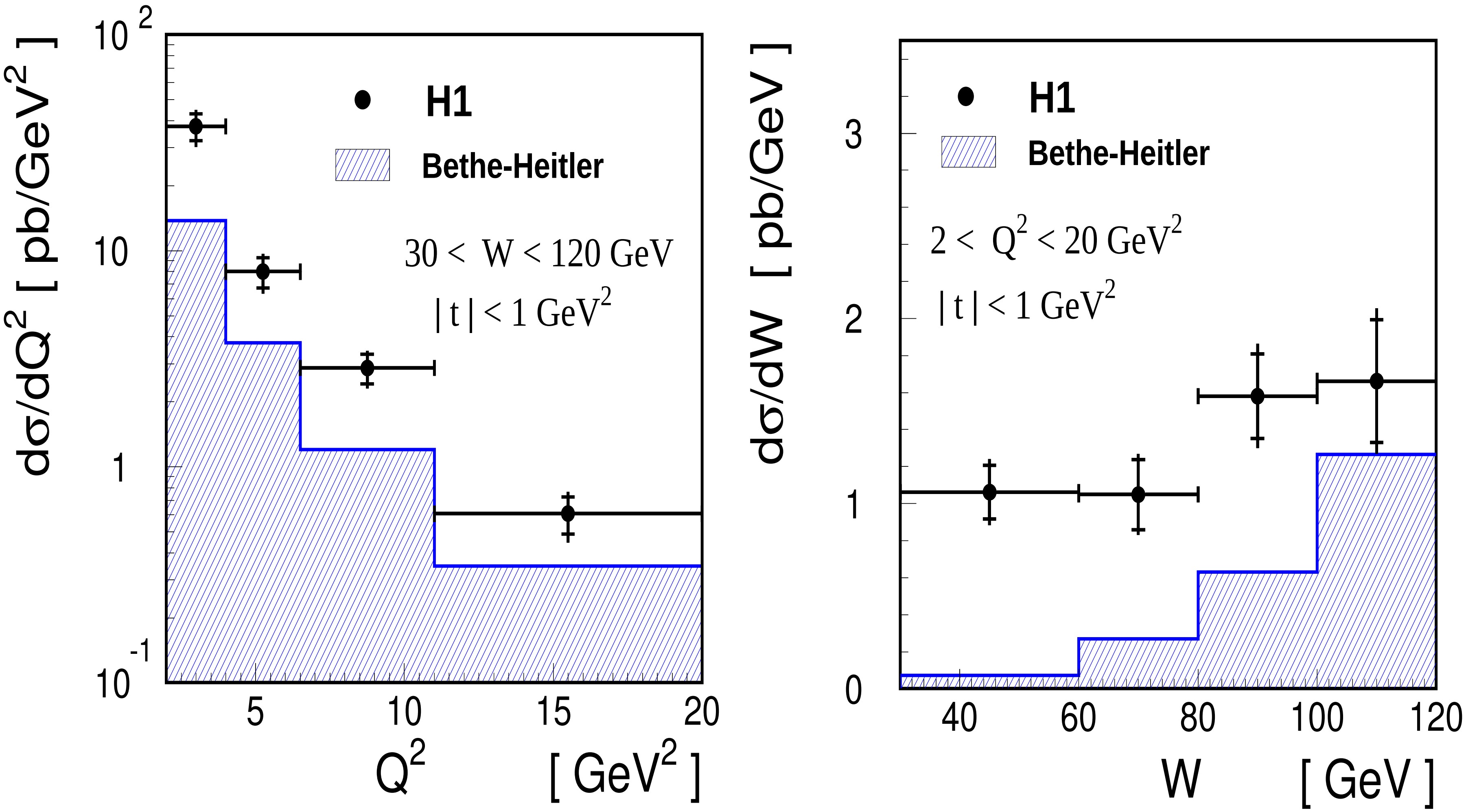
- Generalisations of the usual pdfs for non-forward scattering.
- A probe for correlations in the parton distributions.

Interference Term.

- Interference of QCD amplitude with QED amplitude.
- Allows for measurement of real part of a QCD amplitude.

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

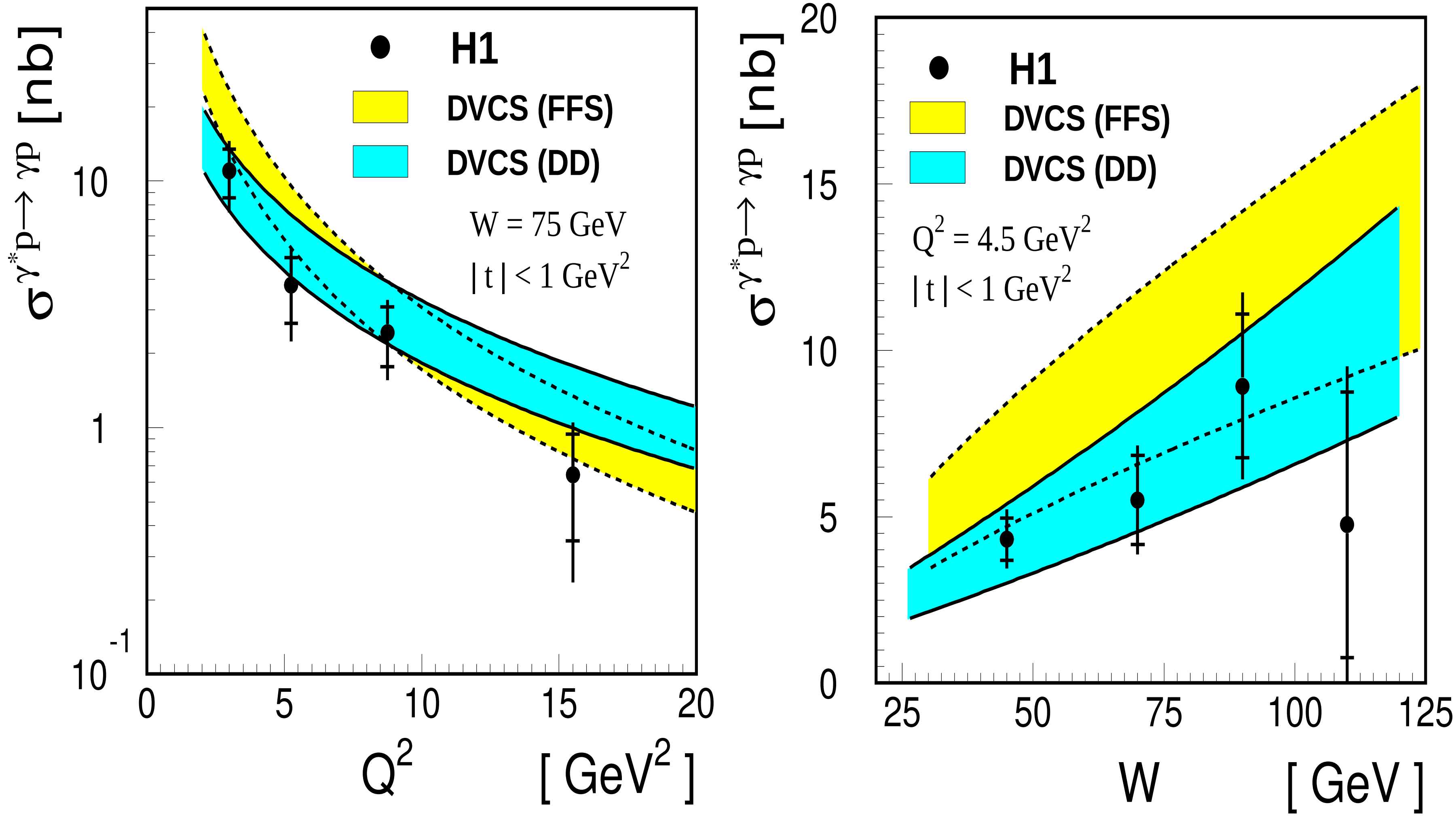
Differential cross sections $d\sigma/dQ^2$ and $d\sigma/dW$



Clear excess above QED Compton prediction

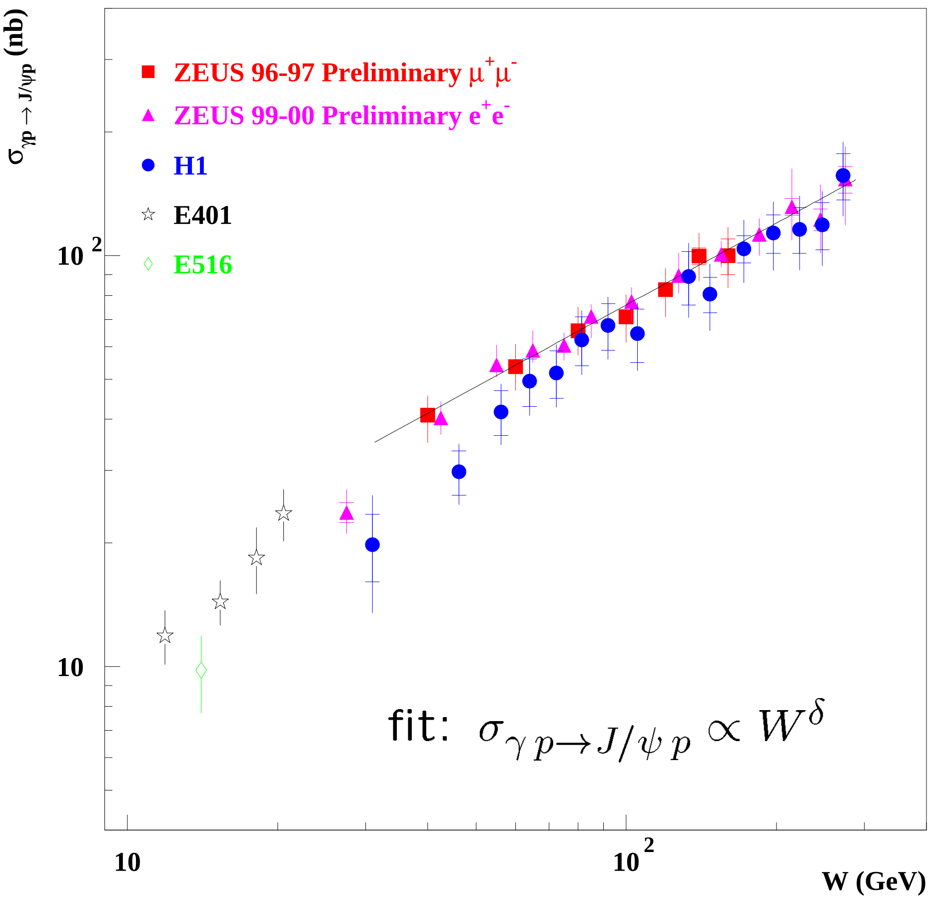
H1 DVCS cross sections

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



Cross sections in general agreement with QCD predictions

Elastic Photoproduction $\gamma\, p \to J/\psi\, p$



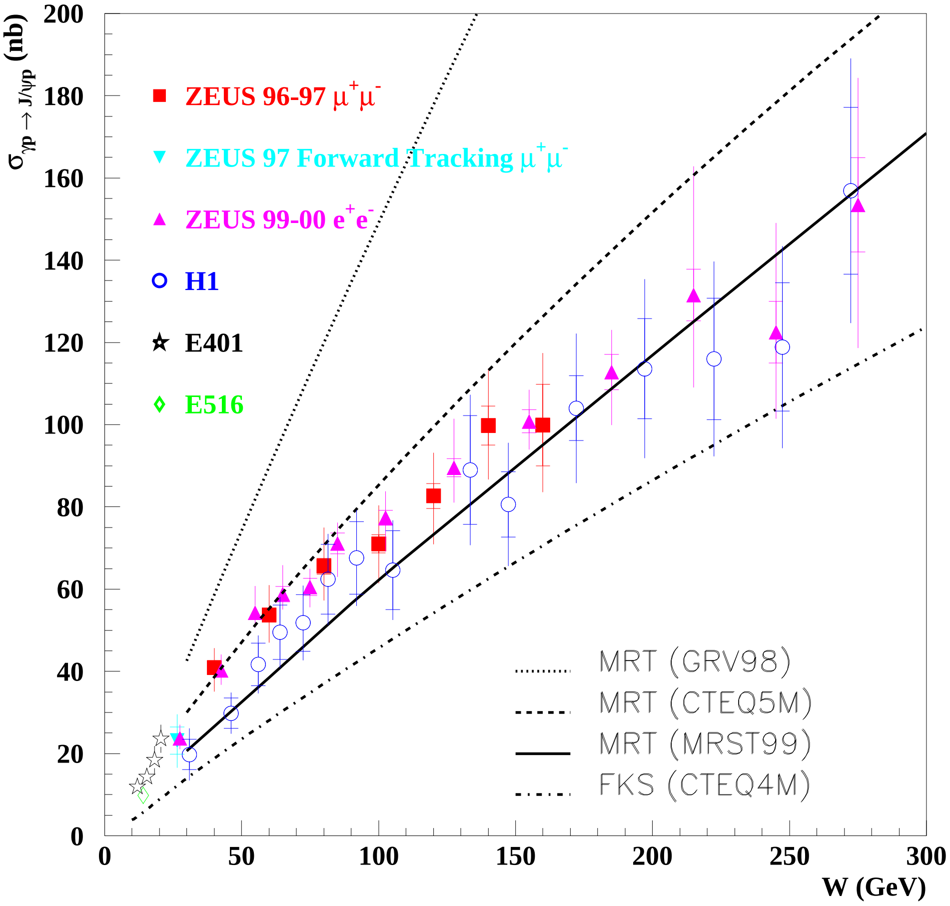
ZEUS: $\delta = 0.65 \pm 0.03 \pm 0.09$ $(J/\psi \to \mu^+\mu^-)$

$\delta = 0.66 \pm 0.02^{+0.05}_{-0.08}$ $(J/\psi \to e^+e^-)$

H1: $\delta = 0.83 \pm 0.07$

$\Rightarrow$ steeper rise than soft pomeron expectation

Elastic Photoproduction $\gamma p \to J/\psi\, p$

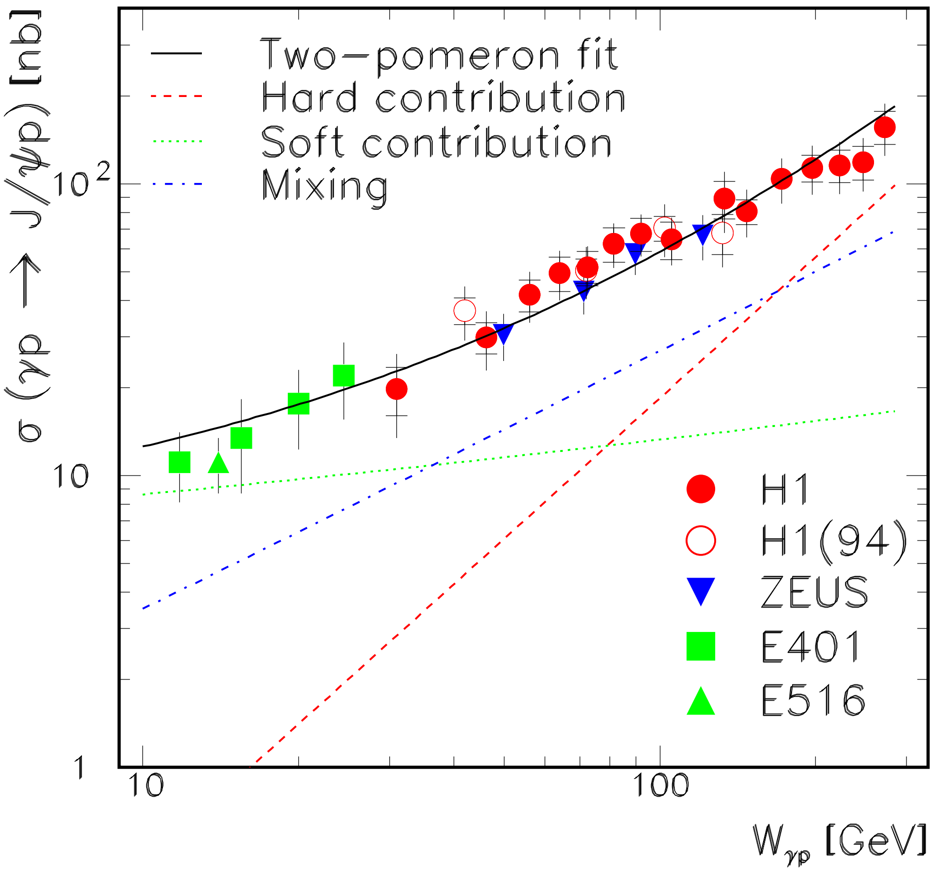


- pQCD approach gives good description

$\Rightarrow$ $M_{J/\psi}$ provides a hard scale

$\Rightarrow$ sensitivity to gluon density in the proton

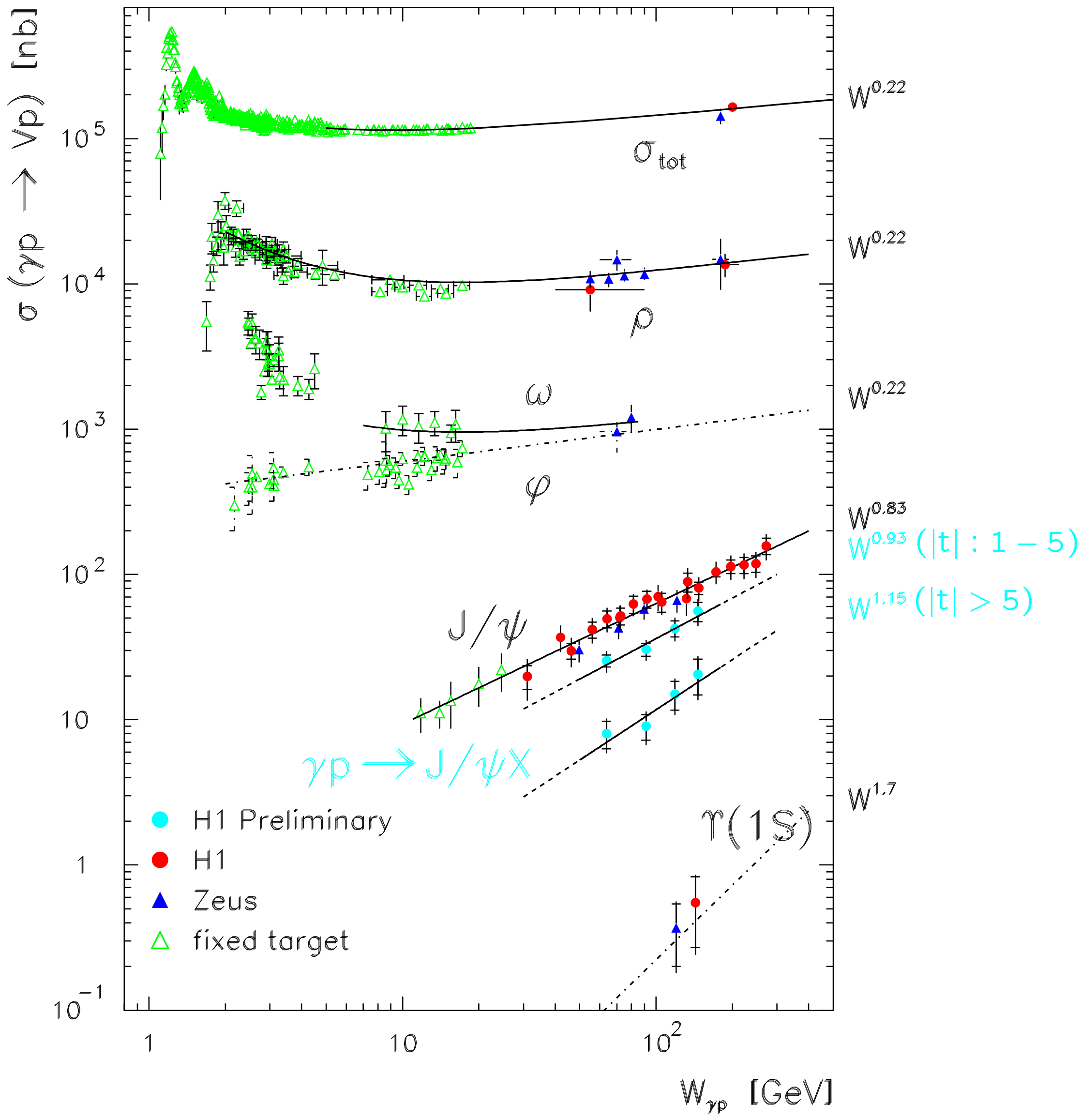
Elastic Photoproduction $\gamma\, p \to J/\psi\, p$



- 'soft' pomeron rise too slow
- add second 'hard' pomeron

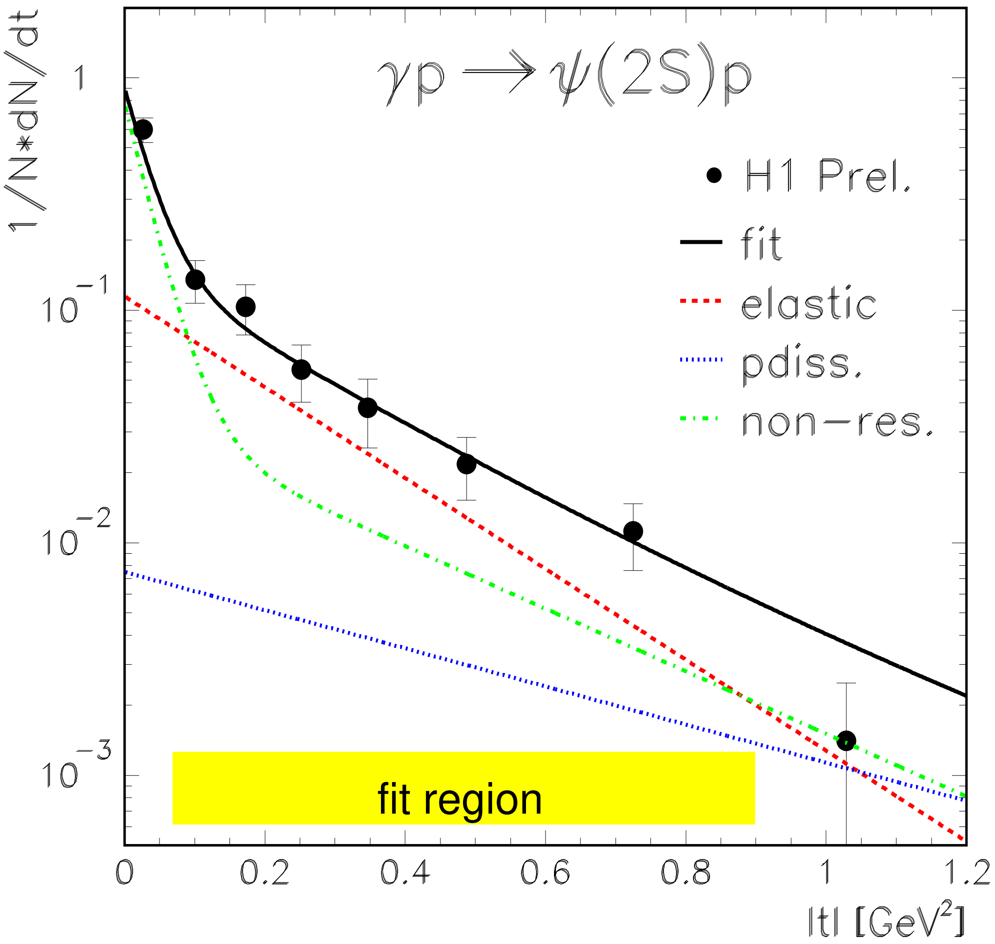
$\Rightarrow$ two pomeron fit gives reasonable description

Vector Meson Total Cross Sections



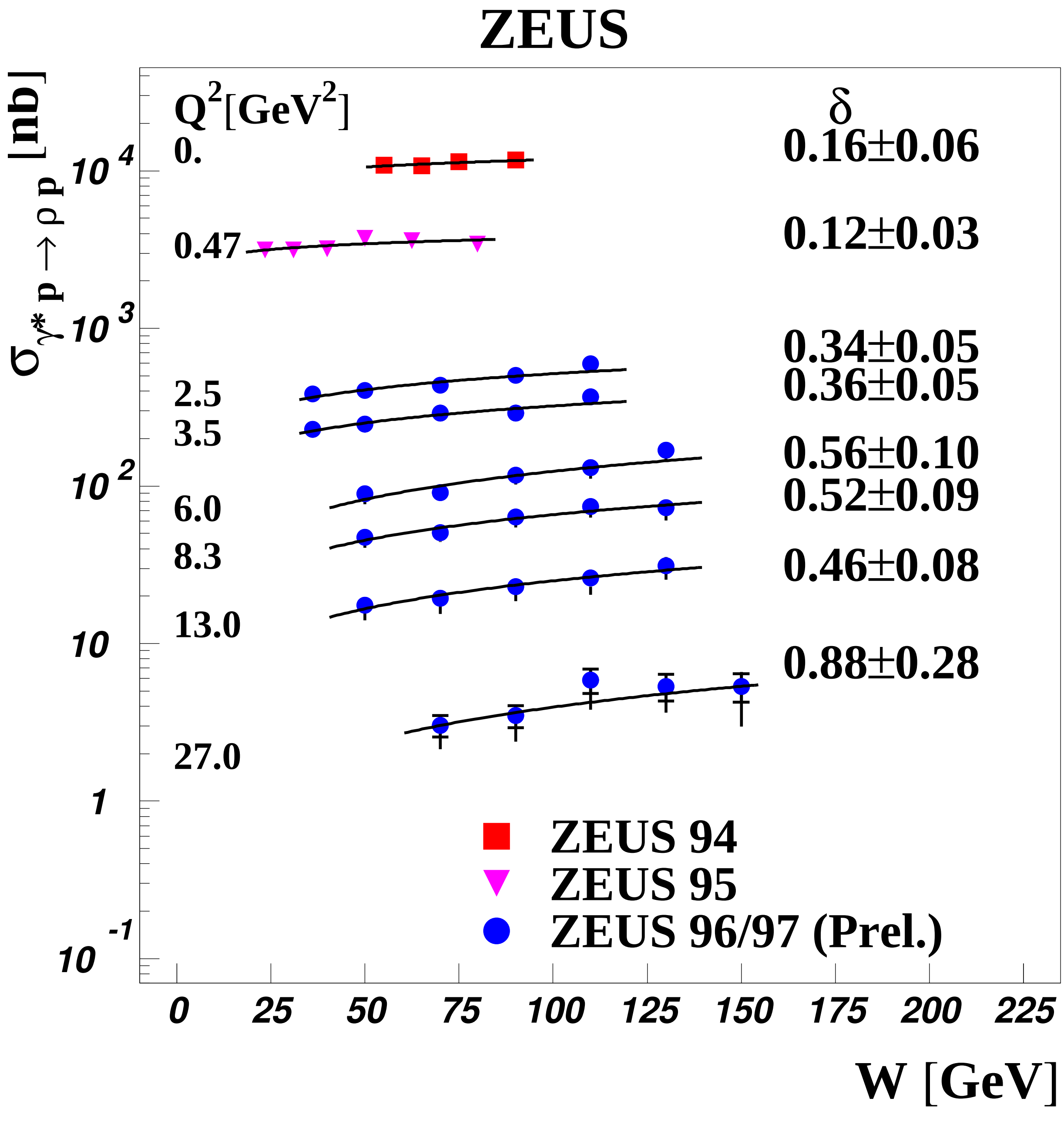
⇒ Consistent with the rise of elastic J/ψ production with $\delta \sim 1$

Elastic Photoproduction $\gamma^* p \to \Psi' p$



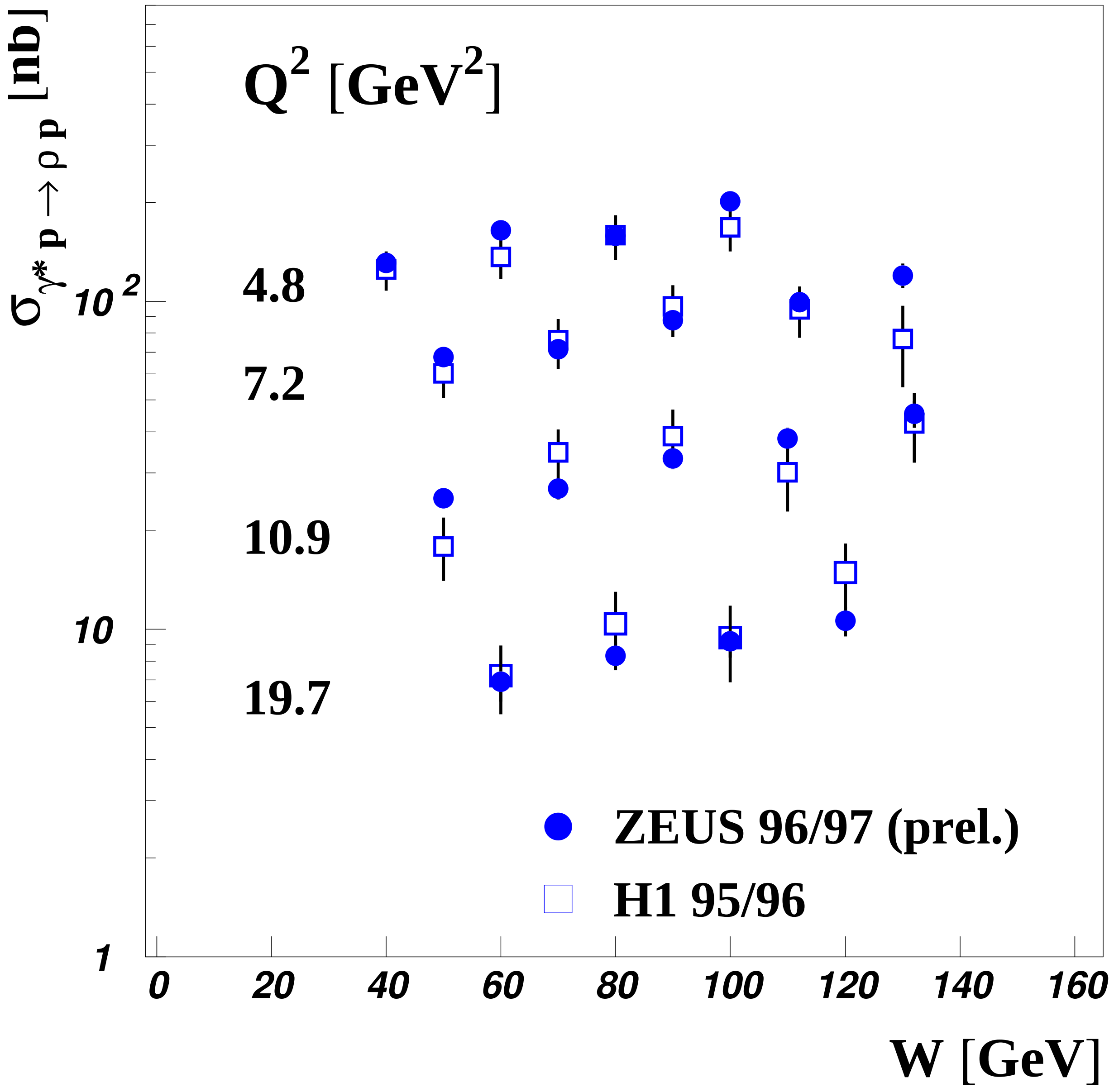
- H1 preliminary
- $b_\psi{}' = 4.5 \pm 1.2^{+1.4}_{-0.7}$
- $b_{J/\psi} = 4.73 \pm 0.25^{+0.30}_{-0.39}$
- QCD prediction : $b_{J/\psi} \simeq b_\psi{}'$

ρ Cross section W dependence



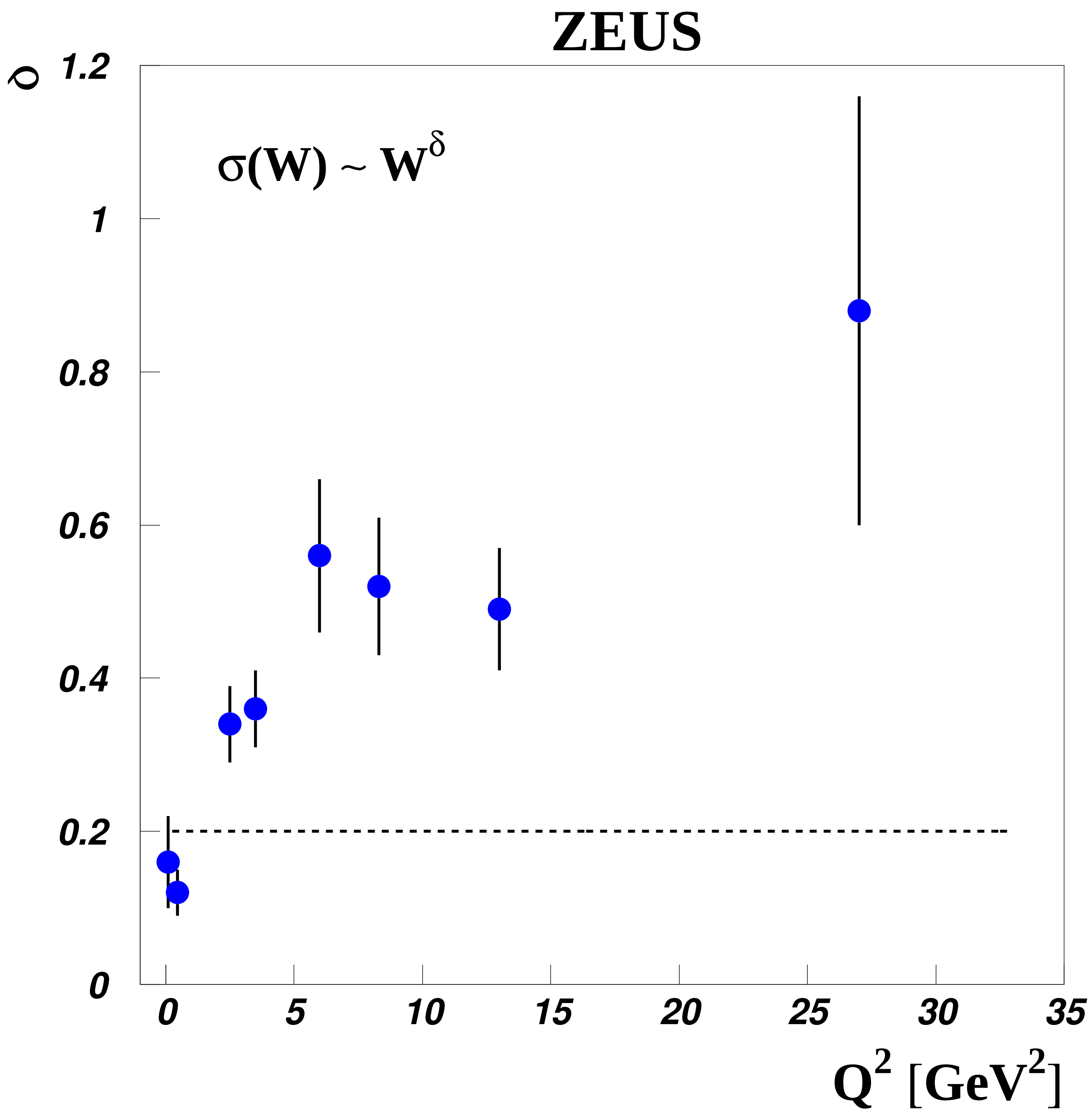
- Cross section W dependence becomes steeper at high Q^2

ρ Cross section W dependence



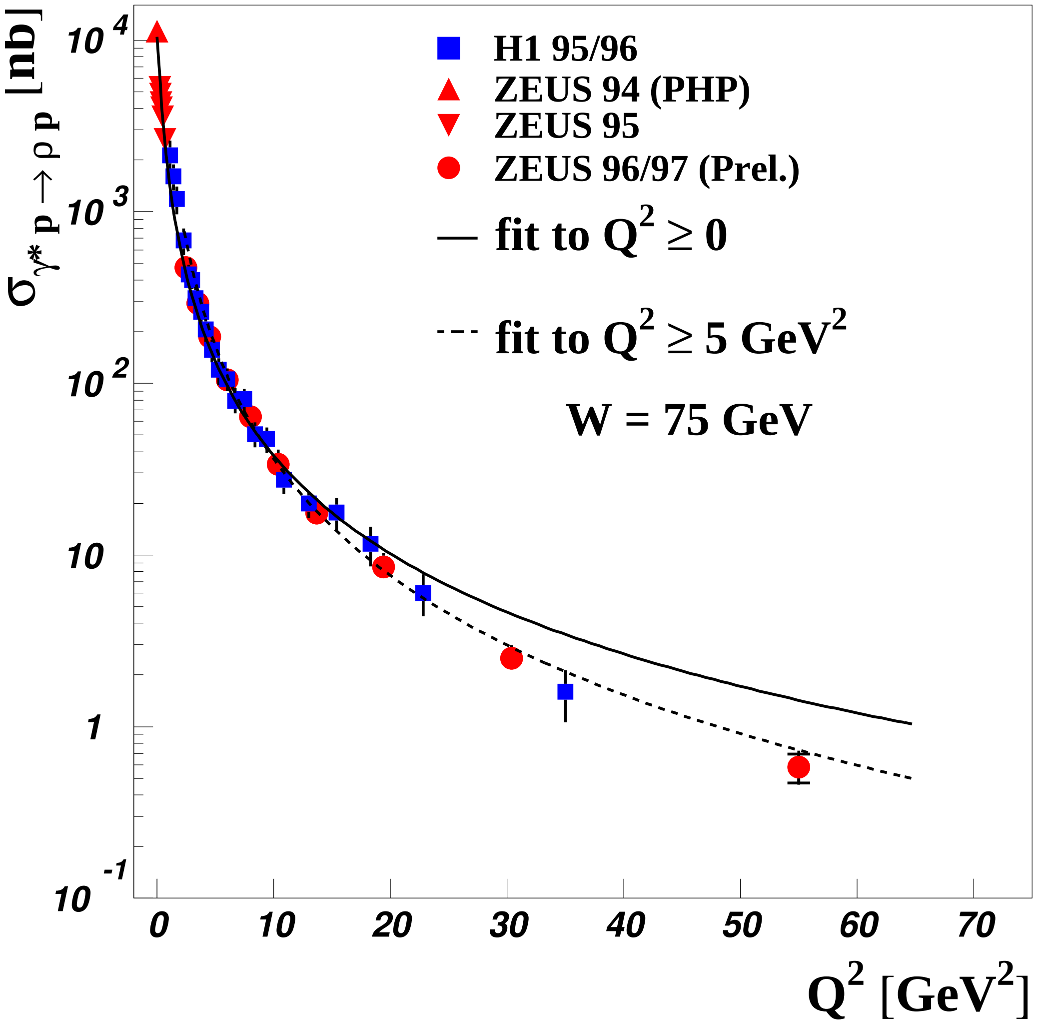
- **H1 and ZEUS are in good agreement**

$\boxed{\rho \text{ Cross section } W \text{ dependence}}$



- **Soft physics predicts for energy dependence,** $\delta \sim \mathbf{0.2}$

ρ Cross section Q^2 dependence

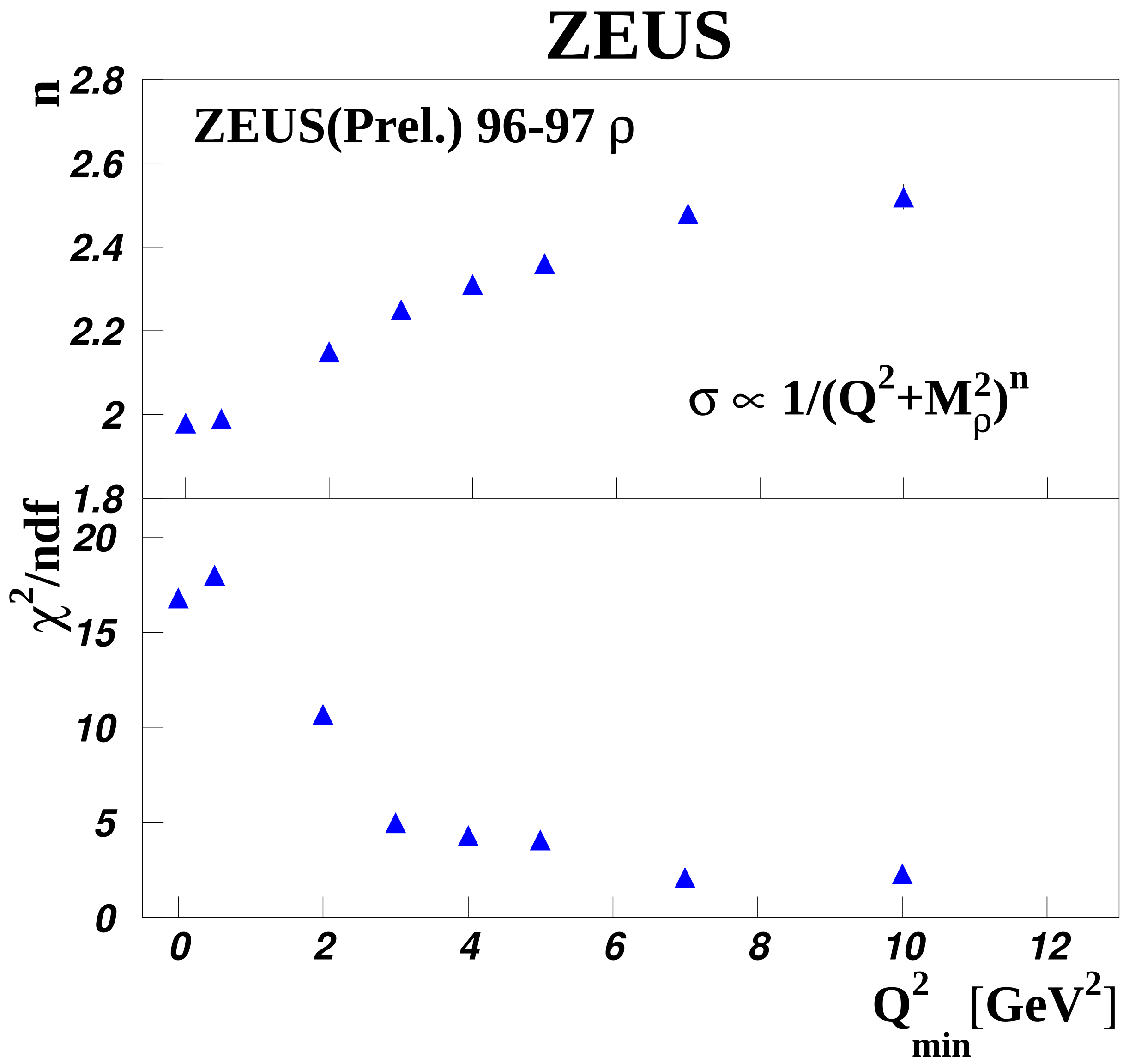


$$\sigma \propto (Q^2 + M^2)^{-n}$$

- $Q^2 \geq 0$ **GeV^2, n=2.00 $\pm$ 0.005,** χ^2**/ndf = 142/12**
- $Q^2 \geq 5$ **GeV^2, n=2.37$\pm$0.02,** χ^2**/ndf = 13.2/5**

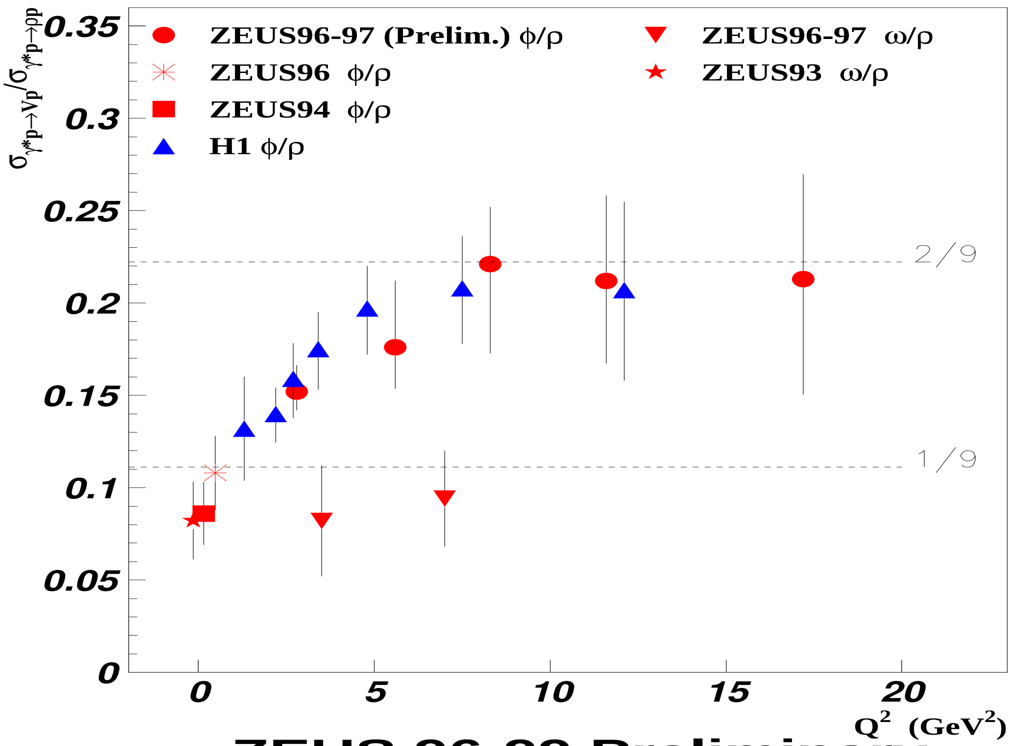
$$\sigma_L \propto \frac{\alpha_S^2(Q)}{Q^6} |xG(x, Q^2)|^2 T(Q^2)$$

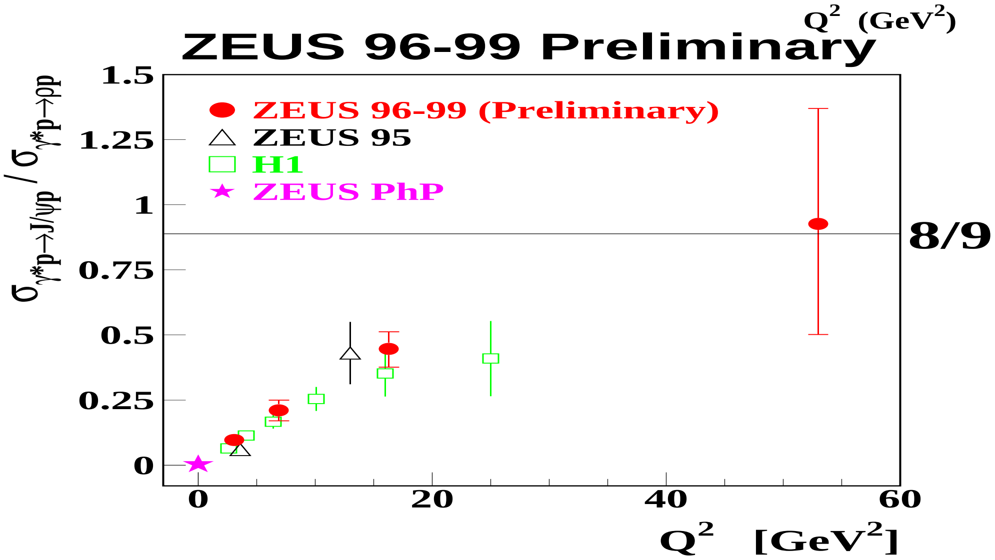
ρ Cross section Q^2 dependence



- The dependence of n on Q^2 could be the first indication that the propagator term $(Q^2 + m_\rho^2)^{-n}$ is substantially modified by other effects: increasing of the gluon density with Q^2 or Q^2-dependent ρ wave-function effects.

Vector Mesons production ratios : Q^2 dependence



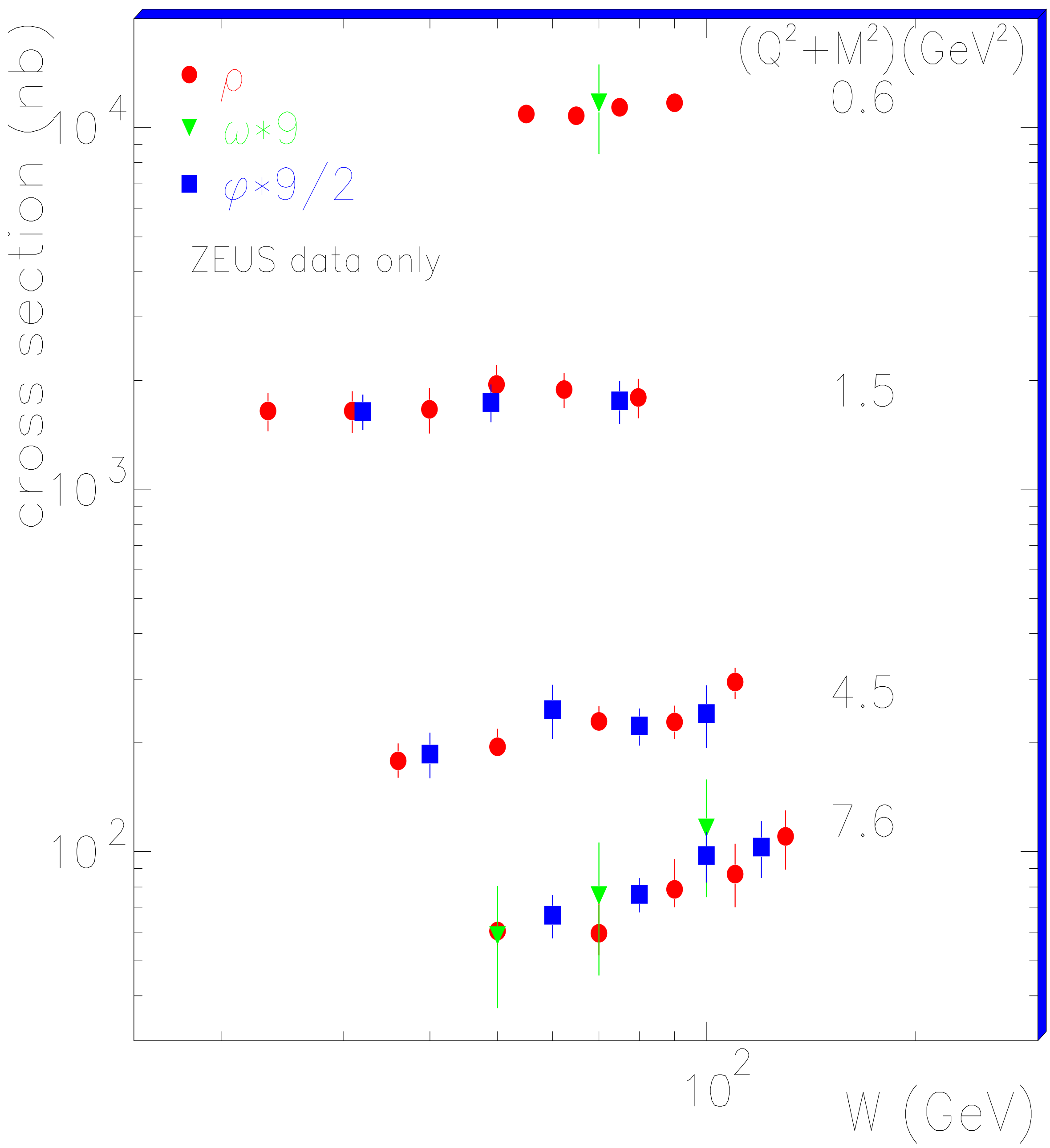


- quark charges of the Vector Meson and flavour independent production mechanism :

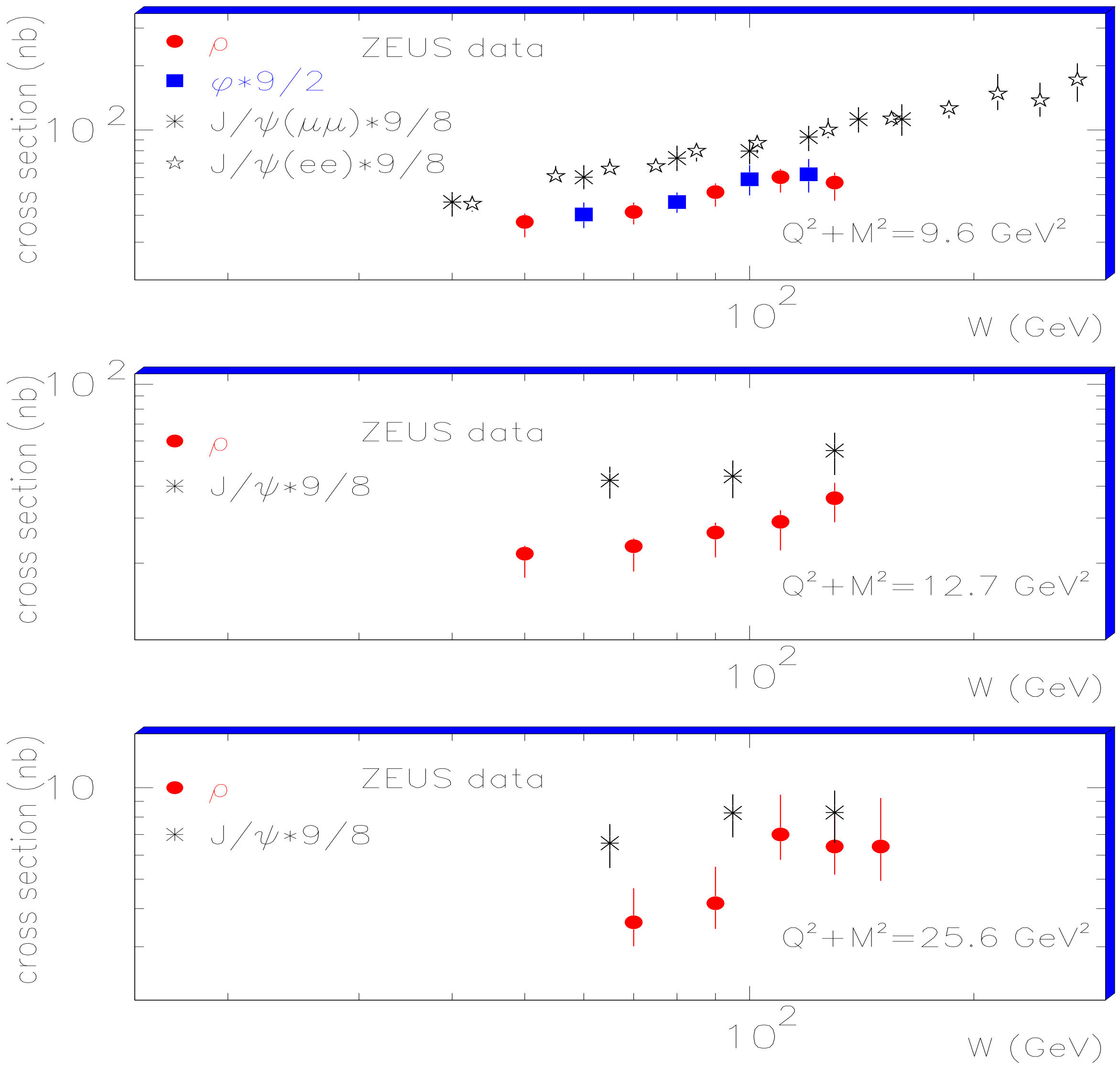
$$\rho : \omega : \phi = 9 : 1 : 2$$

- SU(4) restoration with increasing Q^2

Vector Mesons production ratios : $Q^2 + M^2$ scale

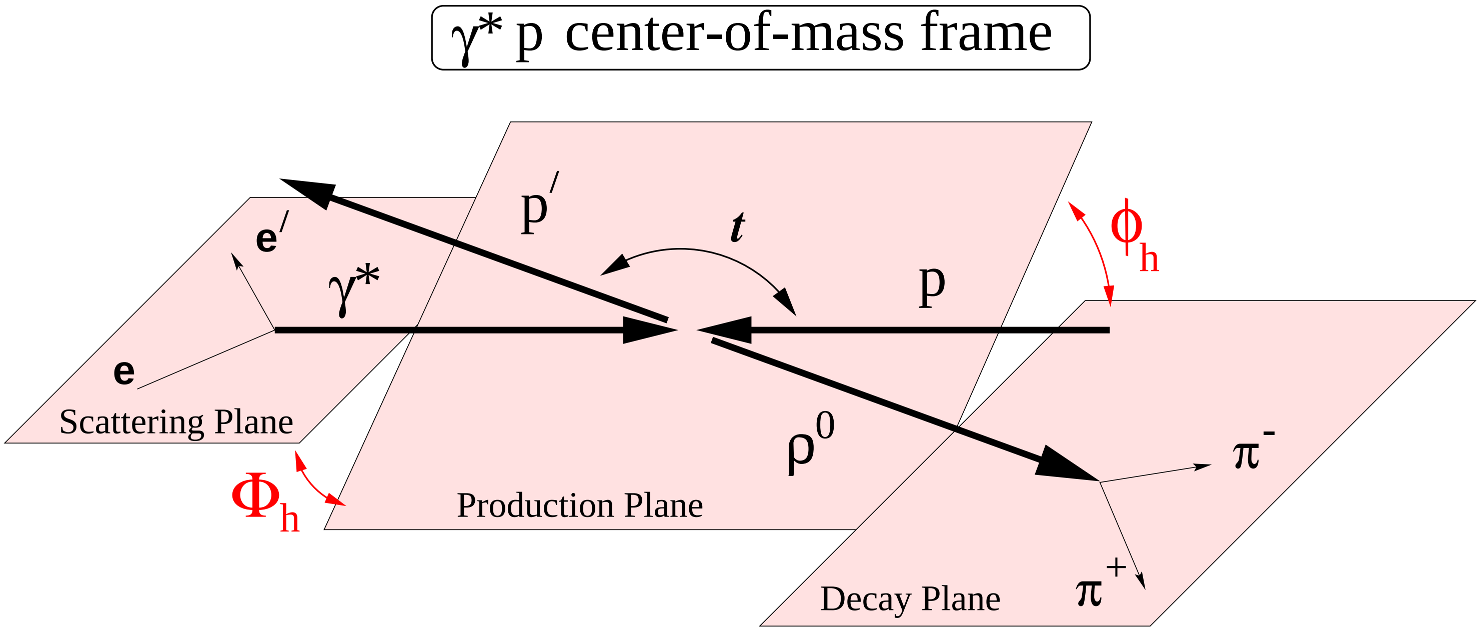


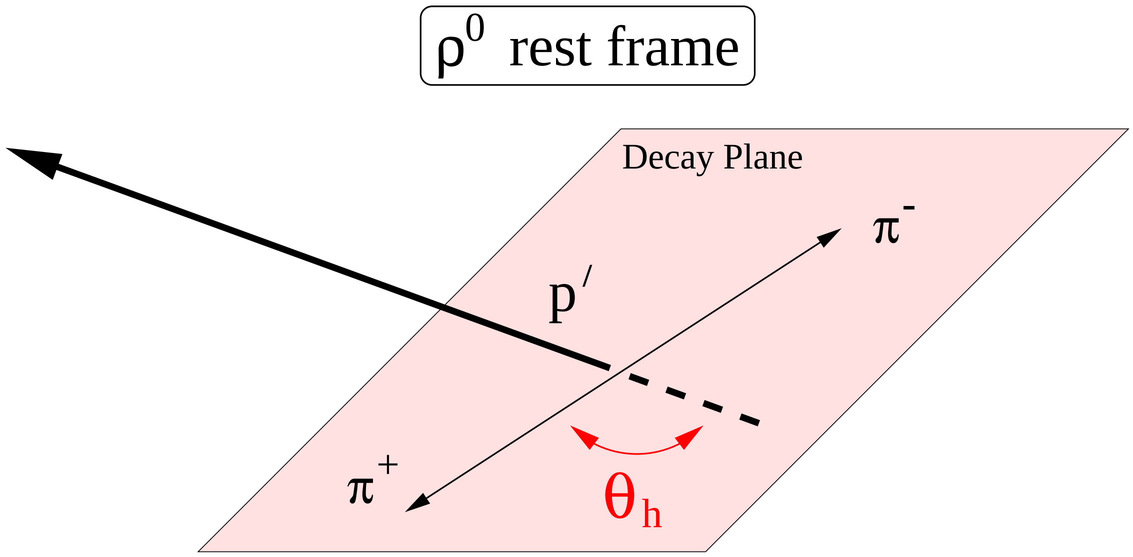
Vector Mesons production ratios : $Q^2 + M^2$ scale



- The variable $Q^2 + M^2$ is a good variable for light Vector Mesons, but not good enough in case of heavy Vector Meson.

Helicity Studies





Angular distribution $\Longrightarrow$ 3 angles (θ_h, ϕ_h and Φ_h) and 15 combinations of spin-density matrix elements

K. Schilling and G. Wolf

Helicity Studies

- **s-channel helicity conservation (SCHC)**
- **natural parity exchange $(P = (-1)^J)$ in the t-channel (NPE)**
- **15 parameters fit to total angular distribution shows :**
- **r^5_{00} deviates from zero !**

$r^5_{00} = 0.095 \pm 0.019 \pm 0.024$ (ZEUS) and $r^5_{00} = 0.093 \pm 0.024^{+0.19}_{-0.10}$ (H1)

- **$r^5_{00} \sim$ single-flip amplitude**

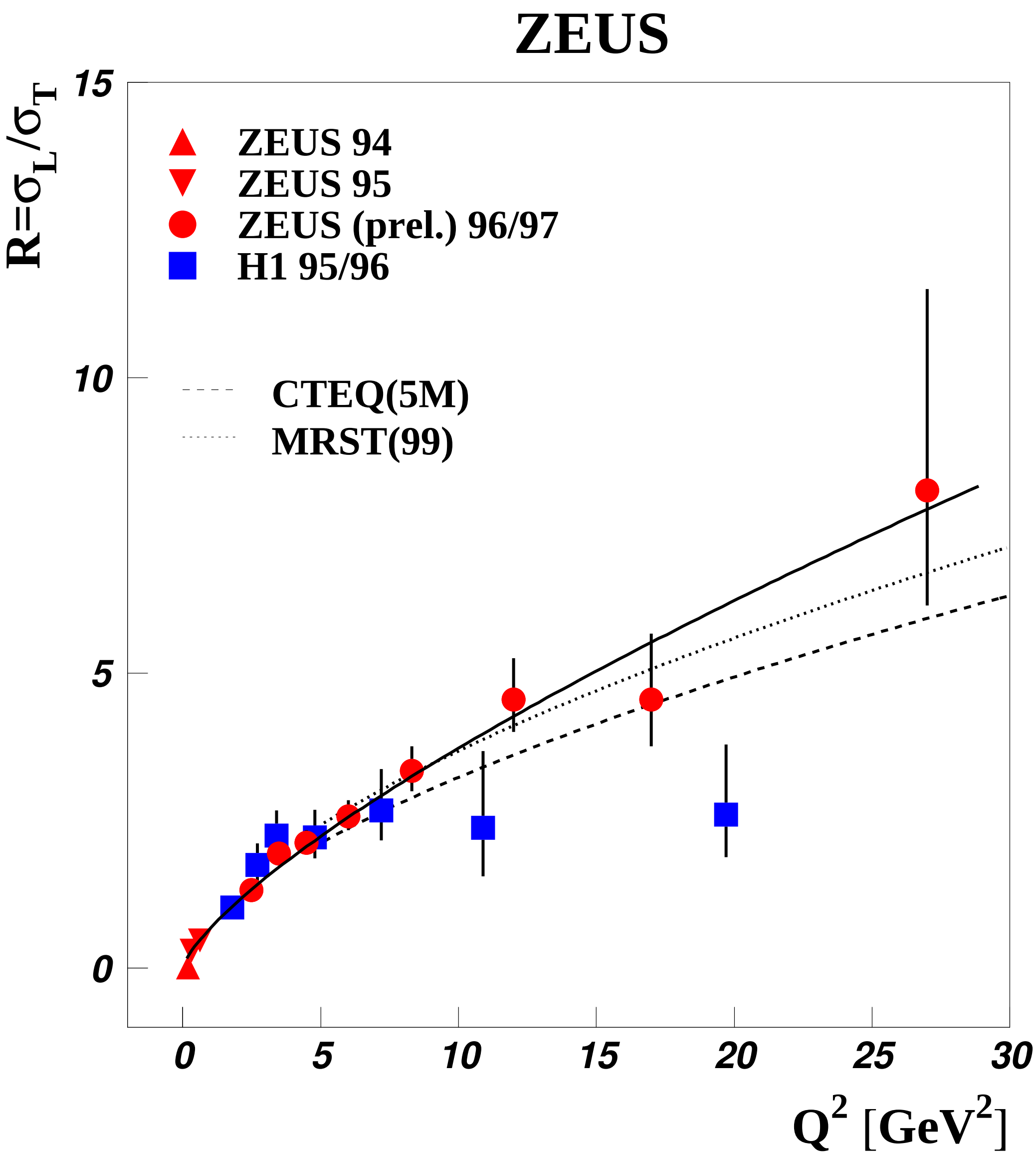
- **single flip $(\gamma^*_T \to \rho_L)$** $\Longrightarrow (7.9 \pm 3.6)\%$
- **pQCD predicts non zero value of r^5_{00} (Ivanov, Kirschner)**

- **$r^5_{00} \to$ sensitive to wave function of VM**
- **if SCHC holds $\to$** $R = \sigma_L/\sigma_T = r^{04}_{00}/\epsilon(1 - r^{04}_{00})$

- **if not $\to$ $r^{04}_{00} \to r^{04}_{00} - \Delta^2$** $\Delta \propto r^5_{00}/\sqrt{2r^{04}_{00}}$

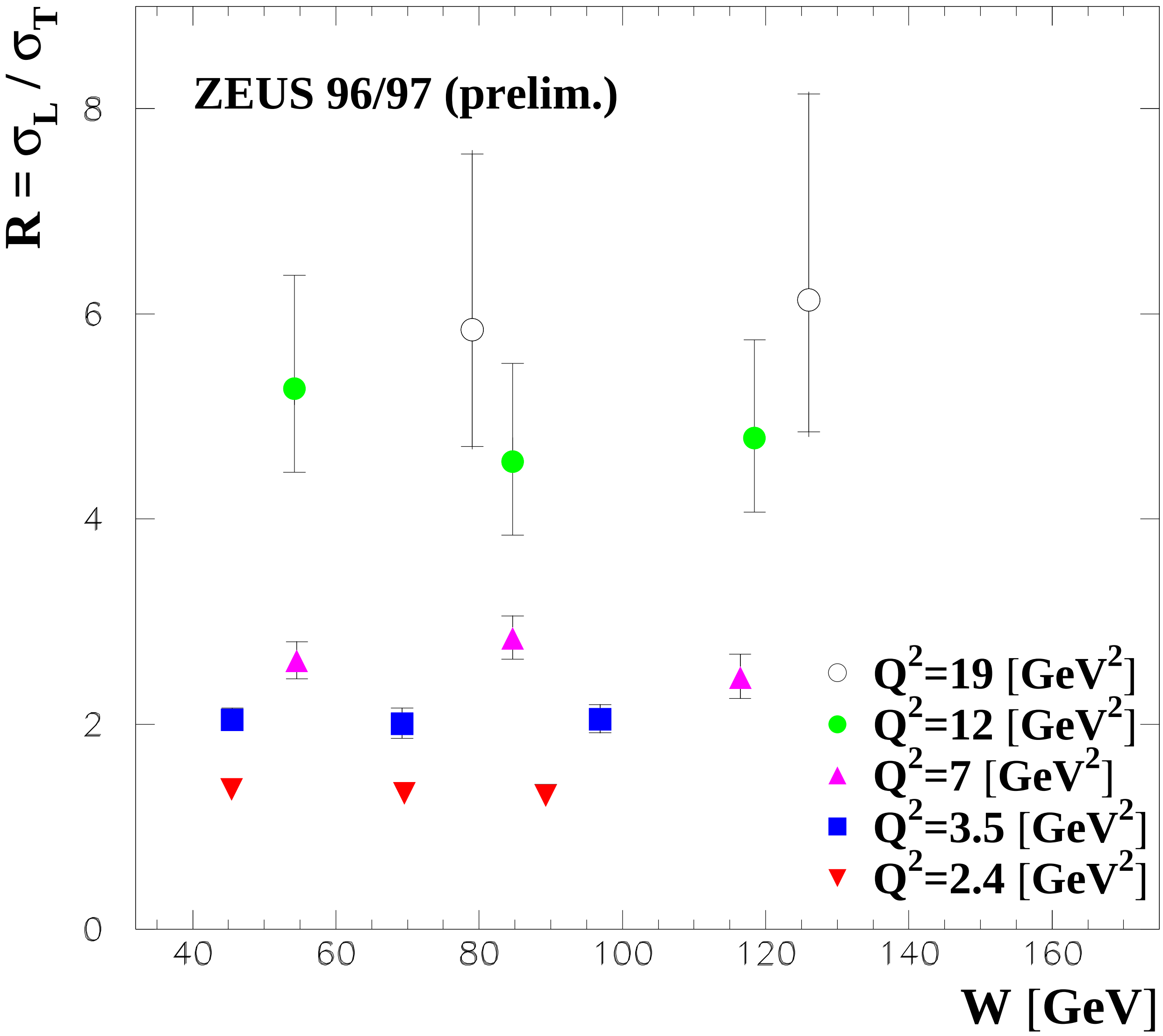
R(SCHC) - R(SCHNC) $\sim$ 3 %

$\boxed{\sigma_L/\sigma_T}$



- **fit to ZEUS only :** $R = \sigma_L/\sigma_T = \xi(Q^2/M^2)^\kappa$
- $\xi = 0.46 \pm 0.04$ **and** $\kappa = 0.75 \pm 0.03$
- R **increases with** Q^2

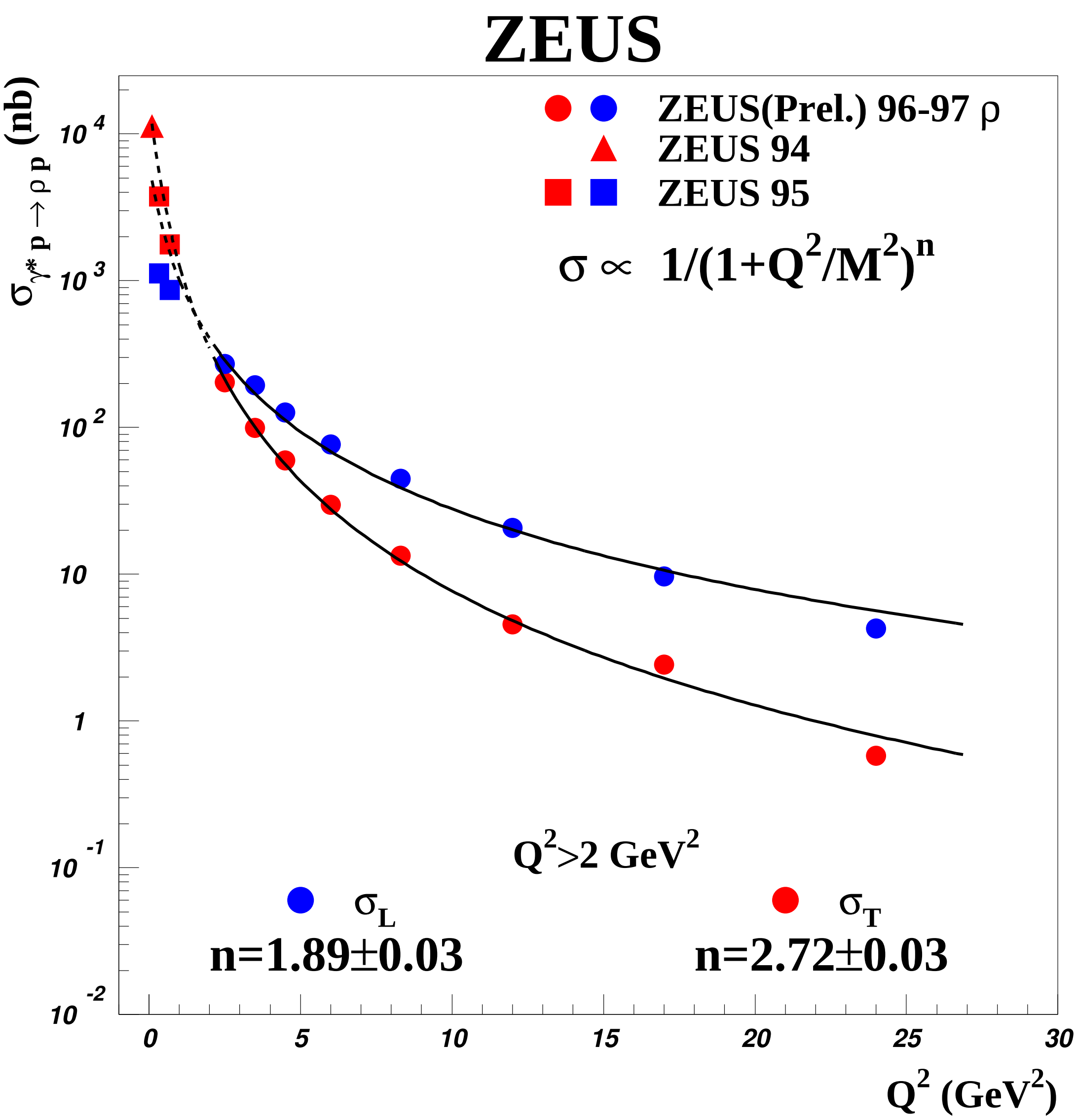
$\boxed{\sigma_L/\sigma_T}$



- within experimental errors R is W independent
- the typical dipole size contributing to ρ production

- independent of the photon polarization ?

$\boxed{\sigma_L, \sigma_T}$

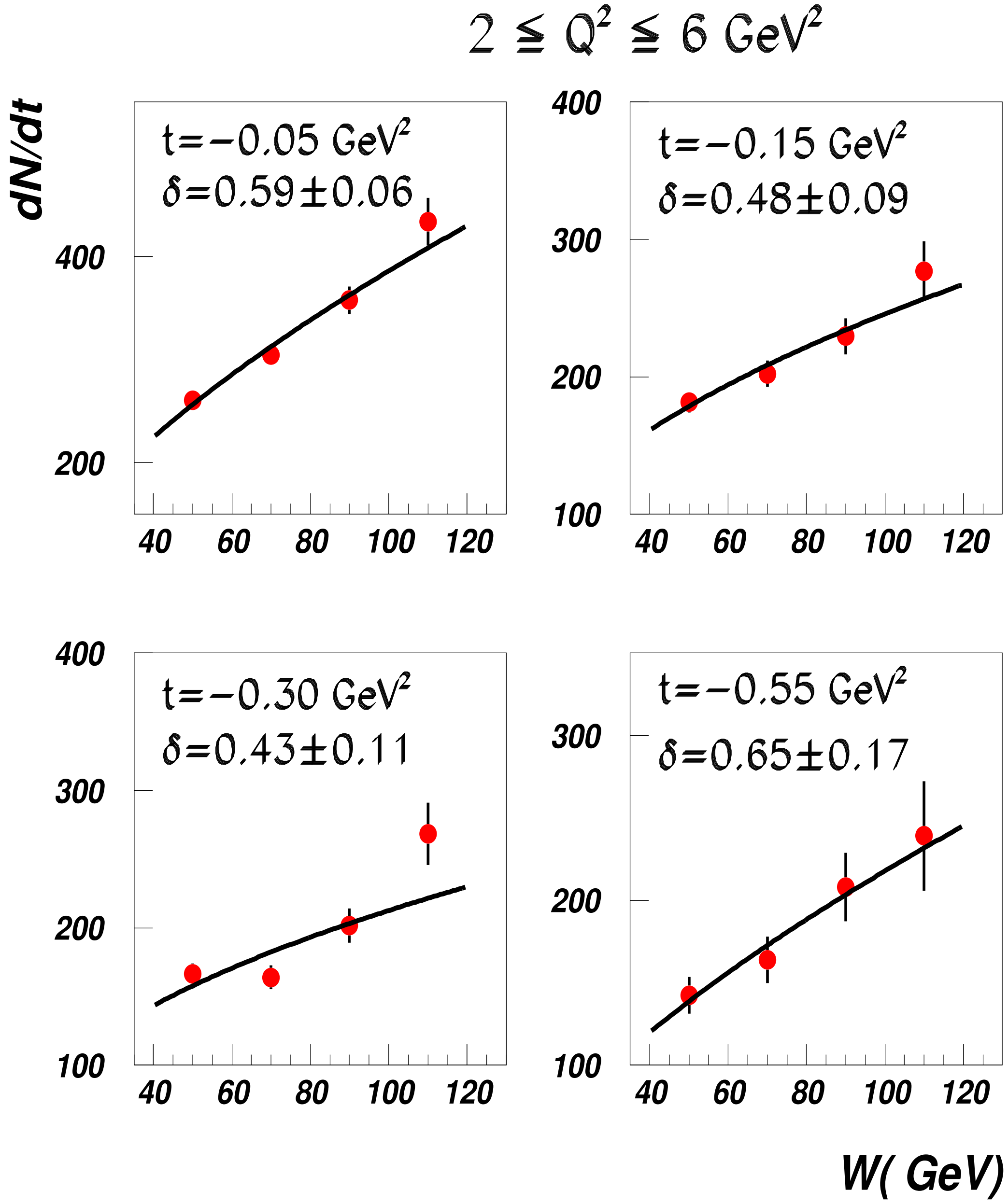


fit to $Q^2 > 2$ GeV^2

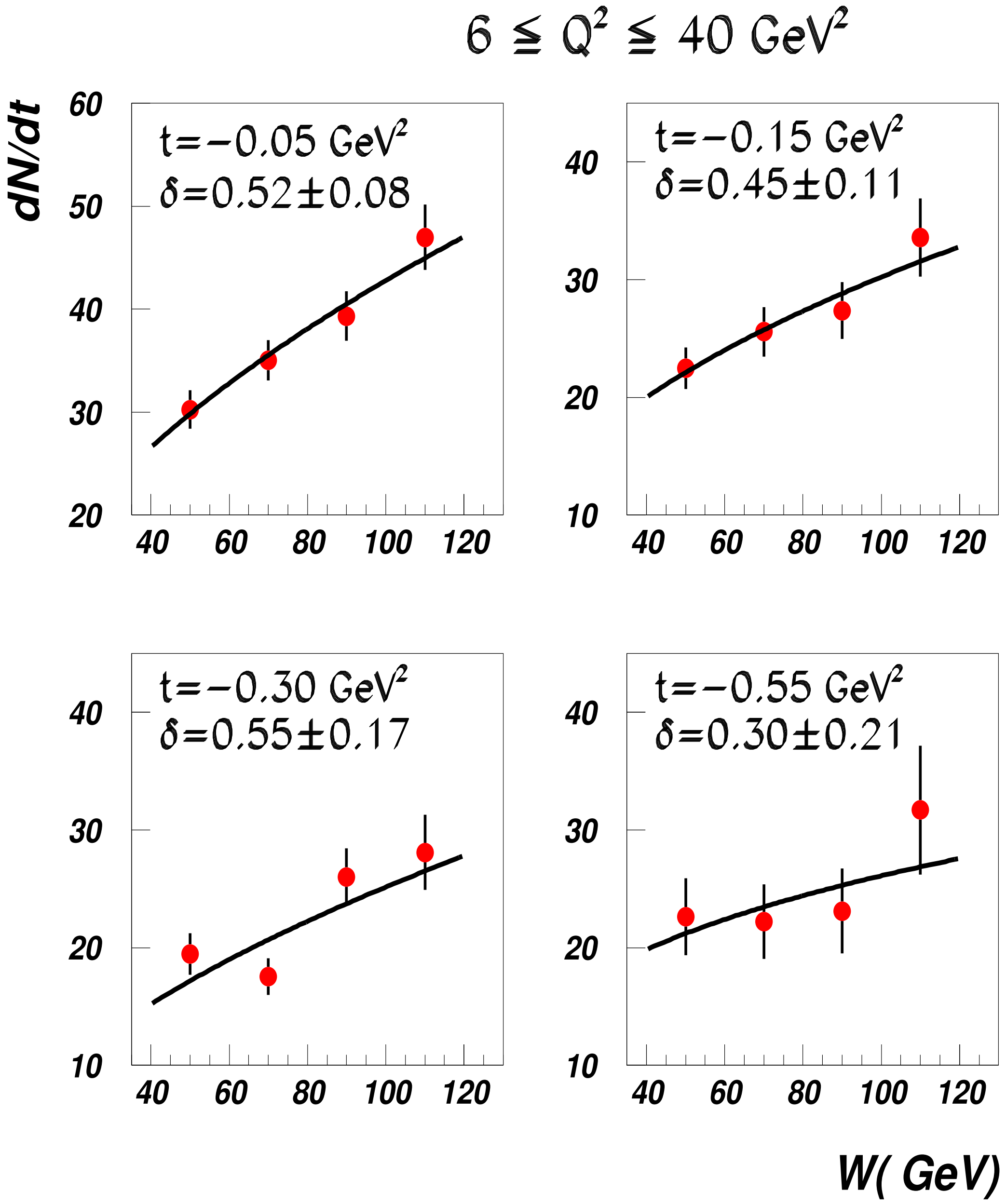
- n_L=1.89 $\pm$ 0.03 and n_T=2.72 $\pm$ 0.06

Pomeron trajectory

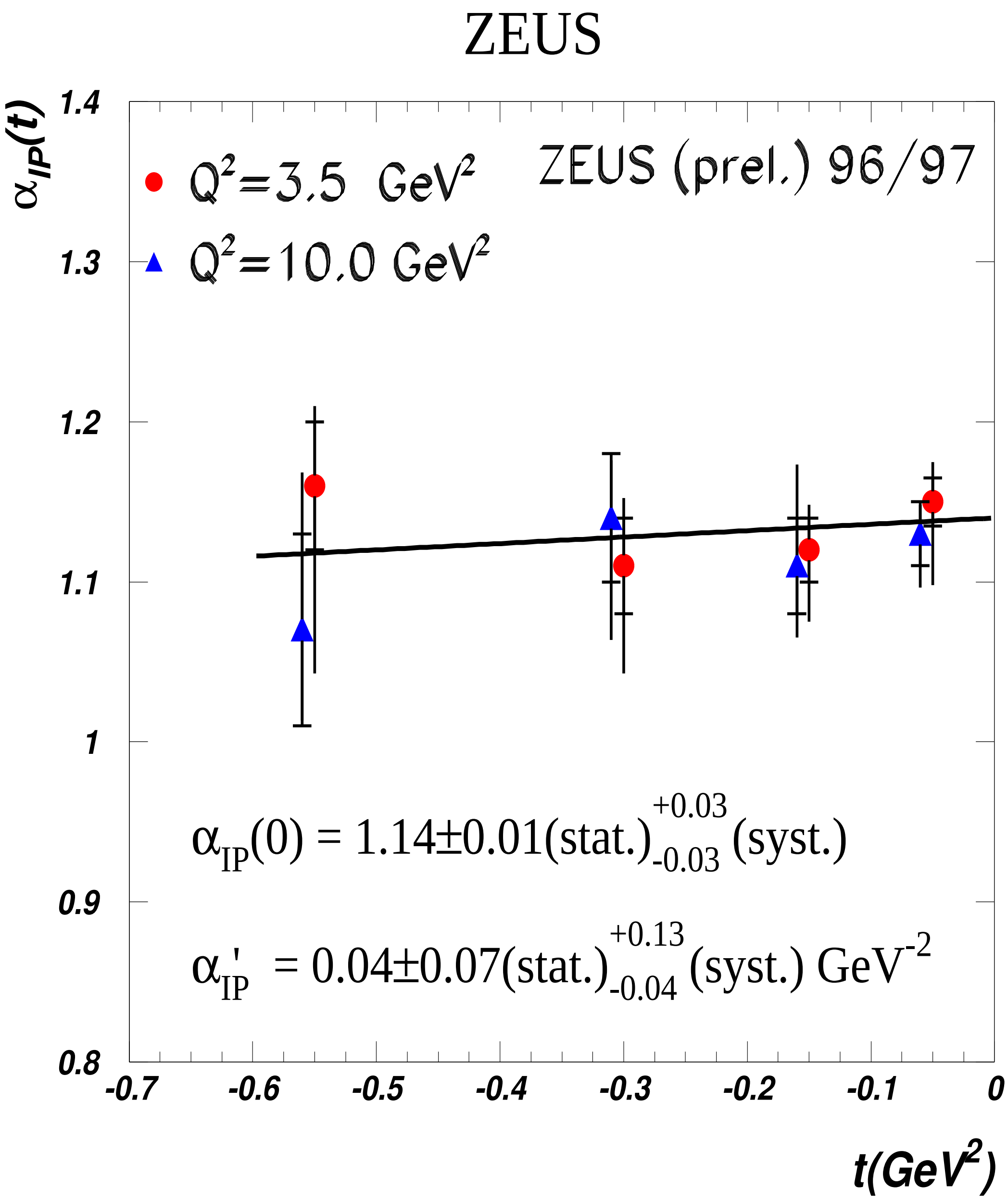
- $\frac{d\sigma(\gamma p \to Vp)}{dt} \propto e^{-b_0|t|}(W^2/W_0^2)^{2(\alpha_{I\!P}(t)-1)}$
- $\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P}t$
- $\frac{d\sigma(\gamma p \to Vp)}{dt} \propto (W/W_0)^{\delta}$
- $\delta = 4(\alpha_{I\!P}(t) - 1)$



Pomeron trajectory

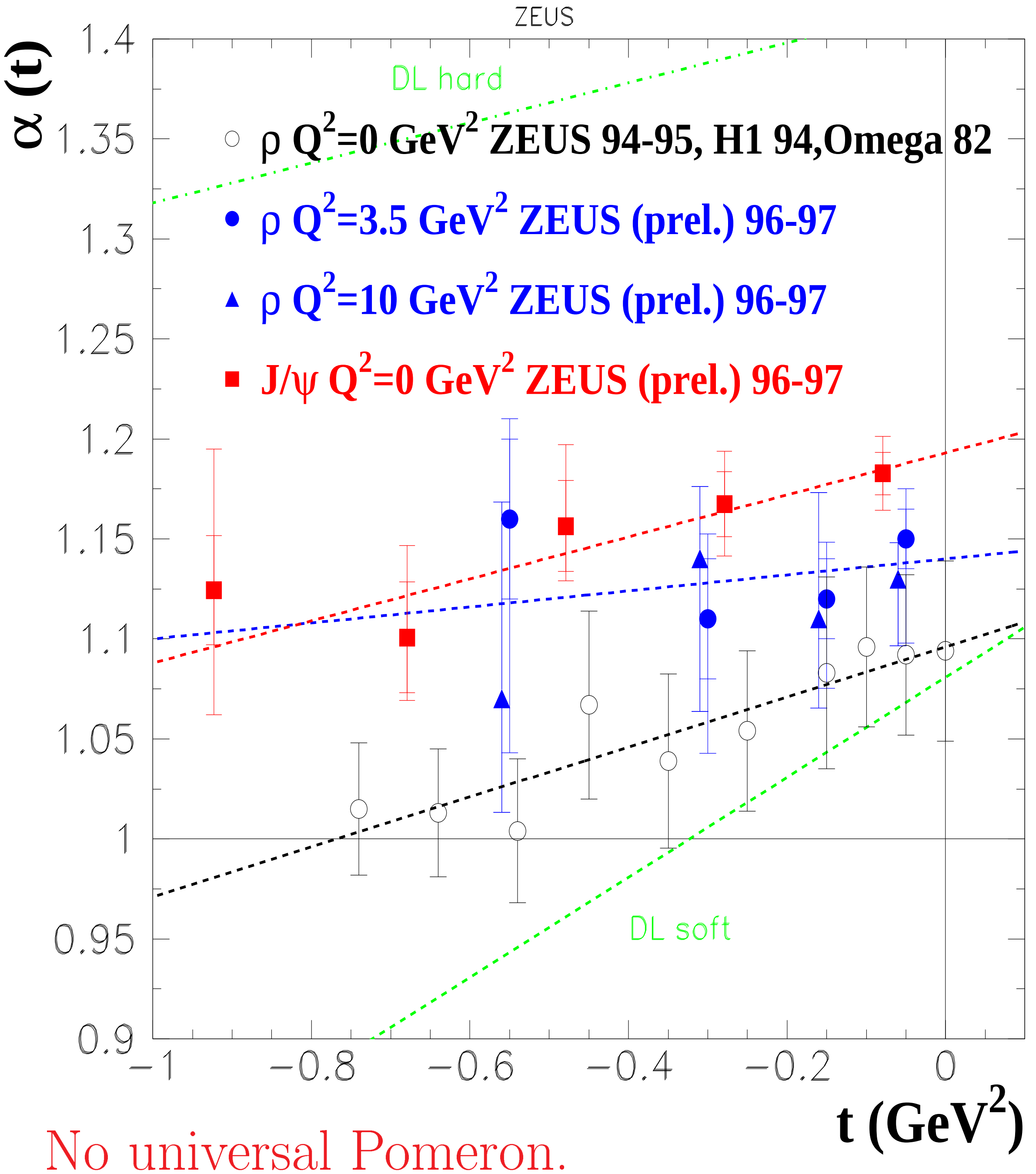


Pomeron trajectory



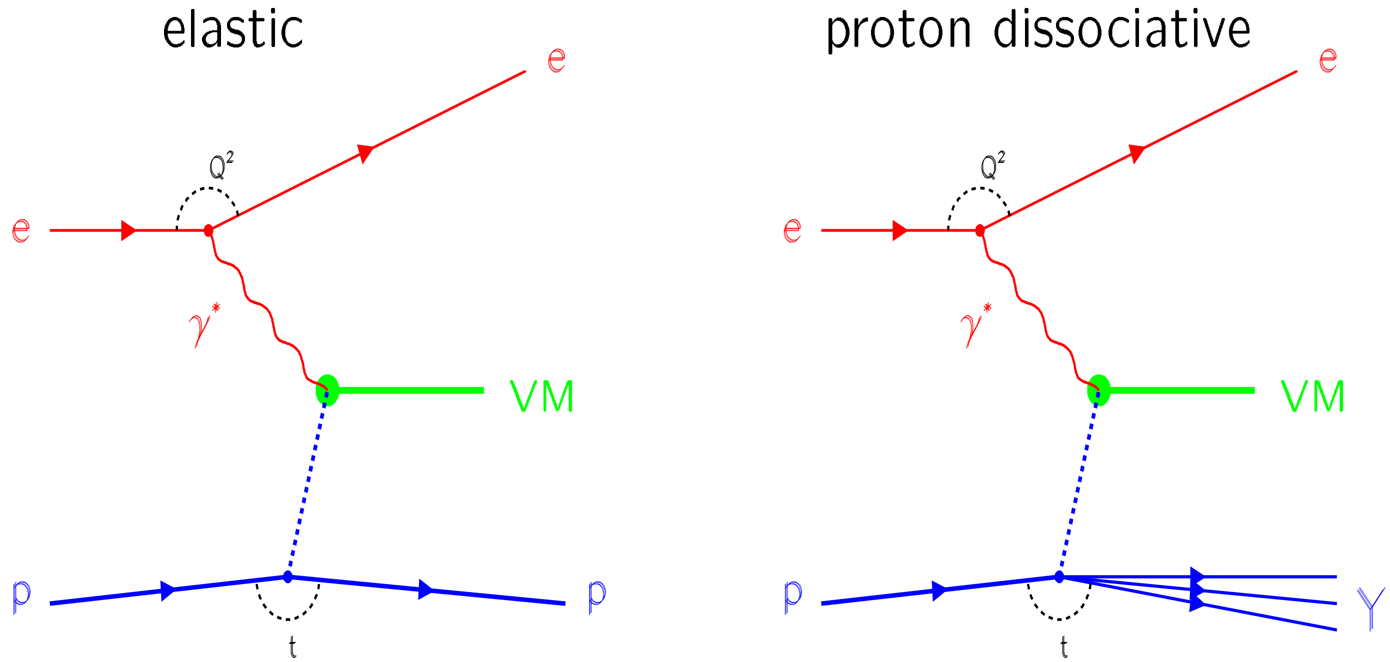
First measurement of $\alpha_{IP}(t)$ in DIS

Pomeron trajectory



No universal Pomeron.

Diffractive Vector Meson Production at HERA



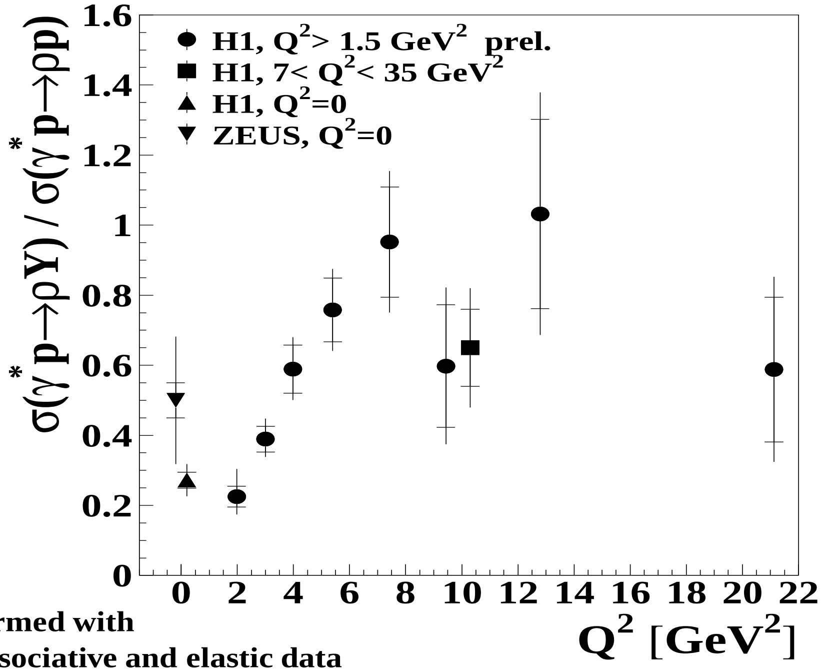
Q^2	γ^* Virtuality	$\sim 0 < Q^2 < 100\,\mathrm{GeV}^2$
$W_{\gamma p}$	CM Energy of $\gamma^* p$ system	$20 < W_{\gamma p} < 290\,\mathrm{GeV}$
t	(4-mom. transfer at p vertex)^2	$\sim 0 < \lvert t \rvert < 20\,\mathrm{GeV}^2$
VM	Vector Meson	$\rho^0,\ \omega,\ \phi,\ J/\psi,\ \psi',\ \Upsilon$

$\Rightarrow$ HERA allows to probe a wide range of several scales: Q^2, t, M_{VM}

Proton Dissociation

- H1 preliminary

$\gamma^* p \rightarrow \rho^\circ Y$ **Ratio p-Diss. / Elastic**



**Ratio formed with
H1 p-dissociative and elastic data
from present analysis**

Strong rise for $Q^2 \lesssim 5$ GeV^2

Effect survives all cross-checks:

Change of W-range and other selection criteria
Use of raw numbers of events for the Ratio

Effect cannot be due to the t' integration:

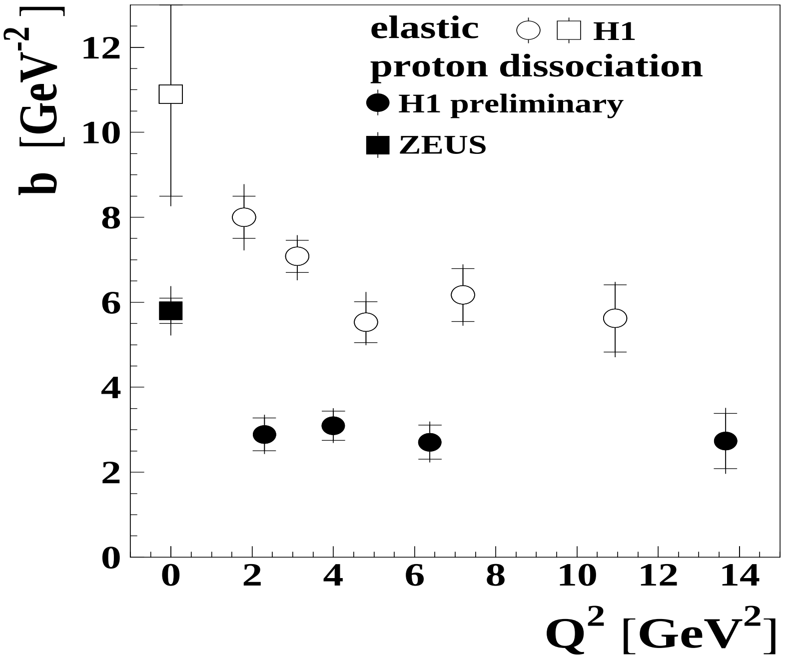
b slope $\sim$ constant with Q^2

Indication of Breaking of Vertex Factorisation !

Proton Dissociation

- H1 preliminary

$\gamma^* p \rightarrow \rho^\circ Y$ **b Slope**



$\mathbf{b}_{\mathrm{pdiss.}}(Q^2 > 0)$ $\propto$ **independent of $\mathbf{Q^2}$**

$\mathbf{b}_{\mathrm{pdiss.}}(Q^2 > 0)$ **significantly lower than** $\mathbf{b}_{\mathrm{pdiss.}}(Q^2 = 0)$

$\mathbf{b}_{\mathrm{pdiss.}}$ **significantly lower than** $\mathbf{b}_{\mathrm{elastic}}$

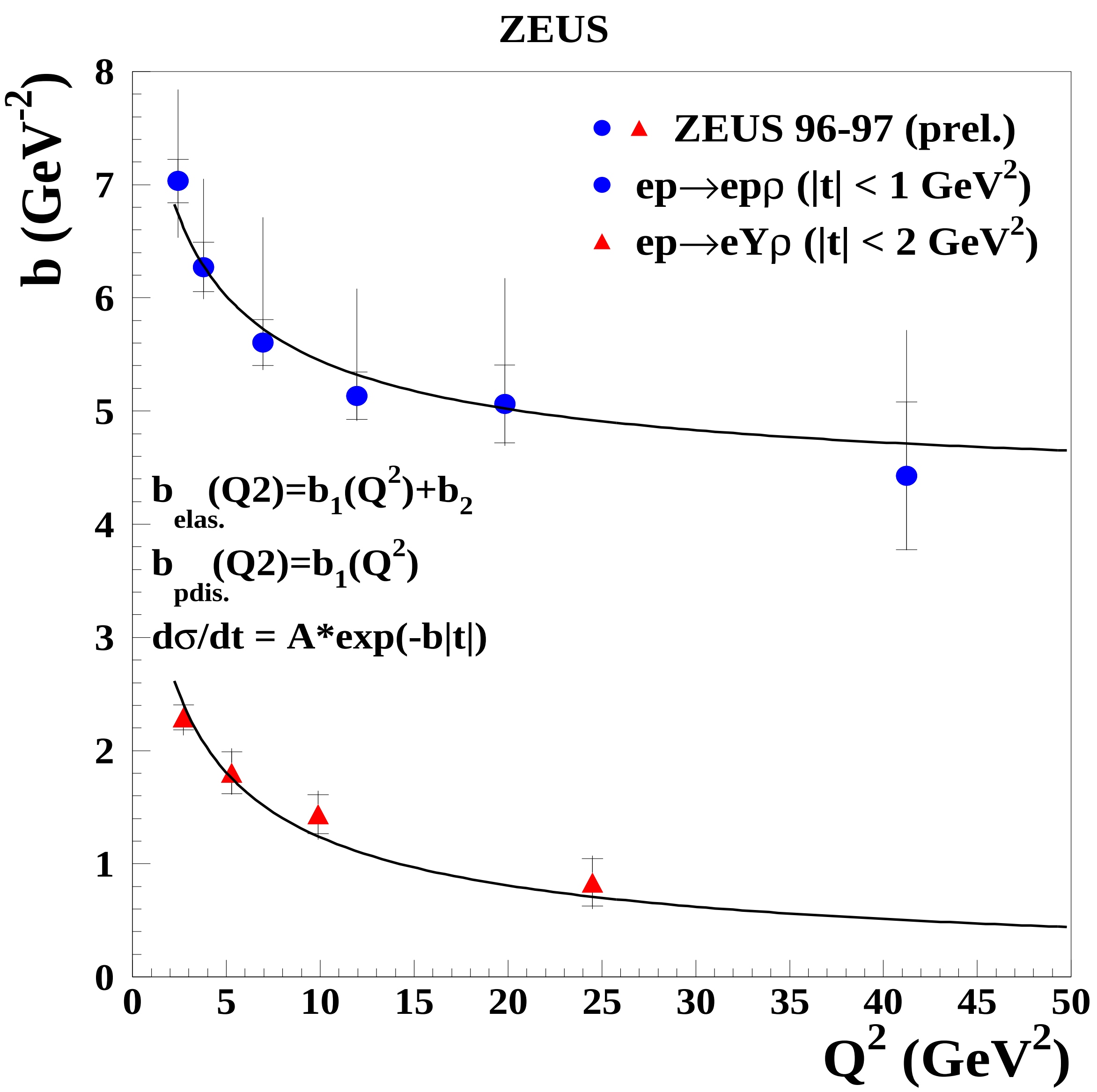
b **is related to the radii of the scattering particles**

$$b \propto R_p^2 \oplus R_{q\bar{q}}^2 \quad \Rightarrow$$

Scattering off a proton fragment !

Proton Dissociation: b slope

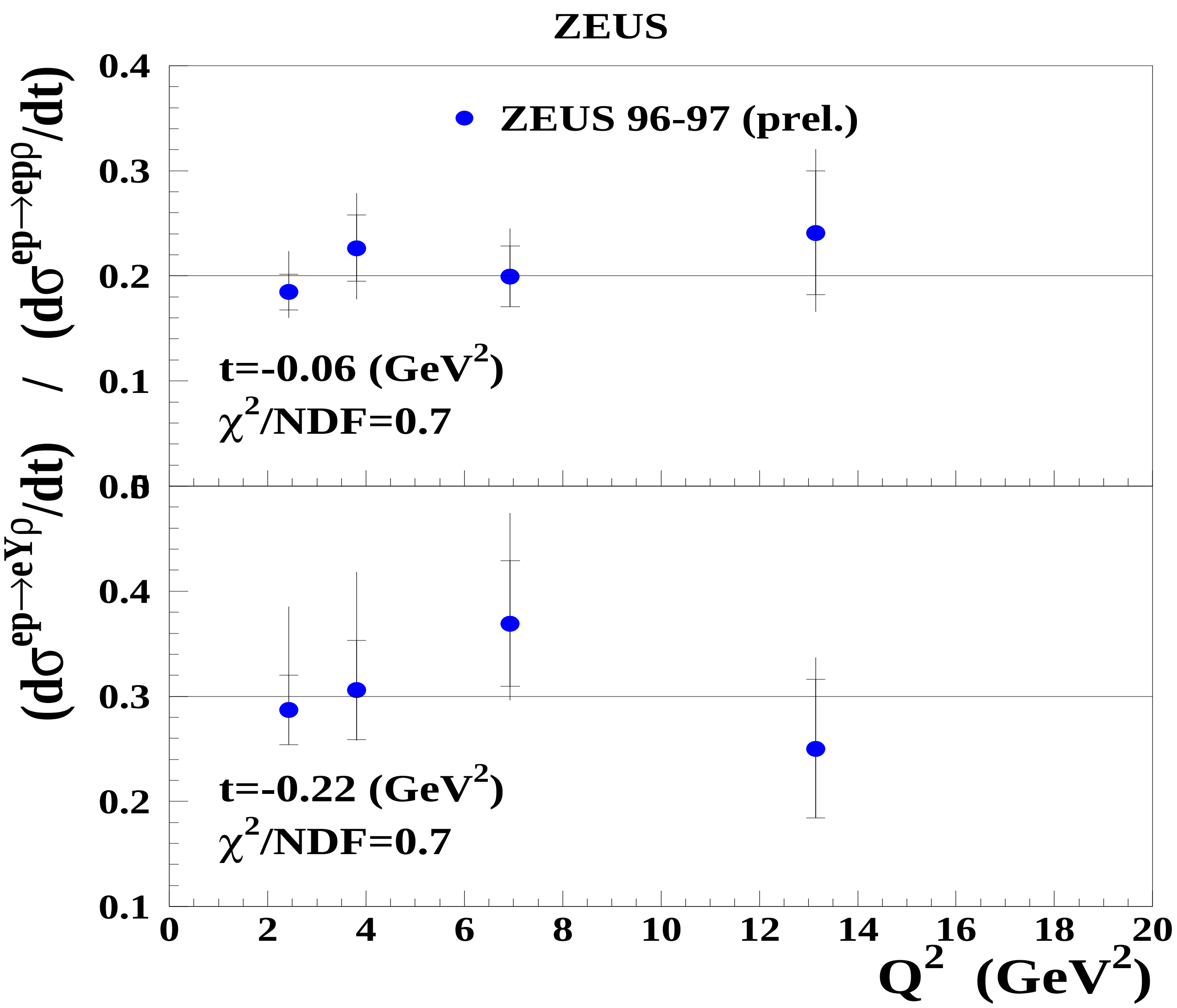
- ZEUS preliminary



- $b_{el}(Q^2) = b_0/(1+R) + b_1$, $\qquad b_{pd} = b_0/(1+R)$
- $R = \sigma_L/\sigma_T = \xi(Q^2/M^2)^\kappa$
- $\xi = 0.46 \pm 0.04$ and $\kappa = 0.75 \pm 0.03$ (Elastic VM production)
- $b_0 = 5.84 \pm 0.23, \qquad b_1 = 4.21 \pm 0.12$

Proton Dissociation: cross sections ratio

- ZEUS preliminary



- cross sections ratio is Q^2 independent !
- H1: b_{pdis} slope is constant with Q^2
- H1: Strong breaking of vertex factorization
- ZEUS: b_{pdis} slope decreases with Q^2
- ZEUS: Vertex factorization holds

Summary

- **Diffractive processes like exclusive production of vector mesons and DVCS have been studied in ep collisions with the H1 and ZEUS detectors at HERA.**

- **typical features of HARD processes $\Longrightarrow$ predicted by pQCD**
  - ⋆ **fast rise of cross section with energy**
  - ⋆ **increasing of σ_L/σ_T with Q^2**
  - ⋆ **small value of α'**
  - ⋆ **SU(4) restoration**

were observed, whenever a hard scale (Q^2 or M^2 or t) is presented.