QCD-N, 3 – 6 April 2002, Ferrara, Italy

Exclusive Vector Meson production at HERA

Jacek Ciborowski
Warsaw University

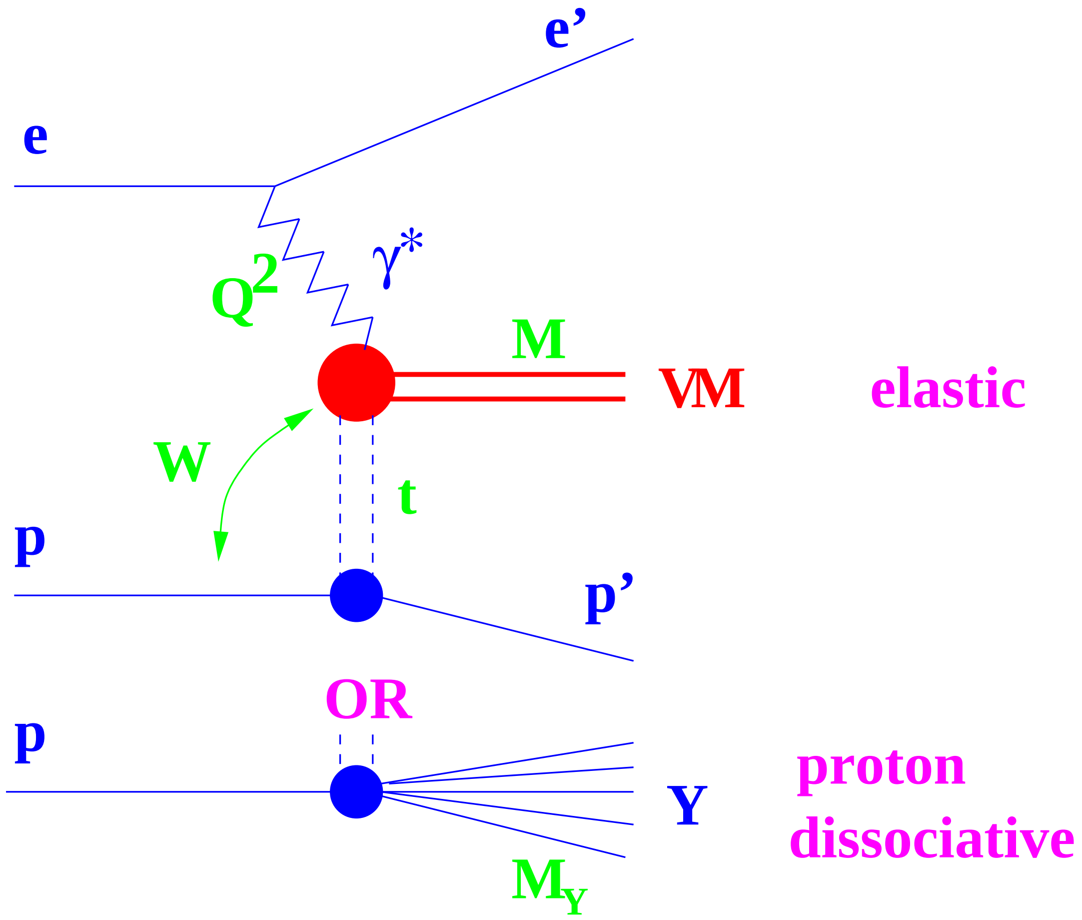
On behalf of the H1 and ZEUS Collaborations

Contents:

- Scales: Q^2, M_V, $|t|$ (soft $\longrightarrow$ hard)
- Pomeron trajectories
- Spin density matrix elements – $|t|$ dependence

Introduction

HERA: $e^{\pm}p$ at CMS energy $\approx$ 300 GeV



W : $\gamma^* p$ CMS energy

$-Q^2$: γ^* 4-momentum squared

t : 4-mom. transfer sq. to the proton vertex

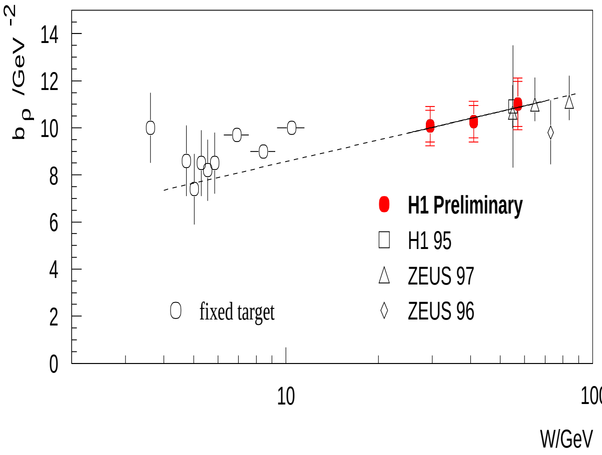
VM : ρ^0, ω, Φ, J/ψ, ψ', Υ

M_Y : hadronic state (proton dissociation)

No scale

Soft processes:

ρ, ω, Φ low $|t|$ PHP



$$\frac{d\sigma}{d|t|} \propto e^{-bt}(W/W_0)^{4(\alpha_P(0)-1)}$$

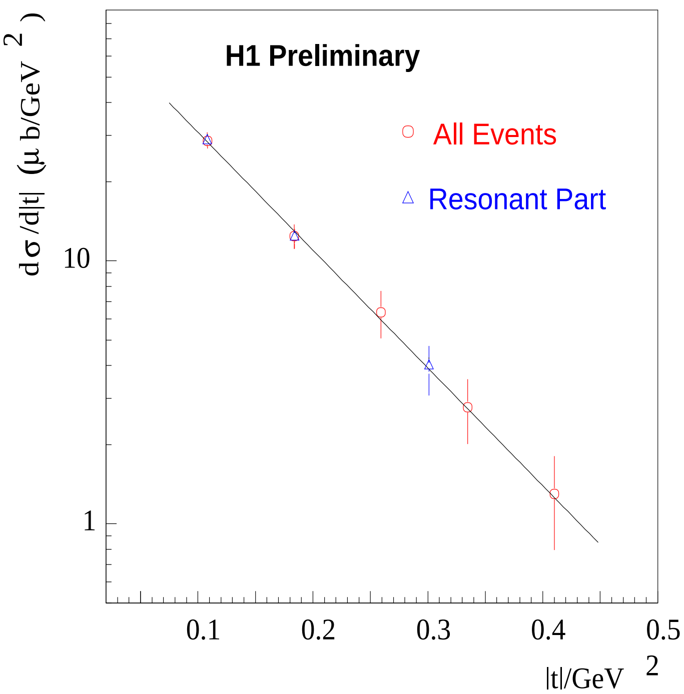
$$b(W) = b_0 + 4\alpha'_P \ln(W/W_0)$$

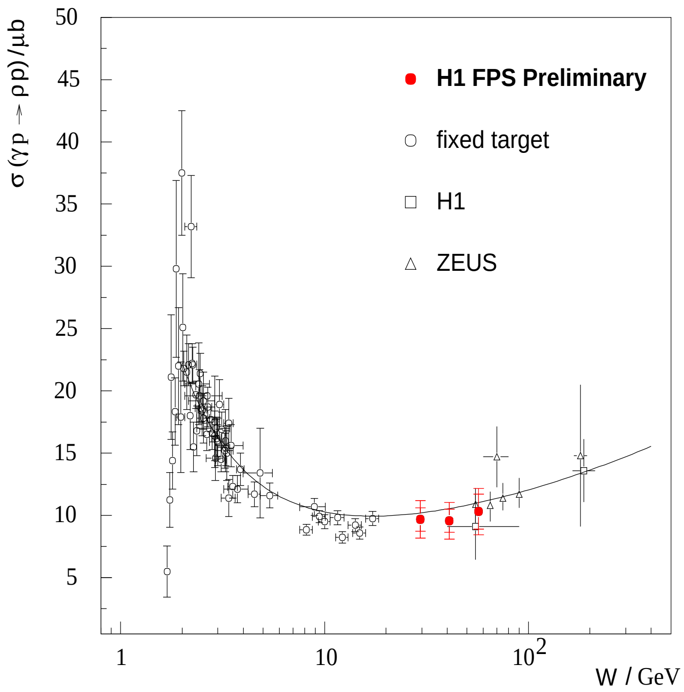
$$\alpha_P(t) = \alpha_P(0) + \alpha'_P\, t$$

$$\alpha_P(0) = 1.08 \quad \alpha'_P = 0.25 \text{ GeV}^{-2}$$

(soft pomeron)

Elastic ρ^0 with a leading p:



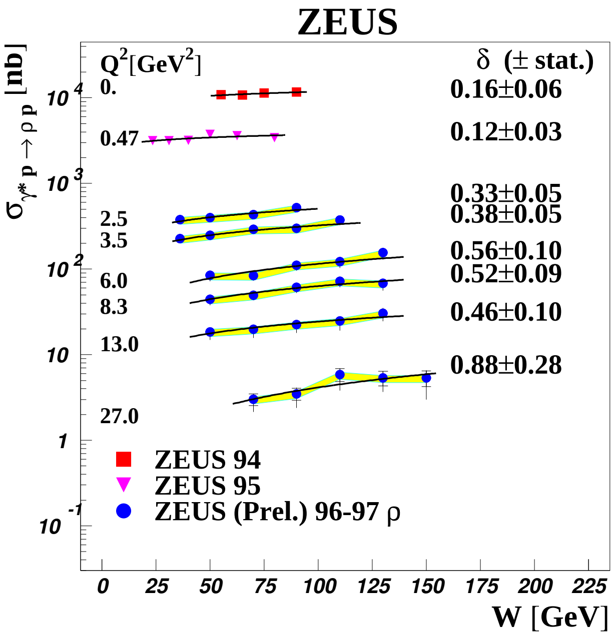


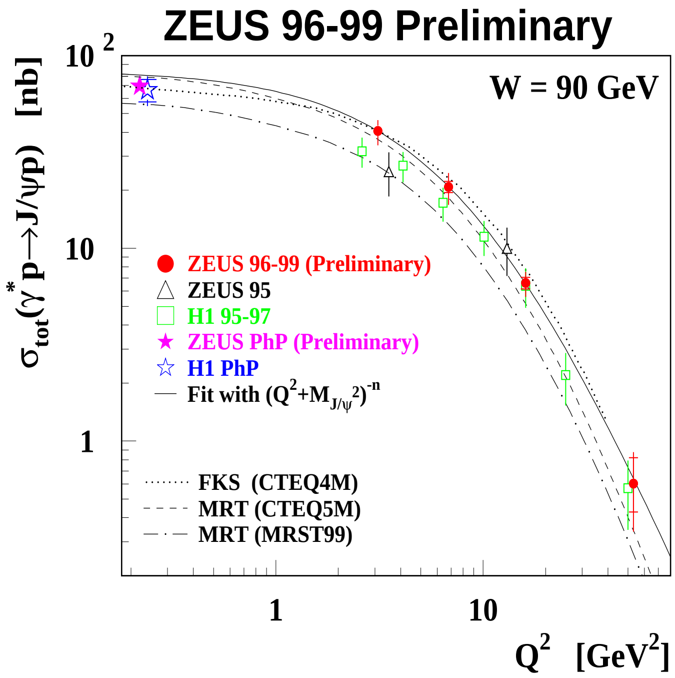
$$b = 10.31 \pm 0.77 \pm 0.53$$

$$\sigma \propto W^{\delta}, \qquad \delta = 0.22$$

Scale: Q^2

ρ^0 in low $|t|$ DIS:



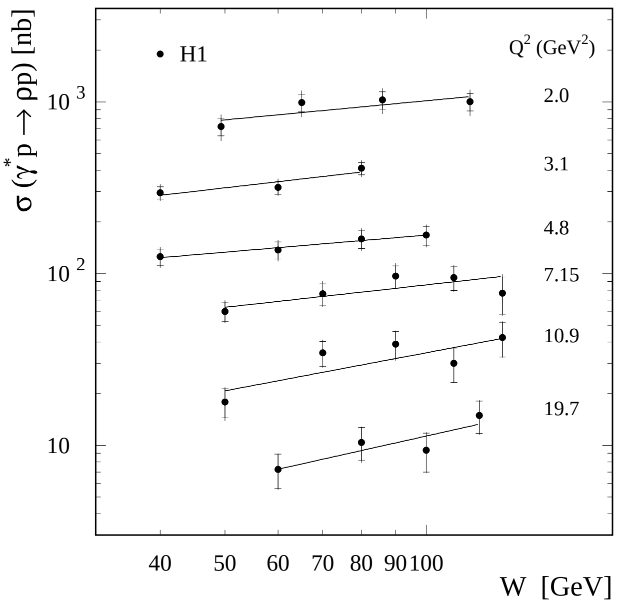


$$\sigma \propto 1/(Q^2 + m_\rho^2)^n$$

only approximately adequate

$$n = 2.60 \pm 0.11^{+0.09}_{-0.08}$$

for $Q^2 \geq 3$ GeV^2



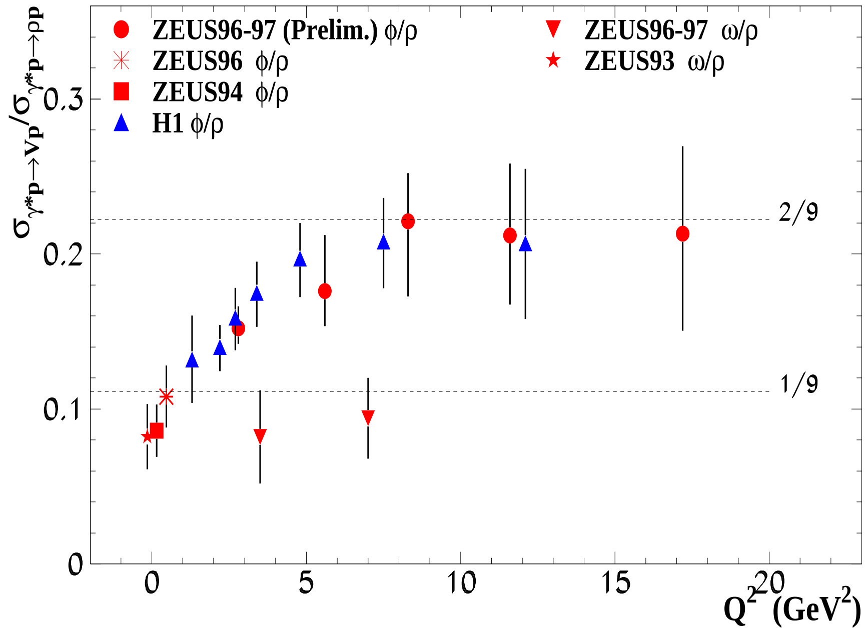
Increasing Q^2: soft $\longrightarrow$ hard

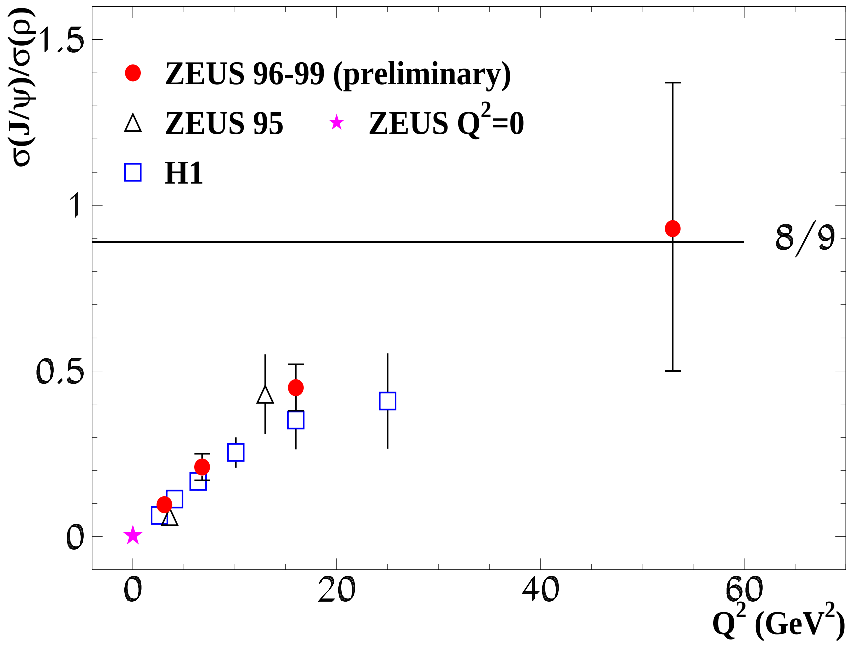
$$\sigma \propto W^\delta$$

Scale: Q^2 - Cross section ratios

$$\rho : \omega : \Phi : J/\psi \quad = \quad 9 : 1 : 2 : 8 \text{ in exact SU(4)}$$

(corrections expected)

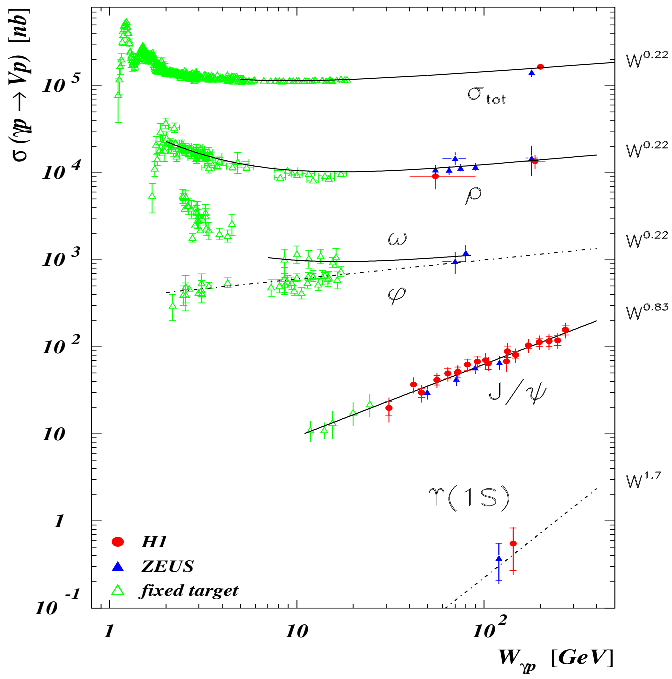




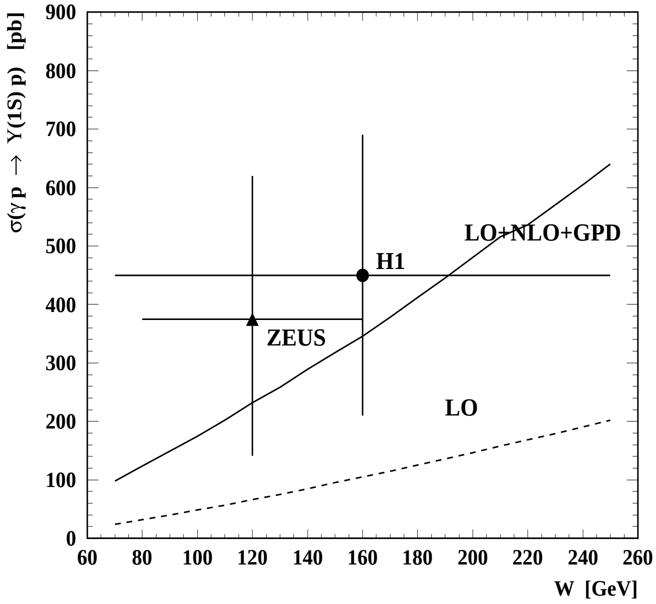
SU(3) restored with increasing Q^2; is SU(4) ?

Scale: M_V

$\rho, \omega, \Phi, J/\psi, \psi', \Upsilon$
in low $|t|$ PHP

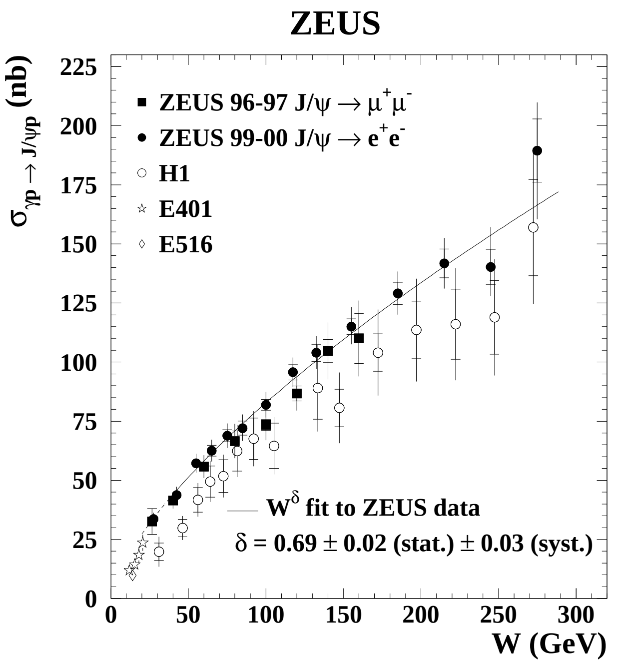


Υ: $\sigma \propto W^{1.7}$ (predicted GPD)
MRT:



Increasing M_V: soft $\longrightarrow$ hard

J/ψ: $\sigma \propto W^{\delta}$ (measured)



ZEUS: $\delta = 0.69 \pm 0.02 \pm 0.03$

H1: $\delta = 0.83 \pm 0.07$

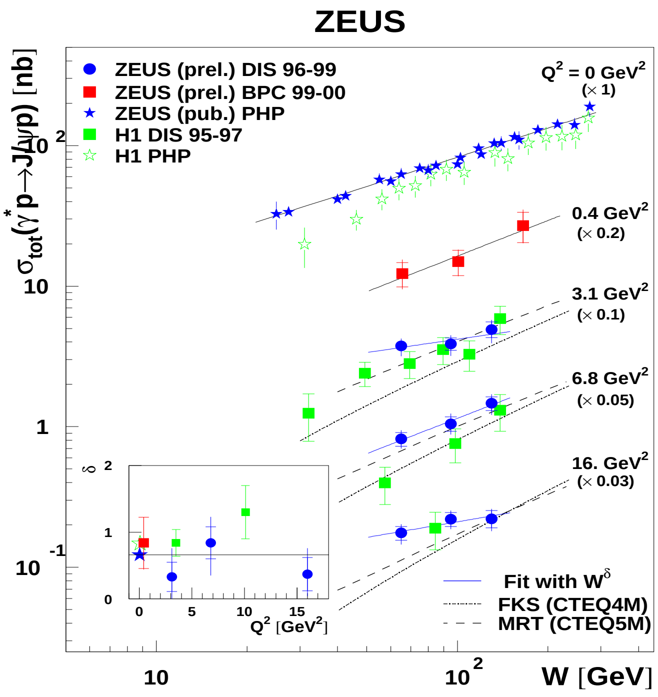
Agreement with pQCD if $g(x)$ from F_2 scaling violation

$$\sigma(W) \propto |xg(x, Q^2_{eff}|^2$$

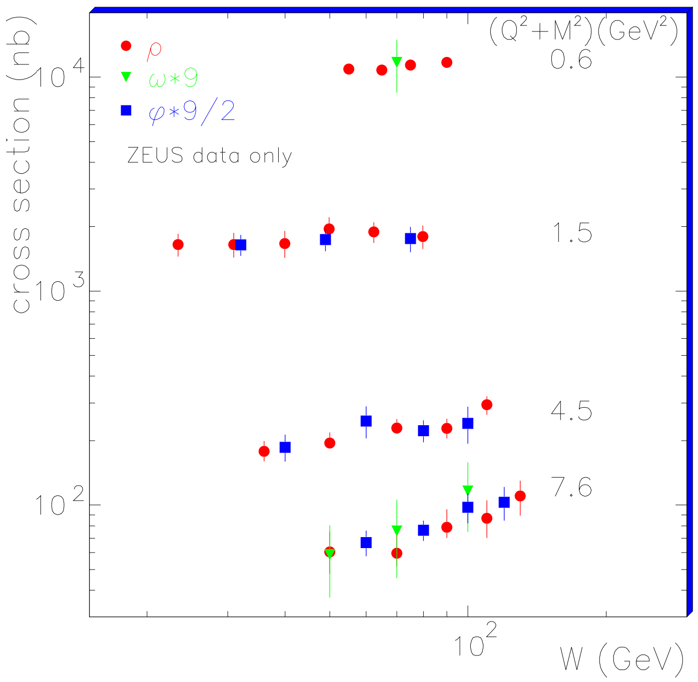
Which effective scale?

Scales: Q^2, M_V

$\rho, \omega, \Phi, J/\psi$ in low $|t|$ DIS:



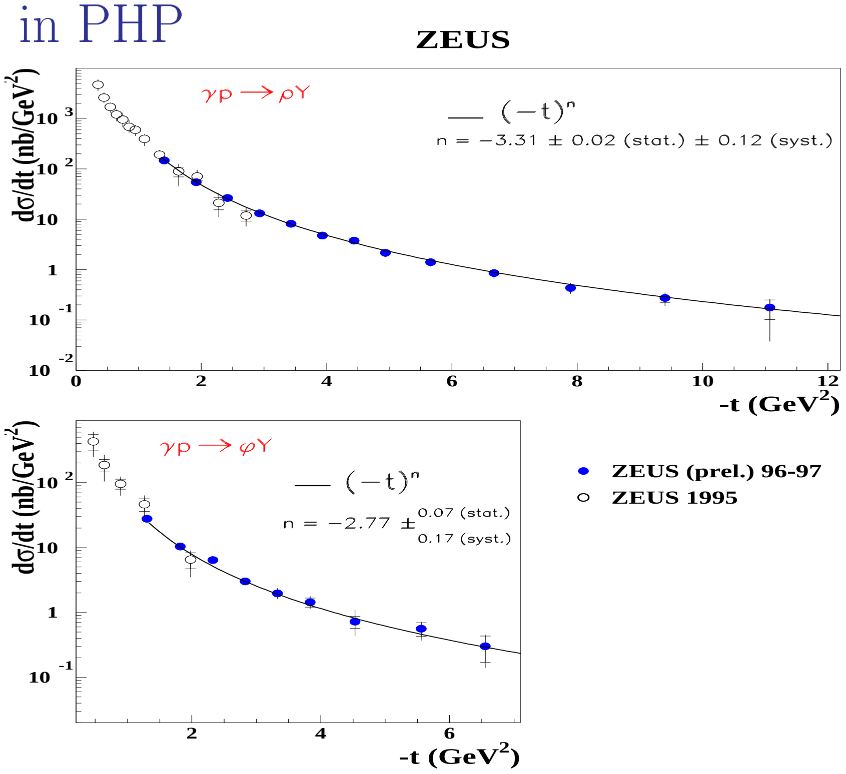
$\delta(Q^2) \approx$ const. at present accuracy (insert)



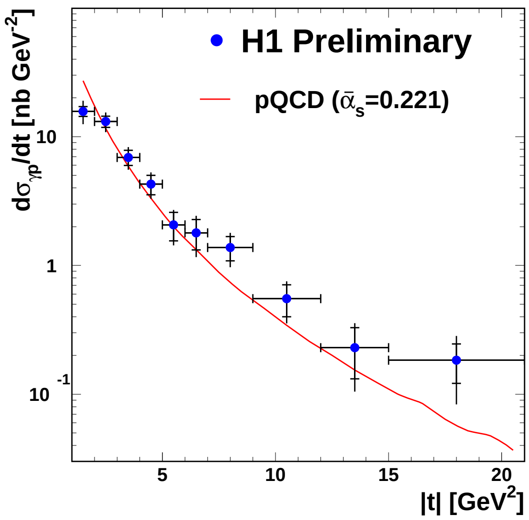
SU(3) restored using $Q^2 + M^2$ – but not SU(4) (not shown)

Scales: $|t|, M_V$

$\rho^0, \Phi, J/\psi$ in PHP

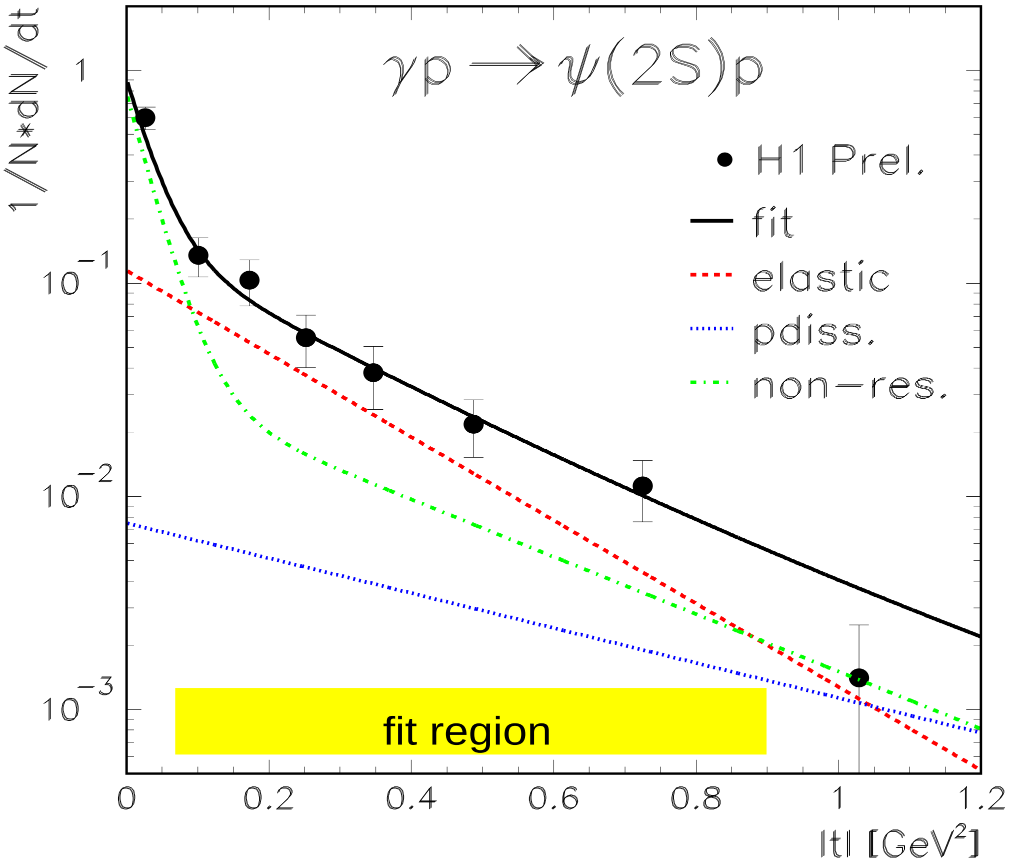


$$d\sigma/dt \propto |t|^{-n}, \quad n \approx 3$$



$$d\sigma/dt \propto |t|^{-n}, \quad n \approx 1.7$$

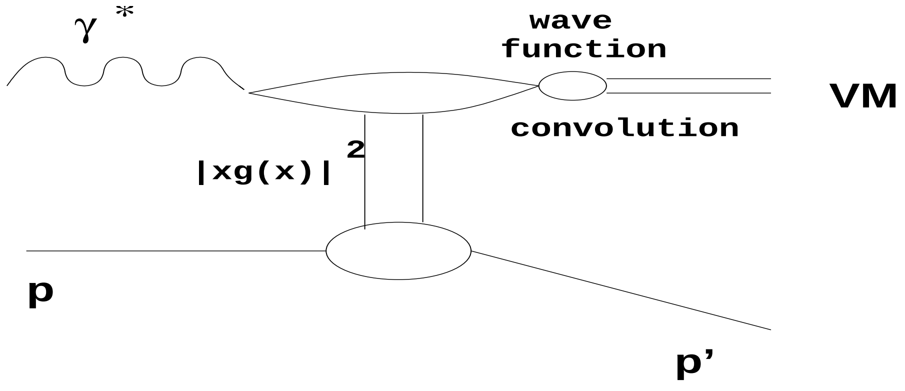
In agreement with LO BFKL (Forshaw, Ryskin, Bartels)



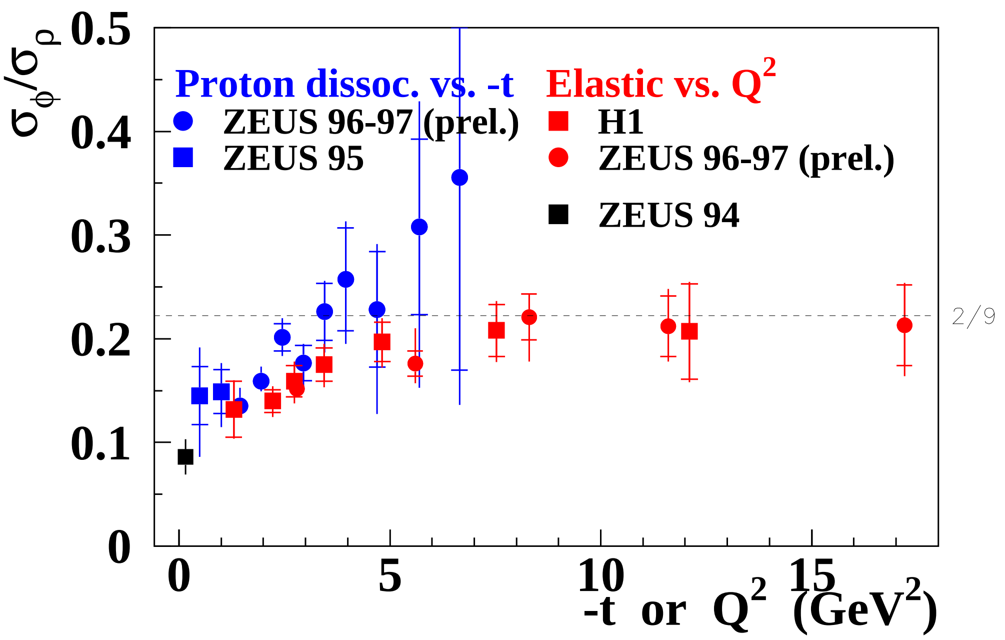
$b_{\psi'} = 4.5 \pm 1.2^{+1.4}_{-0.7}\ \mathrm{GeV}^{-2}$ $\qquad$ $b_{J/\psi} = 4.73 \pm 0.25^{+0.30}_{-0.39}\ \mathrm{GeV}^{-2}$

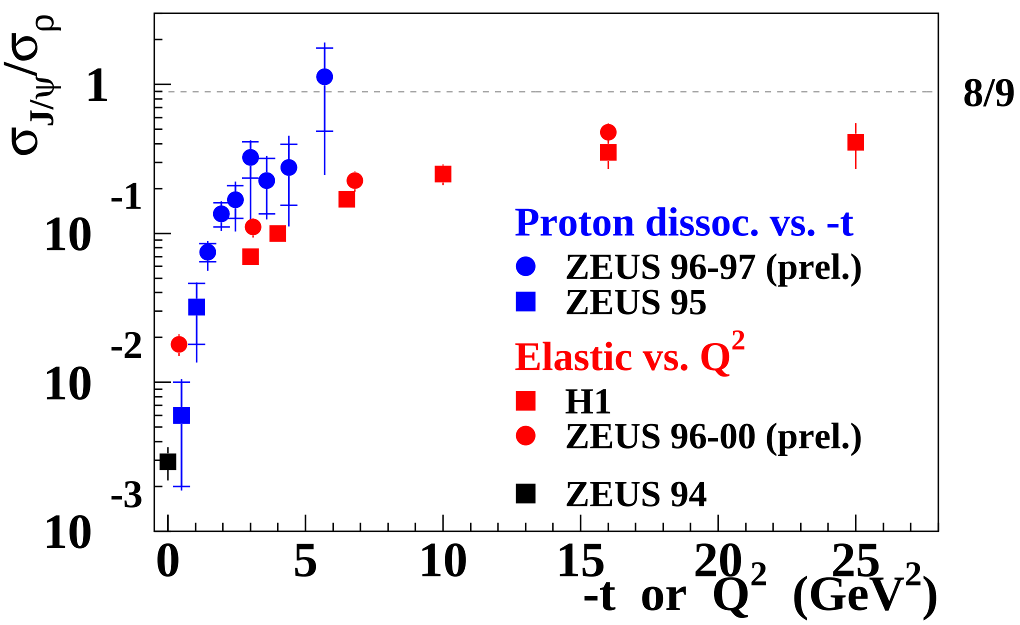
$b_{\psi'} \approx b_{J/\psi}$ in agreement with pQCD + wave function

Kopeliovich, Nemchik *et al.*



Scales: Q^2 and $|t|$ – comparison



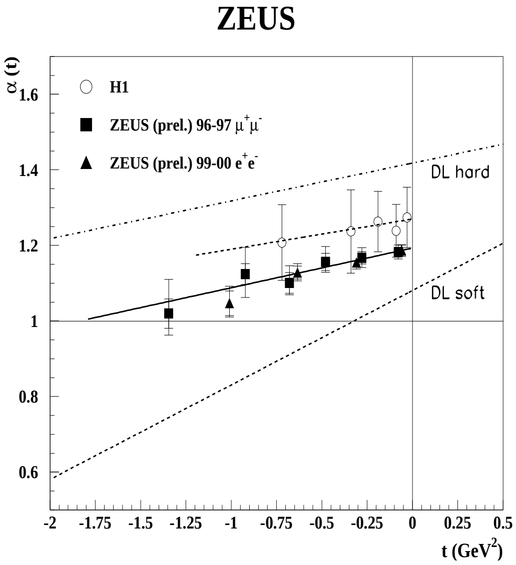


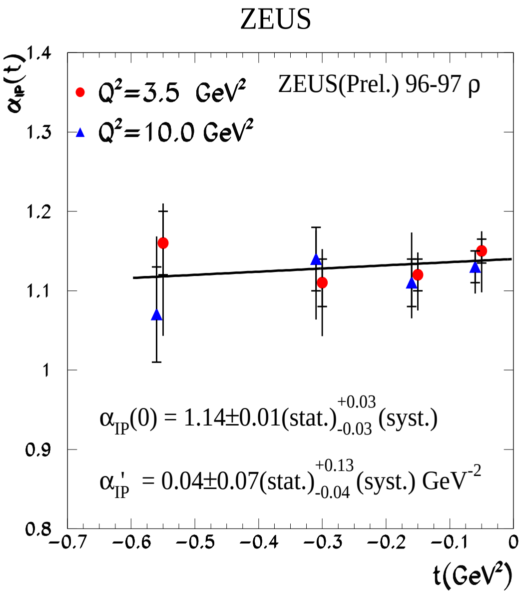
Rise in $|t|$ steeper than in Q^2

$|t|$ also shows a hard scale behaviour

Pomeron trajectory…

…from ρ, J/ψ: $\alpha_P(t) = \alpha_P(0) + \alpha'_P t$

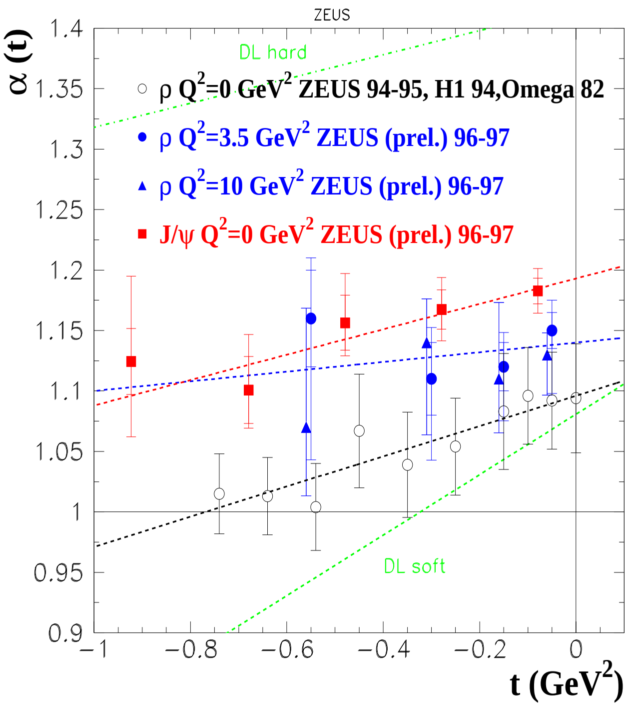




J/ψ PHP:

$$\alpha_P(0) = 1.27 \pm 0.05\ (\mathrm{H1});\ 1.200 \pm 0.009^{+0.004}_{-0.010}\ (\mathrm{ZEUS})$$

$$\alpha'_P = 0.08 \pm 0.17\ (\mathrm{H1});\ 0.115 \pm 0.018^{+0.008}_{-0.015}\ (\mathrm{ZEUS})$$

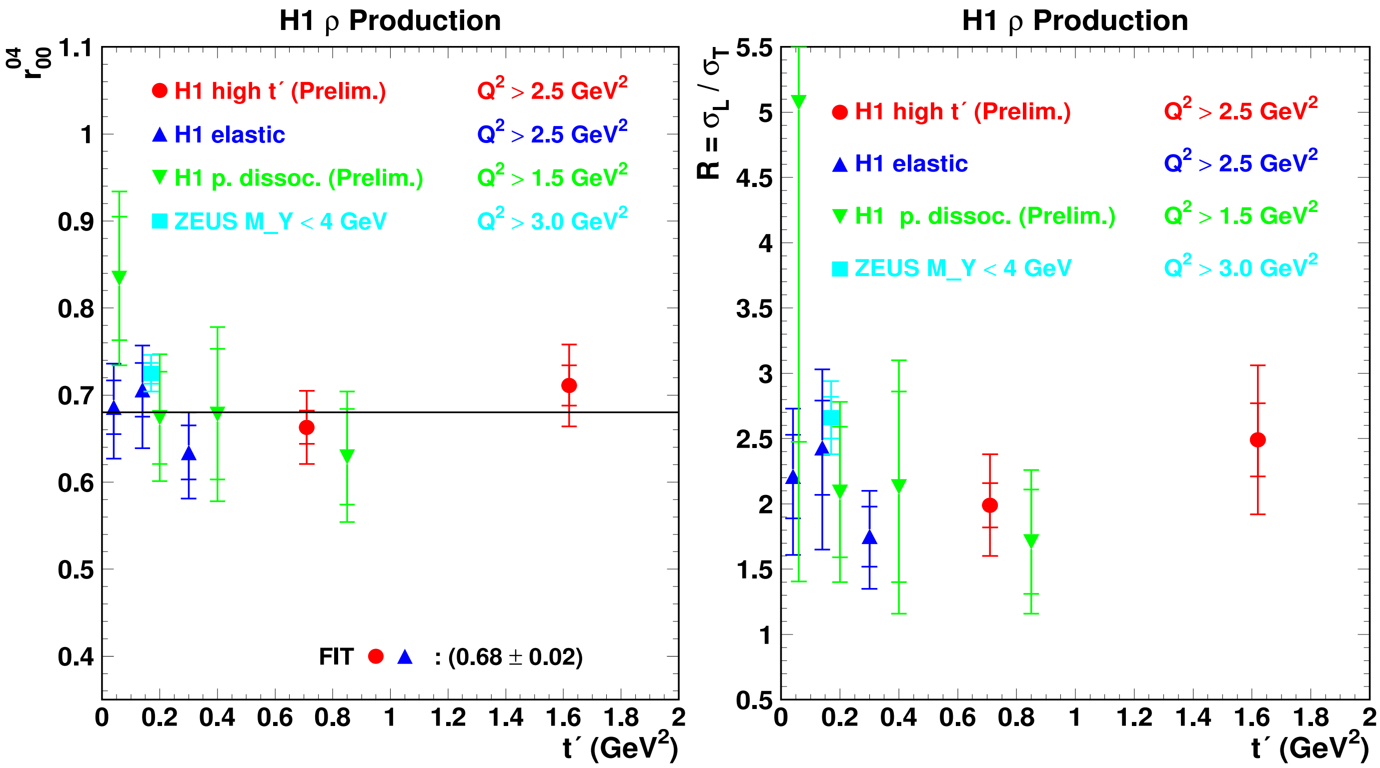


$\alpha_P(t)$ varies with M_V and Q^2 – no universal Pomeron

Spin density ME

ρ^0 in DIS

Low $|t|$: $\gamma_T \to \rho_L$ ($r^5_{00} > 0$) – SCHC violation

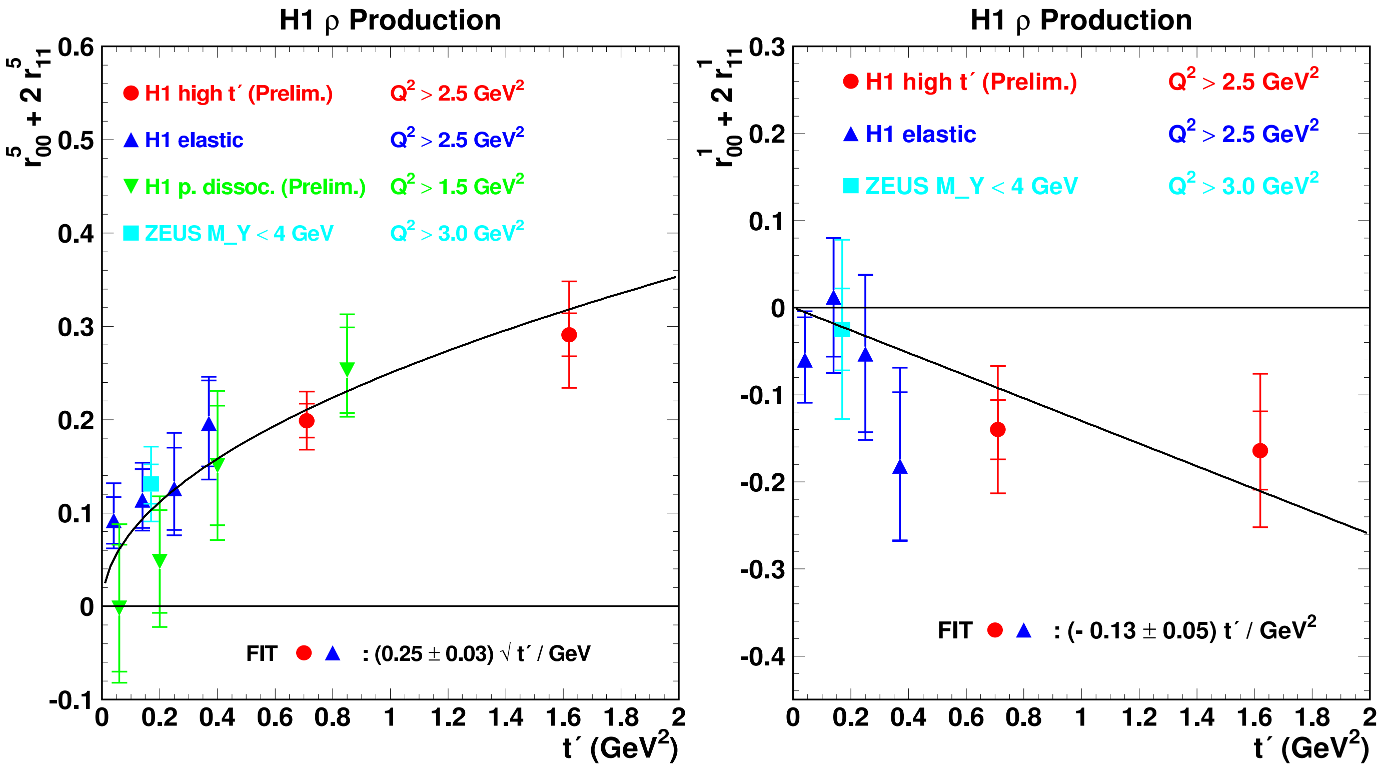


No flip: $r^{04}_{00} \propto |T_{00}|^2 + |T_{01}|^2$

$$R = \frac{r^{04}_{00} - \Delta^2}{\epsilon[1-(r^{04}_{00}-\Delta^2)]}$$

No $t' = |t| - t_{min}$ dependence of r^{04}_{00} and R within present accuracy

Similar behaviour of the proton dissociative data – factorisation



Single flip: $\propto \sqrt{|t|}$ Double flip: $\propto -|t|$

$r^5_{00} \propto T_{00}T^\star_{01}$ $r^5_{11} \propto T_{10}T^\star_{11} + T_{10}T^\star_{1-1}$

$r^1_{00} \propto -|T_{01}|^2$ $r^1_{11} \propto T_{1-1}T^\star_{11} + T^\star_{1-1}T_{11}$

More SCHC violation at large $|t|$

Summary

- Soft processes (no scale): $\alpha_P(0) = 1.08$ $\alpha'_P = 0.25$, $b \approx 10$
- Q^2, M_V and t provide hard scales, the data:
  - $0 \leq Q^2 < 60$ GeV^2
  - $\rho, \omega, \Phi, J/\psi, \psi', \Upsilon$
  - $0 \leq |t| < 20$ GeV^2
- SU(3) restored using $Q^2 + M_V^2$ but not SU(4)
- Accounting for the VM wave function necessary
- Trajectories depend on Q^2 and M_V
- Less shrinkage at $Q^2 > 0$ than in PHP
- More SCHC violation:
  single flip ($\propto \sqrt{t}$), double flip ($\propto t$) transitions
  as $|t|$ increases

Abundant data from HERA II – more conclusive results