IXth 'Blois Workshop'
on Elastic and Diffractive Scattering

Vector meson production at HERA

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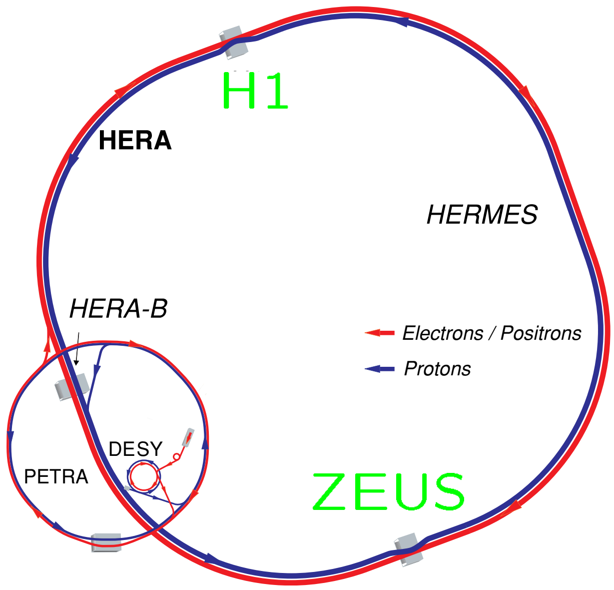
- Elastic vector meson production
  - Photoproduction
  - Electroproduction
- Vector meson production at high $|t|$
- Conclusions

The HERA ep Collider



H1, ZEUS:

$$e^{\pm} \quad \Rightarrow \Leftarrow \quad p$$

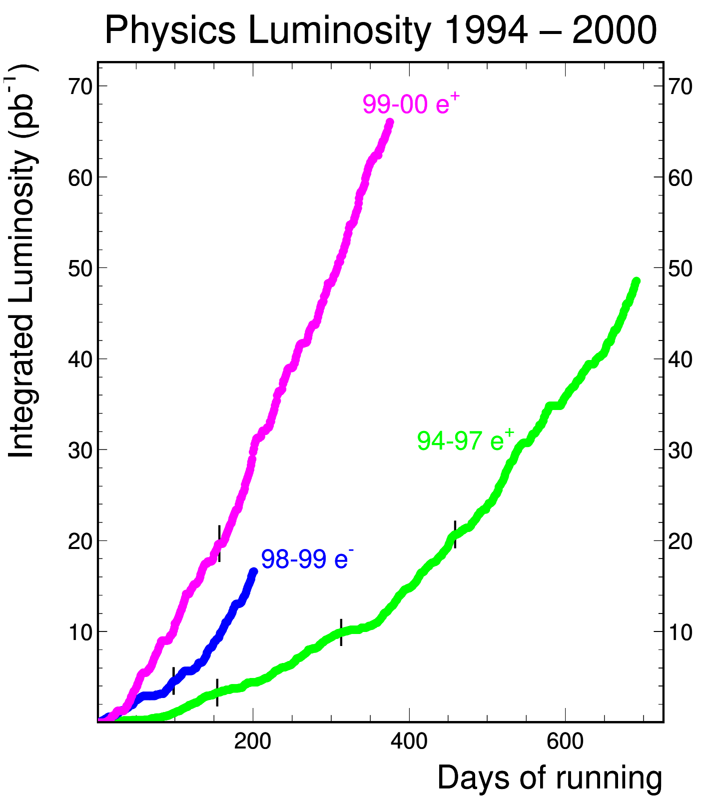
27.5 GeV 820/920 GeV

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

HERMES:

polarized $e^{\pm}$ on gas target

$$\sqrt{s} = 7.5\ \text{GeV}$$



1994 – 1997

e^+p at $\sqrt{s} = 300$ GeV

37 – 48 pb^{-1}

1998 – 1999

e^-p at $\sqrt{s} = 320$ GeV

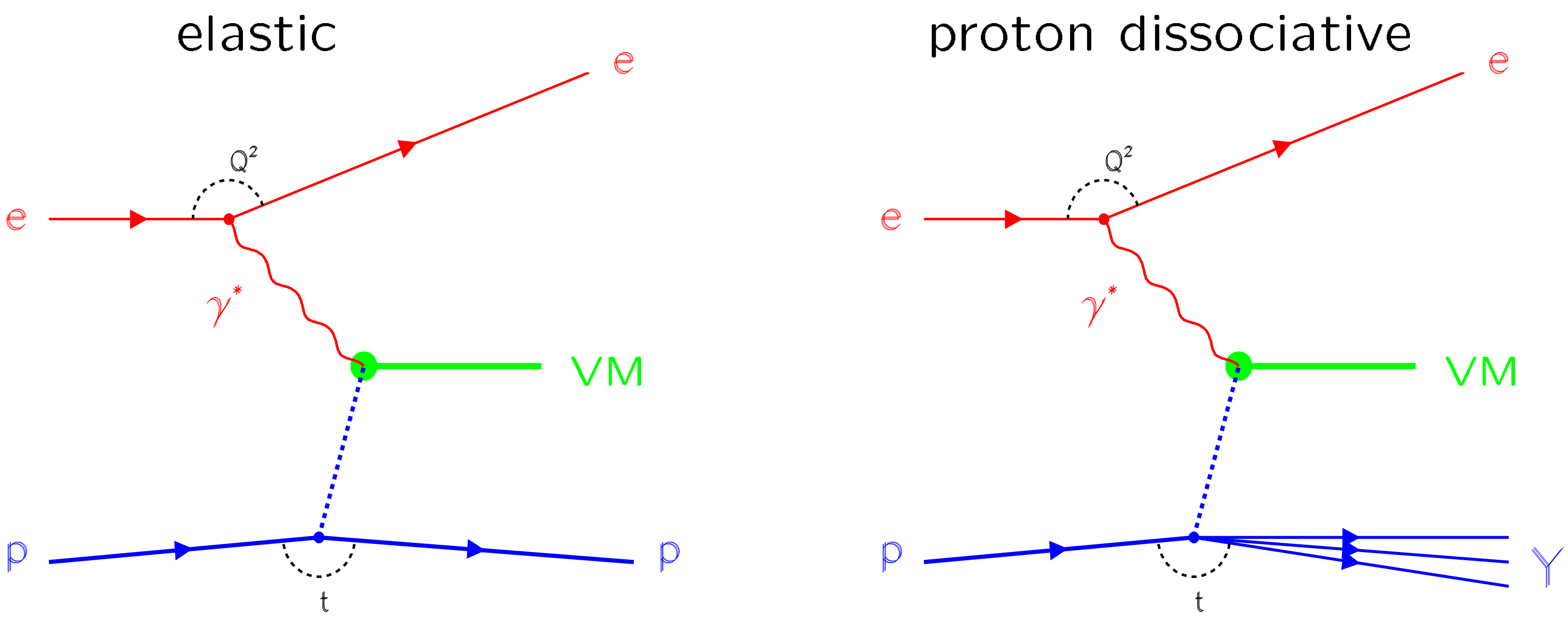
16 pb^{-1}

1999 – 2000

e^+p at $\sqrt{s} = 320$ GeV

68 pb^{-1}

Diffractive Vector Meson Production at HERA

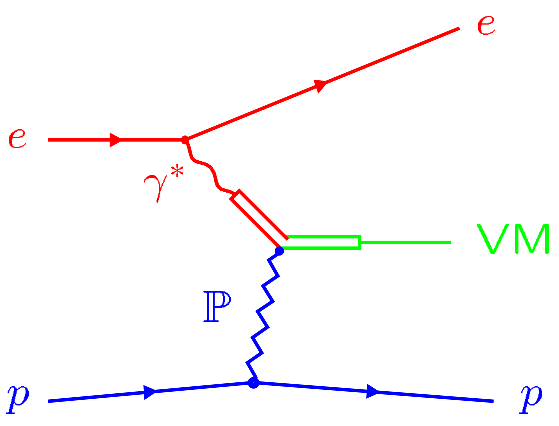


Q^2	γ^* Virtuality	$\sim 0 < Q^2 < 100\,\mathrm{GeV}^2$
$W_{\gamma p}$	CM Energy of $\gamma^* p$ system	$20 < W_{\gamma p} < 290\,\mathrm{GeV}$
t	(4-mom. transfer at p vertex)^2	$\sim 0 < \|t\| < 20\,\mathrm{GeV}^2$
VM	Vector Meson	$\rho^0,\ \omega,\ \phi,\ J/\psi,\ \psi',\ \Upsilon$

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

Expectations for Diffractive Vector Meson Production

Regge Approach



Soft Pomeron exchange

$\alpha_{\mathbb{P}}(t) = \alpha_0 + \alpha' \, t$

$\alpha_0 = 1.08, \ \alpha' = 0.25 \, \mathrm{GeV}^{-2}$

$$\frac{d\sigma}{dt} \propto e^{bt} \left(\frac{W_{\gamma p}}{W_0} \right)^{4(\alpha_0 - 1)}$$

$$b = b_0 + 4\alpha' \ln \left(\frac{W_{\gamma p}}{W_0} \right)$$

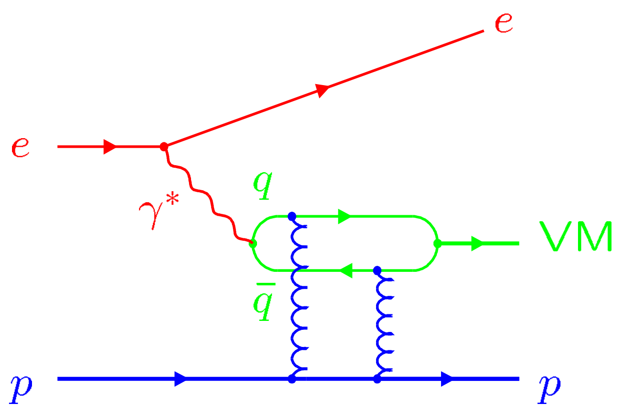
shrinkage: $b = b(W_{\gamma p})$

slow rise $\sigma \propto W_{\gamma p}^{0.22...0.32}$

SCHC

works for light VM at $Q^2 \approx 0, \ t \approx 0$

pQCD Approach



exchange of ≥ 2 gluons

$$\sigma \propto [xg(x, Q^2)]^2$$

no shrinkage

steep rise due to $xg(x, Q^2)$

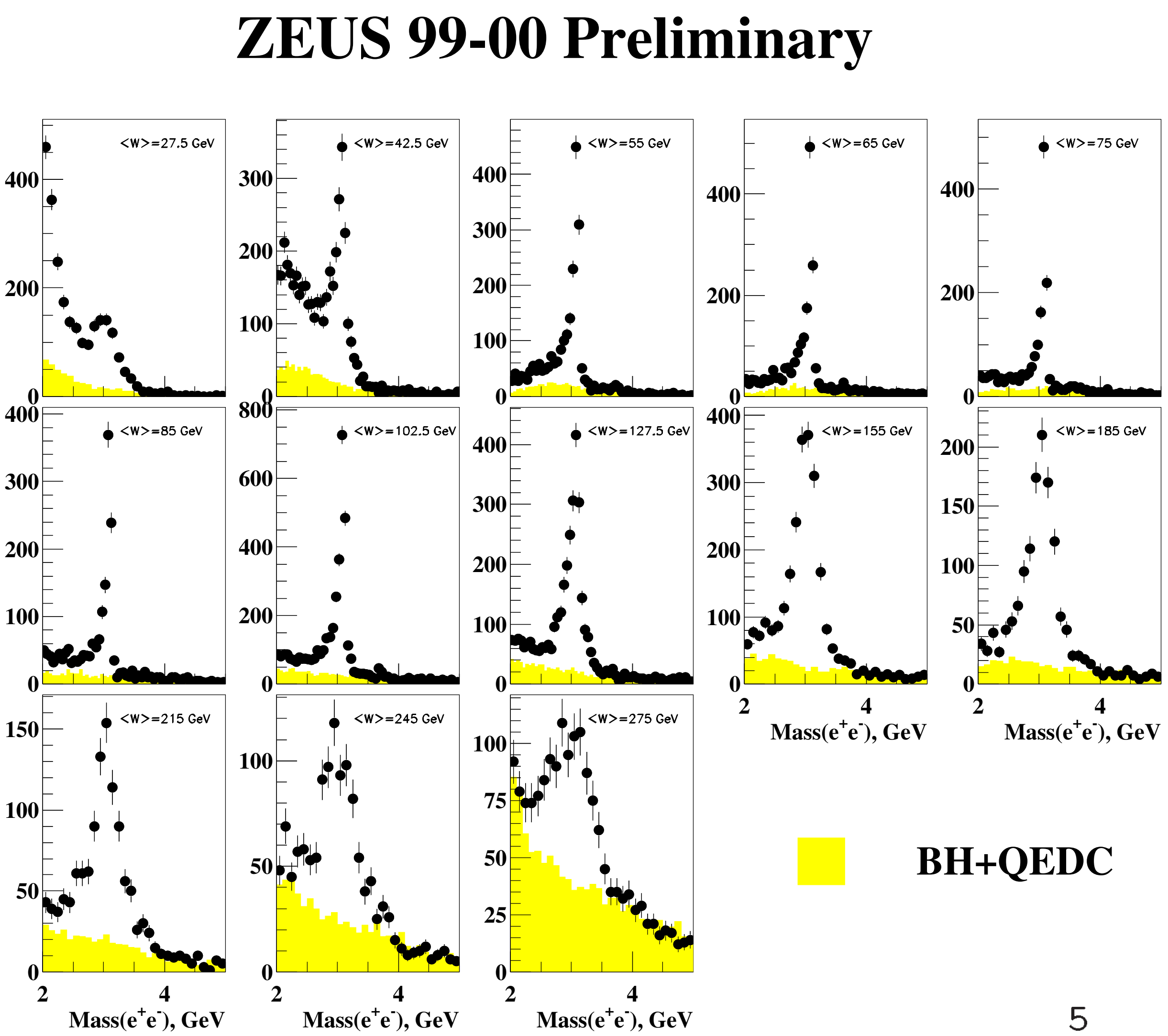
is expected to work in presence of a hard scale

Elastic Photoproduction $\gamma p \to \mathrm{VM}\, p$

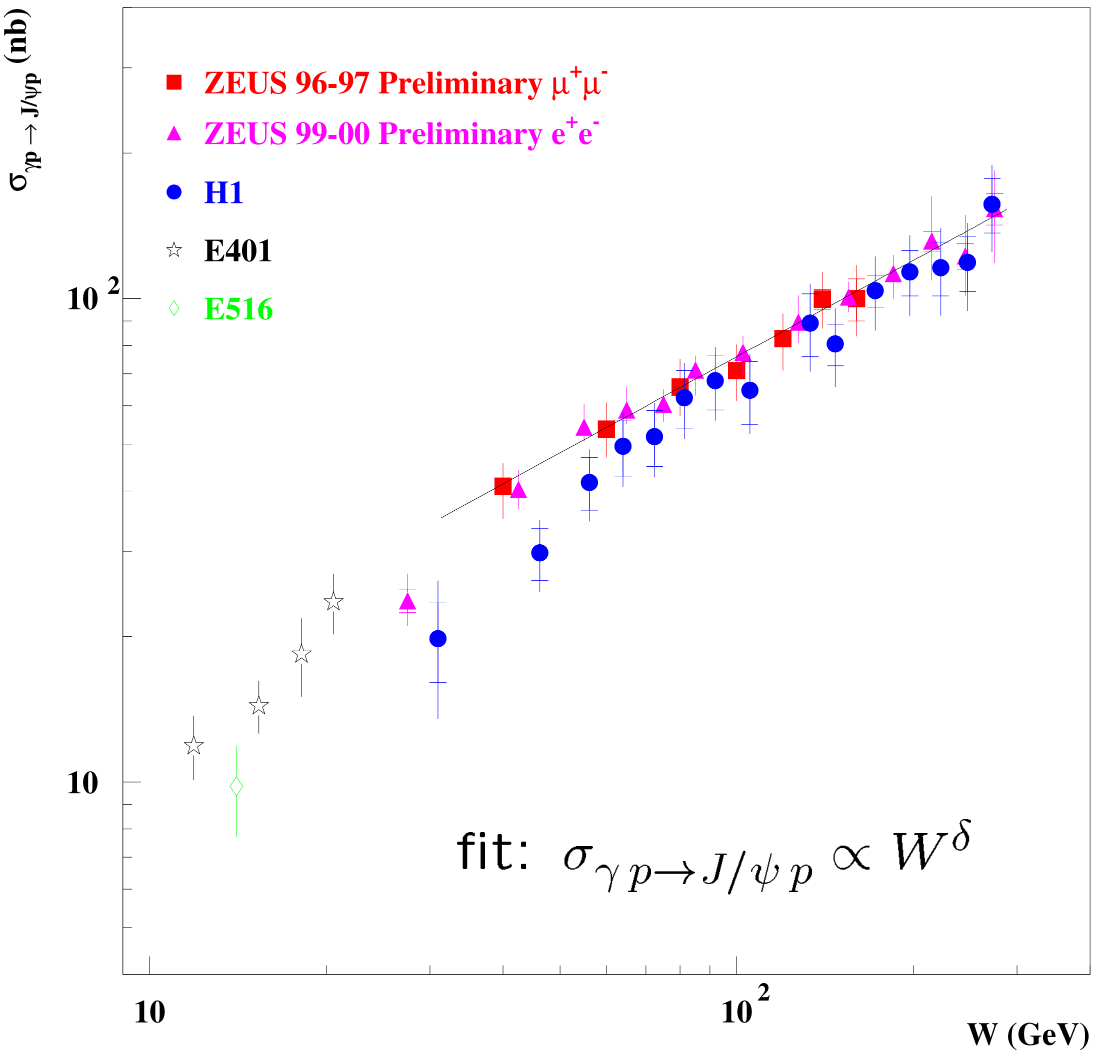
$Q^2 \approx 0 \Rightarrow$ possible hard scales M_{VM}, t

Elastic J/ψ Photoproduction

published H1 data	preliminary ZEUS data
$Q^2 < 1$ GeV^2	$Q^2 < 1$ GeV^2
$26 < W_{\gamma p} < 285$ GeV	$20 < W_{\gamma p} < 290$ GeV
21 pb^{-1}	38 pb^{-1} $(J/\psi \to \mu^+\mu^-)$ 48 pb^{-1} $(J/\psi \to e^+e^-)$



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



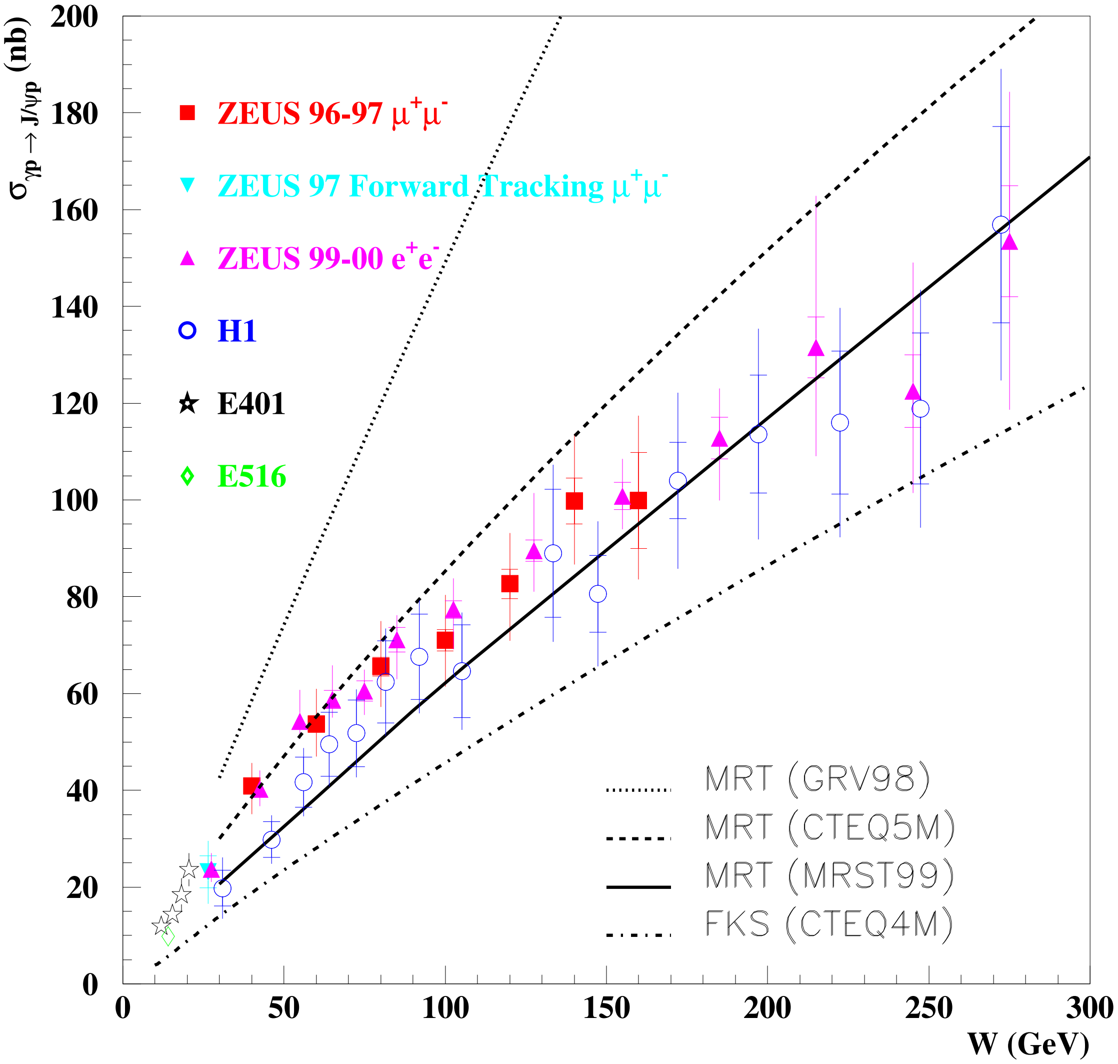
ZEUS: $\delta = 0.65 \pm 0.03 \pm 0.09$ $(J/\psi \to \mu^+\mu^-)$

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

H1: $\delta = 0.83 \pm 0.07$

$\Rightarrow$ steeper rise than soft pomeron expectation

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

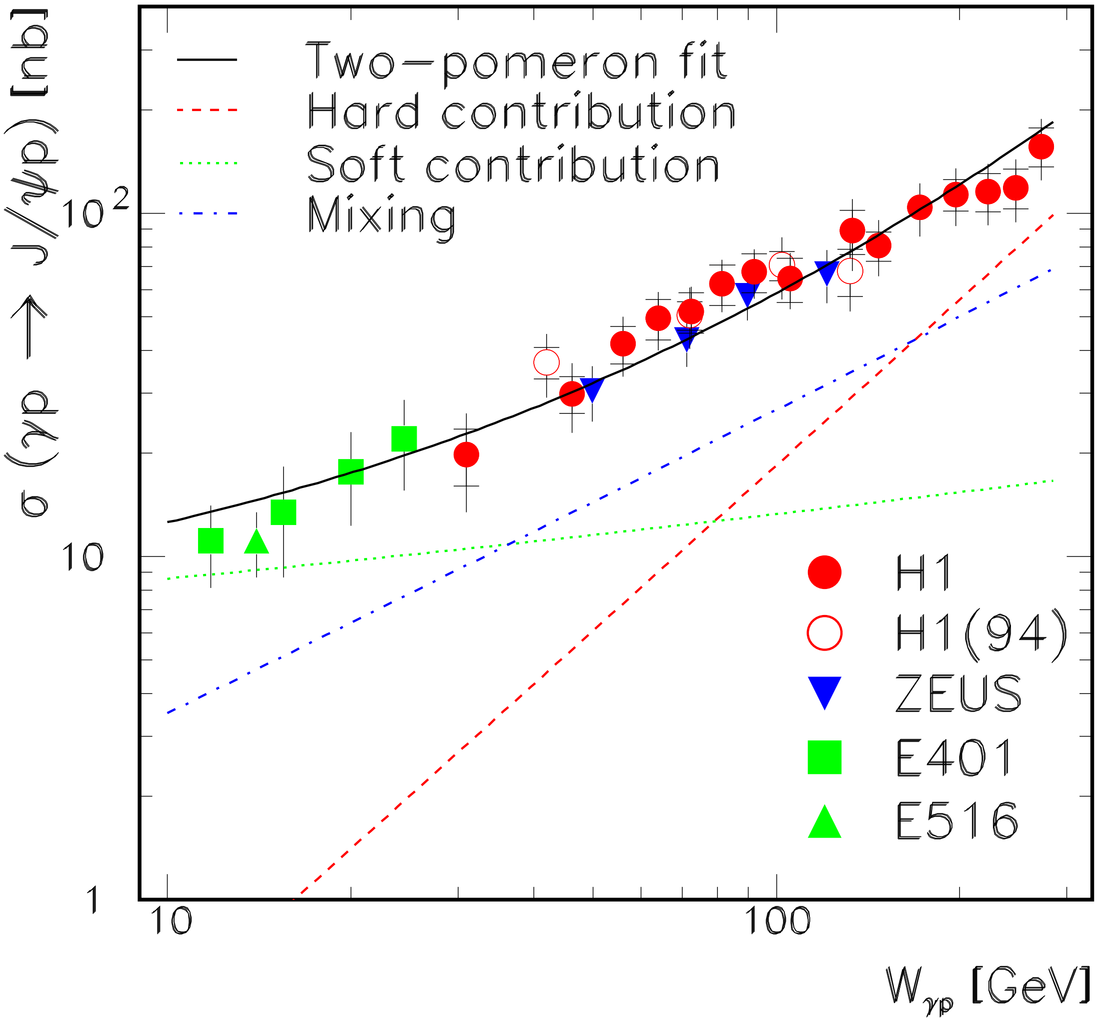


- pQCD approach gives good description

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

$\Rightarrow$ sensitivity to gluon density in the proton

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

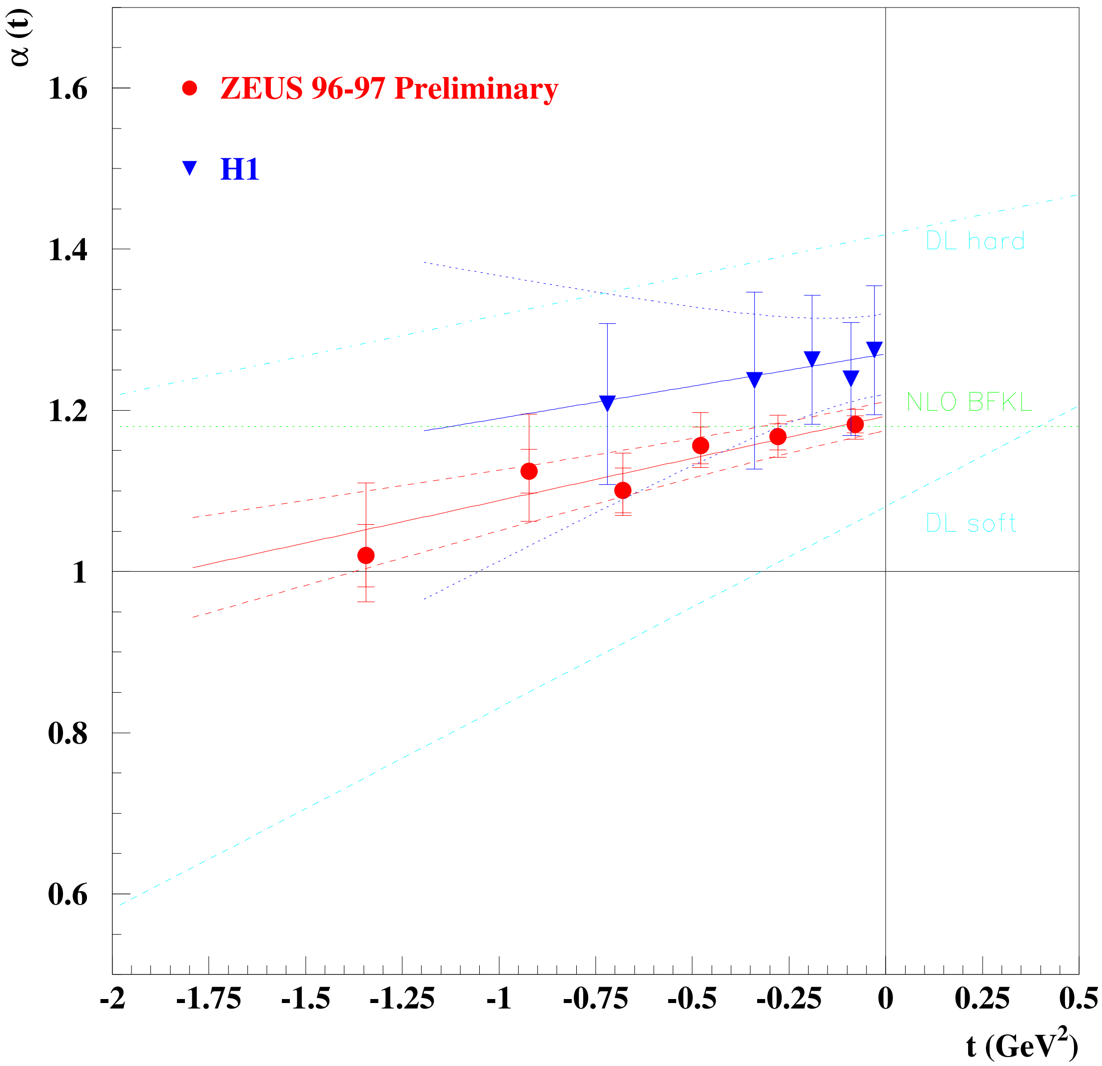


- 'soft' pomeron rise too slow
- add second 'hard' pomeron

$\Rightarrow$ two pomeron fit gives reasonable description

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

Extraction of effective pomeron trajectory:
fit $d\sigma/dt(W_{\gamma p})$ in t regions $\Rightarrow \alpha_{\mathbb{P}}(t)$

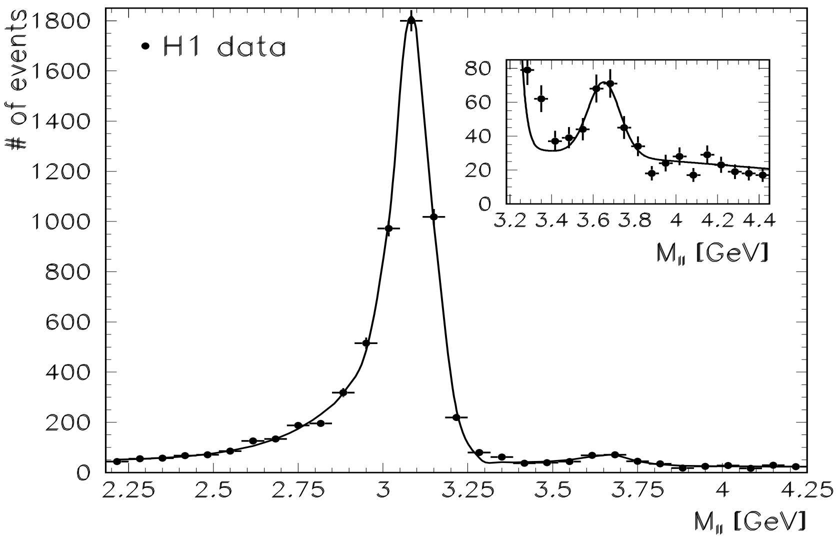


- trajectory lies between 'hard' and 'soft' pomeron

$\Rightarrow$ 'soft' pomeron alone ruled out

- α_0 in agreement with BFKL prediction

Elastic Photoproduction $\gamma p \to \psi' p$

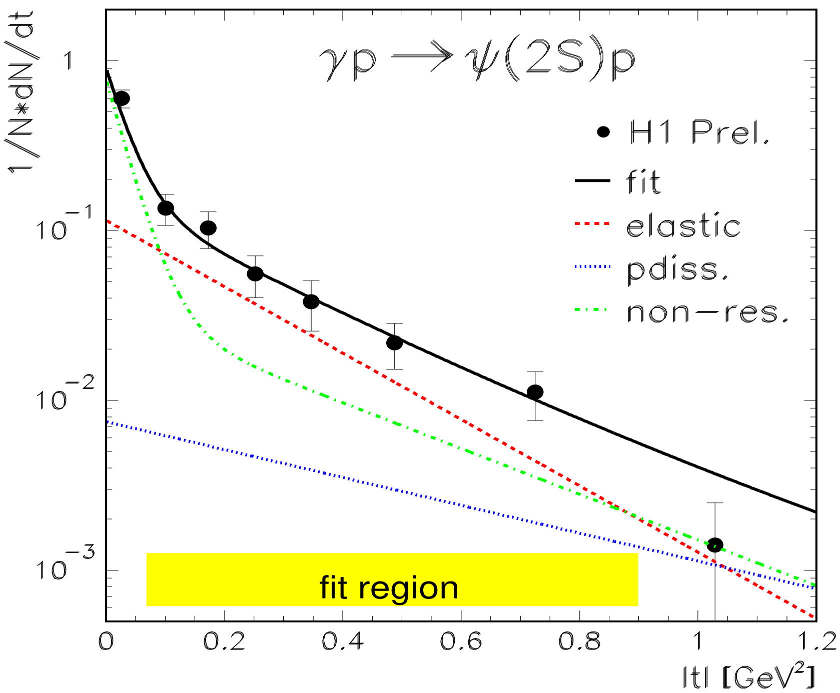


H1 preliminary

$Q^2 < 1\,\text{GeV}^2$

$40 < W_{\gamma p} < 150\,\text{GeV}$

$38\,\text{pb}^{-1}$



$$b_{\psi'} = 4.5 \pm 1.2 \, ^{+1.4}_{-0.7} \;\text{GeV}^{-2}$$

for comparison: $b_{J/\psi} = 4.73 \pm 0.25^{+0.30}_{-0.39}\,\text{GeV}^{-2}$

Expectations:

optical interpretation:
$b \propto R_p^2 + R_{\text{VM}}^2$, $R_{\psi'} \approx 2R_{J/\psi}$ $\Rightarrow$ $b_{\psi'} \gg b_{J/\psi}$

Nemchik et al.:
Colour Dipole Picture, ψ' wave function $b_{\psi'} \lesssim b_{J/\psi}$

Elastic Electroproduction
$\gamma^* p \to \mathrm{VM}\, p$

$Q^2 \gg 0 \Rightarrow$ provides a hard scale

Comparison for different VM: ρ, ϕ, ω, J/ψ:

- $W_{\gamma p}$ dependence as function of Q^2
- $\sigma_{\mathrm{VM}}/\sigma_\rho$
- Q^2 dependence of σ_{tot}, σ_L and σ_T
- spin density matrix elements

new measurements:

Elastic ρ Electroproduction

ZEUS preliminary

$5 < Q^2 < 80\,\mathrm{GeV}^2$

$32 < W < 160\,\mathrm{GeV}$

$38\,\mathrm{pb}^{-1}$

Elastic J/ψ Electroproduction

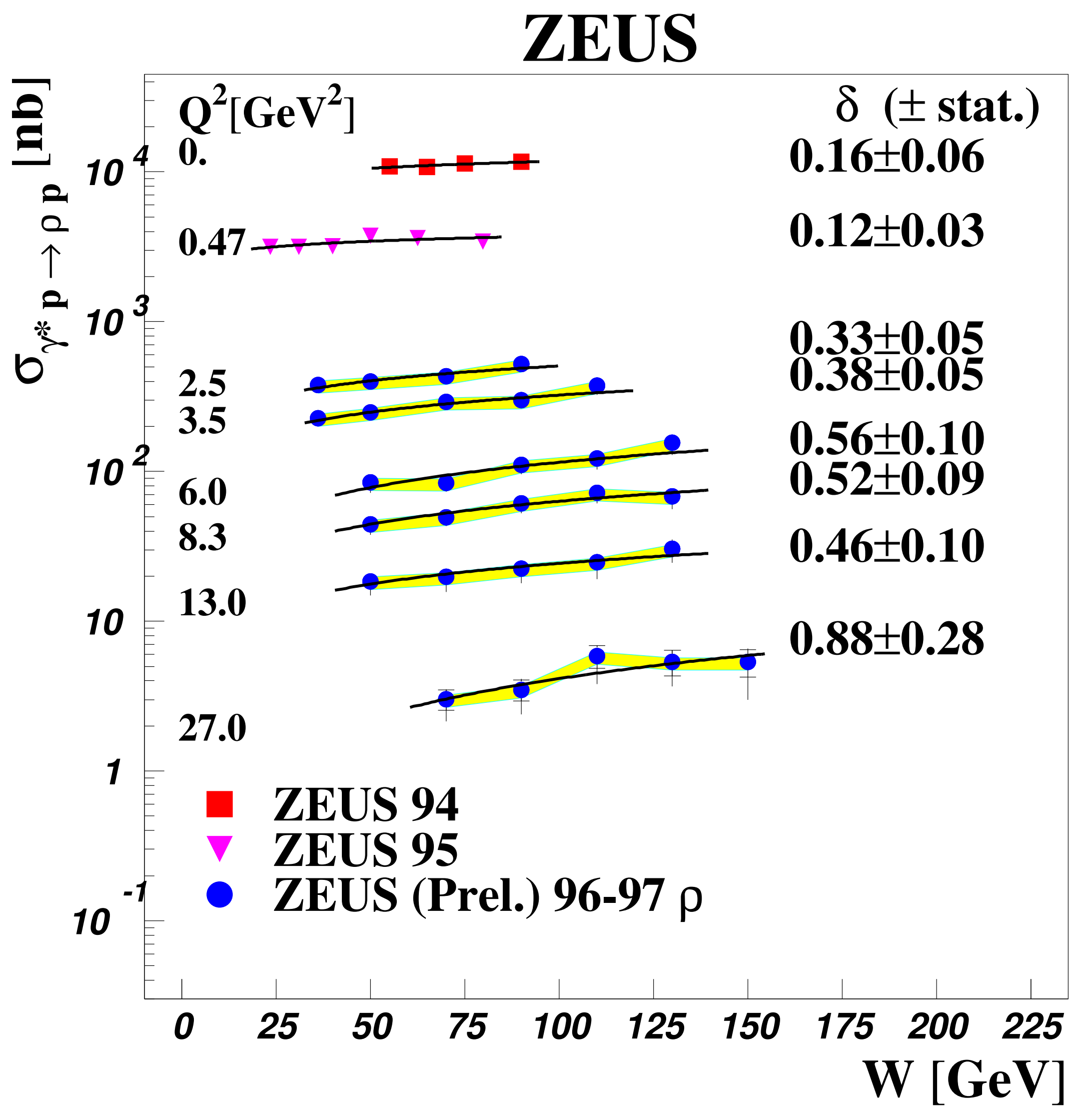
ZEUS preliminary

$2 < Q^2 < 100\,\mathrm{GeV}^2$

$50 < W < 150\,\mathrm{GeV}$

$75\,\mathrm{pb}^{-1}$

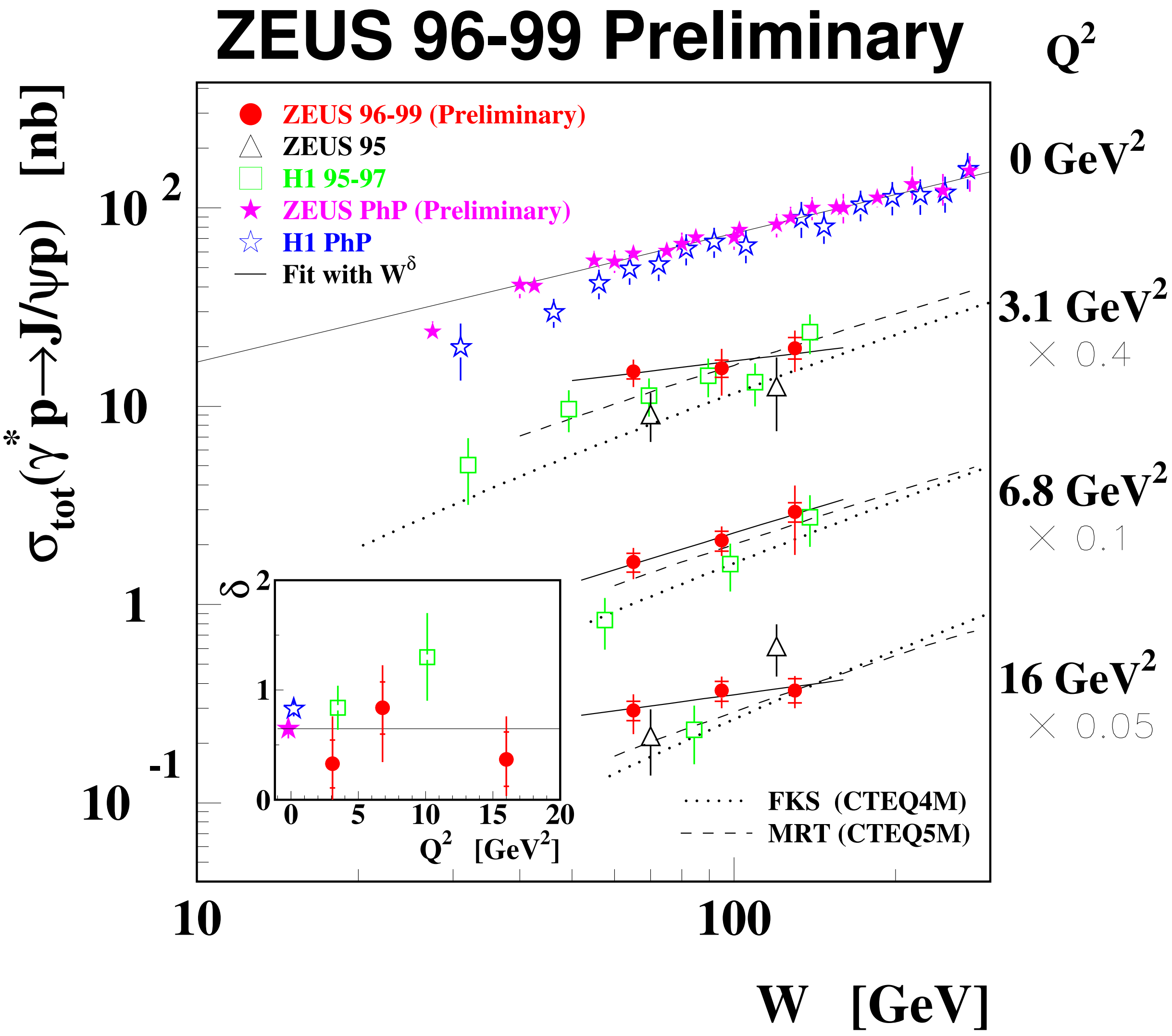
Elastic Electroproduction $\gamma^* p \to \rho p$
$W_{\gamma p}$ dependence as function of Q^2



- δ increasing with Q^2

$\Rightarrow$ transition from soft to hard behaviour

Elastic Electroprod. $\gamma^* p \to J/\psi\, p$
$W_{\gamma p}$ dependence as function of Q^2

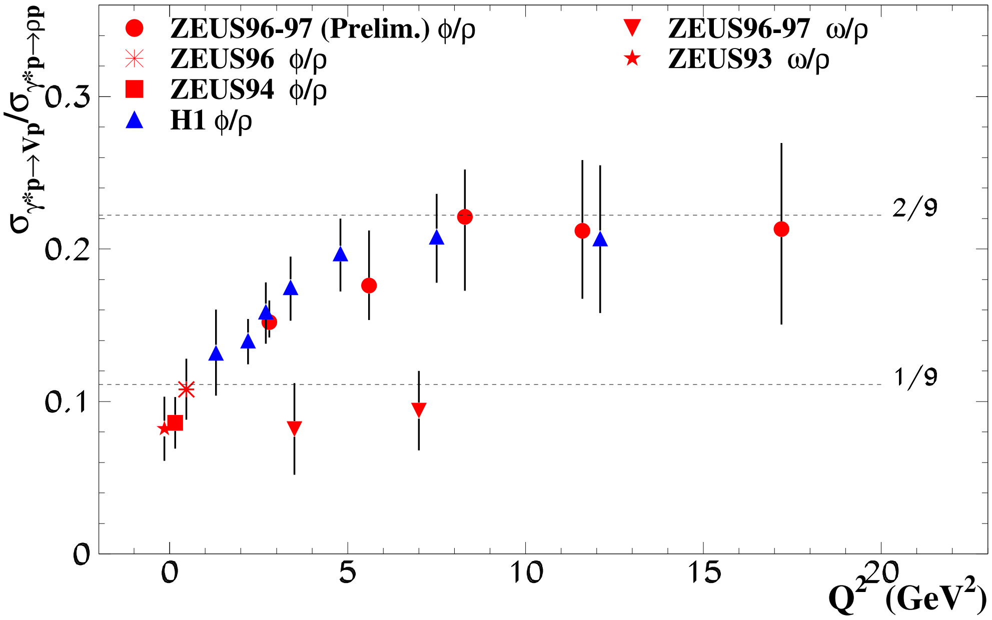


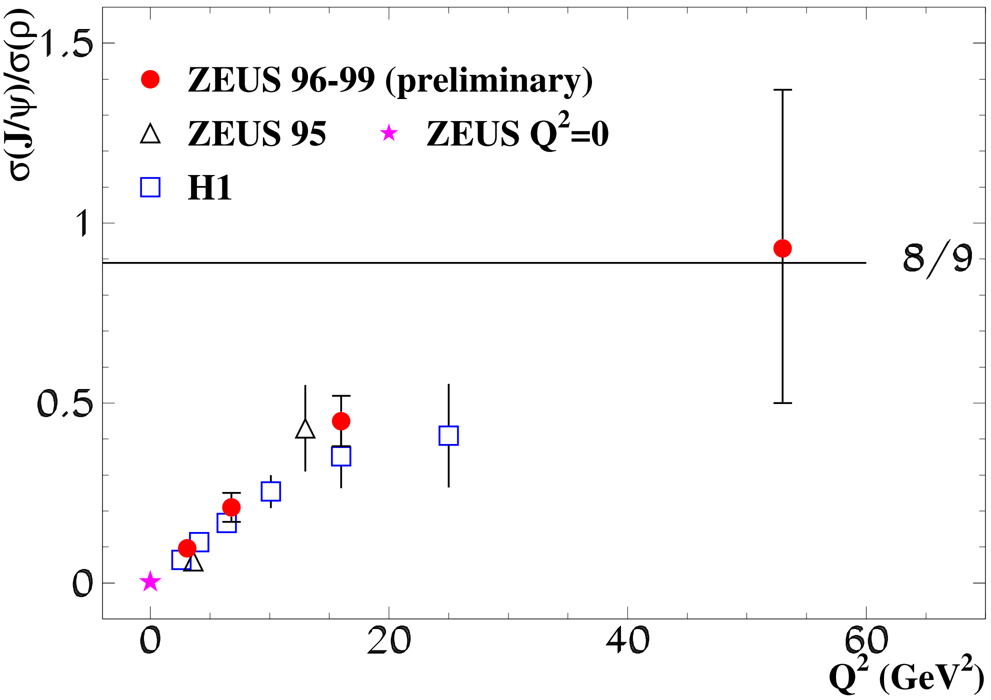
- δ already large at low Q^2

Ratio $\sigma(\gamma^* p \to \text{VM}\, p)/\sigma(\gamma^* p \to \rho\, p)$

Expectation from SU(4) symmetry:

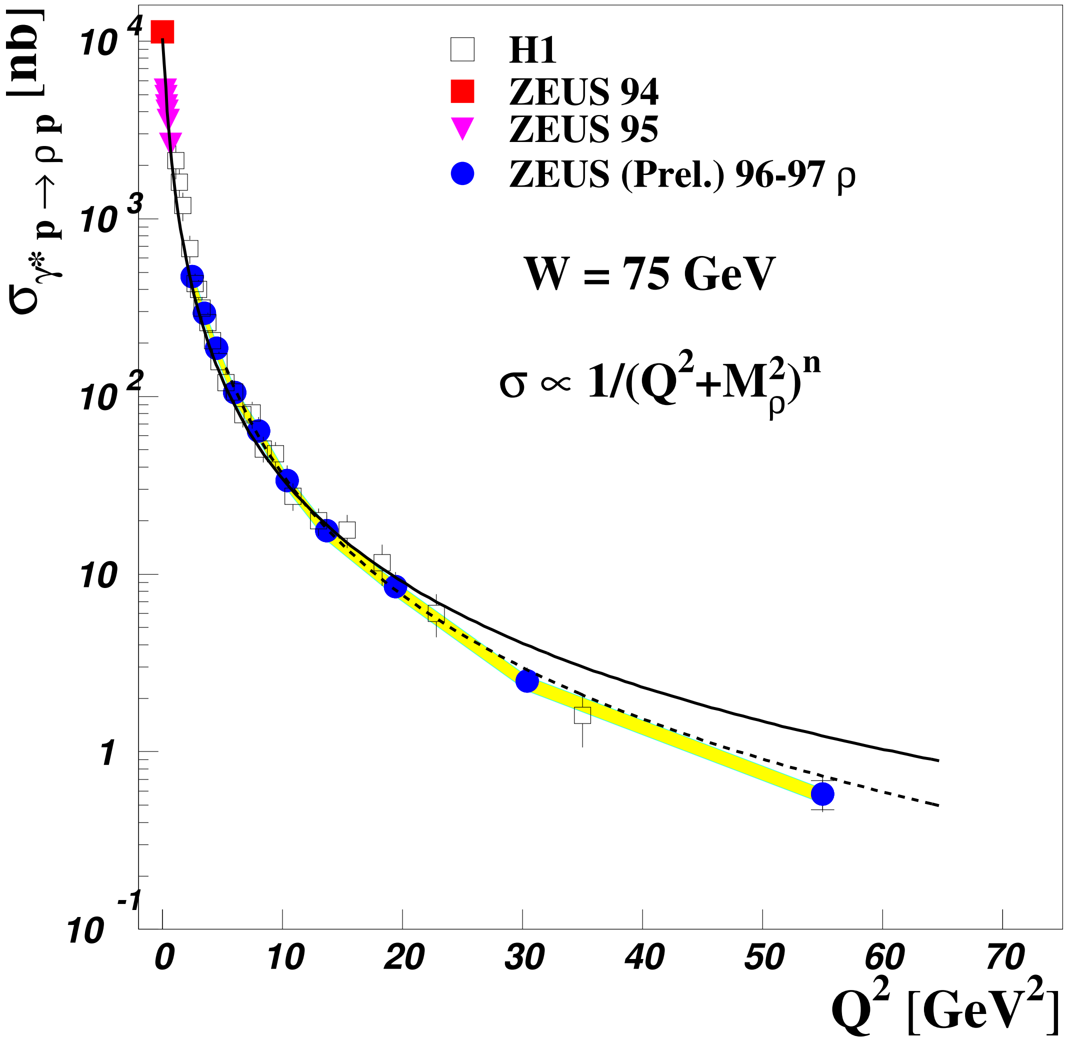
$$\sigma_\rho : \sigma_\omega : \sigma_\phi : \sigma_{J/\psi} = 9 : 1 : 2 : 8$$





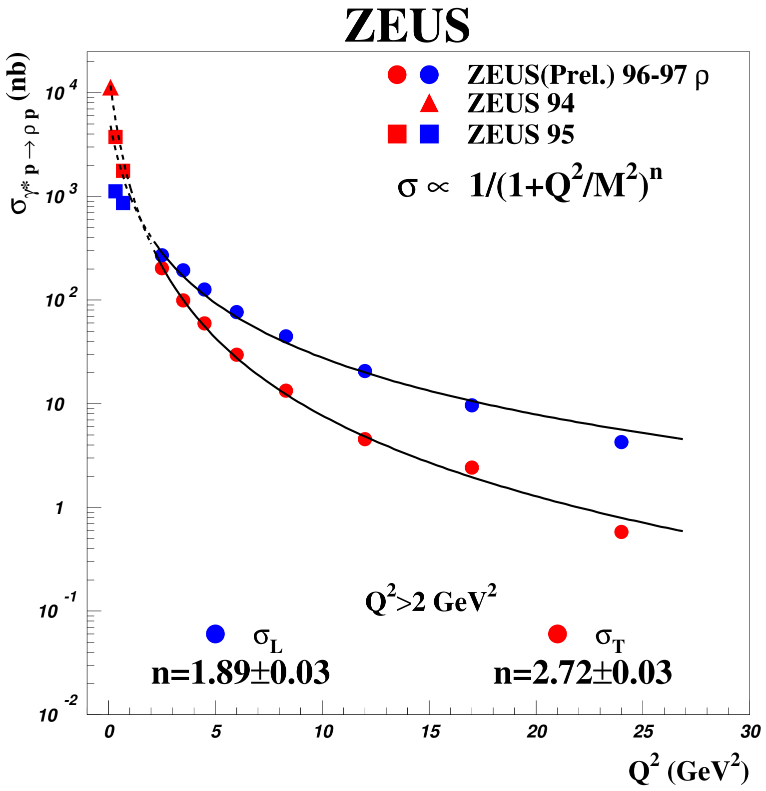
SU(4) restored at large Q^2?

Electroproduction $\gamma^* p \to \rho\, p$
Q^2 dependence

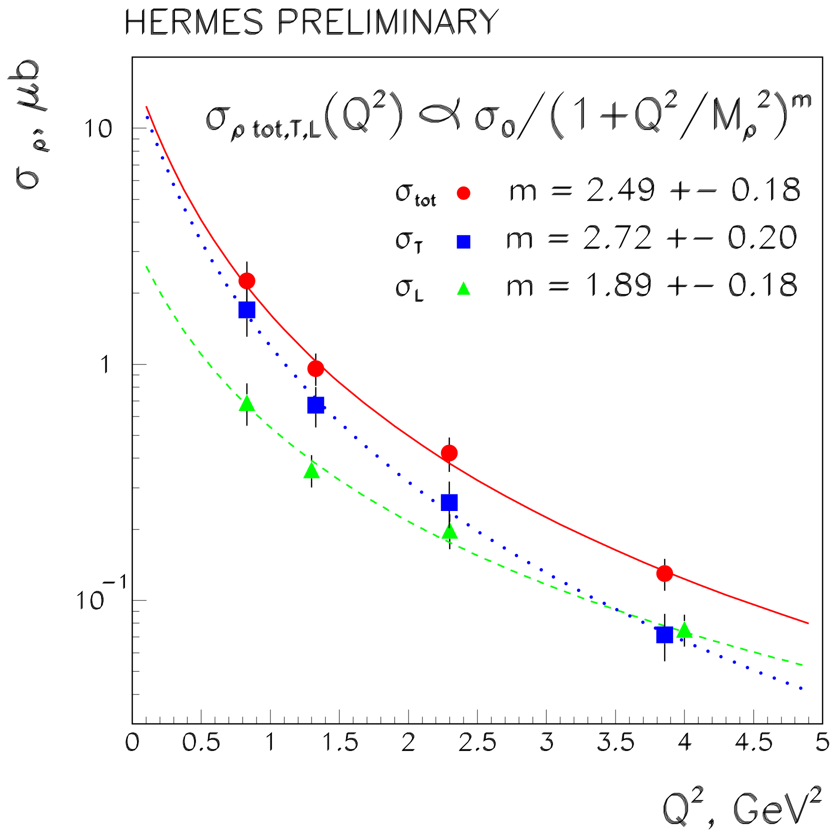


- fits $\propto (Q^2 + M_\rho^2)^{-n}$ not able to describe whole Q^2 region
- $Q^2 > 5\,\mathrm{GeV}^2$: $n = 2.36 \pm 0.04$

Electroprod. $\gamma^* p \to \rho p$: Q^2 dependence of σ_L and σ_T



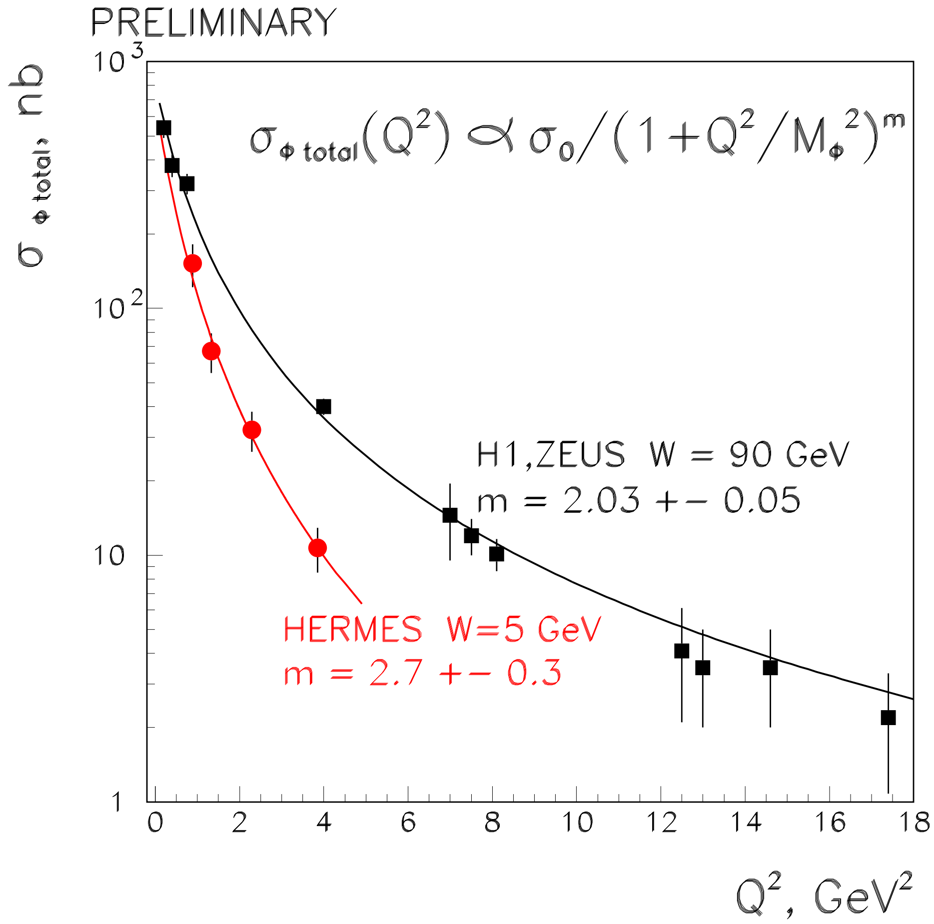
$32 < W < 160$ GeV



$4 < W < 6$ GeV

- same Q^2 dependence at high and low W

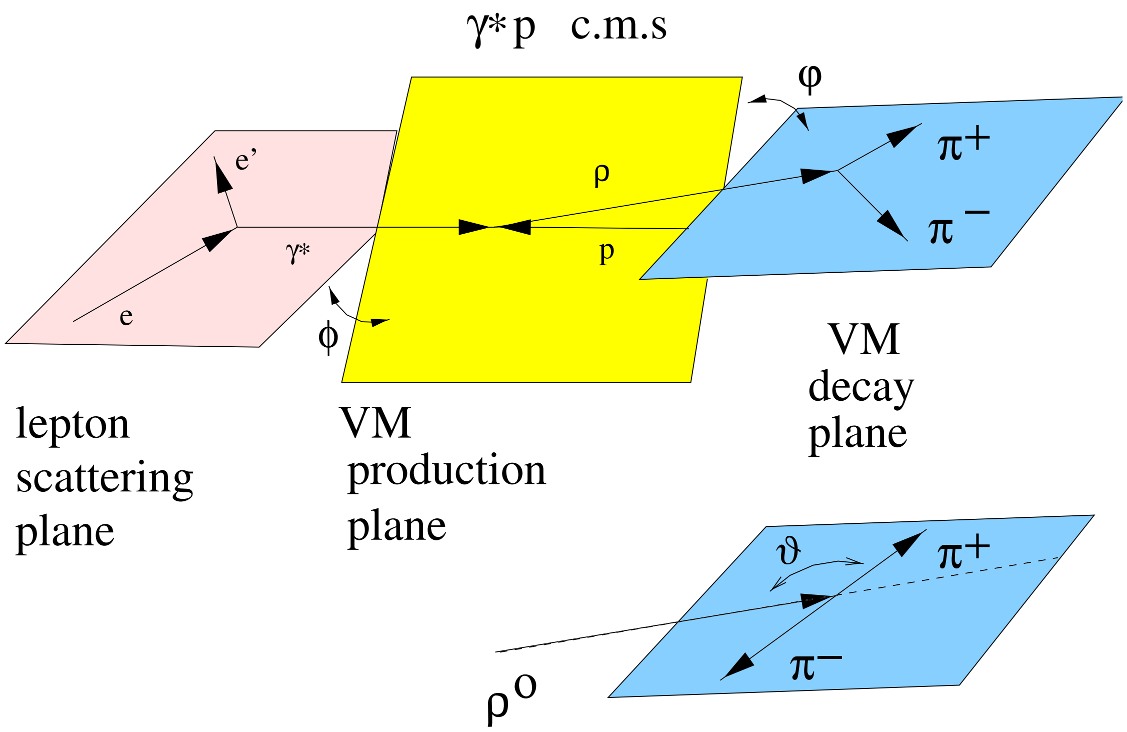
Electroproduction $\gamma^* p \to \phi p$
Q^2 dependence



- Q^2 dependence steeper at low W

Helicity Studies

Helicity frame:



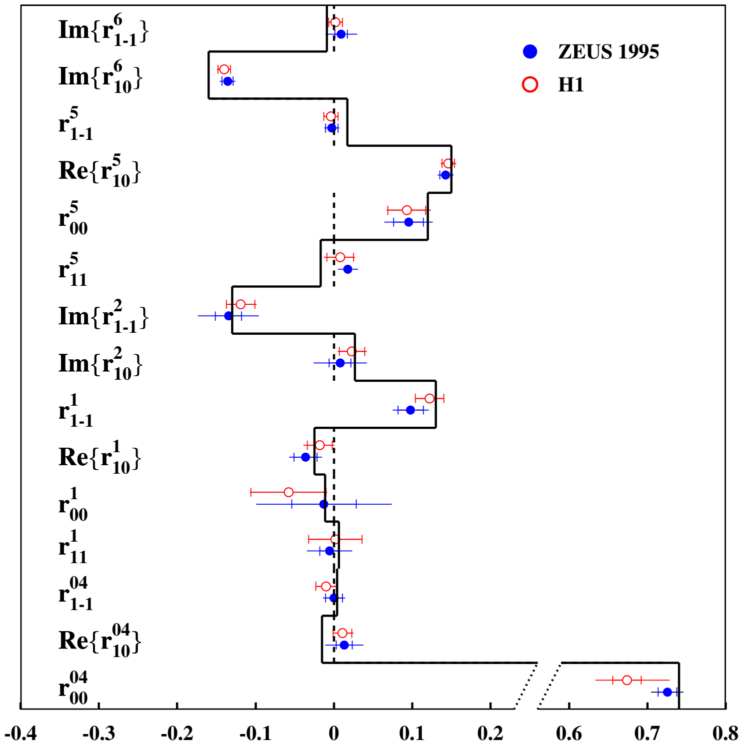
Decay angular distribution $W(\cos(\vartheta), \varphi, \Phi)$

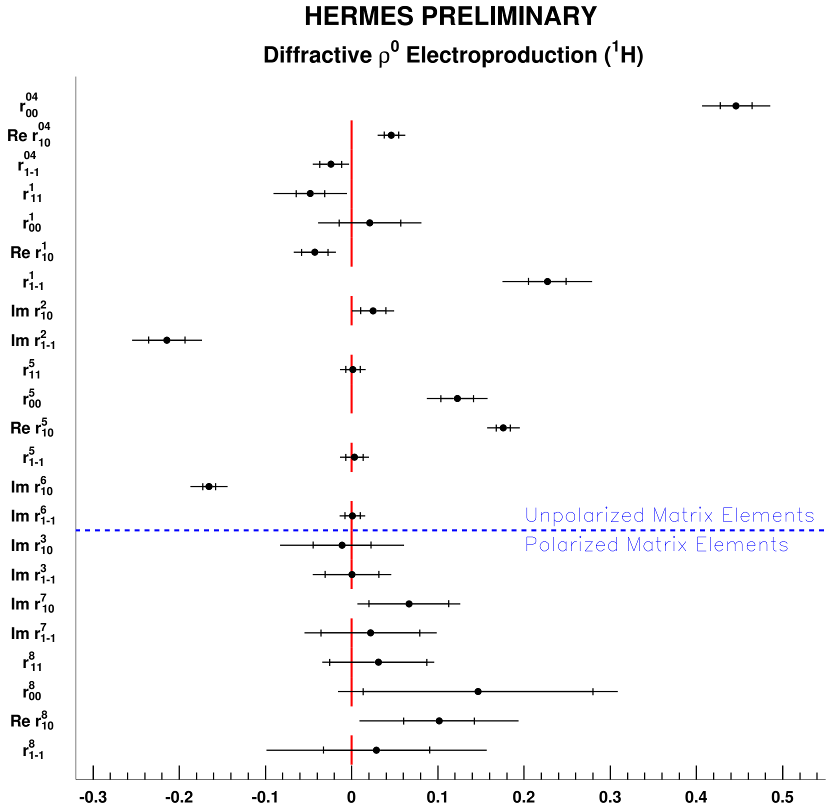
- unpolarized: 15 independent combinations r of spin density matrix elements
- polarized: 8 additional combinations

Expectations: SCHC, NPE:

only 5 unpol. and 2 pol. combinations $\neq 0$

Elastic Electroproduction $\gamma^* p \to \rho p$ spin density matrix elements



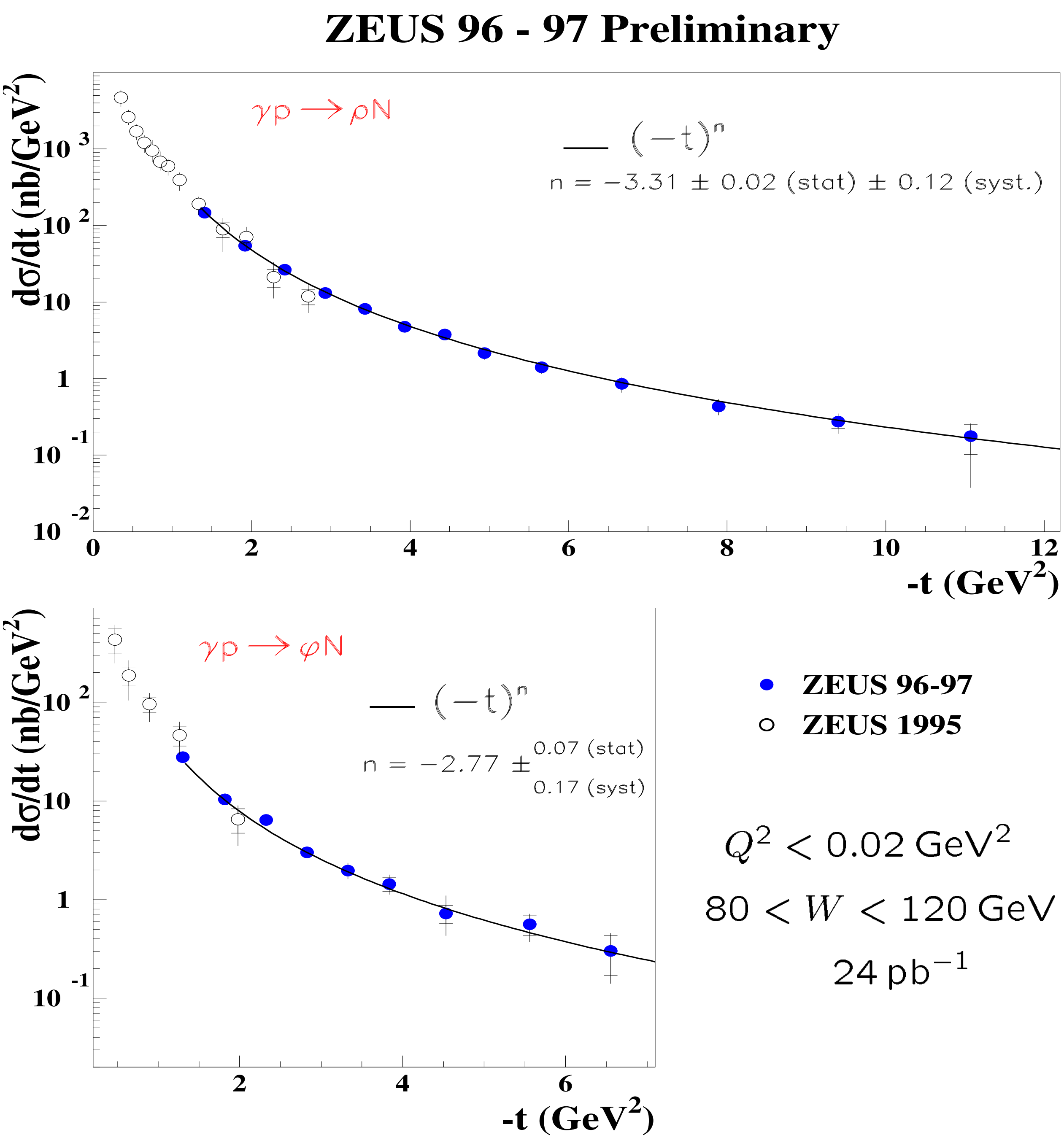


- Violation of SCHC in r^5_{00} at high and low W
- Agreement with QCD model (Ivanov,Kirschner)

Vector meson production at high $|t|$

does $|t|$ also provide a hard scale?

Photoproduction of ρ, ϕ

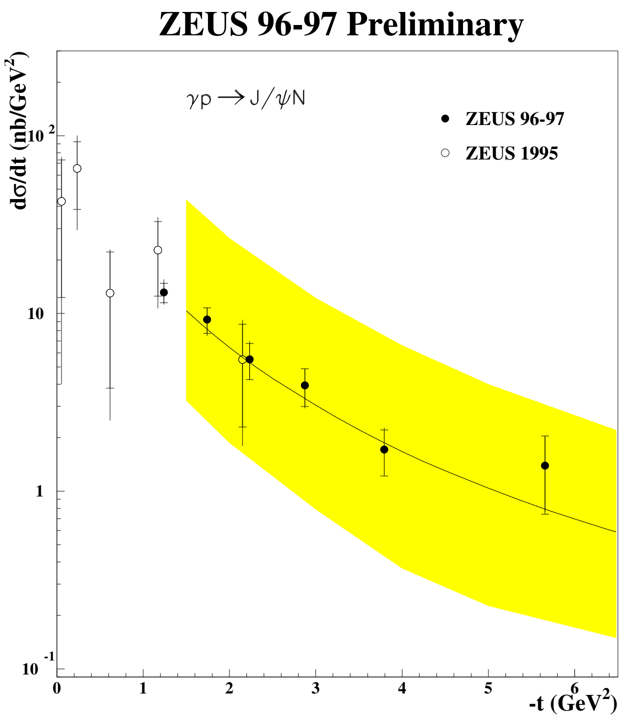


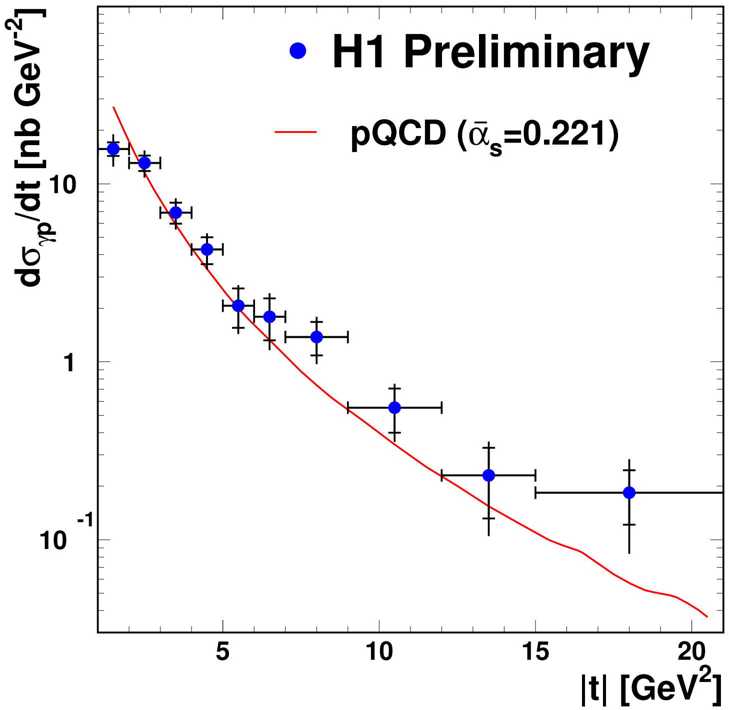
- t dependence at high $|t| \propto (-t)^n$

J/ψ production at high $|t|$

$Q^2 < 0.02\,\mathrm{GeV}^2$
$80 < W < 120\,\mathrm{GeV}$
$24\,\mathrm{pb}^{-1}$

$Q^2 < 1\,\mathrm{GeV}^2$
$50 < W < 160\,\mathrm{GeV}$
$19\,\mathrm{pb}^{-1}$

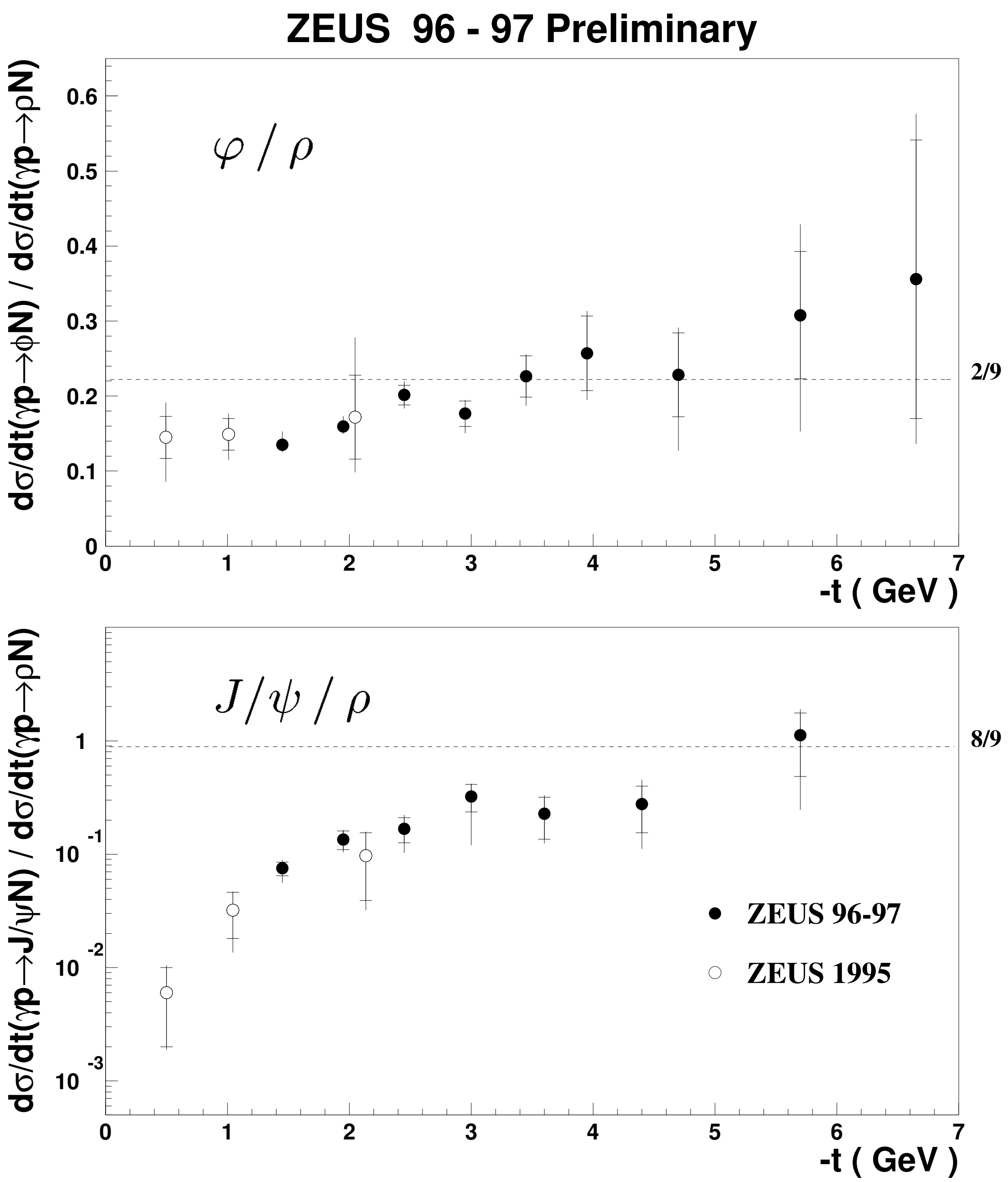




- perturbative QCD model describes data well
- large normalization uncertainties: α_s, scale

Vector meson production at high $|t|$

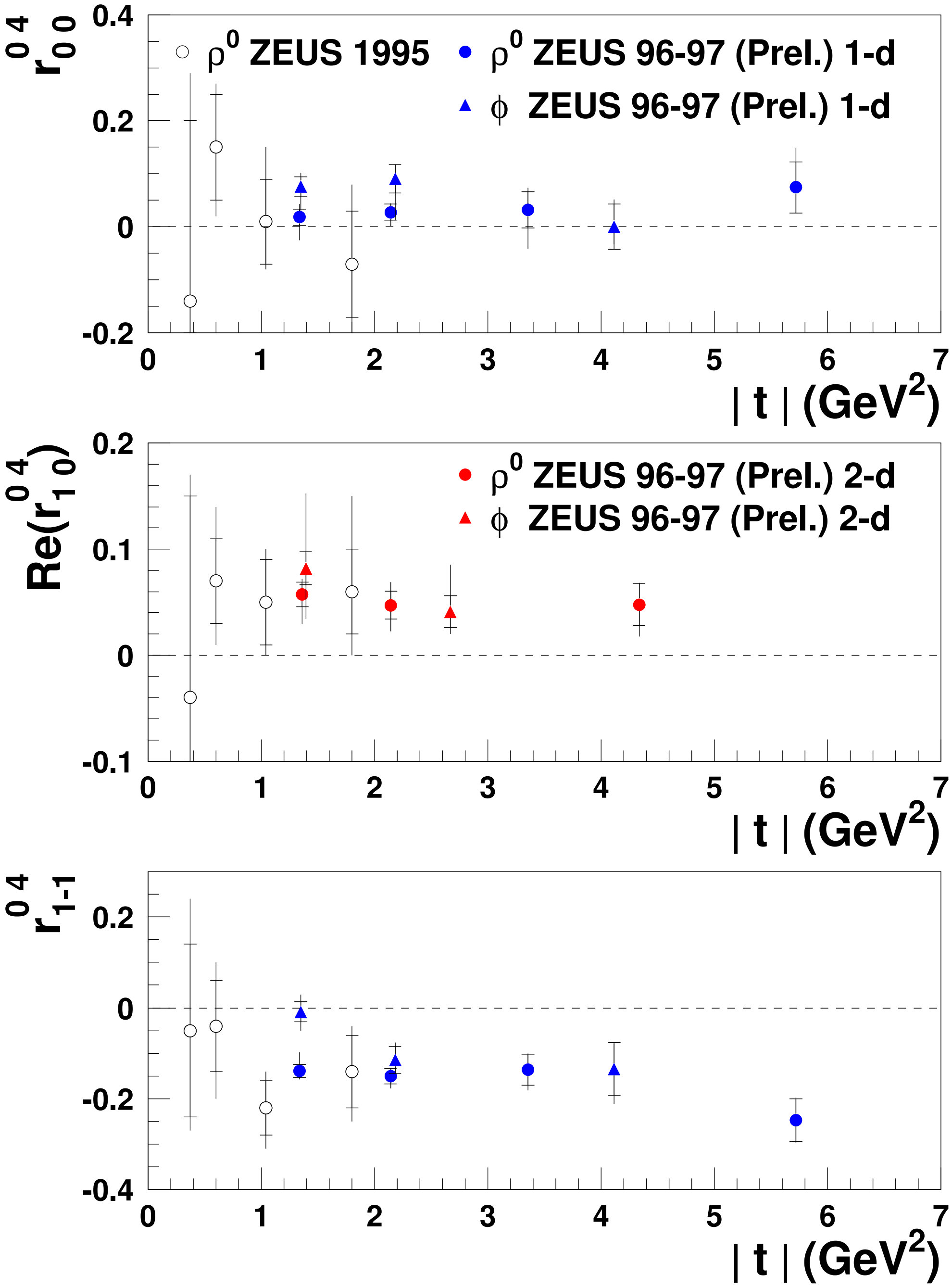
Ratio of φ and J/ψ to ρ



- ratio in agreement with SU(4) at large $|t|$

Vector meson production at high $|t|$

Photoproduction of ρ and φ:
spin density matrix elements

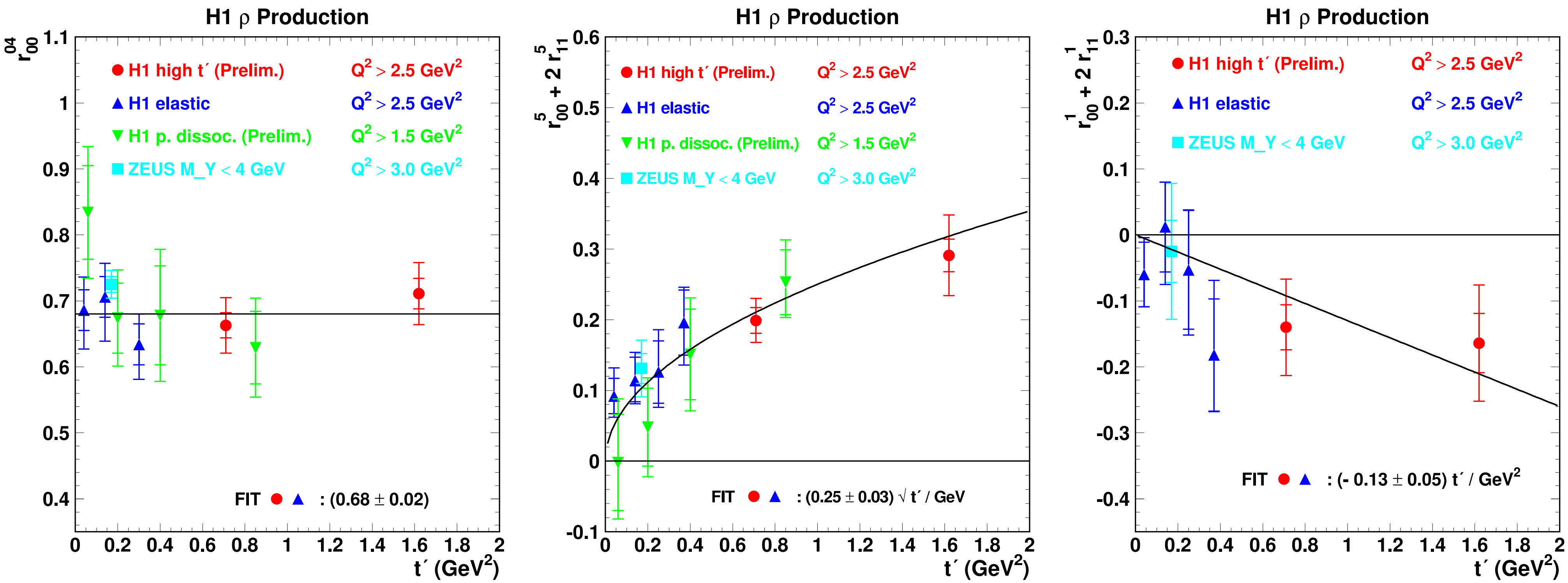


- results similar for ρ and φ
- $Re(r^{04}_{10}) \neq 0 \Rightarrow$ long. ρ from transv. γ
- $r^{04}_{1-1} \neq 0 \Rightarrow$ helicity double flip

$\Rightarrow$ SCHC broken

Vector meson production at high $|t|$

Electroproduction of ρ: $2.5 < Q^2 < 30\,\mathrm{GeV}^2$, $40 < W < 140\,\mathrm{GeV}$, $6\,\mathrm{pb}^{-1}$



- r_{00}^{04} independent of $t' = |t| - t_{min}$
- SCHC violation of $r_{00}^{5} + 2r_{11}^{5}$ increasing with t'
- indication of negative $r_{00}^{1} + 2r_{11}^{1}$
- QCD-inspired fits describe data

Conclusions

- HERA data span the transition region from soft to hard diffraction
- increased luminosity allows more detailed analyses in larger kinematic regions
- clear indications for M_{VM}, Q^2 and $|t|$ providing a hard scale
- further interaction between Theory and Experiment desirable