Vector Meson Production at HERA

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on behalf of

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QCD and High Energy Hadronic Interactions

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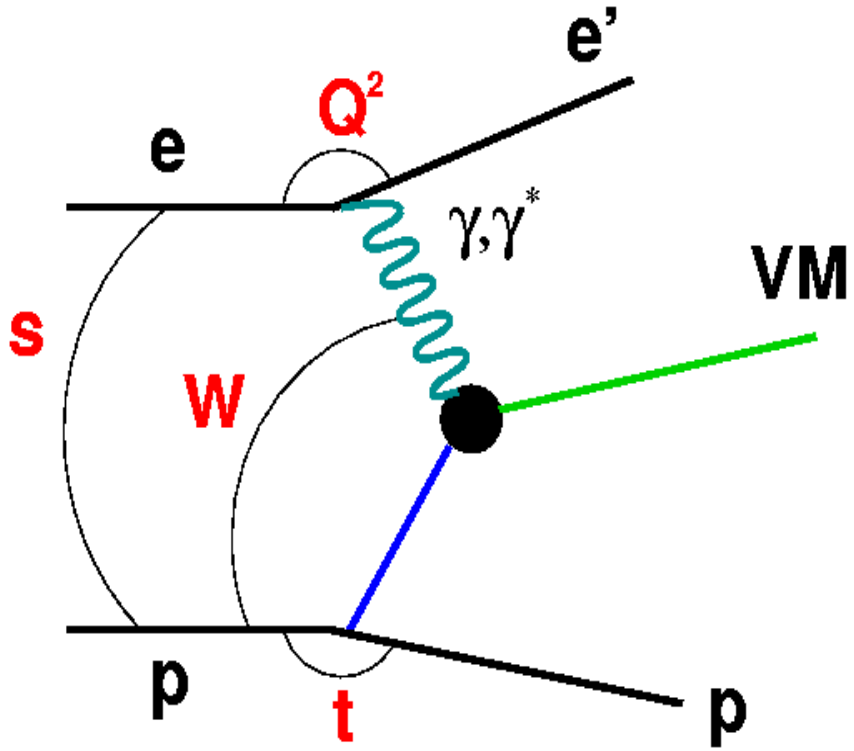
Elastic VM Production



ρ, ω, φ, J/ψ , ψ(2s)

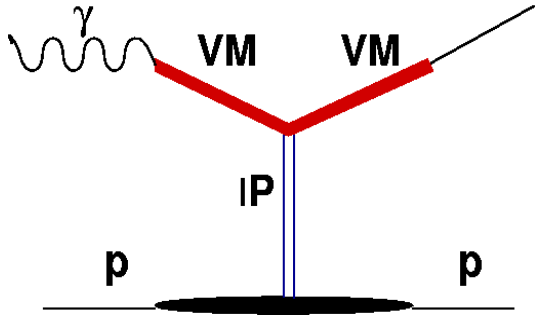
Aim:

- Understand VM production
- Test pQCD in transition regime (soft → hard) at different scales: M, Q^2, t

		kinematical ranges:
VM	Vector meson of mass M	
Q^2	γ^* virtuality	$0 < Q^2 < 100$ GeV²
W	CM energy of $\gamma^* p$ system	$20 < W < 290$ GeV
t	(4 – momentum transfer)² at p vertex	$0 < \|t\| < 20$ GeV²

VM Production Mechanisms

Regge + VDM approach



soft pomeron exchange

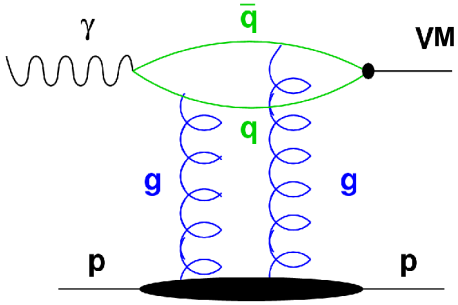
$$\alpha_{IP} = \alpha_0 + \alpha' t, \quad (\alpha_0 = 1.08, \alpha' = 0.25)$$

$$\frac{d\sigma}{dt} \propto e^{b_0 t} (W/W_0)^{4(\alpha_{IP}(t)-1)}$$

expectations:

- slow rise $\sigma(W) \propto W^{\delta}$, $\delta \approx 0.22$
- shrinkage:
  $b(W) = b_0 + 4\alpha' \ln(W/W_0)t$
- s-channel helicity conservation

pQCD approach



two gluon exchange (LO)

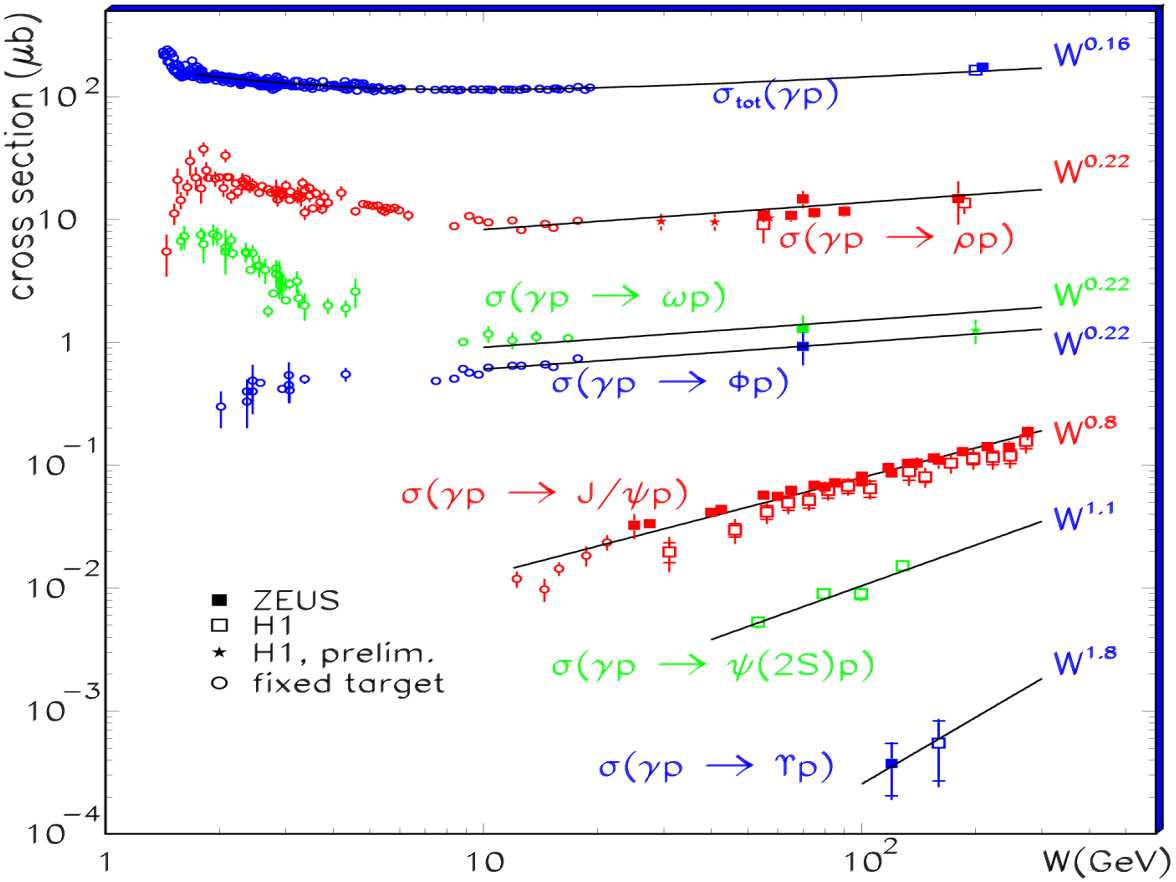
small $q\bar{q}$ size for: large Q^2 or heavy quarks:

$$\sigma_L \sim \frac{\alpha_s}{Q^6} |xG(x, Q^2)|^2$$

expectations:

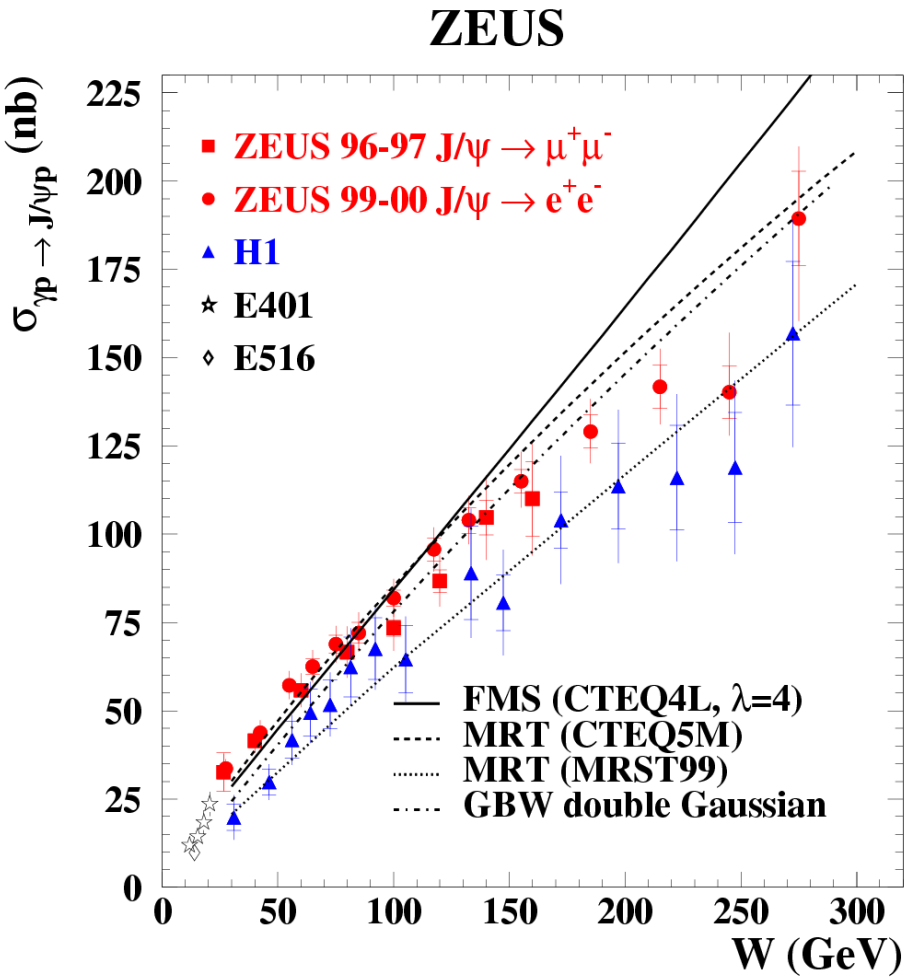
- fast rise $\sigma(W) \propto W^{\delta}$, $\delta \approx 0.8$
- little shrinkage $\alpha' \approx 0$
- breaking of SCHC

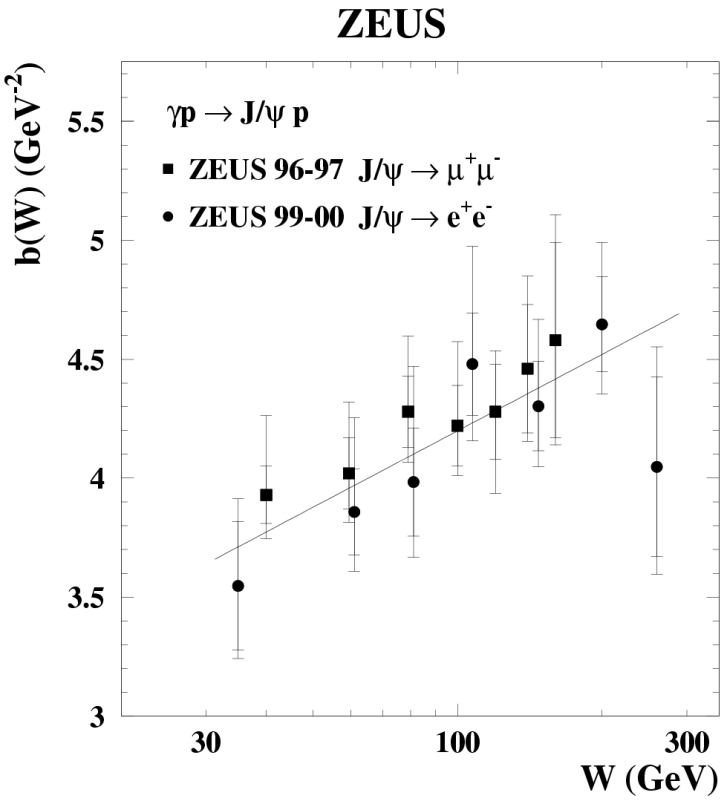
Vector Mesons in Photoproduction



at $Q^2 = 0$ change of regime with mass

J/ψ Photoproduction



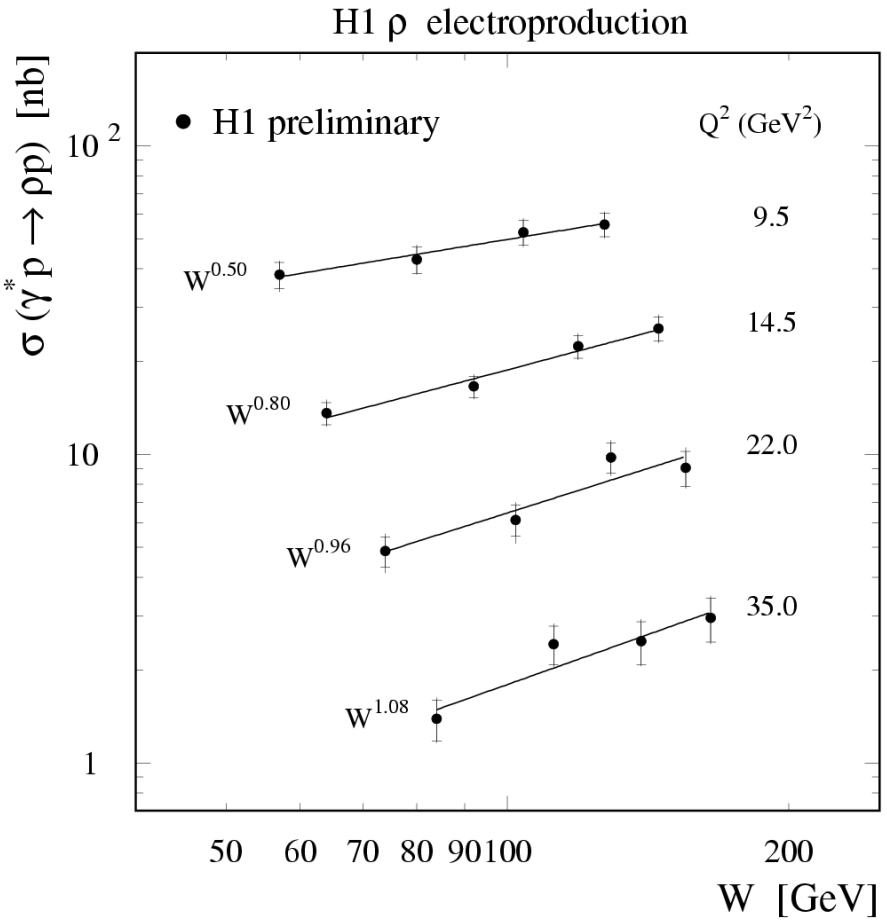


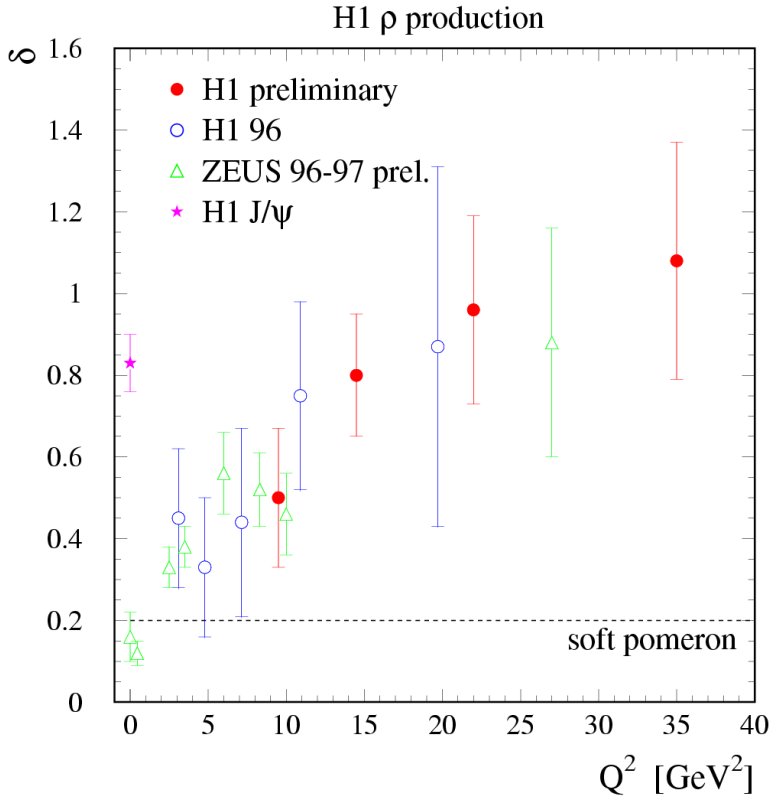
- pQCD describes steep rise of cross section with $M_{J/\psi}$ as hard scale
- Only slight rise with W
- smaller shrinkage: $\alpha' \approx 0.1$ GeV^{-2}

ρ Electroproduction

$\sigma_{\gamma p^* \to \rho p} \propto W^{\delta}$

at different Q^2:

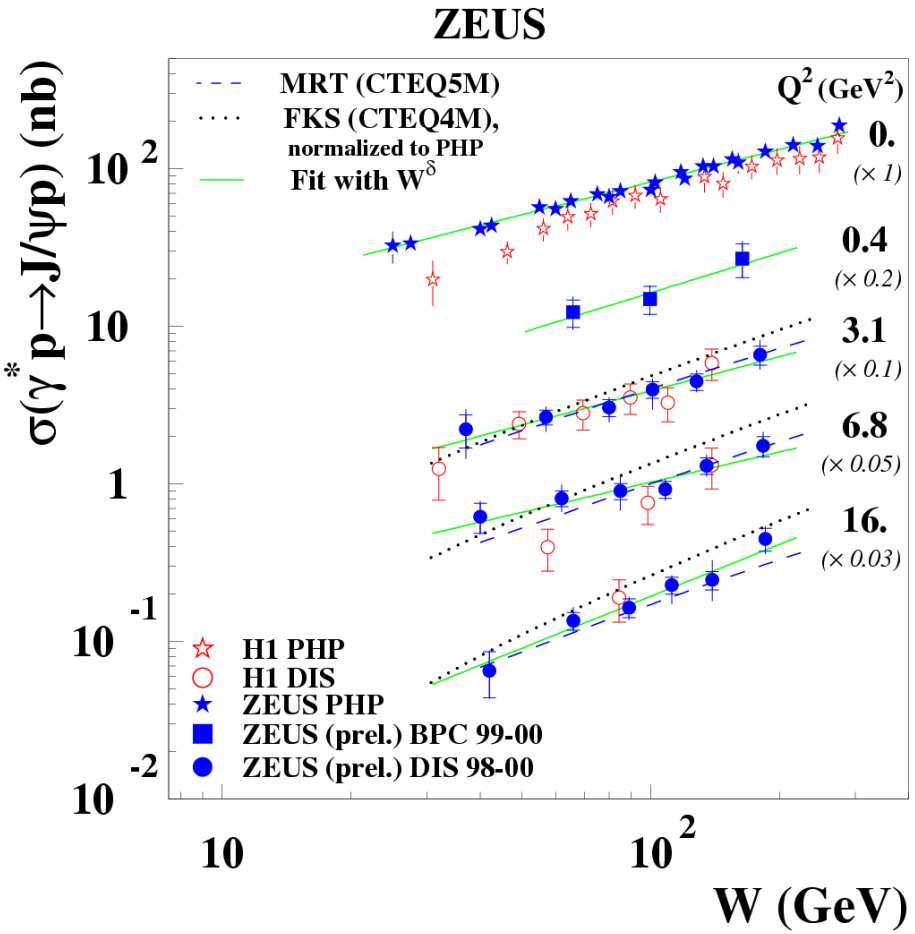


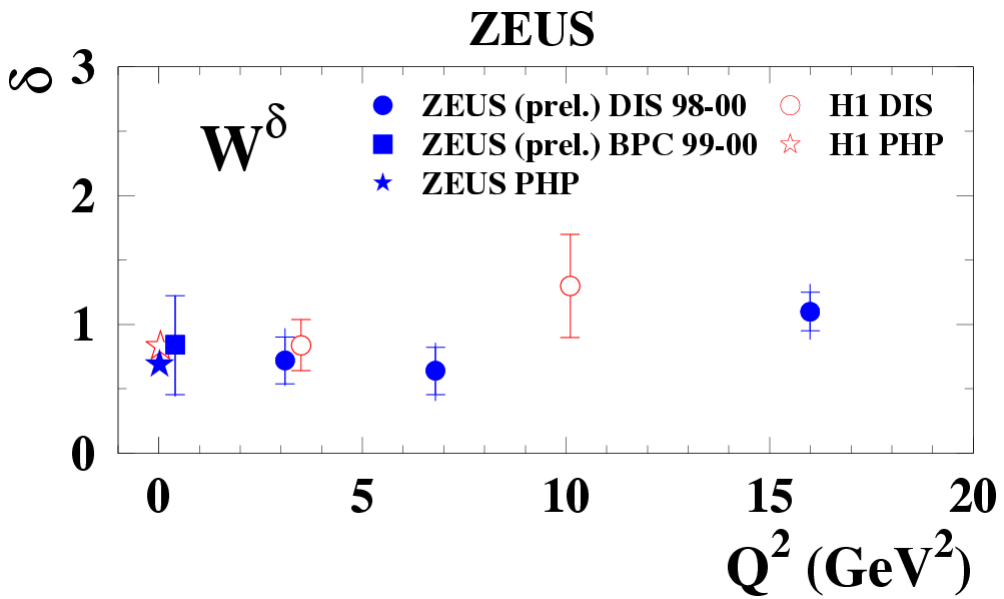


δ increases with Q^2:

transition from 'soft →'hard' scattering

J/ψ Electroproduction





$\sigma_{\gamma^* p \to J/\psi p} \propto W^{\delta}$

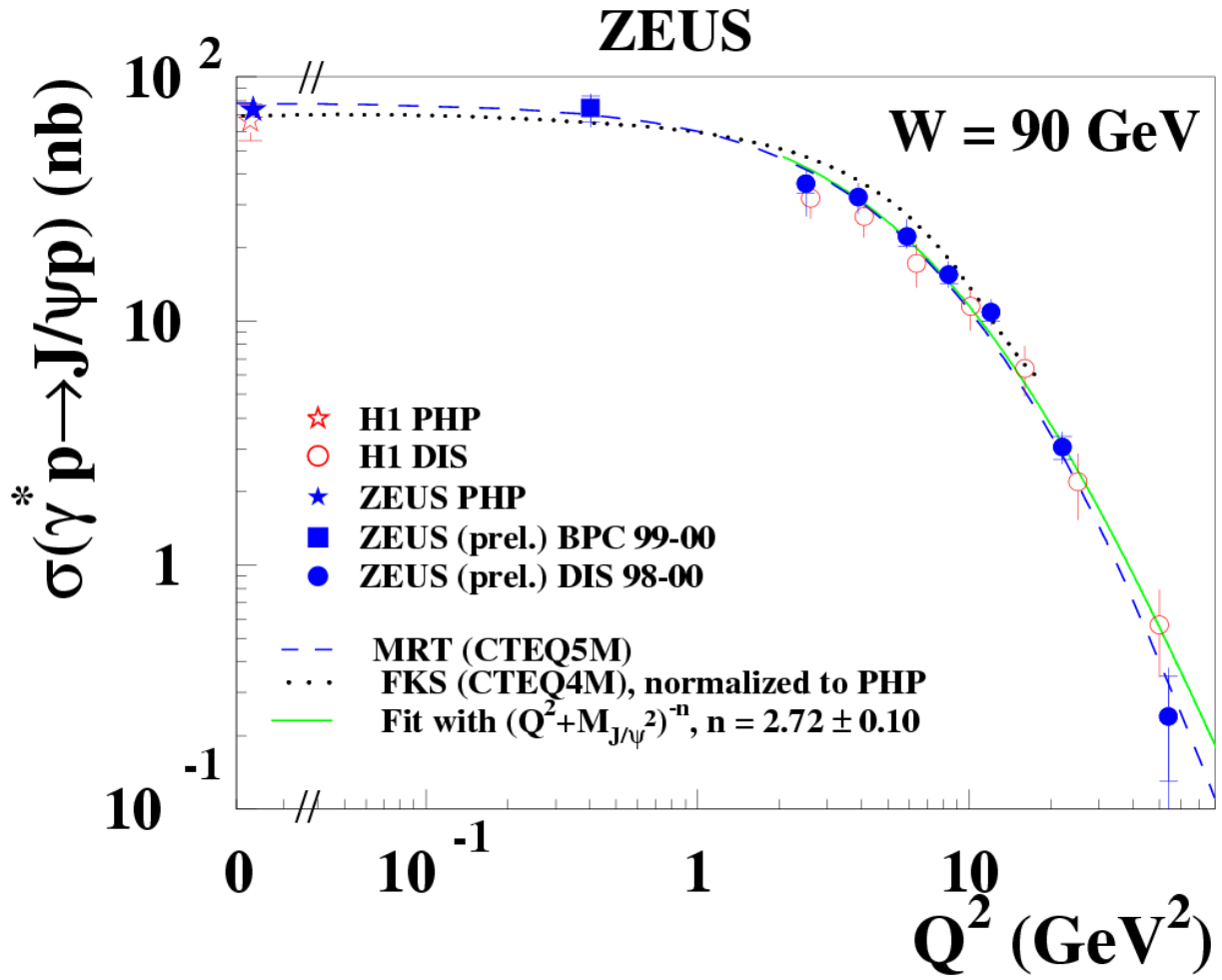
at different Q^2

$\delta \approx 0.8$

No Q^2 dependence:

already at 'hard' regime

J/Ψ Photo- and Electroproduction

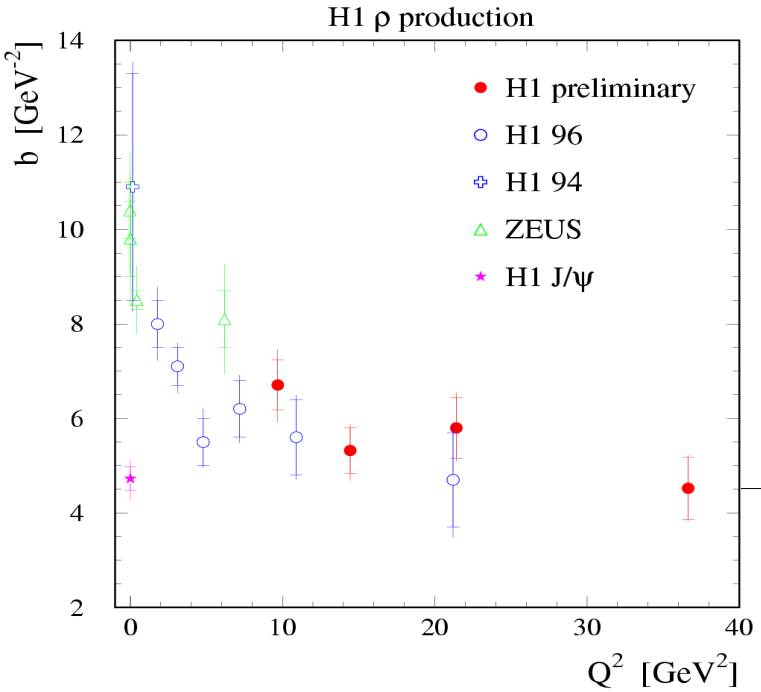


- cross section is well described in shape and normalisation by QCD models

t Dependence

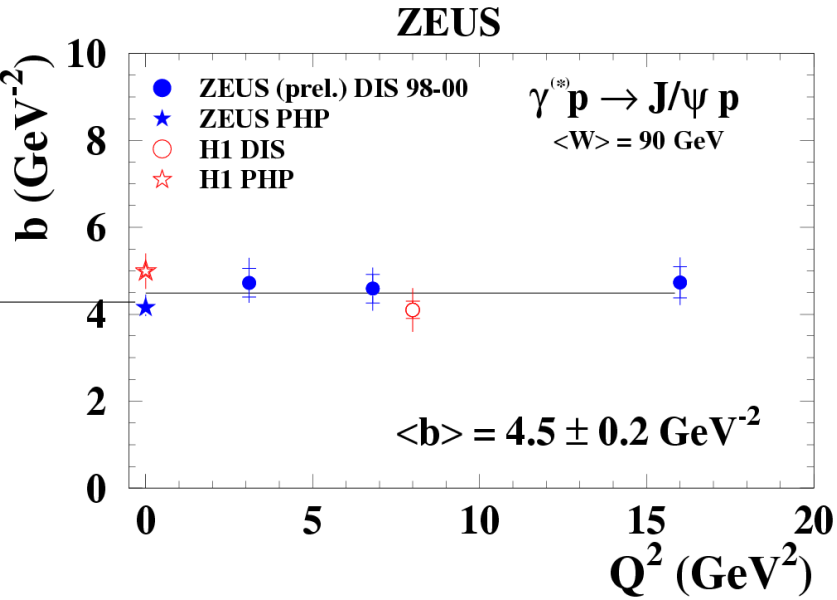
$$\frac{d\sigma}{dt} \propto e^{bt}, |t| < 1\,GeV^2$$

$\sigma_{\gamma * p \to \rho p}$



- b decreases with Q^2
- from diffraction: $b \propto r^2_{proton} + r^2_{VM}$

$\sigma_{\gamma * p \to J/\psi p}$



- b constant with Q^2
- at asymptotic value of proton size $b \propto R^2_{proton}/4$?

ψ(2s) Photoproduction

optical interpretation $b \propto r^2_{proton} + r^2_{VM}$:

$b_{\psi(2s)} > b_{J/\psi}$?

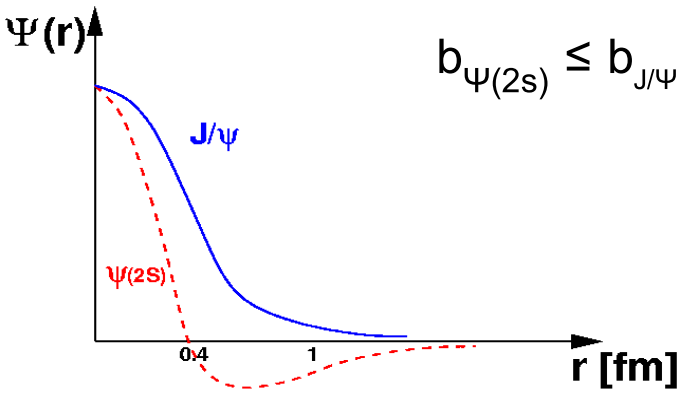
t dependence:

$b_{\psi\,(2s)} = 4.31 \pm 0.6 \pm 0.5\ GeV^2$

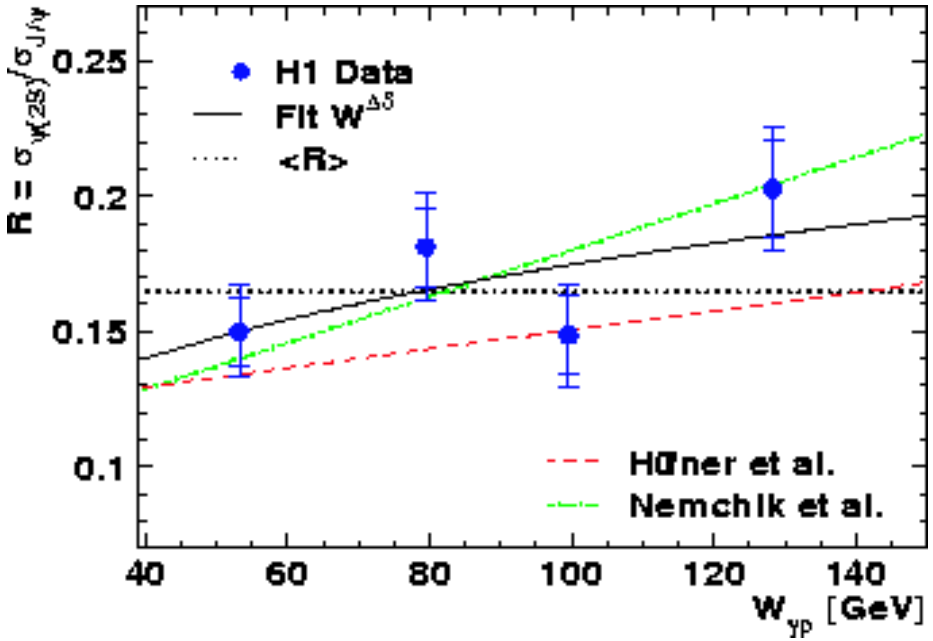
$b_{J/\psi} = 4.99 \pm 0.3 \pm 0.4\ GeV^2$

QCD interpretation:

b sensitive to node in the wave function:



$b_{\psi(2s)} \leq b_{J/\psi}$



W dependence:

- Suppression $R=\sigma_{\psi(2s)}/\sigma_{J/\psi} \approx 0.17$
- $\delta_{\psi\,(2s)} > \delta_{J/\psi}$

→ in agreement with QCD

VM helicity analysis

$$\frac{d\sigma}{d\Phi} \propto 1 + \sqrt{2\epsilon(1+\epsilon)}\cos\Phi\,(r^5_{00} + 2r^5_{11}) - \epsilon\cos 2\Phi\,(r^1_{00} + 2r^1_{11})$$

$$\frac{d\sigma}{d\cos\theta^*} \propto 1 - r^{04}_{00} + (3r^{04}_{00} - 1)\cos^2\theta^*$$

Φ angle between scattering and decay plane
θ* polar angle of positive decay lepton

Angular dist. → spin density matrix elements r^{ij}_{kl} → helicity amplitudes $T_{\lambda\gamma,\lambda_{VM}}$

- $r^{04}_{00} \propto |T_{00}|^2 + |T_{01}|^2$
- $(r^1_{00} + 2r^1_{11}) \propto -|T_{01}|^2 + 2(T_{11}T^{\dagger}_{1-1} + T_{1-1}T^{\dagger}_{11})$
- $(r^5_{00} + 2r^5_{11}) \propto T_{00}T^{\dagger}_{01} + 2(T_{11}T^{\dagger}_{10} - T_{10}T^{\dagger}_{1-1})$

s-channel helicity conservation (SCHC) hypothesis:

VM retains γ^* helicity:

$\gamma^*_L \rightarrow VM_L : T_{00} \neq 0$, $\gamma^*_T \rightarrow VM_T : T_{11} \neq 0$, $T_{01}=T_{10}=T_{1-1}=0$

ρ Electroproduction

$$R = \frac{\sigma_L}{\sigma_T} \simeq \frac{r_{00}^{04}}{\epsilon\,(1 - r_{00}^{04})}$$

(assuming SCHC)

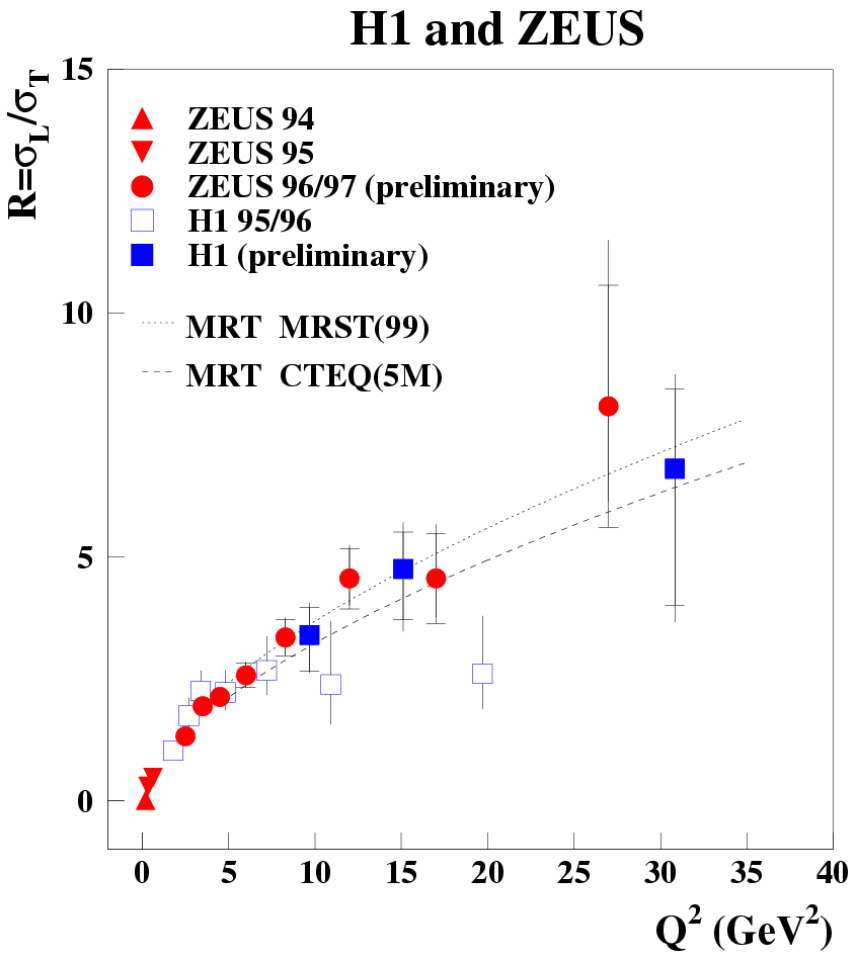
$$r^{04}_{00} \propto |T_{00}|^2 + |T_{01}|^2$$

Expectations from pQCD:

- Hierachy at high Q^2:

$|T_{00}| > |T_{11}| > |T_{01}| > |T_{10}| > |T_{1-1}|$

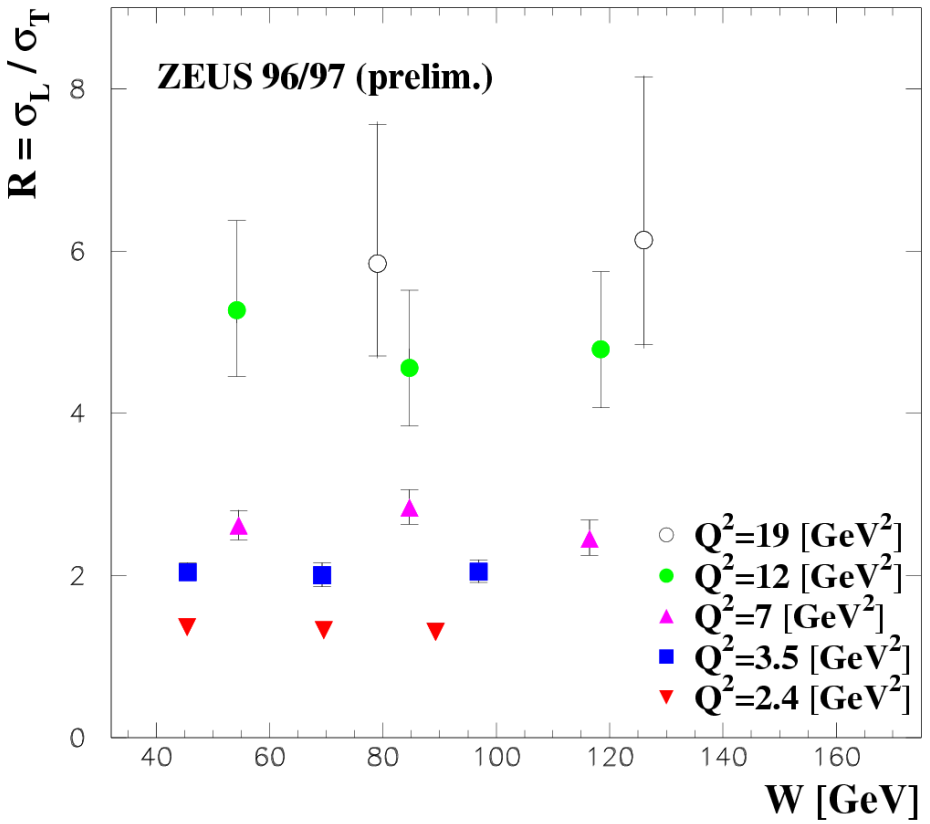
$\rightarrow$ $R = \sigma_L/\sigma_T$ increases with Q^2



$R=\sigma_L/\sigma_T$ increases with Q^2 $\rightarrow$: $|T_{00}| > |T_{11}|$

ρ Electroproduction

$$r^{04}_{00} = \sigma_L/(\sigma_L+\sigma_T)$$



- σ_T and σ_L have same W dependence

High |t| ρ Electroproduction

soft regime:

- s-channel helicity conservation (SCHC)

VM retains γ helicity:

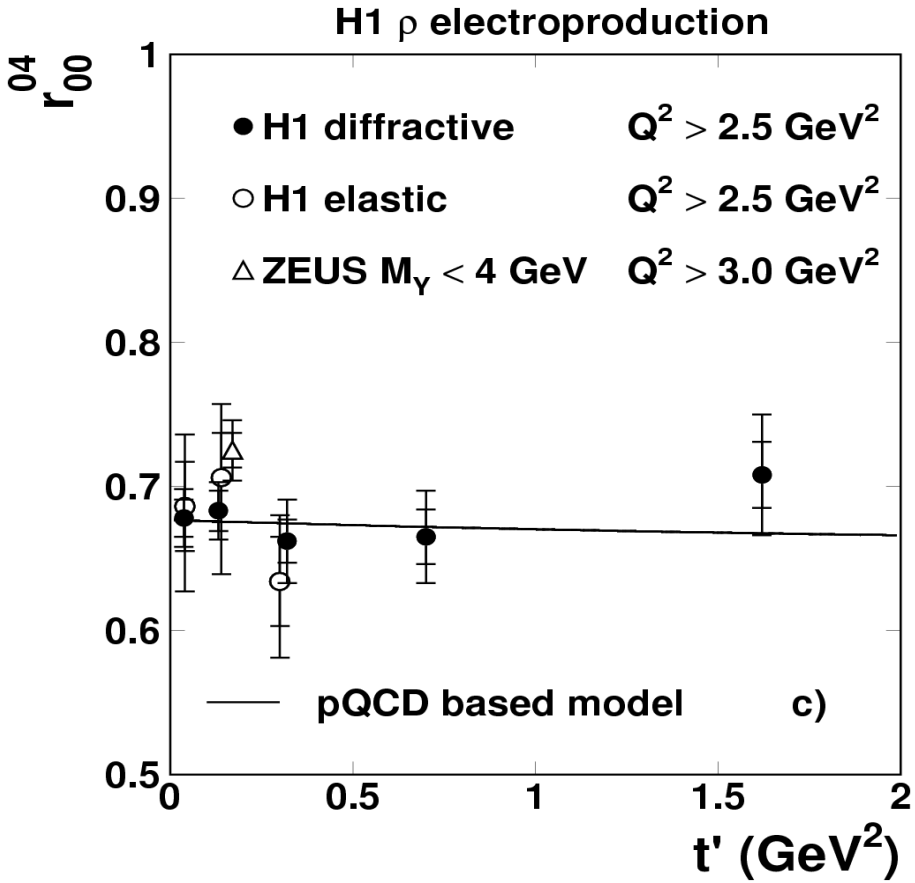
$\gamma^*_L \rightarrow VM_L \quad : T_{00} \neq 0$

$\gamma^*_T \rightarrow VM_T \quad : T_{11} \neq 0$

expected: $T_{01}=T_{10}=T_{1-1}=0$

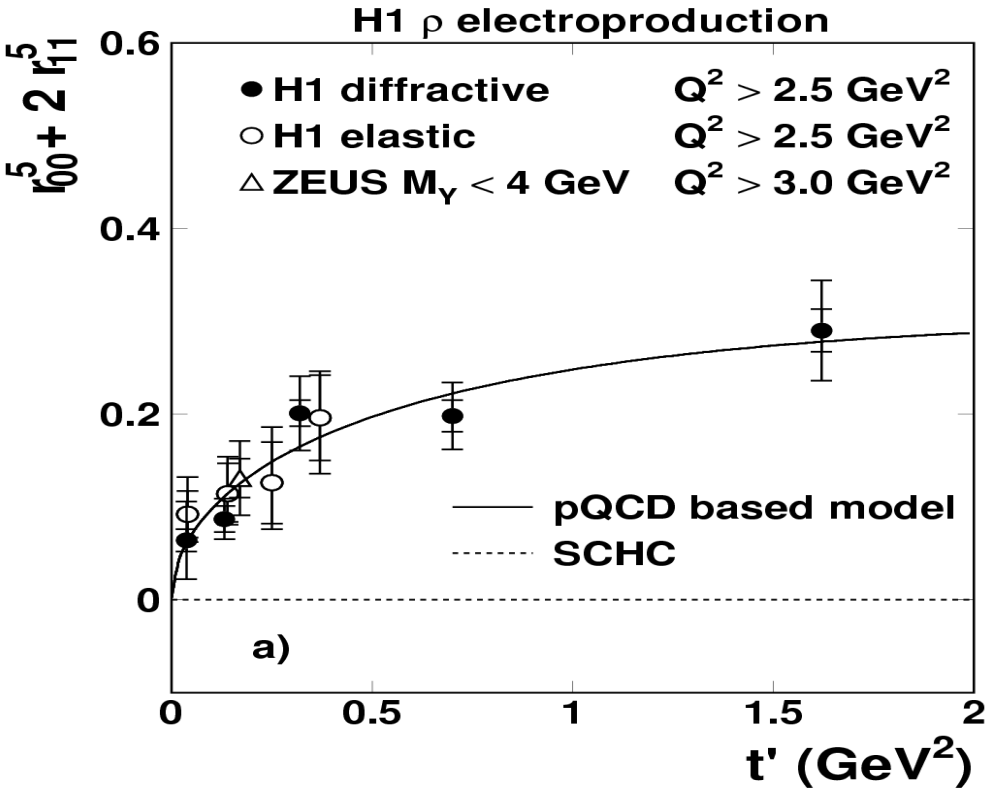
Hard regime (QCD):

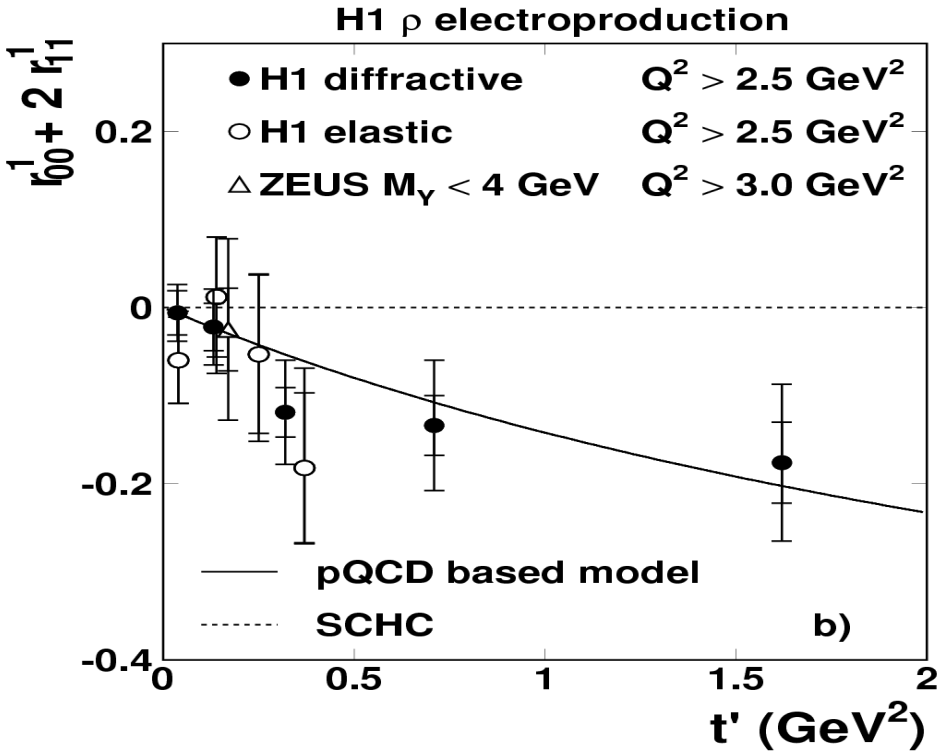
- quantiative breaking of SCHC
- expected: |t| dependence:
  - T_{11}, T_{00} const with |t|
  - $T_{10}\ T_{01}, T_{1-1} \propto t$



- $r^{04}_{00} = \sigma_L/\sigma_{TOT} \propto |T_{00}|^2 + |T_{01}|^2$
- r^{04}_{00} independent of t

High |t| ρ Electroproduction





$$(r^5_{00} + 2r^5_{11}) \propto T_{00}\,T^{\dagger}_{01} + \boxed{2(T_{11}\,T^{\dagger}_{10}} - T_{10}\,T^{\dagger}_{1-1}) \propto \sqrt{t}$$

→dominated by single flip

$$(r^1_{00} + 2r^1_{11}) \propto \boxed{-|T_{01}|^2} + 2(T_{11}\,T^{\dagger}_{1-1} + T_{1-1}\,T^{\dagger}_{11}) \propto \sqrt{t}$$

→dominated by single and double flip

negative sign: $|T_{01}| > |T_{1-1}|$

Summary & Outlook

Progress at HERA

- This talk covers only a small part of the very active field of vector meson production at HERA
- M, Q^2 , t provides hard scales for pQCD:
  - Mass M: In photoproduction ρ is 'soft' while J/ψ has already characteristics of 'hard' scattering
  - with increasing Q^2 also the ρ scattering becomes 'hard'
  - at high |t| ρ scattering also becomes 'hard' and s-channel helicity is not conserved

→ pQCD describes successfully VM data at hard scales

The future: HERA II

- extend all kinematical ranges and masses (i.e. Υ)