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H1 & ZEUS Results for Vector Mesons

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on behalf of the ZEUS and H1 Collaborations

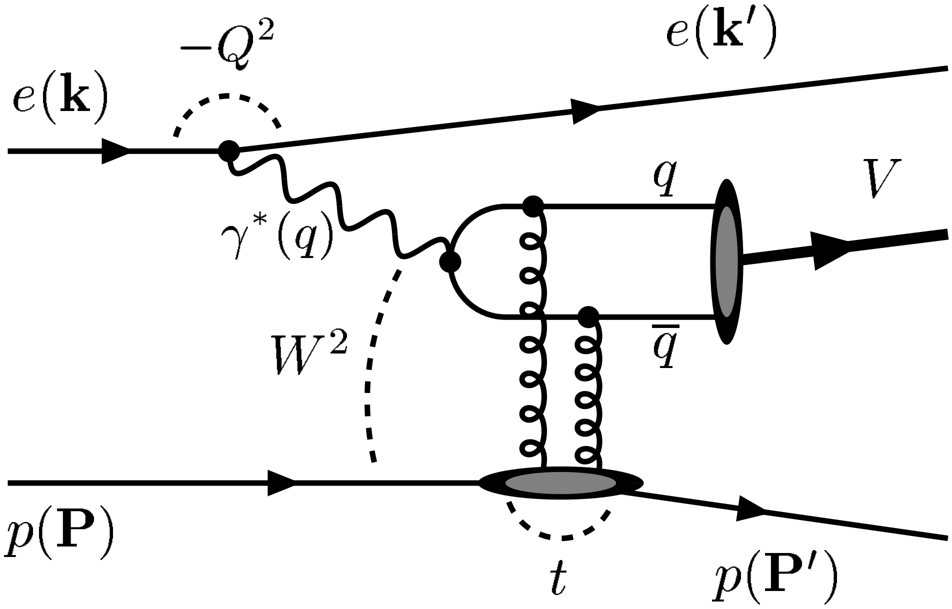
Outline.

- Introduction.
- Energy dependence,
  - for different VM,
  - as a function of Q^2,
  - in bins of t.
- t dependence,
  - for low t and high t,
  - as a function of Q^2,
  - for different VM,
  - elastic versus proton dissociation
- helicity study of different transition amplitudes as a function of Q^2, W and t.
- conclusions

Vector Meson (VM) production at HERA.

HERA ep collider, $E_e = 27.5\,\mathrm{GeV}$

$E_p = 820, (920)\,\mathrm{GeV}$ till, (after) 98.

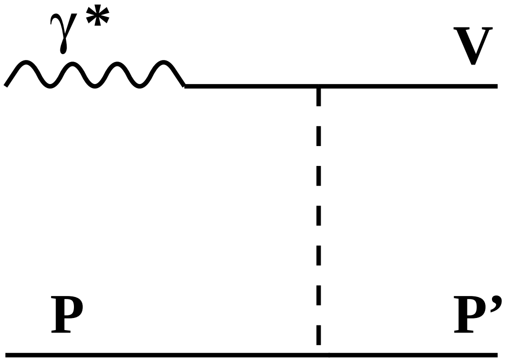


$$Q^2 \equiv -(k-k^{'})^2 \quad W^2 \equiv (p+q)^2$$

$$s \equiv (p+k)^2 \quad t \equiv (p-p^{'})^2$$

$$x \equiv \frac{Q^2}{2pq} \quad y \equiv \frac{2pq}{2pk}$$

VDM



- The photon fluctuates into a vector meson, V, which carries the quantum numbers of the photon ($\gamma \rightarrow$ V)
- The vector meson scatters elastically off the incoming proton (Vp $\rightarrow$ Vp)

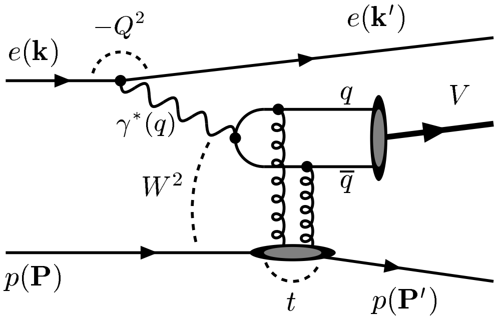
Regge model (soft diffraction) predictions :

- Exchange of Pomeron, trajectory $\alpha(t) = \alpha(0) + \alpha' t$
- $\frac{d\sigma(\gamma p \rightarrow Vp)}{dt} \propto e^{-b_0|t|}(W^2/W_0^2)^{2(\alpha(t)-1)}$
- $\Rightarrow b(W) = b_0 + 2\alpha' \ln{(W^2/W_0^2)}$, $\sigma \propto (\frac{W}{W_0})^{4(\alpha(0)-1)}$

Experimental observations from hadron scattering:

- $\alpha(t) = 1.08 + 0.25t$ (Soft Pomeron)
- b slope increase with energy
- Weak energy dependence of cross section $\sigma \propto W^\delta, \ \delta = 4(\alpha(0) - 1) \simeq 0.2$

pQCD models, (hard diffraction)



- the photon fluctuates into a $q\bar{q}$ state,
- the $q\bar{q}$ pair scatters off the proton target, (color dipole model)
- the scattered $q\bar{q}$ pair turns into a vector meson.

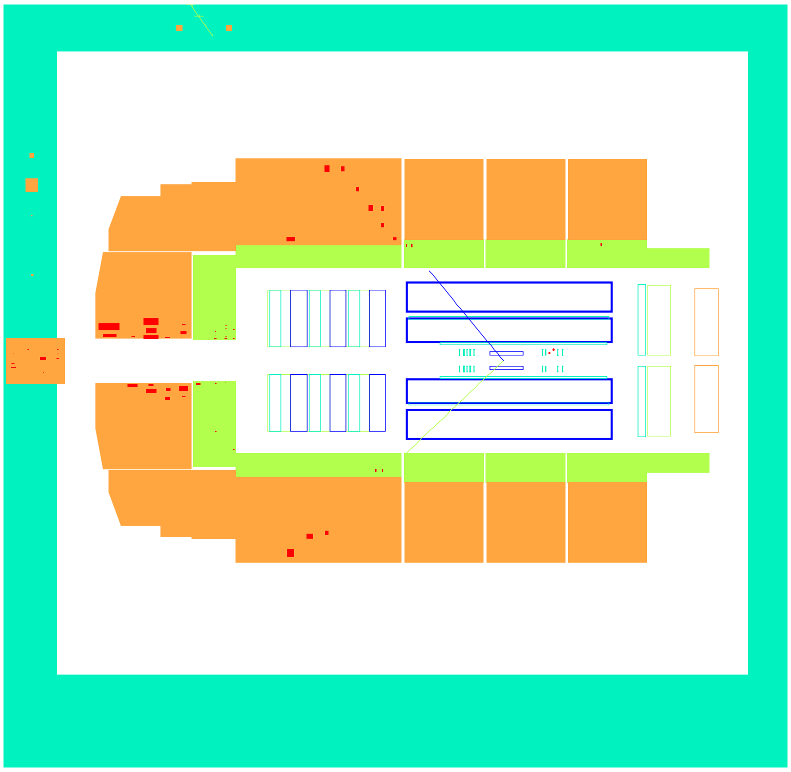
Predictions :

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

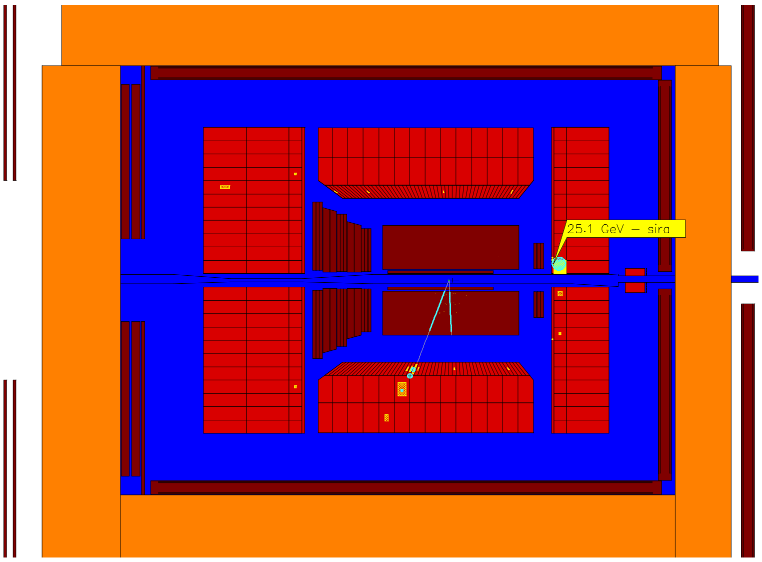
Effects expected for hard diffraction:
(large Q^2, M^2)

- A fast increase of the $\gamma^* p \to Vp$ cross section with energy W
- longitudinal cross section dominates
- Universal exponential t dependence, $b_{el} \sim 4-5\,\mathrm{GeV}^{-2} \quad \Longrightarrow \quad \alpha' \to 0\,?$

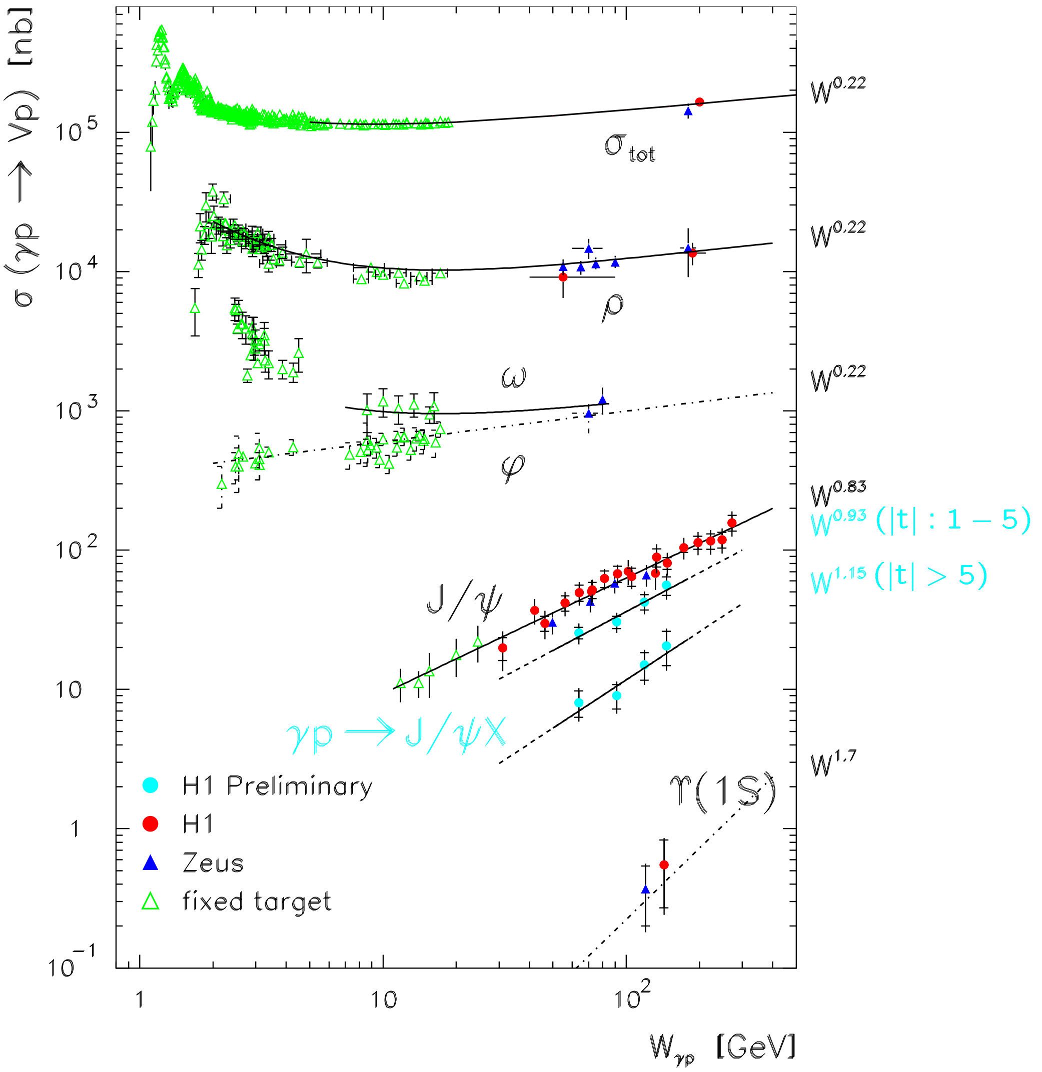
H1 DETECTOR: $\gamma p \to J/\psi Y$ event.



ZEUS DETECTOR: $\gamma^* p \to \rho^0 p$ event.

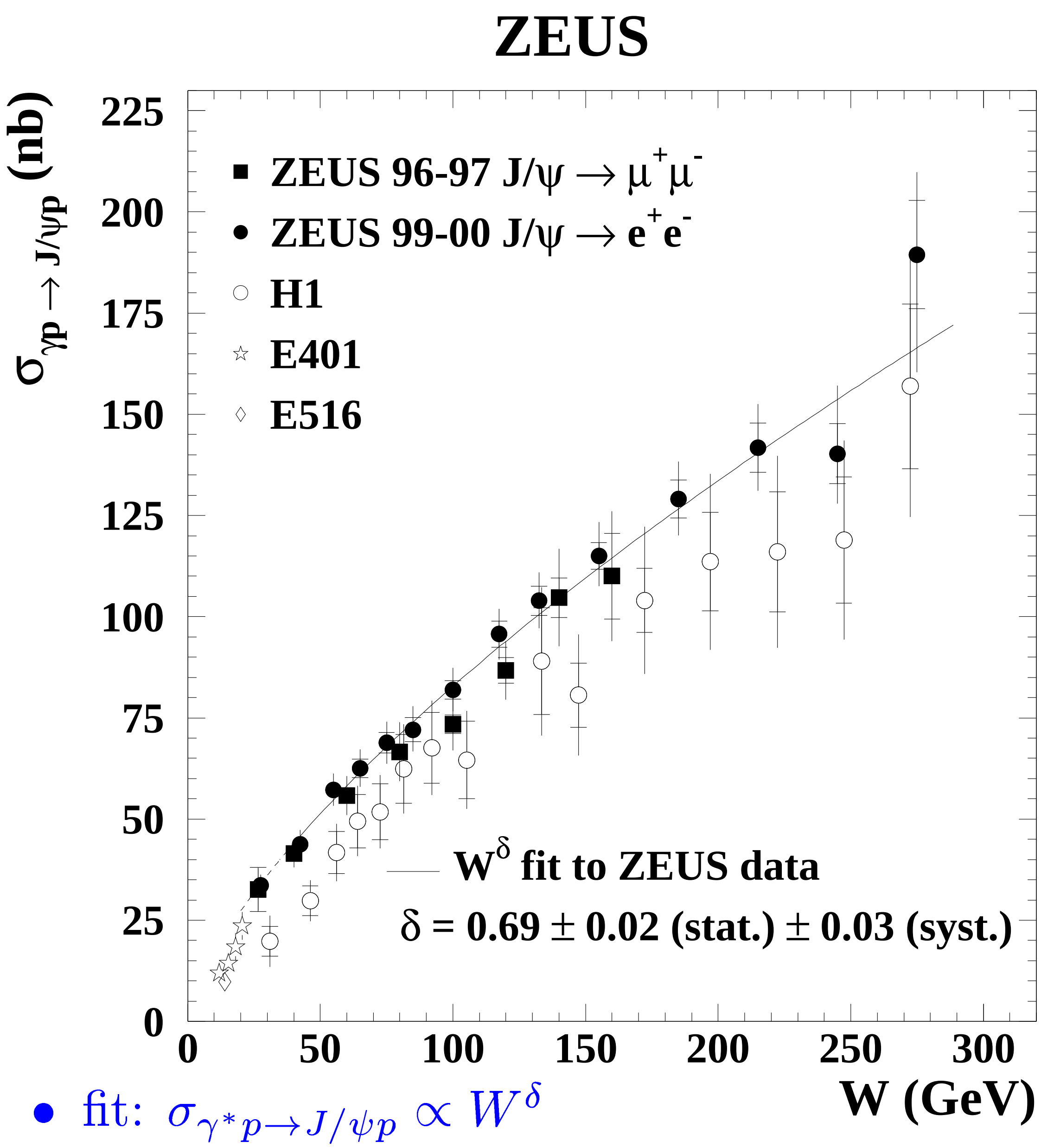


Energy dependence in photoproduction ($Q^2 \approx 0$)



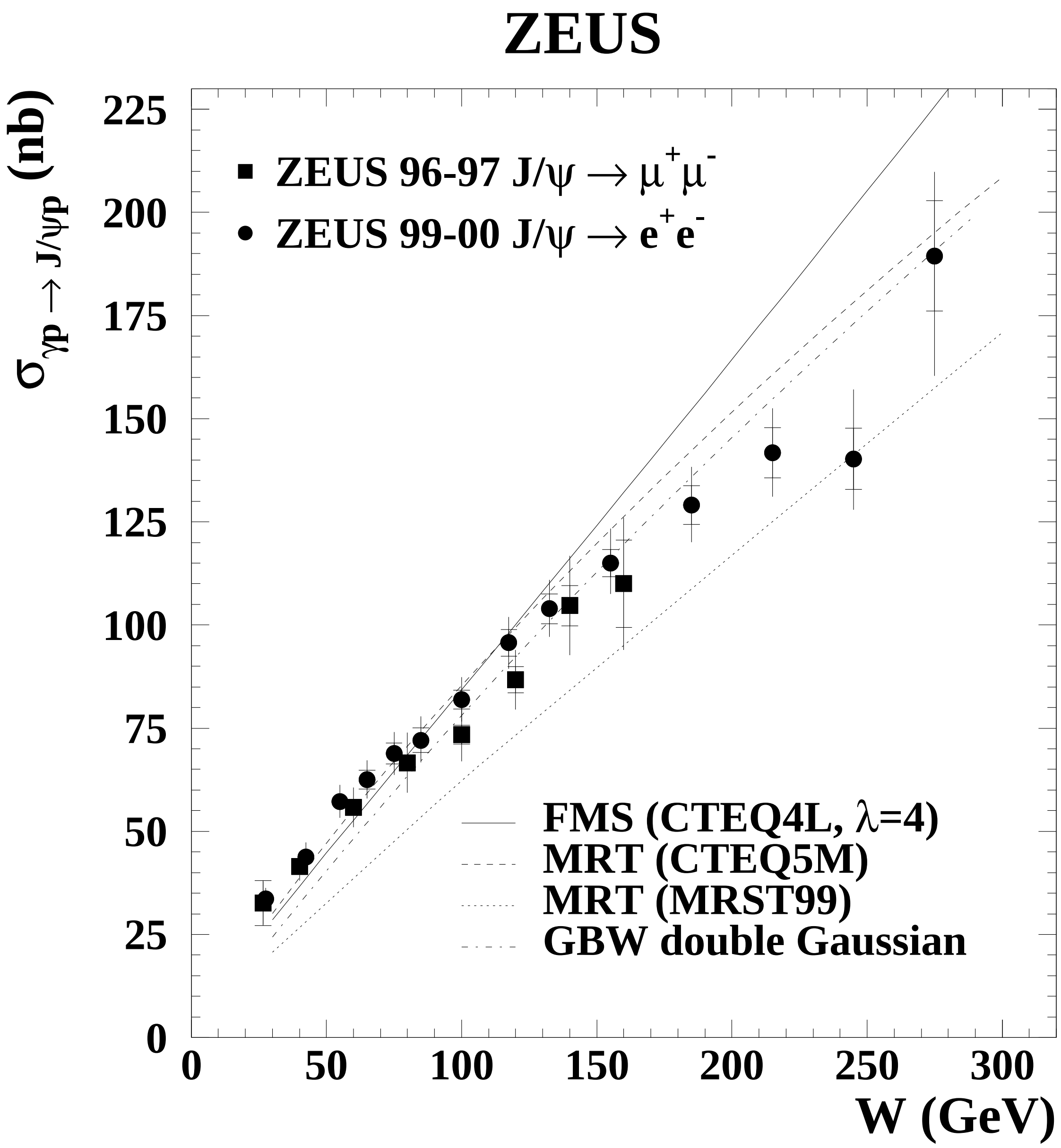
- Energy dependence becomes steeper for heavy VM.

NEW ZEUS J/ψ RESULTS.



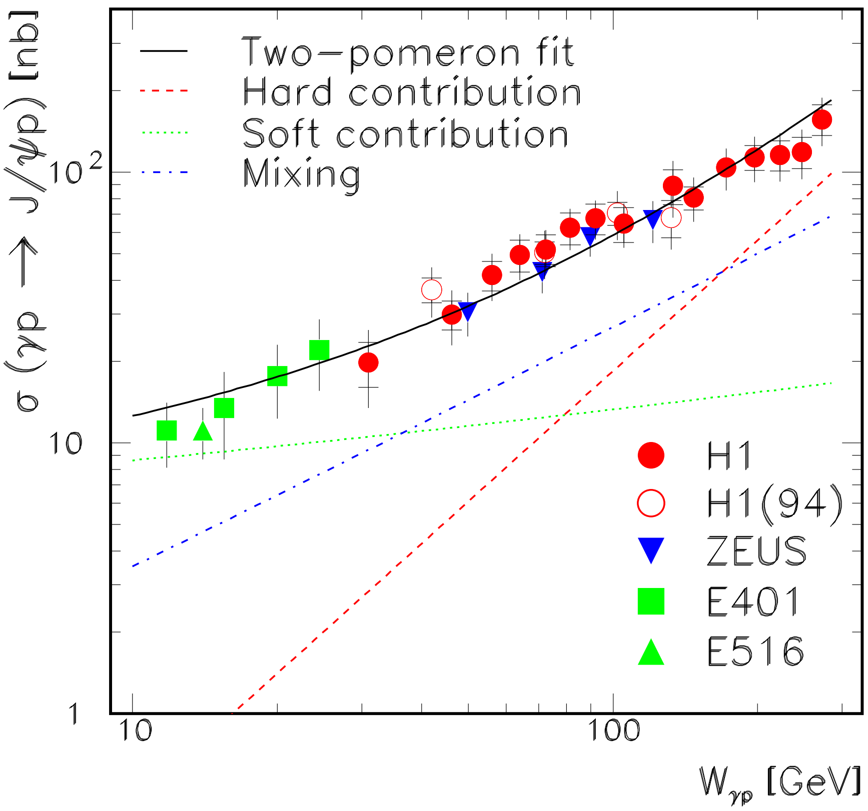
- fit: $\sigma_{\gamma^* p \to J/\psi p} \propto W^\delta$
- ZEUS: $\delta = 0.69 \pm 0.02^{+0.03}_{-0.03}$
- H1: $\delta = 0.83 \pm 0.07$
- steeper rise than observed for light vector mesons photoproduction

New ZEUS J/ψ results.



- pQCD approach describes steep energy behavior.
- $M_{J/\psi}$ provides a hard scale to apply pQCD.
- Exact measurement $\longleftrightarrow$ sensitivity to gluon density within the same model (MRT).

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



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

⇒ two pomeron fit gives reasonable description

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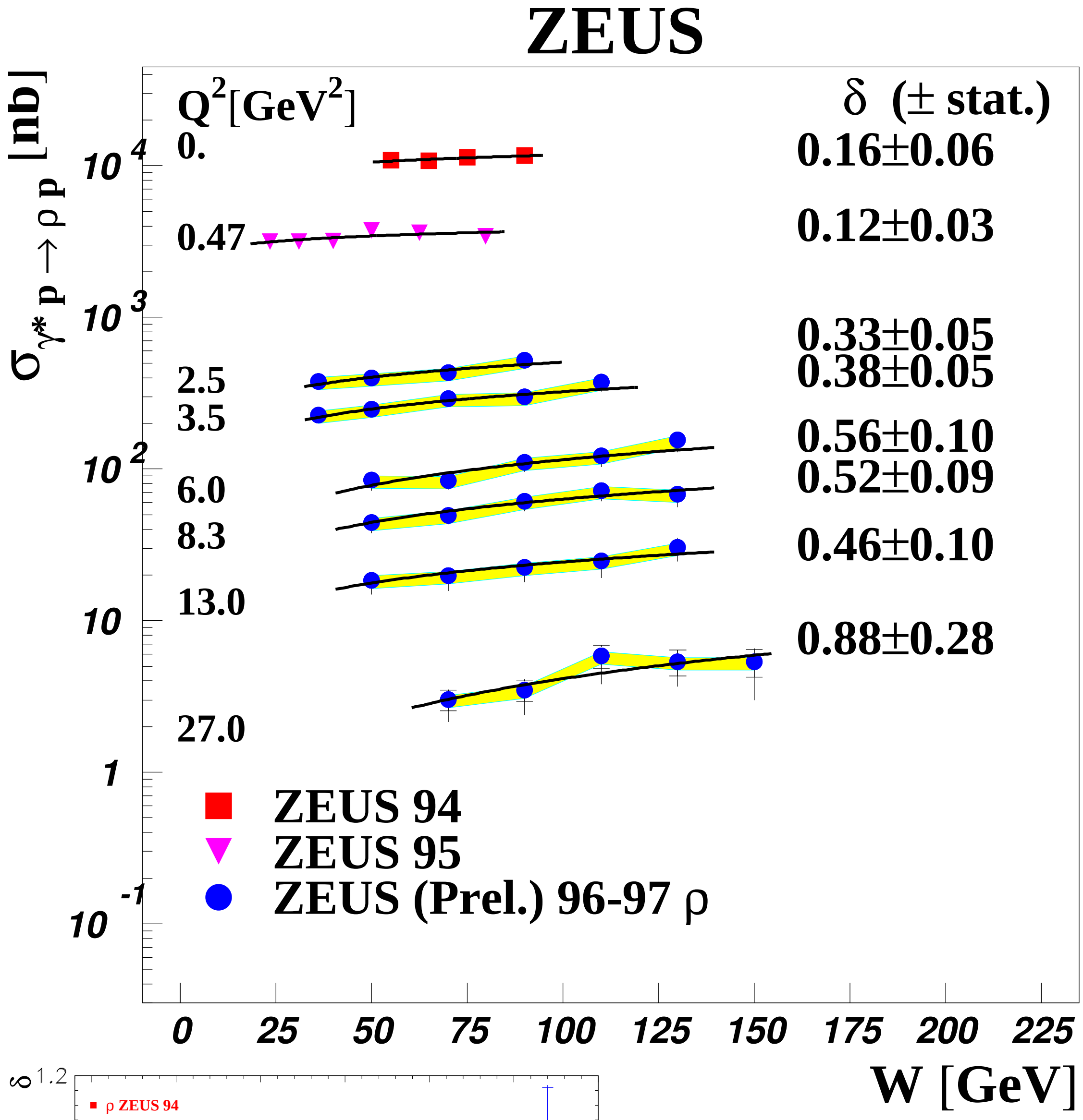
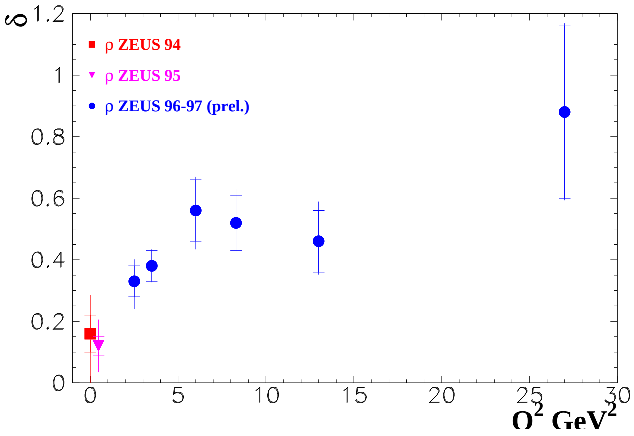
$\sigma_{\gamma * p \to \rho p}(Q^2, W)$

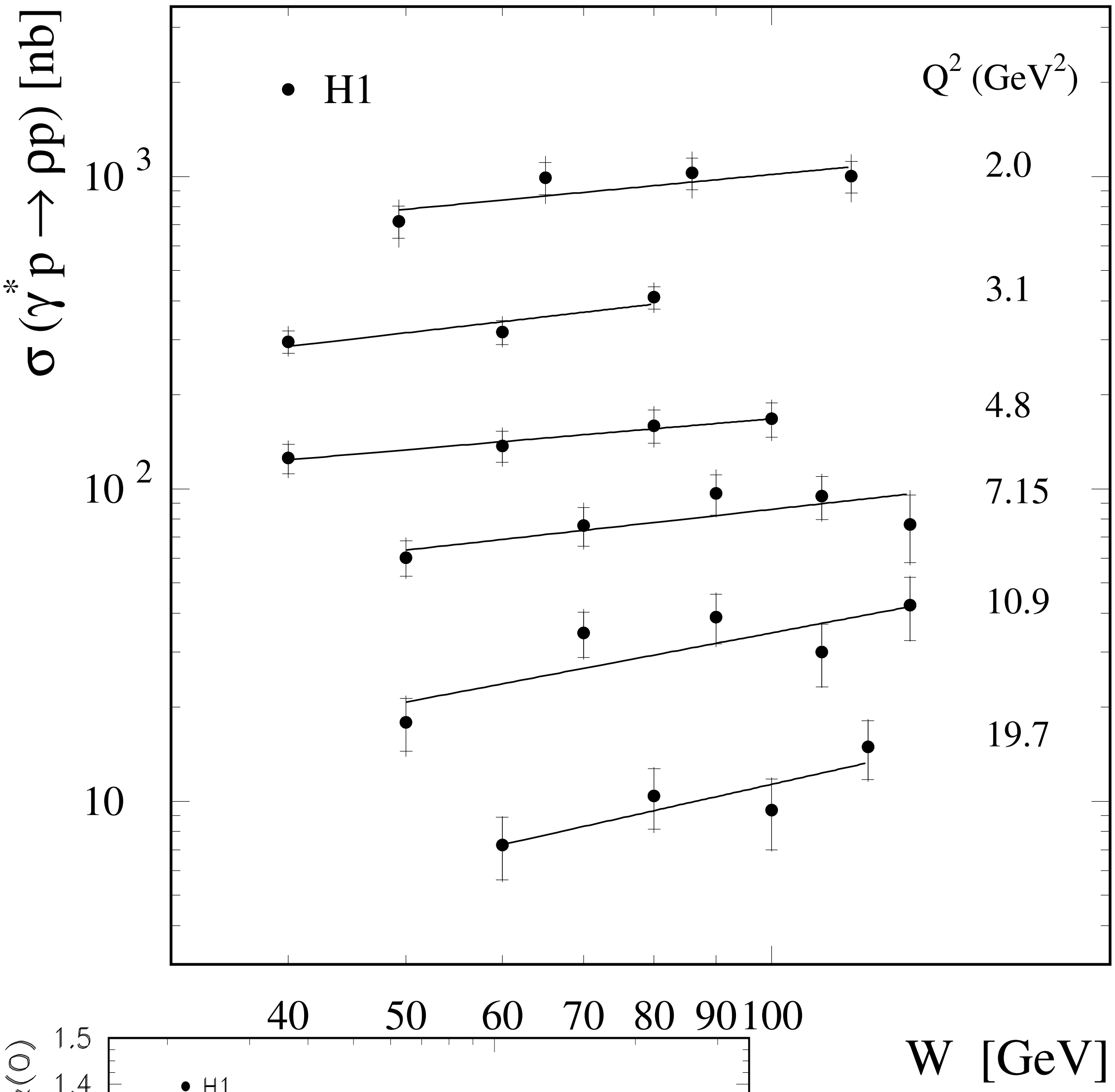


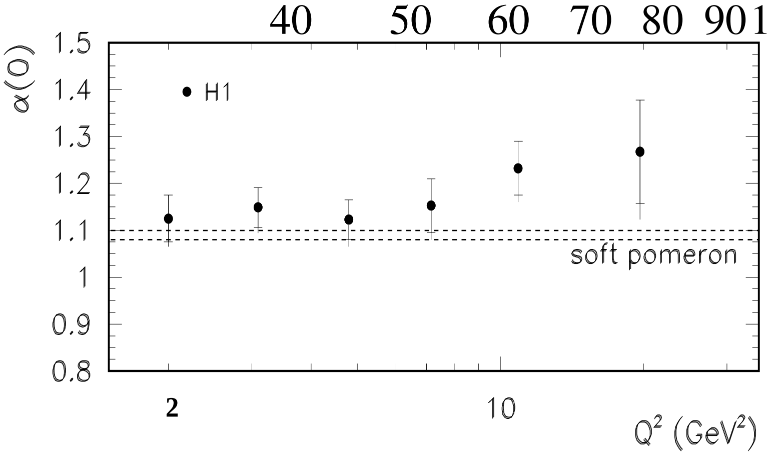


$$\sigma \propto \left(\frac{W}{W_0}\right)^{\delta}$$

Energy dependence becomes steeper with increasing Q^2, as predicted by pQCD.

$\sigma_{\gamma * p \to \rho p}(Q^2, W)$



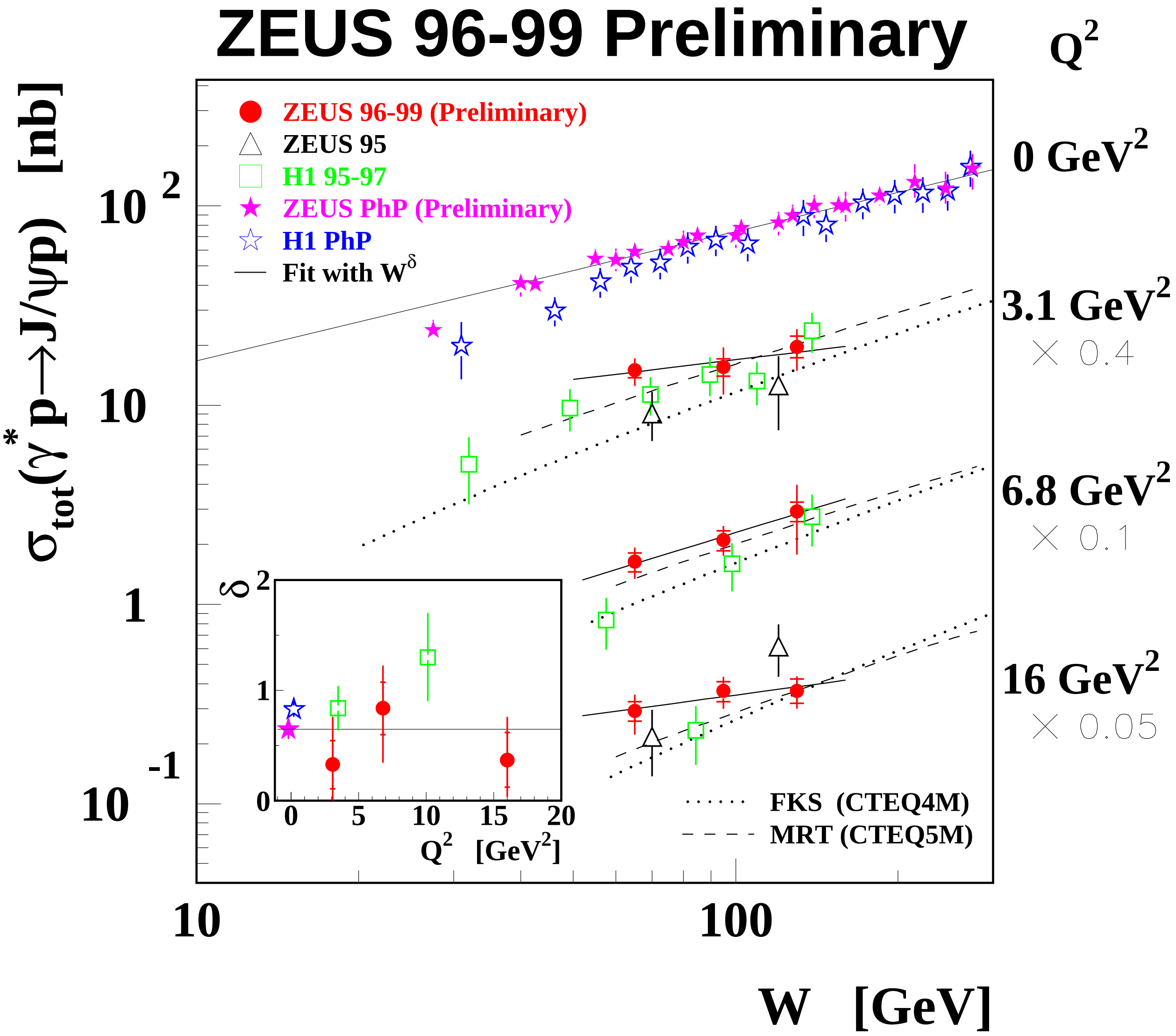


$$\sigma \propto \left(\frac{W}{W_0}\right)^{4(\alpha(0)-1)}$$

Energy dependence becomes steeper with increasing Q^2, as predicted by pQCD.

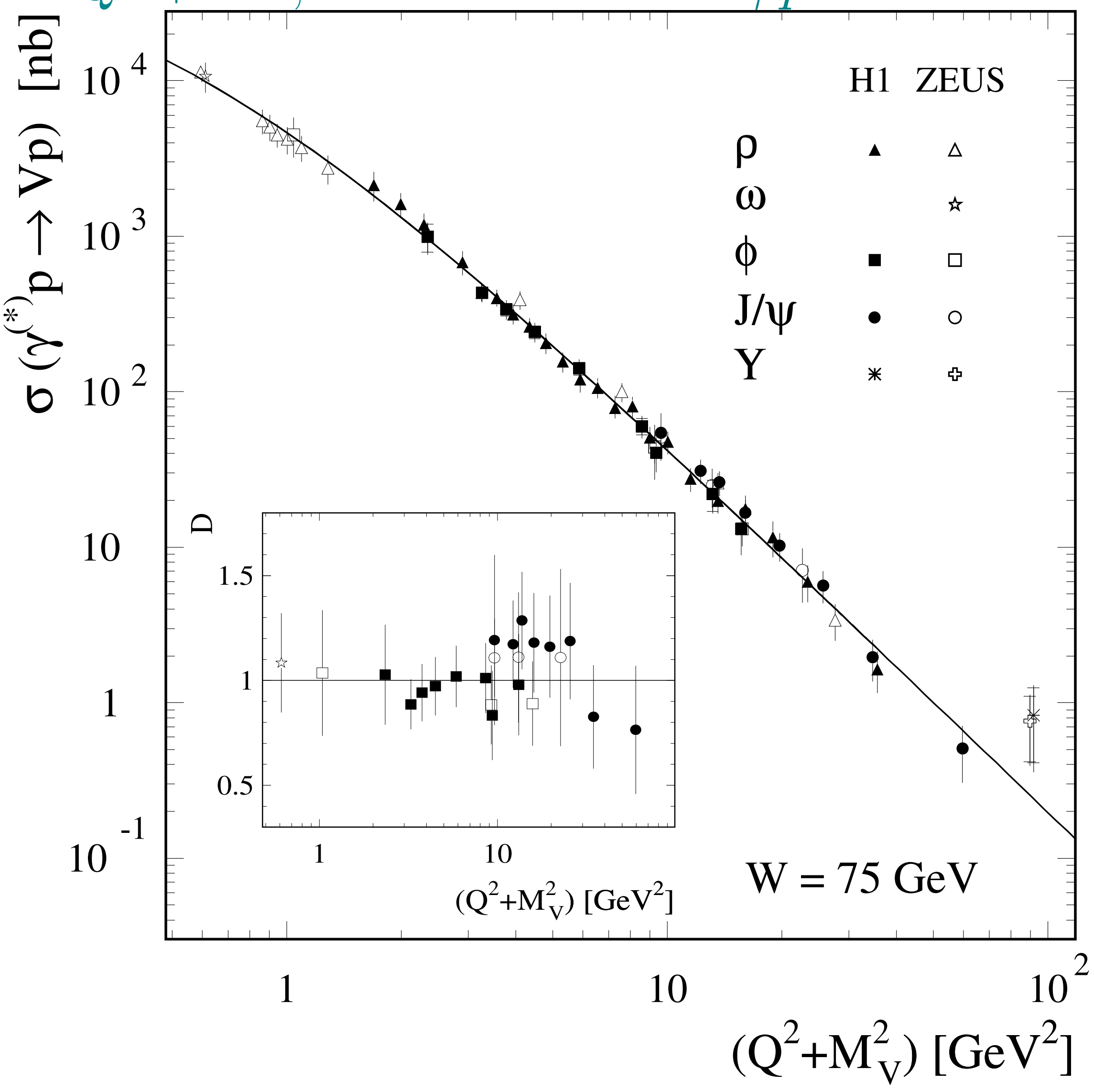
$$\sigma_{\gamma * p \to J/\psi p}(Q^2, W)$$

$\sigma \propto (\frac{W}{W_0})^{\delta}$



No visible dependence on Q^2 for J/ψ

ELASTIC CROSS SECTIONS AS A FUNCTION OF $Q^2 + M^2$, CORRECTED FOR γq COUPLING



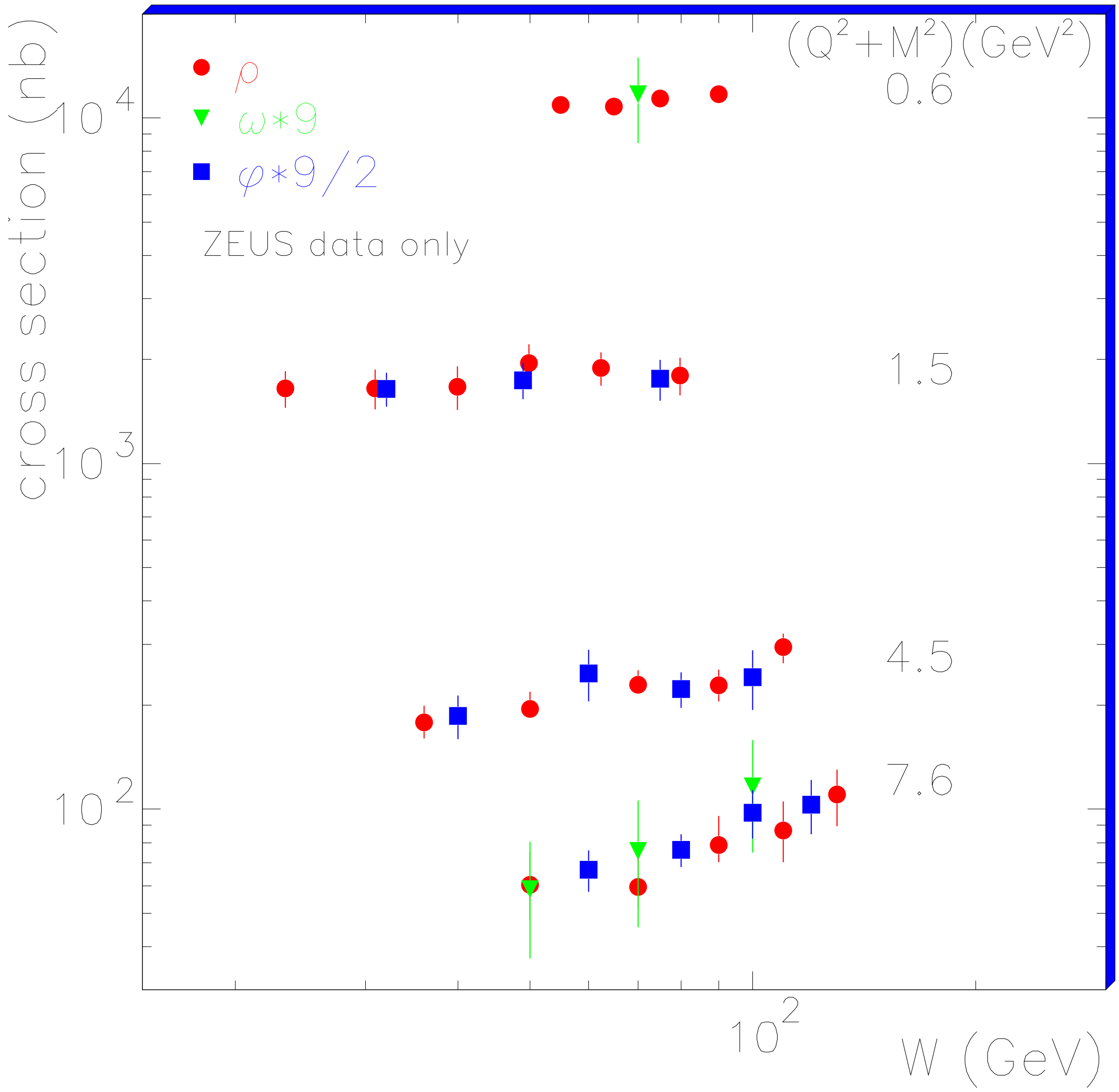
Big picture

- Similar $Q^2 + M^2$ behavior to all VM.

Small picture

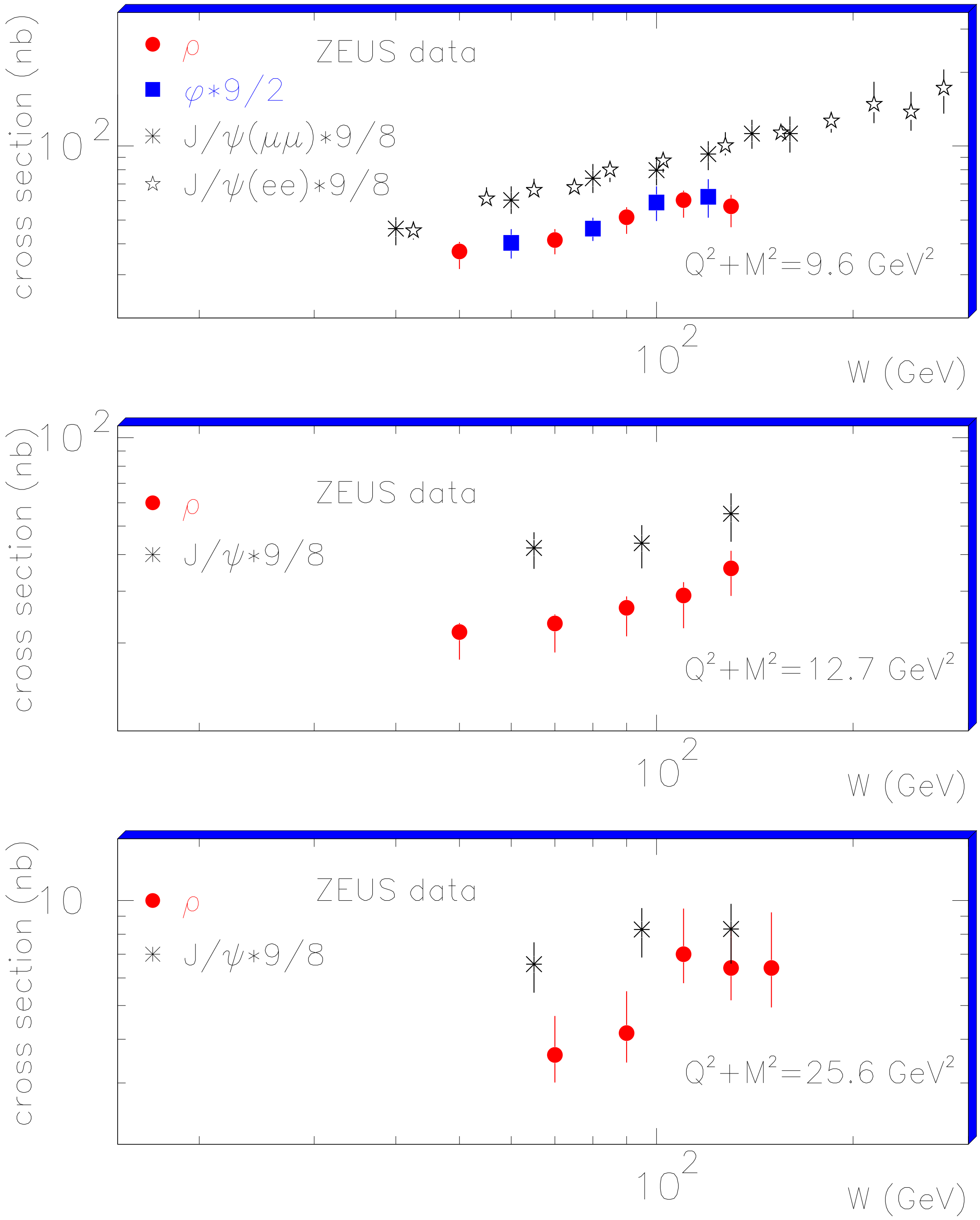
- $D \equiv (measurement)/(global fit)$
- J/ψ points are higher than global fit

Elastic cross sections for light VM corrected for γq coupling $\rho : \omega : \phi$ $9 : 1 : 2$



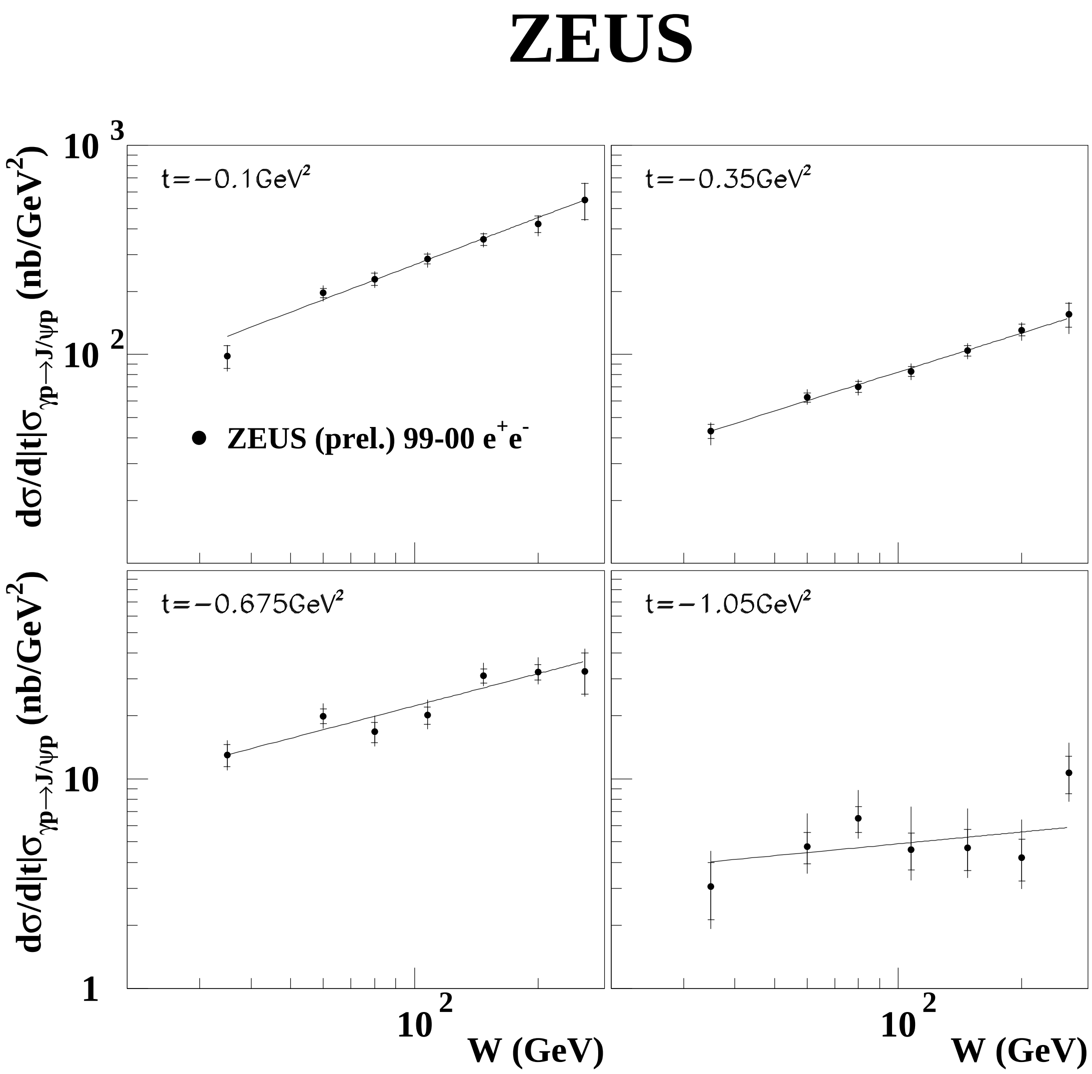
SU(3) symmetry restored by comparing the measurement at the same $Q^2 + M^2$.

COMPARING J/ψ AND LIGHT VM



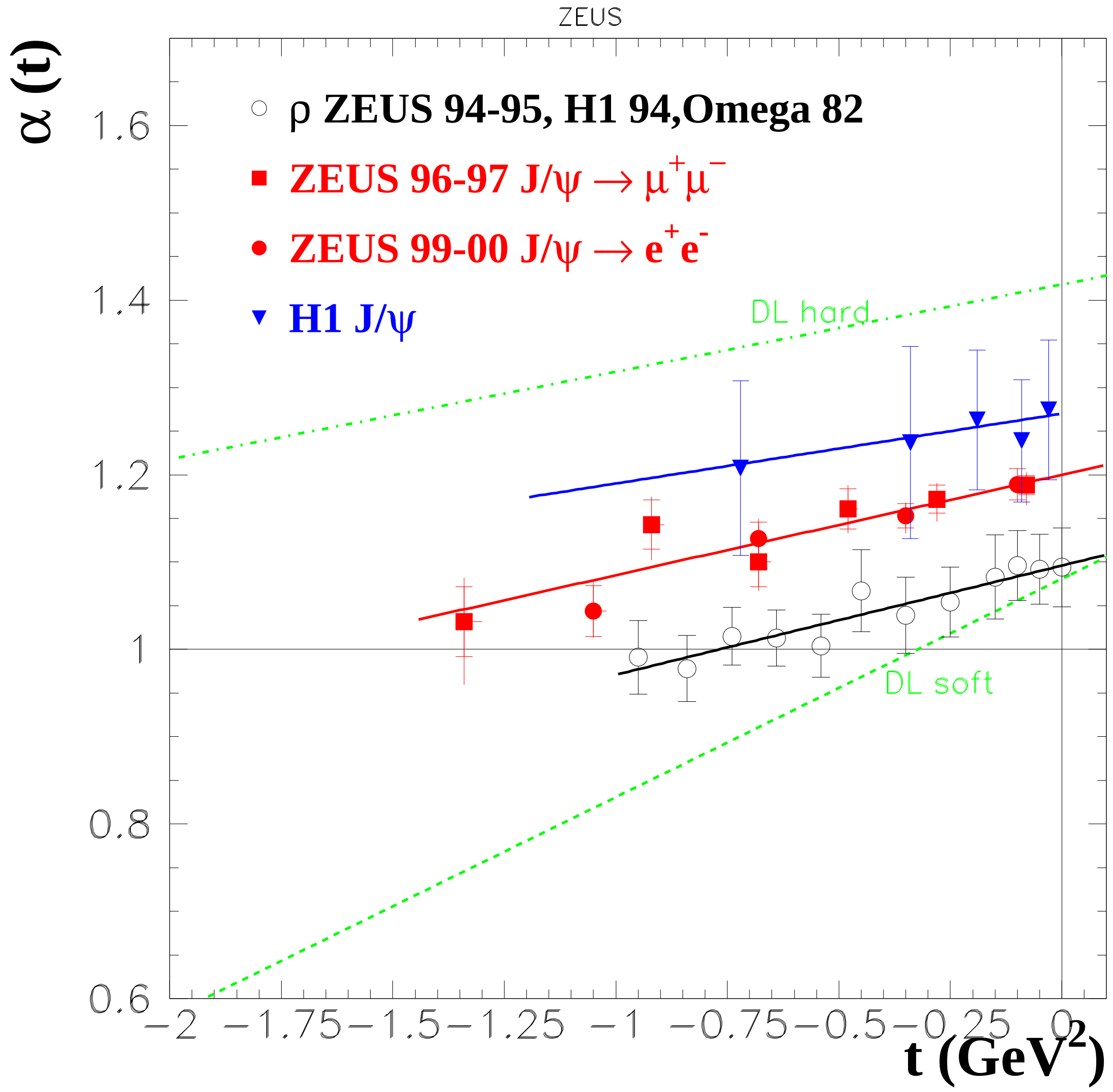
- SU(4) symmetry is not restored just by comparing the measurement at the same $Q^2 + M^2$.

ENERGY DEPENDENCE IN BINS OF t FOR J/ψ IN PHOTOPRODUCTION.



- Regge: $\frac{d\sigma(\gamma p \to V p)}{dt} \propto e^{-b_0|t|}(W^2/W_0^2)^{2(\alpha(t)-1)}$
- In each t bin: $\frac{d\sigma}{dt}|_t \propto (\frac{W}{W_0})^{\delta}$
- From fit in each bin: $\alpha(t) = \frac{\delta}{4} + 1$

$\alpha_{I\!P}(t)$ FROM ρ AND J/ψ IN PHOTOPRODUCTION.



Measured trajectory vary with mass

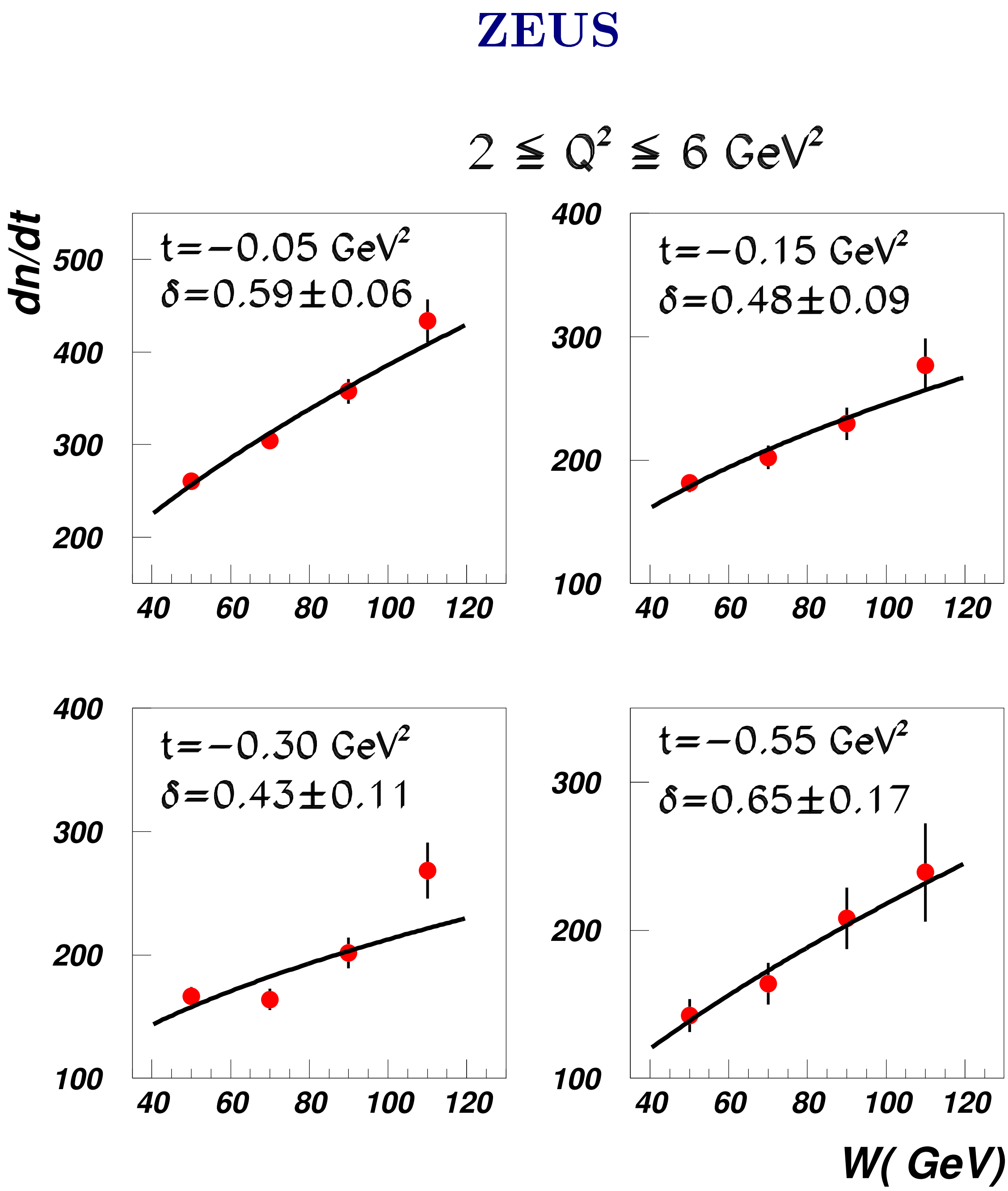
ρ: $\alpha_{I\!P}(t) = (1.096 \pm 0.021) + (0.125 \pm 0.038)t$

$J\psi$ (H1): $\alpha_{I\!P}(t) = (1.27 \pm 0.05) + (0.08 \pm 0.017)t$

$J\psi$ (ZEUS): $\alpha_{I\!P}(t) =$

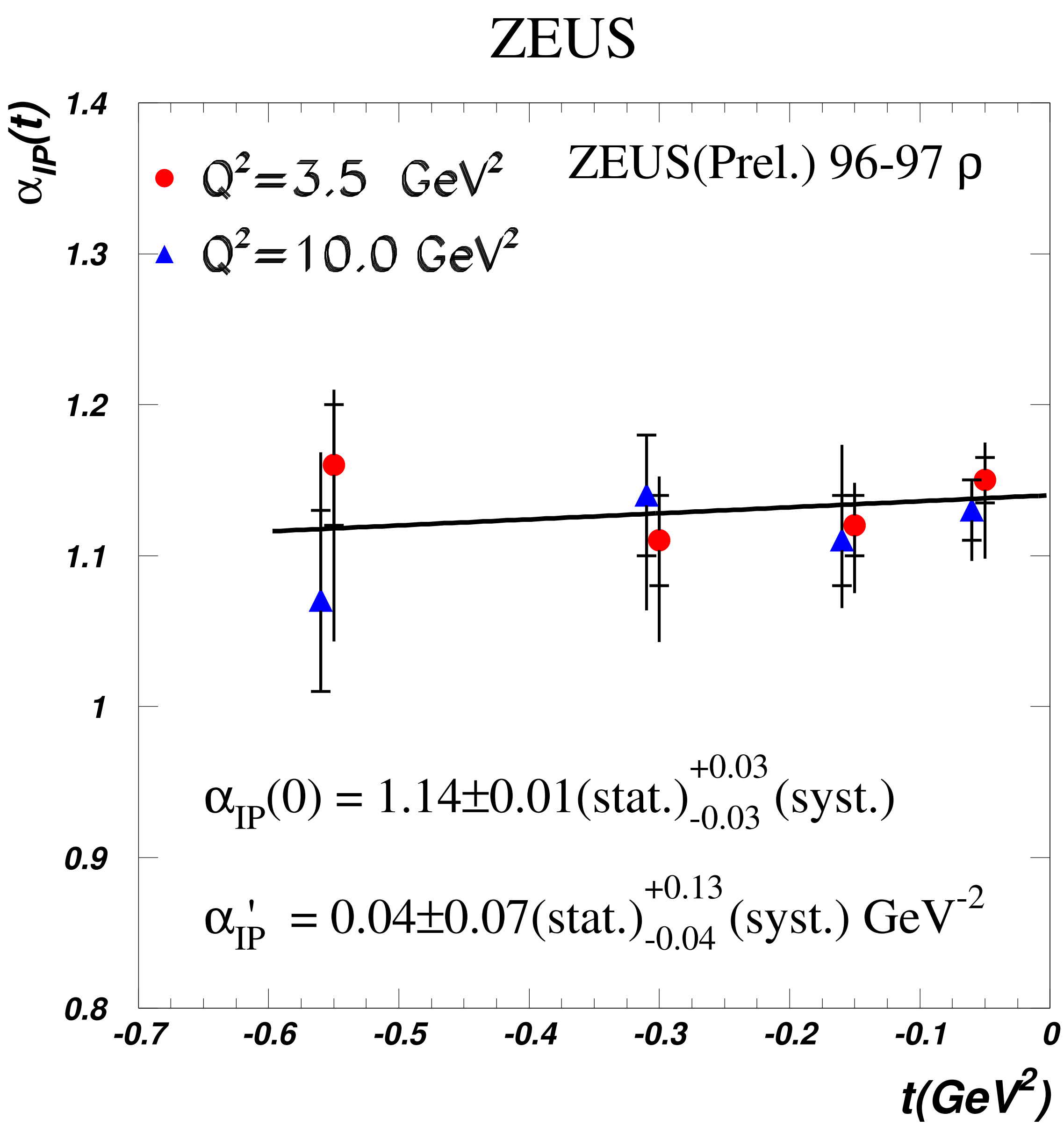
$(1.200 \pm 0.009^{+0.004}_{-0.010}) + (0.115 \pm 0.018^{+0.008}_{-0.015})t$

ENERGY DEPENDENCE IN BINS OF t FOR ρ IN DIS.



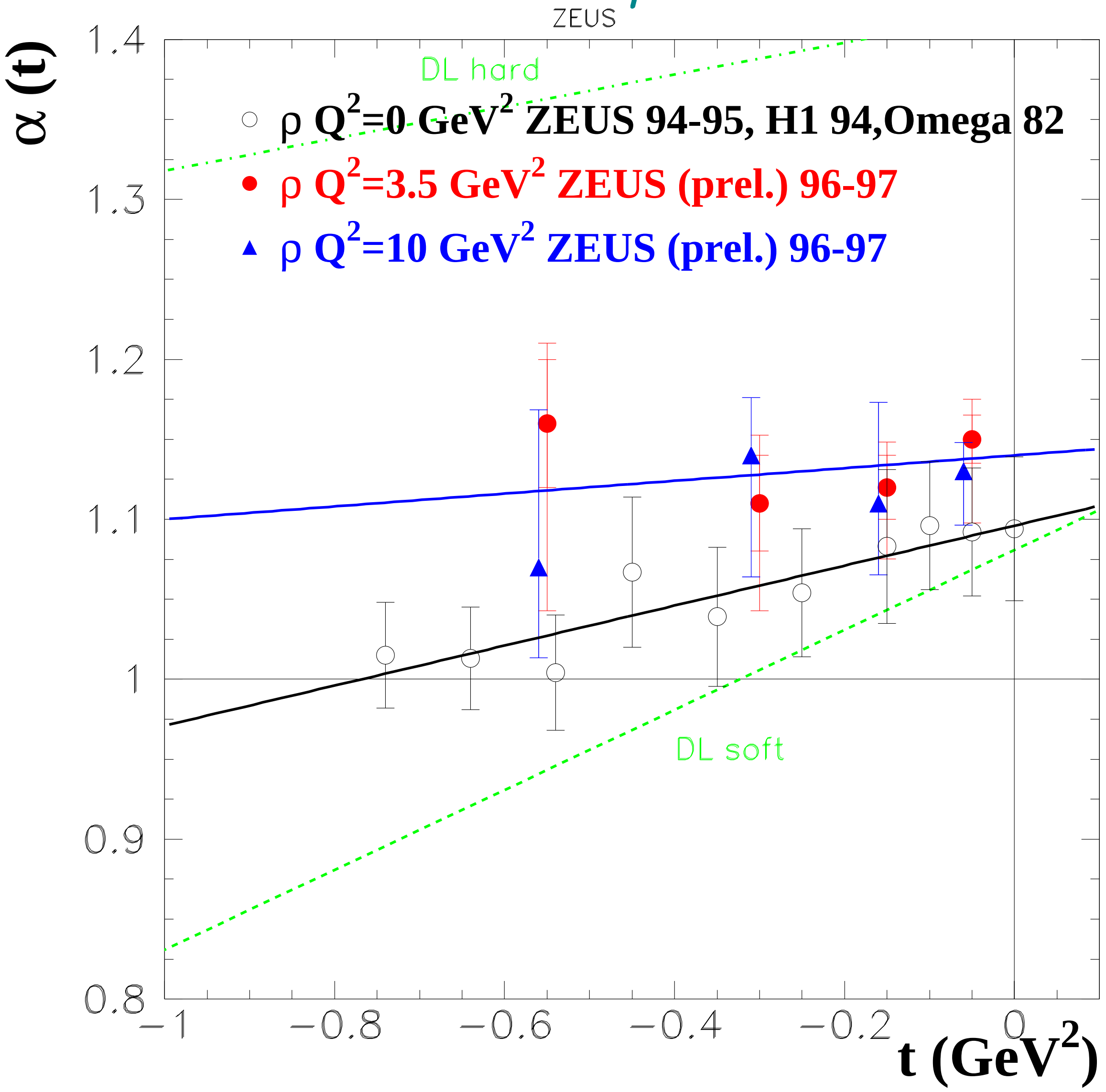
$$\frac{dN}{dt} \propto \left(\frac{W}{W_0}\right)^{\delta} \rightarrow \alpha(t) = \frac{\delta}{4} + 1$$

Pomeron trajectory from DIS ρ



- Trajectory consistent with small shrinkage in DIS
- Different trajectory is measured for ρ DIS and ρ photoproduction

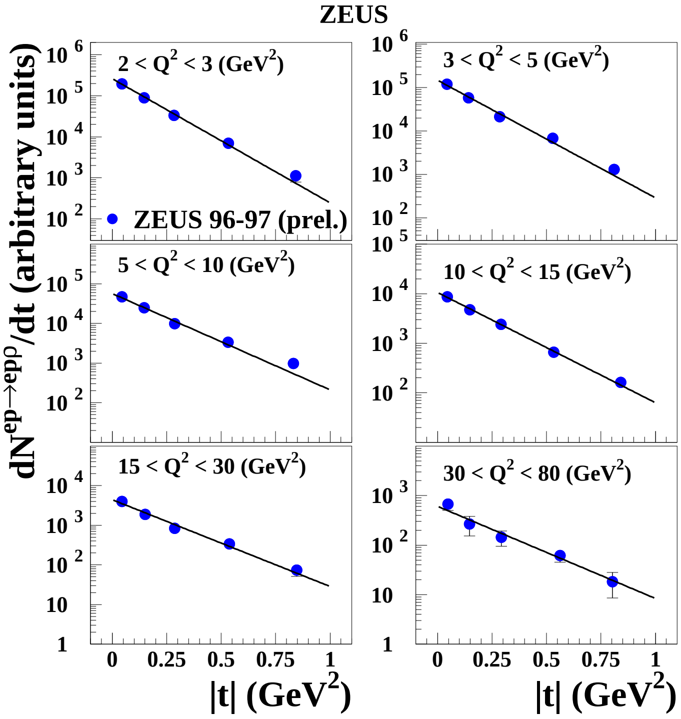
Pomeron trajectory from DIS ρ



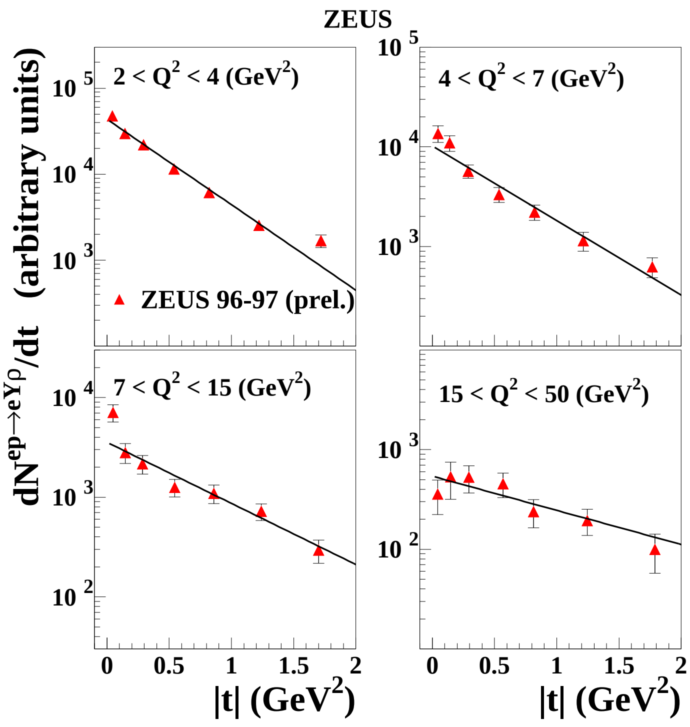
$$\alpha_{I\!P}(t) = (1.14 \pm 0.01^{+0.03}_{-0.03}) + (0.04 \pm 0.07^{+0.13}_{-0.04})t$$

- Trajectory consistent with small shrinkage in DIS
- Different trajectory is measured for ρ DIS and ρ photoproduction

Elastic and proton-dissociation ρ at low t in Q^2 bins

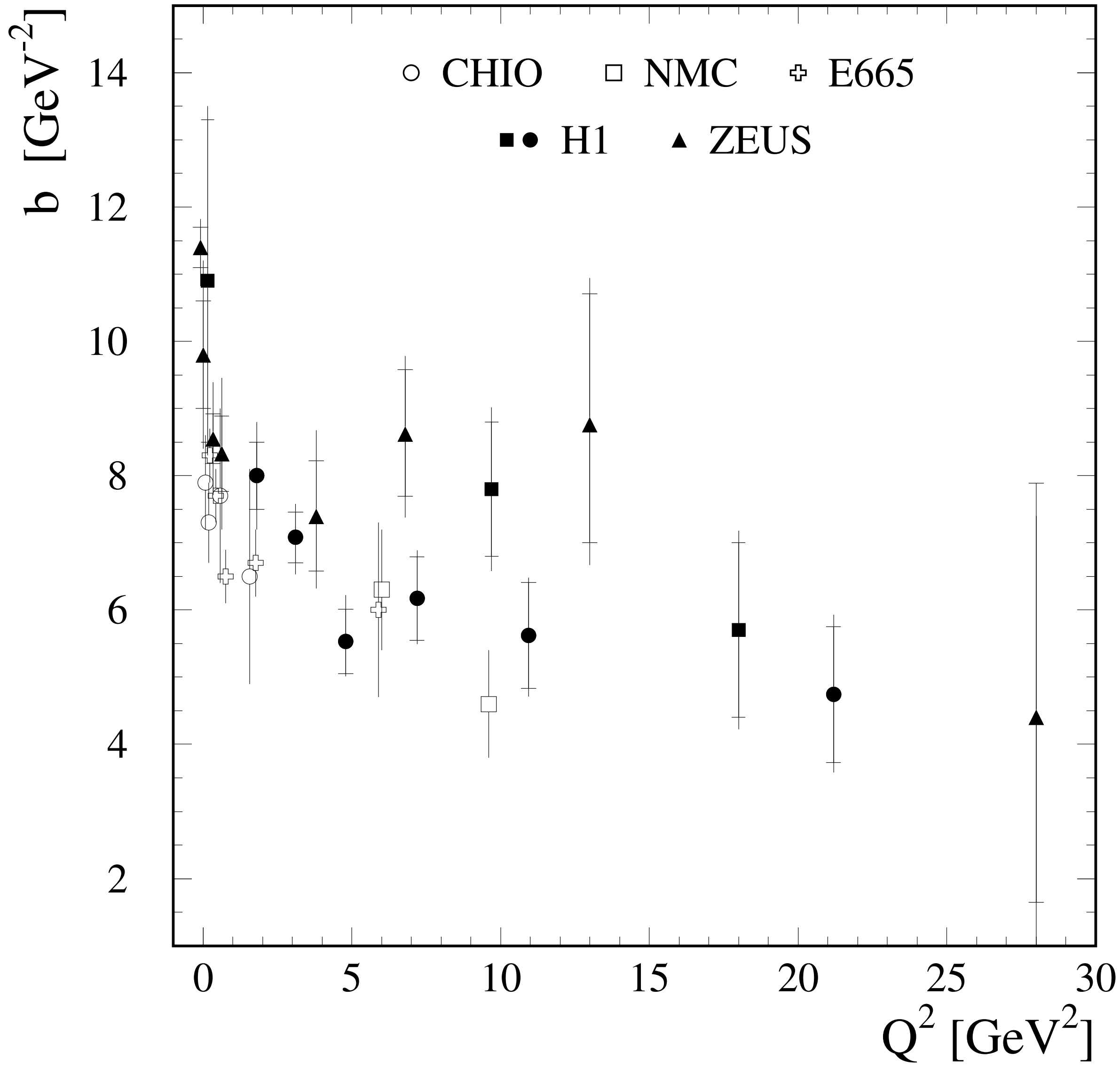


$$\frac{dN}{dt} \propto \exp\left(bt\right)$$



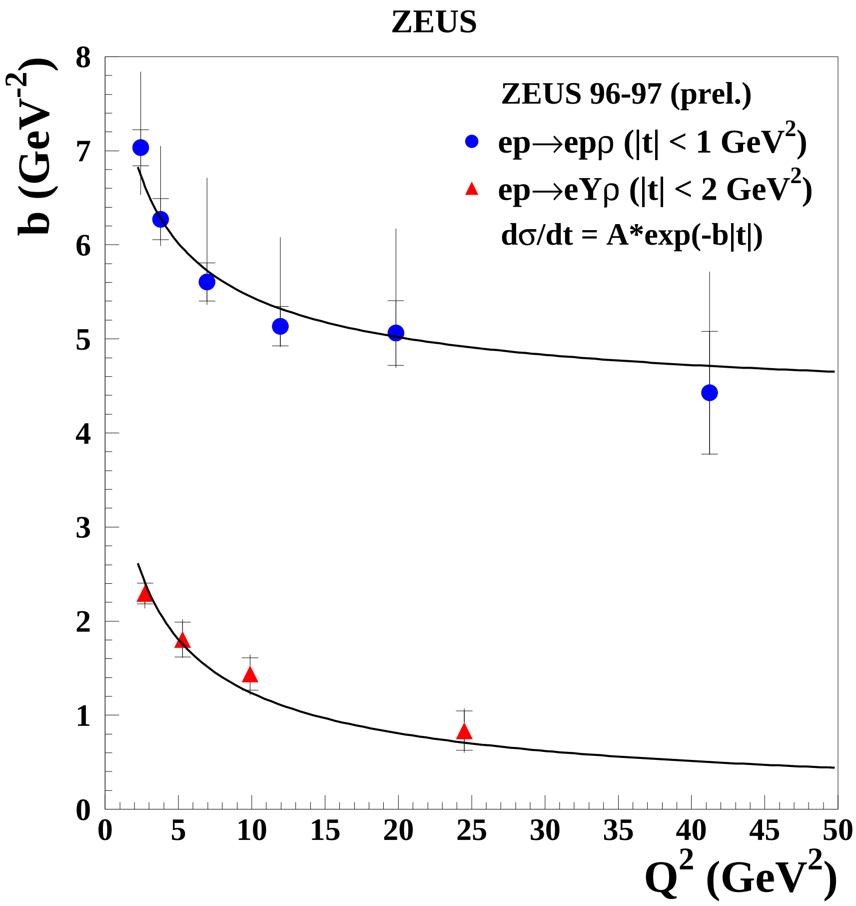
At low t the cross sections decrease exponentially with t.

b slope - Elastic ρ

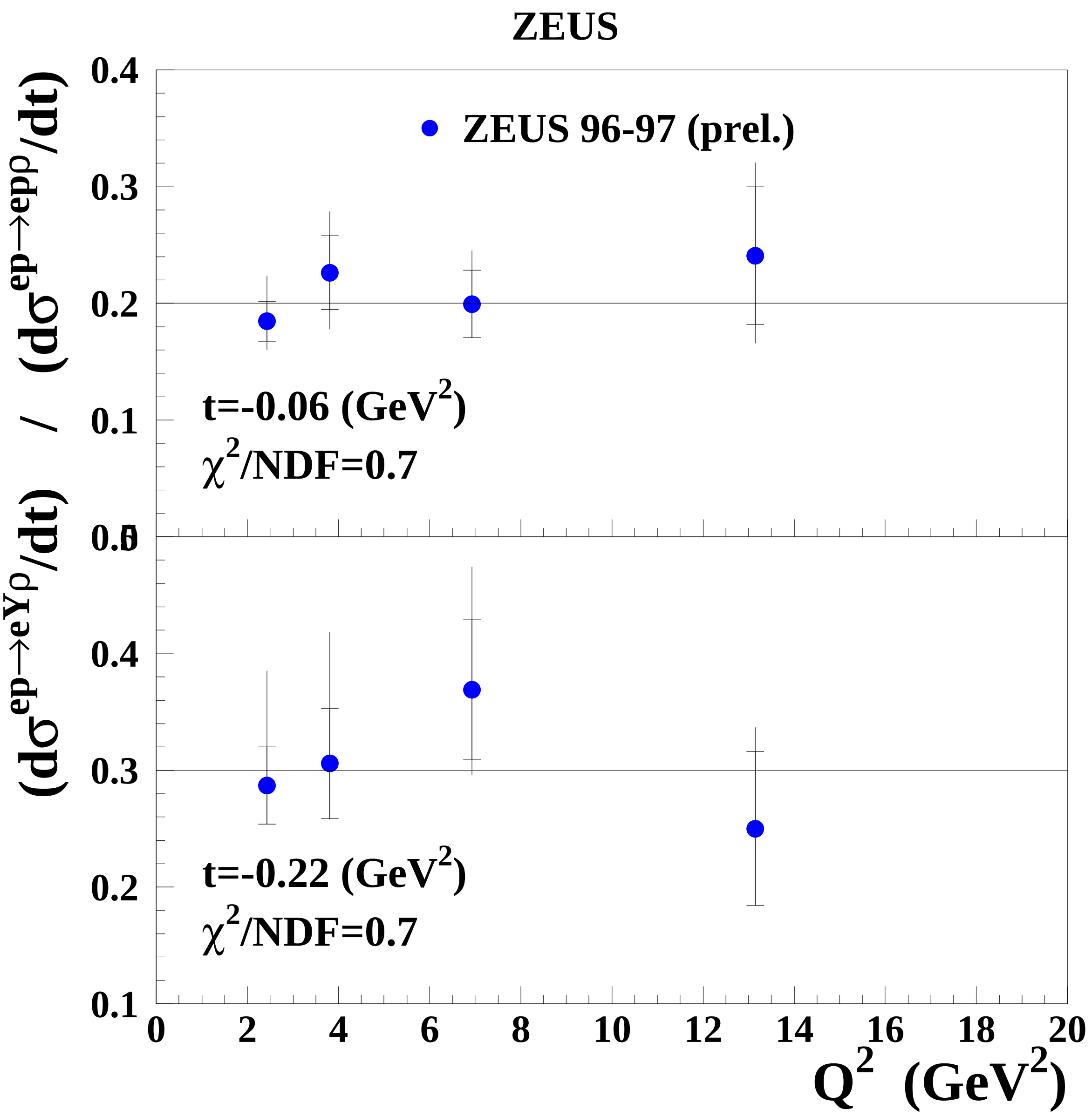


$b(Q^2)$ is observed to decrease with Q^2 to an asimptotic value of $b \approx 4\,\mathrm{GeV}^{-2}$

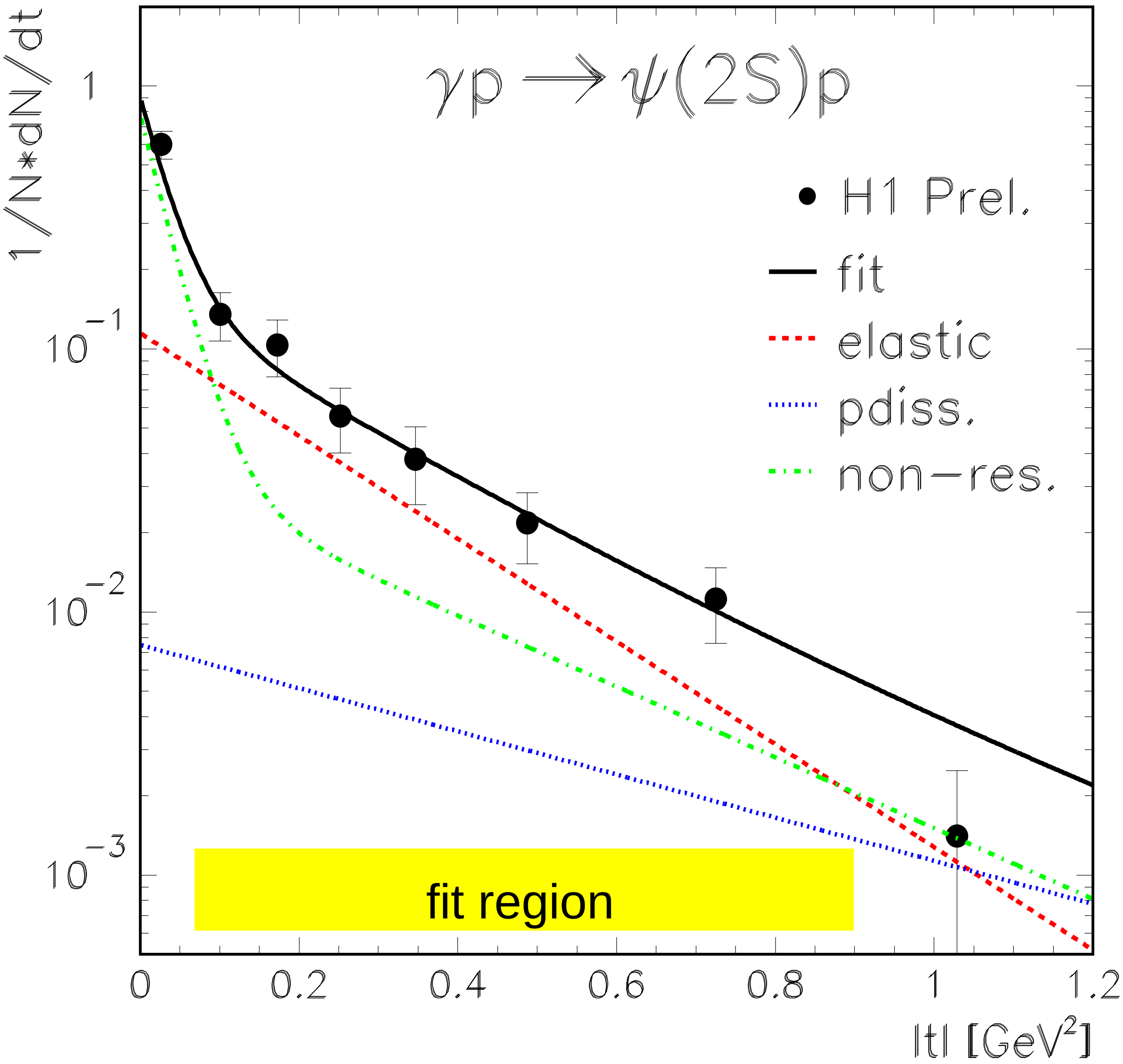
b slope - Elastic and proton-dissociation ρ



- Elastic and proton-dissociation ρ^0 show similar Q^2 behavior.
- b slope is proportional to the size of interaction.
- $b_{el} \propto R^2_{q\bar{q}}(Q^2) \oplus R^2_p, \quad b_{pd} \propto R^2_{q\bar{q}}(Q^2) \oplus ?$
- $b_{pd}(Q^2) = A/(M^2(1+R))$
- $b_{el}(Q^2) = b_{pd}(Q^2) + b_2$
- $R = \frac{\sigma_L}{\sigma_T} = \xi(Q^2/M^2)^\kappa$
- $A = 3.46 \pm 0.14, \quad b_2 = 4.21 \pm 0.12\,\mathrm{GeV}^{-2}$

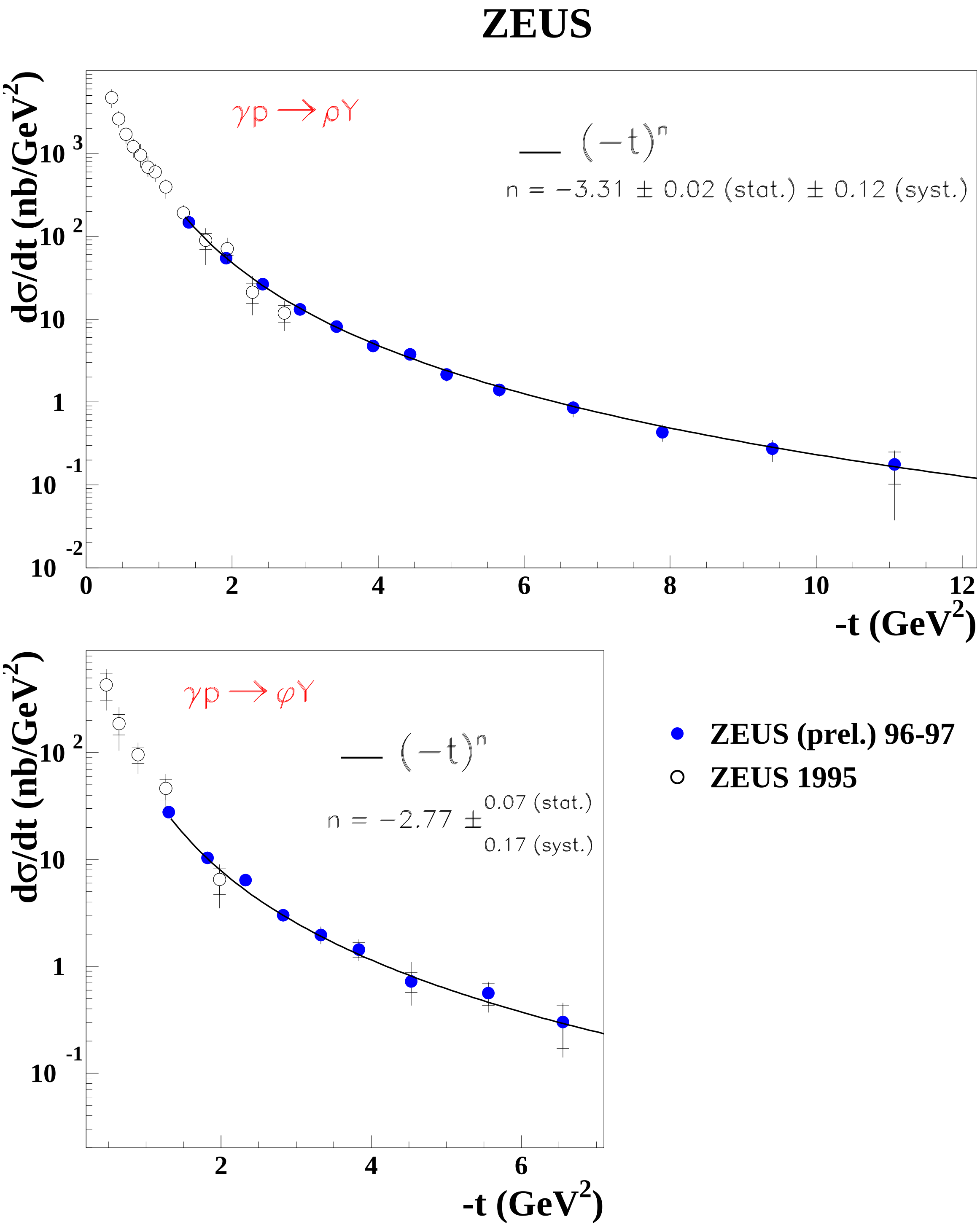


- cross sections ratio is Q^2 independent !
- Vertex factorization holds
- Leads to measurement of proton form factor, $F_p(t)$.



- 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: $b_{J/\psi} \simeq b_{\psi}{}'$
- VDM picture of VM scattering: $b_{J/\psi} < b_{\psi}{}'$

t DEPENDENCE AT HIGH t

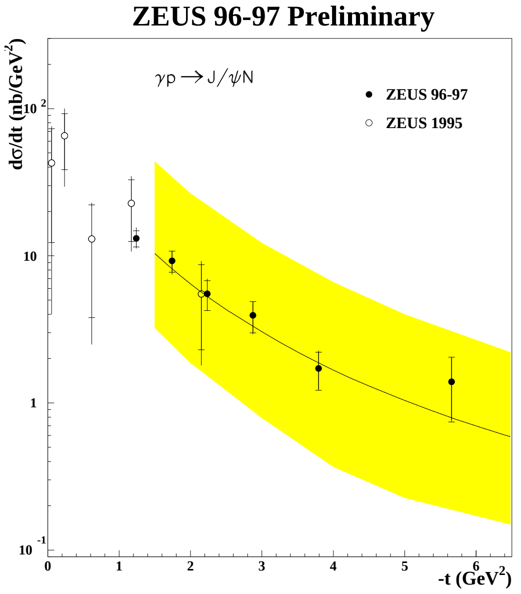


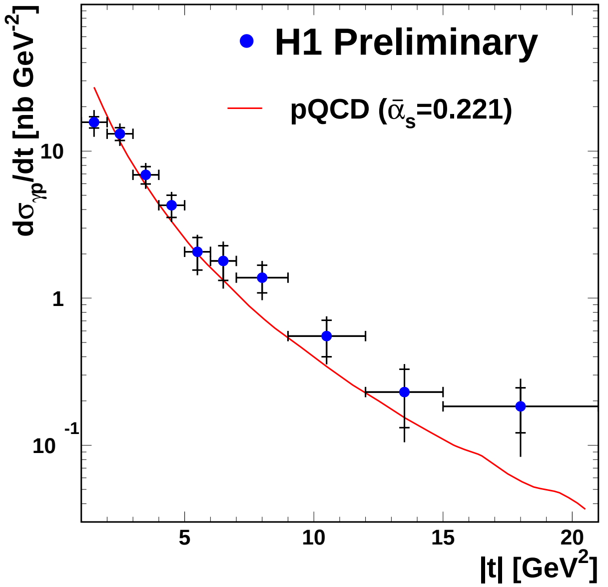
At high t the cross sections have a power-like dependence on t, as predicted by pQCD.

J/ψ production at high $|t|$

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

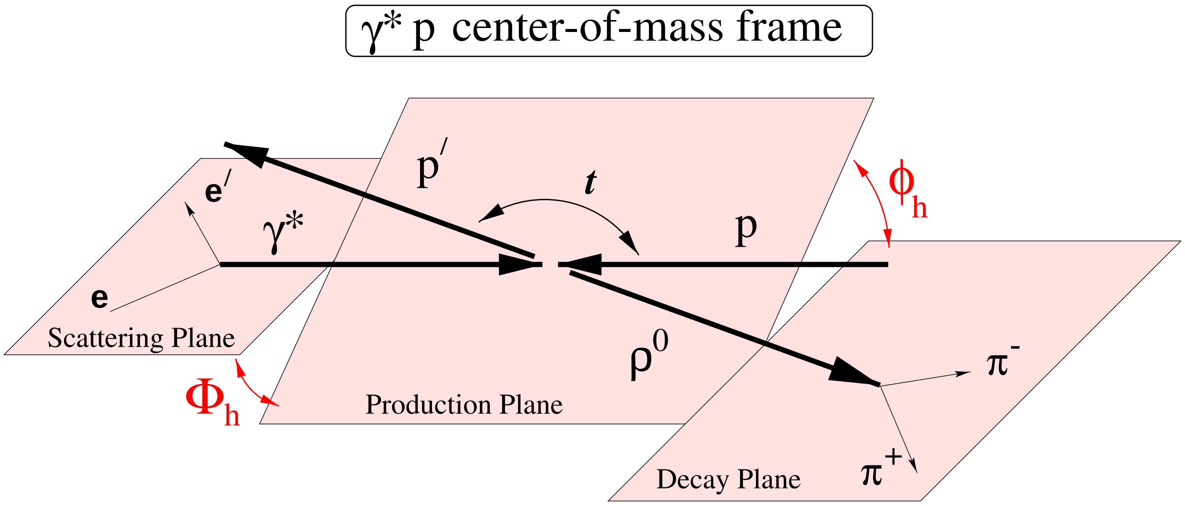
$Q^2 < 1$ GeV^2
$50 < W < 160$ GeV
19 pb^{-1}

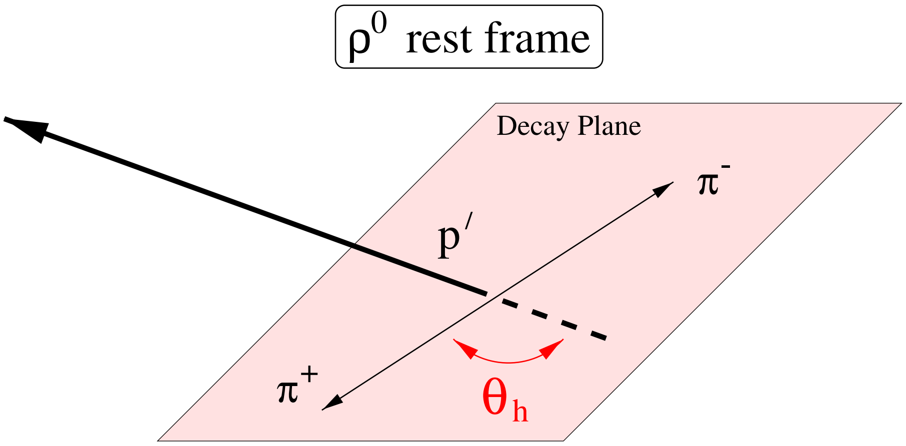




- perturbative QCD model describes data well
- large normalization uncertainties: α_s, scale

Helicity Analyses





Φ_h Angle between the electron scattering plane and the ρ^0 production plane

θ_h Polar angle of π^+ in the ρ^0 rest frame

ϕ_h Azimuthal angle of π^+

Helicity analysis

The angular distribution $W(\cos\theta_h, \phi_h, \Phi_h)$ is parameterized by linear combinations,r_{ij}^{α}, of the ρ^0 spin-density matrix elements.

Transition amplitudes

No helicity flip

$T_{00} : \gamma_L \to \rho_L \quad T_{11} : \gamma_T \to \rho_T$

Single flip

$T_{01} : \gamma_T \to \rho_L \quad T_{10} : \gamma_L \to \rho_T$

Double flip

$T_{1-1} : \gamma_T \to \rho_T$

Relations to transition amplitudes

$r_{00}^{04} \propto \frac{|T_{00}|^2 + |T_{01}|^2}{N}$

$r_{00}^{5} \propto \frac{1}{N}(T_{00}T_{01}^{\dagger})$

$r_{11}^{5} \propto \frac{1}{N}(T_{11}T_{10}^{\dagger} - T_{10}T_{1-1}^{\dagger})$

$r_{00}^{1} \propto -\frac{|T_{01}|^2}{N},$

$r_{11}^{1} \propto \frac{1}{N}(T_{11}T_{1-1}^{\dagger})$

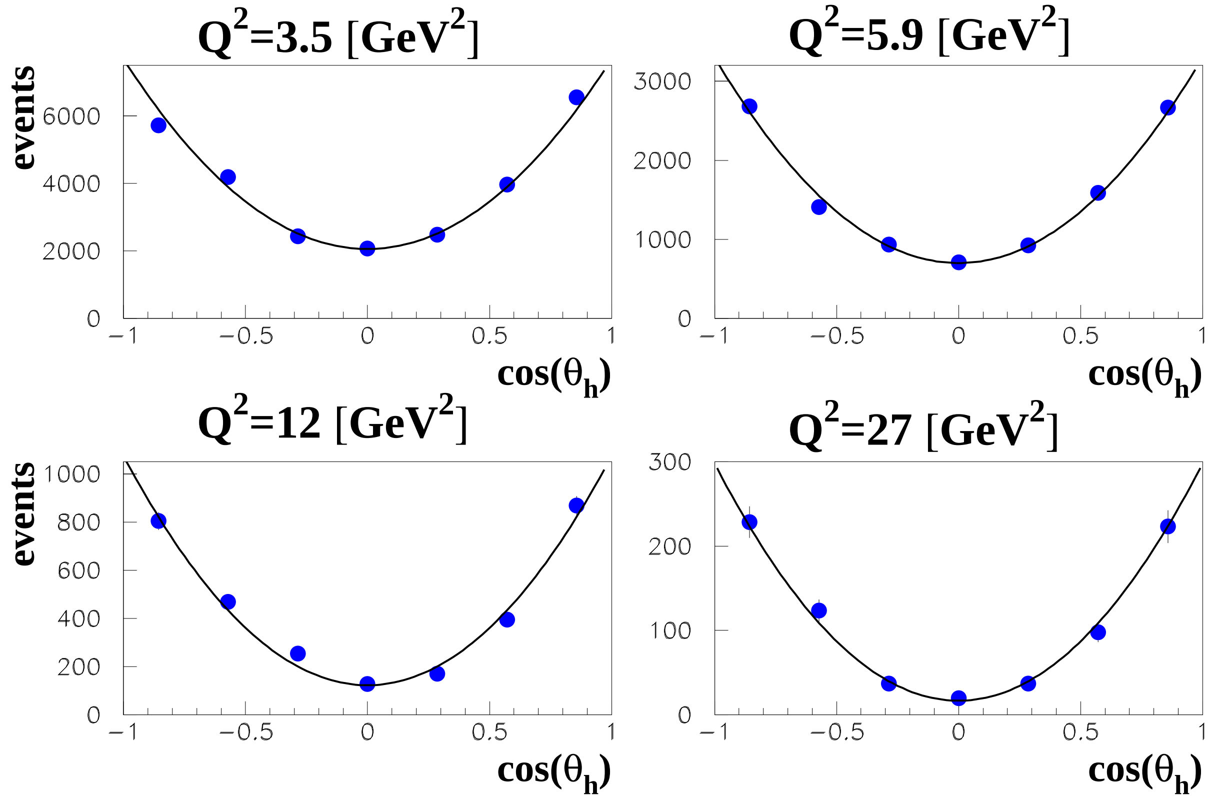
$N = \sum_{i,j} |T_{ij}|^2, \;\; i = \lambda_\rho, j = \lambda_\gamma \;\; = -1, 0, 1$

Helicity analysis

pQCD predictions

- $R = \sigma_L/\sigma_T$ increases with Q^2, σ_L dominates at high Q^2.
- Hierarchy at high Q^2
  $|T_{00}| > |T_{11}| > |T_{01}| > |T_{10}| > |T_{1-1}|$
- t dependence
  - no helicity flip: $T_{11} \propto T_{00}$ constant in t
  - single helicity flip: T_{01}, $T_{10} \propto T_{00}\sqrt{t}$
  - double helicity flip: $T_{1-1} \propto T_{00}t$.

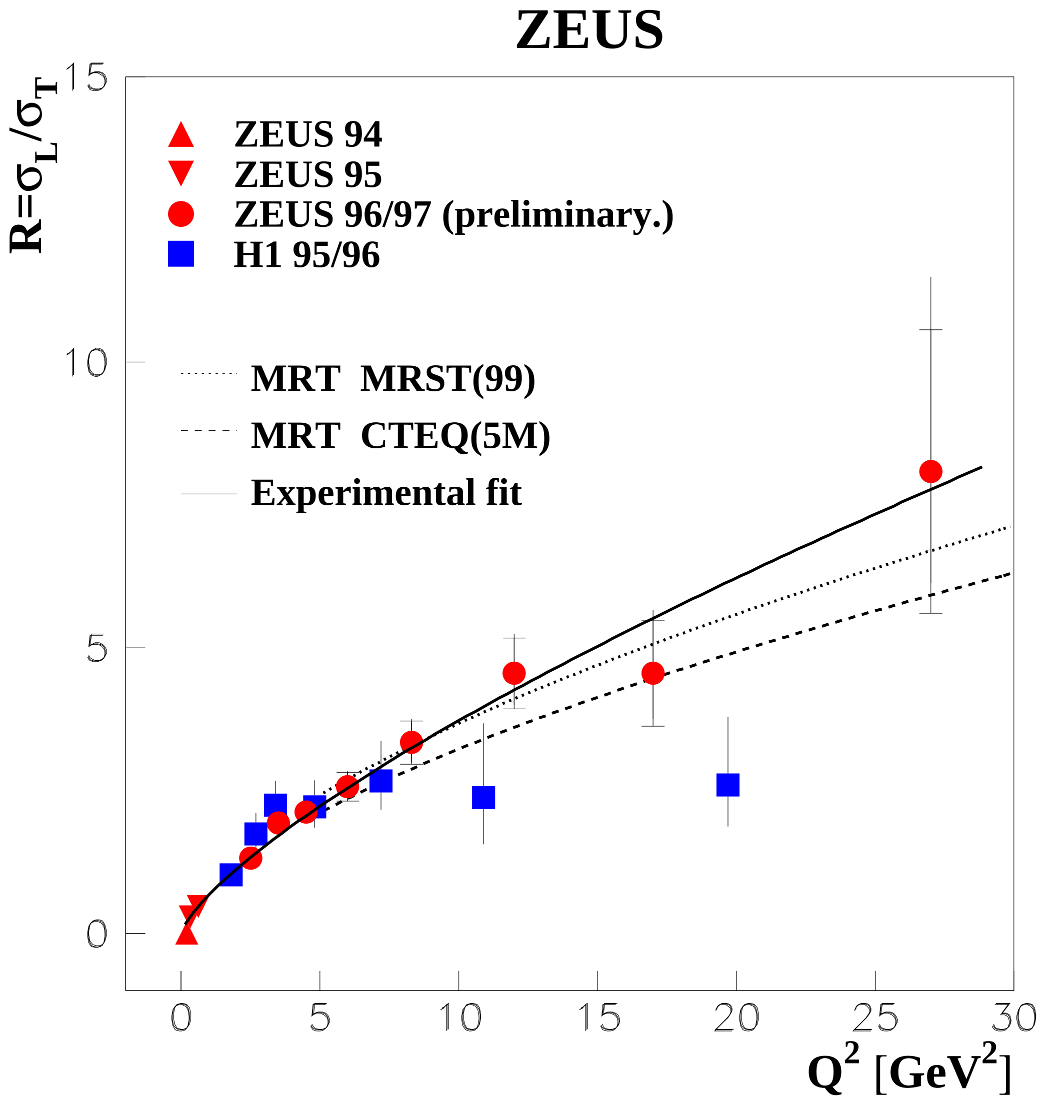
HELICITY ANALYSIS IN BINS OF Q^2 AND W (ZEUS $\gamma_T^* p \to \rho p$)



The $cos(\theta_h)$ distribution

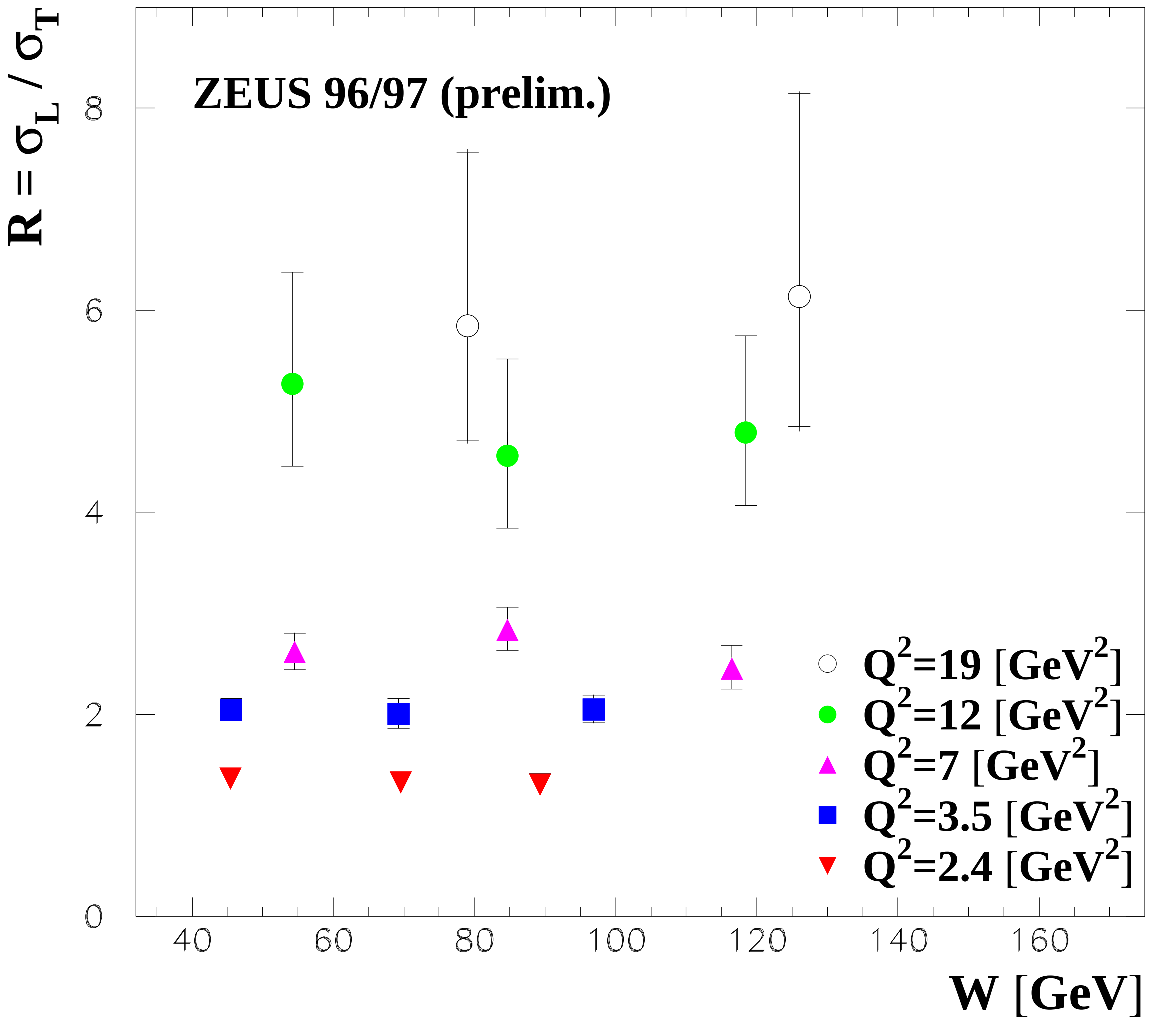
$$W(cos(\theta_h)) = \frac{3}{8\pi}(1 - r_{00}^{04}) + (3r_{00}^{04} - 1)cos^2(\theta_h)\,.$$

$$R = \sigma^{\gamma_L^* p \to \rho p} / \sigma^{\gamma_T^* p \to \rho p}$$



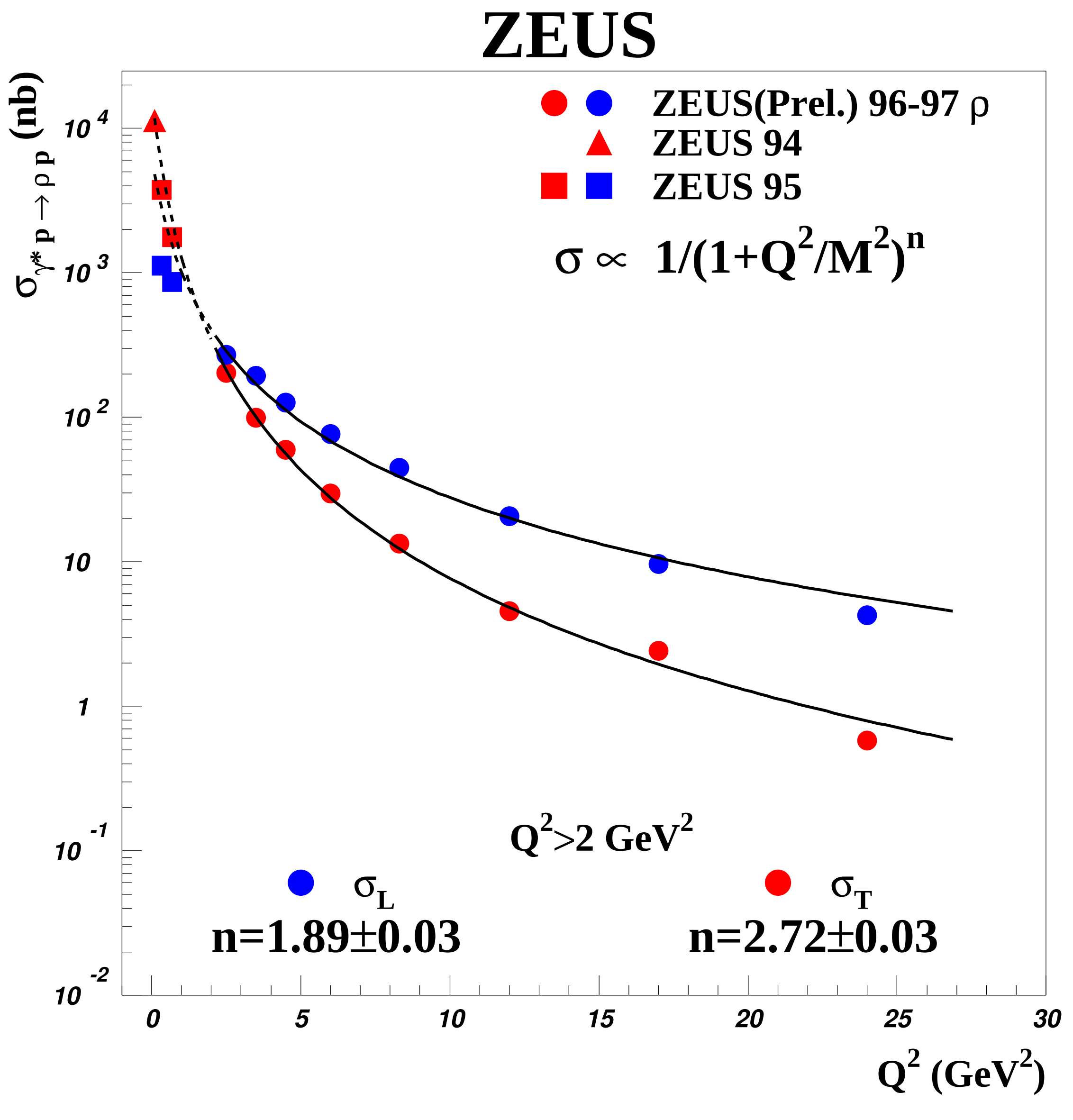
- R increases with Q^2, consistent with pQCD predictions.
- Experimental fit $R(Q^2) = (Q^2/M^2)^\kappa/\xi$
  $\xi = 2.16 \pm 0.05$, $\kappa = 0.74 \pm 0.02$.

$R(W)$ FOR FIXED Q^2
$\gamma_T^* p \to \rho p$



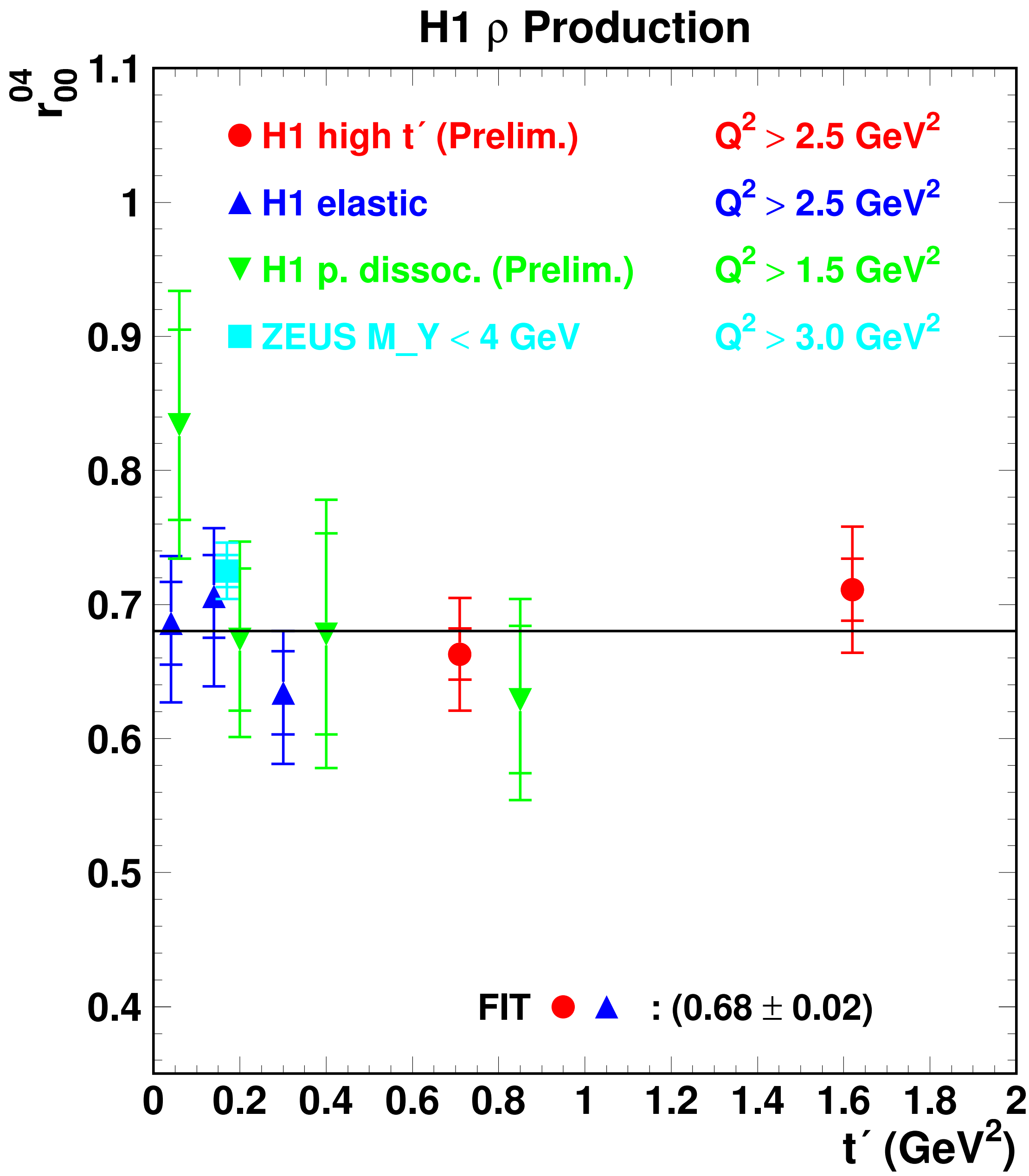
σ_T AND σ_L HAVE SIMILAR ENERGY DEPENDENCE.

$$\sigma_{\gamma^*_{L,T} p \to \rho p}(Q^2)$$



Separate measurement of σ_L and σ_T

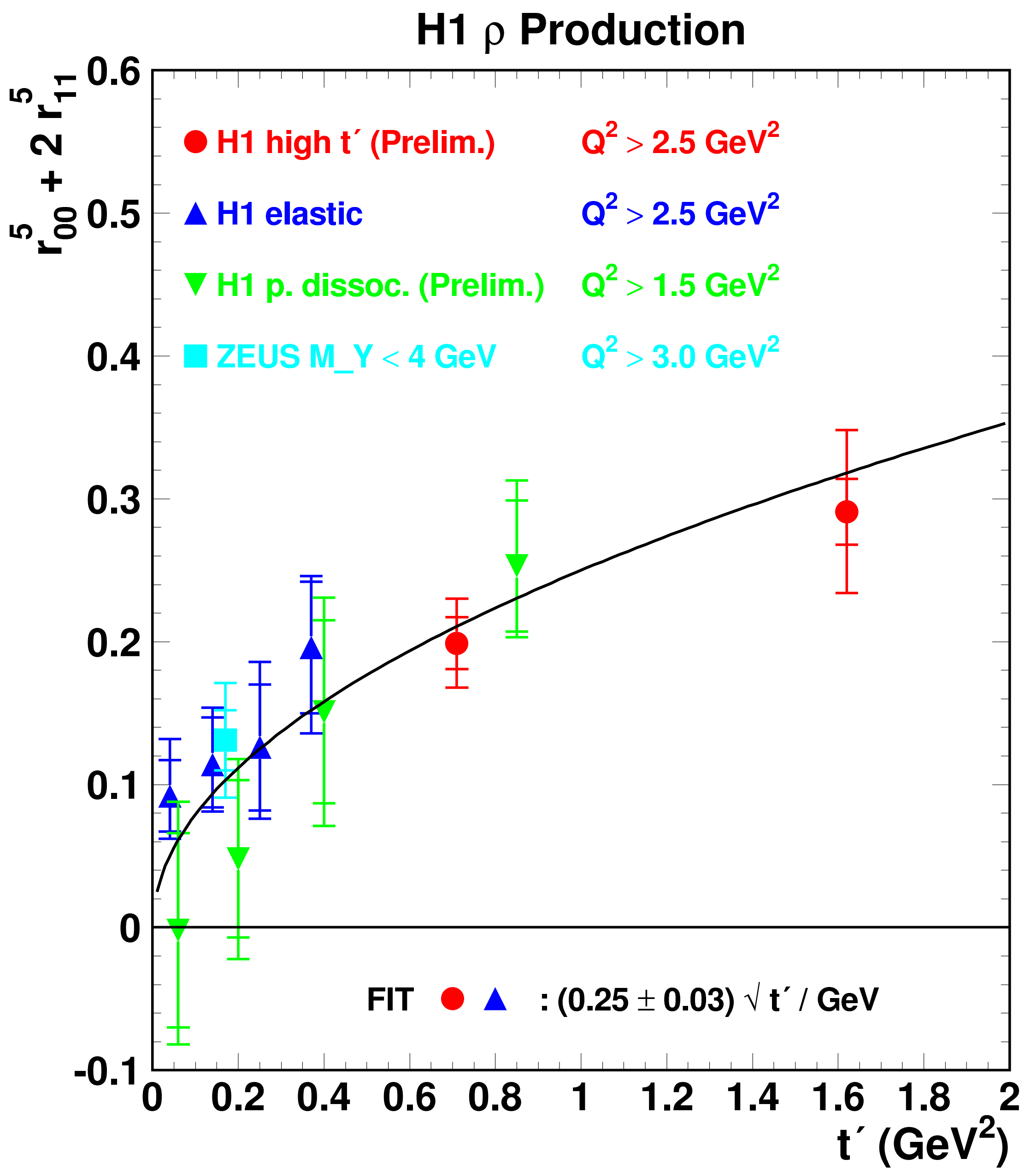
HELICITY ANALYSIS IN BINS OF t



No helicity flip

$$r^{04}_{00} \simeq \frac{|T_{00}|^2+|T_{01}|^2}{N} \simeq \sigma_L/\sigma_{TOT}$$

No visible t dependence, as expected.

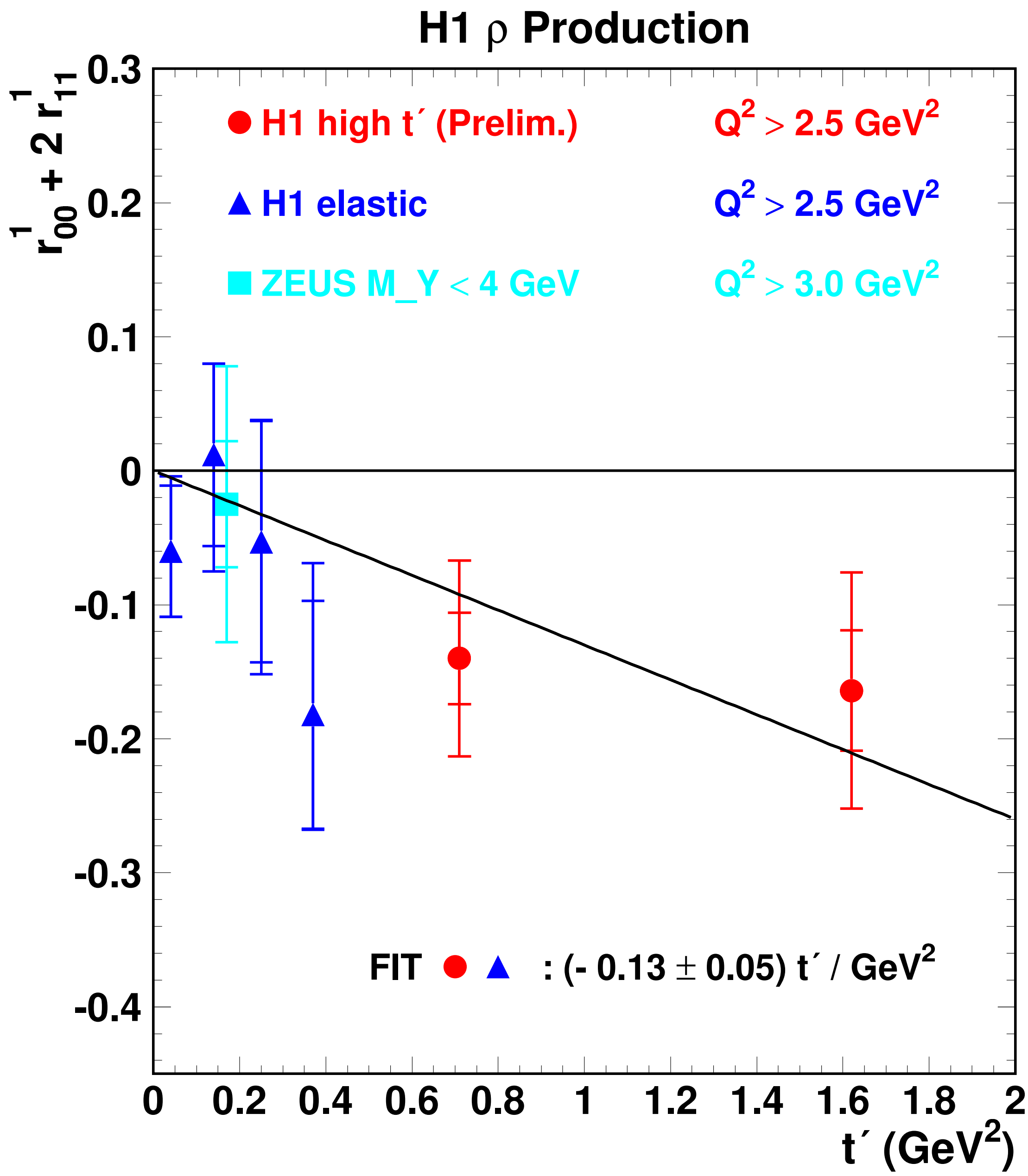


single flip

$$r^5_{00} + 2r^5_{11} \propto \frac{1}{N}(T_{00}T^\dagger_{01} + 2T_{11}T^\dagger_{10} - 2T_{10}T^\dagger_{1-1})$$

t dependence measured to be proportional to $\sqrt{t}$.

t dependence is due to the T_{01} single flip $\gamma_T \to \rho_L$ as expected.



double flip

Proportional to t within large errors

- $r^1_{00} \propto -\frac{|T_{01}|^2}{N} \propto (\sqrt{t})^2 \quad (T_{01}\text{=single flip})$
- $r^1_{11} \propto \frac{1}{N}(T_{11}T^\dagger_{1-1}) \propto t \quad (T_{1-1}\text{=double flip})$
- $|T_{01}|^2 > (T_{11}T^\dagger_{1-1}) \Rightarrow T_{01} > T_{1-1}$ Hierarchy

Summary

- Energy dependence becomes steeper with increasing VM mass.
- Energy dependence becomes steeper with increasing Q^2.
- SU(3) is restored when moving the scale to $(Q^2 + M^2)$ but not SU(4).
- Measured trajectory changes with VM mass and Q^2.
- Elastic and proton-dissociation, ρ^0, b slope show similar Q^2 behavior
- Elastic ρ^0, b slope, decreases with Q^2 to a value $b \approx 4\,\mathrm{GeV}^{-2}$
- proton-dissociation ρ^0, b slope, decreases with Q^2 to a value $b \approx 0$
- t dependence changes from exponential, to power like, at high t photoproduction
- $R = \sigma_L/\sigma_T$, increases with Q^2 but flat with W

Some more points

- For DIS, no helicity flip amplitudes, are constant with t
- Single flip amplitude are proportional to $\sqrt{t}$
- Double flip amplitude are proportional to t

Conclusion

- Many exciting new precise measurements are available for VM production from H1 and ZEUS.
- Looking forward for new results higher precision and more theoretical predictions.