

Results on Vector Meson Production at HERA

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for the H1 and ZEUS Collaborations

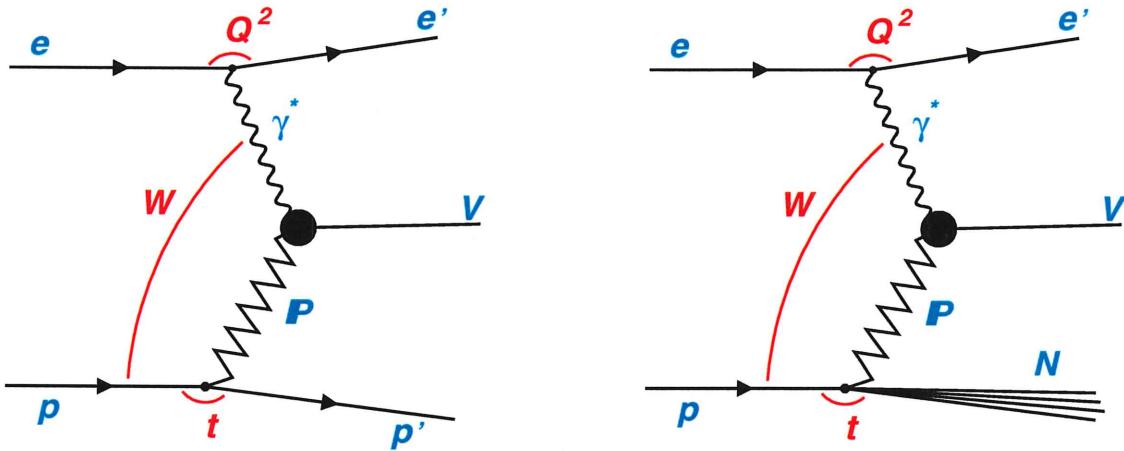
Outline

- 1. Introduction**
- 2. Energy dependence of the cross sections**
- 3. Q^2 dependence of the cross sections**
- 4. ψ' and Υ production**
- 5. Large $|t|$ study**
- 6. Polarisation study**
- 7. Vector meson production ratios**
- 8. Conclusions**

Vector Meson Production at HERA

elastic

proton dissociative

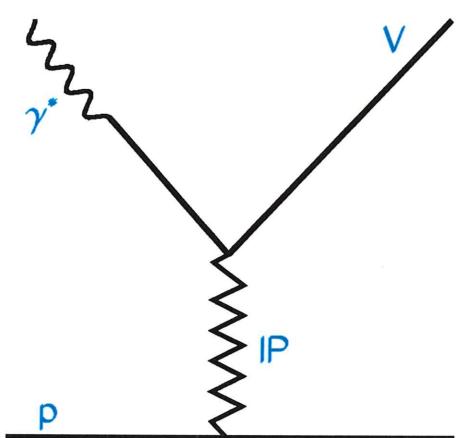


HERA data cover a wide ranges of W , Q^2 and t for several vector mesons

- W : Center-of-mass energy of $\gamma^* - p$ system
(20 – 290 GeV)
- Q^2 : Photon Virtuality
($Q^2 < 100 \text{ GeV}^2$)
- t : Square of the Momentum Transfer at the Proton Vertex
($|t| < 13 \text{ GeV}^2$)
- V : Vector Meson
($\rho, \omega, \phi, J/\psi, \psi', \Upsilon$)

Theoretical Status

- Non-perturbative Model for VM Production Description based on Regge theory and VDM



exchange of the soft Pomeran trajectory

DL parameterization

$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP} t \\ = 1.0808 + 0.25t$$

- Exponential t dependence

$$\frac{d\sigma}{dt} \propto e^{bt}$$

- Shrinkage $b(W) = b_0 + 4\alpha'_{IP} \ln(\frac{W}{W_0})$

- Slow rise of the cross section with W

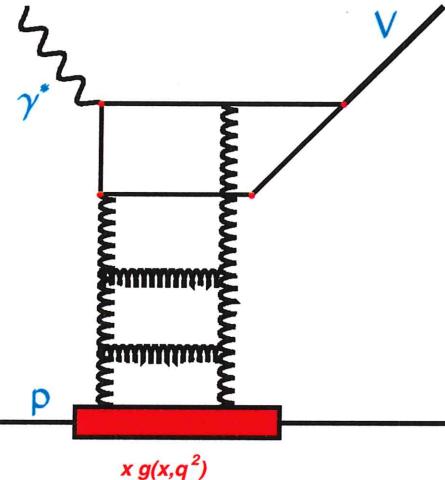
$$\sigma(W) \propto \frac{W^{4(\alpha_{IP}(0)-1)}}{b(W)} \approx W^{0.2-0.3}$$

- Q^2 dependence

$$\sigma(Q^2) \propto \frac{1}{(Q^2 + M_V^2)^2}$$

- Perturbative QCD Models for VM Production

Hard scale needed (Q^2, M_V^2, t)



Several models exist
Common feature:
Pomeron \rightarrow system of gluons

- Steep increase of the cross section with W

$$\sigma \sim [\bar{x}g(\bar{x}, \bar{q}^2)]^2 \sim W^{0.8-1.6}$$

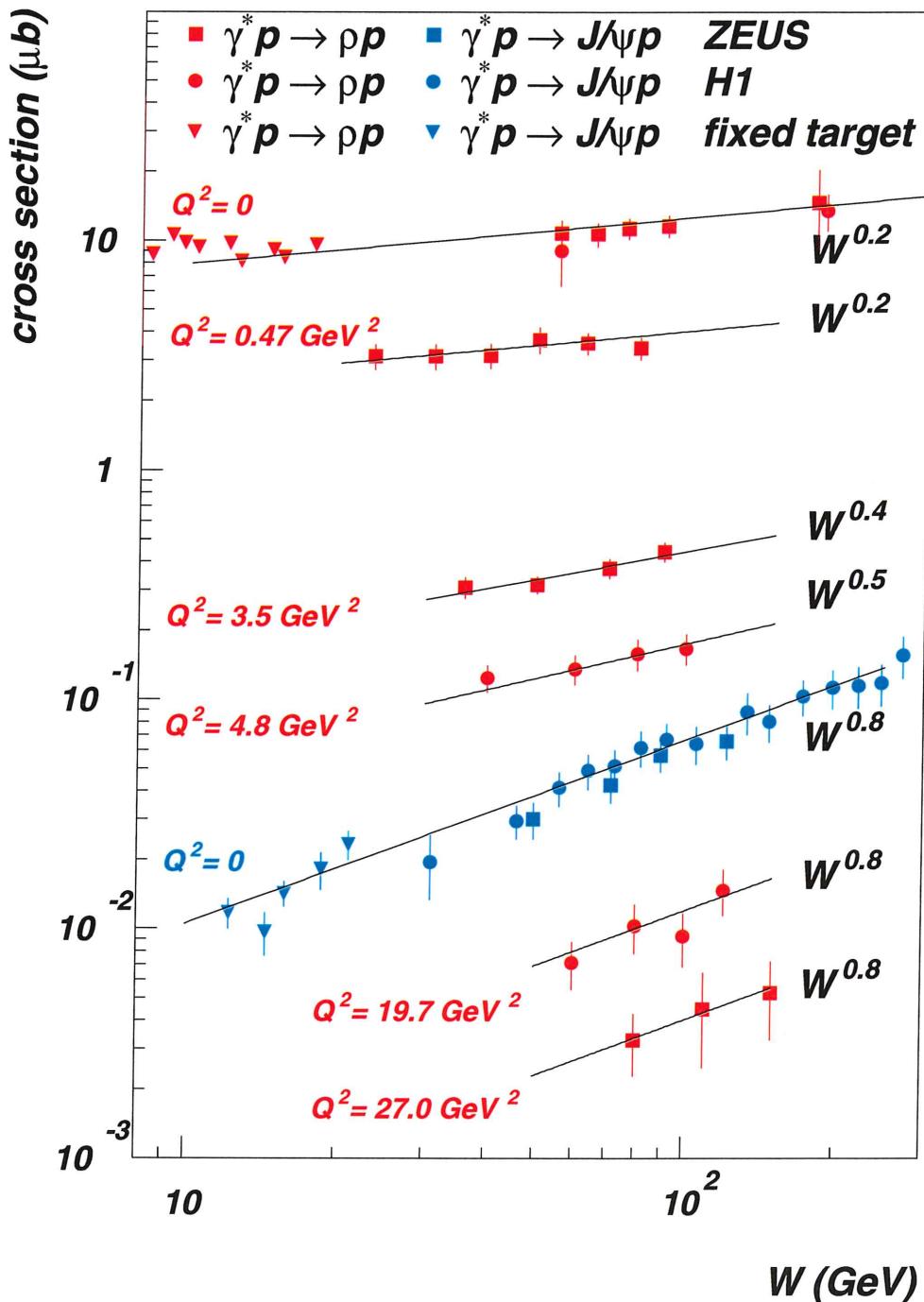
Models differ in the choice of scales:

$$\bar{x} = \frac{Q^2 + M_V^2}{W^2} , \quad \bar{q}^2 = Q^2 + M_V^2$$

$$\bar{x} = \frac{M_V^2 + Q^2 - t}{W^2} , \quad \bar{q}^2 = \frac{M_V^2 + Q^2 - t}{4}$$

- Expect Q^2 and W dependence of $R = \sigma_L/\sigma_T$
- Approximate flavor independence
- $\alpha'_P^{eff} < 0.25$ small shrinkage
- Specific spin structure (breaking SCHC)

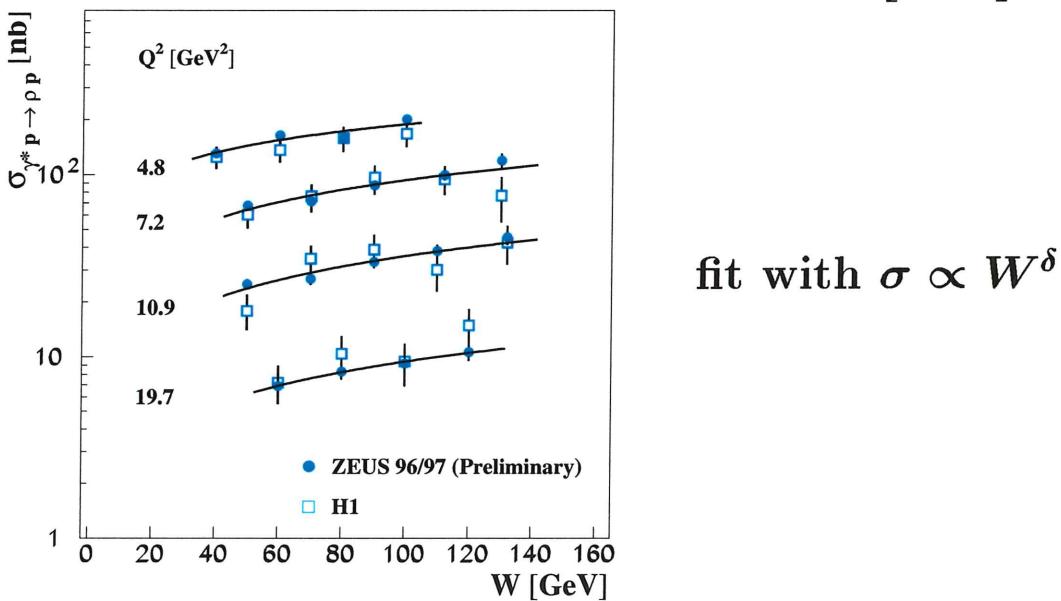
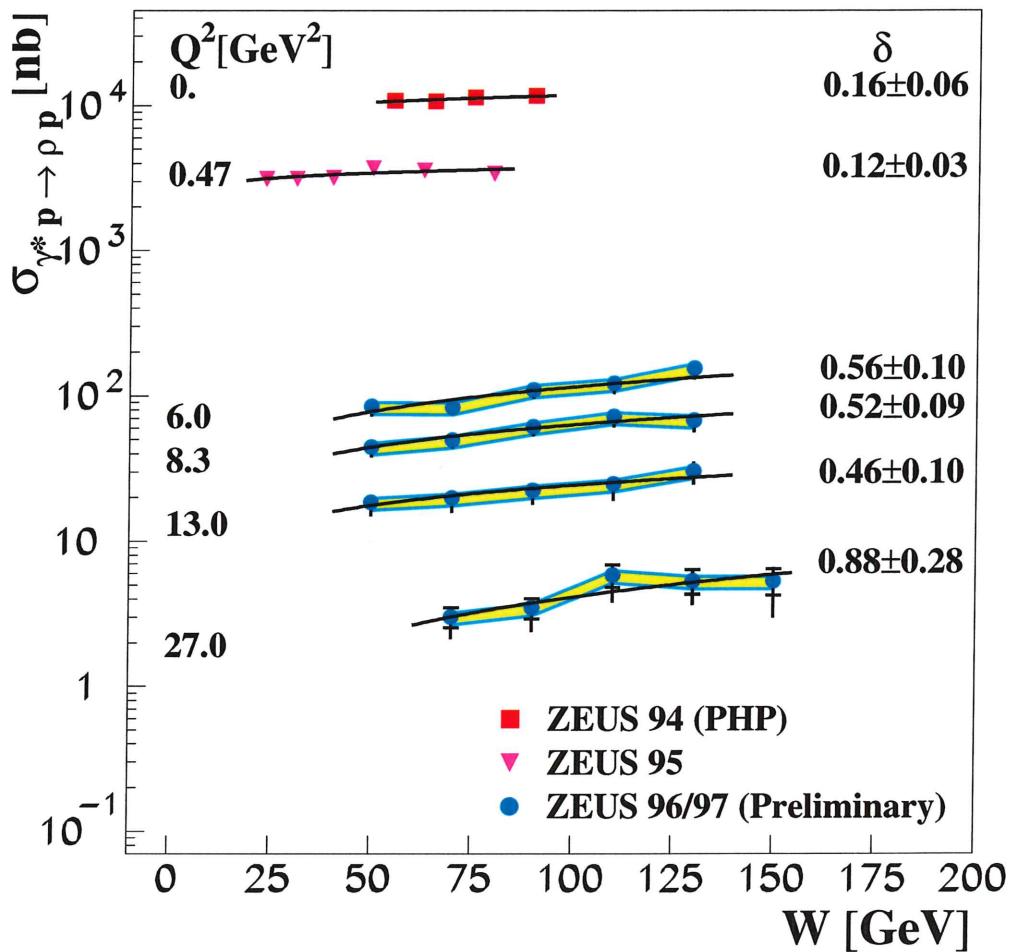
2. Energy dependence of the cross section



low mass, low Q^2 - shallow rise of σ with W

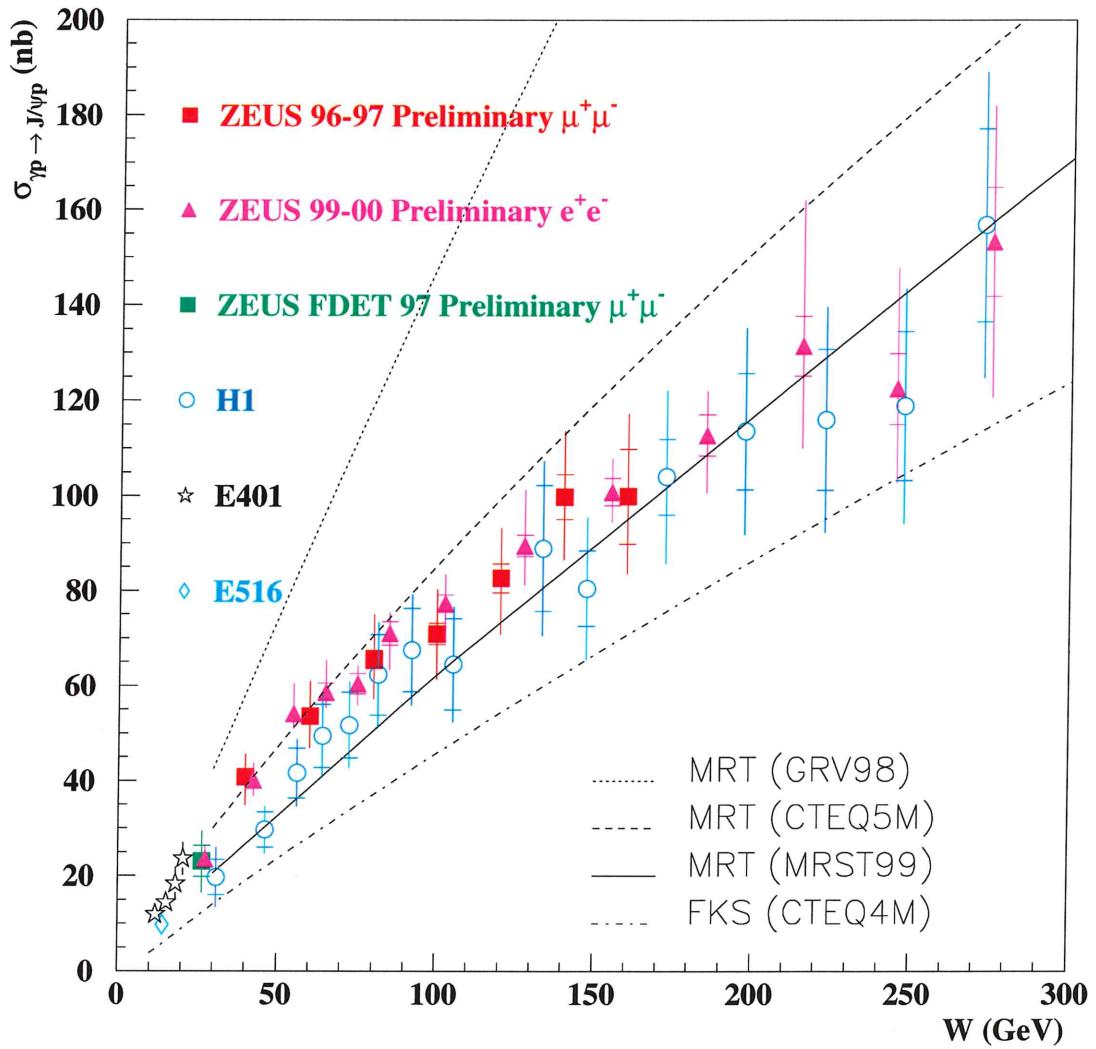
high mass or high Q^2 - steep increase of σ with W

ρ Electroproduction



Data indicate transition to hard regime
H1 and ZEUS results are in good agreement

J/ψ Photoproduction



Steep rise of cross section with W

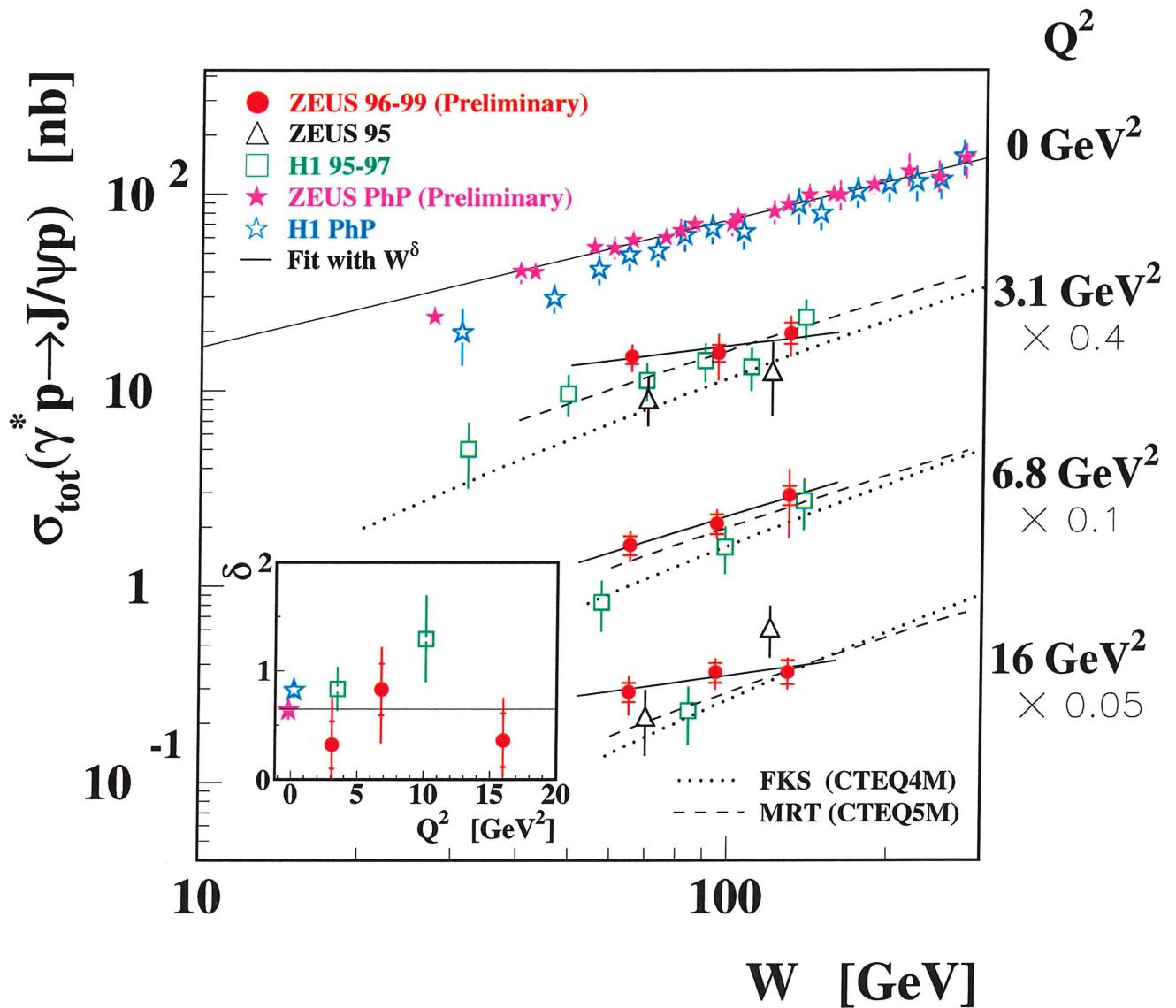
Compatible with models based on pQCD with W dependence coupled to the gluon density

Frankfurt, Koepf and Strikman, Phys. Rev. D 57 (1998) 512

Martin, Ryskin and Teubner, Phys. Lett. B 454 (1999) 339

Sensitivity to the parameterization of the gluon density in the proton

J/ψ Electroproduction

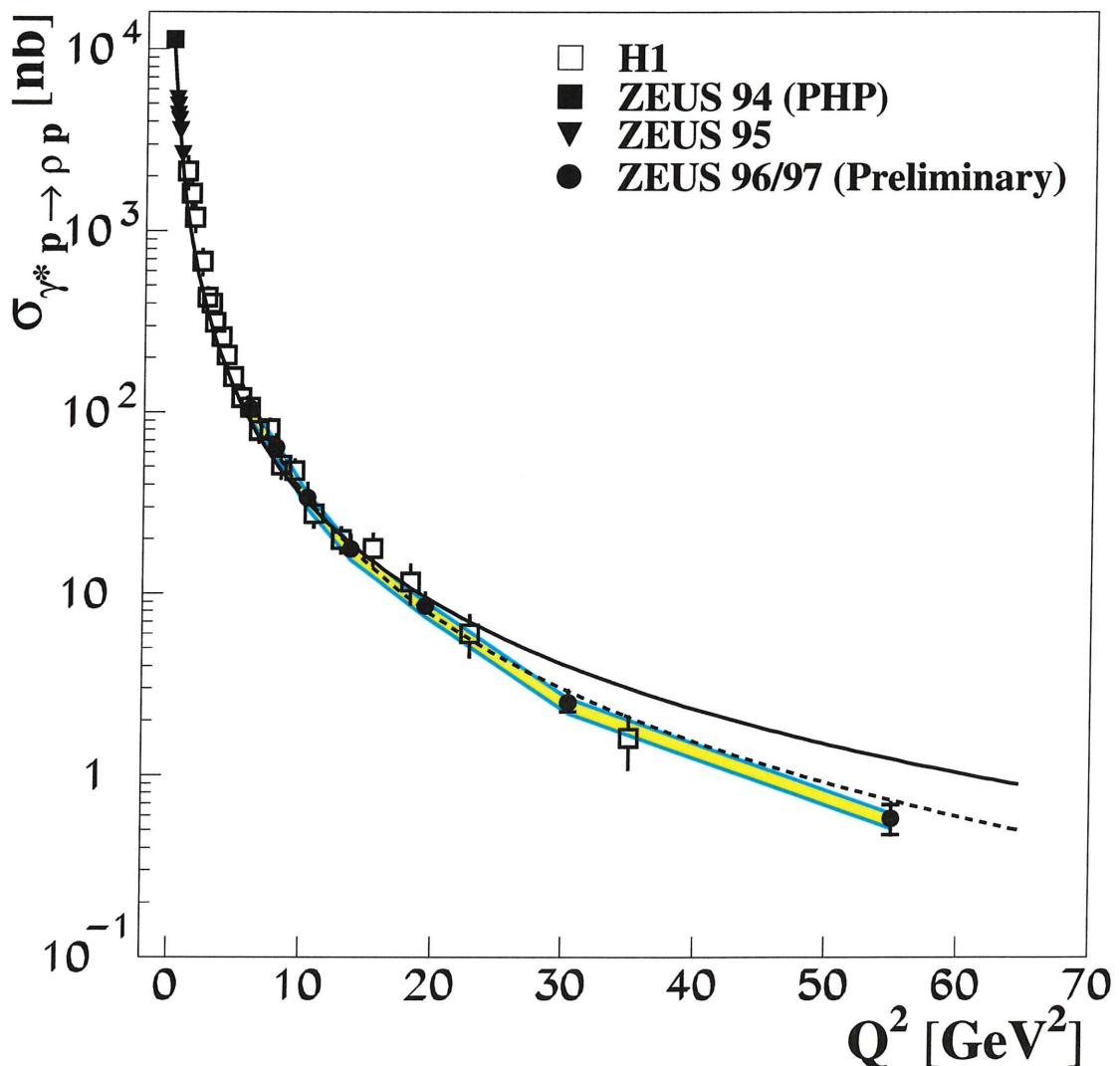


Steep rise of the cross-section with W does not depend on Q^2

Frankfurt, Koepf and Strikman, Phys. Rev. D 57 (1998) 512
 Martin, Ryskin and Teubner, Phys. Rev. D 62 (2000) 339

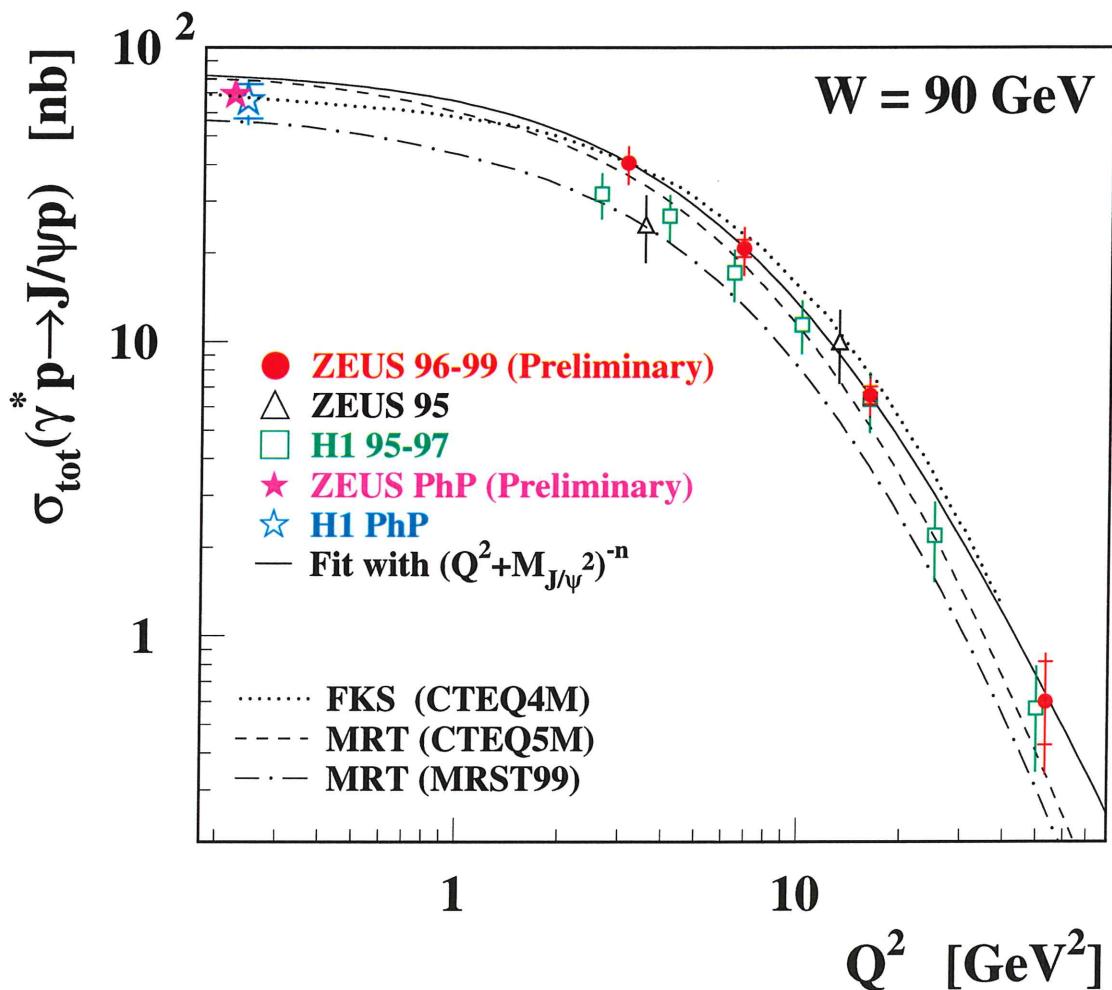
3. Q^2 dependence of the cross sections

ρ^0 Electroproduction



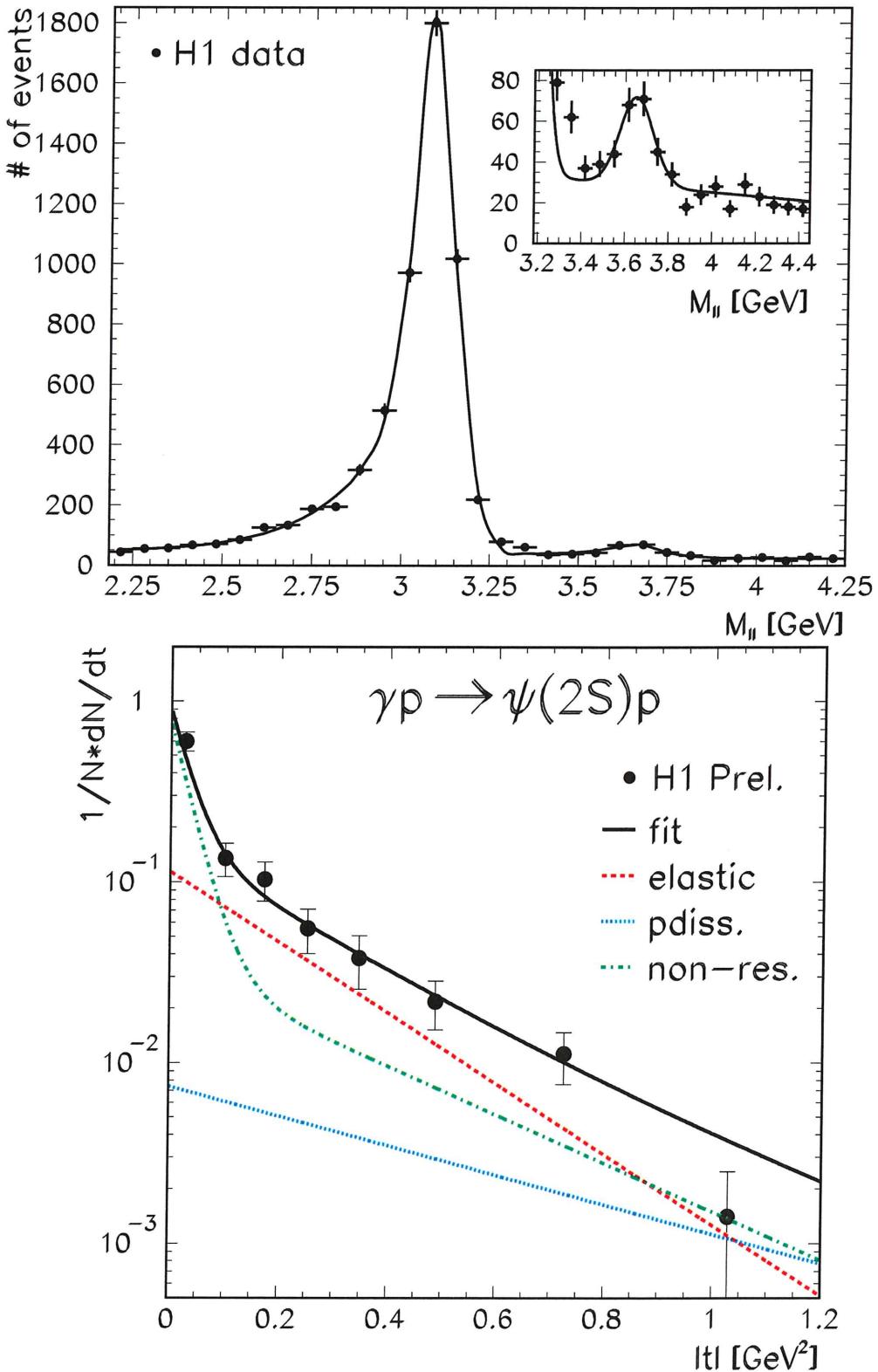
$\sigma \sim (Q^2 + M_\rho^2)^{-n}$ does not fit all Q^2 range

J/ψ Electroproduction



Frankfurt, Koepf and Strikman, Phys. Rev. D 57 (1998) 512
Martin, Ryskin and Teubner, Phys. Rev. D 62 (2000) 339

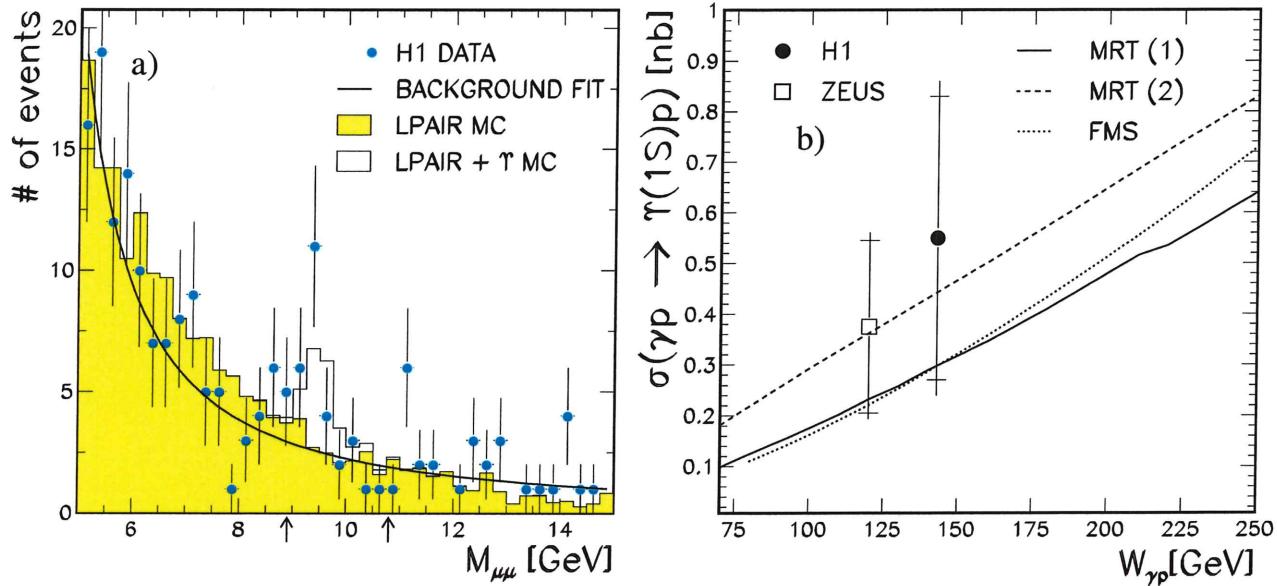
$\psi(2S)$ Photoproduction



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

$$b_{J/\psi} = (4.75 \pm 0.25^{+0.30}_{-0.39}) \text{ GeV}^{-2}$$

Υ Photoproduction



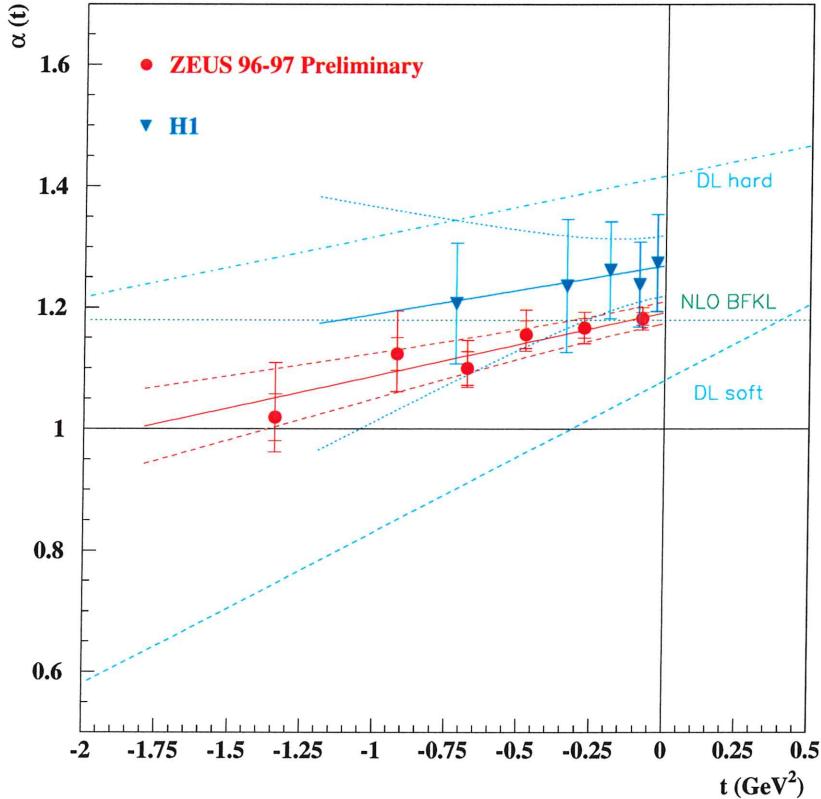
- Hard scale given by M_{Υ}^2 (≈ 100 GeV 2) !!

Frankfurt, McDermott and Strikman, JHEP 02(1999) 002
 Martin, Ryskin and Teubner, Phys. Lett B 454(1999) 339

5. Large $|t|$ study

J/ψ Photoproduction

$$\frac{d\sigma}{dt} = F(t)(W^2)^{[2\alpha(t)-2]}$$



Resulting trajectory lies in between soft and hard pomeron trajectories of DL

[Donnachie, Landshoff, Phys. Lett. B 437 \(1998\) 408](#)
BFKL hard pomeron preferred

[Brodsky et al., JETP Lett. 70 \(1999\) 155](#)

$$H1 : \alpha(t) = (1.27 \pm 0.05) + (0.08 \pm 0.17) \cdot t$$

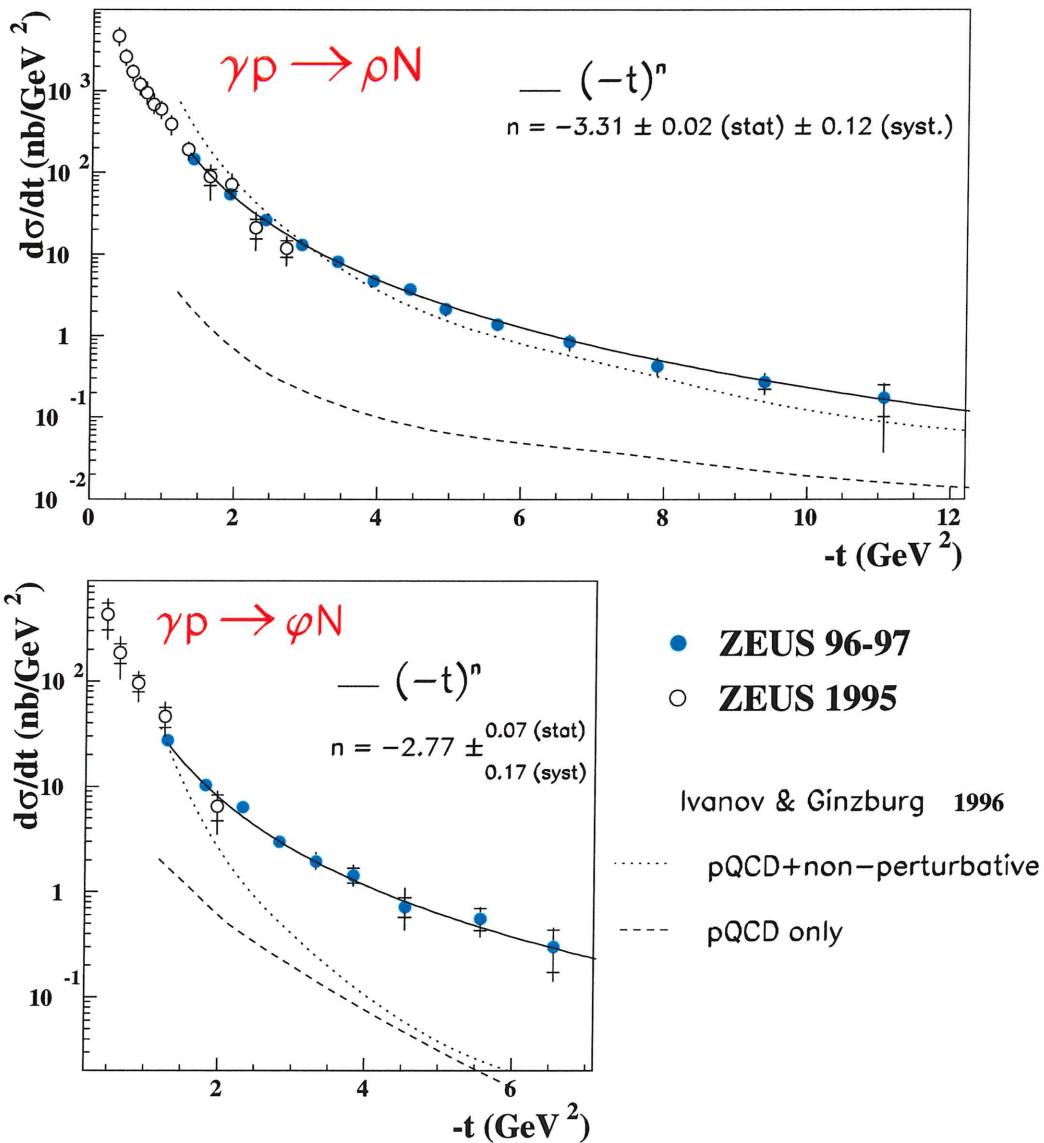
$$ZEUS: \alpha(t) = (1.193 \pm 0.011^{+0.015}_{-0.010}) + (0.105 \pm 0.024^{+0.022}_{-0.020}) \cdot t$$

$$\rho^0 : \quad \alpha(t) = (1.096 \pm 0.021) + (0.125 \pm 0.038) \cdot t$$

$$\phi : \quad \alpha(t) = (1.081 \pm 0.010) + (0.158 \pm 0.028) \cdot t$$

ρ^0 and ϕ Photoproduction with proton dissociation at large $|t|$

ZEUS 96 - 97 Preliminary

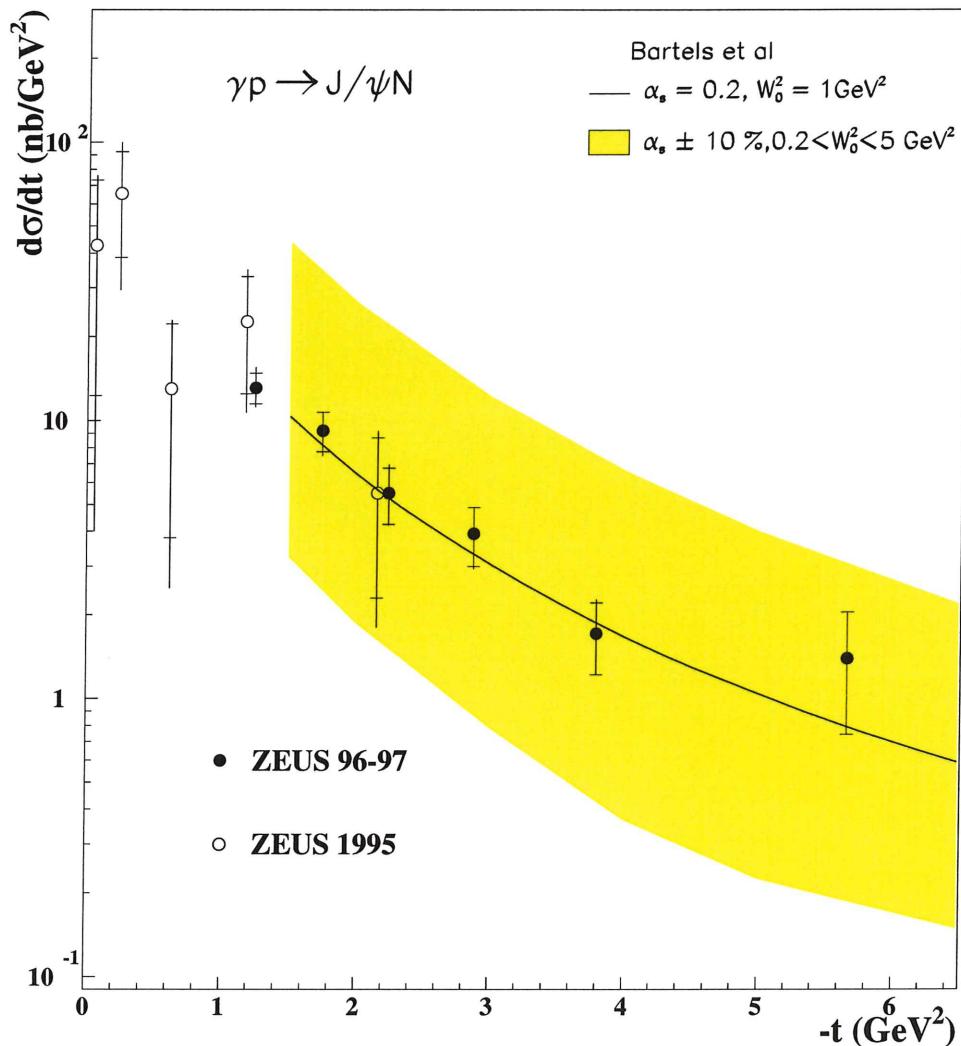


pQCD contribution well below data

D.Yu. Ivanov, Phys. Rev. D 53 (1996) 3564

J/ψ Photoproduction with proton dissociation at large $|t|$

ZEUS 96-97 Preliminary



Good agreement with pQCD model using BFKL formalism

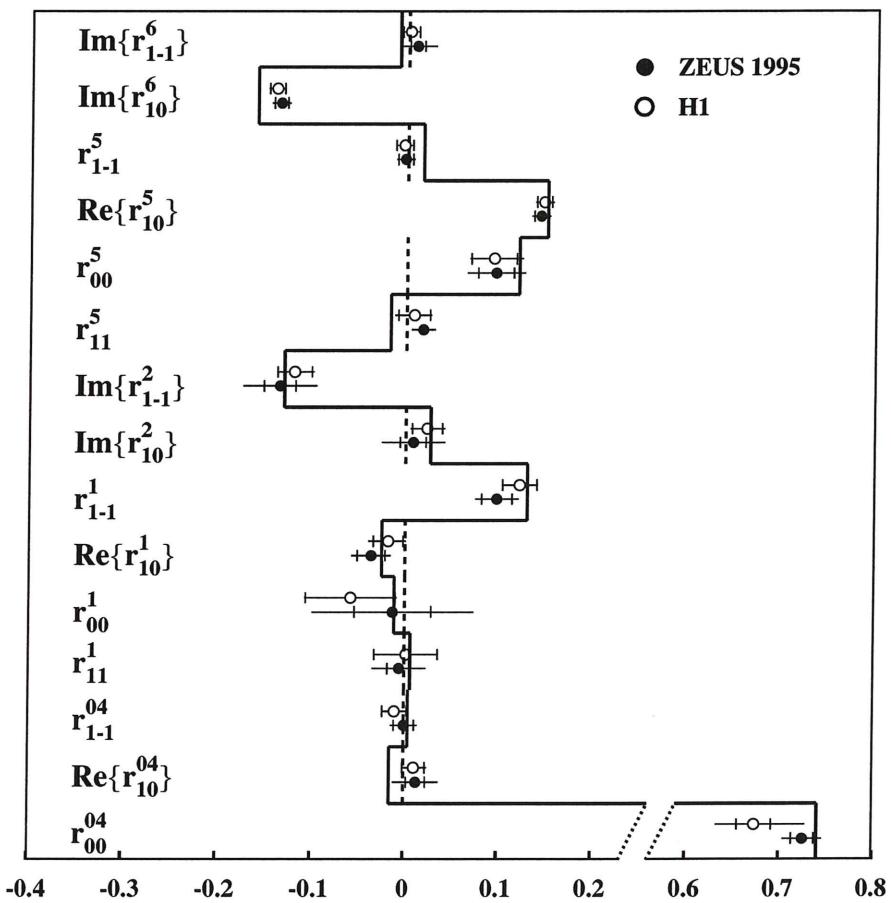
Bartels, Forshaw, Lotter, Wüsthoff, Phys. Lett. B375 301

6. Polarisation study

- Study of the angular distribution of the VM production and decay provides information on photon and VM polarisation¹
- Angular distribution is a function of 15 combinations of the spin density matrix elements, $r_{kl}^{04}, r_{kl}^\alpha$
- $r_{kl}^{04}, r_{kl}^\alpha$ is related to the helicity amplitudes $T_{\lambda_V \lambda_\gamma}$ $\lambda_V = -1, 0, 1; \lambda_\gamma = -1, 0, 1$
- In case *s*-channel helicity conservation ($\lambda_V = \lambda_\gamma$):
 - non-flip helicity amplitudes ($\lambda_V - \lambda_\gamma = 0$) have non-zero values
 - single flip amplitudes ($|\lambda_V - \lambda_\gamma| = 1$) are zero
 - double flip amplitudes ($|\lambda_V - \lambda_\gamma| = 2$) are zero

1 Schilling, Wolf, Nucl. Phys. B61 (1973) 381

ρ^0 electroproduction

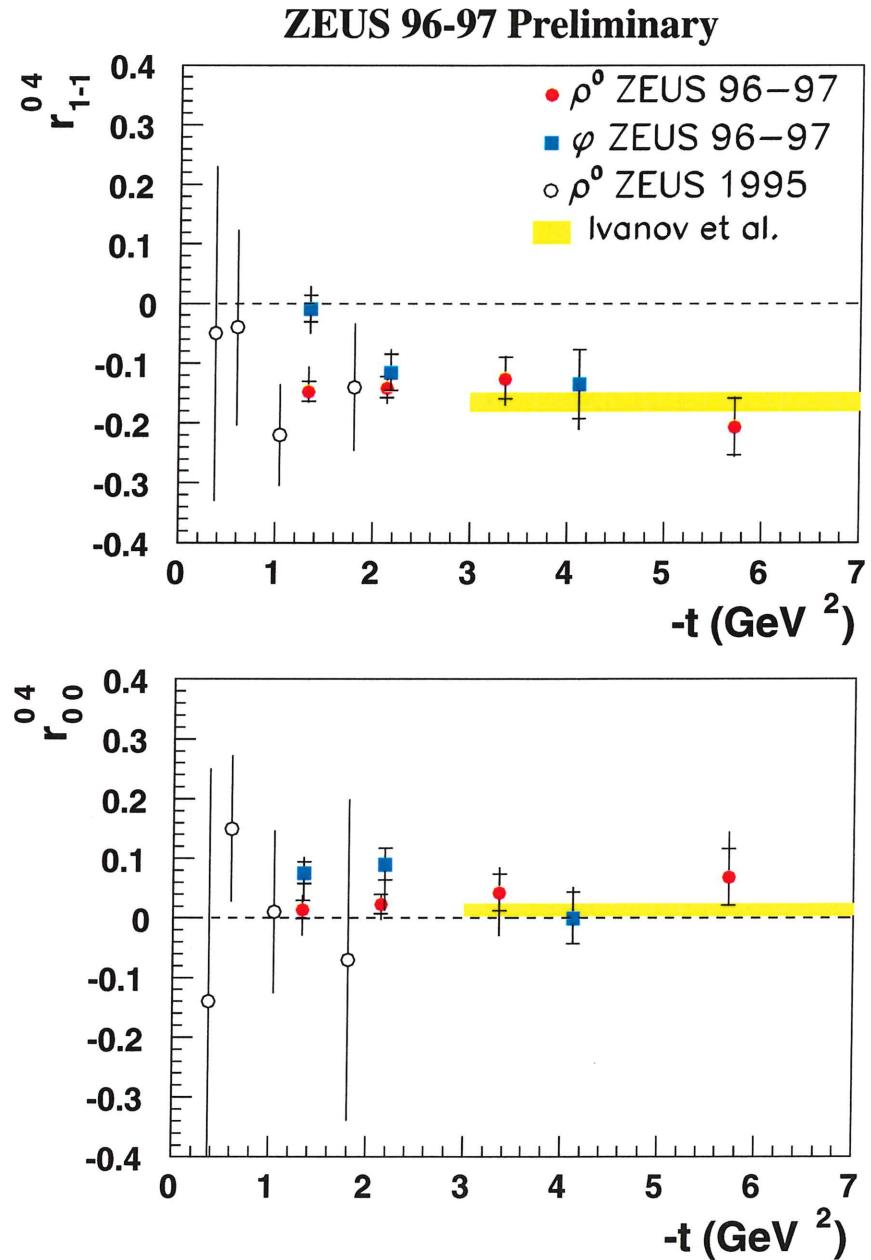


$$r_{00}^5 \propto \text{Re}(T_{00} T_{01}^*)$$

spin density matrix elements are reproduced by QCD model

D.Yu. Ivanov, R. Kirschner, Phys. Rev. D58(1998) 114026

proton-dissociative ρ^0 and ϕ photoproduction



$$r_{1-1}^{04} \propto \text{Re}(T_{11} T_{1-1}^*)$$

spin density matrix elements are reproduced by QCD model

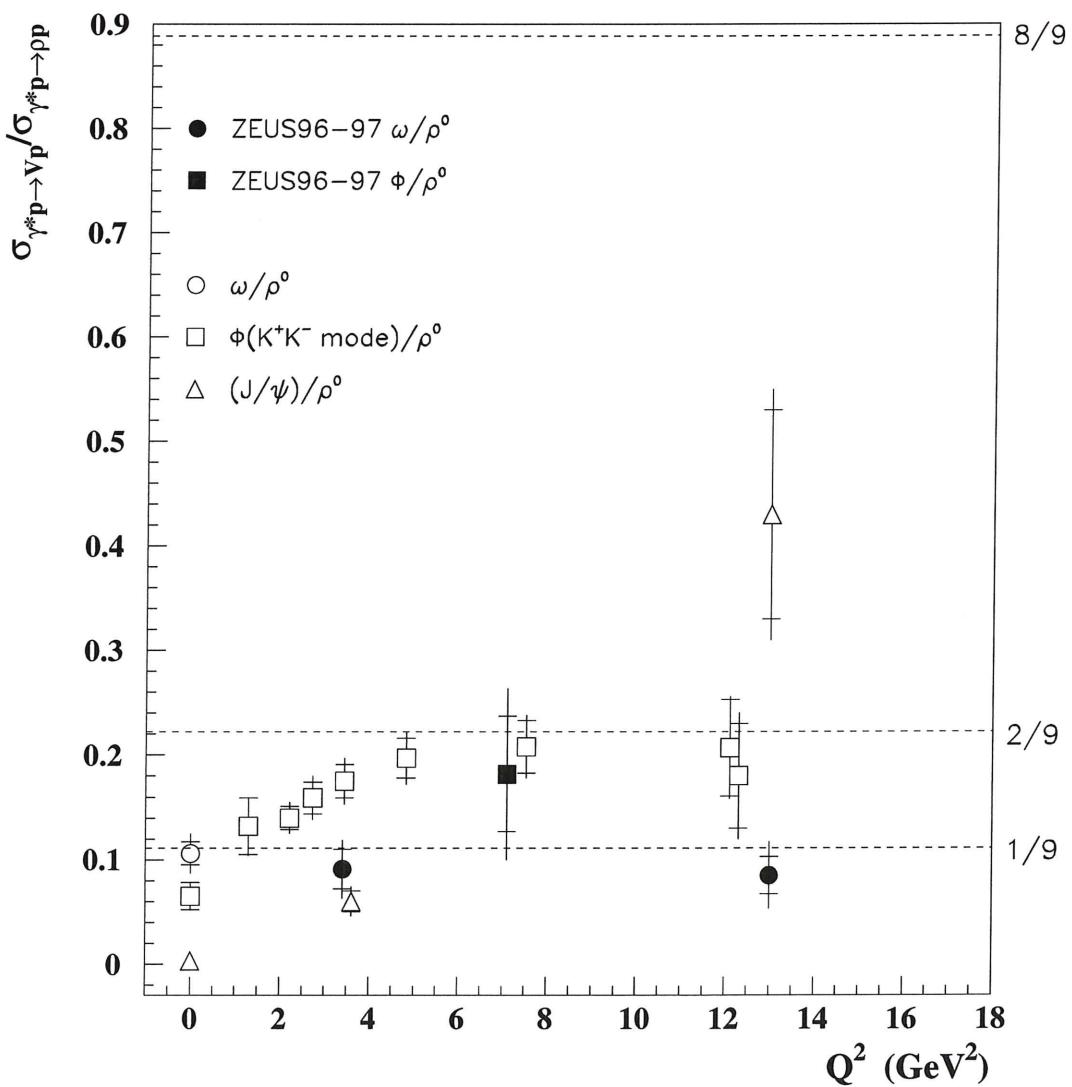
D.Yu. Ivanov et al., Phys. Lett. B 478 (2000) 101

7. VM production ratios

In the presence of a hard scale the interaction should be flavor independent.

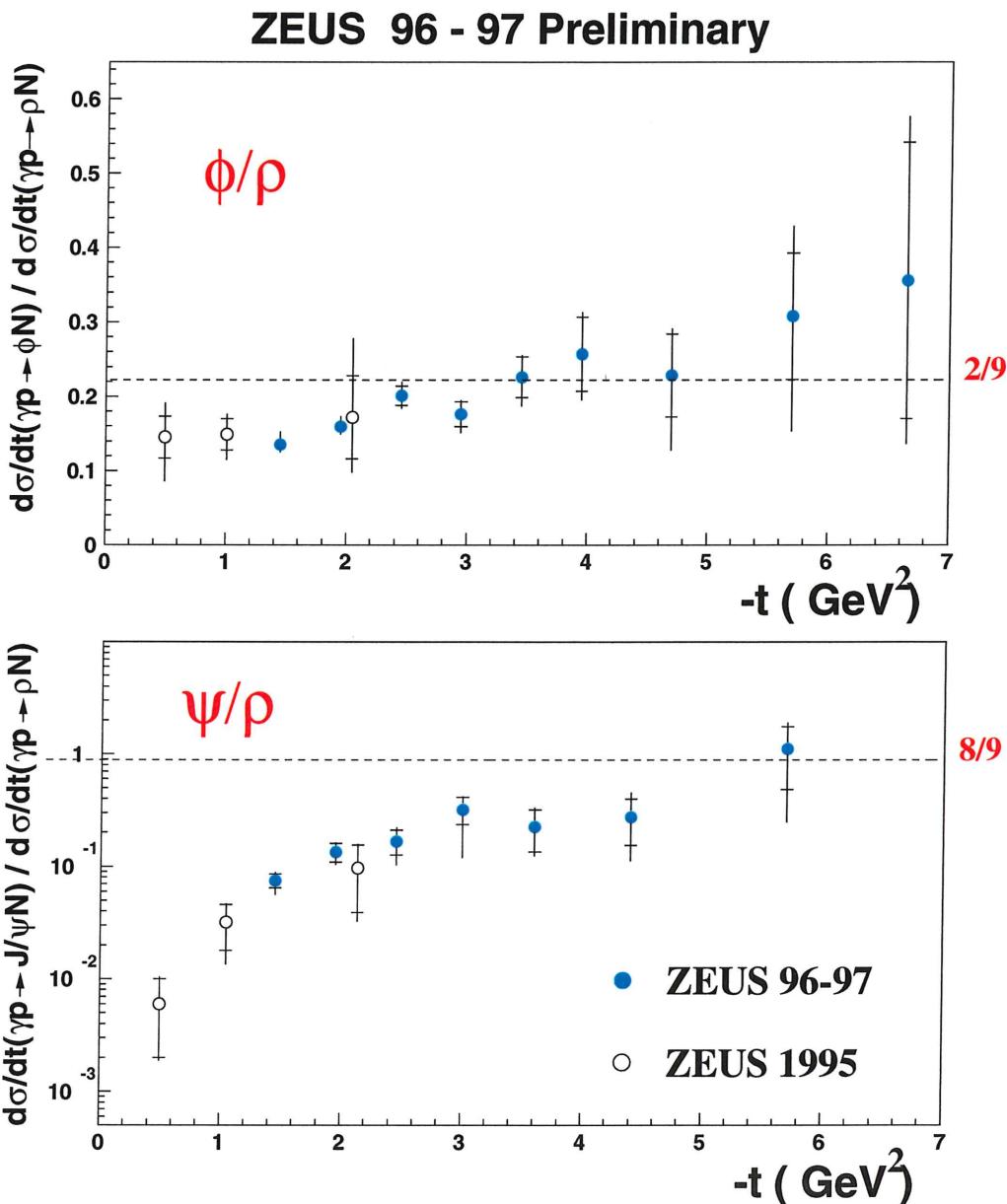
From the quark charges of the vector meson the production cross section is expected to have relative size:

9 : 1 : 2 : 8 for $\rho_0 : \omega^0 : \phi : J/\psi$



Q^2 is not universal scale

ρ , ϕ and J/ψ Photoproduction at large $|t|$



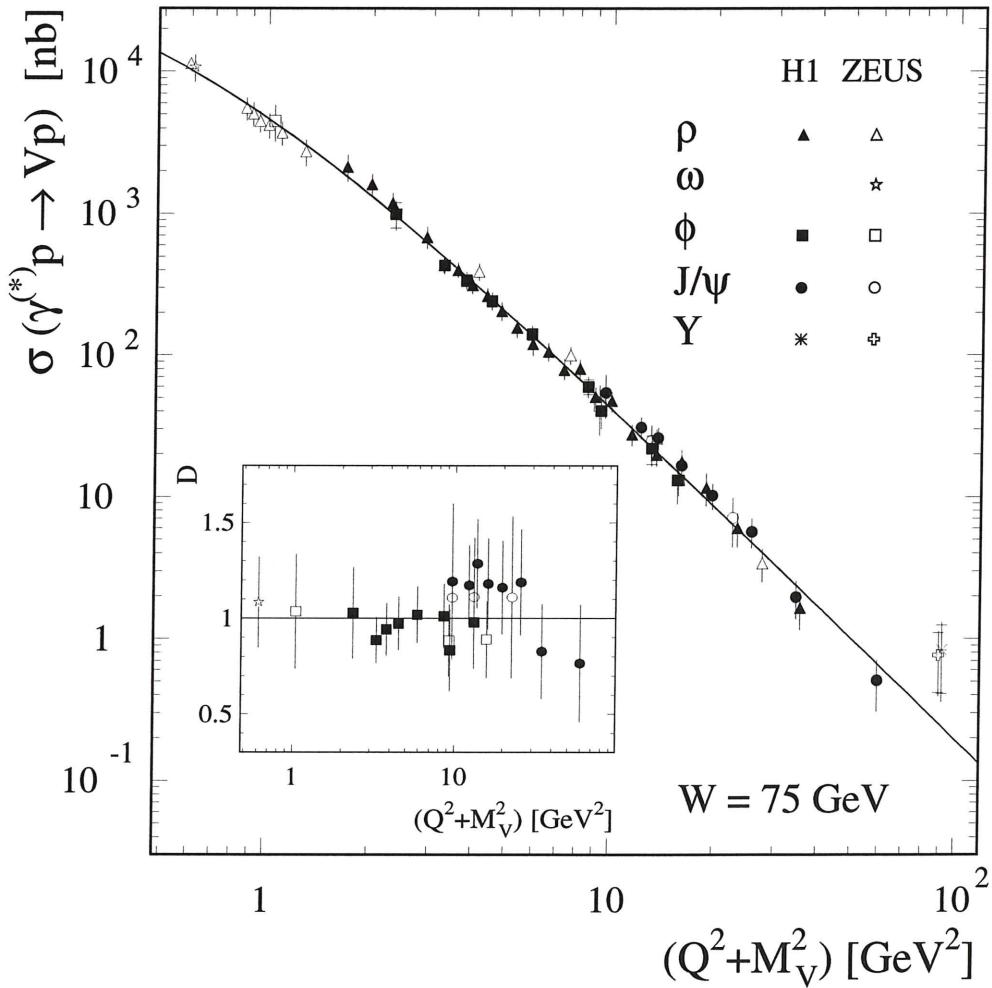
Evidence for $|t|$ providing a hard scale

Q^2 and $|t|$ are not symmetric in the determination of the scale

Elastic VM cross sections

cross sections scaled by the factors expected from the flavor independent production mechanism.

$$9 : 1 : 2 : 8 : 2 \quad \text{for } \rho_0 : \omega^0 : \phi : J/\psi : \Upsilon$$



VM production scales with $Q^2 + M_V^2$

Conclusions

- Numerous measurements of VM production at HERA
- J/ψ (and Υ) production has all features expected from pQCD . Hard scale given by M_V^2 .
- Electroproduction of ρ^0 and ϕ becomes hard at large Q^2 . Hard scale given by Q^2 .
- VM production scales with $Q^2 + M_V^2$ assuming flavor independent production mechanism.
- Evidence for the hard scale to be given by $|t|$ for ρ^0 and ϕ photoproduction.