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Exclusive electroproduction of ρ mesons at HERA

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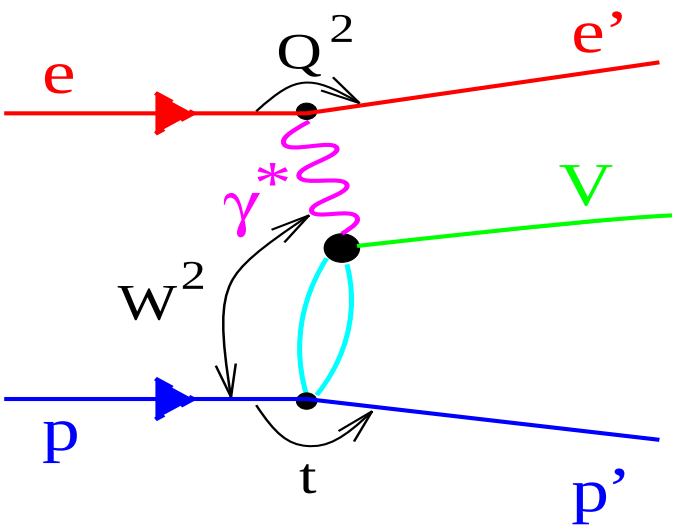
Outline:

- **Introduction**
- **$\sigma_{tot}(\gamma^* p \to \rho^0 p)$ as a function of W and Q^2**
- **Helicity studies: σ_L and σ_T**
- **Summary**

Vector Meson Production

HERA collides positrons(electrons) and protons

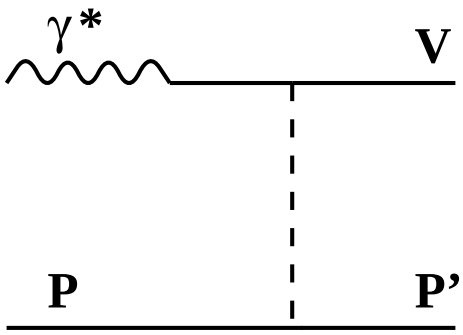
27.5 GeV e $\Longrightarrow$ $\sqrt{s}$ = 300 GeV $\Longleftarrow$ p 820 GeV



$V = (\rho^o, \omega, \phi, J/\psi, \Upsilon)$

- $Q^2 = -(k - k')^2$ photon virtuality
- W is $\gamma^* p$ center of mass (CM) energy
- $t = (p - p')^2$ momentum transfer squared at the proton vertex

VDM and Regge theory



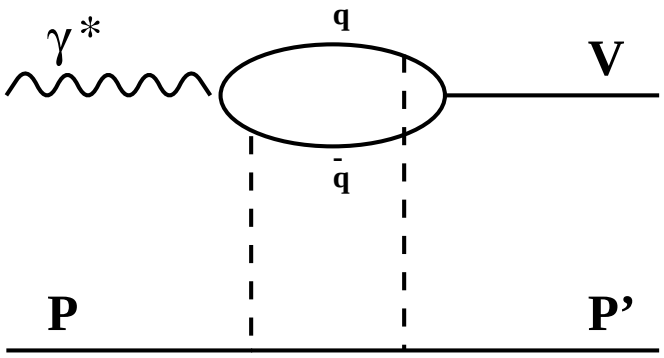
- The photon fluctuates into a light vector meson, V, which carries the same quantum numbers as the photon ($\gamma p \to$ Vp)
- The vector meson scatters elastically off the incoming proton (Vp $\to$ Vp)

Predictions :

- $\frac{d\sigma(\gamma p \to Vp)}{dt} \propto e^{-b_0|t|}(W^2/W_0^2)^{2(\alpha(t)-1)}$
- $\alpha(t) = 1.08 + 0.25t$ (DL parametrization)
- Shrinkage of the diffractive peak $b(W) = b_0 + 2\alpha' \ln(W^2/W_o^2)$
- Weak energy dependence of cross section $d\sigma/dt \propto W^\delta, \qquad \delta \simeq 0.2$

J. J. Sakurai
A. Donnachie and P. V. Landshoff
D. Schildknecht et al.

QCD models



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

Predictions :

- $\sigma_L \propto \frac{\alpha_S^2(Q)}{Q^6}|xG(x,Q^2)|^2$
- A fast increase of the $\gamma^* p \to Vp$ cross section with energy W (longitudinal cross section dominates at large Q^2)
- SU(4) restoration, possibly modified by VM wave functions effects $\rho : \omega : \phi : J/\psi = 9 : 1 : 2 : 8$
- Universal exponential t dependence, $b \sim 4 - 5\,\mathrm{GeV}^{-2} \quad \Longrightarrow \quad \alpha' \to 0\,?$

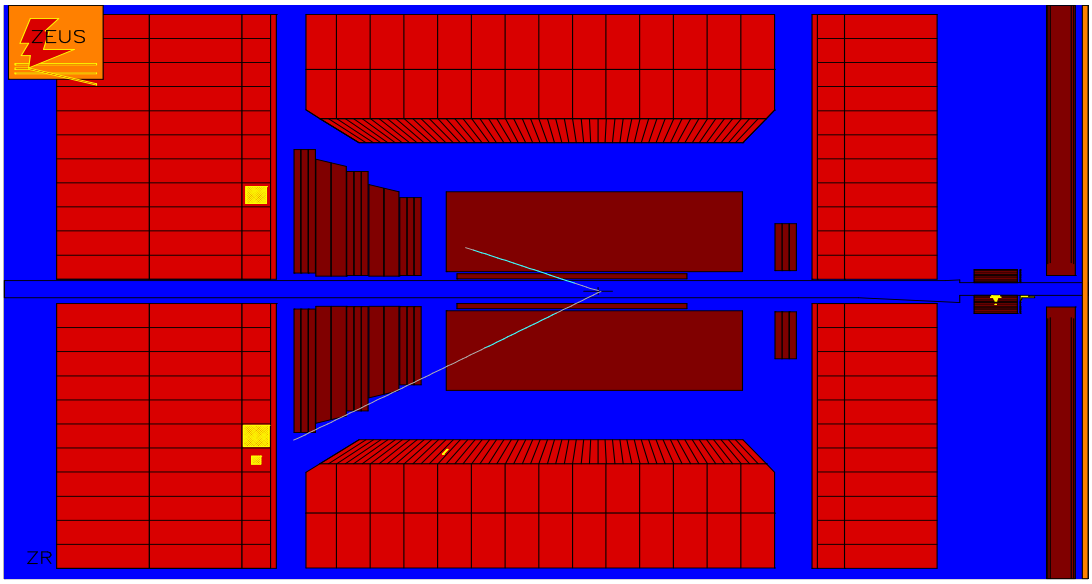
S. J. Brodsky et al.
L. Frankfurt et al.
M. Ryskin et al.
A. D. Martin et al. ...

Exclusive production $\gamma^* p \to V^o p$

Kinematic range

$$
\begin{array}{ccc}
Q^2 & \to & 0 \div 70\,\mathrm{GeV}^2 \\
W & \to & 20 \div 280\,\mathrm{GeV} \\
|t| & \to & 0 \div 10\,\mathrm{GeV}^2
\end{array}
$$

- Photoproduction: $Q^2 \approx 0$
  (do not observe the scattered e in Calorimeter)
- Electroproduction, Q^2 range : $0.25 < Q^2 < 70$ GeV^2
  (observe the scattered e in the main Calorimeter or in special taggers)



- tracks reconstructed by tracking detector
- no energy deposits not associated with tracks or the positron

Cross sections

- The cross section for $\gamma^* p \to \rho^0 p$ has been measured for center-of-mass energies $40 < W < 160 GeV$ and for photon virtualities $5 < Q^2 < 70 GeV^2$, where there are ~ 7000 events after selection cuts.

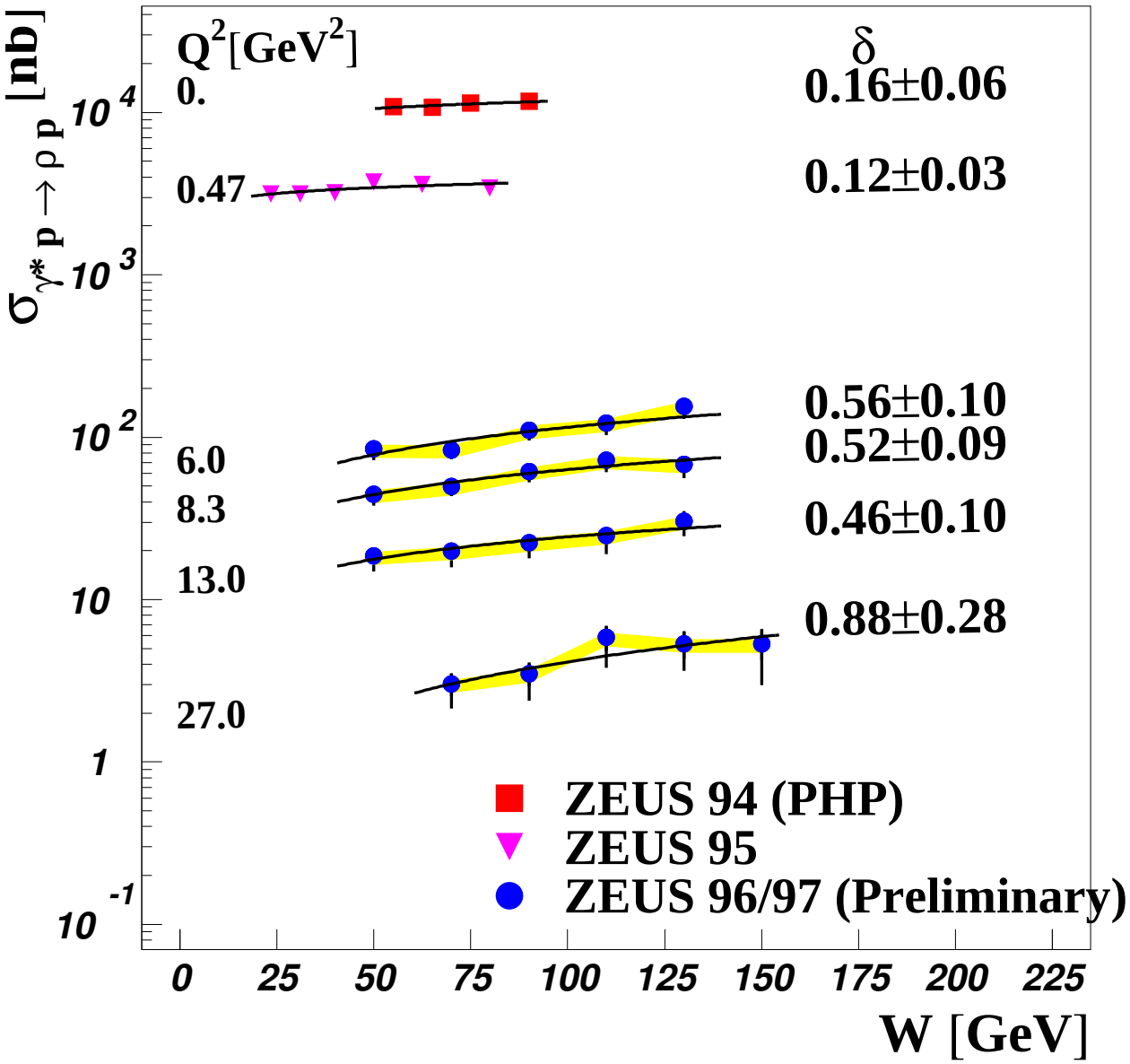
ep cross section $\to \gamma^* p$ cross section

$$\frac{d^2\sigma^{ep}}{dydQ^2} = \Gamma_T(y, Q^2)(\sigma_T^{\gamma^* p} + \epsilon \sigma_L^{\gamma^* p})$$

- $\Gamma_T = \frac{\alpha}{2\pi} \cdot \frac{1+(1-y)^2}{yQ^2}$ **(transverse photons flux)**
- $\epsilon = \frac{\Gamma_L}{\Gamma_T} = \frac{2(1-y)}{1+(1-y)^2}$ **(polarization parameter)**

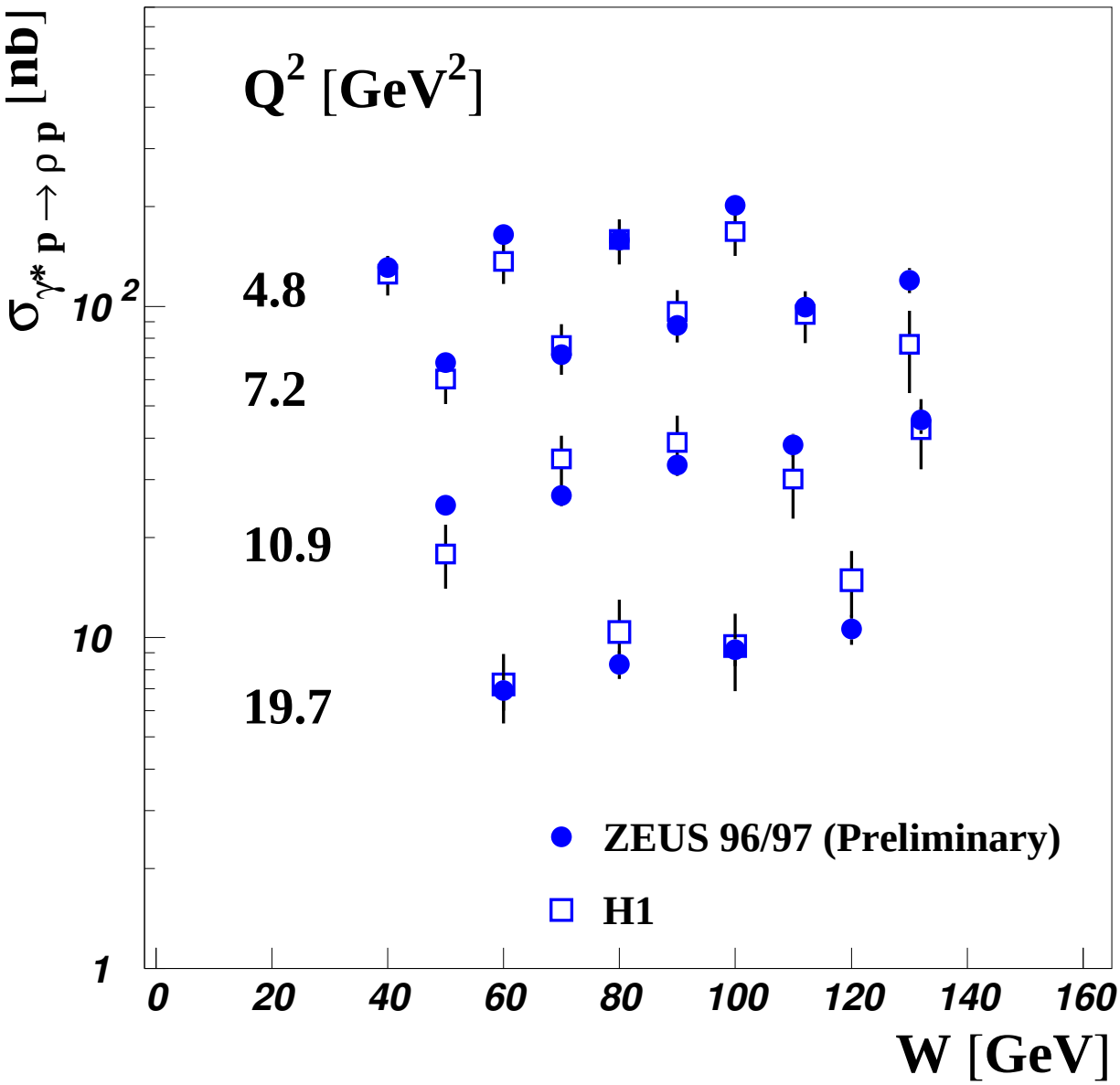
$\epsilon \sim 0.99$ **(at HERA)**

ρ Cross section W dependence



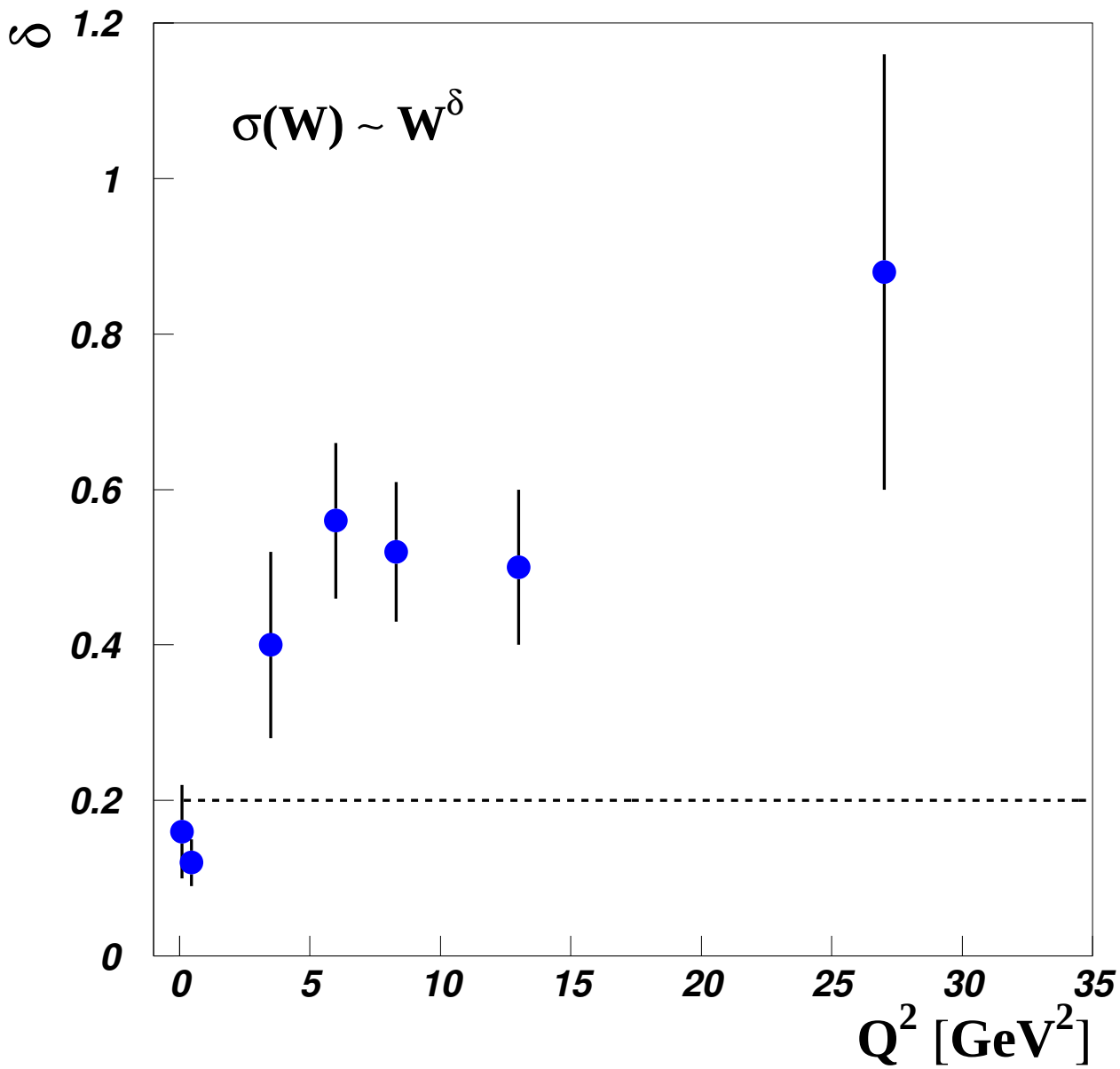
- Cross Section W dependence becomes steeper at high Q^2

ρ Cross section W dependence



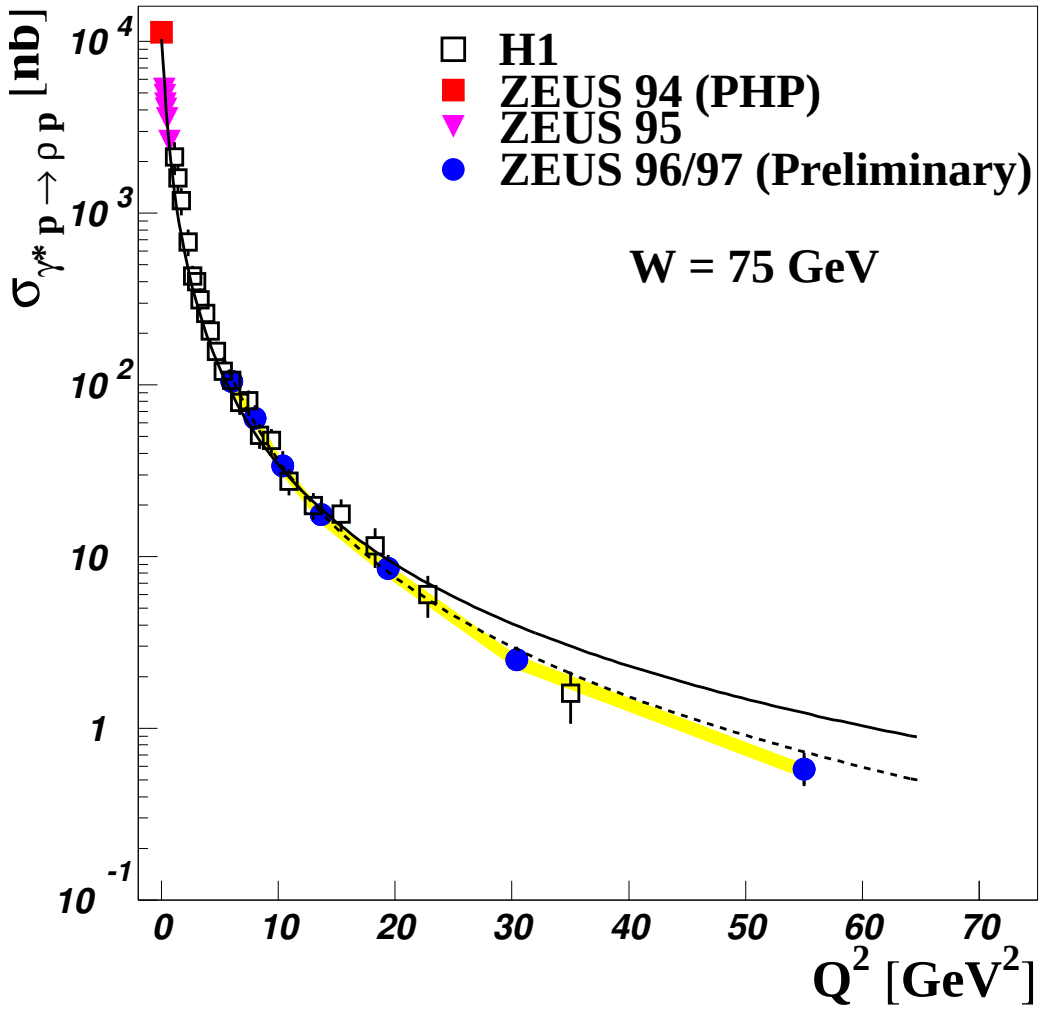
- Both experiments, H1 and ZEUS, are in good agreement

ρ Cross section W dependence



- **ZEUS only: 94,95 and 96/97 (Preliminary)**
- **Soft physics predicts for energy dependence, $\delta \sim 0.2$**

ρ Cross section Q^2 dependence

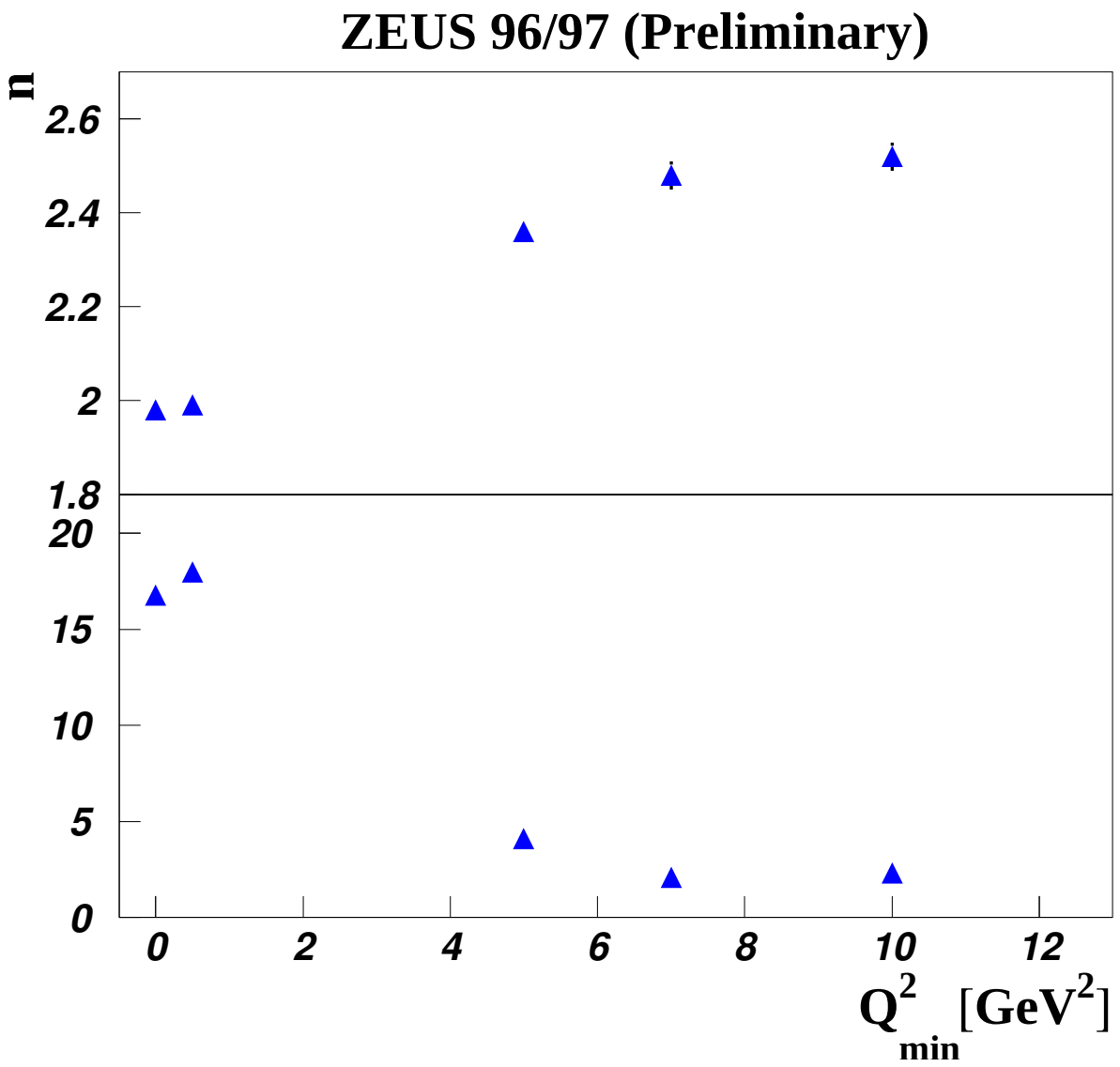


$$\sigma \propto (Q^2 + M^2)^{-n}$$

- $Q^2 \geq$**0 GeV^2, n=2.00 $\pm$ 0.005,** χ^2**/ndf = 142/12**
- $Q^2 \geq$**5 GeV^2, n=2.37$\pm$0.02,** χ^2**/ndf = 13.2/5**

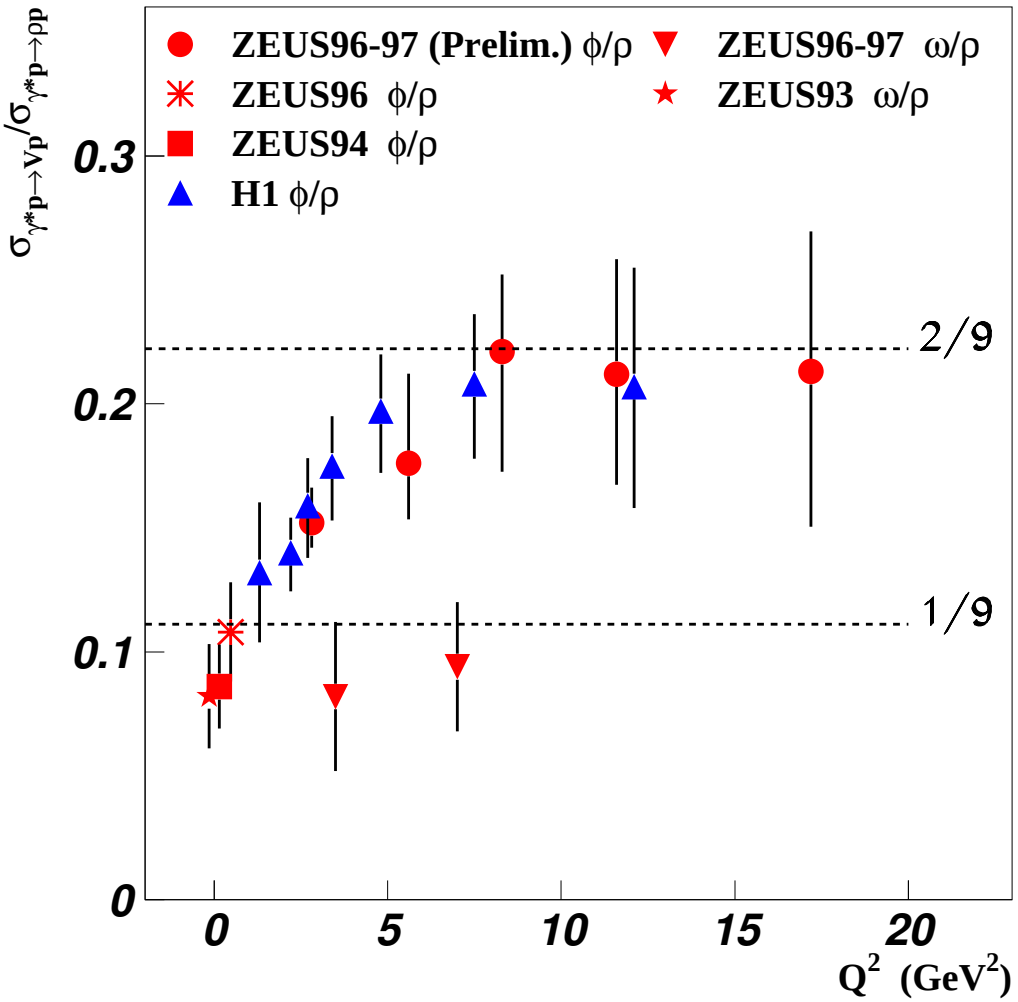
$$\sigma_L \propto \frac{\alpha_S^2(Q)}{Q^6}|xG(x,Q^2)|^2 T(Q^2)$$

ρ Cross section Q^2 dependence



- The dependence of n on Q^2 could be the first indication that the propagator term $(Q^2 + m_\rho^2)^{-n}$ is substantially modified by other effects: increasing of the gluon density with Q^2 or Q^2-dependent ρ wave-function effects.

Vector Mesons production ratios : Q^2 dependence

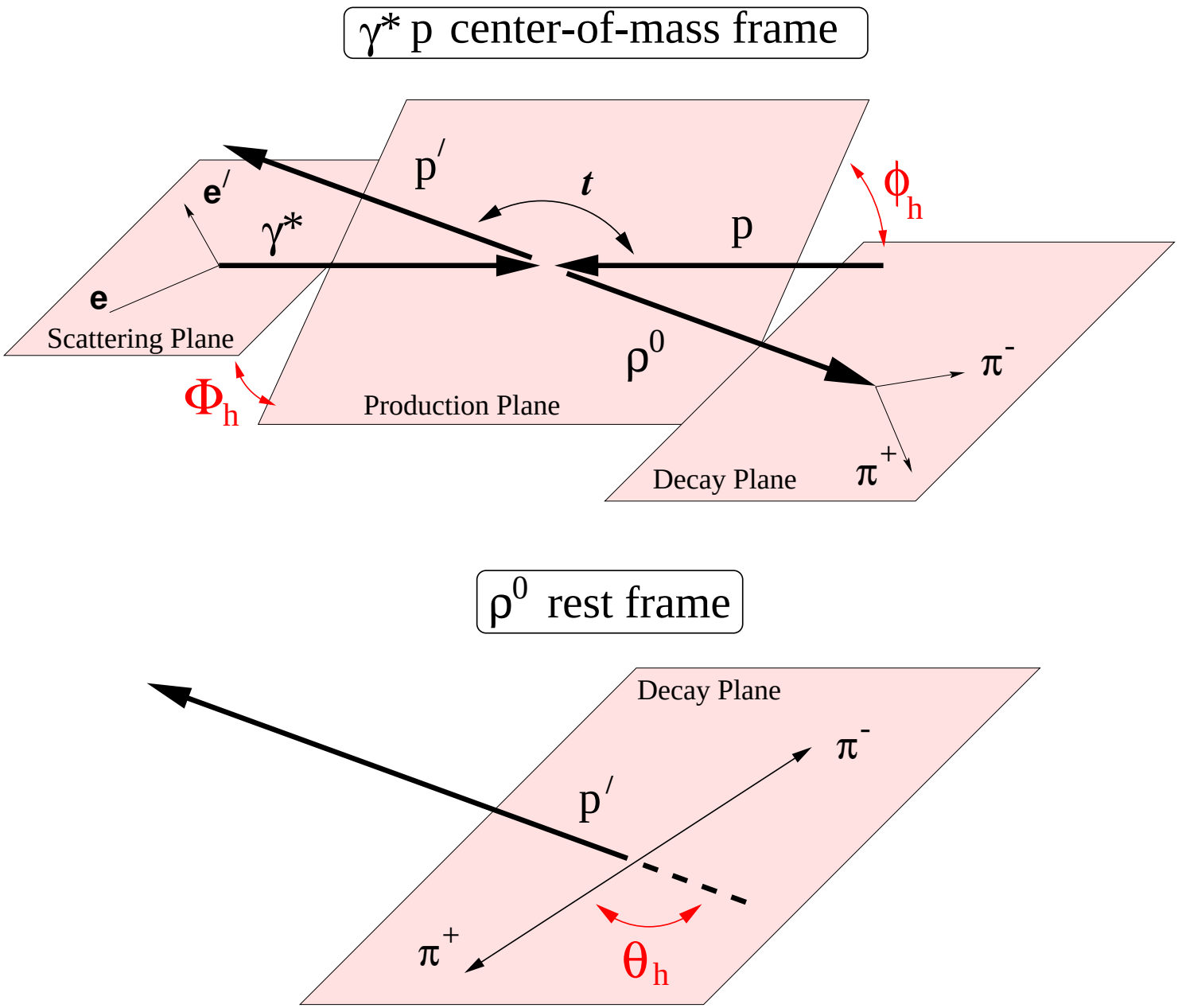


- quark charges of the Vector Meson and flavour independent production mechanism :

$$\rho : \omega : \phi = 9 : 1 : 2$$

- SU(4) prediction is badly broken in photoproduction for ϕ/ρ ratio
- SU(4) restoration with Q^2 increasing

Helicity Studies



Angular distribution $\Longrightarrow$ 3 angles (θ, ϕ and Φ) and 15 combinations of spin-density matrix elements

K. Schilling and G. Wolf

Helicity Studies

- **s-channel helicity conservation (SCHC)**
- **natural parity exchange $(P = (-1)^J)$ in the t-channel (NPE)**
- **15 parameters fit to total angular distribution shows :**
- **r^5_{00} deviates from zero !**

$r^5_{00} = 0.095 \pm 0.019 \pm 0.024$ (ZEUS) and $r^5_{00} = 0.093 \pm 0.024^{+0.19}_{-0.10}$ (H1)

- **$r^5_{00} \sim$ single-flip amplitude**

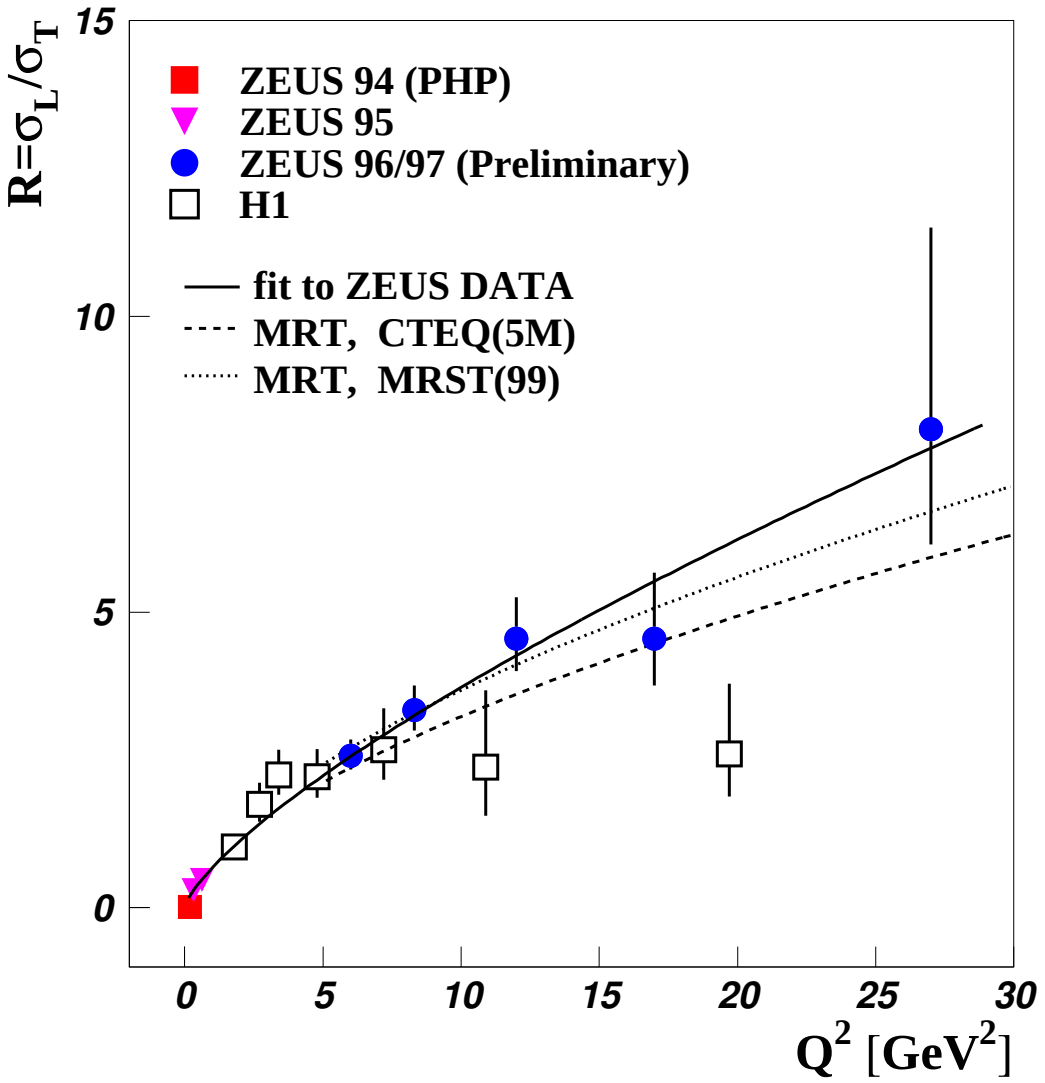
- **single flip** $(\gamma^*_T \to \rho_L)$ $\Longrightarrow (7.9 \pm 3.6)\%$
- **pQCD predicts non zero value of r^5_{00} (Ivanov, Kirschner)**

- **$r^5_{00} \to$ sensitive to wave function of VM**
- **if SCHC holds $\to$** $R = \sigma_L/\sigma_T = r^{04}_{00}/\epsilon(1 - r^{04}_{00})$

- **if not $\to$** $r^{04}_{00} \to \mathbf{r}^{04}_{00} - \Delta^2$

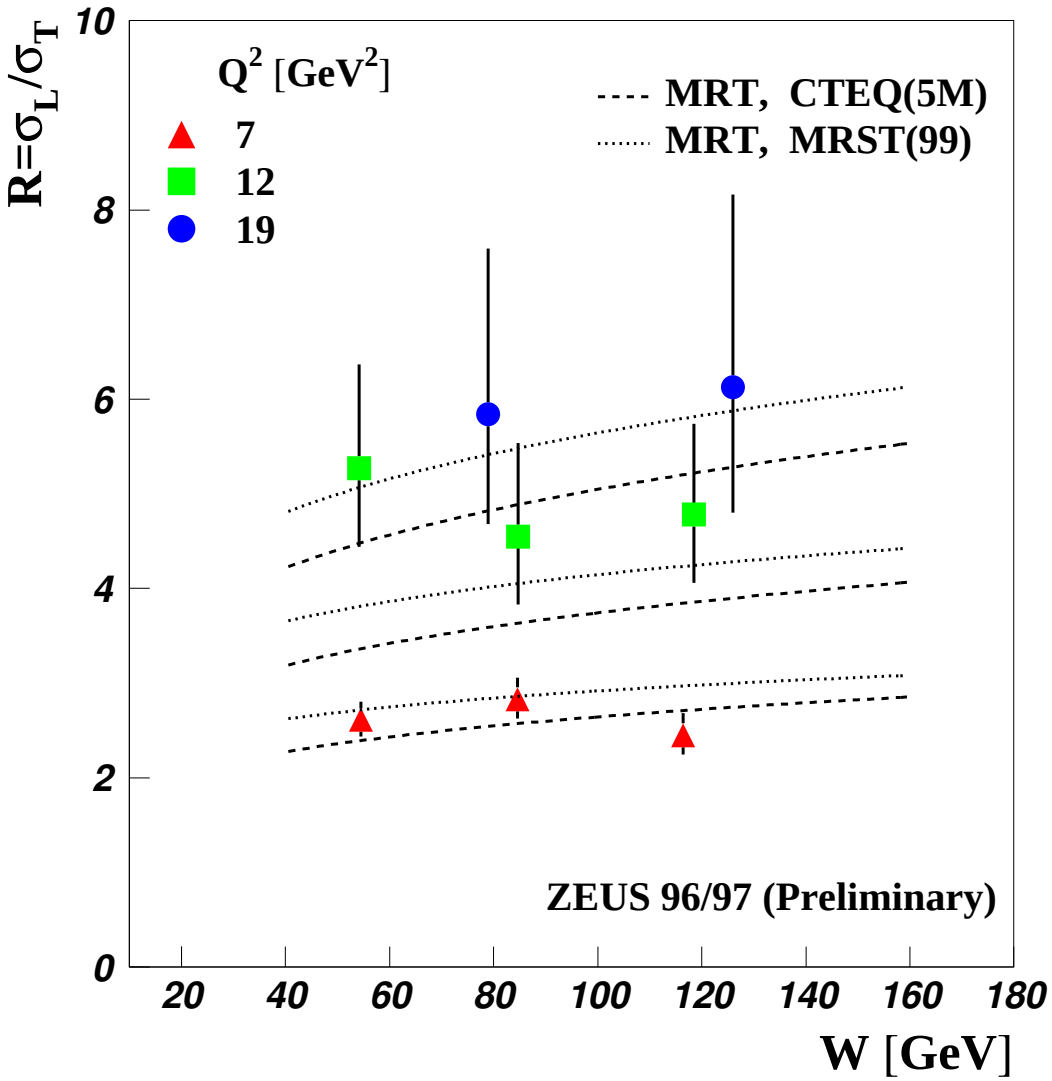
R(SCHC) - R(SCHNC) $\sim$ 3 %

σ_L/σ_T



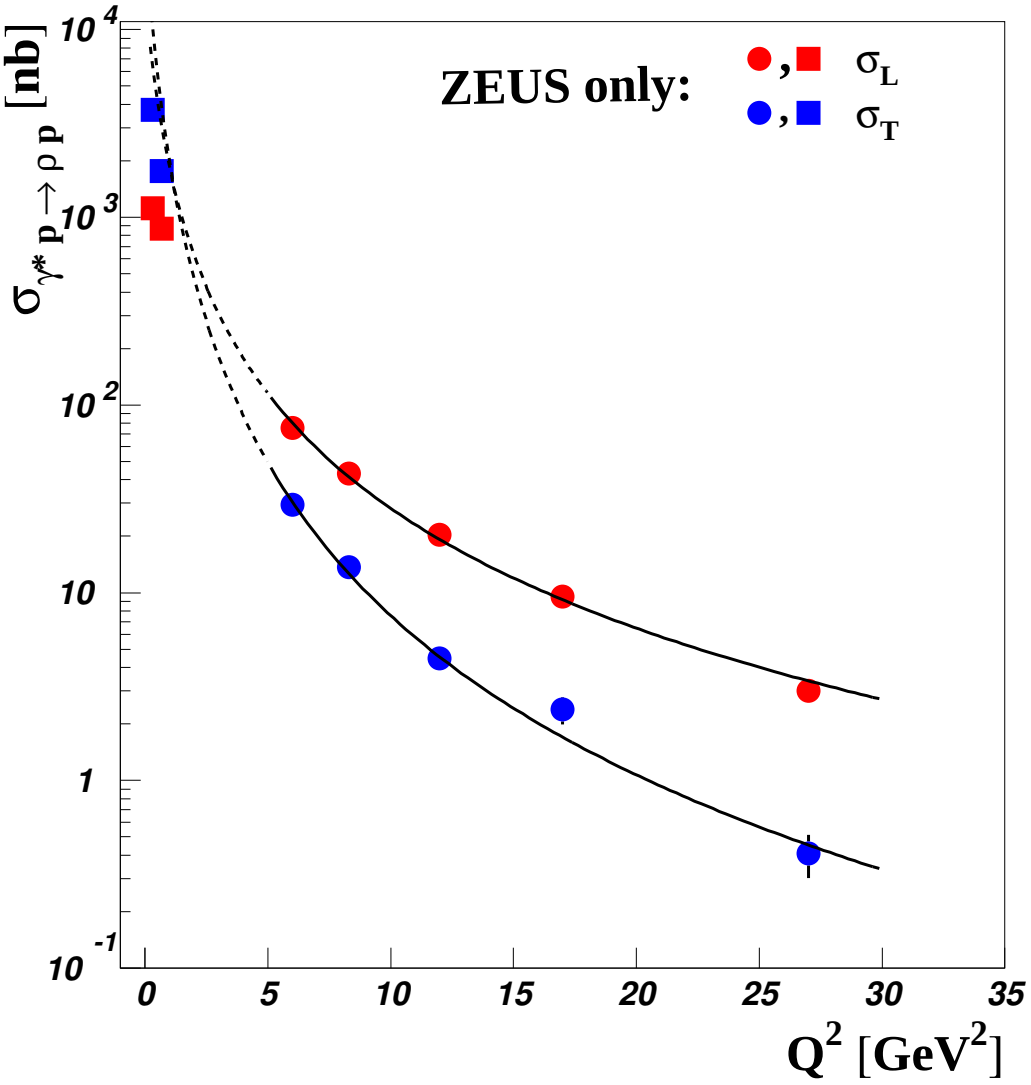
- **fit to ZEUS only :** $R = \sigma_L/\sigma_T = \xi(Q^2/M^2)^\kappa$
- $\xi = 0.46 \pm 0.04$ **and** $\kappa = 0.75 \pm 0.03$
- R **increases with** Q^2

σ_L/σ_T



- within experimental errors R is W independent

σ_L, σ_T



fit to $Q^2 > 5$ GeV^2

- **n_L=2.21 ± 0.03 and n_T=2.94 ± 0.06**

Summary

- exclusive production of ρ^0 mesons has been studied in ep collision with the **ZEUS** detector at **HERA**, using an integrated luminosity of **38** pb^{-1}
- typical features of **HARD** processes $\Longrightarrow$ predicted by **pQCD**
  - ⋆ **fast rise** of cross section with **energy**
  - ⋆ increasing of σ_L/σ_T with Q^2
  - ⋆ **SU(4)** restoration

  were observed
- **new** results:
  - ⋆ The Q^2 dependence of the cross section **cannot be described by a simple** $(Q^2+m_\rho^2)^{-n}$ **functional dependence**
  - ⋆ The value of n changes with Q^2
  - ⋆ σ_L/σ_T is W independent
  - ⋆ question: do we see the ρ^0 **wave-function effects ?**
  - ⋆The Q^2 dependence of the longitudinal, σ_L, and transverse, σ_T, cross sections has been investigated and values

    n_L=**2.21** $\pm$ **0.03 and** n_T=**2.94** $\pm$ **0.06**

    were found

Plans

- ⋆ b dependence of Q^2
- ⋆ b dependence of W energy at fixed Q^2 range
- ⋆ σ_L and σ_T dependence of W energy at fixed Q^2 range