Low x Physics Workshop
Tel Aviv
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Vector Meson Production at HERA

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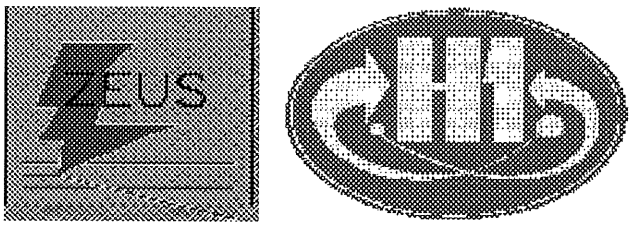


on behalf of the ZEUS and H1 Collaborations

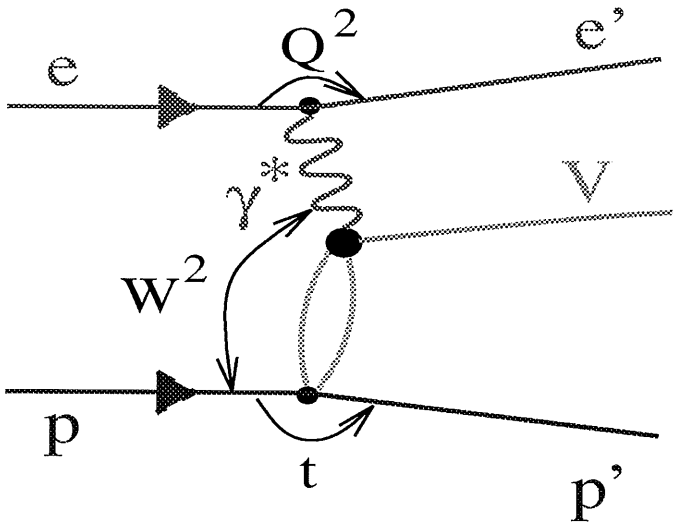
Outline:

- Introduction
- Photoproduction of Vector Mesons
- Electroproduction of Vector Mesons
- Helicity studies
- Summary

Vector Meson Production

HERA collides positrons(electrons) and protons

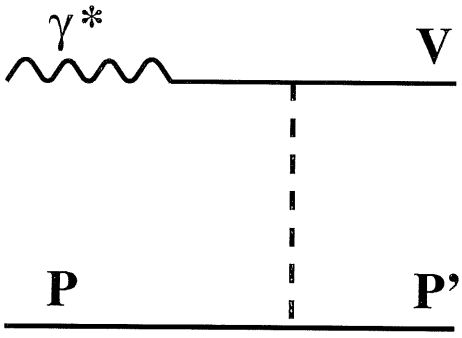
27.5 GeV e $\Longrightarrow$ $\sqrt{s} =$ **300 GeV** $\Longleftarrow$ p **820 GeV**



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

- $Q^2 = -(k - k')^2$ 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



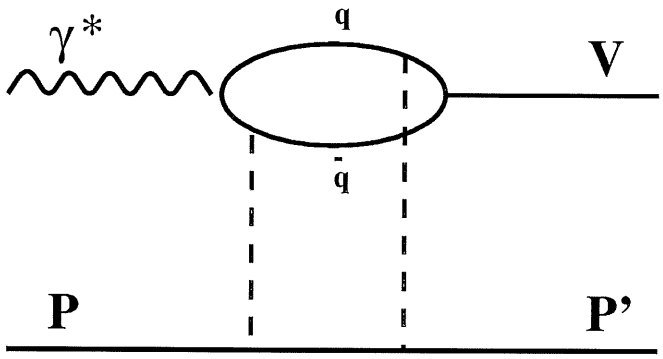
- The photon fluctuates into a light vector meson, V, which carries the same quantum numbers as the photon ($\gamma p \to \mathrm{Vp}$)
- The vector meson scatters elastically off the incoming proton ($\mathrm{Vp} \to \mathrm{Vp}$)

Predictions :

- $\frac{d\sigma(\gamma p \to Vp)}{dt} \propto e^{-b_0|t|}(W^2/W_0^2)^{2(\alpha(t)-1)}$
  $\alpha(t) = \alpha(0) + \alpha' t$ is a linear trajectory,
  b_0 is the slope of exponential t distribution

- $\alpha(t) = 1.08 + 0.25t$ (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
  $d\sigma/dt \propto W^\delta, \qquad \delta \simeq 4(\alpha(0) - \alpha'/b_0 - 1)$
  $\delta \simeq 0.22$ for light VM, $(\mathrm{b}(\mathrm{Q}^2 \sim 0) \simeq 10\,\mathrm{GeV}^{-2})$
  $\delta \simeq 0.12$ for heavy VM, $(\mathrm{b}(\mathrm{Q}^2 \sim 0) \simeq 5\,\mathrm{GeV}^{-2})$

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 :

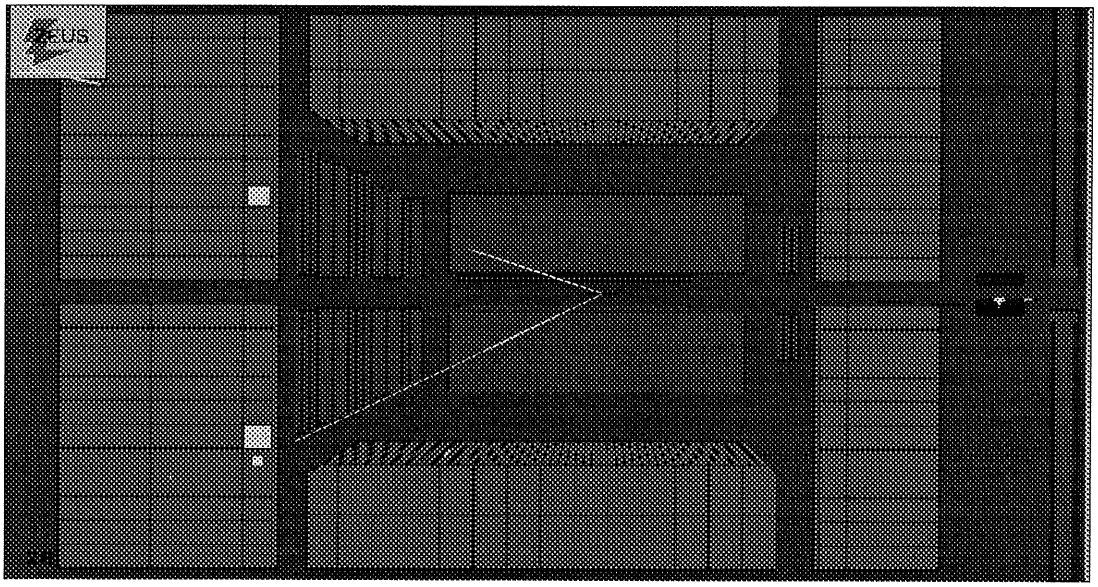
- $\sigma_L \propto \frac{\alpha_S^2(Q)}{Q^6}|xG(x,Q^2)|^2$
- A fast increase of the $\gamma^* p \to Vp$ cross section with energy W (longitudinal cross section dominates at large Q^2)
- SU(4) restoration, possibly modified by VM wave functions effects $\rho : \omega : \phi : J/\psi = 9 : 1 : 2 : 8$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

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

Kinematic range

$$
\begin{array}{lcl}
Q^2 & \to & 0 \div 60\,\mathrm{GeV}^2 \\
W & \to & 20 \div 280\,\mathrm{GeV} \\
|t| & \to & 0 \div 10\,\mathrm{GeV}^2
\end{array}
$$

- Photoproduction: $Q^2 \approx 0$
  (do not observe the scattered e in Calorimeter)
- Electroproduction, Q^2 range : $0.25 < Q^2 < 60\ \mathrm{GeV}^2$
  (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

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

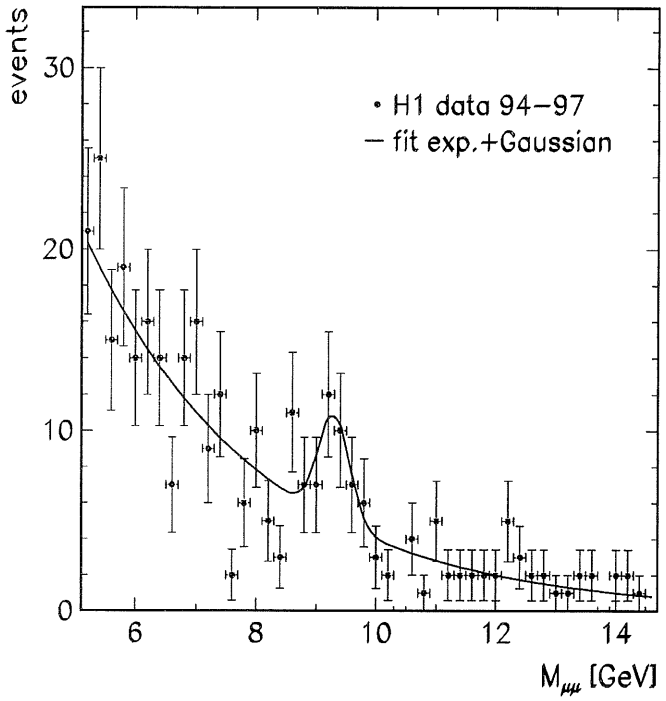
$$\frac{d^2\sigma^{ep}}{dydQ^2} = \Gamma_T(y,Q^2)(\sigma_T^{\gamma^* p} + \epsilon\sigma_L^{\gamma^* p})$$

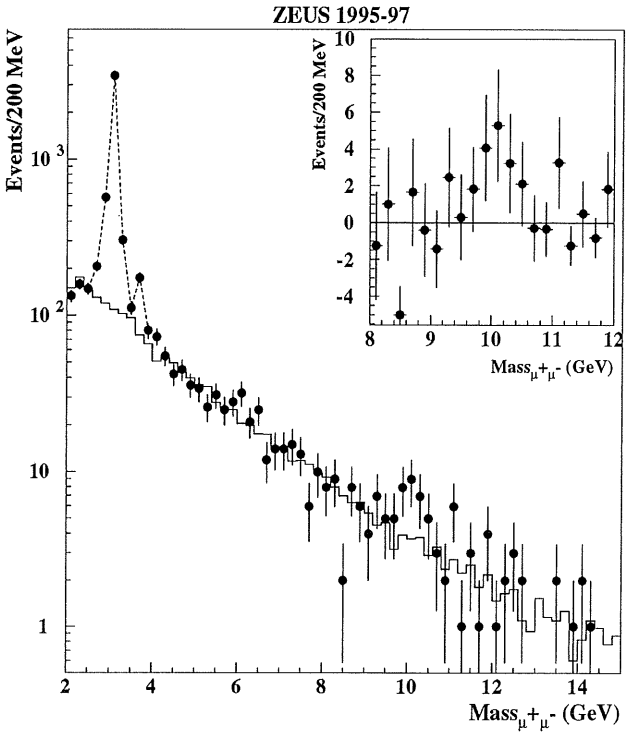
- $\Gamma_T = \frac{\alpha}{2\pi} \cdot \frac{1+(1-y)^2}{yQ^2}$ **(transverse photons flux)**
- $\epsilon = \frac{\Gamma_L}{\Gamma_T} = \frac{2(1-y)}{1+(1-y)^2}$ **(polarization parameter)**

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

VM	**decay mode**	**BR**(%)
ρ^o	$\pi^+\pi^-$	100
ω	$\pi^+\pi^-\pi^0$	88
ϕ	K^+K^-	49
J/ψ	l^+l^-	12
Υ	$\mu^+\mu^-$	2.48

Υ photoproduction





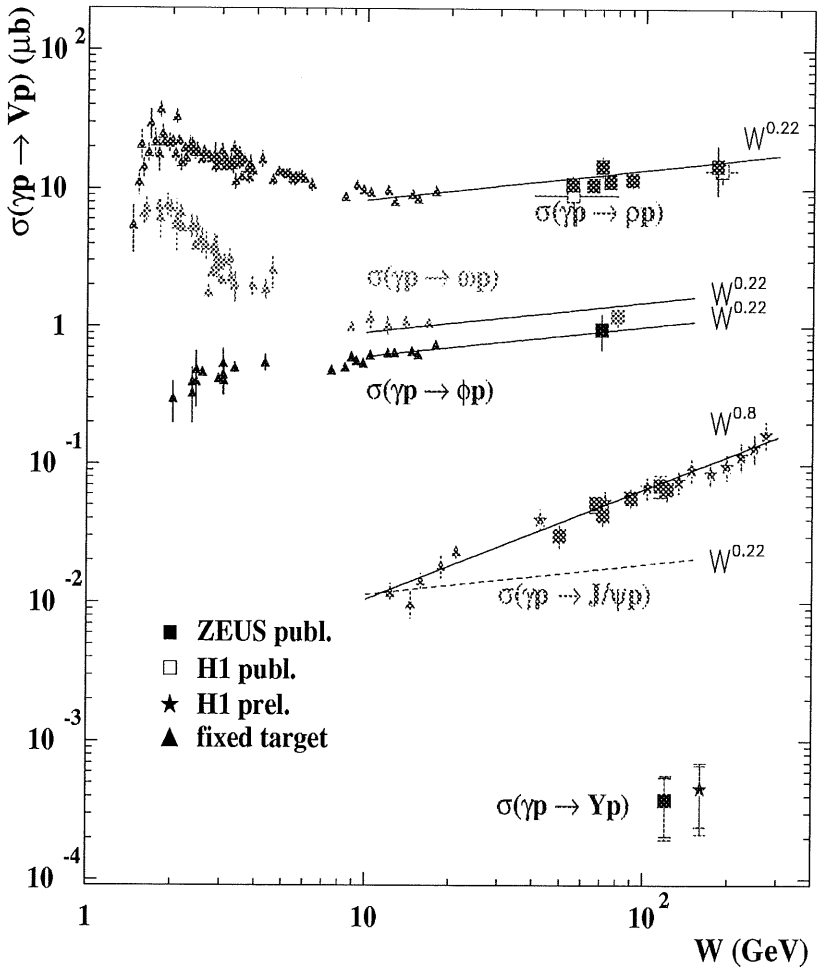
$$\sigma(\gamma p \to \Upsilon p) \cdot BR(\Upsilon \to \mu\mu)$$

$13.3 \pm 6.0^{+2.7}_{-2.5}$ pb at $< W >= 120$ GeV (ZEUS)

$14 \pm 8.0 \pm 4$ pb at $< W >= 160$ GeV (H1 preliminary)

Photoproduction

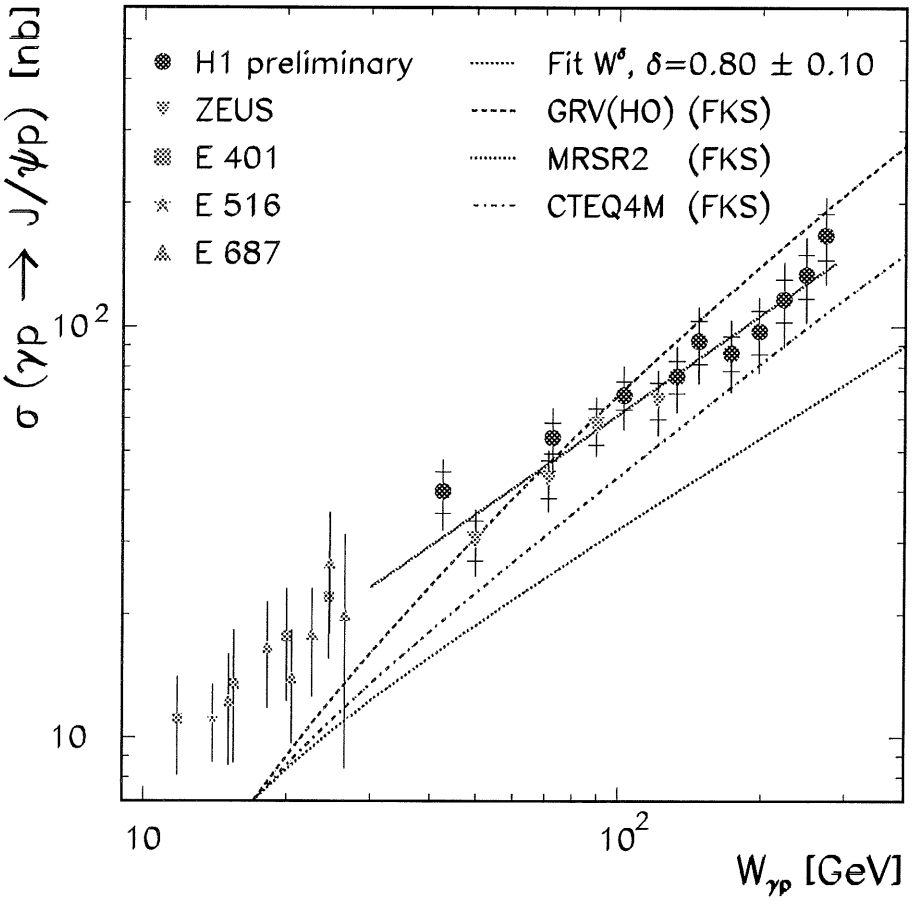
Cross Section vs energy



- light vector mesons have a weak energy behavior: $\sigma(W) \sim W^{0.2}$
- much stronger energy dependence is observed for J/Ψ $\sigma(W) \sim W^{0.8}$

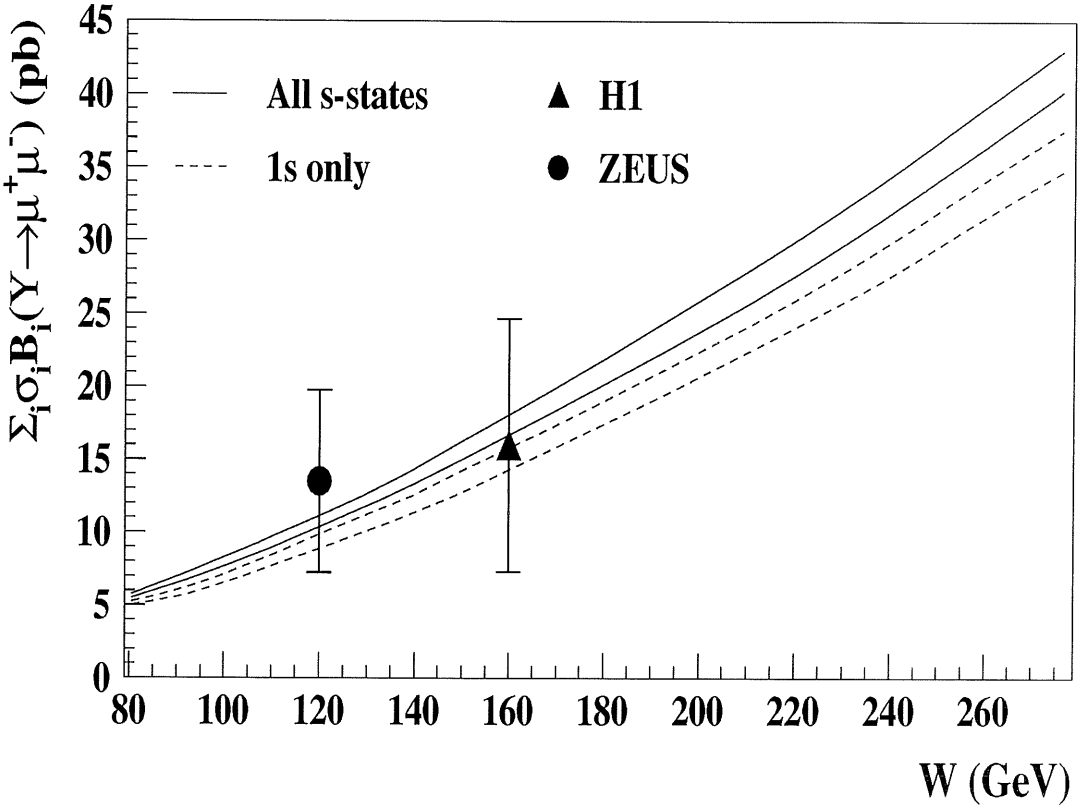
Photoproduction

J/ψ cross section vs energy



- extended range of W energy (H1)
- Fit for H1 and ZEUS data $\rightarrow \sigma(W) \sim W^{\delta}$
  $\delta = 0.80 \pm 0.10$
- in agreement with pQCD calculation (at high W)
- sensitivity to parameterizations of gluon density

Υ photoproduction



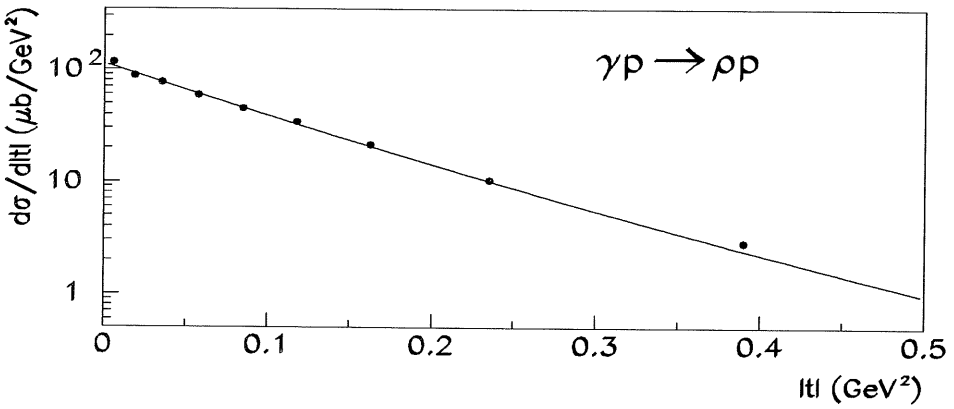
Calculations for the diffractive photoproduction of the Υ family $\Longrightarrow$ two novel effects:

non-diagonal (skewed) gluon distributions,

large magnitude of the real part of the amplitude.

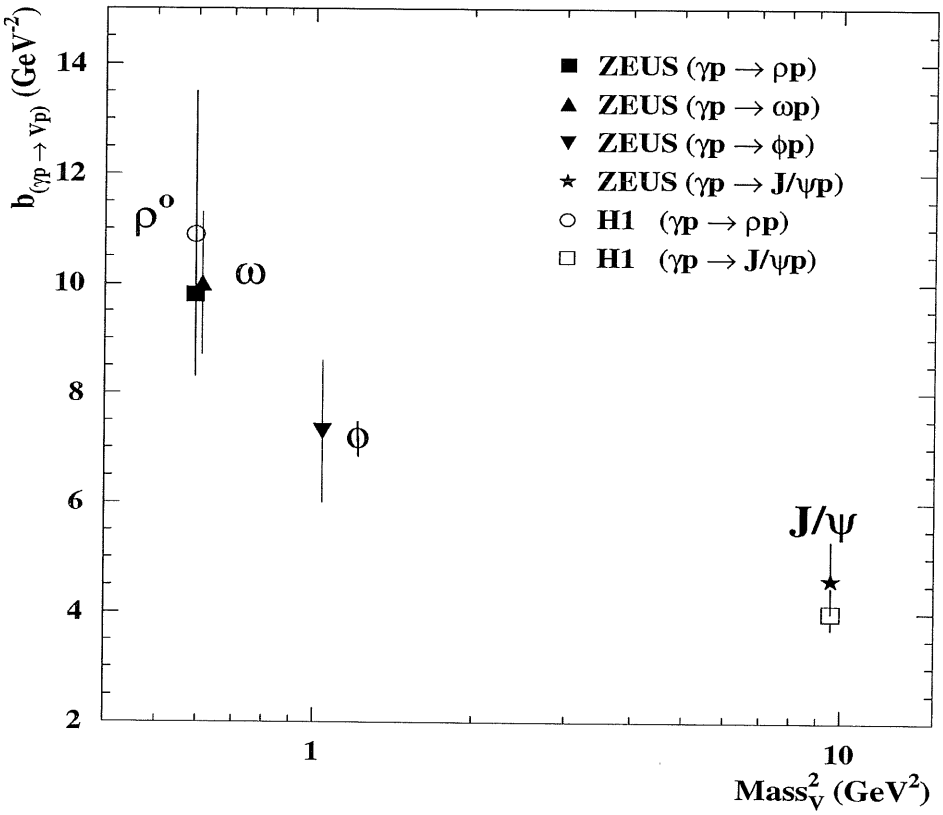
- very strong rise of the cross sections with energy : $\sigma(W) \propto W^{1.7}$!!! $\Longrightarrow$ due to skewed gluon density

Photoproduction : t distribution



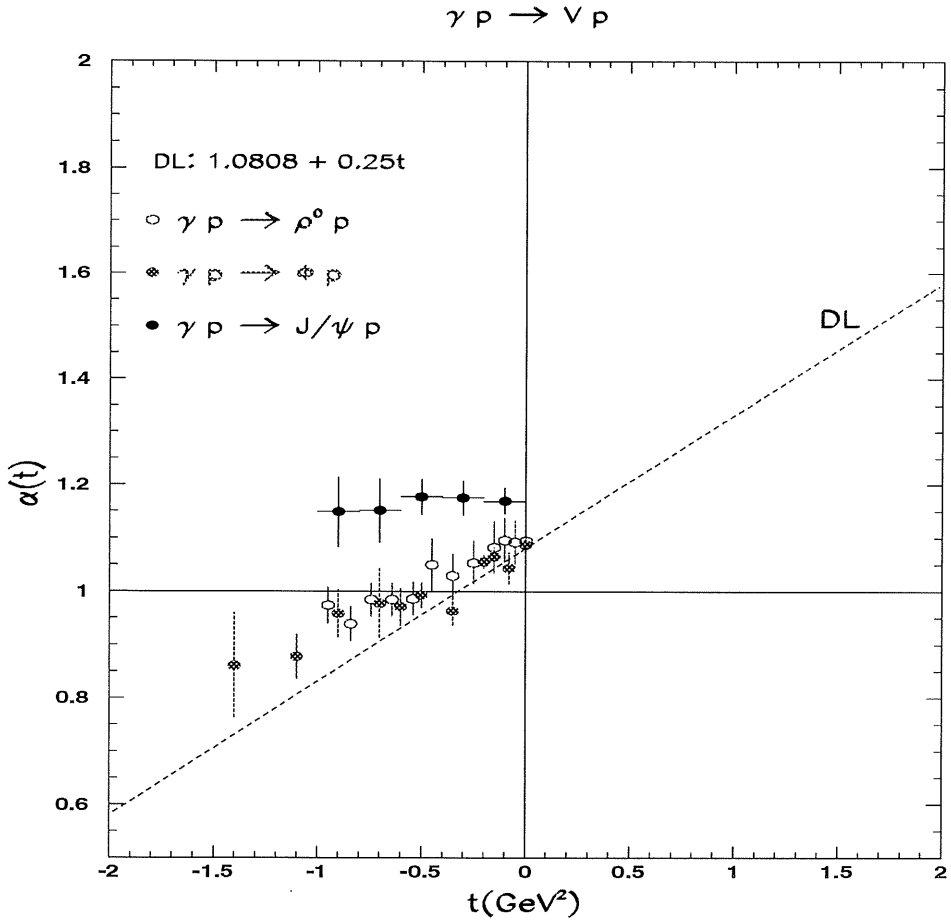
- fit to ZEUS 94 DATA $\Longrightarrow \frac{d\sigma}{d|t|} \propto \exp(-b|t| + c|t|^2)$

- $b = 9.8 \pm 0.8 \pm 1.1 \mathrm{GeV}^{-2}$ $\quad c = 2.7 \pm 0.9^{+1.9}_{-1.7} \mathrm{GeV}^{-4}$



- b decreases with M_V

Photoproduction : Pomeron trajectory



Study the W dependence of $d\sigma/dt$ at fixed t

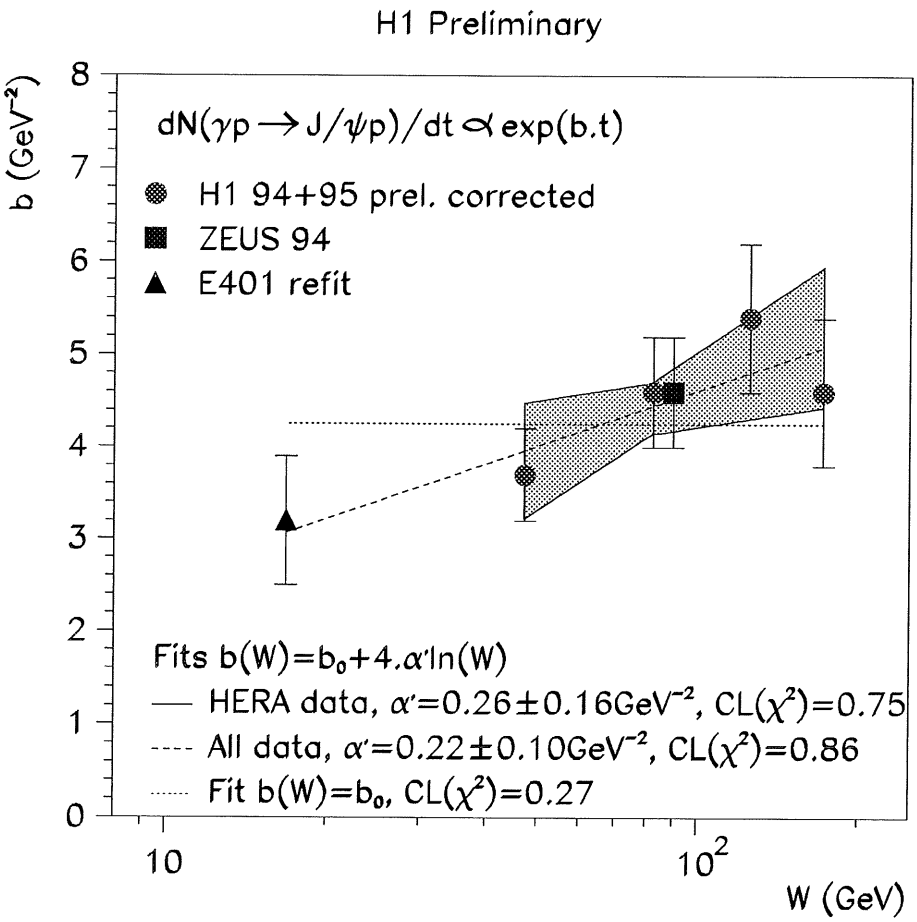
$\star$ fit $\Longrightarrow \mathrm{d}\sigma/\mathrm{dt} \propto (\mathrm{W}^2)^{[2\alpha_{\mathbf{P}}(\mathrm{t})-2]}$ $\qquad \alpha_{\mathbb{P}}(\mathrm{t}) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} \cdot \mathrm{t}$

preliminary results

- ρ : $\alpha_{I\!P}(t) = (1.097 \pm 0.020) + (0.163 \pm 0.035)t$
- ϕ : $\alpha_{I\!P}(t) = (1.083 \pm 0.010) + (0.180 \pm 0.027)t$
- J/Ψ : $\alpha_{I\!P}(t) = (1.175 \pm 0.026) + (0.015 \pm 0.065)t$

J/Ψ data $\rightarrow$ ZEUS + H1 + E401 + EMC

Photoproduction : Pomeron trajectory

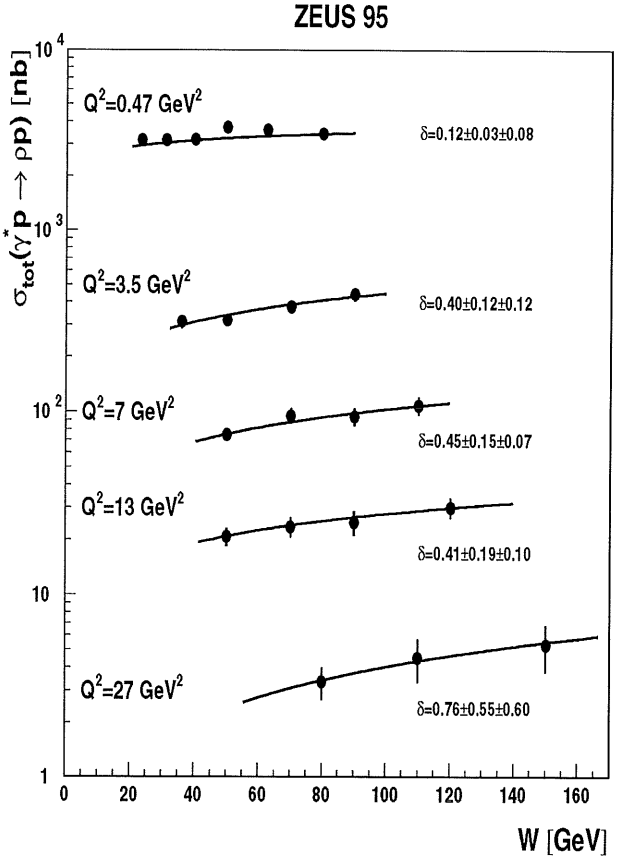


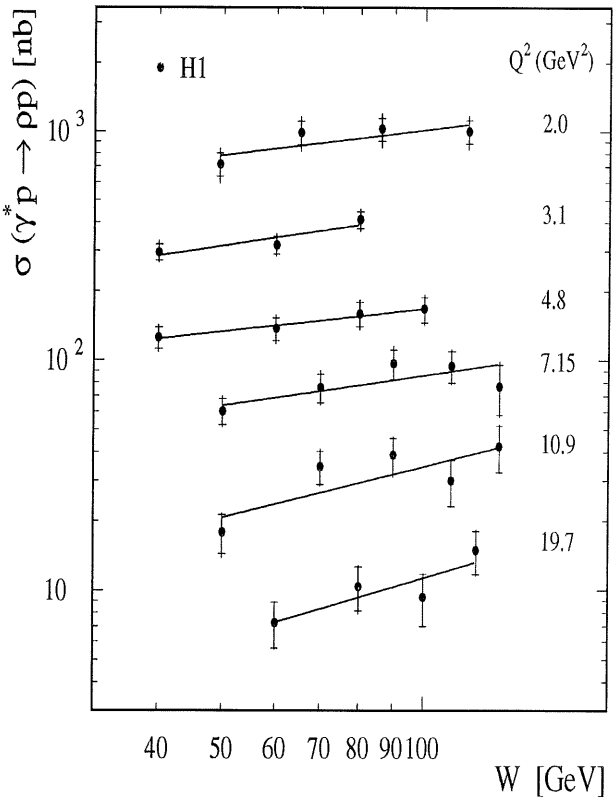
Study the W dependence of b slope

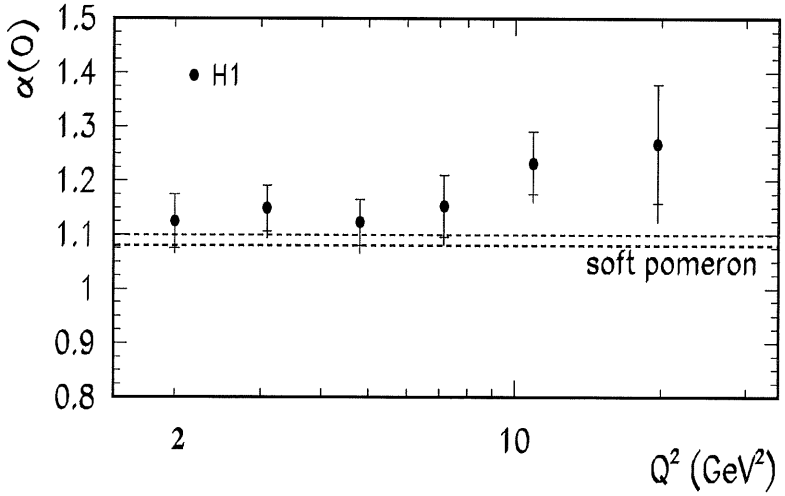
$\star$ fit $\Longrightarrow \frac{d\sigma}{d|t|} \propto \exp(-b|t|)$ $\qquad b = b_0 + 4\alpha'_{\mathbf{P}} \cdot \ln(W)$

- J/Ψ : $\alpha'_{I\!P} = 0.22 \pm 0.10\,\mathrm{GeV}^{-2}$, data $\rightarrow$ ZEUS + H1 + E401
- Shrinkage ?

Electroproduction : ρ Cross section W dependence







Fit H1 data only :

$$\sigma(\gamma^* p \to \rho p) \propto W^{\delta}$$

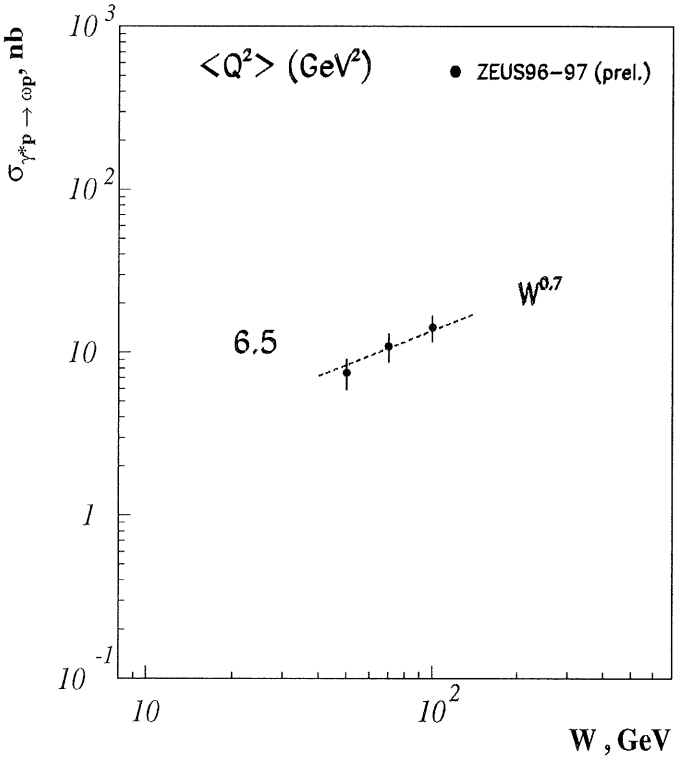
$$\delta \propto 4[\alpha(< |t| >) - 1]$$

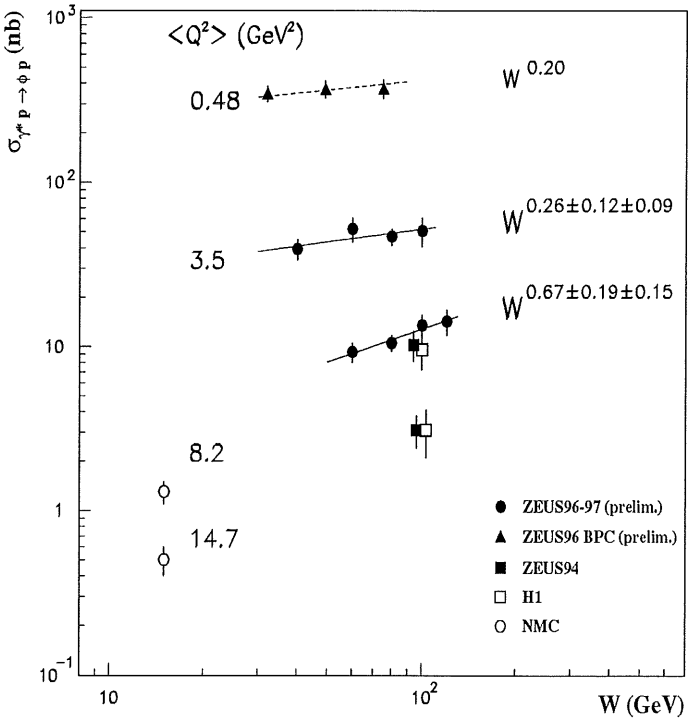
$$\alpha(t) = \alpha(0) + 0.25t$$

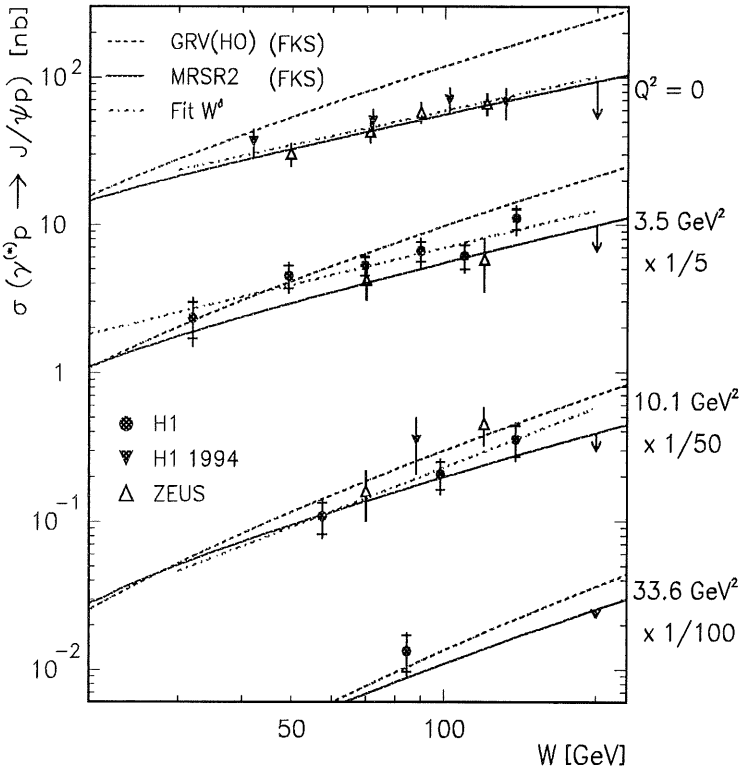
and $< |t| > = 1/b$

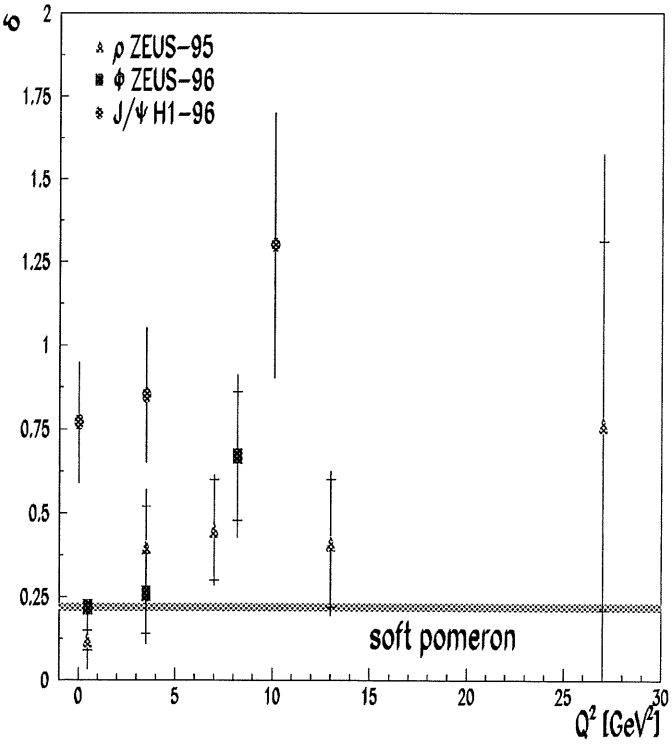
- **Cross Section W dependence becomes steeper at high Q^2**

Electroproduction : VM Cross section W dependence

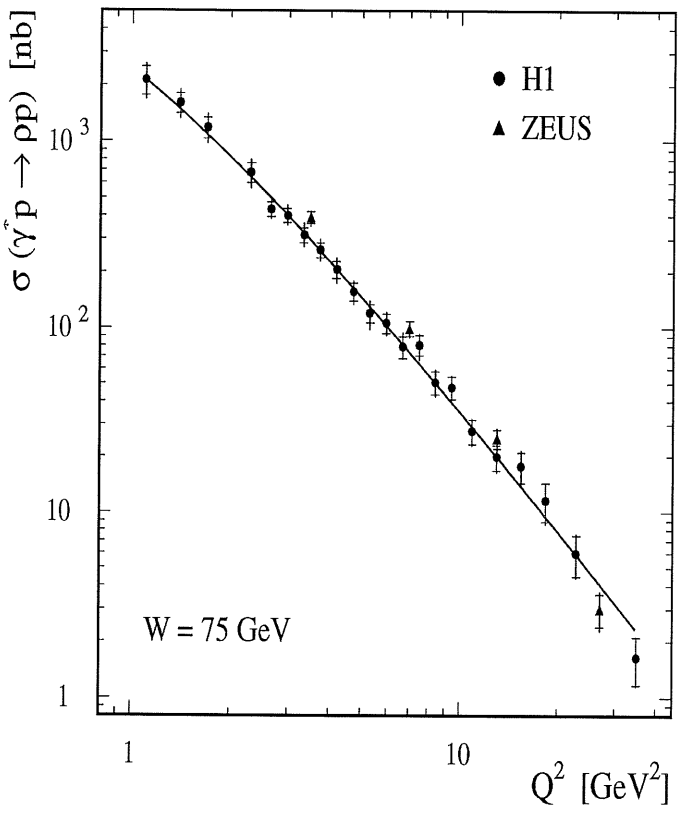


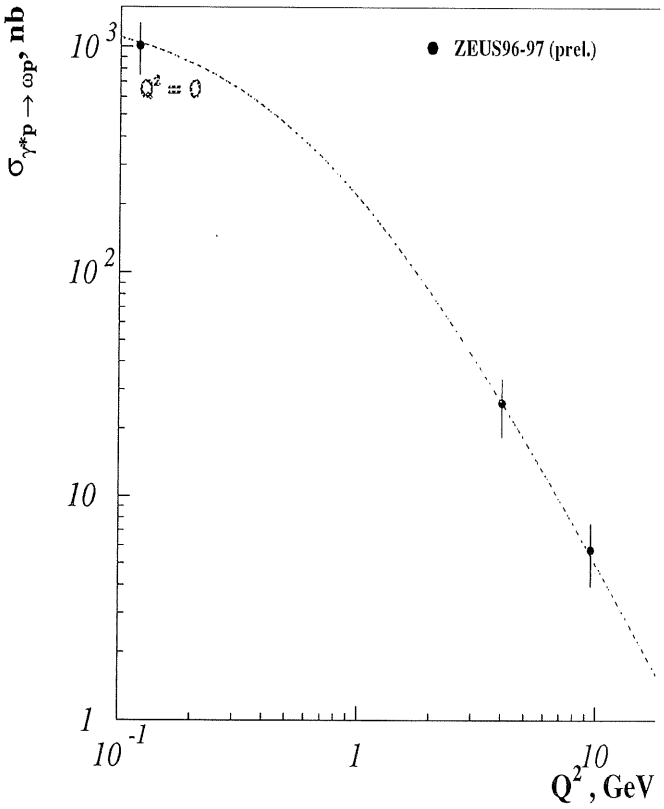


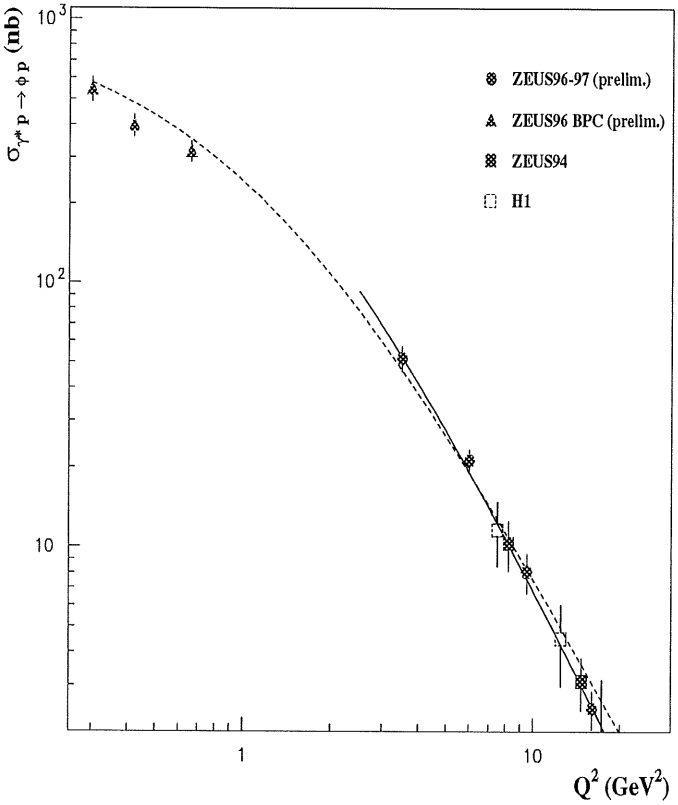


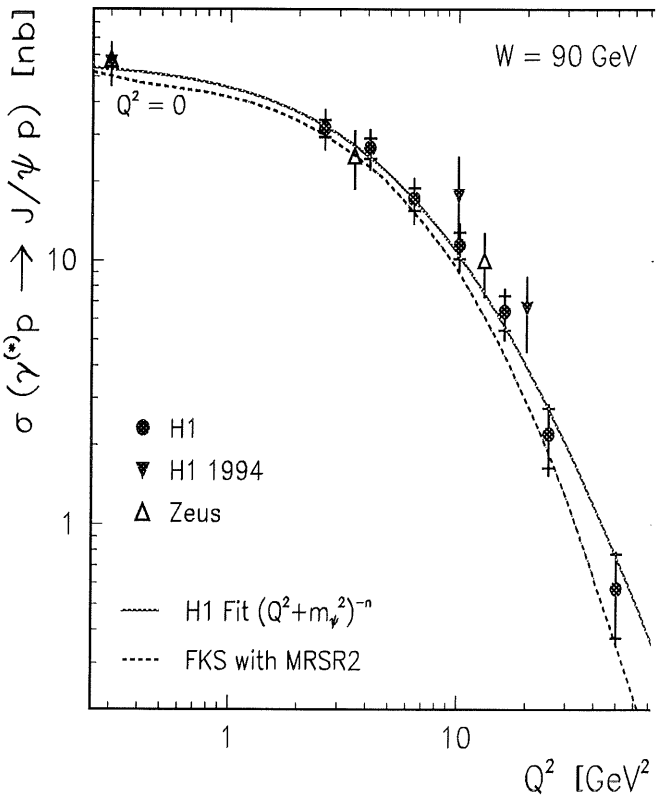


Electroproduction : VM Cross section Q^2 dependence

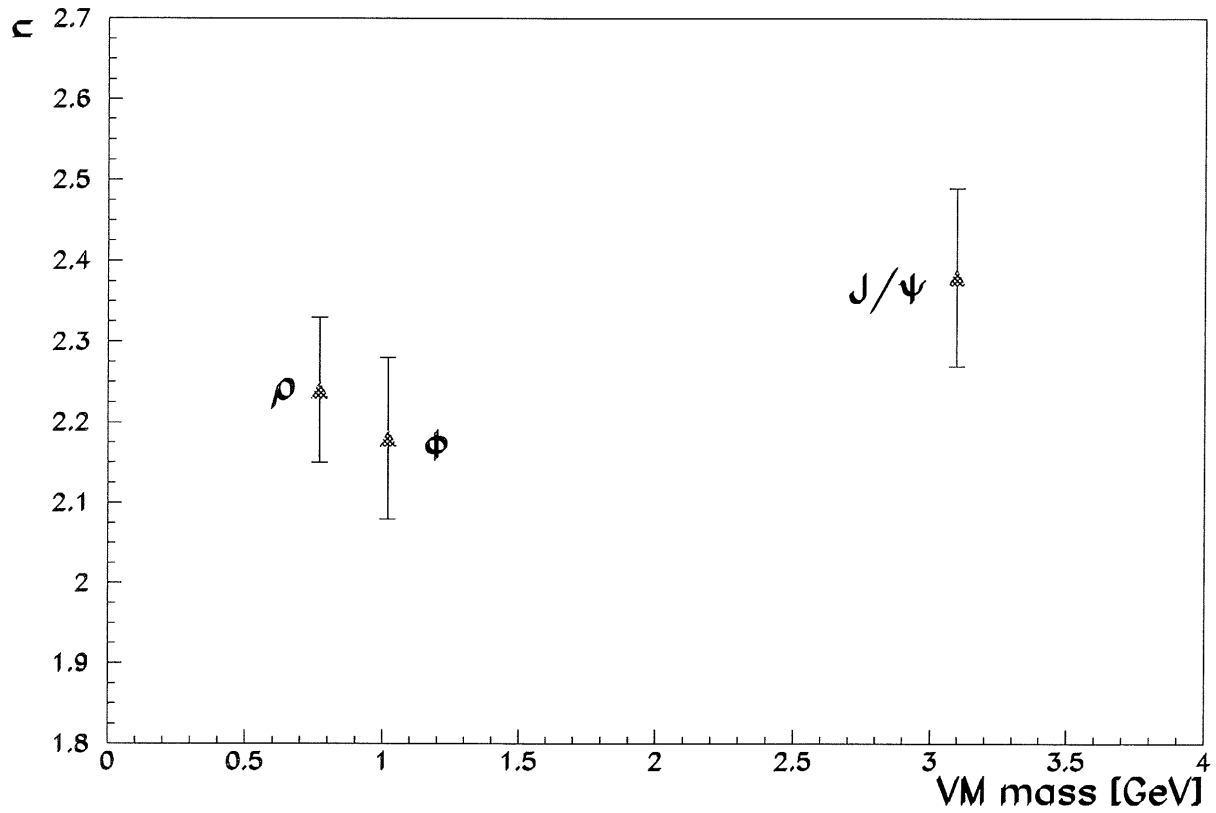








Electroproduction : VM Cross section Q^2 depende

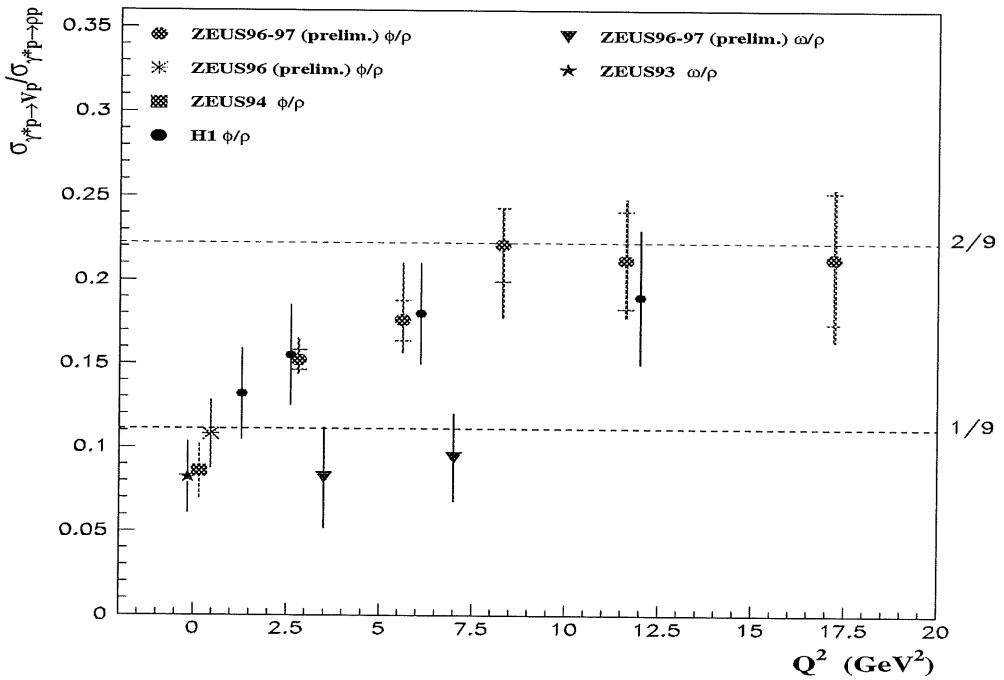


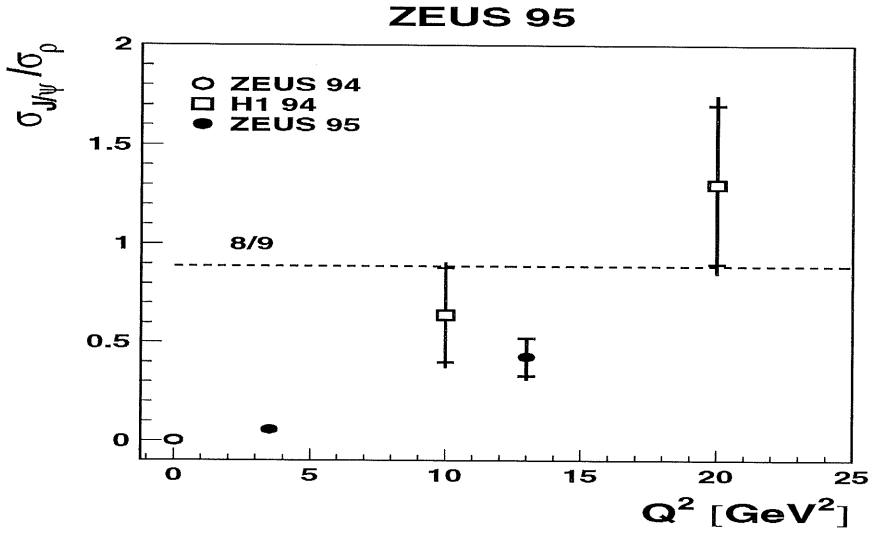
fit $\Longrightarrow \sigma \propto (Q^2 + M^2)^{-n}$ to ρ, ϕ and J/Ψ data

- Soft process $\Longrightarrow$ $\sigma \sim 1/Q^4$ dependence
- pQCD models $\Longrightarrow$ $\sigma_L \sim (\alpha_s(Q^2) \cdot xg(x, Q^2))^2/Q^6$

$(\alpha_s(Q^2) \cdot xg(x, Q^2))^2 \sim Q$ and suppression factor due to quarks
Fermi motion $\Longrightarrow$ $\sigma_L \sim (Q^2)^{-n_{eff}}$, $n_{eff} \sim 2 \div 2.5$

Vector Mesons production ratios : Q^2 dependence





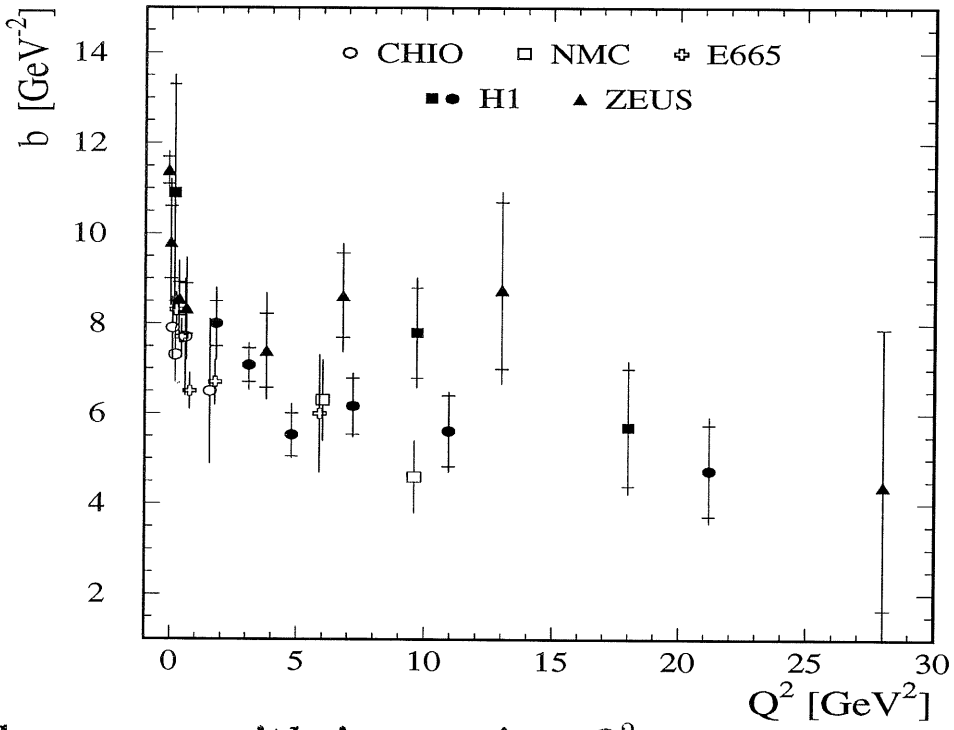
- quark charges of the Vector Meson and flavour independent production mechanism :

$$\rho : \omega : \phi : J/\Psi = 9 : 1 : 2 : 8$$

- SU(4) predictions are badly broken in photoproduction
- SU(4) restoration with Q^2 increasing ?

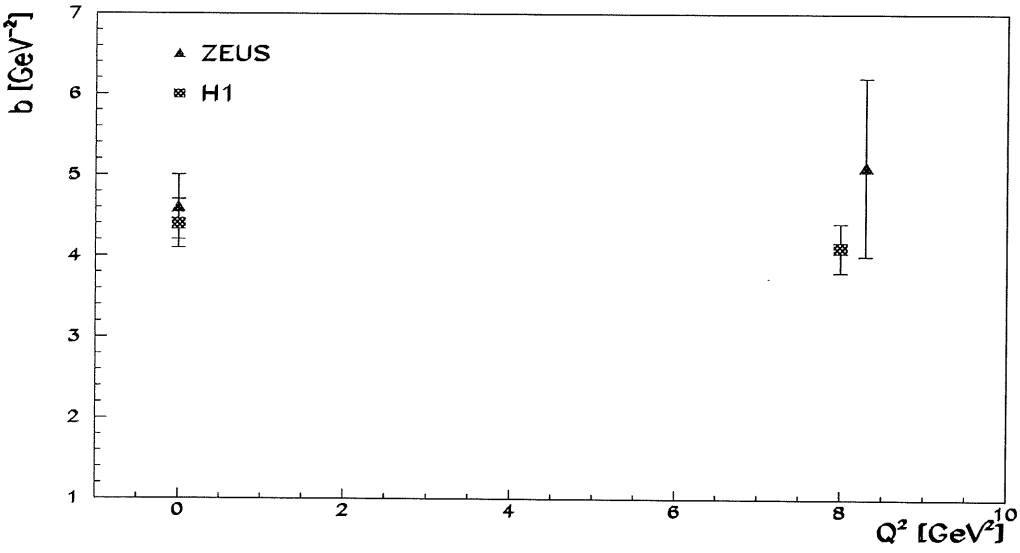
Electroproduction : b slope

$$\gamma^\star p \to \rho p$$

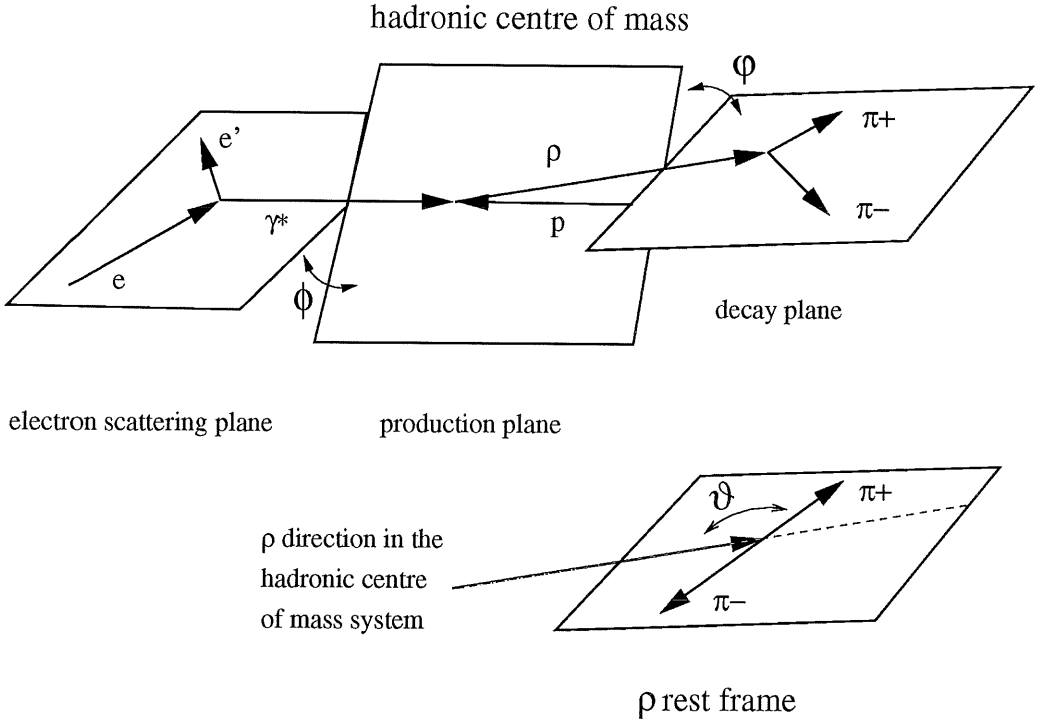


- b decreases with increasing Q^2

$$\gamma^\star p \to J/\Psi p$$

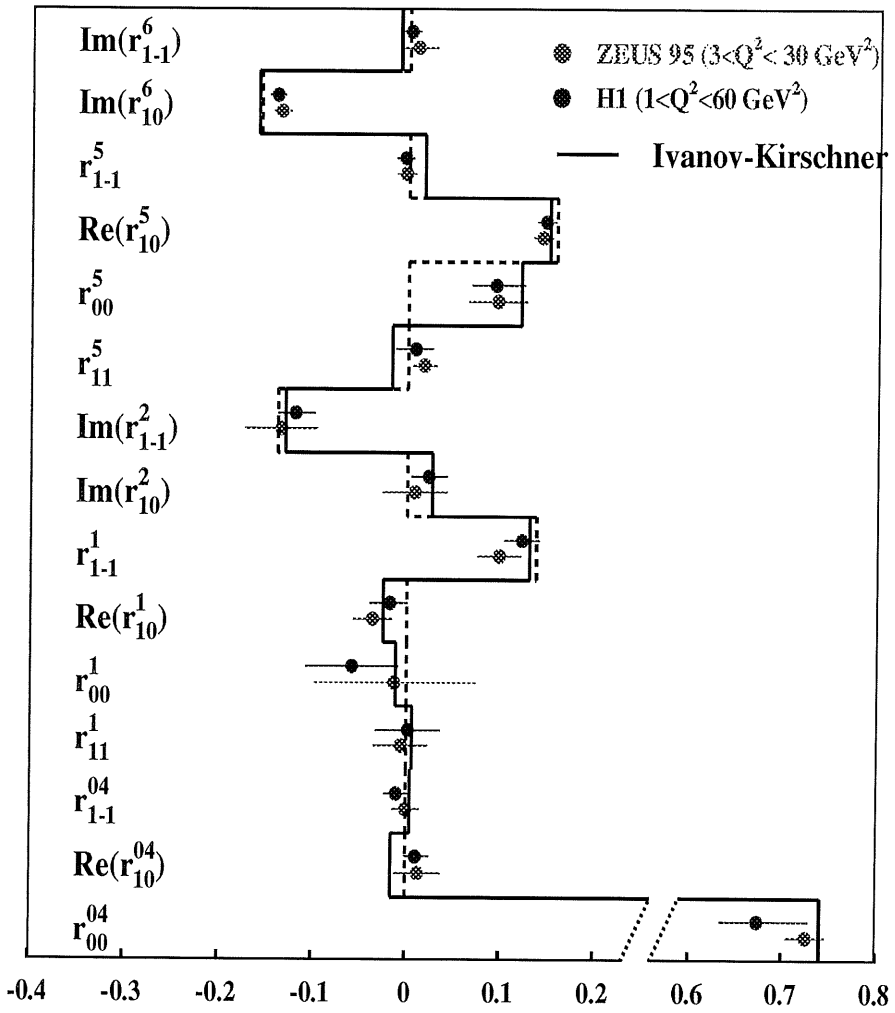


Helicity Studies



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

Helicity Studies



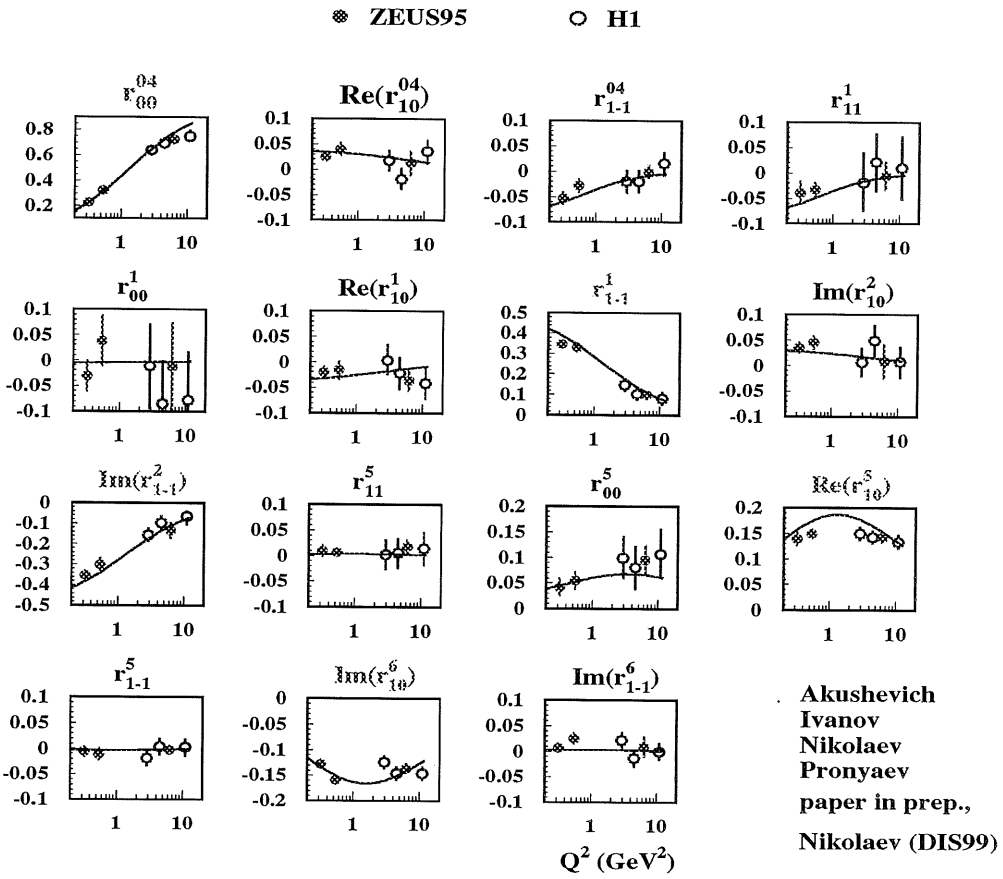
Fit to total angular distribution

- r^5_{00} **deviates from zero !**
- $r^5_{00} \sim$ **single-flip amplitude**

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

- **pQCD predicts non zero value of** r^5_{00}
- $r^5_{00} \rightarrow$ **sensitive to wave function of VM**

Helicity Studies



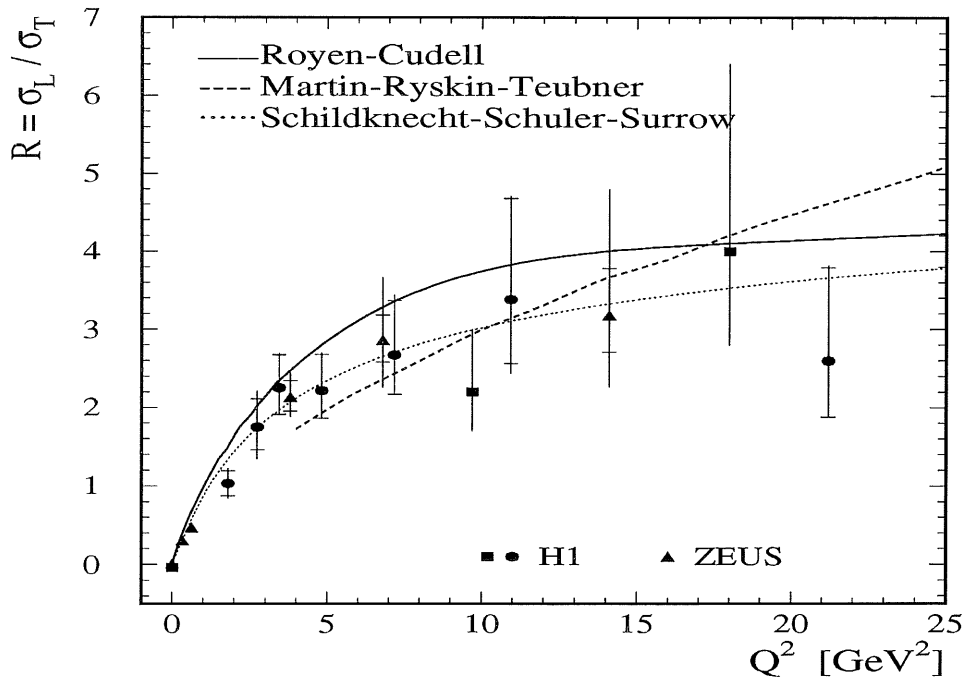
Akushevich
Ivanov
Nikolaev
Pronyaev
paper in prep.,
Nikolaev (DIS99)

- **single flip** $(\gamma^*_T \to \rho_L)$ $\Longrightarrow (7.9 \pm 3.6)\%$
- **single flip** $(\gamma^*_L \to \rho_T)$ $\Longrightarrow \sim 0$
- **double flip** $(\gamma^*_T(\pm 1) \to \rho_T(\mp 1)) \Longrightarrow (4.8 \pm 3.7)\%$

Helicity Studies

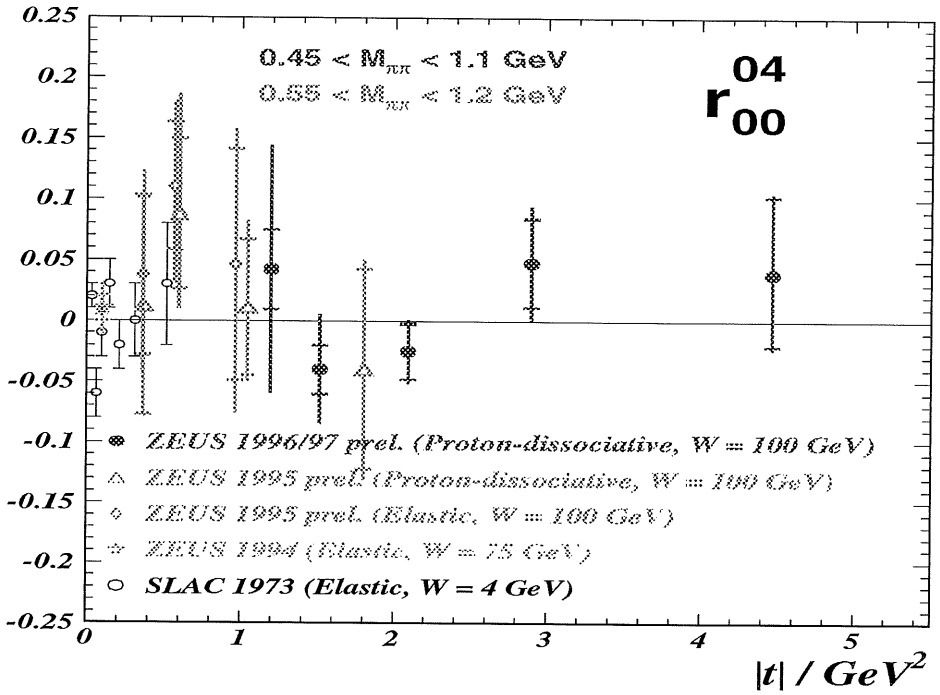
- **s-channel helicity conservation (SCHC)**
- **natural parity exchange ($P = (-1)^J$) in the t-channel (NPE)**
- **if SCHC holds →** $R = \sigma_L/\sigma_T = r_{00}^{04}/\epsilon(1 - r_{00}^{04})$
- **if not →** $r_{00}^{04} \to r_{00}^{04} - \Delta^2$, $\Delta \propto r_{00}^5/\sqrt{2r_{00}^{04}}$

R(SCHC) - R(SCHNC) ~ 3 %



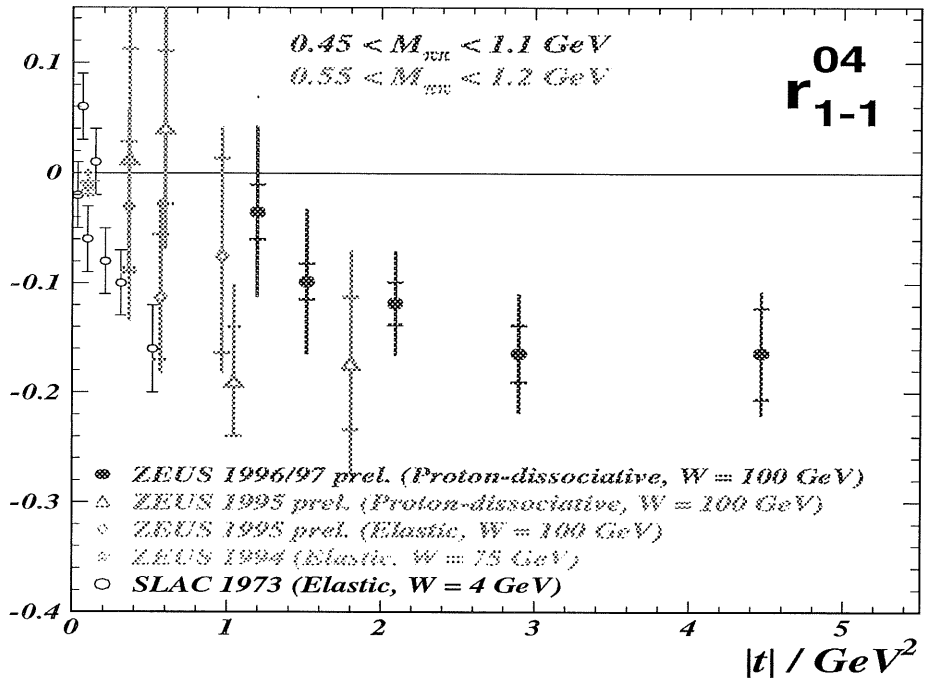
⋆ at large Q^2 $R \to$ const ?

Helicity Studies : Photoproduction



- r_{00}^{04} measures the degree of longitudinal polarization
- no difference elastic/dissociative observed
- at high t ρ meson is produced in helicity ± 1 state

Helicity Studies : Photoproduction



- double-flip observed only at high $|t|$

Summary

- SOFT process:
  - ⋆ photoproduction
  - ⋆ low Q^2 electroproduction of light VM

- HARD process:
  - ⋆ photoproduction of heavy Vector Mesons
  - ⋆ high Q^2 electroproduction of all (light and heavy) Vector Mesons

- typical features of HARD events $\Longrightarrow$ pQCD
  - ⋆ fast rise of cross section with energy
  - ⋆ decreasing slope of t distribution
  - ⋆ SU(4) restoration

- open questions :
  - ⋆ shrinkage (is α' zero for heavy Vector Mesons ?)
  - ⋆ σ_L/σ_T
  - ⋆ SCH non Conservation (non zero double-flip amplitudes)

- which is the HARD scale $\Longrightarrow$ Q^2 or M^2 or $|t|$ or their interplay ?