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Vector Meson Production at HERA

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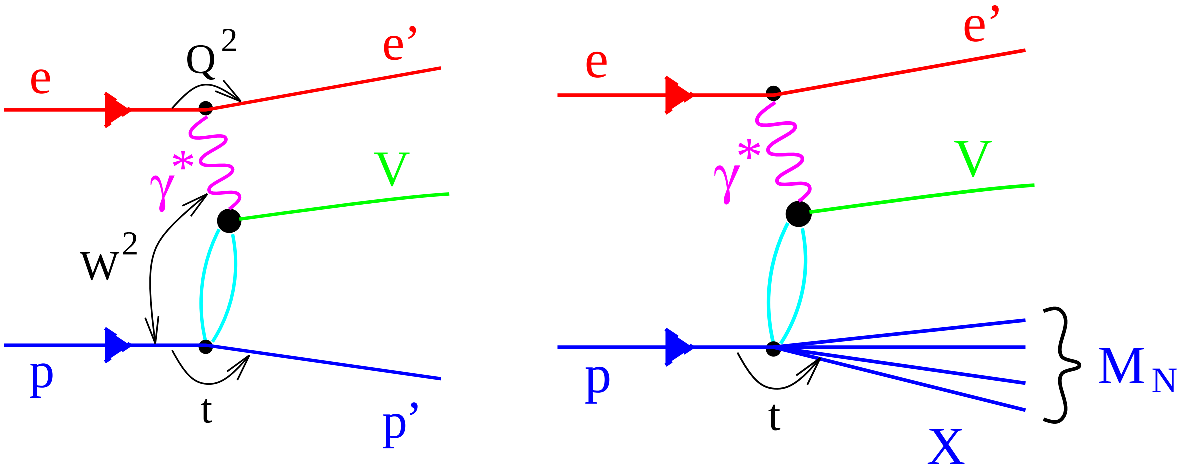
for the H1 and Zeus Collaborations

Outline:

1. Introduction
2. Photoproduction
    - low momentum tranfers $|t|$
    - high momentum transfers $|t|$
3. Intermediate and high Q^2 region
4. Conclusions

Introduction

Vector Meson production in *ep scattering:*



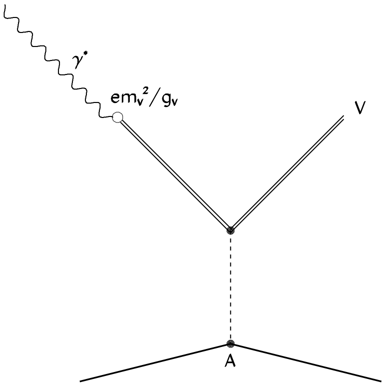
$\mathrm{V} = \rho, \omega, \phi, \rho', \mathrm{J}/\psi, \psi', \Upsilon$

- Q^2 : photon virtuality (10^{-10} - 60 GeV^2)
- W : γ^*-proton c.m. energy (20 - 240 GeV)
- t : four-momentum transfer at the photon vertex squared ($0 < -t < 10$ GeV^2)

⇒ Physics with several scales which can be varied in wide ranges

Theoretical Status

Regge theory and Vector Meson Dominance



exchange of soft $\mathbb{P}$ trajectory

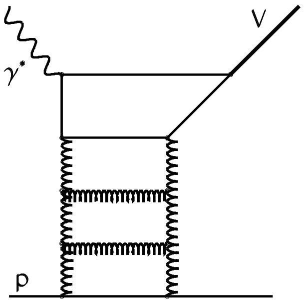
$$\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} \cdot t$$

$$= 1.08 + 0.25t$$

What do we expect for Vector Meson production ?

- weak energy dependence $\sigma(W) \propto W^{4(\alpha_{\mathbb{P}}(0)-1)}/b \sim W^{0.22}$
- shrinkage of the forward peak $\frac{d\sigma}{dt} \propto \exp(bt)$ with $b = b_0 + 2\alpha'_{\mathbb{P}} \cdot ln(W^2)$
- $R = \sigma_L/\sigma_T = \xi_V Q^2/M_V^2$

Models based on pQCD; need hard scale (Q^2, M_V^2, t)



Different models:

Pomeron modeled

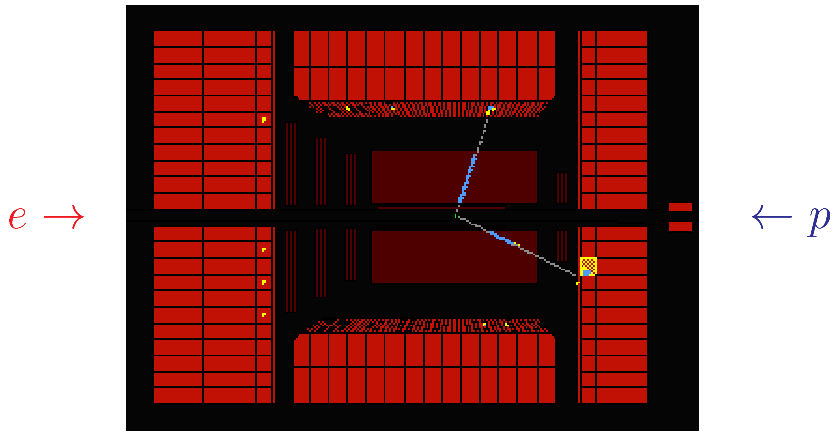
as a system of gluons

Predictions:

- energy dependence $\sigma(W) \propto [xg(x, Q^2)]^2 \sim W^{0.8}$
- b-slope $\approx$ independent of W
- Q^2 and W dependence of $R = \sigma_L/\sigma_T$

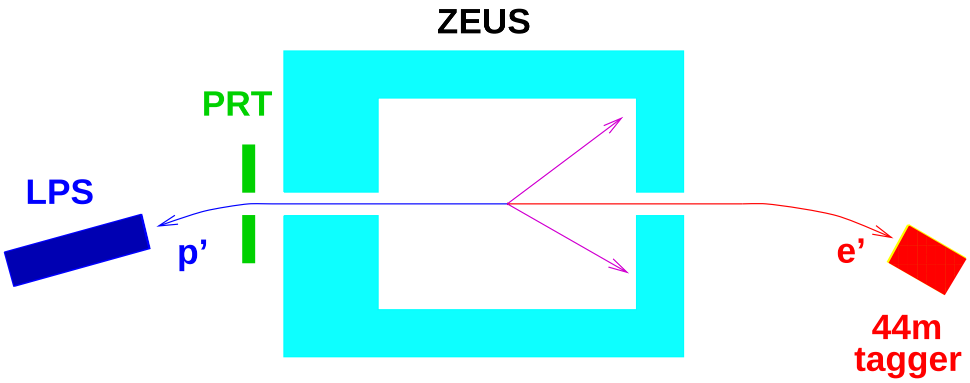
Event Selection

- Reconstruction of the charged decay particles of the VM using central tracking detectors
-
  - Elastic selection: no energy deposits in the main detector (other than decay particles or e')
  - Proton dissociative: energy in the forward detectors
- Scattered e' (not) observed in various detectors
  - e' not observed



$\Rightarrow Q^2 \sim 10^{-6}\ \mathrm{GeV}^2$

  - e' observed in 44m tagger

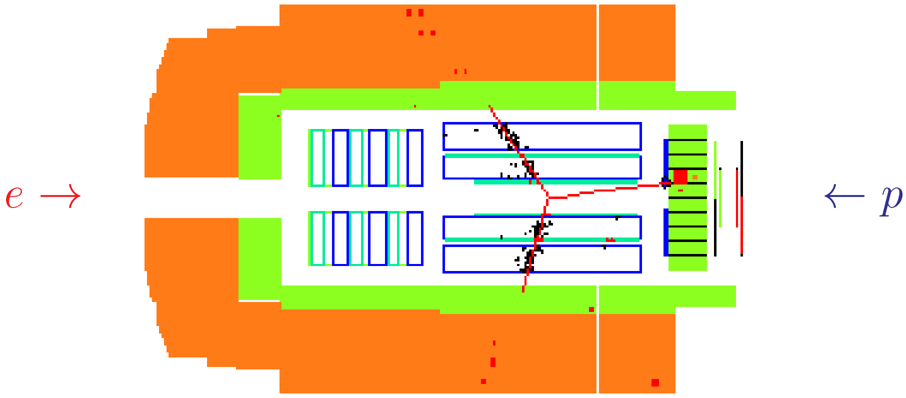


$\Rightarrow Q^2 \lesssim 10^{-2}\ \mathrm{GeV}^2$, high $|t|$

- e' observed in special detectors (BPC)

  $\Rightarrow 0.25\ \mathrm{GeV}^2 < Q^2 < 0.85\ \mathrm{GeV}^2$

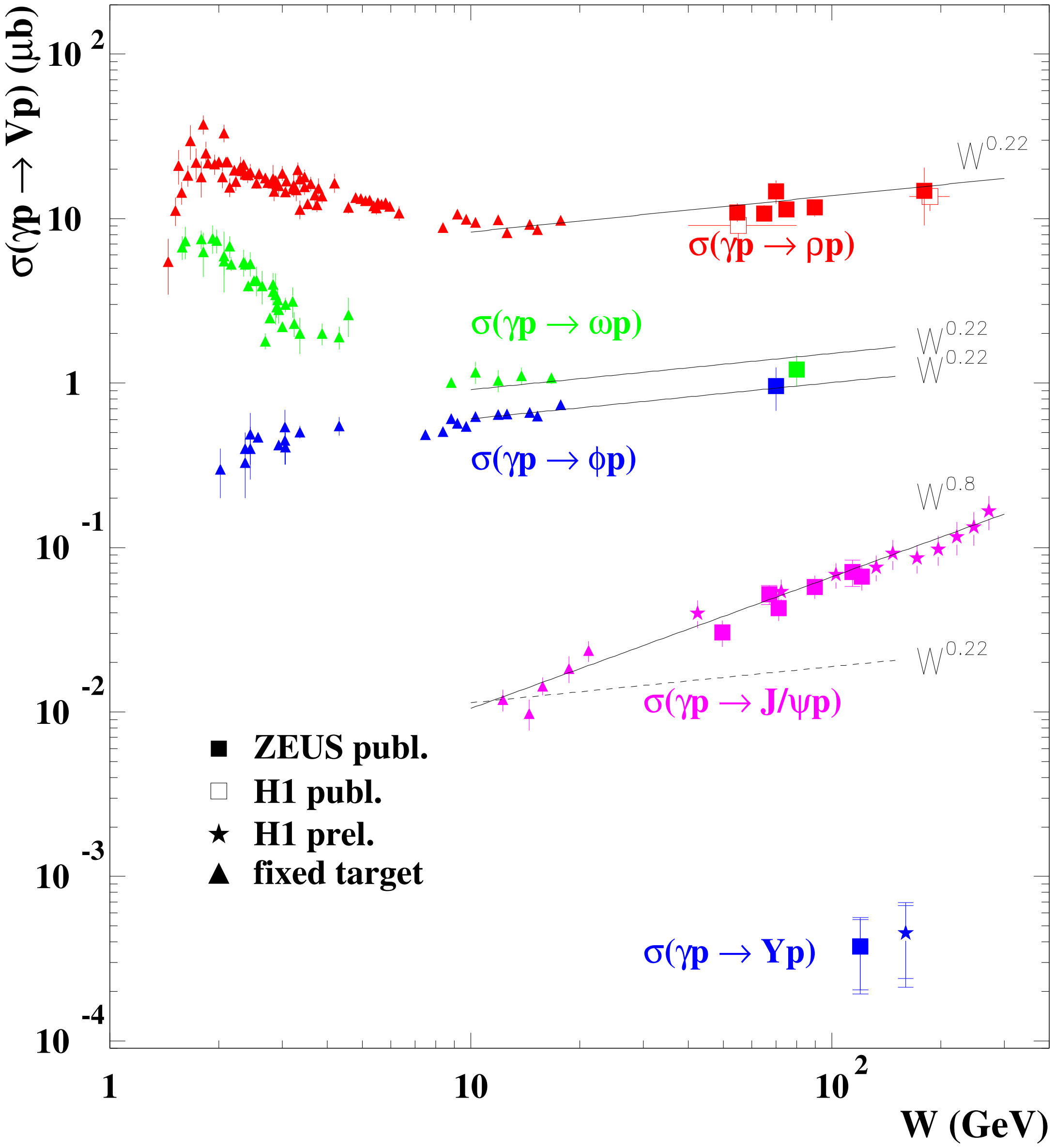
- e' observed in main detector



$\Rightarrow 1\ \mathrm{GeV}^2 < Q^2 < 60\ \mathrm{GeV}^2$

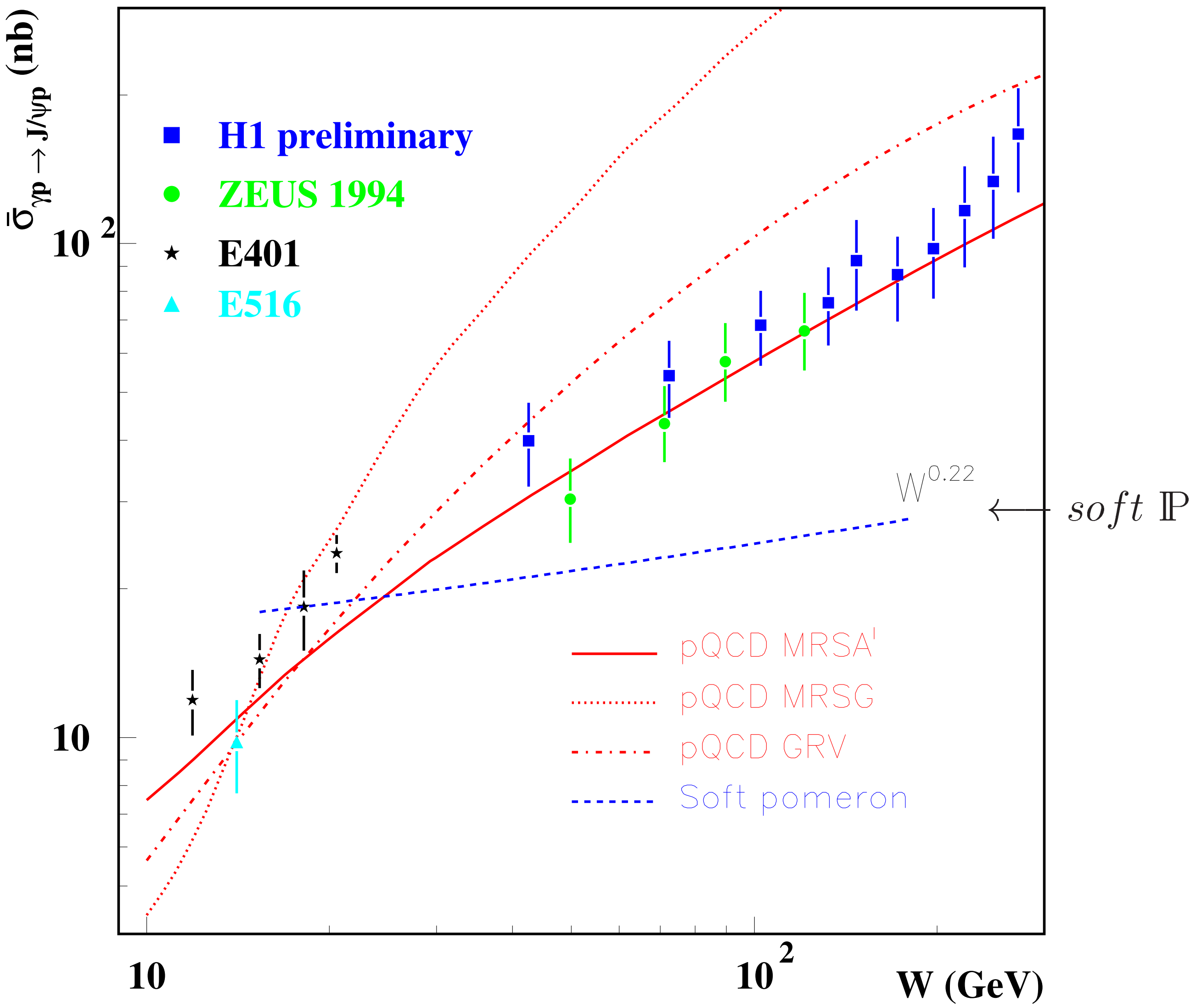
Photoproduction

- cross section vs energy



- ρ, ω and ϕ have a Regge behaviour: $\sigma_{\gamma p \rightarrow Vp} \propto W^{0.22}$
- J/ψ is not described by Regge: much harder dependence on W

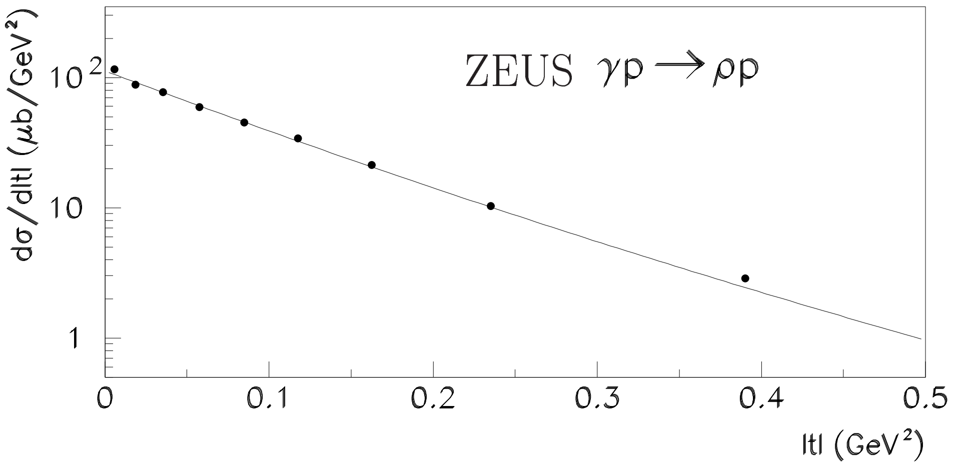
► J/ψ cross section vs energy



In pQCD: $\sigma(W) \propto [xg(x,Q^2)]^2$

High sensitivity to parameterizations of $xg(x)$

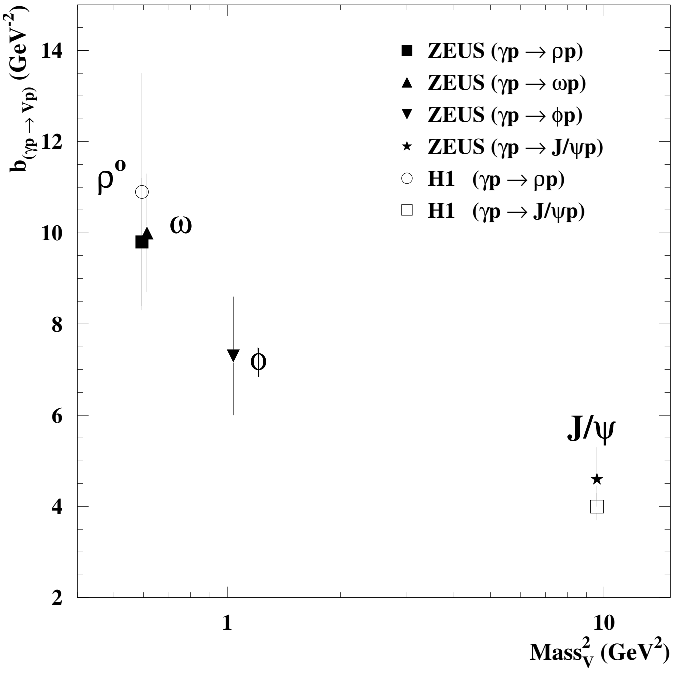
► t-distribution



$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

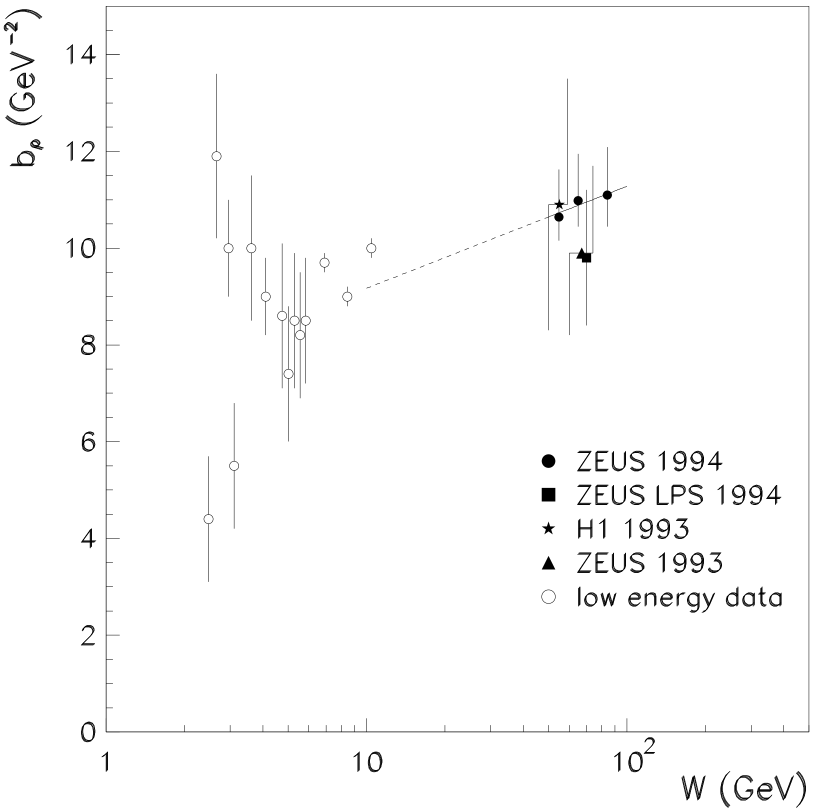
similarity with diffraction of light by a circular aperture $\rightarrow b \propto R^2$

b related to transverse size of the interaction



J/ψ radius smaller than ρ, ω and ϕ radius

▶ Shrinkage



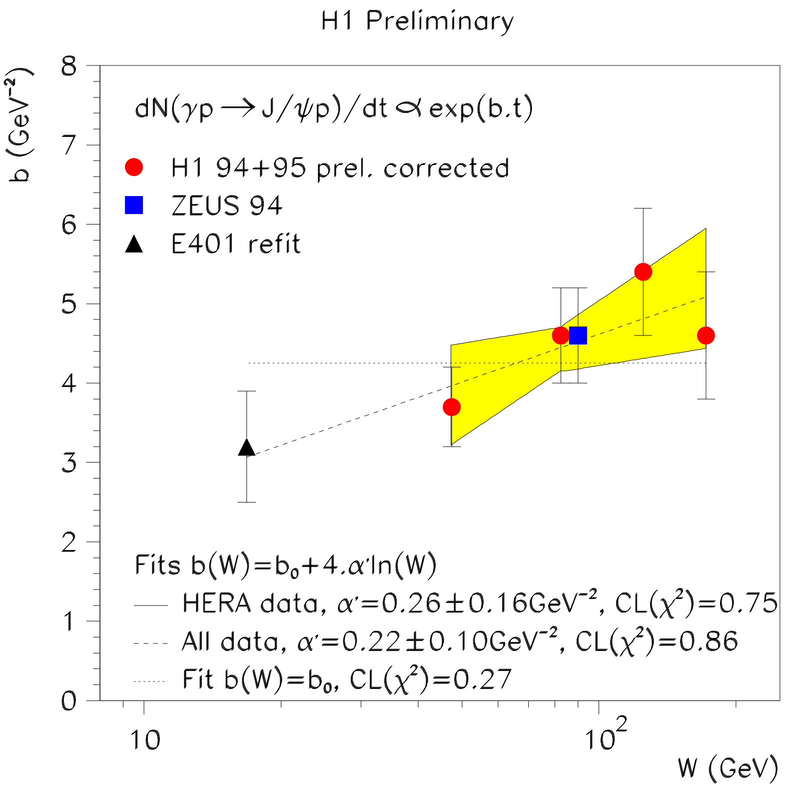
$\Leftarrow \rho$

Fit to the

ZEUS 1994 data:

$b = b_0 + 2\alpha'_{\mathrm{I\!P}} ln W^2$

$\alpha'_{\mathrm{I\!P}} = 0.23 \pm 0.15^{+0.10}_{-0.07}$ GeV^{-2}



$\Leftarrow \mathrm{J}/\psi$

Fit to the

H1+ZEUS+E401 data:

$b = b_0 + 2\alpha'_{\mathrm{I\!P}} ln W^2$

$\alpha'_{\mathrm{I\!P}} = 0.22 \pm 0.10$ GeV^{-2}

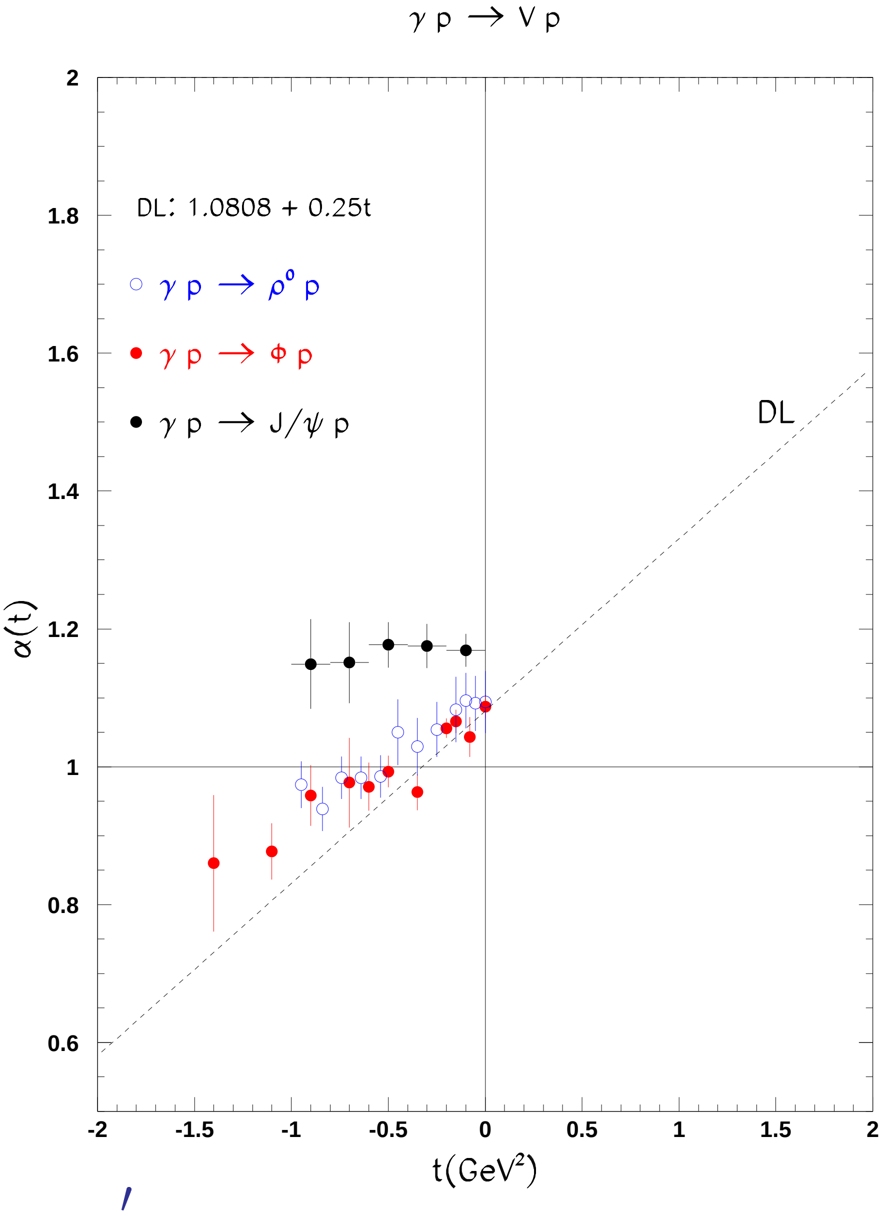
The data indicate that shrinkage may be present but are not conclusive

► Shrinkage

Determination of the trajectory (A.Levy):
Study the W dependence of $d\sigma/dt$ at fixed t

$$d\sigma/dt = f(t)(W^2)^{[2\alpha_{\mathbb{P}}(t)-2]}$$

fit a linear trajectory $\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} \cdot t$

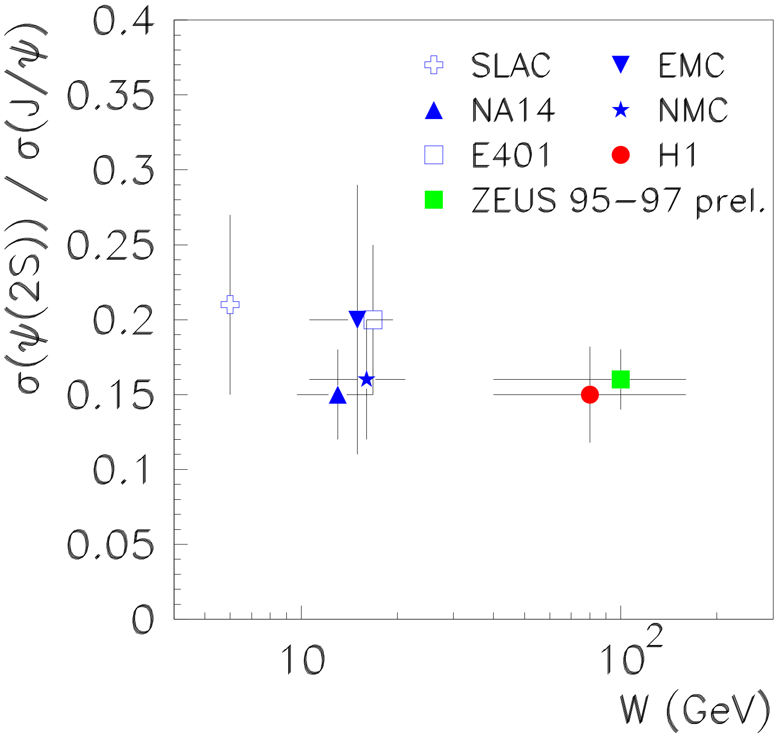


$\Rightarrow \quad \rho: \quad \alpha'_{\mathbb{P}} = 0.163 \pm 0.035$

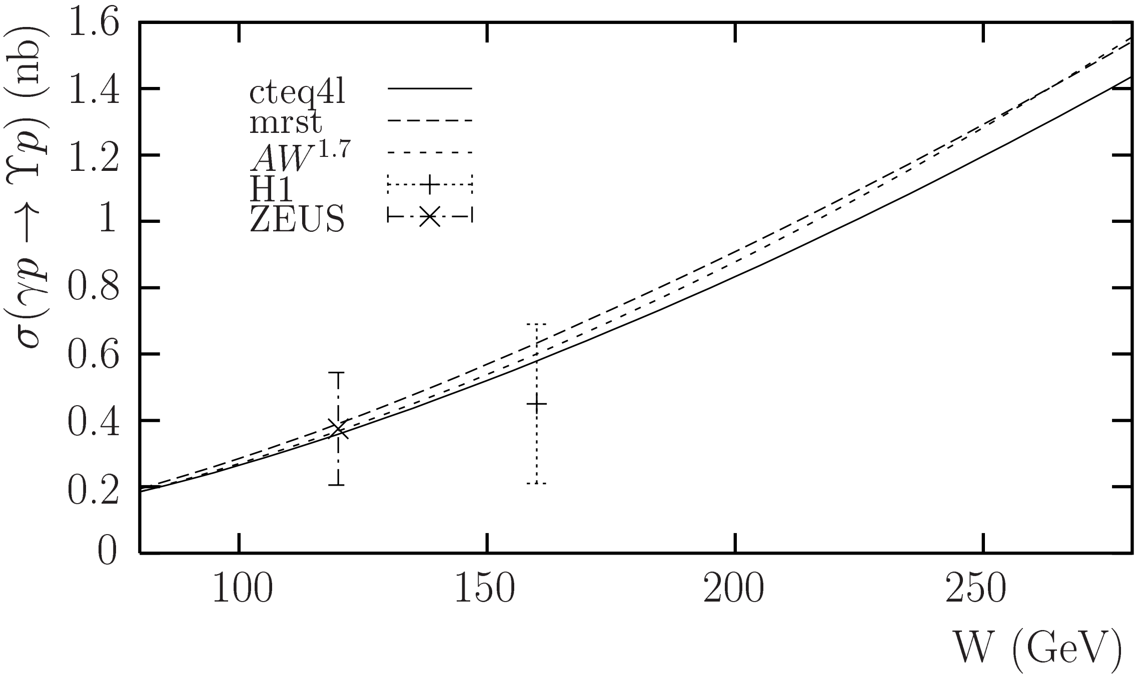
$\Rightarrow \quad \phi: \quad \alpha'_{\mathbb{P}} = 0.180 \pm 0.027$

$\Rightarrow \mathrm{J}/\psi: \ \alpha'_{\mathbb{P}} = 0.015 \pm 0.065$

- heavier resonances: ψ', Υ



⇒ ratio independent of W



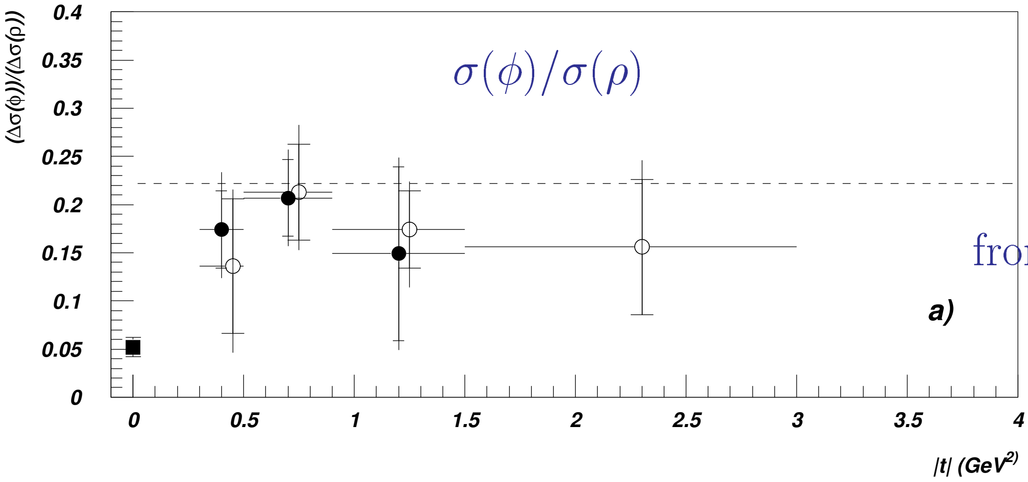
⇒ cross sections in agreement with pQCD calculation

► high t photoproduction

ZEUS: Measurement of the cross section of ρ, ϕ and J/ψ production at different values of $|t|$

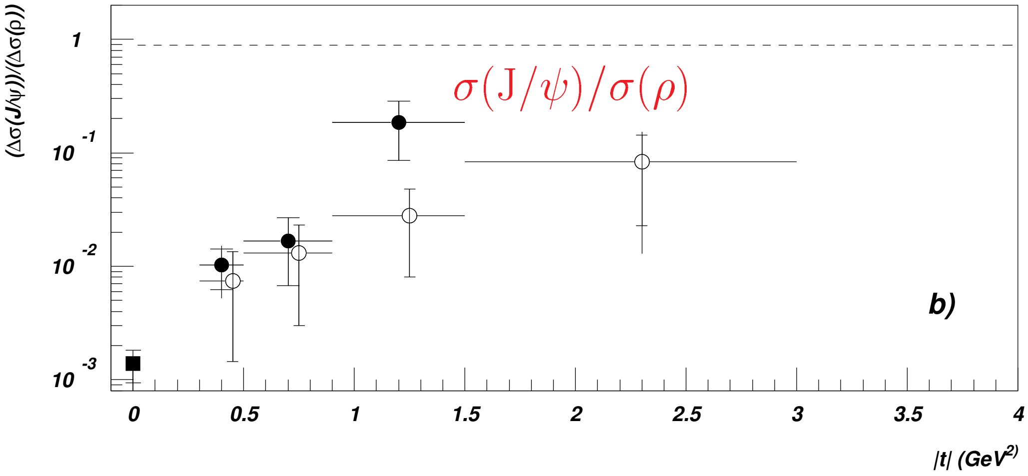
$$85 < W < 105 \text{ GeV}, \; Q^2 < 0.01 \text{ GeV}^2$$

at high $|t|$ mainly $\gamma \, p \to V \; N$



⇒ 2/9

from quark charges



⇒ 8/9

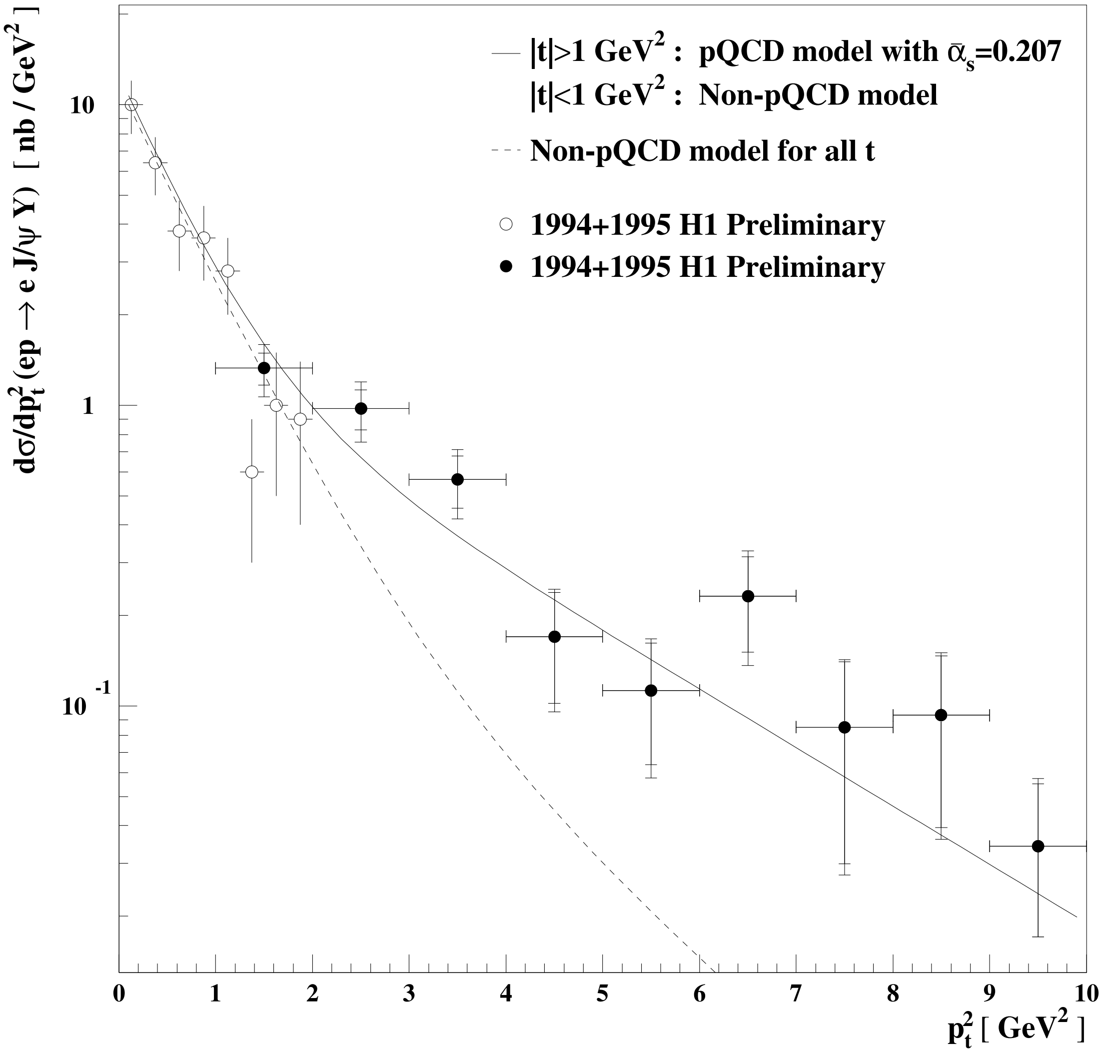
Evidence for $|t|$ providing a hard scale
approach flavour independent values
⇒ pQCD expectations

▶ high t photoproduction

H1: Measure $e\ p \rightarrow \mathrm{J}/\psi\ N$,$\mathrm{J}/\psi \rightarrow \mu^+\mu^-$

$$30 < W < 150\ \mathrm{GeV},\ 1 < P_t^2 < 10\ \mathrm{GeV}^2$$

Comparison to pQCD model (BFKL formalism):



pQCD model (Bartels et al.) describes well
t and W dependence

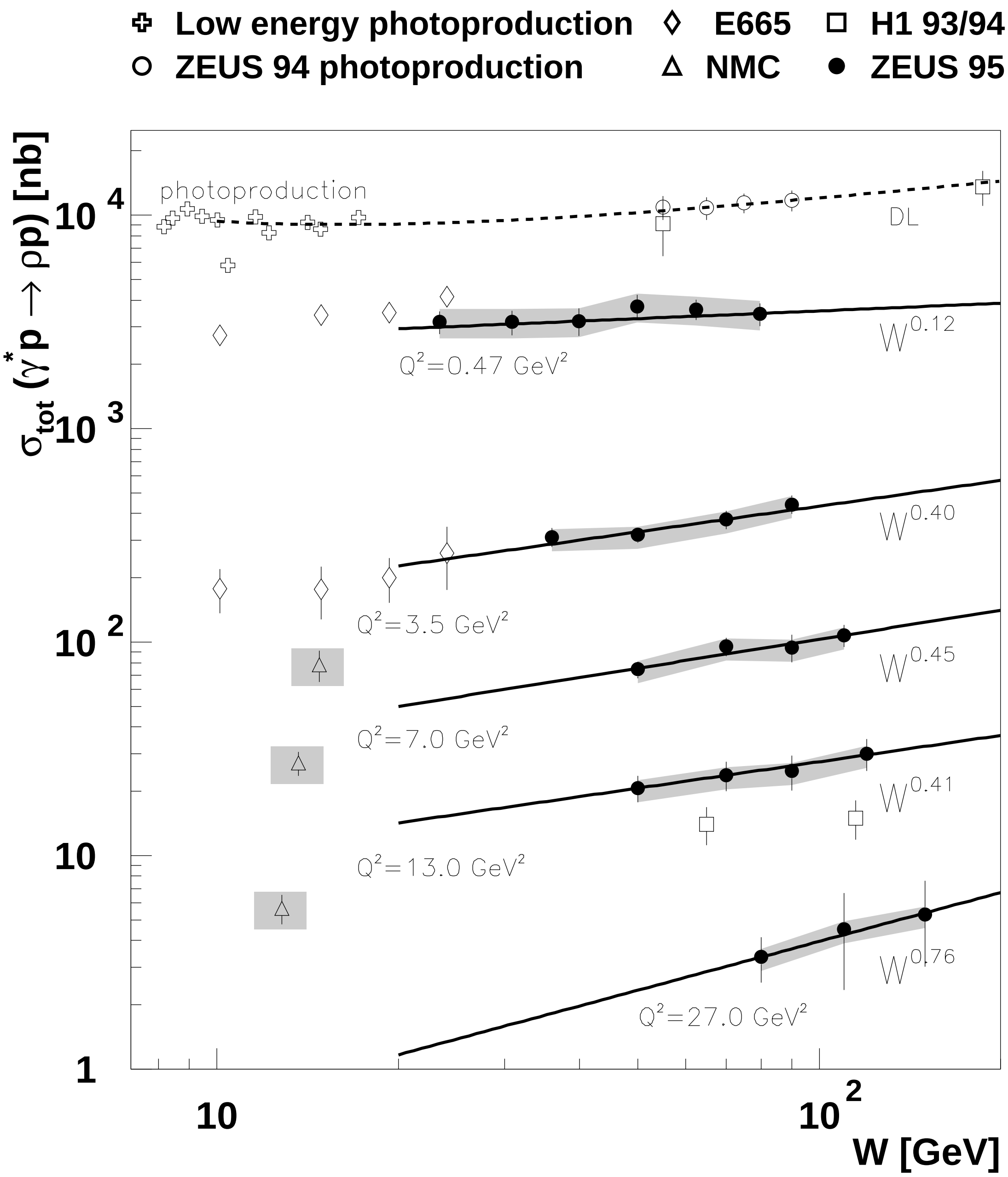
► Summary: Photoproduction of VM

- Photoproduction of light VM(ρ, ϕ, ω) shows the features typical of soft diffractive reactions:
  - weak energy dependence of the cross section
  - shrinkage of the forward peak
- Photoproduction of J/ψ exhibits a steep W dependence, consistent with pQCD calculations
- Evidence for $|t|$ providing a hard scale
- ψ', J/ψ production ratio ~ 0.15 independent of $W : 5 \rightarrow 80$ GeV
- first evidence of Υ photoproduction; first cross section measurement

Intermediate and high Q^2 region

- ρ cross section vs. energy

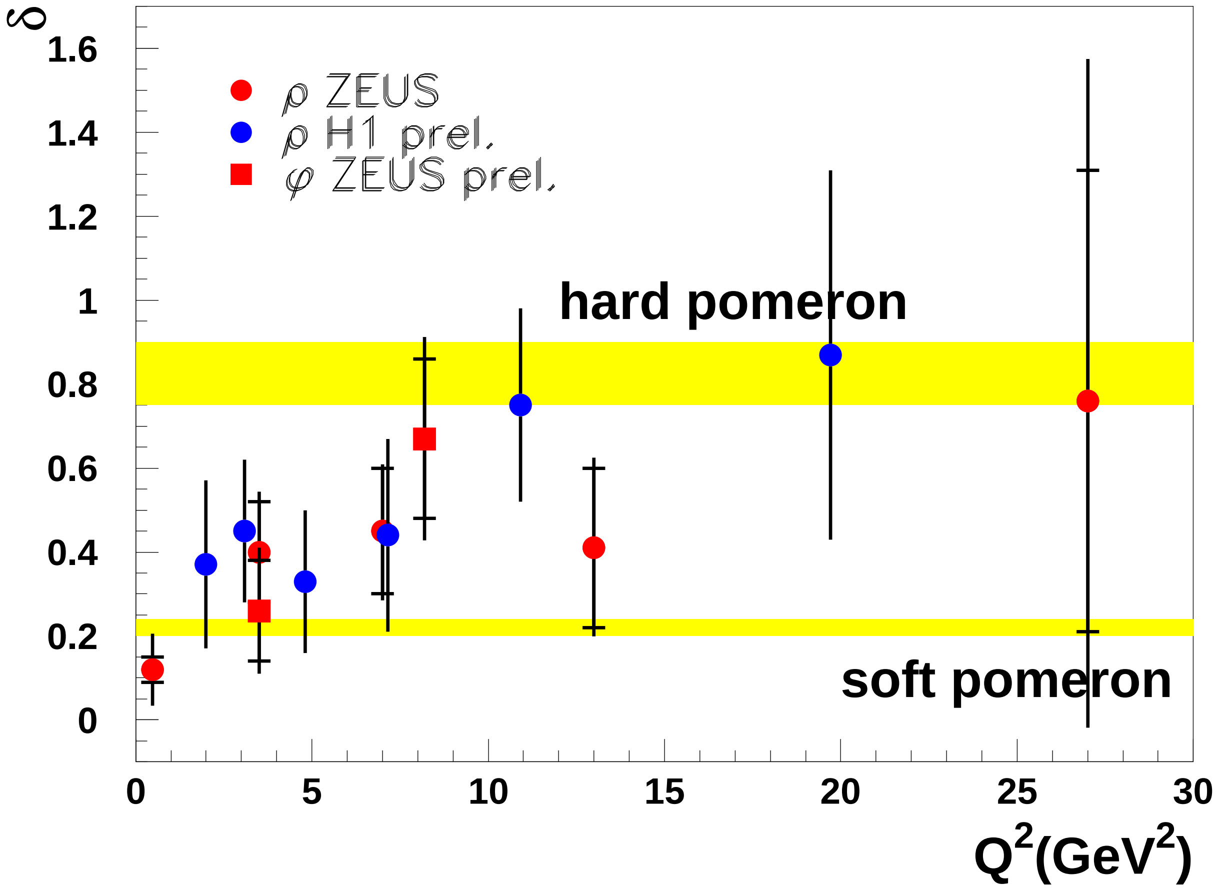
Energy dependence of the cross section for different Q^2



► ρ cross section vs. energy

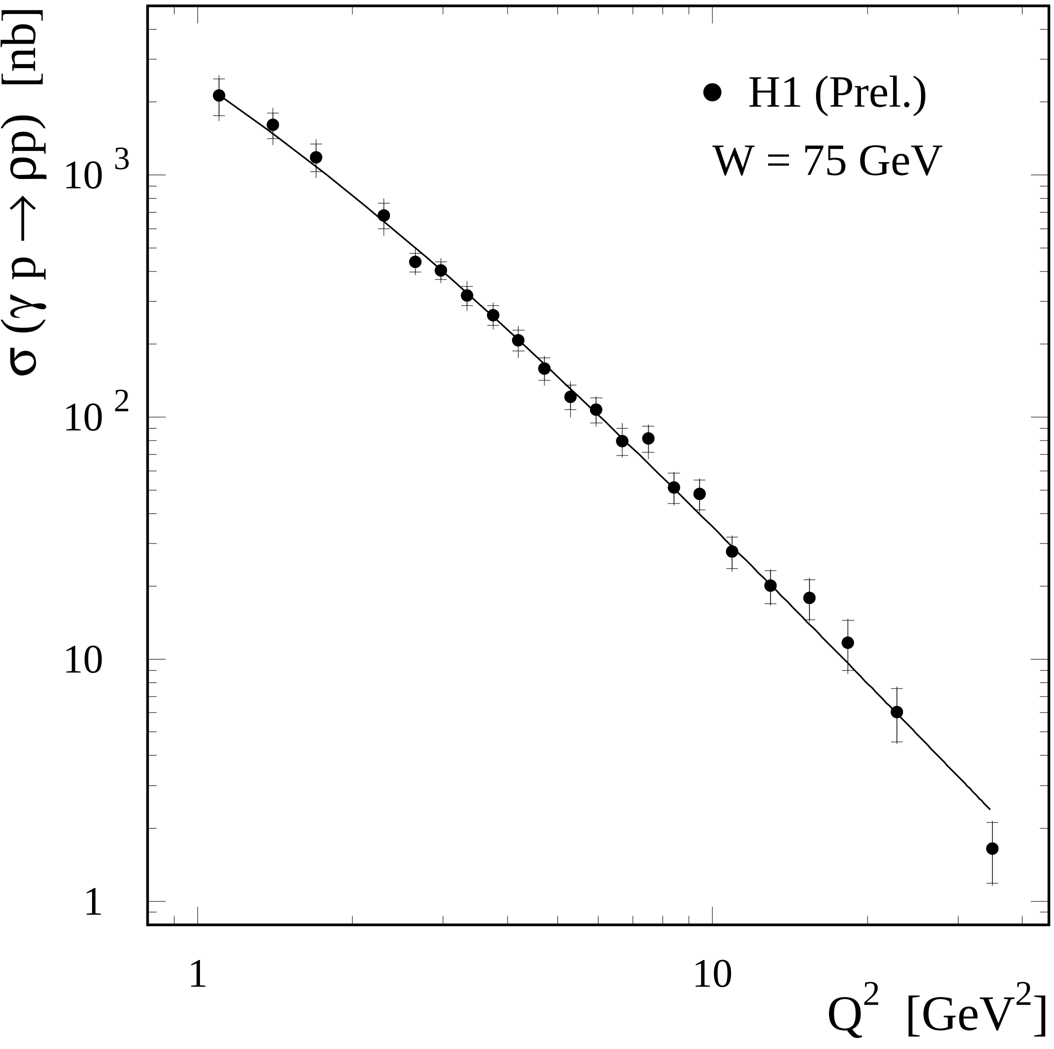
ZEUS and H1: measure of the energy dependence of the cross section within one experiment

Fit: $\sigma \propto W^{\delta}$



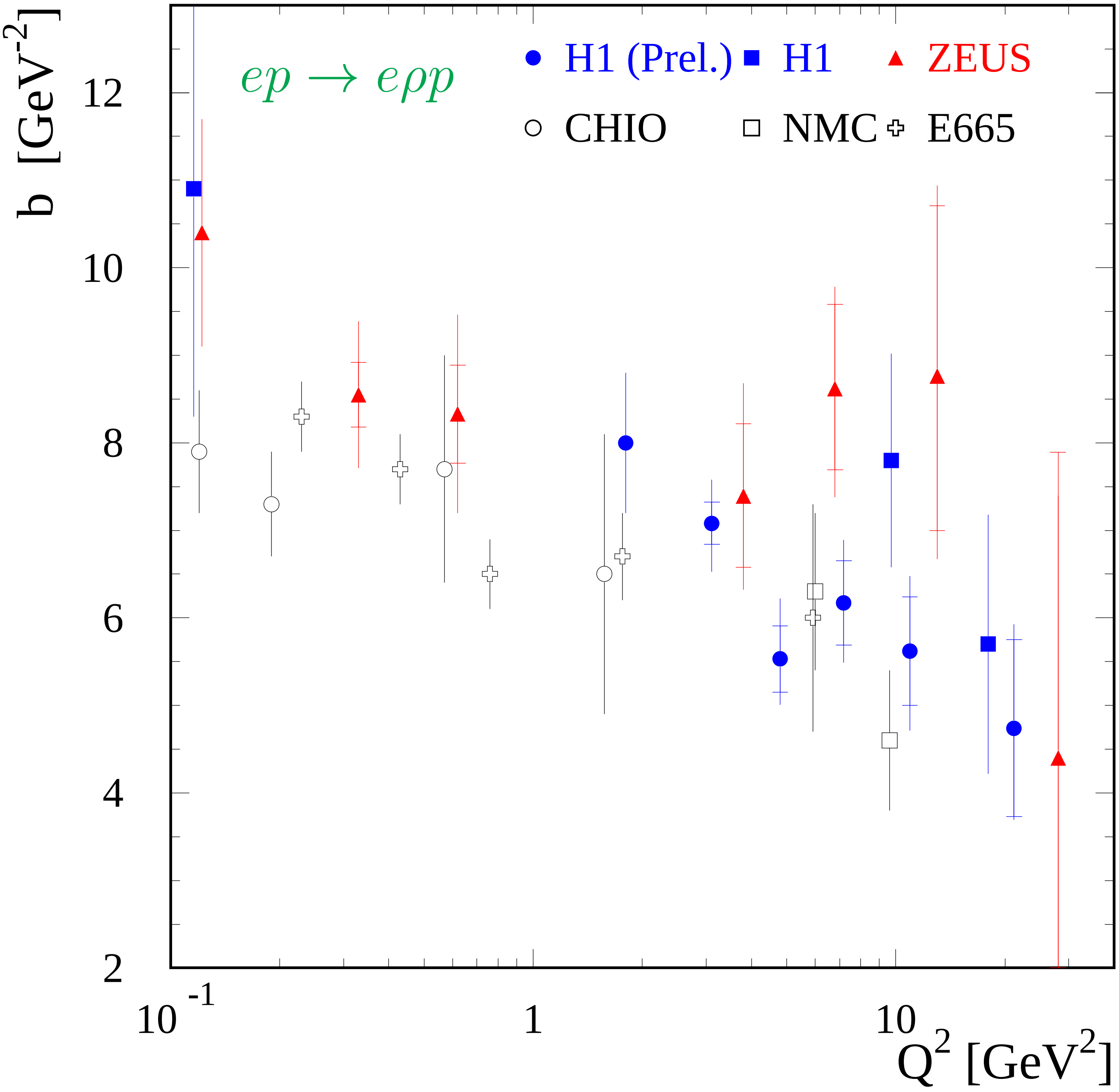
► ρ production at high Q^2

Q^2 dependence of the cross section for fixed W value



- $\sigma(\gamma^* p) \propto 1/(Q^2 + M_\rho)^n \Rightarrow n = 2.24 \pm 0.09$
- Similar results for $\gamma^* p \to \phi\ p$ and for $\gamma^* p \to \mathrm{J}/\psi\ p$

▶ t distribution



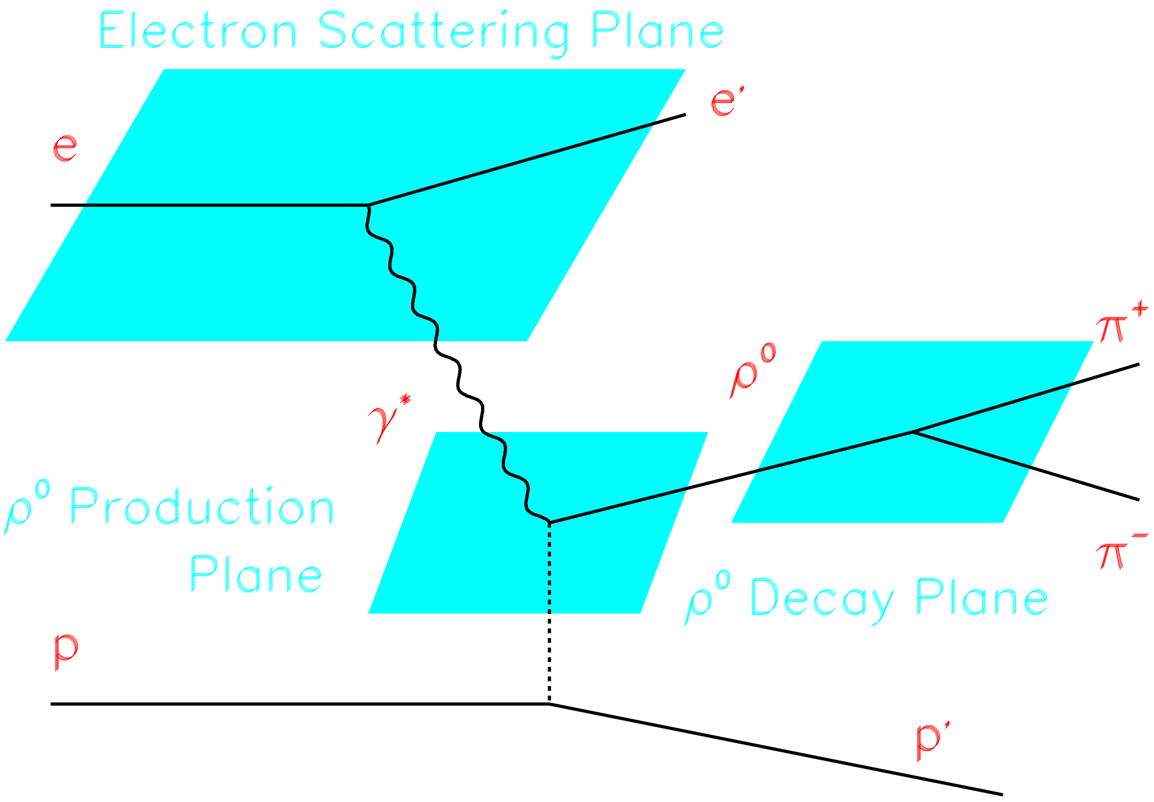
⇒ ρ: b decreases with increasing Q^2

⇒ J/ψ: no strong dependence on Q^2

$Q^2 = 0\ \mathrm{GeV}^2 \rightarrow$ ZEUS: $4.6 \pm 0.6\ \mathrm{GeV}^{-2}$, H1: $4.4 \pm 0.3\ \mathrm{GeV}^{-2}$

$Q^2 \sim 8\ \mathrm{GeV}^2 \rightarrow$ ZEUS: $5.1 \pm 1.3\ \mathrm{GeV}^{-2}$, H1: $3.9 \pm 0.6\ \mathrm{GeV}^{-2}$

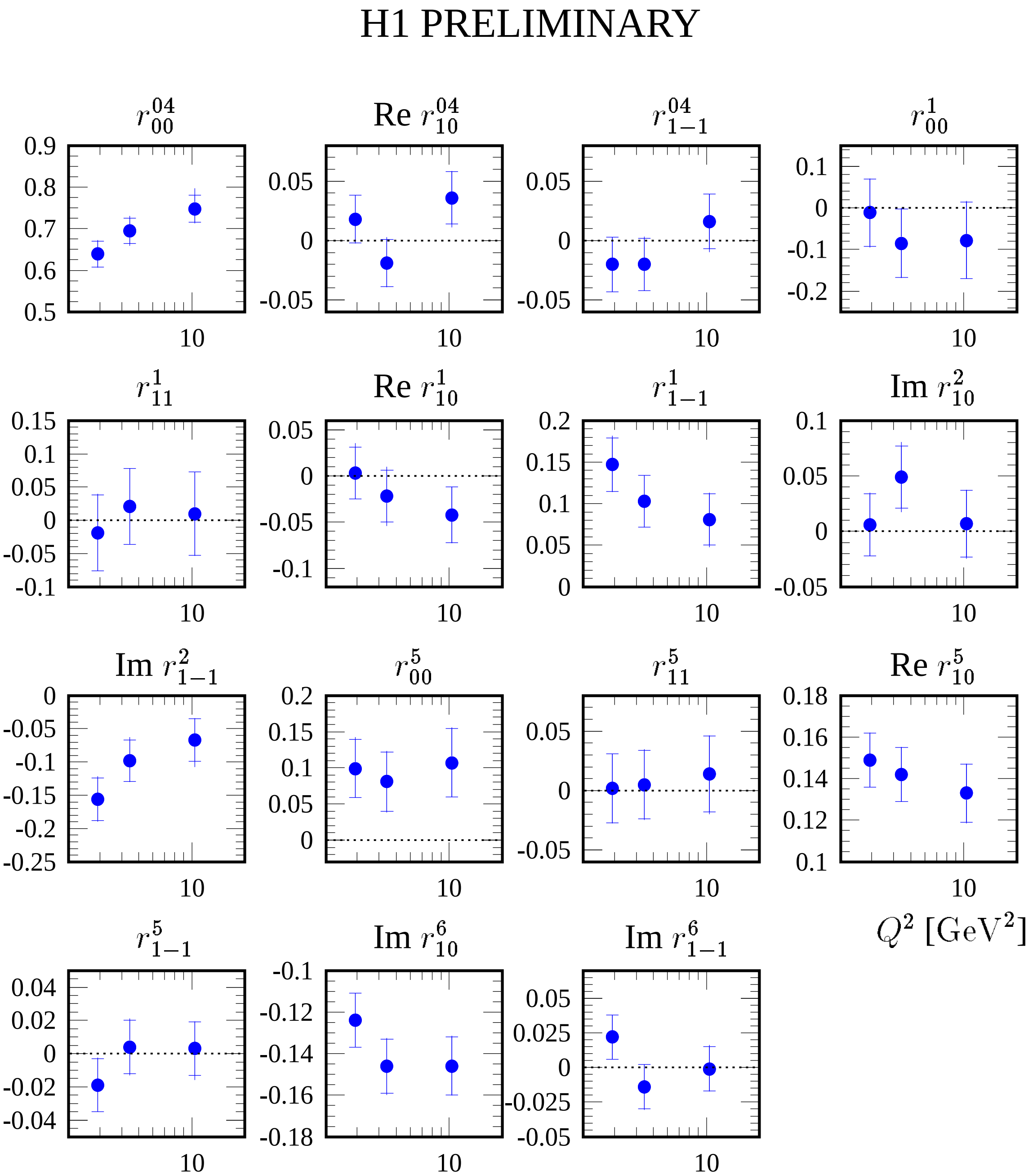
► Decay angular distribution



Helicity angles:
(θ_h,ϕ_h) - polar and azimuthal angles of decay particle in the helicity frame (meson rest frame)
Φ - angle between scattering and production plane

Analysis of the helicity angles → information on γ^* and meson helicity states

▶ Decay angular distribution

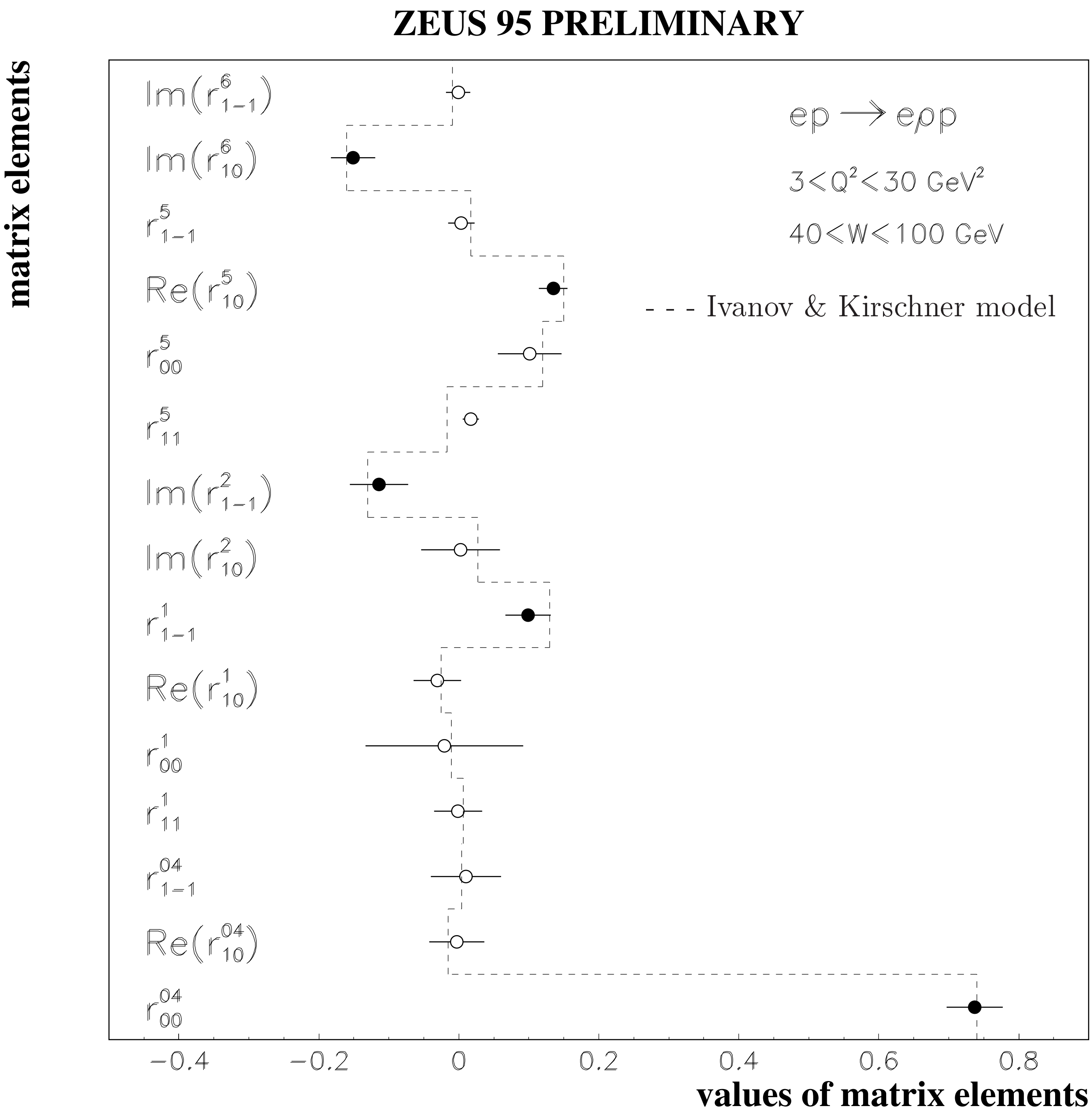


$\Longrightarrow$

SCHC

and Natural Parity Exchange

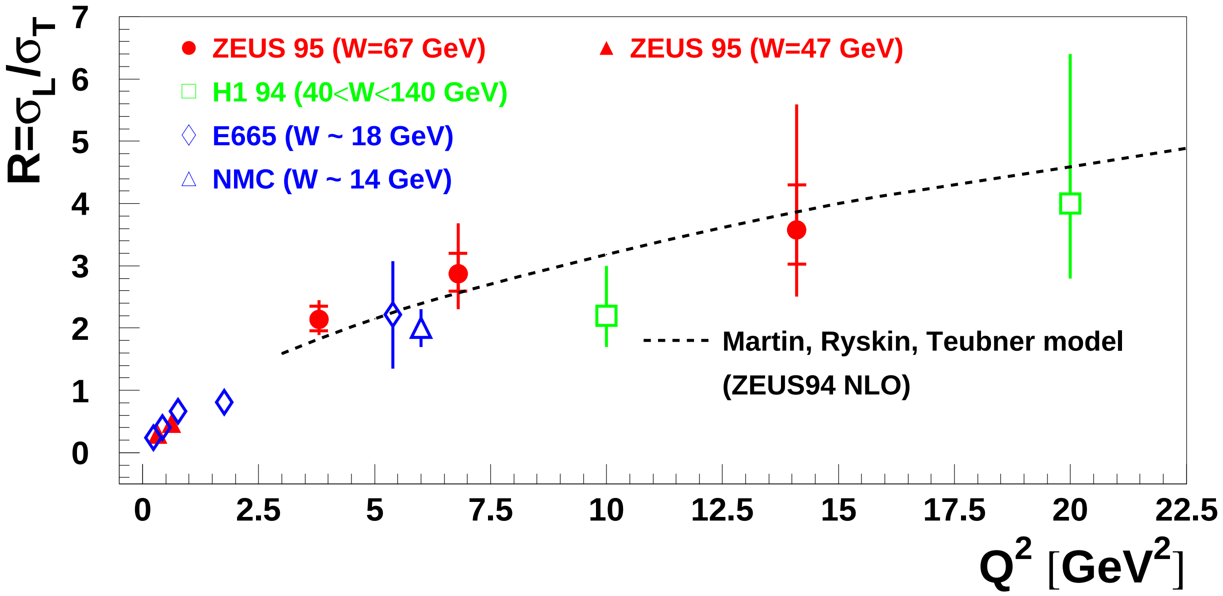
► Decay angular distribution

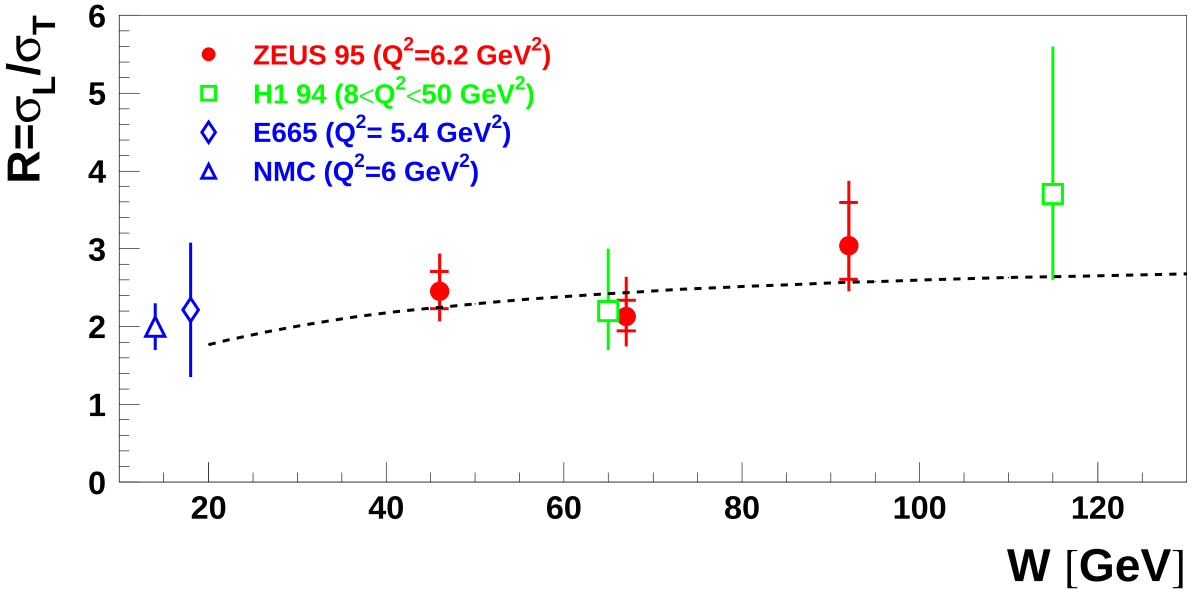


Excellent agreement between data and pQCD calculation (Ivanov and Kirschner)

► $R = \sigma_L/\sigma_T$ for ρ production

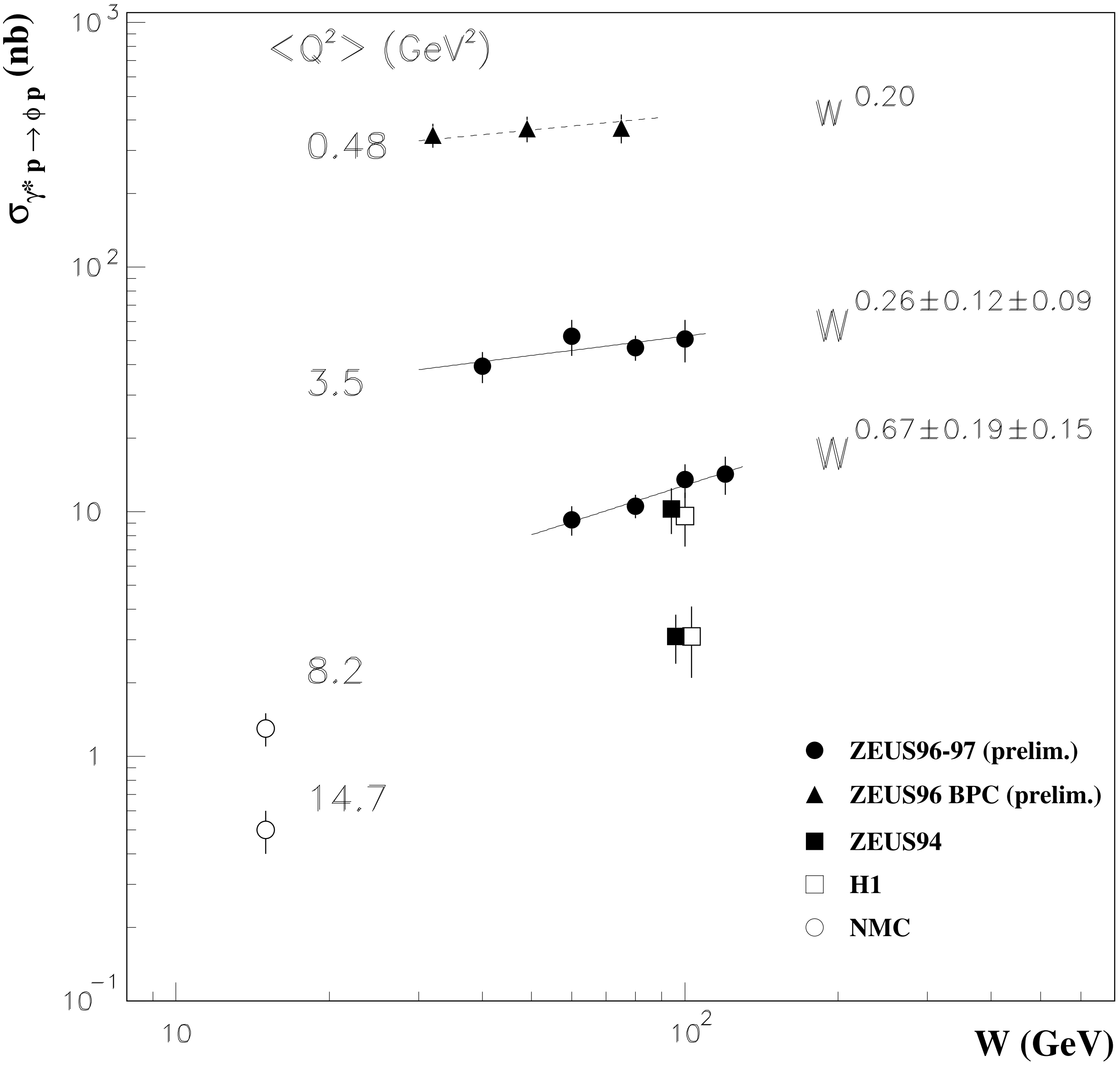
Assume SCHC: $R = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}$





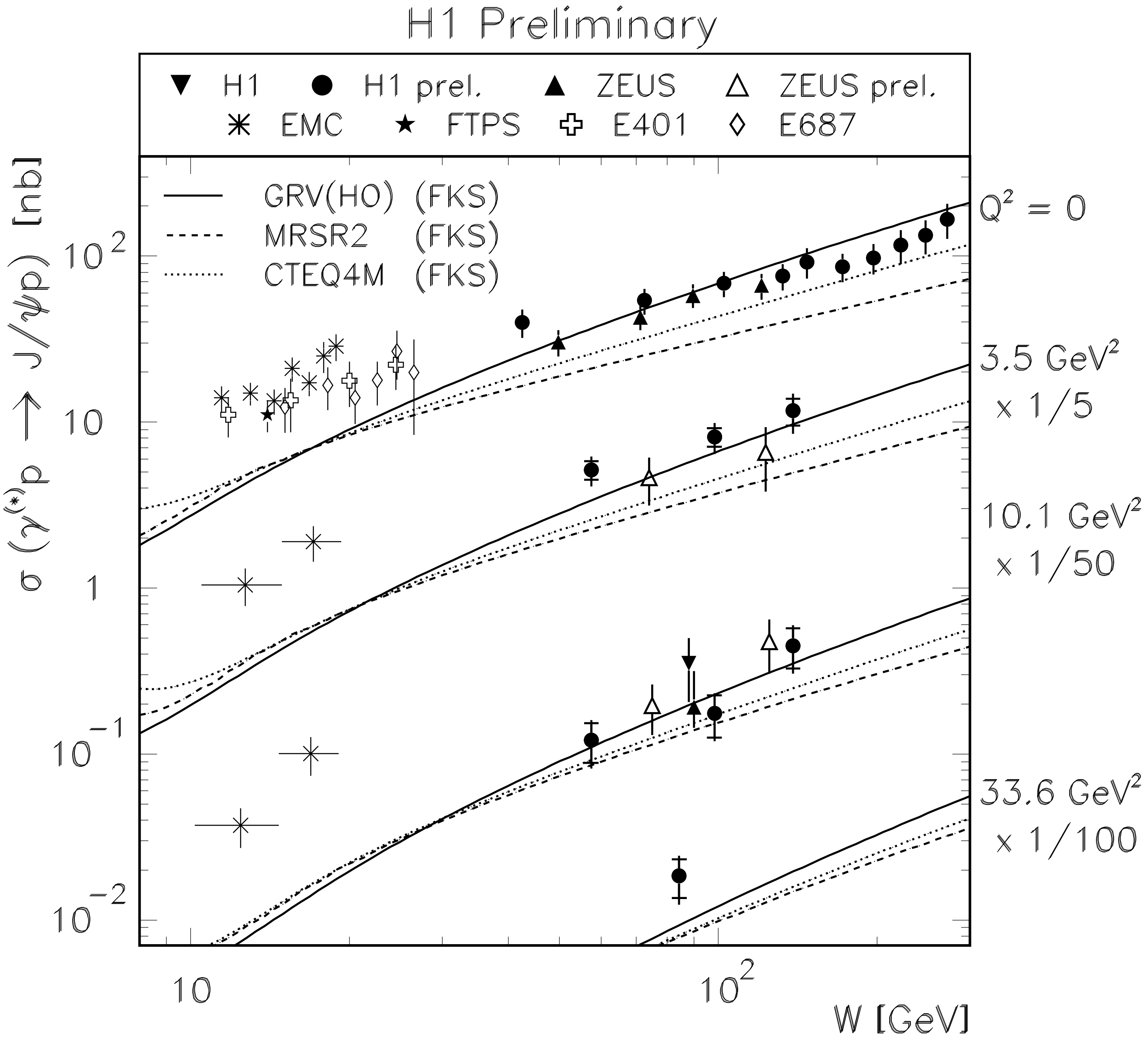
- Q^2 dependence of R not described by VMD $(R = \xi_V Q^2/M_V^2)$
- pQCD model is able to describe the data

► ϕ production at high Q^2



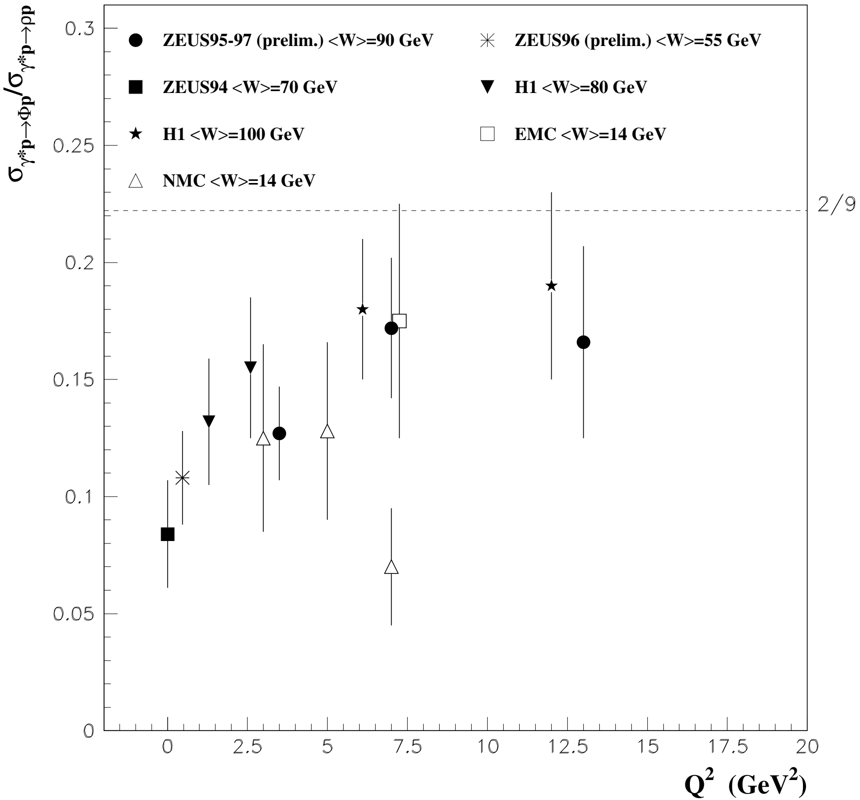
W dependence consistent with that observed in exclusive ρ electroproduction

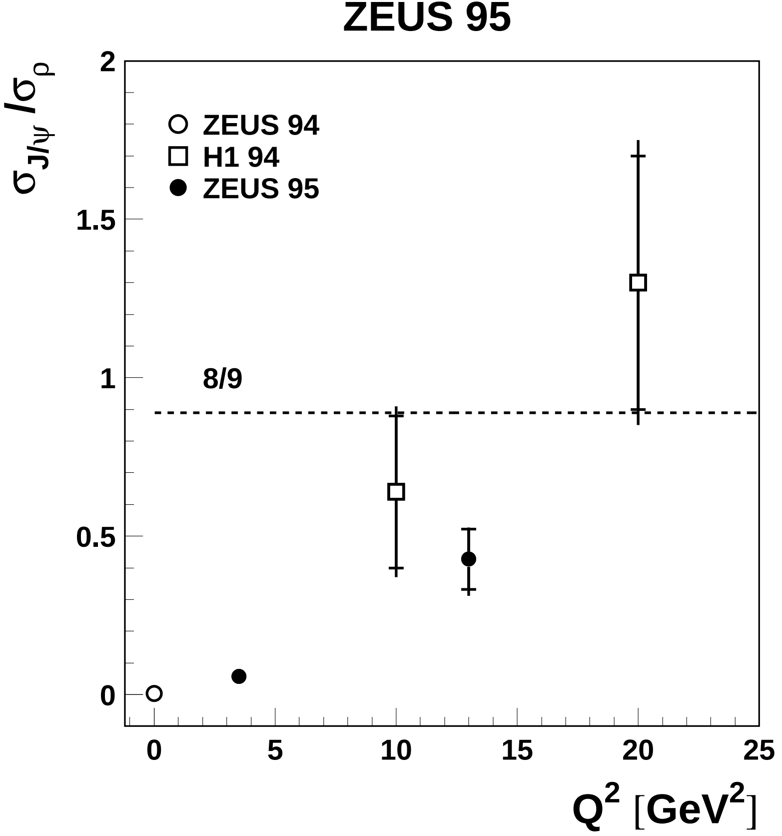
► J/ψ production at high Q^2



The W dependence at fixed positive Q^2 is found to be similar to that at $Q^2 = 0$ GeV^2 (as expected in pQCD)

▶ Ratio of VM production vs. Q^2





With increasing $Q^2 \Rightarrow$ ratio expected from SU(4) (as ≈ expected in pQCD)

Summary

Wealth of precise and interesting data spanning between soft and hard regimes of diffraction

- Evidence increase that indeed for the diffractive meson production at HERA the hard scale can be given either by meson mass, or by Q^2 or $|t|$. At these large scales the meson diffraction seems to proceed in similar, approximately flavour independent fashion, in accord with expectations of pQCD.

$\Rightarrow$ Coherent picture of diffraction is emerging and may provide valuable information on the proton and on the meson structure.