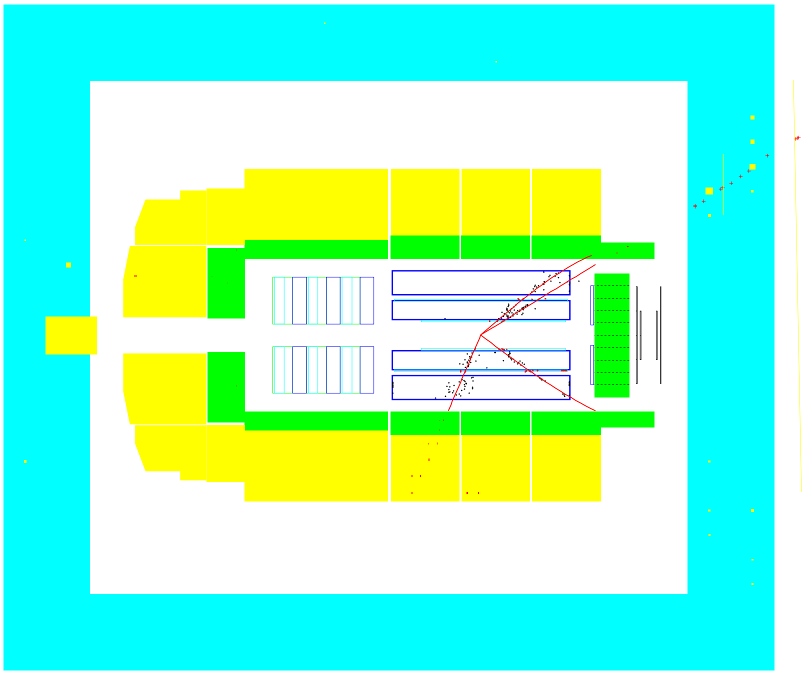
Elastic and Diffractive Scattering 99, Protvino, 28.6 - 2.7.1999

Diffraction and Exclusive Processes at HERA

Jan Olsson, DESY, Hamburg



Introduction

Photoproduction

Electroproduction

Conclusions

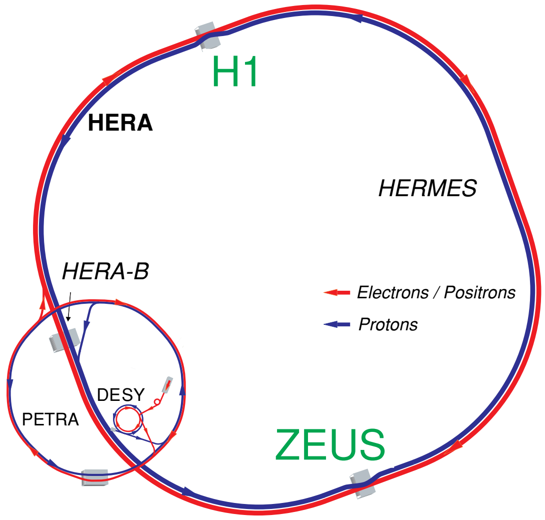
The HERA ep Collider at DESY, Hamburg

H E R A

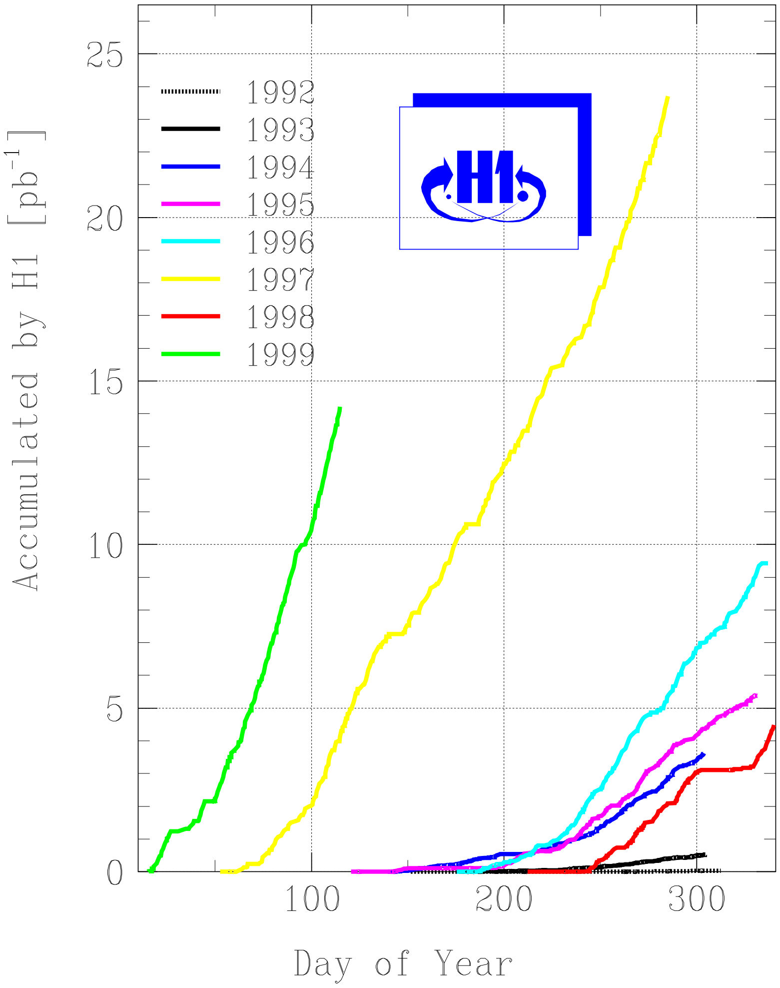
$e^{\pm} \quad \Longrightarrow \quad \Longleftarrow \quad p$

27.5 GeV $\qquad$ 820 − 920 GeV

$\sqrt{s} \;=\; 300 - 320$ GeV



Integrated Luminosity



1992-1994

e^-p **at** $\sqrt{s} = 300$ **GeV**

$0.8 pb^{-1}$

1994-1997

e^+p **at** $\sqrt{s} = 300$ **GeV**

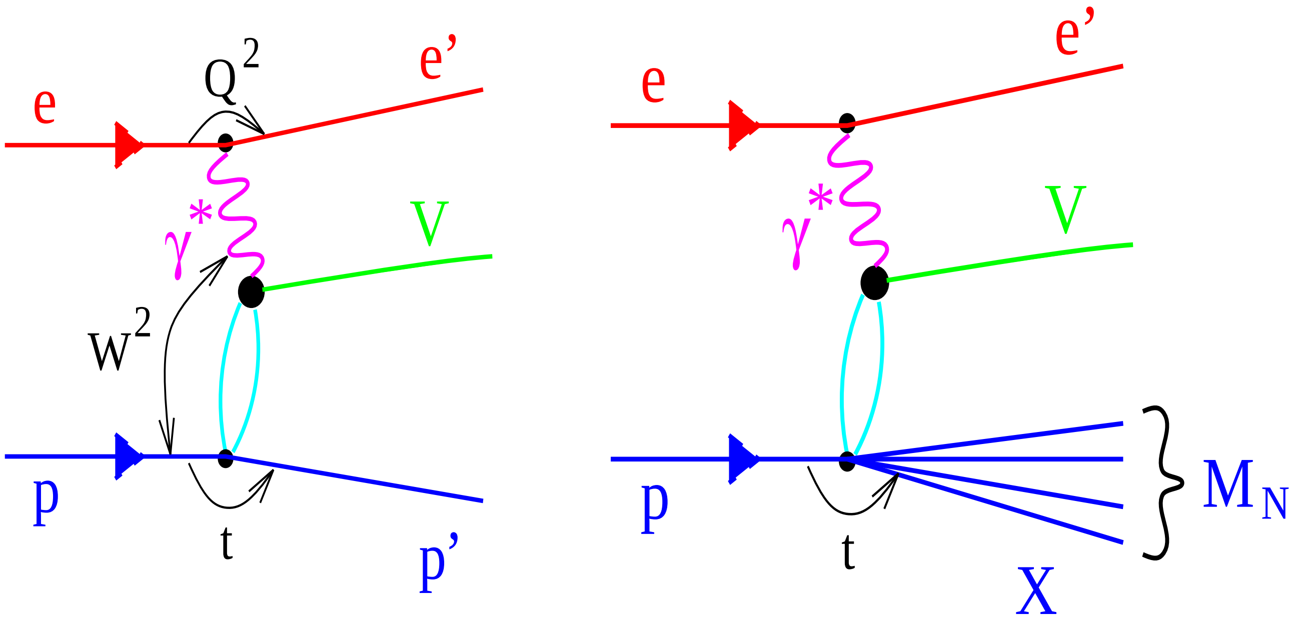
$37 - 48 pb^{-1}$

1998-1999

e^-p **at** $\sqrt{s} = 320$ **GeV**

$15 pb^{-1}$

HERA is a $\gamma^* p$ Collider



γ^* **Virtuality Q^2 :** $\sim 0 < Q^2 <\sim 100\ GeV^2$

$W_{\gamma p}$ **CM Energy of $\gamma^* p$ system:** $20 < W_{\gamma p} < 285$ **GeV**

t **Squared 4-mom. transfer at p vertex:**

$\sim 0 < |t| < 10\ \ GeV^2$

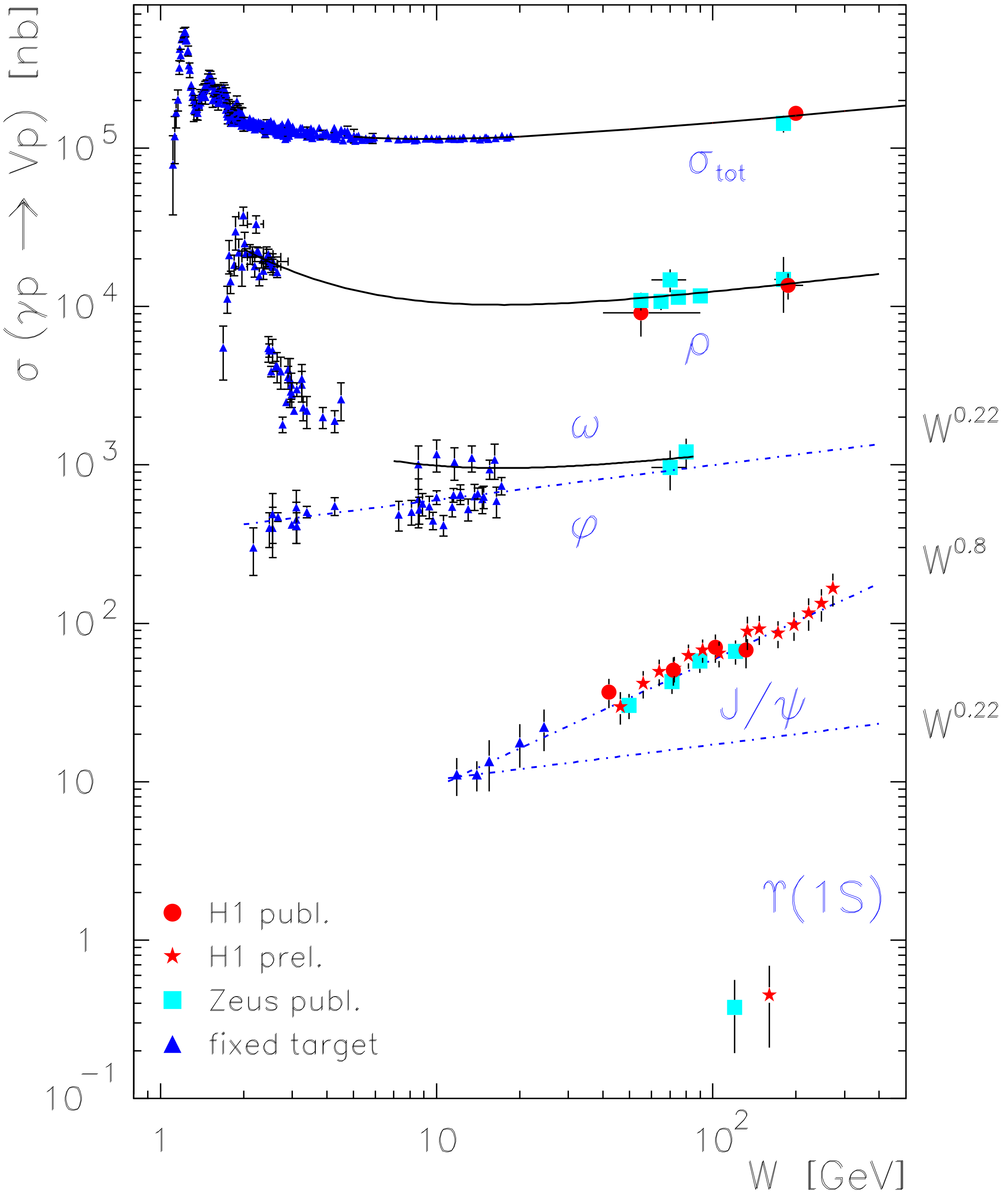
V **Vector Meson:** $\rho^\circ,\ \omega,\ \phi,\ \rho',\ J/\Psi,\ \Psi',\ \Upsilon$

$\Longrightarrow$

HERA makes it possible, within a single experiment, to do physics with a wide variation range of several scales:

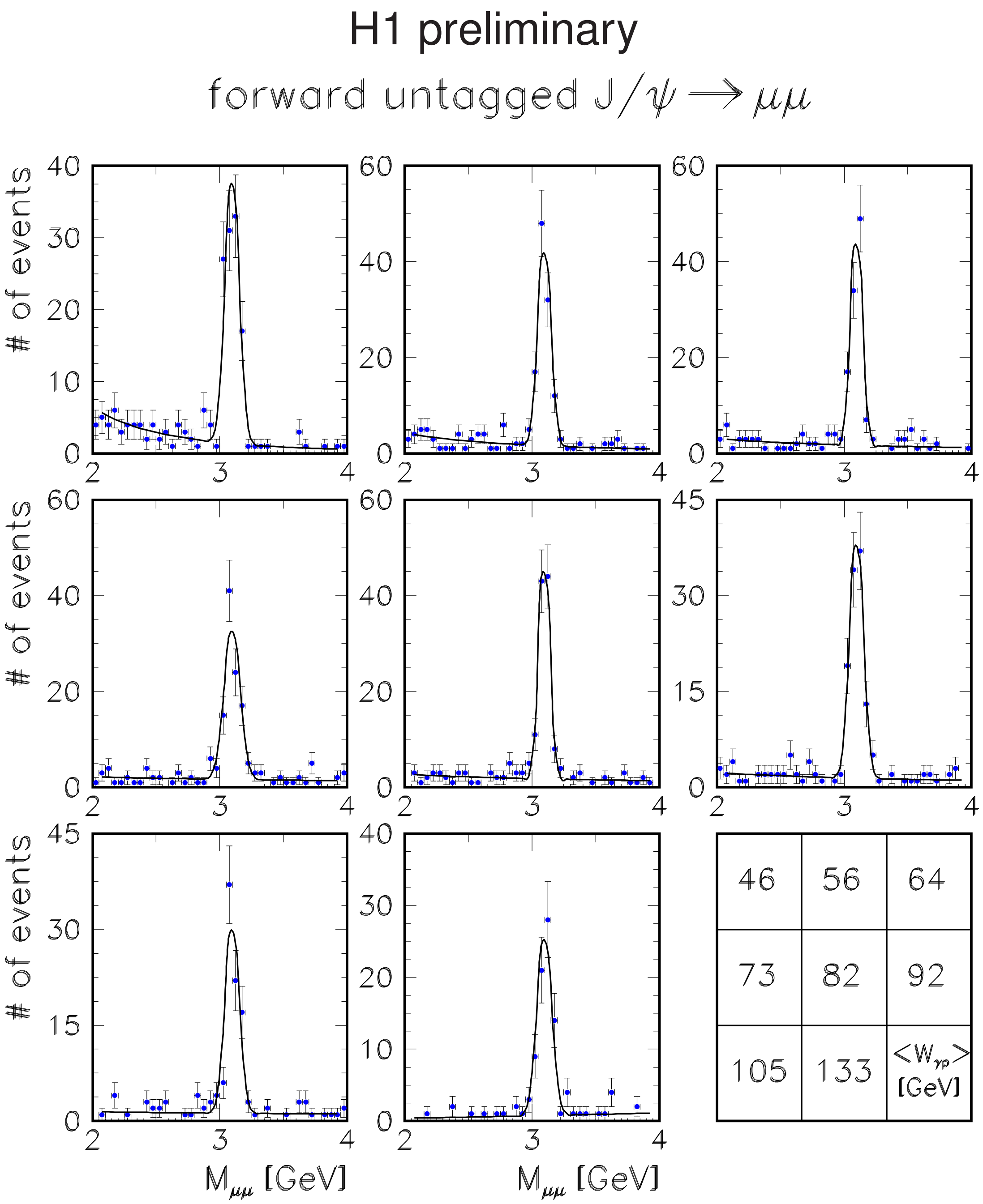
$M_V,\ \ Q^2,\ \ t$

Photoproduction $\gamma p \rightarrow V p$



New preliminary H1 data: $\gamma p \rightarrow J/\Psi p$

Photoproduction $\gamma p \to J/\Psi p$

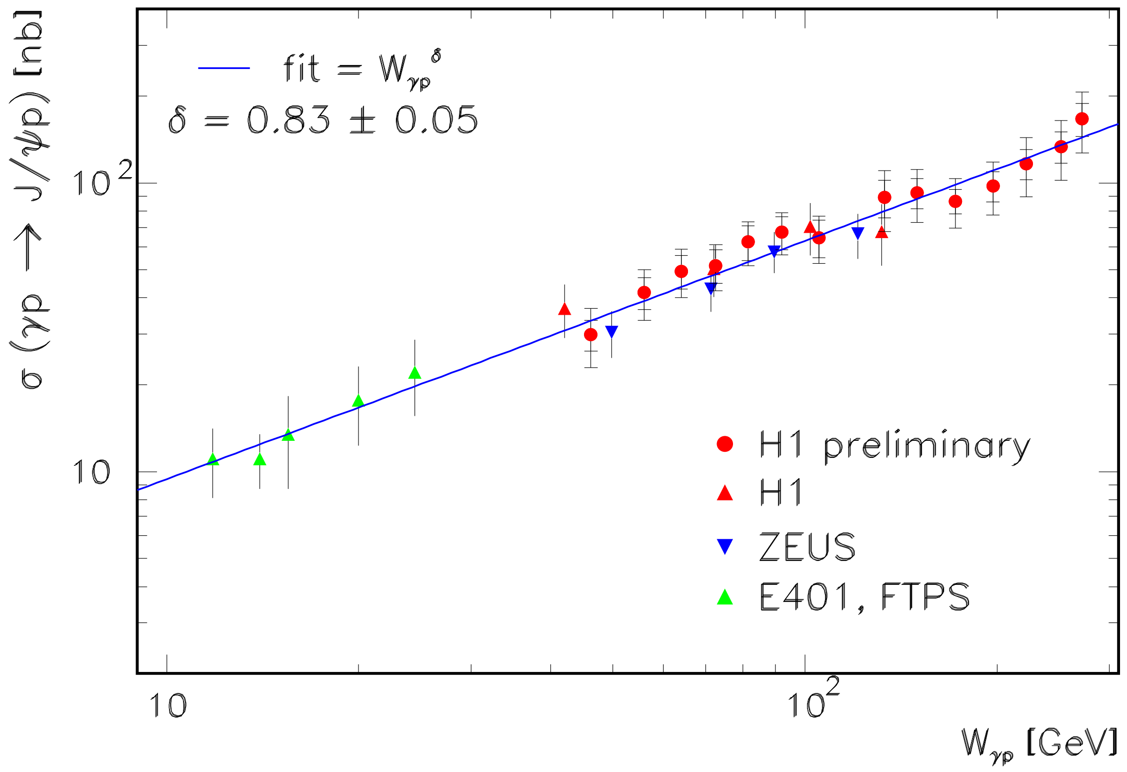


1996 - 1997 data: $21\ pb^{-1}$

$Q^2 < 1\ GeV^2$

$40 \leq W_{\gamma p} \leq 150\ GeV$

Photoproduction $\gamma p \to J/\Psi p$

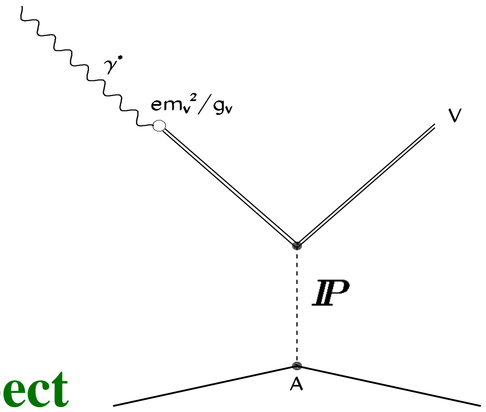


$\sigma_{tot} \sim W^{2\epsilon}$ **Optical Theorem** $\Rightarrow$ $\sigma_{\gamma p \to Vp} \sim W^{4\epsilon}$ $(\delta = 4\epsilon)$

Regge Approach:

σ_{tot} and Light Vector Meson production described via "Soft Pomeron" exchange

$$d\sigma/dt \sim e^{bt}\,(W/W_0)^{4(\alpha_{I\!P}(t)-1)}$$
$$\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P}\,t$$
$$b = b_0 + 4\,\alpha'_{I\!P}\,ln(W/W_0)$$

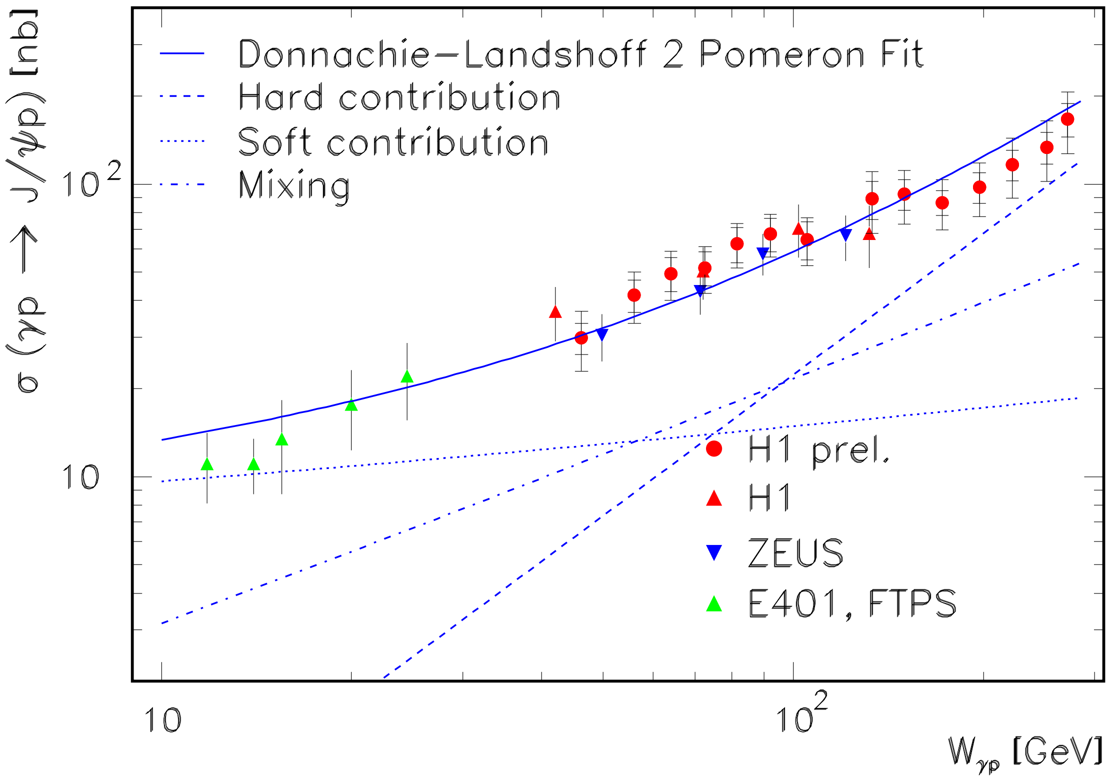


Expect

Slow rise of $\sigma(W)$
Shrinkage
SCHC
$R = \sigma_L/\sigma_T \sim Q^2/M_V^2$

But: J/Ψ data steeper than "soft expectation" $\Longrightarrow$

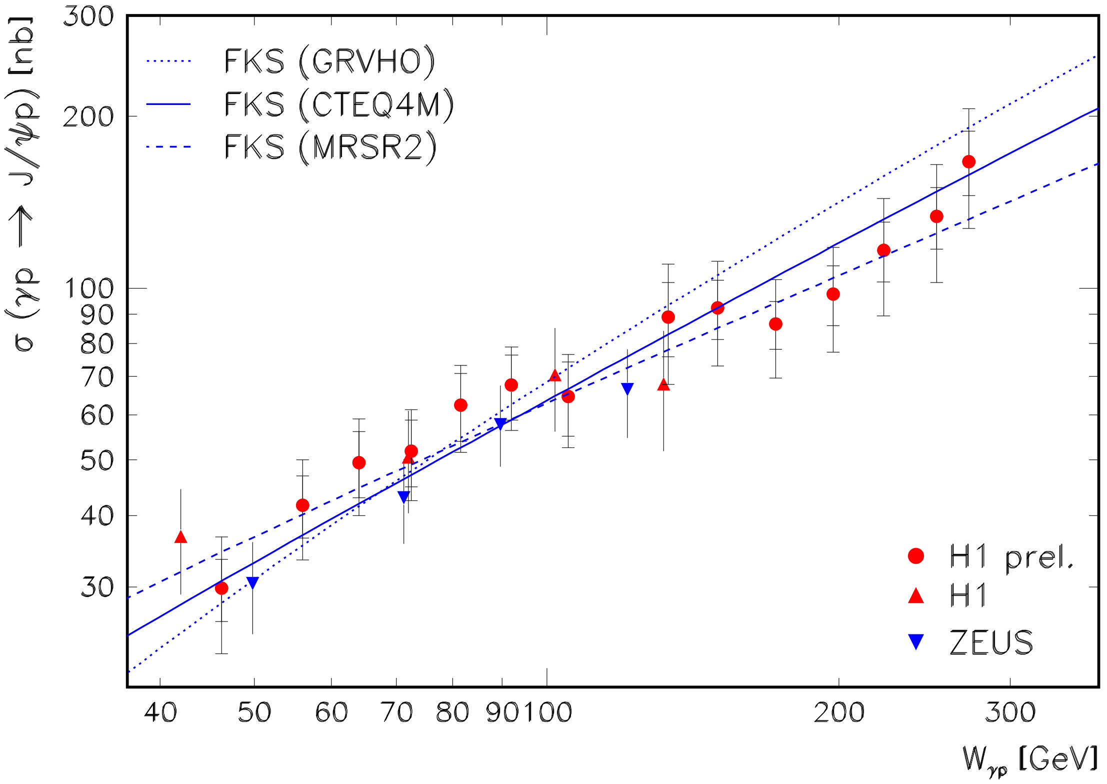
Photoproduction $\gamma\, p \rightarrow J/\Psi\, p$



Add "Hard Pomeron" (Glueball ?)

2 Pomeron fit gives good description of data

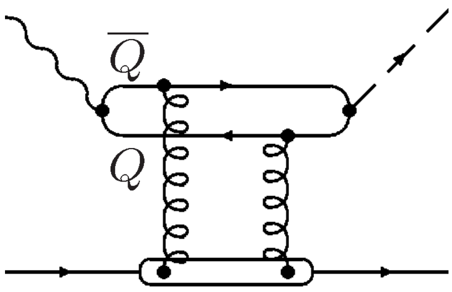
Photoproduction $\gamma\, p \;\rightarrow\; J/\Psi\, p$



The heavy c quark provides a Hard Scale $\Longrightarrow$

pQCD Approach:

Factorization (timescales !)

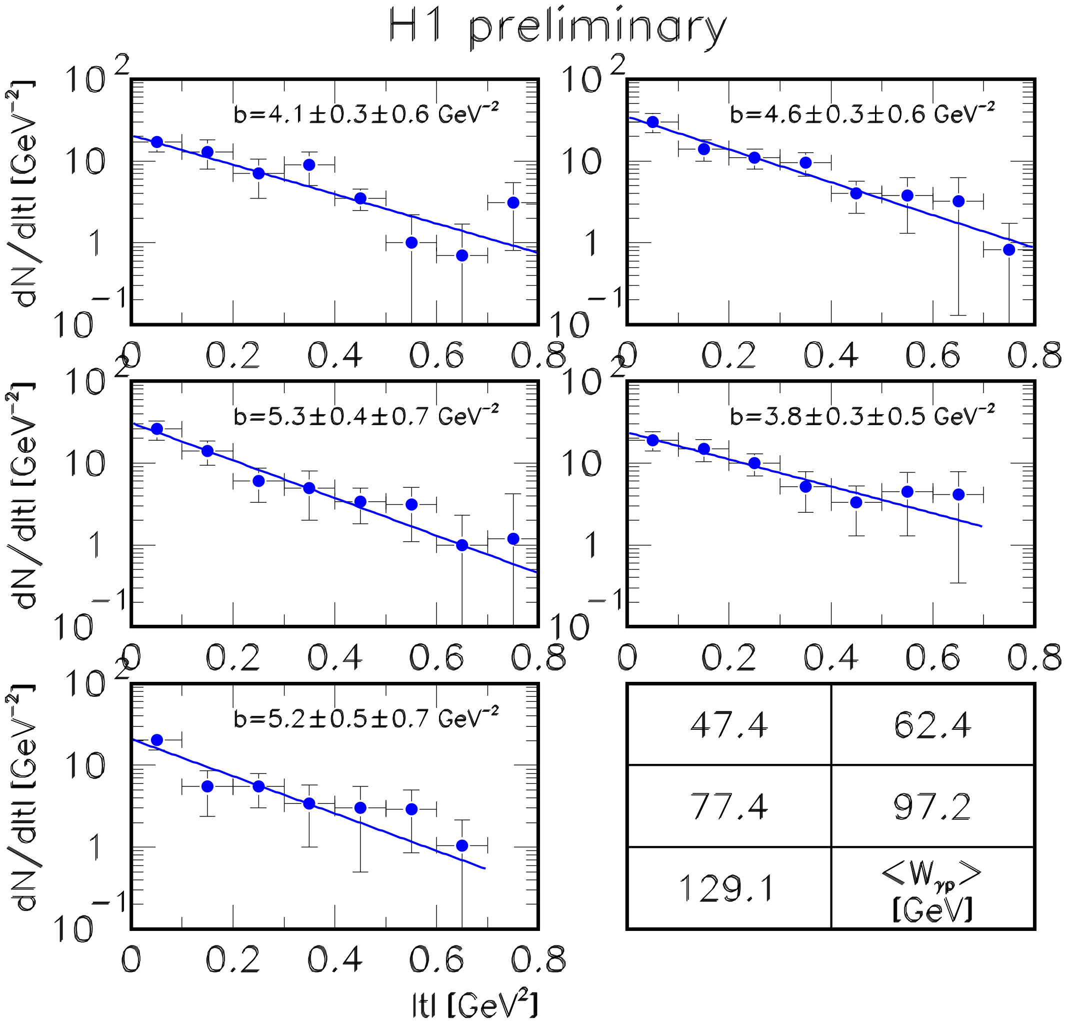


1. Photon fluctuates into $Q\bar{Q}$
2. $Q\bar{Q}$ scatters off proton
3. $Q\bar{Q}$ forms a bound state

$$\sigma \;\sim\; [x\, g(x, Q^2)]^2$$

Good description of data
Sensitivity to parameterisation of
Gluon Density in proton

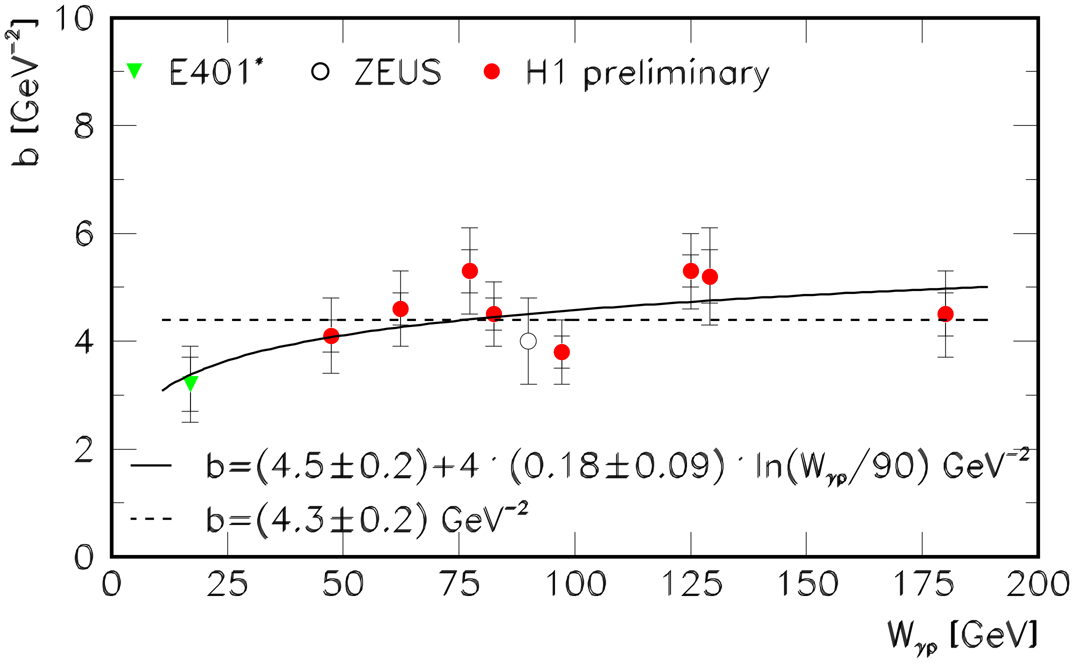
Photoproduction $\gamma\, p \;\rightarrow\; J/\Psi\, p$



In 5 ranges of $W_{\gamma p}$, fit $dN/d|t| \;\sim\; e^{-b|t|}$

Photoproduction $\gamma p \rightarrow J/\Psi p$

Shrinkage or no shrinkage?



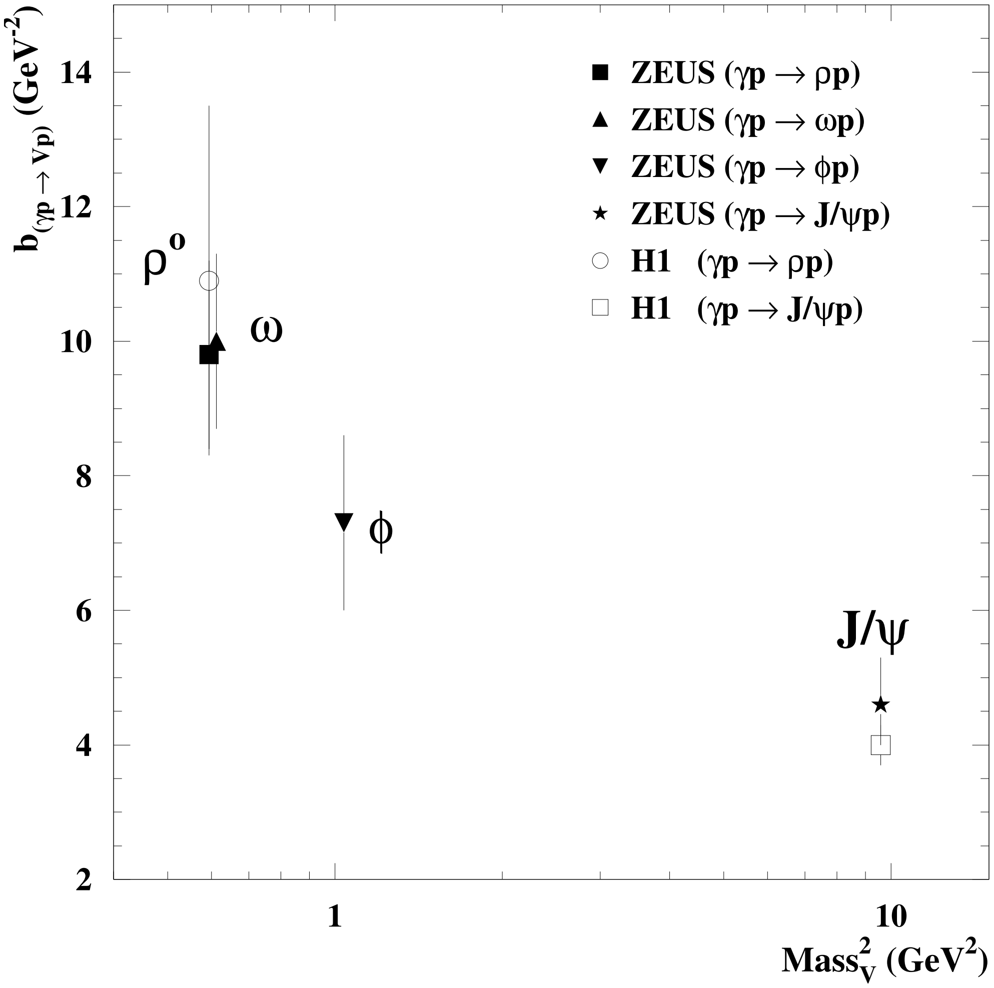
Fit $b = b_0 + 4\,\alpha' \ln(W/W_0)$

Fit results depend on the treatment of low energy, fixed target data!

The HERA data alone do not allow firm conclusions!

Photoproduction $\gamma\, p \;\rightarrow\; V\, p$

Slopes from fits of $d\sigma/dt \;\sim\; e^{b\,t}$



b is related to the radii of the scattering particles

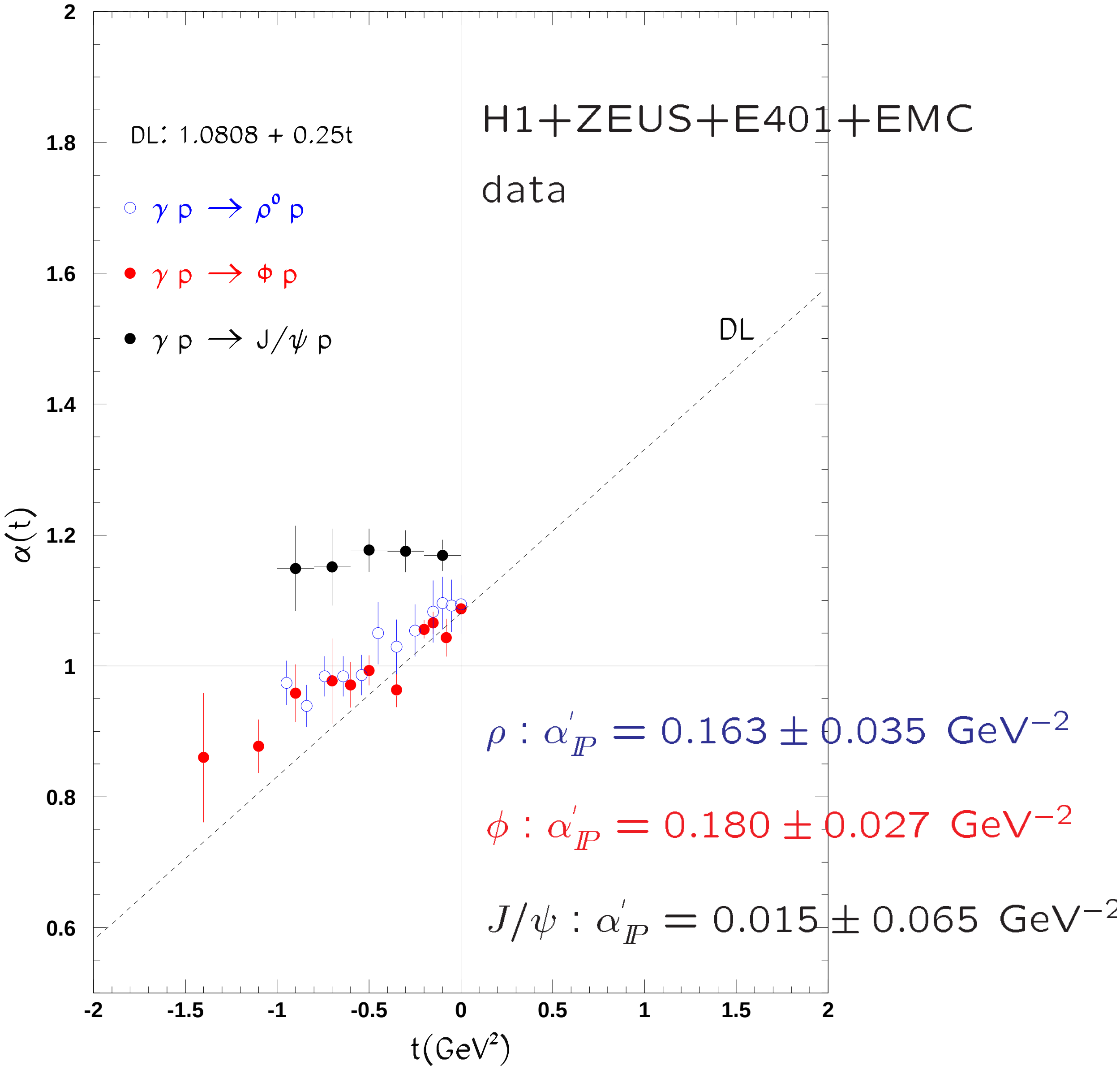
$$b \;\propto\; R_p^2 + R_{q\bar{q}}^2 \qquad R_p^2 \;\sim\; 4GeV^{-2} \qquad \Rightarrow$$

$c\bar{c}$ system small compared to the proton
Probes the proton structure !

Photoproduction $\gamma p \to V p$

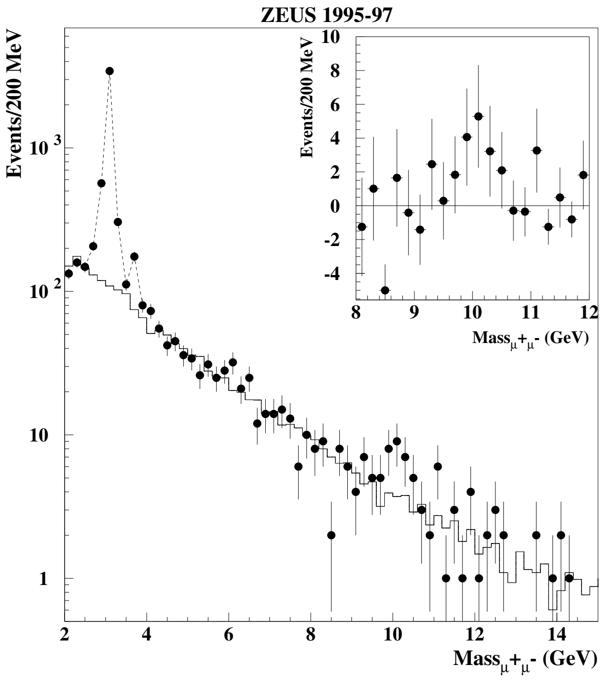
In each $|t|$-bin of data, determine $\alpha(t)$ via $d\sigma/dt \sim W^{4(\alpha(t)-1)}$

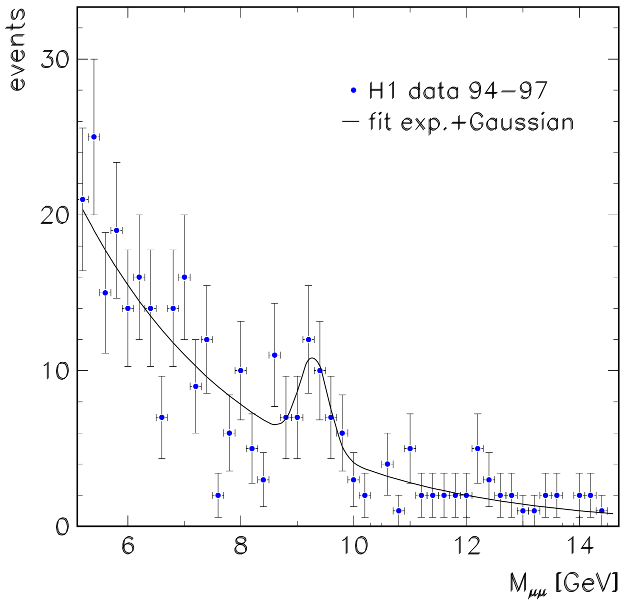
Fit $\alpha(t) = \alpha(0) + \alpha' t$



Pomeron trajectory not universal

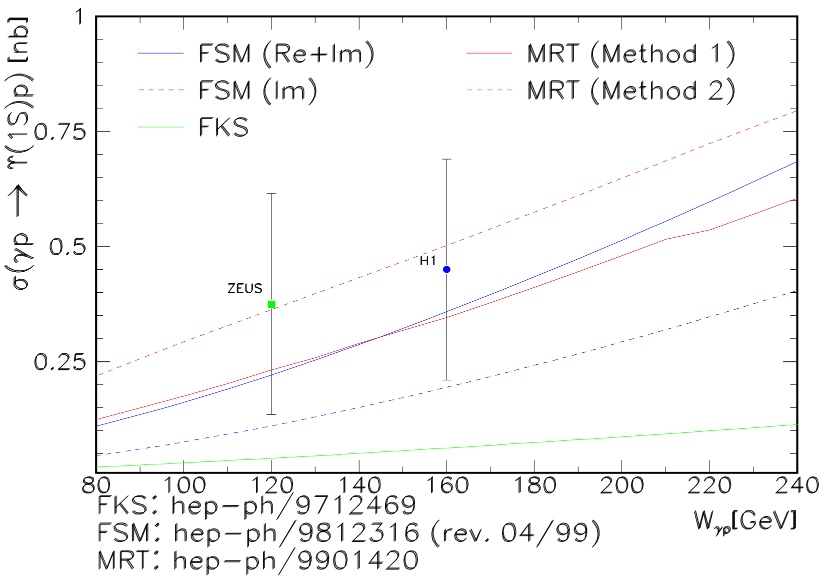
Photoproduction $\gamma\, p \;\rightarrow\; \Upsilon\, p$

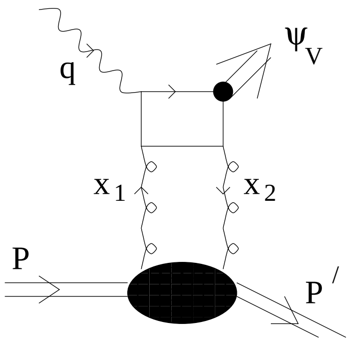




1997-98: First measurements of $\sigma(\gamma\, p \;\rightarrow\; \Upsilon\, p)$ are considerably higher than expected by Theory

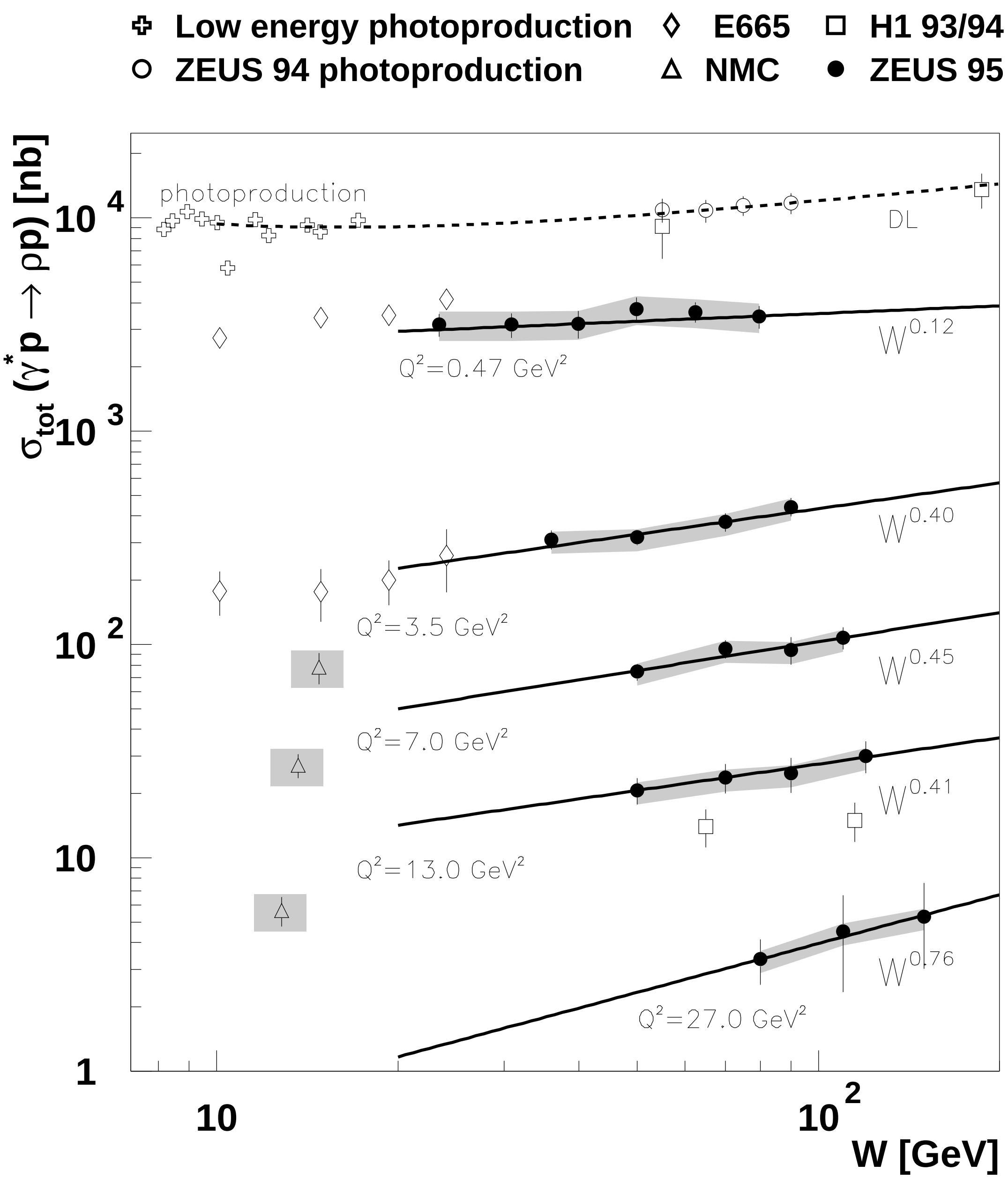
1998-99: New developments in Theory; agreement with data !





Off-Diagonal
Gluon Distribution $x' g(x, x')$
$x \;\simeq\; M_V^2/W^2, \;\; x' \ll x$
Important for large M_V !

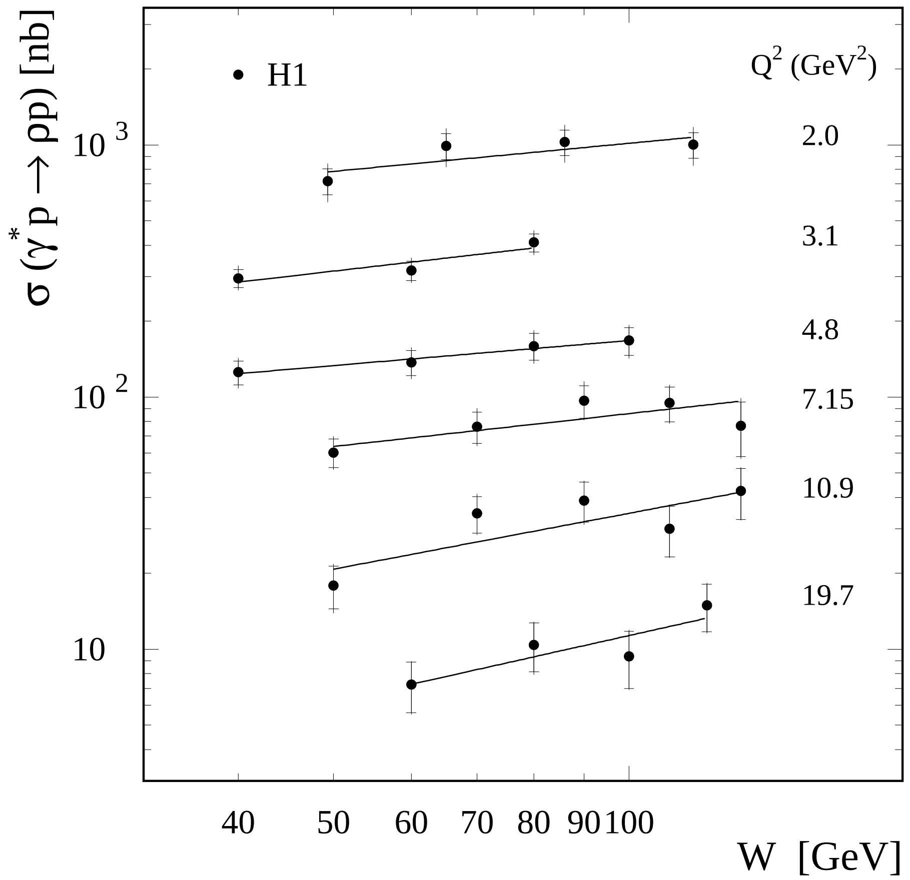
Electroproduction $\gamma^* p \rightarrow \rho^\circ p$

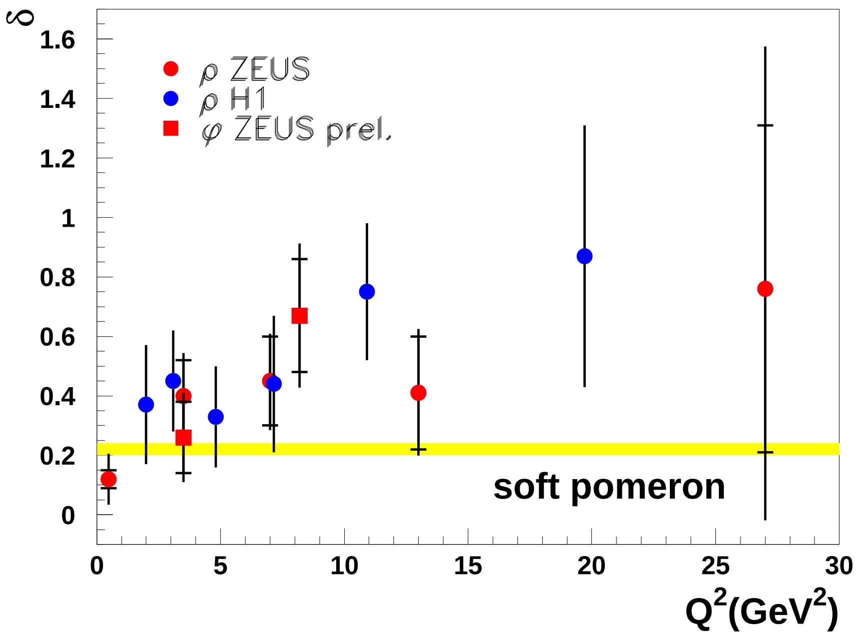


Fits to $\sigma(\gamma^* p \rightarrow \rho^\circ p) = W^\delta$

δ increases with increasing Q^2

Electroproduction $\gamma^* p \rightarrow \rho^\circ p$





"Hard" Diffraction increases with Q^2, expected in QCD

Electroproduction $\gamma^* p \to V p$

The increase of $\sigma_{\gamma^* p \to V p}$ with increasing W
is related to
The increase of DIS cross sections with decreasing x

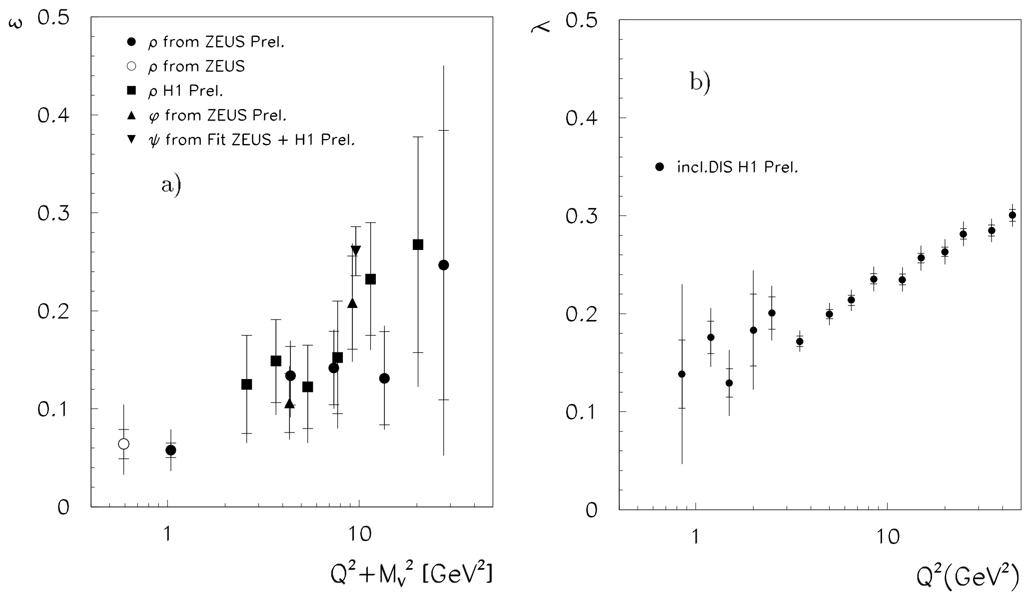
At fixed Q^2 and small x, $F_2^p \sim x^{-\lambda}$

Using the relation $x W^2 \approx Q^2$, one can write

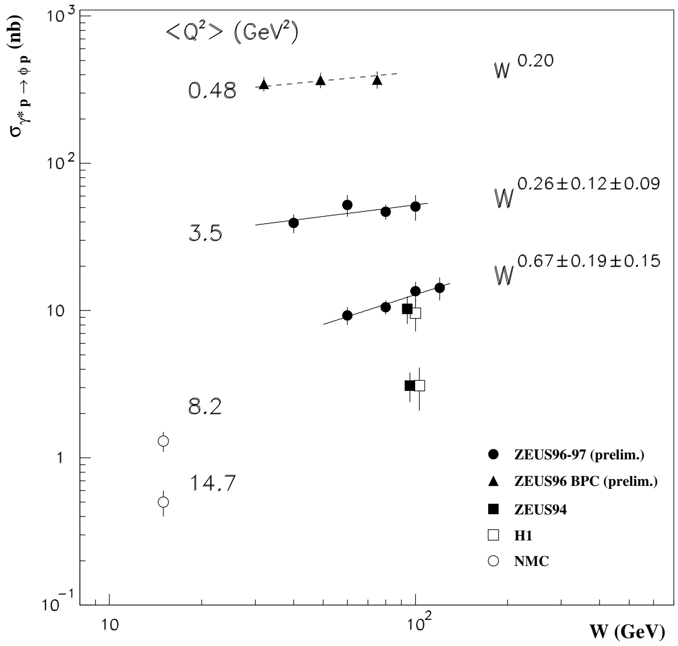
$$\sigma_{\gamma^* p} \sim F_2^p \sim x^{-\lambda} \sim W^{2\lambda} \approx W^{2\epsilon}$$

Thus,
The increase of F_2^p with decreasing x
and
The increase of $\sigma_{\gamma^* p \to V p}$ with increasing W
have a common origin: the Gluon density in the proton

ϵ (δ) and λ have similar Q^2 dependences



Electroproduction $\gamma^* p \to \phi p, \; \omega p$



Electroproduction of ϕ

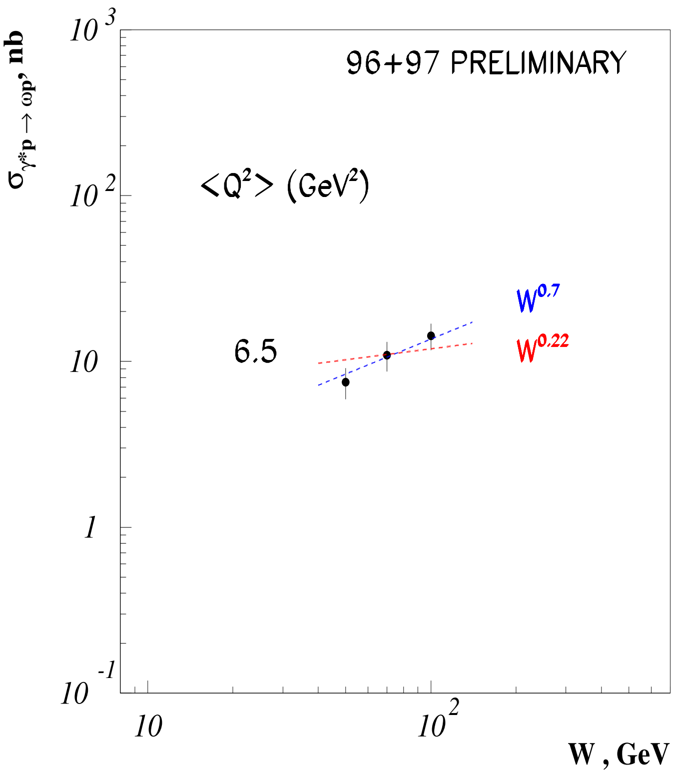
Use $\phi \to K^+K^-$ data

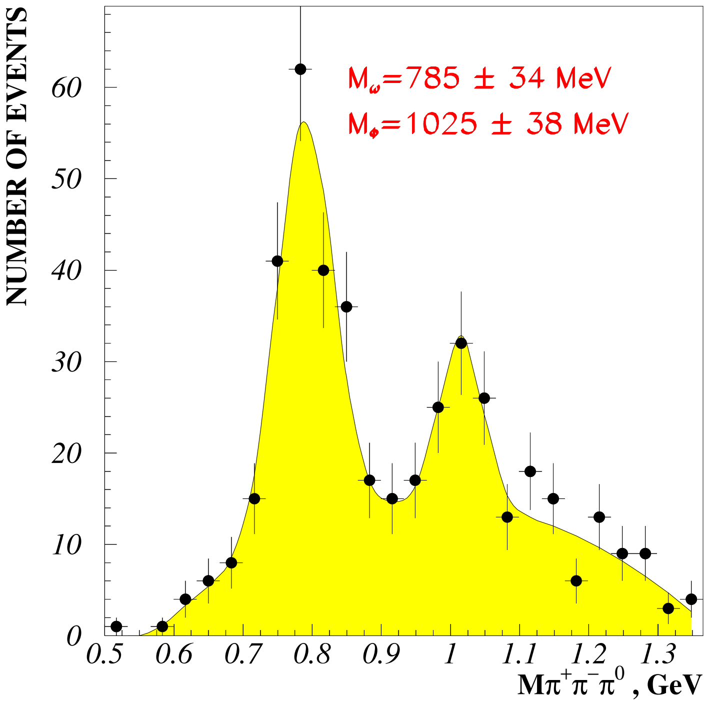
Consistency check with
$\phi \to 3\pi$ data

δ increases with Q^2

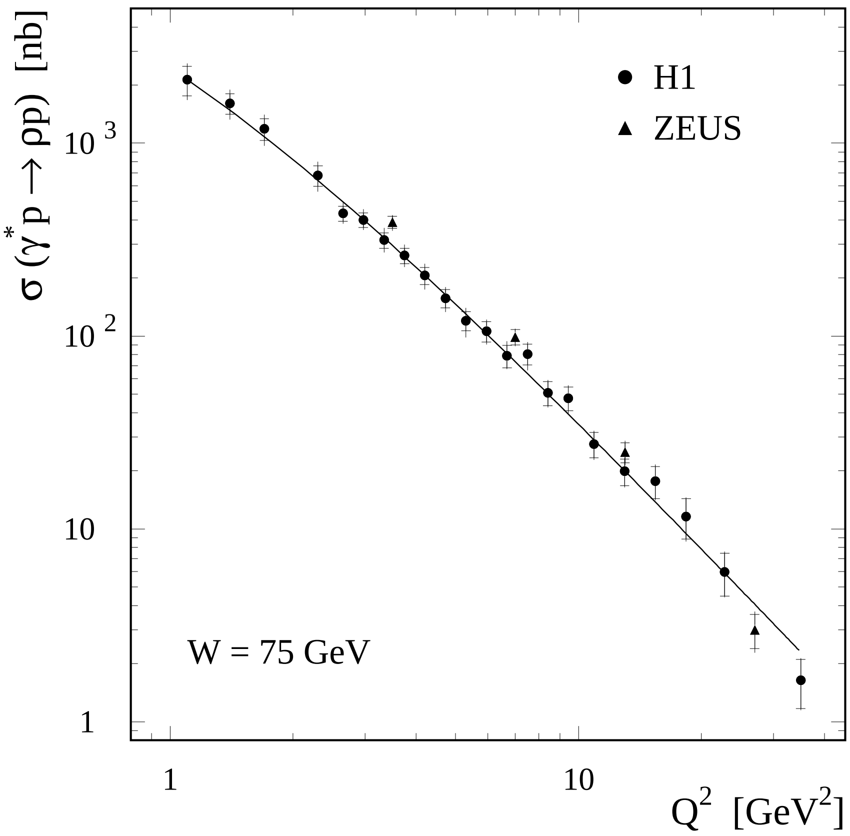
ZEUS Electroproduction of ω:

$37 \; pb^{-1}$ from 1996-97
$3 < Q^2 < 30 \; GeV^2$
$40 < W < 120 \; GeV$





Electroproduction $\gamma^* p \rightarrow \rho^\circ p, \phi p, \omega p$



ρ°: **Fit to**

$\sigma \sim 1/(M_V^2 + Q^2)^n$

$n = 2.24 \pm 0.09$

ϕ: **Fit to**

$\sigma \sim 1/(Q^2)^n$

$n = 2.18 \pm 0.10 \pm 0.15$

ω: **No fit!**

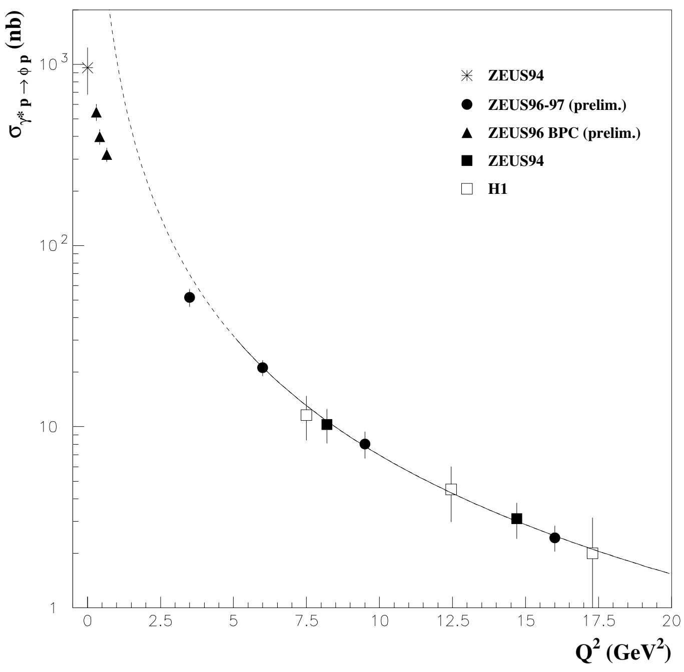
Data agree perfectly with

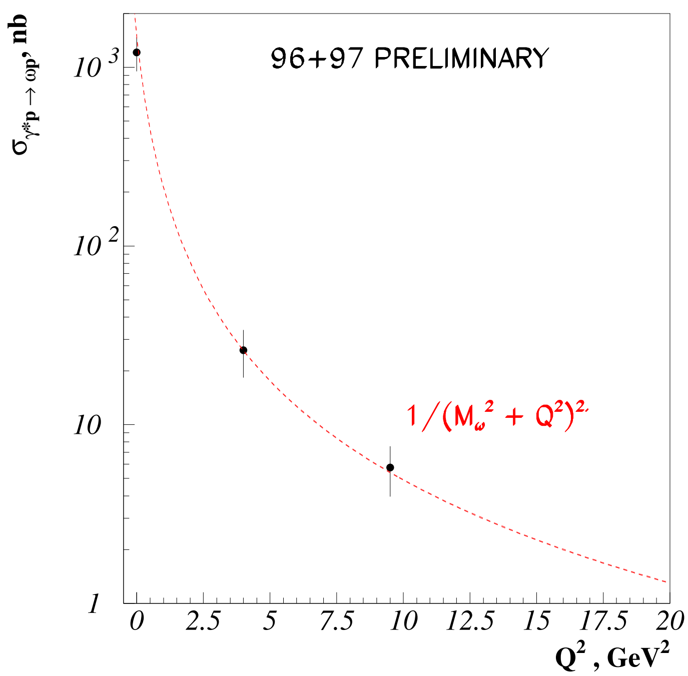
$1/(M_V^2 + Q^2)^2$

pQCD:

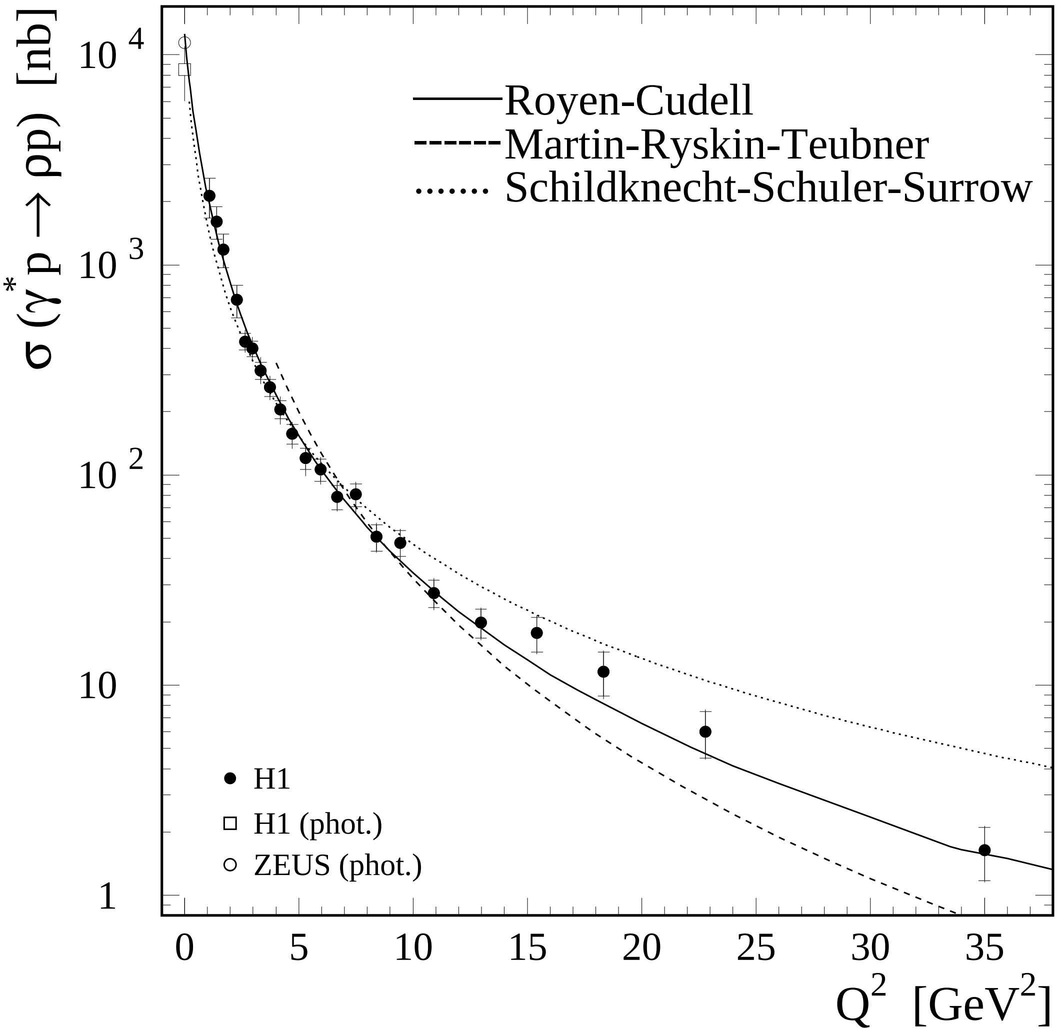
$\sigma \sim \alpha_s^2(Q^2)/Q^{4.8}$

cfr. "Soft" Diffraction, $\sigma \sim Q^{-6}$

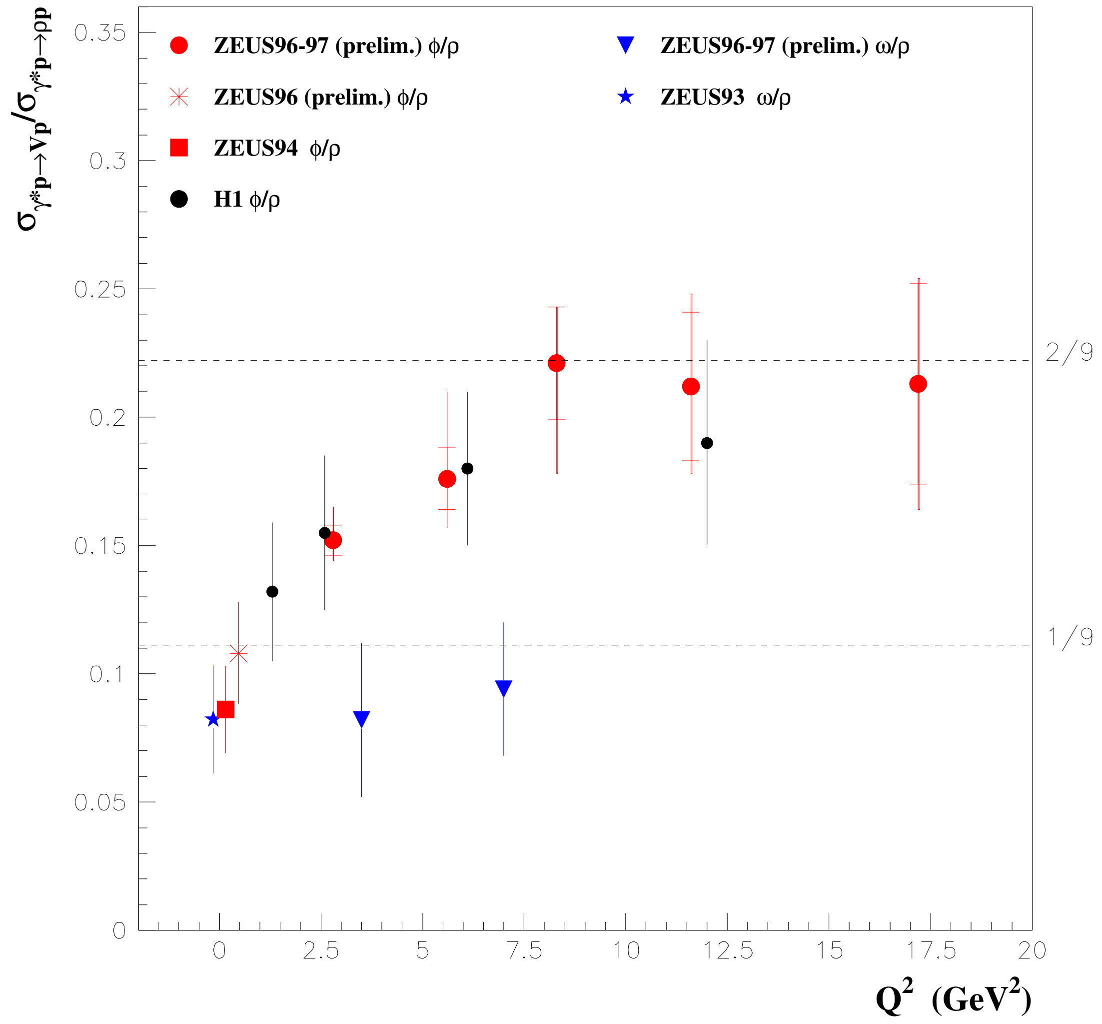




Electroproduction $\gamma^* p \to \rho^\circ p$



Electroproduction $\sigma(V)\,/\,\sigma(\rho^\circ)$



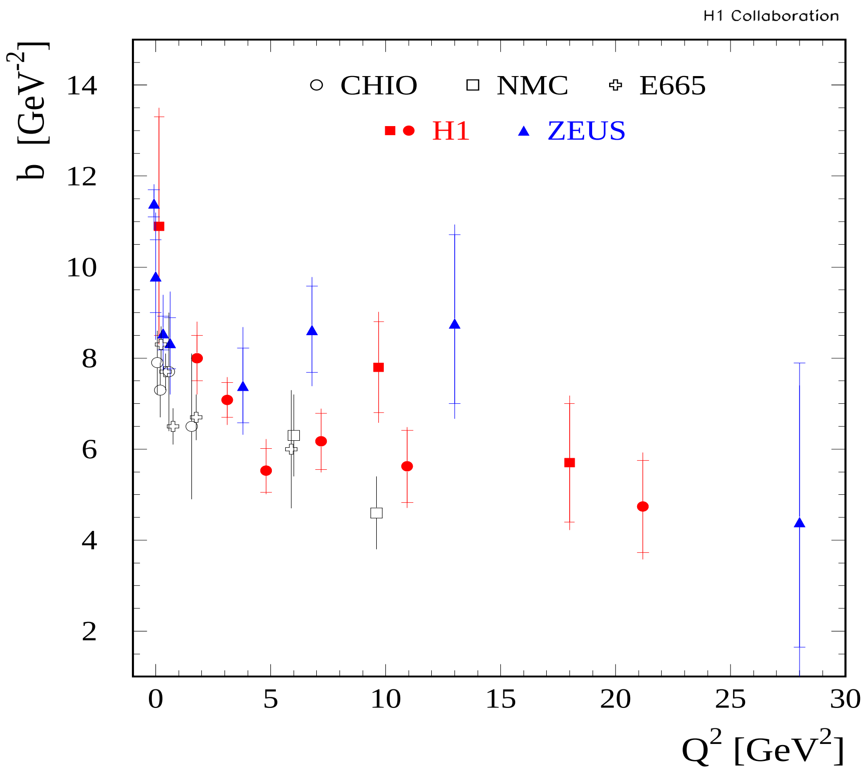
Flavour Independence approached, as Q^2 increases

SU(4) prediction, from direct el.magn. coupling of γ to quarks

$$\sigma(\rho^\circ)\ :\ \sigma(\omega)\ :\ \sigma(\phi)\ :\ \sigma(J/\Psi)\ =\ 9:1:2:8$$

Electroproduction $\gamma^* p \rightarrow \rho^\circ p$

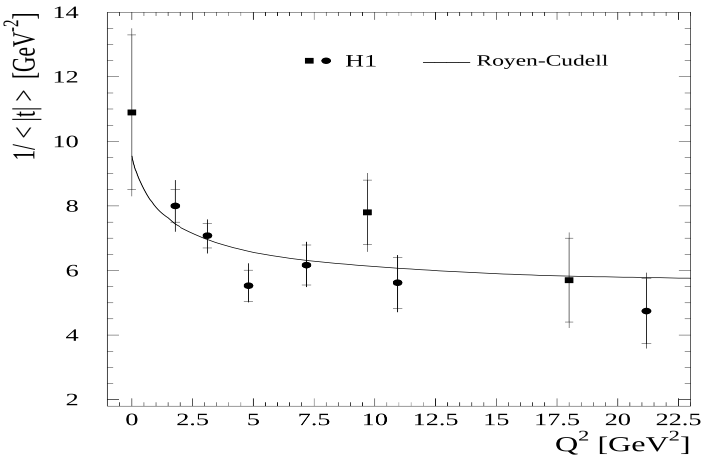
Q^2 dependence of the slope b



b decreases with increasing Q^2

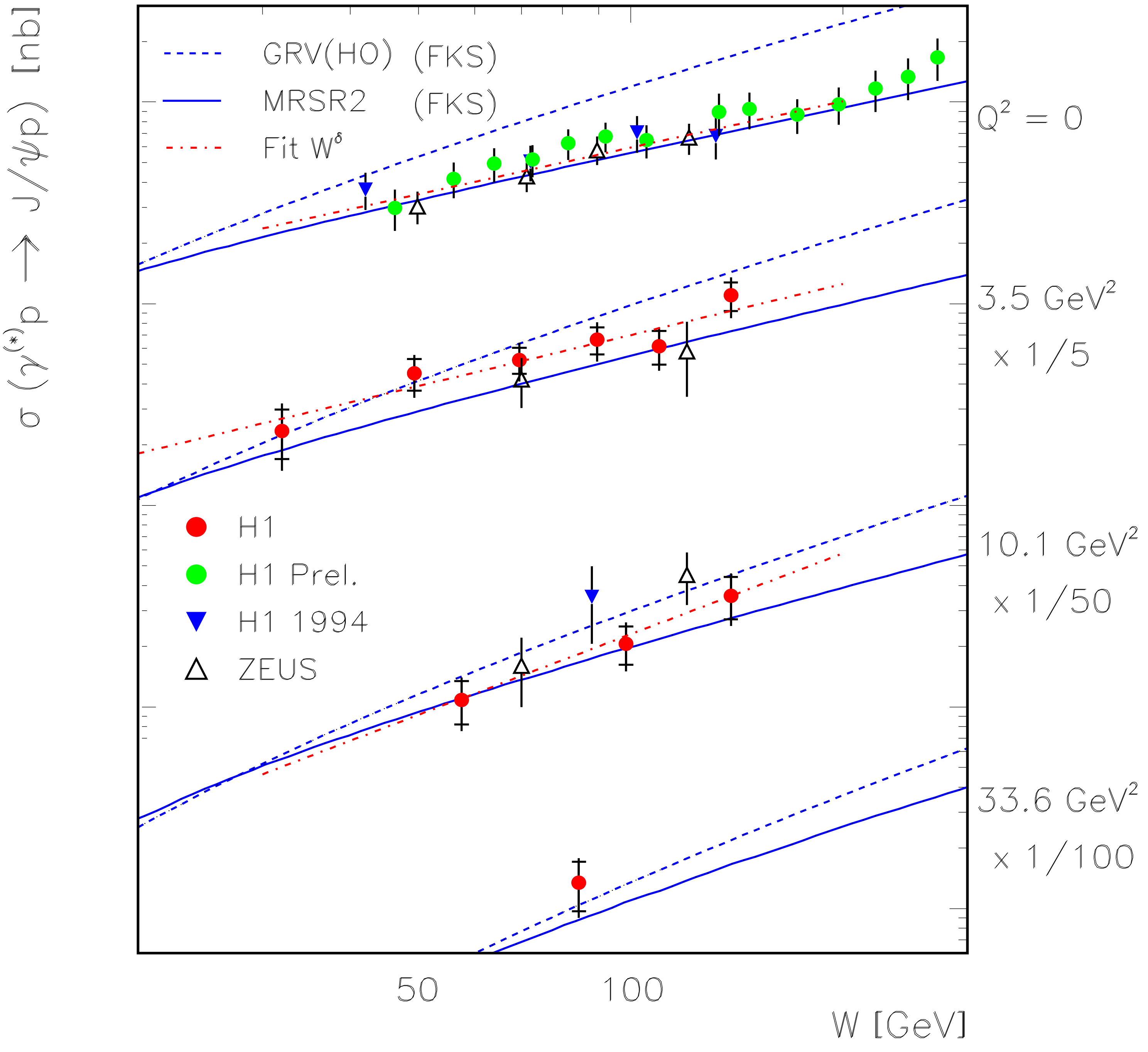
$q\bar{q}$ transverse size decreases with Q^2

Fixed Target data below HERA data $\Longrightarrow$
Suggests Shrinkage of Diffractive peak with increasing W



Compare with pQCD based model

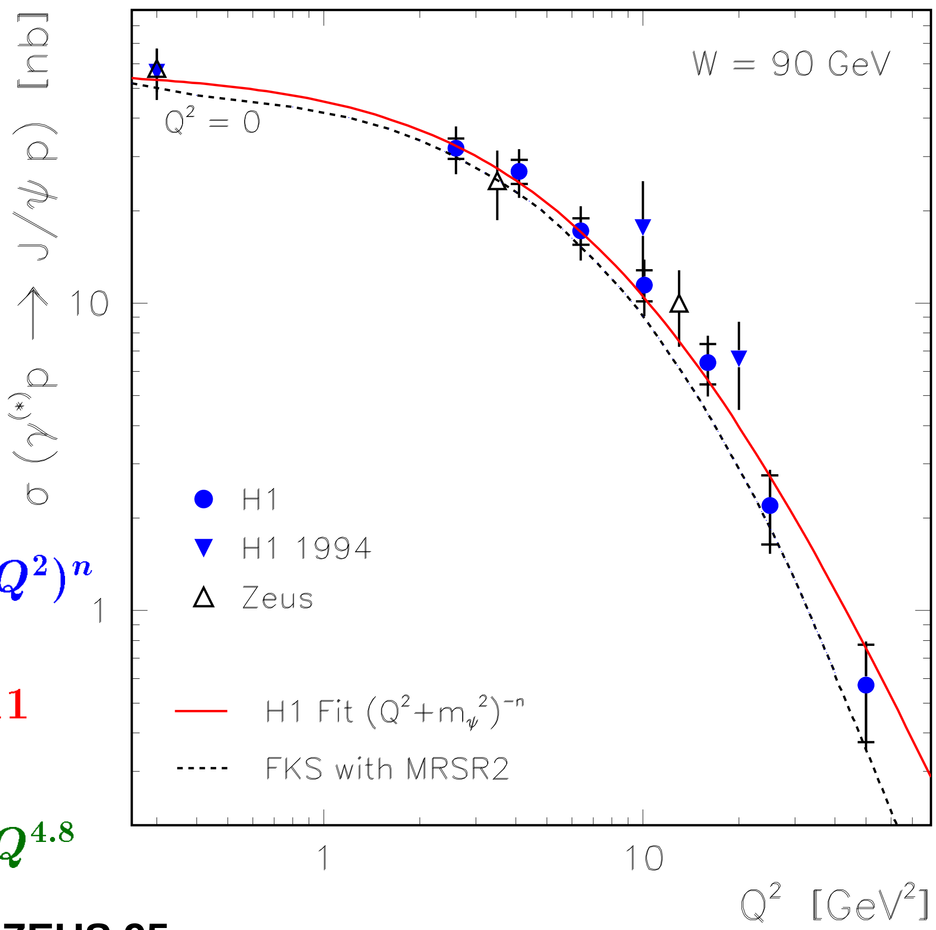
Electroproduction $\gamma^* p \to J/\Psi\, p$



δ $\sim$ independent of Q^2,
steep already in Photoproduction

Sensitivity to parameterisations of the gluon density

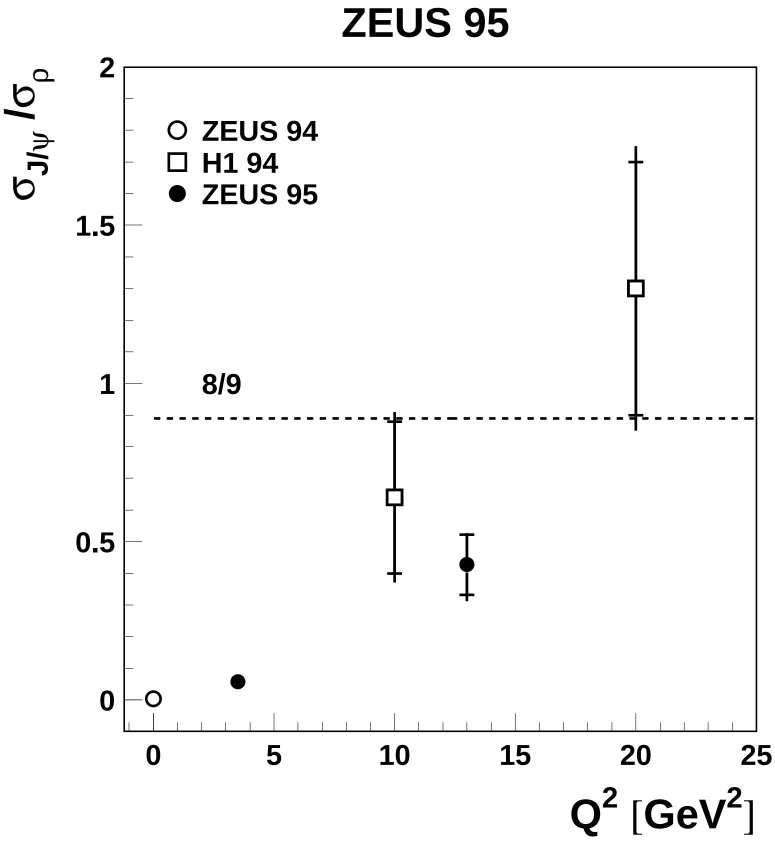
Electroproduction $\gamma^* p \to J/\Psi\, p$



Fit to
$\sigma \sim 1/(M_V^2 + Q^2)^n$

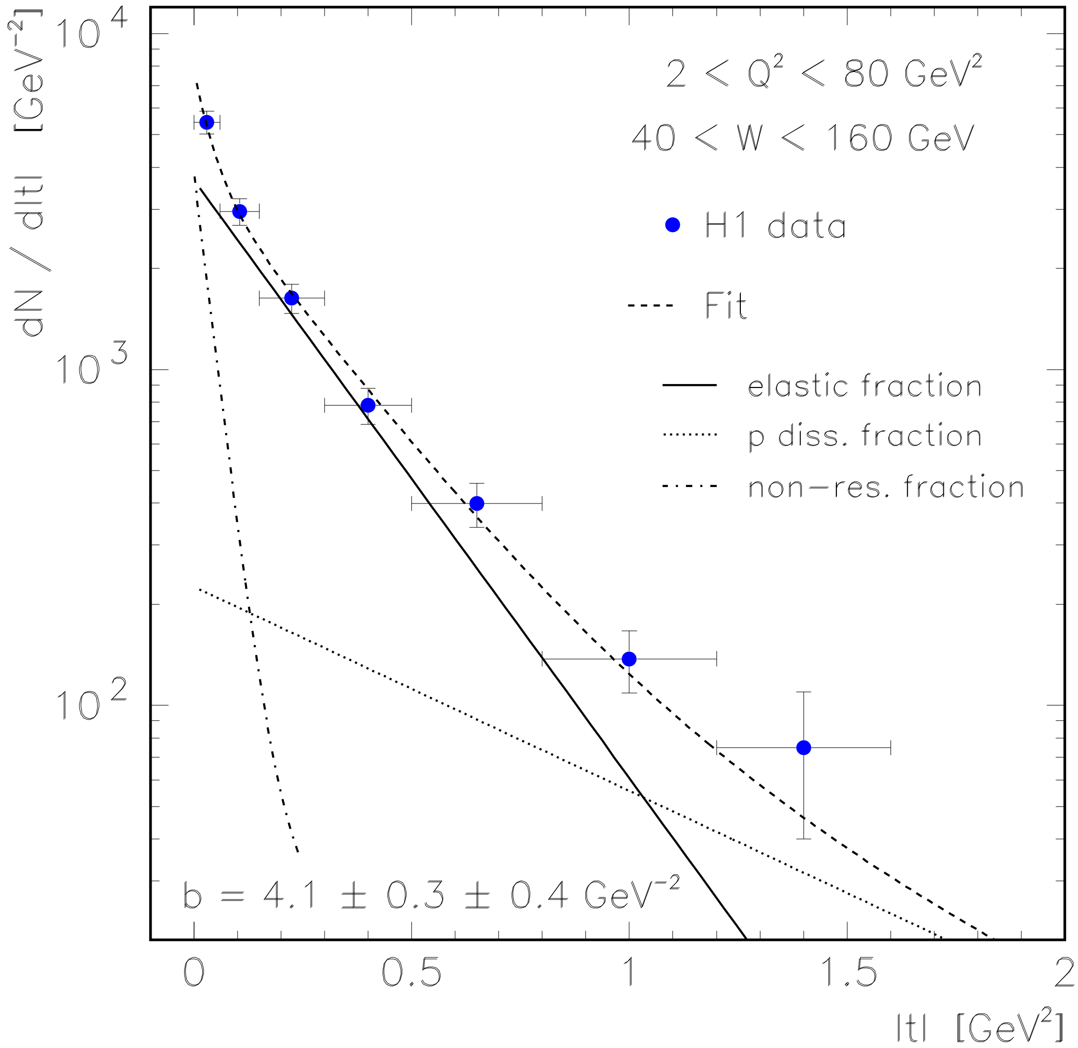
$n = 2.38 \pm 0.11$

pQCD:
$\sigma \sim \alpha_s^2(Q^2)/Q^{4.8}$



The approach to the Flavour Independence limit is slower for J/Ψ than for the light Vector Mesons

Electroproduction $\gamma^* p \to J/\Psi\, p$



$b \sim$ same as in Photoproduction of J/Ψ

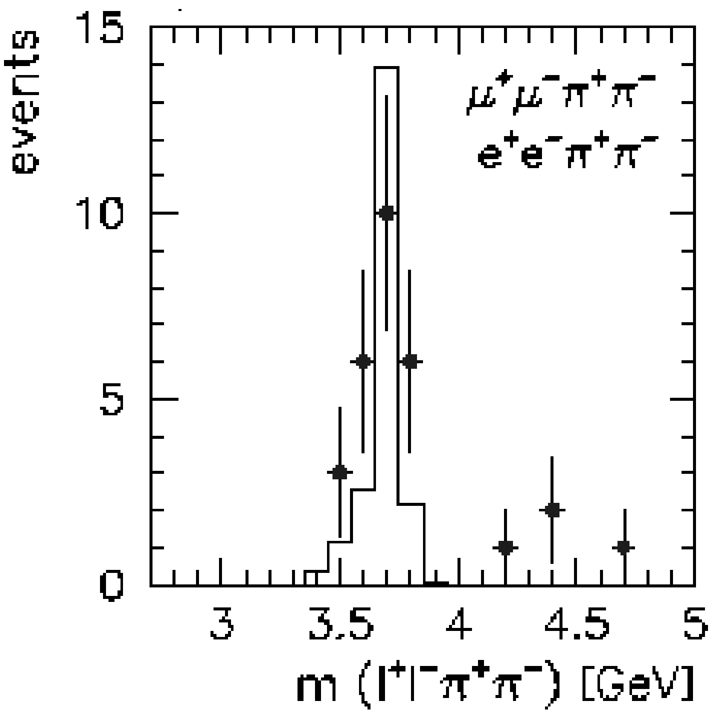
Q^2 dependence of b ?

H1:

$$2 < Q^2 < 8 \;\; GeV^2 \qquad b = 4.4 \pm 0.4 \pm 0.4$$
$$8 < Q^2 < 80 \; GeV^2 \qquad b = 2.5 \pm 0.6 \pm 0.6$$

Indication for decrease of b with increasing Q^2

Electroproduction $\gamma^* p \rightarrow \Psi(2S)\, p$

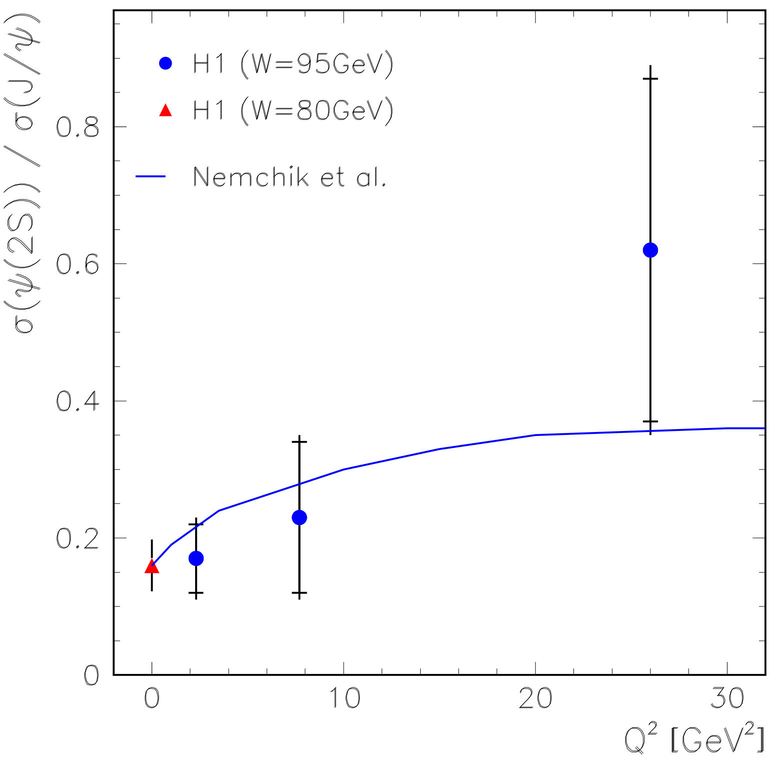


$27 pb^{-1}$

No separation between elastic and p-dissociative reactions

$1 < Q^2 < 80\ GeV^2$

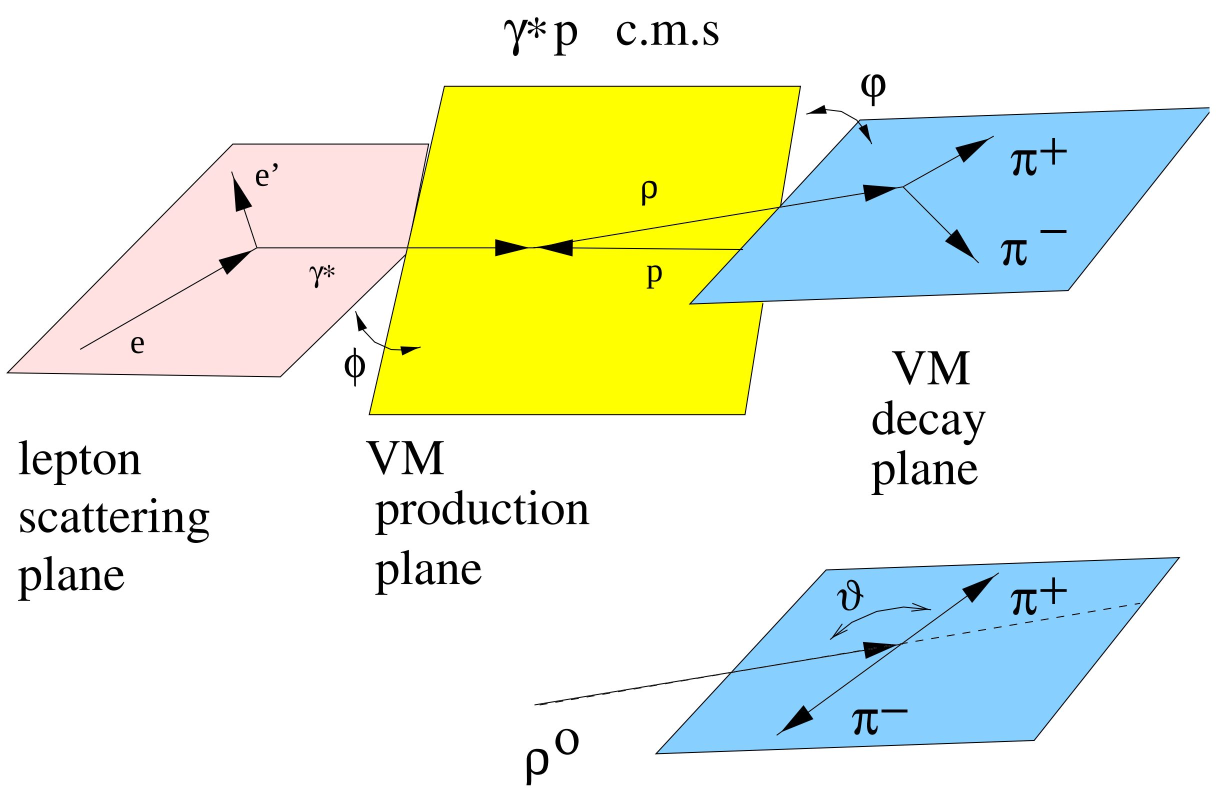
$40 < W_{\gamma p} < 180\ GeV$



$\leftarrow$ Asymptotic limit (FKS) for $Q^2 \gg M^2_{J/\Psi}$

Good agreement between Photoproduction (H1, ZEUS) and low Q^2

Helicity Studies



Use Helicity Frame

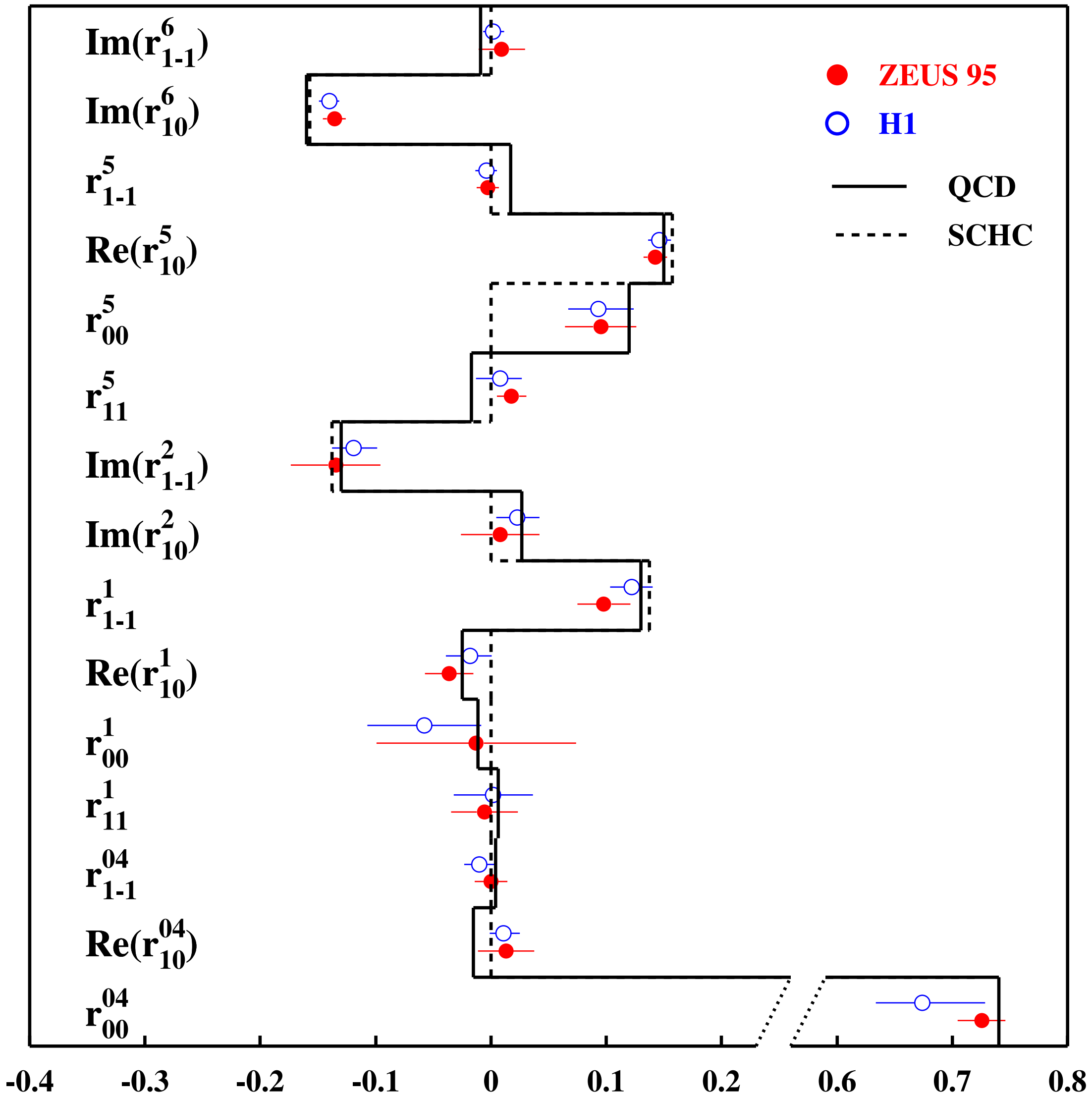
Decay angular distribution $W(\cos\theta, \varphi, \phi)$,
15 indep. combinations of spin-density matrix elements

SCHC, NPE: Only 5 combinations $\neq 0$

Determine all 15 combinations from the data

Full analysis for ρ° (H1, ZEUS) and ϕ (ZEUS)
Limited analysis for J/Ψ (H1, ZEUS)

Electroproduction $\gamma^* p \rightarrow \rho^\circ p$



SCHC violated in combination r^5_{00}

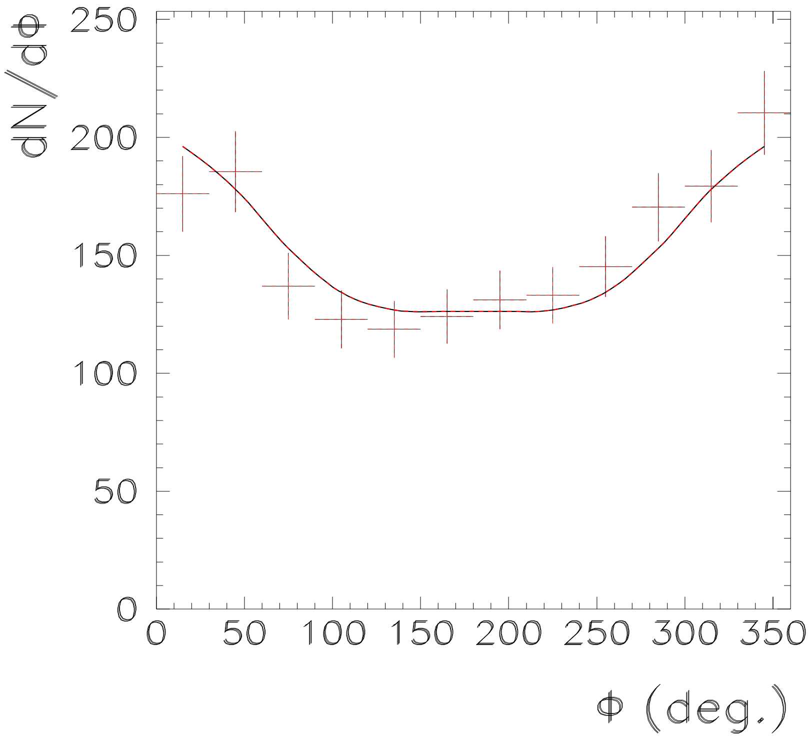
Excellent agreement between H1 and ZEUS

pQCD model (Ivanov, Kirschner) describes data well

Electroproduction $\gamma^* p \rightarrow \rho^\circ p$

$$W(\phi) \propto 1 - \epsilon \cos 2\phi(2r^1_{11} + r^1_{00}) + \sqrt{2\epsilon(1+\epsilon)} \cos\phi(2r^5_{11} + r^5_{00})$$

(integrate over $\cos\theta, \varphi$)



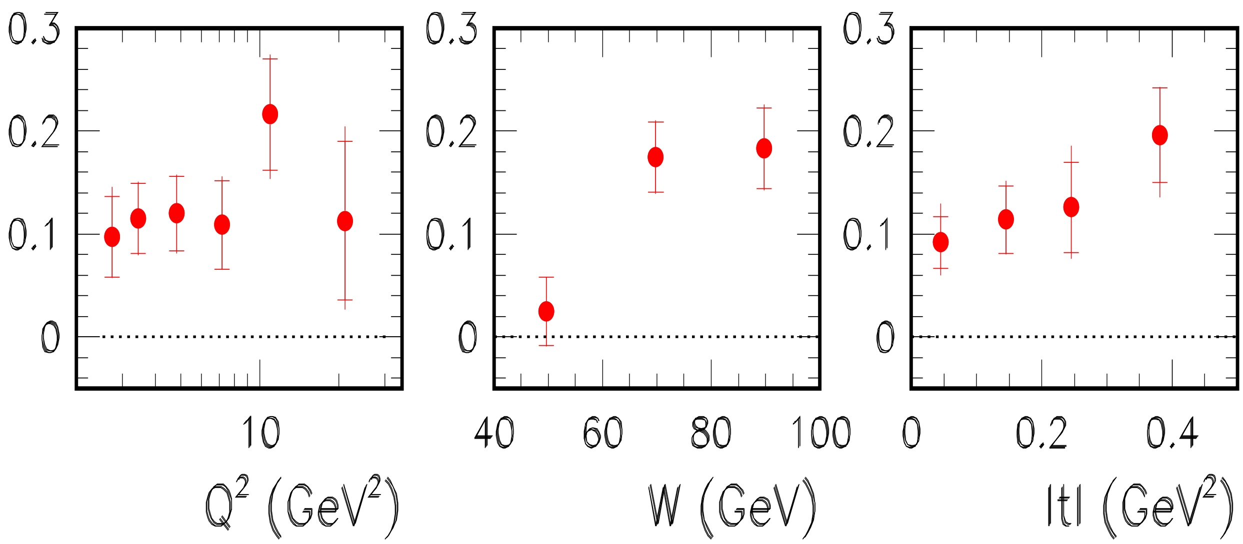
SCHC: expect uniform ϕ distribution

$$r^5_{00} \sim \frac{\sqrt{2}\,R}{1+\epsilon R} \frac{|T_{01}|}{|T_{11}|}$$

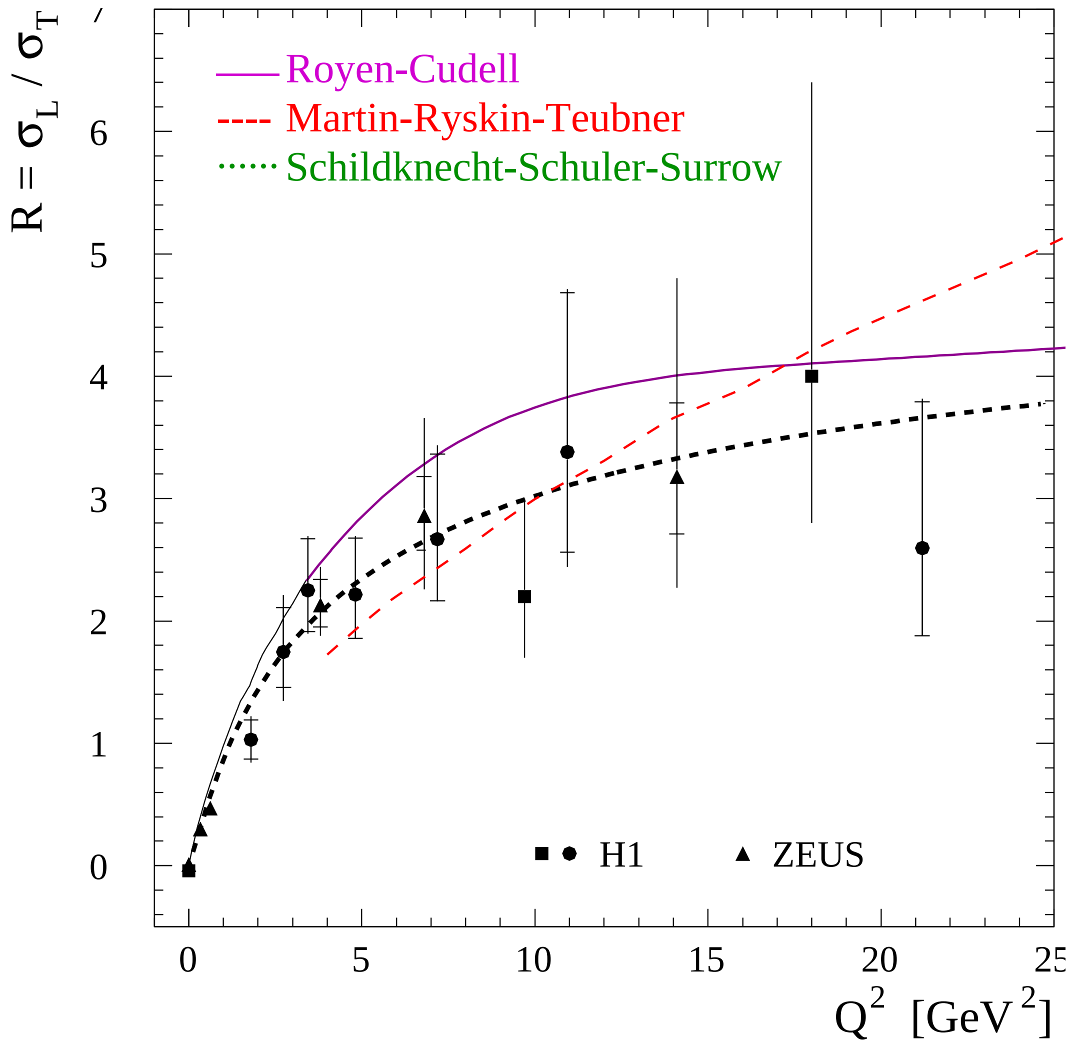
$$\simeq 8 \pm 3\%$$

T_{01}: Amplitude for a transverse photon to produce a longitudinal ρ°

$$(2r^5_{11} + r^5_{00})$$



Electroproduction $\gamma^* p \rightarrow \rho^\circ p$



SCHC violation effect $\sim$ 8%

influence on R : $2-3\%$

Assuming SCHC,

$$R = \sigma_L/\sigma_T = \frac{1}{\epsilon}\frac{r^{04}_{00}}{(1-r^{04}_{00})}$$

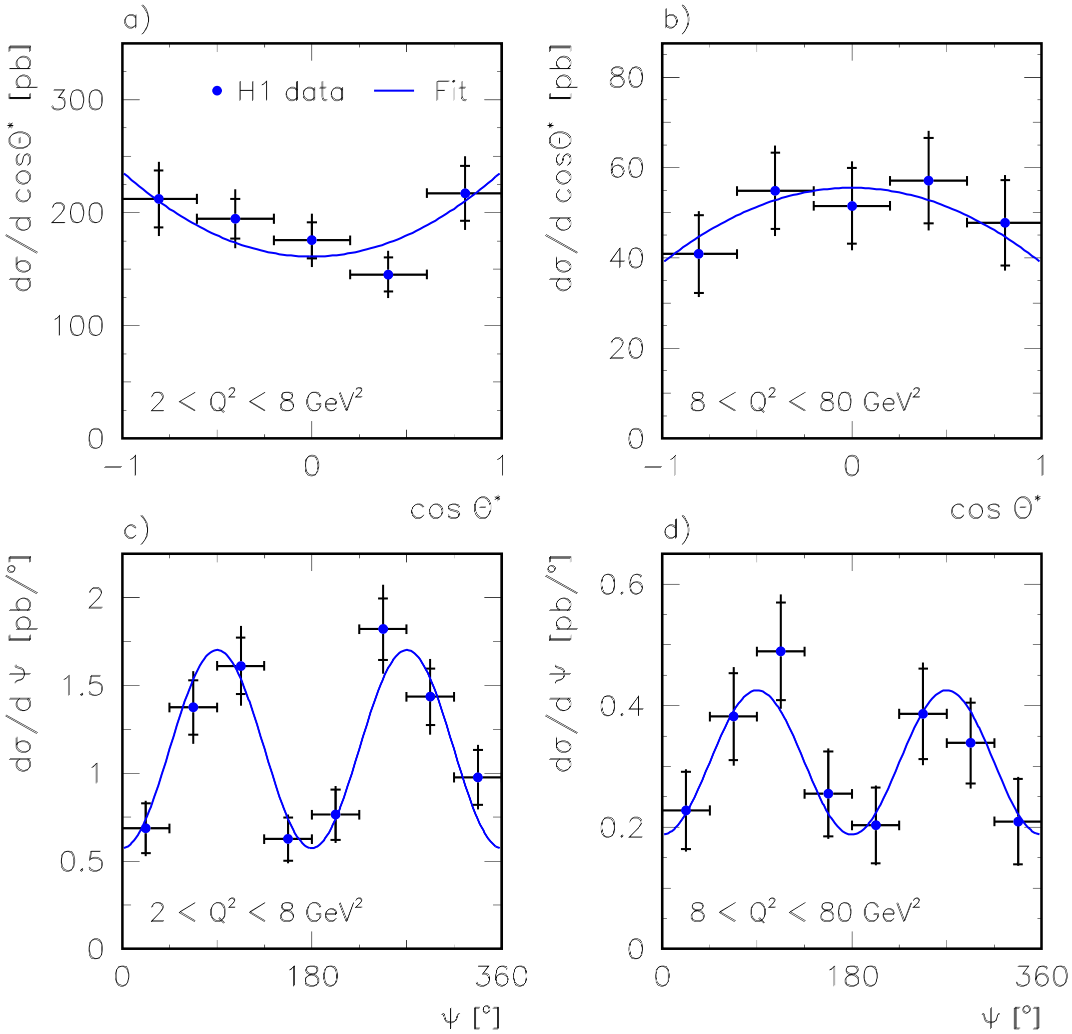
r^{04}_{00} : **probability to produce longitudinal ρ°,**

from either transverse or longitudinal γ^*

Dependence of R on Q^2 described by pQCD and GVDM

Electroproduction $\gamma^* p \rightarrow J/\Psi\, p$

Helicity Analysis of J/Ψ in 2 bins of Q^2



$$d\sigma/d\cos\theta \sim 1 + r^{04}_{00} + (1+3\,r^{04}_{00})\cos^2\theta$$

$$\Psi = \varphi - \phi$$

$$d\sigma/d\Psi \sim 1 - r^1_{1-1}\cos 2\Psi$$

Assume SCHC, NPE $\Longrightarrow r^1_{1-1} = \frac{1}{2}(1 - r^{04}_{00})$

Measurement confirms assumption

H1:

$$< Q^2 > = 4 \quad GeV^2 \qquad R = 0.18^{+0.18}_{-0.14}$$

$$< Q^2 > = 16 \quad GeV^2 \qquad R = 0.94^{+0.79}_{-0.43}$$

ZEUS:

$$< Q^2 > = 5.9 \; GeV^2 \qquad R = 0.41^{+0.45}_{-0.52}$$

Data suggest that R increases with Q^2

High $|t|$ Photoproduction $\gamma\, p \;\rightarrow\; \rho^\circ\, p$

ZEUS Preliminary

Tagged Photoproduction data: $30\; pb^{-1}$ **from 1995-97**

Electron Tagger at 44 m (Tungsten/Scintillator calorimeter)

$$Q^2 \;<\; 0.01\; GeV^2$$

$$80 \;<\; W \;<\; 120\; GeV$$

$$2\,10^{-8} \;<\; |t| \;<\; 9\; GeV^2$$

$$t \;\approx\; -\, p_t^2\; (K^+K^-,\; \pi^+\pi^-,\; \mu^+\mu^-)$$

Proton Remnant Tagger (Scintillator System)

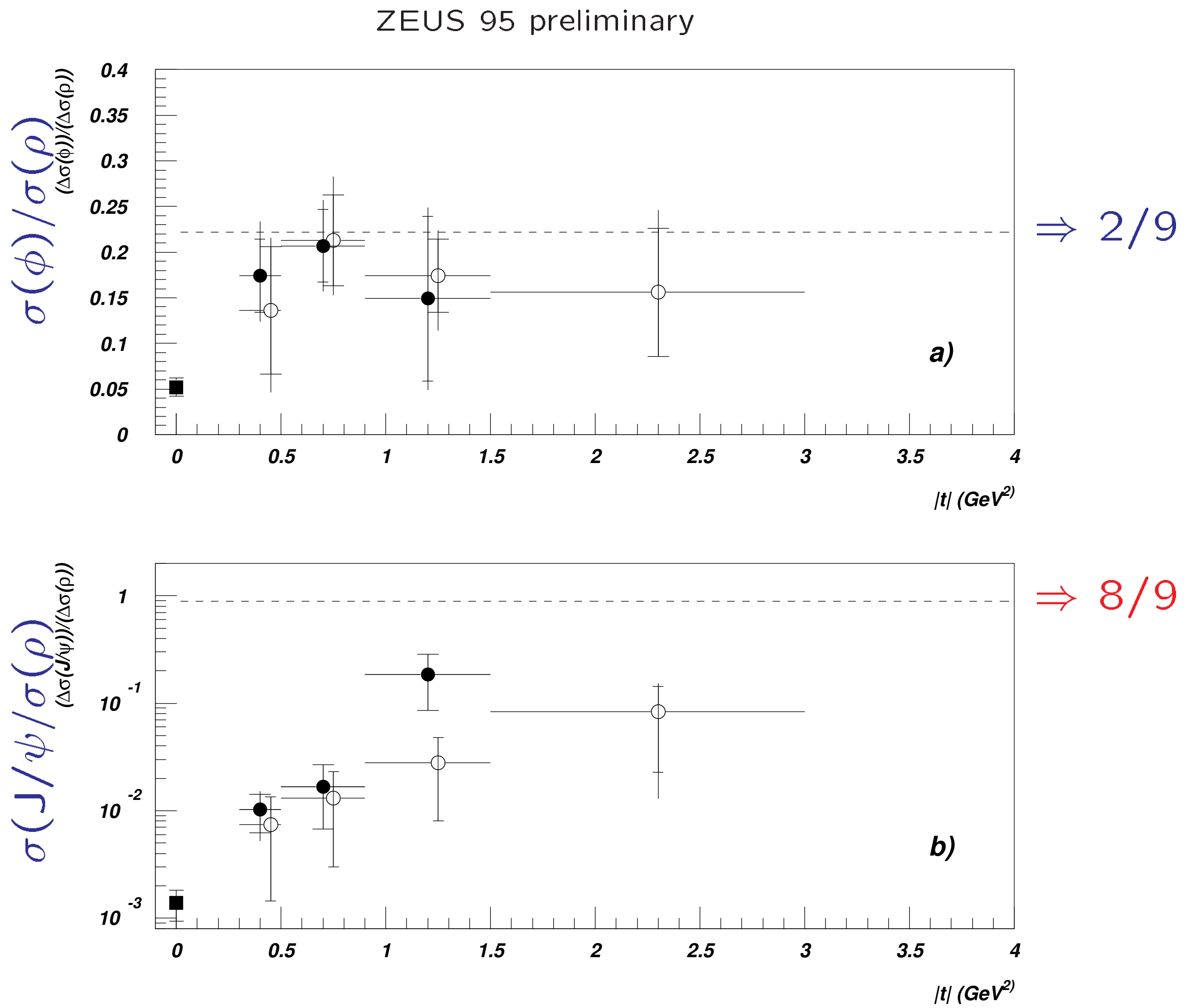
Distinguishes Elastic and Proton Dissociative reactions

Exclusive ρ°, ϕ, J/Ψ production

pQCD prediction (Ginzburg, Ivanov, Brodsky a.o.):
At high $|t|$ values, production of Longitudinal ρ° dominates
Test this with Decay Angle Analysis
(for this, demand that $|t| \;<\; 1\; GeV^2$)

But first, check Cross Section Ratios at large $|t|$ $\Longrightarrow$

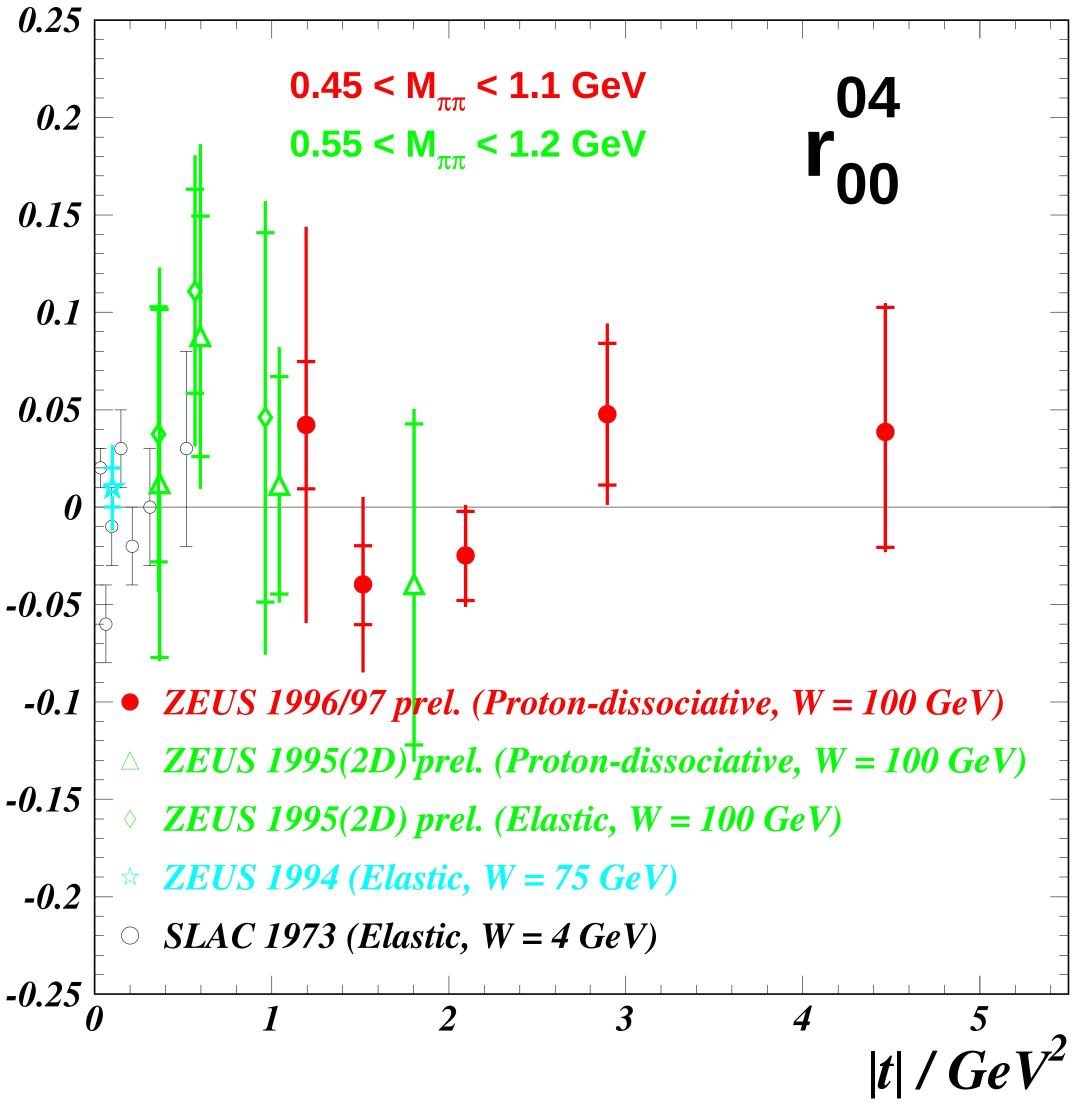
High $|t|$ Photoproduction $\gamma p \rightarrow V p$



Data approach the Flavour Independence limit, as $|t|$ increases

Slower approach for J/Ψ than for light Vector Mesons

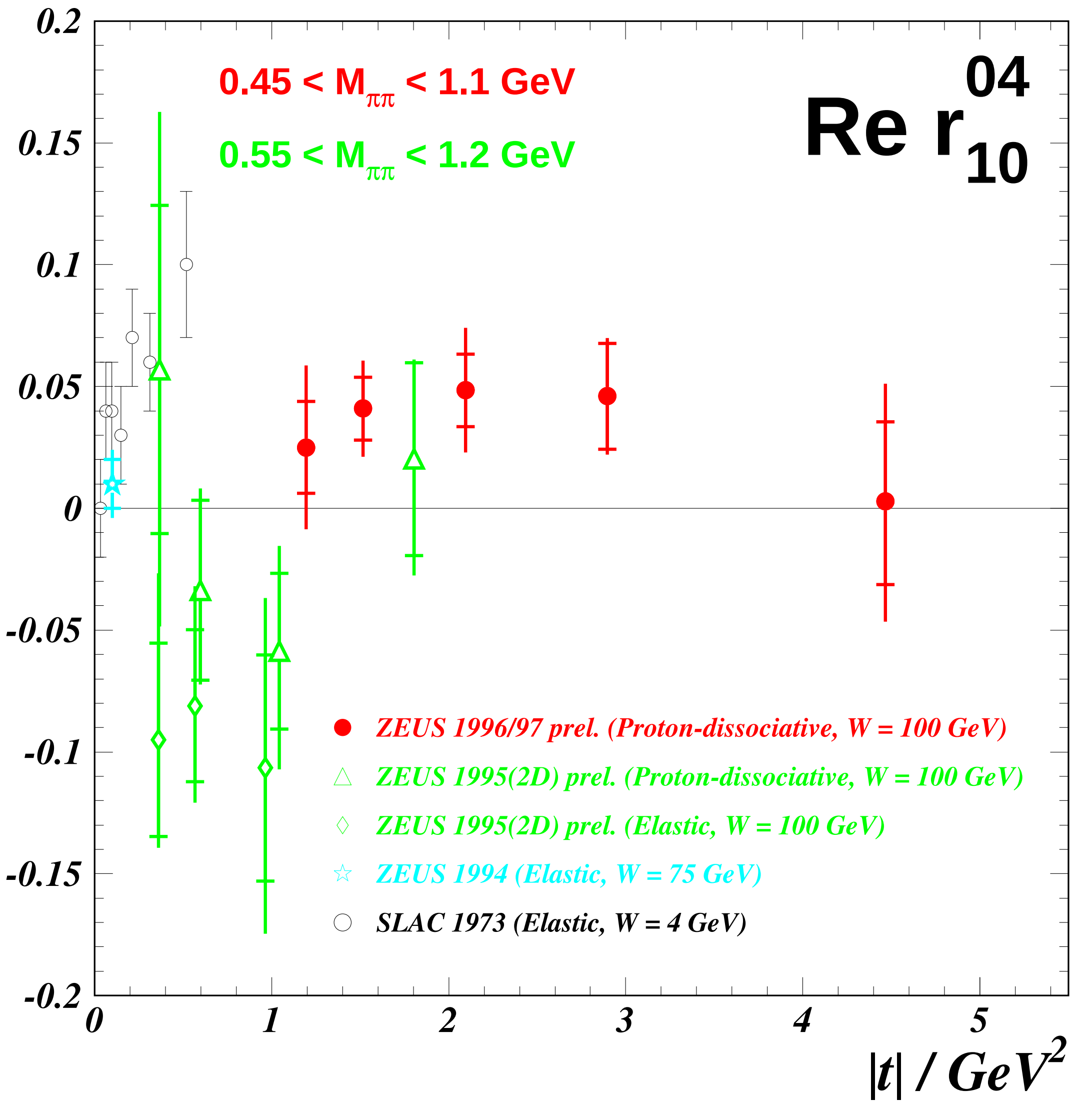
High $|t|$ Photoproduction $\gamma p \to V p$



r_{00}^{04}: Probabllity to obtain Longitudinal ρ°

No dominance at high $|t|$!

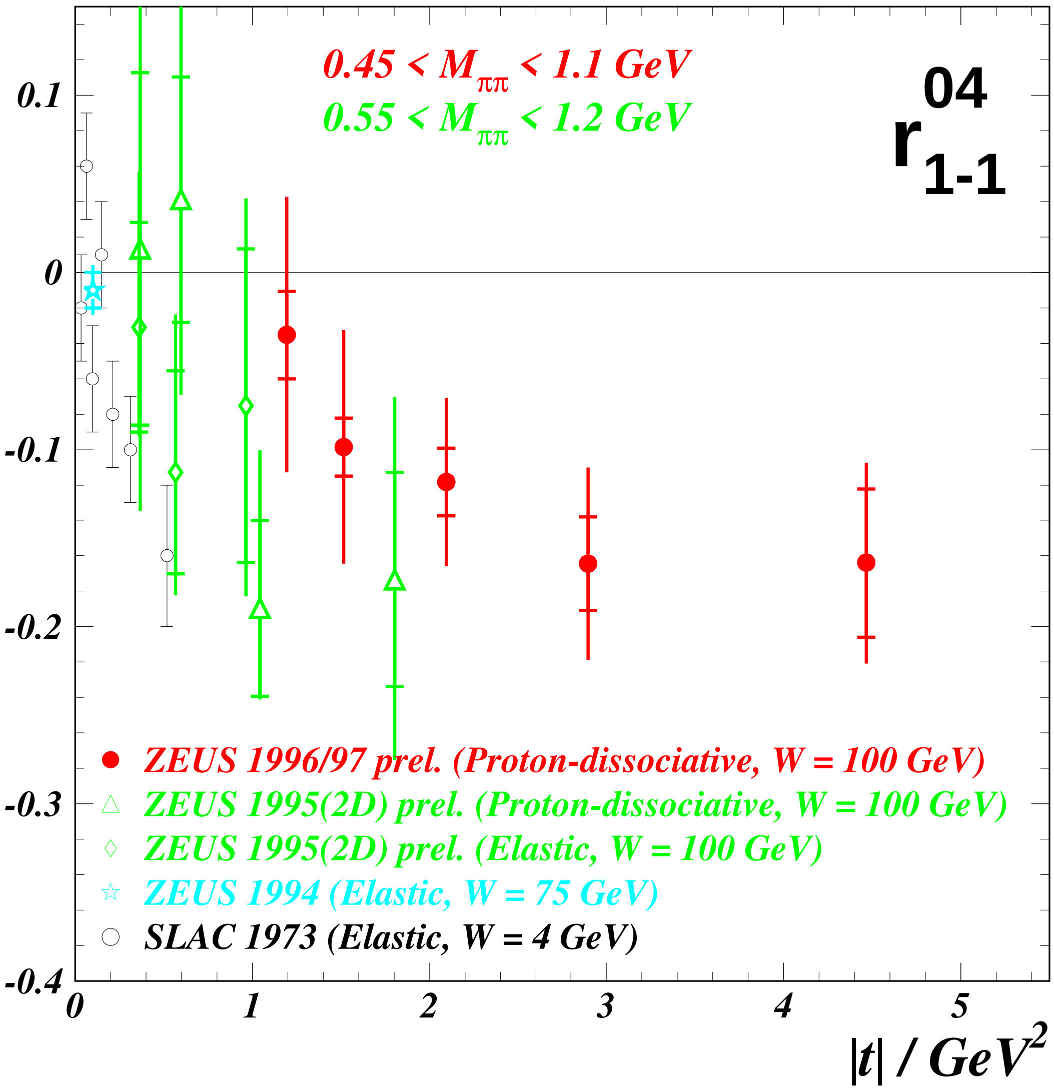
High $|t|$ Photoproduction $\gamma\, p \;\rightarrow\; V\, p$



$Re\ (r^{04}_{10})$: Interference between Helicity Conserving and Single-Flip amplitudes

Indication of a small Single-Flip contribution

High $|t|$ Photoproduction $\gamma p \to V p$



Clear Double-Flip contribution at high $|t|$ values !

confirms SLAC data at lower $|t|$ values

CONCLUSIONS

- **The last years of high luminosity running at HERA have opened up a rich field of precise data, spanning the transition region between Soft and Hard Diffraction**

- **Good evidence that M_V, Q^2 and $|t|$ all serve as Hard Scales in Diffraction**

- **Elastic and Diffractive Vector Meson production is a very active field of research, and perturbative QCD is emerging as the fundamental understanding of this field**

- **Further fruitful interaction between Theory and Experiment will provide new and interesting knowledge about the proton and Vector Meson structures**