Experimental aspects of Vector Meson production at HERA

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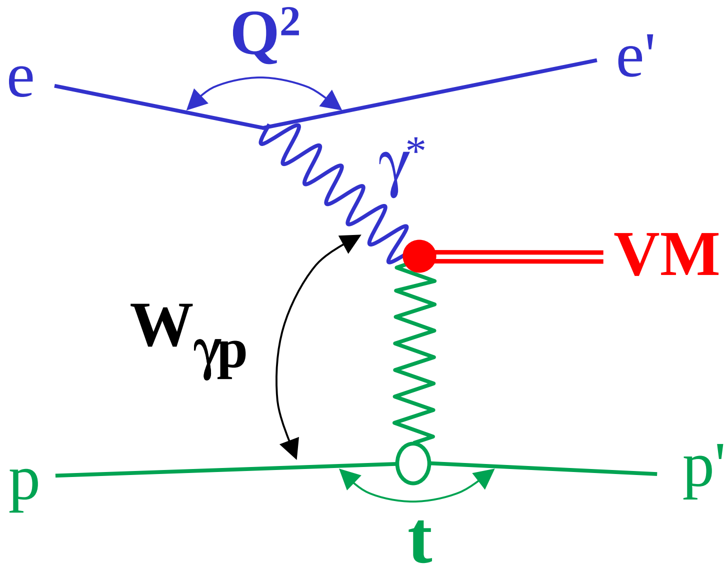
Focus on a few interesting aspects of
elastic and proton dissociative VM production:

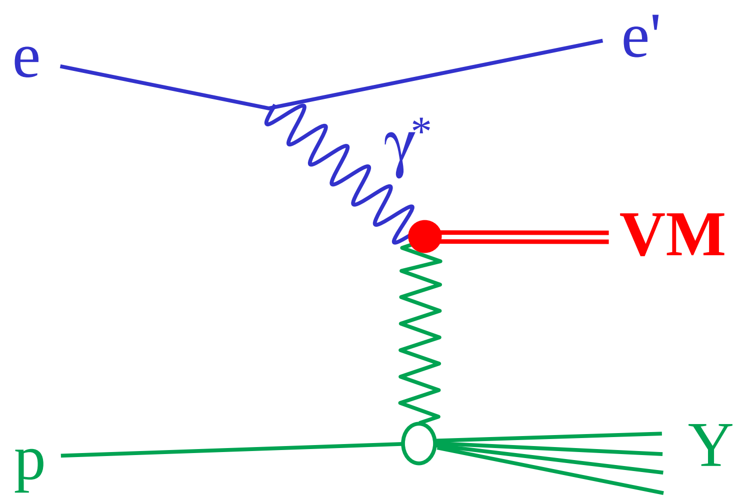
- ❑ **W dependence** (pQCD vs. Regge); **trajectories**
- ❑ hard **scales**: Q^2, $|t|$, M_{VM}^2, and their combination
- ❑ VM **ratios**: SU(4) vs. pQCD expectations

Vector Mesons production at HERA

Elastic (or exclusive)



proton dissociative



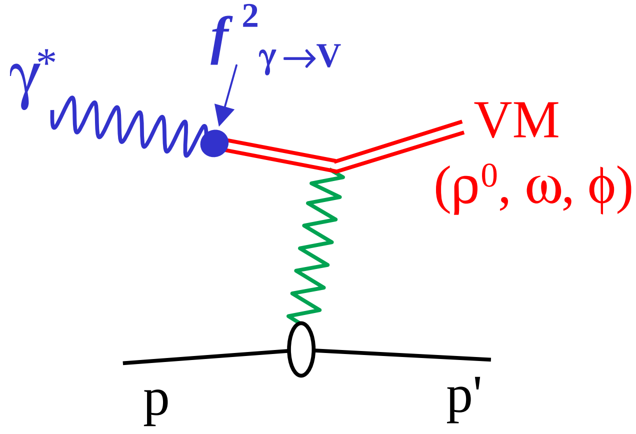
Experimentally: very clean processes in wide kinematic range

Q^2	γ^* virtuality	$0 < Q^2 < 100$ GeV^2
$W_{\gamma p}$	c.m. energy of $\gamma^* p$ system	$20 < W_{\gamma p} < 290$ GeV
t	4-mom. transfer squared at p-vertex	$0 < \lvert t \rvert < 20$ GeV^2
VM	Vector Meson	ρ^0, ω, ϕ, J/ψ, ψ', Υ

HERA $\Rightarrow$ simultaneous control of different quantities: Q^2, t, M^2_{VM}

Models for Elastic VM production

Elastic Photoproduction (Q^2, t ~ 0) of light Vector Mesons (VM) is a soft process.
No hard scale $\Rightarrow$
Vector Dominance Model $\times$ Regge theory:
γ^* fluctuates into VM **before** the interaction



$$\Rightarrow \sigma_{\gamma p\to Vp} = f^2_{\gamma\to V} \otimes \sigma_{Vp\to Vp}$$

$\sigma_{Vp\to Vp}$: exchange of soft-Pomeron trajectory,
in linear approximation: $\alpha_P(t) = \alpha_P(0) + \alpha'_P \cdot t$

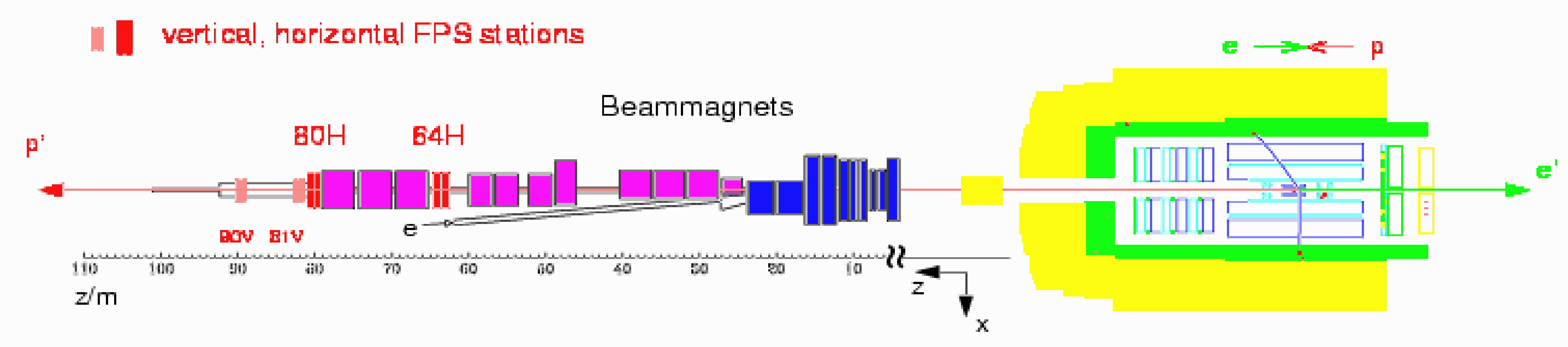
$$\Rightarrow \; d\sigma_{el}/dt = e^{-b_0 t} \cdot W^{4(\alpha_P(t)-1)} = e^{-b(W)t} \cdot W^{4(\alpha_P(0)-1)}$$

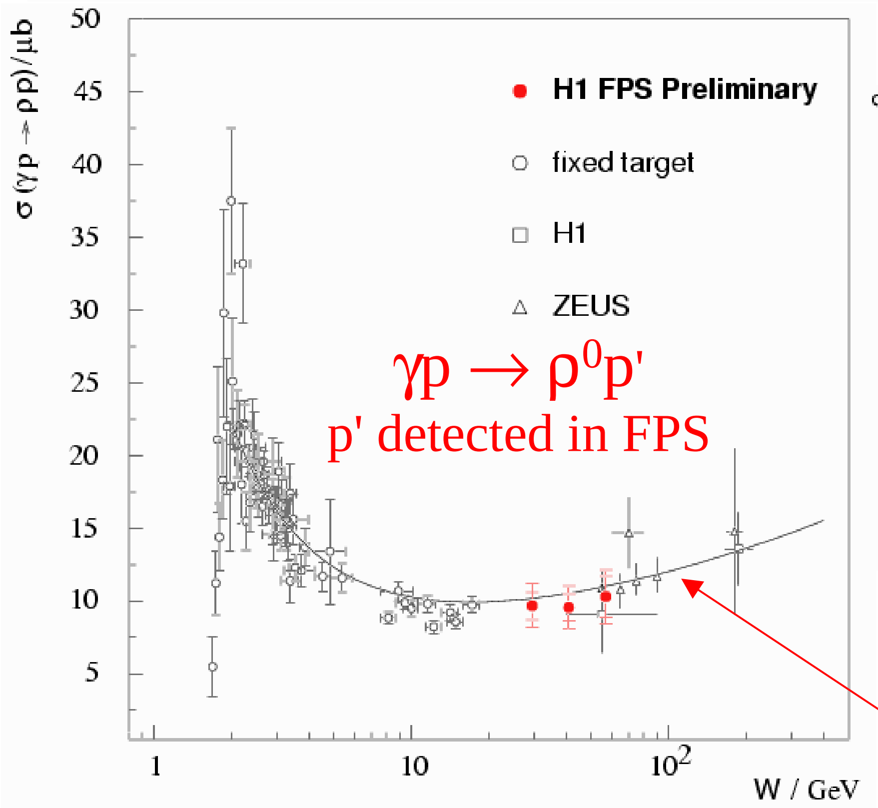
where: $b = b(W) = b_0 + 4 \cdot \alpha'_P \cdot \mathit{ln}(W)$

Experimentally, from hadronic collisions:

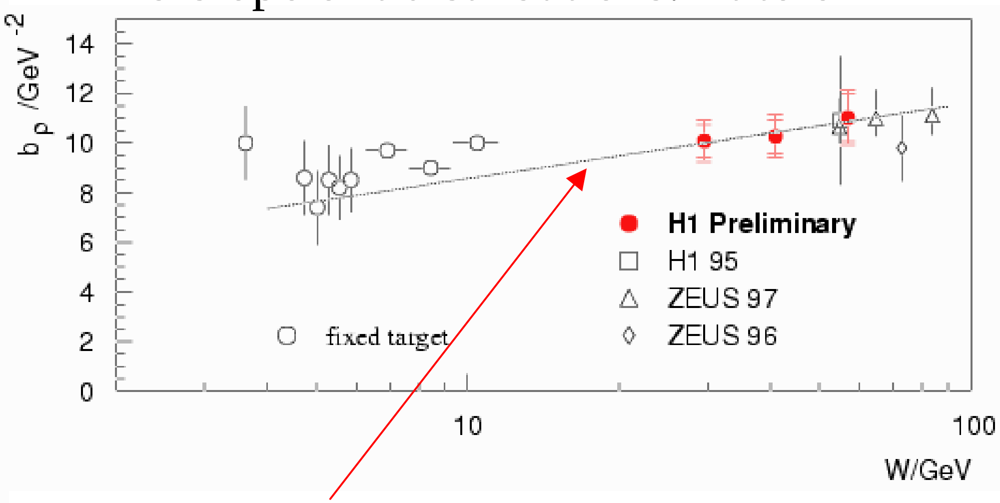
- ❑ $\alpha_P(0) = 1.08 \Rightarrow$ **slow rise of** $\sigma_{el} \propto \dfrac{W^{4(\alpha_P(0)-1)}}{b(W)} \approx \dfrac{W^{0.32}}{b(W)} = W^{0.22}$
- ❑ $\alpha'_P = 0.25 \Rightarrow$ **b slope increasing with W ("shrinkage")**

Elastic ρ^0 photoproduction: soft process





b-slope of t distributions: fit to $e^{-b_\rho |t|}$



$b_\rho \propto \mathit{ln}\,(W)$

$\sigma_{\gamma p \to \rho p} \propto W^{0.2}$

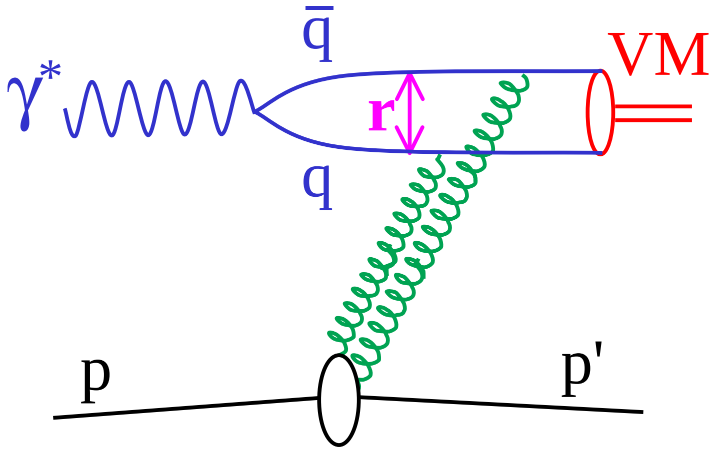
Consistent with Regge phenomenology

Models for Hard VM production

A hard scale is often present at HERA $\Rightarrow$ perturbative QCD applicable

<u>In target frame</u>, VM production is a 3-step process:

1. $\gamma^* \rightarrow q\bar{q}$ fluctuation
2. $q\bar{q}$ scatters off the proton by a colour-singlet exchange (two gluons at lowest order)
3. VM is formed (well after the interaction)



If dipole size: $\mathbf{r = \dfrac{1}{\sqrt{z(1-z)Q^2 + m_q^2}}}$ **is small**

(when m_q is large or there is a γ^*_L at high Q^2)

$\Rightarrow$ qq pair resolves gluons $\Rightarrow$ **pQCD is applicable**

Elastic VM at large Q^2: pQCD predictions

Model by Brodsky et al. for longitudinal photons:

1. Fast rise with energy:

gluon from F_2 scaling violation

$$\sigma^{L}_{\gamma^* p\to Vp} \propto \frac{1}{Q^6}\cdot \alpha_s^2(Q^2_{eff})\cdot [xg(x,Q^2_{eff})]^2 \approx [x^{-0.2}]^2$$

and since $x \approx 1/W^2$ at small x $\Rightarrow \sigma^{L}_{\gamma^* p\to Vp} \approx W^{0.8}$

2. Approximate universality of t-dependence, $e^{-(b_0+2\alpha'_P \ln W^2)\cdot|t|}$:

two-gluon approx.: $\alpha'_P = 0$ $\Rightarrow b \equiv b_0 \approx 4\ \mathrm{GeV}^2$
BFKL LLA: $\alpha'_P \lesssim 0.1\ \mathrm{GeV}^{-2}$ $\Rightarrow$ weak dep. of b on W
$\Rightarrow \alpha'_P$ = "small"

3. Approximate restoration of flavour independence:

at asymptotic Q^2, the VM cross sections are in the ratio

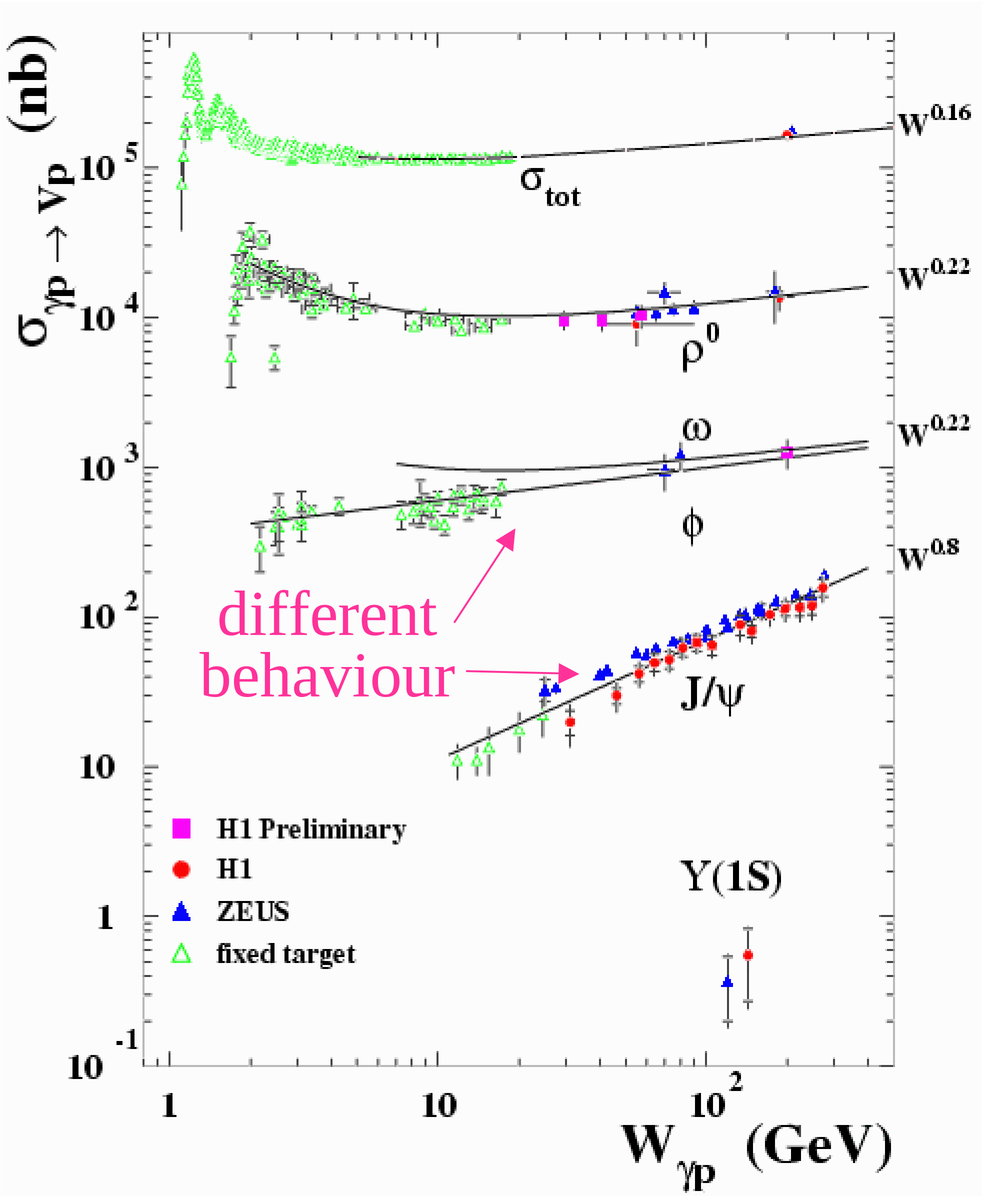
$$\rho^0 : \omega : \phi : J/\psi = 9 : 1\,(\cdot 0.8) : 2\,(\cdot 1.2) : 8\,(\cdot 3.5)$$

At which scale Q^2_{eff} should xg be evaluated?

i.e. which (or which combination) of Q^2, M_{VM}^2 and $|t|$ is the scale of the process? e.g., in Ryskin model $Q^2_{eff} = ¼ \cdot (Q^2 + M_{VM}^2 + |t|)$

W dependence: pQCD vs. Regge and Pomeron trajectory

Elastic VM in photoproduction ($Q^2 = 0$)

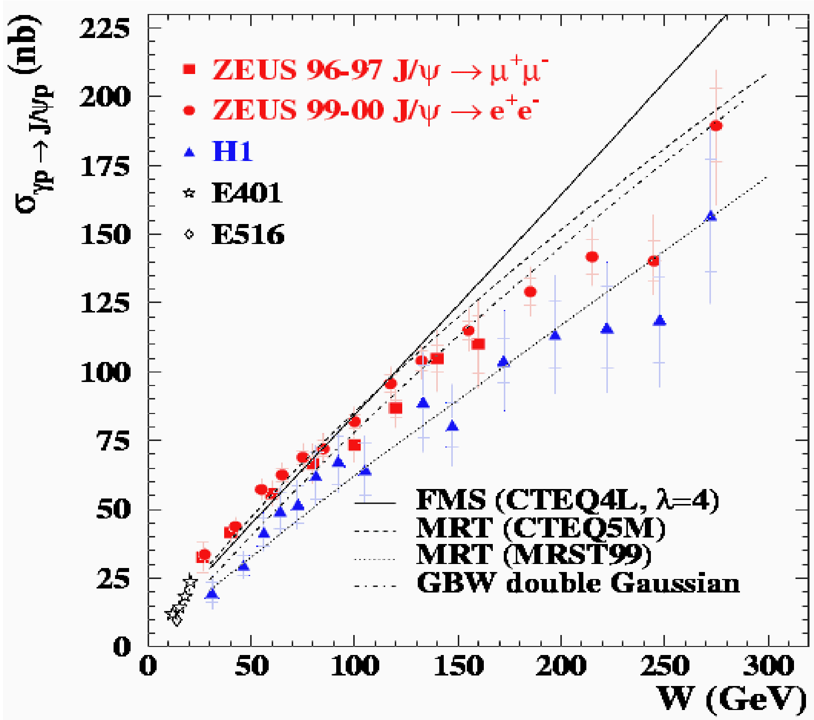


Fit $\sigma^{el} \propto W^{\delta}$ $(\delta \approx 2(\alpha_P(<t>))$ gives:

$\delta \approx 0.22$ "soft" W-dep. for ρ^0, ω, ϕ

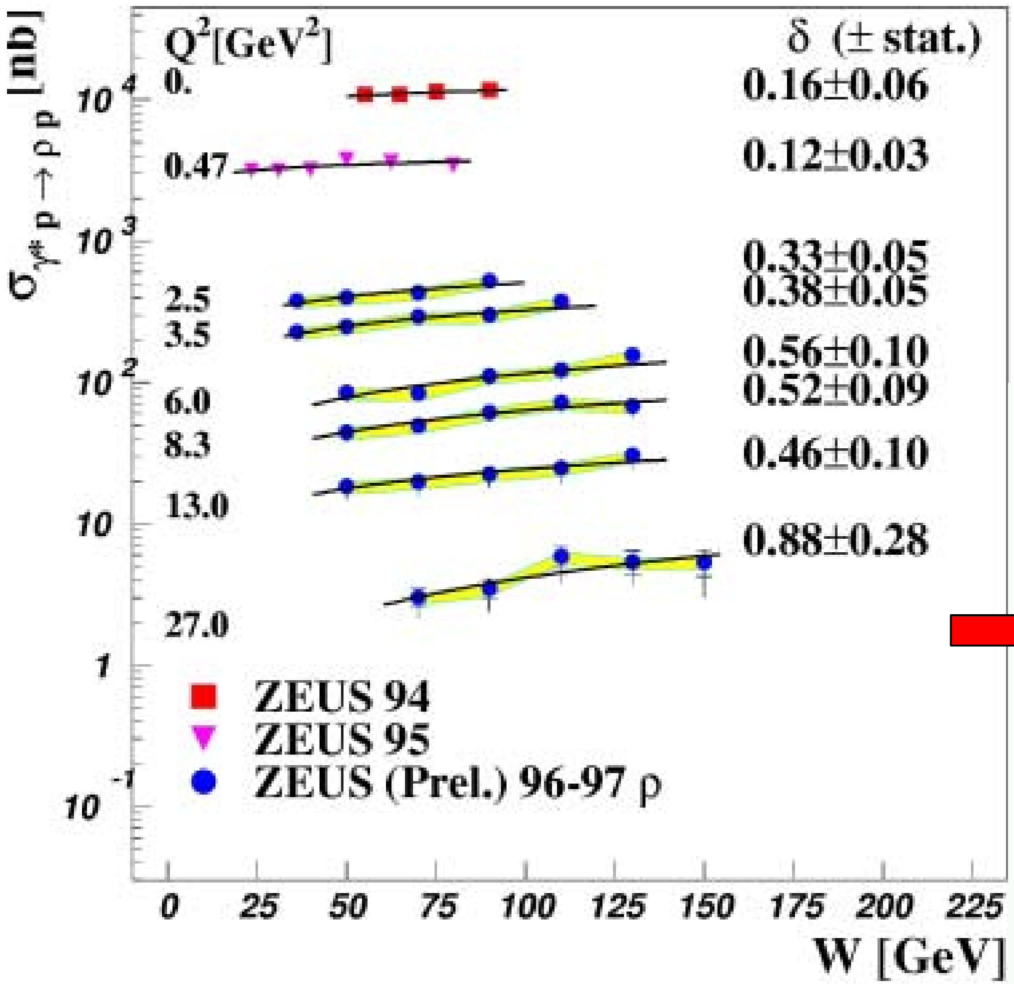
$\delta \approx 0.8$ "hard" W-dep. for J/Ψ

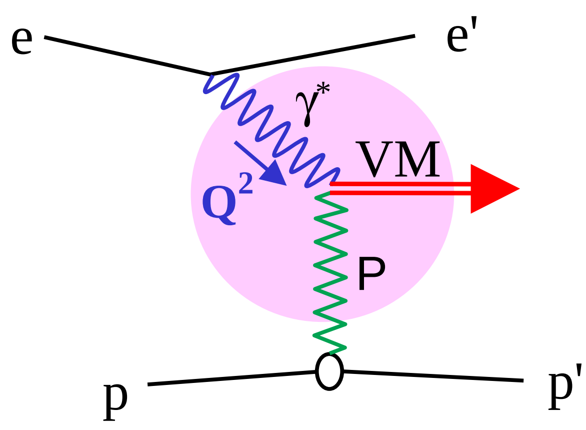
J/Ψ described by pQCD models (below) if steep gluon from fits to F_2 scaling violations are used:

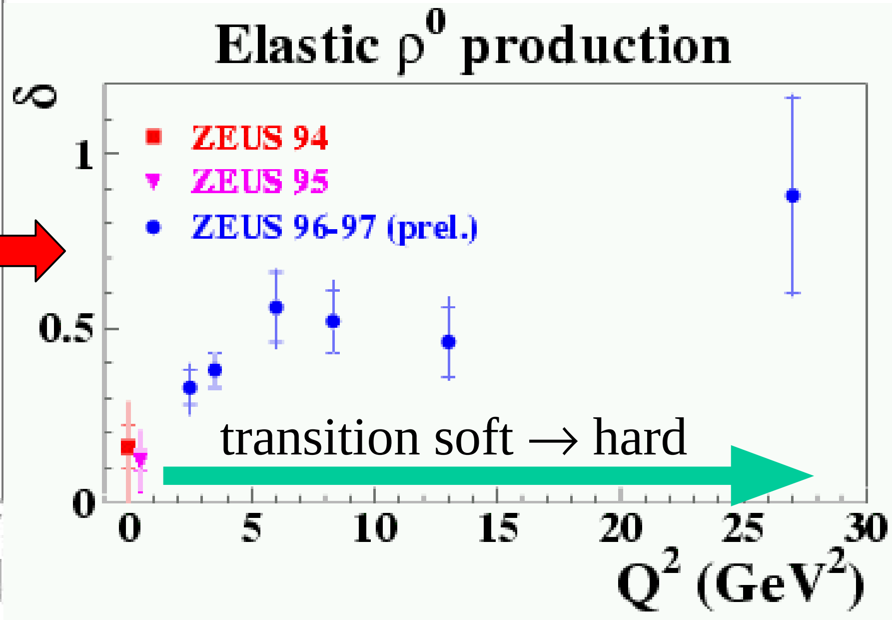


W-dependence of elastic ρ^0 vs. Q^2

Fit ρ^0 **elastic cross sections** with W^{δ}:



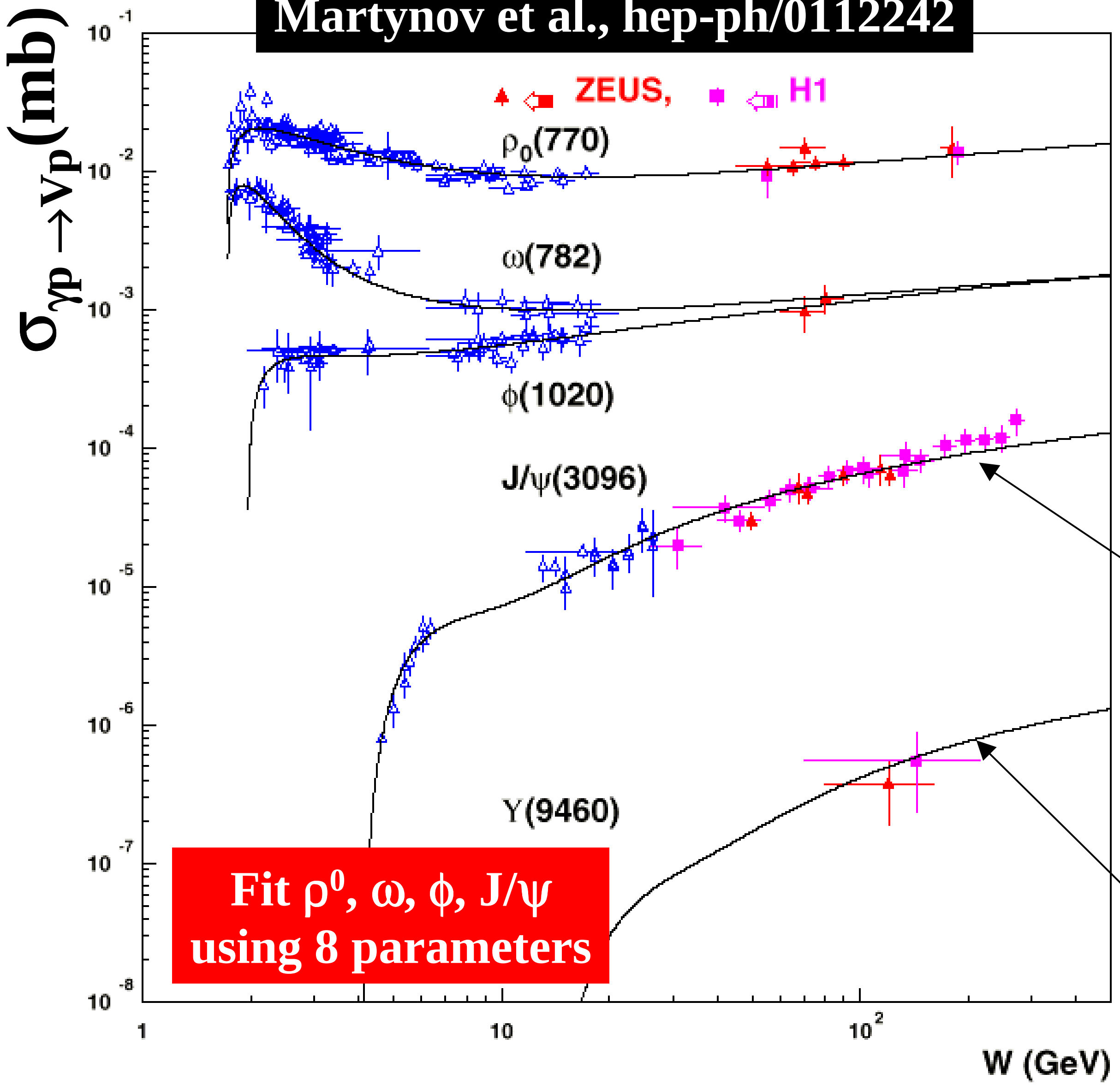




Energy dep. steepens with $Q^2 \Rightarrow$ reaching hard-regime (like for $M_{J/\psi}$)

Double-pole Pomeron models at $Q^2 \sim 0$

Martynov et al., hep-ph/0112242



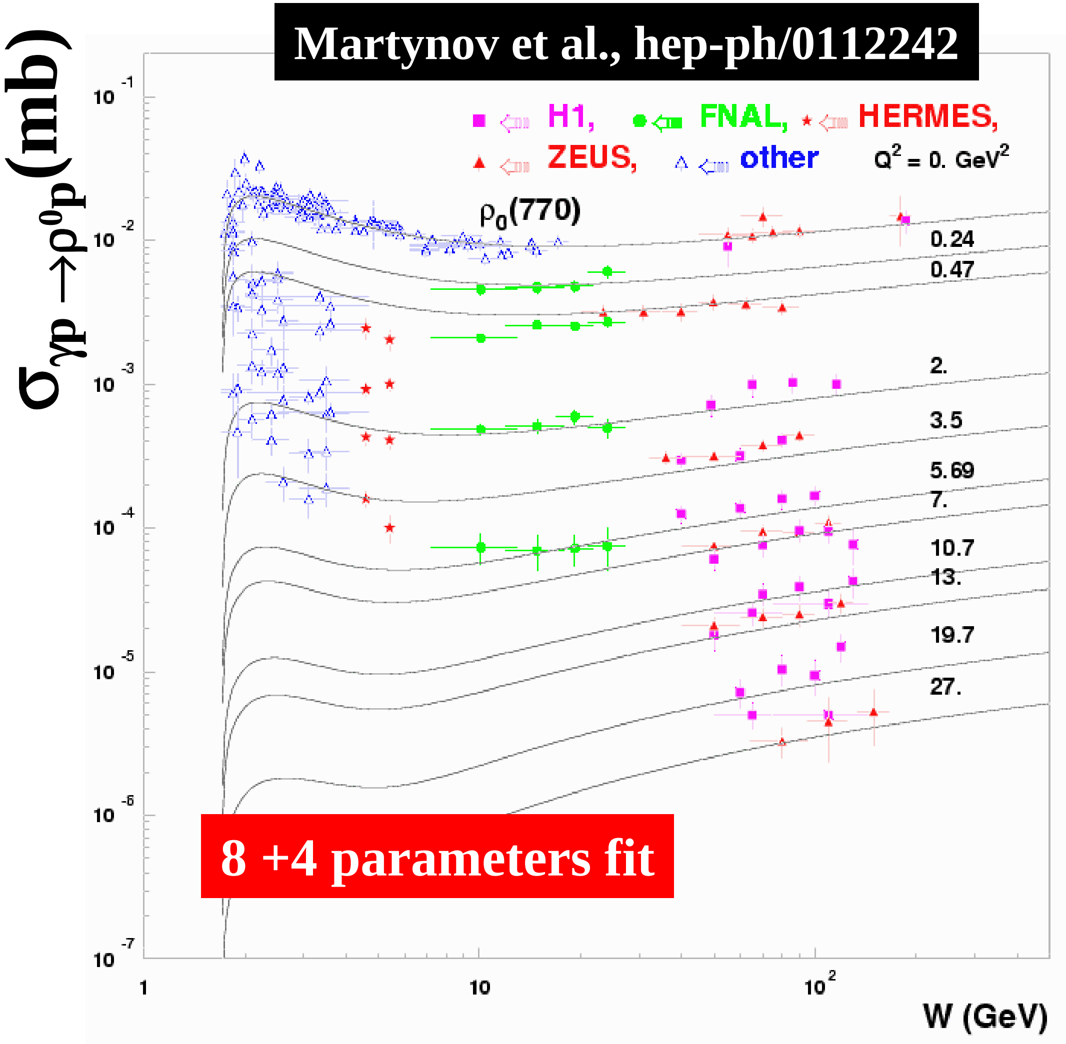
Fit ρ^0, ω, φ, J/ψ using 8 parameters

Elastic VM photoproduction ($Q^2 = 0$) can also be described by **double-pole Pomeron models** which use **a single P with intercept $\alpha_P(0) = 1$**

The rapid rise of the J/ψ is interpreted as: "a transition effect of the onset of the asymptotic behaviour"
⇒ still at threshold

The Upsilon curve is a prediction

Double-pole Pomeron models: VM in DIS

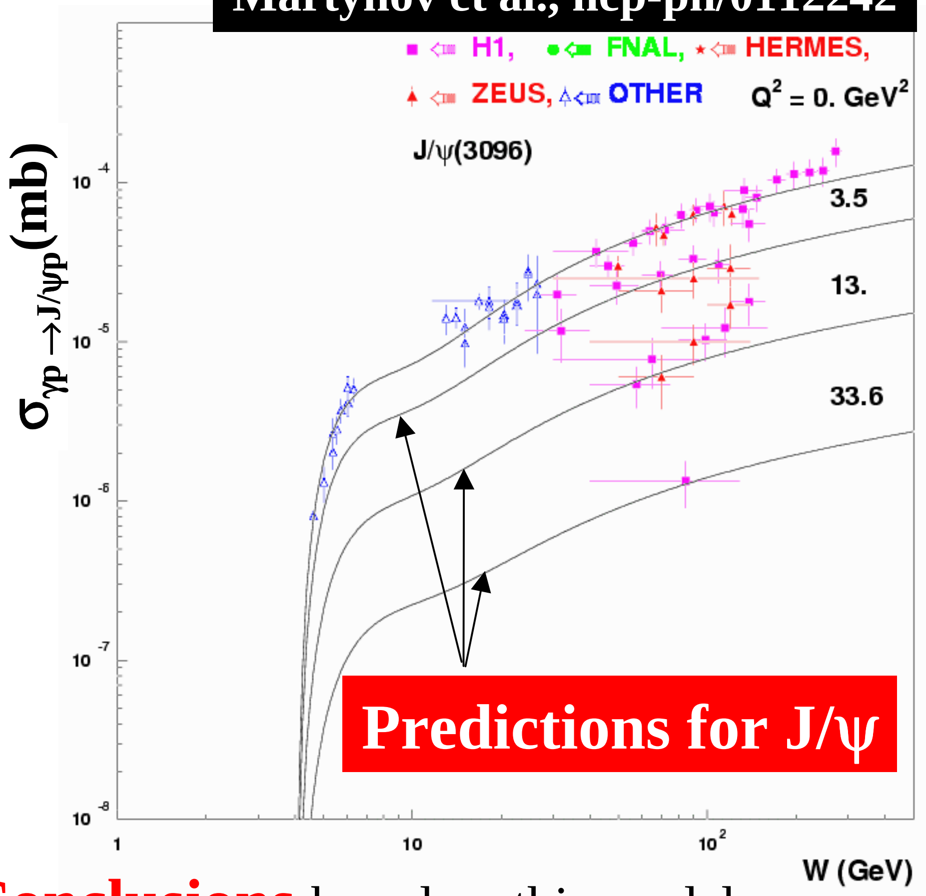


Assume R = σ_L/σ_T from pQCD (Brodsky et al.) and **fit ρ^0 cross sections** vs. W in Q^2 bins **using** the previous 8 + 4 extra = **12 parameters.**

Then **predict ω, ϕ and J/ψ cross sections.**

Double-pole Pomeron models: VM in DIS

Martynov et al., hep-ph/0112242



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Then **predict ω, φ and J/ψ cross sections.**

Conclusions based on this model**:**

VM production can be described for **1.7 < W < 250 GeV, 0 < Q^2 < 35 GeV^2.**

No hard-pomeron contribution (like for DL) necessary:

the VM mass is the only parameter which governs the transition!

Trajectories as tool to parameterise data

Language of Regge phenomenology still alive at HERA.

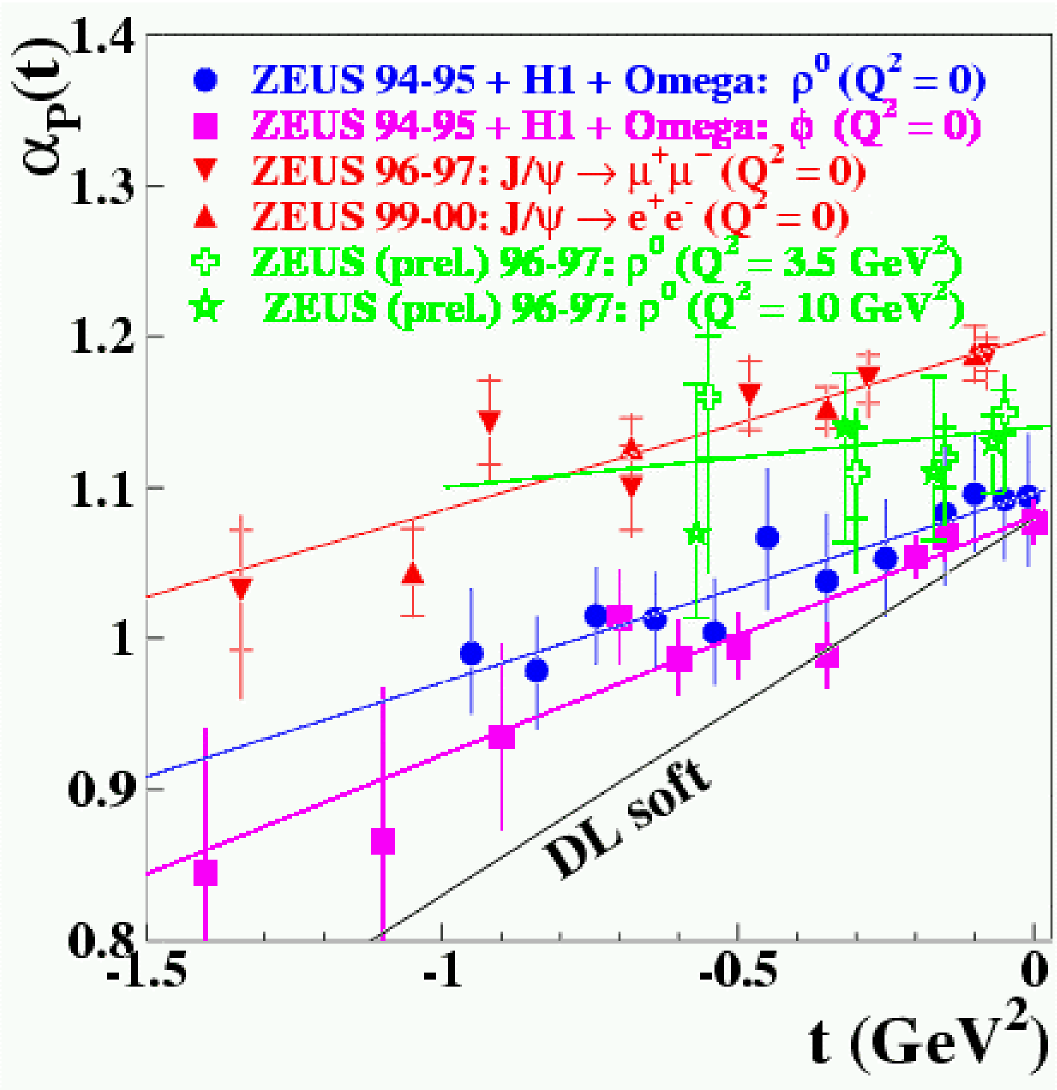
Indeed the **trajectories** (collective states exchanged in Regge theory) contain the relevant quantities to describe hadronic interactions at a macroscopic level: in the linear approximation, $\alpha_P(t) = \alpha_P(0) + \alpha'_P \cdot t$, they are a **convenient way to parameterise data**:

- **$\alpha_P(0)$ and α'_P : fundamental parameters** in hadronic interactions
- which govern the W dependence ($\alpha_P(0)$) and the t dependence (α'_P)
  $\Rightarrow$ the profile of the colour cloud responsible for strong interactions

Therefore, be able to compute the P trajectory from first principles (e.g. using QCD) $\Rightarrow$ fully understand hadronic interactions.

An **effective P trajectory** can be extracted from simultaneous study of the W and t dependences $\Rightarrow$ fit $d\sigma/dt \propto W^{4(\alpha_P(<t>)-1)}$ in each t bin $\longrightarrow$

Effective P-trajectories from elastic VM



J/ψ: $(1.198 \pm 0.012) + (0.114 \pm 0.025) \cdot t$

DIS ρ^0 prelim.:
$(1.14 \pm 0.03) + (0.04^{+0.15}_{-0.08}) \cdot t$

ρ^0: $(1.096 \pm 0.021) + (0.125 \pm 0.038) \cdot t$

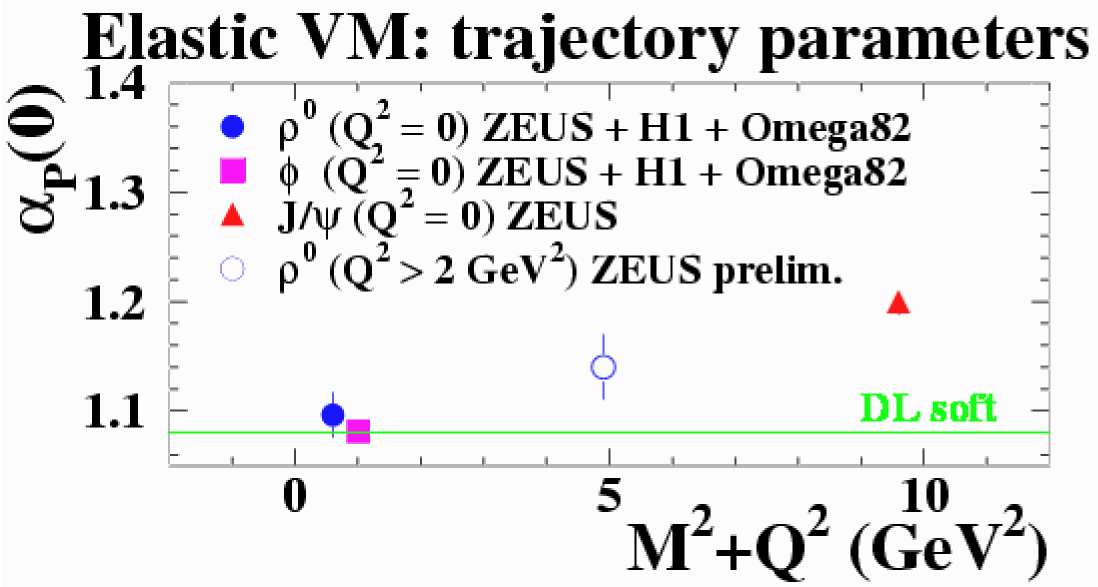
ϕ: $(1.081 \pm 0.010) + (0.158 \pm 0.028) \cdot t$

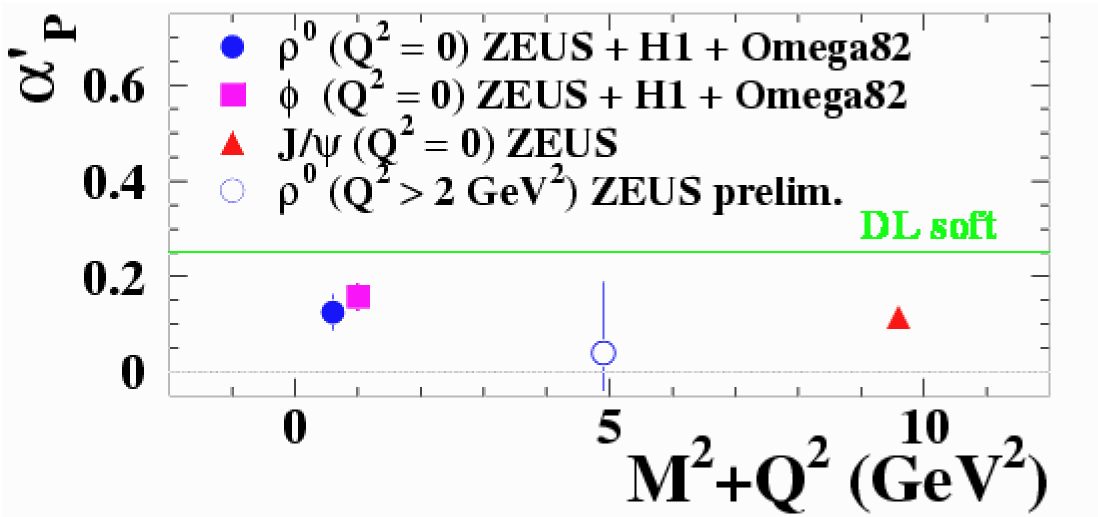
Precise HERA results (in photoproduction):

$\Downarrow$

different P trajectories from Donnachie-Landshoff soft:
$1.08 + 0.25 \cdot t$

Different behaviour of $\alpha_P(0)$ and α'_P





Clear increase of $\alpha_P(0)$:
interaction gets "harder"
- with increasing M^2_{VM}
- and (likely) with Q^2

$\alpha'_P \approx 0.1 \div 0.15$ GeV^{-2}
(smaller than DL soft)
for ρ^0, ϕ and J/ψ
in photoproduction (Q^2=0)
$\Rightarrow$ **no dependence on M_{VM}**

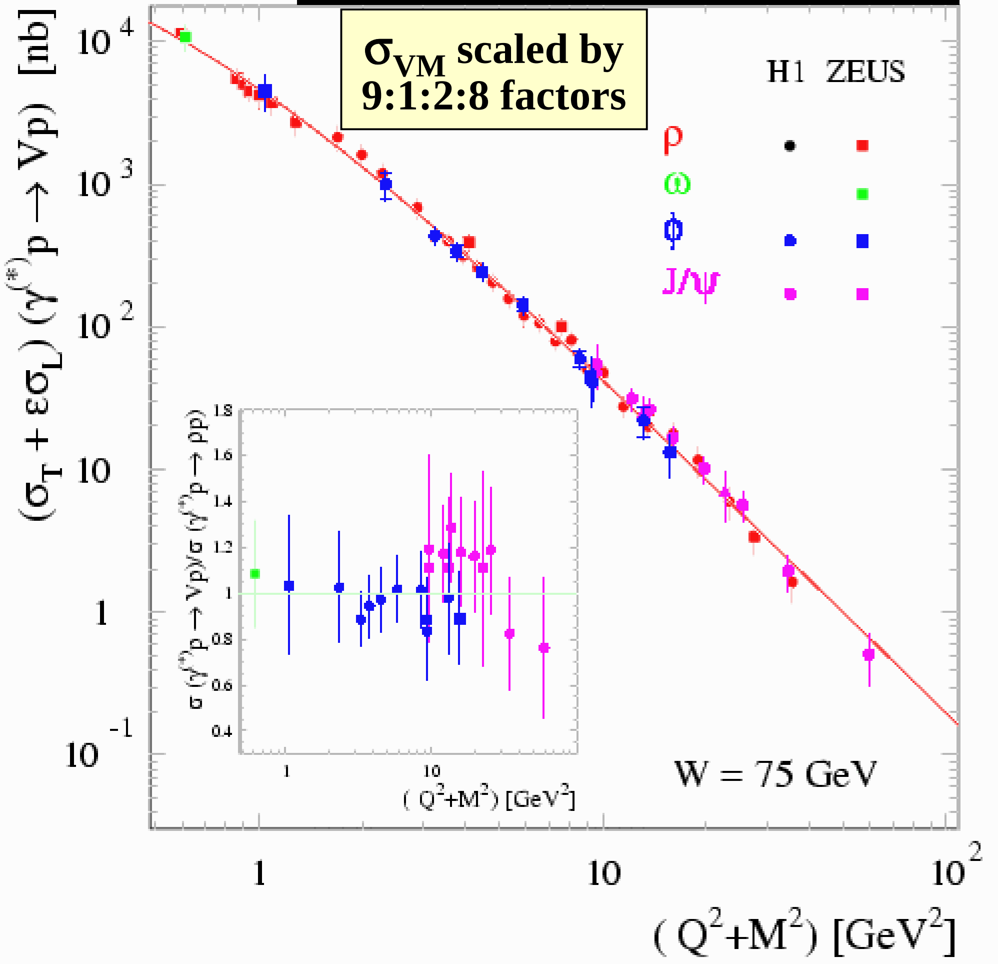
In DIS, need more data:
present data not conclusive

$Q^2 + M^2_{VM}$

as a "scale" for VM production

Elastic VM dependence on $Q^2 + M_{VM}^2$

H1, Phys. Lett. B483 (2000)



Universal behaviour of VM cross-sections scaled by the SU(4) factors:

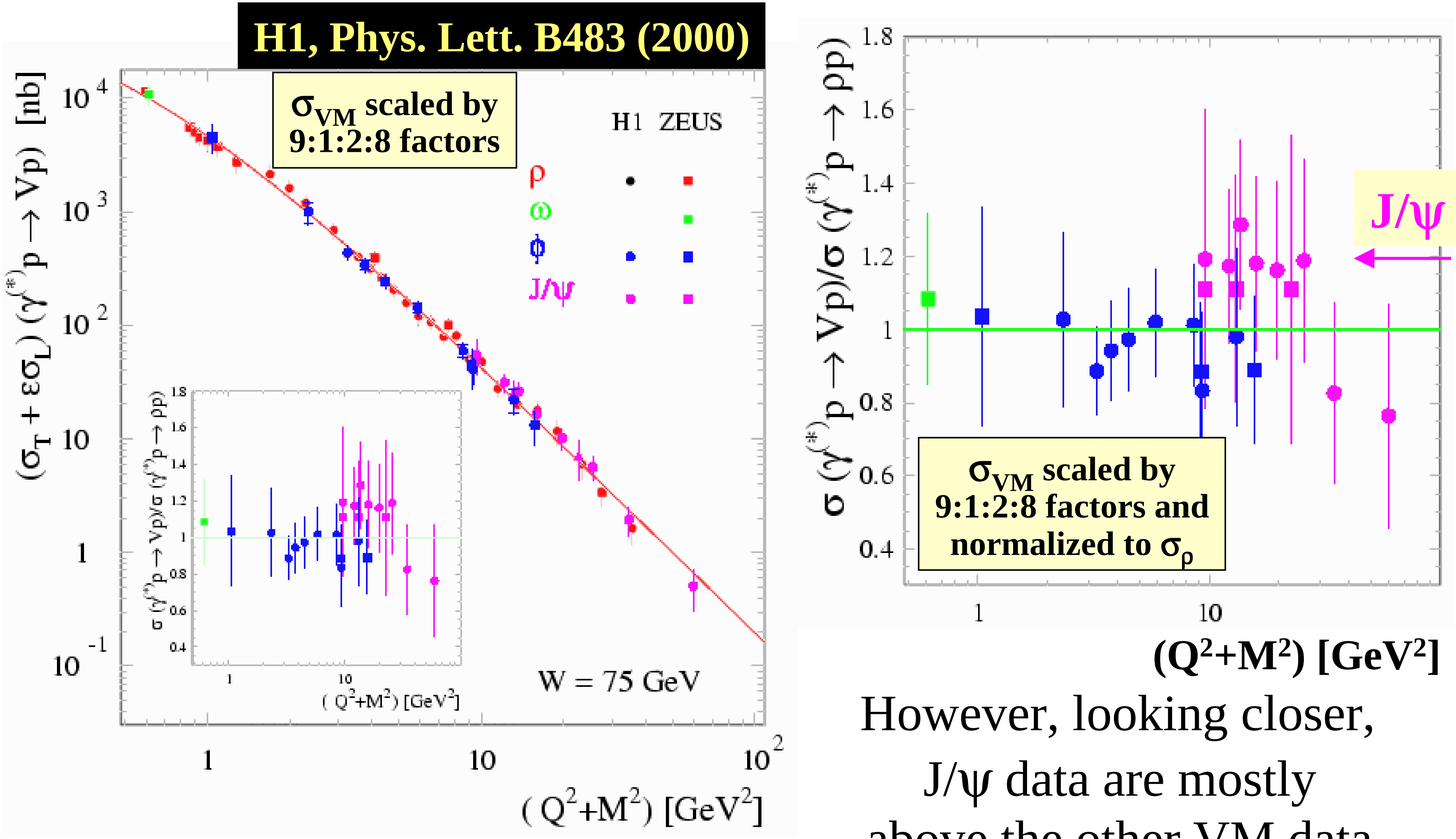
$\rho^0 : \omega : \phi : J/\psi \;=\; \mathbf{9 : 1 : 2 : 8}$

versus $\mathbf{Q^2 + M^2_{VM}}$

Good piece of work!

However, looking closer,

Elastic VM dependence on $Q^2 + M_{VM}^2$



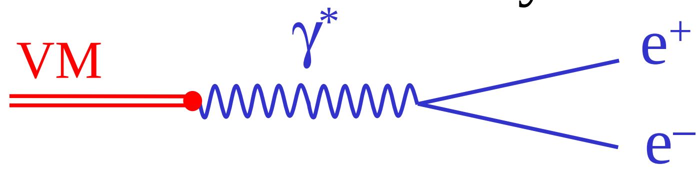
However, looking closer,
J/ψ data are mostly
above the other VM data

Indeed, pQCD does **not** expected the SU(4) relation to hold. ⟶

The SU(4) prediction $\rho:\omega:\phi:J/\psi = 9:1:2:8$

The factors 9:1:2:8 come from the leptonic widths of VM decays:

$$\Gamma_{VM\to e^+e^-} = 16\pi\alpha^2_{em}\,\frac{|\Psi_{VM}(0)|^2}{M^2_{VM}}\,|\Sigma a_i Q_i|^2$$



If: $\frac{|\Psi_{VM}(0)|^2}{M^2_{VM}}$ does not depend on the VM, then the ratio of widths will depend only on the charge assignments Q_i of the quarks:

VM	Q_i	$\lvert\Sigma a_i Q_i\rvert^2$	Factor	Measured
ρ^0	$^1/_{\sqrt{2}} \cdot (uu - dd)$	$(^1/_{\sqrt{2}})^2 \cdot [^2/_3 - (-\,^1/_3)]^2$	**9**	9
ω	$^1/_{\sqrt{2}} \cdot (uu + dd)$	$(^1/_{\sqrt{2}})^2 \cdot [^2/_3 + (-\,^1/_3)]^2$	**1**	0.8
ϕ	ss	$[-\,^1/_3]^2$	**2**	1.8
J/ψ	cc	$[^2/_3]^2$	**8**	7

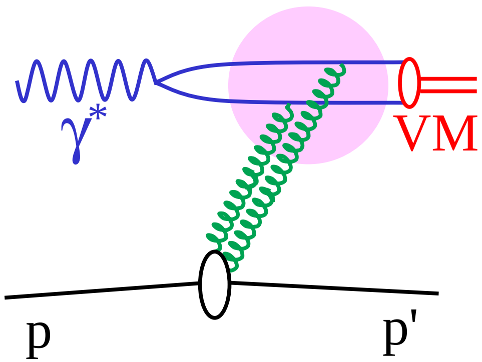
The question is: does the $\sigma_{ep\to eVp}$ depend on M_{VM} **only** through $\Gamma_{VM\to e^+e^-}$?

pQCD prediction for $\sigma^L_{\gamma^* p \to Vp}$ in DIS

For $Q^2 \gg M^2_{VM}$ expect **flavour independence:**
$\gamma^* \to q\bar{q}$ able to resolve gluons from the proton

$\Downarrow$

For longitudinal photons:



Brodsky et al.:

integrated wave function

pQCD part

$$\left.\frac{d\sigma^L_{\gamma^* p \to VMp}}{dt}\right|_{t=0} \approx \Gamma_{VM \to e^+e^-} \cdot M_{VM} \cdot \eta^2_{VM} \cdot \overbrace{\frac{\alpha_s^2(Q^2_{eff}) \cdot [xg(x, Q^2_{eff})]^2}{Q^6}}^{\text{pQCD part}}$$

At asymptotic Q^2, η^2_{VM} can be assumed universal, and:

$$\mathrm{Ratio}(VM_1, VM_2) \approx \frac{\Gamma_{VM1 \to e^+e^-} \cdot \mathbf{M_{VM1}}}{\Gamma_{VM2 \to e^+e^-} \cdot \mathbf{M_{VM2}}}$$

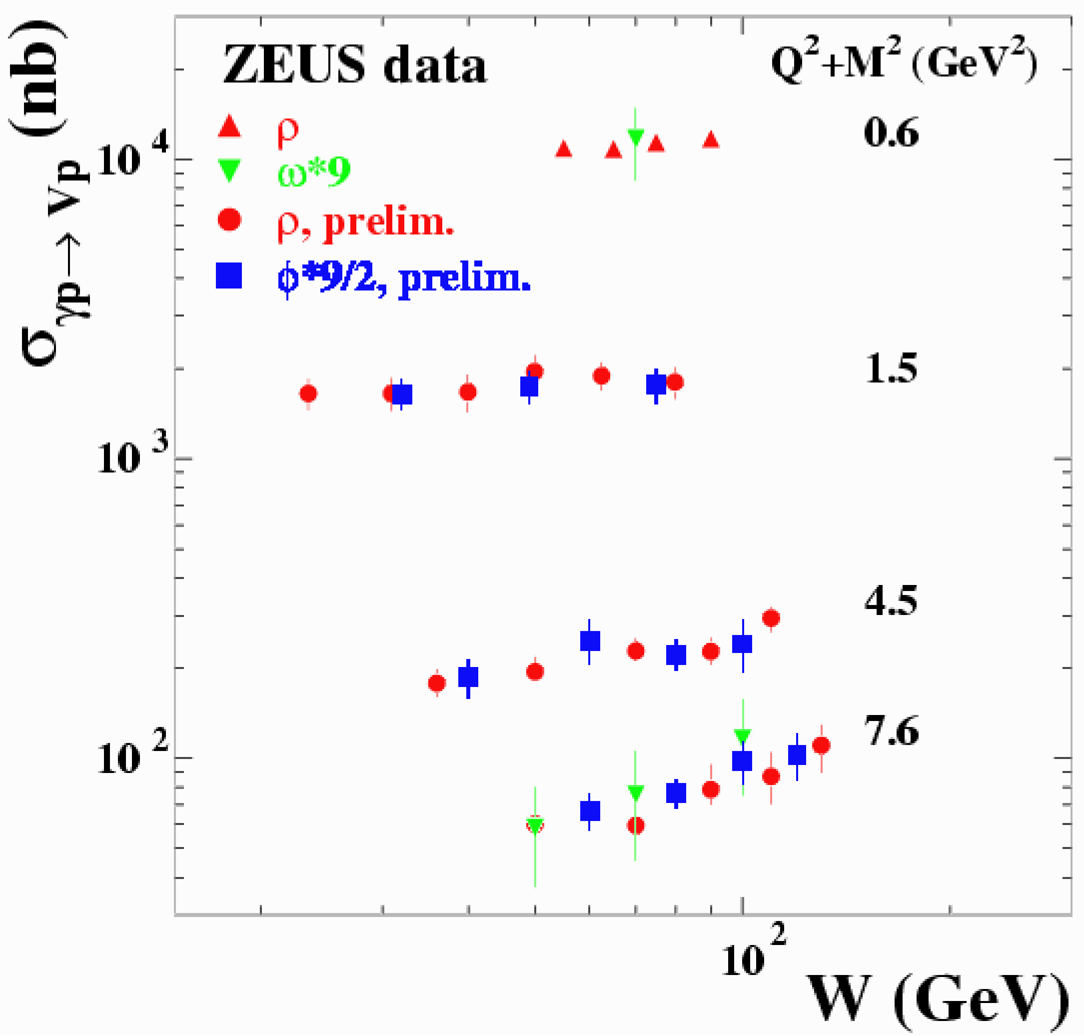
cannot neglect this!

$\Rightarrow$ $\rho : \omega : \phi : J/\psi =$ **9 : 1 ·0.8 : 2 ·1.2 : 8 ·3.5 = 9 : 0.8 : 2.4 : 28.1**

Therefore, the simple **SU(4) relation 9 : 1 : 2 : 8 should NOT hold**.

Elastic VM dependence on $Q^2 + M_{VM}^2$

New and more precise data:



σ_ω and σ_ϕ when scaled by SU(4) factors 1/9 and 2/9 lie on top of σ_ρ

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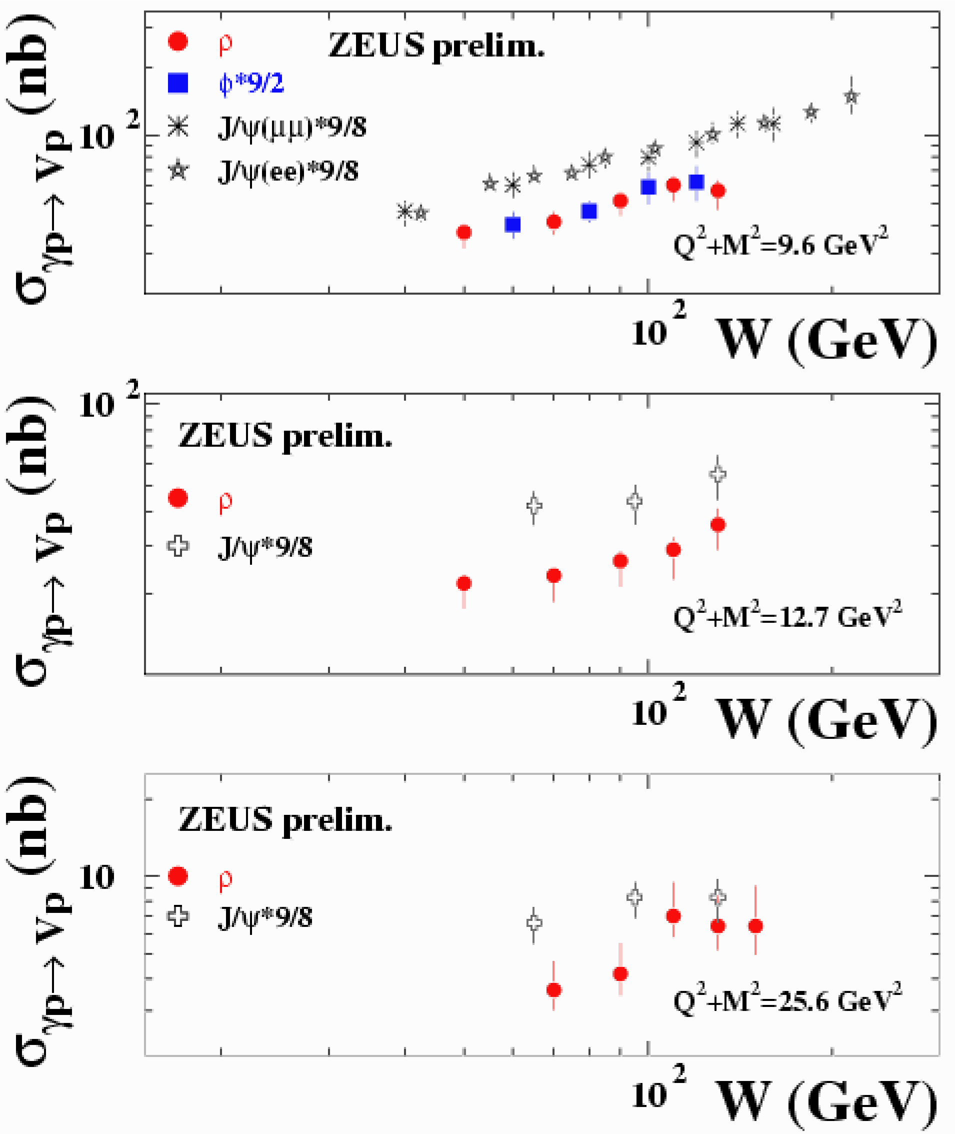


σ_ω and σ_ϕ when scaled by SU(4) factors 1/9 and 2/9 lie on top of σ_ρ

$\sigma_{J/\psi}$ scaled by the SU(4) factor 9/8 is **≈ 40% higher!**

⇒ the 9:1:2:8 factors do not work for the J/ψ

With future data, check if **W dependence** of VM's at fixed Q^2+M^2 is the same

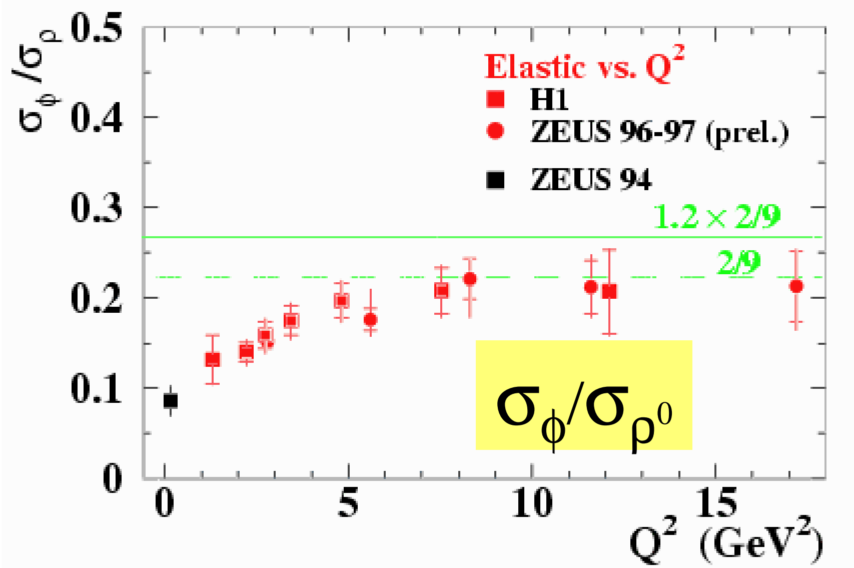
Ratios of Vector Mesons vs. Q^2

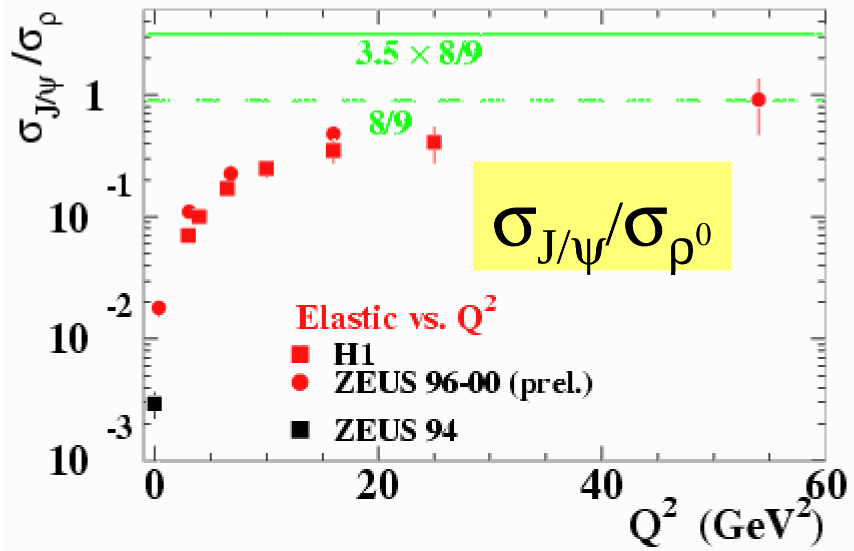
Another way to look at it:
now plotting ratio vs. Q^2 (not Q^2+M^2)

Three **pQCD "predictions"**:

- ❑ VM ratios increase with Q^2
- ❑ much faster rise for $\sigma_{J/\psi} / \sigma_{\rho^0}$ than for $\sigma_\phi / \sigma_{\rho^0}$
- ❑ reaching, **for $Q^2 \gg M_{VM}^2$** :

  $\rho : \omega : \phi : J/\psi = 9 : 1{\cdot}0.8 : 2{\cdot}1.2 : 8{\cdot}3.5$





The first two are confirmed by data.
No evidence yet for the last one:
need **more data and at larger Q^2**

However...

Simple VDM describes the rise of ratios

VDM form: $\sigma_{\gamma p \to Vp} \propto \dfrac{\Gamma_{V \to e^+e^-}}{(Q^2 + M_V^2)^2}$

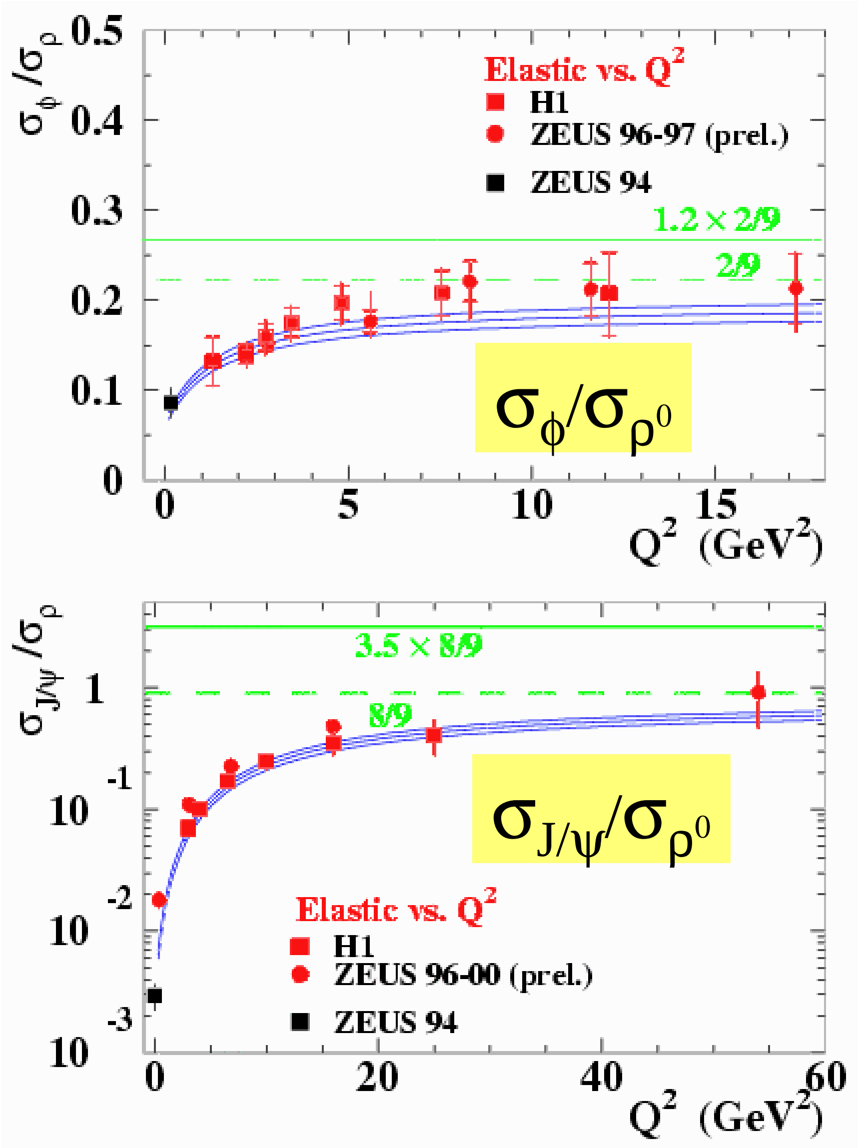
Plot the ratios:

$$\frac{\sigma_{\gamma p \to V_1 p}}{\sigma_{\gamma p \to V_2 p}} \propto \frac{\Gamma_{V_1 \to e^+e^-}}{\Gamma_{V_2 \to e^+e^-}} \cdot \frac{(Q^2 + M_{V_2}^2)^2}{(Q^2 + M_{V_1}^2)^2}$$

using the experimental measurements for the $\Gamma_{V \to e+e-}$

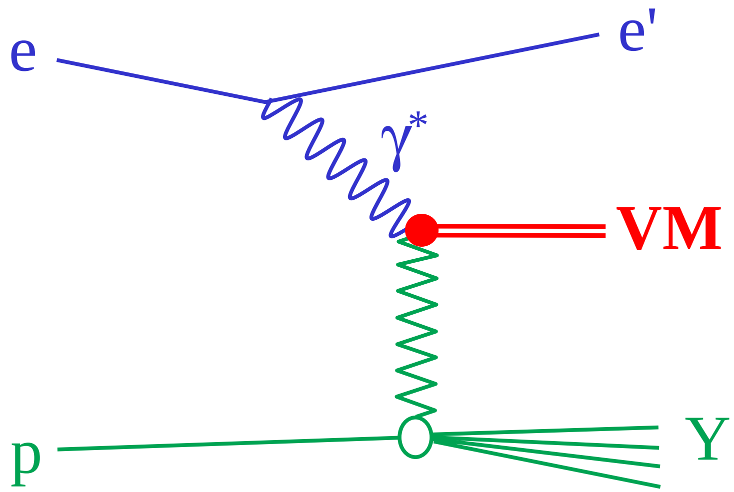
$\Downarrow$

The rise and the speed of the rise are well described by VDM (the bands show the errors on $\Gamma_{V \to e+e-}$): we **do not really need pQCD here!**



proton dissociative VM production

$$ep \to eVY$$



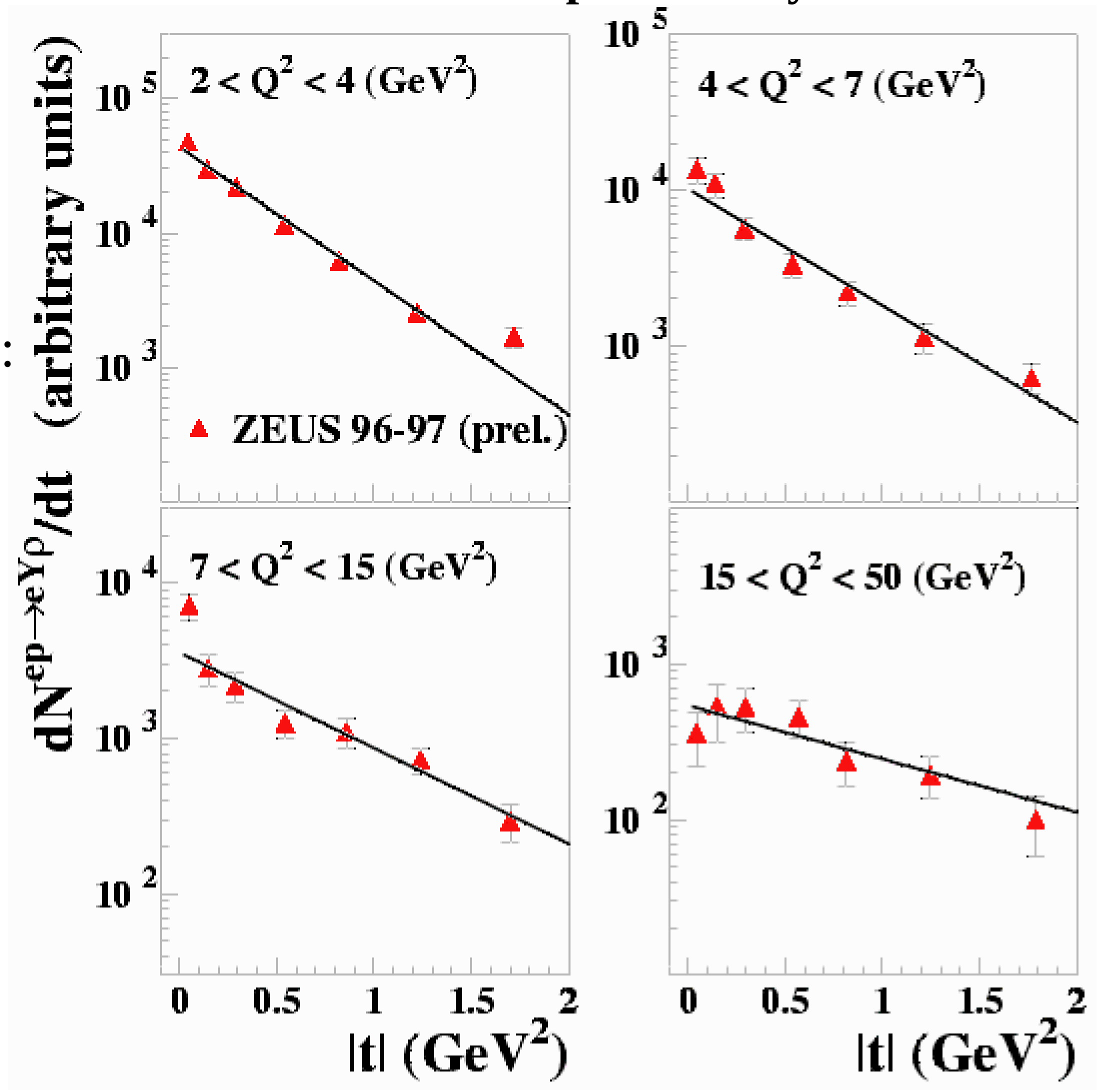
Proton-dissociative ρ^0 electroproduction

$d\sigma_{ep \to e\rho^0 Y}$ /d|t| in bins of Q^2

$2 < Q^2 < 50$ GeV^2
$|t| < 2$ GeV^2

Fit $d\sigma/d|t| \propto e^{-bt}$ and compare p-dissoc. b slopes to elastic ones:

ZEUS preliminary



Proton-dissociative ρ^0 electroproduction

$d\sigma_{ep \to e\rho^0 Y}$ /d|t| in bins of Q^2

$2 < Q^2 < 50$ GeV^2
|t| < 2 GeV^2

Fit $d\sigma/d|t| \propto e^{-bt}$ and compare p-dissoc. b slopes to elastic ones:

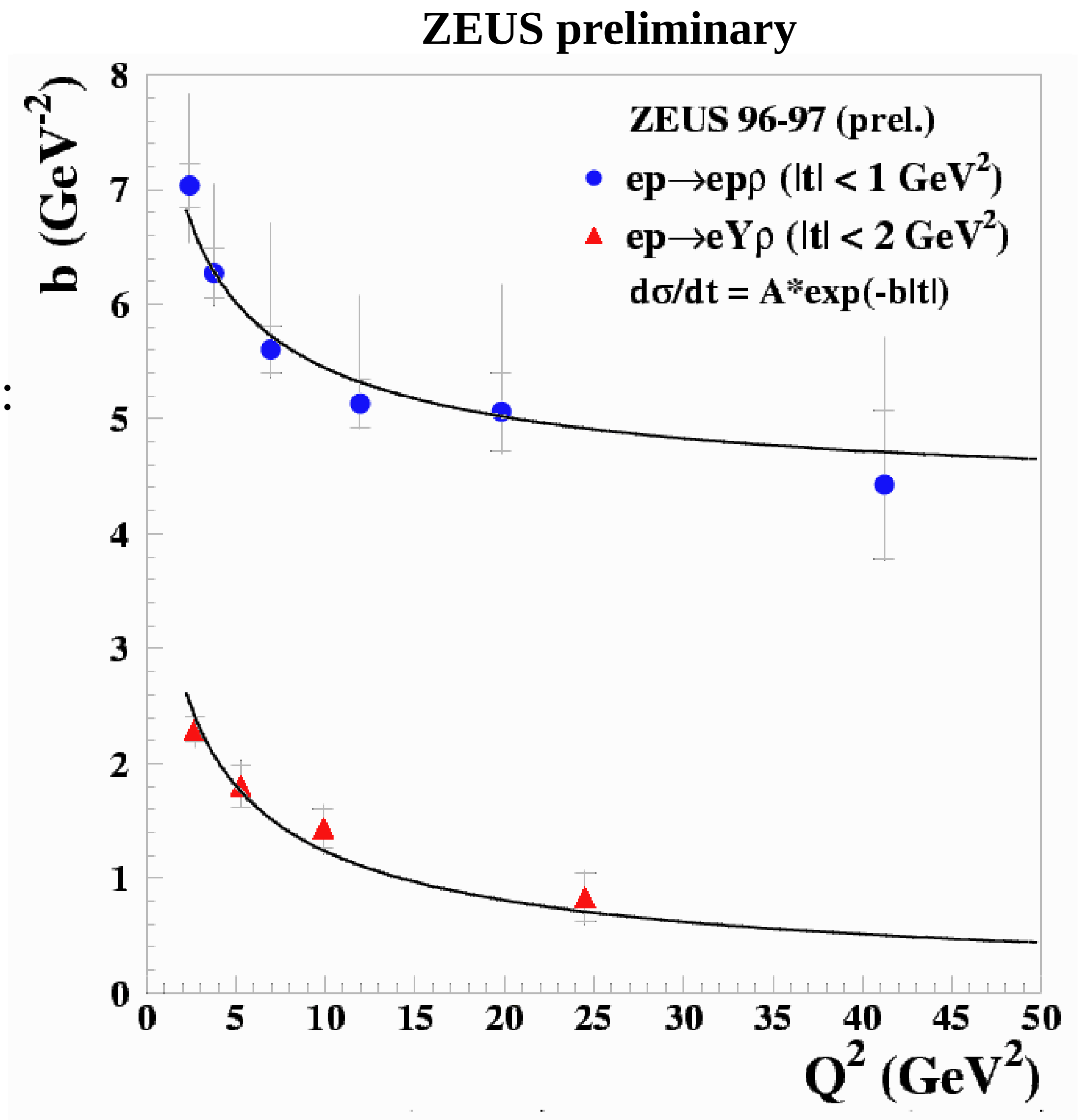
similar behaviour vs. Q^2

In a geometrical picture,
$b \propto (\text{interaction size})^2$

$\Downarrow$

$$b_{el} \propto R^2_{qq}(Q^2) \oplus R^2_{proton}$$
$$b_{pdiss} \propto R^2_{qq}(Q^2) \oplus R^2_{????}$$

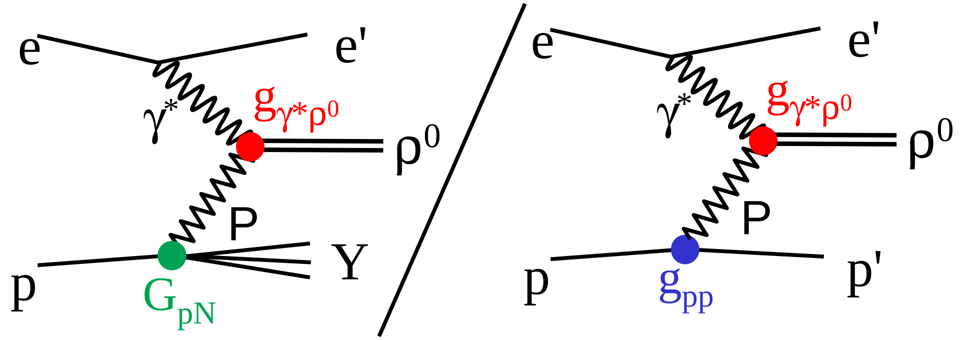
$\Downarrow$



Scattering off much smaller objects than the proton

Ratio of p-dissociation and exclusive ρ^0 electroproduction

Schematically, $ep \to e\rho^0 p$ / $ep \to e\rho^0 Y$:



Assuming vertex factorization:

$$\frac{\sigma_{\gamma p\to\rho Y}}{\sigma_{\gamma p\to\rho p}} \propto \left[\frac{g_{\gamma^*\rho^0}(t,Q^2,\lambda)\cdot G_{pN}(t,M_Y)}{g_{\gamma^*\rho^0}(t,Q^2,\lambda)\cdot g_{pp}(t)}\right]^2 \cdot \left[\frac{(W^2/M_Y^2)^{\alpha(t)-1}}{(W^2/W_0^2)^{\alpha(t)-1}}\right]^2 = f(t,M_Y)$$

$\Rightarrow$ the ratio should not depend on Q^2

Ratio $(d\sigma^{ep\rightarrow eY\rho^0}/dt) / (d\sigma^{ep\rightarrow ep\rho^0}/dt)$ vs. Q^2

Ratio: $\frac{\text{p-dissociative}}{\text{elastic}}$

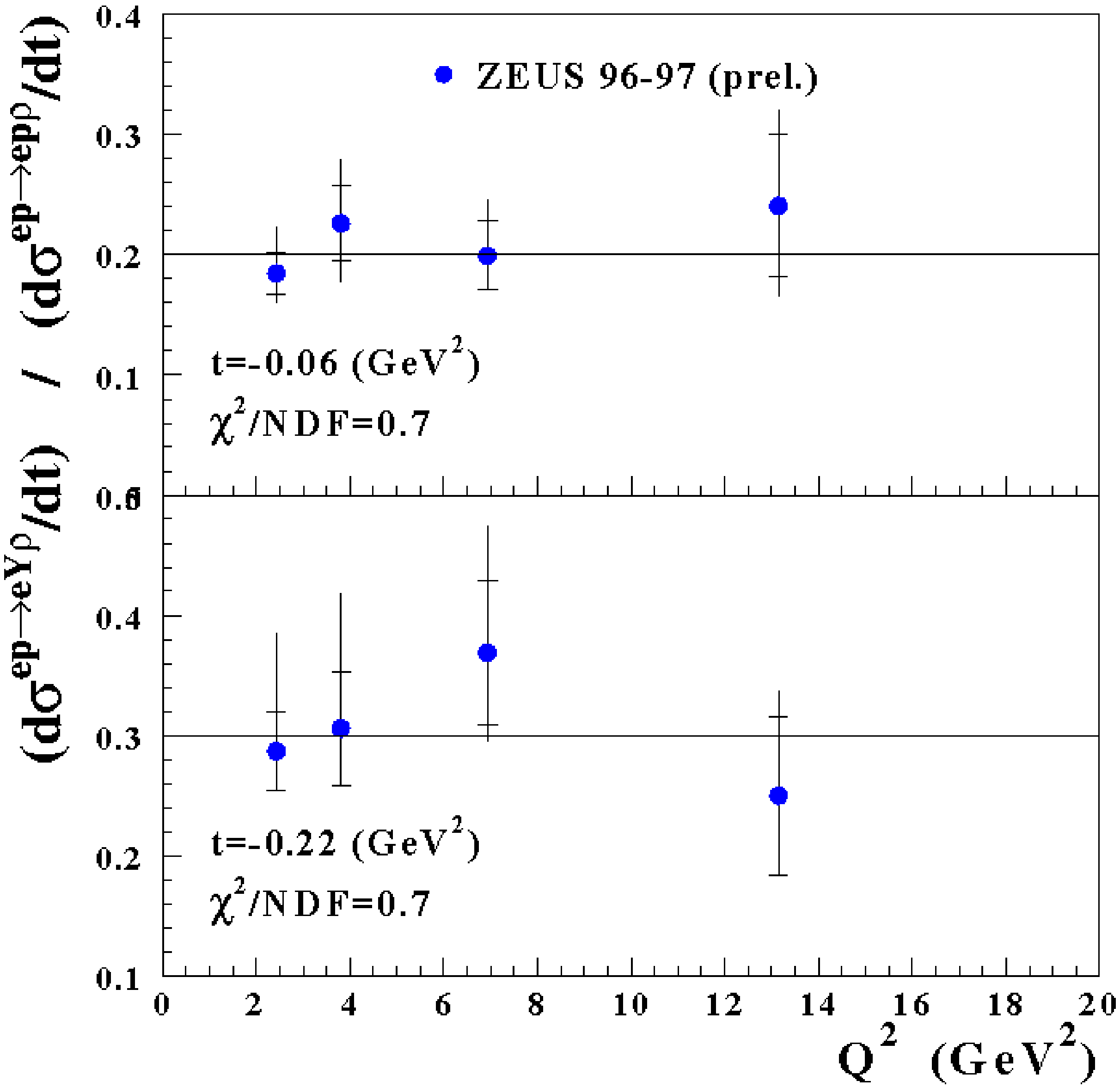
in two bins of t:

independent of Q^2

$\Downarrow$

within experimental uncertainties

vertex factorization holds



VM production at high |t|:

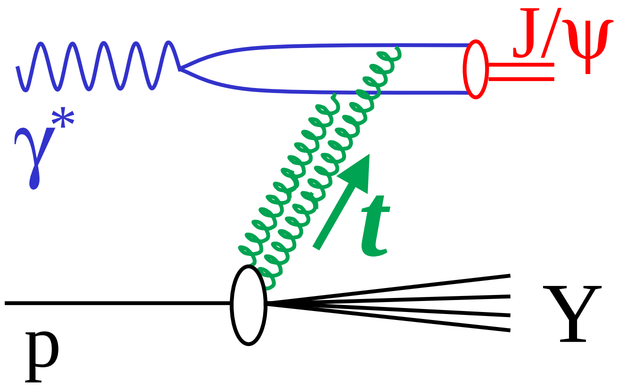
are |t| and Q^2 equivalent scales?

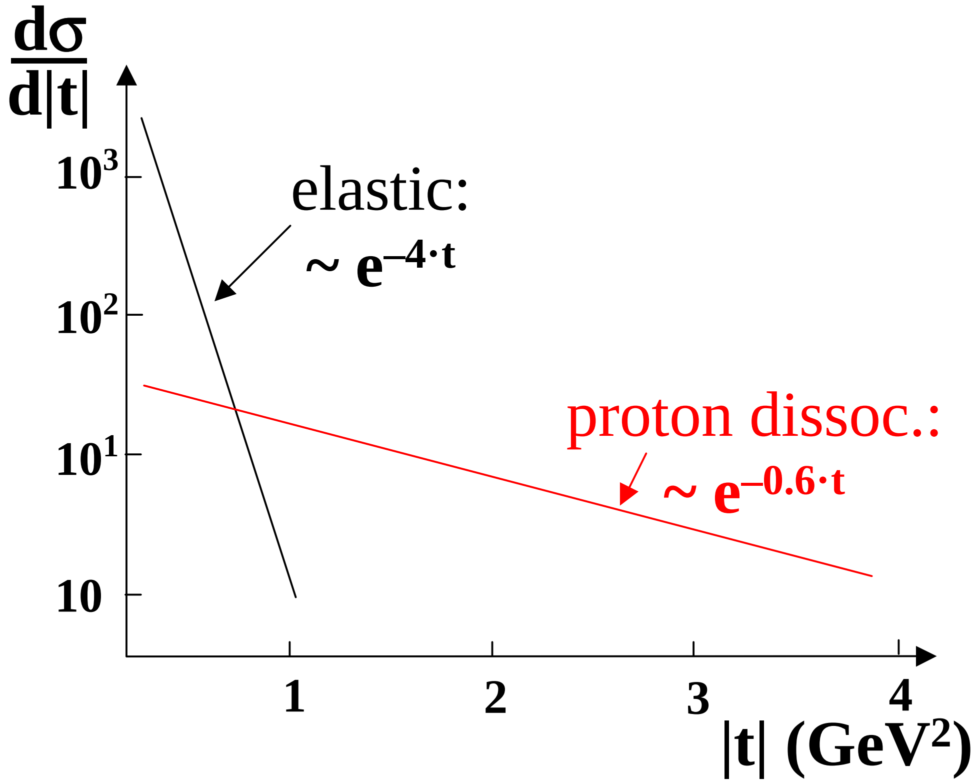
Photoprod. of proton-dissoc. VM at high |t|

High-|t| domain: little explored so far.

At high-|t|, proton dissociative production dominates. Example:

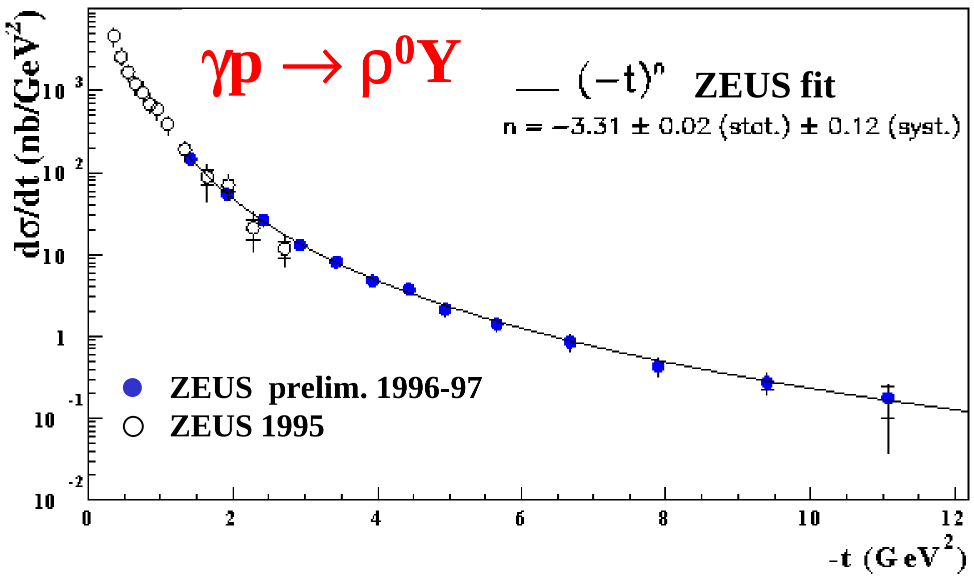
$\gamma^* p \to J/\psi Y$ at $Q^2 \sim 0$

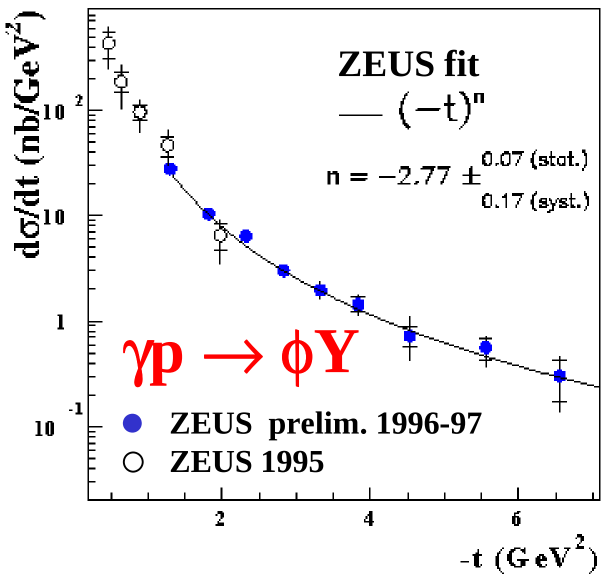


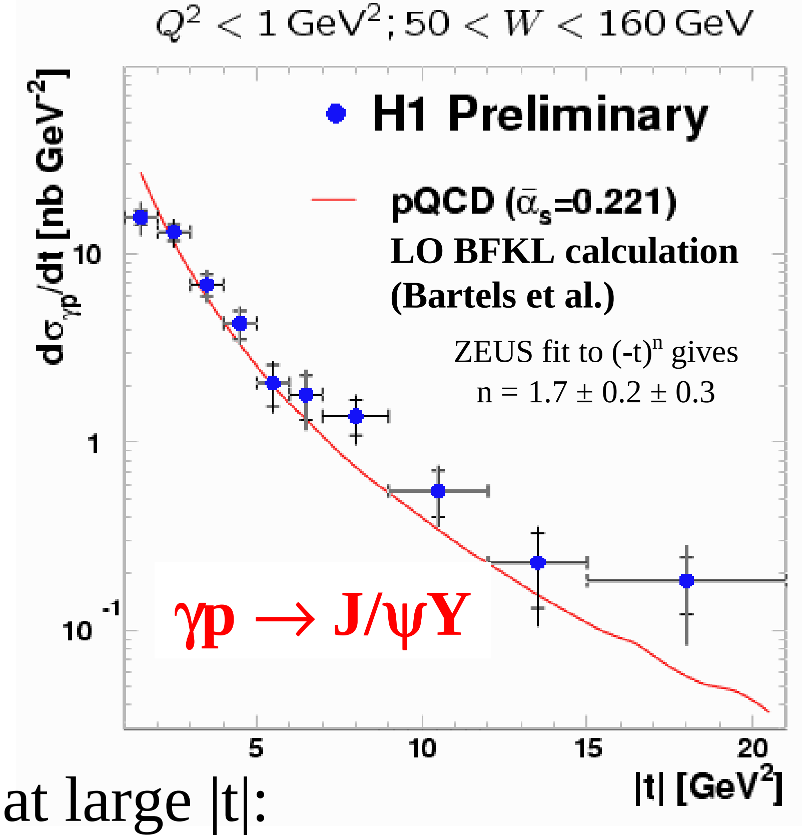


⇒ study proton dissociation to investigate high-|t| dynamics

Photoprod. of proton-dissoc. VM at high |t|







Dependence at large |t|:

- ❑ **$d\sigma_{\gamma p \to VY}$ /d|t| ∝ |t|$^{-n}$** (<u>not</u> exponential)
- ❑ described by LO BFKL-models (large uncert. on magnitude)

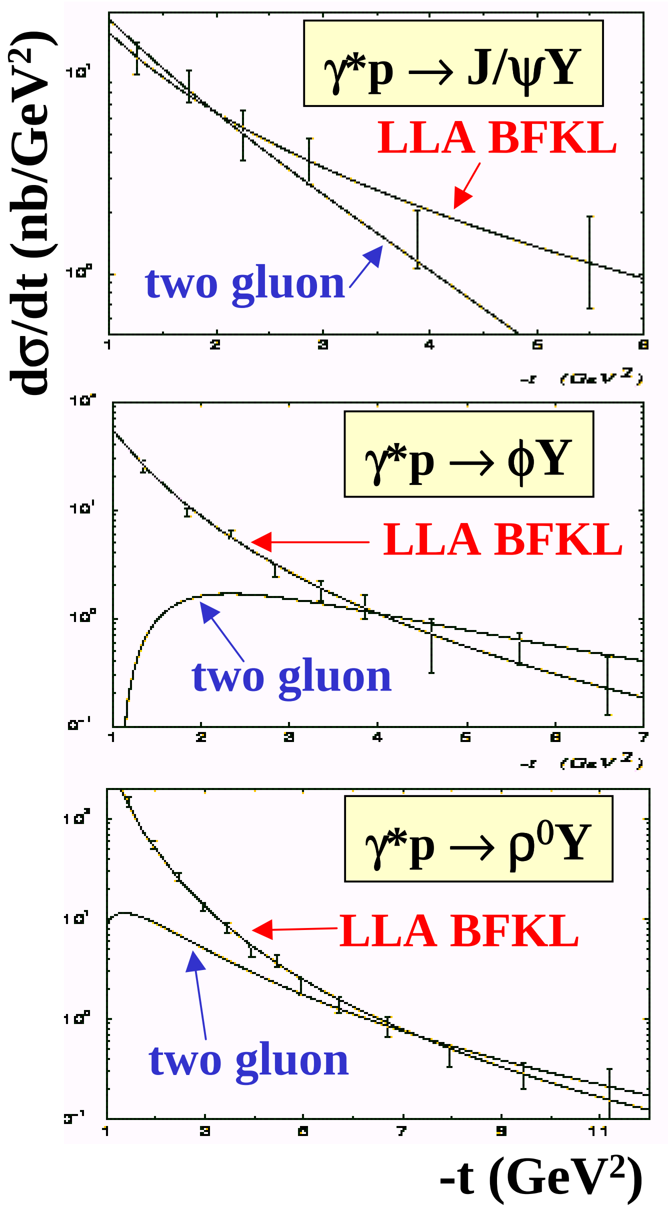
⇒ indication that **large |t| may provide a hard scale to apply perturbative QCD**

Photoprod. of proton-dissoc. VM at high |t|

Recently, Forshaw and Poludniowski fitted ZEUS preliminary data for p-dissociative photoproduction of ρ^0, ϕ and J/ψ mesons:

- BFKL LLA approach: consistent with data
- two-gluon-exchange approach at LO: inadequate

“Smoking gun for BFKL?”



Extraction of α'_P from high |t| VM

Tagged photoproduction,
$80 < W < 120$ GeV, with
large correlated uncertainties
in e-tagging efficiency
as a function of W

$\Downarrow$

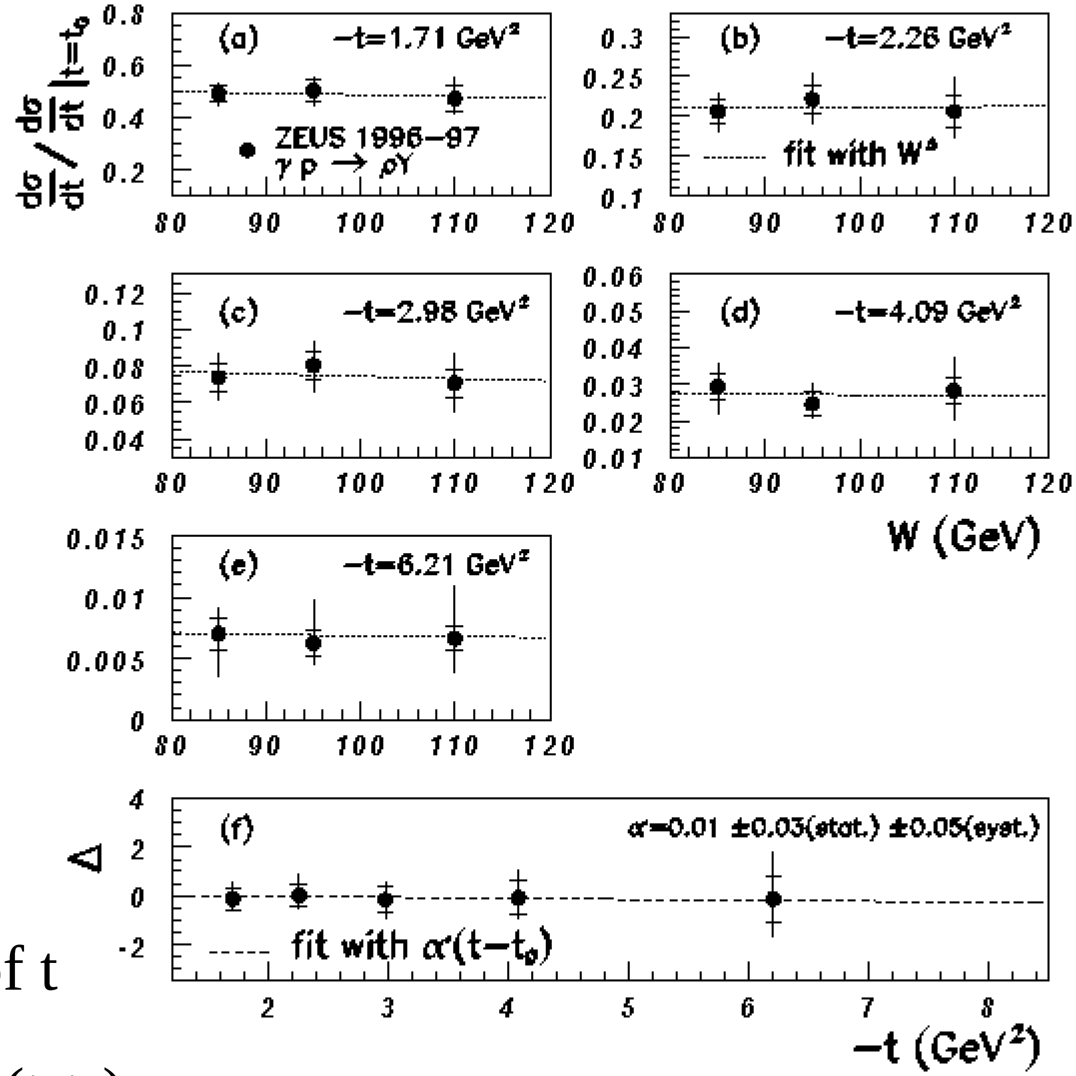
Normalise $d\sigma/dt$
to first bin in t

$\Downarrow$

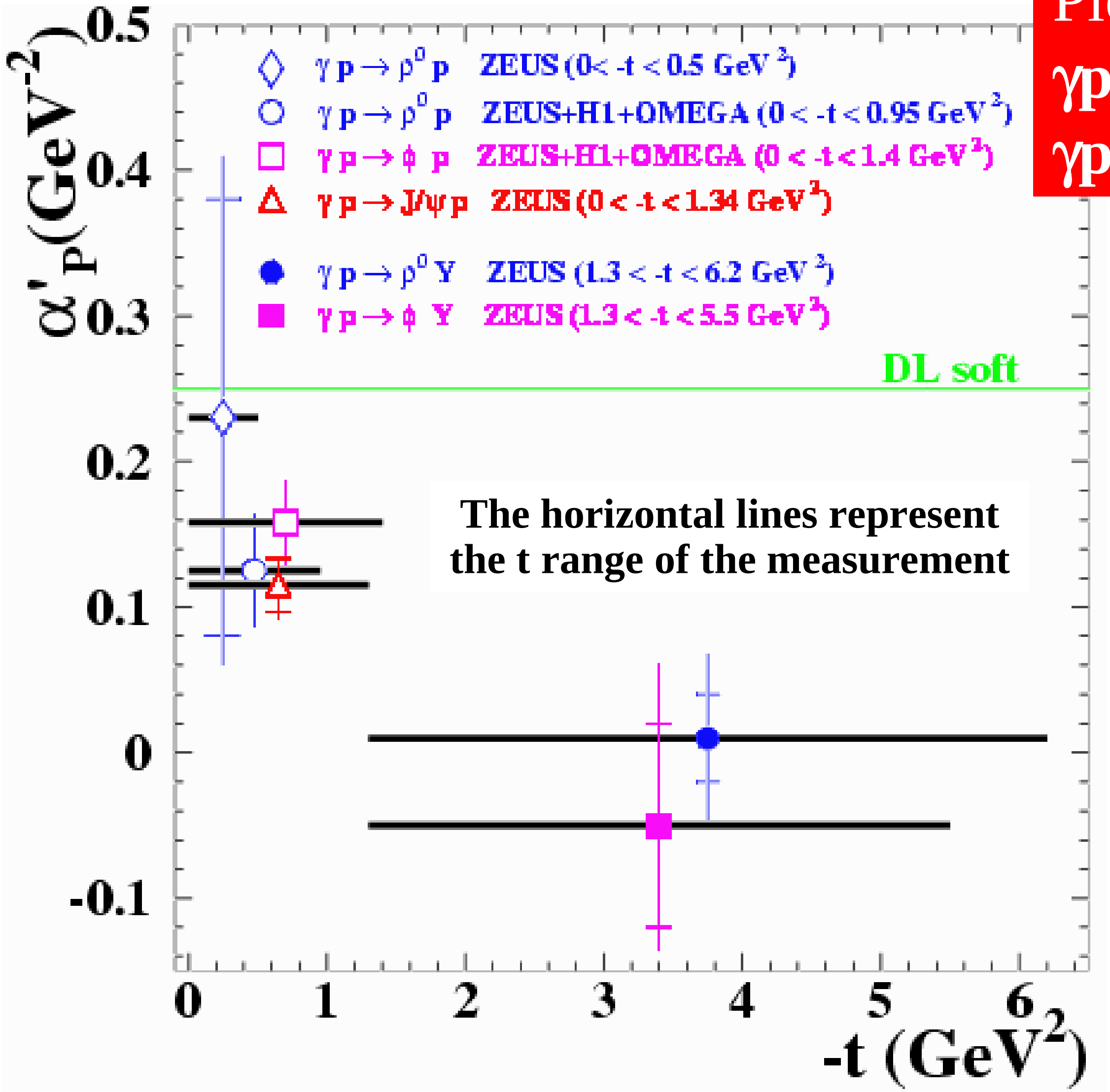
ratios avoid large systematic
uncertainties which would
affect $\alpha_P(0)$ but not α'_P

Fit $\dfrac{d\sigma/dt}{d\sigma/dt|_{t=t_0}}$ to W^Δ in bins of t

$\Delta = 4\,\alpha'_P\,(t-t_0)$



α'_P depends on the t-range measured



Plotting together:

$\gamma p \to V\ p$ (dominates at small |t|)

$\gamma p \to V\ Y$ (dominates at large |t|)

For $|t| > 1.3$ GeV^2 :

α'_P = "small"

as expected by pQCD

Need more precise data.

Similar to what was found for inclusive diffraction in hadronic interactions →

$\mathbb{P}$ trajectory: comparison between *ep* and *pp*

UA8 single diffraction data:
$p\bar{p} \to pX$ or $\bar{p}X$, with scattered p or $\bar{p}$ detected with $x_F > 0.9$

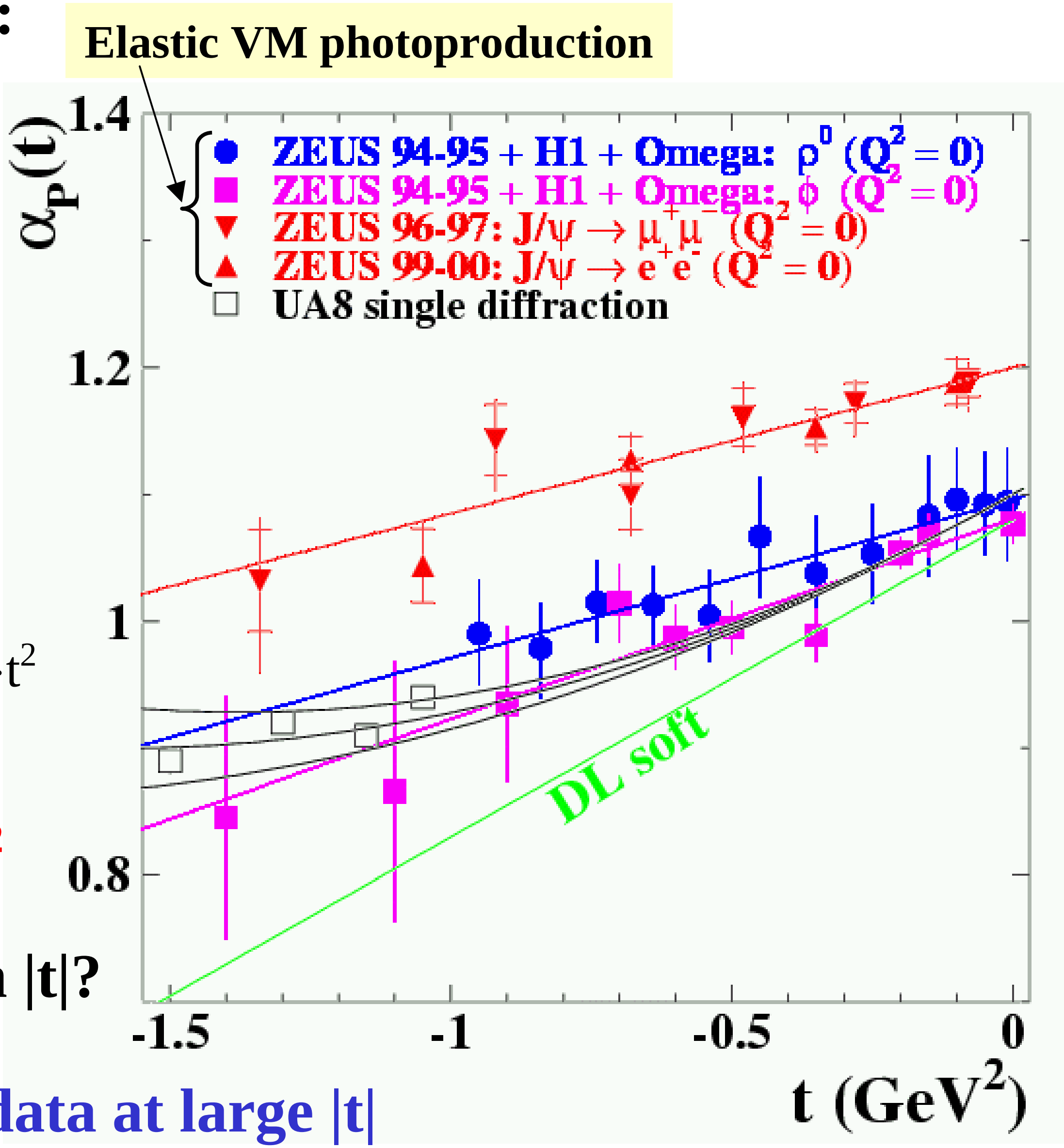
Good agreement at low |t|.

Flattening of P trajectory observed at large |t|
fitted using:

$$\alpha_P(t) = \alpha_P(0) + \alpha'_P \cdot t + \alpha''_P \cdot t^2$$
$$= \mathbf{1.10} + \mathbf{0.25} \cdot t + \mathbf{(0.078 \pm 0.013)} \cdot t^2$$

similar to HERA $\gamma p \to V Y$ (ρ^0, ϕ) data at |t| > 1.3 GeV^2

Same P traject. also at high |t|?



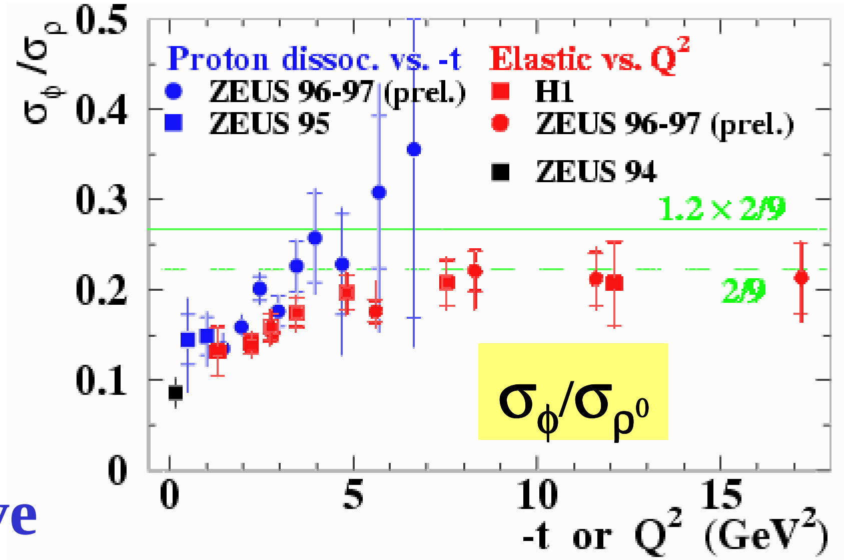
Need more precise HERA data at large |t|

Ratios of Vector Mesons

We have discussed VM ratios in DIS exclusive production, ep $\rightarrow$ eVp vs. Q^2:

- ❑ VM ratios increase with Q^2
- ❑ faster rise for $\sigma_{J/\psi} / \sigma_{\rho^0}$ than $\sigma_{\phi} / \sigma_{\rho^0}$
- ❑ asymptotically should reach:

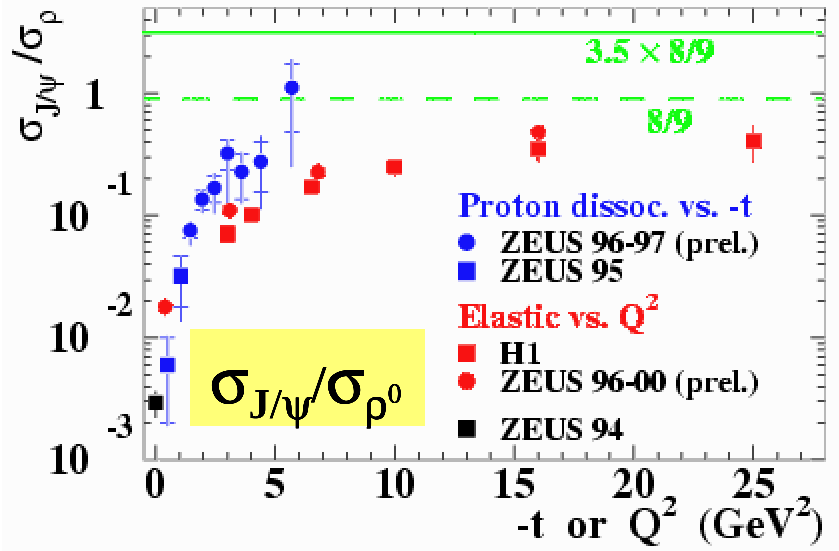
$\rho : \omega : \phi : J/\psi = 9 : 1 \cdot 0.8 : 2 \cdot 1.2 : 8 \cdot 3.5$



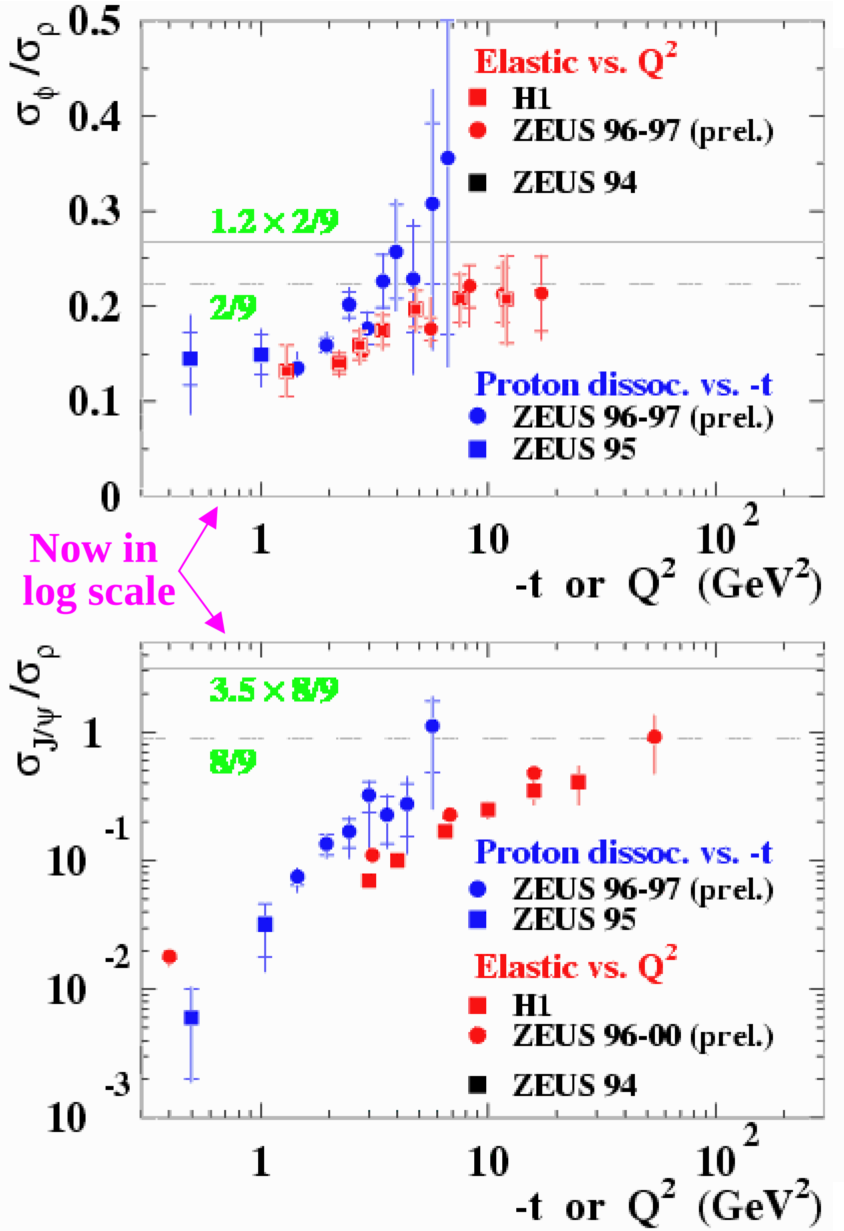
What happens in proton-dissociative photoproduction $\gamma^* p \rightarrow VY$ vs. |t| ?

ZEUS Preliminary measurement:

- ❑ ratios rising with increasing |t|
  $\Rightarrow$ indication QCD is taking over
- ❑ **rise in |t| faster than in Q^2**:
  how should we interpret this?



Ratios of Vector Mesons: Q^2 vs. |t|



Why ratios of **proton dissoc. vs. |t|** are rising faster than **elastic vs. Q^2** ?

Difference generated by the fact that:

1. We mix **Elastic** and **p-dissociative**?
   No: naïvely, vertices should factorise.

2. are Q^2 and |t| <u>not</u> equivalent scales?
   Possible: if the true scale is
   $Q^2_{eff} = \alpha \cdot Q^2 + \beta \cdot |t| + \gamma \cdot M^2_V$
   not necessarily $\alpha \equiv \beta \equiv \gamma$.

3. Different cross section dependence?
   Possible, in view of what
   pQCD expects ⟶

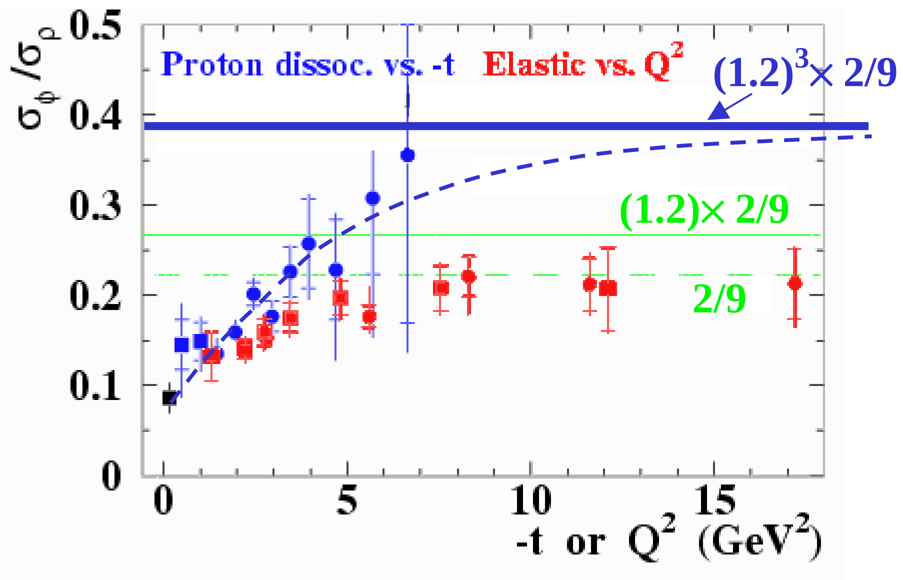
Ratios of Vector Mesons: Q^2 vs. $|t|$

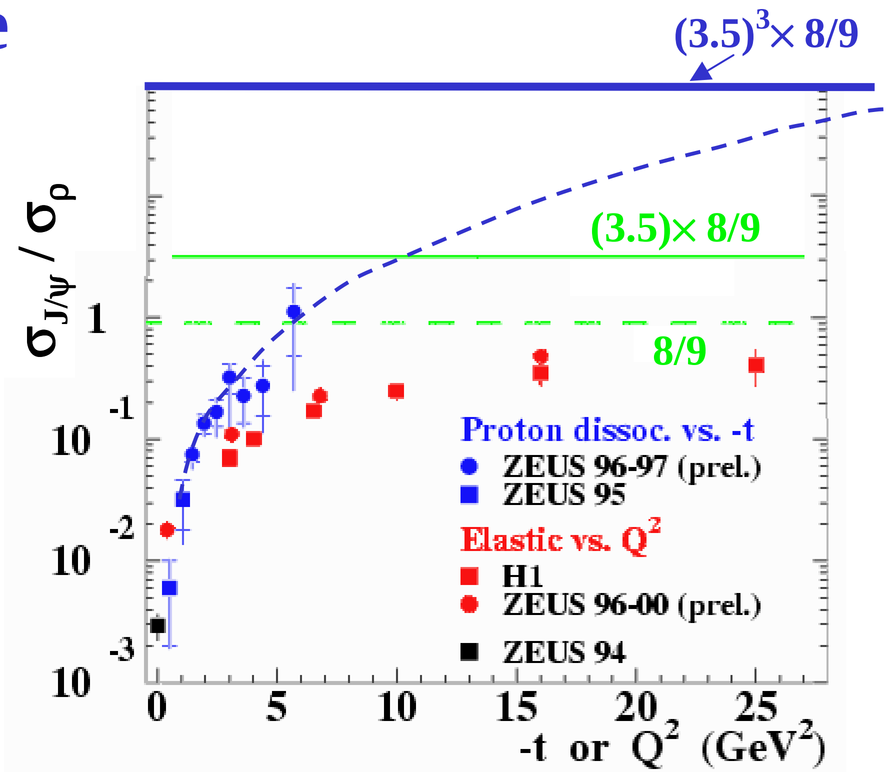
pQCD expectations **depend on the photon helicity**. <u>Asymptotically:</u>

$$\sigma^{\mathbf{L}}_{\gamma^* p\to Vp} \propto \Gamma_{VM\to e^+e^-}\cdot M_V \otimes \text{pQCD} \Rightarrow \frac{\gamma_L^* p \to V_1 p}{\gamma_L^* p \to V_2 p} \propto \frac{M_{V_1}}{M_{V_2}}$$ (Brodsky et al.)

$$\sigma^{\mathbf{T}}_{\gamma p\to VY} \propto \Gamma_{VM\to e^+e^-}\cdot M_V^{\mathbf{3}} \otimes \text{pQCD} \Rightarrow \frac{\gamma_T p \to V_1 Y}{\gamma_T p \to V_2 Y} \propto \left[\frac{M_{V_1}}{M_{V_2}}\right]^{\mathbf{3}}$$ (Forshaw et al., Ivanov)

Is this different dependence what we are observing?





Future prospects: 99-00 data & HERA II

Data discussed today: mostly up to 1997 data (~ 40 pb^{-1}).

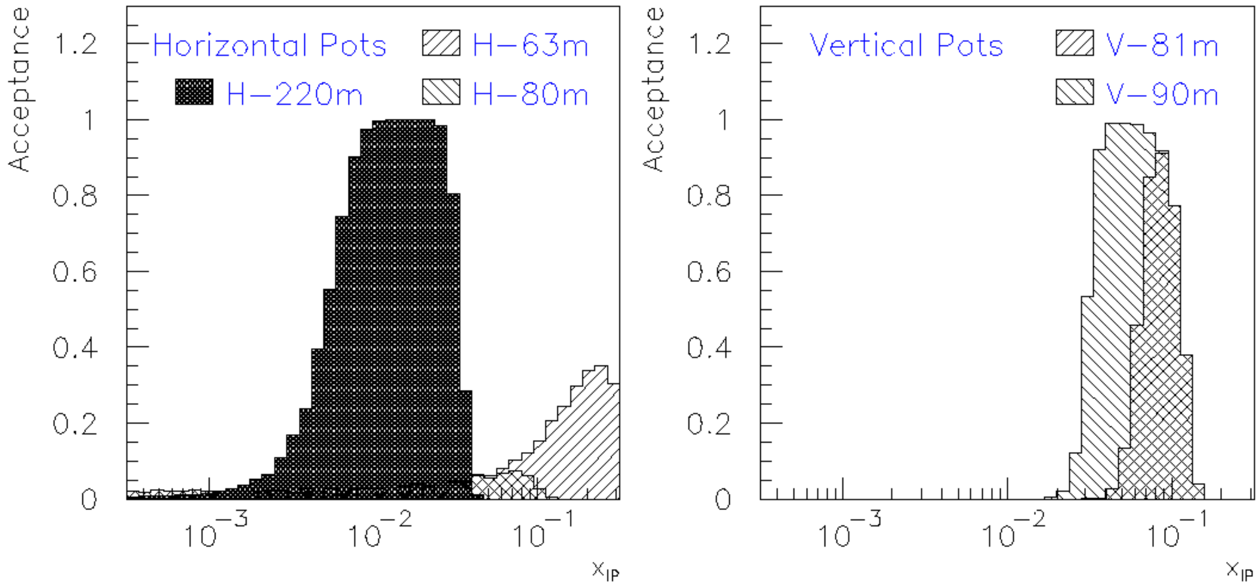
Still ~ 80 pb^{-1} on tape to analyse +

expect $\gtrsim$ 5 times larger luminosity from HERA II

Increase in luminosity: overall factor $\gtrsim$ 10

$\Rightarrow$ better precision and extension of Q^2, $|t|$ and M_{VM} ranges

H1: future installation of **Very Forward Proton Spectrometer** with increased acceptance for x_L ~ 1:



Conclusions

1. **pQCD can describe VM data for large Q^2, $|t|$ or M^2_{VM}** . However,

2. **Regge theory still alive**: two pomerons? two-pole structure?
   Remember: both pQCD and Regge are fundamental tests for future theories which aim to describe the dynamics of large color systems.

3. **P trajectory:**
   $\alpha'_P \sim 0.1$ **GeV^{-2}** for ρ^0, ϕ **and J/ψ** at $|t| < 1.3$ GeV^2
   $\alpha'_P \sim 0$ **GeV^{-2}** for ρ^0, ϕ at $|t| > 1.3$ GeV^2;
   the **flattening measured at large |t|** is similar to pp single diffr.
   $\Rightarrow$ **P trajectory universality also at large |t| ?**

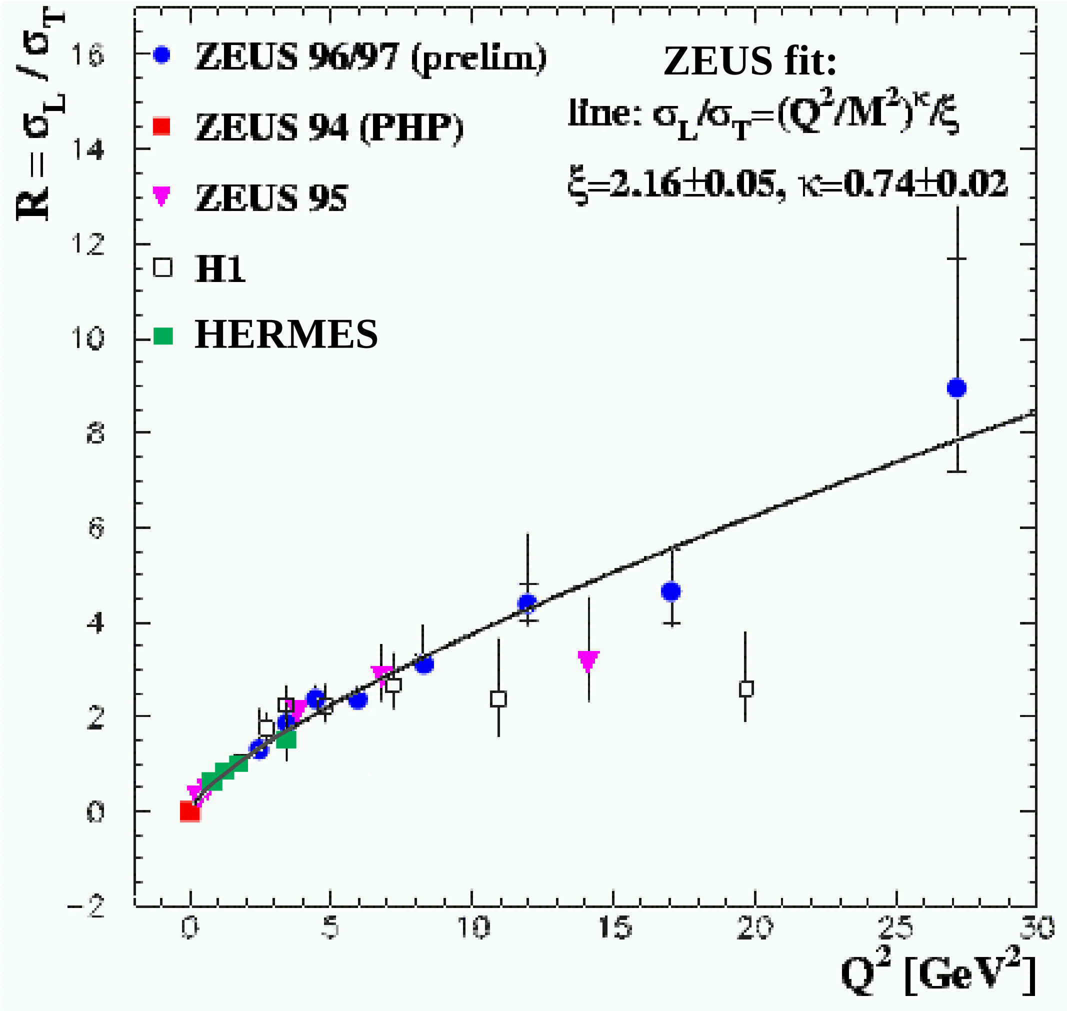
4. **VM ratios** as a test of pQCD at asymptotic scales.
   pQCD suggests large correction factors for the J/ψ:
   forget the SU(4) factors 9 : 1 : 2 : 8 ? !

Reserve

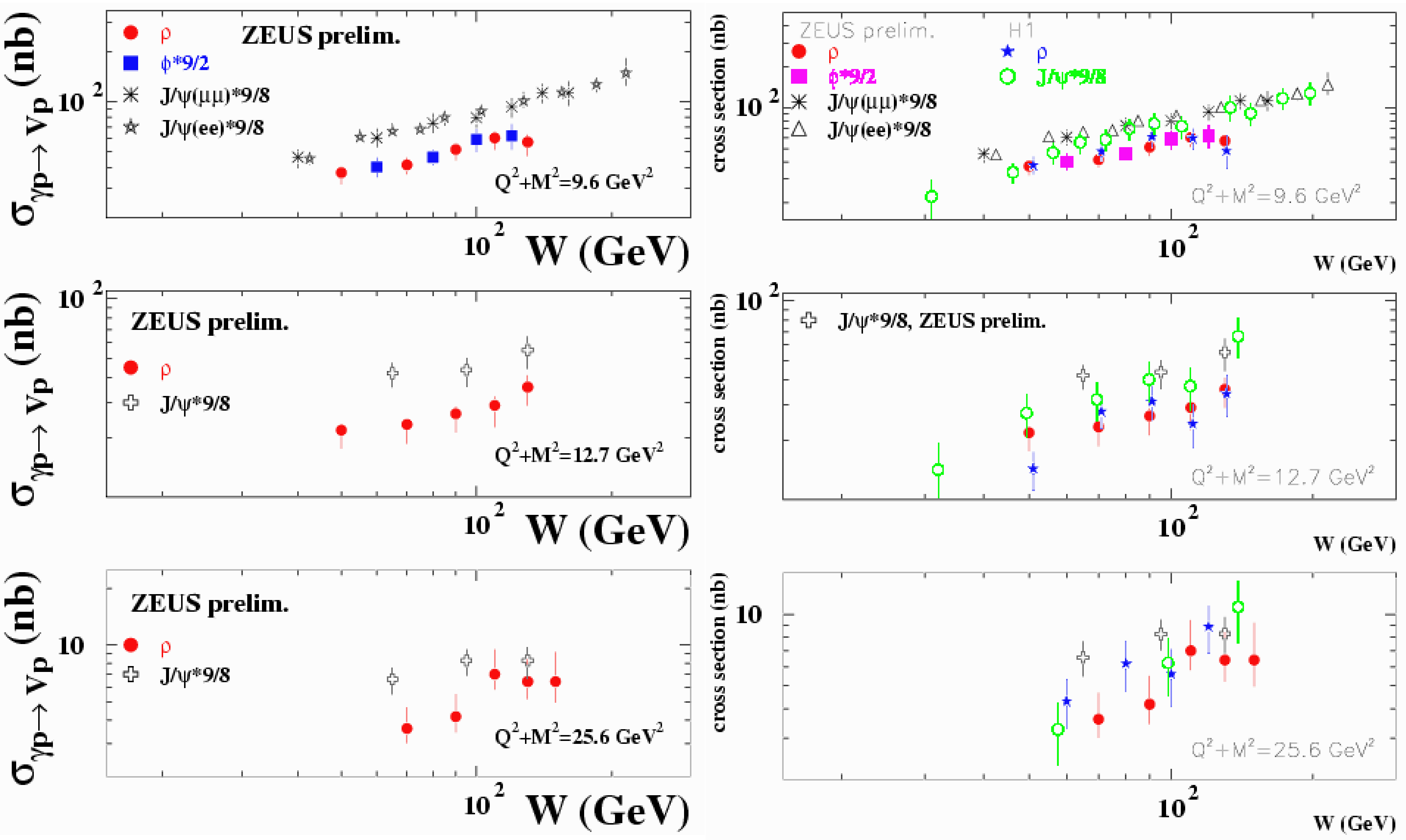
$R = \sigma_L/\sigma_T$ for elastic ρ^0 electroproduction

Early pQCD prediction: different Q^2 dep. for σ_L and σ_T

$\Rightarrow$ R expected to increase with Q^2



in agreement with data


ZEUS prelim.
ρ
ϕ*9/2
J/ψ(μμ)*9/8
J/ψ(ee)*9/8
Q²+M²=9.6 GeV²
σγp→Vp (nb)
W (GeV)
ZEUS prelim.
H1
ρ
ϕ*9/2
J/ψ*9/8
J/ψ(μμ)*9/8
J/ψ(ee)*9/8
cross section (nb)
ZEUS prelim.
ρ
J/ψ*9/8
Q²+M²=12.7 GeV²
J/ψ*9/8, ZEUS prelim.
Q²+M²=25.6 GeV²

t-slope of ψ(2S)

$$d\sigma/d|t| \propto e^{-b_{\psi(2S)}\cdot|t|}$$

In Vector Dominance Model:
VM scatters off the proton

$\Rightarrow b_{\psi(2S)} \propto r_p^2 + r_{VM}^2$

$\Rightarrow b_{\psi(2S)} > b_{J/\psi}$

due to different wave-functions

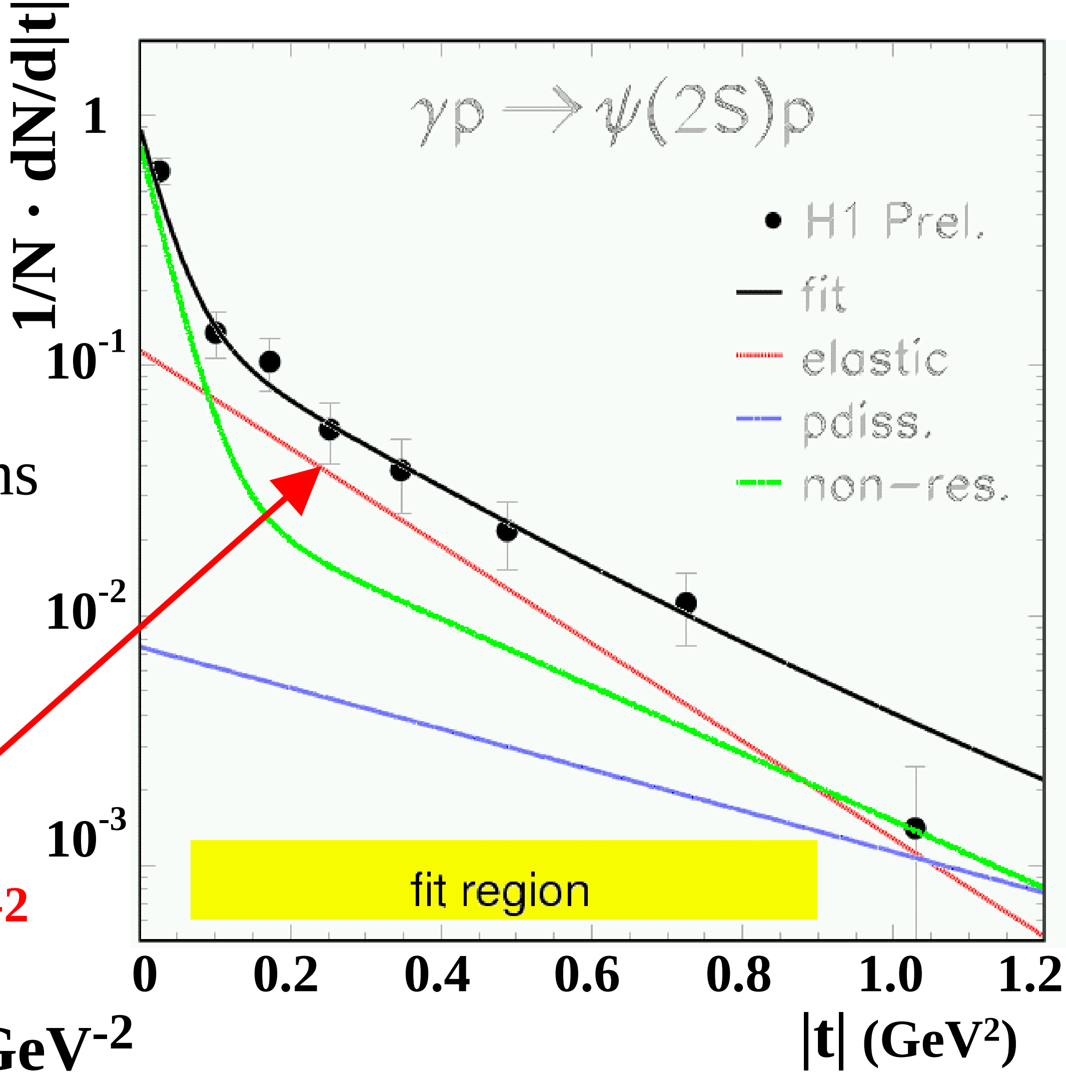
In pQCD: $q\bar{q}$ scatters off the proton $\Rightarrow b_{\psi(2S)} \propto r_p^2 + r_{q\bar{q}}^2$

$\Rightarrow b_{\psi(2S)} \approx b_{J/\psi}$

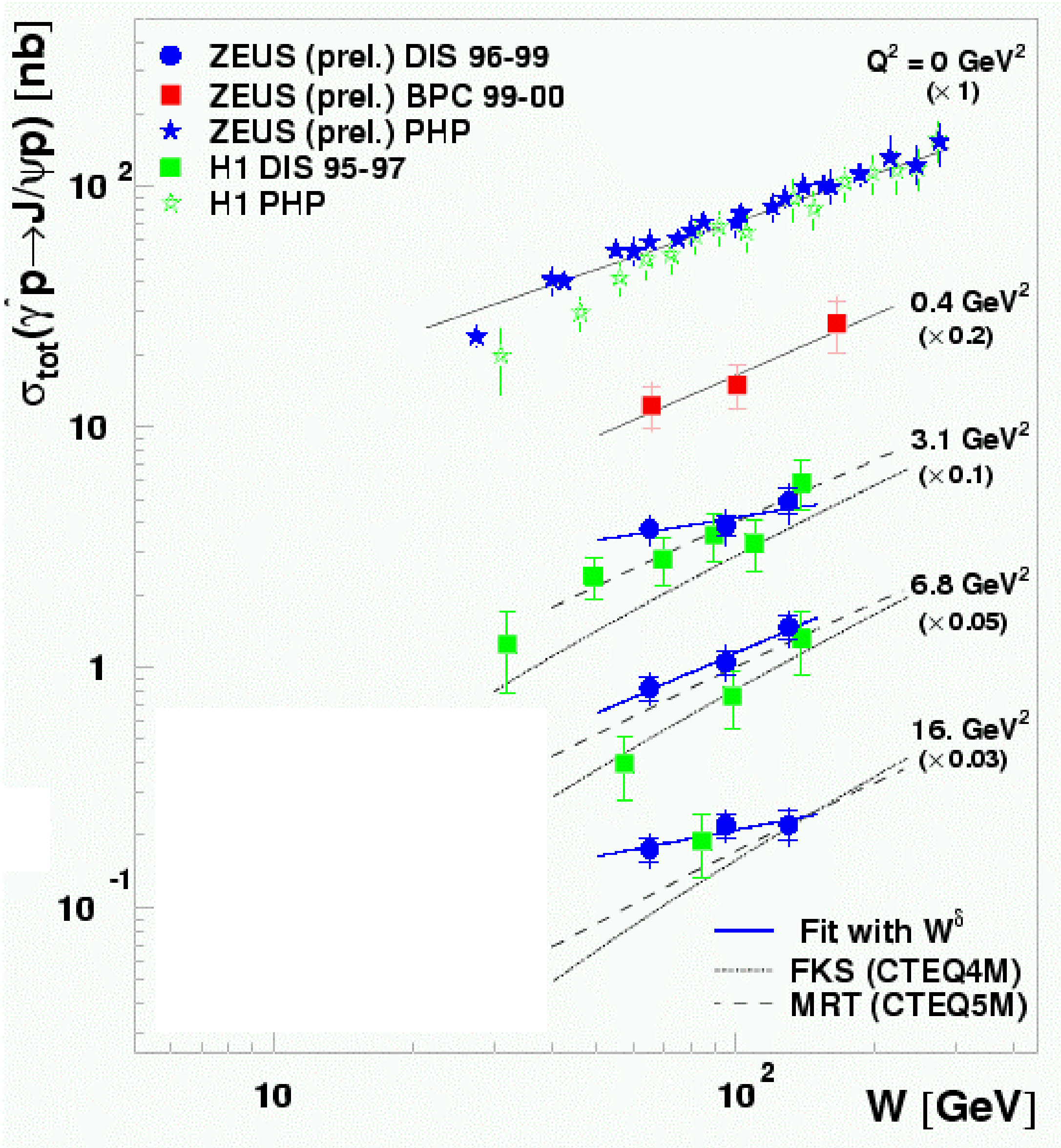
H1 measurements:

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

$$b_{J/\psi} = (4.73 \pm 0.25^{+0.30}_{-0.39})\ \mathrm{GeV}^{-2}$$

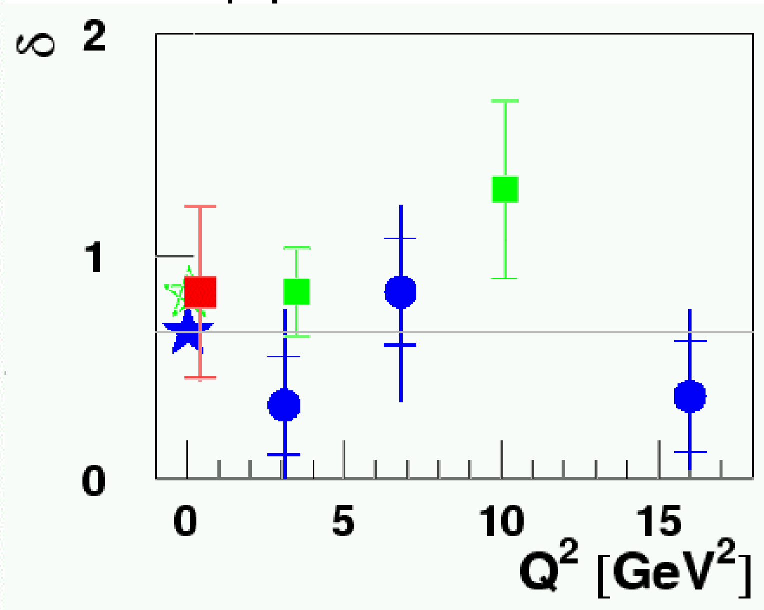


W-dependence of elastic J/ψ vs. Q^2



Different situation than for ρ^0 production:

increasing Q^2 has no visible effect on the W dependence of J/ψ production



More data needed here