Vector Meson Production at HERA

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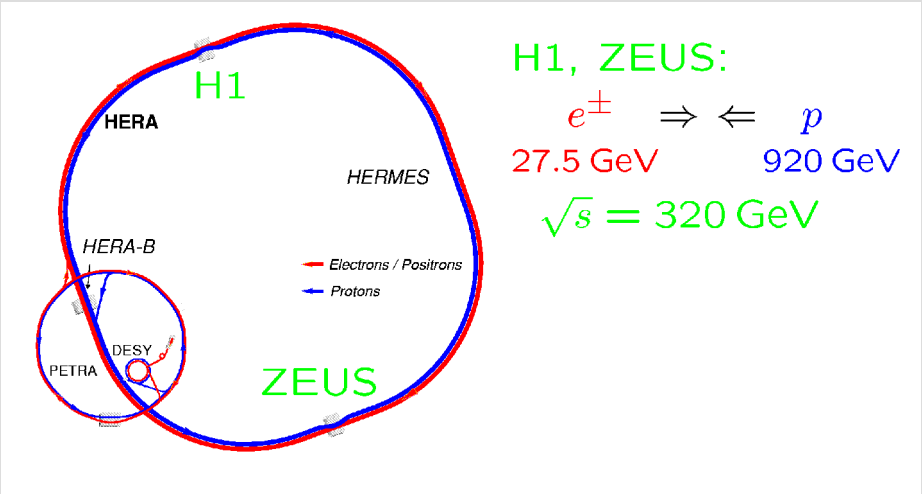
On behalf of ZEUS and H1 collaborations

- Introduction
- New results on elastic photo- and electroproduction
- Pomeron trajectory
- Looking for universality in VM production
- Proton-dissociative electro- and photoproduction
- Helicity studies
- Summary and Outlook

Hadron Structure 02, Herlany, Slovakia, September 22 - 27, 2002

HERA *ep* collider

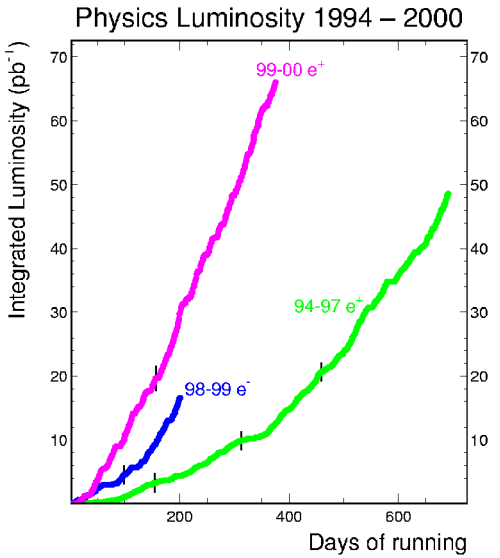


H1, ZEUS:

$e^{\pm}$ $\Rightarrow \Leftarrow$ p

27.5 GeV 920 GeV

$\sqrt{s} = 320$ GeV



1994 – 1997

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

$45\,\mathrm{pb}^{-1}$

1998 – 1999

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

$16\,\mathrm{pb}^{-1}$

1999 – 2000

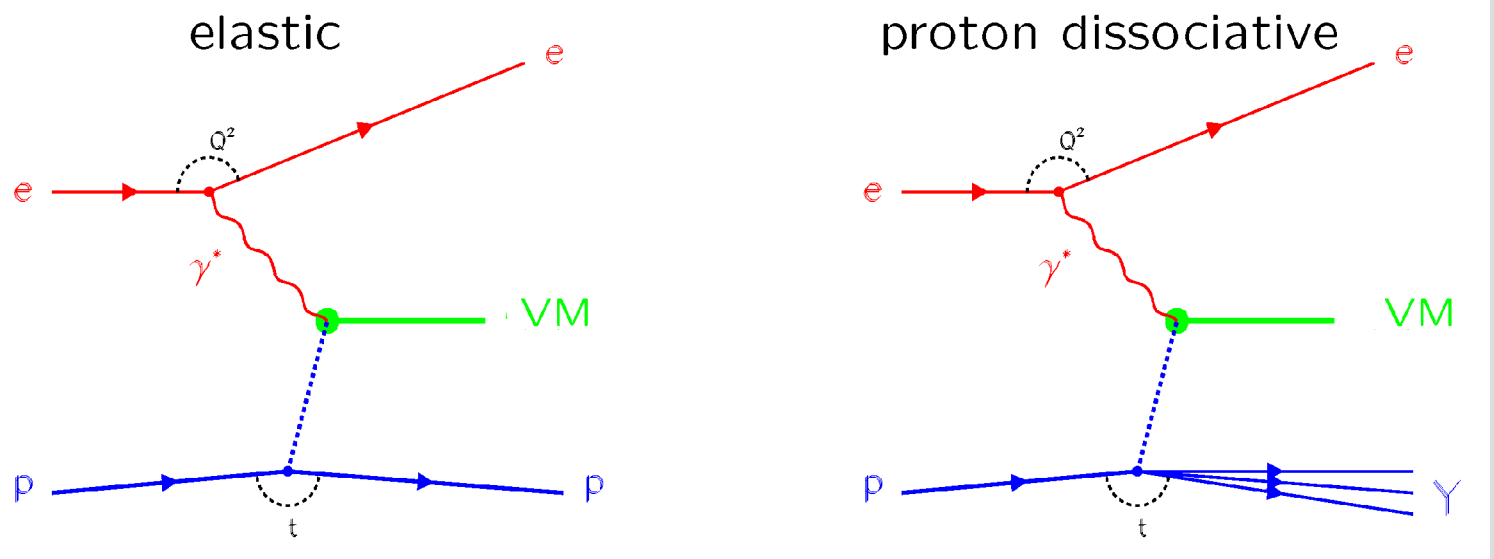
e^+p at $\sqrt{s} = 320$ GeV

$68\,\mathrm{pb}^{-1}$

Half of the HERA I luminosity collected in 1999 - 2000 !

Only part of the data analysed so far!

Diffractive vector meson production at HERA



VM	Vector Meson	ρ^0, ω, ϕ, J/ψ, ψ', Υ
Q^2	γ^* virtuality	$0 < Q^2 < 70$ GeV^2
W	CM energy of γ^* p system	$20 < W < 290$ GeV
t	(4-mom. transfer)^2	$0 < \lvert t \rvert < 20$ GeV^2

At HERA we control all these variables!

Vector Meson Detection

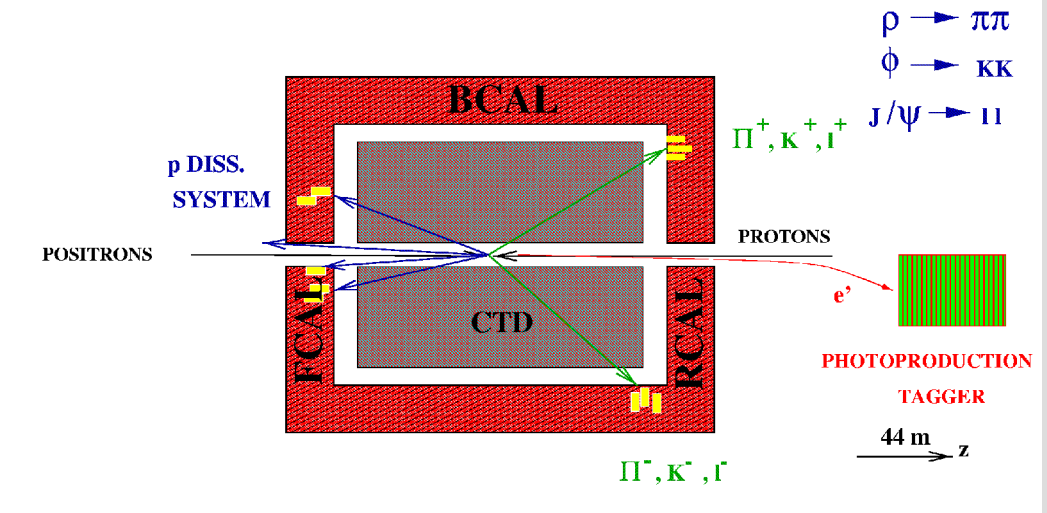
Schematic view of the ZEUS detector:

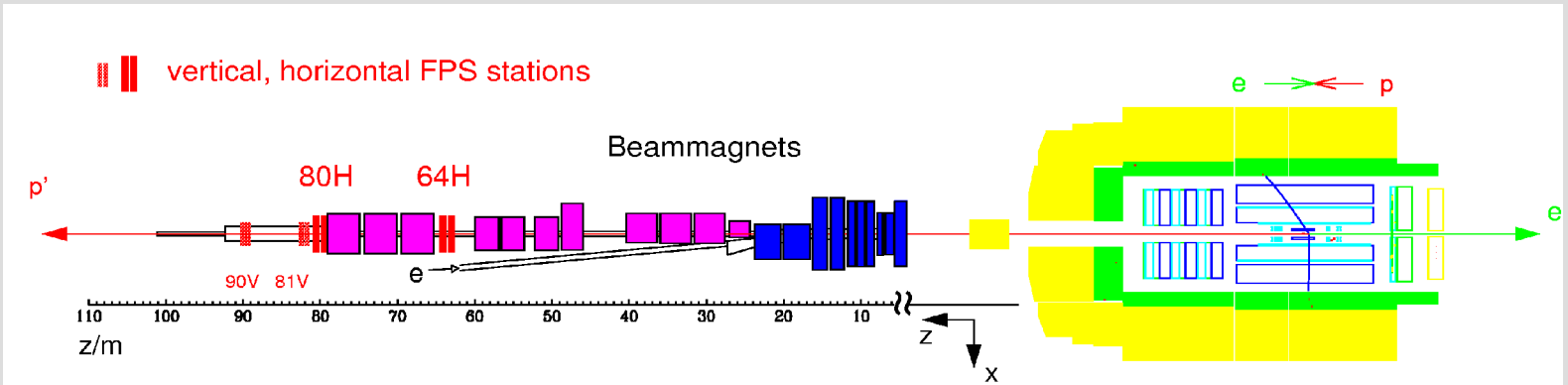
- charged tracks - VM (+positron in DIS)
- energy deposits in calorimeters
- extra detectors:

  for protons,

  proton remnants,

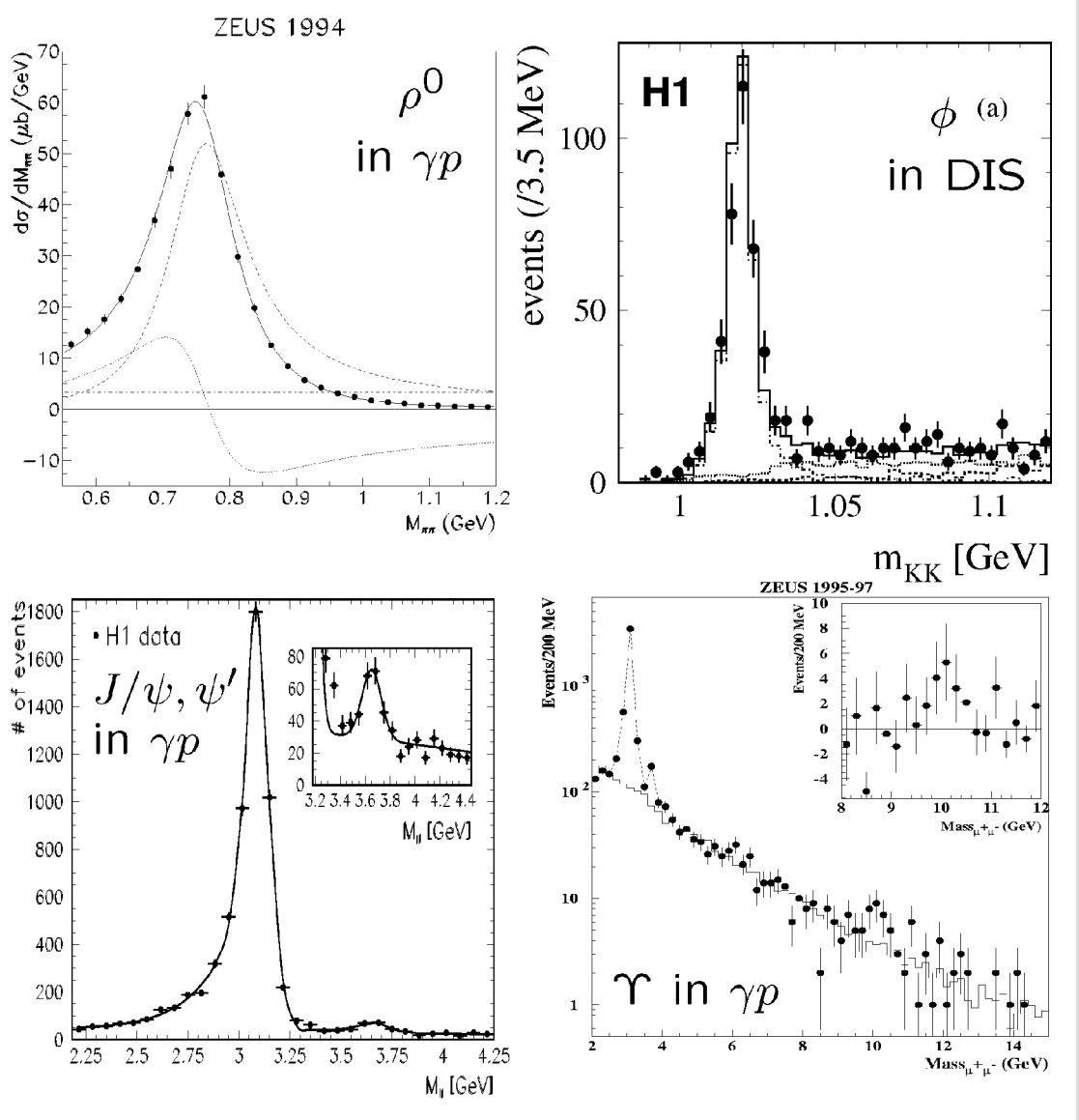
  photoproduction tagger



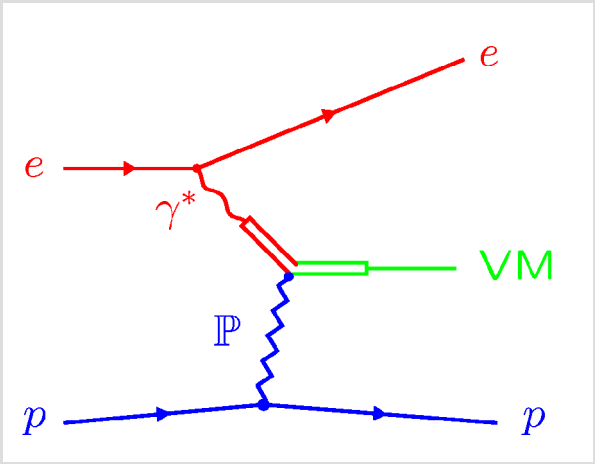


Elastic ρ^0 photoproduction in H1 detector with a leading proton detected in the Forward Proton Spectrometer

Vector Meson Signals



Diffractive Vector Meson Production Models



VDM + Regge: $\gamma^* p \rightarrow Vp = (\gamma^* \rightarrow V) \times (Vp \rightarrow Vp)$

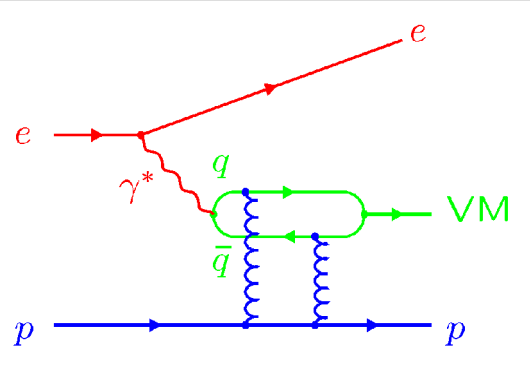
- $Vp \rightarrow Vp$ = "soft" interaction $\Rightarrow$ Pomeron exchange
- $\alpha_P(t) = \alpha_0 + \alpha' t = 1.08 + 0.25\, t$ (Donnachie-Landshoff)
- $d\sigma/dt \sim e^{b(W)\, t}$, $b \sim R_{int}^{\,2}$
- $b(W) = 2(b_{VM} + b_p + \alpha' \ln (W^2))$ $\Rightarrow$ shrinkage
- $\sigma_{Vp} \sim W^{4(\alpha_0 - 1)} / b(W) \sim W^{\delta}$, $\delta \approx 0.22 \Rightarrow$ weak energy dependence
- S Channel Helicity Conservation - VM retains γ^* helicity

Diffractive Vector Meson Production Models

BUT: "large" Q^2, M_{VM} or $|t|$ = "small" VM and interaction size $\Rightarrow$ "hard" interaction

$\Rightarrow$ perturbative QCD applicable:

VM = qq dipol, exchange of ≥ 2 gluons (color singlet - QCD Pomeron)



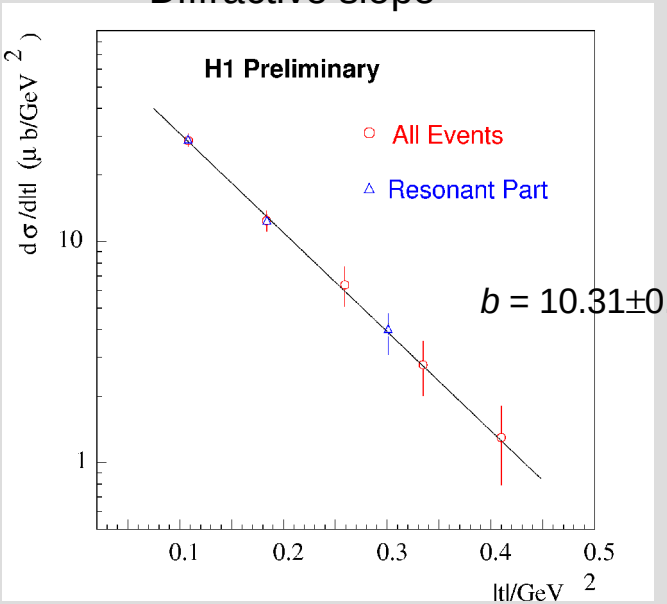
- Steeper rise of σ_{Vp} with W, ($\sigma_{Vp} \sim [\, x\, g(x, Q^2)]^2$, $x \approx Q^2/W^2$)
- Weaker t dependence, less shrinkage with W
- dominant longitudinal γ^* polarisation
- possible SCHC violation

VM at HERA: transition between soft and hard regime $\Rightarrow$ testbed for pQCD scales:

M_{VM}^2 , Q^2, $|t|$

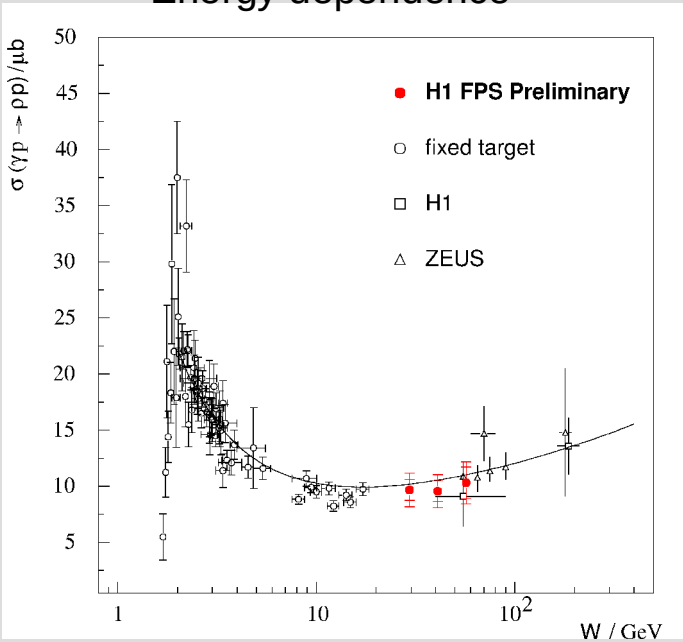
Elastic ρ^0 photoproduction with a leading *p*

Diffractive slope



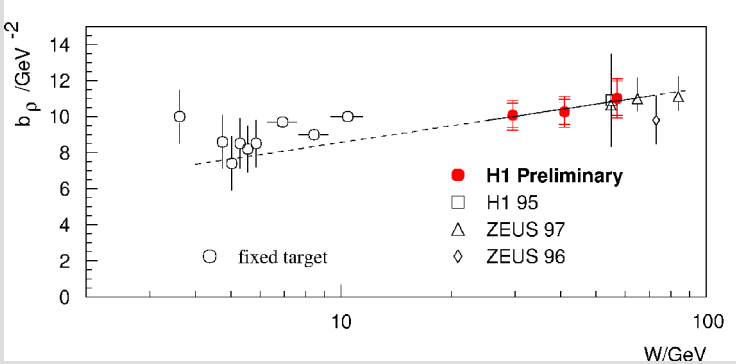
b = 10.31±0.77 ±0.52 GeV^{-2}

Energy dependence



$\sigma(\gamma p \rightarrow \rho p) \sim W^{0.22}$

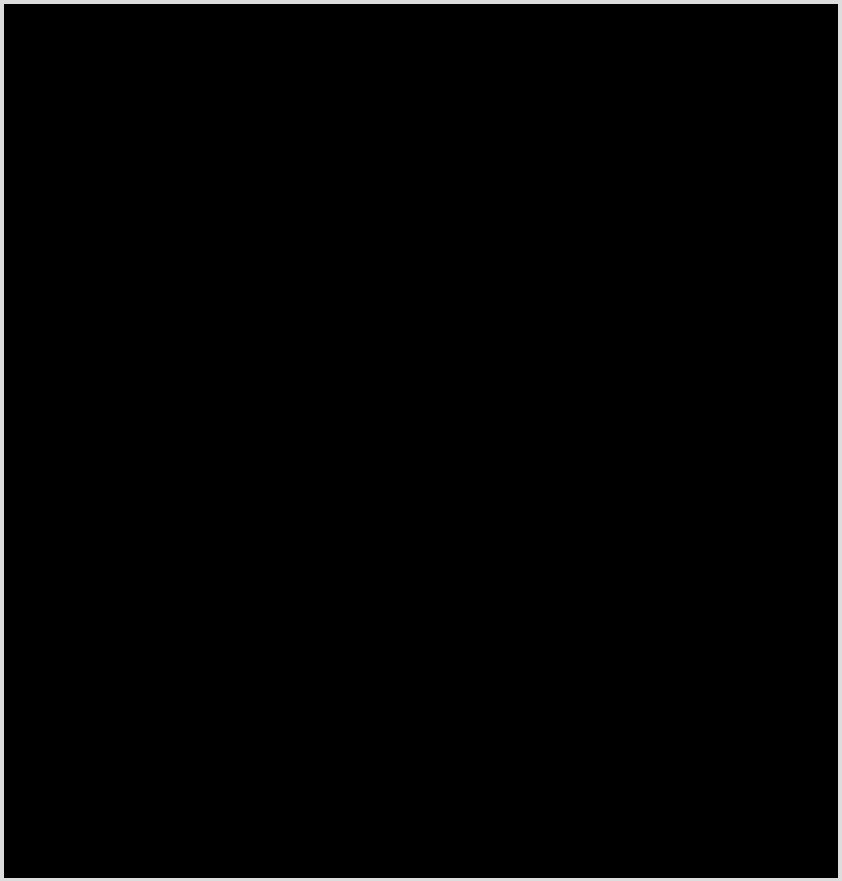
Pomeron trajectory

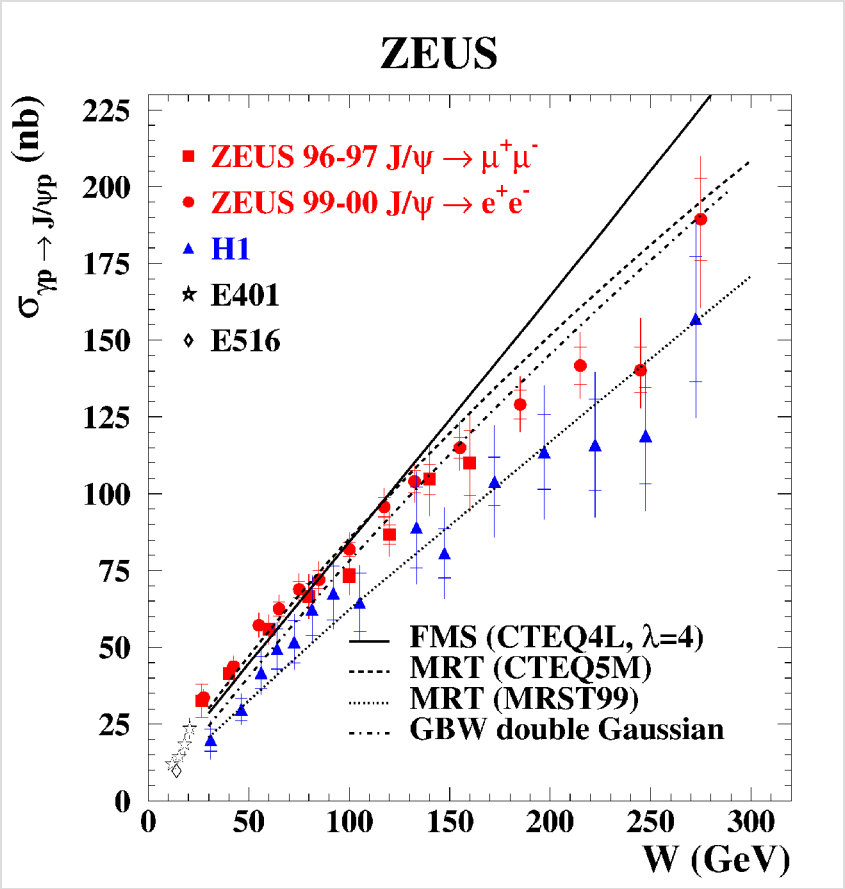


$b(W) = b_0 + 4*0.25*\ln(W)$

ρ^0 photoproduction is "soft"

Elastic J/ψ photoproduction



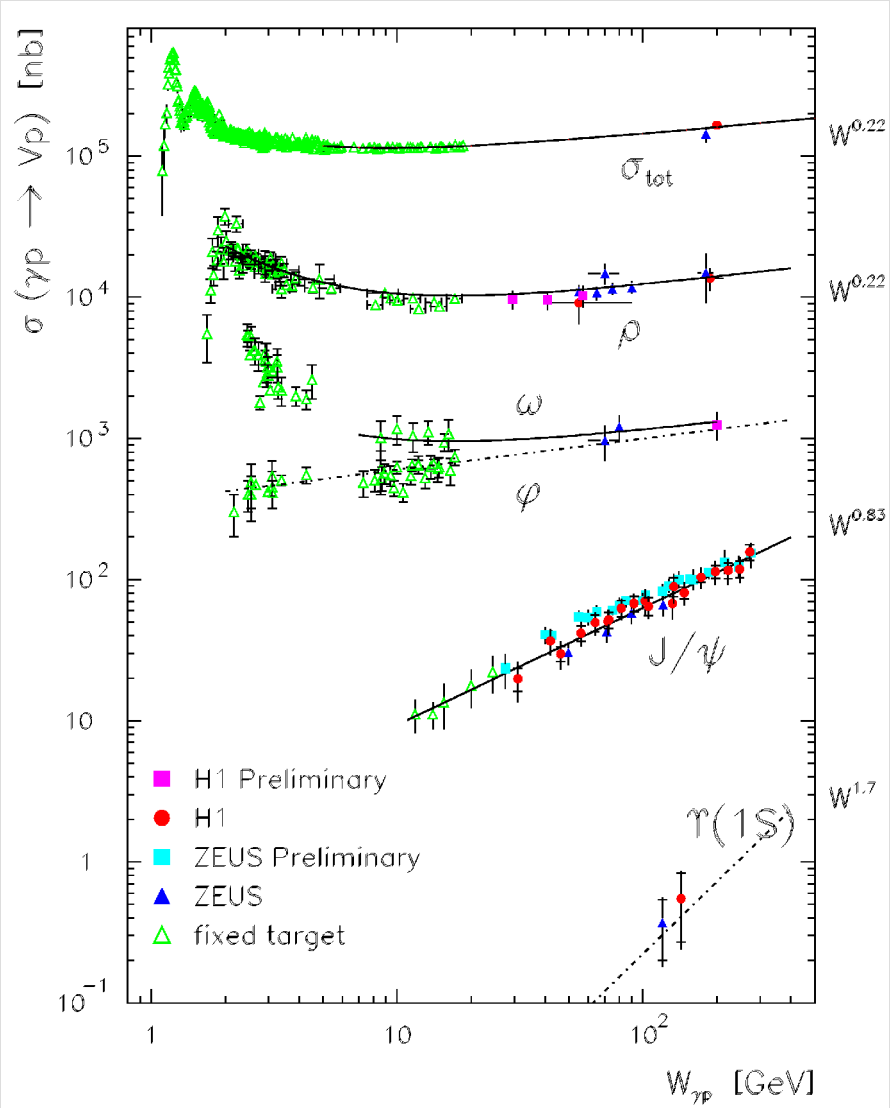


Large M_ψ is a hard scale: pQCD in action ⇒ steep rise of cross section with *W.*

The pQCD-based models reproduce the data.

J/ψ photoproduction is "hard"!

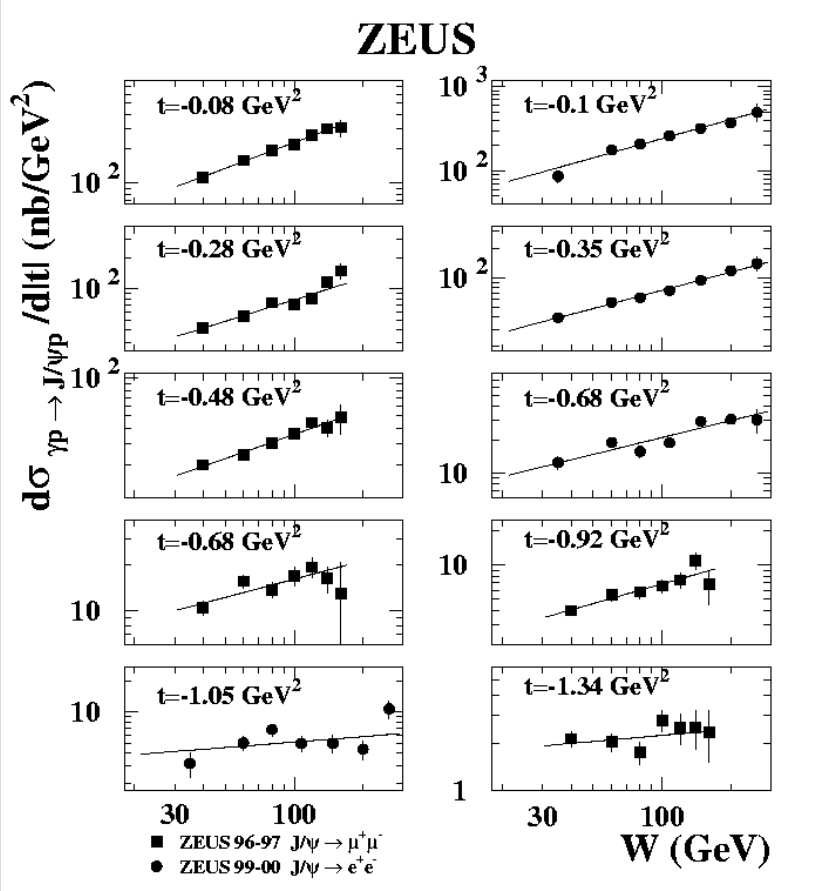
VM cross sections in photoproduction

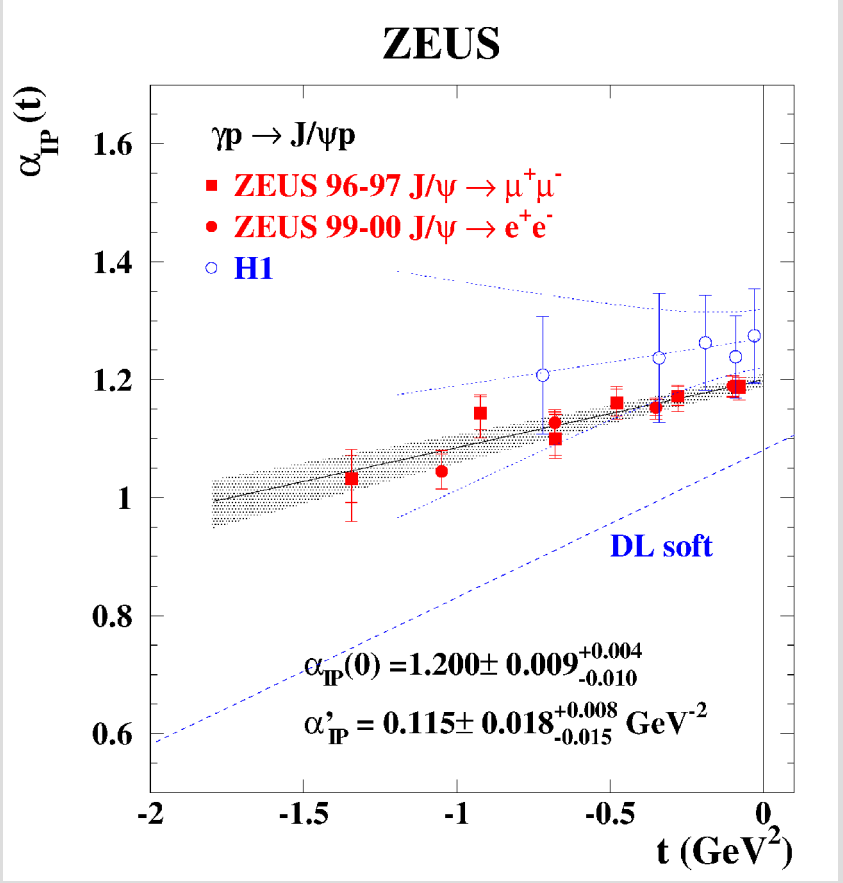


Increasing M_{VM} : transition from soft to hard regime.

Elastic J/ψ photoproduction

Simultaneous W and t dependence $d\sigma/dt \sim (W^2)^{(2\alpha(t)-2)} \Rightarrow$ effective "Pomeron" trajectory





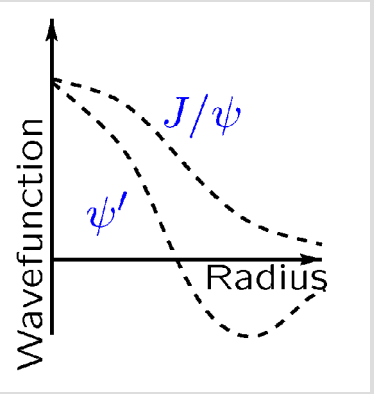
"Soft" Pomeron alone is excluded by the data!

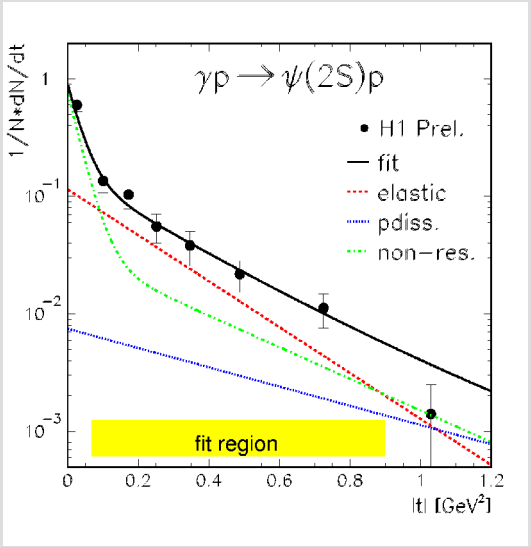
Elastic ψ(2s) photoproduction

cc radial excitation; optical interpretation $\Rightarrow$ $b_{\psi(2s)} > b_{J/\psi}$

BUT: QCD + ψ(2s) wave function (with node) $\Rightarrow$

- $b_{\psi(2s)} \leq b_{J/\psi}$
- $\sigma_{\psi(2s)} / \sigma_{J/\psi} < 1$

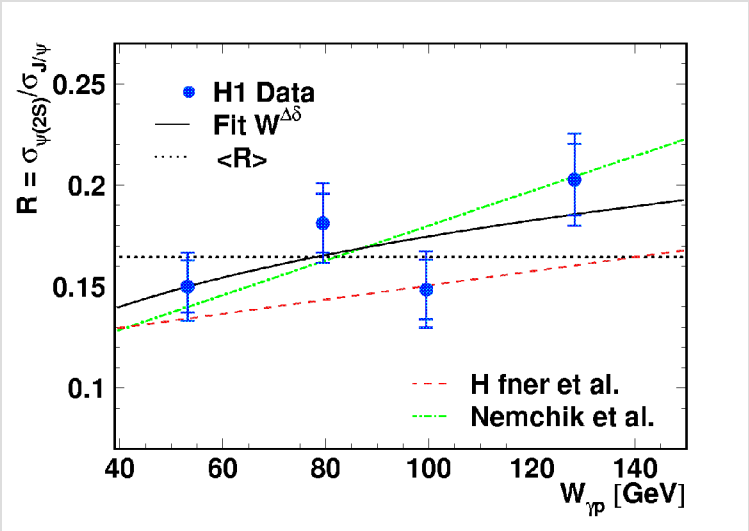




$b_{\psi(2s)} = 4.31 \pm 0.57 \pm 0.46$

$b_{J/\psi} = 4.99 \pm 0.13 \pm 0.39$

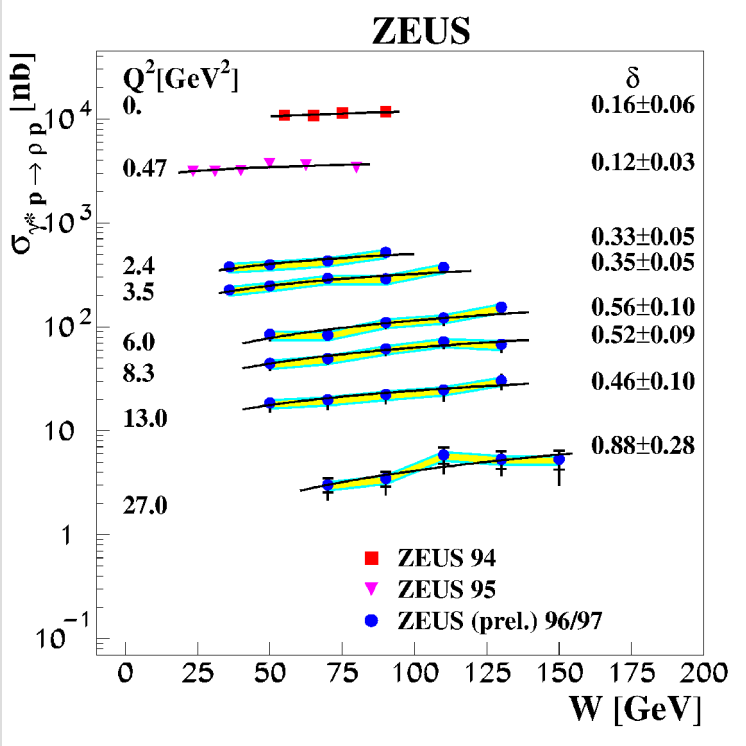
$\sigma_{\psi(2s)} / \sigma_{J/\psi} \approx 0.17$

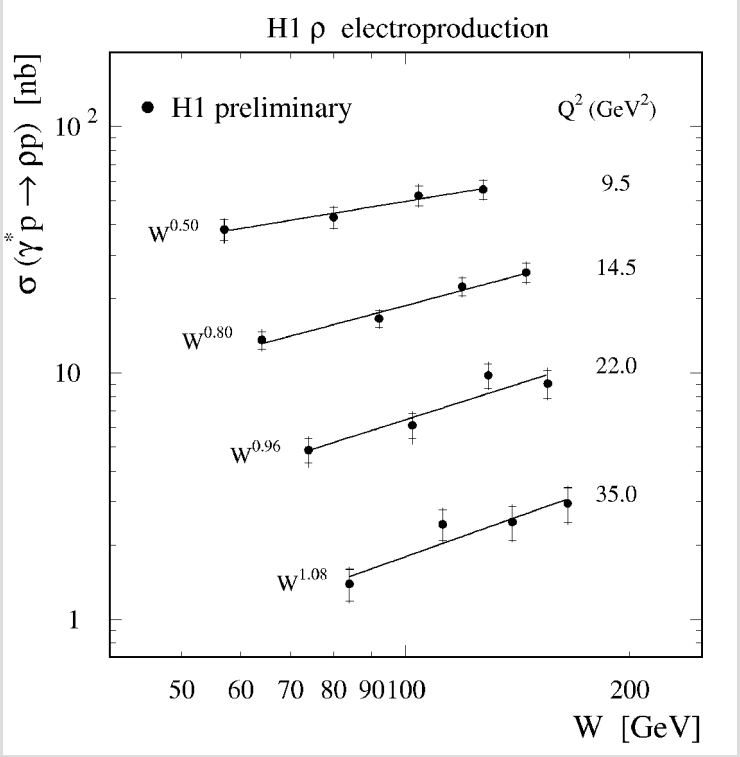


QCD + wave function $\Rightarrow$ OK!

Elastic ρ^0 electroproduction

Cross section $\sim W^{\delta}$ in Q^2 intervals

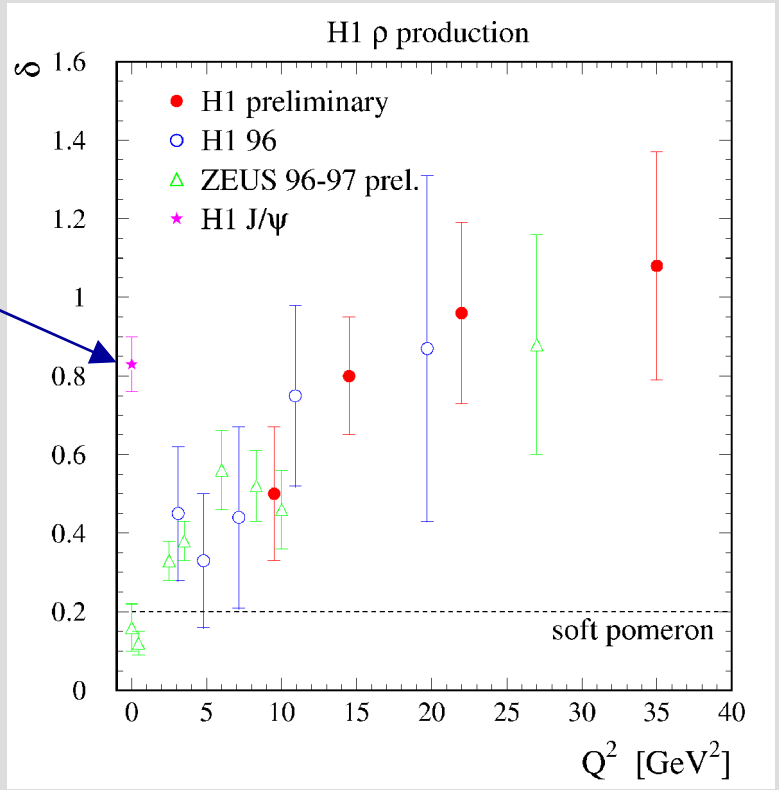




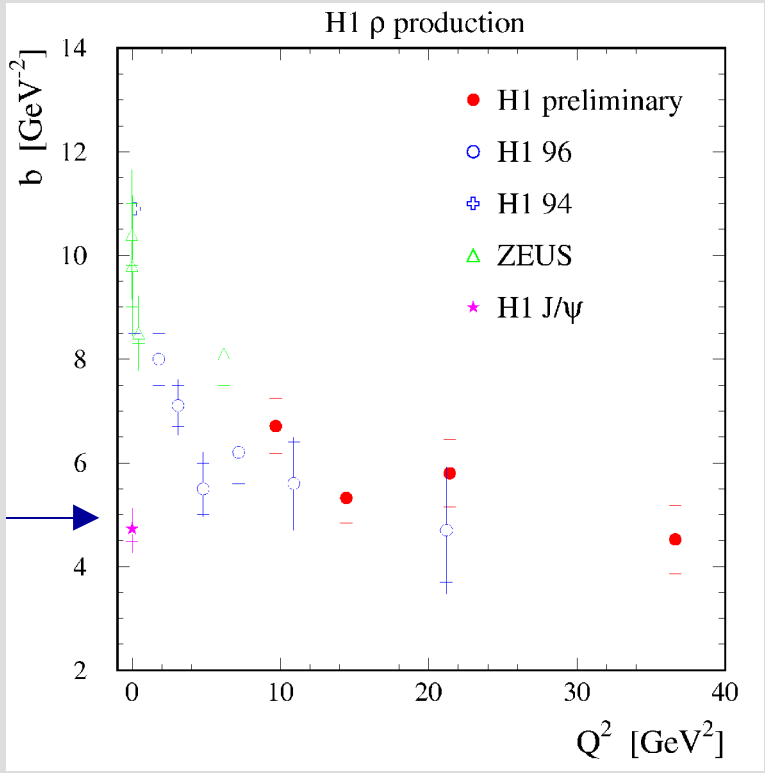
- $Q^2 \approx 0$: $\delta \approx 0.2$, weak W dependence - soft regime
- Large Q^2 is hard scale: large δ - steeper W dependence, as expected from color singlet exchange!

Elastic ρ^0 electroproduction

Cross section $\sim W^{\delta}$ in Q^2 intervals



slope b: $d\sigma/dt \sim \exp(-b|t|)$

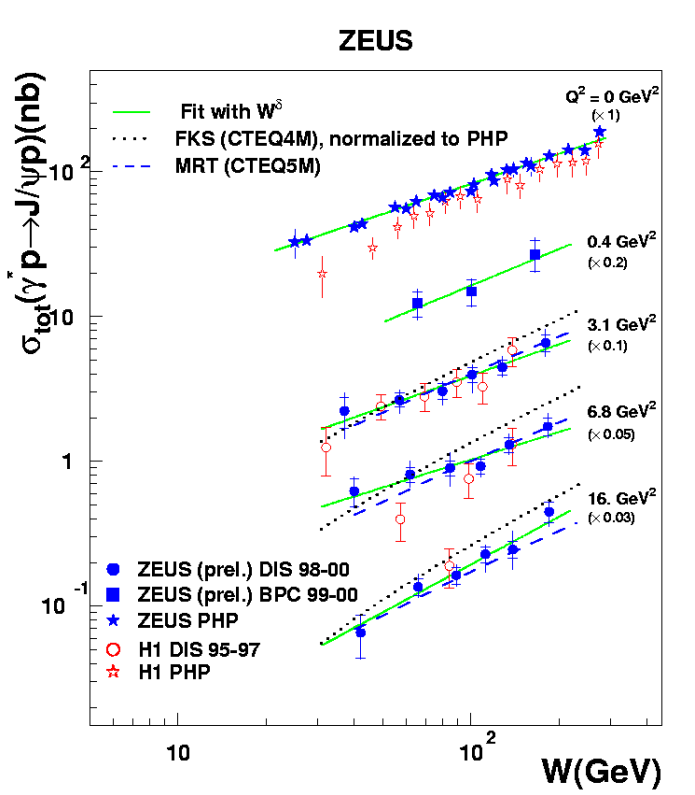


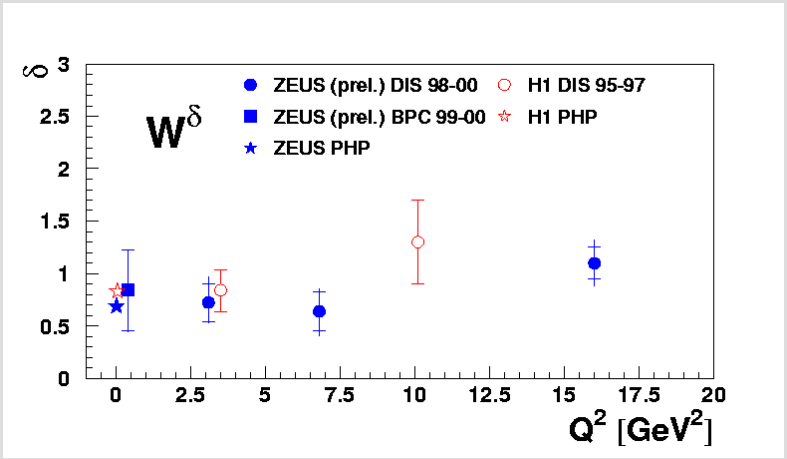
- power δ increases and slope b ($\Rightarrow$ transverse size of qq pair!) decreases with Q^2

Q^2 controls soft - hard regime transition!

Elastic J/ψ electroproduction

Cross section $\sigma_{J/\psi} \sim W^{\delta}$ in Q^2 intervals

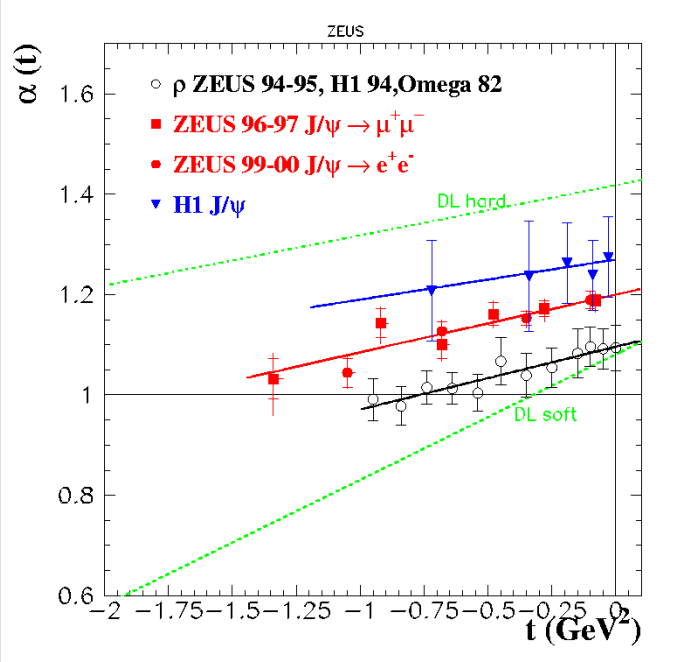


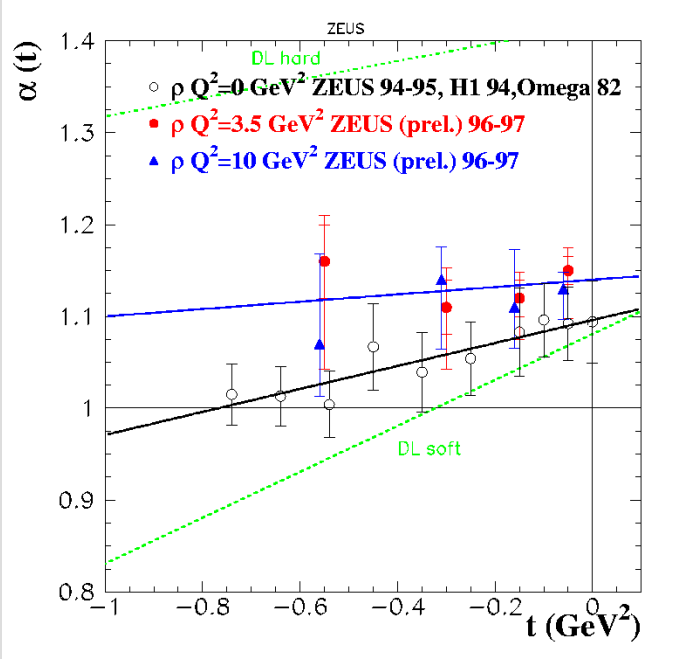


- Steep rise of $\sigma_{J/\psi}$ ($\delta \geq 0.65$) depends weakly on Q^2, large M_{ψ} is sufficient hard scale
- pQCD models using gluon densities are ~OK.

Pomeron trajectory...

J/ψ, ρ^0 photoproduction, ρ^0 electroproduction





V	$\alpha_{I\!P}(0)$	$\alpha'_{I\!P}$ (GeV^{-2})
ρ^0, $(Q^2 \simeq 0)$	1.096 ± 0.021	0.125 ± 0.038
J/ψ (H1)	1.27 ± 0.05	0.08 ± 0.017
J/ψ (ZEUS)	$1.200 \pm 0.009^{+0.004}_{-0.010}$	$0.115 \pm 0.018^{+0.008}_{-0.015}$
ρ^0 (ZEUS, DIS)	$1.14 \pm 0.01^{+0.03}_{-0.03}$	$0.04 \pm 0.07^{+0.13}_{-0.04}$

$\alpha_P(0)$ increases with M_V (Q^2 ?)

$\alpha'_P < 0.25$ GeV^{-2} ("soft" Pomeron)

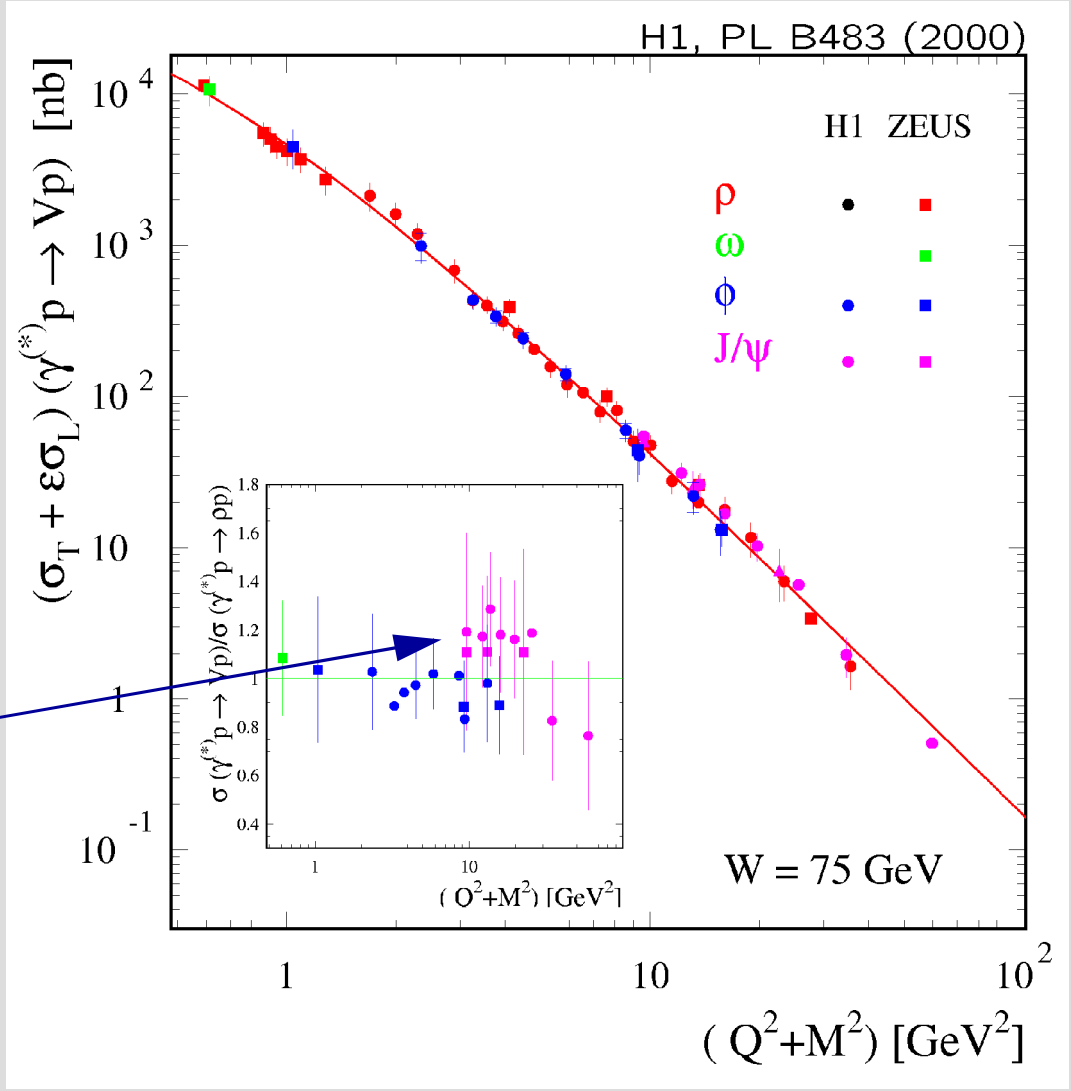
Looking for universality in VM production...

- Combined scale: $Q^2 + M^2$
- VM elastic cross sections "scaled" by SU(4) factors (assuming flavour independence and ignoring mass and wave function differences):

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

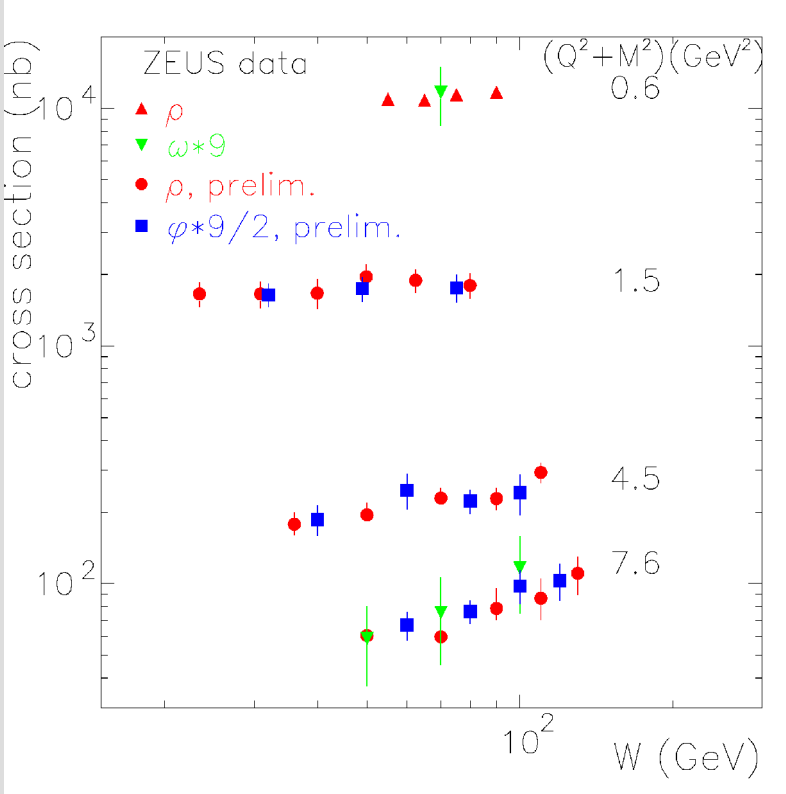
Looks good for light mesons

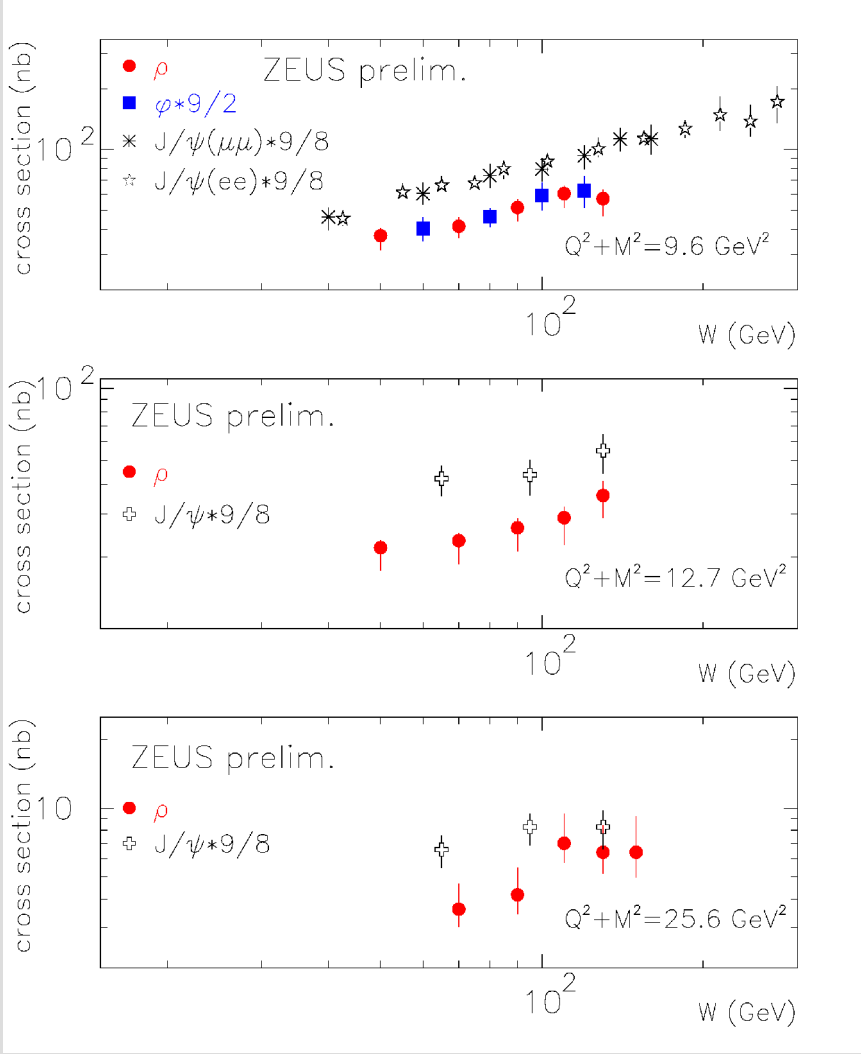
but J/ψ ...?



Looking for universality in VM production...

"Scaled" cross sections



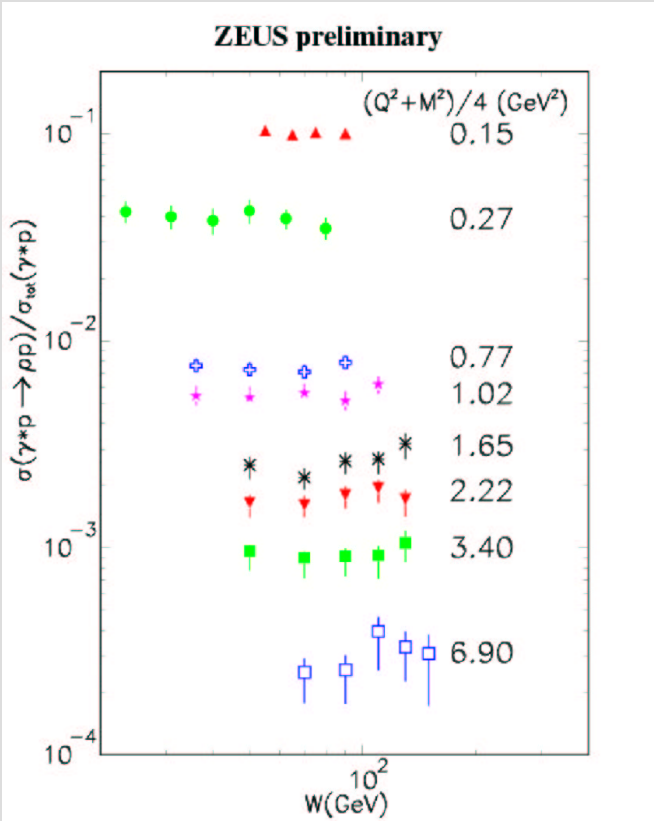


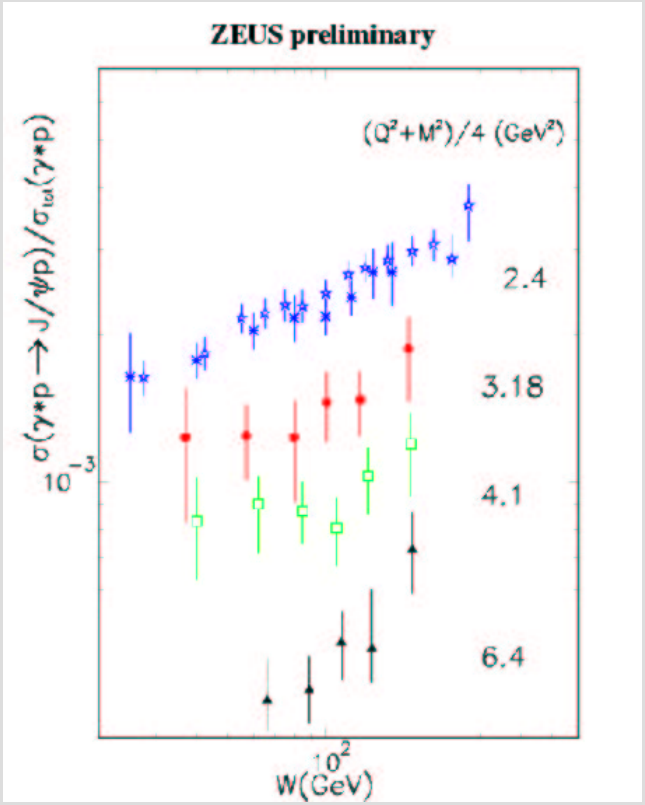
Recent data:

- universality for light VM
- J/ψ clearly enhanced above ρ and ϕ (???)

Looking for universality in VM production...

VDM+Regge: ratio: $\sigma_{VM}/\sigma_{tot}(\gamma^* p) \sim W^{(2\alpha(0)-1)}/b = W^{(2\alpha(0)-1)}/(b_0 + 4\alpha' \ln W) \Rightarrow ???$

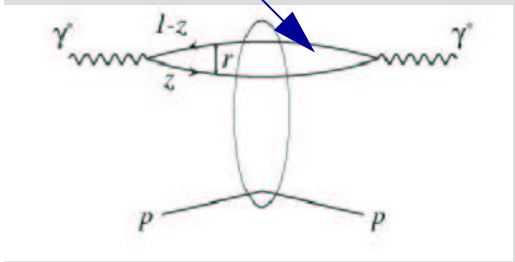


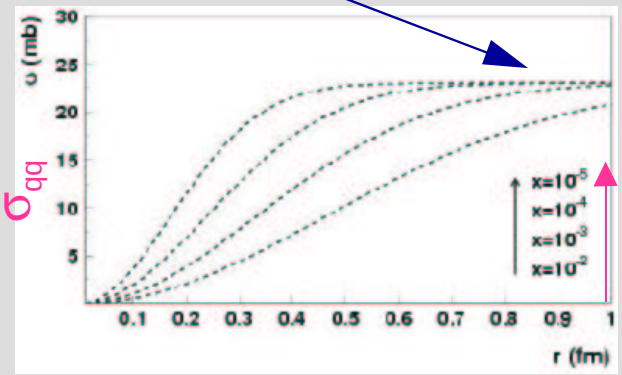


- σ_ρ/σ_{tot} does not depend on W ...(?)
- σ_ψ/σ_{tot} clearly rises with W ...(?)

Looking for universality in VM production...

Dipol (saturation) model (GB-W):





$$\sigma_{tot} \sim \int d^2r... \Psi_\gamma^* \sigma_{qq}(x,r) \Psi_\gamma$$

$$\sigma_{VM} \sim |\int d^2r... \Psi^*_{VM} \sigma_{qq}(x,r) \Psi_\gamma|^2$$

$$\sigma_{diff} \sim \int d^2r... |\Psi_\gamma|^2 (\sigma_{qq}(x,r))^2$$

Qalitative (up to now) considerations:

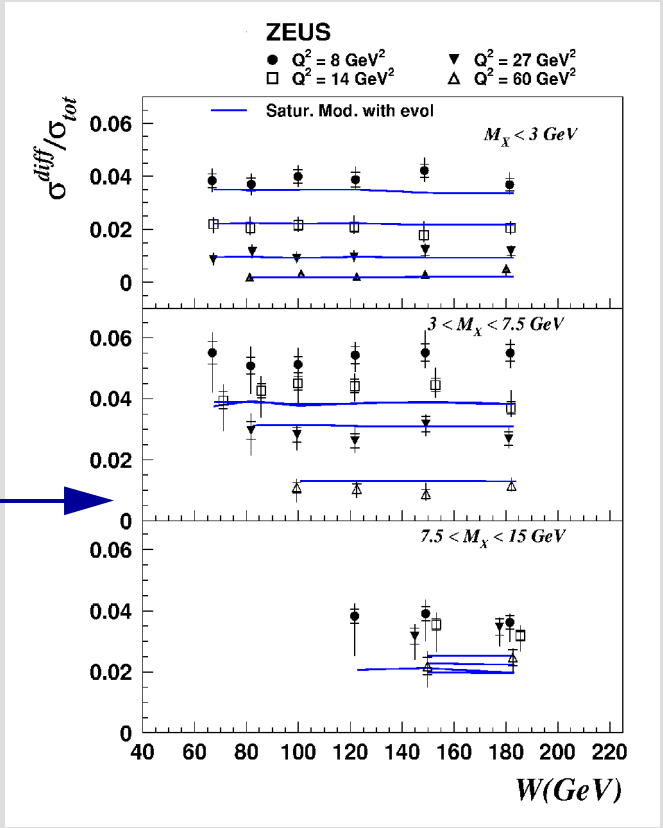
Interplay $\sigma_{qq}(x,r)$ $\Leftrightarrow$ qq dipol size(Q^2,M_q^2)

$\Rightarrow \sigma_{diff}/\sigma_{tot} \approx$ const(W) (also quantitatively)

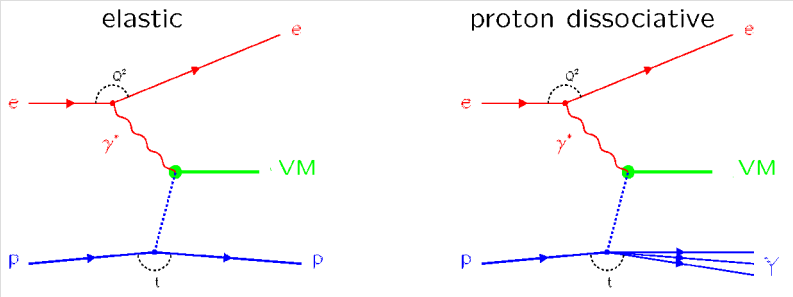
$\Rightarrow \sigma_\rho/\sigma_{tot} \approx$ const(W) (?)

$\Rightarrow \sigma_\psi/\sigma_{tot}$ rises with W (?)

Saturation model has great potential!



Proton-dissociative ρ^0 electroproduction

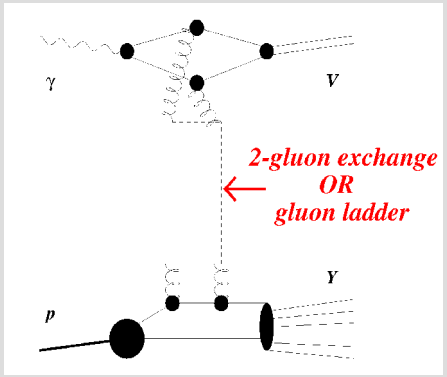


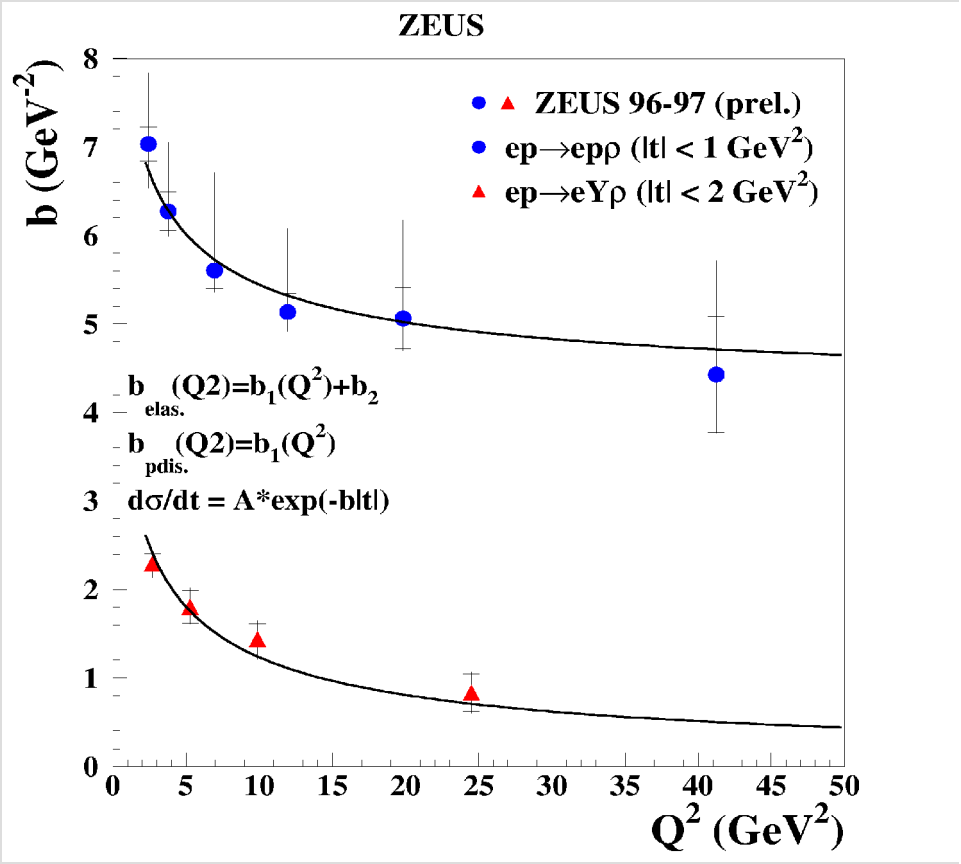
At "small" $|t|$: $d\sigma/dt \sim \exp(-b|t|)$

slope $b \sim$ (interaction size)^2

$b_{pdiss.} < b_{el.} \Rightarrow$

proton-dissociative interaction - scattering off parton!





Proton-dissociative VM photoproduction at large $|t|$

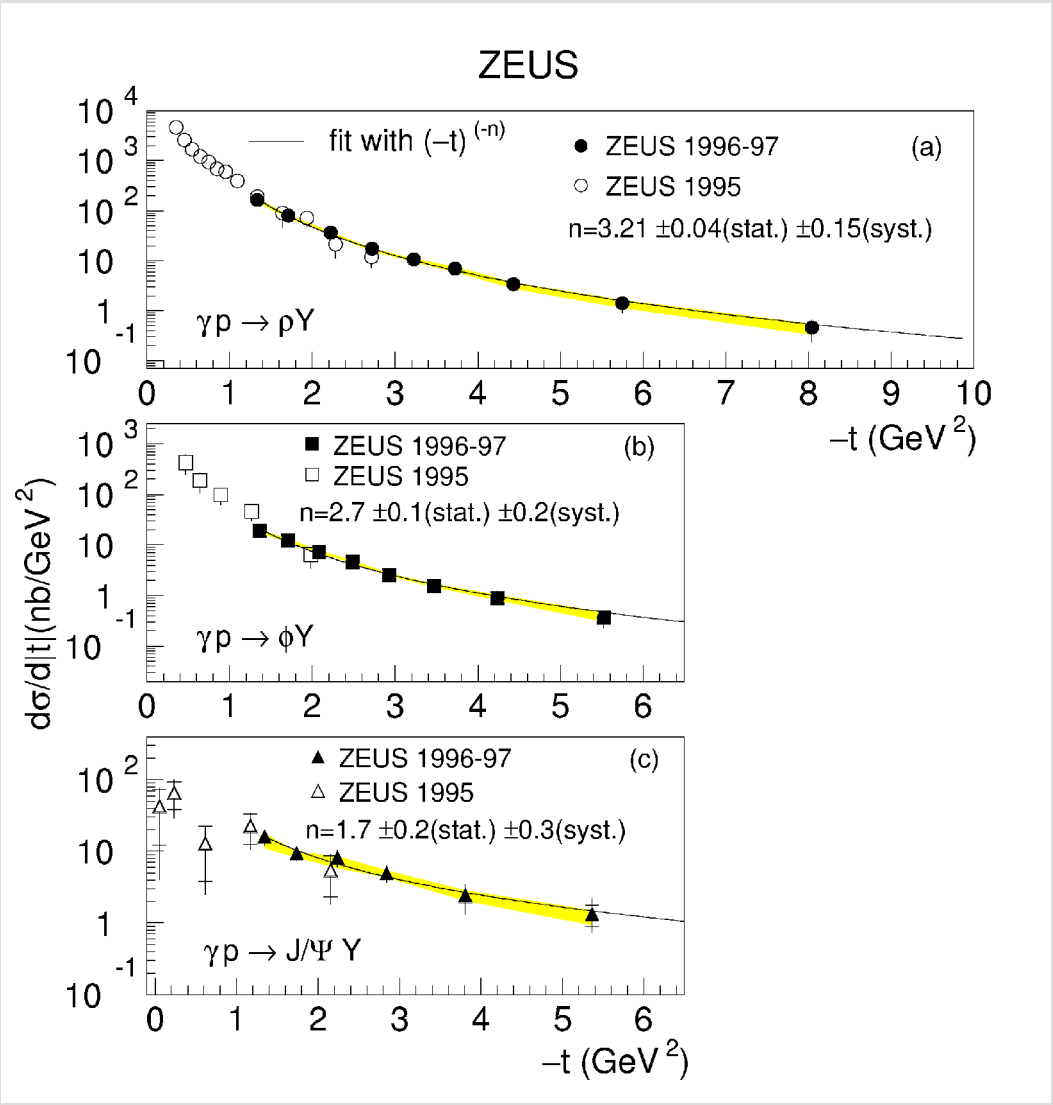
Does t provide hard pQCD scale?

VM = ρ, ϕ, J/ψ

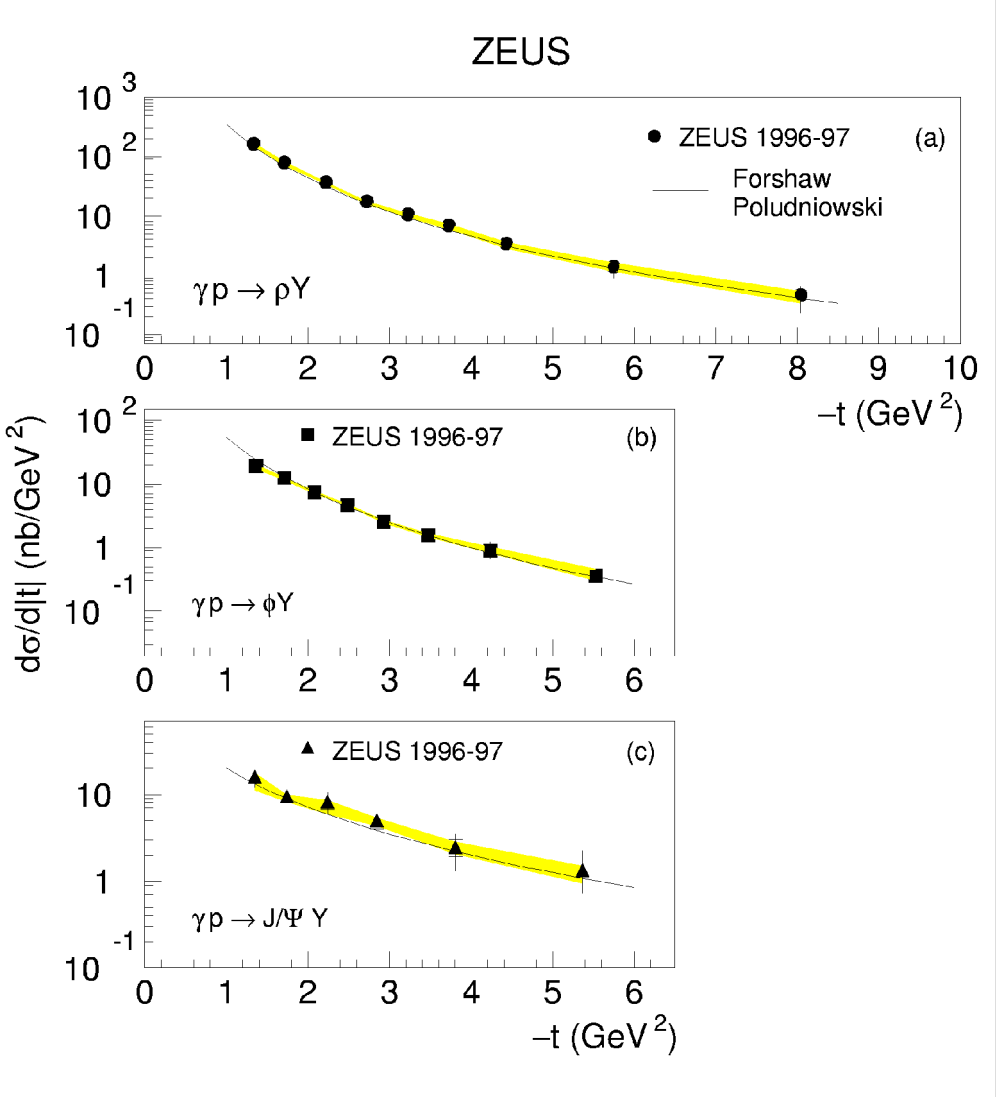
- $Q^2 < 0.02$ GeV^2
- $1.2 < |t| < 10$ GeV^2
- $80 < W < 120$ GeV

pQCD: $d\sigma/dt \sim |t|^{-n}$

- the heavier VM - the harder t distribution



Proton-dissociative VM photoproduction at large |*t*|



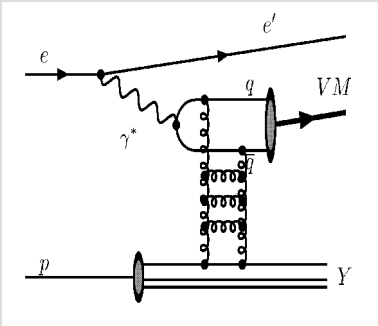
Forshaw & Poludniowski model:

- BFKL Pomeron
- coupling to single parton
- non-relativistic VM wave function (not proper for light VM)
- 3 parameters fitted to ZEUS data

BFKL exchange describes the data well

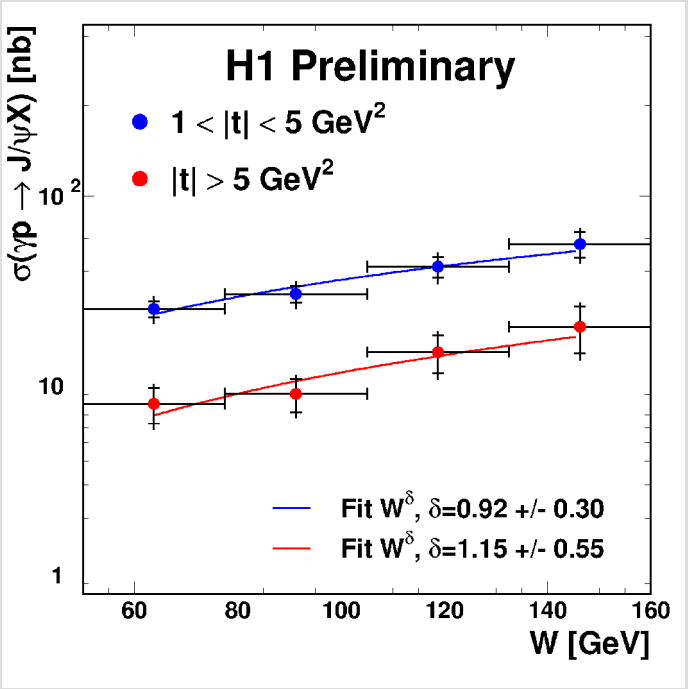
t is a hard scale...

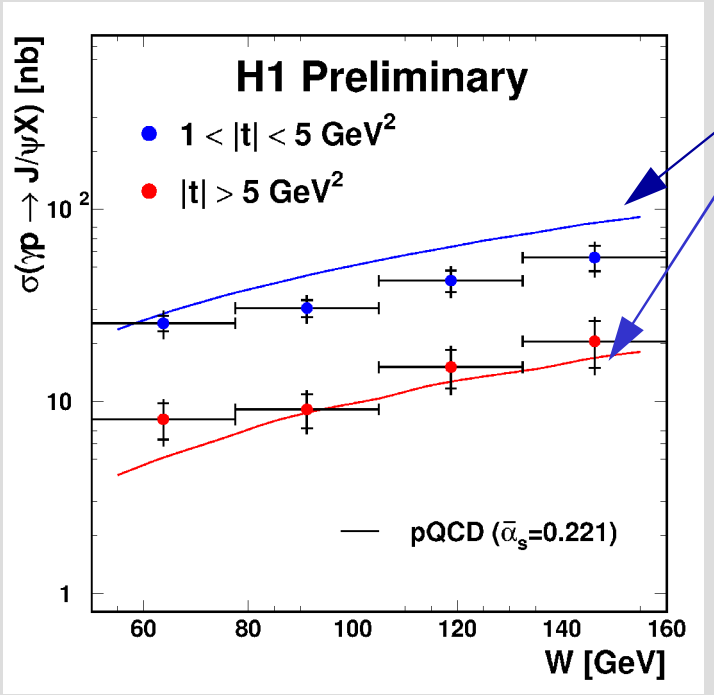
Proton-dissociative J/ψ photoproduction at large |*t*|



$\gamma p \rightarrow J/\psi Y$, $|t| < 20\ GeV^2$ (!)

BFKL exchange: rise of $d\sigma/dt$ with energy (in contrast with 2-gluon exchange!)





Bartels *et al.*

Indication of BFKL ?!

Proton-dissociative VM photoproduction at large $|t|$

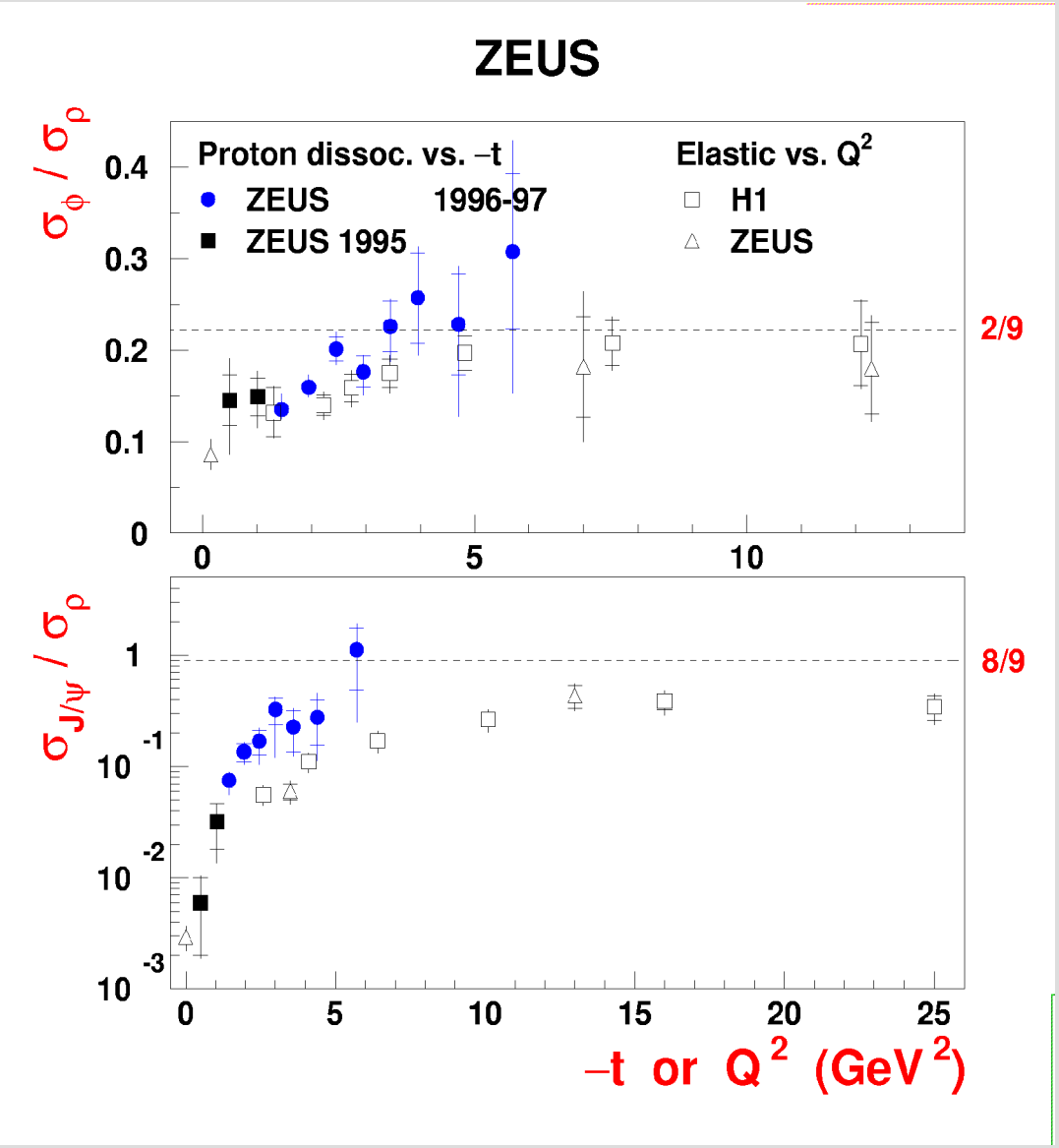
Cross section ratios in function of:

- $-t$ for p-diss. photoproduction
- Q^2 for elastic electroproduction

The ϕ/ρ ratios approach SU(4) value, as well as ψ/ρ in photoproduction

The cross section ratios rise faster with $-t$ than with Q^2

$|t|$ and Q^2 are NOT equivalent scales!



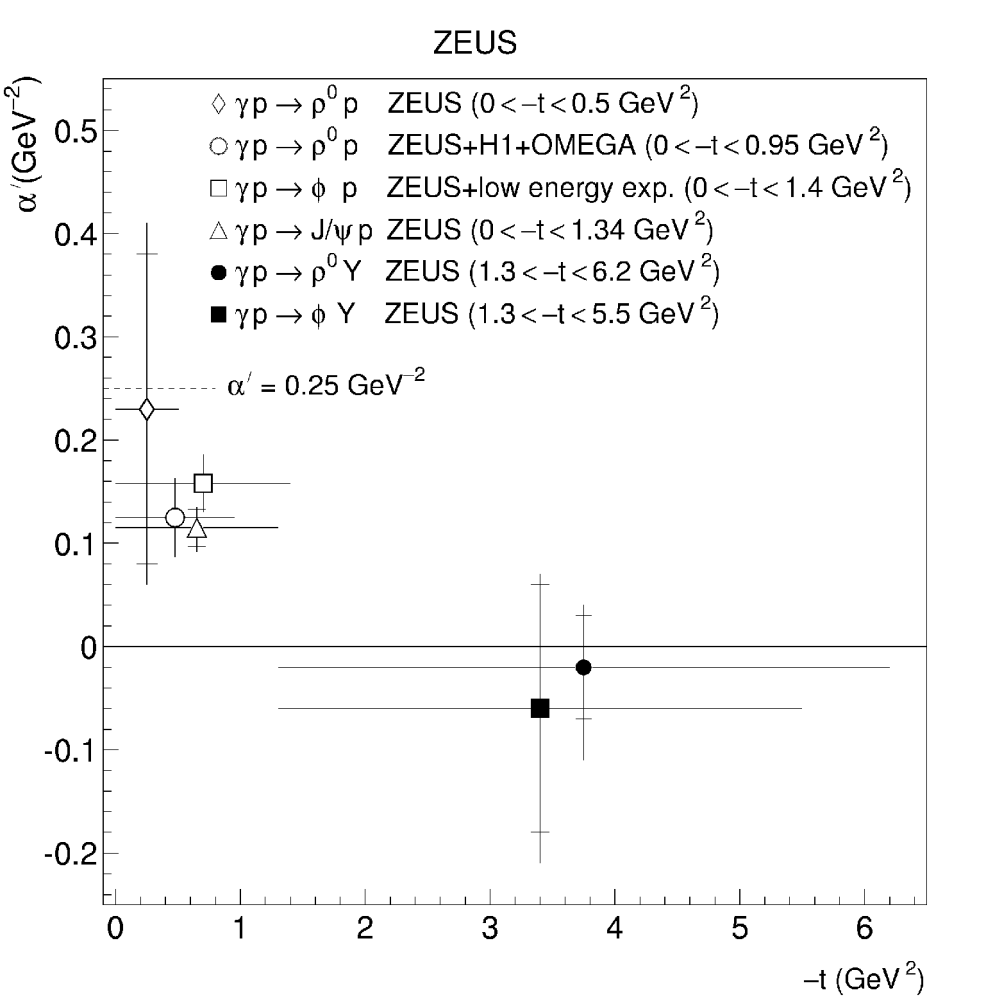
Proton-dissociative VM photoproduction at large |*t*|

Effective slope of Pomeron trajectory α'

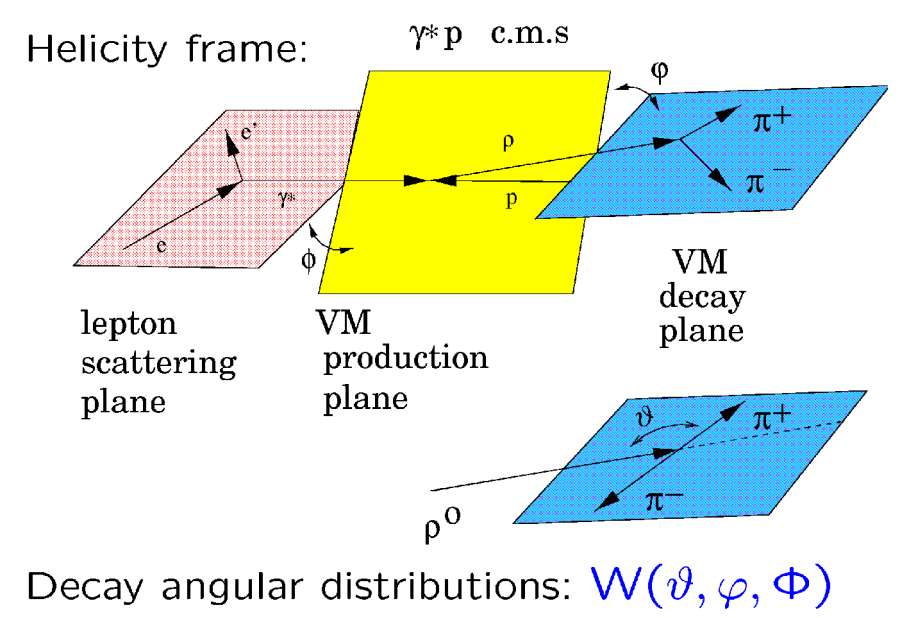
To avoid large correlated systematic errors "normalized" (W,t) distribution:

$$d\sigma/dt \,/\, d\sigma/dt(t=t_0) = W^{\,4\,\alpha'(t-\,to)}$$

With rising $-t$ transition from soft to hard regime...



Helicity studies



Helicity amplitudes $T_{\lambda VM\ \lambda\gamma}$

15 spin density matrix elements:

$$r^{\alpha\beta}_{ij} \sim T_{\lambda 1',\lambda 2'}\ T_{\lambda 1\ \lambda 2}$$

T_{00} , T_{11} : no helicity flip

T_{01} , T_{10} : single flip

$T_{1\text{-}1}$: double flip

VDM legacy: S-Channel Helicity Conservation

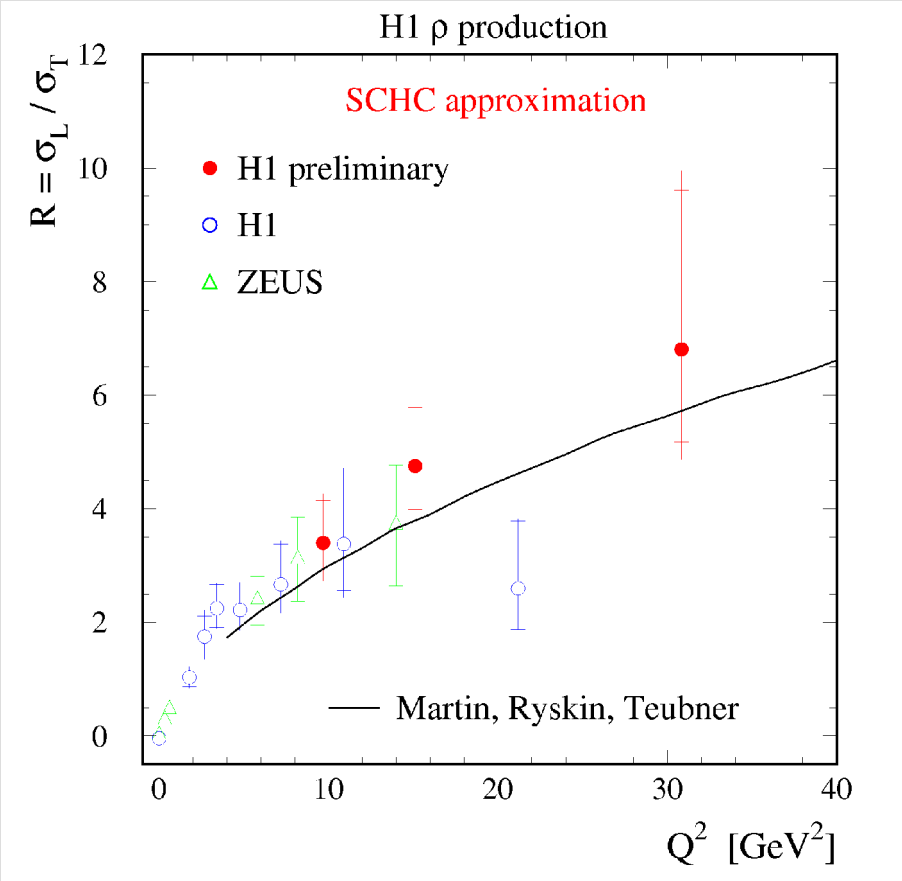
pQCD: quantitative predictions on transitions between γ^* and VM helicity states,

in particular dominance of longitudinal γ^* polarisation and small SCHC breaking

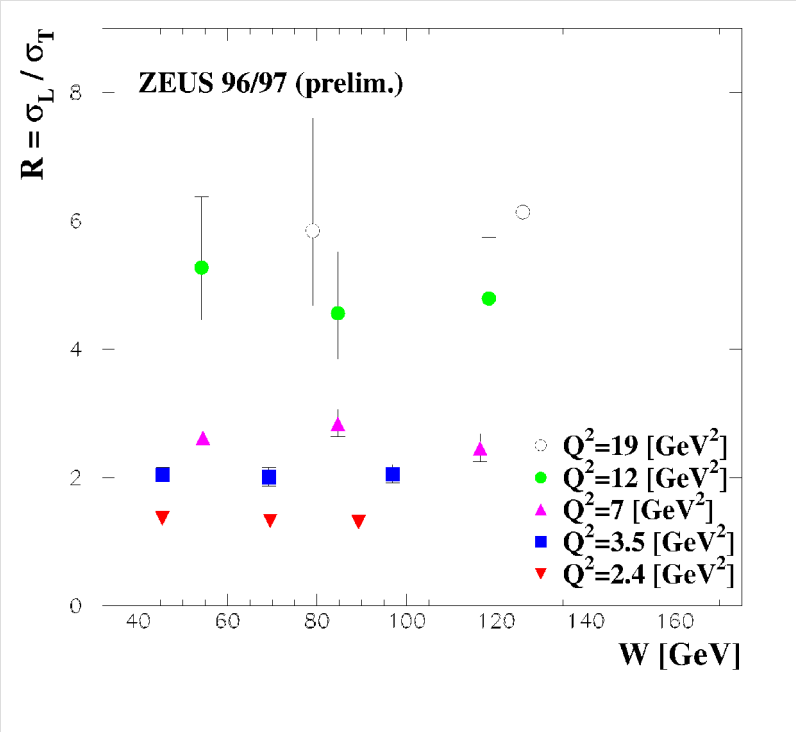
Experiment: approximate SCHC (small breaking)

Helicity studies

Elastic ρ^0 electroproduction:



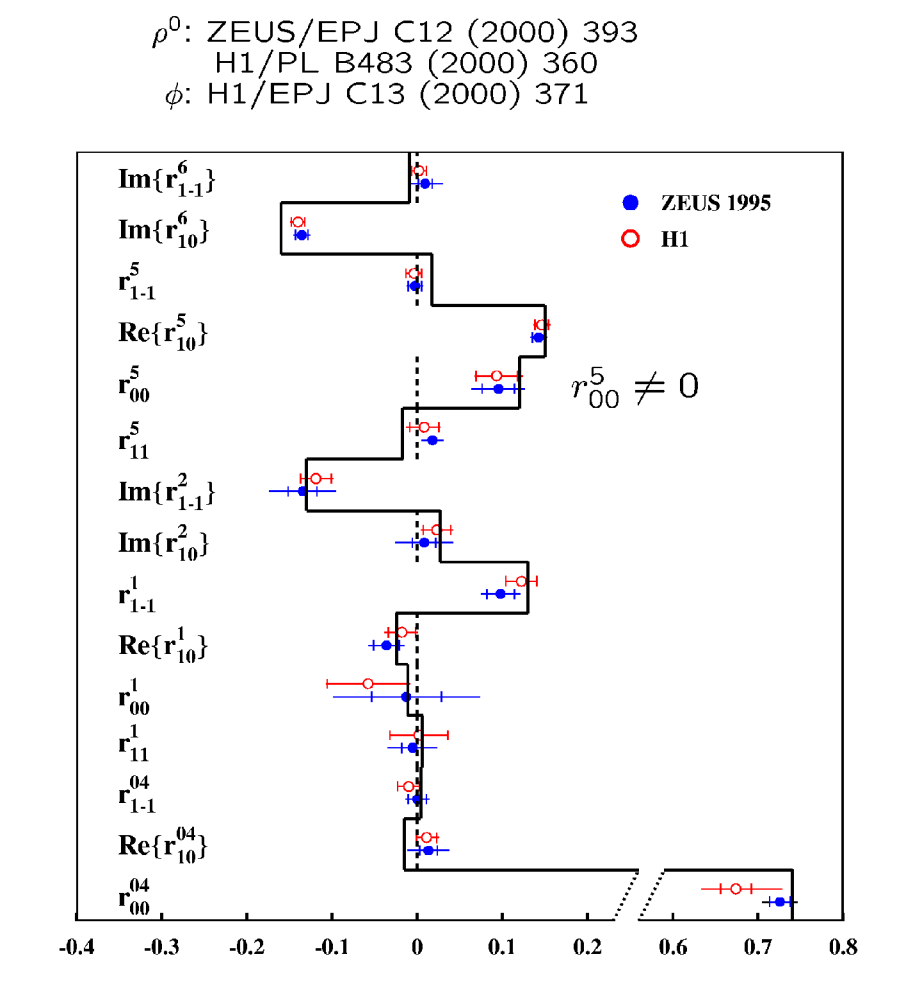
$$W(\theta) \Rightarrow R = \sigma_L/\sigma_T = \frac{r_{00}^{04}}{\varepsilon\,(1 - r_{00}^{04})}$$



R increase with Q^2 as predicted by pQCD but does not depend on *W*...

Helicity studies

Elastic ρ^0 electroproduction: $1 < Q^2 < 60$ GeV^2



$$r_{00}^{5} \sim T_{00} T^{*}_{01} + T_{01} T^{*}_{00} \neq 0$$

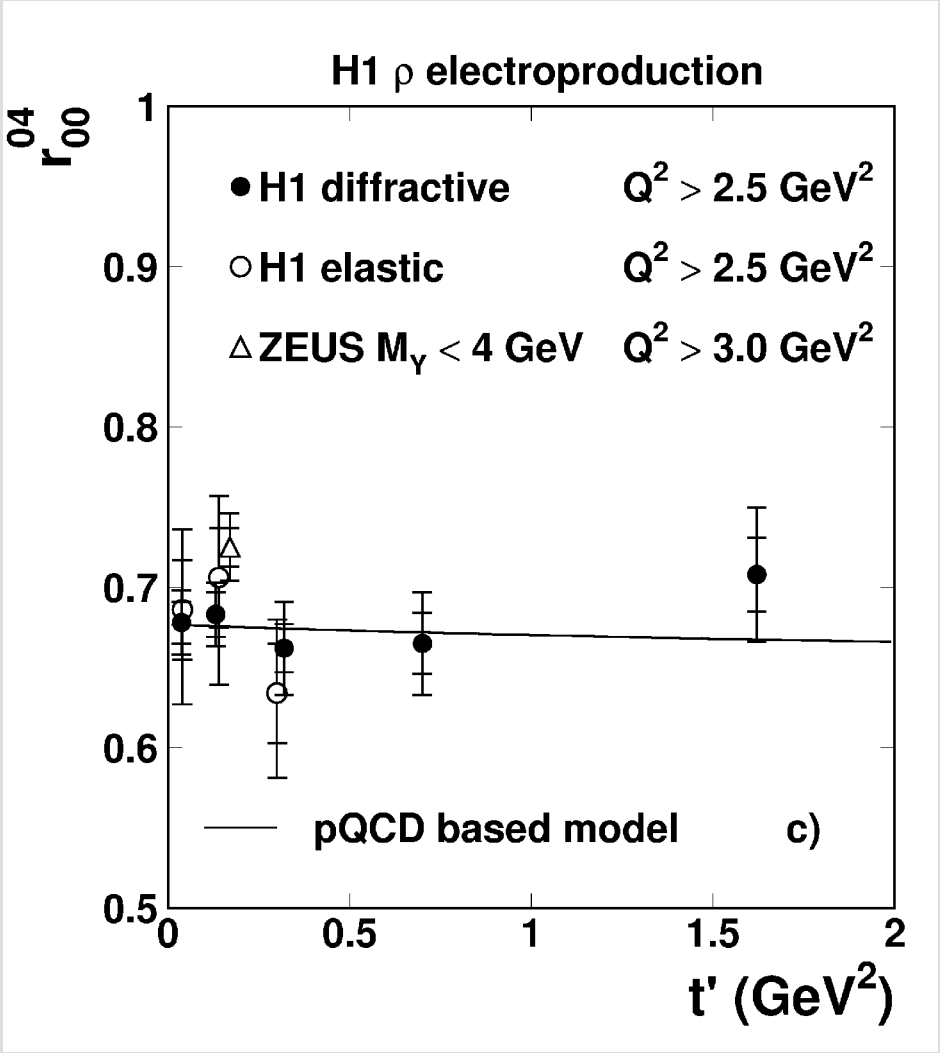
$\Rightarrow$ $\gamma_T \rightarrow \rho_L$ transition observed

SCHC breaking predicted by pQCD model (Ivanov, Kirschner): qq interaction with proton

$\Rightarrow$ helicity flip

Helicity studies

Elastic and p-diss. ρ^0 electroproduction: *t* dependence of SDME

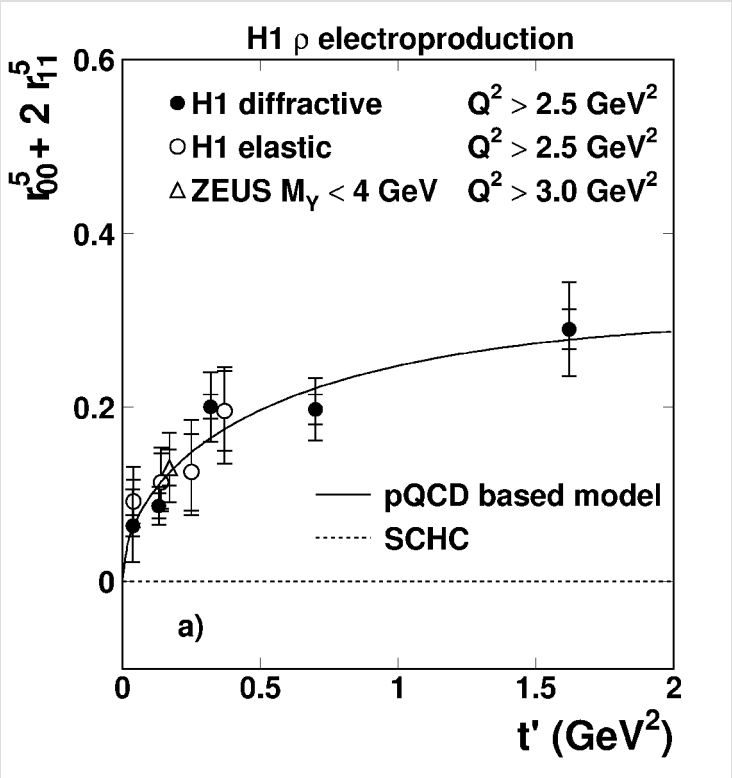


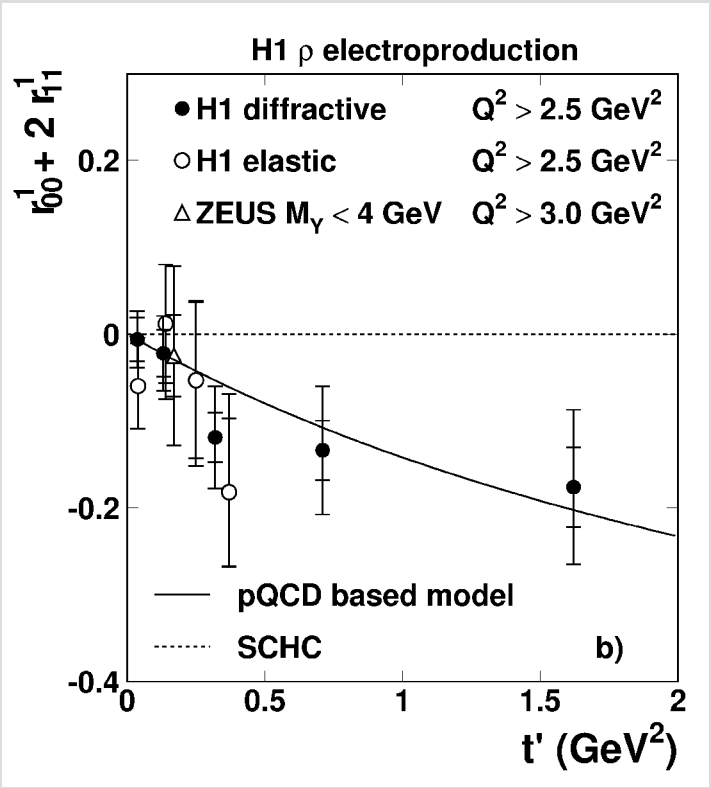
$$R = \sigma_L/\sigma_T = \frac{r_{00}^{04}}{\varepsilon\,(1 - r_{00}^{04})}$$

No r_{00}^{04} (and *R*) dependence on *t*

Helicity studies

Elastic and p-diss. ρ^0 electroproduction: *t* dependence of SDME

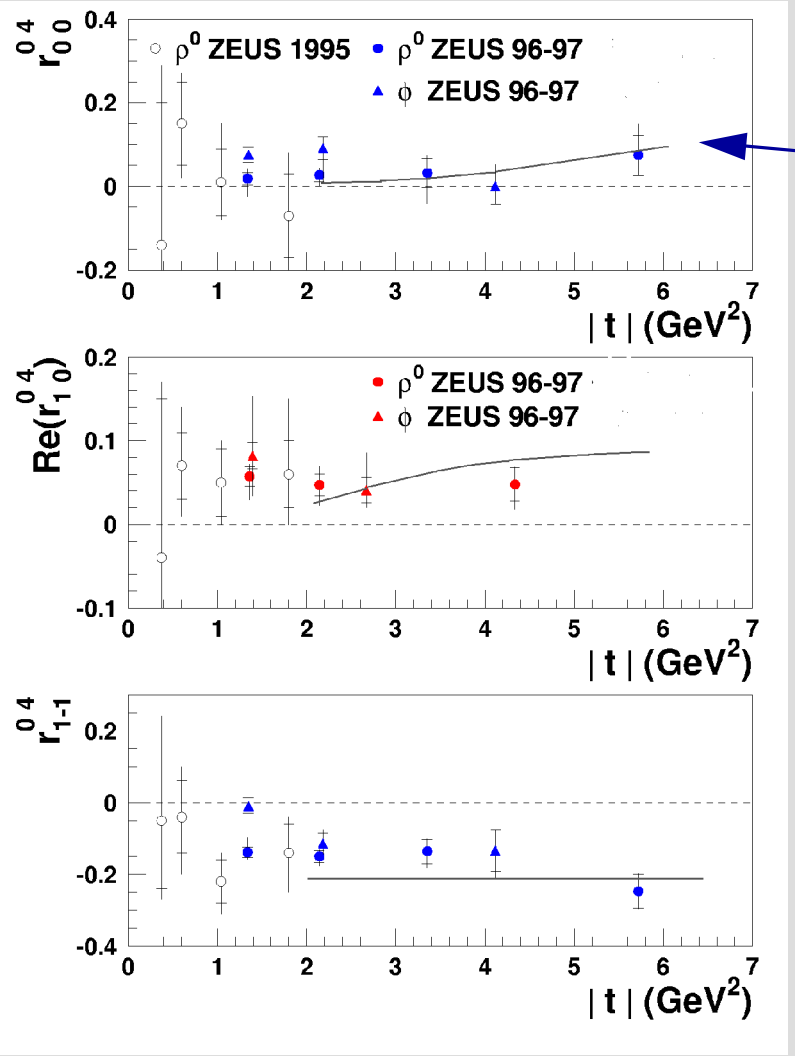




These SDME are dominated by single and double flip helicity amplitudes and exhibit SCHC violation at larger |*t*|, in accord with pQCD expectation.

Helicity studies

Proton-dissociative ρ^0 and ϕ photoproduction:



~ single flip

Model Enberg, Motyka & Poludniowski:
VM wave functions a la Ivanov *et al.*,
BFKL exchange with higher conformal spins $\Rightarrow$ OK!

~ single/double flip

~ double flip

SCHC violated at large $|t|$!

Summary and Outlook

- Continued analysis of HERA I data

  $\Rightarrow$ new results of higher precision, in large kinematic region

- Production of vector mesons: non-perturbative - perturbative QCD playground

- At large M^2_{VM} , Q^2 or $|t|$ the VM production shows expected features of a short distance (hard) process:

  steep rise of the cross section with energy,

  harder $|t|$ distribution,

  SCHC breaking

- Universality in VM production - still an open question

Summary and Outlook

- $|t|$ is confirmed as a hard scale, however not equivalent to Q^2

- In the presence of a hard scale perturbative QCD describes many aspects of the data - there is room for improvement however

- Outlook:
  Still ongoing HERA I data analysis,
  HERA II - 1 fb^{-1} luminosity expected and upgraded detectors
  $\Rightarrow$ extension of the kinematic range to higher Q^2 and $|t|$