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Vector Meson Production at Large Q^2 and $|t|$ at HERA

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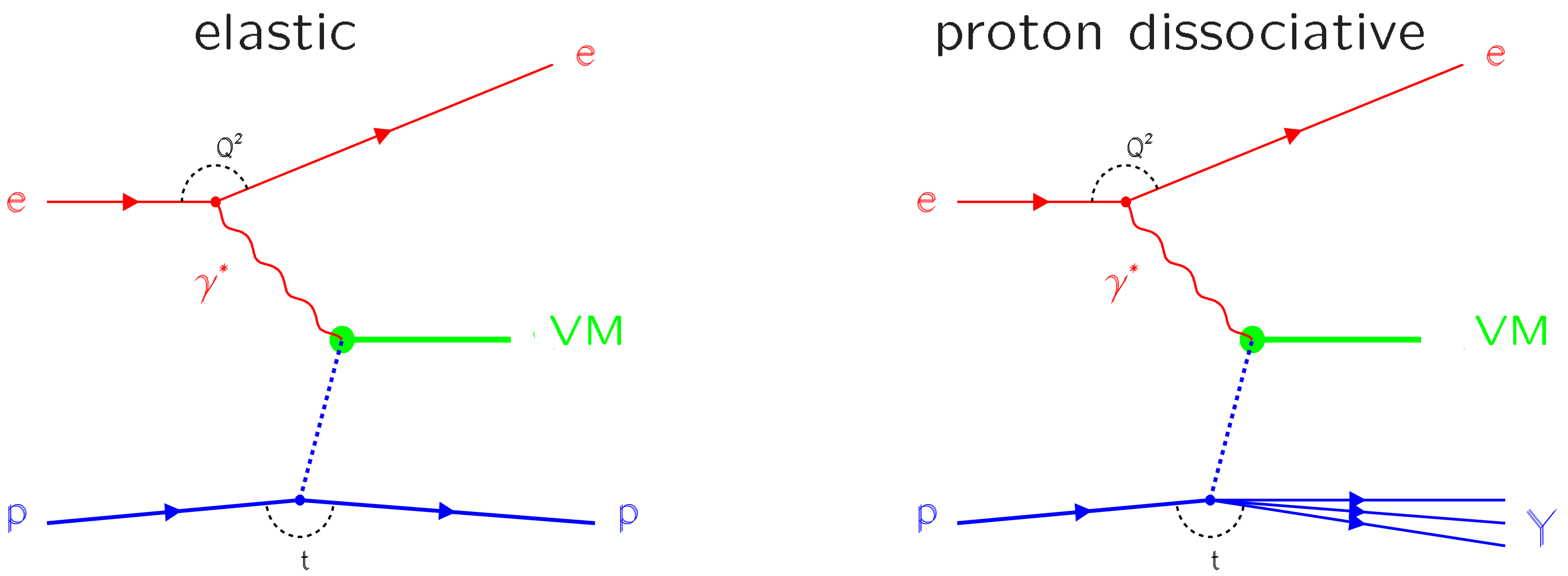
- Introduction
- ρ^0 and J/ψ Electroproduction (# 559, 594)
- VM Production at large $|t|$ (# 556, 806)
- Helicity Studies (# 796, 556)
- Conclusions

Diffractive Vector Meson Production at HERA

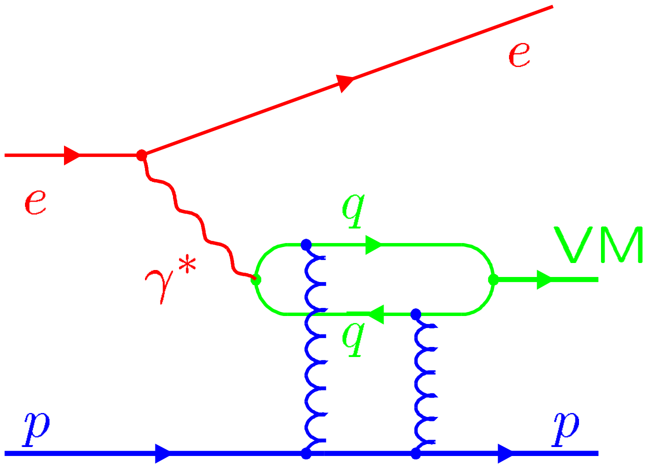


Q^2	γ^* Virtuality	$0 < Q^2 < 100\,\text{GeV}^2$
$W_{\gamma p}$	CM Energy of $\gamma^* p$ system	$20 < W_{\gamma p} < 290\,\text{GeV}$
t	(4-mom. transfer at p vertex)^2	$0 < \lvert t\rvert < 20\,\text{GeV}^2$
VM	Vector Meson	$\rho^0,\ \omega,\ \phi,\ J/\psi,\ \psi',\ \Upsilon$

$\Rightarrow$ HERA: Simultaneous control of different scales (Q^2, t, M_{VM})

$\Rightarrow$ At large $|t|$: proton dissociation process dominates

Vector Meson Production



Perturbative QCD in lowest order:

2-gluon exchange

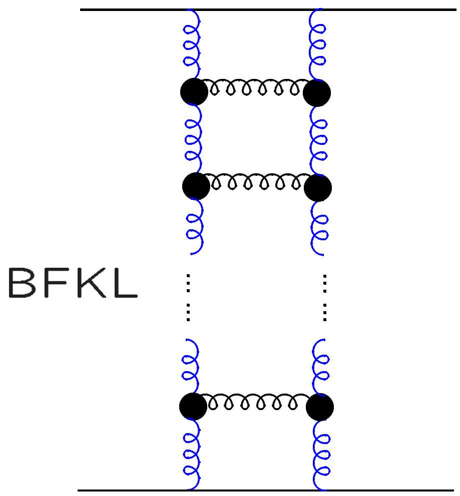
$$\sigma \propto [xg(x, Q^2)]^2$$

$$x = \frac{Q^2 + M_V^2}{W^2}$$

- Steep rise with W
- At large $|t|$: $\frac{d\sigma}{dt} \propto |t|^{-n}$

  Weaker dependence
- Q^2 and M_V^2 are hard scales
- What about $|t|$?
- At large $|t| \gtrsim 1\text{GeV}^2$: Cross section calculations available in LO (BFKL)

  Forshaw, Ryskin (1995), Bartels et al. (1996)



Effective diagram

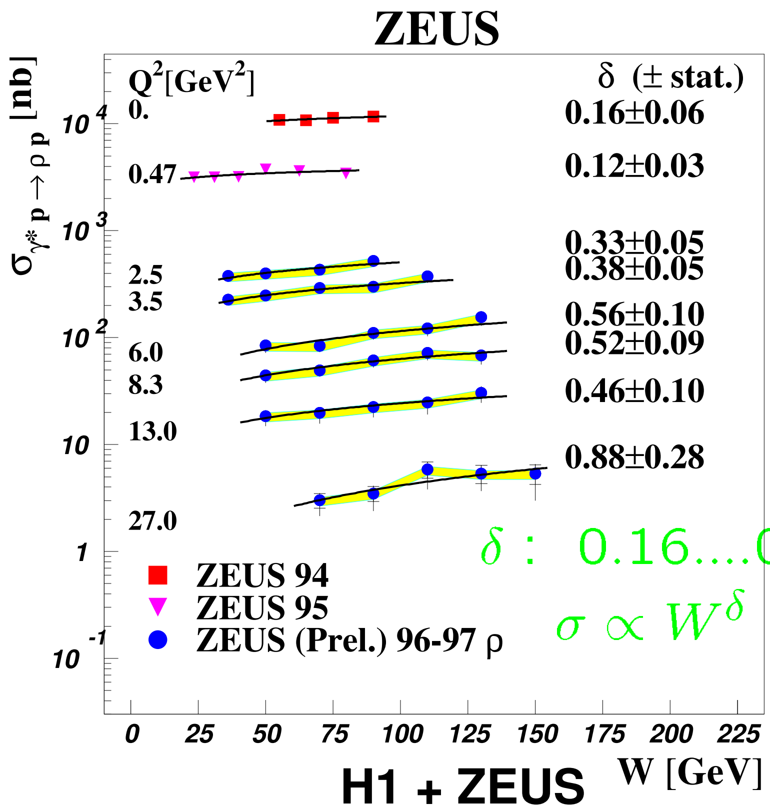
Energy Dependence

Elastic Electroproduction

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

Slope rising with Q^2

Transition
soft $\rightarrow$ hard



δ : 0.16....0.88

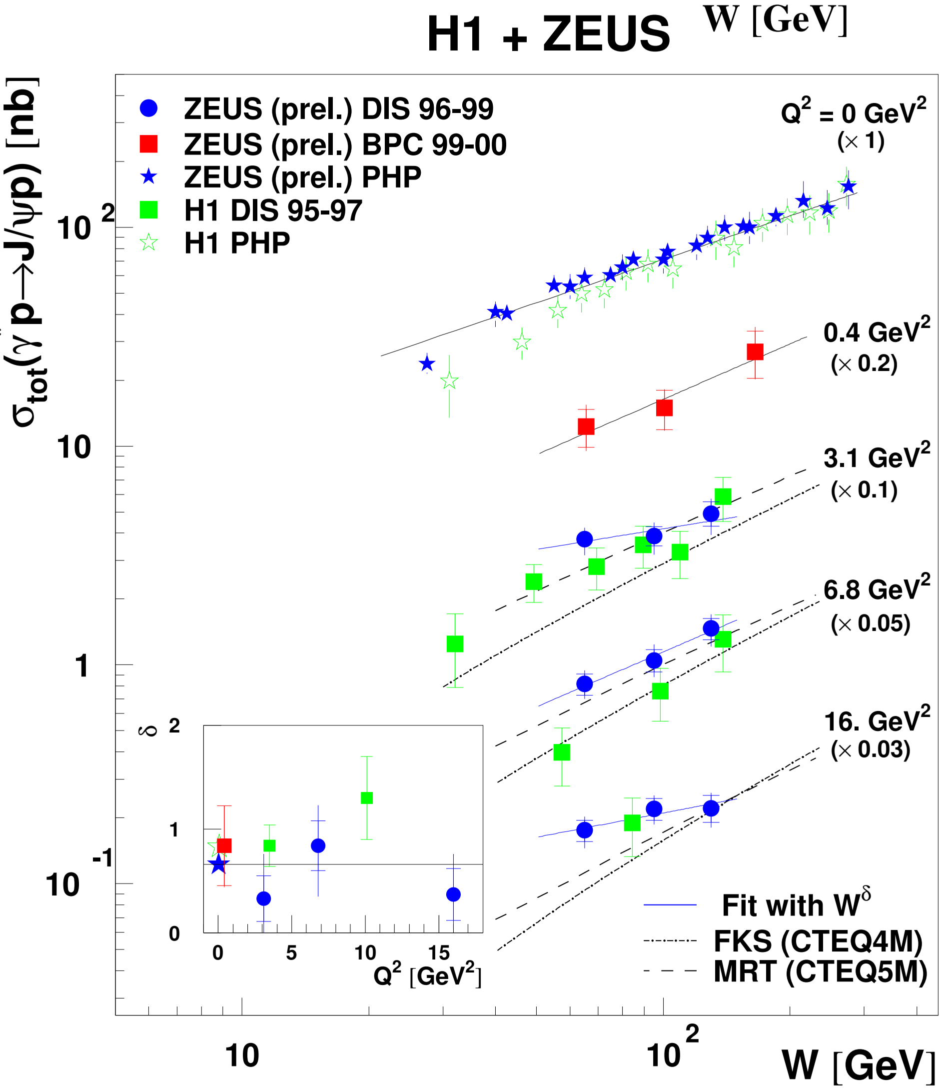
$\sigma \propto W^\delta$

$\gamma^* p \rightarrow J/\psi p$

New data in
transition region
(ZEUS)

Steep rise already
at $Q^2 \sim 0$

$M^2_{J/\psi}$ provides
a hard scale



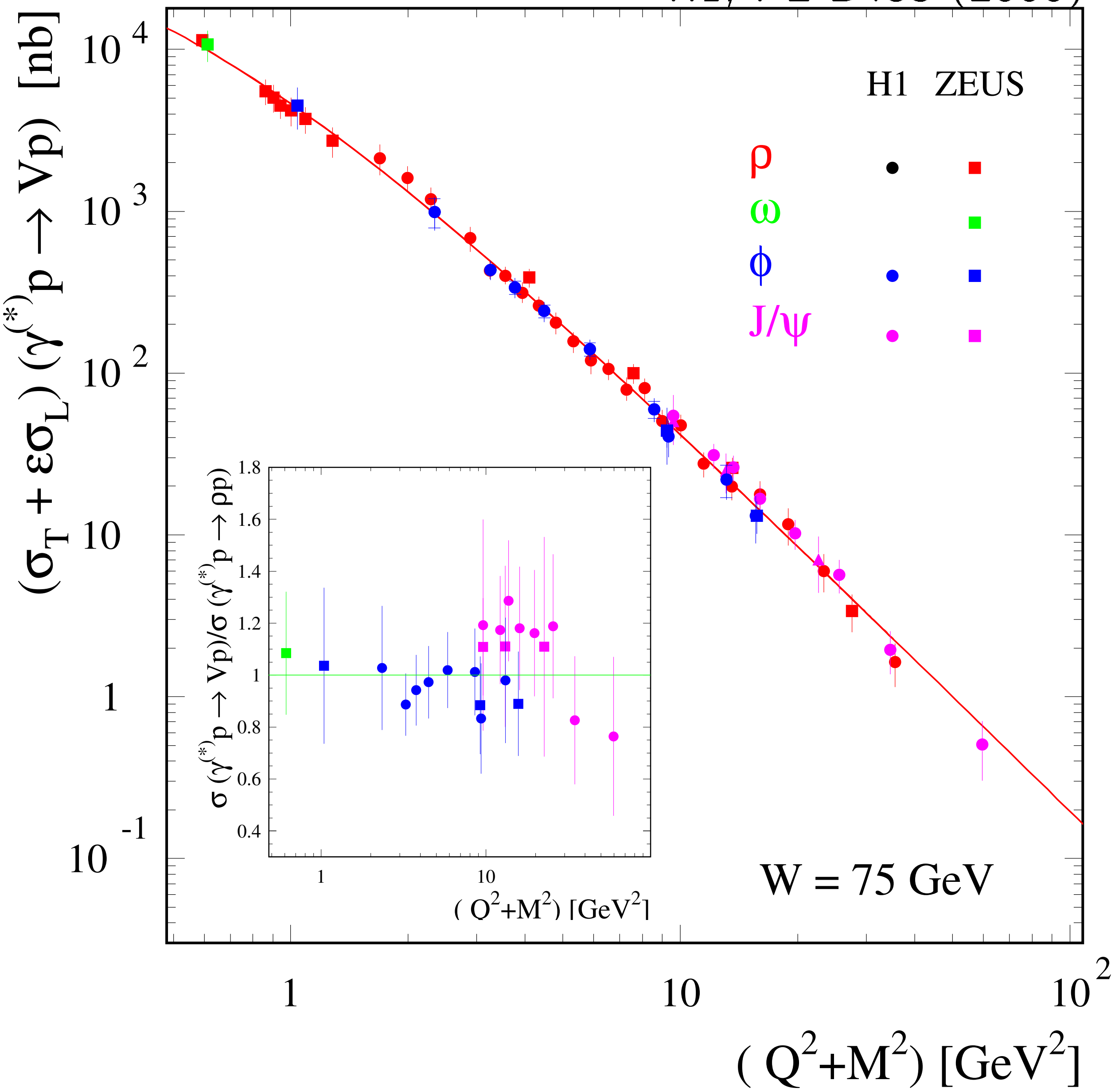
Universal Behaviour

Interplay between Q^2 and M_V^2 scales:

Elastic VM total cross sections

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

H1, PL B483 (2000)



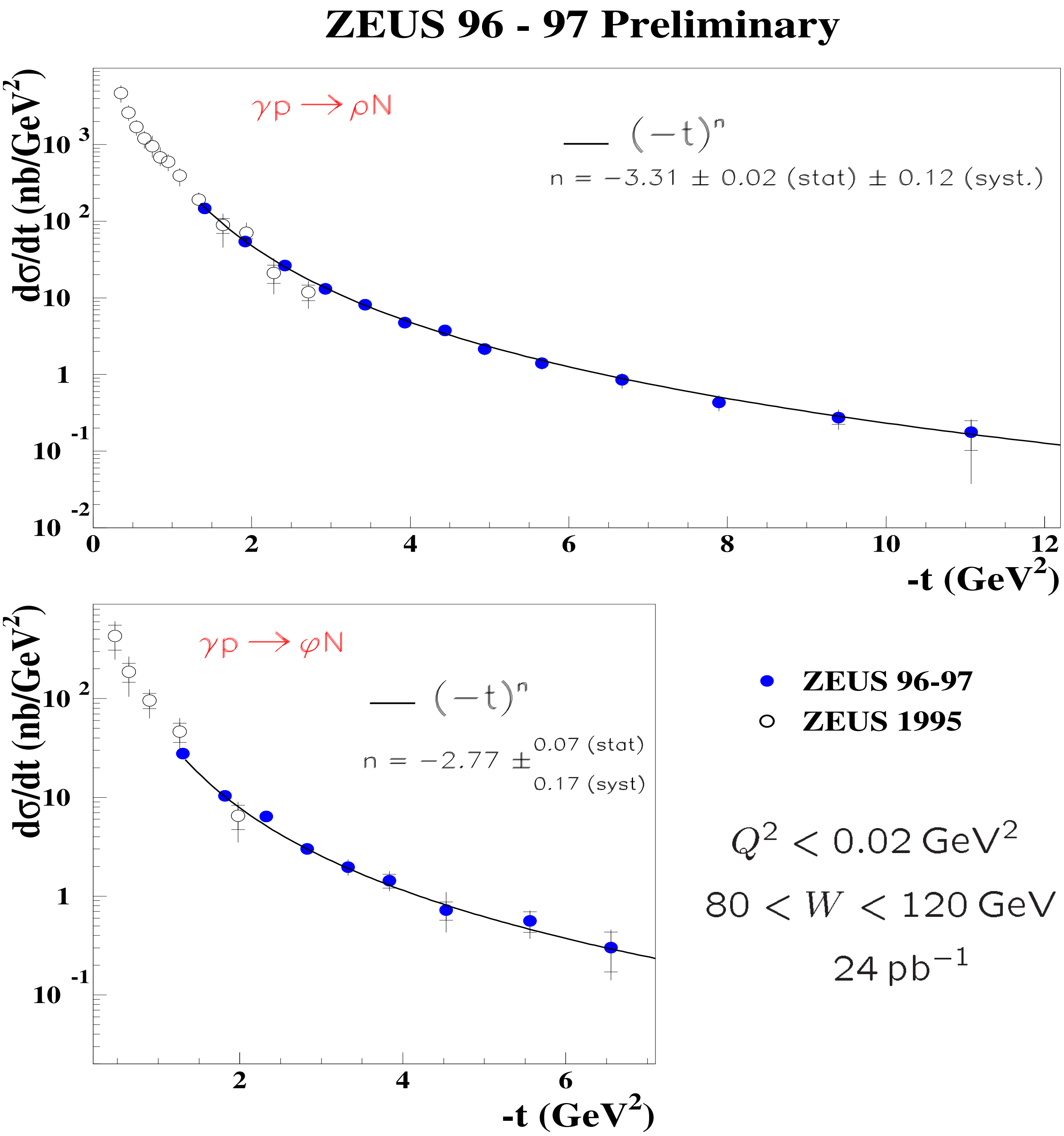
$(Q^2 + M_V^2)$ appears to be a universal scale

(cf. talk by B. Mellado)

VM Production at high $|t|$

Proton-Dissoc. Photoproduction of ρ, ϕ

Does $|t|$ also provide a hard scale?



$Q^2 < 0.02$ GeV^2

$80 < W < 120$ GeV

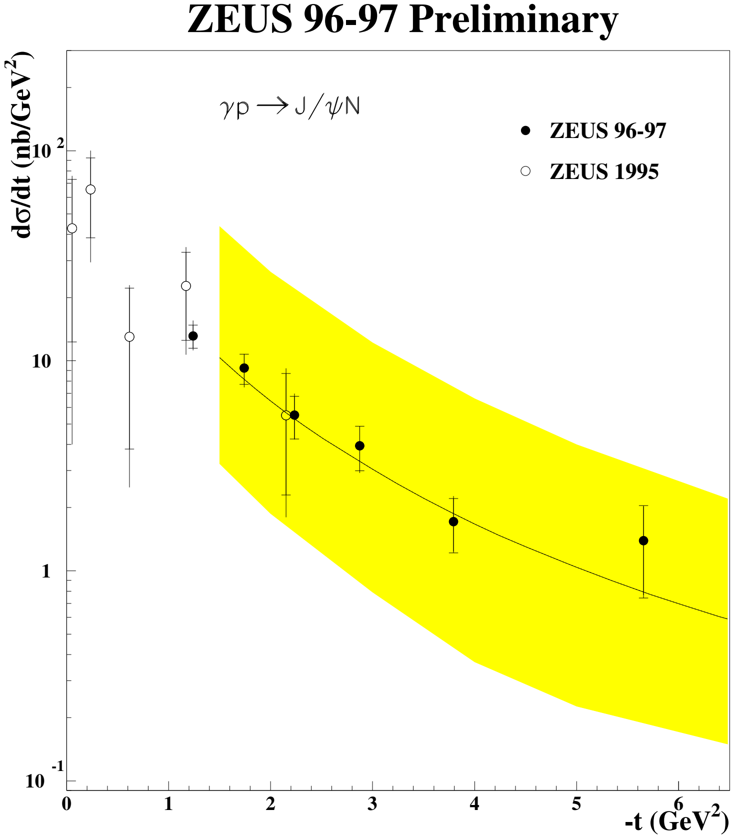
$24\ \mathrm{pb}^{-1}$

- t dependence at high $|t| \propto -t^n$
- $n \sim -3$ for both ρ and ϕ mesons

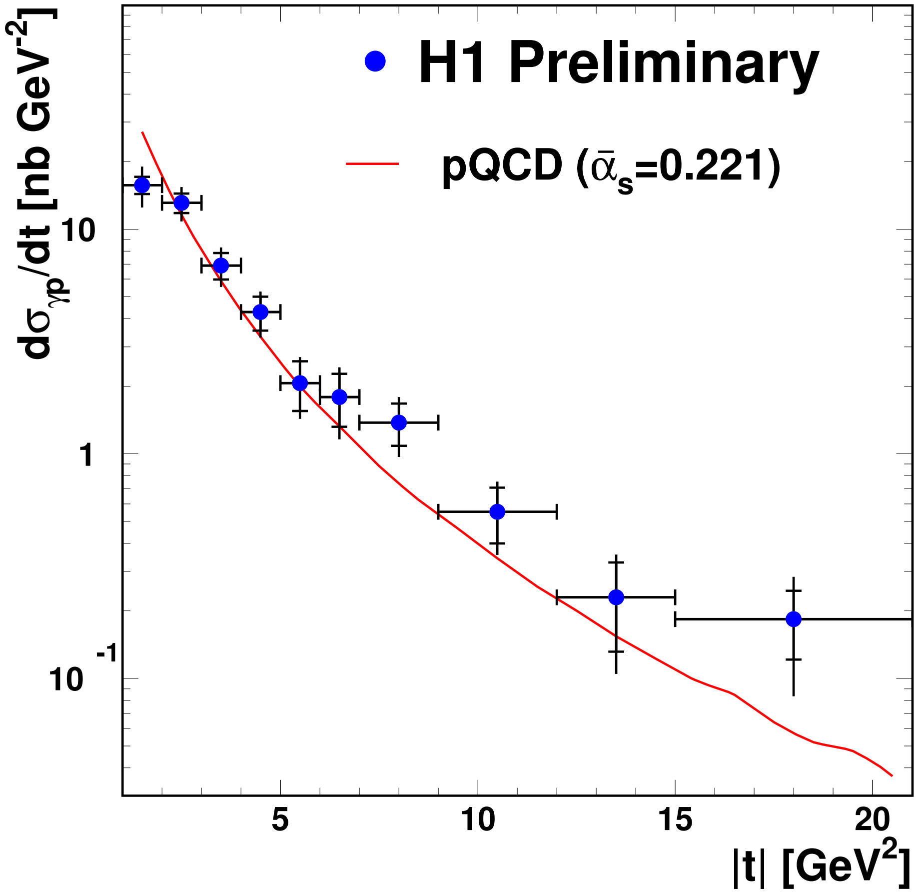
J/ψ production at high $|t|$

Proton-Dissoc. Photoproduction: $\gamma p \to J/\psi X$

$Q^2 < 0.02\ \mathrm{GeV}^2; 80 < W < 120\ \mathrm{GeV}$



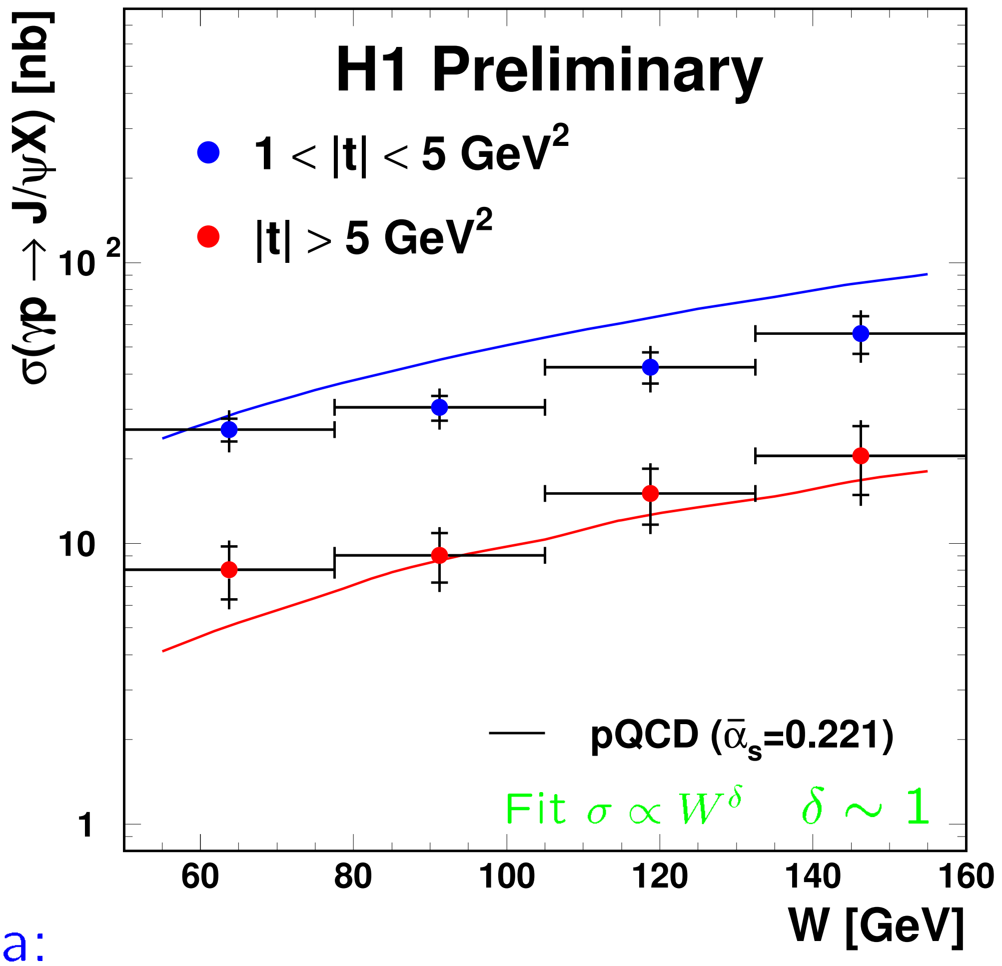
$Q^2 < 1\ \mathrm{GeV}^2; 50 < W < 160\ \mathrm{GeV}$



- t-dependence $\propto t^{-1.7}$, even flatter than for ρ and ϕ
- Data well reproduced by LO BFKL model (Forshaw, Ryskin 1995)
- Large normalization uncertainty: Choice of $\bar{\alpha_s}$

Energy Dependence at high $|t|$

Proton-Dissoc. Photoproduction: $\gamma p \to J/\psi X$



Data:

- W-dependence similar to elastic J/ψ at low $|t|$

BFKL LO Calculation predicts:

$$\sigma_{\gamma p \to J/\psi X}(W) \propto W_{\gamma p}^{4(a_P(0)-1)}$$

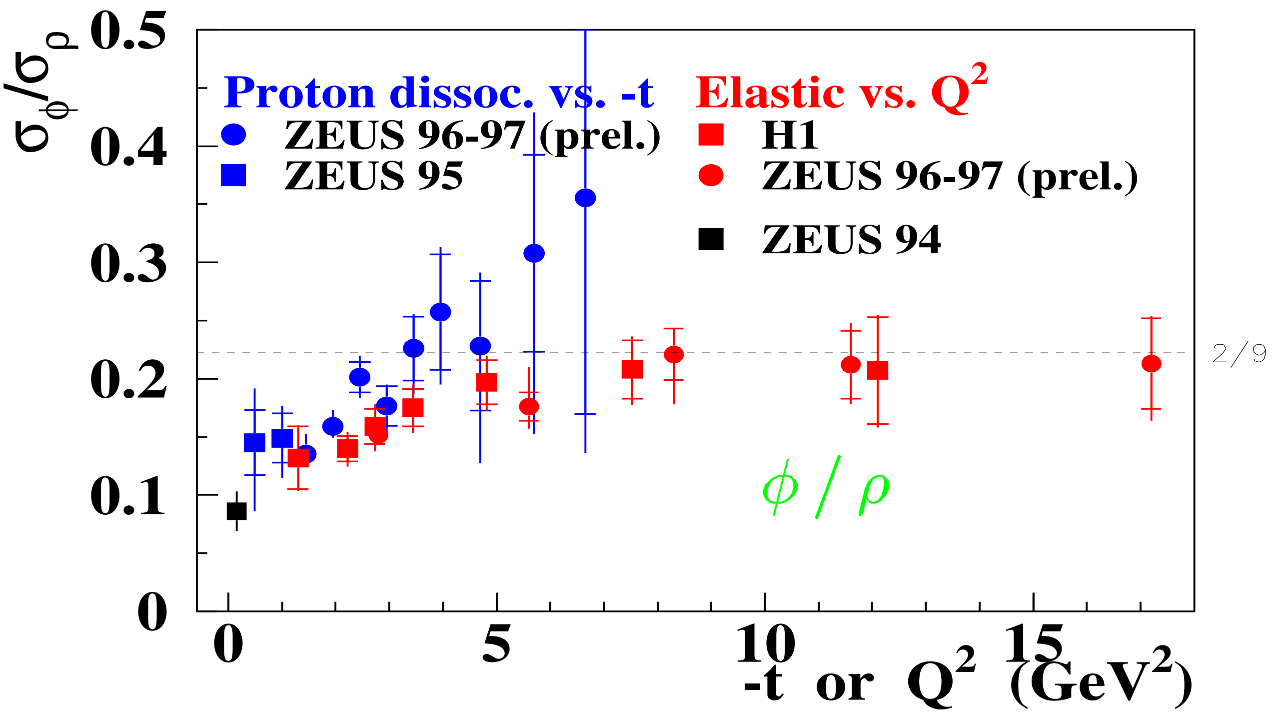
$$\text{with} \quad a_P(t) = 1 + 4\bar{\alpha}_s \ln 2$$

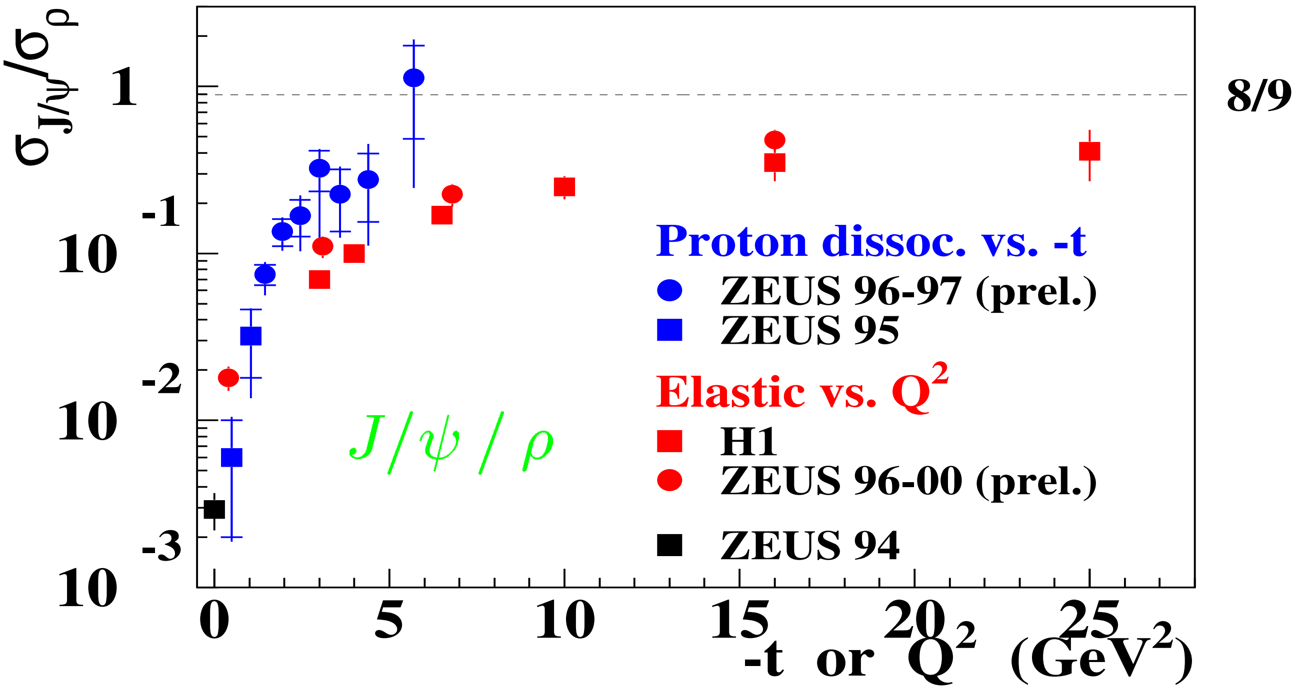
$\Rightarrow$ W-dependence sensitive to $\bar{\alpha}_s$.
$|t|$-dependence is not very sensitive.

$\Rightarrow$ Choice of $\bar{\alpha}_s \sim 0.20$:
Fair description of data in both t and W

Comparison of $|t|$ and Q^2

VM Production Cross Section Ratios





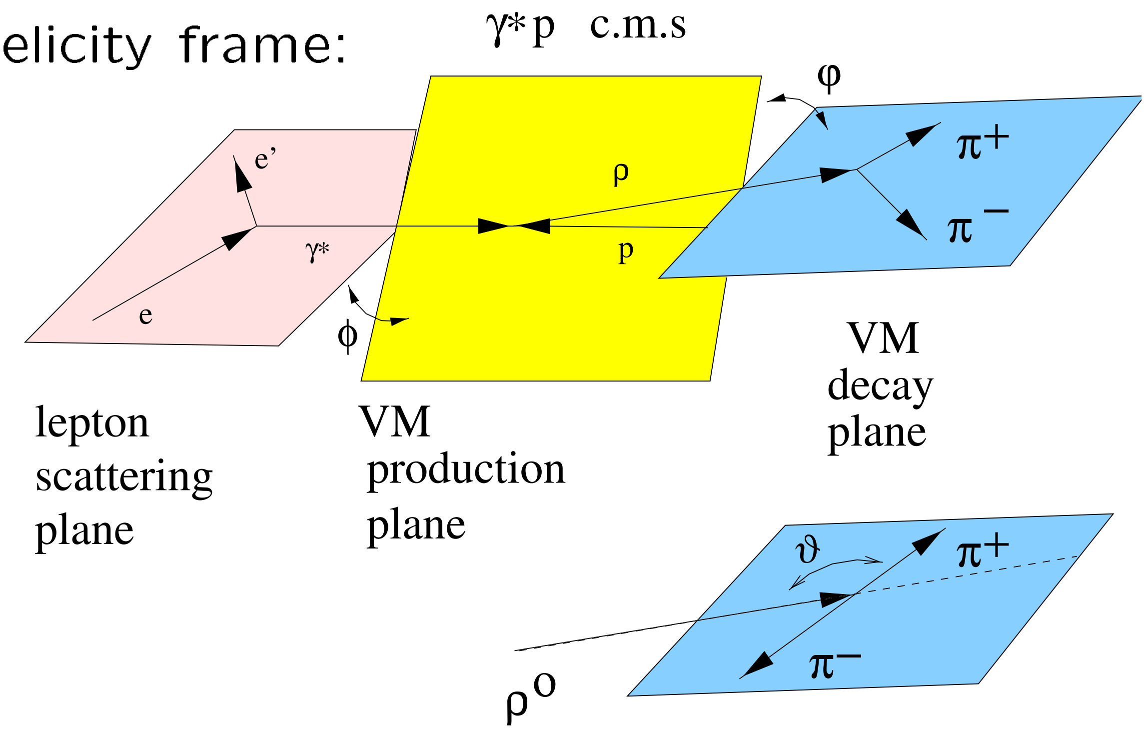
- Small $|t|$, Q^2: Rise in $|t|$ steeper than in Q^2
- Large $|t|$, Q^2: $|t|$ shows hard scale behaviour

Helicity Studies

- Study transitions between γ and VM helicity states

$\Rightarrow$ pQCD provides quantitative predictions (Ivanov, Kirschner)

Helicity frame:



Decay angular distributions: $W(\vartheta, \varphi, \Phi)$

15 combinations of spin density ME: $r_{ij}^{\alpha\beta}$

Products of helicity amplitudes: $T_{\lambda_{VM}\lambda_\gamma}$

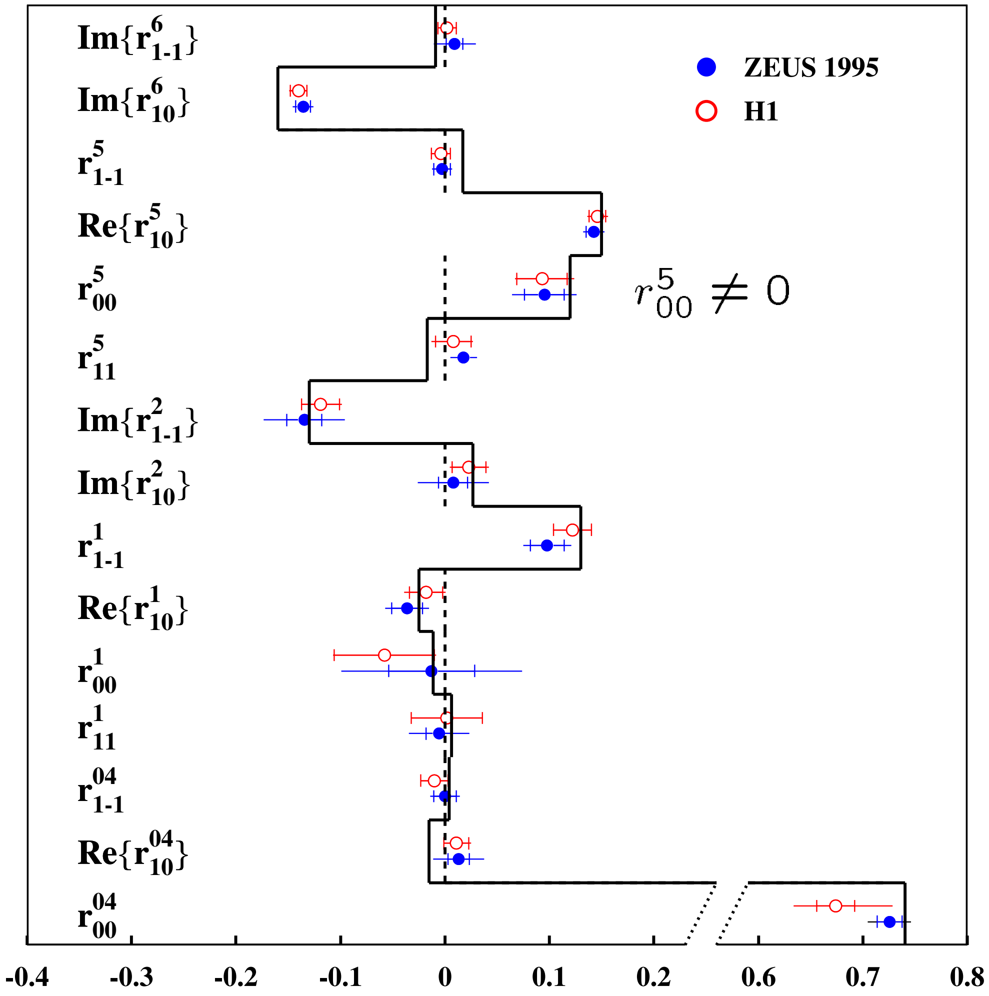
$$R = \frac{\sigma_L}{\sigma_T} = \frac{T_{00}^2 + 2T_{10}^2}{T_{01}^2 + T_{11}^2 + T_{1-1}^2}$$

- s-Channel Helicity Conservation: Expect $\gamma_T \to \rho_T$ and $\gamma_L \to \rho_L$ transitions only

Spin Density Matrix Elements

Elastic Electroproduction $\gamma^* p \to \rho^0 p$

ρ^0: ZEUS/EPJ C12 (2000) 393
H1/PL B483 (2000) 360
ϕ: H1/EPJ C13 (2000) 371



- $r^5_{00} \propto \mathrm{T}_{00}\mathrm{T}^*_{01} + \mathrm{T}_{01}\mathrm{T}^*_{00} \neq 0$

$\Rightarrow \gamma_T \to \rho_L$ transition measured

- Breaking of SCHC:

$\Rightarrow$ predicted by model using pQCD

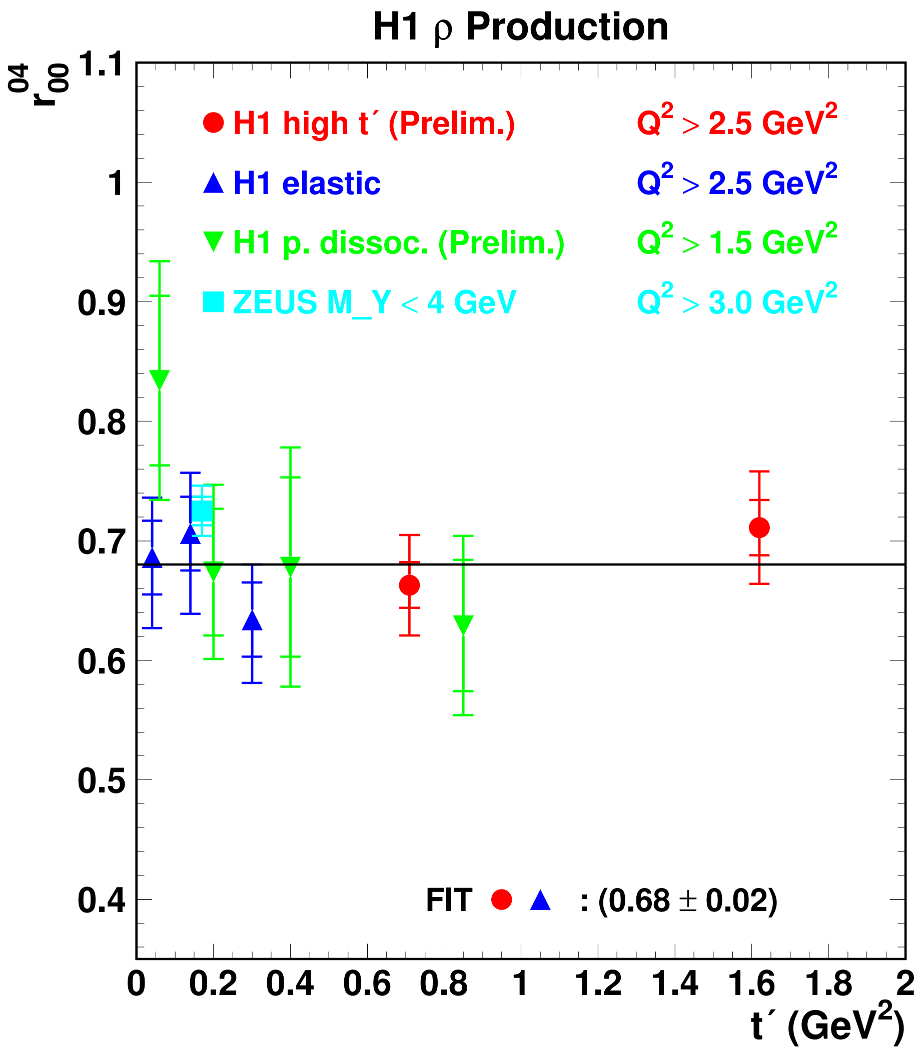
Helicity Amplitudes with $|t|$

Proton-Dissoc. Electroproduction: $\gamma^* p \rightarrow \rho^0 X$

($2.5 < Q^2 < 30\,\text{GeV}^2$, $40 < W < 140\,\text{GeV}$, $6\,\text{pb}^{-1}$)

Evaluate θ-Distributions $W(\vartheta)$ in bins of $|t|$:

$$W(\cos(\vartheta)) \propto 1 - r_{00}^{04} + (3r_{00}^{04} - 1)\cos^2\vartheta$$



$$r_{00}^{04} \propto |T_{01}|^2 + |T_{00}|^2$$

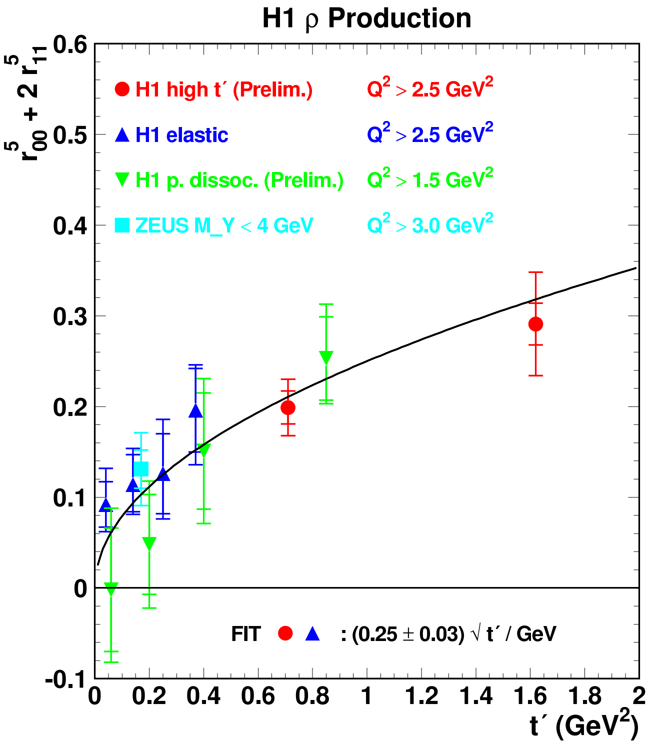
$$R = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1 - r_{00}^{04}}$$

- Flat $|t|$-dependence
- Protondissociation data similar to elastic data $\rightarrow$ Factorization of diffractive vertices

Helicity Amplitudes with $|t|$

Proton-Dissoc. Electroproduction: $\gamma^* p \to \rho^0 X$

Evaluate Φ-Distributions $W(\Phi)$ in bins of $|t|$



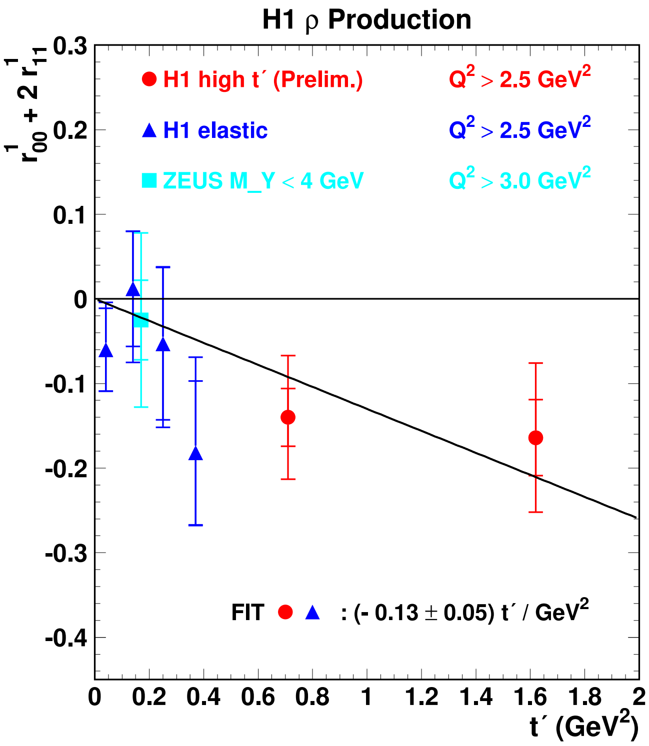
$W(\cos(\Phi)) \Rightarrow r^5_{00} + 2r^5_{11}$

$r^5_{00} \propto T_{00}T^*_{01}$

$r^5_{11} \propto T_{10}T^*_{11} + T_{10}T^*_{1-1}$

SCHC violation
in proton dissociation

Curve: $\sqrt{t}$-fit



$W(\cos(2\Phi)) \Rightarrow r^1_{00} + 2r^1_{11}$

$r^1_{00} \propto -|T_{01}|^2$

$r^1_{11} \propto T_{1-1}T^*_{11} + T_{11}T^*_{1-1}$

Contributions:

r^1_{00} : $\gamma_T \to \rho_L$ dominant

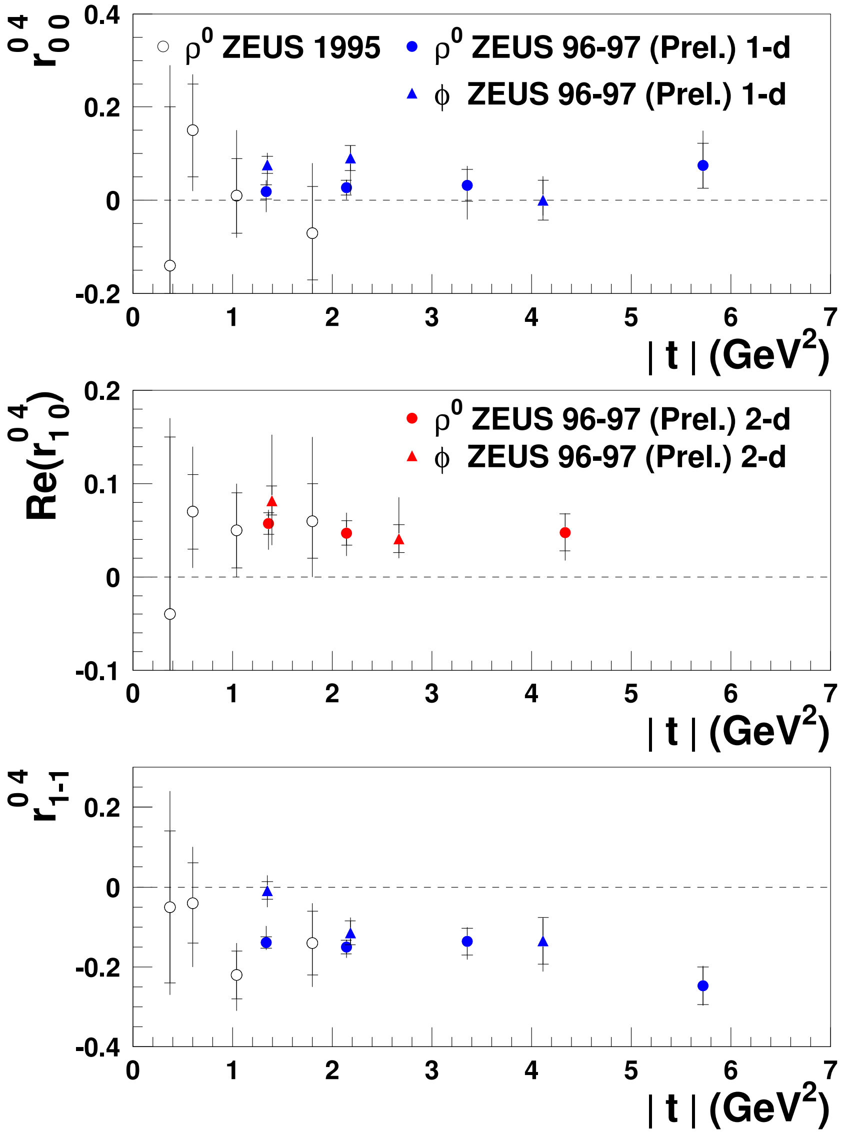
r^1_{11} : double-flip ?

Data described by pQCD-inspired fits

Helicity Amplitudes with $|t|$

Proton-Diss. Photoproduction of ρ and ϕ:

Evaluate $W(\varphi, \vartheta)$



$W(\cos^2\vartheta)$:

$r^{04}_{00} \propto |T_{01}|^2$

$W(\sin 2\vartheta \cos\varphi)$:

$Re(r^{04}_{10}) \propto Re(T_{11}T^*_{01})$

$\gamma_T \to \rho_L$: several %

$W(\sin^2\vartheta \cos 2\varphi)$:

$r^{04}_{1-1} \propto Re(T_{11}T^*_{1-1})$

Non-zero double-flip

- Results for ρ and ϕ mesons similar
- Flat t-dependence

Conclusions

Diffractive vector meson production at HERA
is an ideal testing ground of pQCD

- New results on Vector Meson Production:
  Higher precision in larger kinematic region

- Large $|t|$: proton dissociation data
  reveal pQCD features, ie.
  SU(4)-symmetry (ρ^0, ϕ), $|t|^{-n}$-dependence

- VM Production Ratios:
  $|t|$-behaviour qualitatively similar to Q^2

- $\gamma p \to J/\psi X$ at very large $|t|$:
  reproduced by LO BFKL calculation

- Helicity studies at large $|t|$:
  New data on $\gamma \to$ VM helicity transitions
  match with pQCD predictions

- $|t|$ is confirmed as a hard scale variable

More data exploring the transition region
between soft and hard diffraction is underway