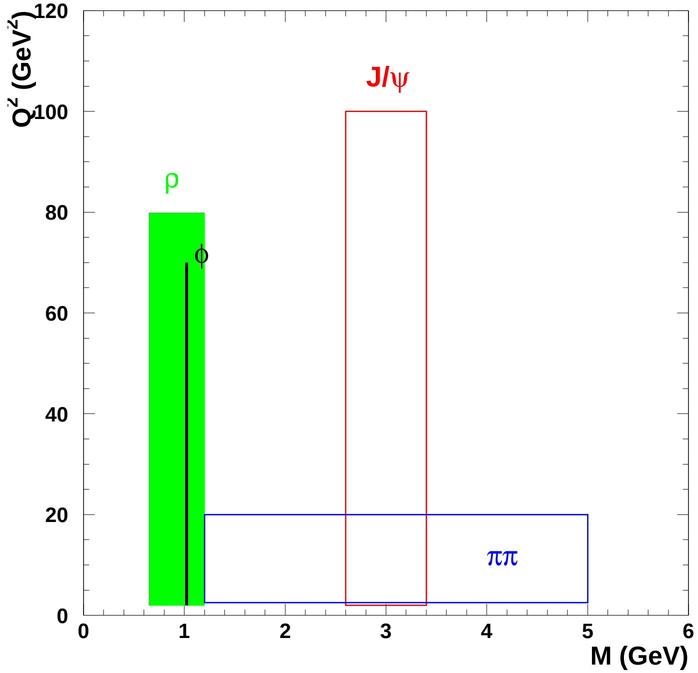
Vector Mesons at ZEUS

Dorota Szuba
DESY, Hamburg

on behalf of the ZEUS Collaboration

International Workshop on Diffraction in High-Energy Physics
DIFFRACTION 2006, September 5-10 2006, Milos, Greece

Outline



- Exclusive ϕ electroproduction

(Nuc. Phys. B 695 (2004) 3)

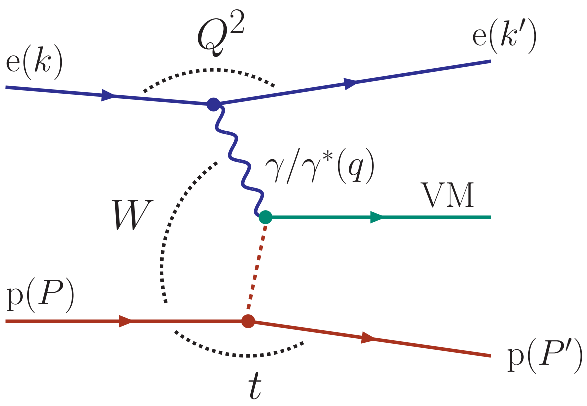
- Exclusive di-pion production

(preliminary status)

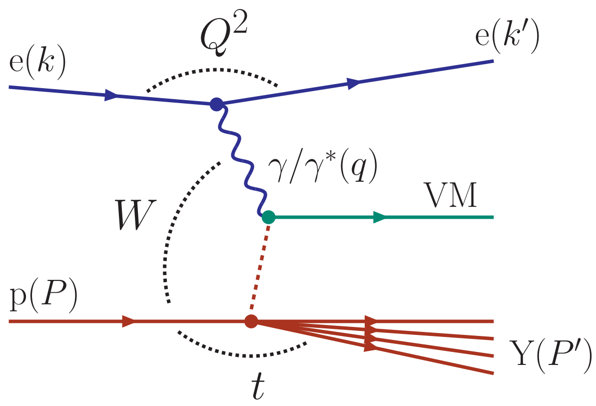
- Proton-dissociative J/ψ photoproduction at high $|t|$ (DIS05)

Diffractive vector meson production in $\gamma^* p$

'elastic' (exclusive)



proton dissociative



experimentally: very clean process in wide kinematic range

VM	Vector Meson	$\rho, \omega, \phi, J/\psi, \psi', \Upsilon$
Q^2	photon virtuality	$Q^2 = -q^2 = -(k - k')^2$
W	c.m. energy of γp system	$W = (q + p)^2$
t	(4-mom. transfer)^2 at p-vertex	$t = (P - P')^2$

$\longrightarrow$ **VM at HERA: transition between soft and hard regime**

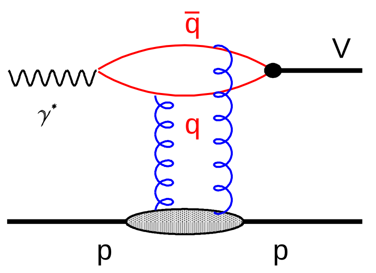
$\longrightarrow$ **simultaneous control of different scales:** Q^2, $|t|$, M_{VM}^2

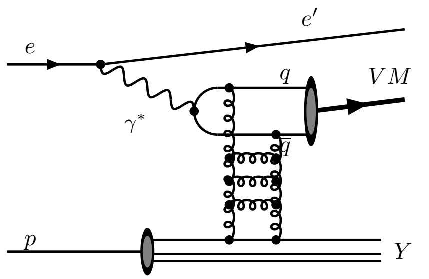
Diffractive vector meson production in pQCD

VM = $q\bar{q}$ dipol, exchange of $\geq$ 2 gluons (color singlet – QCD Pomeron)

large Q^2, M^2_{VM} or $|t| \Rightarrow$ small $q\bar{q}$ and interaction size

hard interaction $\Rightarrow$ perturbative QCD applicable, factorization holds





'Exclusive' VM electroproduction:

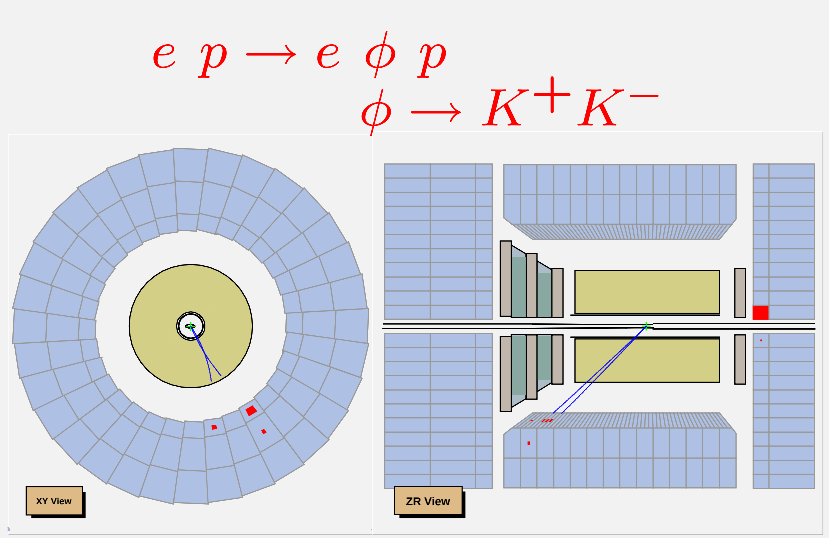
- steep rise of $\sigma(W)$, $\sigma \sim \frac{\alpha_S(Q^2)}{Q^6}[xg(x,Q^2)]^2$, $x \approx Q^2/W^2$
- universal t dependence: $\sim \exp^{-b_{2g}|t|}$, $b_{2g} \sim 4-5\,\mathrm{GeV}^{-2}$ and $\alpha'_{I\!P} \approx 0$
- possible SCHC violation

'Proton dissociative' VM photoproduction;

- $d\sigma/d|t| \sim |t|^{-n}$
- 2-gluon exchange - no energy dependence

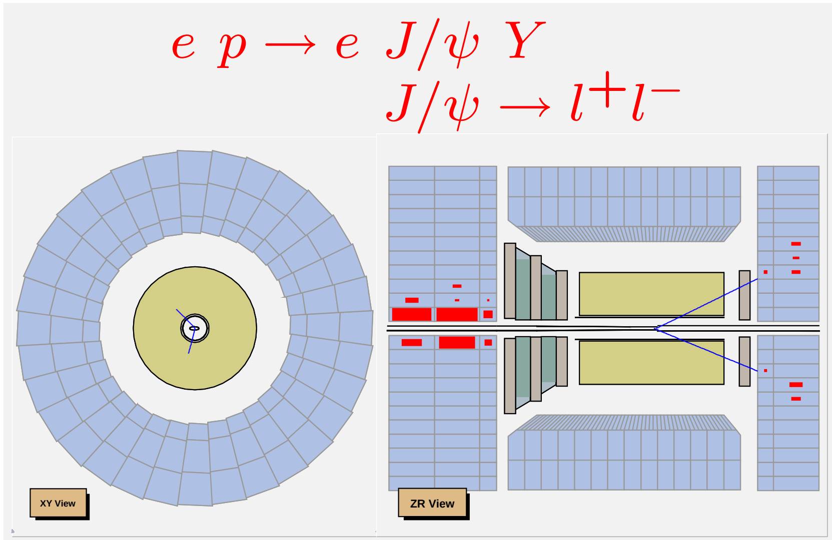
gluon ladder exchange – energy dependence:
– weak (DGLAP)
– strong (BFKL)

Clean experimental signature



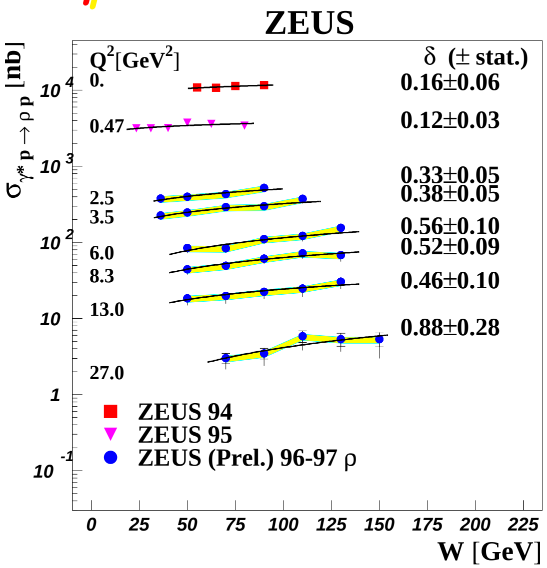
- scattered e reconstructed in CAL (DIS) or undetected (γp)
- scattered p undetected (elastic) or dissociated and deposited in forward part of CAL (p. diss.)

- two tracks reconstructed in CTD associated to identified in CAL kaons (ϕ), pions ρ, electrons or muons (J/ψ)

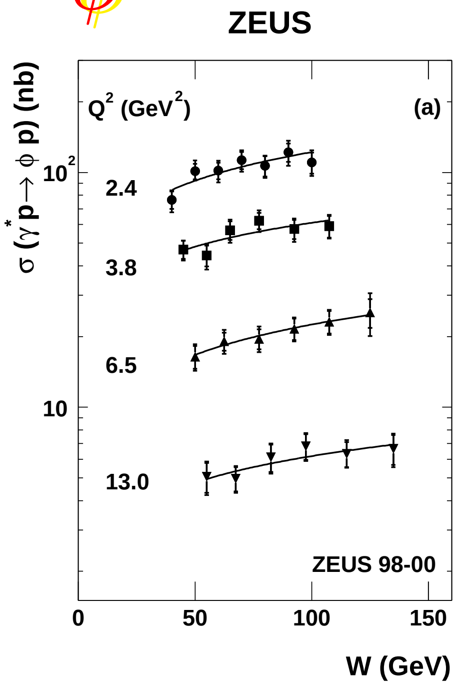


W dependence as a function of Q^2

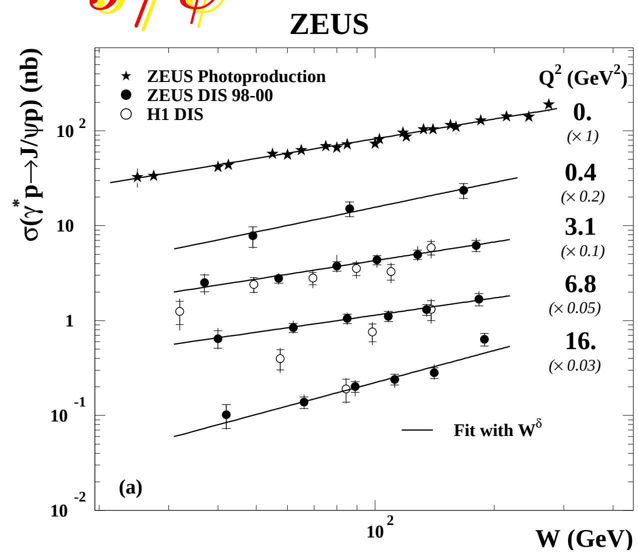
ρ



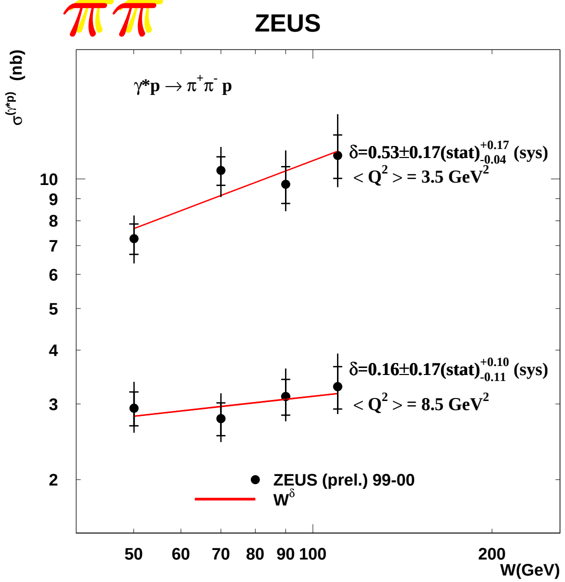
ϕ



J/ψ



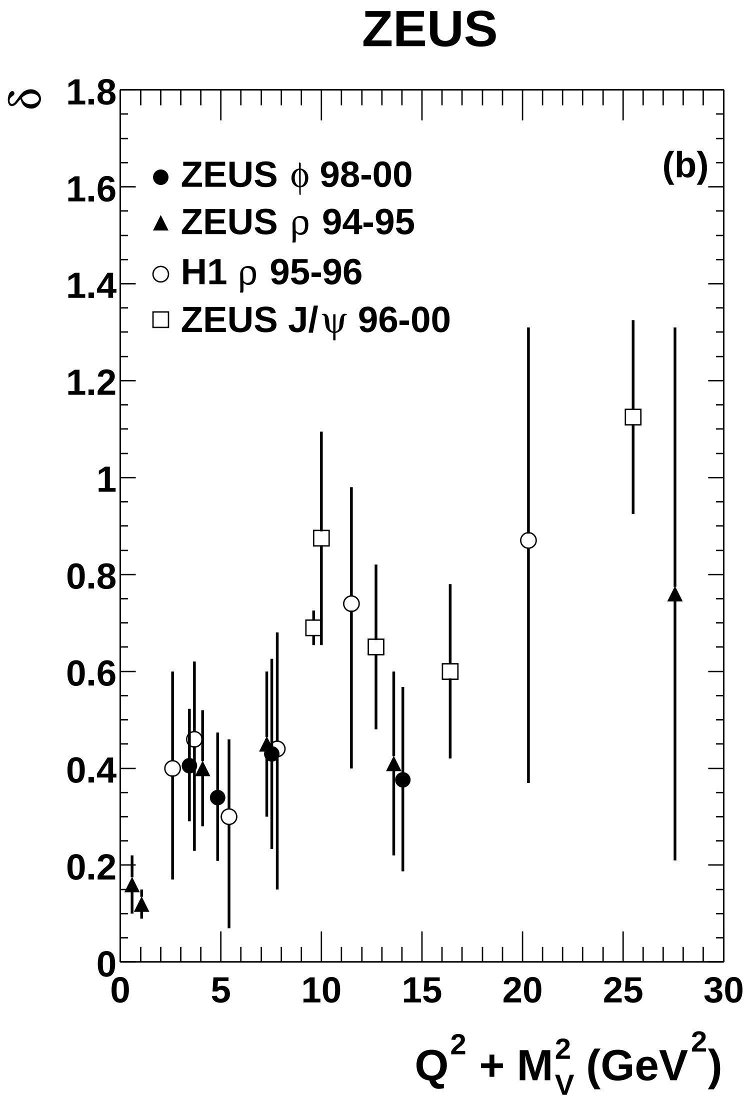
$\pi\pi$



- $\delta \sim W^\delta$
- δ_ρ increases with Q^2, at $Q^2 > 10\,\mathrm{GeV}^2$ as J/ψ
- $\delta_\phi \sim 0.4$
- $\delta_{J/\psi} \sim 0.8$

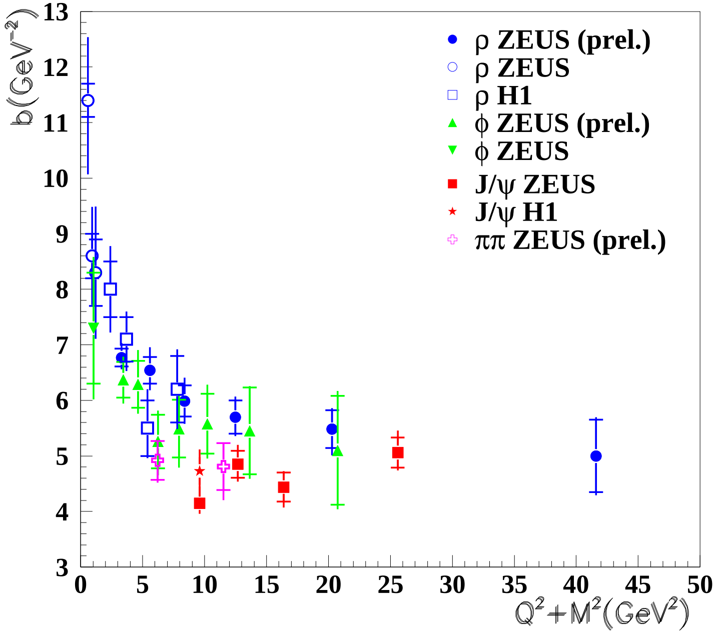
$\longrightarrow$ transition from soft to hard regime

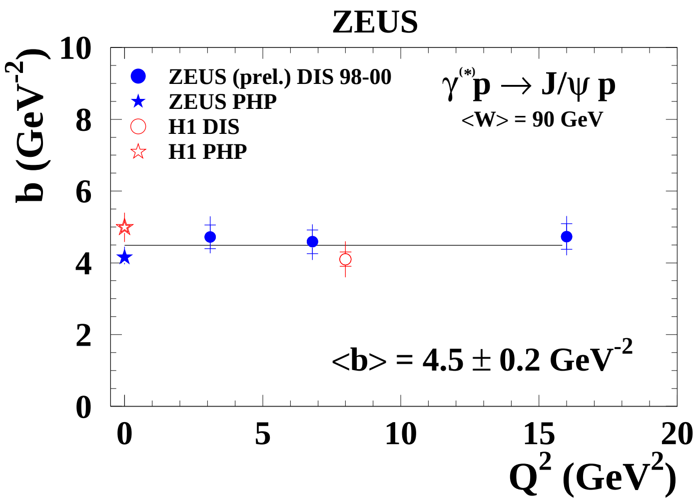
δ as a function of $Q^2 + M_{VM}^2$



- fit to $\delta \sim W^{\delta}$
- "universal" dependence of δ on $Q^2 + M_{VM}^2 \rightarrow$ transition scale
- ρ, ϕ in between from soft to hard regime
- J/ψ hard already in photoproduction

b dependence as a function of $Q^2 + M_{VM}^2$

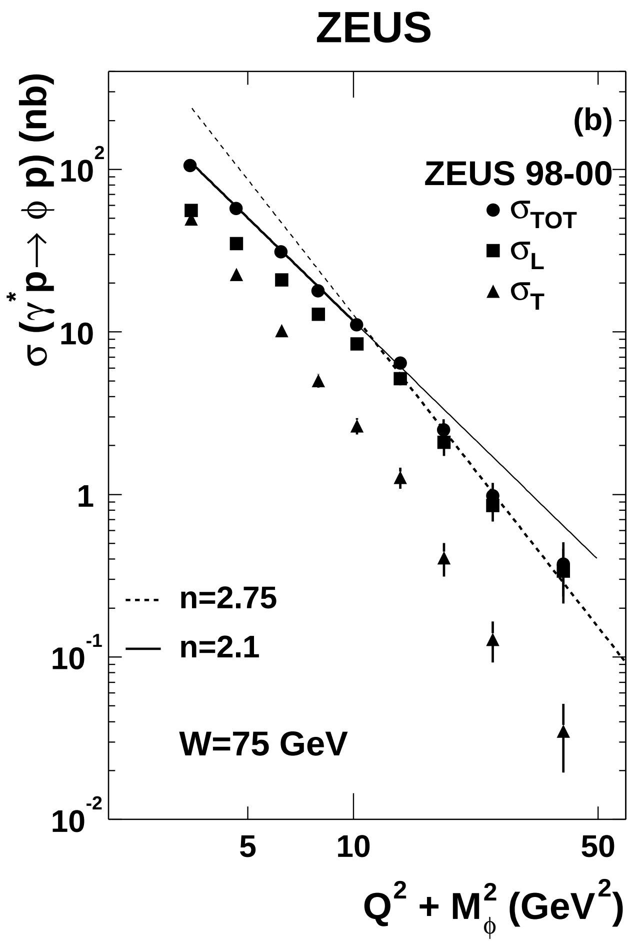


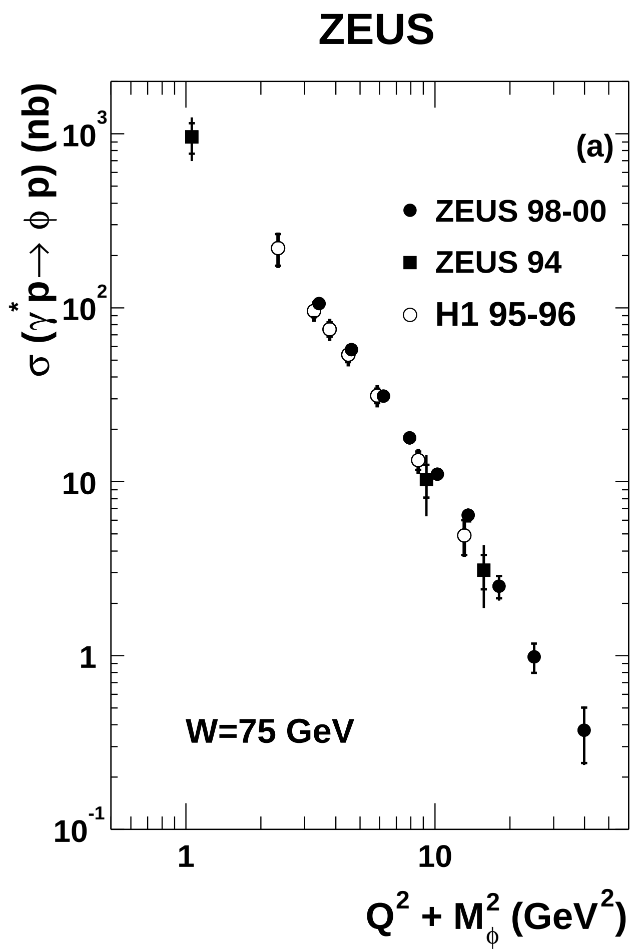


- $b \sim r^2_{\perp q\bar{q}} + r^2_{proton}$ is the size of interaction
- fit: $\frac{d\sigma}{dt} \propto \exp^{-b|t|}$
- $b_{\rho,\phi}$ decreases with $Q^2 \Rightarrow$ transverse size of $q\bar{q}$ decreases with Q^2
- $b_{\rho,\phi,\pi\pi}(Q^2 \gg 0) \longrightarrow b_{J/\psi}(Q^2 \approx 0)$
- $b \sim 4.5\,\text{GeV}^{-2}$
- b size similar to proton size $\rightarrow$ at hard scale the VM production is point-like

Q^2 dependence

- Q^2 dependence different for σ_L and σ_T
- Q^2 dependence for $W = 75$ GeV
- $\sigma \propto (Q^2 + M_\phi^2)^{-n}$



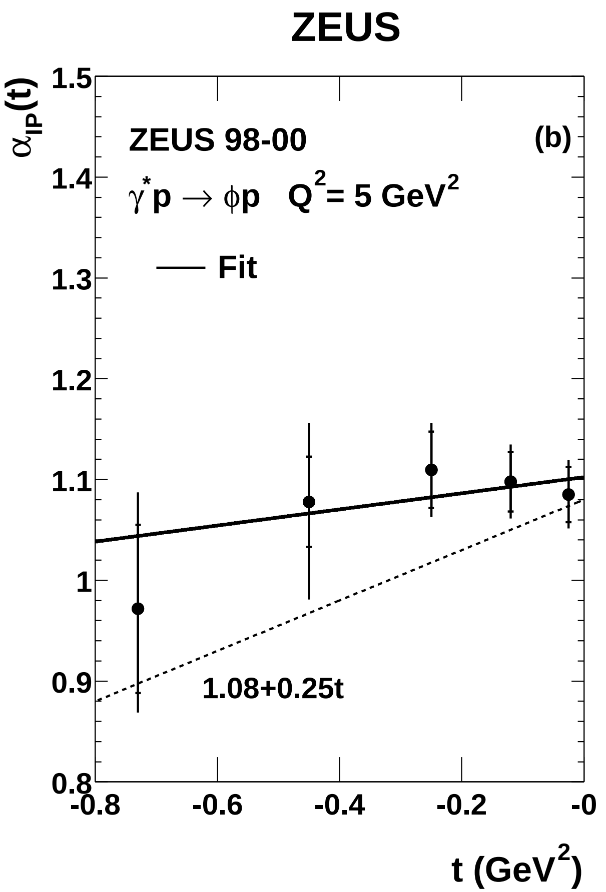


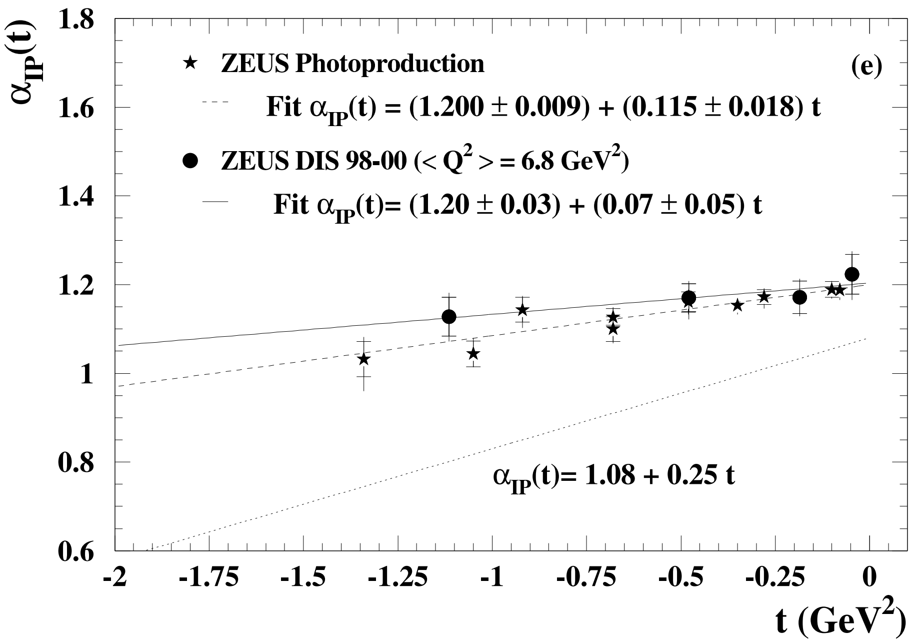
$n = 2.087 \pm 0.055_{stat} \pm 0.050_{syst}$ for $2.4 \leq Q^2 \leq 9.2$ GeV^2

$n = 2.75 \pm 0.13_{stat} \pm 0.07_{syst}$ for $9.2 \leq Q^2 \leq 70$ GeV^2

- similar results as for ρ ($n = 2.44 \pm 0.09$ for $Q^2 > 10$ GeV^2) and J/ψ ($n = 2.44 \pm 0.08$)

- fit to $\sigma \propto W^{\delta}$ at fixed Q^2
- δ related to pomeron trajectory: $\delta = 4(\alpha_{IP}(t) - 1)$ and $\alpha_{IP}(t) = \alpha_0 + \alpha' \cdot t$





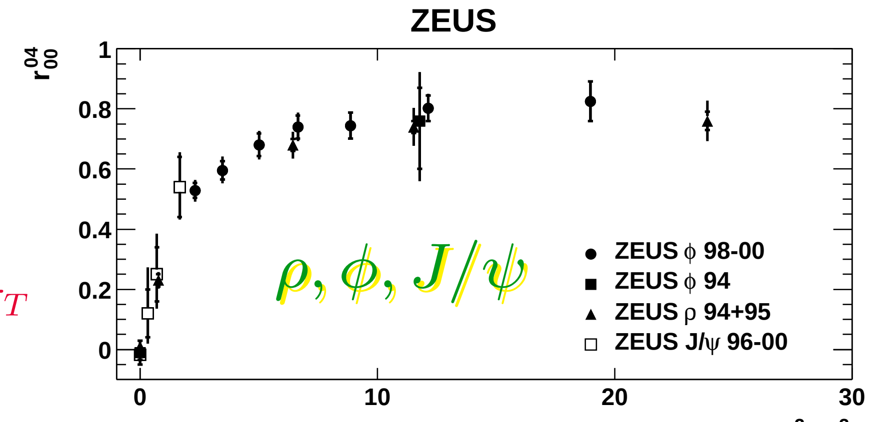
all results in well agreement

but away from 'soft' Pomeron

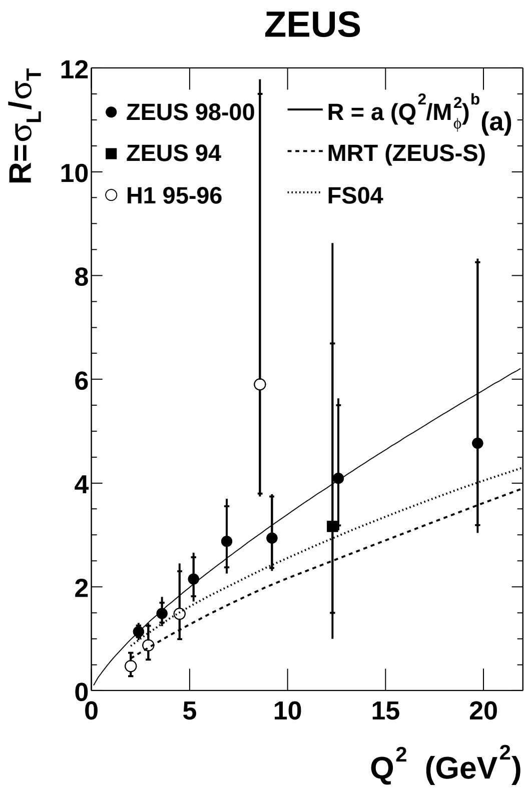
ϕ:
$\alpha_{IP}(0) = 1.10 \pm 0.2(stat.) \pm 0.2(syst.)$
$\alpha'_{IP} = 0.08 \pm 0.09(stat.) \pm 0.08(syst.)$ GeV^{-2}

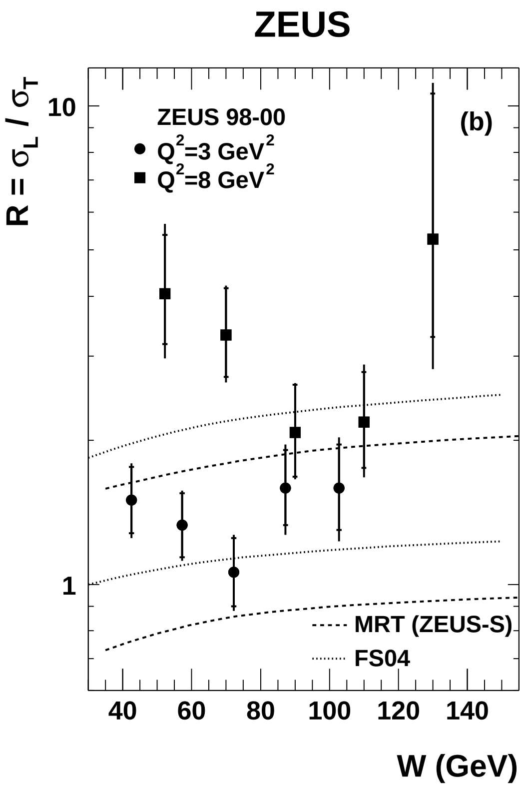
ϕ − helicity analysis

- $\frac{1}{N}\frac{dN}{d\cos(\theta_h)} = \frac{3}{8}(1 + r_{00}^{04} + (1 - 3r_{00}^{04}\cos^2\theta_h))$
- $\sigma = \sigma_T + \epsilon\sigma_L$
- angular distributions allow to extract σ_L/σ_T
- $R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1-r_{00}^{04}}$, $\epsilon \approx 0.99$



scaling with Q^2/M_{VM}^2 observed





- rise of R with Q^2
- fit to $R = a(Q^2/M_\phi^2)^b$

  $a = 0.51 \pm 0.07_{stat} \pm 0.05_{syst}$

  $b = 0.86 \pm 0.11_{stat} \pm 0.05_{syst}$
- weak W dependence of R

ϕ production vs pQCD - transition region

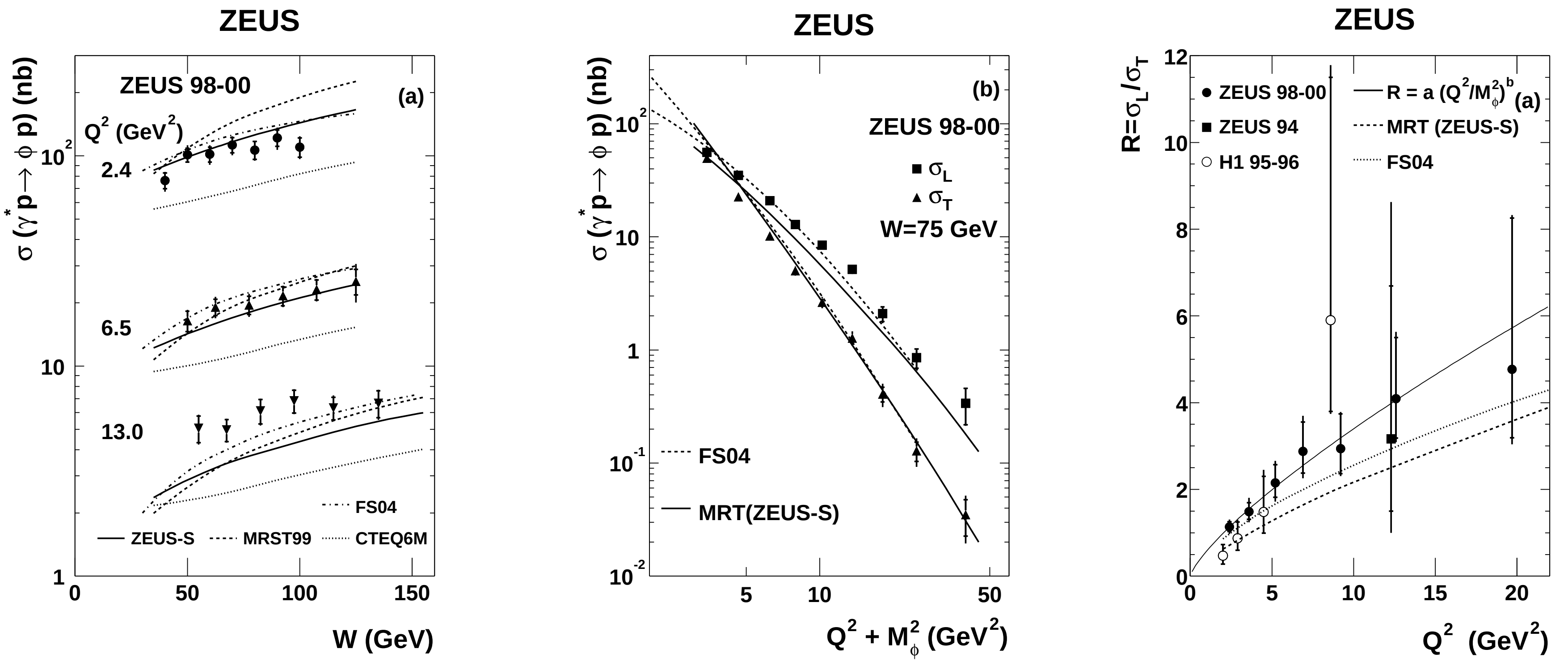
- pQCD models – different assumptions on gluon densities

- MRT (Martin, Ryskin, Teubner) – ZEUS-S, MRST99, CTEQ6M pdfs

Phys. Rev. D62(2000)14022

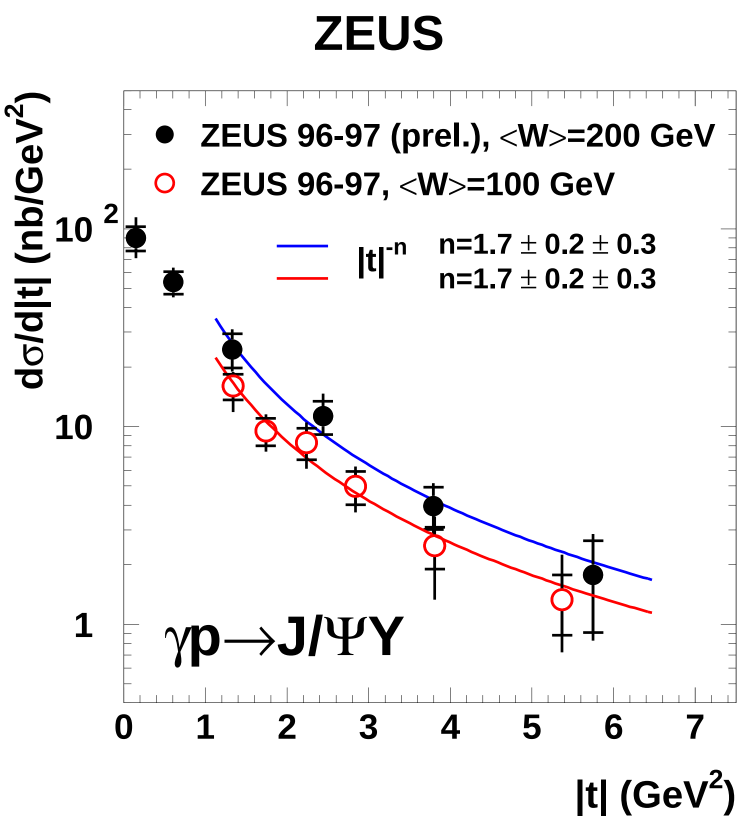
- FS04 (Forshaw,Shaw) JHEP 0412(2004)052

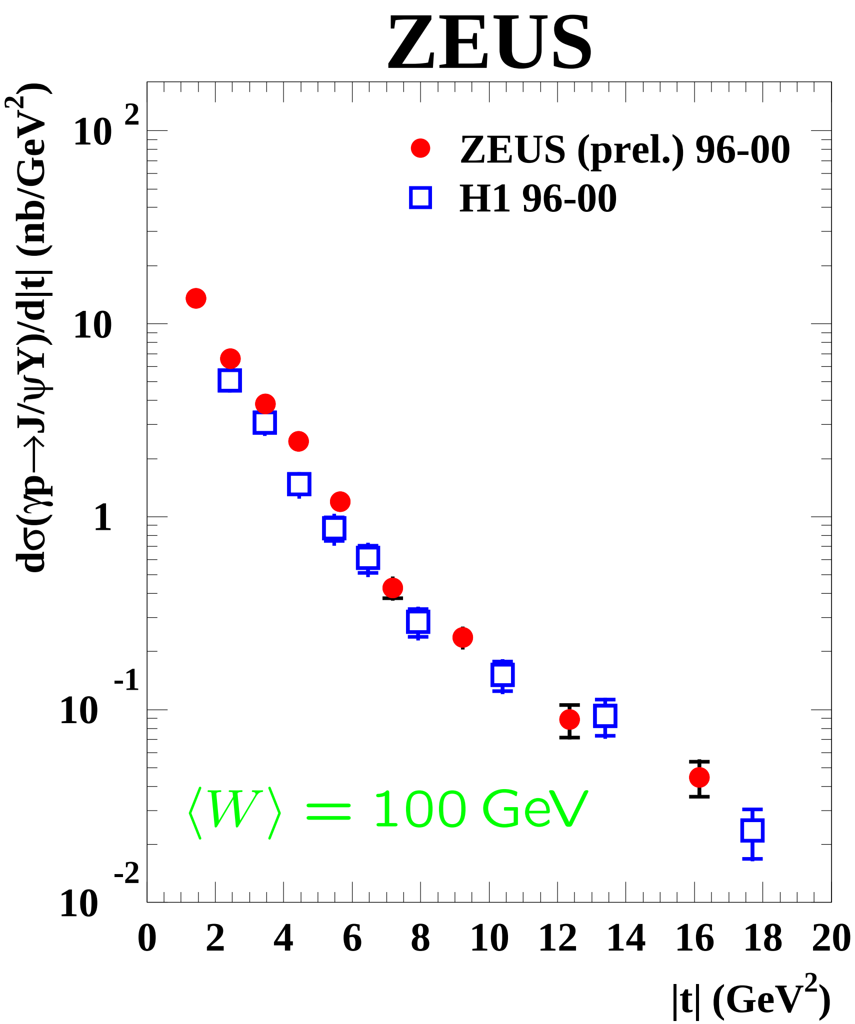
- qualitative description OK ...



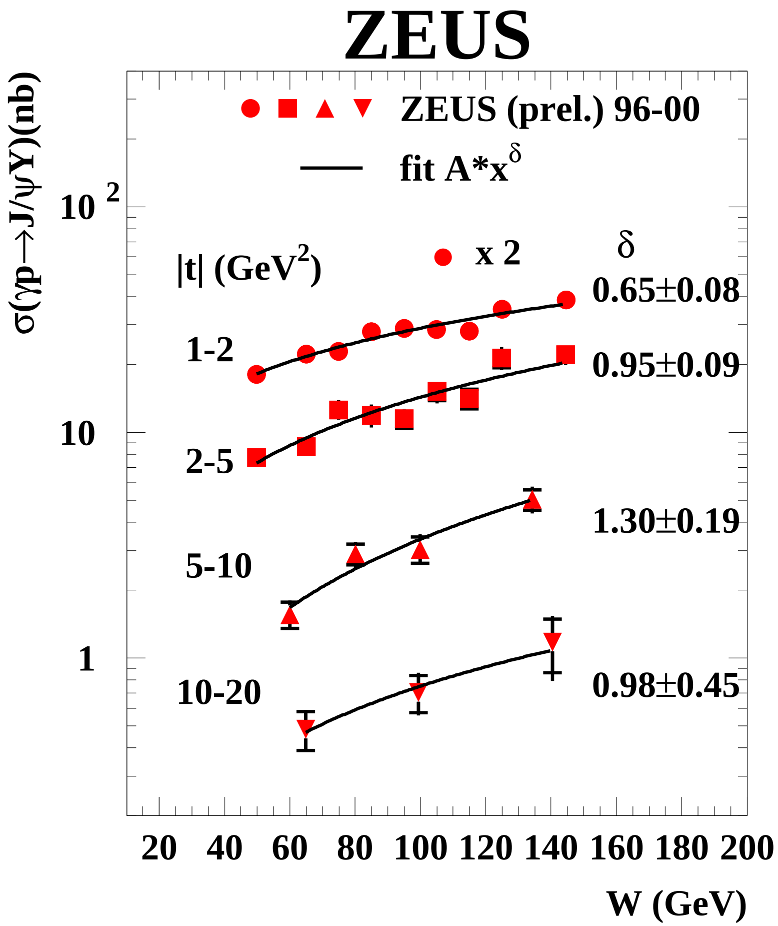
J/ψ photoproduction at high $|t|$

- $|t|$ – dependence of the cross section





J/ψ at high $|t|$ – W dependence



- fit form: $\sigma \propto (W/90\,\text{GeV})^{\delta}$
- δ rising with $|t|$
- effective pomeron trajectory

$\delta = 4\alpha_{IP}(t) - 4$

$\alpha_{IP} = \alpha(0) + \alpha'(t)$

$\alpha(0) = 1.153 \pm 0.048_{stat} \pm 0.039_{syst}$

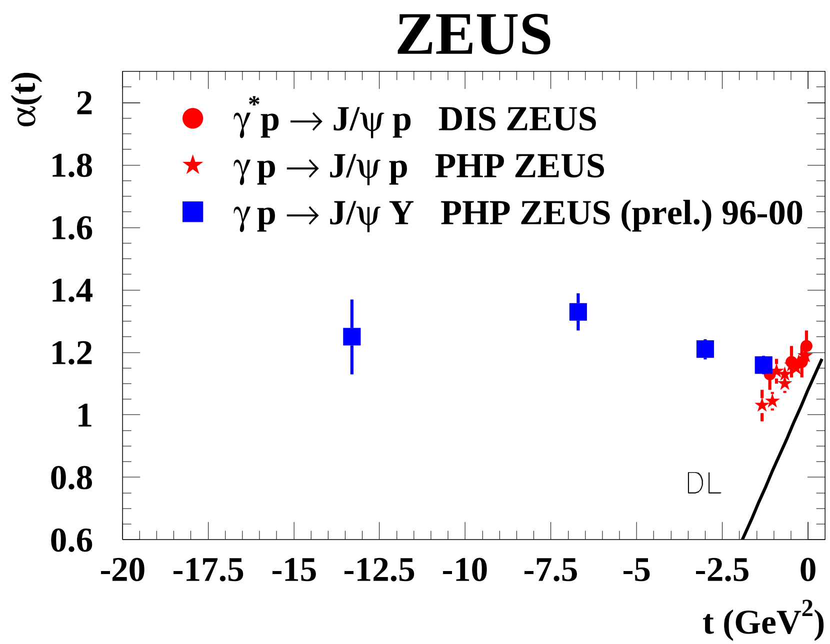
$\alpha' = -0.020 \pm 0.014_{stat} \pm 0.010\,\text{GeV}^{-2}_{syst}$

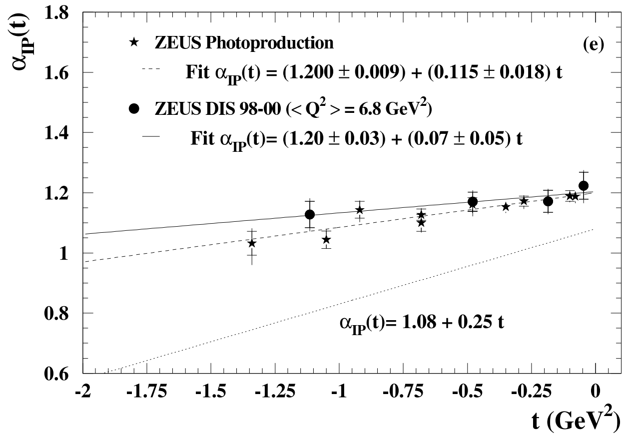
- consistent with:

H1 p-diss. J/ψ and ZEUS exclusive J/ψ

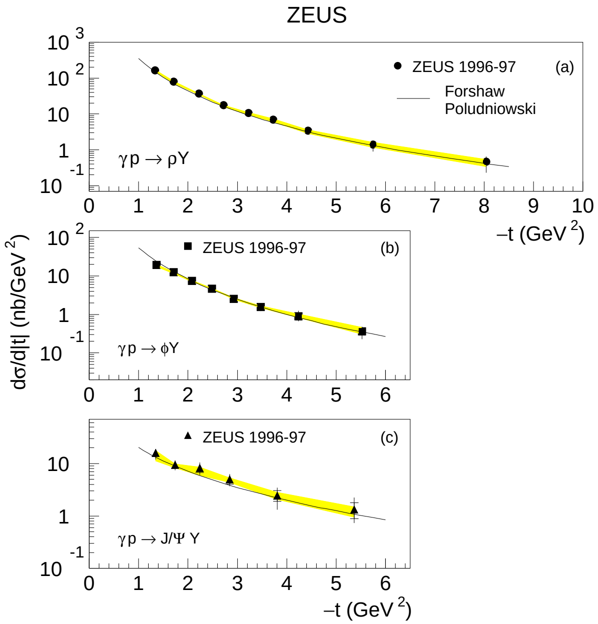
J/ψ production – QCD Pomeron

$\gamma p \to J/\psi\ p$ (Eur. Phys. J. C24(2002)345)	$\alpha_{IP}(t) = (1.200 \pm 0.009) + (0.115 \pm 0.018)t$
$\gamma^* p \to J/\psi\ p$ (Nucl. Phys. B695(2004)3)	$\alpha_{IP}(t) = (1.20 \pm 0.03) + (0.07 \pm 0.05)t$
$\gamma p \to J/\psi\ Y$ (DIS2005)	$\alpha_{IP}(t) = (1.153 \pm 0.048) - (0.020 \pm 0.014)t$





- Universal QCD Pomeron?
- t-dependence of hard Pomeron is nor linear neither monotonic



BFKL:

Bartels, Forshaw, Lotter, Wüsthoff; Phys.Lett. B375(1996)301

Forshaw, Ryskin; Z.Phys. C68(1995)137

Enberg, Motyka, Poludniowski; Eur. Phys.J. C26(2002)219

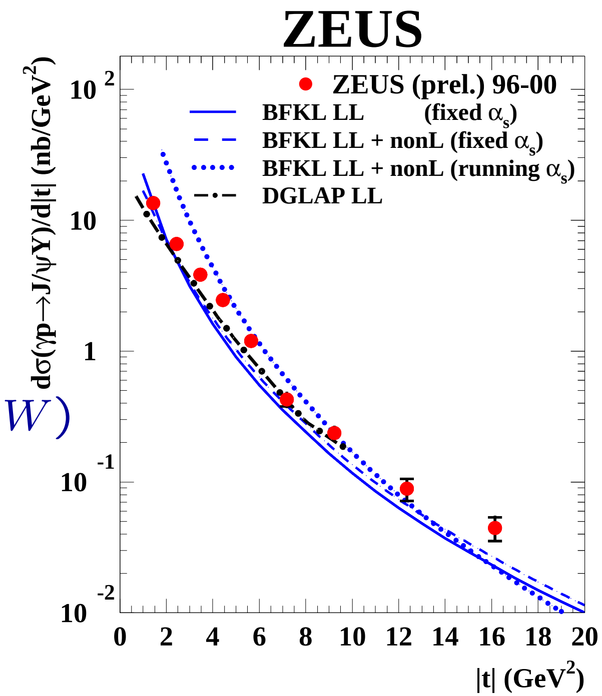
DGLAP:

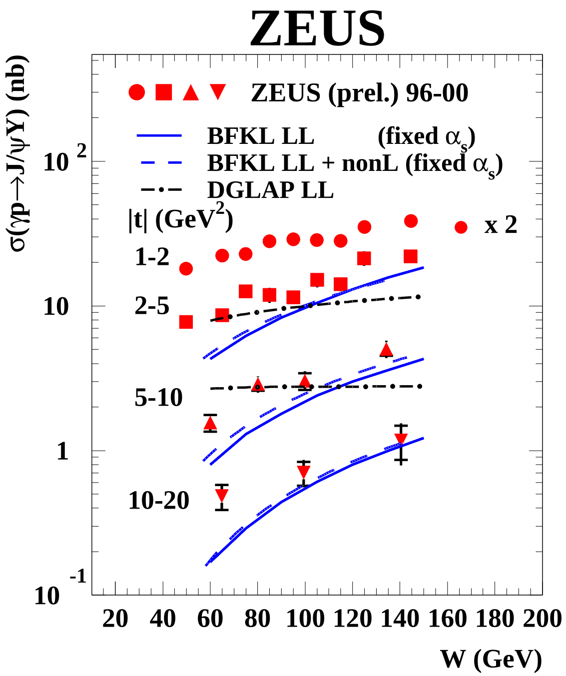
Gotsman, Levin, Maor, Naftali; Phys.Lett. B352(2002)37

- parameters tuned to the previous ZEUS data at $\langle W \rangle = 100\,\text{GeV}$

- BFKL and DGLAP reproduce $|t|$ dependence

- DGLAP – problems with $\sigma(W)$





Summary

pQCD provides satisfactory description of VMs production

- light VMs show transition from soft to hard regime as Q^2 rises
- pQCD can describe light VMs in the presence of hard scale $(Q^2, |t|)$
- VM production shows at large M^2_{VM}, Q^2 or $|t|$ features of hard process:

– steep rise of the cross section with energy

– harder $|t|$ distribution

Outlook:

- HERA II $\Rightarrow$ more statistics in larger kinematic range
- HERA data are still an inspiration for development of the theory