Vector mesons at ZEUS

Jan Figiel

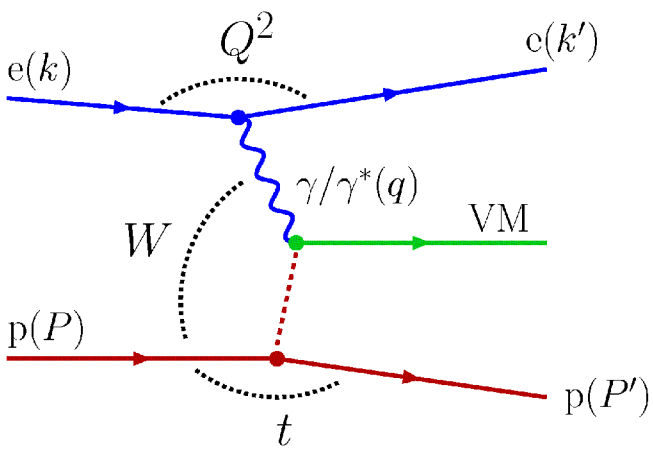
INP-PAS Cracow

- Introduction
- Electroproduction of φ meson
- Photoproduction of J/ψ meson
- Summary

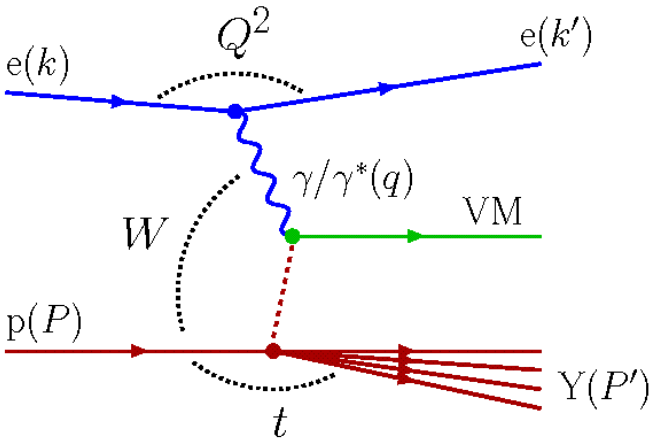
LowX, Sinaia, Romania, 29.06 - 3.07.2005

Diffractive vector meson production at HERA

'elastic' (exclusive)



'proton-dissociative'



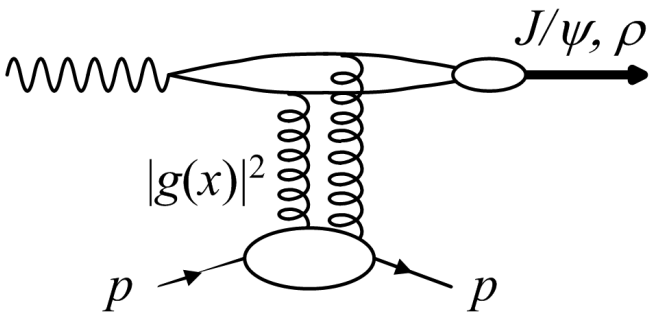
Experimentally clean processes, in wide kinematic range

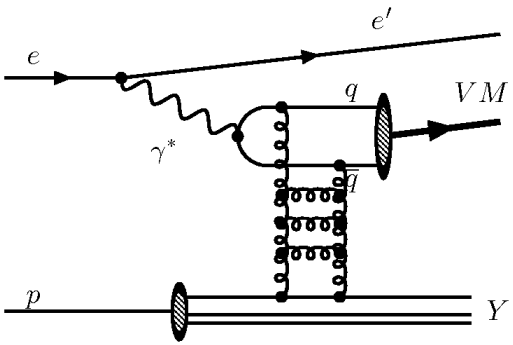
VM	vector meson	$\rho,\ \omega,\ \varphi,\ J/\psi ...$
Q^2	photon virtuality	$Q^2 = -q^2 = -(k-k')^2$
W	c. m. energy of the γp system	$W = (q+p)^2$
t	(4-mom. transfer)^2	$t = (p-p')^2$

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

Diffractive vector meson production in pQCD

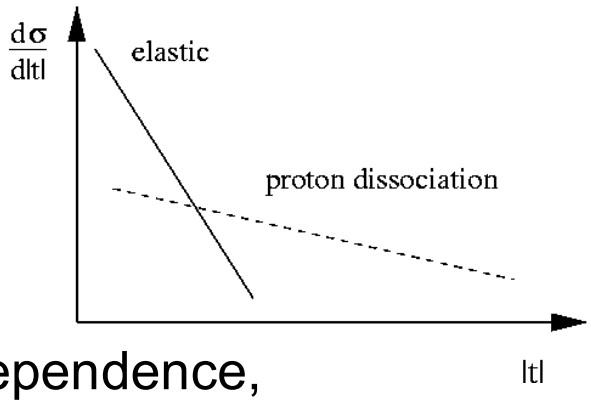
VM = $q\bar{q}$ dipole, exchange of ≥ 2gluons (color singlet – QCD Pomeron)
large Q^2, $|t|$, M_{VM} $\Rightarrow$ small $q\bar{q}$ and interaction size
$\Rightarrow$ perturbative QCD, factorisation holds





'Exclusive' hard VM electroproduction:

- Universal $|t|$ dependence, $d\sigma/dt \sim exp([-(4\text{-}5)\ \mathrm{GeV}^{-2}]\ |t|)$, no shrinkage
- Steep rise $\sigma(W) \sim [xg(x,Q^2)]^2 \approx W^{0.8}$, $x \approx Q^2/W^2$
- Possible SCHC violation



'Proton-dissociative' hard VM photoproduction:

- $d\sigma/dt \sim |t|^{-n}$
- 2-gluon exchange – no energy dependence,
  gluon ladder exchange: DGLAP evolution – weak W dependence,
  BFKL evolution – strong W dependence!

VM at HERA: transition between soft and hard regime

Exclusive electroproduction of φ meson

$$\gamma^* p \rightarrow \varphi\, p \rightarrow K^+ K^- p$$

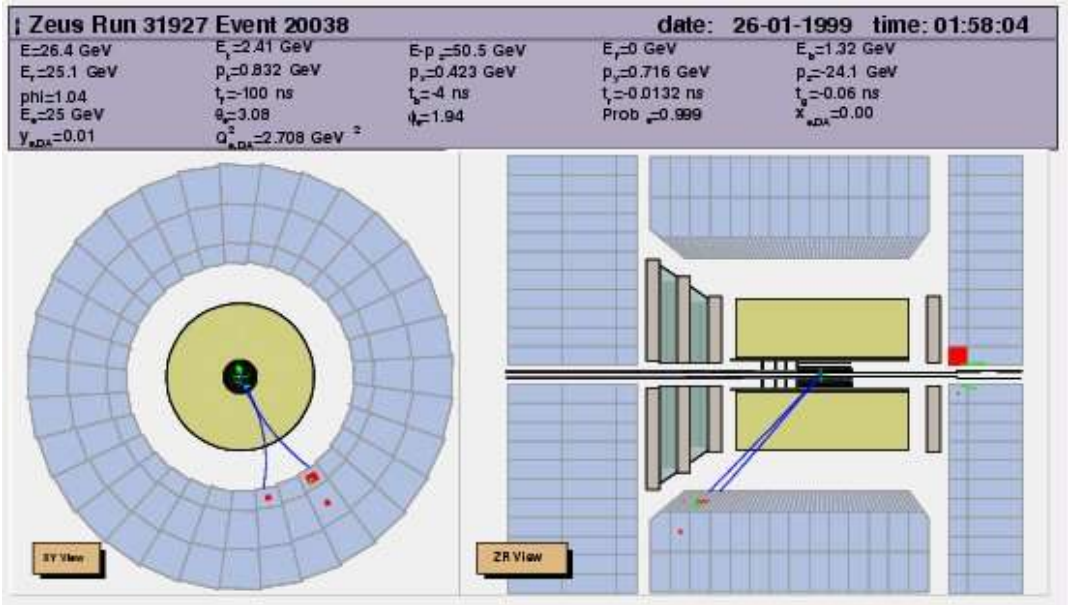
1998 – 2000, L = 65 pb^{-1}

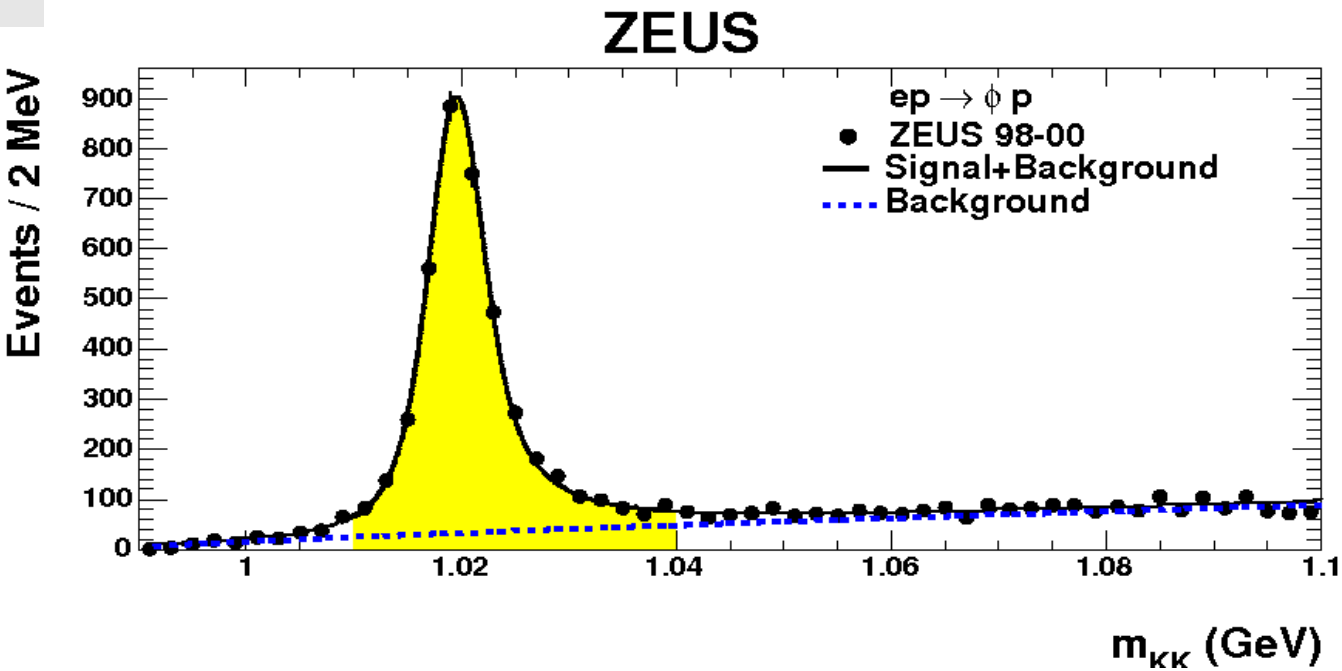
35 < W < 145 GeV

2 < Q^2 < 70 GeV^2

$|t|$ < 1 GeV^2

3642 events





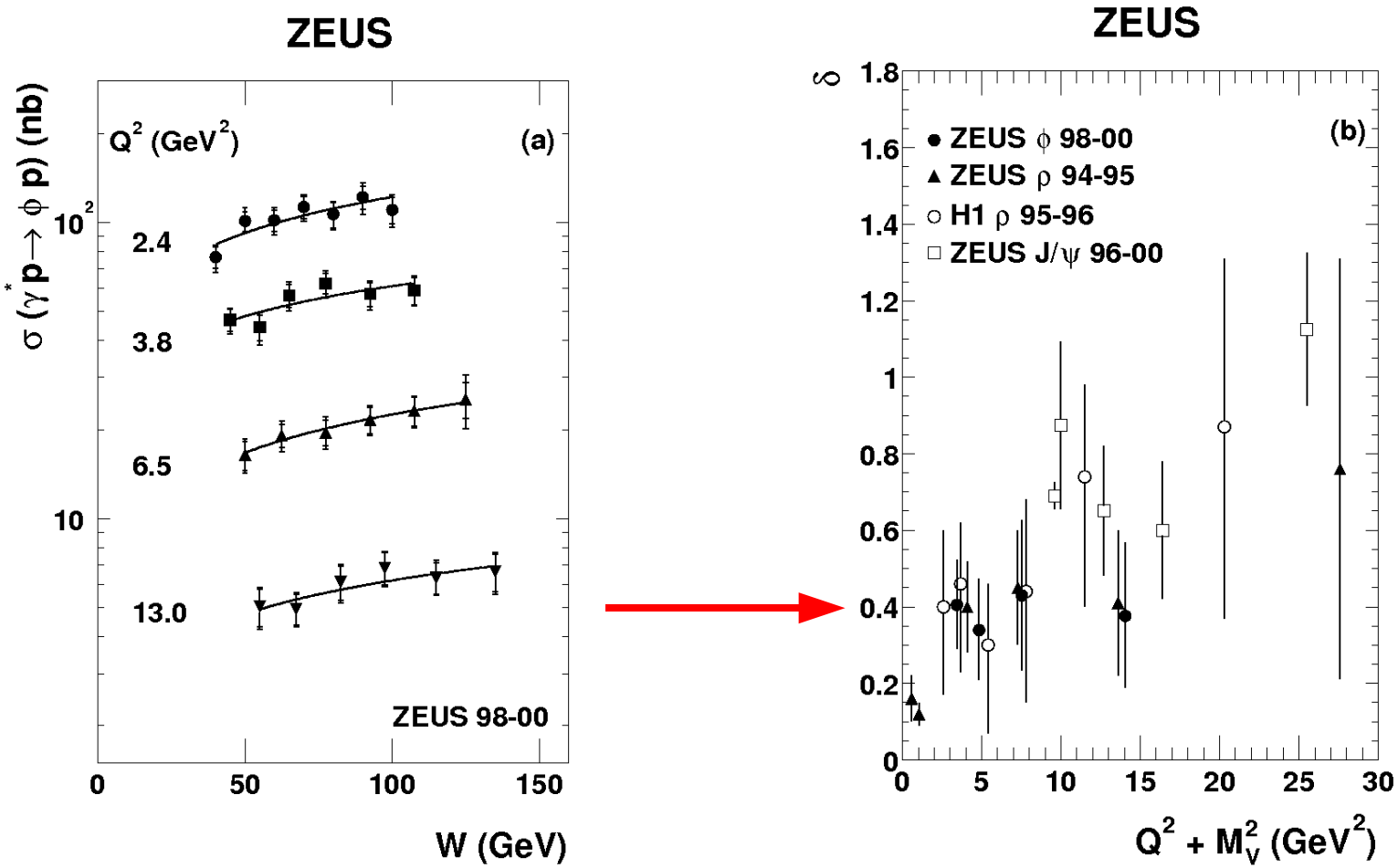
M_φ, $|t|$ - small

Q^2 controls

soft – hard transition?

Exclusive electroproduction of φ meson

W dependence in function of Q^2

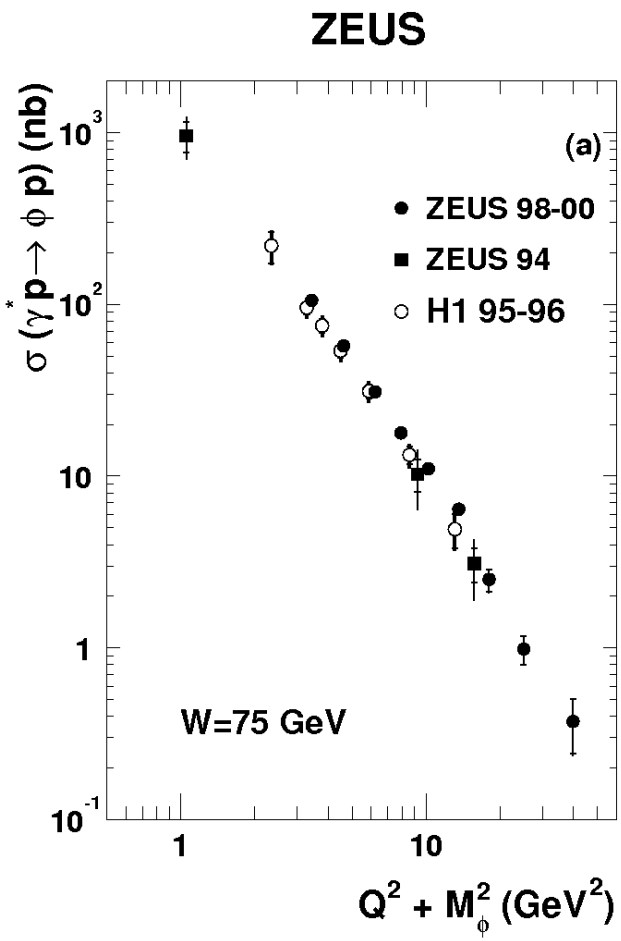


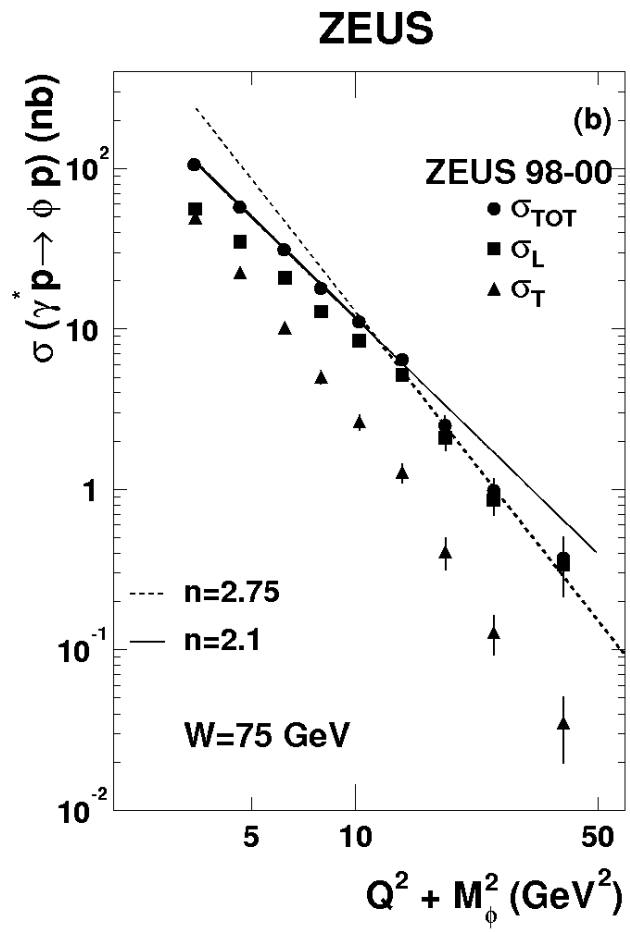
- $\sigma \sim W^{\delta}$, $\delta \approx 0.4$, between 'soft' and 'hard' regime, independent of Q^2
- "universal" dependence of δ on $Q^2 + M_{VM}{}^2$ ≈ transition scale

Exclusive electroproduction of φ meson

Q^2 dependence at W = 75 GeV

$$\sigma = \sigma_T + \varepsilon\,\sigma_L, \quad \varepsilon \approx 0.99$$





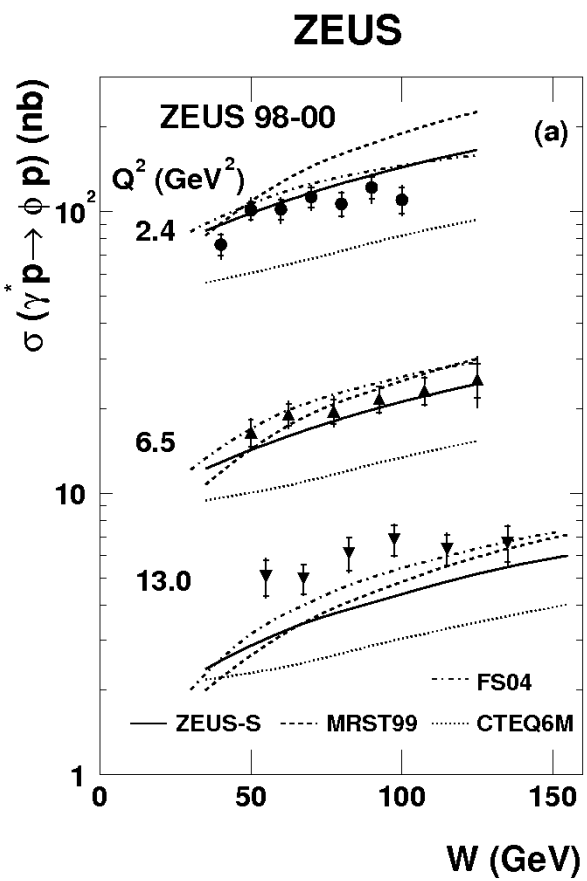
- $\sigma \sim (Q^2 + M_{VM}^2)^{-n}$, $n = 2.087 \pm 0.055 stat \pm 0.050 syst$ for $2.4 \le Q^2 \le 9.2$ GeV²

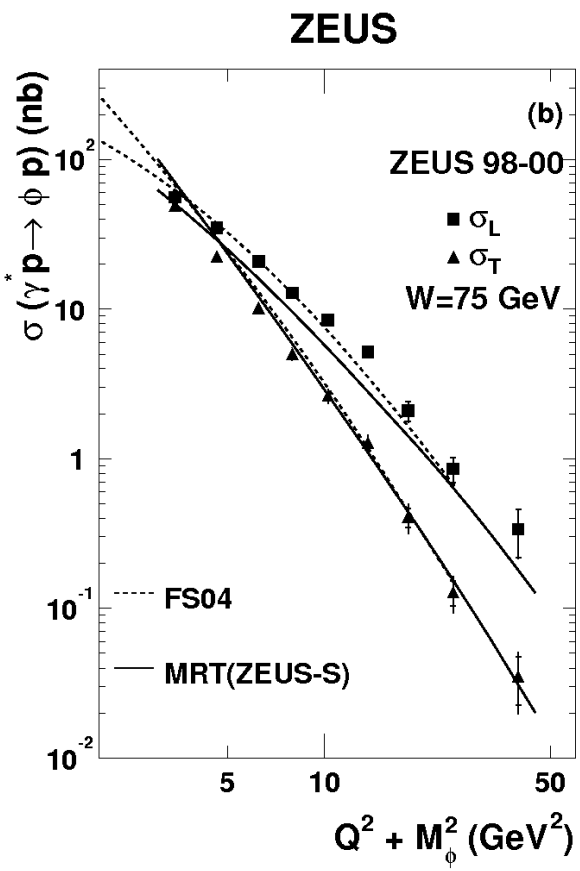
  $n = 2.75 \pm 0.13 stat \pm 0.07 syst$ for $9.2 \le Q^2 \le 70$ GeV²
- Different Q^2 dependence of σ_L and σ_T

Exclusive electroproduction of φ meson

W and Q^2 dependence: models

- MRT (Martin, Ryskin, Teubner) – ZEUS-S, MRST99, CTEQ6M pdfs
- FS04 (Forshaw, Shaw)
- Qualitatively OK...

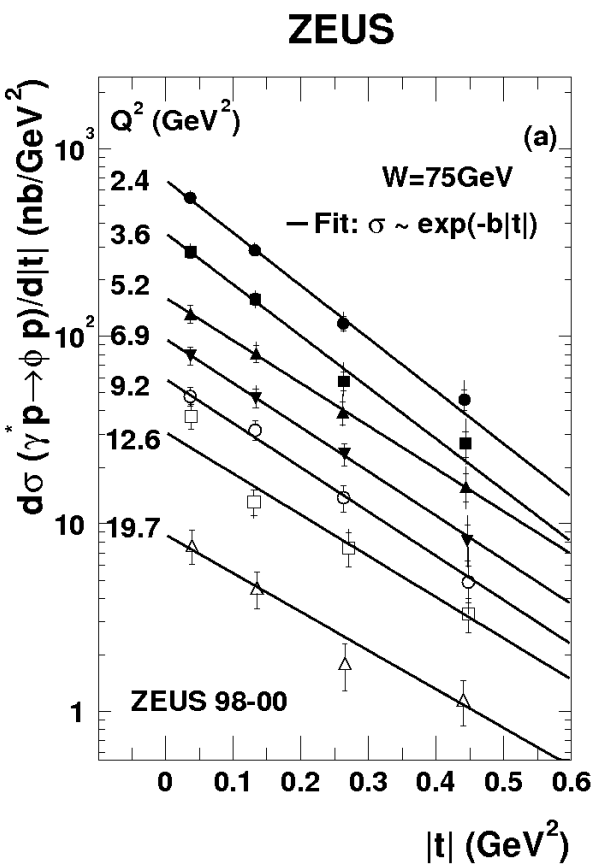


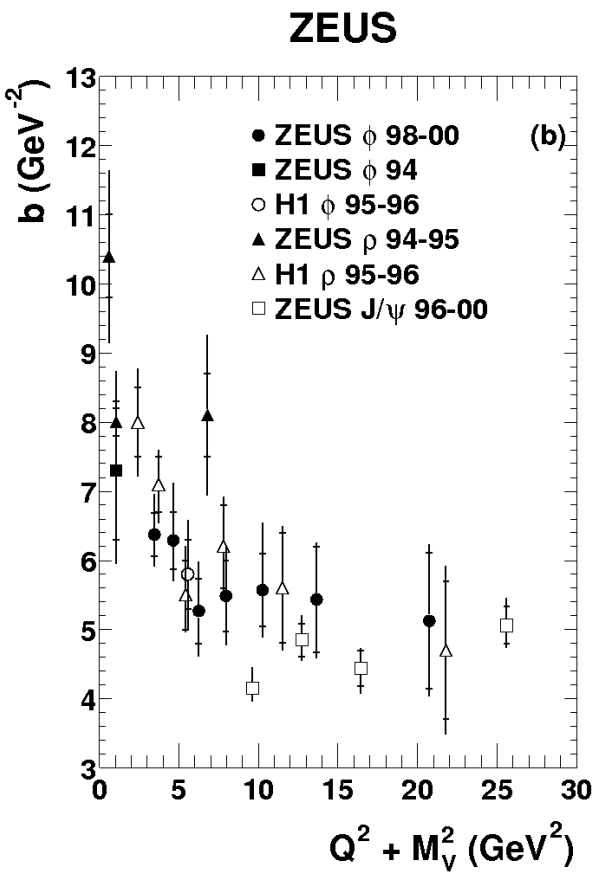


Exclusive electroproduction of φ meson

t dependence at W = 75 GeV:

- $d\sigma/dt \sim exp(-b|t|)$, $b \approx 5 - 6$ GeV^{-2}
- transition to small configuration with $Q^2 + M_{VM}^2$





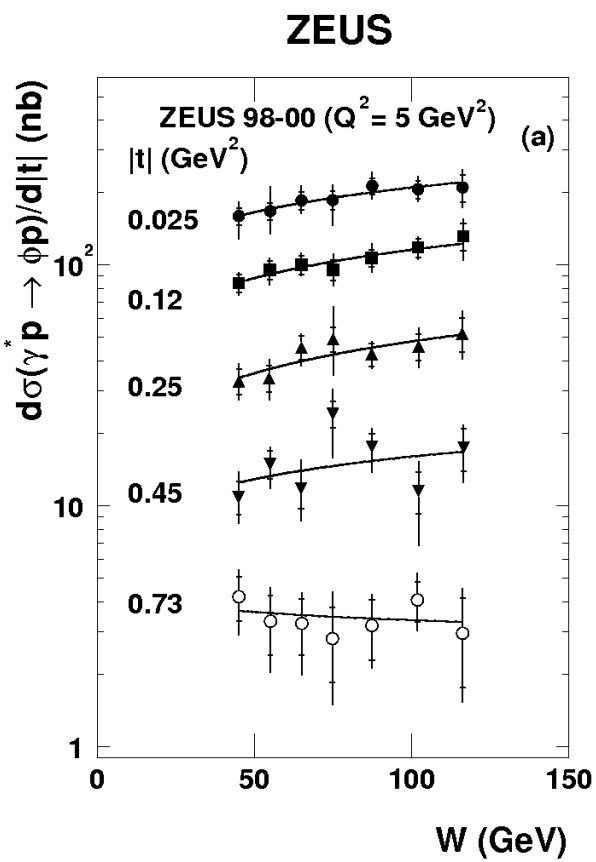
Exclusive electroproduction of φ meson

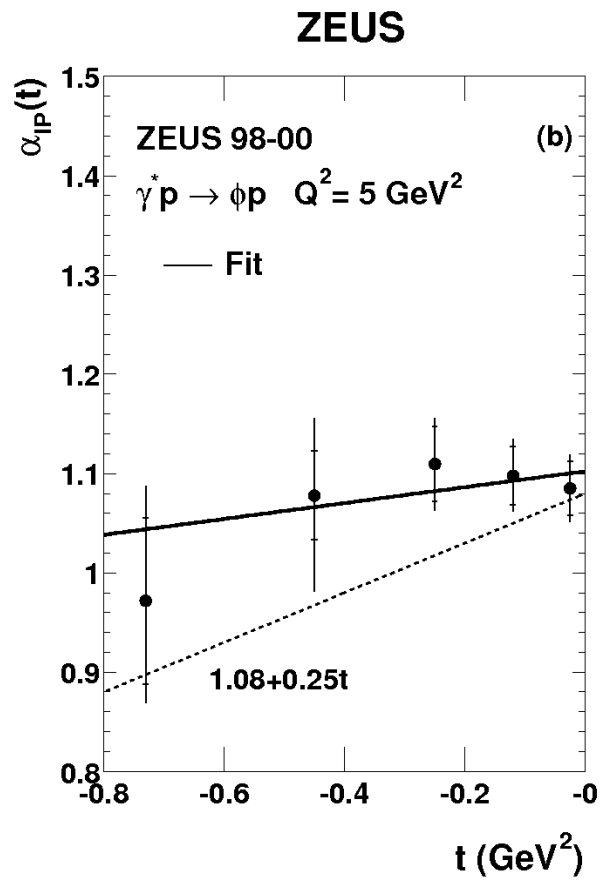
$W - t$ dependence at Q^2 = 5 GeV^2 : Pomeron trajectory

- $\sigma \sim W^{\delta}, \qquad \delta = 4\alpha_{IP}(t) - 4, \qquad \alpha_{IP}(t) = \alpha(0) + \alpha' t$
- δ ~ independent of t

  $\alpha(0) = 1.10 \pm 0.2 stat \pm 0.2 syst$

  $\alpha' = 0.08 \pm 0.09 stat \pm 0.08 syst$ GeV^{-2}

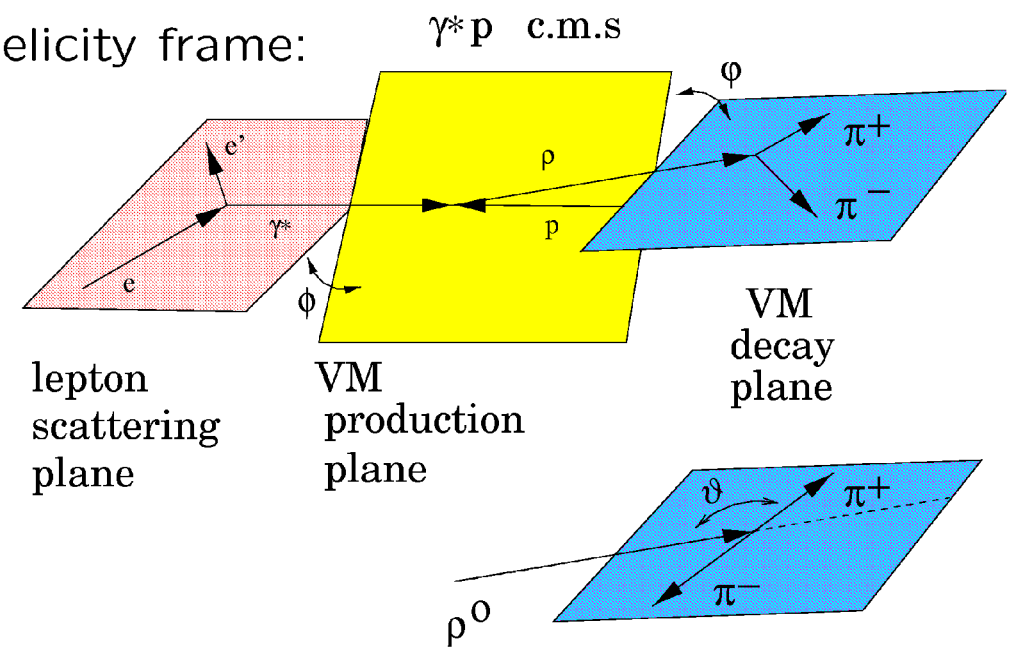




Exclusive electroproduction of φ meson

Helicity analysis:

Helicity frame:



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

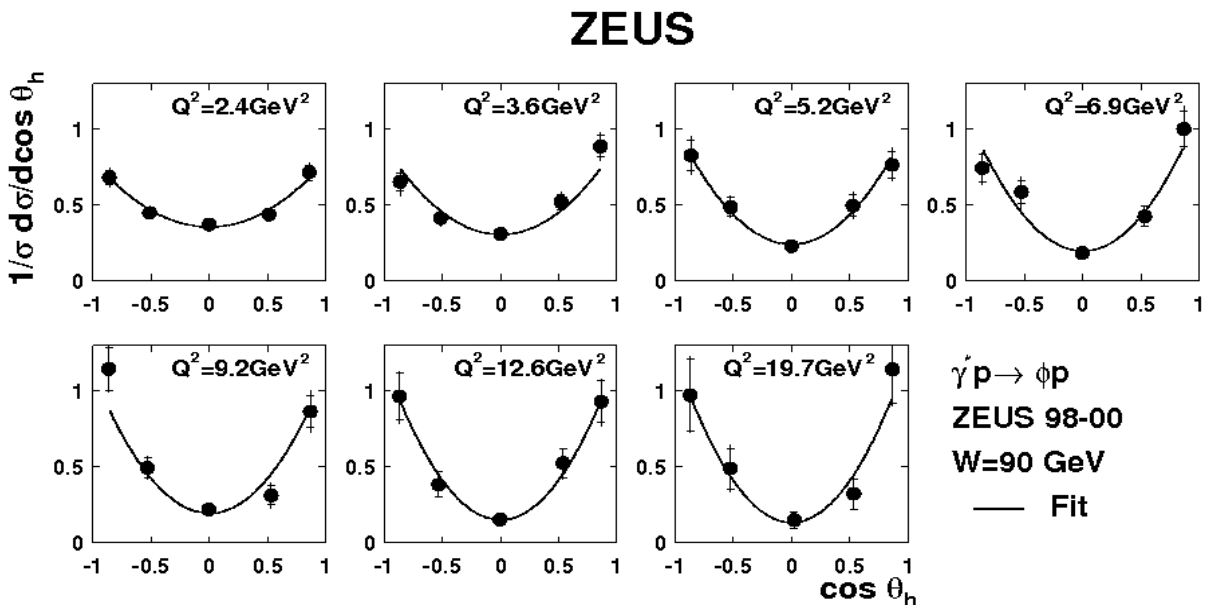
$$\frac{1}{N}\frac{dN}{d\cos(\theta_h)} = \frac{3}{8}(1 + r^{04}_{00} + (1 - 3r^{04}_{00}\cos^2\theta_h))$$ (SCHC)

$$R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}, \quad \epsilon \approx 0.99$$

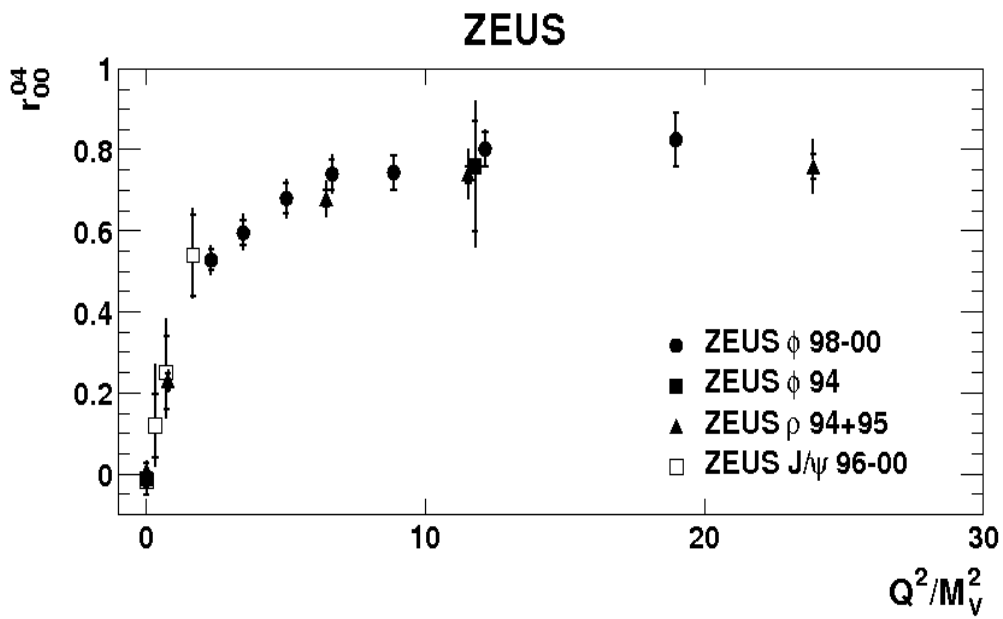
r^{04}_{00} : γ^* (0,1) $\rightarrow$ φ (0)

Exclusive electroproduction of φ meson

Helicity analysis:



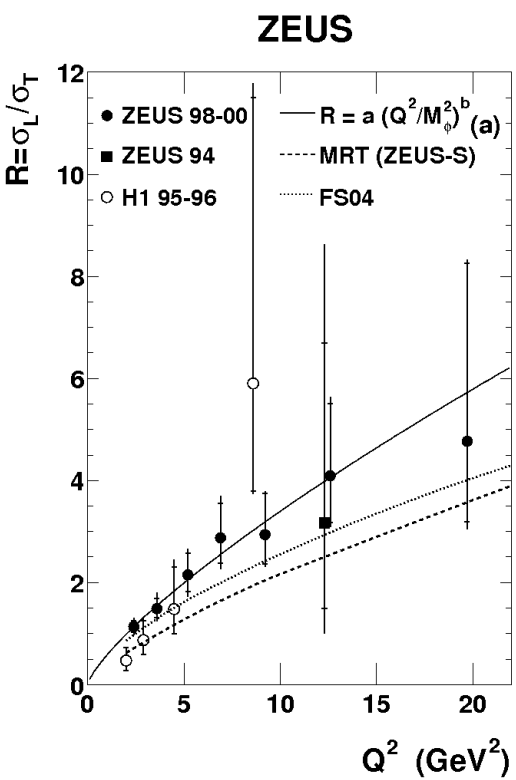
r_{00}^{04} : scaling with Q^2/M_{VM}^2

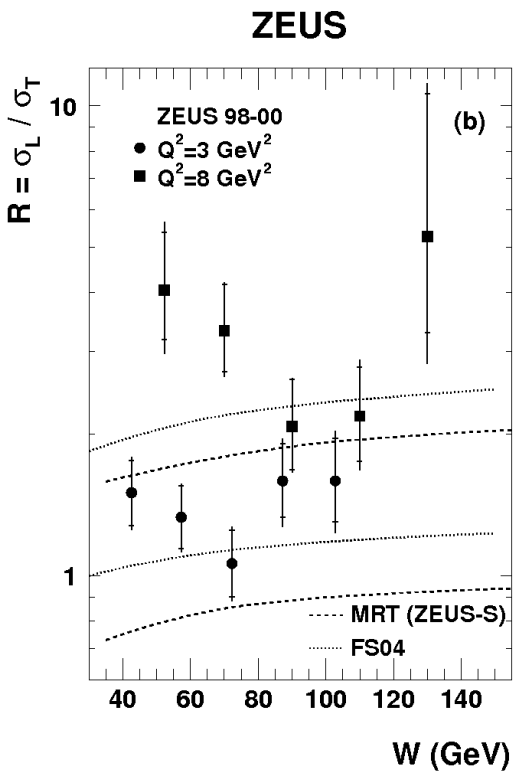


Exclusive electroproduction of φ meson

Helicity analysis:

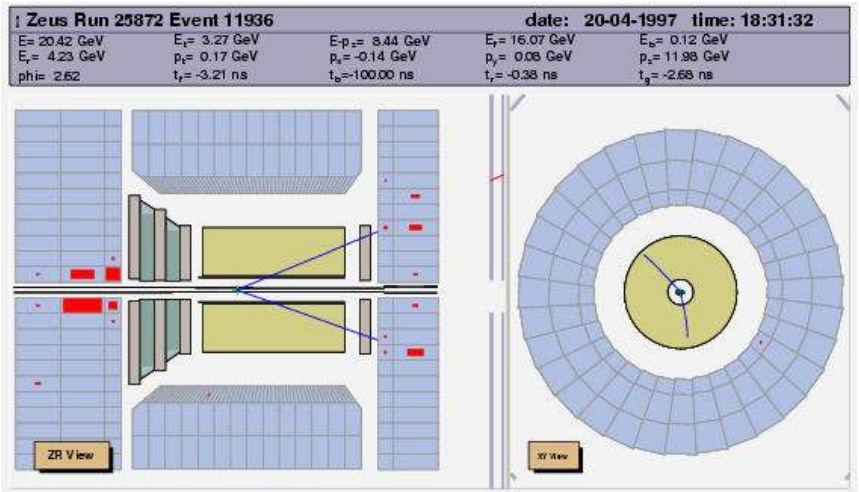
- $\sigma = \sigma_T + \varepsilon \sigma_L, \quad \varepsilon \approx 0.99, \quad R = \sigma_T / \sigma_L$
- For φ fit: $R = 0.51\,(Q^2/M_\varphi^{\,2})^{0.86}$
- Weak W dependece of R
- Models MRT and FS04 qualitatively OK





J/ψ photoproduction at large $|t|$

$$\gamma\, p \rightarrow J/\psi\, Y \rightarrow \mu^+ \mu^- Y$$



Data 1996 – 2000, L =112 pb^{-1},

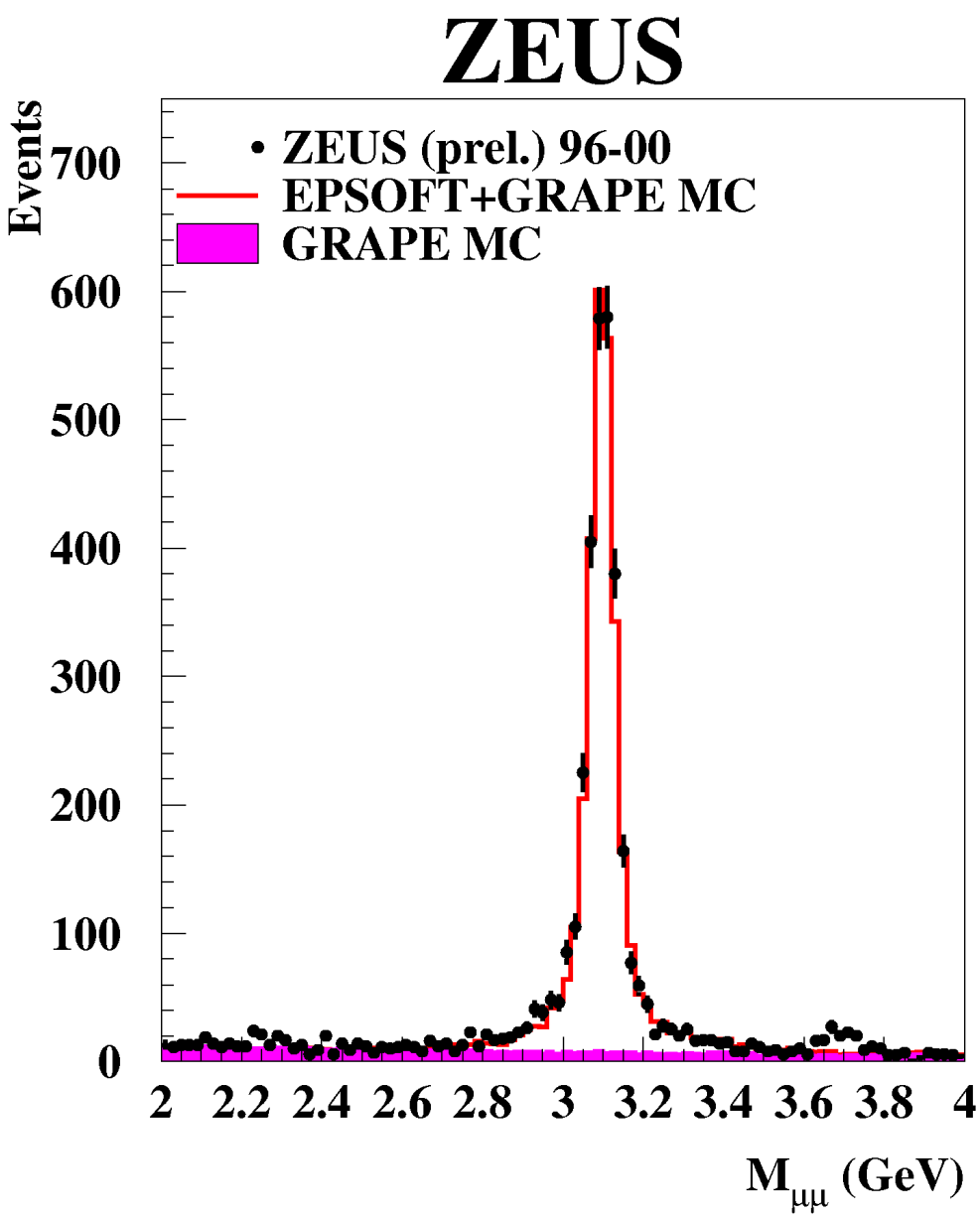
~ 3000 events,

$1 < |t| < 20$ GeV^2

$50 < W < 150$ GeV

$z = (p \cdot p_{J/\psi}) / (p \cdot q) > 0.95$

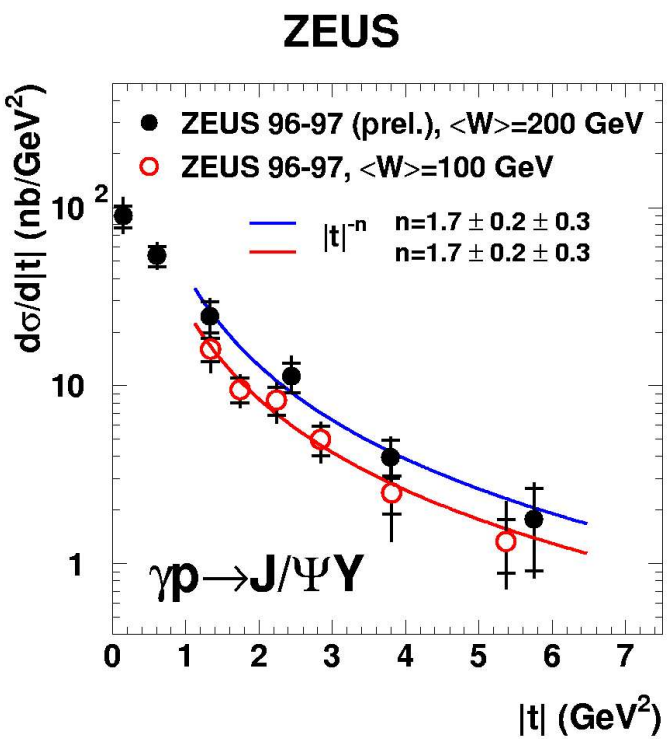
$M_Y < 30$ GeV

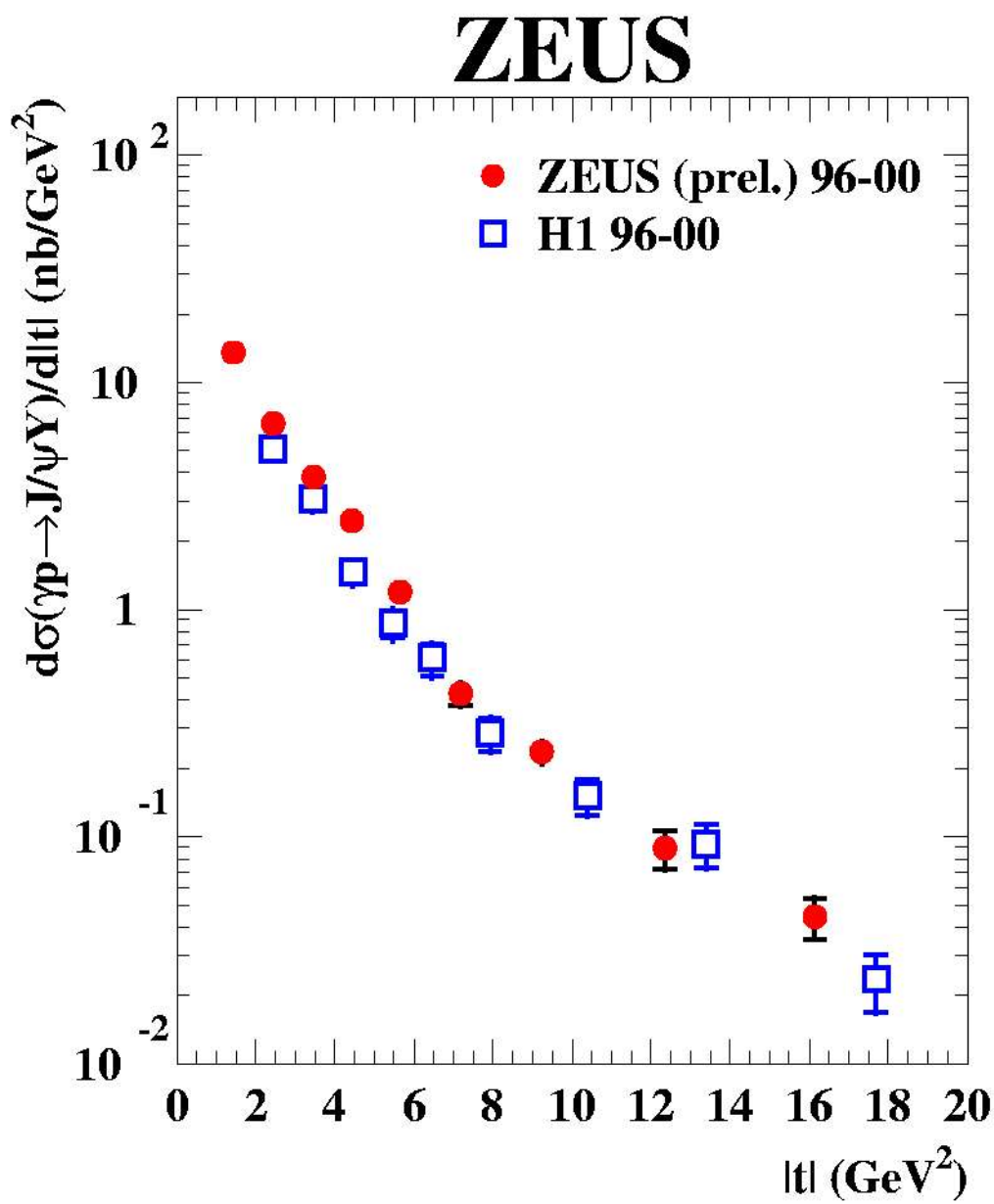


J/ψ photoproduction at large $|t|$

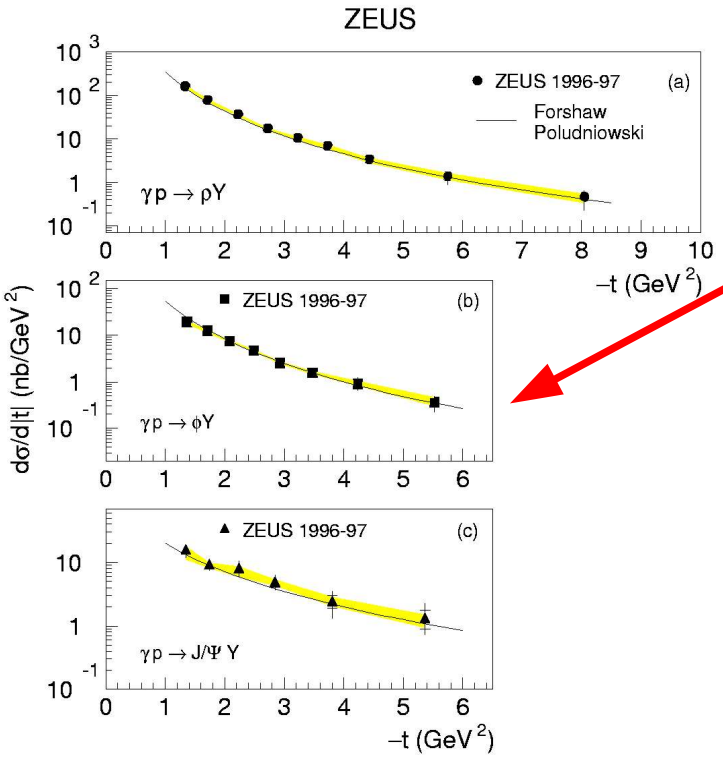
t-dependence of the cross-section:

EPS2003



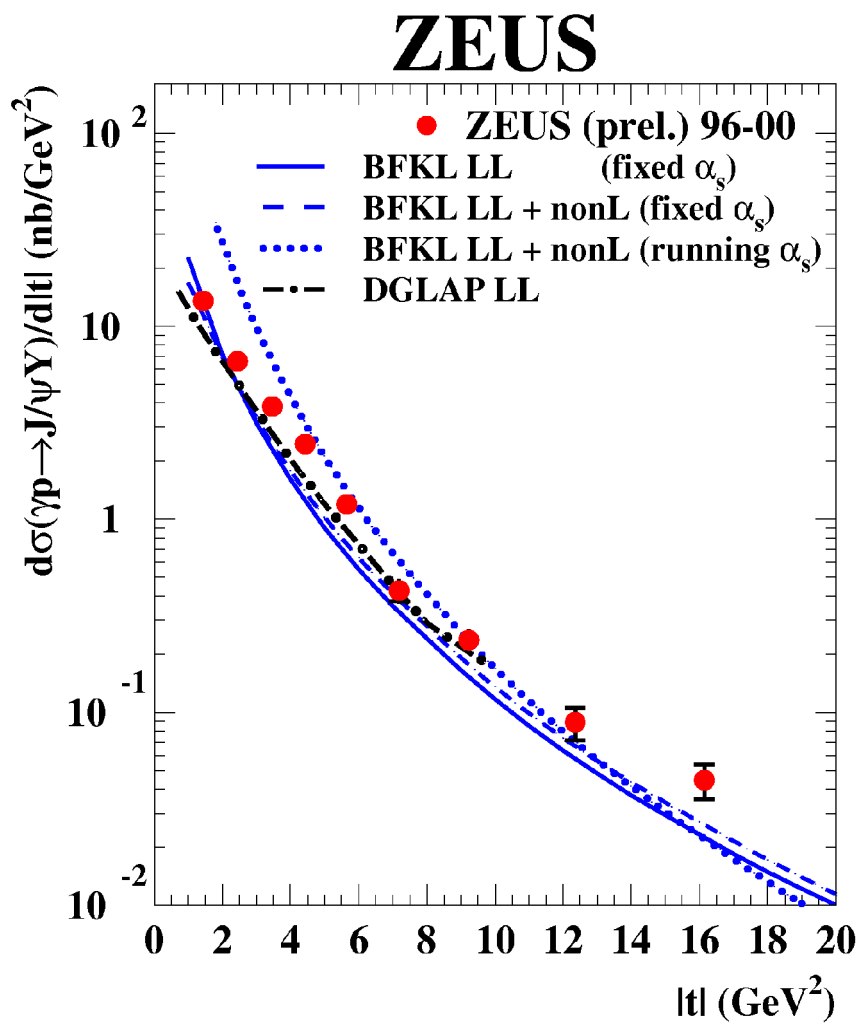


J/ψ photoproduction at large $|t|$: pQCD models



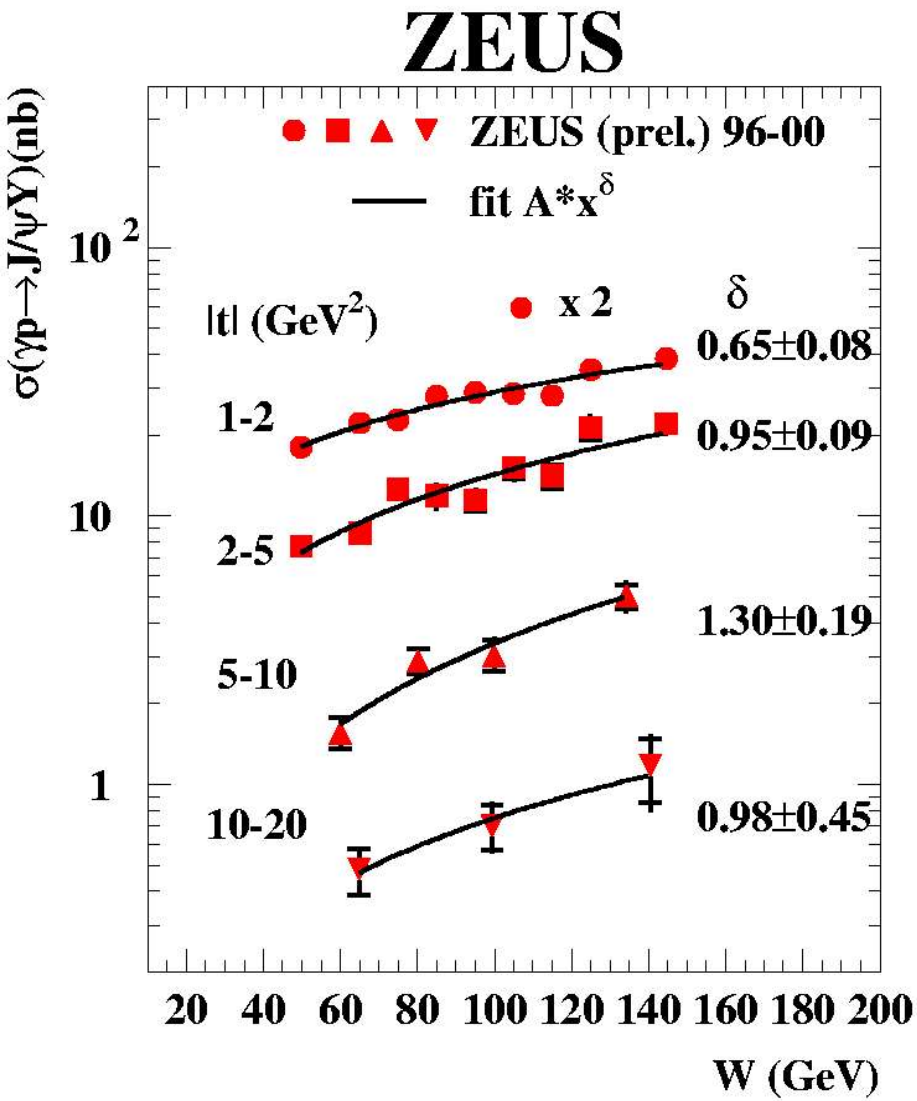
EPJ **C26** (2003) 389: $W \approx 100$ GeV

BFKL: Bartels, Forshaw, Lotter, Wüsthoff
Forshaw, Ryskin
Enberg, Motyka, Poludniowski
DGLAP: Gotsman, Levin, Maor, Naftali;
parameters tuned to previous ZEUS data at $W \approx 100$ GeV!



- DGLAP and BFKL with fixed α_S ~ OK,
- with running α_S - too steep
- full NLO BFKL calculations wanted...

J/ψ photoproduction at large $|t|$



- Fit: $\sigma \sim W^{\delta}$
- δ rises with $|t|$
- Effective Pomeron trajectory:

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

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

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

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

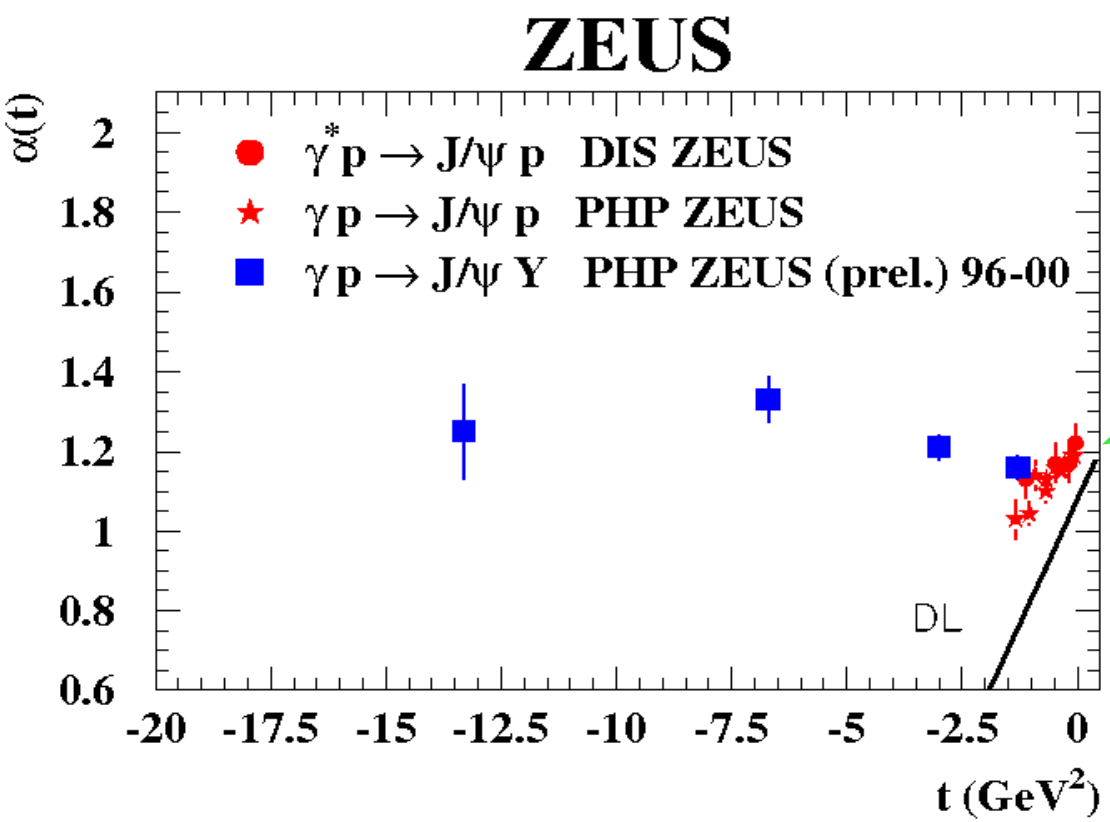
- consistent with:

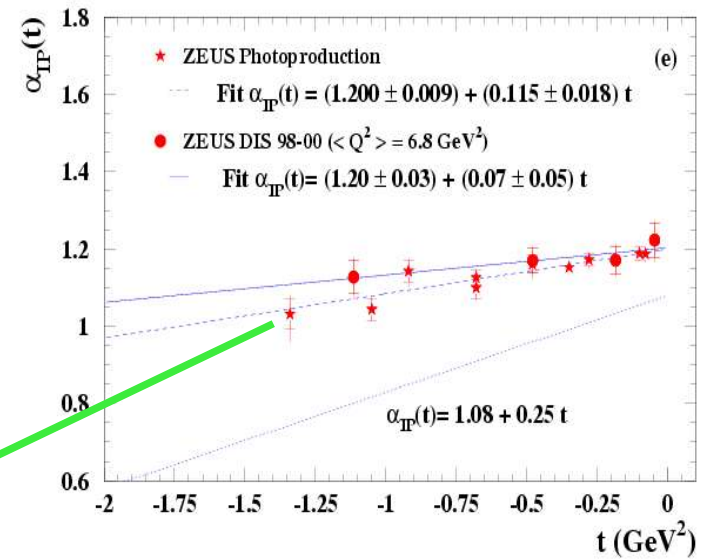
  H1 p-diss. J/ψ and ZEUS exclusive J/ψ,

  BFKL NLO Pomeron: Brodsky et al. 1999

J/ψ at ZEUS: 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)	$\alpha_{IP}(t) = 1.153 \pm 0.048 - (0.020 \pm 0.014)t$

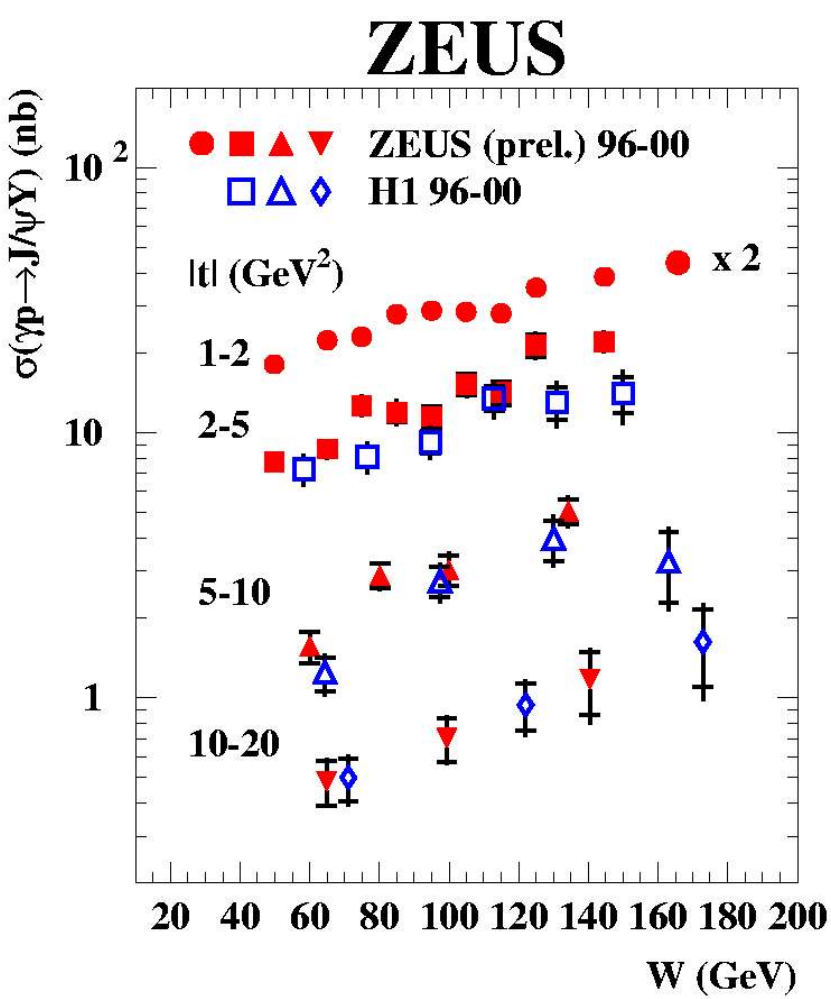


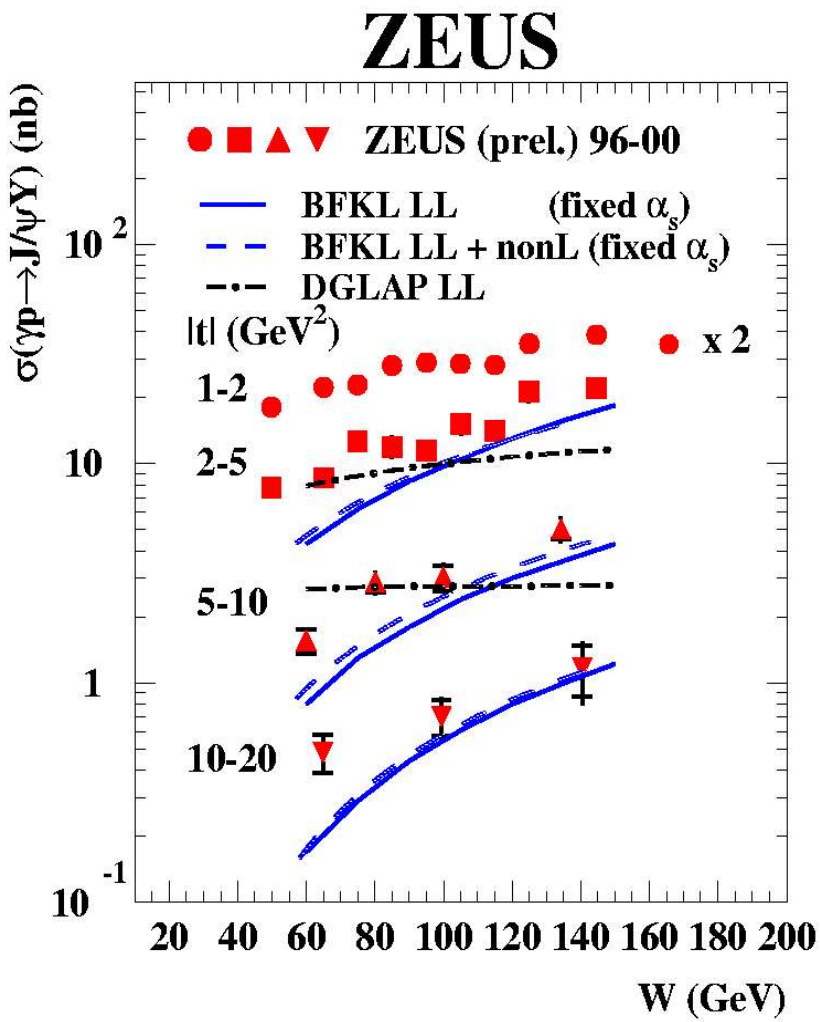


- Universal QCD Pomeron?
- non linear, non monotonic *t*-dependence of BFKL Pomeron

(Ivanov, Nikolaev, Savin, DESY 04-243)

J/ψ photoproduction at large $|t|$





- DGLAP does not describe rise of σ with W
- BFKL reproduces this rise!

Models parameters tuned to previous ZEUS data at $W \approx 100$ GeV!

Summary

Analysis of HERA I data on vector mesons in ZEUS is approaching final stage:

- In exclusive electroproduction of VM the combination of the photon vituality and VM mass seems to govern the transition between soft and hard regime

- Perturbative QCD models in LL approximation describe qualitatively the data in hard domain $\rightarrow$ room for improvement (NLO...)

- In proton-dissociative J/ψ photoproduction strong rise of the cross section with energy is observed at large 4-mom. transfer suggesting onset of BFKL dynamics