Vector meson production with ZEUS detector at HERA

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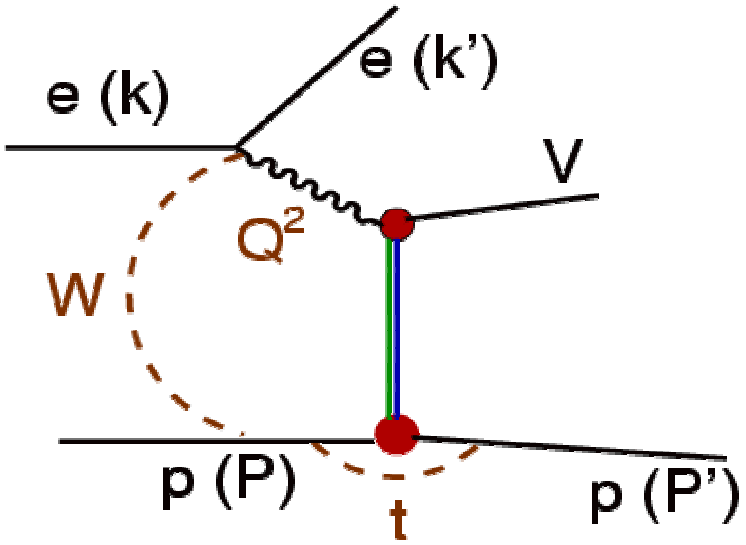
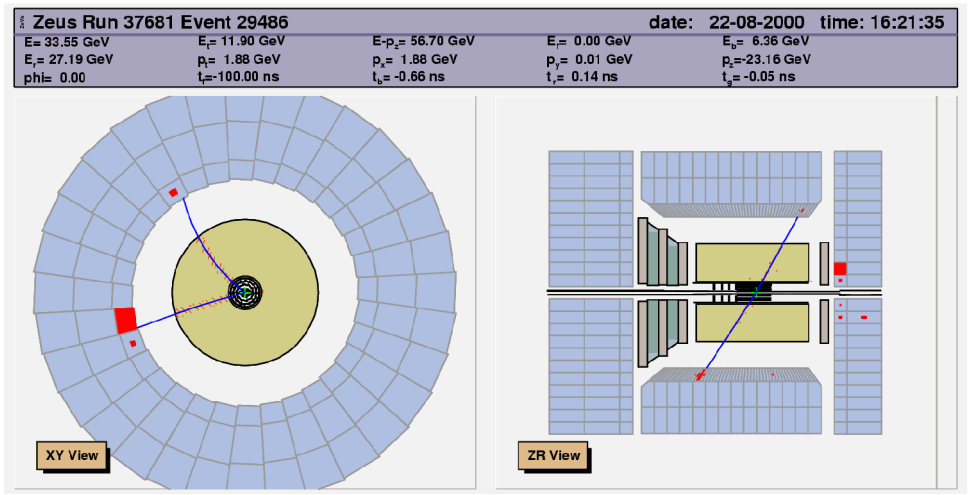
- Introduction and motivation
- Elastic vector meson production electroproduction ρ,J/ψ
- Energy dependence of the proton dissociative J/ψ photoproduction
- Summary

Exclusive VM Production

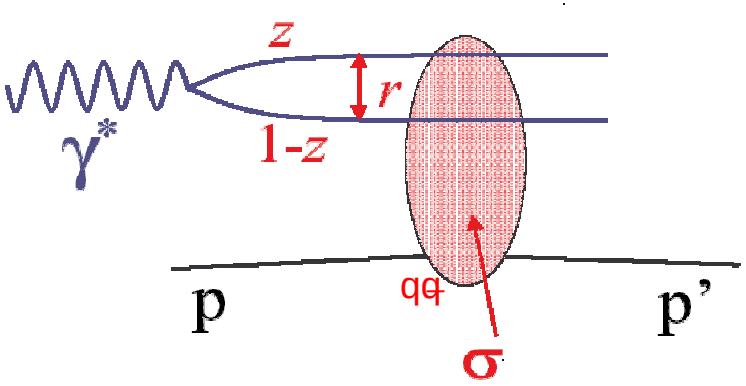
- Experiment: process measured over large phase space in all variables





E_p = 820-920 GeV	E_e = 27.5 GeV	
M_{VM}	VM mass, ρ, φ, ω, J/ψ	0.77 – 3.1 GeV
$Q^2 = -q^2 = (k-k')^2$	Virtuality of exchanged γ*	0 – 100 GeV²
$W^2 = (q+p)^2$	γ *p centre of mass energy	20 – 290 GeV
$t = (P-P')^2$	4-momentum transfer squared at p vertex	-1 – 0 GeV² (exclusive) -20 – 0 GeV² (p-diss.)

Theoretical models for VM production : dipole model



Dipole picture in proton rest frame

- $\gamma^* \rightarrow q\bar{q}$
- $q\bar{q}$ scattering on the proton
- VM is formed (after interaction)

$\sigma(x,Q^2) = \int d^2r dz\, |\Psi(r,z,Q^2)|^2 \cdot \sigma_{qq}(x,r)$

Ψ_L: $\gamma^*_L \rightarrow q\bar{q}$ wave function (parametrizations exist DGKP,NNPZ etc.)

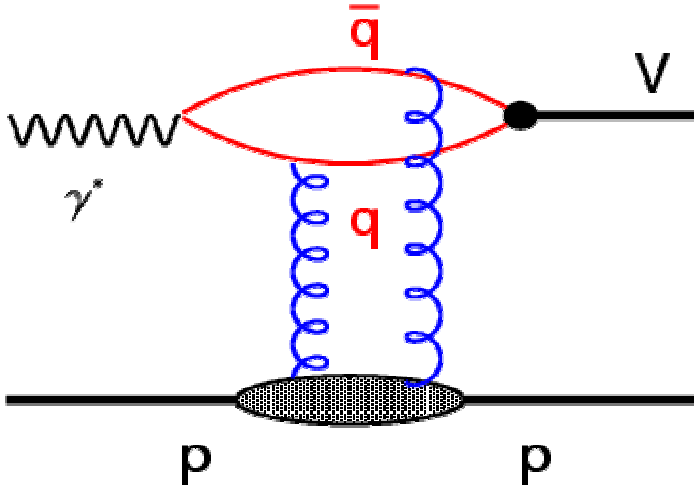
σ_{qq}: $q\bar{q}$-proton cross-section (make predictions for dipole cross-section GBW, pQCD etc.)

r: transverse separation of $q\bar{q}$ $r \sim [z(1-z)Q^2 + m_q^2]^{-1/2}$, $z = p_q/p_{\gamma^*}$

small dipoles (large Q^2 or m_q^2) => pQCD

large dipoles (small Q^2 for light VM) => soft interactions

Theoretical models for VM production : pQCD



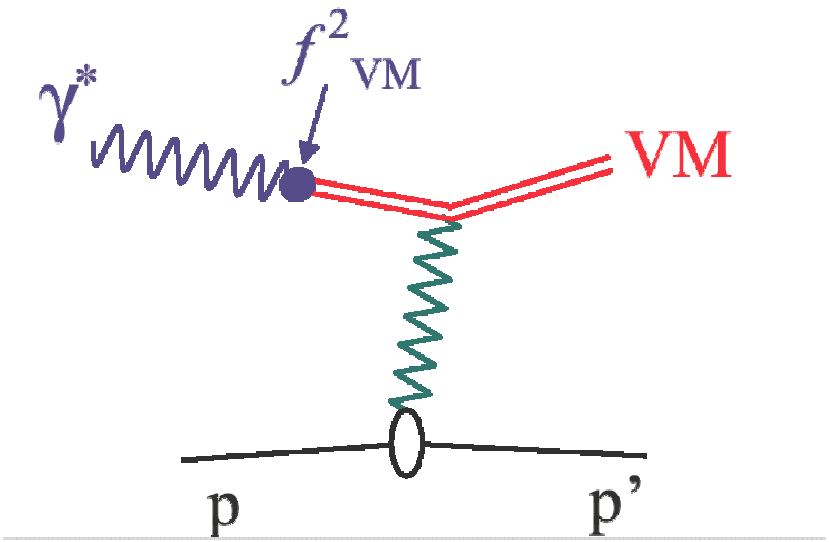
- leading order 2 gluon exchange
- gluon ladder calculations exist

$$\sigma_L \propto \alpha_s^2(Q_{eff}^2)/Q^6\,|xG(x,Q_{eff}^2)|^2$$

MRT: Phys.Rev.D62, (2000) 14022
FKS : Phys.Rev.D57, (1998) 512

- Fast rise $\sigma(W) \propto [x^{-0.2}]^2$, $(x \approx Q^2/W^2)$ $\propto W^\delta$, $\delta \approx 0.8$
- Universal t dependence $d\sigma/dt \propto e^{bt}$,$b = b_{2g} \approx$ 4 GeV^{-2} (const. with W)
- Extraction of gluon density still not possible
  NLO calculations needed
  VM wave function effects
  At which scale to evaluate Q_{eff}? Ryskin: $Q_{eff}^2 = \frac{1}{4}(Q^2 + M_{VM}^2 + |t|)$
- Problems for σ_T : large dipole sizes

Theoretical models for VM production : VMD and Regge



- Large dipoles = soft interactions
  => pQCD not valid
- phenomenology must be used

$\gamma^* \rightarrow$ VM oscillation (before interaction)

Soft pomeron exchange

$\alpha(t) = \alpha_0 + \alpha' t$, „trajectory“

($\alpha_0 = 1.08$, $\alpha' = 0.25$ GeV^{-2})

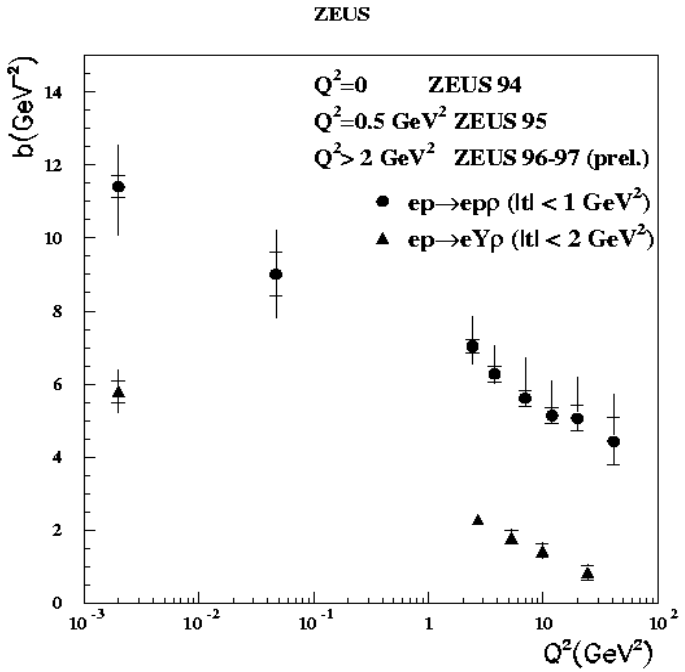
$d\sigma/dt \propto e^{bt} (W/W_0)^{4(\alpha(t)-1)}$

Predictions:

Slow rise $\sigma(W) \propto W^{\delta}$, $\delta \approx 0.22$

Shrinkage: $b(W) = b_0 + 4\alpha' \ln(W/W_0)$

Measurement of t dependence



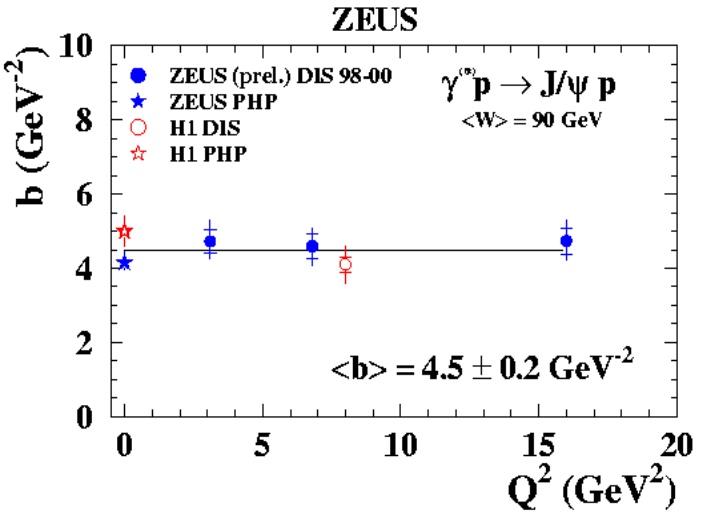
- expect $d\sigma/dt \propto e^{-b|t|}$
- power law for high |t| ?
- t is Fourier conjugate of impact parameter

=> b is related to transverse size of interaction

$b \sim 1/4\,(r^2_p + r^2_{VM})$ „$b = b_{2g} + b_{VM}$“

- pQCD: universal b slope

$b = b_{2g} \approx$ 4 GeV^{-2} (size of the proton)

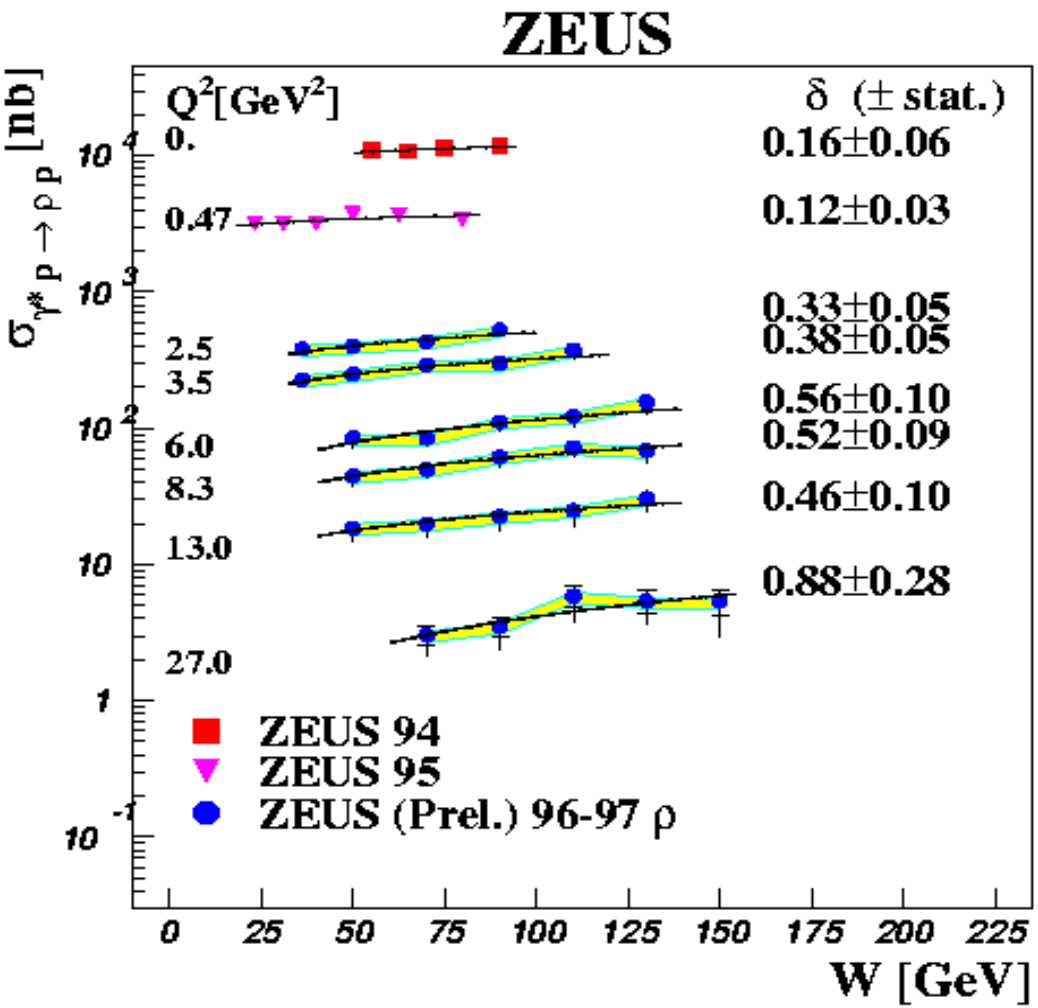


- ρ : steep decrease of b with Q^2

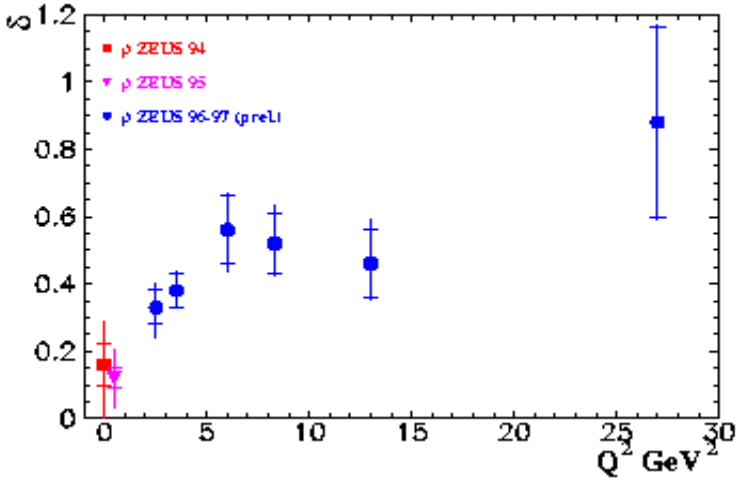
  high Q^2 = small dipole size
- J/ψ : constant with Q^2

  => size of J/ψ << size of proton

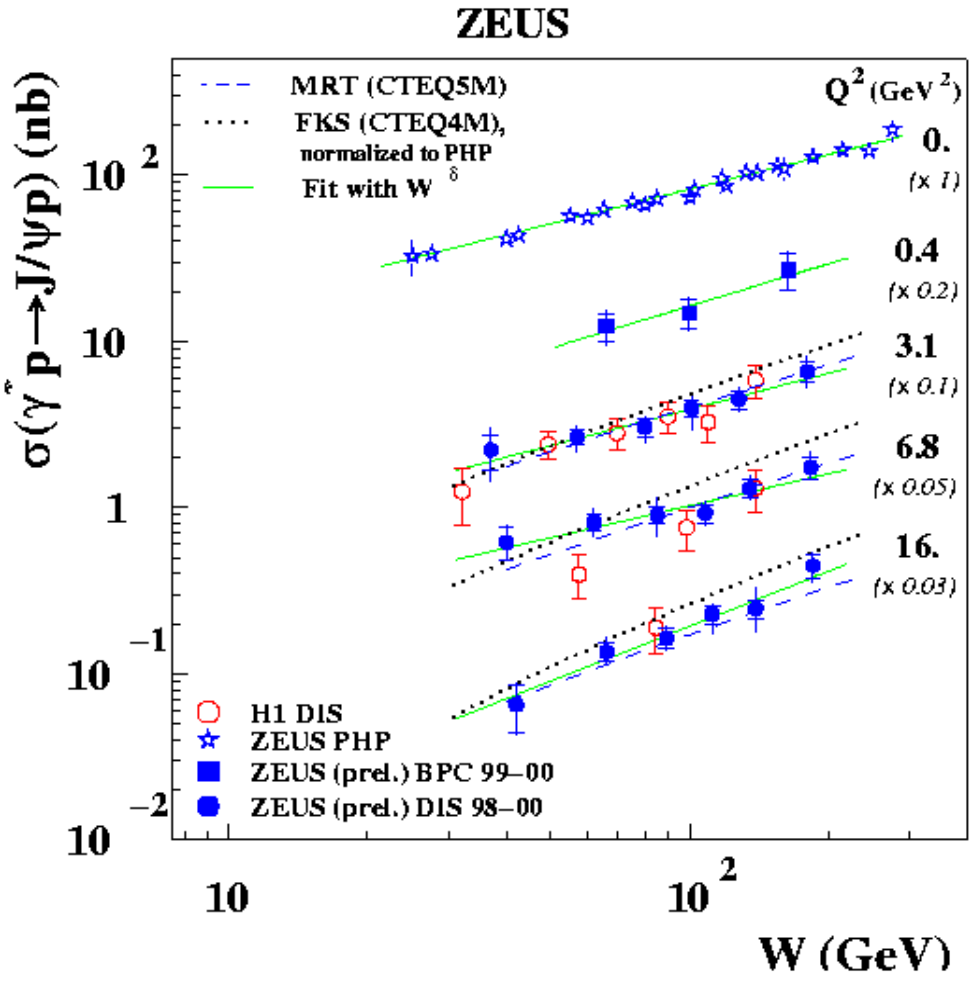
W dependence of ρ production



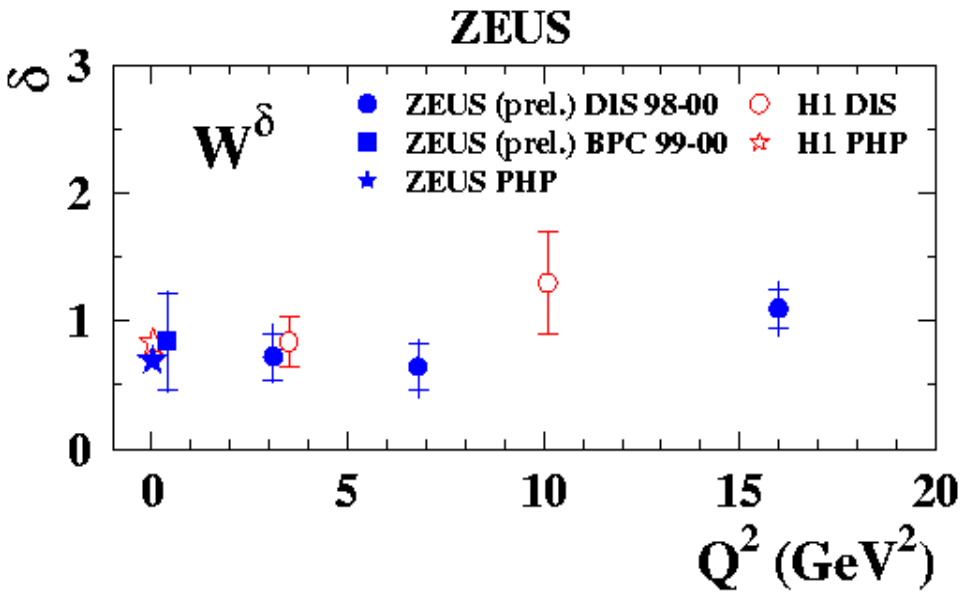
- δ rising with Q^2
- Smooth transition from soft to hard regime observed
- Which Q^2 is “hard”?



W dependence of J/ψ production



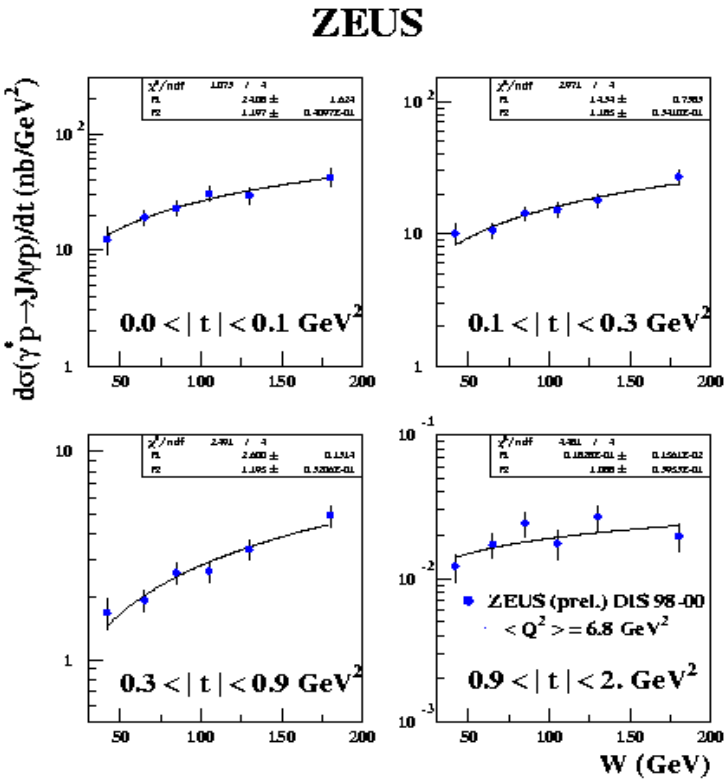
Fit $\sigma(W) \propto W^{\delta}$

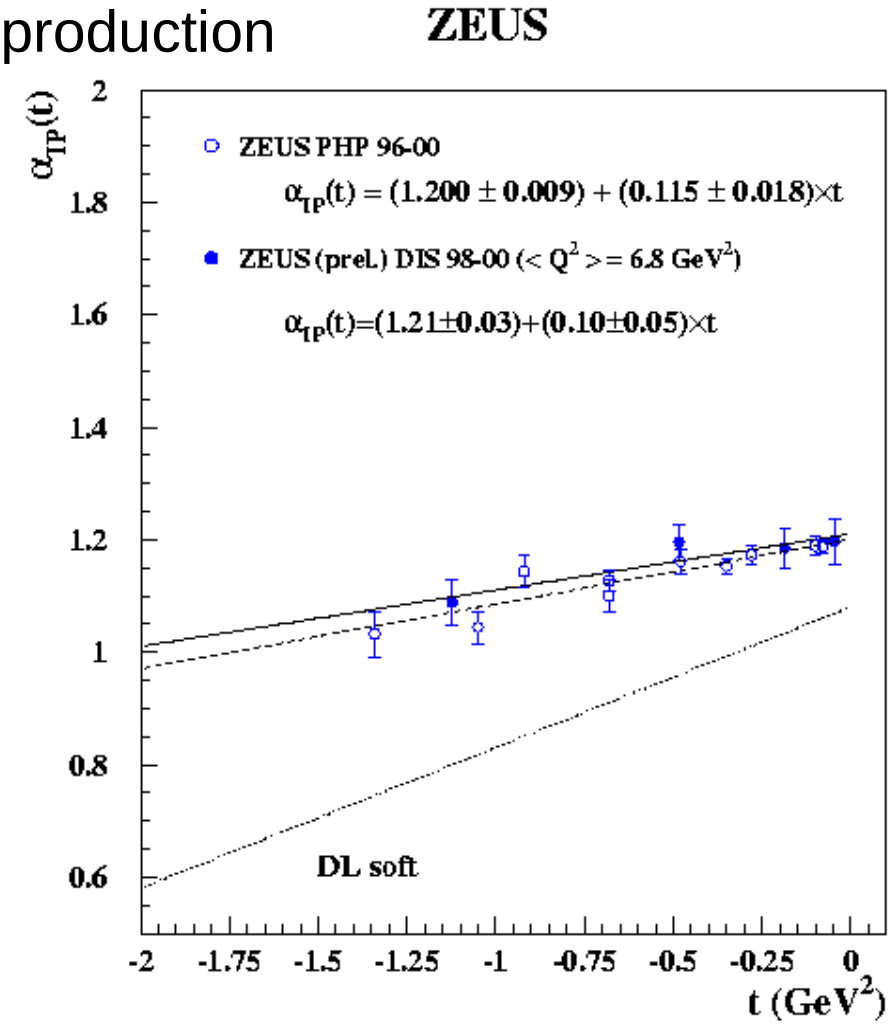


- No change of W dependence with Q^2
- Mass of J/ψ sets the scale already in photoproduction
- Consistent with pQCD expectation

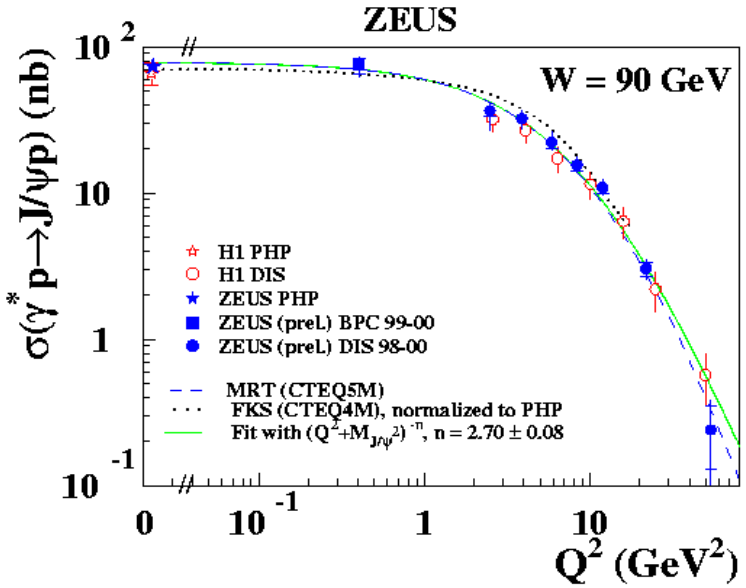
Pomeron trajectory for J/ψ

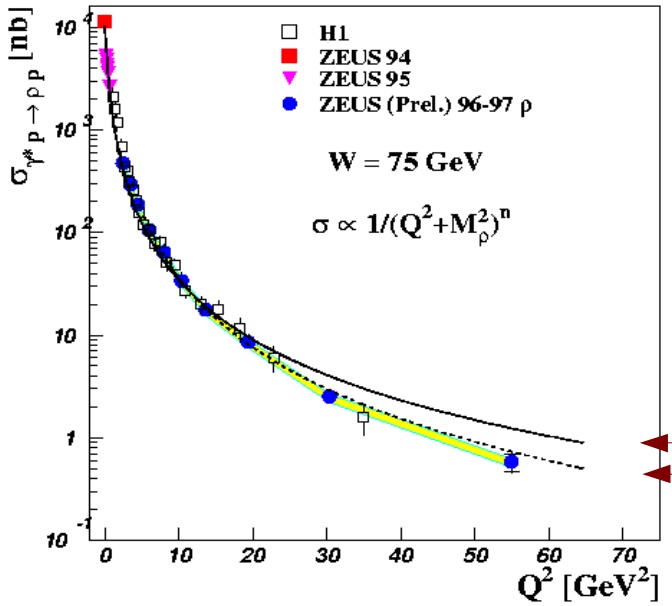
- Measure W dependence in bins of t
- Extract pomeron trajectory $d\sigma/dt \propto (W/W_0)^{4\,(\alpha(t)-1)}$
- High Q^2 results compatible with photoproduction
- Intercept compatible with BFKL





Q^2 dependence of VM production





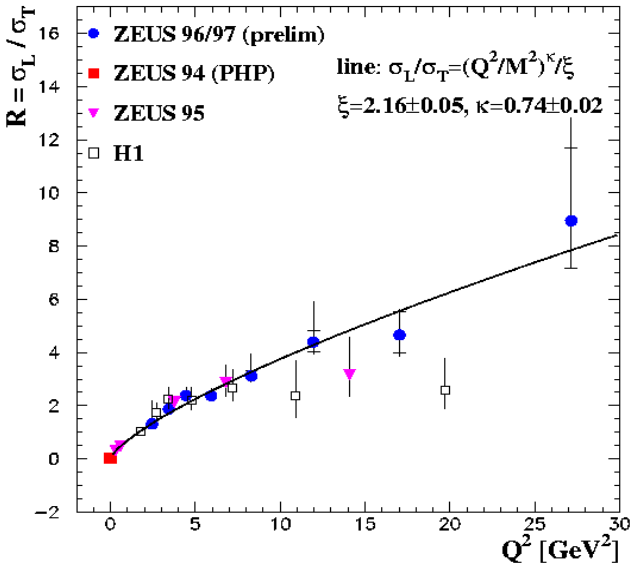
- Cross section for J/ψ well described in shape and normalisation by pQCD models (MRT)

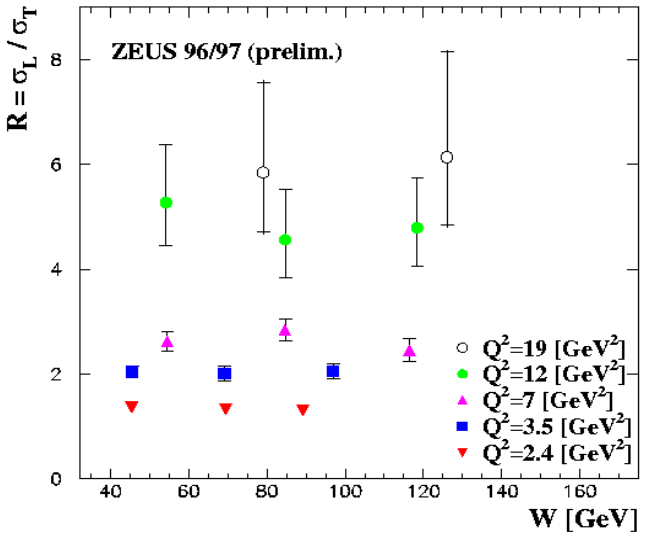
Fit $\sigma(Q^2) \propto (Q^2+M_{J/\psi}^2)^{-n}$

- J/ψ :
  simple fit describes the data well
- light vector mesons :
  n increases with Q^2
  possible wave function effects

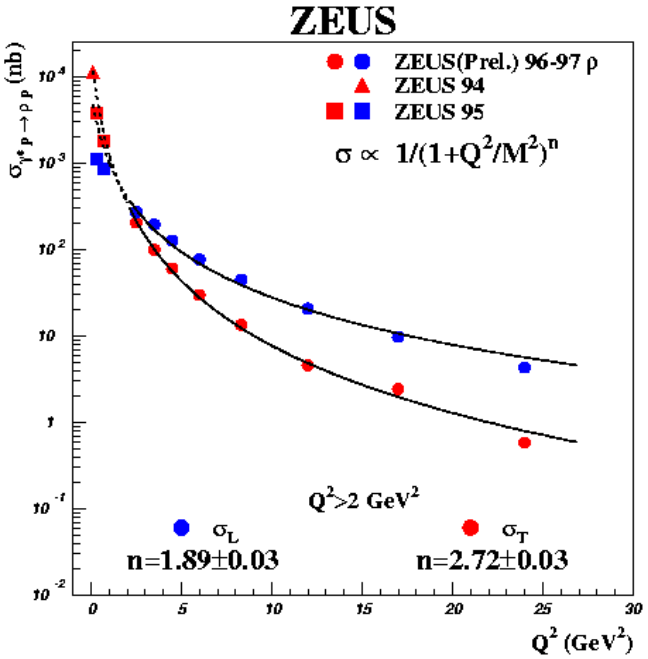
Fit in full range
Fit for Q^2>5GeV ^{2}

Measurement of R = σ_L/σ_T

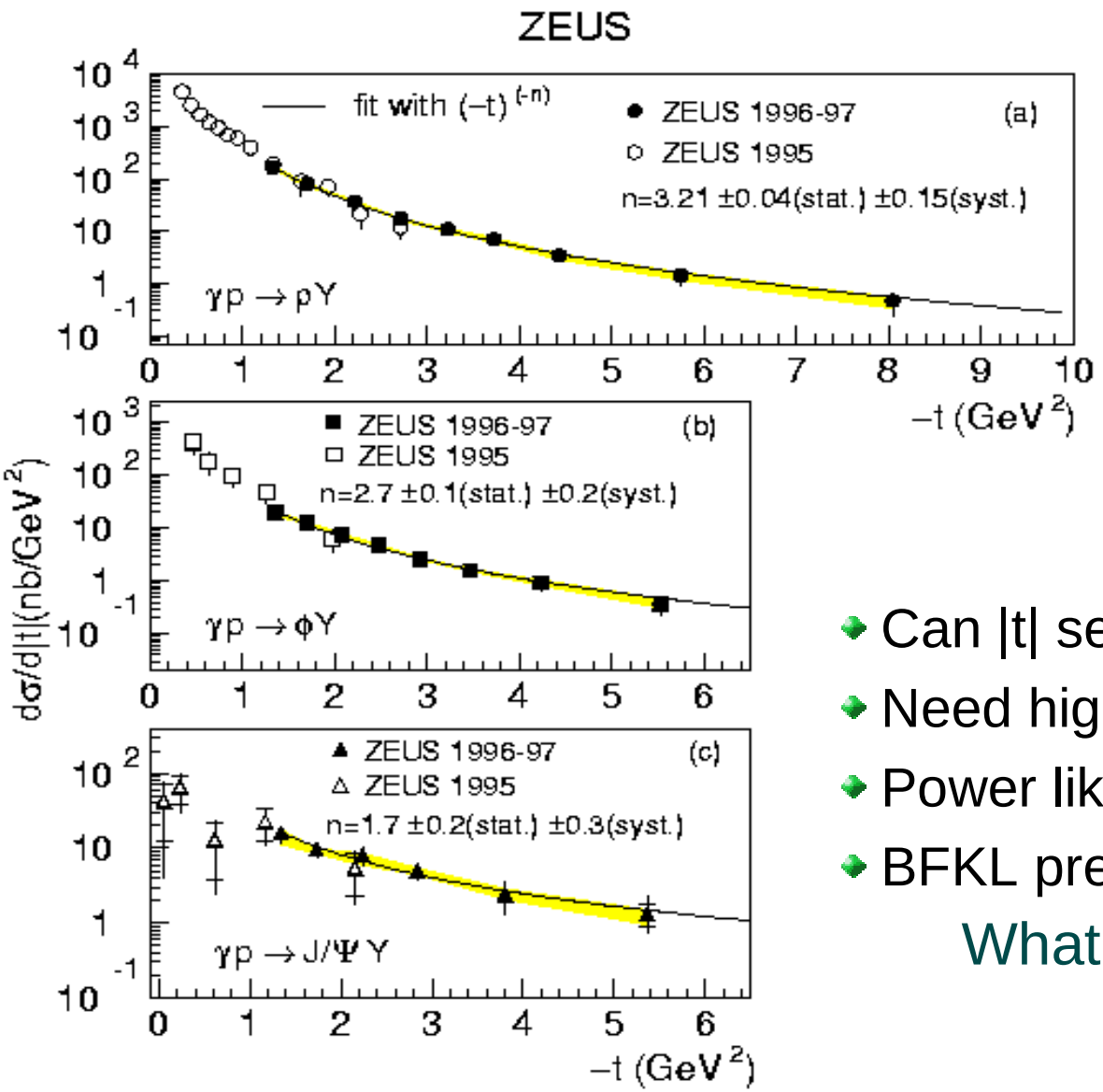


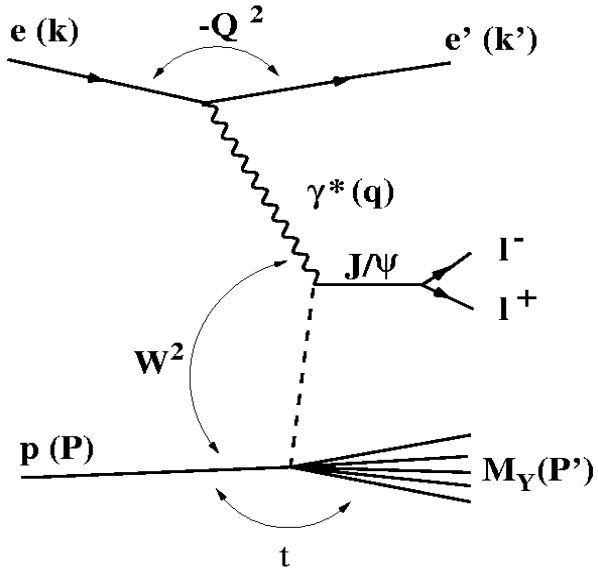


- R = σ_L/σ_T measured through angular distributions of the final state
- s-channel helicity conservation valid for low t
- Rise with Q^2 observed – expected
- No dependence on W
- Different Q^2 dependence for σ_T and σ_L



Proton dissociative VM photoproduction





- Can |t| serve as a hard scale?
- Need high |t| => proton dissociation
- Power like behaviour
- BFKL predictions describe data well

  What happen at higher W?

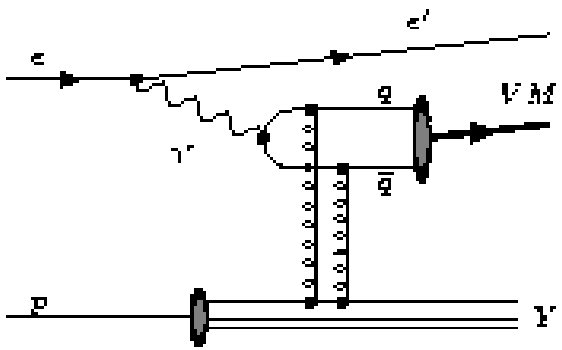
Proton dissociative J/ψ photoproduction at high W

- Require hard scale (large M_{VM}, large |t|)
- Electron tagged at small angle => 185<W<245GeV
- DGLAP: no energy dependence predicted
- BFKL: parameters tuned to data at W=100GeV
  predicts rise with W

Which approach describes the data?

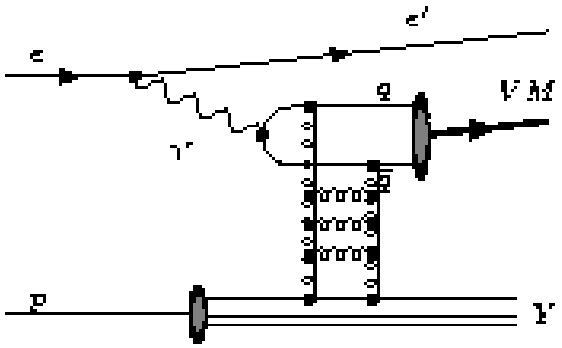
DGLAP

Gotsman et al., Phys.Lett. B532, 37



BFKL

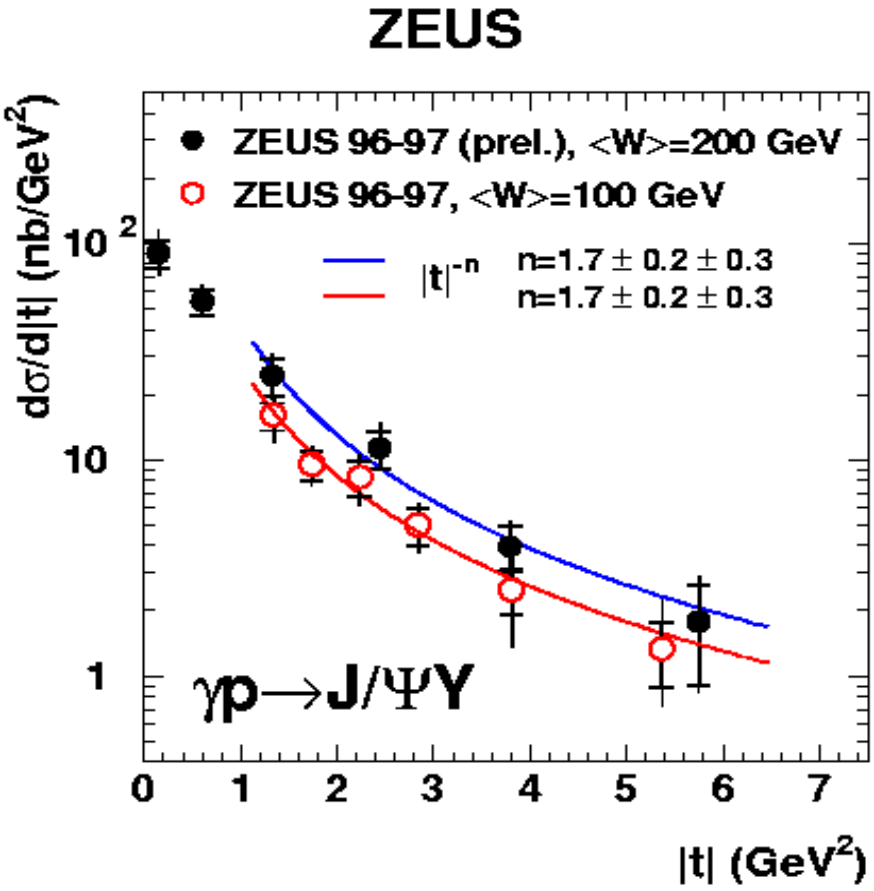
Forshaw et al, Eur.Phys.J. C26 (2003) 411
Engberg et al, Eur.Phys.J. C26 (2003) 219



abs. 549

Proton dissociative J/ψ photoproduction at high W

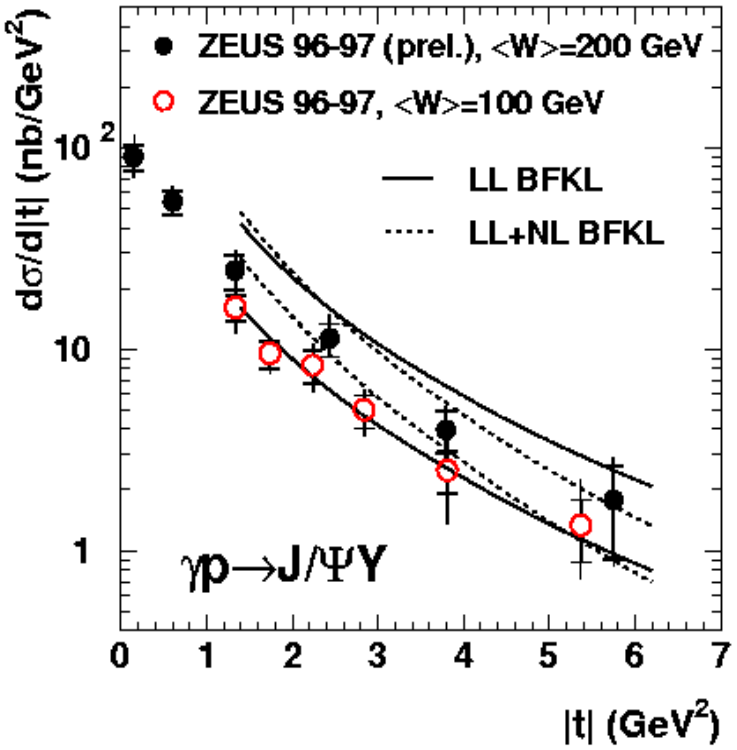
- Rise with energy observed
- Power law describes the data well
- Same power for different energies

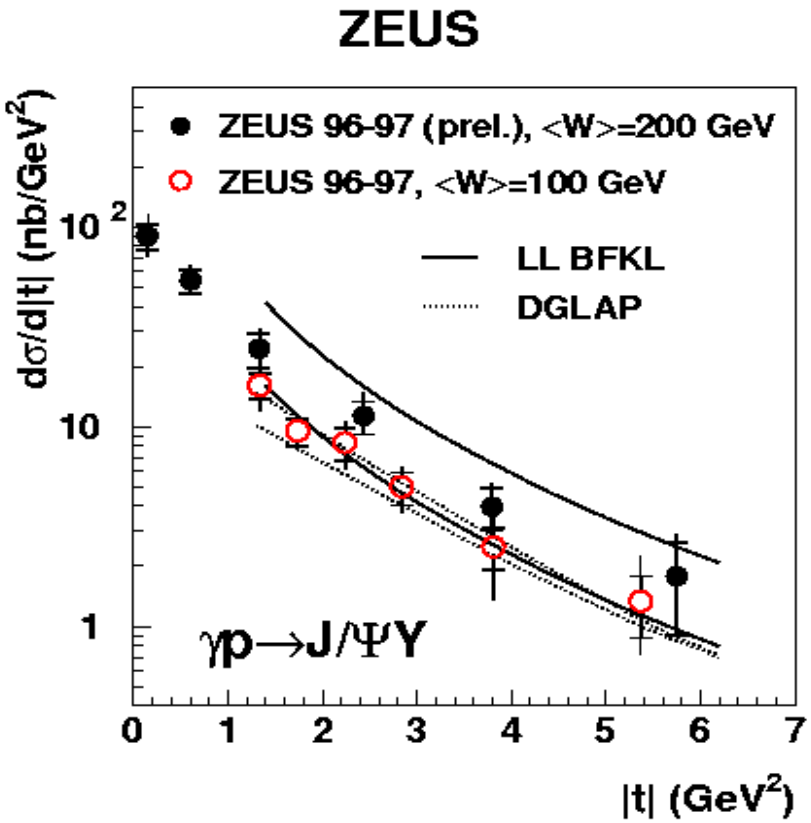


Proton dissociative J/ψ photoproduction at high W

- LL BFKL predicts stronger rise with W
- LL+NL BFKL disfavoured by the data
- DGLAP – no evolution with W

Sign of BFKL evolution?





Summary

- ρ shows smooth transition from soft to hard physics
- J/ψ well described by pQCD based models. Hard scale observed already in photoproduction.
- Energy dependence observed for J/ψ photoproduction – sign of BFKL evolution?