Vector Mesons and pQCD at HERA

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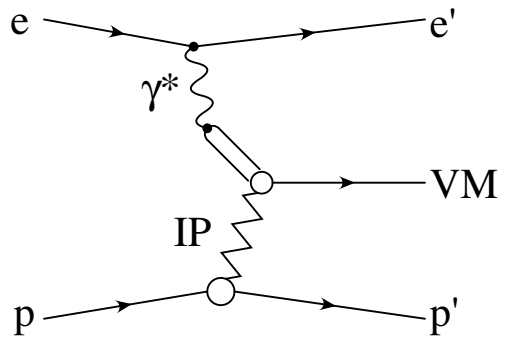
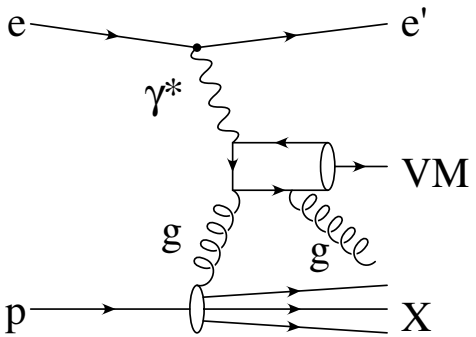
Vector Meson Production

diffractive production:



- γ* fluctuates into VM*
- colorless exchange with p
  (soft: IP **or** hard: ≥ 2g)
- elasticity $z = E_{VM}/E_{\gamma} \approx 1$
- low multiplicities
- elastic: p'=p
- proton dissociative:
  p'=X with small M_x

inelastic production:



- boson gluon fusion
- $q\bar{q} \rightarrow$ VM by g emission
- all z
- high multiplicities

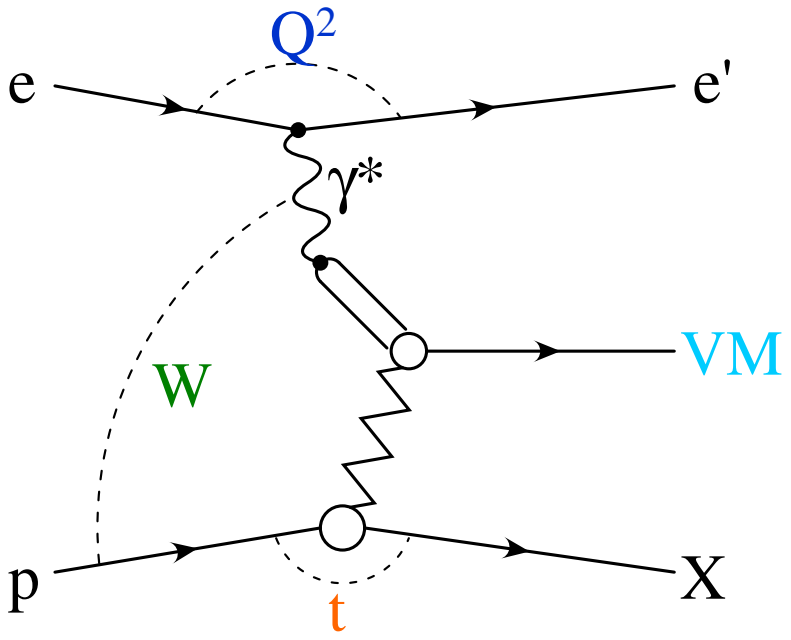
Kinematics in Vector Meson Production

photoproduction:

$Q^2 \approx 0$

electroproduction:

$Q^2 > 2$ GeV^2



Q^2	γ^* virtuality	$0<Q^2<100$ GeV^2
W	energy of γ^*p system	$20<W<290$ GeV
t	(4 mom. transfer)^2 at p vertex	$0<\|t\|<20$ GeV^2
VM	vector meson	ρ^0, ω, ϕ, J/ψ, Υ

HERA $\Rightarrow$ probe wide range of different scales: M^2, Q^2, t

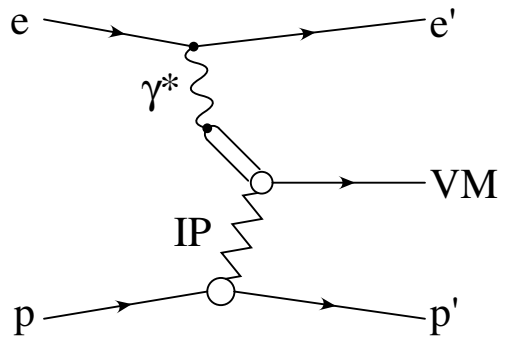
Outline

- diffractive vector mesons:
  - § energy dependence (W)
  - § test of different scales (M^2, Q^2, $|t|$)

- inelastic vector mesons:
  - § new results on J/ψ electroproduction to test two competing models

Diffractive Vector Meson Production

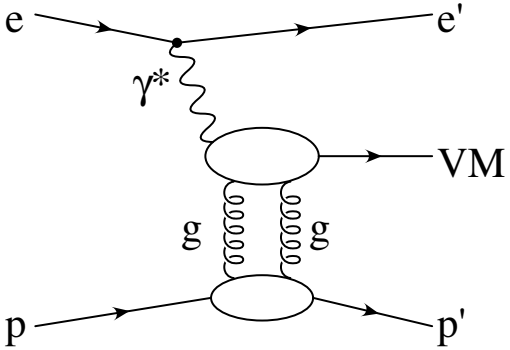
Regge approach:



- soft IP exchange
  $\alpha(t)=\alpha(0)+\alpha' \cdot t$
- $\sigma \propto W^{4(\alpha(t)-1)} = W^{0.22}$
- $\sigma \propto e^{-b \cdot t}$

$\Rightarrow$ works reasonably for light VM at $Q^2 \approx 0$, $t \approx 0$

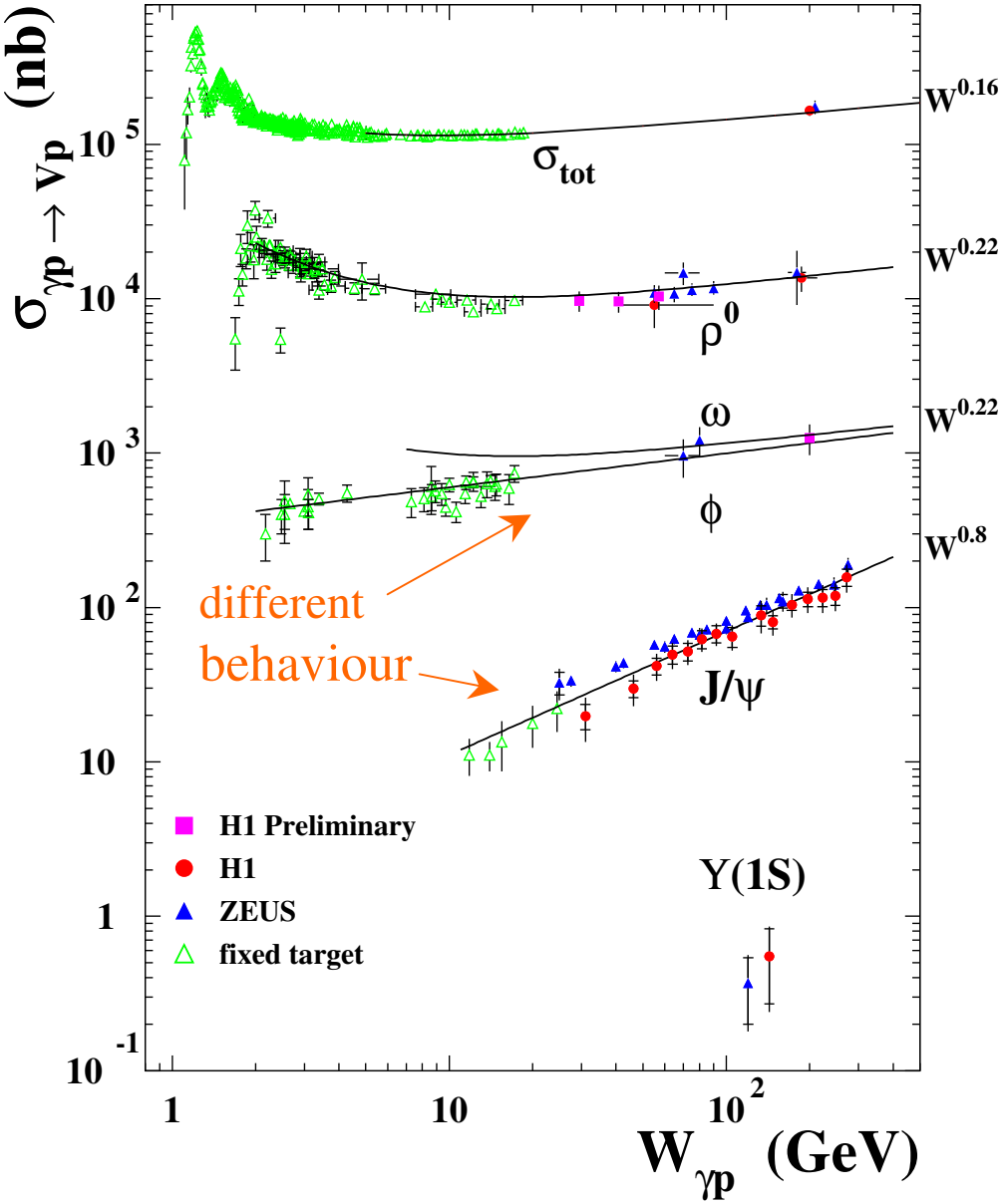
perturbative QCD:



- exchange of $\geq 2g$
- $\sigma \propto [xg(x,Q_{eff}^2)]^2$
  what Q_{eff}^2 is the right one??
  (M^2, Q^2, t, $Q^2 + M^2$, …)
- fast rise with $W \propto 1/x$
  $\sigma \sim W^{0.8}$
- $\sigma \propto |t|^{-n}$

$\Rightarrow$ works in presence of hard scales (heavy VM, Q^2, t)

Elastic VM in Photoproduction ($Q^2 \approx 0$)

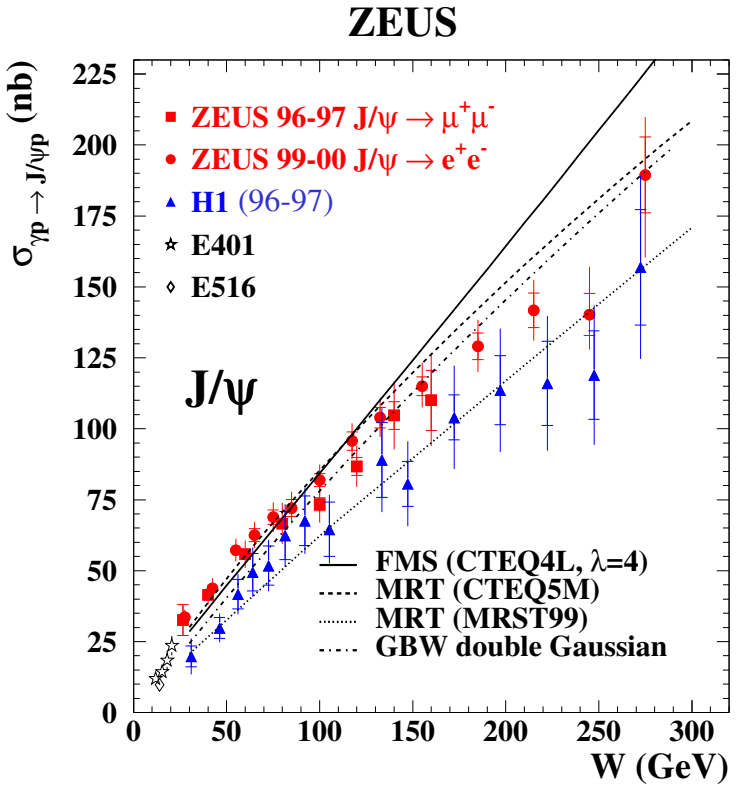


fit $\sigma \sim W^{\delta}$ yields:

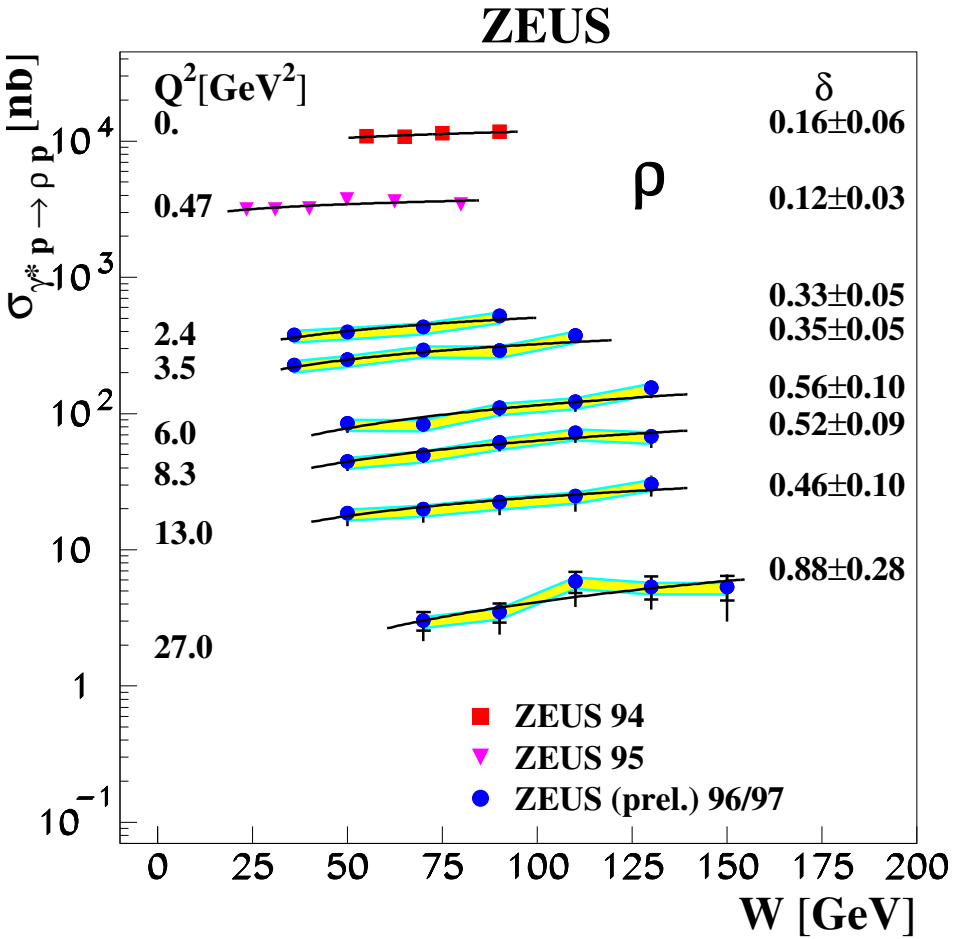
light VM: $\delta \approx 0.22$ (soft W dep.)

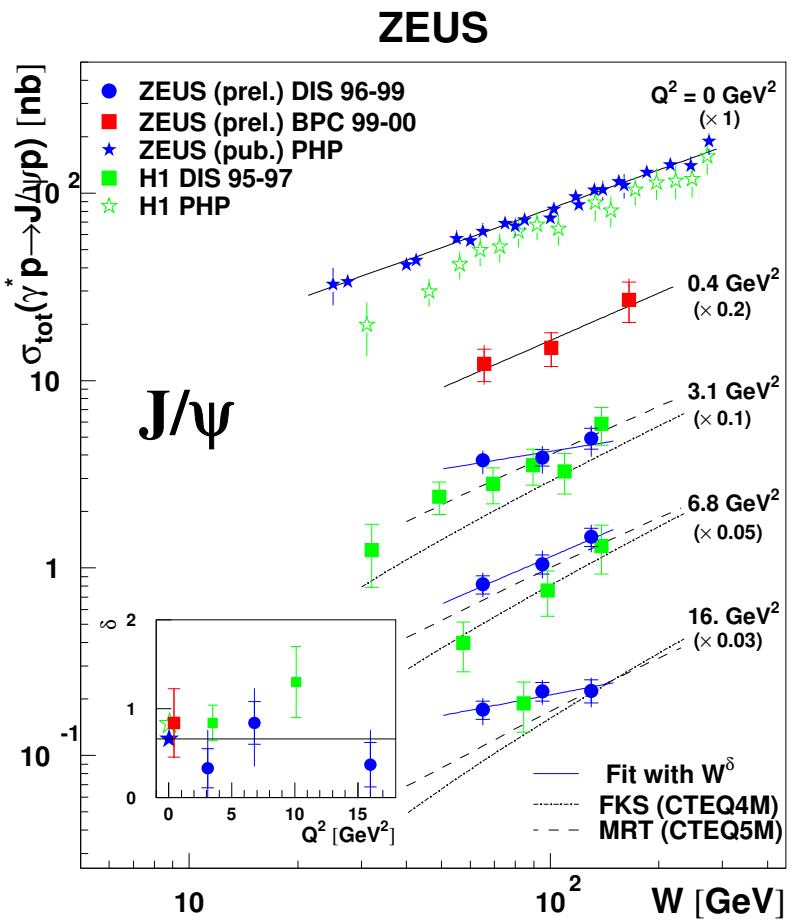
for J/ψ: $\delta \approx 0.8$ (hard W dep.)

$\Rightarrow$ is described in pQCD



W dependence for increasing Q^2





- δ rises with Q^2

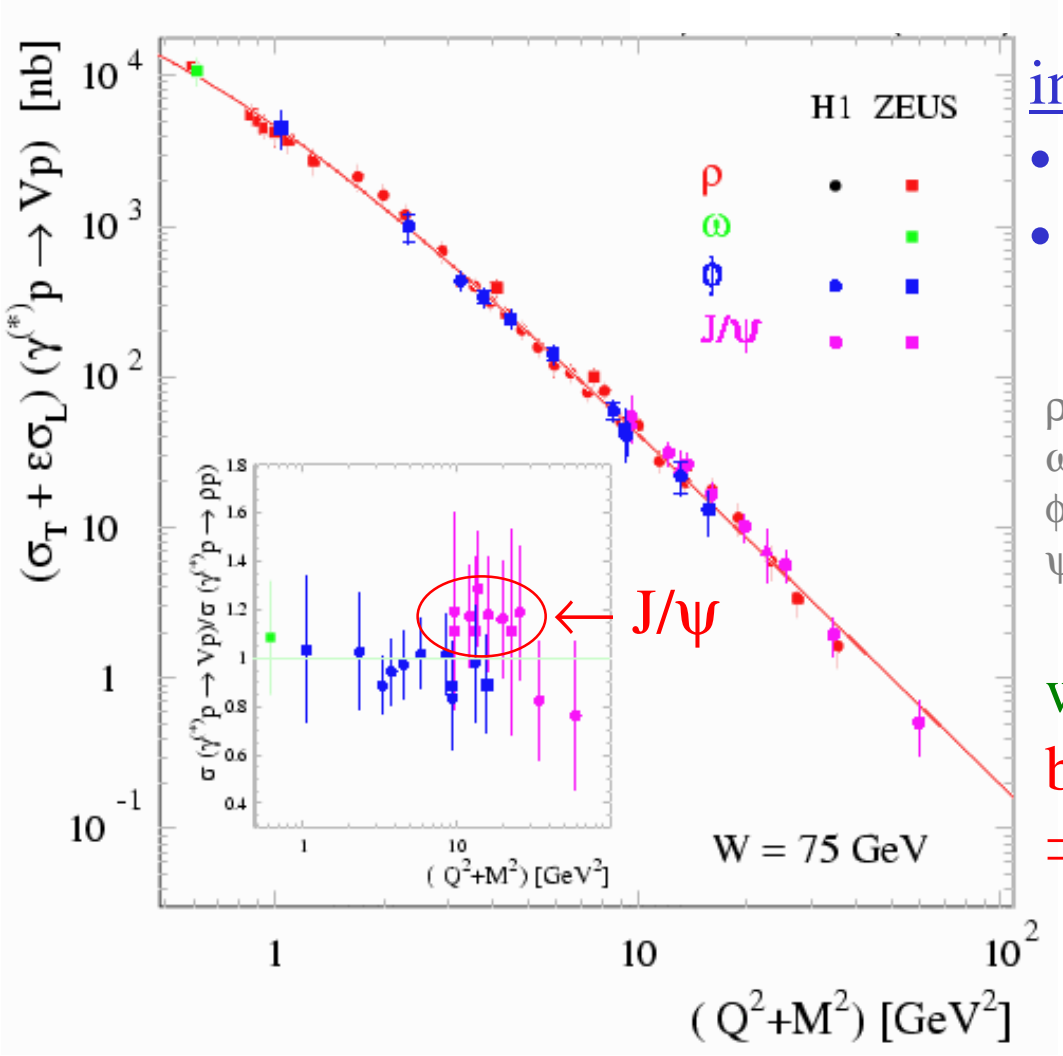
⇒ transition from soft to hard

- δ similar for different Q^2, but large uncertainties

VM and SU(4) – Q^2+M^2-dependence

- VM multiplied by factors $\rho^0:\omega:\phi:J/\psi = 9:1:2:8$

  $\rightarrow$ factors from coupling of VM to γ: $\Gamma \propto \Sigma |a_i Q_i|^2$



in SU(4) ← quark model

- masses of VM neglected
- only quark content $a_i Q_i$ taken into account:

$\rho = 1/\sqrt{2}(uu-dd) \rightarrow (1/\sqrt{2})^2 \cdot [2/3 - (-1/3)]^2 \Rightarrow 9$

$\omega = 1/\sqrt{2}(uu+dd) \rightarrow (1/\sqrt{2})^2 \cdot [2/3 + (-1/3)]^2 \Rightarrow 1$

$\phi = ss \rightarrow [-1/3]^2 \Rightarrow 2$

$\psi = cc \rightarrow [2/3]^2 \Rightarrow 8$

works quite well,

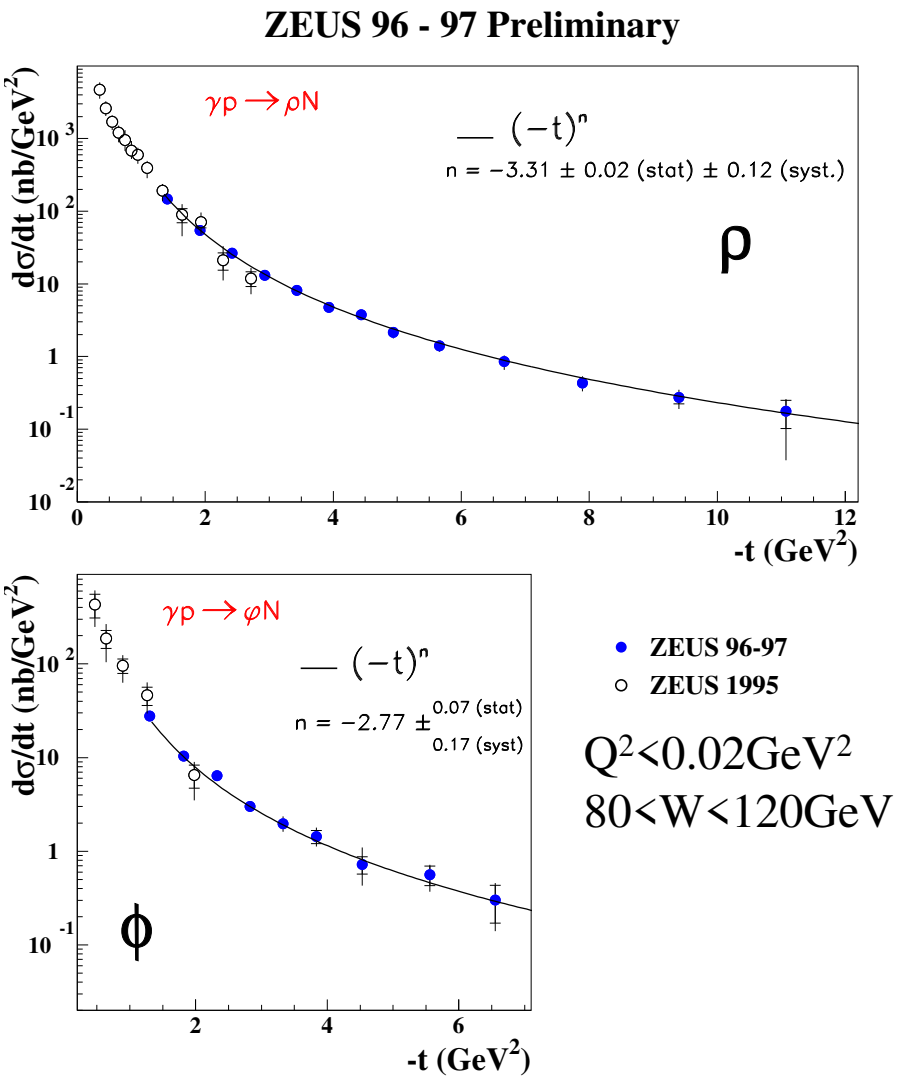
but J/ψ mostly above other VM

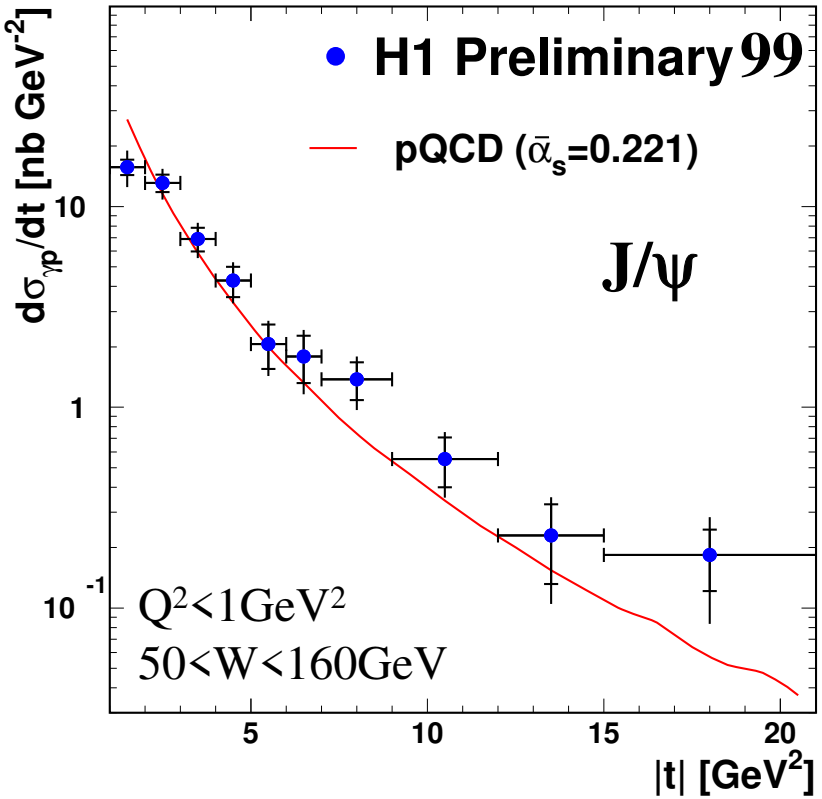
$\Rightarrow$ hint, that mass not negligible in pQCD:

$$VM_1/VM_2 \approx \Gamma_1 \cdot M_1/\Gamma_2 \cdot M_2$$

VM production at high |t|

- at high |t|: proton dissociative production dominates
- dependence in pQCD: $\sigma \propto |t|^{-n}$ (Regge (soft): $\sigma \propto e^{-b \cdot t}$)

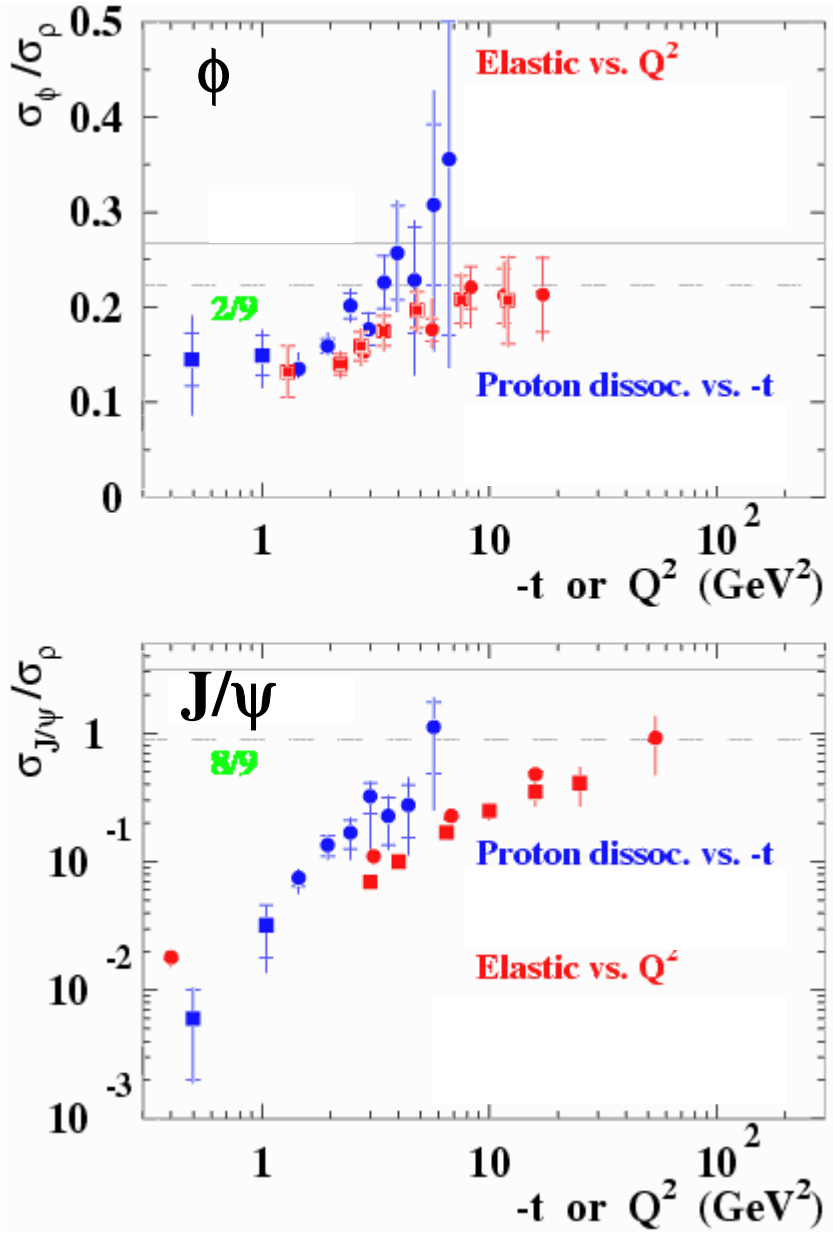




- dependence at large $|t| \sim |t|^{-n}$
- described by pQCD
  (large norm. uncertainties)

$\Rightarrow$ indication: |t| is a hard scale

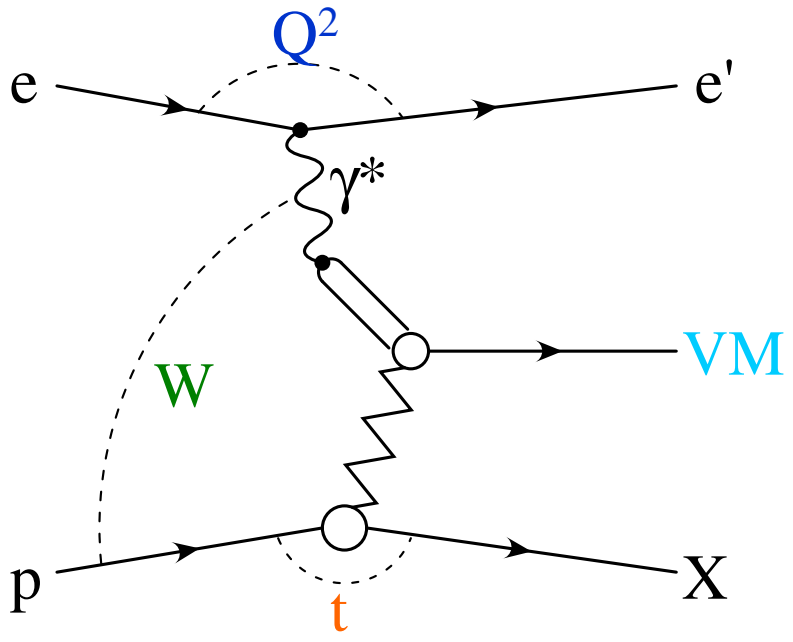
VM production at high |t| (cont.)



- ratios rising with increasing |t| or Q^2
  ⇒ indication: pQCD takes over

- rise in |t| faster than in Q^2
  ⇒ how to interpret?
  - § Q^2 and |t| not equivalent scales?
  - § different cross section dependences (as expected by pQCD)?

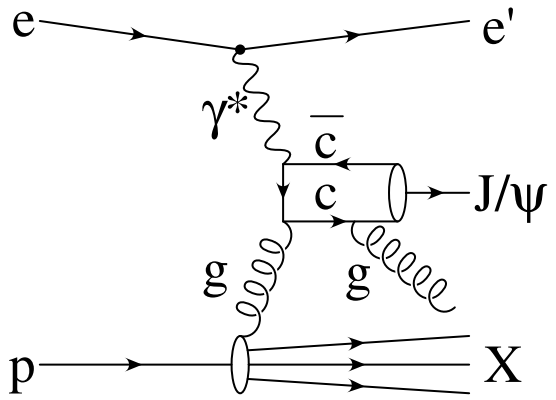
Conclusion on diffractive VM production



- HERA data span transition from soft to hard diffraction
- clear indication that Q^2, M^2 and $|t|$ provide a hard scale
- pQCD works well for production at large Q^2, M^2, $|t|$

Inelastic J/ψ production

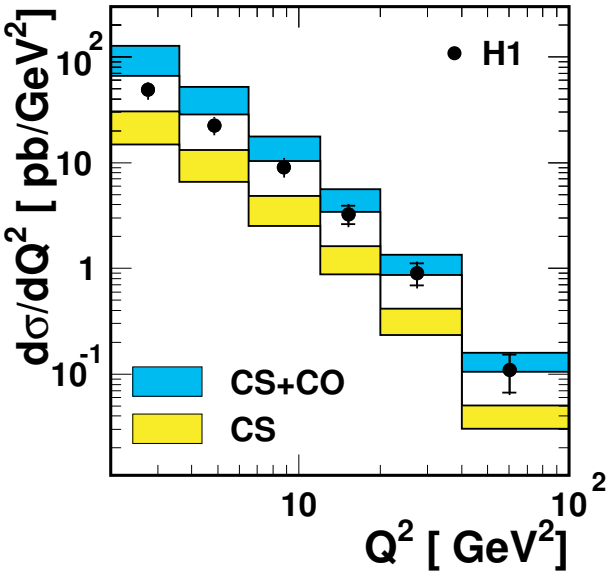
- Photon Gluon Fusion
- $\sigma \propto xg(x,Q_{eff}^2)$

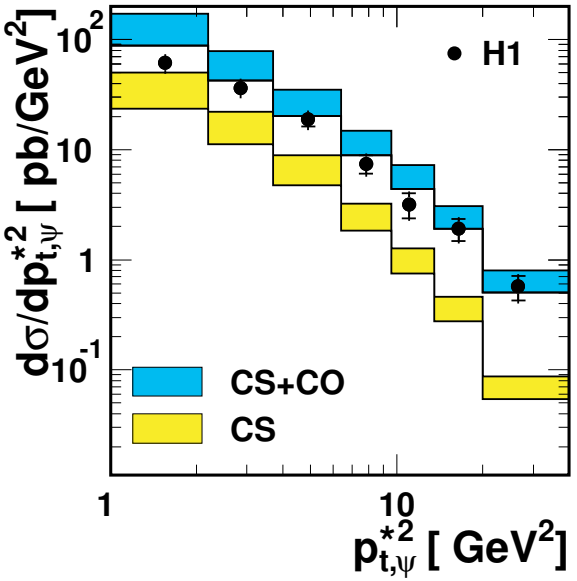


- two competing models:

Color Singlet Model	"Color Octet Model"
(CS)	(CS+CO)
• intermediate $c\bar{c}$ in CS state	• intermediate $c\bar{c}$ may be in CS **or** CO state
• fully calculable in pQCD	• not fully calculable → free universal parameters (for prediction taken from fits to results in $p\bar{p}$ scat.)

Inelastic J/ψ electroproduction





$e\ p \rightarrow e\ J/\psi\ X$

kinem. range: $2<Q^2<100\text{GeV}^2$

$50<W<225\text{GeV}$

$z = E_\psi/E_\gamma$ $\quad 0.3<z<0.9$

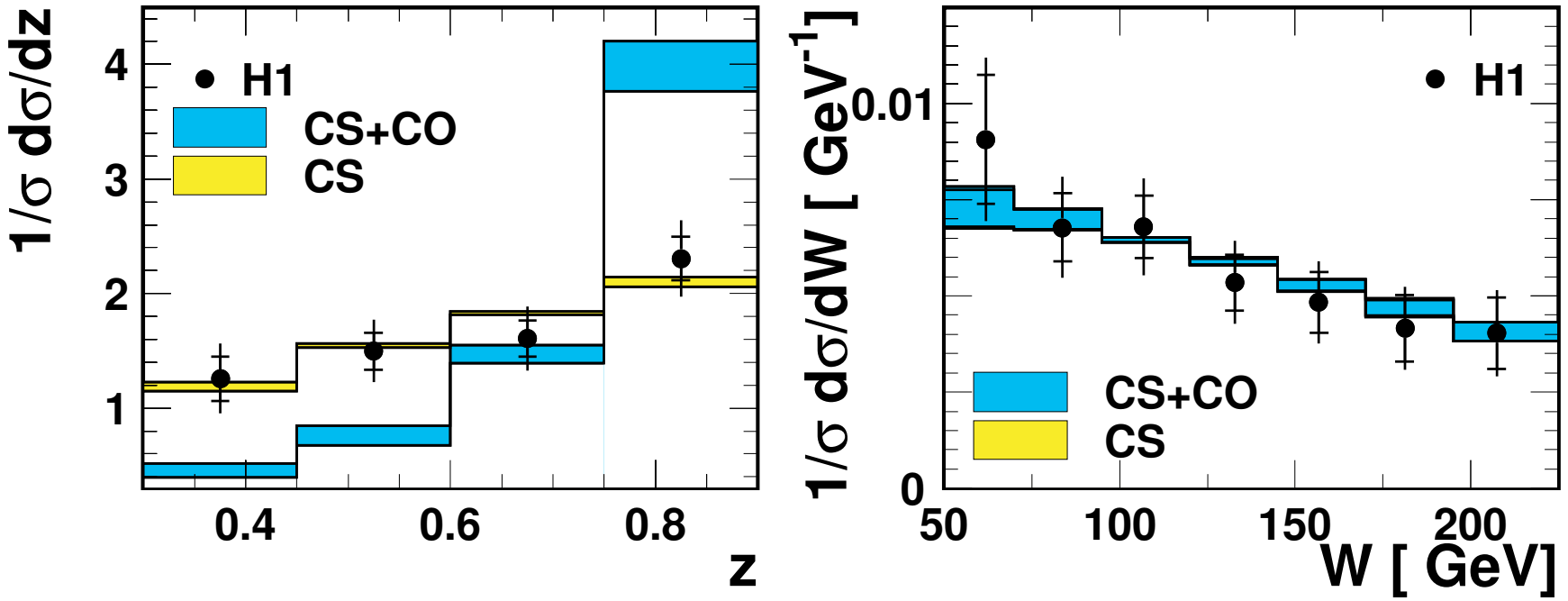
$p_t^{*2}>1\ \text{GeV}^2$

data compared to LO predictions

- CS below data (factor 2.7)
- CS too steep in p_t^{*2}
  (**but** from photoproduction: NLO has large influence at large p_t^{*2})
- CS+CO ok at high Q^2, p_t^{*2}

Inelastic J/ψ electroproduction (cont.)

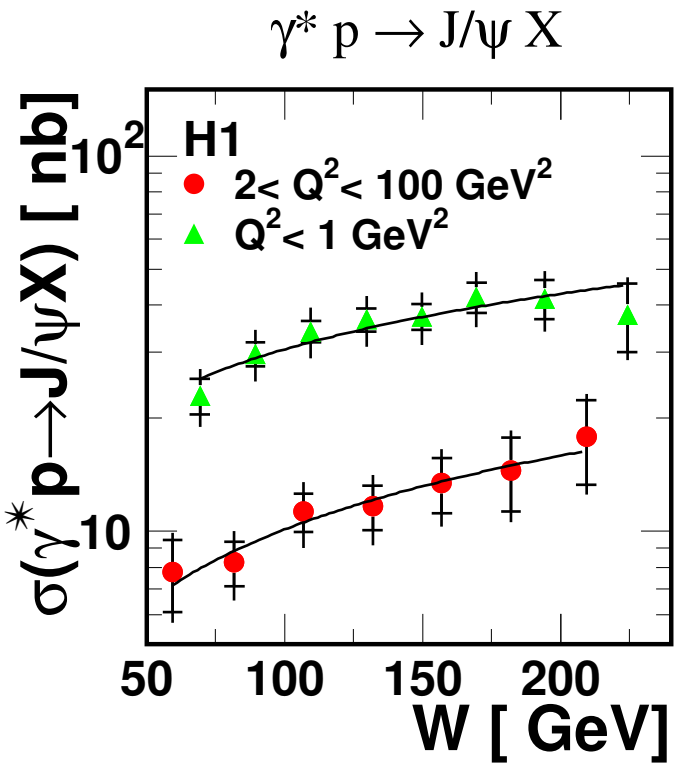
$e\,p \rightarrow e\,J/\psi\,X$



- CS+CO fails in z
  → probably limited phase space for emission of soft gluons
- no sensitivity in W: both models describe dependence well

cross sections normalized to provide shape comparison

W dependence of inelastic J/ψ's



parameterization $\sigma \sim W^{\delta}$

$Q^2 \approx 10 GeV^2$: $\delta = 0.65 \pm 0.25$

$Q^2 \approx 0$: $\delta = 0.49 \pm 0.16$

⇨ similar for photo- and electroproduction

Conclusions on inelastic VM production

§ new results for electroproduction $Q^2 > 2$ GeV^2
compared to two competing models

§ CS below data

§ CS+CO ok at high Q^2, p_t^{*2}

§ similar W dependence as in photoproduction