

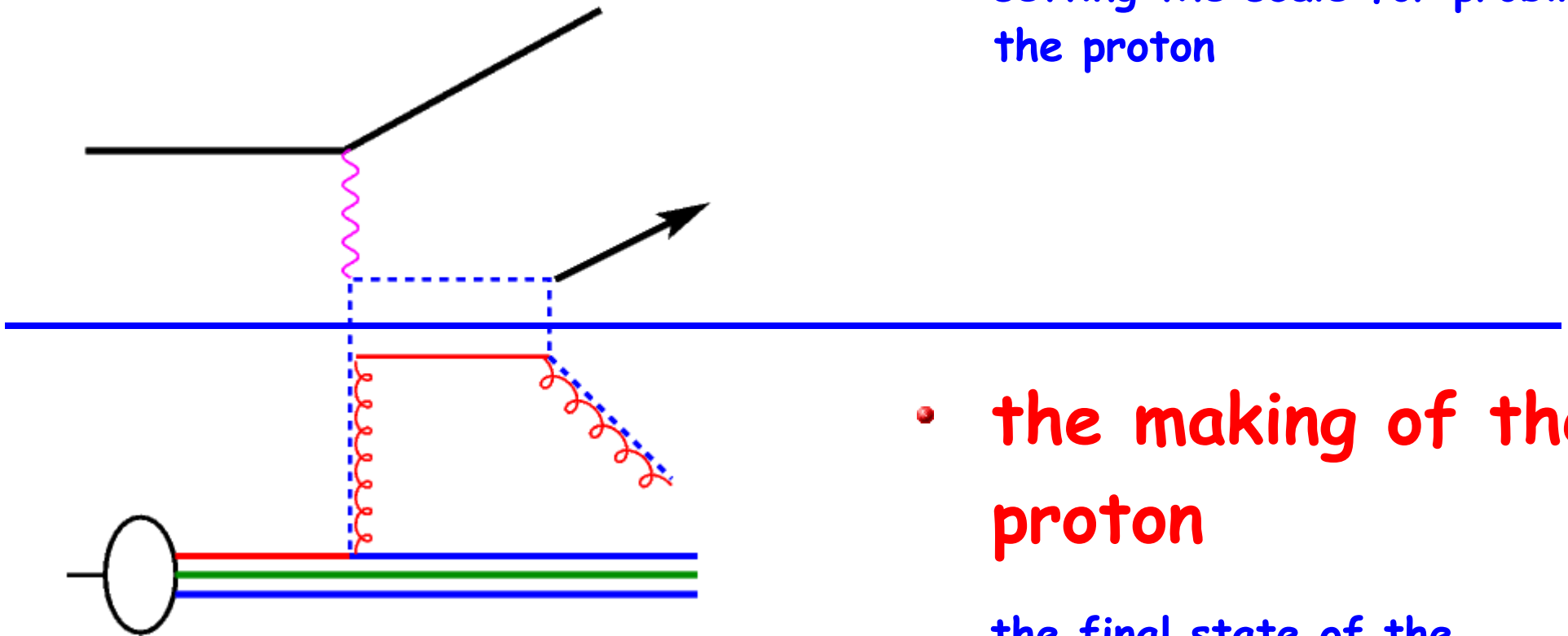
Vector meson and DVCS cross-sections at HERA

H. Jung (DESY)
on behalf of
H1 and ZEUS collaboration

- what are we measuring and why ?
- summary of vector-meson cross sections:
 - inelastic vector-meson production
 - elastic (exclusive) vector-meson production
- what did we learn ?

What we are measuring ?

- **the scene**
setting the scale for probing the proton



- **the making of the proton**
the final state of the interaction

What we are measuring ?

- **the scene**
setting the scale for probing the proton

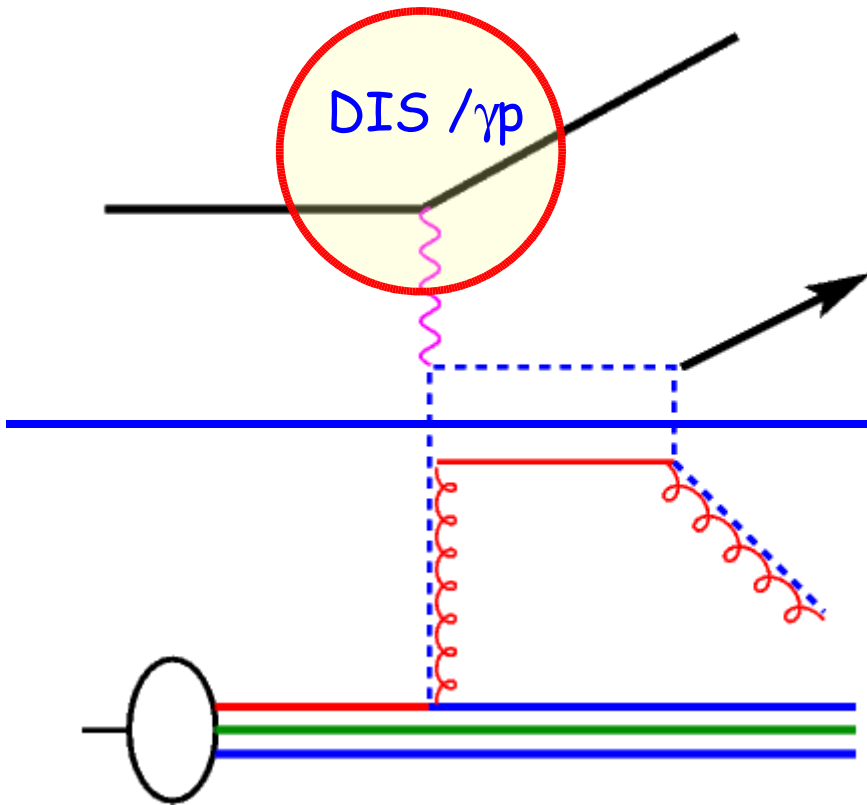
$$\text{DIS: } Q^2 = -(p_e - p_{e'})^2 \gg 0$$

or

$$\text{photoproduction: } Q^2 \sim 0$$

- **the making of the proton**

the final state of the interaction



What we are measuring ?

- **the scene**

setting the scale for probing the proton

Vector mesons:

$\rho, \omega, \phi, J/\psi, \Upsilon$

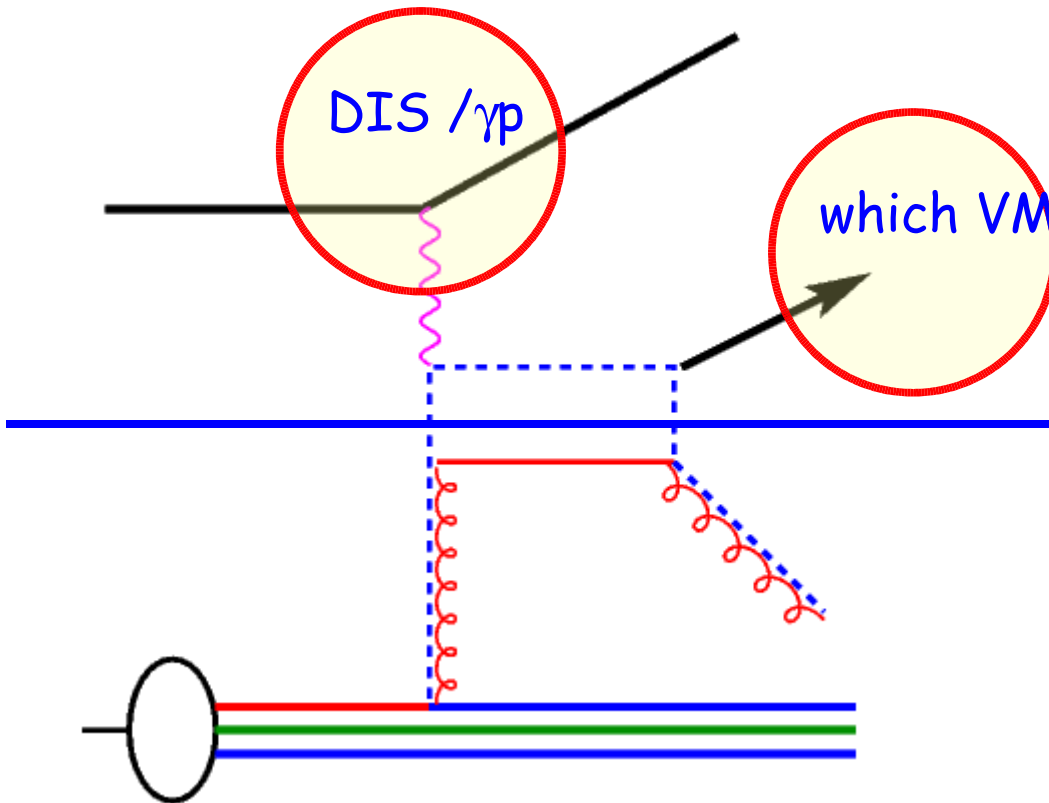
but also γ

define:

$$z = \frac{E_{VM}}{E_\gamma}$$

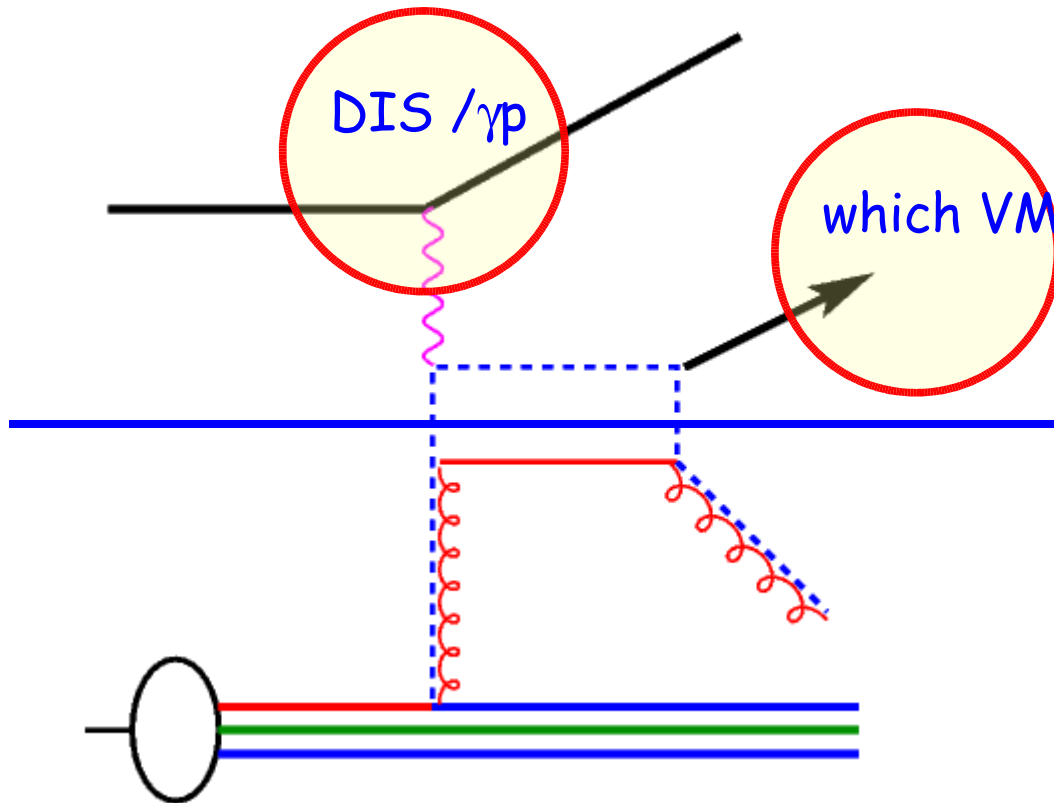
- **the making of the proton**

the final state of the interaction



What we are measuring ?

- **the scene**
setting the scale for probing the proton



- **the making of the proton**

the final state of the interaction

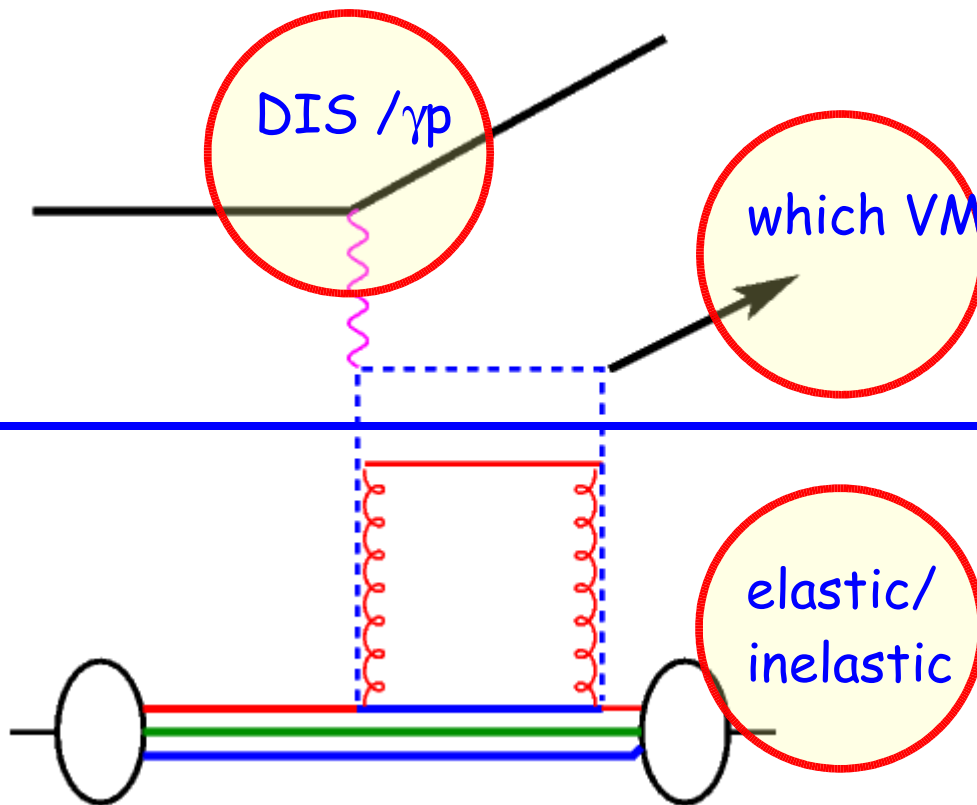
parton densities

parton evolution equations

DGLAP/BFKL/CCFM

What we are measuring ?

- **the scene**
setting the scale for probing the proton



single parton exchange

or

two gluon exchange

- **the making of the proton**

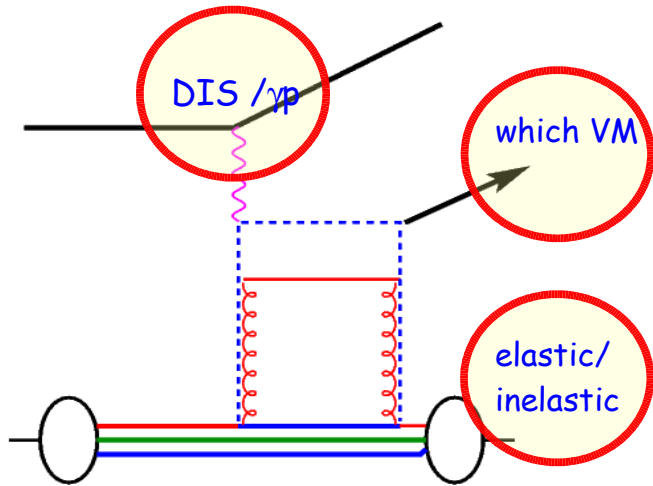
the final state of the interaction

parton densities

parton evolution equations

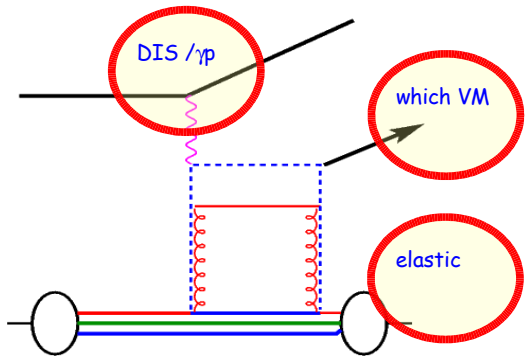
DGLAP/BFKL/CCFM

What we are measuring and why ?

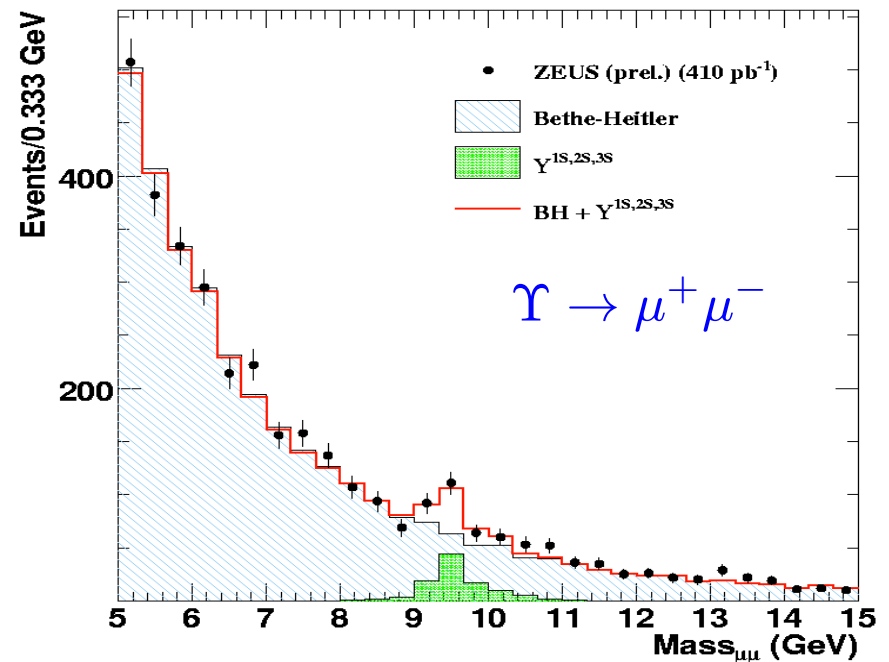
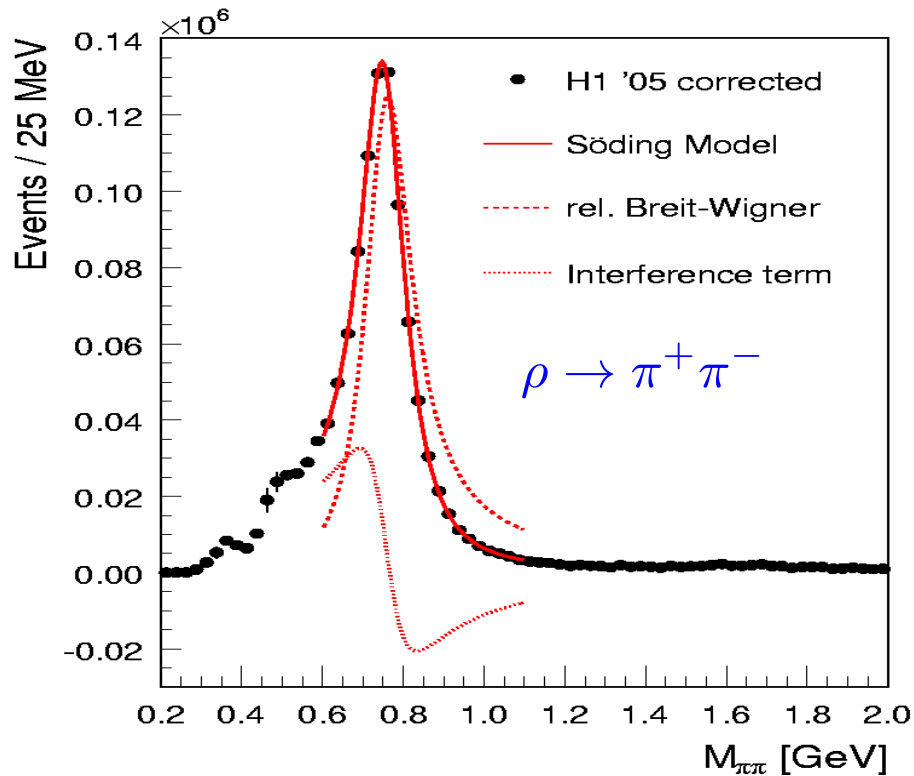
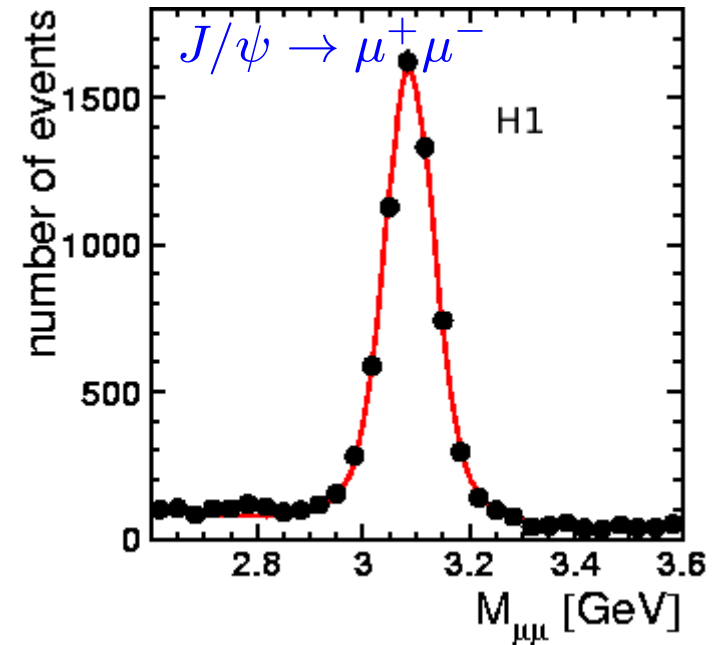


- is VM production calculable and where ?
- is inelastic and elastic VM production related ?
- $\sigma \sim xG(x, \mu^2)$ $\sigma \sim [xG(x, \mu^2)]^2$
- what is the energy dependence (x-dependence) of gluons inside the proton ?
- what is the spatial distribution of gluons inside the proton ?

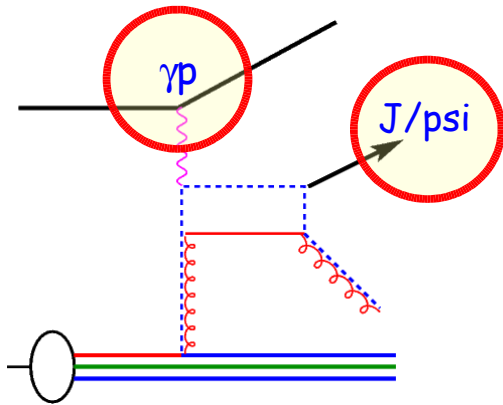
Which VMs do we see ?



- measured are:
 $\gamma, \rho, \phi, J/\psi, \Upsilon$

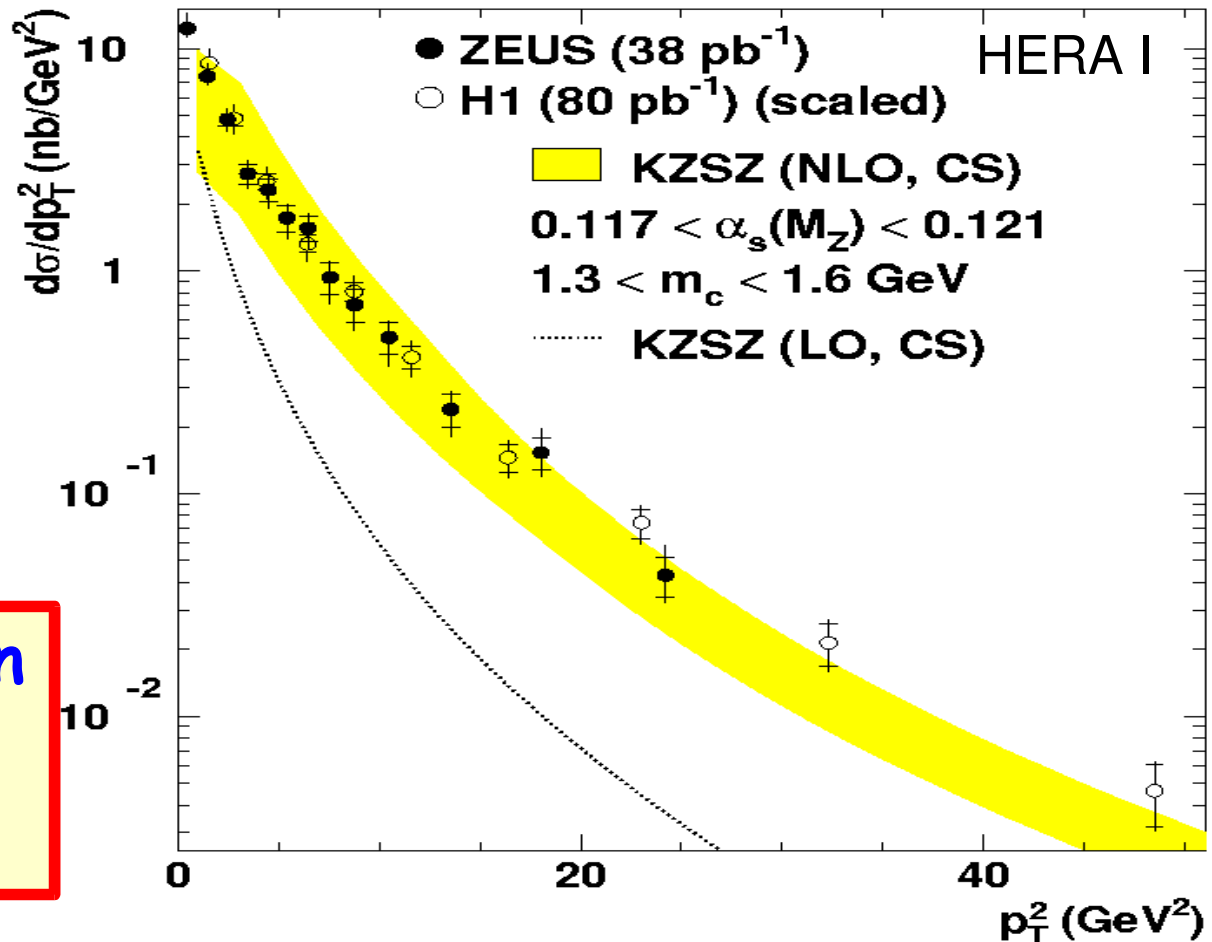


Inelastic J/psi photoproduction



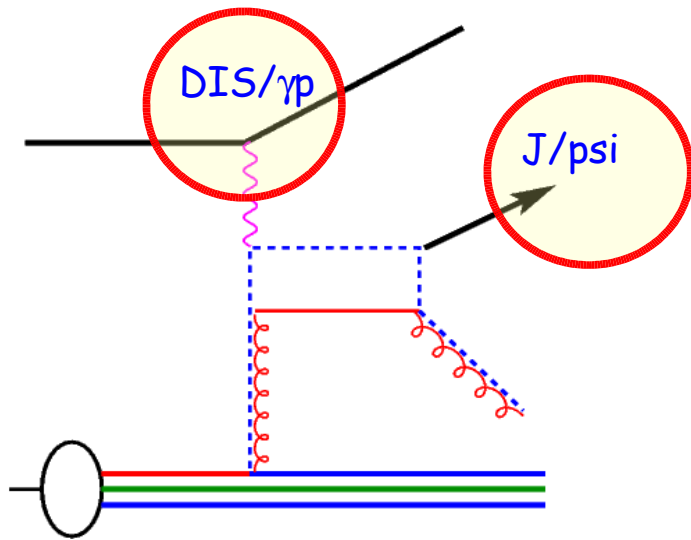
- photoproduction: $Q^2 \sim 0$
- Comparison with pQCD calculations:
- ➔ **NLO** (KZSZ Krämer et al MRST01)

- using Color Singlet Model
- need higher order QCD contributions



good description within uncertainties by pQCD calculations !

Inelastic J/psi production

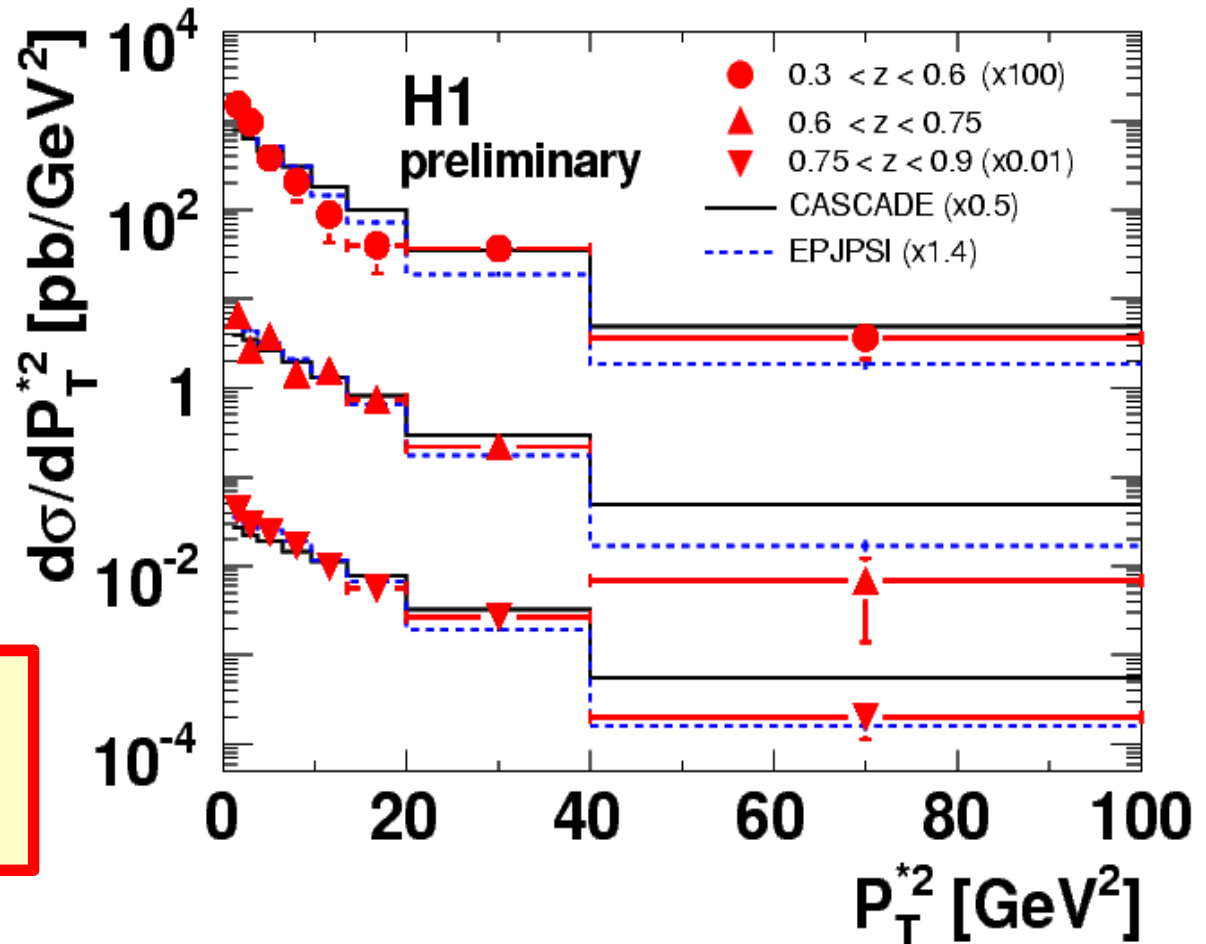


- Define Inelasticity (in p-rest):

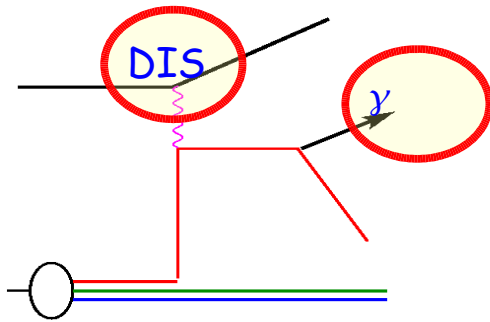
$$z = \frac{E_{J/\psi}}{E_\gamma}$$

reasonable description
by pQCD calculations !

- Measurement at large Q^2 :
 $3.6 < Q^2 < 100 \text{ GeV}^2$
- reconstruct: $J/\psi \rightarrow l^+ l^-$
- Data: 2004 - 2006, $\int \mathcal{L} dt = 258 \text{ pb}^{-1}$



Inelastic photon-production in DIS

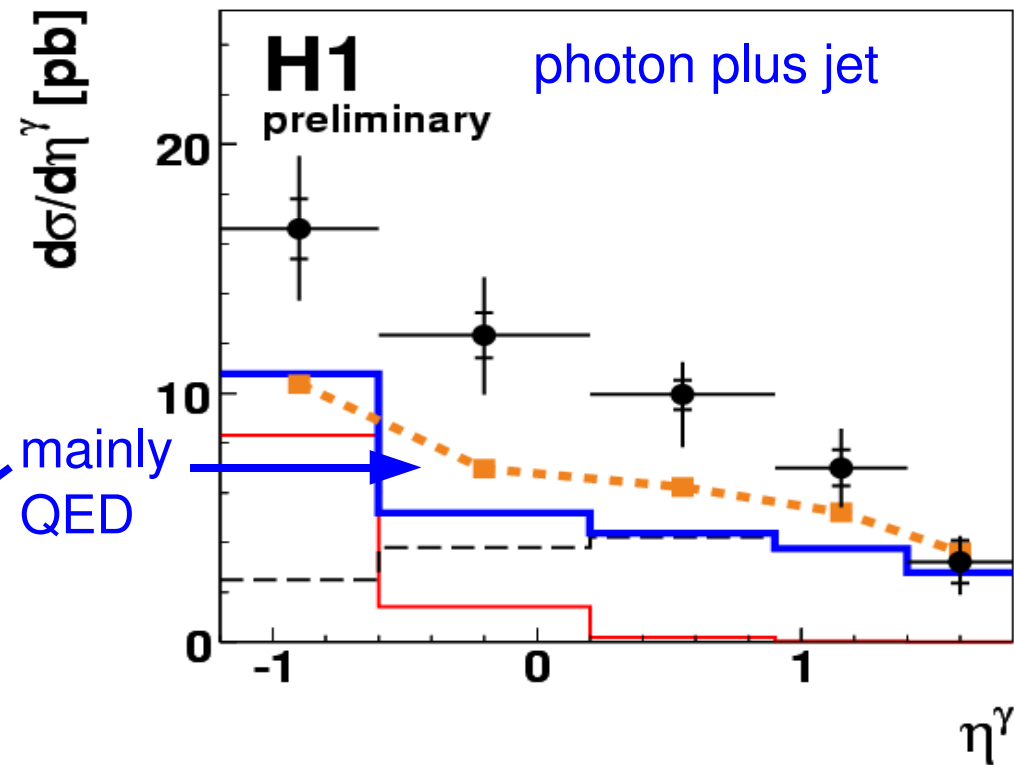
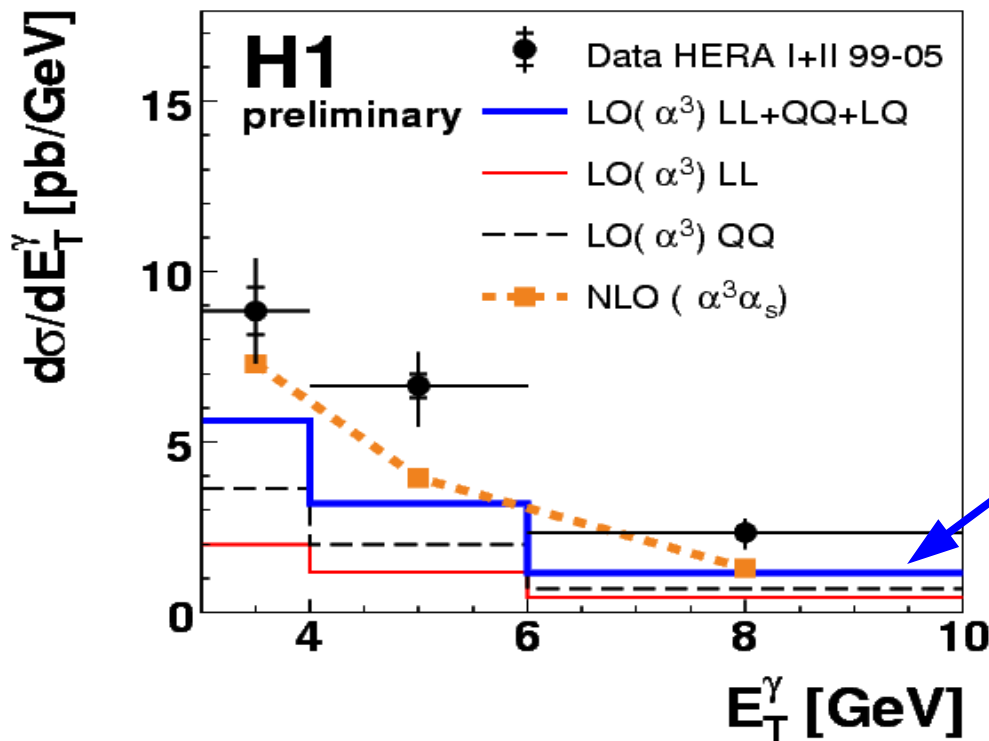


- better known as **prompt photon** production ...
- $4 < Q^2 < 150 \text{ GeV}^2$
- $3 < E_T^\gamma < 10 \text{ GeV}$
- $-1.2 < \eta^\gamma < 1.8$
- $E_T^{jet} > 2.5 \text{ GeV}$
- $-1.0 < \eta^{jet} < 2.1$

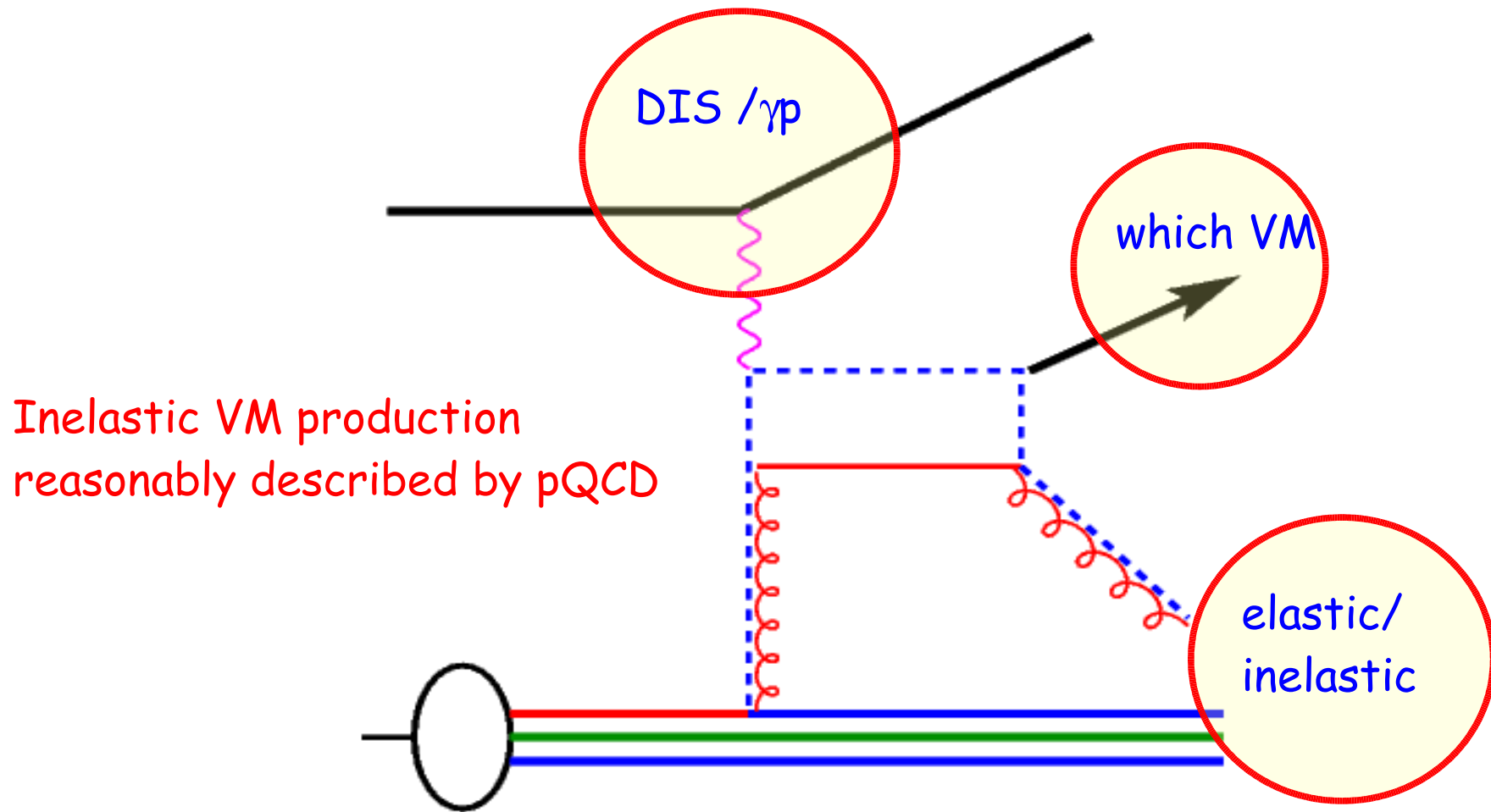
Hmm....

- ... quarks not negligible !!!
- ... large higher order corrections
- **NLO gets closer to data**
- higher order gluon radiation needed

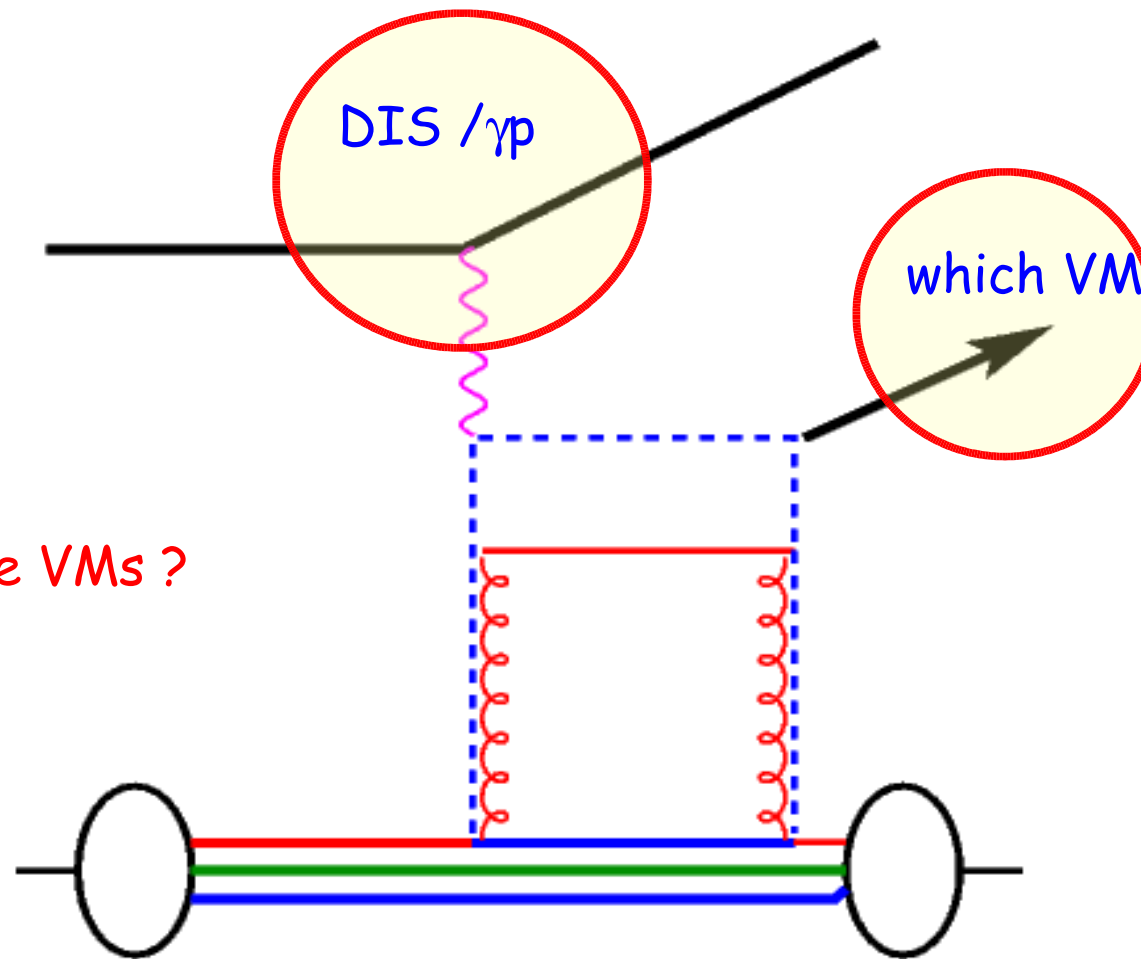
photon plus jet



From inelastic to elastic

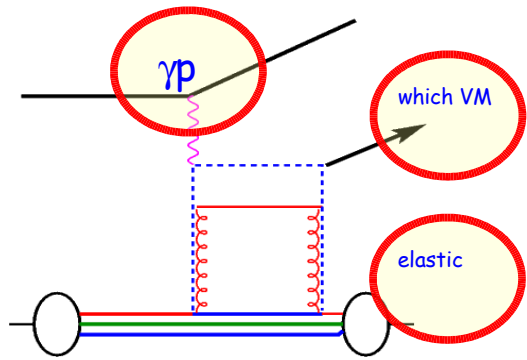


From inelastic to elastic



What about
elastic/exclusive VMs ?

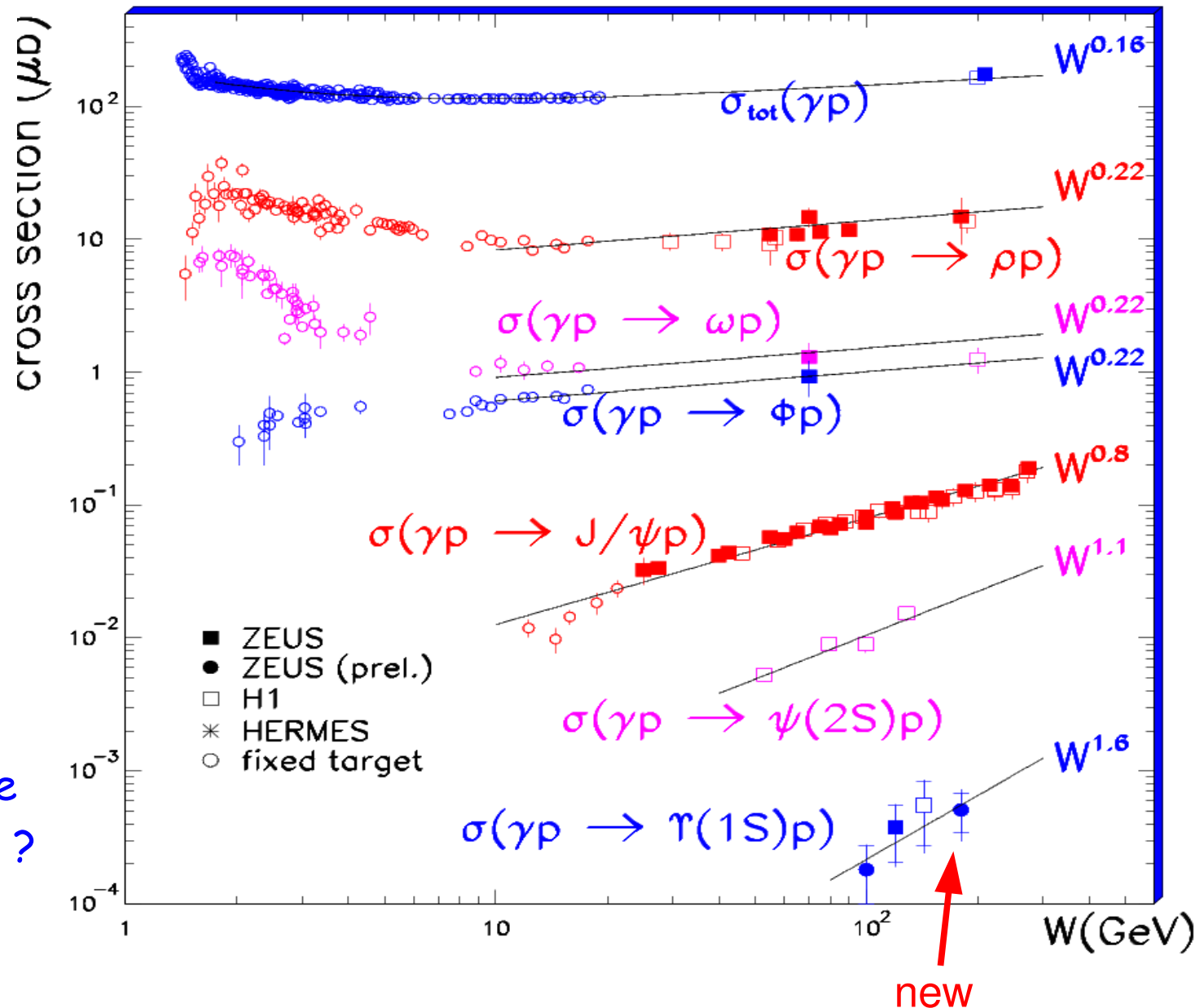
Elastic vectormesons at $Q^2 \sim 0$



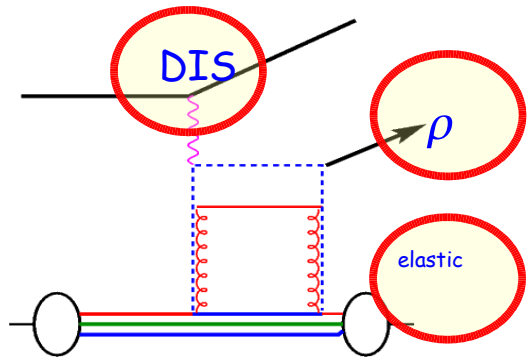
$$W = (\gamma + p)^2$$

$$\sigma \propto W^\delta$$

- δ increases with increasing mass of vector meson:
- from $W^{0.22}$ to $W^{1.6}$
- mass sets the scale
- calculable in pQCD?



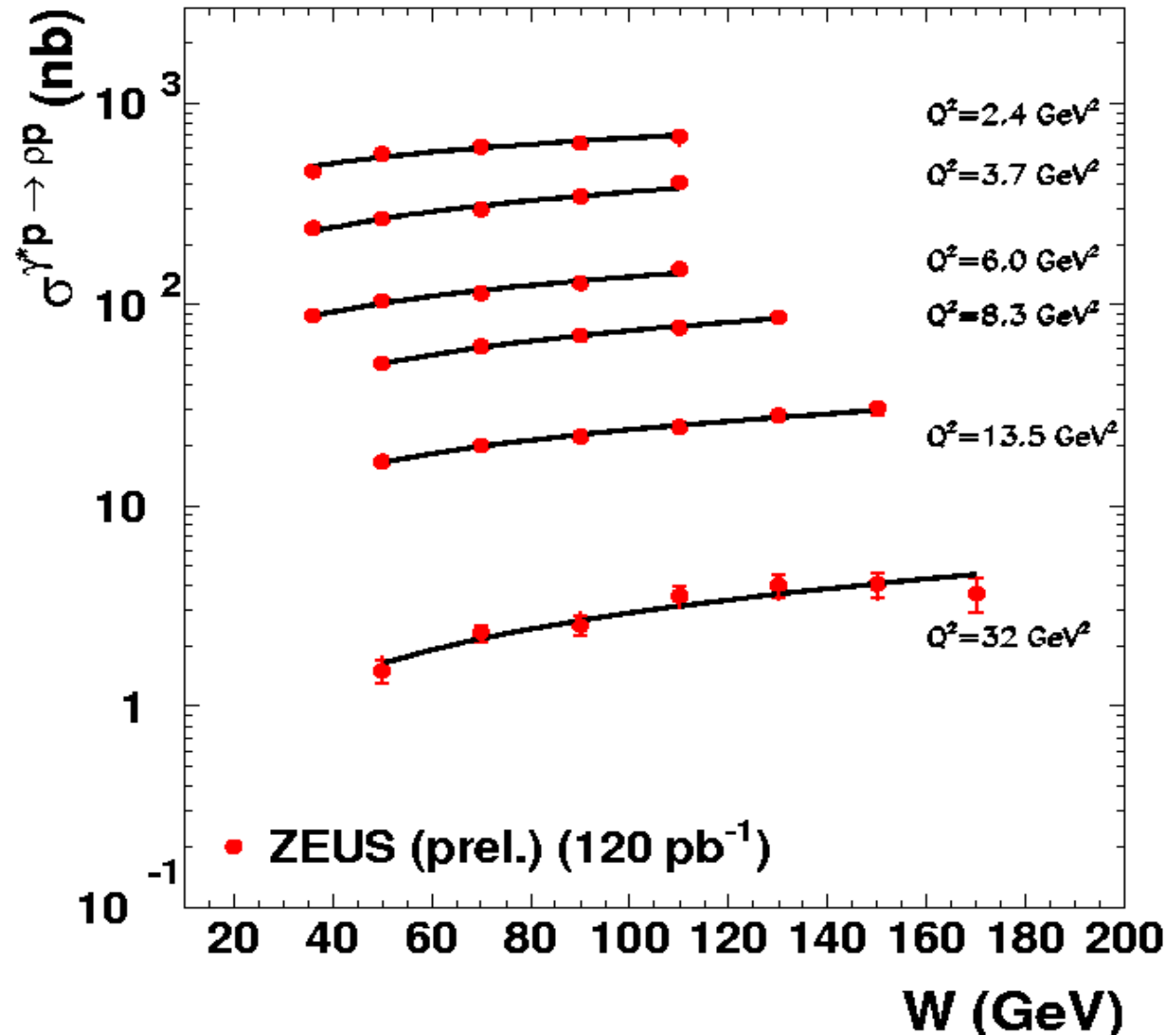
Elastic ρ -mesons at large Q^2



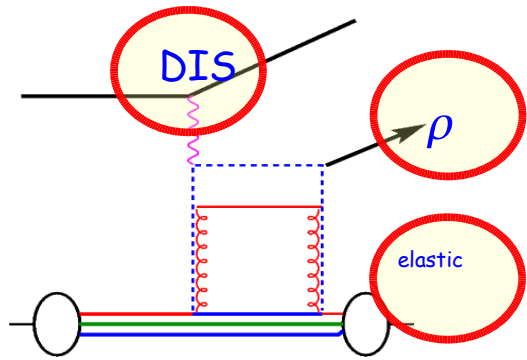
- observe steeper energy dependence with increasing Q^2
- hard scale set by Q^2 ...
- parametrize:

$$\sigma \sim W^\delta$$

ZEUS



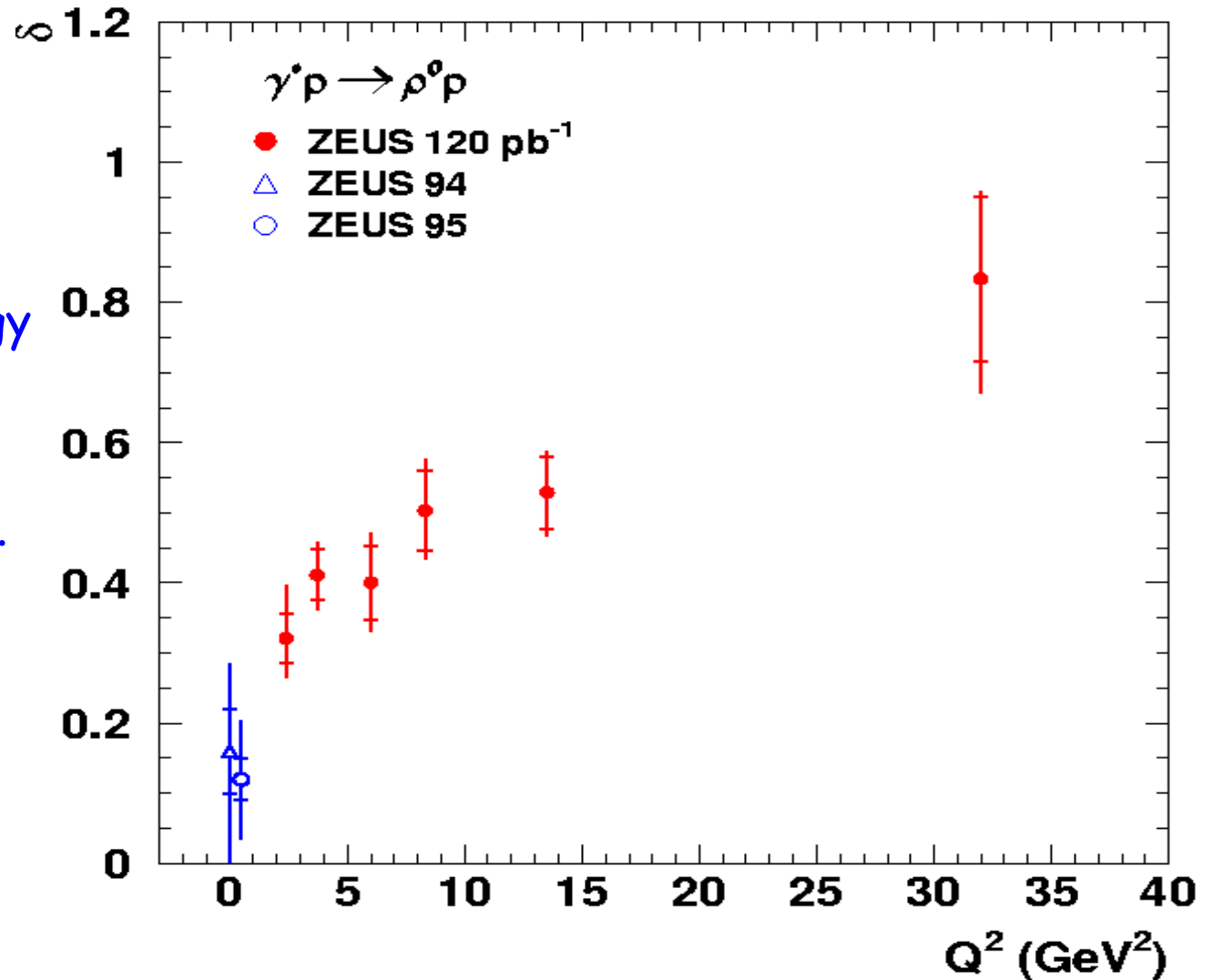
Elastic ρ -mesons at large Q^2



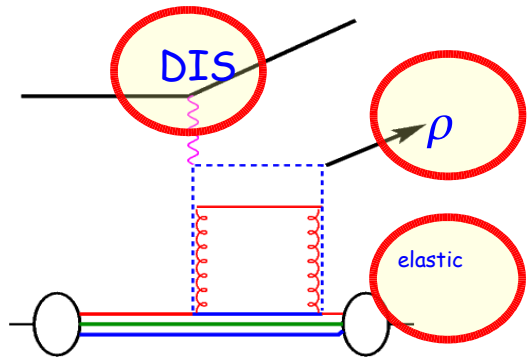
- observe steeper energy dependence with increasing Q^2
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- parametrize:

$$\sigma \sim W^\delta$$

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Elastic ρ -mesons at large Q^2



• is this picture correct ?

• inclusive scattering:

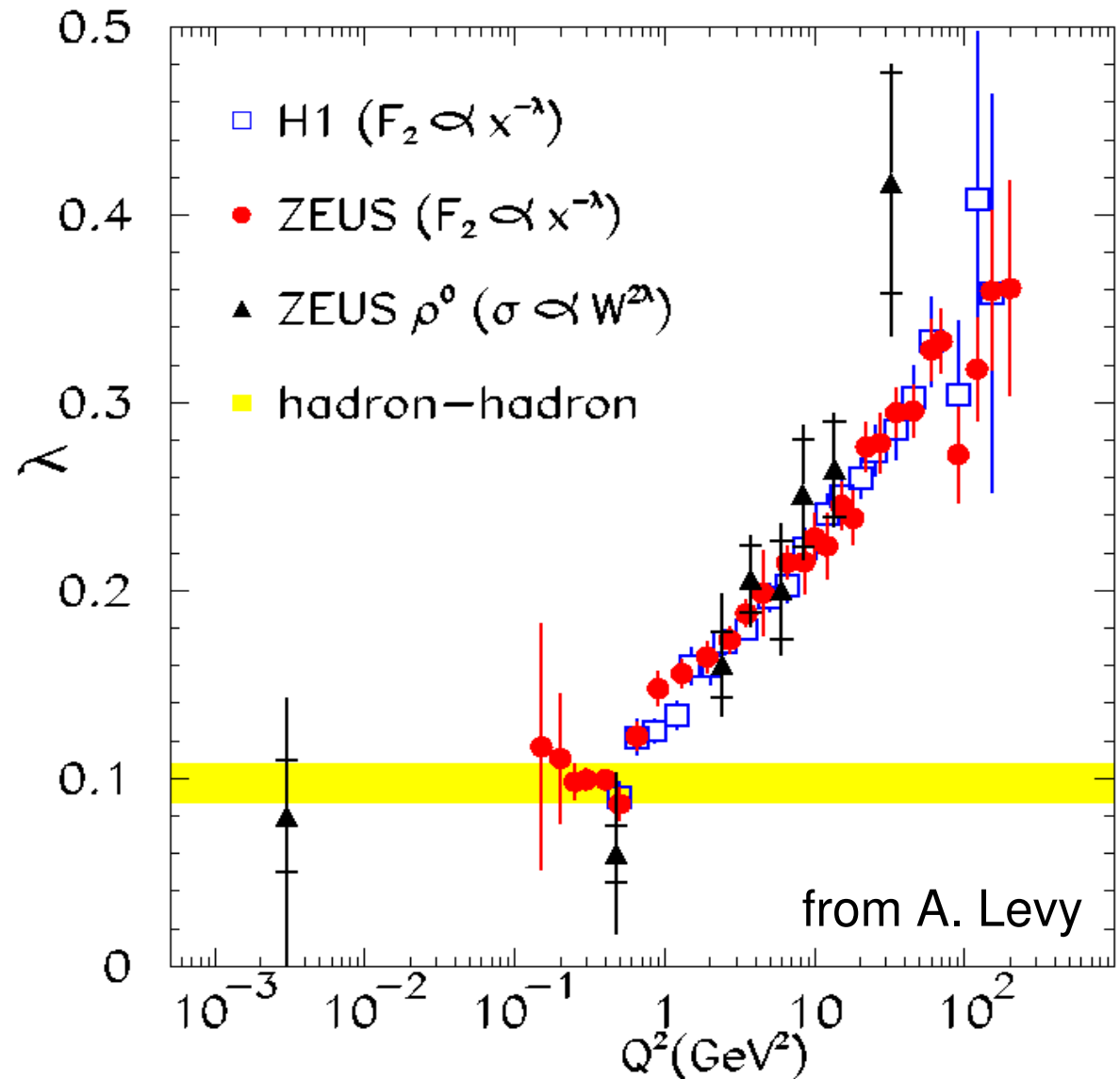
$$\begin{aligned} \sigma(\gamma^* p \rightarrow X) &\sim xG(x, \mu^2) \\ &\sim x^{-\lambda} \sim W^{2\lambda} \end{aligned}$$

• if elastic VM via 2gluon:

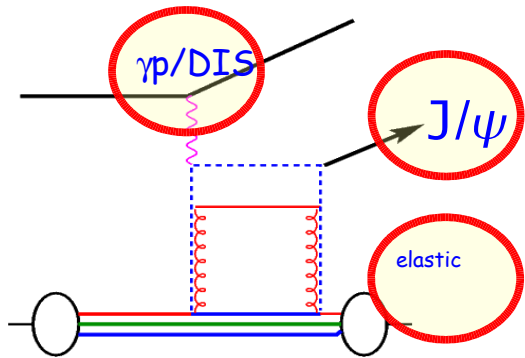
$$\begin{aligned} \sigma(\gamma^* p \rightarrow \rho p) &\sim [xG(x, \mu^2)]^2 \\ &\sim x^{-2\lambda} \sim W^{4\lambda} \end{aligned}$$

→ BUT observe: $\sim W^{2\lambda}$

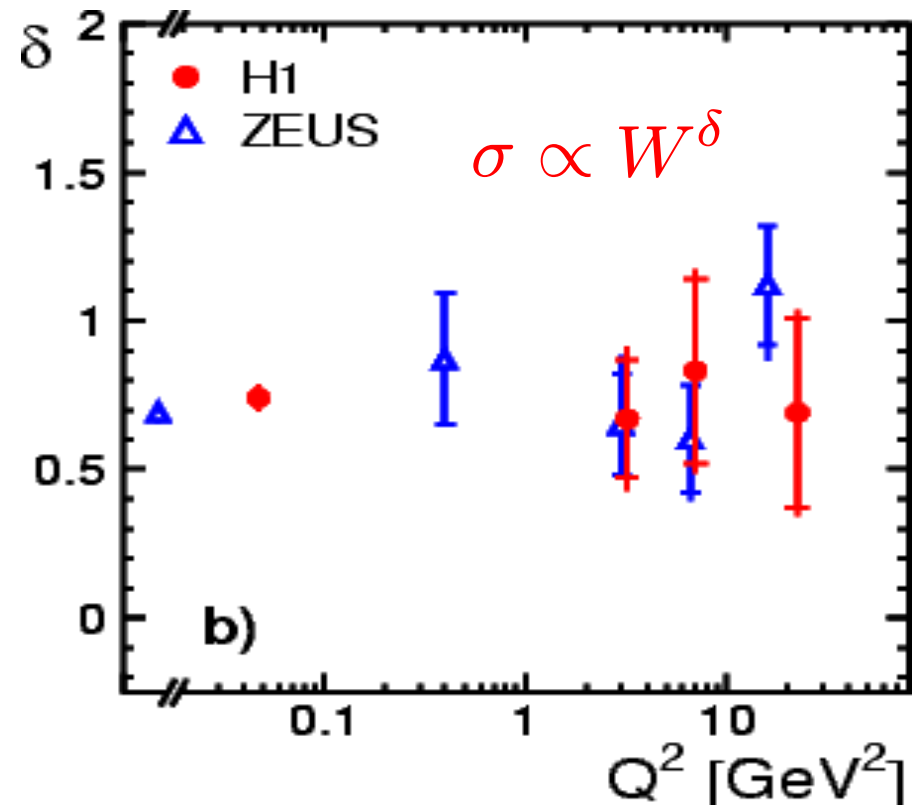
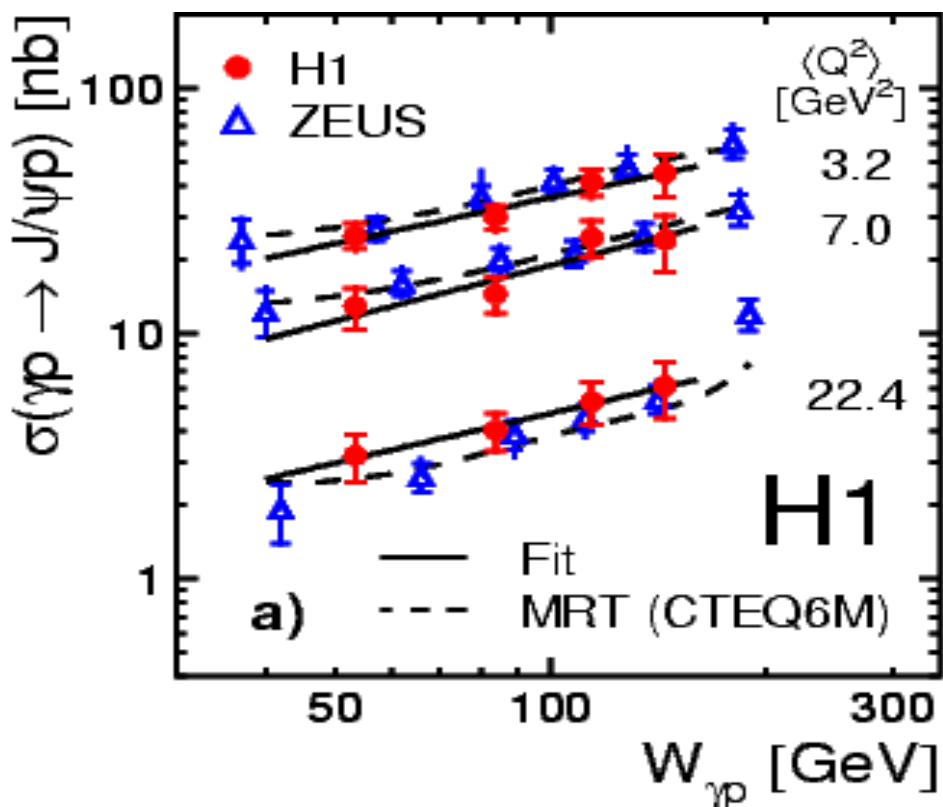
→ similar behavior as: $\frac{\sigma_{diff}}{\sigma_{tot}}$



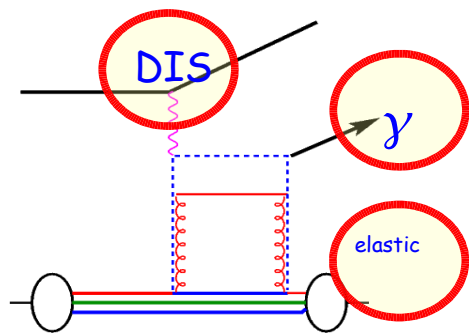
Elastic J/ψ production at large Q^2



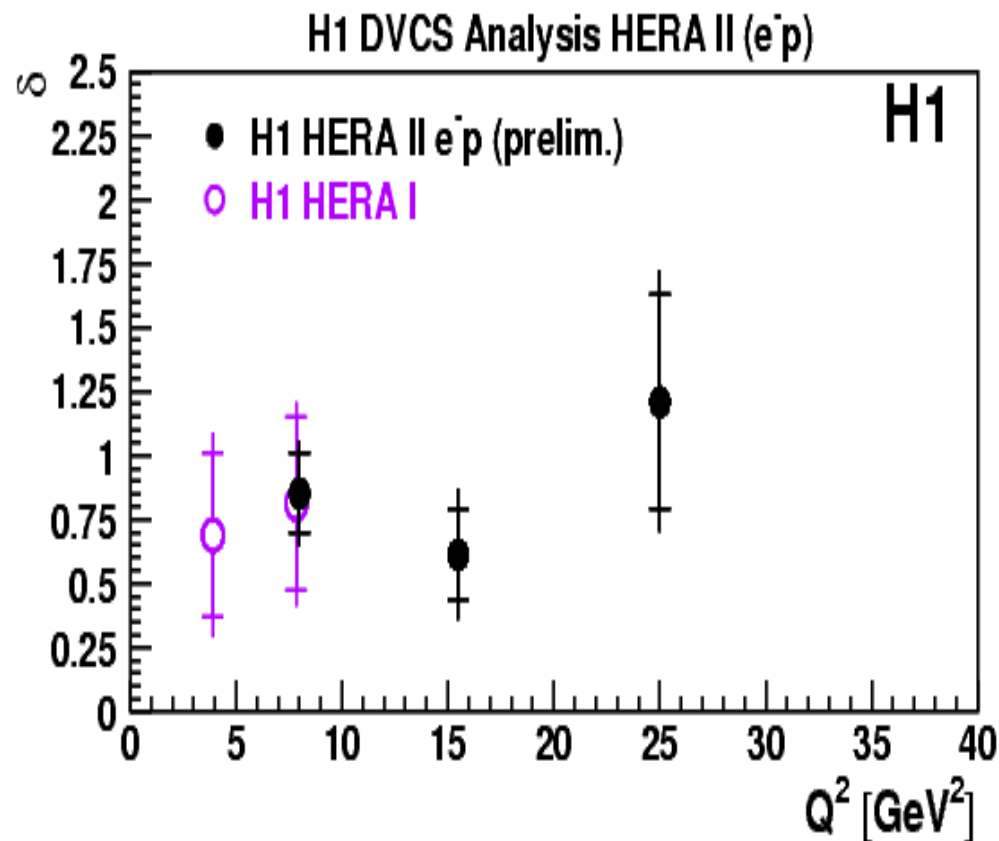
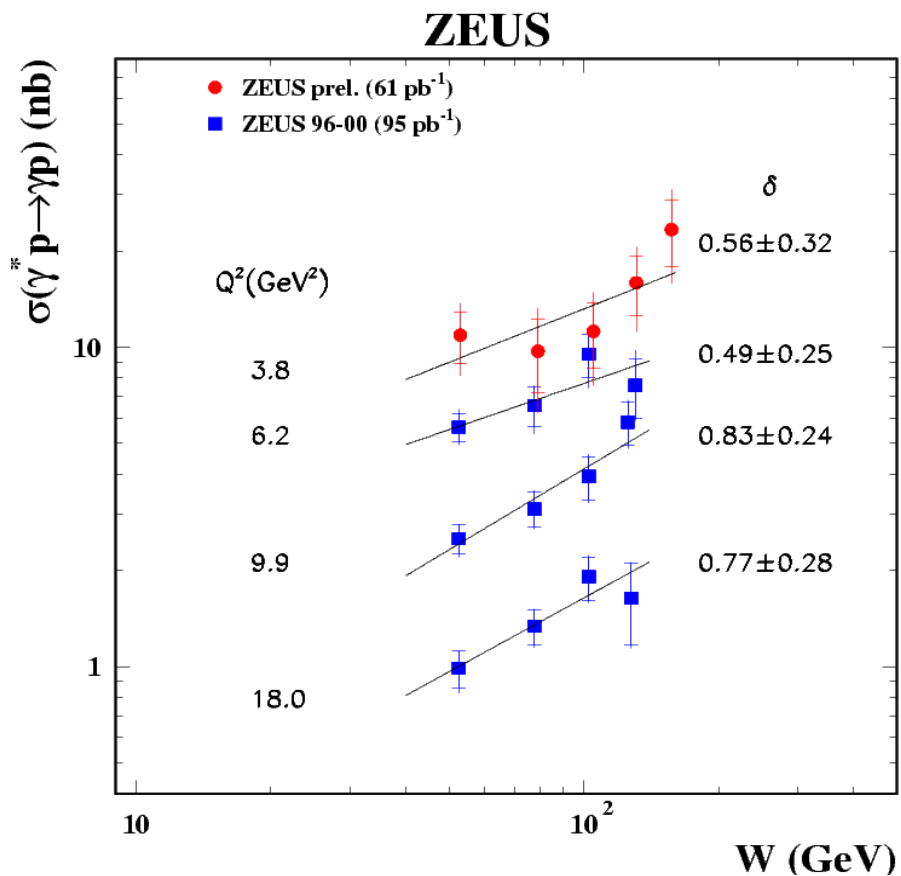
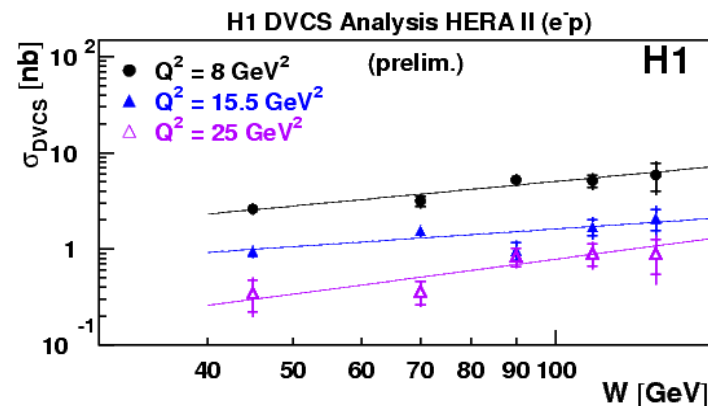
- strong energy dependence
- no significant change with Q^2 in range $0.05 < Q^2 < 20 \text{ GeV}^2$
- δ is large, consistent with ρ -meson production, but large uncertainties



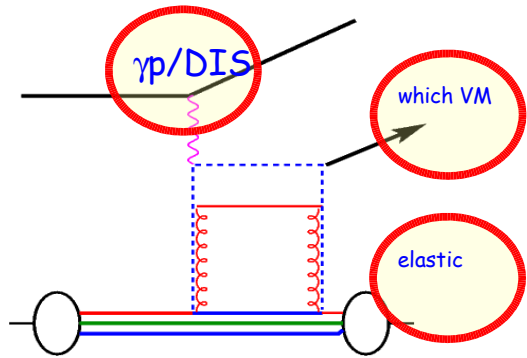
"Elastic" γ -production at large Q^2



- better known as DVCS
 - steep rise for large Q^2 observed in H1 and ZEUS
- similar to heavy VMs !!!



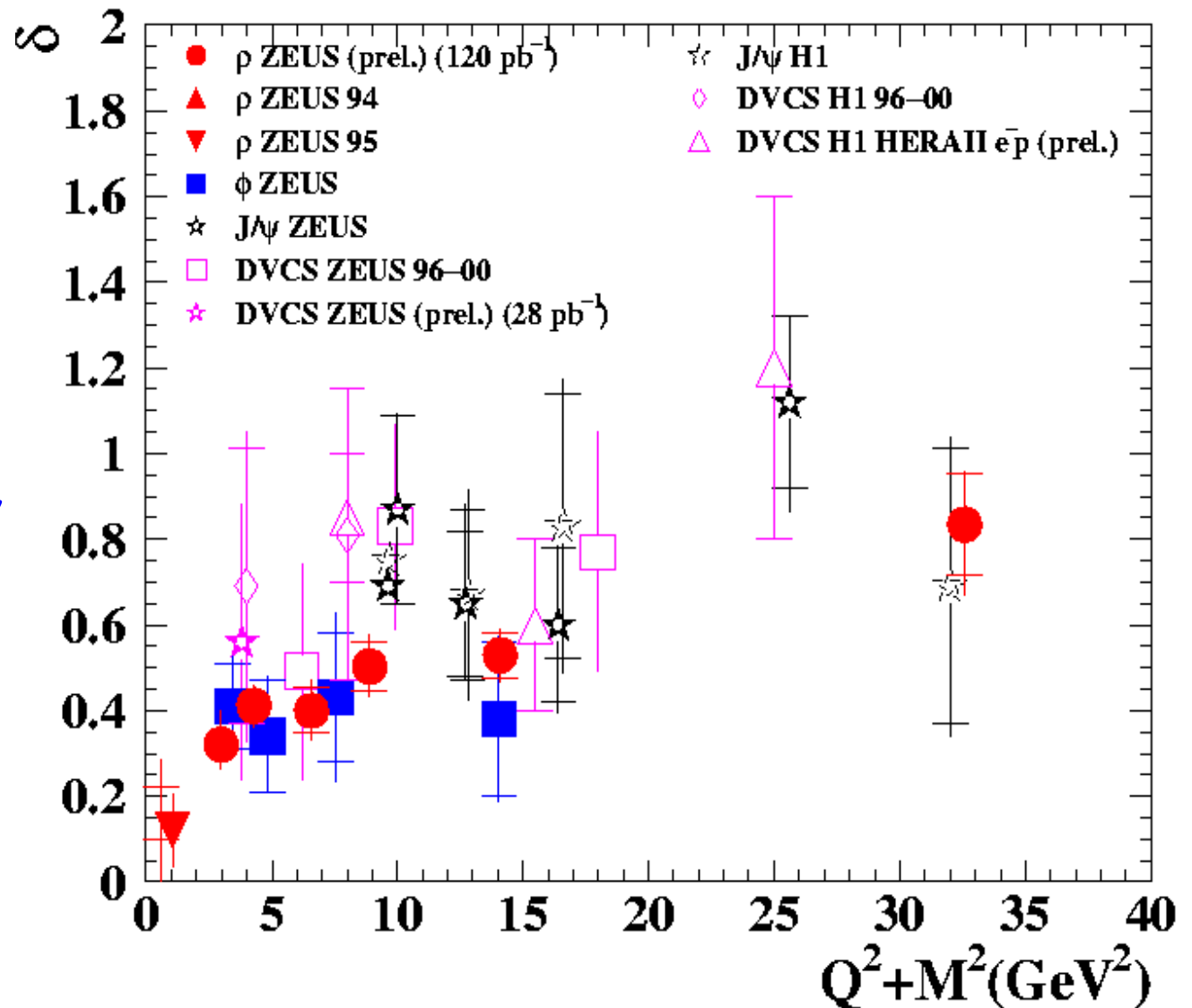
Energy dependence of VM production



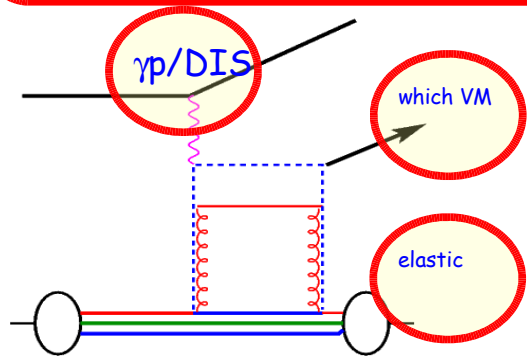
- steep slope observed for all vector mesons, ($\gamma, \rho, J/\psi$) in the presence of a hard scale:

→ Q^2 and/or M^2

→ process calculable perturbatively

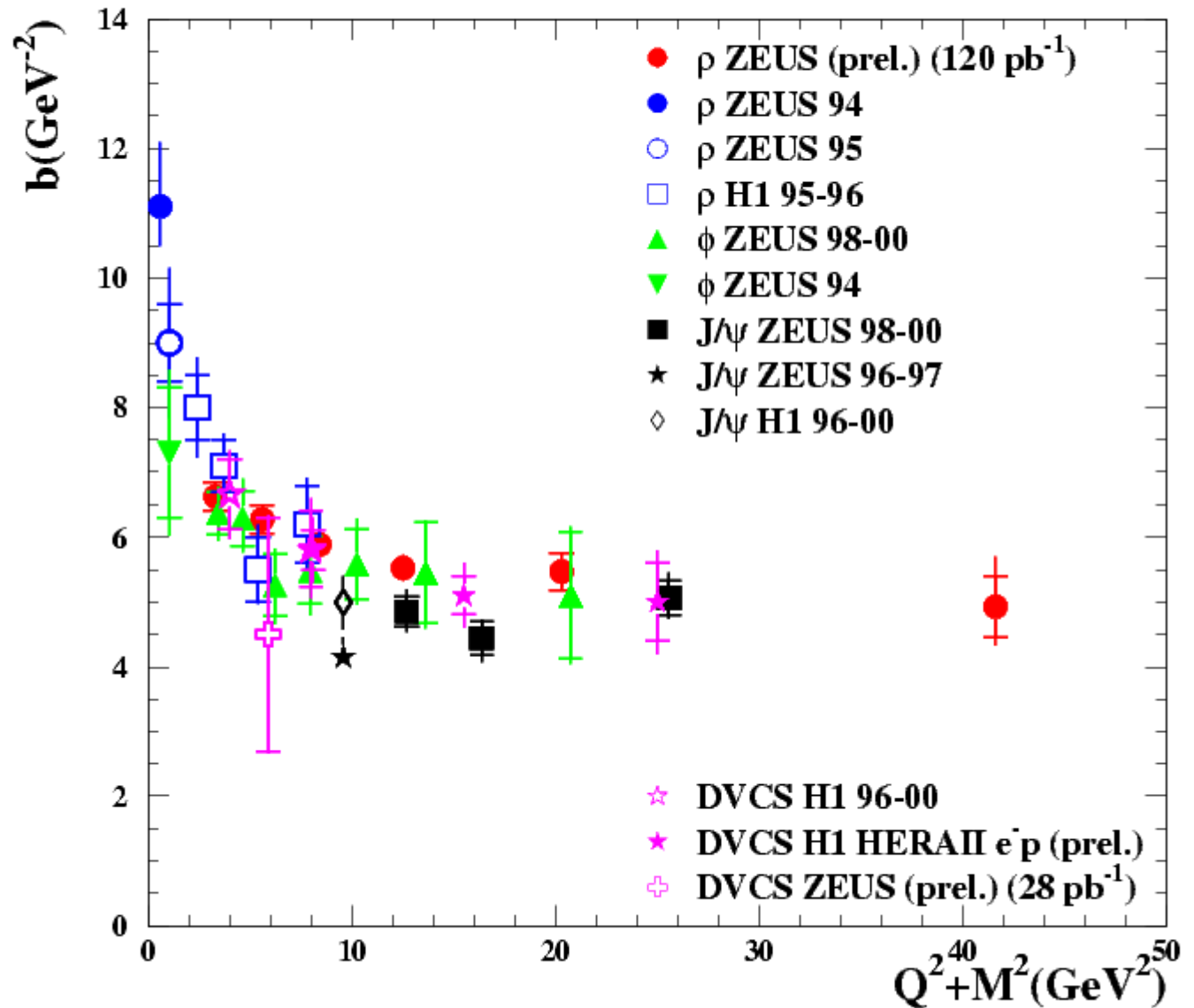


$d\sigma/dt$ - cross section



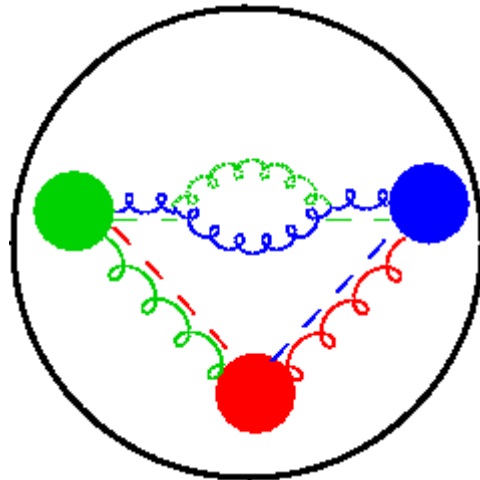
$$\frac{d\sigma}{d|t|} \propto \exp(-b|t|)$$

- b -slope decreases with increasing scale:
- Q^2 and/or M_{VM}^2
- similar b -slope for all VMs as function of Q^2+M^2

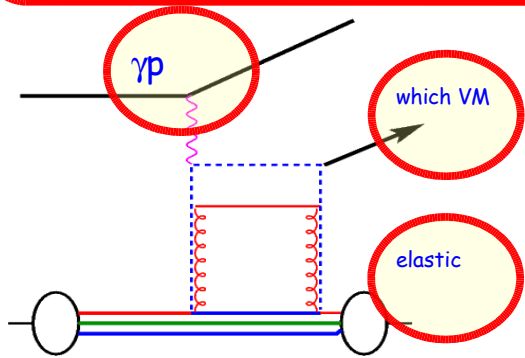


The spatial distribution of gluons

- From $\frac{d\sigma}{d|t|} \propto \exp(-b|t|)$ via Fourier transform to impact parameter
(Kowalski, Motyka, Watt PRD 74, 074016 (2006))
with $\langle r^2 \rangle \simeq 2 \cdot b$ giving for $b \sim 4.5 \text{ GeV}^{-2}$ a radius of $r \sim 0.6 \text{ fm}$
- gives average gluon radius in proton, if process dominated by gluons
- compare to charged proton radius of $r \sim 0.8 \text{ fm}$
- gluons are confined in smaller area than quarks !



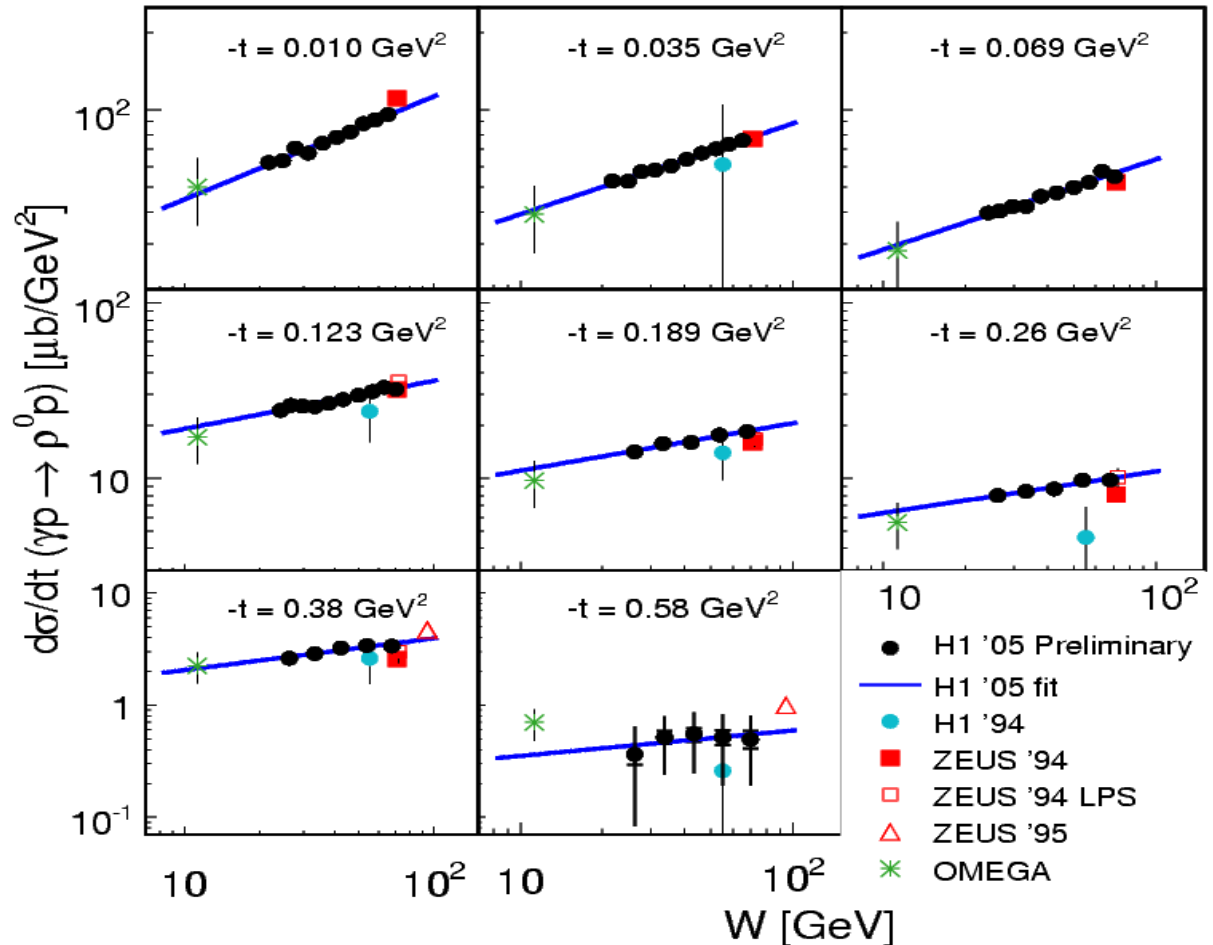
Soft or hard gluonic ladders



- soft gluons ... soft Pomeron ... shrinkage ..

$$\frac{d\sigma^{\gamma p}(W)}{dt} = \frac{d\sigma^{\gamma p}(W_0)}{dt} \left(\frac{W}{W_0} \right)^{4(\alpha_{IP}(t)-1)}$$

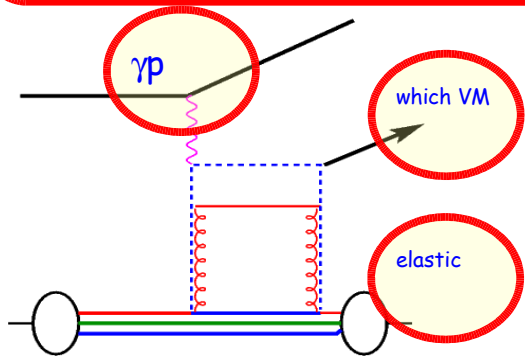
H1 PRELIMINARY



$20 < W < 90 \text{ GeV}$
 $|t| < 3 \text{ GeV}^2$

- photoproduction of $\gamma p \rightarrow \rho p$
- measure W dependence as function of t
- measurement within **one experiment** ...

Soft or hard gluonic ladders

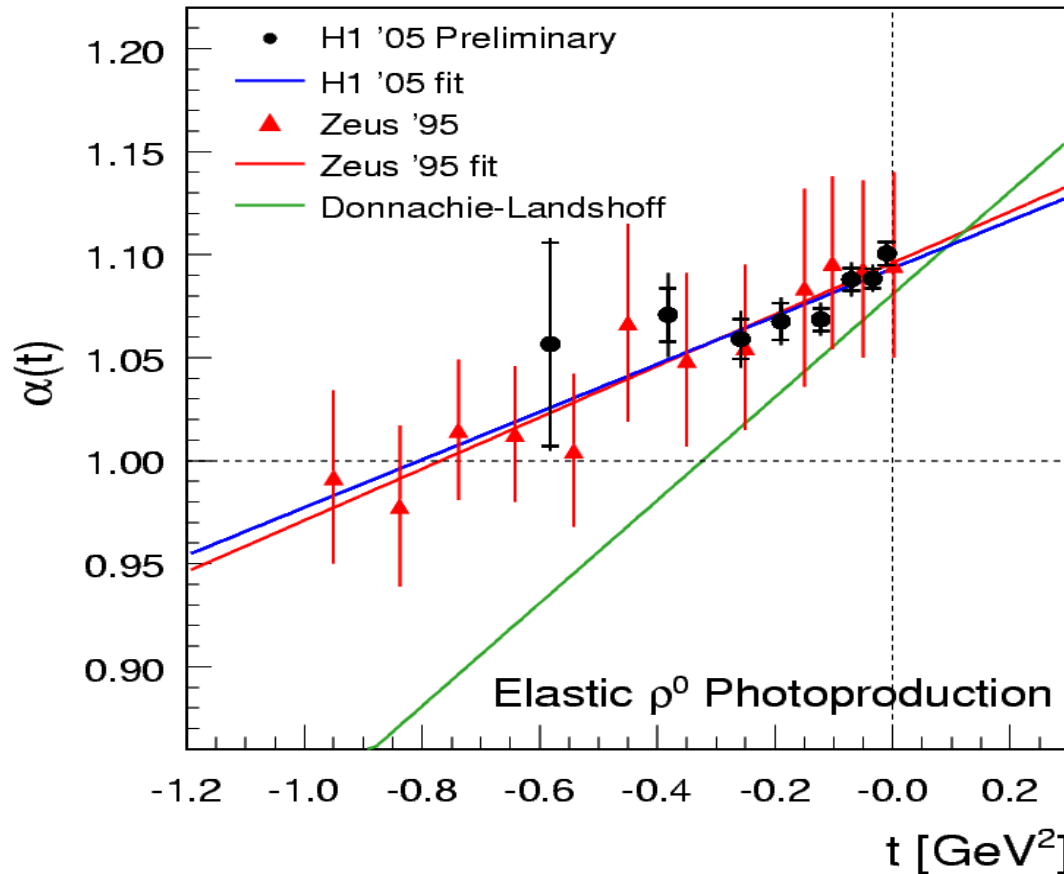


H1 PRELIMINARY

- soft gluons ... soft Pomeron ... shrinkage ..

$$\frac{d\sigma^{\gamma p}(W)}{dt} = \frac{d\sigma^{\gamma p}(W_0)}{dt} \left(\frac{W}{W_0} \right)^{4(\alpha_{IP}(t)-1)}$$

$$\begin{aligned} \rightarrow \text{with } \alpha_{IP}(t) &= \alpha_{IP}(0) + \alpha'_{IP} \cdot t \\ &= 1.096 \pm 0.021 + (0.125 \pm 0.038) \cdot t \end{aligned}$$



α'_{IP} in ρ - photoproduction is smaller than expected from soft hadron-hadron interaction



Soft or hard process

$$\frac{d\sigma^{\gamma p}(W)}{dt} = \frac{d\sigma^{\gamma p}(W_0)}{dt} \left(\frac{W}{W_0} \right)^{4(\alpha_{IP}(t)-1)}$$

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

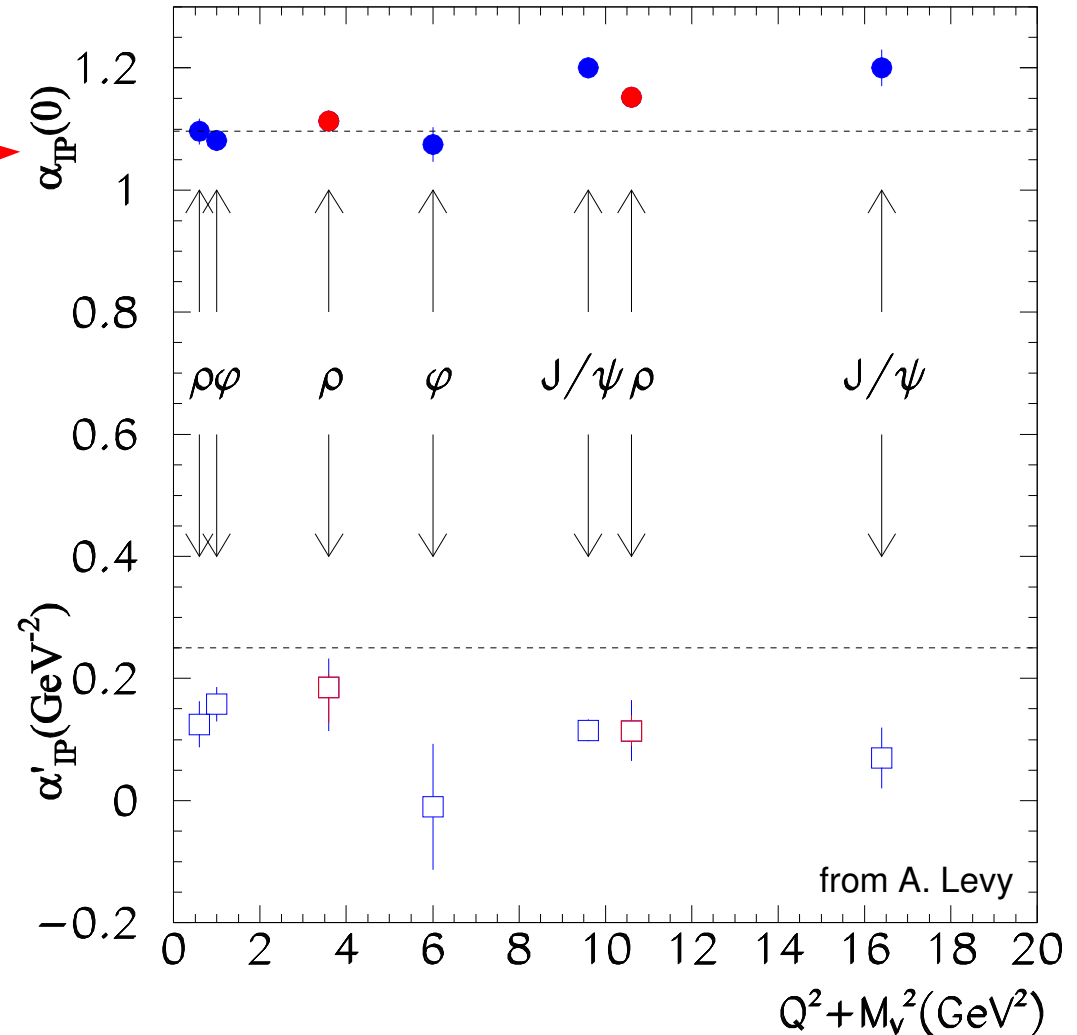
- from soft hadronic process expect:

$$\alpha_{IP}(0) \sim 1.08$$

and

$$\alpha'_{IP} \sim 0.25$$

BUT ...



What did we learn ?

- new high statistics measurements on γ , ρ and J/ψ
- inelastic VM production reasonably well described by pQCD calculations using PDFs from inclusive fits
- BUT prompt photon production in DIS is still challenging
- elastic heavy VM production follows naive expectation of energy dependence: $\sim |xG(x,\mu^2)|^2$
- BUT: ρ production in DIS is different.... has similar energy dependence to σ_{tot}
- from $d\sigma/dt$ average gluon radius extracted.... smaller than charged radius.... gluons are confined in smaller area ...
- ρ photoproduction does not show shrinkage as expected from hadron-hadron interaction ... α'_{IP} is smaller....

VM production, inelastic & elastic
is still challenging

Backup Slides

Longitudinal ρ x-section

- σ_L increases with Q^2
-
- but is \sim independent of W

ZEUS

