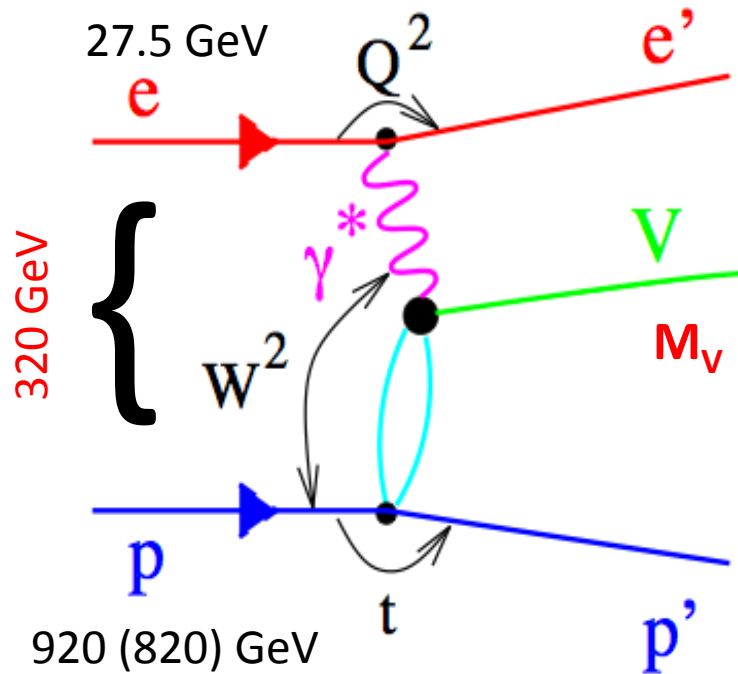




Vector Meson electro-production at HERA

Sampa Bhadra
on behalf of the H1 and ZEUS
collaborations

The kinematics



s : cme squared of ep system

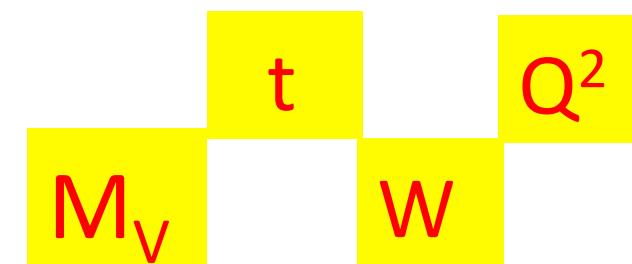
Q : photon virtuality
 - large range in DIS regime
 - if $\sim 0 \text{ GeV}^2$, photoproduction

W^2 : cme squared of γ^*p system

t : squared mom transfer @ p vertex

M_V : mass of the produced VM

Several "hard" scales

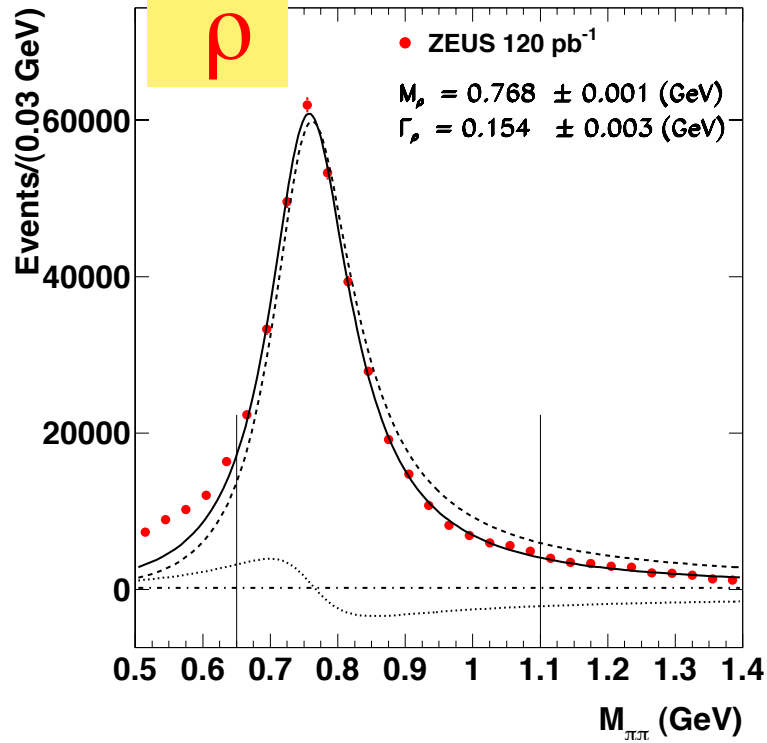


Why VM? Clear signal

$$V = \rho, \Psi, Y$$

-> e.g. $\pi^+\pi^- / e^+e^- / \mu^+\mu^-$

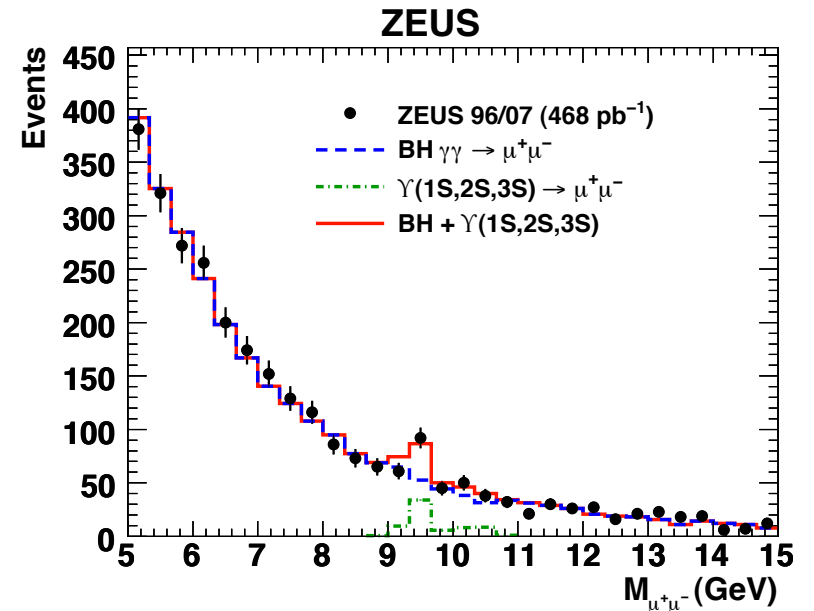
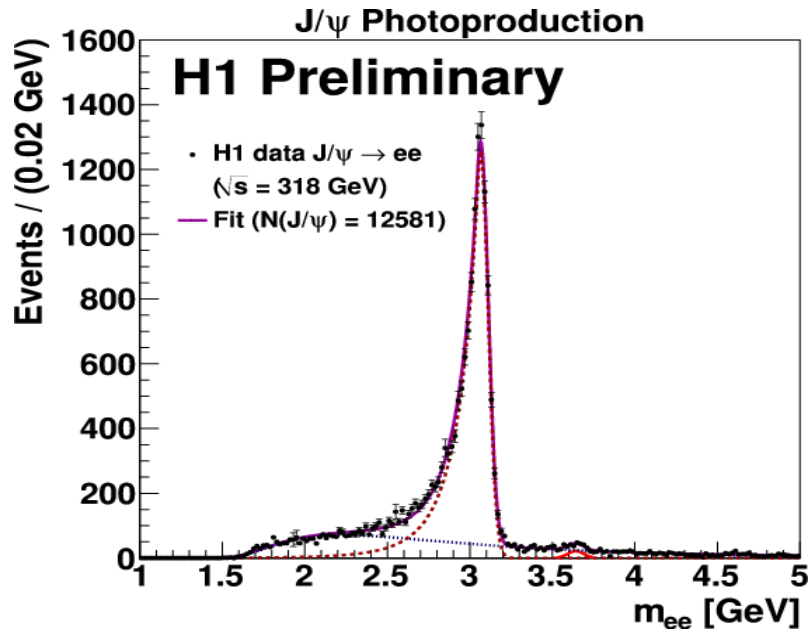
ZEUS



Examples of VM mass distributions at HERA

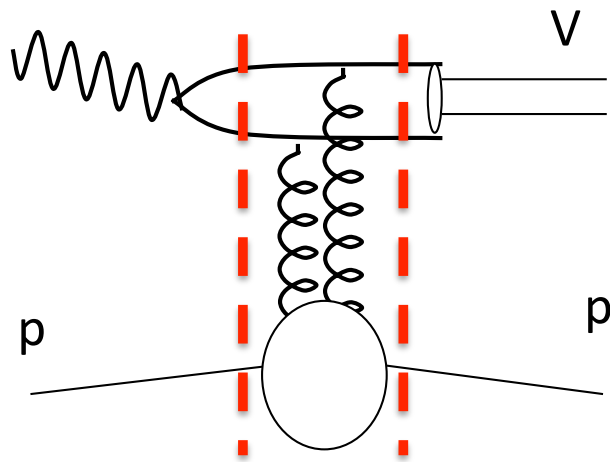
J/psi

Y



Vector meson production can be viewed as a three step process:

1. the virtual photon γ^* fluctuates into a $q\bar{q}$ pair
2. which interacts with the proton through a two-gluon ladder and
3. hadronizes into a vector meson, V , the production of ground-state vector mesons, $V = \rho, \omega, \phi, J/\psi, Y \dots$



$$W^2 \sim 1/x$$

x is the momentum fraction of the gluon in proton

$$\propto \frac{1}{\sqrt{Q^2 + M_{q\bar{q}}^2}}$$

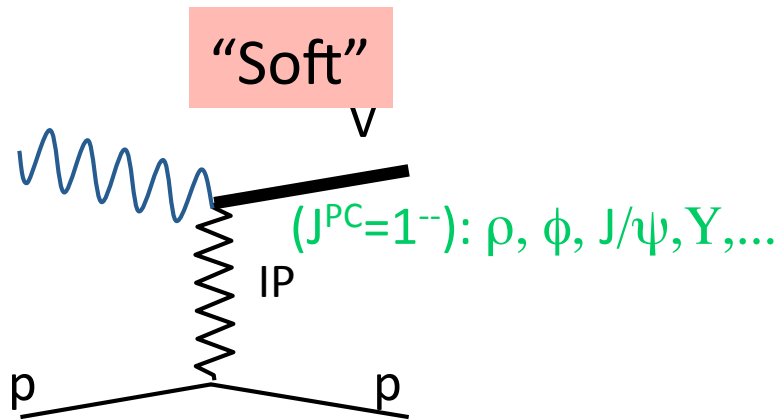
Change probe size with increasing scale!

- M_V ($\rho = .770$, $J/\Psi = 3.1$, $Y = 9.5$ GeV)

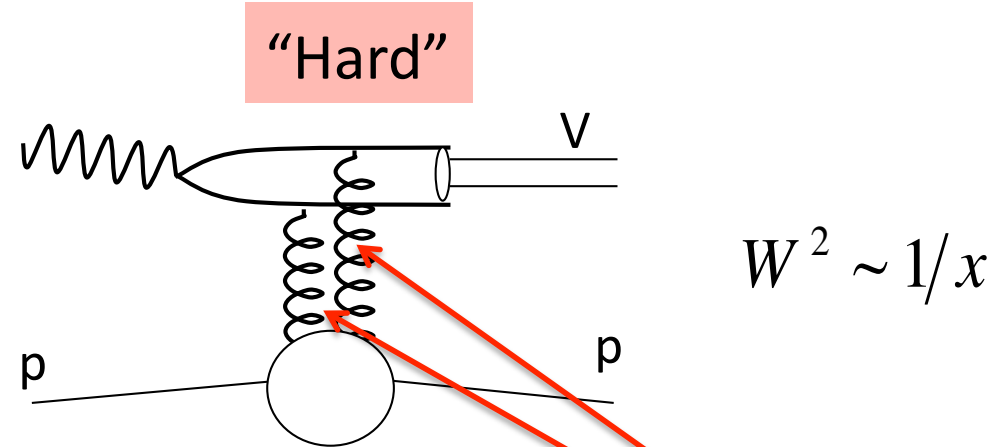
- Q^2



Vector Mesons - $\rho, \omega, \phi, J/\psi, \Upsilon$



$$\sigma(W) \propto W^\delta$$



x is the momentum fraction
carried by gluon
 g = gluon density in proton

With a hard scale (e.g. M_V, t, Q, W),
can use pQCD for calculations

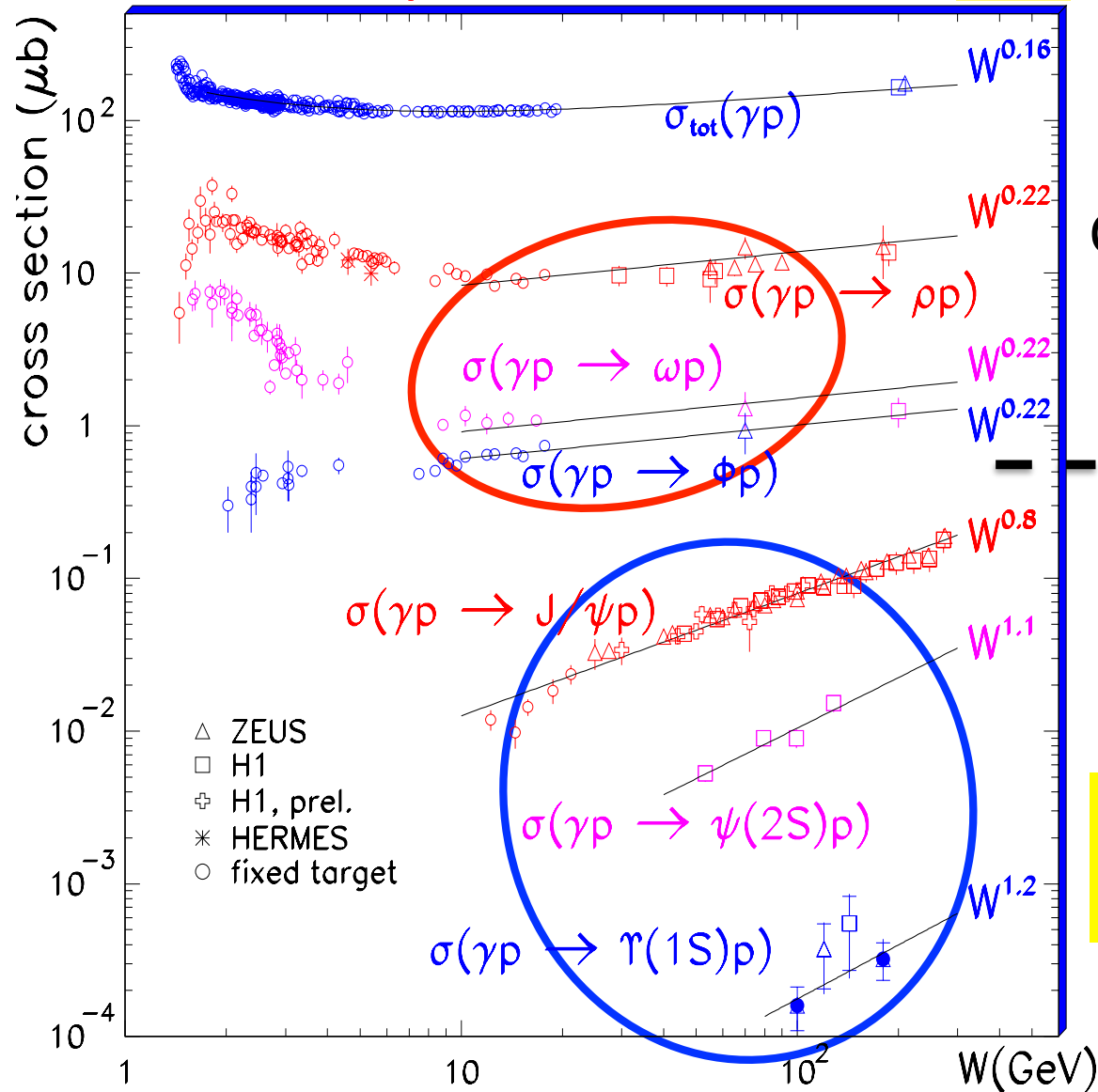
Does data match expectations?

Ryskin (1993), Nikolaev et al (1994),
Brodsky et al (1994),... Etc.

$$\left\{ \begin{array}{l} \sigma \propto [x g(x, \mu^2)]^2 \\ x = \mu^2 / W^2 \\ \mu^2 \propto (Q^2 + M_V^2) \end{array} \right.$$

Photoproduction data

W^δ



- △ ZEUS
- H1
- ⊕ H1, prel.
- * HERMES
- fixed target

$W^{0.16}$

Consistent with “soft” models
 σ rises slowly $\sim W^{0.2}$

But for J/psi, Y
 σ rises faster $\sim W^{.8-1.2}$

VM - sensitivity
 to gluons in proton

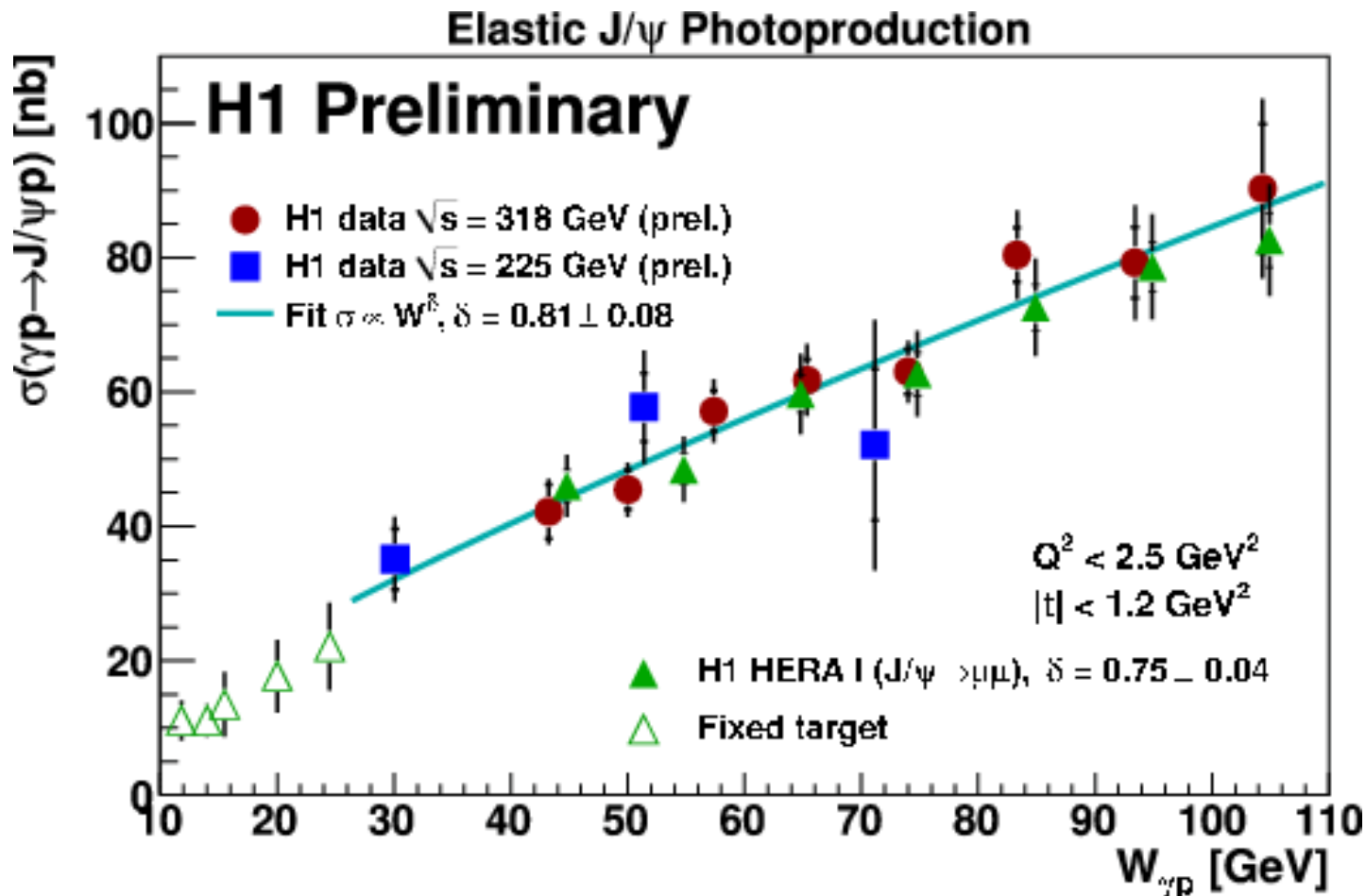
$$\sigma \propto [x g(x, M_V^2)]^2$$



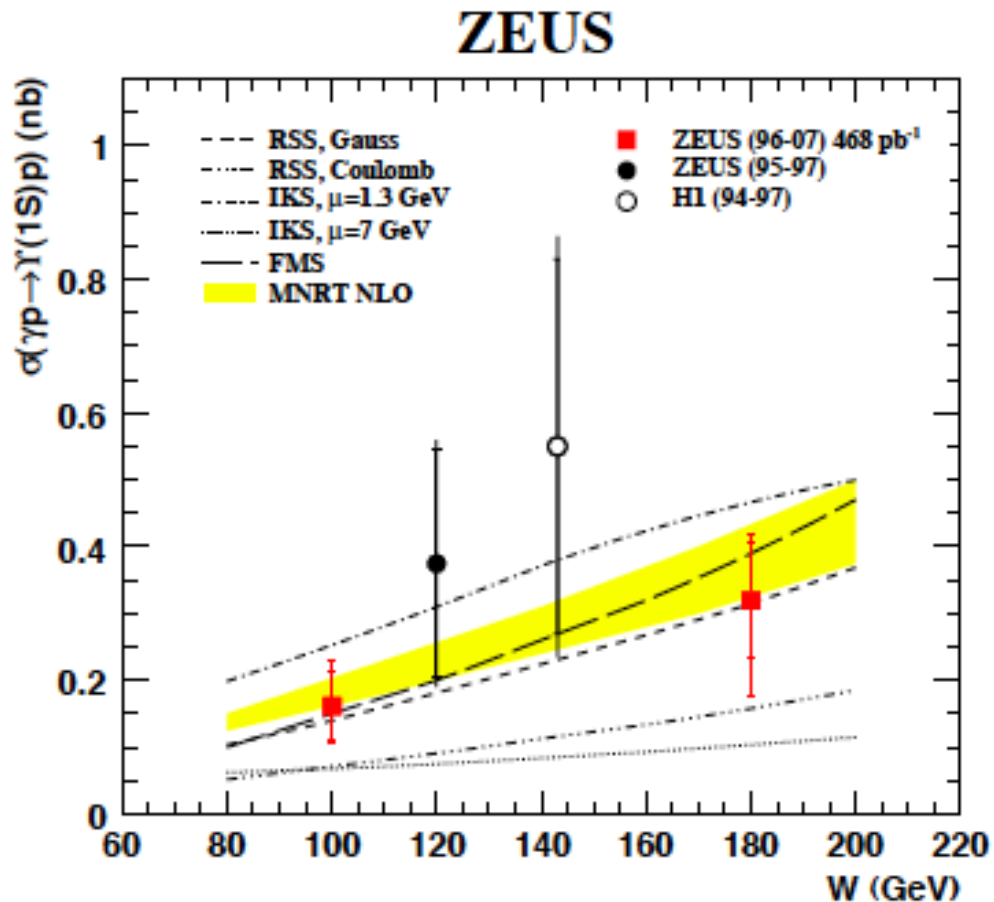
$$W \propto 1/\sqrt{x} \qquad x = M_V^2/W^2$$

New! photoproduction of J/ψ extension to lower $W_{\gamma p}$

Two proton energies: nominal (920 GeV) and
low-energy (460 GeV)



W^δ : Photoproduction of Y

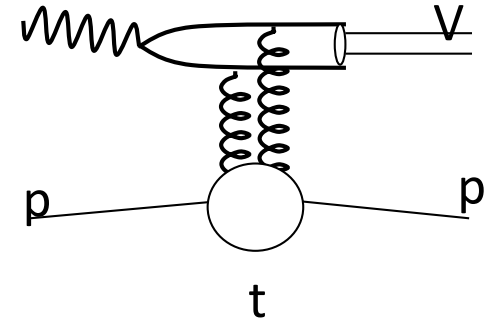


$$\delta = 1.2 \pm 0.8$$

- Comparison to pQCD models
- sensitive to vector meson wave function
- sensitive to hard scale value

Expectation for t: Elastic

$$d\sigma_{\gamma p \rightarrow \nu p} / dt \approx e^{-bt}$$

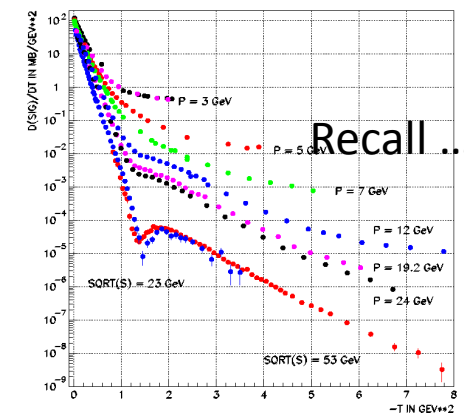


b is related to quadratic sum of sizes of target and projectile (if intact)

$$b = b_V + b_p$$

$$b_V \sim 1 / (Q^2 + M_V^2)$$

- b decreases from “soft” ($b \sim 10 \text{ GeV}^{-2}$) to “hard” ($b \sim 4-5 \text{ GeV}^{-2}$) with M_V
- b increases as $\ln s$ (or $\ln W$ for photoproduction)
- with decreasing transverse size of the dipole the t distribution is expected to become universal Independent of the scale and of the VM.

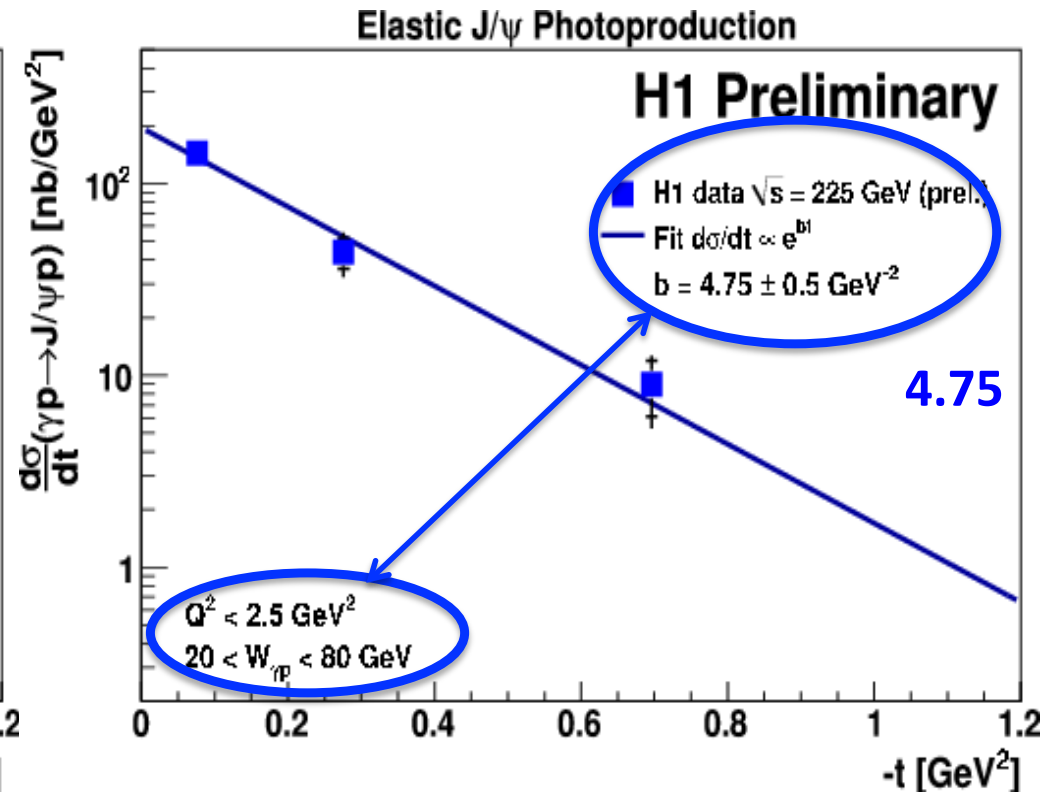
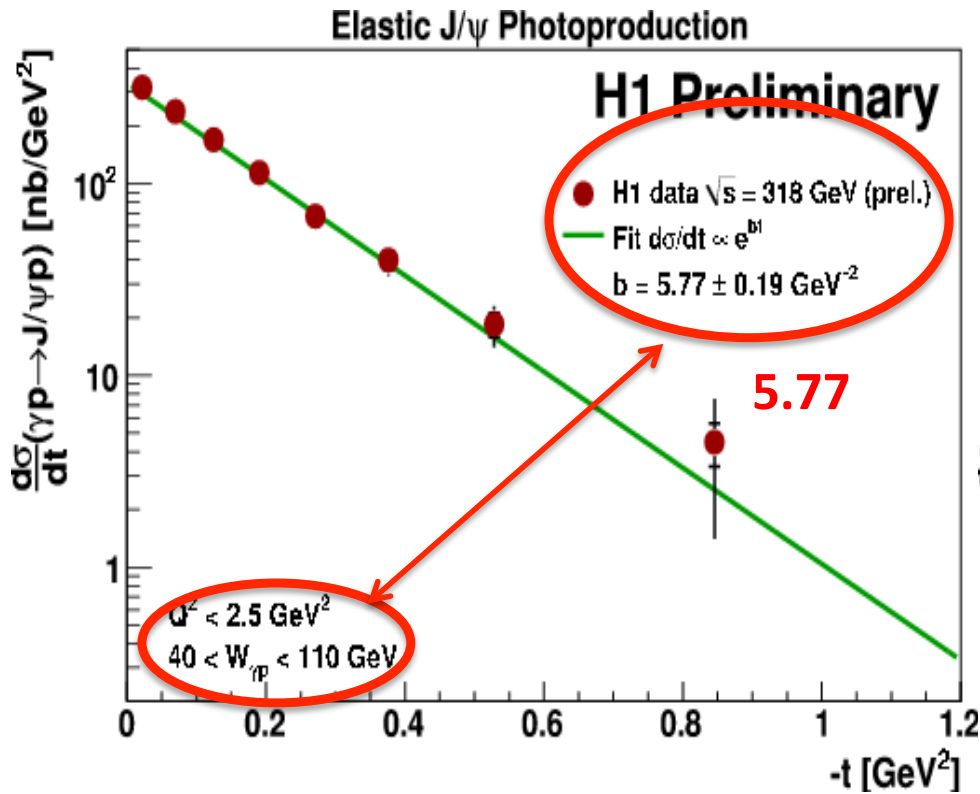


Is the expectation from pQCD validated from HERA data?

Photoproduced J/ψ b from Elastic

High energy period

Low energy period



Slope increases with W

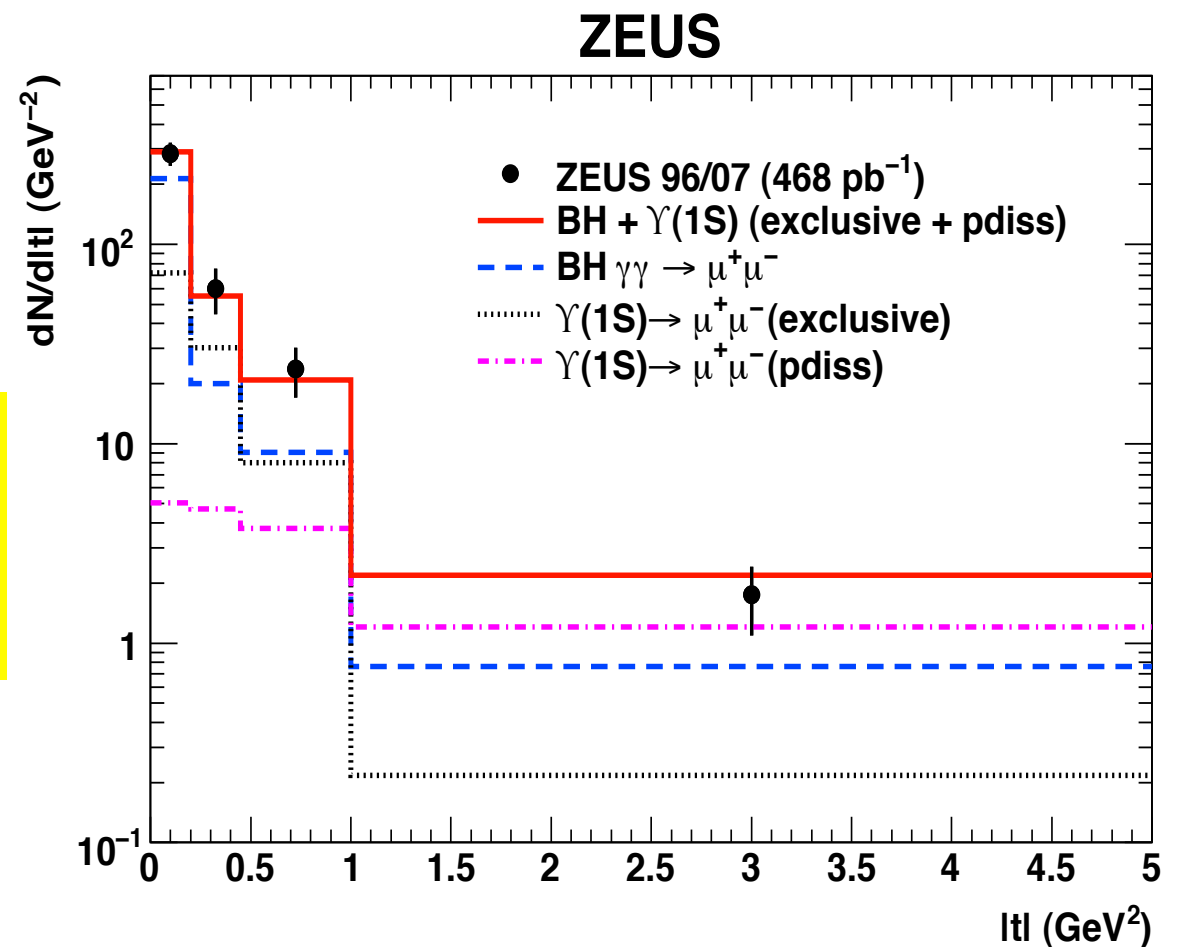
Photoproduced Υ : first determination b from Elastic

Fit dN/dt to sum of exclusive
and proton dissociation

$b_\Upsilon =$

$$4.3^{+2.0}_{-1.3}(\text{stat.})^{+0.5}_{-0.6}(\text{syst.}) \text{ GeV}^{-2}$$

Phys. Lett. B 708 (2012) 14-20



b vs. $Q^2 + M_V^2$

$$b = b_v + b_p$$

$$\langle r^2 \rangle = b \cdot (hc)^2$$

Target (proton) tr. size:

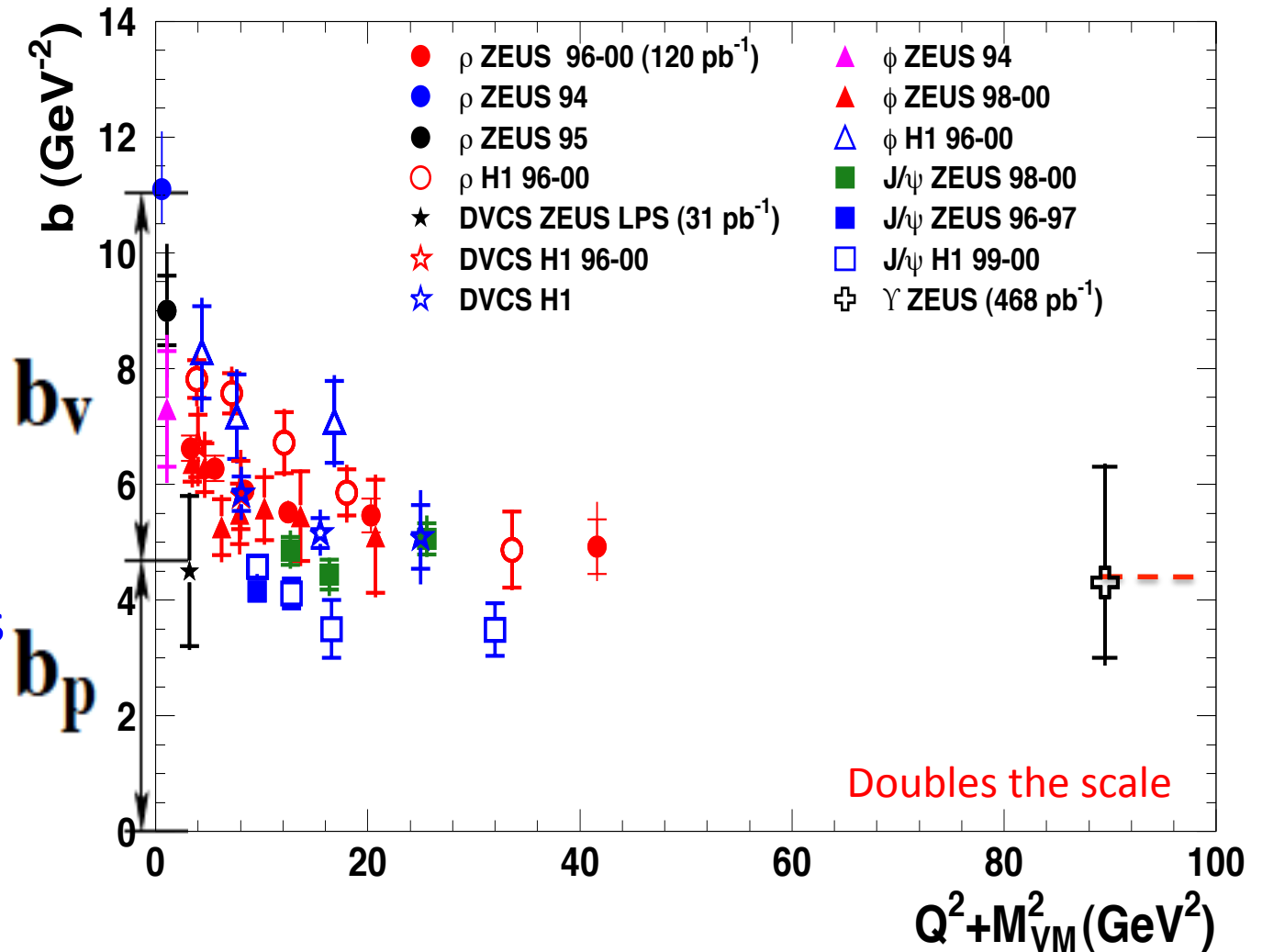
$$b_p \sim 5 \text{ GeV}^{-2}$$

Can be interpreted as

$$r_{\text{gluon}} \sim 0.6 \text{ fm}$$

less than proton radius

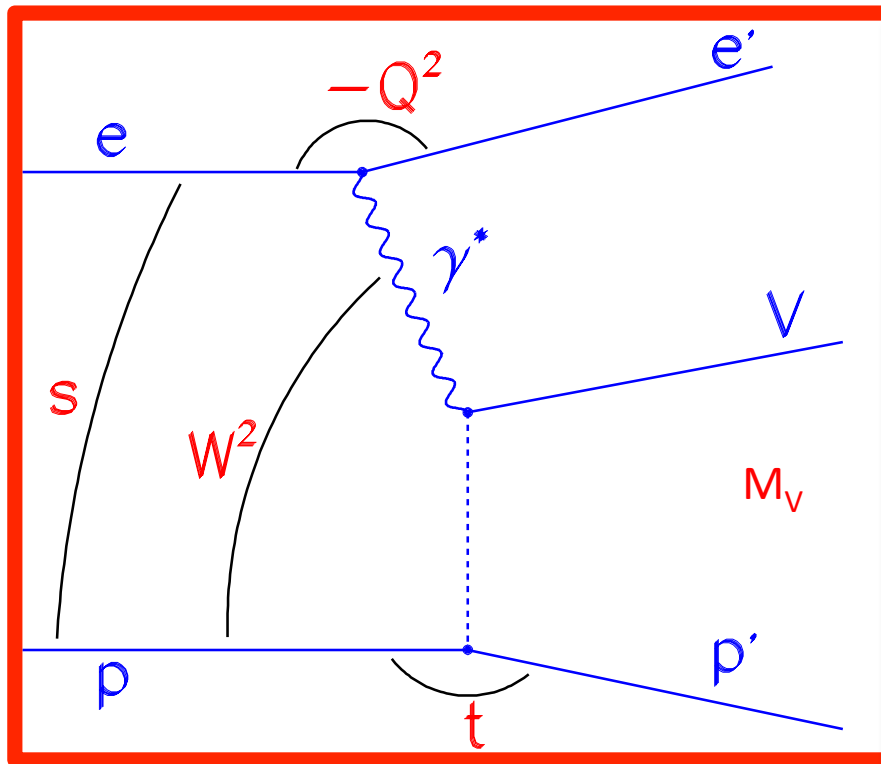
$$r_{\text{em}} \sim 0.8 \text{ fm}$$



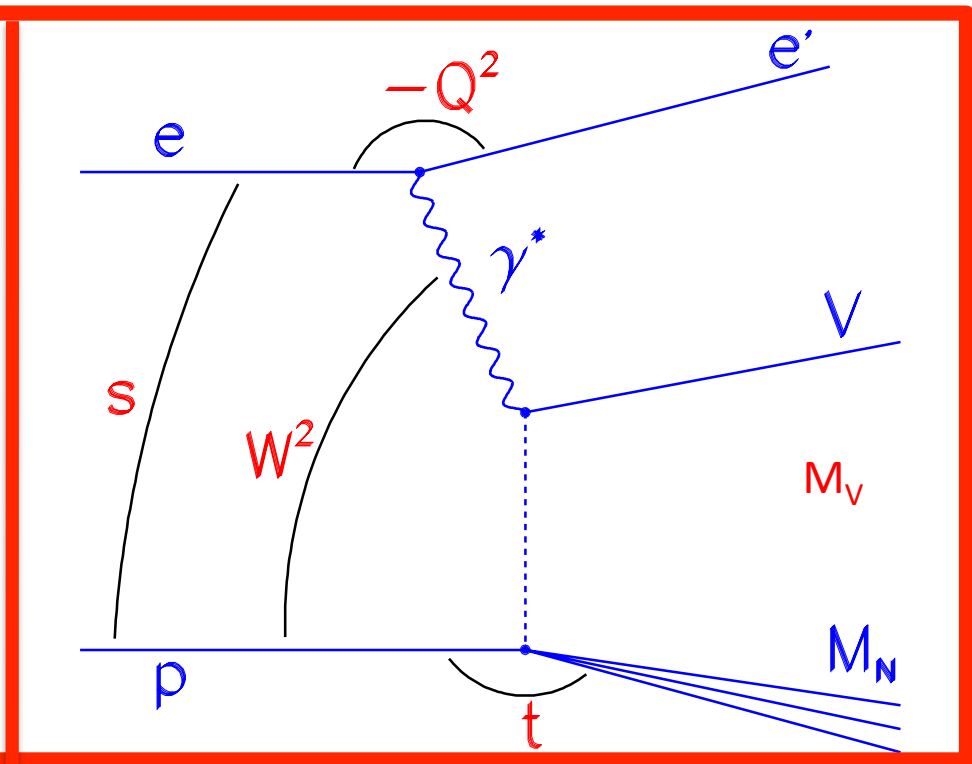
Agree with predictions:

asymptotic behaviour of the slope parameter as a function of the effective scale present in the process: $Q^2 + M^2$

Elastic

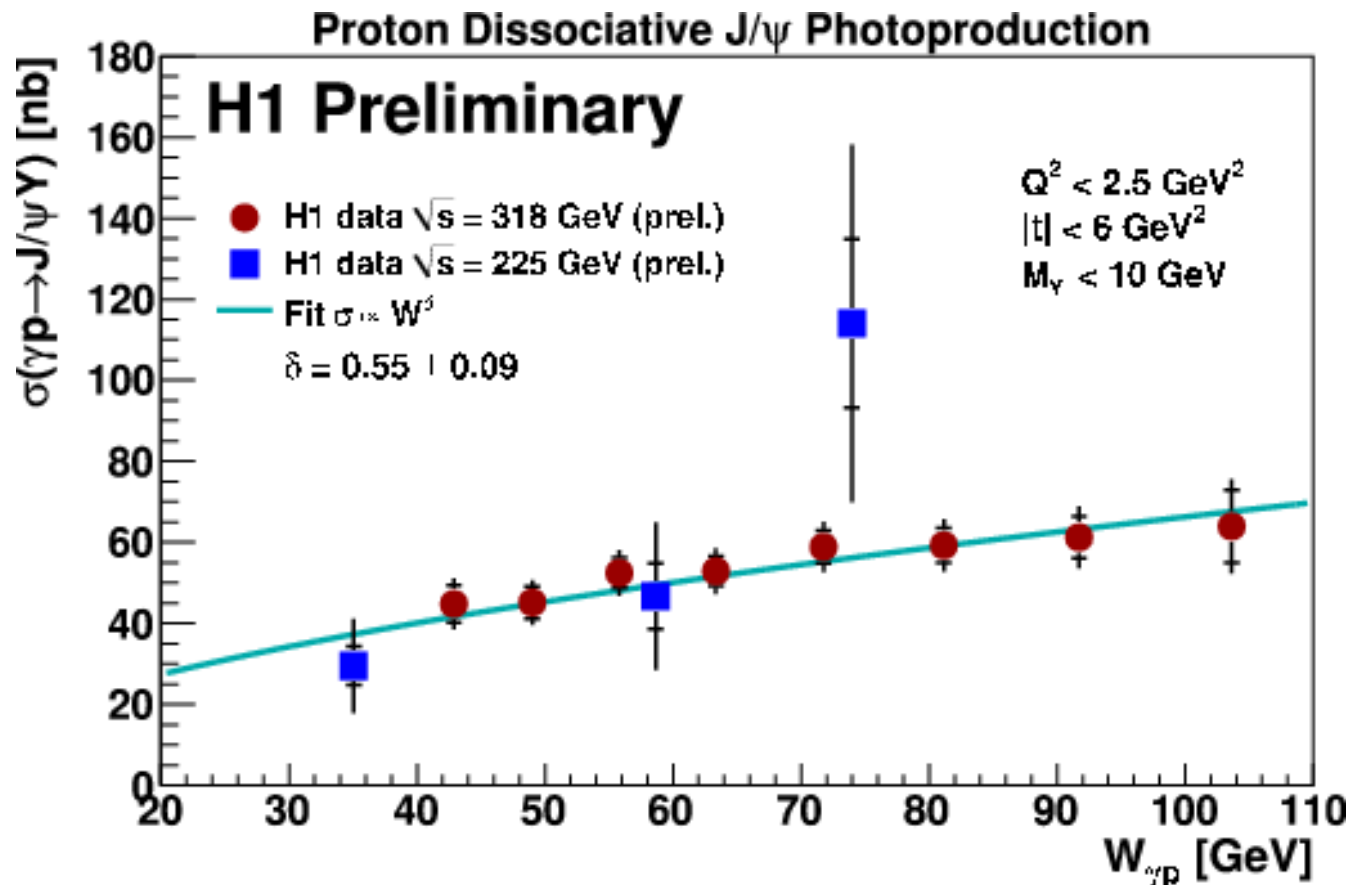


Proton Dissociation



What happens at the proton vertex?

New: $\sigma(W)$ of proton dissociative J/ ψ

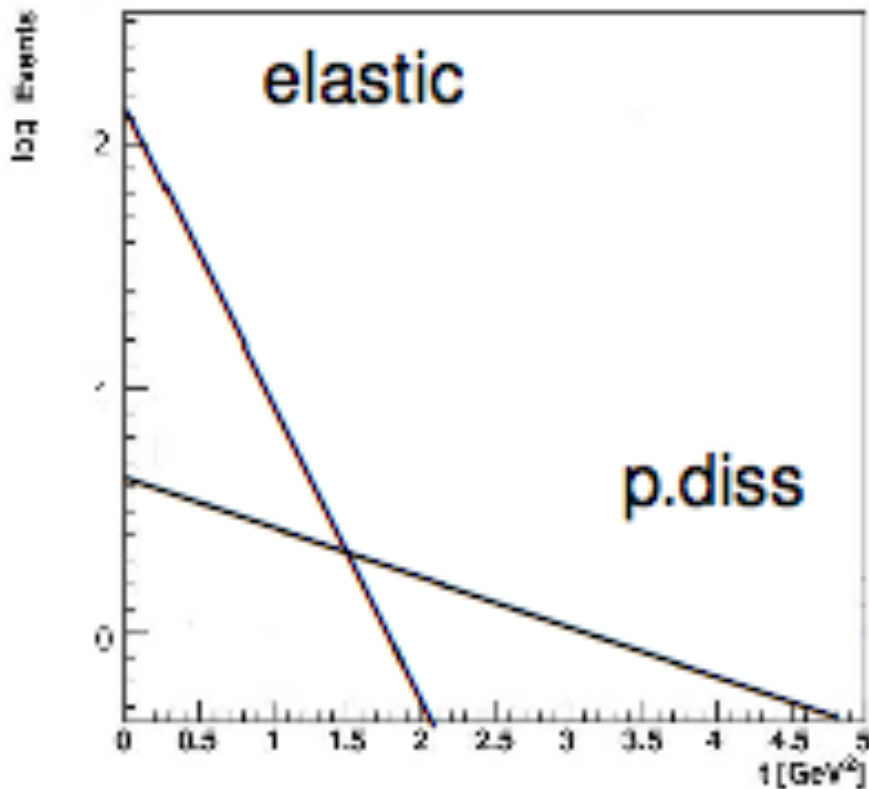


Simultaneous extraction of cross sections of elastic and p-diss
- possible because of new unfolding methods

http://www-h1.desy.de/publications/H1preliminary.short_list.html
H1prelim-11-011 ref for slides 10, 14, 16

Expectation for t: proton dissociation

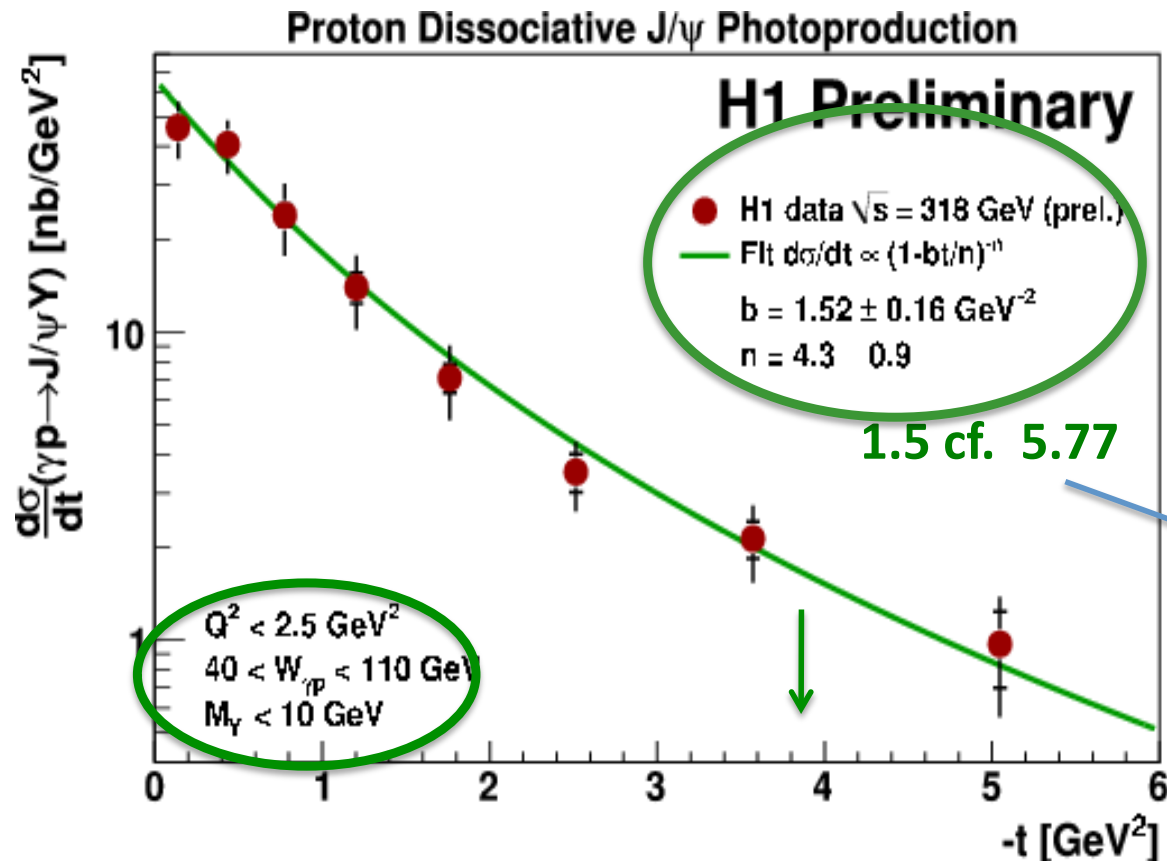
$$b = b_v + b_p$$



- If the target i.e proton breaks, the size b_p doesn't count, so b has to be smaller for p-dissociation cf. to elastic
- Since x-sec for elastic and p_diss are similar, the data has to extend to larger t

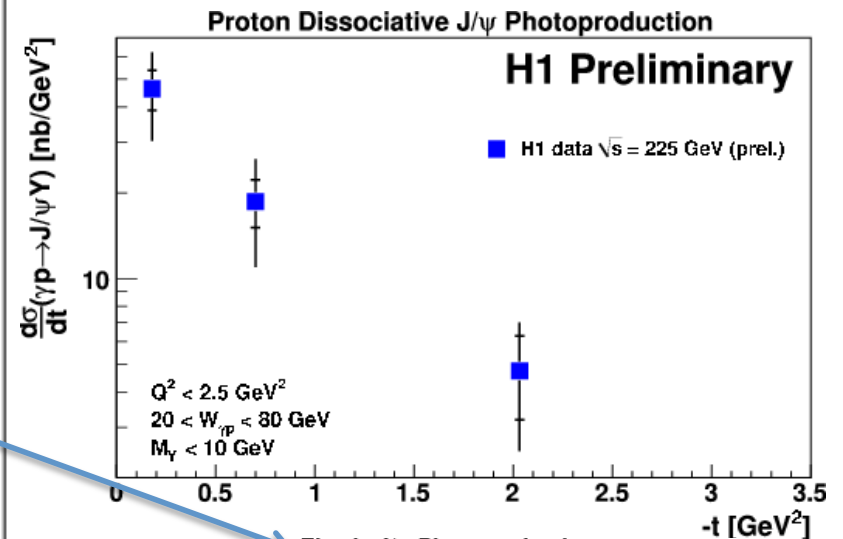
What does HERA data say about this?

$d\sigma/dt$ of photoproduced J/ψ proton-dissociative

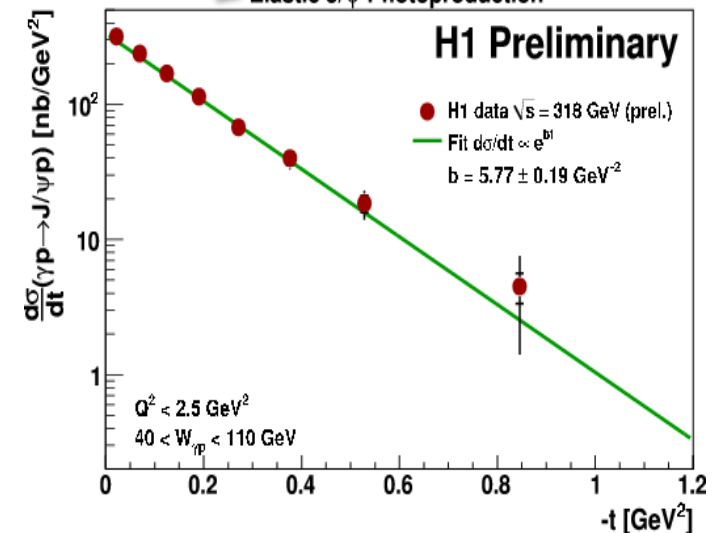


Small t : exp behaviour + High t : power law behaviour

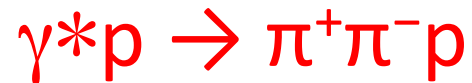
Slope smaller than Elastic



Elastic J/ψ Photoproduction



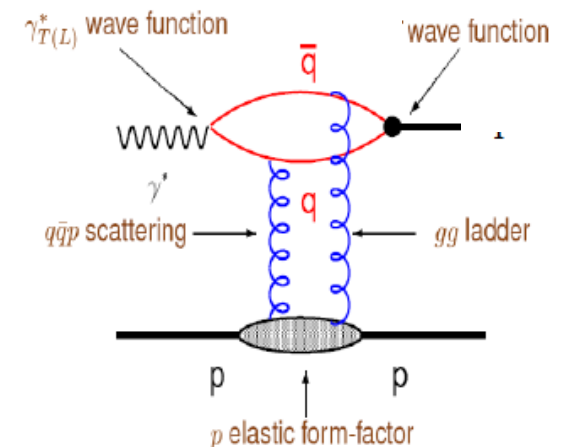
Pion Form Factor from Exclusive Electroproduction of two pions



Form factors are important in hadron physics –
information on structure (shape and size of hadron)

$$\frac{dN(M_{\pi\pi})}{dM_{\pi\pi}} \propto |F_{\pi}(M_{\pi\pi})|^2$$

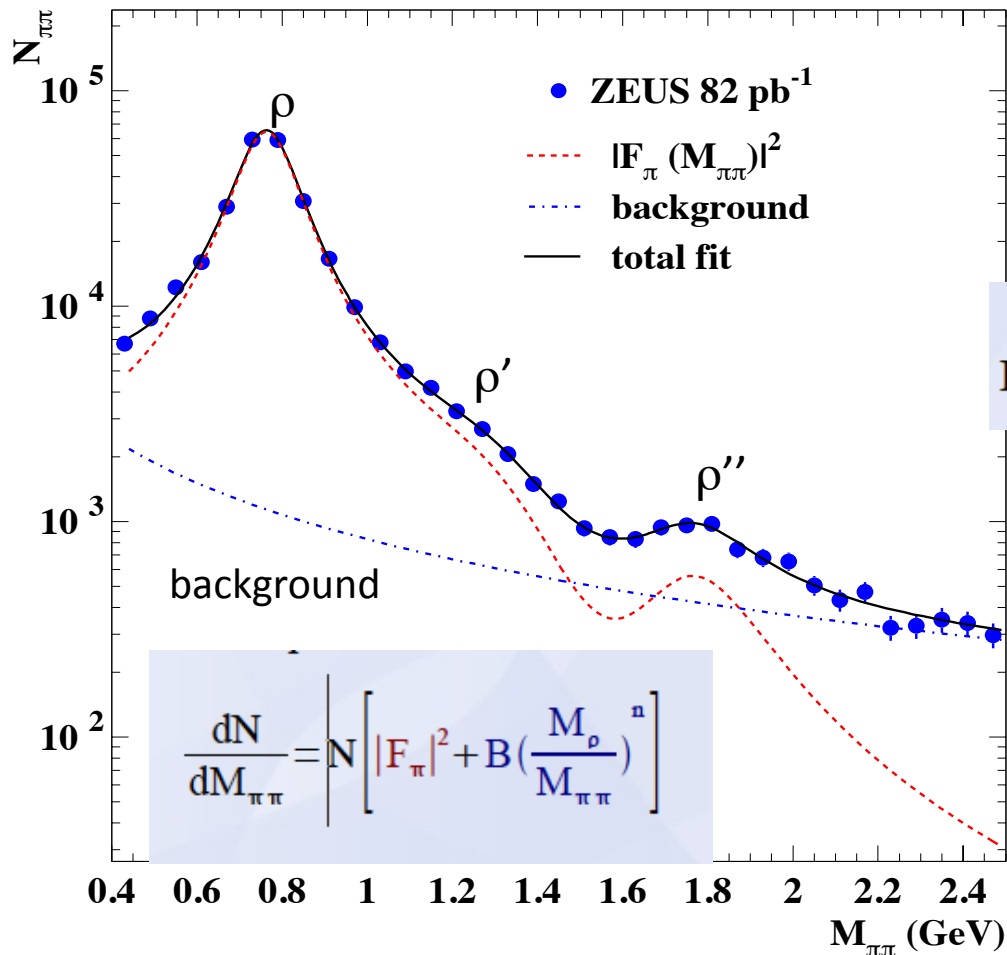
“at asymptotically large Q^2 QCD predicts unambiguously the shape of the dipion mass distribution”
Clerbaux and Polyakov



Exclusive dipion: $\gamma^* p \longrightarrow p \pi^+ \pi^-$

Two-pion decay mode of these resonances is related to the pion electromagnetic form factor, $F_\pi(M_{\pi\pi})$

ZEUS



Kuhn-Santamaria parametrization:

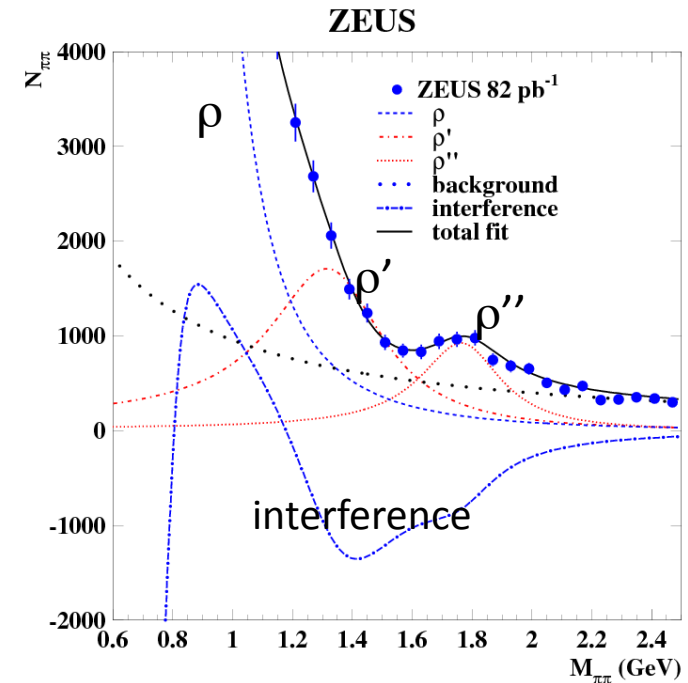
$$F_\pi(M_{\pi\pi}) = \frac{BW_\rho(M_{\pi\pi}) + \beta |BW_{\rho'}(M_{\pi\pi}) + \gamma BW_{\rho''}(M_{\pi\pi})}{1 + \beta + \gamma}$$

$$BW_V(M_{\pi\pi}) = \frac{M_V^2}{M_V^2 - M_{\pi\pi}^2 - i M_V \Gamma_V(M_{\pi\pi})}$$

negative interference between all the resonances results in the ρ' shoulder

Fit of F_π

Parameter	ZEUS	PDG
M_ρ (MeV)	$771 \pm 2^{+2}_{-1}$	775.49 ± 0.34
Γ_ρ (MeV)	$155 \pm 5 \pm 2$	149.1 ± 0.8
β	$-0.27 \pm 0.02 \pm 0.02$	
$M_{\rho'}$ (MeV)	$1350 \pm 20^{+20}_{-30}$	1465 ± 25
$\Gamma_{\rho'}$ (MeV)	$460 \pm 30^{+40}_{-45}$	400 ± 60
γ	$0.10 \pm 0.02^{+0.02}_{-0.01}$	
$M_{\rho''}$ (MeV)	$1780 \pm 20^{+15}_{-20}$	1720 ± 20
$\Gamma_{\rho''}$ (MeV)	$310 \pm 30^{+25}_{-35}$	250 ± 100
B	$0.41 \pm 0.03 \pm 0.07$	
n	$1.30 \pm 0.06^{+0.18}_{-0.13}$	



Masses and widths consistent with expectations (but ρ' mass lower than PDG)

Interference important !

Relative amplitudes measured, **found to be real**

Santamaria parametrization:

$$F_\pi(M_{\pi\pi}) = \frac{BW_\rho(M_{\pi\pi}) + \beta BW_{\rho'}(M_{\pi\pi}) + \gamma BW_{\rho''}(M_{\pi\pi})}{1 + \beta + \gamma}$$

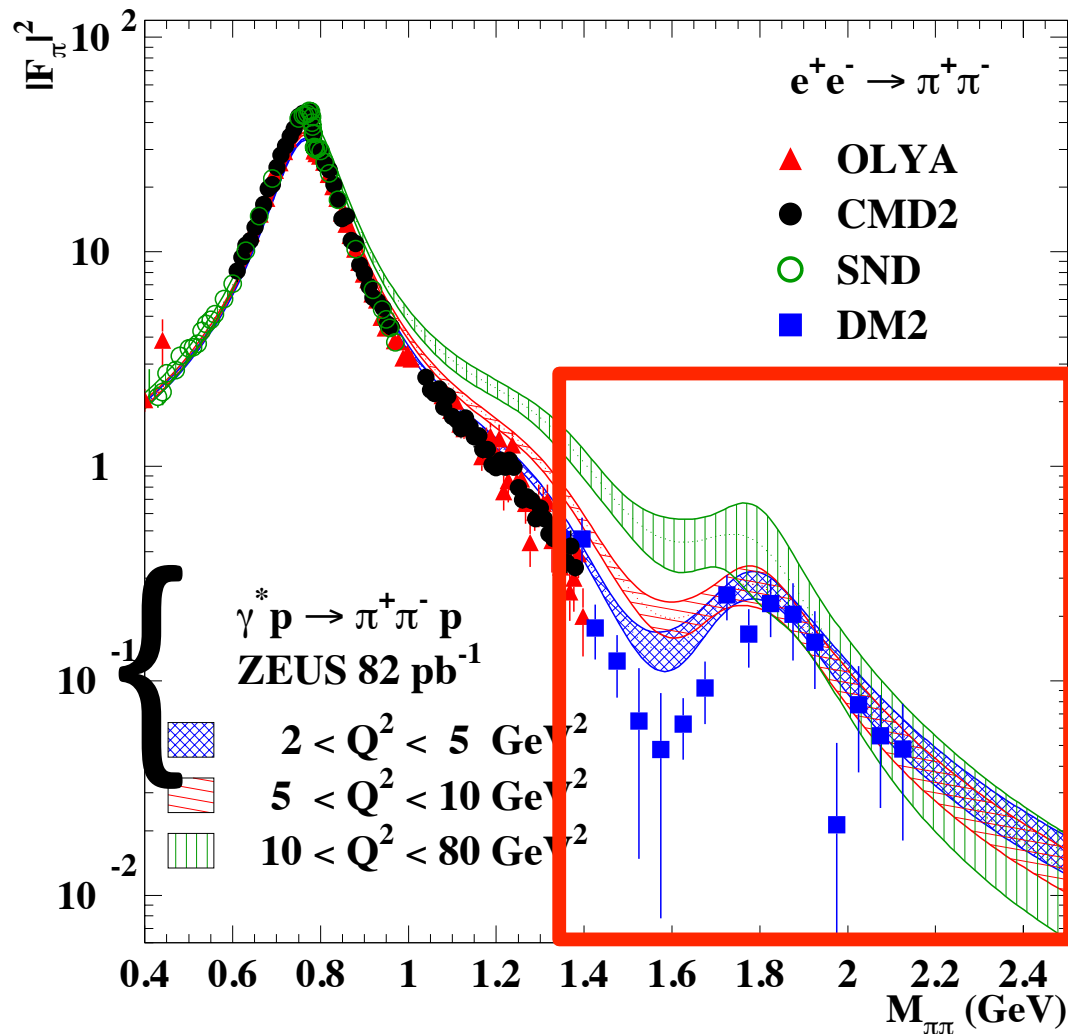
with Breit-Wigner

$$BW_V(M_{\pi\pi}) = \frac{M_V^2}{M_V^2 - M_{\pi\pi}^2 - iM_V\Gamma_V(M_{\pi\pi})}$$

Exclusive dipion: $\gamma^* p \longrightarrow p \pi^+ \pi^-$

$Q^2(\text{GeV}^2)$	2-5	5-10	10-80
β	$-0.249 \pm 0.008^{+0.005}_{-0.003}$	$-0.282 \pm 0.008^{+0.005}_{-0.008}$	$-0.35 \pm 0.02 \pm 0.01$
γ	$0.100 \pm 0.009 \pm 0.003$	$0.098 \pm 0.012^{+0.005}_{-0.003}$	$0.118 \pm 0.022^{+0.008}_{-0.006}$

ZEUS



A Q^2 dependence of F_π is observed.

cf. $F_\pi(M_{\pi\pi})$ with e^+e^- data

-shape similar in general despite different production mechanisms $g\gamma^*$ vs. γ^*

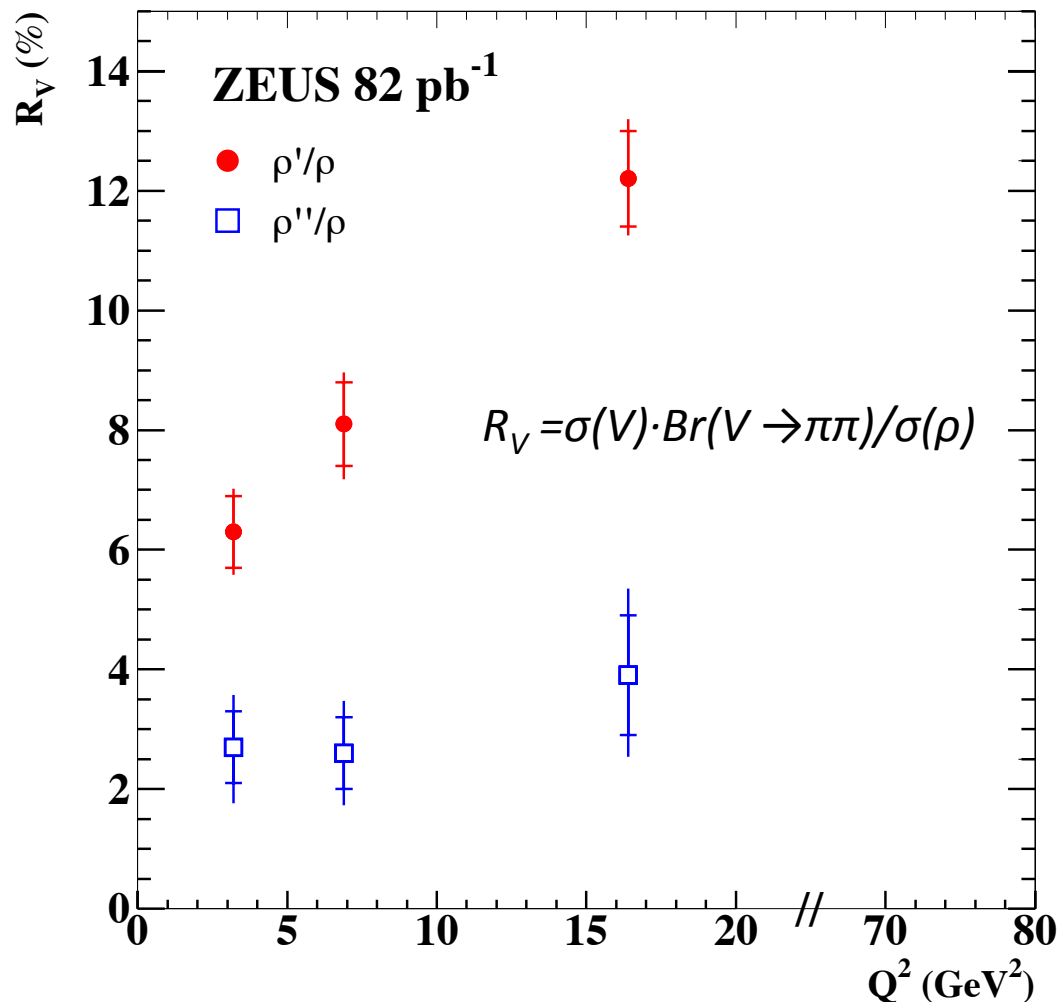
but

- some differences especially in the interference region

Exclusive dipion: $\gamma^* p \longrightarrow p \pi^+ \pi^-$

Ratio of excited ρ states
as function of Q^2 .

ZEUS



$R_{\rho'}$ increases with Q^2 :

- expected in QCD inspired models due to node in ρ' wave function (suppression at low Q^2)

Acta Phys. Polon. B 33 (2002) 3517.

Phys. Lett. B 339 (1994) 194.

Surveys High Energy Phys. 11(1997)

Phys. Rev D 54 (1996) 3194

Less clear conclusions from $R_{\rho'}$,

Conclusions

HERA provides large amount of vector meson data in a wide kinematical range.

Interplay of soft and hard region can extensively be tested

Perturbative QCD predictions can reproduce general behaviour of data. But no model is able to produce all details.

Results :

- W dependence of J/Psi now w/ low energy measurement (H1)
- slope of t distribution : Elastic (Jpsi and Upsilon)
- slope of t distribution : proton dissociative J/Psi
- asymptotic behaviour of b vs. (Q^2+M^2) as scale
- Q^2 dependence of the pion form factor