Vector Mesons and DVCS at HERA

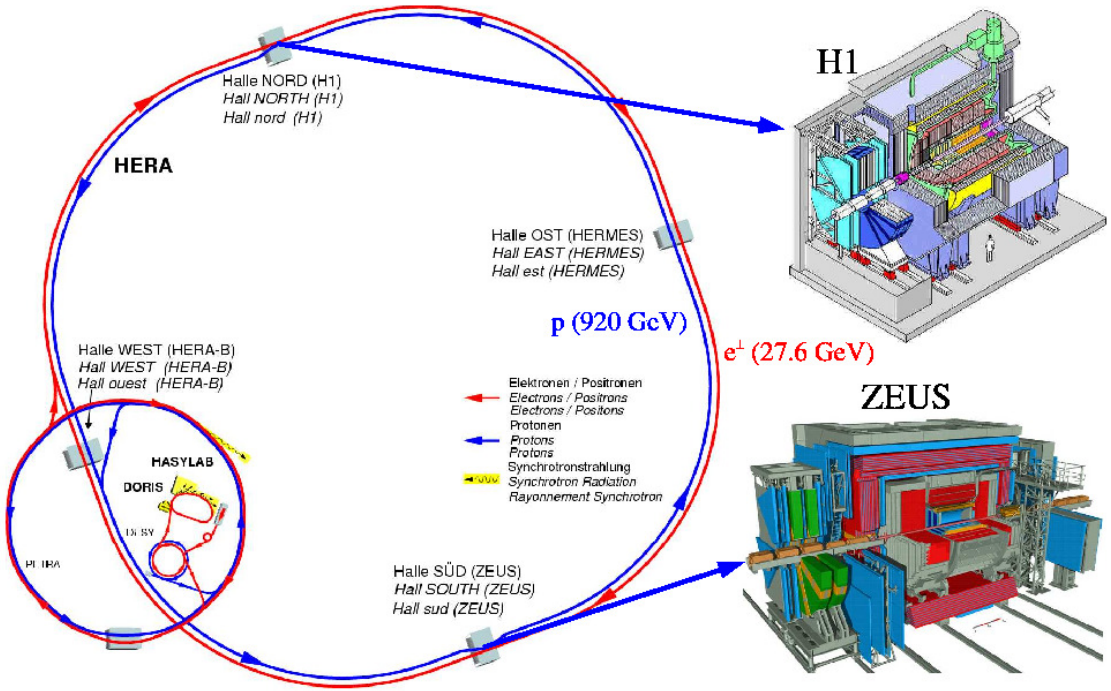
Università della Calabria
Dipartimento di Fisica

Marcella Capua

Calabria University and INFN

On behalf of the  **and**  **Collaborations**

HERA colliding experiments



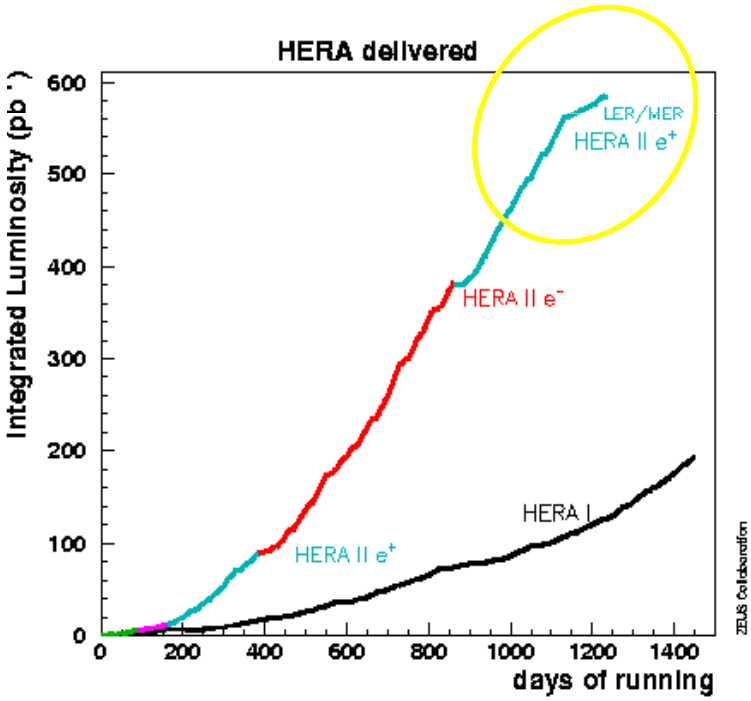
Detectors not originally designed for diffractive physics.

Forward instrumentation added:

ZEUS LPS for HERA I only

H1 FPS for HERA I and II

H1 VFPS for HERA II



Lots of results achieved in diffraction at HERA:

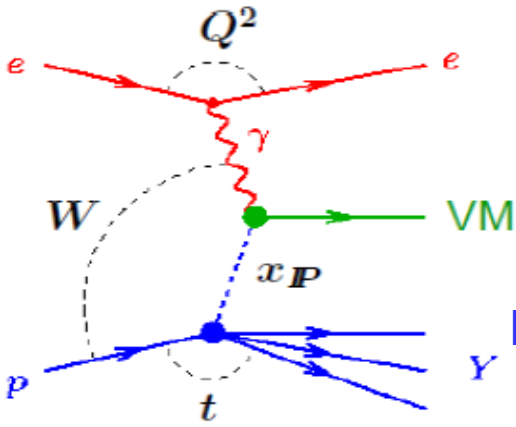
✓ **Inclusive diffraction**

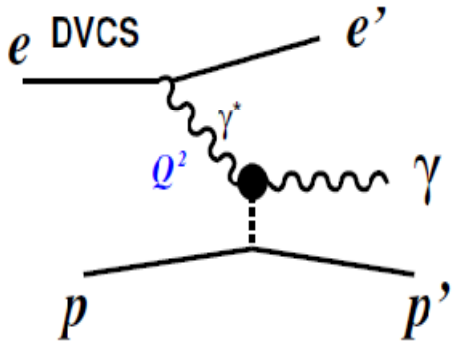
✓ **Exclusive diffraction**

✓ **Leading Baryons**

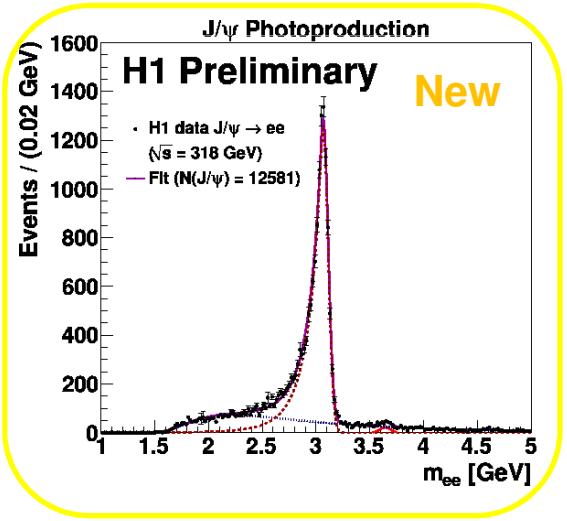
HERA I + HERA II ~0.5 fb^{-1}

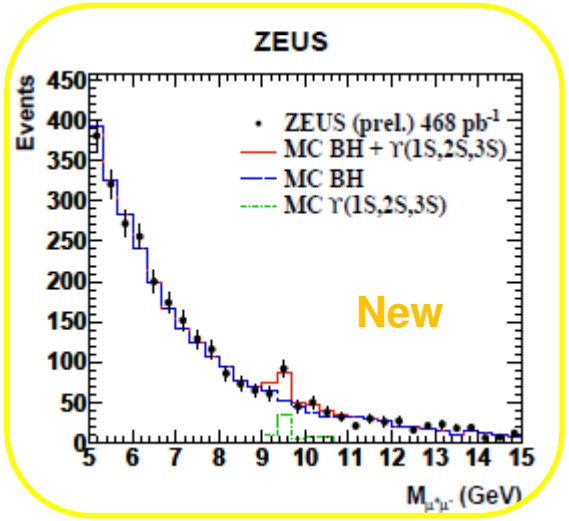
A large variety of VM and DVCS processes have been studied in a wide kinematic range at HERA

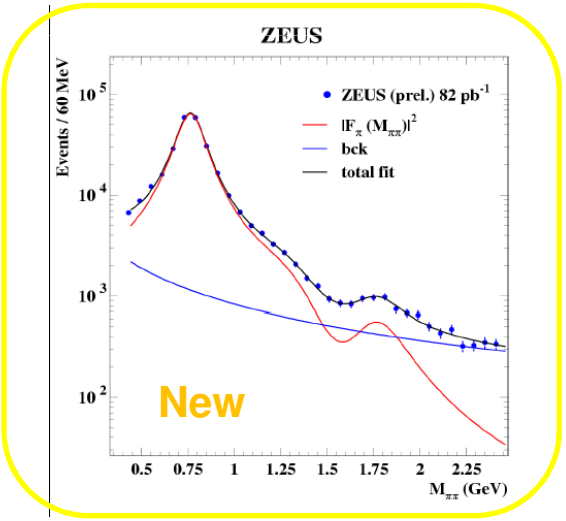




Proton stays intact (Y=p) or dissociates

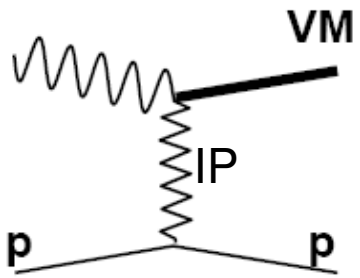




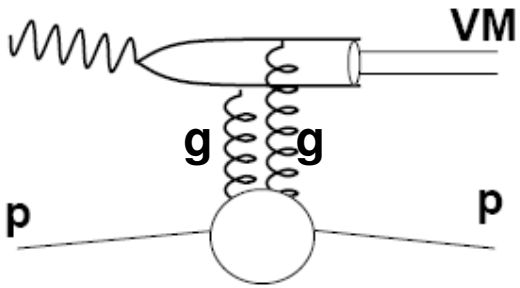


***W*, Q^2 and *t* cross section dependence for VM and DVCS used to investigate the transition from soft to hard processes and to learn more about the proton structure**

Soft and hard diffraction



'soft'



'hard'

Pomeron trajectory:

$$\alpha(t) = \alpha(0) + \alpha' t$$

$$\frac{d\sigma_{pp\to Vp}}{dt} \propto e^{-b(W)t} (W/W_0)^{4(\alpha(0)-1)}$$

shrinkage:

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

2-gluon exchange (pQCD) at LO
Gluon density in the proton

$$\begin{cases} \sigma \propto [\, x\, g(x, \mu^2)]^2 \\ \mu^2 \propto (Q^2 + M_V^2) \end{cases}$$

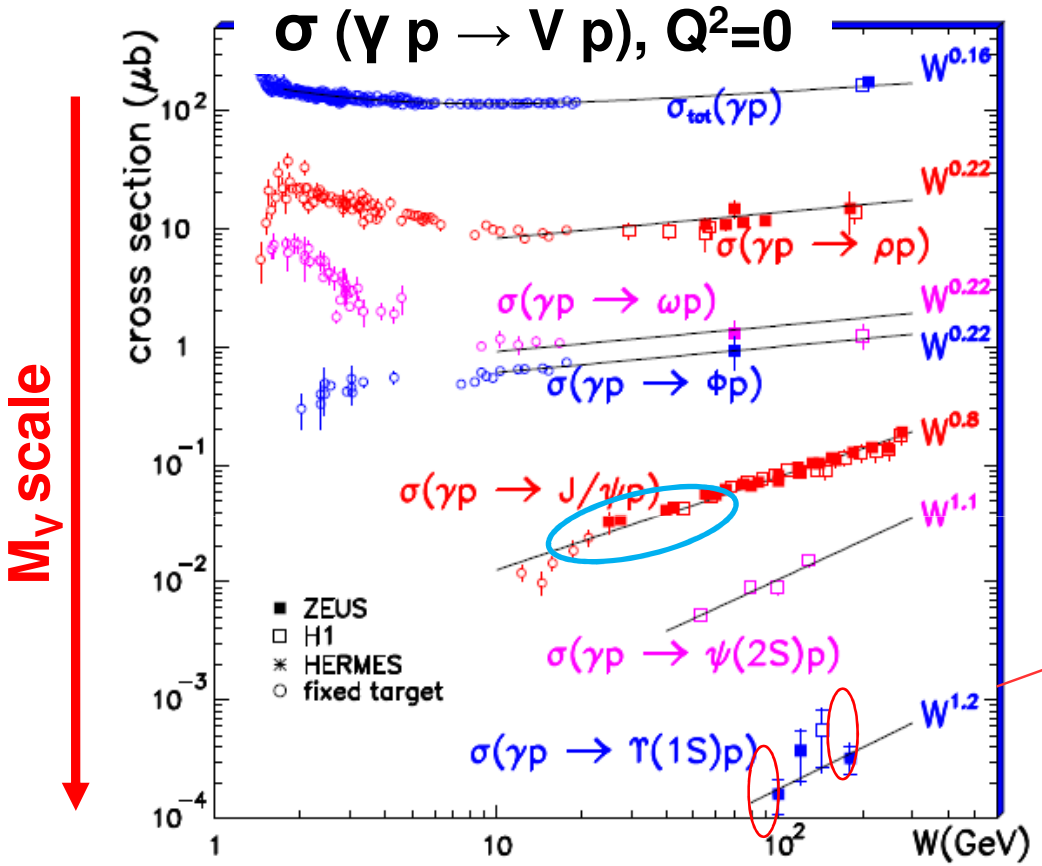
Fast increase of cross section proportional to probability of finding 2 gluons in the proton. Small or no shrinkage

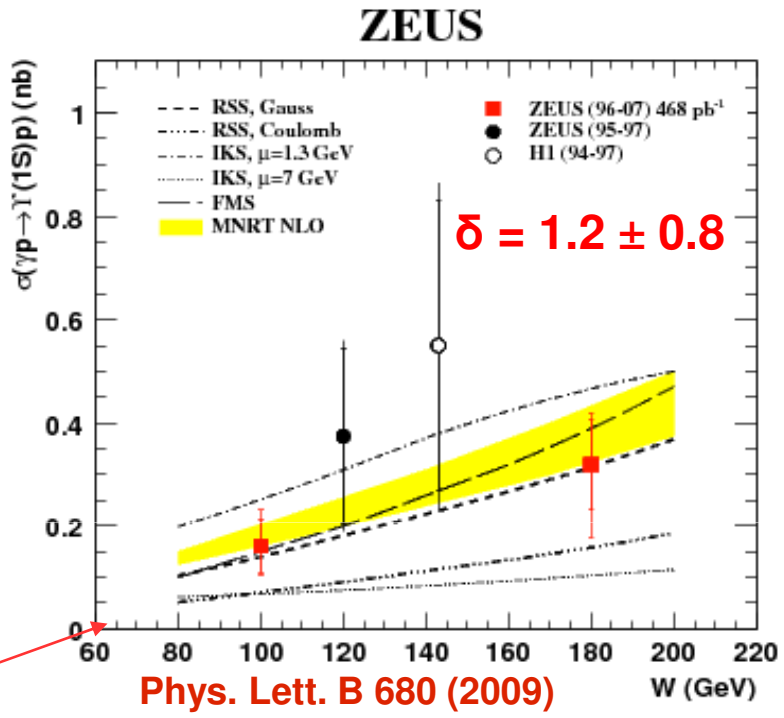
$\sigma(W) \propto W^{\delta}$ ➡ **δ expected to increase from soft (~0.2) to hard Pomeron (~1)**

$\frac{d\sigma}{dt}$ ➡ ***b*** **expected to decrease from soft (~10 GeV^{-2}) to hard (~4-5 GeV^{-2})**

W dependence

W-dependence in Photoproduction (PHP)





comparison compatible with pQCD

Fit: $\sigma \sim W^{\delta}$

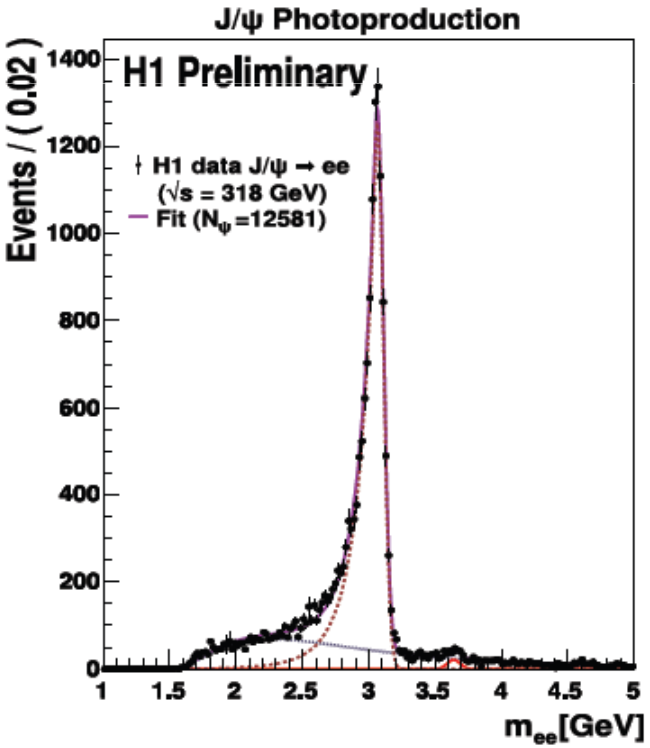
As the VM mass increases, the process gets harder: large M_V supplies a scale for hard processes → apply pQCD models

J/ψ in PHP (new results)

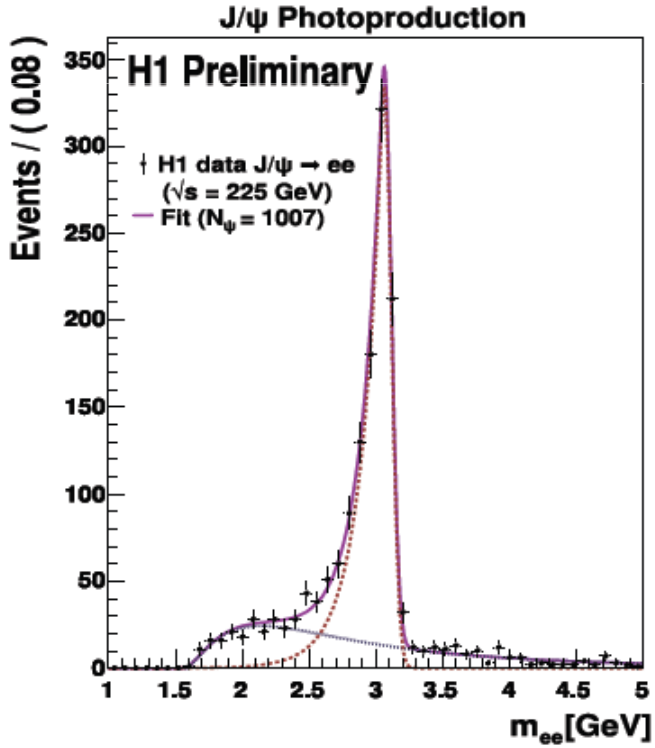
H1prelim-11-011

Two samples: extended phase space towards lower photon-proton centre of mass energies $W_{\gamma p}$

E_p= 920 GeV
$Q^2 \leq$ 2.5 GeV^2
40 ≤ W ≤ 110 GeV
t ≤ 6 GeV^2

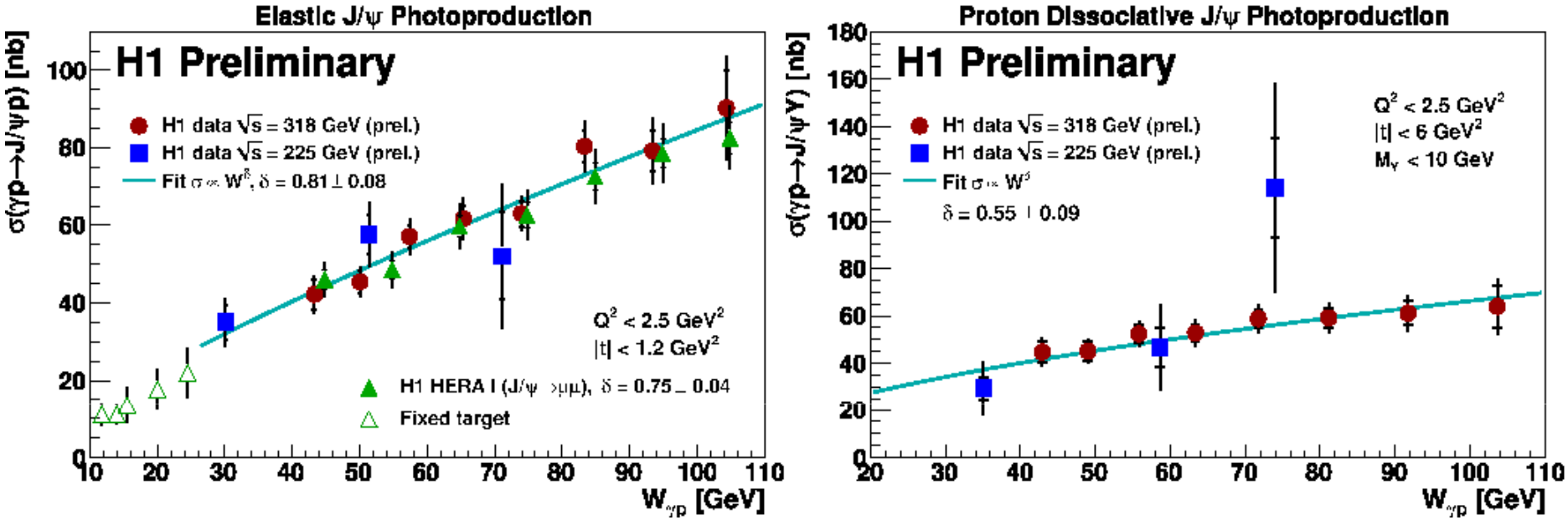


E_p= 460 GeV
$Q^2 \leq$ 2.5 GeV^2
20 ≤ W ≤ 80 GeV
t ≤ 3.5 GeV^2



W-dependence in PHP (new results)

H1prelim-11-011



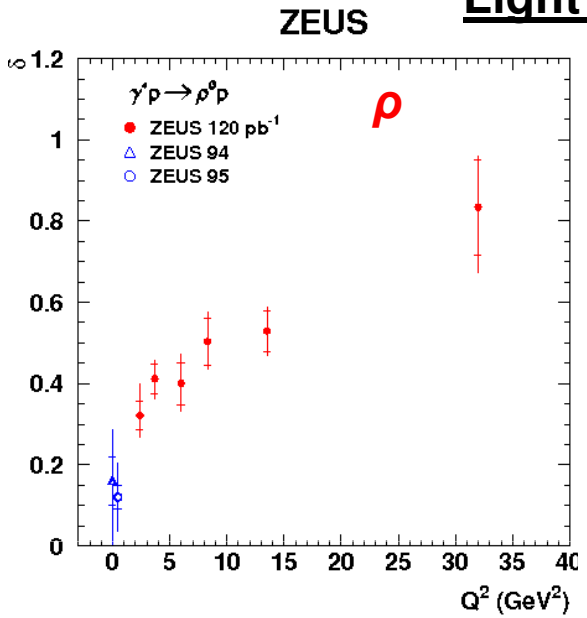
Elastic measurements in agreement with previous results:

H1 δ=0.75±0.03±0.03

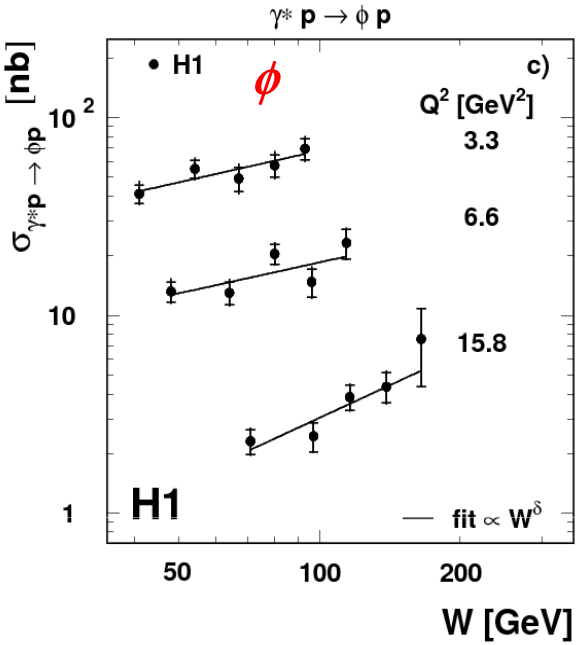
ZEUS δ= 0.69±0.02±0.03

W-dependence vs Q^2

Light VM

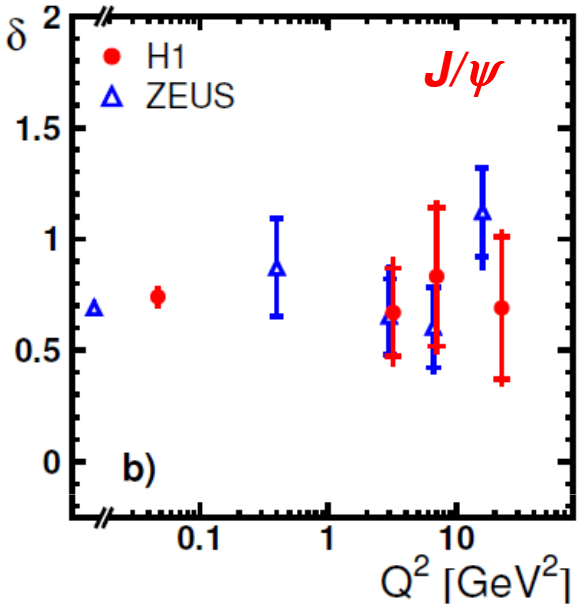


PMC Physics A 1, 6



JHEP05 (2010)

Heavy VM



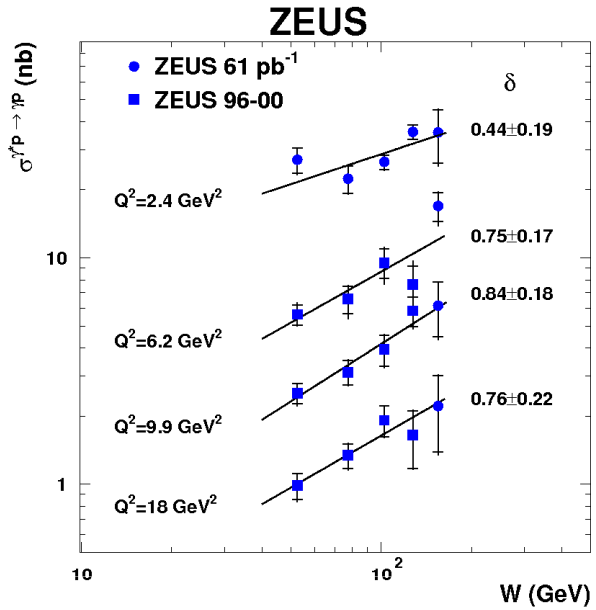
Eur.Phys.J. C46 (2006)

Fit: $\sigma \sim W^{\delta}$

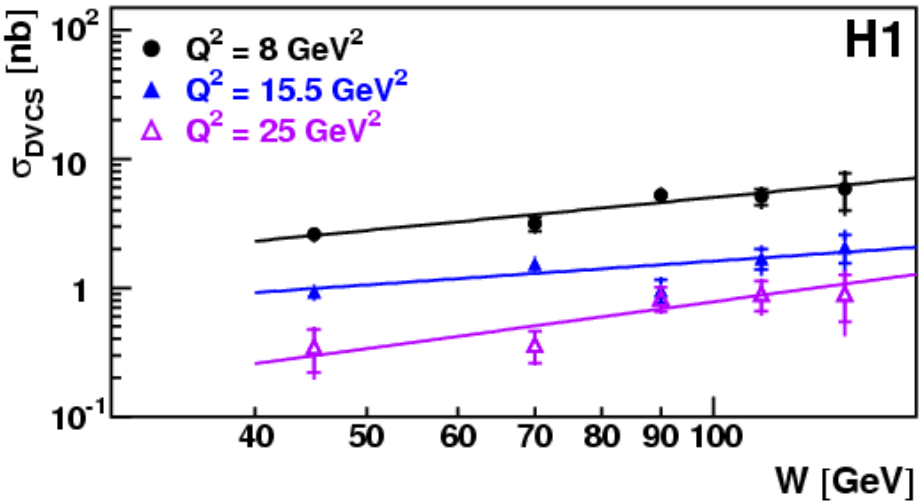
The light VM, like ρ and φ, **W dependence gets steeper from soft to hard region in Q^2**

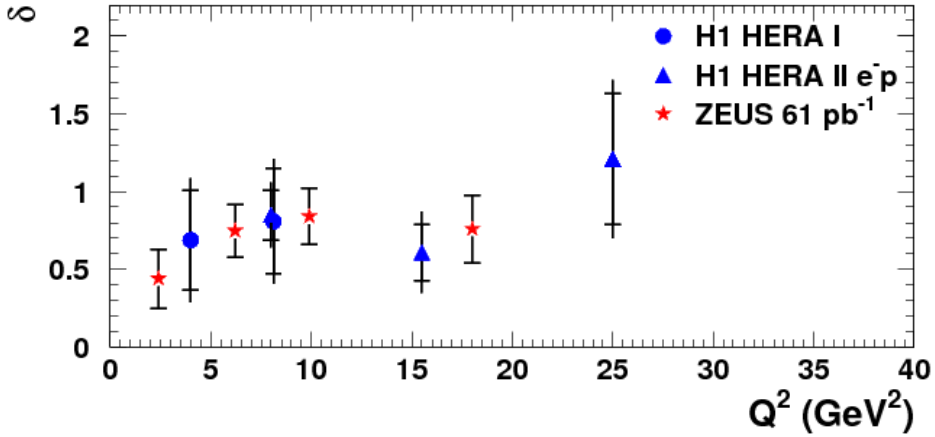
The heavy VM, like J/ψ, **W dependence is constant even at low Q^2 Hard region at low Q^2 because of mass**

DVCS - W-dependence vs Q^2



Fit: $\sigma \sim W^{\delta}$

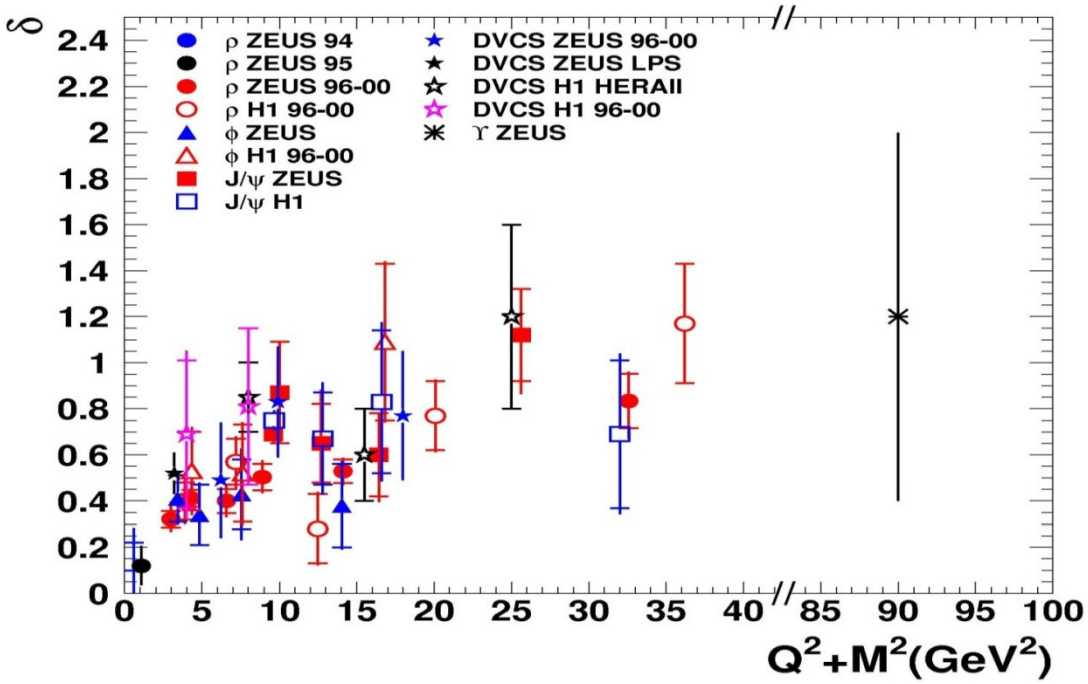


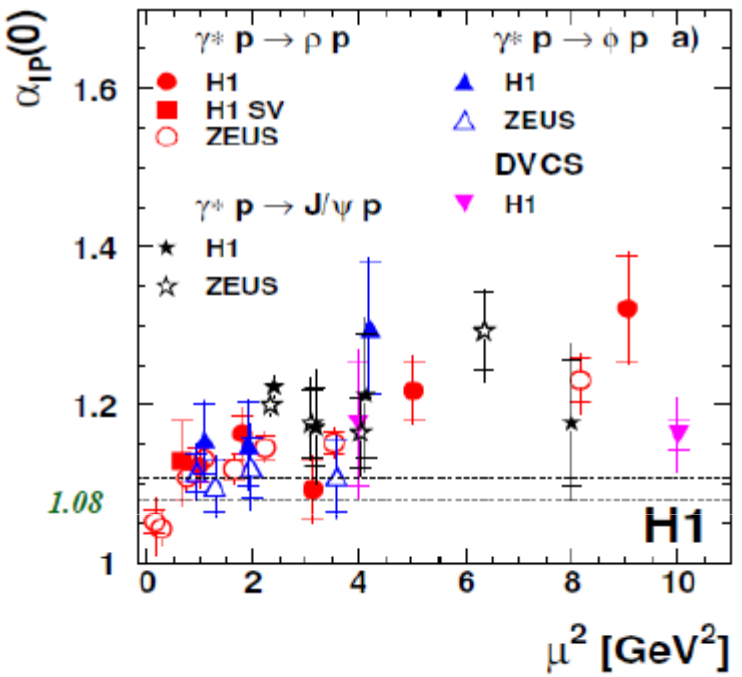


ZEUS: JHEP05 108 (2009)
H1: Phys.Lett.B681 (2009)

DVCS W-dependence shows a hard regime even at low Q^2

W-dependence summary





$$\begin{cases} \sigma(W) \propto W^{\delta} \\ \delta(t) = 4(\alpha_{IP}(t) - 1) \end{cases} \rightarrow \begin{cases} \alpha_{IP}(0) = 1 + \delta/4 + \alpha'_{IP}/\langle|t|\rangle \\ \mu^2 = (Q^2 + M^2)/4 \quad \rightarrow \text{for VMs} \\ \mu^2 = Q^2 \quad \rightarrow \text{for DVCS} \end{cases}$$

Common hardening of $\alpha_{IP}(0)$ with μ^2

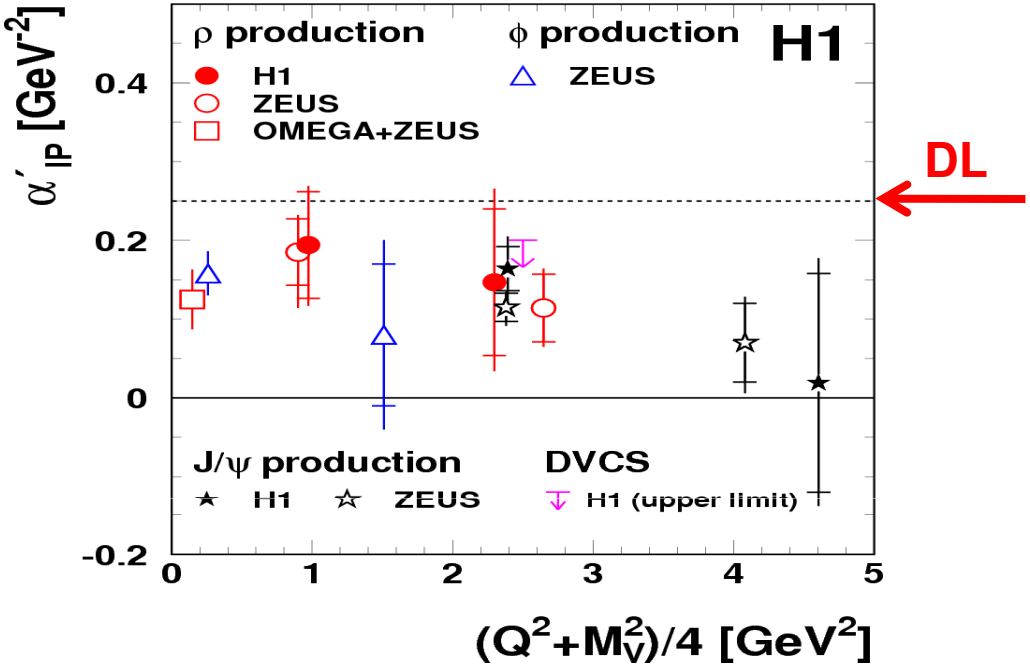
δ increases with μ^2 (from soft to hard)

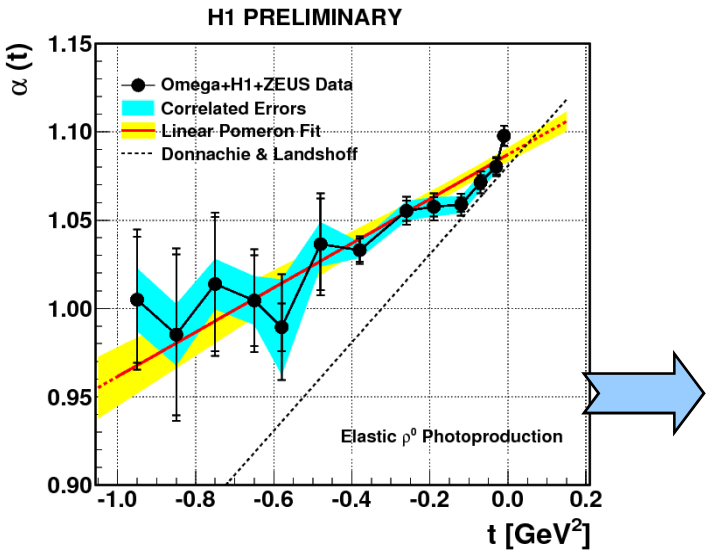
Pomeron trajectory in ep collisions

From SOFT to HARD

$$\alpha(t) = \alpha(0) + \alpha' t$$

In electron-proton interactions:
As the scale gets harder the intercept grows up to 1.2
The Pomeron slope is around ~0.1





H1-prelim-09-016

ρ^0 PHP from H1, ZEUS+Omega:

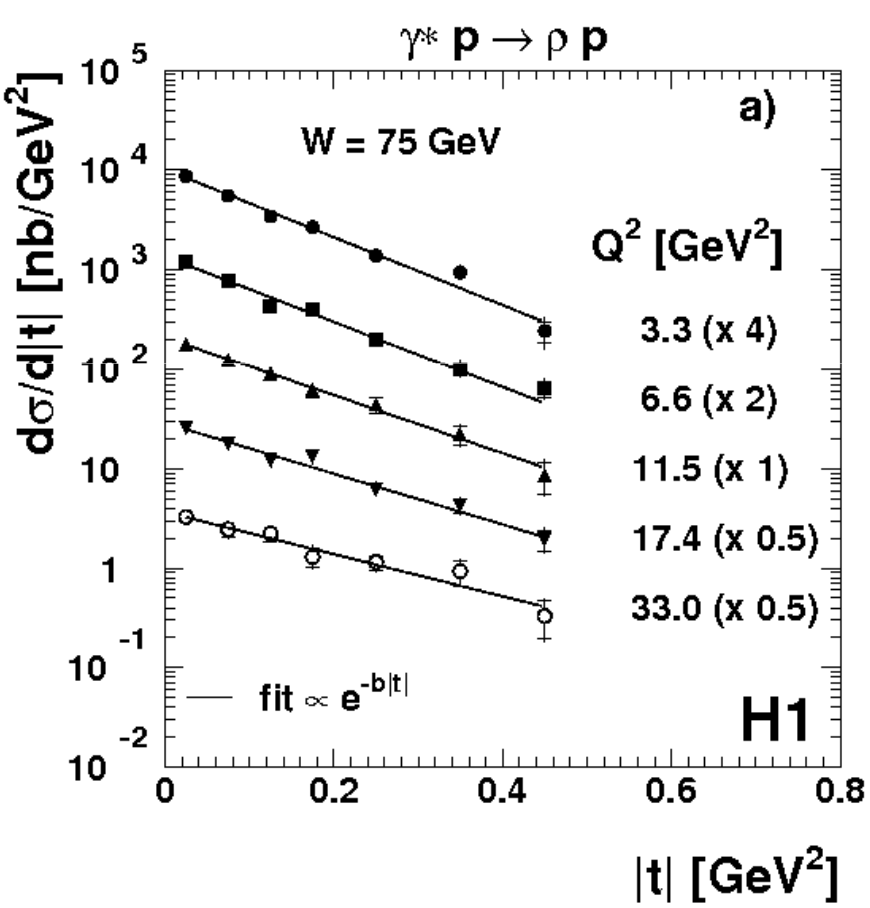
$\alpha(0) = 1.087 \pm 0.003 \pm 0.003$
$\alpha' = 0.126 \pm 0.013 \pm 0.012$ GeV^{-2}

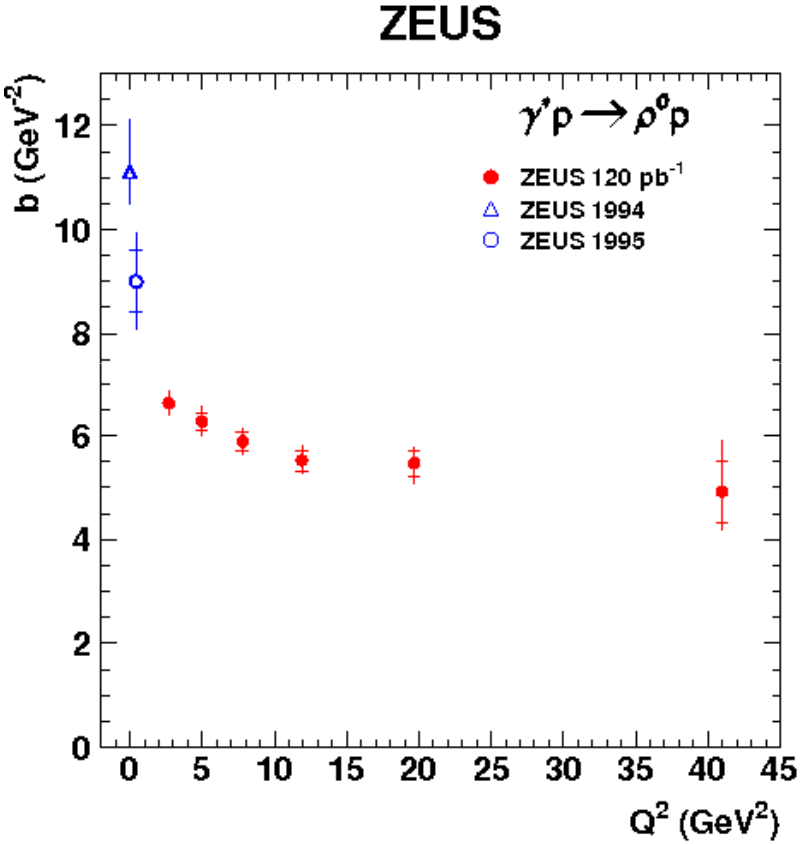
$$\alpha_{IP}(t) = 1.08 + 0.25t \quad \text{(D.L.)}$$

t dependence

ρ - t dependence

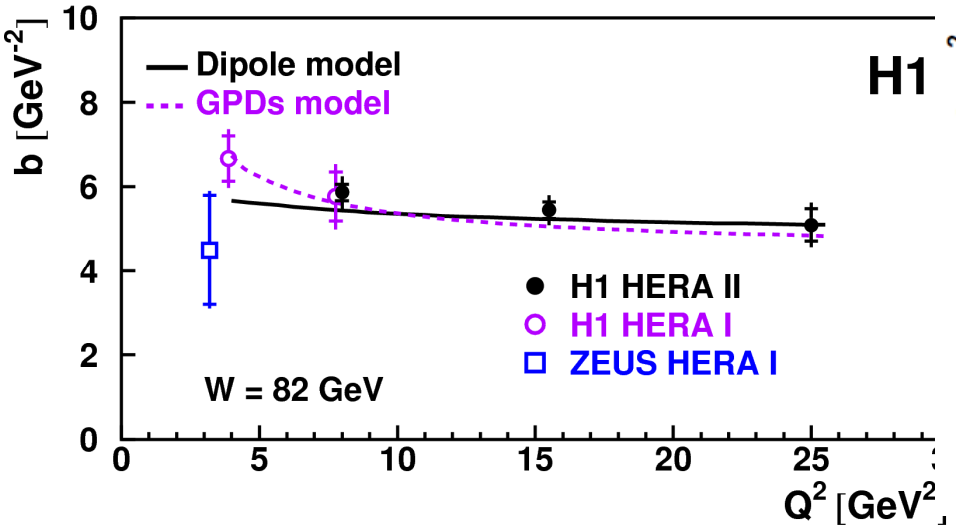
$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

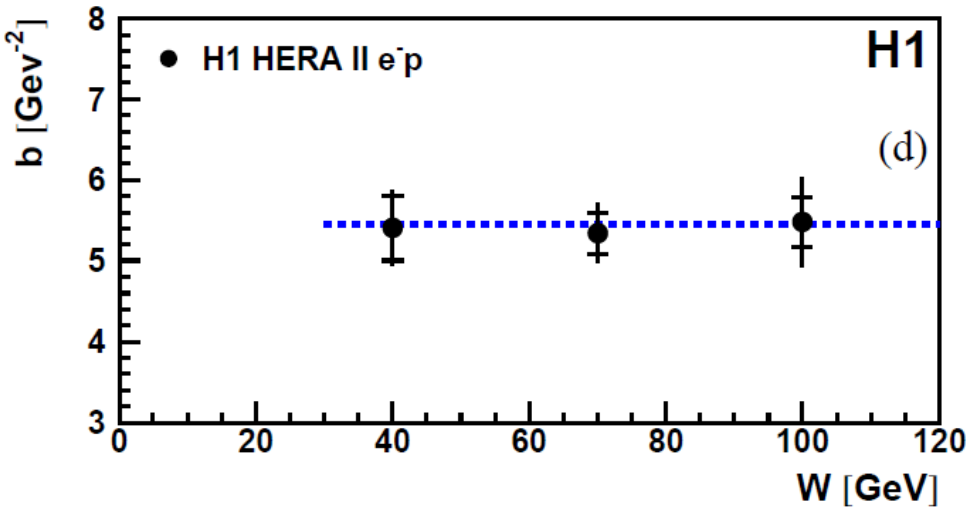




b decreases from soft (~10 GeV^{-2}) to pQCD expected values (~4-5 GeV^{-2})

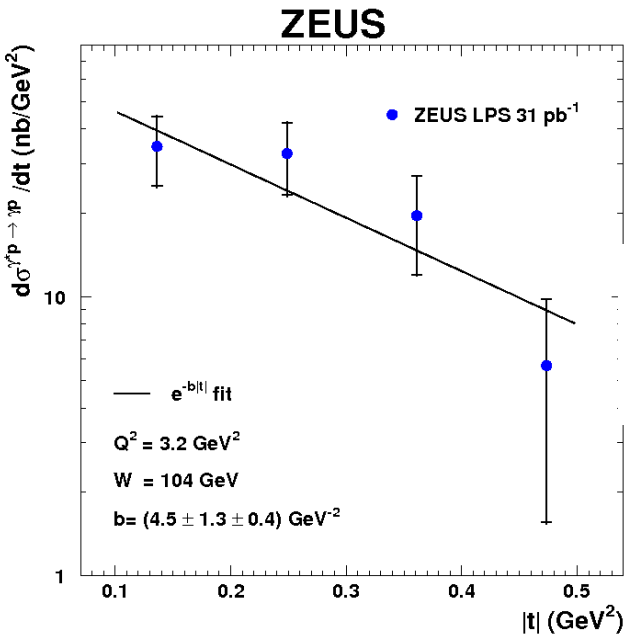
DVCS - t dependence





$b = 5.45 \pm 0.19 \pm 0.34$ GeV^{-2}
($Q^2 = 8$ GeV^2)

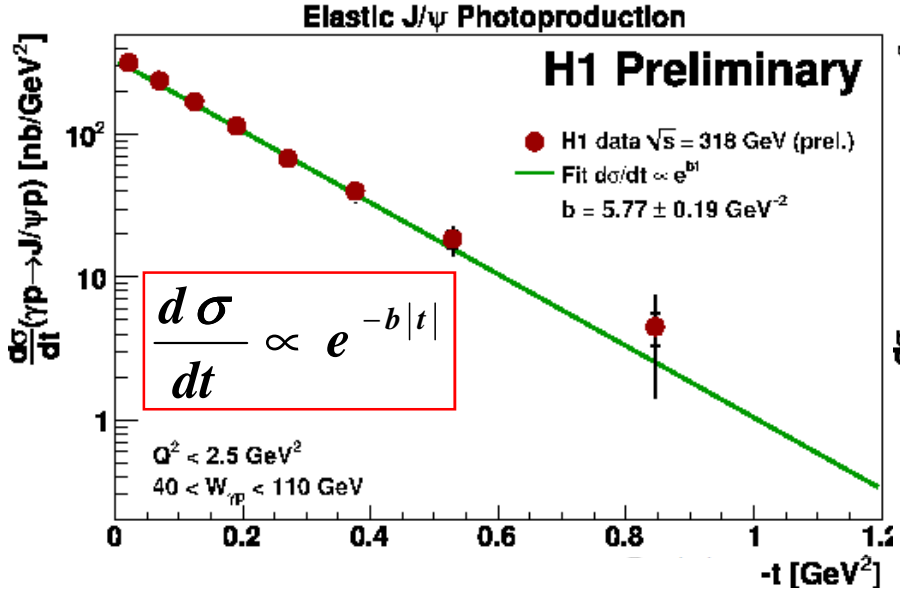
no strong Q^2 dependence

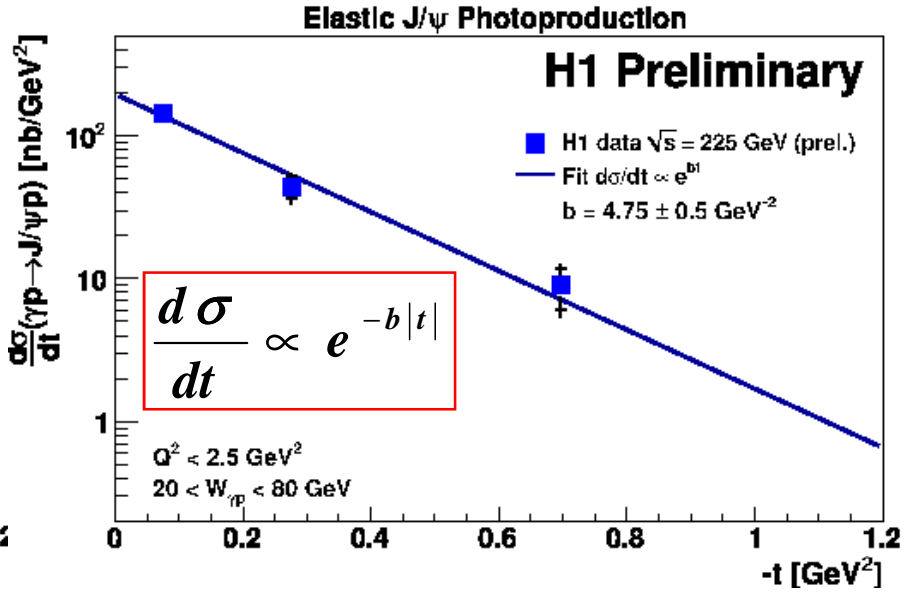


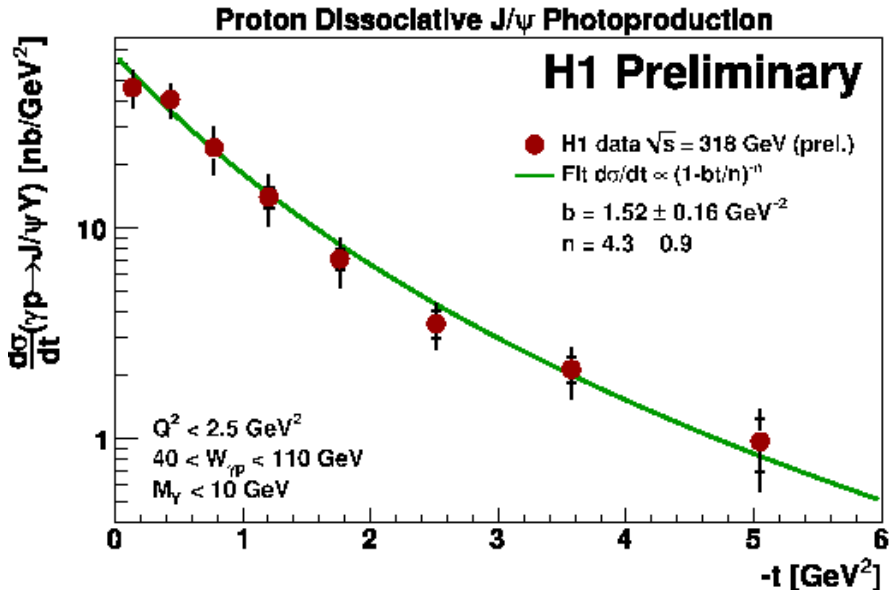
$b = 4.5 \pm 1.3 \pm 0.4$ GeV^{-2}
($Q^2 = 3.2$ GeV^2)

ZEUS: JHEP05(2009)108
H1: Phys.Lett.B659:796-806,2008

J/ψ - t dependence (new results)





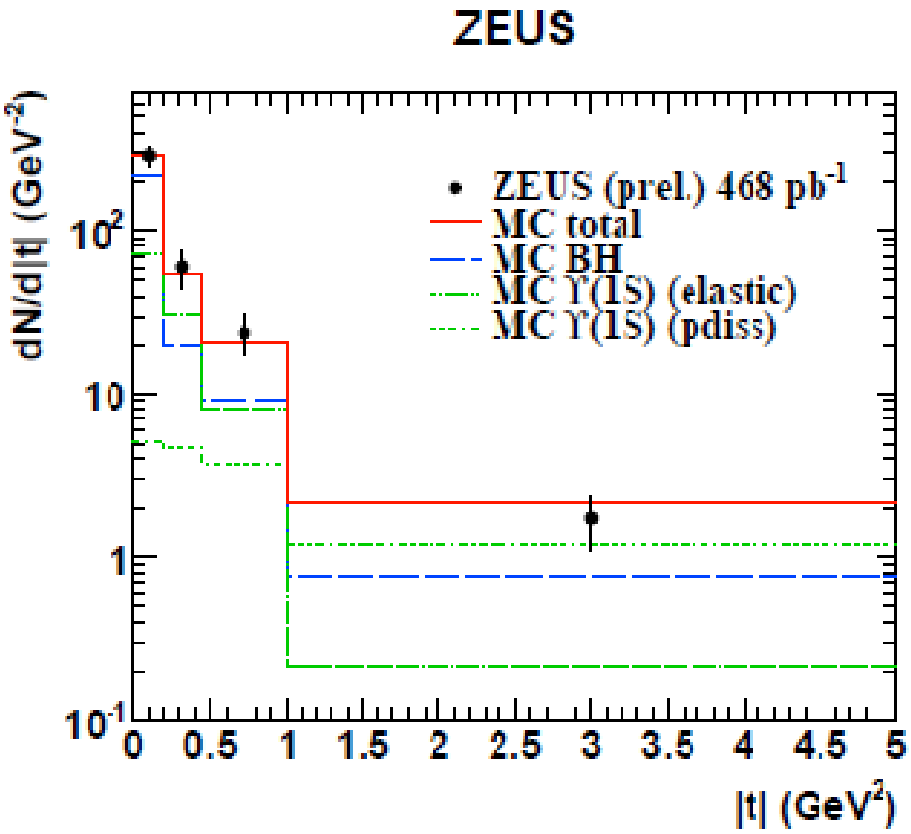


H1prelim-11-011

Small W dependence of b (elastic case)

$$\frac{d\sigma}{dt} \propto (1 + b/n|t|)^{-n}$$

Υ - t dependence (new result)



$Q^2 \leq 1\ GeV^2$
$60 \leq W \leq 220\ GeV$

Υ(1s) elastic PHP t-slope:

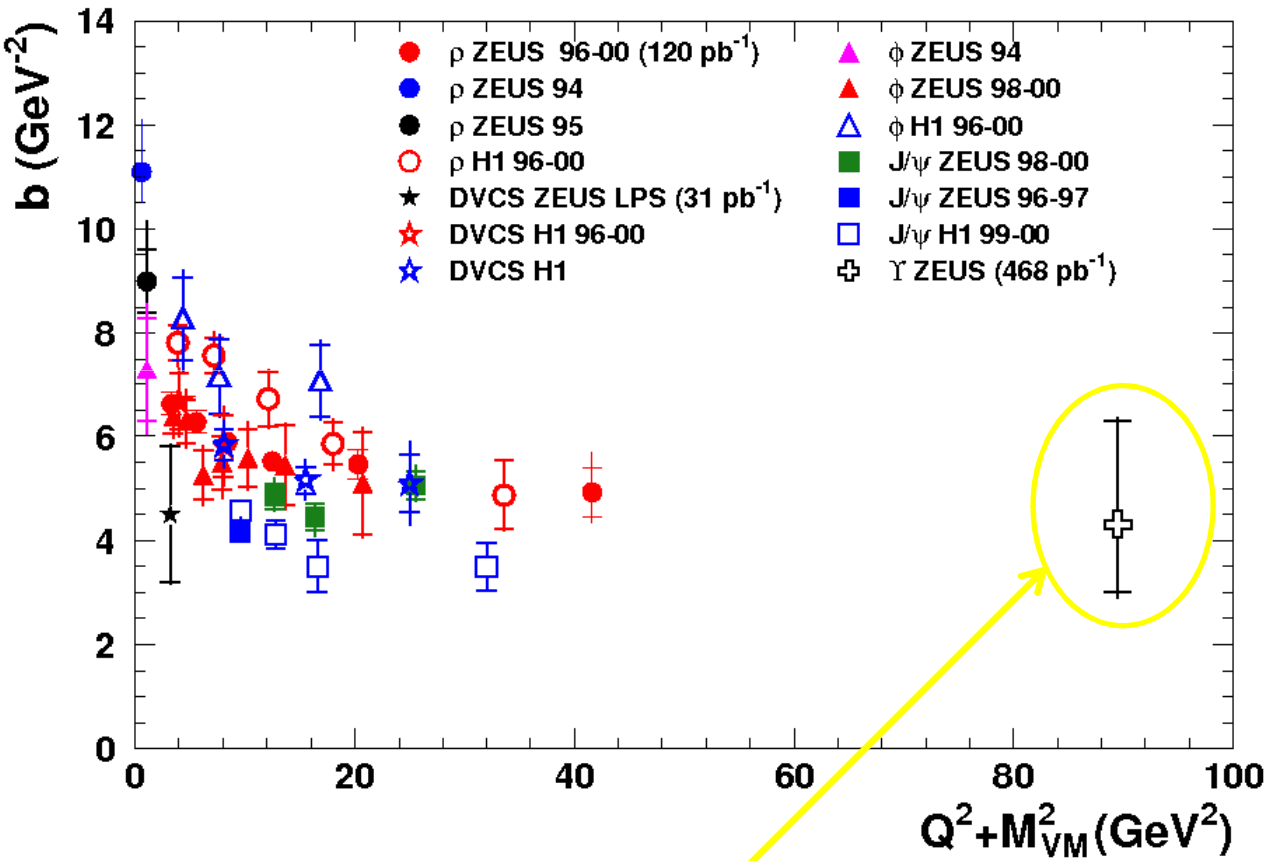
$$b = 4.3^{+1.7}_{-1.1} \pm 0.5 GeV^{-2}$$

Proton dissociation contribution dominates at high t

Submitted to Physics Letters B, ref. no. PLB-D-11-01630

t dependence

Similar slope for all VM vs scale

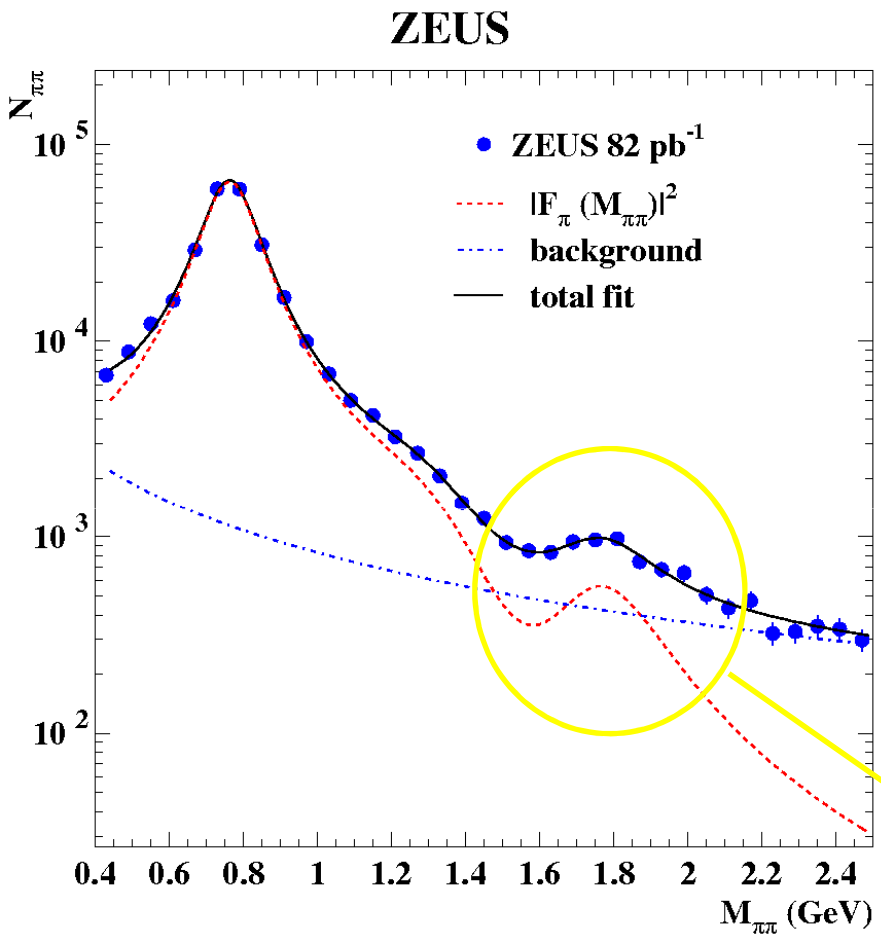


- b characterize the transversal size of interaction ($b=b_V+b_p$), large dipole for light VM, the size became smaller with scale, where:
  $b_V=1/(Q^2+M^2)$
  b_p~5 GeV^{-2}

- b decreases with increasing scale (from soft to hard)

Exclusive two pions production in DIS (new results)

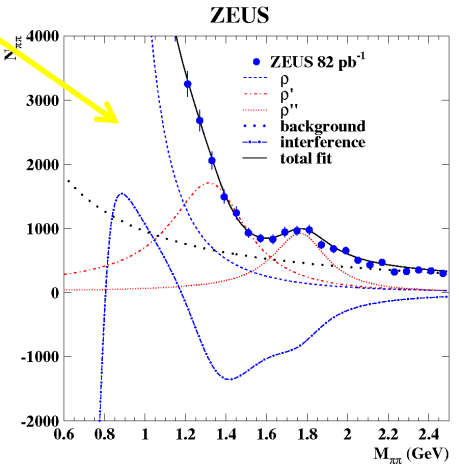
$0.4<M_{\pi\pi}<2.5$ GeV $2<Q^2<80$ GeV^2 $32<W<180$ GeV



Fit with 3 resonances: ρ, ρ', ρ''

- $\frac{dN(M_{\pi\pi})}{dM_{\pi\pi}} = N\left[|F_\pi(M_{\pi\pi})|^2 + \frac{B}{M^n_{\pi\pi}}\right]$
- $F_\pi(M_{\pi\pi}) = \frac{BW(\rho)+\beta BW(\rho')+\gamma BW(\rho'')}{1+\beta+\gamma}$

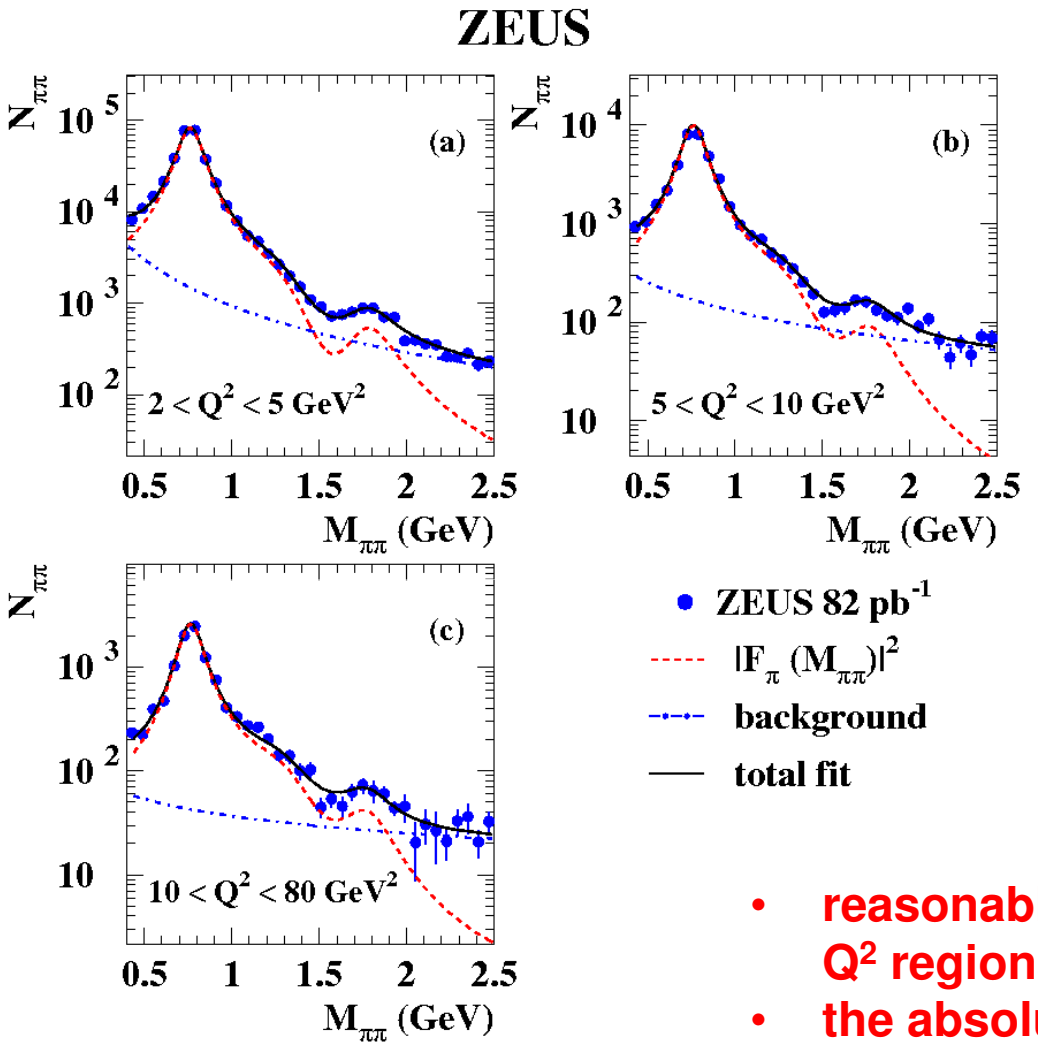
Parameter	ZEUS (prel.)	PDG
M_ρ (GeV)	$772 \pm 2^{+2}_{-1}$	775.49±0.34
Γ_ρ	$155 \pm 5 \pm 2$	149.4±1.0
β	$-0.27 \pm 0.02 \pm 0.02$	
$M_{\rho'}$ (GeV)	$1360 \pm 20^{+20}_{-30}$	1465±25
$\Gamma_{\rho'}$	$460 \pm 30^{+40}_{-45}$	400±60
γ	$0.10 \pm 0.02^{+0.02}_{-0.01}$	
$M_{\rho''}$ (GeV)	$1770 \pm 20^{+15}_{-20}$	1720±20
$\Gamma_{\rho''}$	$310 \pm 30^{+25}_{-35}$	250±100



Distribution well described by the pion form factor

DESY-11-220 (submitted to EPJC-11-11-054)

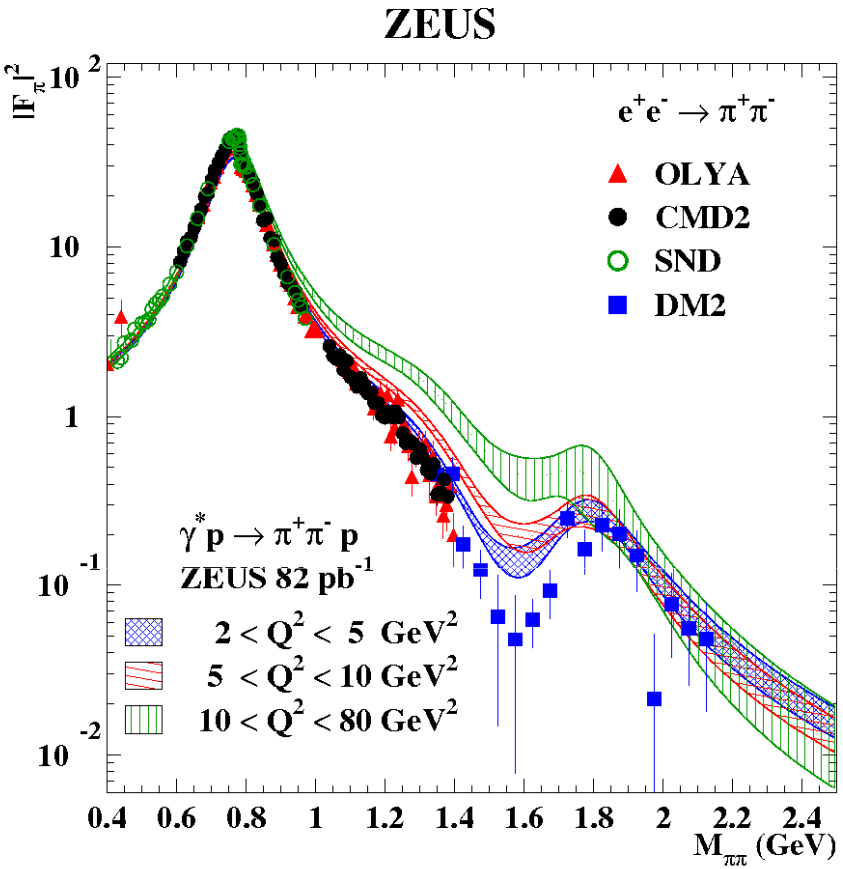
Exclusive two pions production in DIS (new results)



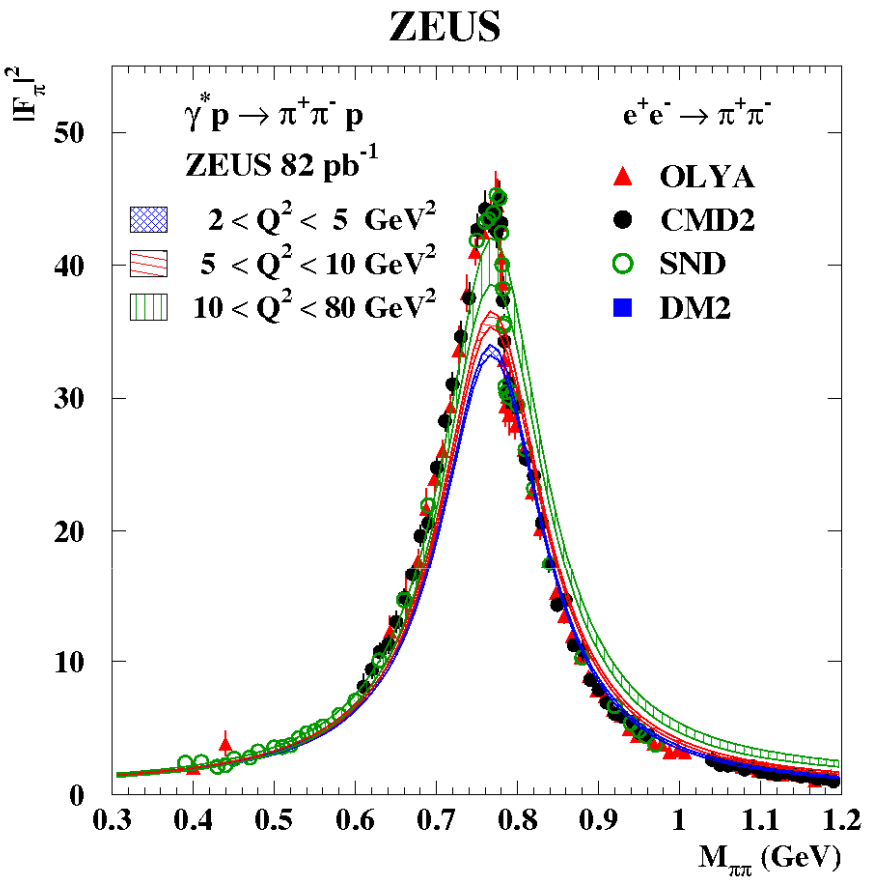
Three Q^2 bins:
the masses and the widths of the three resonances were fixed to the values found in overall fit.

- **reasonable description of data in three Q^2 regions**
- **the absolute value of β increases with Q^2**
- **γ is consistent with no Q^2 dependence within the uncertainties**

Exclusive two pions production in DIS (new results)



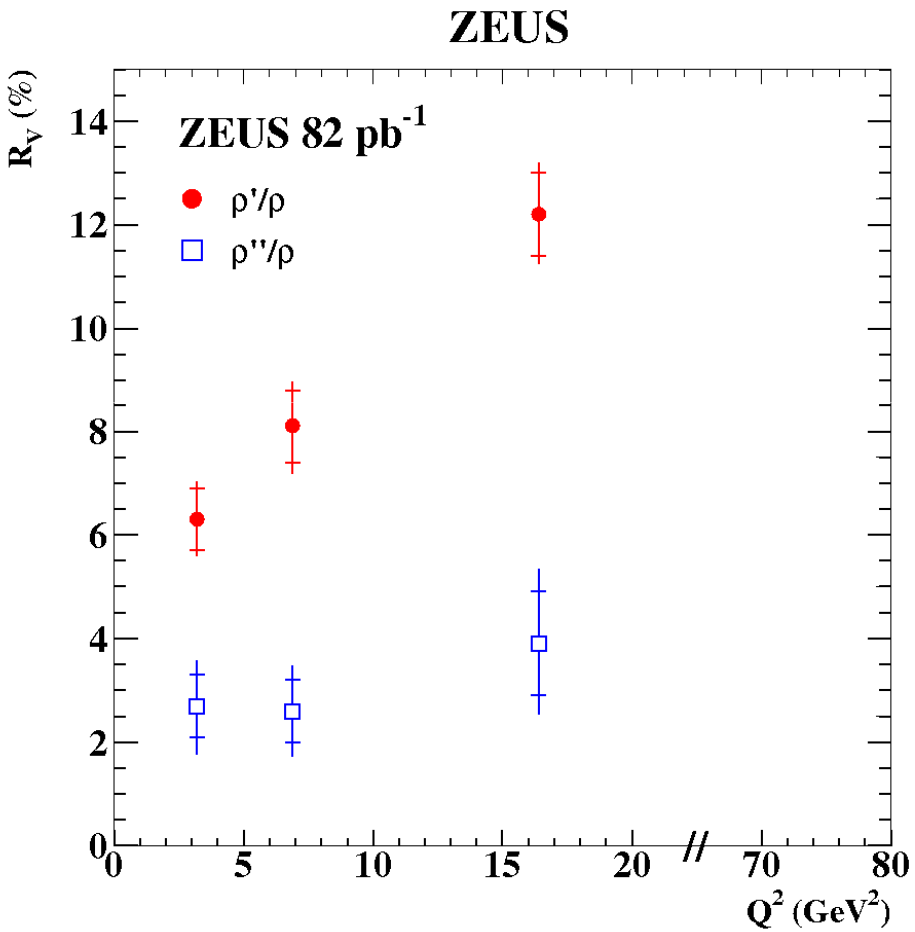
Data from various $e^+e^- \to \pi^+\pi^-$ measurements
Curves from this analysis



Region of the ρ peak

A Q^2 dependence of the pion f.f. is visible in particular in the interference region between ρ' and ρ''

Exclusive two pions production in DIS (new results)



Q^2 dependence:

ρ'/ρ increases strongly with Q^2 as expected in QCD-inspired models

Summary

- A large variety of VM and DVCS studied at HERA and new measurements are coming

- New exclusive measurements presented (two pions, J/Ψ and Υ)

- VM measurements allow the study the transition from the soft to the hard regime

- Effective Pomeron trajectory differs from "soft" Pomeron

HERA represents a powerful 'instrument' to understand diffraction in perturbative regime and to complete the mapping of the proton structure

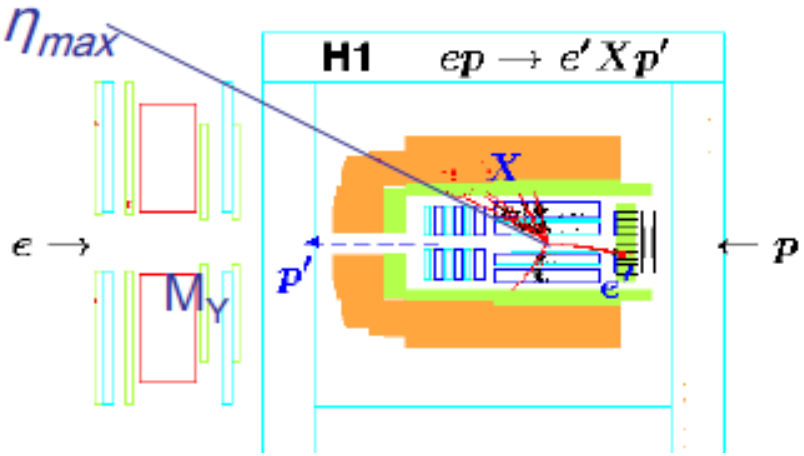
Backup

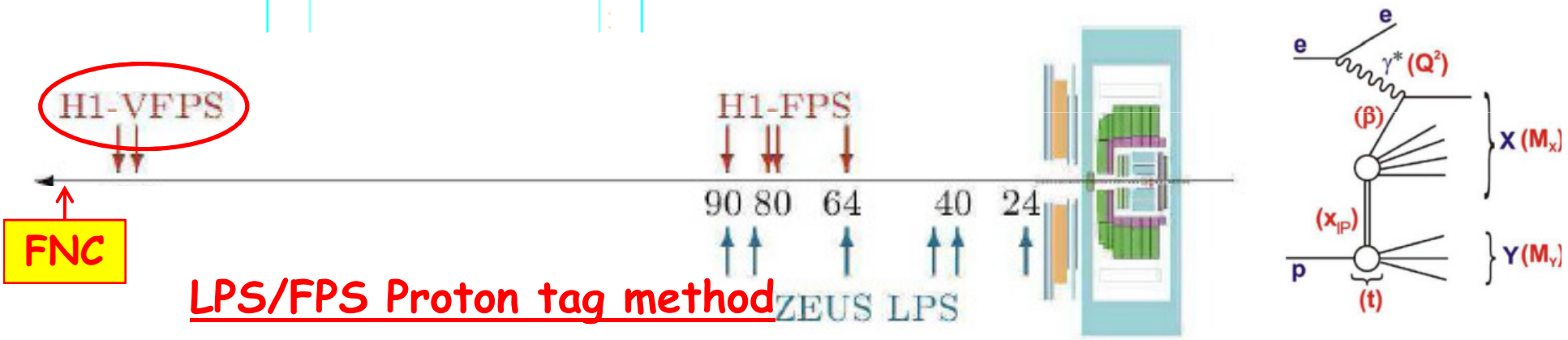
$\Psi(2S)/(J/\Psi)$
H1 Collab., Phys. Lett. B421 (1998) 385

Selection methods

LRG method

Large rapidity gap method (H1 and ZEUS):
→ No activity in the forward direction
High statistics, p-diss (~20%)
Measurements integrated over t

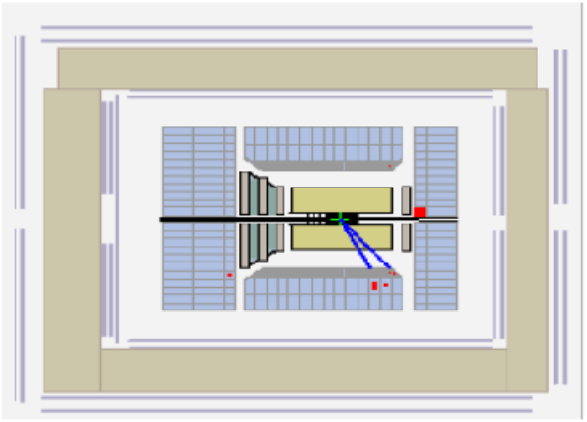




LPS/FPS Proton tag method

Dedicated detectors:
ZEUS-LPS for HERA I only
H1-FPS for HERA I and II
H1-VFPS for HERA II
Low statistics but no p-diss bkg and $M_Y=m_p$
Measurements of x_{IP} and t

Exclusive diffraction



Signature: VM decay particle and nothing else in the main detector!

Q^2 = γ* 4-momentum squared = $-q^2 = -(e-e')^2$

W = γ*-proton centre of mass energy = $(p+q)^2$

t = squared 4-momentum transfer at proton vertex = $(p-p')^2$