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Diffractive Vector Meson Production at HERA

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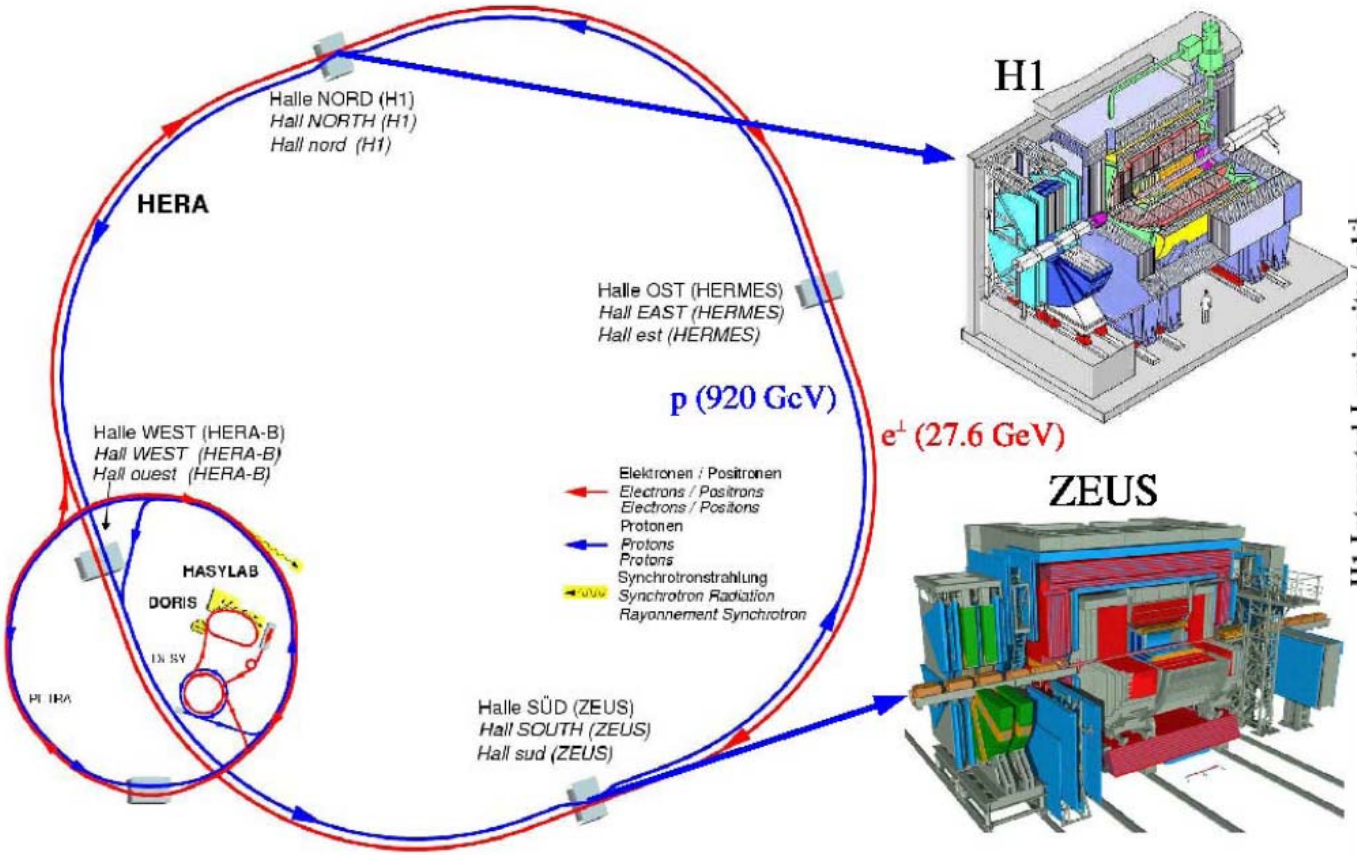
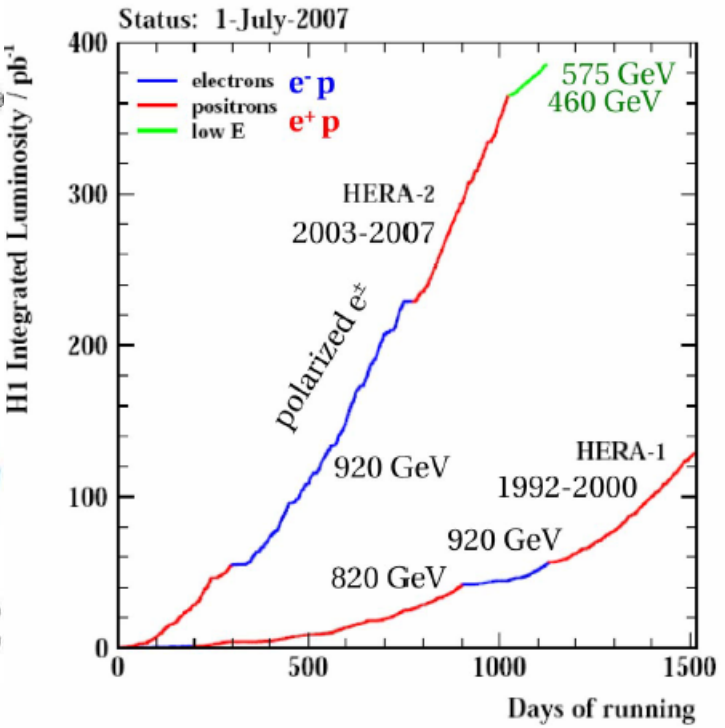
On behalf of the H1 and ZEUS Collaborations

- Introduction
- Diffractive J/ψ photoporoduction [H1 Coll., *arXiv:1304.5162*]
- |t| dependence of exclusive ϒ(1S) photoproduction [ZEUS Coll., *PLB 708 (2012) 14*]
- Pion from factor from exclusive di-pion electroproduction [ZEUS Coll., *EPJC 72 (2012) 1869*]

HERA

The world's only electron/positron-proton collider at DESY, Hamburg
E_e = 27.6 GeV E_p = 920 GeV (also 820, 460 and 575 GeV)
(total centre-of-mass energy of collision up to $\sqrt{s} \approx 320$ GeV)

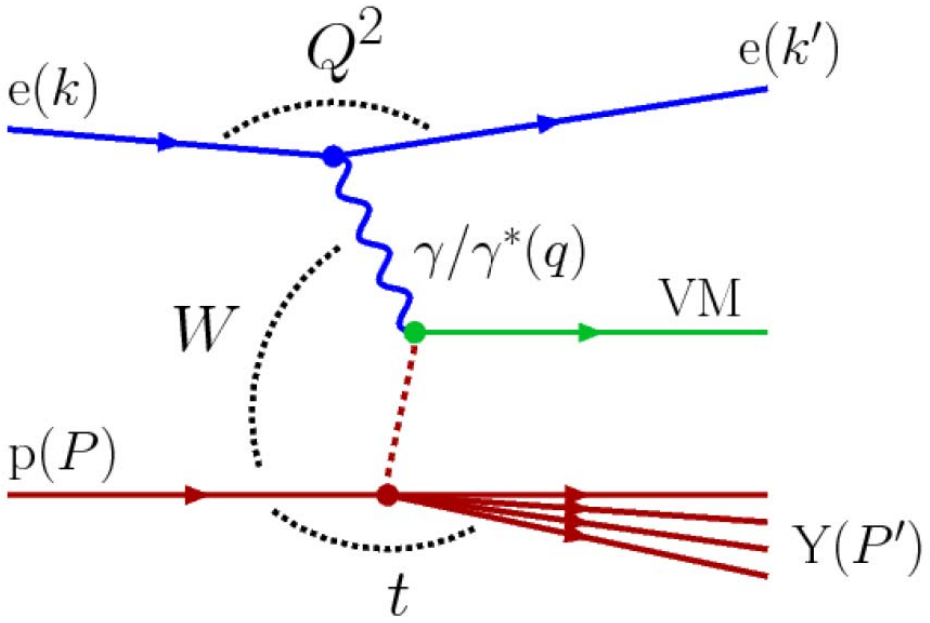




Two collider experiments: H1 and ZEUS

HERA-1: 1992 - 2000
HERA-2: 2003 - 2007
total lumi: 0.5 fb^{-1} per experiment

Introduction



V=(ρ, ω, ϕ, J/ψ, ψ′,ϒ, γ)

- no quantum numbers exchanged in the interaction
- the proton stays intact or dissociates

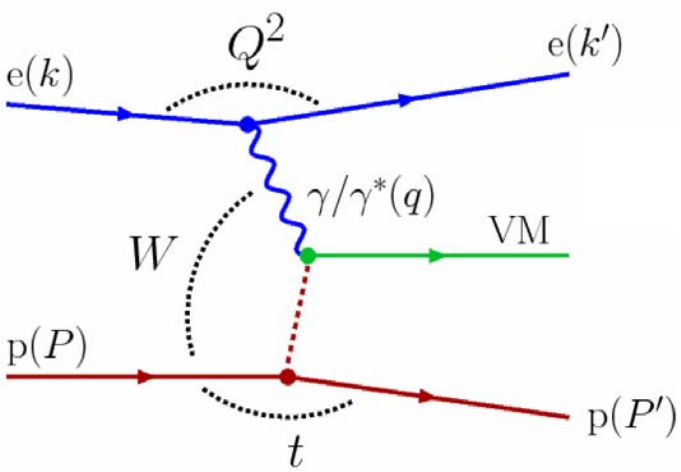
- $Q^2=-(k-k')^2$ - photon virtuality:
  $Q^2 \sim 0$ → 'photoproduction'
  $Q^2 > 0$ → Deep Inelastic Scattering (DIS)

- W - γ*p center of mass energy

- $t=(P-P')^2$ -momentum transfer squared at the proton vertex

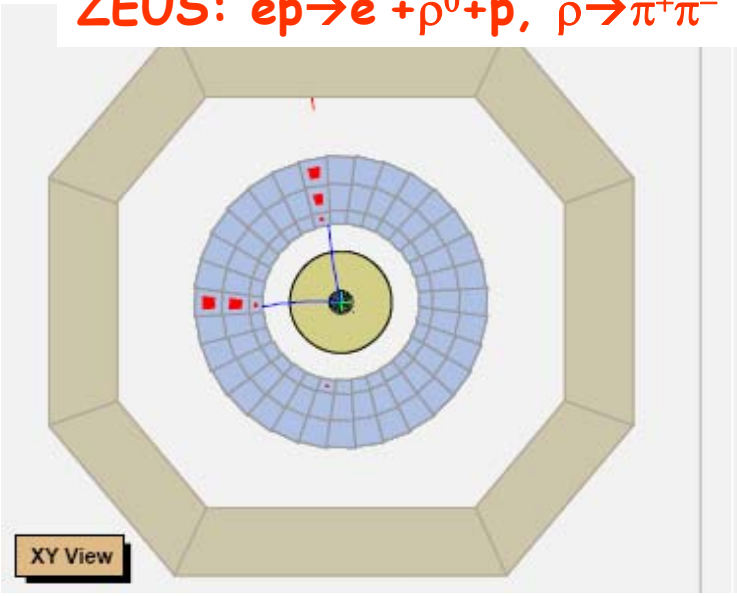
Introduction

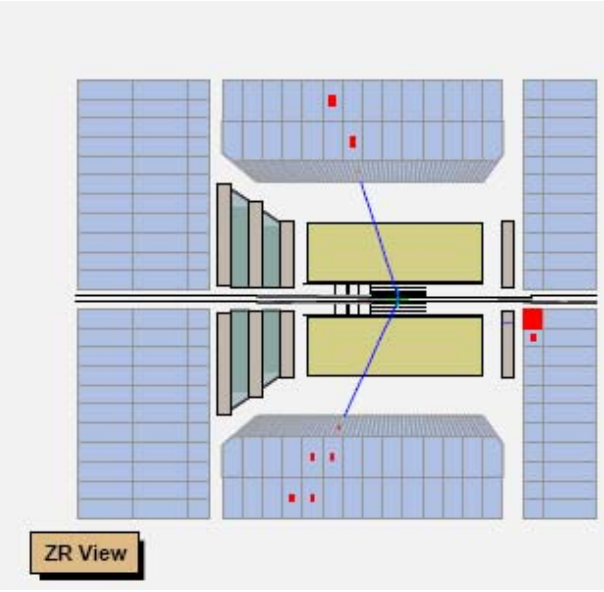
Exclusive Vector Meson production – clean experimental signatures



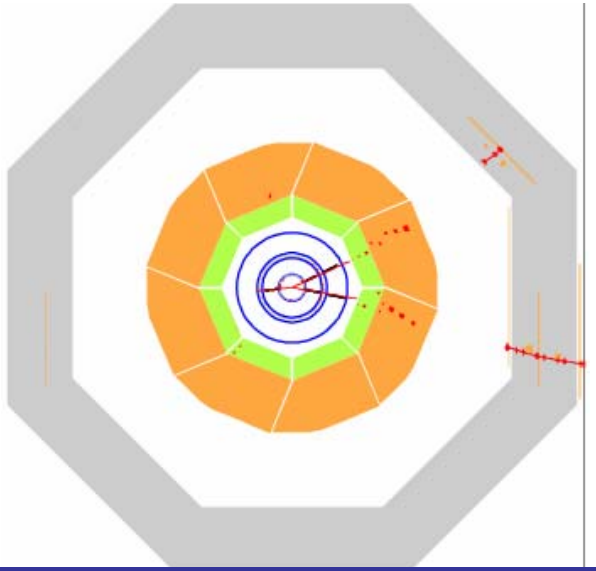
- scattered e± reconstructed in e/m calorimeters (DIS) or undetected (photoproduction)
- scattered p undetected
- decay products of VM
- nothing else in the central detector

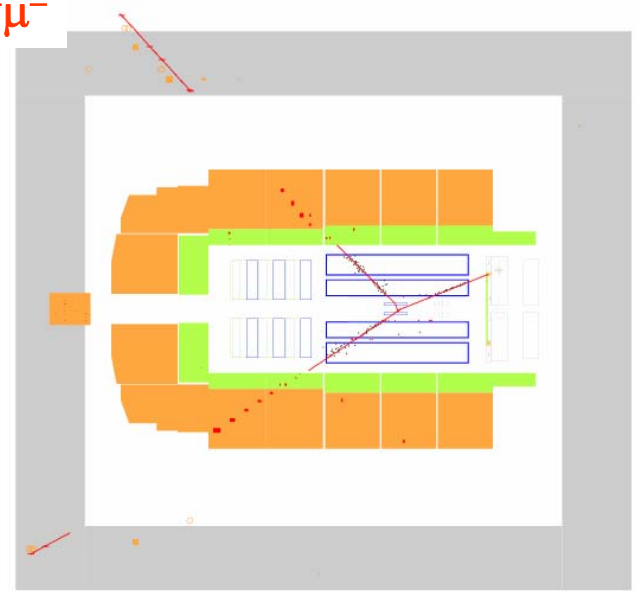
ZEUS: ep→e'+ρ^0+p, $\rho\rightarrow\pi^+\pi^-$



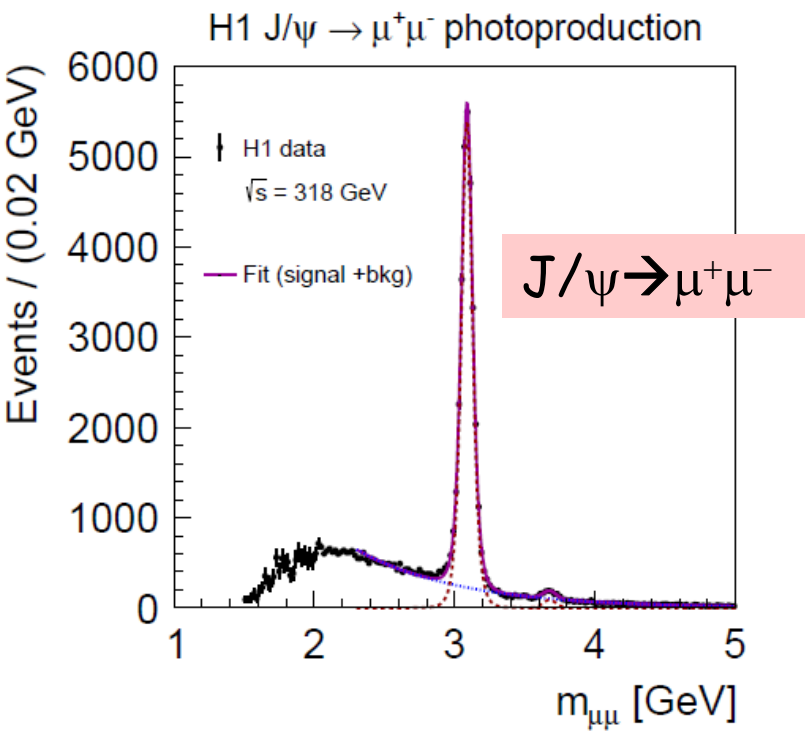


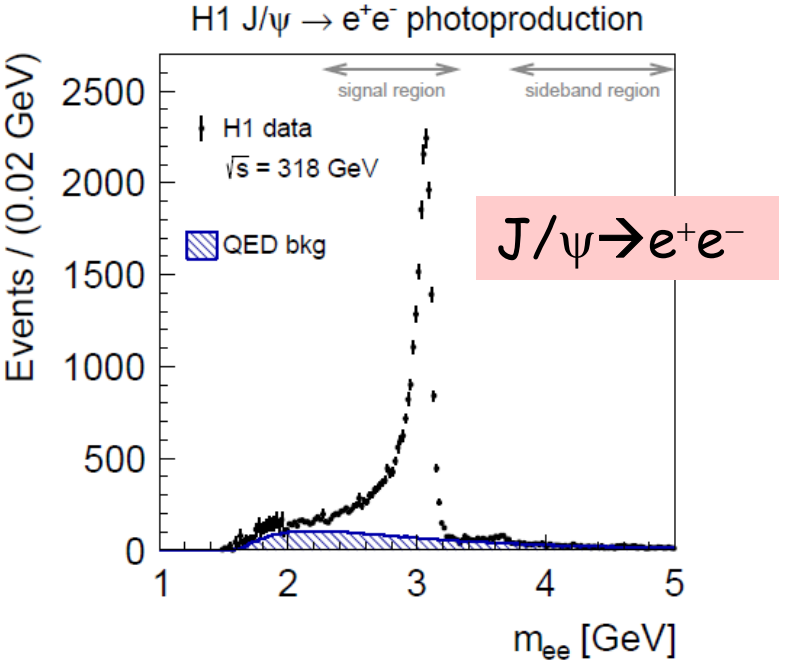
H1: ep→e'+J/Ψ+p, J/Ψ→$\mu^+\mu^-$

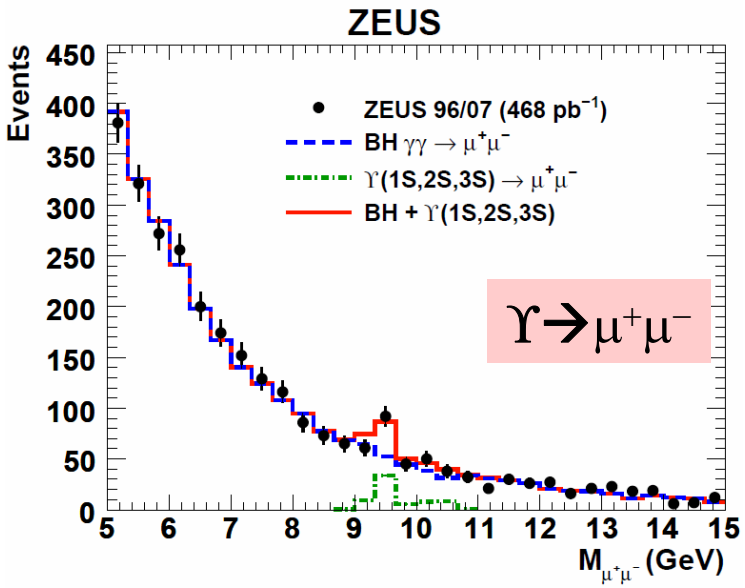


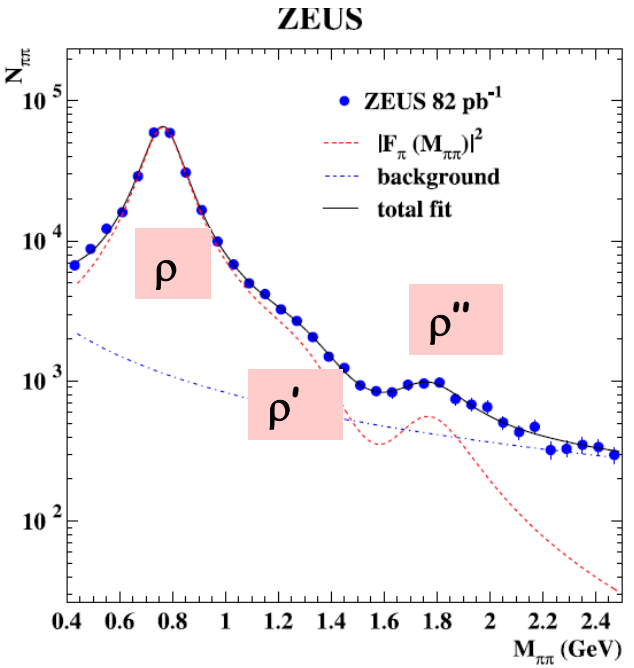


Vector Mesons mass distributions



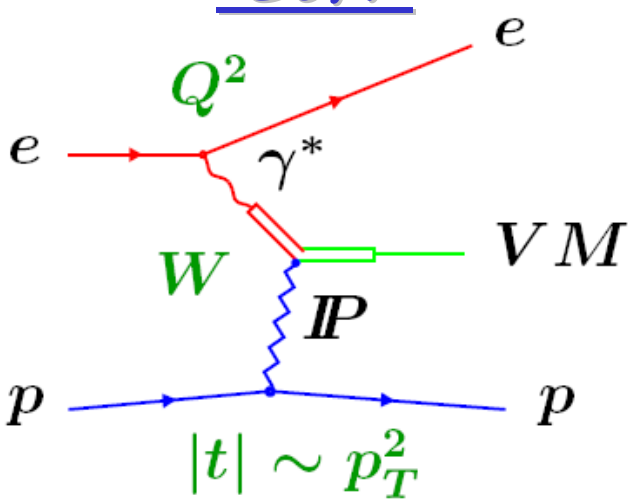






Description of diffractive Vector Meson production

"Soft"



Regge theory and VDM model

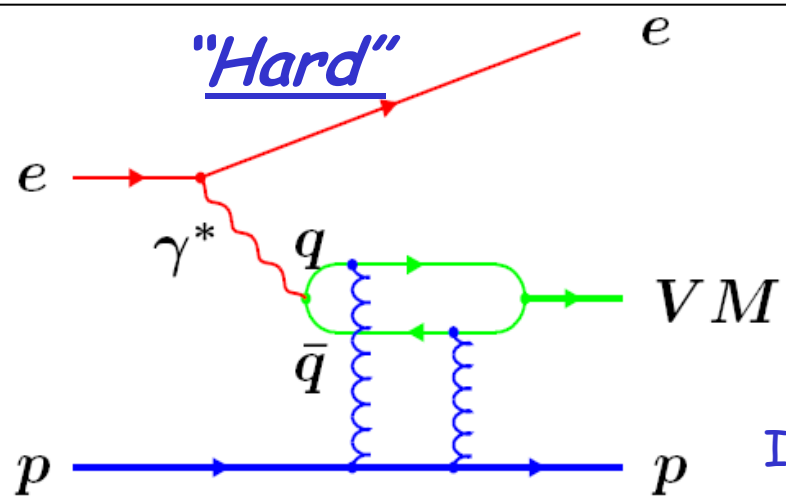
$\sigma \propto W^{\delta}$ -Weak energy dependence, δ~0.2

$\delta = 4(\alpha_{IP}(t) - 1)$ $\alpha_{IP}(t)=1.08+0.25 \cdot t$ (DL)

$\frac{d\sigma}{dt} \propto e^{-bt}$ -Shrinkage of diffractive peak

$$b(W) = b_0 + 4\,\alpha' ln\left(\frac{W}{W_0}\right); \quad b_0 \sim 10\ GeV^{-2}$$

"Hard"



in presence of hard scale: Q^2, M_{VM} or t

pQCD description (exchange of ≥2 gluons)

-Fast increase of cross section with energy due to gluon density in proton

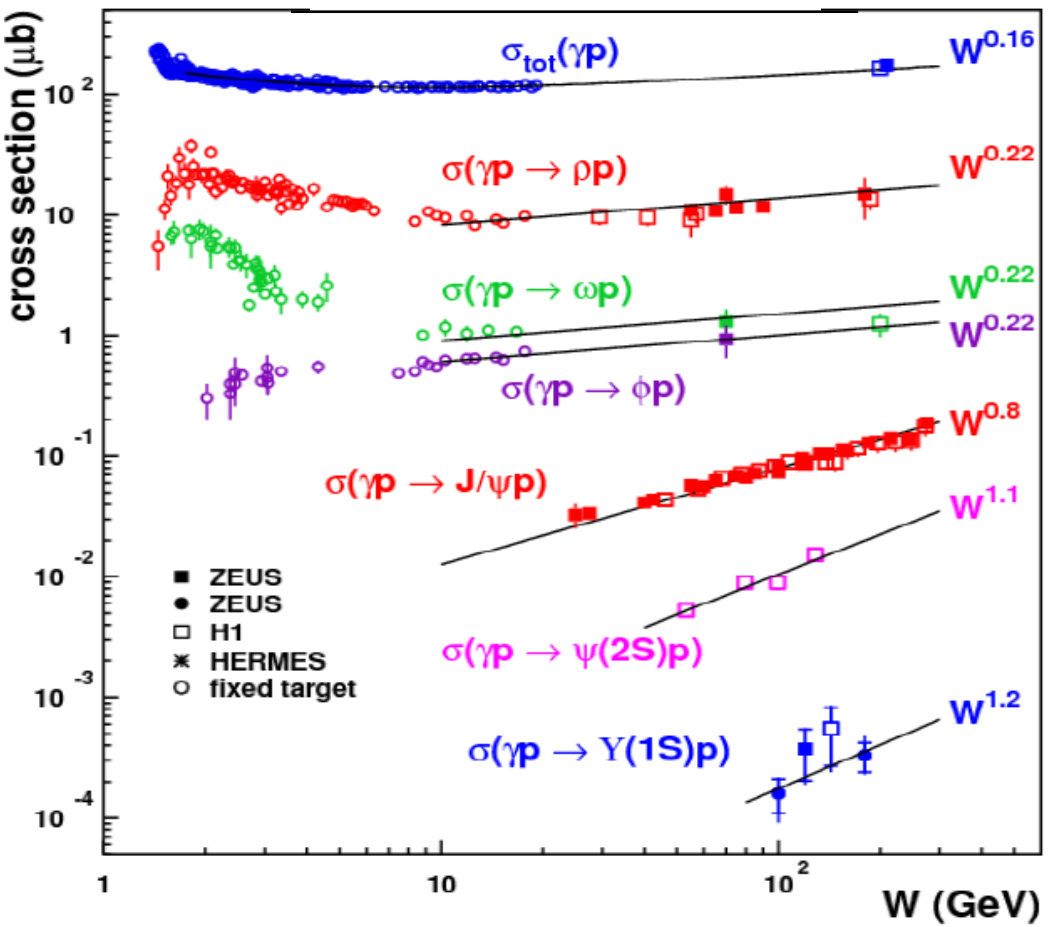
$$\sigma \sim \left| x\ g(x,Q^2) \right|^2$$

Increasing *W* corresponds to going to small *x* $W^2 \propto \frac{1}{x}$

- Expect δ to increase from 'soft' (~0.2) to 'hard' (~0.8)
- Expect b to decrease from 'soft' (~10 GeV^{-2}) to 'hard' (~4÷5 GeV^{-2})

With HERA data it is possible to investigate the transition from "soft" to "hard" pomeron exchange processes with increasing of Q^2, M_{VM} or *t*.

Elastic photoproduction of Vector Mesons $\gamma p \rightarrow VM+p$ ($V=\rho,\phi,\omega,J/\psi,\psi',\Upsilon$)



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

Low mass (ρ, ω, ϕ) – no perturbative scale
→ weak energy dependence

High mass (J/ψ, ψ', Υ)– perturbative scale
→ strong energy dependence

VM mass sets the hard scale of interaction

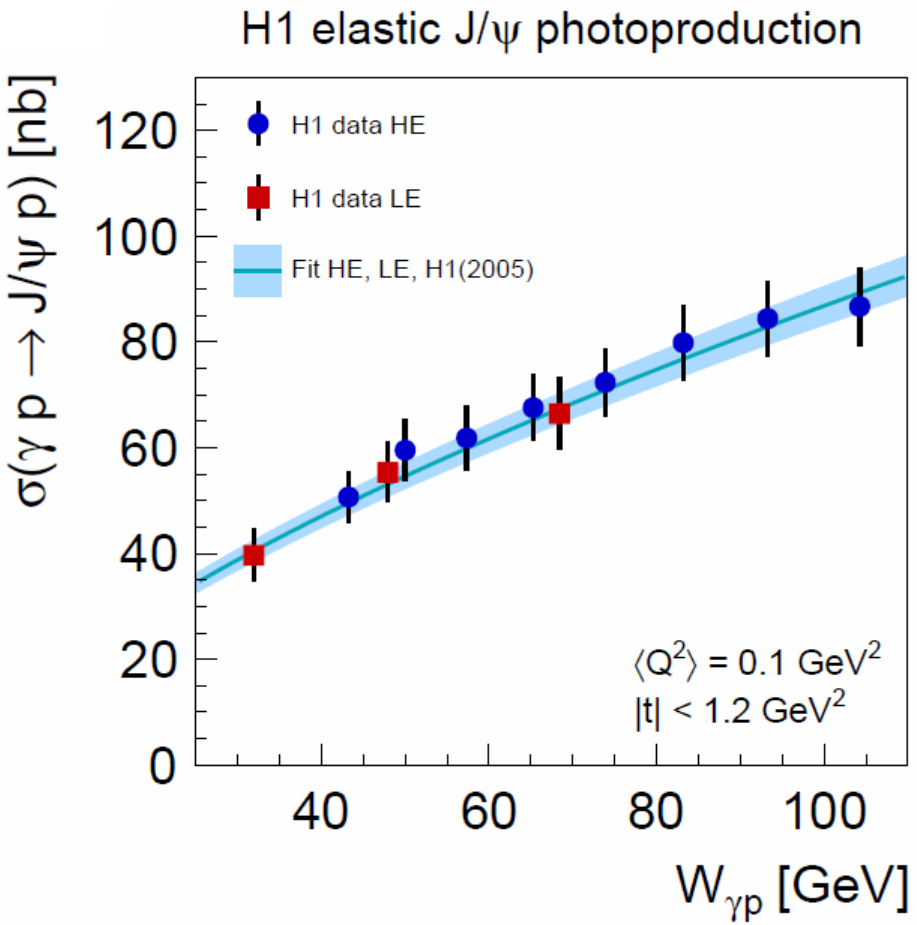
Process becomes hard (steeper W dependence) as M_{VM} becomes larger (J/ψ, ψ', Υ)

Elastic J/ψ photoproduciton cross Sections vs $W_{\gamma p}$

New H1 measurement: extension to lower $W_{\gamma p}$: two energy ranges

HE ($W_{\gamma p}$=40-110 GeV, $\sqrt{s}$=318 GeV) and **LE** ($W_{\gamma p}$=25-80 GeV, $\sqrt{s}$=225 GeV)

arXiv:1304.5162

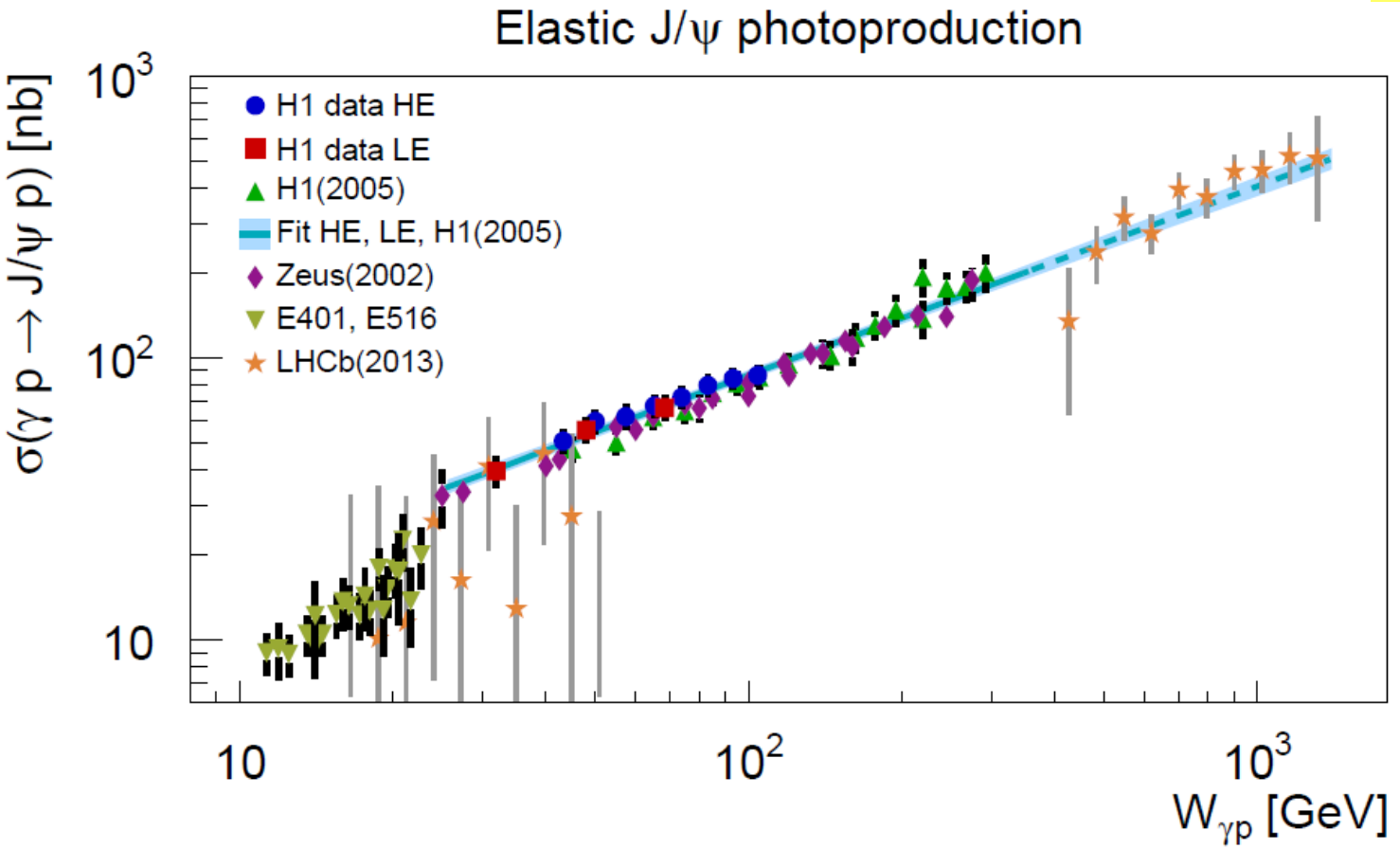


Fit function $\sigma \sim W_{\gamma p}^{\delta_{el}}$

δ_{el}=0.67 ± 0.03

HERA data in comparison with fixed target and LHCb data

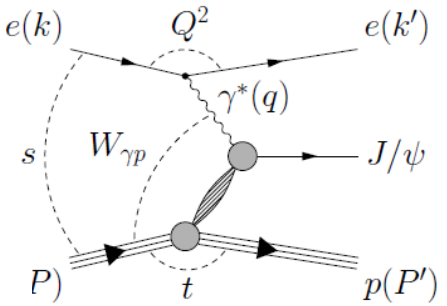
arXiv:1304.5162



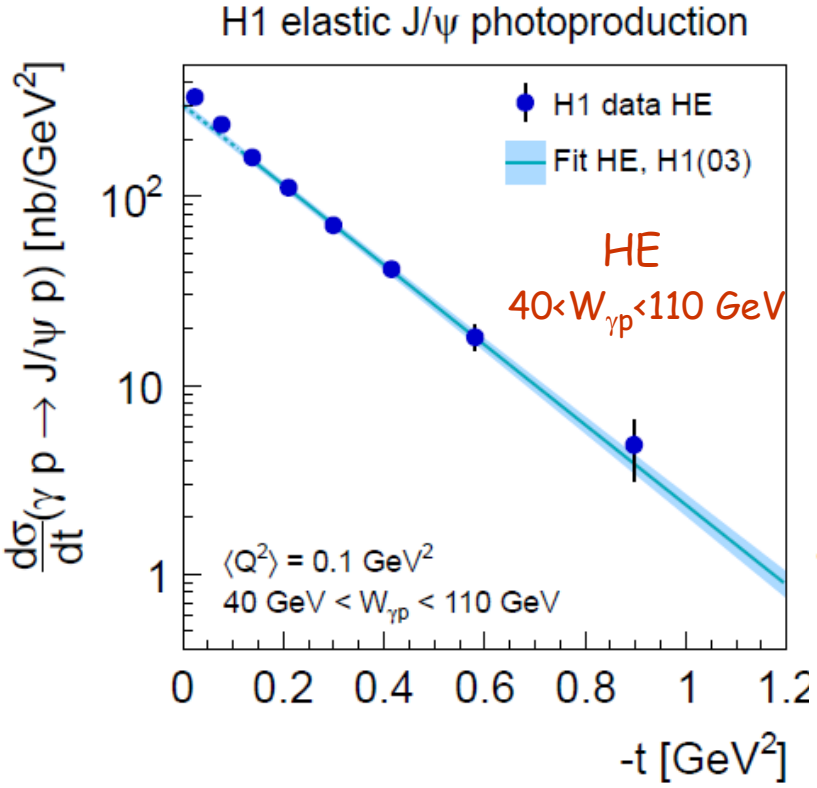
- New measurements in the transition region from fixed target to previous HERA data
- Good agreement with previous HERA measurements
- Fixed target data: steeper slope, lower normalisation
- Fit to H1 data extrapolated to higher $W_{\gamma p}$ describes the LHCb data

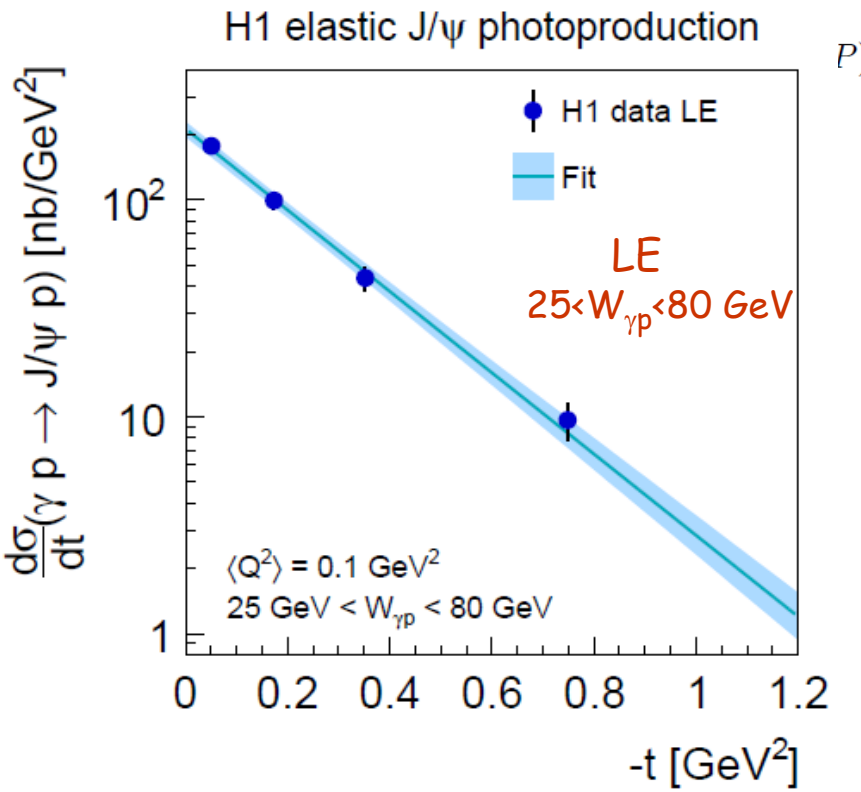
Elastic J/ψ Cross Sections vs t ; b-slope

arXiv:1304.5162



t –momentum transfer squared at the proton vertex





$$\frac{d\sigma}{dt} \sim e^{-b_{el}|t|}$$

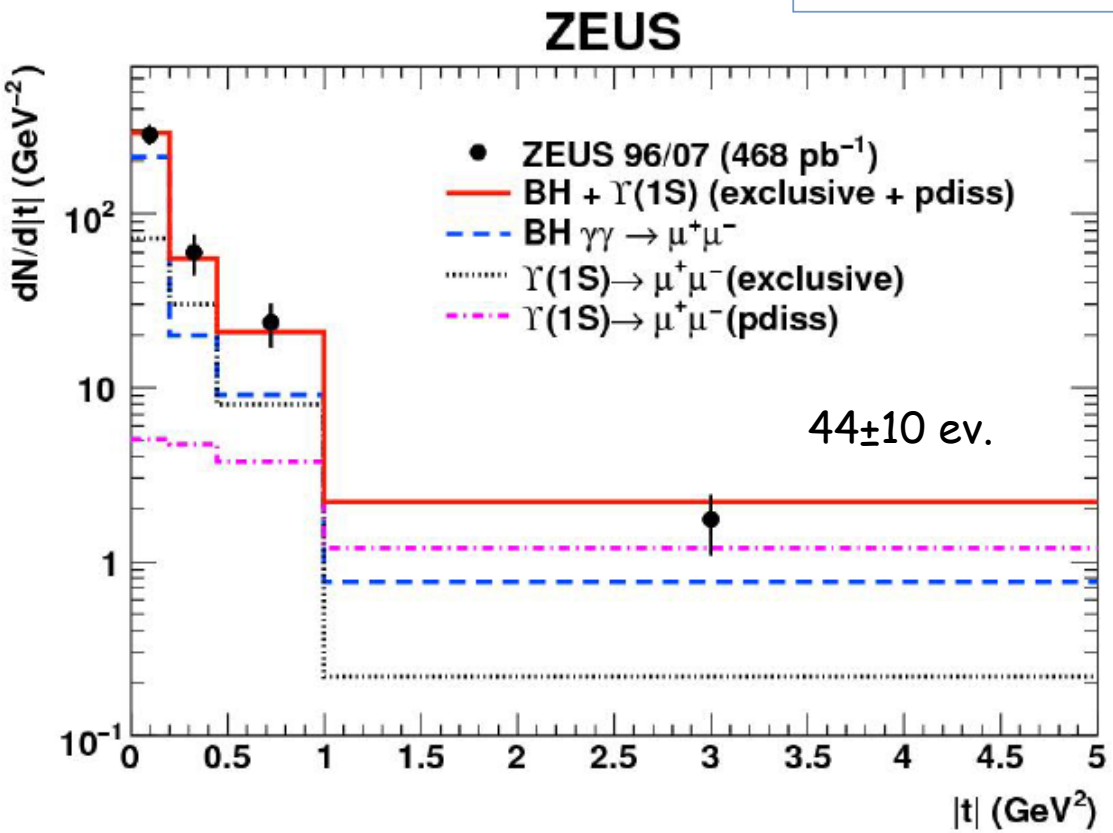
b_{el}= 4.88 ± 0.15 GeV² (HE)

b_{el}= 4.3 ± 0.2 GeV² (LE)

Elastic $\Upsilon(1s)$ in photoproduction: b-slope

Phys.Lett.B 708 (2012) 14

$\mathcal{L}$=468 pb^{-1}
$Q^2 < 1\ GeV^2$
$60 < W < 220\ GeV$



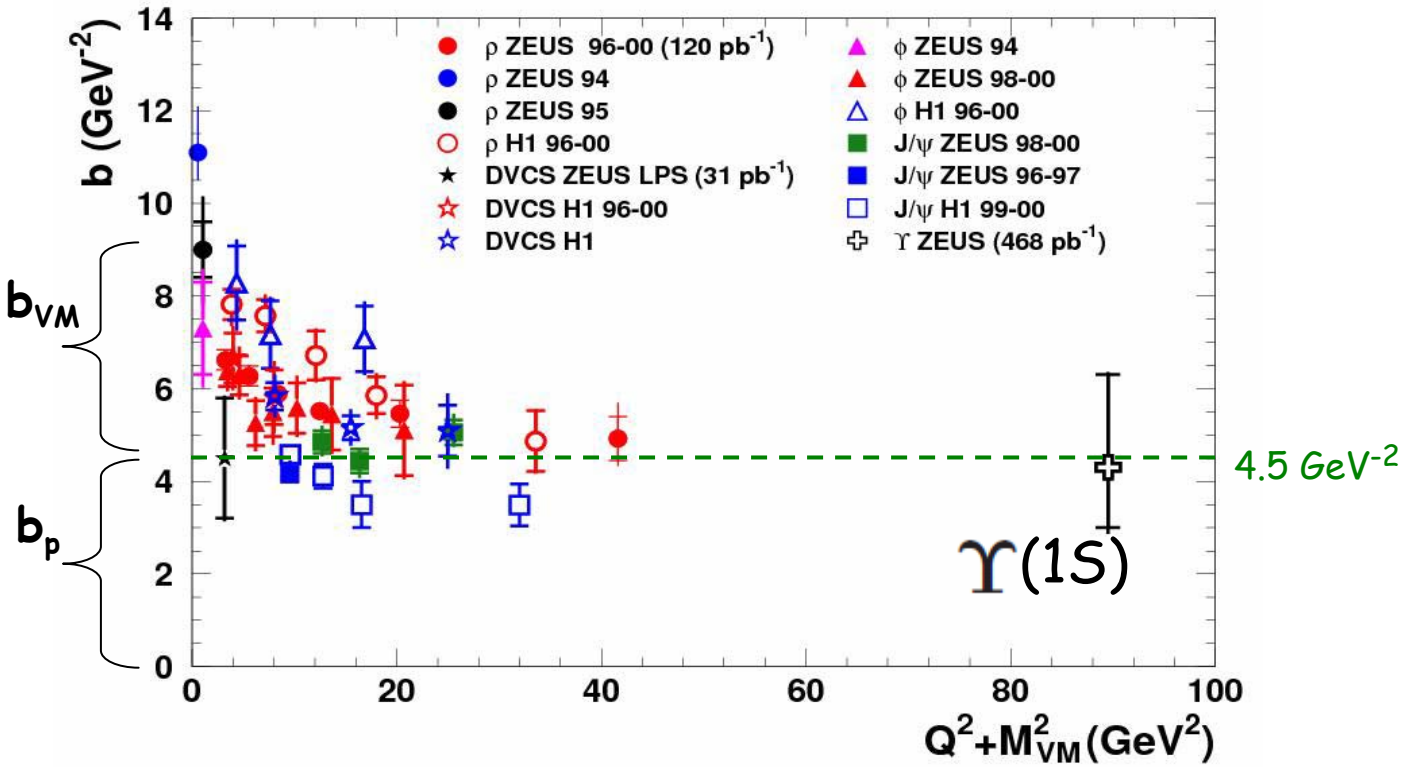
$$\frac{d\sigma}{dt} \sim e^{-b|t|}$$

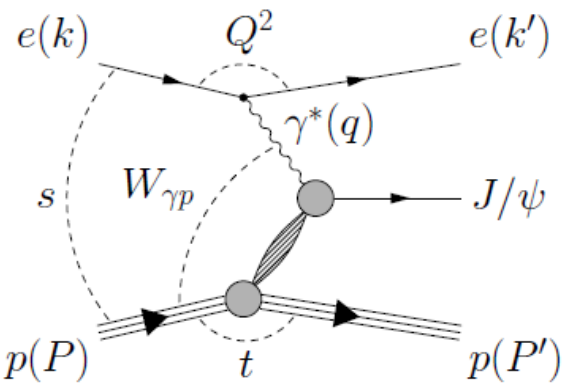
$$b = 4.3\ ^{+2.0}_{-1.3}\ (stat.)\ ^{+0.5}_{-0.6}\ (syst.)\ GeV^{-2}$$

First determination of b slope for Υ (1S)

VM production and DVCS: t-slope $b(Q^2+M^2)$

Phys.Lett.B 708 (2012) 14





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

Asymptotic behaviour of the slope parameter *b* with effective scale $Q^2+M_V^2$

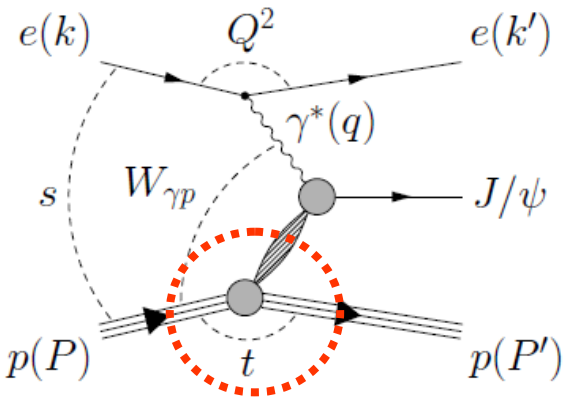
- ***b*** characterizes the size of interaction ($b=b_{VM}+b_p$), expect ***b*** to decrease from 'soft' to 'hard'
- ***b*** decreases with Q^2+M^2 from ~10 GeV^{-2} (soft process) to ~4.5 GeV^{-2} (hard process)

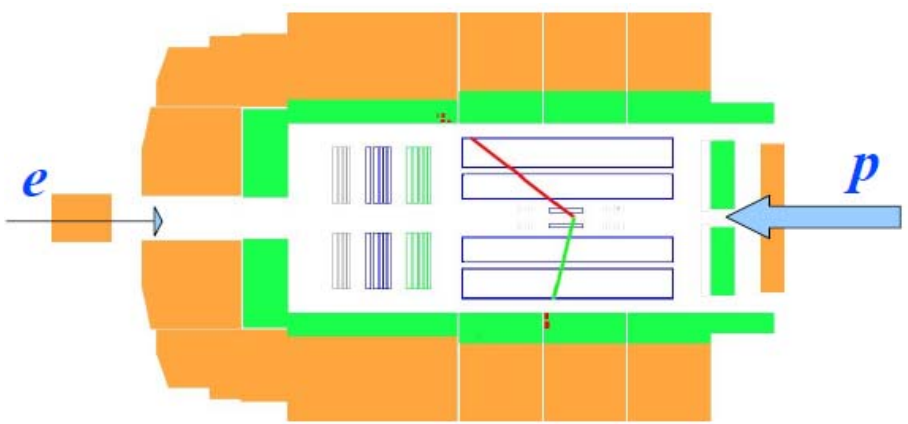
➔size of scattered VM getting smaller with Q^2+M^2

Elastic vs proton dissociative J/ψ photoproduction

What happens at the proton vertex ?

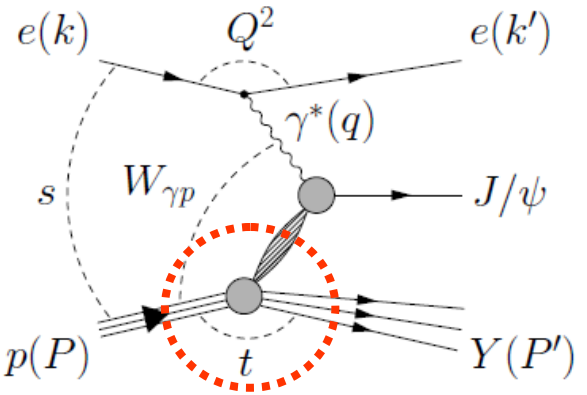
Elastic process ep→e J/ψ p

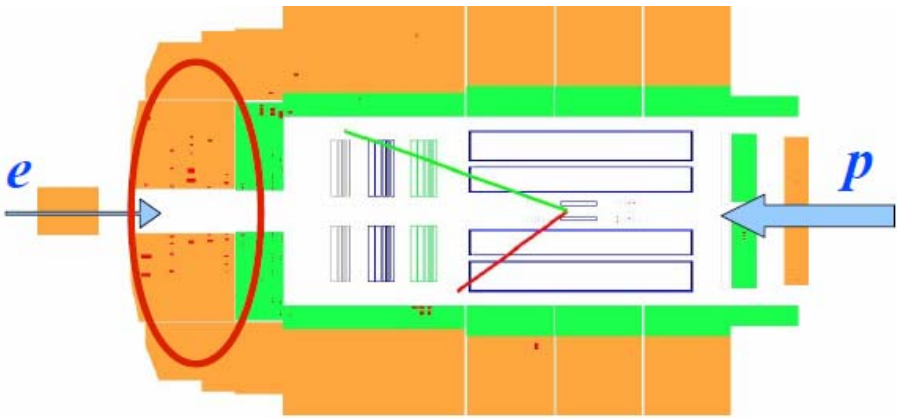




$M_Y = m_p$

Proton dissociation process ep→e J/ψ Y



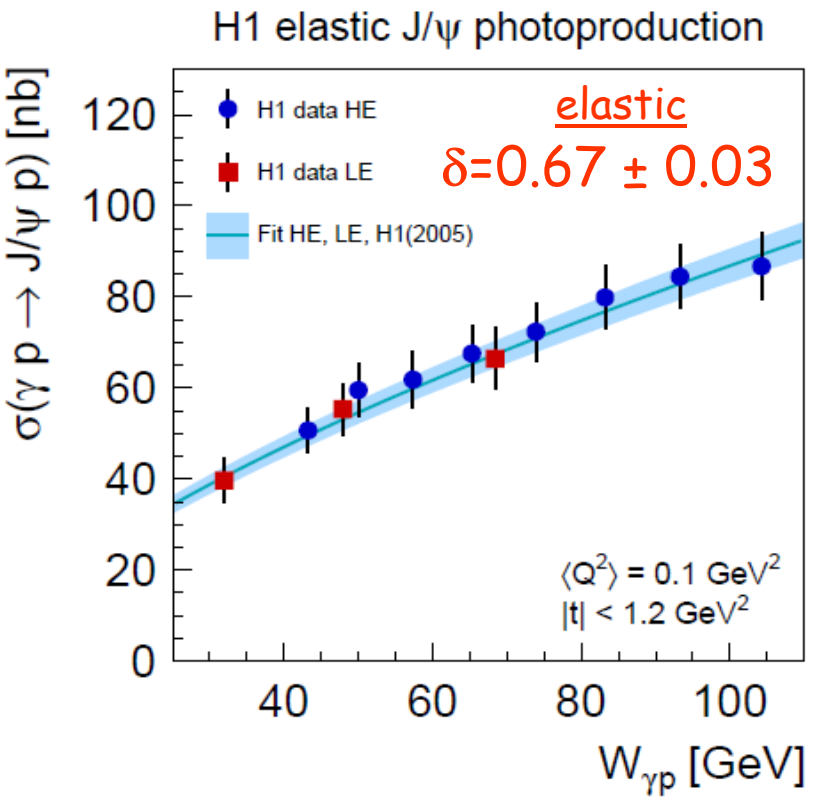


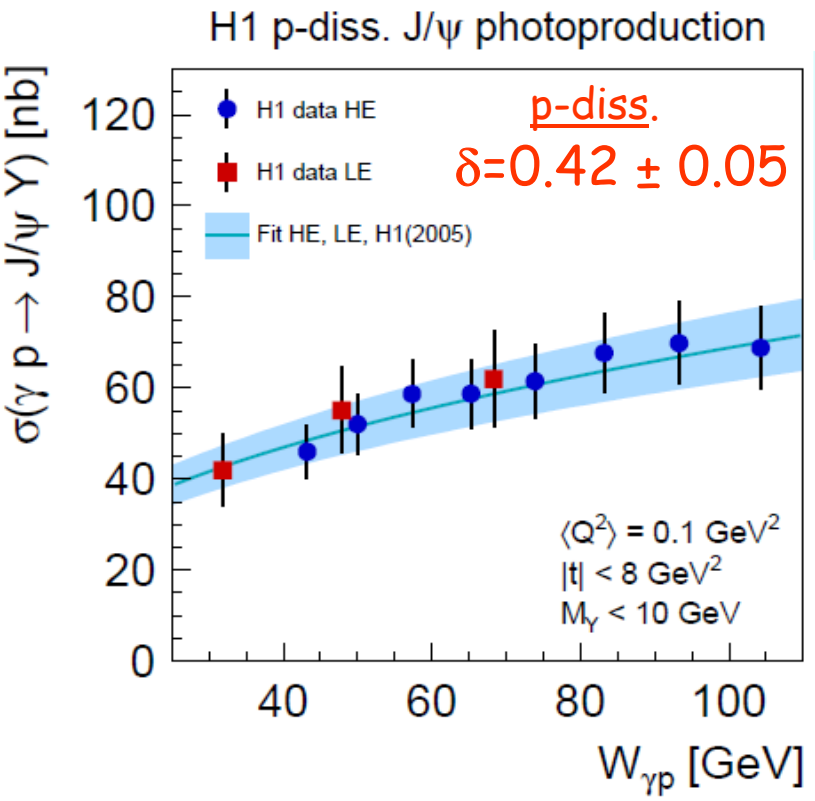
$m_p < M_Y < 10\,GeV$

Elastic and p-dissociation Cross Sections vs $W_{\gamma p}$

arXiv:1304.5162

Elastic and proton-dissociation cross sections measured simultaneously using Regularised Unfolding





$$\sigma = N\left(\frac{W_{\gamma p}}{W_0}\right)^{\delta}$$

W_0= 90 GeV

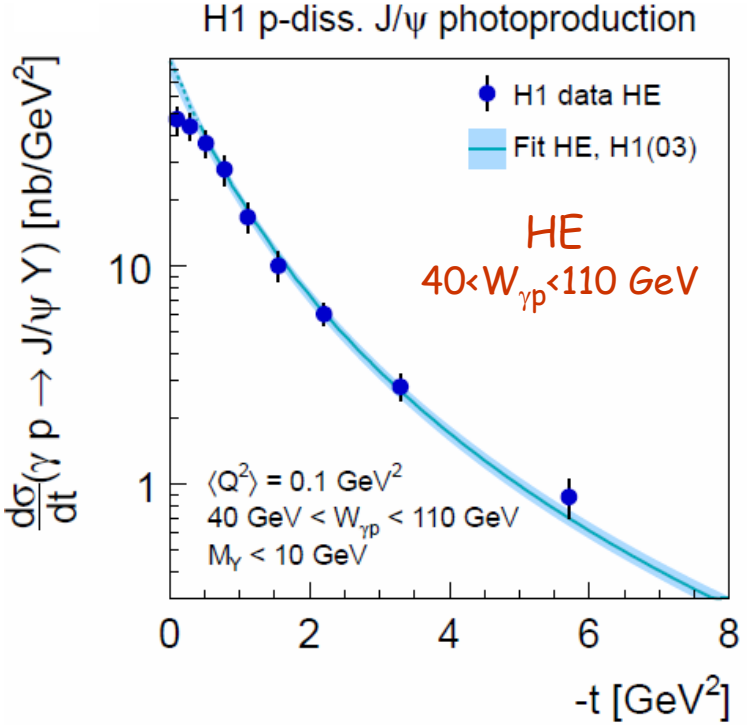
- Simultaneous fit, taking into account correlations between elastic and p-diss. cross sections

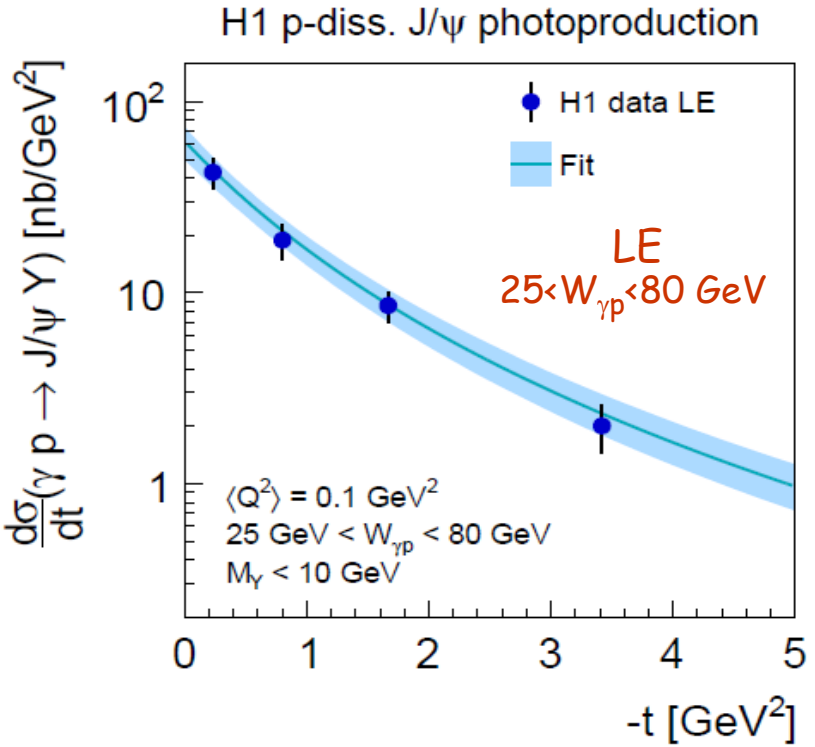
N_{pd}/N_{el} =0.81 ± 0.10 $\delta_{pd}-\delta_{el}$ = -0.25 ± 0.06

- Ratio σ_{pd}/σ_{el} slowly decreasing with $W_{\gamma p}$

Proton dissociative J/ψ Cross Sections vs t ; b-slope

arXiv:1304.5162





$$\frac{d\sigma}{dt} = N_{pd}\left(1+\frac{b_{pd}}{n}|t|\right)^{-n}$$

b_{pd}= 1.79 ± 0.12 GeV² (HE)

b_{pd}= 1.6 ± 0.2 GeV² (LE)

(→to be compared to b_{el}= 4.88 ± 0.15 GeV²)

b_{pd} is significantly lower than b_{el}

(b is related to the transverse size of interaction:
for p-diss. proton breaks → b_{pd} is smaller then b_{el})

Pion Form Factor from Exclusive Dipion Production $\gamma^* p \to \pi^+\pi^- p$

Eur.Phys.J.C 72 (2012) 1869

The two-pion invariant-mass distribution
- is related to the pion electromagnetic form factor
- includes the contributions of ρ, ρ′ (radially excited 2S state) and ρ″ (orbitally excited 2D state) vector mesons

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

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

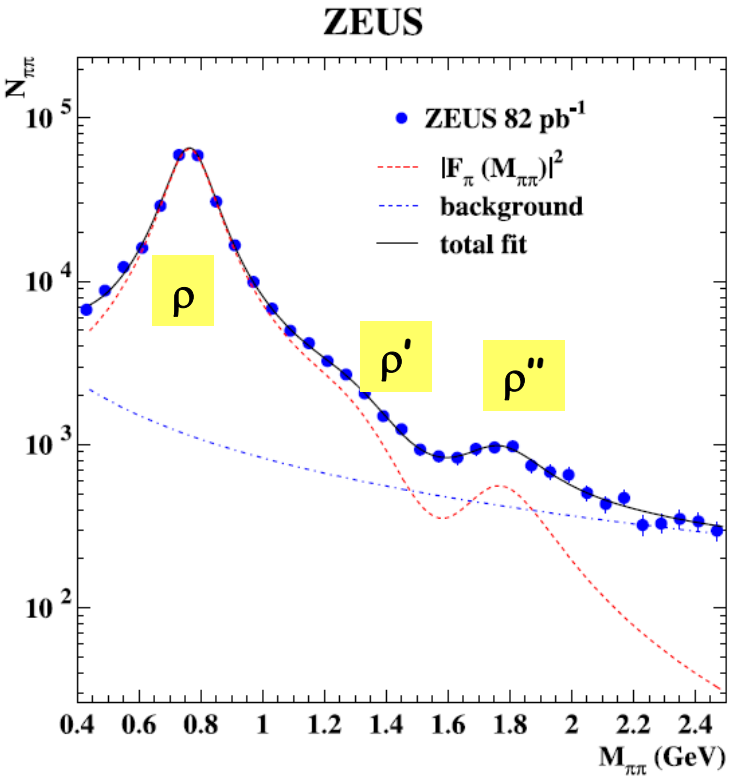
Kuhn-Santamaria parameterisation
For $M_{\pi\pi}$<2.5 GeV includes contributions from ρ(770), ρ′(1450) and ρ″(1700)

β, γ – relative amplitudes

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

Breit-Wigner amplitide

Exclusive dipion production $\gamma^*p \to \pi^+\pi^-p$; fit to F_π



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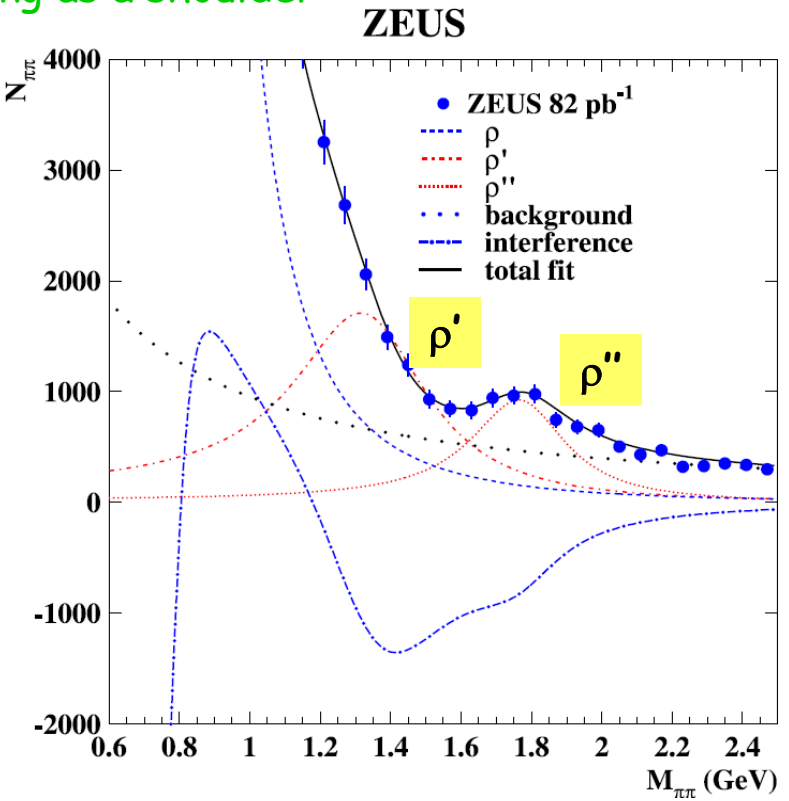
Fit to three resonances

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

Negative interference between ρ, ρ' and ρ'' results in ρ' signal appearing as a shoulder



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
- Relative amplitudes found to be real

Exclusive dipion production $\gamma^*p \to \pi^+\pi^-p$; Q^2 dependence of F_π

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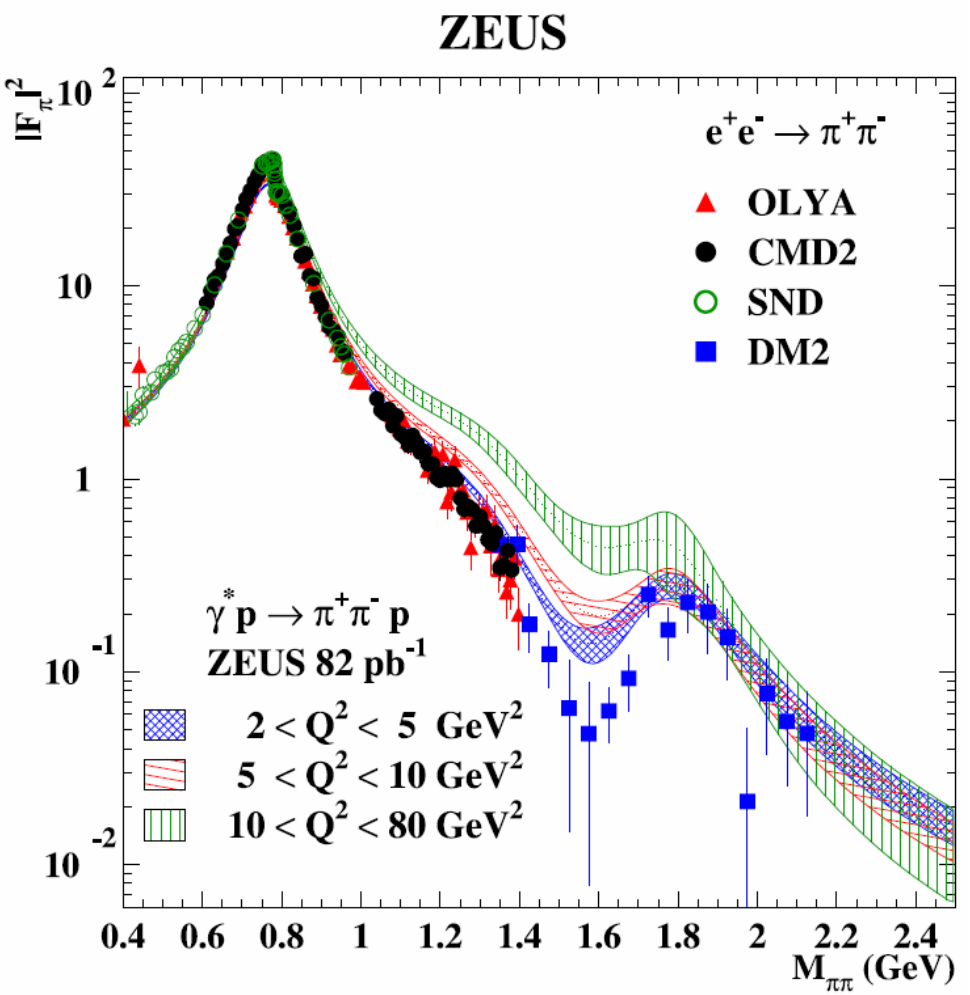

$$F_\pi(M_{\pi\pi}) = \frac{BW_\rho(M_{\pi\pi}) + \beta \times BW_{\rho'}(M_{\pi\pi}) + \gamma \times BW_{\rho''}(M_{\pi\pi})}{1 + \beta + \gamma}$$

- β increases with Q^2
- γ is independent of Q^2

Features of pion form factor in ep are similar to e^+e^-
(some differences in the interference region)

In the ρ peak, the pion form factor is highest at highest Q^2

$Q^2(\mathrm{GeV}^2)$	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	$0.100 \pm 0.009 \pm 0.003$	$0.098 \pm 0.012^{+0.005}_{-0.003}$	$0.118 \pm 0.022^{+0.008}_{-0.006}$

Exclusive dipion production $\gamma^*p \to \pi^+\pi^-p$

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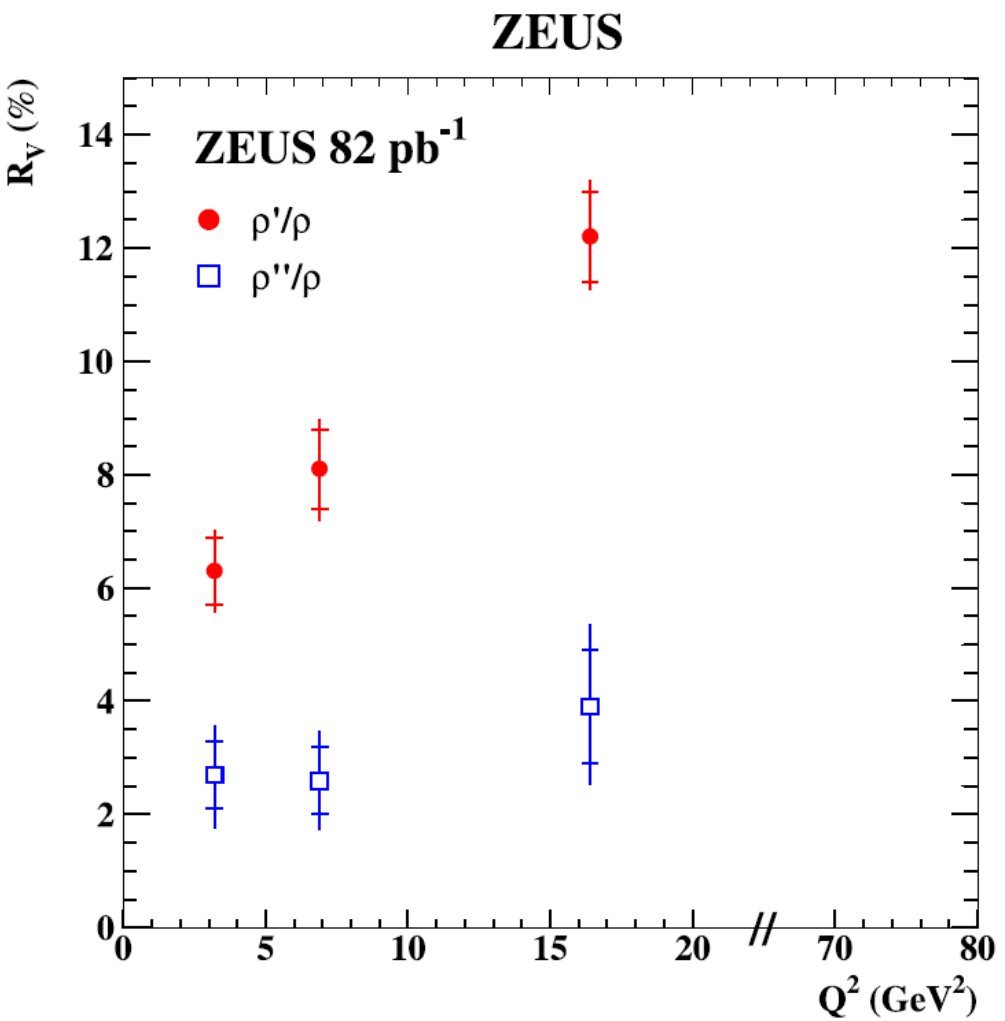
Ratios of ρ'/ρ and ρ''/ρ vs Q^2



$$R_V = \frac{\sigma_V \cdot Br_{V\to\pi\pi}}{\sigma_\rho} \quad V = \rho', \rho''$$

ρ'/ρ ratio increases with Q^2
- predicted by pQCD
- suppression at low Q^2 due to a node in the ρ' wave function

ρ'' behaviour differs from that of ρ'

Conclusions

- HERA provides large amount of vector meson data in a wide kinematic range
- Interplay of soft and hard region can extensively be tested

New results:

- Differential cross sections have been measured for elastic and proton dissociative diffractive J/ψ production as function of t and $W_{\gamma p}$ in the kinematical range $|t| < 8$ GeV^2 and $25 < W_{\gamma p} < 110$ GeV.

- Differential cross section of elastic $\Upsilon(1S)$ production as a function of t is measured; for the first time the b-slope for Υ is determined

- Asymptotic behaviour of b-slope vs (Q^2+M^2) is observed

- Pion formfactor $F_\pi(M_{\pi\pi})$ has been extracted, Q^2 dependence is observed

- Ratios of ρ'/ρ and ρ''/ρ vs Q^2 are measured. Strong rise of ρ'/ρ with Q^2 is observed