Exclusive vector meson production at HERA

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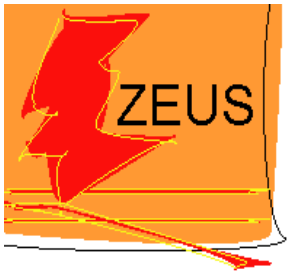
on behalf of



Diffraction2012, Puerto del Carmen, Spain

Vector meson production at HERA

Outline

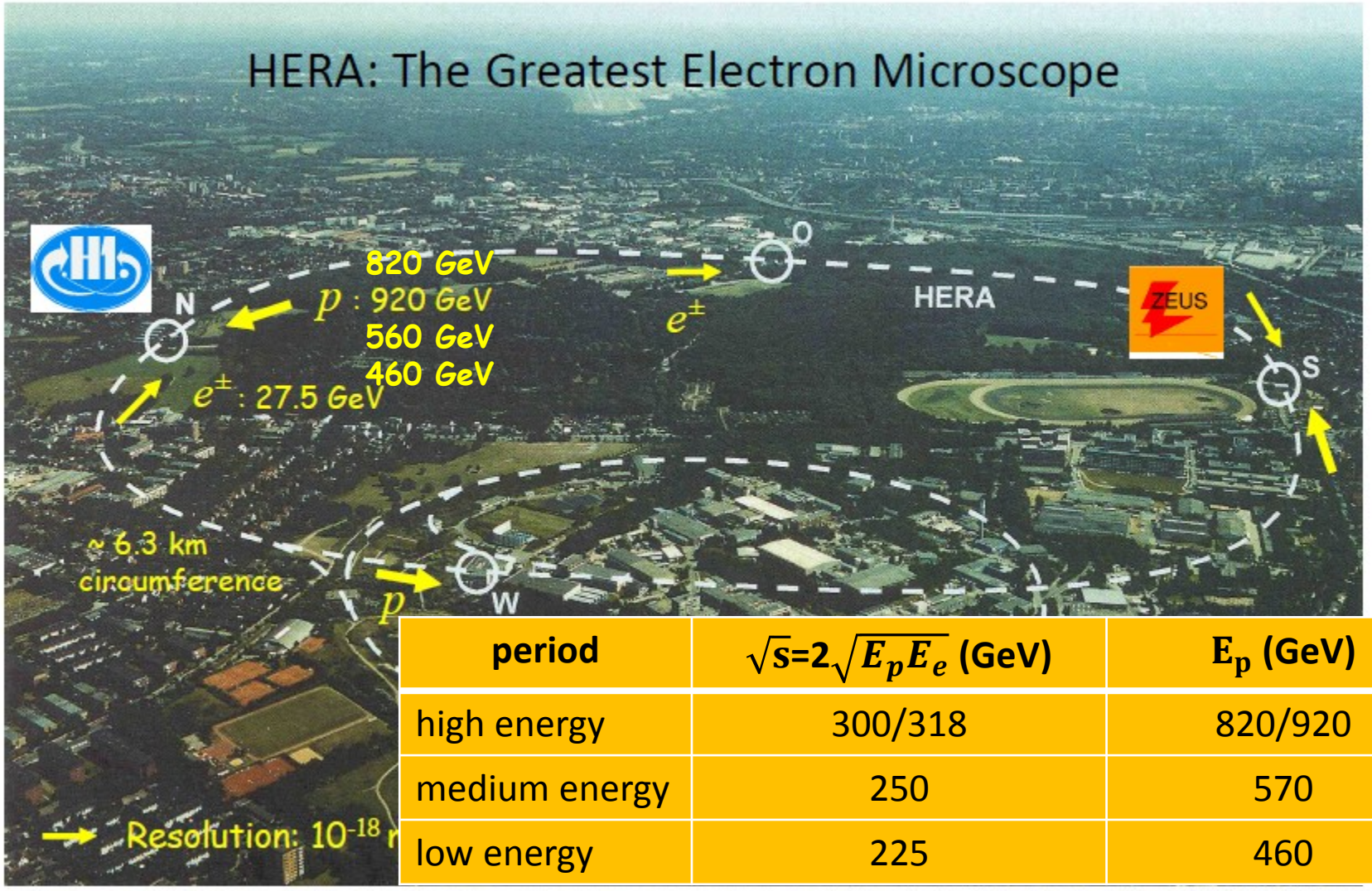
- Introduction to vector meson production in e-p interactions
- Recent results from HERA:
  - J/ψ photoproduction at low $W_{\gamma p}$

    H1prelim-12-111
  - |t| dependence in exclusive Y(1S) photoproduction

    Phys. Lett. B 708 (2012) 14-20
  - exclusive electroproduction of two pions

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

H1 and ZEUS experiments at HERA

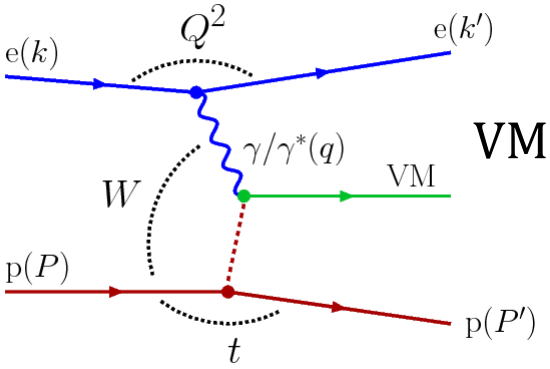


period	$\sqrt{s}=2\sqrt{E_p E_e}$ (GeV)	E_p (GeV)
high energy	300/318	820/920
medium energy	250	570
low energy	225	460

Diffractive vector meson production

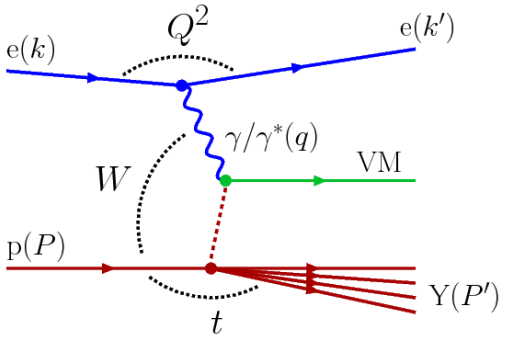
experimentally: very clean process in wide kinematic range

elastic (exclusive)



$VM = \rho,\omega,\varphi,J/\psi,\psi',\Upsilon$

proton dissociative



|t|<1 GeV²

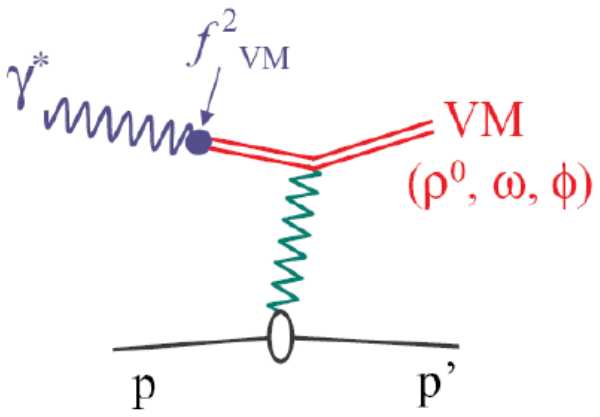
dominates at high |t|

Q^2	photon virtuality	$Q^2 = -q^2 = -(k - k')^2$
W	CMS energy of γp system	$W^2 = (q + P)^2$
t	(4-mom. transfer)² at p-vertex	$t = (P - P')^2$
x	Bjorken *x* = fractional parton momentum in proton Breit frame	$x \approx \frac{Q_2}{W_2}$

$Q^2 \approx 0$ (PHP)
$Q^2 > 0$ (DIS)

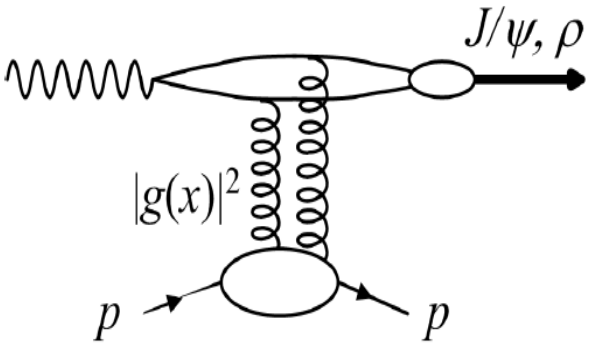
VM at HERA: tool to study transition between soft and hard regime

Diffractive vector meson production



Vector Dominance Model +Regge

- $\gamma^* p \to VM\, p = (\gamma^* \to VM) \otimes (VM\, p \to VM\, p)$
- $VM\, p \to VM\, p \Rightarrow$ (DL) IPomeron exchange
- $\frac{d\sigma}{dt} \sim \exp(-b(W)t)\,,\ b \sim \mathrm{R}^2_{\mathrm{int}} \approx 10\ GeV^{-2}$
- $b(W) = (b_{VM} + b_p + \alpha' \ln(W^2))$ (shrinkage)
- $\sigma_{VMp} \sim \frac{W^{4(\alpha_0 - 1)}}{b(W)} \sim W^{\delta}, \delta \approx 0.22$



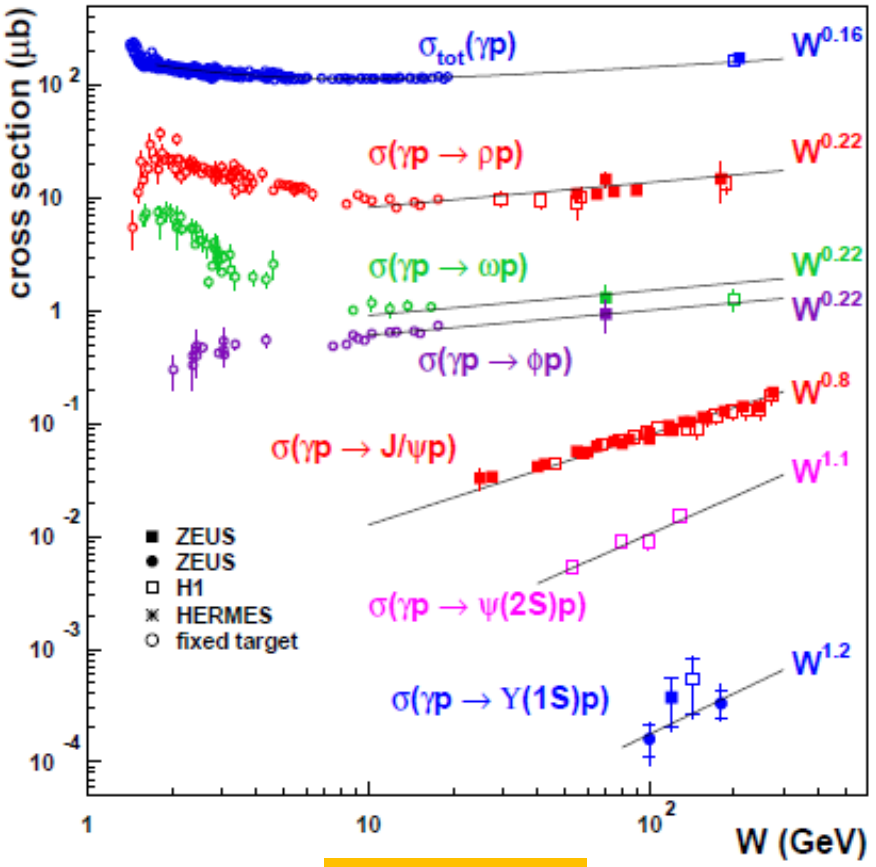
Perturbative QCD

- In proton rest frame:
  long fluctuation length of $q\bar{q}$ $\sim 1/(m_p x)$
- Large Q^2, M_{VM} or $|t| \to$ small $q\bar{q}$ dipol
- QCD IPomeron exchange $\geq$ 2 gluons (colour singlet)
- $\sigma_{VMp} \sim \big(xg(x)\big)^2 \sim W^{0.8}$
- $b \sim 4 - 5\ GeV^{-2}$, weak shrinkage

J/ψ and ϒ(1S) photoproduction

Energy dependence in PHP

$Q^2 \approx 0$



$\sigma \propto W^{\delta}$

SOFT

HARD

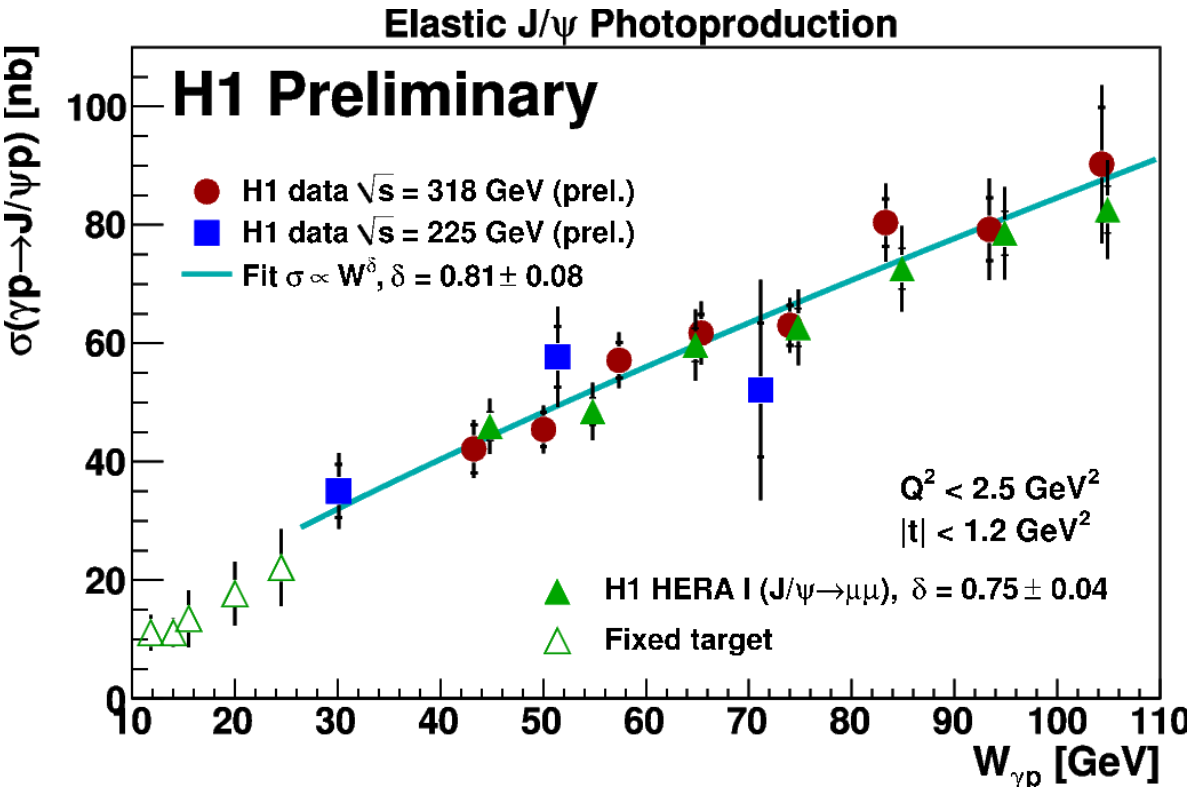
- ✓ Low mass VM (ρ,ω,ϕ)
- ✓ Weak W dependence

- ✓ High mass VM (J/ψ,ψ,ϒ) sets a hard scale
- ✓ strong W dependence

Elastic J/ψ in PHP: extension towards lower W

$\gamma p \rightarrow J/\psi\, p$

$J/\psi \rightarrow e^+e^-$



$Q^2 < 2.5\ GeV^{-2}$

High energy period ($\sqrt{s} = 318\ GeV$)

$\mathcal{L}$=112 pb^{-1}

$|t| < 6\ GeV^2$

$40 < W < 110\ GeV$

Low energy period ($\sqrt{s} = 225\ GeV$)

$\mathcal{L}$=11 pb^{-1}

$|t| < 3.5\ GeV^2$

$20 < W < 80\ GeV$

$\sigma \propto W^{\delta}$

$\delta = 0.81 \pm 0.08$

Simultaneous measurement of elastic and proton dissociative J/ψ cross sections using regularised unfolding procedure.

Elastic J/ψ in PHP: b-slope

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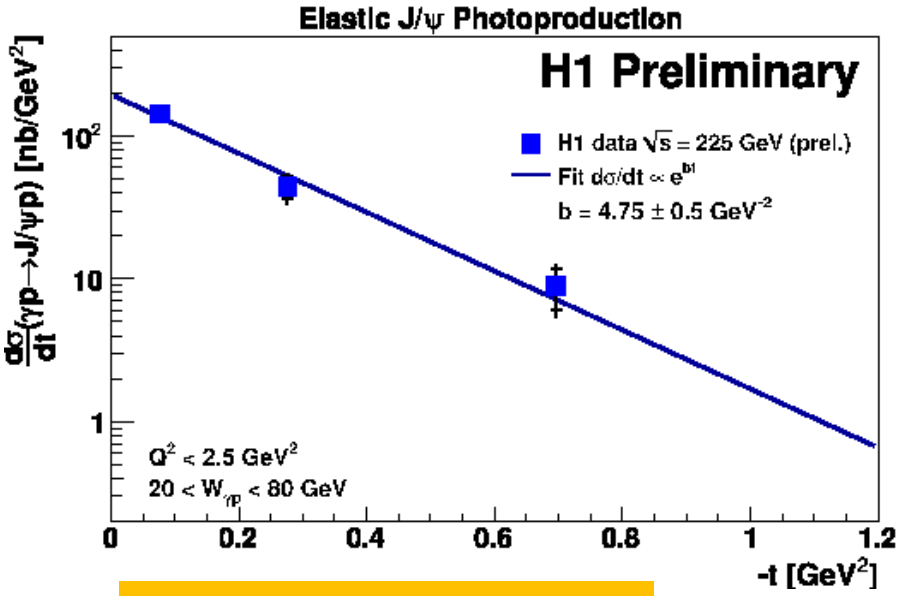
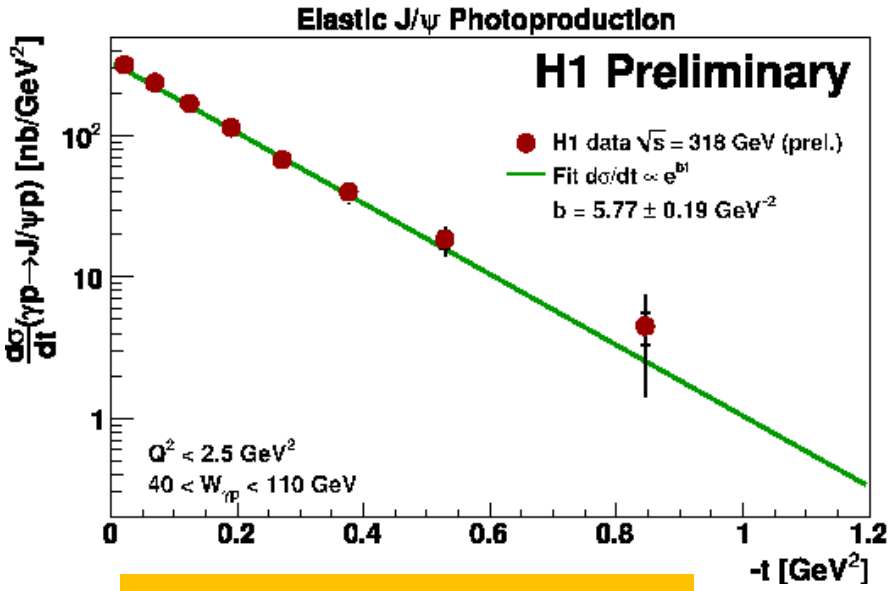
$$\frac{d\sigma}{d|t|} \sim \exp(-b|t|)$$

Low energy data $\sqrt{s}$= 225 GeV



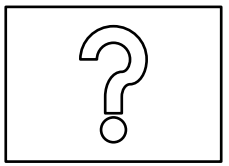
$b=4.75\pm0.5$ GeV^{-2}

High energy data $\sqrt{s}$= 318 GeV



$b=5.77\pm0.19$ GeV^{-2}

Slope increases with W



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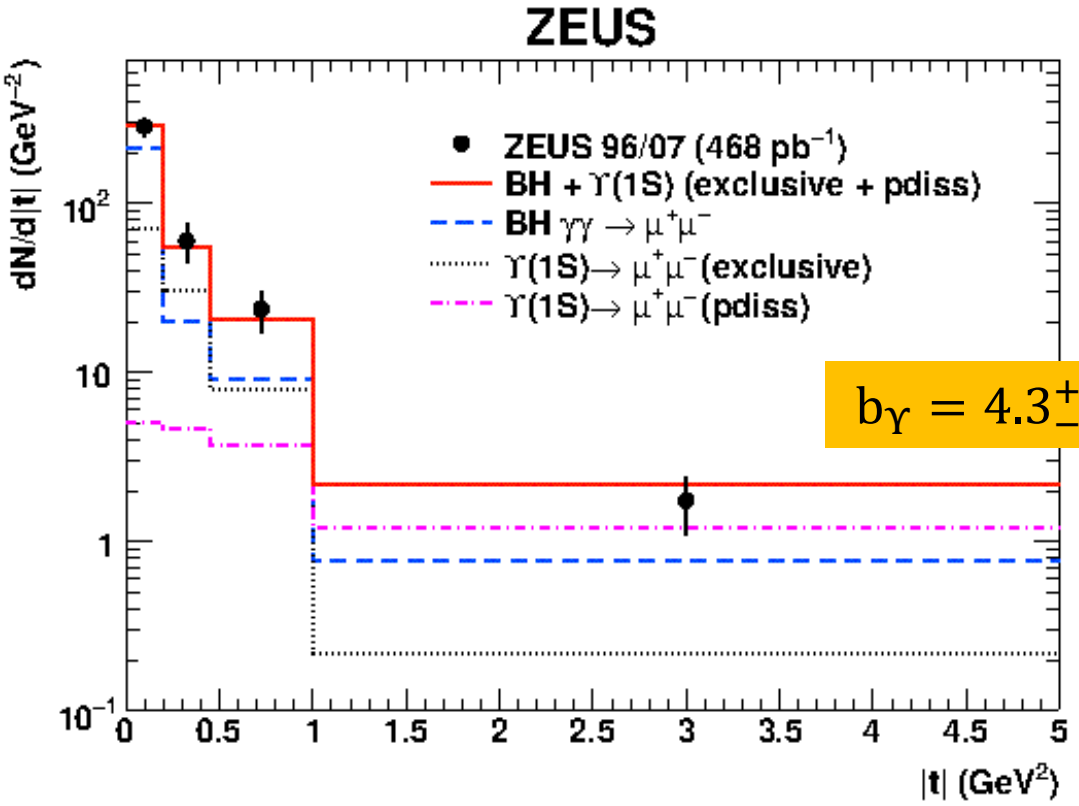
Elastic $\Upsilon(1S)$ in PHP: b-slope

Measurement performed at the highest scale achieved for vector mesons: $Q^2 + M_V^2 = 89.5\ \mathrm{GeV}^{-2}$

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



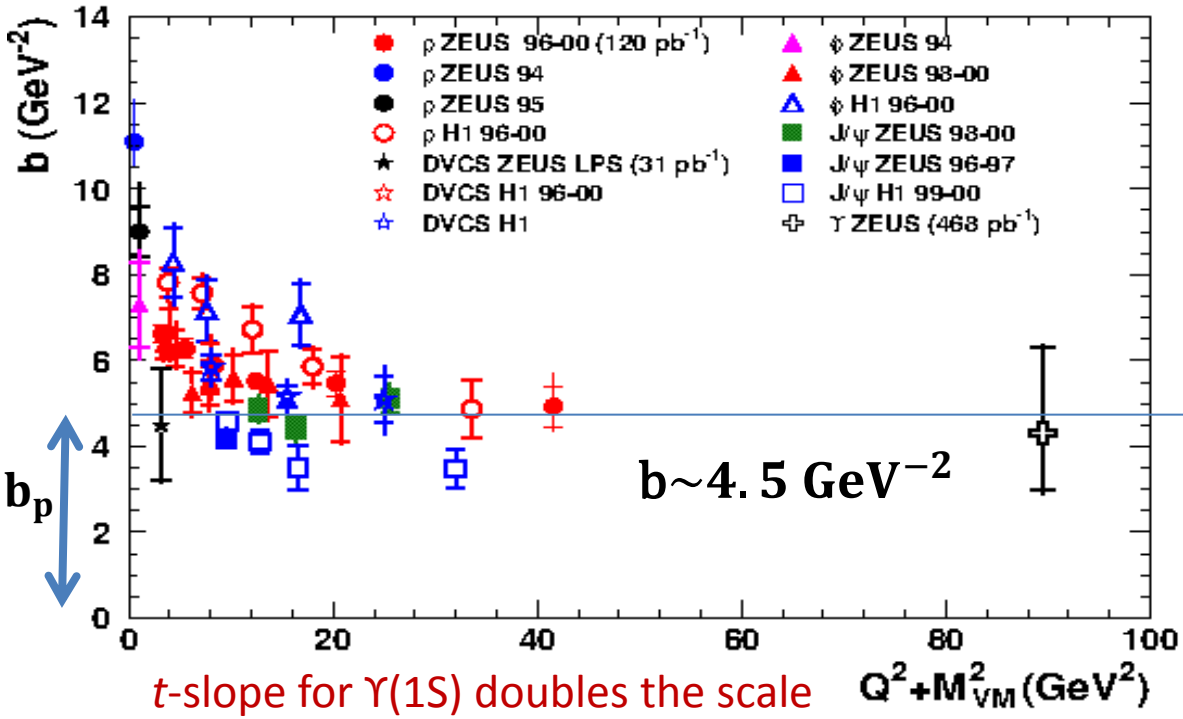
$$\frac{d\sigma}{d|t|} \sim \exp(-b|t|)$$

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

b ($Q^2+M_V^2$)

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

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



Geometric picture:

Transverse size of interaction:

$$b = r^2_{\perp qq} + r^2_{proton}$$

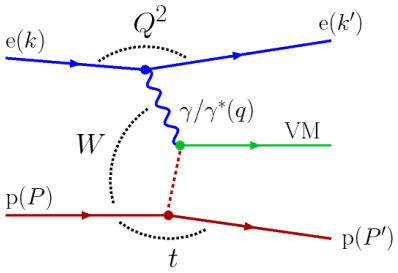
$$b_{VM} = \frac{1}{M^2_{VM} + Q^2}$$

t-slope for ϒ(1S) doubles the scale

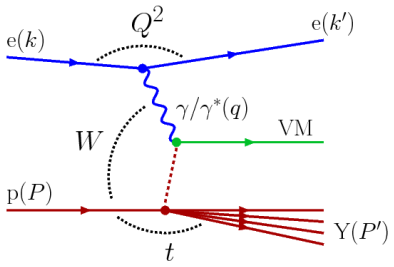
size of the gluons: $\langle r^2 \rangle = 2 * b * (\hbar c)$

$r_g \sim$ 0.6fm – smaller than charge radius of the proton ~0.8fm

→ gluons are confined in smaller space than quarks



Elastic vs proton. diss. production



What happens at the proton vertex …

Elastic and proton dissociative J/ψ PHP: energy dependence

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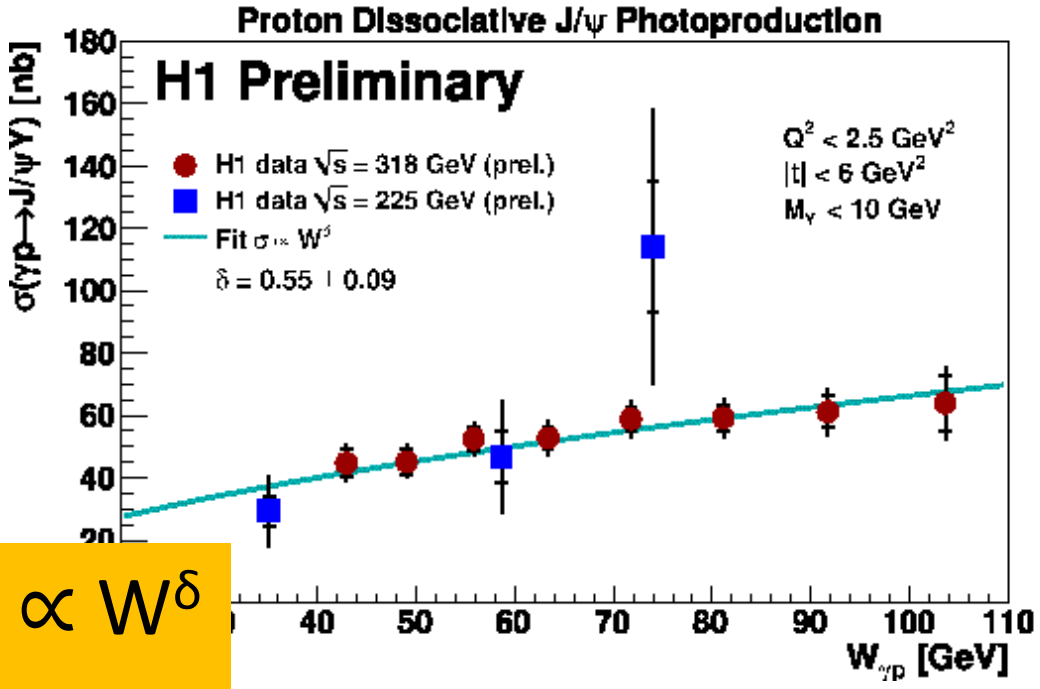

$\sigma_{pdiss} \propto W^{\delta}$

$\delta = 0.55 \pm 0.09$

Comparing with the slope of elastic part is not possible since no data are available in the same phase space.

Proton dissociative J/ψ photoproduction: dσ/d|t|

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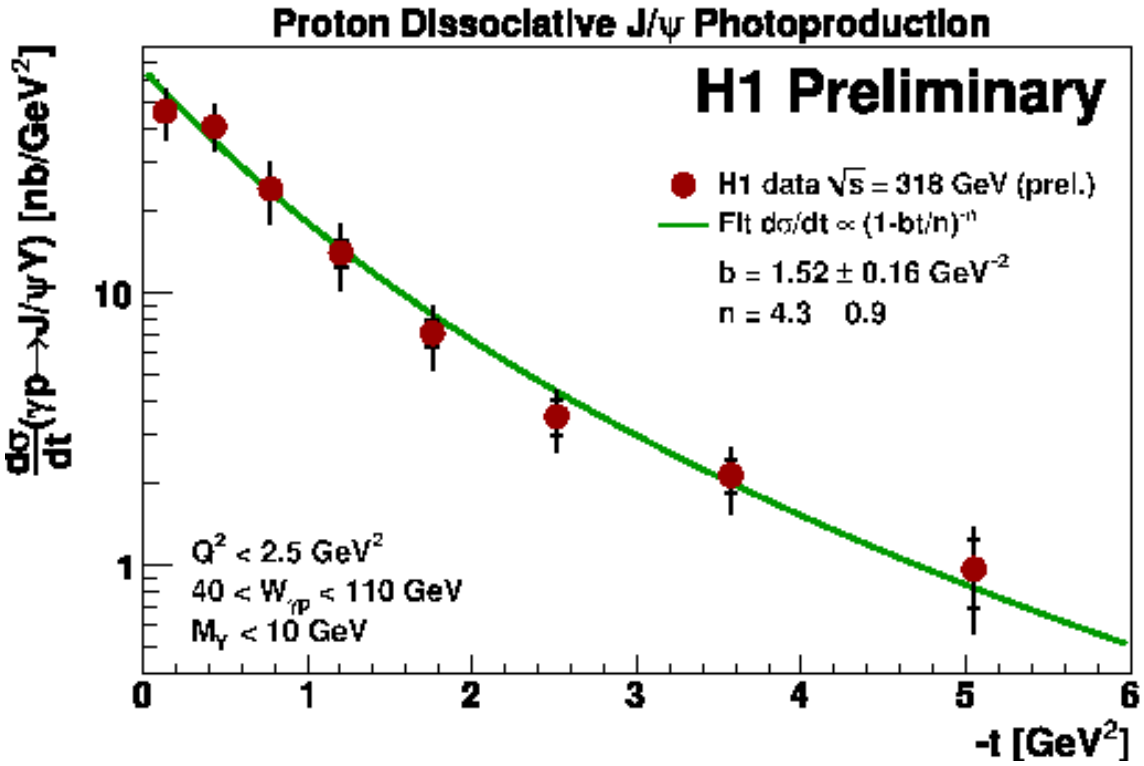


$d\sigma/d|t| \propto (1-bt/n)^{-n}$

$b=1.52\pm0.16\ \mathrm{GeV}^{-2}$

smaller than elastic

$b=5.77\pm0.19\ \mathrm{GeV}^{-2}$

At small t exponential behaviour, at high t powerlike behaviour

When the target (proton) breaks the size b_p does not count, hence p-diss interaction radius expected to be smaller than elastic one

Exclusive dipion electroproduction

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

Exclusive dipion production

$$\gamma^* p \to \pi^+ \pi^- p$$

$\mathcal{L}$=82 pb^{-1}
$0.4 < M_{\pi\pi} < 2.5$ GeV
$2 < Q^2 < 80$ GeV^2
$32 < W < 180$ GeV
$|t| < 0.6$ GeV^2

The two-pion invariant-mass distribution includes the contribution of ρ, ρ’ (radially excited 2S state) and ρ’’ (an orbitally excited 2D state) vector mesons

- after subtraction of non-resonant background is related to the pion electromagnetic form factor

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

$F_\pi (M_{\pi\pi})$ ⇒ source of information on shape and size of hadron

Pion form factor

- Kuhn-Santamarta parameterization (KS) has been chosen
- For $M_{\pi\pi}$<2.5 GeV KS parametrization includes contributions from ρ (770), ρ'(1450) and ρ''(1700)

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

relative amplitudes

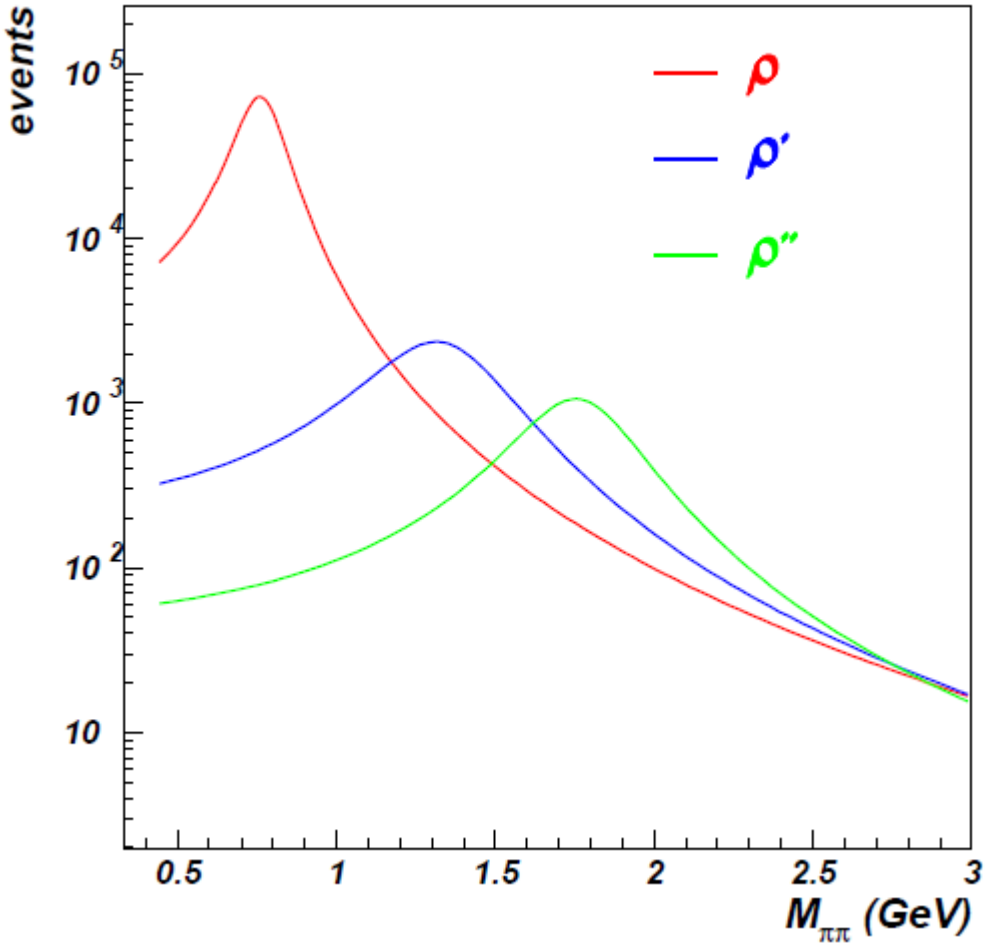
Breit-Wigner amplitude:

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

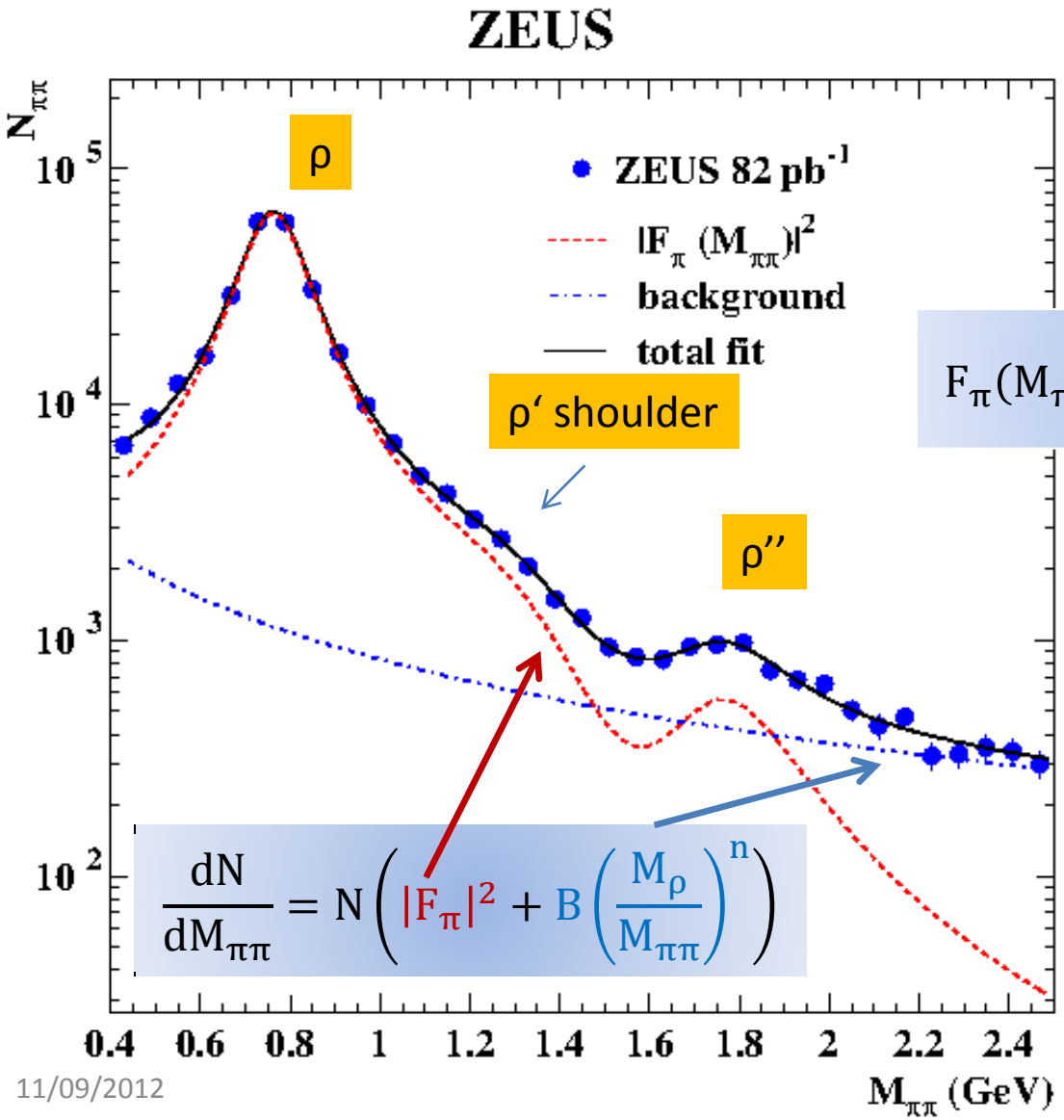
vector-meson mass

momentum-dependent width

How the ideal picture looks like?



Fit to all the three resonances



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

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

Details of the fit

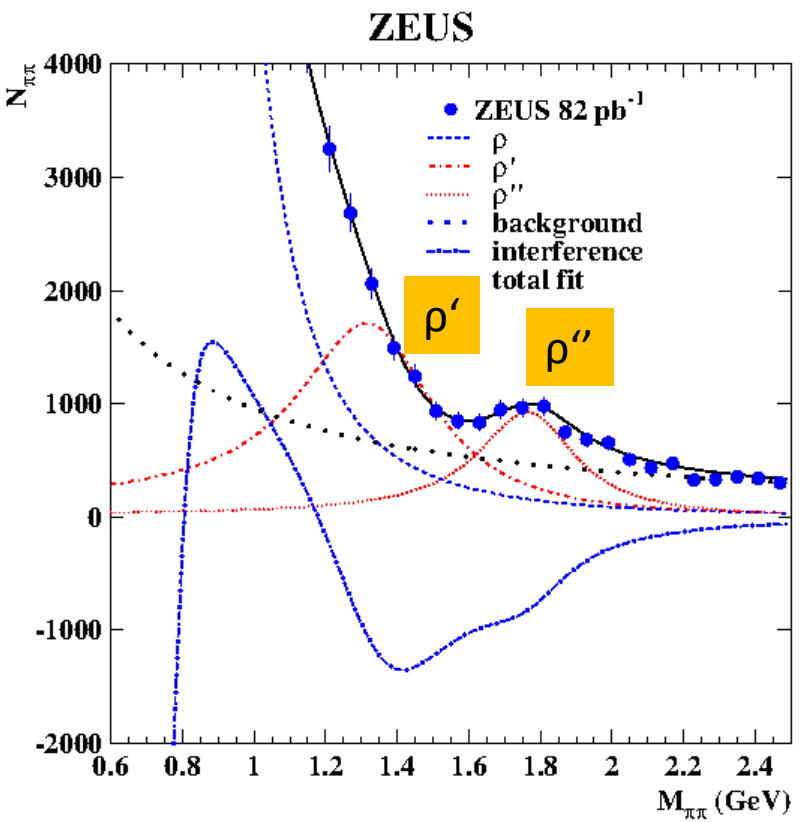
Parameter	ZEUS	PDG
M_ρ (MeV)	$771 \pm 2^{+2}_{-1}$	775.49±0.34
Γ_ρ (MeV)	$155 \pm 5 \pm 2$	149.1±0.8
β	$-0.27 \pm 0.02 \pm 0.02$	
$M_{\rho'}$ (MeV)	$1350 \pm 20^{+20}_{-30}$	1465±25
$\Gamma_{\rho'}$ (MeV)	$460 \pm 30^{+40}_{-45}$	400±60
γ	$0.10 \pm 0.02^{+0.02}_{-0.01}$	
$M_{\rho''}$ (MeV)	$1780 \pm 20^{+15}_{-20}$	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 expectation (ρ' lower than PDG)

Interference important!

Relative amplitudes found to be real.

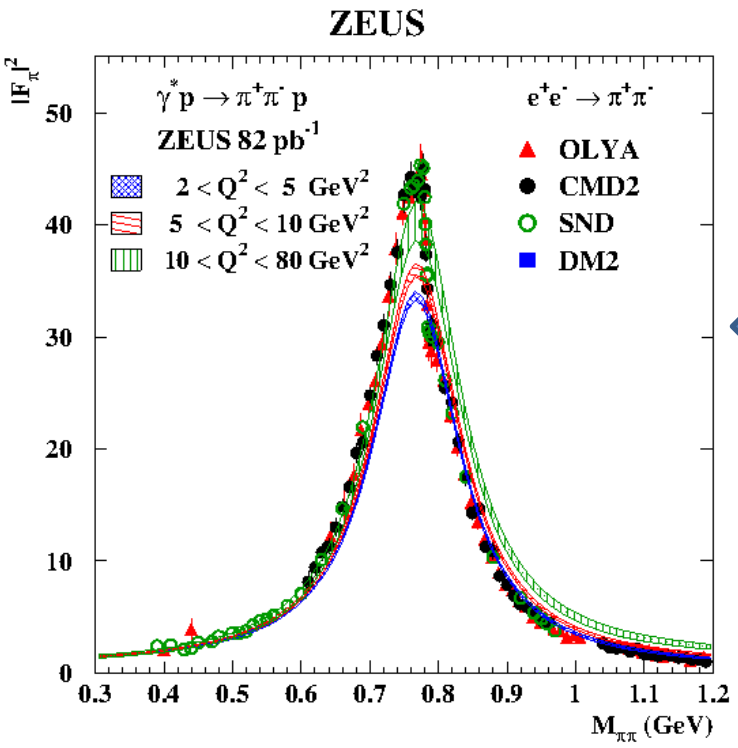
ρ' and ρ'' mass region

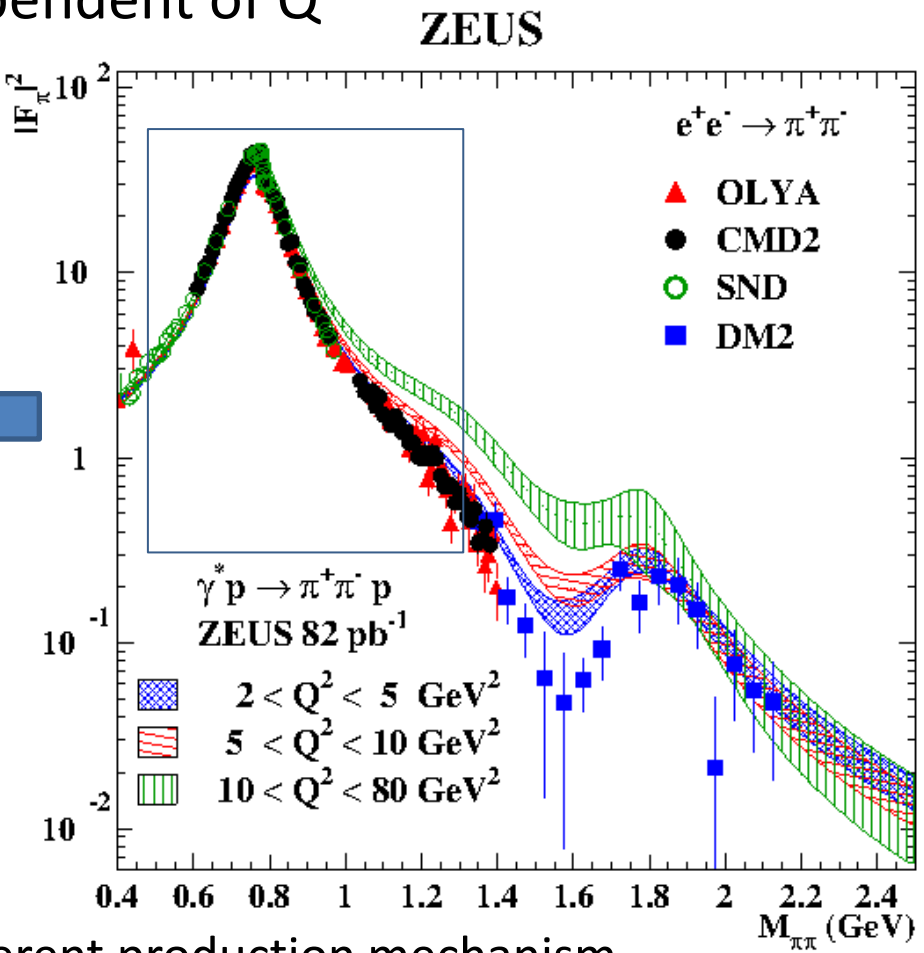


Q^2 dependence of F_π

Q^2 dependence of F_π observed

$|\beta|$ rising with Q^2, while γ independent of Q^2





Comparison with e^+e^- data:

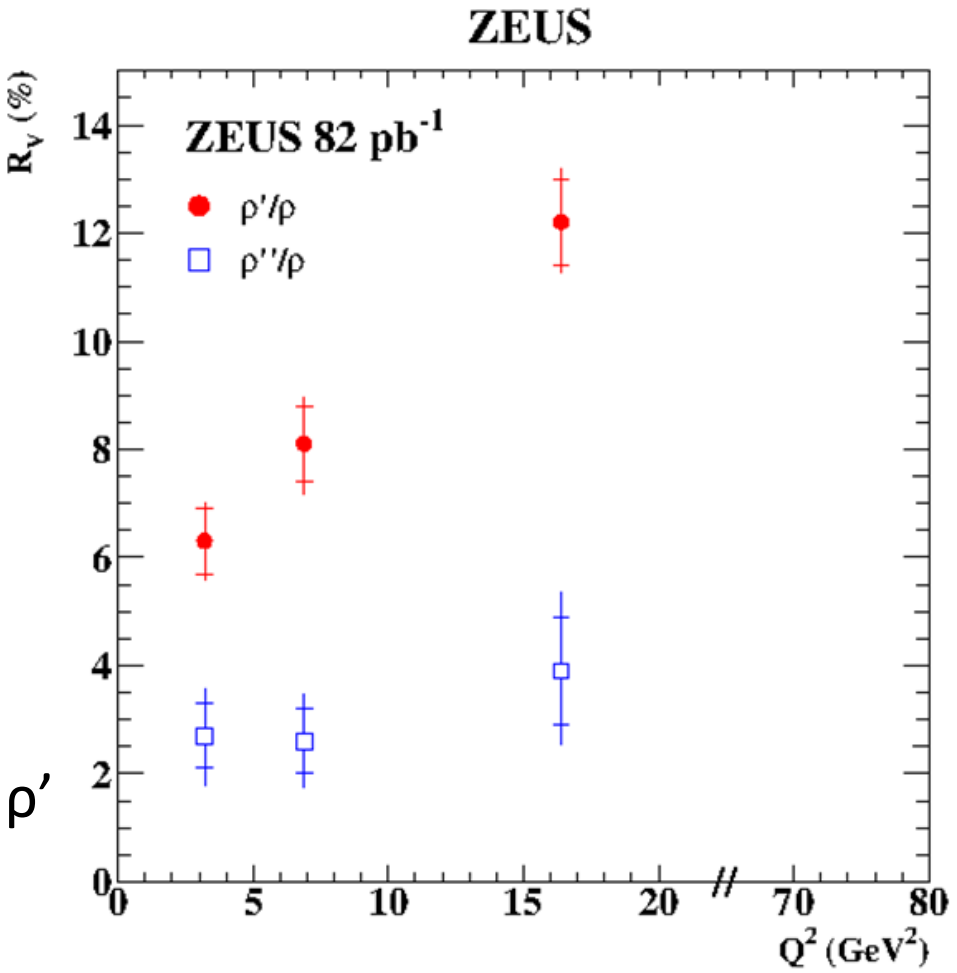
→ generally similar shape despite different production mechanism

Ratios of ρ’/ρ and ρ’’/ρ vs Q^2

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

with V = ρ’, ρ’’

- $R_{\rho'}$ rises with Q^2
  - predicted by pQCD
  - suppression at low Q^2 due to a node in ρ’ wave function
- ρ’’ behaviour differs from that of ρ’



Summary

- J/ψ photoproduction has been measured with an extension towards low energy
- b-slope parameter for ϒ(1S) is in an agreement with the previous measurements while those for J/ ψ photoproduction seem to be slightly deviated
- J/ψ energy dependence and ds/d|t| for proton dissociative production has been measured
- $F_\pi(M_{\pi\pi})$ has been extracted and found to be Q^2 dependent
- Ratios of ρ'/ρ and ρ''/ρ vs Q^2 were measured – strong rise with Q^2 observed for ρ'/ρ while ρ''/ρ behaves differently