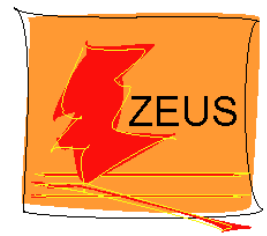
Vector Meson Production at HERA

On behalf of the H1 and Zeus Collaborations



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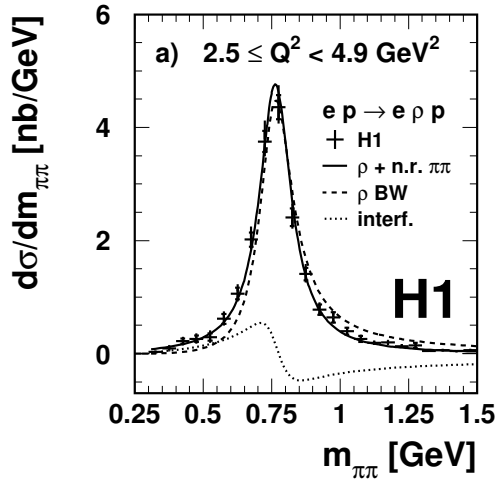
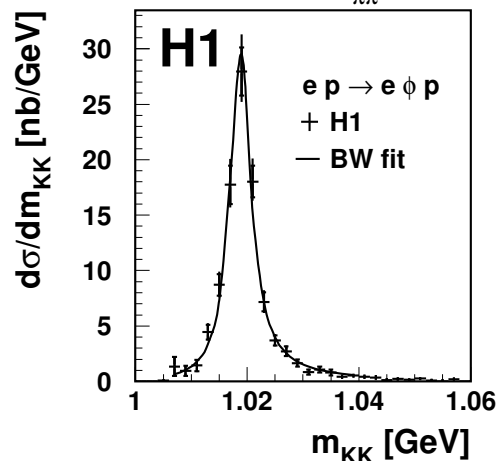
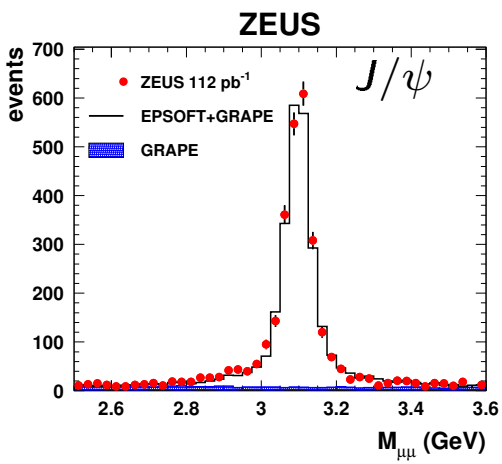
Florian Huber
Physikalisches Institut Heidelberg

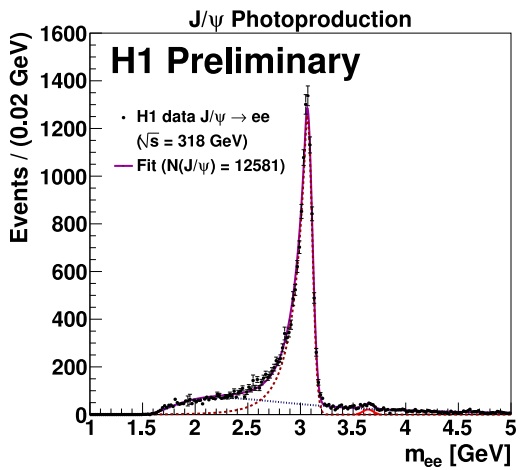
Outline:

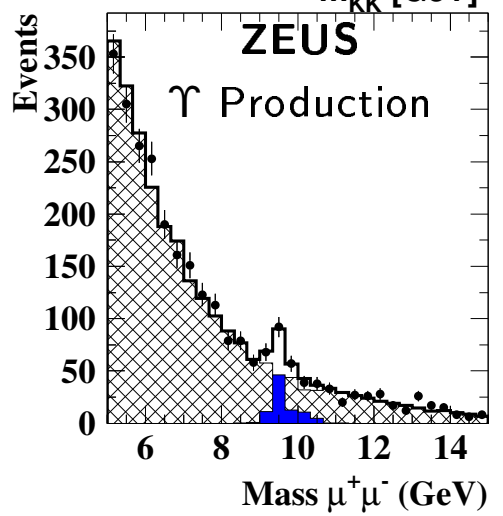
1. Introduction
2. Overview of $W_{\gamma p}$, t and Q^2 Dependence
3. New Results
4. Summary







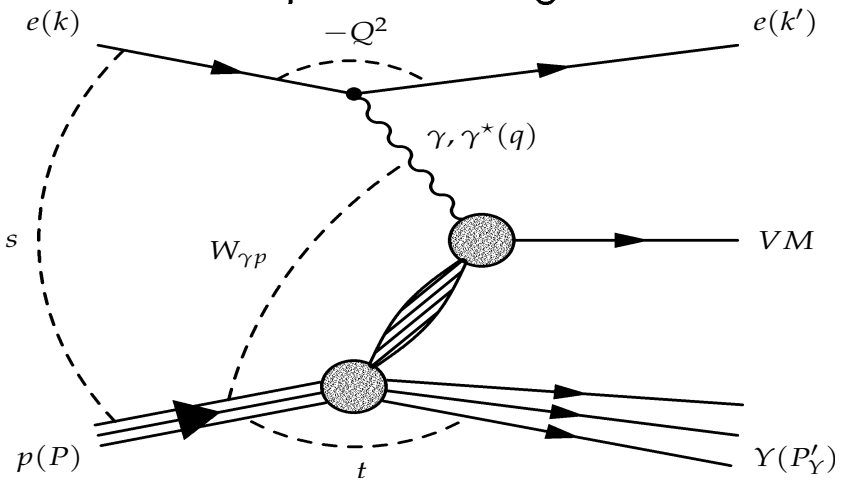




Introduction

Exclusive Vector Meson Production

Diffractive vector meson production in ep – scattering



- VM = (ρ, ω, ϕ, J/ψ, ψ', Υ)
- Diffractive process characterised by exchange of object with vacuum quantum numbers.
- The proton stays intact ($Y = P$) or dissociates.

photon virtuality

$Q^2 \equiv -q^2 = -(k - k')^2$
$Q^2 \sim 0$: Photoproduction
$Q^2 > 0$: Deep inelastic scattering

squared momentum transfer at proton vertex

$t \equiv (P - \sum_X P'_X)^2$

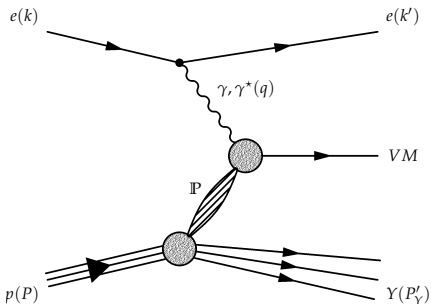
cms energy in photon proton rest frame

$W^2_{\gamma p} \equiv (P + q)^2$
$\simeq ys - Q^2$

y: inelasticity

Soft Region versus Hard Region

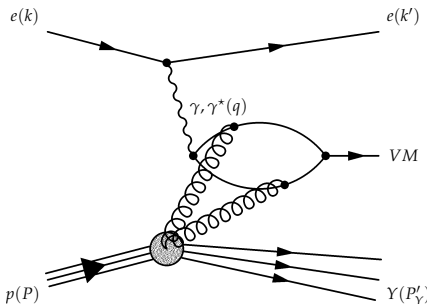
Soft region



Not perturbatively accessible → Regge framework

- $\frac{d\sigma}{dt} \propto e^{-b(W)|t|} \left(\frac{W}{W_0}\right)^{4(\alpha_{\mathbb{P}}(0)-1)}$
  with $b(W) = b0 + 4\alpha' \log\left(\frac{W}{W_0}\right)$
  and linear Regge trajectory
  $\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha' t$
- Weak energy dependence $\sigma \propto W^{\delta}$ with $\delta \sim 0.2$

Hard region



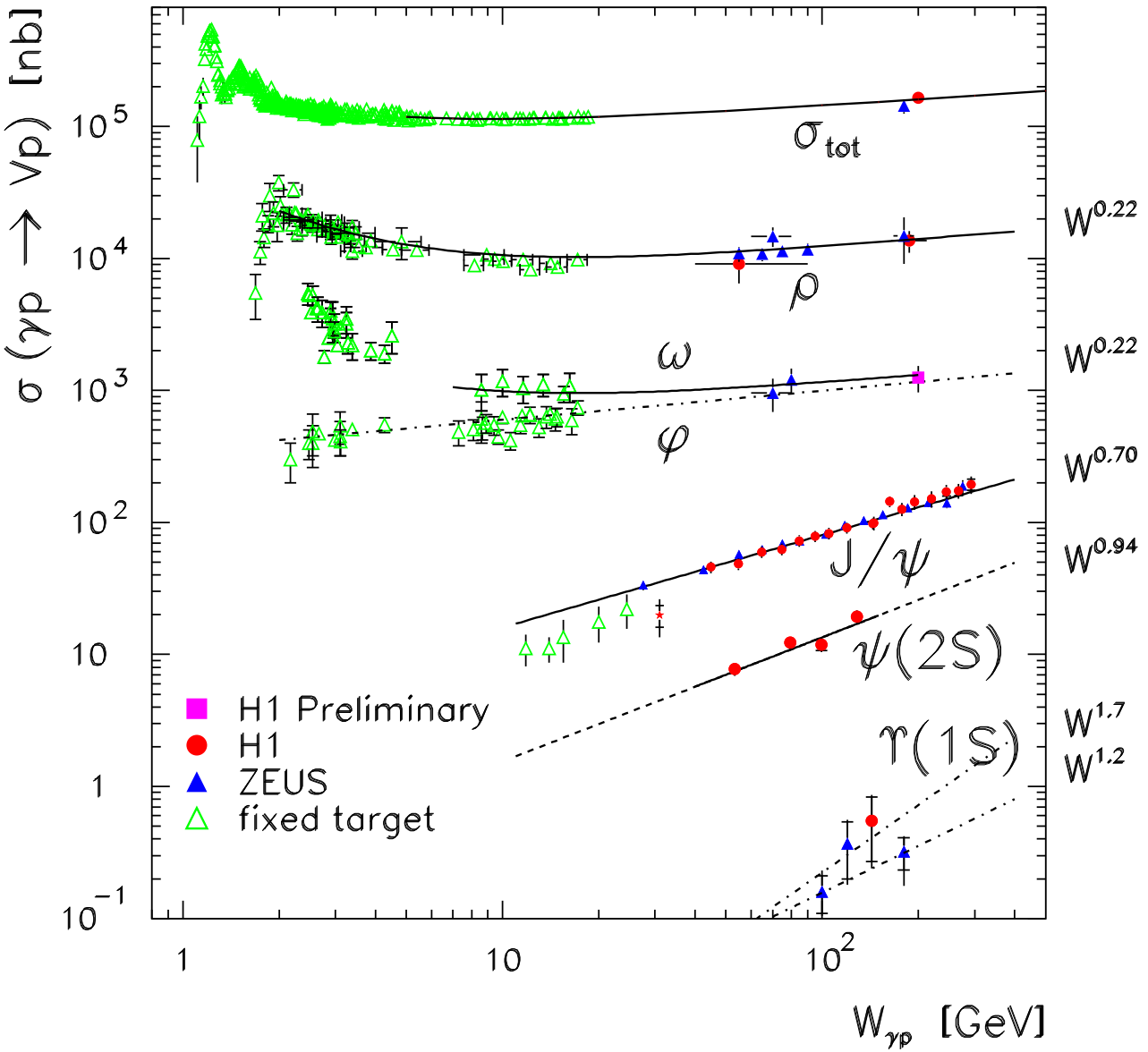
Two or more gluon exchange

- Needed hard scales for perturbative QCD calculation: Q^2, M_V or t
- Prediction:
  $\sigma \propto \left(\alpha_S(Q^2) x g(x, Q^2)\right)^2$

  I.e. cross section rises fast with W because $W \propto 1/\sqrt{x}$ and gluon density increases while going to lower x values.

Overview of $W_{\gamma p}$, t and Q^2 Dependence

$W_{\gamma p}$ Dependence for Elastic VM Photoproduction



With increase of vector meson mass (M_V) process gets harder.

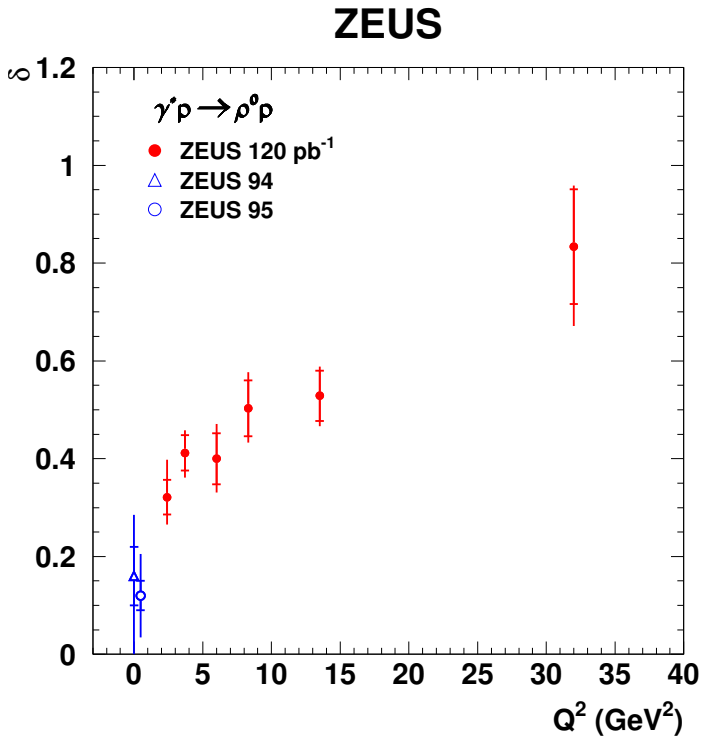
$\sigma \propto W^{\delta}$

- Soft: $\delta \approx 0.22$
- Hard: $\delta \sim 1.0$

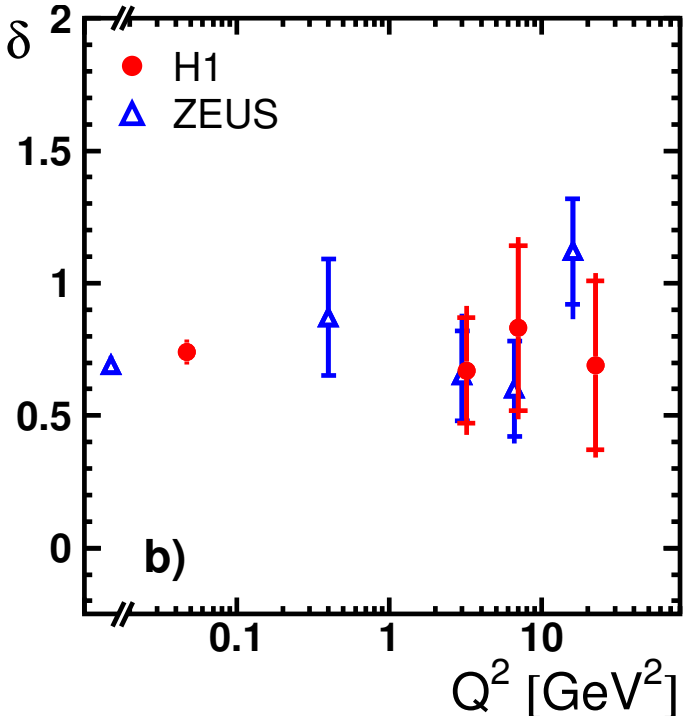
Vector meson mass sets scale of process.

δ Fit Parameter ($\sigma \propto W_{\gamma p}^{\delta}$) for Light and Heavy VM

$\gamma^{(\star)} p \to \rho p$



$\gamma^{(\star)} p \to J/\psi p$

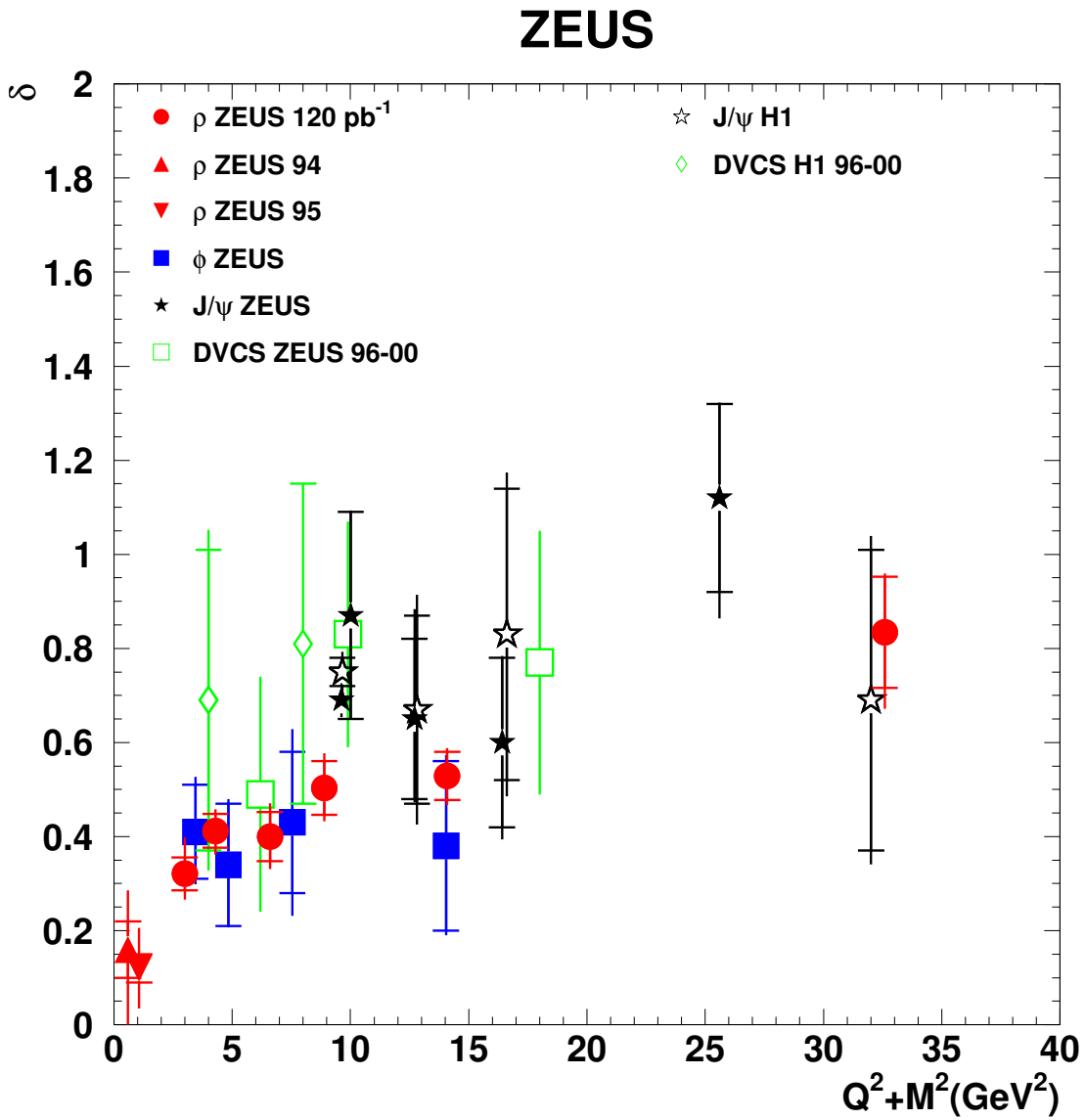


For ρ Cross section as function of $W_{\gamma p}$ gets steeper from soft to hard region in Q^2. (Same for ϕ, not shown)

For J/ψ $W_{\gamma p}$ cross section dependence is constant w.r.t. Q^2 and δ is compatible to values extracted from photoproduction.

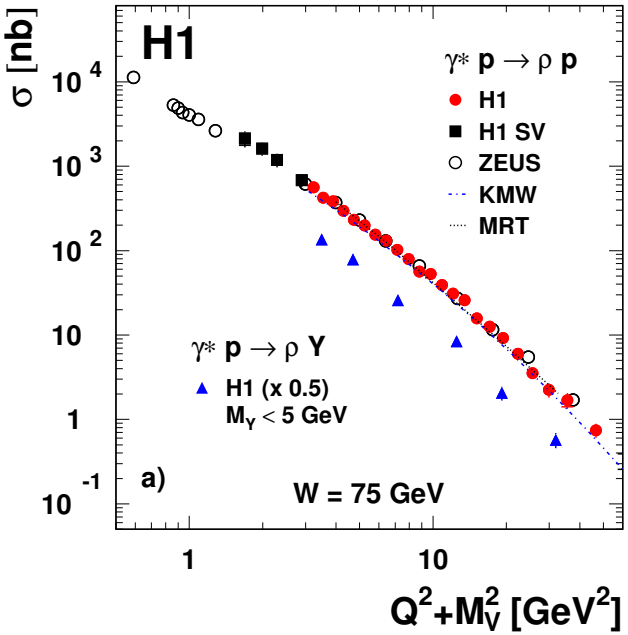
$\to$ J/ψ already in hard region at low Q^2 because of mass.

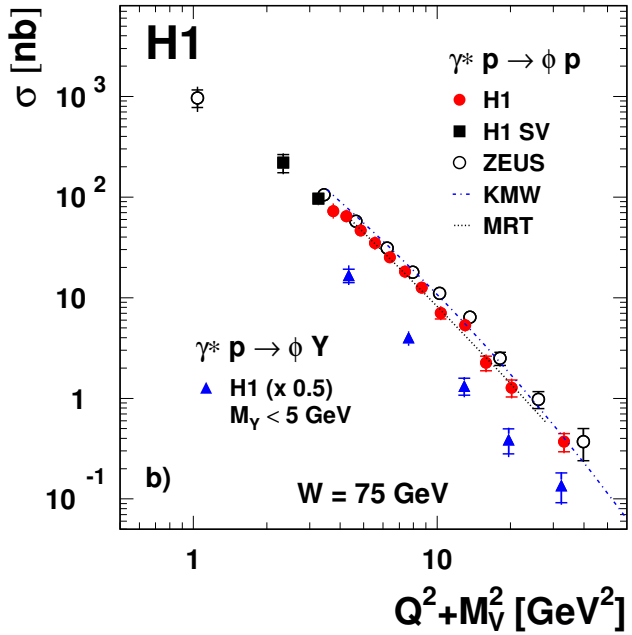
Summary of δ Fit Parameter ($\sigma \propto W_{\gamma p}^{\delta}$)



- Good scale for observing transition from soft to hard region: $Q^2 + M^2$
- Same behaviour for ρ and ϕ
- J/ψ and Υ (not shown) for $Q^2 \sim 0\,\mathrm{GeV}^2$ already in hard region

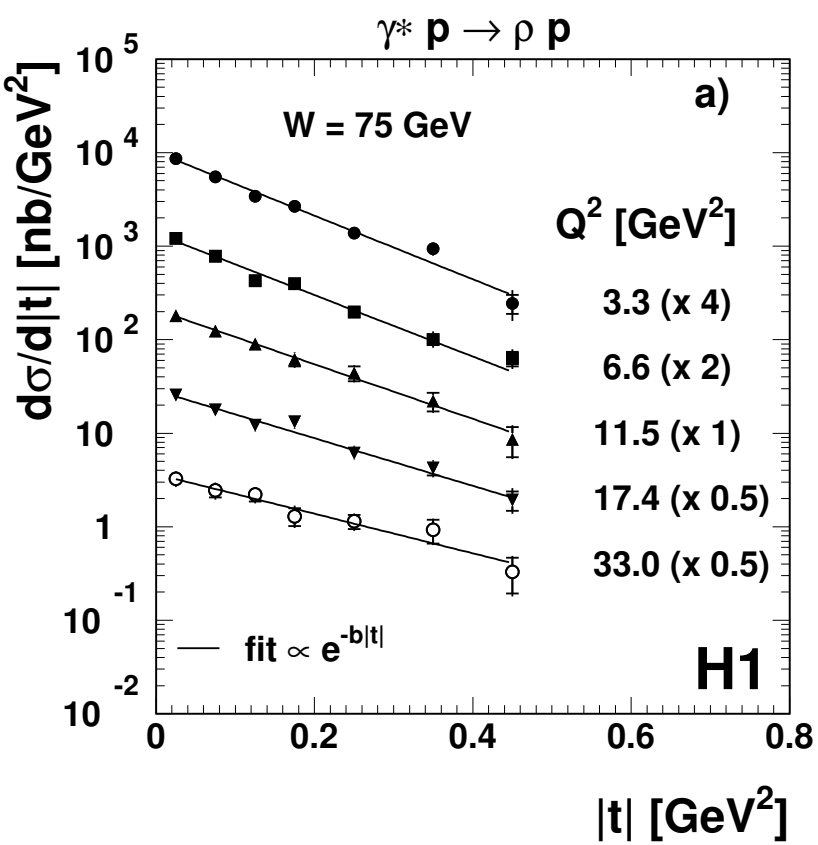
Q^2 Dependence at the Example of ρ and ϕ Production

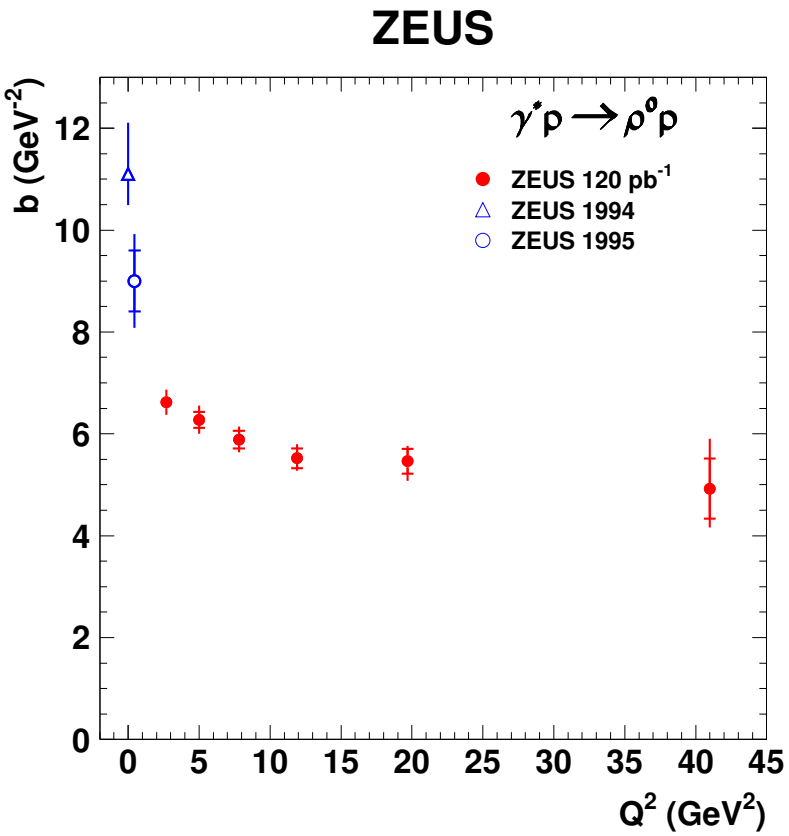




- Good agreement between Zeus and H1 measurement.
- Elastic and proton dissociative have same behaviour.
  (Note: Proton dissociative is scaled by factor 0.5)
- Fit with $\sigma_{\gamma p} \propto \left(M_V^2 + Q^2\right)^n$ and $n = c_1 + c_2(M_V^2 + Q^2)$ produces better results than a constant n.
- c_1 is consistent within errors to 2, which is predicted by VDM model in the limit $Q^2 \to 0$.

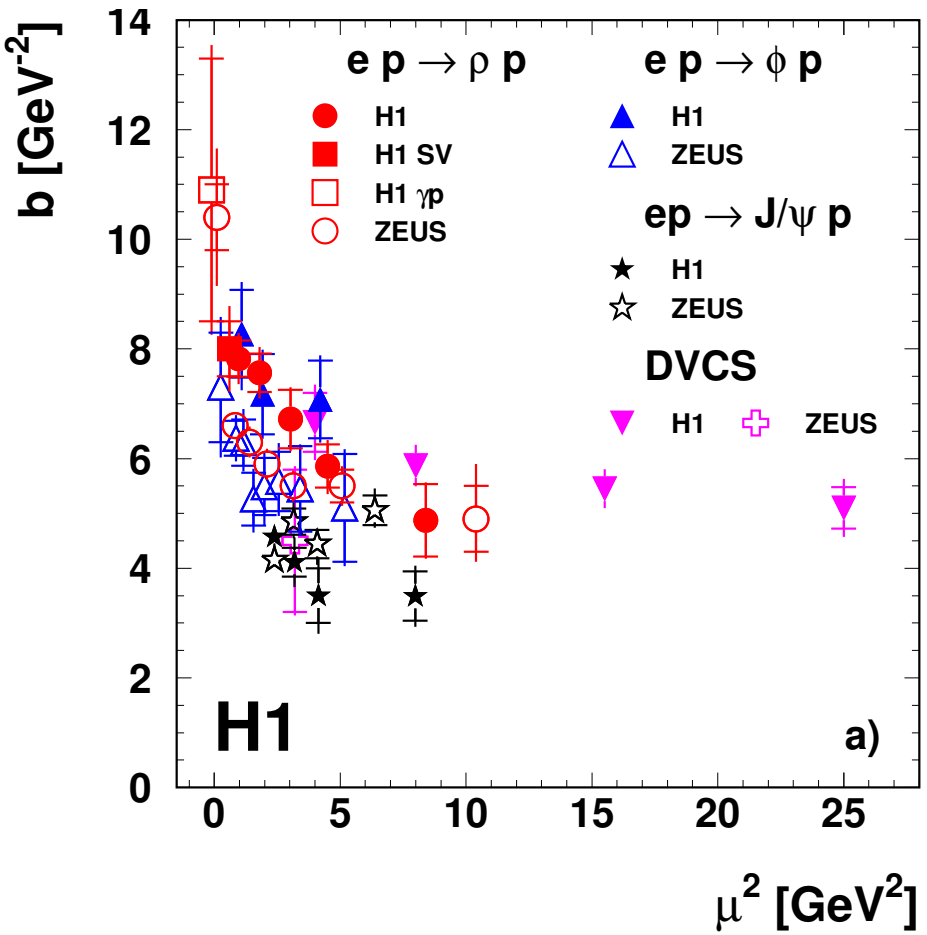
t Dependence at the Example of Elastic Produced ρ Meson





- Fitting differential cross sections with an exponential: $\frac{d\sigma}{dt} \propto e^{bt}$
- b characterize the size of transverse interaction
- Exponential behavior in t is equivalent with a Gaussian proton radius shape.
- b decreases to $\sim 5\,\mathrm{GeV}$ in soft region, which is expected by pQCD.

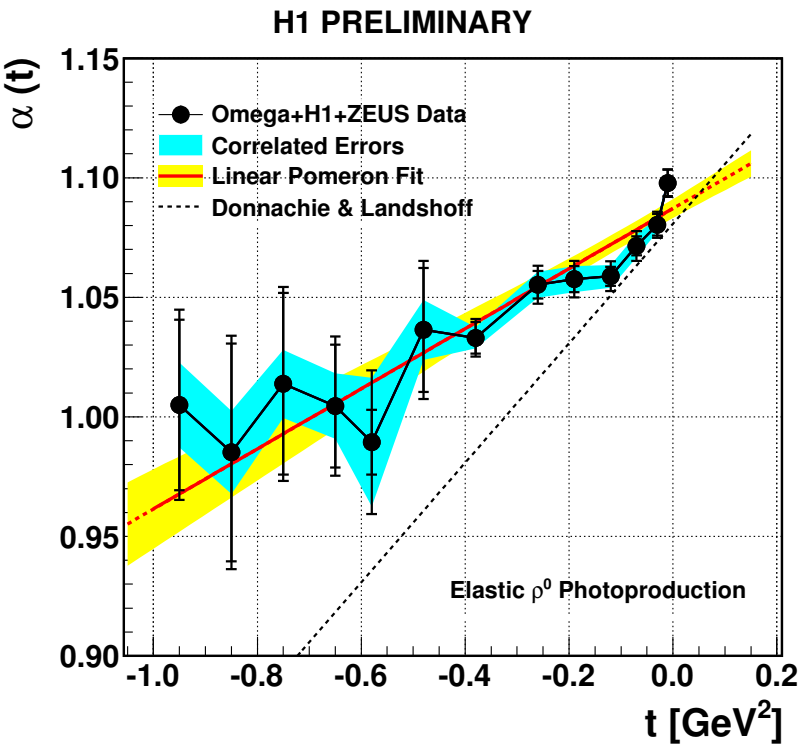
Summary t Dependence of VM



- Scale $\mu^2 = (Q^2 + M_V^2)/4$
- Similar behaviour of slope b for ρ, ϕ, J/ψ (and DVCS) as function of μ^2.
- b decreases with μ from $\sim 10\,\mathrm{GeV}^{-2}$ (soft) to $\sim 5\,\mathrm{GeV}^{-2}$ (soft)
- b parameter connected to the transverse gluonic dipole size. Can be written as $b = b_P + b_V$ with
  - $b_V \sim \frac{1}{Q^2 + M_V^2}$ connected to the vector meson transverse size.
  - $b_p \sim 5\,\mathrm{GeV}^{-2}$ connected to the proton transverse size. Which corresponds to $R_{\mathrm{gluon}} = \sqrt{(2b)} \sim 0.6\,\mathrm{fm}$. Radius smaller then charged radius of proton $\approx 0.9\,\mathrm{fm}$.

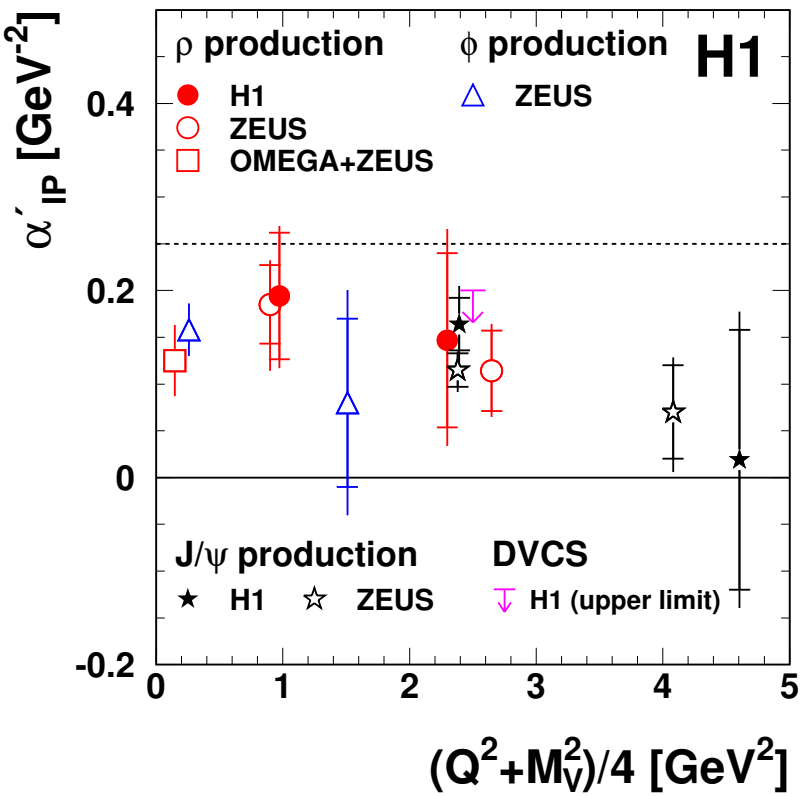
Pomeron Trajectory

$$\frac{d\sigma(W)}{dt} \propto \left(\frac{W}{W_0}\right)^{4(\alpha_{\mathbb{P}}(t)-1)}$$



- Global fit to ρ^0 photoproduction data from H1, Omega and Zeus.
- Linear Pomeron trajectory:
  $\alpha_{\mathbb{P}}(t) = \alpha_0 + \alpha' t$
  $\alpha_0 = 1.0871 \pm 0.0026 \pm 0.0030$
  $\alpha' = 0.126 \pm 0.013 \pm 0.012$
- Donnachie and Landshoff (DL) fit to pp scattering gives soft pomeron trajectory of $1.08 + 0.25t$.
  $\Rightarrow \alpha_0$ consistent with DL
  $\Rightarrow \alpha'$ twice smaller than DL

Summary of Pomeron Slope Parameter α'



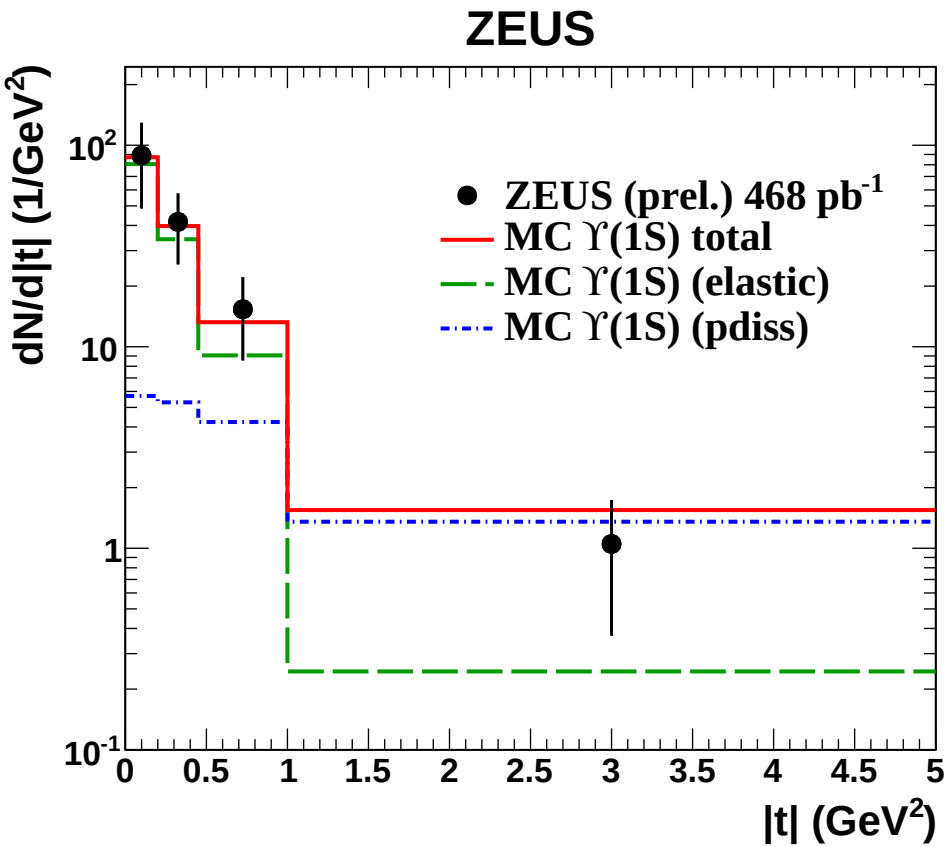
- As a reminder:
  $d\sigma/dt \propto e^{-b(W)|t|}$ with
  $b(W) = b_0 + 4\alpha' \log\left(\frac{W}{W_0}\right)$
- α' for ρ, ϕ and J/ψ below $0.25\,\mathrm{GeV}^{-2}$ (DL)
- α' for J/ψ in DIS seems consistent with 0.

New Results

Upsilon (1S) photoproduction t-slope measurement at HERA

ZEUS-prel-10-020

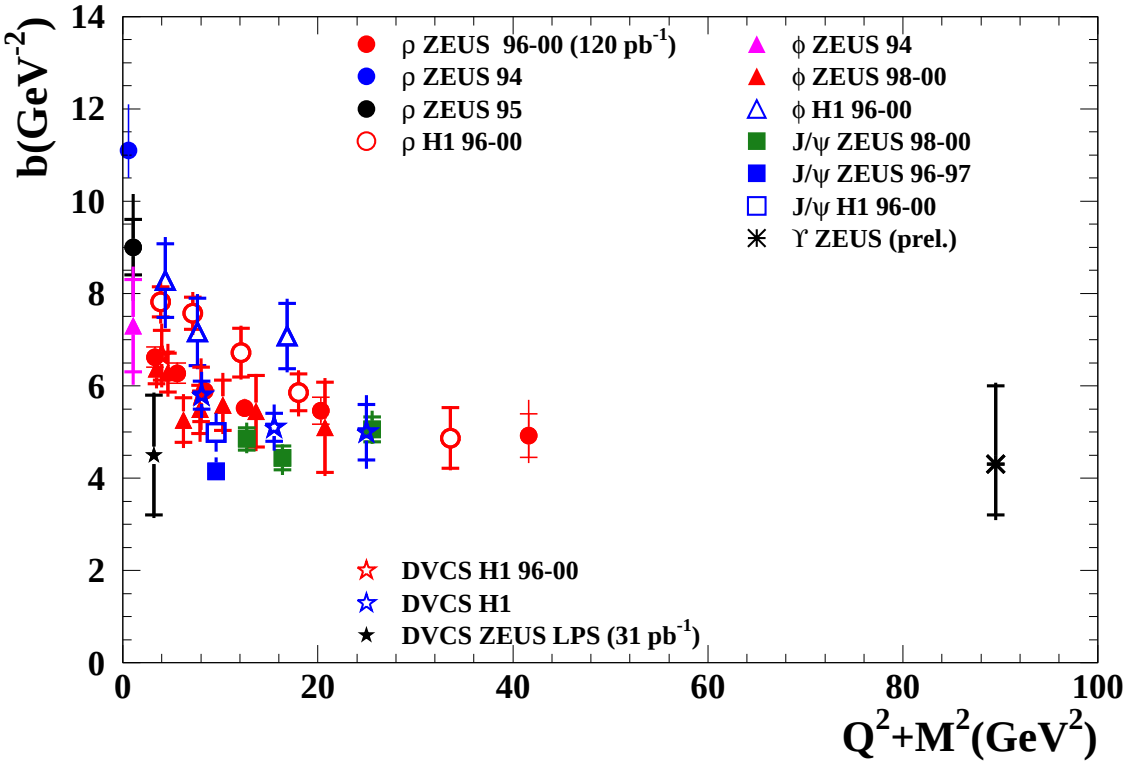
$\Upsilon(1S)$ t Dependence



- Integrated luminosity: $486\,\mathrm{pb}^{-1}$
- Kinematic range: $Q^2 < 1\,\mathrm{GeV}^2$, $60 < W_{\gamma p} < 220\,\mathrm{GeV}$
- dN/dt distribution in mass range $(9.33 - 9.66)\,\mathrm{GeV}$ is fitted with exponential.

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

$\Upsilon(1S)$ t Dependence



- New data point at $Q^2 + M^2 = 89.5\,\mathrm{GeV}^2$
- Range in $Q^2 + M^2$ is extended by about a factor of 2.

New Results

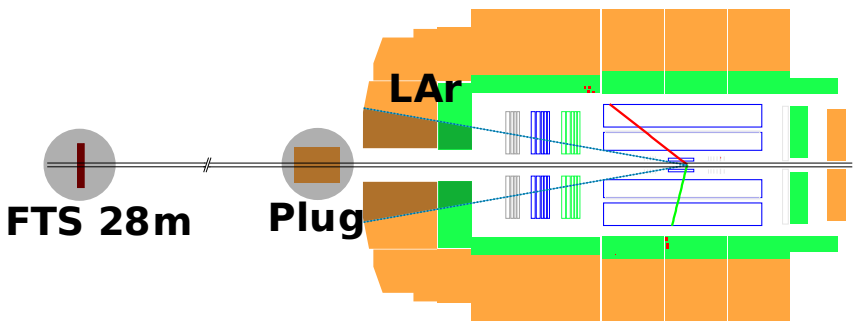
Exclusive diffractive J/ψ production at low $W_{\gamma p}$ with the H1 detector at HERA

H1prelim-11-011

Experimental Aspects

Experimentally always overlap of two processes: elastic and proton dissociative J/ψ production.
To disentangle them and measure them separately, two steps are done:

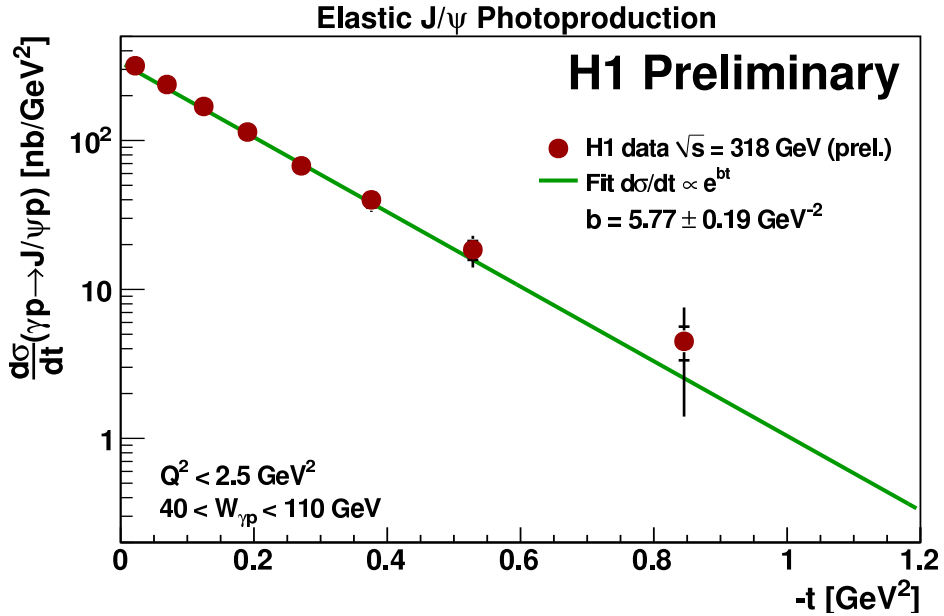
- A tag flag, composed of signals from forward detectors, splits the sample in two groups of enriched elastic (no tag) and enriched proton dissociative (tagged) events.

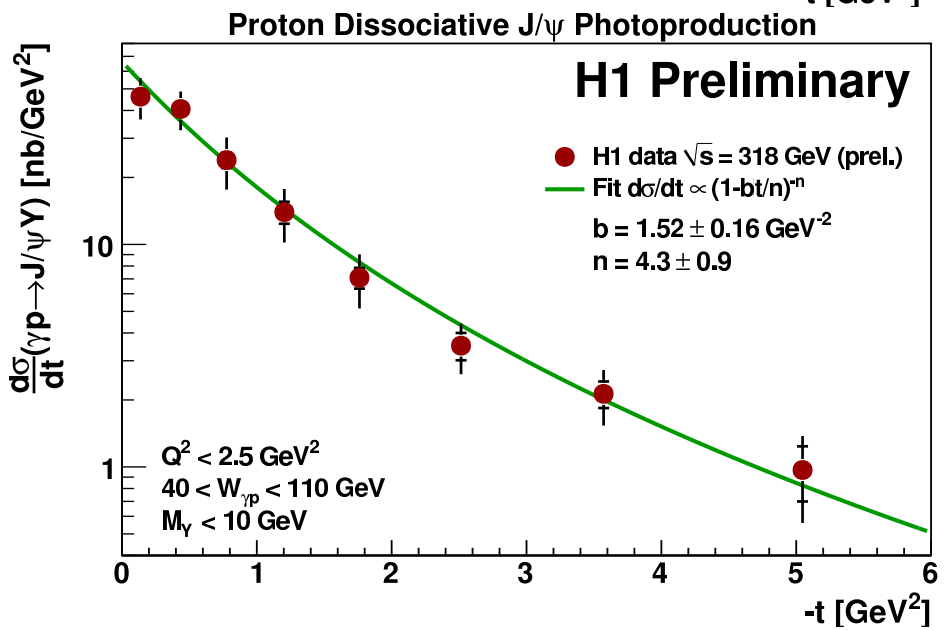


- Unfolding uses information from tagging and returns as a result the number of elastic and proton dissociative events.

In addition the unfolding allows also correct treatment of migration effects. $\Rightarrow$ Improved uncertainty treatment.

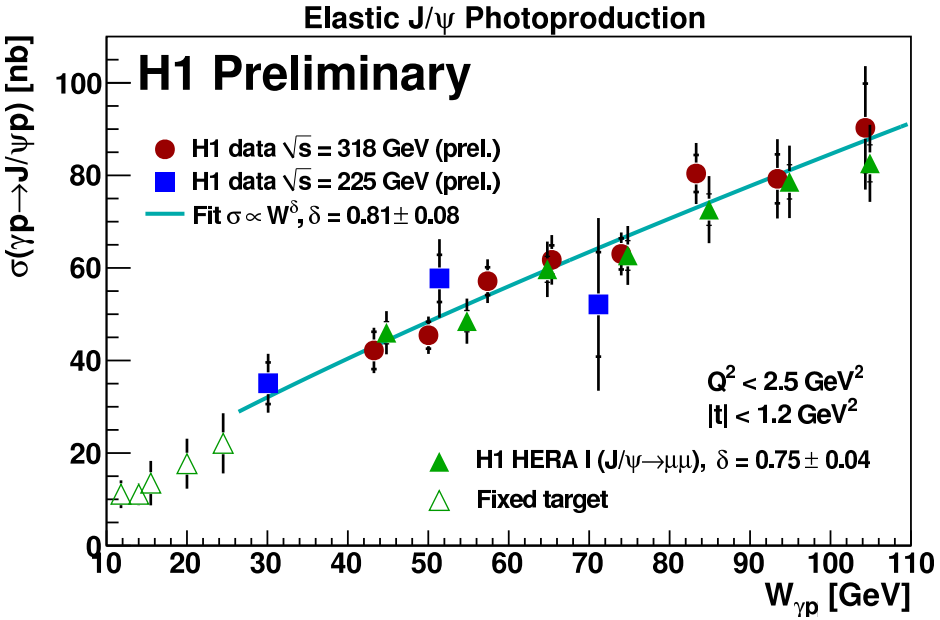
t Slope Measurement

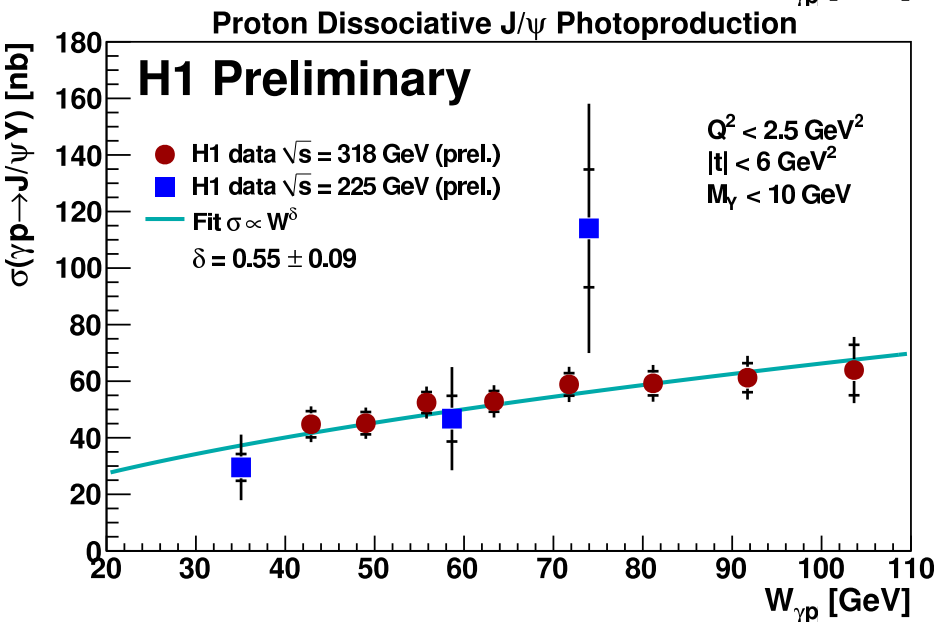




- Elastic cross section follows an exponential function.
  $d\sigma/dt \propto e^{-b|t|}$ with
  $b = 5.77 \pm 0.19\,\mathrm{GeV}^{-2}$
  (Error includes statistical and systematic uncertainty.)
- Proton dissociative cross section fitted with function proportional to $(1 + b/n|t|)^{-n}$, which behaves like an exponential at small $|t|$ an like a power law at large $|t|$ values.

$W_{\gamma p}$ Measurement





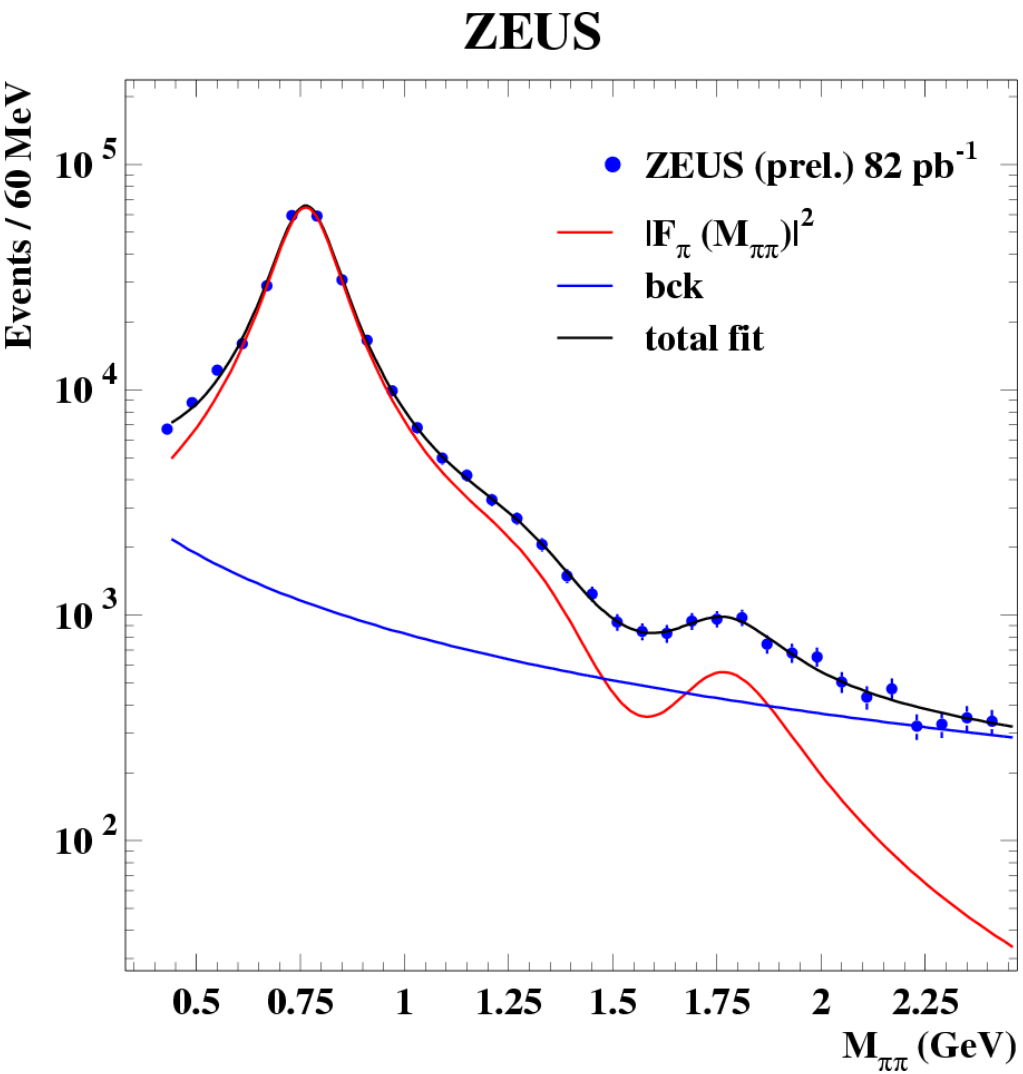
- Two data sets with different center of mass energy are used.
- Fit with $\sigma \propto W^{\delta}$ gives for elastic $\delta = 0.81 \pm 0.08$ and for proton dissociative $\delta = 0.55 \pm 0.09$.
- Elastic δ slope in agreement with H1 (HERA I) measurement (DESY-05-161): $\delta = 0.75 \pm 0.03 \pm 0.03$. Zeus measurement (DESY-02-008): $\delta = 0.69 \pm 0.02 \pm 0.03$

New Results

Exclusive electroproduction of two pions at HERA

ZEUS-prel-10-012

Fitting ρ, ρ', ρ'' Resonances



- Fitting ρ, ρ' and ρ'' resonances with

$$\frac{dN(M_{\pi\pi})}{dM_{\pi\pi}} = N\left[|F_\pi(M_{\pi\pi})|^2 + \frac{B}{M^n_{\pi\pi}}\right]$$

with pion form factor

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

(Kuhn-Santamaria parametrisation)

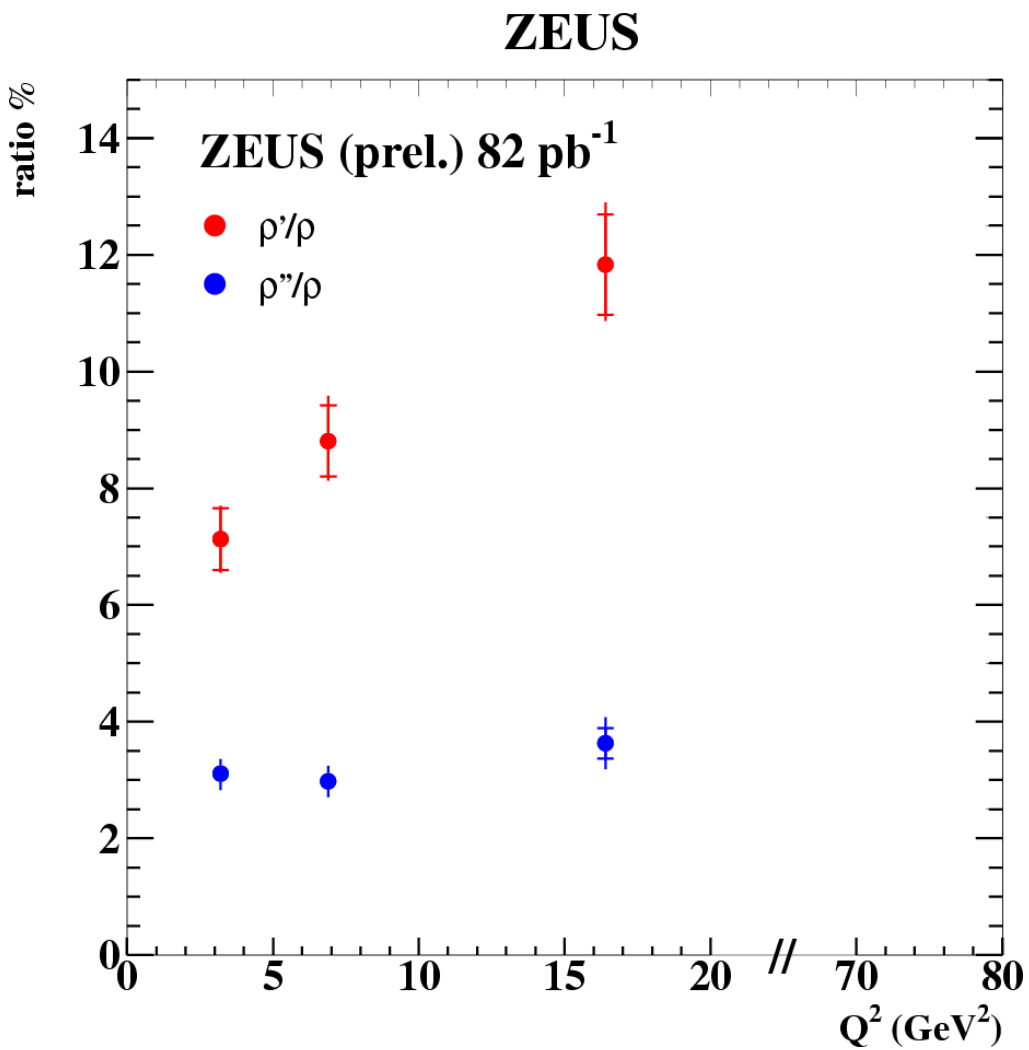
- β and γ relative amplitudes
  BW: Breit-Wigner distributions

Result from the Fit

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

- Relative sign pattern $+ - +$. Behaviour is the same as in $e^+e^- \to \pi^+\pi^-$.

Cross Section Ratios as Function of Q^2



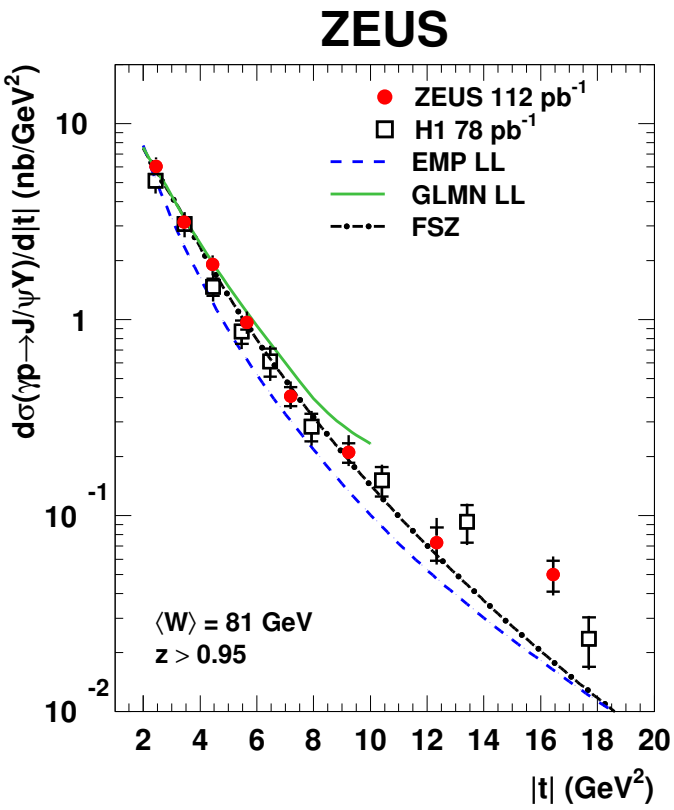
- Interesting behaviour of ρ'/ρ and ρ''/ρ ratios:
  - ρ'/ρ increases with Q^2
  - ρ''/ρ is constant in Q^2
- ratio $= \sigma(V)BR(V \to \pi\pi)/\sigma(\rho)$ with $V = \rho', \rho''$
- Last Q^2 bin: $10 - 80\,\mathrm{GeV}^2$

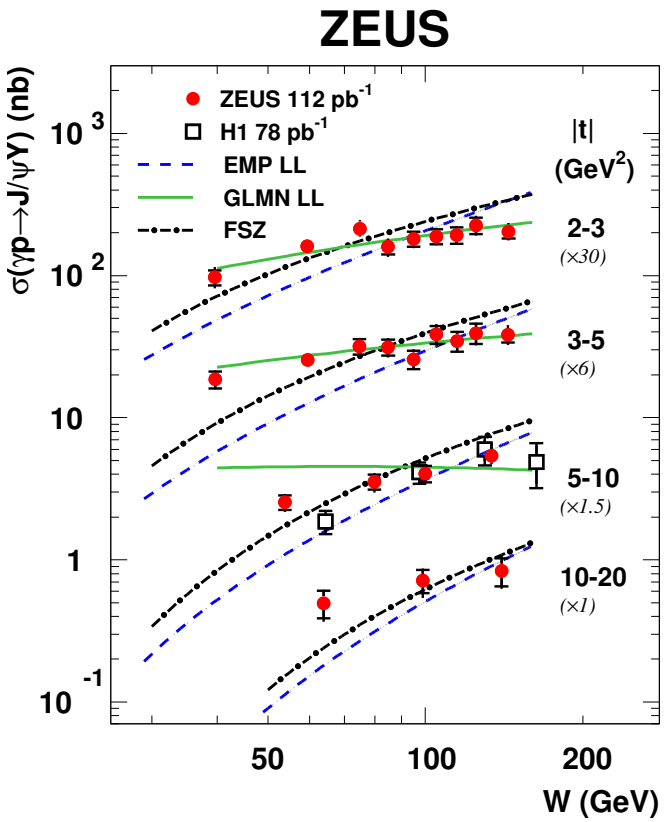
Summary

- HERA provides a large amount of vector meson data in a wide kinematic range.
- Interplay of soft and hard region can extensively be tested.
- New measurements of Υ, J/ψ and ρ, ρ', ρ''.

Backup

High $|t|$ analysis (DESY-09-137)





- Elastic process heavily suppressed for $|t| > 2\,\mathrm{GeV}^2$
- Hard scale provided by $|t|$ and J/ψ mass.

- No exponential behaviour anymore, but power law ($\frac{d\sigma}{d|t|} \propto |t|^{-n}$) does well describe the data.
  $n = 1.9 \pm 0.1, \quad 2 < |t| < 5\,\mathrm{GeV}^2$
  $n = 3.0 \pm 0.1, \quad 5 < |t| < 20\,\mathrm{GeV}^2$
- No given model is able to describe the data in the full shown phase space:
  - GLMN (DGLAP) description well up to $t = 5\,\mathrm{GeV}^2$
  - EMP (BFKL) lies below the data
  - FSZ describes data up do to $t = 12\,\mathrm{GeV}^2$, but fails to describe the $W_{\gamma p}$ dependence.

Helicity

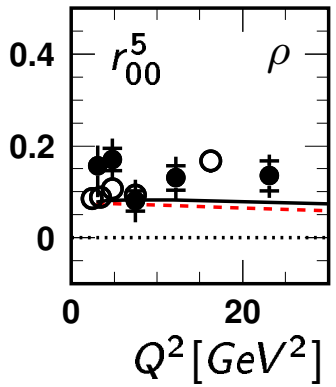
- Complex helicity amplitudes: $T_{\lambda_V \lambda_p, \lambda_\gamma \lambda_Y}$
- Helicity of Y not measured and Proton not polarised $\Big\} \rightarrow T_{\lambda_V, \lambda_\gamma}$

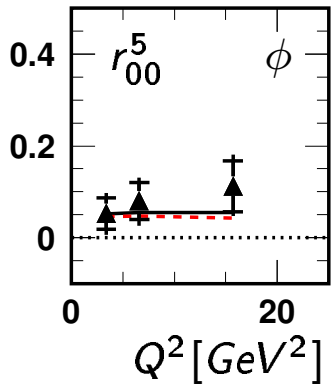
  $\Rightarrow$ 15 independent spin matrix elements r^i_{jk} measurable
- Natural parity exchange (NPE): $T_{-\lambda_V \lambda_p, -\lambda_\gamma \lambda_Y} = (-1)^{\lambda_V - \lambda_\gamma} T_{\lambda_V \lambda_p, \lambda_\gamma \lambda_Y}$

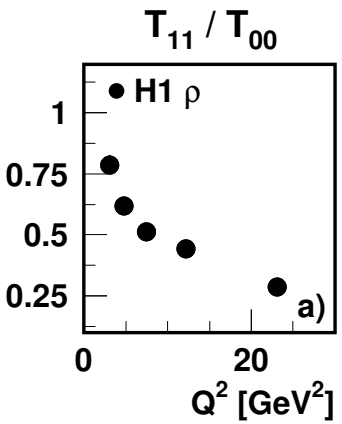
  $\Rightarrow$ 5 independent amplitudes:

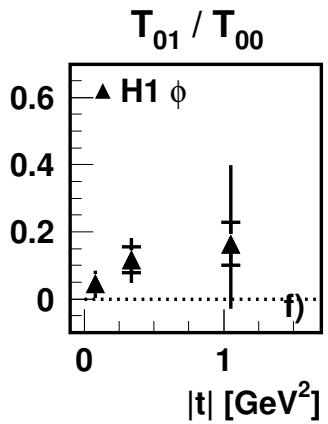
Helicity conserving	T_{00}, T_{11}
Single flip	T_{01}, T_{10}
Double flip	T_{-11}
- s-channel helicity conservation (SCHC)
  Helicity of virtual photon is transferred to the VM.
  $\Rightarrow$ Single and double flip amplitudes are zero. Only T_{00} and T_{11} are non-zero.
- For NPE and SCHC: Only two independent parameters left.
  Can be chosen as: $R = \sigma_L / \sigma_T$ and phase δ between T_{00} and T_{11}

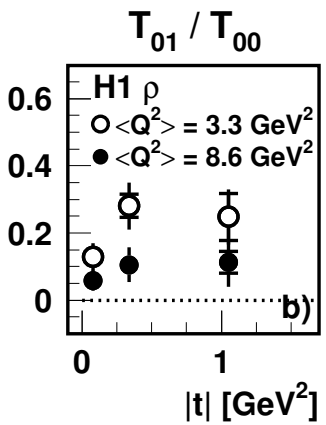
Helicity Amplitudes

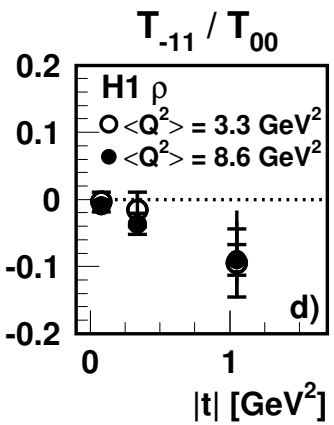






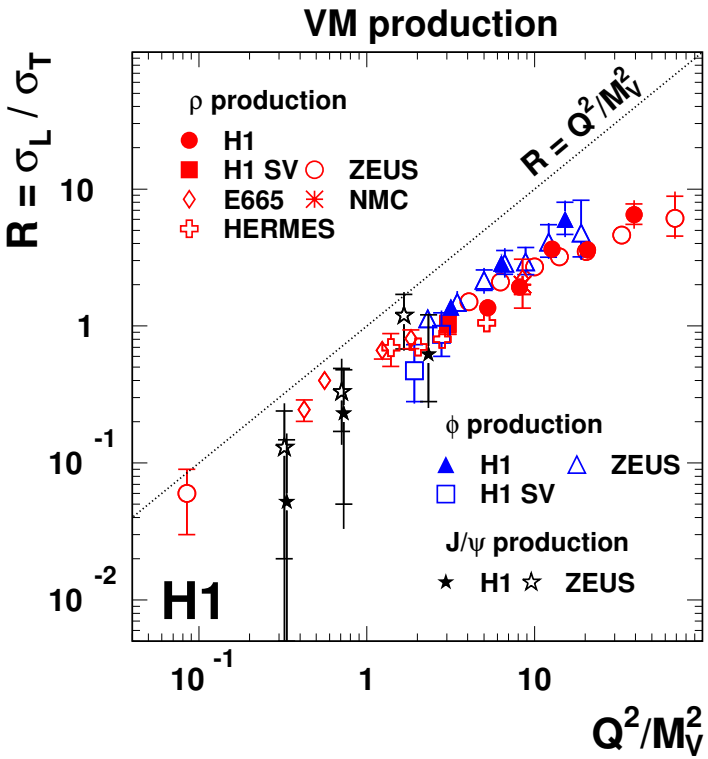






- Significant violation of SCHC, because of non-zero values of r^5_{00}, especially at large $|t|$
- T_{11}/T_{00} decrease consistent with increase of R in Q^2
- T_{01}/T_{00} increases with $|t| \Rightarrow$ SCHC is increasing with $|t|$
- Non-zero values for double flip amplitude T_{-11}

Cross Section Ratio $R = \sigma_L/\sigma_T$



- R sensitive to interacting dipole size and VM wave function.
- R behaviour consistent with theory.
- Q^2/M_V^2 provides common scale for ρ, ϕ and J/ψ.