Low x Workshop
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Diffractive Production of Vector Particles

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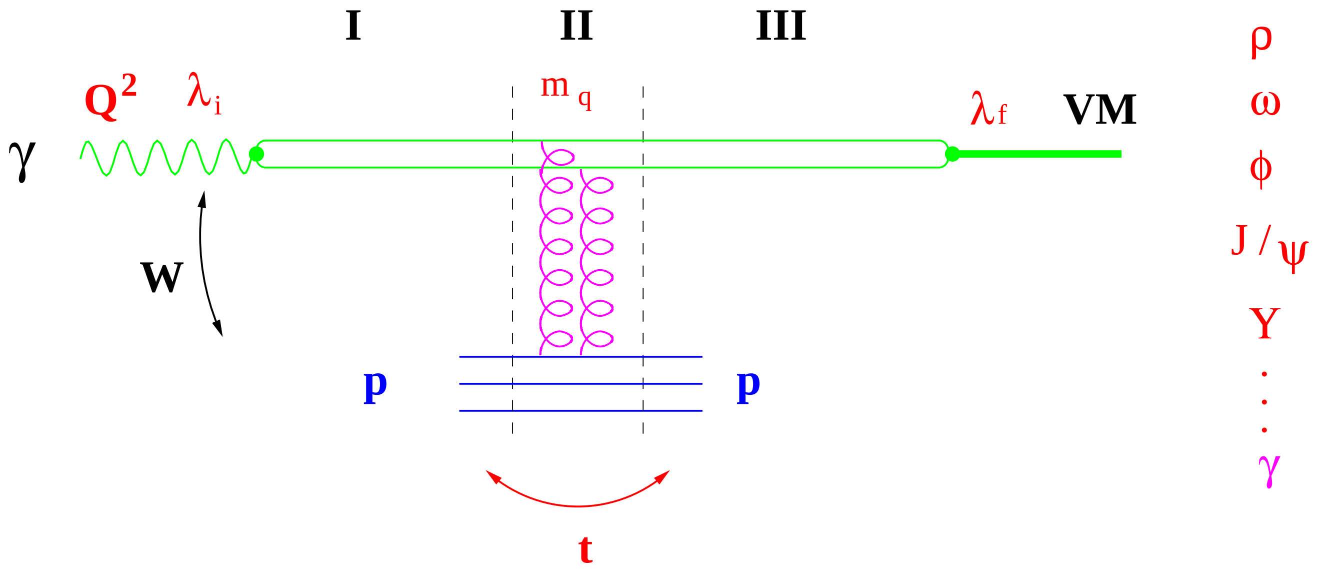
Contents

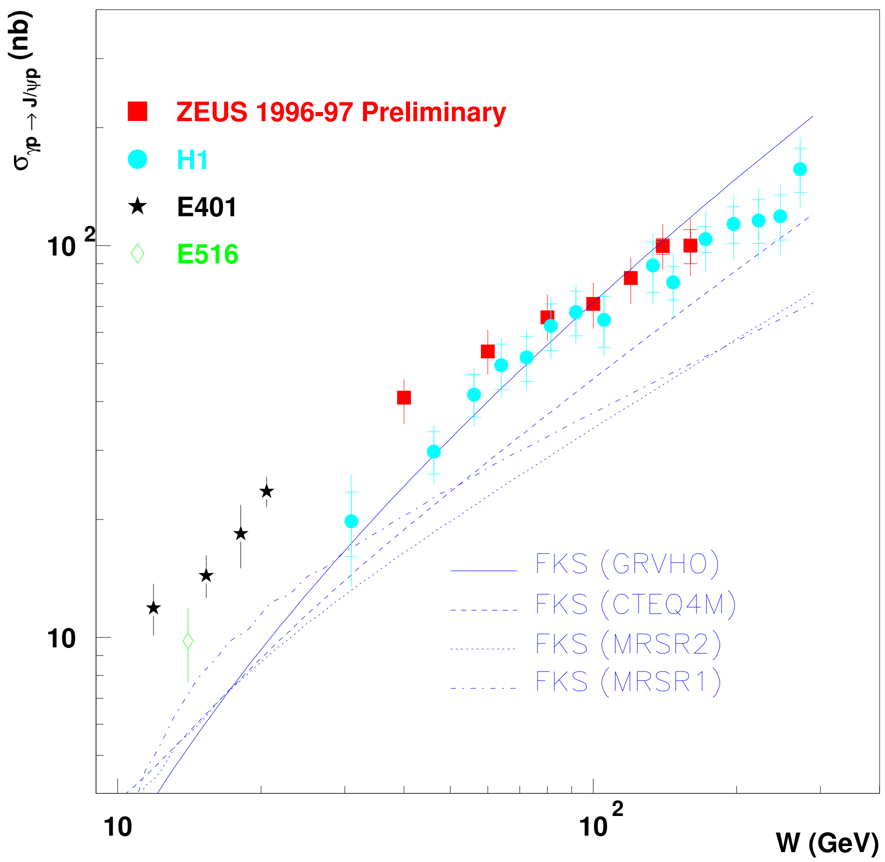
Vector particle production in QCD:



- new results from Vector Mesons
  - J/ψ in Photoproduction (m_q)
  - ρ, ω and ϕ electroproduction (Q^2, t)
  - ρ, ϕ Helicity studies (λ)
- Deeply Virtual Compton Scattering (γ)

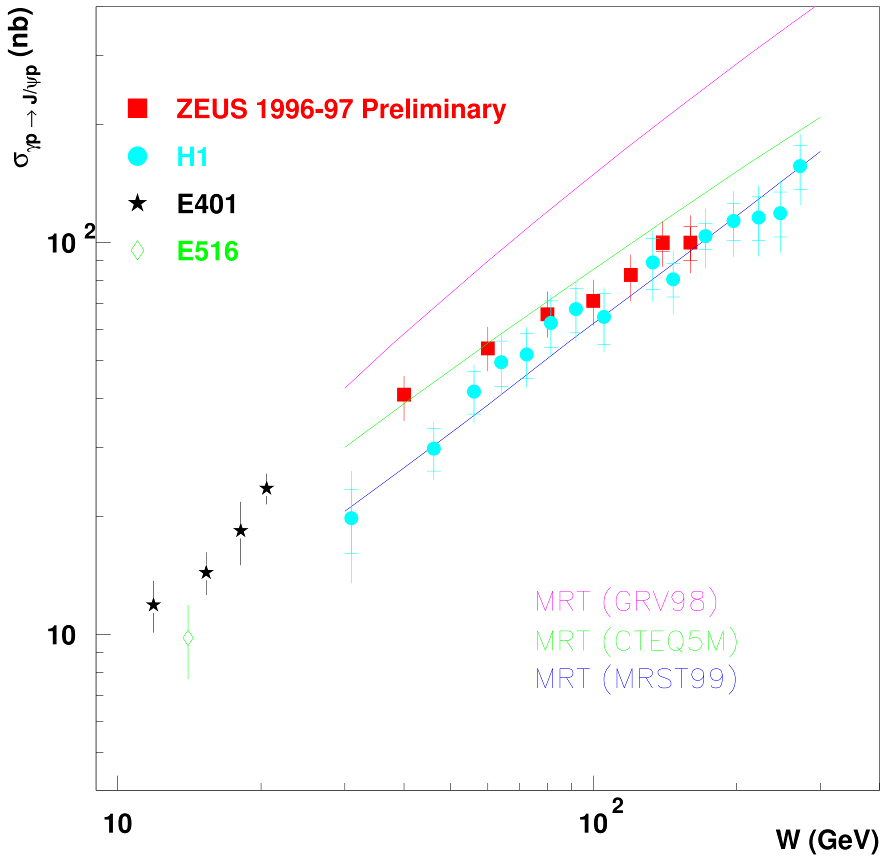
J/Ψ in Photoproduction

- observation of 'hard' behaviour
- $\sigma \sim W^{\delta}$
  $\Rightarrow \delta = 0.8 \;\; (\mathrm{J}/\psi) \Longleftrightarrow 0.22 \;\; (\text{soft physics})$



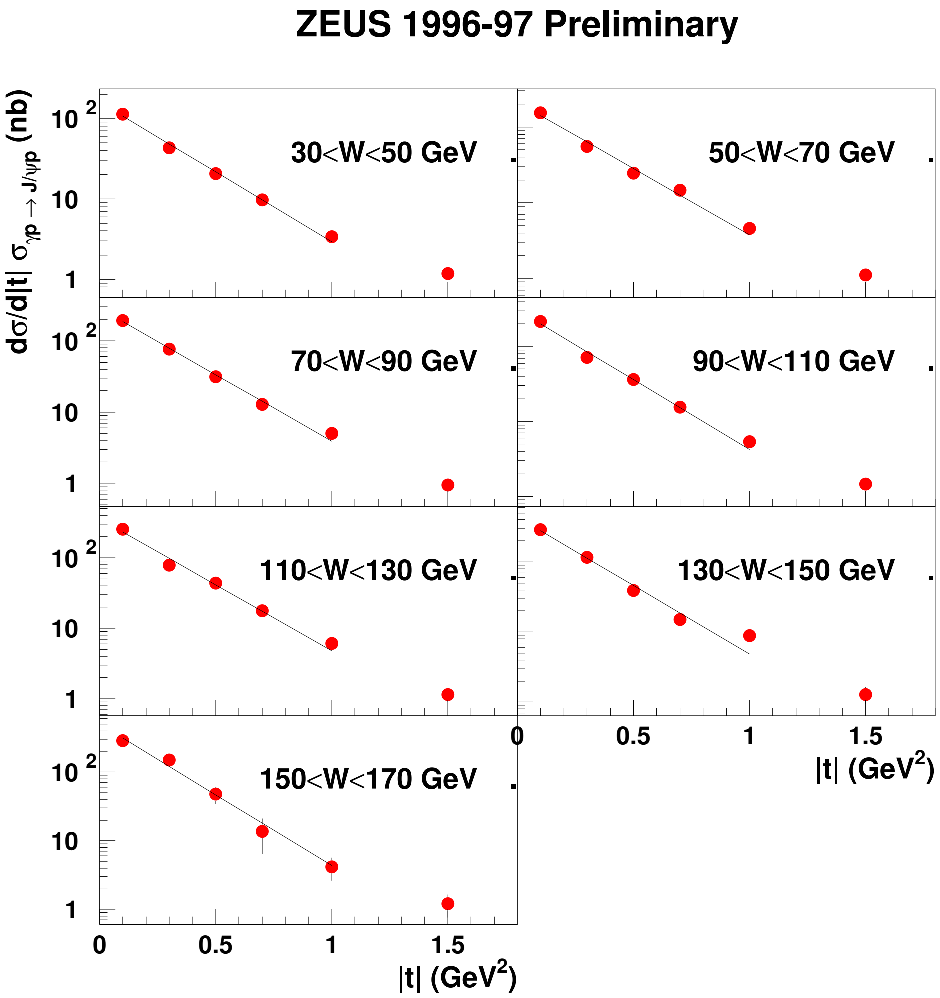
- extended kinematic range
- high precision
- sensitivity to different parameterizations of the gluon density $\Rightarrow \sigma \sim (xg(x))^2$
- uncertainties (real part of Amplitude, off diagonal gluon, Fermi motion, ...)

J/Ψ in Photoproduction



J/Ψ in Photoproduction

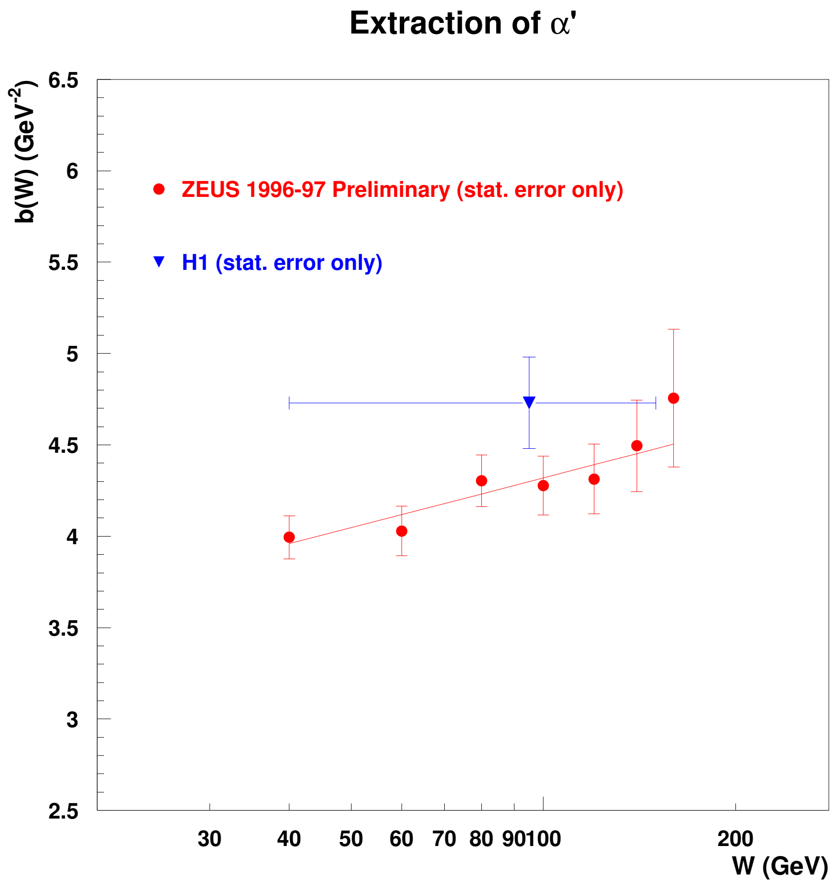
- Regge Phenomenology: $\frac{d\sigma}{dt} \sim e^{-b|t|}$
  - $b = b_0 + 2\alpha' log\left(\frac{W}{W_0}\right)^2$
  - $\alpha(t) = \alpha_0 + \alpha' t$



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

J/Ψ in Photoproduction

- Regge phenomenology:
  - $\frac{d\sigma}{dt} \sim e^{-b|t|}$
  - $b = b_0 + 2\alpha' log\left(\frac{W}{W_0}\right)^2$
  - $\alpha' = 0.25\,\mathrm{GeV}^{-2}$ (DL) $\Rightarrow$ shrinkage
  - QCD: no shrinkage

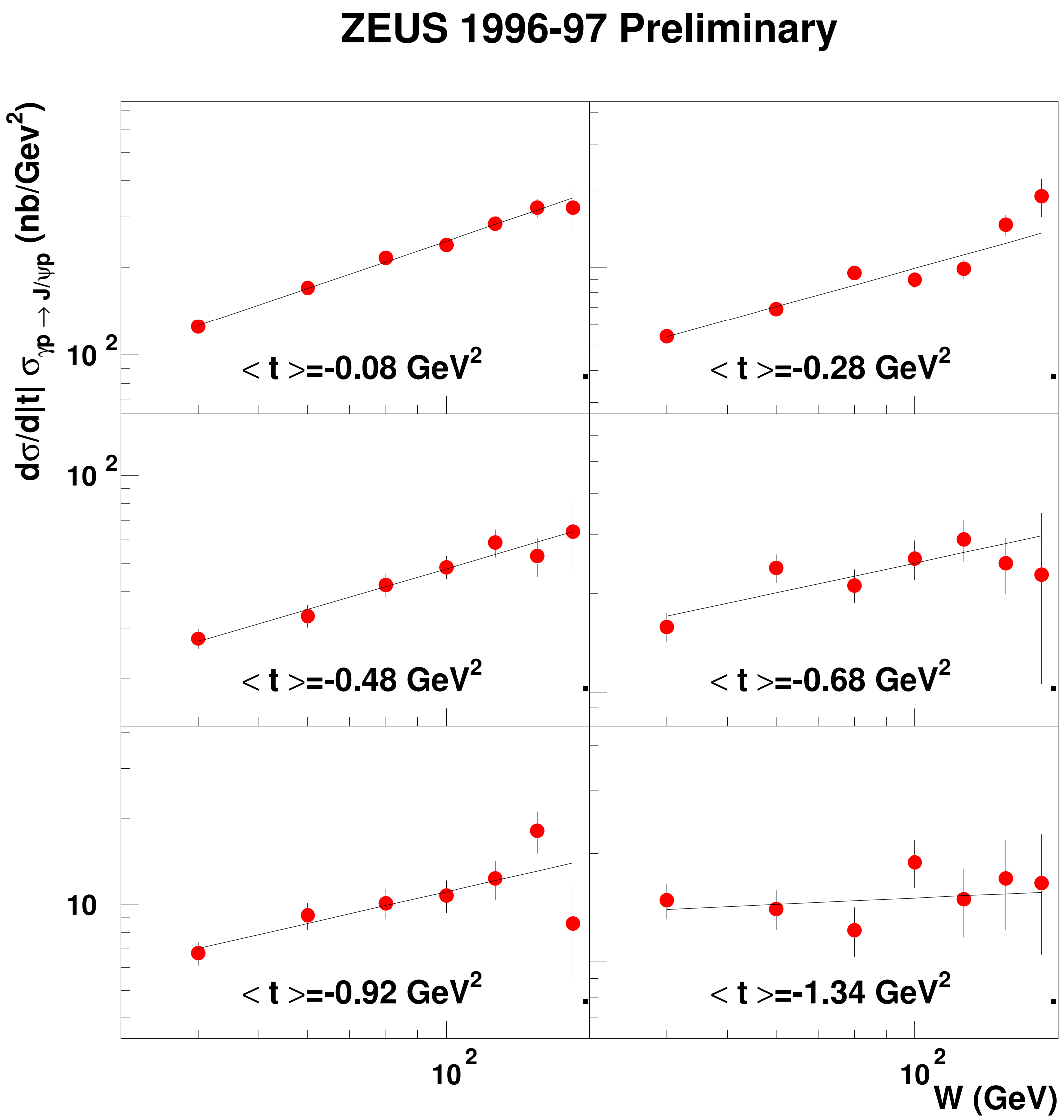


- ZEUS: $\alpha' = (0.098 \pm 0.035(stat) \pm 0.050(syst))\,\mathrm{GeV}^{-2}$

$\Rightarrow$ α' smaller than expected for soft physics and compatible with 0.

J/Ψ in Photoproduction

- $W_{\gamma p}$ dependence of $d\sigma/dt$ at fixed t
- $\frac{d\sigma}{dt} = f\,(t)\,(W^2)^{(2\alpha(t)-2)}$



- fit: $\frac{d\sigma}{dt} \sim (W^2)^{(2\alpha(t)-2)}$

J/Ψ in Photoproduction

- $W_{\gamma p}$ dependence of $d\sigma/dt$ at fixed t
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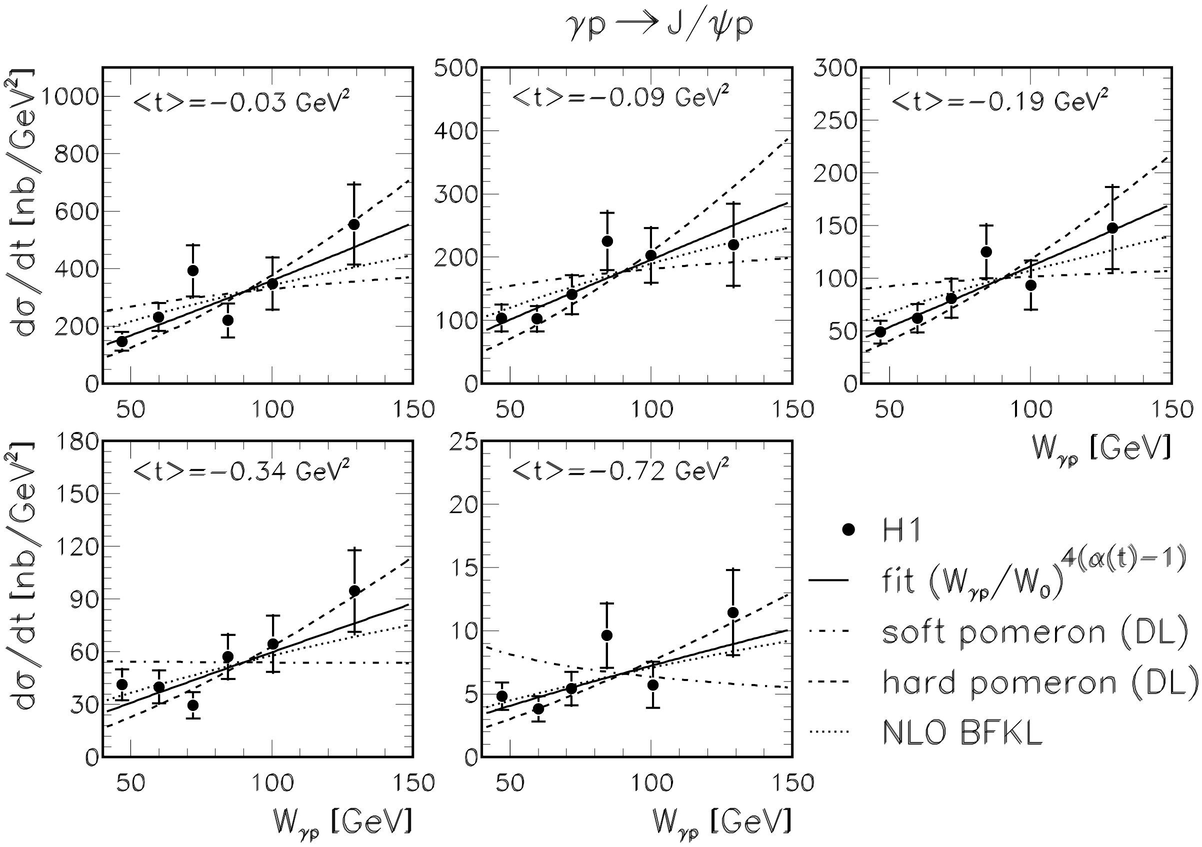
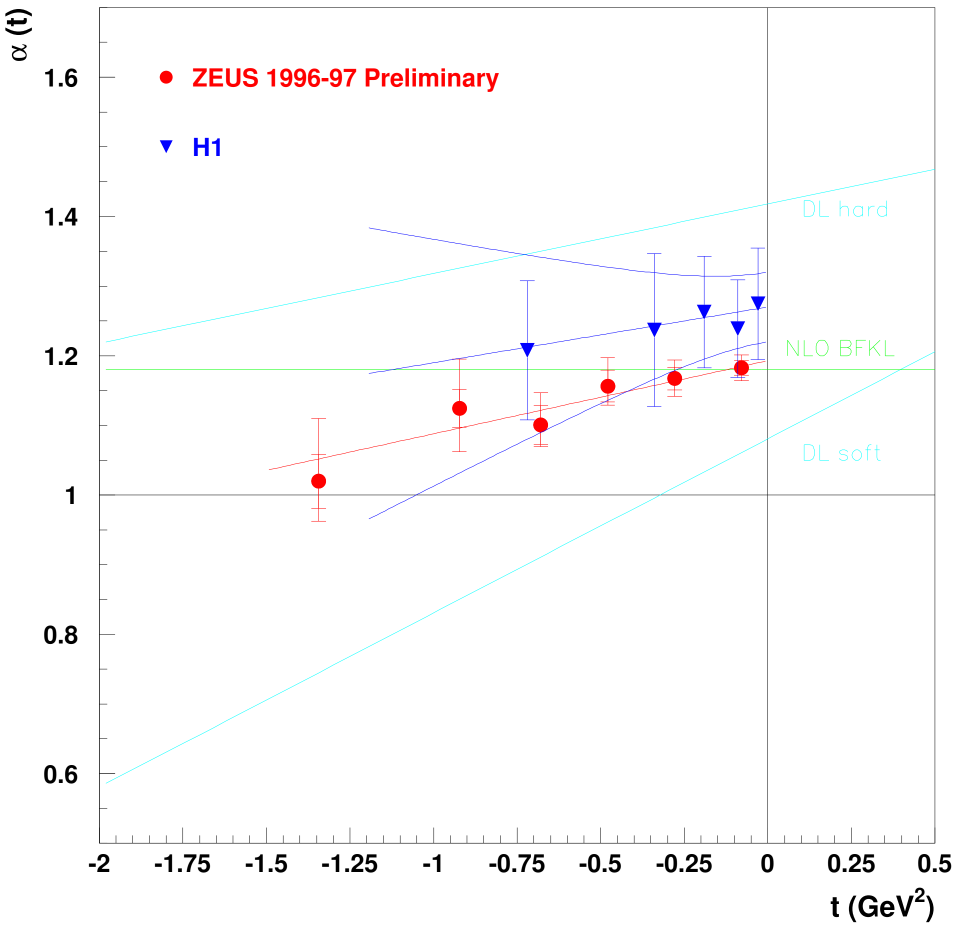


- fit: $\frac{d\sigma}{dt} \sim (W^2)^{(2\alpha(t)-2)}$

J/Ψ in Photoproduction

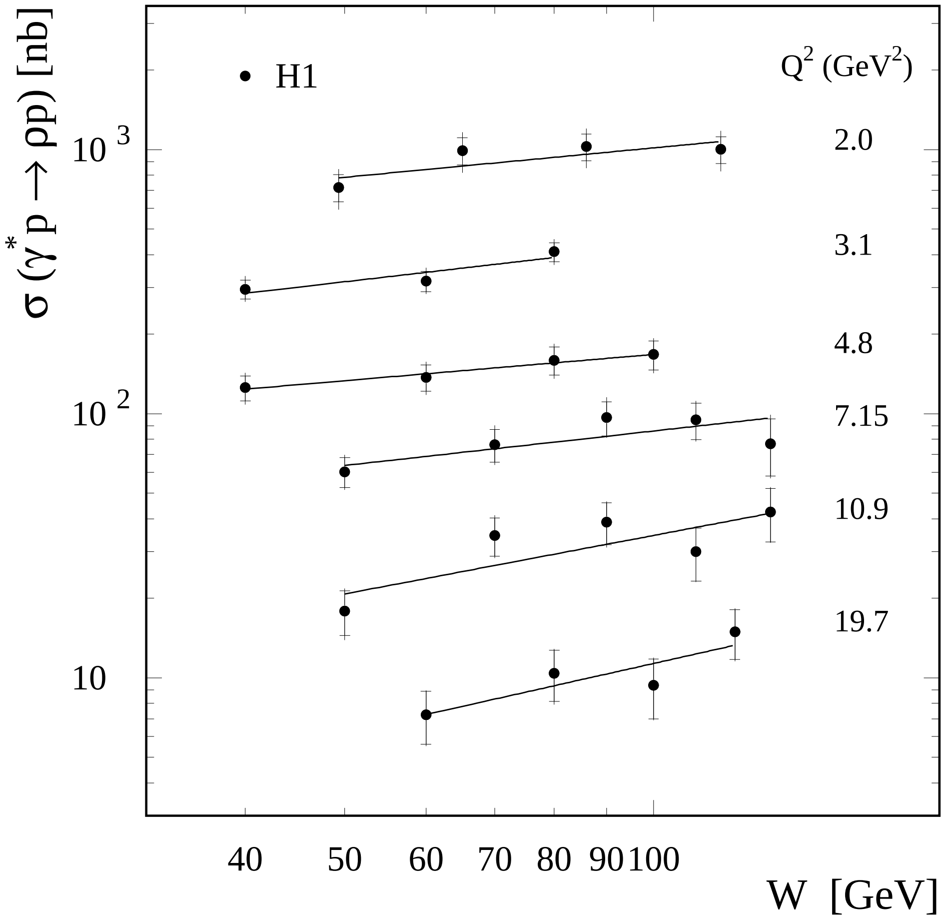
- fit: $\alpha\left(t\right) = \alpha_0 + \alpha' t$



- Results:
  - H1: $\alpha_0 = 1.27 \pm 0.05$
    $\alpha' = (0.08 \pm 0.17)\,\mathrm{GeV}^{-2}$
  - ZEUS: $\alpha_0 = 1.193 \pm 0.011^{+0.015}_{-0.010}$
    $\alpha' = \left(0.105 \pm 0.024^{+0.022}_{-0.020}\right)\,\mathrm{GeV}^{-2}$
  - DL: $\alpha_0 = 1.08$
    $\alpha' = (0.25)\,\mathrm{GeV}^{-2}$

ρ electroproduction

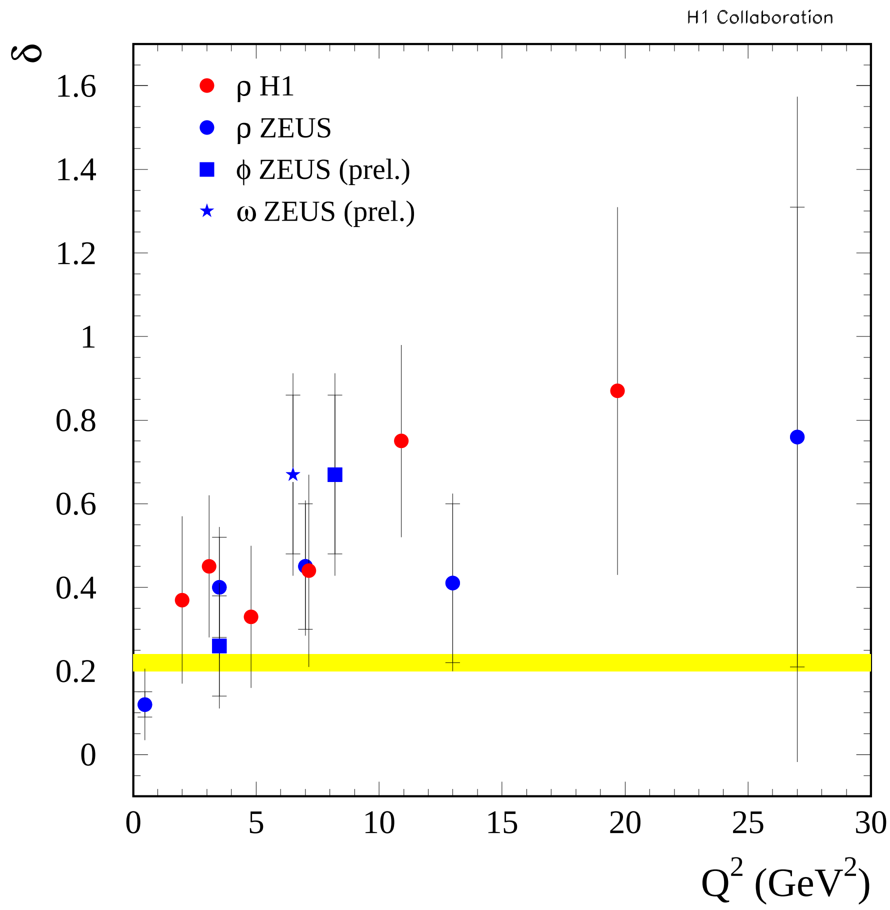
- $W_{\gamma p}$ dependence in function of Q^2



- fit: $\sigma \sim W^\delta$
- $\delta = 0.8\,(J/\psi) \Leftrightarrow 0.22\,(\text{soft physics})$

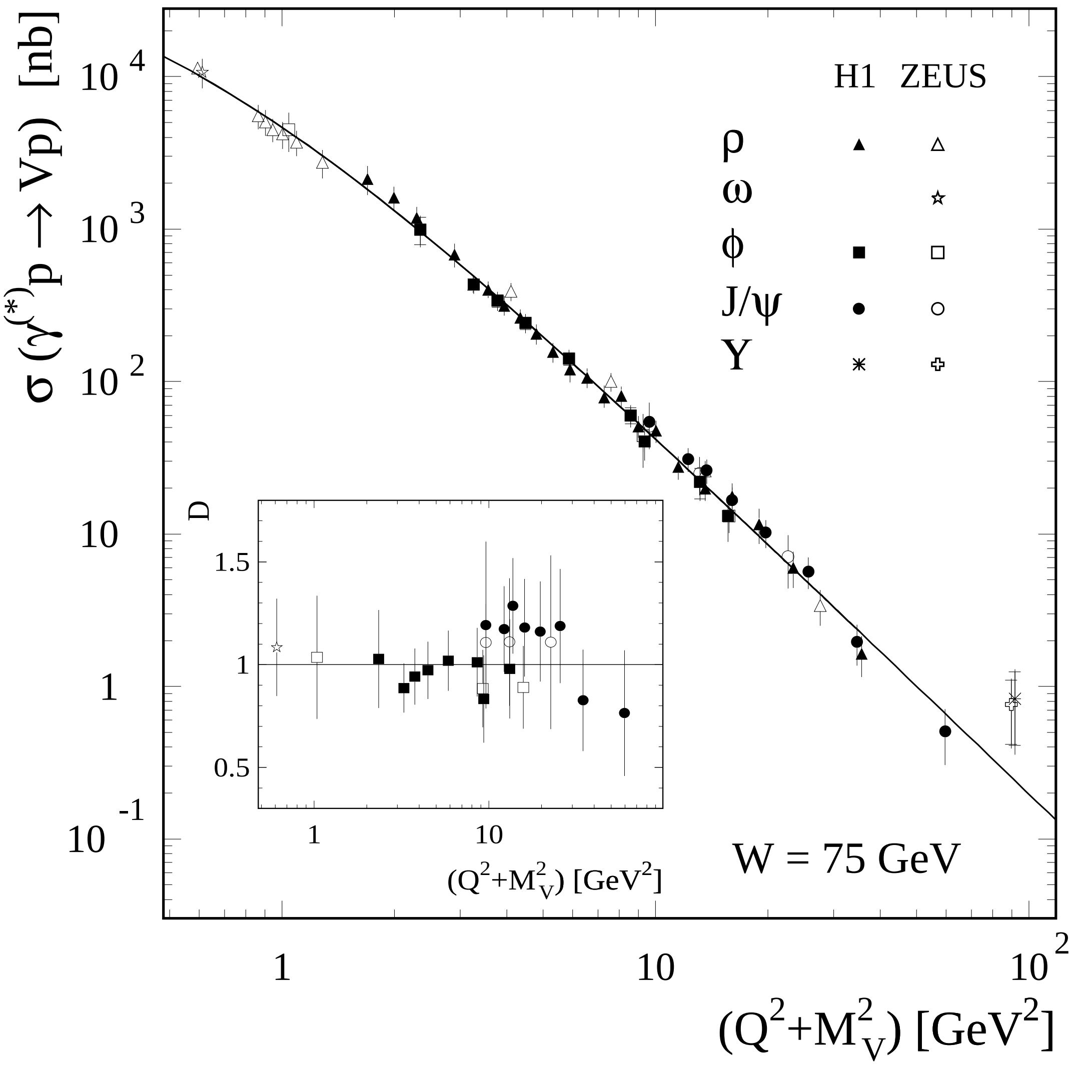
light VM electroproduction

- fit: W^δ
- determine δ for all light vector mesons as function of Q^2



- tendency of 'hard' behaviour observed
- more precise data needed

total cross section of VM production



- universal behaviour as function of $Q^2 + M_V^2$

$\Rightarrow$ σ flavor independent

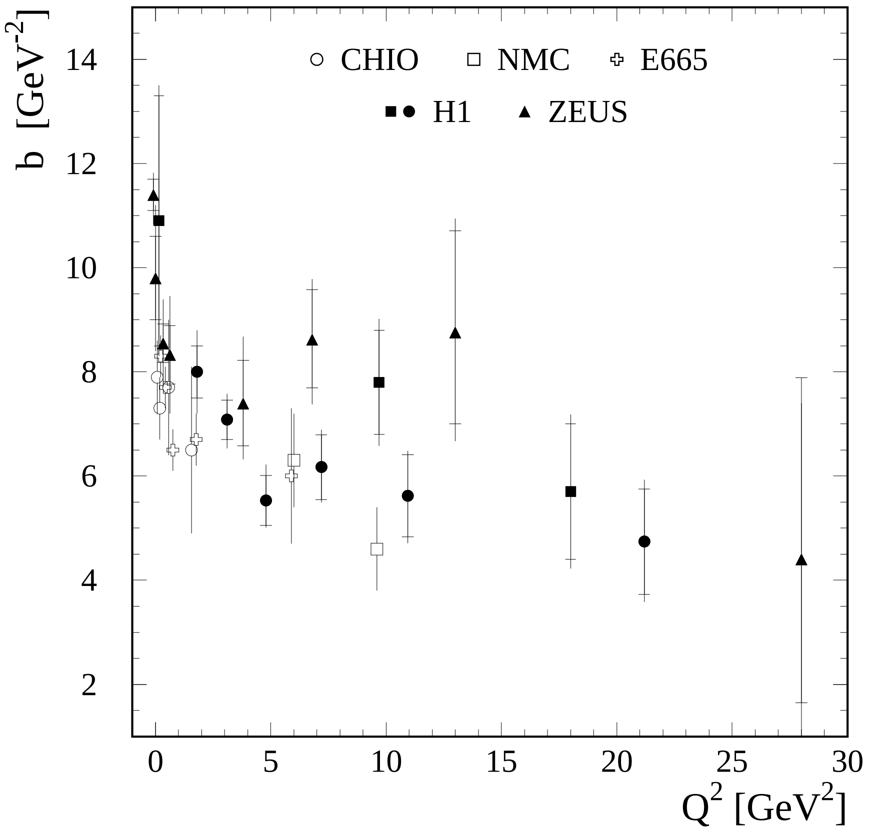
$\Rightarrow$ non perturbative effects are not large

$\Rightarrow$ relevant variable used in the wavefunction is $Q^2 + M_V^2$

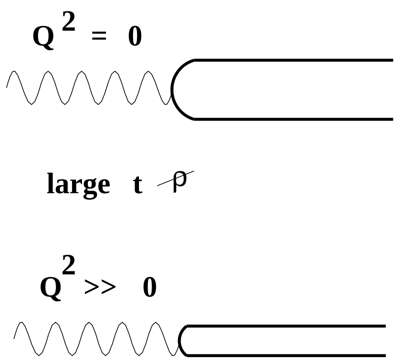
$\Rightarrow$ challenge for perturbative QCD

t-dependence of ρ electroproduction

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

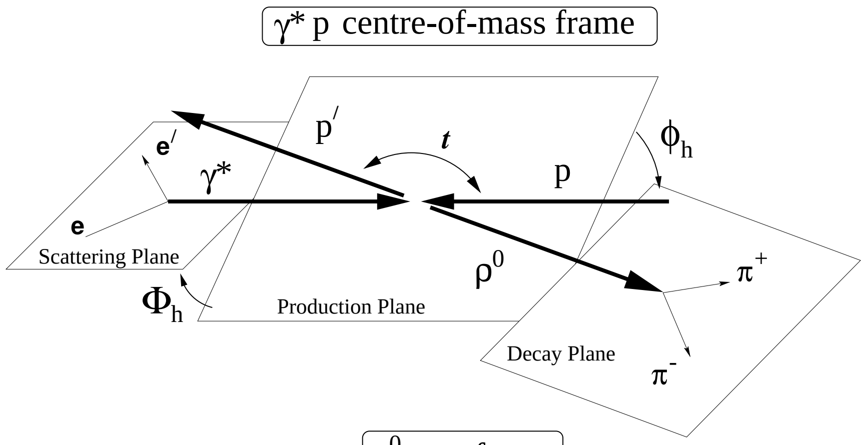


- transverse size of $q\bar{q}$ decreases with Q^2: $r_\perp^2 \sim \frac{1}{Q^2}$
  $\Rightarrow$ b decreases with increasing Q^2

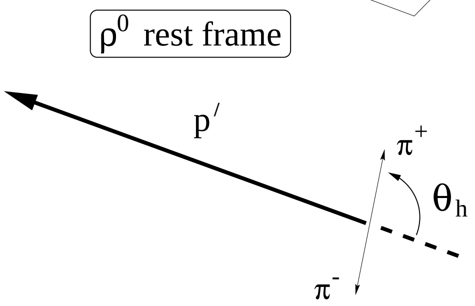


ρ and ϕ helicity studies

a)



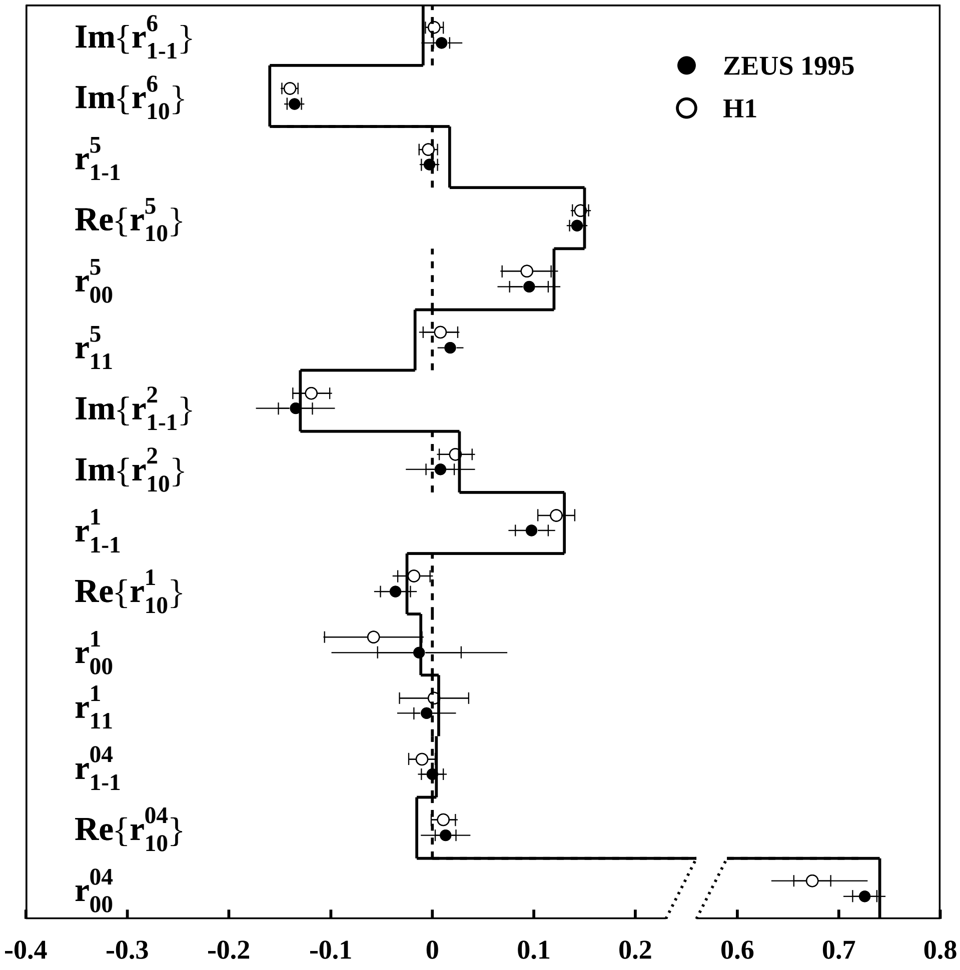
b)



Decay angular distribution $W(\cos\theta, \varphi, \phi)$:

$$
\begin{aligned}
W(\cos\theta,\varphi,\phi) = \frac{3}{4\pi} \Big\{ & \frac{1}{2}(1 - r^{04}_{00}) + \frac{1}{2}(3\, r^{04}_{00} - 1)\ \cos^2\theta \\
& - \sqrt{2}\ \mathrm{Re}\ r^{04}_{10}\ \sin 2\theta \cos\varphi - r^{04}_{1-1}\ \sin^2\theta \cos 2\varphi \\
& - \varepsilon\ \cos 2\phi \left(r^{1}_{11}\ \sin^2\theta + r^{1}_{00}\ \cos^2\theta - \sqrt{2}\ \mathrm{Re}\ r^{1}_{10}\ \sin 2\theta \cos\varphi \right. \\
& \qquad \left. - r^{1}_{1-1}\ \sin^2\theta \cos 2\varphi \right) \\
& - \varepsilon\ \sin 2\phi \left(\sqrt{2}\ \mathrm{Im}\ r^{2}_{10}\ \sin 2\theta \sin\varphi + \mathrm{Im}\ r^{2}_{1-1}\ \sin^2\theta \sin 2\varphi \right) \\
& + \sqrt{2\varepsilon\ (1+\varepsilon)}\ \cos\phi\ \Big[r^{5}_{11}\ \sin^2\theta + r^{5}_{00}\ \cos^2\theta \\
& \qquad - \sqrt{2}\ \mathrm{Re}\ r^{5}_{10}\ \sin 2\theta \cos\varphi - r^{5}_{1-1}\ \sin^2\theta \cos 2\varphi \Big] \\
& + \sqrt{2\varepsilon\ (1+\varepsilon)}\ \sin\phi\ \Big[\sqrt{2}\ \mathrm{Im}\ r^{6}_{10}\ \sin 2\theta \sin\varphi \\
& \qquad + \mathrm{Im}\ r^{6}_{1-1}\ \sin^2\theta \sin 2\varphi \Big] \Big\}
\end{aligned}
$$

ρ helicity studies

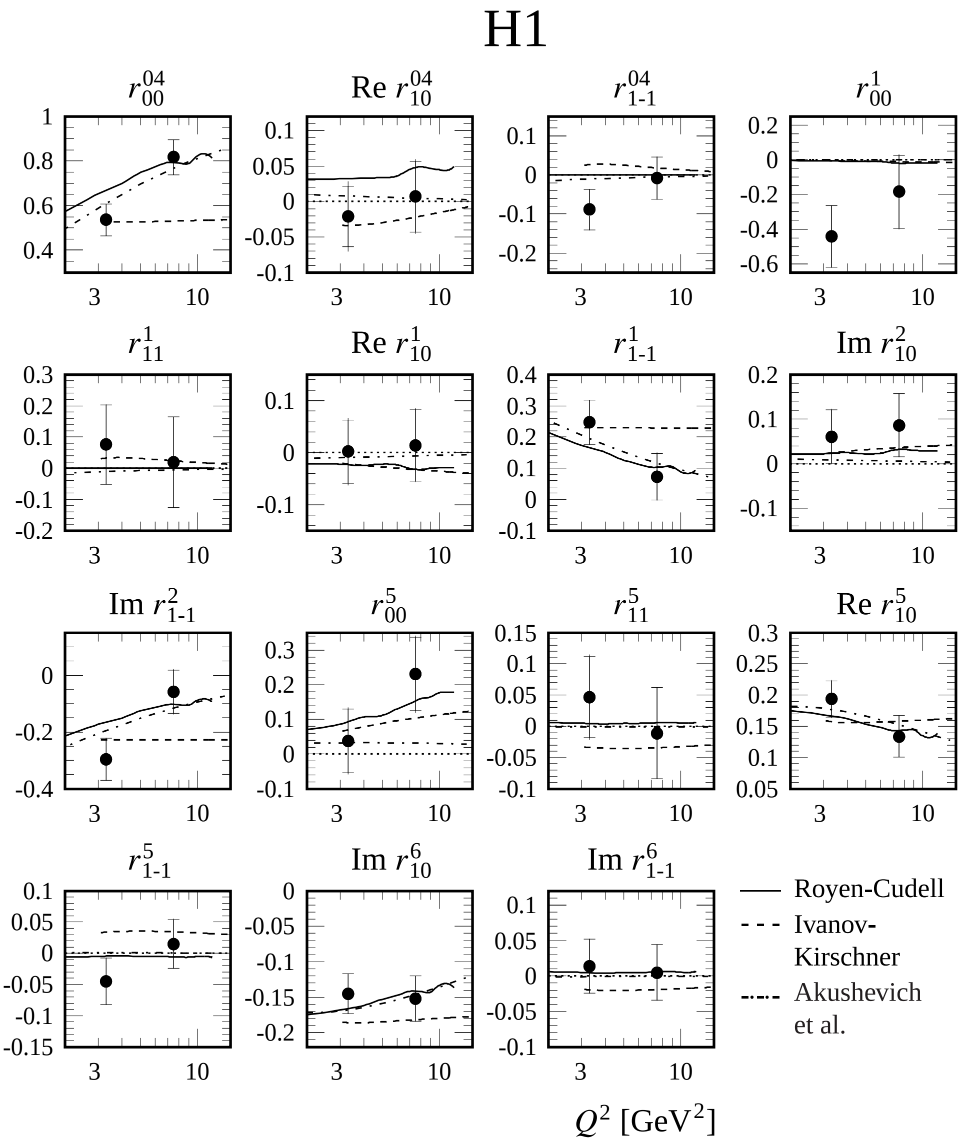


– – – SCHC

—— Ivanov and Kirschner

- observation of SCHC violation
- agreement with perturbative QCD

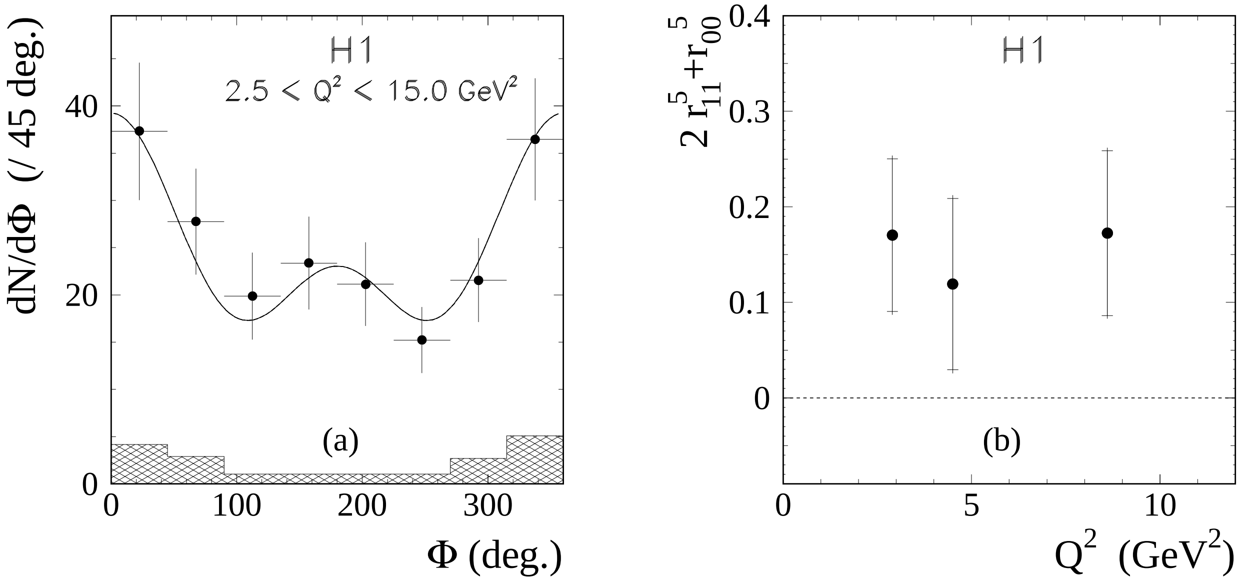
ϕ helicity analysis



- observation of SCHC violation
- agreement with perturbative QCD

ϕ helicity studies

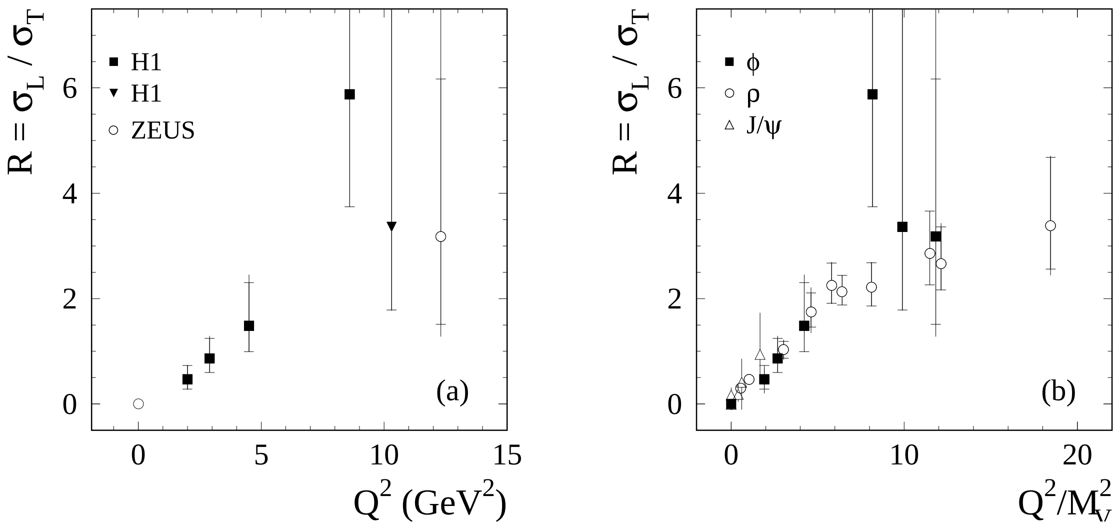
- integrate over ϕ and θ
  $\Rightarrow W(\Phi) \sim$
  $$1 - \epsilon \cos 2\Phi \left(2r^1_{11} + r^1_{00}\right) + \sqrt{2\epsilon\left(1+\epsilon\right)} \cos \Phi \left(2r^5_{11} + r^5_{00}\right)$$
- $W(\Phi)$ flat for SCHC



- observation of SCHC violation

light vector meson helicity studies

- extract $R = \frac{\sigma_L}{\sigma_T}$
- $R = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}$

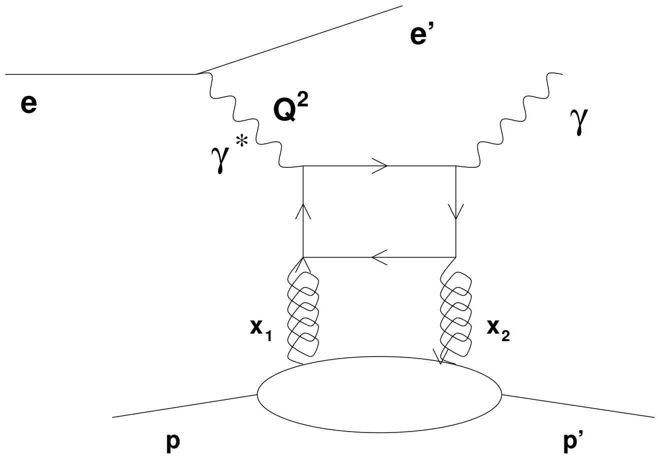


- observation of universal behaviour of R as function of Q^2/M_V^2
- R increases with Q^2 and indication of flattening at high Q^2

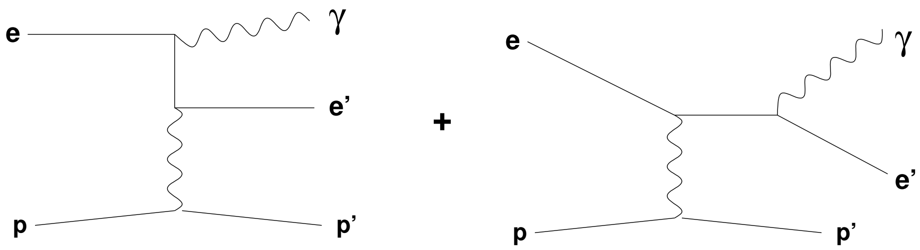
$\Rightarrow$ flavour independence
$\Rightarrow$ small higher order corrections

Deeply Virtual Compton Scattering

$\Rightarrow ep \longrightarrow e\gamma p$



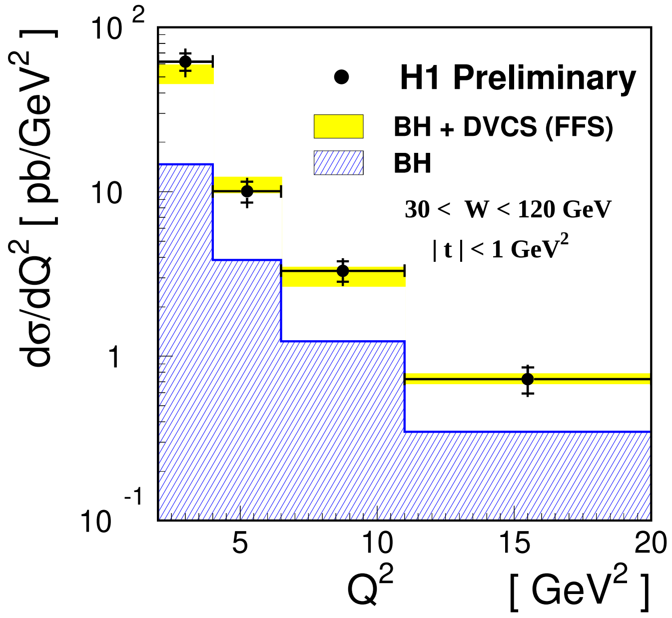
- smaller uncertainties than VM production (wave function)
- $|xg(x,Q^2)|^2 \longrightarrow G\,(x_1, x_2, Q^2)$
- Bethe–Heitler process



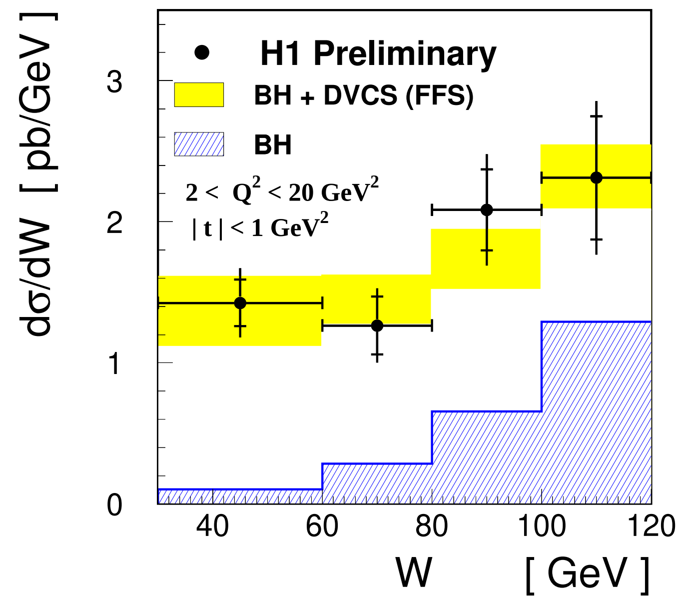
- interference $\Rightarrow$ access to the real part of the QCD Amplitude

Deeply Virtual Compton Scattering

- Q^2 dependence



- W dependence



$\Rightarrow$ good description of the data by LO QCD calculations

Conclusions

- hard behaviour in J/ψ production observed
- indication for hard behaviour in light VM production
- universal description of total cross section for VM production as function of $Q^2 + M_V^2$
- universal description of $R = \frac{\sigma_L}{\sigma_T}$ as function of Q^2/M^2
- DVCS starts is a new laboratory for testing pQCD