New Results on Vector Meson Production in Elastic and Diffractive *ep* Collisions at HERA

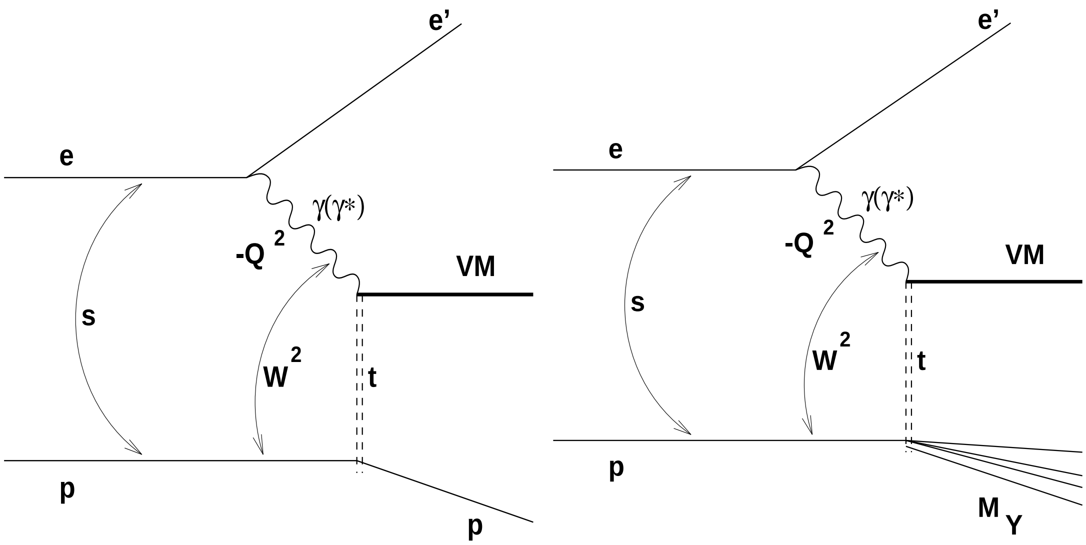
Jacek Ciborowski
Institute of Experimental Physics
University of Warsaw, Poland
cib@fuw.edu.pl

On behalf of the H1 and ZEUS Collaborations

HEP99
15 – 21 July 1999
Tampere, Finland

Introduction

2 HERA: $e^{\pm}p$ at CMS energy ≈ 300 GeV



W : $\gamma^* p$ CMS energy

$-Q^2$: γ^* four-momentum squared

t : 4-mom. transfer sq. to the proton vtx

VM : ρ^0, ω, Φ, J/ψ

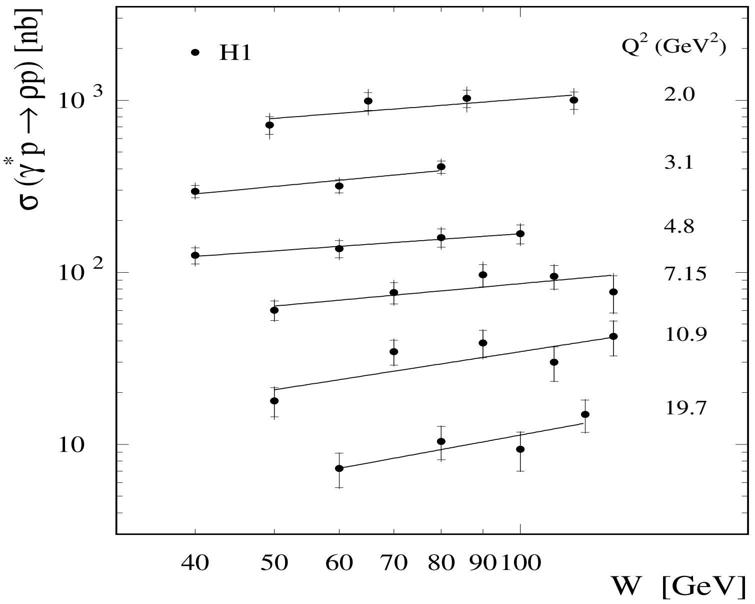
M_Y : hadronic state (proton diss.)

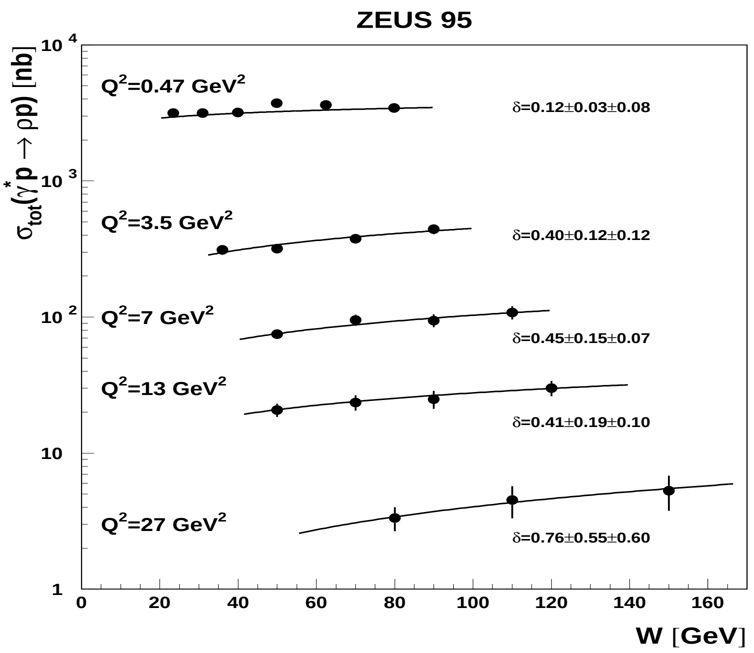
Physics

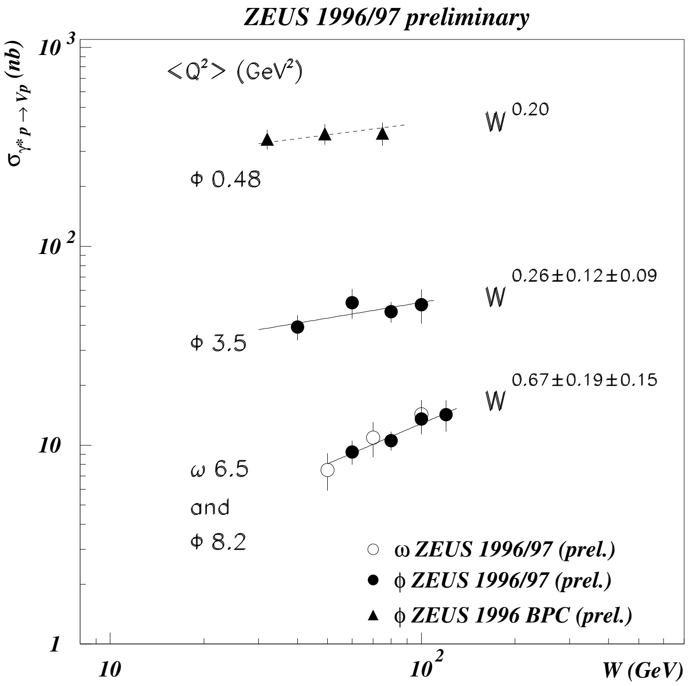
	transition	
SOFT	——————>	HARD
non-perturbative		pQCD
$\propto W^{0.22}$	$\sigma(W)$	$\propto W^{\delta};\ \delta \approx 0.8$
$\propto Q^2/M_V^2$	$R = \sigma_L/\sigma_T$	$R(Q^2, W)$, flattening
transverse	dominant VM polarisation	longitudinal
dependence	flavour	independence
———	scales	$M_V(m_q),\ Q^2,\ \lvert t\rvert$

W dependence (DIS)

Exclusive production of ρ^0, ω and Φ:

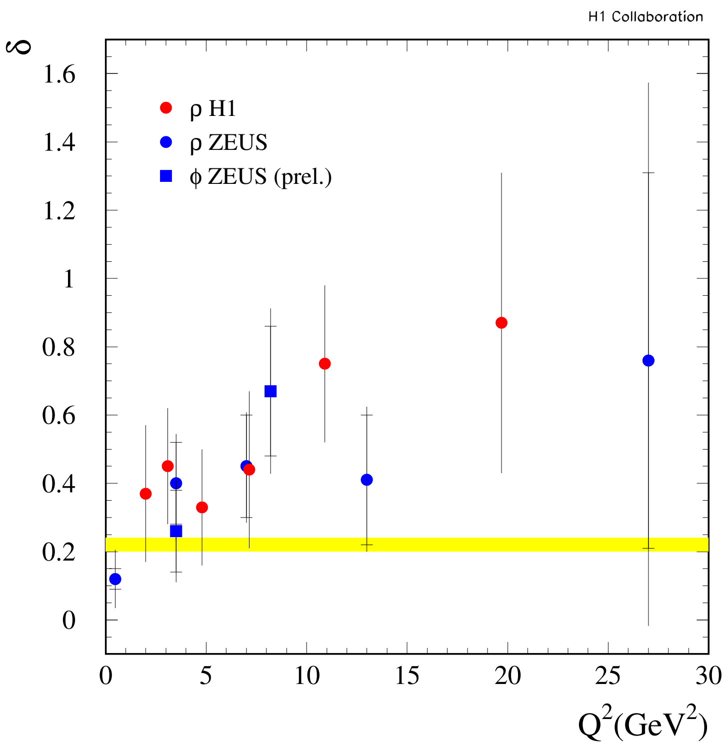






ω, Φ – comparable slopes; in DIS larger than in PHP

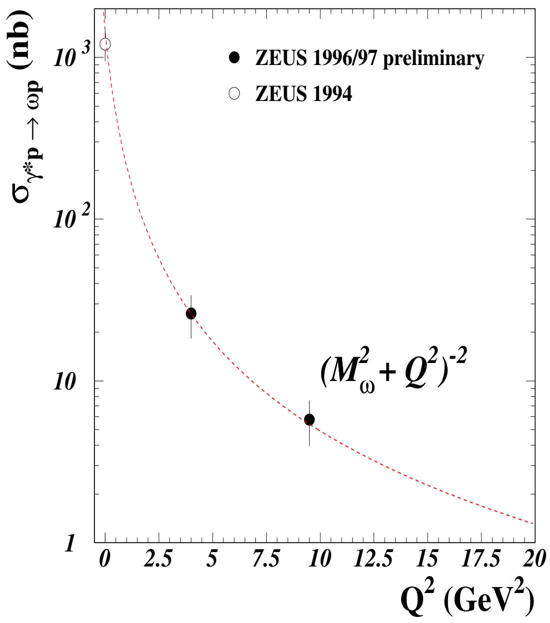
$$\sigma \propto W^{\delta}$$

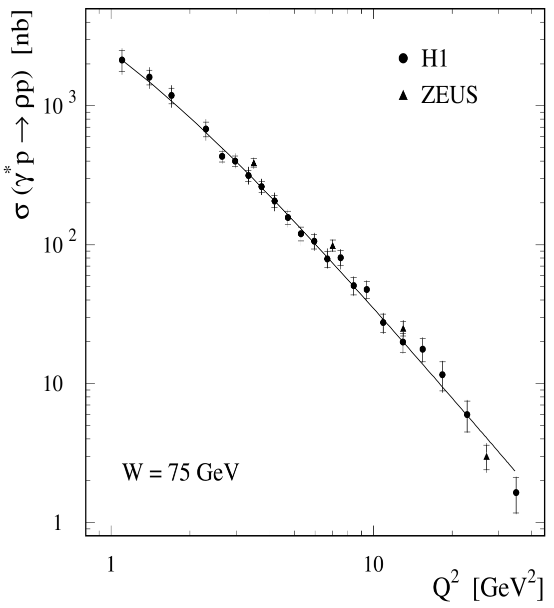


Values of δ increasing with Q^2

Waiting for larger lumi at HERA

Q^2 dependence

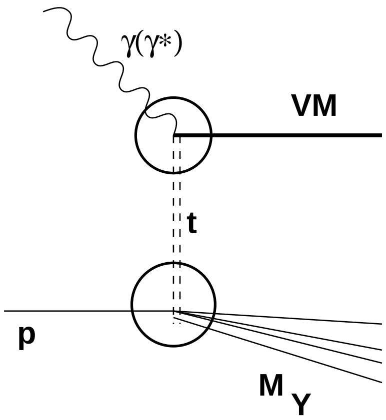




$$\text{Fit } \rho^0\text{: } \sigma \propto 1/(Q^2+m_\rho^2)^n \qquad n = 2.24 \pm 0.09$$

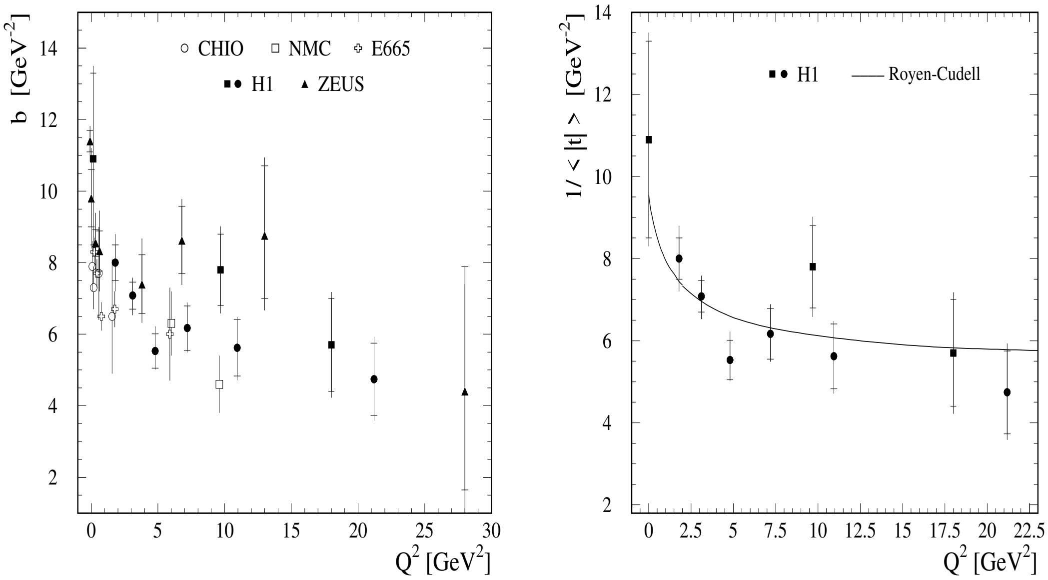
$$\text{QCD: } \sigma \propto \frac{\alpha_s^2(Q^2)}{Q^6}|xg(x,Q^2)|^2 \approx \alpha_s^2(Q^2)/Q^{4.8}$$

t dependence (DIS)



In diffractive processes: $\frac{d\sigma}{dt} \propto e^{-b|t|}$ ($|t| < 1$ GeV^2)

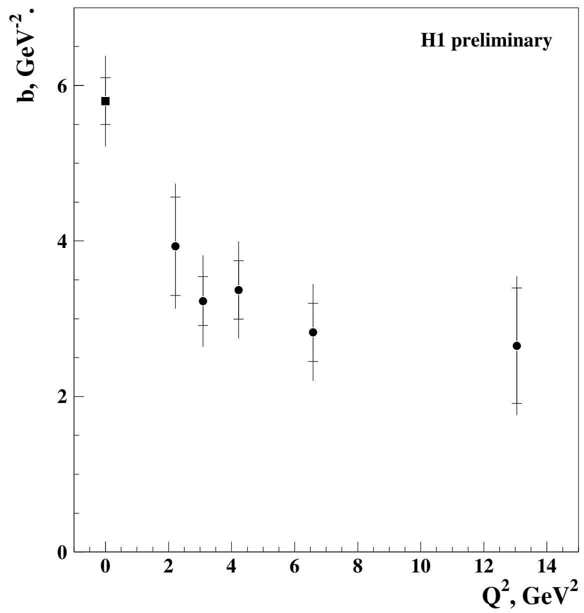
$b \longleftrightarrow R_\perp^2(\text{VM vtx}) \oplus R_\perp^2(\text{p vtx})$

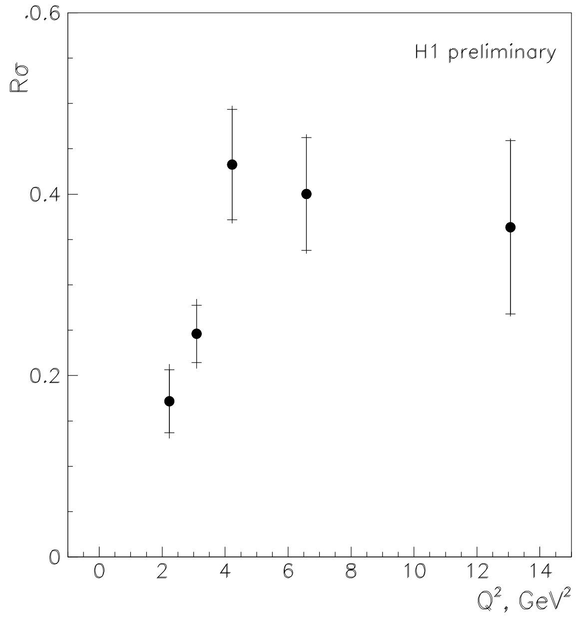


(elastic ρ^0)

Royen & Cudell – QCD (quark off-shellness)

… with proton dissociation





$b \approx 3$ GeV^{-2}: proton vertex $\perp$ size $<$ the proton size

$(|t| < 0.9$ GeV$^2)$

Test of factorisation:

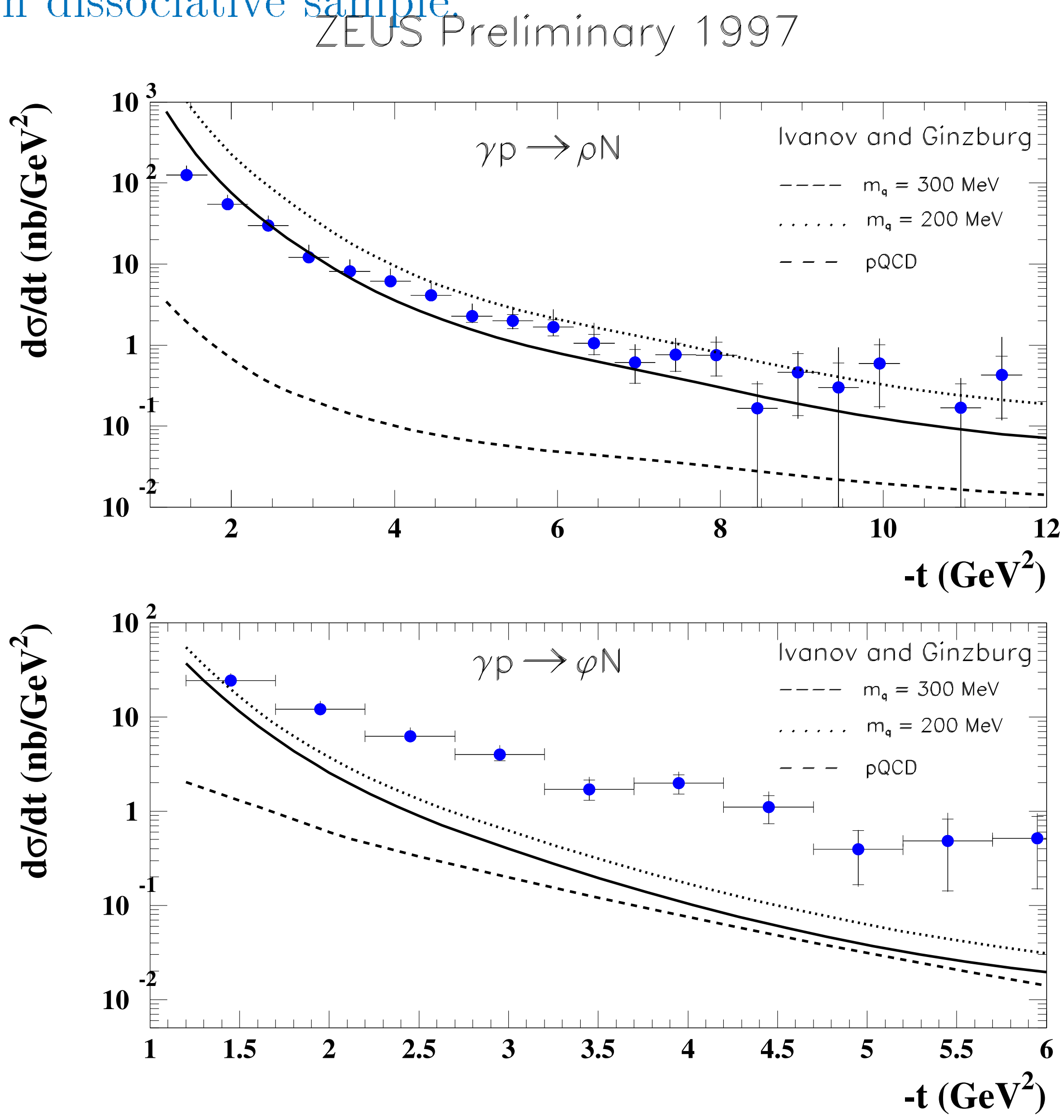
Ratio of proton dissociative and elastic ρ^0 cross sections:

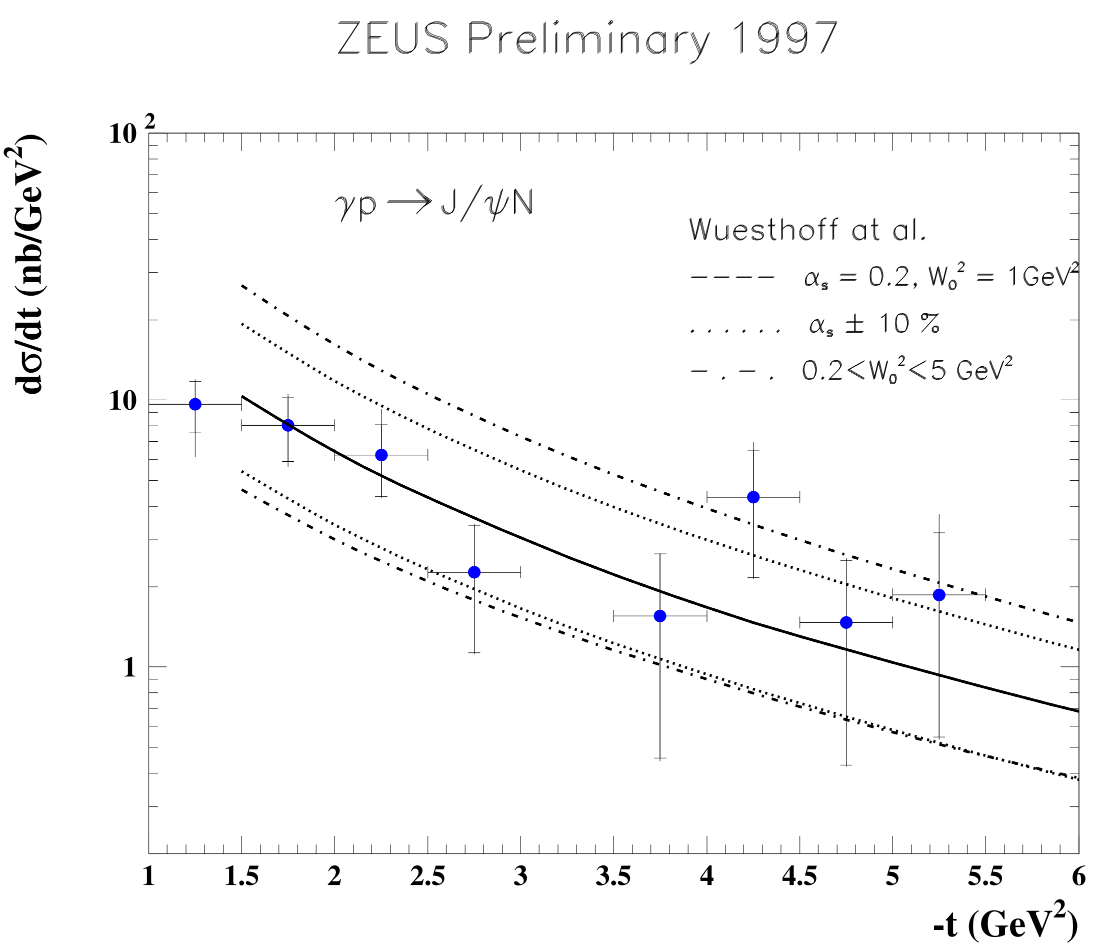
$$R_\sigma = \frac{\sigma_{pdiss.}}{\sigma_{el.}}\ (t = 0)$$

R_σ constant if factorisation holds

t dependence – high t (PHP)

Proton dissociative sample:



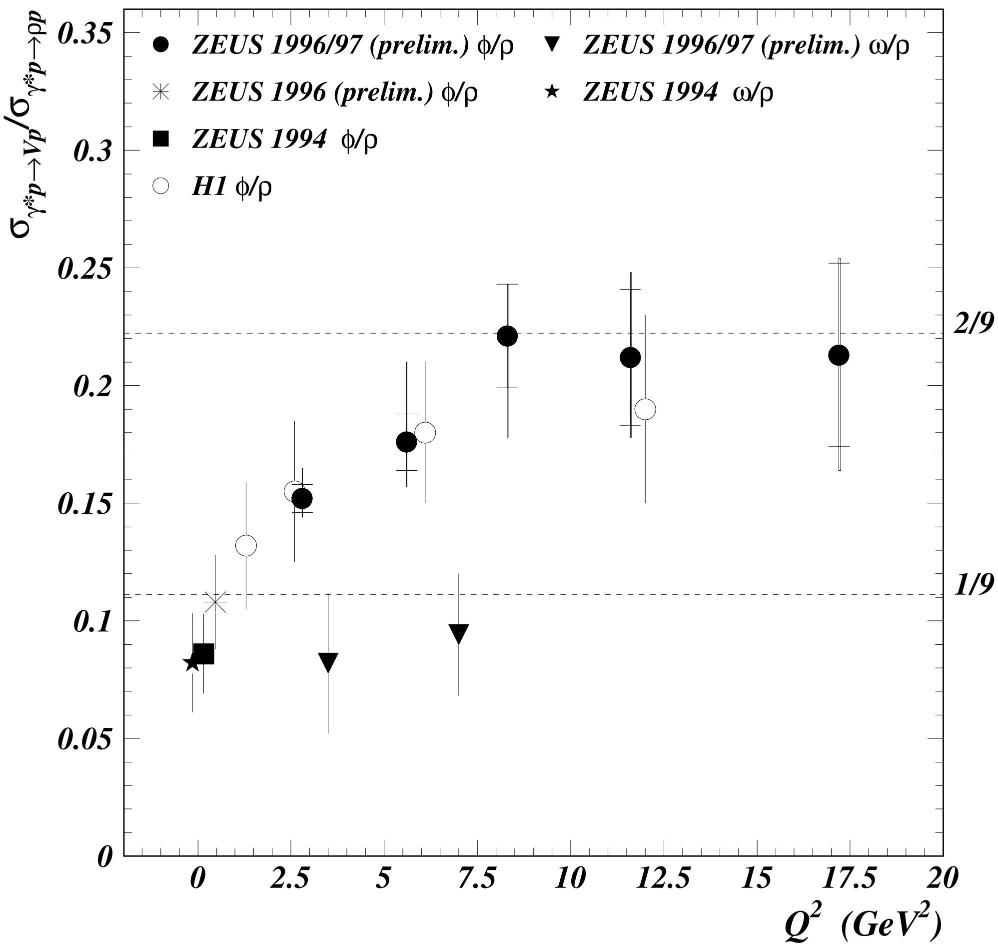

ZEUS Preliminary 1997
$\gamma p \longrightarrow J/\psi N$
Wuesthoff at al.
α_s = 0.2, W_0^2 = 1GeV^2
α_s ± 10 %
0.2<W_0^2<5 GeV^2
dσ/dt (nb/GeV^2)
-t (GeV^2)
10^2
10
1
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6

VM production ratios

If γ^* couples directly to quarks:

$$\rho \ : \ \omega \ : \Phi \ : J/\psi \ = \ 9 \ : \ 1 \ : \ 2 \ : \ 8$$

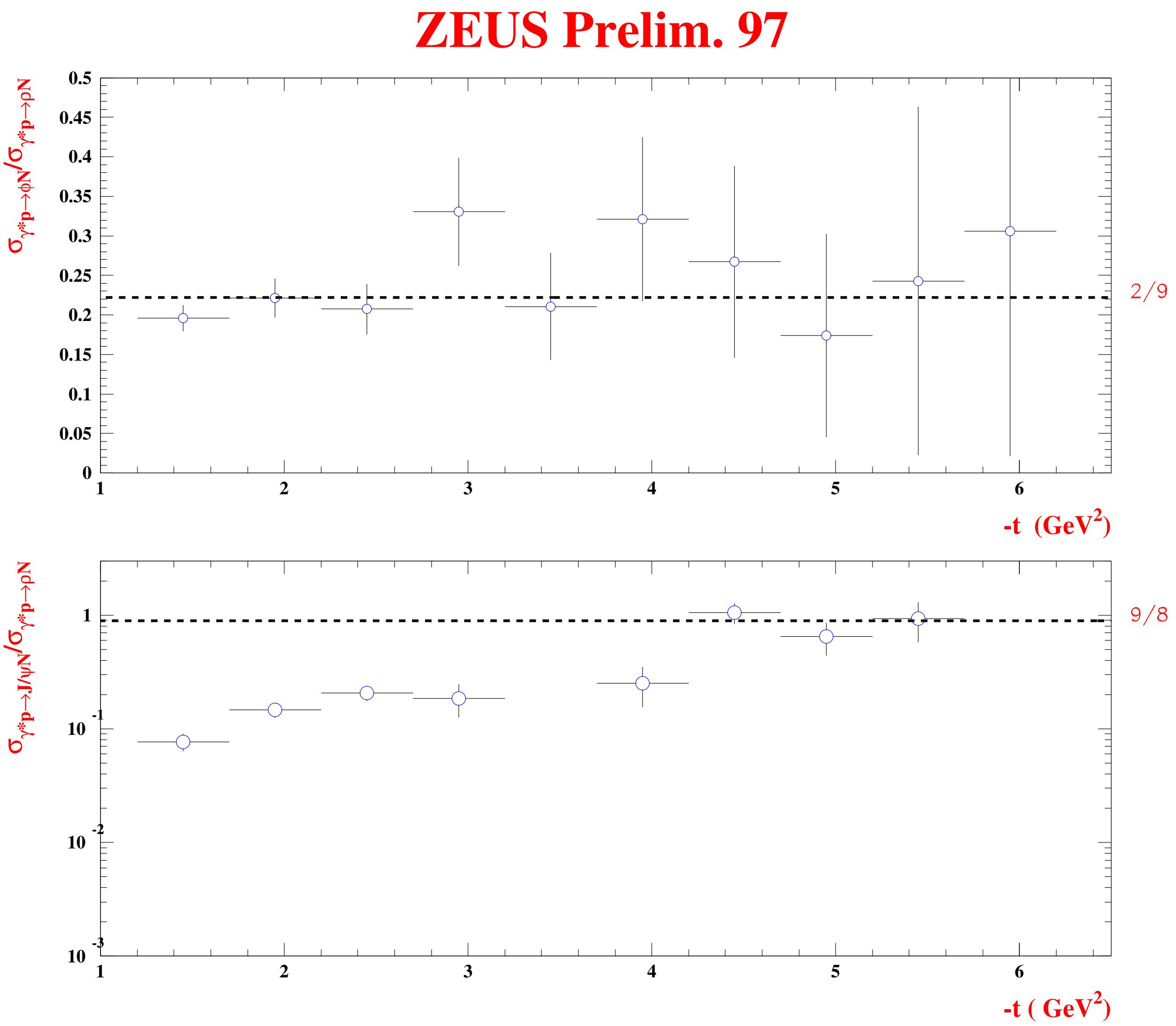
DIS:



Q^2 providing a hard scale

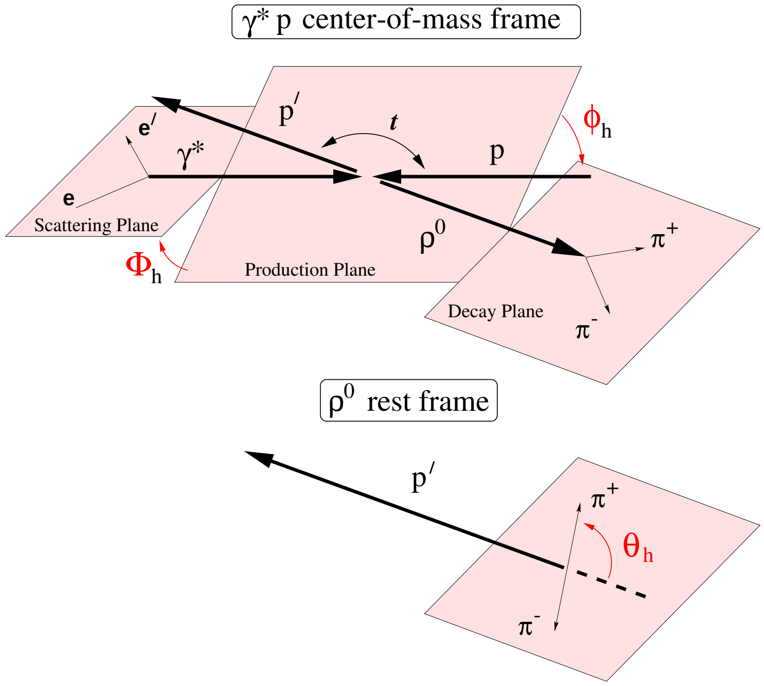
Increasing Q^2 $\Longrightarrow$ flavour independence

PHP – high t (proton dissociative sample): :



Evidence for t providing a hard scale

Helicity studies



$$
\begin{aligned}
W(\cos\theta_h,\phi_h,\Phi_h) \;=\; & \frac{3}{4\pi}[\frac{1}{2}(1-r^{04}_{00}) + \frac{1}{2}(3r^{04}_{00}-1)\cos^2\theta_h \\
& -\sqrt{2}\mathrm{Re}\{r^{04}_{10}\}\sin 2\theta_h\cos\phi_h - r^{04}_{1-1}\sin^2\theta_h\cos 2\phi_h \\
& -\epsilon\cos 2\Phi_h(r^1_{11}\sin^2\theta_h + r^1_{00}\cos^2\theta_h \\
& -\sqrt{2}\mathrm{Re}\{r^1_{10}\}\sin 2\theta_h\cos\phi_h \\
& -r^1_{1-1}\sin^2\theta_h\cos 2\phi_h) \\
& -\epsilon\sin 2\Phi_h(\sqrt{2}\mathrm{Im}\{r^2_{10}\}\sin 2\theta_h\sin\phi_h \\
& +\mathrm{Im}\{r^2_{1-1}\}\sin^2\theta_h\sin 2\phi_h) \\
& +\sqrt{2\epsilon(1+\epsilon)}\cos\Phi_h(r^5_{11}\sin^2\theta_h + r^5_{00}\cos^2\theta_h \\
& -\sqrt{2}\mathrm{Re}\{r^5_{10}\}\sin 2\theta_h\cos\phi_h \\
& -r^5_{1-1}\sin^2\theta_h\cos 2\phi_h) \\
& +\sqrt{2\epsilon(1+\epsilon)}\sin\Phi_h(\sqrt{2}\mathrm{Im}\{r^6_{10}\}\sin 2\theta_h\sin\phi_h \\
& +\mathrm{Im}\{r^6_{1-1}\}\sin^2\theta_h\sin 2\phi_h)]
\end{aligned}
$$

15 parameters related to amplitudes $T_{\lambda_\rho \lambda_\gamma}$:

$$r^{04}_{00} = \frac{\epsilon T^2_{00}}{N_T+\epsilon N_L} + \frac{T^2_{01}}{N_T+\epsilon N_L}$$

$$\mathrm{Re}\{r^{04}_{10}\} = \frac{1}{2}\frac{\mathrm{Re}\{T_{11}T^\star_{01}\}}{N_T+\epsilon N_L} + \frac{1}{2}\frac{\epsilon \mathrm{Re}\{T_{10}T^\star_{00}\}}{N_T+\epsilon N_L} + \frac{1}{2}\frac{\mathrm{Re}\{T_{1-1}T^\star_{0-1}\}}{N_T+\epsilon N_L}$$

$$r^{04}_{1-1} = -\frac{\epsilon T^2_{10}}{N_T+\epsilon N_L} + \frac{\mathrm{Re}\{T_{11}T^\star_{1-1}\}}{N_T+\epsilon N_L}$$

$$r^{1}_{11} = \frac{\mathrm{Re}\{T_{1-1}T^\star_{11}\}}{N_T+\epsilon N_L}$$

$$r^{1}_{00} = -\frac{T^2_{01}}{N_T+\epsilon N_L}$$

$$\mathrm{Re}\{r^{1}_{10}\} = \frac{1}{2}\frac{\mathrm{Re}\{T_{11}T^\star_{0-1}\}}{N_T+\epsilon N_L} + \frac{1}{2}\frac{\mathrm{Re}\{T_{1-1}T^\star_{01}\}}{N_T+\epsilon N_L}$$

$$r^{1}_{1-1} = \frac{1}{2}\frac{T^2_{11}}{N_T+\epsilon N_L} + \frac{1}{2}\frac{T^2_{1-1}}{N_T+\epsilon N_L}$$

$$\mathrm{Im}\{r^{2}_{10}\} = -\frac{1}{2}\frac{\mathrm{Re}\{T_{11}T^\star_{0-1}\}}{N_T+\epsilon N_L} + \frac{1}{2}\frac{\mathrm{Re}\{T_{1-1}T^\star_{01}\}}{N_T+\epsilon N_L}$$

$$\mathrm{Im}\{r^{2}_{1-1}\} = -\frac{1}{2}\frac{T^2_{11}}{N_T+\epsilon N_L} + \frac{1}{2}\frac{T^2_{1-1}}{N_T+\epsilon N_L}$$

$$r^{5}_{11} = \frac{1}{\sqrt{2}}\frac{\mathrm{Re}\{T_{10}T^\star_{11}\}}{N_T+\epsilon N_L} - \frac{1}{\sqrt{2}}\frac{\mathrm{Re}\{T_{10}T^\star_{1-1}\}}{N_T+\epsilon N_L}$$

$$r^{5}_{00} = \frac{\sqrt{2}\mathrm{Re}\{T_{00}T^\star_{01}\}}{N_T+\epsilon N_L}$$

$$\mathrm{Re}\{r^{5}_{10}\} = \frac{1}{2\sqrt{2}}\frac{\mathrm{Re}\{T_{11}T^\star_{00}\}}{N_T+\epsilon N_L} + \frac{1}{\sqrt{2}}\frac{\mathrm{Re}\{T_{10}T^\star_{01}\}}{N_T+\epsilon N_L} - \frac{1}{2\sqrt{2}}\frac{\mathrm{Re}\{T_{1-1}T^\star_{00}\}}{N_T+\epsilon N_L}$$

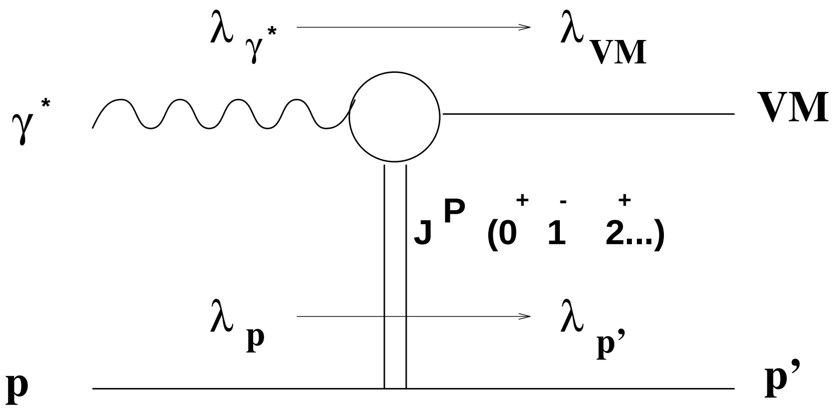
$$r^{5}_{1-1} = \frac{1}{\sqrt{2}}\frac{\mathrm{Re}\{T_{11}T^\star_{-10}\}}{N_T+\epsilon N_L} + \frac{1}{\sqrt{2}}\frac{\mathrm{Re}\{T_{10}T^\star_{-11}\}}{N_T+\epsilon N_L}$$

$$\mathrm{Im}\{r^{6}_{10}\} = -\frac{1}{2\sqrt{2}}\frac{\mathrm{Re}\{T_{11}T^\star_{00}\}}{N_T+\epsilon N_L} - \frac{1}{2\sqrt{2}}\frac{\mathrm{Re}\{T_{1-1}T^\star_{00}\}}{N_T+\epsilon N_L}$$

$$\mathrm{Im}\{r^{6}_{1-1}\} = -\frac{1}{\sqrt{2}}\frac{\mathrm{Re}\{T_{-10}T^\star_{11}\}}{N_T+\epsilon N_L} + \frac{1}{\sqrt{2}}\frac{\mathrm{Re}\{T_{10}T^\star_{-11}\}}{N_T+\epsilon N_L}$$

where $N_L = T^2_{00} + 2T^2_{10}$ $\qquad N_T = T^2_{11} + T^2_{1-1} + T^2_{01}$

s – channel helicity conservation (SCHC):



Natural parity exchange (NPE): $J^P = 0^+, 1^-, ...$

15 parameters $\Longrightarrow$ 3 parameters: r^{04}_{00}, r^{1}_{1-1}, $\mathrm{Re}r^{5}_{10}$

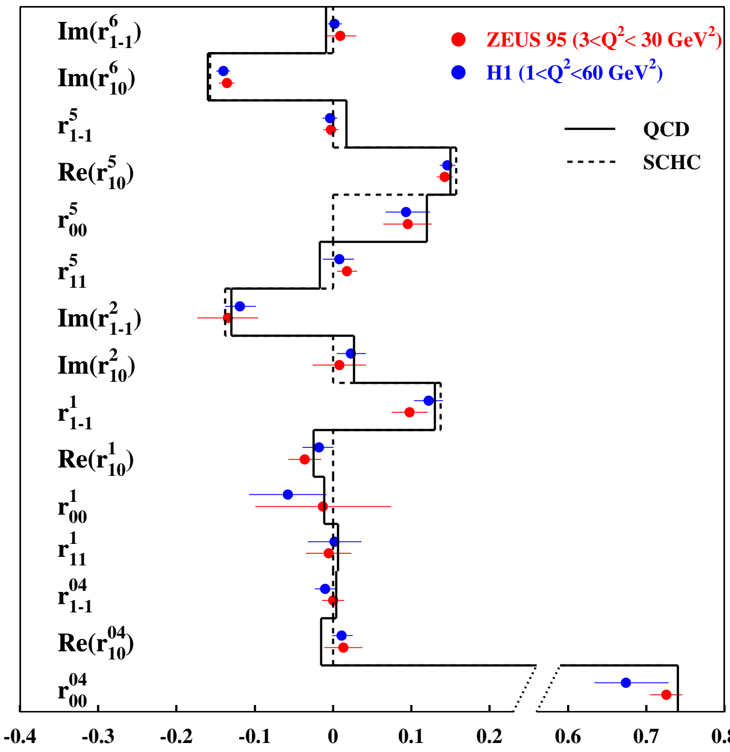
NPE sum rule:

$$\mathcal{Z} \equiv 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^{1}_{11} - 2r^{1}_{1-1} = 0$$

$\mathcal{Z} = 0.058 \pm 0.027 \pm 0.074$ ZEUS $\quad \langle Q^2 \rangle \approx 0.5$ GeV^2

$\mathcal{Z} = 0.091 \pm 0.016 \pm 0.065$ ZEUS $\quad$ DIS $Q^2 > 1$ GeV^2

Fit of 15 parameters r^{α}_{ij} to DIS data – ρ^0:



Dashed line – SCHC; solid line – Ivanov & Kirschner (QCD)

Non-zero value of r^5_{00} $\Longrightarrow$ violation of SCHC:

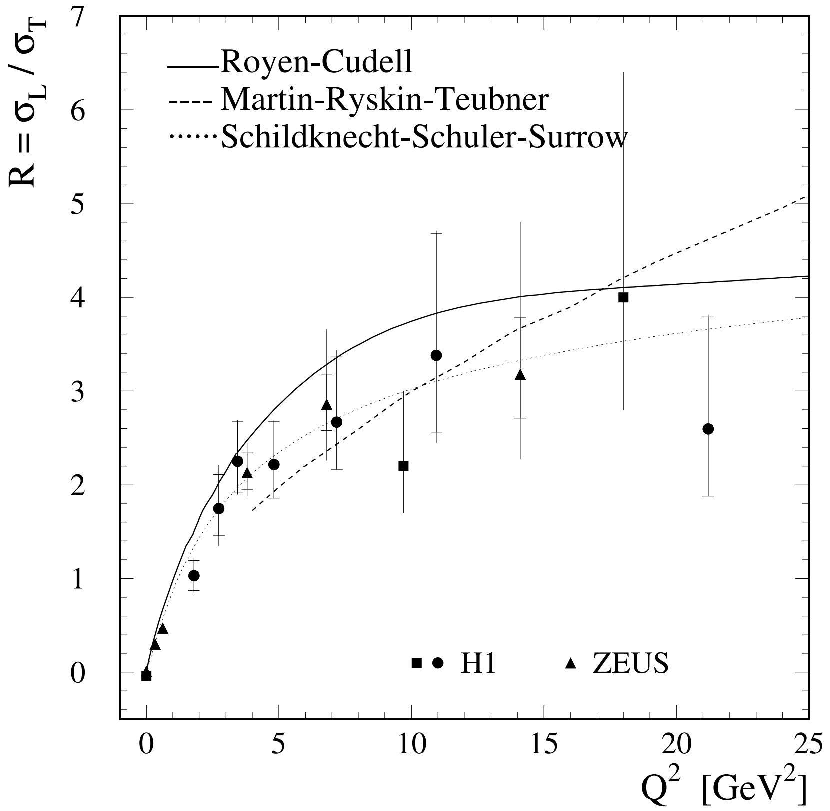
production of longitudinal ρ^0's from transverse γ's

(also measured in proton dissociative ρ^0 production)

Excellent agreement between H1 and ZEUS results!

$$\text{SCHC: } R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1-r_{00}^{04}} \quad (\text{HERA: } 0.95 \le \epsilon \le 1)$$

$$|R(\text{no SCHC}) - R(\text{SCHC})| \;\le\; 3\%$$

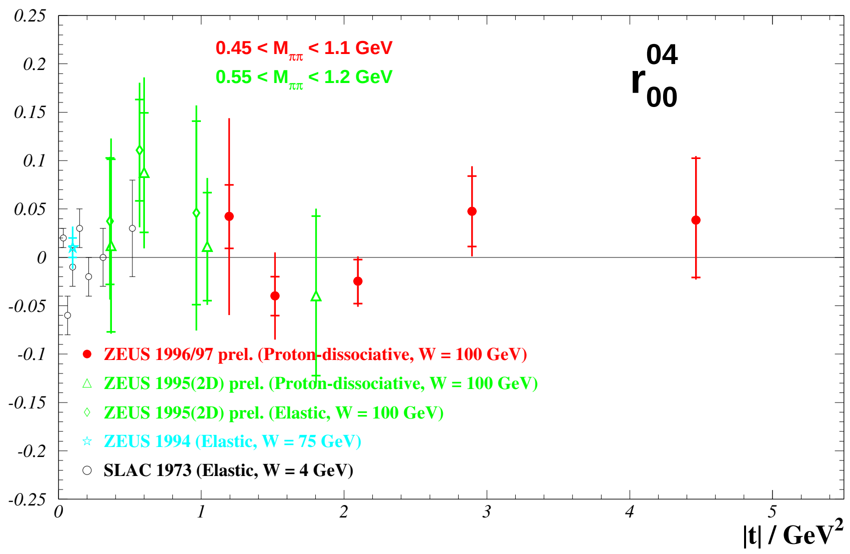


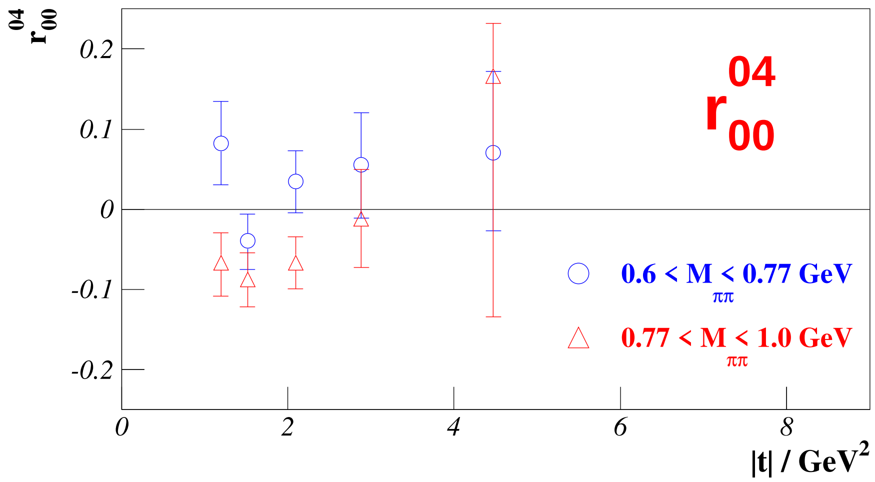
ρ^0: fast $\Longrightarrow$ slow increase of R with Q^2

domination of longitudinally polarised ρ^0's at higher Q^2

Royen & Cudell – QCD (quark off-shellness)
Martin, Ryskin & Teubner – QCD (parton-hadron duality)
Schildknecht, Schuler & Surrow – GVMD

Helicity studies - high $|t|$ PHP

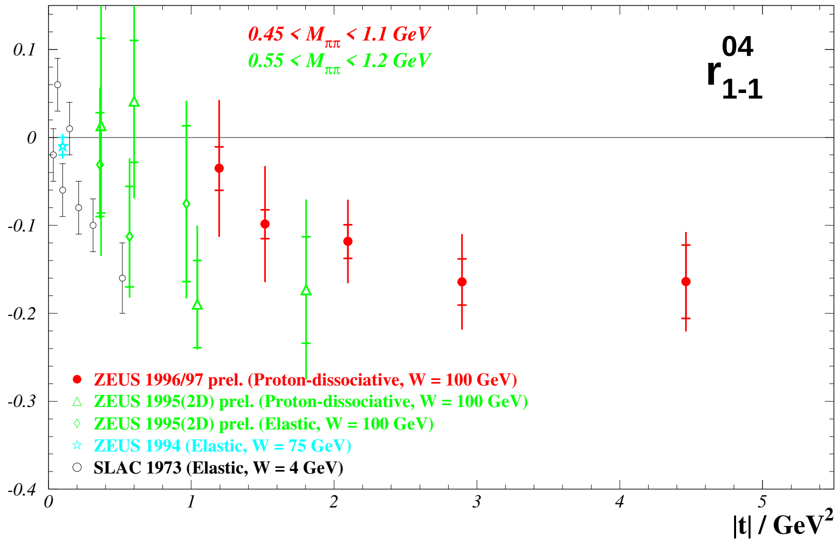


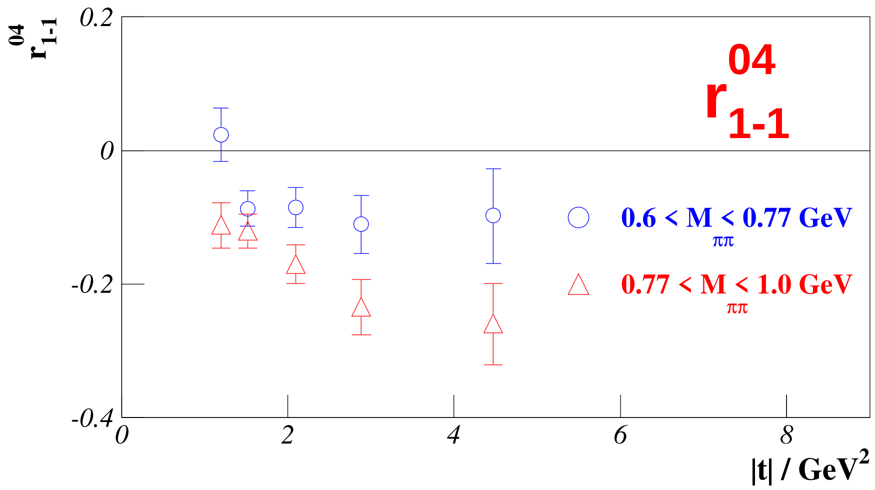


Longitudinal ρ^0's not dominant

r^{04}_{00} (or R) differs for resonant and non-resonant $\pi\pi$ production

Helicity studies - high $|t|$ PHP

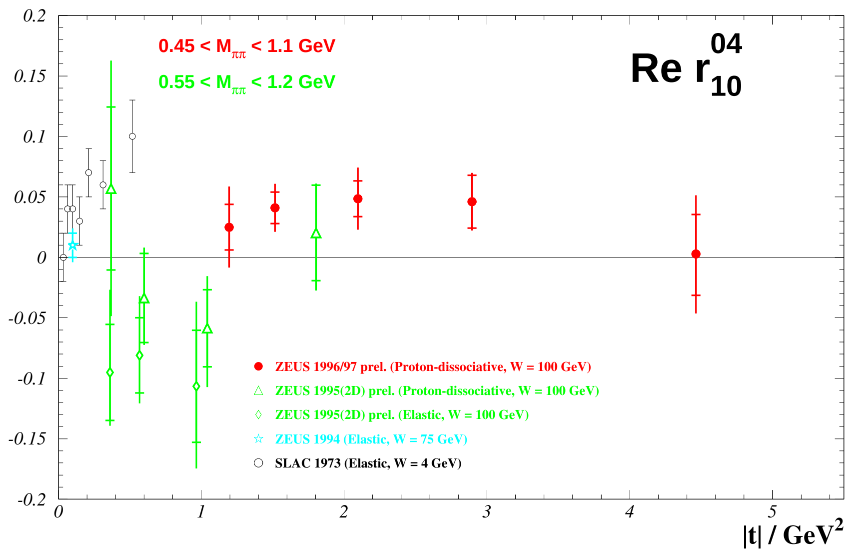


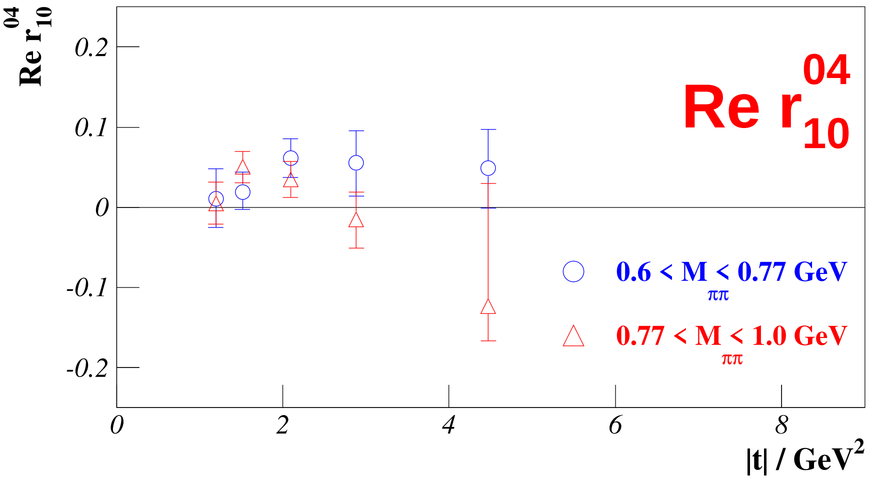


Evidence for a double flip amplitude at high $|t|$

r^{04}_{1-1} differs for resonant and non-resonant $\pi\pi$ production

Helicity studies - high $|t|$ PHP





Indication of a non-zero single flip amplitude

Summary

- Abundant data from H1 and ZEUS on elastic and proton dissociative production of light VM's
- $\sigma \propto W^\delta$ – δ increases with Q^2 (ρ^0, ω, Φ)
- t dependence – slope b decreases with Q^2; falls below the proton radius in proton dissociative VM production
- helicity studies – fit of 15 r_{ij}^α parameters; small SCHC violation, amplitude depending on whether $\pi\pi$ pairs are produced resonantly or not (cf. mass shapes)
- test of factorisation in proton dissociative ρ^0 production
- $d\sigma/d|t|$ measured for t up to 12 GeV^2 in PHP (pdiss.)
- t provides a hard scale
- INTERESTING PROSPECTS AFTER HERA UPGRADE!

Contributed papers: **157af, 157n, 499, 502**