

On behalf of the H1 Collaboration



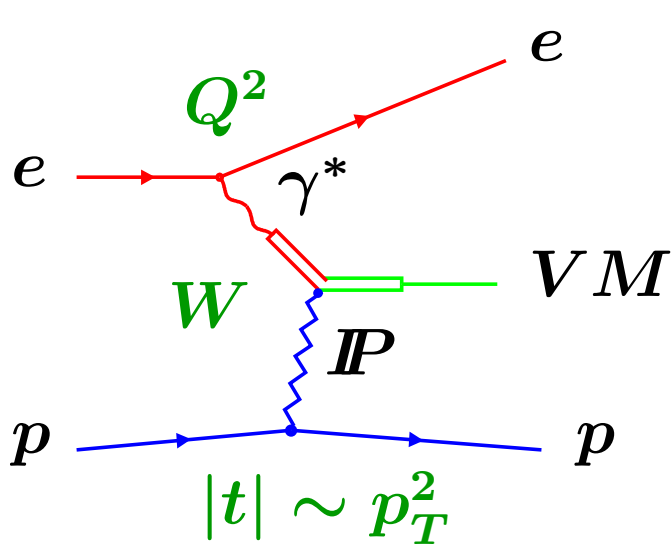
Diffractional electroproduction of ρ and ϕ mesons at H1

XVI International Workshop on Deep-Inelastic Scattering and Related Subjects

London, UK, 7th-11th April, 2008

Introduction

$$e + p \rightarrow e + VM(\rho, \omega, \phi, J/\psi, \dots) + p \text{ (or } Y)$$

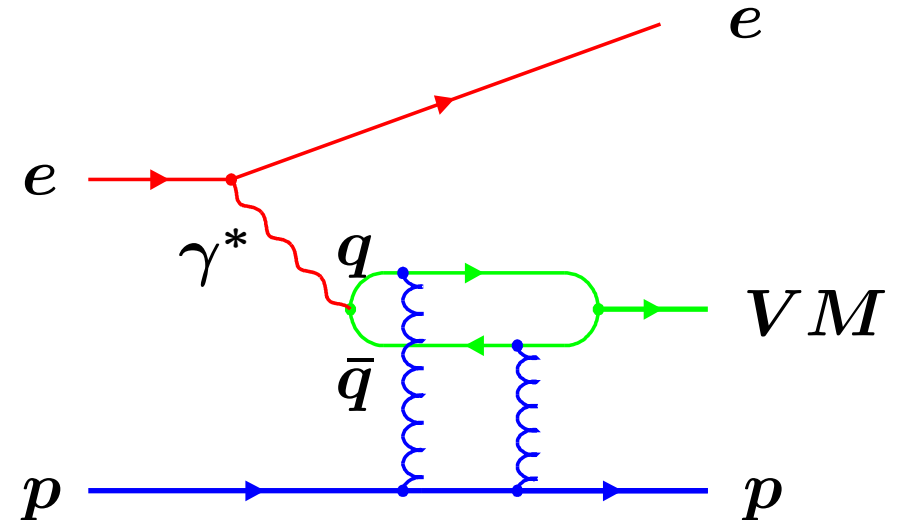


Regge Theory

= Soft P omeron exchange

$$\sigma \propto \left(\frac{W}{W_0}\right)^{4(\alpha_P(t)-1)}$$

$$\alpha_P(t) = 1.08 + 0.25 t \text{ (DL)}$$



pQCD Models

Exchange of ≥ 2 gluons

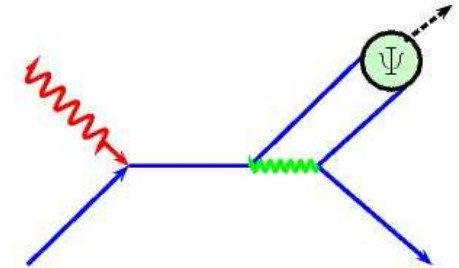
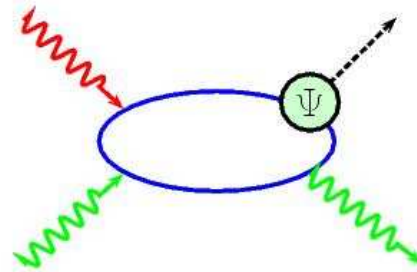
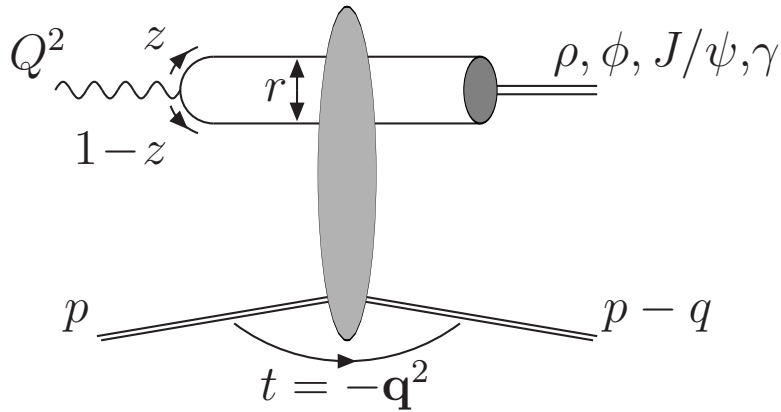
$$\sigma \propto (xG(x, Q^2))^2$$

Steep rise of $xG(x, Q^2)$

Light VM at low Q^2 and low $|t|$ Requires hard scale: Q^2 , t or m_q

$\implies \rho$ and ϕ : Investigate transition between soft and hard regimes

Models



- **Saturation** : C.Marquet, R.Peschanski, G.Soyez [[hep-ph/0702171](#)]

- Dipole cross-section from fit to previous ρ , ϕ and J/ψ data
- Geometric scaling extended to non-forward amplitude
- Saturation scale is t -dependent

- **k_t -factorisation**: I.Ivanov, N.Nikolaev, A.Savin [[hep-ph/0501034](#)]

- Dipole x-section obtained from BFKL Pomeron
- Use k_t -unintegrated PDF and off-forward factor

- **GPD based**: S.Goloskokov and P.Kroll [[hep-ph/07083569](#)]

- Factorisation of hard process and proton GPD (Proven for γ_L)
- GPD constructed from standard PDF with skewing profile function

Data Selection

$$e^+ + p \rightarrow e^+ + \rho + p \text{ (or } Y) \quad ; \quad \rho \rightarrow \pi^+ + \pi^-$$

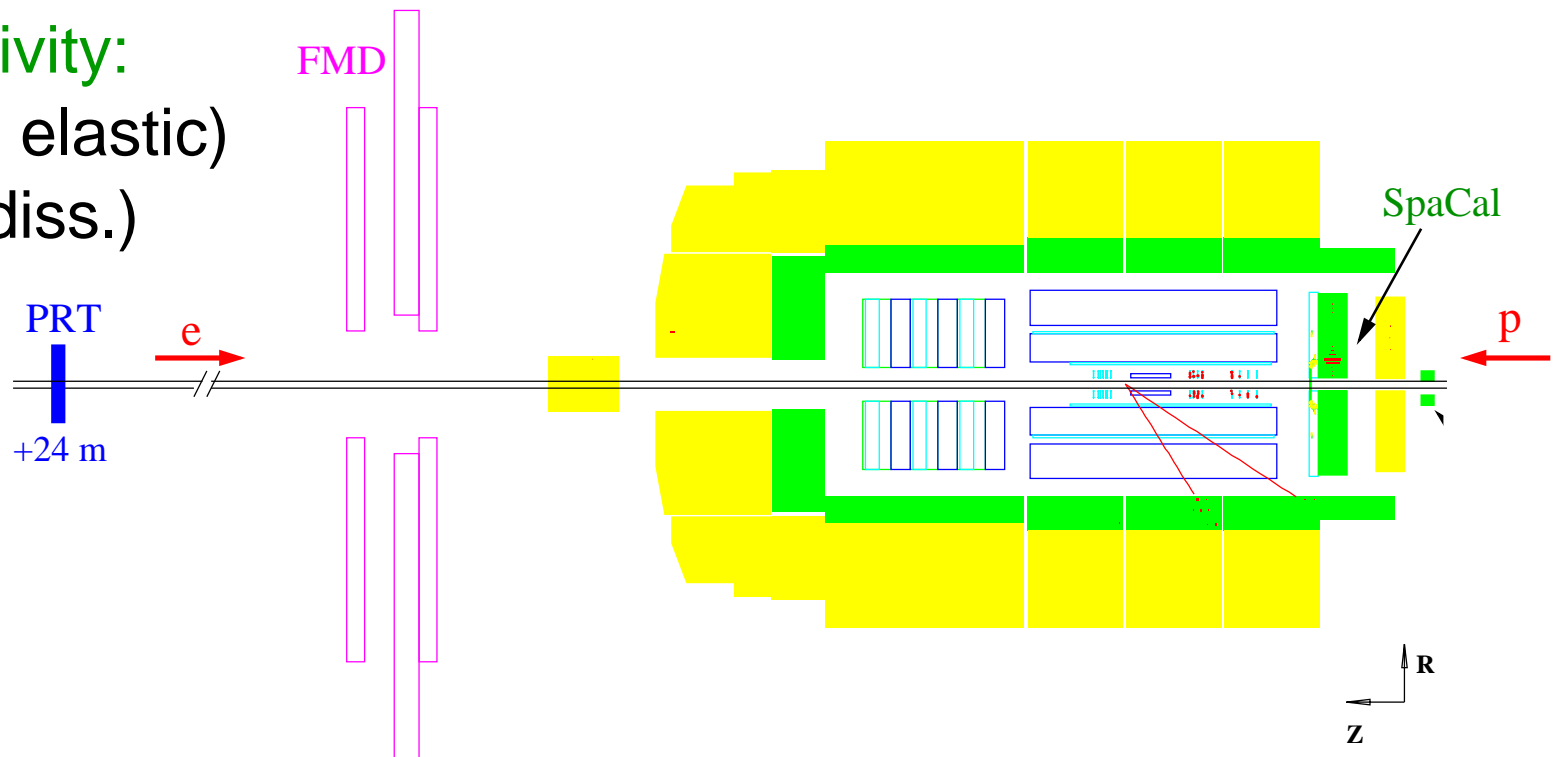
$$e^+ + p \rightarrow e^+ + \phi + p \text{ (or } Y) \quad ; \quad \phi \rightarrow K^+ + K^-$$

HERA-1 data (1996-97, 1999-2000) $\rightarrow 51 \text{ pb}^{-1}$

Forward activity:

NOTAG (\simeq elastic)

TAG (\simeq p-diss.)



$$2.5 < Q^2 < 60 \text{ GeV}^2$$

$$35 < W < 180 \text{ GeV}$$

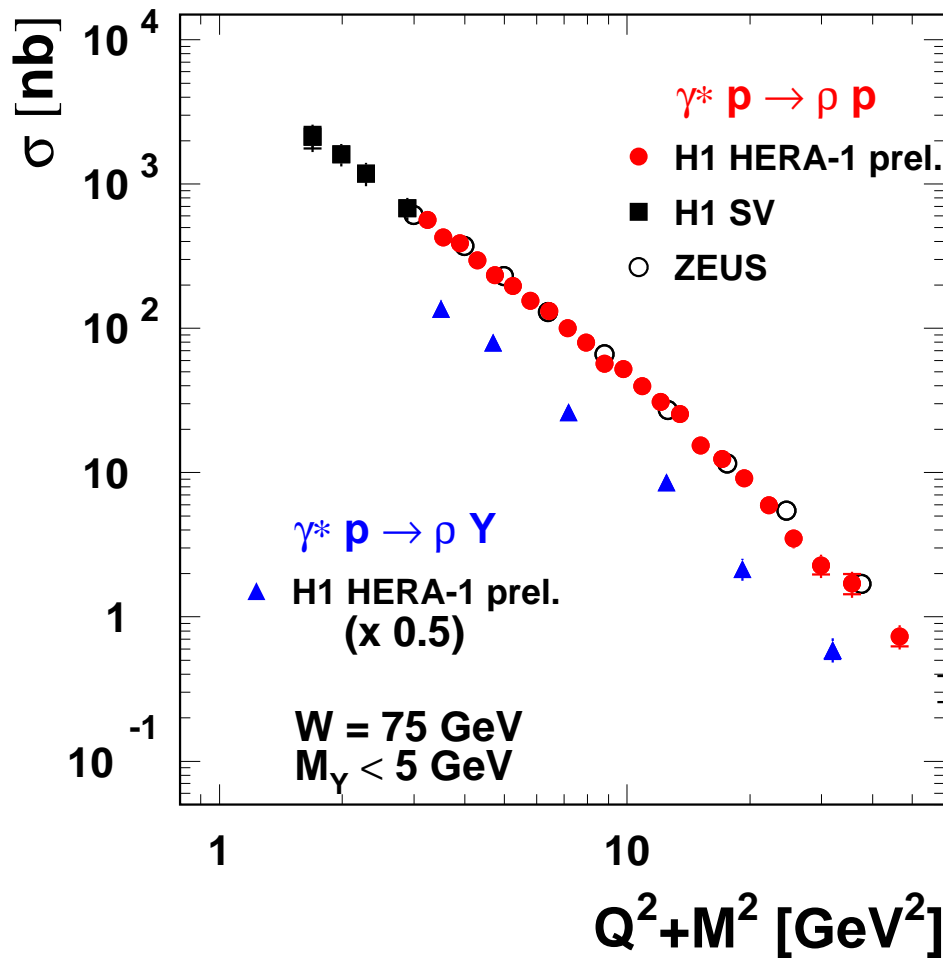
elastic: $|t| < 0.5 \text{ GeV}^2$

p-diss.: $|t| < 3.0 \text{ GeV}^2$

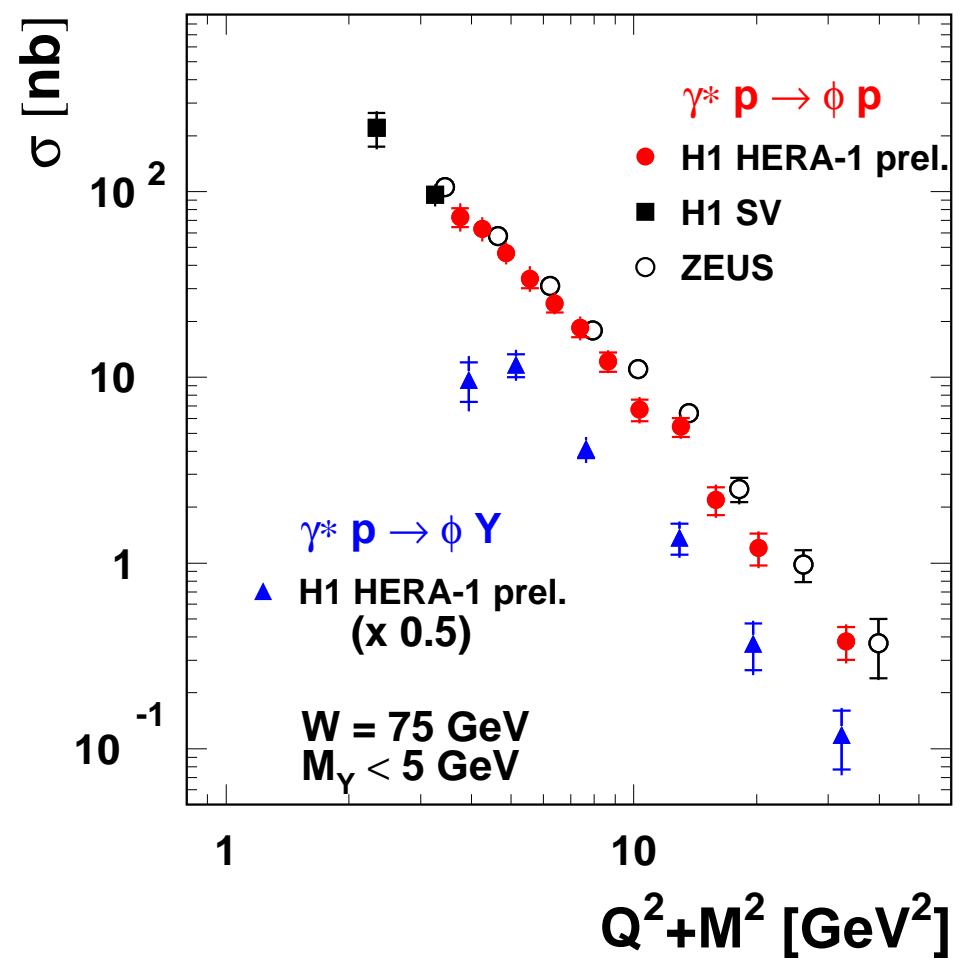
$$M_Y < 5 \text{ GeV}$$

Cross-sections - $\sigma_{\gamma^* p}(Q^2)$

H1 ρ electroproduction (preliminary)



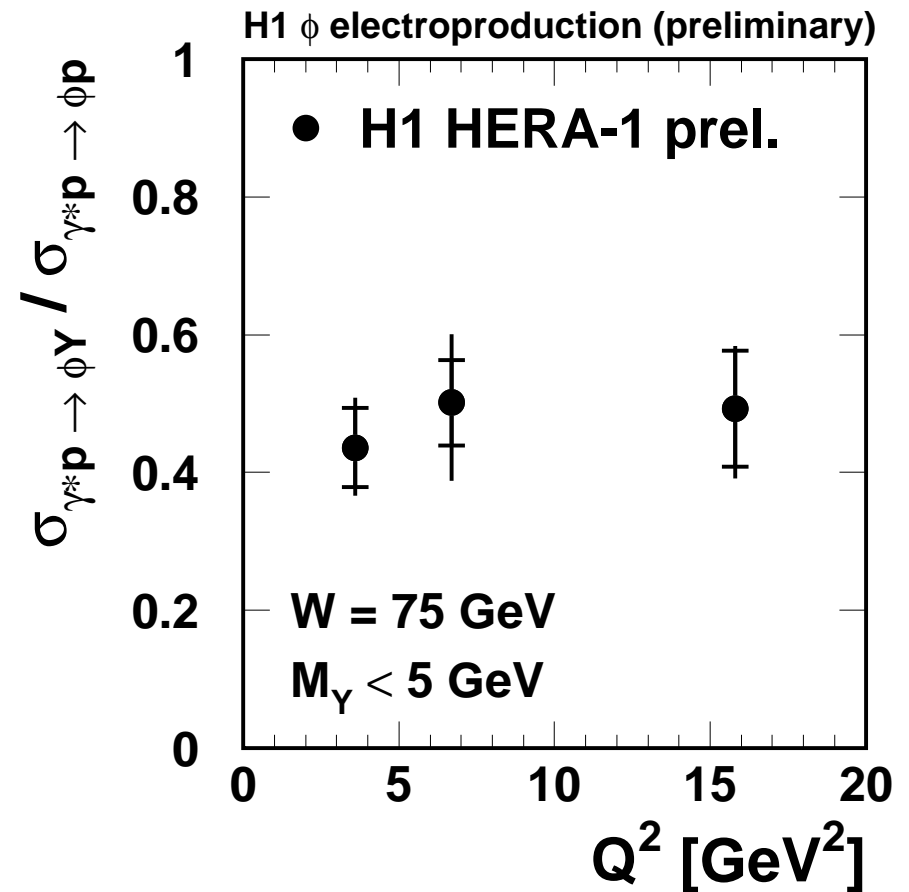
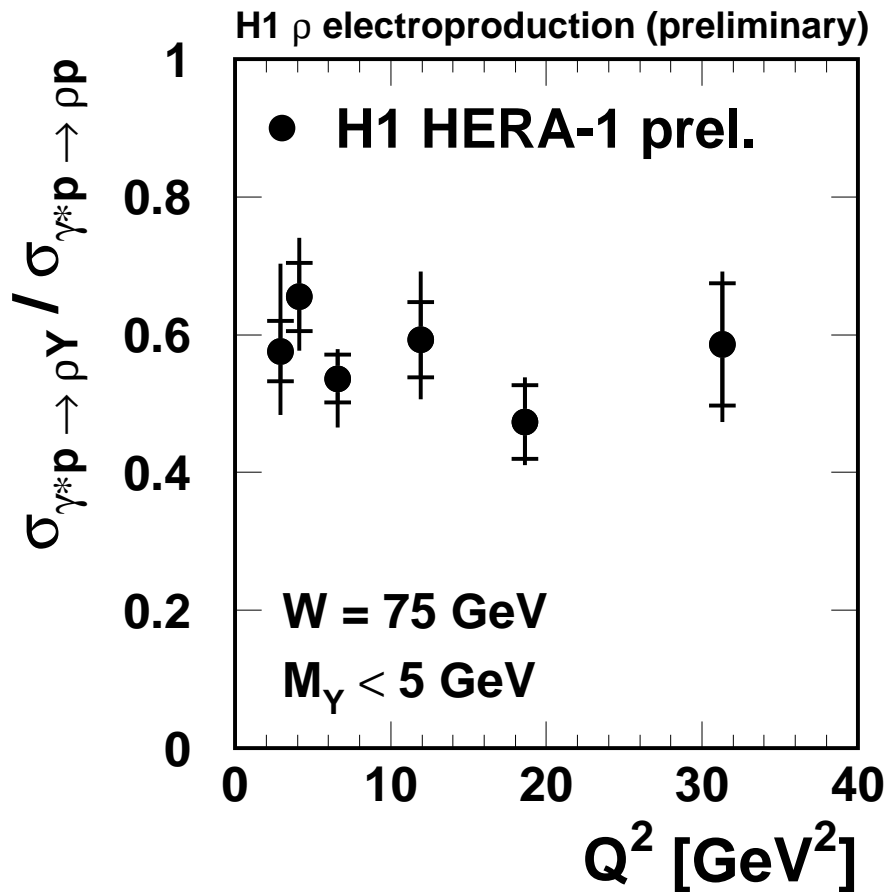
H1 ϕ electroproduction (preliminary)



- High precision for elastic cross-sections; First ϕ p-diss. cross-section

- $\sigma_{\gamma^* p}(Q^2) \propto 1/(Q^2 + M_{VM}^2)^{n(Q^2)}$; $n(Q^2) = a + b Q^2$
 $a \simeq -2.15$; $b \simeq -0.70 \text{ GeV}^{-2}$

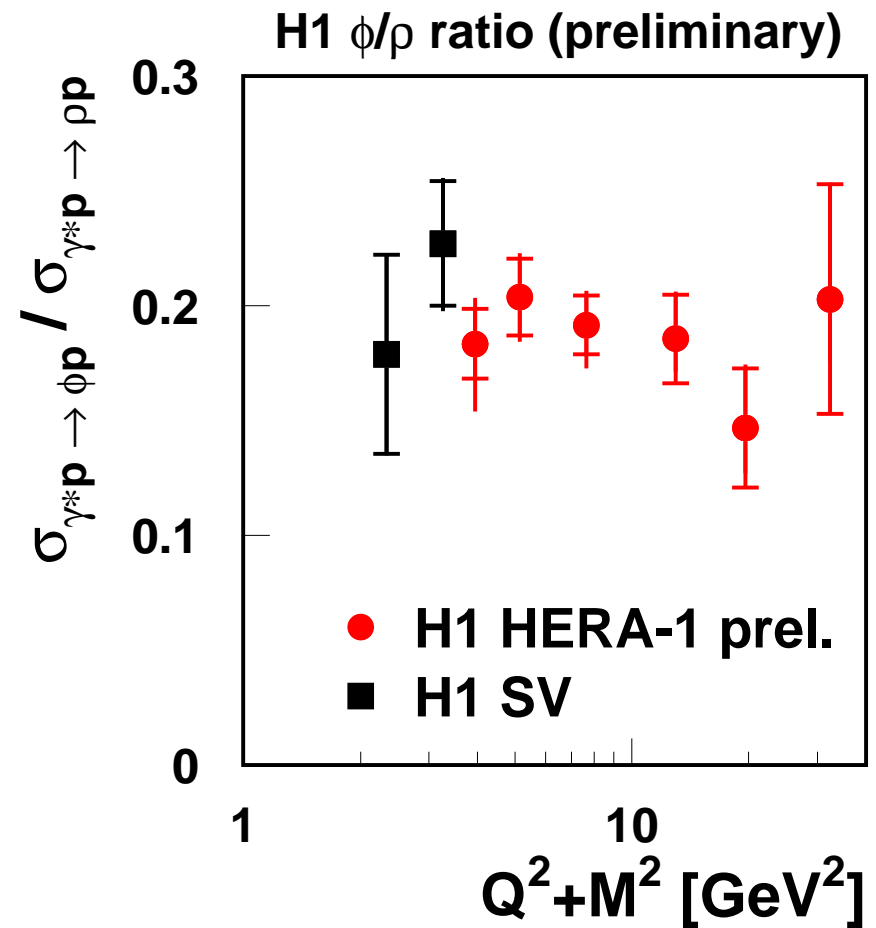
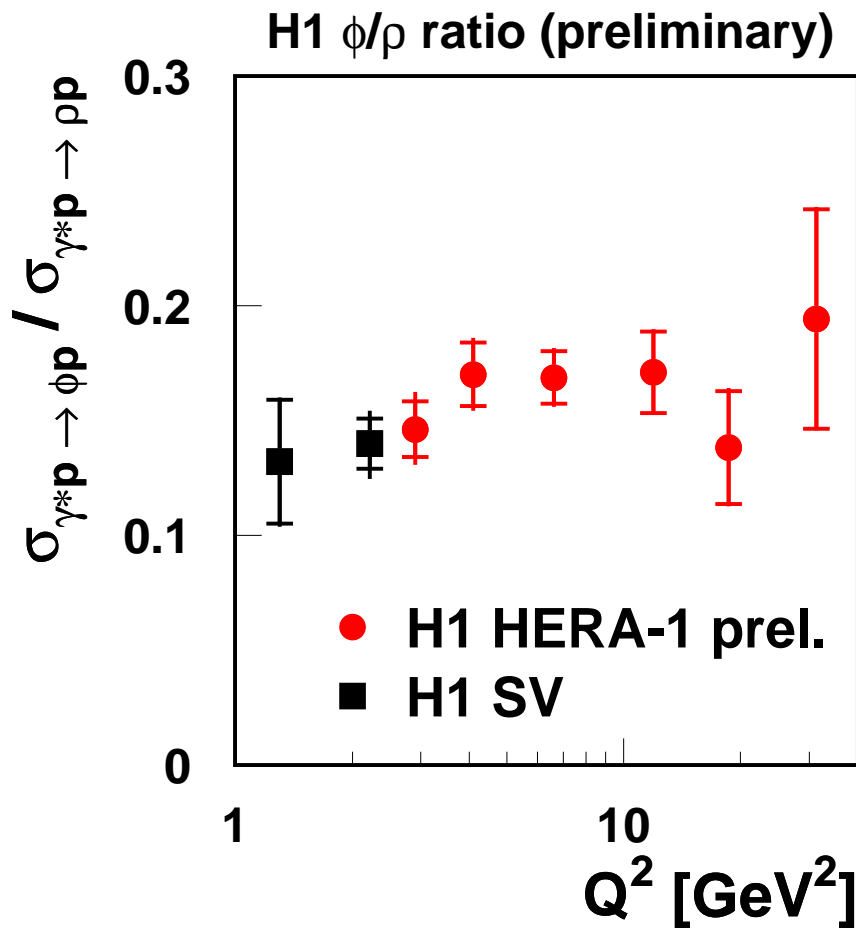
p-diss. / Elastic Ratio - vs. (Q^2)



- p-diss. / elastic ratio independent of Q^2
- Similar ratio within errors for ρ and ϕ

→ Proton vertex factorisation for $Q^2 > 2.5 \text{ GeV}^2$

ϕ/ρ ratio - Elastic cross-sections



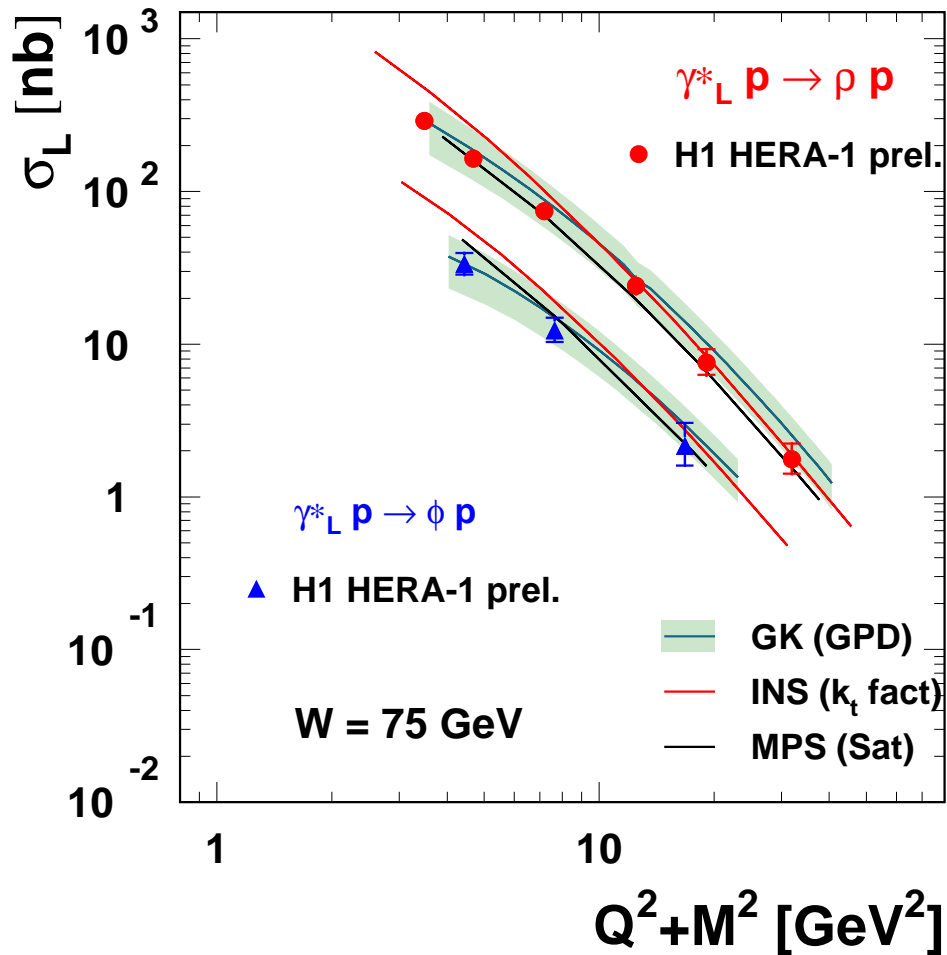
⇒ Ratio independent of $Q^2 + M^2$

⇒ At low Q^2 , $q\bar{q}$ size $\propto 1/M$, at high Q^2 , $q\bar{q}$ size $\propto Q^2$

Cross-sections - $\sigma_{\gamma^*p}(Q^2)$ - Polarised

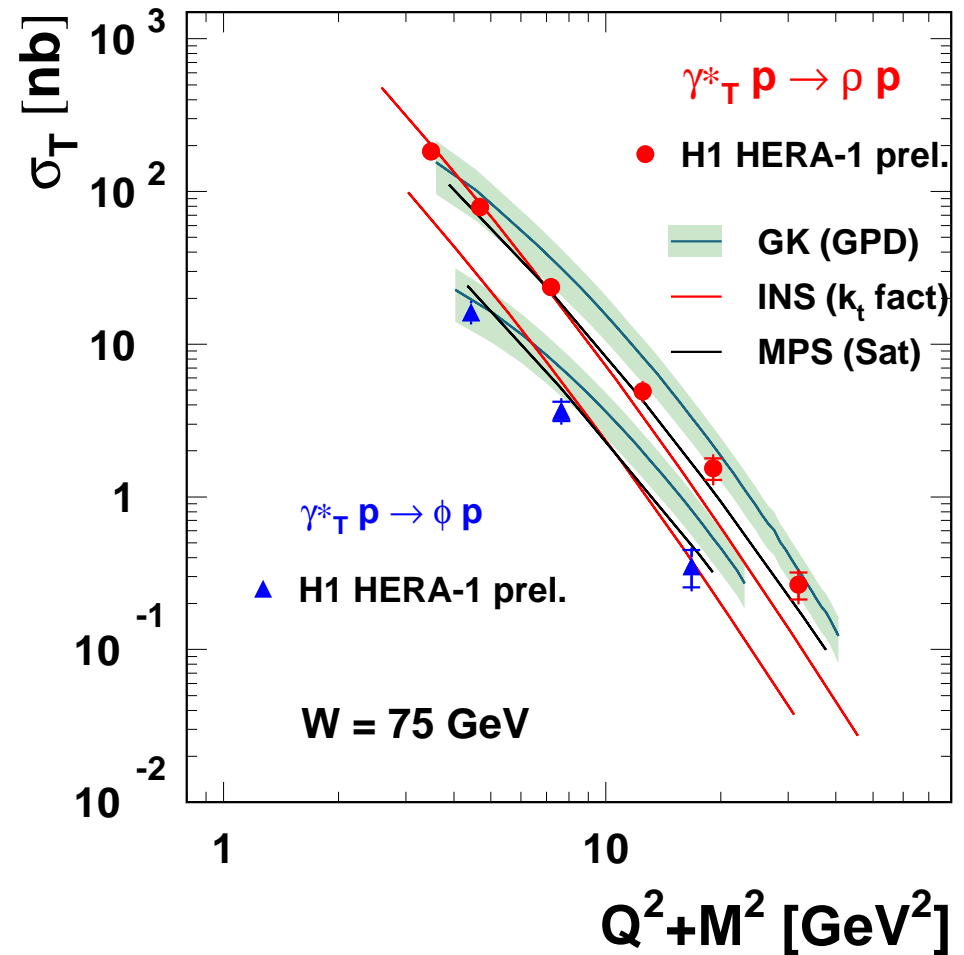
Longitudinal

H1 ρ and ϕ electroproduction (preliminary)



Transverse

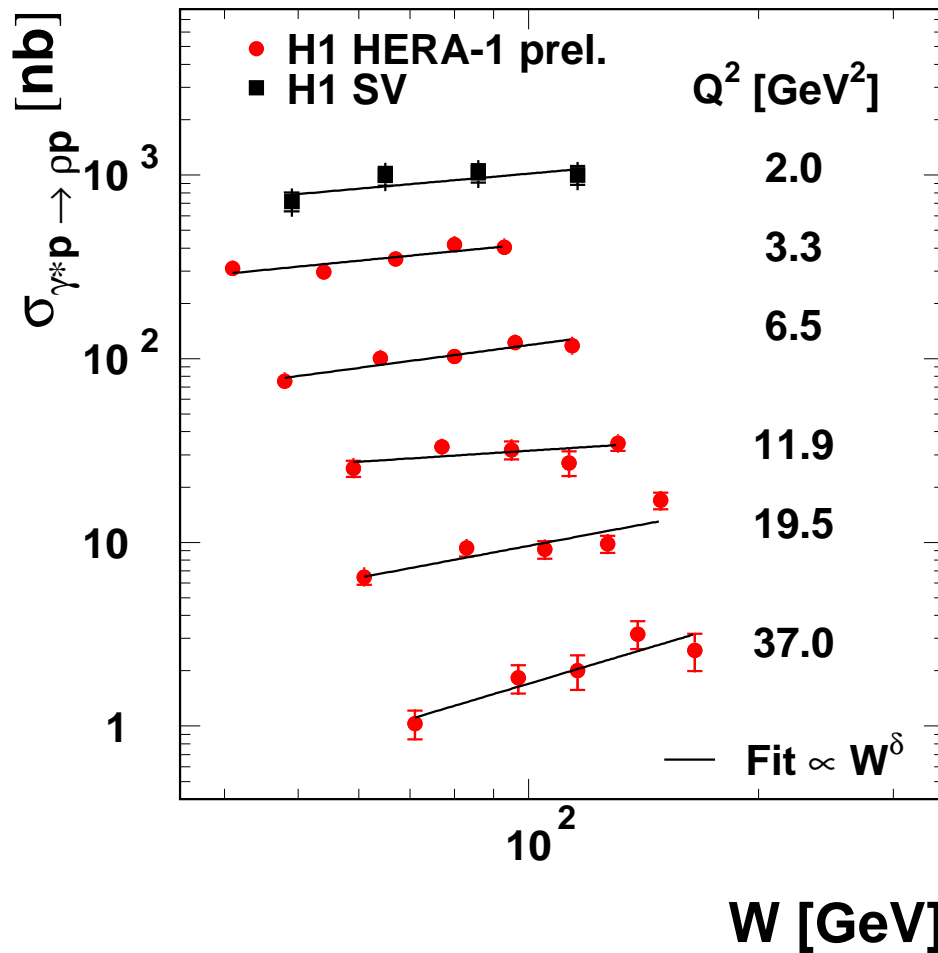
H1 ρ and ϕ electroproduction (preliminary)



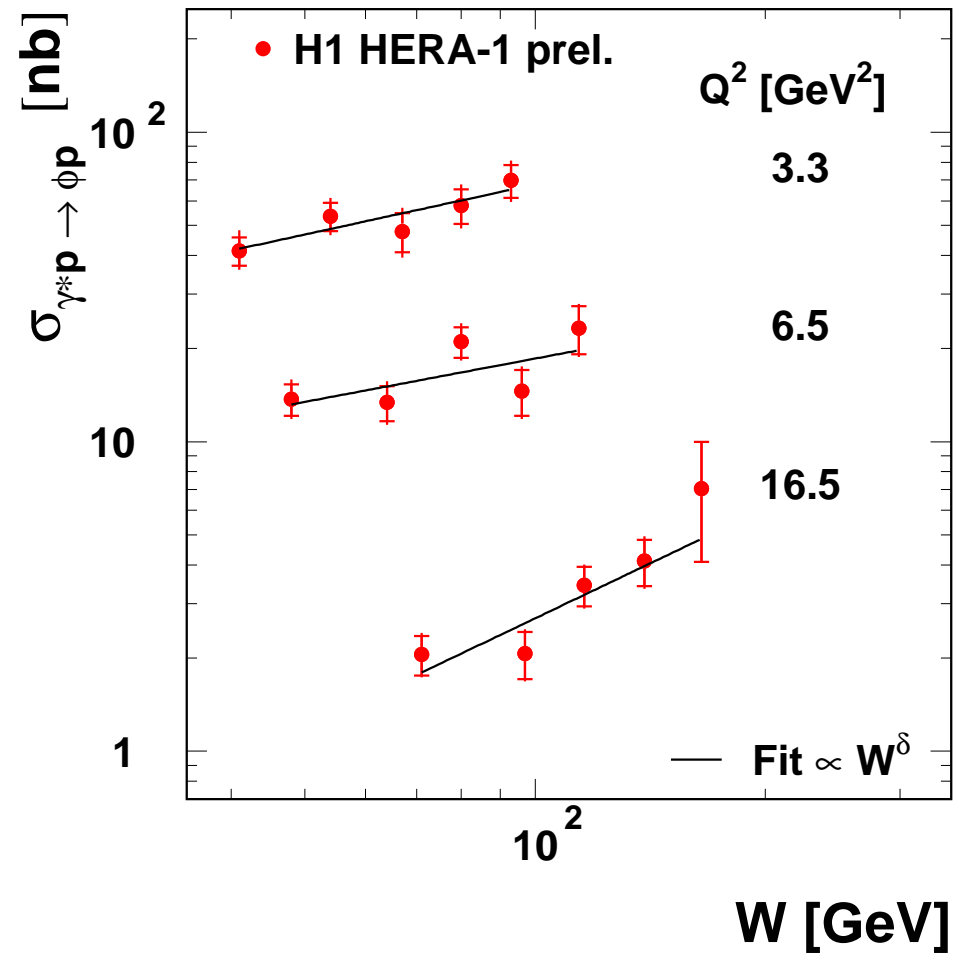
- Different $Q^2 + M^2$ dependences of σ_L and σ_T ($\sigma_L = 0$ at $Q^2 = 0$)
- Best description of σ_L by GK (GPD) model; σ_T not described

Elastic Cross-sections - $\sigma_{\gamma^*p}(W)$

H1 ρ electroproduction (preliminary)



H1 ϕ electroproduction (preliminary)

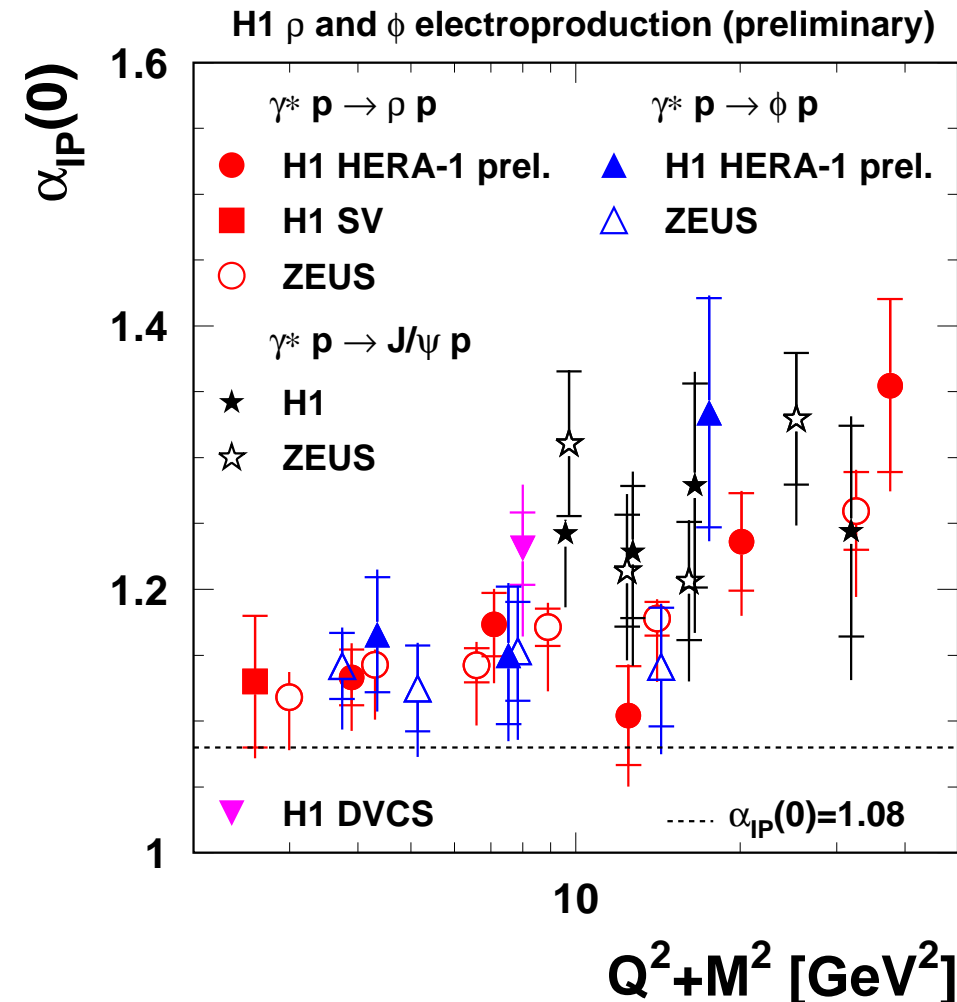


Fit parametrisation : $\sigma_{\gamma^*p}(W) \propto W^\delta$

$$\delta = 4(\langle \alpha_{\mathbb{P}}(t) \rangle - 1)$$

Elastic Cross-sections - $\sigma_{\gamma^*p}(W)$

$$\alpha_P(0) = 1 + \delta/4 + \alpha'_P / \langle |t| \rangle ; \alpha'_P = 0 - 0.25 \text{ GeV}^{-2}$$



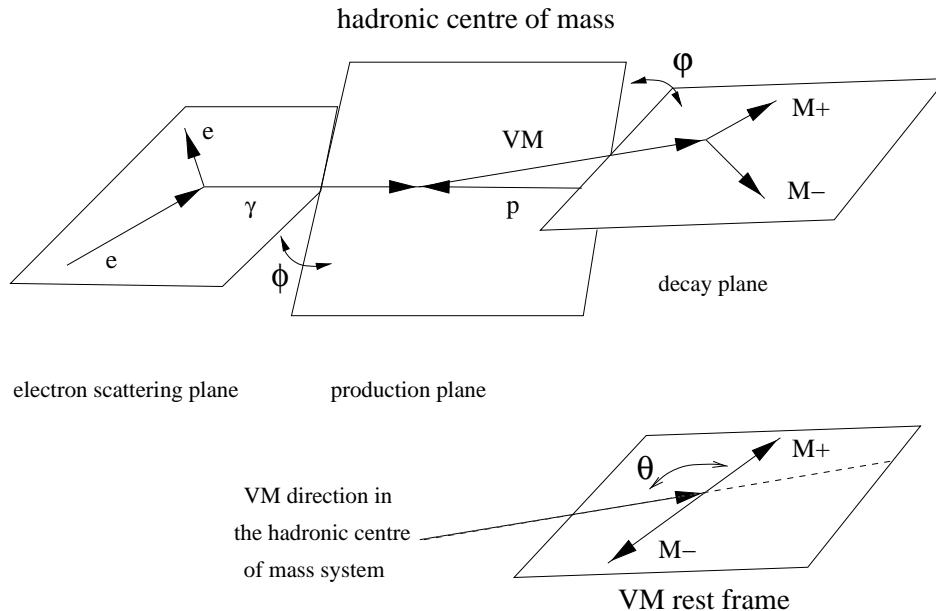
- Significant hardening of $\alpha_P(0)$ with Q^2 for ρ and ϕ
- Common increase vs. $Q^2 + M^2$ for all VM (J/ψ and DVCS)

⇒ Transition from soft to hard regime with $Q^2 + M^2$

SPIN DENSITY MATRIX ELEMENTS

$$\theta^*, \Phi, \varphi \iff 15 \text{ SDMEs} : r_{kl}^{ij} \propto T_{\lambda'_\rho \lambda'_\gamma} T_{\lambda_\rho \lambda_\gamma}$$

$T_{\lambda_\rho \lambda_\gamma}$: helicity amplitudes



No helicity flip: $T_{00} : \gamma_L \rightarrow \rho_L$

$T_{11} : \gamma_T \rightarrow \rho_T$

Single flip: $T_{01} : \gamma_T \rightarrow \rho_L$

$T_{10} : \gamma_L \rightarrow \rho_T$

Double flip: $T_{1-1} : \gamma_T \rightarrow \rho_T$

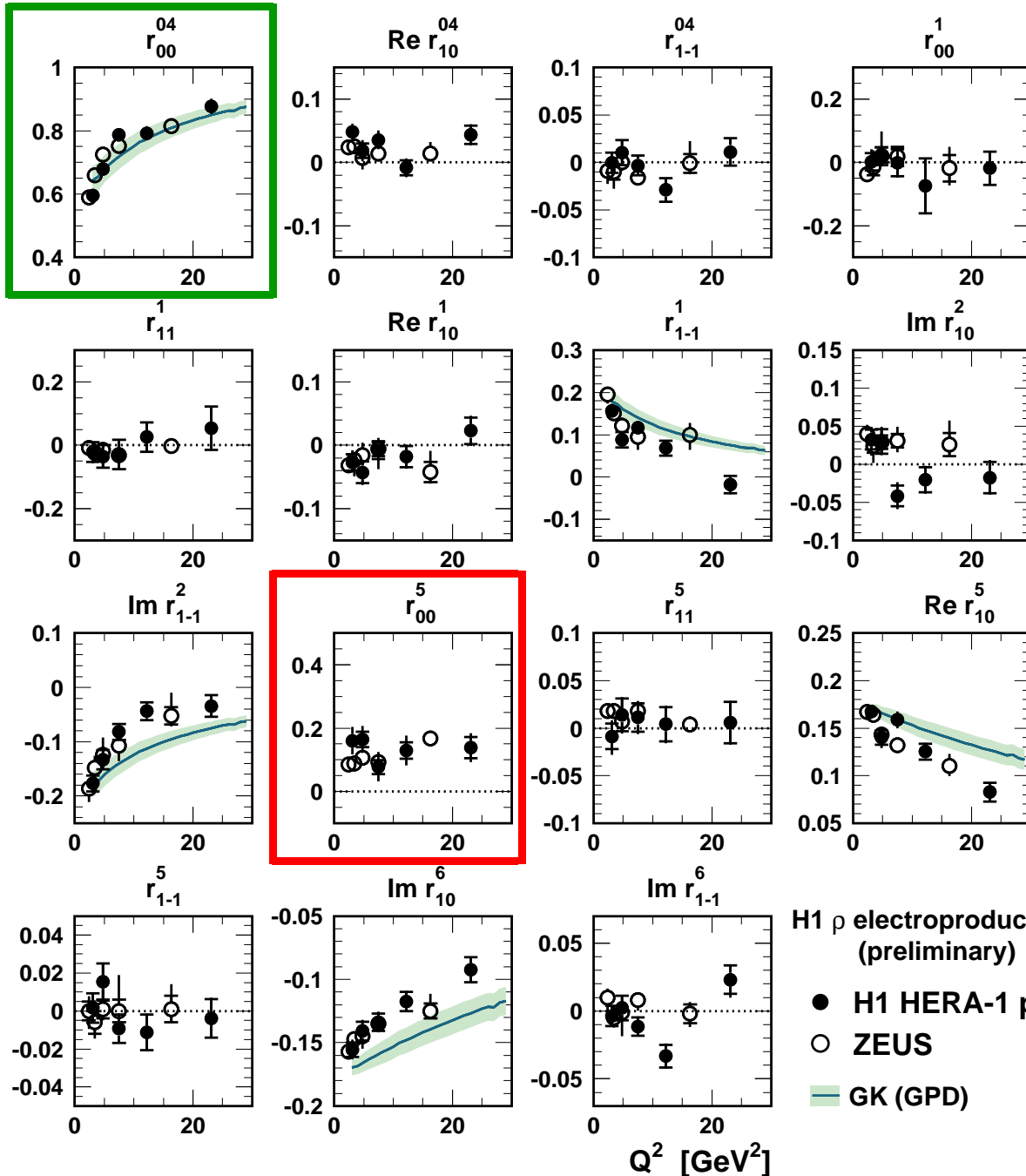
s -Channel Helicity Conservation (SCHC): $T_{01} = T_{10} = T_{1-1} = 0$

pQCD models:

- SCHC violation (single flip $\propto \sqrt{|t|}$, double $\propto |t|$)
- Hierarchy: $|T_{00}| > |T_{11}| > |T_{01}| > |T_{10}| > |T_{1-1}|$

D. Yu Ivanov and R. Kirschner
[hep-ph/9807324]

ρ Polarisation - SDMEs vs. Q^2



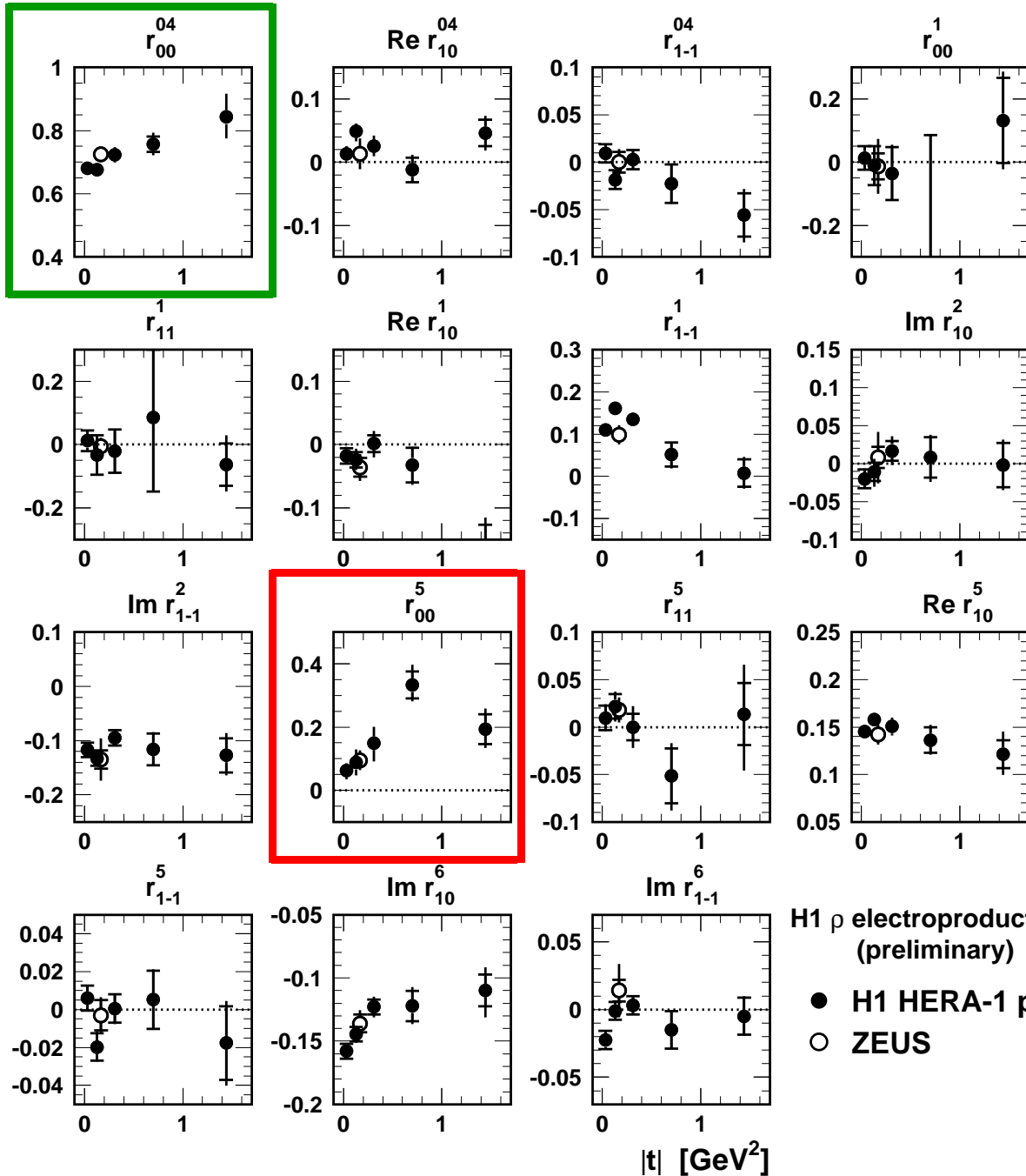
- r_{00}^{04} increases with Q^2
- ↔ similar effects for r_{1-1}^1 , $\text{Im } r_{1-1}^2$, $\text{Re } r_{10}^5$ and $\text{Im } r_{10}^6$ (in SCHC)
- ↔ Fair description by GK (GPD) model

- r_{00}^5 violates SCHC
- Other SDME $\simeq 0$

H1 ρ electroproduction (preliminary)

- H1 HERA-1 prel.
- ZEUS
- GK (GPD)

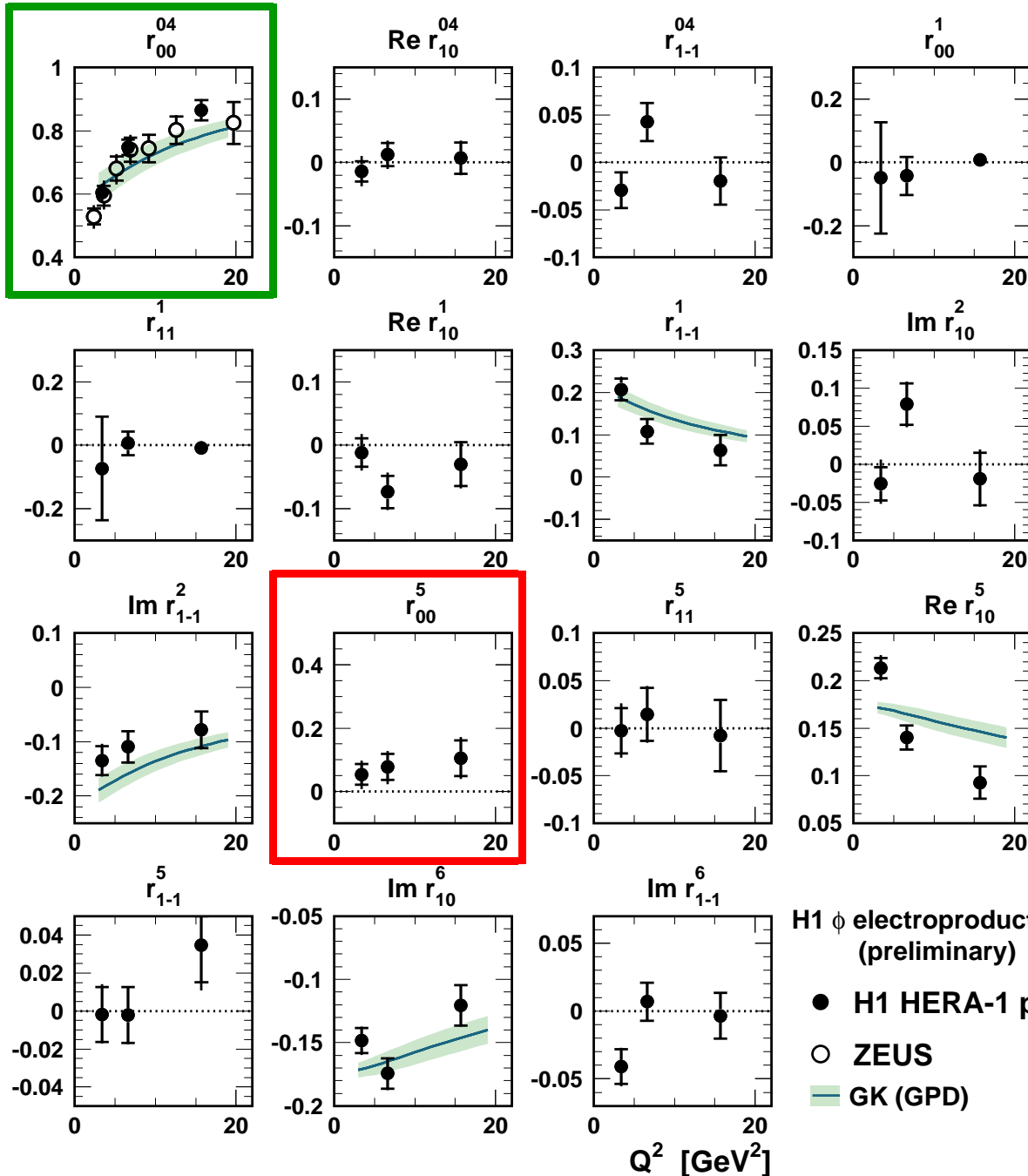
ρ Polarisation - SDMEs vs. $|t|$



● r_{00}^5 increases with $|t|$
 \leftrightarrow SCHC violation increases with $|t|$

● r_{00}^{04} increases with $|t|$
 \leftrightarrow similar effects for r_{1-1}^1 ,
 $\text{Im } r_{1-1}^2$, $\text{Re } r_{10}^5$ and
 $\text{Im } r_{10}^6$ (in SCHC)

ϕ Polarisation - SDMEs vs. Q^2



- r_{00}^{04} increases with Q^2
 ↔ Fair description by GK (GPD) model

- r_{00}^5 violates SCHC
 But larger error than for ρ

- Other SDME $\simeq 0$

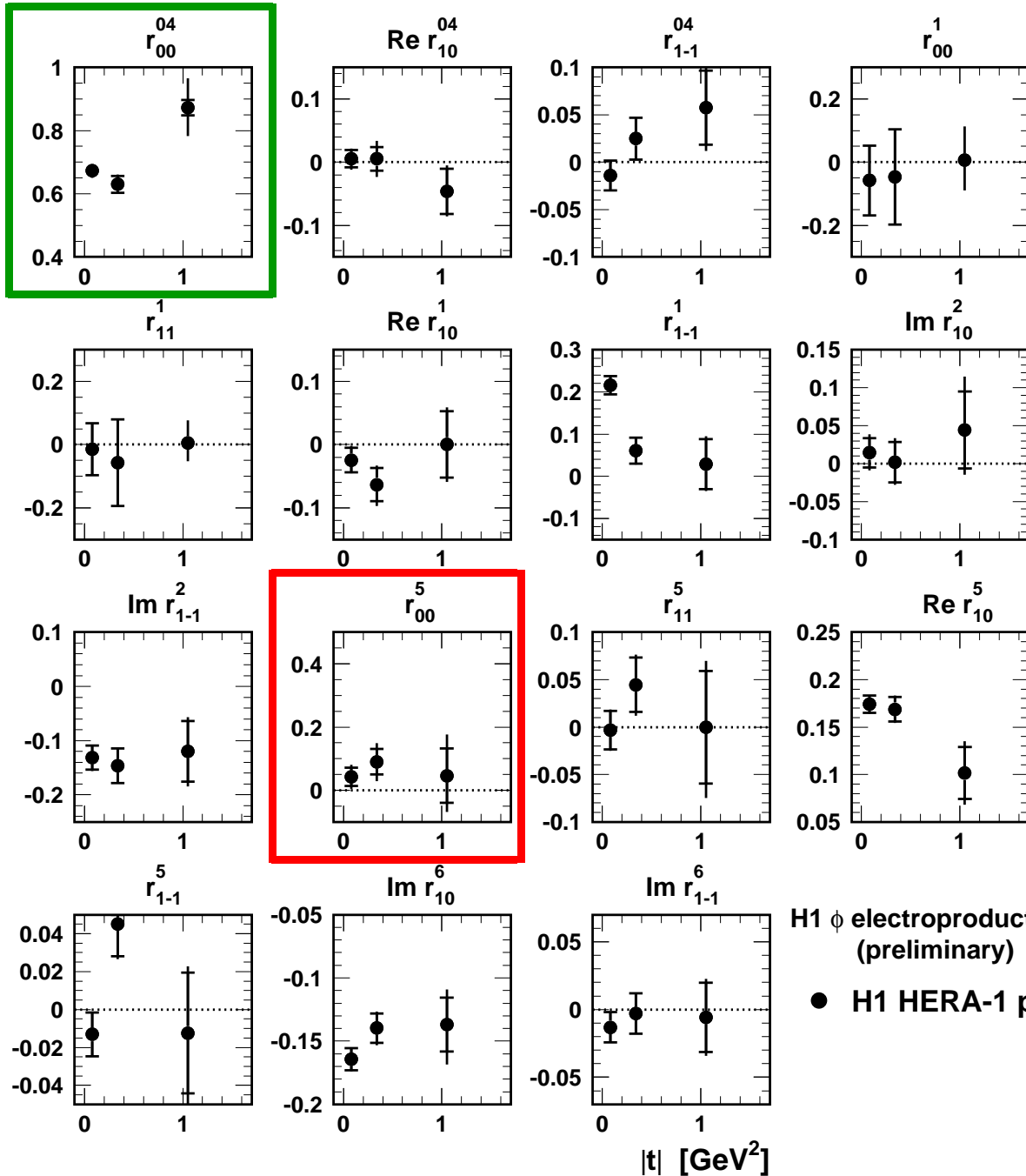
H1 ϕ electroproduction (preliminary)

● H1 HERA-1 prel.

○ ZEUS

— GK (GPD)

ϕ Polarisation - SDMEs vs. $|t|$



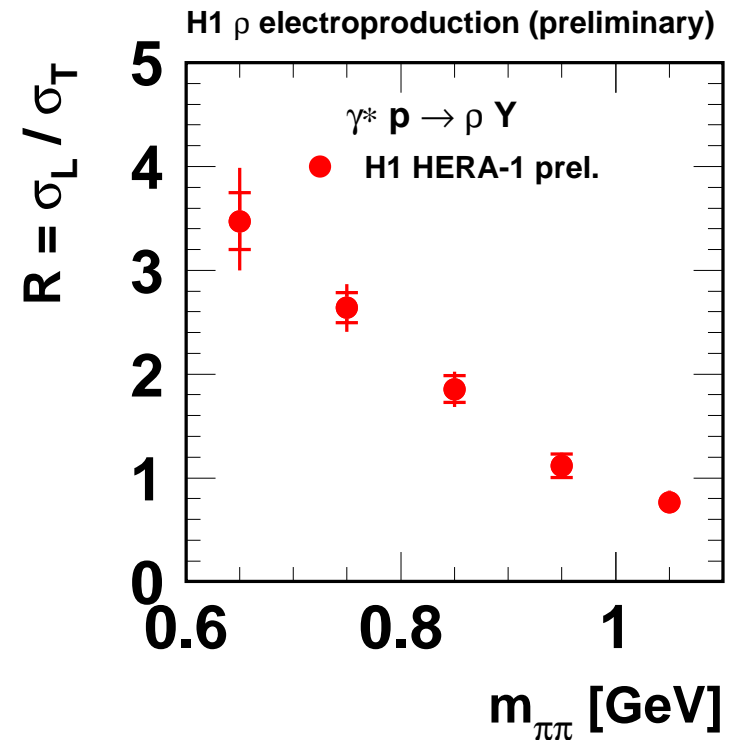
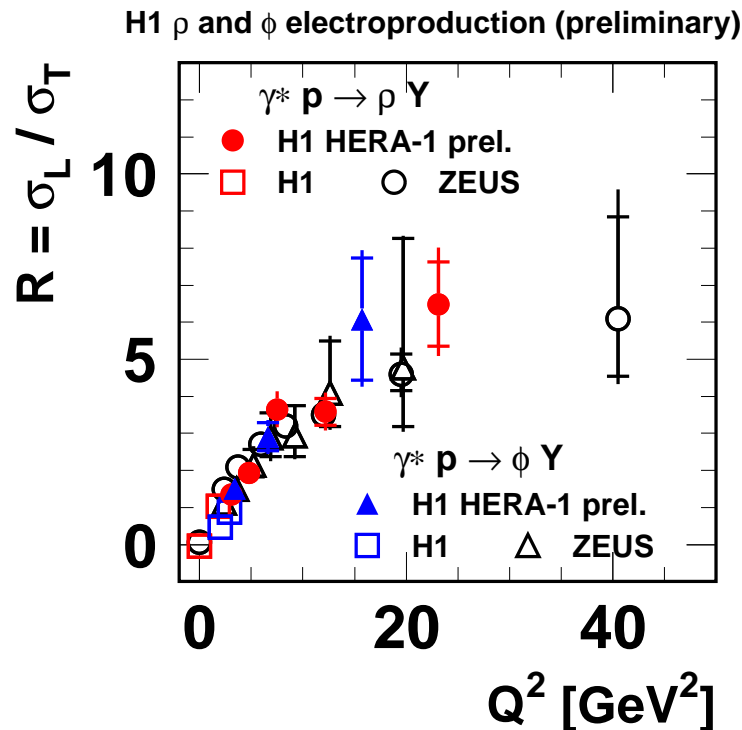
- Within large errors, no increase with $|t|$ of r_{00}^5
- Indication of a change with $|t|$ of r_{00}^{04} , r_{1-1}^1 , $\text{Re } r_{10}^5$ and $\text{Im } r_{10}^6$

H1 ϕ electroproduction
(preliminary)

● H1 HERA-1 prel.

Polarisation - $R = \sigma_L / \sigma_T$

$$R_{SCHC} = \frac{|T_{00}|^2}{|T_{11}|^2} = \frac{1}{\epsilon} \frac{r_{00}^{04}}{1 - \epsilon r_{00}^{04}}$$



- Naive $R \propto Q^2 / M^2$ dependence damped at high Q^2
- Similar R for ϕ and ρ
- Strong invariant mass dependence in ρ case

Polarisation - Retrieving Amplitude ratios

Assume purely imaginary amplitudes \longrightarrow phase = ± 1 !

\longrightarrow Extract $|T_{11}|/|T_{00}|$, $|T_{01}|/|T_{00}|$, $|T_{10}|/|T_{00}|$ and $|T_{-11}|/|T_{00}|$ from fit to the 15 SDMEs:

$$\begin{aligned}
 r_{00}^{04} &= B (\varepsilon + \beta^2) \\
 \text{Re } r_{10}^{04} &= B/2 (2\varepsilon\delta + \beta\alpha - \beta\eta) \\
 r_{1-1}^{04} &= B (\alpha\eta - \varepsilon\delta^2) \\
 r_{00}^1 &= -B \beta^2 \\
 r_{11}^1 &= B \alpha\eta \\
 \text{Re } r_{10}^1 &= B/2 \beta(\eta - \alpha) \\
 r_{1-1}^1 &= B/2 (\alpha^2 + \eta^2) \\
 \text{Im } r_{10}^2 &= B/2 \beta(\alpha + \eta) \\
 \text{Im } r_{1-1}^2 &= B/2 (\eta^2 - \alpha^2) \\
 r_{00}^5 &= \sqrt{2} B \beta \\
 r_{11}^5 &= B/\sqrt{2} \delta(\alpha - \eta) \\
 \text{Re } r_{10}^5 &= B/(2\sqrt{2}) (2\beta\delta + \alpha - \eta) \\
 r_{1-1}^5 &= B/\sqrt{2} \delta(\eta - \alpha) \\
 \text{Im } r_{10}^6 &= -B/(2\sqrt{2}) (\alpha + \eta) \\
 \text{Im } r_{1-1}^6 &= B/\sqrt{2} \delta(\alpha + \eta)
 \end{aligned}$$

$$\begin{aligned}
 \alpha &= |T_{11}|/|T_{00}| \\
 \beta &= |T_{01}|/|T_{00}| \\
 \delta &= |T_{10}|/|T_{00}| \\
 \eta &= |T_{-11}|/|T_{00}|
 \end{aligned}$$

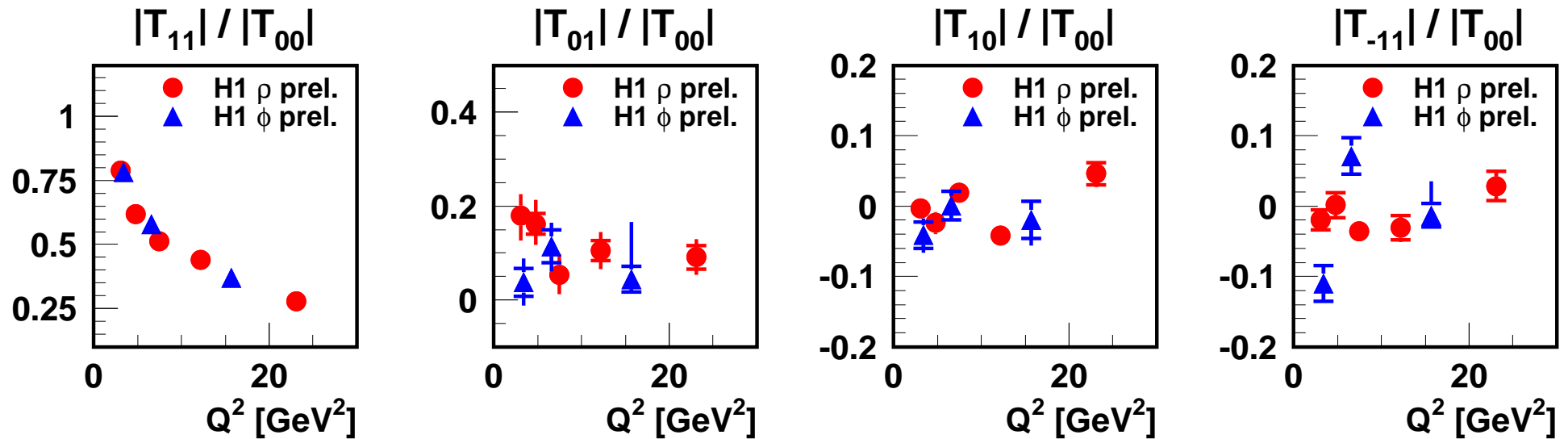
$$\begin{aligned}
 B &= \frac{1}{N_T + \varepsilon N_L} = \frac{R}{1 + \varepsilon R} \\
 N_T &= \alpha^2 + \beta^2 + \eta^2 \\
 N_L &= 1 + 2\delta^2
 \end{aligned}$$

Polarisation - Amplitude ratios vs. Q^2

pQCD (IK):

- $|T_{11}|/|T_{00}| = \frac{M}{Q} \frac{1+\gamma}{\gamma}$
- $|T_{10}|/|T_{00}| = -\frac{M}{Q^2} \frac{\sqrt{|t|}}{\gamma} \frac{\sqrt{2}}{\gamma}$
- $|T_{01}|/|T_{00}| = \frac{\sqrt{|t|}}{Q} \frac{1}{\sqrt{2}\gamma}$

γ : gluon anomalous dim.



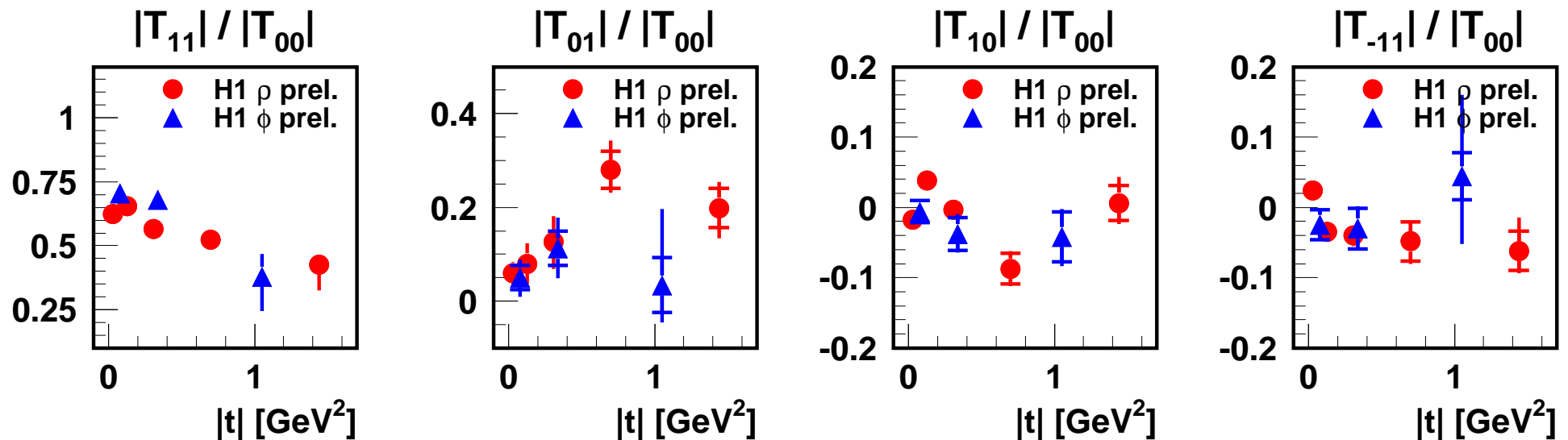
- $|T_{11}|/|T_{00}|$ decreases with $Q^2 \leftrightarrow \sigma_L/\sigma_T$ increases with Q^2
 - $|T_{01}|/|T_{00}| > 0 \leftrightarrow$ SCHC violation
 - $|T_{10}|/|T_{00}|$ and $|T_{-11}|/|T_{00}|$ are small
- $\Rightarrow |T_{00}| > |T_{11}| > |T_{01}| > |T_{10}|, |T_{-11}| \leftrightarrow$ hierarchy observed

Polarisation - Amplitude ratios vs. $|t|$

pQCD (IK):

- $|T_{11}|/|T_{00}| = \frac{M}{Q} \frac{1+\gamma}{\gamma}$
- $|T_{10}|/|T_{00}| = -\frac{M}{Q^2} \frac{\sqrt{|t|}}{\gamma} \frac{\sqrt{2}}{\gamma}$
- $|T_{01}|/|T_{00}| = \frac{\sqrt{|t|}}{Q} \frac{1}{\sqrt{2}\gamma}$

γ : gluon anomalous dim.



- $|T_{11}|/|T_{00}|$ decreases with $|t|$
- $|T_{01}|/|T_{00}|$ increases with $|t| \leftrightarrow$ SCHC violation increases with $|t|$
- $|T_{10}|/|T_{00}|$ and $|T_{-11}|/|T_{00}|$ are small but some $|t|$ dependence
- $|T_{11}|/|T_{00}|$ decrease compensated by $|T_{01}|/|T_{00}|$ increase
 $\Rightarrow \sigma_L/\sigma_T$ mainly constant with $|t|$

CONCLUSIONS

H1 analysis of Diffractive Electroproduction of ρ and ϕ , including elastic and proton dissociative channels, using the full HERA-1 data

Preliminary cross-section measurements:

- High precision reached at high Q^2 ; First ϕ p-diss. measurement
- p-diss. / elastic ratio: proton vertex factorisation observed
- Polarised cross-sections have been extracted
- W dependence: transition from soft to hard regime observed

Polarisation properties:

- 15 SDMEs measured as a function of Q^2 and $|t|$
- Amplitude ratios extracted from SDMEs
- σ_L/σ_T increases with Q^2 and constant with $|t|$
- σ_L/σ_T decreases with ρ invariant mass
- Violation of SCHC: $|T_{10}|/|T_{00}|$ increases with $|t|$
- Hierarchy: $|T_{00}| > |T_{11}| > |T_{01}| > |T_{10}|, |T_{-11}|$ observed