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On behalf of the H1 Collaboration

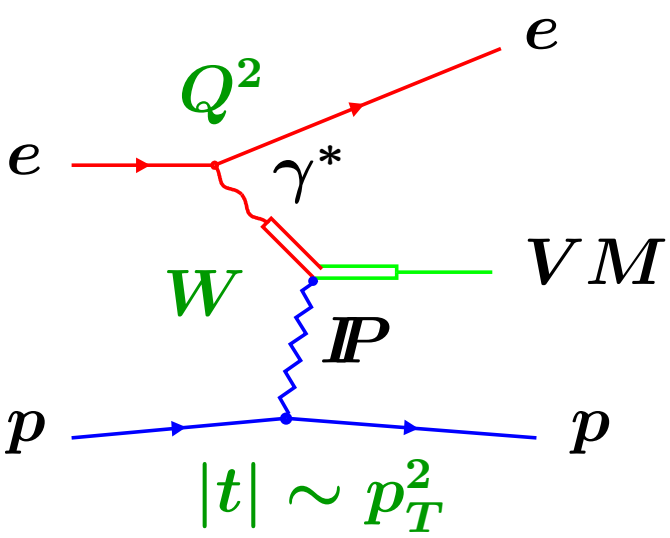
Diffractive electroproduction of ρ and ϕ mesons at H1

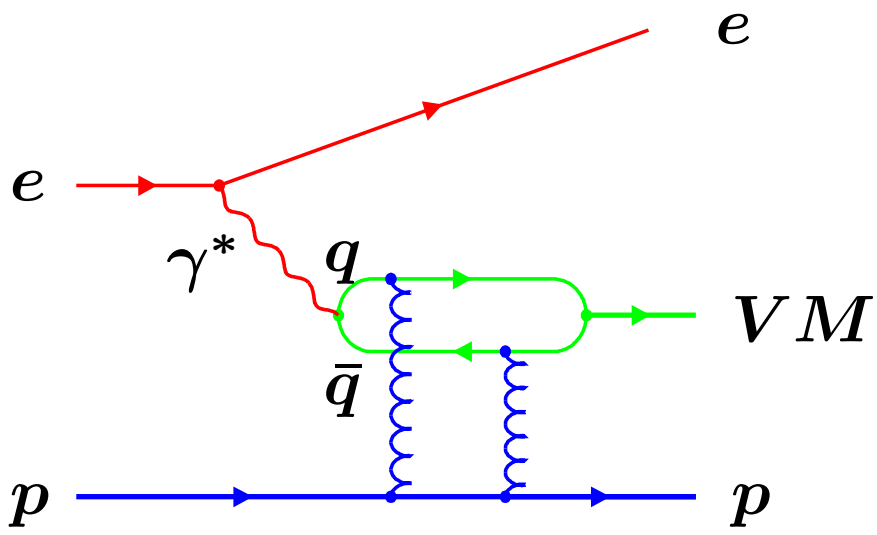
XVI International Workshop on Deep-Inelastic Scattering and Related Subjects

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

Introduction

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





Regge Theory

= Soft IPomeron exchange

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

$$\alpha_{I\!P}(t) = 1.08 + 0.25\,t \text{ (DL)}$$

pQCD Models

Exchange of ≥ 2 gluons

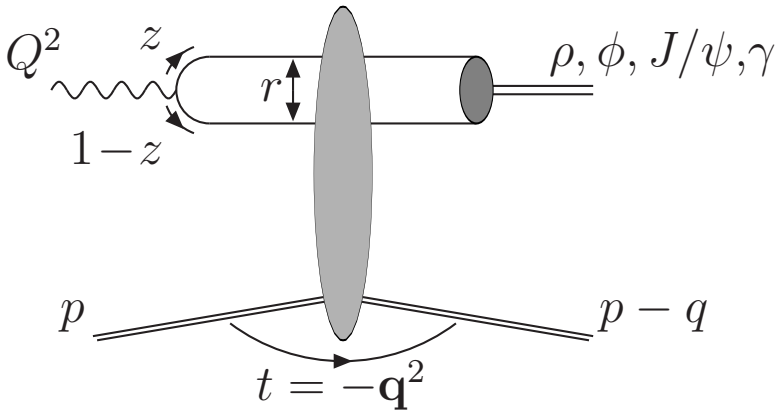
$$\sigma \propto (xG(x, Q^2))^2$$

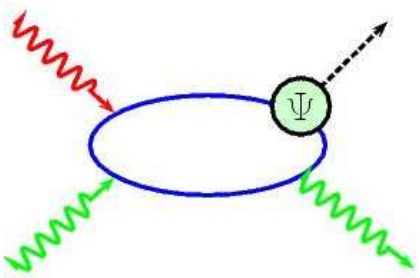
Steep rise of $xG(x, Q^2)$

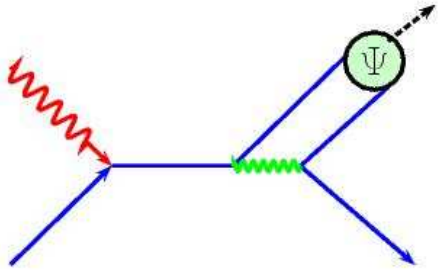
Light VM at low Q^2 and low $|t|$ Requires hard scale: Q^2, t or m_q

$\Longrightarrow$ ρ 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

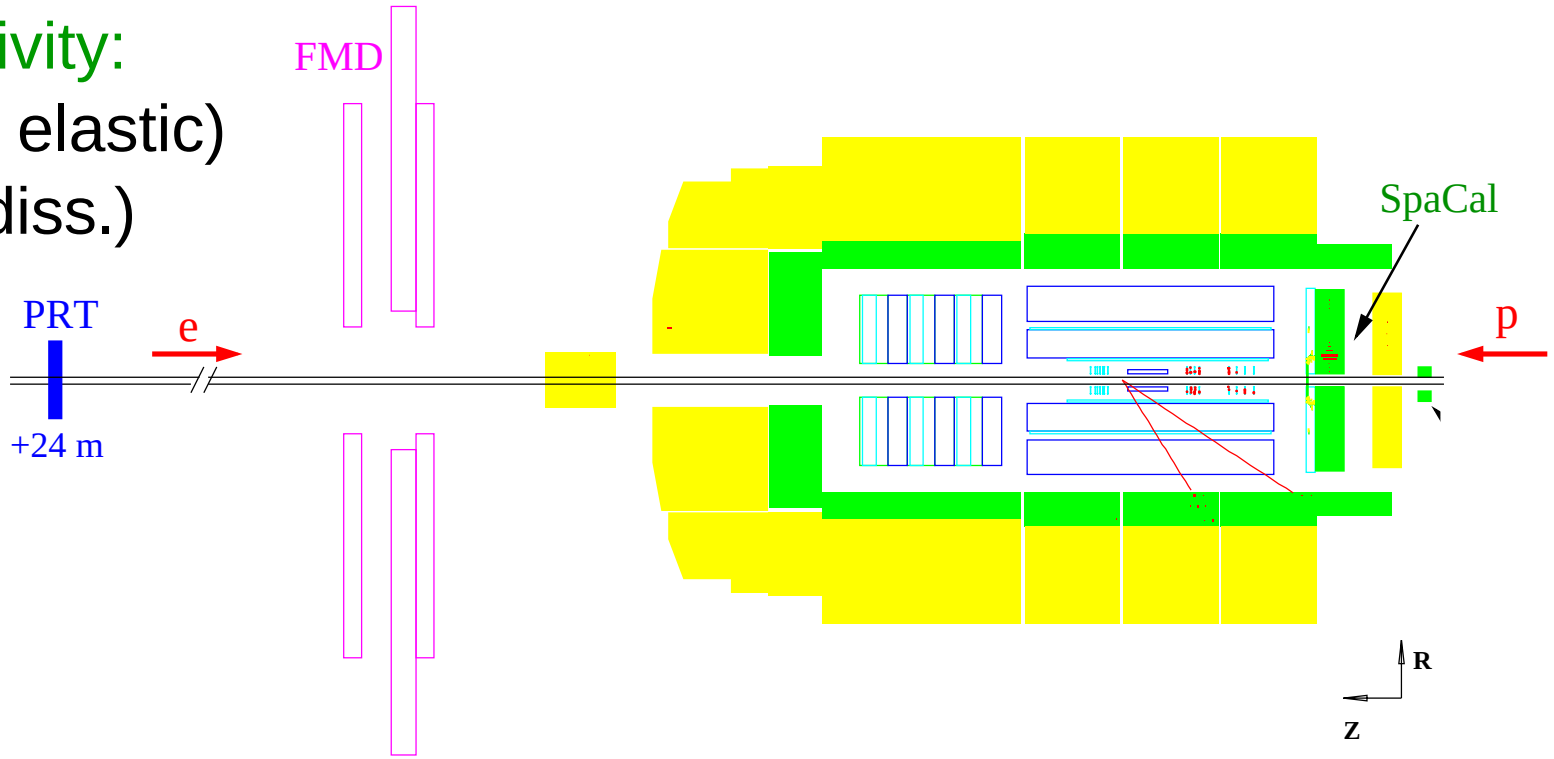
$$e^+ + p \to e^+ + \rho + p \text{ (or } Y) \quad ; \quad \rho \to \pi^+ + \pi^-$$
$$e^+ + p \to e^+ + \phi + p \text{ (or } Y) \quad ; \quad \phi \to K^+ + K^-$$

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

Forward activity:

NOTAG ($\simeq$ elastic)

TAG ($\simeq$ p-diss.)

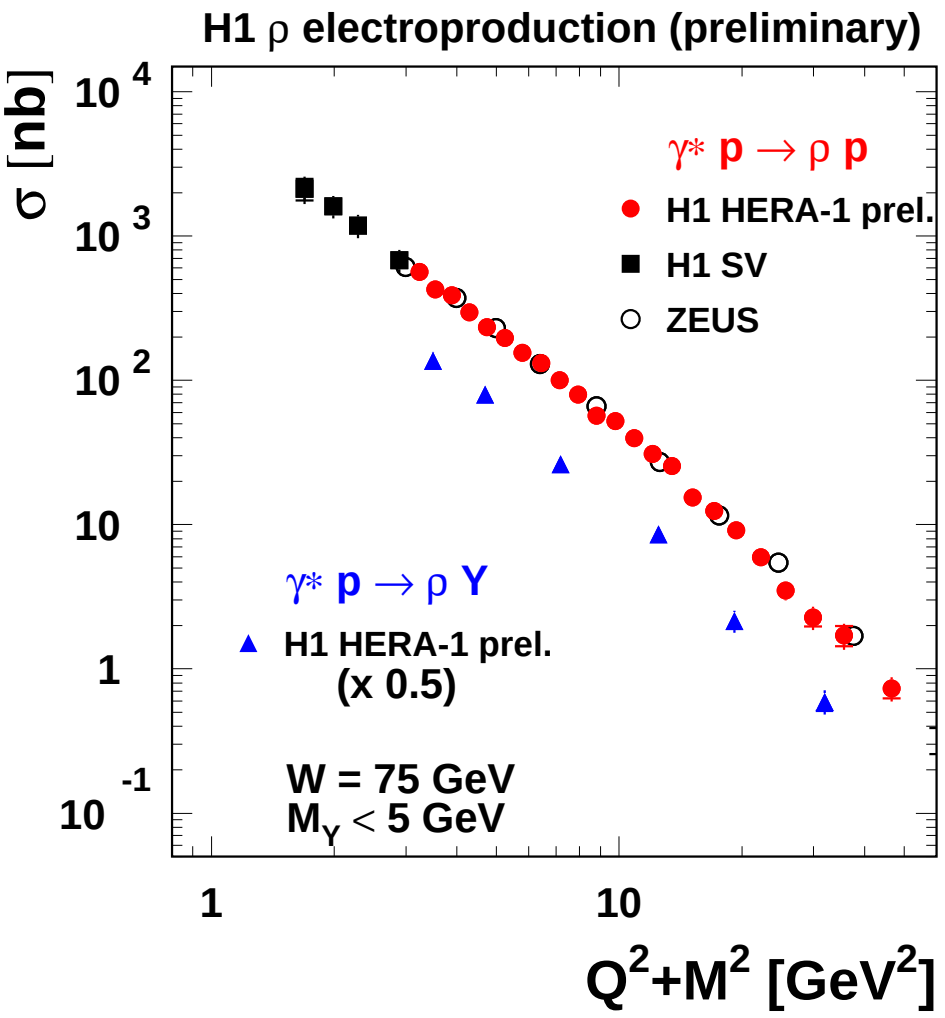


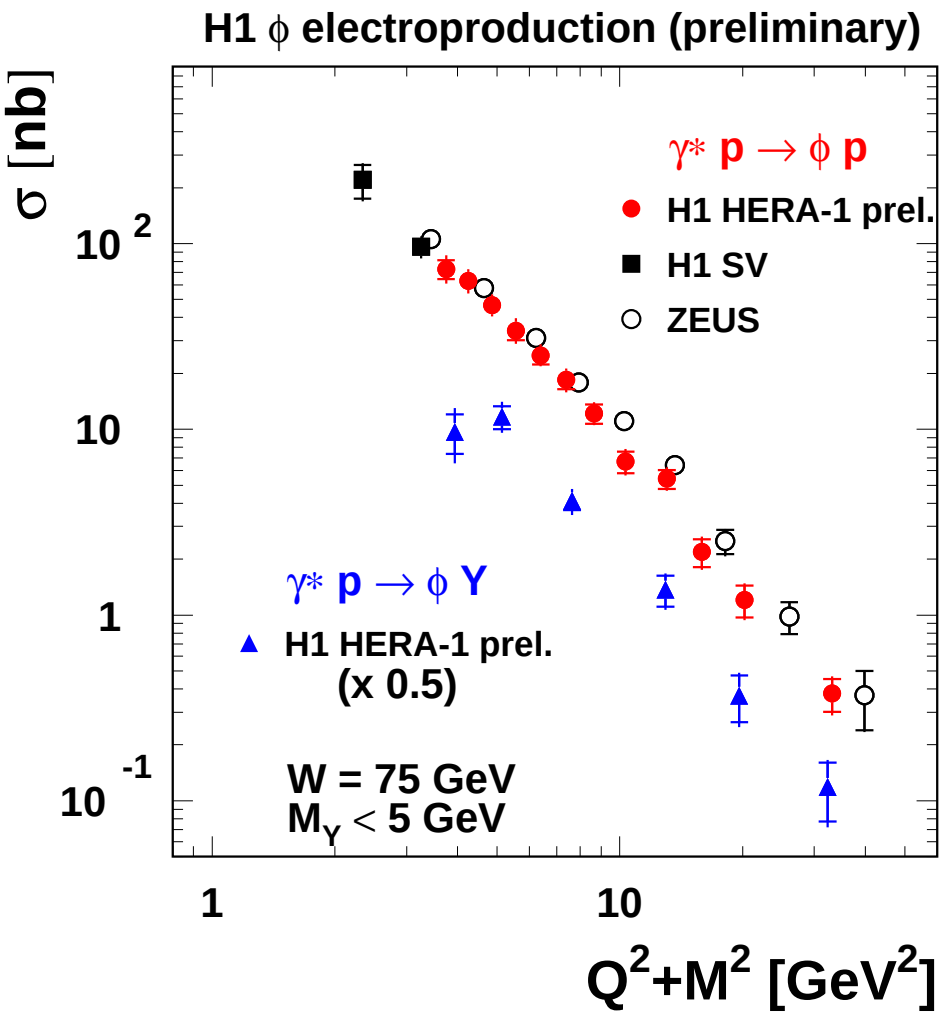
$2.5 < Q^2 < 60\ \mathrm{GeV}^2$ elastic: $|t| < 0.5\ \mathrm{GeV}^2$

$35 < W < 180\ \mathrm{GeV}$ p-diss.: $|t| < 3.0\ \mathrm{GeV}^2$

$M_Y < 5\ \mathrm{GeV}$

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

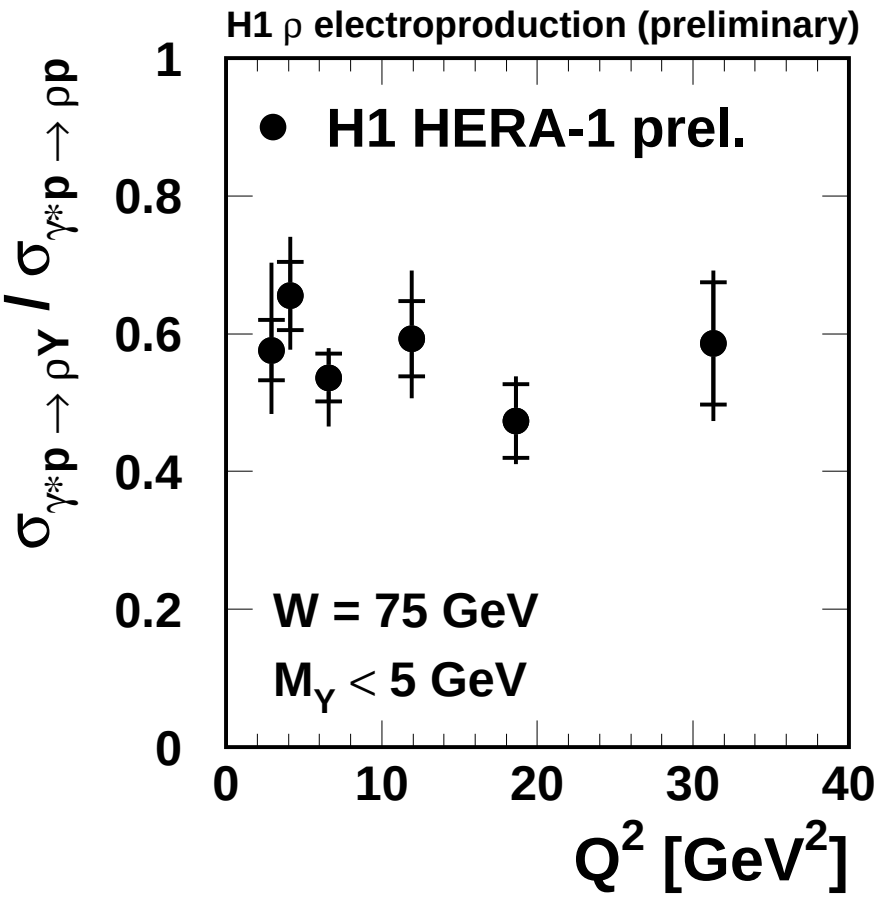


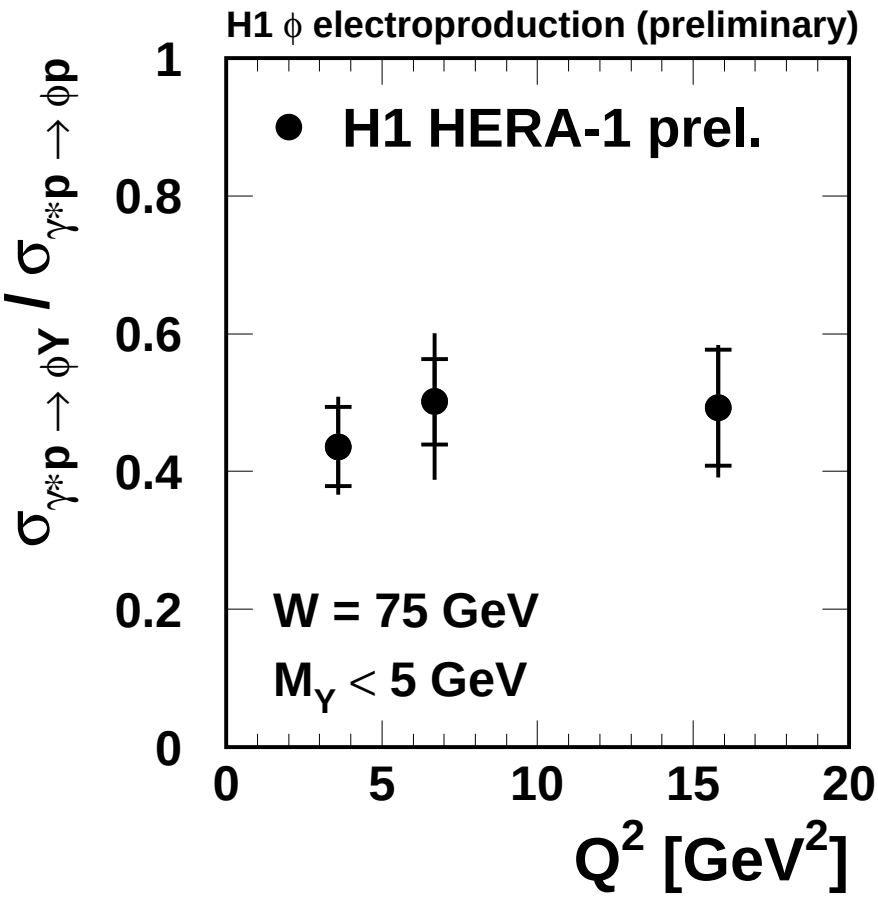


- High precision for elastic cross-sections; First ϕ p-diss. cross-section
- $\sigma_{\gamma^* p}(Q^2) \propto 1/(Q^2 + M_{VM}^2)^{n(Q^2)}$; $n(Q^2) = a + b\,Q^2$

  $a \simeq -2.15$; $b \simeq -0.70$ GeV^{-2}

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

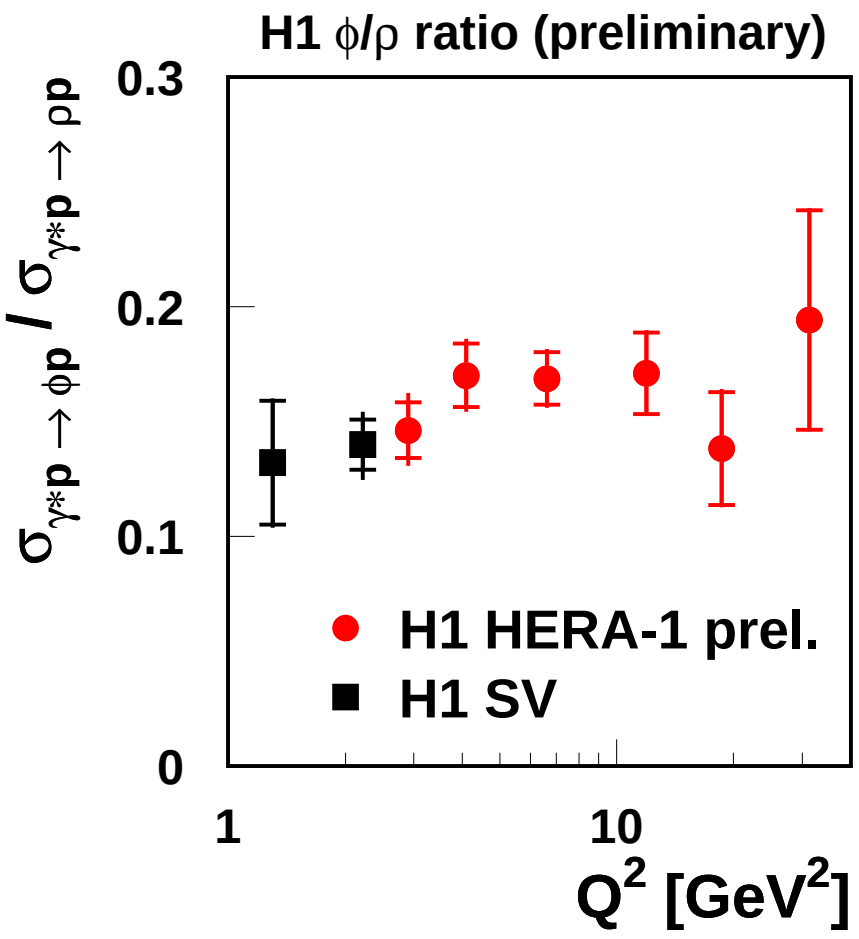


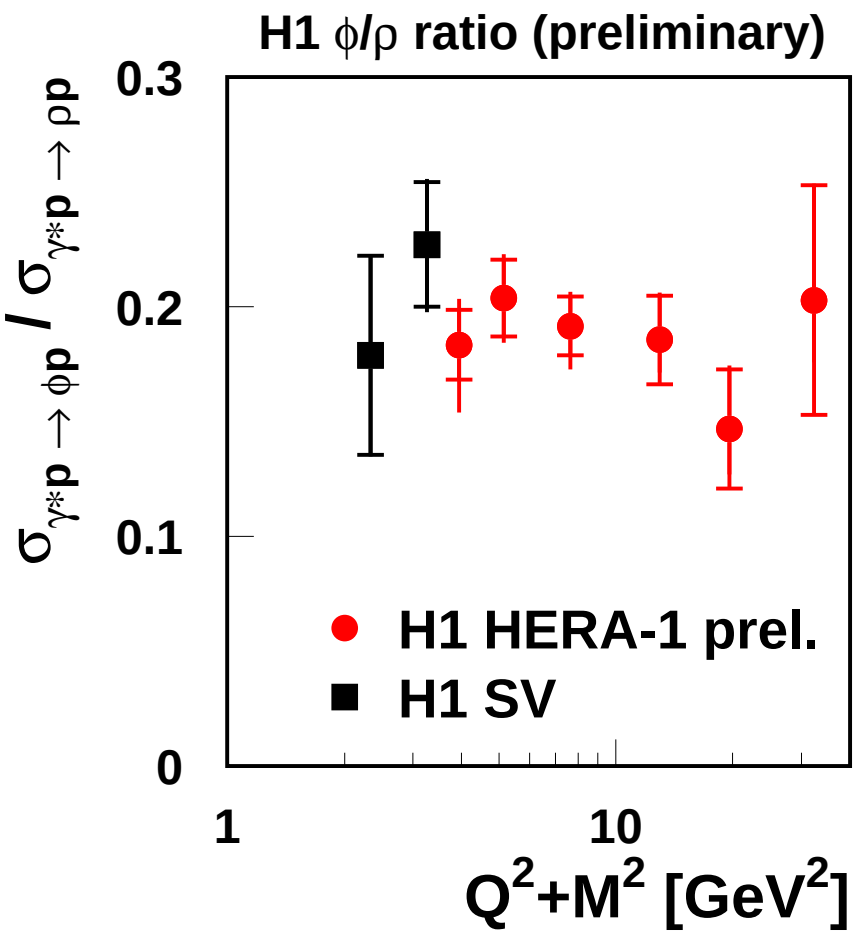


- p-diss. / elastic ratio independent of Q^2
- Similar ratio within errors for ρ and ϕ

$\longrightarrow$ Proton vertex factorisation for $Q^2 > 2.5\ \mathrm{GeV}^2$

ϕ/ρ ratio - Elastic cross-sections



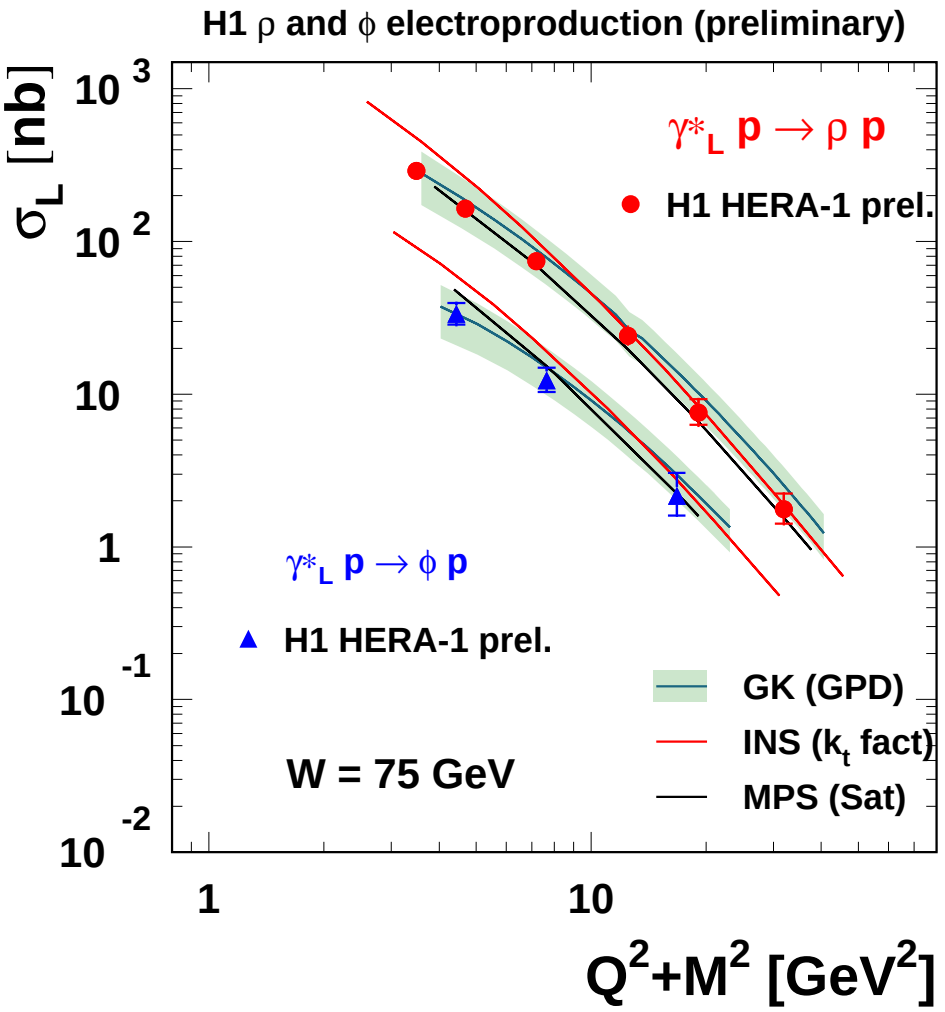


$\Rightarrow$ Ratio independent of $Q^2 + M^2$

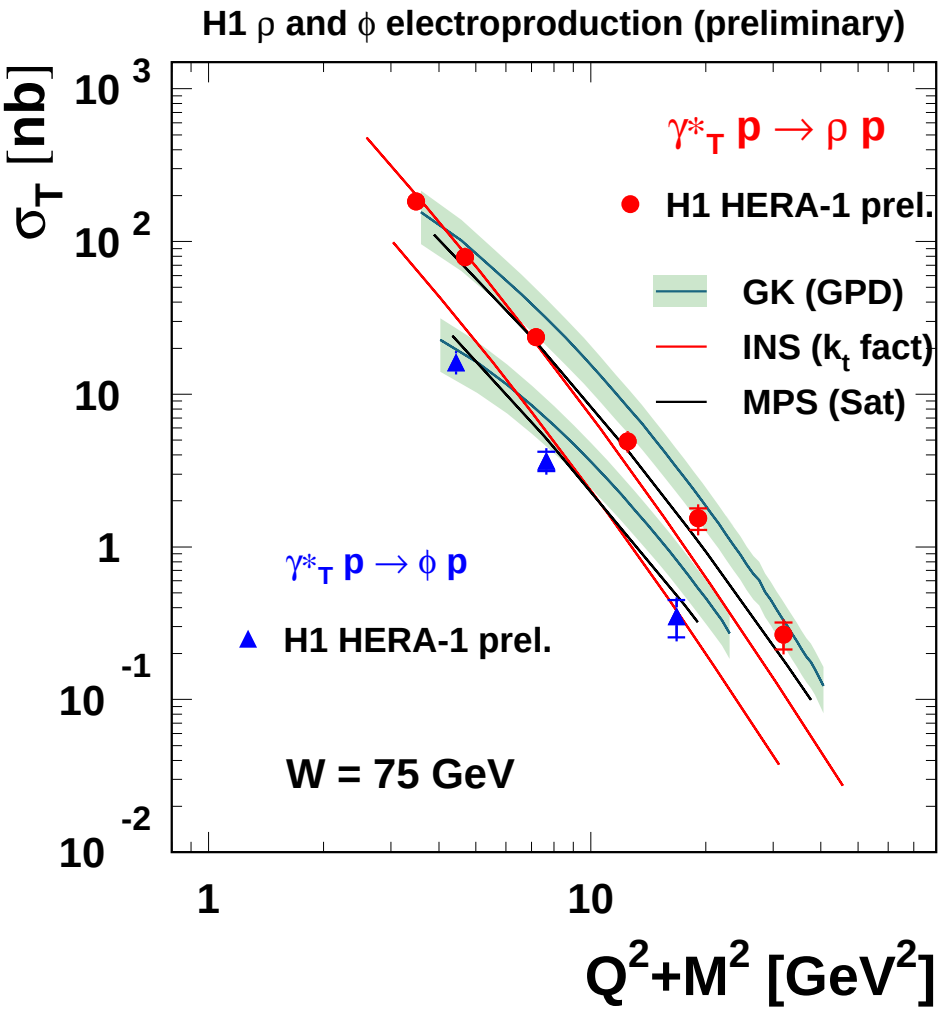
$\Rightarrow$ At low Q^2, $q\bar{q}$ size $\propto 1/M$, at high Q^2, $q\bar{q}$ size $\propto Q^2$

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

Longitudinal

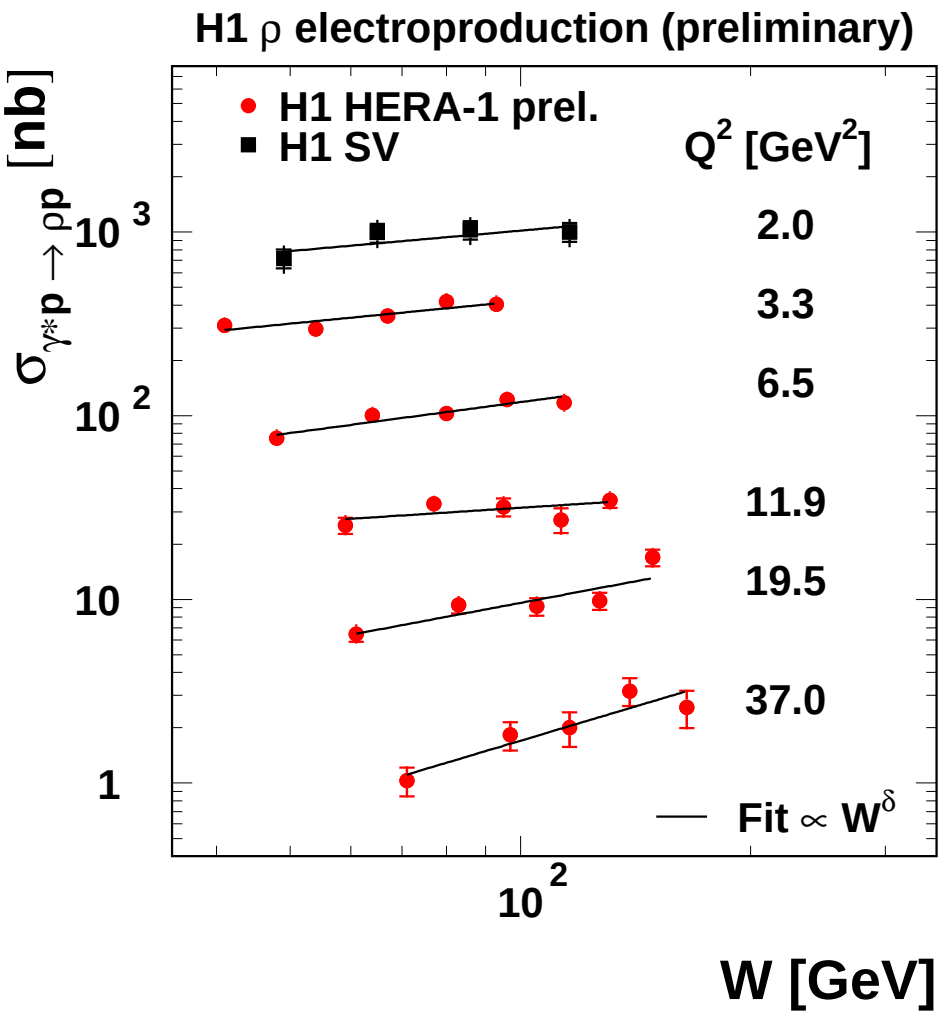


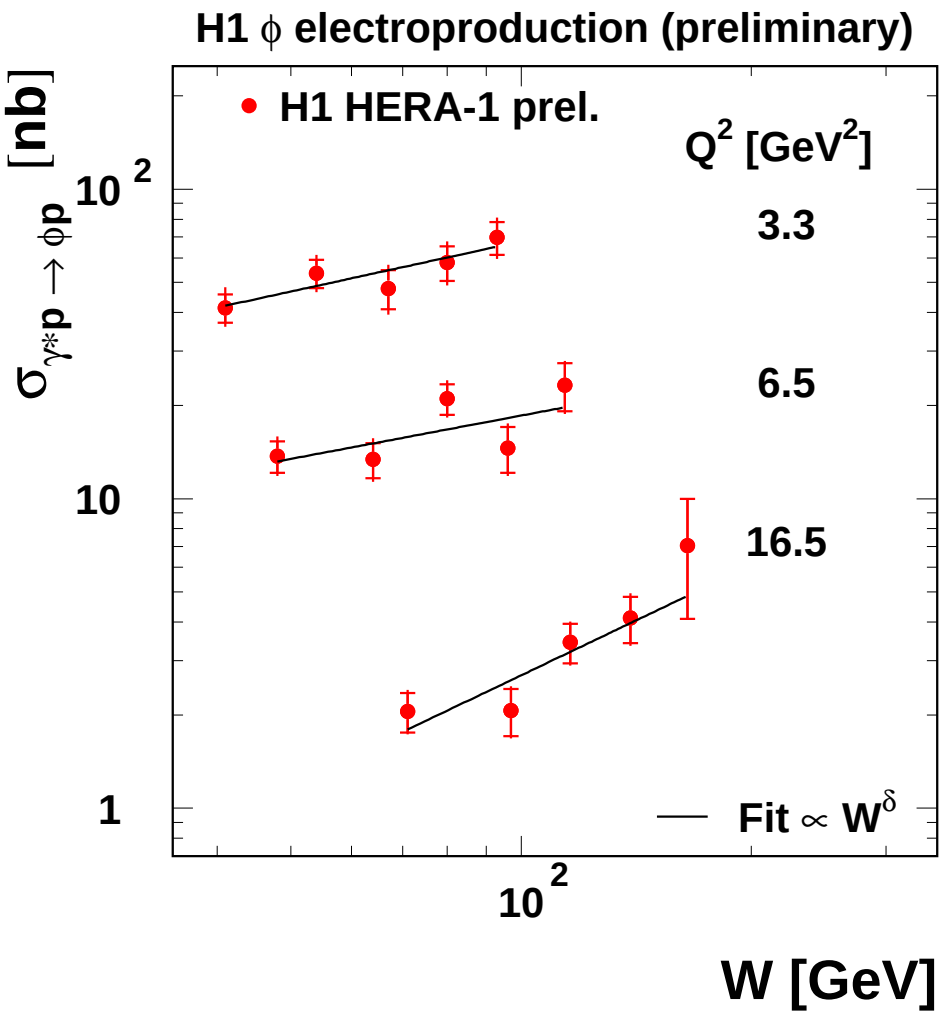
Transverse



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



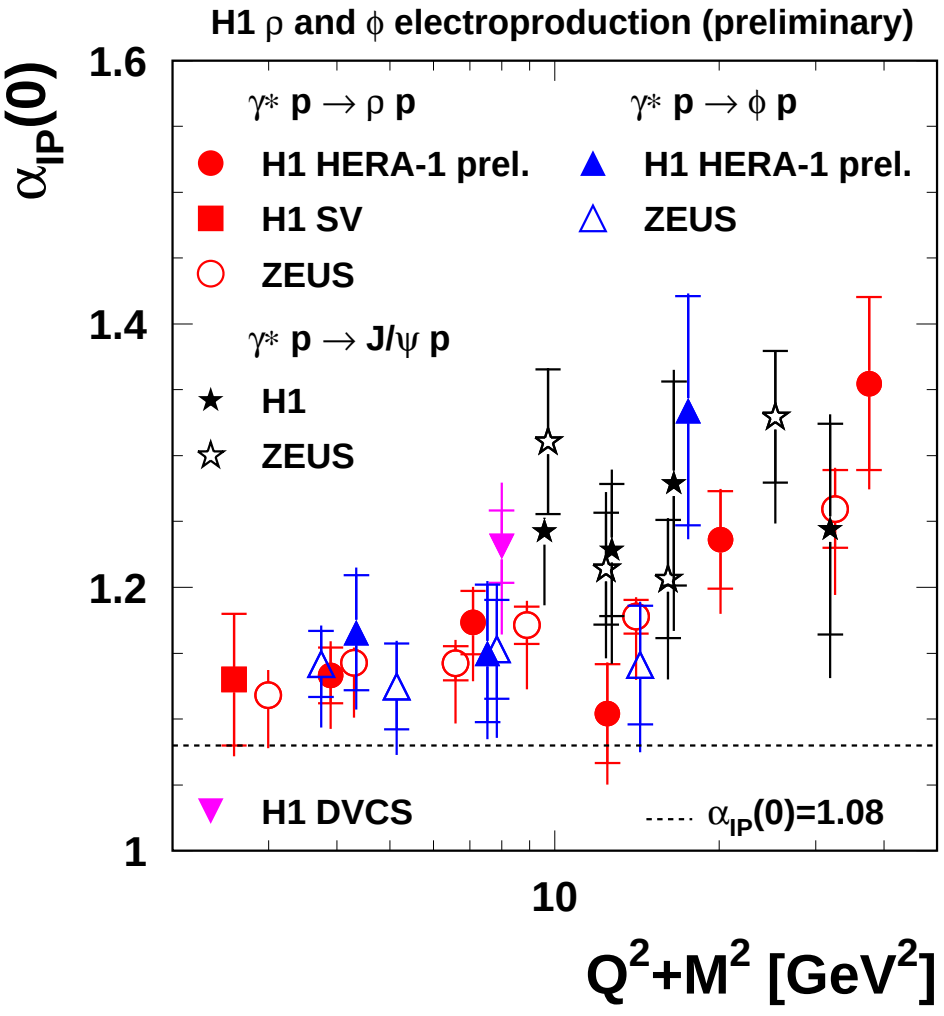


Fit parametrisation : $\sigma_{\gamma^* p}(W) \propto W^{\delta}$

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

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

$$\alpha_{I\!P}(0) = 1 + \delta/4 + \alpha'_{I\!P}/\langle|t|\rangle \;\; ; \;\; \alpha'_{I\!P} = 0 - 0.25\ \mathrm{GeV}^{-2}$$



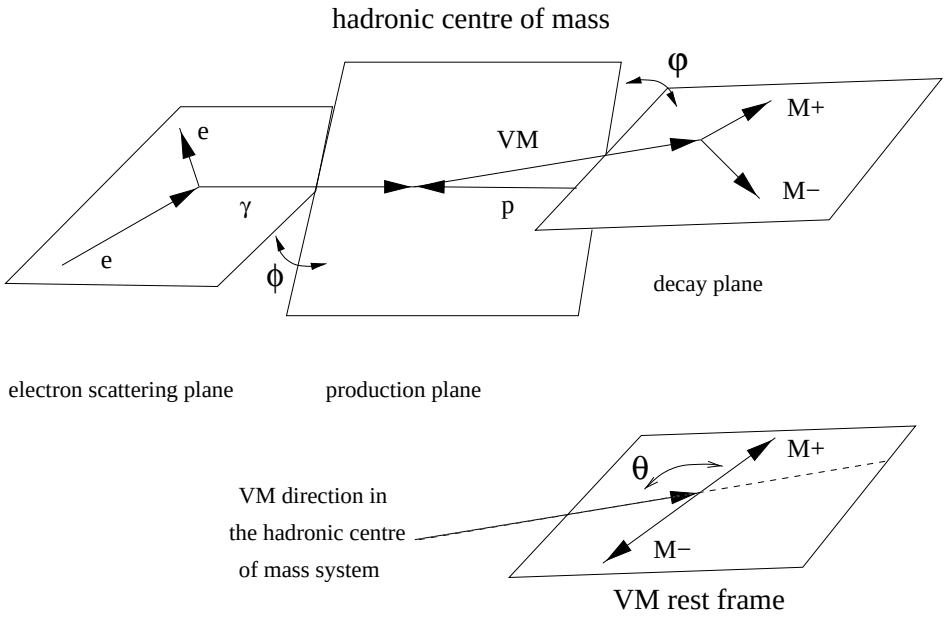
- Significant hardening of $\alpha_{I\!P}(0)$ with Q^2 for ρ and ϕ
- Common increase vs. $Q^2 + M^2$ for all VM (J/ψ and DVCS)

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

SPIN DENSITY MATRIX ELEMENTS

θ^* , Φ , $\varphi \Longleftrightarrow$ 15 SDMEs : $r^{ij}_{kl} \propto T_{\lambda'_\rho \lambda'_\gamma} T_{\lambda_\rho \lambda_\gamma}$

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



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

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

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

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

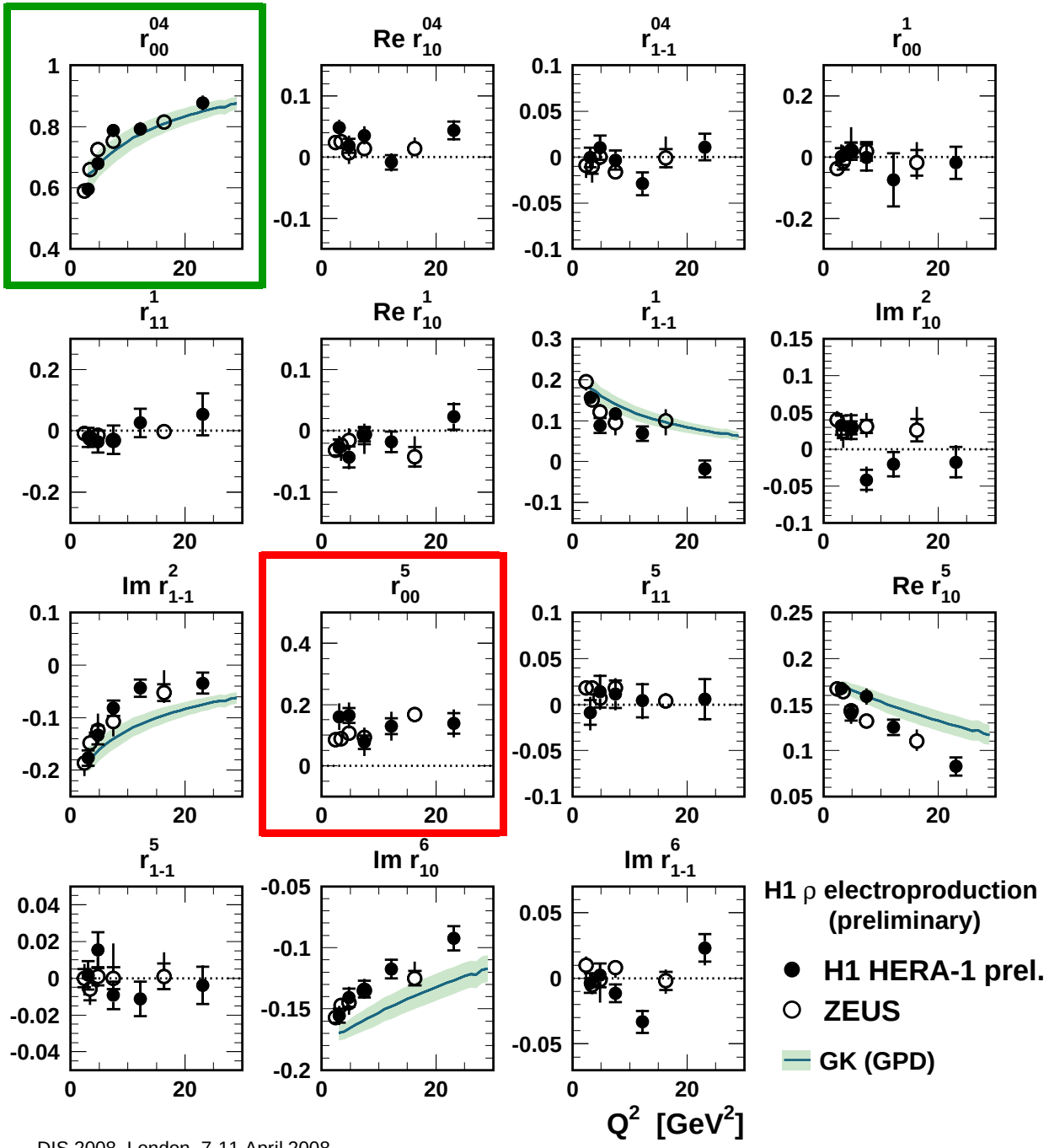
Double flip: $T_{1-1} : \gamma_T \longrightarrow \rho_T$

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

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

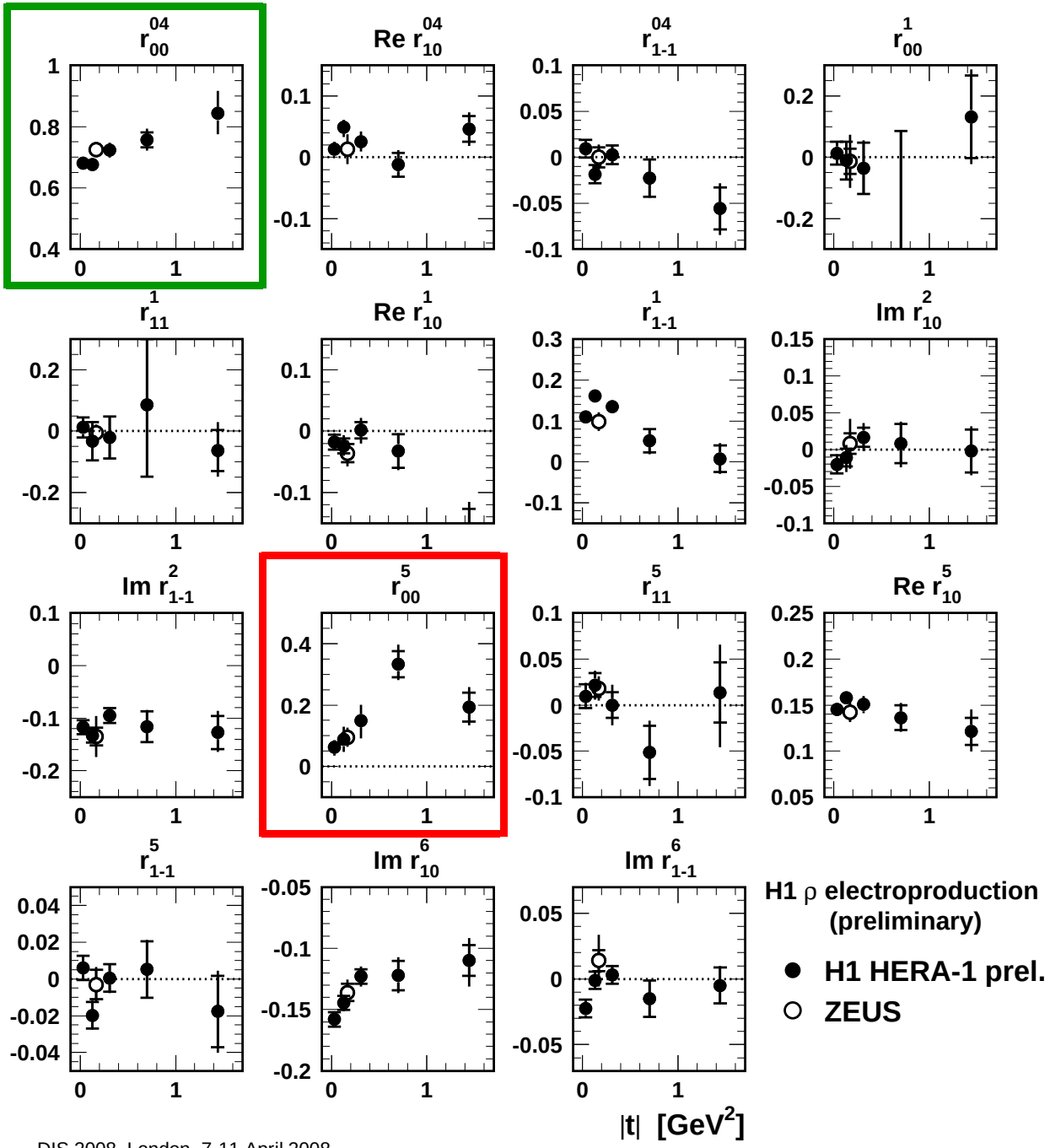
- SCHC violation (single flip $\propto \sqrt{|t|}$, double $\propto |t|$)
- Hierarchy: $|T_{00}| > |T_{11}| > |T_{01}| > |T_{10}| > |T_{1-1}|$

ρ Polarisation - SDMEs vs. Q^2



- r^{04}_{00} increases with Q^2
  $\leftrightarrow$ similar effects for r^{1}_{1-1}, Im r^{2}_{1-1}, Re r^{5}_{10} and Im r^{6}_{10} (in SCHC)
  $\leftrightarrow$ Fair description by GK (GPD) model
- r^{5}_{00} violates SCHC
- Other SDME $\simeq 0$

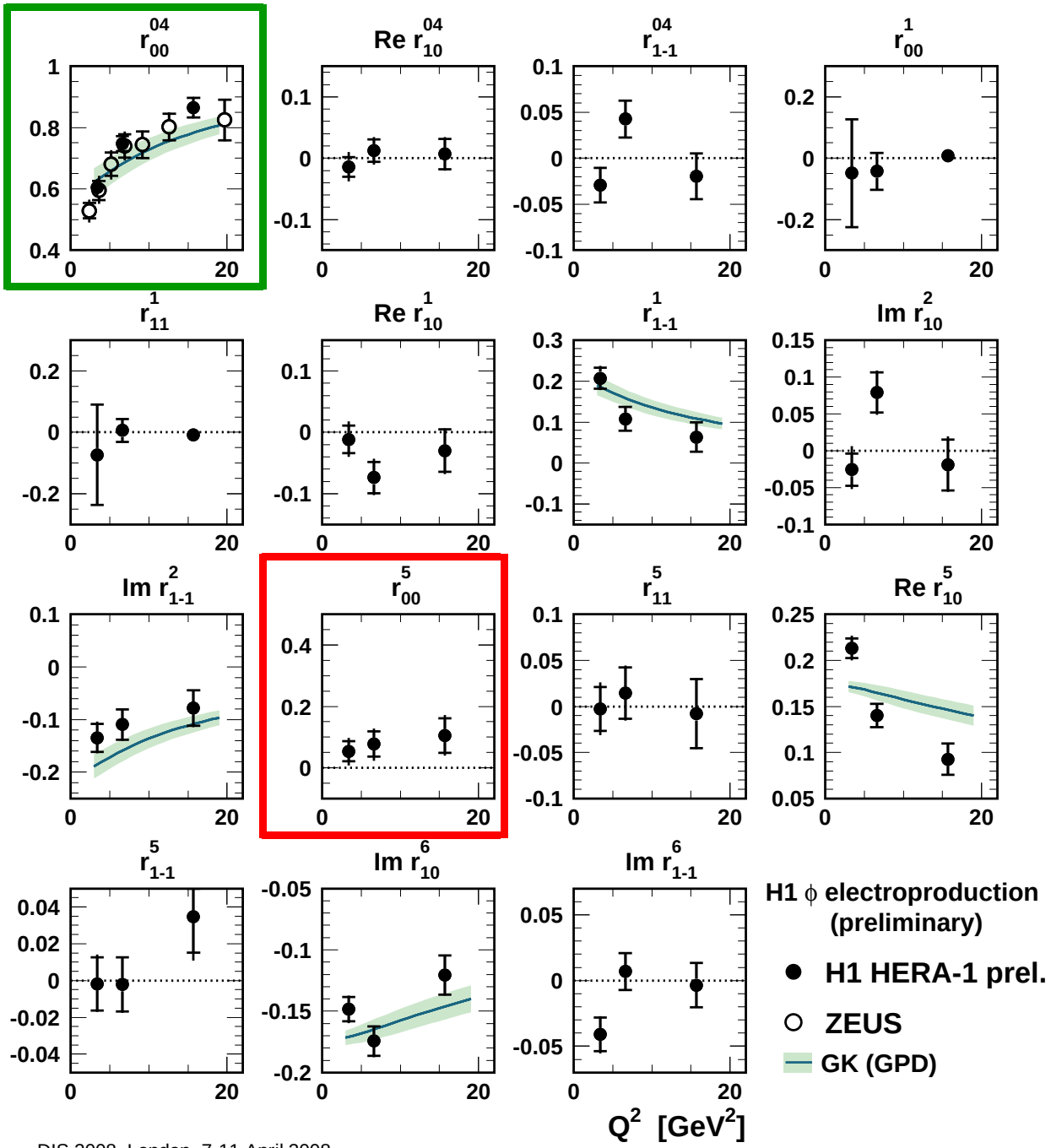
ρ Polarisation - SDMEs vs. $|t|$



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

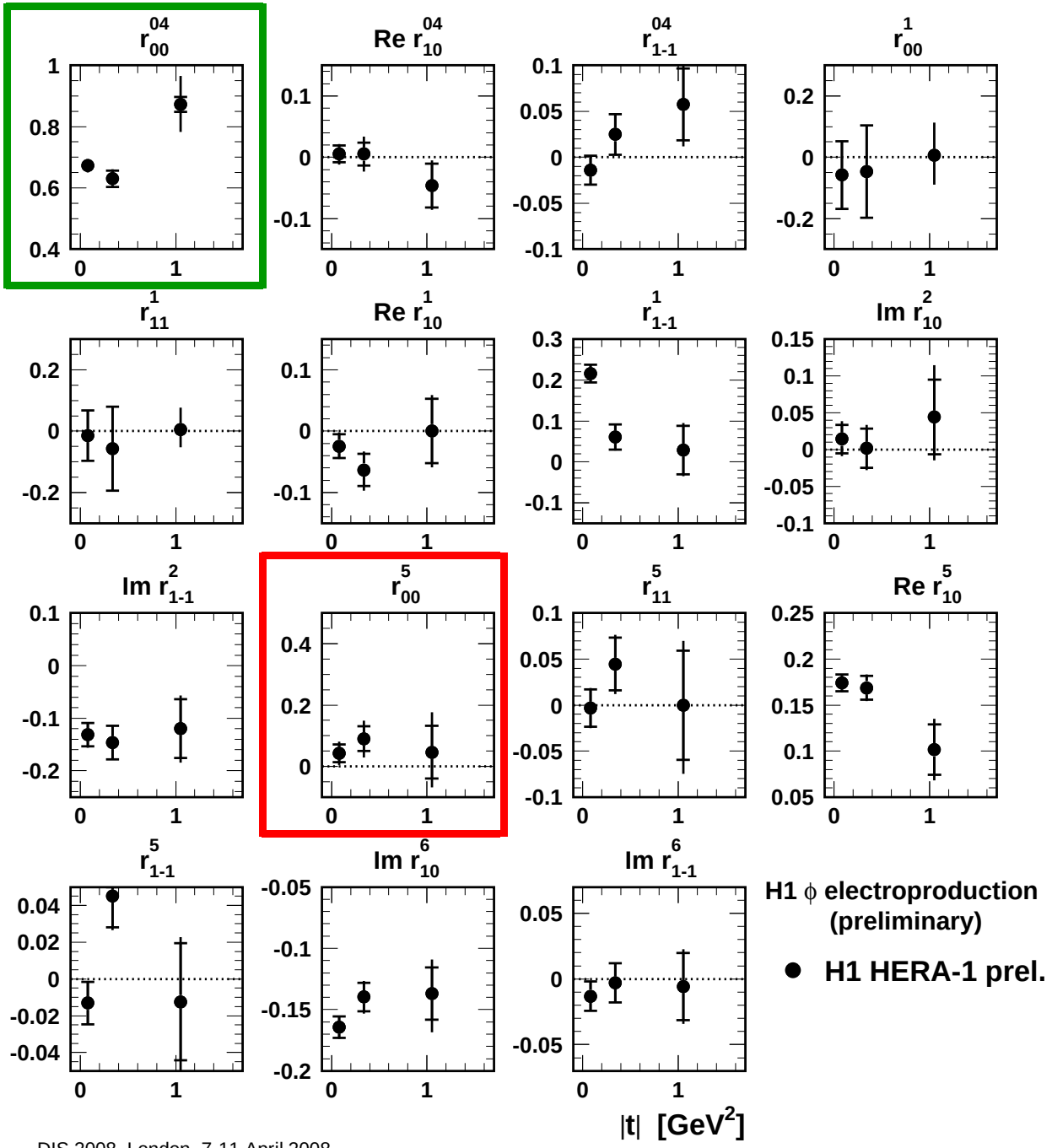
- r_{00}^{04} increases with $|t|$
  $\leftrightarrow$ similar effects for r_{1-1}^{1}, Im r_{1-1}^{2}, Re r_{10}^{5} and Im r_{10}^{6} (in SCHC)

ϕ Polarisation - SDMEs vs. Q^2



- r^{04}_{00} increases with Q^2
  $\leftrightarrow$ Fair description by GK (GPD) model
- r^{5}_{00} violates SCHC
  But larger error than for ρ
- Other SDME $\simeq 0$

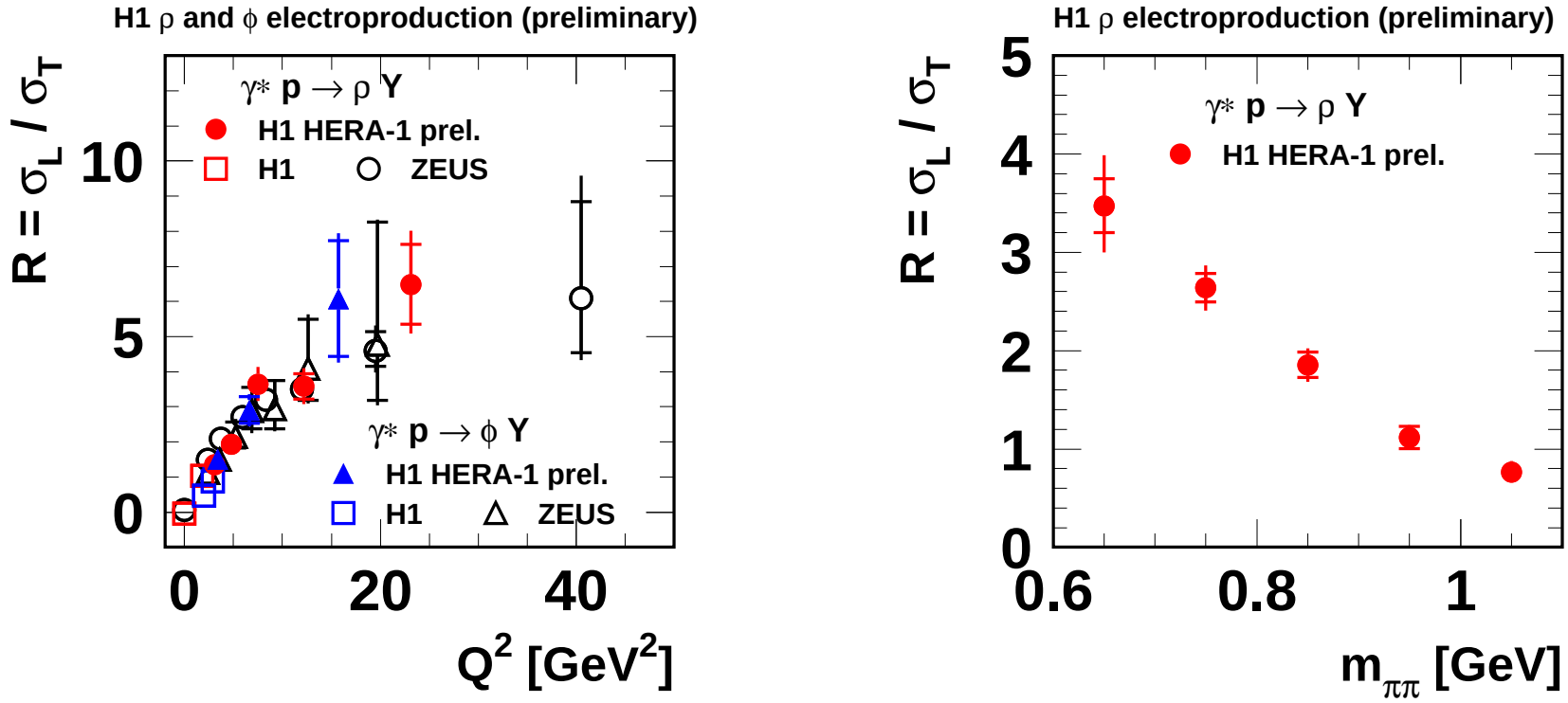
ϕ Polarisation - SDMEs vs. $|t|$



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

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 = $\pm$ 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:

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

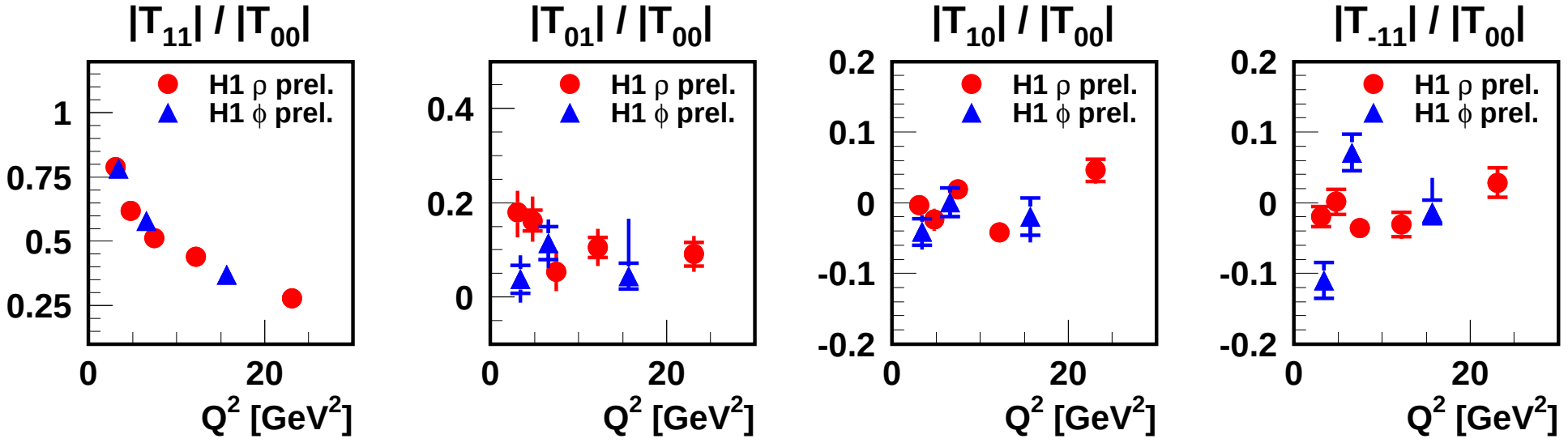
$$
\begin{aligned}
\alpha &= |T_{11}|/|T_{00}| \\
\beta &= |T_{01}|/|T_{00}| \\
\delta &= |T_{10}|/|T_{00}| \\
\eta &= |T_{-11}|/|T_{00}|
\end{aligned}
$$

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

Polarisation - Amplitude ratios vs. Q^2

pQCD (IK): • $|T_{11}|/|T_{00}| = \frac{M}{Q}\,\frac{1+\gamma}{\gamma}$ • $|T_{10}|/|T_{00}| = -\frac{M\sqrt{|t|}}{Q^2}\,\frac{\sqrt{2}}{\gamma}$

• $|T_{01}|/|T_{00}| = \frac{\sqrt{|t|}}{Q}\,\frac{1}{\sqrt{2}\gamma}$ γ : gluon anomalous dim.



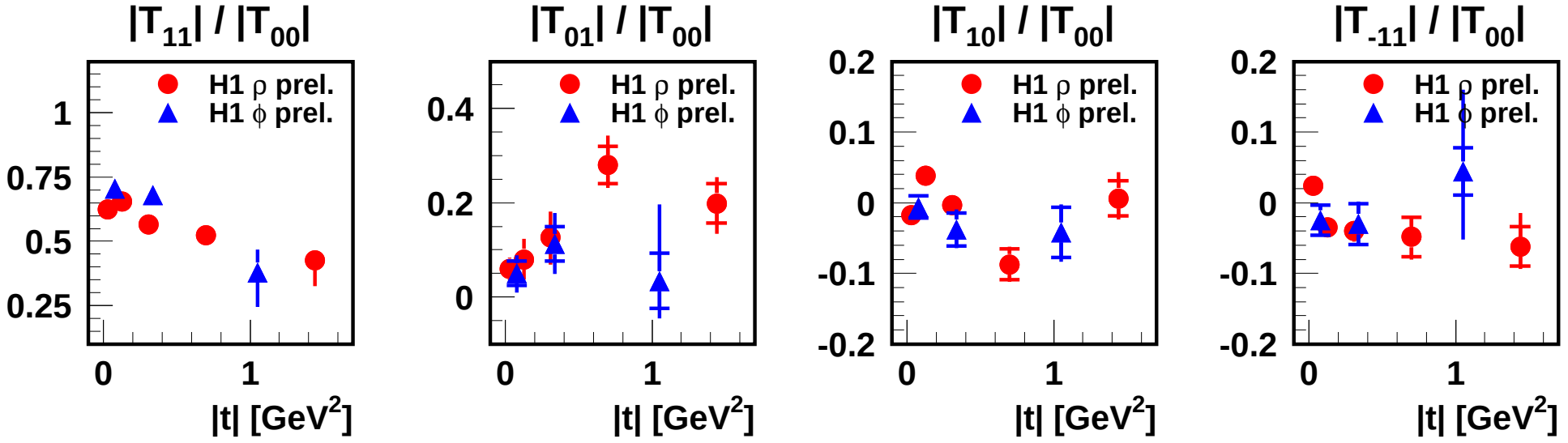
- $|T_{11}|/|T_{00}|$ decreases with $Q^2 \leftrightarrow \sigma_L/\sigma_T$ increases with Q^2
- $|T_{01}|/|T_{00}| > 0 \leftrightarrow$ SCHC violation
- $|T_{10}|/|T_{00}|$ and $|T_{-11}|/|T_{00}|$ are small

  $\Rightarrow |T_{00}| > |T_{11}| > |T_{01}| > |T_{10}|, |T_{-11}| \leftrightarrow$ hierarchy observed

Polarisation - Amplitude ratios vs. $|t|$

pQCD (IK): • $|T_{11}|/|T_{00}| = \frac{M}{Q}\,\frac{1+\gamma}{\gamma}$ • $|T_{10}|/|T_{00}| = -\frac{M\sqrt{|t|}}{Q^2}\,\frac{\sqrt{2}}{\gamma}$

• $|T_{01}|/|T_{00}| = \frac{\sqrt{|t|}}{Q}\,\frac{1}{\sqrt{2}\gamma}$ 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