



Diffraction electroproduction of ρ and ϕ mesons at HERA

[arXiv:0910.5831]

Xavier Janssen

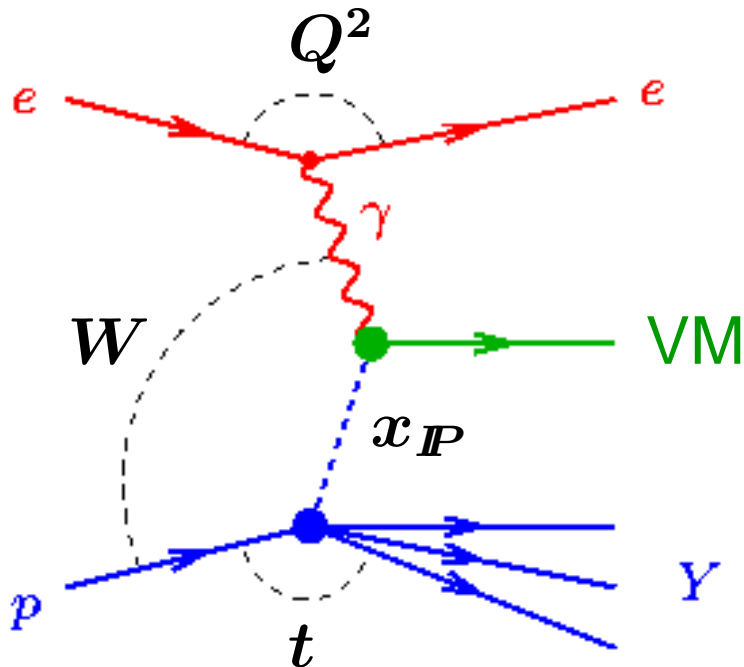


DIS 2010

19-23 April 2010, Firenze, Italy

Diffractive Vector Meson Production

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



- Q^2 Photon Virtuality
Photoproduction: $Q^2 \sim 0$
- W γp CMS energy
- t 4-momentum transfer squared
- $x_{\mathbb{P}}$ Momentum fraction of the colour singlet exchange

Regge Theory

= Soft \mathbb{P} omeron exchange

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

$$\alpha_{\mathbb{P}}(t) = 1.08 + 0.25 t \text{ (DL)}$$

Light VM at low Q^2 and low $|t|$

\implies Investigate transition between soft and hard regimes

pQCD Models

Exchange of ≥ 2 gluons

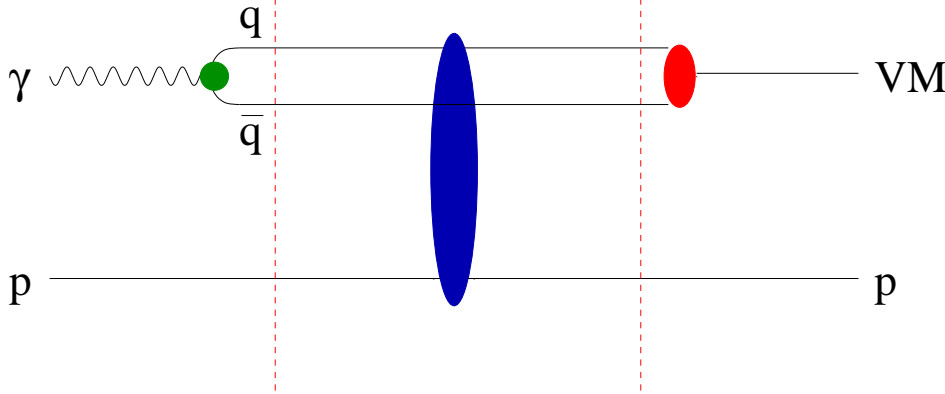
$$\sigma \propto (xG(x, Q^2))^2$$

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

Requires hard scale: Q^2, t or m_q

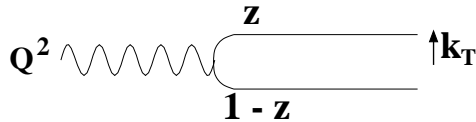
VM theory: Perturbative QCD approaches

Dipole approach (k_t factorisation)



$$\mathcal{A} = \Psi_{q\bar{q}}^\gamma \otimes \sigma_{q\bar{q}-p} \otimes \Psi_{q\bar{q}}^V$$

Scanning radius decrease with increasing Q^2 or $M_V^2 \rightarrow \mu^2 = z(1-z)(Q^2 + M_V^2)$



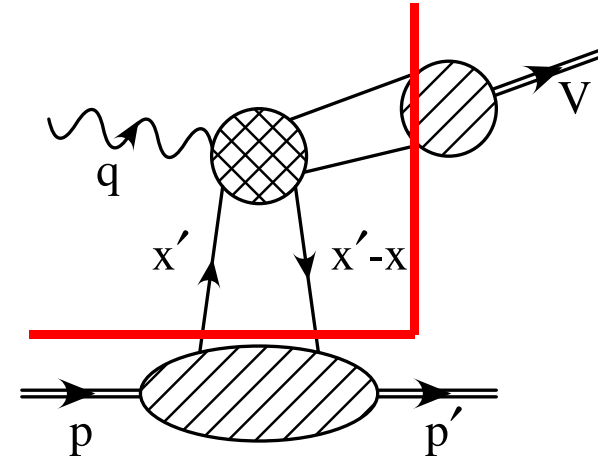
$$\rightarrow \sigma_L \propto \frac{Q^2/M_V^2}{(Q^2 + M_V^2)^4} [\alpha_s(\mu^2) G(x, \mu^2)]^2$$

with $z \simeq 1/2 \rightarrow \mu^2 \simeq 1/4(Q^2 + M_V^2)$

$$\rightarrow \sigma_T \propto \frac{1}{(Q^2 + M_V^2)^4} [\alpha_s(\mu^2) G(x, \mu^2)]^2$$

with $z = 0, 1$ endpoints contributions
 \rightarrow hard scale damped

Collinear factorisation theorem



$$\mathcal{A}_L = f(x, x', t, \mu) \otimes H \otimes \Psi^V$$

where f_i : non-forward PDF ($x' \neq x$)
 \rightarrow Generalized Parton Density

Theorem proven for σ_L ; often assumed for σ_T
 Collins, Frankfurt & Strikman [hep-ph/9611433]

Dipole - Saturation:

Kowalski, Motyka, Watt (KMW) [hep-ph/0606272]
 Marquet, Peschanski, Soyez (MPS) [hep-ph/0702171]

Dipole - k_T factorisation:

Ivanov, Nikolaev, Savin (INS) [hep-ph/0501034]

Collinear - GPD:

Goloskokov, Kroll (GK) [hep-ph/07083569]

Parton hadron duality:

Martin, Ryskin, Teubner (MRT) [hep-ph/9609448]

VM theory: Main features / expectations

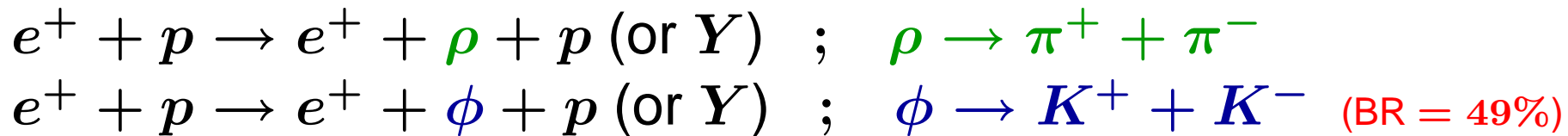
$\sigma(Q^2)$: $\sigma_L \propto Q^{-6}$; $\sigma_T \propto Q^{-8}$ **but** modified by gluon pdf Q^2 depend., quark Fermi motion and virtuality, $\alpha_s(Q^2)$, higher order.
→ Naive $R = \sigma_L/\sigma_T \propto Q^2/M_V^2$ also modified.

$\sigma(W)$: ● For σ_L at high Q^2 and heavy VM, hard (universal) W depend. expected from $1/x$ hard gluon pdf evolution.
● For light VM, delayed approach to hard pQCD regime (σ_T).

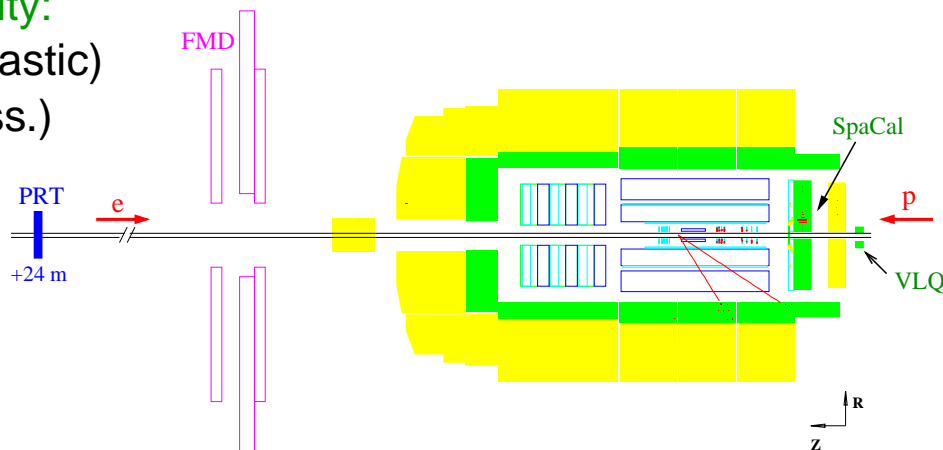
$d\sigma/dt$: $\propto \exp(-b|t|)$ for low $|t|$, where $b = b_{q\bar{q}} \otimes b_{\mathbf{P}} \otimes b_p$
● Expect common b for σ_L at high Q^2 and heavy VM.
→ Naive universality of b vs. $\mu^2 = 1/4(Q^2 + M_V^2)$
● Larger dipole in σ_T than in σ_L → expect $b_T > b_L$
→ Delayed universality of b vs. μ^2

Helicity amplitudes: see later

Data Selection



Forward activity:
 NOTAG (\simeq elastic)
 TAG (\simeq p diss.)



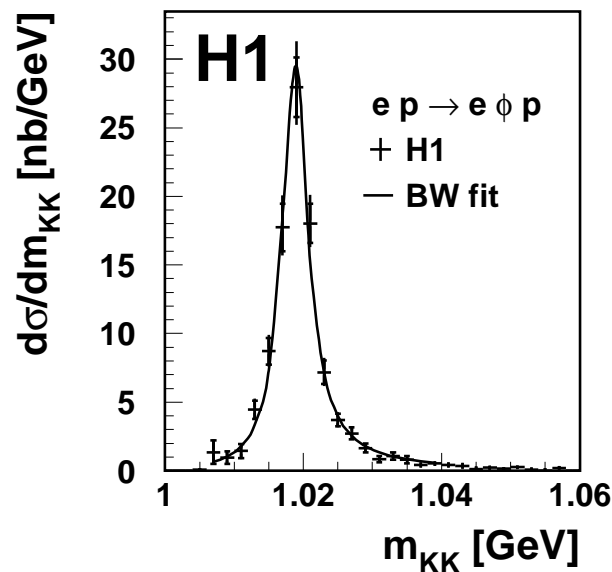
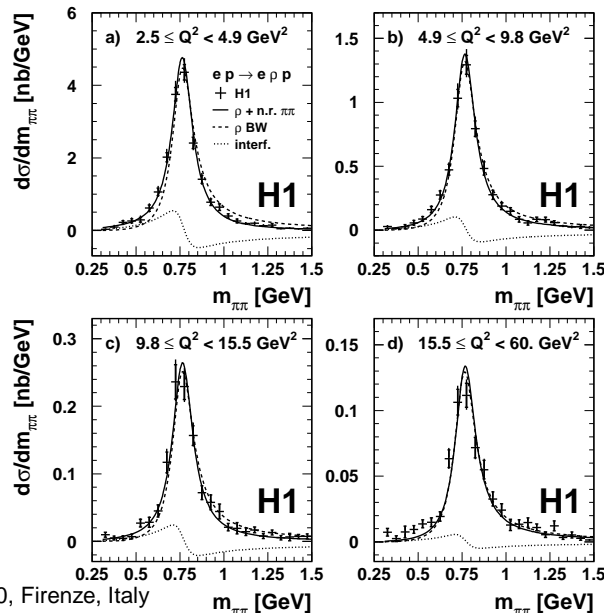
$$2.5 < Q^2 < 60 \text{ GeV}^2$$

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

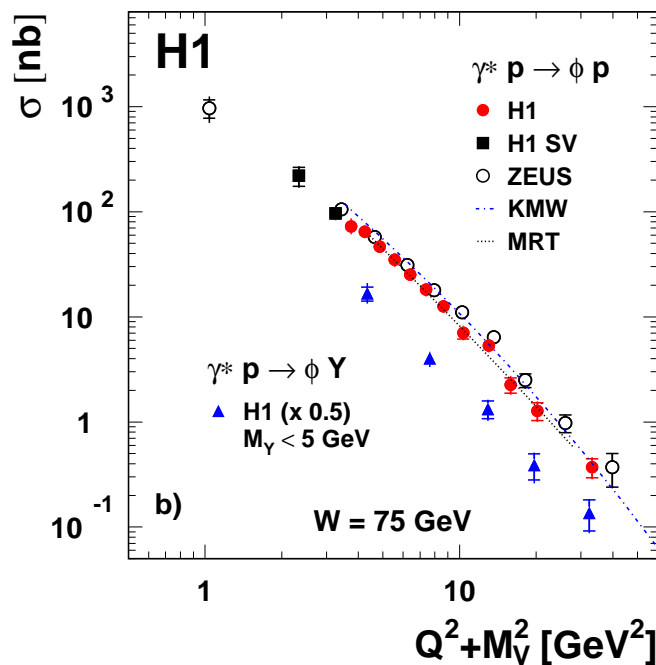
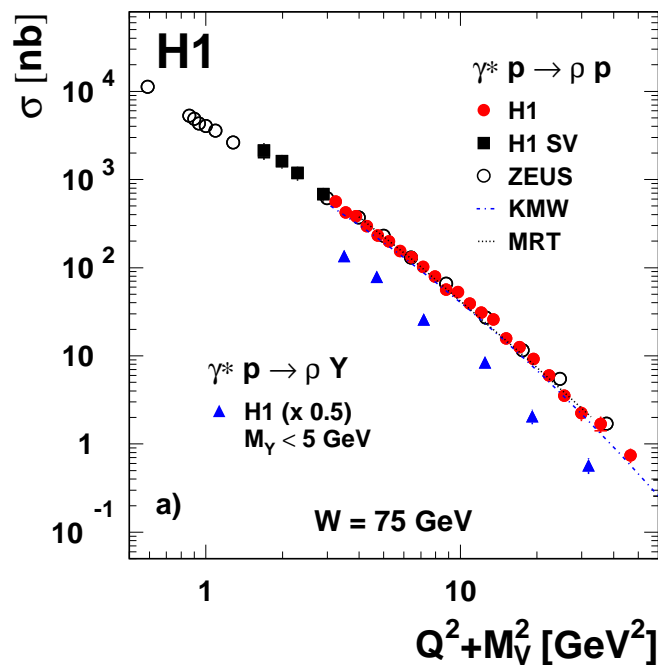
$$\text{elastic: } |t| < 0.5 \text{ GeV}^2$$

$$\text{p diss.: } |t| < 3 \text{ GeV}^2$$

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

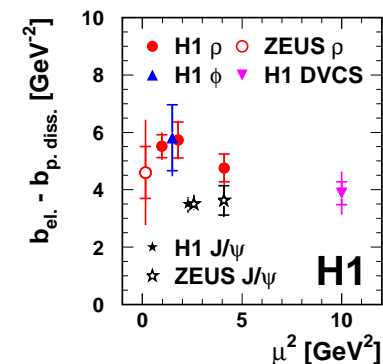
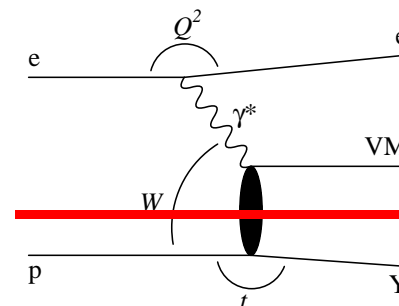
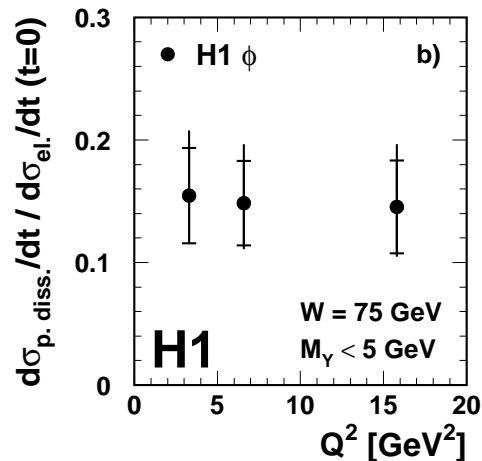
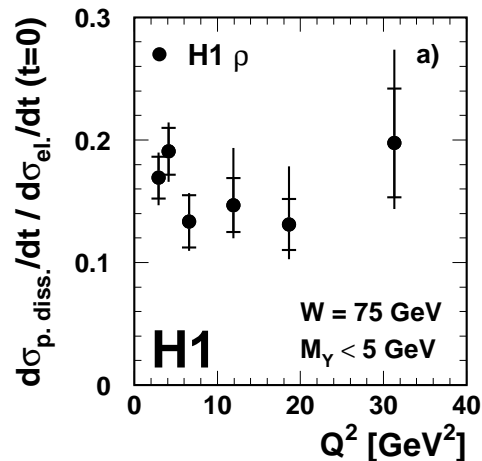


Q^2 dependence



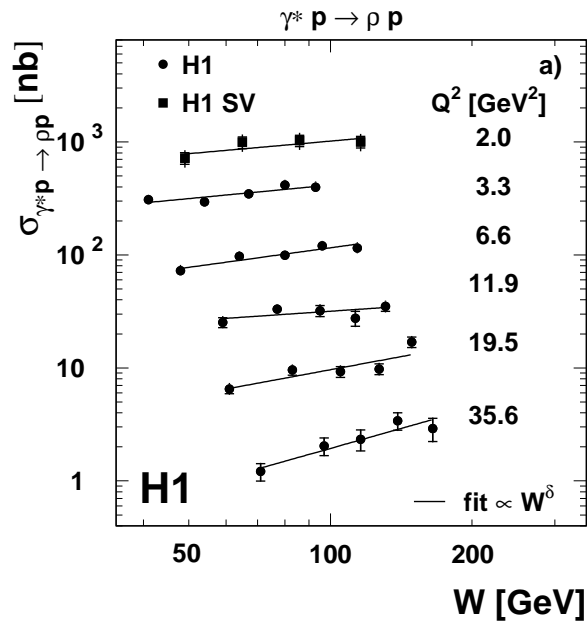
- High precision for elastic cross-sections
- First ϕ p-diss. cross-section
- H1 Zeus relative agreement

Test of vertex ("Regge") factorisation:



- p.diss/el : no Q^2 dep.
 - t -depend. : no Q^2 dep.
- vertex factorisation

Soft to hard transition - $\sigma(W)$



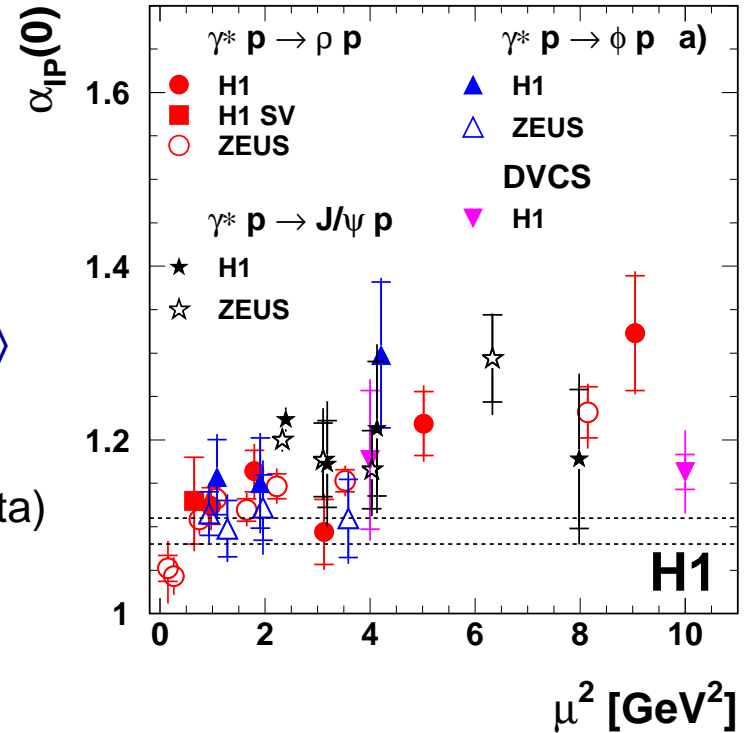
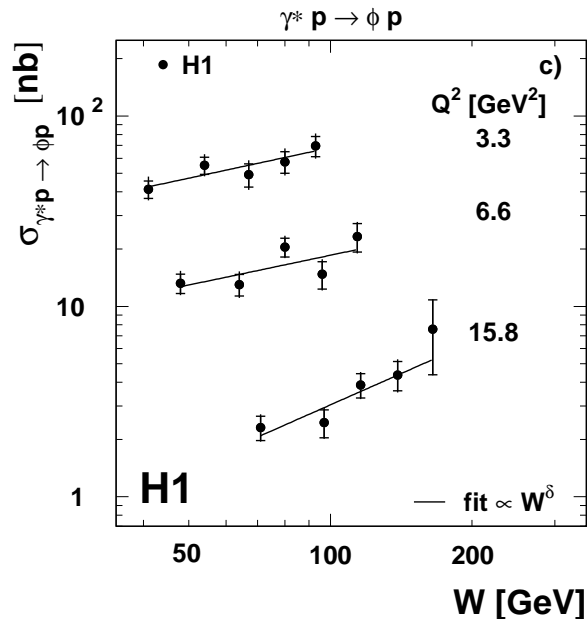
$$\sigma(W) \propto W^\delta$$

$$\alpha_P(0) = 1 + \delta/4$$

$$+ \alpha'_P / \langle |t| \rangle$$

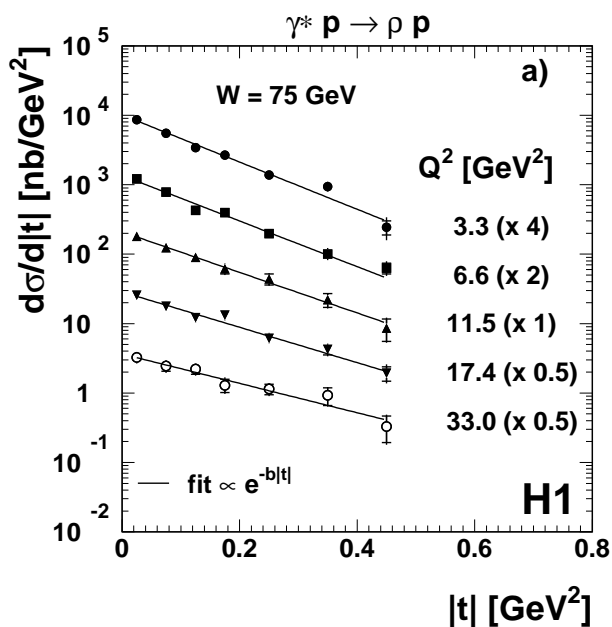
$$\alpha'_P: 0-0.25 \text{ (} \rightarrow \text{data)}$$

$$\langle |t| \rangle: \text{b-slopes (} \rightarrow \text{data)}$$



- Common hardening of $\alpha_P(0)$ with $Q^2 + M^2$ for all VM and DVCS
 \Rightarrow Transition from soft to hard regime with $\mu^2 = (Q^2 + M^2)/4$
- Soft contributions (in σ_L ?) up to $\mu^2 \sim 5 \text{ GeV}^2$ for ρ and ϕ

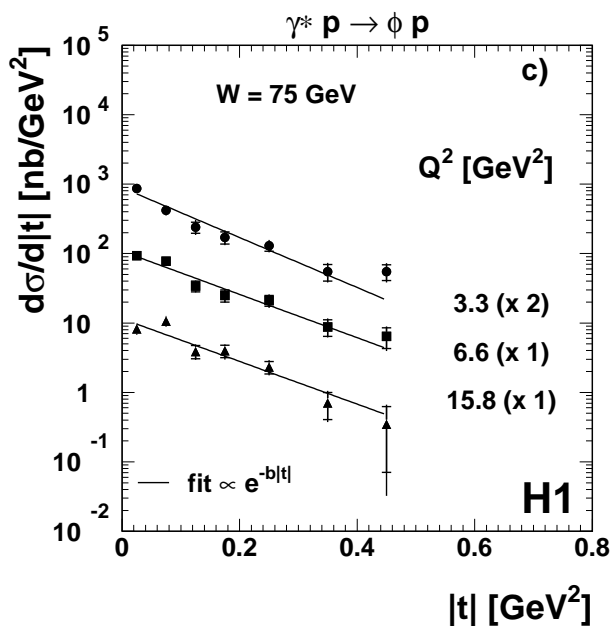
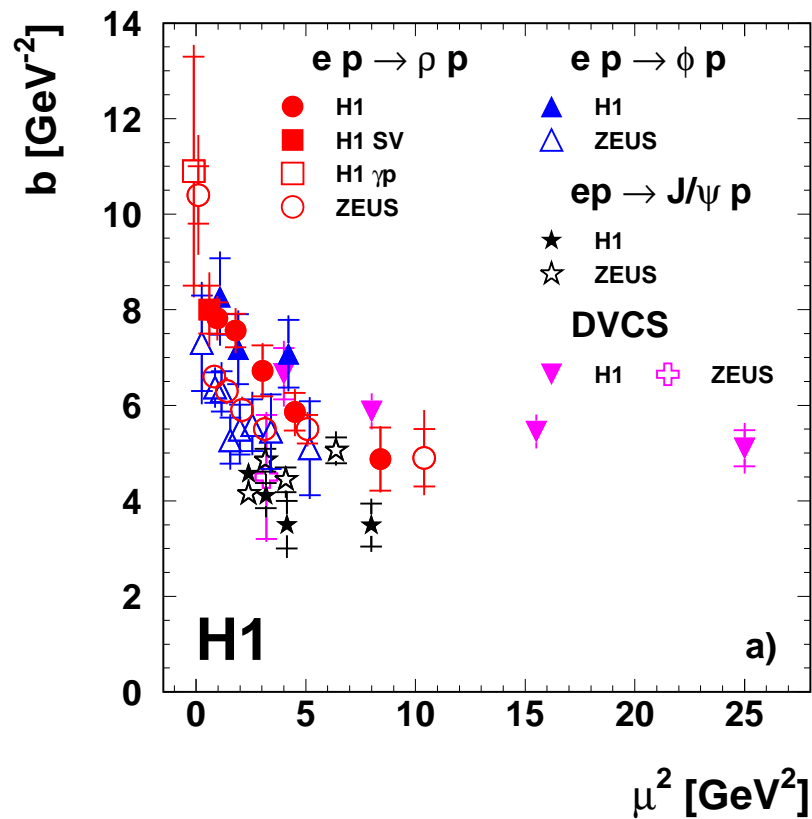
Soft to hard transition - t dependences



fit $e^{-b|t|}$

$$b = b_p \otimes b_{q\bar{q}} \otimes b_{\mathbb{P}}$$

$\rightarrow b \propto q\bar{q}$ dipole size

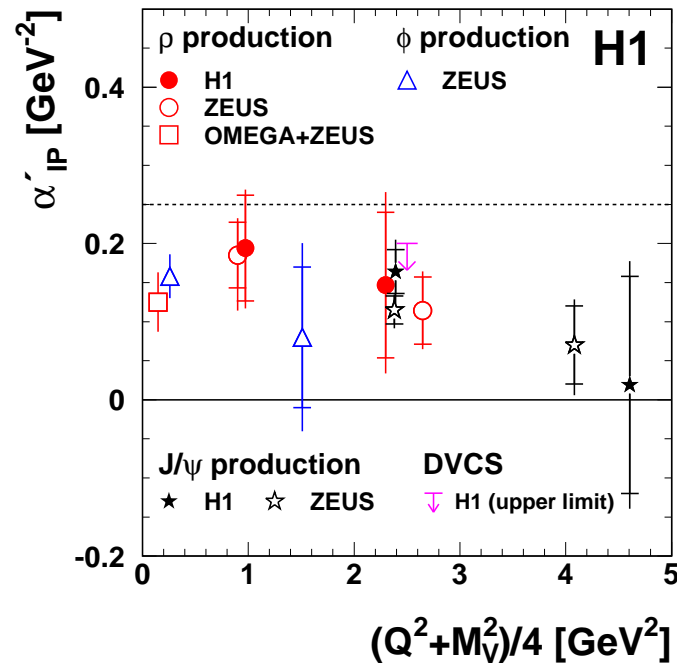
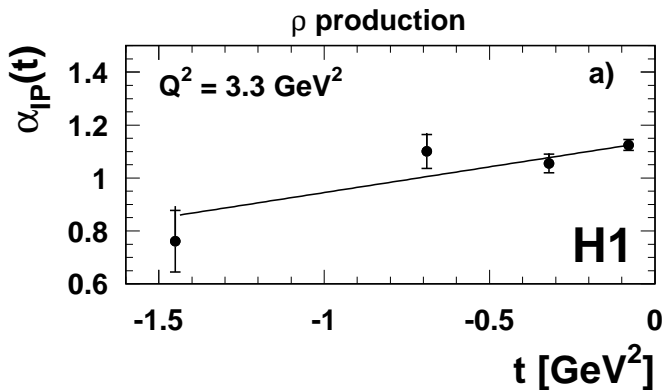
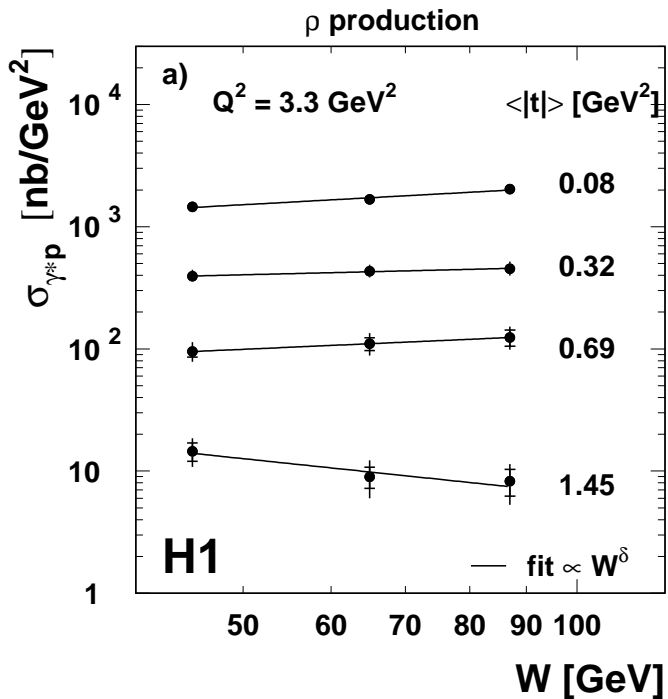


- b_ρ and b_ϕ decrease with μ^2
 - Common value with J/ψ for $\mu^2 > 5$ GeV 2
 - Large dipole for light VM at low Q^2
- \Rightarrow Transition from soft to hard regime with μ^2

Shrinkage : $\alpha'_{\mathbb{P}}$ measurements

$$\frac{d\sigma}{dt}(W) \propto e^{b_0 t} W^{4(\alpha_{\mathbb{P}}(t)-1)}$$

1. Study W depend. in bins of t :
 \rightarrow Fit: $W^\delta \rightarrow \alpha_{\mathbb{P}}(t) = 1 + \delta/4$
2. Study $\alpha_{\mathbb{P}}(t)$ trajectories:
 \rightarrow Fit: $\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} t$

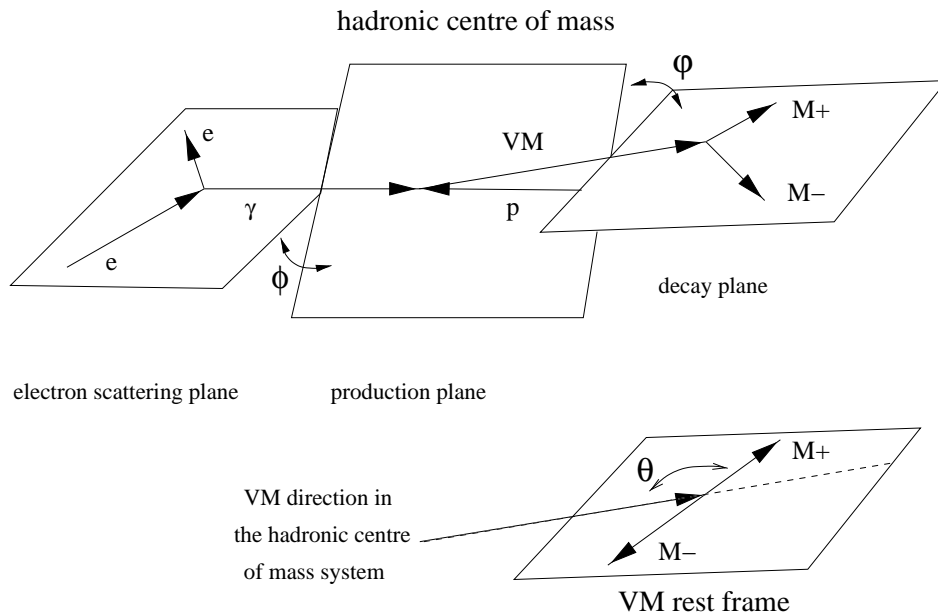


\Rightarrow For all VM, $\alpha'_{\mathbb{P}}$ smaller than 0.25 (DL, $p\bar{p}$)
 (cf BFKL, multiple \mathbb{P} exchange)

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

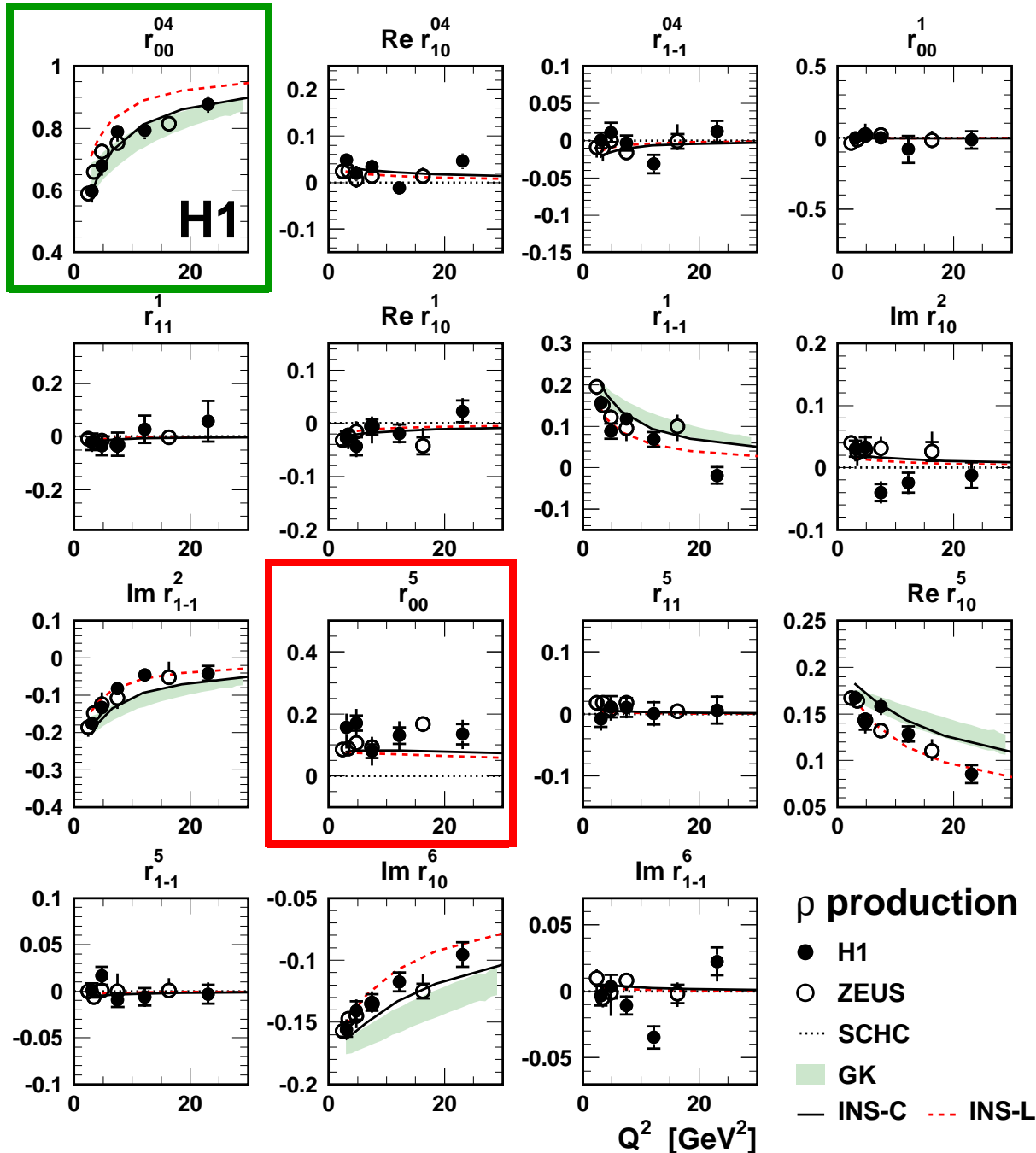
$T_{10} : \gamma_L \rightarrow \rho_T$

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]

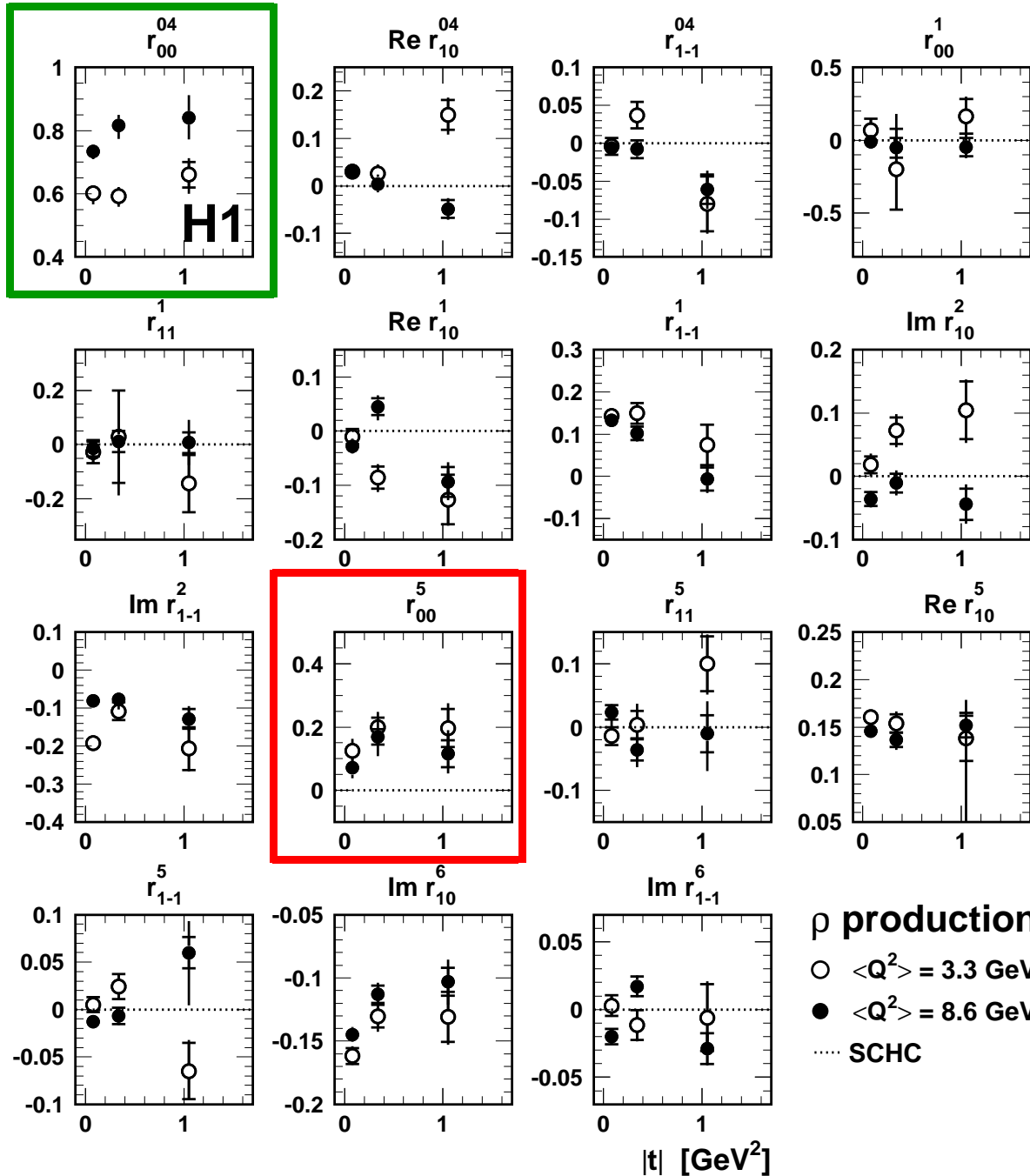
ρ Polarisation - SDMEs vs. Q^2



- 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 $\simeq 0$

ρ Polarisation - SDMEs vs. $|t|$



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

● r_{00}^{04} increases with $|t|$
 ↔ 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)

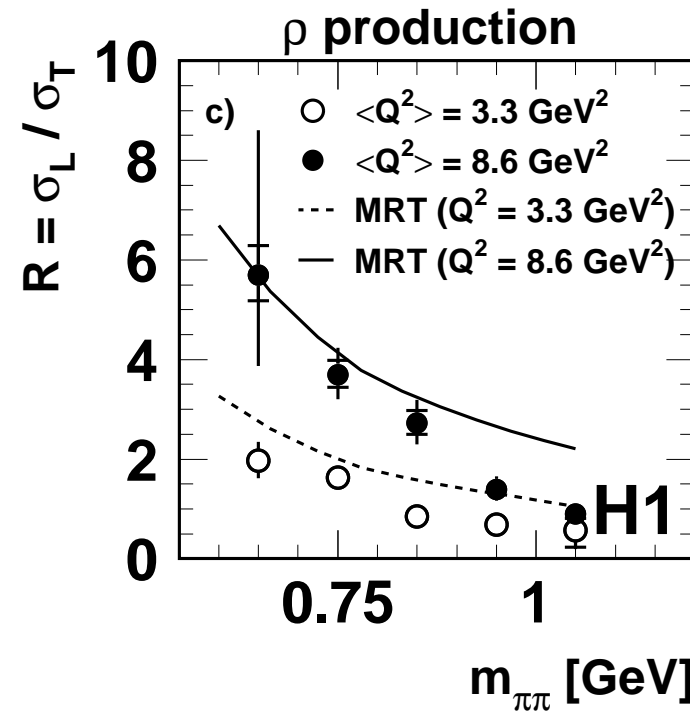
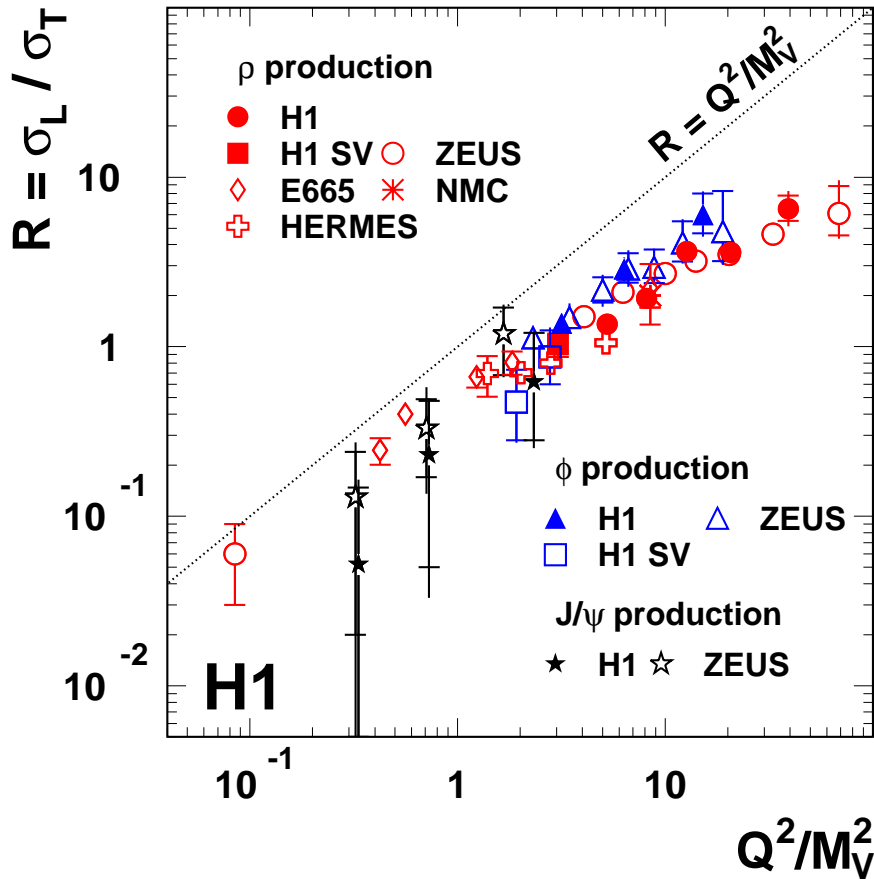
ρ production

○ $\langle Q^2 \rangle = 3.3 \text{ GeV}^2$
 ● $\langle Q^2 \rangle = 8.6 \text{ GeV}^2$
 SCHC

ρ and ϕ Polarisation - $R = \sigma_L / \sigma_T$

$$R_{SCHC} = \frac{1}{\epsilon} \frac{r_{00}^{04}}{1 - \epsilon r_{00}^{04}} = \frac{|T_{00}|^2}{|T_{11}|^2} + \text{non SCHC corrections from } T_{01}$$

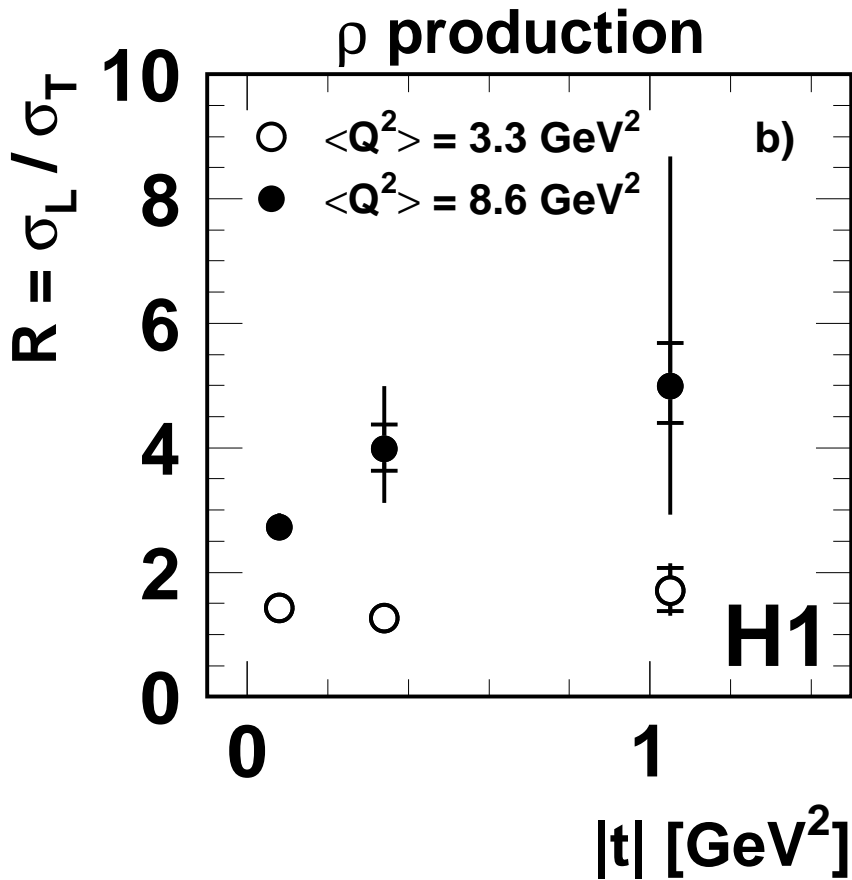
VM production



- Formal pQCD: $R \propto Q^2 / M^2$
- Scaling for all VM with Q^2 / M_V^2
- Damping at large Q^2

- Strong invariant mass dependence in ρ case
- formal pQCD: $R \propto Q^2 / M^2$ but M being diquark mass cf Martin, Ryskin, Teubner calculation

ρ and ϕ Polarisation - $R(t)$ and $b_L - b_T$



$$R(t) \propto \frac{\sigma_L}{\sigma_T} \exp(-(b_L - b_T)|t|)$$

@ $Q^2 = 3.3 \text{ GeV}^2$:

$$b_L - b_T = -0.03 \pm 0.27^{+0.19}_{-0.17}$$

@ $Q^2 = 8.6 \text{ GeV}^2$:

$$b_L - b_T = -0.65 \pm 0.14^{+0.41}_{-0.51}$$

- $(b_L - b_T) < 0$ by 1.5σ for $Q^2 > 5 \text{ GeV}^2$
- also a t dependance of T_{11}/T_{00} - see later
 - Small difference of transverse size of $q\bar{q}$ dipoles from transverse and longitudinal photons
 - large dipole in σ_L at low Q^2

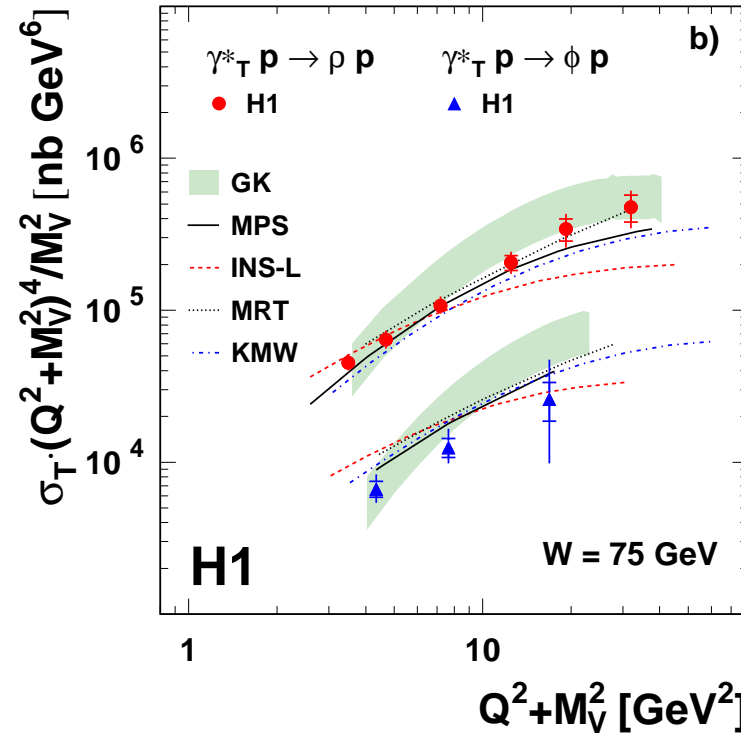
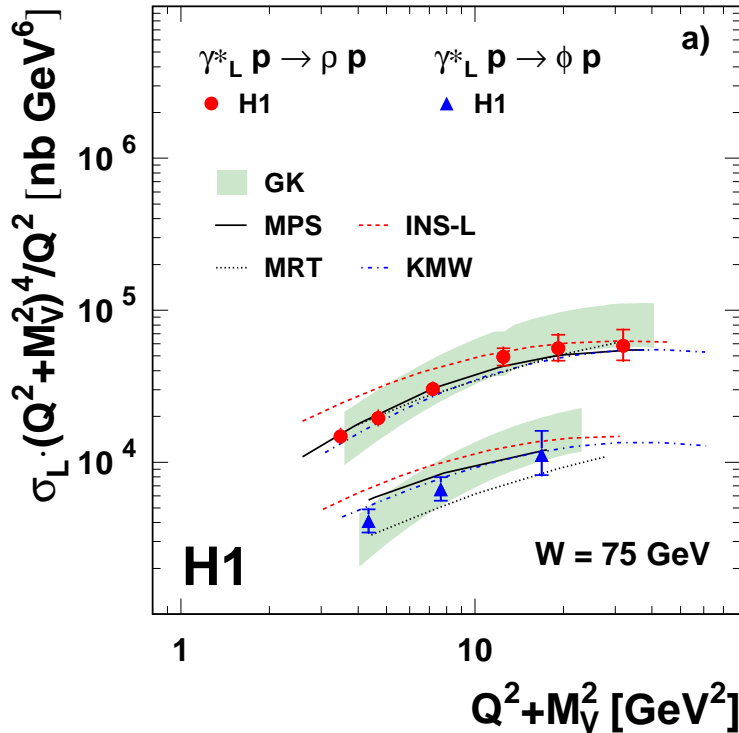
ρ and ϕ Polarisation - Cross-sections

Longitudinal

$$\sigma_L \propto \frac{Q^2/M_V^2}{(Q^2+M_V^2)^4} [\alpha_s(\mu^2) G(x, \mu^2)]^2$$

Transverse

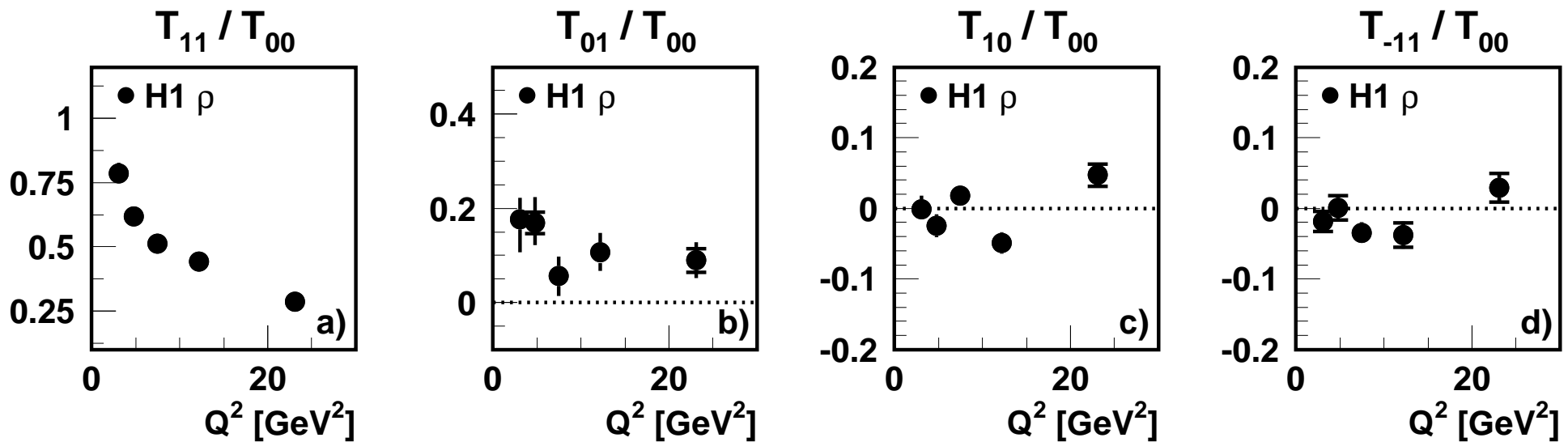
$$\sigma_T \propto \frac{1}{(Q^2+M_V^2)^4} [\alpha_s(\mu^2) G(x, \mu^2)]^2$$



- Different $Q^2 + M^2$ dependences of σ_L and σ_T ($\sigma_L = 0$ at $Q^2 = 0$)
 - Good description by models with some differences
 - Effect of Q^2 dependences of $[\alpha_s(\mu^2) G(x, \mu^2)]^2$ visible
- N.B.: data at fixed $W \rightarrow$ varying x with $Q^2 + M_V^2$

Polarisation - Amplitude ratios vs. Q^2

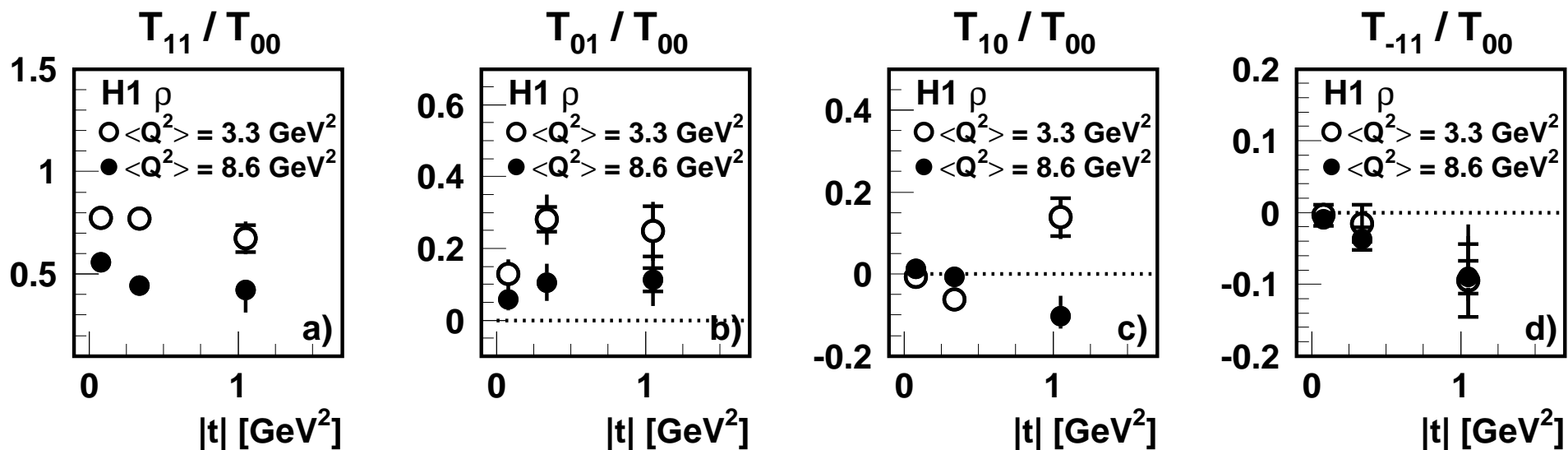
- pQCD (IK):
- $T_{11}/T_{00} \propto \frac{M}{Q} \frac{1+\gamma}{\gamma}$
 - $T_{10}/T_{00} \propto -\frac{M \sqrt{|t|}}{Q^2} \frac{\sqrt{2}}{\gamma}$
 - $T_{01}/T_{00} \propto \frac{\sqrt{|t|}}{Q} \frac{1}{\sqrt{2}\gamma}$
- γ : gluon anomalous dim.



- 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):
- $T_{11}/T_{00} \propto \frac{M}{Q} \frac{1+\gamma}{\gamma}$
 - $T_{10}/T_{00} \propto -\frac{M}{Q^2} \frac{\sqrt{|t|}}{\gamma} \frac{\sqrt{2}}{\gamma}$
 - $T_{01}/T_{00} \propto \frac{\sqrt{|t|}}{Q} \frac{1}{\sqrt{2}\gamma}$
 - γ : gluon anomalous dim.



- T_{11}/T_{00} decreases with $|t|$ (cf. $b_L - b_T$)
- 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

CONCLUSIONS

VM cross-section measurements:

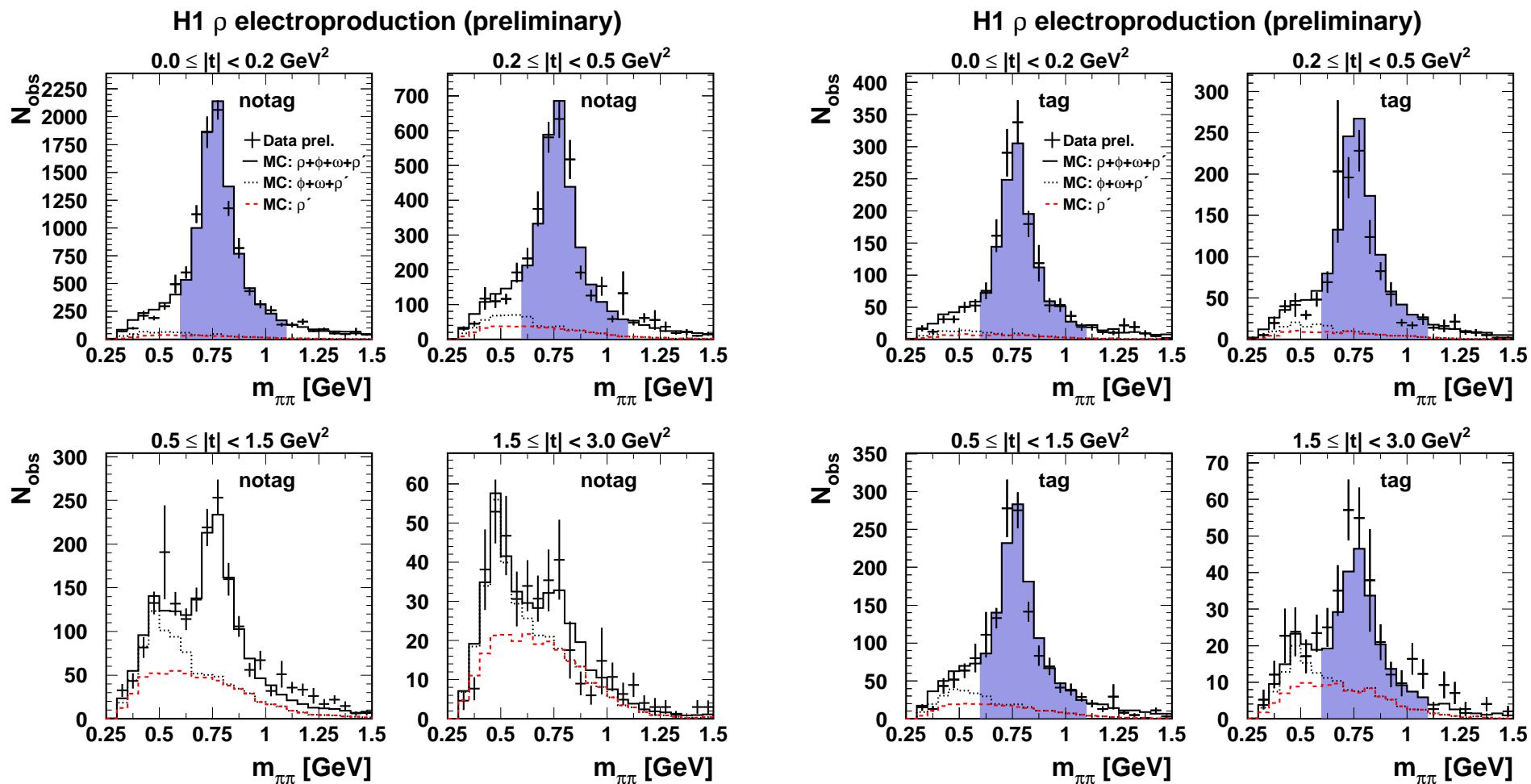
- Hard regime reached only around $\mu^2 = \frac{Q^2 + M^2}{4} = 5 \text{ GeV}^2$ as observed in measurements of $\alpha_{\mathbb{P}}(0)$ and b -slopes.
 - Possible soft component in σ_L up to "high" Q^2 for light VM.
- p diss. / elastic ratio: proton vertex factorisation observed

VM polarisation properties:

- Polarised cross-section and amplitude ratios have been extracted
- σ_L/σ_T increases with Q^2 and maybe with $|t|$ at high Q^2
 - ↔ $|t|$ depend. expected in pQCD from \neq dipole in σ_L and σ_T .
- Violation of SCHC: significant T_{01}/T_{00} increases with $|t|$
- σ_L/σ_T decreases with ρ invariant mass
 - ↔ Predicted by MRT / limited influence of VM wave function.

pQCD models: GPD and dipole ones describe main features, but differences in details

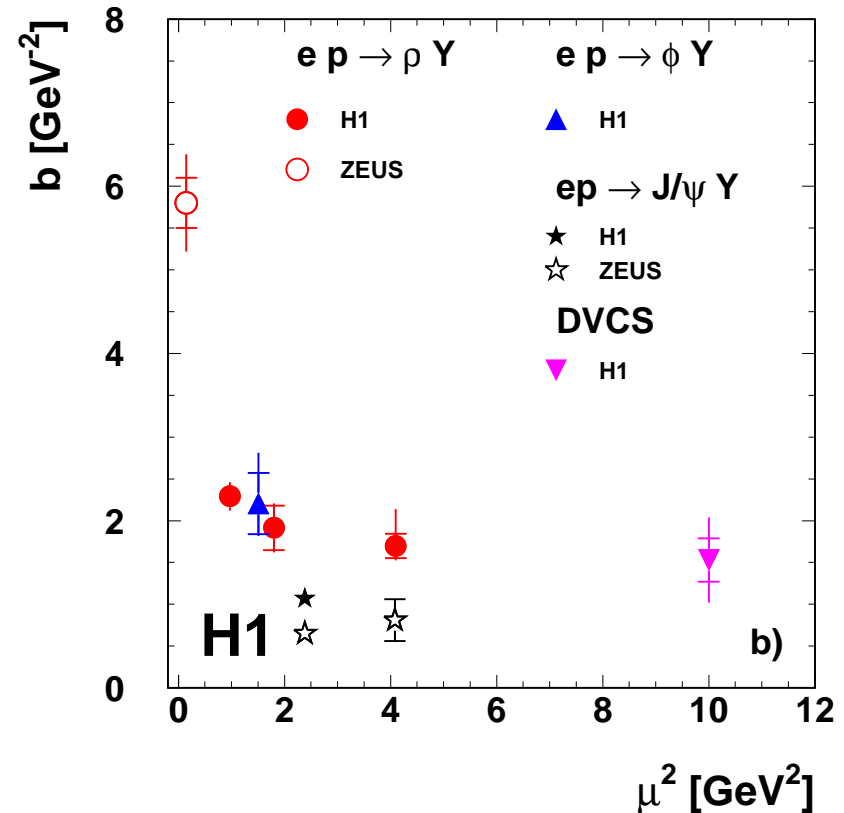
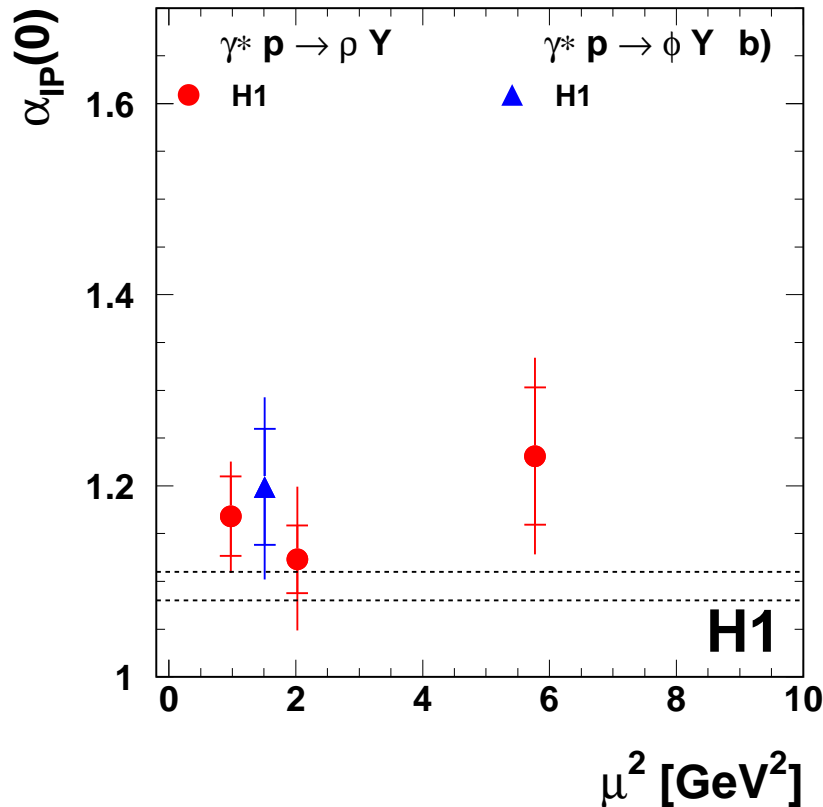
H1 background subtraction



Soft to hard transition - proton dissociation

$$\sigma(W) \propto W^\delta$$

$$d\sigma/dt \propto \exp(-bt)$$



- First measurements of $\alpha_{IP}(0)$ and b -slopes for ρ and ϕ in electroproduction at HERA.
- Smaller values but similar features as for elastic channel

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:

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

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

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