

# Exclusive Diffraction at HERA

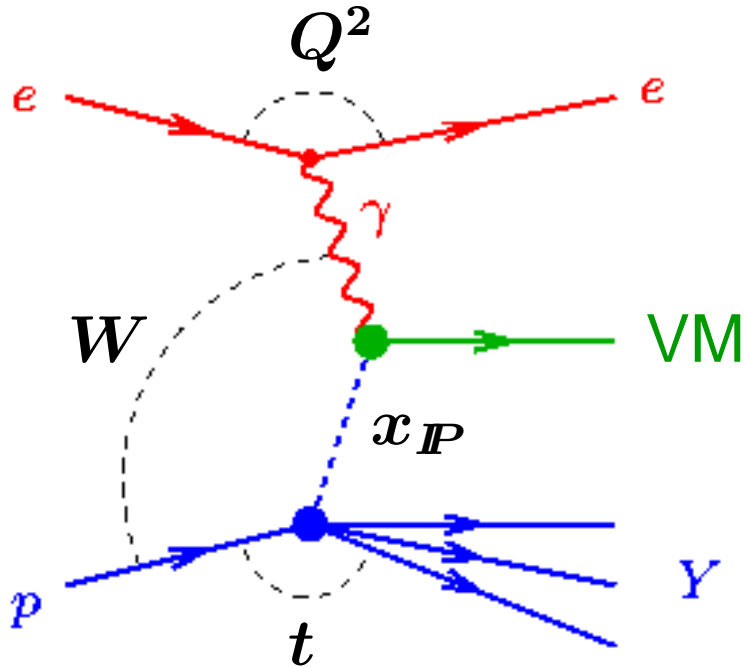
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**XXXIX International Symposium on Multiparticle Dynamics  
4-9 September 2009, "Golden Sands" ,Gomel Region, Belarus**

# Diffractive Vector Meson Production and DVCS

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



$Q^2$  Photon Virtuality  
Photoproduction:  $Q^2 \sim 0$

$W$   $\gamma p$  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  $|t|$

$\Rightarrow$  Investigate transition between soft and hard regimes

## pQCD Models

Exchange of  $\geq 2$  gluons

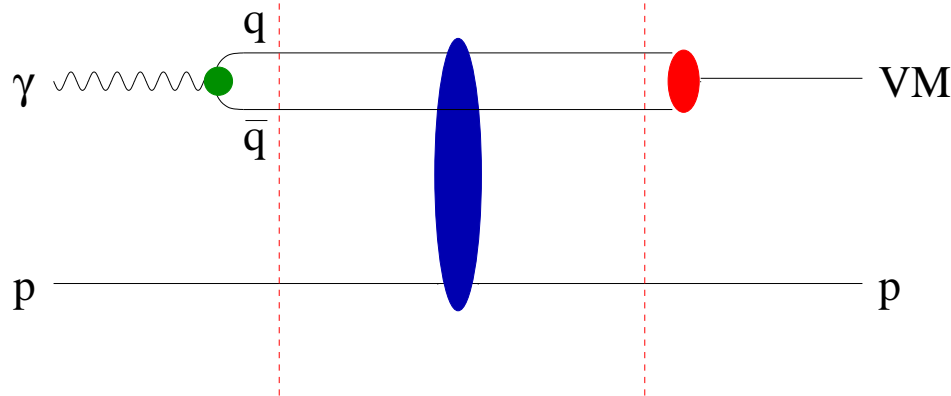
$$\sigma \propto (xG(x, Q^2))^2$$

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

Requires hard scale:  $Q^2$ ,  $t$  or  $m_q$

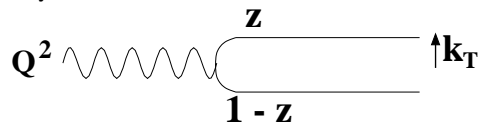
# VM theory: Perturbative QCD approaches

## 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  $M_V^2 \rightarrow \mu^2 = z(1-z)(Q^2 + M_V^2)$



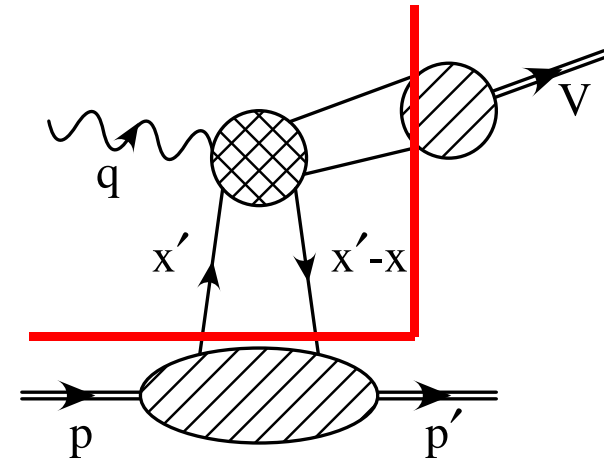
$$\rightarrow \sigma_L \propto \frac{Q^2/M_V^2}{(Q^2 + M_V^2)^4} [\alpha_s(\mu^2) G(x, \mu^2)]^2$$

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  $\sigma_L$ ; often assumed for  $\sigma_T$   
 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

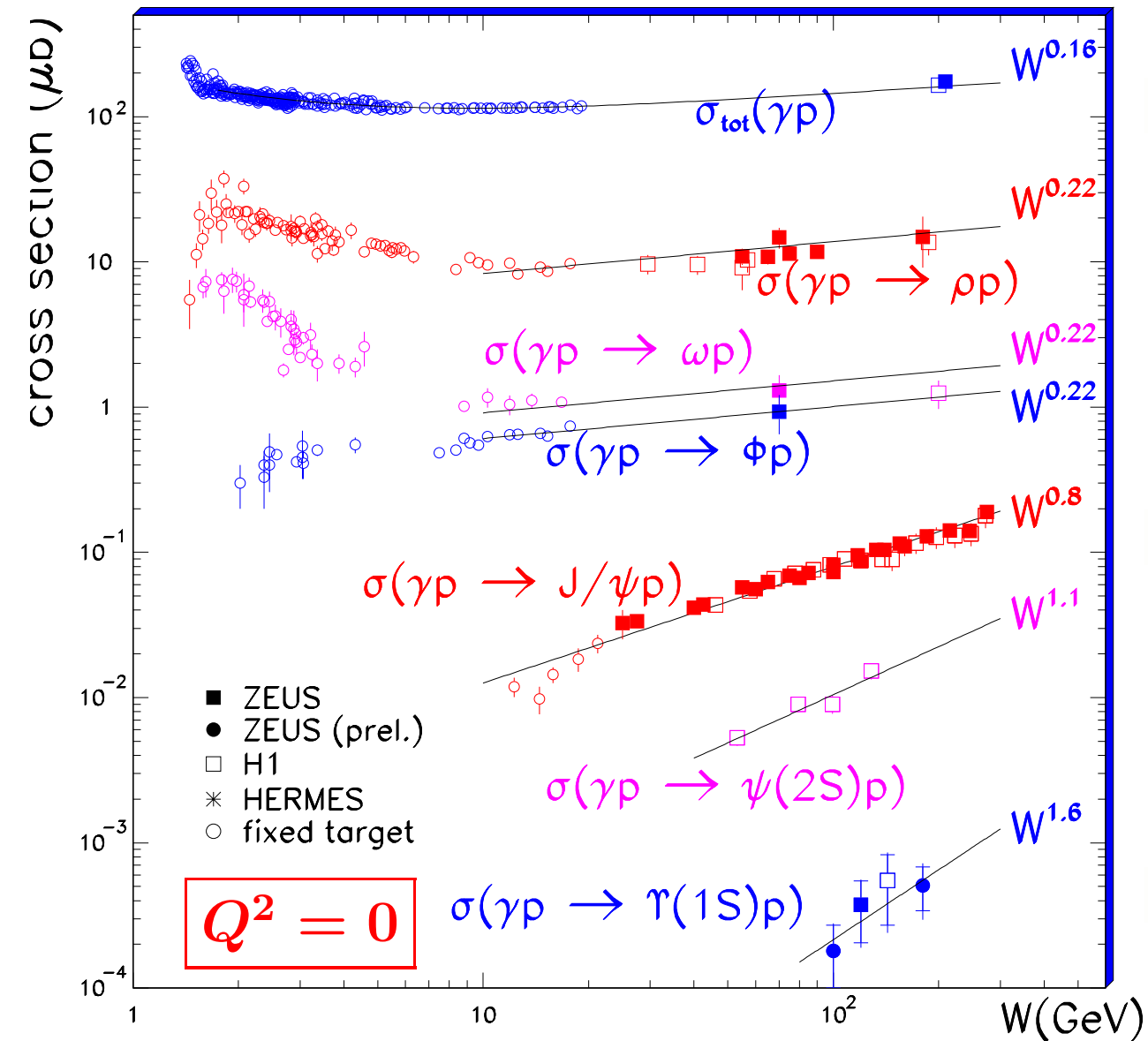
$\sigma(Q^2)$ :  $\sigma_L \propto Q^{-6}$ ;  $\sigma_T \propto Q^{-8}$  **but** modified by gluon pdf  $Q^2$  depend., quark Fermi motion and virtuality,  $\alpha_s(Q^2)$ , higher order.  
→ Naive  $R = \sigma_L/\sigma_T \propto Q^2/M_V^2$  also modified.

$\sigma(W)$ : ● For  $\sigma_L$  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 ( $\sigma_T$ ).

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

Helicity amplitudes: see later

# Soft to hard transition: mass



- Low mass ( $\rho, \phi, \omega$ ;  $M_V^2 \simeq 1 \text{ GeV}^2$ ):  
no pert. scale  
→ weak energy dep. (soft regime)
- High mass ( $J/\psi, \psi$ ): pert. scale  
→ strong energy dep. (hard regime)
- Large mass ( $\Upsilon$ ) important skewing effect

# Upsilon Photoproduction

## New ZEUS result:

1996-2007 data:  $468 \text{ pb}^{-1}$

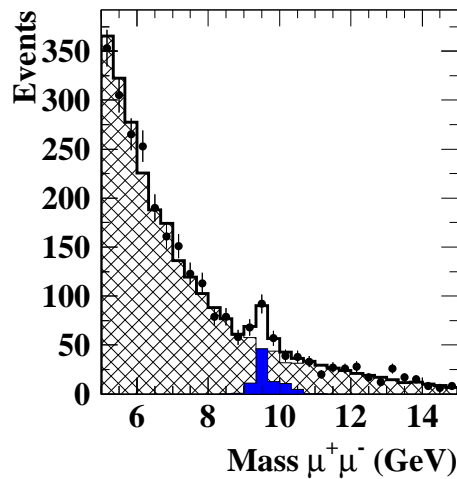
$60 < W < 220 \text{ GeV}$ ,  $Q^2 < 1 \text{ GeV}^2$

DESY-09-036 (accepted by PLB)

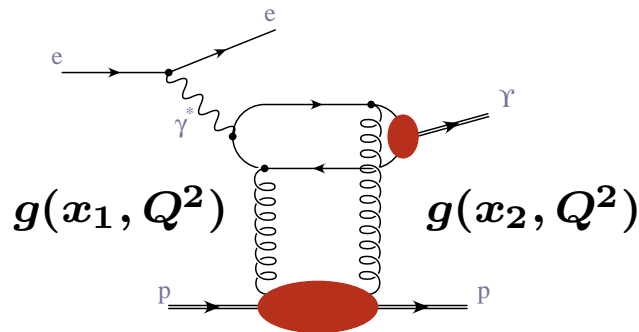
$$e + p \rightarrow e + \Upsilon + p$$

$$\Upsilon \rightarrow \mu^+ + \mu^-$$

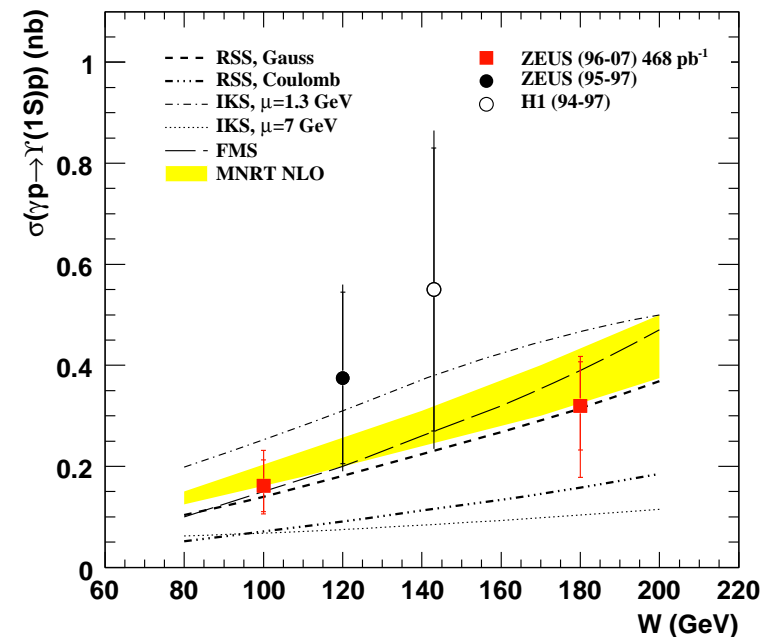
## ZEUS



- ZEUS 96/07 ( $468 \text{ pb}^{-1}$ )
- ▨ GRAPE  $\gamma\gamma \rightarrow \mu^+\mu^-$  (BH)
- DIFFVM  $\Upsilon \rightarrow \mu^+\mu^-$
- BH +  $\Upsilon$



## ZEUS



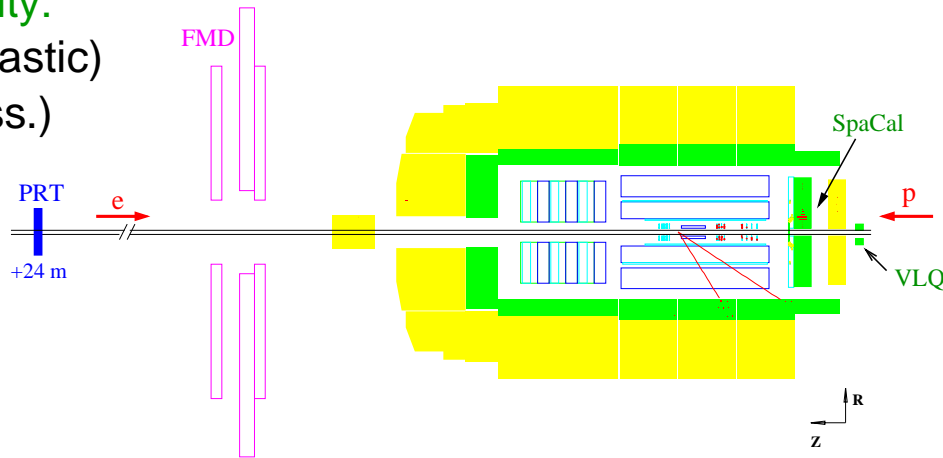
$W$  dependence of the cross section is in agreement with pQCD models including skewing, i.e.  $x_1 \neq x_2$

# Light VM in DIS: Data Selection

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

$$e^+ + p \rightarrow e^+ + \phi + p \text{ (or } Y) \quad ; \quad \phi \rightarrow K^+ + K^- \quad (\text{BR} = 49\%)$$

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



H1:  $\rho$  and  $\phi$

elastic and p diss. channels

1996-2000 data:  $51 \text{ pb}^{-1}$

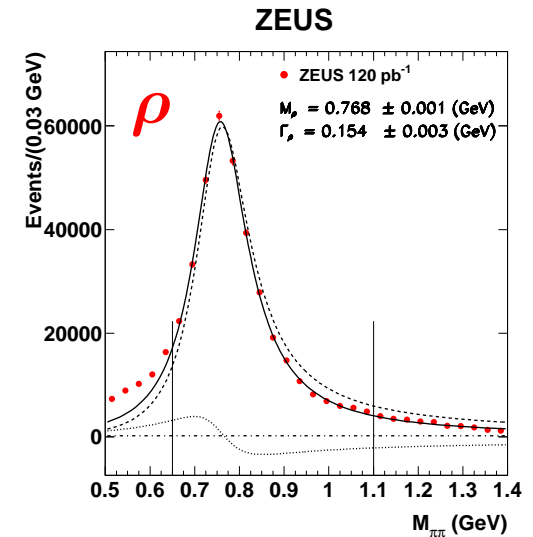
$$2.5 < Q^2 < 60 \text{ GeV}^2$$

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

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

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

H1prelim-08-013 & H1prelim-09-017



ZEUS:  $\rho$

mostly elastic channel

1996-2000 data:  $119 \text{ pb}^{-1}$

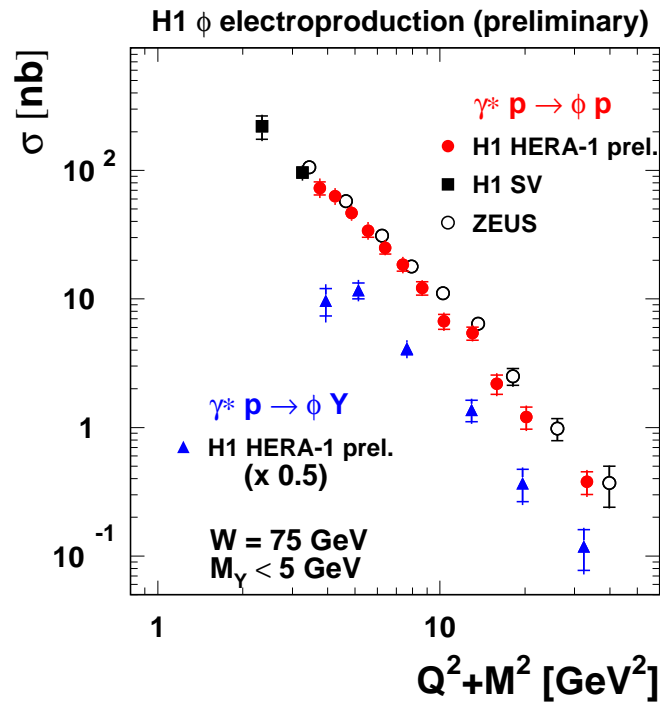
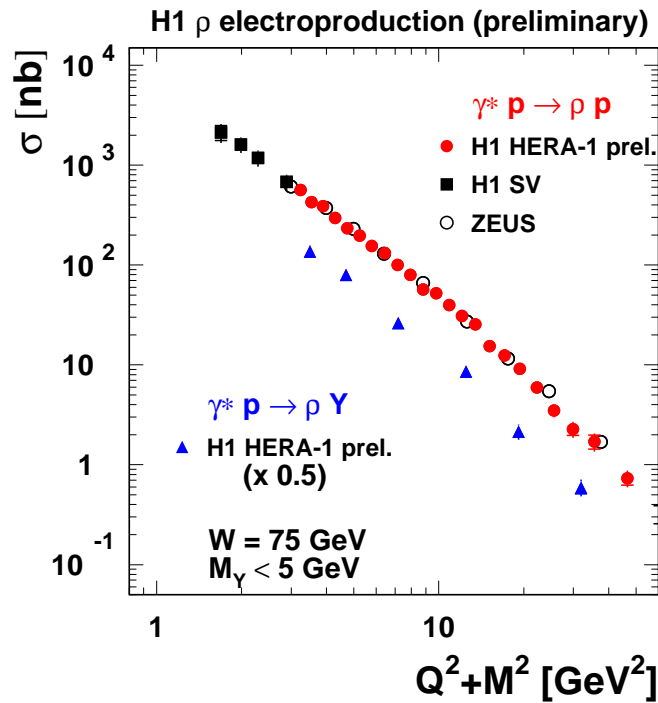
$$2 < Q^2 < 160 \text{ GeV}^2$$

$$32 < W < 180 \text{ GeV}$$

$$|t| < 1 \text{ GeV}^2$$

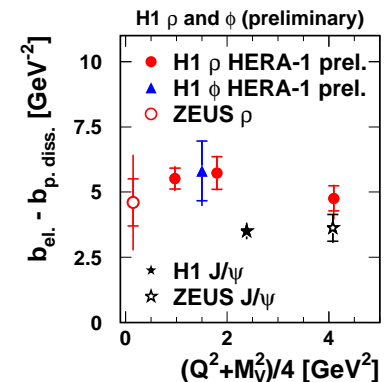
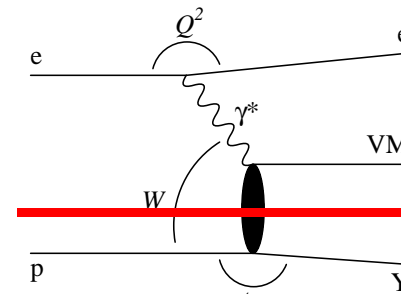
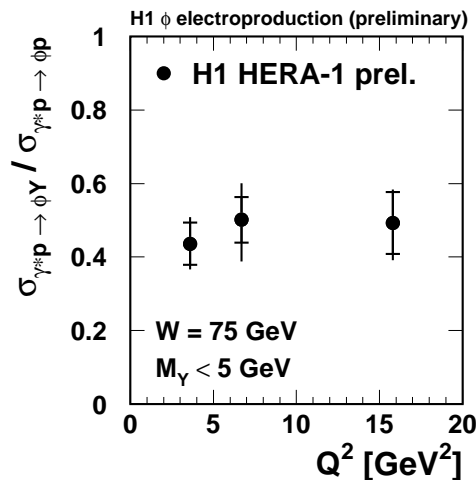
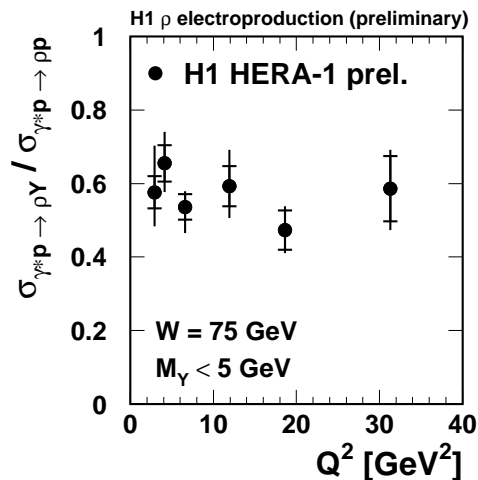
DESY-07-118 (PMC Physics A 1,6)

# Light VM Cross-sections : $Q^2$ dependence



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

## Test of vertex (“Regge”) factorisation:

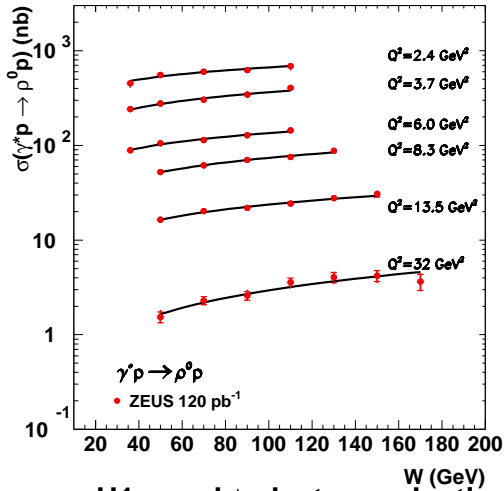


- p.diss/el : no  $Q^2$  dep.
  - $t$ -depend. : no  $Q^2$  dep.
- vertex factorisation

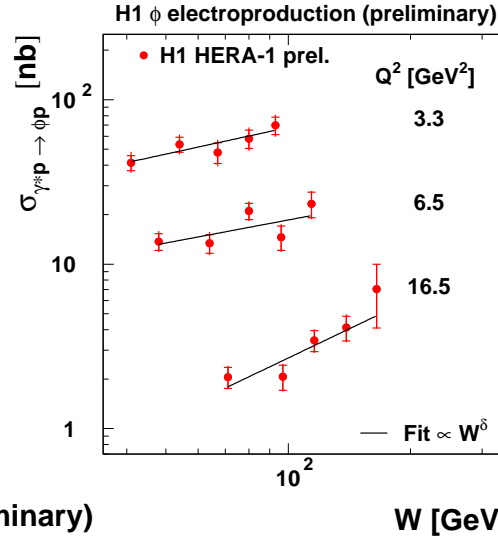


# Soft to hard transition: $Q^2$

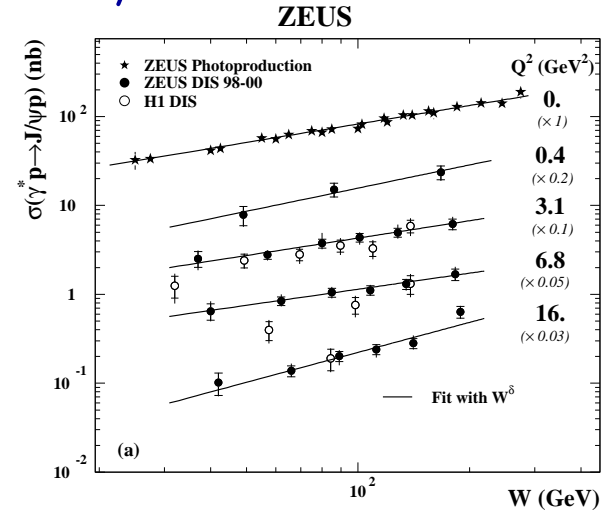
$\rho$ : ZEUS



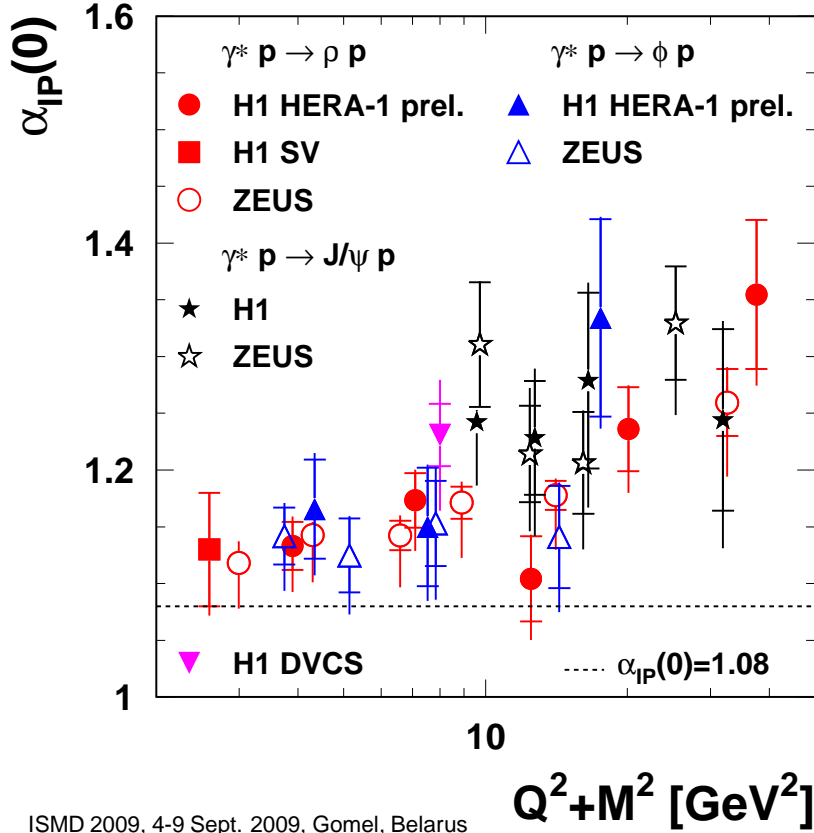
$\Phi$ :



$J/\psi$ :



H1  $\rho$  and  $\phi$  electroproduction (preliminary)



$$\alpha_{IP}(0) = 1 + \delta/4 + \alpha'_{IP}/\langle |t| \rangle$$

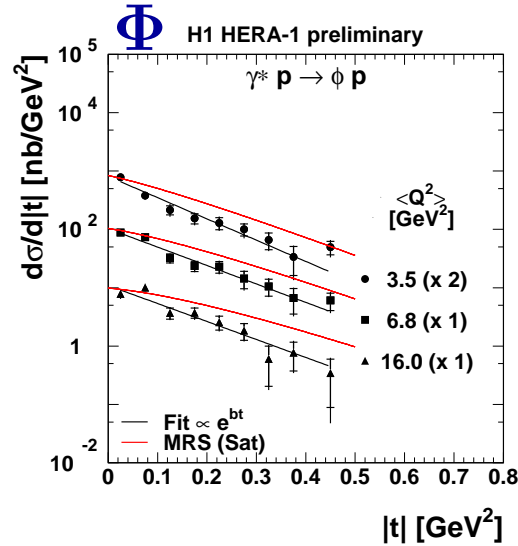
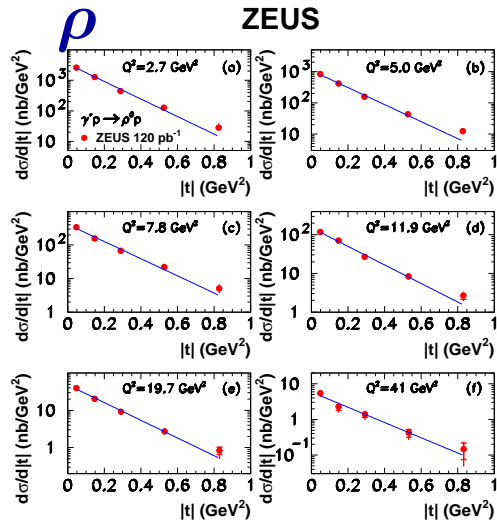
$$\alpha'_{IP} = 0 - 0.25 \text{ GeV}^{-2}$$

- Common hardening of  $\alpha_{IP}(0)$  with  $Q^2 + M^2$  for all VM and DVCS

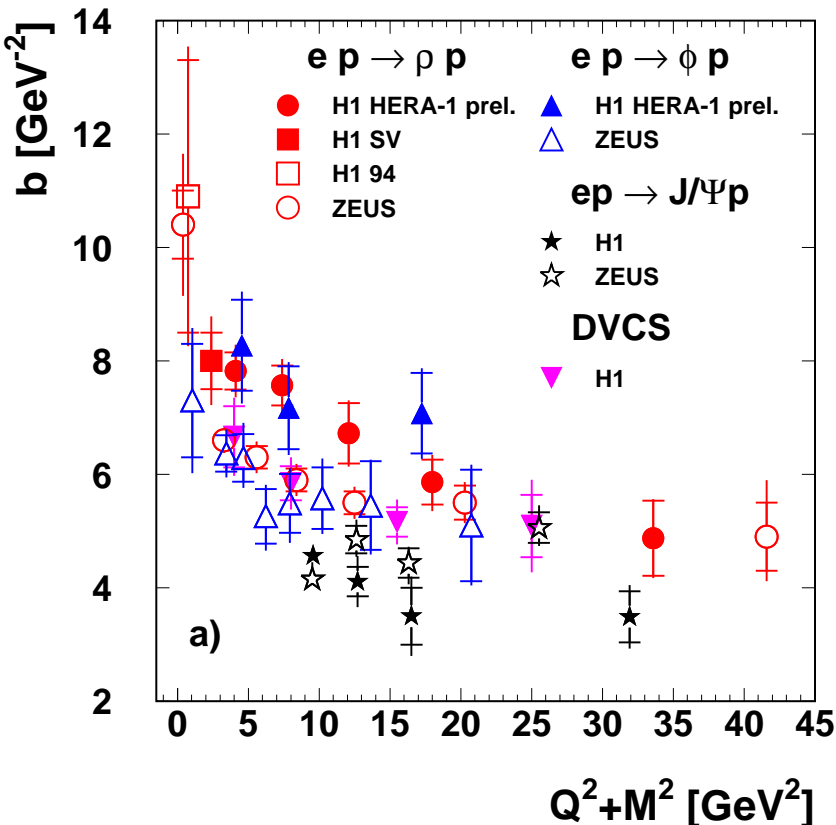
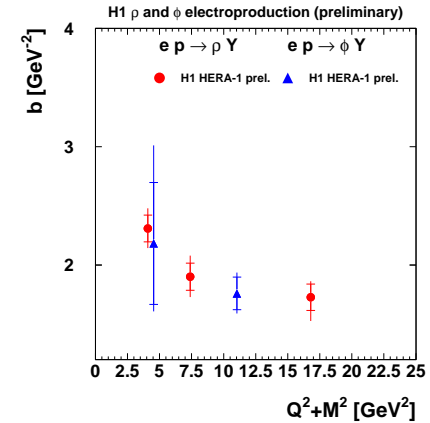
$\Rightarrow$  Transition from soft to hard regime with  $Q^2 + M^2$

- Soft contributions (in  $\sigma_L$  ?) up to  $Q^2 \sim 20 \text{ GeV}^2$  for  $\rho$  and  $\phi$

# *t* dependences: Universality and hard diffraction



## Proton dissociation:



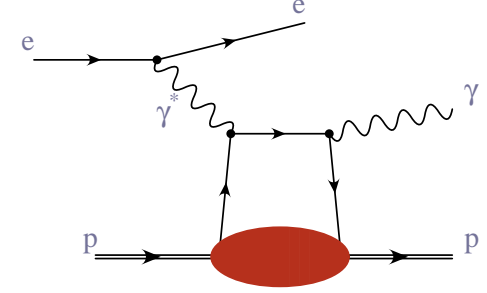
fit  $e^{-b|t|}$ :  $b = b_p \otimes b_{q\bar{q}} \otimes b_{\mathbb{P}}$   
 $\rightarrow b \propto q\bar{q}$  dipole size

- $b_\rho$  and  $b_\phi$  decrease  $Q^2 + M^2$
- Common value with  $J/\psi$  for  $Q^2 + M^2 > 20 \text{ GeV}^2$
- Large dipole for light VM at low  $Q^2$

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

# Note on the scale and universality

DVCS is like DIS (at LO):



Photon interacts directly with a resolved quark

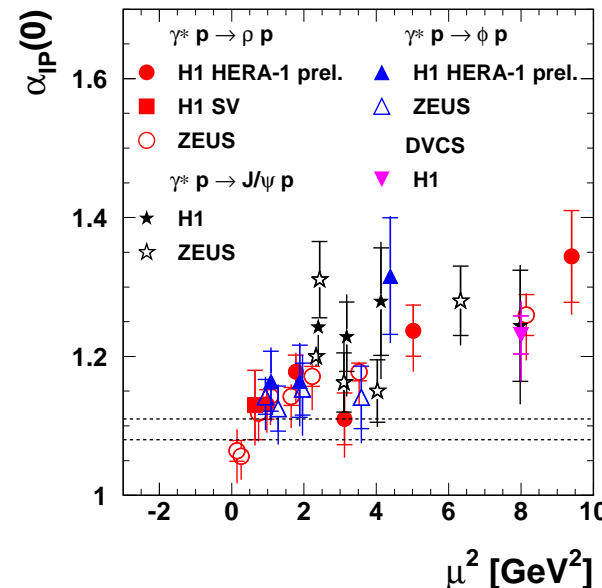
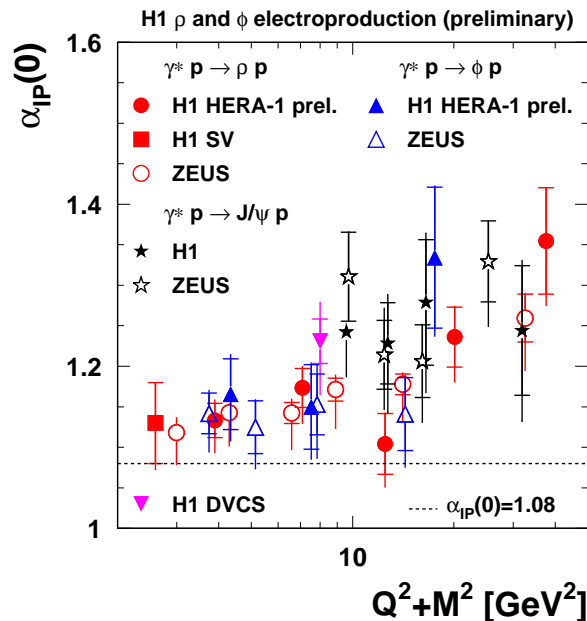
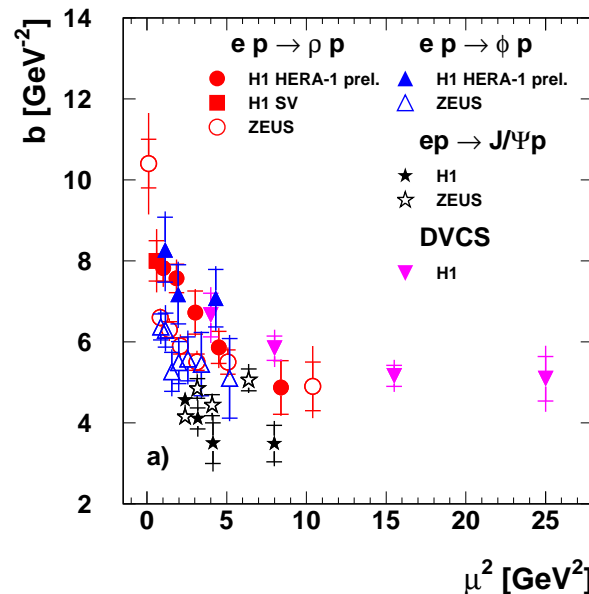
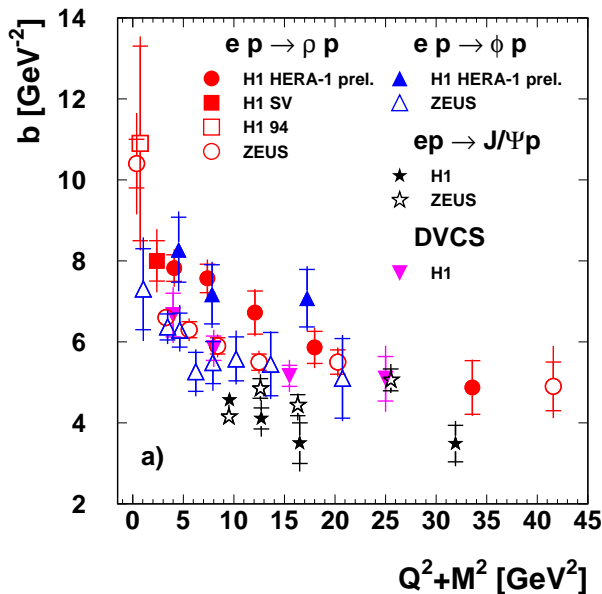
→ Hard scales are:

for DVCS:  $\mu^2 = Q^2$

for VM:  $\mu^2 = \frac{Q^2 + M^2}{4}$

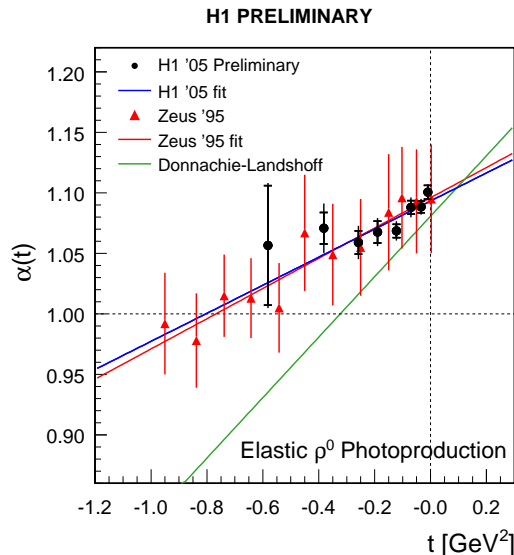
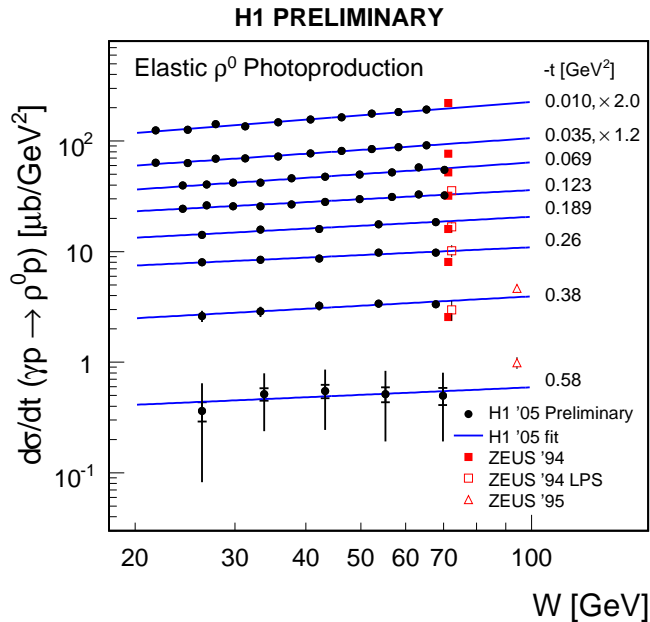
→ Universality vs  $\mu^2$ :

Soft/hard transition around  $\mu^2 \sim 5 \text{ GeV}^2$



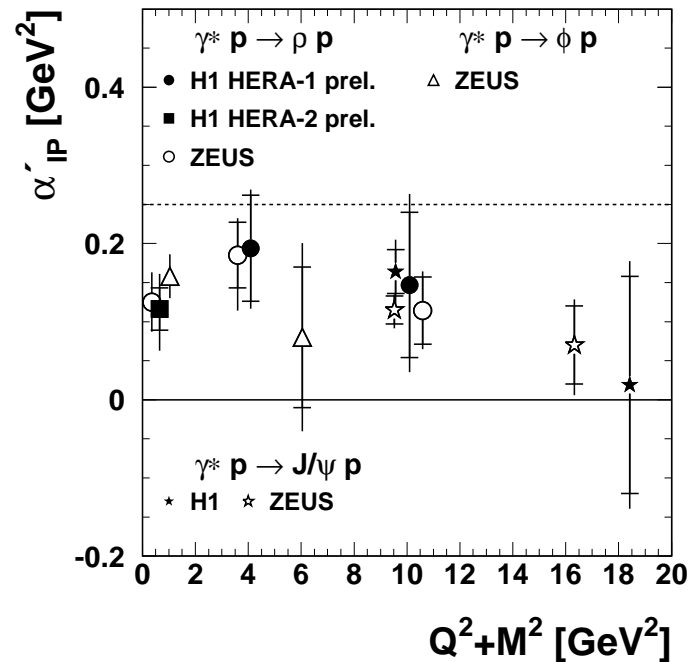
# Shrinkage : $\alpha'_{\mathbb{P}}$ measurements

H1  $\rho$  photoproduction 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:  $\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} t$

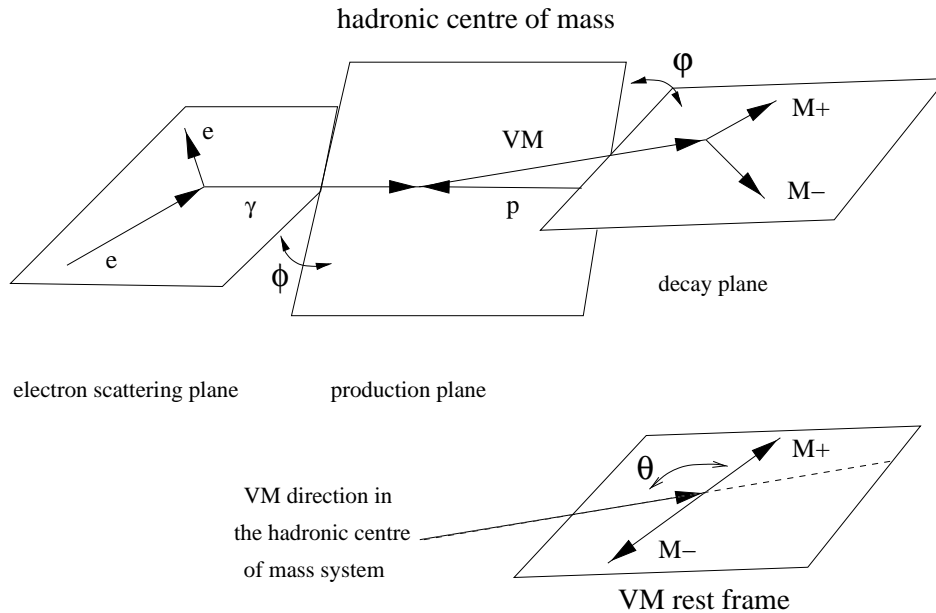


$\Rightarrow$  For all VM,  $\alpha'_{\mathbb{P}}$  smaller than 0.25 (DL,  $p\bar{p}$ )  
 (cf BFKL, multiple  $\mathbb{P}$  exchange)

# 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:  $T_{1-1} : \gamma_T \rightarrow \rho_T$

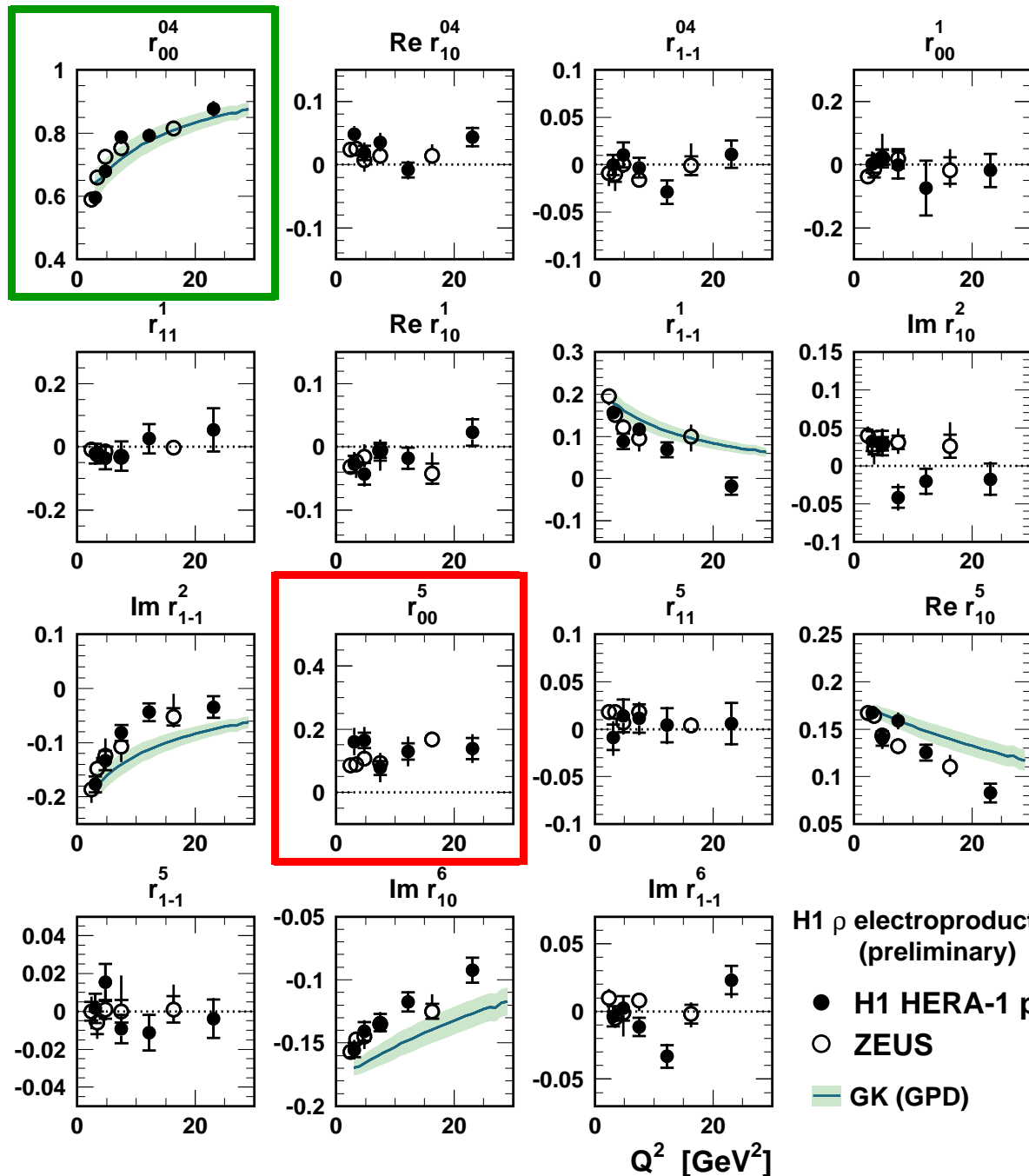
**s-Channel Helicity Conservation (SCHC):**  $T_{01} = T_{10} = T_{1-1} = 0$

**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]

# $\rho$ 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

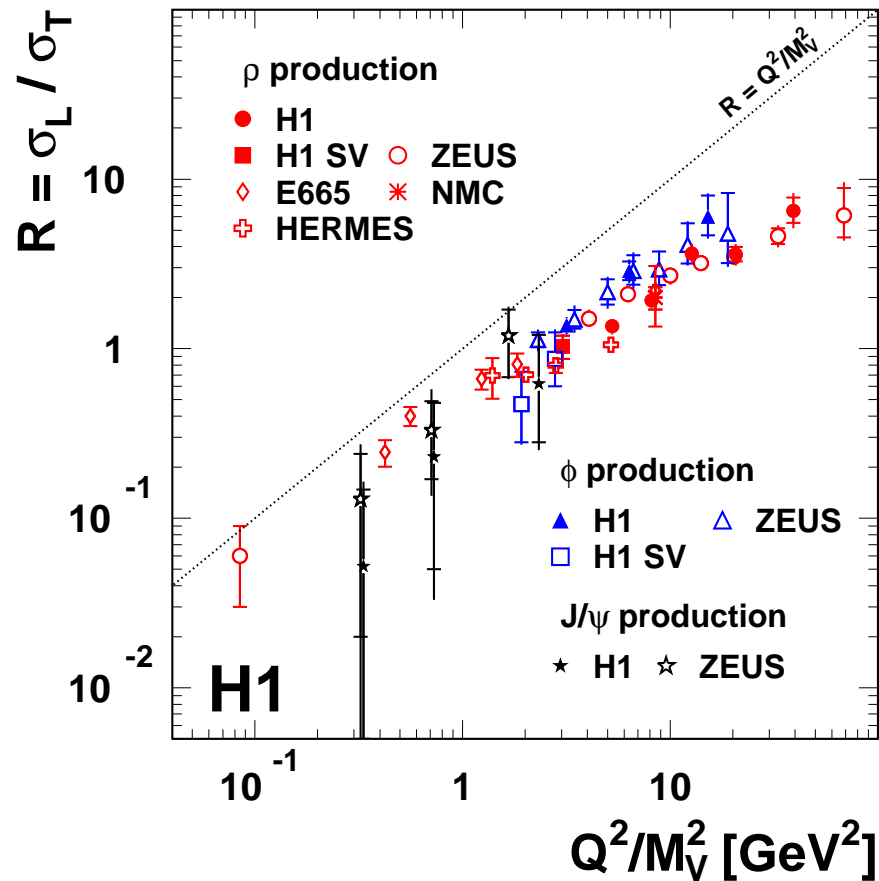
- $r_{00}^5$  violates SCHC
- Other SDME  $\simeq 0$

H1  $\rho$  electroproduction (preliminary)

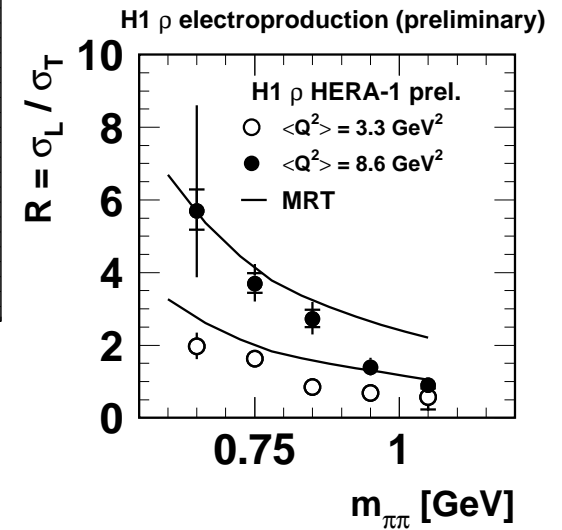
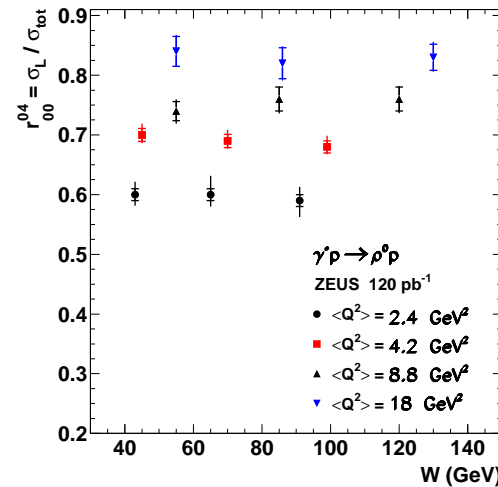
- H1 HERA-1 prel.
- ZEUS
- GK (GPD)

# $\rho$ and $\phi$ Polarisation - $R = \sigma_L / \sigma_T$

$$R_{SCHC} = \frac{1}{\epsilon} \frac{r_{00}^{04}}{1 - \epsilon r_{00}^{04}} = \frac{|T_{00}|^2}{|T_{11}|^2} + \text{non SCHC corrections in H1 case}$$



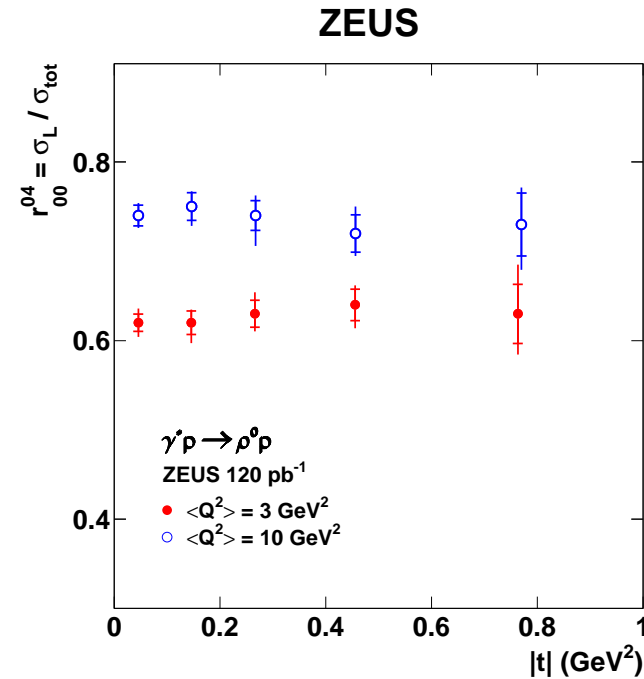
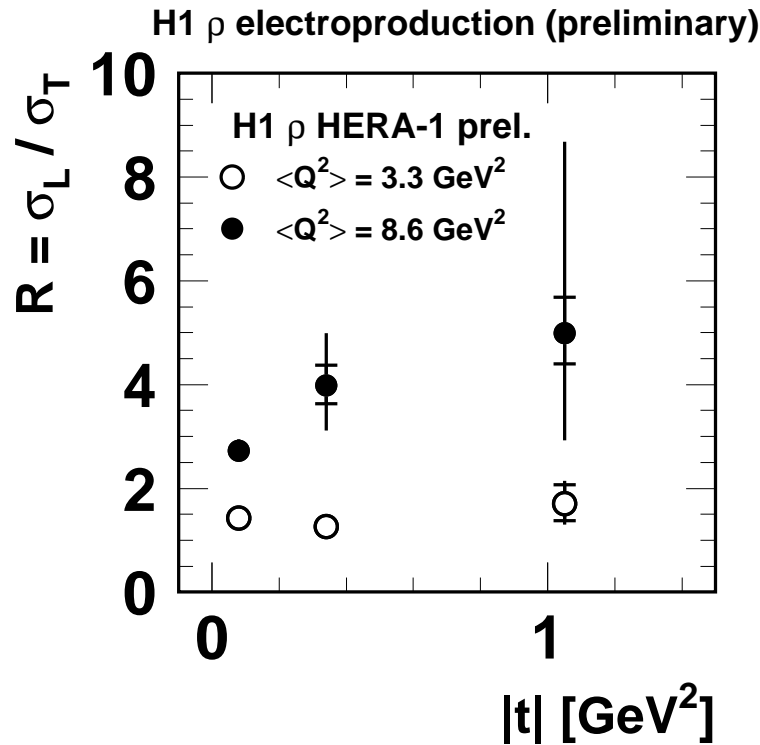
●  $\rho$ : no  $W$  dependance of  $R$



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

# $\rho$ and $\phi$ Polarisation - $R(t)$ and $b_L - b_T$



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

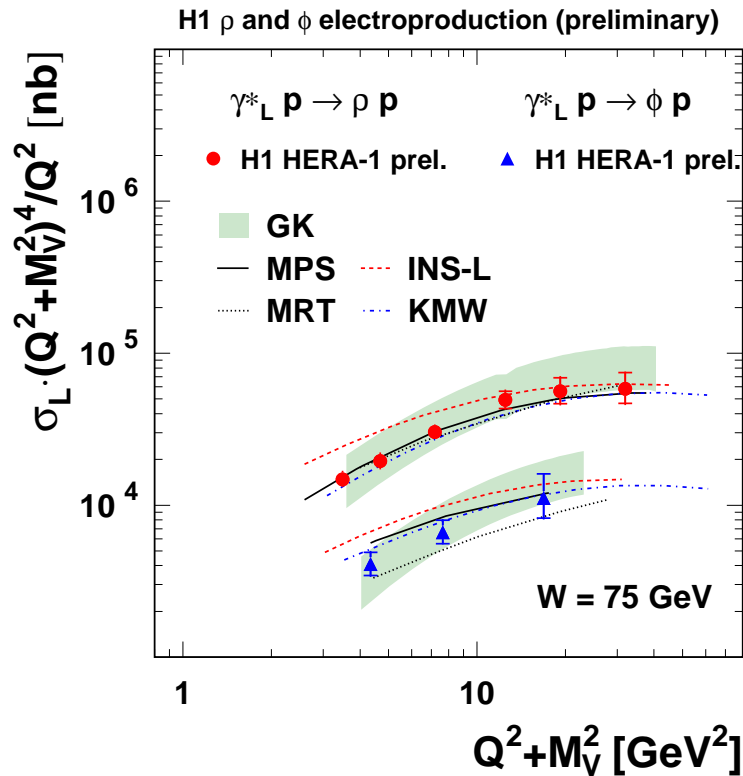
- **H1:**  $(b_L - b_T) < 0$  by  $1.5\sigma$  for  $Q^2 > 5 \text{ GeV}^2$
- also a  $t$  dependance of  $T_{11}/T_{00}$  - see later
- Small difference of transverse size of  $q\bar{q}$  dipoles from transverse and longitudinal photons



# $\rho$ and $\phi$ Polarisation - Cross-sections

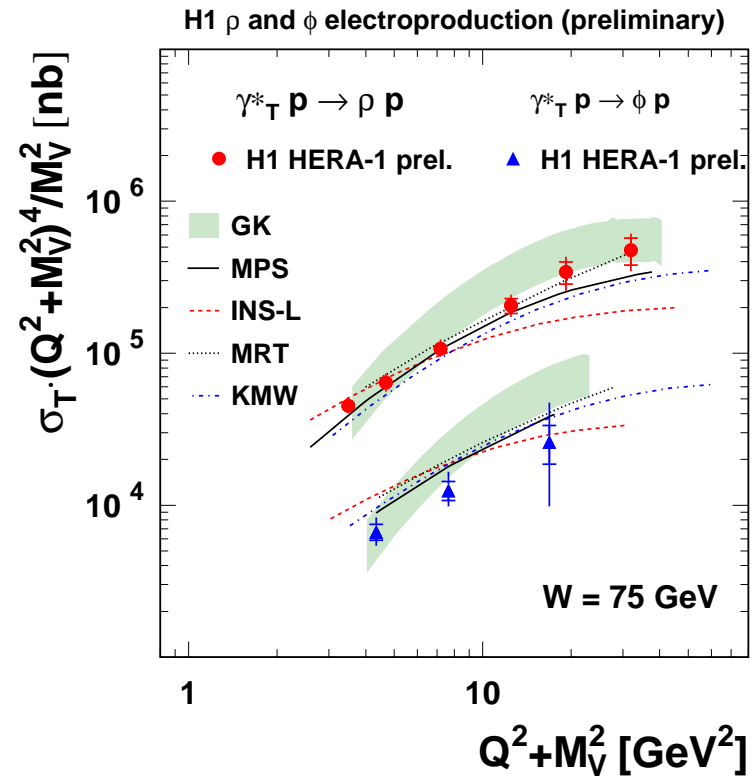
## Longitudinal

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



## 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  $\sigma_L$  and  $\sigma_T$  ( $\sigma_L = 0$  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

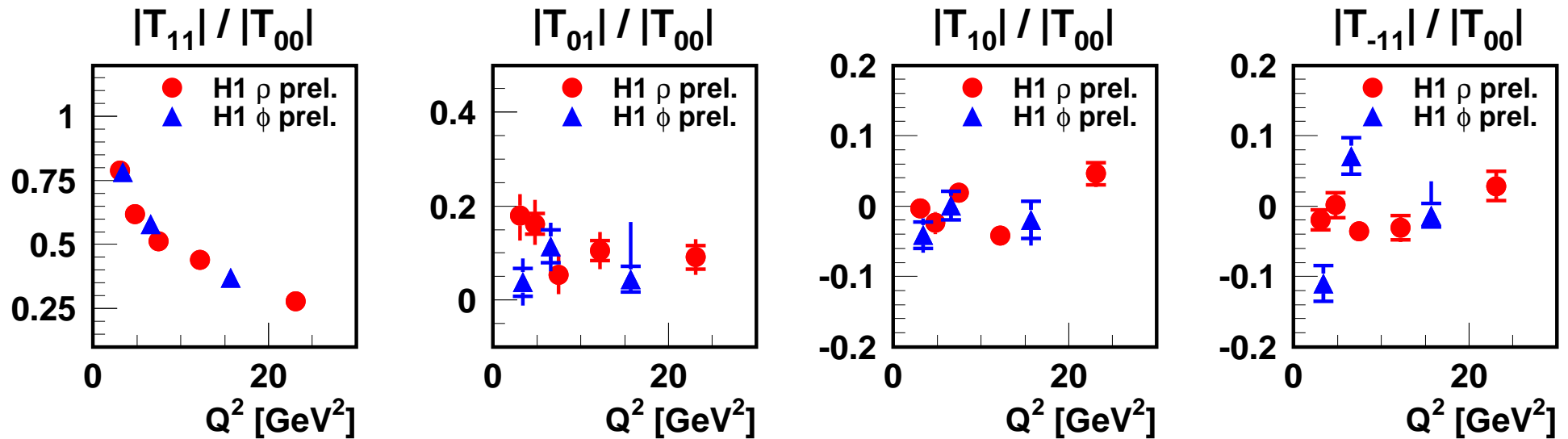
N.B.: data at fixed  $W \rightarrow$  varying  $x$  with  $Q^2 + M_V^2$

# ***Polarisation - Amplitude ratios vs. $Q^2$***

pQCD (IK):

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

$\gamma$  : gluon anomalous dim.



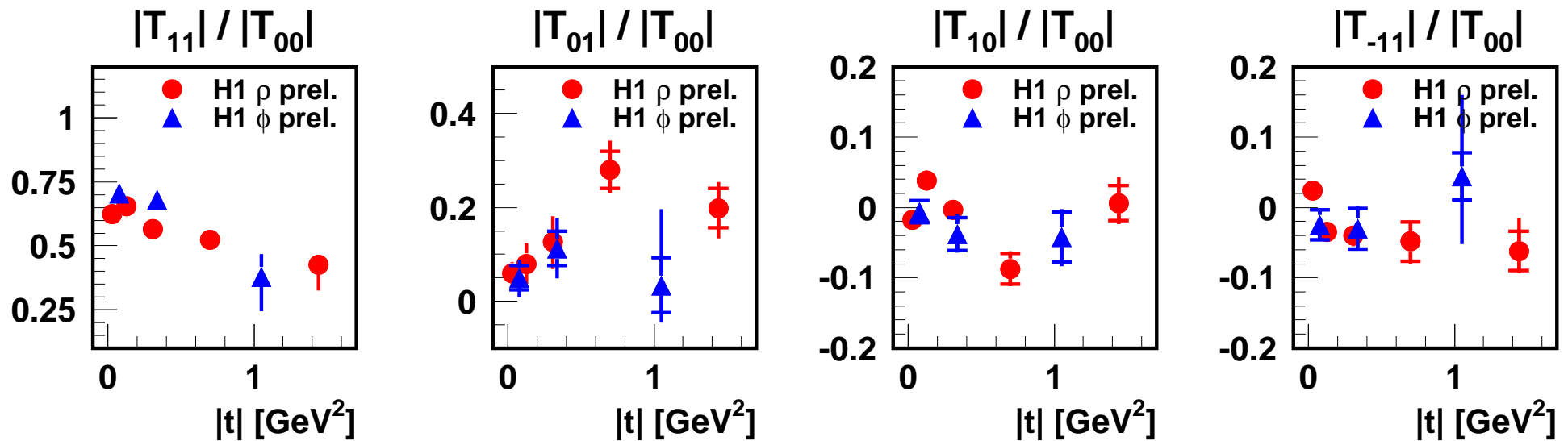
- $T_{11}/T_{00}$  decreases with  $Q^2 \leftrightarrow \sigma_L/\sigma_T$  increases with  $Q^2$
  - $T_{01}/T_{00} > 0 \leftrightarrow$  SCHC violation
  - $T_{10}/T_{00}$  and  $T_{-11}/T_{00}$  are small
- $\Rightarrow |T_{00}| > |T_{11}| > |T_{01}| > |T_{10}|, |T_{-11}| \leftrightarrow$  hierarchy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

# Polarisation - Amplitude ratios vs. $|t|$

pQCD (IK):

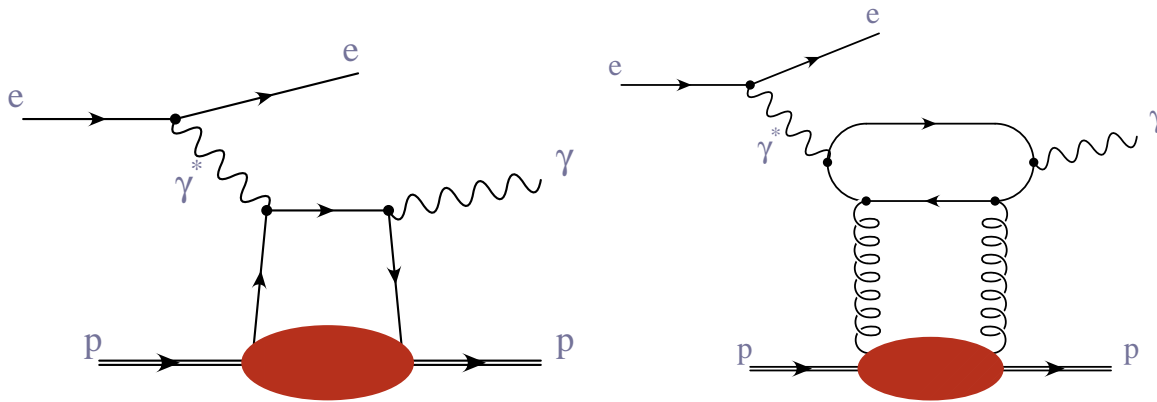
- $T_{11}/T_{00} \propto \frac{M}{Q} \frac{1+\gamma}{\gamma}$
- $T_{10}/T_{00} \propto -\frac{M}{Q^2} \frac{\sqrt{|t|}}{\gamma} \frac{\sqrt{2}}{\gamma}$
- $T_{01}/T_{00} \propto \frac{\sqrt{|t|}}{Q} \frac{1}{\sqrt{2}\gamma}$

$\gamma$  : gluon anomalous dim.

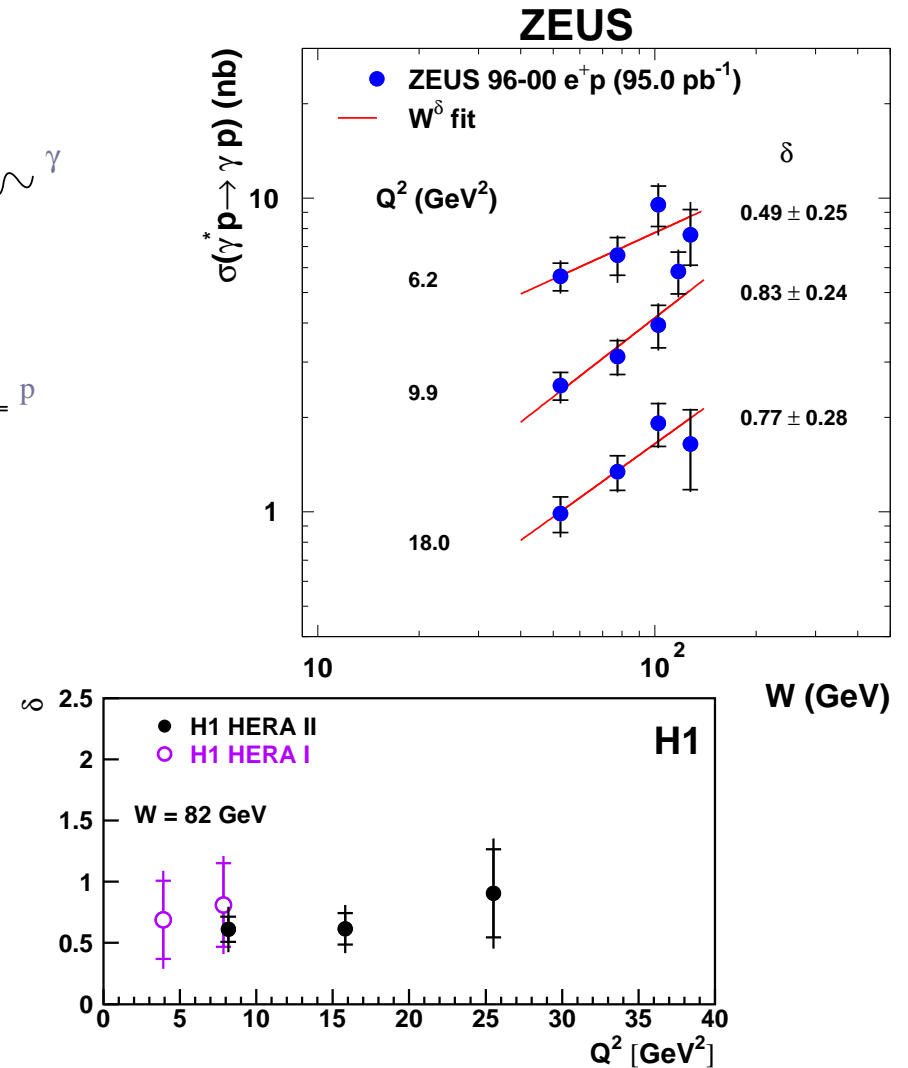
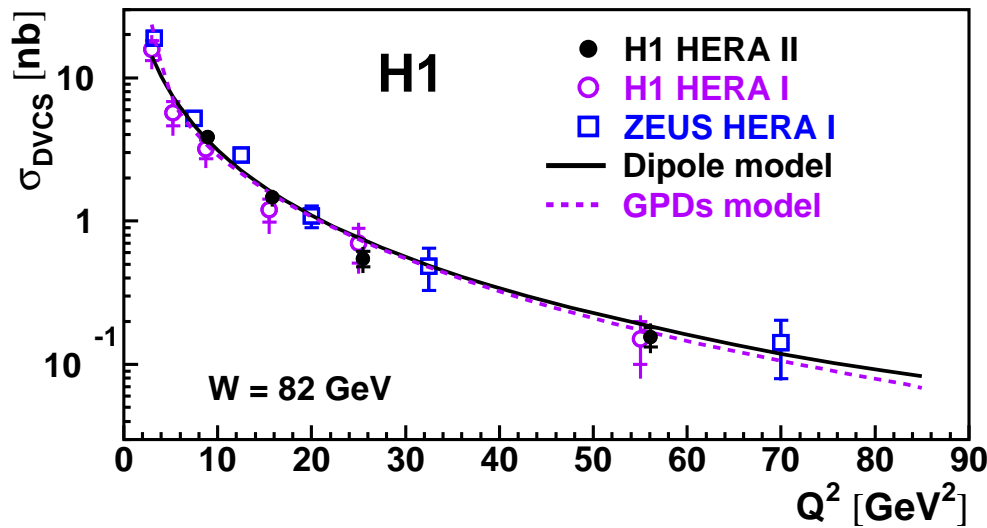


- $T_{11}/T_{00}$  decreases with  $|t|$  (cf.  $b_L - b_T$ )
- $T_{01}/T_{00}$  increases with  $|t| \leftrightarrow$  SCHC violation increases with  $|t|$
- $T_{10}/T_{00}$  and  $T_{-11}/T_{00}$  are small but some  $|t|$  dependence

# Deep Virtual Compton Scattering



- fully calculable in pQCD
- Access to the full QCD amplitude
- Constrain gluon GPDs



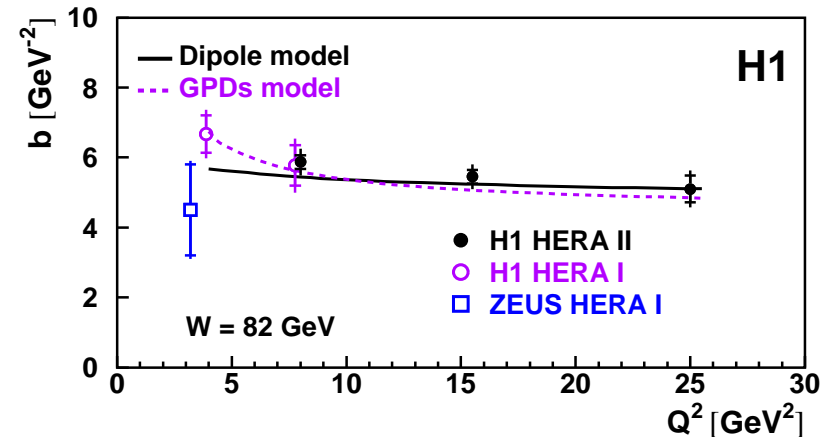
$W$  dependence indicates a hard regime (similar to  $J/\Psi$ )

# DVCS: $t$ slope and Beam Charge Asymmetry

H1 measurement based on 291  $pb^{-1}$  of HERA II data ( $e^+$  and  $e^-$ ).

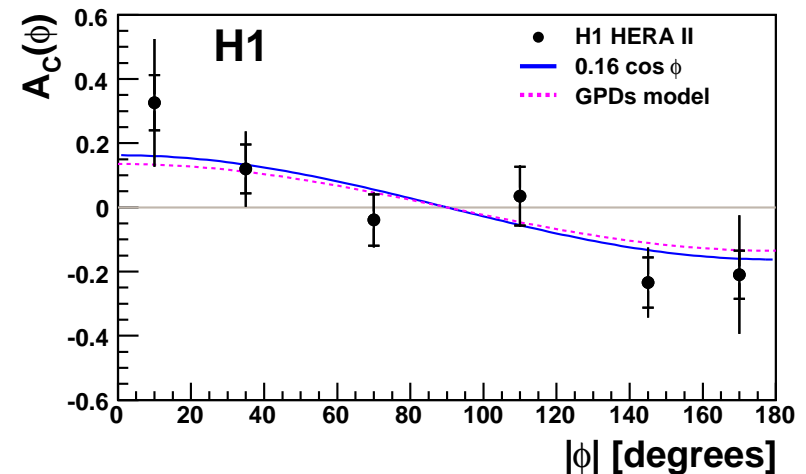
- $t$  slope as a function of  $Q^2$

⇒ Similar behaviour with VM using the scale  $Q^2 + M_{VM}^2$



- First DVCS BCA measured at HERA.

$$BCA \equiv \frac{\sigma(e^+p) - \sigma(e^-p)}{\sigma(e^+p) + \sigma(e^-p)} \sim p_1 \cos(\Phi)$$



# DVCS: QCD interpretation

- correct  $Q^2$  dependence of the propagator and of  $b$  in the cross section:

$$S = \sqrt{\frac{\sigma_{DVCS} Q^4 b(Q^2)}{(1 + \rho^2)}}$$

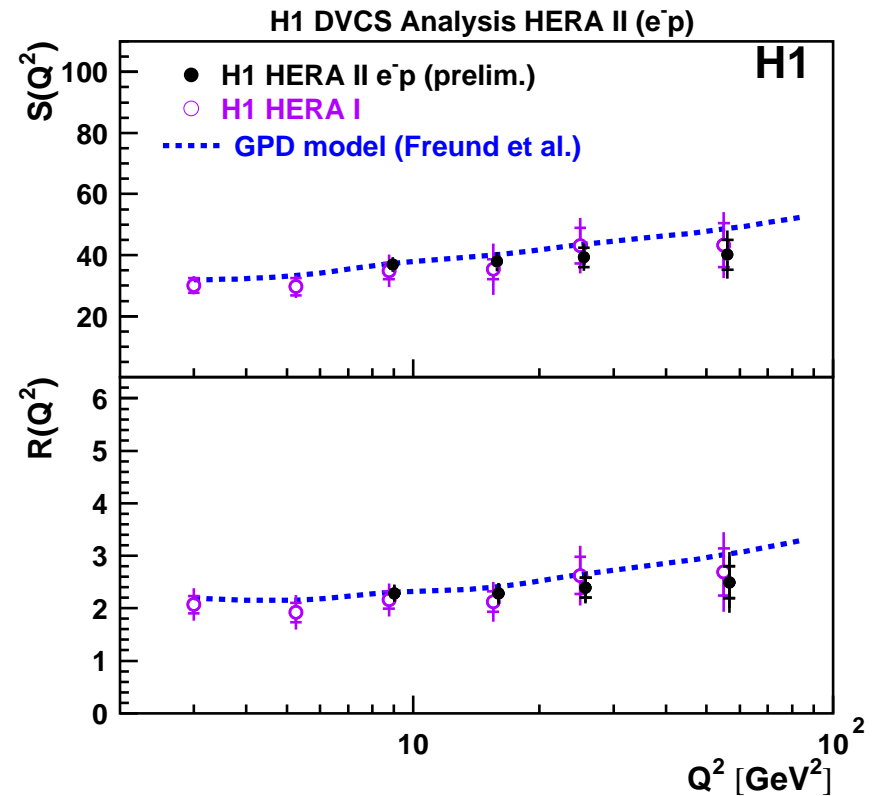
- **skewing** factor: around 2

$$R = \frac{\text{Im } A(\gamma^* p \rightarrow \gamma p)}{\text{Im } A(\gamma^* p \rightarrow \gamma^* p)}$$

$$= \frac{4 \sqrt{\pi \sigma_{DVCS} b(Q^2)}}{\sigma_T(\gamma^* p \rightarrow X) \sqrt{(1 + \rho^2)}}$$

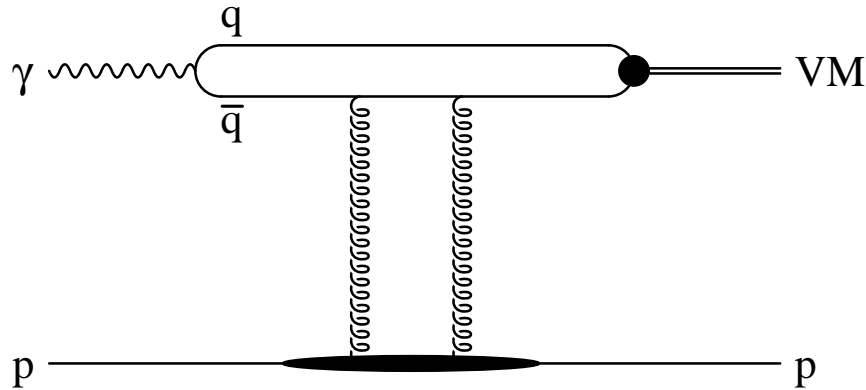
⇒ important skewing factor

⇒  $Q^2$  evolution close to the one of DIS (pure DGLAP)

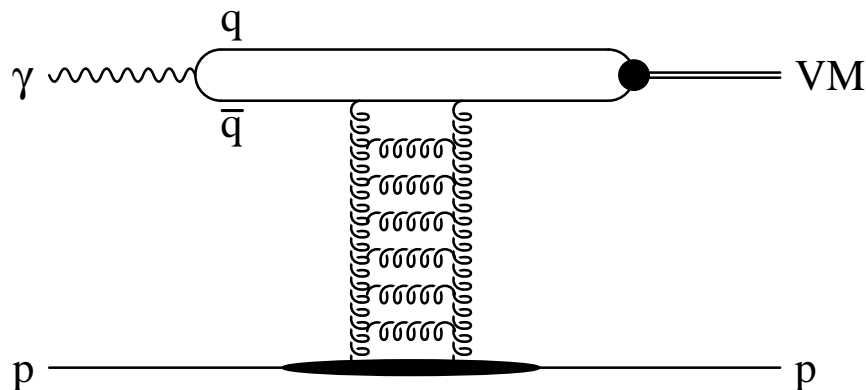


# High $|t|$ Exclusive Photoproduction: Introduction

LO: 2 gluon exchange



LLA: Gluon ladder



DGLAP Evolution ( $|t| < M_{VM}^2$ ):

**Strong**  $k_T$  ordering along ladder

$$\rightarrow d\sigma/dt \sim e^{bt}$$

$\rightarrow$  No increase of  $d\sigma/dt$  with  $W$

BFKL Evolution ( $|t| > M_{VM}^2$ ):

- $p_T$  fully transferred from  $p$  to  $q\bar{q}$

- high  $W \rightarrow$  small  $x_{Bj}$

**No**  $k_T$  ordering in ladder

$$\rightarrow d\sigma/dt \sim |t|^{-n}; n = 3 - 4$$

$\rightarrow$  Increase of  $d\sigma/dt$  with  $W$

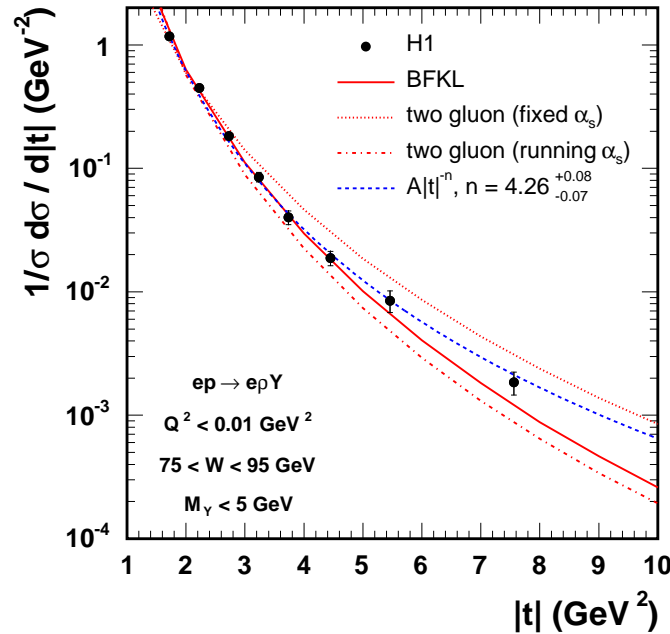
$\rightarrow$  Little shrinkage

$\rightarrow$  VM: SCHC expected

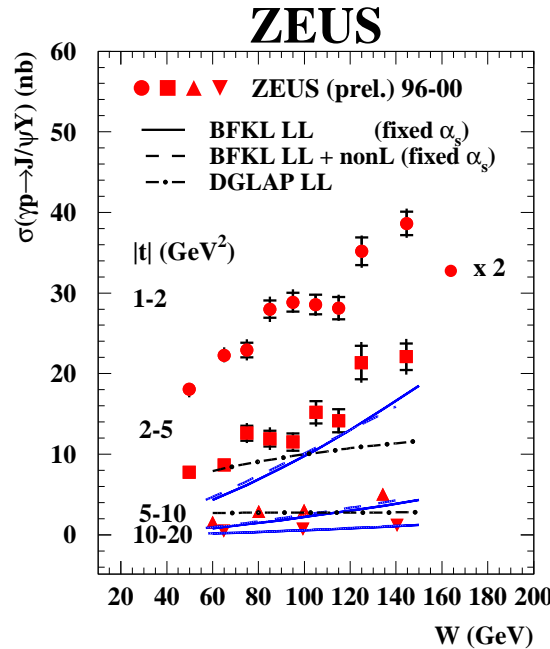
Models: Forshaw et al.

# High $|t|$ : Vector Meson Cross-Sections

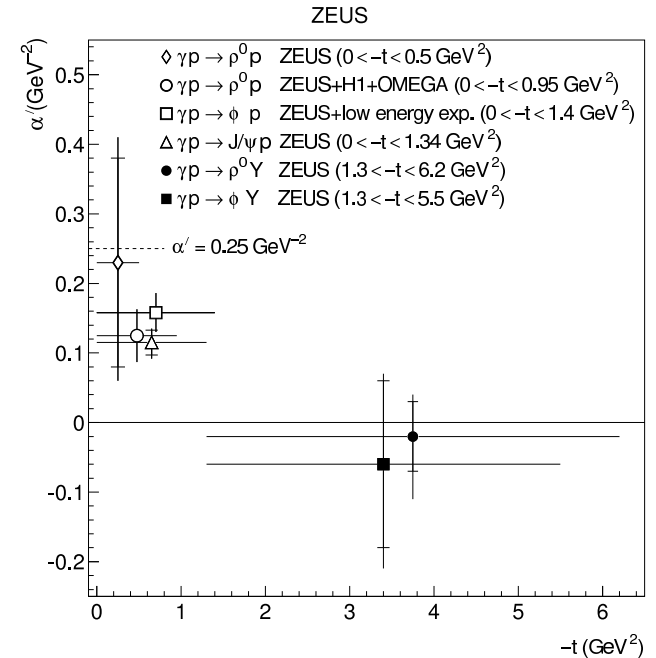
$\rho$  vs  $t$



$J/\psi$  vs  $W$



$\alpha'$  vs  $t$

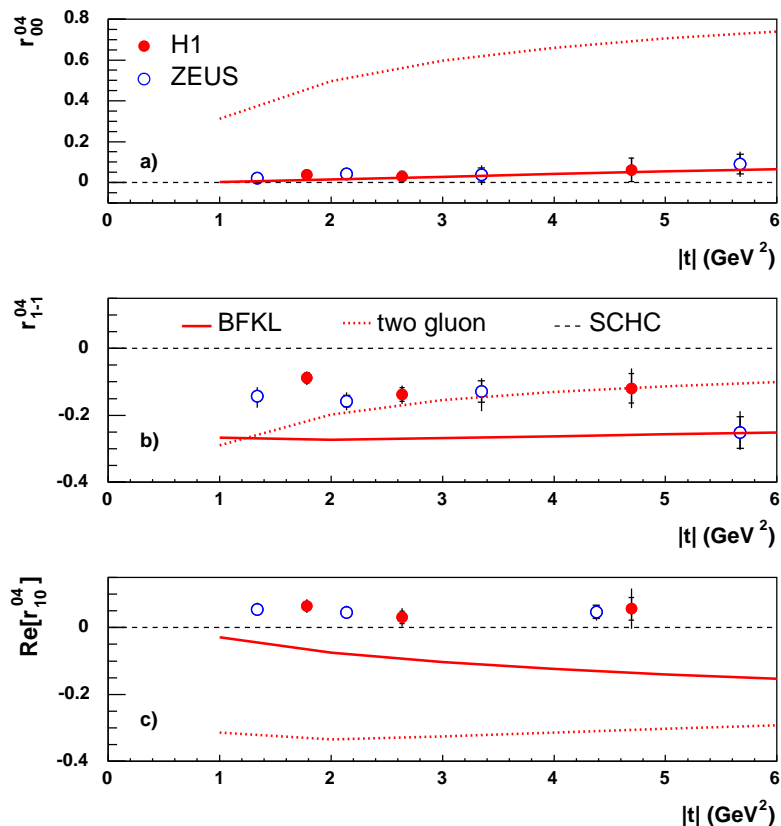


- Data follow  $|t|^{-n}$
- BFKL describes data
- 2-gluon (DGLAP-like) fails
- Hardening of  $W$  depend. with  $|t|$
- BFKL reproduces rise with  $W$
- DGLAP fails at high  $|t|$
- $\alpha'$  decreases with  $|t|$
- No shrinkage as expected for BFKL



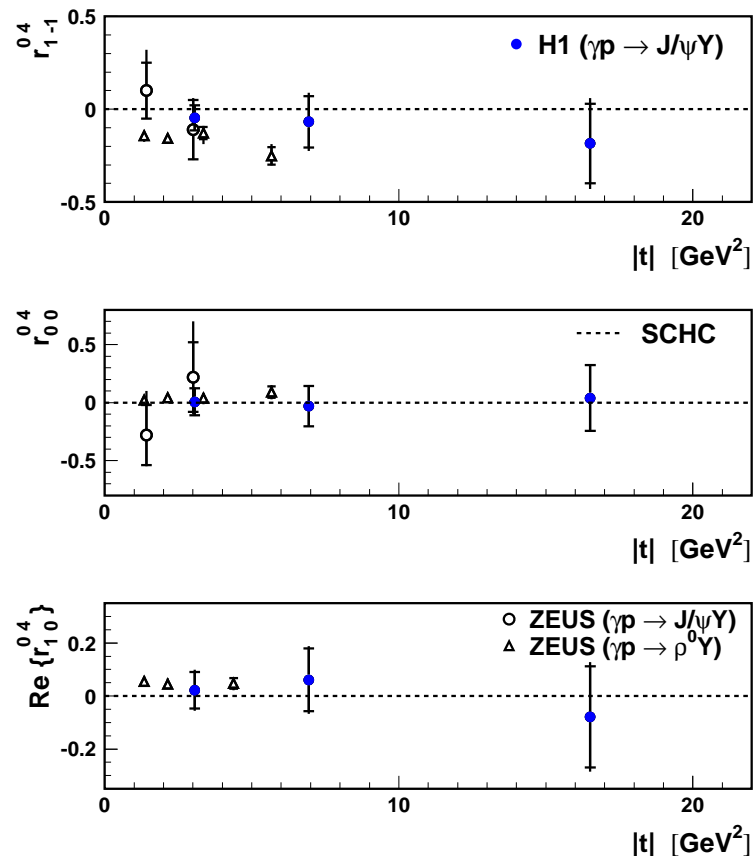
# High $|t|$ : Vector Meson Polarisation

$\rho$



- $\rho$  data: SCHC violation for  $r_{1-1}^{04}$  and  $\text{Re}[r_{10}^{04}]$
- Two-gluon and BFKL models are unable to describe data

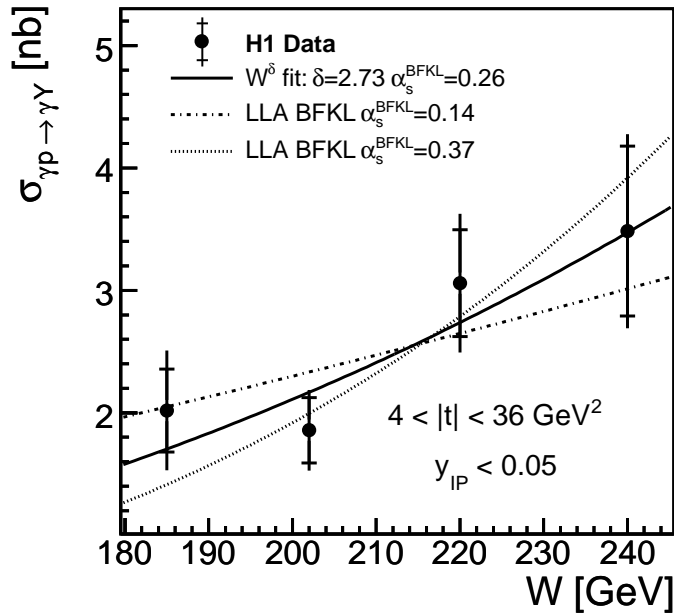
$J/\psi$



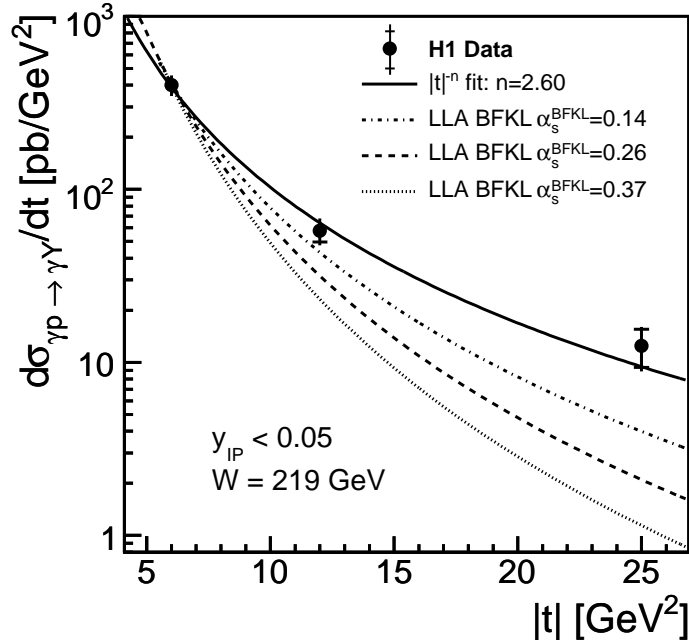
- $J/\psi$  data: SCHC holds
- non-relativistic WF is OK  
i.e. equal long. momentum sharing between  $q$  and  $\bar{q}$

# High $|t|$ : Diffractive High $P_T$ Photons

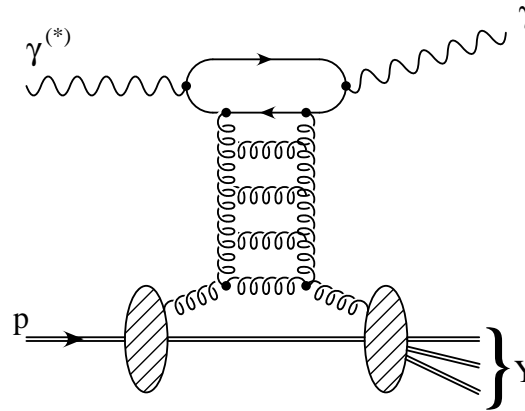
H1 Diffractive Scattering of  $\gamma$  at large  $|t|$



H1 Diffractive Scattering of  $\gamma$  at large  $|t|$



## First measurement of high $P_T$ photons



H1 99-00 Data:  $46 \text{ pb}^{-1}$

$$Q^2 < 0.01 \text{ GeV}^2$$

$$175 < W < 247 \text{ GeV}$$

$$4 < |t| < 36 \text{ GeV}^2$$

$$y_{\text{IP}} \simeq e^{-\Delta\eta} < 0.05$$

$$E_\gamma > 8 \text{ GeV}$$

## Strong $W$ dependence:

- $W^\delta$  fit  $\rightarrow \delta = 2.73 \pm 1.02^{+0.56}_{-0.78}$   
 $\rightarrow \alpha_s^{\text{BFKL}} = 0.26 \pm 0.10^{+0.05}_{-0.07} \text{ } \color{red}{<} J/\psi : \alpha_s \sim 0.18$
- LLA BFKL (with  $\alpha_s = 0.26$ ) prediction describe the  $W$  dependence

## $t$ dependence:

- $|t|^{-n}$  fit  $\rightarrow n = 2.60 \pm 0.19^{+0.03}_{-0.08}$
- LLA BFKL too steep for  $t$  dependence

# CONCLUSIONS

Important progresses in precision for VM and DVCS leading to the understanding of the underlying dynamics

## VM cross-section measurements:

- New  $\Upsilon$  photoproduction results
- Hard regime reached only around  $\mu^2 = \frac{Q^2 + M^2}{4} = 5 \text{ GeV}^2$  as observed in measurements of  $\alpha_P(0)$  and  $b$ -slopes.
  - Possible soft component in  $\sigma_L$  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
- $\sigma_L/\sigma_T$  increases with  $Q^2$  and maybe with  $|t|$  at high  $Q^2$ 
  - ↔  $|t|$  depend. expected in pQCD from  $\neq$  dipole in  $\sigma_L$  and  $\sigma_T$ .
- Violation of SCHC: significant  $T_{01}/T_{00}$  increases with  $|t|$
- $\sigma_L/\sigma_T$  decreases with  $\rho$  invariant mass
  - ↔ Predicted by MRT / limited influence of VM wave function.

# CONCLUSIONS

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Important progresses in precision for VM and DVCS leading to the understanding of the underlying dynamics

## DVCS:

- $W$  dependence indicates hard regime
- Significant skewing factor measured  $\rightarrow$  GPD
- First Beam Charge Assymetry measured

## High $|t|$ :

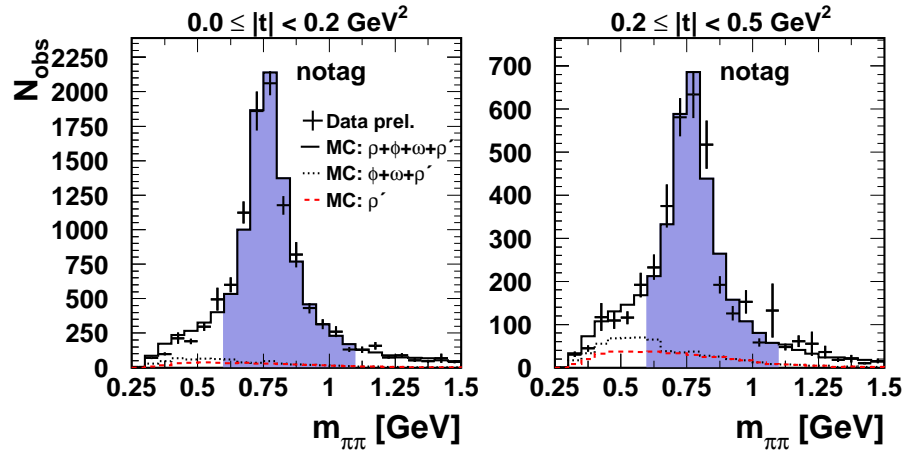
- High  $|t|$  VM data are showing BFKL like behaviours
- High  $P_T$  photons measurement roughly agree with BFKL

## pQCD models:

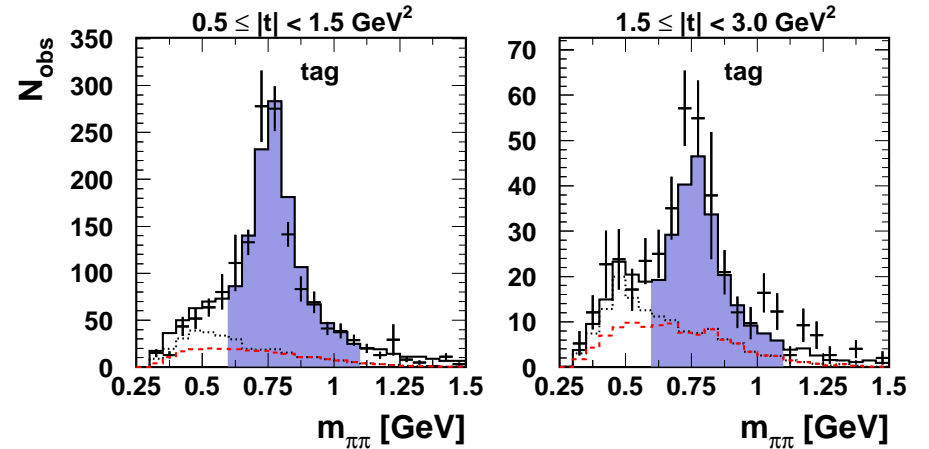
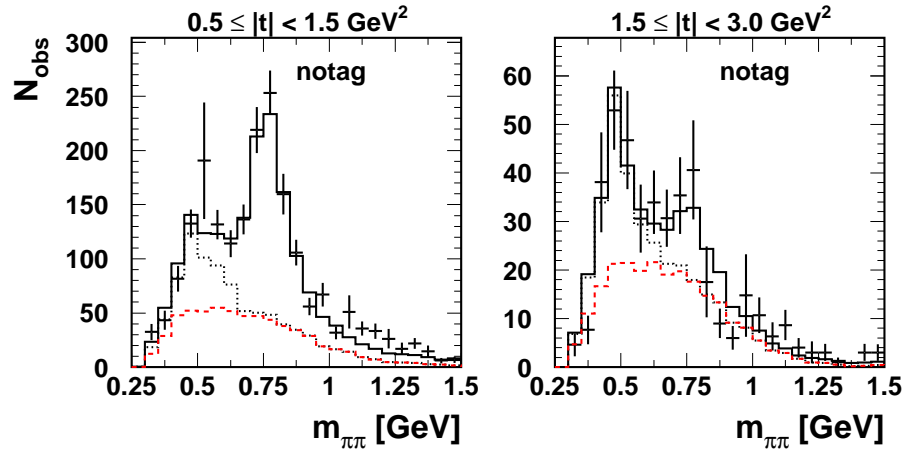
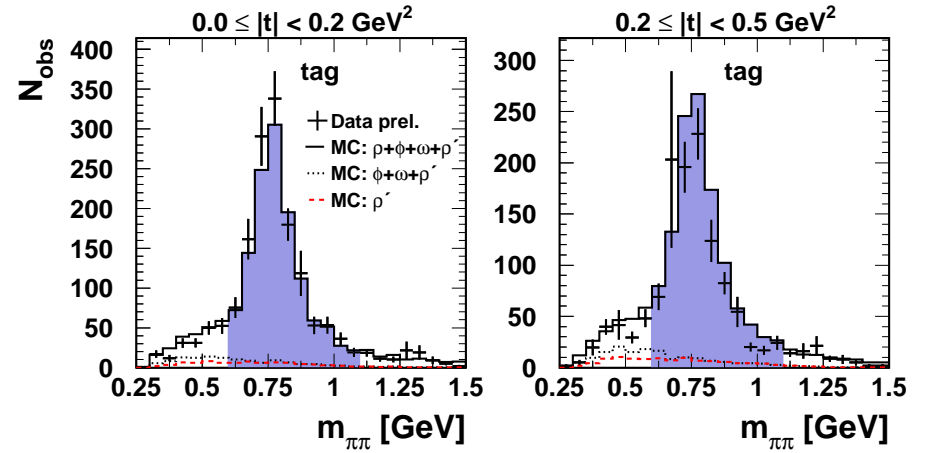
- GPD and dipole models describe main features of data
- Some differences in details

# H1 background subtraction

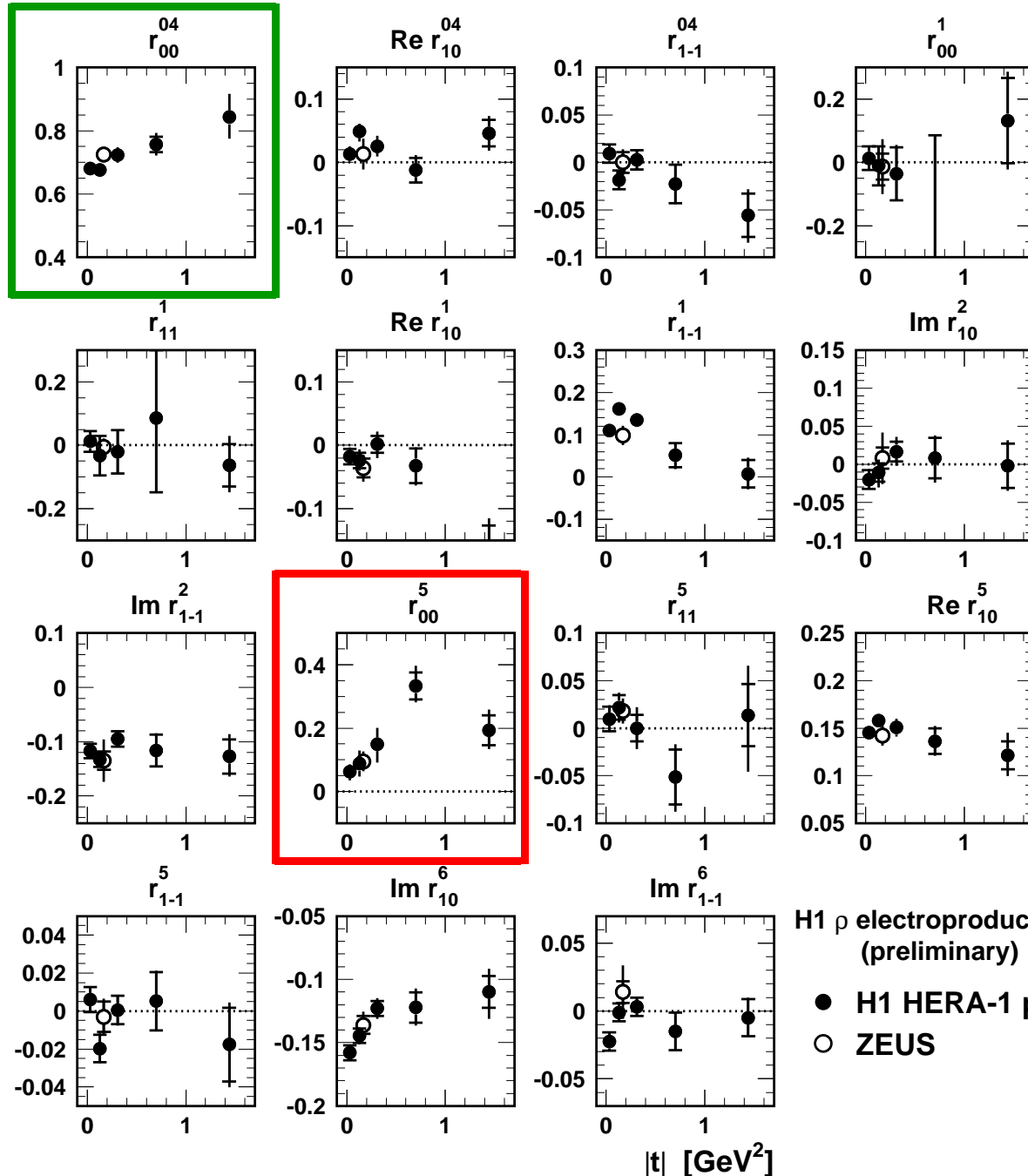
H1  $\rho$  electroproduction (preliminary)



H1  $\rho$  electroproduction (preliminary)



# $\rho$ Polarisation - SDMEs vs. $|t|$



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

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

H1  $\rho$  electroproduction  
 (preliminary)

● H1 HERA-1 prel.  
 ○ ZEUS

# ***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:

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

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

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