Elastic ρ Meson Production at HERA

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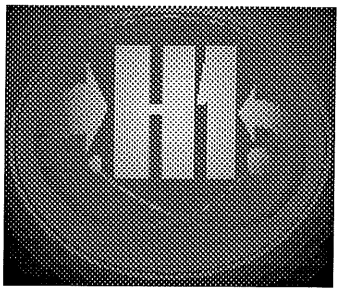
For the H1 Collaboration



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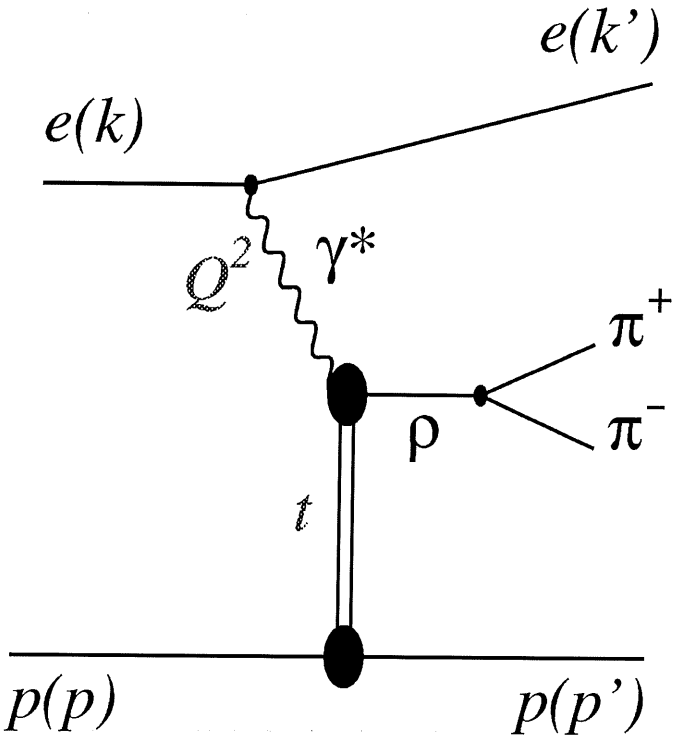
Reaction and kinematics

$$e + p \rightarrow e + p + \rho$$
$$\rho \rightarrow \pi^+\pi^- \ (\mathrm{BR} \simeq 100\ \%)$$



$$W = \sqrt{(\gamma + p)^2} \qquad \sqrt{s} = \sqrt{(k + p)^2}$$
$$Q^2 = -q^2 \qquad \text{decay angles}$$
$$t = (p' - p)^2$$

Elastic process (proton is not broken)

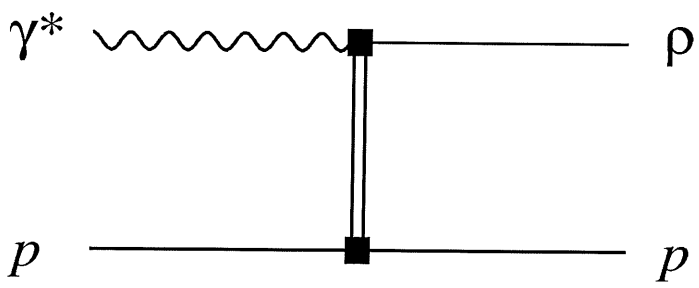
Motivations

- Total cross sections:

"SOFT" energy dep.	$\Longrightarrow$	at high Q^2: "HARD" energy dep.
$\sigma \simeq$ indep. of energy		strong rize of F_2 (and $xg(x)$) with en.

$\Updownarrow$ linked via the Optical Theorem

- Vector meson production: (elastic prod.)

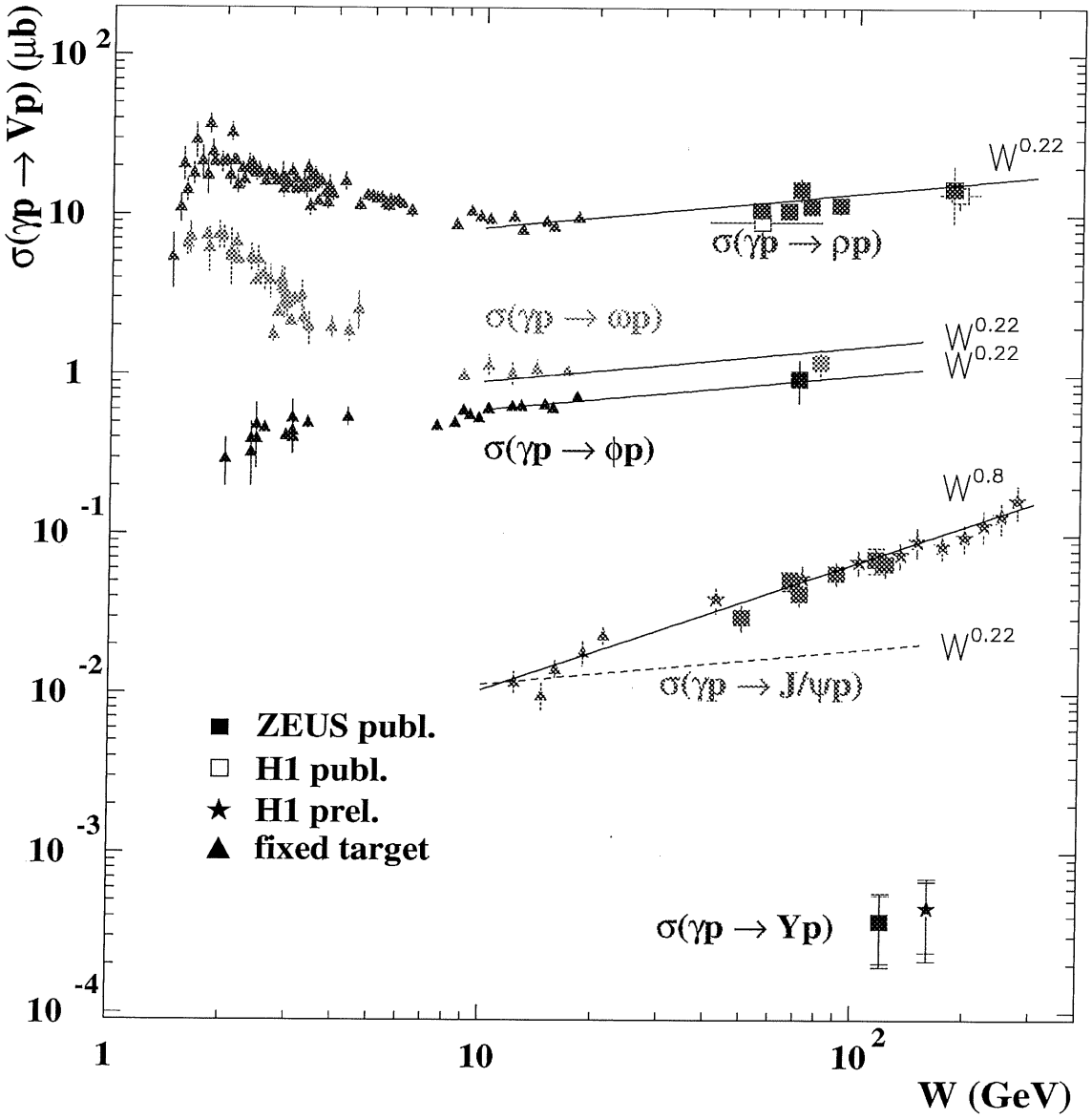


$I\!P$ exchange, $I\!P \simeq$ gluons

$\rightarrow$ do we observe a hard behaviour in VM prod. ?

$\rightarrow$ in which kinematical range ?

- Photoproduction of VM: $(Q^2 \simeq 0)$



$$\sigma = \frac{W^{4\epsilon}}{b(W)} \sim W^{\delta} \qquad (\text{"SOFT" dep.: } \delta{=}0.22)$$

$\Rightarrow m_q$: hard scale

$\Rightarrow$ what about light VM at high Q^2

Models for ρ production

- The phenomenological pomeron:

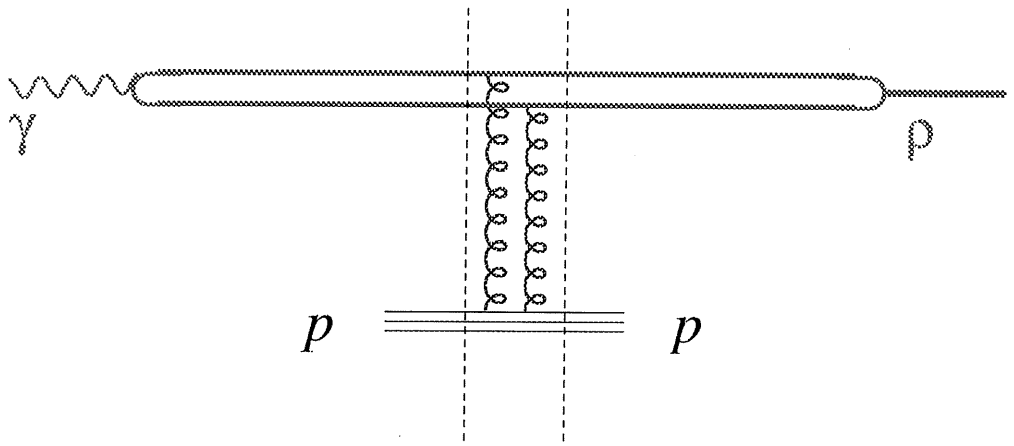
VDM + Regge

- Models based on pQCD:

hard scale: $\rightarrow$ large Q^2

common features of most models:

1. time ordering: (in p rest frame)



$\rightarrow \mathcal{M} \propto \psi^{V}_{\lambda_1,\lambda_2}{}^{*}\; T_{\lambda_1,\lambda_2}\; \psi^{\gamma}_{\lambda_1,\lambda_2}$ (T_{λ_1,λ_2} = helicity ampl.)

2. cross section:

$$\sigma_{\gamma p} \sim \frac{\alpha_s^2(Q^2)}{Q^6} \left| x g(x, Q^2) \right|^2$$

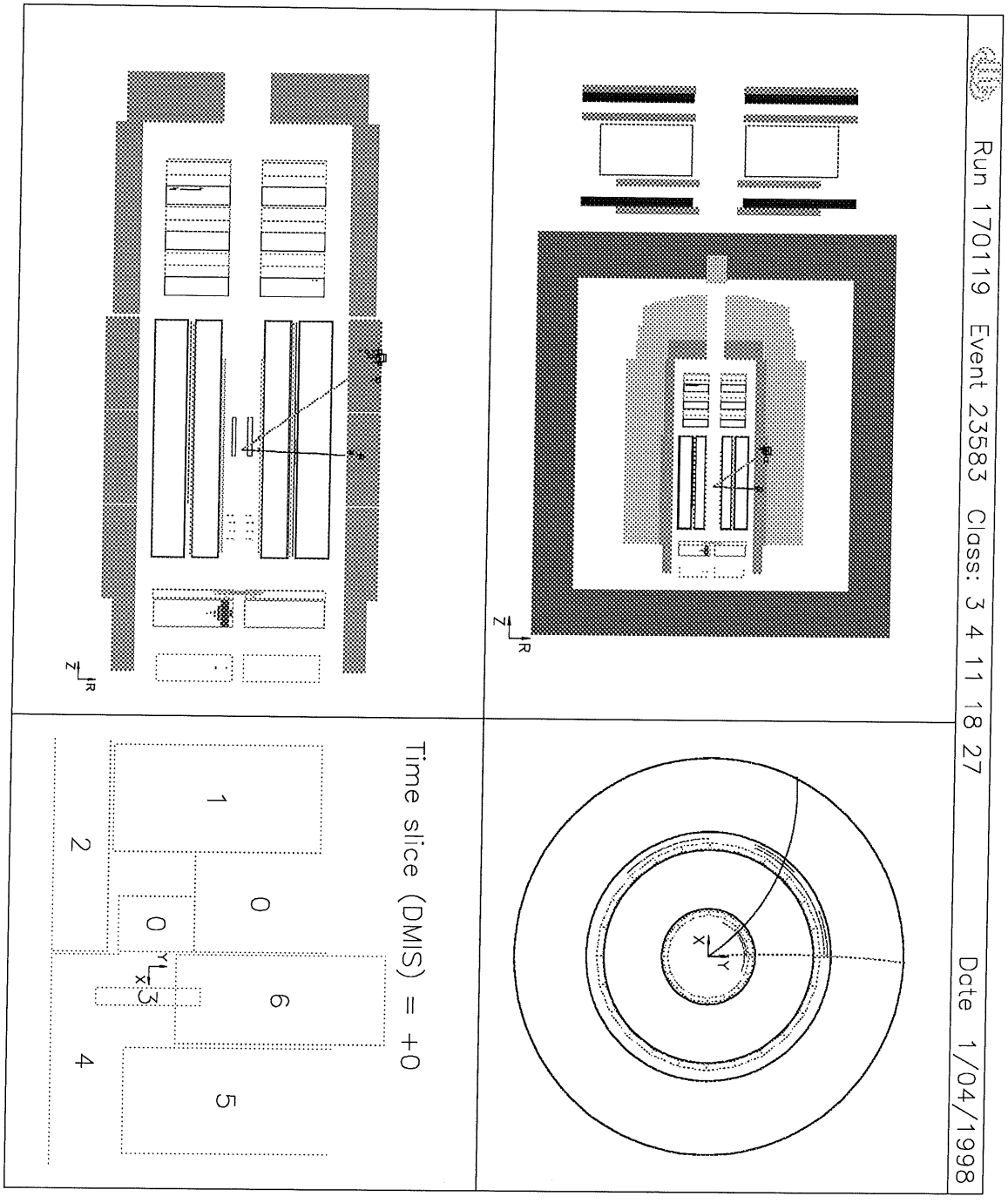
$\Rightarrow$ Steep rise of $\sigma_{\gamma p}(W)$, driven by $x\, g(x)$

Uncertainties: choice of the scale, high order corrections, ϱ wave function (Fermi motion), gluon distribution.

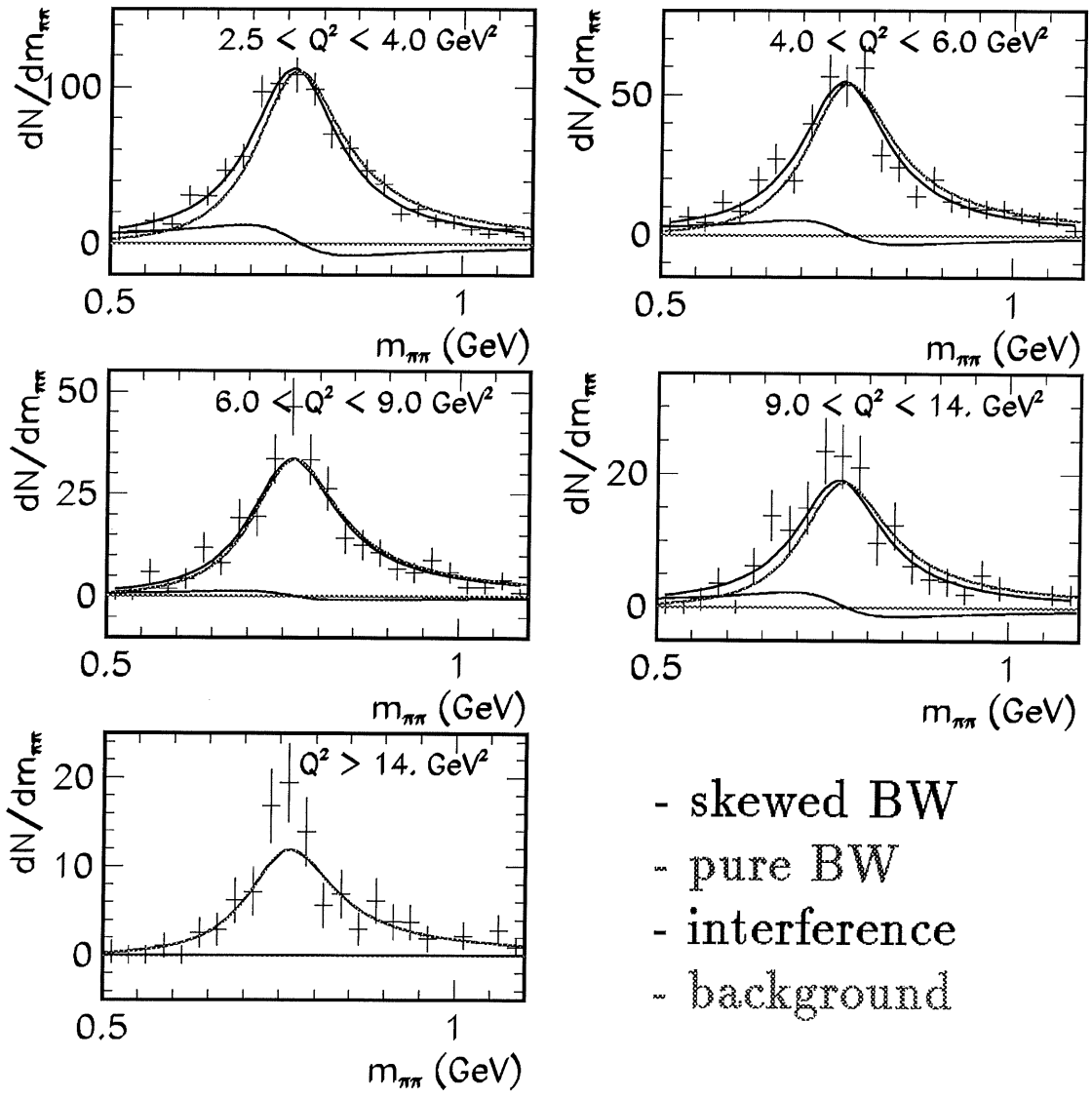
Data Selection

year	luminosity	Q^2 range	N events
94	2.8 pb^{-1}	$Q^2 > 8$ GeV^2	180
95	125 nb^{-1}	$1 < Q^2 < 5$ GeV^2	498
96	3.87 pb^{-1}	$2.5 < Q^2 < 60$ GeV^2	1807

new 95/96 data: DESY-99-010, submitted to *Eur. Phys. Jour. C.*



Skewing of the mass distribution

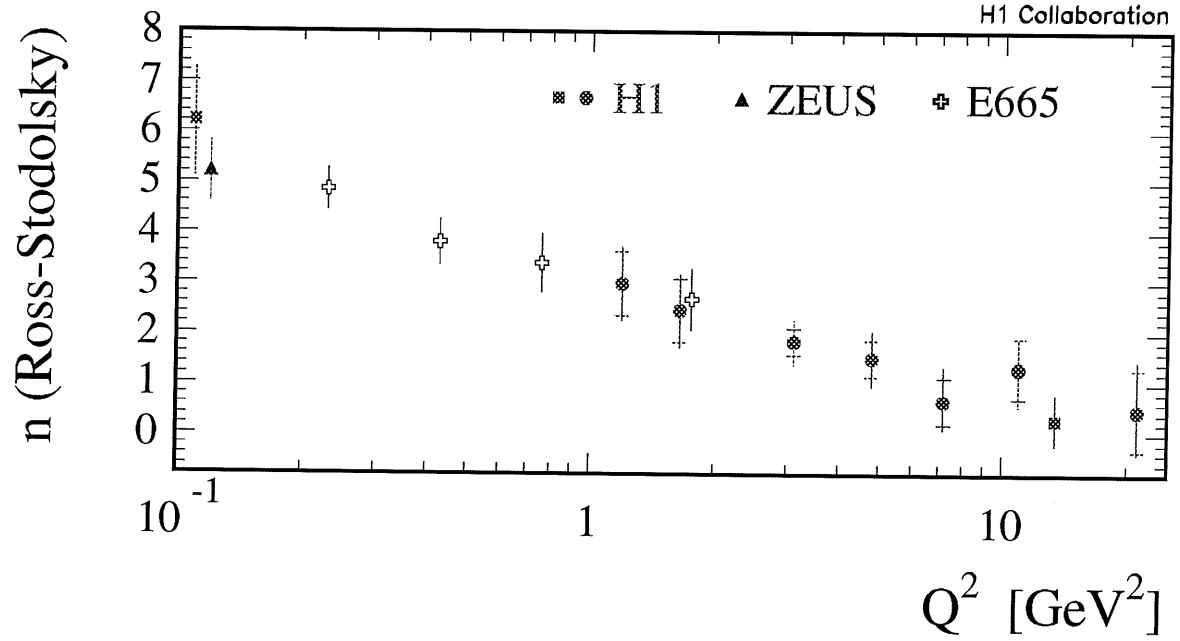


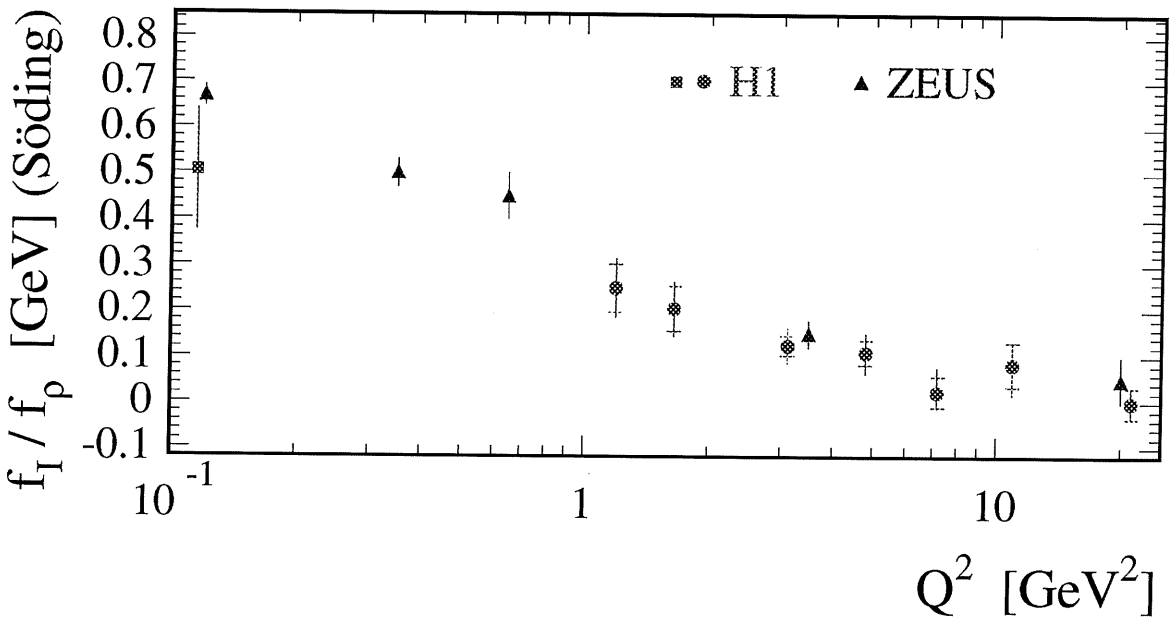
- skewed BW
- pure BW
- interference
- background

Söding parametrisation (interference between resonant and non resonant pion pair):

$$\frac{dN(m_{\pi\pi})}{dm_{\pi\pi}} = f_\rho . BW_\rho(m_{\pi\pi}) + f_I . I(m_{\pi\pi}) + f_{NR}$$

- Q^2 evolution of the skewing:





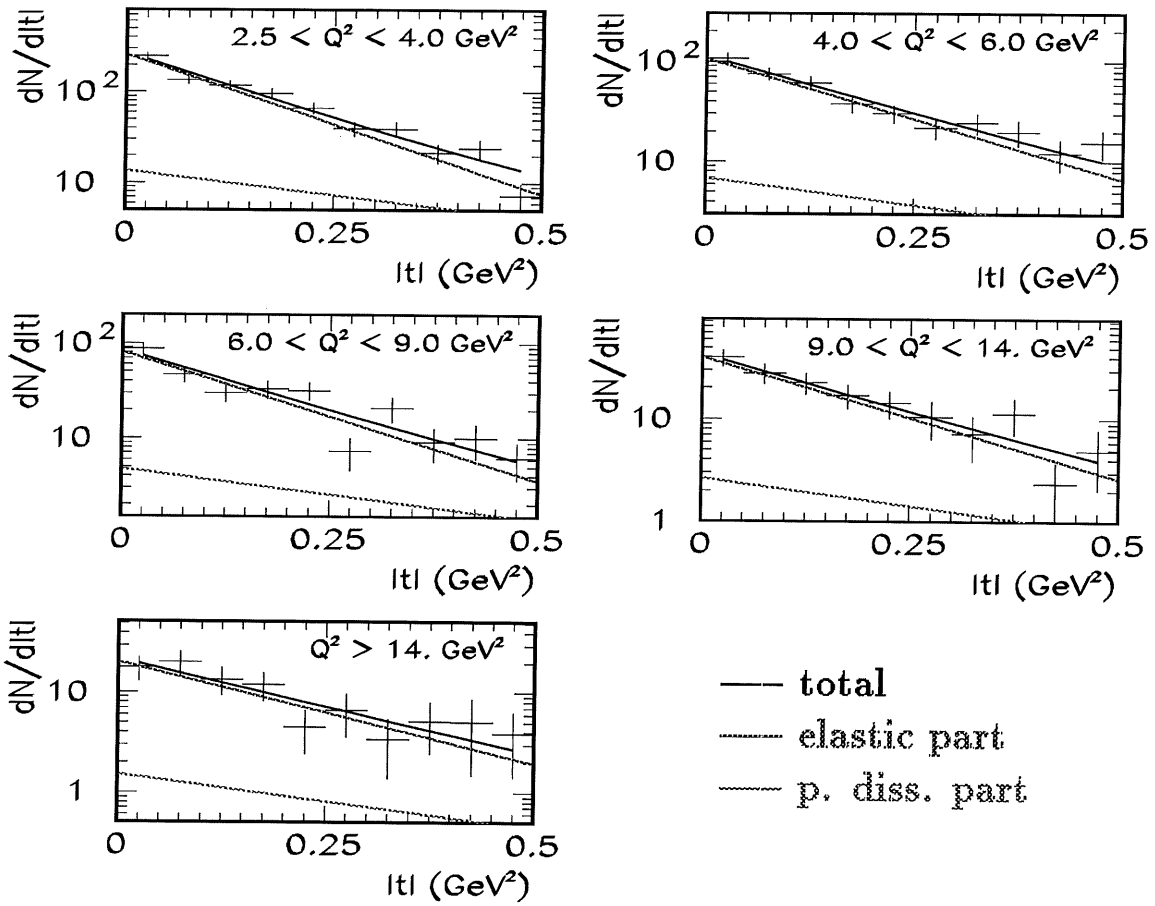
- Ryskin et Shabelsky:

$|A_\rho + A_{n.r.}|^2$, simple pheno. parametrisation

$A_{n.r.} \propto Q^{-8} \rightarrow$ skewing decreases with Q^2

t dependence

M7



$\Rightarrow$ typical diffractive behaviour:

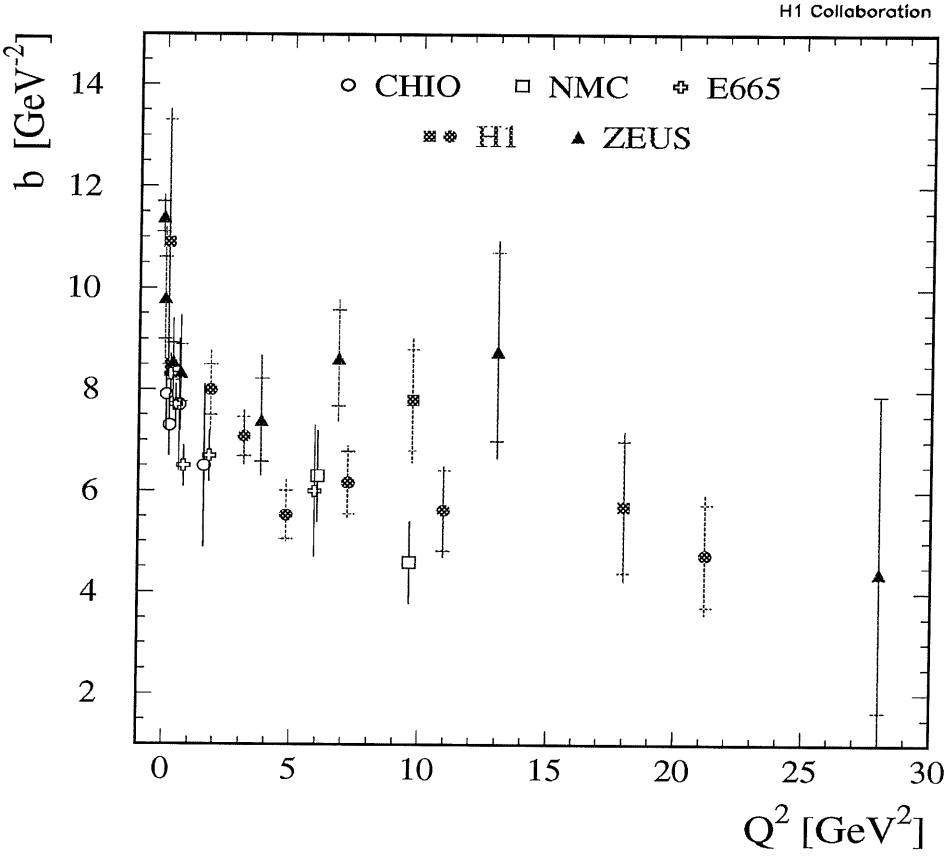
$$\frac{d\sigma}{dt} \propto \mathrm{e}^{-b|t|}$$

$$b \propto R^2_{\{q\bar{q}\}} \oplus R^2_p$$

$$b(Q^2, m_V, W)?$$

ρ prod.

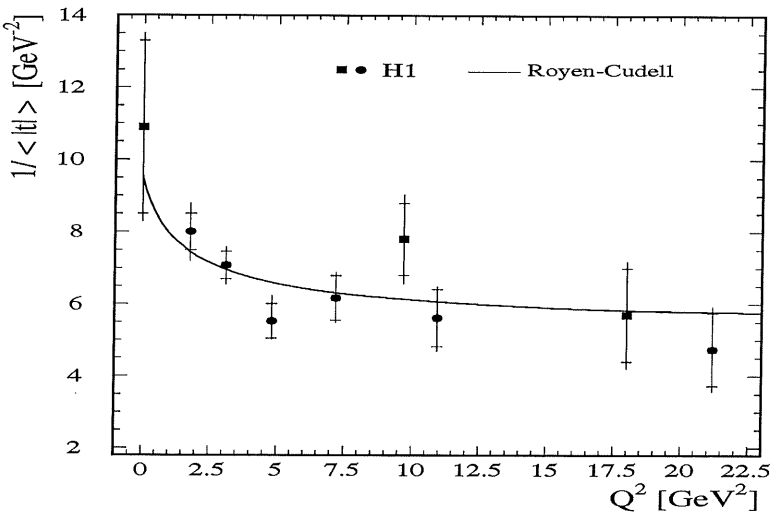
- Q^2 dependence of the b slope:



→ b decreases with increasing Q^2

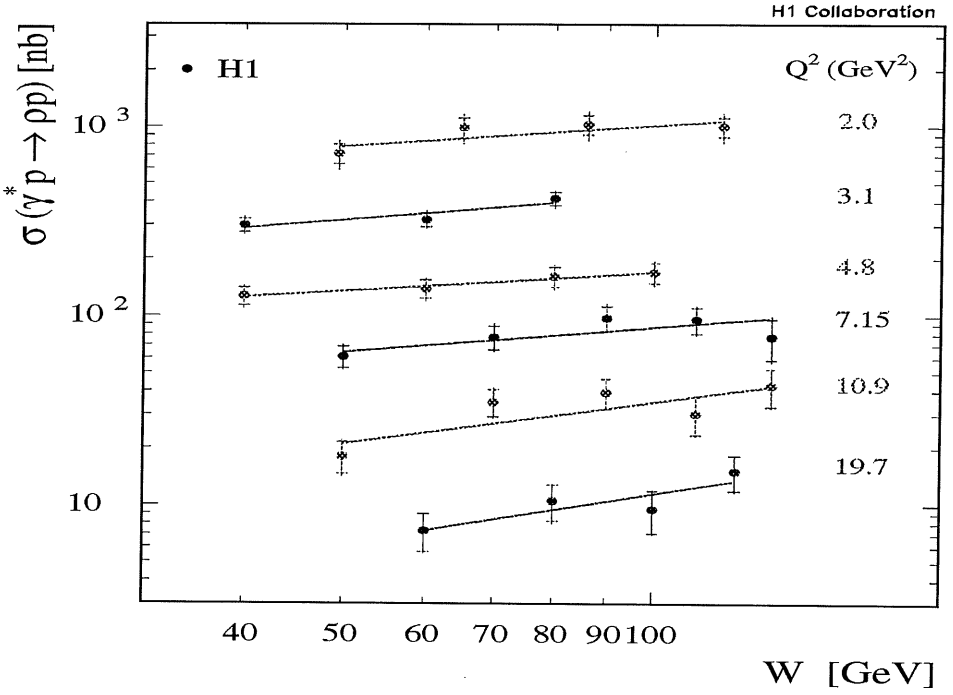
$\{q\bar{q}\}$ system transverse size decreases with Q^2

- Comparison with a pQCD based model:

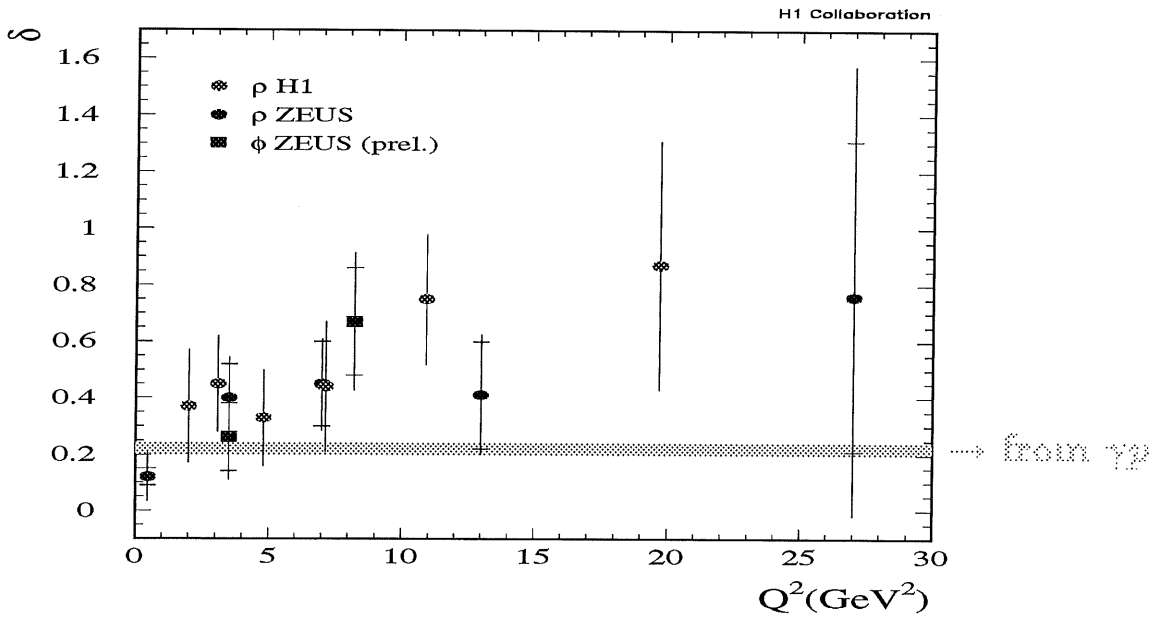


$\sigma(\gamma^* p \to \rho p)$ cross section

- W dependence:



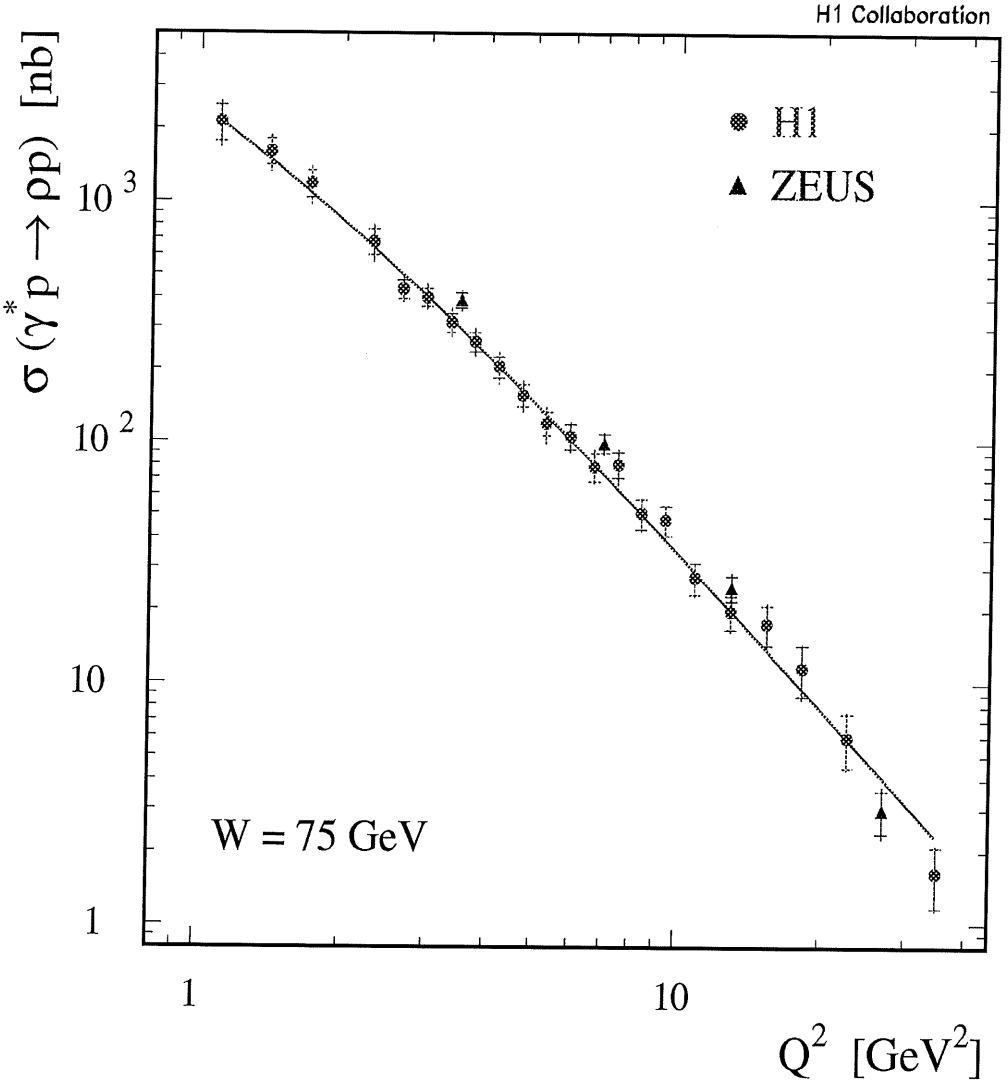
parametrisation: $\sigma \propto W^{\delta}$:



$\Rightarrow$ indication for an increase of δ with Q^2

in agreement with pQCD predictions: $\sigma \sim |xg(x, Q^2)|^2$

- Q^2 dependence:



fit:

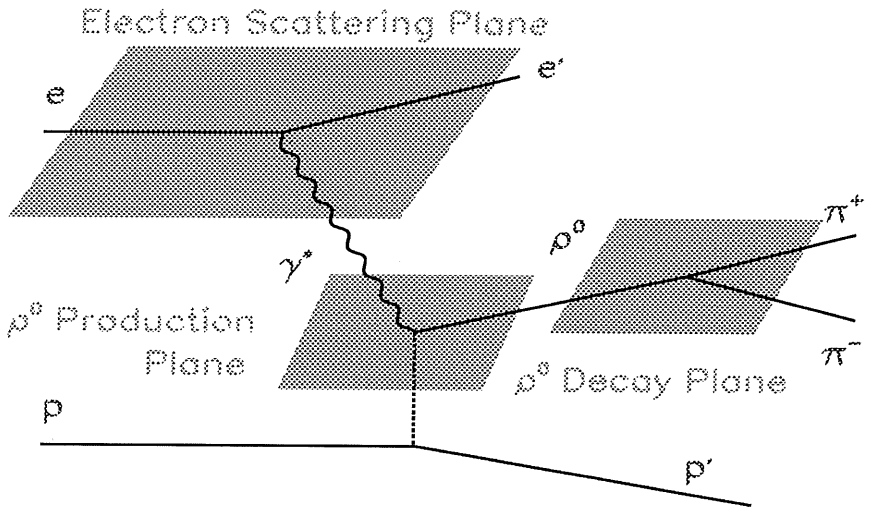
$\sigma \propto (Q^2 + m_\rho^2)^{-n}$

$n = 2.24 \pm 0.09$

$$\text{pQCD} : \sigma \propto \frac{\alpha_s^2(Q^2)}{Q^6} \left| xg(x, Q^2) \right|^2 \propto \frac{\alpha_s^2(Q^2)}{Q^6} (Q^2)^{2\gamma} \propto \frac{\alpha_s^2(Q^2)}{Q^{4.8}}$$

Helicity studies

Decay angle definitions in the helicity frame:



(θ, φ) polar and azimuthal angles of π^+ in ρ c.m.

ϕ angle between scatt. and production planes (had. c.m.)

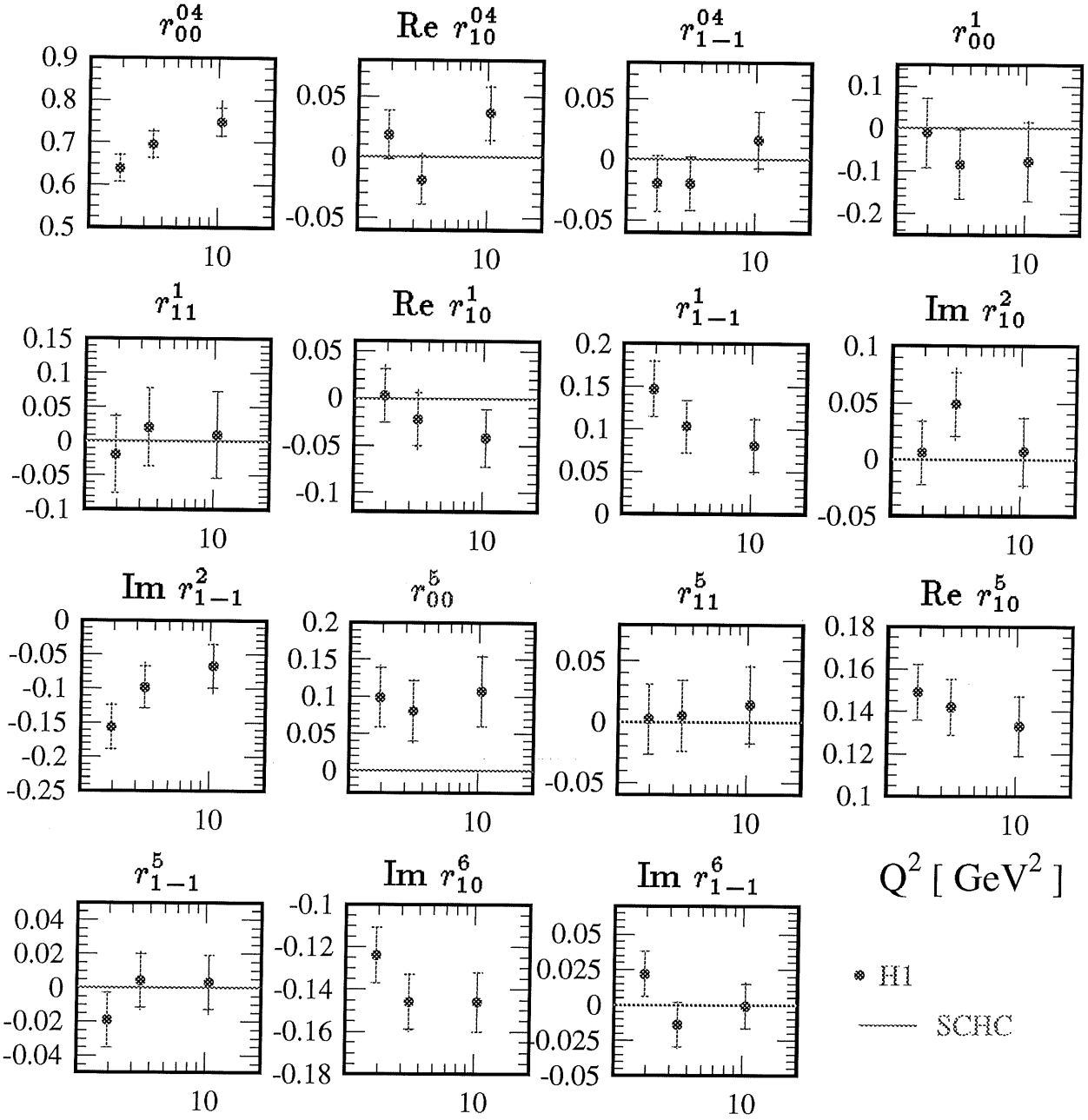
Decay angular distribution $W(\cos\theta, \varphi, \phi)$:

$$
\begin{aligned}
W(\cos\theta,\varphi,\phi) = \frac{3}{4\pi} \Big\{ & \frac{1}{2}(1 - r^{04}_{00}) + \frac{1}{2}(3\, r^{04}_{00} - 1)\, \cos^2\theta \\
& - \sqrt{2}\ \mathrm{Re}\ r^{04}_{10}\ \sin 2\theta \cos\varphi - r^{04}_{1-1}\ \sin^2\theta \cos 2\varphi \\
& - \varepsilon\ \cos 2\phi \left(r^{1}_{11}\ \sin^2\theta + r^{1}_{00}\ \cos^2\theta - \sqrt{2}\ \mathrm{Re}\ r^{1}_{10}\ \sin 2\theta \cos\varphi \right. \\
& \qquad \left. - r^{1}_{1-1}\ \sin^2\theta \cos 2\varphi \right) \\
& - \varepsilon\ \sin 2\phi \left(\sqrt{2}\ \mathrm{Im}\ r^{2}_{10}\ \sin 2\theta \sin\varphi + \mathrm{Im}\ r^{2}_{1-1}\ \sin^2\theta \sin 2\varphi \right) \\
& + \sqrt{2\varepsilon\,(1+\varepsilon)}\ \cos\phi \left[r^{5}_{11}\ \sin^2\theta + r^{5}_{00}\ \cos^2\theta \right. \\
& \qquad \left. - \sqrt{2}\ \mathrm{Re}\ r^{5}_{10}\ \sin 2\theta \cos\varphi - r^{5}_{1-1}\ \sin^2\theta \cos 2\varphi \right] \\
& + \sqrt{2\varepsilon\,(1+\varepsilon)}\ \sin\phi \left[\sqrt{2}\ \mathrm{Im}\ r^{6}_{10}\ \sin 2\theta \sin\varphi \right. \\
& \qquad \left. + \mathrm{Im}\ r^{6}_{1-1}\ \sin^2\theta \sin 2\varphi \right] \Big\}
\end{aligned}
$$

r^{α}_{ik} and $r^{\alpha\beta}_{ik}$ $\Rightarrow$ related to helicity amplitudes $T_{\lambda_\rho \lambda_\gamma}$

$W(\cos\theta, \varphi, \phi)$ $\Rightarrow$ information on γ^* and ρ meson helicities

- Measurement of the 15 matrix elements:

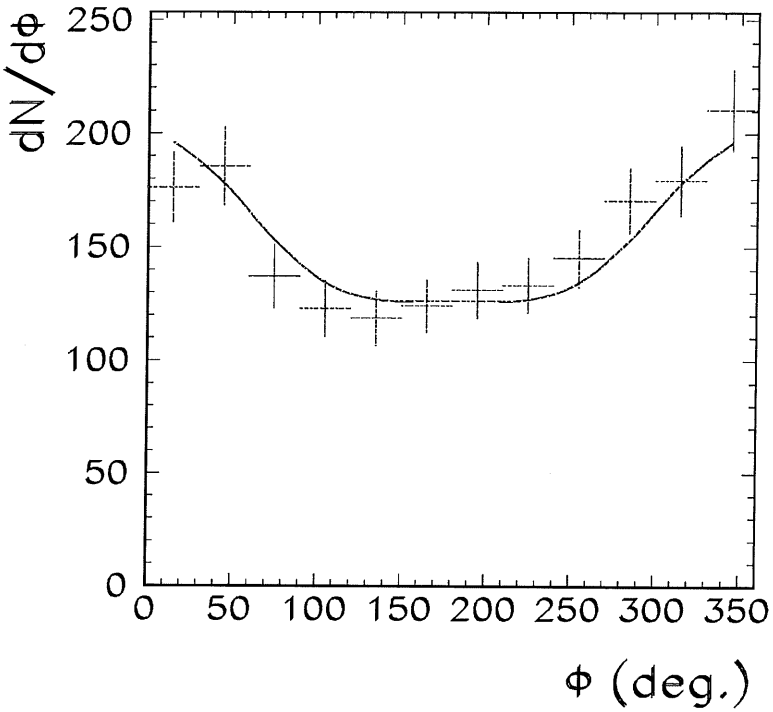


—— = SCHC approx. ($T_{01} = T_{10} = T_{-11} = T_{1-1}$=0)

$\Rightarrow$ measurements in agreement with SCHC, except for r^{5}_{00}

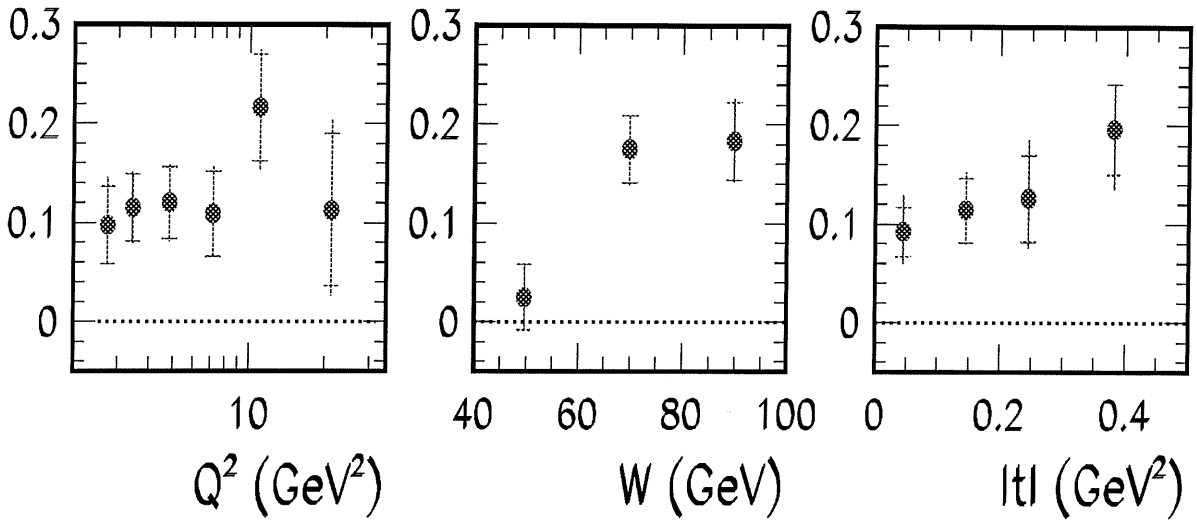
- **Helicity flip amplitude:** $\mathrm{W}(\cos\theta, \varphi, \phi)$

$$W(\phi) \propto 1 - \varepsilon \cos 2\phi \, (2r^1_{11} + r^1_{00}) + \sqrt{2\varepsilon(1+\varepsilon)} \cos\phi \, (2r^5_{11} + r^5_{00})$$



in SCHC approx.:
uniform ϕ distr.

$(2r^5_{11} + r^5_{00})$

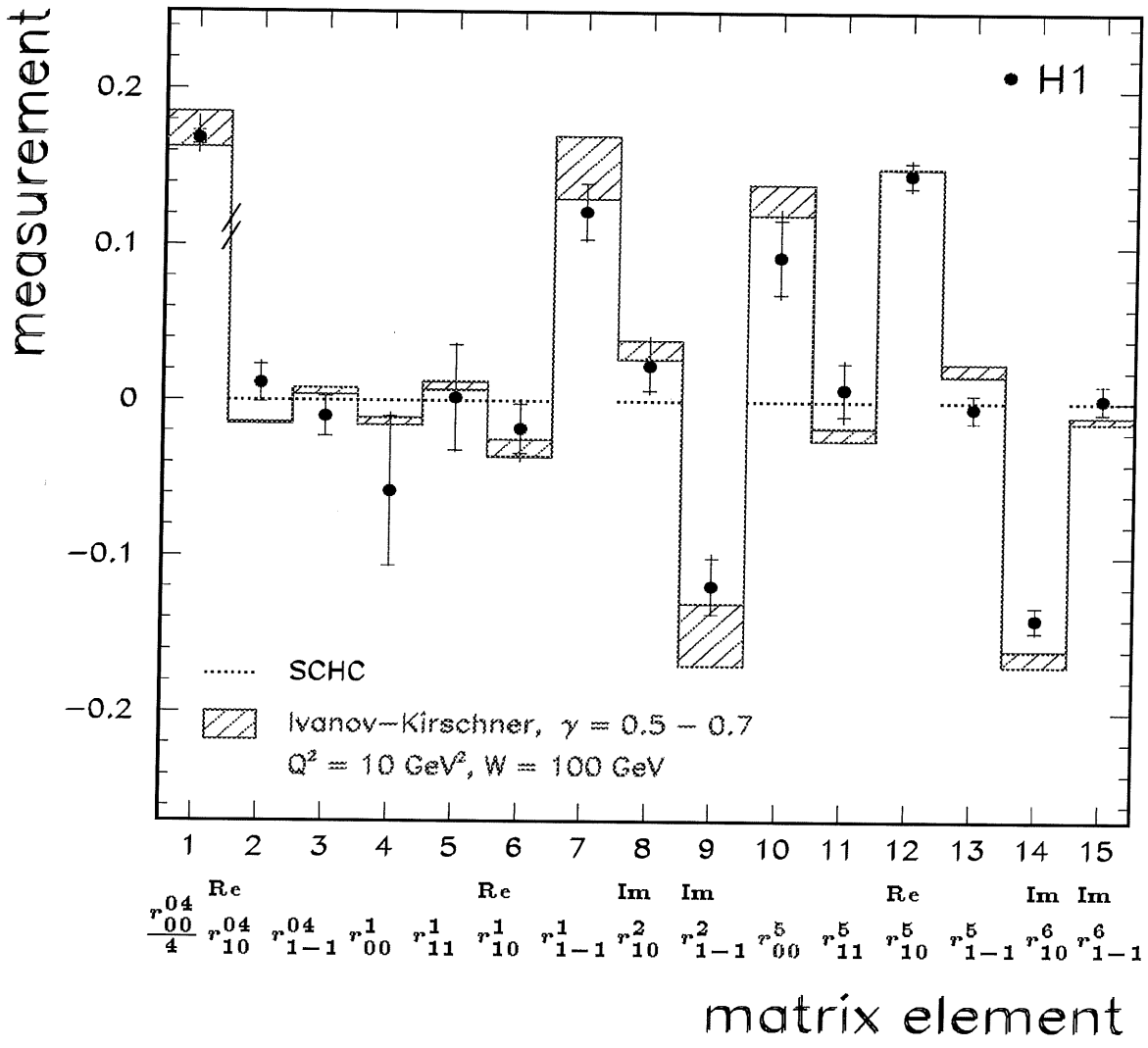


$\Rightarrow$ violation of SCHC

In agreement with pQCD calculations of Ivanov-Kirschner:

$$|T_{00}| > |T_{11}| > |T_{01}| > |T_{10}| > |T_{1-1}| \qquad (T_{\lambda_\rho \lambda_\gamma})$$

$$r^5_{00} \propto T_{01}$$



- Ratio of helicity flip to non helicity flip amplitudes:

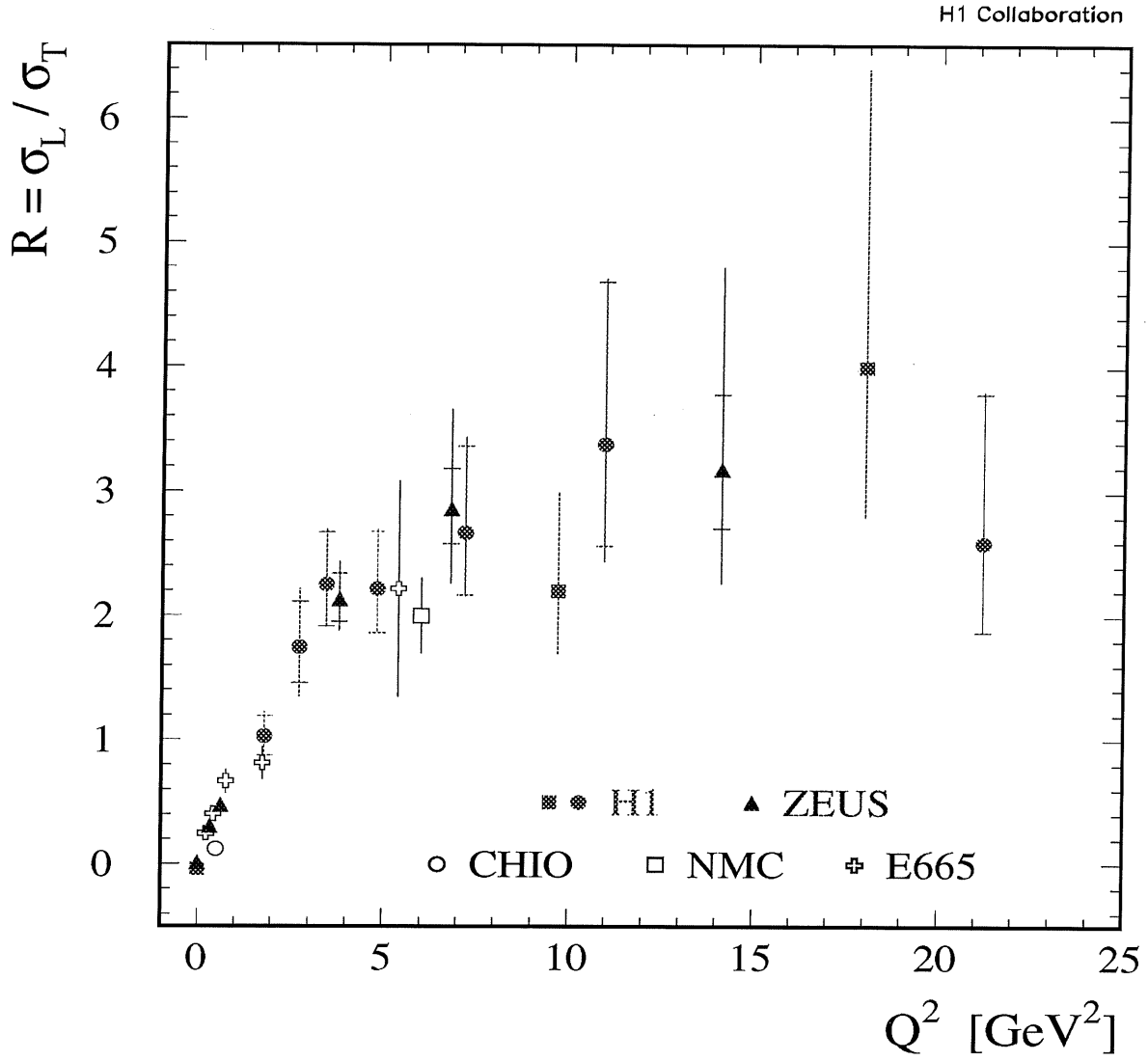
$$\frac{|T_{01}|}{\sqrt{|T_{00}|^2 + |T_{11}|^2}} \simeq r^5_{00} \sqrt{\frac{1+R}{2R}} \simeq 8.0 \pm 3.0\%$$

- Measurement of $R \equiv \sigma_L/\sigma_T$:

$$W(\cos\theta) \propto 1 - r_{00}^{04} + (3\, r_{00}^{04} - 1)\ \cos^2\theta$$

r_{00}^{04}: probability to find the ρ meson longitudinally polarized

In the SCHC approximation: $R = \frac{1}{\varepsilon}\frac{r_{00}^{04}}{1-r_{00}^{04}}$



$\longrightarrow$ R increases with Q^2
and flattening at high Q^2

- Comparison with 3 models :

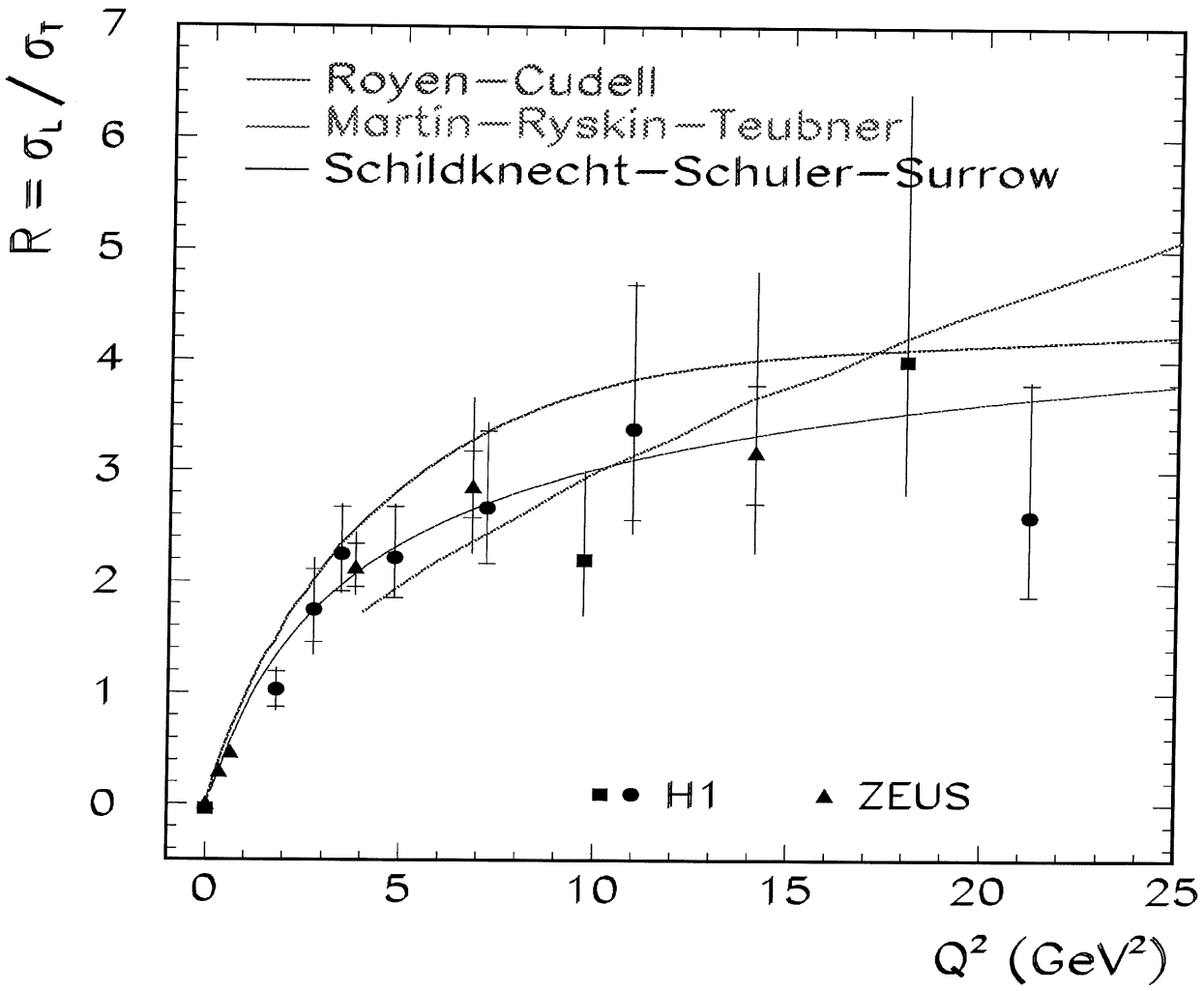
  - based on pQCD:

    - Royen-Cudell model
    - Martin-Ryskin-Teubner model

      $$R \simeq \frac{Q^2}{m_V^2}\left(\frac{\gamma}{\gamma+1}\right)^2$$

  - based on GVDM:

    - Schildknecht-Schuler-Surrow model



Summary

- Precise H1 measurement of elastic ρ production in a wide Q^2 domain
  $\rightarrow$ scan regions between soft and hard processes

- Skewing decreases with Q^2
  still present for $Q^2 \approx 10$ GeV^2

- t dependence: b slope decreases with Q^2
  $b \approx 5$ GeV^{-2} for $Q^2 = 20$ GeV^2

- $\gamma^* p$ cross section increases faster with W at larger Q^2
  $\rightarrow$ Q^2 provides a hard scale in the process
  $\rightarrow$ suggest: hard diffraction dominates for $Q^2 \gtrsim 10$ GeV^2

- Full polarisation study:

  - meas. of 15 matrix elements, study of $\cos\theta$, φ, ϕ dep.
  $\rightarrow$ small but significant breaking of SCHC
  $\rightarrow$ hierarchy: $|T_{00}| > |T_{11}| > |T_{01}| > |T_{10}| > |T_{1-1}|$

  - measurement of $R = \sigma_L/\sigma_T$:
  $\rightarrow$ R increases with Q^2 and $R \approx 3-4$ for $Q^2 = 20$ GeV^2
  $\rightarrow$ well described by: Royen-Cudell, Martin-Ryskin and Teubner, and Schildkecht, Schuler and Surrow models