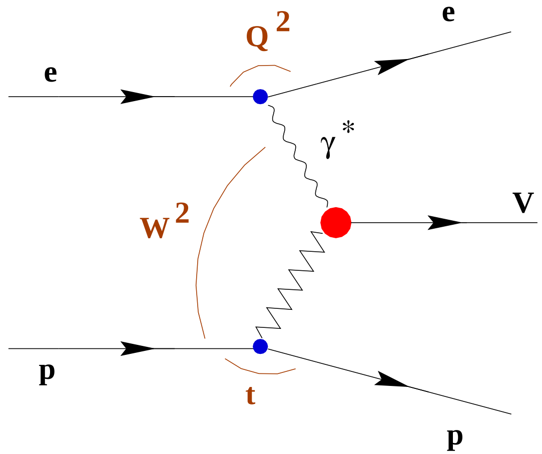
XII WORKSHOP ON HIGH ENERGY SPIN PHYSICS

Dubna, Russia, 04.09.2007

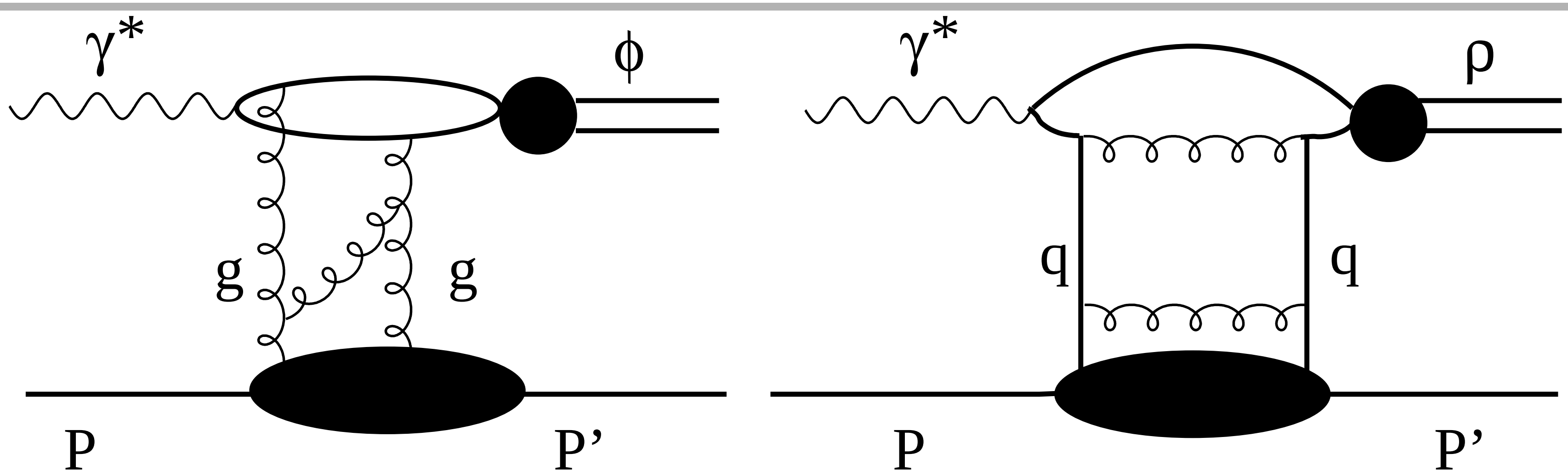
New results on exclusive ρ^0 and ϕ meson production at hermes



- Objectives: Generalized Parton Distributions
- Total and Longitudinal Cross Sections of ρ^0 and ϕ
- ρ^0 and ϕ Meson Spin Density Matrix Elements
  - Longitudinal-to-Transverse Cross-Section Ratios
  - Kinematic dependences
  - Hierarchy of Helicity Amplitudes
  - Unnatural Parity Exchange
- Beam and target polarization asymmetries
- Summary and Outlook

Alexander Borissov, DESY, on behalf of HERMES Collaboration

Test of GPDs via Exclusive Vector Meson Production



Properties of ρ^0 and ϕ meson data:

- different pQCD production mechanisms:
  - only two-gluon exchange for ϕ,
  - both two-gluon and quark exchanges for ρ^0

  $\longrightarrow$ GPDs as a flavor filter

- quark exchange mediated by
  - vector or scalar meson: ρ^0, ω, a_2 (natural parity: $J^P = 0^+, 1^-$)
    $\longrightarrow$ unpolarized GPDs: H, E
  - pseudoscalar or axial meson: π, a_1, b_1 (unnatural parity $J^P = 0^-, 1^+$)
    $\longrightarrow$ polarized GPDs: $\tilde{H}$, $\tilde{E}$

Experimental observables:

- total and logitudinal cross sections σ_{tot}, σ_L

- Spin Density Matrix Elements (SDMEs):
  $r^{\alpha}_{\lambda_\rho \lambda'_\rho} \sim \rho(V) = \frac{1}{2} T \rho(\gamma) T^+$
  vector meson spin-density matrix $\rho(V)$ via photon matrix $\rho(\gamma)$ and helicity amplitude $T_{\lambda_V \lambda_\gamma}$
  - *s-channel helicity conservation (SCHC)?* i.e. helicity of γ^* = helicity of ρ^0
  - Extracted from SDMEs natural and unnatural parity *helicity amplitudes and its ratios*

- Beam and target polarization asymmetries

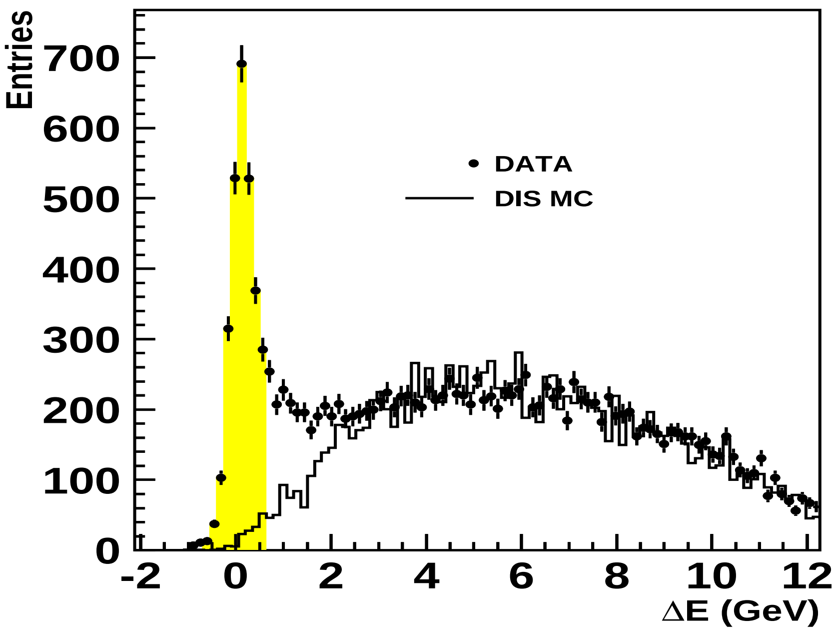
$\Longrightarrow$ **Comparison with GK model of GPDs:** *talk of S.V.Goloskokov,* **arXiv:0708.3569 hep-ph 27.08.07**

Exclusive ρ^0 and ϕ Meson Production

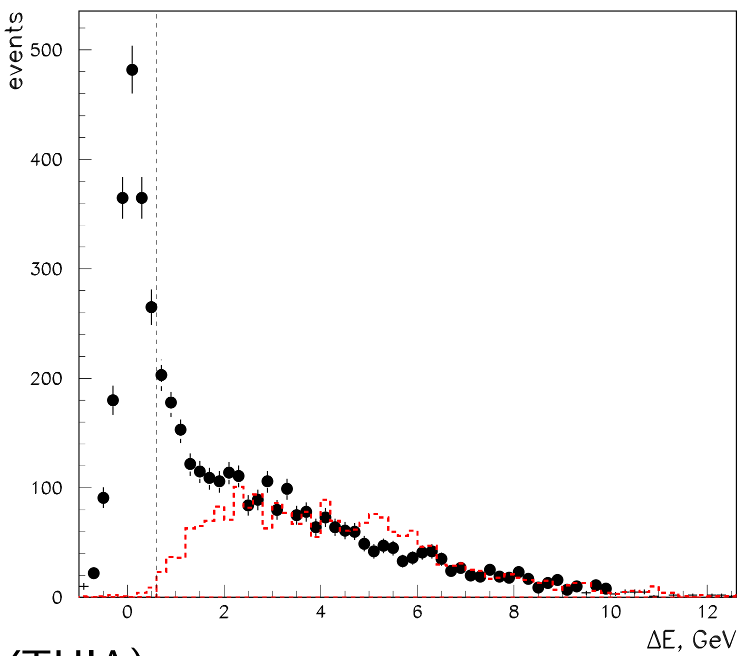
$$e + p \rightarrow e' + p' + \rho^0 \rightarrow \pi^+\pi^- \qquad e + p \rightarrow e' + p' + \phi \rightarrow K^+K^-$$

Clean ρ^0 exclusivity peaks of missing energy $\Delta E = \frac{M_X^2 - M_p^2}{2M_p}$ for

ρ^0



ϕ



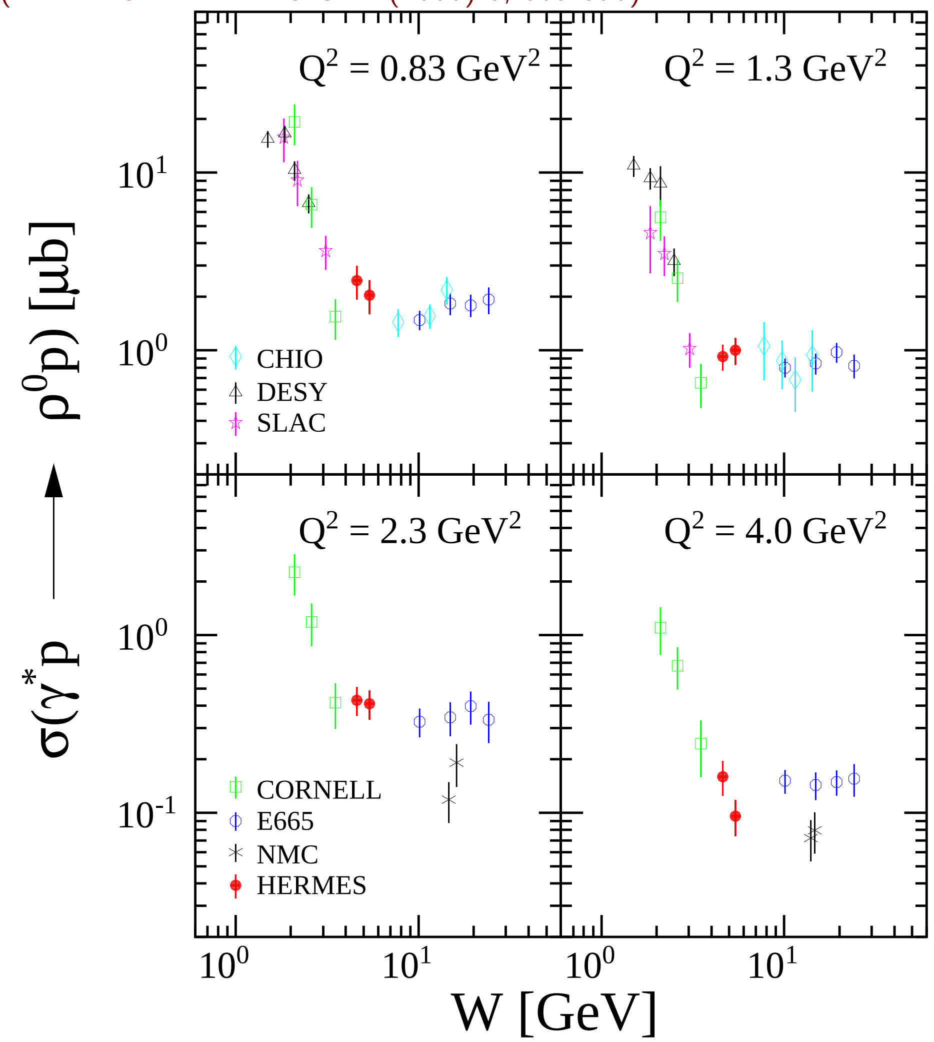
Background is subtracted using MC (PYTHIA)

Kinematics:

- $\nu = 5 \div 24$ GeV, $< \nu >= 13.3$ GeV, $Q^2 = 0.5 \div 7.0$ GeV^2,$< Q^2 >= 2.3$ GeV^2
- $W = 3.0 \div 6.5$ GeV, $< W >= 4.9$ GeV, $x_{Bj} = 0.01 \div 0.35$,$< x_{Bj} >= 0.07$
- $t' = 0 \div 0.4$ GeV^2, $< t' > = 0.13$ GeV^2

ρ^0 Total and Longitudinal Cross Sections, application of GPDs

(HERMES collab. EPJ C 17 (2000) 3, 389-398).



→ HERMES data in the transition region

→ which production mechanisms are involved?

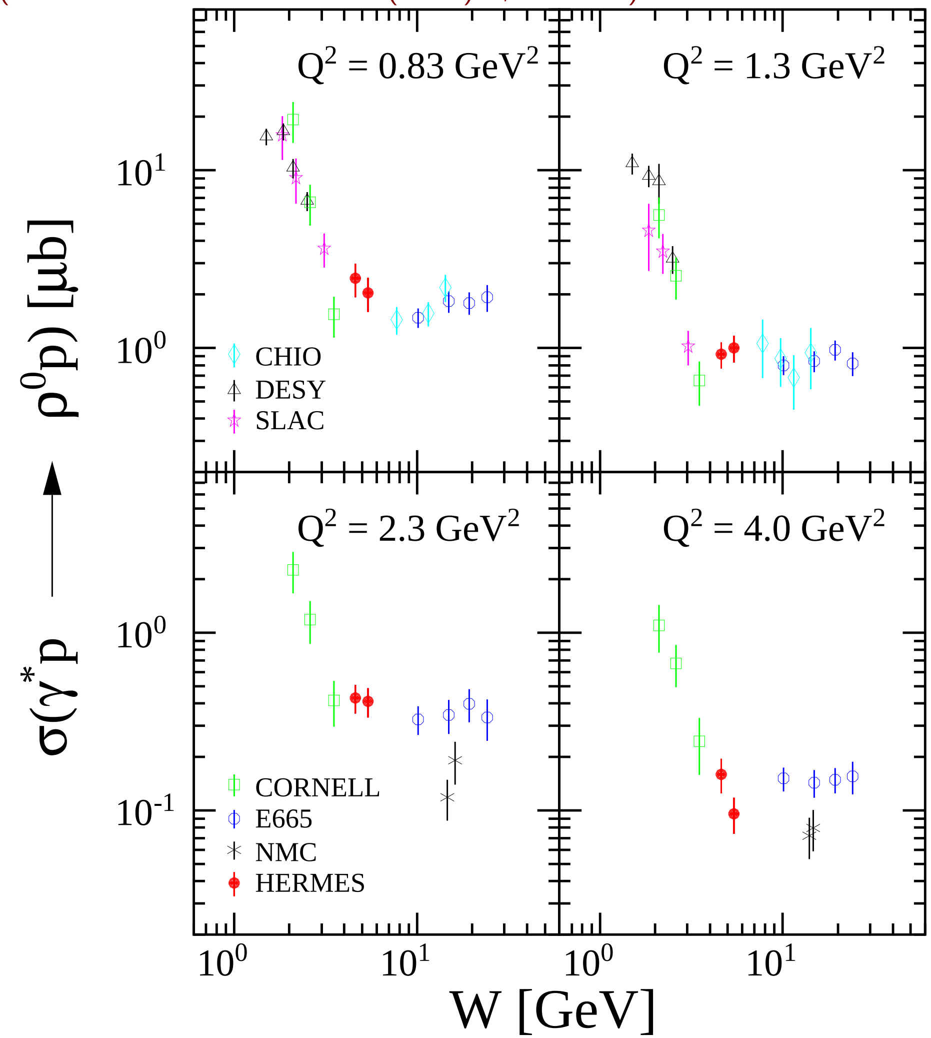
- The QCD factorization theorem is proven for the longitudinal part of the cross section J.Collins,L.L.Frankfurt,M.Strikman Phys.Rev.D**56**,2982 (1997);
- assuming SCHC:
  $\sigma_L = \frac{R}{1+\epsilon R}\sigma_{tot}$,
  where $R = \sigma_L/\sigma_T = \frac{r^{04}_{00}}{\epsilon(1-r^{04}_{00})}$
  - SDME r^{04}_{00} is measured from the fit of angular distributions (explained below)
  - longitudinal-to-transverse ratio of virtual photon fluxes

$$\epsilon = \frac{1 - y - \frac{Q^2}{E^2}}{1 - y + \frac{y^2}{2} + \frac{Q^2}{E^2}} \approx 0.8$$

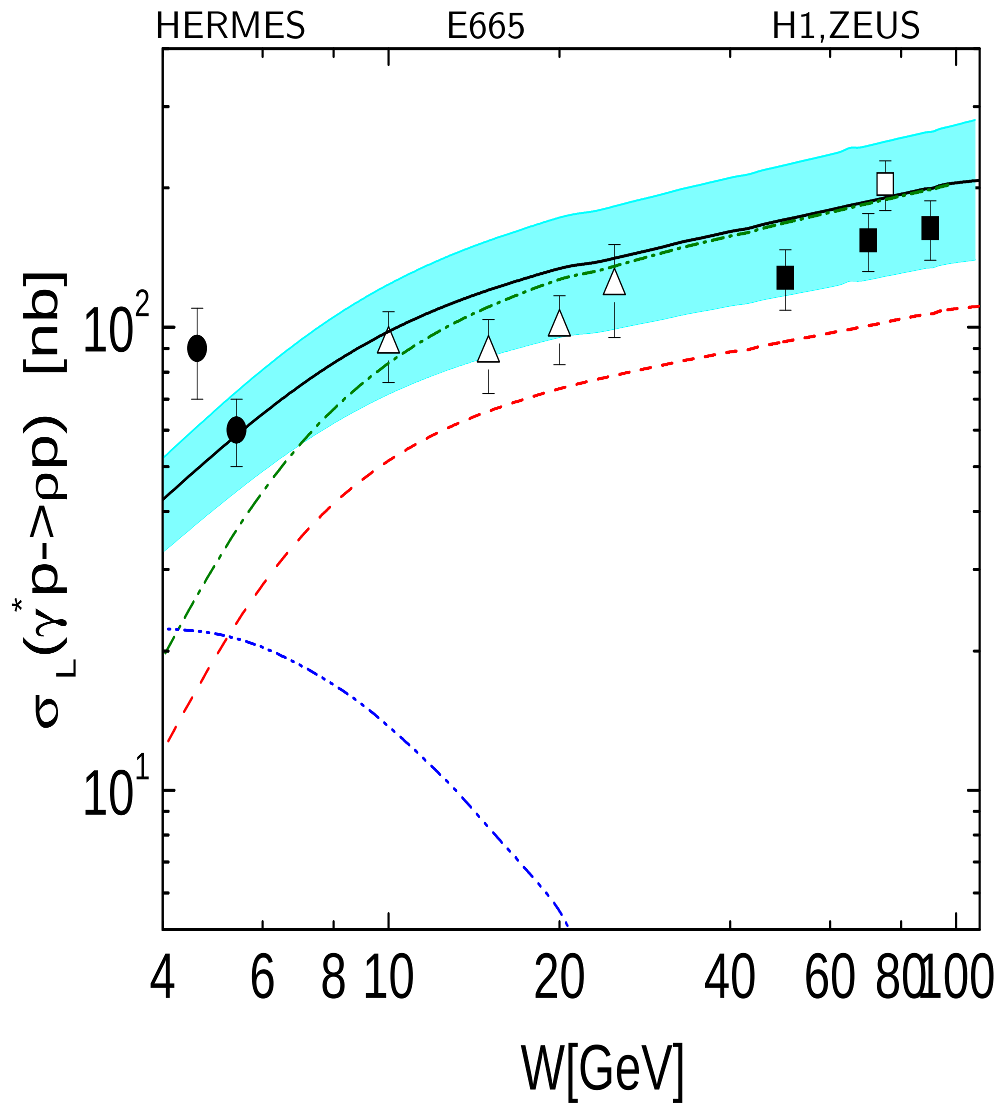
$\Longrightarrow$ σ_L for the tests of GPDs

ρ^0 Total and Longitudinal Cross Sections, and GK Model

(HERMES collab. EPJ C 17 (2000) 3, 389-398).



S.V.Goloskokov, hep-ph/0611290.



→ HERMES data in the transition region

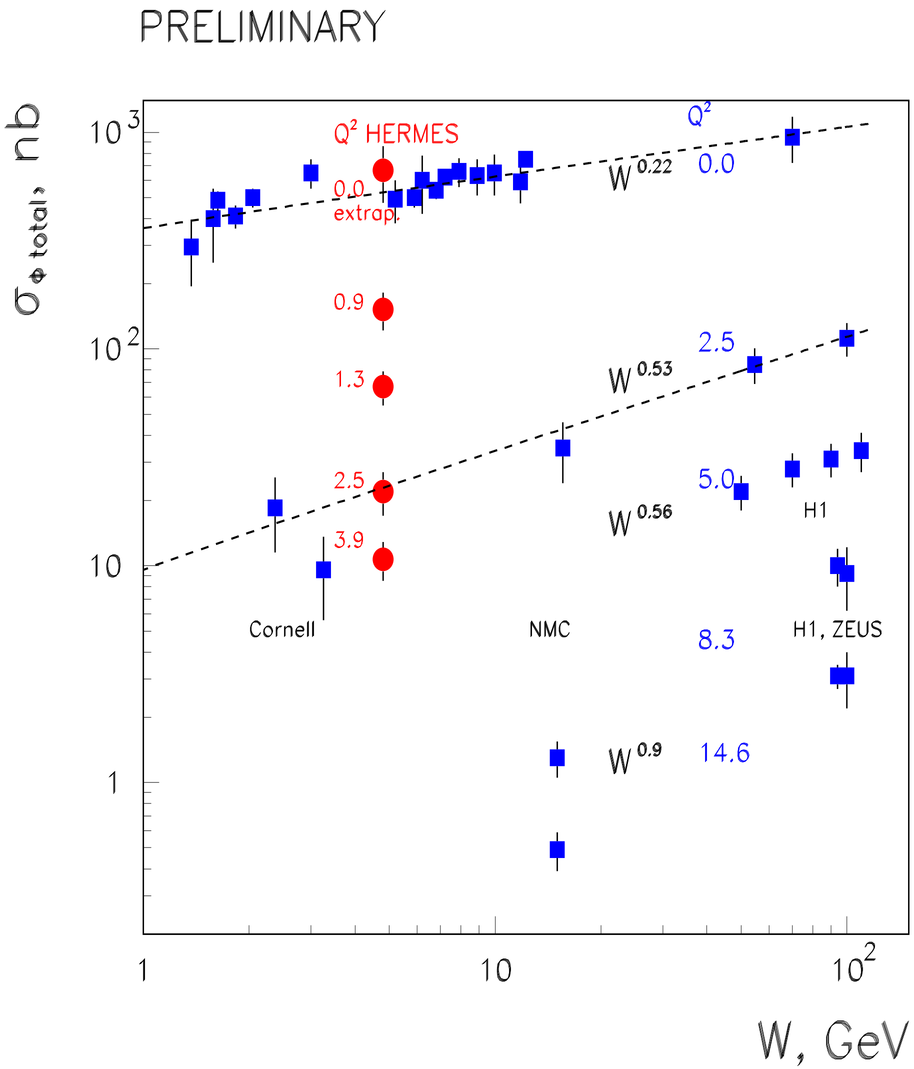
→ which production mechanisms are involved?

two-gluon exchange,two-gluon+sea interference,quark exchange,sum

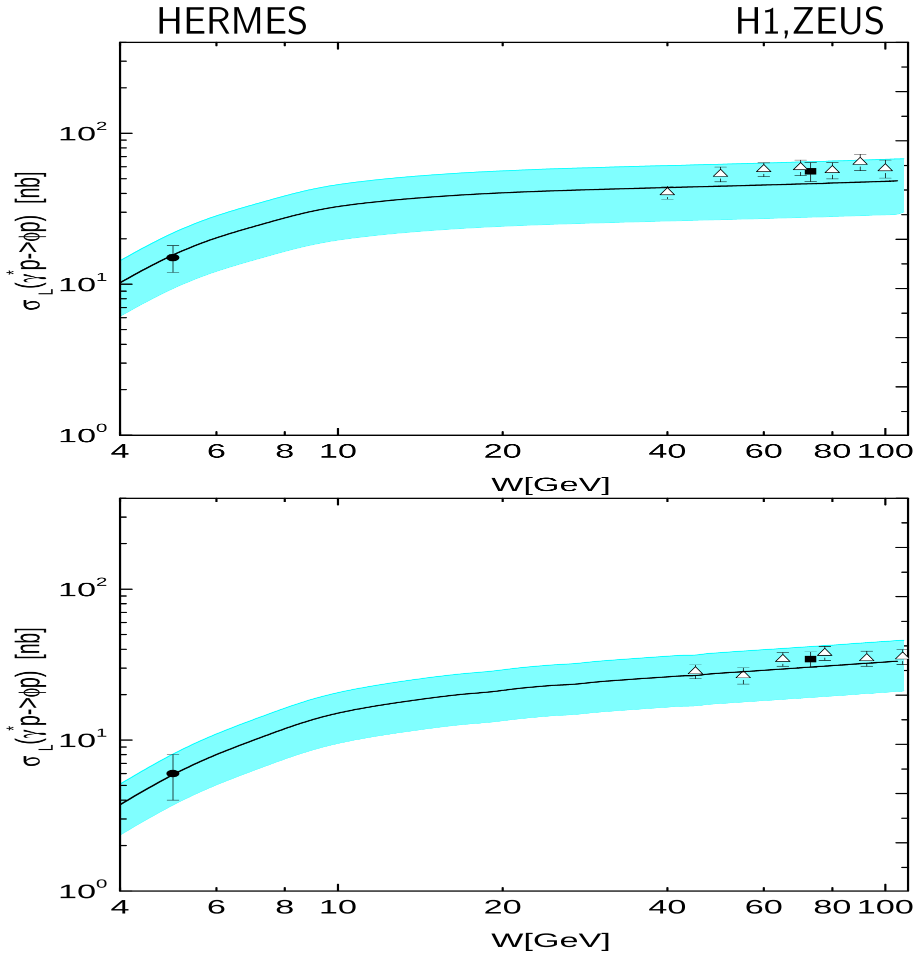
Band represents uncertainties in σ_L from Parton Distributions

$\Longrightarrow$ Quark exchange is important for HERMES, i.e. at $W \leq 5$ GeV

ϕ Total and Longitudinal Cross Sections, and GK model



S.V.Goloskokov,P.Kroll,Eur.Phys.J. C 42,2005; hep-ph/0611290



$\rightarrow W^{\delta_\phi(Q^2)}$ dependence over all W

$\delta_\phi = 0.22$ at $Q^2 = 0$, $\delta_\phi = 0.53$ at $Q^2 = 2.5$ GeV^2

$\rightarrow$ Two-gluon exchange is sufficient for σ^{ϕ}_{tot}

$\sigma_{L(\phi)}$: two-gluon exchange only

Band represents uncertainties in σ_L from Parton Distributions

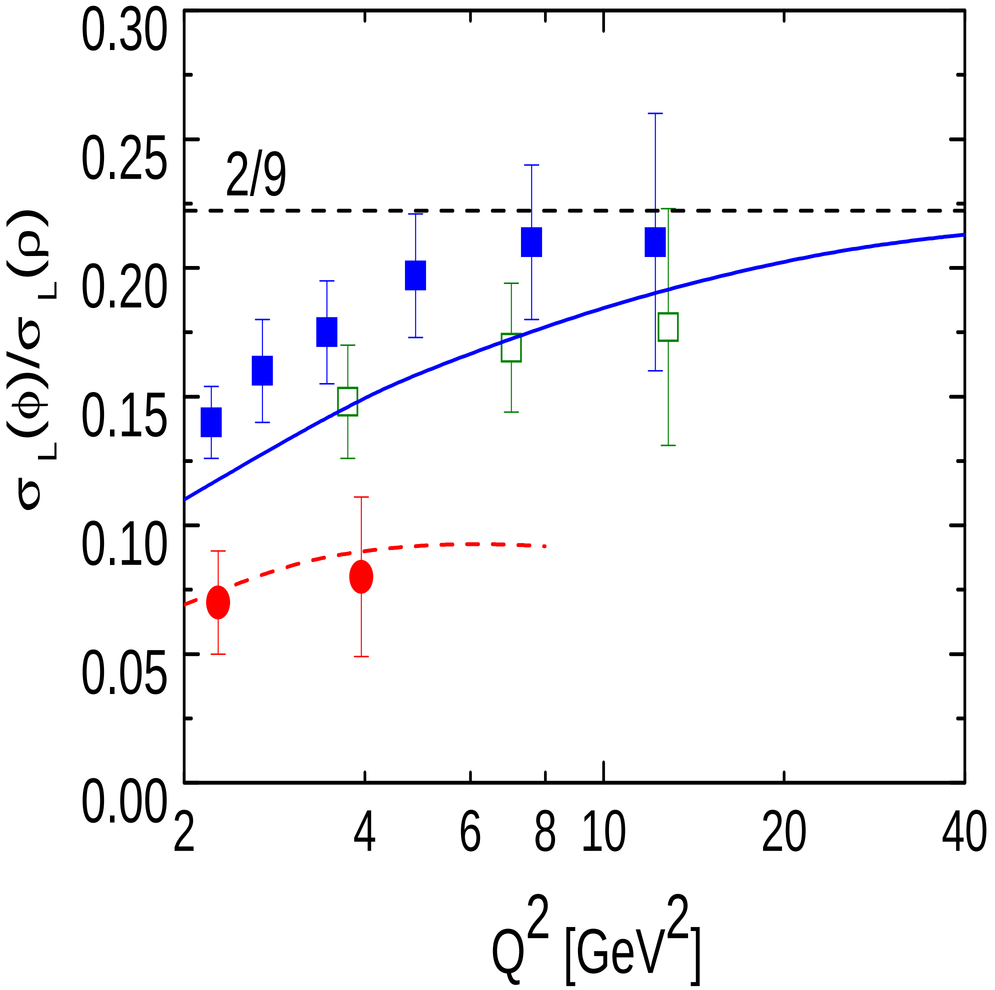
$\rightarrow$ Good agreement of GK model calculations of $\sigma_L(W)$ at $Q^2 = 2.3, 3.8$ GeV^2.

$\Longrightarrow$ **Two-gluon exchange is sufficient to describe σ_L in ϕ-meson production**

Longitudinal Cross Section Ratios: $\sigma_{L(\phi)}/\sigma_{L(\rho^o)}$

Asymptotic SU(4) pQCD predicts: $\rho^o : \omega : \phi : J/\Psi = 9 : 1 : 2 : 8$

S.V.Goloskokov,P.Kroll,Eur.Phys.J. C 42,2005; hep-ph/0611290



W=75 GeV (H1,ZEUS), W=5 GeV (HERMES)

$\longrightarrow$ Remarkable agreement of calculations with W-dependence of $\sigma_{L(\phi)}/\sigma_{L(\rho^o)}$ ratio

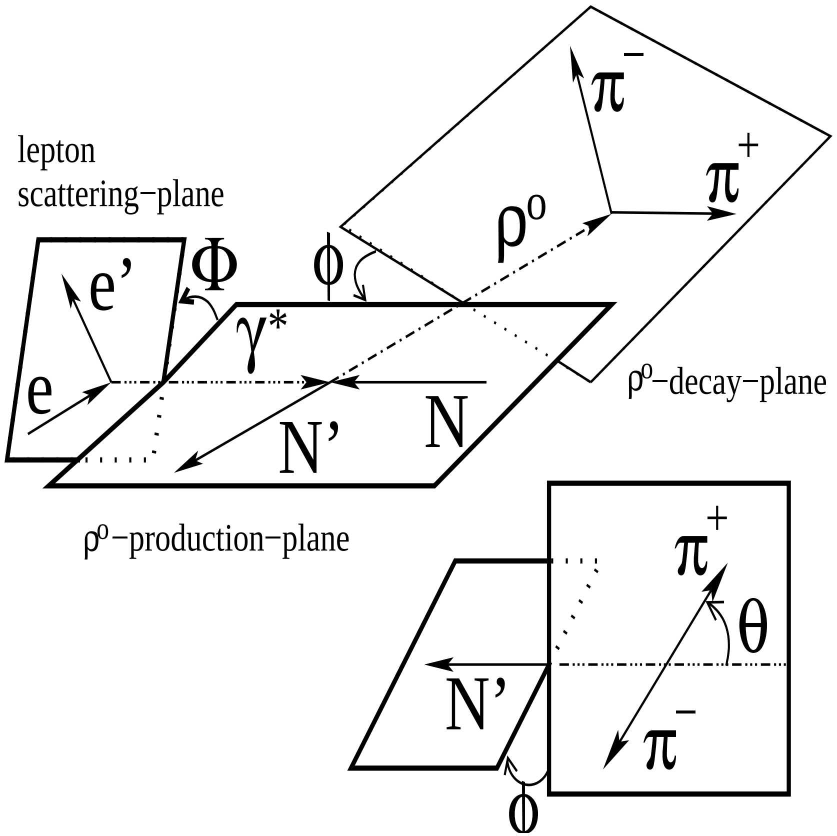
ρ^0 & ϕ-meson Spin Density Matrix Elements (SDMEs)

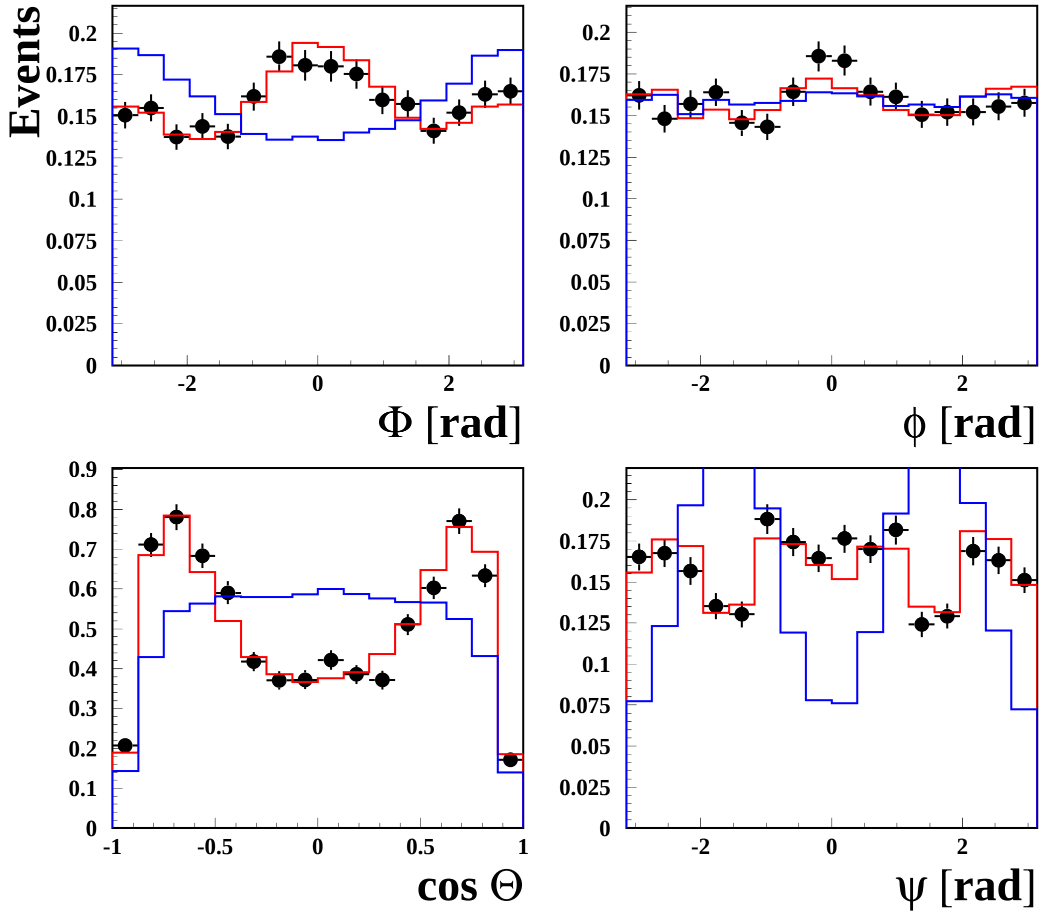
- $\gamma^* + N \to \rho^0(\phi) + N'$ is perfect to study the spin structure of production mechanism:
  - spin state of γ^* is known
  - $\rho^0 \to \pi^+\pi^-$ decay is self-analysing

- SDMEs: $r^{\alpha}_{\lambda_\rho \lambda'_\rho} \sim \rho(V) = \frac{1}{2} T_{\lambda_V \lambda_\gamma} \rho(\gamma) T^+_{\lambda_V \lambda_\gamma}$
  spin-density matrix of the vector meson $\rho(V)$ in terms of the photon matrix $\rho(\gamma)$ and helicity amplitude $T_{\lambda_V \lambda_\gamma}$
  - presented according K.Schilling and G.Wolf (Nucl. Phys. B61 (1973) 381)
    $\alpha = 04, 1-3, 5-8$ long. or trans. photon, $\lambda_\rho = -1, 0, 1$ - polarization of $\rho^0(\phi)$
  - measured experimentally at $5 < W < 75$ GeV (HERMES,COMPASS,H1,ZEUS)
  - compared with ones calculated in GK GPD model at $W = 5$ GeV, $Q^2 = 3$ GeV^2
    (*talk of S.V. Goloskokov,* S.V.Goloskokov,P.Kroll arXiv:0708.3569 [hep-ph] 27.08.07; Eur.Phys.J. C 50,829 (2007) hep-ph/0601290; Eur.Phys.J. C 42,281 (2005) hep-ph/0501242)
  - provide access to *helicity amplitudes* $T_{\lambda_V \lambda_\gamma}$, which are:
    - ∗ extracted experimentally from SDMEs
    - ∗ calculated from GPDs

$\Longrightarrow$ **Constraints and detailed tests of GPDs**

Fit of Angular Distributions Using Max. Likelihood Method in MINUIT





- Simulated Events: matrix of fully reconstructed MC events at initial uniform angular distribution

- Binned Maximum Likelihood Method: $8 \times 8 \times 8$ bins of $\cos(\Theta)$, ϕ, Φ. Simultaneous fit of 23 SDMEs $r^{\alpha}_{ij} = W(\Phi, \phi, \cos\Theta)$ for data with negative and positive beam helicity ($<|P_b|>= 53.5\%$, $\Psi = \Phi - \phi$)

$\Longrightarrow$ **Full agreement of fitted angular distributions with data**

Function for the Fit of 23 SDME r_{ij}^{α}

$$W(\cos\Theta,\phi,\Phi) = W^{unpol} + W^{long.pol},$$

$$W^{unpol}(\cos\Theta,\phi,\Phi) = \frac{3}{8\pi^2}\Bigg[\frac{1}{2}(1-r_{00}^{04}) + \frac{1}{2}(3r_{00}^{04}-1)\cos^2\Theta - \sqrt{2}\mathrm{Re}\{\mathrm{r}_{10}^{04}\}\sin 2\Theta\cos\phi - \mathrm{r}_{1-1}^{04}\sin^2\Theta\cos 2\phi$$

$$- \epsilon\cos 2\Phi\Big(r_{11}^{1}\sin^2\Theta + r_{00}^{1}\cos^2\Theta - \sqrt{2}\mathrm{Re}\{\mathrm{r}_{10}^{1}\}\sin 2\Theta\cos\phi - \mathrm{r}_{1-1}^{1}\sin^2\Theta\cos 2\phi\Big)$$

$$- \epsilon\sin 2\Phi\Big(\sqrt{2}\mathrm{Im}\{\mathrm{r}_{10}^{2}\}\sin 2\Theta\sin\phi + \mathrm{Im}\{\mathrm{r}_{1-1}^{2}\}\sin^2\Theta\sin 2\phi\Big)$$

$$+ \sqrt{2\epsilon(1+\epsilon)}\cos\Phi\Big(r_{11}^{5}\sin^2\Theta + r_{00}^{5}\cos^2\Theta - \sqrt{2}\mathrm{Re}\{\mathrm{r}_{10}^{5}\}\sin 2\Theta\cos\phi - \mathrm{r}_{1-1}^{5}\sin^2\Theta\mathrm{cos}2\phi\Big)$$

$$+ \sqrt{2\epsilon(1+\epsilon)}\sin\Phi\Big(\sqrt{2}\mathrm{Im}\{\mathrm{r}_{10}^{6}\}\sin 2\Theta\sin\phi + \mathrm{Im}\{\mathrm{r}_{1-1}^{6}\}\sin^2\Theta\sin 2\phi\Big)\Bigg],$$

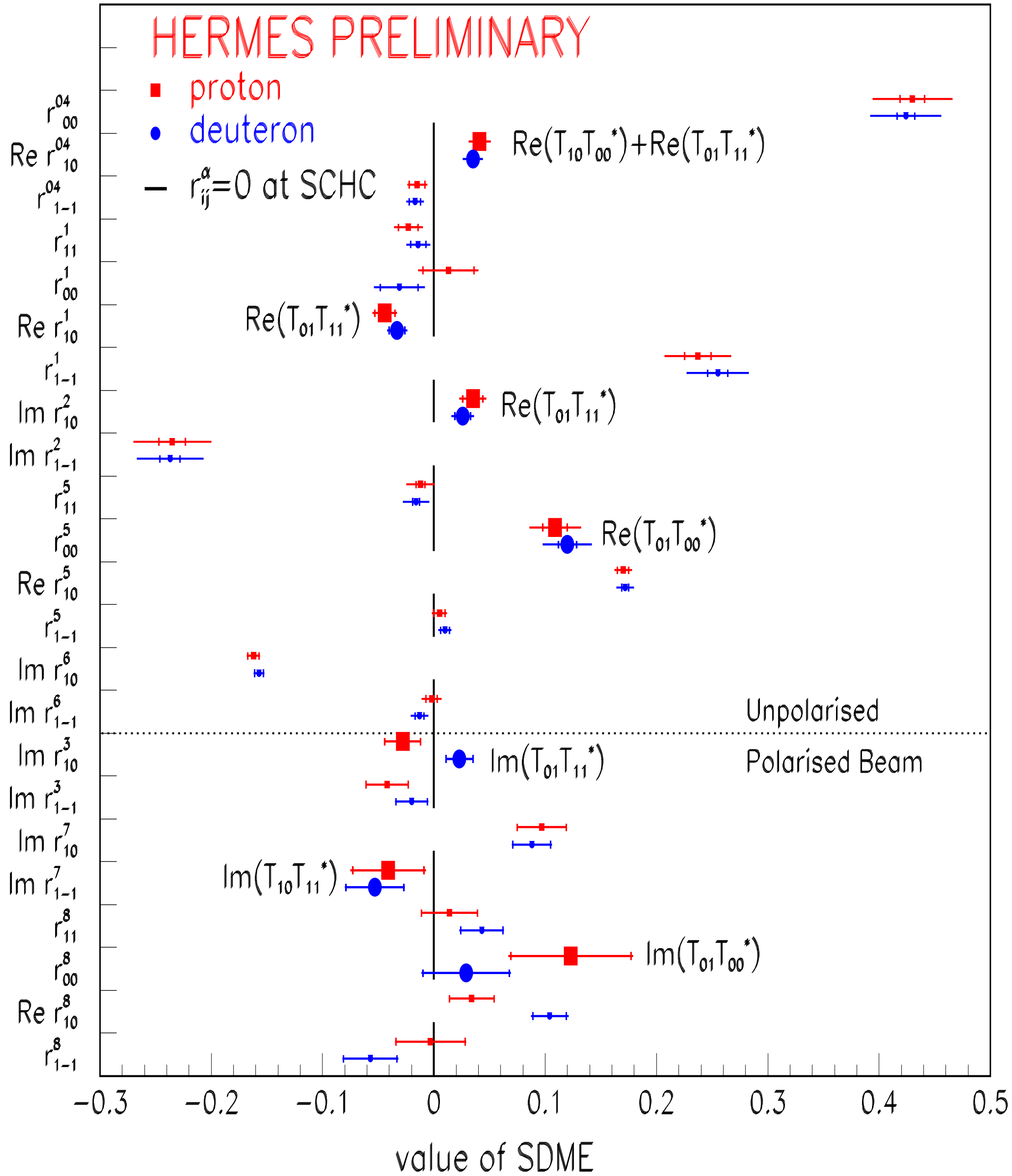
$$W^{long.pol.}(\cos\Theta,\phi,\Phi) = \frac{3}{8\pi^2}P_{beam}\Bigg[\sqrt{1-\epsilon^2}\Big(\sqrt{2}\mathrm{Im}\{\mathrm{r}_{10}^{3}\}\sin 2\Theta\sin\phi + \mathrm{Im}\{\mathrm{r}_{1-1}^{3}\}\sin^2\Theta\sin 2\phi\Big)$$

$$+ \sqrt{2\epsilon(1-\epsilon)}\cos\Phi\Big(\sqrt{2}\mathrm{Im}\{\mathrm{r}_{10}^{7}\}\sin 2\Theta\sin\phi + \mathrm{Im}\{\mathrm{r}_{1-1}^{7}\}\sin^2\Theta\sin 2\phi\Big)$$

$$+ \sqrt{2\epsilon(1-\epsilon)}\sin\Phi\Big(r_{11}^{8}\sin^2\Theta + r_{00}^{8}\cos^2\Theta - \sqrt{2}\mathrm{Re}\{\mathrm{r}_{10}^{8}\}\sin 2\Theta\cos\phi - \mathrm{r}_{1-1}^{8}\sin^2\Theta\cos 2\phi\Big)\Bigg]$$

ρ^0 23 Spin Density Matrix Elements

at $0 < t' < 0.4$ GeV^2 and $1 < Q^2 < 5$ GeV^2



- SDMEs: $r^{\alpha}_{\lambda_\rho \lambda'_\rho} \sim \rho(V) = \frac{1}{2} T \rho(\gamma) T^+$
  $\Longrightarrow$ Beam-polarization dependent SDMEs measured for the first time

- $q\bar{q}$-exchange with isospin 1 can be observed in case of difference between proton and deuteron data,
  $\Longrightarrow$ No significant difference between proton and deuteron, as well as for ϕ meson SDMEs

- SCHC?

$\Longrightarrow$ **Enlarged** SDMEs are violating SCHC $(2 \div 5 \ \sigma)$. Indication on hierarchy of non-zero spin-flip amplitudes: T_{01}, T_{10}, T_{1-1}

SDMEs According to Hierarchy of Amplitudes with(out) Helicity Flip: ρ^0 ϕ

- A, $\gamma^*_L \to \rho^0_L$ and $\gamma^*_T \to \rho^0_T$

  $|T_{11}|^2 \propto 1 - r^{04}_{00} \propto r^1_{1-1} \propto -Im\{r^2_{1-1}\}$

- B, Interference: γ^*_L, ρ^0_T

  $Re\{T_{00}T^*_{11}\} \propto Re\,\{r^5_{10}\} \propto -Im\{r^6_{10}\}$

  $Im\{T_{11}T^*_{00}\} \propto Im\{r^7_{10}\} \propto Re\{r^8_{10}\}$

- C, Spin Flip: $\gamma^*_T \to \rho^0_L$

  $Re\{T_{11}T^*_{01}\} \propto Re\{r^{04}_{10}\} \propto Re\{r^1_{10}\} \propto Im\{r^2_{10}\}$

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

  $|T_{01}|^2 \propto r^1_{00}$

  $Im\{T_{01}T^*_{11}\} \propto Im\{r^3_{10}\}$

  $Im\{T_{01}T^*_{00}\} \propto r^8_{00}$

- D, Spin Flip: $\gamma^*_L \to \rho^0_T$

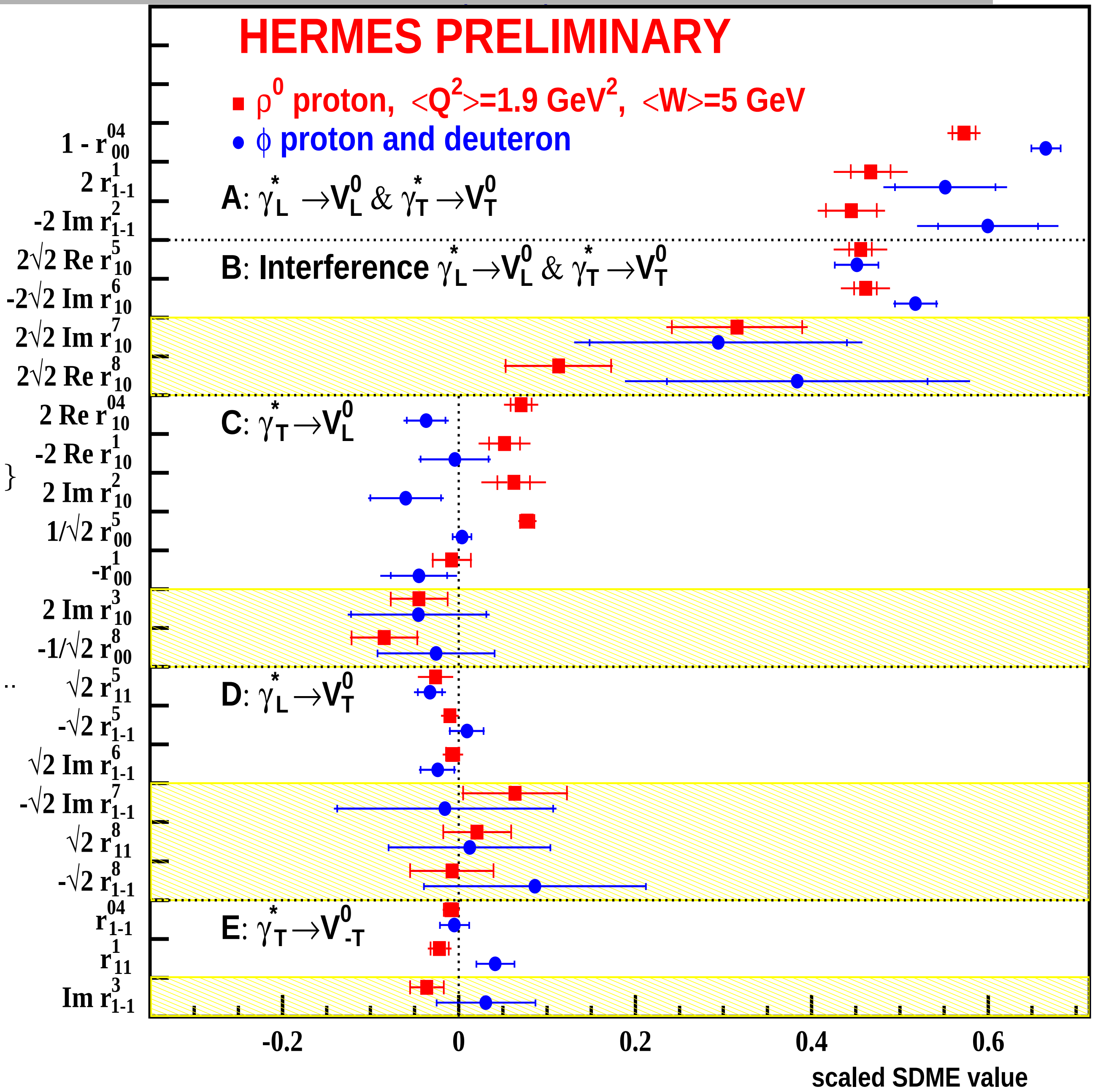
  $Re\{T_{10}T^*_{11}\} \propto r^5_{11} \propto r^5_{1-1} \propto Im\{r^6_{1-1}\}$

  $Im\{T_{10}T^*_{11}\} \propto Im\{r^7_{1-1}\} \propto r^8_{11} \propto r^8_{1-1}$

- E, Spin Flip: $\gamma^*_T \to \rho^0_{-T}$

  $Re\{T_{1-1}T^*_{11}\} \propto r^{04}_{1-1} \propto r^1_{11}$

  $Im\{T_{1-1}T^*_{11}\} \propto Im\{r^3_{1-1}\}$



$\Longrightarrow$ **Hierarchy of ρ^0 amplitudes:** $|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \gtrsim |T_{1-1}|$, $(0 \to L, 1 \to T)$

$\Longrightarrow$ ϕ meson SDMEs are consistent with SCHC, $|T_{00}| \sim |T_{11}|$

Equations for SDMEs Ordered According Helicity Transfer Amplitudes

A: $\gamma^*_L \longrightarrow \rho^0_L \text{and} \gamma^*_T \longrightarrow \rho^0_T$

$r^{04}_{00} = \widetilde{\sum}\{\epsilon|T_{00}|^2 + |T_{01}|^2 + |U_{01}|^2/\}/N_{full}$,

$r^1_{1-1} = \frac{1}{2}\widetilde{\sum}\{|T_{11}|^2 + |T_{1-1}|^2 - |U_{11}|^2 - |U_{1-1}|^2\}/N_{full}$,

$\text{Im}\{r^2_{1-1}\} = \frac{1}{2}\widetilde{\sum}\{-|T_{11}|^2 + |T_{1-1}|^2 + |U_{11}|^2 - |U_{1-1}|^2\}/N_{full}$,

B :interferenceof $\gamma^*_L \longrightarrow \rho^0_L \text{and} \gamma^*_T \longrightarrow \rho^0_T$

$\text{Re}\{r^5_{10}\} = \frac{1}{\sqrt{8}}\widetilde{\sum}\text{Re}\{2T_{10}T^*_{01} + (T_{11} - T_{1-1})T^*_{00}\}/N_{full}$,

$\text{Im}\{r^6_{10}\} = \frac{1}{\sqrt{8}}\widetilde{\sum}\text{Re}\{2U_{10}U^*_{01} - (T_{11} + T_{1-1})T^*_{00}\}/N_{full}$,

$\text{Im}\{r^7_{10}\} = \frac{1}{\sqrt{8}}\widetilde{\sum}\text{Im}\{2U_{10}U^*_{01} + (T_{11} + T_{1-1})T^*_{00}\}/N_{full}$,

$\text{Re}\{r^8_{10}\} = \frac{1}{\sqrt{8}}\widetilde{\sum}\text{Im}\{-2T_{10}T^*_{01} + (T_{11} - T_{1-1})T^*_{00}\}/N_{full}$,

C :$\gamma^*_T \longrightarrow \rho^0_L$

$\text{Re}\{r^{04}_{10}\} = \widetilde{\sum}\text{Re}\{\epsilon T_{10}T^*_{00} + \frac{1}{2}T_{01}(T_{11} - T_{1-1})^* + \frac{1}{2}U_{01}(U_{11} + U_{1-1})^*\}/N_{full}$,

$\text{Re}\{r^1_{10}\} = \frac{1}{2}\widetilde{\sum}\text{Re}\{-T_{01}(T_{11} - T_{1-1})^* + U_{01}(U_{11} + U_{1-1})^*\}/N_{full}$,

$\text{Im}\{r^2_{10}\} = \frac{1}{2}\widetilde{\sum}\text{Re}\{T_{01}(T_{11} + T_{1-1})^* - U_{01}(U_{11} - U_{1-1})^*\}/N_{full}$,

$r^5_{00} = \sqrt{2}\widetilde{\sum}\text{Re}\{T_{01}T^*_{00}\}/N_{full}$,

$r^1_{00} = \widetilde{\sum}\{-|T_{01}|^2 + |U_{01}|^2\}/N_{full}$,

$\text{Im}\{r^3_{10}\} = -\frac{1}{2}\widetilde{\sum}\text{Im}\{T_{01}(T_{11} + T_{1-1})^* + U_{01}(U_{11} - U_{1-1})^*\}/N_{full}$,

$r^8_{00} = \sqrt{2}\widetilde{\sum}\text{Im}\{T_{01}T^*_{00}\}/N_{full}$,

D :$\gamma^*_L \longrightarrow \rho^0_T$

$r^5_{11} = \frac{1}{\sqrt{2}}\widetilde{\sum}\text{Re}\{T_{10}(T_{11} - T_{1-1})^* + U_{10}(U_{11} - U_{1-1})^*\}/N_{full}$,

$r^5_{1-1} = \frac{1}{\sqrt{2}}\widetilde{\sum}\text{Re}\{-T_{10}(T_{11} - T_{1-1})^* + U_{10}(U_{11} - U_{1-1})^*\}/N_{full}$,

$\text{Im}\{r^6_{1-1}\} = \frac{1}{\sqrt{2}}\widetilde{\sum}\text{Re}\{T_{10}(T_{11} + T_{1-1})^* - U_{10}(U_{11} + U_{1-1})^*\}/N_{full}$,

$\text{Im}\{r^7_{1-1}\} = \frac{1}{\sqrt{2}}\widetilde{\sum}\text{Im}\{T_{10}(T_{11} + T_{1-1})^* - U_{10}(U_{11} + U_{1-1})^*\}/N_{full}$,

$r^8_{11} = -\frac{1}{\sqrt{2}}\widetilde{\sum}\text{Im}\{T_{10}(T_{11} - T_{1-1})^* + U_{10}(U_{11} - U_{1-1})^*\}/N_{full}$,

$r^8_{1-1} = \frac{1}{\sqrt{2}}\widetilde{\sum}\text{Im}\{T_{10}(T_{11} - T_{1-1})^* - U_{10}(U_{11} - U_{1-1})^*\}/N_{full}$,

E :$\gamma^*_T \longrightarrow \rho^0_{-T}$

$r^{04}_{1-1} = \widetilde{\sum}\text{Re}\{-\epsilon|T_{10}|^2 + \epsilon|U_{10}|^2 + T_{1-1}T^*_{11} - U_{1-1}U^*_{11}\}/N_{full}$,

$r^1_{11} = \widetilde{\sum}\text{Re}\{T_{1-1}T^*_{11} + U_{1-1}U^*_{11}\}/N_{full}$,

$\text{Im}\{r^3_{1-1}\} = -\widetilde{\sum}\text{Im}\{T_{1-1}T^*_{11} - U_{1-1}U^*_{11}\}/N_{full}$,

where N_{full} is normalized total ρ^0 production cross section

ρ^0 Longitudinal-to-Transverse Cross-Section Ratio

Presented commonly measured $R^{04} = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}$,

$$r^{04}_{00} = \sum\{\epsilon|T_{00}|^2 + |T_{01}|^2 + |U_{01}|^2\}/\sigma_{tot}$$

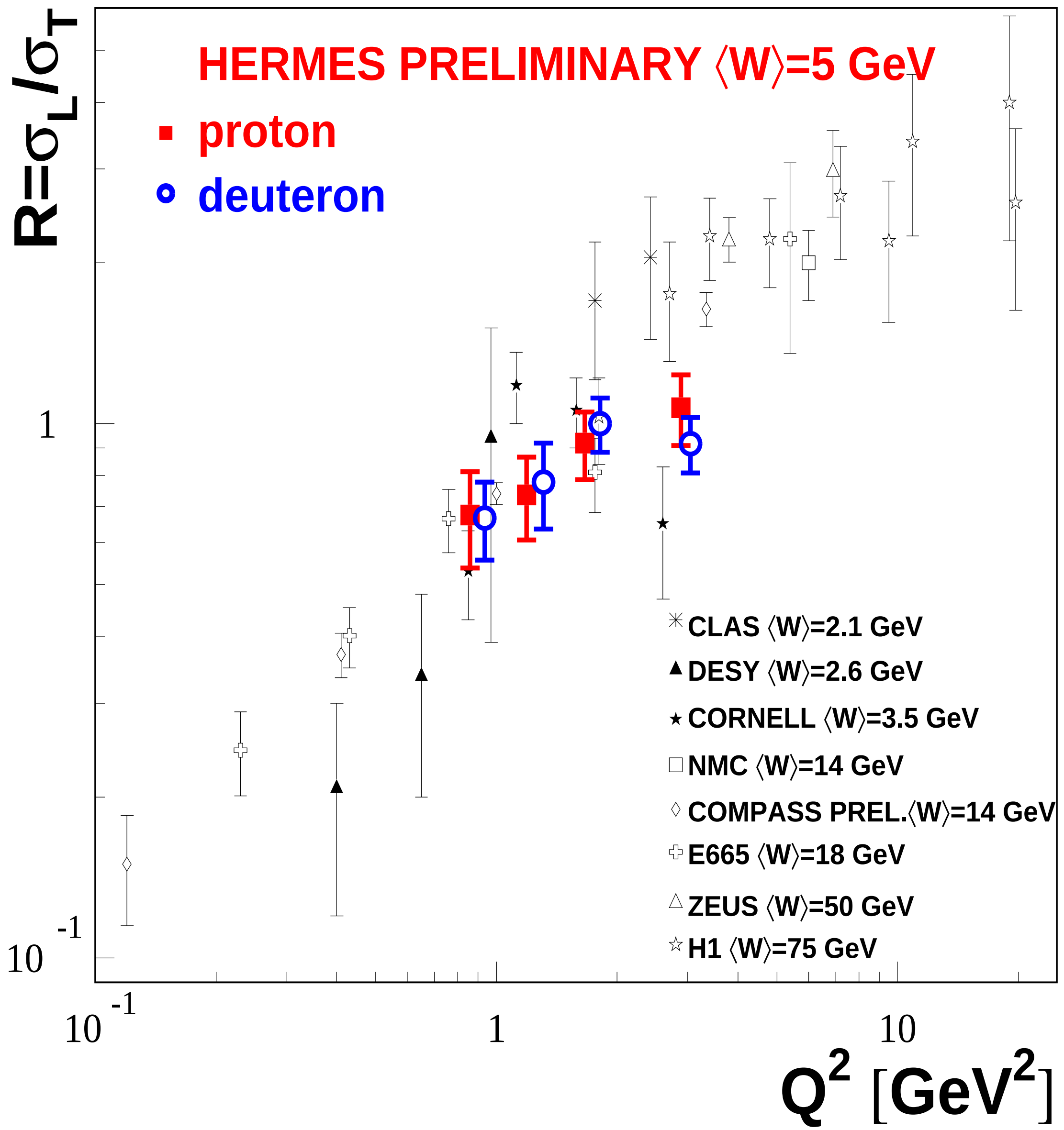
$$\sigma_{tot} = \epsilon\sigma_L + \sigma_T$$

$$\sigma_T = \sum\{|T_{11}|^2 + |T_{01}|^2 + |T_{1-1}|^2 + |U_{11}|^2\}$$

$$\sigma_L = \sum\{|T_{00}|^2 + 2|T_{10}|^2\}$$

Due to the helicity-flip and unnatural parity amplitudes R^{04} depends on kinematic conditions, and is not identical to $R \equiv |T_{00}|^2/|T_{11}|^2$ at SCHC and NPE dominance.

$\Longrightarrow$ Second order contribution of spin-flip amplitudes to R^{04}



$\Longrightarrow$ **HERMES ρ^0 data on R^{04} are suggestive to R(W)-dependence**

ϕ Longitudinal-to-Transverse Cross-Section Ratio

Presented commonly measured $R^{04} = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}$,

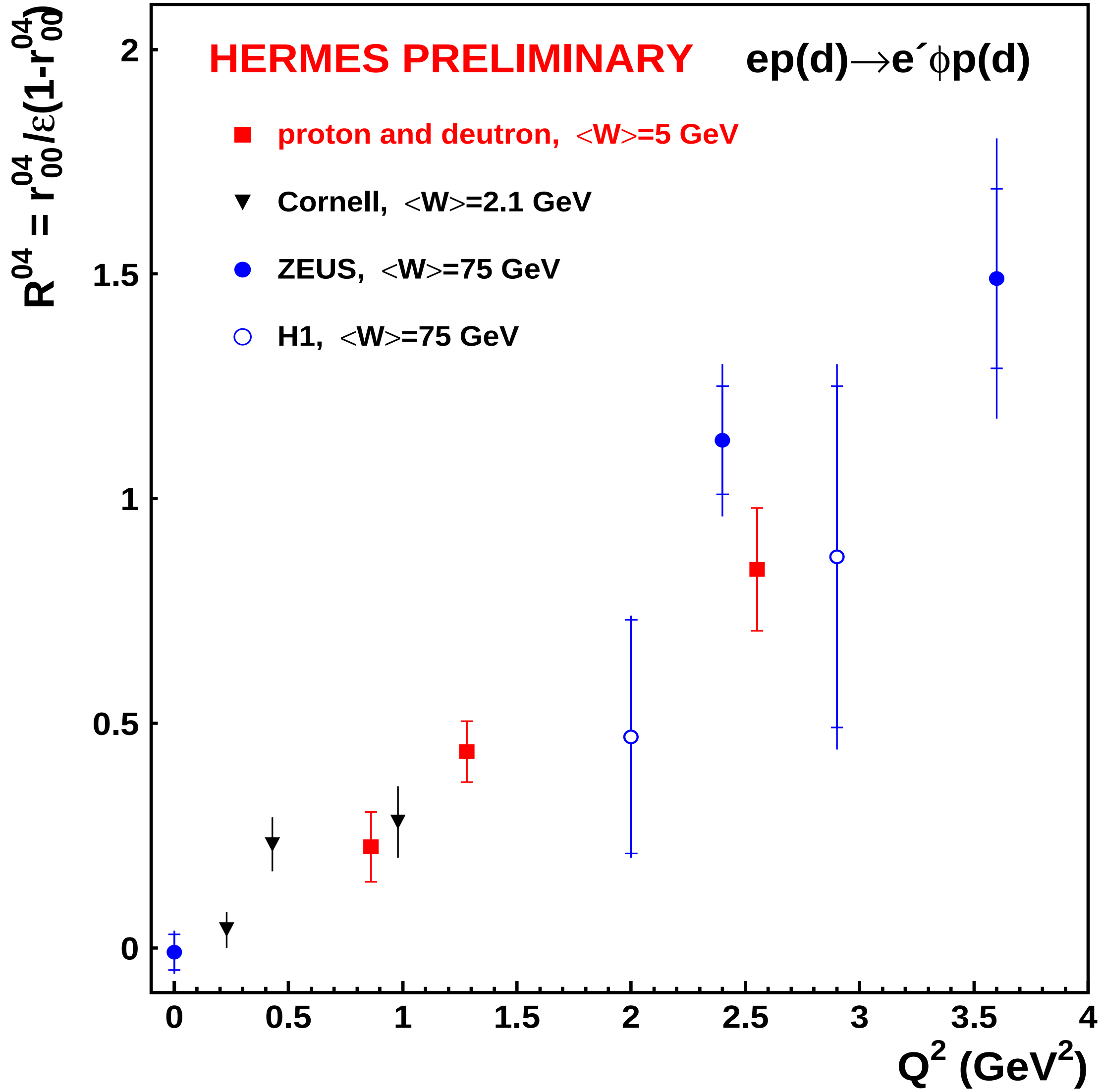
where:

$$r^{04}_{00} = \sum\{\epsilon|T_{00}|^2 + \}/\sigma_{tot}$$

$$\sigma_{tot} = \epsilon\sigma_L + \sigma_T$$

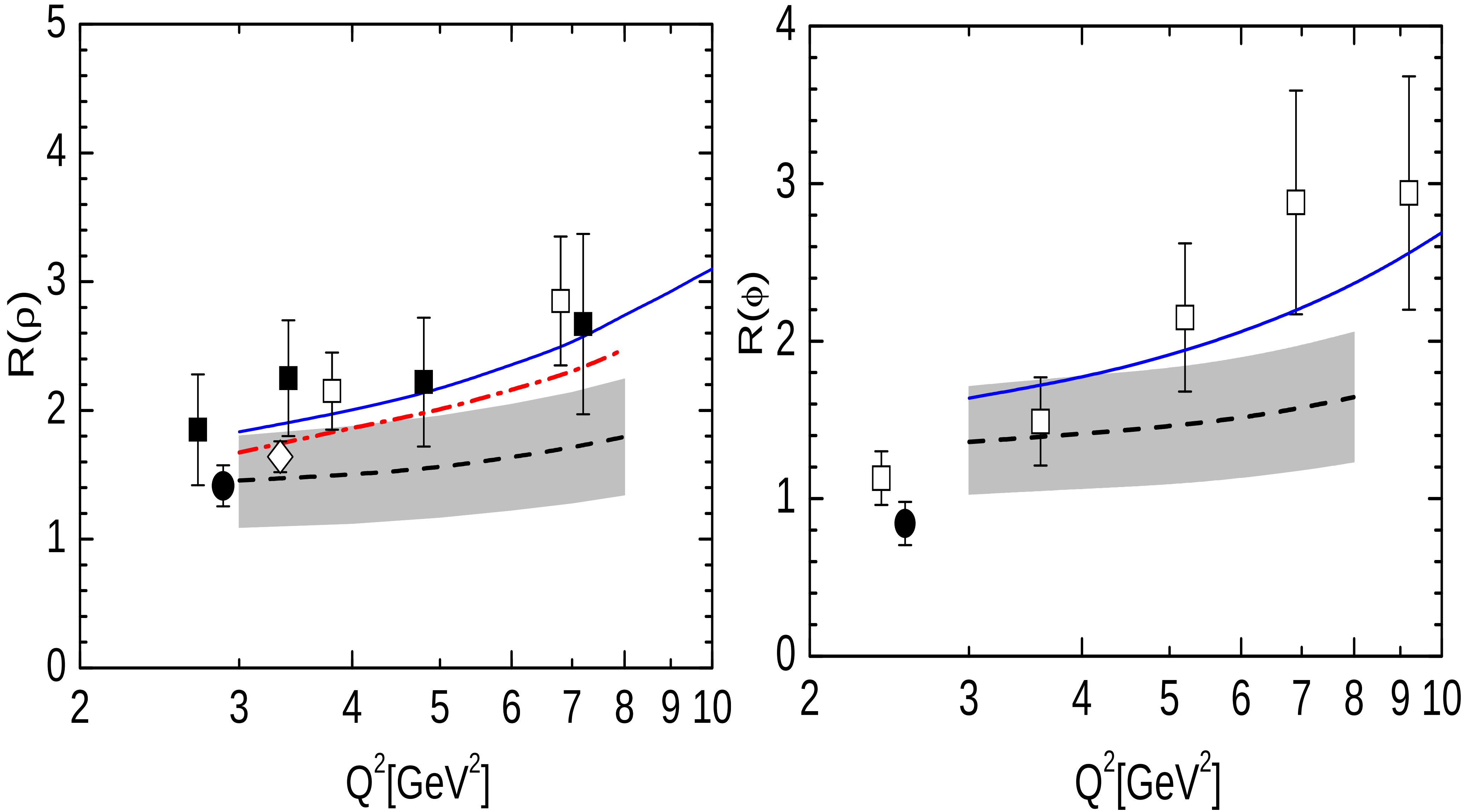
$$\sigma_T = \sum\{|T_{11}|^2\}$$

$$\sigma_L = \sum\{|T_{00}|^2\}$$



$\Longrightarrow$ R^{04} **for ϕ meson at HERMES is in fair agreement with world data**

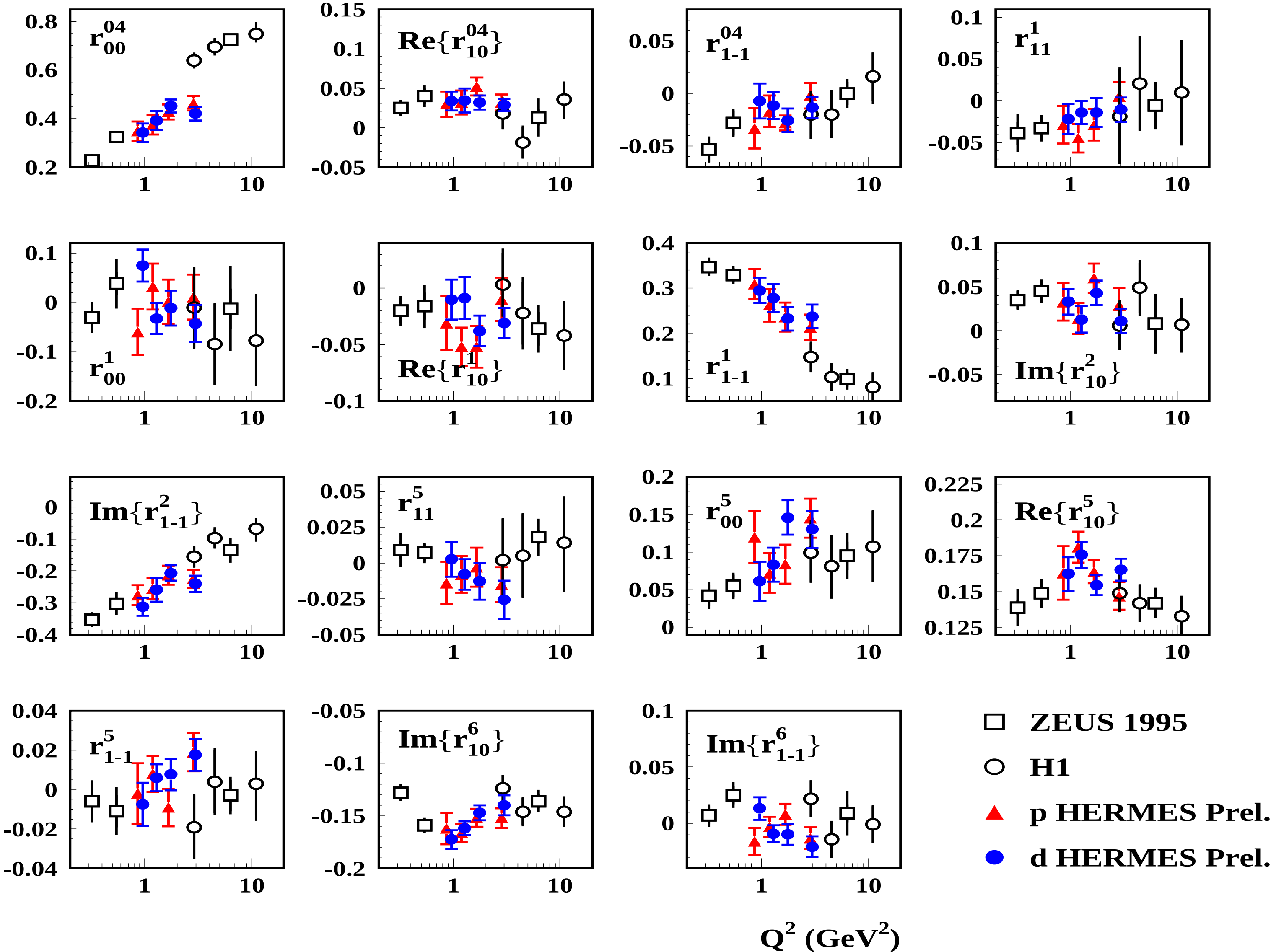
R^{04} of ρ^0 and ϕ-meson Compared with GK Model Calculations



blue line W=90 GeV, squares: H1, ZEUS, red line W=10 GeV, diamond: COMPASS,
black line W=5 GeV, circle: HERMES, corrected to subtract UPE contribution for ρ^0

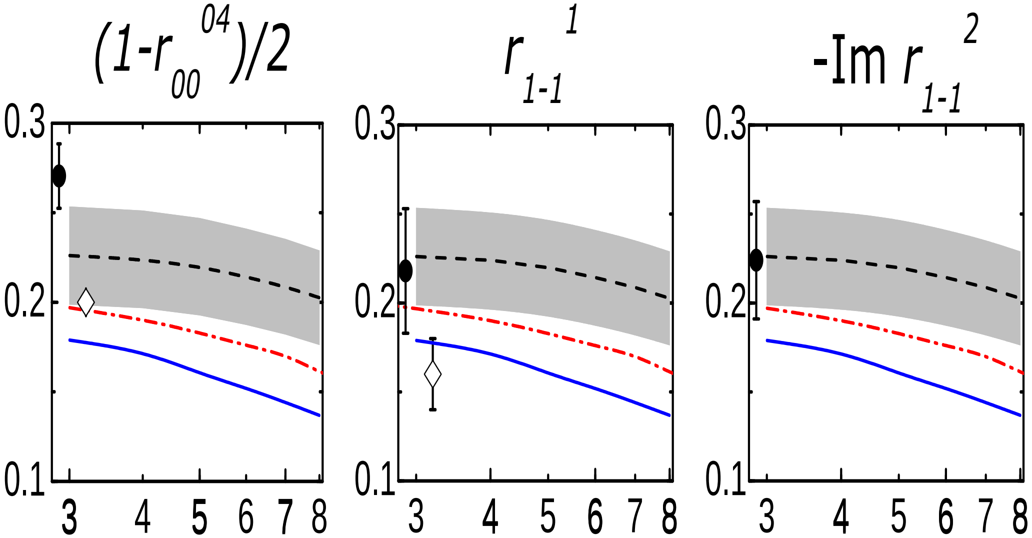
$\Longrightarrow$ $R^{04}(W)$**-dependence confirmed by calculations**

Q^2-dependence of HERMES ρ^0 SDMEs at W=5 GeV on proton and deuteron compared with H1 and ZEUS Data at W=75 GeV



$\Longrightarrow$ Several SDMEs ($r^{04}_{00}, r^{1}_{1-1}, Im(r^{2}_{1-1}...)$ indicate possible W-dependence, in addition to Q^2-dependence

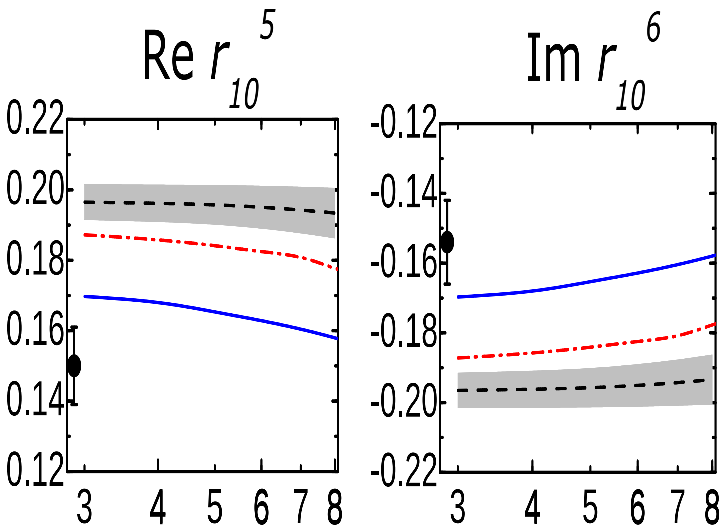
ρ^0 SDMEs Compared with GK Model Calculations



$1 - r^{04}_{00} \propto r^1_{1-1} \propto -Im\{r^2_{1-1}\} \propto |T_{11}|^2$
i.e. amplitudes for $\gamma^*_L \to \rho^0_L$, $\gamma^*_T \to \rho^0_T$

- W=90 GeV
- W=10 GeV, diamond: COMPASS
- W=5 GeV, circle: HERMES

$\Longrightarrow$ Fair agreement with data, as well as for the same SDMEs of ϕ meson production



Re r^5_{10} and Im r^6_{10} correspond to interference of γ^*_L, ρ^0_T amplitudes

$\Longrightarrow$ data provide phase difference for
p: $\delta_{LT} = 28.1 \pm 2.8_{stat} \pm 3.7_{syst}$ degrees
d: $\delta_{LT} = 30.2 \pm 2.0_{stat} \pm 3.7_{syst}$ degrees,
while from the handbag apprroach $\delta_{LT} = 3.1$ degrees at W=5 GeV

Observation of Unnatural Parity Exchange (UPE) in ρ^0 Leptoproduction

- Natural-parity exchange: interaction is mediated by a particle of 'natural' parity: vector or scalar meson: $J^P = 0^+, 1^-$ e.g. ρ^0, ω, a_2
- Unnatural parity exchange is mediated by pseudoscalar or axial meson: $J^P = 0^-, 1^+$, e.g. π, a_1, b_1 $\longrightarrow$ only quark-exchange conribution
- UPE amplitudes correspond to the contributions of polarized GPDs: $\tilde{E}$, $\tilde{H}$
- No interference between NPE and UPE contributions on unpolarized target
- Extracted from SDMEs:

$$U2 + iU3 \propto (U_{11} + U_{1-1}) * U_{10}$$

$$U2 = r^5_{11} + r^5_{1-1}$$

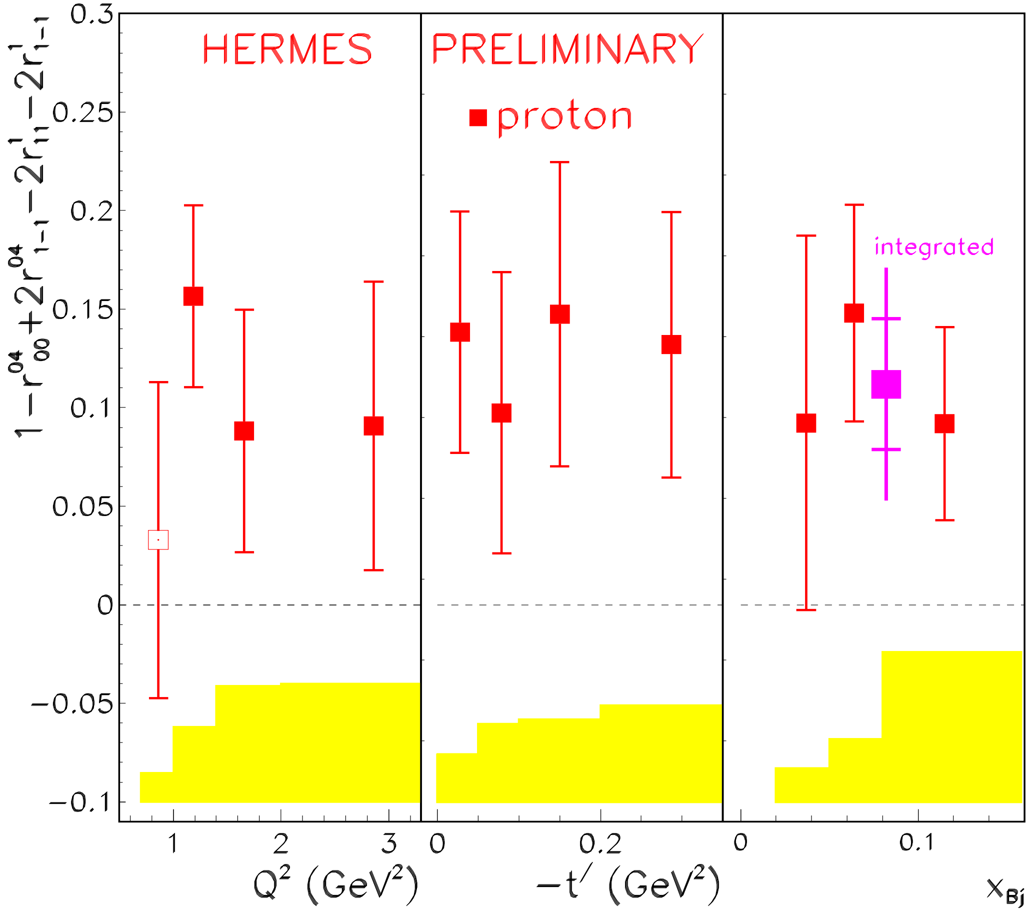
p: $U2 = -0.012 \pm 0.006_{stat} \pm 0.012_{syst}$

d: $U2 = -0.008 \pm 0.0046_{stat} \pm 0.010_{syst}$

$$U3 = r^5_{11} + r^5_{1-1}$$

p: $U3 = -0.020 \pm 0.050_{stat} \pm 0.007_{syst}$

d: $U3 = -0.021 \pm 0.038_{stat} \pm 0.011_{syst}$



- $U1 \propto \epsilon |U_{10}|^2 + 2|U_{11} + U_{1-1}|^2$
  $U1 = 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^1_{11} - 2r^1_{1-1}$

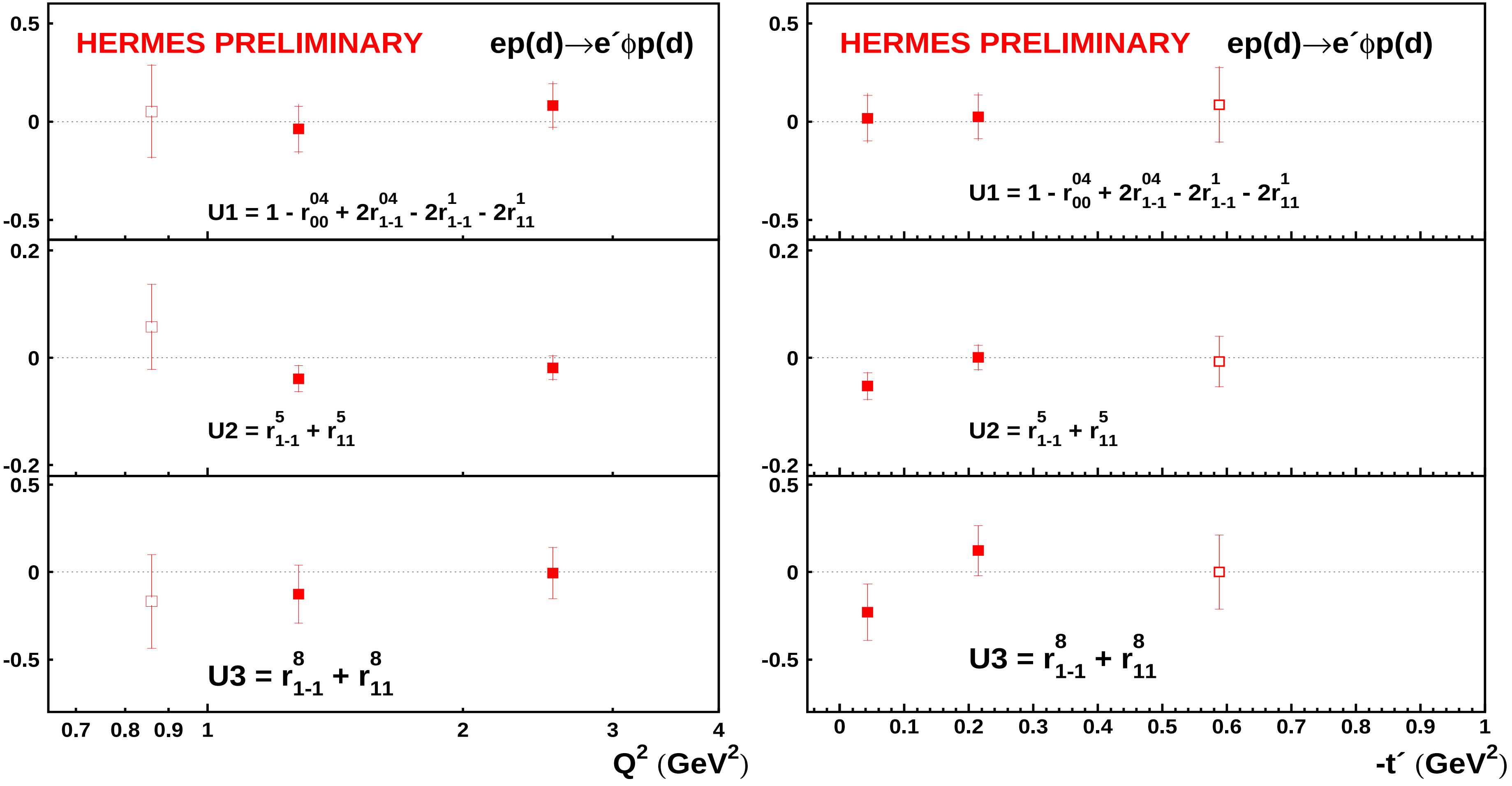
  p: $U1 = 2|U_{11}|^2 = 0.132 \pm 0.026_{st} \pm 0.053_{syst}$

  d: $U1 = 0.094 \pm 0.020_{st} \pm 0.044_{syst}$

  p+d: $U1 = 0.109 \pm 0.037_{tot}$

$\Longrightarrow$ **Indication on hierarchy of ρ^0 UPE amplitudes:** $|U_{11}| \gg |U_{10}| \sim |U_{01}|$

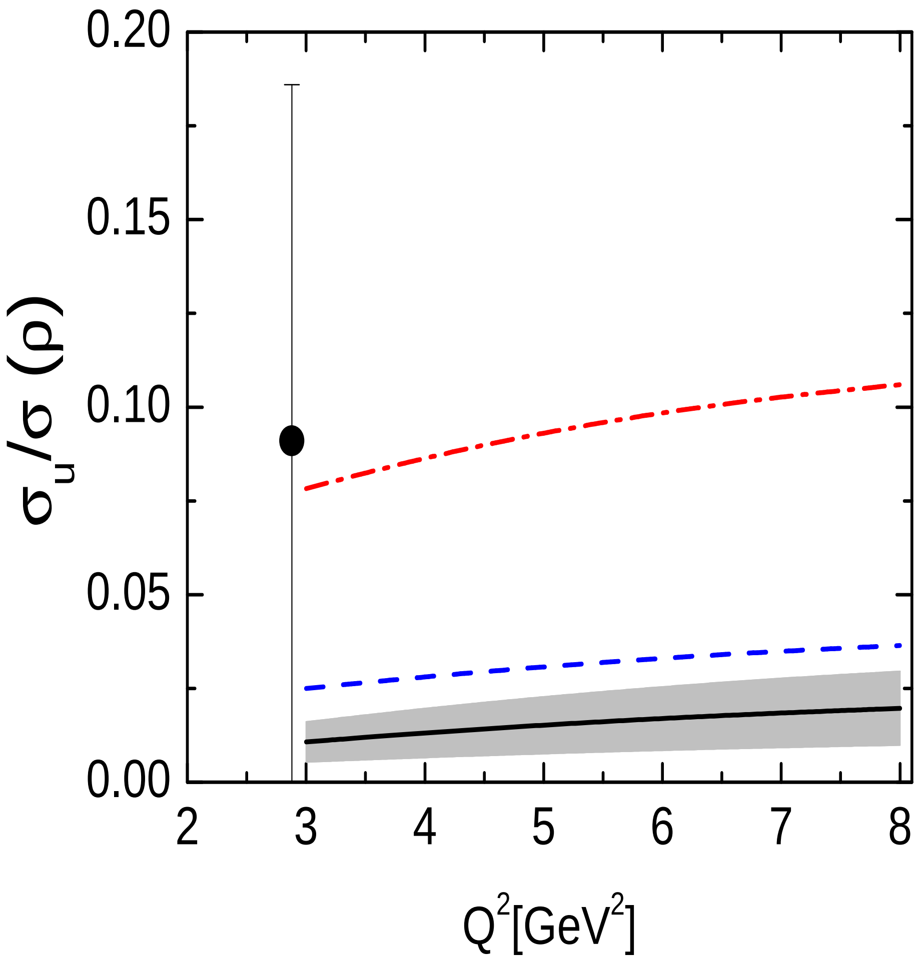
...Only Natural Parity Exchange in ϕ Meson Leptoproduction



$$U1 = 0.02 \pm 0.07_{stat} \pm 0.16_{syst}$$
$$U2 = -0.03 \pm 0.01_{stat} \pm 0.03_{syst}$$
$$U3 = -0.05 \pm 0.11_{stat} \pm 0.07_{syst}$$

$\Longrightarrow$ **no UPE for ϕ meson production, as expected**

Unnatural Parity Exchange contribution in GK model



calculated at W=5 GeV

- Measured at $Q^2 = 3$ GeV^2 $U1$ corresponds to calculated

  $$\sigma_U/\sigma(\rho^0) = 0.5 \cdot (1 - r_{00}^{04} - 2r_{1-1}^{1}) = 2|U_{11}|^2/\sigma(\rho^0)$$
- UPE requies $\tilde{H}$ GPD
- $\sigma_U \propto e_u \tilde{H}_{val}^u - e_d \tilde{H}_{val}^d$ for ρ^0 production

  Lines:

  – extreme assumption for valence quarks: $\tilde{H}_{val}^u = H_{val}^u$ and $\tilde{H}_{val}^d = H_{val}^d$

  – extreme assumption for valence quarks: $\tilde{H}_{val}^u = H_{val}^u$ and $\tilde{H}_{val}^d = -H_{val}^d$

  – $\sigma_U \approx 0.013$ for gluons and sea contribution
- σ_U small for H1 and ZEUS ρ^0 data as gluon and sea contribution dominate
- σ_U small for ϕ at HERMES as gluon contribution dominate

...Better precision of $|U_{11}|^2$ measurement at $Q^2 \approx 3$ GeV^2 is planned

ρ^o Double Spin Asymmetry and Unnatural Parity Exchange

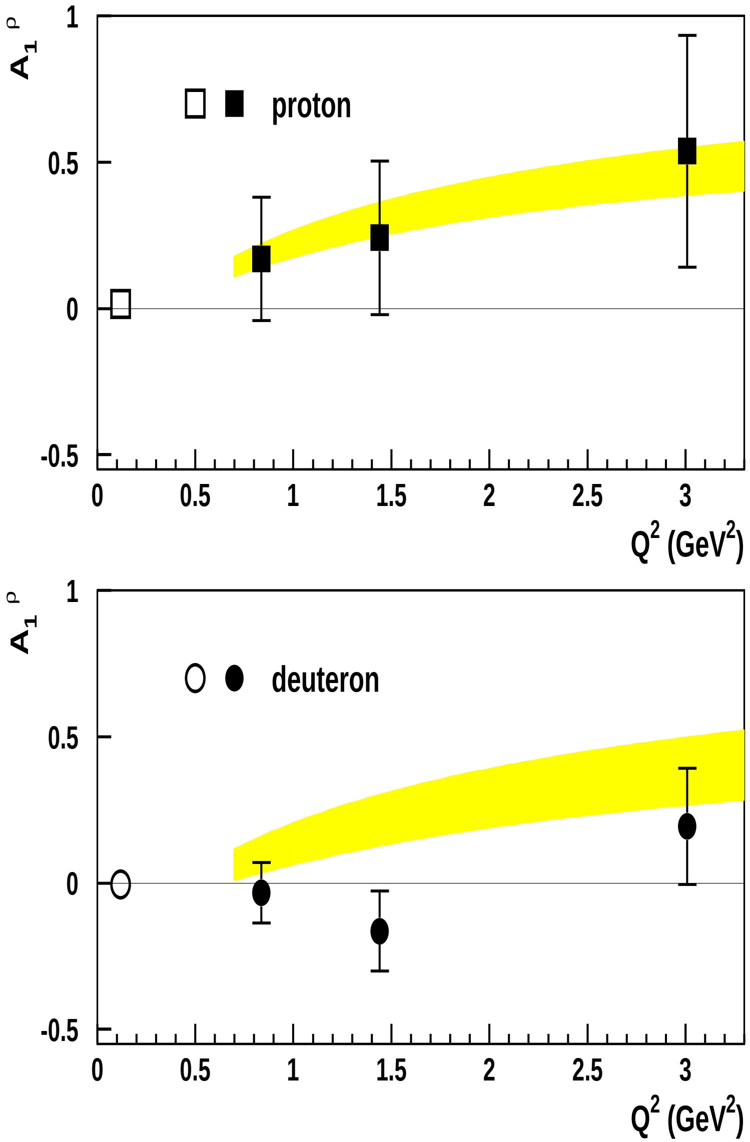
$$A_1^\rho = \frac{\sigma_{1/2}-\sigma_{3/2}}{\sigma_{1/2}+\sigma_{3/2}} = \frac{A_{LL}}{D} - \eta\sqrt{R_\rho}$$

$D \approx 0.40$ photon depolarization factor
$\eta \approx 0.06$ kinematical factor, $R_\rho = \sigma_L/\sigma_T$

$$A_{LL} = \frac{1}{p_B p_T}\frac{N^{\uparrow\Downarrow}L^{\uparrow\Downarrow} - N^{\uparrow\Uparrow}L^{\uparrow\Uparrow}}{N^{\uparrow\Downarrow}L^{\uparrow\Downarrow} + N^{\uparrow\Uparrow}L^{\uparrow\Uparrow}} \approx \frac{A_1^\rho}{2.5}$$

$N^{\uparrow\Downarrow}$ for ρ^o measured with antiparallel target helicity relative lepton helicity, L luminosity

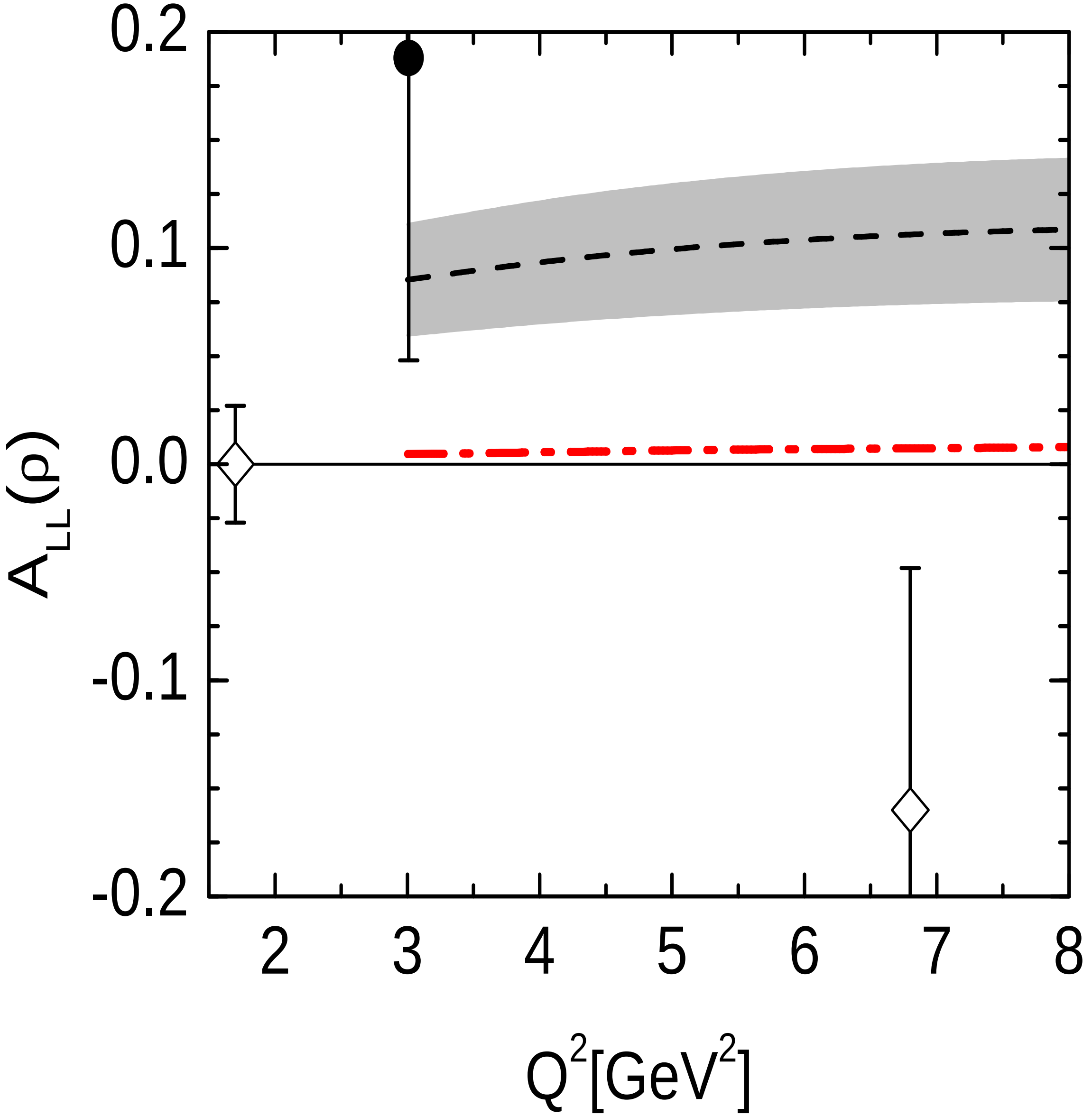
- A_1^ρ due to the linear contribution of unnatural parity amplitudes process mediated by di-quark objects:
  H.Fraas, Nucl. Phys. **B113**, 532, (1976);
  N.I.Kochelev et al, Phys.Rev. **D67** (2003) 074014
- i.e. interference effect for A_{LL}



HERMES collab., Phys.Lett.B 513 (2001) 301-310, and Eur.Phys.J. C 29, 171 - 179 (2003)

(A_1^ϕ consistent with zero)

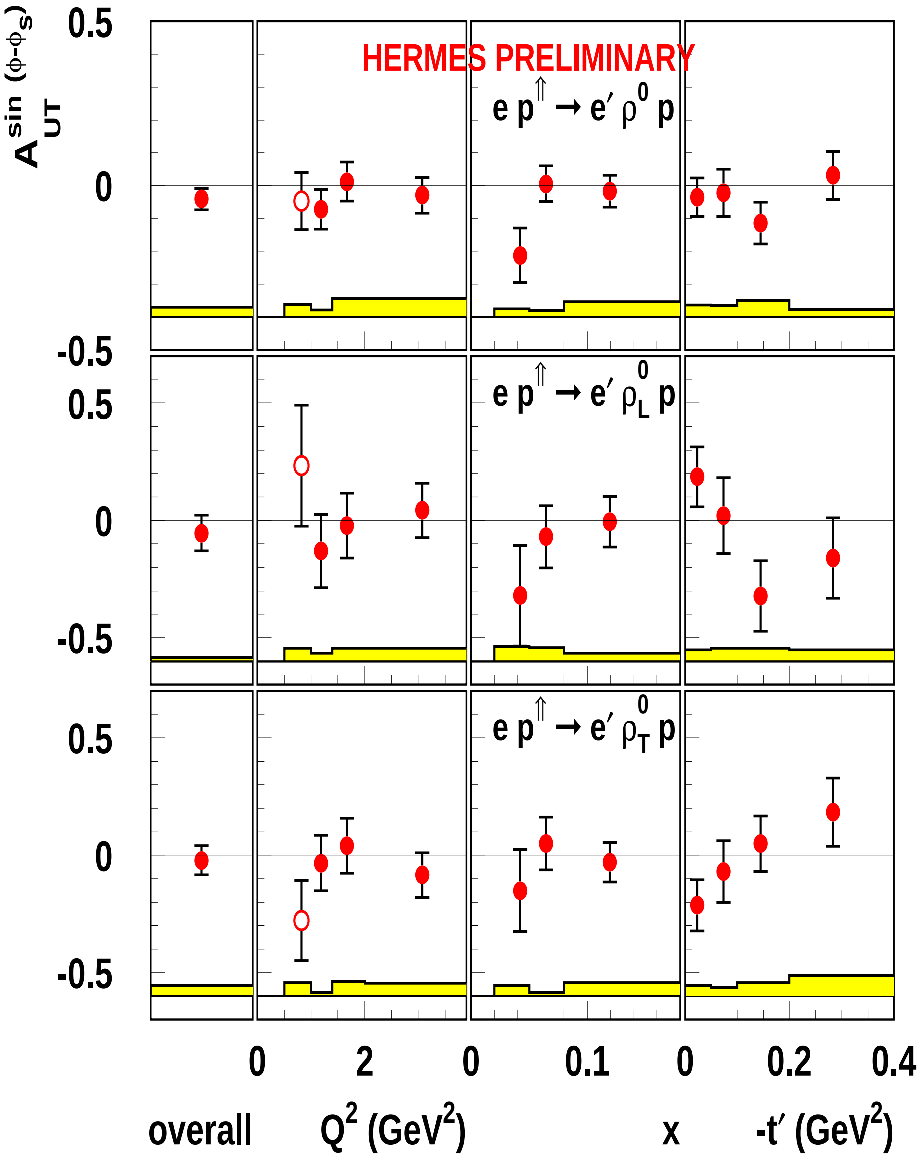
ρ^o Double Spin Asymmetry in GK model



calculated at W=5 GeV

- Interference between leading NPE and UPE amplitudes on longitudinally polarized target results to A_{LL}
- $A_{LL} = 4\sqrt{1-\epsilon^2}\frac{Re(T_{11}U^*_{11})}{\sigma(\rho^0)}$
- Lines:
  – W=10 GeV, diamods: COMPASS
  – W=5 GeV, circle: HERMES
- A_{LL} small for ϕ at HERMES

ρ^o Transverse Target Spin Asymmetry



$A_{UT}^{\rho^0} = -0.033 \pm 0.058$

cf. talk of V.Korotkov

In GK model (arXiv:0708.3569)

- A_{UT} requires the proton helicity flip amplitudes $M^N_{\rho^o p', \gamma^* p} \propto e_u E^u_{val} - e_d E^d_{val}$
- GK model handbag calculations for HERMES provide

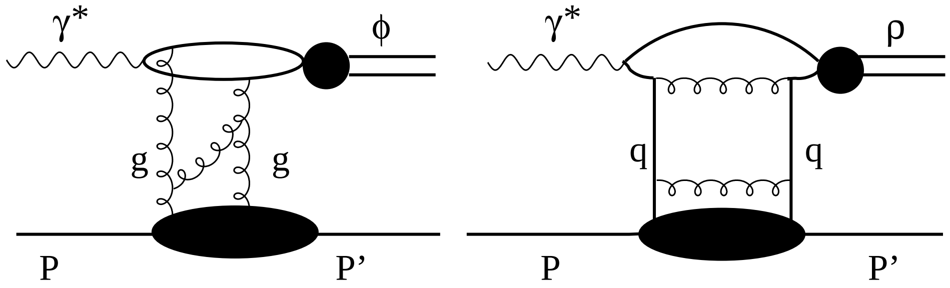
$$A_{UT} = 4\frac{Im\{M^N_{+-,++} M^{N*}_{+-,++}\} + \epsilon Im\{M^N_{0-,0+} M^{N*}_{0+,0+}\}}{\sigma(\rho)}$$

$$A_{UT} = 0.02 \pm 0.01$$

- A_{UT} small for ϕ at HERMES

Summary

- HERMES data are unique due to the sensitivity to *both quark and two-gluon exchange processes* at sufficiently large W and Q^2 for the comparison with GPD handbag diagram based calculations:



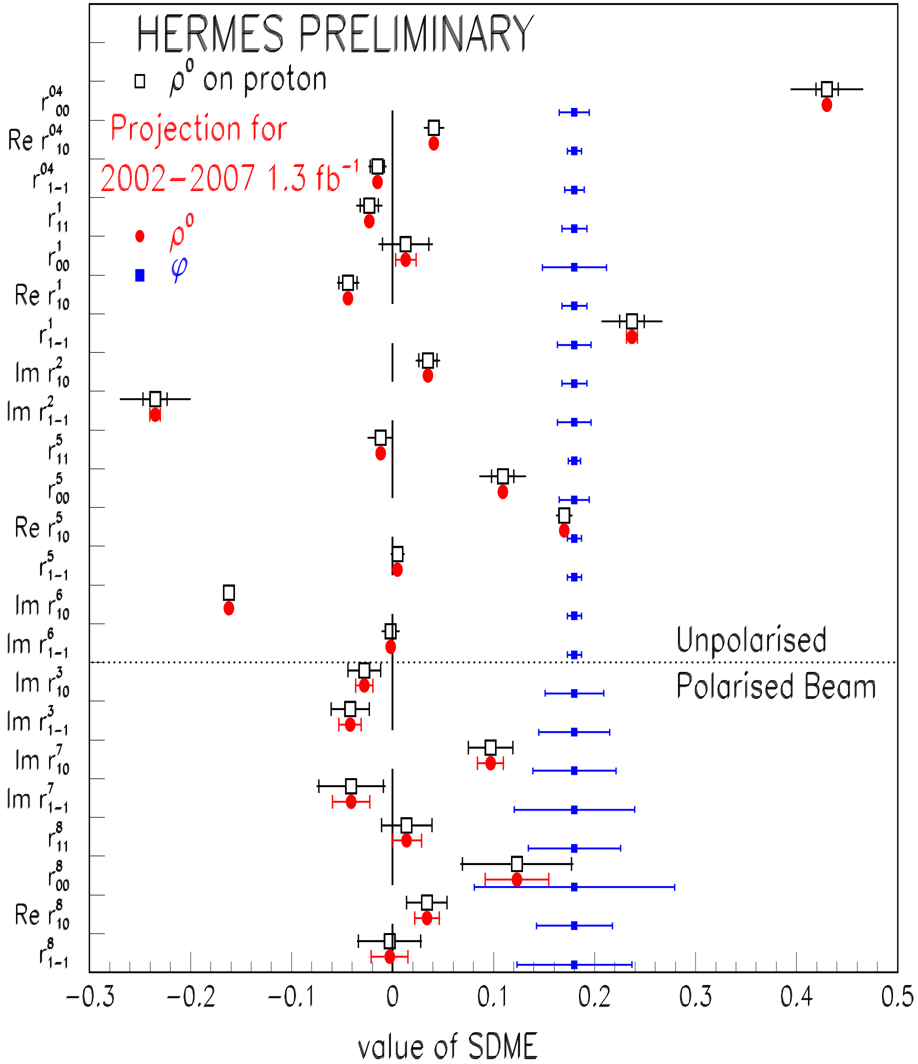
- *First comprehensive comparision* of data on vector meson production with GK model calculations is in fair agreement for:
  - longitudinal and total cross sections of ρ^0 and ϕ mesons
  - values of SDMEs and hierarchy of corresponding amplitudes
  - violation of SCHC in ρ^0 prioduction
  - W-dependence of ρ^0 and ϕ SDMEs and σ_L/σ_T ratios

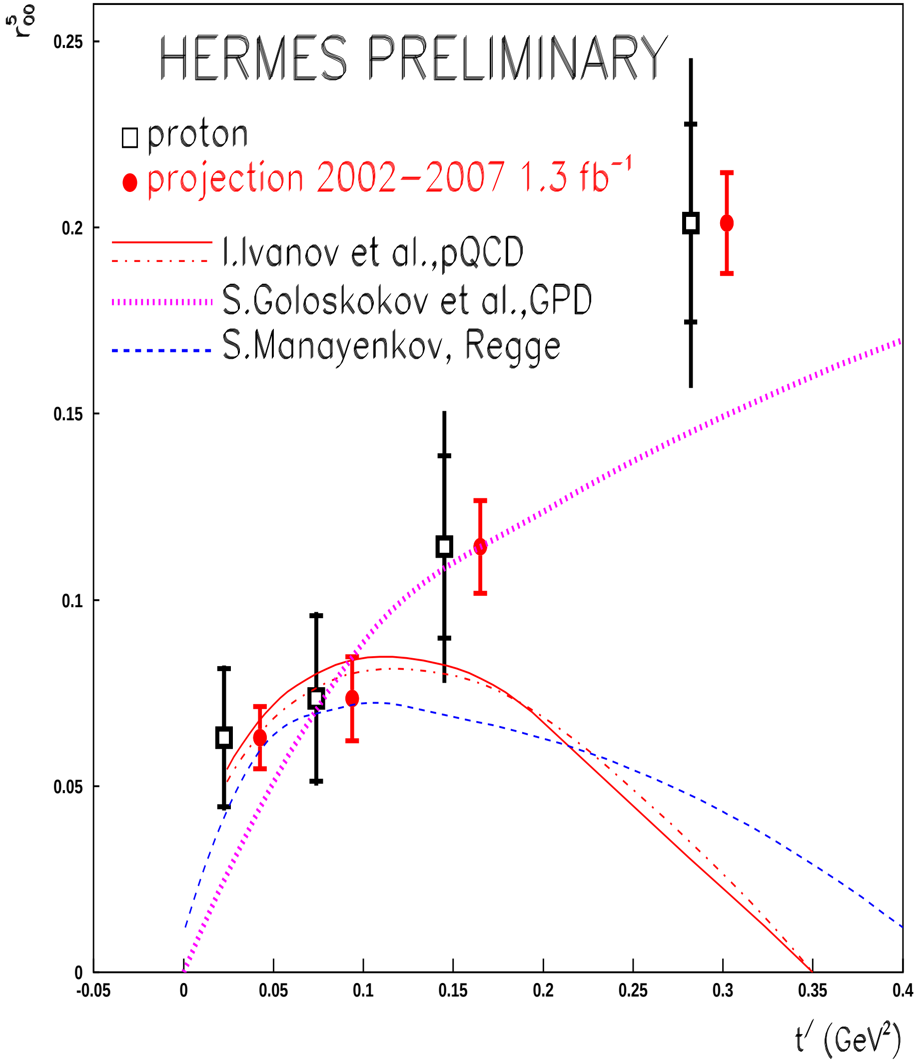
- Constraints of HERMES data in GPDs are for:
  - *phase difference* in the interference of $\gamma_L^* \rightarrow \rho_L^0 \& \gamma_T^* \rightarrow \rho_T^0$ transitions
  - $\tilde{H}_{val}^{u,d}$ contribution in Unnatural Parity Exchange amplitude and A_{LL}^{ρ}
  - $E_{val}^{u,d}$ contribution in $A_{UT}^{\rho^0}$ asymmetry

Outlook

- Target-polarization dependent SDMEs are under analysis in M.Diehl representation
  (DESY-07-049, Apr 2007, e-Print: arXiv:0704.1565 [hep-ph])

- More data from 2006-2007 at Luminosity ~ 1.3 fb^{-1} will be available soon:



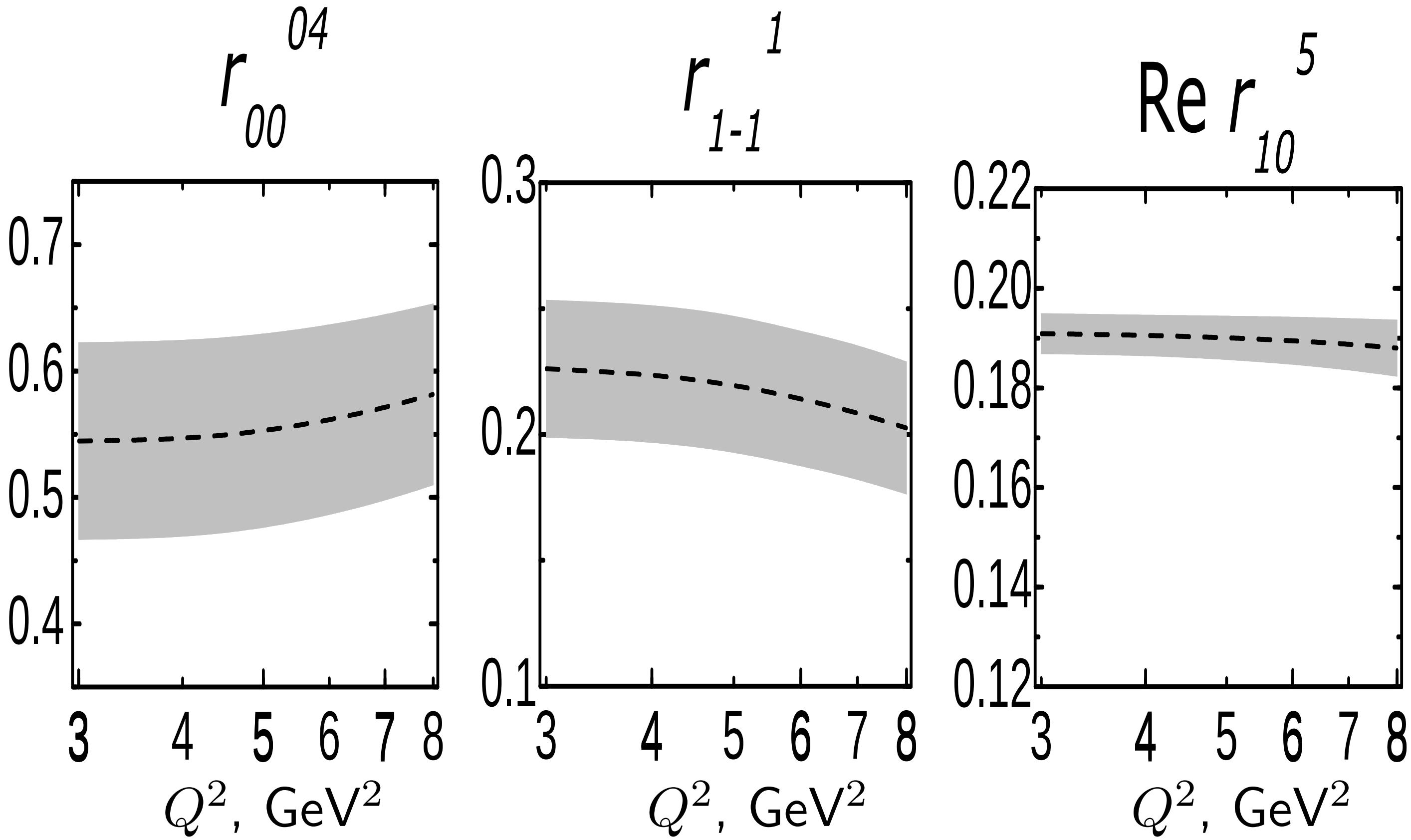


BACKUP SLIDES !!!

ϕ-meson SDMEs and R Compared with GK Model Calculations

HERMES proton data at $Q^2 = 2.9$ GeV^2:

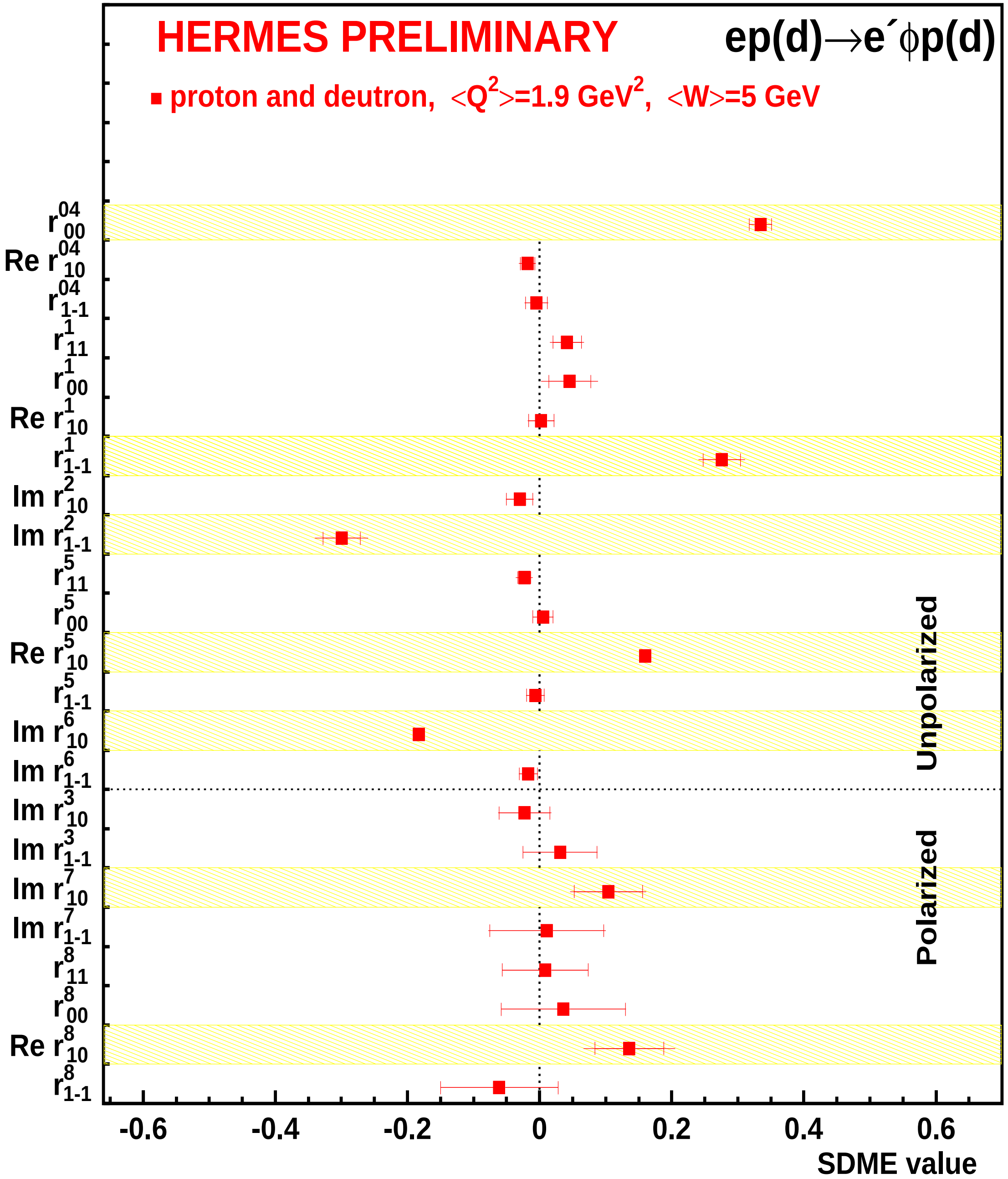
$r^{04}_{00} = 0.41 \pm 0.026 \qquad r^{1}_{1-1} = 0.23 \pm 0.045 \qquad$ Re $r^{5}_{10} = 0.175 \pm 0.013$



$\Longrightarrow$ **Calculations for $W = 5$ GeV are fairly compartible with data**

ϕ-meson 23 Spin Density Matrix Elements

at $0 < t' < 0.4$ GeV^2 and $1 < Q^2 < 7$ GeV^2



- SDMEs: $r^{\alpha}_{\lambda_\rho \lambda'_\rho} \sim \rho(V) = \frac{1}{2} T \rho(\gamma) T^+$

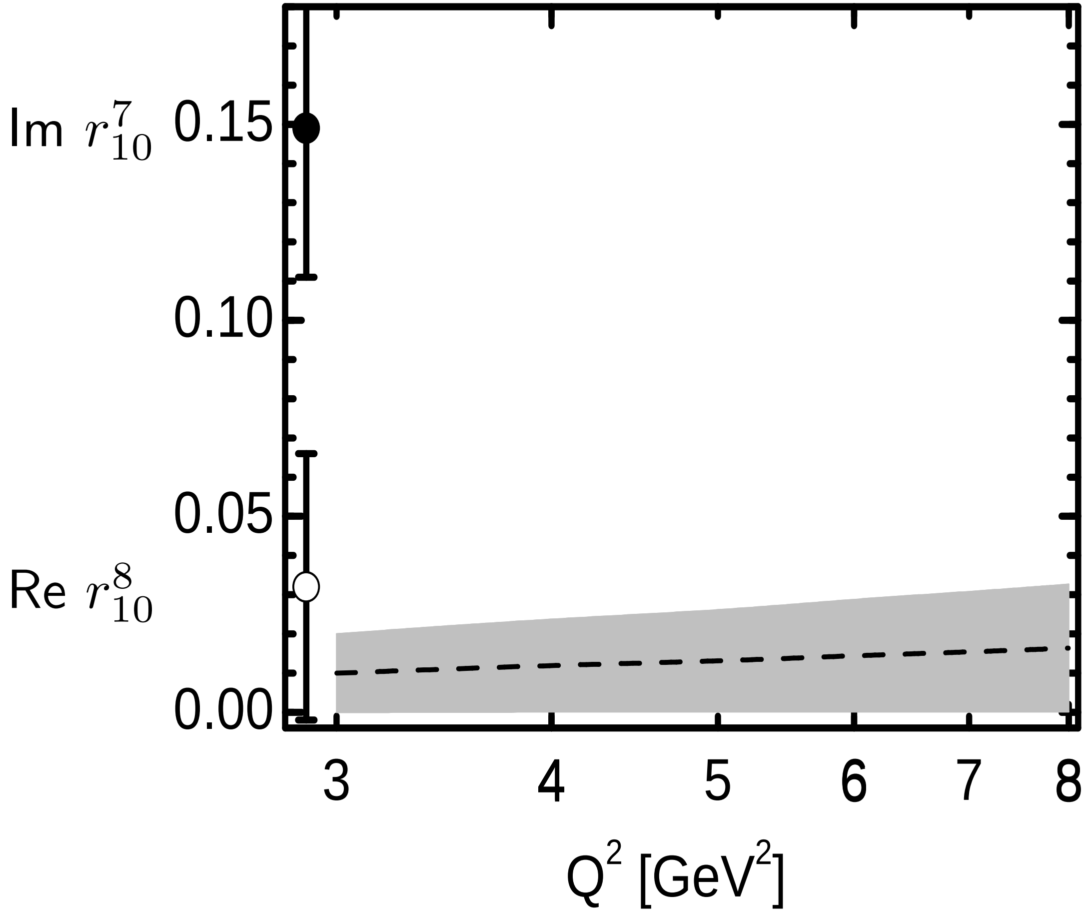
  $\Longrightarrow$ Beam-polarization dependent SDMEs measured for the first time

- SCHC?

  $\Longrightarrow$ SDMEs are consistent with SCHC: non-zero elements only in yellow bands

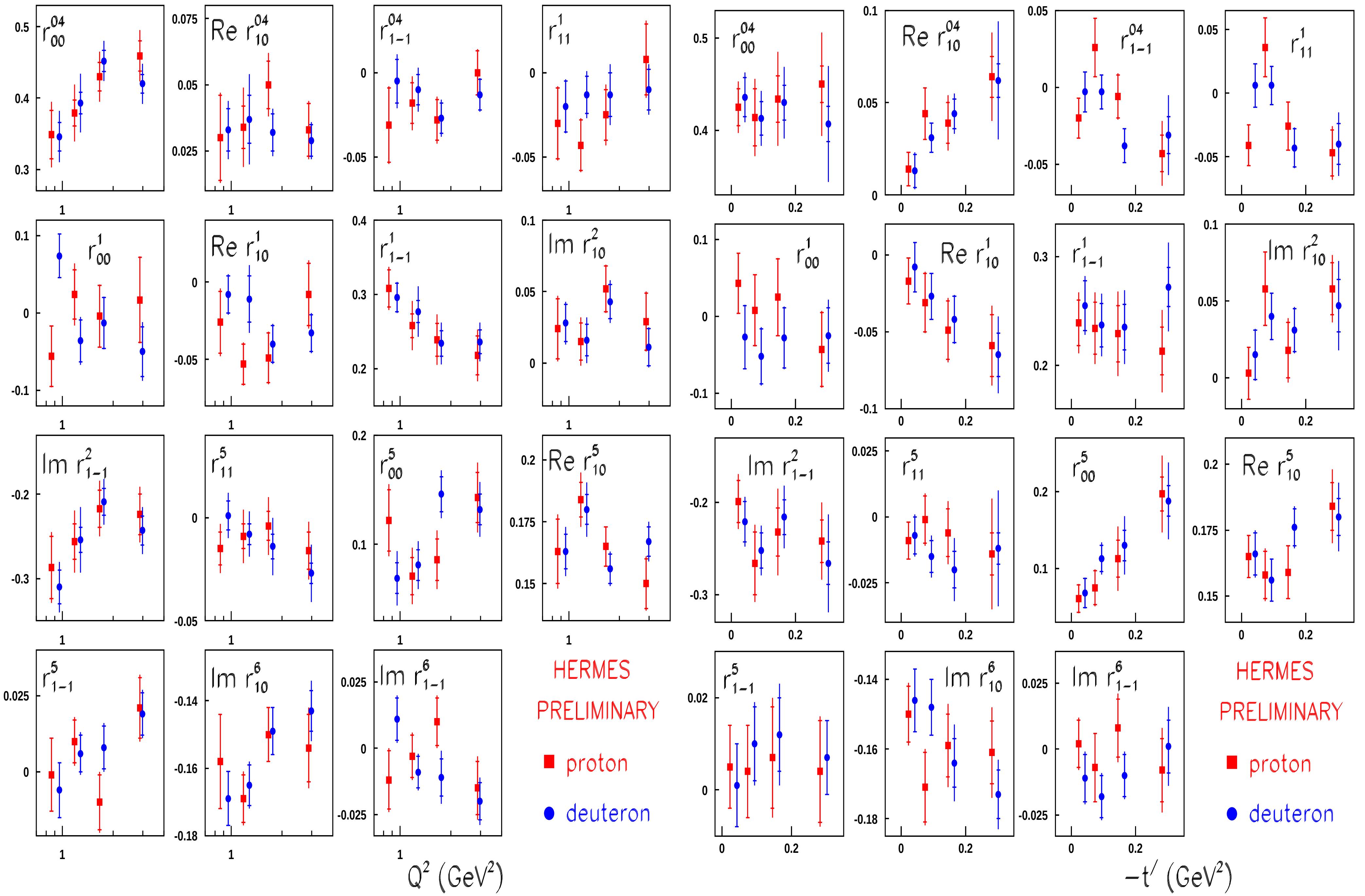
- proton and deuteron data combined, checked that no significant difference between proton and deuteron SDMEs

Comment on ρ^0 SDMEs Compared with GK Model Calculations (arXiv:0708.3569)

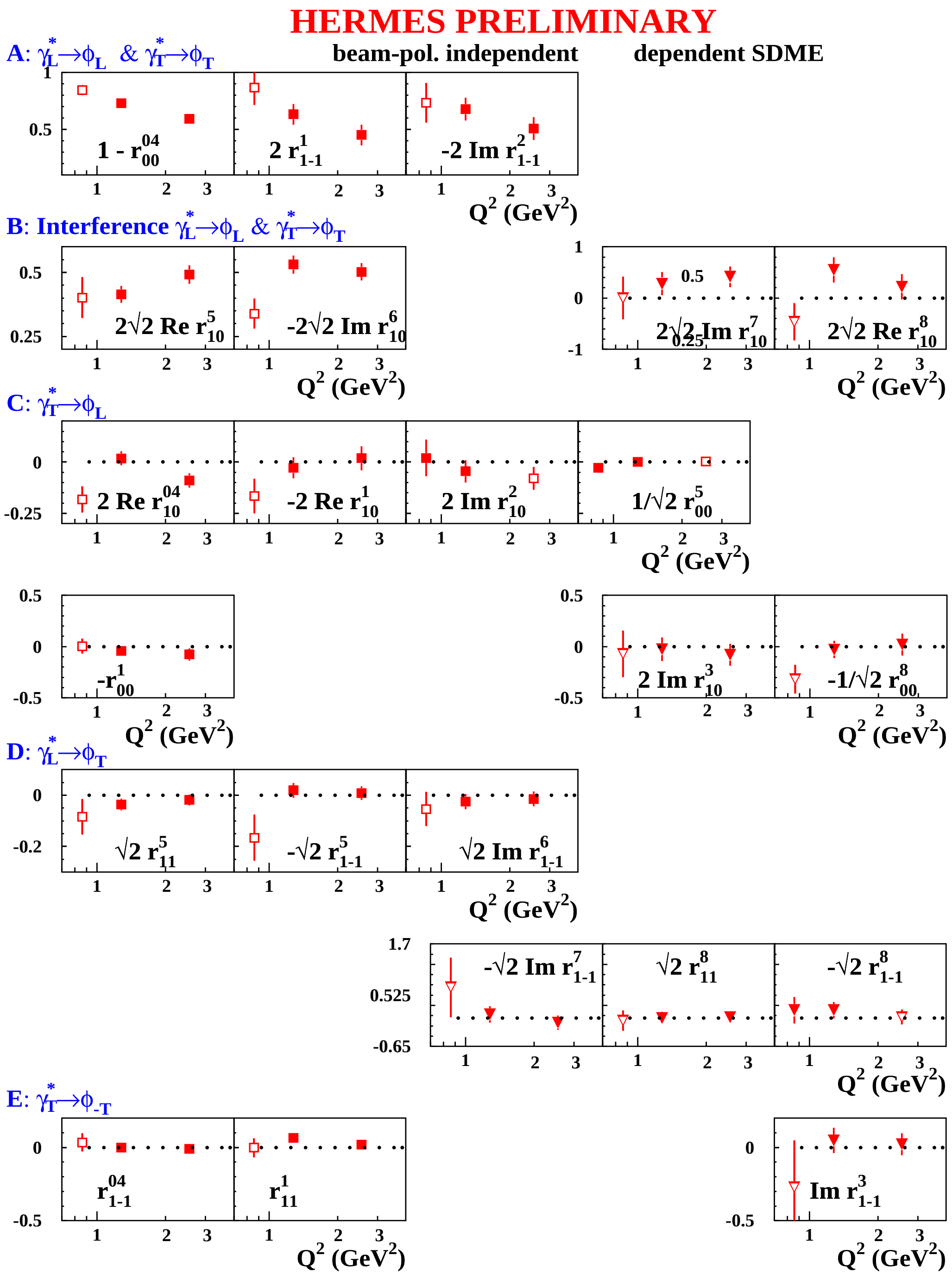


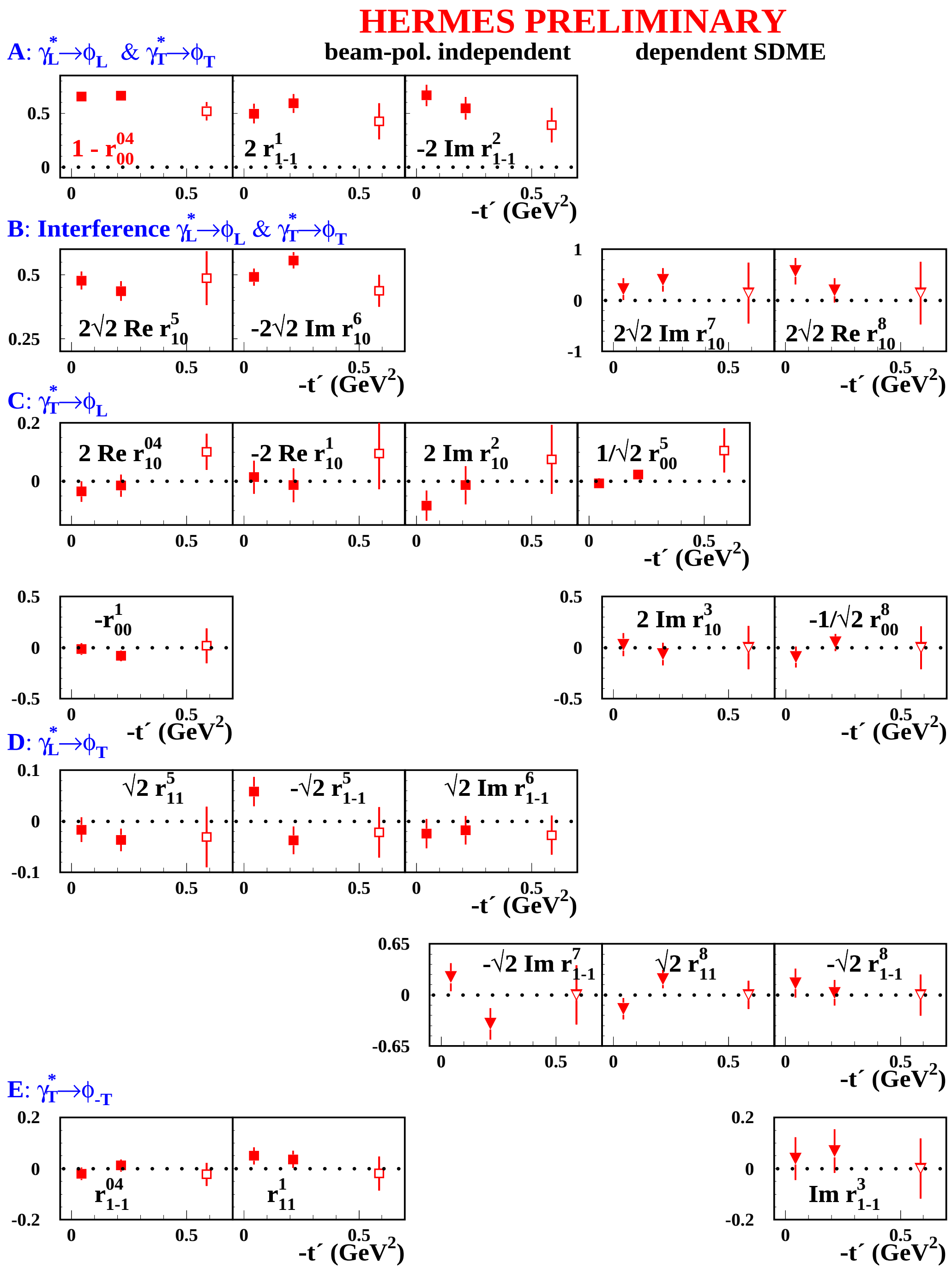
Difference between Im r^7_{10} and Re r^8_{10} of about 3 σ is seen only in preliminary proton data and treated as a possible statistical fluctuation of Im r^7_{10}. These elements are completely compartible in deuteron data with Re r^8_{10} on proton.

Q^2 and t'-Dependences of ρ^0 SDMEs



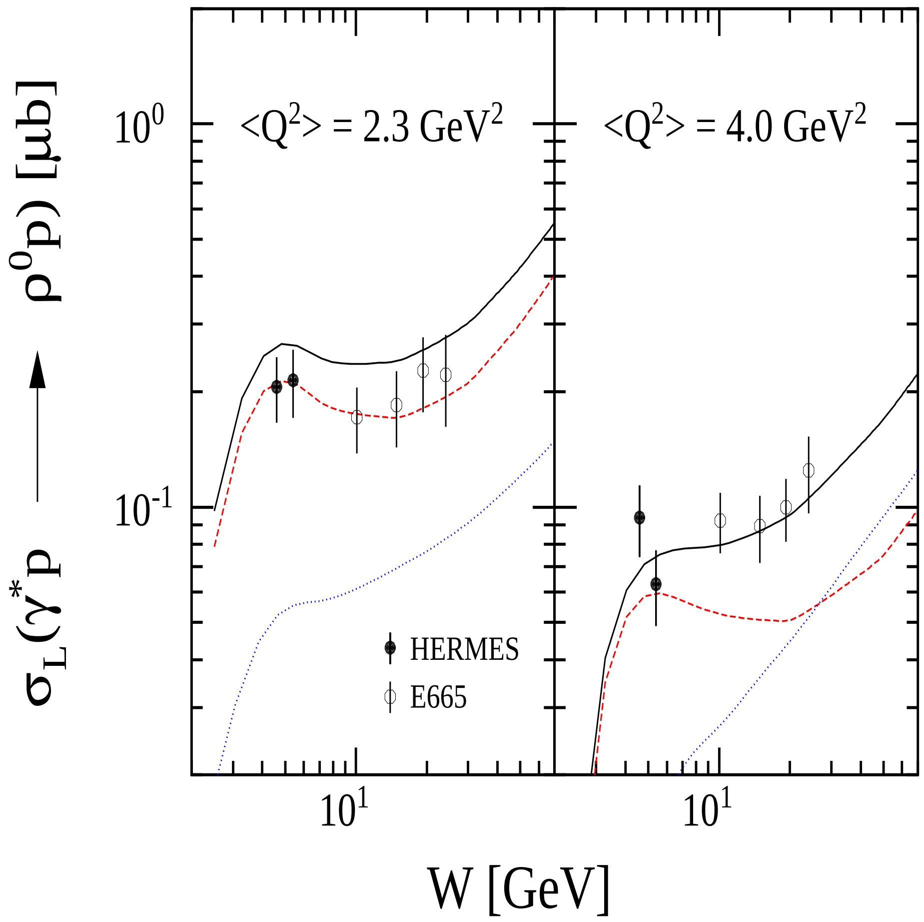
Q^2 and t'-Dependences of ϕ-meson SDMEs

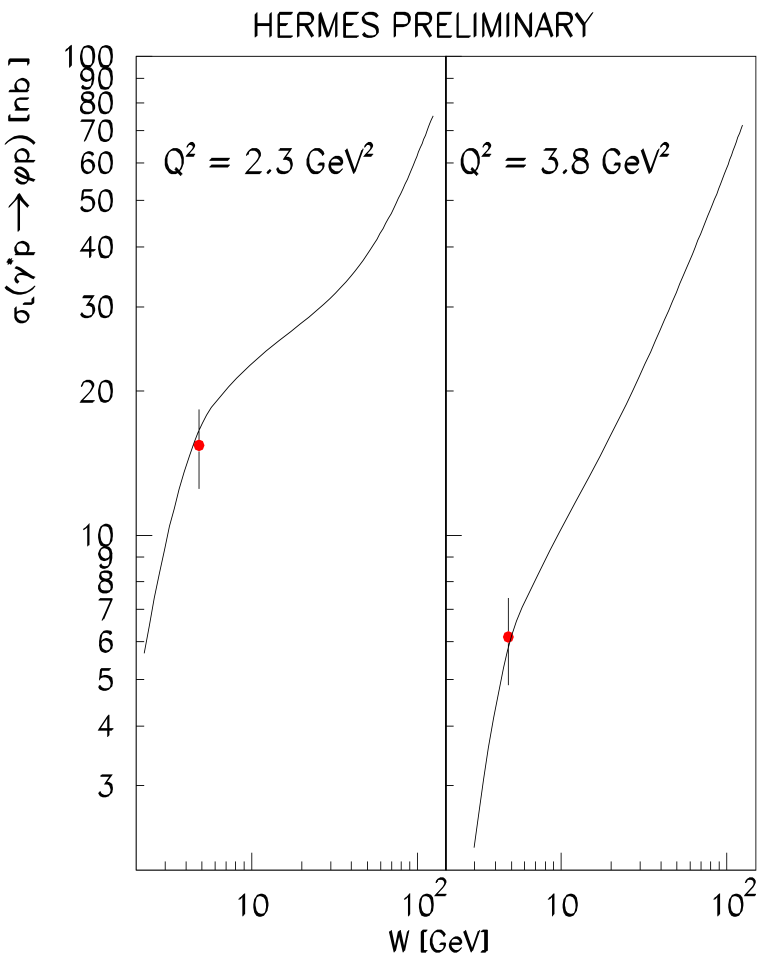




ρ^o and ϕ Longitudinal Cross Sections, and VGG Model

first approach: GPD calculations of M.Vanderhaeghen, P.A.M. Guichon, M. Guidal,Phys.Rev.Let.**80** 5064, (1998); Phys.Rev.D **60** 094017 (1999)

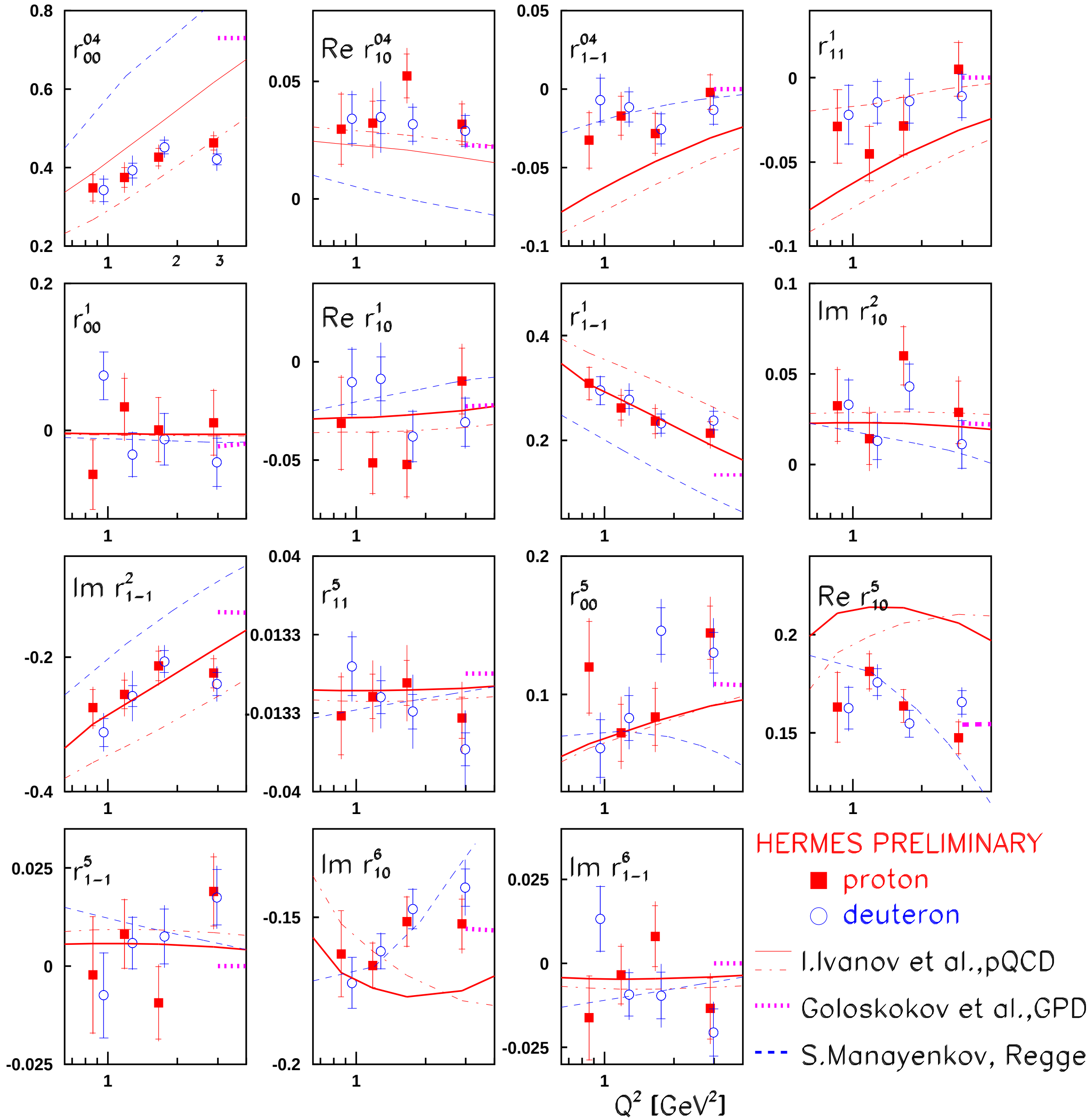




2-gluon exchange, quark exchange, sum of both, two-gluon exchange for ϕ

$\rightarrow$ Domination of quark exchange for ρ^o and two-gluon for ϕ from VGG model

Q^2-Dependence of SDMEs Compared with Calculations



Reasonable agreement for a majority of SDMEs of 12 elements.

To be compared with calculations, for example:

(S.V.Goloskokov and P.Kroll, Eur.Phys.J. C **42** 2005 281)

$$T_{01} \sim T \to L : \qquad \mathcal{H}^V \propto \frac{\sqrt{-t}}{Q}$$

$$T_{11} \sim T \to T : \qquad \mathcal{H}^V \propto \frac{\langle k_\perp^2 \rangle^{1/2}}{Q}$$

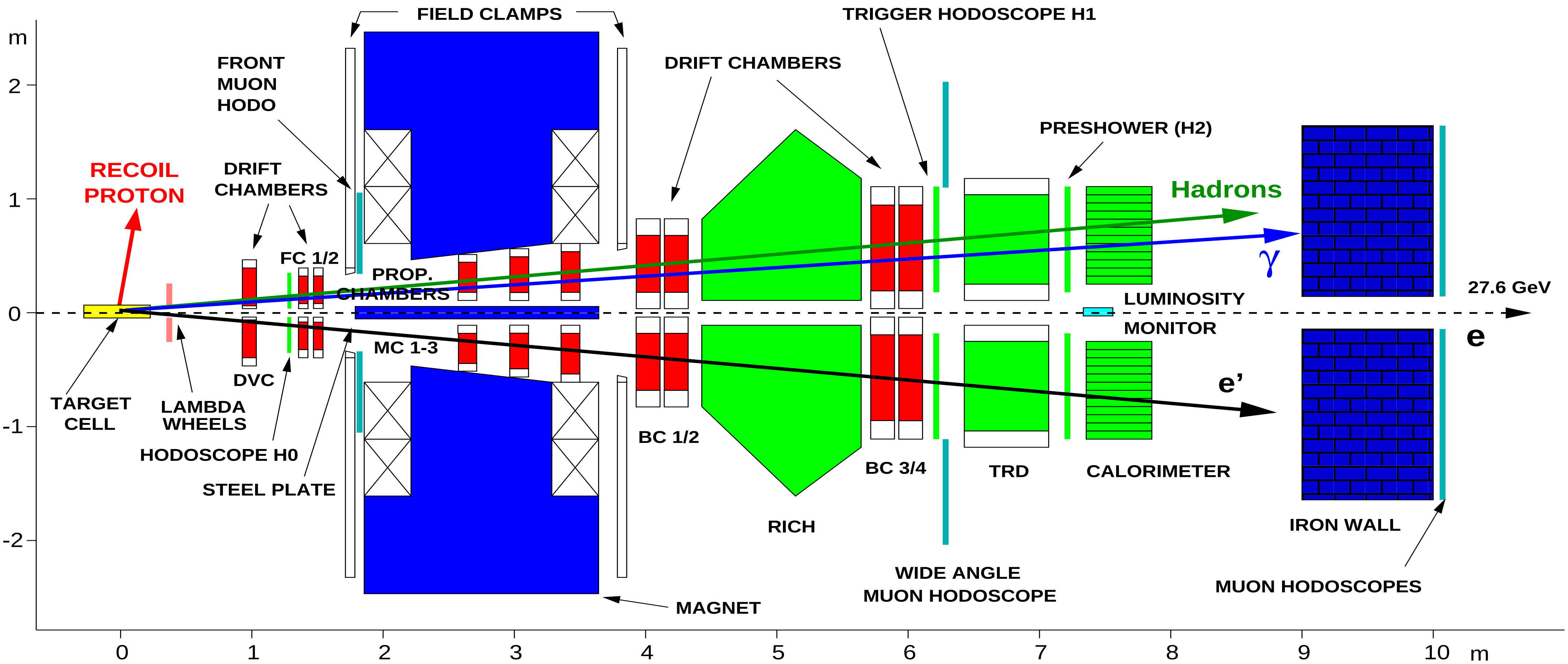
$$T_{10} \sim L \to T : \qquad \mathcal{H}^V \propto \frac{\sqrt{-t}}{Q} \frac{\langle k_\perp^2 \rangle^{1/2}}{Q}$$

$$T_{1-1} \sim T \to -T : \qquad \mathcal{H}^V \propto \frac{-t}{Q^2} \frac{\langle k_\perp^2 \rangle^{1/2}}{Q}$$

HERMES Detector is Two Identical Halves of Forward Spectrometer

- Beam: $P = 27.56$ GeV/c, $50 ... 100$ mA, longitudinal polarization $\sim 55\%$, accuracy of 2%

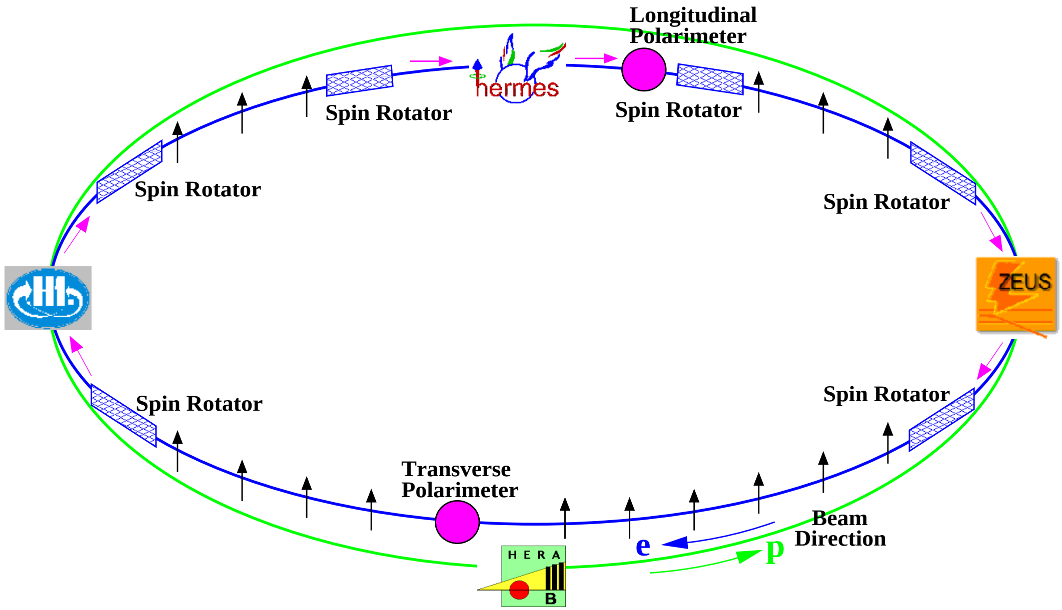
- Target: ^{1}H, ^{2}H gases, integrated over polarization states

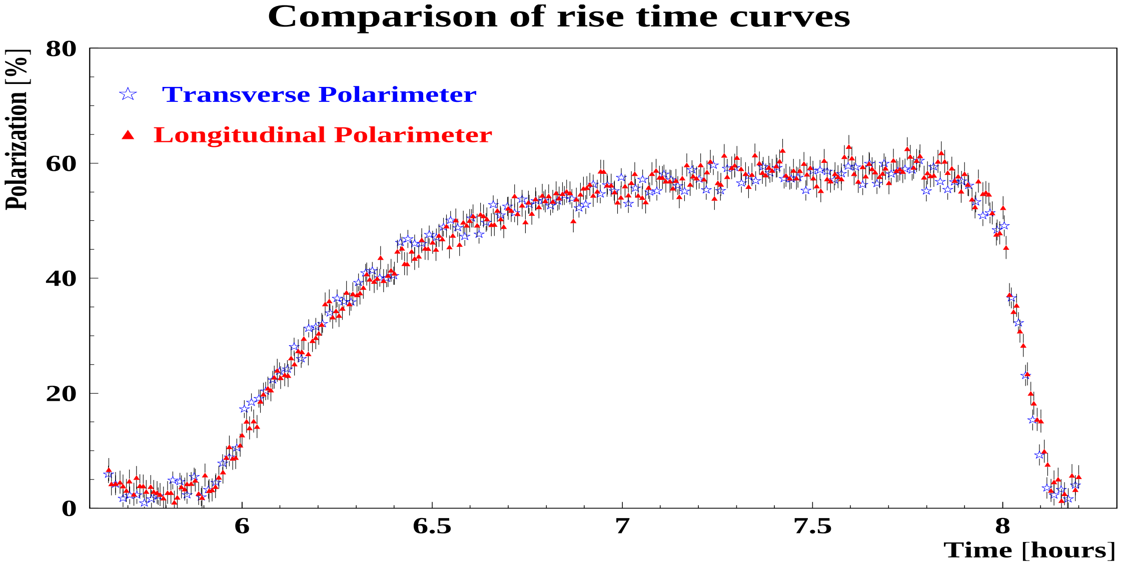


- Acceptance: $40 < \Theta < 220$ mrad, $|\Theta_x| < 170$ mrad, $40 < |\Theta_y| < 140$ mrad

Longitudinally Polarized $e^{+(-)}$ Beam at HERA

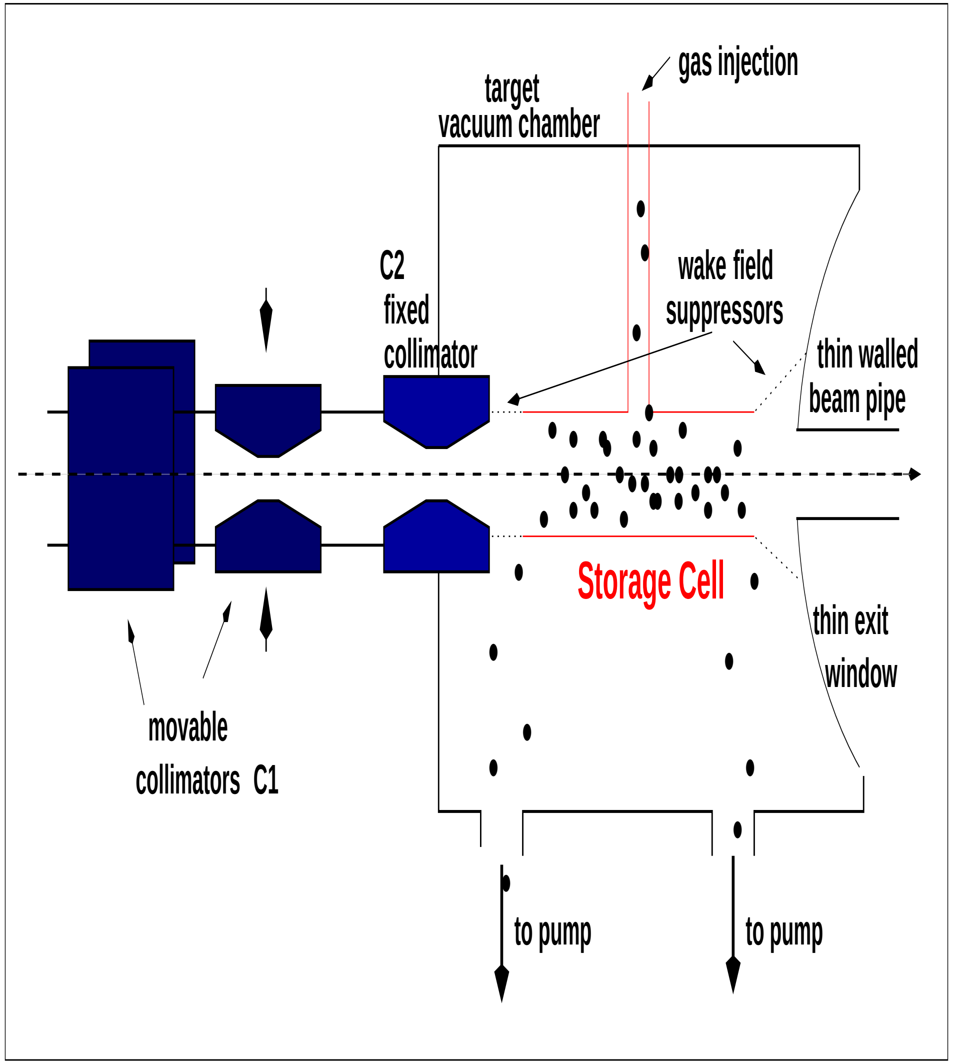
$P = 27.56$ GeV/c, current $50 \ldots 100$ mA, polarization of about 55%, measured with accuracy of 2%

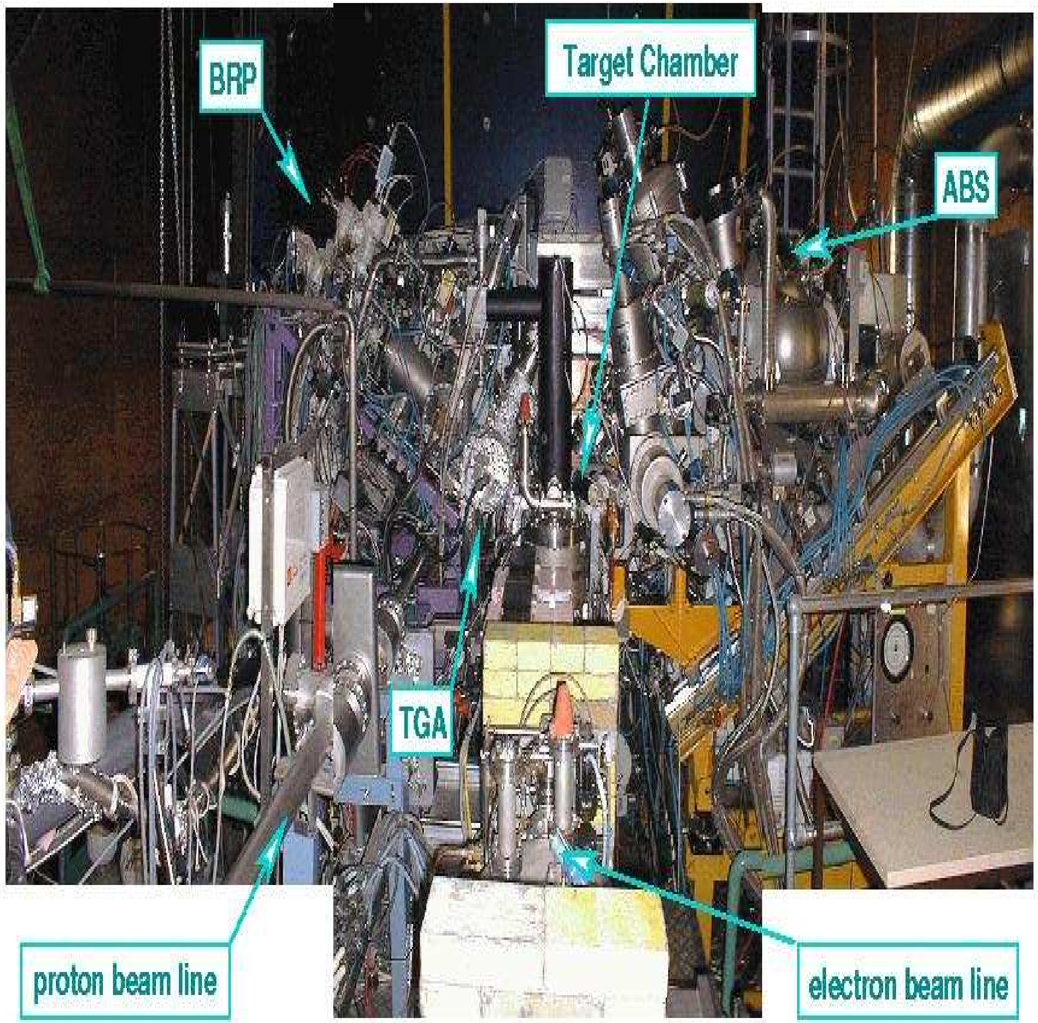




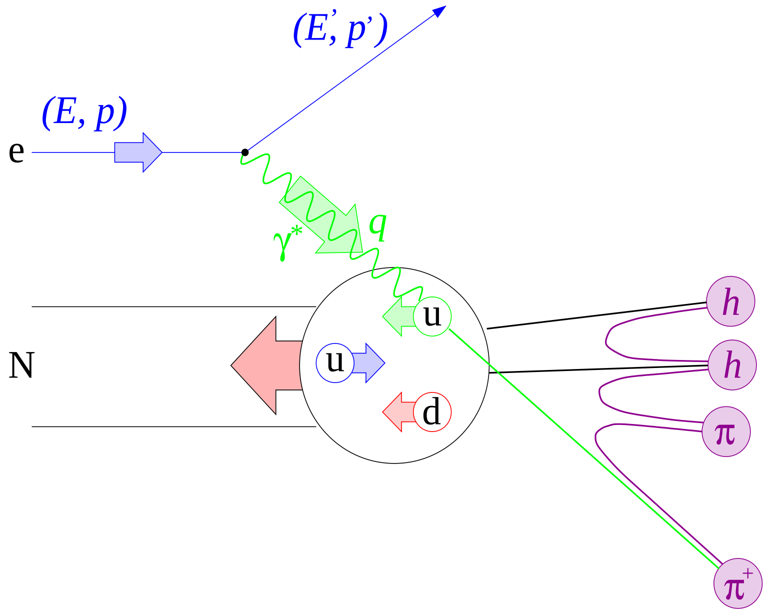
Internal Storage Cell Gas Target

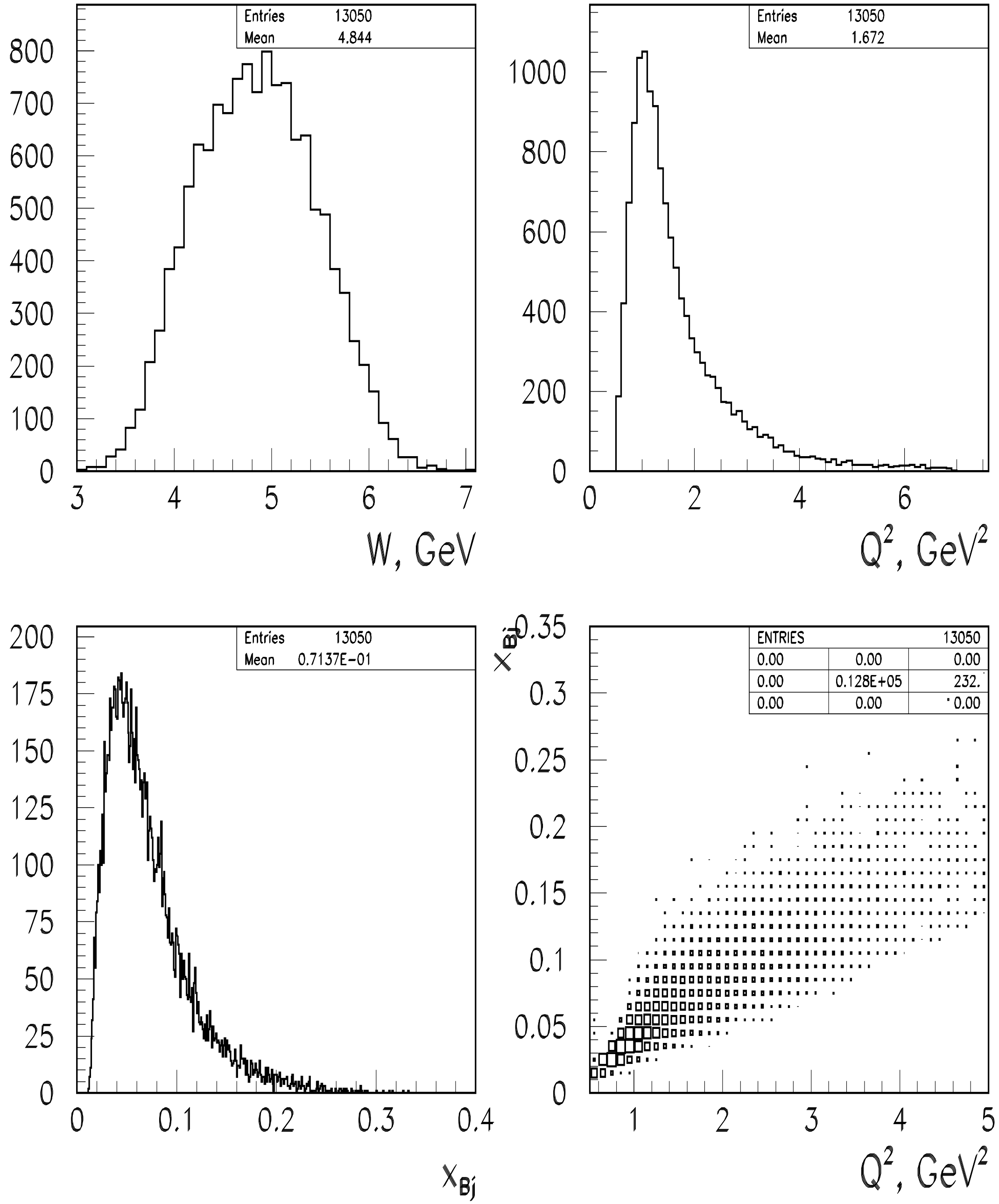
polarized: $\sim 10^{14}$ nucl/cm^2, longitudinal polarization $\sim 98(92)\%$: ^{1}H, (^{2}H); transverse $\sim 76\%$: ^{1}H
unpolarized: $\sim 5 \cdot 10^{15}$ nucl/cm^2: ^{1}H, ^{2}H, ^{4}He, ^{14}N, ^{20}Ne, ^{84}Kr, ^{131}Xe





Deep Inelastic Scattering: Important Variables and Kinematic Distributions

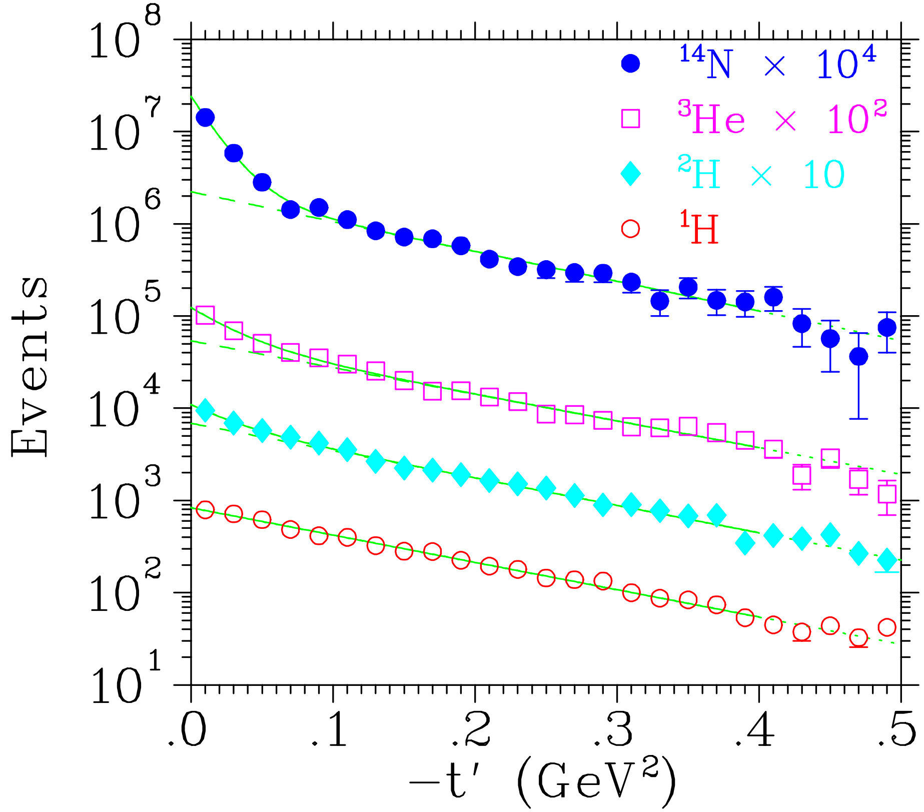


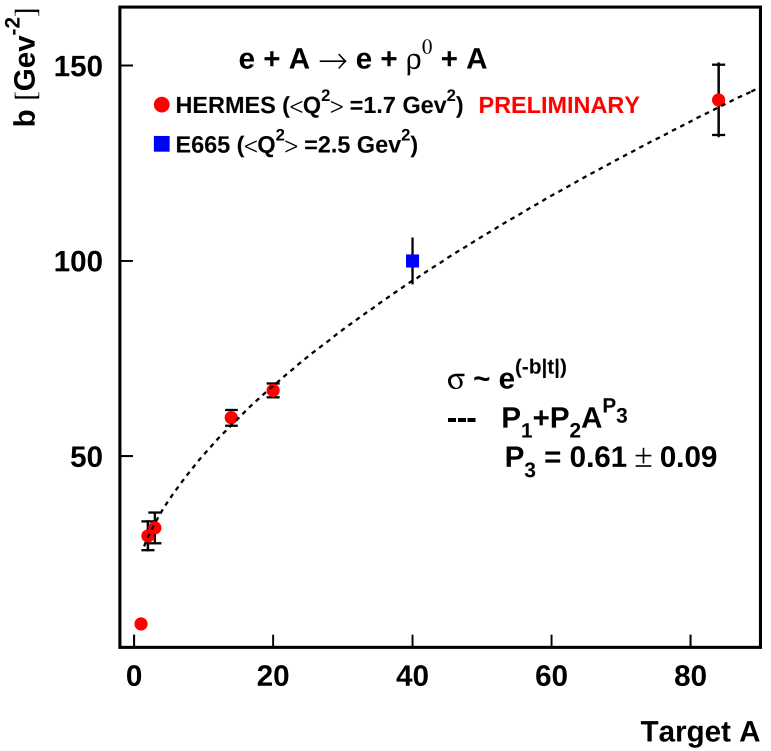


- $Q^2 \stackrel{lab}{=} 4EE' \sin^2(\Theta/2)$
- $\nu \stackrel{lab}{=} E - E'$
- $x_{Bj} \stackrel{lab}{=} Q^2/2M\nu$
- $W^2 \stackrel{lab}{=} M^2 + 2M\nu - Q^2$

Coherent and Incoherent ρ^0 Production

HERMES collab., Phys.Lett.B 513 (2001) 301-310; Eur.Phys.J. C 29, 171 - 179 (2003)



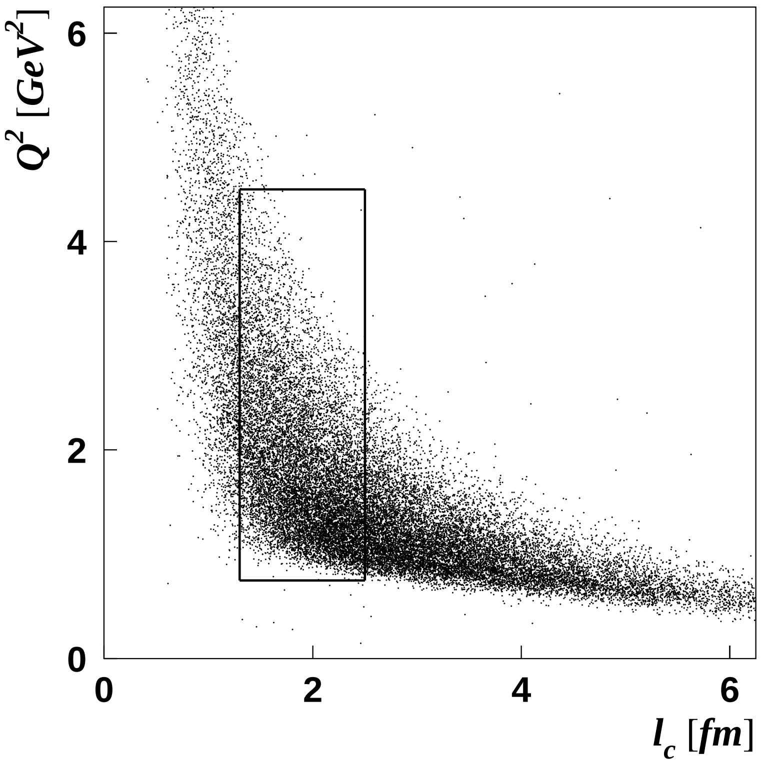


At $-t \lesssim 0.045$ GeV^2 coherent ρ^0 dominates at $-t \gtrsim 0.1$ GeV^2 incoherent.

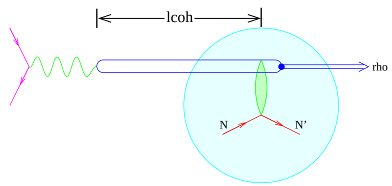
$b_{(coh)} \approx r_A^2/3$ is in agreement with world data of nuclear size measurements

(H.Alvensleben et al,Phys.Rev.Let. **24**,792 (1970)).

Kinematics of exclusive ρ^o matches dimension of Nuclei



- radius of the nucleus: $r_{14_N} \simeq 2.5$ fm
- coherence length: distance traversed by qq



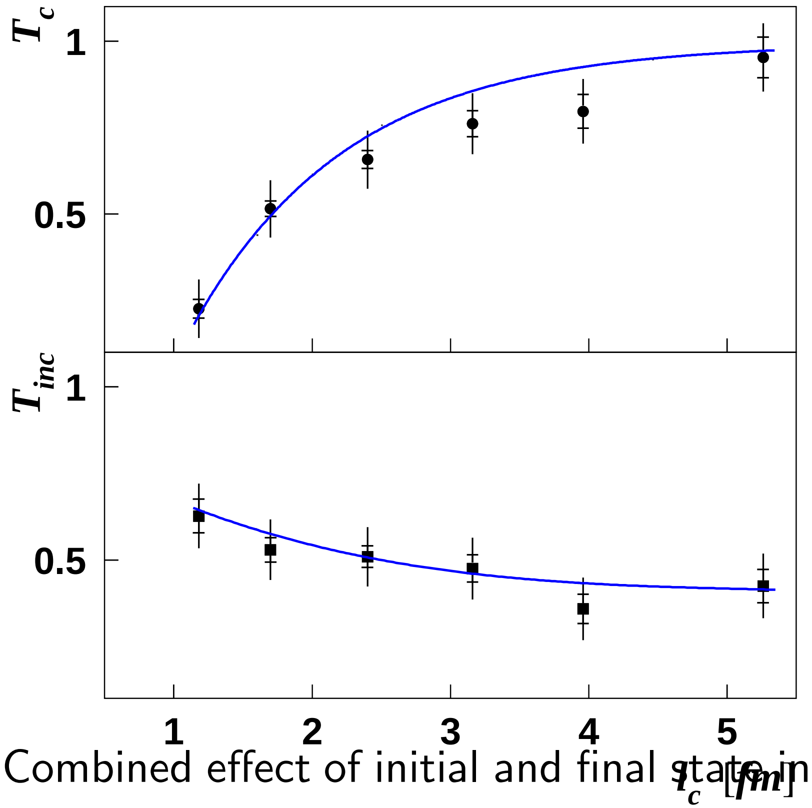
$l_c = \frac{2 \cdot \nu}{Q^2 + m_V^2} = 0.6 \div 8$ fm,
$< l_c >= 2.7$ fm

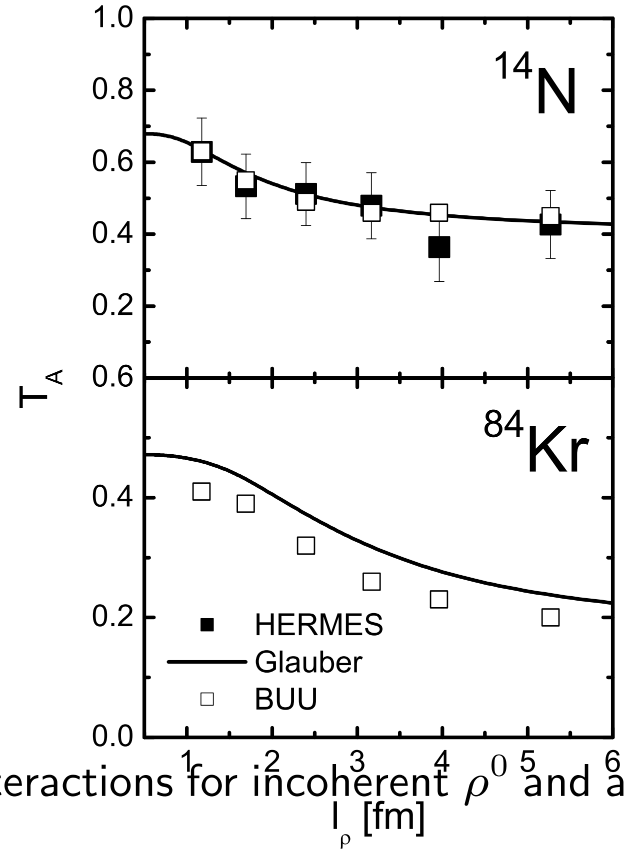
- transverse size of the qq wave packet
$r_{q\bar{q}} \sim 1/ < Q^2 > \simeq 0.4$ fm $< r_p = 1$ fm
- formation length: distance needed for qq to develop into hadron:
$l_{form} = \frac{2 \cdot \nu}{m_{V'}^2 - m_V^2} = 1.3 \div 6.3$ fm
$< l_{form} >= 3.47$ fm

$\longrightarrow$ ρ^0 absorbtion at $l_c \gtrless r_{14_N}$
$\longrightarrow$ 2-dimensional analysis of Q^2, l_c dependences

Coherent Length Effect

(HERMES collab., Phys.Rev.Let., **90**, 5, 2003) $T_{c/inc}(l_c) = \frac{\sigma_{Ac/inc}}{A\sigma_H} = \frac{N_{Ac/inc} \cdot L_H}{A \cdot N_H \cdot L_A}$, $A = ^{14}$N

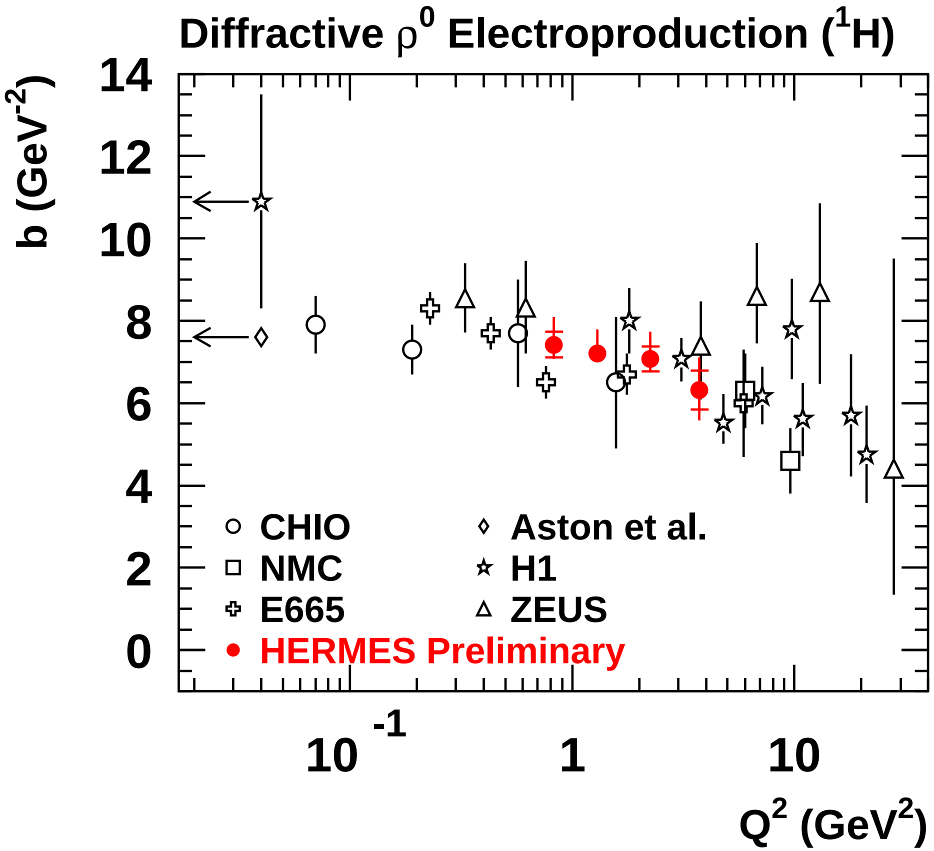




Combined effect of initial and final state interactions for incoherent ρ^0 and additionional effect of nuclear formfactor for coherent ρ^0. Agreement with calculations (blue curves, left panel) based on CT aprroach (B.Z. Kopeliovich et al, Phys.Rev. C, **65**, 035201, 2002).

Calculations for incoherent production of semi-classical transport model without CT presented on right panel. (T.Falter, W.Cassing, K.Gallmeister and U.Mosel, nucl-th/0309057).

b(Q^2) 'Photon Shrinkage' a Prerequisite for Color Transparency



→ Size of virtual photon controlled via Q^2

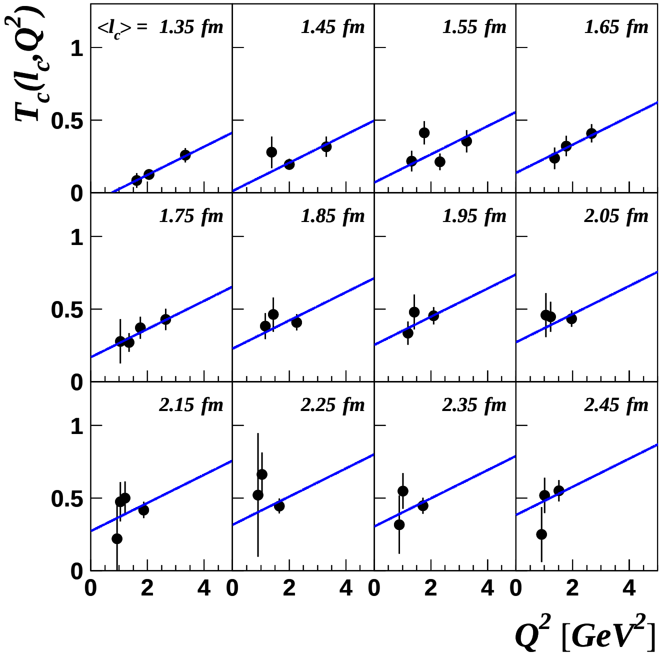
→ No strong W−dependence

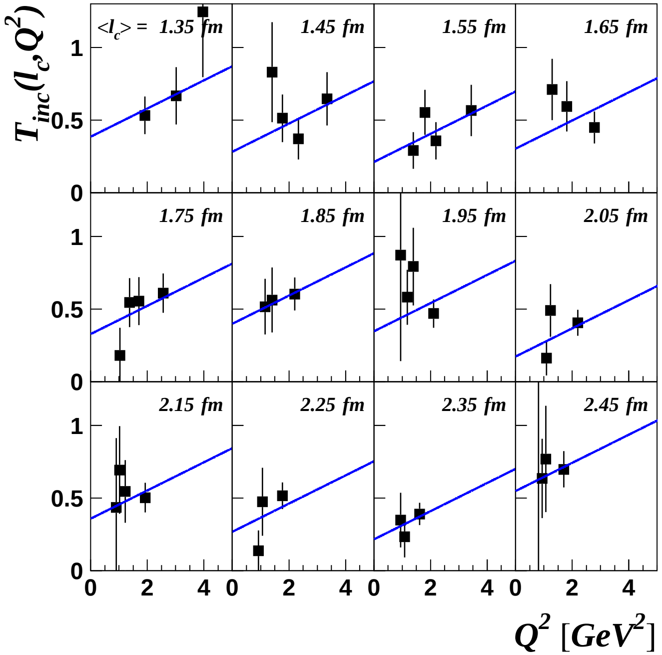
Color Transparency Effect

(HERMES collab., Phys.Rev.Let.,**90**,5,052501,2003) The QCD factorization theorem rigorously not possible without the onset of the color transparency:

$\rightarrow r(qq)$ decreases with the increase of Q^2 $\rightarrow Tr^A(Q^2, l_{coh}) = \sigma^A_{(in)coh}/\sigma^H$ grows with Q^2

At fixed l_{coh}:





data	Slope of Q^2-dependence, GeV^{-2}	Prediction, GeV^{-2}
N incoh.	$0.089 \pm 0.046_{st} \pm 0.020_{syst}$	0.060
N coh.	$0.070 \pm 0.027_{st} \pm 0.017_{syst}$	0.048
N combined	0.074 ± 0.023	0.058

Agreement with theoretical calculations where positive slope of Q^2-dependence was derived from the onset of the color transparency effect (B.Z. Kopeliovich et al, Phys.Rev. C, **65**, 035201, 2002)