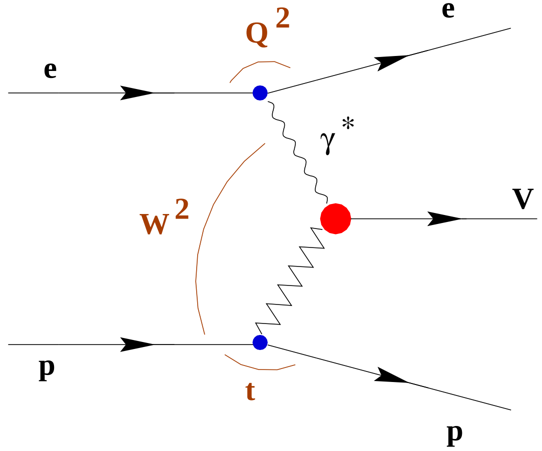
BARYONS'07, Seul, Korea, 14.06.2007

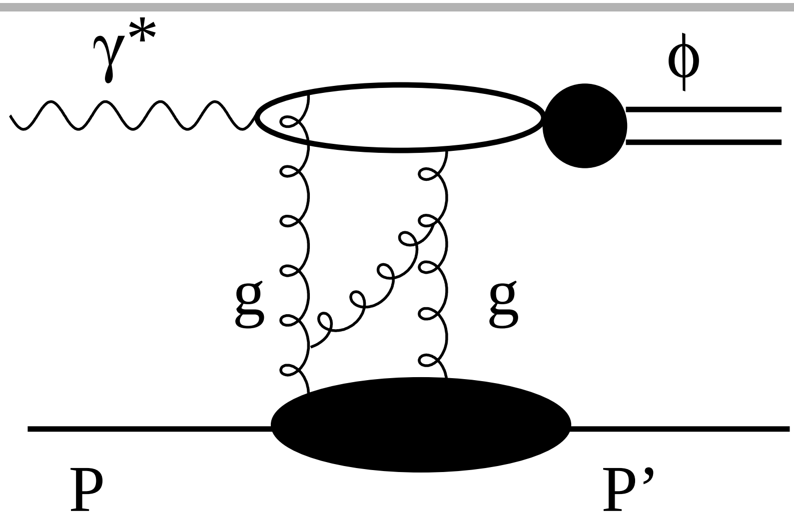
New results on exclusive ρ^0 and ϕ meson production at hermes

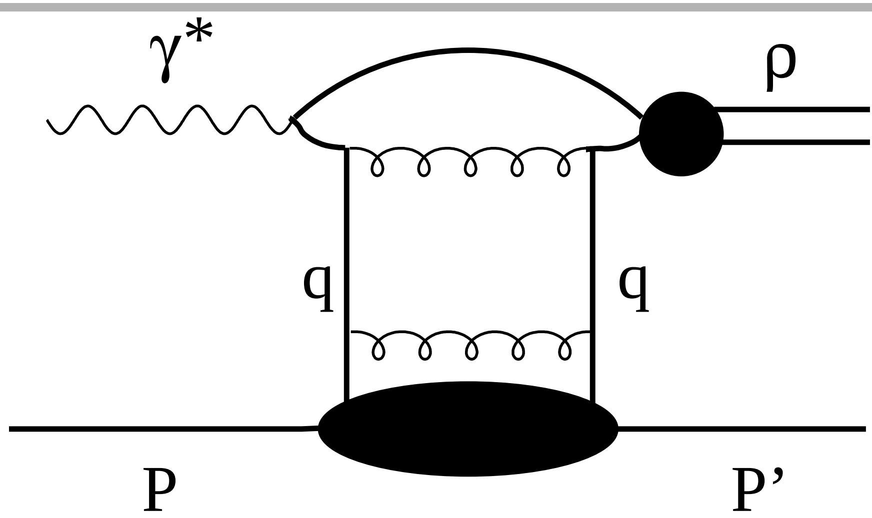
- Objectives: Generalized Parton Distributions
- HERMES Experiment
- Total and Longitudinal Cross Sections of ρ^0 and ϕ
- ρ^0 and ϕ Meson Spin Density Matrix Elements
  - Kinematic dependences
  - Longitudinal-to-Transverse Cross-Section Ratios
  - Hierarchy of Helicity Amplitudes
  - Unnatural Parity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



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, $\tilde{H}$
  - pseudoscalar or axial meson: π, a_1, b_1 (unnatural parity $J^P = 0^-, 1^+$)

    $\Longrightarrow$ polarized GPDs: E, $\tilde{E}$

Experimental observables:

- total (σ_{tot}) and logitudinal (σ_L) cross sections:
  $\sigma_L = \frac{R}{1+\epsilon R}\sigma_{tot}$, where $R = \sigma_L/\sigma_T = \frac{r^{04}_{00}}{\epsilon(1-r^{04}_{00})}$

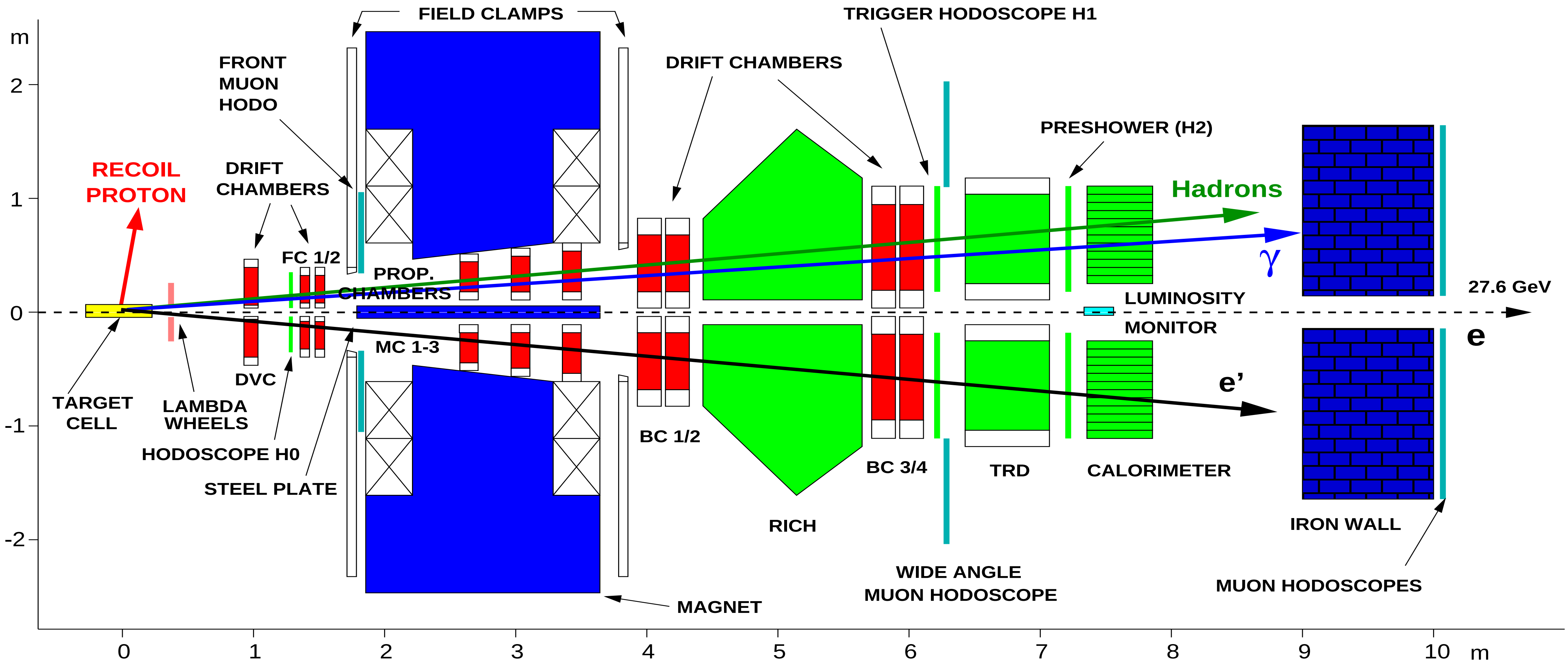
- Spin Density Matrix Elements (SDMEs):
  $r^{\alpha}_{\lambda_\rho \lambda'_\rho} \sim \rho(V) = \frac{1}{2} T \rho(\gamma) T^+$
  Vector meson spin-density matrix $\rho(V)$ in terms of the photon matrix $\rho(\gamma)$ and helicity amplitude $T_{\lambda_V \lambda_\gamma}$

- SCHC: helicity of $\gamma^* =$ helicity of ρ^0, any violation?

- Extracted from SDMEs Natural and Unnatural Parity Helicity Amplitudes

HERMES Detector is Two Identical Halves of Forward Spectrometer

- Beam: $P = 27.56$ GeV/c, $50 \ldots 100$ mA, longitudinal polarization $\sim 55\%$, accuracy of 2%
- Target: ^{1}H, ^{2}H gases, integrated over polarization states



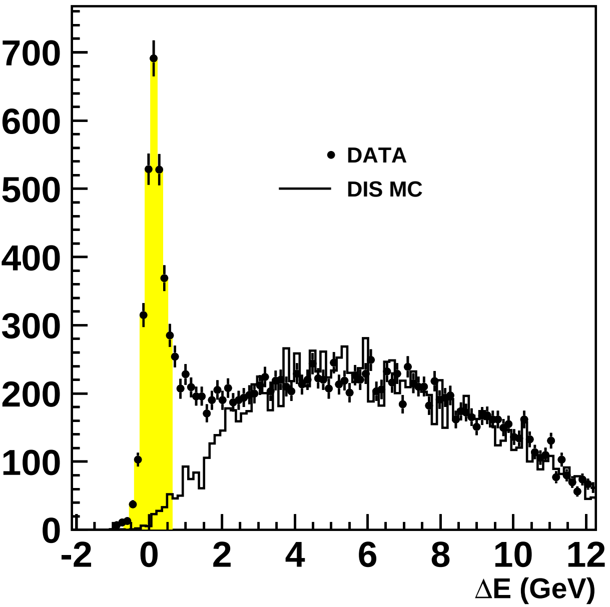
- Acceptance: $40 < \Theta < 220$ mrad, $|\Theta_x| < 170$ mrad, $40 < |\Theta_y| < 140$ mrad
- Resolution: $\delta p/p \leq 1\%$, $\delta\Theta \leq 0.6$ mrad

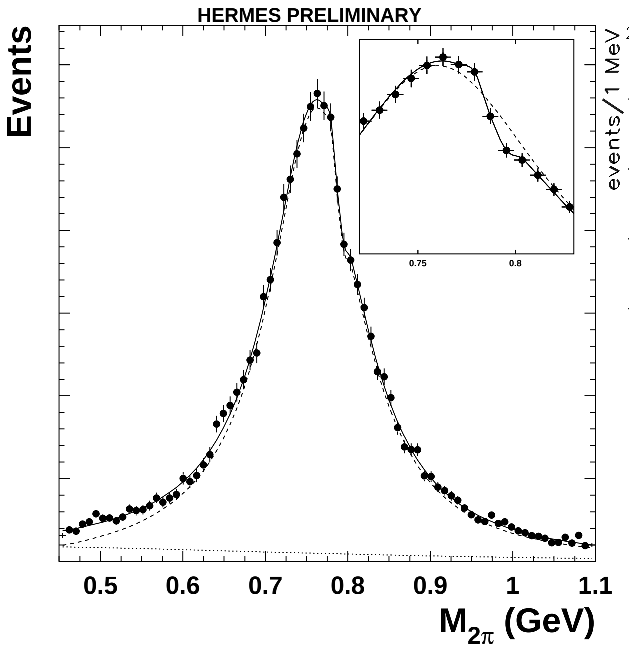
Kinematics of exclusive ρ^0 and ϕ meson production

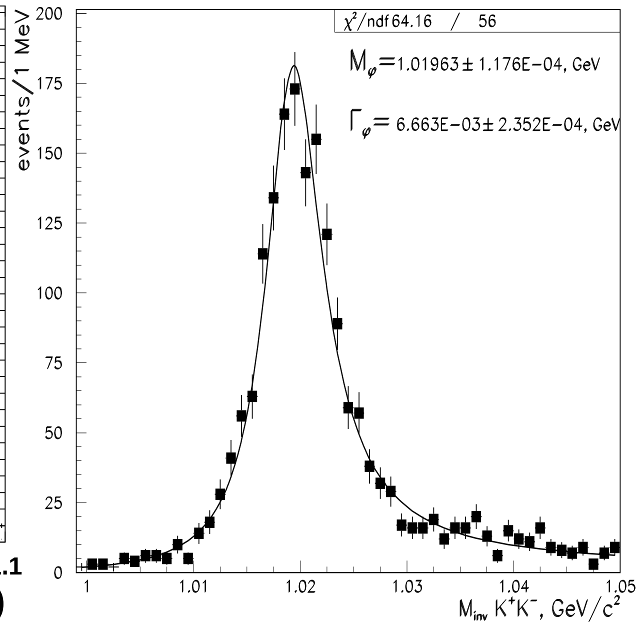
$$e + p \rightarrow e' + p' + \rho^0 \rightarrow \pi^+\pi^- \qquad\qquad e + p \rightarrow e' + p' + \phi \rightarrow K^+K^-$$

Clean ρ^0 exclusivity peak

$\Delta E = \frac{M_X^2 - M_p^2}{2M_p}$, $M_X^2 = (p + q - v)^2$, $\quad$ $M_{inv}: \rho^0 \rightarrow \pi^+\pi^-$ $\qquad$ $\phi \rightarrow K^+K^-$





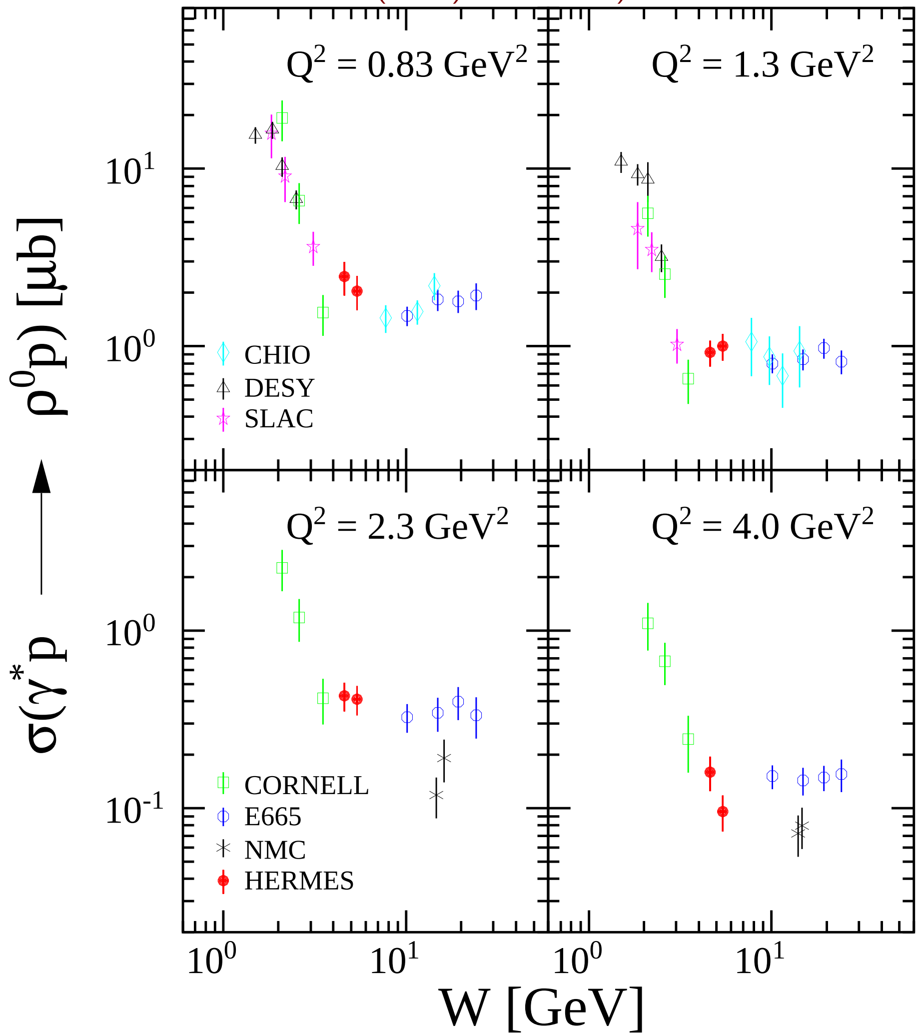


- Background is subtracted using MC (PYTHIA)

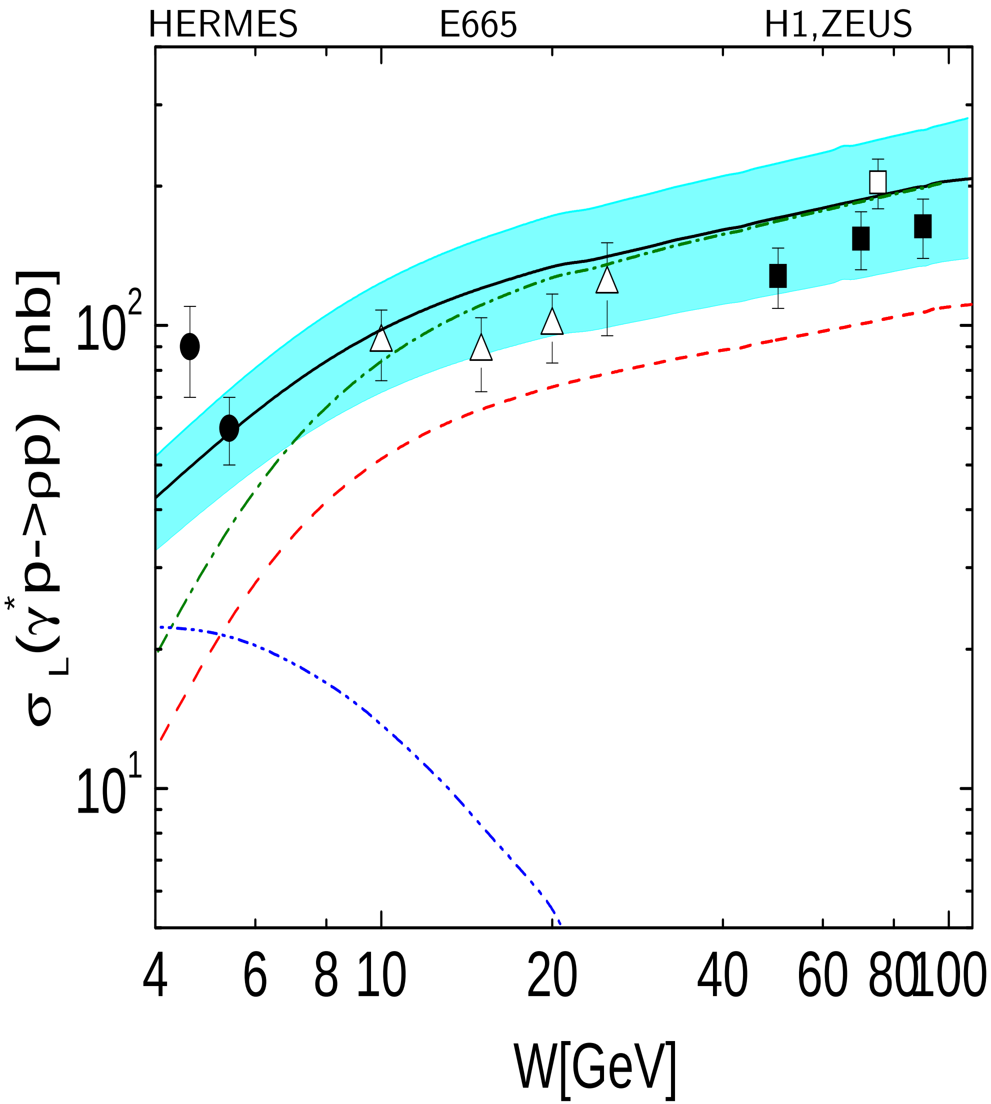
- $\nu = 5 \div 24$ GeV, $<\nu>= 13.3$ GeV, $\qquad Q^2 = 1.0 \div 5.0$ GeV^2, $< Q^2 >= 2.3$ GeV^2
- $W = 3.0 \div 6.5$ GeV, $< W >= 4.9$ GeV, $\quad x_{Bj} = 0.01 \div 0.35, < x_{Bj} >= 0.07$

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

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



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



→ HERMES data in the transition region

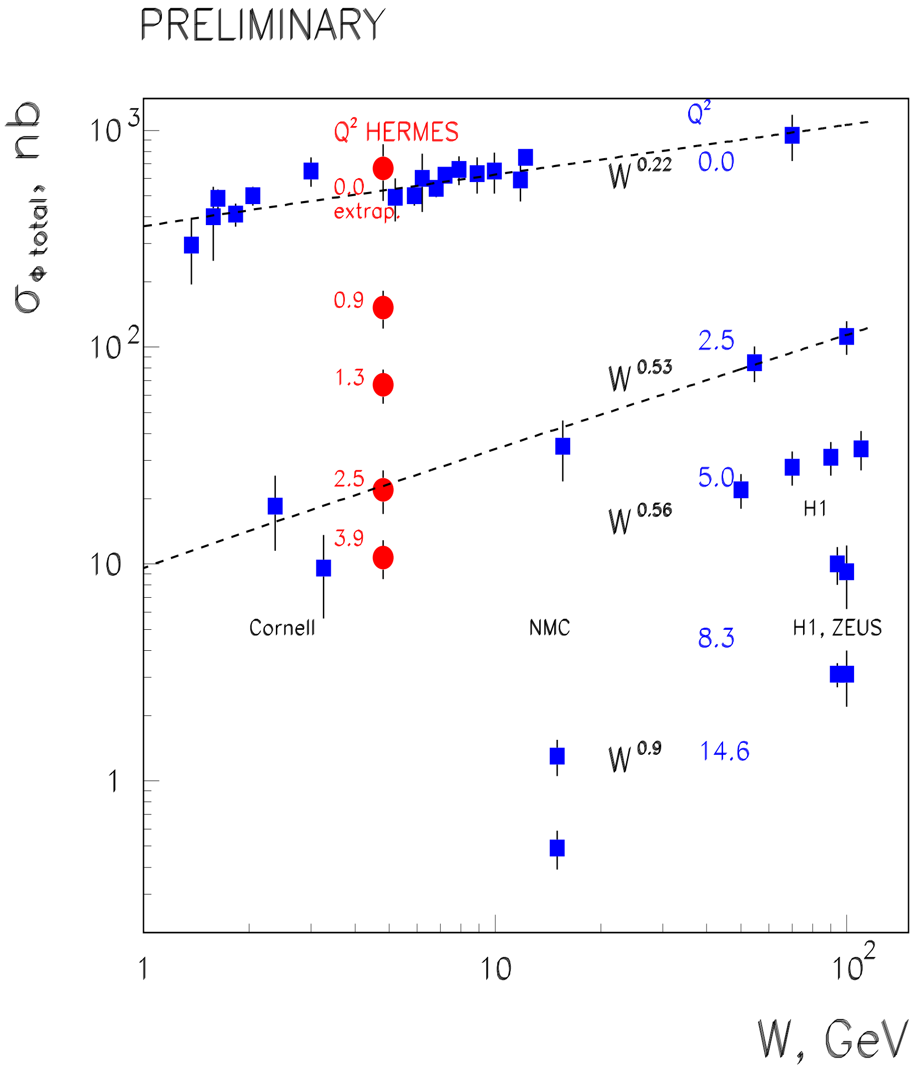
→ which production mechanisms are involved?

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

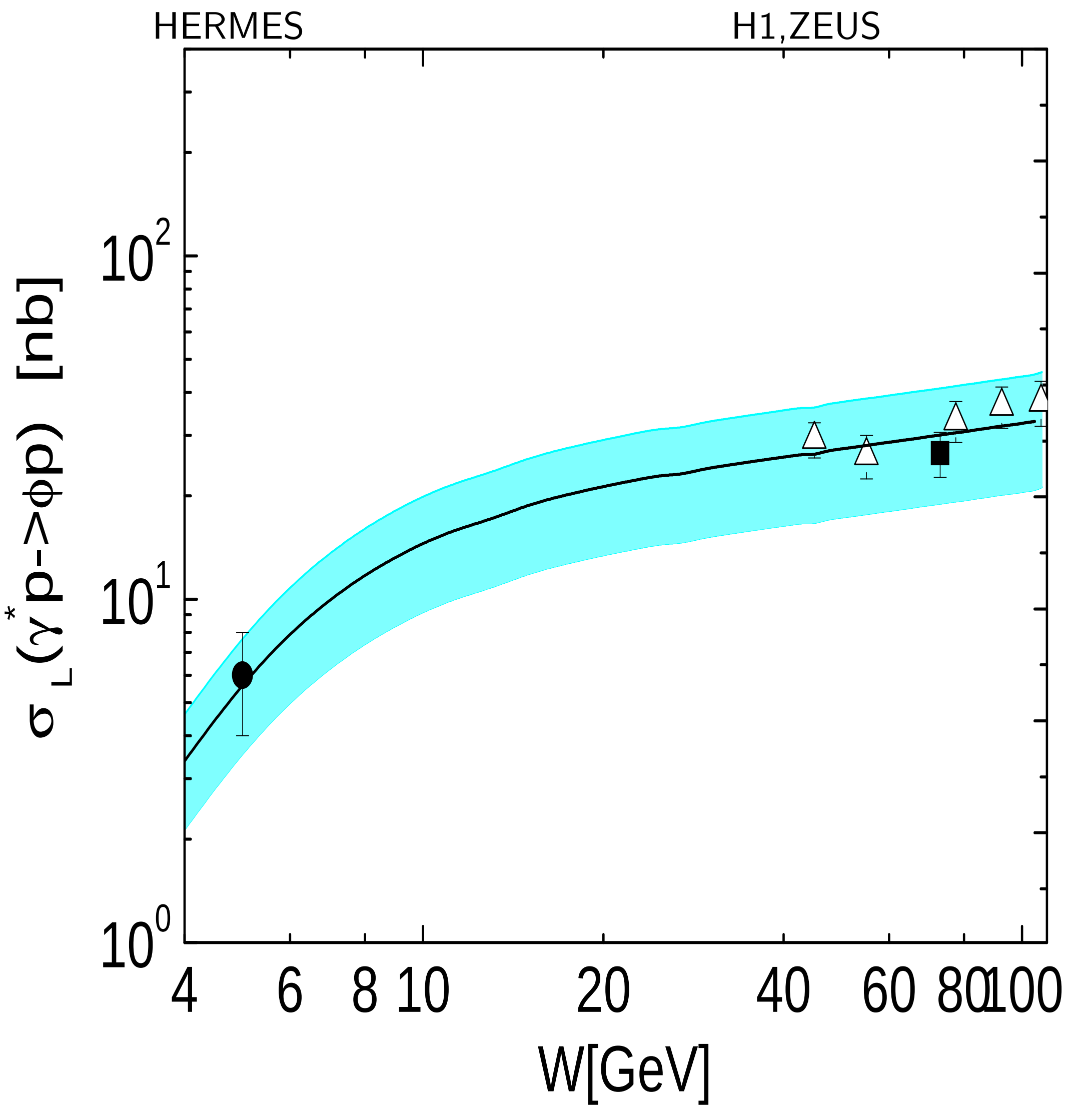
Band represents uncertainties in σ_L from Parton Distributions

$\Longrightarrow$ 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



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

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

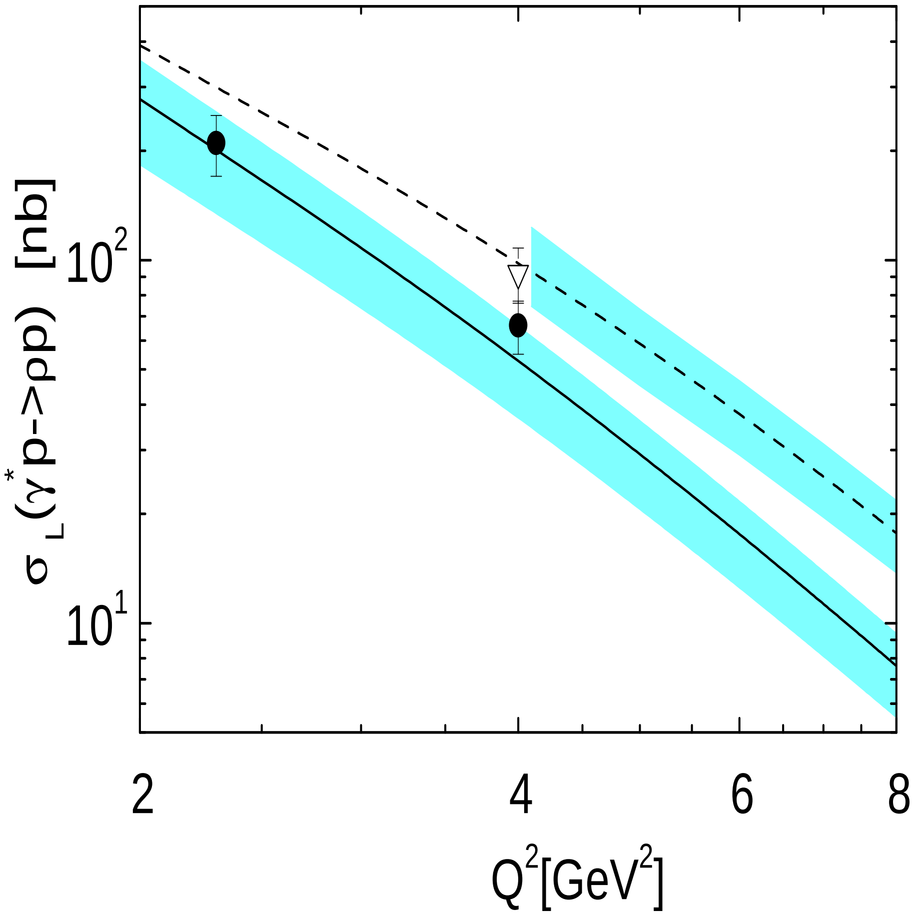
→ Two-gluon exchange is sufficient for ϕ

ϕ: two-gluon exchange only

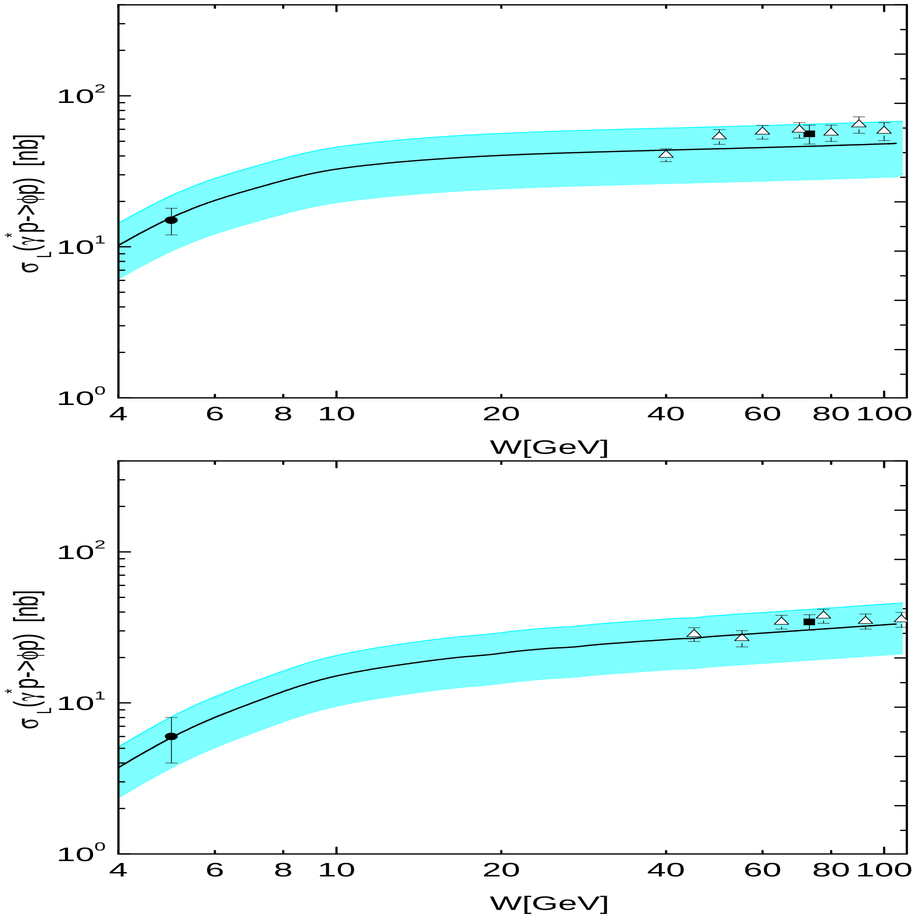
Band represents uncertainties in σ_L from Parton Distributions

⟹ **Good agreement of GK $\sigma_L(W)$-dependence**

Q^2-dependence of σ_L from GK model for ρ^0 and ϕ at HERMES



$W = 5$ GeV, black circules - HERMES



Top: $Q^2 = 2.4$ GeV^2

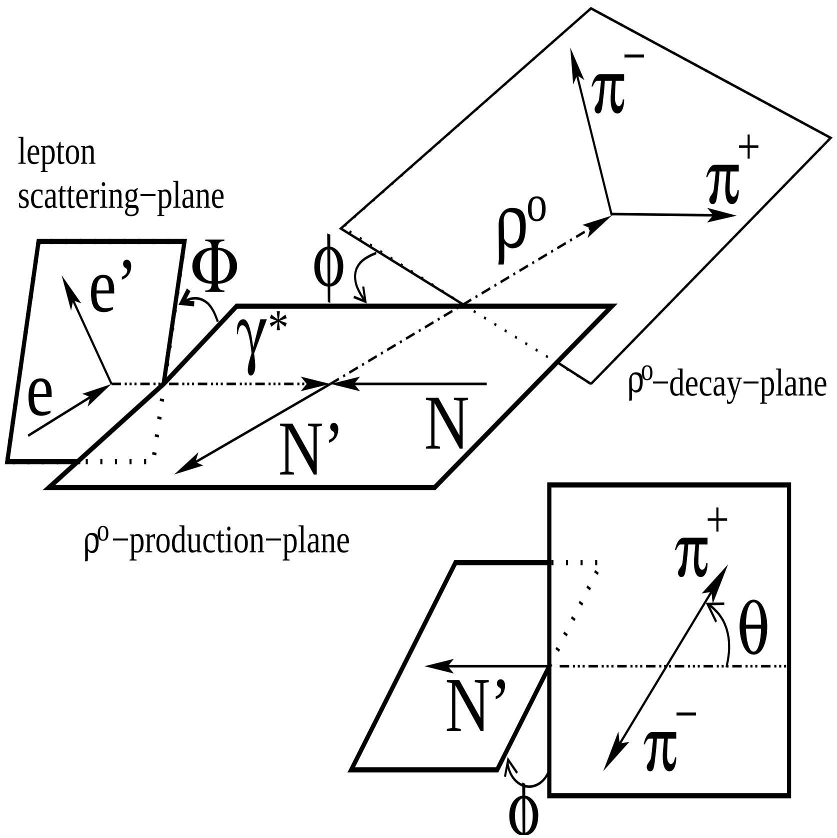
Bottom: $Q^2 = 3.8$ GeV^2

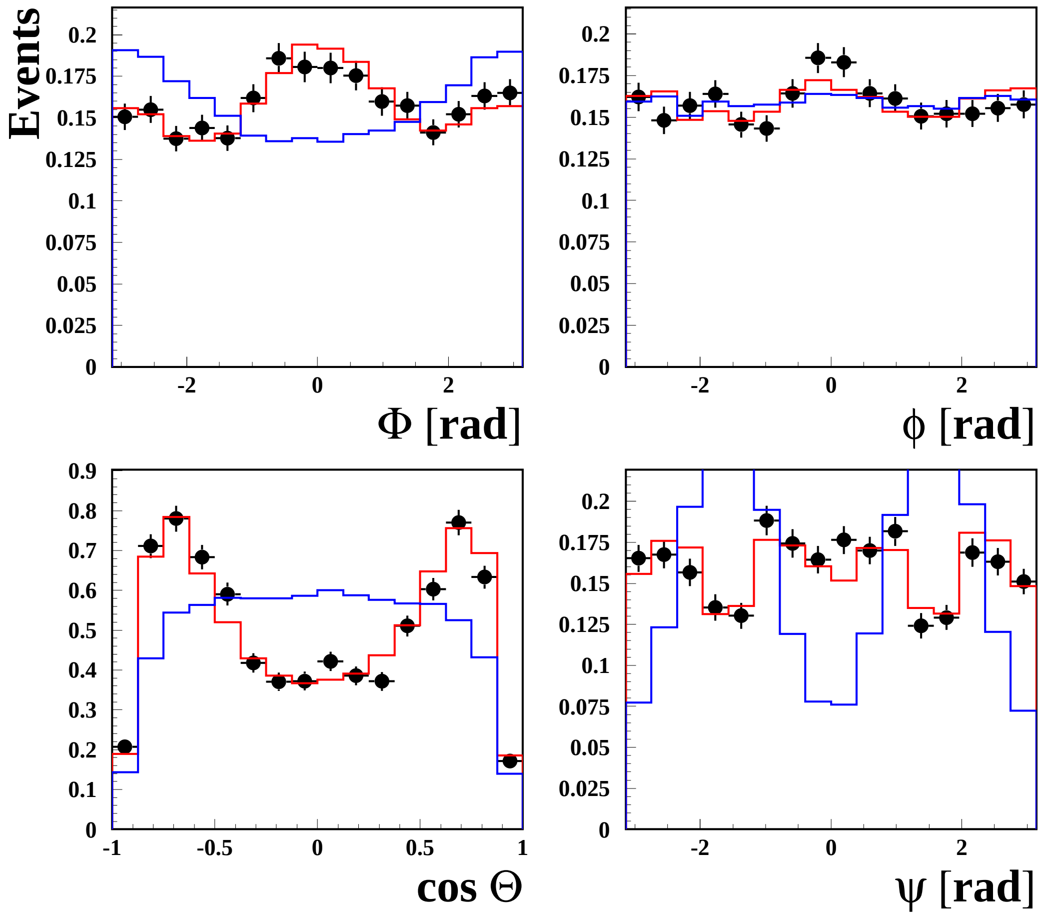
$\rightarrow$ Full agreement of σ_L with HERMES data at $Q^2 > 2.0$ GeV^2

(Uncertainties of HERMES data are smaller then ones from the GK calculations)

$\Longrightarrow$ **What's about σ_T?**

Fit of Angular Distributions Using Max. Likelihood Method in MINUIT



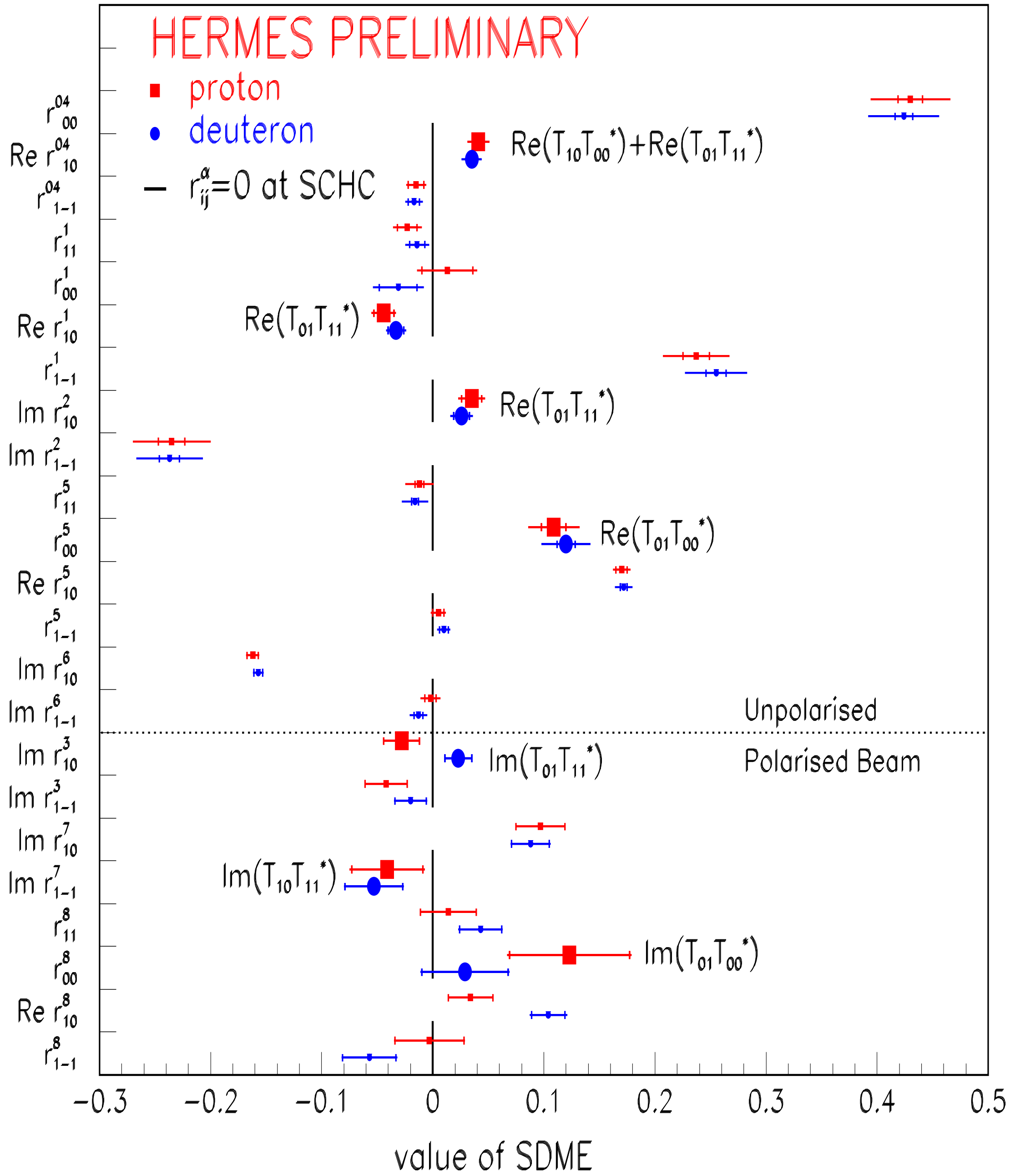


- Simulated Events: matrix of fully reconstructed MC events at initial uniform angular distribution
- Binned Maximum Likelihood Method: $8 \times 8 \times 8$ bins of $\cos(\Theta), \phi, \Phi$. Simultaneous fit of 23 SDMEs $r^{\alpha}_{ij} = W(\Phi, \phi, \cos\Theta)$ for data with negative and positive beam helicity ($< P_b >= 53.5\%$)

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

23 Spin Density Matrix Elements $r^{\alpha}_{\lambda_\rho\lambda'_\rho}$ from $\gamma^* + N \to \rho^0 + N'$

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



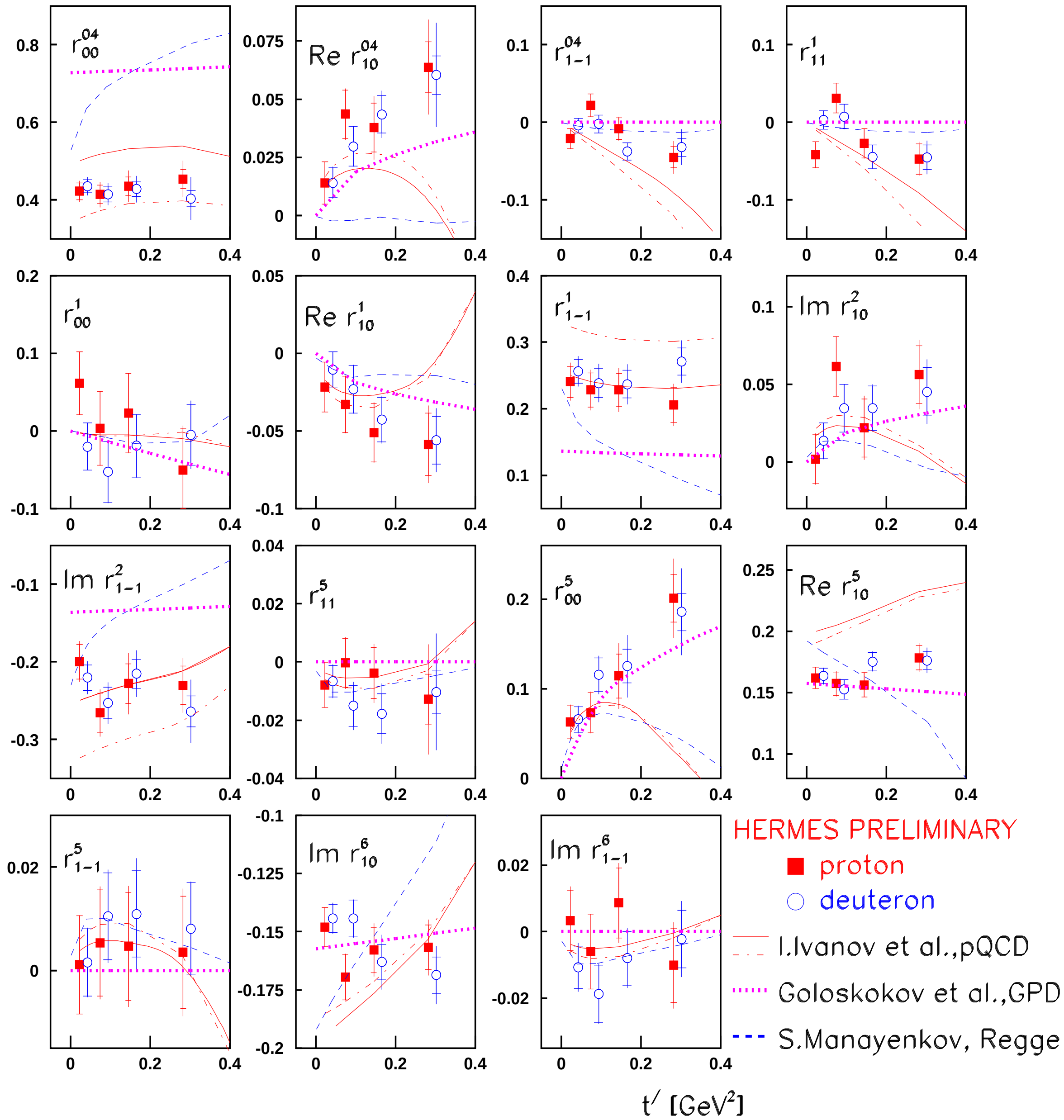
- $\gamma^* + N \to \rho^0(\phi) + N'$ is perfect to study the spin structure of production mechanism:
  - spin state of γ^* is known
  - $\rho^0 \to \pi^+\pi^-$ decay is self-analysing

- SDMEs: $r^{\alpha}_{\lambda_\rho\lambda'_\rho} \sim \rho(V) = \frac{1}{2} T \rho(\gamma) T^+$ in terms of the photon matrix $\rho(\gamma)$ and helicity amplitude $T_{\lambda_V\lambda_\gamma}$
  $\Longrightarrow$ Beam-polarization dependent SDMEs, in a first time

- SCHC?
  $\Longrightarrow$ enlarged SDMEs violating SCHC $(2 \div 5\ \ \sigma)$, indicating non-zero spin-flip amplitudes: T_{01}, T_{10}, T_{1-1}

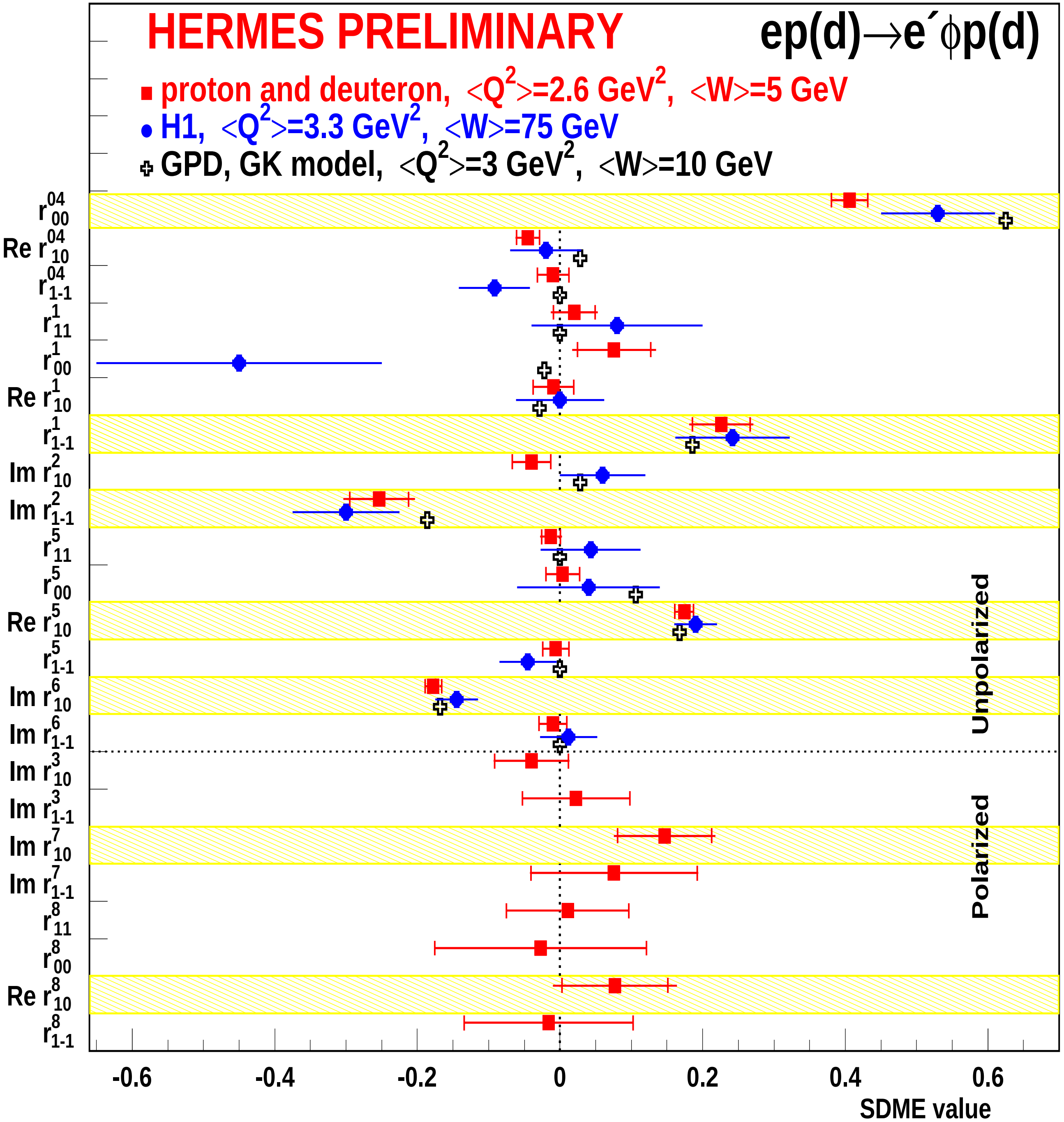
- $q\bar{q}$-exchange with isospin 1 can be observed in case of difference between proton and deuteron data
  $\Longrightarrow$ No significant difference between proton and deuteron

t'-Dependence of ρ^0 SDMEs Compared with Calculations



- GK model calculations done for $Q^2 > 3.0$ GeV^2 for two-gluon exchange only (S.V.Goloskokov and P.Kroll, Eur.Phys.J. C **42** (2005) 281)
- Incorporation of quark-exchange into GK model is under development
- Reasonable agreement for a majority of SDMEs (12 elements) at low t': Re r^{04}_{10}, r^{5}_{00}...
- The most crucial disagreement with data for GK model: r^{04}_{00}, r^{1}_{1-1}, $\mathrm{Im}\{r^{2}_{1-1}\}$ connected with σ_L/σ_T ratio
- No model describes well all unpolarized SDMEs.

ϕ Meson SDMEs Compared with Calculations and High Energy Data



- Note: GK model calculations done for $Q^2 = 3.0$ GeV^2 and two-gluon exchange

  $\Longrightarrow$ Reasonable agreement for a majority of SDMEs

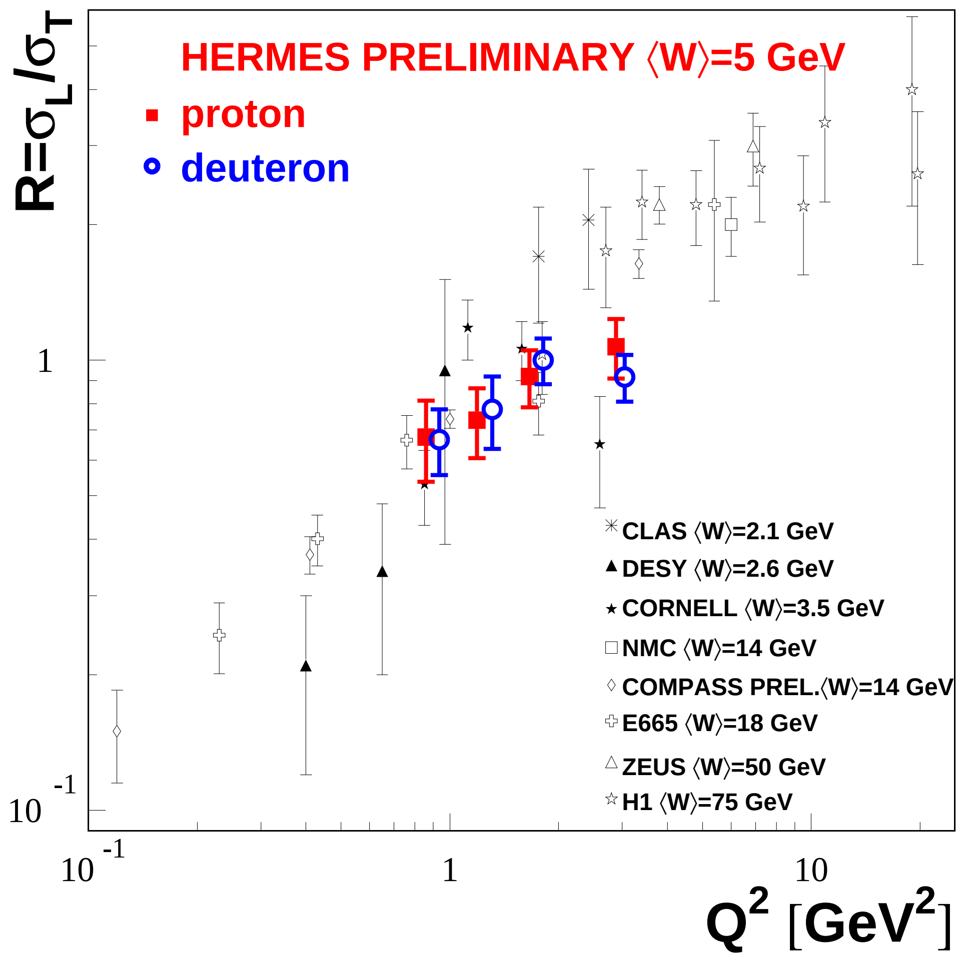
- Disagreement with data for GK Model:
  - $r^{04}_{00} \longrightarrow \sigma_L/\sigma_T$ ratio
  - $r^{5}_{00} \longrightarrow$ SCHC in data, but not in the model

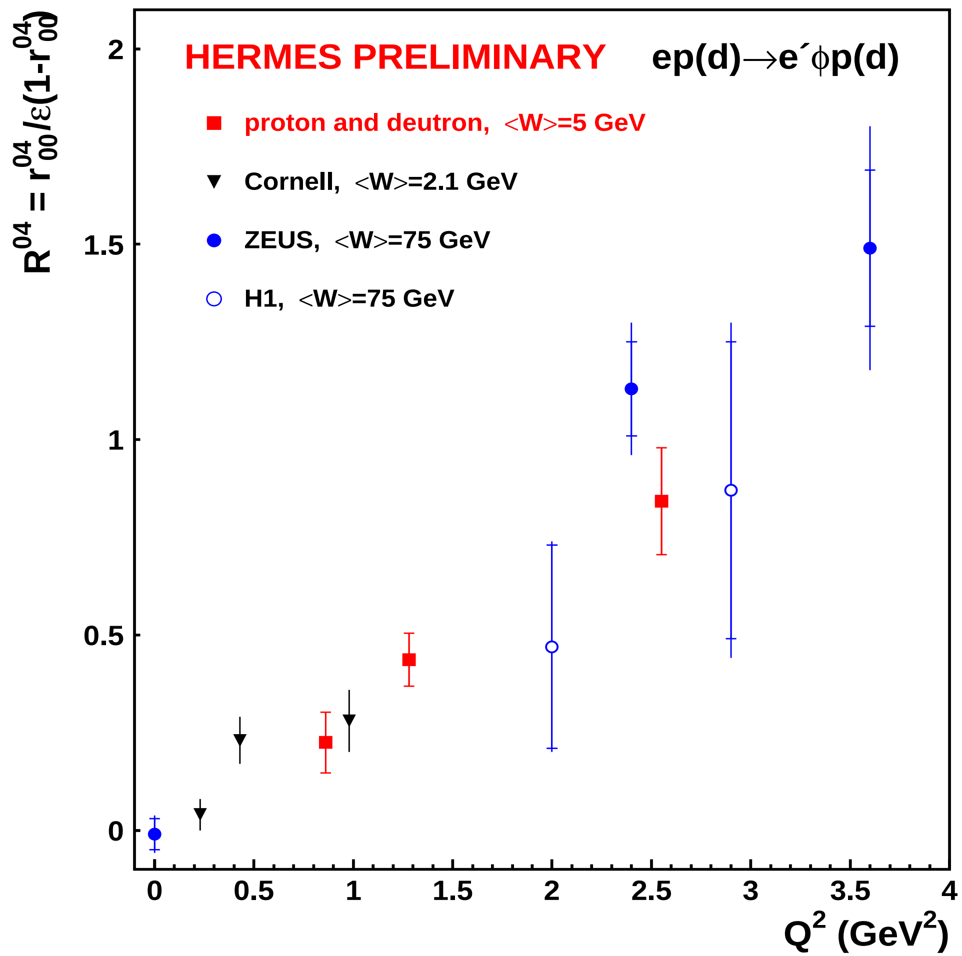
$\Longrightarrow$ Further development of GK model

ρ^0 and ϕ Longitudinal-to-Transverse Cross-Section Ratio $R^{04} = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}$,

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

$\sigma_T = \sum\{|T_{11}|^2 + |T_{01}|^2 + |T_{1-1}|^2 + |U_{11}|^2\}, \quad \sigma_L = \sum\{|T_{00}|^2 + 2|T_{10}|^2\}$





$\Longrightarrow$ 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

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

SDMEs According to Hierarchy of Amplitudes without&with Helicity Flip: ρ^0, ϕ

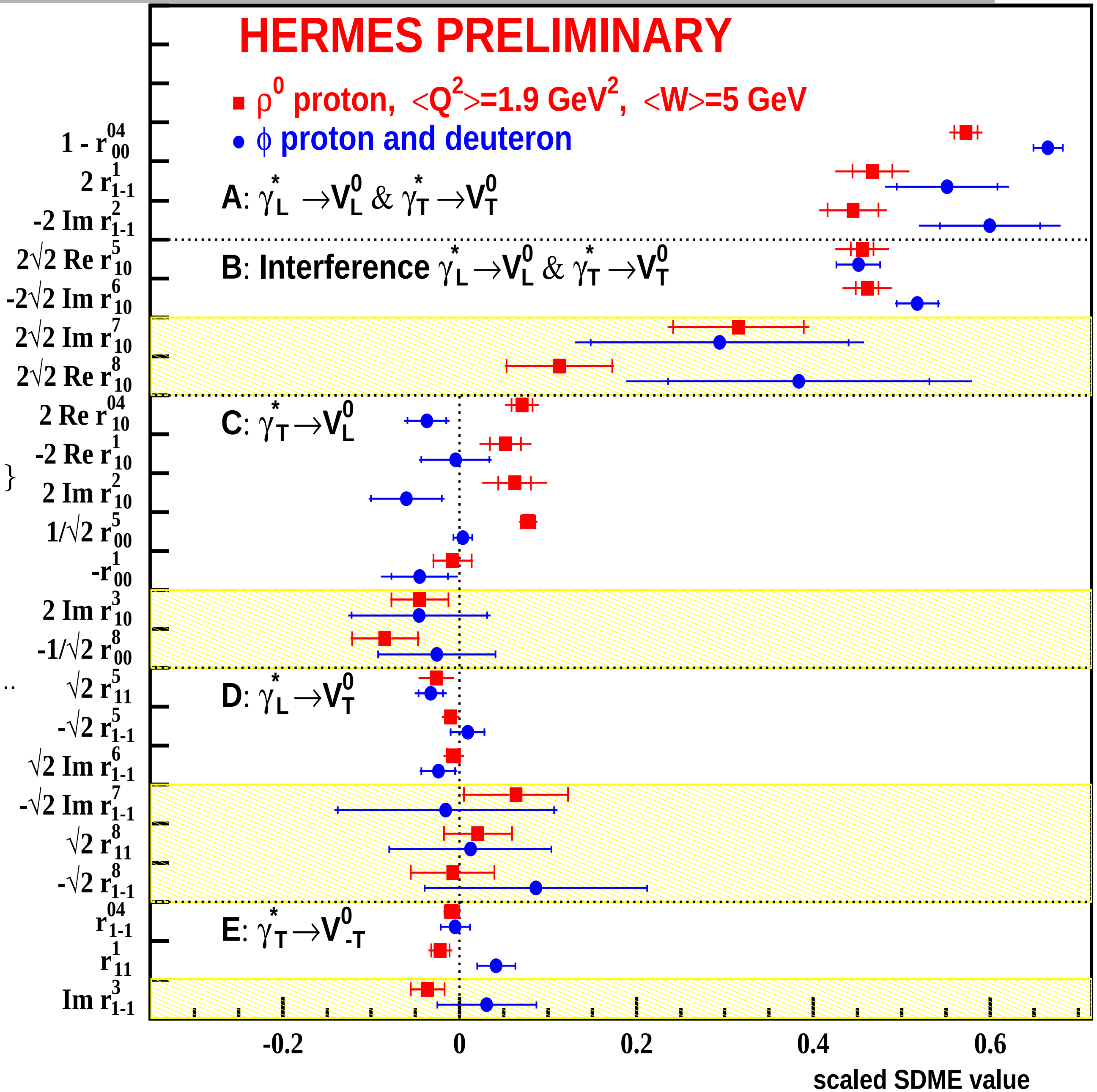
- A, $\gamma^*_L \to \rho^0_L$ and $\gamma^*_T \to \rho^0_T$
  $|T_{11}|^2 \propto 1 - r^{04}_{00} \propto r^1_{1-1} \propto -Im\{r^2_{1-1}\}$

- 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: $\gamma^*_T \to \rho^0_{-T}$
  $Re\{T_{1-1}T^*_{11}\} \propto r^{04}_{1-1} \propto r^1_{11}$
  $Im\{T_{1-1}T^*_{11}\} \propto Im\{r^3_{1-1}\}$

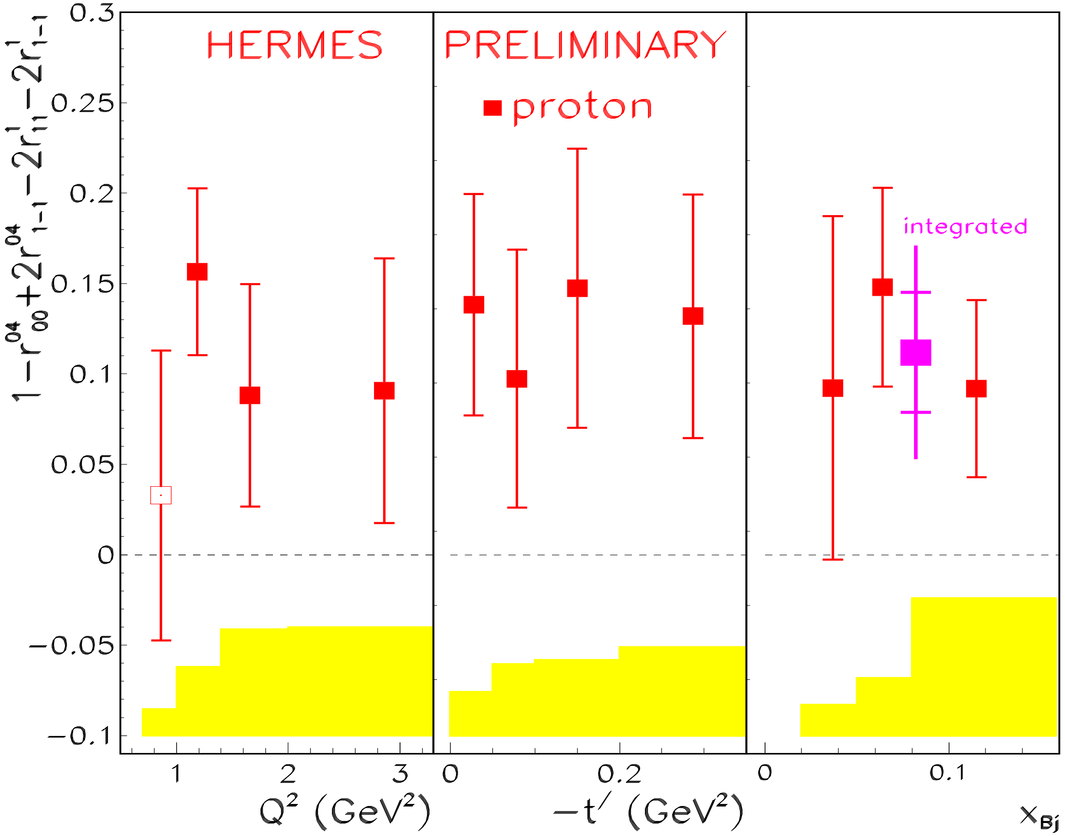


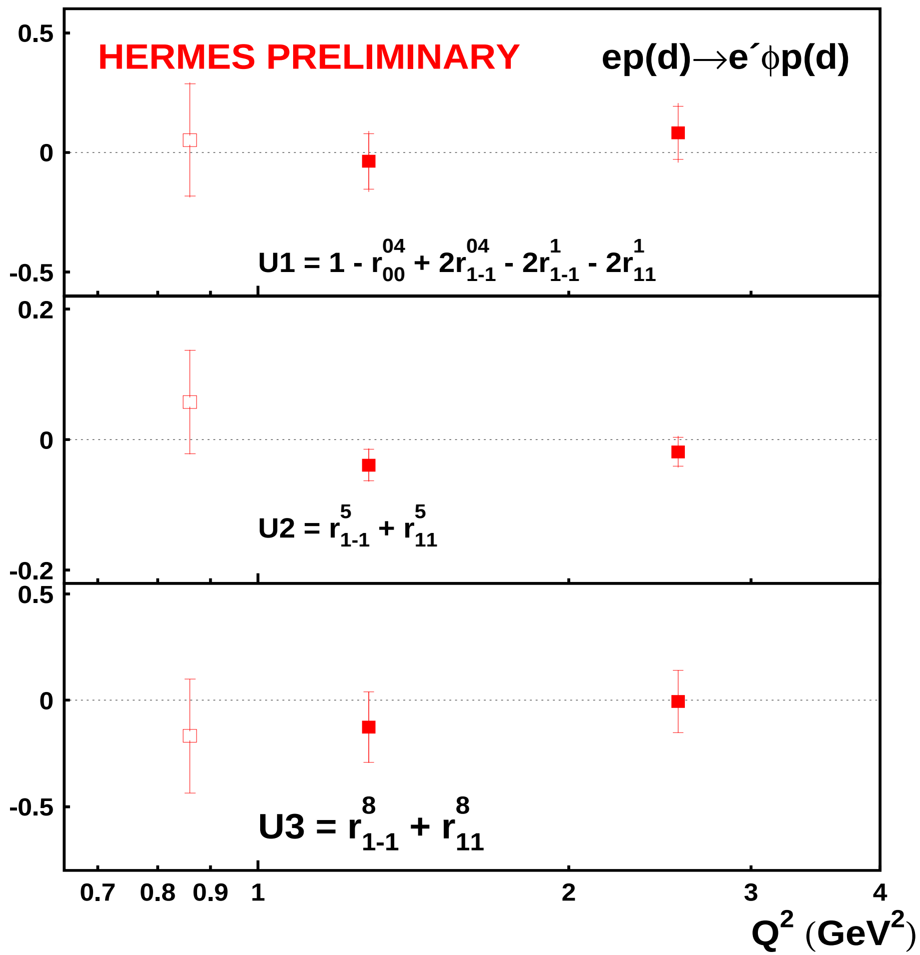
$\Longrightarrow$ **Hierarchy of ρ^0 amplitudes:** $|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \gtrsim |T_{1-1}|$, $(0 \to L, 1 \to T)$

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

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
- UPE amplitudes correspond to the contributions of polarized GPDs: E, $\tilde{E}$





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

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

$U2 \propto |U_{10}|^2 = 0$, $U3 \propto |U_{01}|^2 = 0$

$\Longrightarrow$ **no UPE for ϕ meson production**

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

Summary

- ρ data:
  - Longitudinal cross section well described by GPD models
  - Incorporation of *quark-exchange* mechanism for calculation of 15 beam-polarization-independent SDMEs in GK model is under way
  - Further tuning of GK model for transversal cross section
  - $R \equiv \sigma_L/\sigma_T$ ratio is suggestive to W-dependence
  - Hierarchy of (un)natural helicity transfer amplitudes is established

- ϕ meson data:
  - Total and Longitudinal cross section consistent with *two-gluon* exchange
  - SCHC dominace
  - Further tuning of GK model for transversal cross section
  - $R \equiv \sigma_L/\sigma_T$ is consistent with wold data
  - Natural-parity-exchange dominance

...Target-polarization dependent SDMEs are under analysis

More data from 2006-2007 will be available

BACKUP SLIDES !!!

Equations for Unpolarized SDMEs from Helicity Transfer Amplitudes

$D = \epsilon N_L + N_T$
$N_T = \sum^\star \{|T_{11}^N|^2 + |T_{01}^N|^2 + |T_{1-1}^N|^2 + |T_{11}^U|^2 + |T_{01}^U|^2 + |T_{1-1}^U|^2\}$
$N_L = \sum^\star \{|T_{00}|^2 + 2|T_{10}^N|^2 + 2|T_{10}^U|^2\}$

$r_{00}^{04} = \sum^\star \{\epsilon|T_{00}|^2 + |T_{01}^N|^2 + |T_{01}^U|^2\}/D$
$\Re\{r_{10}^{04}\} = \sum^\star \Re\{\epsilon T_{10}^N T_{00}^* + \frac{1}{2}T_{01}^N(T_{11}^N - T_{1-1}^N)^* + \frac{1}{2}T_{01}^U(T_{11}^U + T_{1-1}^U)^*\}/D$
$r_{1-1}^{04} = \sum^\star \Re\{-\epsilon|T_{10}^N|^2 + \epsilon|T_{10}^U|^2 + T_{1-1}^N(T_{11}^N)^* - T_{1-1}^U(T_{11}^U)^*\}/D$
$r_{11}^{1} = \sum^\star \Re\{T_{1-1}^N(T_{11}^N)^* + T_{1-1}^U(T_{11}^U)^* \ /D$
$r_{00}^{1} = \sum^\star \{-|T_{01}^N|^2 + |T_{01}^U|^2\}/D$
$\Re\{r_{10}^{1}\} = \frac{1}{2}\sum^\star \Re\{-T_{01}^N(T_{11}^N - T_{1-1}^N)^* + T_{01}^U(T_{11}^U + T_{1-1}^U)^*\}/D$

$r_{1-1}^{1} = \frac{1}{2}\sum^\star \{|T_{11}^N|^2 + |T_{1-1}^N|^2 - |T_{11}^U|^2 - |T_{1-1}^U|^2\}/D \sim |T_{11}^N|^2 - |T_{11}^U|^2$
$\Im\{r_{1-1}^{2}\} = \frac{1}{2}\sum^\star \{-|T_{11}^N|^2 + |T_{1-1}^N|^2 + |T_{11}^U|^2 - |T_{1-1}^U|^2\}/D \sim -|T_{11}^N|^2 + |T_{11}^U|^2$

$\Im\{r_{10}^{2}\} = \frac{1}{2}\sum^\star \Re\{T_{01}^N(T_{11}^N + T_{1-1}^N)^* - T_{01}^U(T_{11}^U - T_{1-1}^U)^*\}/D$
$r_{11}^{5} = \frac{1}{\sqrt{2}}\sum^\star \Re\{T_{10}^N(T_{11}^N - T_{1-1}^N)^* + T_{10}^U(T_{11}^U - T_{1-1}^U)^*\}/D$
$r_{00}^{5} = \sqrt{2}\sum^\star \Re\{T_{01}^N T_{00}^*\}/D \ \Re r_{10}^{5} = \frac{1}{\sqrt{8}}\sum^\star \Re\{2T_{10}^N(T_{01}^N)^* + (T_{11}^N - T_{1-1}^N)T_{00}^*\}/D$
$r_{1-1}^{5} = \frac{1}{\sqrt{2}}\sum^\star \Re\{-T_{10}^N(T_{11}^N - T_{1-1}^N)^* + T_{10}^U(T_{11}^U - T_{1-1}^U)^*\}/D$

$\rightarrow T_{11}^U$ decreases r_{1-1}^1 and increases $\Im\{r_{1-1}^2\}$ No other SDMEs contain T_{11}^U in the numerator
$\rightarrow$ can be checked with SDMEs!

$\rightarrow T_{10}^U, T_{01}^U, T_{1-1}^U$ omitted in the fit function

Equations for Polarized SDMEs from Helicity Transfer Amplitudes

$$\Im r^6_{10} = \frac{1}{\sqrt{8}} \sum^\star \Re\{2T^U_{10}(T^U_{01})^* - (T^N_{11} + T^N_{1-1})T^*_{00}\}/D$$

$$\Im r^6_{1-1} = \frac{1}{\sqrt{2}} \sum^\star \Re\{T^N_{10}(T^N_{11} + T^N_{1-1})^* - T^U_{10}(T^U_{11} + T^U_{1-1})^*\}/D$$

$$\Im r^3_{10} = -\frac{1}{2} \sum^\star \Im\{T^N_{01}(T^N_{11} + T^N_{1-1})^* + T^U_{01}(T^U_{11} - T^U_{1-1})^*\}/D$$

$$\Im r^3_{1-1} = -\sum^\star \Im\{T^N_{1-1}(T^N_{11})^* - T^U_{1-1}(T^U_{11})^*\}/D$$

$$\Im r^7_{10} = \frac{1}{\sqrt{8}} \sum^\star \Im\{2T^U_{10}(T^U_{01})^* + (T^N_{11} + T^N_{1-1})T^*_{00}\}/D$$

$$\Im r^7_{1-1} = \frac{1}{\sqrt{2}} \sum^\star \Im\{T^N_{10}(T^N_{11} + T^N_{1-1})^* - T^U_{10}(T^U_{11} + T^U_{1-1})^*\}/D$$

$$r^8_{11} = -\frac{1}{\sqrt{2}} \sum^\star \Im\{T^N_{10}(T^N_{11} - T^N_{1-1})^* + T^U_{10}(T^U_{11} - T^U_{1-1})^*\}/D$$

$$r^8_{00} = \sqrt{2} \sum^\star \Im\{T^N_{01}T^*_{00}\}/D$$

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

$$r^8_{1-1} = \frac{1}{\sqrt{2}} \sum^\star \Im\{T^N_{10}(T^N_{11} - T^N_{1-1})^* - T^U_{10}(T^U_{11} - T^U_{1-1})^*\}/D$$

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

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

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

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

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

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

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

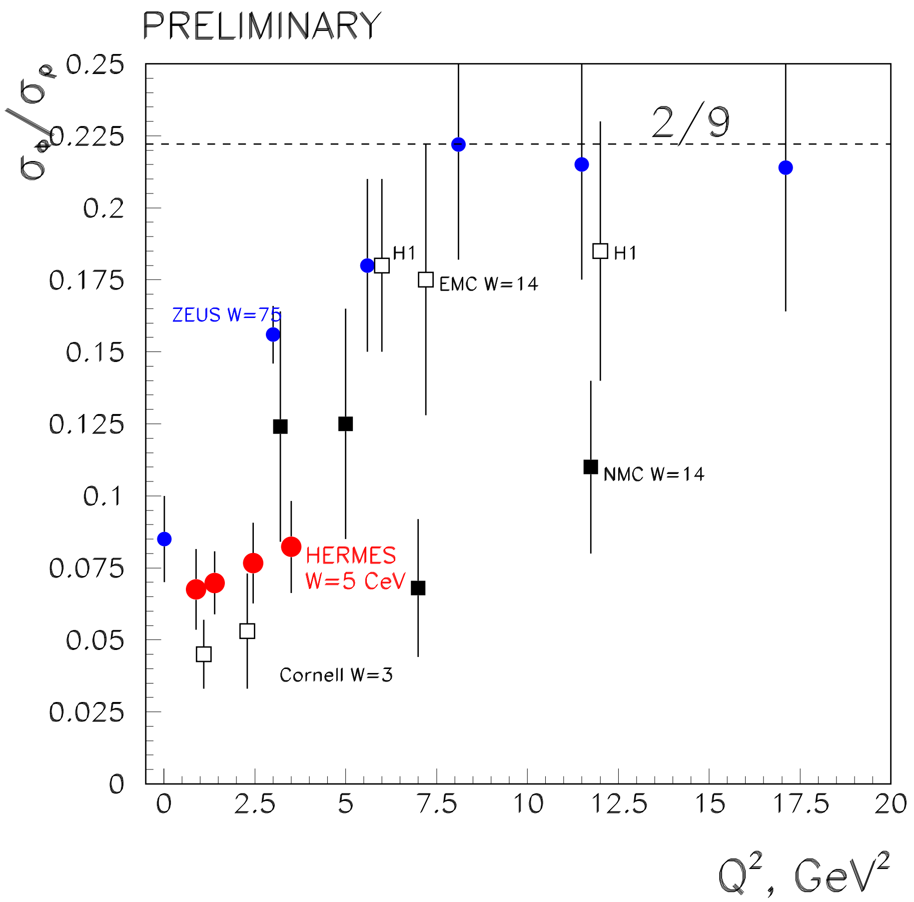
$$\mathrm{W}^{long.pol.}(\cos\Theta,\phi,\Phi) = \frac{3}{8\pi^2}P_{beam}\Bigg[\sqrt{1-\epsilon^2}\Big(\sqrt{2}\mathrm{Im}\{\mathrm{r}^{3}_{10}\}\sin 2\Theta\sin\phi + \mathrm{Im}\{\mathrm{r}^{3}_{1-1}\}\sin^2\Theta\sin 2\phi\Big)$$

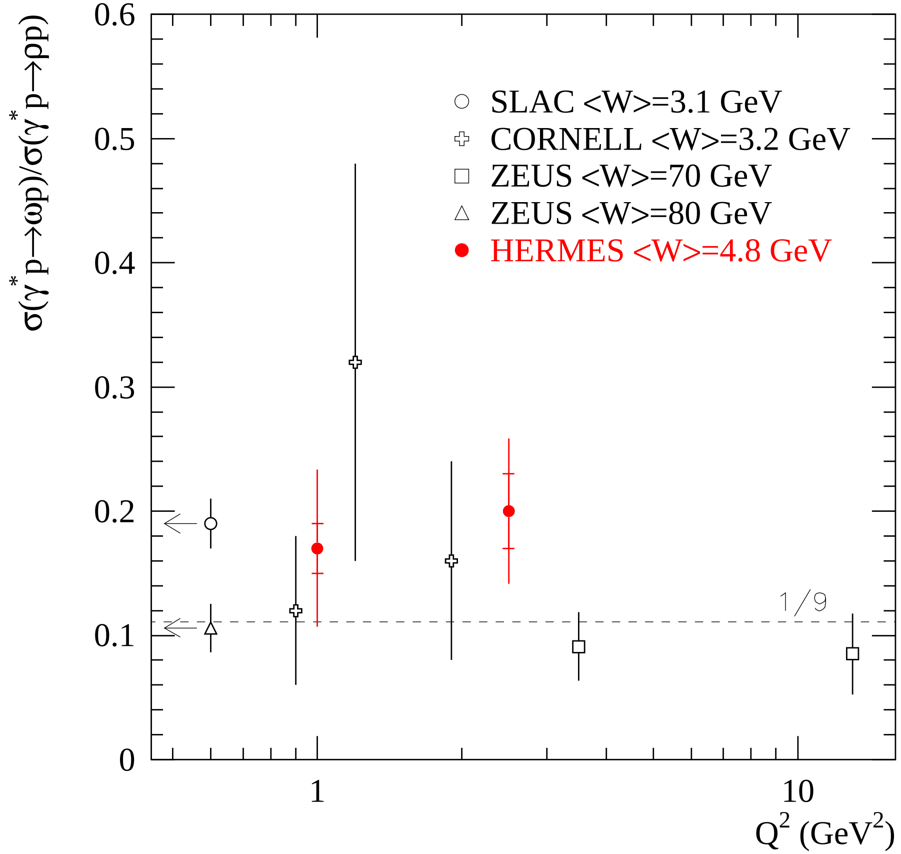
$$+\ \sqrt{2\epsilon(1-\epsilon)}\cos\Phi\Big(\sqrt{2}\mathrm{Im}\{\mathrm{r}^{7}_{10}\}\sin 2\Theta\sin\phi + \mathrm{Im}\{\mathrm{r}^{7}_{1-1}\}\sin^2\Theta\sin 2\phi\Big)$$

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

Cross Section Ratios: $\sigma_\phi/\sigma_{\rho^o}$, $\sigma_\omega/\sigma_{o^o}$

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





$\longrightarrow$ $W-$dependence at $Q^2 = 2.5 \sim 4$ GeV^2

$\longrightarrow$ $W-$dependence of $\sigma_\omega/\sigma_{\rho^o}$

$\longrightarrow$ Substantial two-gluon contribution for ρ^0
(M.Diehl and A.V.Vinnikov Phys.Lett. **B609** (2005) 286)

$\longrightarrow$ VGG model: $\sigma_L^\omega/\sigma_L^{\rho^o} \sim 0.2$

ρ^0/phi ratio of σ_L from GK model

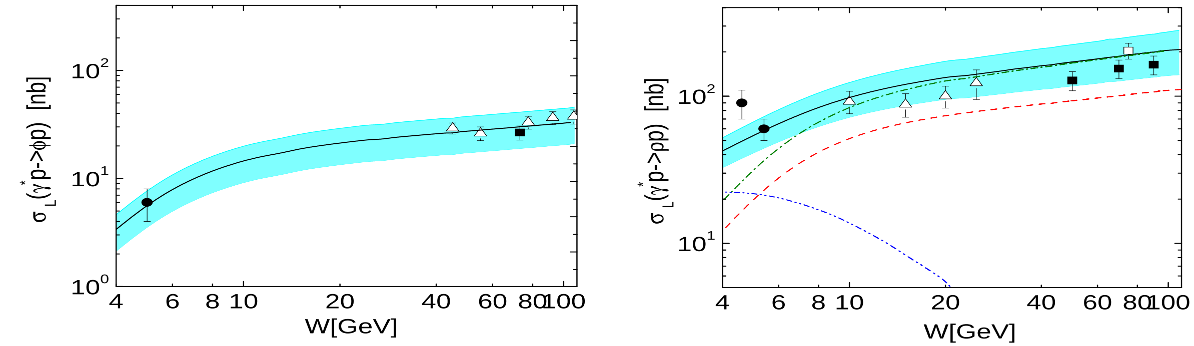


Figure 11: The longitudinal cross section for ϕ (left) and ρ (right) electroproduction versus W at $Q^2 = 3.8$ GeV^2 and 4 GeV^2, respectively. The handbag predictions are evaluated from the interval $-t' \leq 0.5$ GeV^2. Data for ϕ production are taken from HERMES [41] (solid circle), ZEUS [13] (open triangles) and H1 [37] (solid square). The data for ρ production are taken from HERMES [42] (solid circles), E665 [43] (open triangles), ZEUS [12] (open square) and H1 [11] (solid square). The dashed (dash-dotted, dash-dot-dotted) line represents the gluon (gluon + sea, (gluon + sea)-valence interference plus valence quark) contribution. For other notations cf. Fig. 7.

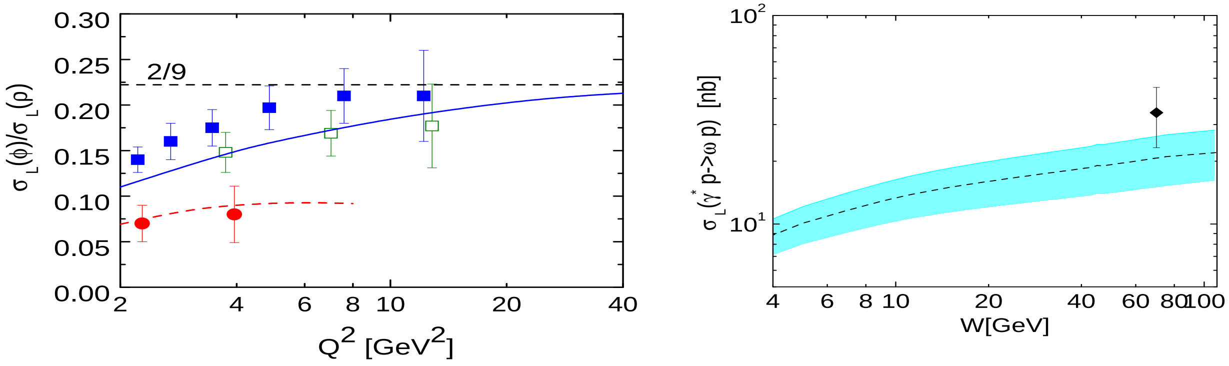
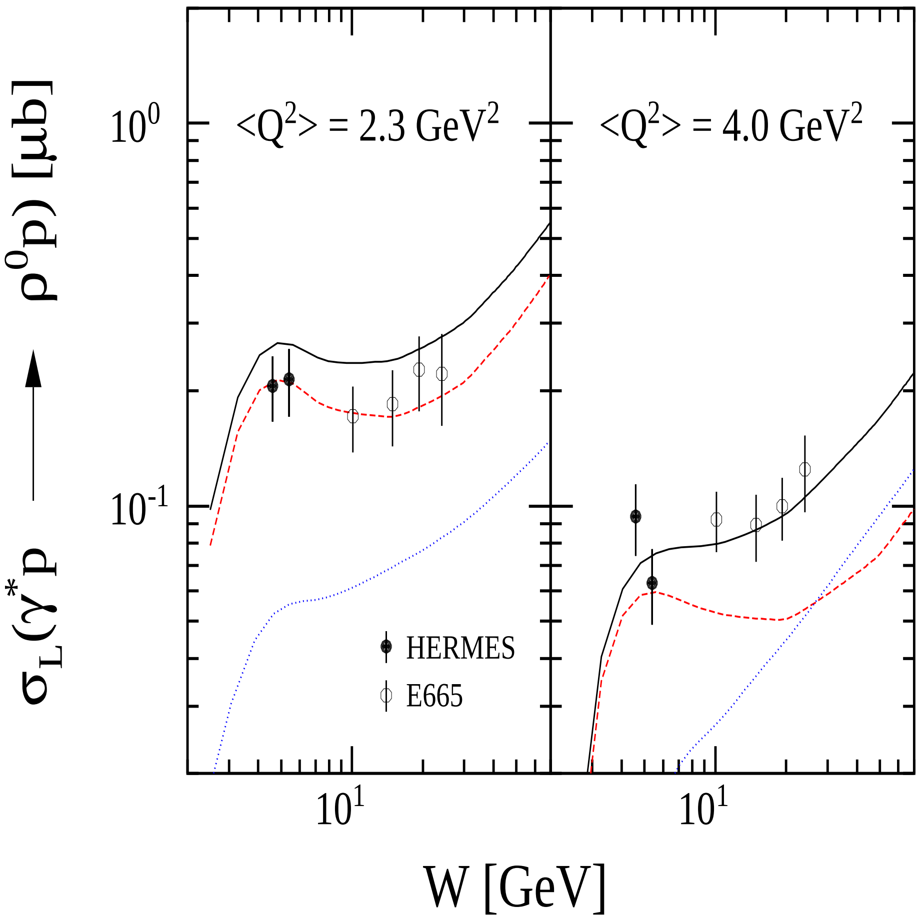
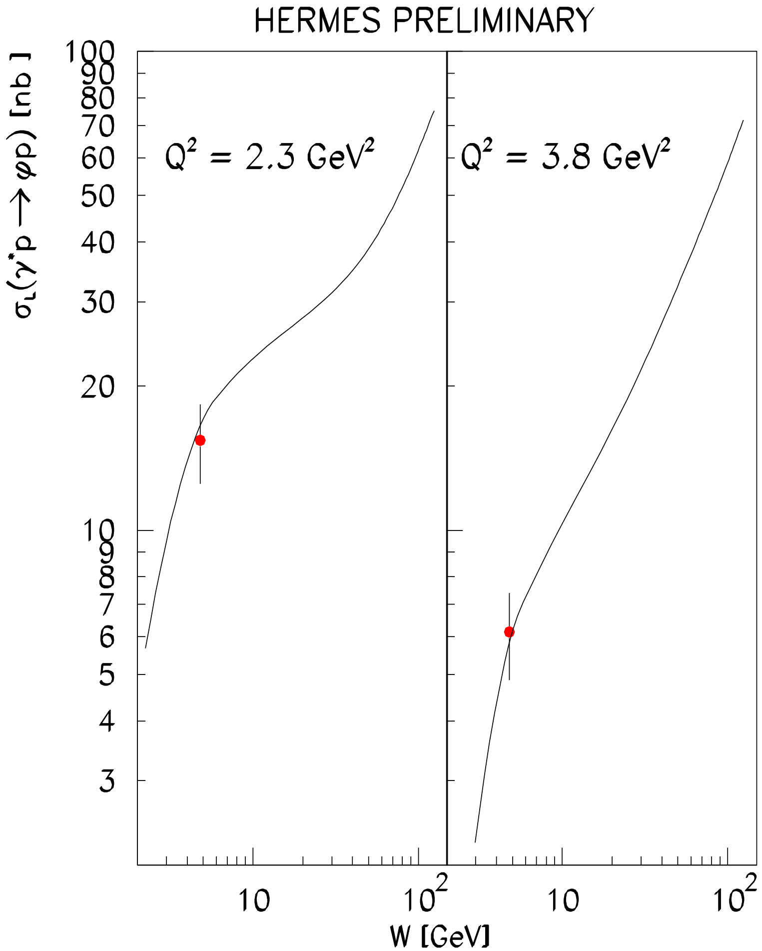


Figure 12: Left: The ratio of the longitudinal cross sections for ϕ and ρ production. Data are taken from H1 [11, 37] (solid squares), ZEUS [12, 13] (open squares) and HERMES [41, 42] (solid circles). The solid (dashed) line represents the handbag predictions at $W = 75(5)$ GeV. Right: Predictions for ω electroproduction versus W at $Q^2 = 3.5$ GeV^2. For comparison the full cross section for ω production, measured by ZEUS [49], is also shown (solid diamond).

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)



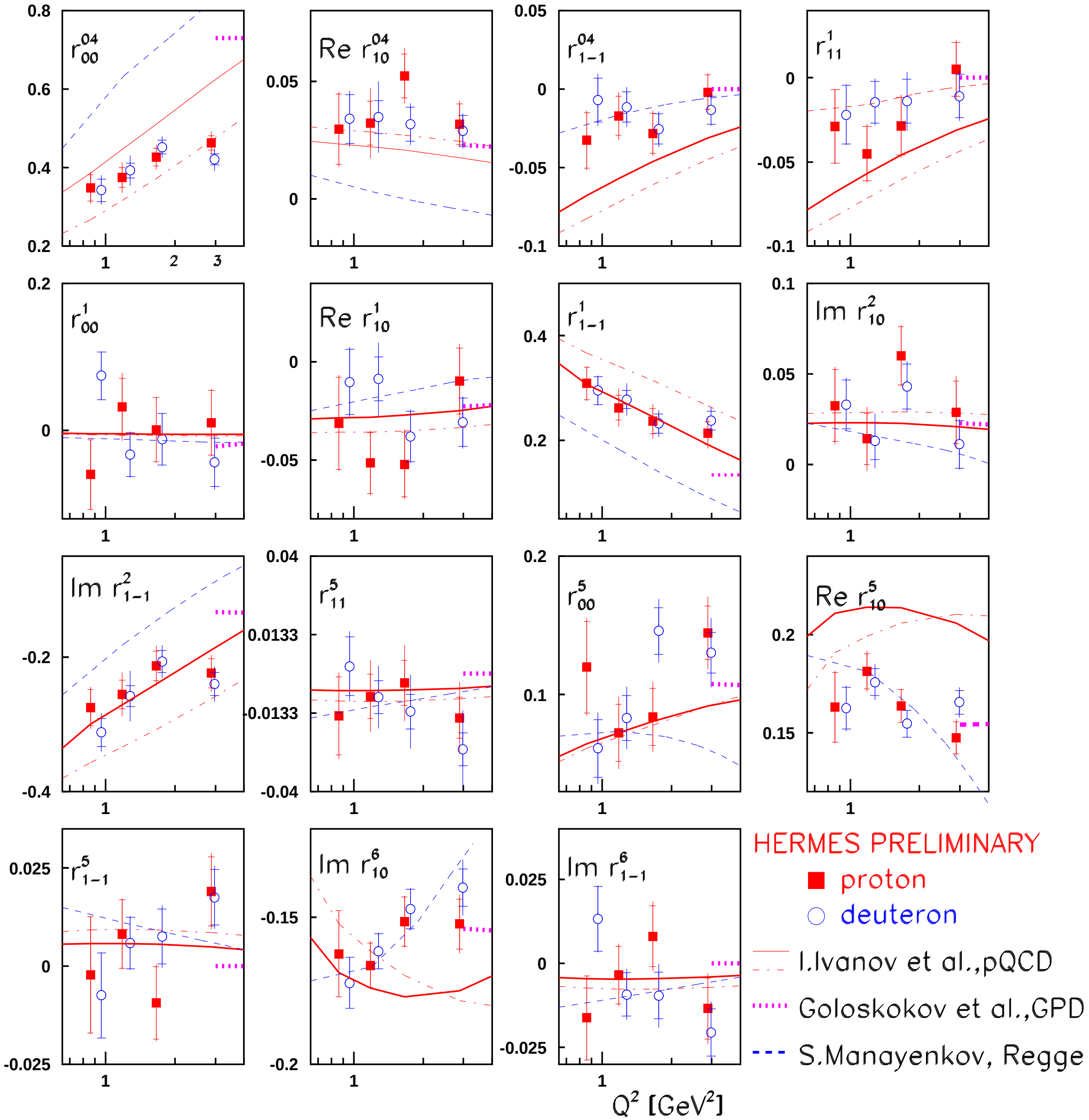


2-gluon exchange, quark exchange, sum of both, two-gluon exchange for ϕ

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

...since BARYONS'04:

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)

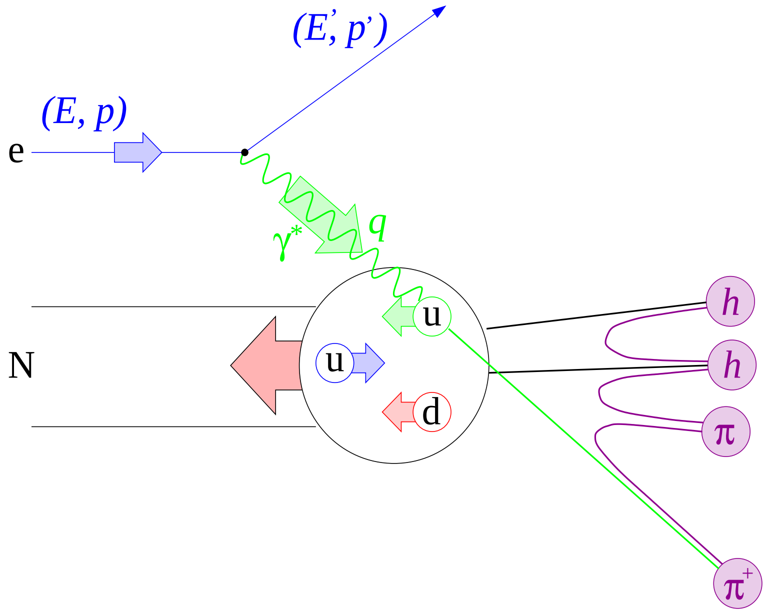
$$T_{01} \sim T \to L : \qquad \mathcal{H}^V \propto \frac{\sqrt{-t}}{Q}$$

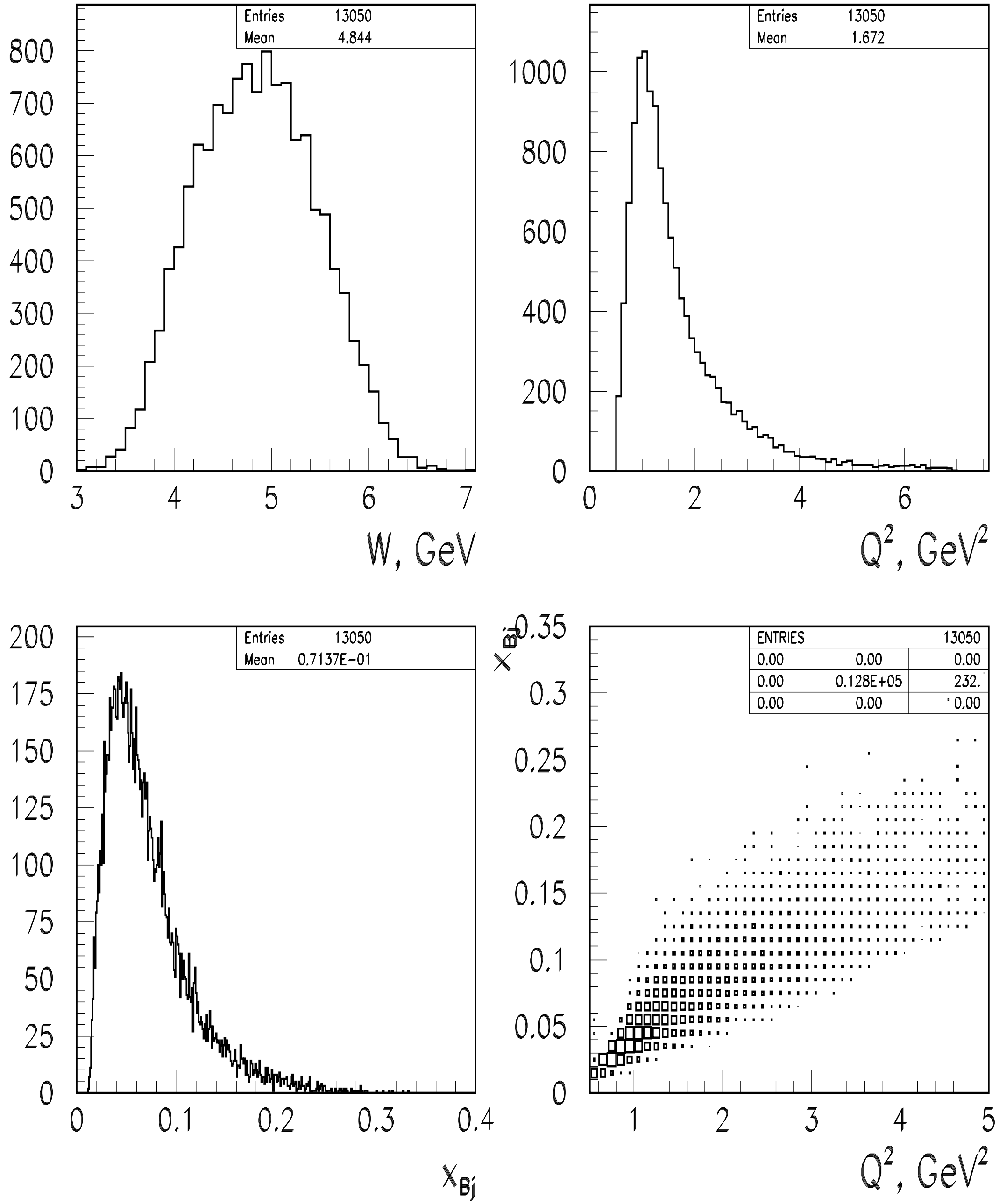
$$T_{11} \sim T \to T : \qquad \mathcal{H}^V \propto \frac{\langle k_\perp^2 \rangle^{1/2}}{Q}$$

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

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

Deep Inelastic Scattering: Important Variables and Kinematic Distributions

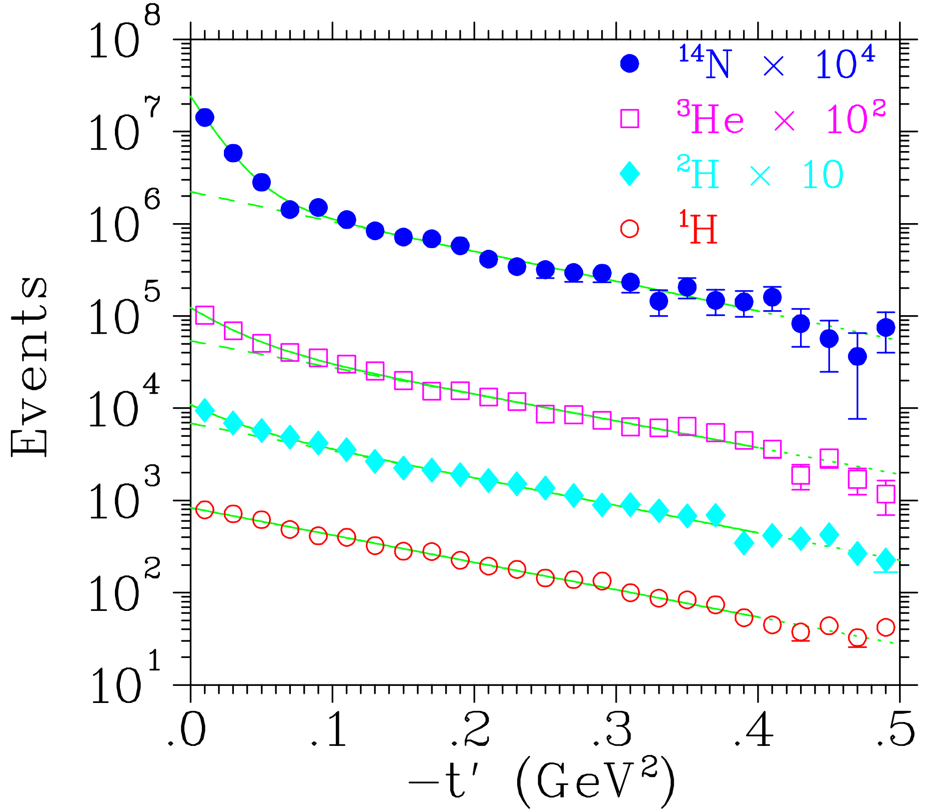


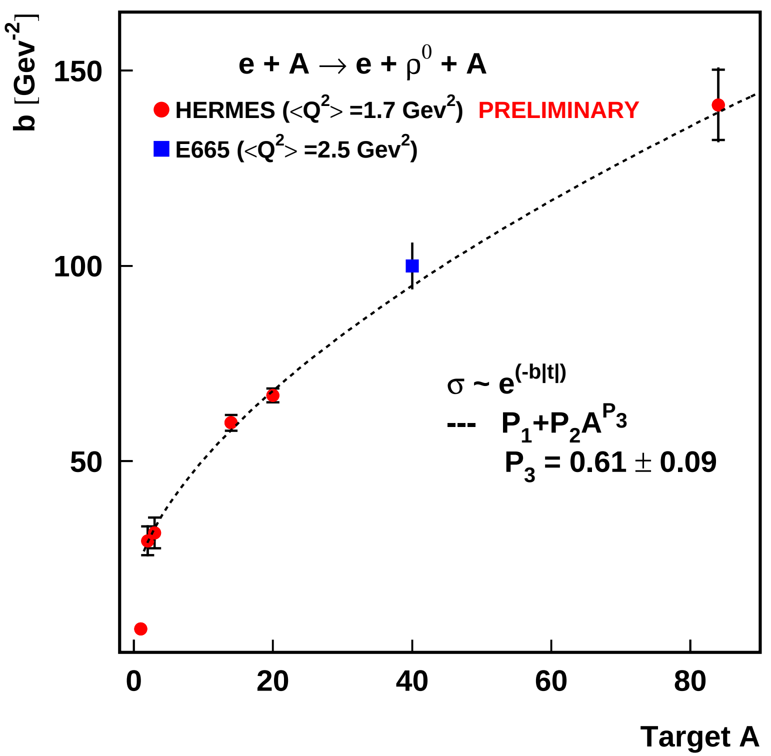


- $Q^2 \stackrel{lab}{=} 4EE' \sin^2(\Theta/2)$
- $\nu \stackrel{lab}{=} E - E'$
- $x_{Bj} \stackrel{lab}{=} Q^2/2M\nu$
- $W^2 \stackrel{lab}{=} M^2 + 2M\nu - Q^2$

Coherent and Incoherent ρ^0 Production

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



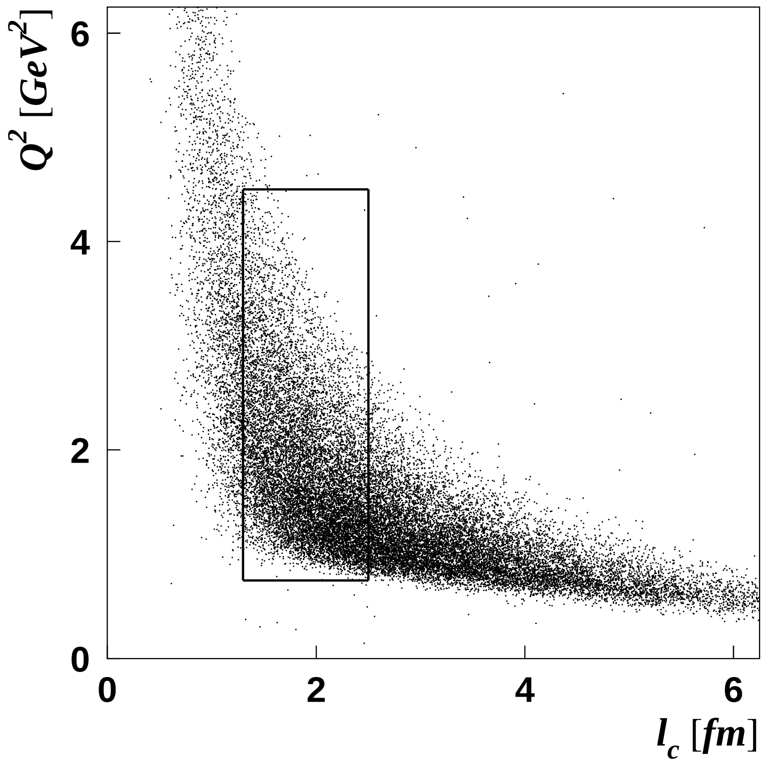


At $-t \lesssim 0.045$ GeV^2 coherent ρ^0 dominates at $-t \gtrsim 0.1$ GeV^2 incoherent.

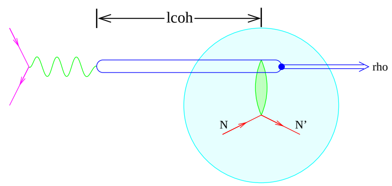
$b_{(coh)} \approx r_A^2/3$ is in agreement with world data of nuclear size measurements

(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



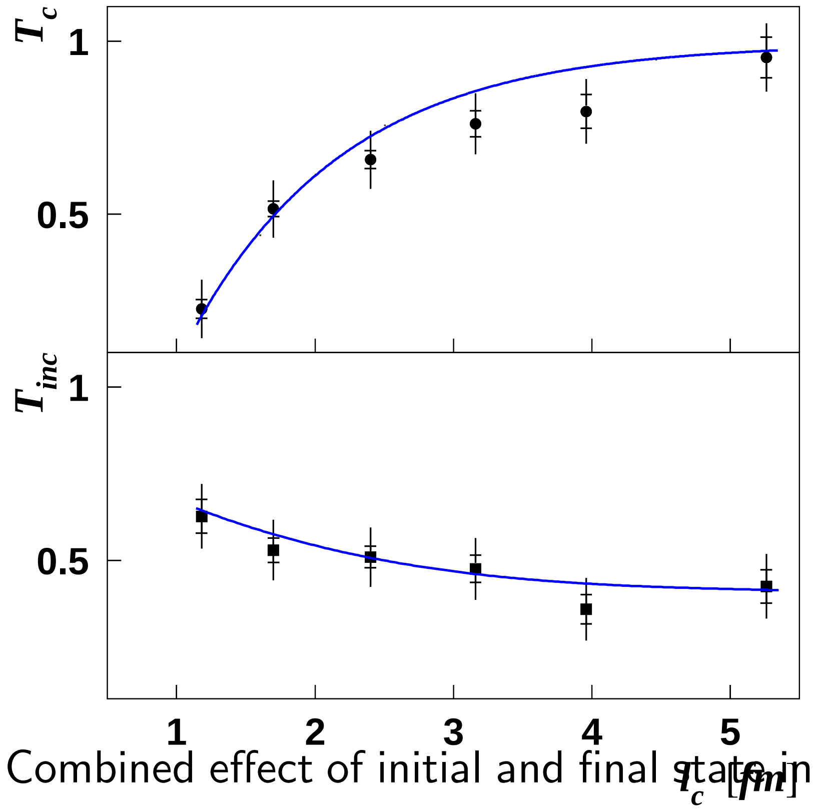
$l_c = \frac{2\cdot\nu}{Q^2+m_V^2} = 0.6 \div 8$ fm,
$< l_c >= 2.7$ fm

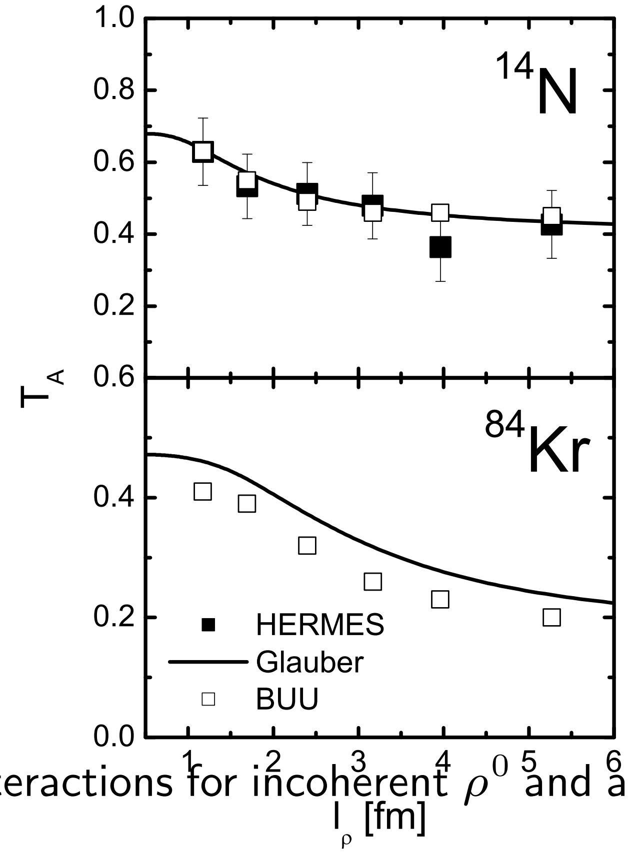
- transverse size of the qq wave packet
  $r_{q\bar{q}} \sim 1/ < Q^2 >\simeq 0.4$ fm $< r_p = 1$ fm
- formation length: distance needed for qq to develop into hadron:
  $l_{form} = \frac{2\cdot\nu}{m_{V'}^2 - m_V^2} = 1.3 \div 6.3$ fm
  $< l_{form} >= 3.47$ fm

$\longrightarrow$ 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

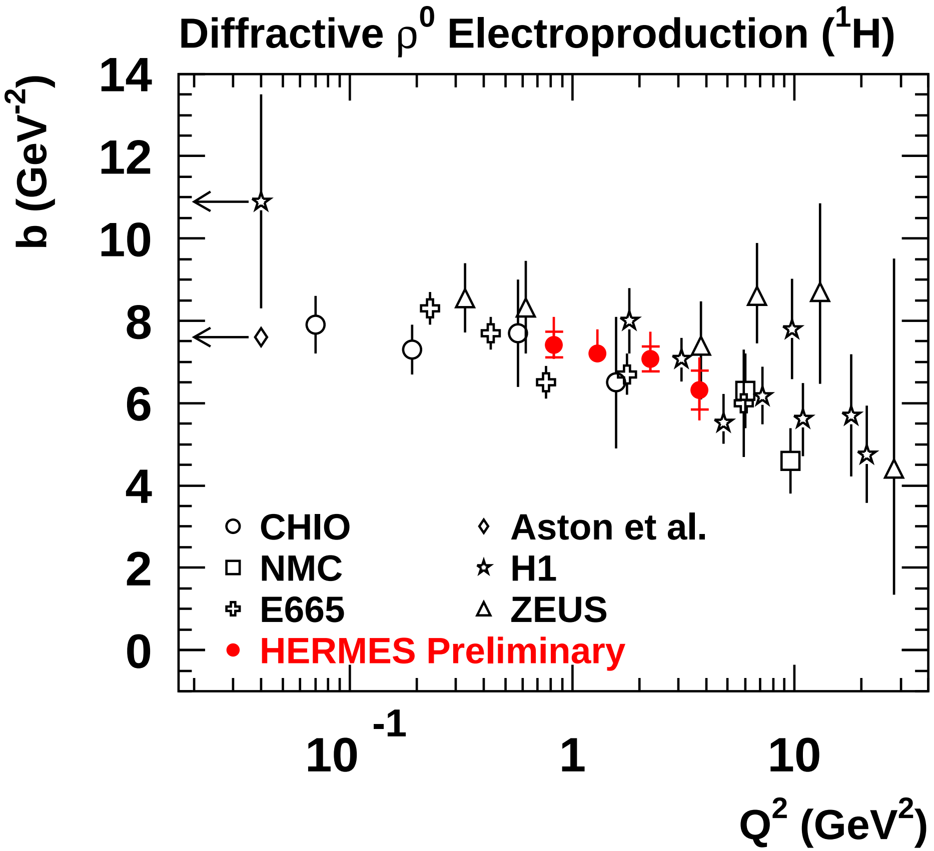




Combined effect of initial and final state interactions for incoherent ρ^0 and additionional effect of nuclear formfactor for coherent ρ^0. Agreement with calculations (blue curves, left panel) based on CT aprroach (B.Z. Kopeliovich et al, Phys.Rev. C, **65**, 035201, 2002).

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



$\longrightarrow$ Size of virtual photon controlled via Q^2

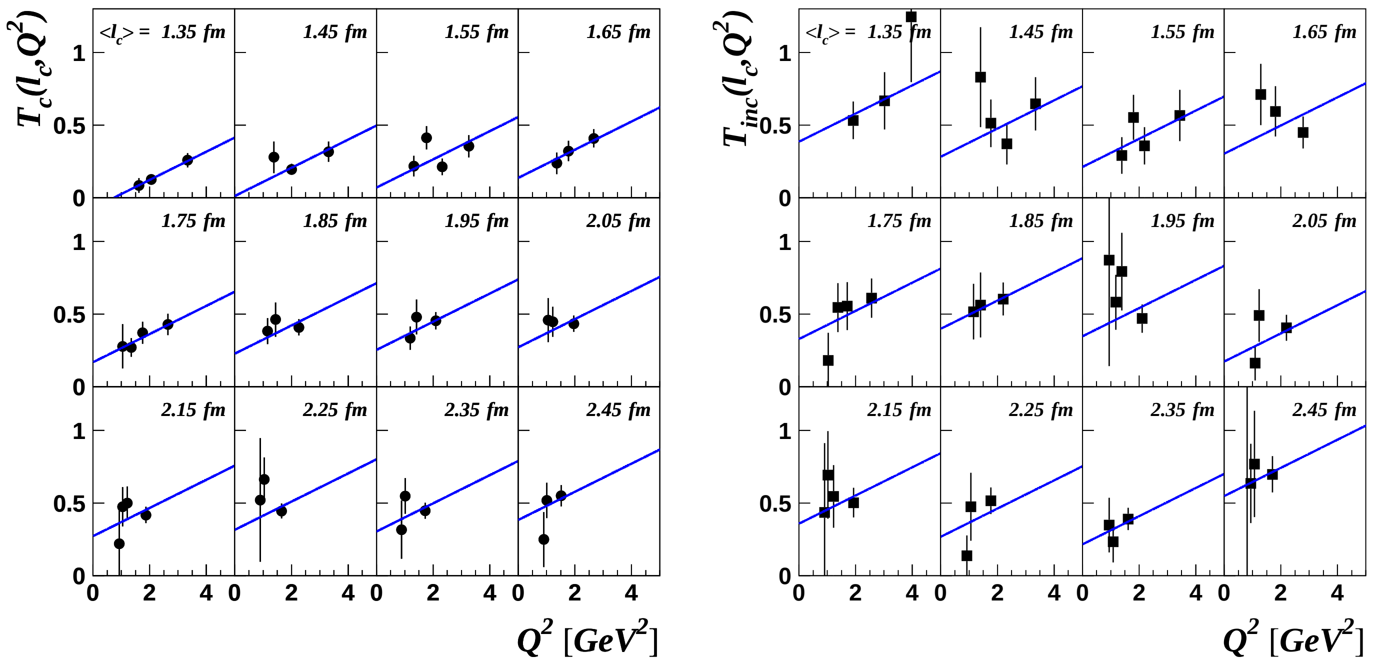
$\longrightarrow$ No strong $W-$dependence

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)