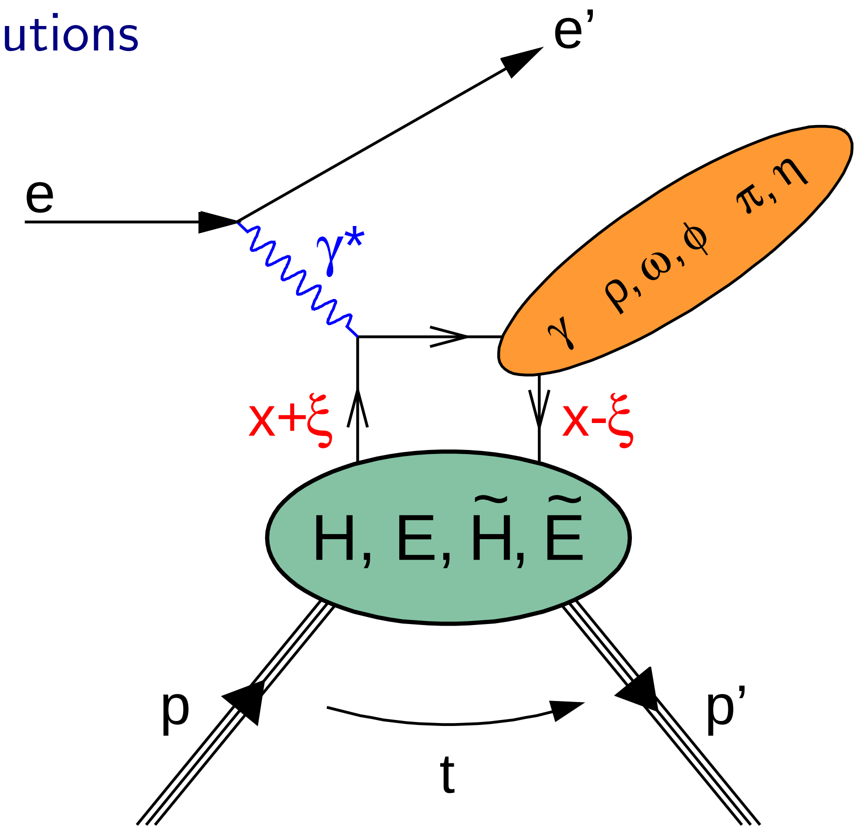
The First CLAS12 European Workshop, February 27th, 2009, Genoa, Italy

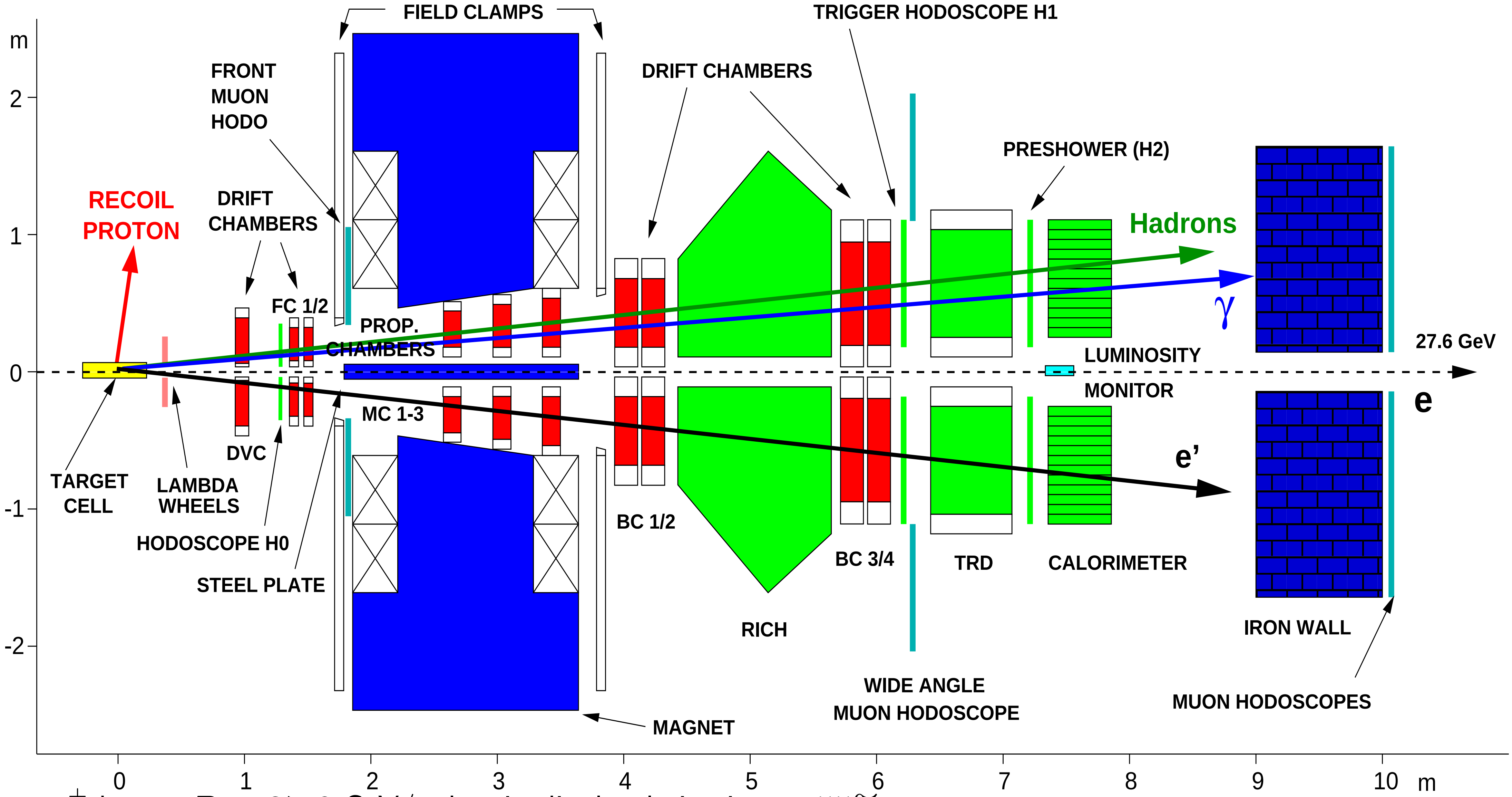
Latest Results on Exclusive Meson Production at

- Calculations Based on Generalized Parton Distributions for Exclusive Meson Production
- ρ^0 and ϕ Meson Production
  - Total and Longitudinal Cross Sections
  - Spin Density Matrix Elements
    - ∗ L-to-T Cross-Section Ratios
    - ∗ Hierarchy of Helicity Amplitudes
    - ∗ Unnatural Parity Exchange
  - Transverse Target Polarization Asymmetries
- Exclusive π^+ Production
  - Total Cross Section
  - Transverse Target Polarization Asymmetry
- Summary and Outlook



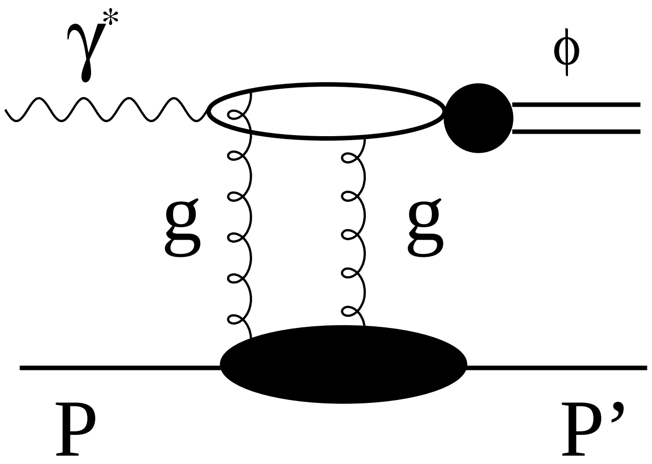
Alexander Borissov, DESY

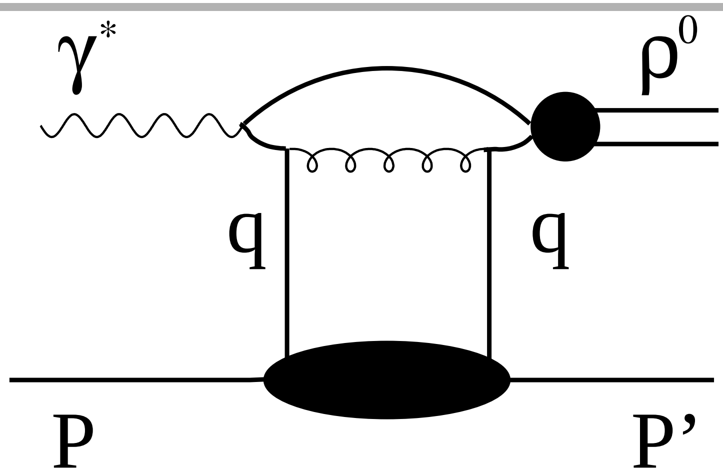
HERMES Detector *was* Two Identical Halves of Forward Spectrometer



- $e^{\pm}$ beam, $P = 27.6$ GeV/c, longitudinal polarization $\sim 55\%$
- $\sim 80\%$ longitudinally or transversely polarized hydrogen target
- 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, in $2006 \div 2007$ data from the recoil detector

GPD Based Calculations for Exclusive Meson Production





Properties of ρ^0, ϕ and π^+ 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: $J^P = 0^+, 1^-$)

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

    $\longrightarrow$ GPDs: $\tilde{H}$, $\tilde{E}$

Experimental observables:

- total and longitudinal 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
- Transverse target polarization asymmetries

$\Longrightarrow$ **Comparison of data with GPD based calculations:**

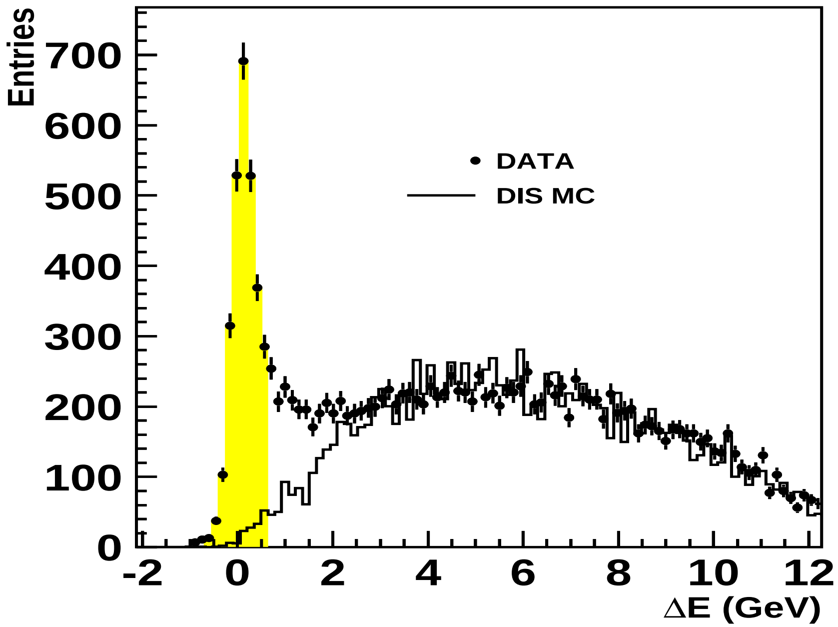
S. V. Goloskokov, P. Kroll, Eur. Phys. J. C 53(2008) 367; New: arXiv:0809.4126

Exclusive ρ^0 and ϕ Meson Production

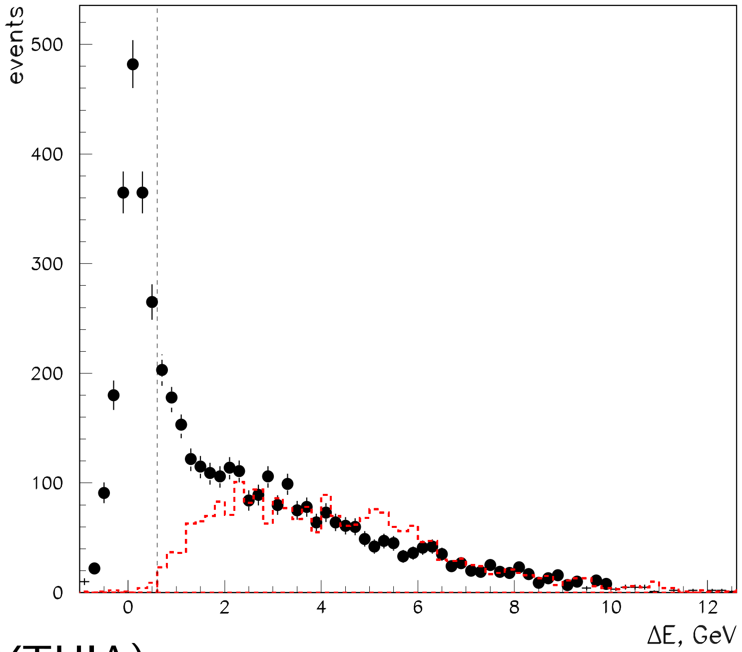
$$e + p \rightarrow e' + p' + \rho^0 \rightarrow \pi^+\pi^- \qquad e + p \rightarrow e' + p' + \phi \rightarrow K^+K^-$$

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

ρ^0



ϕ



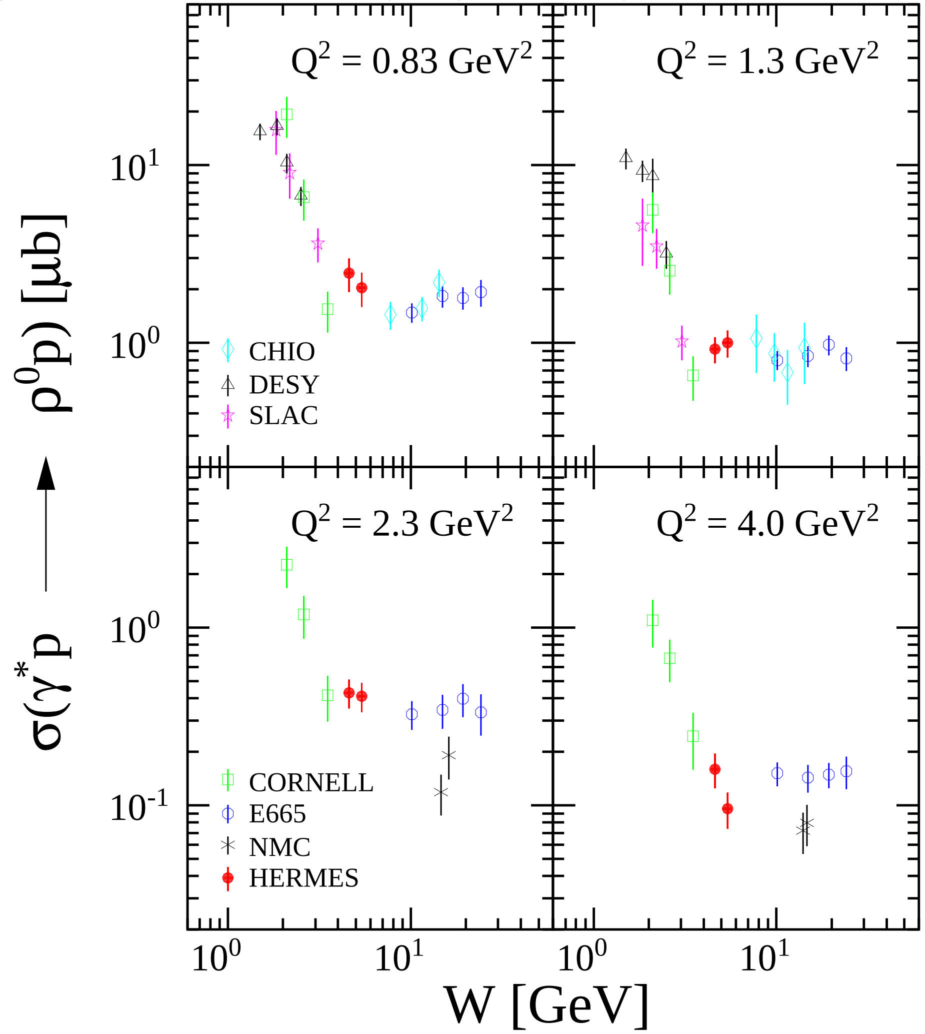
Background is subtracted using MC (PYTHIA)

Kinematics:

- $Q^2 = 0.5 \div 7.0$ GeV^2, $\langle Q^2 \rangle = 2.3$ GeV^2 $\qquad W = 3.0 \div 6.5$ GeV, $\langle W \rangle = 4.9$ GeV,
- $x_{Bj} = 0.01 \div 0.35$, $\langle x_{Bj} \rangle = 0.07$ $\qquad -t' = 0 \div 0.4$ GeV^2, $\langle -t' \rangle = 0.13$ 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

- 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

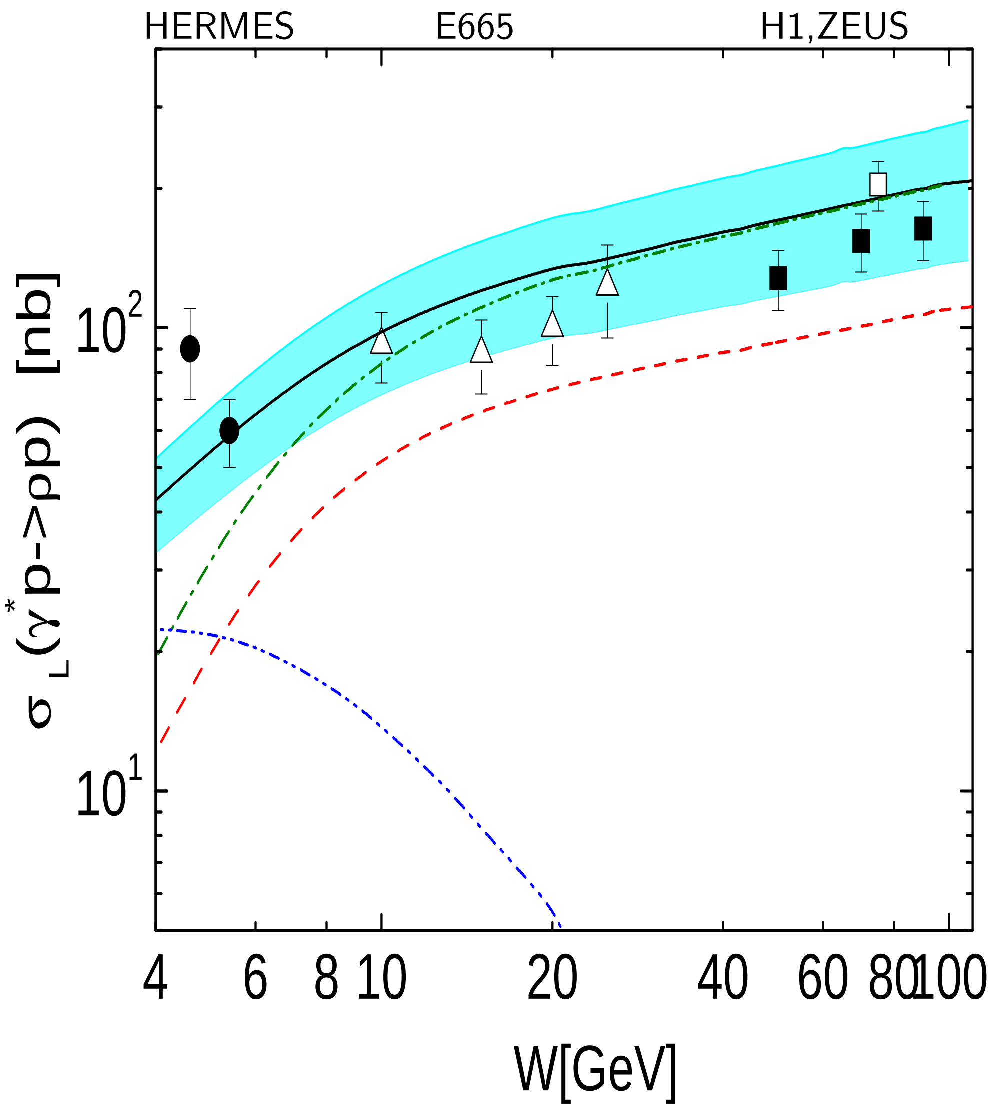
$$\epsilon = \frac{1-y-\frac{Q^2}{E^2}}{1-y+\frac{y^2}{2}+\frac{Q^2}{E^2}} \approx 0.8$$

$\Longrightarrow$ σ_L for the tests of spin-independent GPD function H

$\Longrightarrow$ **Which production mechanisms are involved?**

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

S.V.Goloskokov,P.Kroll,Eur.Phys.J. C 42,2005

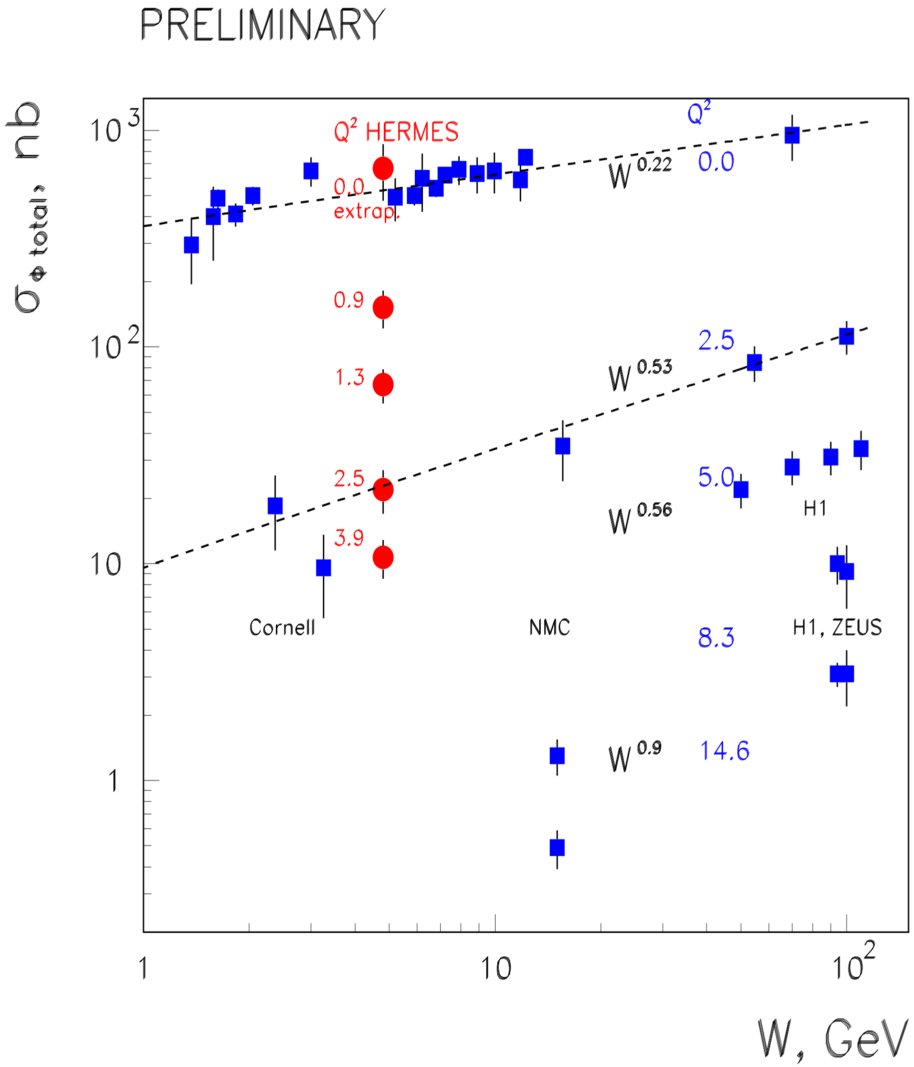


Which production mechanisms are involved?

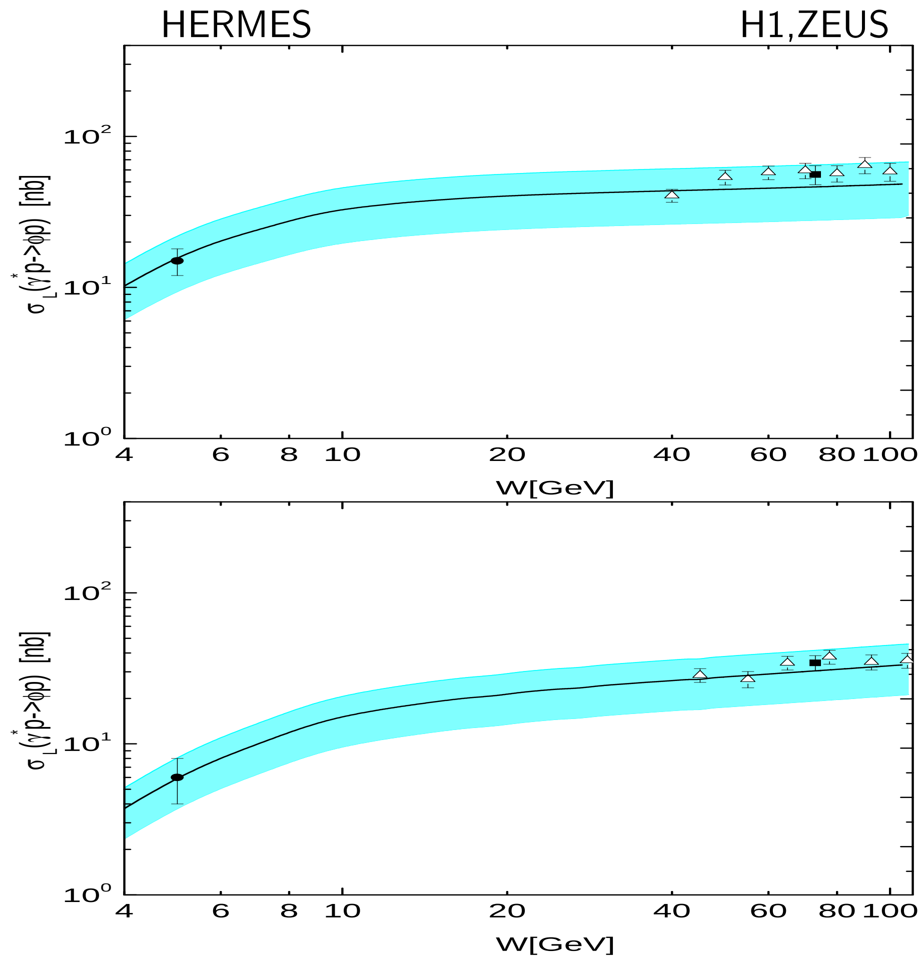
- two-gluon exchange
- two-gluon+sea interference
- quark exchange,
- sum,
- band represents uncertainties from Parton Distributions

$\Longrightarrow$ **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



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

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

$\longrightarrow$ 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

$\longrightarrow$ 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**

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

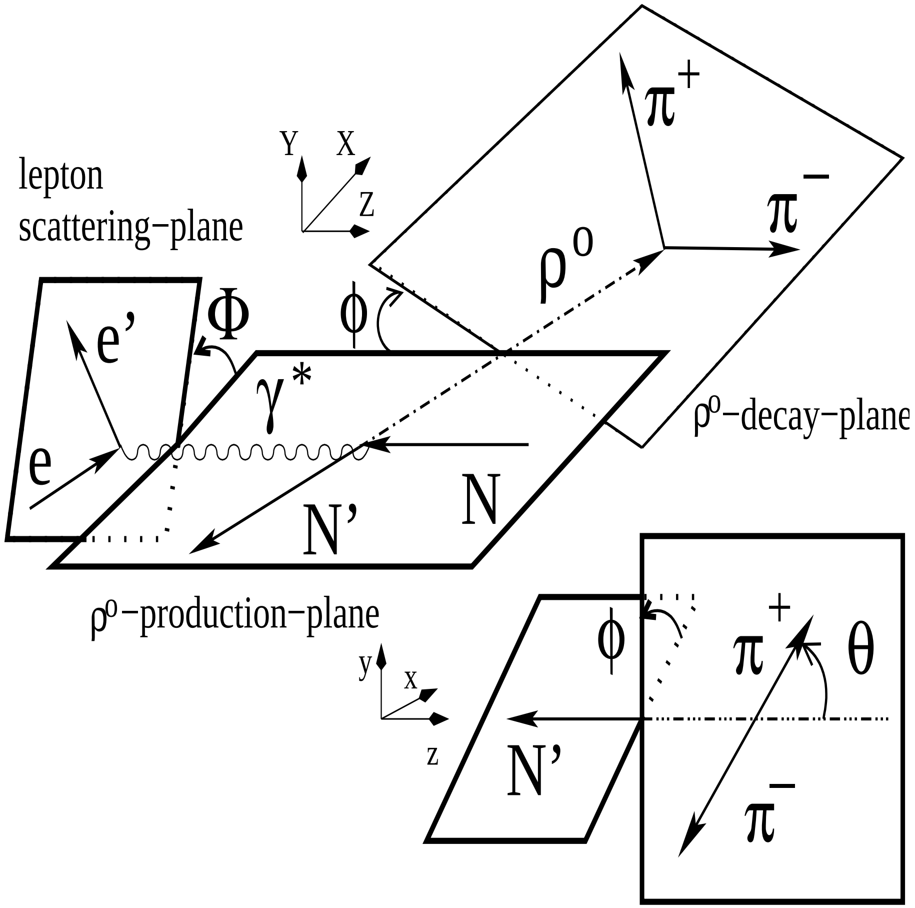
- $\gamma^* + N \to \rho^0(\phi) + N'$ is perfect to study the spin structure of production mechanism:
  - spin state of γ^* is known
  - $\rho^0 \to \pi^+\pi^-$ and $\phi \to K^+K^-$ decays are self-analysing

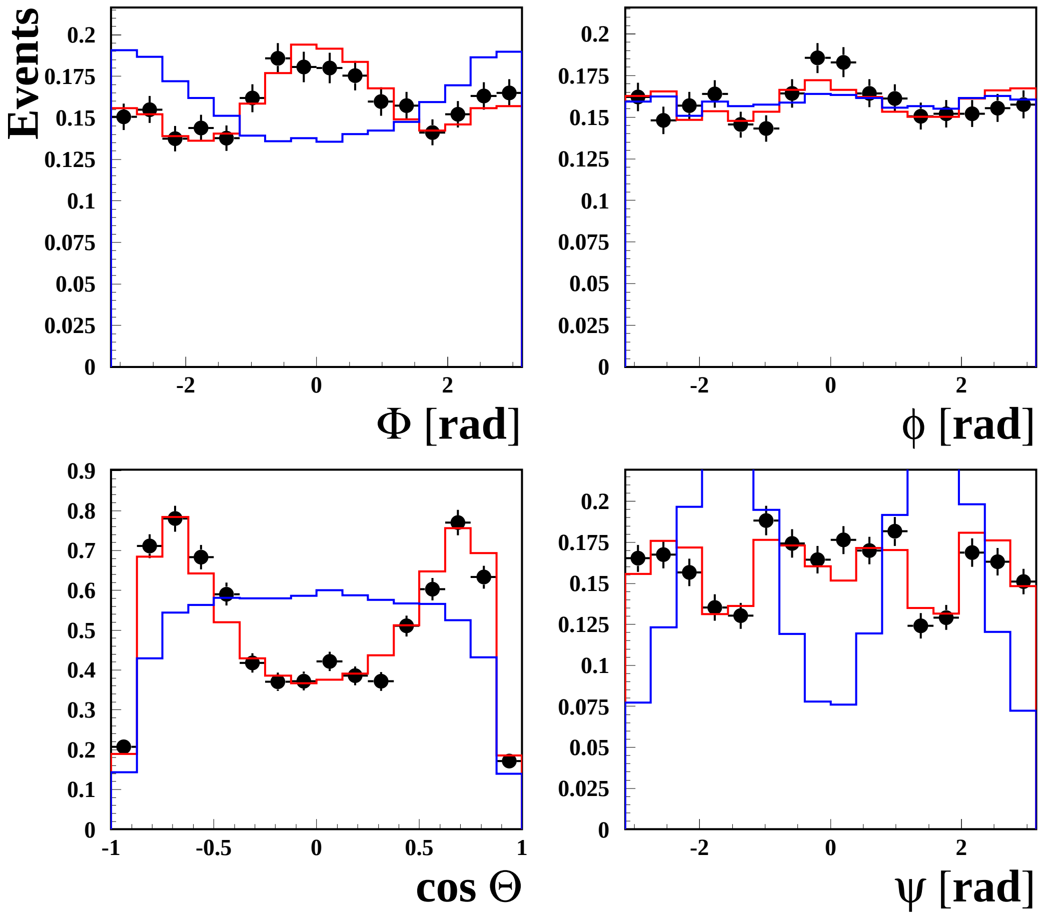
- SDMEs: $r^{\alpha}_{\lambda_\rho \lambda'_\rho} \sim \rho(V) = \frac{1}{2} T_{\lambda_V \lambda_{\gamma^*}} \rho(\gamma^*) T^{+}_{\lambda_V \lambda_{\gamma^*}}$
  spin-density matrix of the vector meson $\rho(V)$ in terms of the photon matrix $\rho(\gamma^*)$ and helicity amplitude $T_{\lambda_V \lambda_{\gamma^*}}$
  - presented according K.Schilling and G.Wolf (Nucl. Phys. B61 (1973) 381)
    $\alpha = 04, 1 \div 3, 5 \div 8$ 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)
  - SDMEs are calculated in GK GPD model at $W = 5$ GeV, $Q^2 = 3$ GeV^2

    S. V. Goloskokov and P. Kroll, Eur. Phys. J. C **53** (2008) 367; Eur.Phys.J. C **50**,829 (2007); Eur.Phys.J. C **42**,281 (2005)
  - provide access to *helicity amplitudes* $T_{\lambda_V \lambda_{\gamma^*}}$, which are:
    * extracted experimentally from SDMEs
    * calculated from GPDs

$\Longrightarrow$ **Comparison of SDMEs with GPD based calculations**

Fit of Angular Distributions Using Max. Likelihood Method in MINUIT





- Fit of 23 SDMEs after full detector simulation done using initial uniform angular distribution
- Binned Maximum Likelihood Method: $8 \times 8 \times 8$ bins of $\cos(\Theta), \phi, \Phi$. Simultaneous fit of 23 SDMEs: $r_{ij}^{\alpha} = W(\Phi, \phi, \cos\Theta)$ for data with negative and positive beam helicity ($\langle |P_b| \rangle = 53.5\%$, $\Psi = \Phi - \phi$). 15 "unpolarized" plus, for the first time, 8 "polarized" SDMEs.

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

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

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

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

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

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

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

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

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

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

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

$\Longrightarrow$ **"Polarized" SDMEs are measurable with the longitudinally polarized beam and $\epsilon < 1$**

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

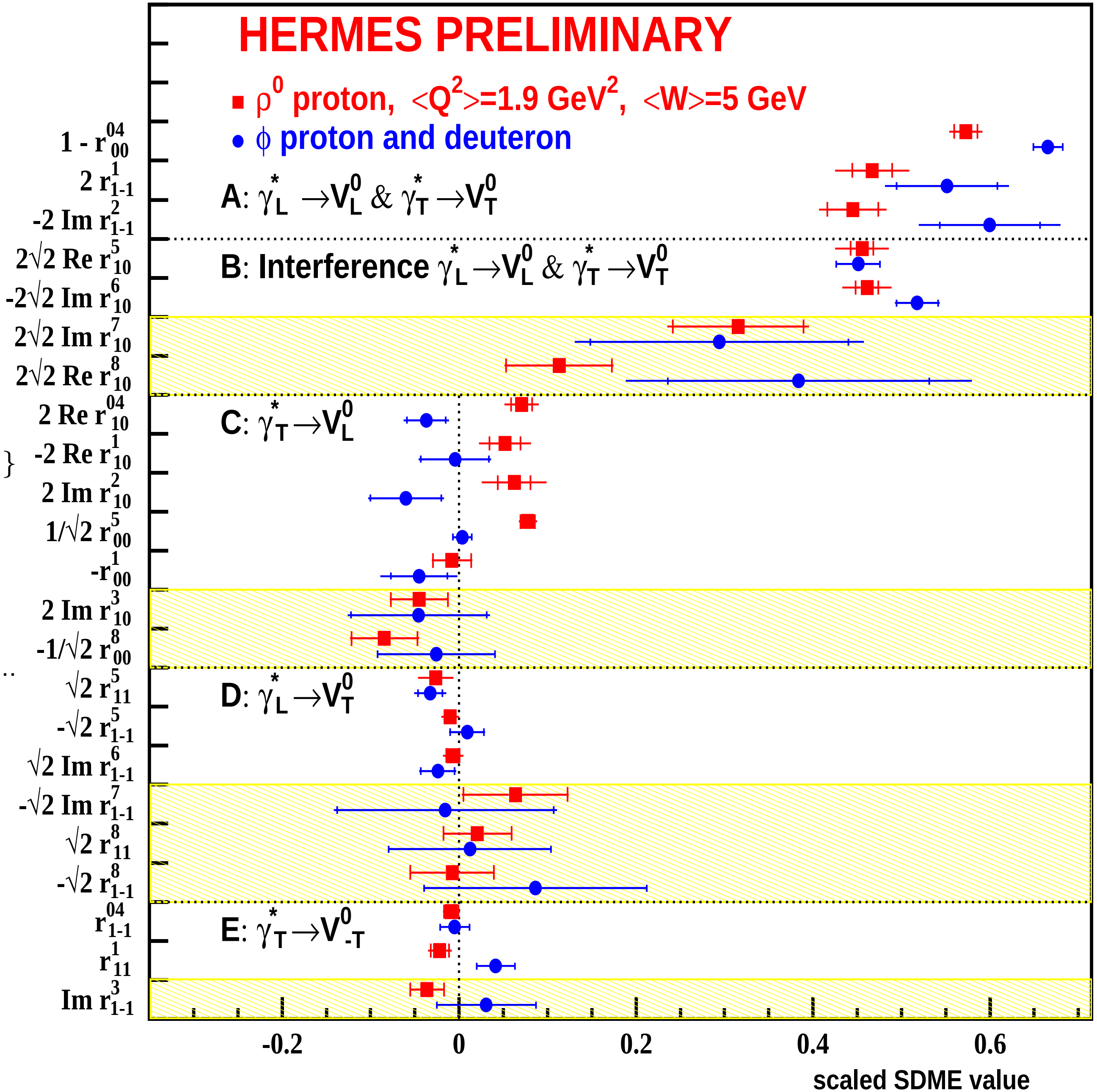
- A, $\gamma_L^* \to \rho_L^0$ and $\gamma_T^* \to \rho_T^0$
  $|T_{11}|^2 \propto 1 - r_{00}^{04} \propto r_{1-1}^1 \propto -Im\{r_{1-1}^2\}$

- B, Interference: γ_L^*, ρ_T^0
  $Re\{T_{00}T_{11}^*\} \propto Re\,\{r_{10}^5\} \propto -Im\{r_{10}^6\}$
  $Im\{T_{11}T_{00}^*\} \propto Im\{r_{10}^7\} \propto Re\{r_{10}^8\}$

- C, Spin Flip: $\gamma_T^* \to \rho_L^0$
  $Re\{T_{11}T_{01}^*\} \propto Re\{r_{10}^{04}\} \propto Re\{r_{10}^1\} \propto Im\{r_{10}^2\}$
  $Re\{T_{01}T_{00}^*\} \propto r_{00}^5$
  $|T_{01}|^2 \propto r_{00}^1$
  $Im\{T_{01}T_{11}^*\} \propto Im\{r_{10}^3\}$
  $Im\{T_{01}T_{00}^*\} \propto r_{00}^8$

- D, Spin Flip: $\gamma_L^* \to \rho_T^0$
  $Re\{T_{10}T_{11}^*\} \propto r_{11}^5 \propto r_{1-1}^5 \propto Im\{r_{1-1}^6\}$
  $Im\{T_{10}T_{11}^*\} \propto Im\{r_{1-1}^7\} \propto r_{11}^8 \propto r_{1-1}^8$

- E, Spin Flip: $\gamma_T^* \to \rho_{-T}^0$
  $Re\{T_{1-1}T_{11}^*\} \propto r_{1-1}^{04} \propto r_{11}^1$
  $Im\{T_{1-1}T_{11}^*\} \propto Im\{r_{1-1}^3\}$



$\Longrightarrow$ **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, $|T_{00}| \sim |T_{11}|$

W.Augustyniak, A.B., S.I.Manayenkov (for HERMES) arXiv:0808.0669

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

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

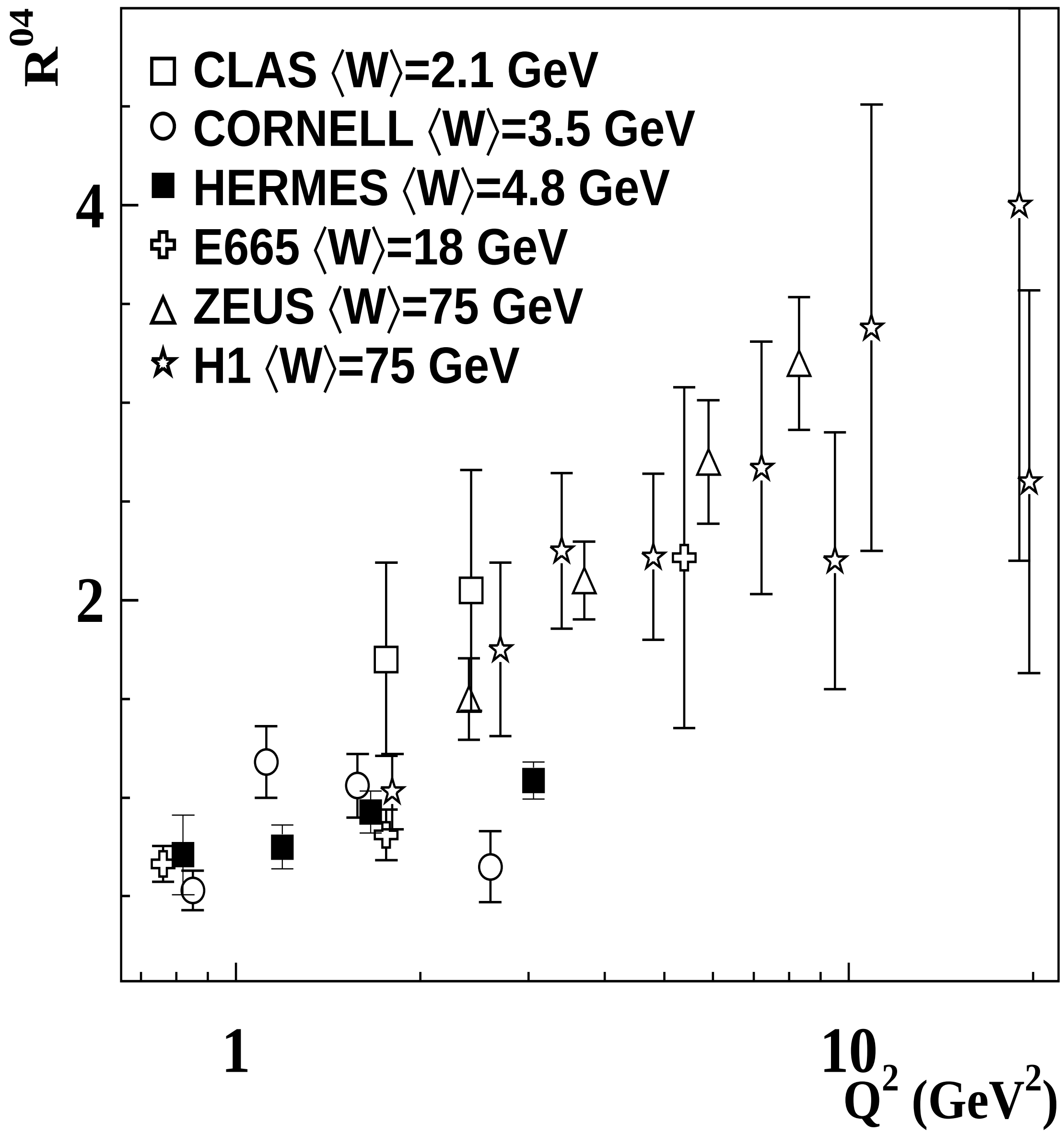
$$r^{04}_{00} = \sum\{\epsilon|T_{00}|^2 + |T_{01}|^2 + |U_{01}|^2\}/\sigma_{tot}$$

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

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

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

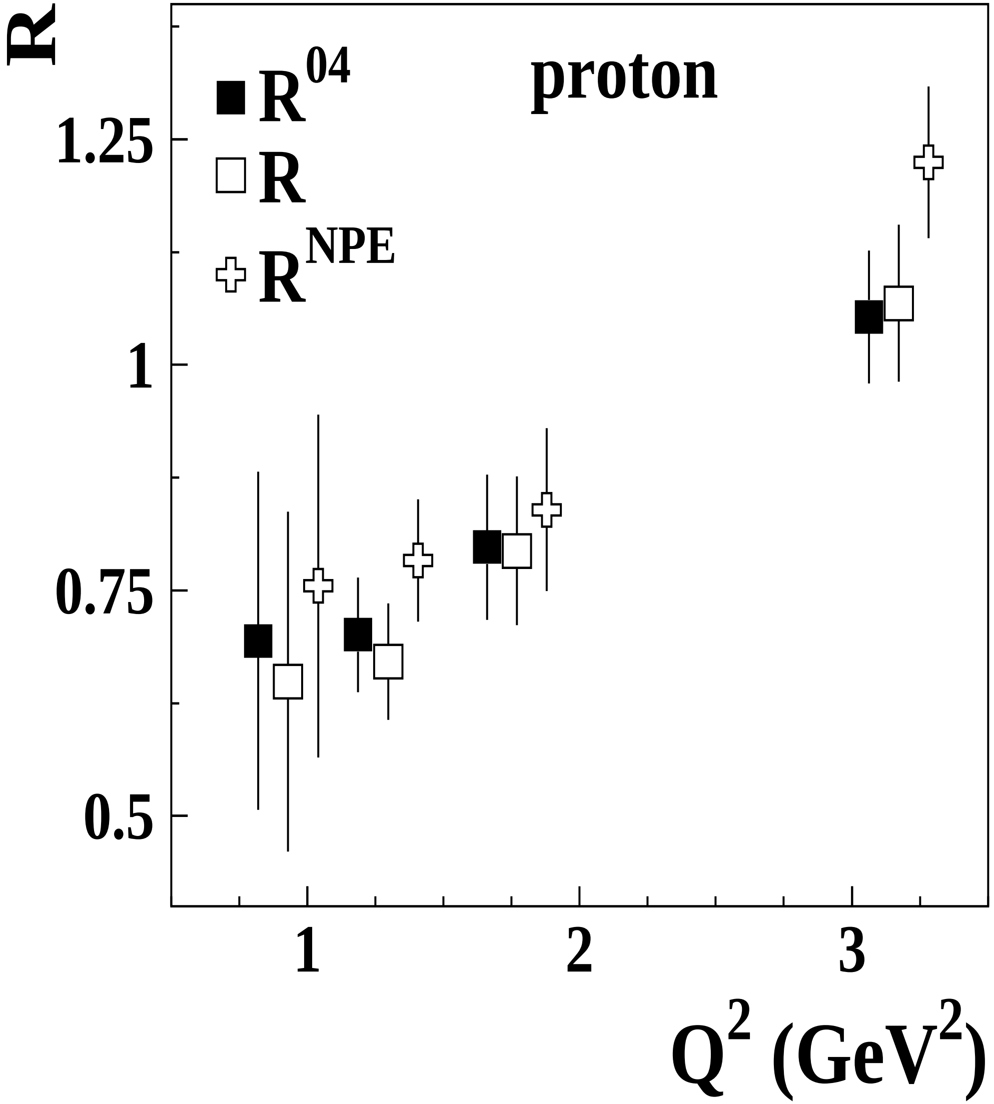
Due to the helicity-flip and unnatural parity amplitudes R^{04} depends on kinematic conditions, and is not identical to $R \equiv |T_{00}|^2/|T_{11}|^2$ for SCHC and NPE dominance.

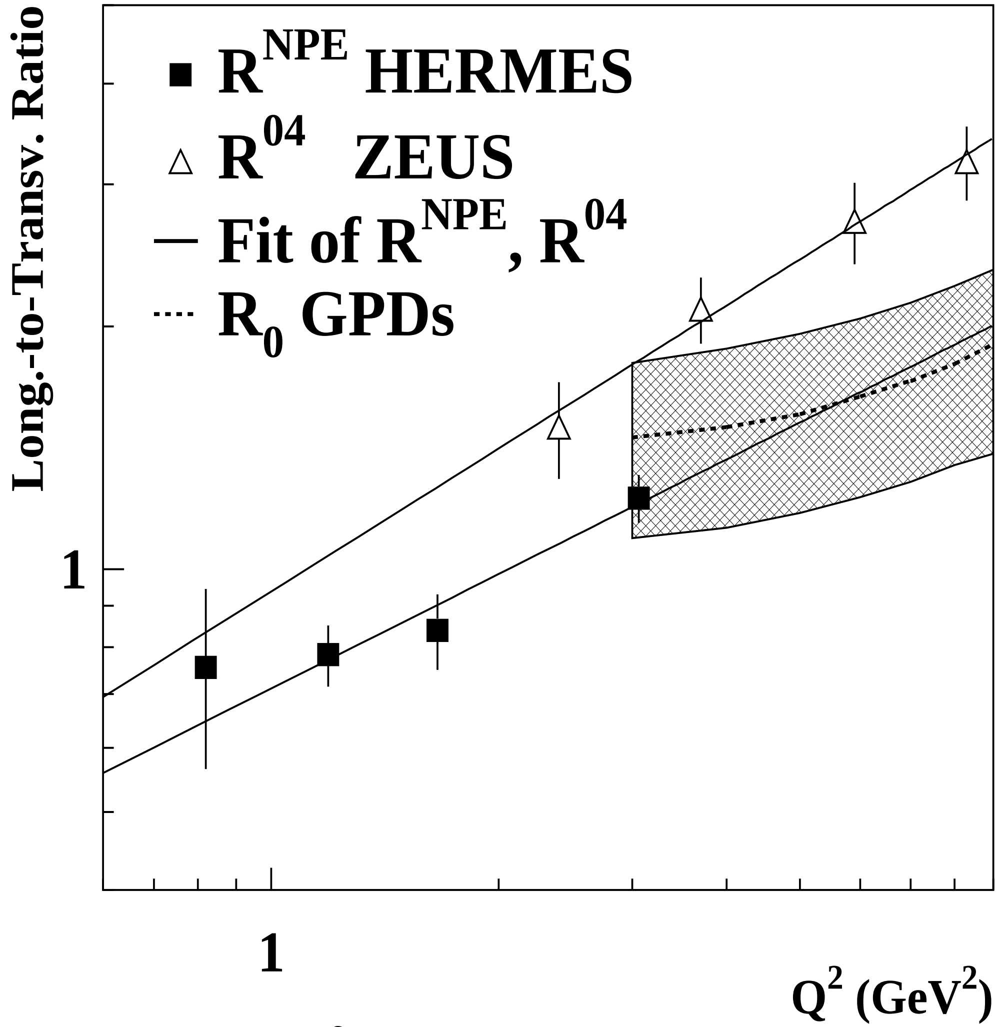


HERMES collab. arXiv:0901.0701, DESY 08-203

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

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





$R \equiv |T_{00}|^2/|T_{11}|^2$

$R^{NPE} \approx R^{04}[1 + 0.5u_1(1 + \epsilon R^{04})]$

see HERMES collab. arXiv:0901.0701, DESY 08-203

$R(Q^2) = c_o(\frac{Q^2}{M_V^2})^{c_1}$

HERMES: $c_0 = 0.56 \pm 0.08$, $c_1 = 0.47 \pm 0.12$, $\chi^2/d.o.f. = 0.45$

ZEUS: $c_0 = 0.69 \pm 0.22$, $c_1 = 0.59 \pm 0.15$, $\chi^2/d.o.f. = 0.15$

$\Longrightarrow$ W-dependence of c_0 and c_1

ϕ Longitudinal-to-Transverse Cross-Section Ratio

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

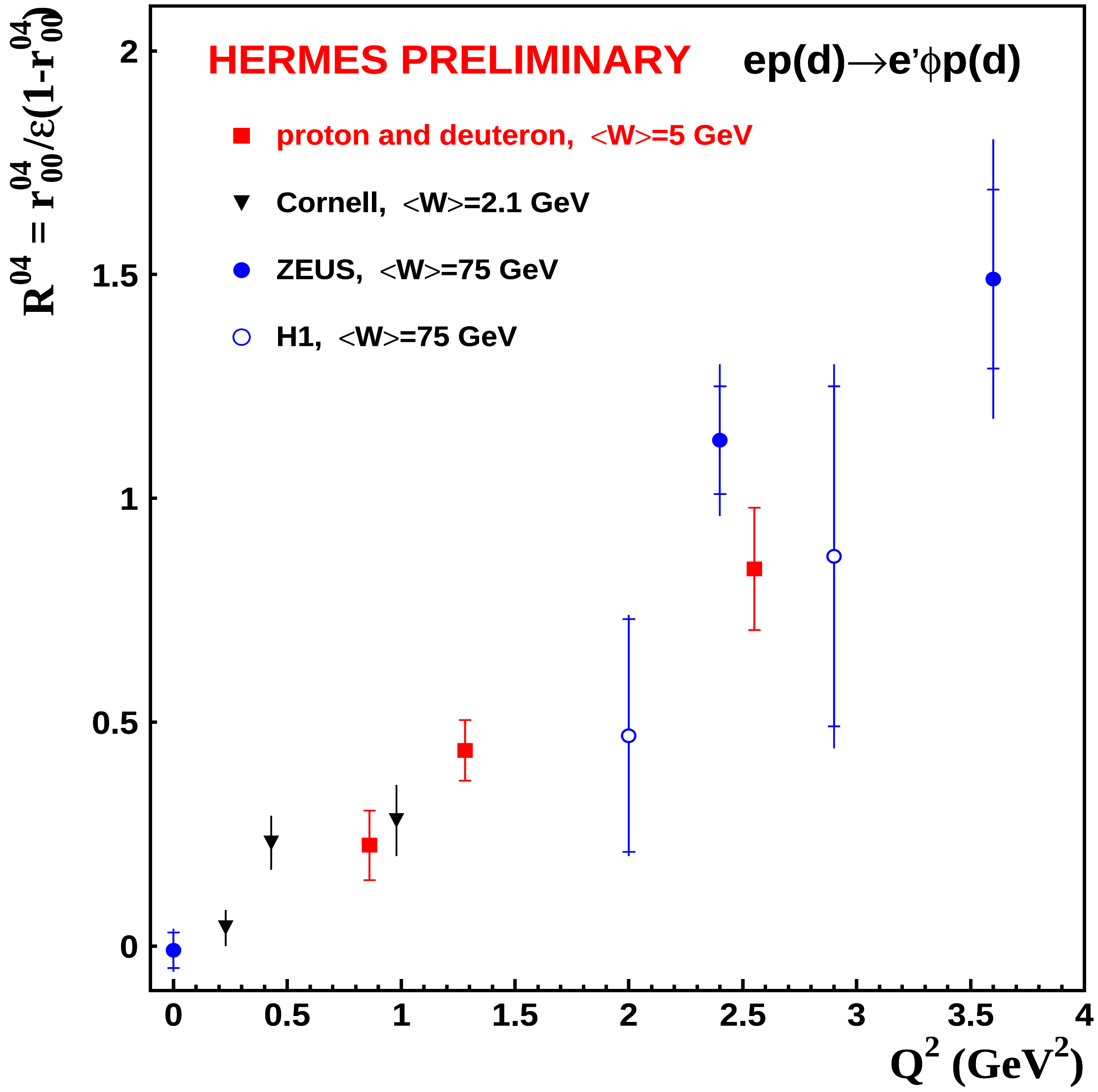
from the SDMEs analysis:

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

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

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

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

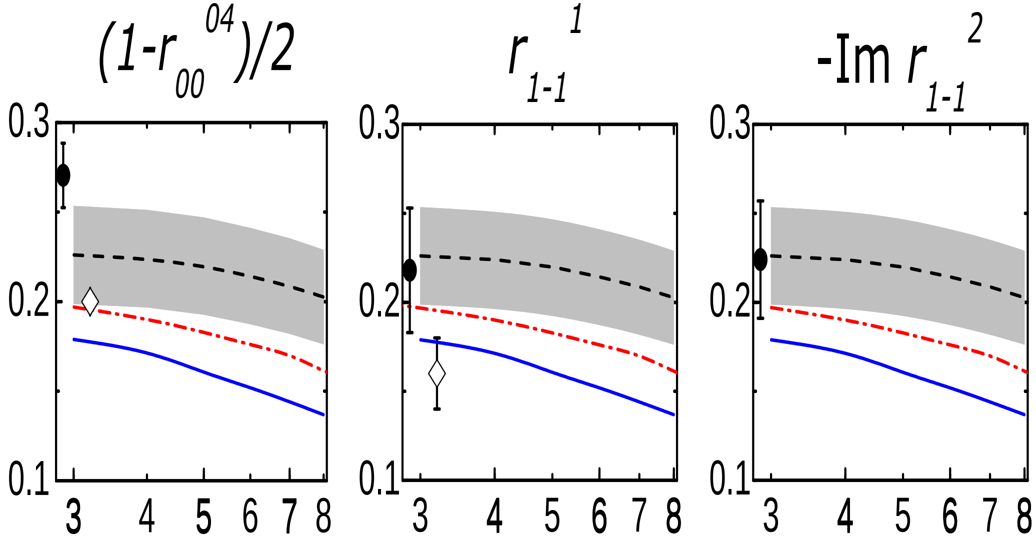


$\Longrightarrow$ R^{04} **for ϕ meson at HERMES is in good agreement with world data**

Weak W-dependence of R^{04} is supported by calculations, S. V. Goloskokov and P. Kroll, Eur. Phys. J. C **53** (2008) 367;

ρ^0 SDMEs Compared with GK Model Calculations

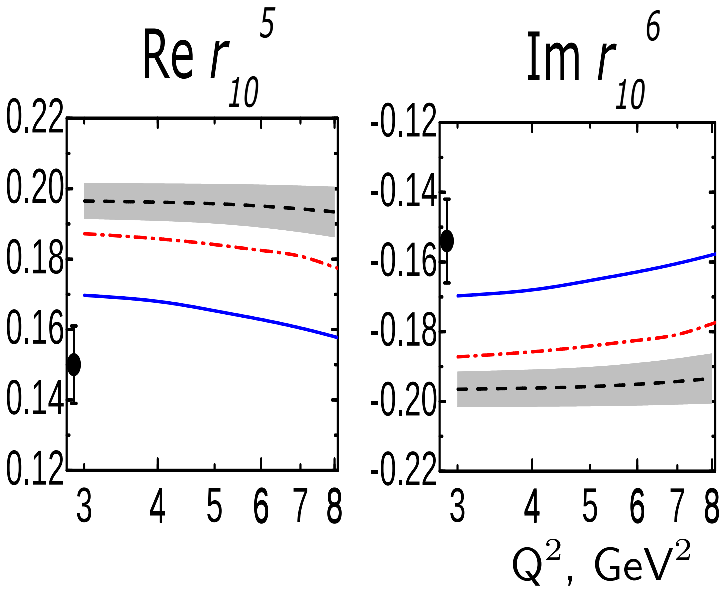
S. V. Goloskokov and P. Kroll, Eur. Phys. J. C **53** (2008) 367;



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

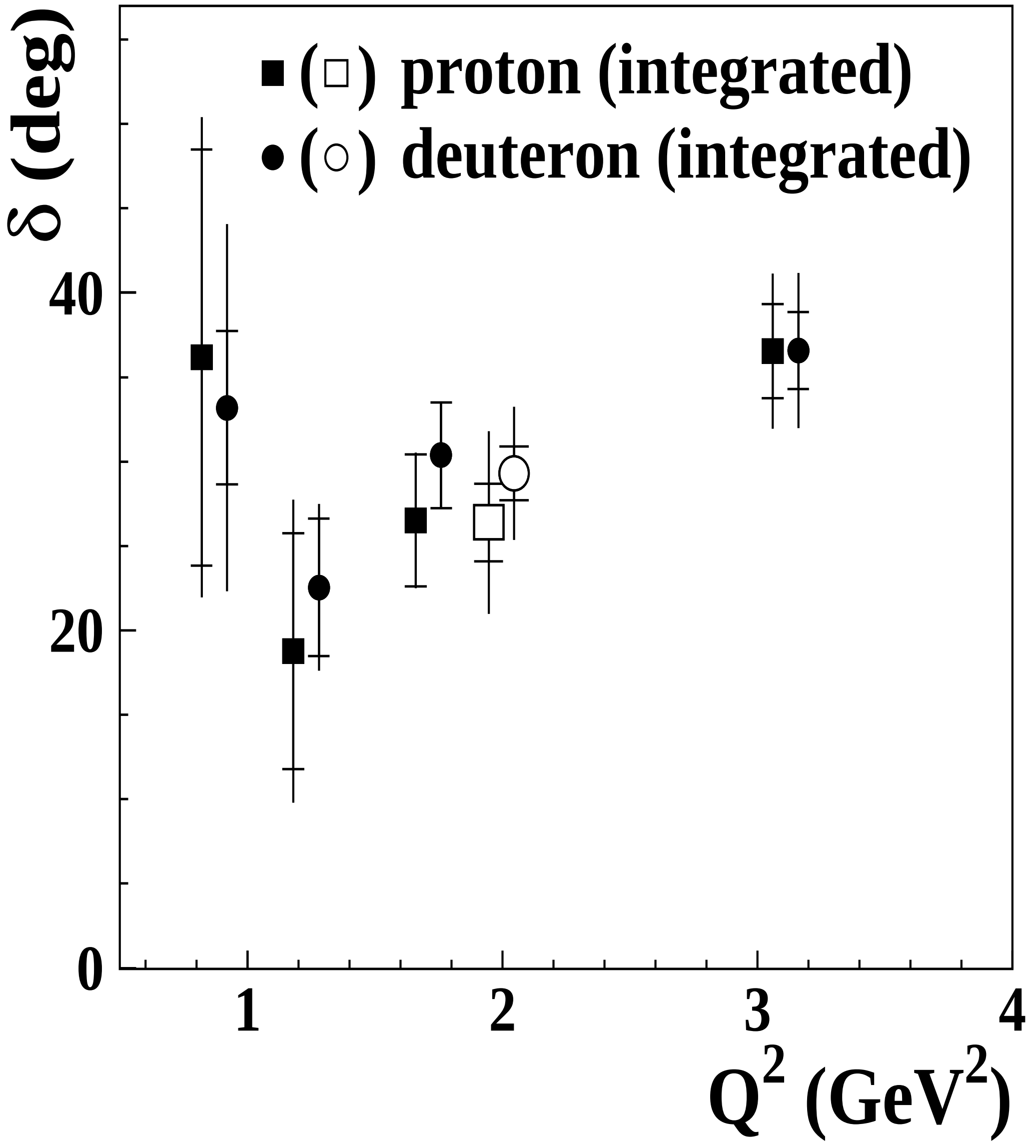
- W=90 GeV
- W=10 GeV, diamond: COMPASS
- W=5 GeV, circle: HERMES PRELIMINARY

$\Longrightarrow$ Fair agreement with data



Re r^5_{10} and Im r^6_{10} correspond to interference of γ^*_L, ρ^0_T amplitudes, phase difference between T_{11} and T_{00}

Phase Difference δ between T_{11} and T_{00} amplitudes



$$\sin\delta = \frac{2\sqrt{\epsilon}(\mathrm{Re}\{r^8_{10}\} + \mathrm{Im}\{r^7_{10}\})}{\sqrt{r^{04}_{00}(1 - r^{04}_{00} + r^1_{1-1} - \mathrm{Im}\{r^2_{1-1}\})}}.$$

ρ^0 p: $\delta = 30.6 \pm 5.0_{stat} \pm 2.4_{syst}$ deg
ρ^0 d: $\delta = 36.3 \pm 3.9_{stat} \pm 1.7_{syst}$ deg

ϕ p+d: $\delta = 33.0 \pm 7.4_{total}$ deg
W.Augustyniak,A.B.,S.I.Manayenkov
(for HERMES) arXiv:0808.0669

But in GK model $\delta = 3.1$ deg at W=5 GeV

$\Longrightarrow$ Indication on Q^2-dependence of δ

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

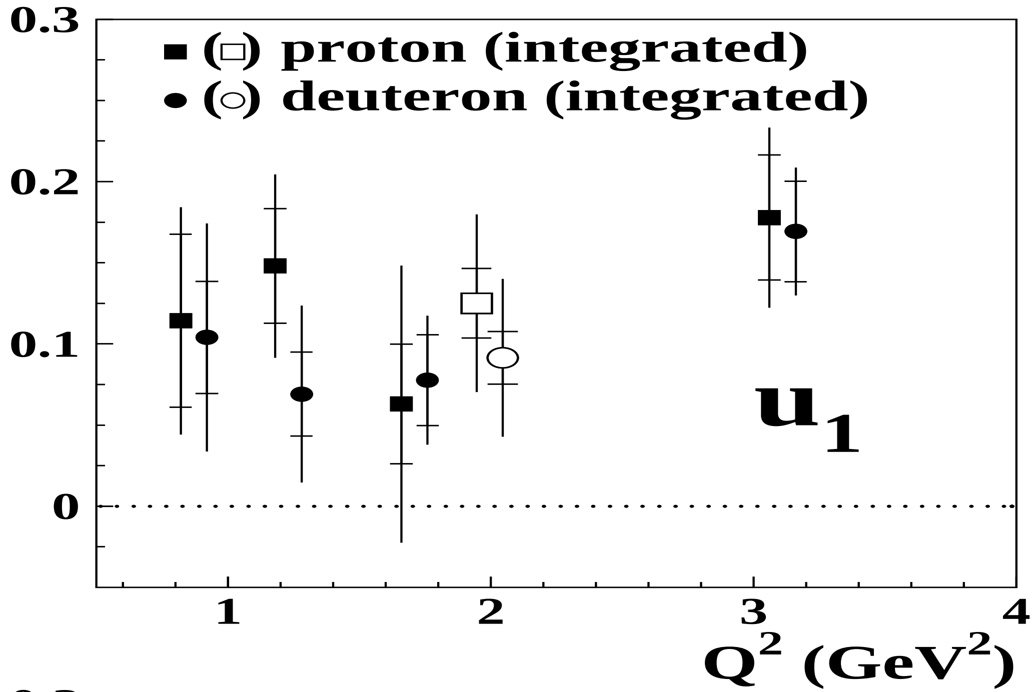
- Unnatural parity exchange is mediated by pseudoscalar or axial meson: $J^P = 0^-, 1^+$, e.g. π, a_1, b_1 $\longrightarrow$ only quark-exchange conribution
- No interference between NPE and UPE contributions on unpolarized target
- Extracted from SDMEs:
  - $u_1 \propto \epsilon |U_{10}|^2 + 2|U_{11} + U_{1-1}|^2$
    $u_1 = 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^1_{11} - 2r^1_{1-1}$

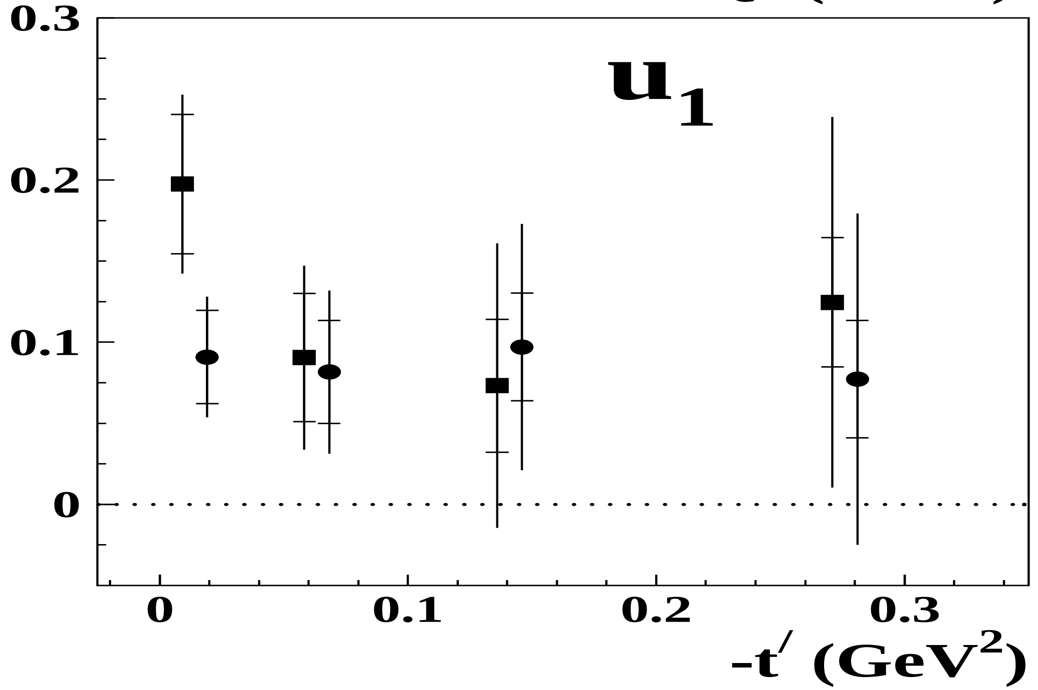
p: $u_1 = 2|U_{11}|^2 = 0.125 \pm 0.021_{stat} \pm 0.050_{syst}$
d: $u_1 = 0.091 \pm 0.016_{stat} \pm 0.046_{syst}$
p+d: $u_1 = 0.106 \pm 0.036$

  - $u_2 + iu_3 \propto (U_{11} + U_{1-1}) * U_{10}$

$u_2 = r^5_{11} + r^5_{1-1}$
p: $u_2 \approx -0.011 \pm 0.013$
d: $u_2 \approx -0.008 \pm 0.011$

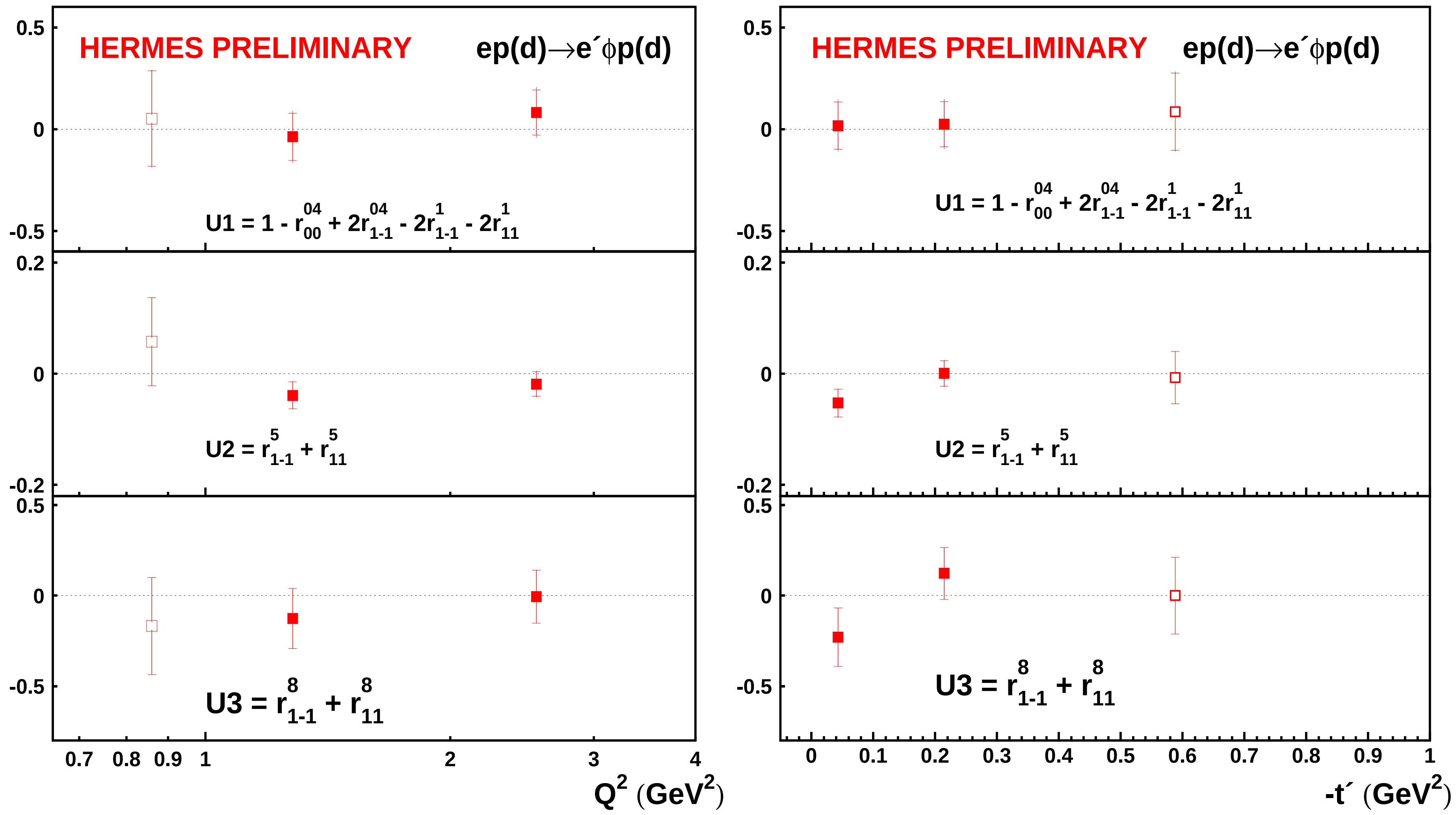
$u_3 = r^8_{11} + r^8_{1-1}$
p: $u_3 \approx 0.055 \pm 0.050$
d: $u_3 \approx -0.040 \pm 0.040$





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

...Only Natural Parity Exchange in ϕ Meson Leptoproduction



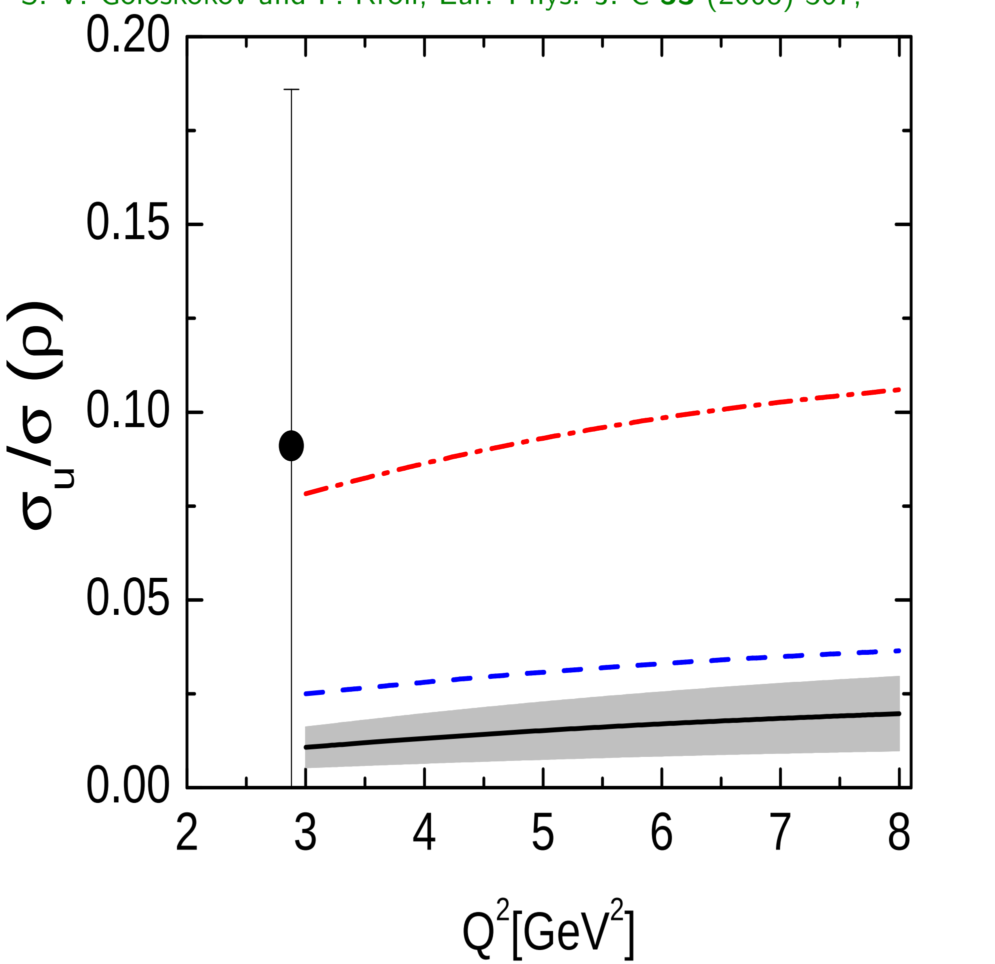
$$U1 \approx 0.02 \pm 0.17, \quad U2 \approx -0.03 \pm 0.04, \quad U3 \approx -0.05 \pm 0.13$$

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

W.Augustyniak, A.B., S.I.Manayenkov (for HERMES) arXiv:0808.0669

Unnatural Parity Exchange contribution in GK model

S. V. Goloskokov and P. Kroll, Eur. Phys. J. C **53** (2008) 367;



HERMES PRELIMINARY point plotted, W=5 GeV

- In GK model UPE requires $\tilde{H}$ GPD:

  $\sigma_U \propto e_u \tilde{H}^u_{val} - e_d \tilde{H}^d_{val}$ for ρ^0 production

  $\sigma_U/\sigma(\rho^0) = 2|U_{11}|^2/\sigma(\rho^0)$

  Lines:

  – extreme assumption for valence quarks: $\tilde{H}^u_{val} = H^u_{val}$ and $\tilde{H}^d_{val} = H^d_{val}$

  – extreme assumption for valence quarks: $\tilde{H}^u_{val} = H^u_{val}$ and $\tilde{H}^d_{val} = -H^d_{val}$

  – $\sigma_U \approx 0.013$ for gluons and sea contribution

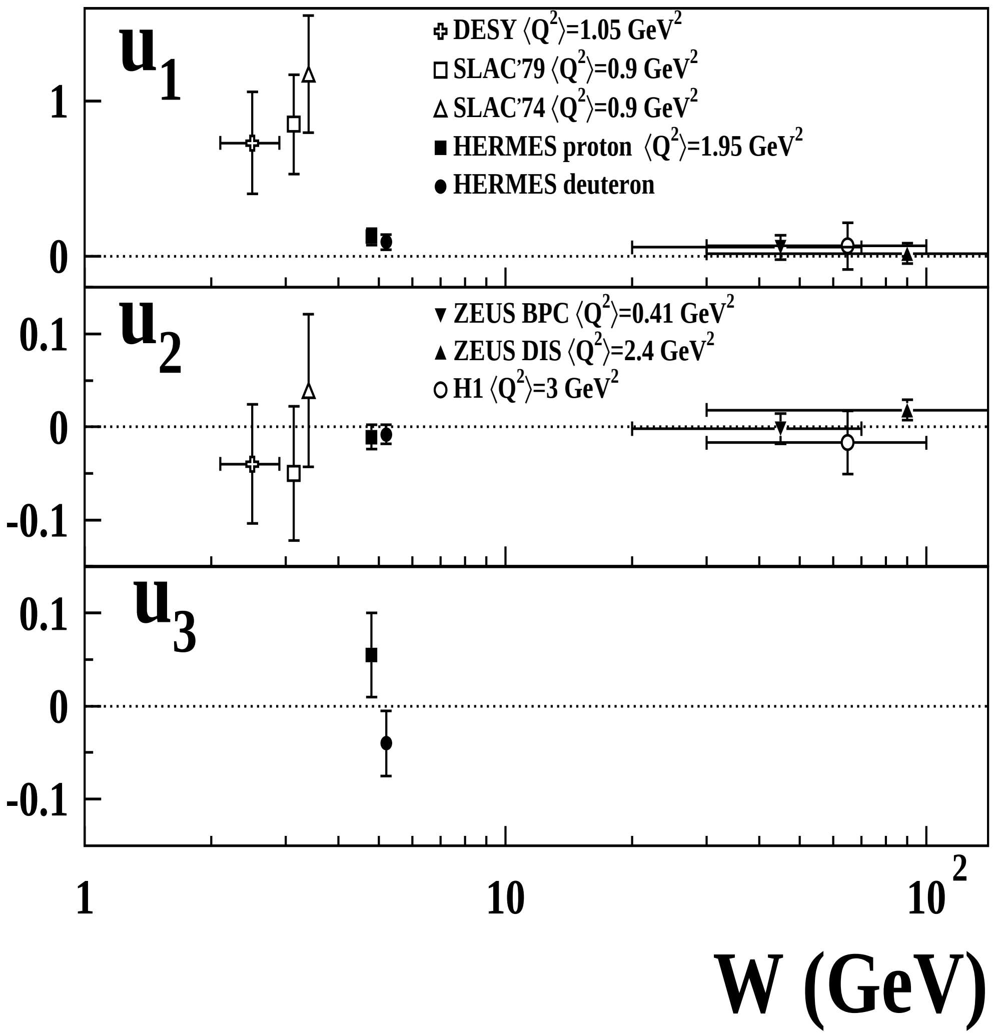
- σ_U small for H1 and ZEUS ρ^0 data as gluon and sea contribution dominates
- σ_U small for ϕ at HERMES as gluon contribution dominates

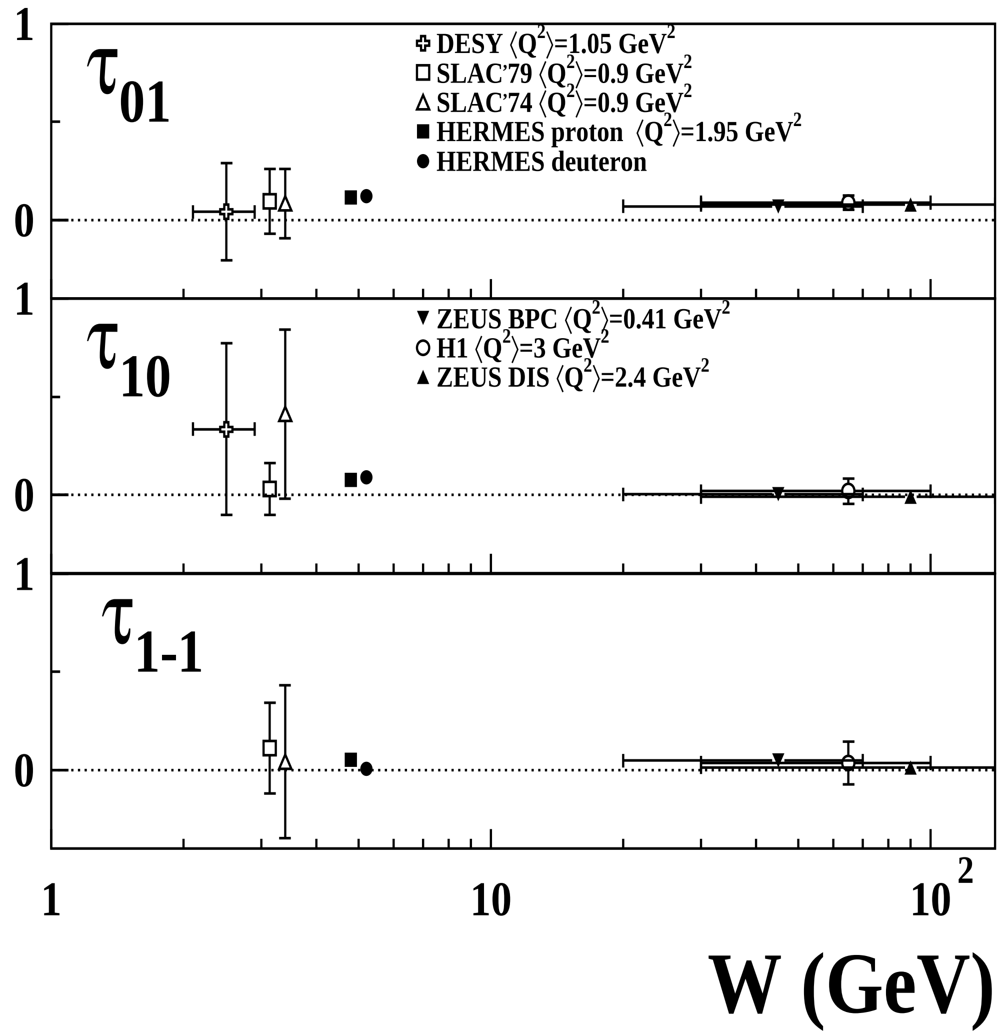
$\Longrightarrow$ **At $\langle Q^2 \rangle = 3.05$ GeV^2 (HERMES collab. arXiv:0901.0701, DESY 08-203) larger u_1 measured :**

p: $u_1 = 0.178 \pm 0.038_{stat} \pm 0.040_{syst}$

d: $u_1 = 0.169 \pm 0.032_{stat} \pm 0.024_{syst}$

World data on Unnatural Parity Exchange and Spin-Flip Contributions for ρ^0





$$\langle u_1^{lowW} \rangle = 0.70 \pm 0.16$$

$$\tau_{ij} = \frac{|T_{ij}|}{\sqrt{\sum_{ij} |T_{ij}|^2}}, \qquad \tau_{ij}^2 = \frac{|T_{ij}|^2}{\sigma_{tot}}$$

$\Longrightarrow$ W-dependence of u_1

Transverse Target Polarization Asymmetry A_{UT}

$$A_{UT} \approx \frac{\sqrt{t_0 - t}}{m_p} \frac{Im(E_V^* H_V)}{|H_V|^2} = \frac{\sqrt{t_0 - t}}{m_p} \left|\frac{E_V}{H_V}\right| \sin \delta_V,$$

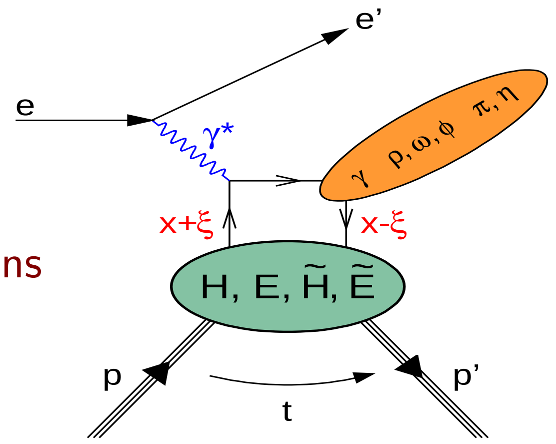
where $\delta_V = arg(H_V/E_V)$, is relative phase between H_V and E_V

$\Longrightarrow$ Access to GPD function E which is sensitive to the angular momentum of quarks and gluons

GPD based calculations of A_{UT}^V:

- M.Diehl, W.Kugler (Eur.Phys.J.C52:933-966,2007, arXiv:0708.1121, DESY-07-17) LO and NLO, at $Q^2 \geq 4$ GeV^2, $t = -0.4$ GeV^2, $V = \rho^0$, ω, ϕ
- D.Ivanov (arXiv:0712.3193, and HERMES seminar, DESY, 9.12.2008): stable results for a resummation of NLO amplitudes for vector mesons are presented for fixed target experiments only.
- S. V. Goloskokov, P. Kroll, (Eur. Phys. J. C 53(2008) 367; and arXiv:0809.4126) LO, at $W = 5$ GeV, $Q^2 \geq 3$ GeV^2, $0 < -t < 0.4$ GeV^2, i.e. at HERMES kinematic conditions, $V = \rho^0, \phi, \omega, \rho^+, K^{*0}$

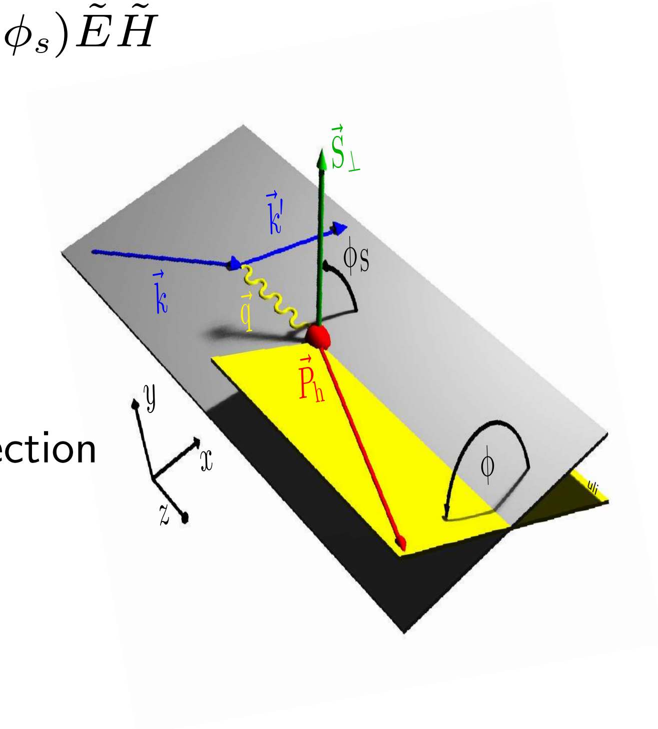
$\Longrightarrow$ Comparison of HERMES data with the GPD based calculations



Measurement of Transverse Target Polarization Asymmetry A_{UT}

Frankfurt,Polyakov,Strikman,Vanderhaeghen(2000) : $A_{UT}^{\pi^+} \propto |S_T| \sin(\phi - \phi_s)\tilde{E}\tilde{H}$

Goeke,Polyakov,Vanderhaeghen(2001): $A_{UT}^{\rho^0} \propto |S_T| \sin(\phi - \phi_s) EH$



$S_T = \frac{\cos\theta_\gamma P_T}{(\sqrt{(1-\sin^2\theta_\gamma \sin^2\phi_s)}}$ defined with respect to the γ^* direction,

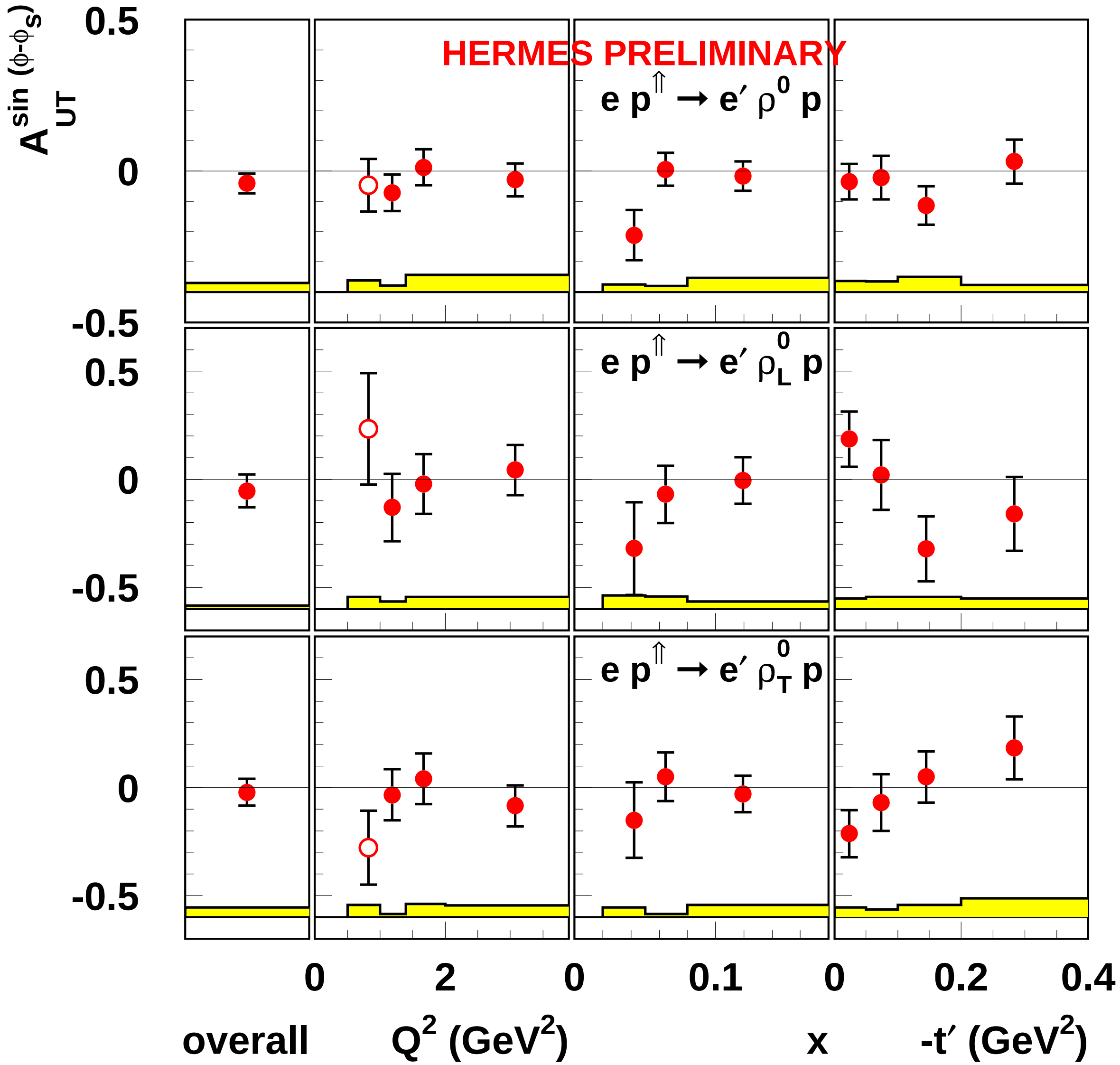
where transverse target polarization P_T with respect to the lepton beam direction

M.Diehl, S.Sapeta (Eur.Phys.J.C41:515-533,2005; arXiv:hep-ph/0503023):
cross section decomposition in terms of 6 $\sin(m * \phi + n * \phi_s)$ moments:

In leading twist: $A_{UT}(\phi, \phi_s) = \frac{\sigma_{UT}}{\sigma_{UU}} = A_{UT}^{\phi-\phi_s} \sin(\phi - \phi_s)$

$\Longrightarrow$ Maximum Likelihood Fit of $\sin(m * \phi - n * \phi_s)$ distributions

ρ^0 Transverse Target Polarization Asymmetry



- Average kinematics:
  $\langle -t' \rangle = 0.13$ GeV^2
  $\langle x_B \rangle = 0.09$
  $\langle Q^2 \rangle = 1.95$ GeV^2

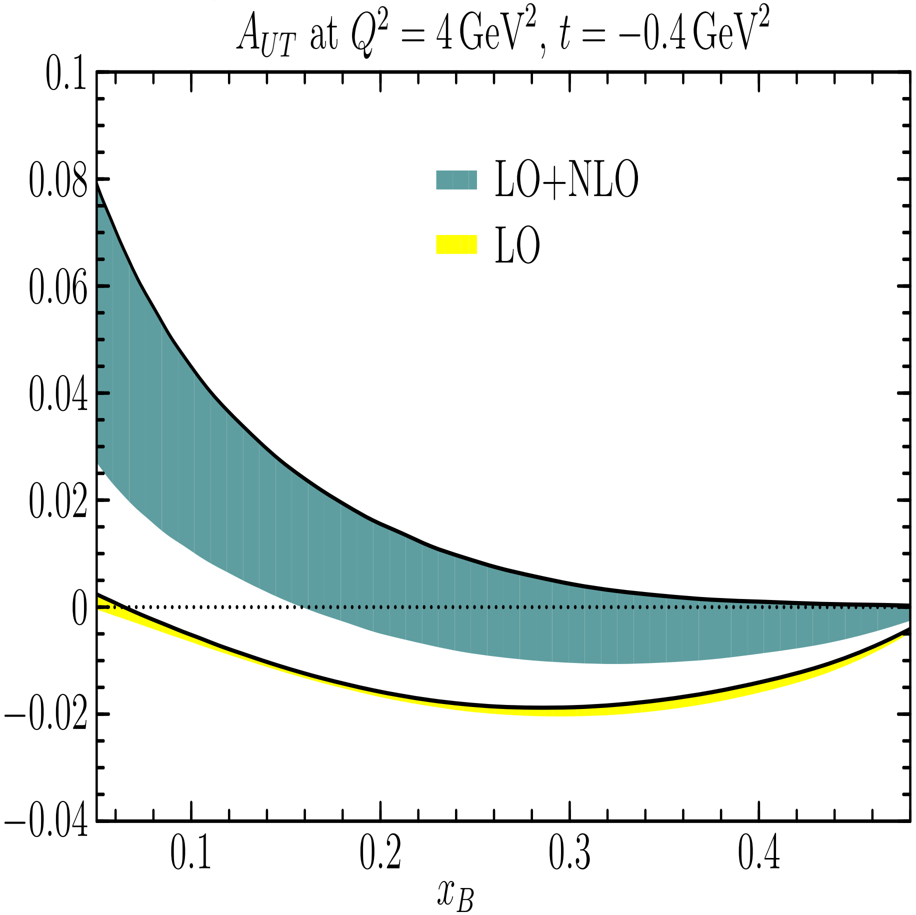
- σ_L and σ_T separation done using the ρ^0 SDMEs

  J.Dreschler, A.Rostomyan (for HERMES) arXiv:0707.2486

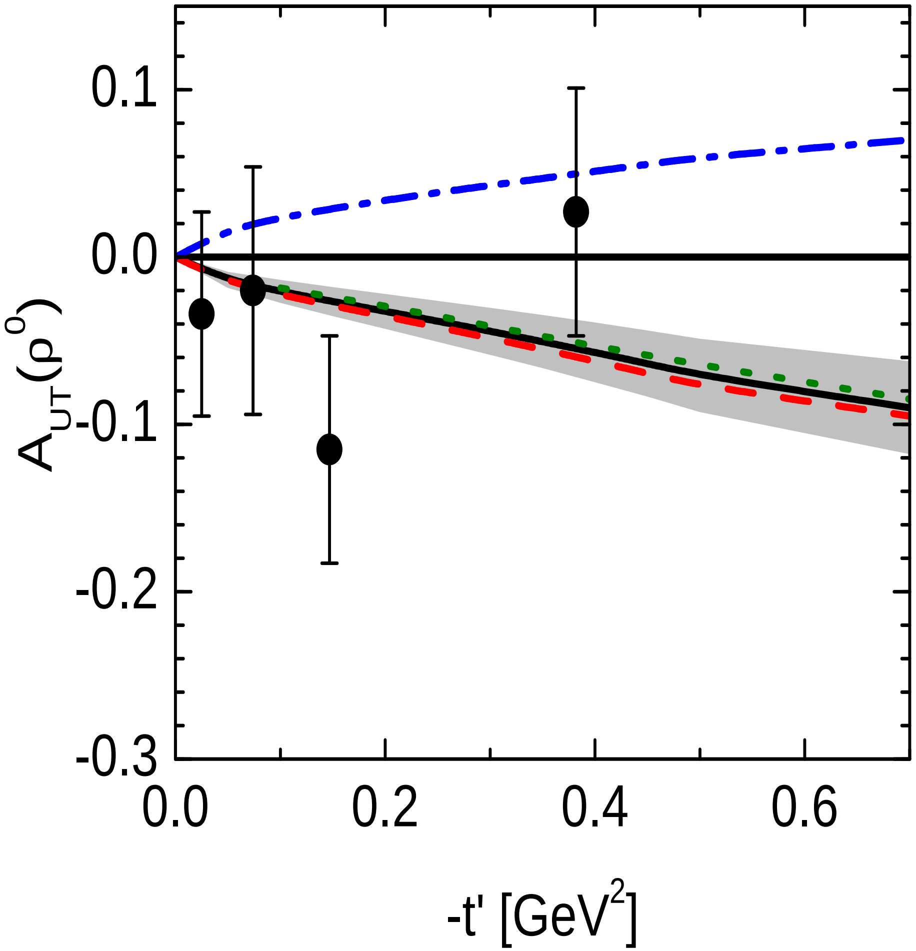
$\Longrightarrow$ Compartible with zero overall value for leading amplitude: $A_{UT}^{\rho^0} = -0.033 \pm 0.058$

ρ^0 Transverse Target Polarization Asymmetry

M.Diehl, W.Kugler Eur.Phys.J.C52,2007



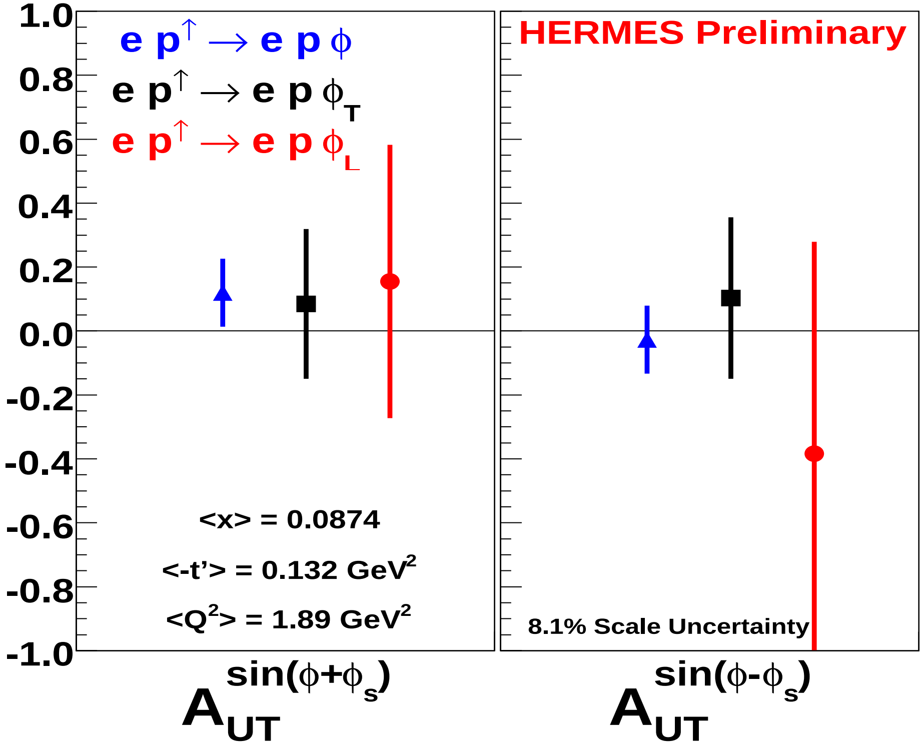
S. V. Goloskokov, P. Kroll arXiv:0809.4126

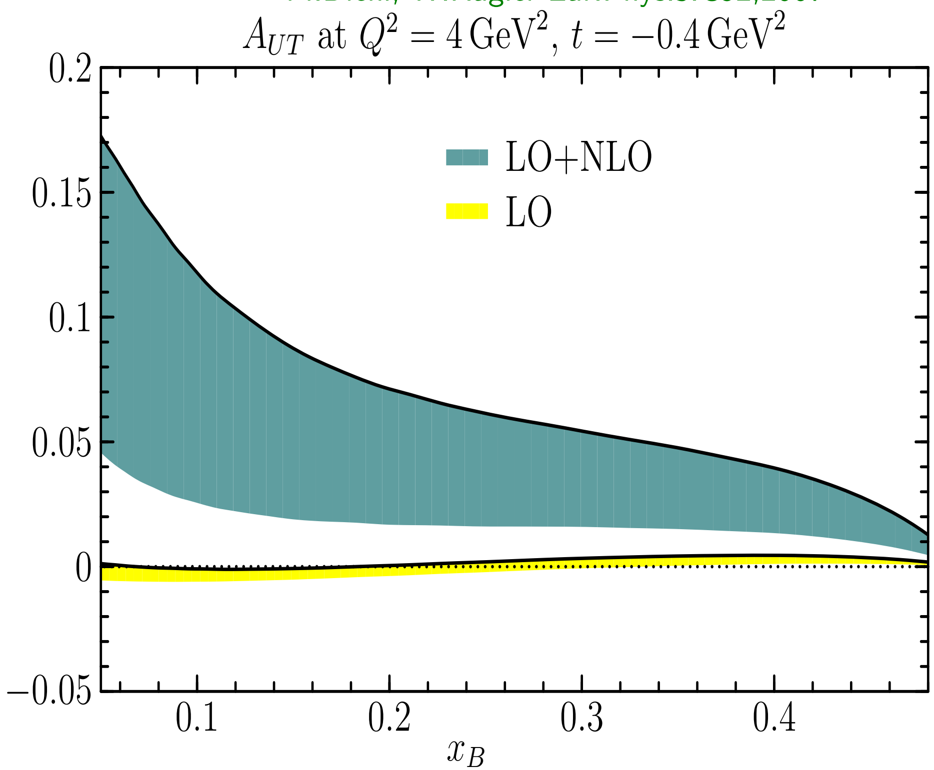


HERMES PRELIMINARY

$\Longrightarrow$ $A_{UT}^{\rho^0}$ is small

ϕ Meson Transverse Target Polarization Asymmetry



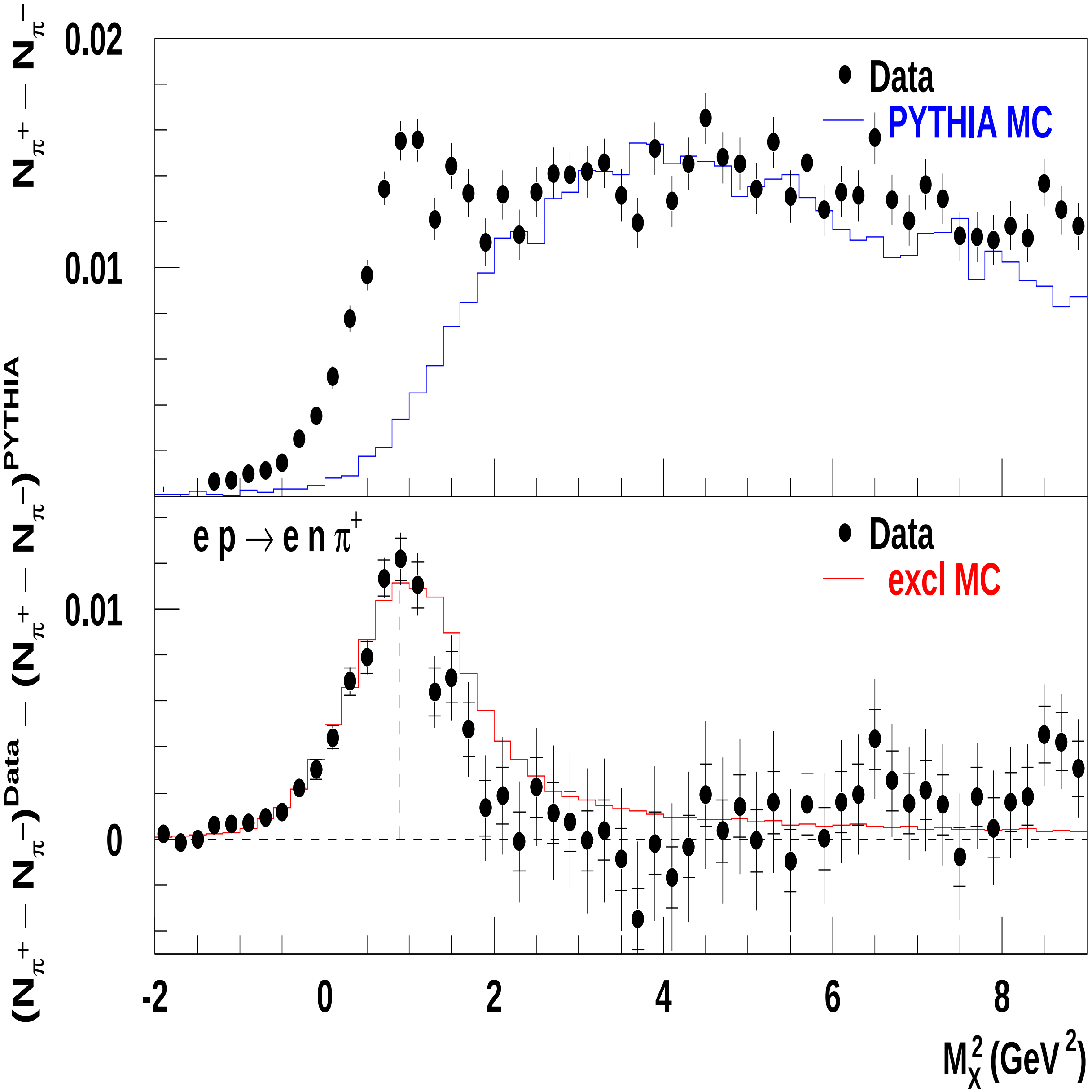


$\Longrightarrow$ $A_{UT}^{\phi}(\phi - \phi_s)$ is small in data, LO of M.Diehl, W.Kugler calculations and GK model.

...Note the predictions for $A_{UT}^{\omega} \approx -0.10$ and $A_{UT}^{\rho^+} \approx 0.40$ in S. V. Goloskokov, P. Kroll arXiv:0809.4126.

$\Longrightarrow$ Analysis is in progres

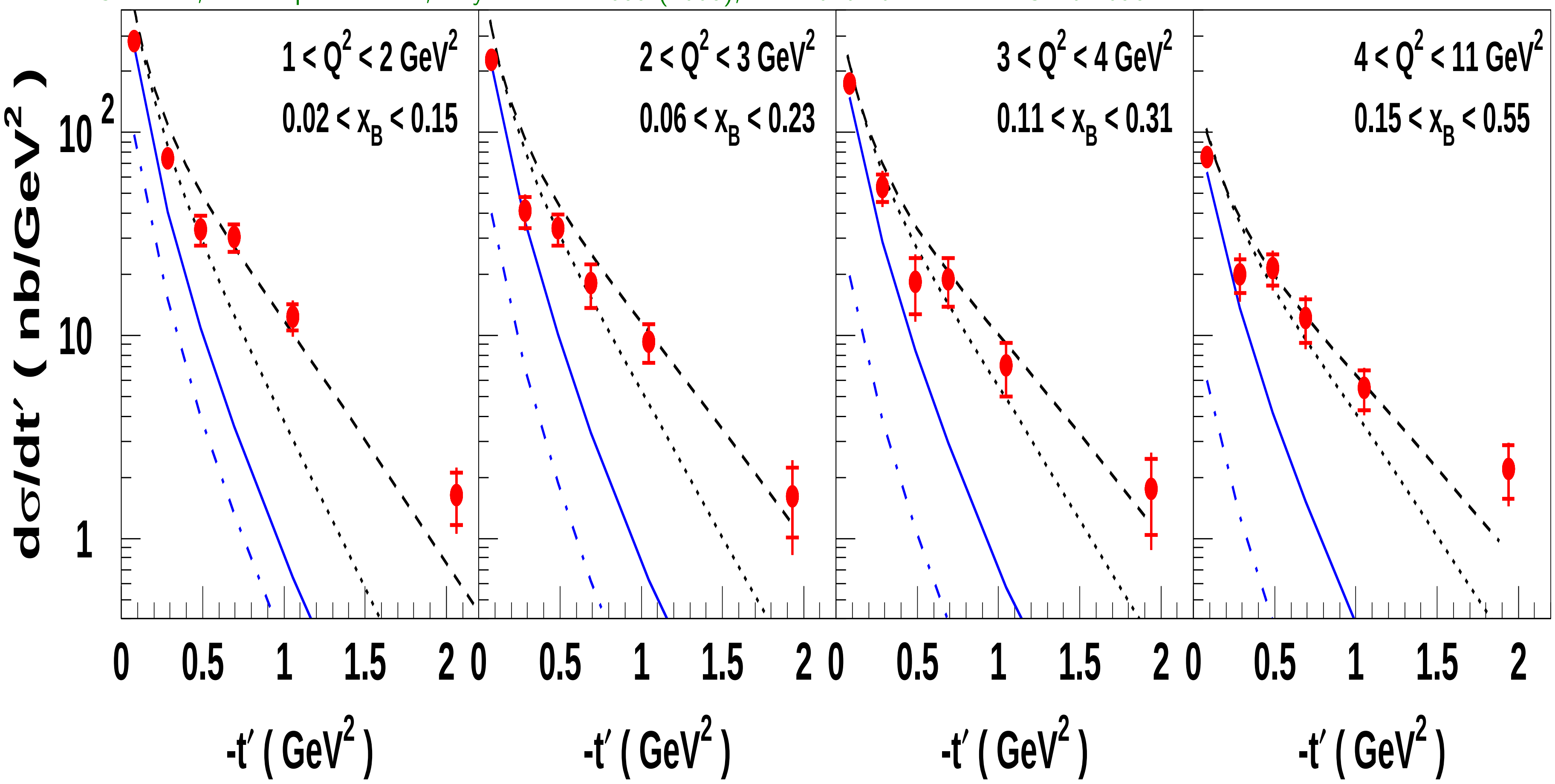
Exclusive π^+ Production: $ep \to e'\pi^+(n)$



- $M_x^2 = (P_e + P_p - P'_e - P_{\pi^+})^2$
- $\pi^+ - \pi^-$ yield difference used to subtract non-exclusive background
- exclusive peak centered at the nucleon mass
- agreement with the simulation of exclusive π^+ production

Cross Section of Exclusive π^+ Leptoproduction

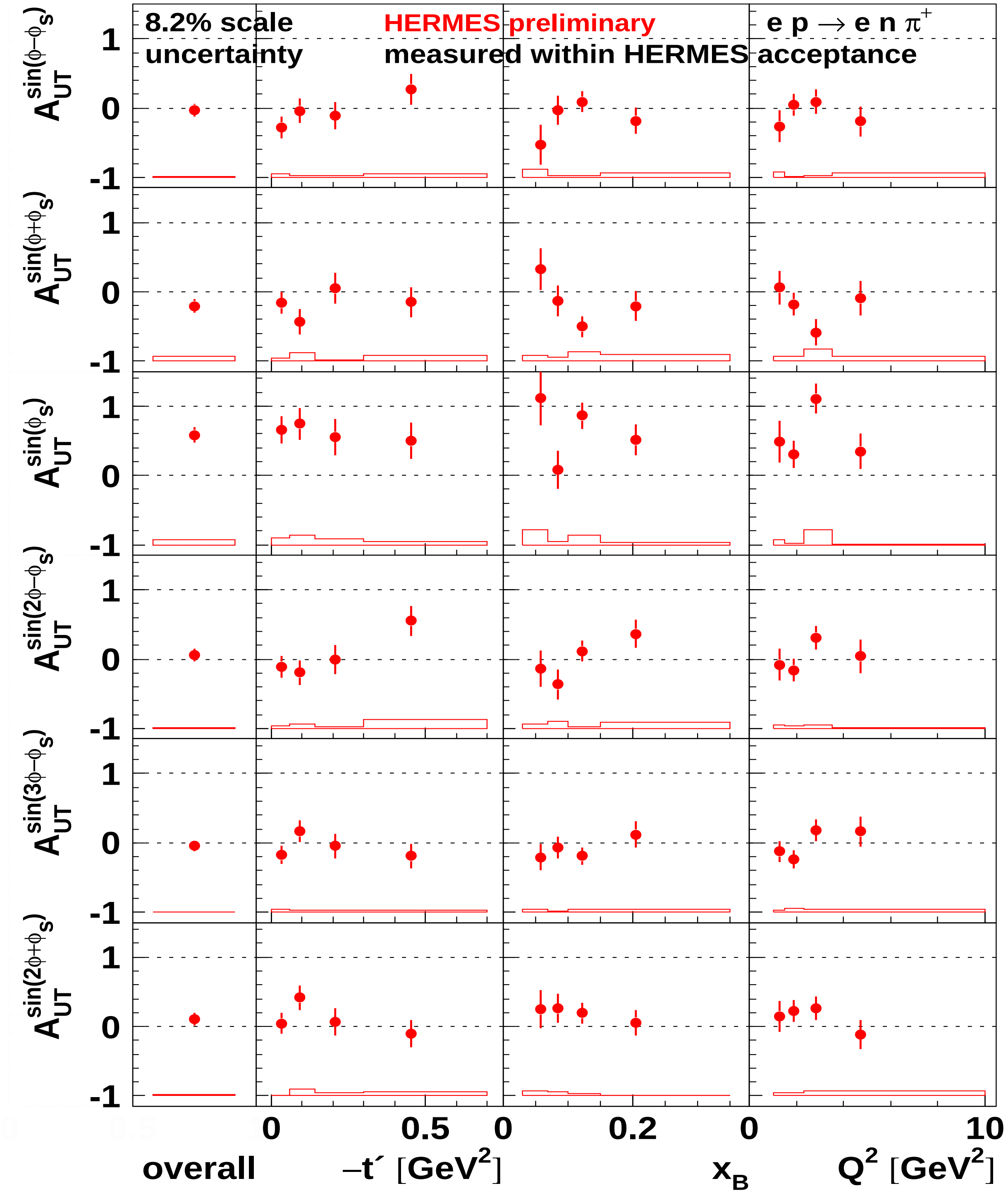
HERMES collab., A. Airapetian et al, Phys. Lett. B 659 (2008), arXiv:0707.0222 and DESY-07-098



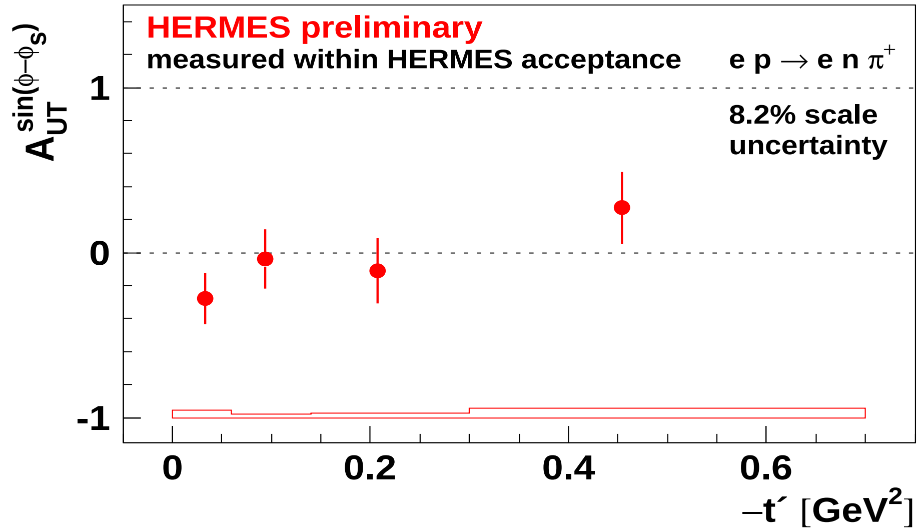
GPD model for $d\sigma_L/dt'$ $\longrightarrow$ fair agreement with data only at lower t'

Regge model for $d\sigma_L/dt'$ and $d\sigma_T/dt'$: σ_T is predicted to be 15-25 % of σ
$\longrightarrow$ good description of magnitude and Q^2 and $-t'$ dependences of the data

π^+ Transverse Target Polarization Asymmetry



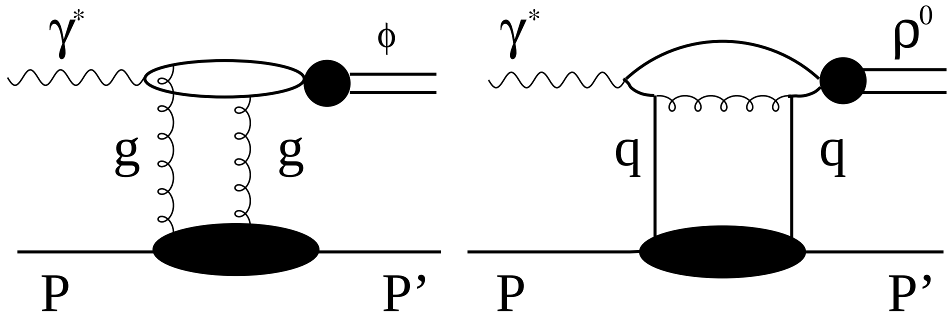
- Fit of six moments: $A_{UT}(\phi,\phi_s) = \frac{\sigma_{UT}}{\sigma_{UU}} = \sum A_{UT}^{m*\phi+n*\phi_s}\sin(m*\phi+n*\phi_s)$
- Average kinematics:
  $\langle -t' \rangle = 0.18$ GeV^2
  $\langle x_B \rangle = 0.13$
  $\langle Q^2 \rangle = 2.38$ GeV^2
- small overall value for leading moment $A_{UT}^{\sin(\phi-\phi_s)}$
- indication on the change of sign of leading moment in t'-dependence:



- unexpected large overall value for moment $A_{UT}^{\sin(\phi_s)} \approx 0.6$

Summary

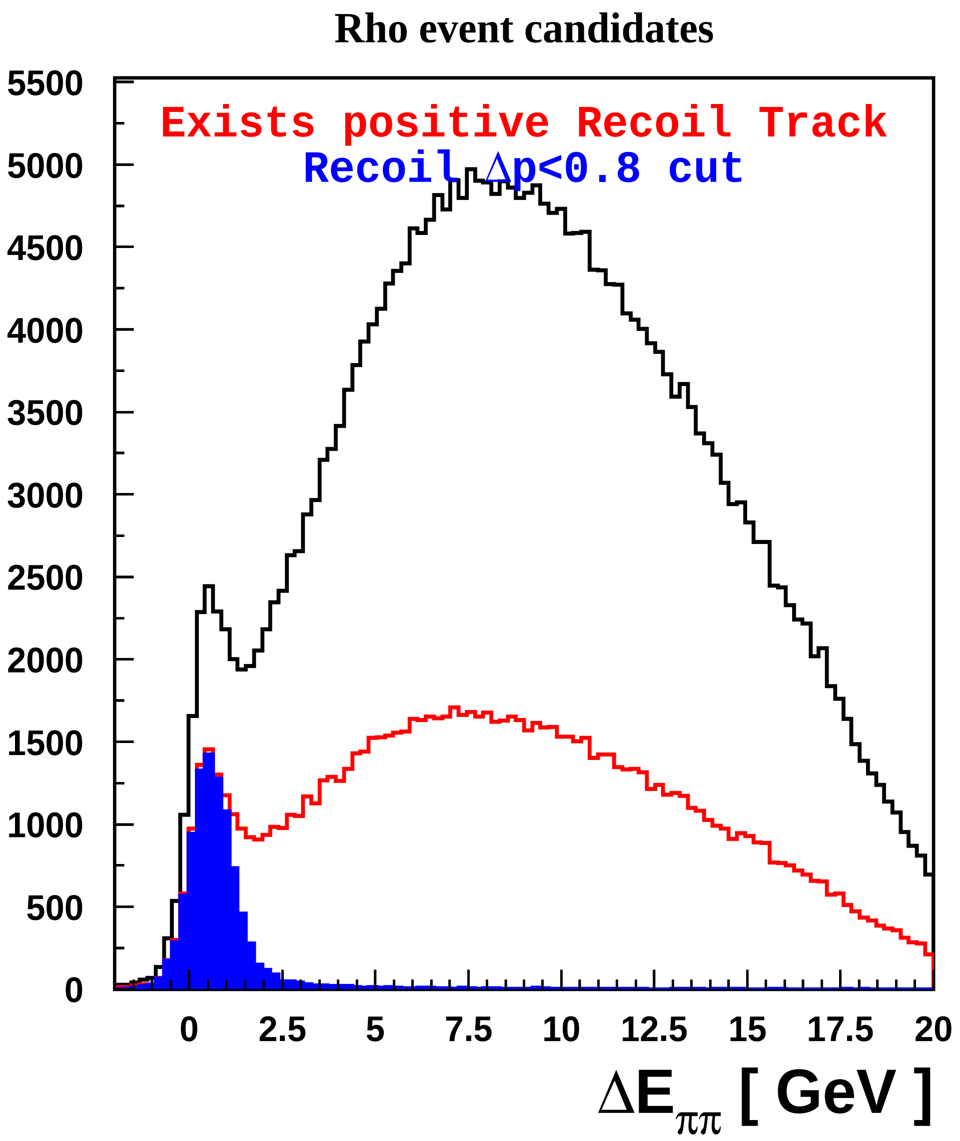
- HERMES data are unique due to the sensitivity to *both quark and two-gluon exchange processes* at sufficiently large W and Q^2 for the comparison with GPD handbag diagram based calculations:

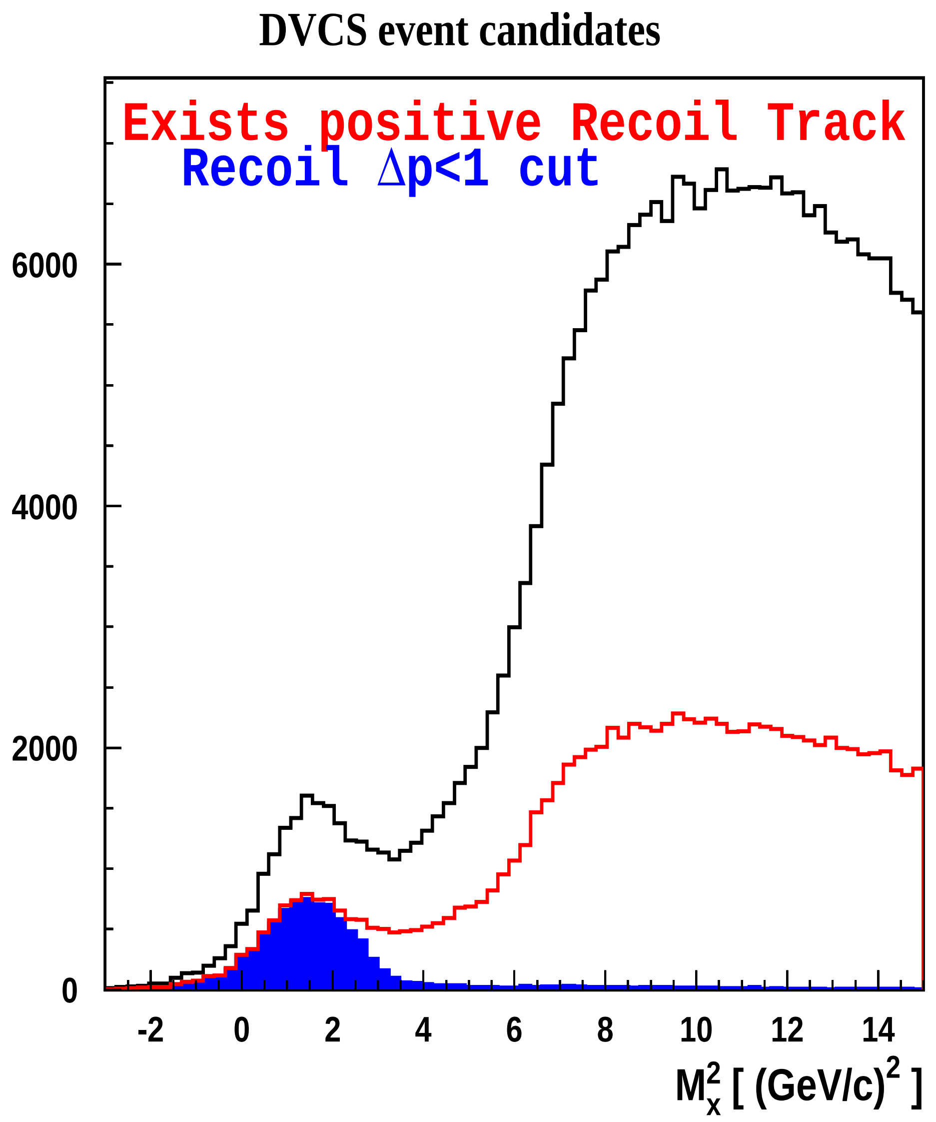


- *First comprehensive comparison* of data on ρ^0 and ϕ meson production with GK model calculations is in fair agreement for:
  - longitudinal and total cross sections of ρ^0 and ϕ mesons
  - values of SDMEs and hierarchy of corresponding amplitudes
  - violation of SCHC in ρ^0 production
  - W-dependence of ρ^0 and ϕ SDMEs and σ_L/σ_T ratios
  - small values of transverse target polarization asymmetries
- Remaining points for the GPD based calculations are for:
  - *phase difference* in the interference of $\gamma^*_L \rightarrow \rho^0_L \& \gamma^*_T \rightarrow \rho^0_T$ transitions
  - $\tilde{H}^{u,d}_{val}$ contribution in Unnatural Parity Exchange amplitude

- Cross section of exclusive π^+ is in fair agreement with the calculations for lower t'
- t'-dependence of the π^+ transverse target polarization asymmetry can be supported by the calculations

Outlook. Firs Data from HERMES Spectrometer and Recoil Detector





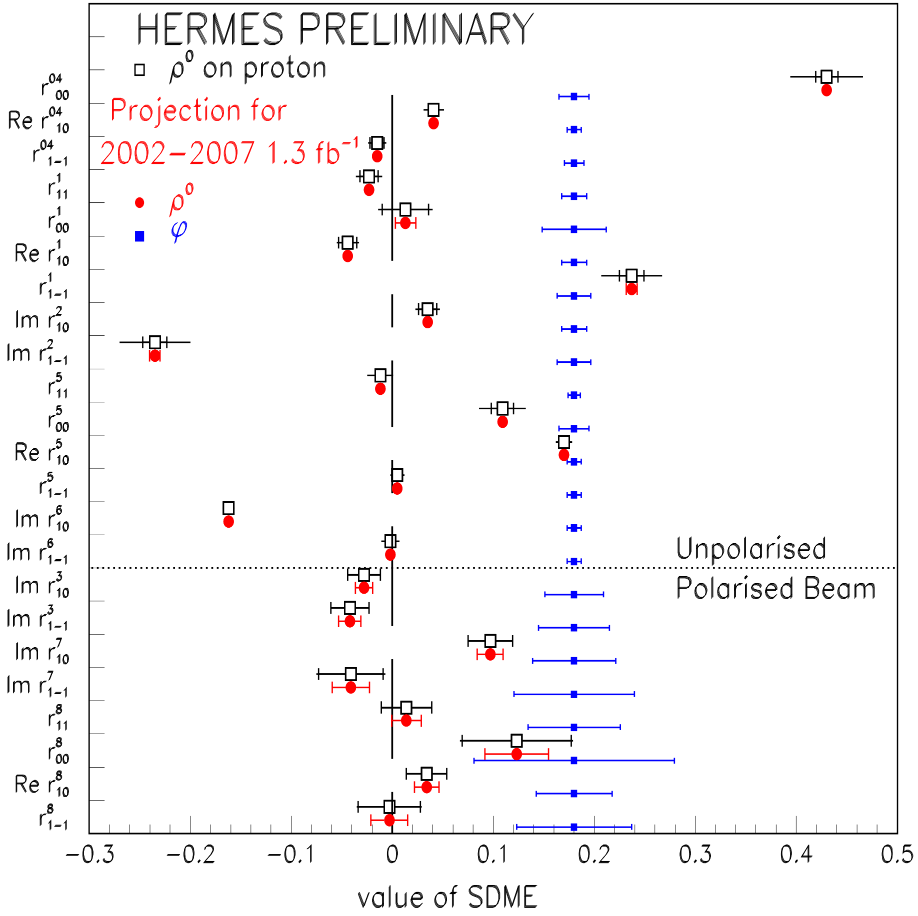
Black histogram - event candidates without Recoil Detector

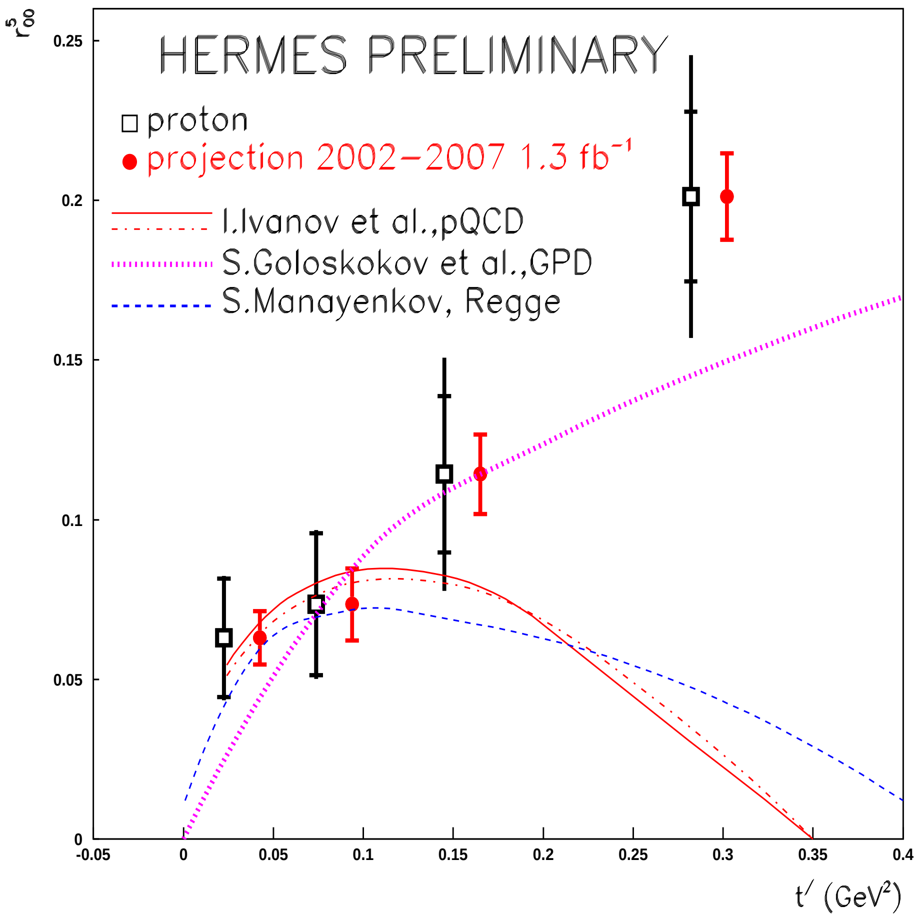
$\Delta P = P_{meas}(p') - P_{calc}$, small ΔP (GeV) corresponds to the exclusive reactions

$\Longrightarrow$ Subsample of data with detected p' contains significantly reduced background

Outlook

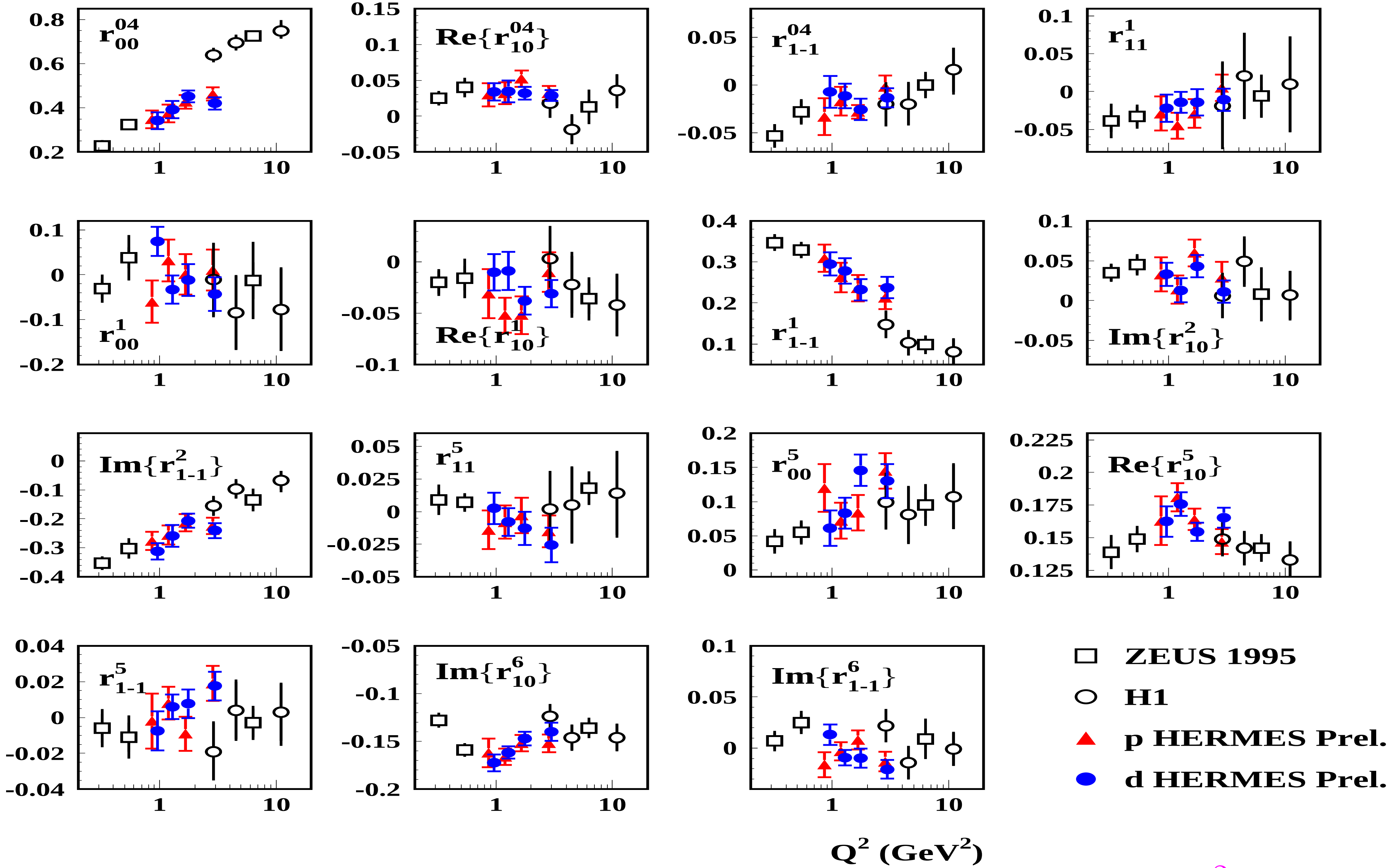
Projections for ρ^0 and ϕ meson SDMEs for 2006-2007 data at $\mathcal{L} \sim 1.3$ fb^{-1} with detected p':





$\Longrightarrow$ **Exclusive meson production with detected recoil proton is under study**

Backup Slides: 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

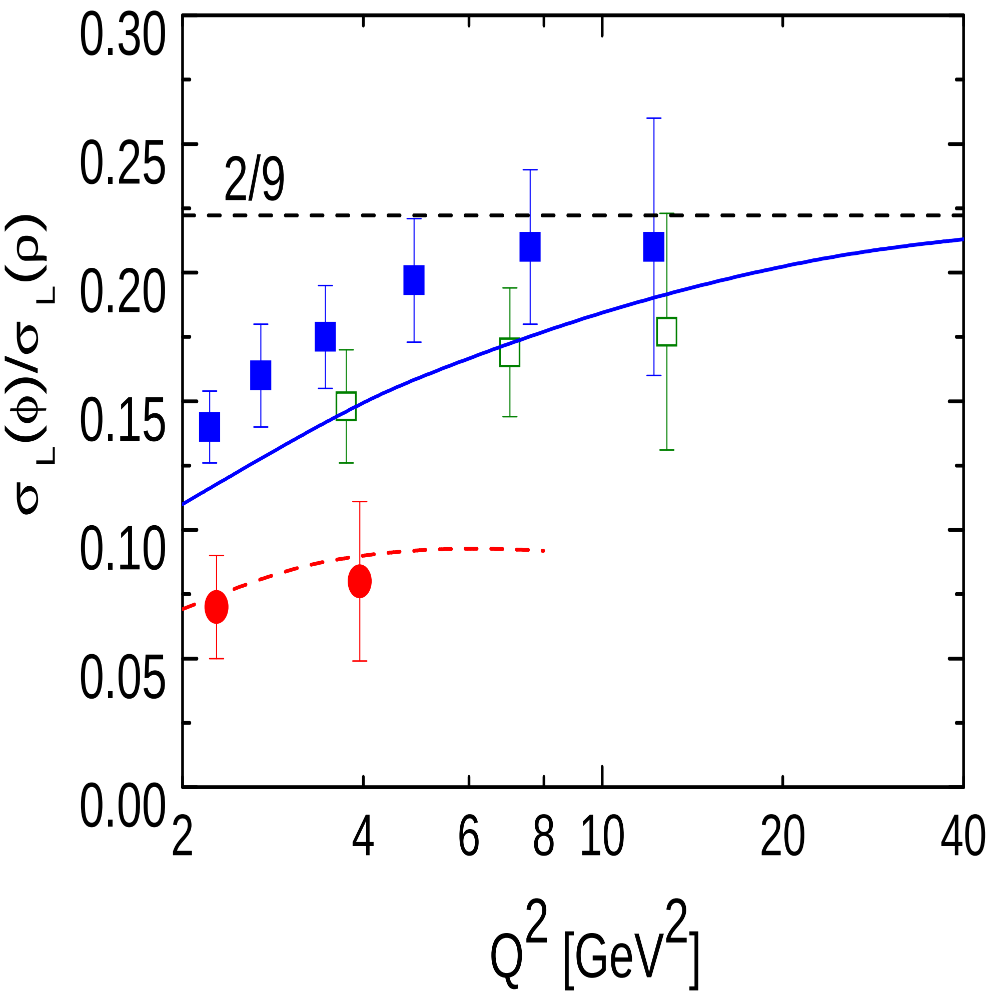


$\Longrightarrow$ Several SDMEs indicate possible W-dependence, in addition to Q^2-dependence

Backup Slides: 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



W=75 GeV, H1 (closed),ZEUS (open squares), W=5 GeV, HERMES PRELIMINARY (circules)

$\Longrightarrow$ **Remarkable agreement of calculations with W-dep. of $\sigma_{L(\phi)}/\sigma_{L(\rho^o)}$ ratio**