Hard exclusive electroproduction of vector mesons at HERMES

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on behalf of HERMES Collaboration

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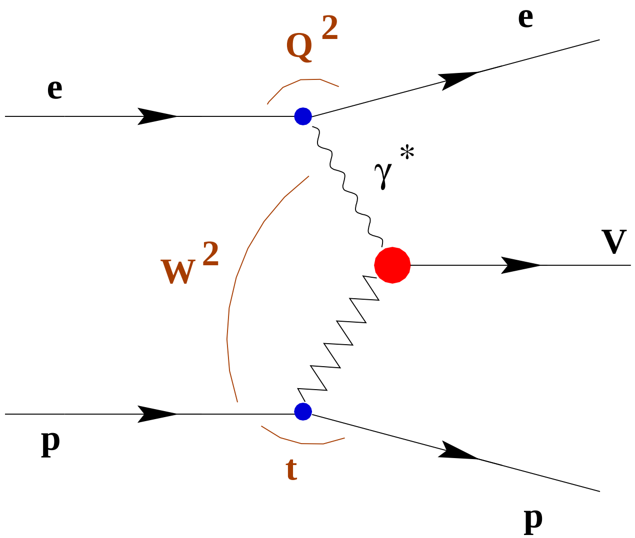
- **Basics**
- **Spin Density Matrix Elements (SDMEs) : definitions and their determination**
- **The observables derived :**
  - **SDME's for ϕ and ρ^0 vector mesons**
  - **Dependences of SDME's on Q^2 and t$'$**
  - $R = \frac{\sigma_L}{\sigma_T}$
  - **the signatures of the Natural or Unnatural Parity Exchange amplitudes**
- **Ratio of Helicity Amplitudes for Exclusive ρ^0**
- **The Transverse Target Spin Asymmetry - A_{UT}**
- **Conclusions**

$e + p \rightarrow e' + p' + V$: Basics



Kinematics:

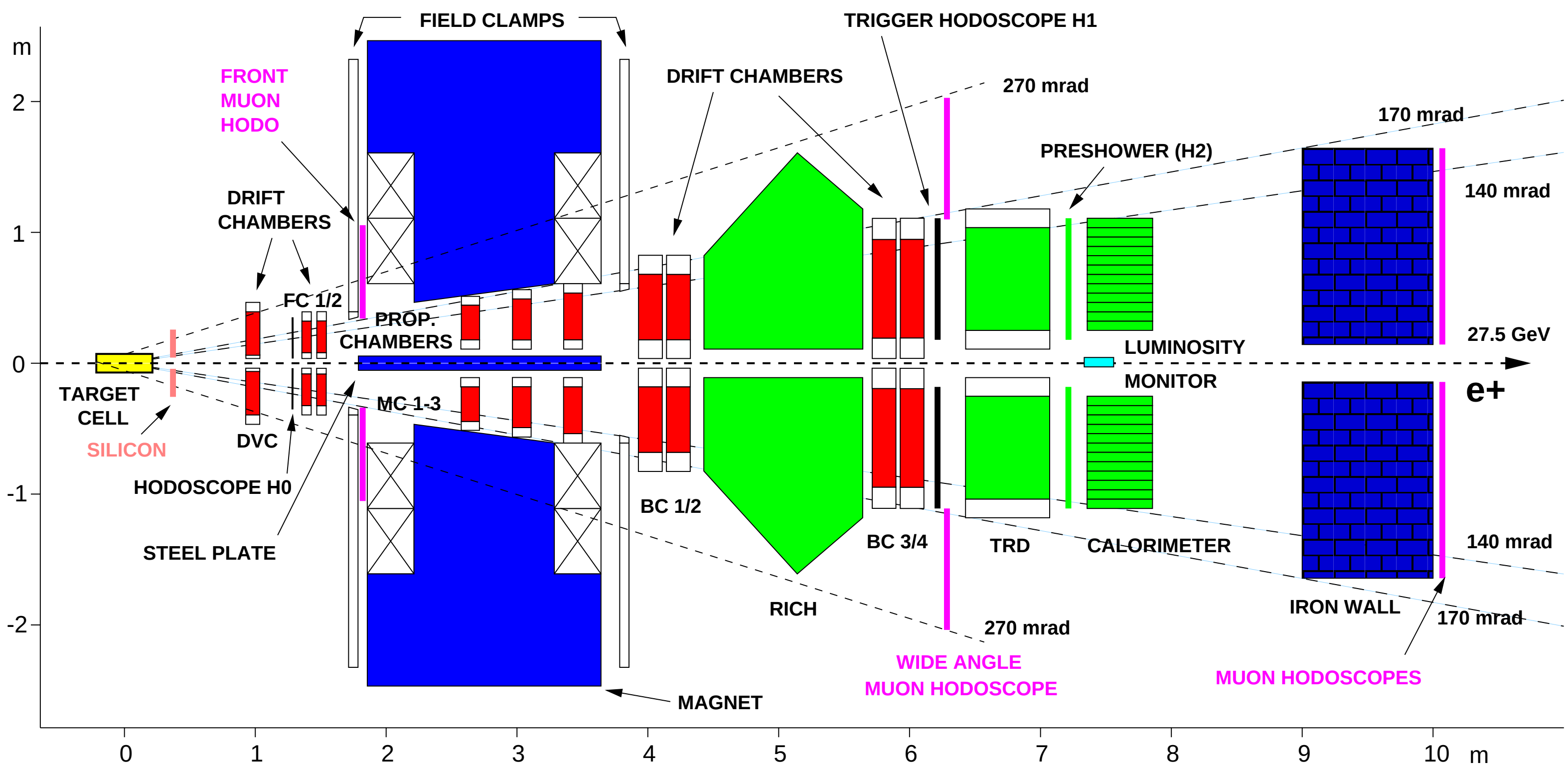
- $\nu = 3.5 \div 24$ **GeV,**
- $Q^2 = 1.0 \div 7.0$ **GeV^2,**
- $W = 3.0 \div 6.5$ **GeV,**
- $x_{Bj} = 0.01 \div 0.35$**,**
- -$t' = (t - t_{min})$
  -$t' = 0 \div 0.4$ **GeV^2,**

- In the one photon approximation $\equiv \gamma^* + p \rightarrow p' + V$
- The amplitude of this process can be factorized:
  $A = \Phi^*_{\gamma^* \rightarrow q\bar{q}} \otimes A_{q\bar{q}+p \rightarrow q\bar{q}+p} \otimes \Phi_{q\bar{q} \rightarrow V}$.
  In these three steps the interaction time of $(q\bar{q})$ with target is shorter than the time of γ^* fluctuation and formation of VM. (Collins,Frankfurt and Strikman Phys.Rev D56(1997)2982)
- $\gamma^* + N \rightarrow V + N'$ is a good tool to study the helicity conservation:
  - helicity state of γ^* is easy to determine (QED)
  - helicity of VM from angular distributions of decay products: $\phi \rightarrow K^+K^-$ and $\rho^0 \rightarrow \pi^+\pi-$

Spin Density Matrix Elements (SDMEs)

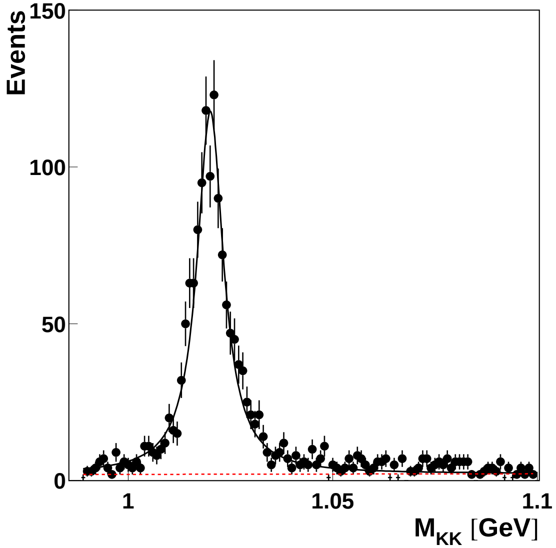
- SDMEs: $r^{\alpha}_{\lambda_V \lambda'_V} \sim \rho(V) = \frac{1}{N} \sum_{\lambda'_\gamma, \lambda_\gamma} (T_{\lambda_V \lambda_\gamma} \rho(\gamma) T^{+}_{\lambda'_V \lambda'_\gamma}$)
  spin-density matrix of the vector meson $\rho(V)$ expressed in terms of the photon matrix $\rho(\gamma)$
  and helicity amplitude $T_{\lambda_V \lambda_\gamma}$
- presented according to K.Schilling and G.Wolf (Nucl. Phys. B61 (1973) 381)
  $\alpha =$ 0,4 - longtd. or transv. photon with $\lambda_V = 0$; $\alpha =$ 1-2 - transv. with lin. pol. ;
  $\alpha =$ 3 - transv. with cir. pol.; $\alpha =$ 5-8 - interf. transv./longtd. terms.
- measured at $5 < W < 75$ GeV (HERMES, COMPASS, H1, ZEUS)
- provide access to helicity amplitudes $T_{\lambda_V \lambda_\gamma}$ and phases, which are:
  - extracted from SDMEs
  - calculated from GPDs: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

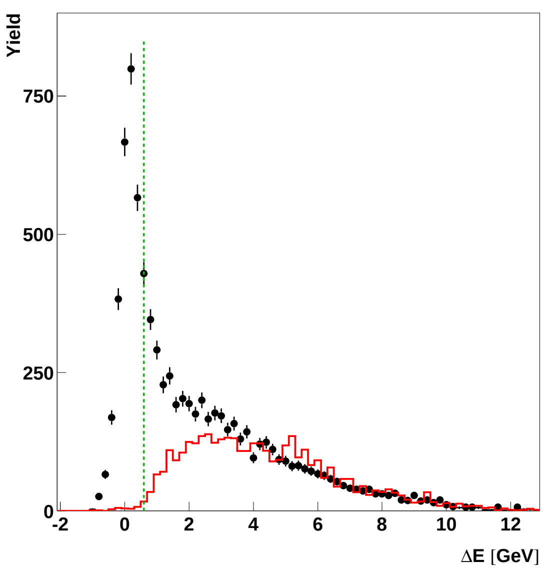
HERMES SPECTROMETER



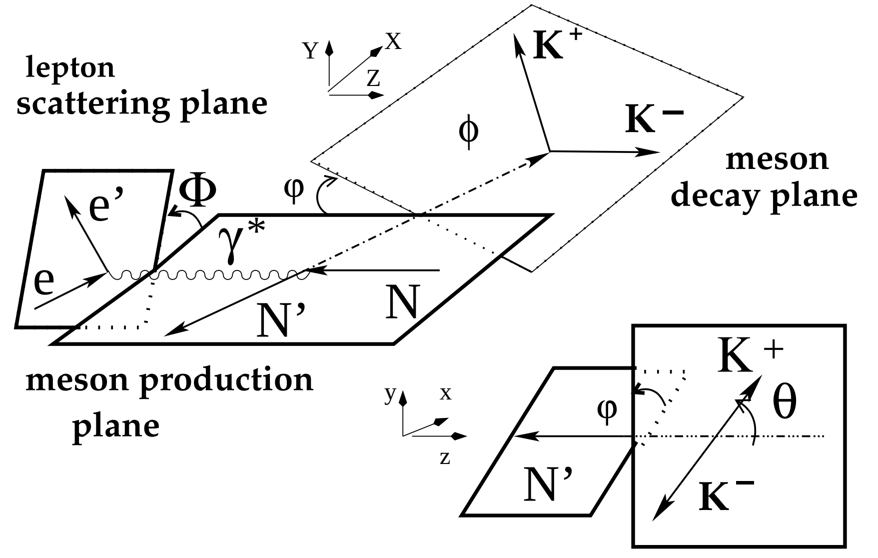
- **Acceptance:** $|\Theta_x| < 170$ **mrad, 40** $< |\Theta_y| < 140$ **mrad,**
- **Resolution** δ**p/p** $< 1\ \%$**,** $\delta\Theta < 0.6$ **mrad,**
- **Identification efficiency: positron/electron above 99% , hadron average is 99%,**
- **Contamination of hadrons (positrons) in the positron (hadron) sample - below 0.01% (0.6%)**
- **Good separation of pions, kaons, protons and other hadrons for momenta between 2- 15 GeV,**
- **Average target polarization (years 2002-2005) is 72 %.**

Excl. Events. Method of determination SDMEs





$$\Delta E = \frac{M_x^2 - M_p}{2M_p}.$$



Definition of angles.

- **Simulated events: matrix of fully reconstructed MC events from 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 (**$< |P_b| >= 53.5\%$**)**

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SDMEs for: ρ^0, ϕ

A- SCHC $\gamma^*_L \to \phi_L$ **and** $\gamma^*_T \to \phi_T$

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

B- Interference: $\gamma^*_L \to \phi_L$ **and** $\gamma^*_T \to \phi_T$

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: $\gamma^*_T \to \phi_L$

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: $\gamma^*_L \to \phi_T$

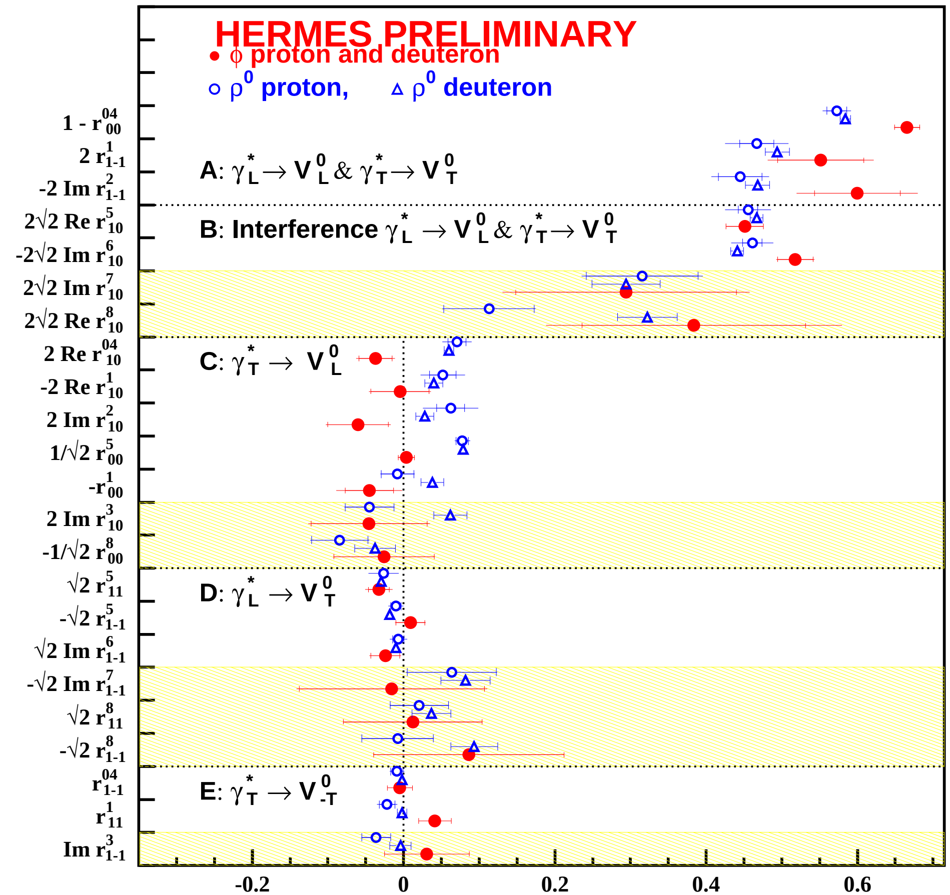
Re $\{T_{10}T^*_{11}\} \propto r^5_{11} \propto r^5_{1-1} \propto$ **Im**$\{r^6_{1-1}\}$

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

E- Double Spin Flip: $\gamma^*_T \to \phi_{-T}$

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

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



Diff. for class A :$|T^{\phi}_{11}|^2 > |T^{\rho}_{11}|^2$ **(**$\sim 20\%$**)** scaled SDME

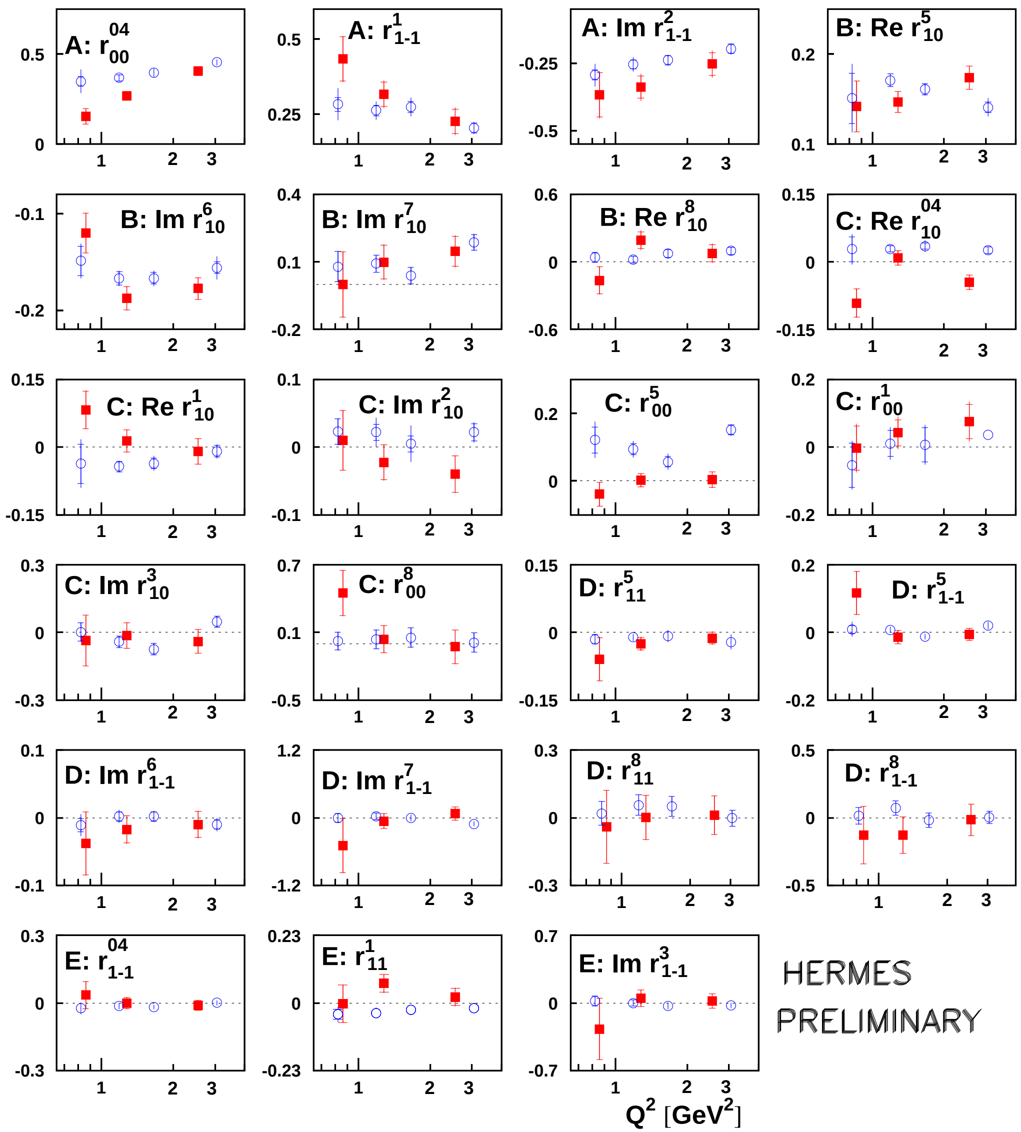
B:(T$_{11}$**T**$^*_{00}$**),** $\rho^0 \sim \phi$ **diff. phases T**$_{11}$ **and T**$_{00}$

tg(δ^{ϕ}**)=(Im** r^7_{10} **+ Re r**$^8_{10}$**) / (Re r**$^5_{10}$ **- Im r**$^6_{10}$**),**

$\delta^{\phi}_{p+d} = 33.0^0 \pm 7.4^0$, $\delta^{\rho}_{p} = 30.0^0 \pm 5.0^0 \pm 2.4^0$

and C: for $\rho^0 > 0$**,**

Dependences of SDME's on Q^2



The dependences of SDME's on Q^2 for proton and deuteron data. The outer bars represent the total, the inner ones the statistical errors.

ϕ - red closed squares, ρ^0 - open blue circles.

See classes A, B; C -r^5_{00}.

NOTATION:

A- SCHC $\gamma^*_L \to \phi_L$ **and** $\gamma^*_T \to \phi_T$

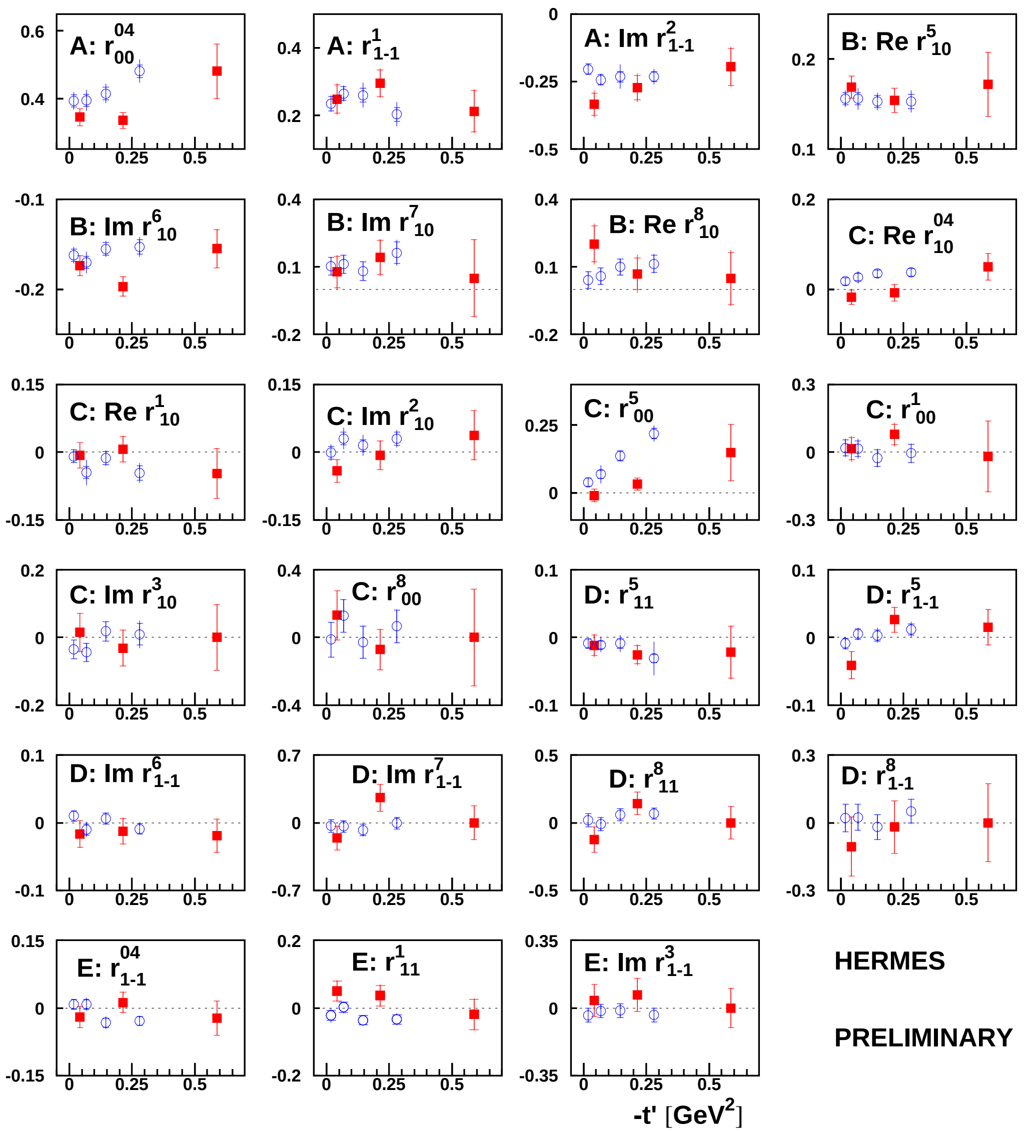
B- Interference: $\gamma^*_L \to \phi_L$ **and** $\gamma^*_T \to \phi_T$

C- Spin Flip: $\gamma^*_T \to \phi_L$

D-Spin Flip: $\gamma^*_L \to \phi_T$

E- Double Spin Flip: $\gamma^*_T \to \phi_{-T}$

Dependences of SDME's on t'



The dependences of SDME's on t' for proton and deuteron data. The outer bars represent the total, the inner ones the statistical errors. ϕ - red closed squares, ρ^0 - open blue circles. See class C .

NOTATION:

A- SCHC $\gamma^*_L \longrightarrow \phi_L$ **and** $\gamma^*_T \longrightarrow \phi_T$

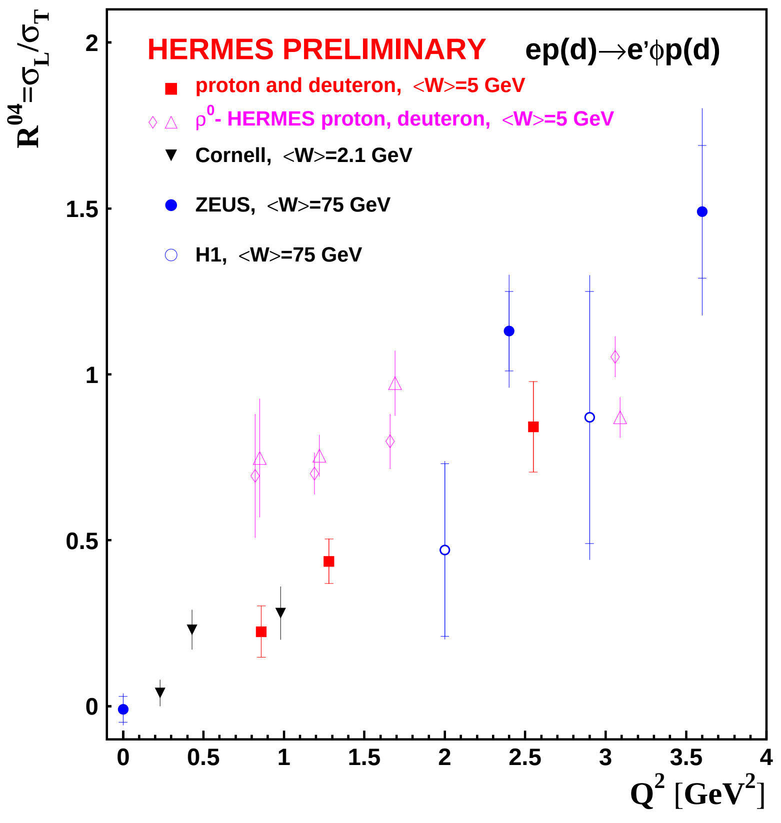
B- Interference: $\gamma^*_L \longrightarrow \phi_L$ **and** $\gamma^*_T \longrightarrow \phi_T$

C- Spin Flip: $\gamma^*_T \longrightarrow \phi_L$

D-Spin Flip: $\gamma^*_L \longrightarrow \phi_T$

E- Double Spin Flip: $\gamma^*_T \longrightarrow \phi_{-T}$

Longitudinal-to-Transverse Cross-Section Ratio



Comparison of commonly measured:

$$R^{04} = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}},$$

where:

$$r^{04}_{00} = \sum\{\epsilon|T_{00}|^2 + |T_{11}|^2\}/\sigma_{tot}$$

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

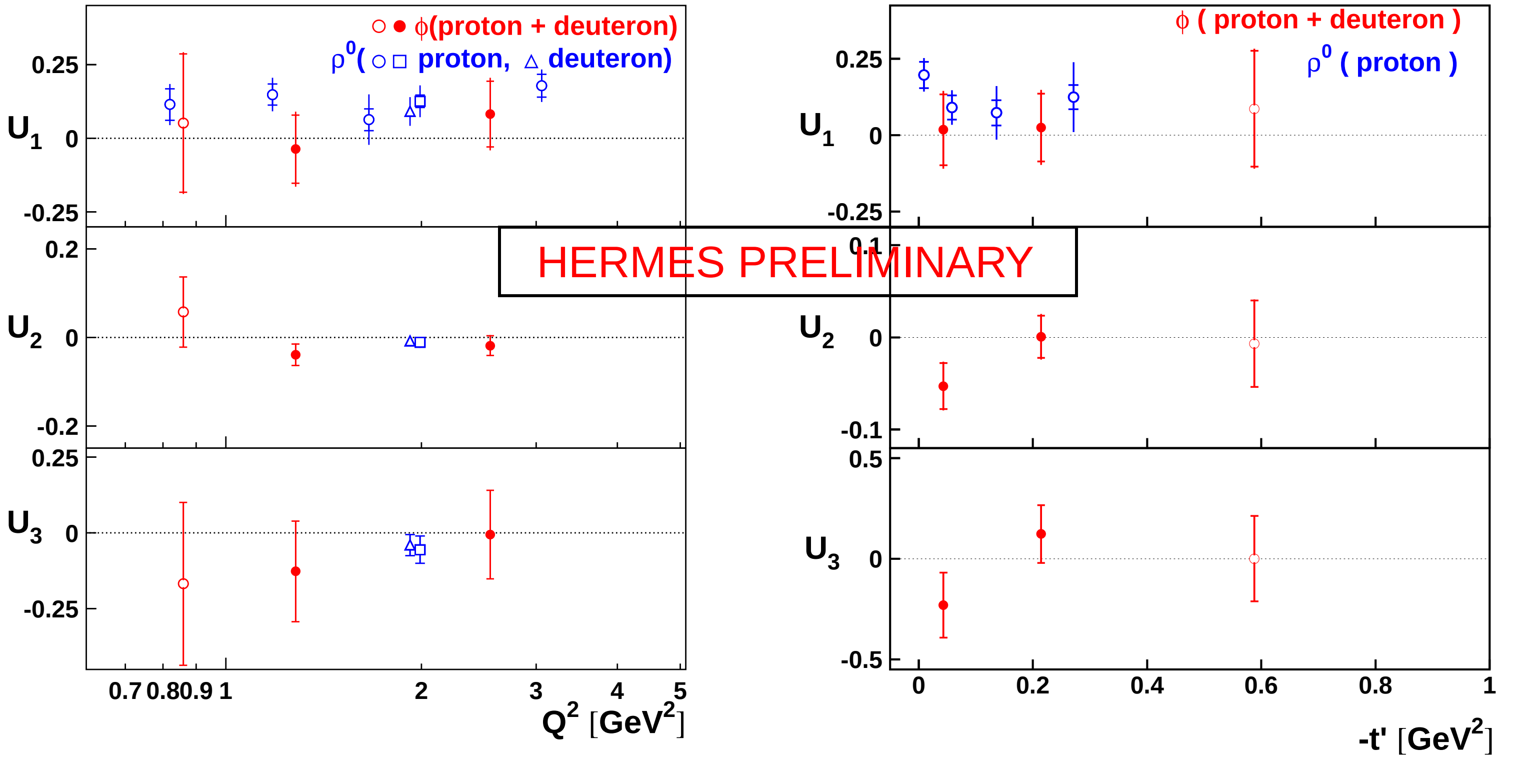
Theory: $R = \frac{Q^2}{M_V^2}$,

S. Brodsky et al., Phys. Rev. **D50**(1994) 3134

Modifications to those dependences are expected due to the Q^2 dependence of gluon density, the quark transverse movement(Fermi motion) and quark virtuality as well as the Q^2 dependence of the strong coupling constant α_s. L. Frankfurt et al., Phys. Rev.**D54** (1996) 3194, (Fermi motion) I. Royen et al., Nucl. Phys. **B 545** (1999) 505 and Phys. Lett. **B 513** (2001) 337

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

Unnatural Parity Exchange in ϕ Meson Leptoproduction



$U_1 = 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^{1}_{1-1} - 2r^{1}_{11}$; $\quad U_1 = \widetilde{\Sigma}(4\epsilon|U_{10}|^2 + 2|U_{11} + 2U_{-11}|^2)/\mathcal{N}$;

$U_2 = r^{5}_{1-1} + r^{5}_{11}$; $U_3 = r^{8}_{1-1} + r^{8}_{11}$. $\quad U_2 + iU_3 = \sqrt{(2)}\widetilde{\Sigma}\{(U_{11} + U_{-11})^* U_{10}\}/\mathcal{N}$.

$$\widetilde{\Sigma} U_{\lambda_V \lambda_\gamma} U^*_{\lambda'_V \lambda'_\gamma} = \frac{1}{2} \sum_{\lambda_N, \lambda_{N'}} U_{\lambda_V \lambda'_N ; \lambda_\gamma \lambda_N} U^*_{\lambda'_V \lambda'_N ; \lambda^*_\gamma \lambda_N}$$

hierarchy: $\widetilde{\Sigma}|U_{11}|^2 >> \widetilde{\Sigma}|U_{10}|^2, \widetilde{\Sigma}|U_{01}|^2, \widetilde{\Sigma}|U_{-11}|^2$,

no interference NPE and UPE: $\widetilde{\Sigma} T_{\lambda_V, \lambda_\gamma} U^*_{\lambda'_V, \lambda'_\gamma} = 0$

Ratios of Helicity Amplitudes

EXPERIMENT

The real and imaginary parts of ratios of natural-parity-exchange helicity amplitudes:

T$_{11}$ **(**$\gamma^*_T \rightarrow \rho_T$**), T**$_{01}$ **(**$\gamma^*_T \rightarrow \rho_L$**), T**$_{10}$ **(**$\gamma^*_L \rightarrow \rho_T$**), T**$_{1-1}$ **(**$\gamma^*_{-T} \rightarrow \rho_T$**) to T**$_{00}$ **(**$\gamma^*_L \rightarrow \rho_L$**)**

and for the unnatural-parity-exchange amplitude U$_{11}$ **the ratio** $|$**U**$_{11}|/|$**T**$_{00}|$ **were obtained.**

Beam: longitudinaly polarized electron/positron 27.6 GeV

Targets: hydrogen and deuterium unpolarized

Kinematical region: 0.5 GeV^2 $<$ **Q**^{2} $<$ **7.0 GeV**^{2}**, 3.0 GeV** $<$ **W** $<$ **6.3 GeV, -t**$'$ $<$ **0.4 GeV**^{2}

The Q^2 **and -t**$'$ **dependences are also extracted.**

Divided in 16 bins for Q^2**: 0.5**$\div$ **1.0** $\div$ **2.0** $\div$ **7.0 GeV**^{2}**;**

for -t$'$ **0.0** $\div$ **0.04** $\div$ **0.10** $\div$ **0.2** $\div$ **0.4 GeV**^{2}**.**

Extractions: use angular distributions: $\cos(\theta)$, Φ **and** ϕ **as well as isotropic simulation sample (RHOmc).**

Ratios of Helicity Amplitudes

Theoretical studies:

D. Yu. Ivanov and R. Kirshner Phys. Rev. D58(1998) 114026 [hep-ph/9807324],

E.V. Kuraev, N.N. Nikolaev, and B.G. Zakharov,Pis'ma ZHETF,68,(1998) 667

pQCD:

$$t_{11} = \frac{T_{11}}{T_{00}} \propto \frac{M_V}{Q},$$

$$t_{01} = \frac{T_{01}}{T_{00}} \propto \frac{\sqrt(-t')}{Q},$$

$$t_{10} = \frac{T_{10}}{T_{00}} \propto \frac{M_V \sqrt(-t')}{Q^2+M_V^2},$$

$$t_{1-1} = \frac{T_{1-1}}{T_{00}} \propto \frac{-t' M_V}{Q} \left(\frac{C_1}{Q^2+M_V^2} + \frac{C_2}{\mu^2} \right),$$

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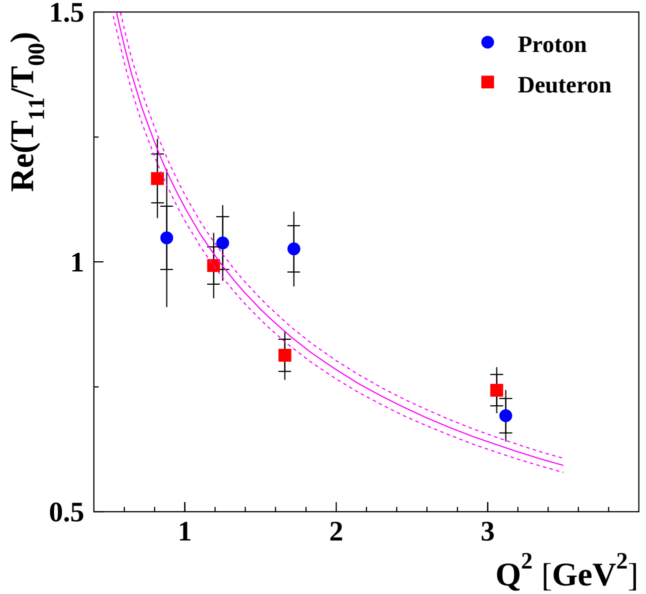
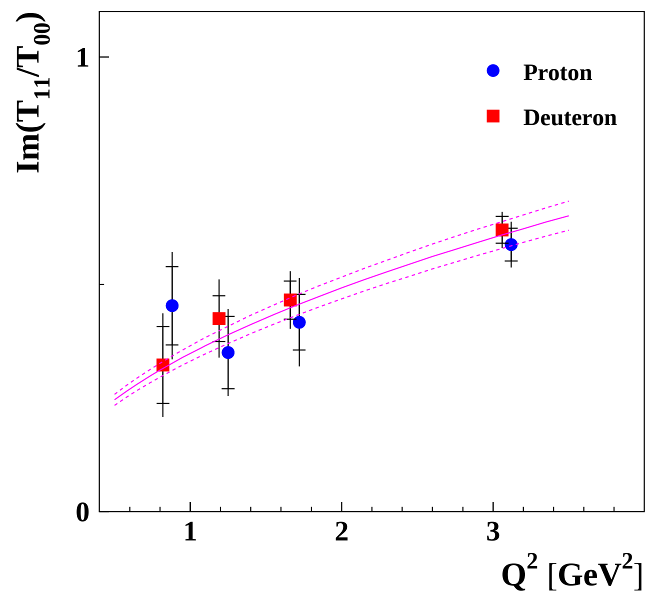
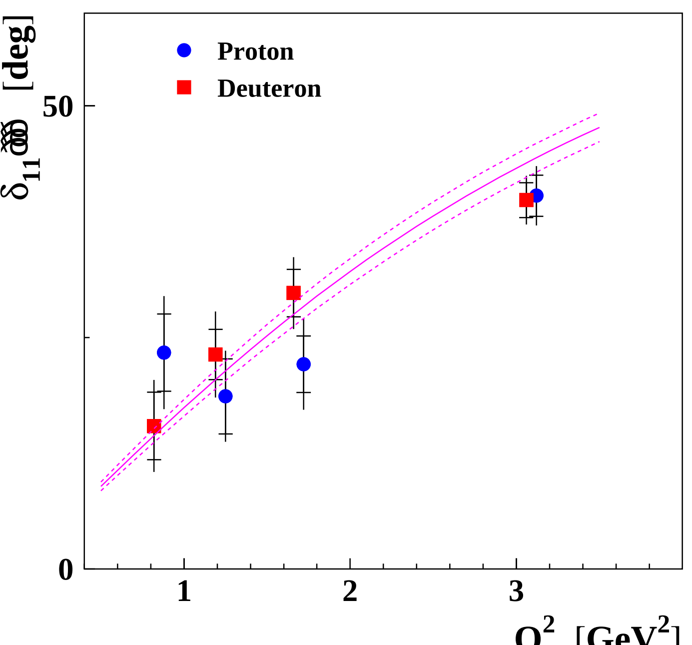
Ratios of Helicity Amplitudes t_{11}

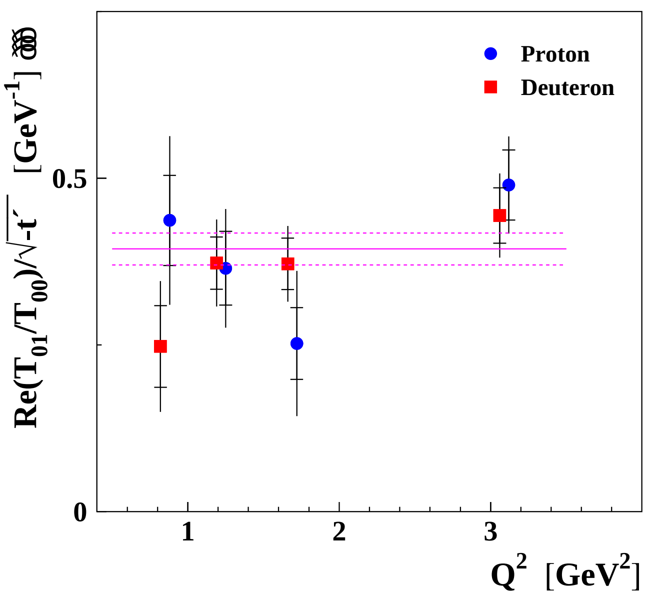


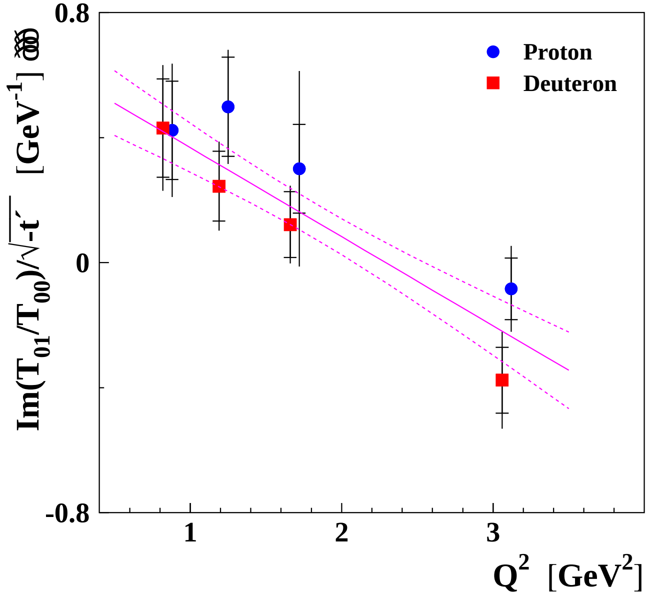


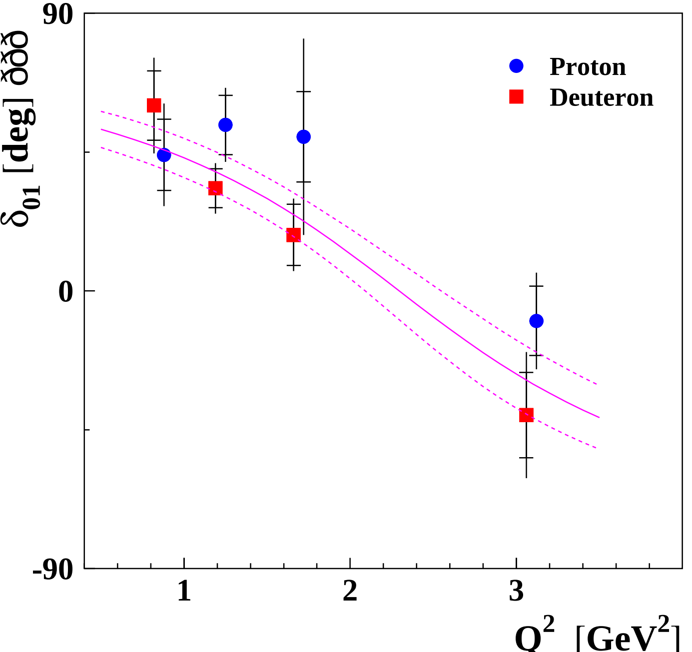


Q^2 dependence of Re(T_{11}/T_{00}), Im(T_{11}/T_{00}) and their phase difference δ_{11}, for hydrogen and deuterium targets. Parameterization is given by the function: Re(t_{11})=a/Q and Im(t_{11})=bQ. (The function for Im(T_{11}/T_{00}) different from theoretical predictions.) High value of δ_{11} is observed.

Ratios of Helicity Amplitudes t_{01}



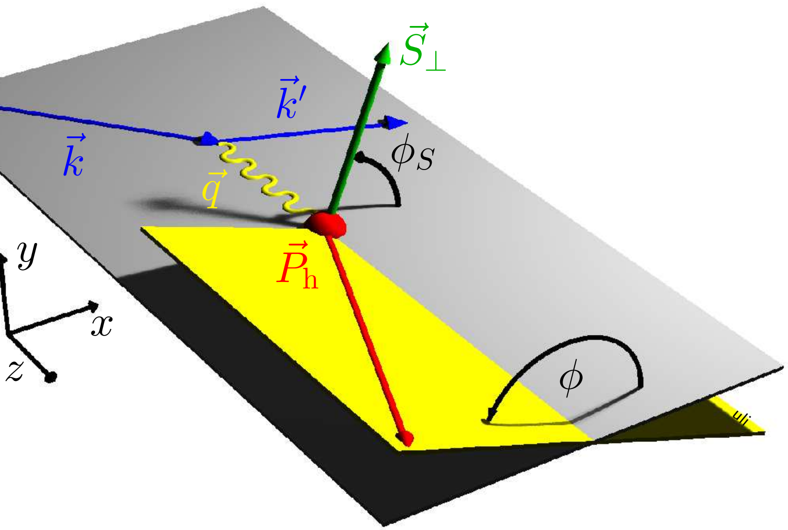




Q^2 dependence of Re(T_{01}/T_{00}), Im(T_{01}/T_{00}) and their phase difference δ_{01} for hydrogen and deuterium targets. The Q^2 dependence was observed only for Im(t_{01}).

A_{UT}: Definition of the azimuthal angles

TRENTO CONVENTION



$$\cos\phi = \frac{(\vec{q}\times\vec{v})\cdot(\vec{k}\times\vec{k}')}{|\vec{q}\times\vec{v}|\cdot|\vec{k}\times\vec{k}'|}, \quad \sin\phi = \frac{[(\vec{k}\times\vec{v})\cdot\vec{q}]}{|\vec{k}\times\vec{q}|\cdot|\vec{q}\times\vec{v}|},$$

$$\cos\phi_S = \frac{(\vec{q}\times\vec{S})\cdot(\vec{k}\times\vec{k}')}{|\vec{q}\times\vec{S}|\cdot|\vec{k}\times\vec{k}'|}, \quad \sin\phi_S = \frac{[(\vec{k}\times\vec{S})\cdot\vec{q}]}{|\vec{k}\times\vec{q}|\cdot|\vec{q}\times\vec{S}|},$$

ϕ and ϕ_S are angles defined by the lepton-scattering plane and the VM production plane or target spin vector in the center-of-mass system (γ^*,p).

Relation between the azimuthal angles in the selected frames:

$$F^{q\perp S}(S_T, S_L, \phi, \phi_S) = \mathcal{R}(\theta,\gamma) F^{k\perp S}(P_T, P_L, \psi, \psi_S),$$

where: $\sin\theta = \gamma(1-y-\frac{1}{4}y^2\gamma^2)/(1+\gamma^2), \quad \gamma = 2x_B M_p/Q.$

$$S_T = \frac{P_T\cos\theta}{\sqrt{1-\sin^2\theta\sin^2\phi_S}}.$$

A_{UT}: Main definitions and relations

M.Diehl, S. Sapeta

hep-ph/0503023

$$\left[\frac{\cos\theta}{1-\sin^2\theta\,\sin^2\phi_S}\right]^{-1}\left[\frac{\alpha_{em}}{8\pi^3}\,\frac{y^2}{1-\varepsilon}\,\frac{1-x_B}{x_B}\,\frac{1}{Q^2}\right]^{-1}\frac{d\sigma}{dx_B\,dQ^2\,d\phi\,d\phi_S}\Bigg|_{P_L=0}$$

$$= \text{ terms independent of } P_T$$

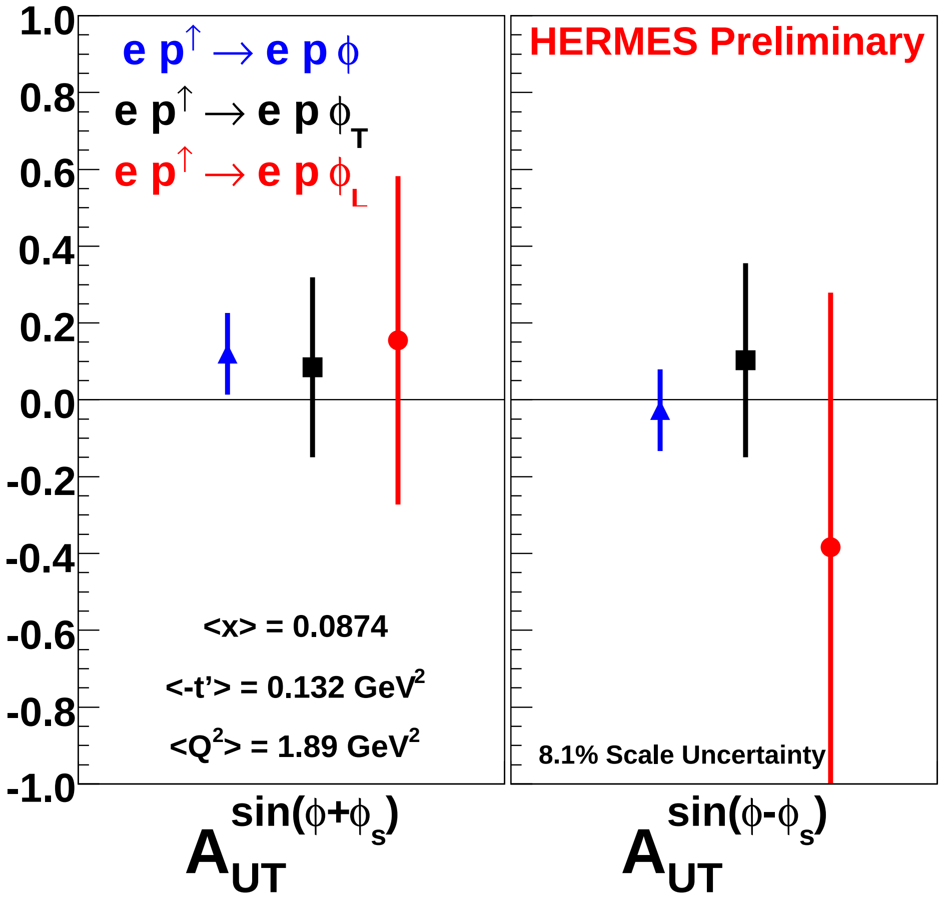
$$- \frac{P_T}{\sqrt{1-\sin^2\theta\,\sin^2\phi_S}}\Bigg[\sin\phi_S\,\cos\theta\sqrt{\varepsilon(1+\varepsilon)}\,\mathrm{Im}\,\sigma_{+0}^{+-}$$
$$+\sin(\phi-\phi_S)\left(\cos\theta\,\mathrm{Im}\,(\sigma_{++}^{+-}+\varepsilon\sigma_{00}^{+-})+\frac{1}{2}\sin\theta\sqrt{\varepsilon(1+\varepsilon)}\,\mathrm{Im}\,(\sigma_{+0}^{++}-\sigma_{+0}^{--})\right)$$
$$+\sin(\phi+\phi_S)\left(\cos\theta\,\frac{\varepsilon}{2}\,\mathrm{Im}\,\sigma_{+-}^{+-}+\frac{1}{2}\sin\theta\sqrt{\varepsilon(1+\varepsilon)}\,\mathrm{Im}\,(\sigma_{+0}^{++}-\sigma_{+0}^{--})\right)$$
$$+\sin(2\phi-\phi_S)\left(\cos\theta\sqrt{\varepsilon(1+\varepsilon)}\,\mathrm{Im}\,\sigma_{+0}^{-+}+\frac{1}{2}\sin\theta\,\varepsilon\,\mathrm{Im}\,\sigma_{+-}^{++}\right)$$
$$+\sin(2\phi+\phi_S)\,\frac{1}{2}\sin\theta\,\varepsilon\,\mathrm{Im}\,\sigma_{+-}^{++}$$
$$+\sin(3\phi-\phi_S)\,\cos\theta\,\frac{\varepsilon}{2}\,\mathrm{Im}\,\sigma_{+-}^{-+}\Bigg]$$

$$A_{UT} \sim \cos\theta\ \mathrm{Im}\ (\ \sigma_{++}^{+-} + \epsilon\sigma_{00}^{+-}\ )$$

where: $\sigma_{mn}^{ij}(Q^2, x_B)$ are cross sections or interference terms with indices: (i, j) describing polarization of the protons (p and p′) as well as (m,n) - polarization of (γ^* and VM),

ϵ - ratio of longitudinal to transverse photon flux

A_{UT} for ϕ vector mesons



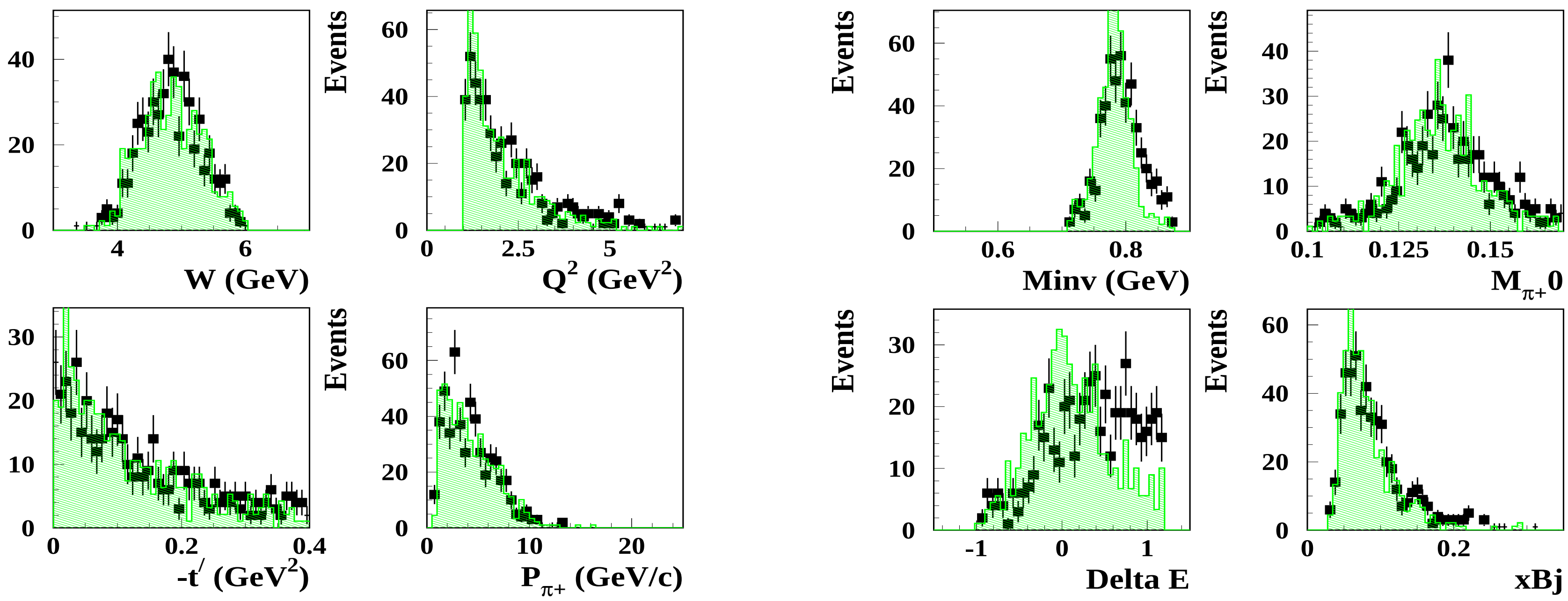
Used cuts:

- Fiducial cuts
- Determine: $e^{\pm}$, K^{+}, K^{-}
- Cut for the opening angle of decaying ϕ meson
- Cut for $P_{\phi} > 7.5$ GeV/c
- Kinematical cuts $Q^2 >$1GeV, $-t' < 0.5$ GeV^2, W$>$ 5GeV

Amplitudes A_{UT} determined for ϕ vector mesons (blue) and separated for longitudinal (red) as well as transverse (black) ϕ mesons components.

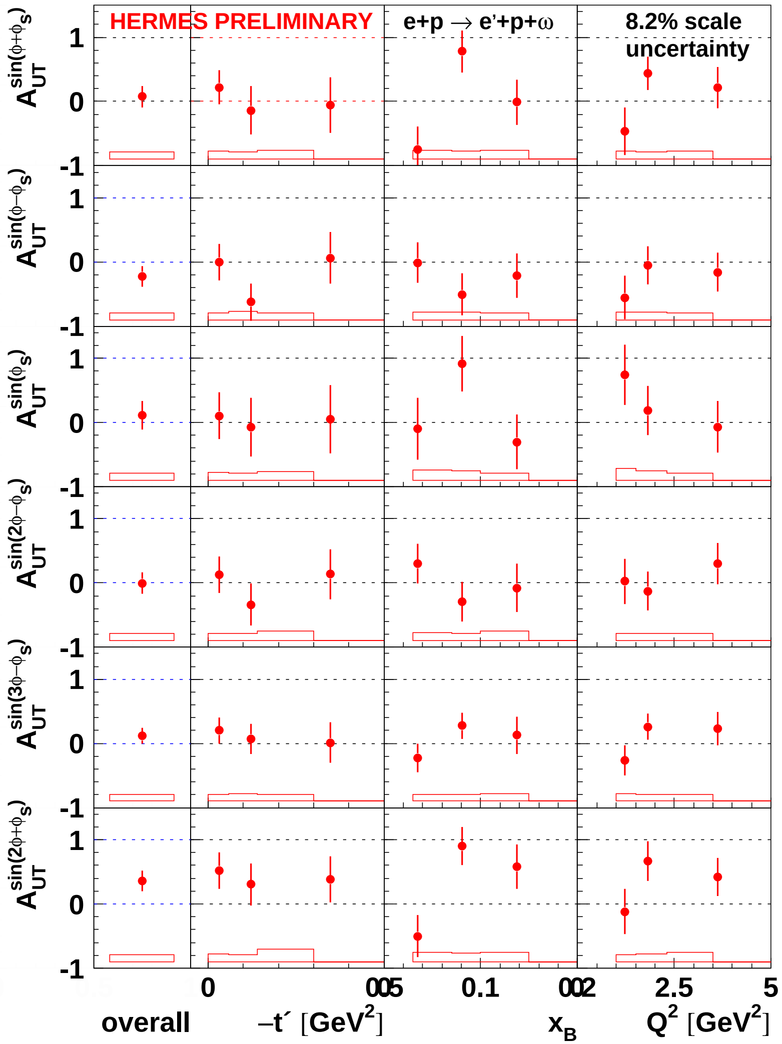
Transverse Target Spin Asymmetry (TTSA) method provide information about E GPDs function that are sensitive to helicity-flip. E GPDs functions contain information about the orbital angular momentum of the quarks.

Main observables for ω



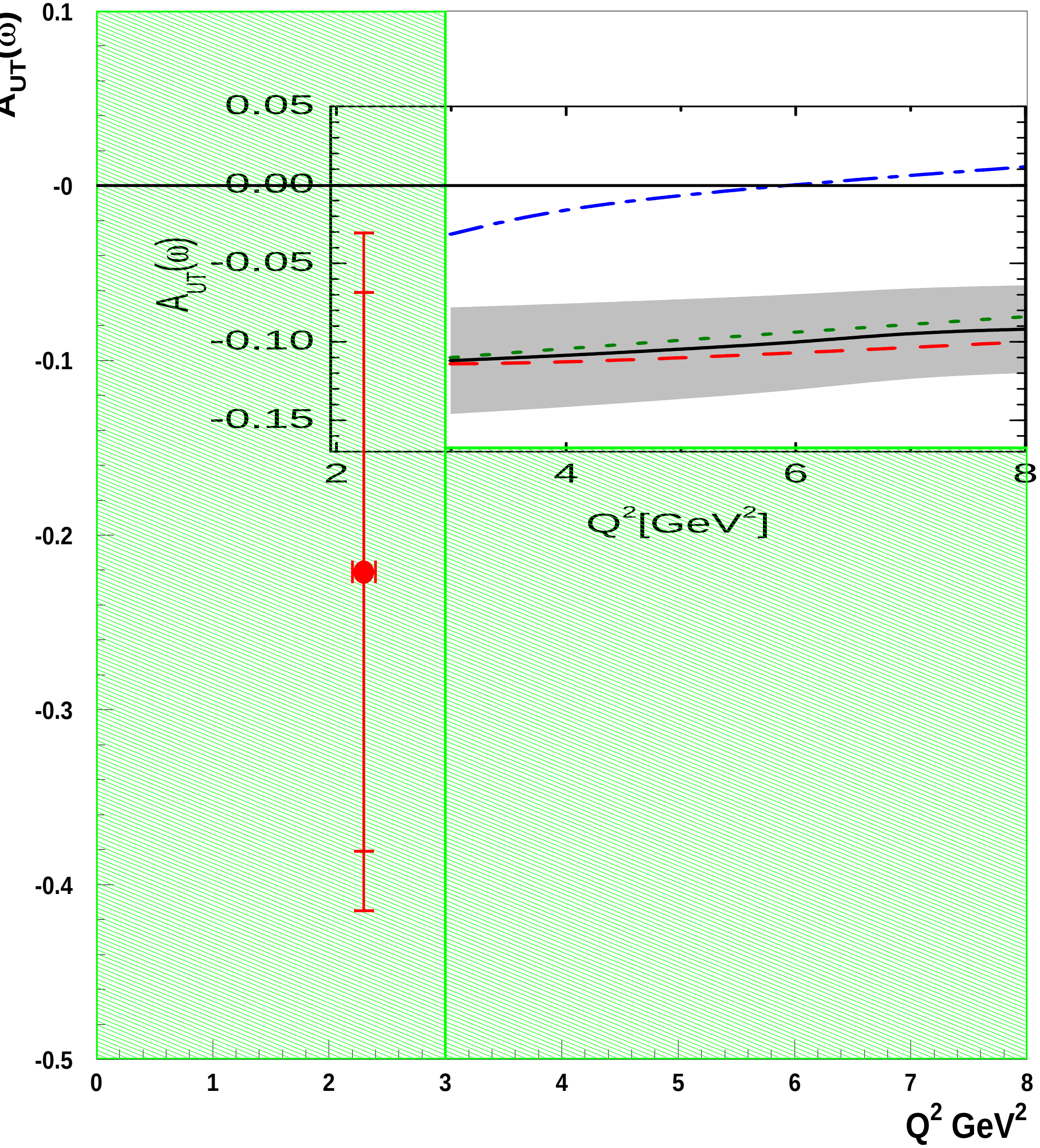
Distributions of several kinematic variables from data on exclusive ω meson leptoproduction (black squares) in comparison with simulated events from PYTHIA (dashed areas). Simulated events are normalized to the data.

A_{UT} for ω



The moments of A_{UT} for ω in the common kinematic interval and their $-t'$, x_B and Q^2-dependences after background subtraction. Statistical uncertainties are shown as error bars. Red boxes at the bottom of each plot represent the systematic uncertainties.

A_{UT} results for ω



A_{UT}: experimental value and theoretical predictions. The theoretical predictions from GK model. The solid, dashed, dotted and dash-dotted lines represent the results for different variants. The shaded band indicates the theoretical uncertainty for one variant. The other variants have similar uncertainties.

Conclusions

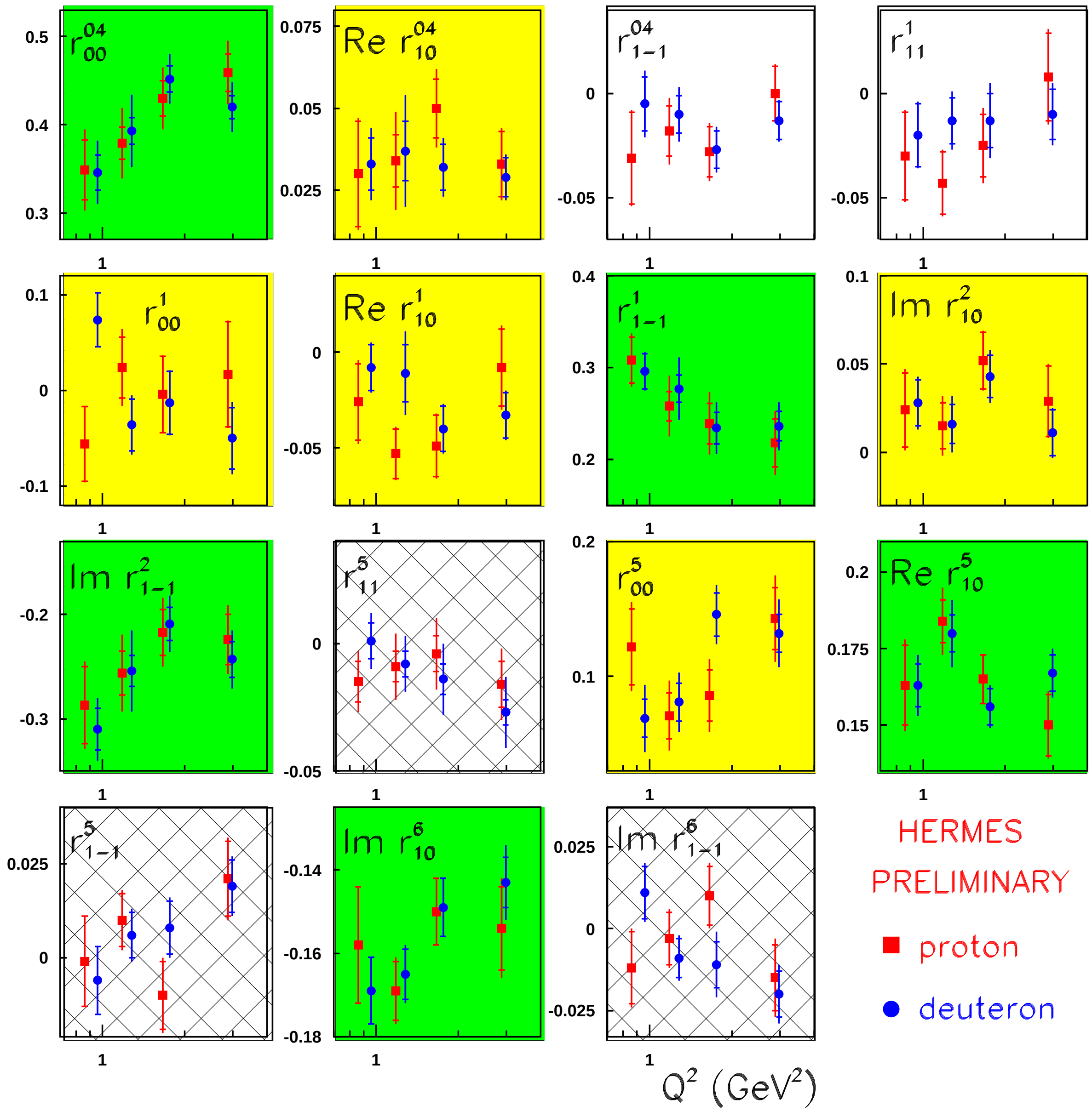
- **Comparison of SDMEs for ϕ and ρ^0**
  - **SDMEs $\sim |T_{11}|^2$ (class A) are higher ($\sim$ 20$\%$) for ϕ compared to those for ρ^0**
  - **Values of SDMEs belonging to class B are similar. Sign and value of the difference phases T_{11} and T_{00} is found**
  - **Class C: in the case of ϕ , SDMEs fluctuate near zero opposite to ρ^0 where non-zero elements indicate a single-spin-flip.**
- **Dependences of SDMEs and other observables on Q^2 and t'**
  - **Regular dependence of SDMEs on Q^2 and different behaviour for ϕ and ρ^0 is observed**
  - **Dependence $R^{04} = \frac{\sigma_L}{\sigma_T}$ on Q^2 agrees with other measurements**
  - **Different dependences of R^{04} on Q^2 for ϕ and ρ^0 vector mesons are observed**
  - **Observed dependence of r^5_{00} on t' for ρ^0 is not seen for ϕ**
  - **Observed signals of unnatural parity exchange for ρ^0 are not seen for ϕ**
- **Ratios of Helicity Amplitudes**
  - **Different dependences on Q^2 of real and imaginary ratios: t_{11} and t_{01} are observed.**

Conclusions

- A$_{UT}$
  - Near zero value of A$_{UT}$ for ϕ is found
  - Negative value of A$_{UT}$ for ω is found
  - Both values are predicted by theoretical models:S.V. Goloskolov, P. Kroll hep-ph/0809412 and F.Ellinghaus et al, Eur. Phys. J C46 729 (2006)

Additional slides

Dependencies of ρ^0 meson SDME's on Q^2



INDICATIONS:

green: SCHHC - $\gamma^*_L \longrightarrow V_L, \gamma^*_T \longrightarrow V_T$

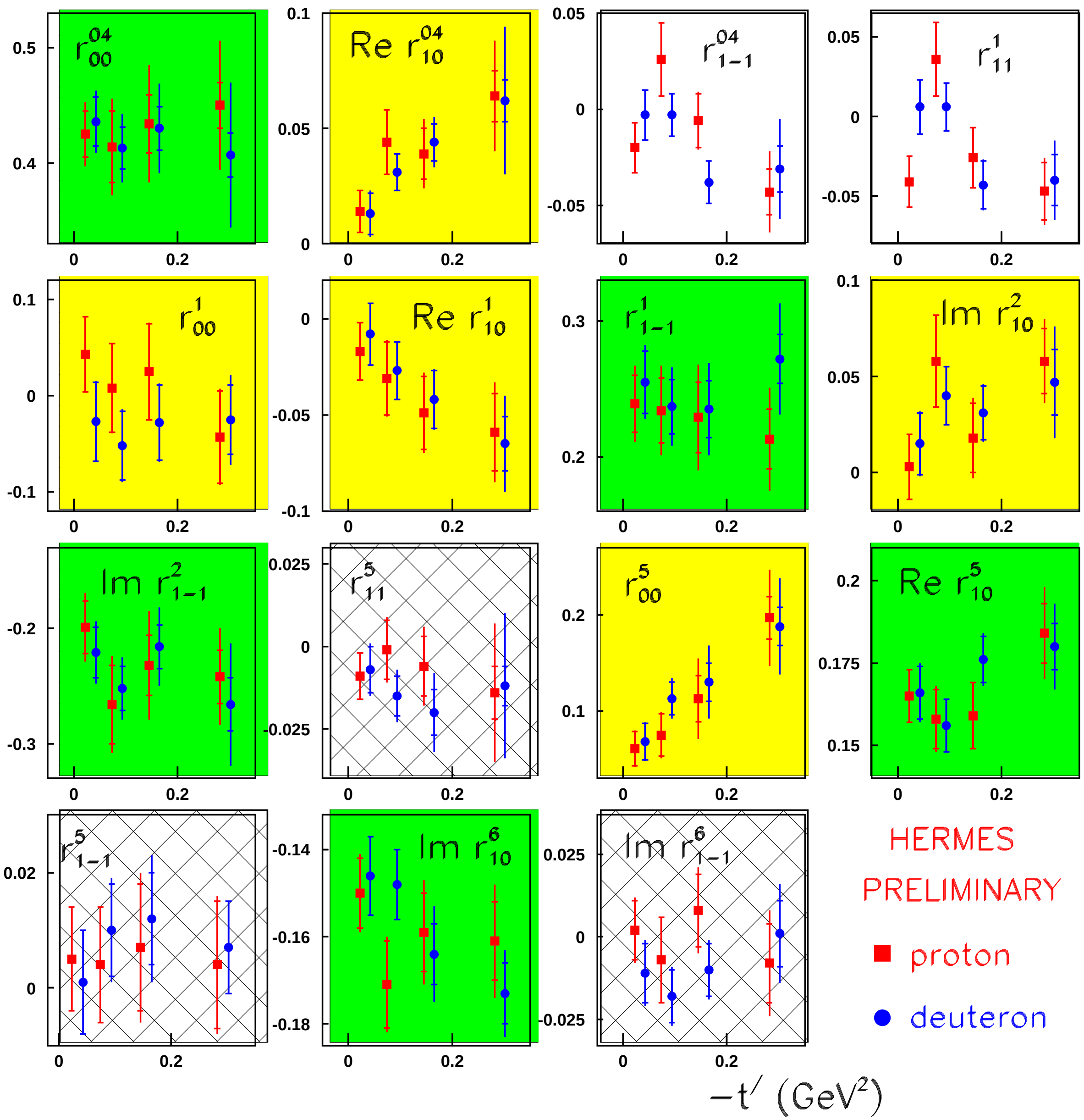
yellow: Single Flip - $\gamma^*_T \longrightarrow V_L$

grid: Single Flip - $\gamma^*_L \longrightarrow V_T$

blank: Double Flip - $\gamma^*_T \longrightarrow V_{-T}$

hermes

Dependencies of ρ^0 meson SDME's on t'



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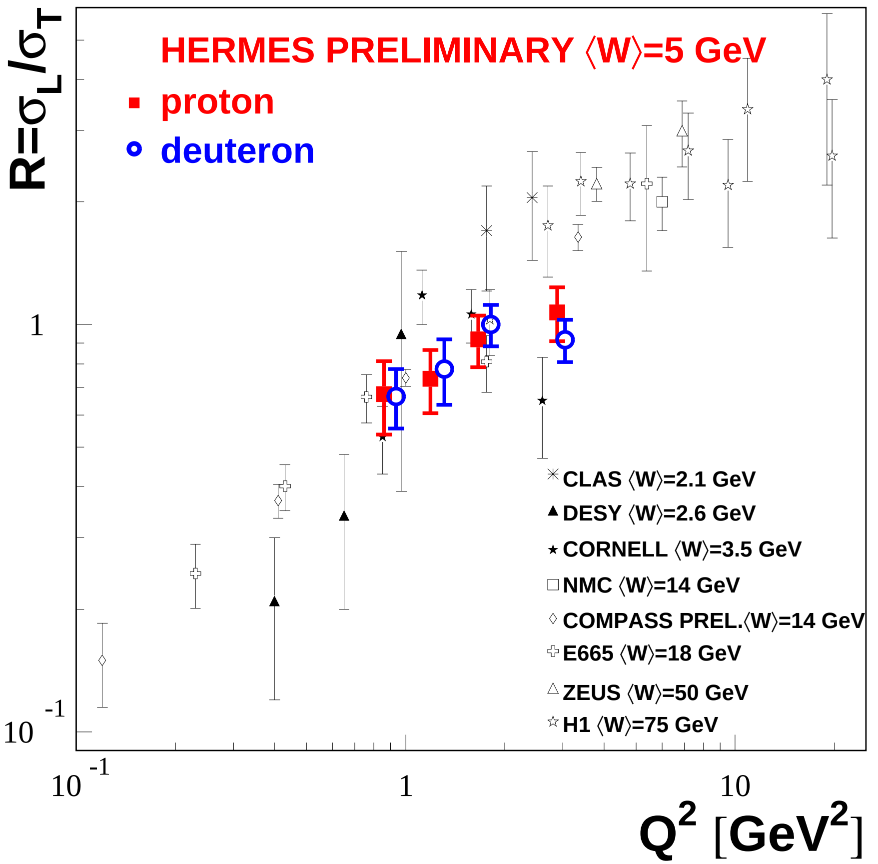
ρ^0 Longitudinal-to-Transverse Cross-Section Ratio



Comparison of commonly measured:

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

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

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

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

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

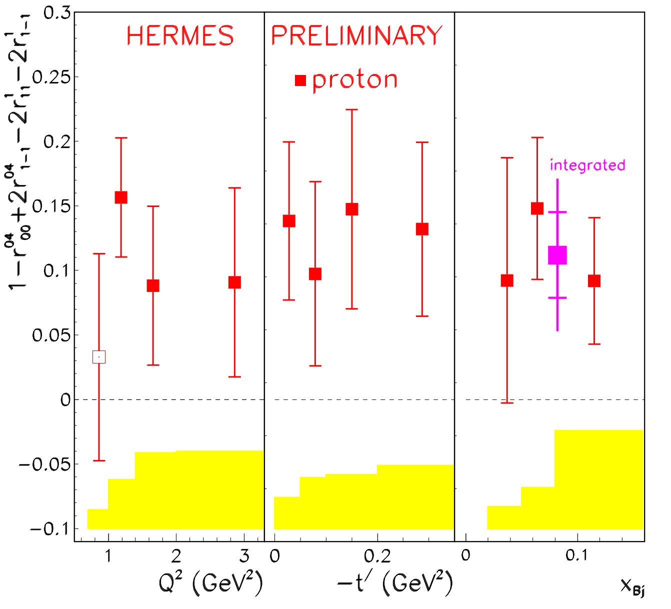
Due to the helicity-flip and unnatural parity amplitudes R^{04} depends on kinematic conditions, and is not identical to $R \equiv |T_{00}|^2/|T_{11}|^2$ at SCHC and NPE dominance.

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

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

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
- 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:**
$|U_{11}| \gg |U_{10}| \sim |U_{01}|$

A_{UT} and GPDs

$$A_{UT} = -2\frac{\text{Im}[\mathcal{M}^*_{+-,++}\mathcal{M}_{++,++} + \epsilon\text{Im}[\mathcal{M}^*_{0-,0+}\mathcal{M}_{0+,0+}]}{\Sigma_{\nu'}[|\mathcal{M}_{+\nu',++}|^2 + \epsilon|\mathcal{M}_{0\nu',0+}|^2]},$$

$$\mathcal{M}_{\mu,+,\mu+}(V) = \frac{e}{2}\{\sum_a e_a \mathcal{C}_V^{aa}\langle H\rangle^g_{V\mu} + \sum_{ab}\mathcal{C}_V^{ab}\langle H\rangle^{ab}_{V\mu}\},$$

$${}_{,-,\mu+}(V) = -\frac{e}{2}\frac{\sqrt{(-t)}}{M+m}\{\sum_a e_a \mathcal{C}_V^{aa}\langle E\rangle^g_{V\mu} + \sum_{ab}\mathcal{C}_V^{ab}\langle E\rangle^{ab}_{V\mu}\},$$

$$\langle F\rangle^g_{V\mu} = \sum_\lambda \int_0^1 d\bar{x}\mathcal{H}^{Vg}_{\mu\lambda,\mu\lambda}(\bar{x},\xi,Q^2,t=0)F^g(\bar{x},\xi,t),$$

$$\langle F\rangle^{ab}_{V\mu} = \sum_\lambda \int_{-1}^1 d\bar{x}\mathcal{H}^{Vab}_{\mu\lambda,\mu\lambda}(\bar{x},\xi,Q^2,t=0)F^{ab}(\bar{x},\xi,t),$$

$$\mathcal{H}^{Vab}_{\mu\lambda,\mu\lambda} = \int d\tau d^2b\hat{\Psi}_{V\mu}(\tau,-\mathbf{b})\hat{\mathcal{F}}(\bar{x},\xi,\tau,Q^2,\mathbf{b})$$

$$\mathbf{x}\alpha_s(\mu_R)\exp[-S(\tau,\mathbf{b},Q^2)],$$

$$(\tau,\mathbf{k}_\perp) = 8\pi^2\sqrt{2N_C}f_{Vj}(\mu_F)a^2_{Vj}[1 + B_1^{Vj}(\mu_F)C_1^{3/2}(2\tau-1)$$

$$+B_2^{Vj}(\mu_F)C_2^{3/2}(2\tau-1)]\exp[-a^2_{Vj}\mathbf{k}^2_\perp/(\tau\bar{\tau})].$$

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Important characteristics of G.K. theory:

Introduce the quark transverse momenta with model regulation : $\frac{1}{dQ^2} = \frac{1}{dQ^2+k_\perp^2}$.

The weight factors comprise the flavor structure of VM:

$C^{uu}_\omega = C^{dd}_\omega = \frac{1}{\sqrt{2}}$, $C^{ss}_\phi = 1$,

F(=H,E),

$\hat{F}$ - hard scattering kernel

Sudakov effect in b space.

Parameters of wave function.