Exclusive electroproduction of vector mesons in lepton-nucleon scattering at the HERMES experiment

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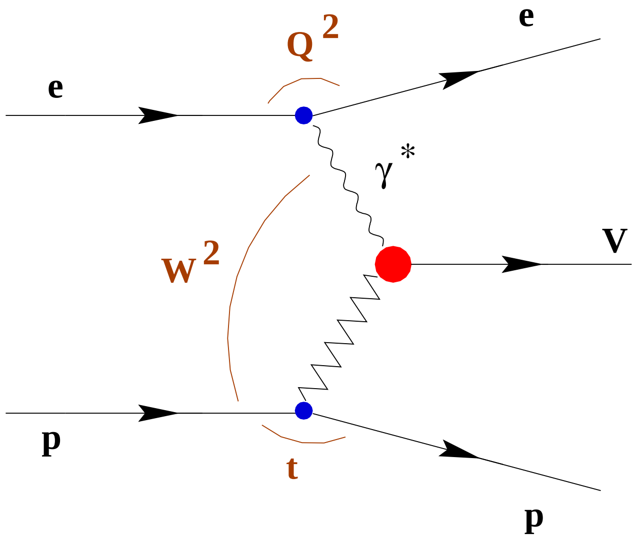
- **Basics**
- **Spin Density Matrix Elements (SDMEs) : definitions and their determination**
- **The observables derived :**
  - **SDME's for ω and ρ^0 vector mesons**
  - **Dependences of SDME's on Q^2 and t$'$**
  - $R = \frac{\sigma_L}{\sigma_T}$
  - **the signatures of the Natural or Unnatural Parity 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:

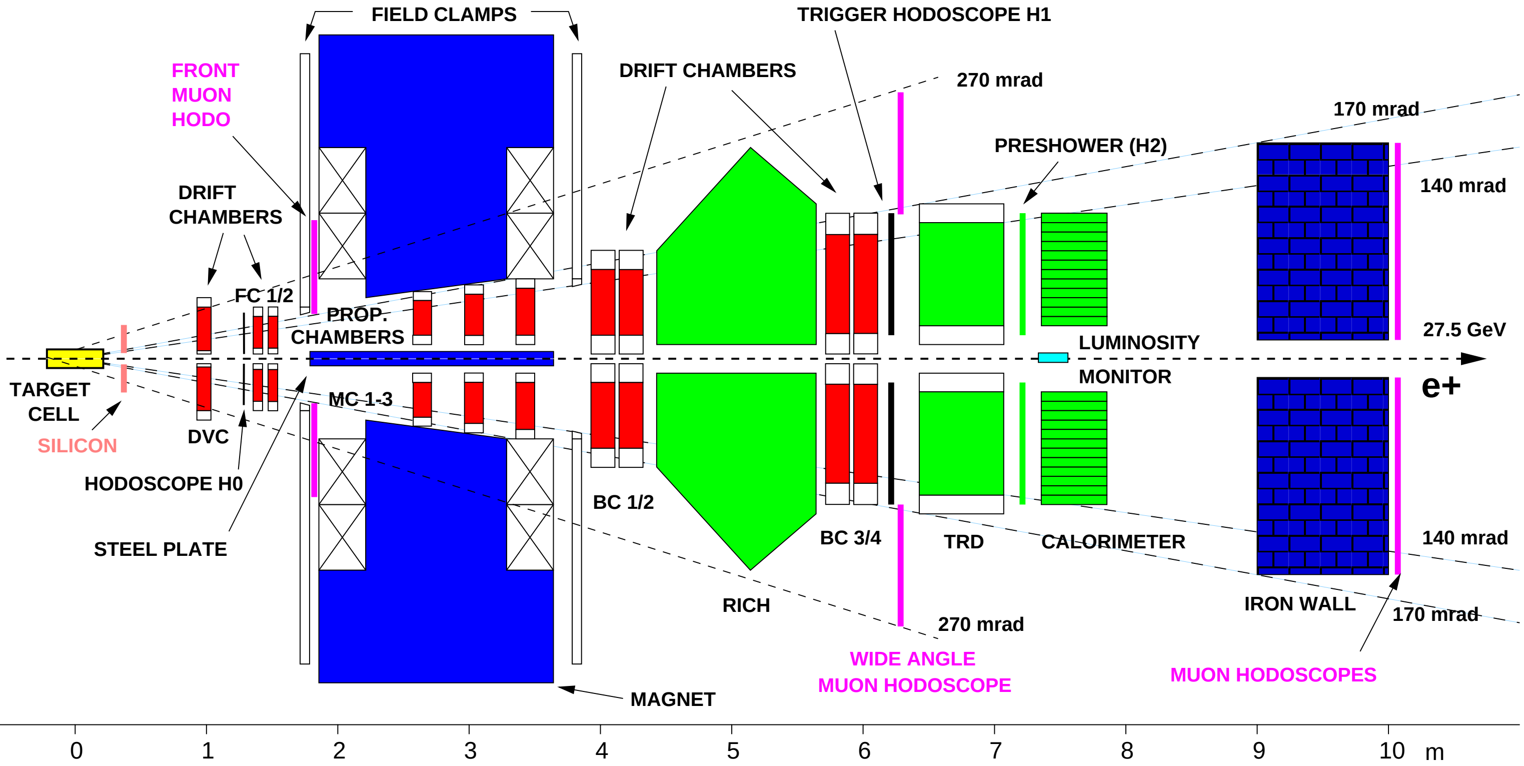
- $\nu = 3.5 \div 24$ **GeV,**
- $Q^2 = 1.0 \div 7.0$ **GeV^2,**
- $W = 3.0 \div 6.5$ **GeV,**
- $x_{Bj} = 0.01 \div 0.35$,
- -$t' = (t - t_{min})$
  -$t' = 0 \div 0.4$ **GeV^2,**

- 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)
- $\gamma^* + p \rightarrow V + p$ is a good tool to study the helicity conservation:
  - helicity state of γ^* is determined by QED
  - helicity of VM from angular distributions of decay products: $\phi \rightarrow K^+K^-$, $\omega \rightarrow \pi^+\pi^-\pi^0$ and $\rho^0 \rightarrow \pi^+\pi^-$

Spin Density Matrix Elements (SDMEs)

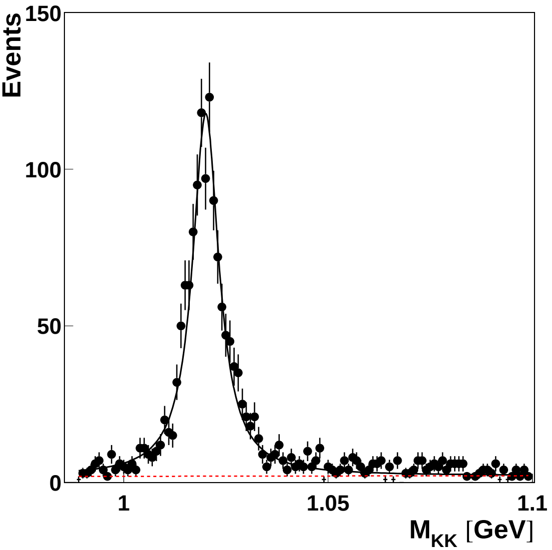
- **SDMEs:** $r^{\alpha}_{\lambda_V \lambda'_V} \sim \rho(V) = \frac{1}{N} \sum_{\lambda'_\gamma, \lambda_\gamma} (T_{\lambda_V \lambda_\gamma} \rho(\gamma) T^{+}_{\lambda'_V \lambda'_\gamma}$)
  spin-density matrix of the vector meson $\rho(V)$ **expressed in terms of the photon matrix** $\rho(\gamma)$ **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, JLab)**
- **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**

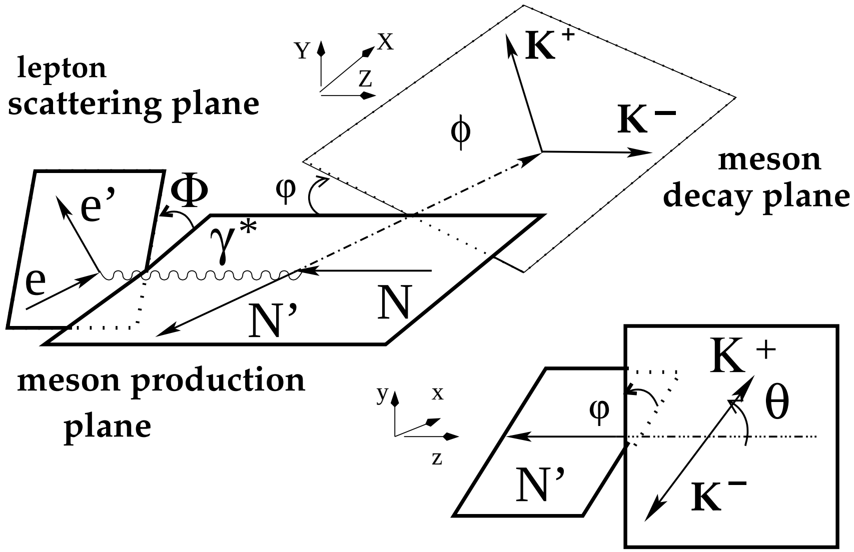
HERMES SPECTROMETER



- **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 %.**

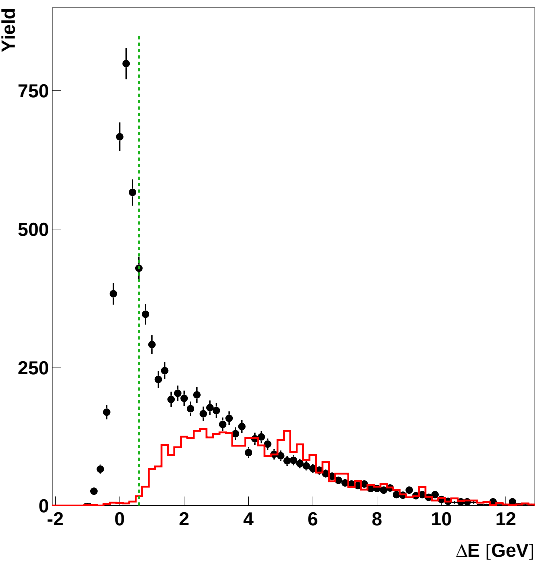
Excl. Events. Method of determination SDMEs





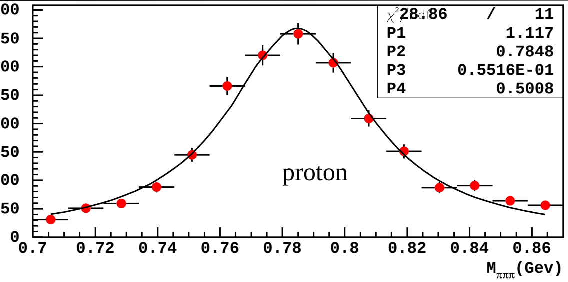
Definition of angles.

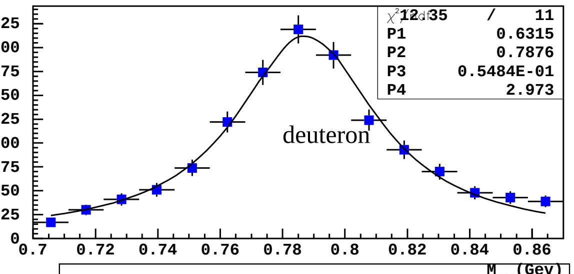
- Simulated events: matrix of fully reconstructed MC events from initial uniform angular distribution
- Binned Maximum Likelihood Method: $8 \times 8 \times 8$ bins of $\cos(\Theta), \phi, \Phi$. Simultaneous fit of 23 SDMEs $W(r^{\alpha}_{ij}, \Phi, \phi, \cos\Theta)$ for data with negative and positive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

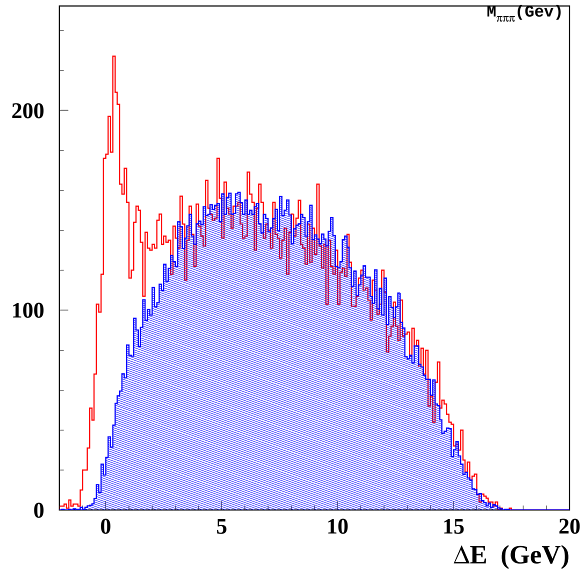


$$\Delta E = \frac{M_x^2 - M_p}{2M_p}.$$

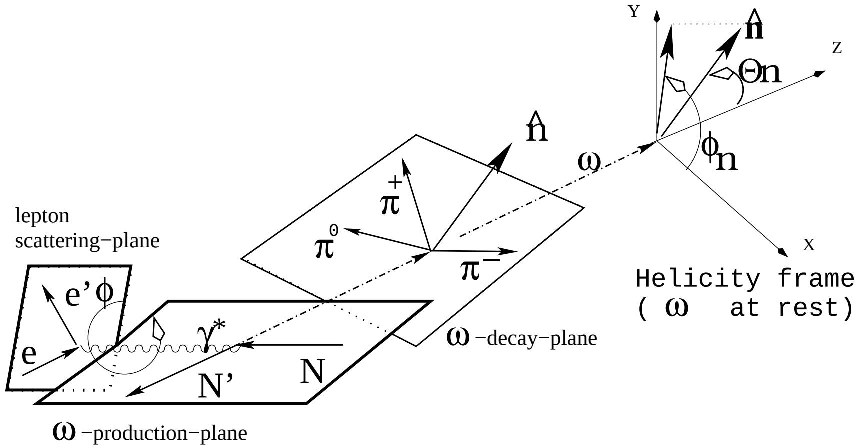
Excl. Events. Method of determination SDMEs







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



Definition of angles.

- **Simulated events: matrix of fully reconstructed MC events from initial uniform angular distributions**
- **Maximum Likelihood Method:** $\cos(\Theta), \phi, \Phi$. **Simultaneous fit of 23 SDMEs** $W(r_{ij}^{\alpha}, \Phi, \phi, \cos\Theta)$ **for data with negative and positive beam helicity.**

SDMEs for ρ^0 VM

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**$\{r^2_{1-1}\}$

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**$\{r^8_{10}\}$

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

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

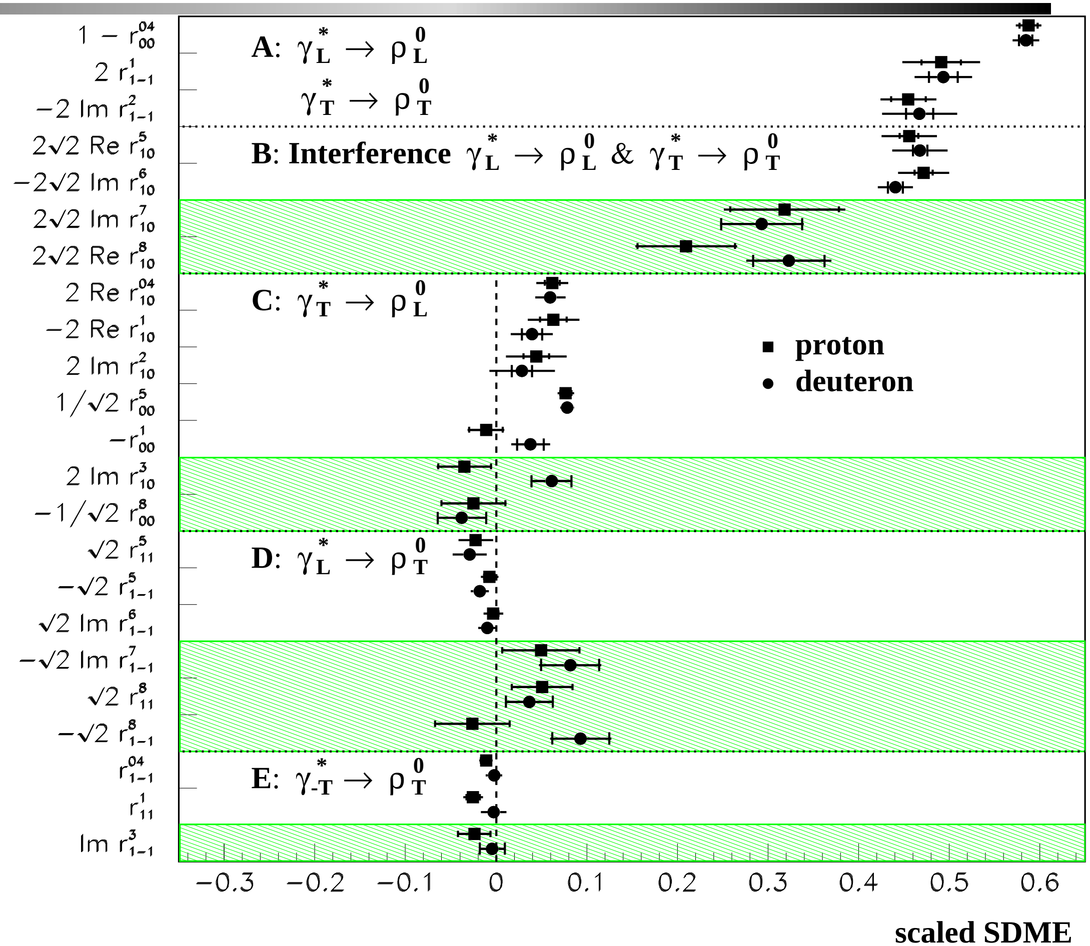
Re $\{T_{10}T^*_{11}\} \propto r^5_{11} \propto r^5_{1-1} \propto$ **Im**$\{r^6_{1-1}\}$

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

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** $\{r^3_{1-1}\}$

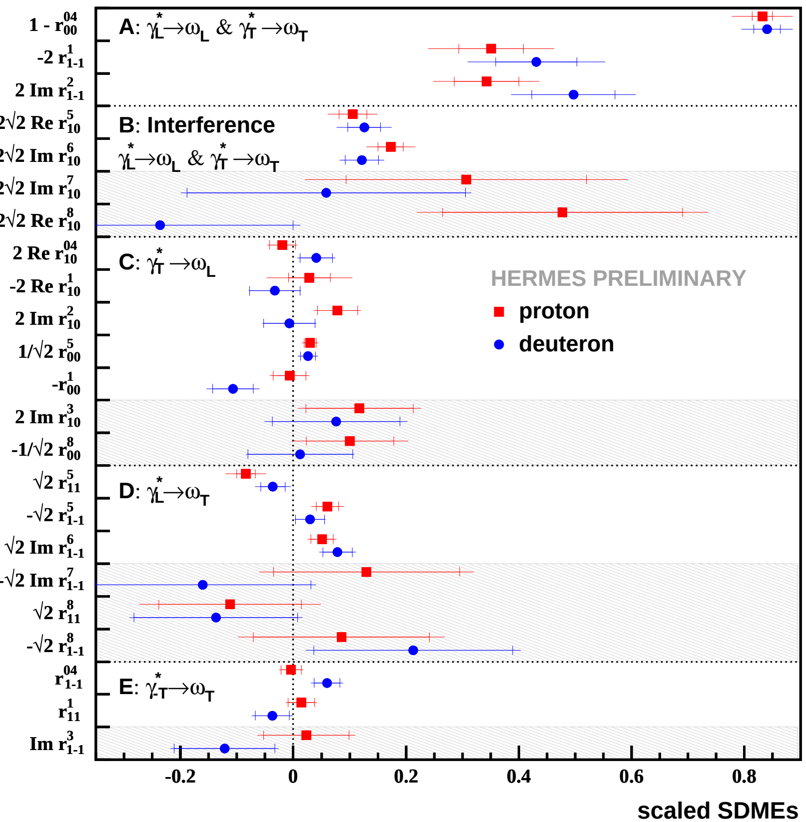


Diff. for class A :$|T^{\phi}_{11}|^2$ **B:(**$T_{11}T^*_{00}$**),tg(**δ^{ϕ}**)=(Im** r^7_{10} **+ Re** r^8_{10}**) / (Re** r^5_{10} **- Im** r^6_{10}**),**

$\delta^{\rho}_p = 30.0^0 \pm 5.0^0 \pm 2.4^0$

and C: $r^5_{00} > 0$

SDME's for ω



Scaled SDME's for proton and deutron data.

SDMEs for ω's sets for proton and deutron targets.

A- SCHC (1-r^{04}_{00}):$T_{11}(\omega) > T_{11}(\phi)$.

A- SCHC r^1_{1-1}: different signs.

A- SCHC $r^1_{1-1}(\omega) < 0$, $r^1_{1-1}(\phi) > 0$.

A- SCHC Im $r^2_{1-1}(\omega) > 0$, Im $r^2_{1-1}(\phi) < 0$.

$$r^1_{1-1} = \frac{1}{2}\widetilde{\sum}(|T_{11}|^2 + |T_{1-1}|^2 - |U_{11}|^2 - |U_{1-1}|^2)/\mathcal{N}$$

$$\text{Im } r^2_{1-1} = \frac{1}{2\mathcal{N}}\widetilde{\sum}(-|T_{11}|^2 + |T_{1-1}|^2 + |U_{11}|^2 - |U_{1-1}|^2)$$

$|U_{11}|^2 + |U_{1-1}|^2 > |T_{11}|^2 + |T_{1-1}|^2$ for ω meson

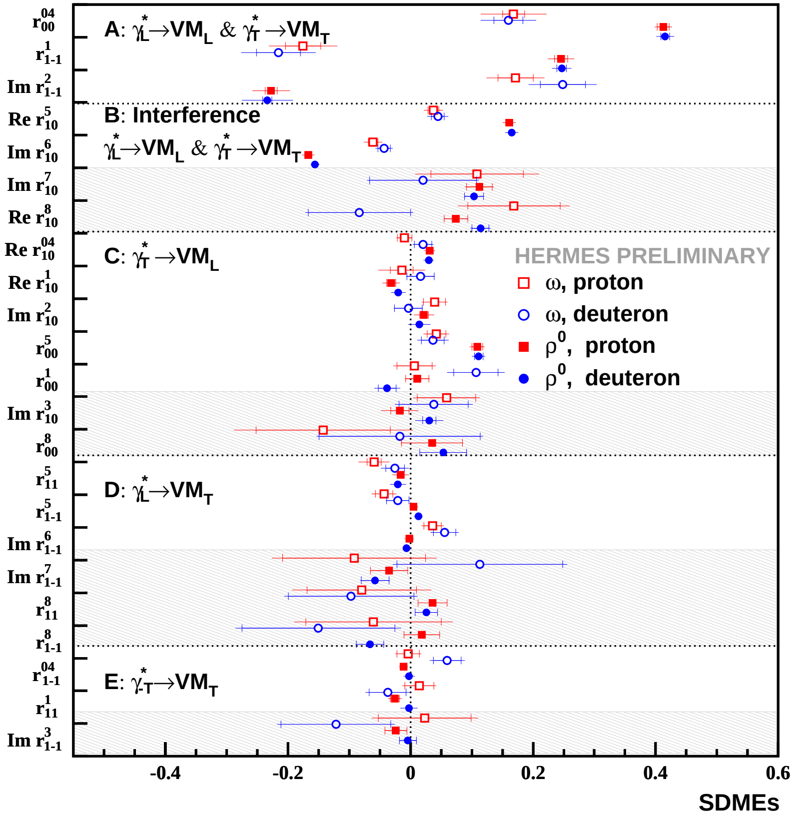
$|T_{1-1}|^2 + |U_{11}|^2 > |T_{11}|^2 + |U_{1-1}|^2$ for ω meson

if $|T_{1-1}|^2 \approx |U_{1-1}|^2$ we get $|U_{11}|^2 > |T_{11}|^2$

B- Int Re $r^5_{10}(\omega) <$ Re $r^5_{10}(\phi)$:$\sim T_{01}T^*_{01}$ + ...

B- Int Re $r^6_{10}(\omega) <$ Re $r^6_{10}(\phi)$:$\sim U_{01}U^*_{01}$ + ...

SDME's for ω and ρ^0

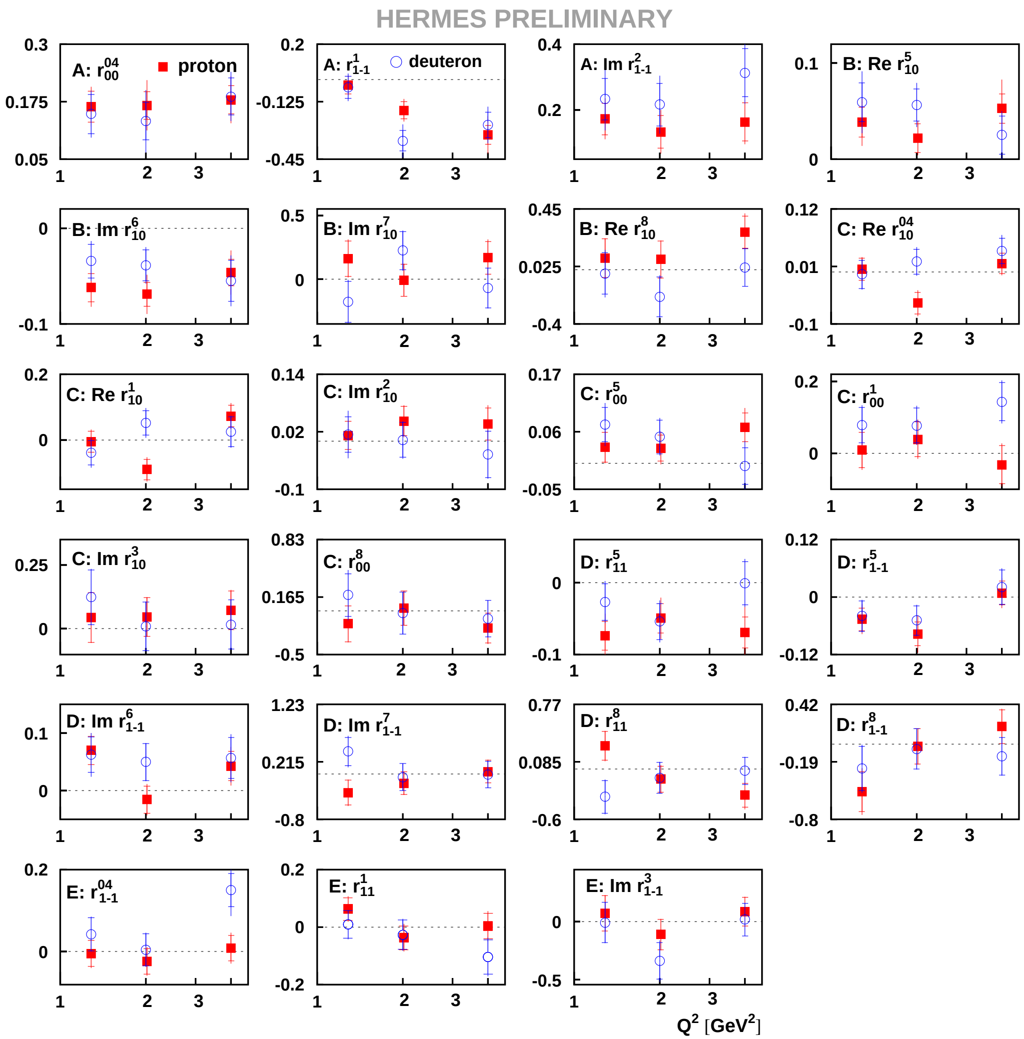


SDME from C class: $\gamma^*_T \to$ VM$_L$.

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

$\rho \neq$ 0, $\omega \simeq$ 0, $\phi \simeq$ 0.

ω 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.

-t$'$: 0.0-0.4 GeV^2.

NOTATION:

A- SCHC $\gamma^*_L \to \omega_L$ **and** $\gamma^*_T \to \omega_T$

r$^1_{1-1}$ and Im r$^2_{1-1}$ U$_{11}\pm$U$_{1-1}$ dependence on Q^2

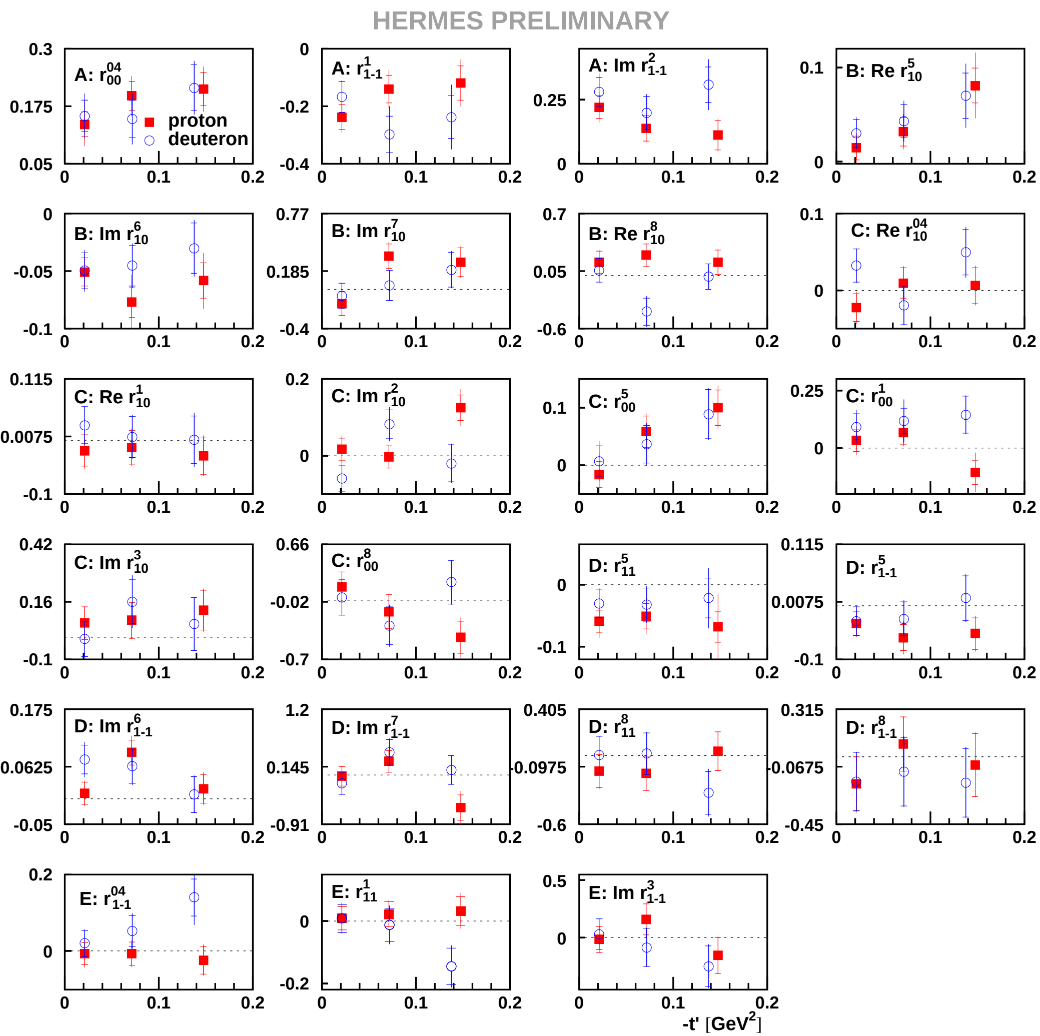
B- Interference: $\gamma^*_L \to \omega_L$ **and** $\gamma^*_T \to \omega_T$

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

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

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

ω 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. Q^2: 1.0 - 7.0 GeV^2.

NOTATION:

A- SCHC $\gamma^*_L \to \omega_L$ **and** $\gamma^*_T \to \omega_T$

r^1_{1-1} **and Im** r^2_{1-1} $U_{11} \pm U_{1-1}$ **dependence on t′**

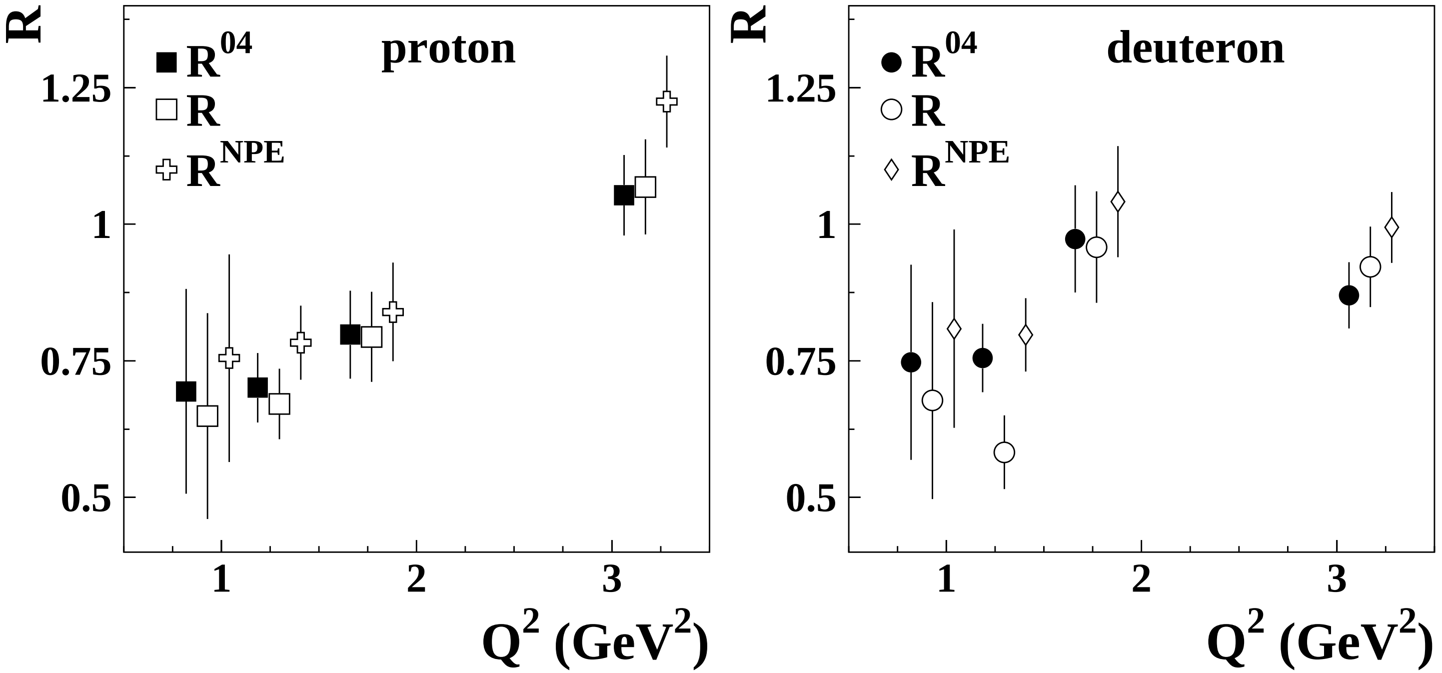
B- Interference: $\gamma^*_L \to \omega_L$ **and** $\gamma^*_T \to \omega_T$

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

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

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

ρ Longitudinal-to-Transverse Cross-Section Ratio



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

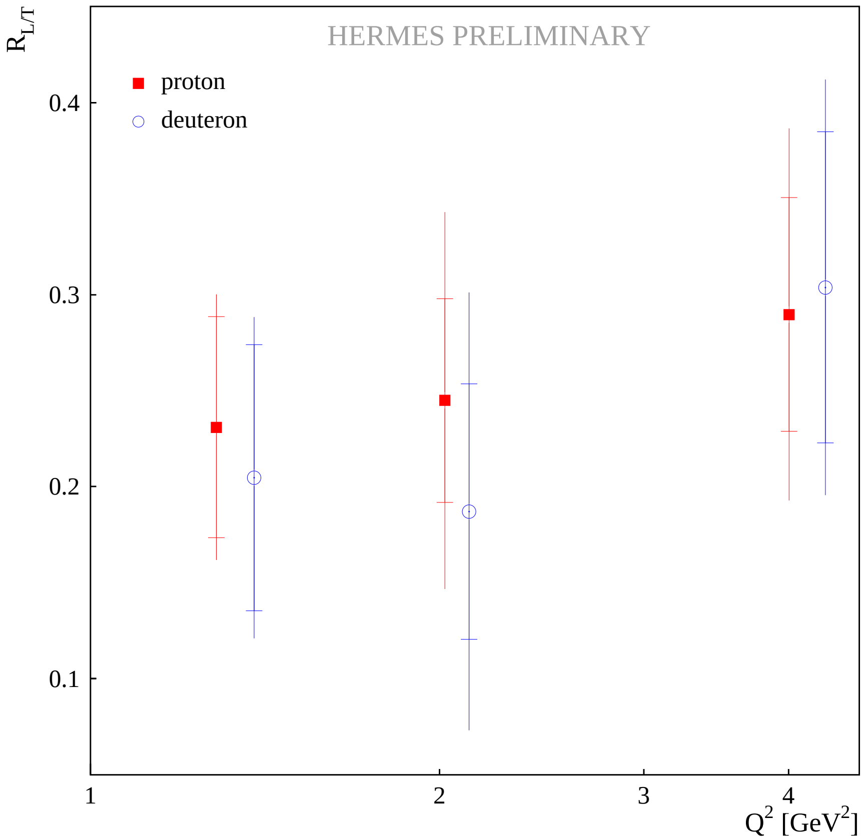
$R = R^{04} - \frac{\eta(1 - \epsilon R^{04})}{\epsilon(1-\eta)}$

where: η small contribution from helicity flip.

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

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

Longitudinal to Transverse cross section ratio for ω meson

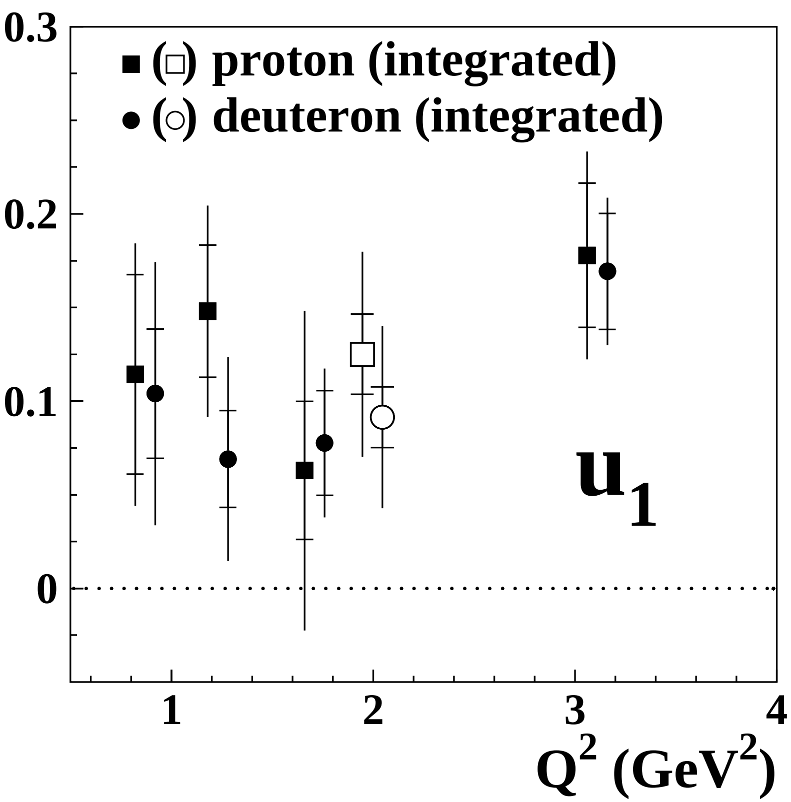


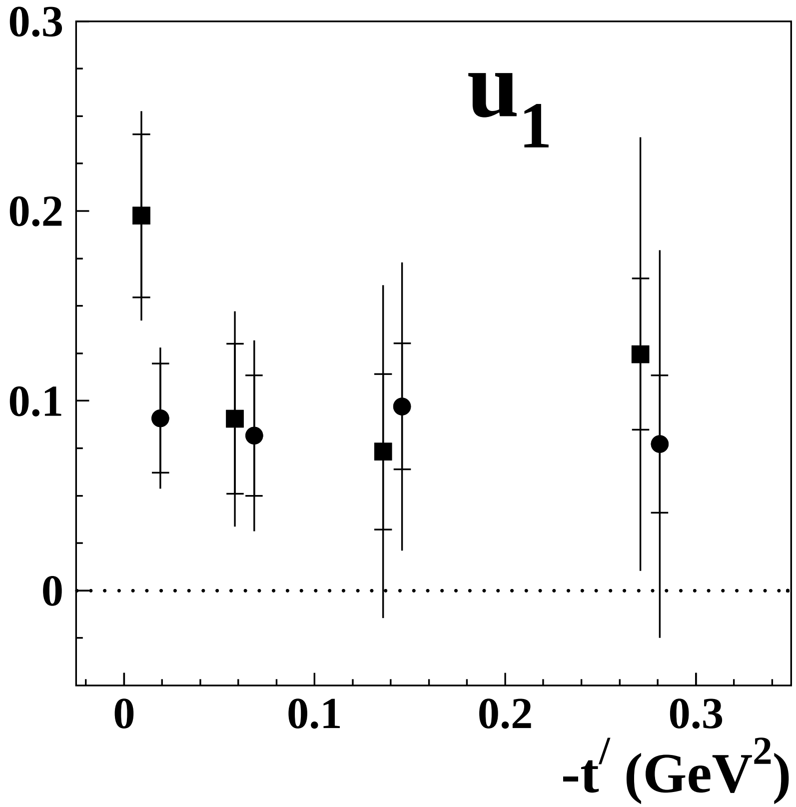
$$R_{L/T} = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}, \quad r^{04}_{00} = \widetilde{\sum}\{\epsilon|T_{00}|^2+|T_{01}|^2+|U_{01}|^2,\}/\mathcal{N} \quad \mathcal{N} = \epsilon\sigma_L+\sigma_T$$

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

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

Unnatural-Parity Exchange for leptoproduction of ρ^0 Mesons





U_1=1-r^{04}_{00}+2r^{04}_{1-1}-2r^{1}_{1-1} -2r^{1}_{11};

U_2=r^{5}_{1-1}+r^{5}_{11} ; U_3=r^{8}_{1-1}+r^{8}_{11}.

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

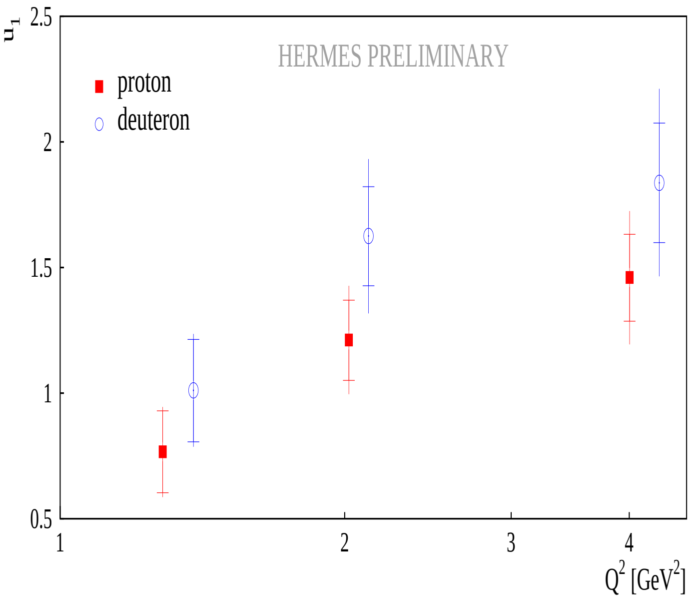
U_2+iU_3=$\sqrt{(}2)\widetilde{\Sigma}\{(U_{11}+U_{-11})^*U_{10}\}/\mathcal{N}$.

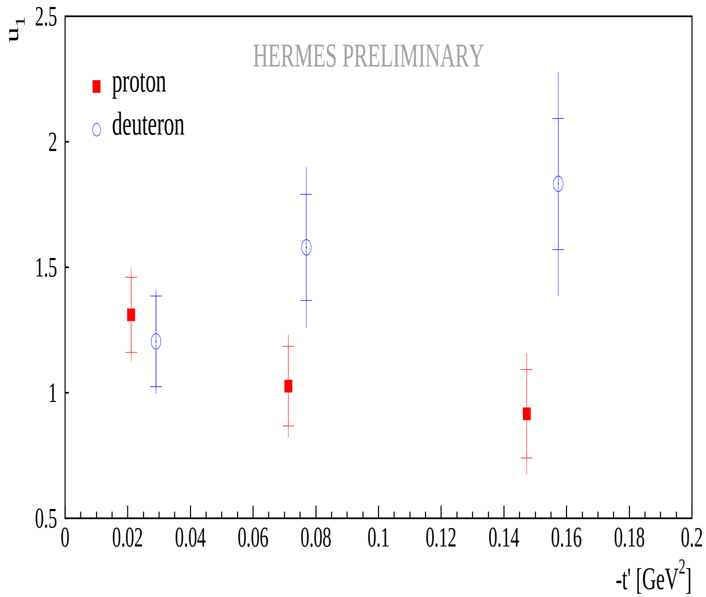
$$\widetilde{\Sigma}U_{\lambda_V\lambda_\gamma}U^*_{\lambda'_V\lambda'_\gamma}=\frac{1}{2}\sum_{\lambda_N,\lambda_{N'}}U_{\lambda_V\lambda'_N;\lambda_\gamma\lambda_N}U^*_{\lambda'_V\lambda'_N;\lambda^*_\gamma\lambda_N}$$

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: $\widetilde{\Sigma}T_{\lambda_V,\lambda_\gamma}U^*_{\lambda'_V,\lambda'_\gamma}=0$

Unnatural-Parity Exchange for leptoproduction of ω meson





Signal of UPE in SDME method

$$u_1 = 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^{1}_{11} - 2r^{1}_{1-1}$$

$$u_1 = \sum_{\lambda_N \lambda'_N} \frac{2\epsilon|U_{10}|^2 + |U_{11} + U_{-11}|^2}{N}$$

u1 $>$ 0 means contribution of UPE

where $N = N_T + \epsilon N_L$**,**

$$N_T = \sum_{\lambda_N \lambda'_N} (|T_{11}|^2 + |T_{01}|^2 + |T_{-11}|^2 + |U_{11}|^2 + |U_{01}|^2 + |U_{-11}|^2$$

$$N_L = \sum_{\lambda_N \lambda'_N} (|T_{00}|^2 + |T_{10}|^2 + |T_{-10}|^2 + |U_{10}|^2 + |U_{-10}|^2).$$

$u1(p)$ **= 1.15$\pm$ 0.09 $\pm$ 0.12** $u1(d)$ **= 1.47$\pm$ 0.12$\pm$ 0.18 for integrated data**

Ratios of Helicity Amplitudes

EXPERIMENT

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

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

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:

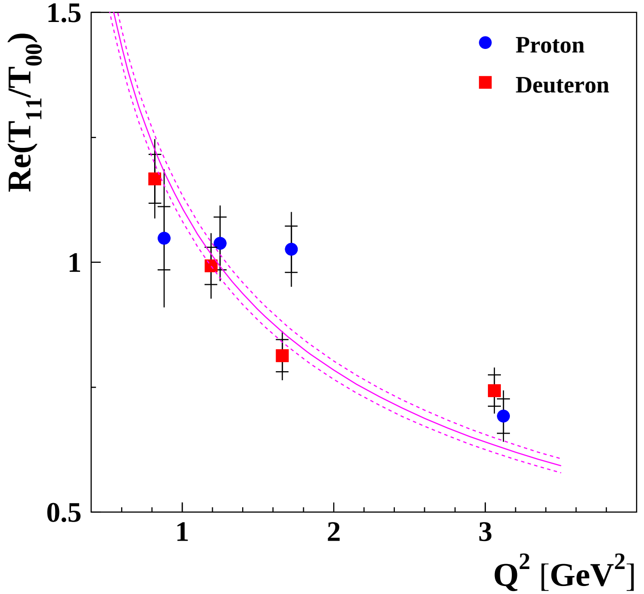
$$t_{11} = \frac{T_{11}}{T_{00}} \propto \frac{M_V}{Q},$$

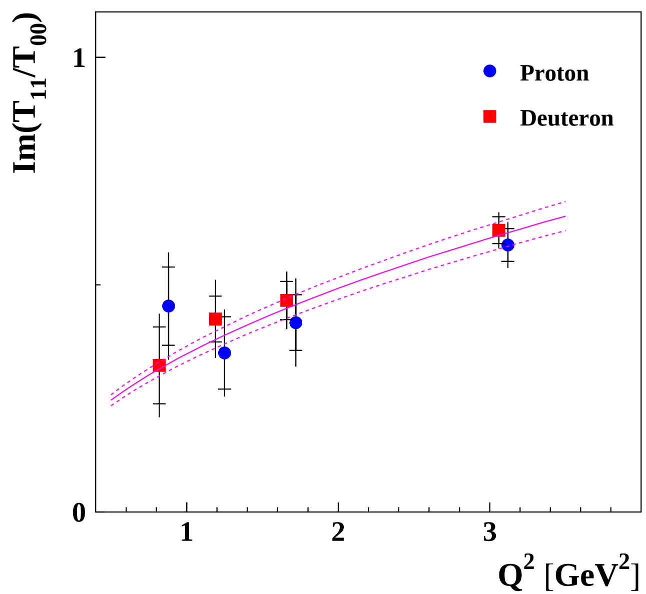
$$t_{01} = \frac{T_{01}}{T_{00}} \propto \frac{\sqrt{(-t')}}{Q},$$

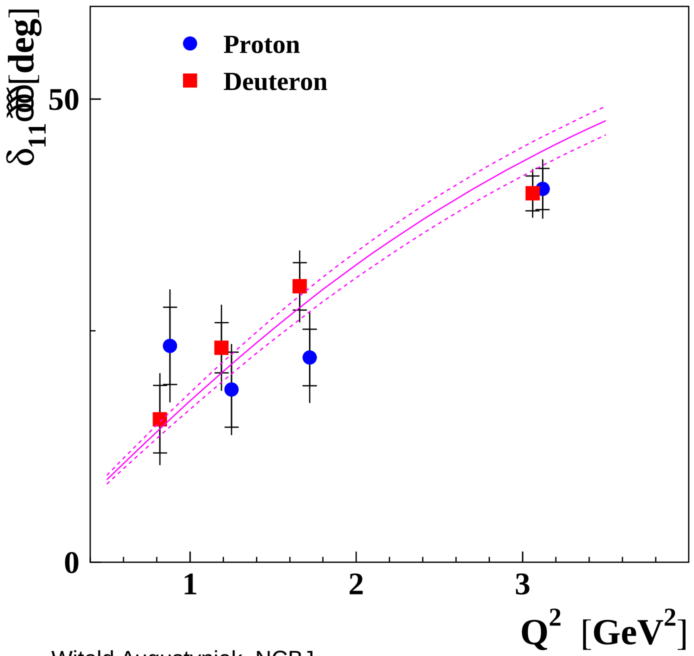
$$t_{10} = \frac{T_{10}}{T_{00}} \propto \frac{M_V \sqrt{(-t')}}{Q^2+M_V^2},$$

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

Ratios of Helicity Amplitudes t_{11}

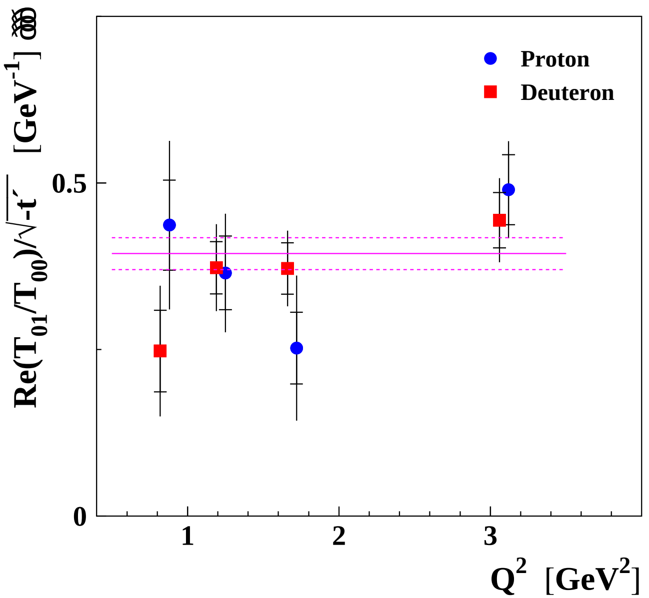


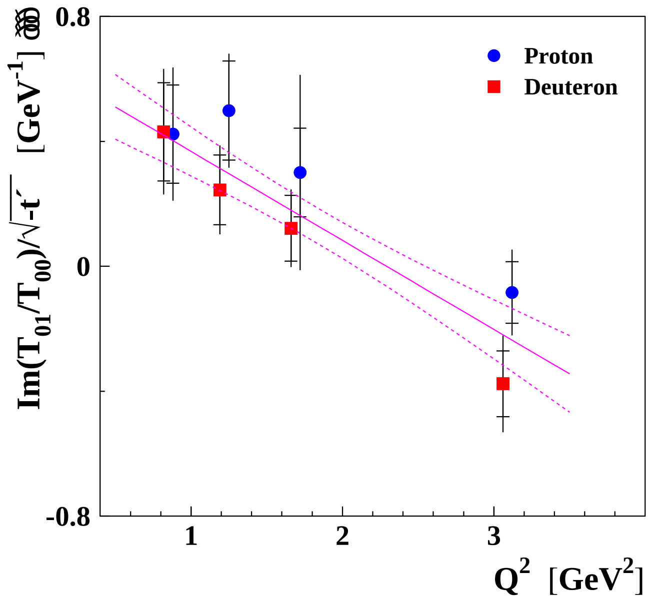


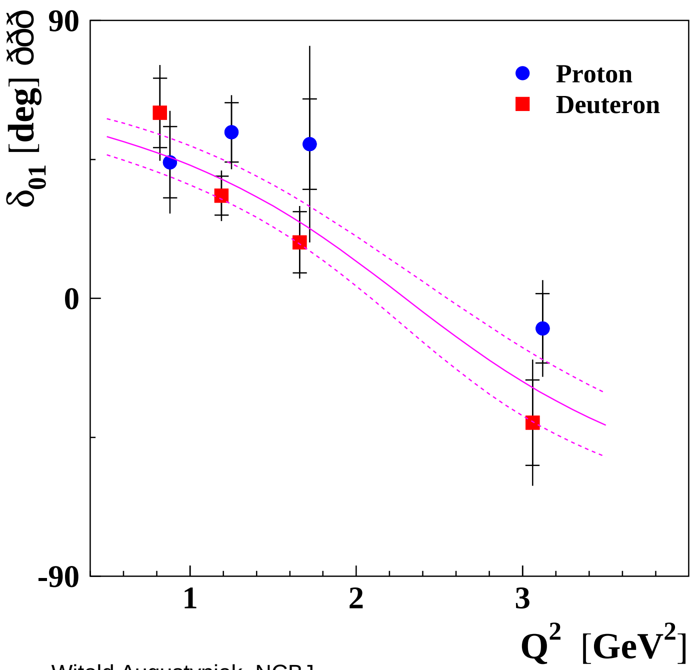


Q^2 dependence of Re(T_{11}/T_{00}), Im(T_{11}/T_{00}) and their phase difference δ_{11}, for hydrogen and deuterium targets. Parameterization is given by the function: Re(t_{11})=a/Q and Im(t_{11})=bQ. The function for Im(T_{11}/T_{00}) different from theoretical predictions. High value of δ_{11} is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

Ratios of Helicity Amplitudes t_{01}



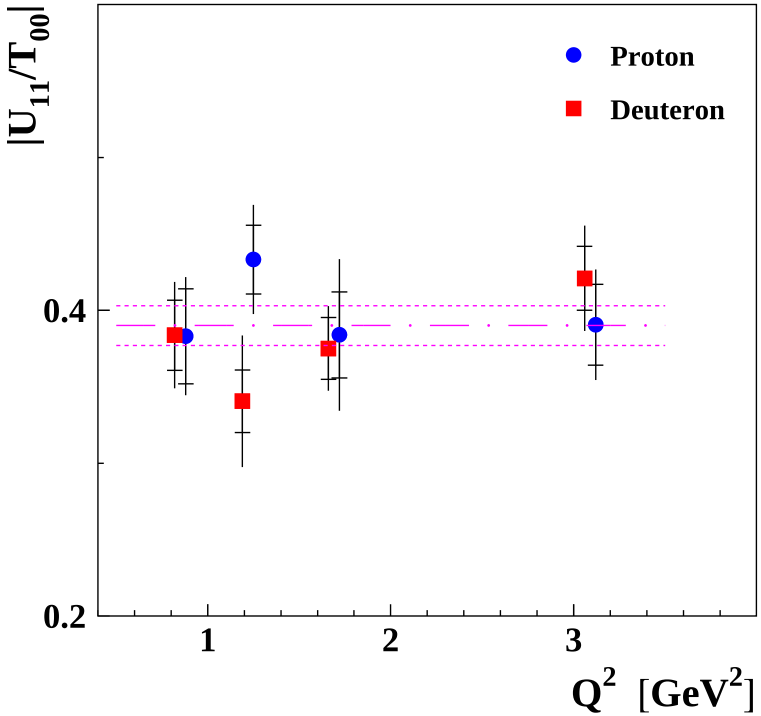


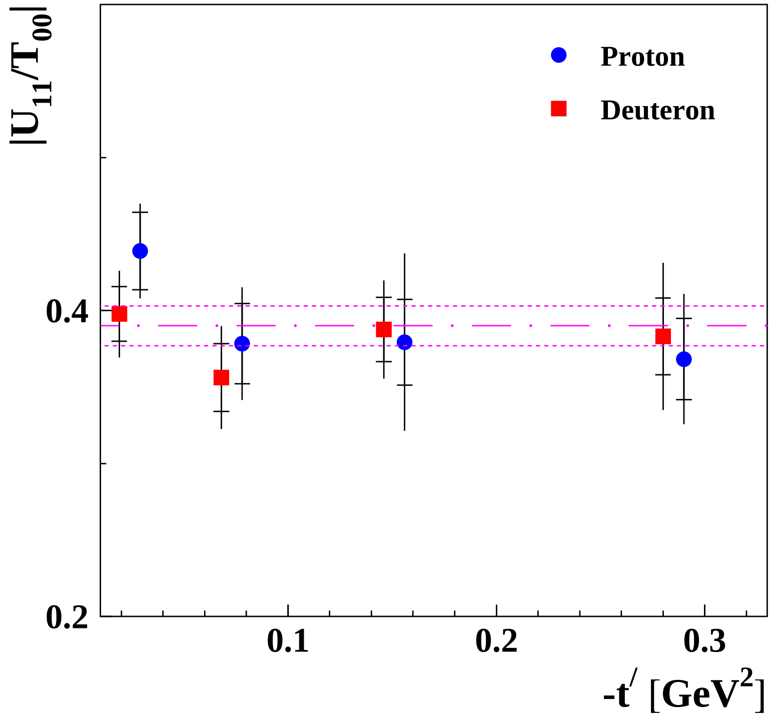


Q^2 dependence of Re(T_{01}/T_{00}), Im(T_{01}/T_{00}) and their phase difference δ_{01} for hydrogen and deuterium targets. The Q^2 dependence was observed only for Im(t_{01}).

Im(t_{01}) is found to be in agreement with asymptotic pQCD behavior, $\sqrt{-t'})/Q^2$ opposite to Re(t_{01}).

Ratios of Helicity Amplitudes u_{11}

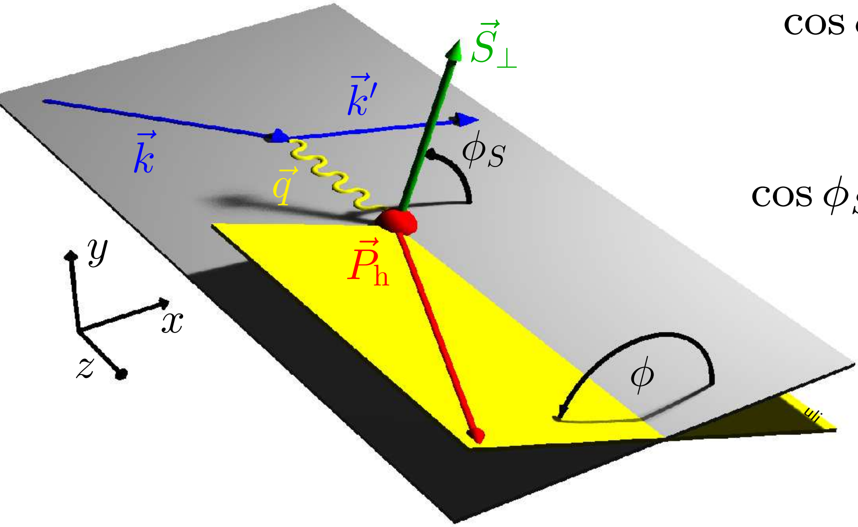




Dependece of $\left|U_{11}/T_{00}\right|$ on Q^2 and t'. for hydrogen and deuterium targets. UPE describe transition from transversely polarized photon to transversely polarized VM. Supresed by factor M_V/Q.

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
Eur.Phys.J.C41 515 (2005)
hep-ph/0503023

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

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

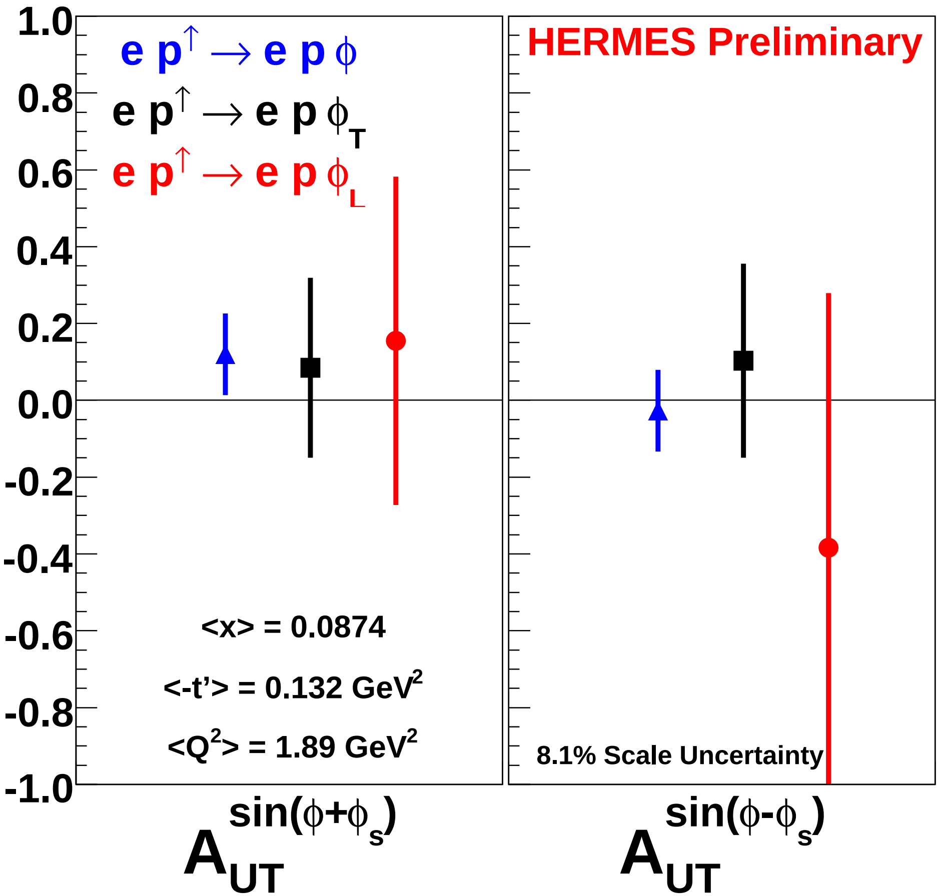
$$- \frac{P_T}{\sqrt{1-\sin^2\theta\,\sin^2\phi_S}}\Bigg[\sin\phi_S\,\cos\theta\sqrt{\varepsilon(1+\varepsilon)}\,\mathrm{Im}\,\sigma_{+0}^{+-}$$
$$+\sin(\phi-\phi_S)\Big(\cos\theta\,\mathrm{Im}\,(\sigma_{++}^{+-}+\varepsilon\sigma_{00}^{+-})+\frac{1}{2}\sin\theta\sqrt{\varepsilon(1+\varepsilon)}\,\mathrm{Im}\,(\sigma_{+0}^{++}-\sigma_{+0}^{--})\Big)$$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

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

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



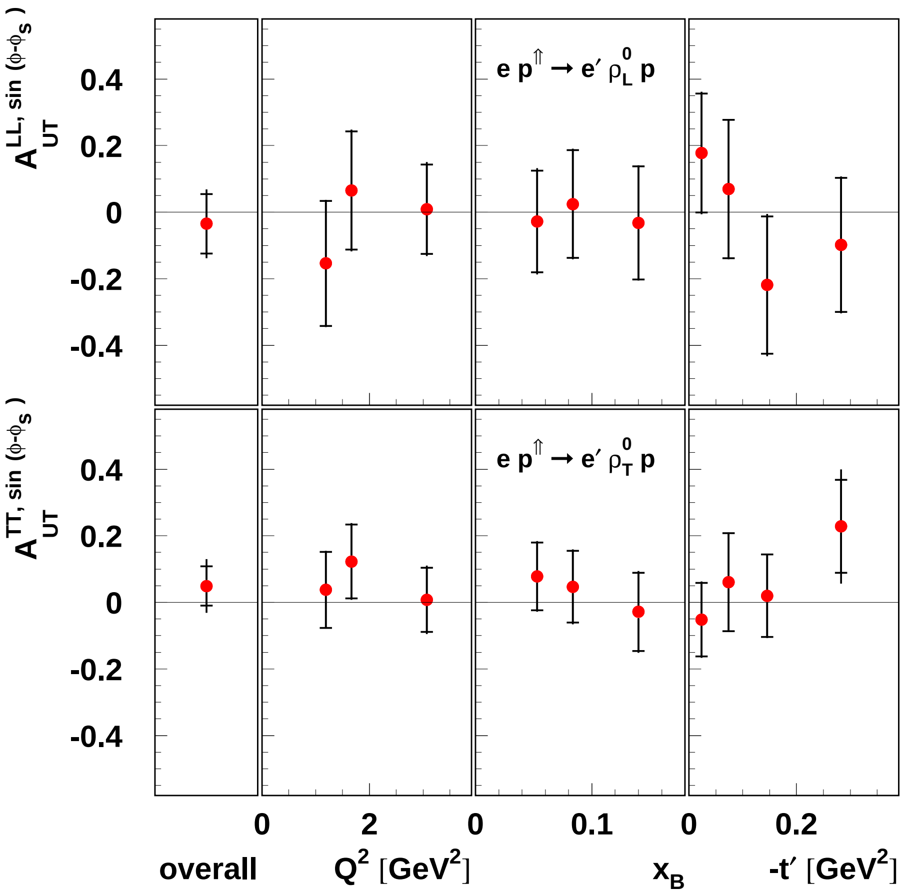
Used cuts:

- 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 provides information about E GPDs function that are sensitive to helicity-flip. E GPDs functions contain information about the orbital angular momentum of partons.

A_{UT} for ρ^0 vector mesons



$$A_{UT}^{L\sin(\phi-\phi_S)} = \frac{Im(n^{00}_{++} + \epsilon n^{00}_{00})}{u^{00}_{++} + \epsilon u^{00}_{00}},$$

$$A_{UT}^{T\sin(\phi-\phi_S)} = \frac{Im(n^{++}_{++} + n^{--}_{++} + 2\epsilon n^{++}_{00})}{1 - (u^{00}_{++} + \epsilon u^{00}_{00})}.$$

Here letters u, n and s stand for unpolarized, normal and sideway SDME's def. for transvesely polarized target by : M.Diehl,J.High Energy Phys. JHEP09(2007) 064.

Amplitudes A_{UT} determined for ρ^0 vector mesons separated for longitudinal and transverse components. Dependence of amplitudes A_{UT} on Q^2, x_B and -t′.

A_{UT} and GPDs

$$J^q = \frac{1}{2}\int_{-1}^{1} dx x[H^q(x,\xi,t=0)+E^q(x,\xi,t=0)],$$

$$J^g = \frac{1}{2}\int_{-1}^{1} dx[H^g(x,\xi,t=0)+E^g(x,\xi,t=0)].$$

- **Experiment:**
  A^L_{UT}= -0.035 $\pm$ 0.103
- **F.Elinghous,W-D.Nowak, A.V.Vinnikov and Z.Ye, Eur. Phys. J. C46 (2006) 729**
  E^q was parameterized by: J^u [0.0 - 0.4], J^d=0 and contribution E^g
  Results: A_{UT} 0.0 - 0.15 for ρ^0,
  0.0 for ϕ
- **S.V. Goloskokov and P. Kroll Eur. Phys. J. C59 (2009) 809**
  GPDs were modeled using the data of form factor, sum rules and positivity constrains.
  J^u=0.22, J^d=0.0.
  Results: A_{UT} -0.03 $\pm$ 0.02 for ρ^0,
  0.0 for ϕ
- **M. Diehl and W. Kugler Eur. Phys. J C52 (2007) 933**
  Assumptions and results similar like Goloskokov& Kroll

hermes

A_{UT} and GPDs continuation

- The gluon and sea quark moments have to cancel each other almost completely. (M.D $\&$ W.K from Ji's sum rules and positivity relations)

S.V.Goloskokov and P.Kroll

Eur. Phys. J. C59 (2009) and hep-ph/0809412

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:

$C_\omega^{uu} = C_\omega^{dd} = C_{\rho^0}^{uu} = C_{\rho^0}^{dd} = \frac{1}{\sqrt{2}}, C_\phi^{ss} = 1,$

F(=H,E),

$\hat{F}$ - hard scattering kernel

Sudakov effect in b space.

Parameters of wave function.

Conclusions

- **SDMEs for VM: ω and ρ^0**
  - **Values and sings of SDME's from class A: r^1_{1-1} and Im r^2_{1-1}, indicate that $|U_{11}|^2 > |T_{11}|^2$ for electroproduction of ω meson. Processes with UPE dominate in electroproduction of ω meson**
  - **For ρ^0 processes with NPE dominate**
  - **Non-zero values of the observable U_1 for ρ^0 indicates for contribution of processes with UPE**
  - **Class B: Sign and value of the difference phases T_{11} and T_{00} were determined.**
  - **For ω, elements from class B are small as interference of U amplitudes.**
  - **Class C: for ρ^0, where non-zero elements indicate a single-spin-flip.**
  - **No significant differences between SDME's sets with proton and deuteron targets were observed.**

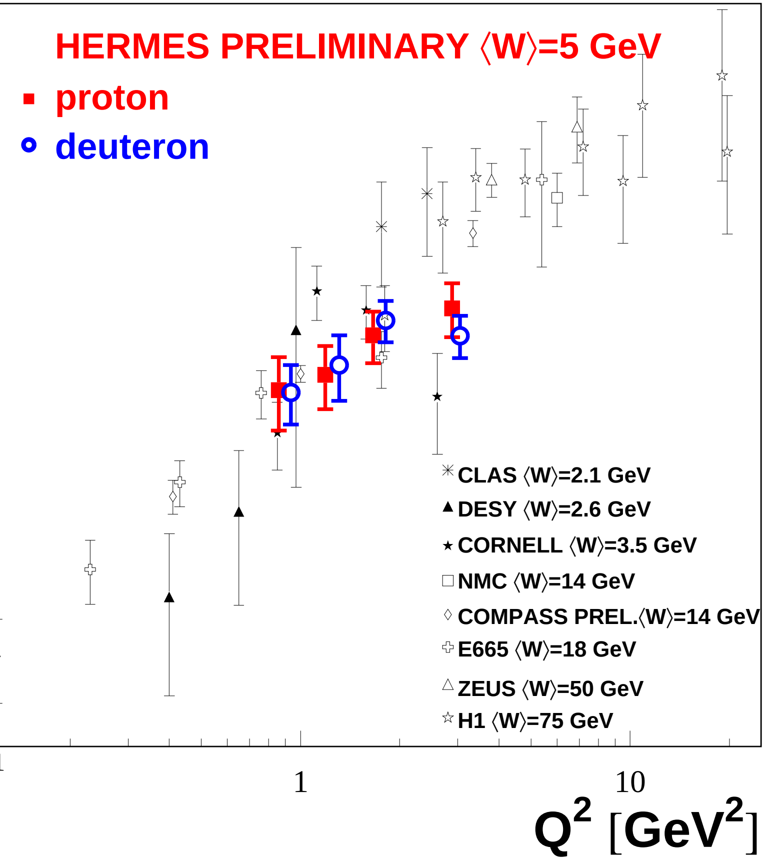
Conclusions continuation

- Dependences of SDMEs and other observables on Q^2 and t'
  - Dependences of SDMEs on Q^2 are observed in case of ρ^0 for classes A and B.
  - For r_{00}^{04} difference for value and dependence on Q^2 between ω and ρ^0 are substantial.
  - Difference like that was observed in value as well as dependence of $\frac{\sigma_L}{\sigma_T}$ on Q^2. Far from expected behaviour: $\frac{Q^2}{M_v^2}$
  - Observed dependence of C class in particularly r_{00}^{5} as growing function of t' for ω, ρ^0.
- Ratios of Helicity Amplitudes
  - Agreement with asymptotic pQCD predictions was found for Re(t_{11}) and Im(t_{01})
  - Disagreement for Im(t_{11}) and Re(t_{01}).
  - $|U_{11}/T_{00}|$ is found to be contant in HERMES kinematics.
- A_{UT}
  - Near zero value of A_{UT} for ϕ is found
  - Zero value for A_{UT} was predicted by theoretical models:S.V. Goloskolov, P. Kroll Eur. Phys. JC59 (2009) 808 and F.Ellinghaus et al, Eur. Phys. J C46 729 (2006)
  - The values predicted by models for ρ^0 are in agreement with experiment.

THANK YOU

Additional slides

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**

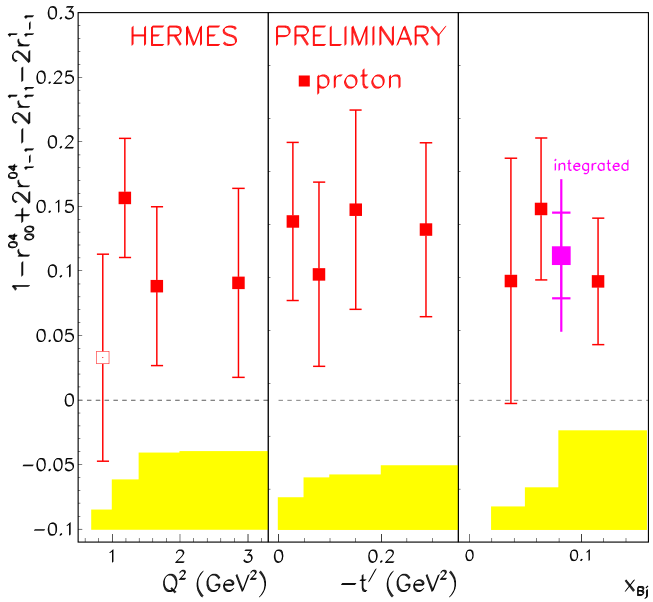
Unnatural Parity Exchange (UPE) in ρ^0 Leptoproduction

latural-parity exchange: interaction is
nediated by a particle of 'natural' parity:
ector or scalar meson:
$J^P = 0^+, 1^-$ e.g. ρ^0, ω, a_2

Jnnatural parity exchange is mediated by
oseudoscalar or axial meson:
$J^P = 0^-, 1^+$, e.g. π, a_1, b_1 $\rightarrow$ 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:**
$|U_{11}| \gg |U_{10}| \sim |U_{01}|$

hermes

A_{UT} and GPDs

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

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

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

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

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

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

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

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

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

S.V.Goloskokov and P.Kroll

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F(=H,E),

$\hat{F}$ - hard scattering kernel

Sudakov effect in b space.

Parameters of wave function.

SDMEs for: ρ^0, ϕ and ω VM

SCHC $\gamma_L^* \to \phi_L$ **and** $\gamma_T^* \to \phi_T$

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

Interference: $\gamma_L^* \to \phi_L$ **and** $\gamma_T^* \to \phi_T$

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**$\{r_{10}^8\}$

Spin Flip: $\gamma_T^* \to \phi_L$

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 $\{T_{01}T_{00}^*\} \propto r_{00}^8$

Spin Flip: $\gamma_L^* \to \phi_T$

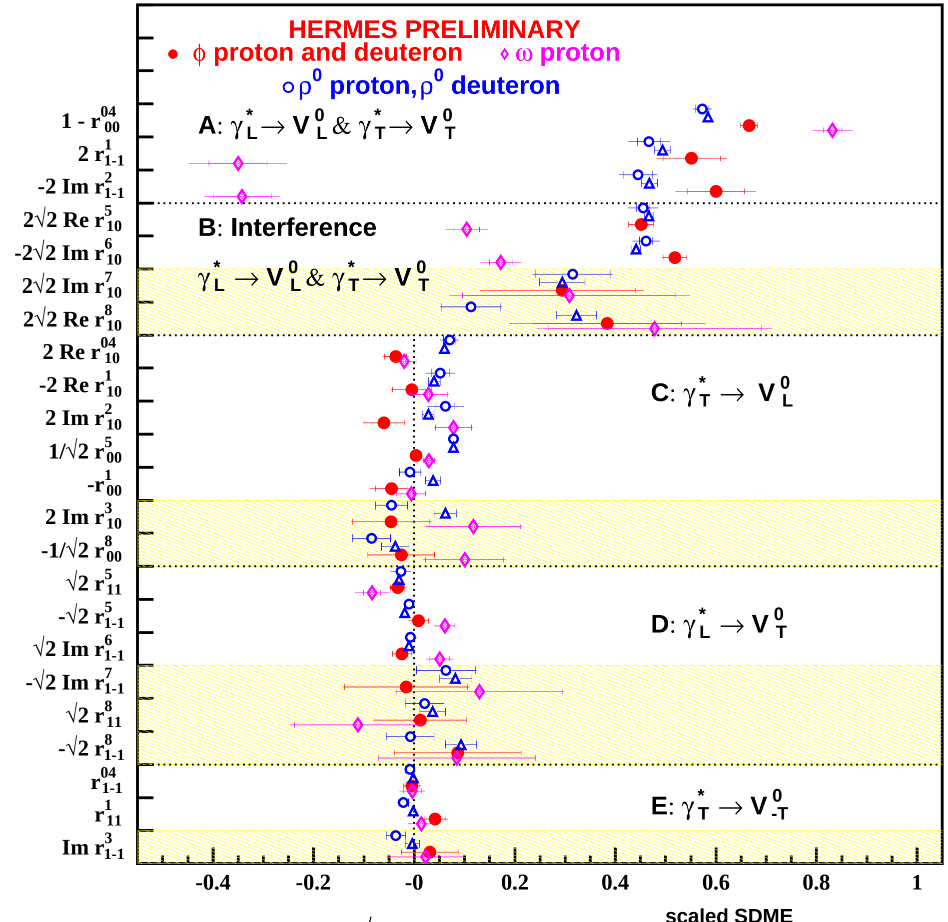
Re $\{T_{10}T_{11}^*\} \propto r_{11}^5 \propto r_{1-1}^5 \propto$ **Im**$\{r_{1-1}^6\}$

Im $\{T_{10}T_{11}^*\} \propto$ **Im** $\{r_{1-1}^7\} \propto r_{11}^8 \propto r_{1-1}^8$

Double Spin Flip: $\gamma_T^* \to \phi_{-T}$

Re$\{T_{1-1}T_{11}^*\} \propto r_{1-1}^{04} \propto r_{11}^1$

Im $\{T_{1-1}T_{11}^*\} \propto$ **Im** $\{r_{1-1}^3\}$



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

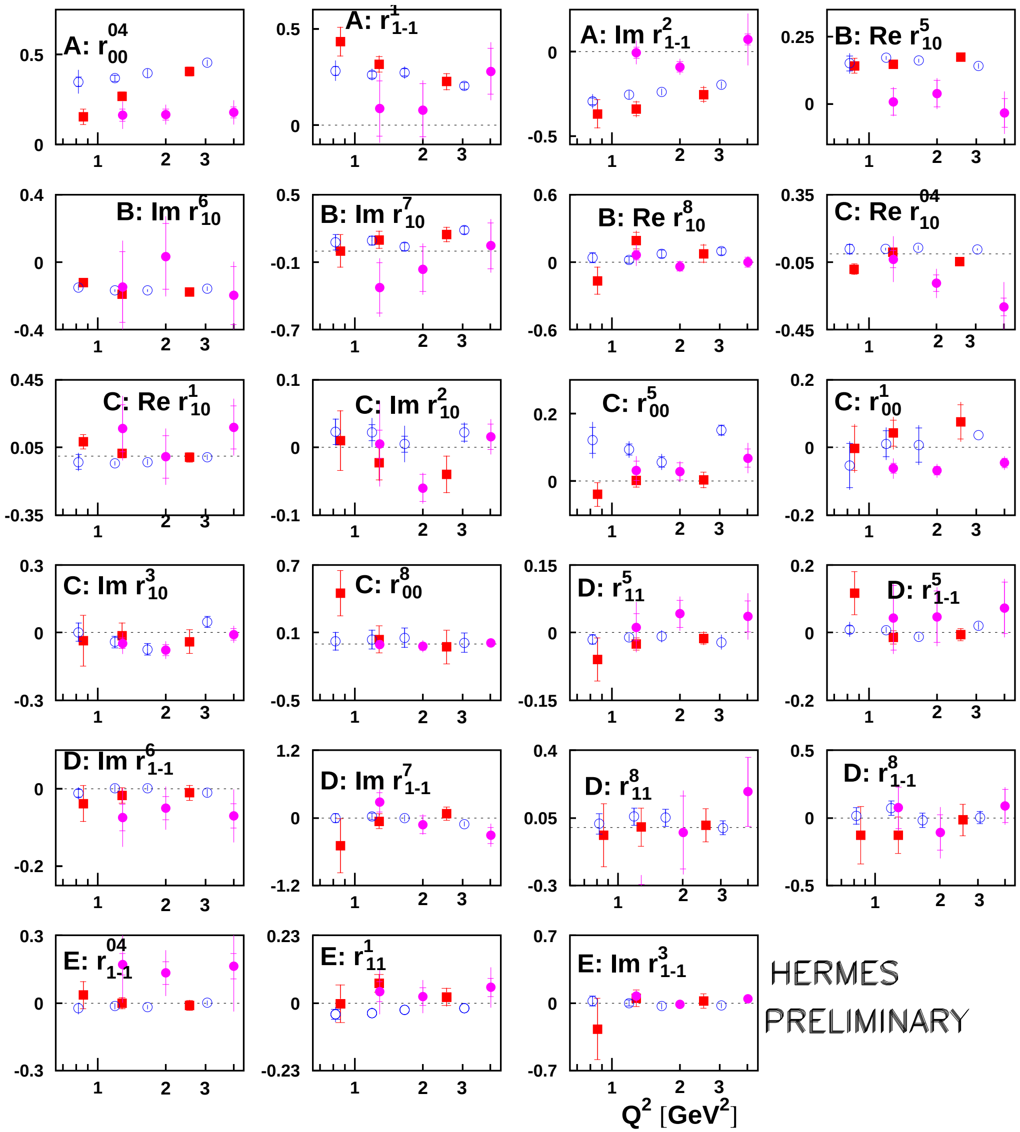
B:(T$_{11}$**T**$^*_{00}$**),** $\rho^0 \sim \phi$ **diff. phases T**$_{11}$ **and T**$_{00}$

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

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

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

ω 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.

Q^2: 1.0 - 7.0 GeV^2, -t$'$: 0.0-0.4 GeV^2.

NOTATION:

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

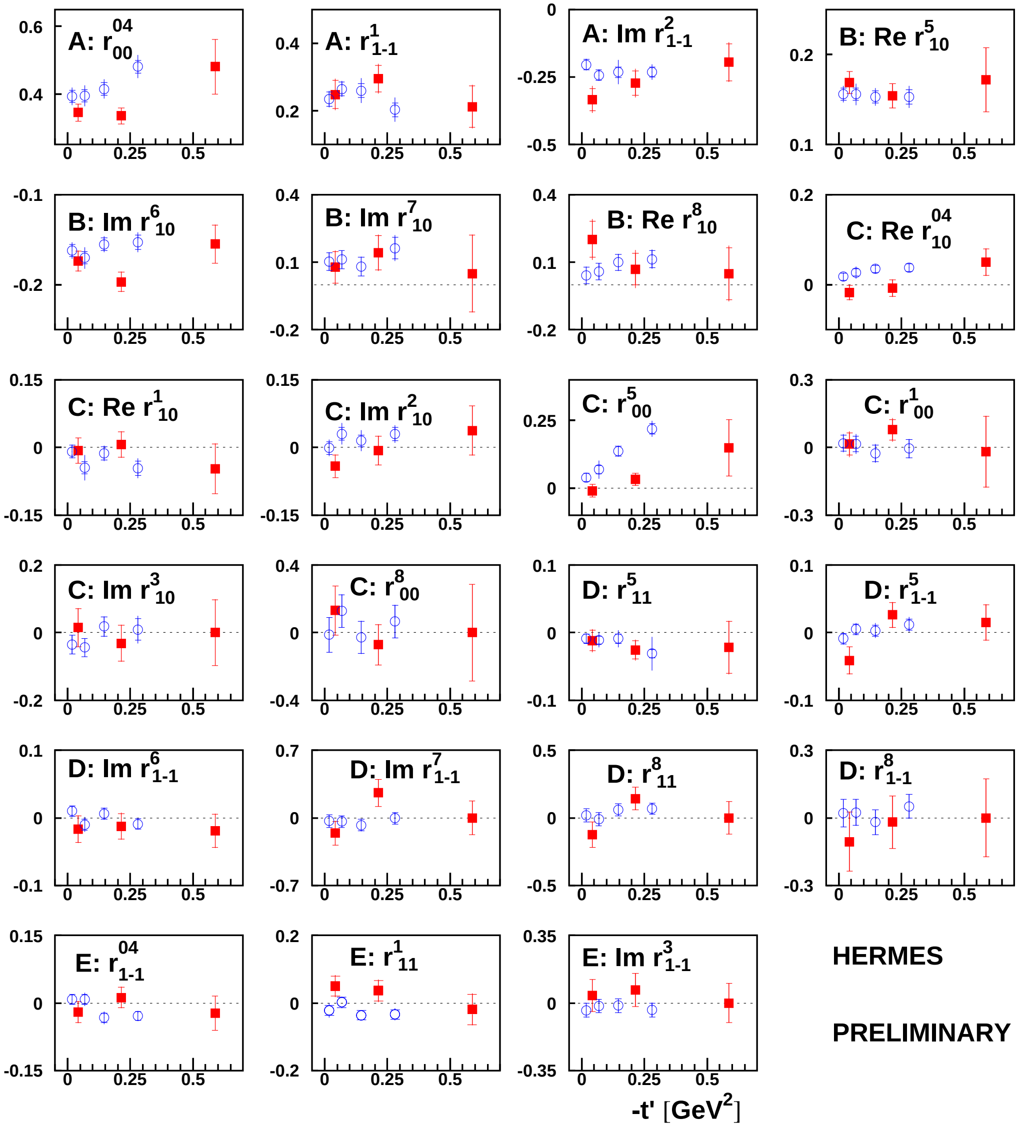
B- Interference: $\gamma^*_L \to \phi_L$ **and** $\gamma^*_T \to \phi_T$

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

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

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

ϕ and ρ^0 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 $\gamma^*_L \to \phi_L$ **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: $\gamma^*_T \to \phi_{-T}$