Spin Density Matrix Elements in hard exclusive electroproduction of ω mesons

B. Marianski

bohdan@fuw.edu.pl

National Centre for Nuclear Studies Warsaw, Poland

for HERMES Collaboration

DIS2013 - XXI International Workshop on Deep-Inelastic Scattering and Related Subjects,

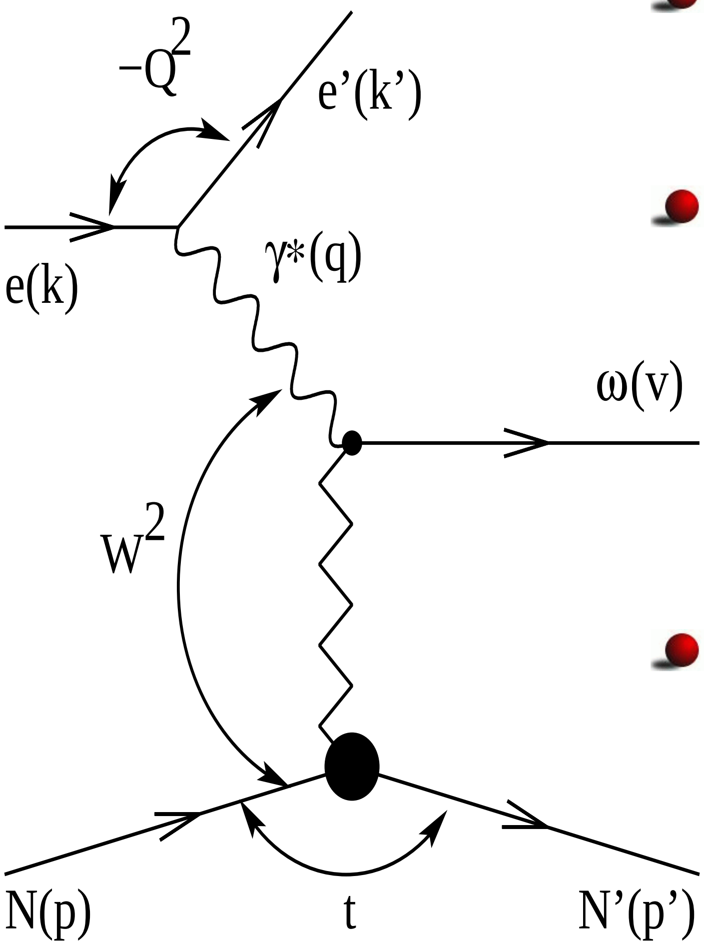
Marseilles, Provence (France)

Contents

- Vector meson Spin Density Matrix Elements (SDMEs).
- SDMEs, helicity amplitudes and angular distribution.
- HERMES Experiment and data processing.
- Results.
  - SDMEs for the integrated data.
  - Kinematic dependences of SDMEs.
  - Unnatural-Parity Exchange for ω meson.
  - Longitudinal to Transverse cross section ratio for ω meson.
- Summary.

Spin Density Matrices in reaction

$$e + N \to e' + \omega + N$$

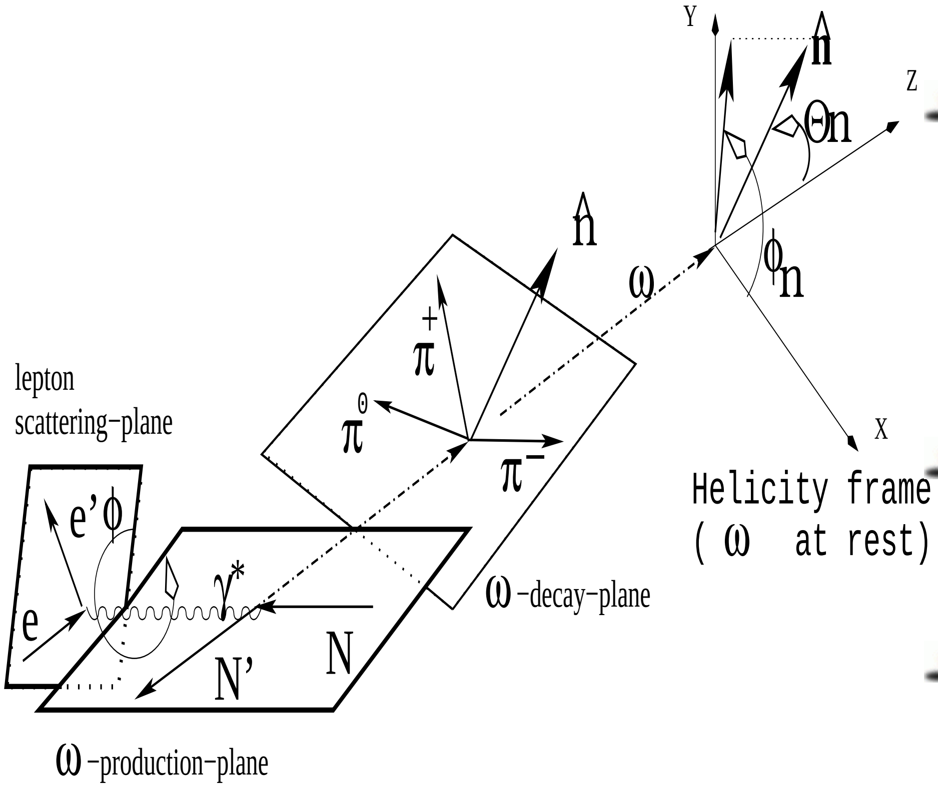


- $e \to e' + \gamma^*$ (QED). Spin-density matrix $\varrho^{U+L}_{\lambda_\gamma \lambda'_\gamma}(\epsilon, \Phi) = \varrho^{U}_{\lambda_\gamma \lambda'_\gamma} + P_{beam}\varrho^{L}_{\lambda_\gamma \lambda'_\gamma}$ of the virtual photon is known. U - unpolarized, L - polarized beam
- $\gamma^* + N \to \omega + N \to \pi^+ + \pi^- + \pi^0 + N$ (QCD). Vector-meson spin-density matrix $\rho_{\lambda_V \lambda'_V}$ is expressed by helicity amplitudes $F_{\lambda_V \lambda'_N; \lambda_\gamma \lambda_N}(W, Q^2, t')$. In CM frame of $\gamma^* N$ is given by the von Neumann formula:
  $\rho_{\lambda_V \lambda'_V} =$
  $\frac{1}{2N} \sum_{\lambda_\gamma \lambda'_\gamma \lambda_N \lambda'_N} F_{\lambda_V \lambda'_N; \lambda_\gamma \lambda_N} \ \varrho^{U+L}_{\lambda_\gamma \lambda'_\gamma} \ F^*_{\lambda'_V \lambda'_N; \lambda'_\gamma \lambda_N}$
- $\varrho^{L+U}_{\lambda_\gamma \lambda'_\gamma}$ decomposes into the set of nine hermitian matrices(3$\times$3)Σ^α (α=0$\div$3 - transv.,4 - long. 5$\div$8 - interf.), $\rho_{\lambda_V \lambda'_V} \to \rho^{\alpha}_{\lambda_V \lambda'_V}$. When we can not separate transverse and longitudinal photons, Spin Density Matrix Elements (SDMEs) are defined:

$$r^{04}_{\lambda_V \lambda'_V} = (\rho^{0}_{\lambda_V \lambda'_V} + \epsilon R \rho^{4}_{\lambda_V \lambda'_V})/(1 + \epsilon R),$$

$$r^{\alpha}_{\lambda_V \lambda'_V} = \begin{cases} \frac{\rho^{\alpha}_{\lambda_V \lambda'_V}}{(1+\epsilon R)}, & \alpha = 1, 2, 3, \\ \frac{\sqrt{R}\rho^{\alpha}_{\lambda_V \lambda'_V}}{(1+\epsilon R)}, & \alpha = 5, 6, 7, 8. \end{cases} \qquad R = \sigma_L/\sigma_T$$

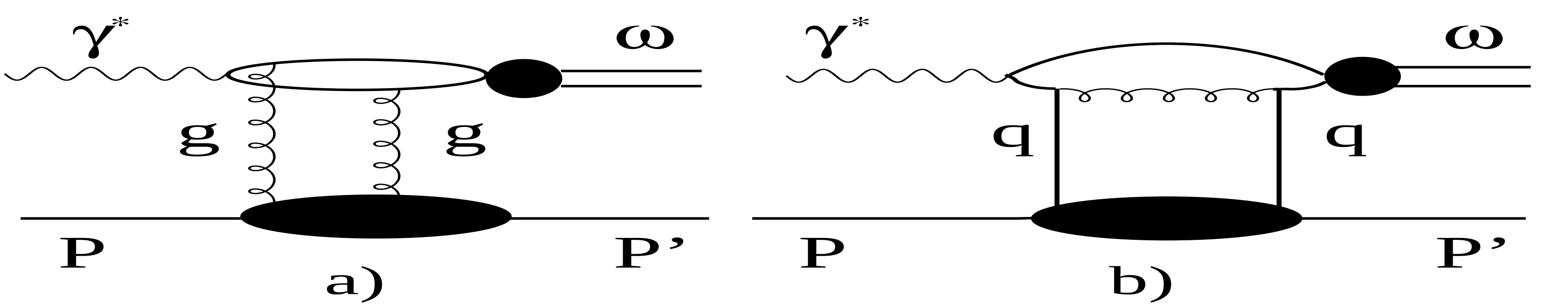
Angular distribution in reaction $e + p \to e' + p' + \omega \to (\pi^+\pi^-\pi^0(\to 2\gamma))$



- $\omega \;\Rightarrow\; \pi^+\pi^-\pi^0$ (conservation of $\vec{J}$) $|\omega;1m> \to \; |\pi^+\pi^-\pi^0;1m> \Rightarrow \; Y_{1m}(cos(\theta),\phi)$, $(m=\pm 1,0)$. Angular distribution $\mathcal{W}(r^{\alpha}_{\lambda_V\lambda'_V},\Phi,\phi_n,\cos\Theta_n)$ depends linearly on $r^{\alpha}_{\lambda_V\lambda'_V}$ and beam polariztion P_b.
- For longitudinally polarized beam and unpolarized target there are 23 SDMEs,(15 unpolarized and 8 polarized).
- The SDMEs are determined from the fit of angular distribution of pions from decay $\omega \;\Rightarrow\; \pi^+\pi^-\pi^0$, by angular distribution $\mathcal{W}(r^{\alpha}_{\lambda_V\lambda'_V},\Phi,\phi_n,\cos\Theta_n)$, with Maximum Likelihood method.

General properities of helicity amplitudes

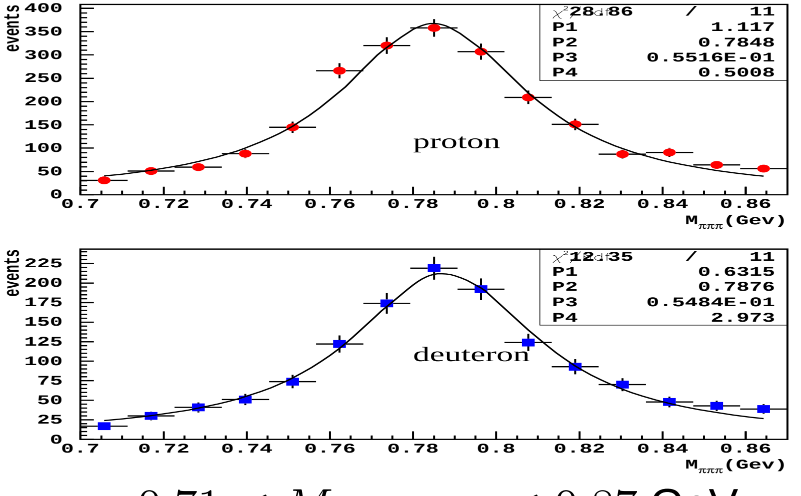
- $\mathsf{F}_{\lambda_V \lambda'_N;\lambda_\gamma \lambda_N} = T_{\lambda_V \lambda'_N;\lambda_\gamma \lambda_N} + U_{\lambda_V \lambda'_N;\lambda_\gamma \lambda_N}$
  T - natural-parity exchange (NPE)($P = (-1)^J$)
  U - unnatural - parity exchange (UPE)($P = -(-1)^J$)
- On unpolarized target nucleon-helicity-flip amplitudes are suppresed. $T_{\lambda_V \lambda_\gamma} = T_{\lambda_V \frac{1}{2} \lambda_\gamma \frac{1}{2}}$
  Helicity concerving - T_{00}, T_{11}, U_{11}, helicity non concerving - T_{01}, T_{10}, T_{1-1}, U_{01}, U_{10}, U_{1-1}
  The dominance of diagonal transitions is called s-channel helicity concervation (SCHC).
- NPE ($J^P = 0^+,\ 1^-, ...$) amplitudes $T_{\lambda_V \lambda_\gamma}$ (Two-gluon exchange = pomeron, ρ, ω,a_2,...reggeons = $q\bar{q}$ exchange). UPE($J^P = 0^-,\ 1^+, ...$) amplitudes $U_{\lambda_V \lambda_\gamma}$ (π, a_1, b_1,...reggeons = $q\bar{q}$ exchange)

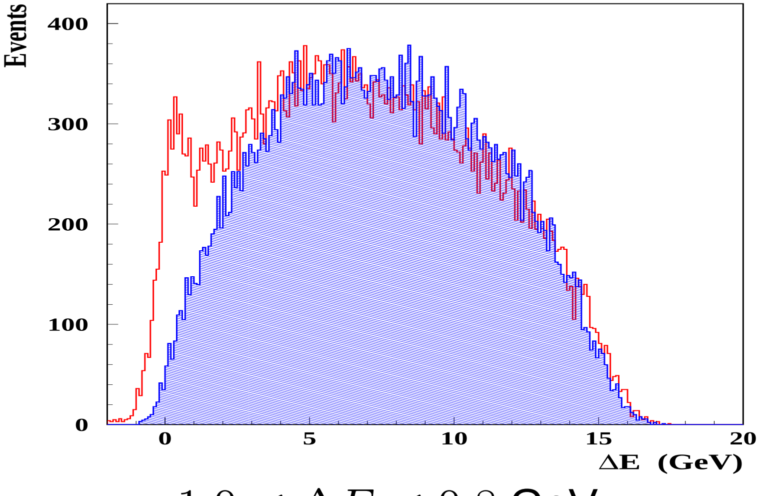


Exclusive ω-meson production at HERMES

- $W = 3.0 \div 6.3$ GeV, $< W >= 4.8$ GeV — total number ofevents — $W^2 = (q+p)^2$
- $Q^2 = 1.0 \div 10.0$ GeV^2, $< Q^2 >= 1.9$ GeV^2 — Hydrogen: ω-2260 — $Q^2 = -(k-k^{'})^2$
- $x_B = 0.01 \div 0.35$, $< x_B >= 0.08$ — Deuterium: ω -1332 — $x_B = \frac{Q^2}{2pq}$
- $0 \le -t' \le 0.2$ GeV^2, $< -t' >= 0.08$ GeV^2 — with $t' = t - t_{min}$ — $t = (q-v)^2$

$\Delta E = \frac{M_X^2 - M_p^2}{2M_p}$ with $M_X^2 = (p + q - p_{\pi^+} - p_{\pi^-} - p_{\pi^0})^2$ and M_X being missing mass, p, q, p_{π^+}, p_{π^-} p_{π^0} are 4-momenta of proton, γ^* and pions. Beam polarization $\approx 40\%$.

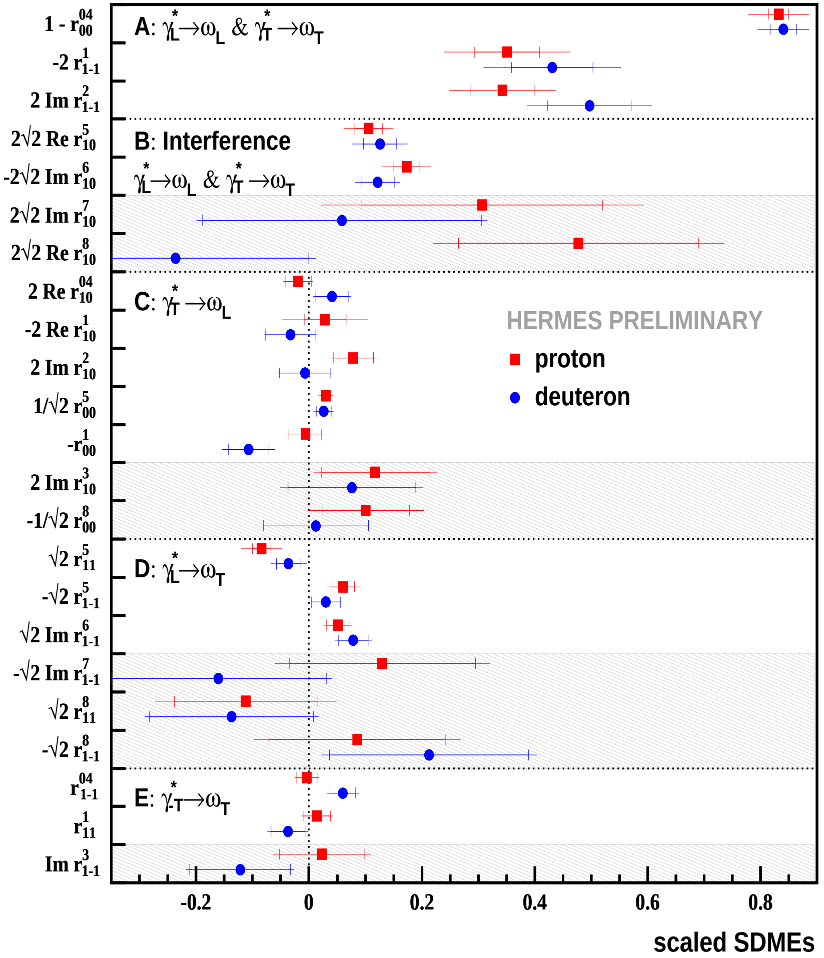




$0.71 < M_{\pi^+\pi^-\pi^0} < 0.87$ GeV, $-1.0 < \Delta E < 0.8$ GeV,

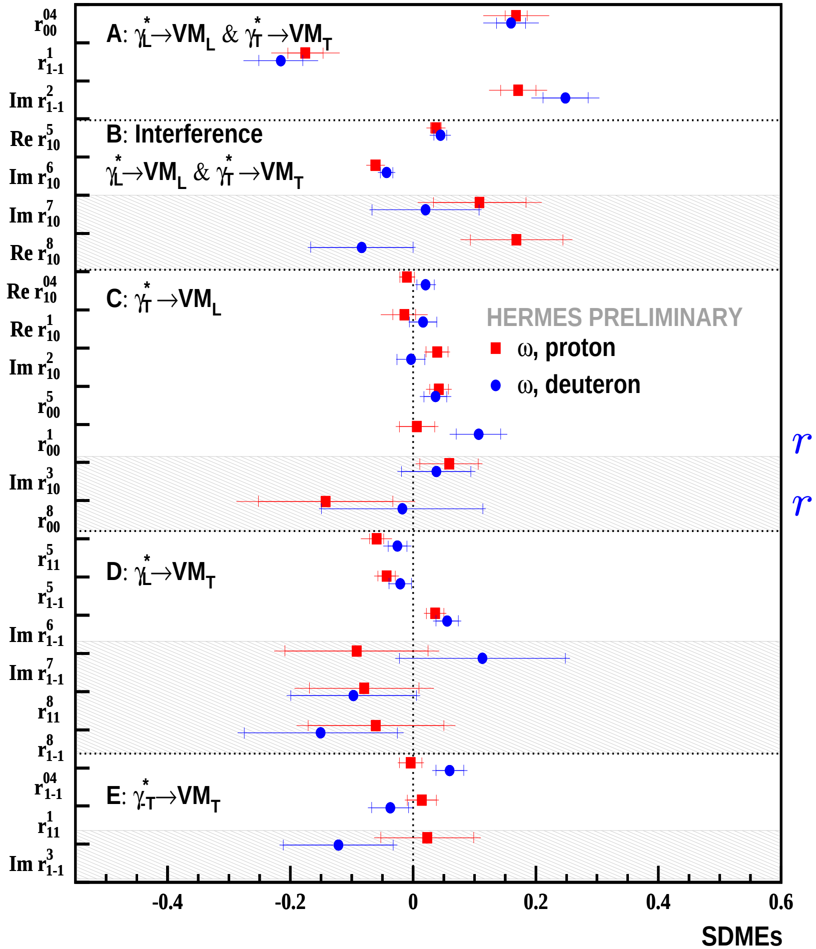
SIDIS background($\approx 20\%$) is subtracted using MC PYTHIA

SDME of exclusive ω production for the integrated data



- A, $\gamma^*_L \to \omega_L$ and $\gamma^*_T \to \omega_T$
  B, Interference: γ^*_L, ω_T
  C, Spin Flip: $\gamma^*_T \to \omega_L$
  D, Spin Flip: $\gamma^*_L \to \omega_T$
  E, Spin Flip: $\gamma^*_T \to \omega_{-T}$
- The SDMEs for hydrogen and deuteron are similar.
- if SCHC holds:
  $r^1_{1-1} = -Im\{r^2_{1-1}\}$
  $Re\ \{r^5_{10}\} = -Im\{r^6_{10}\}$
  $Im\{r^7_{10}\} = Re\{r^8_{10}\}$
  for hydrogen
  $r^1_{1-1} + Imr^2_{1-1} = -0.004 \pm 0.038 \pm 0.017,$
  $Rer^5_{10} + Imr^6_{10} = -0.024 \pm 0.013 \pm 0.003,$
  $Imr^7_{10} - Rer^8_{10} = -0.060 \pm 0.010 \pm 0.044,$
  for deuterium
  $r^1_{1-1} + Imr^2_{1-1} = 0.033 \pm 0.049 \pm 0.004$
  $Rer^5_{10} + Imr^6_{10} = 0.001 \pm 0.016 \pm 0.015,$
  $Imr^7_{10} - Rer^8_{10} = 0.10 \pm 0.11 \pm 0.17,$

SDME in exclusive ω production for the integrated data



- Test of SCHC Hypothesis
  - CLASS D, Spin Flip: $\gamma_L^* \to \omega_T$

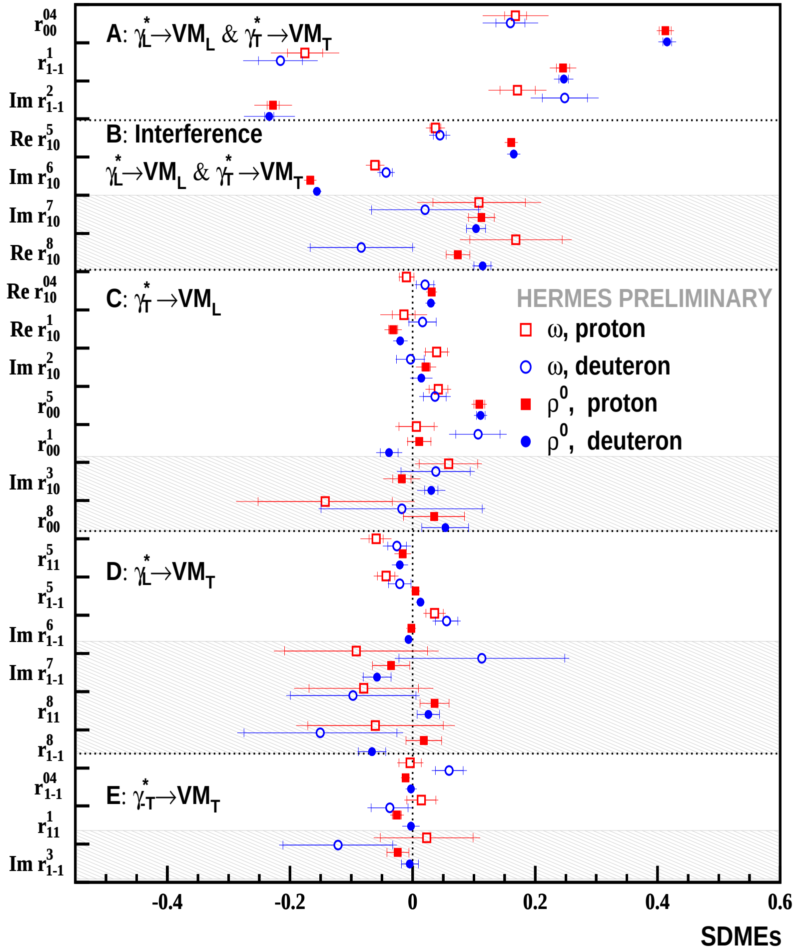
$$r^5_{11} \approx Re[U_{10}U^*_{11}]$$
$$r^5_{1-1} \approx Re[U_{10}U^*_{11}]$$
$$Im\{r^6_{1-1}\} \approx Re[-U_{10}U^*_{11}]$$

$r^5_{11} + r^5_{1-1} - Im\{r^6_{1-1}\} = -0.14 \pm 0.02 \pm 0.04$ for hydrogen
$r^5_{11} + r^5_{1-1} - Im\{r^6_{1-1}\} = -0.10 \pm 0.03 \pm 0.03$ for deuterium

  - SCHC Hypothesis seems to be violated.

Comparison of SDME in exclusive ω and ρ^0 production for the integrated data

ρ^0 SDMEs, HERMES, Eur. Phys. J. C62 (09) 659.



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

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

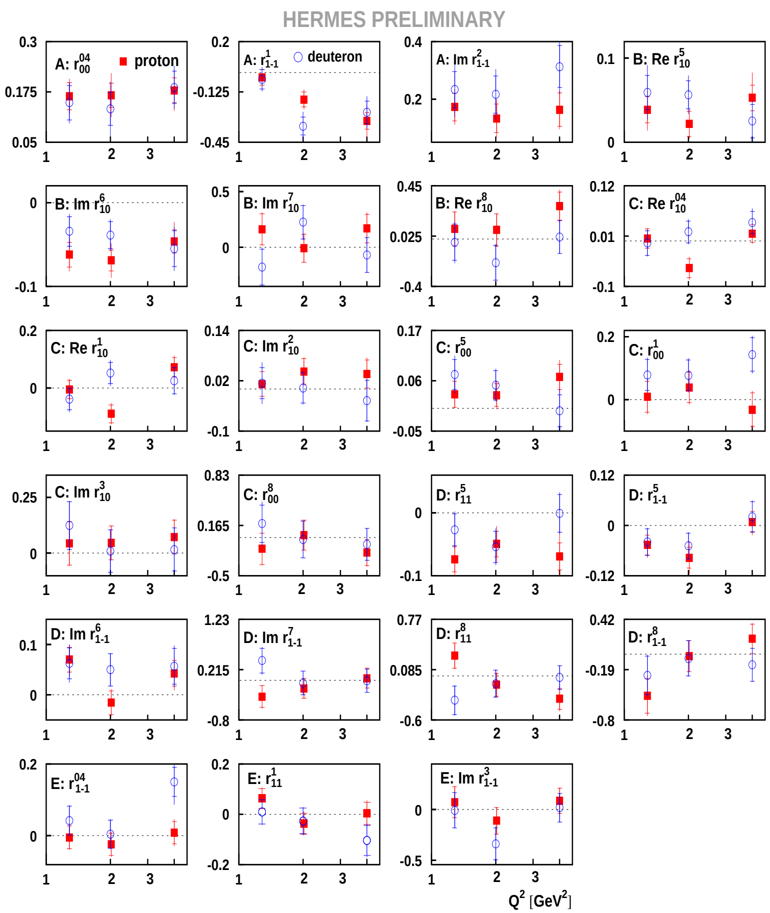
$$\text{Im}\,\{r^2_{1-1}\} = \frac{1}{2}\widetilde{\sum}\{-|T_{11}|^2 + |T_{1-1}|^2 + |U_{11}|^2 - |U_{1-1}|^2\}/\mathcal{N}$$

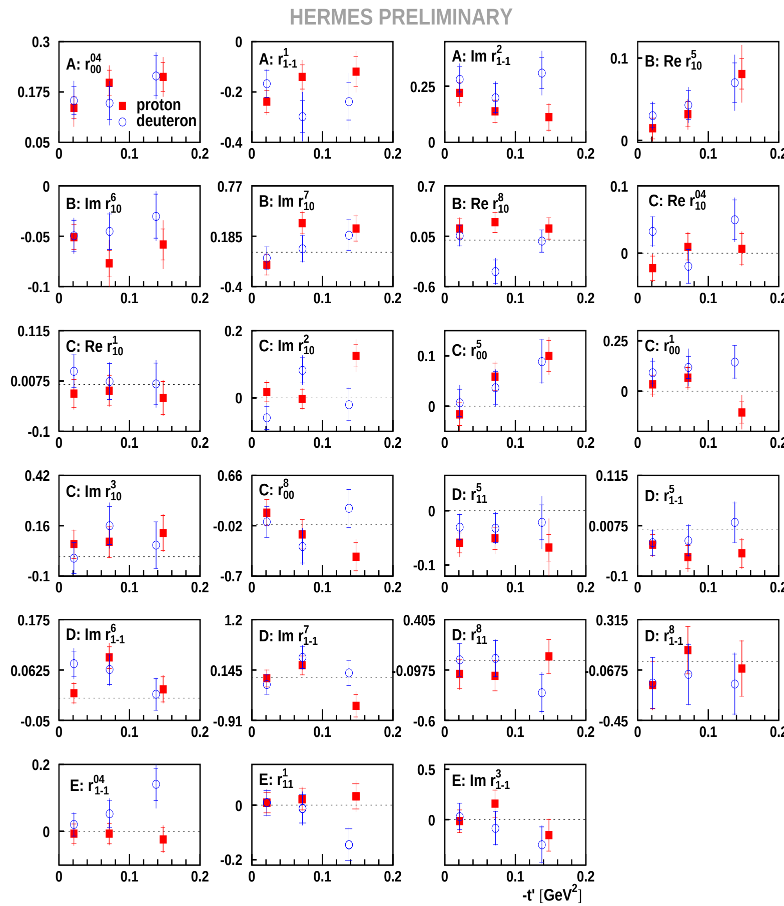
$|U_{11}|^2 + |U_{1-1}|^2 > |T_{11}|^2 + |T_{1-1}|^2$ for ω meson

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

Assuming $|T_{1-1}|^2 \approx |U_{1-1}|^2$ we get $|U_{11}|^2 > |T_{11}|^2$ for ω meson

Dependences of ω SDME on q^2 and t'





q^2 intervals 1.0 -1.57 - 2.55 - 10.0 GeV^2, -t' intervals 0.0 -0.044 - 0.105 - 0.2 GeV^2

Test of Unnatural-Parity Exchange for ω meson

Signal of UPE in SDME method

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

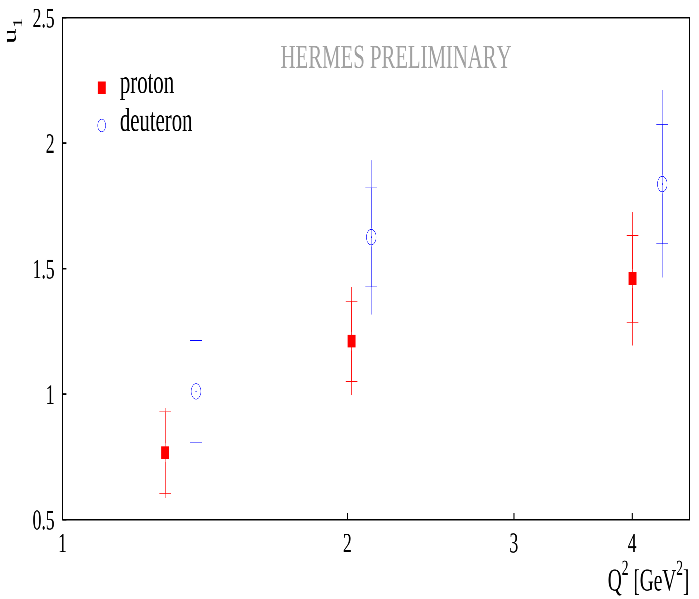
$$u_1 = \sum_{\lambda_N \lambda'_N} \frac{2\epsilon |U_{10}|^2 + |U_{11} + U_{-11}|^2}{N}$$

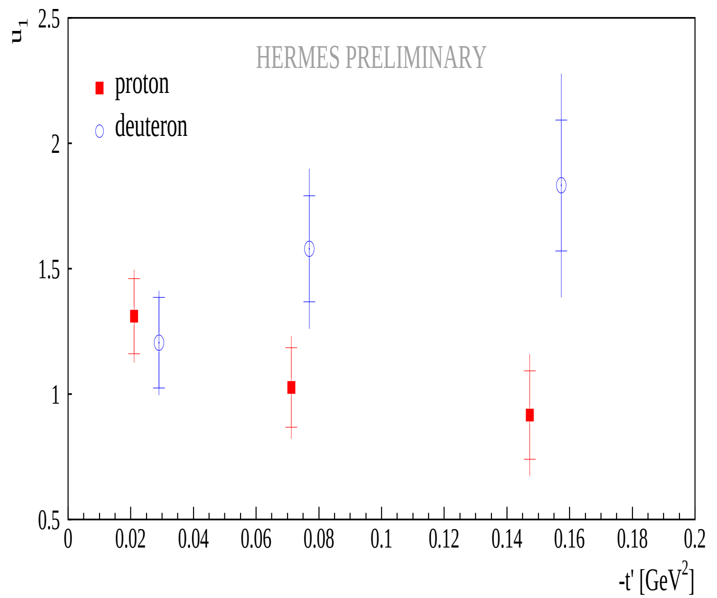
u1 > 0 means contribution of UPE

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

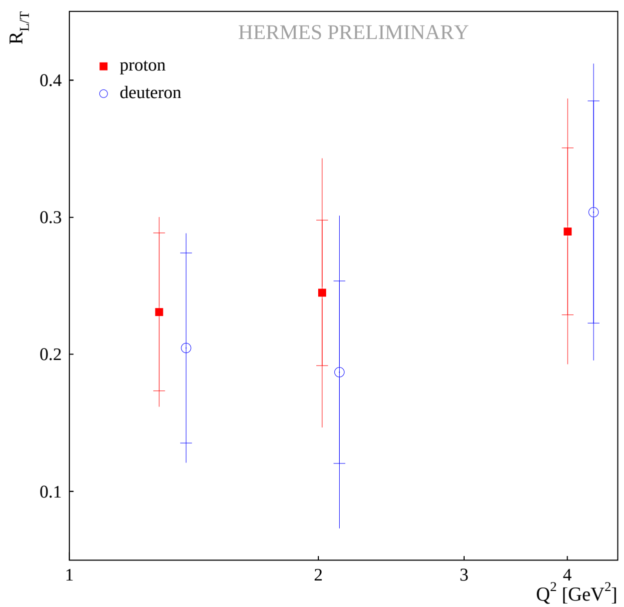
Large UPE contribution

Longitudinal to Transverse cross section ratio for ω meson

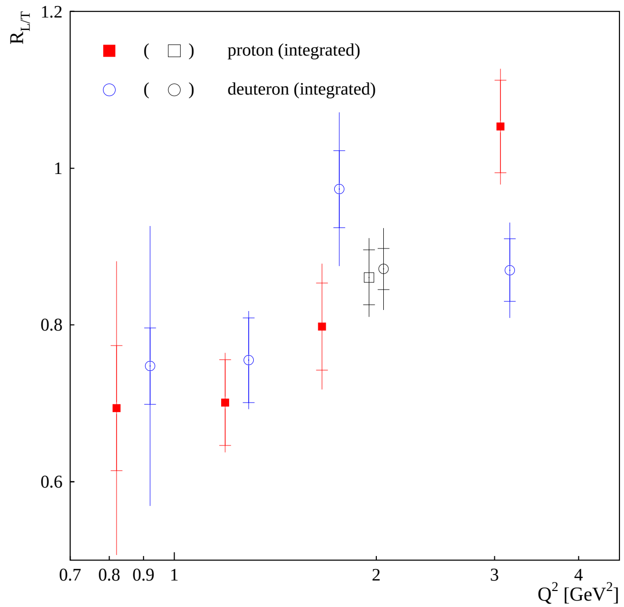
$$R_{L/T} = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}, \qquad r^{04}_{00} = \widetilde{\sum}\{\epsilon|T_{00}|^2 + |T_{01}|^2 + |U_{01}|^2,\}/\mathcal{N} \qquad \mathcal{N} = \epsilon\sigma_L + \sigma_T$$

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

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



ω meson



ρ^0 meson (HERMES, Eur. Phys. J. C62 (09) 659.)

$R_{L/T}(p)$ = 0.25$\pm 0.0.03 \pm 0.07$ R$_{L/T}(d)$ = 0.024$\pm 0.04 \pm$ 0.0.08 for integrated data

U/N asymmetry of the transverse cross section

$$P = \frac{\sigma_T^N - \sigma_T^U}{\sigma_T^N + \sigma_T^U} = (1+\epsilon R)(2r^1_{1-1} - r^1_{00})$$

$P < (2r^1_{1-1} - r^1_{00})$= -0.35

large part of the transverse cross section is due to unnatural parity exchange.

Summary

- The SDMEs were extracted for electroproduction of ω vector meson on proton and deuteron at HERMES.
- They are presented grouped into five classes according to the helicity transition.
- The Hypothesis SCHC in ω meson production seems to be violated.
- The UPE contribution seems to be very large(dominant) for ω meson production.
- Longitudinal to Transverse cross section ratio for ω meson is smaller than for ρ^0 .