Spin Density Matrix Elements in exclusive production of ω mesons at Hermes

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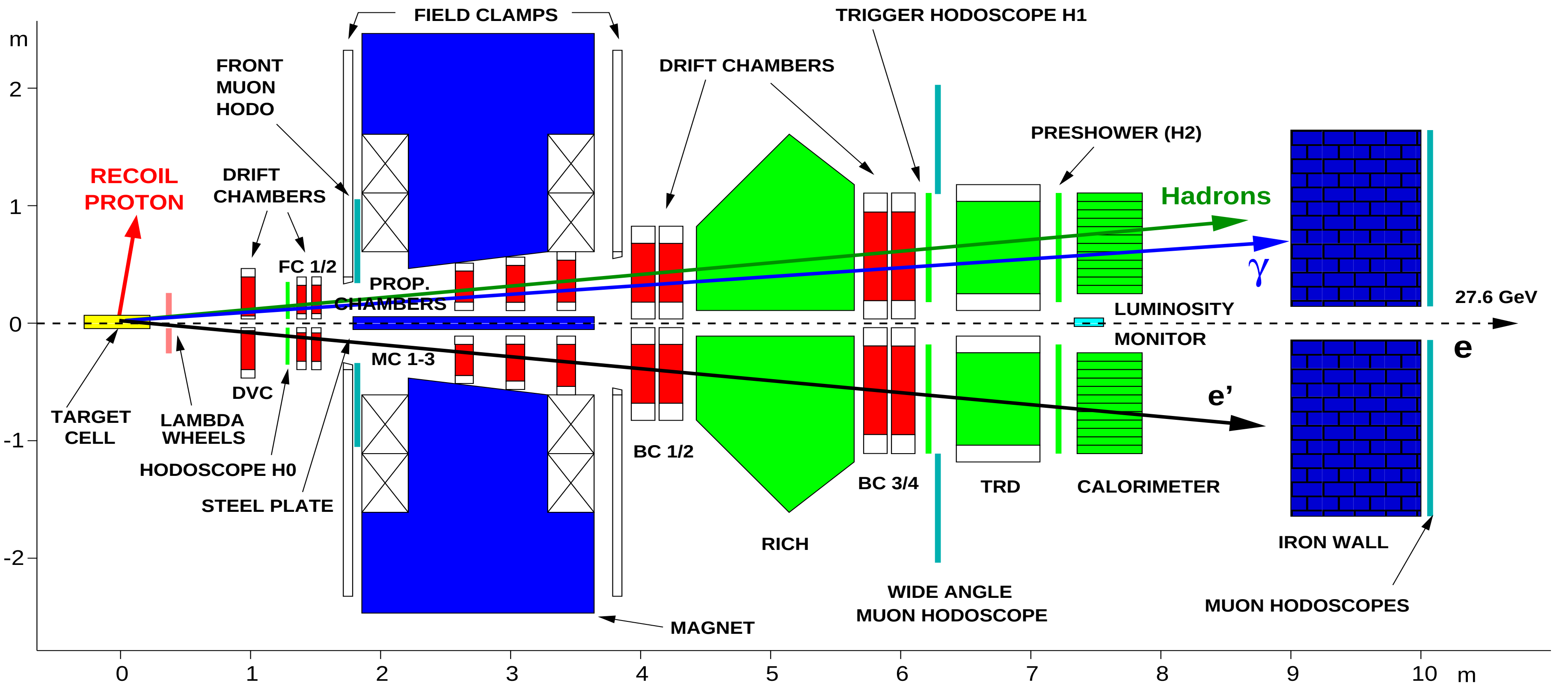
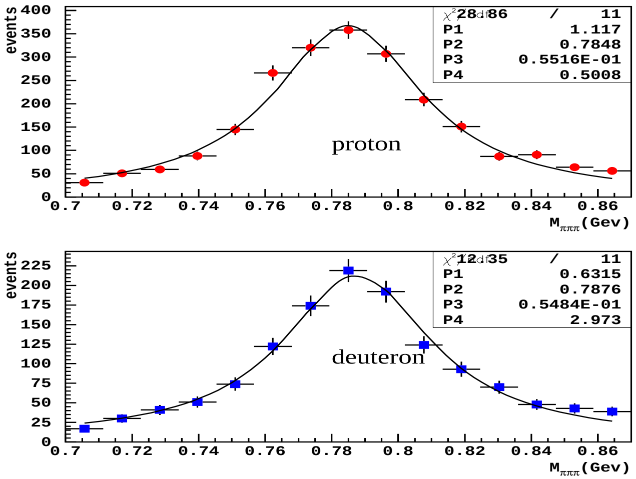
Hermes Detector was Two Identical Halves of Forward Spectrometer

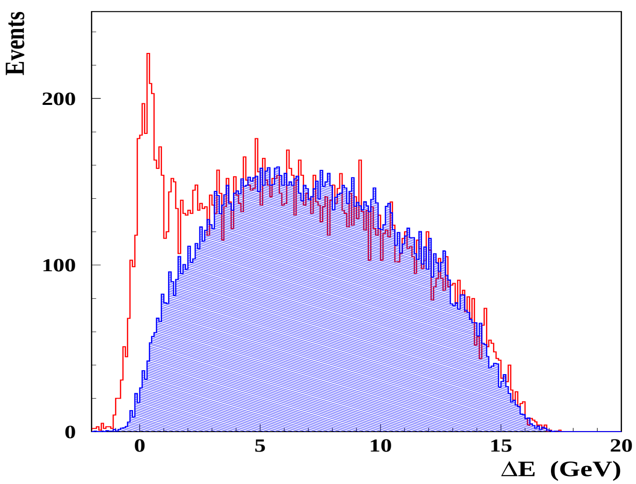


- Beam $e^{\pm}$, P = 27.56 GeV/c longitudinal polarization $\sim$ 55 %.
- Target longitudinally, transversely polarized H or D or unpolarized gas target.
- Acceptance: $|\Theta_x|$ < 170 mrad, 40 < $|\Theta_y|$ < 140 mrad.
- Resolution $\delta P/P \leq 1\%$, $\delta\Theta \leq 0.6$ mrad.
- PID: RICH, TRD, Preshower, Calorimeter.

Exclusive ω-meson production at HERMES



$0.71 < M_{\pi^+\pi^-\pi^0} < 0.87$ GeV

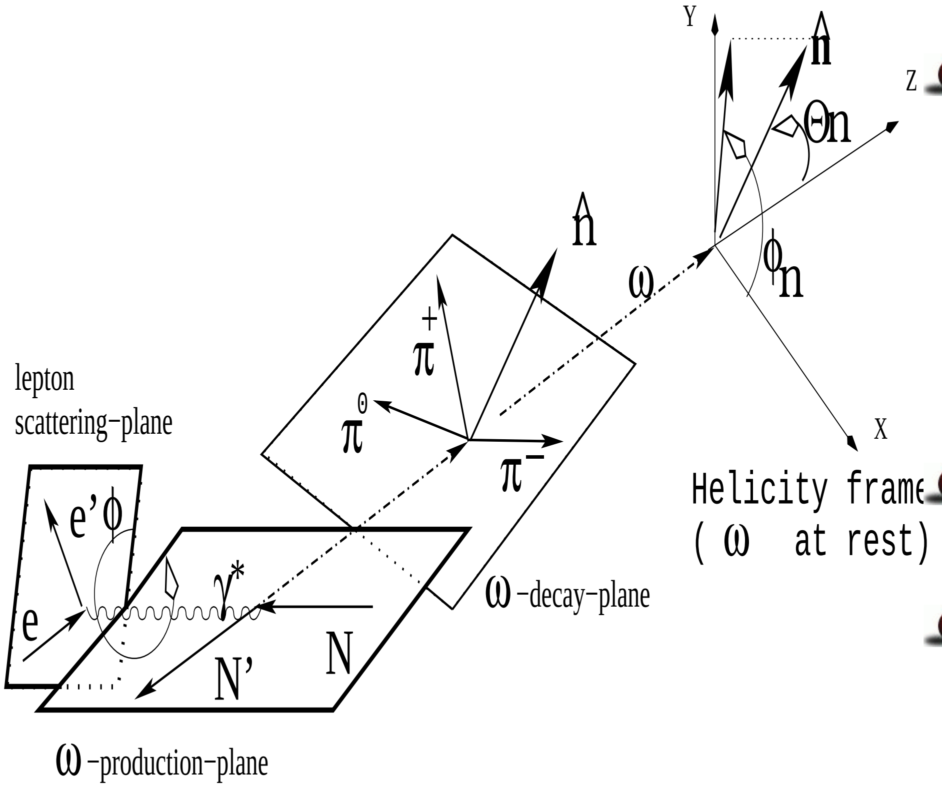


$-1.0 < \Delta E < 0.8$ GeV

- $e(k) + N(p) \rightarrow e'(k') + N(p') + \omega \rightarrow (\pi^+\pi^-\pi^0(\rightarrow 2\gamma))$
- $e \rightarrow e' + \gamma^*$ (QED).
- $\gamma^*(q\bar{q}) + N \rightarrow \omega + N \rightarrow \pi^+ + \pi^- + \pi^0 + N$ (QCD).
- $Q^2 = -q^2 = -(k-k')^2 = 1.0 \div 10.$ GeV^2,$\langle Q^2 \rangle = 1.9$ GeV^2
- $W = \sqrt{(q+p)^2} = 3.0 \div 6.3$ GeV, $\langle W \rangle = 4.8$ GeV
- $x_B = \frac{Q^2}{2pq} = 0.01 \div 0.35$, $\langle x_B \rangle = 0.08$
- $t' = t - t_{min}$, $0 \leq -t' \leq 0.2$ GeV^2, $\langle -t' \rangle = 0.08$ GeV^2
  $t = (p-p')^2 = (q-v)^2$
- Number of ω events Hydrogen: -2260 , Deuterium: -1332
- $\Delta E = \frac{M_X^2 - M_p^2}{2M_p}$ 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.
- Exclusive process ΔE = 0
- SIDIS background($\approx 20\%$) is subtracted using MC PYTHIA

Angular distribution in reaction

$e + p \rightarrow e' + p' + \omega \rightarrow (\pi^+\pi^-\pi^0(\rightarrow 2\gamma))$

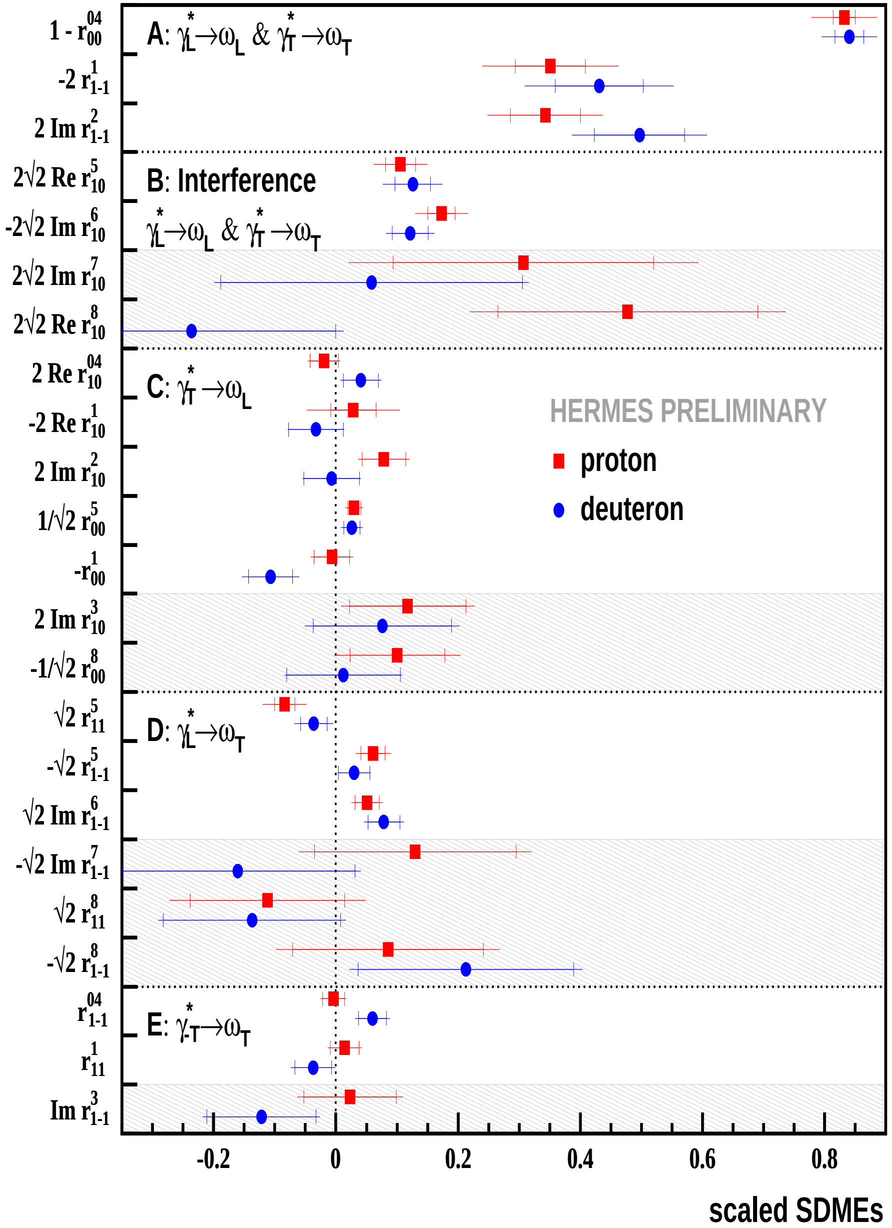


- $\omega \Rightarrow \pi^+\pi^-\pi^0$ (conservation of $\vec{J}$) $|\omega; 1m> \rightarrow |\pi^+\pi^-\pi^0; 1m> \Rightarrow Y_{1m}(cos(\theta), \phi)$ $(m = \pm 1, 0)$. Angular distribution $\mathcal{W}(r^{\alpha}_{\lambda_V \lambda'_V}, \Phi, \phi_n, \cos\Theta_n)$ depends linearly on Spin Density Matrix Elements(SDMEs) - $r^{\alpha}_{\lambda_V \lambda'_V}$ and beam polariztion P_b.
- SDMEs are bilinear combination of helicity amplitudes.
- 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

Spin Density Matrix Elements (SDMEs)

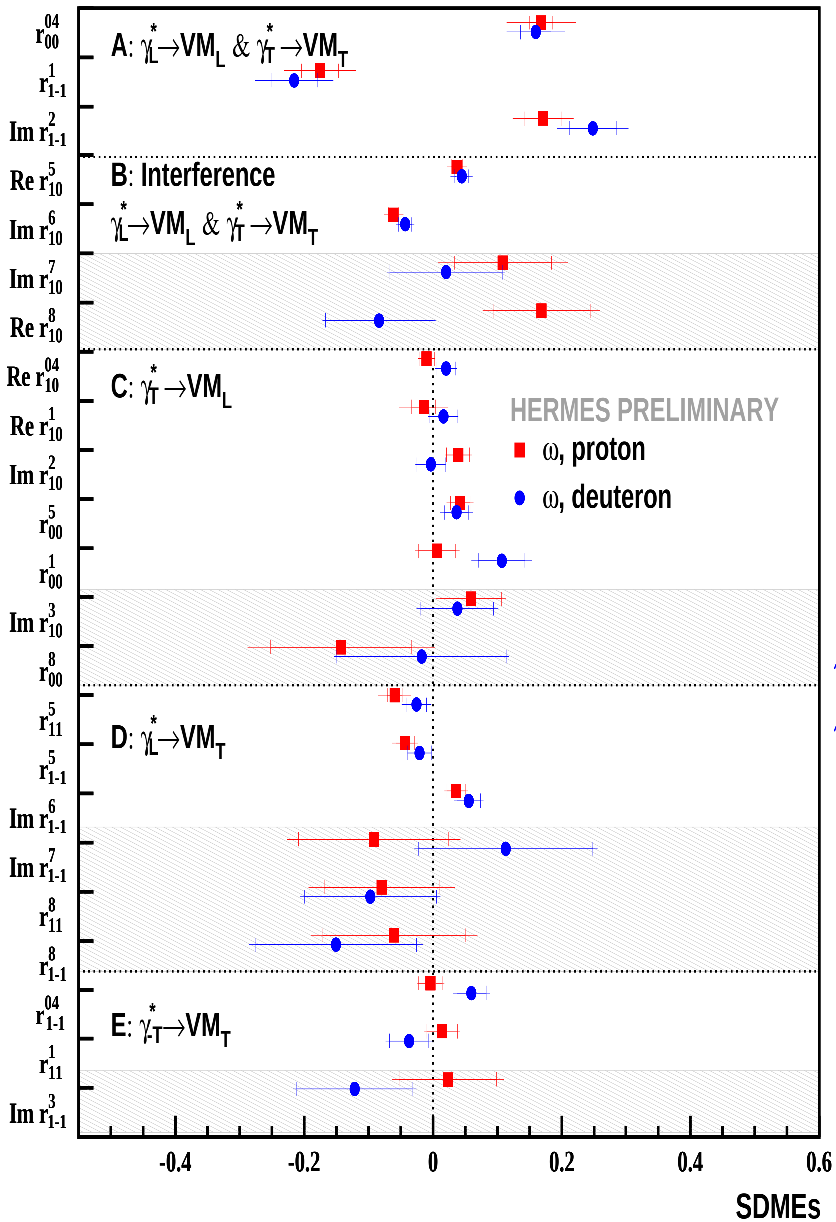
- (SDMEs) - $r^{\alpha}_{\lambda_V \lambda'_V}$ are expressed by helicity amplitudes $F_{\lambda_V \lambda'_N;\lambda_\gamma \lambda_N}(W, Q^2, t')$
- In CM frame of $\gamma^* N$ they are given by the von Neumann formula:
  $r^{\alpha}_{\lambda_V \lambda'_V} \sim \rho_{\lambda_V \lambda'_V} = \frac{1}{2\mathcal{N}} \sum_{\lambda_\gamma \lambda'_\gamma \lambda_N \lambda'_N} F_{\lambda_V \lambda'_N;\lambda_\gamma \lambda_N}\ \varrho_{\lambda_\gamma \lambda'_\gamma}\ F^*_{\lambda'_V \lambda'_N;\lambda'_\gamma \lambda_N}$
  $\varrho_{\lambda_\gamma \lambda'_\gamma}$ - photon spin density matrix
  α = 0÷3 - transverse photon ,4 - longitudinal photon 5÷8 - transverse/longitudinal interference
  $(\lambda_\gamma, \lambda_V)$ - (photon helicity, meson helicity)
- On unpolarized target nucleon-helicity-flip amplitudes are suppresed $F_{\lambda_V \frac{1}{2} \lambda_\gamma \frac{1}{2}} \rightarrow F_{\lambda_V \lambda_\gamma}$
- Example: $r^1_{1-1} = \frac{1}{2}\widetilde{\sum}\{|T_{11}|^2 + |T_{1-1}|^2 - |U_{11}|^2 - |U_{1-1}|^2\}/\mathcal{N}$
  T - natural-parity exchange (NPE) ($P = (-1)^J$)
  U - unnatural - parity exchange (UPE) ($P = -(-1)^J$)
  F=T+U
- Helicity conserving - 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 conservation (SCHC).

SDME of exclusive ω production at average kinematics



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

SDME in exclusive ω production at average kinematics



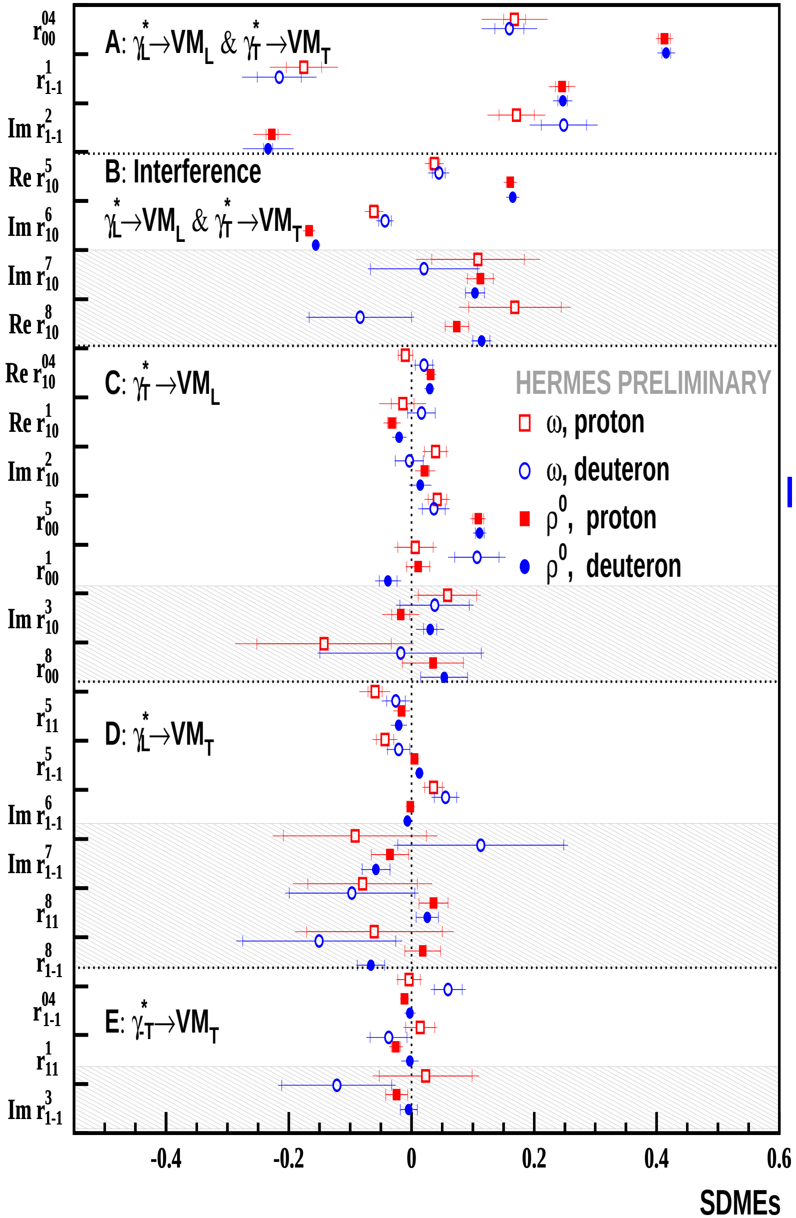
- Test of SCHC Hypothesis
  - CLASS D, Spin Flip: $\gamma^*_L \to \omega_T$

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

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

  - SCHC hypothesis seems to be slightly violates.

Comparison of SDME in exclusive ω and ρ^0 production at average kinematics



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

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

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

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

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

Test of unnatural-parity exchange for ω meson

Signal of UPE

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

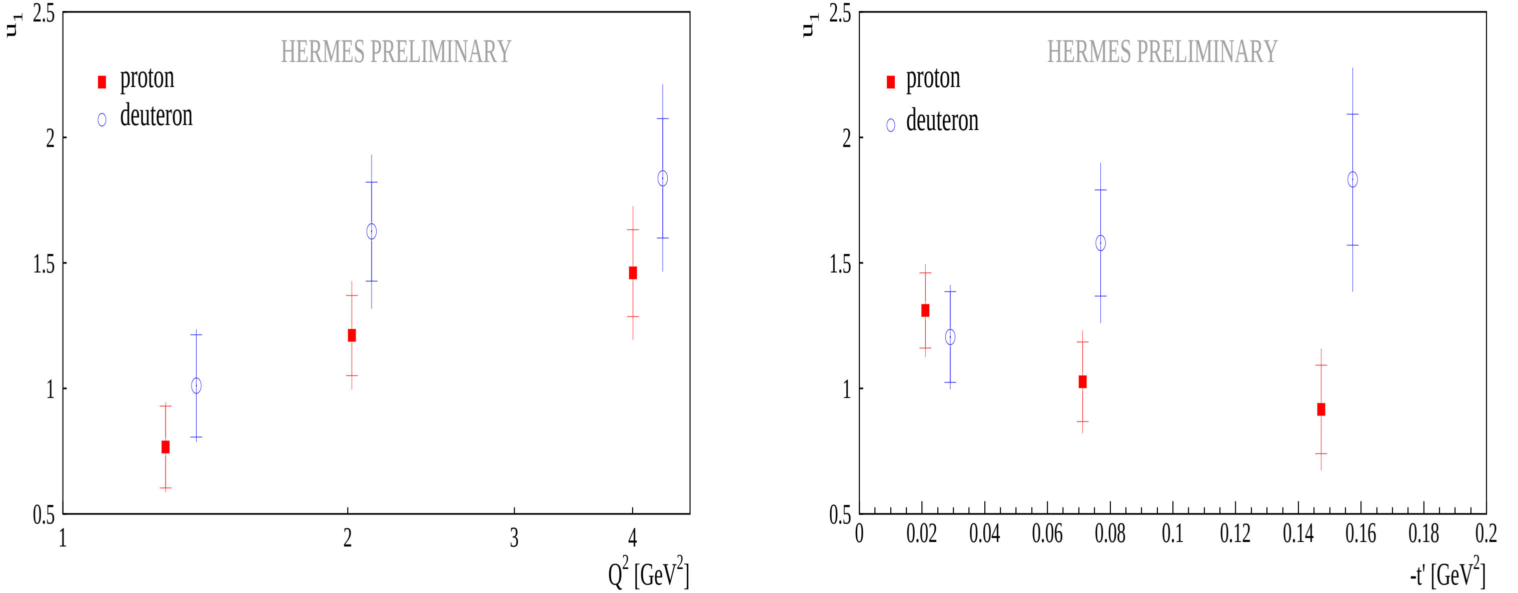
$$u_1 = \sum_{\lambda_N \lambda'_N} \frac{2\epsilon |U_{10}|^2 + |U_{11} + U_{-11}|^2}{N}$$

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± 0.09 ± 0.12 u1(d) = 1.47 ± 0.12 ± 0.18 at average kinematics

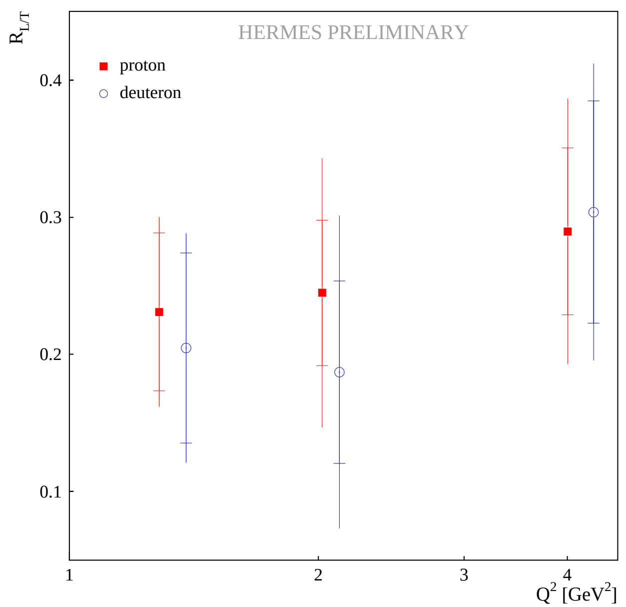
Large UPE contribution

Longitudinal to Transverse cross section ratio

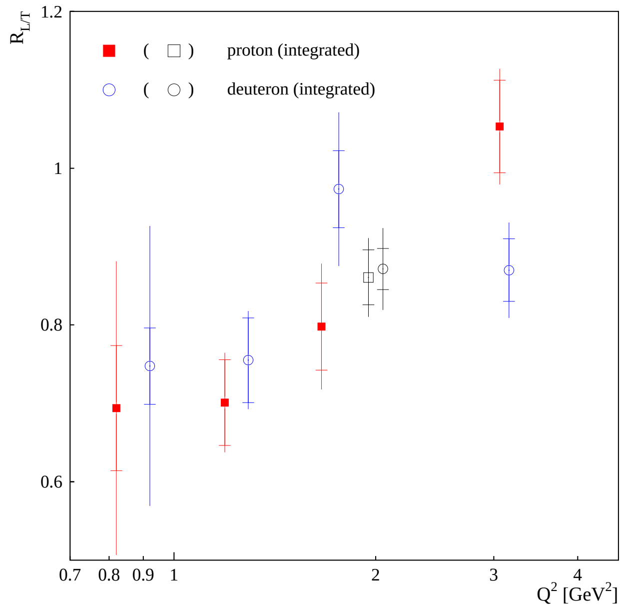
$$R_{L/T} = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}, \qquad r^{04}_{00} = \widetilde{\sum}\{\epsilon|T_{00}|^2 + |T_{01}|^2 + |U_{01}|^2,\}/\mathcal{N} \qquad \mathcal{N} = \epsilon\sigma_L + \sigma_T$$

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

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



ω meson



ρ^0 meson (HERMES, Eur. Phys. J. C62 (2009) 659)

at average kinematics

$R_{L/T}(p)$ = 0.25$\pm 0.03 \pm 0.07$

$R_{L/T}(d)$ = 0.024$\pm 0.04 \pm$ 0.0.08

Summary

- The SDMEs were extracted for electroproduction of ω vector meson on proton and deuteron at HERMES.
- They are presented divided into five classes according to the helicity transition.
- The hypothesis SCHC in ω meson production seems to be slightly violates.
- 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 .