Study of Spin Density Matrix Elements in hard exclusive electroproduction of ϕ meson on proton and deuteron at HERMES.

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DIS2011 - XIX International Workshop on Deep-Inelastic Scattering and Related Subjects,Newport News, VA USA

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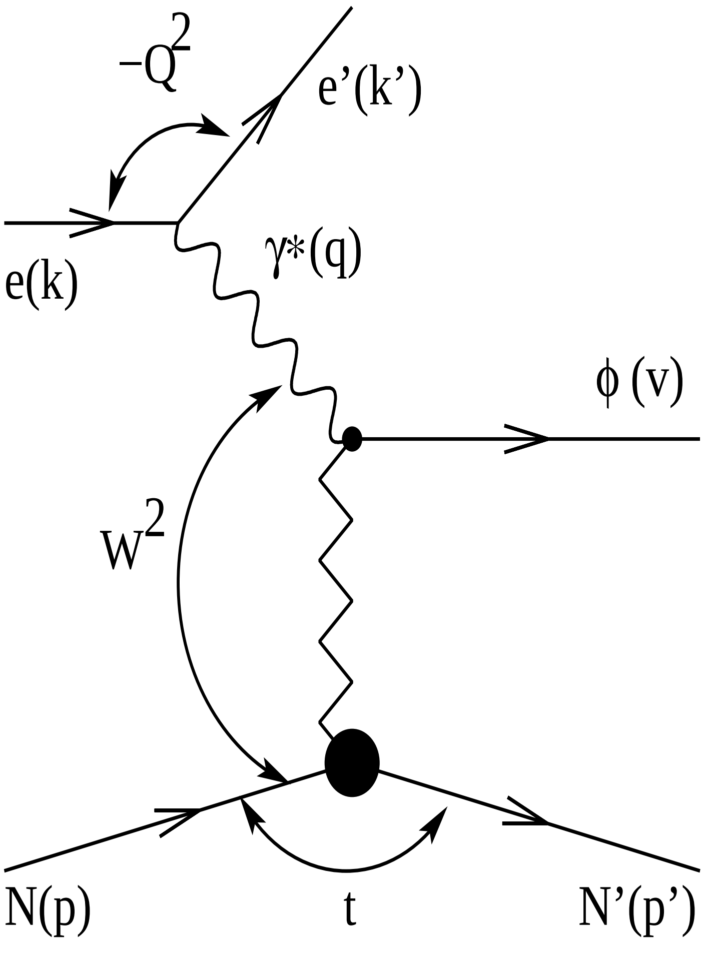
Spin Density Matrices in reaction

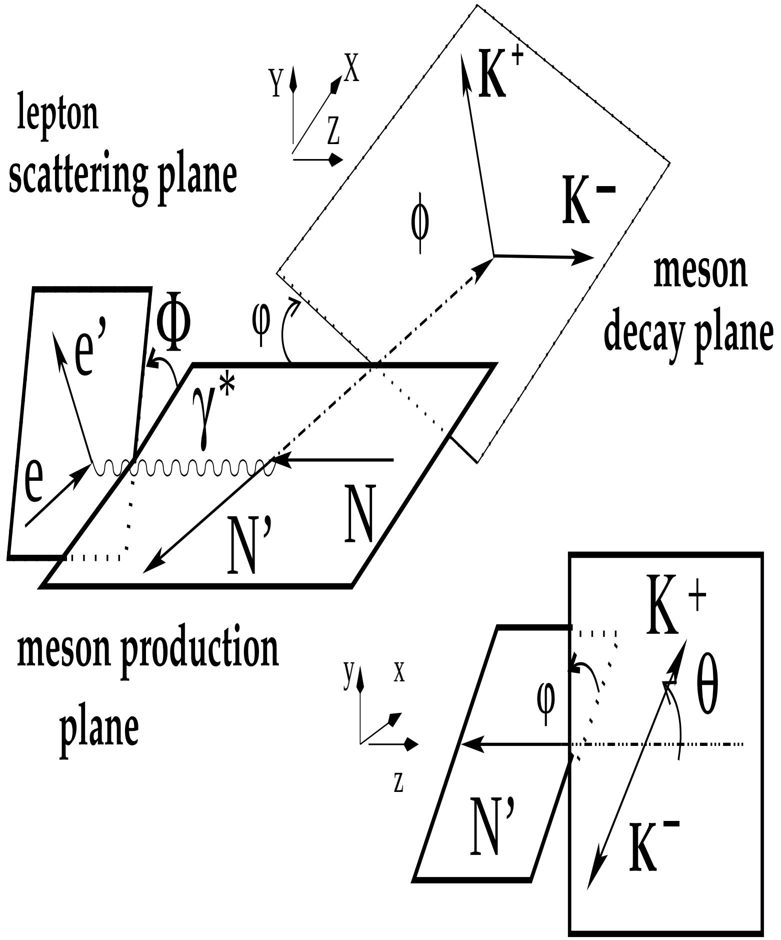
$$e + N \rightarrow e^{'} + \phi + N$$



- $e \rightarrow e' + \gamma^*$ (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
- $\gamma^* + N \rightarrow \phi + N \rightarrow K^+ + K^- + N$ (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:
  $\rho_{\lambda_V \lambda'_V} =$
  $\frac{1}{2\mathcal{N}} \sum_{\lambda_\gamma \lambda'_\gamma \lambda_N \lambda'_N} F_{\lambda_V \lambda'_N; \lambda_\gamma \lambda_N} \; \varrho^{U+L}_{\lambda_\gamma \lambda'_\gamma} \; F^*_{\lambda'_V \lambda'_N; \lambda'_\gamma \lambda_N}$
- $\varrho^{L+U}_{\lambda_\gamma \lambda'_\gamma}$ decompose into the set of nine hermitian matrices(3$\times$3)Σ^α (α=0$\div$3 - transv.,4 - long. 5$\div$8 - interf.), $\rho_{\lambda_V \lambda'_V} \rightarrow \rho^{\alpha}_{\lambda_V \lambda'_V}$. When we can not separate transverse and longitudinal photons, Spin Density Matrix Elements (SDMEs) are defined:
  $r^{04}_{\lambda_V \lambda'_V} = (\rho^{0}_{\lambda_V \lambda'_V} + \epsilon R \rho^{4}_{\lambda_V \lambda'_V})/(1+\epsilon R),$

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

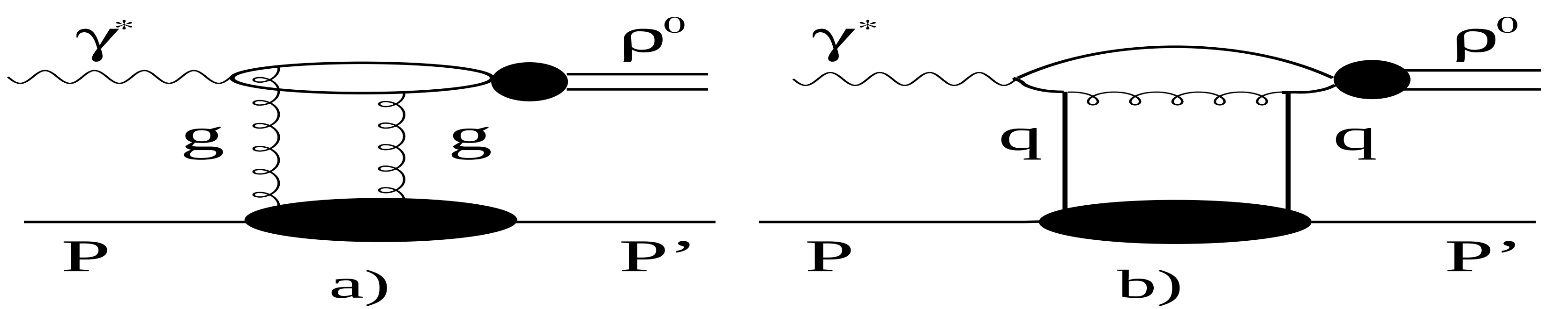
Angular distribution in reaction $e + N \to e' + \phi + N \to e' + K^+ + K^- + N$



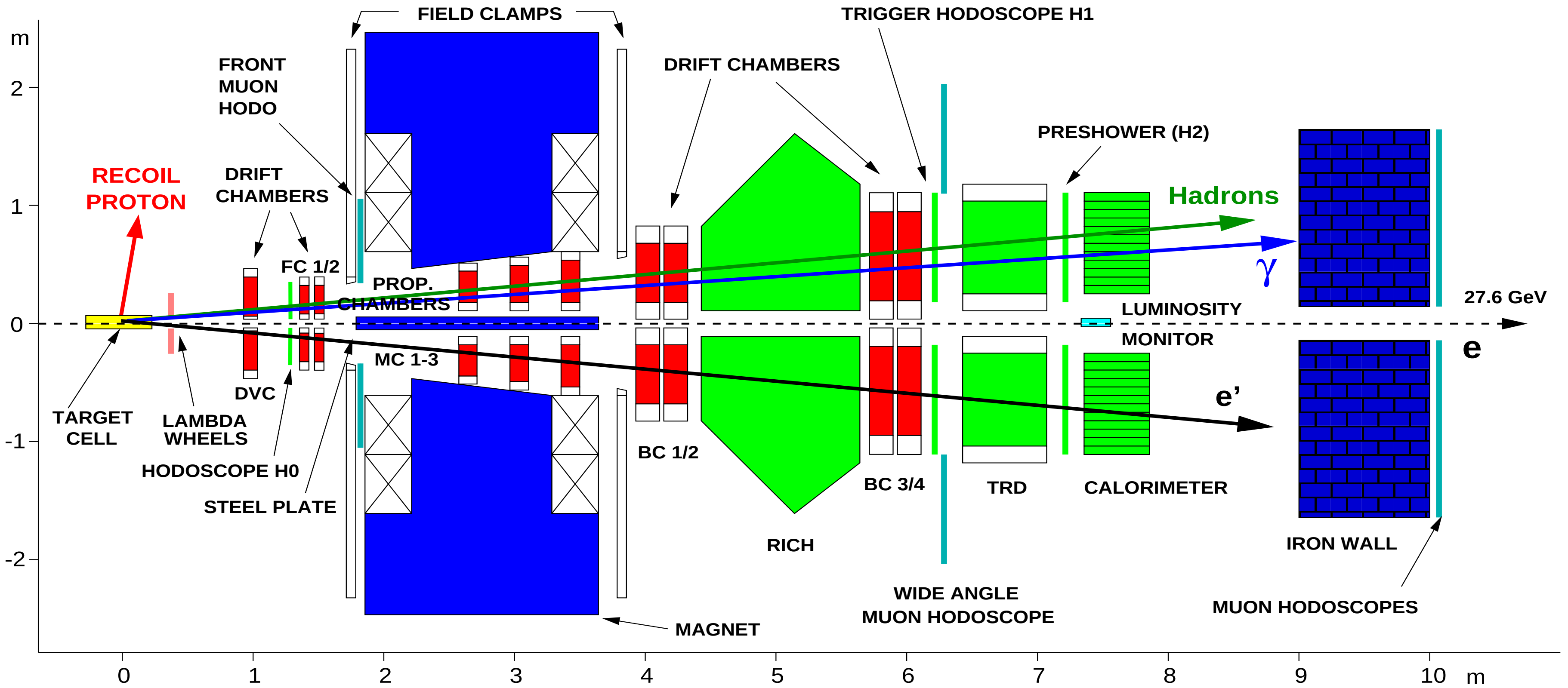
- $\phi \Rightarrow K^+K^-$ (conservation of $\vec{J}$) $|\phi; 1m > \to |K^+K^-; 1m > \Rightarrow Y_{1m}(cos(\theta), \phi)$, $(m = \pm 1, 0)$. Angular distribution $\mathcal{W}(\Phi, \phi, \cos\Theta)$ depends linearly on $r^{\alpha}_{\lambda_V \lambda'_V}$ and beam polariztion P_b.
- For longitudinally polarized beam and unpolarized target there are 23 SDMEs,(15 unpolarized and 8 polarized) which are determined from the fit of angular distribution of Kaons from decay $\phi \Rightarrow K^+K^-$.
- SDMEs are bilinear combination of helicity amplituds.

General properities of helicity amplitudes

- $F_{\lambda_V \lambda'_N;\lambda_\gamma \lambda_N} = T_{\lambda_V \lambda'_N;\lambda_\gamma \lambda_N} + U_{\lambda_V \lambda'_N;\lambda_\gamma \lambda_N}$
  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}, helicity non concerving - T_{01}, T_{10}, T_{1-1}
  The dominance of diagonal transitions is called s-channel helicity concervation (SCHC).
- $|T_{00}|^2 \sim |T_{11}|^2 \gg |T_{01}|^2 > |T_{10}|^2 \sim |T_{-1-1}|^2$.
- 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)



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 ϕ-meson production at HERMES

- $W = 3.0 \div 6.3$ GeV, $< W >= 4.8$ GeV
- $Q^2 = 1.0 \div 7.0$ GeV^2, $< Q^2 >= 1.9$ GeV^2
- $x_B = 0.01 \div 0.35$, $< x_B >= 0.08$
- $0 \leq -t' \leq 0.4$ GeV^2, $< -t' >= 0.13$ GeV^2 with $t' = t - t_{min}$

total number of events (1996-2000)

Deuteron: ρ^0 - 1038

Hydrogen: ρ^0 - 711

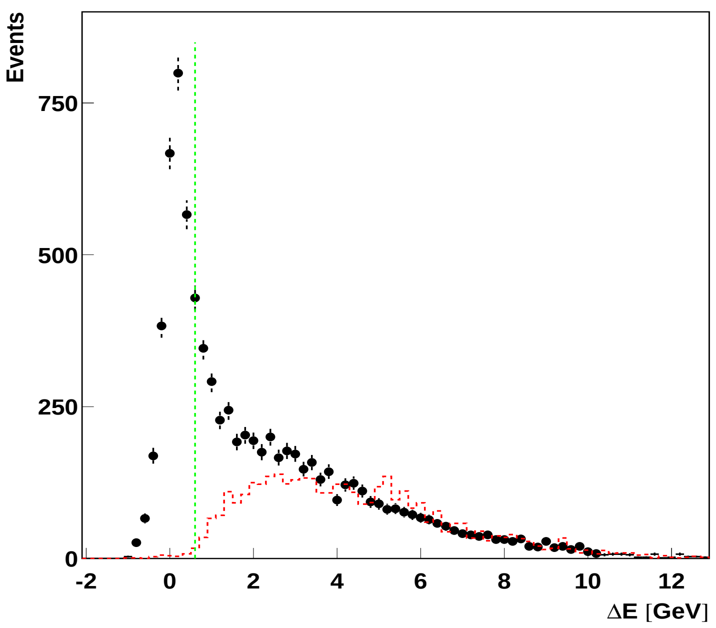
$W^2 = (q+p)^2$

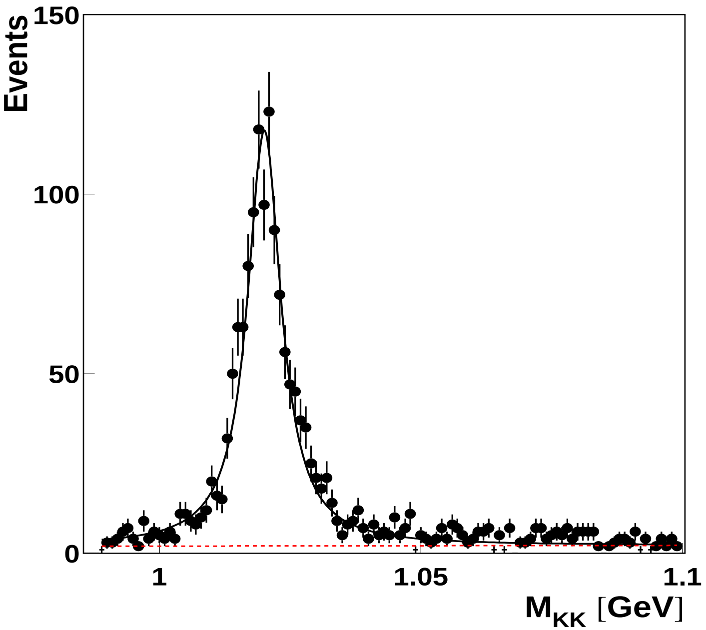
$Q^2 = -(k - k')^2$

$x_B = \frac{Q^2}{2pq}$

$t = (q - v)^2$

$\Delta E = \frac{M_X^2 - M_p^2}{2M_p}$ with $M_X^2 = (p + q - p_{K+} - p_{K-})^2$ and M_X being missing mass, p, q, p_{K+}, p_{K-} are 4-momenta of proton, γ^* and Kaons.



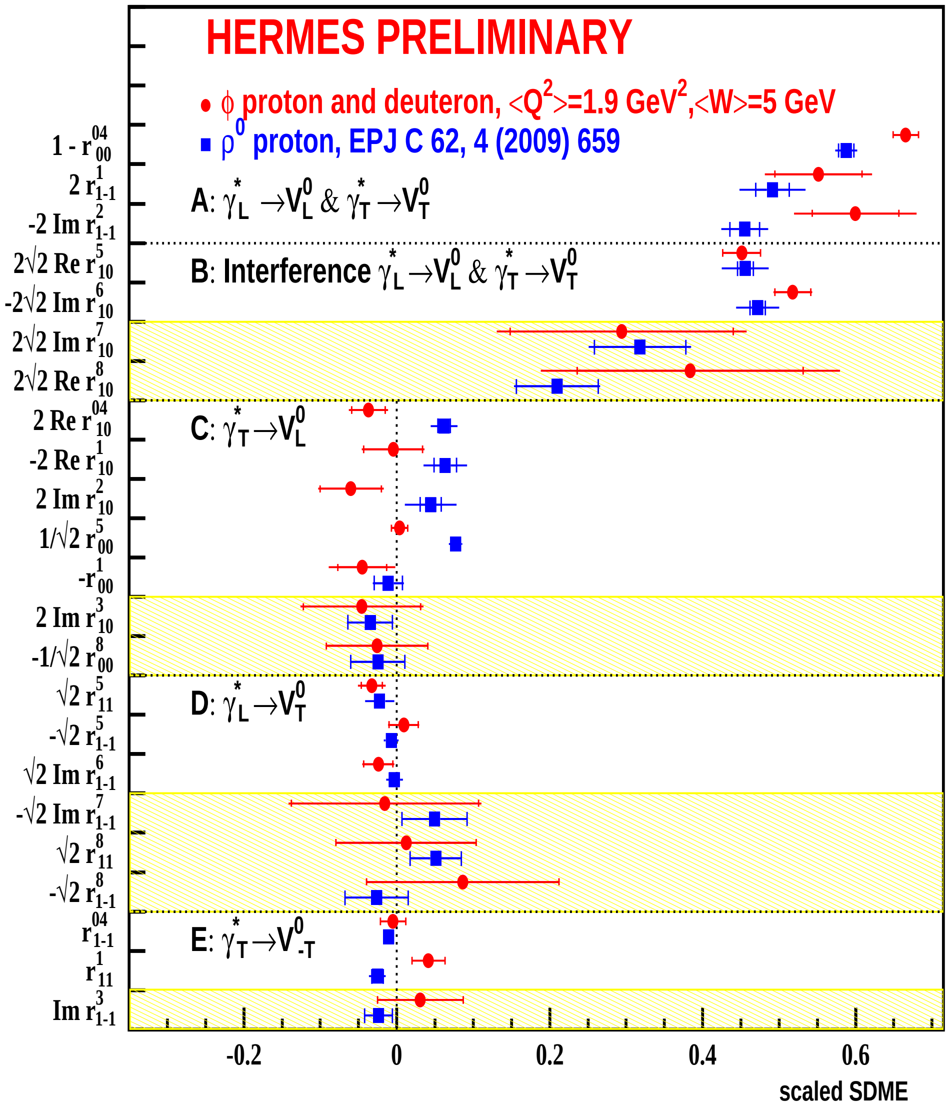


$-1.0 < \Delta E < 0.6$ GeV,

$0.99 < M_{KK} < 1.04$ GeV,

SIDIS background is subtracted using MC PYTHIA

SDME of exclusive ϕ production for the integrated data



$\Longrightarrow$ **Hierarchy of ρ^0 amplitudes:**

$|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \gtrsim |T_{1-1}|$,

- A, $\gamma^*_L \to \phi_L$ 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: γ^*_L, ϕ_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: $\gamma^*_L \to \phi_T$

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

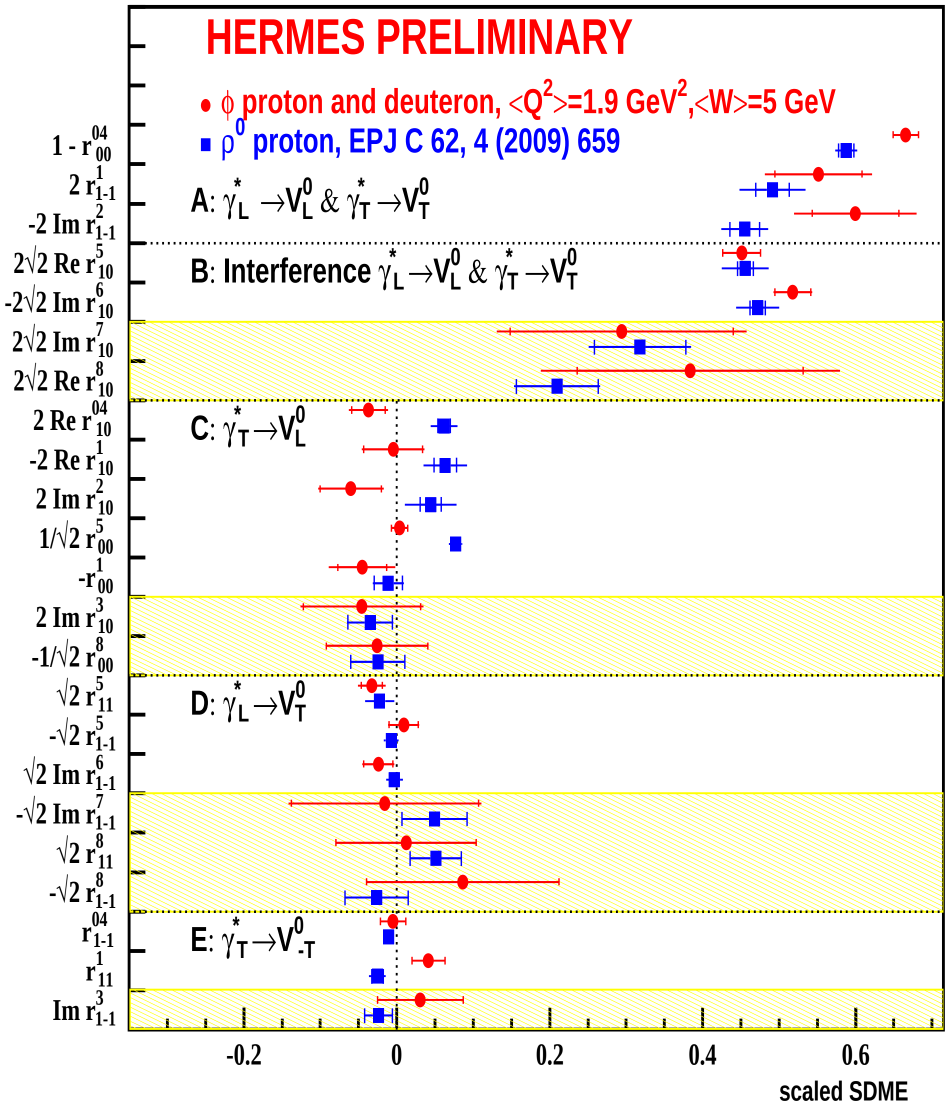
  Im { $T_{10}T^*_{11}$ }$\propto Im\{r^7_{1-1}\} \propto r^8_{11} \propto r^8_{1-1}$

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

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

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

SDME of exclusive ϕ production for the integrated data, class A and B



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

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

  SDMEs(ϕ) larger by 10% -20% than SDMES(ρ^0)

  $|T_{11}/T_{00}|(\phi) > |T_{11}/T_{00}|(\rho_0)$

- B, Interference: γ^*_L, ϕ_T

  $Re\{T_{00}T^*_{11}\} \propto Re\ \{r^5_{10}\} \propto -Im\{r^6_{10}\}$

  $Im\{T_{11}T^*_{00}\} \propto Im\{r^7_{10}\} \propto Re\{r^8_{10}\}$

- if SCHC holds:

  $r^1_{1-1} = -Im\{r^2_{1-1}\}$

  $Re\ \{r^5_{10}\} = -Im\{r^6_{10}\}$

  $Im\{r^7_{10}\} = Re\{r^8_{10}$

- Phase difference of T_{11} and T_{00}

  tan$\delta =$

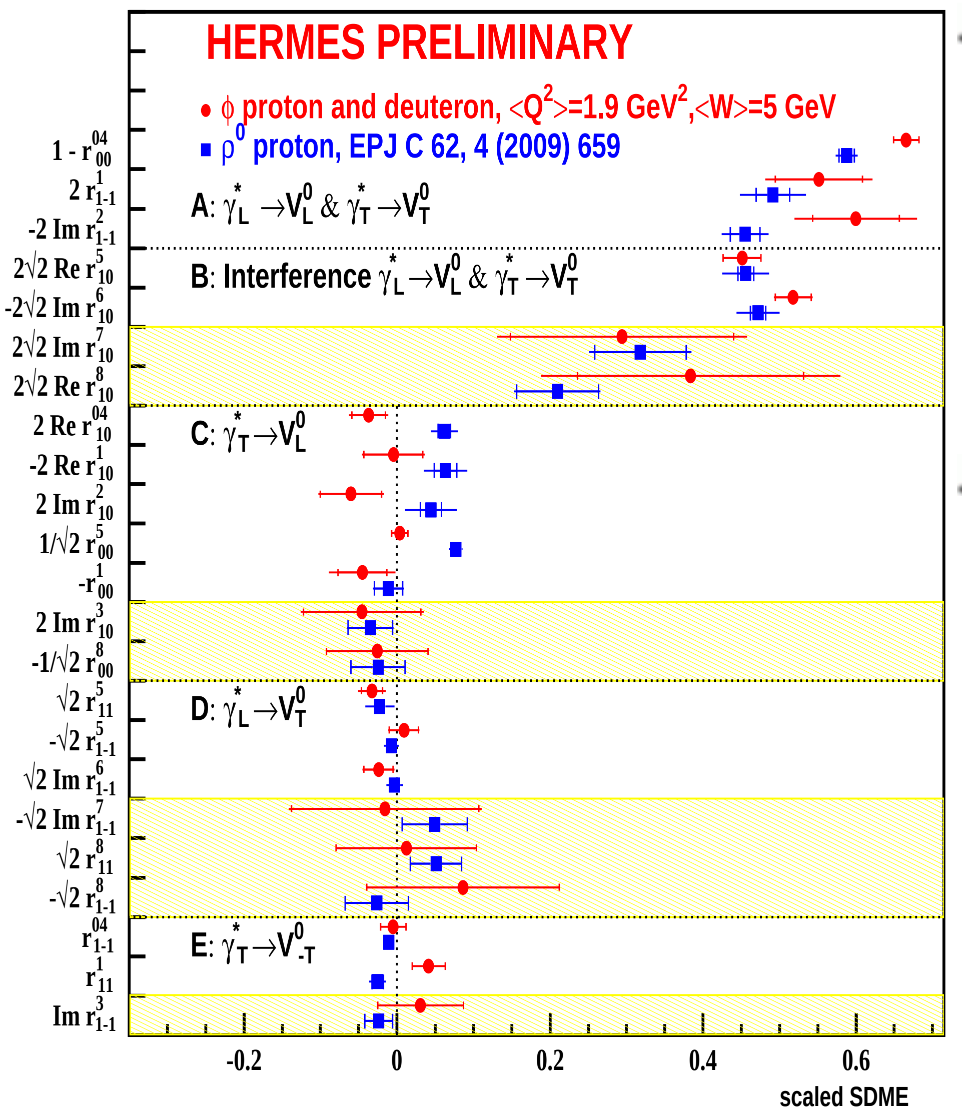
  $(Im\{r^7_{10}\} + Re\{r^8_{10}\})/(Re\ \{r^5_{10}\} - Im\{r^6_{10}\})$

  $\delta = 33.0 \pm 7.4$ deg

$\Longrightarrow$ **Hierarchy of ρ^0 amplitudes:**

$|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \gtrsim |T_{1-1}|$,

SDME of exclusive ϕ production for the integrated data class C,D,E



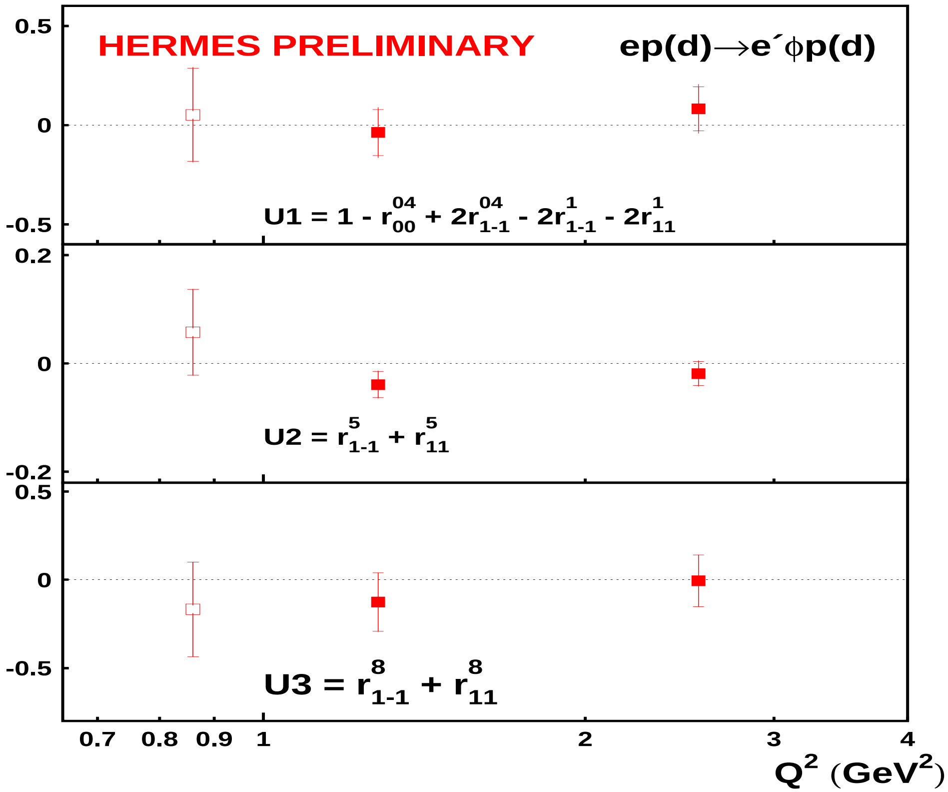
- C, Spin Flip: $\gamma^*_T \to \phi_L$
  $Re\{T_{11}T^*_{01}\} \propto Re\{r^{04}_{10}\} \propto Re\{r^1_{10}\} \propto Im\{r^2_{10}\}$
  Re $\{ T_{01}T^*_{00}\} \propto r^5_{00}$
  $| T_{01}|^2 \propto r^1_{00}$
  Im $\{ T_{01}T^*_{11}\} \propto Im\{r^3_{10}\}$
  Im $\{ T_{01}T^*_{00}\} \propto r^8_{00}$
  ϕ meson SDMEs are consistent with SCHC

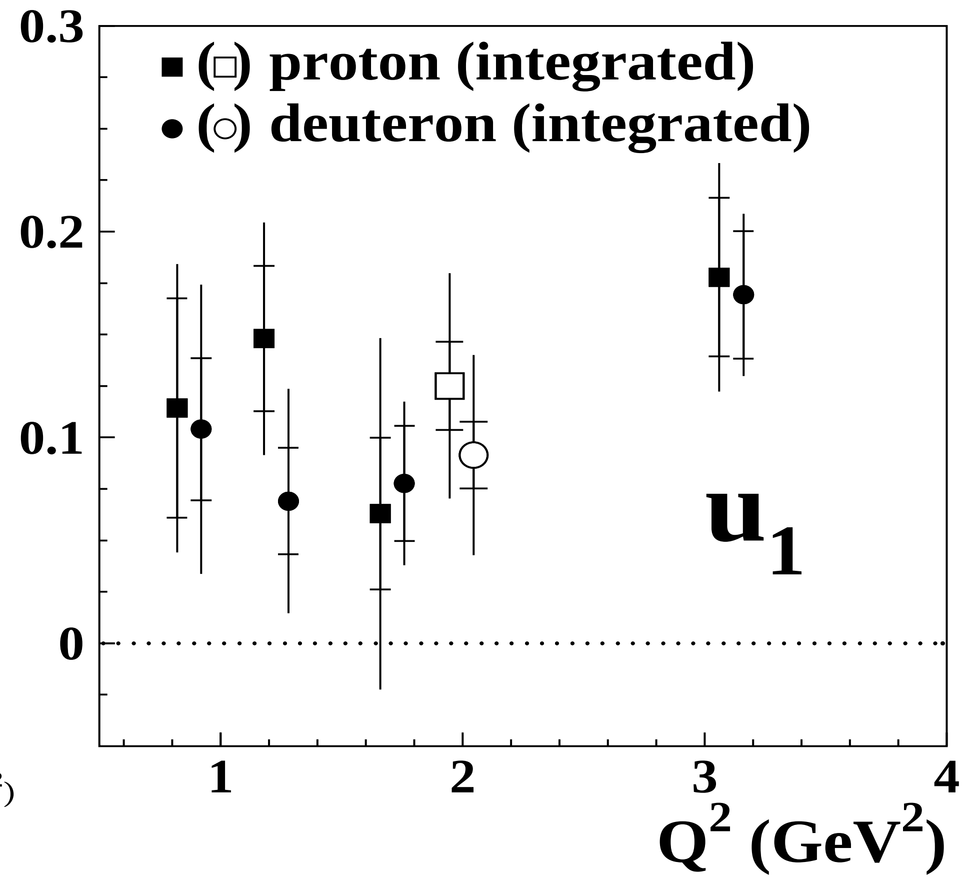
- Pronounced differences for r^5_{00} and Re $\{r^{04}_{10}\}$ between ρ and ϕ
  $r^5_{00} \propto Re(T_{11}T^*_{01}) = |T_{01}||T_{11}|cos\delta_{01}$
  $r^8_{00} \propto Im(T_{11}T^*_{01}) = |T_{01}||T_{11}|sin\delta_{01}$
  $|T_{01}|(\phi) < |T_{01}|(\rho^0)$
  $T_{01} \sim 0$ in the absence of longitudinal quark motion in meson.
  smaller longitudinal quark motion in the ϕ meson as compared to the ρ^0

$\Longrightarrow$ **Hierarchy of ρ^0 amplitudes:**

$$|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \gtrsim |T_{1-1}|,$$

Test of Unnatural-Parity Exchange for ϕ meson





$u_1(\phi)$=0.021 $\pm 0.071_{stat} \pm 0.159_{syst}$

$u_1(\rho^0)$=0.106 $\pm 0.036_{tot}$ (H+D)

- Signal of UPE in SDME method

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

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

HERMES, Eur. Phys. J. C62 (09) 659.

hermes

Summary

- The SDMEs were extracted for electroproduction of ϕ vector meson on proton and deuteron at HERMES.
- They are presented grouped into five classes according to the hierarchy of helicity amplitudes.
- It was found that $|T_{11}/T_{00}|$ for ϕ meson is larger than for ρ^0 meson.
- The violation of SCHC by SDMEs is not seen for ϕ meson.
- $|T_{01}|$ is very small for ϕ production - smaller longitudinal quark motion in the ϕ meson as compared to ρ^0 meson.
- The UPE contribution is not seen for ϕ meson production.