Hard exclusive φ meson leptoproduction at HERMES

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Outline

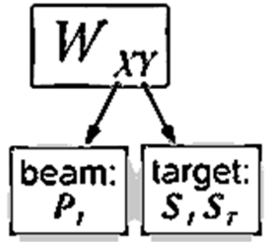
- Introduction
- HERMES experiment
- Data sample
- φ meson SDMEs
- Comparison of φ and ρ^0 SDMEs
- Summary

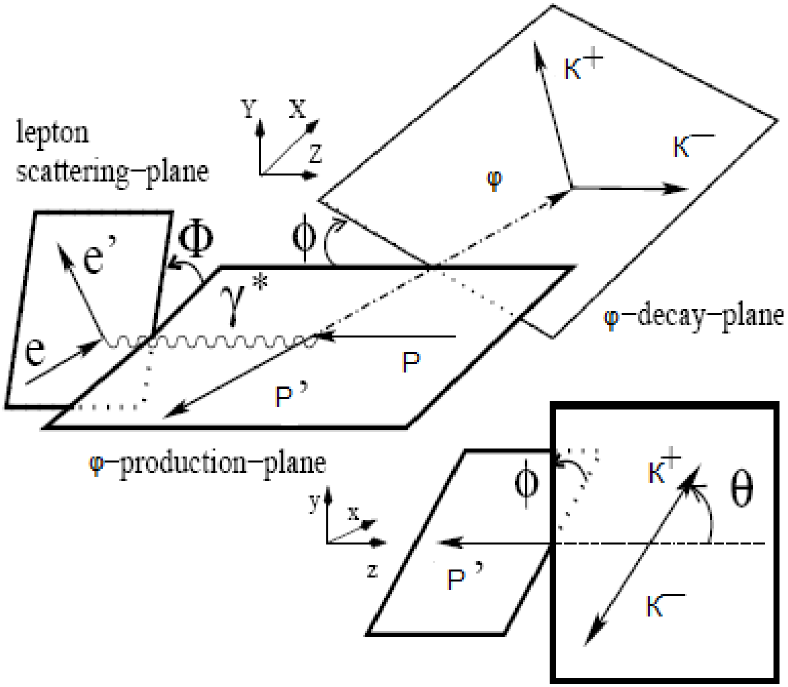
Cross section and decay angular distribution

$$ep \to e'p'\varphi,\ \varphi \to K^+K^-$$

$$\frac{d\sigma}{dx_B\,dQ^2\,dt\,d\phi_S\,d\phi\,d\cos\theta\,d\Phi} \approx \frac{d\sigma}{dx_B\,dQ^2\,dt} W(x_B, Q^2, t, \phi_S, \phi, \cos\theta, \Phi)$$

$$W = W_{UU} + P_l W_{LU} + S_L W_{UL} + P_l S_L W_{LL} + S_T W_{UT} + P_l S_T W_{LT}$$





$$\sin\phi = \frac{[(q\times v)\times v]\cdot(P_{K^+}\times v)}{|(q\times v)\times v|\cdot|P_{K^+}\times v|}$$

$$\cos\phi = \frac{(q\times v)\cdot(v\times P_{K^+})}{|q\times v|\cdot|v\times P_{K^+}|}$$

$$\sin\Phi = \frac{[(q\times v)\times(k\times k')]\cdot|q|}{|q\times v|\cdot|k\times k'|\cdot|q|}$$

$$\cos\Phi = \frac{(q\times v)\cdot(k\times k')}{|q\times v|\cdot|k\times k'|}$$

$$\cos\theta = \frac{-P'\cdot P_{K^+}}{|P'|\cdot|P_{K^+}|}$$

ϕ - azimuthal angle of the K^+ decay in the φ meson rest frame

θ polar angle of the K^+ decay in the φ meson rest frame

Φ angle between φ meson-production plane and the lepton scattering plane

Spin density matrix elements & helicity amplitudes

$$\gamma^*(\lambda_\gamma)N(\lambda_N)\to V(\lambda_V)N'(\lambda_{N'})$$

$W(x_B, Q^2, t, \phi_S, \phi, \cos\theta, \Phi)$ can be parameterized by:

- helicity amplitudes $T_{\lambda_V\lambda_\gamma}$

  connected with SDMEs; calculated from GPDs

- spin density matrix $r^{\alpha}_{\lambda_V\lambda'_V}\to\rho(V)=\frac{1}{2}T_{\lambda_V\lambda_\gamma}\,\rho(\gamma)T^*_{\lambda_V\lambda_\gamma}$

  $\rho(V)$ – spin density matrix of the vector meson

  $\rho(\gamma)$ - spin density matrix of the virtual photon

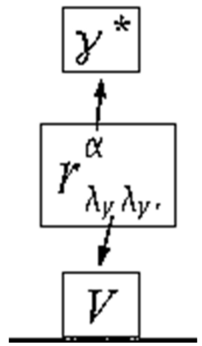
$$r^{\alpha}_{\lambda_V\lambda'_V(V)}=\frac{1}{2N_\alpha}\sum_{\lambda_{N'},\lambda_N\lambda_\gamma\lambda'_\gamma}T_{\lambda_V\lambda_{N'},\lambda_\gamma\lambda_N}\Sigma^{\alpha}_{\lambda_\gamma\lambda'_\gamma}T^*_{\lambda'_V\lambda_{N'},\lambda'_\gamma\lambda_N}$$

N_α are normalization factors

$T_{\lambda_V\lambda_{N'},\lambda_\gamma\lambda_N}$ - helicity amplitudes, $T_{\lambda_V\lambda_{N'},\lambda_\gamma\lambda_N}\to T_{\lambda_V\lambda_\gamma}$

$\Sigma^{\alpha}_{\lambda_\gamma\lambda'_\gamma}$ - hermitian matrices with α 0÷8 - virtual photon polarization

Schilling, Wolf



The angular distribution

$$W^{U+L}(\Phi,\phi,\cos\Theta) = W^{UU}(\Phi,\phi,\cos\Theta) + W^{LU}(\Phi,\phi,\cos\Theta)$$

For unpolarized target and beam:

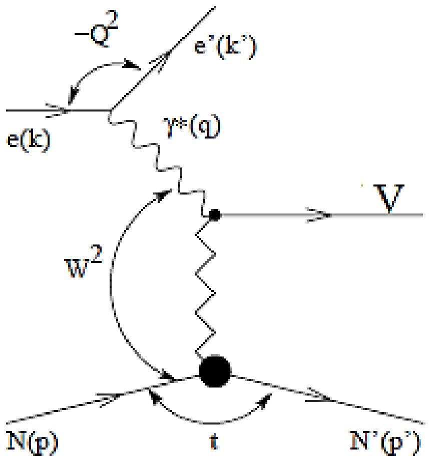
$$\begin{aligned}W^{UU}(\Phi,\phi,\cos\theta) = \frac{3}{8\pi^2}[&\frac{1}{2}\left(1-r_{00}^{04}\right)+\frac{1}{2}\left(3r_{00}^{04}-1\right)\cos^2\theta-\sqrt{2}\,\mathrm{Re}\left\{r_{10}^{04}\right\}\sin 2\theta\cos\phi-r_{1-1}^{04}\sin^2\theta\cos 2\phi \\ &-\varepsilon\cos 2\Phi\left(r_{11}^{1}\sin^2\theta+r_{00}^{1}\cos^2\theta-\sqrt{2}\,\mathrm{Re}\left\{r_{10}^{1}\right\}\sin 2\theta\cos\phi-r_{1-1}^{1}\sin^2\theta\cos 2\phi\right) \\ &-\varepsilon\sin 2\Phi\left(\sqrt{2}\,\mathrm{Im}\left\{r_{10}^{2}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r_{1-1}^{2}\right\}\sin^2\theta\sin 2\phi\right) \\ &+\sqrt{2\varepsilon(1+\varepsilon)}\cos\Phi\left(r_{11}^{5}\sin^2\theta+r_{00}^{5}\cos^2\theta-\sqrt{2}\,\mathrm{Re}\left\{r_{10}^{5}\right\}\sin 2\theta\cos\phi-r_{1-1}^{5}\sin^2\theta\cos 2\phi\right) \\ &+\sqrt{2\varepsilon(1+\varepsilon)}\sin\Phi\left(\sqrt{2}\,\mathrm{Im}\left\{r_{10}^{6}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r_{1-1}^{6}\right\}\sin^2\theta\sin 2\phi\right)]\end{aligned}$$

For unpolarized target and longitudinally polarized beam:

$$\begin{aligned}W^{LU}(\Phi,\phi,\cos\theta) = \frac{3}{8\pi^2}P_{Beam}[&\sqrt{1-\varepsilon^2}\left(\sqrt{2}\,\mathrm{Im}\left\{r_{10}^{3}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r_{1-1}^{3}\right\}\sin^2\theta\sin 2\phi\right) \\ &+\sqrt{2\varepsilon(1-\varepsilon)}\cos\Phi\left(\sqrt{2}\,\mathrm{Im}\left\{r_{10}^{7}\right\}\sin 2\theta\sin\phi+\mathrm{Im}\left\{r_{1-1}^{7}\right\}\sin^2\theta\sin 2\phi\right) \\ &+\sqrt{2\varepsilon(1-\varepsilon)}\sin\Phi\left(r_{11}^{8}\sin^2\theta+r_{00}^{8}\cos^2\theta-\sqrt{2}\,\mathrm{Re}\left\{r_{10}^{8}\right\}\sin 2\theta\cos\phi-r_{1-1}^{8}\sin^2\theta\cos 2\phi\right)]\end{aligned}$$

$$\varepsilon = \frac{1-y-y^2\frac{Q^2}{4\nu^2}}{1-y+\frac{1}{4}y^2(\frac{Q^2}{\nu^2}+2)}$$ - the ratio of virtual photon fluxes for longitudinal and transverse polarization

Vector meson production

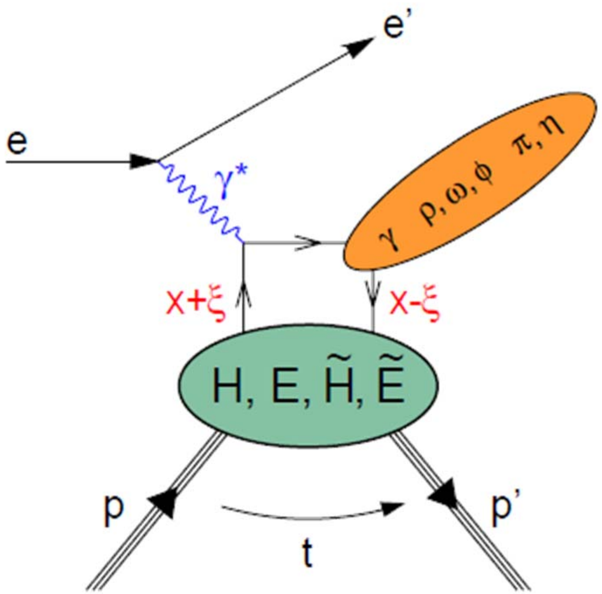


VMD model

$$ep \rightarrow e'p'\varphi,\ \varphi \rightarrow K^+K^-$$

$$ep \rightarrow e'p'\rho^0,\ \rho^0 \rightarrow \pi^+\pi^-$$

GPD model



- Four leading-twist GPDs for spin-½ targets
- H and $\widetilde{H}$ correspond to the nucleon helicity conservation
- E and $\widetilde{E}$ correspond to the nucleon helicity flip
- Factorization theorem proved only for σ_L
  $\gamma_L^* \Rightarrow \varphi_L, \omega_L, \rho_L \Rightarrow H, E$
- $\gamma_T^* \Rightarrow \rho_T^0$ transition can be calculated $\widetilde{H}$

Ji relation:

Quarks: $$J_q = \frac{1}{2} \lim_{t\to 0} \int_{-1}^{1} dx\, x\, [H_q(x,\xi,t) + E_q(x,\xi,t)]$$

Gluons: $$J_g = \frac{1}{2} \lim_{t\to 0} \int_{0}^{1} dx\, [H_g(x,\xi,t) + E_g(x,\xi,t)]$$

Properties of vector meson production

S-channel helicity conservation (SCHC) S-channel helicity non-conservation

Helicity conserving amplitudes : Helicity flip amplitudes:

$T_{\lambda\lambda'}$, $\lambda_V = \lambda_\gamma$ >> $T_{\lambda\lambda'}$, $\lambda_V \neq \lambda_\gamma$

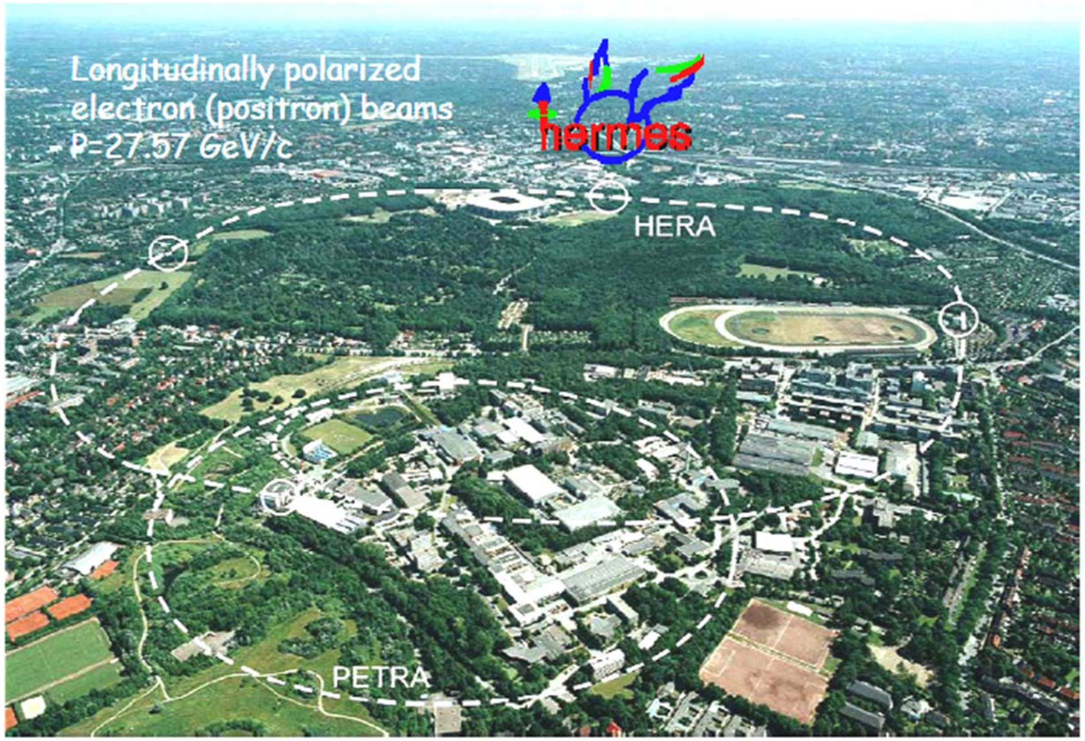
Theoretically predicted amplitudes hierarchy for HEMES kinematics for φ

$|T_{00}| \sim |T_{11}| >> |T_{01}|, |T_{10}| \approx |T_{-11}| \approx 0.$

Theoretically predicted amplitudes hierarchy for HEMES kinematics for ρ^0

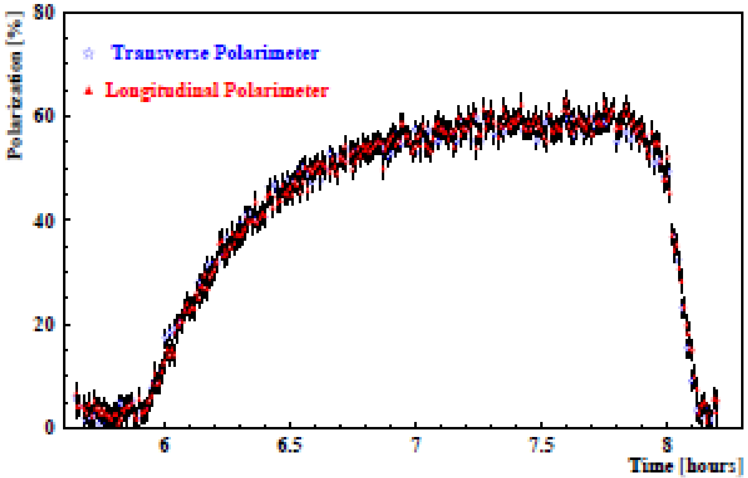
$|T_{00}|^2 \sim |T_{11}|^2 \gg |T_{01}|^2 > |T_{10}|^2 \sim |T_{-11}|^2$

HERMES at HERA



Beam

Longitudinally polarized lepton beam with energy 27.6 GeV, $P_{beam} \sim 40 - 60\%$

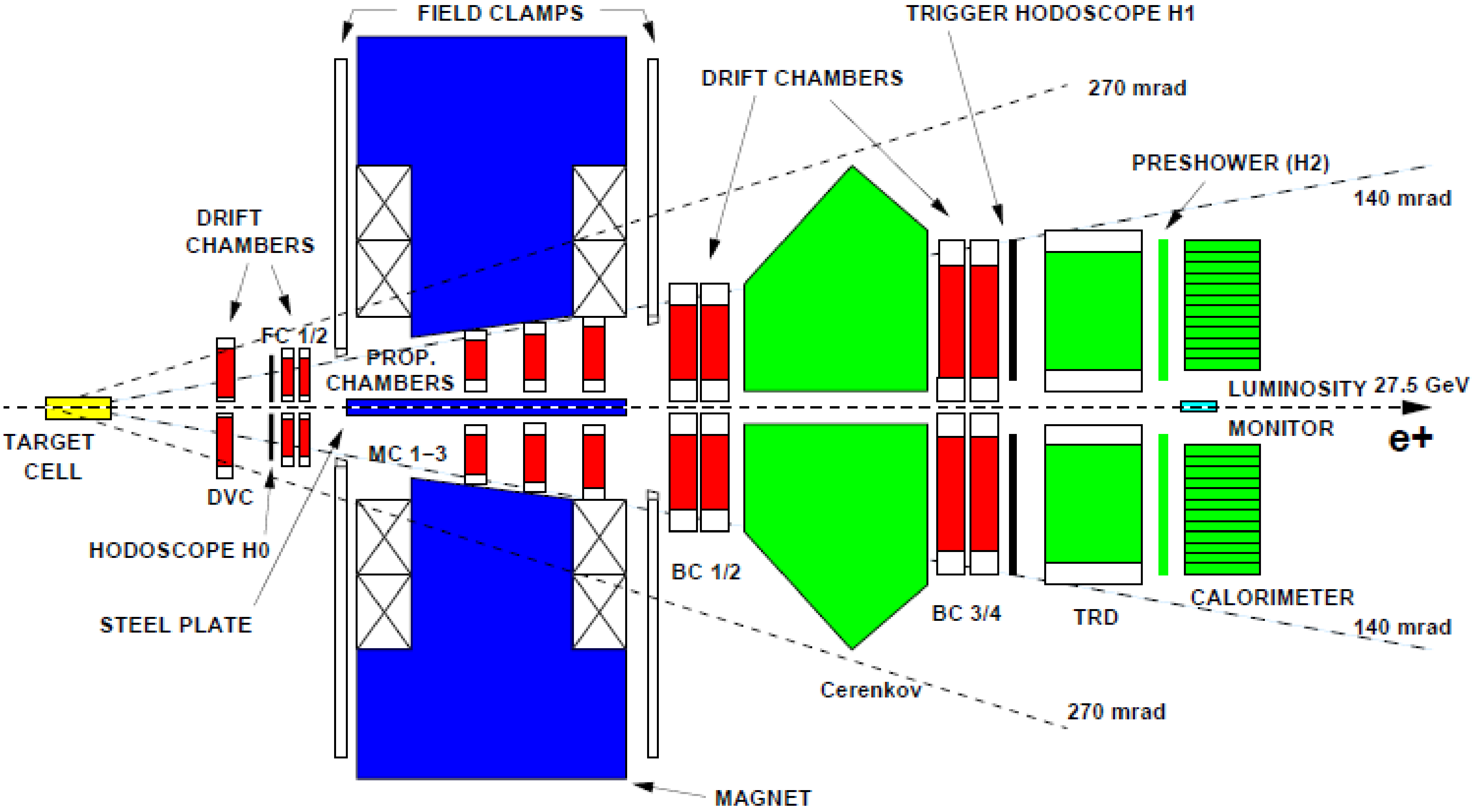


Target

Internal gas target:

- Unpolarized H, D, ^{4}He, N, Ne, Kr, Xe
- Polarized: longitudinally H, D, transversely H

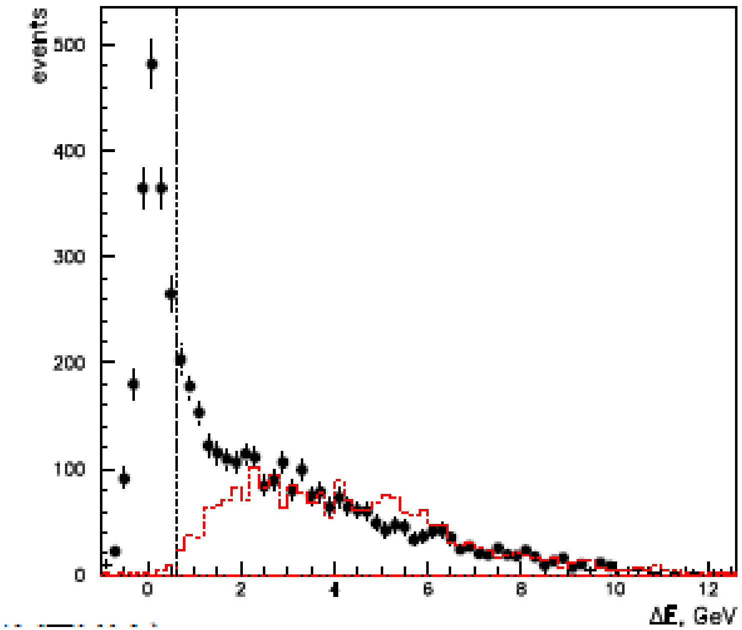
The HERMES spectrometer

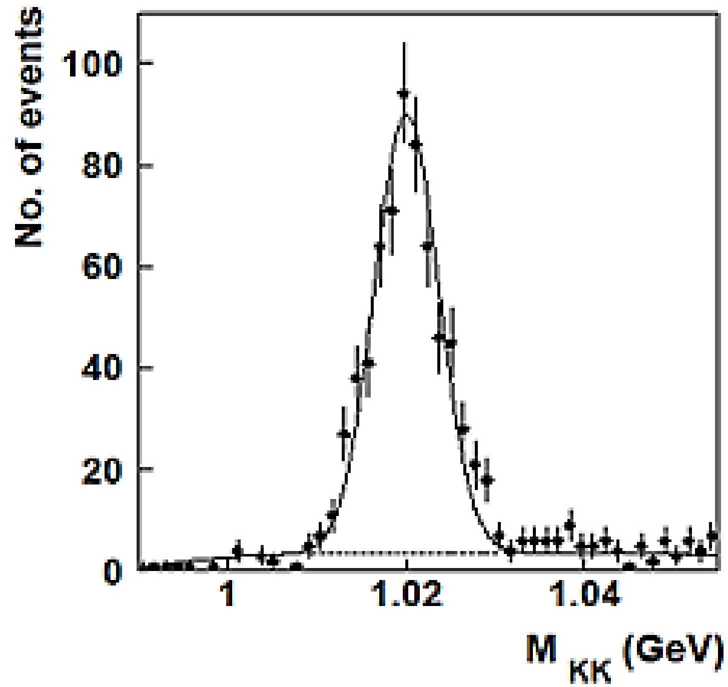


- Acceptance $40 < \theta < 220$ mrad, $|\theta_x| < 170$ mrad, $40 < |\theta_y| < 140$ mrad
- Momentum resolution $\frac{\Delta P}{P} \leq 1\%$, angular resolution $\frac{\Delta\theta}{\theta} \leq 0.6$ mrad

φ meson event selection

$ep \to e'p'\varphi$, $\varphi \to K^+K^-$ Exclusive region: $\Delta E = \frac{(M_x^2 - M^2)}{2M} = 0$





Eur. Phys. J. C 29, 171 - 179 (2003), hep-ex/0302012

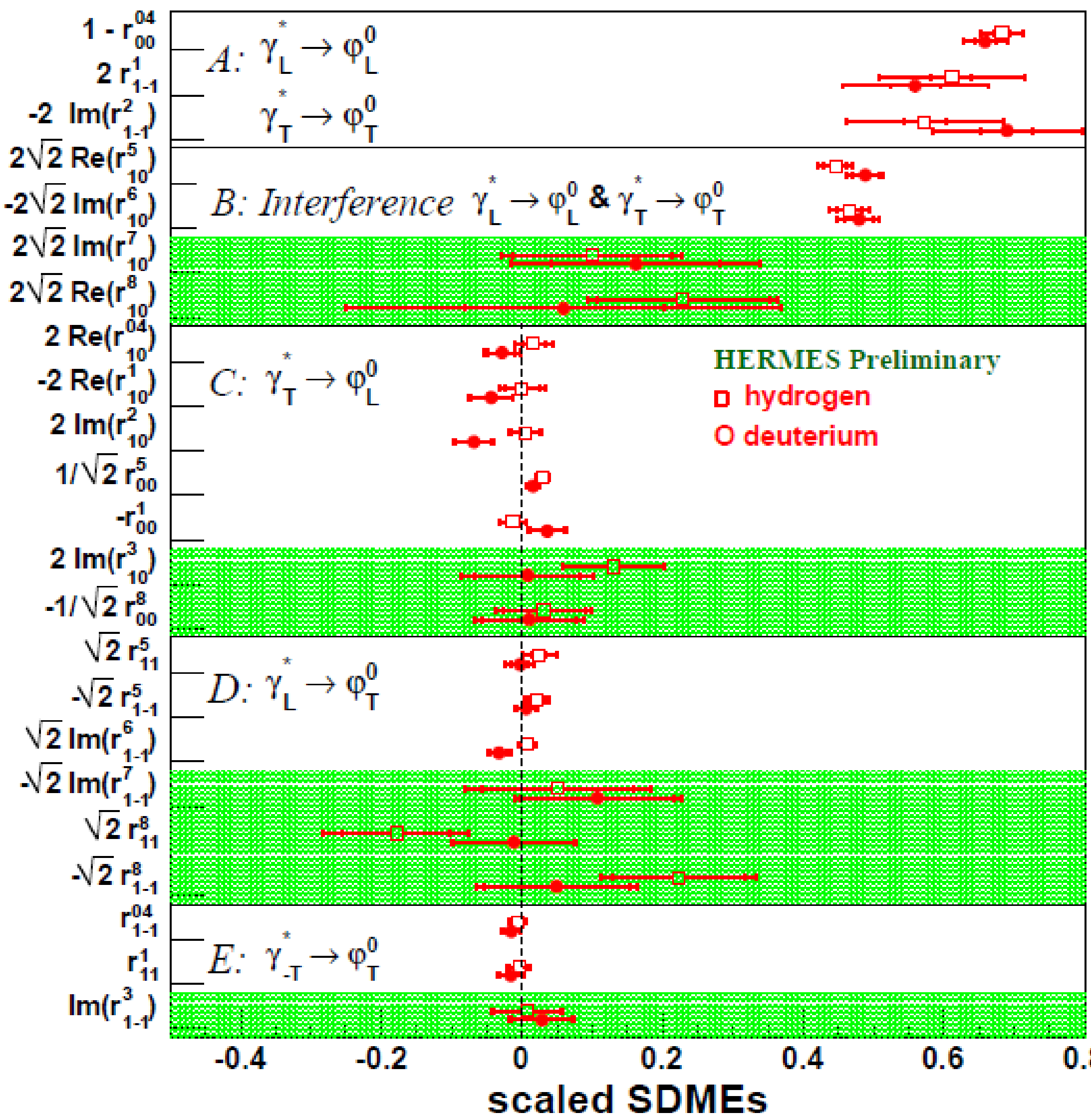
Kinematics:

- $1 < Q^2 < 7$ GeV^2, $\langle Q^2 \rangle = 1.95$ GeV^2
- $W^2 > 9$ GeV^2 , $\langle W^2 \rangle = 21.89$ GeV^2
- 1.012 GeV $< M_{KK} <$ 1.028 GeV
- $-t' < 0.4$ GeV^2
- $\Delta E < 0.6$ GeV
- $\langle x_B \rangle = 0.088$

SDMEs for φ meson production

Unpolarized (white areas) and beam-polarized (green areas) SDMEs

Are shown for the first time for the whole RICH data set



- A, $\gamma_L^* \to \rho_L^0$ and $\gamma_T^* \to \rho_T^0$

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

- B, Interference: γ_L^*, ρ_T^0

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

  $Im\{T_{11}T_{00}^*\} \propto Im\{r_{10}^7\} \propto Re\{r_{10}^8\}$

- C, Spin Flip: $\gamma_T^* \to \rho_L^0$

  $Re\{T_{11}T_{01}^*\} \propto Re\{r_{10}^{04}\} \propto Re\{r_{10}^1\} \propto Im\{r_{10}^2\}$

  $Re\{T_{01}T_{00}^*\} \propto r_{00}^5$

  $|T_{01}|^2 \propto r_{00}^1$

  $Im\{T_{01}T_{11}^*\} \propto Im\{r_{10}^3\}$

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

- D, Spin Flip: $\gamma_L^* \to \rho_T^0$

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

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

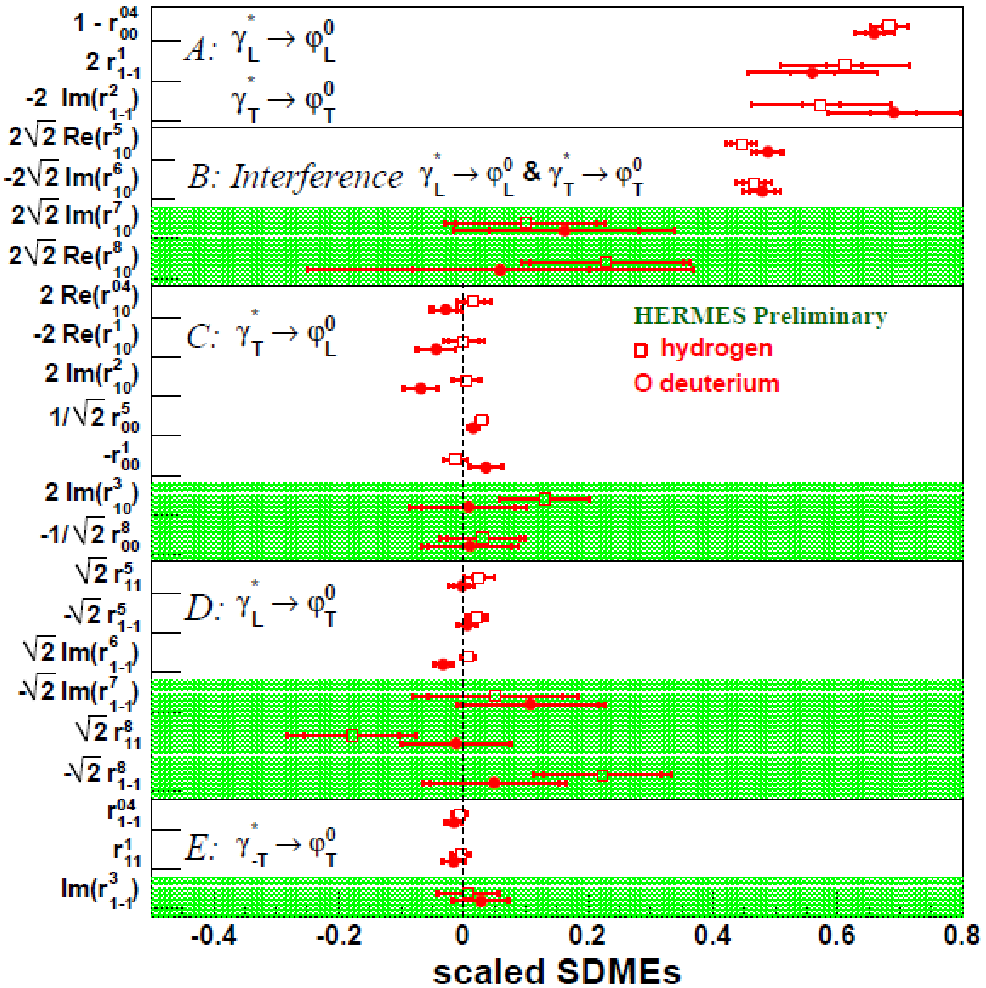
- E, Spin Flip: $\gamma_T^* \to \rho_{-T}^0$

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

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

SDMEs for φ meson production

Unpolarized (white areas) and beam-polarized (green areas) SDMEs



Are shown for the first time for the whole RICH data set

- no statistically significant difference between proton and deuteron
- s-channel helicity conservation

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

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

$\mathrm{Re}\{r^8_{10}\} = \mathrm{Im}\{r^7_{10}\}$, -large uncertainties

- s-channel helicity violation

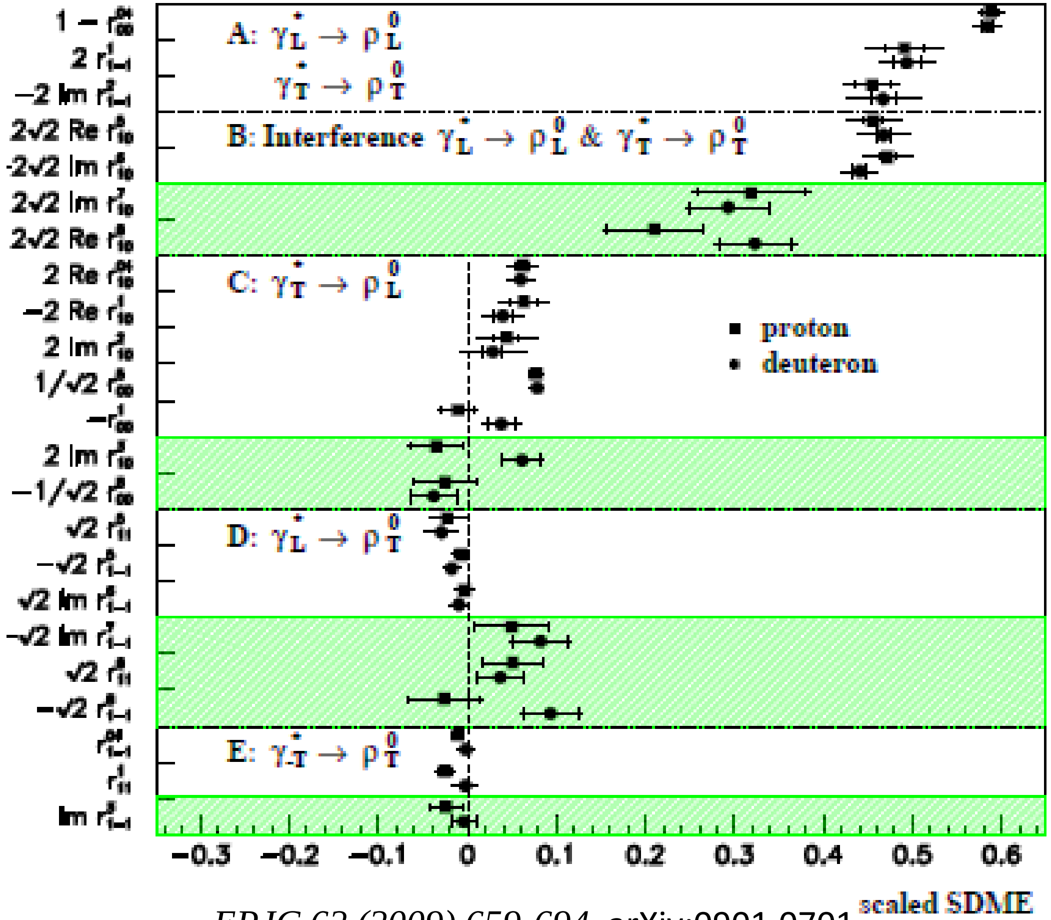
φ SDMEs classes C, D, E are compatible with 0 supporting SCHC, except from r^5_{00}

Amplitudes hierarchy for φ meson:

$|T_{00}| \sim |T_{11}| >> |T_{01}|, |T_{10}| \approx |T_{-11}| \approx 0.$

SDMEs for ρ^0 meson production

Unpolarized (white areas) and beam-polarized (green areas) SDMEs



EPJC 62 (2009) 659-694, arXiv:0901.0701

- no statistically significant difference between proton and deuteron

s-channel helicity conservation (conservation the helicity of γ^* in $\gamma^*_L \to \rho^0_L$ and $\gamma^*_T \to \rho^0_T$) – non-zero SDMEs of classes A,B

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

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

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

- s-channel helicity violation

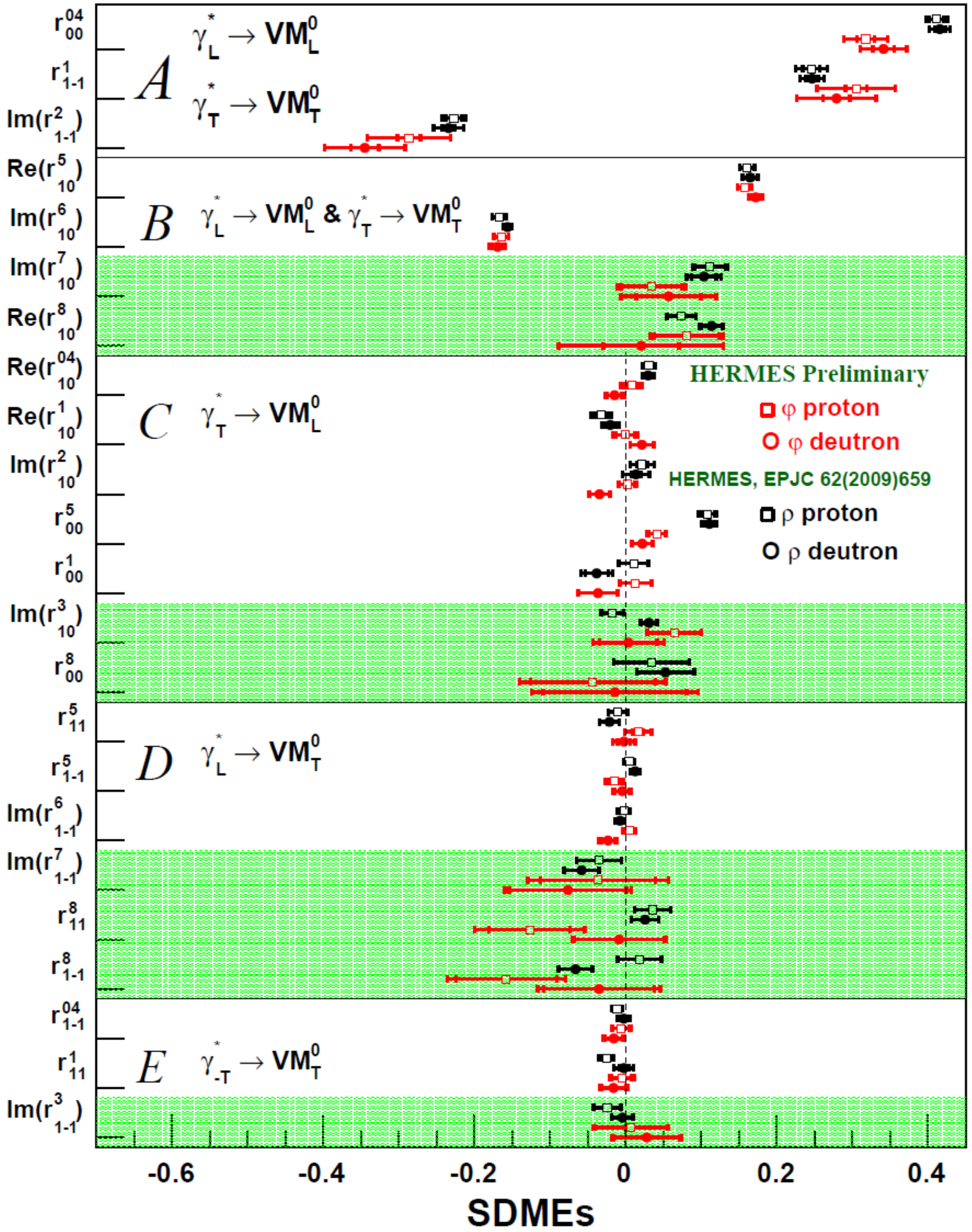
significant $\gamma^*_T \to \rho^0_L$ - non-zero elements of class C, not so significant $\gamma^*_{-T} \to \rho^0_T$ and $\gamma^*_L \to \rho^0_T$ - non-zero elements of classes D,E

Hierarchy of amplitudes at HERMES kinematics for ρ^0:

$|T_{00}|^2 \sim |T_{11}|^2 \gg |T_{01}|^2 > |T_{10}|^2 \sim |T_{-11}|^2$

Comparison of φ and ρ^0 SDMEs

Unpolarized (white areas) and beam-polarized (green areas) SDMEs



- r_{00}^{04} is 10-20% larger for φ than for ρ^0
- SDMEs of class B are compatible for φ and
- SDMEs of class C shows pronounced differences between φ and ρ^0
- For classes D and E no significant differences are seen.

Summary

- Unpolarized and beam-polarized SDMEs are extracted on proton and deuteron targets for φ (preliminary result) and ρ^0 (published result)
- Compatible results on proton and deuteron targets for φ and ρ^0
- Helicity amplitudes hierarchy for φ and ρ^0 mesons tested
- Pronounced s-channel helicity violation for ρ^0
- Less pronounced s-channel helicity violation for φ