Hard exclusive vector meson leptoproduction at HERMES

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Outline

- HERMES experiment
- Physics motivation
- Data samples
- ρ^0 and φ spin density matrix elements
- ρ^0, φ, ω transverse target spin asymmetry
- Summary

Access to Generalized parton distributions in HERMES

Deeply virtual Compton scattering

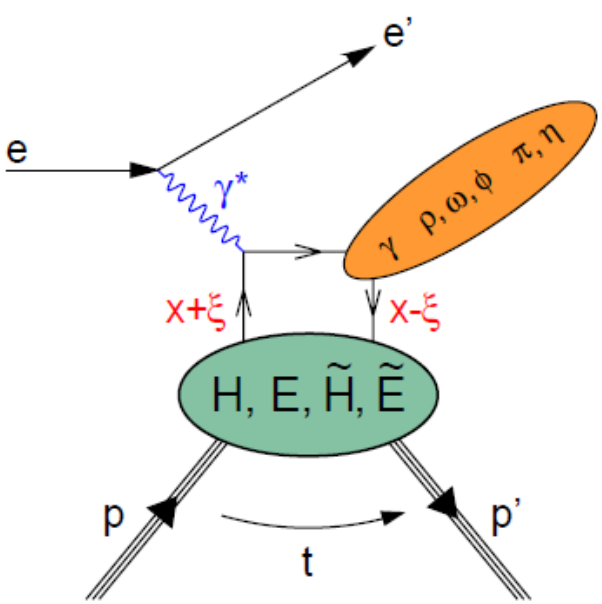
GPD

Exclusive meson electroproduction

Ji relation:

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

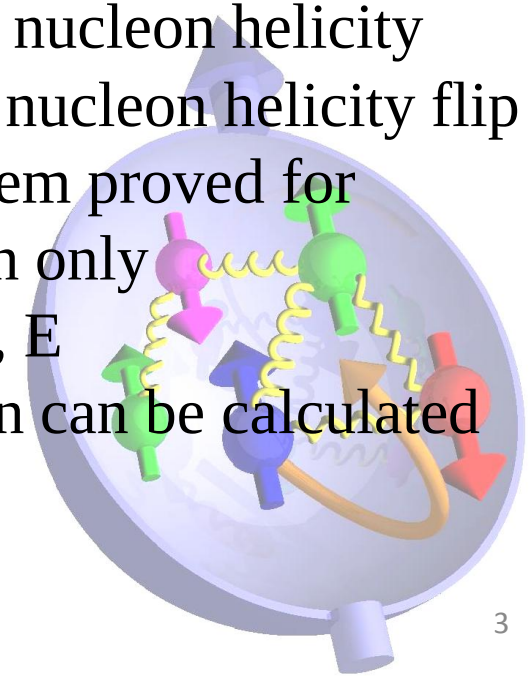
Gluons: $$J_g = \frac{1}{2} \lim_{t \to 0} \int_{0}^{1} dx\, [H_g(x,\xi,t) + E_g(x,\xi,t)]$$



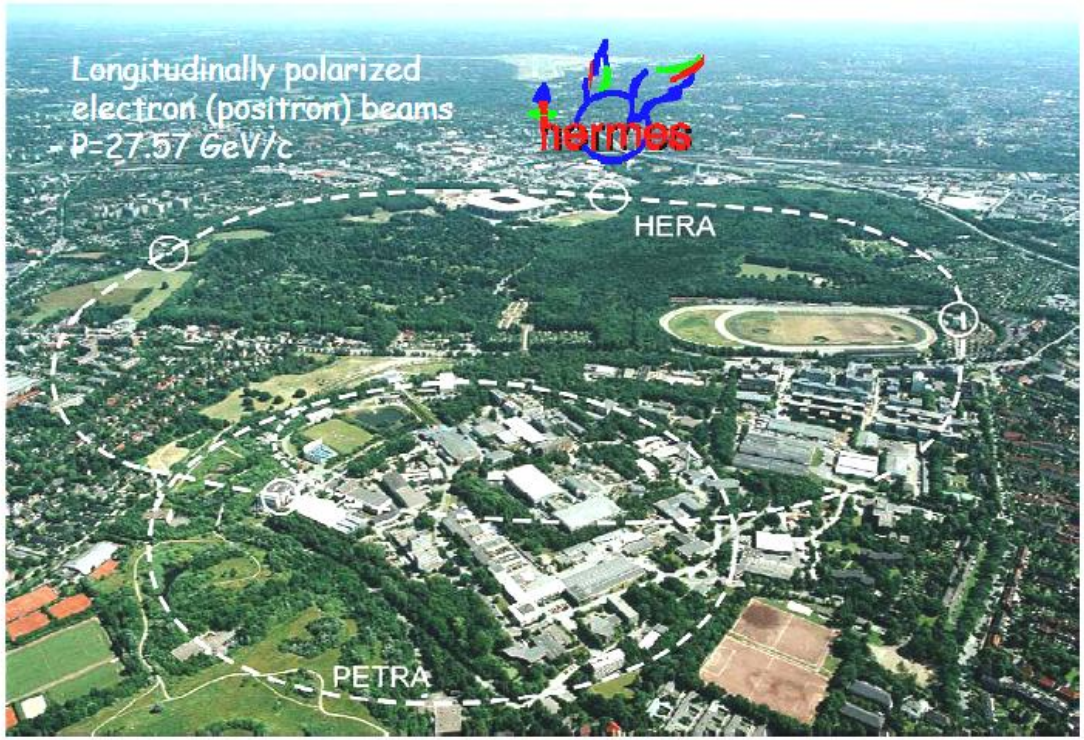
- H and $\widetilde{H}$ require the nucleon helicity
- E and $\widetilde{E}$ require the nucleon helicity flip
- Factorization theorem proved for longitudinal production only

$\gamma_L^* \Rightarrow \varphi_L, \omega_L, \rho_L \Rightarrow H, E$

- $\gamma_T^* \Rightarrow \rho_T^0$ transition can be calculated

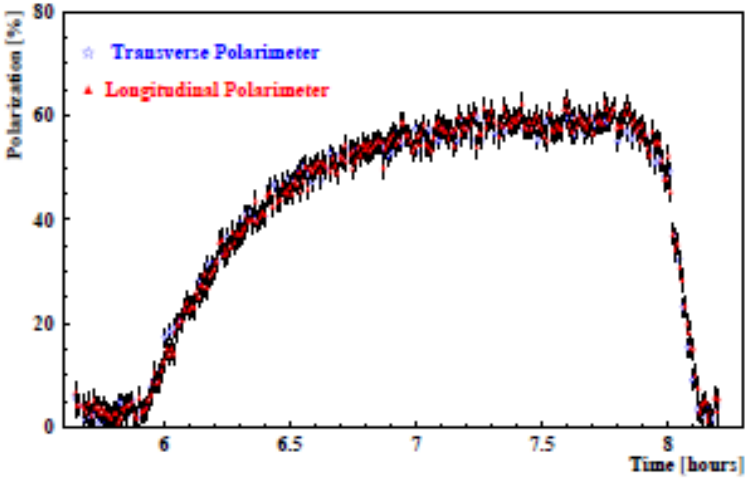


HERMES at HERA



Beam

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

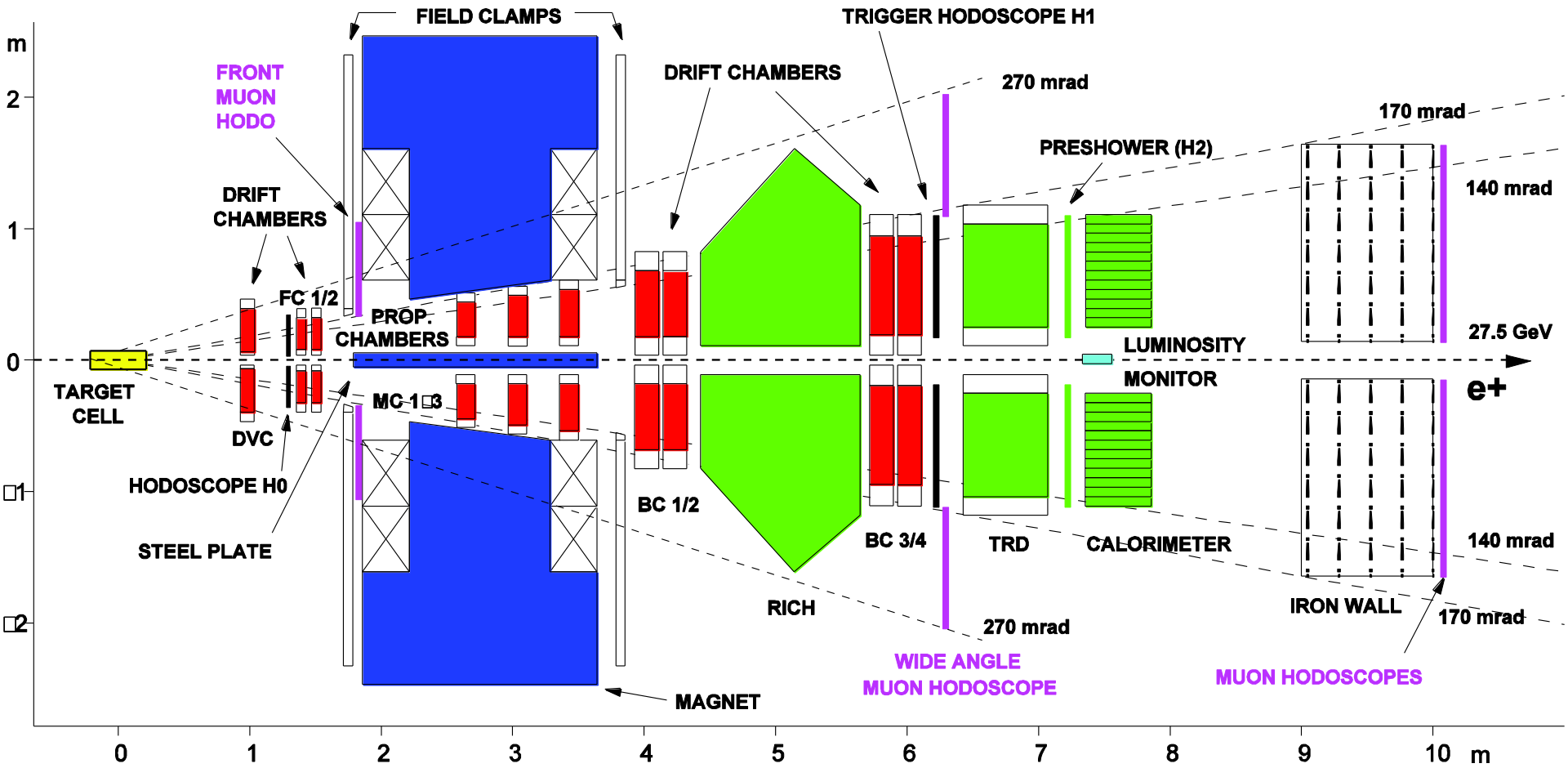


Target

Internal gas target:

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

The HERMES spectrometer

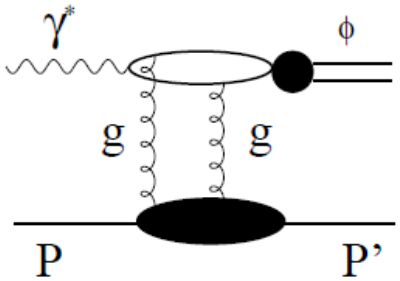


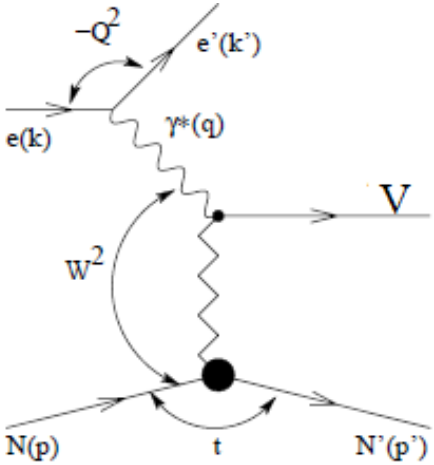
- Acceptance $40 < \Theta < 220$ mrad, $|\Theta_x| < 170$ mrad, $40 < |\Theta_y| < 140$ mrad
- Momentum resolution $\leq 1\%$, $\delta\Theta \leq 0.6$ mrad

Vector meson production

Natural parity exchange

- ρ, φ meson production
- Exchange of a particle of natural parity: $P = (-1)^J$
- Suppressed by factor M/W
- Related to GPDs H and E

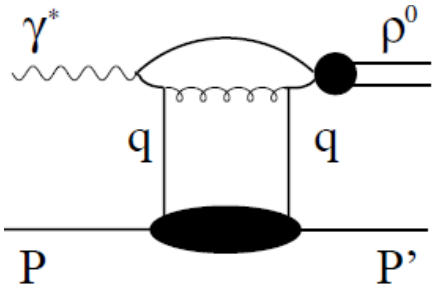




VMD model

Unnatural parity exchange

- ρ meson production
- Exchange of a particle of unnatural parity: $P = -(-1)^J$
- Suppressed by factor M/W^2
- Is expected only at low W-values
- Related to GPDs $\tilde{H}$ and $\tilde{E}$



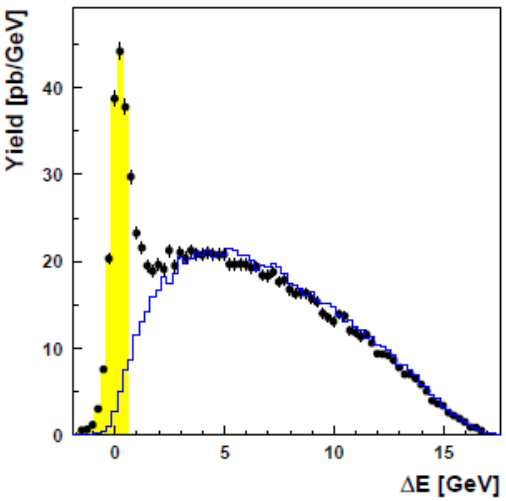
$$ep \rightarrow e'p\varphi, \varphi \rightarrow K^+K^-$$

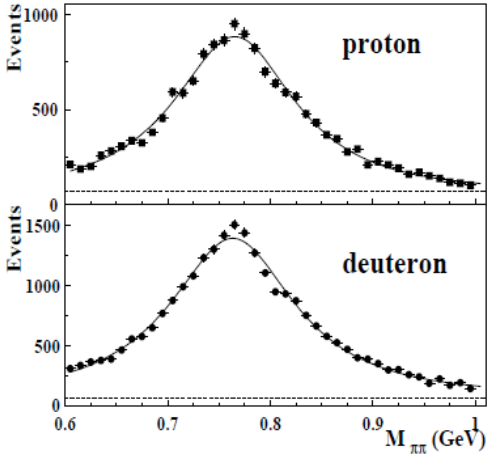
$$ep \rightarrow e'p\rho^0, \rho^0 \rightarrow \pi^+\pi^-$$

ρ^0, φ meson event selection

ρ^0 meson production

Phys. Lett. B679 (2009) 100-105, arXiv:0906.5160 *EPJC 62 (2009) 659-694*, arXiv:0901.0701



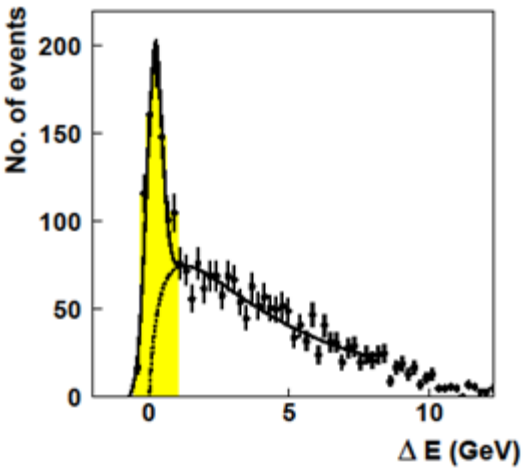


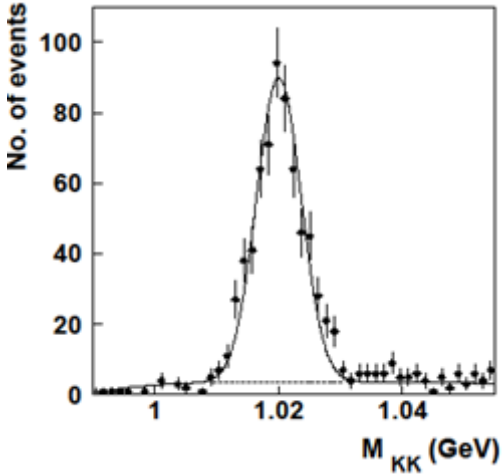
Exclusive region:

$$\Delta E = \frac{(M_x^2 - M^2)}{2M} = 0$$

φ meson production

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





Kinematic cuts:

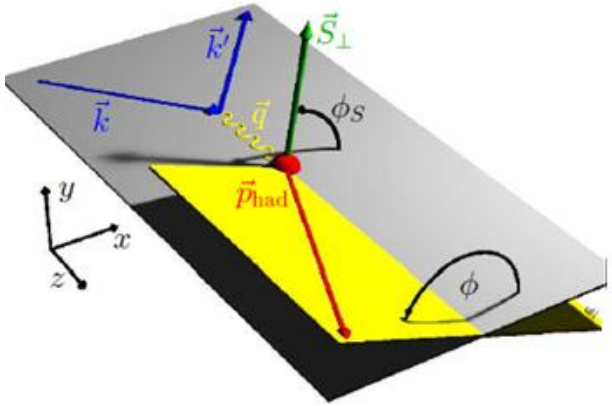
- $1 < Q^2 < 7$ GeV^2
- $3 < W^2 < 6.3$ GeV^2
- $-t' < 0.4$ GeV^2
- $\Delta E < 0.6$ GeV

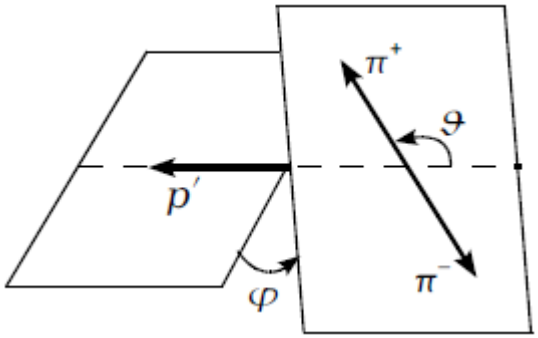
For ρ^0 additionally

- $M_{2K} > 1.04$ GeV

Decay angular distribution of vector meson

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



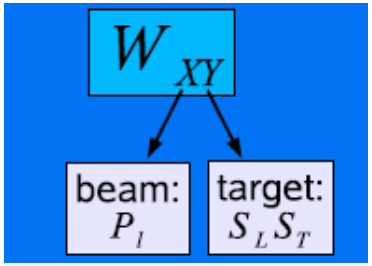


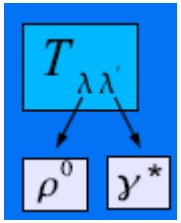
Decay angular distribution

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

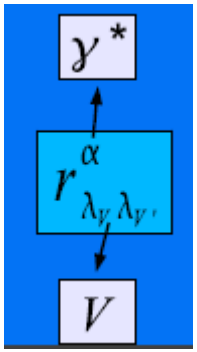
parameterized by:

helicity amplitudes $T_{\lambda\lambda'}$ and spin density matrix elements $r^{\alpha}_{\lambda_V \lambda_{V'}}$

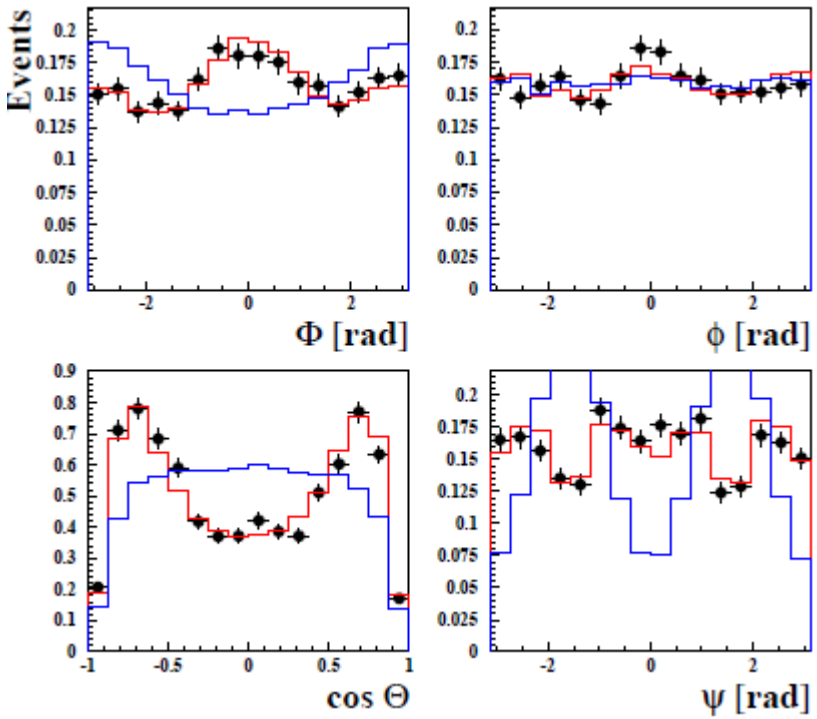




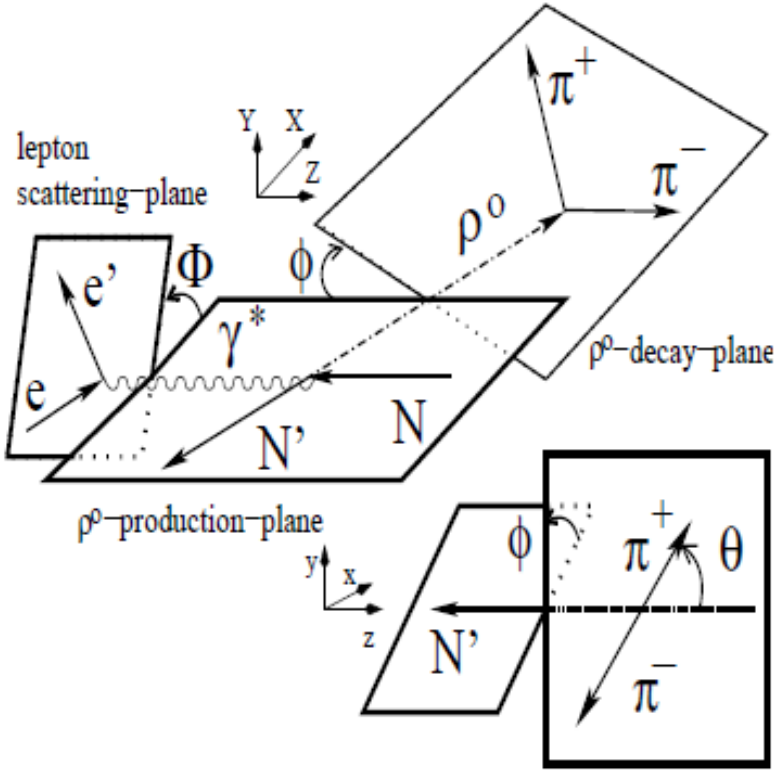
Schilling, Wolf 1973



SDMEs extraction procedure



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



Binned maximum likelihood method:

- Two 8x8x8-binned angular distributions in $(\cos\theta, \Phi, \phi)$ for data and for Monte Carlo
- Start from uniform ('fully reconstructed') MC angular distribution (blue lines).
- To fit data to MC with 23 SDMEs (15 unpolarized and 8 longitudinally polarized) as free parameters
- Good agreement of fitted MC distributions (red lines) and data (points)

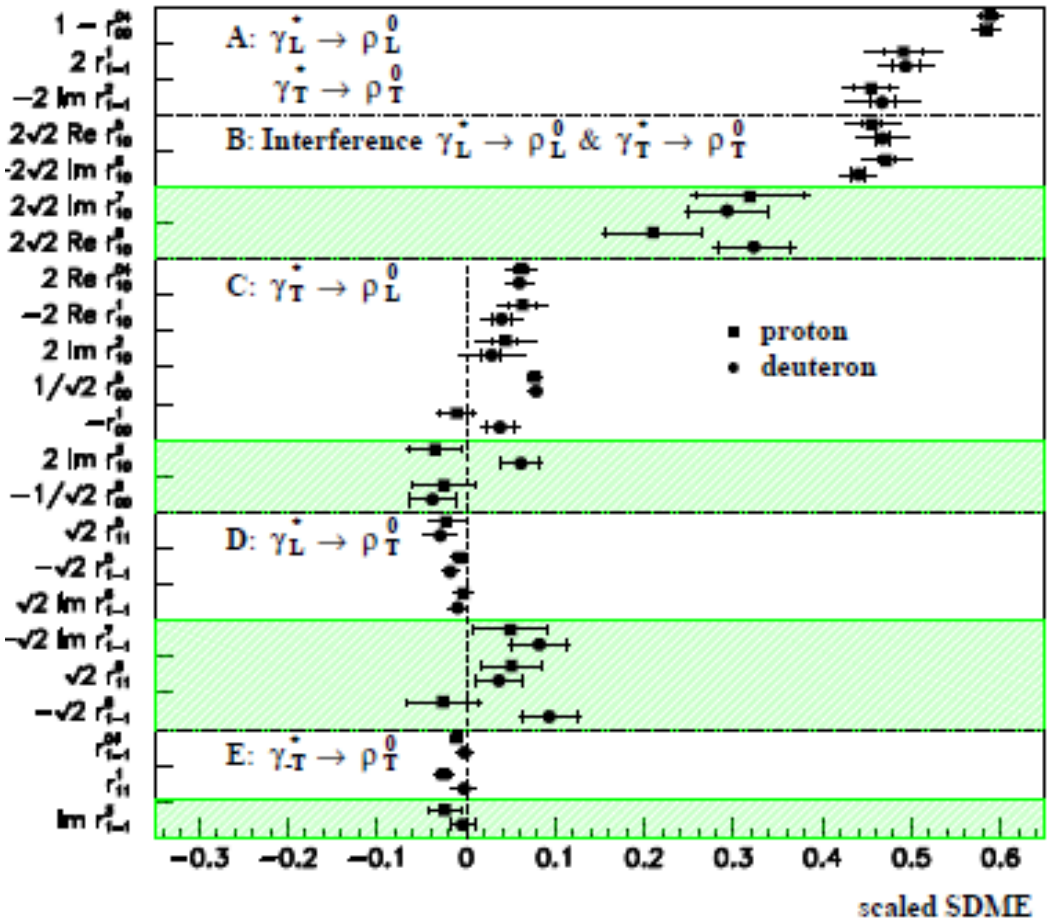
Angular distribution in terms of SDMEs

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

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

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

SDMEs for ρ^0 meson production



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

Hierarchy of amplitudes at HERMES kinematics:

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

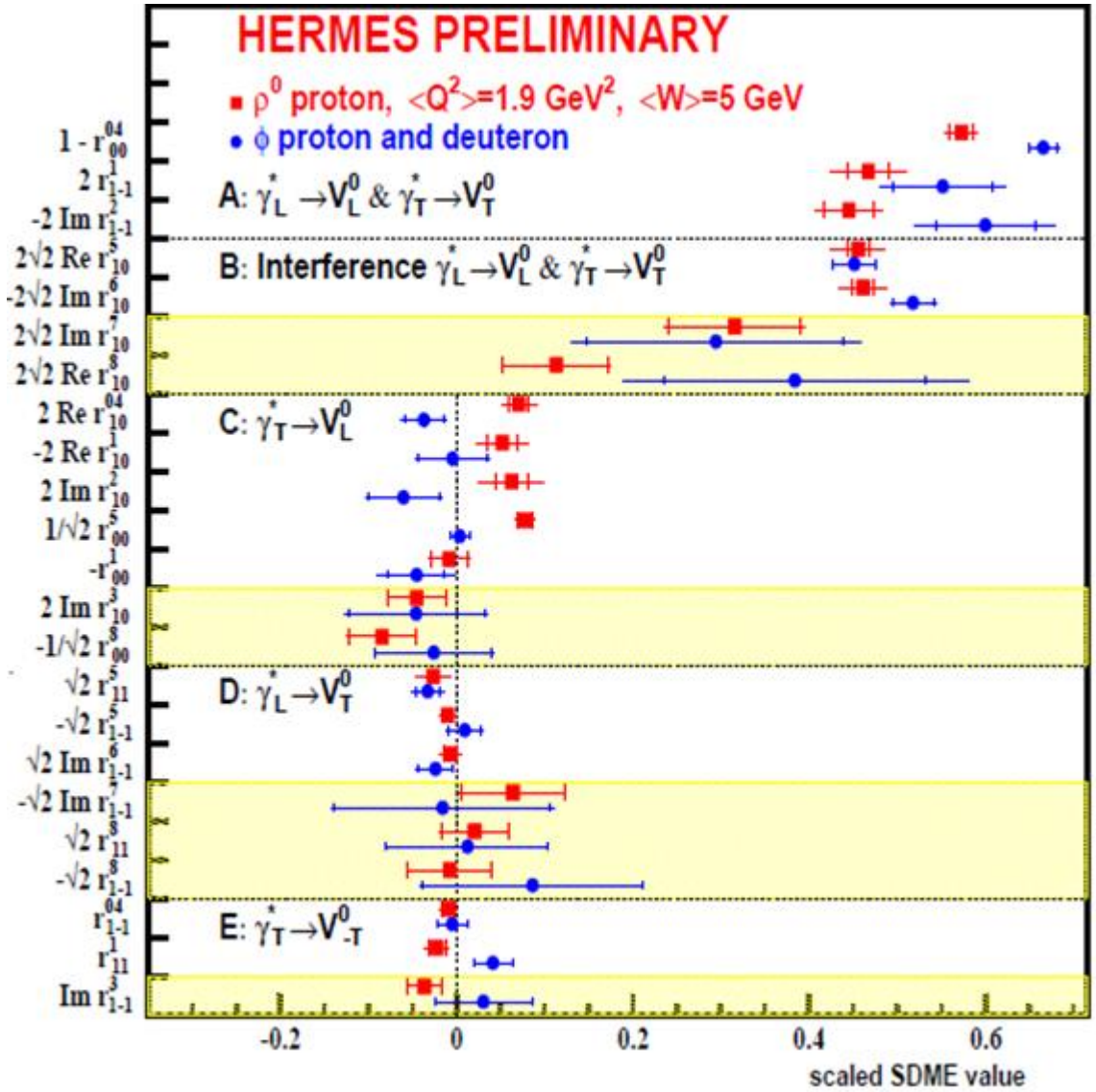
- Unpolarized (white areas) and beam-polarized (green areas) SDMEs
- Squares are proton, circles are deuteron data
- s-channel helicity conservation (conservation the helicity of γ^* $\gamma_L^* \to \rho_L^0$ and $\gamma_T^* \to \rho_T^0$)
- s-channel helicity violation significant $\gamma_T^* \to \rho_L^0$, not so significant $\gamma_{-T}^* \to \rho_T^0$ and $\gamma_L^* \to \rho_T^0$
- Unnatural parity exchange – non-zero combinations

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

$$u_2 = r_{11}^{5} + r_{1-1}^{5}$$

$$u_3 = r_{11}^{8} + r_{1-1}^{8}$$

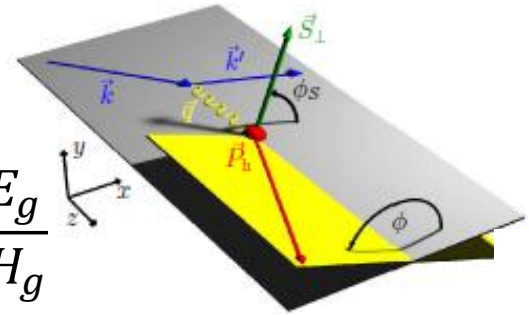
Comparison of φ and ρ^0 SDMEs



- Unpolarized (white areas) and beam-polarized (yellow areas) SDMEs
- Squares are proton data for ρ^0, circles are deuteron data for φ
- No statistically significant difference between proton and deuterium
- No s-channel helicity violation for φ meson
- Amplitudes hierarchy for φ meson: $|T_{00}| \sim |T_{11}|$, $|T_{01}| \approx |T_{10}| \approx |T_{-11}| \approx |U_{11}| \approx 0$.

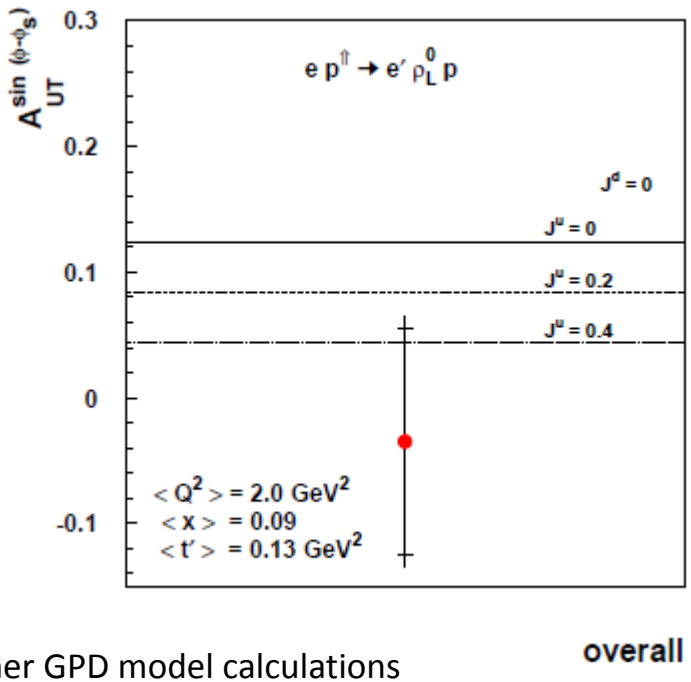
The target-spin asymmetry for ρ^0 production

Theoretically:

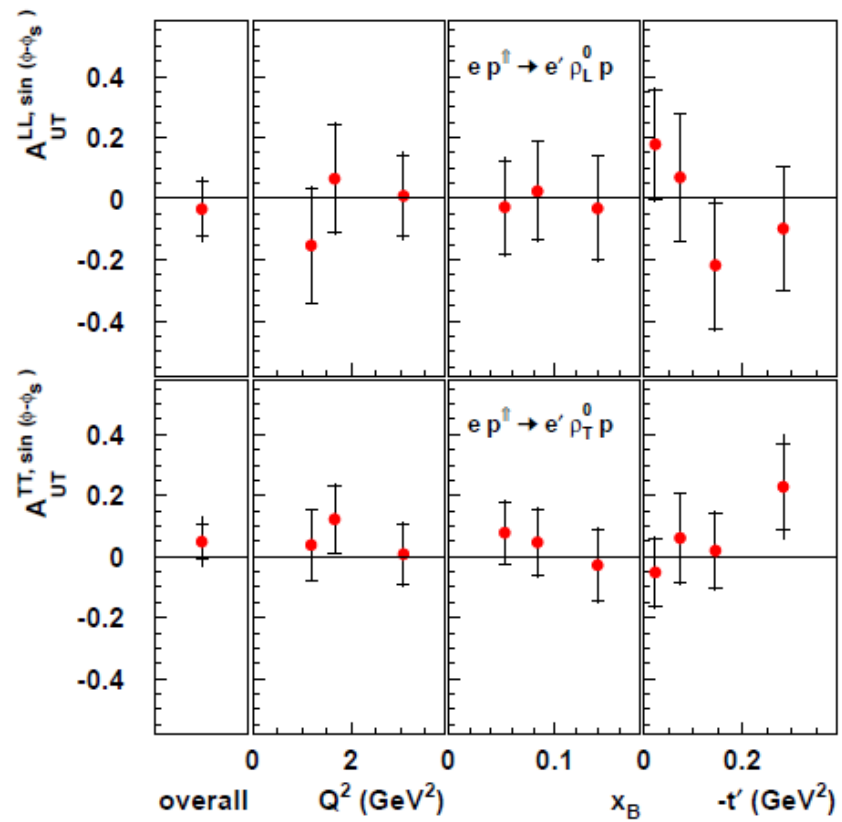


$$A_{UT}^{\sin(\phi-\phi_S)} \sim \frac{E}{H} \sim \frac{E_q \oplus E_g}{H_q \oplus H_g}$$

Ellinghaus, Nowak, Vinnikov, Ye (2004)



Experimentally:



Phys. Lett. B679 (2009) 100-105, arXiv:0906.5160

other GPD model calculations

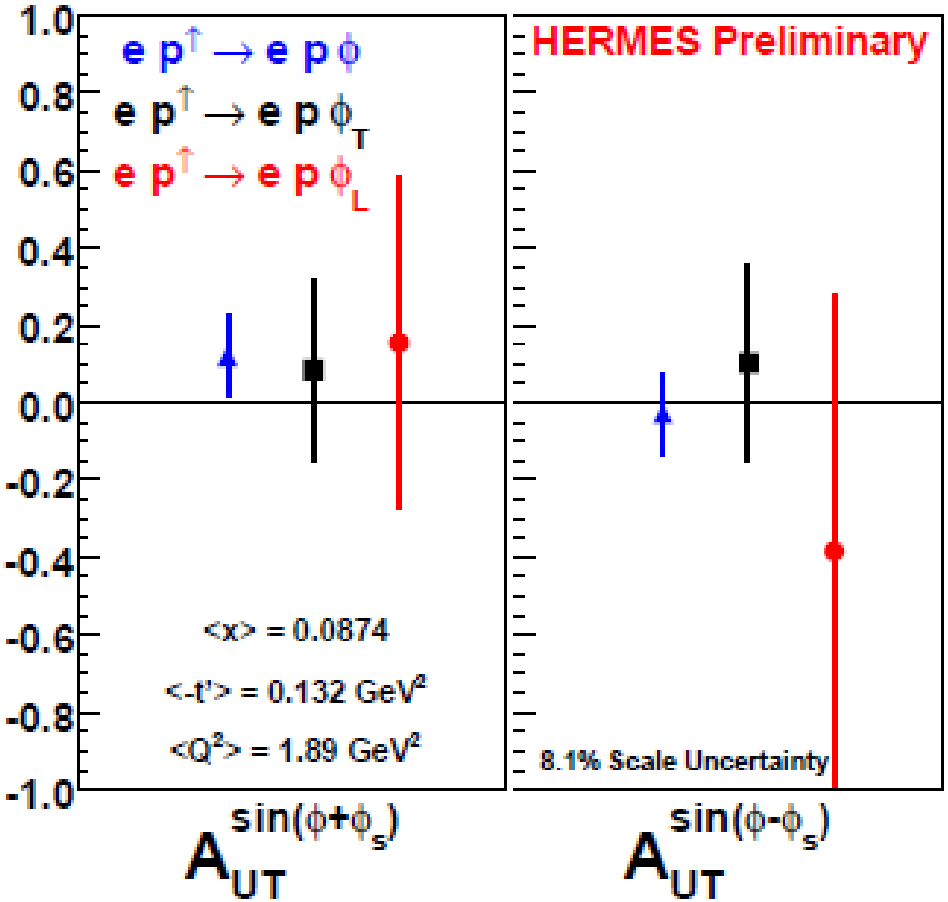
- Goeke, Polyakov, Vanderhaeghen (1999)-

-Goloskokov, Kroll (2007)-

-Diehl, Kugler (2008)-

Compatible with zero overall value: $A_{UT}^{\rho_L^0,\sin(\phi-\phi_S)} = -0.033 \pm 0.058$

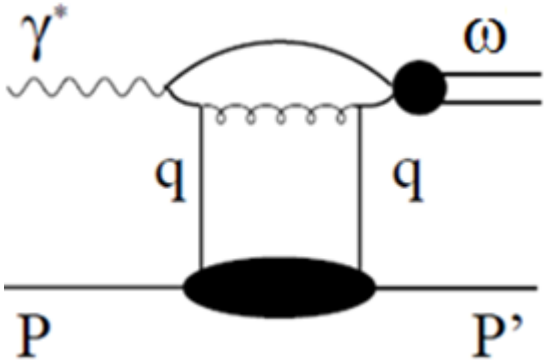
The target-spin asymmetry for φ production

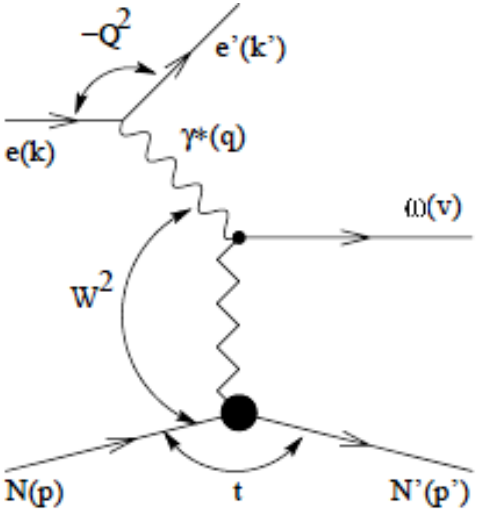


- Low statistic
- Small overall value, what is in agreement with theory predictions

ω meson production

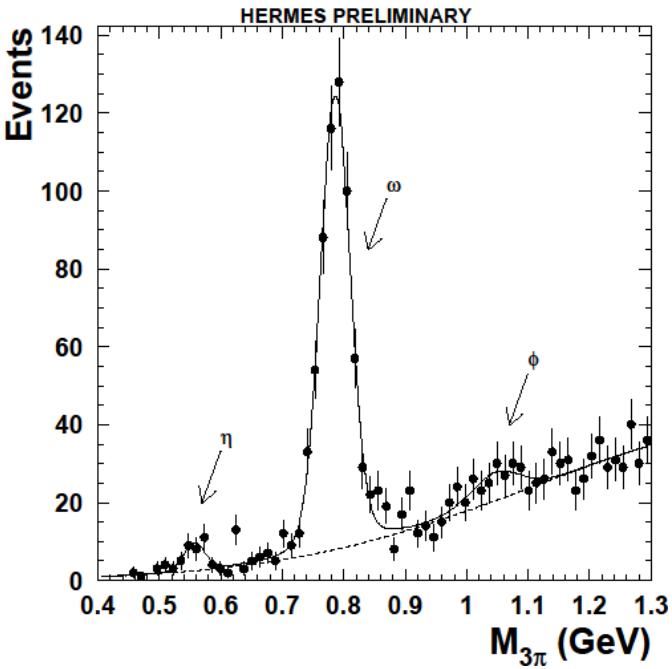
$$ep \rightarrow e'p\omega, \omega \rightarrow \pi^+\pi^-\pi^0, \pi^0 \rightarrow \gamma\gamma$$



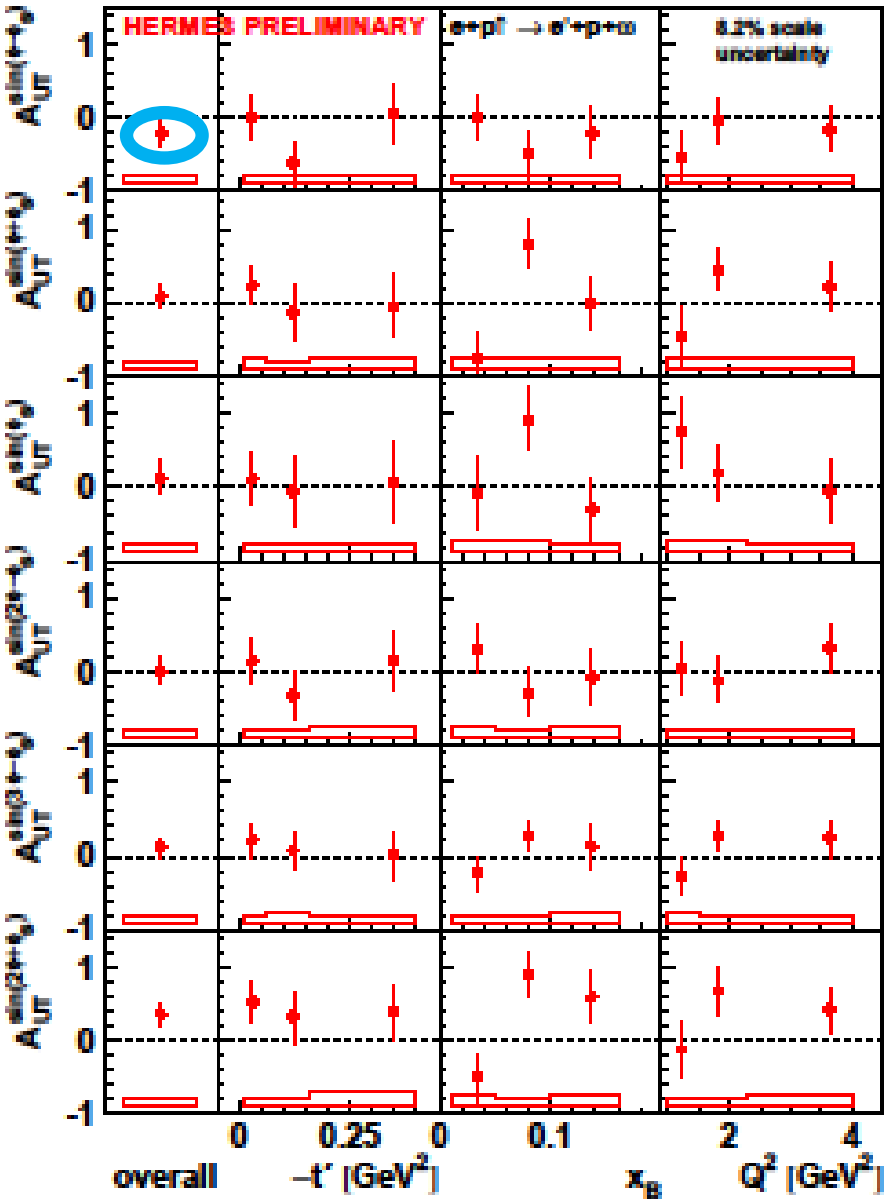


Kinematic cuts:

- $1 < Q^2 < 7\ GeV^2$
- $3 < W^2 < 6.3\ GeV^2$
- $t` < 0.4\ GeV^2$
- $\Delta E < 0.6$ GeV
- $0.1 < M_{2\gamma} < 0.17$ GeV



The target-spin asymmetry for omega production



Large negative asymmetry amplitude

$$A_{UT}^{\sin(\phi-\phi_S)} = -0.22 \pm 0.16_{stat} \pm 0.11_{syst}$$

Summary

- Extraction of unpolarized and polarized SDMEs on unpolarized proton and deuteron
  - For ρ^0 and φ compatible results on proton and deuteron
  - Helicity amplitudes hierarchy for ρ^0 and φ mesons presented
  - s-channel helicity conservation for φ
  - s-channel helicity violation for ρ^0
  - NPE for φ
  - Contribution from UPE for ρ^0
- A_{UT} for ρ^0 , φ, ω

- Small values for ρ^0 and φ - confirmation theory expectation
- Significantly negative value for ω, which is in agreement with theoretical predictions