Exclusive Vector Meson Production and DVCS at HERMES

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on behalf of the

hermes Collaboration

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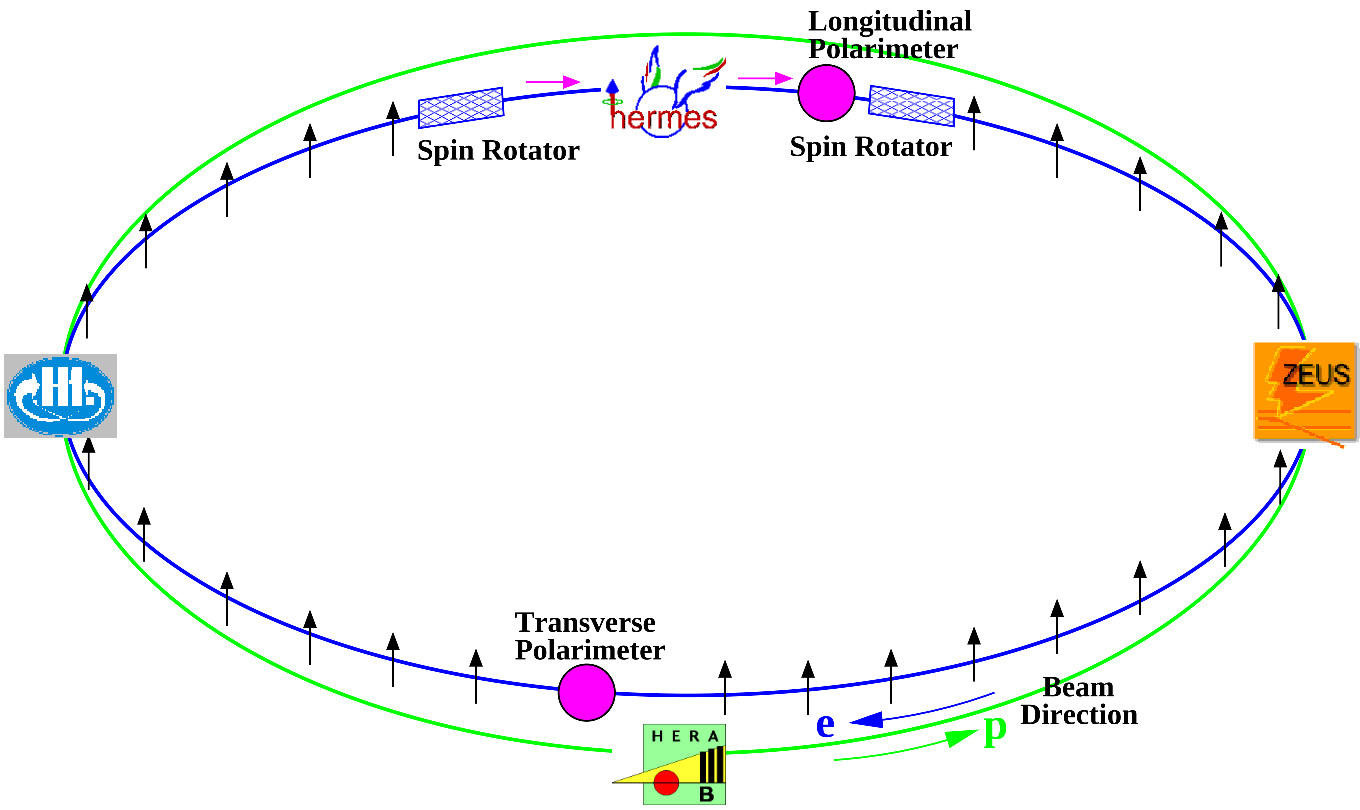
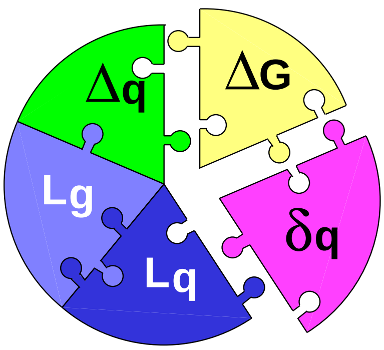
- The HERMES experiment
- Exclusive physics and GPD formalism
- Vector meson production at HERMES
- DVCS measurements at HERMES
- Summary & outlook

The HERMES Experiment

- **HERA** experiment with 27.5 GeV $\vec{e}$ beam
- Internal gas targets, polarized: H, D, He ($\sim 10^{14}\ nucl/cm^2$)

  unpolarized: $H,\ D,\ He,\ N\ , Ne,\ Kr$ ($\sim 1 \div 5 \cdot 10^{15}\ nucl/cm^2$)





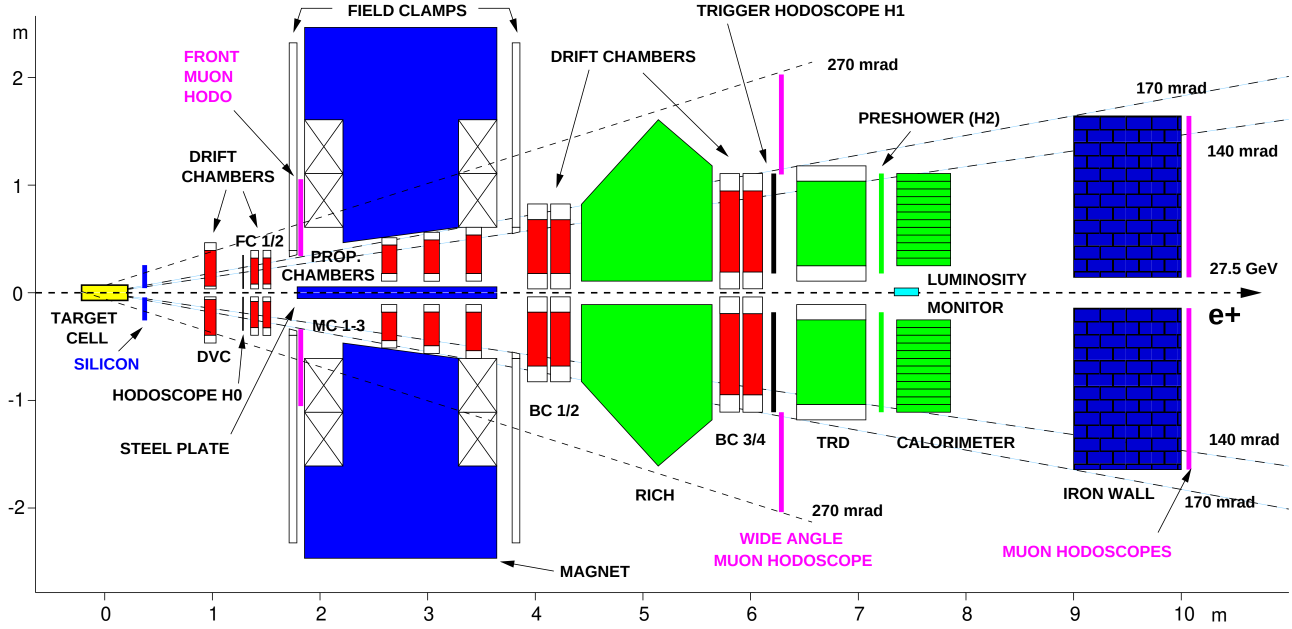
Spin of nucleon $J = \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g$

Beam polarization $40 - 60\%$

Target polarization $\sim 88\%$

HERMES-I data (1996-2000) $\sim 1 fb^{-1}/nucl$

The HERMES Spectrometer



- Forward spectrometer with acceptance $40 < \theta < 220$ **mrad**,

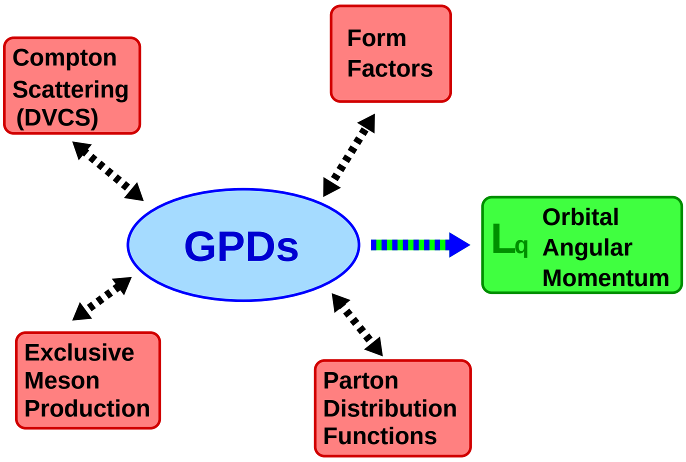
  momentum and angular resolutions: $\delta P/P \sim 1\%$, $\delta\theta < 0.6$ **mrad**

- Electromagnetic calorimeter: $\Delta E/E\ (\%) = 1.5 + 5.1/\sqrt{E[GeV]}$

- Particle ID: RICH, TRD, Preshower, Calorimeter

- Electron identification: efficiency $> 98\%$, hadron contamination $< 1\%$

Exclusive Processes and GPD Formalism



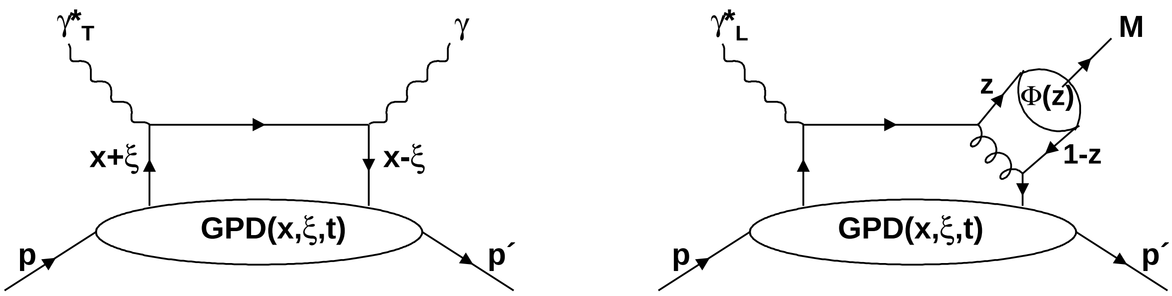
Generalized Parton Distributions :

Unified theoretical description of

hard exclusive processes.

4 GPDs on nucleon:

$$H^q(x,\xi,t)\ ,\quad \widetilde{H}^q(x,\xi,t) \qquad E^q(x,\xi,t)\ ,\quad \widetilde{E}^q(x,\xi,t)$$



Handbag diagrams for DVCS (left) and for meson production (right).

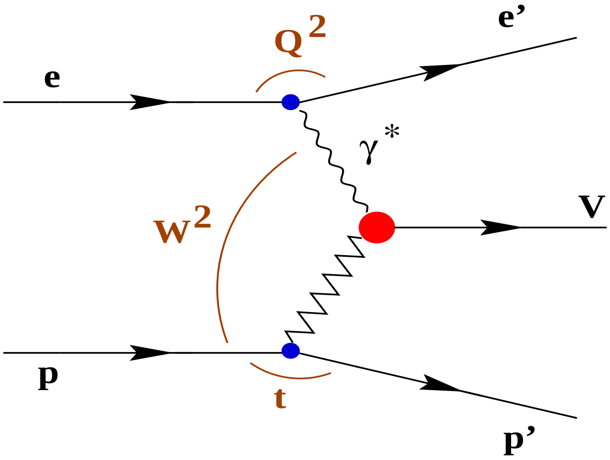
For $\xi \to 0$ and $t \to 0$: $H^q(x,0,0) = q(x), \quad \widetilde{H}^q(x,0,0) = \Delta q(x),$

First moments of GPDs $\to$ flavor dependent elastic form-factors.

Access to L_q through sum rule

$$\lim_{t\to 0} \frac{1}{2}\int_{-1}^{+1} dx\, x\, \left[H^q(x,\xi,t) + E^q(x,\xi,t)\right] = J^q$$

Exclusive Vector Meson Production

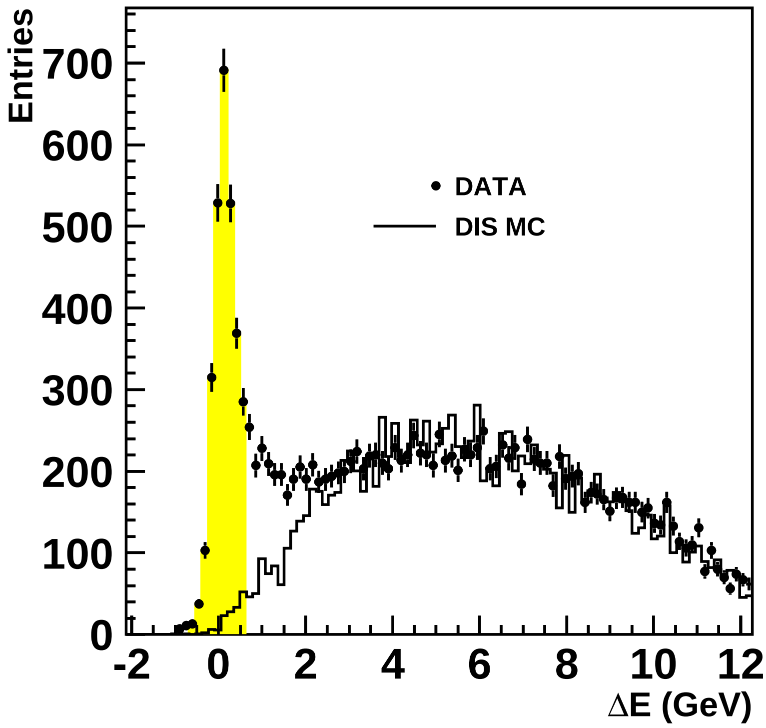


$\rho(770) \to \pi^+\pi^-(100\%)$

$\omega(782) \to \pi^+\pi^-\pi^o(89.1\%)$

$\phi(1020) \to K^+K^-(49.2\%)$

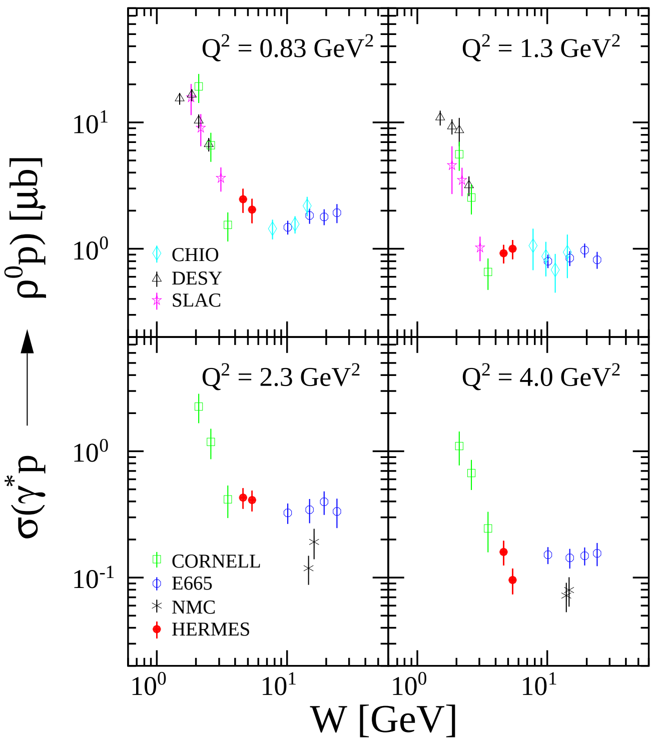
$$\Delta E = \frac{M_X^2 - M^2}{2M} \quad M_X^2 = (p_p + p_{\gamma^*} - p_v)^2 \quad \Delta E < 0.4 \text{ GeV}$$

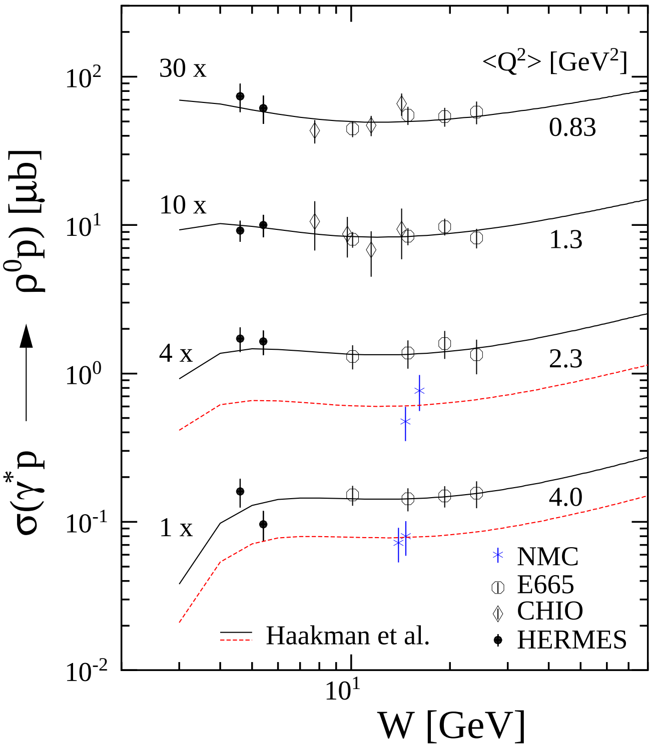


$0.6 < Q^2 < 6 \ \text{GeV}^2 \qquad 3 < W < 6.5 \text{ GeV}$

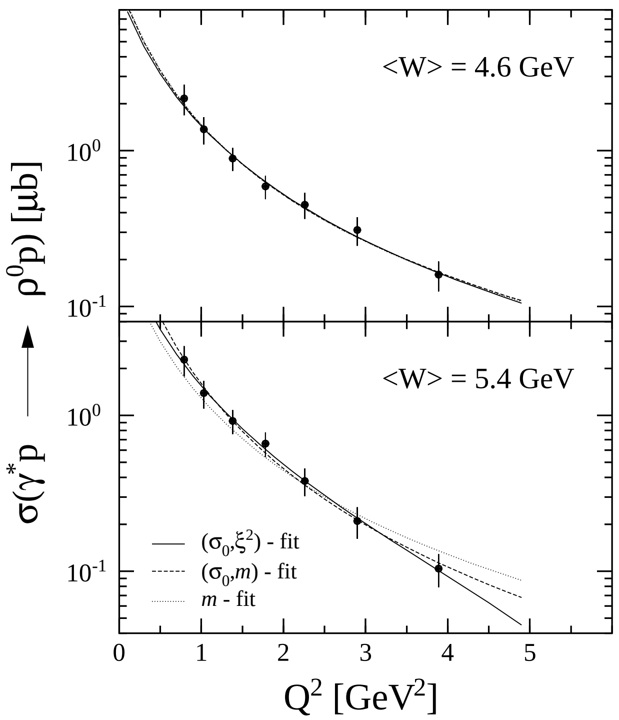
- Cross-sections (σ, σ_L) EPJ, C17(2000),389; C18(2000),303
- Spin effects PL, B513(2001),301; EPJ, C29(2003),171
- Nuclear effects: PRL, 82(1999),3025; 90 (2003)052501

Exclusive ρ^o Production





Exclusive ρ^o cross-section versus W. **HERMES Coll., EPJ, C18(2000),303**



$$\sigma(Q^2) = \sigma_0 \cdot \left(\frac{M_\rho^2}{Q^2+M_\rho^2}\right)^m \times$$

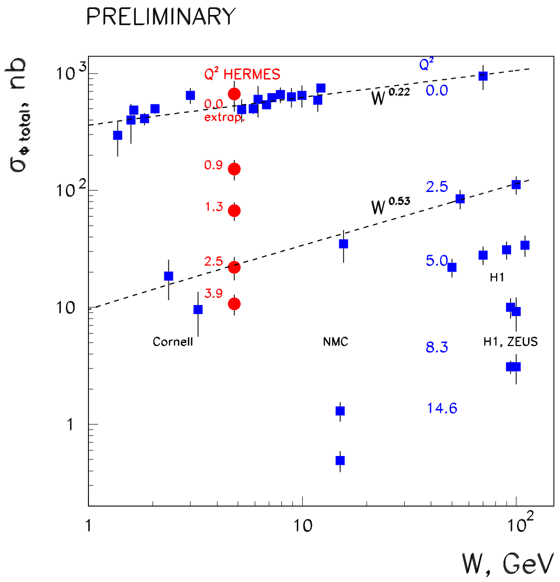
$$(1+\epsilon R(Q^2))$$

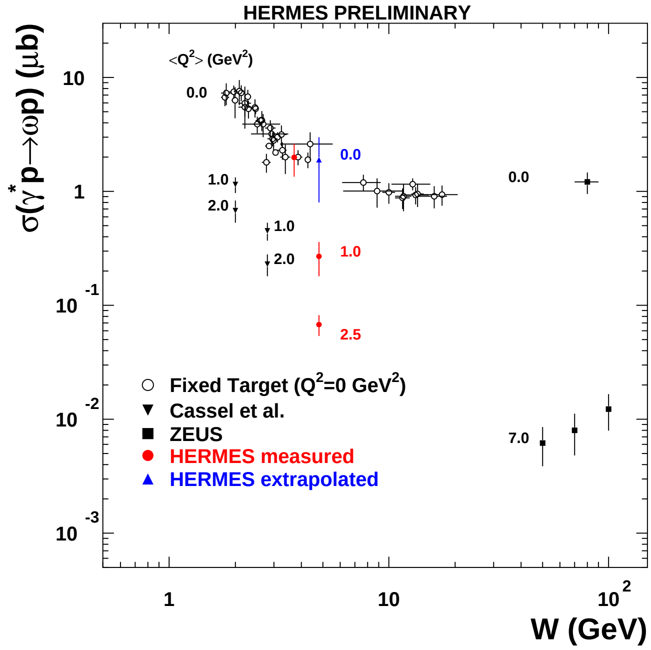
$$R = c_0(W)\cdot(Q^2/M_\rho^2)^{c1}$$

$$m = 2.44 \pm 0.05 \quad 2.46 \pm 0.05$$

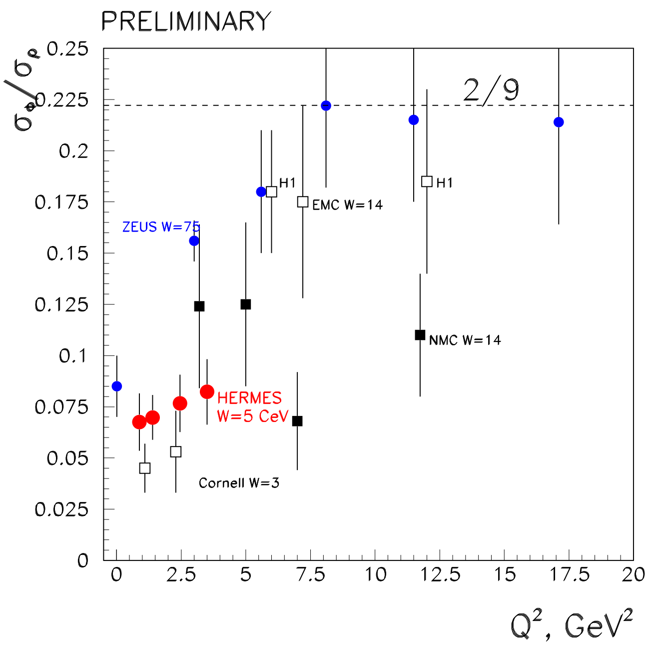
$\langle W\rangle$= 4.6 5.4 GeV

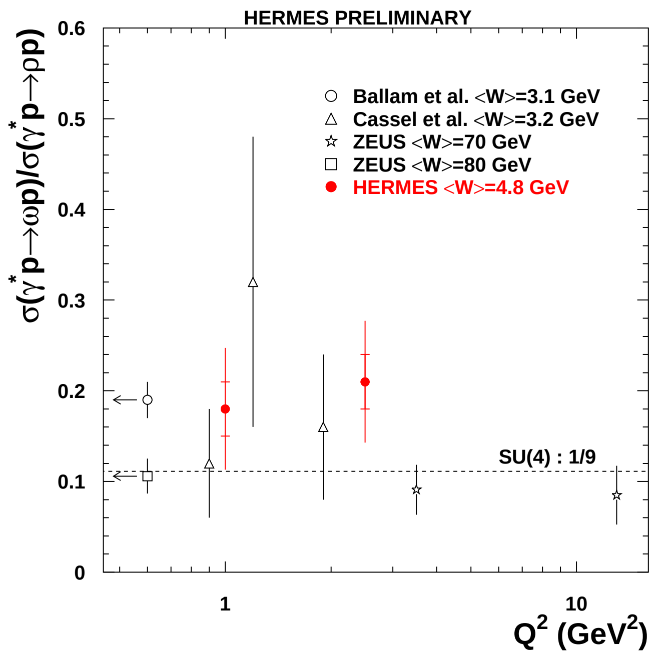
Exclusive ϕ and ω Production





ϕ and ω data. Curves in ϕ correspond to W^{δ}.

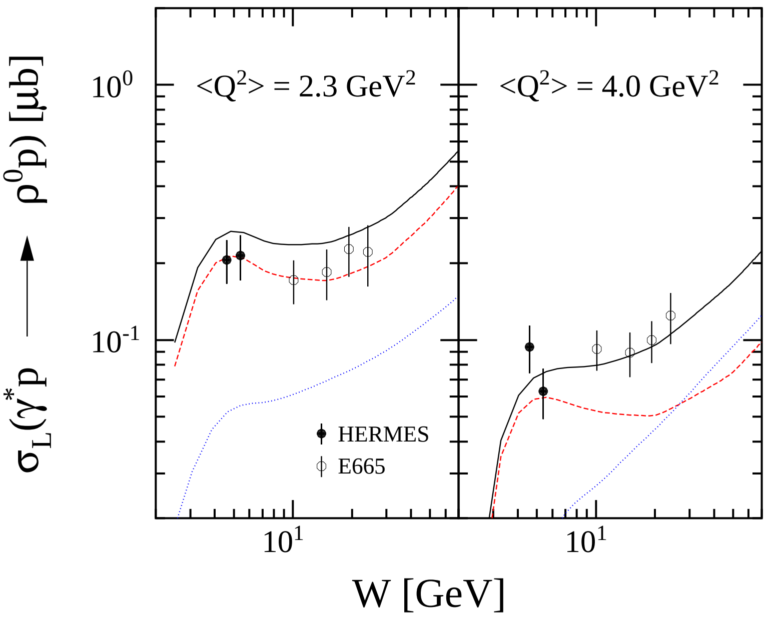




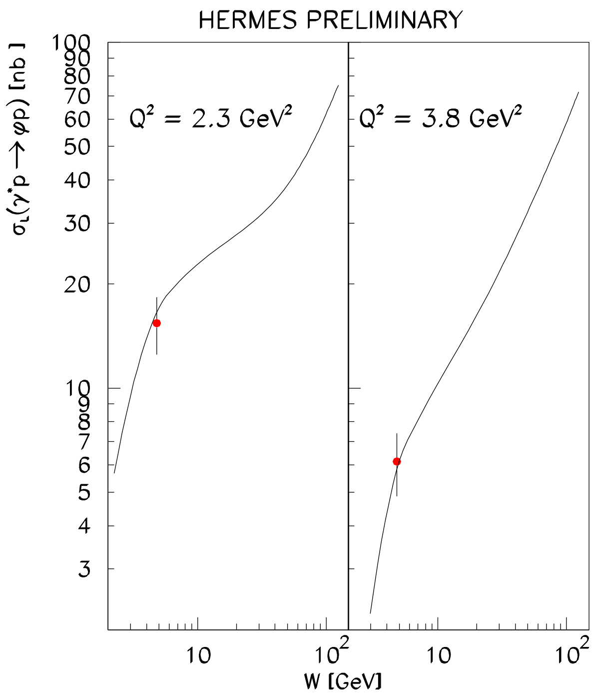
Asymptotic SU(4) $pQCD$ prediction: $\rho : \omega : \phi = 9 : 1 : 2$

Longitudinal Cross Sections for Exclusive ρ and ϕ

HERMES Coll., EPJ, C18(2000),303



GPD calculations for quark and 2-gluon exchange.



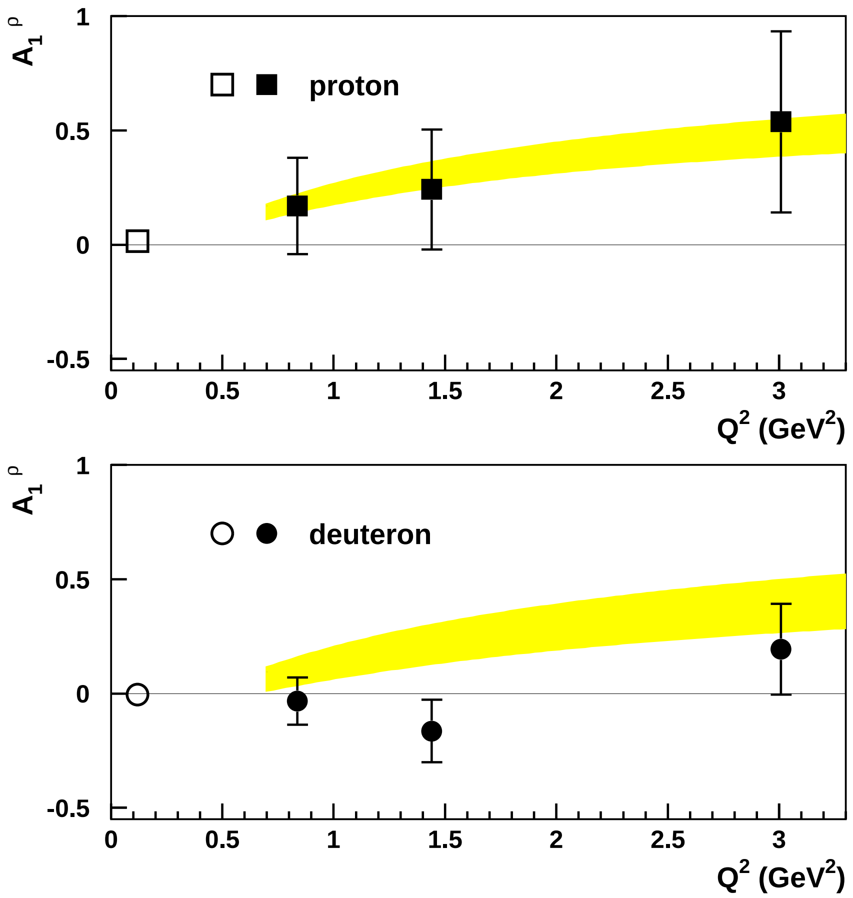
curve: 2-gluon exchange.

M.Vanderhaeghen et al., PRL, 80(1998),5064,

Double-spin Asymmetry of Exclusive ρ^o

HERMES Coll., EPJ, C29(2003),171

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$



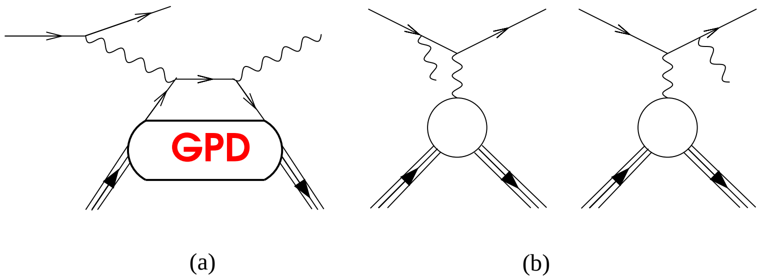
Open symbols: quasi-real photoproduction.

Shaded area: range for the theoretical predictions.

N.Kochelev et al., PR, D61,(2000),094008; D65,(2002),097504;

Y.Oh et al., *PR*, D62,(2000),17504

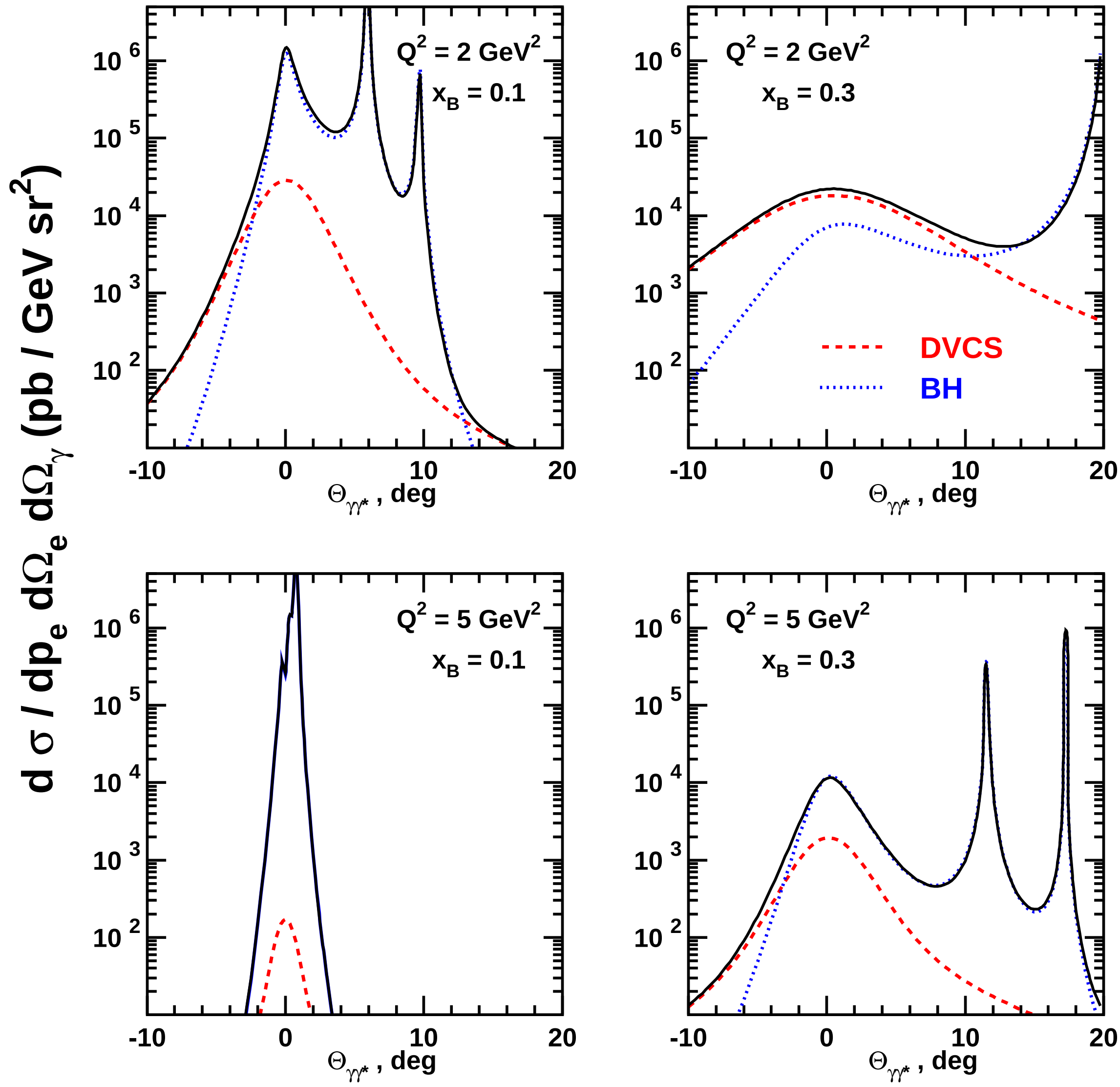
Single Photon Electroproduction



a) Deeply Virtual Compton Scattering (DVCS)

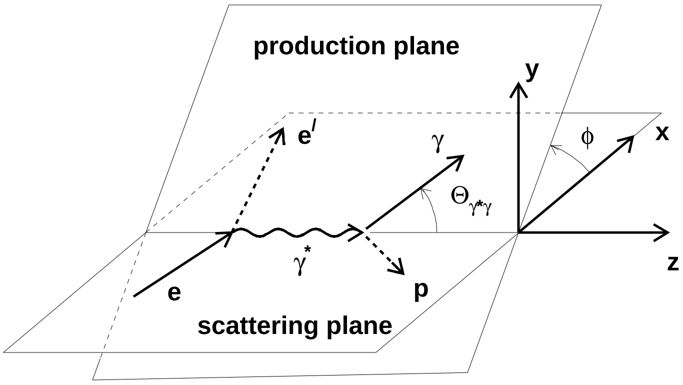
b) Bethe-Heitler (BH)

E= 27.5 GeV



DVCS Associated Asymmetries

DVCS asymmetries $\Rightarrow$ interference term of DVCS-BH amplitude.



- Beam-spin asymmetry:

$$d\Delta\sigma_{LU} \equiv d\sigma(\overrightarrow{e}p) - d\sigma(\overleftarrow{e}p) \sim \sin(\phi) \times Im A_1$$

- Target-spin asymmetry:

$$d\Delta\sigma_{UL} \equiv d\sigma(e\overrightarrow{d}) - d\sigma(e\overleftarrow{d}) \sim \sin(\phi) \times Im A_2$$

- Beam-charge asymmetry:

$$d\Delta\sigma_{C} \equiv d\sigma(e^+p) - d\sigma(e^-p) \sim \cos(\phi) \times Re A_3$$

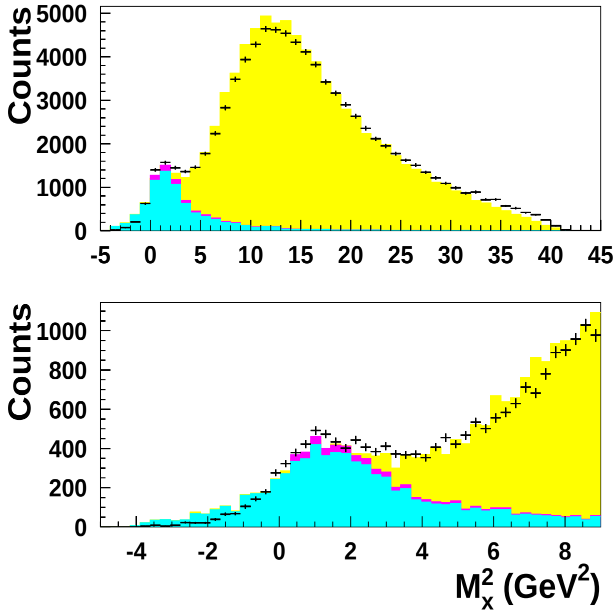
A_1, A_2 and A_3 are function of GPDs: H^q, $\widetilde{H}^q$, E^q, $\widetilde{E}^q$

Beam-spin Azimuthal Asymmetry

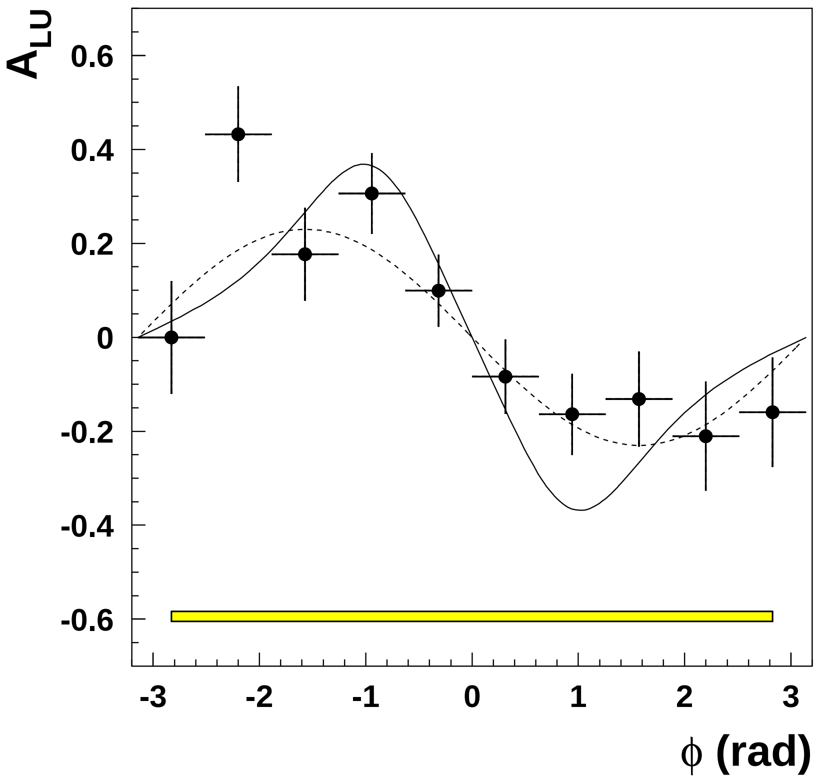
- $Q^2 > 1$, $W^2 > 4$ GeV^2, $\nu < 24$ GeV.
- $E_\gamma > 1$ GeV, $15 < \theta_{\gamma\gamma^*} < 70$ mrad
- $M_X < 1.7$ GeV, $M_X^2 = (P + q - p_\gamma)^2$

$$A_{LU} = \frac{1}{<|P_B|>} \frac{\overrightarrow{N}(\phi) - \overleftarrow{N}(\phi)}{\overrightarrow{N}(\phi) + \overleftarrow{N}(\phi)}$$

$\overrightarrow{N}$, $\overleftarrow{N}$ $\Rightarrow$ luminosity-normalized events



HERMES Coll., PRL, 87(2001),182001



Solid: N.Kivel,M.Polyakov and M.Vanderhaeghen, *PR, D63(2001), 114014*

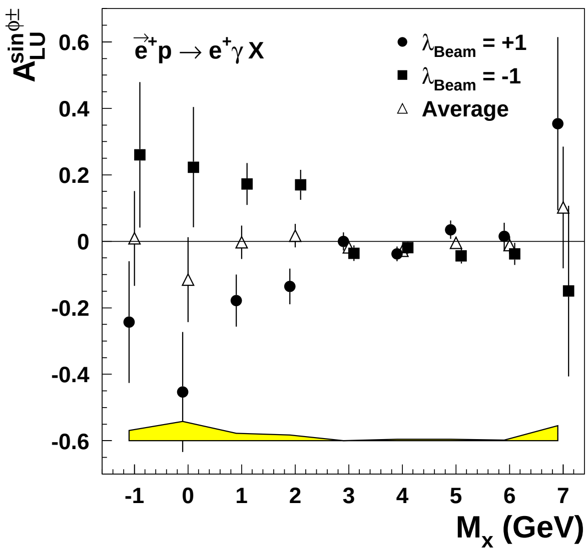
Dashed: $\sin\phi$ dependence with an amplitude of -0.23.

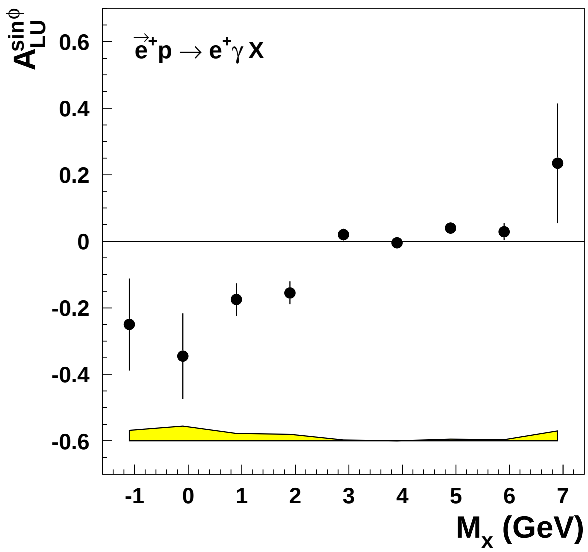
Beam-spin Asymmetry - $sin\phi$ Moments

$$\frac{2 < sin\phi >}{< |P_B| >} = \frac{2\int_o^{2\pi} d\phi(d\sigma/d\phi)sin\phi}{< |P_B| > \int_o^{2\pi} d\phi(d\sigma/d\phi)}$$

HERMES Coll., PRL, 87(2001),182001.

$$A_{LU}^{\sin\phi^{\pm}} = \frac{2}{N^{\pm}}\sum_{i=1}^{N^{\pm}}\frac{\sin\phi_i}{|P_B|_i} \qquad A_{LU}^{\sin\phi} = \frac{2}{N}\sum_{i=1}^{N}\frac{\sin\phi_i}{(P_B)_i},$$





$$A_{LU}^{\sin\phi} = -0.23 \pm 0.04(stat) \pm 0.03(syst)$$

$\langle Q^2\rangle = 2.6$ GeV^2, $\langle x_B\rangle = 0.11$, $\langle -t\rangle = 0.27$ GeV^2

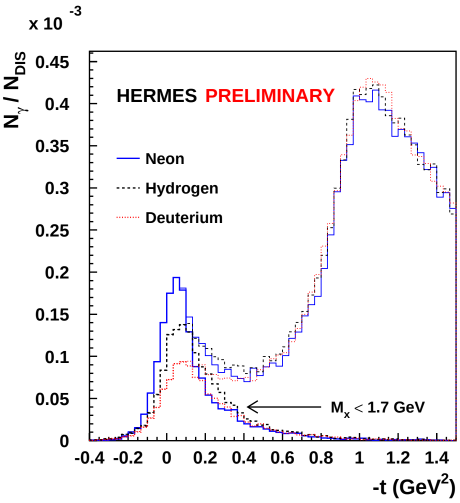
$A_{LU}^{\sin\phi}$ from: H, D, Ne, Kr

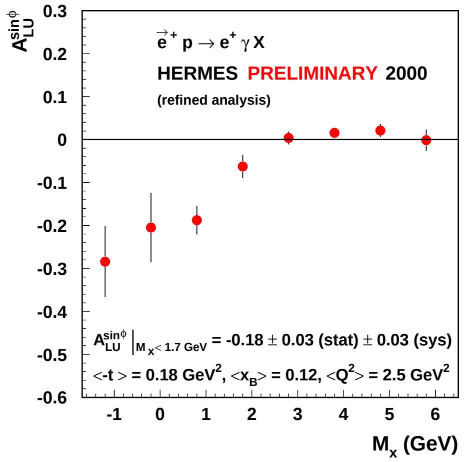
$A_{LU}^{\sin\phi}$ from:

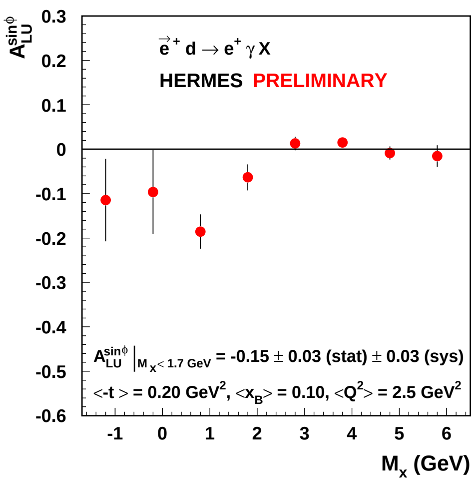
proton (spin-1/2)

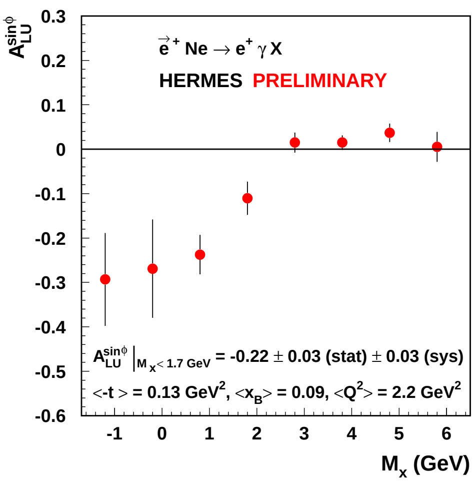
Deuteron (spin-1)

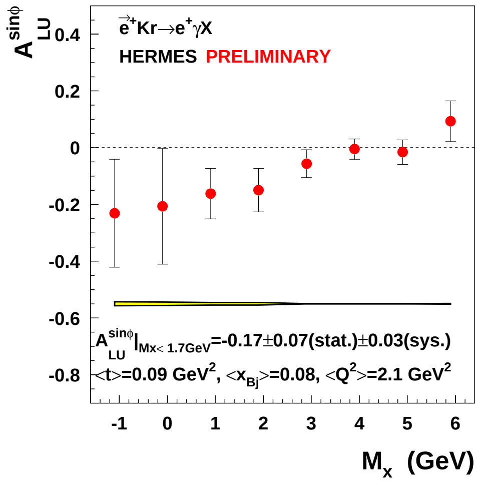
Ne, Kr (spin-0)











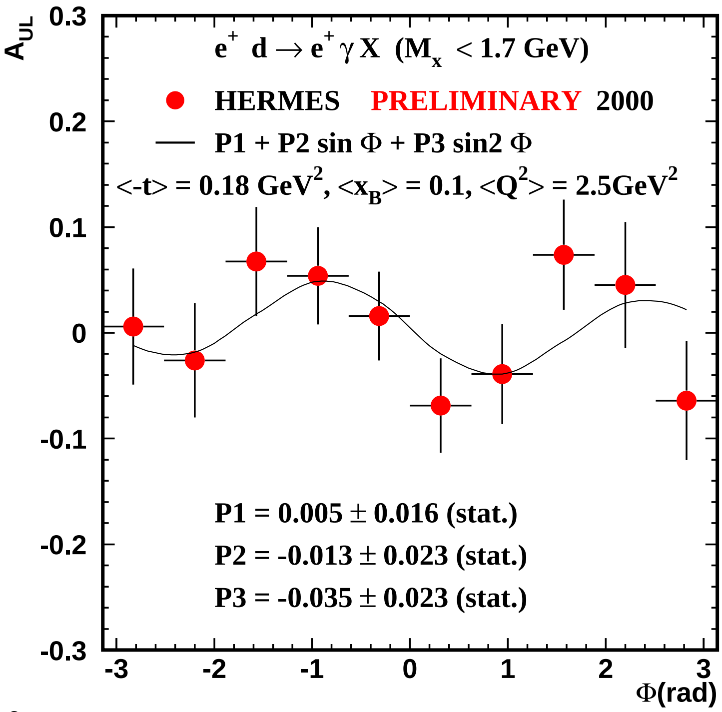
$A_{LU}^{\sin\phi}$ from different targets

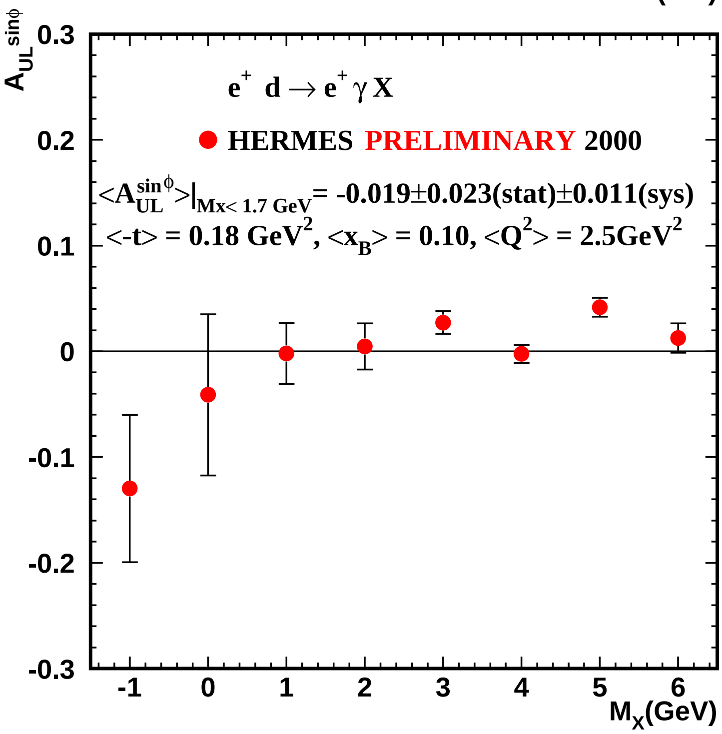
	$\langle Q^2 \rangle$ GeV ^{2}	$\langle x_{Bj} \rangle$	$\langle -t \rangle$ GeV ^{2}	$A_{LU}^{\sin\phi}$	$A_{LU}(\phi)$ fit
H	2.5	0.12	0.18	-0.18 $\pm$ 0.03$\pm$0.3	-0.18$\pm$0.03
D	2.5	0.10	0.20	-0.15 $\pm$ 0.03$\pm$0.3	-0.15$\pm$0.03
Ne	2.2	0.09	0.13	-0.22 $\pm$ 0.03$\pm$0.3	-0.22$\pm$0.02
kr	2.1	0.08	0.09	-0.17 $\pm$ 0.07$\pm$0.3	-

A.Kirchner, D.Müller, hep-ph/0302007
V.Guzey, M.Strikman, hep-ph/03-01216

Target-spin Azimuthal Asymmetry

$$A_{UL} = \frac{1}{<|P_T|>}\frac{N^{\Uparrow}(\phi)-N^{\Downarrow}(\phi)}{N^{\Uparrow}(\phi)+N^{\Downarrow}(\phi)}$$



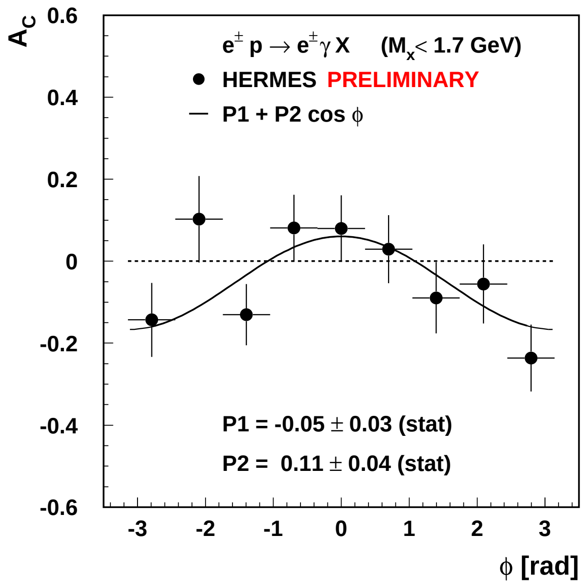


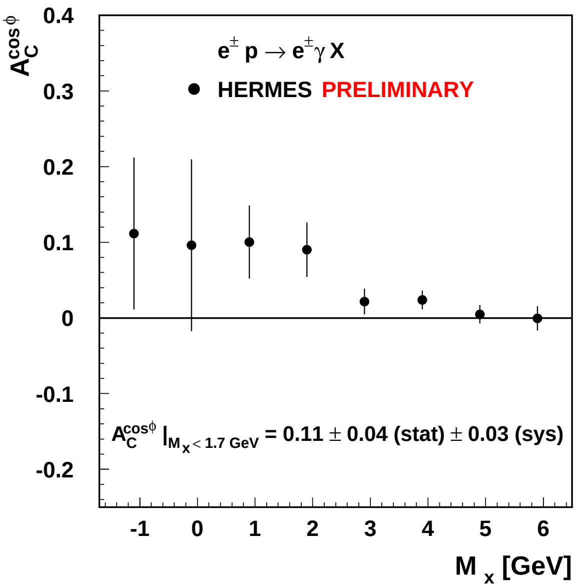
The Beam-charge Azimuthal Asymmetry

$$A_C^{cos\phi} = \frac{2\int_o^{2\pi} d\phi (d\sigma/d\phi) cos\phi}{\int_o^{2\pi} d\phi (d\sigma/d\phi)}$$

$$A_C(\phi) = \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

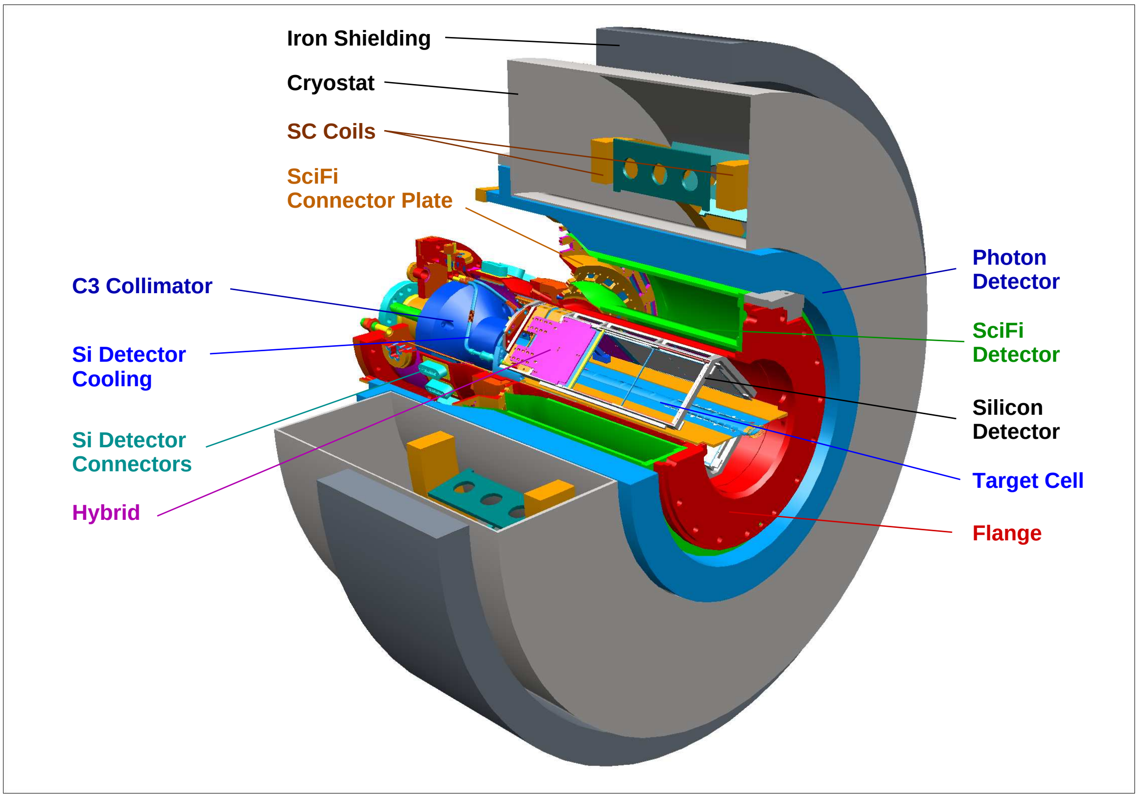
$$A_C^{\cos\phi} = \frac{A^{\cos\phi^+} - A^{\cos\phi^-}}{2}$$





$$A_C^{cos\phi} = 0.11 \pm 0.04(stat) \pm 0.03(sys)$$

HERMES Recoil Detector



- **Expected detector performance according to MC simulation :**
  - $\Rightarrow$ θ-acceptance $\rightarrow$ $0.4 - 1.35\, rad$
  - $\Rightarrow$ p-acceptance $\rightarrow$ $0.1 - 1.4\, GeV/c$
  - $\Rightarrow$ $\Delta p/p$ resolution: $\rightarrow$ $\simeq\ 10\%$
  - $\Rightarrow$ π/p PID: $\rightarrow$ $135 - 600\, MeV$
  - $\Rightarrow$ Δ suppression $\rightarrow$ 92%

Summary and Outlook

- HERMES exclusive vector meson data:

  - Total(longitudinal) cross-sections and

  - Double-spin asymmetries for ρ and ω

  consistent with theoretical (GPD) predictions.

- DVCS associated azimuthal asymmetries:

  - Beam-spin from H, D, Ne, Kr

  - Target-spin from D

  - Beam-charge from H

  in agreement with GPD predictions.

- Outlook for exclusive physics at HERMES:

  - Data from transversely polarized target

  - Measurements with Recoil Detector