

Exclusive Vector Meson Production and DVCS at HERMES

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on behalf of the



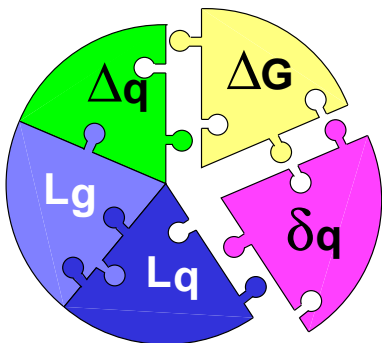
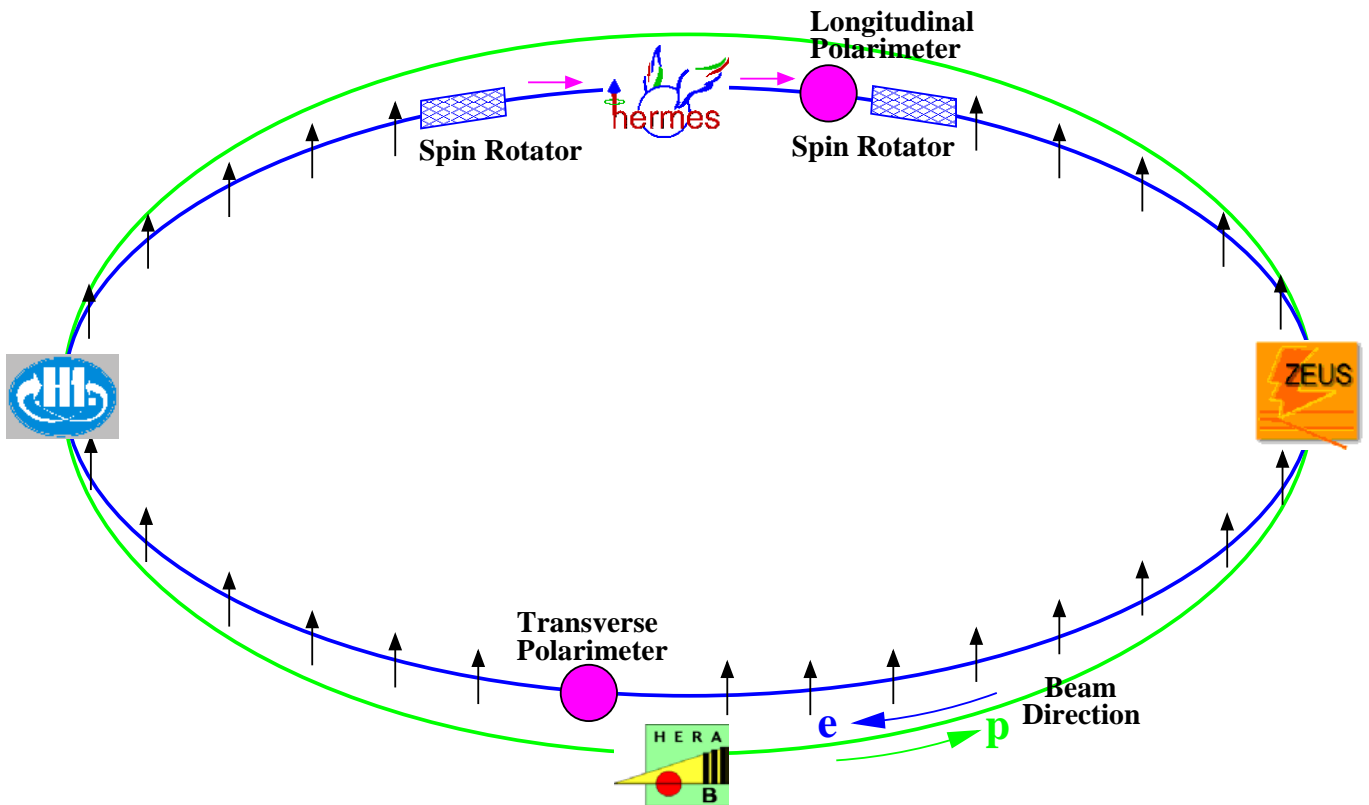
HEP2003 Europhysics Conference

Aachen, 17 - 23 July, 2003

- **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 $27.5 \text{ GeV } \vec{e}$ beam
- Internal gas targets, **polarized**: H, D, He ($\sim 10^{14} \text{ nucl/cm}^2$)
unpolarized: H, D, He, N, Ne, Kr ($\sim 1 \div 5 \cdot 10^{15} \text{ nucl/cm}^2$)



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

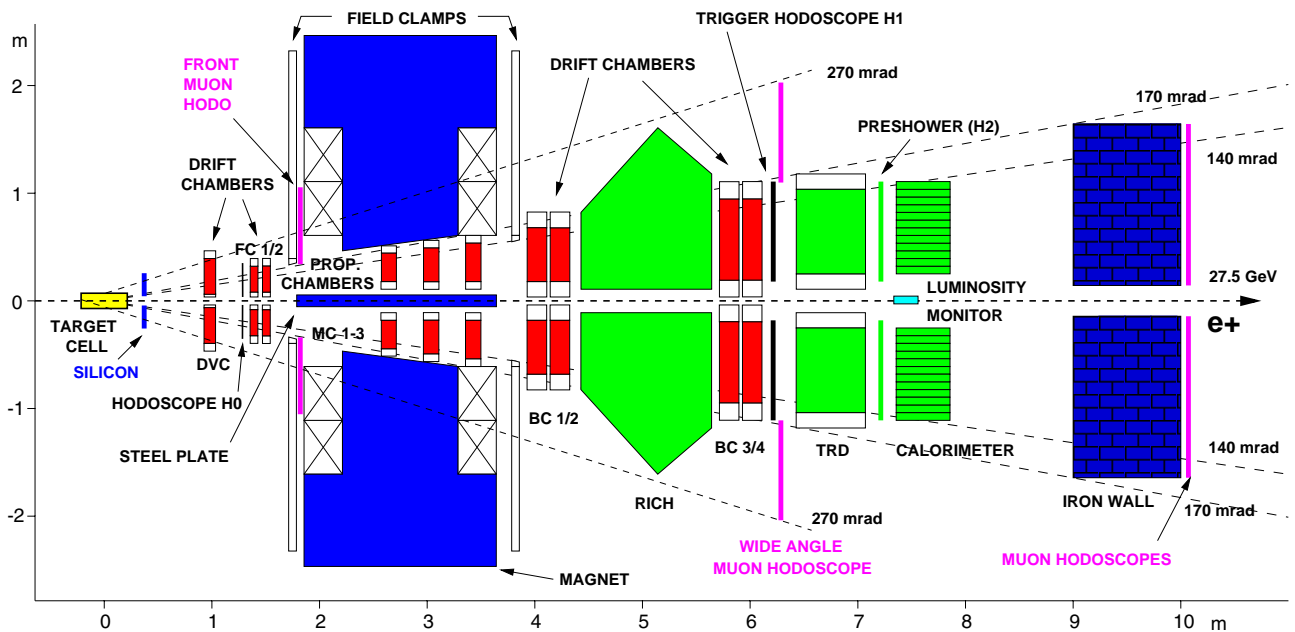
Beam polarization 40 – 60%

Target polarization $\sim 88\%$

HERMES-I data (1996-2000)

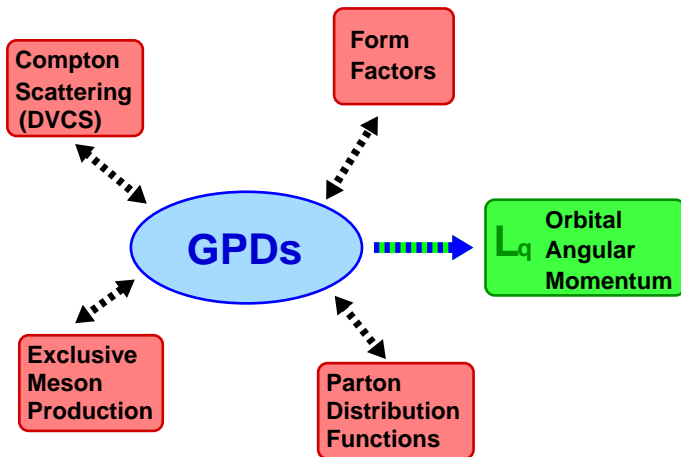
$\sim 1 \text{ fb}^{-1} / \text{nucl}$

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

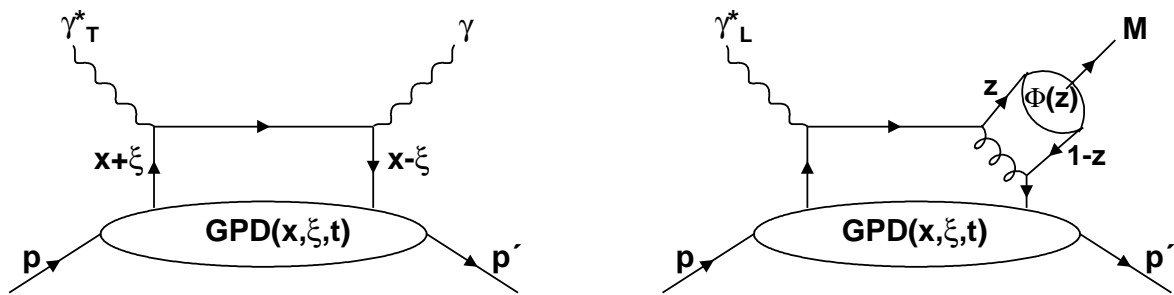


Generalized Parton Distributions :

Unified theoretical description of hard exclusive processes.

4 GPDs on nucleon:

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



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

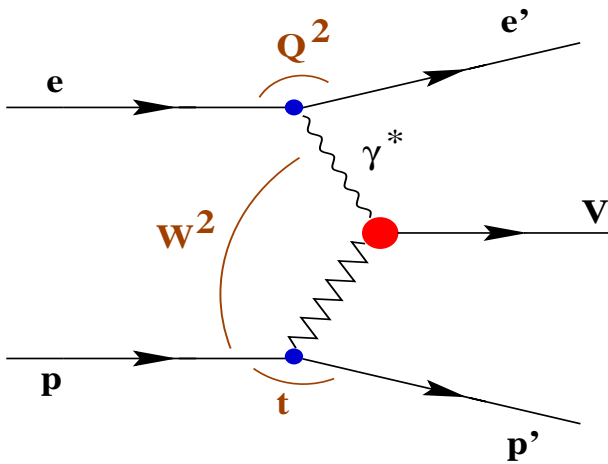
For $\xi \rightarrow 0$ and $t \rightarrow 0$: $H^q(x, 0, 0) = q(x)$, $\tilde{H}^q(x, 0, 0) = \Delta q(x)$,

First moments of **GPDs** \rightarrow flavor dependent elastic form-factors.

Access to L_q through sum rule

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

Exclusive Vector Meson Production

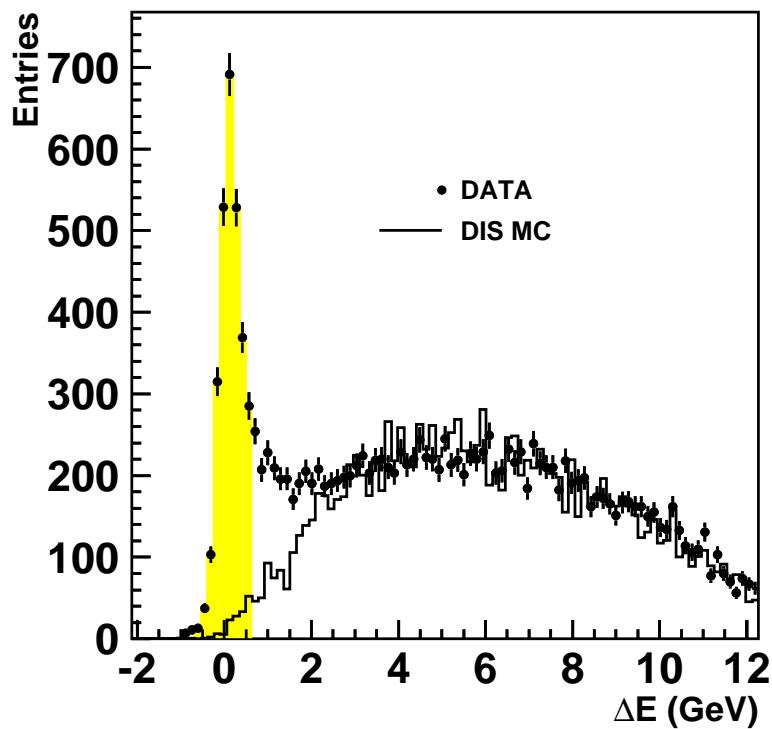


$\rho(770) \rightarrow \pi^+ \pi^- (100\%)$

$\omega(782) \rightarrow \pi^+ \pi^- \pi^0 (89.1\%)$

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

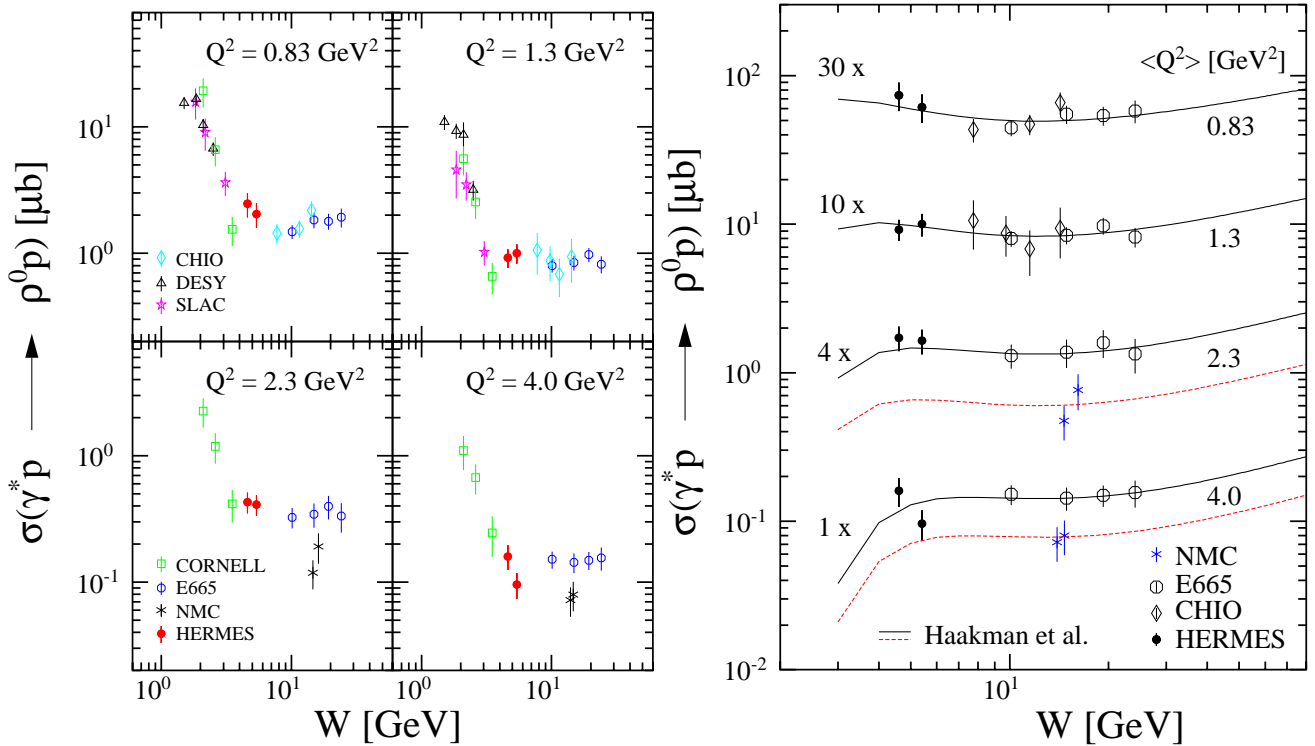
$$\Delta E = \frac{M_X^2 - M^2}{2M} \quad M_X^2 = (p_p + p_{\gamma^*} - p_v)^2 \quad \Delta E < 0.4 \text{ GeV}$$



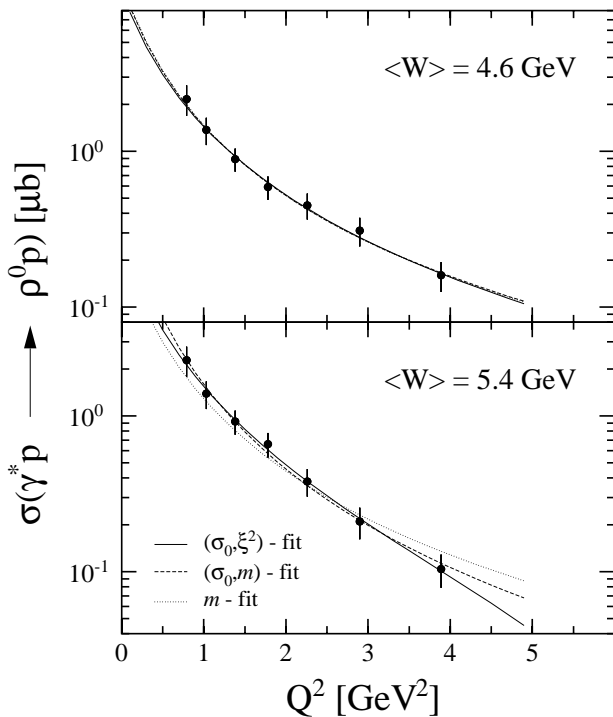
$$0.6 < Q^2 < 6 \text{ GeV}^2 \quad 3 < W < 6.5 \text{ GeV}$$

- 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^0 Production



Exclusive ρ^0 cross-section versus W . HERMES Coll., EPJ, C18(2000),303



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

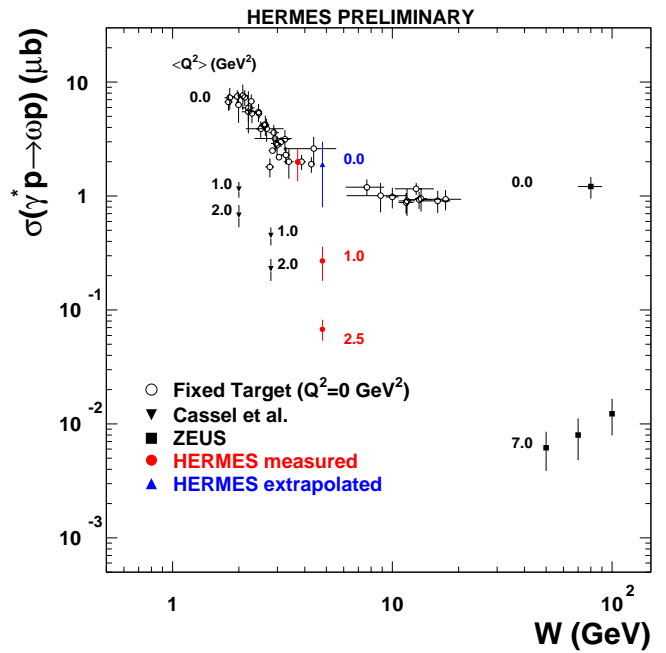
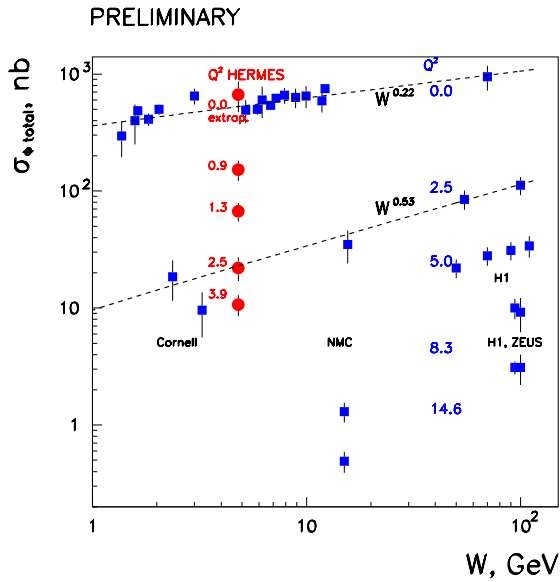
$$(1 + \epsilon R(Q^2))$$

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

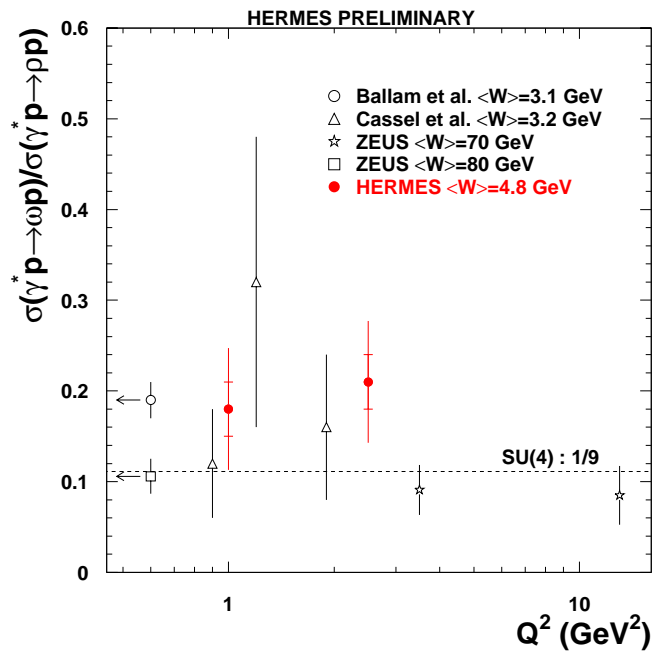
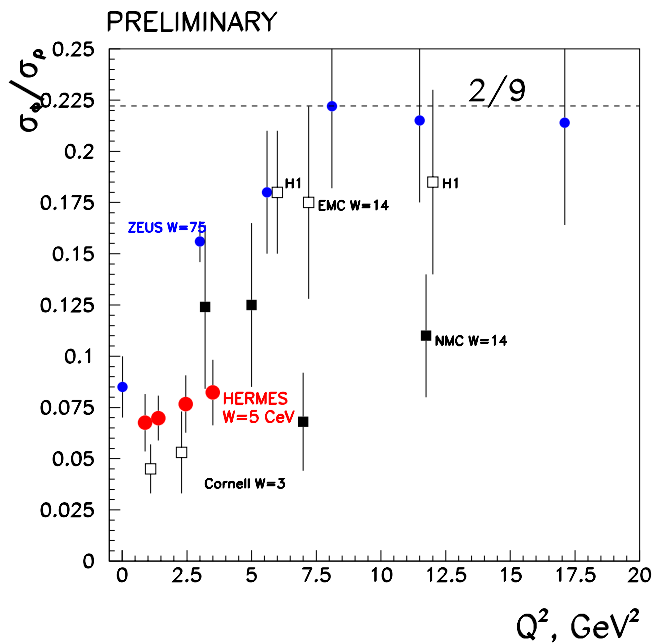
$$m = 2.44 \pm 0.05 \quad 2.46 \pm 0.05$$

$$\langle W \rangle = 4.6 \quad 5.4 \text{ GeV}$$

Exclusive ϕ and ω Production



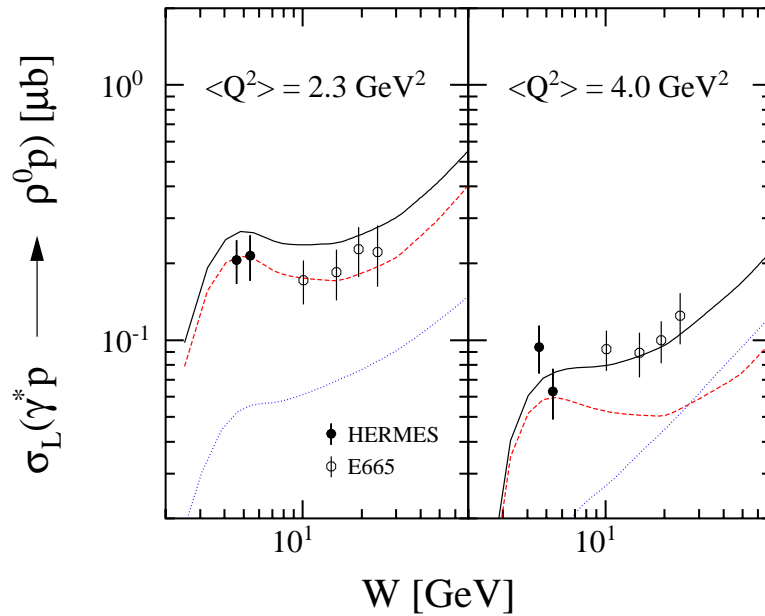
ϕ and ω data. Curves in ϕ correspond to W^δ .



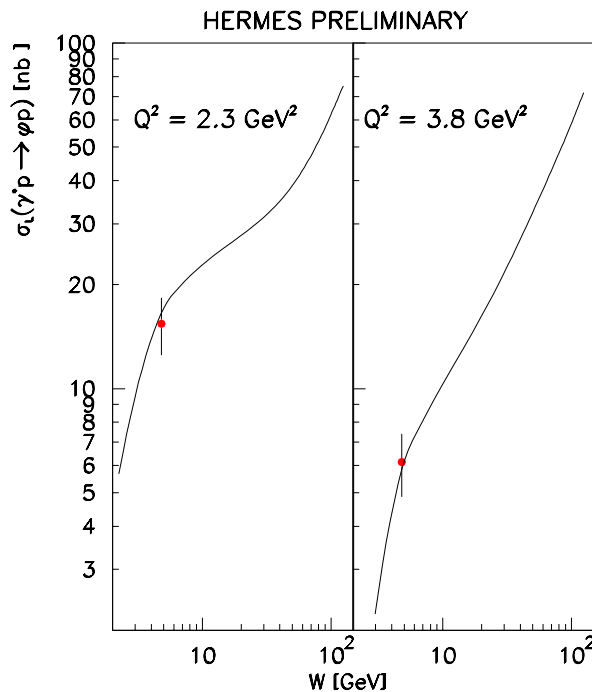
Asymptotic SU(4) $pQCD$ prediction: $\rho : \omega : \phi = 9 : 1 : 2$

Longitudinal Cross Sections for Exclusive ρ and ϕ

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



GPD calculations for quark and 2-gluon exchange.



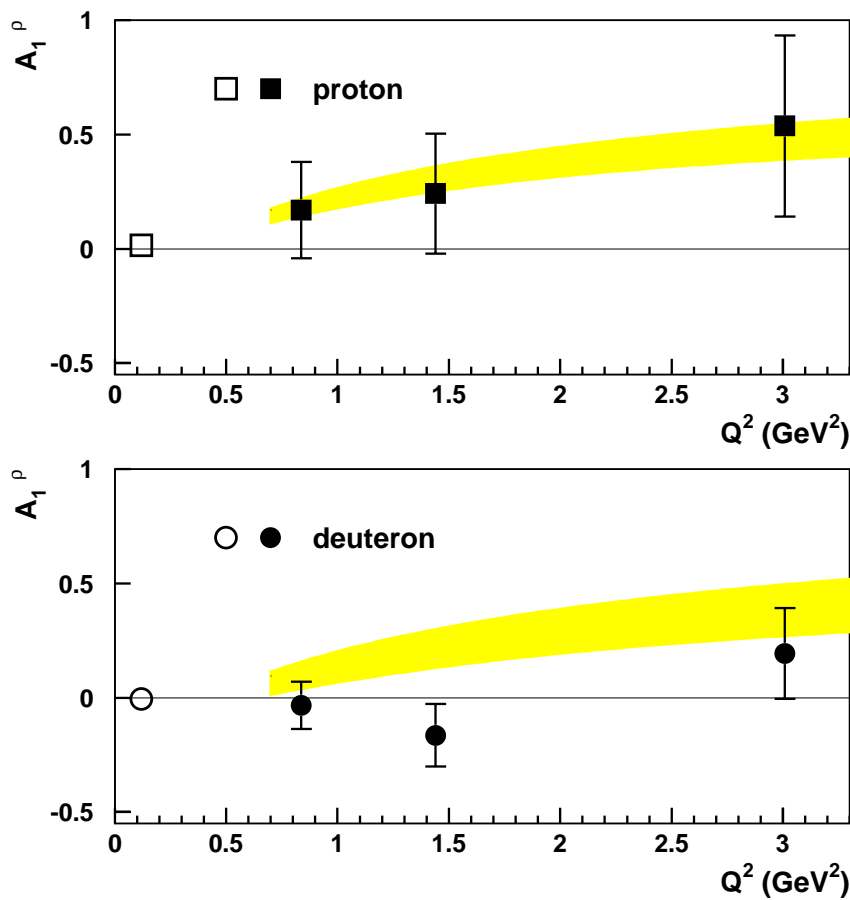
curve: 2-gluon exchange.

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

Double-spin Asymmetry of Exclusive ρ^0

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

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



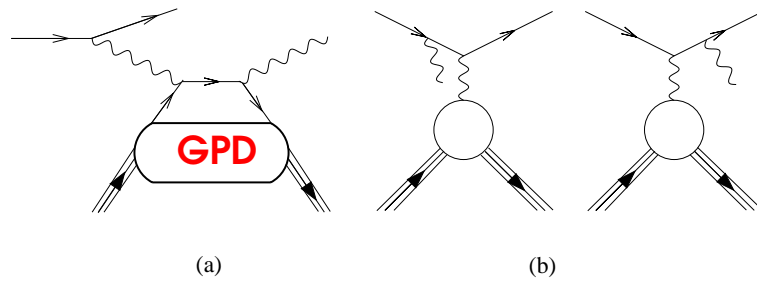
Open symbols: quasi-real photoproduction.

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

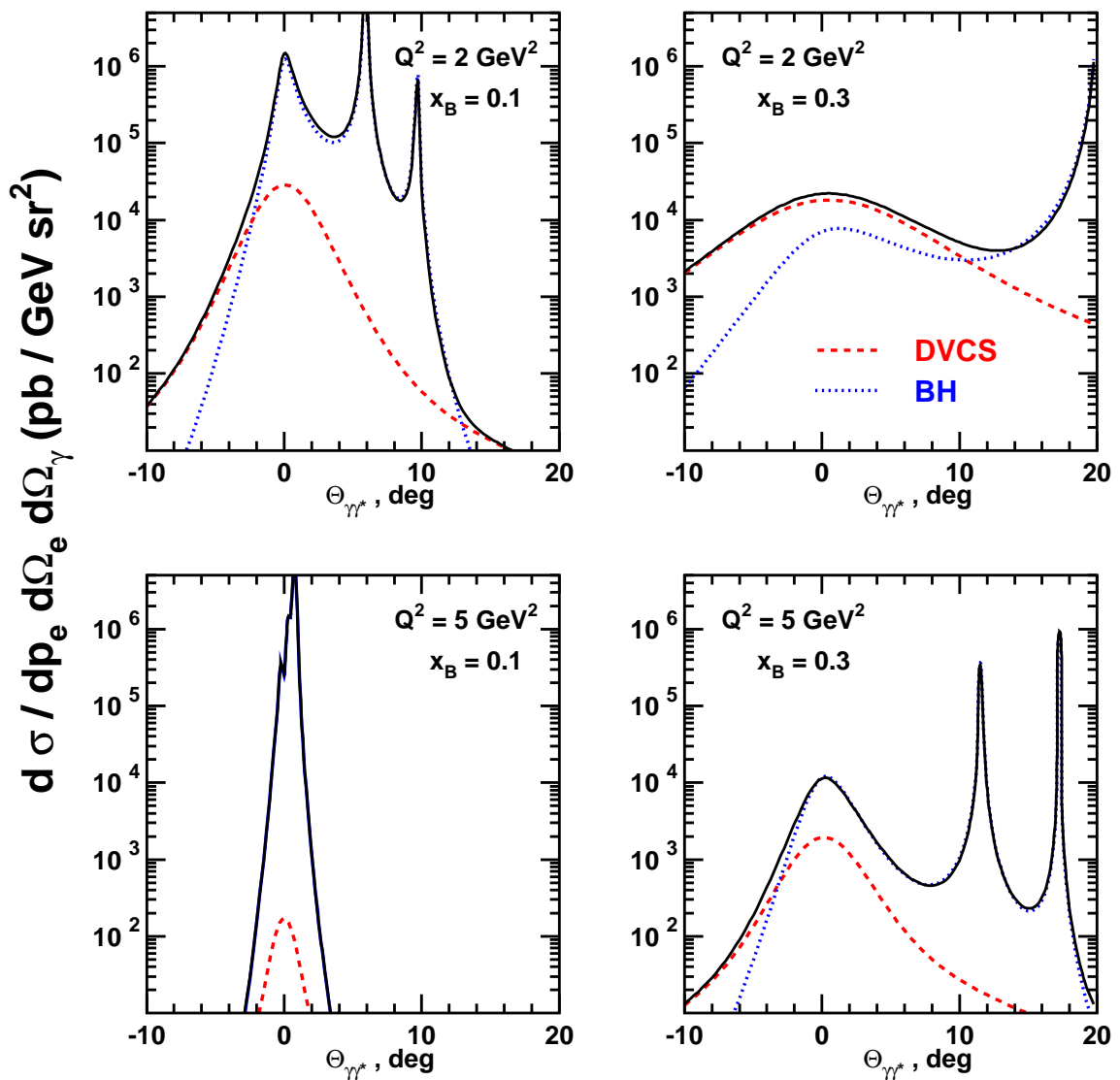
Single Photon Electroproduction



a) Deeply Virtual Compton Scattering (DVCS)

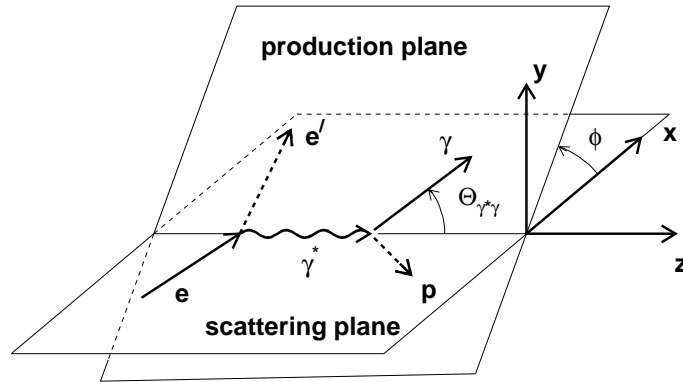
b) Bethe-Heitler (BH)

$E = 27.5 \text{ GeV}$



DVCS Associated Asymmetries

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



- **Beam-spin asymmetry:**

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

- **Target-spin asymmetry:**

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

- **Beam-charge asymmetry:**

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

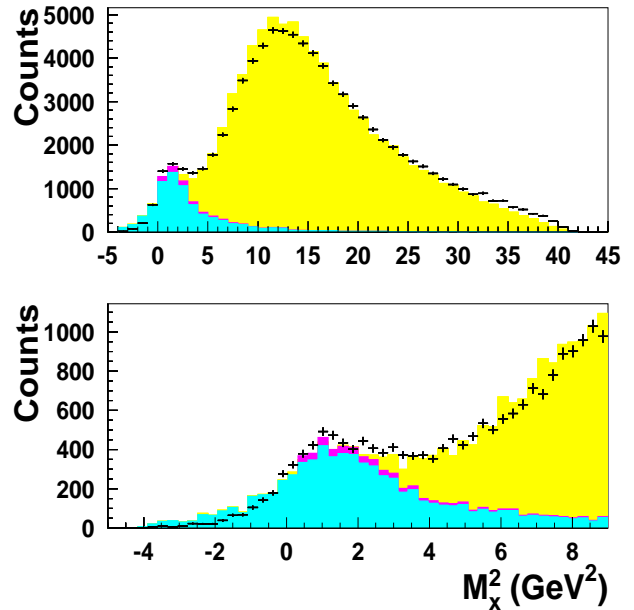
A_1, A_2 and A_3 are function of GPDs: $H^q, \tilde{H}^q, E^q, \tilde{E}^q$

Beam-spin Azimuthal Asymmetry

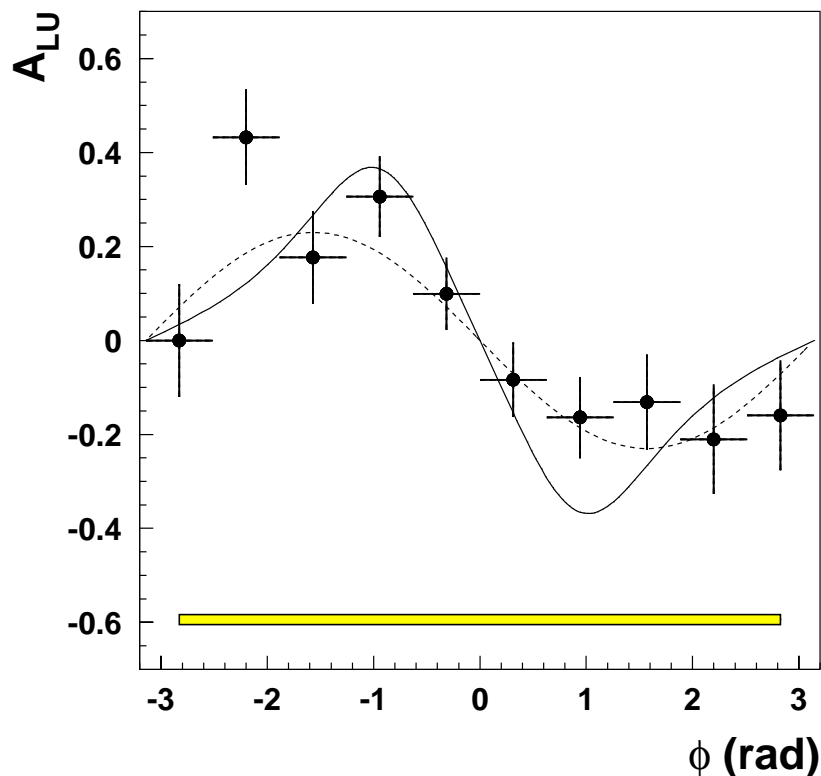
- $Q^2 > 1$, $W^2 > 4 \text{ GeV}^2$, $\nu < 24 \text{ GeV}$.
- $E_\gamma > 1 \text{ GeV}$, $15 < \theta_{\gamma\gamma^*} < 70 \text{ mrad}$
- $M_X < 1.7 \text{ GeV}$, $M_X^2 = (P + q - p_\gamma)^2$

$$A_{LU} = \frac{1}{\langle |P_B| \rangle} \frac{\vec{N}(\phi) - \overleftarrow{N}(\phi)}{\vec{N}(\phi) + \overleftarrow{N}(\phi)}$$

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



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



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

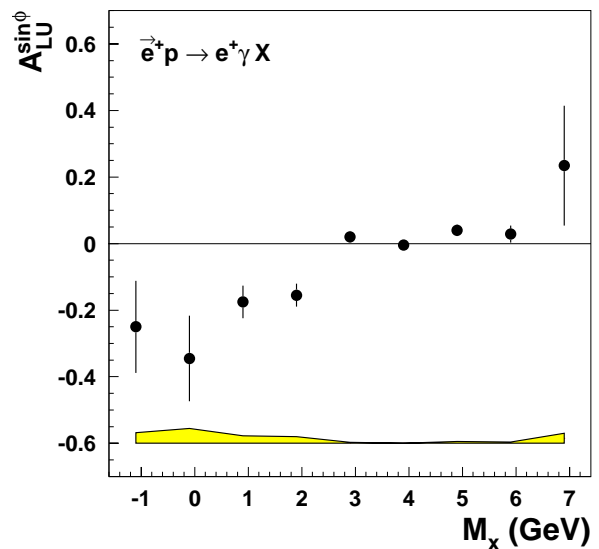
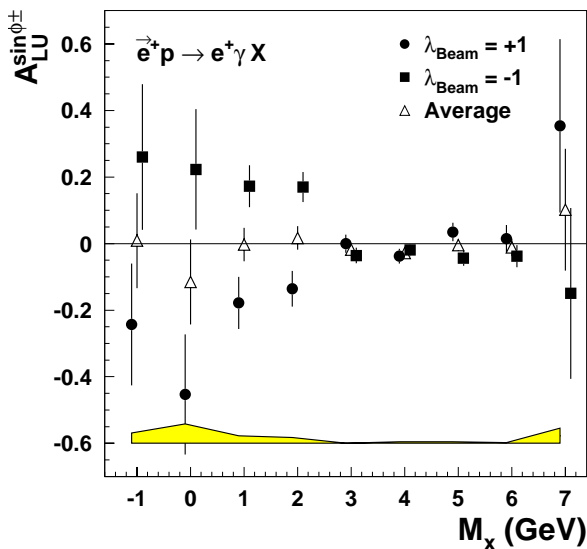
Dashed: $\sin \phi$ dependence with an amplitude of -0.23.

Beam-spin Asymmetry - $\sin\phi$ Moments

$$\frac{2 \langle \sin\phi \rangle}{\langle |P_B| \rangle} = \frac{2 \int_0^{2\pi} d\phi (d\sigma/d\phi) \sin\phi}{\langle |P_B| \rangle \int_0^{2\pi} d\phi (d\sigma/d\phi)}$$

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

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



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

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

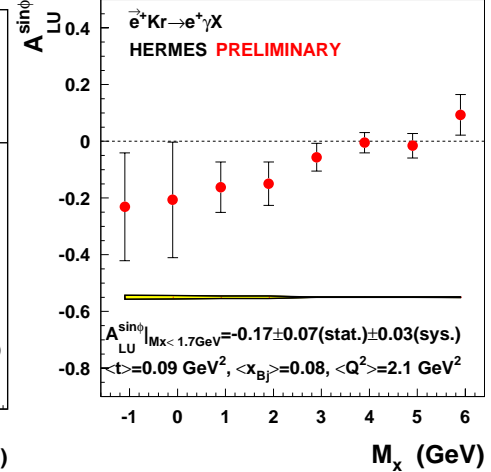
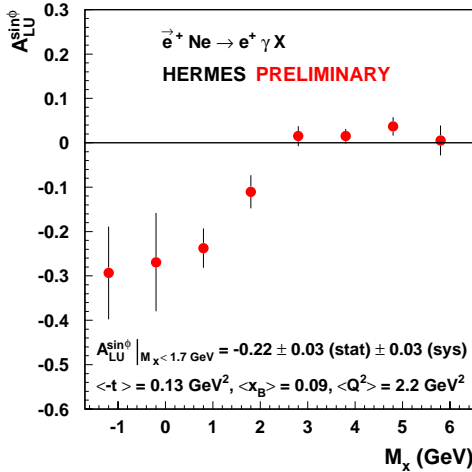
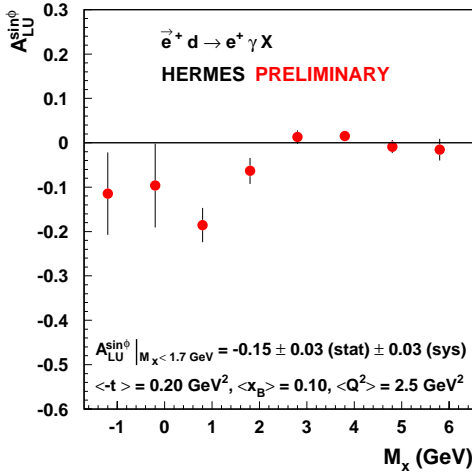
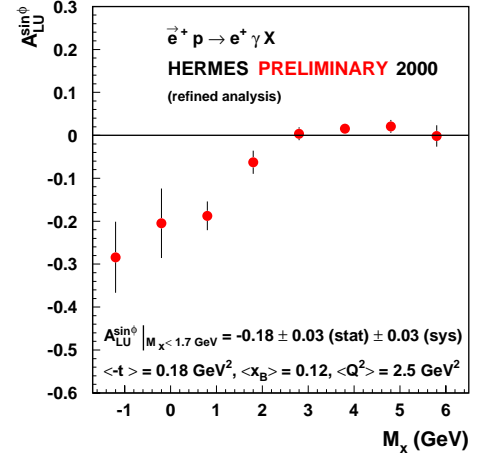
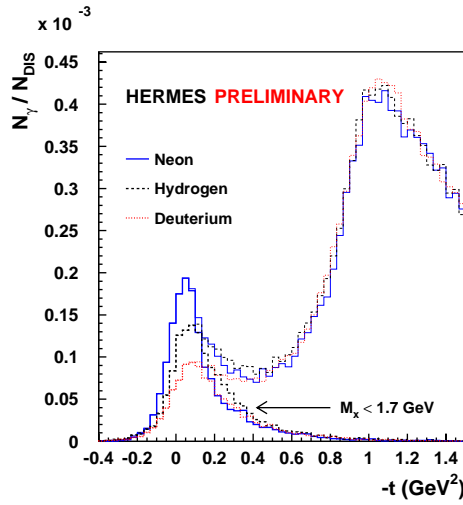
$A_{LU}^{sin\phi}$ from: H, D, Ne, Kr

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

proton (spin-1/2)

Deuteron (spin-1)

Ne, Kr (spin-0)



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

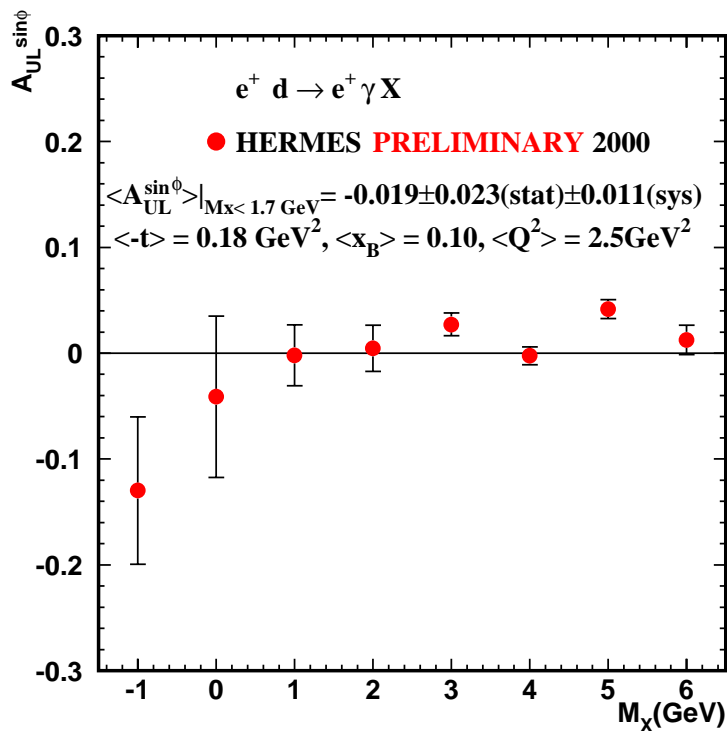
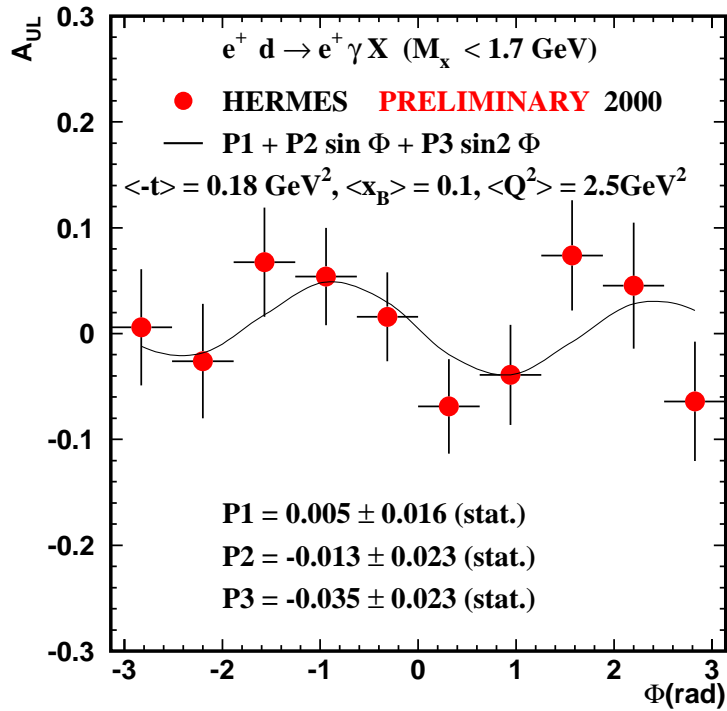
	$\langle Q^2 \rangle$ GeV ²	$\langle x_{Bj} \rangle$	$\langle -t \rangle$ GeV ²	$A_{LU}^{sin\phi}$	$A_{LU}(\phi)$ £t
H	2.5	0.12	0.18	$-0.18 \pm 0.03 \pm 0.3$	-0.18 ± 0.03
D	2.5	0.10	0.20	$-0.15 \pm 0.03 \pm 0.3$	-0.15 ± 0.03
Ne	2.2	0.09	0.13	$-0.22 \pm 0.03 \pm 0.3$	-0.22 ± 0.02
kr	2.1	0.08	0.09	$-0.17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

A.Kirchner, D.Müller, hep-ph/0302007

V.Guzey, M.Strikman, hep-ph/03-01216

Target-spin Azimuthal Asymmetry

$$A_{UL} = \frac{1}{\langle |P_T| \rangle} \frac{N^{\uparrow}(\phi) - N^{\downarrow}(\phi)}{N^{\uparrow}(\phi) + N^{\downarrow}(\phi)}$$

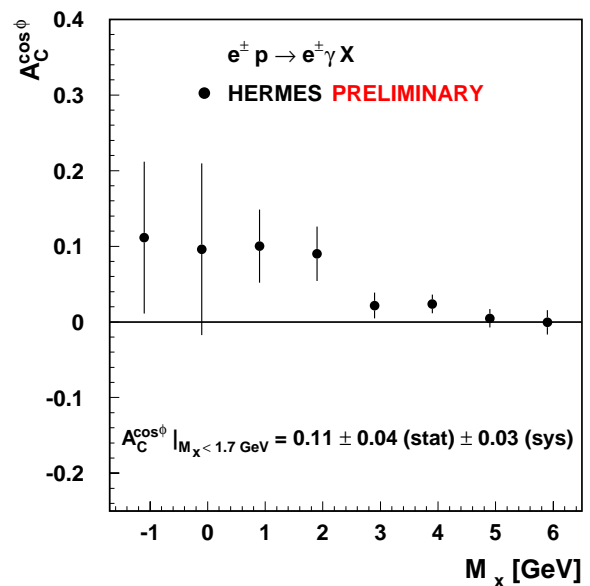
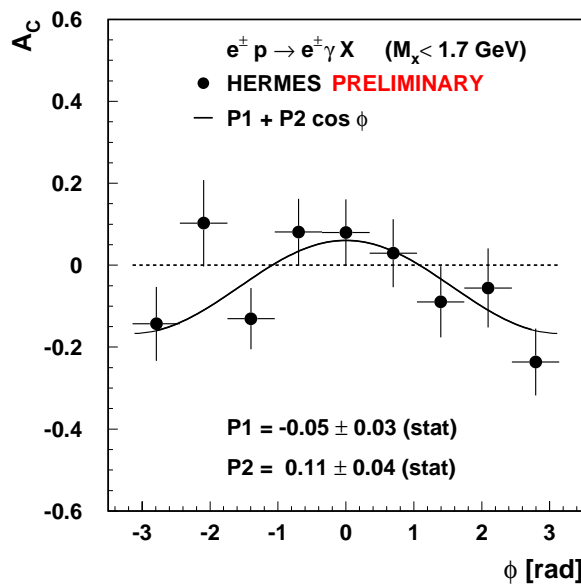


The Beam-charge Azimuthal Asymmetry

$$A_C^{\cos\phi} = \frac{2 \int_0^{2\pi} d\phi (d\sigma/d\phi) \cos\phi}{\int_0^{2\pi} d\phi (d\sigma/d\phi)}$$

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

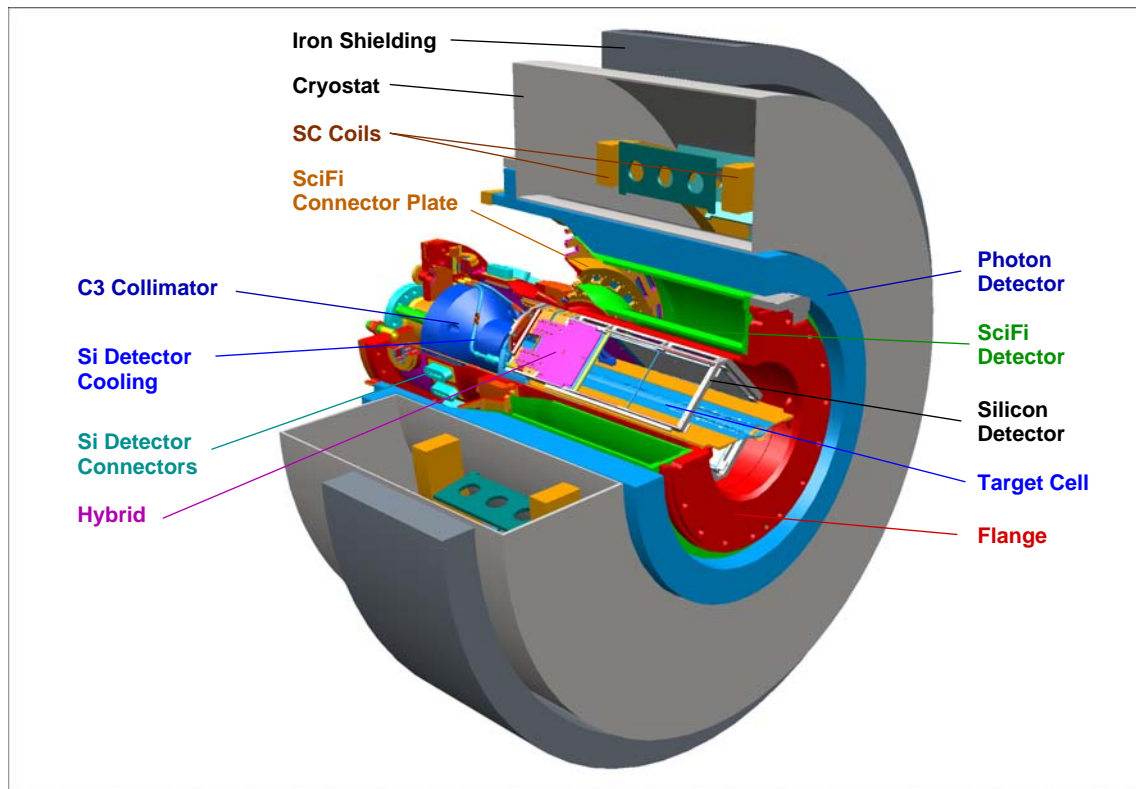
$$A_C^{\cos\phi} = \frac{A^{\cos\phi^+} - A^{\cos\phi^-}}{2}$$



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

Future Exclusive Measurements at HERMES

HERMES Recoil Detector



- Expected detector performance according to MC simulation :

⇒ θ -acceptance	→	$0.4 - 1.35 \text{ rad}$
⇒ p -acceptance	→	$0.1 - 1.4 \text{ GeV}/c$
⇒ $\Delta p/p$ resolution:	→	$\simeq 10\%$
⇒ π/p PID:	→	$135 - 600 \text{ MeV}$
⇒ Δ suppression	→	92%

Summary and Outlook

- **HERMES** exclusive Vector meson data:
 - Total (**longitudinal**) cross-sections and
 - Double-spin asymmetries for ρ and ωconsistent with theoretical (**GPD**) predictions
- **DVCS** associated azimuthal asymmetries:
 - **Beam-spin** from H, D, **Ne, Kr**
 - **Target-spin** from D
 - **Beam-charge** from Hin agreement with **GPD** formalism.
- **Outlook** for exclusive physics at **HERMES**:
 - Data from **transversely polarized target**
 - Measurements with **Recoil Detector**