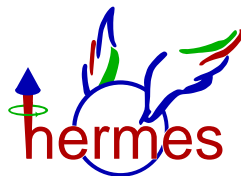


Measurements of DVCS at HERMES

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DESY-Zeuthen, Germany
on behalf of the
HERMES Collaboration



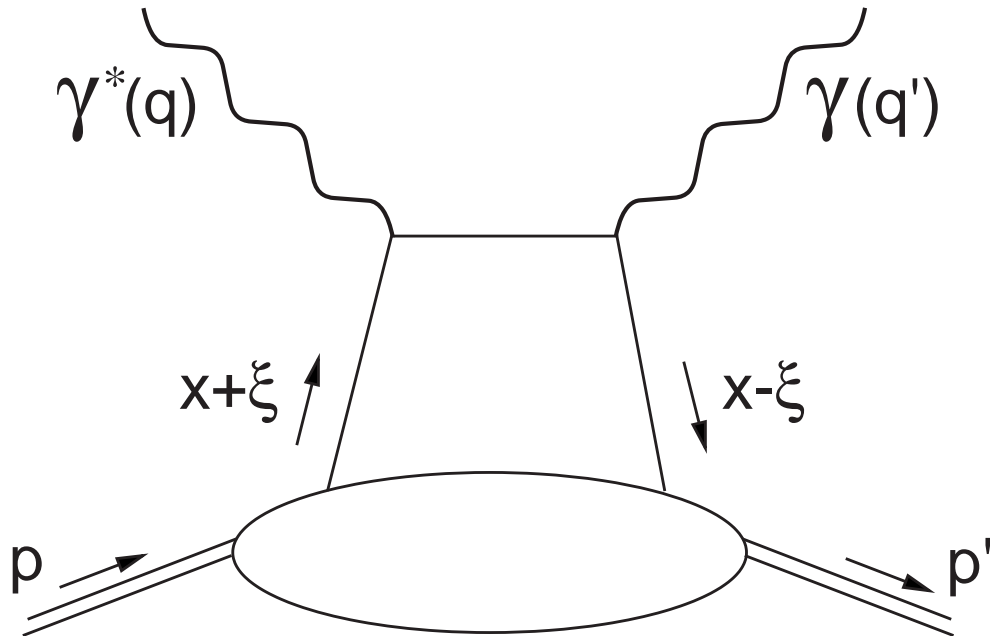
DIS 2003

XI International Workshop
on Deep Inelastic Scattering
23-27 April, 2003
St. Petersburg, Russia

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- **INTRODUCTION**
- GPD's and Angular Momentum Sum Rule
- (DVCS+BH): Cross sections and Amplitudes
- Spin and Charge Asymmetries:
- Beam-spin asymmetry results on H, D and Ne targets
- Target-spin asymmetry results on polarised D target
- Lepton Charge Asymmetry results on H target
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DVCS Handbag Diagram



- In hard regime DVCS process factorizes
- In the off-forward domain described by new functions: H , \tilde{H} , E , \tilde{E}

GPD's - General Formalism

- The functions $H, \tilde{H}, E, \tilde{E}$ depend upon three variables: x, ξ, t .
- Where the light-cone momentum fraction is defined by $k^+ = xP^+, \xi = -\Delta^+/2P^+$ ($\Delta = P' - P$) and $-t = \Delta^2$.
- In the Bjorken limit $2\xi \rightarrow x_{Bj}/(1-x_{Bj}/2)$.
- E, \tilde{E} are new functions vanishing at $t \rightarrow 0$ limit of DIS
- In the limit of $\xi \rightarrow 0$ and $t \rightarrow 0$ H and \tilde{H} reduce to the ordinary parton distributions:

$$H(x, 0, 0) = q(x)$$

$$\tilde{H}(x, 0, 0) = \Delta q(x)$$

GPD's - General Formalism

Integration over x gives the following sum rules:

$$\int_{-1}^1 dx H(x, \xi, t) = F_1(t)$$

$$\int_{-1}^1 dx E(x, \xi, t) = F_2(t)$$

$$\int_{-1}^1 dx \tilde{H}(x, \xi, t) = G_A(t)$$

$$\int_{-1}^1 dx \tilde{E}(x, \xi, t) = G_P(t),$$

where F_1 and F_2 are the Dirac and Pauli form factors and G_A and G_P are the axial-vector and pseudo-scalar form factors.

Angular Momentum

Angular momentum operator in QCD is the sum of **quark** and **gluon** contributions

$$\vec{J}_{\text{QCD}} = \vec{J}_q + \vec{J}_g$$

where

$$\vec{J}_q = \int d^3x \vec{x} \times \vec{T}_q$$

$$\vec{J}_g = \int d^3x \vec{x} \times (\vec{E} \times \vec{B})$$

Here \vec{T}_q and $\vec{E} \times \vec{B}$ are the quark and gluon momentum densities, respectively.

Separate **quark** and **gluon** contributions to the **nucleon spin** can be deduced by **an analogy with the magnetic moment**, if the form factors of the momentum density are known **at zero momentum transfer**.

Ji Angular Momentum Sum Rule

Second moments of off-forward parton distributions yield the form factors of the energy-momentum tensor

$$\int_{-1}^1 \mathbf{x}[\mathbf{H}(\mathbf{x}, \xi, t) + \mathbf{E}(\mathbf{x}, \xi, t)]d\mathbf{x} = \mathbf{A}(t) + \mathbf{B}(t)$$

where the ξ dependence drops out.

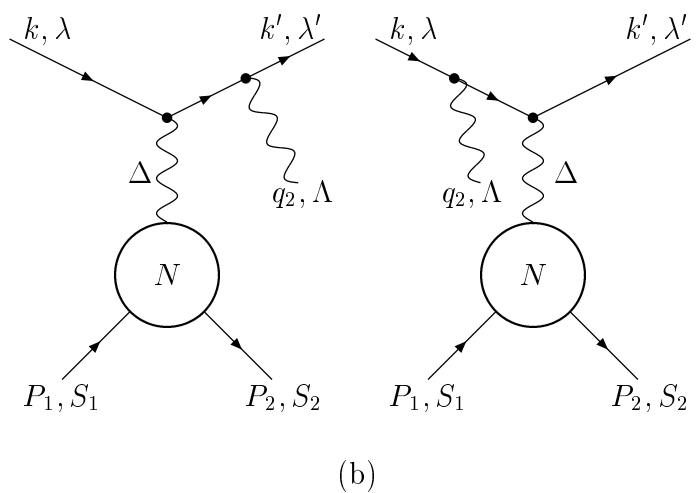
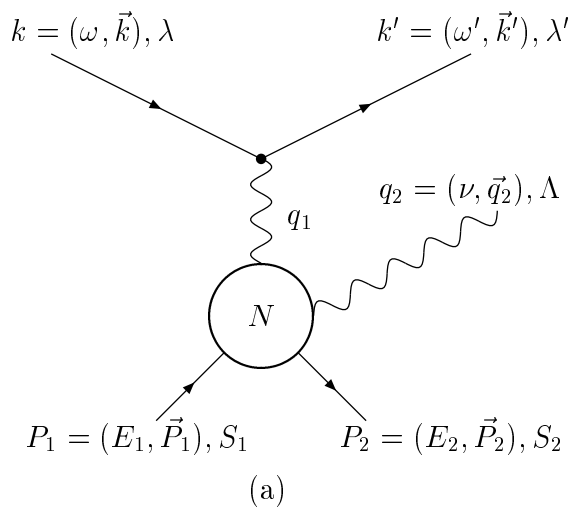
Extrapolating the sum rule to $t \rightarrow 0$, one gets fractions of the nucleon spin carried by quarks and gluons:

$$\mathbf{J}_{q,g} = \frac{1}{2}[\mathbf{A}_{q,g}(0) + \mathbf{B}_{q,g}(0)]$$

where

$$\mathbf{J}_q + \mathbf{J}_g = \frac{1}{2}$$

DVCS and Bethe-Heitler



Two **different** subprocesses have the **same** **initial** and **final** states

Therefore DVCS and BH subprocesses **interfere!**

Cross Sections and Amplitudes

Cross section for electro-production of real photons formally looks like:

$$d\sigma \sim |\tau_{BH} + \tau_{DVCS}|^2 = |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + I$$

I is the **interference** term

$$I = \tau_{BH}^* \tau_{DVCS} + \tau_{DVCS}^* \tau_{BH}$$

Leading **beam-spin** dependent part looks as

$$I \sim e_l h_l \sin(\phi) \cdot \text{Im}A$$

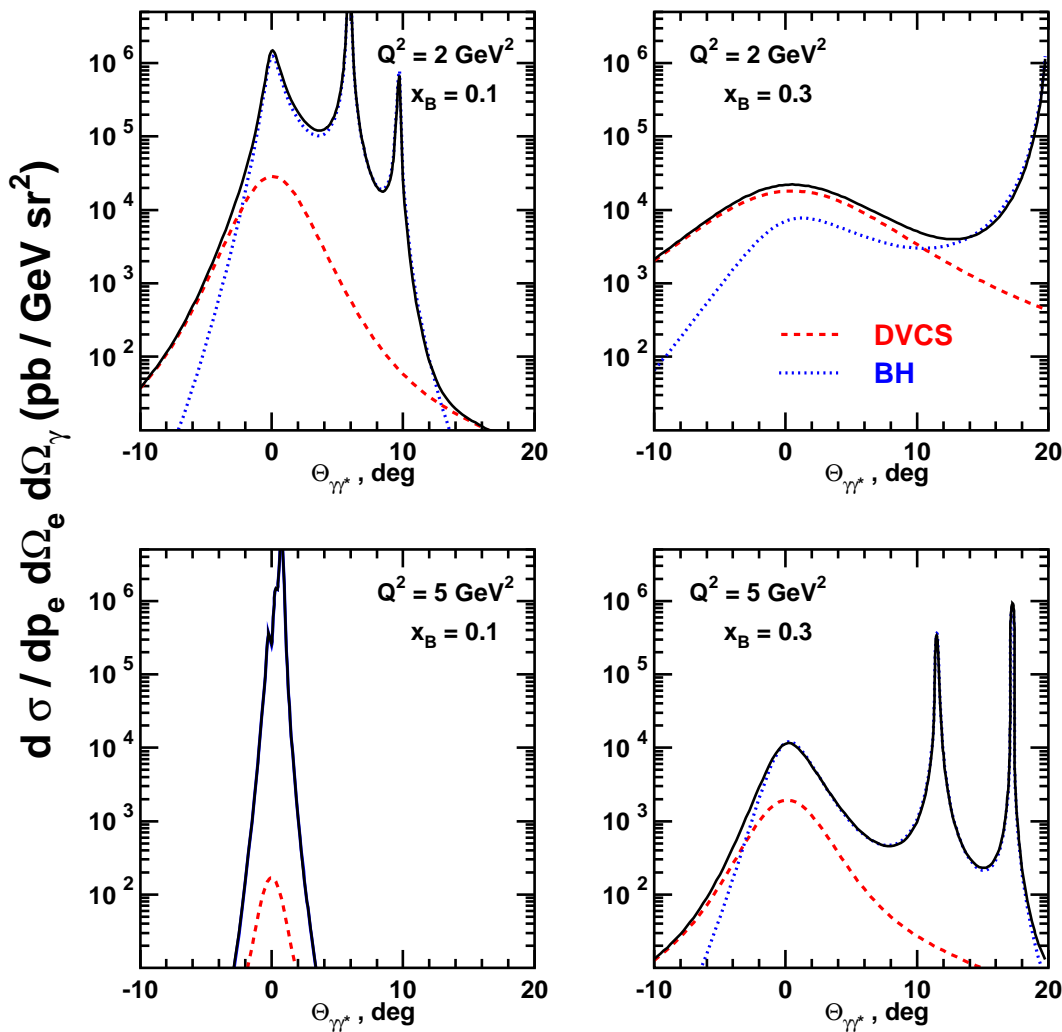
Leading **beam-charge** dependent part looks as

$$I \sim e_l \cos(\phi) \cdot \text{Re}A$$

where e_l, h_l are lepton charge and helicity

DVCS and BH Cross Sections

In-plane differential cross-sections for the DVCS and BH at $E = 27.5$ GeV beam energy:



The cross-section of DVCS is smaller than that of BH in the whole kinematical region

Unpolarized Target

Following A.V. Belitsky, D. Müller, L. Niedermeier and A. Schäfer (hep-ph/0004059)

1. Polarized beam :

$$d\sigma \equiv d\sigma^\uparrow - d\sigma^\downarrow \sim \sin(\phi) \times \text{Im} \left\{ F_1 \mathcal{H}_1 + \frac{x}{2-x} (F_1 + F_2) \tilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2} F_2 \mathcal{E}_1 \right\}$$

2. Charge asymmetry in unpolarized experiment:

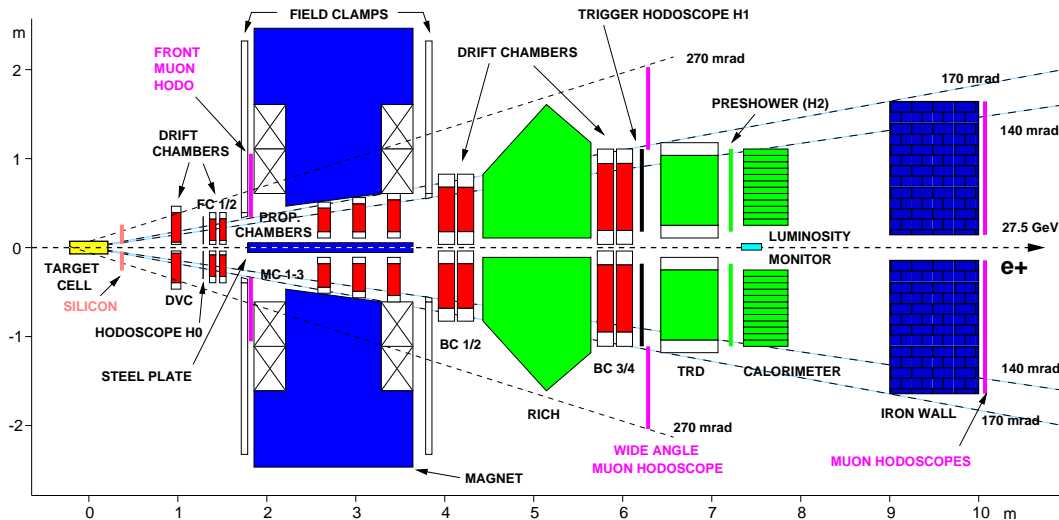
$$d\sigma \equiv d^+\sigma^{\text{unp}} - d^-\sigma^{\text{unp}} \sim \cos(\phi) \times \text{Re} \left\{ F_1 \mathcal{H}_1 + \frac{x}{2-x} (F_1 + F_2) \tilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2} F_2 \mathcal{E}_1 \right\}$$

Unpolarized Beam

3. Longitudinally polarized target:

$$d\sigma \equiv \sigma_{\uparrow} - d\sigma_{\downarrow} \sim \sin(\phi) \times \text{Im} \left\{ F_1 \tilde{\mathcal{H}}_1 \right. \\ \left. + \frac{x}{2-x} (F_1 + F_2) \mathcal{H}_1 + \frac{x}{2-x} \left(\frac{x}{2} F_1 + \frac{\Delta^2}{4M^2} F_2 \right) \tilde{\mathcal{E}}_1 \right\}$$

The HERMES Spectrometer

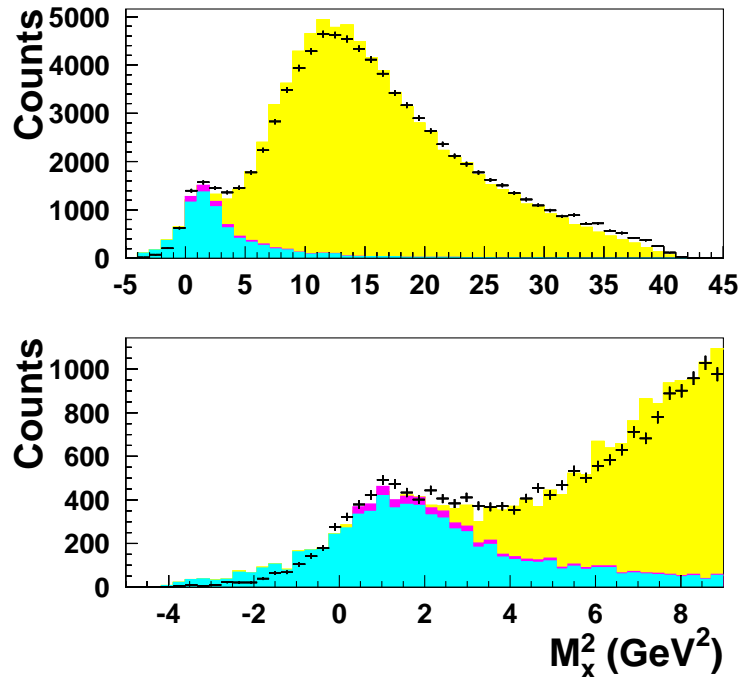


- Polarized positrons of energy 27.5 GeV in the HERA storage ring with $P_B \sim 0.5$
- Forward spectrometer ($0.04 < \theta < 0.22$) rad.
- Particle ID: RICH (Threshold Cherenkov), TRD, Preshower, Lead Glass Calorimeter
- Track reconstruction:
 $\delta P/P = 0.7 \div 1.3(2.6)\%$, $\delta\theta \leq 0.6$ mrad.

Event Selection

- H, D(polarized and unpolarized) and ^{20}Ne targets
- **Only one track** -scattered positron e^+ in spectrometer
- **Only one cluster** in calorimeter without associated track
- $W^2 > 4 \text{ GeV}^2$, $Q^2 > 1 \text{ GeV}^2$, $\nu < 24 \text{ GeV}$
- **Opening Angle** $\Theta_{\gamma^*\gamma} < 0.070 \text{ rad.}$

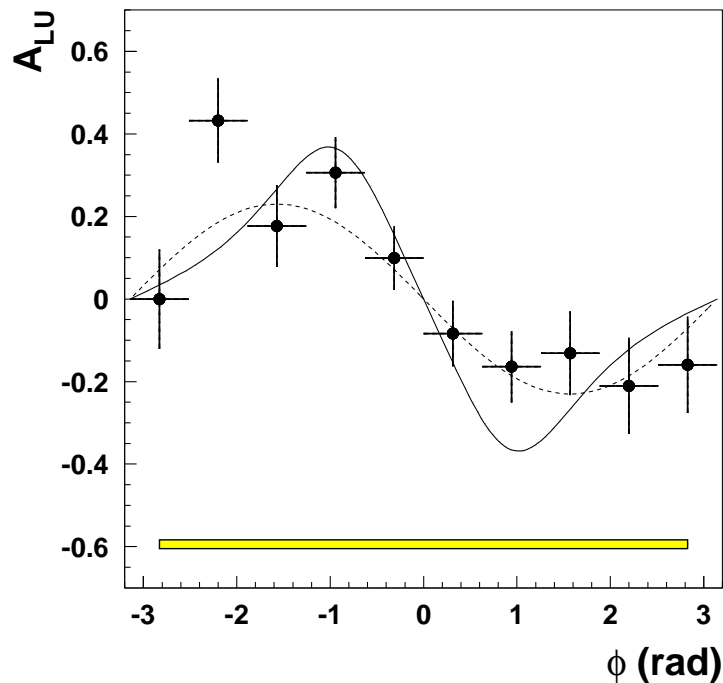
Electroproduction of Photons



$$M_x = q - P_\gamma + P_p$$

- Cross points are data
- Blue color shows contribution from BH for N-N transition
- Pink color shows contribution from BH for N- Δ transition
- Yellow histogram shows contribution from decay of neutral mesons

Single Spin Azimuthal Asymmetry



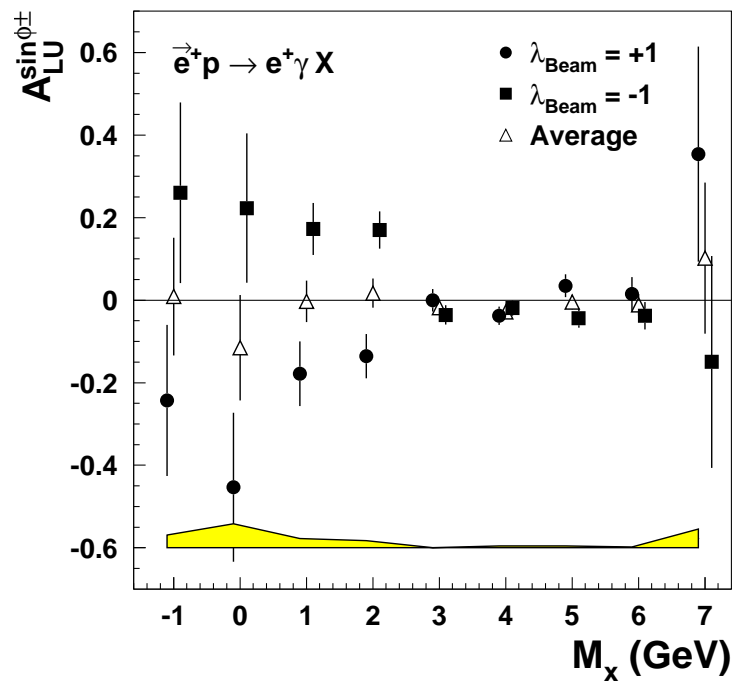
$$A_{LU}(\phi) = \frac{1}{\langle |P_l| \rangle} \cdot \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

$N^{+(-)}$ – luminosity-normalized yields of events
 $-1.5 < M_x < 1.7$ GeV: 4015 events

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

Solid curve is the result of GPD calculation including twist-3 effects (N.Kivel, M.Polyakov, M.Vanderhaeghen, hep-ph/0012136)

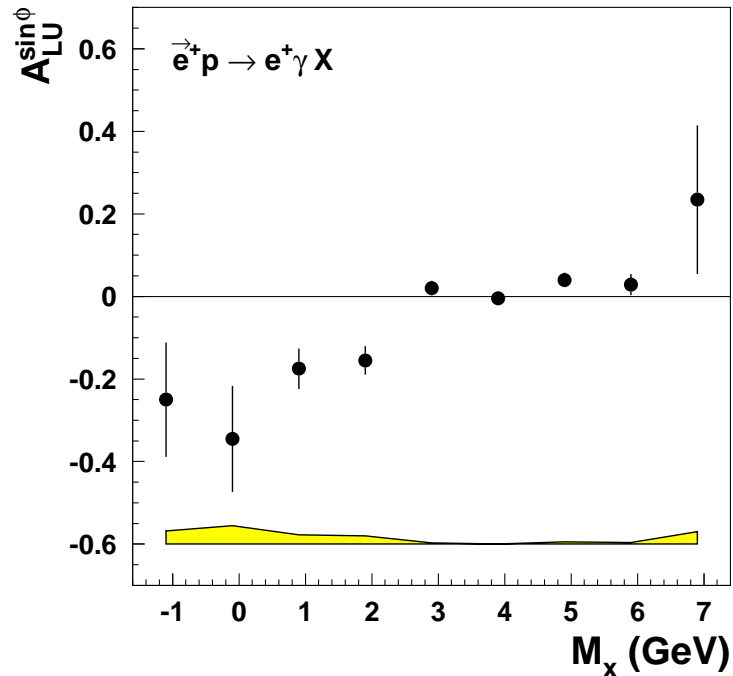
Sin- ϕ Moments versus M_x



The $\sin(\phi)$ moment is defined as:

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

Combined Sin- ϕ Moments versus M_x

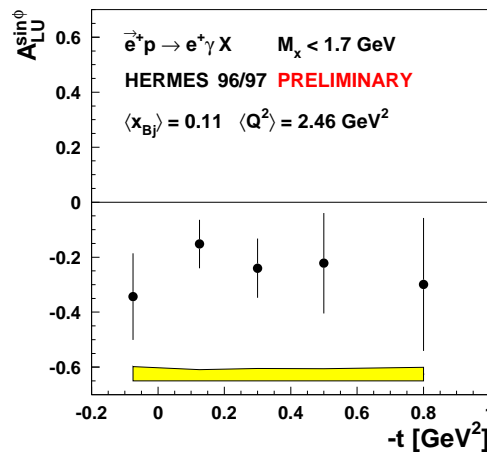
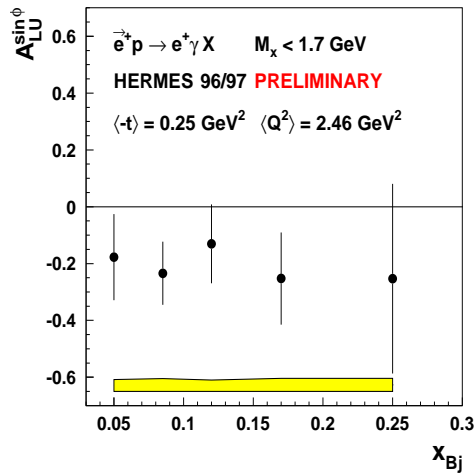
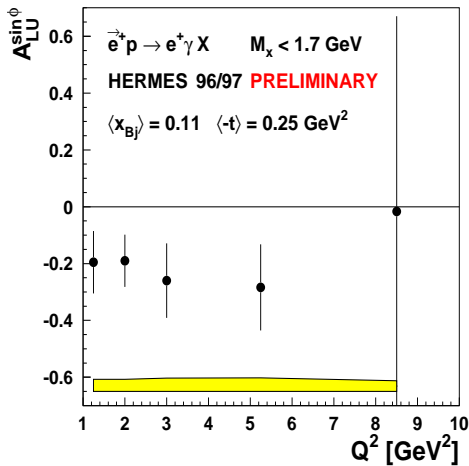


For combined lepton-helicity states:

$$A_{LU}^{\sin\phi} = \frac{2 \int_0^{2\pi} d\phi (d\sigma^+ / d\phi - d\sigma^- / d\phi) \sin(\phi)}{\langle |P_b| \rangle \int_0^{2\pi} d\phi (d\sigma^+ / d\phi + d\sigma^- / d\phi)}$$

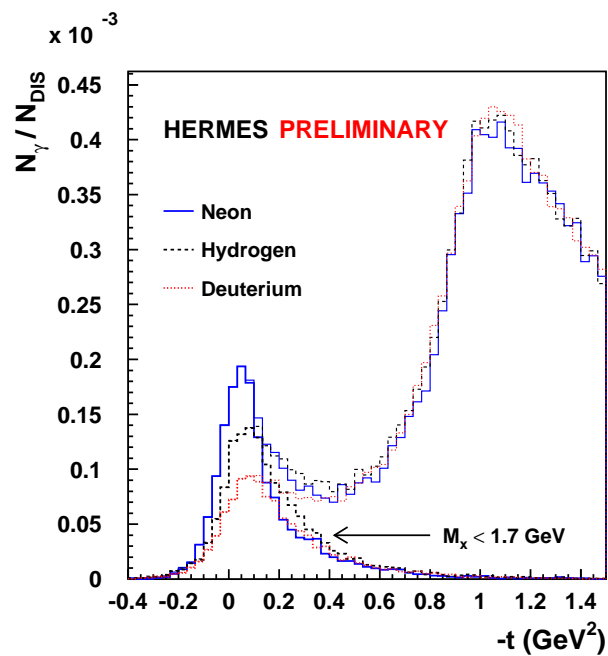
where $^{+,-}$ superscripts are for parallel and anti-parallel helicities of incoming lepton beam

Sin- ϕ Moments versus Q^2 , x and -t



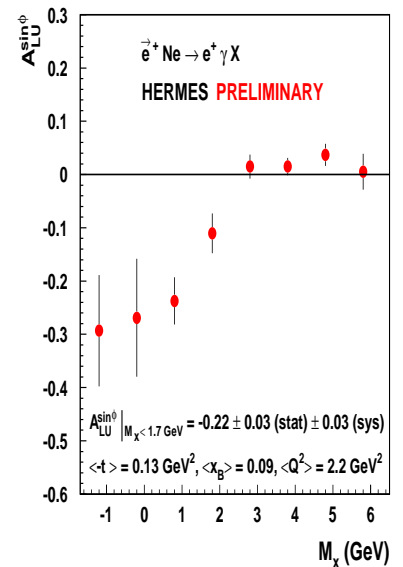
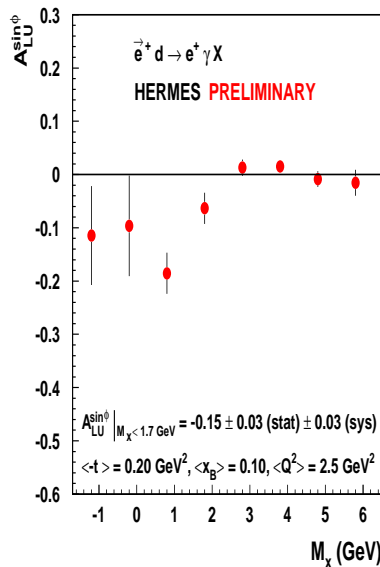
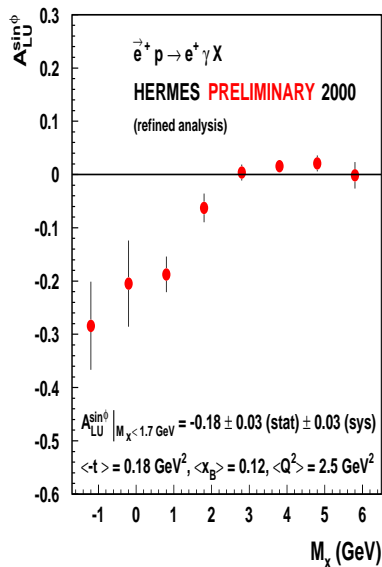
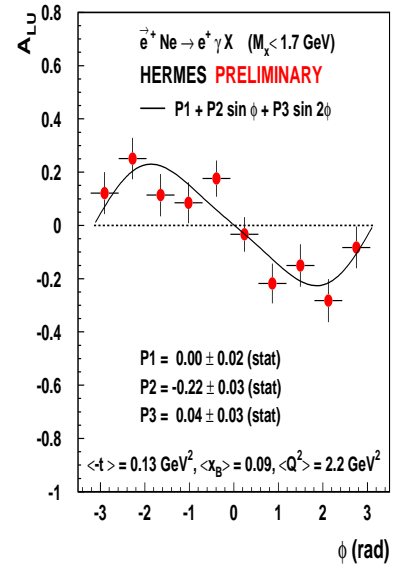
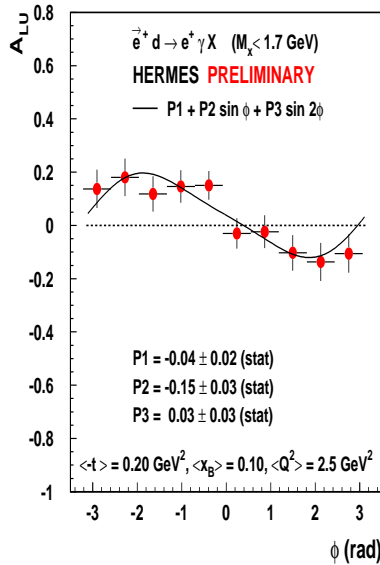
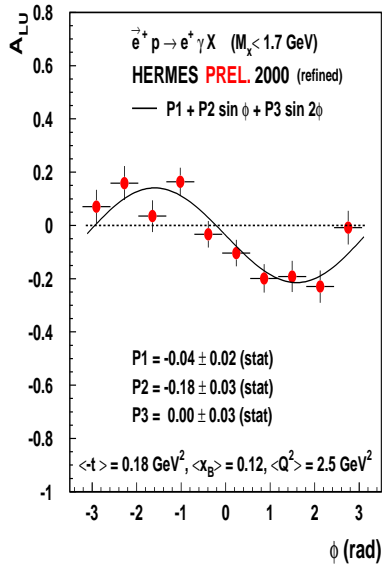
Q^2 , x and t dependences of A_{LU} are weak within HERMES kinematical range

Normalized Yield for H, D, Ne Targets



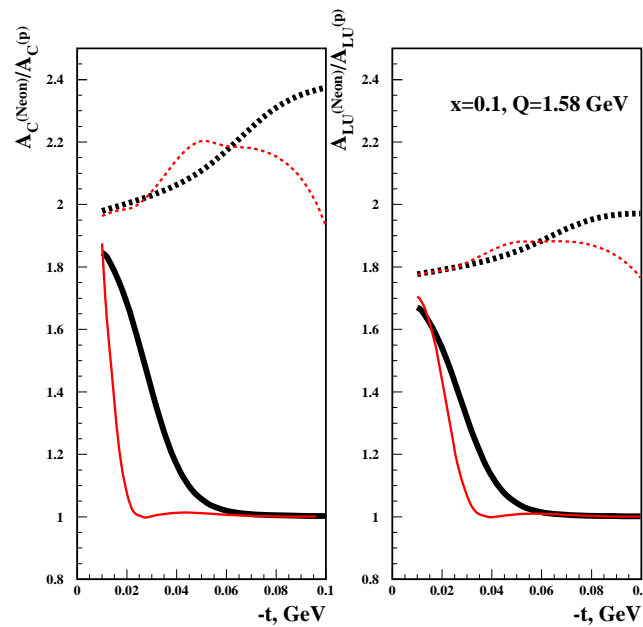
Prominent peak on Ne is due to coherent BH process

BSA for H, D, Ne Targets



BSA on H and Ne are similar

BCA and BSA on Nuclear Target (theory)

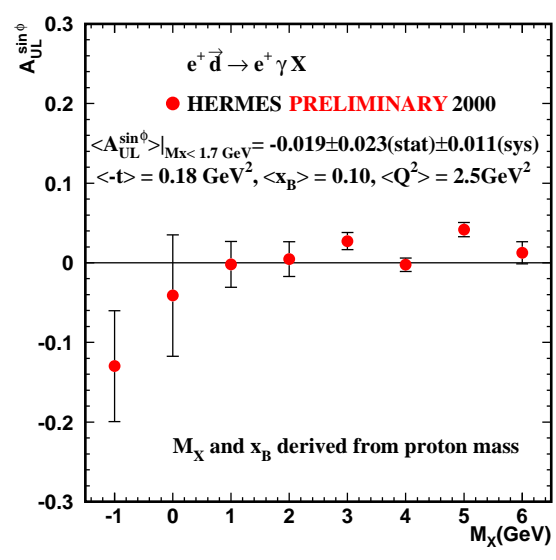
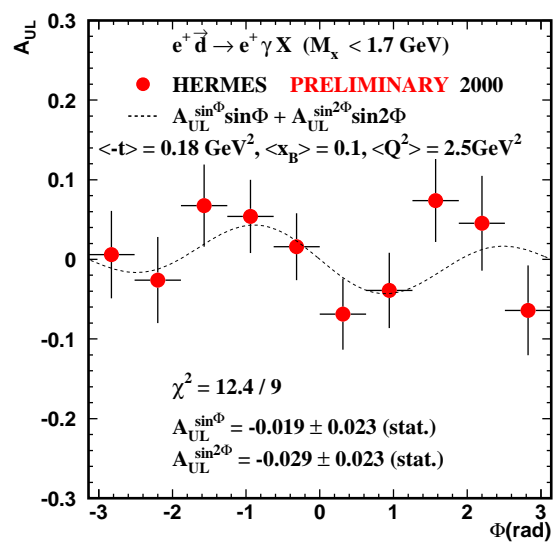


$$A_{LU}^{\text{nucleus}} = \frac{\tau_{\text{BH}} \cdot \tau_{\text{DVCS}}}{|\tau_{\text{BH}}|^2} \frac{A \cdot Z}{Z^2} \cdot \frac{F_A(t)}{F_{\text{ch}}(t)}$$

(V.Guzey and M.Strikmann hep-ph/0301216)

- Missing input for **equation of state** of nuclear matter and mass-radius relation of **neutron star**
- DVCS on nuclei provides an access to GPD's and strong forces inside nuclei (M.Polyakov Phys.Lett.B 555:57-62, 2003)
- See also (A.Kirchner, D.Muller hep-ph/0302007)

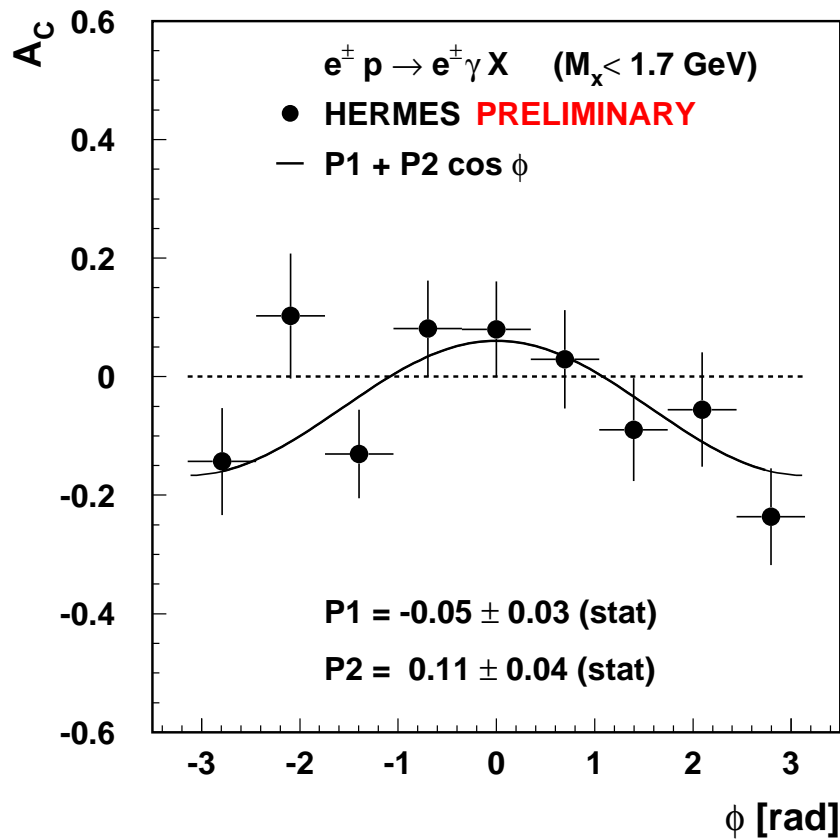
Target-Spin Asymmetry on Deuteron



A_{UL} is small as expected $\sim \tilde{H}$



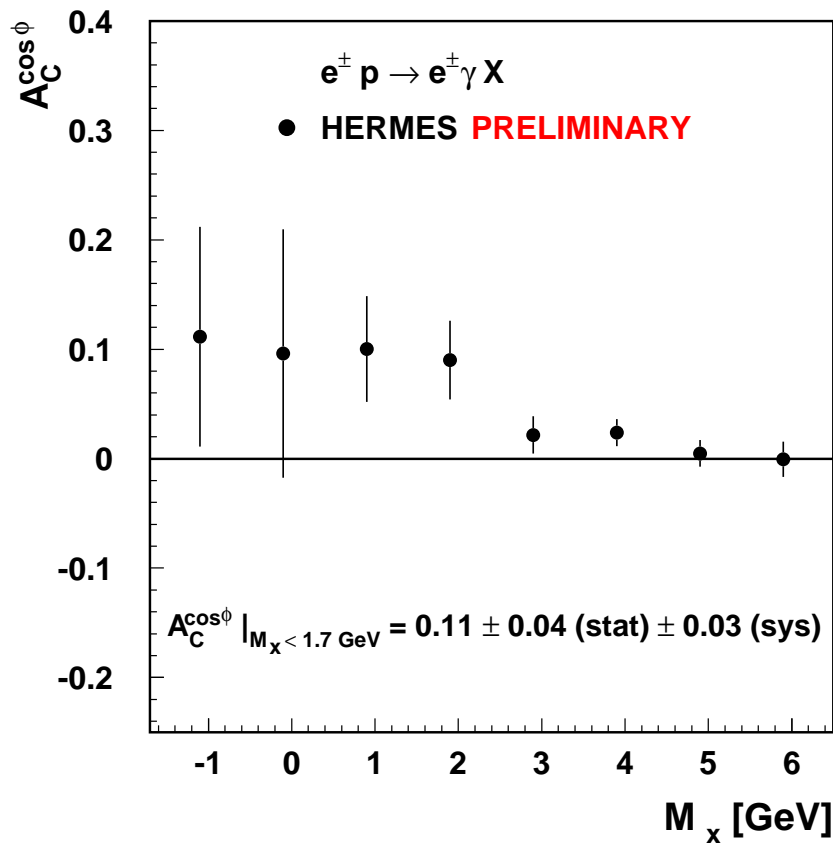
Beam Charge Asymmetry (BCA)



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

where $^+, -$ superscripts are for positron/electron beam respectively

cos ϕ -Moment of BCA



$$A_{LU}^{\cos\phi} = \frac{2 \int_0^{2\pi} d\phi (d\sigma^+ / d\phi - d\sigma^- / d\phi) \cos(\phi)}{\int_0^{2\pi} d\phi (d\sigma^+ / d\phi + d\sigma^- / d\phi)}$$

where $^{+,-}$ superscripts are for positron/electron beam respectively

OUTLOOK

- Presented experimental results are based on data collected during 96+97 and 98-00 running periods
- Single Beam-Spin Asymmetry is measured for H, D and ^{20}Ne targets (analysis of Kr data is in progress)
- Target-Spin Asymmetry is measured on a deuteron (TSA on hydrogen is in progress)
- Beam Charge Asymmetry is measured for hydrogen (BCA on deuteron is in progress)
- In the long range plan with recoil detector HERMES will improve in statistics and in precision significantly
- Hermes experiment is planning to get a first results on different GPD's using HERA polarized beams of e^+/e^- by the end of 2006