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# HERMES run II

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**Abstract.** The two main physics objectives for running the HERMES experiment in the years 2003-2006 are the study of the transverse spin structure of the nucleon and measurements of cross section asymmetries in exclusive reactions in order to obtain information on Generalized Parton Distributions.

## 1 Introduction

Spin-dependent ('polarized') parton distribution functions (PDFs) attracted the attention of experimentalists and theorists in the late eighties when it was found in Deep Inelastic Scattering (DIS) experiments that – in contrast to the expectation – only a very small fraction (about 0.1) of the *longitudinal* spin of the nucleon is made up by the spins of the quarks [1,2]. The experiment HERMES at HERA [3] very recently published [4] the first five-fold flavor separation analysis in leading order QCD from which a somewhat larger fraction (about 0.4) was derived.

The spin-dependent PDFs describe the imbalance between the distributions $q^{\uparrow}(x)$ and $q^{\downarrow}(x)$ ($q^{\rightarrow}(x)$ and $q^{\leftarrow}(x)$) in which quark spins are aligned parallel and antiparallel to that of the transversely (longitudinally) polarized parent nucleon: for the quark species $q$ the transversity distribution is given by $h_1^q(x) \equiv \delta q(x) = q^{\uparrow}(x) - q^{\downarrow}(x)$ and the helicity distribution by $g_1^q(x) \equiv \Delta q(x) = q^{\rightarrow}(x) - q^{\leftarrow}(x)$. The sum of either pair constitutes the spin-independent ('unpolarized') distribution $f_1^q(x) \equiv q(x)$. Here $x$ is the fraction of the nucleon's momentum carried by the struck parton, in a system where the nucleon has infinite momentum. Note that the additional (weak) dependence of the PDFs on $Q^2$, the four-momentum transfered by the virtual photon in DIS, is omitted for simplicity. The $1^{st}$ moment $\delta\Sigma = \sum_q \int_0^1 dx(h_1^q(x) - \bar{h}_1^q(x))$ describes the tensor charge of the nucleon while its axial charge is given by $\Delta\Sigma = \sum_q \int_0^1 dx(g_1^q(x) + \bar{g}_1^q(x))$.

The *transverse* spin structure of the nucleon has not yet been studied in any detail. It is the last unknown piece in the complete leading-twist spin structure of the nucleon and comprises new information on the dynamics of quarks inside hadrons, thereby allowing the verification of the validity of two yet untested QCD predictions:
i) the tensor charge is larger than the axial charge,
ii) the transversity distribution has a weaker $Q^2$ evolution than the helicity distribution.

Generalized Parton Distributions (GPDs) constitute a unified theoretical description of inclusive and (hard) exclusive processes. The GPDs $H^q$ and $\tilde{H}^q$ reduce to the ordinary PDFs $f_1^q(x)$ and $g_1^q(x)$, respectively, for vanishing momentum transfer $t$ at the nucleon vertex, while the GPDs $E^q$ and $\tilde{E}^q$ are not accessible in DIS. The GPDs bear qualitatively new information on the structure of the nucleon, especially on parton-parton correlations, and thus provide a more complete picture of the nucleon as compared to ordinary PDFs.

GPDs can in principle be accessed through measurements of hard exclusive processes. Their $t$-dependence provides information on the distribution of partons *transverse* to the nucleon's direction of motion. This may eventually lead to the development of a 3-dimensional picture of the partonic structure of the nucleon [5,6,7]. A measurement of the $2^{nd}$ moment of the sum of the unpolarized GPDs $H^q$ and $E^q$, in the limit of vanishing $t$, may eventually allow the determination of the *total angular momentum* carried by quarks in the nucleon [8].

At HERMES, the determination of the $u$-quark transversity distribution $h_1^u(x) \equiv \delta u(x)$ is the main goal of the measurements planned until 2004, facilitated by the installation of a transverse target magnet surrounding an internal polarized hydrogen target. Projections will be discussed in chapter 2. For a possible measurement of $Im\ H$, considered to be the ultimate goal of HERMES running in the years 2005-06, projections will be discussed in chapter 3. More details on transversity and GPDs, as seen from an experimentalist's point of view, can be found in [9].

## 2 Transverse spin structure of the nucleon

Recently the decades-old theoretical debate was revived on how to correctly interpret data from measurements of single-spin azimuthal asymmetries for pion production in semi-inclusive deep inelastic scattering (SIDIS). The most recent status, including explanation of variables, (some) theoretical predictions and a full list of references is given in, e.g., [10]. The observed non-zero cross section asymmetries can be explained by two different mechanisms,

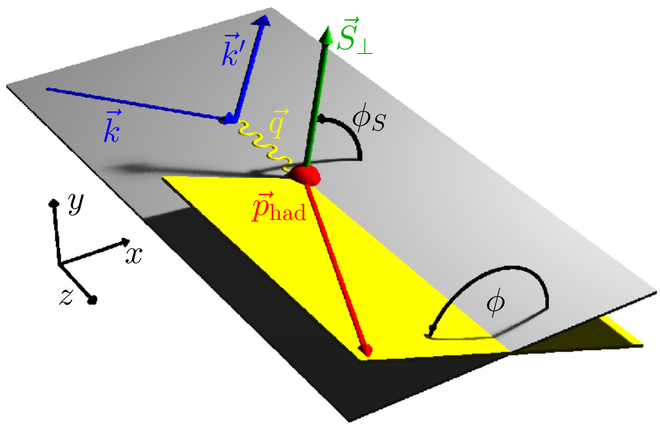


**Fig. 1.** Definition of azimuthal angles for transversity measurements

named after their inventors 'Sivers mechanism' [11] and 'Collins mechanism' [12]. The former explains the asymmetries observed in the azimuthal distribution of the outgoing quark, i.e. of the outgoing pion after the fragmentation, by the existence of a quark distribution function ($f_{1T}^\perp$) that depends on the quark's transverse momentum $k_\perp$. The latter mechanism assumes, as the observed cross section asymmetries are chirally even, that the two involved chirally-odd functions are non-zero. In SIDIS these are the transversity $h_1^q(x)$ and the 'Collins fragmentation function' $H_1^\perp$. It appears that the relative weight of both mechanisms can eventually only be determined by experimental data.

Experimentally, a differentiation between both mechanisms requires data obtained from semi-inclusive scattering of unpolarized (U) leptons on a transversely (T) polarized target: $eN^\uparrow \longrightarrow e'\pi X$. The azimuthal dependence of the asymmetry in the measured count rates $N^\uparrow, N^\downarrow$ reads

$$A(\phi) = \frac{1}{\langle P \rangle} \cdot \frac{N^\uparrow(\phi) - N^\downarrow(\phi)}{N^\uparrow(\phi) + N^\downarrow(\phi)},$$

where $\langle P \rangle$ stands for the average target polarization while the arrows' notation was explained above. The azimuthal angles are defined in Fig. 2, where $k(k')$ is the 4-vector of incoming (outgoing) lepton, $p_{had}$ the outgoing pion momentum vector, and $S_\perp$ denotes the target spin vector. For the Sivers and Collins mechanism the weighted cross section asymmetries, or the $\sin\phi$-moments of the cross section, are respectively given by

$$A_{UT}^{\sin(\phi-\phi_S)} \sim \sum_q e_q^2 f_{1T}^{\perp(1),q}(x_B) D_1^q(z),$$

$$A_{UT}^{\sin(\phi+\phi_S)} \sim \sum_q e_q^2 h_1^q(x_B) H_1^{\perp(1),q}(z).$$

Here $e_q$ denotes the quark charge, the superscript (1) indicates that the corresponding function was integrated over $k_\perp$, $x_B$ is Bjorken's scaling variable, and $D_1^q$ is the spin-independent fragmentation function with $z$ being the fraction of the virtual photon's energy carried by the outgoing pion.

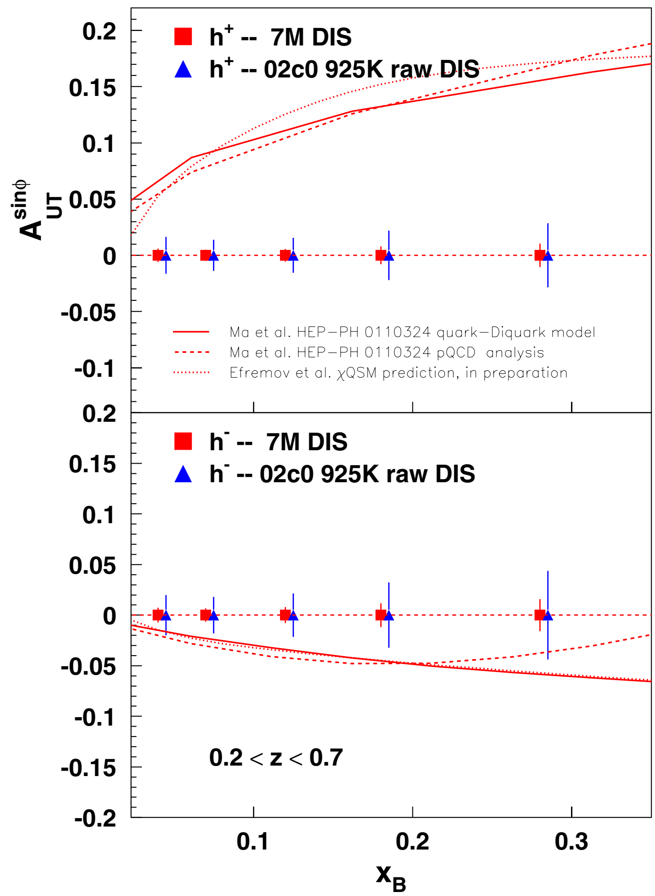


**Fig. 2.** Projected accuracy of HERMES measurements of the single transverse target-spin asymmetry

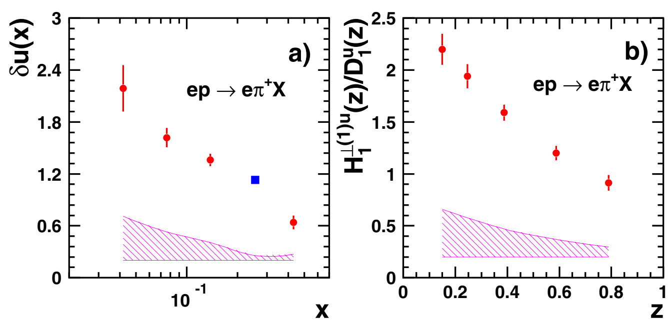


**Fig. 3.** Projected accuracy of HERMES measurements of transversity and the ratio of polarized to unpolarized fragmentation functions for the $u$-quark. The *square* denotes the normalization point (*see text*)

Data taking at HERMES in 2002/2003, using a transversely polarized hydrogen target, resulted in 725k events after data quality cuts corresponding to 925k raw DIS events. The analysis is in progress; the expected statistical accuracy in the asymmetry $A_{UT}^{\sin\phi}$ is shown in Fig. 2 for the present data set and the projected final data set of 7M events, in comparison to several model predictions for the Collins mechanism. Distinguishing between contemporary model predictions will at best be possible with the maximum expected statistics, the more important issue of this first measurement of $A_{UT}^{\sin\phi}$ being its overall size and shape. For the final data set a simultaneous extraction of the $u$-quark transversity distribution and the ratio of polarized to unpolarized fragmentation functions has been simulated [13], as can be seen from Fig. 3. Note that here the Sivers mechanism was not considered and the basically undetermined overall normalization was taken from the expected similarity of transversity and helicity distribution at low $Q^2$ and medium $x$.

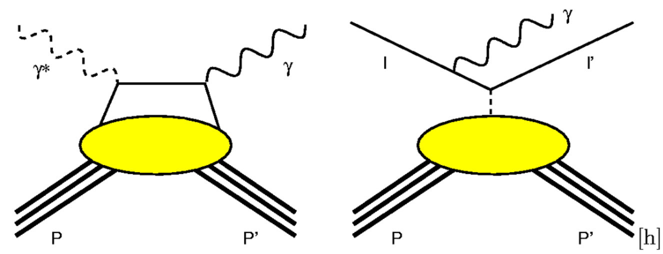


**Fig. 4.** *Left*: Deeply Virtual Compton Scattering. *Right*: Bethe-Heitler process

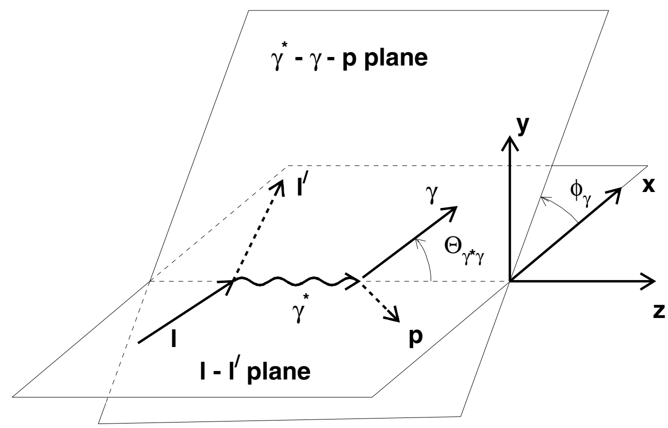


**Fig. 5.** Definition of the azimuthal angle $\phi_\gamma$ in DVCS

## 3 Towards measuring GPDs in DVCS

The – theoretically – simplest hard exclusive process in electroproduction is Deeply Virtual Compton Scattering (DVCS): $\gamma^* p \to \gamma p$. In the Bjorken limit the dominating pQCD subprocess is described by the 'hand-bag diagram' shown in the left panel of Fig. 4. The Bethe-Heitler (BH) process that leads to an identical final state is shown in the right panel of the same figure.

At HERMES kinematics the DVCS process cannot be measured directly as it is dominated by the BH process. Interference between both, however, opens access to *both* the real and imaginary parts of (certain combinations of) DVCS amplitudes. They can be accessed by measuring the azimuthal dependences of certain cross section asymmetries, the most prominent ones being the lepton charge asymmetry $A_C$ (unpolarized beam, unpolarized target):

$$A_C \sim d\sigma(e^+p) - d\sigma(e^-p) \sim \cos(\phi_\gamma) \times \mathrm{Re}\,\mathcal{I},$$

and the lepton helicity asymmetry $A_{LU}$ (L: longitudinally polarized beam, U: unpolarized target):

$$A_{LU} \sim d\sigma(\overrightarrow{e^+}p) - d\sigma(\overleftarrow{e^+}p) \sim \sin(\phi_\gamma) \times \mathrm{Im}\,\mathcal{I}.$$

Here $\mathcal{I}$ represents the interference term in the DVCS/BH cross section. The definition of $\phi_\gamma$ is explained in Fig. 5. The GPDs are buried in generally complicated integrals describing the DVCS amplitudes. Practically, a direct determination of GPDs is impossible. Models of GPDs must be used to construct 'predictions' that have to be compared to corresponding experimental results, thus launching an iterative procedure whose precision is very hard to assess at present. Similarly as in the case of transversity measurements, a measurement of the azimuthal ($\phi_\gamma$) dependence of the (above given) cross section asymmetries is the tool of choice.

Presently, the HERMES collaboration is pursuing the construction of a Recoil Detector [14] that is expected to be commissioned in 2004-05. It will surround an unpolarized gas target with a silicon tracker that resides inside the beam pipe. The next layers are a scintillating fibre detector, a photon detector and a 1 Tesla superconducting solenoid magnet. The Recoil detector, designed for measuring mainly recoil protons leaving the target under large polar angles (between 0.1 and 1.35 rad) will serve two main purposes:
i) the $t$-resolution at low values of $-t$, where the kinematic dependence of GPDs is especially interesting, will be improved dramatically, by more than one order of magnitude (from 0.2 to below 0.02 GeV/c$^2$);
ii) the detection of recoil protons will allow the reduction of the undetected fraction of events that have an excited nucleon state instead of a proton ('associated DVCS') down to below 1%.

Preliminary HERMES results on the azimuthal dependence of the lepton charge asymmetry in Fig. 6 can be compared with projections in Fig. 7 based on an integrated luminosity of 2 fb$^{-1}$ obtained on a hydrogen target [15]. The latter are displayed for $x_B > 0.2$ as the asymmetry exhibits a quite different behavior at low $x_B$. As can be seen, the projected data for HERMES Run II can clearly distinguish between GPD predictions. For details on the different GPD models used we refer to [15]. Note that all projections given here and in the following are based on a sample of purely exclusive events.

Preliminary HERMES results on the missing mass dependence of the lepton helicity asymmetry are shown in Fig. 8. Projections on its $t$-dependence, obtained as explained above, are displayed separately for low and high values of $x_B$ in Fig. 9 [16]. Quite detailed measurements of the $t$-dependence can be expected in both regions of $x_B$.

On the basis of the same expected statistics, an attempt has been made to obtain projections for measuring $Im\ H$ [17]. Working in the region of low $-t$ ($-t < 0.15$ (GeV/c)$^2$) it has been found that the relative contribution of the GPD $H$ largely dominates and the lepton helicity asymmetry $A_{LU}^{\sin\phi}$ mainly depends on $Im\ H$. For two different GPD parameterizations (A) and (B) the dependence on the skewedness variable $\xi$ is shown in Fig. 10. As $\xi = x_B/(2 - x_B)$, this variable resembles for small val-

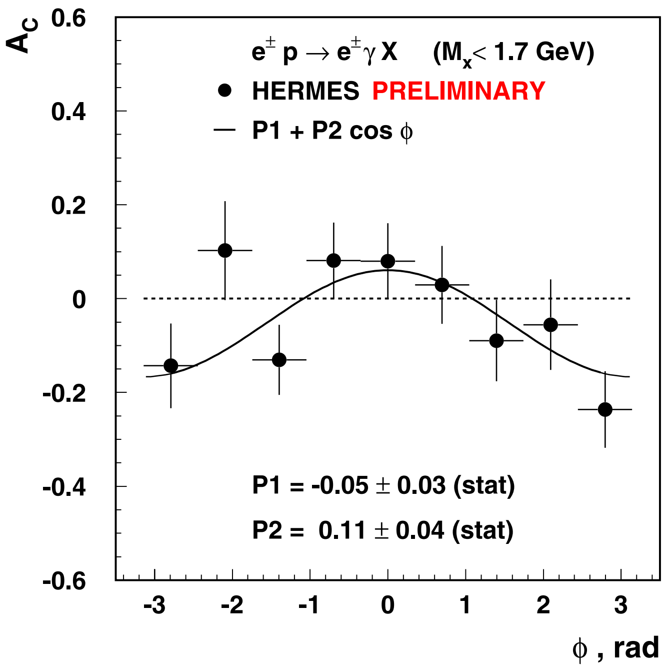


**Fig. 6.** Preliminary HERMES results on the azimuthal dependence of the lepton charge asymmetry in DVCS

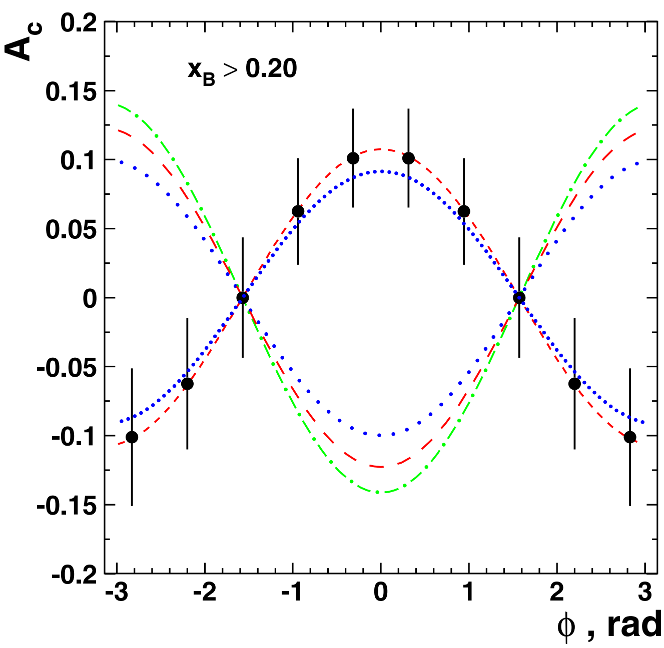


**Fig. 7.** Projections for the azimuthal dependence of the lepton charge asymmetry in DVCS from 2005-06 running (*see text*)

ues of $x_B$ essentially a $1/x_B$-dependence; for more details we refer to [17]. While the bands in the figure represent the expected statistical uncertainty, the shaded areas indicate a possible systematic uncertainty of the extraction method used. It is obvious, as already stated in the beginning, that the extraction of GPD-related information will be a complicated task.

It is concluded that the measurements planned for HERMES Run II will constitute important steps into yet uncharted territory and thus are expected to considerably enhance the knowledge on the partonic structure of the nucleon.

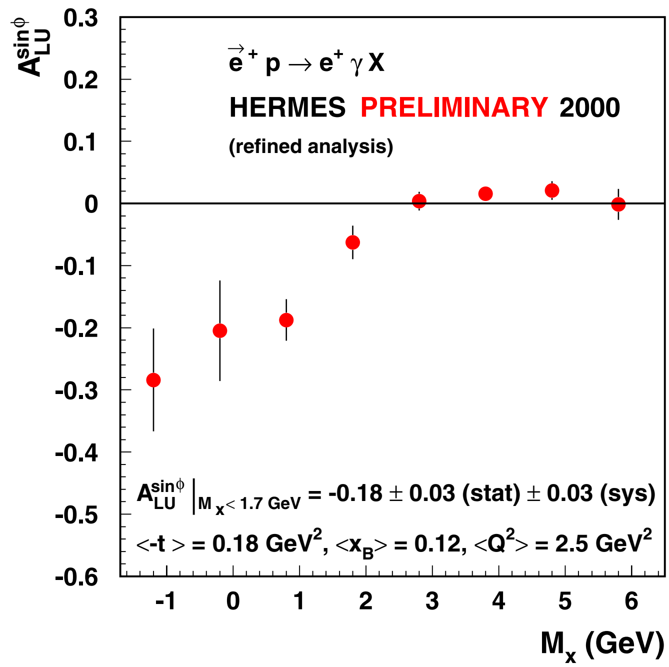


**Fig. 8.** Preliminary HERMES results on the missing mass dependence of the lepton helicity asymmetry in DVCS

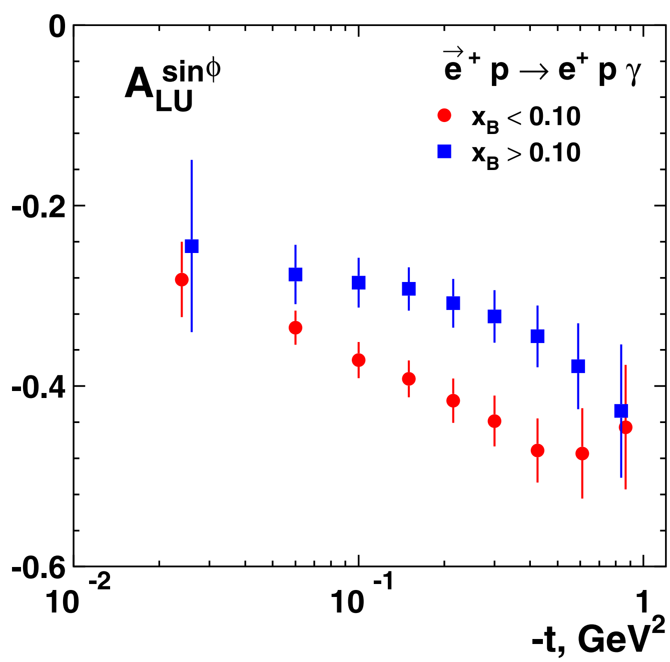


**Fig. 9.** Projections for the lepton helicity asymmetry in DVCS from 2005-06 running (*see text*)

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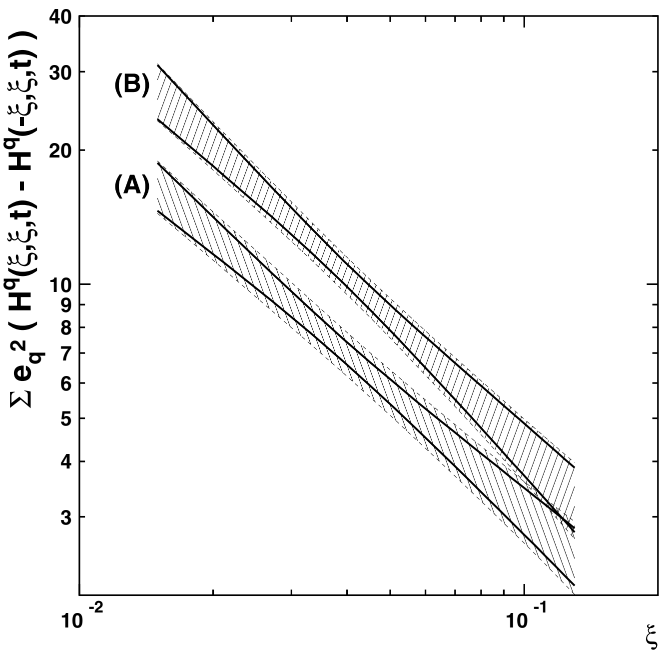


**Fig. 10.** Projected extraction of *Im H* from measuring DVCS at HERMES with a Recoil Detector (*see text*). The two shaded areas represent two different calculations of this unmeasured quantity

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