New Results on DVCS from HERMES

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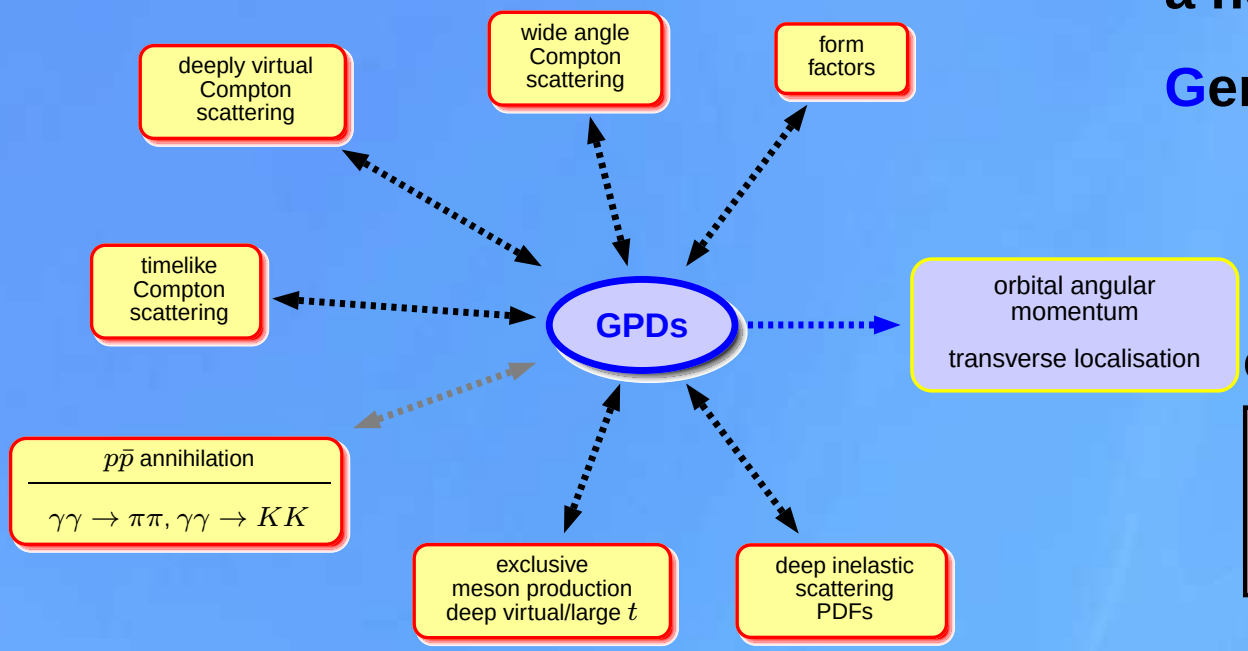
DESY

The Hunt for L_q



Study of hard exclusive processes leads to a new class of PDFs

Generalised Parton Distribut ions

$\mathbf{H^q, E^q, \tilde{H}^q, \tilde{E}^q}$

$\Rightarrow$ **possible access to orbital angular momentum**

$$J_q = \frac{1}{2}\left(\int_{-1}^{1} x\mathrm{d}x(H^q + E^q)\right)_{t\to 0}$$
$$J_q = \frac{1}{2}\Delta\Sigma + L_q$$

exclusive: all products of a reaction are detected

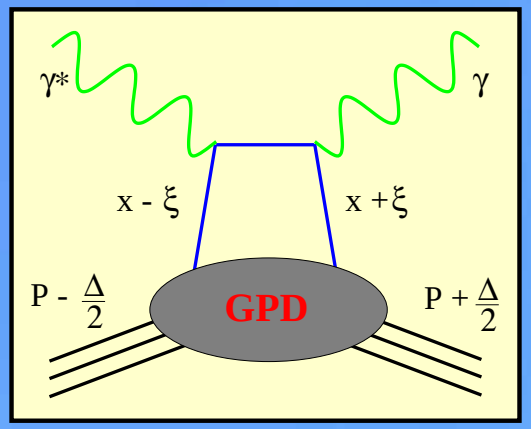
$\Longrightarrow$ **missing energy (ΔE) and missing Mass (M_x) = 0**

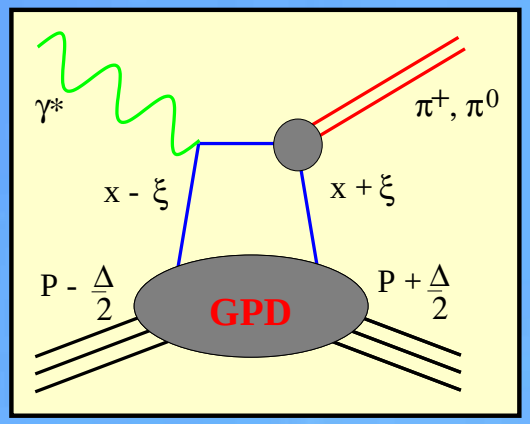
GPDs Introduction I

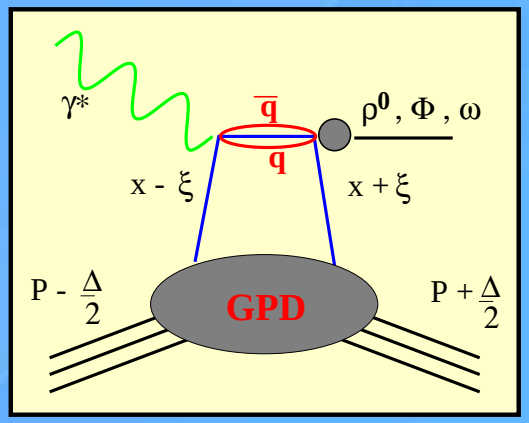
What does GPDs characterize?

unpolarized	polarized	
$\mathbf{H^q(x,\xi,t)}$	$\mathbf{\tilde{H}^q(x,\xi,t)}$	**conserve nucleon helicity**
		$H^q(x,0,0) = q$ **,** $\tilde{H}^q(x,0,0) = \Delta q$
$\mathbf{E^q(x,\xi,t)}$	$\mathbf{\tilde{E}^q(x,\xi,t)}$	**flip nucleon helicity**
		not accessible in DIS

quantum numbers of final state $\Rightarrow$ select different GPDs







DVCS:
$\mathbf{H^q, E^q, \tilde{H}^q, \tilde{E}^q}$
$\mathbf{A_C, A_{LU}, A_{UL}, A_{UT}}$

pseudo-scalar mesons
$\mathbf{\tilde{H}^q, \tilde{E}^q}$
$\mathbf{A_{UL}, A_{UT}}, \sigma_{\pi^+}$

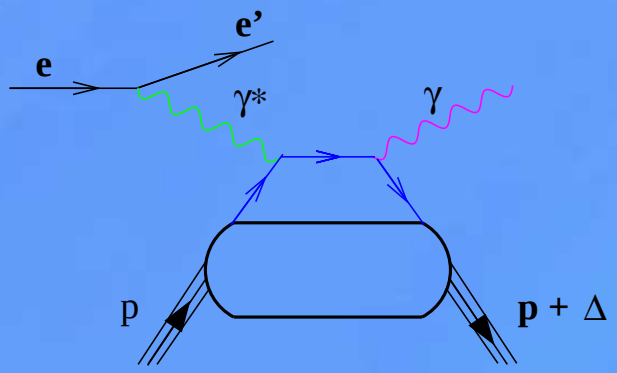
vector mesons
$\mathbf{H^q, E^q}$
$\mathbf{A_{UL}}, \sigma_{\rho,\phi,\omega}, \mathbf{A_{UT}}$

x, t, ξ **defined on the light cone**

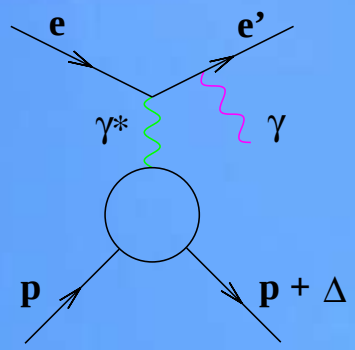
x**: unobservable internal variable in DVCS** t**: momentum transfer (**$t = \Delta^2$**)**

ξ**: longitudinal momentum transfer between 2 partons (**$\xi = \frac{x_{Bj}}{2-x_{Bj}}$**)**

DVCS $ep \to e'\gamma p$



DVCS



Bethe-Heitler (BH)

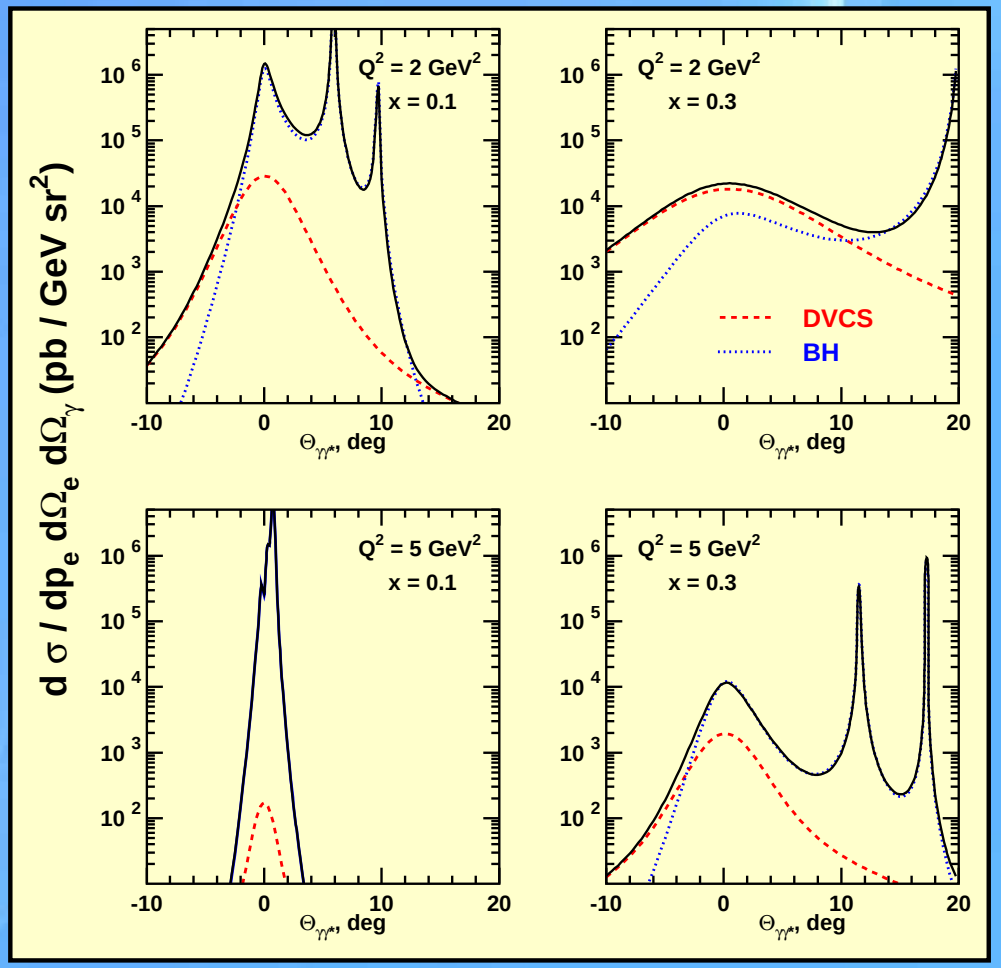
$$d\sigma \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + (\mathcal{T}^*_{BH}\mathcal{T}_{DVCS} + \mathcal{T}^*_{DVCS}\mathcal{T}_{BH})$$

HERMES, JLAB:
DVCS-BH interference:

$\Longrightarrow$ **use BH as a vehicle to study DVCS**

H1, ZEUS:
measure DVCS cross section directly

HERMES / JLAB kinematics:
BH cross section larger than DVCS

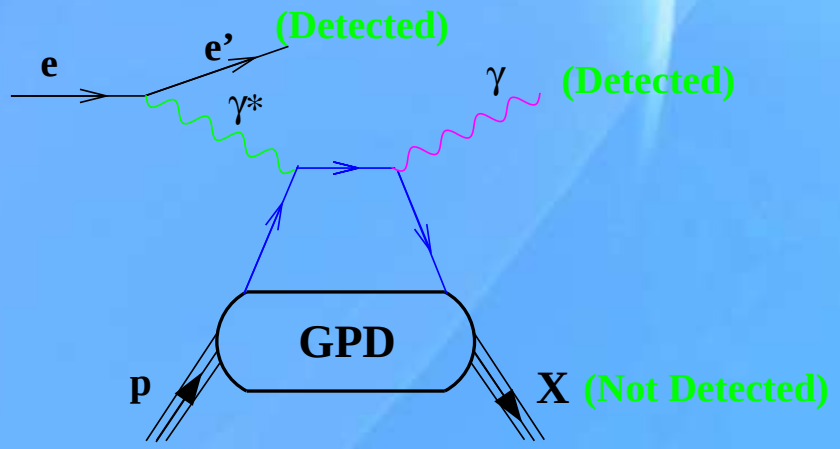


[Korotkov, Nowak, hep-ph/0108077]

DVCS azimuthal asymmetries

$$\mathbf{d}\sigma \propto (\mathcal{T}^*_{BH}\mathcal{T}_{DVCS} + \mathcal{T}^*_{DVCS}\mathcal{T}_{BH}) + |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2$$

isolate BH-DVCS interference term $\Longrightarrow$ non-zero azimuthal asymmetries



$\Rightarrow$ **unpolarized target**

- **beam helicity asymmetry:**

$$\mathbf{d}\sigma_{\overleftarrow{\mathbf{e}^+}} - \mathbf{d}\sigma_{\overrightarrow{\mathbf{e}^+}} \propto \mathrm{Im}\,(\mathcal{T}_{BH}\mathcal{T}_{DVCS}) \propto \sin\phi \Longrightarrow \mathbf{H^u(x,\xi,t)}$$

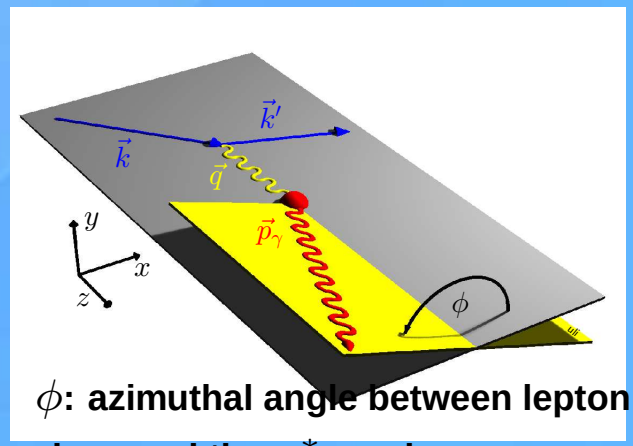
- **beam charge asymmetry:**

$$\mathbf{d}\sigma_{\mathbf{e}^+} - \mathbf{d}\sigma_{\mathbf{e}^-} \propto \mathrm{Re}\,(\mathcal{T}_{BH}\mathcal{T}_{DVCS}) \propto \cos\phi \Longrightarrow \mathbf{H^u(x,\xi,t)}$$

$\Rightarrow$ **unpolarized beam**

- **longitudinal target spin asymmetry:**

$$\mathbf{d}\sigma_{\overleftarrow{\mathbf{p}}} - \mathbf{d}\sigma_{\overrightarrow{\mathbf{p}}} \propto \mathrm{Im}\,(\mathcal{T}_{BH}\mathcal{T}_{DVCS}) \propto \sin\phi \Longrightarrow \mathbf{\tilde{H}^u(x,\xi,t)}$$

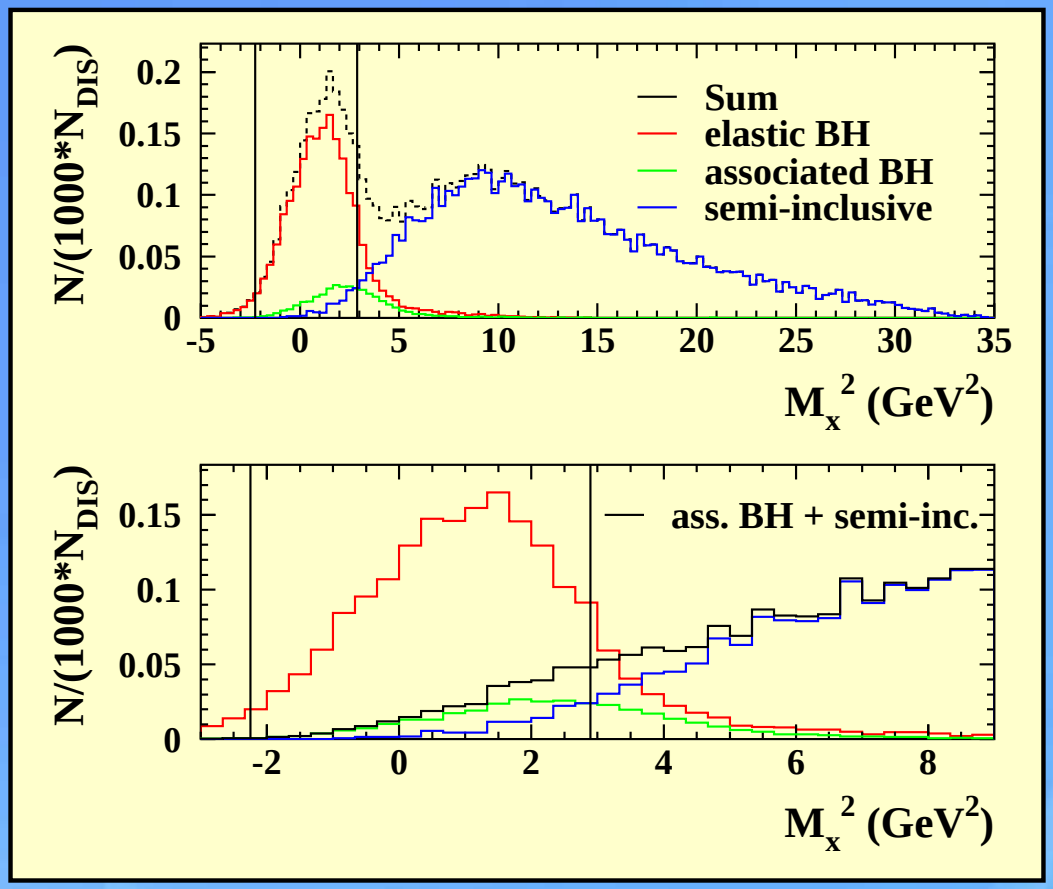


ϕ: azimuthal angle between lepton scattering plane and the $\gamma^*\gamma$ - plane

DVCS at HERMES

$\Longrightarrow$ **Exclusivity has to be ensured by missing mass:** $\mathbf{M_x^2} = (q + p - p_\gamma)^2 = M_p^2$

$\Longrightarrow$ **Energy resolution in exclusive region:** $\sigma(\mathrm{M_x}) \approx$ **0.8 GeV**



MC:

- **Elastic contribution 85%**
- **Associated (with excitation of the nucleon into resonance, e.g. Δ) 10%**
- **Semi-inclusive background (mostly from π^0) 5%**

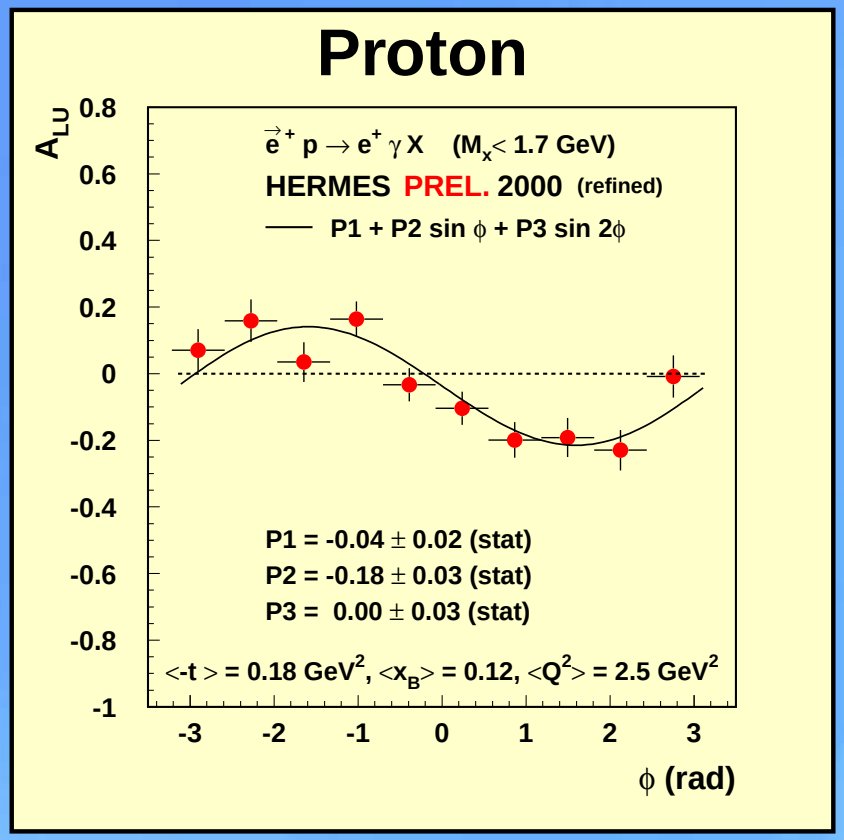
Exclusive Bin:

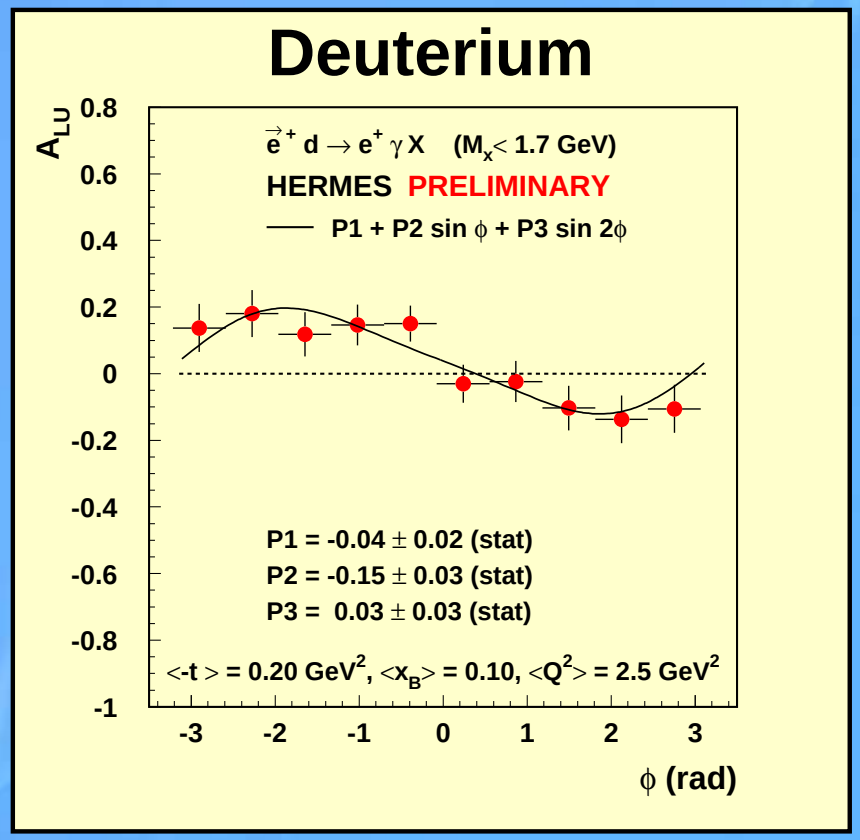
-1.5 $< \mathrm{M_x} <$ **1.7 GeV**

Beam Spin Asymmetry

$$\mathbf{d}\sigma_{\overrightarrow{\mathbf{e}^+}} - \mathbf{d}\sigma_{\overleftarrow{\mathbf{e}^+}} \Longrightarrow \mathbf{A}_{\mathbf{LU}}^{\sin\phi} \propto \mathrm{Im}\mathbf{H}^{\mathbf{u}}(\mathbf{x}, \xi, \mathbf{t})$$

$$\mathbf{A}_{\mathbf{LU}}(\phi) = \frac{\mathbf{1}}{\langle \mathbf{P}_{\mathbf{B}} \rangle} \frac{\overrightarrow{\mathbf{N}}(\phi) - \overleftarrow{\mathbf{N}}(\phi)}{\overrightarrow{\mathbf{N}}(\phi) + \overleftarrow{\mathbf{N}}(\phi)}$$

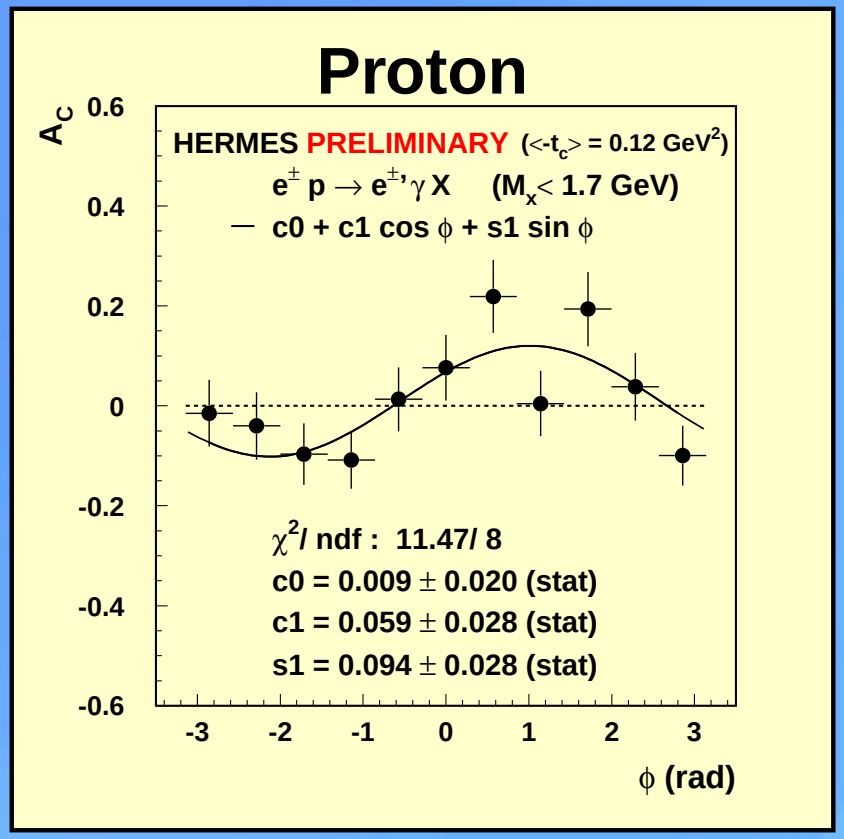


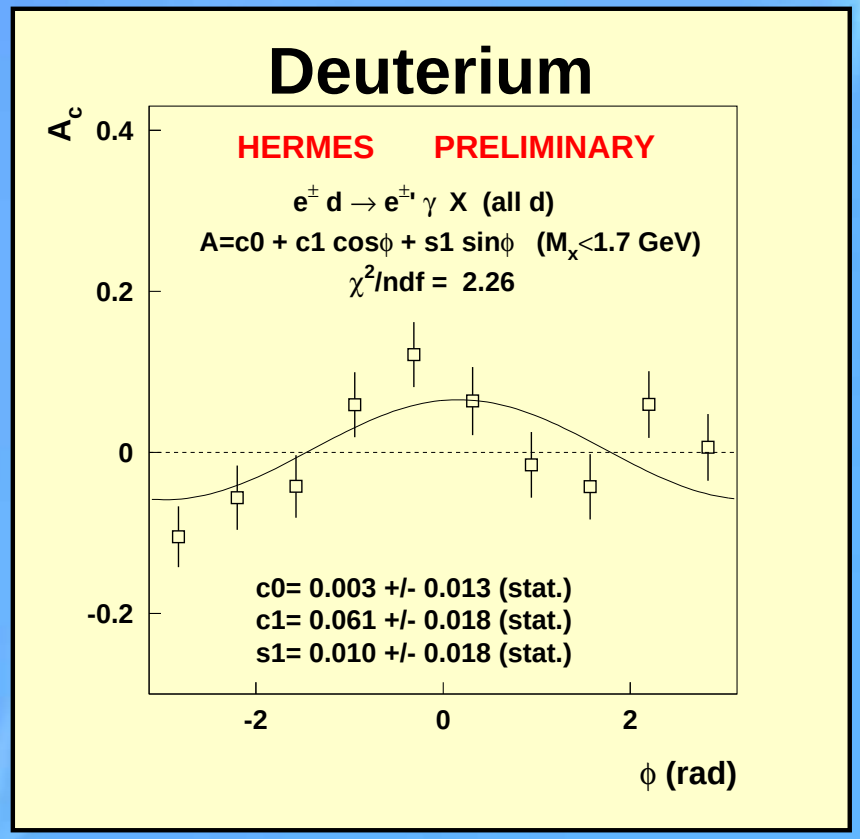


Beam Charge Asymmetry

$$d\sigma_{e^+} - d\sigma_{e^-} \Longrightarrow A_C^{\cos\phi} \propto \mathrm{Re}H^u(x,\xi,t)$$

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

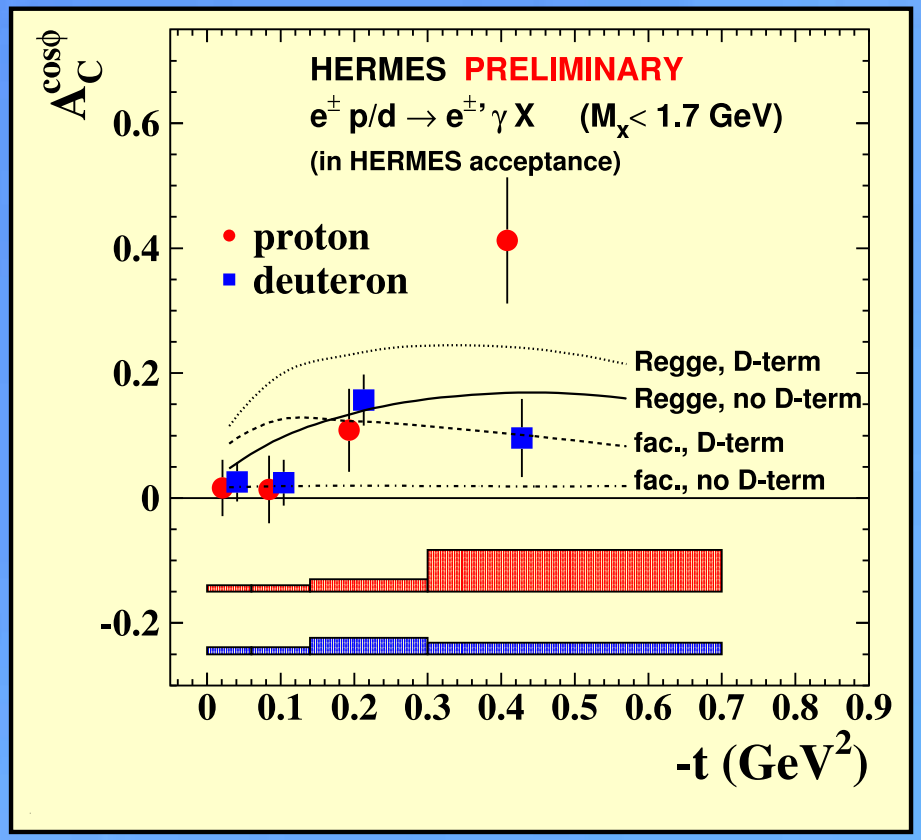




$A_C^{\sin\phi} \neq 0 \Longrightarrow$ **Non zero** P_B

$A_{C,\mathrm{Proton}} \sim A_{C,\mathrm{Deuteron}}$

Beam Charge Asymmetry vs. t



GPD model: M. Vanderhaeghen et al.

Proton vs. Deuterium

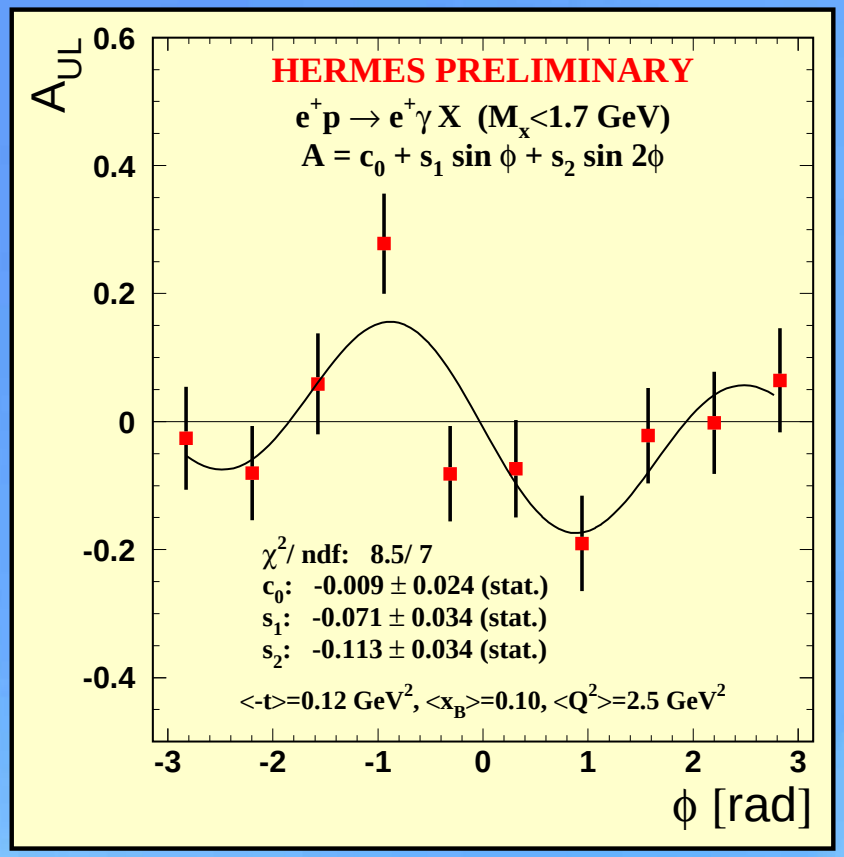
- 1st Deuterium bin has 40% coherent contribution
  $\Longrightarrow$ No difference between eP and eD
- Possible difference in last bin
  ($\Longrightarrow$ neutron)
- t-dependence of BCA high sensitivity to GPD models
- tiny e^-p sample ($\sim 10\mathrm{pb}^{-1}$)
  $\Longrightarrow$ factor 8 more on tape

Longitudinal Target Spin Asymmetry

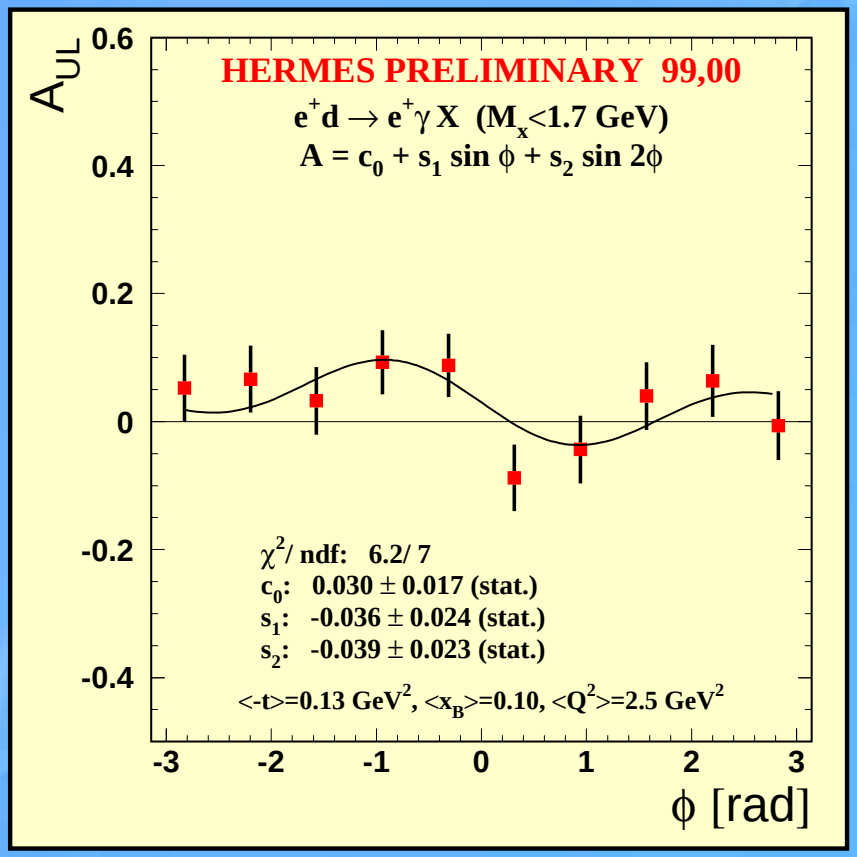
$$d\sigma_{\vec{p}} - d\sigma_{\overleftarrow{p}} \Longrightarrow A_{UL}^{\sin\phi} \propto \mathrm{Im}\tilde{H}^{u}(x,\xi,t)$$

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

Proton

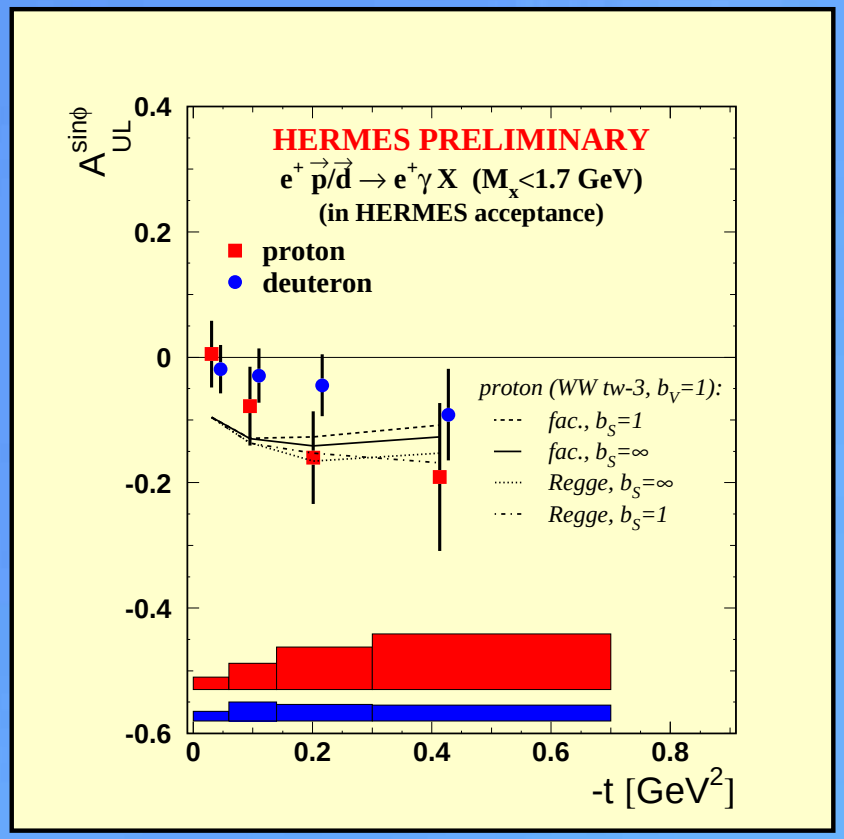


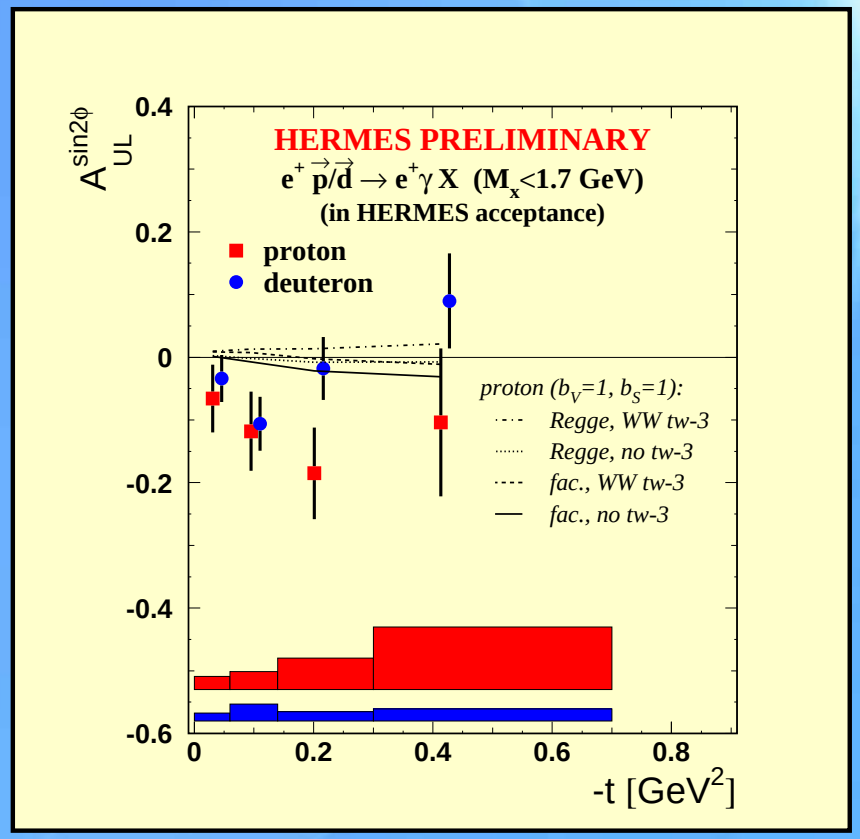
Deuterium



Sizeable unexpected $A_{UL}^{\sin 2\phi} \Longrightarrow$ sensitive to e.g. twist-3 Im $(H^3\tilde{H}^3)$

Longitudinal Target Spin Asymmetry vs. t





- eD coherent production 40% in 1st bin
  $\Longrightarrow$ No difference between eP and eD
- Possible difference in last bin ($\Longrightarrow$ neutron)
- $A_{UL}^{\sin 2\phi}$ twist 3 not fully included in the model

What about the GPD E

$\Rightarrow$ **unpolarized beam**

- **transverse target spin asymmetry:**

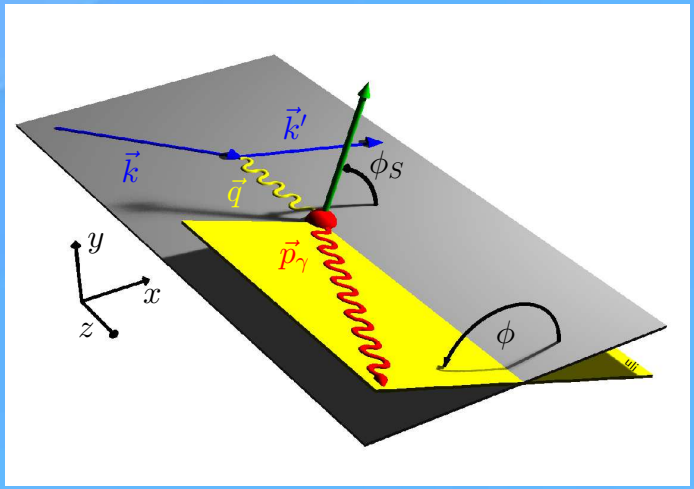
$$\mathbf{d}\sigma_{\mathbf{P}\Uparrow} - \mathbf{d}\sigma_{\mathbf{P}\Downarrow} \quad \propto \quad \underbrace{\mathrm{Im}(F_2 H_1 - F_1 E_1)}_{\mathbf{A}_{\mathbf{UT}}^{\sin(\phi-\phi_s)\cos(\phi)}} \cdot \sin(\phi - \phi_s)\cos(\phi) +$$

$$\underbrace{\mathrm{Im}(F_2 \tilde{H}_1 - F_1 \xi \tilde{E}_1)}_{\mathbf{A}_{\mathbf{UT}}^{\cos(\phi-\phi_s)\sin(\phi)}} \cdot \cos(\phi - \phi_s)\sin(\phi)$$

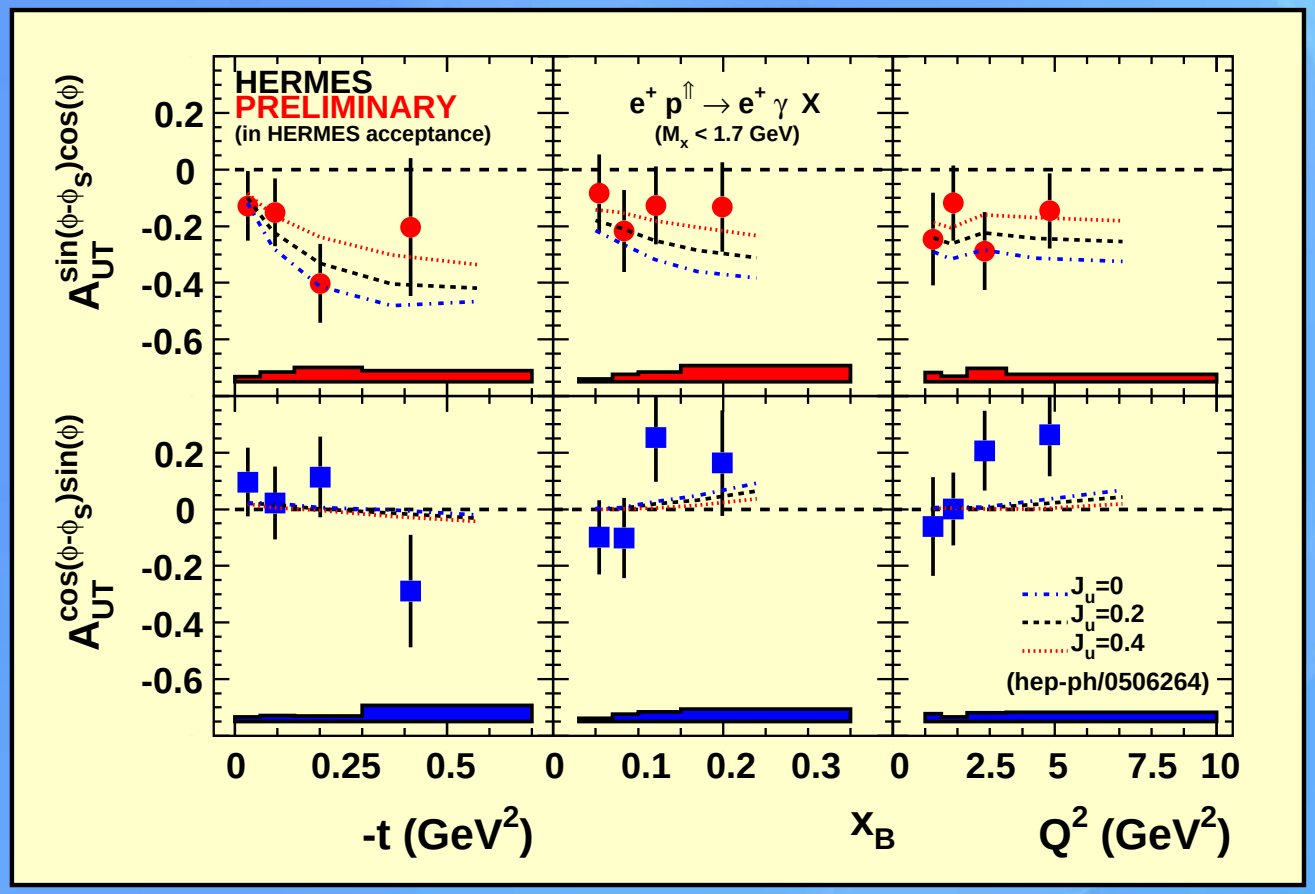
- **2D asymmetry: in ϕ and $(\phi - \phi_s)$**

$$\mathbf{A_{UT}}(\phi, \phi_s) = \frac{\mathbf{N}^{\Uparrow}(\phi, \phi - \phi_s) - \mathbf{N}^{\Downarrow}(\phi, \phi - \phi_s)}{\mathbf{N}^{\Uparrow}(\phi, \phi - \phi_s) - \mathbf{N}^{\Downarrow}(\phi, \phi - \phi_s)}$$

- $\mathbf{A}_{\mathbf{UT}}^{\sin(\phi-\phi_s)\cos(\phi)}$ **is sensitive 'to parameterizations involving different $\mathbf{J_u}$**



Transverse Target Spin Asymmetry



- $A_{UT}^{\sin(\phi-\phi_s)\cos(\phi)} \sim \mathrm{Im}(F_2 H_1 - F_1 E_1)$
- $A_{UT}^{\cos(\phi-\phi_s)\sin(\phi)} \sim \mathrm{Im}(F_2 \tilde{H}_1 - F_1 \xi \tilde{E}_1)$

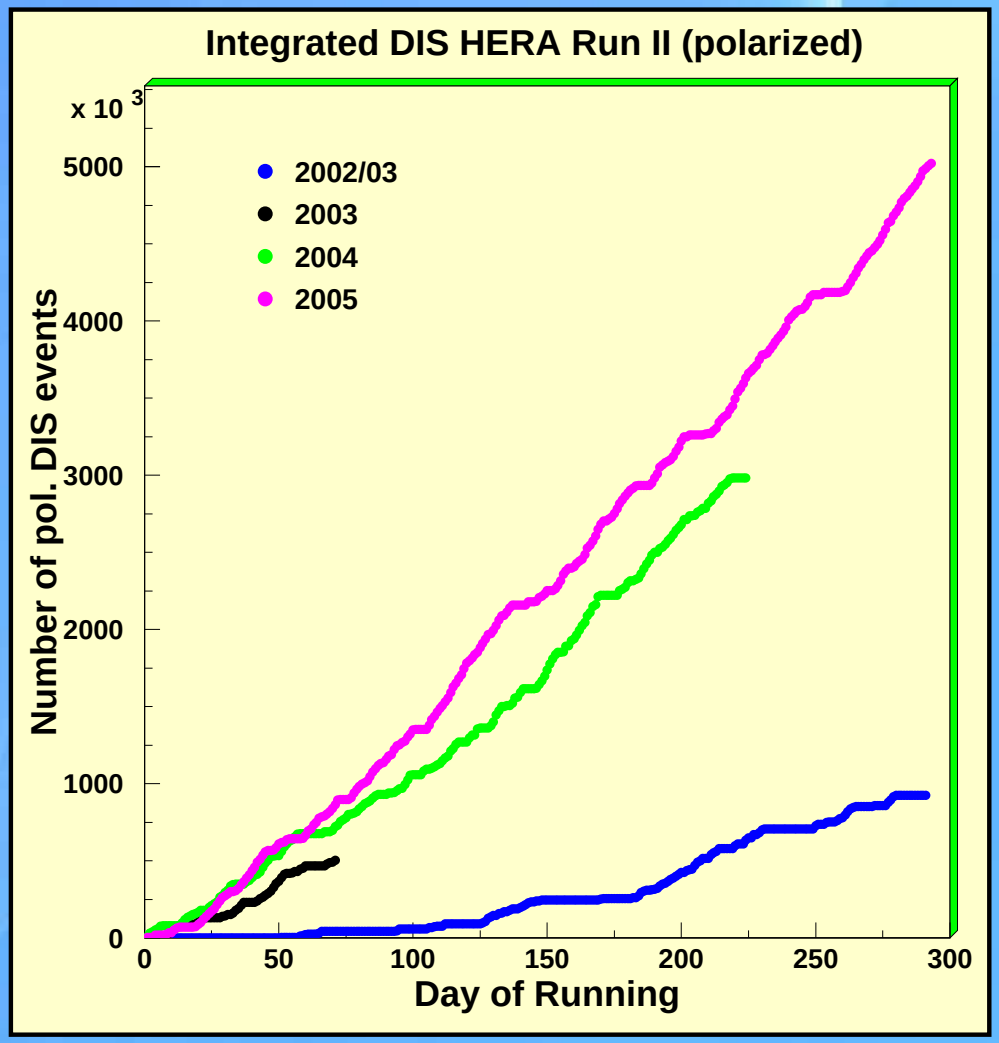
- $A_{UT}^{\sin(\phi-\phi_s)\cos(\phi)}$ **largely independent on all model parameters but** J_u
- **first model dependent extraction of** J_u **possible**

and Summary

- **HERMES can constrain all GPDs (H^q, E^q, $\tilde{H}^q$, $\tilde{E}^q$) via different complementary observables**

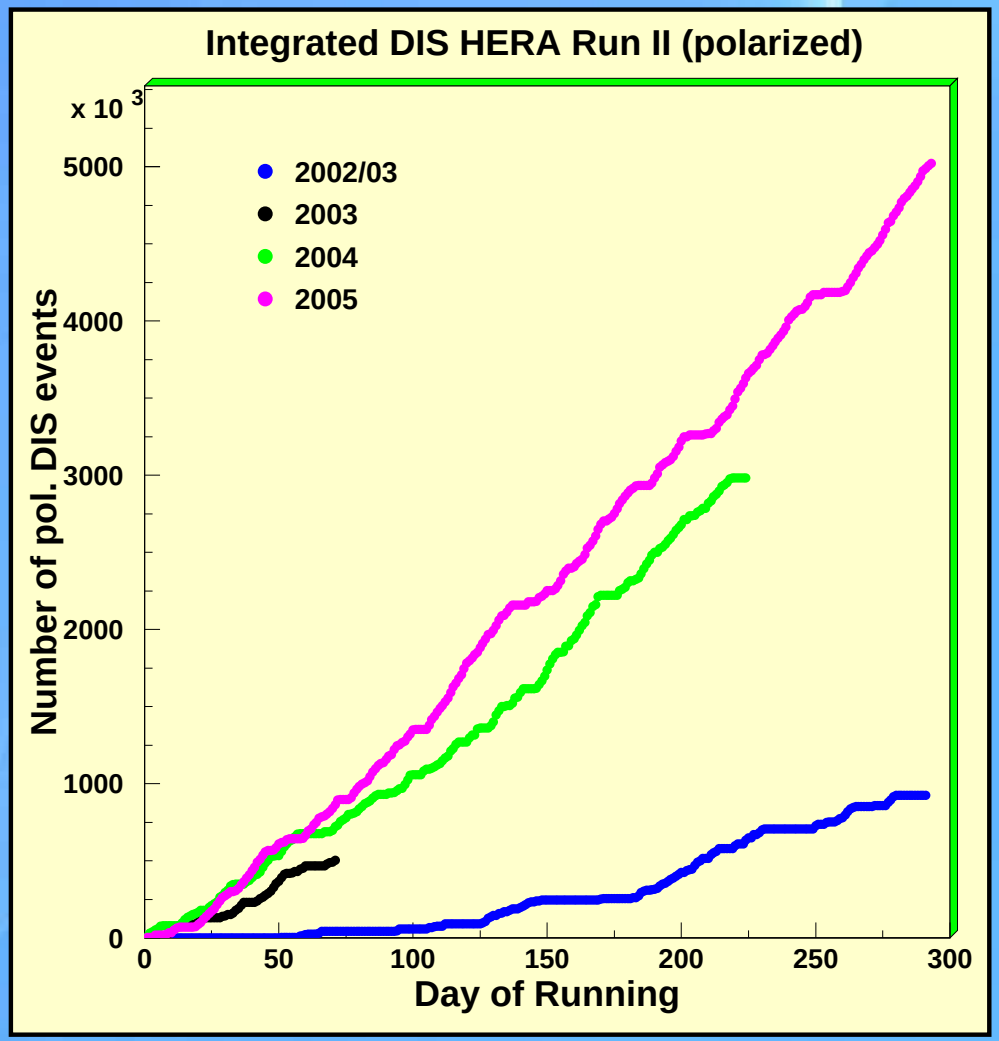
Outlook and Summary

- HERMES can constrain all GPDs (H^q, E^q, $\tilde{H}^q$, $\tilde{E}^q$) via different complementary observables
- HERMES continues happily taking data with a transverse polarized p-target
  $\Longrightarrow$ Will more than double 2002 - 2004 statistics



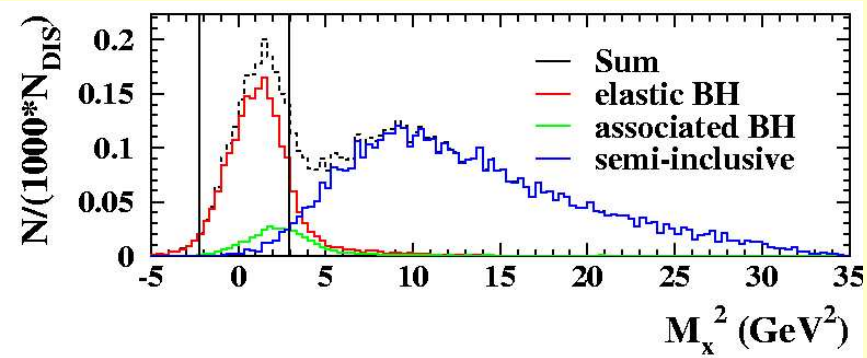
Outlook and Summary

- HERMES can constrain all GPDs (H^q, E^q, $\tilde{H}^q$, $\tilde{E}^q$) via different complementary observables
- HERMES continues happily taking data with a transverse polarized p-target
  $\Longrightarrow$ Will more than double 2002 - 2004 statistics
- 2006/2007 HERMES running dedicated to measure BSA and BCA



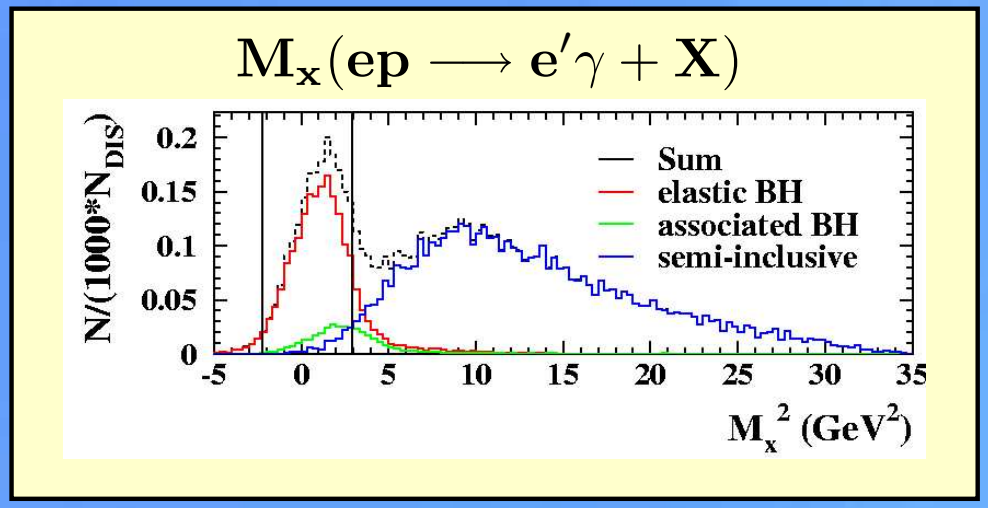
Improve Exclusivity

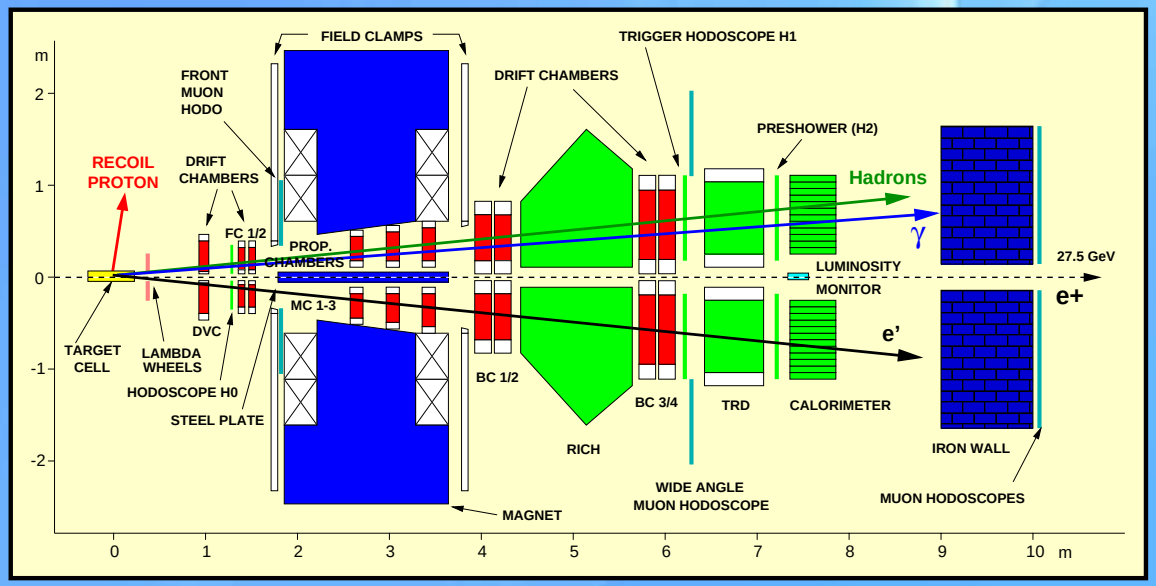
$$\mathbf{M_x(ep \longrightarrow e'\gamma + X)}$$



Exclusivity by missing mass $\mathrm{M_x}$

Improve Exclusivity



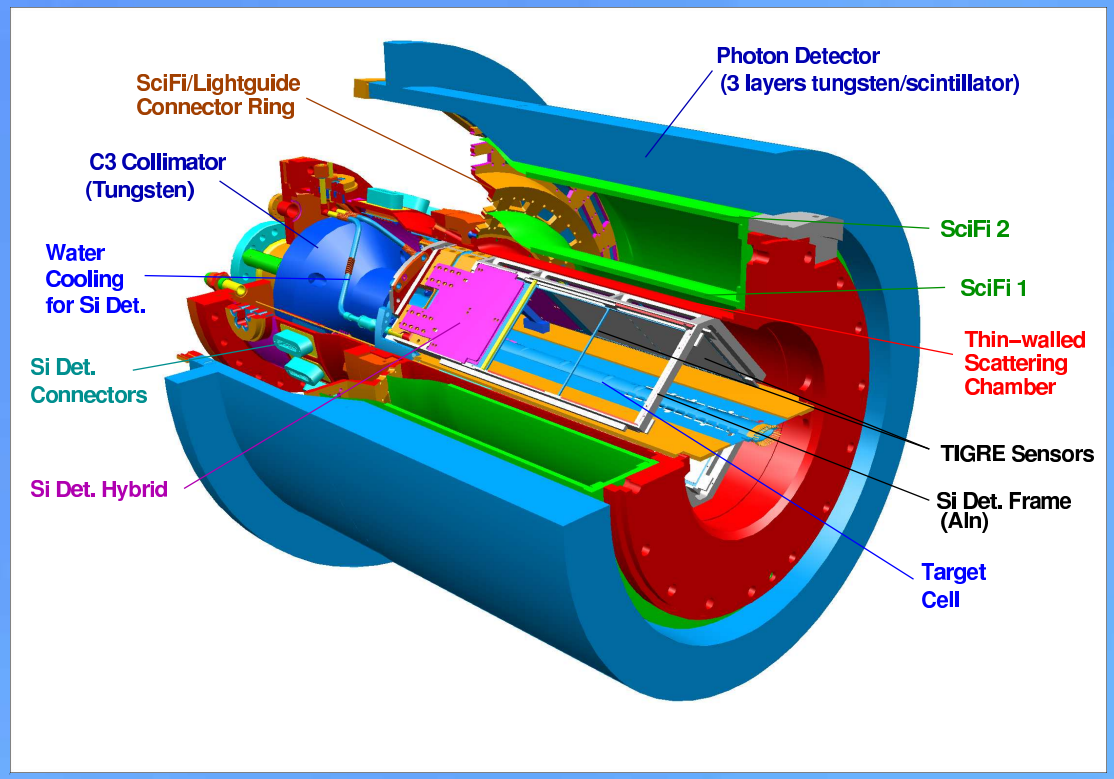


Exclusivity by missing mass M_x

$\Longrightarrow$ **Modify target region**

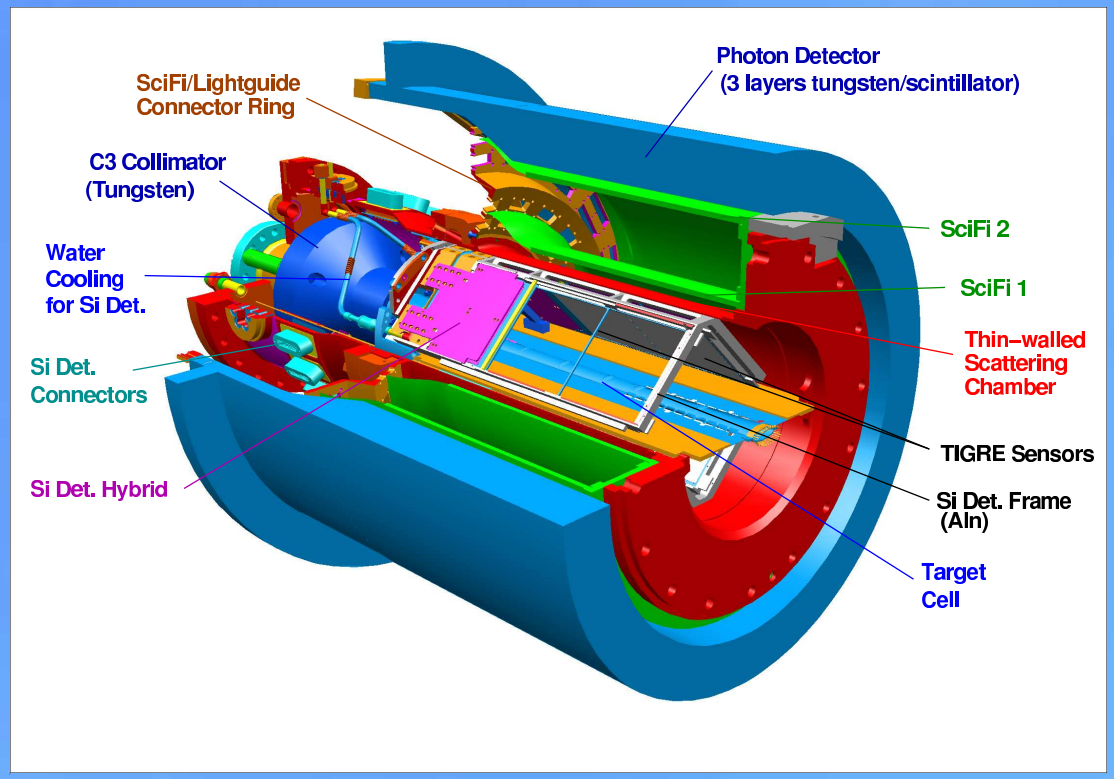
$\Rightarrow$ **detect recoiling proton** $\Longrightarrow$ **select exclusive events**

The HERMES Recoil Detector



build by DESY, Erlangen, Ferrara, Frascati, Gent, Giessen and Glasgow

The HERMES Recoil Detector



build by DESY, Erlangen, Ferrara, Frascati, Gent, Giessen and Glasgow

- **detection of the recoiling proton**
  - $\Rightarrow$ **p: 135 - 1200 MeV /c**
  - $\Rightarrow$ **76 % ϕ acceptance**
  - $\Rightarrow$ **π/p-PID via dE/dx**
- **Background Suppression**
  - $\Rightarrow$ **semi-incl.: 5% $\rightarrow$ $<<$1%**
  - $\Rightarrow$ **associated: 11% $\rightarrow$ $\sim$1%**
- **improved t-resolution**
  - $\Rightarrow$ **study kinematical dependences**
- **data taking in 2006/2007**