DVCS at hermes

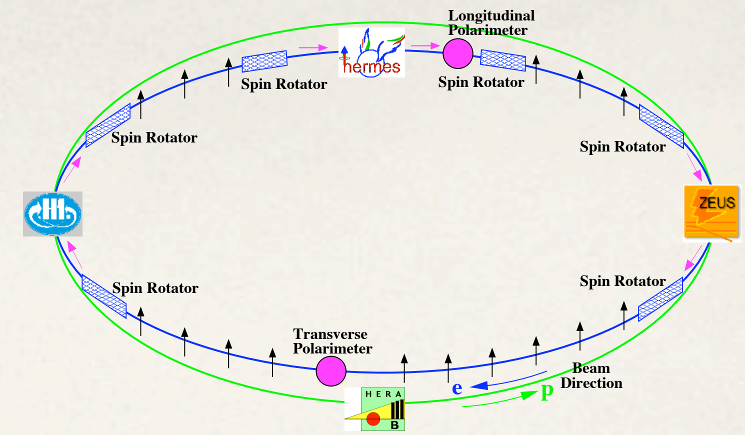
HERA DVCS Working Group Meeting
Hamburg, 28.10.2009

Caroline Riedl
for the HERMES Collaboration

Outline: DVCS at HERMES

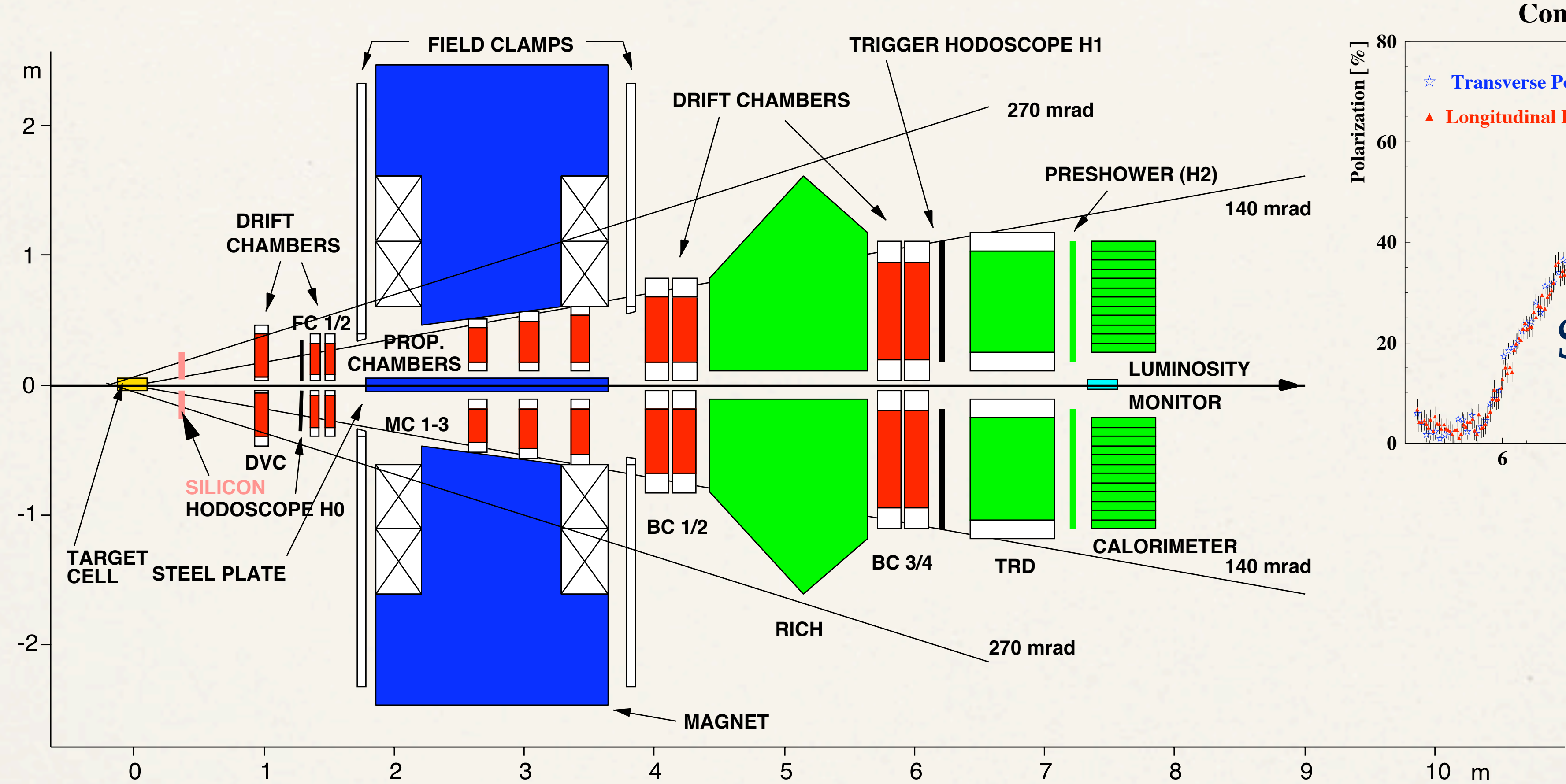
- HERMES and HERA
- Generalized Parton Distributions
- Azimuthal Asymmetry Amplitudes
- The Recoil detector upgrade

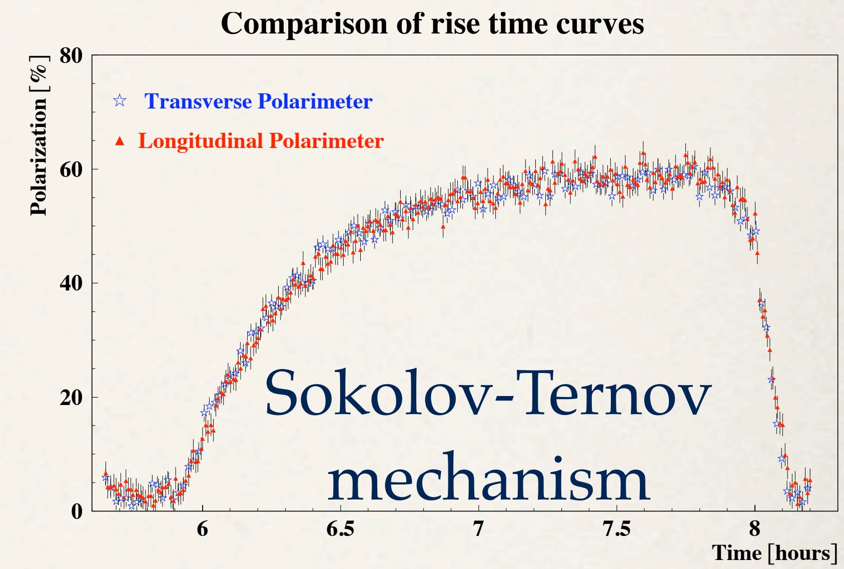
HERMES and HERA



e±

27.6 GeV





Sokolov-Ternov mechanism

- P_B = 30...65%
- 2 beam helicities
- e^+ and e^-

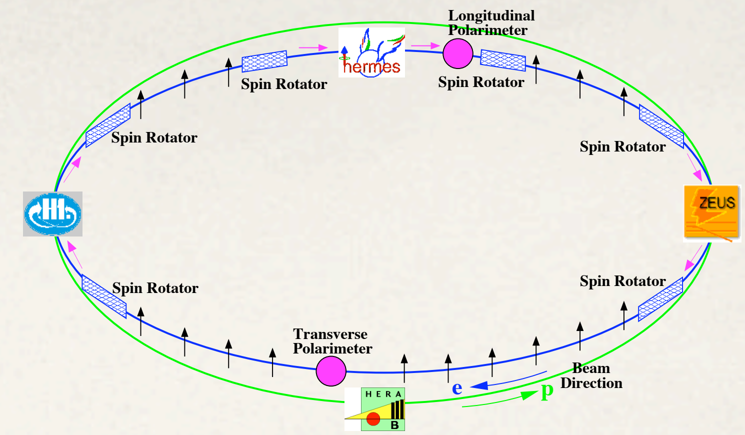
$\vec{H}$, $\vec{H}$, $\vec{D}$

H, D
He, N, Ne, Kr, Xe

Tracking
momentum resolution: ≤ 2%
angular resolution:
0.3...0.6 mrad

Particle IDentification
electron ID: 98-99%
hadron contamination <1%
RICH: 2...15 GeV

HERMES and HERA



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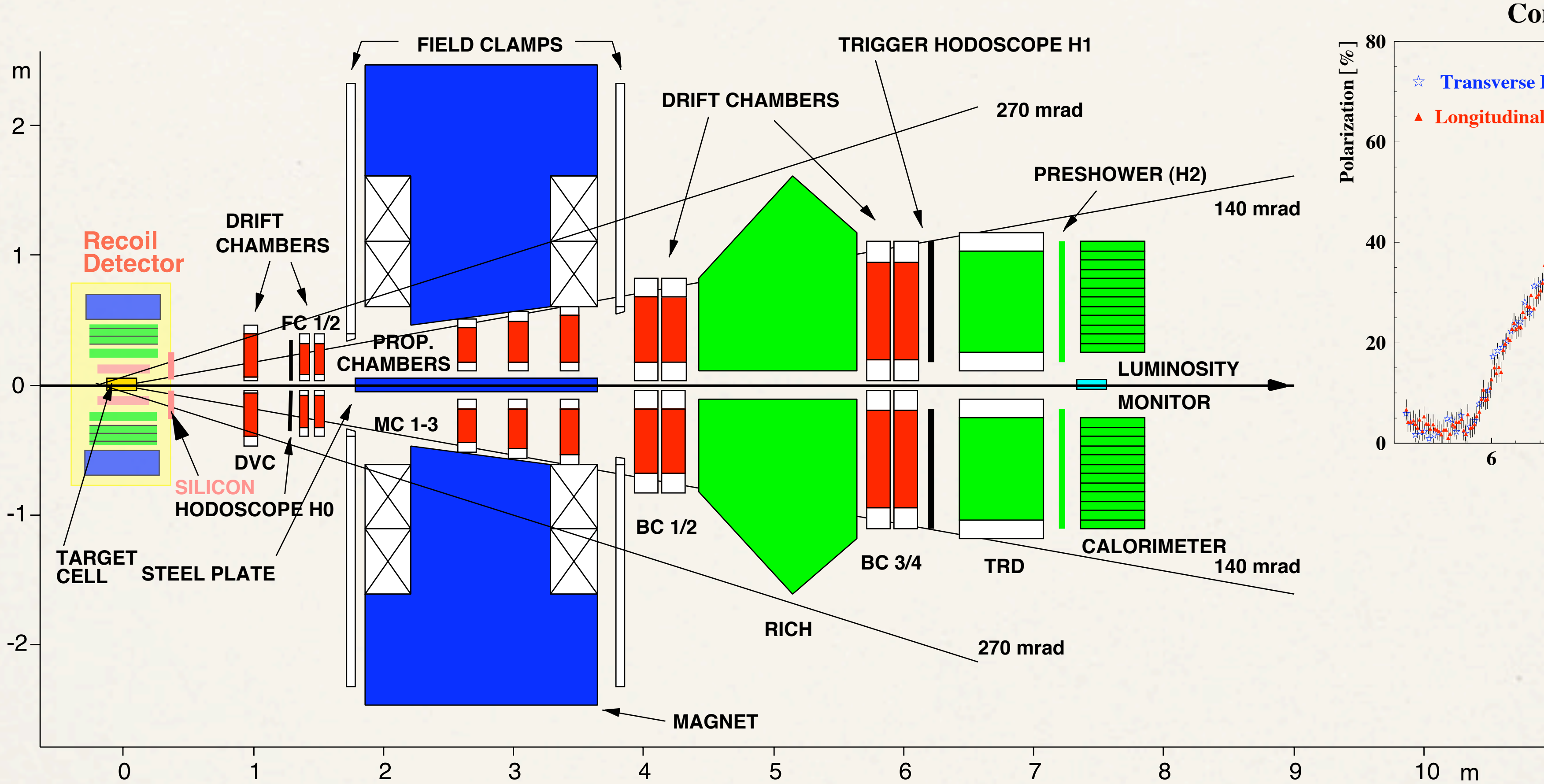

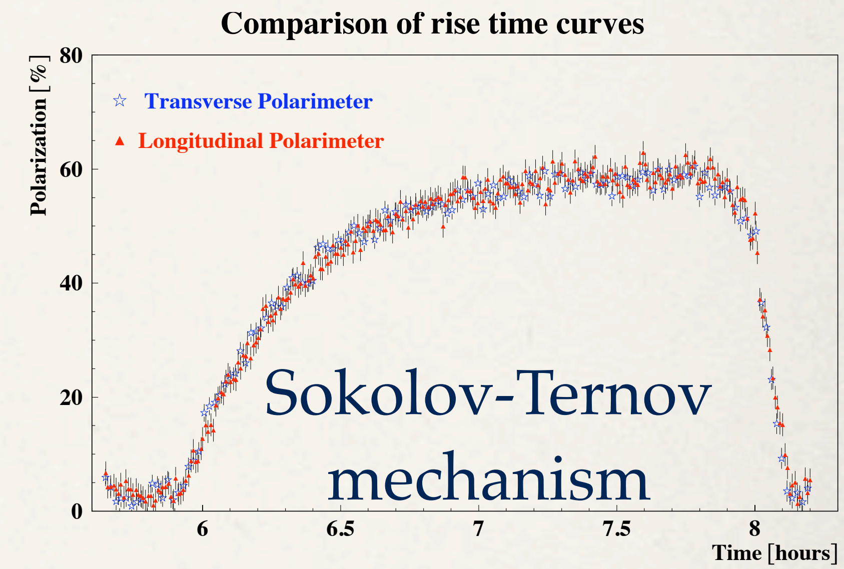

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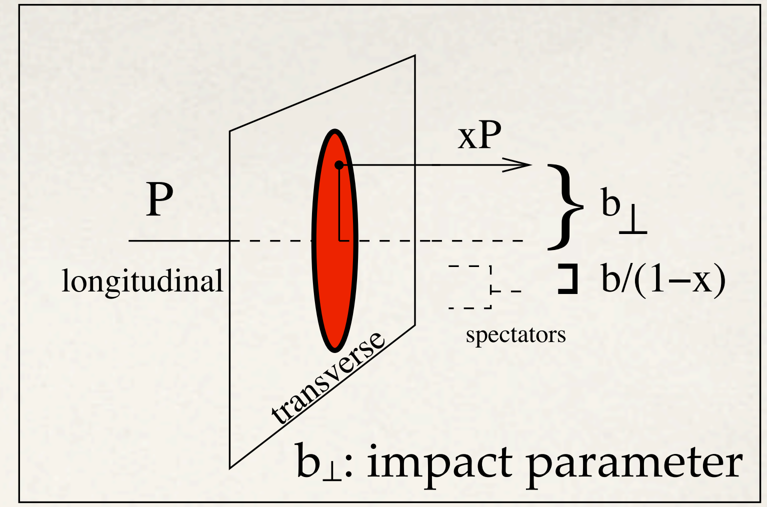
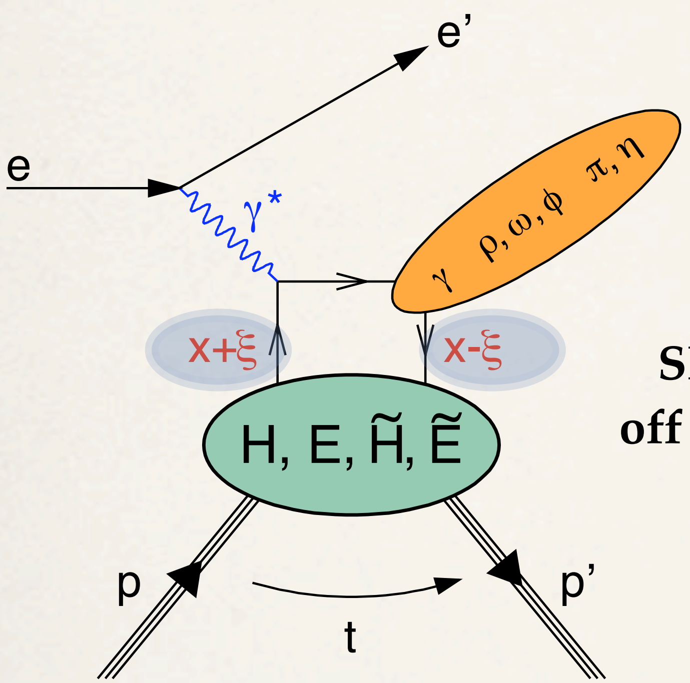
Generalized Parton Distributions





Skewing: ξ≠0
off forward limit

"Nucleon tomography"

- PDFs: longitudinal momentum

  forward limit ξ=0, t=0: $H^{\mathrm{q}}(x,0,0) = q(x)$

- Form Factors: transverse position

  moments of GPDs: $\int_{-1}^{1} \mathrm{d}x H^{\mathrm{q}}(x,\xi,t) = F_1^{\mathrm{q}}(t)$

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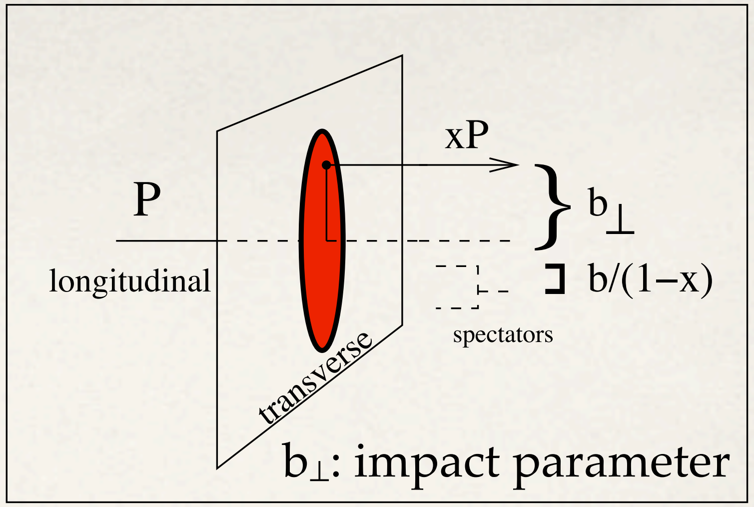

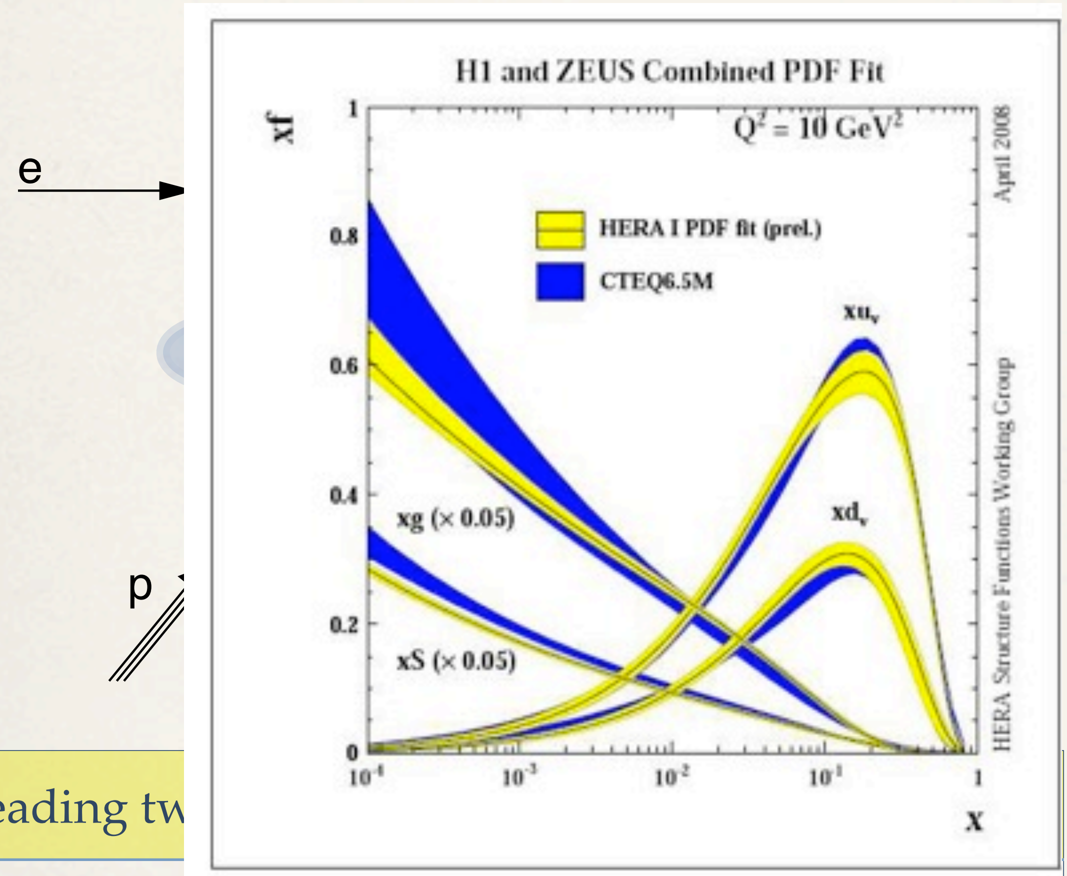

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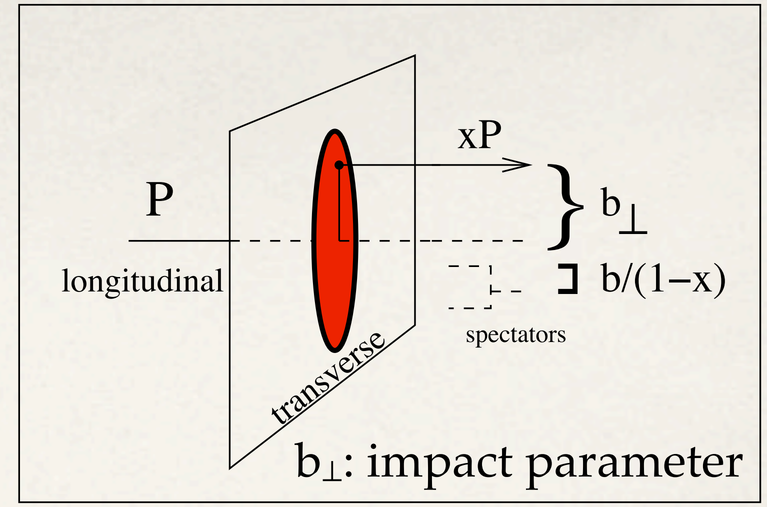

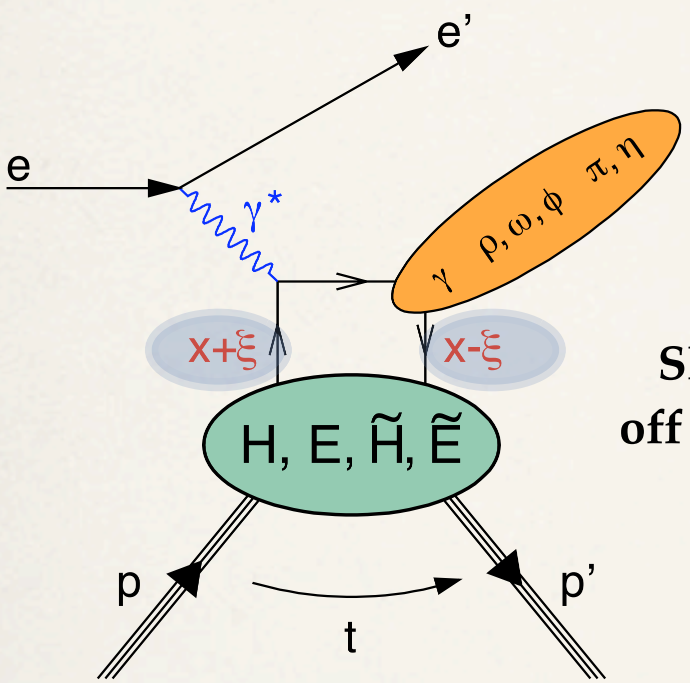

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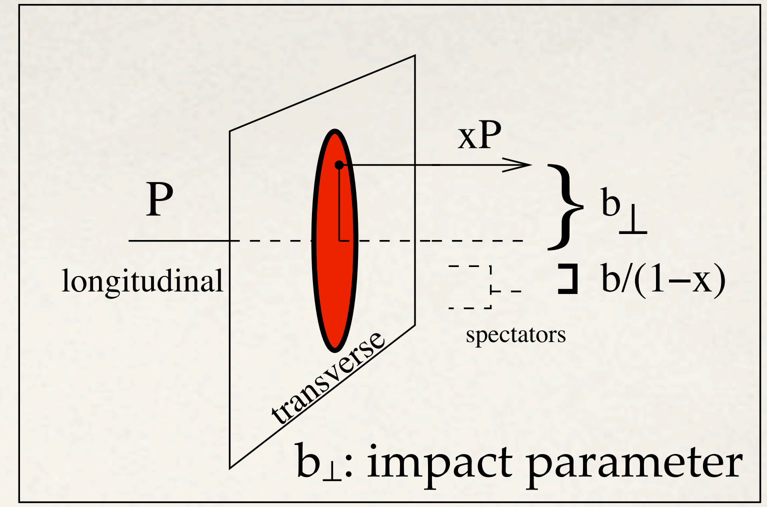

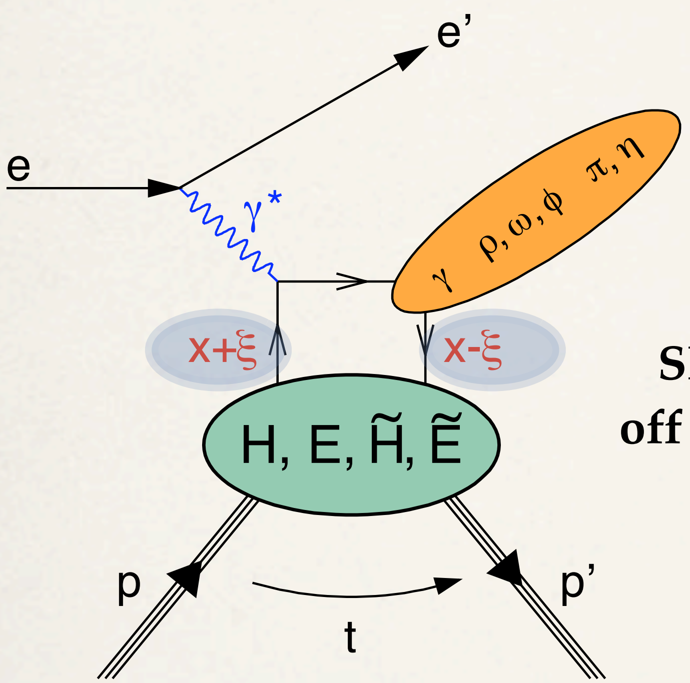

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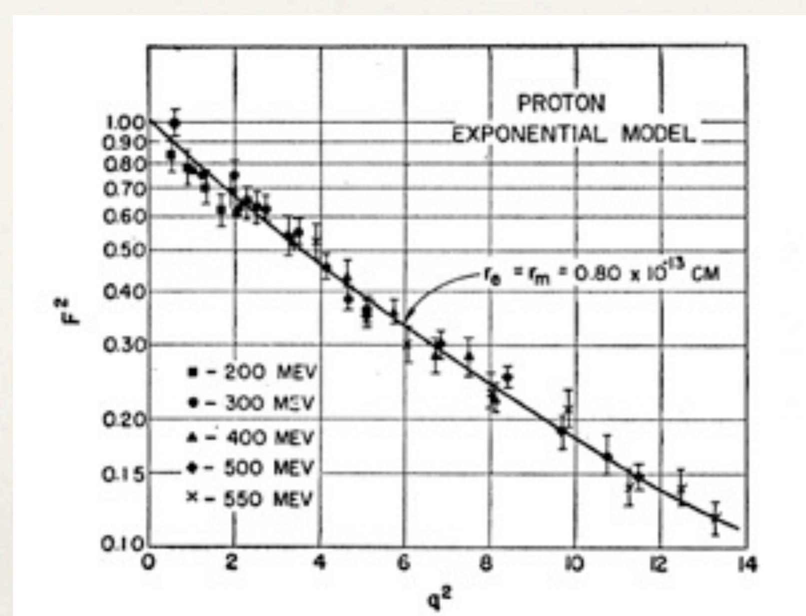
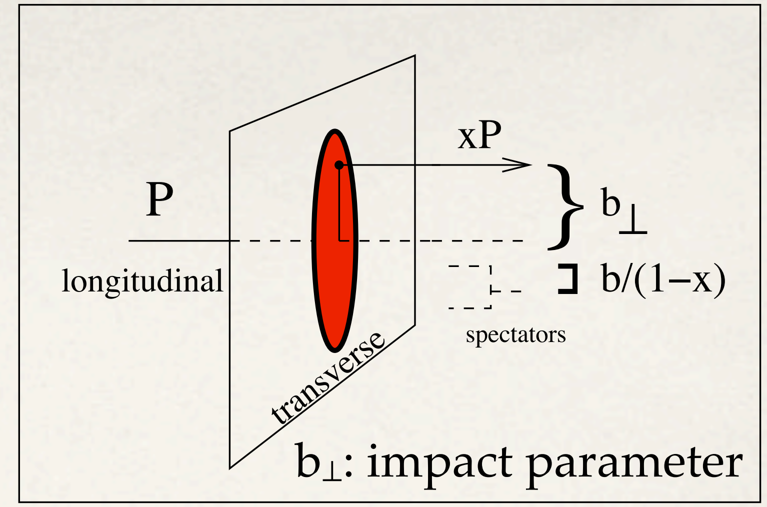
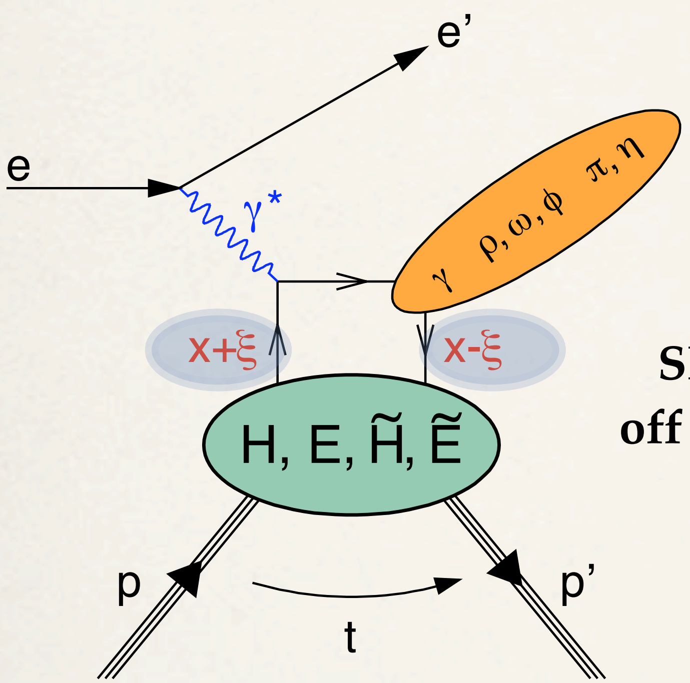


angular momentum

$H^q(x,\xi,t) + E^q(x,\xi,t)]$

Generalized Parton Distributions





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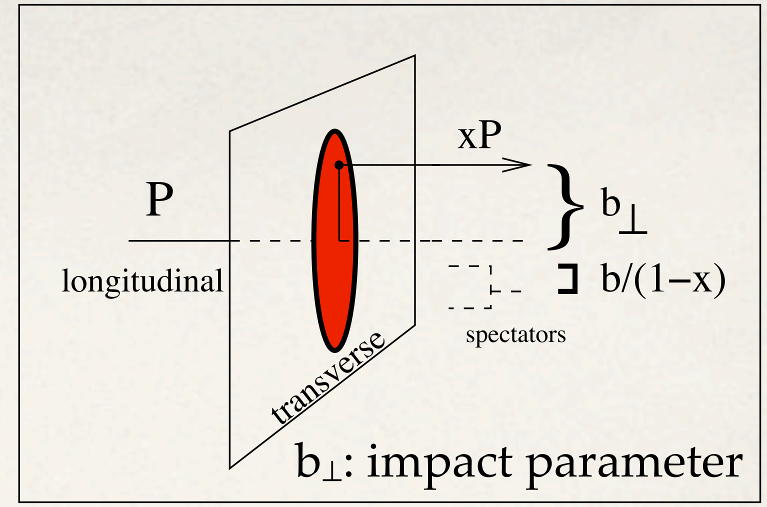

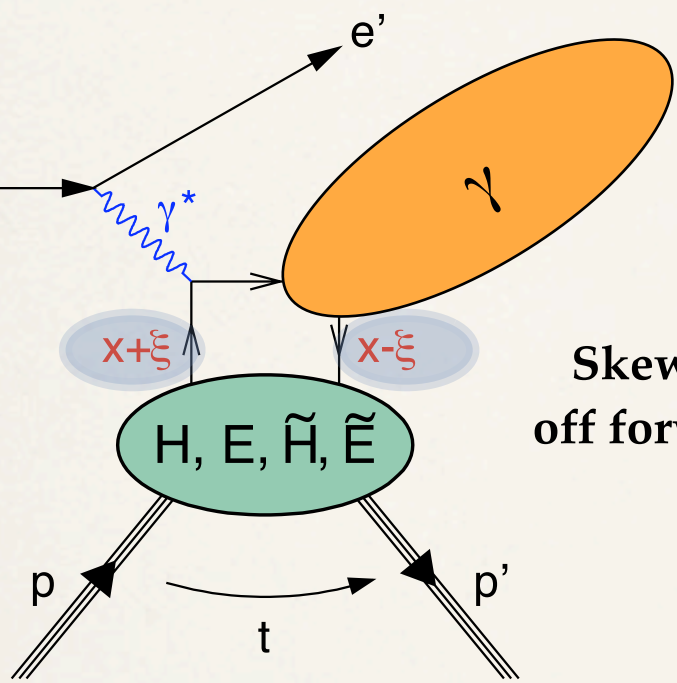

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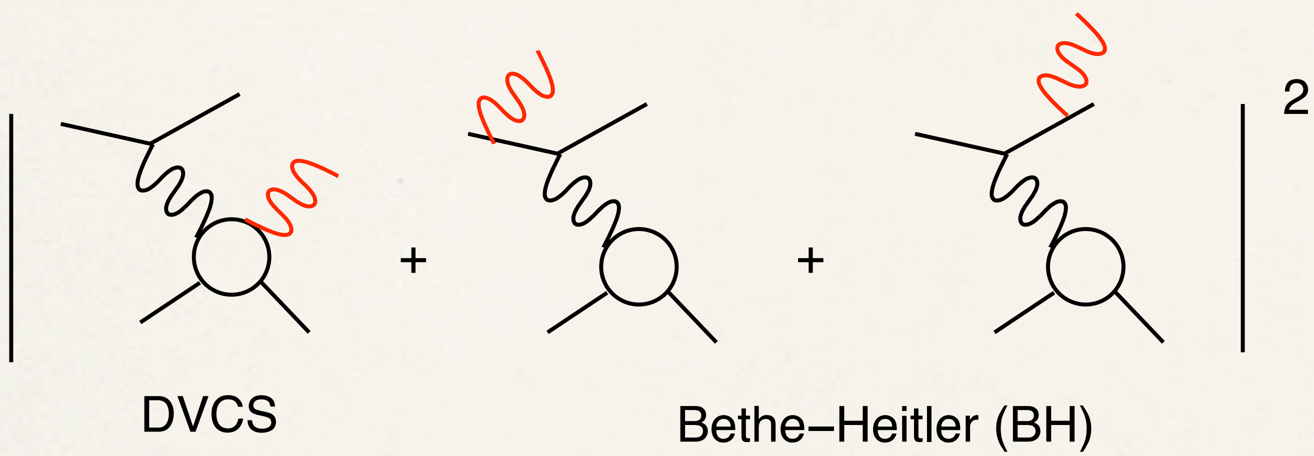
Deeply Virtual Compton Scattering

$\sigma_{\gamma^*\gamma N} \sim$



$$= |\tau_{DVCS}|^2 + |\tau_{BH}|^2 + \tau_{DVCS}\tau_{BH}^* + \tau_{DVCS}^*\tau_{BH}$$

DVCS-BH

interference term $\mathcal{I}$

Contribution at colliders.
Fixed target:
$|\tau_{DVCS}|^2 \ll |\tau_{BH}|^2$

Exactly calculable in QED given the nucleon elastic form factors F_1 and F_2

<u>Holographic principle:</u>

- BH reference amplitude magnifies DVCS
- Measure magnitude A **and** phase φ of DVCS amplitude $\tau_{DVCS} = Ae^{i\varphi}$

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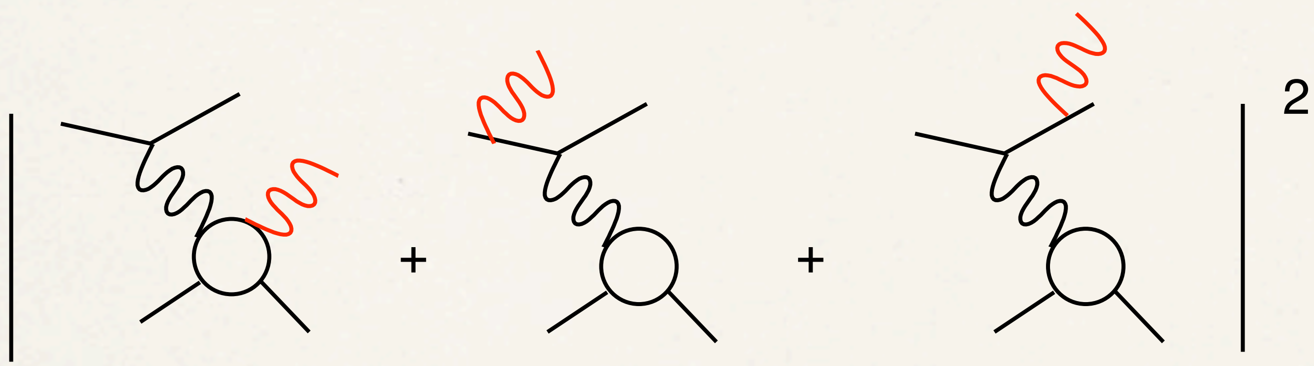
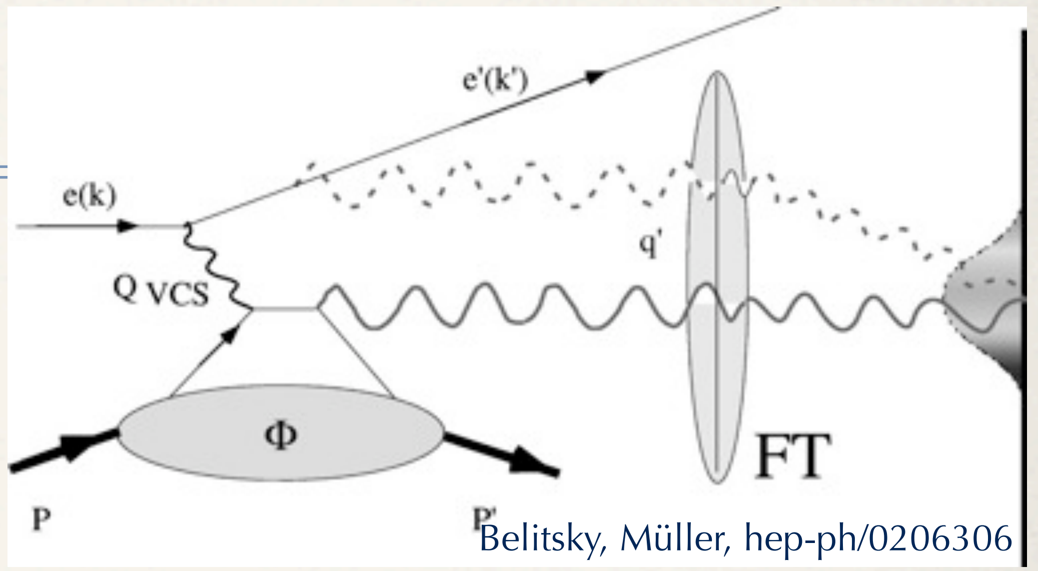


DVCS

Bethe–Heitler (BH)



$= |\tau_{DVCS}|^2 + |\tau_{BH}|^2 + \tau_{DVCS}\tau_{BH}^* + \tau_{DVCS}^*\tau_{BH}$

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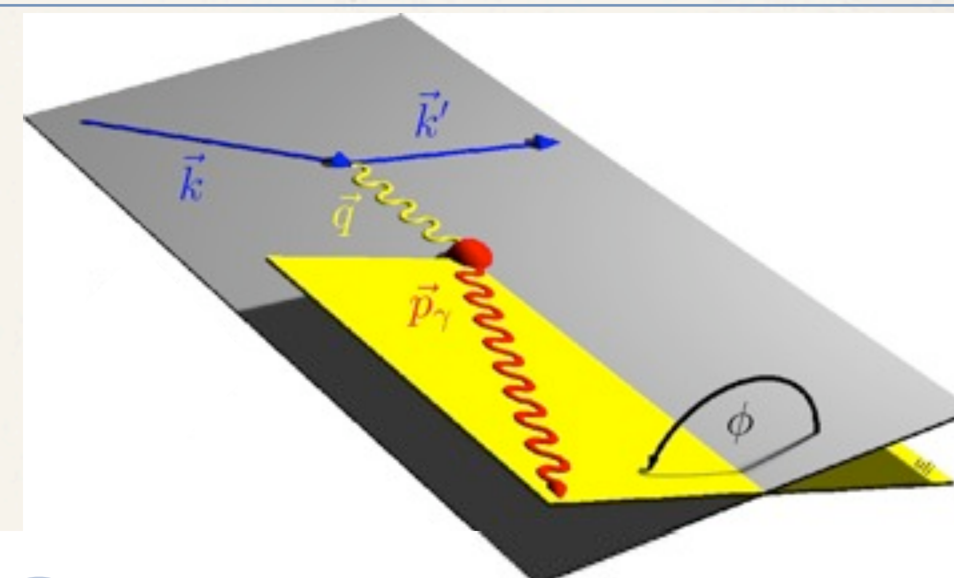
Azimuthal Dependences in $\gamma^* N \rightarrow \gamma N$

- Unpolarized target
- Lepton beam with charge C_B and polarization P_B



Fourier expansion in azimuthal angle ϕ

$$|\mathcal{T}_{\mathrm{BH}}|^2 = \frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \sum_{n=0}^{2} c_n^{\mathrm{BH}} \cos(n\phi)$$

$$|\mathcal{T}_{\mathrm{DVCS}}|^2 = K_{\mathrm{DVCS}} \left[\sum_{n=0}^{2} c_n^{\mathrm{DVCS}} \cos(n\phi) + P_B \sum_{n=1}^{1} s_n^{\mathrm{DVCS}} \sin(n\phi) \right]$$

$$\mathcal{I} = \frac{C_B K_{\mathcal{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left[\sum_{n=0}^{3} c_n^{\mathcal{I}} \cos(n\phi) + P_B \sum_{n=1}^{2} s_n^{\mathcal{I}} \sin(n\phi) \right]$$

Bethe-Heitler propagators $\mathcal{P}(\phi)$

Wanted: Fourier coefficients s_n and c_n of BH, DVCS, and $\mathcal{I}$ terms

Measured Azimuthal Asymmetries in DVCS

Born cross-section:

$$\sigma(\phi; P_B, C_B) = \sigma_{\mathrm{UU}}(\phi) \cdot [1 + P_B \mathcal{A}_{\mathrm{LU}}^{\mathrm{DVCS}}(\phi) + C_B P_B \mathcal{A}_{\mathrm{LU}}^{\mathcal{I}}(\phi) + C_B \mathcal{A}_{\mathrm{C}}(\phi)]$$

$\mathcal{A}_{\mathrm{LU}}$

Beam Target

Beam helicity asymmetries

Beam charge asymmetry

BSA:
projects out imaginary part of τ_{DVCS}

BCA:
projects out real part of τ_{DVCS}

Old approach at HERMES and CLAS: single charge BSA

$$\mathcal{A}_{\mathrm{LU}}(\phi) \equiv \frac{d\sigma^{\rightarrow} - d\sigma^{\leftarrow}}{d\sigma^{\rightarrow} + d\sigma^{\leftarrow}}$$

no separate access to $s_1^{\mathcal{I}}$ and s_1^{DVCS}

$$\mathcal{A}_{\mathrm{C}}(\phi) \equiv \frac{d\sigma^{+} - d\sigma^{-}}{d\sigma^{+} + d\sigma^{-}}$$

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New approach at HERMES: $s_1^{\mathcal{I}}$ and s_1^{DVCS} can be disentangled

Charge difference BSA:

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{I}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) - (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

Charge average BSA:

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{DVCS}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

From Azimuthal Asymmetries to GPDs

- Express asymmetries in terms of Fourier coefficients **c** and **s**

  ≡asymmetry amplitudes

- Compton Form Factors (CFFs) $\mathcal{F}(\xi,t) = \sum_q \int_{-1}^{1} \mathrm{d}x \, C_q^{\mp}(\xi,x) F^q(x,\xi,t)$

  twist-2 GPD

  - Define linear combination of CFFs:

$$\mathcal{C}^{\mathcal{I}}_{\text{unp}} = F_1 \mathcal{H} + \xi(F_1 + F_2)\widetilde{H} - \frac{t}{4M^2} F_2 \mathcal{E}$$

  - $F_1(t)$, $F_2(t)$: Dirac, Pauli nucleonic form factors

- At leading twist level (twist-2):

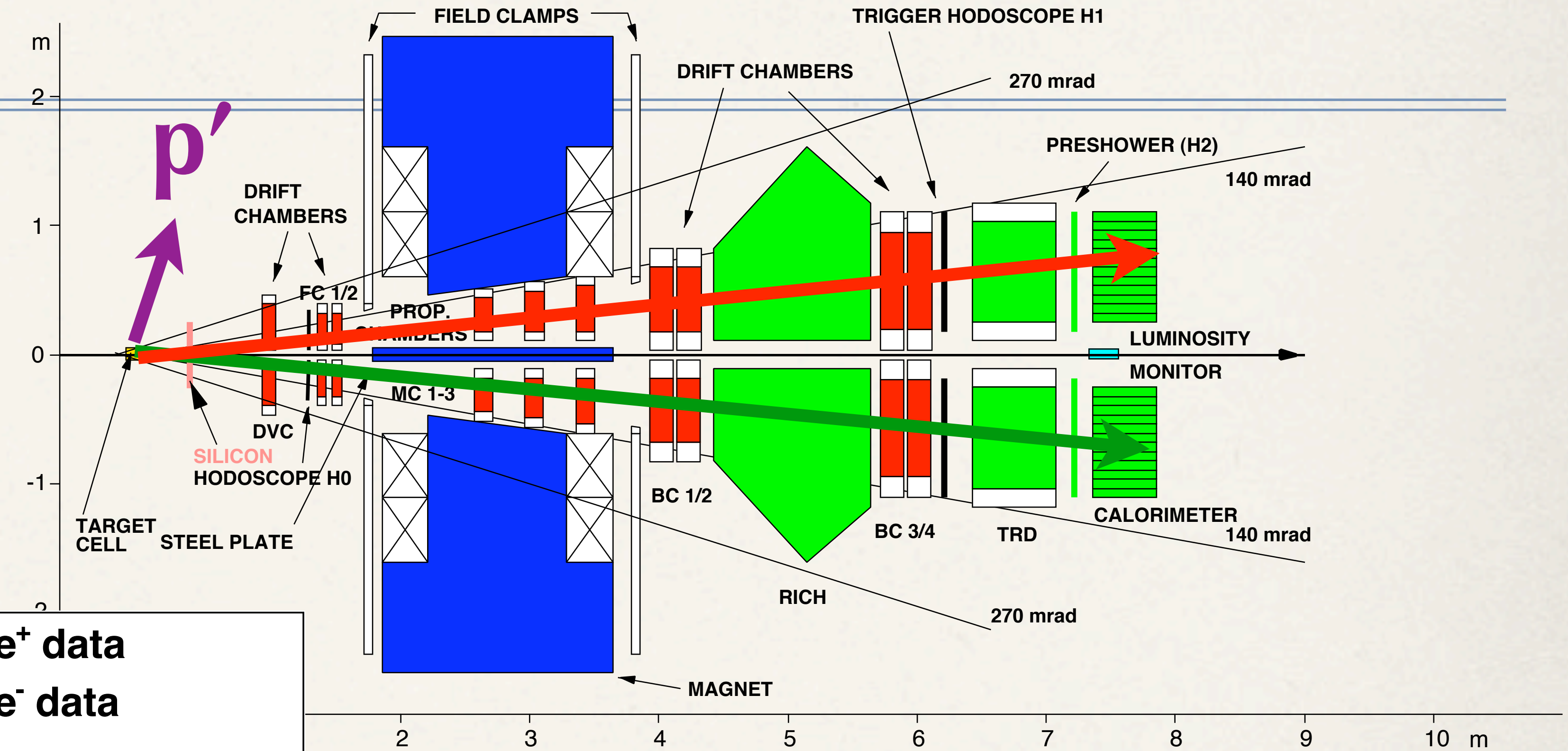
$$c_1^{\mathcal{I}} \propto \frac{\sqrt{-t}}{Q} \Re\left[\mathcal{C}^{\mathcal{I}}_{\text{unp}}\right] \propto -\frac{Q}{\sqrt{-t}} c_0^{\mathcal{I}} \qquad s_1^{\mathcal{I}} \propto \frac{\sqrt{-t}}{Q} \Im\left[\mathcal{C}^{\mathcal{I}}_{\text{unp}}\right]$$

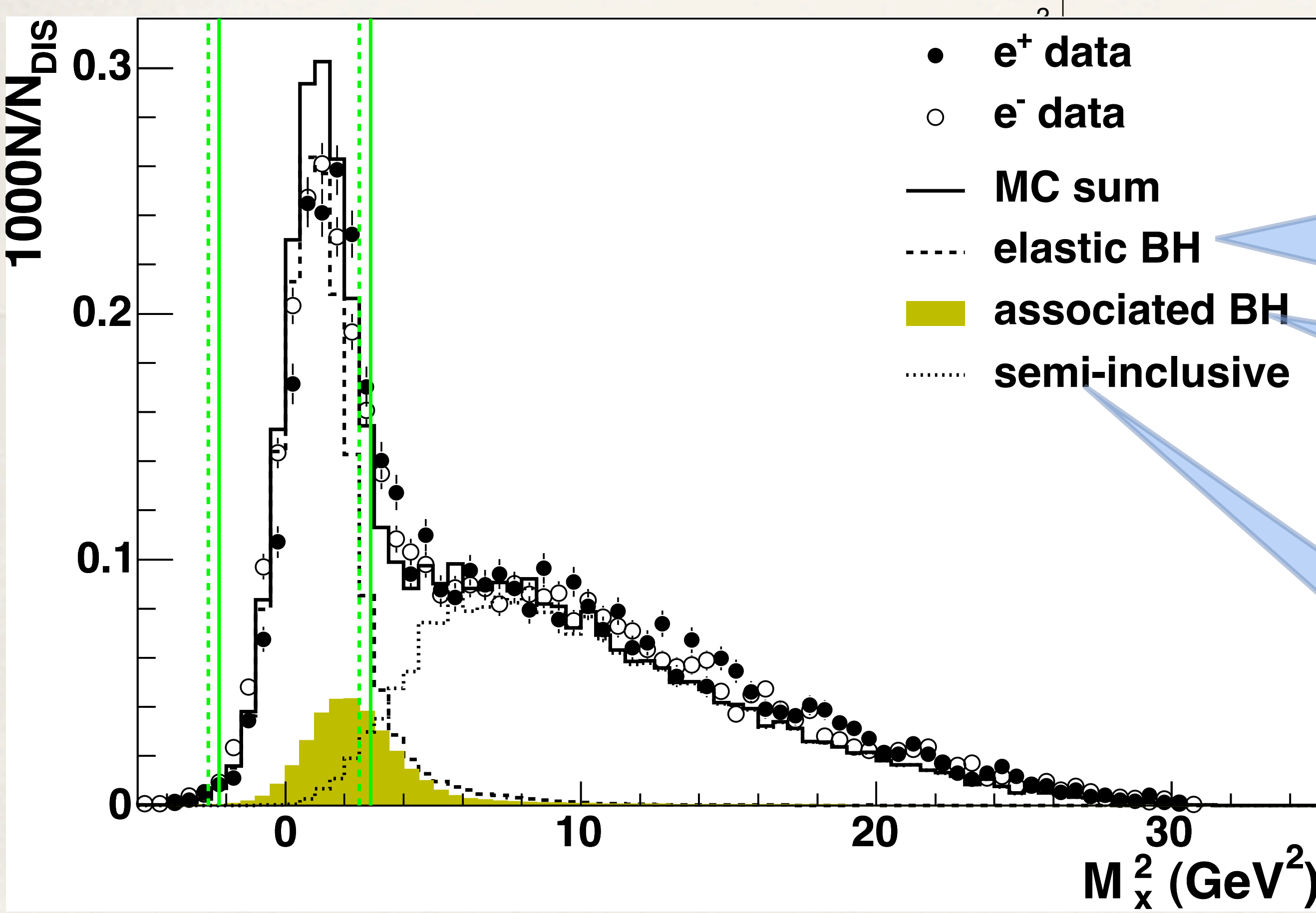
BCA **constant term** **BSA**

DVCS at HERMES 1996-2005 (w/o Recoil)

Detected particles:
electron and photon

Missing mass technique for
$ep \rightarrow eX\gamma$
$M_X^2=(p+q-p_\gamma)^2$





X=p

resonant excitation: $X=\Delta^+$

$p\pi^0$

$n\pi^+$

$X=\pi^0+\ldots$

hydrogen target:
25k events
(400 pb^{-1})

unpolarized deuterium:
15k events
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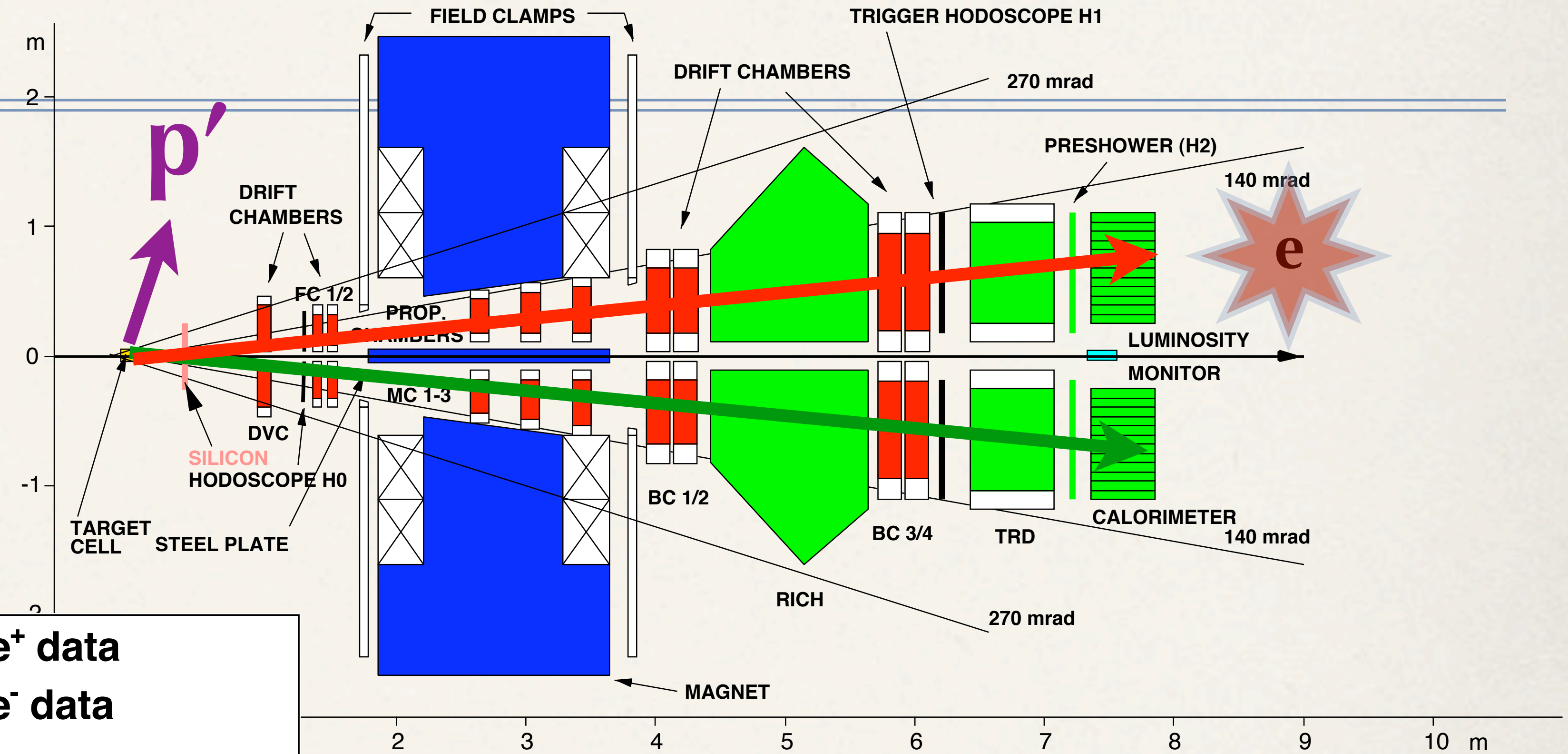

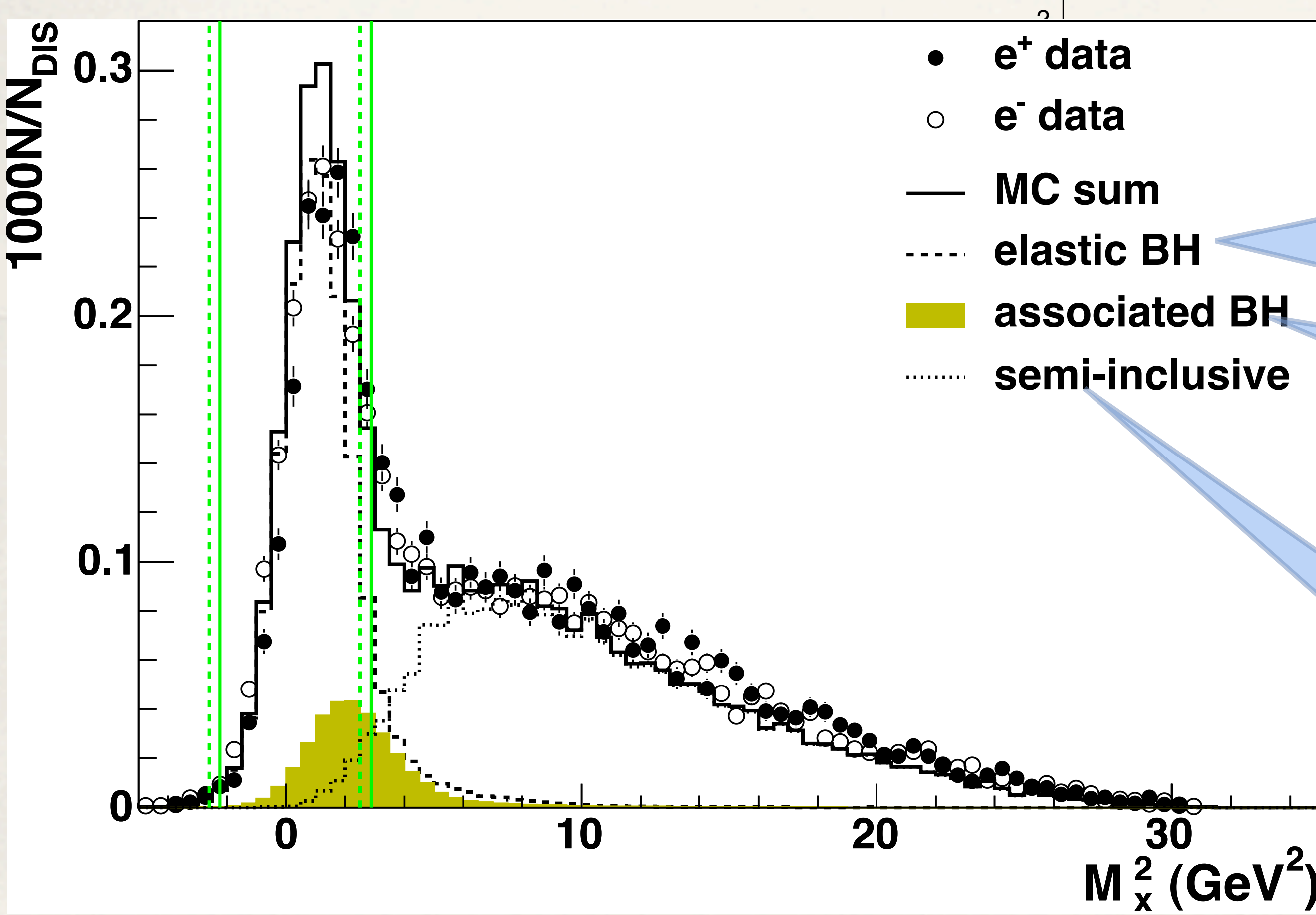

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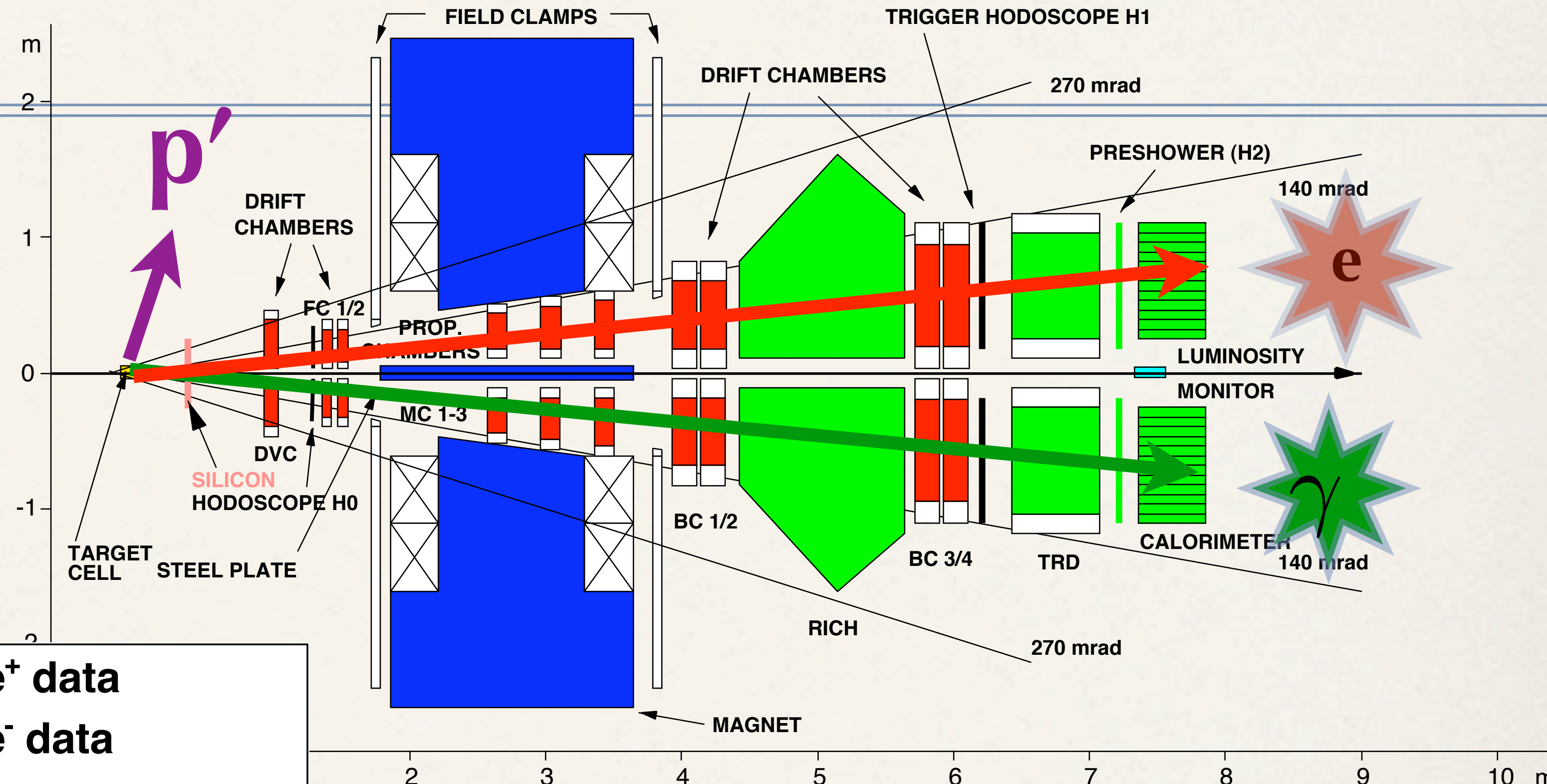

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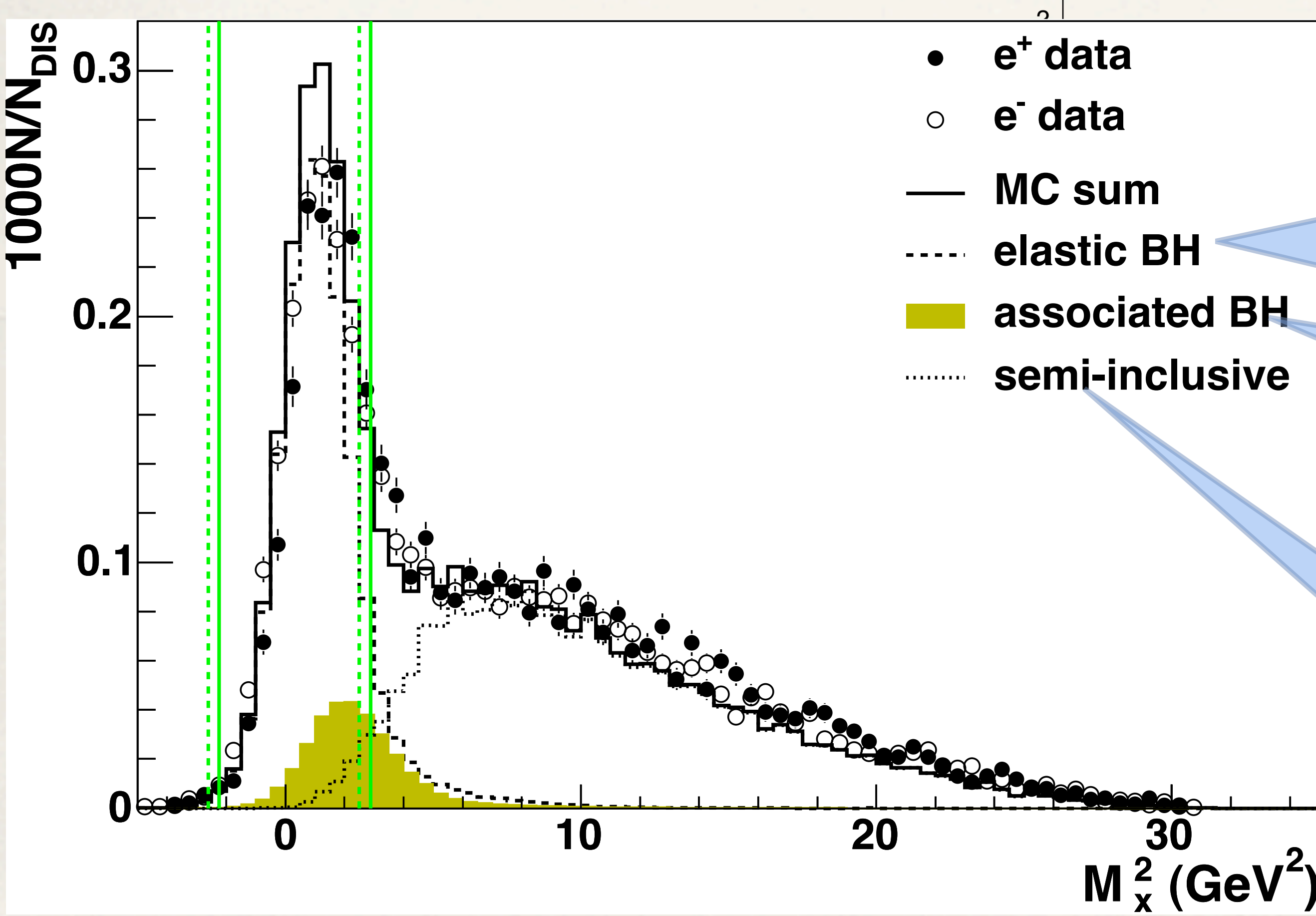

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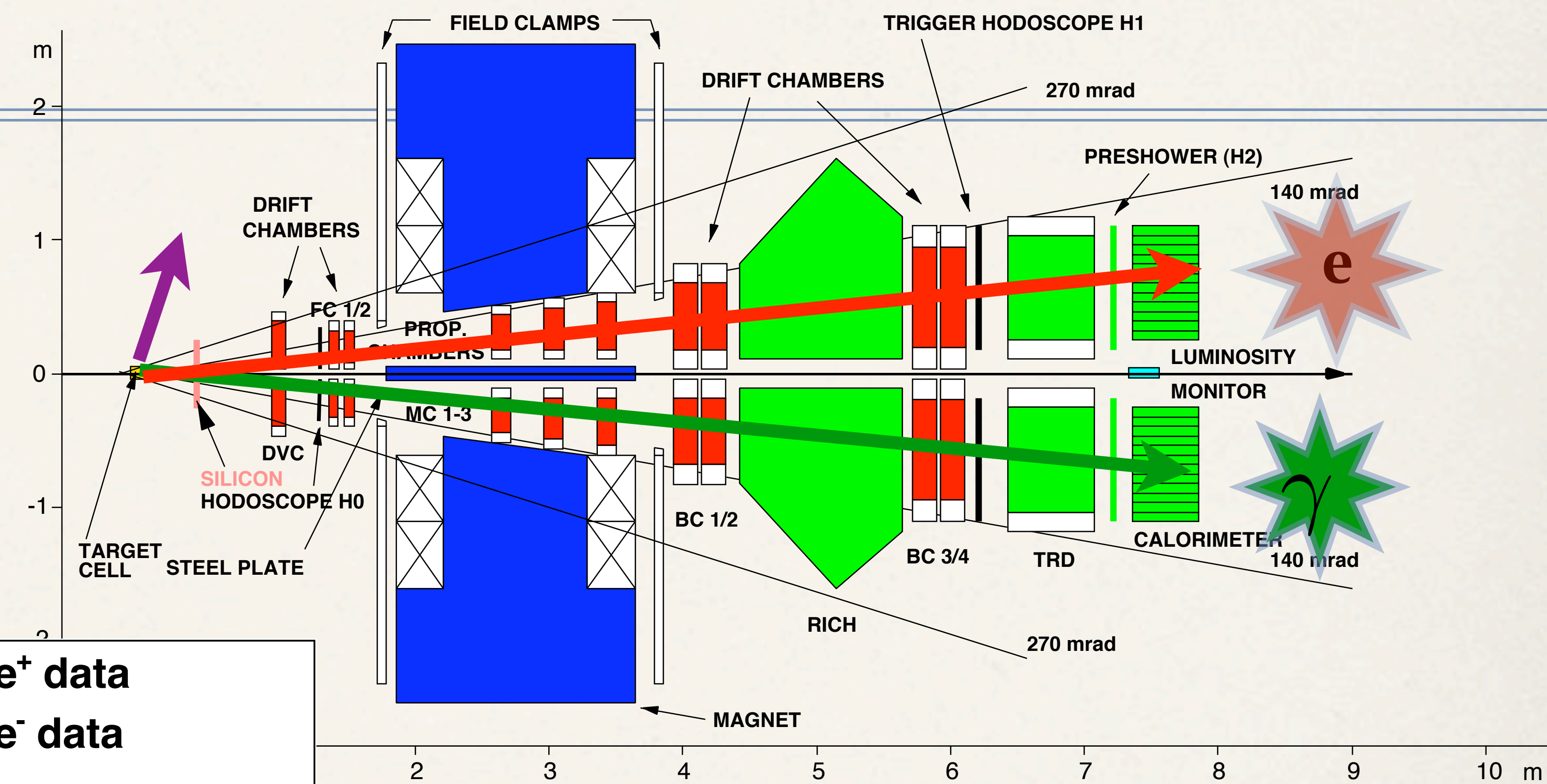

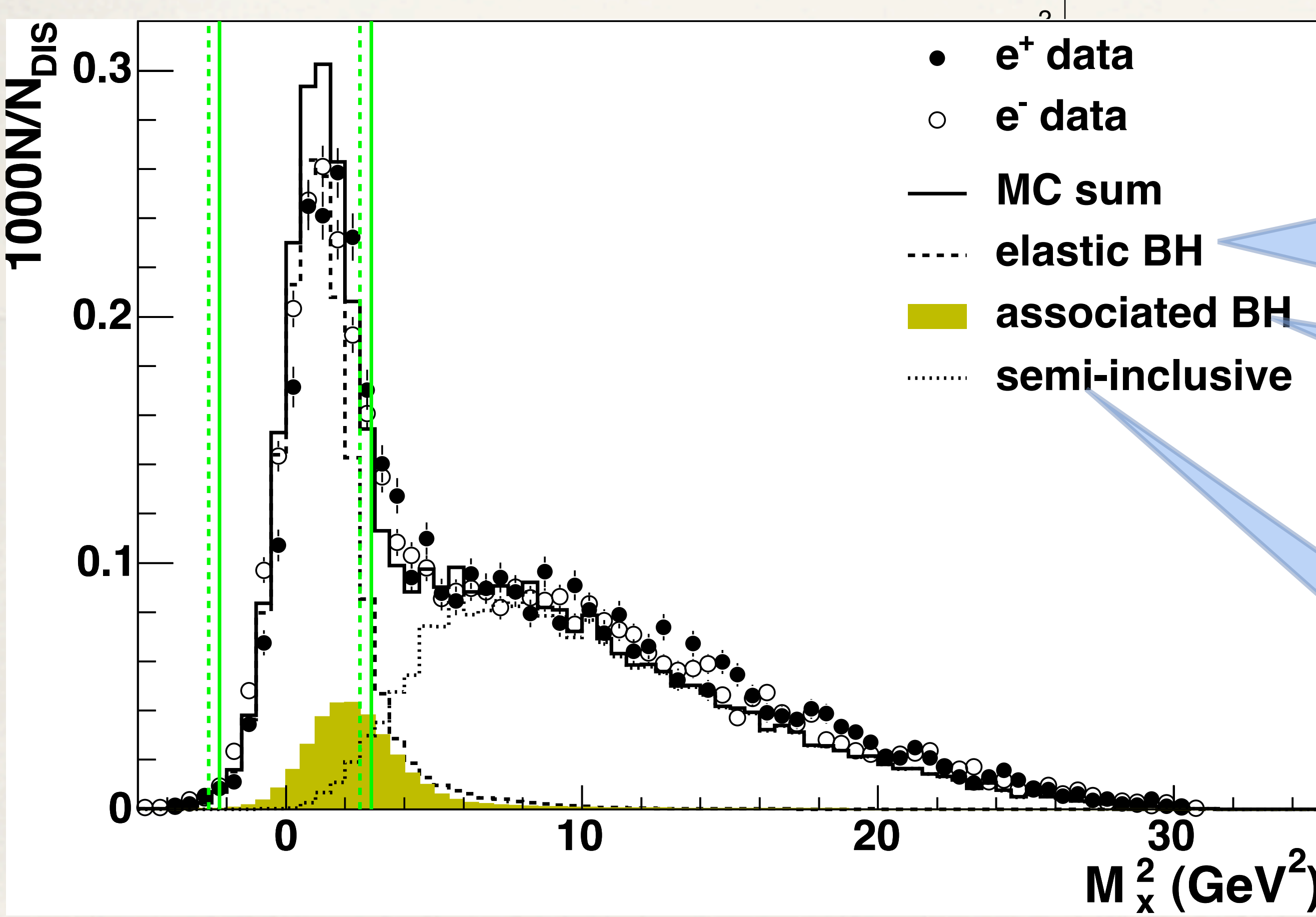

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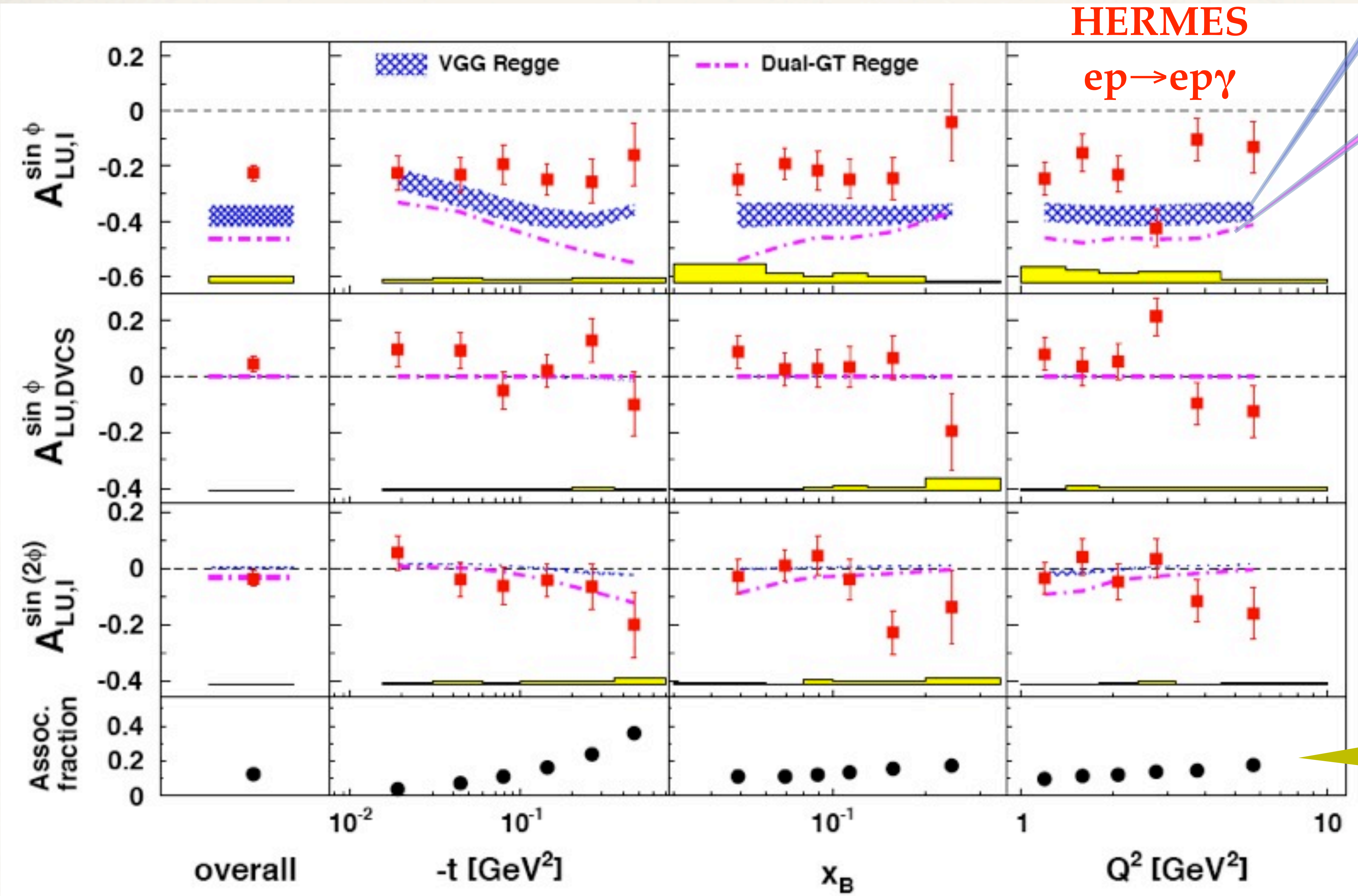
DVCS Beam Helicity Asymmetries

Phys.Rev. **D60** (1999) 094017 and Prog.Nucl.Phys. **47** (2001) 401

Phys.Rev. **D79** (2009) 017501



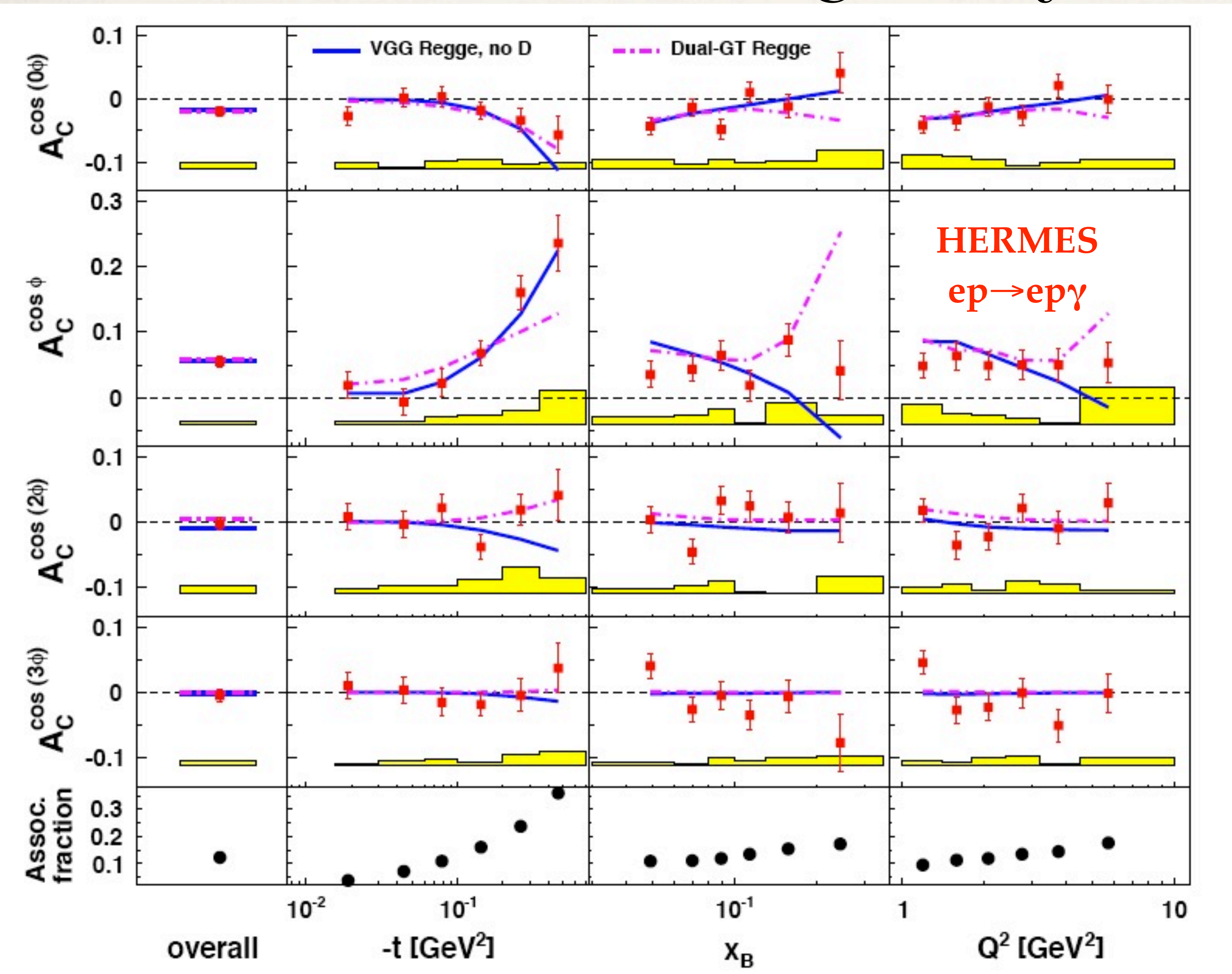
$\propto \Im\left[F_1\mathcal{H}\right]$

Higher twist (twist-3)

Fraction of resonant excitation

all data 1996-2005, arXiv:0909.3587, accepted by JHEP

DVCS Beam Charge Asymmetry



constant term:

$\propto -A_C^{\cos\phi}$

$\propto \Re\left[F_1 \mathcal{H}\right]$

← Higher twist (twist-3)

← Gluon leading twist

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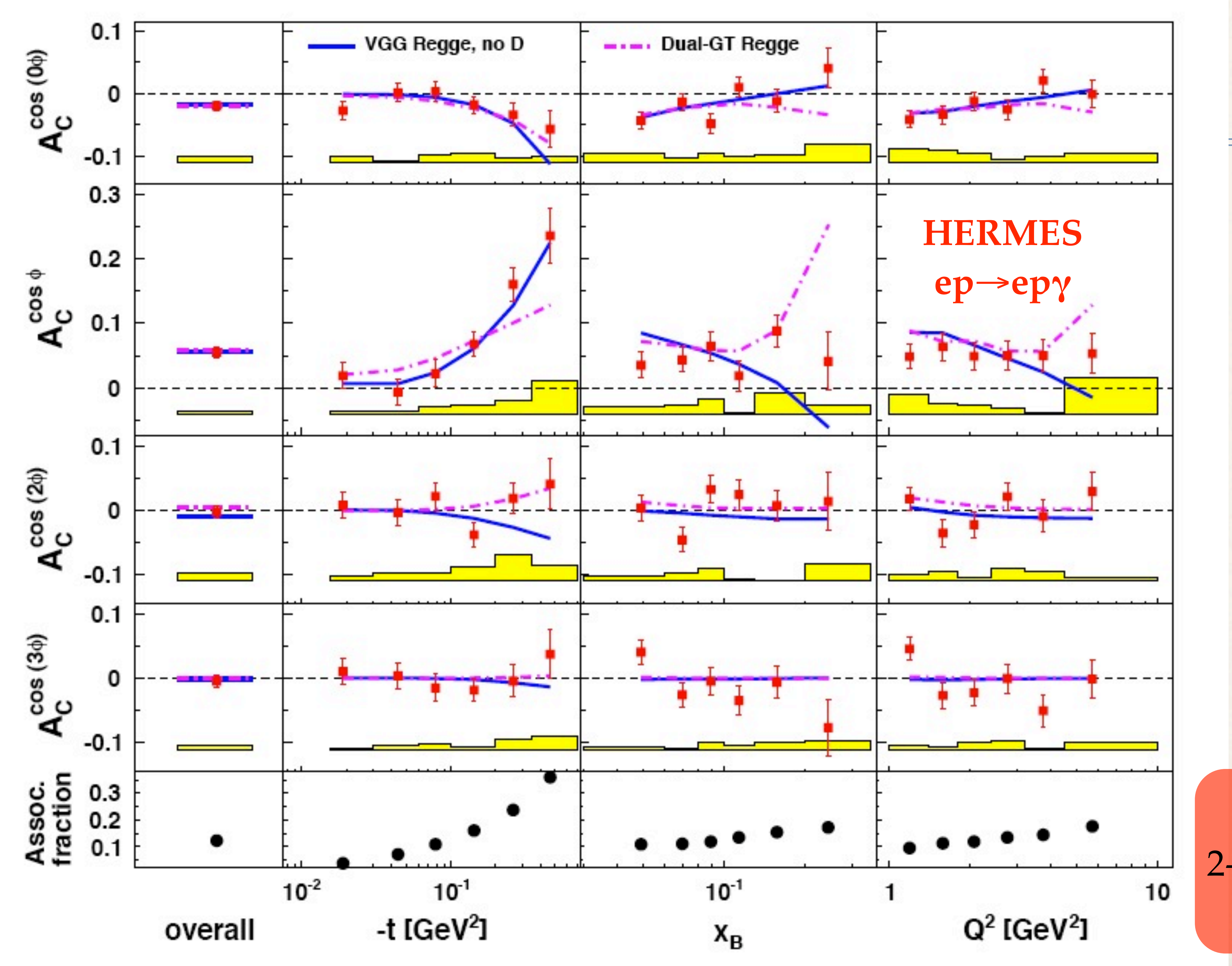


constant term:
$\propto -A_C^{\cos\phi}$

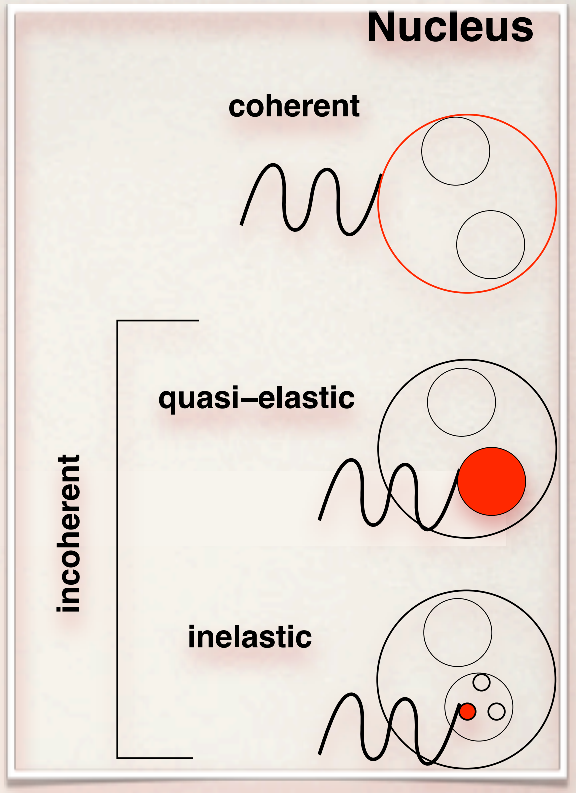
$\propto \Re\left[F_1\mathcal{H}\right]$

← Higher twist (twist-3)

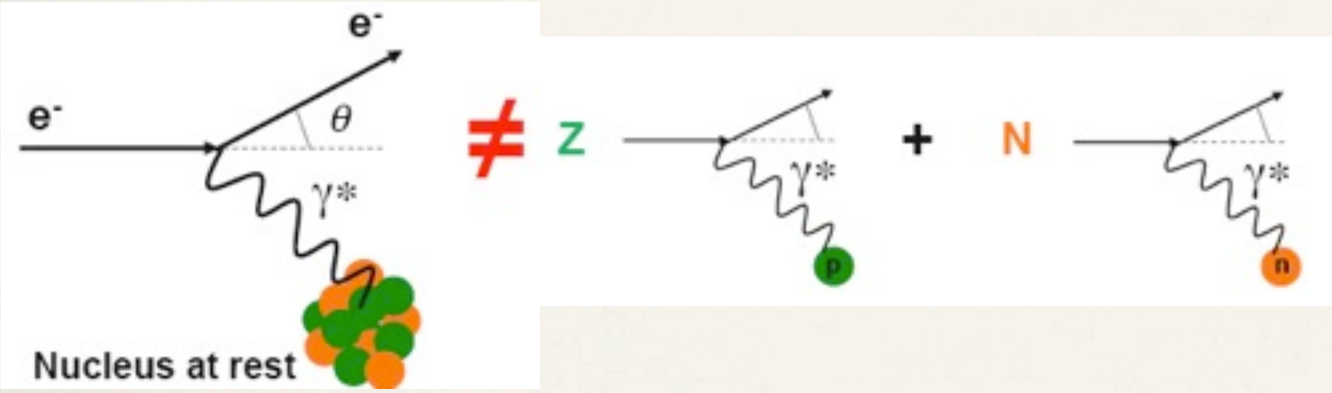
← Gluon leading twist

Also available:
2-dim (x_B,t) binning
(BSAs and BCA)

DVCS on Nuclear Targets

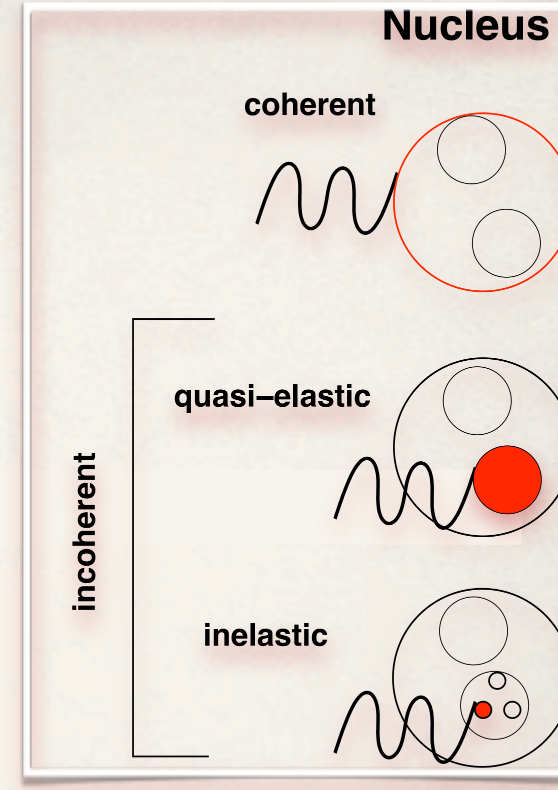


- How does the nuclear environment modify parton-parton correlations?
- How do nucleon properties change in the nuclear medium?
- DVCS in coherent region: new insights into 'generalized EMC effect'?



- Nuclear GPDs ≠ GPDs of free nucleon
- Enhancement of effect when leaving forward limit?
- Strong increase of real part of τ_{DVCS} with atomic mass number A?

DVCS on Nuclear Targets



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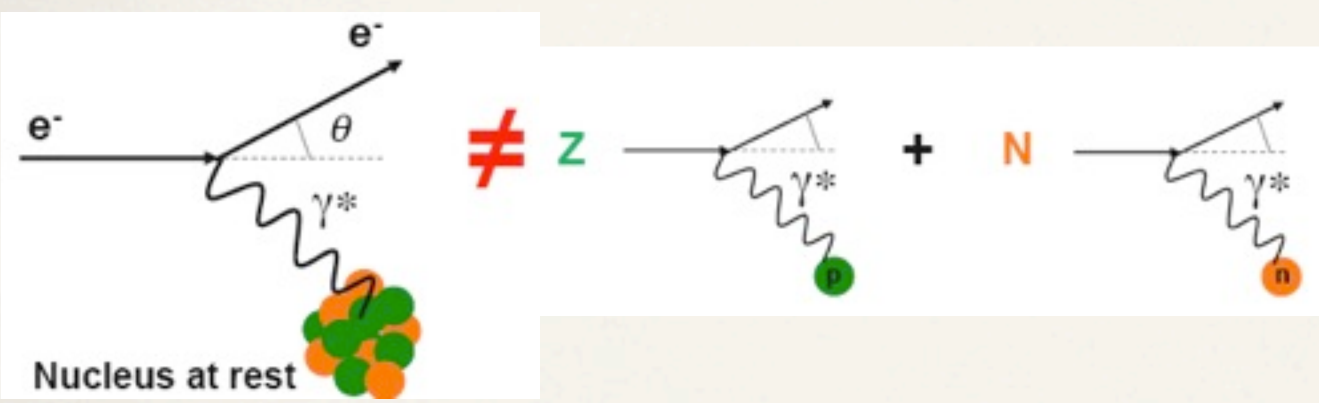

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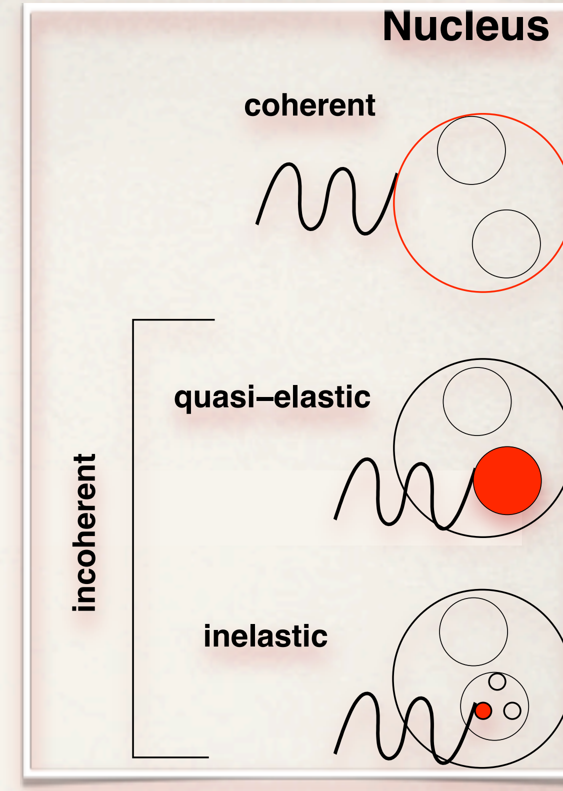
HERMES measurements on nuclear targets

Target	spin	L (pb^{-1})
H	1/2	227
He	0	32
N	1	51
Ne	0	86
Kr	0	77
Xe	0, 1/2, 3/2	47

DVCS on Nuclear Targets



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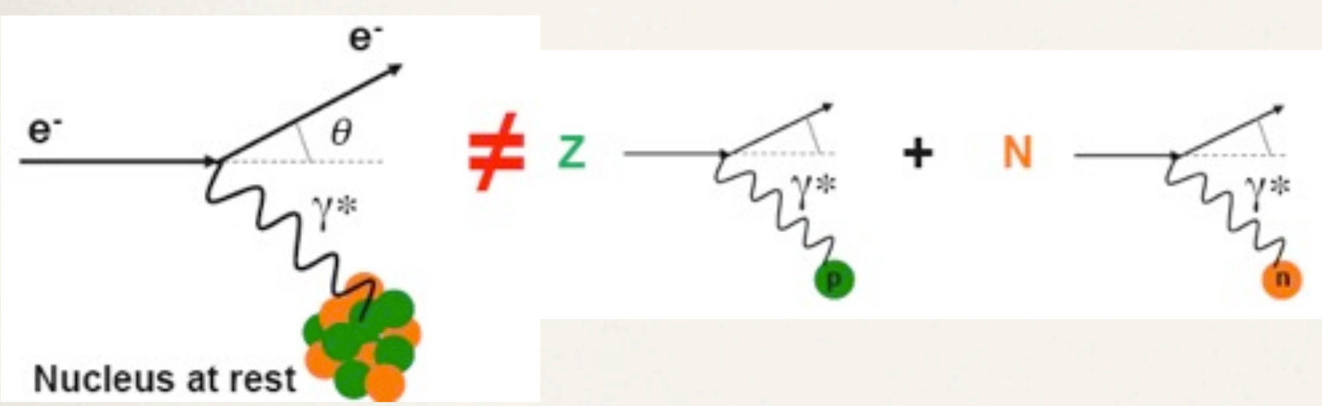

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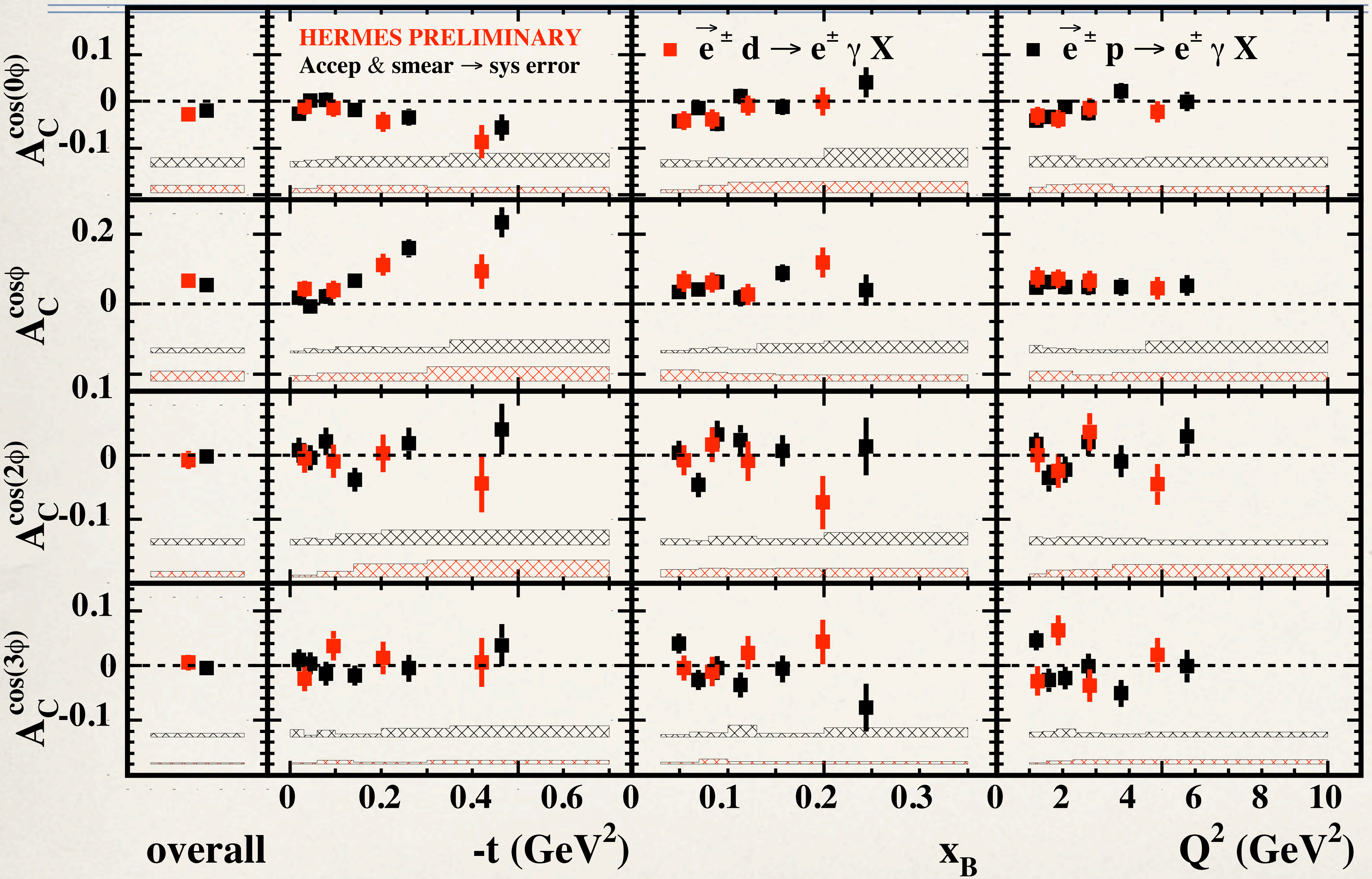
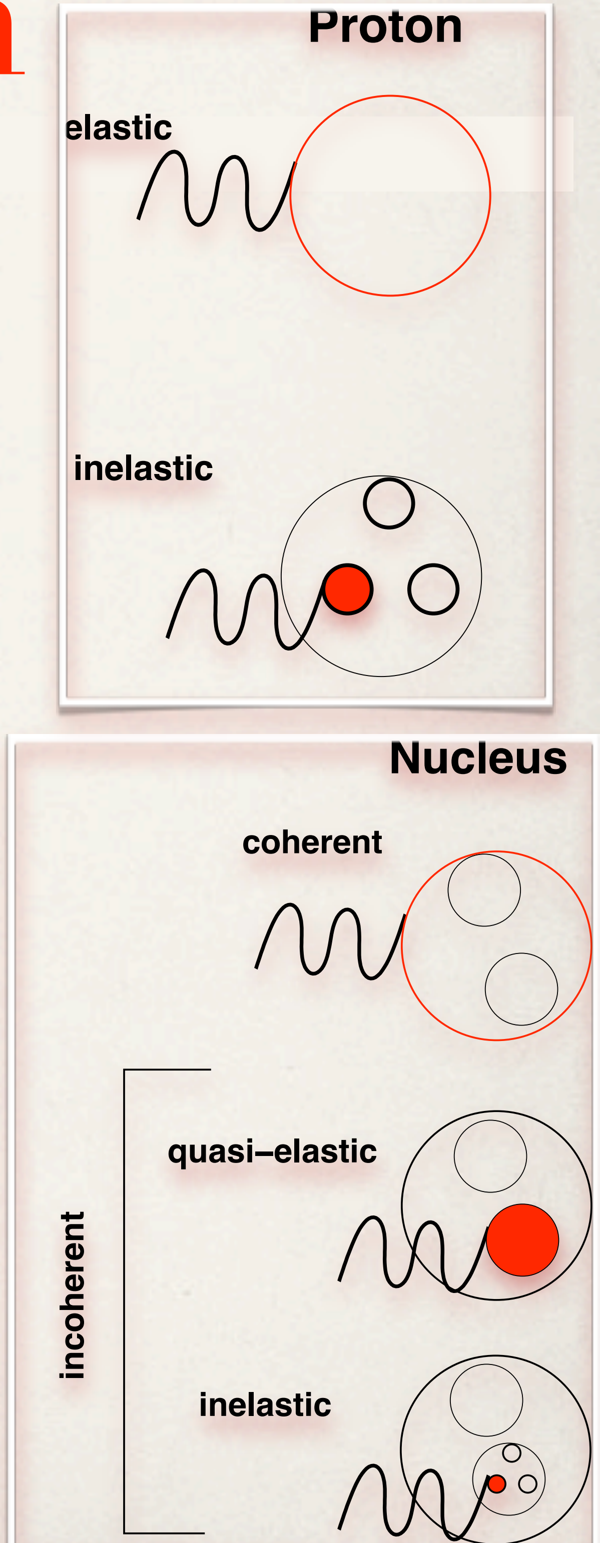
+ deuterium, spin-1, 300 pb^{-1}

DVCS Beam Charge Asymmetry on hydrogen and deuterium





Caroline Riedl (DESY), HERA DVCS Working Group Meeting, Hamburg 28.10.2009

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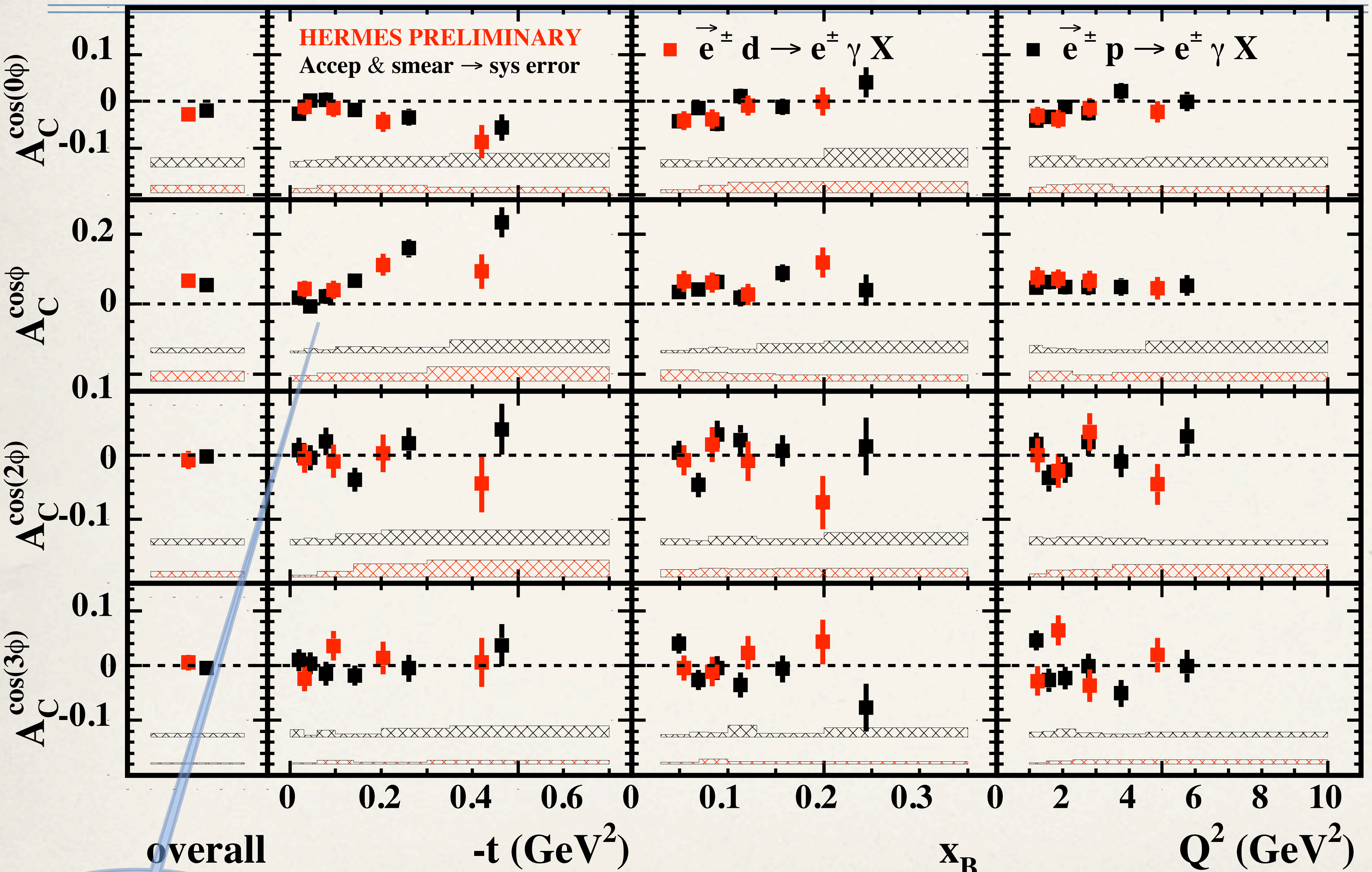
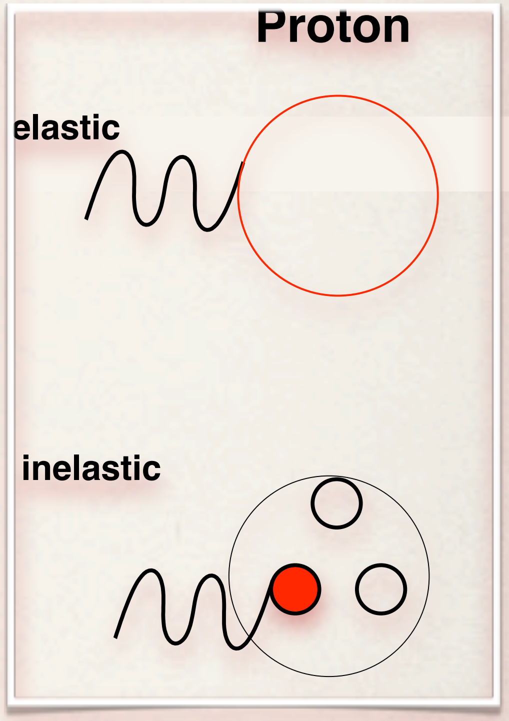
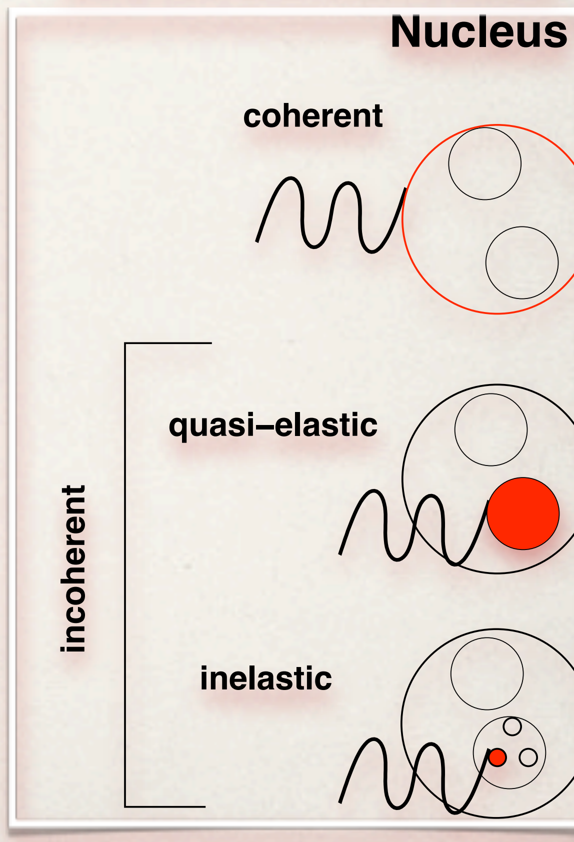
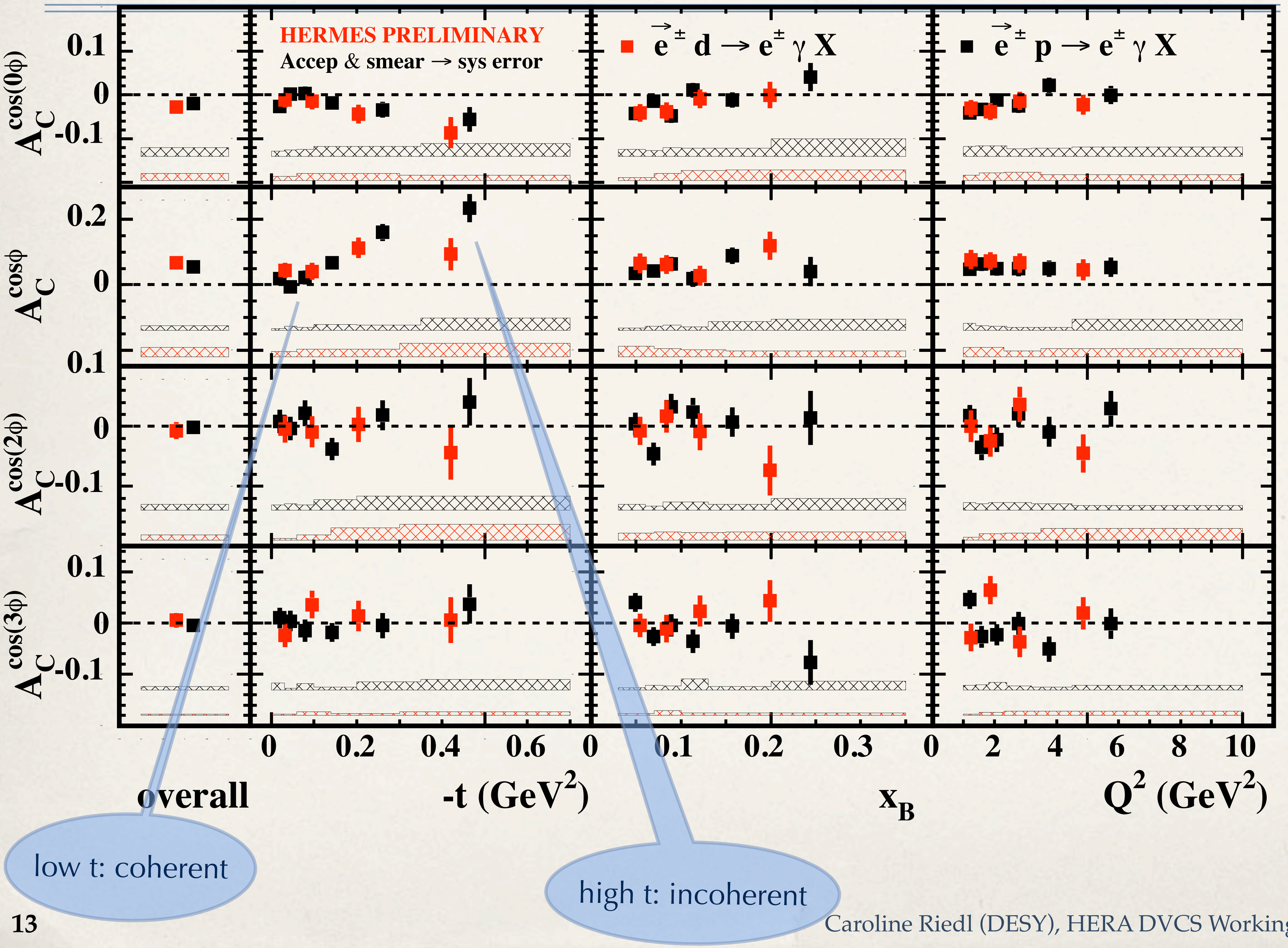


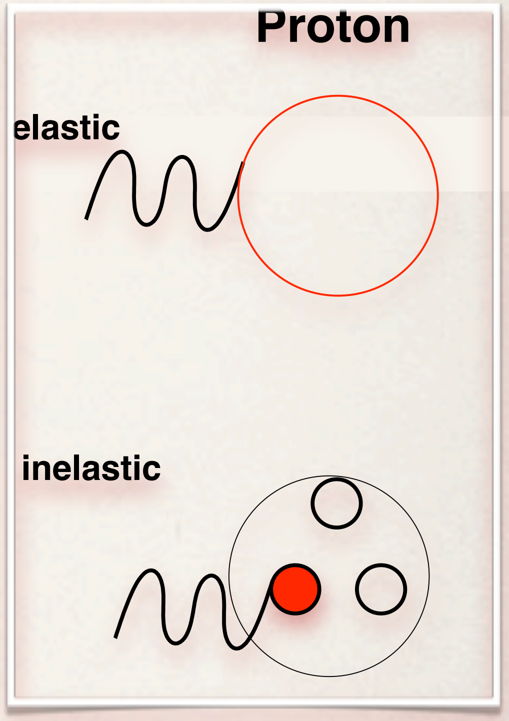
low t: coherent

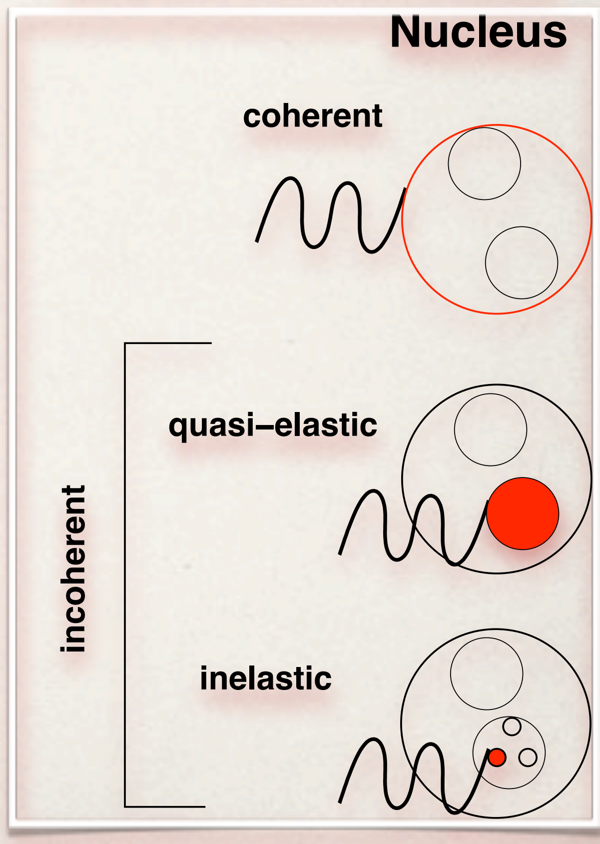




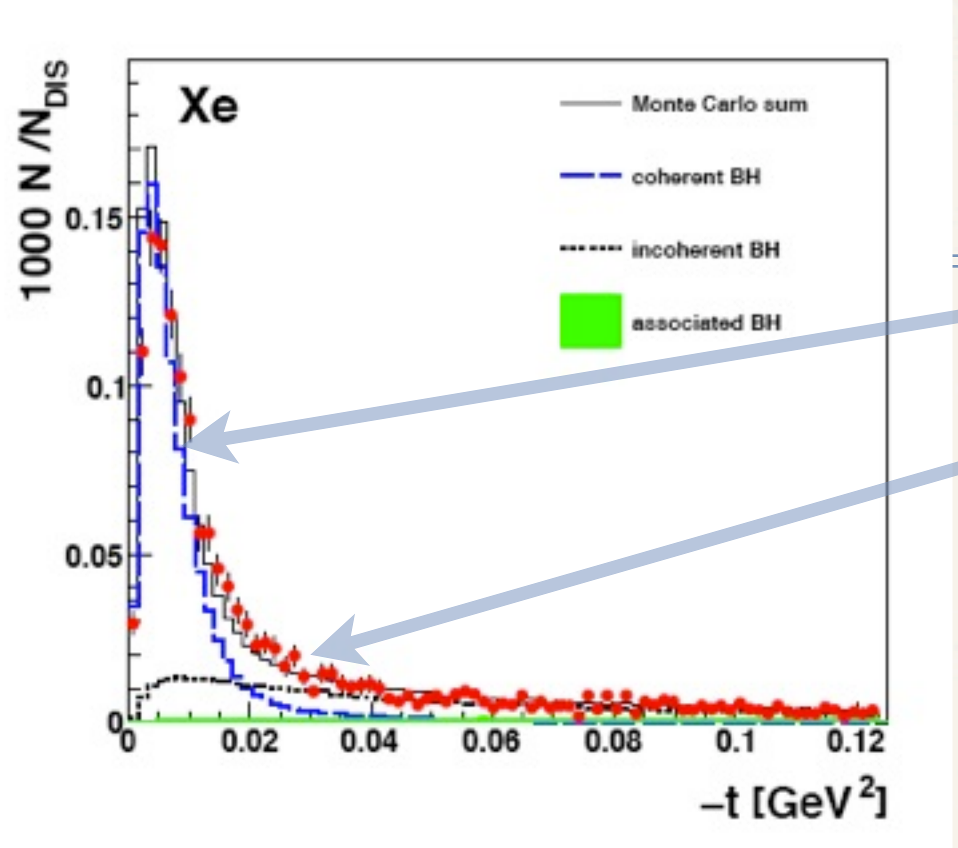
DVCS Beam Charge Asymmetry on hydrogen and deuterium







DVCS Nuclear Mass Dependence



Select for each target two samples (t-cutoffs):

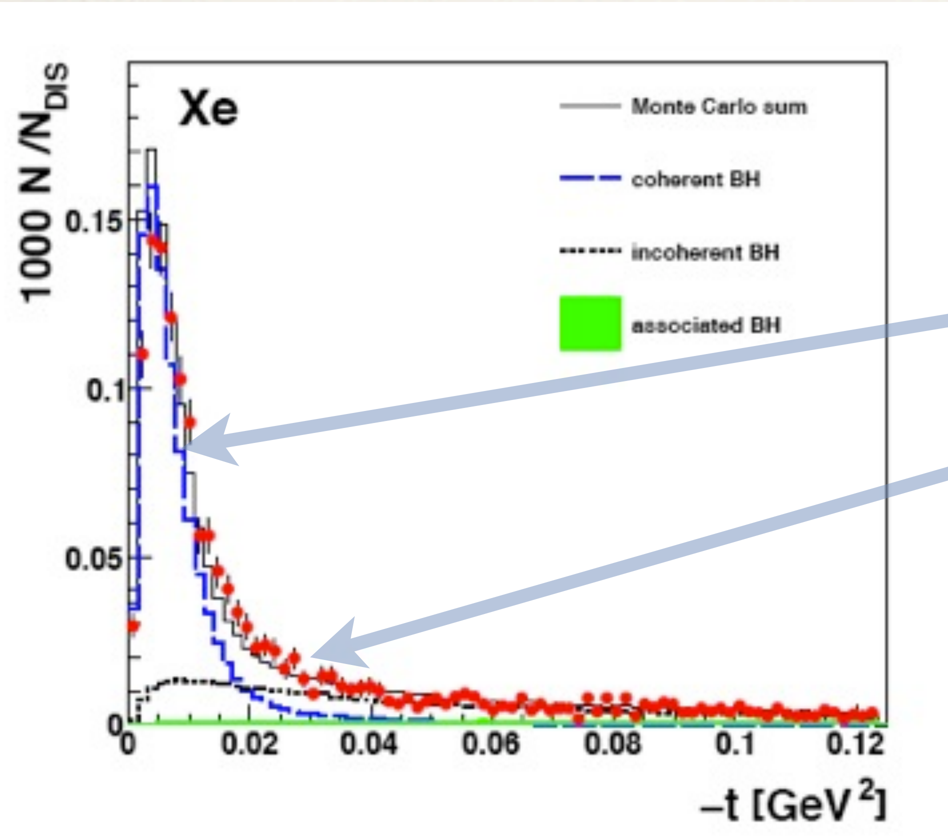
➢ **coherent enriched**

(≈ 65% coherent fraction)

➢ **incoherent enriched**

(≈ 60% incoherent fraction)

DVCS Nuclear Mass Dependence



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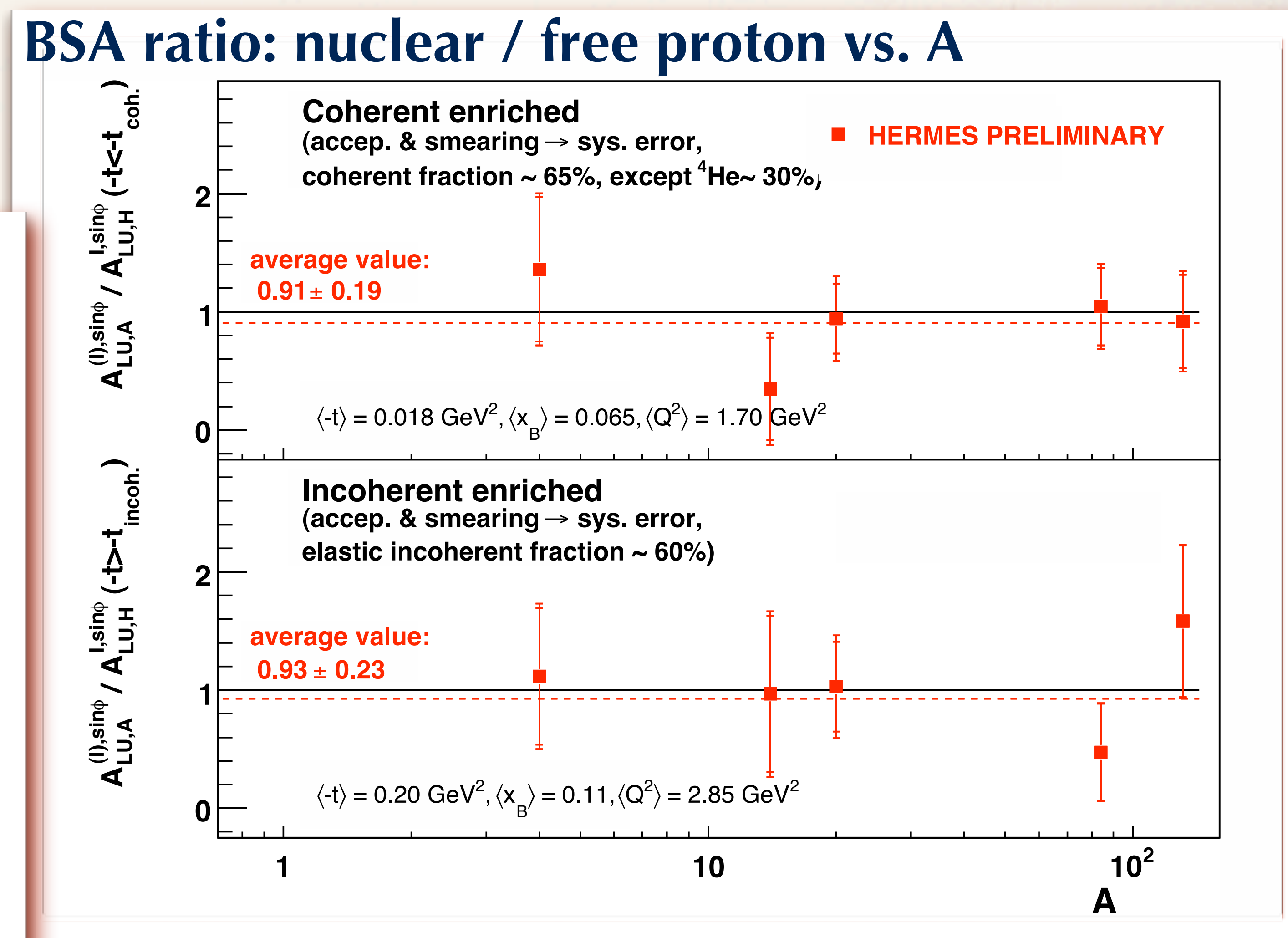

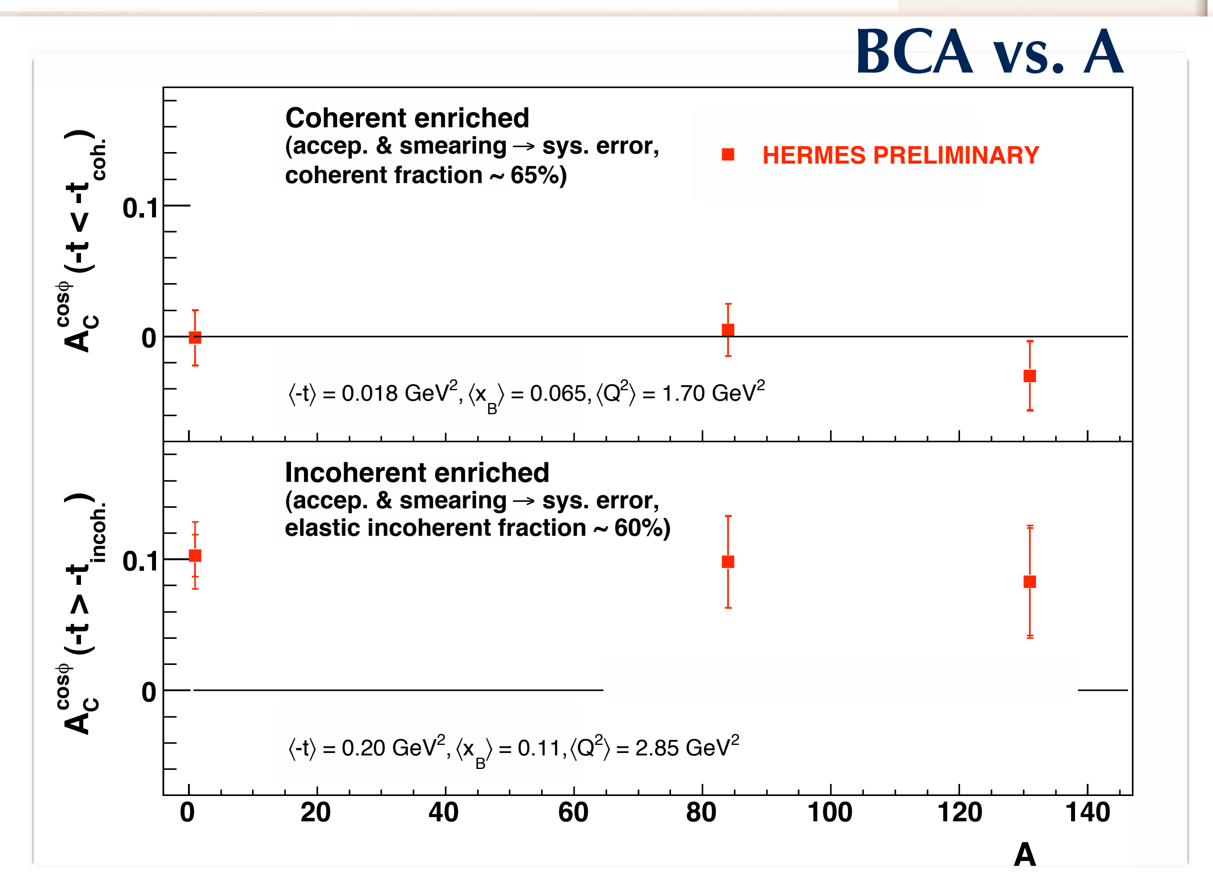

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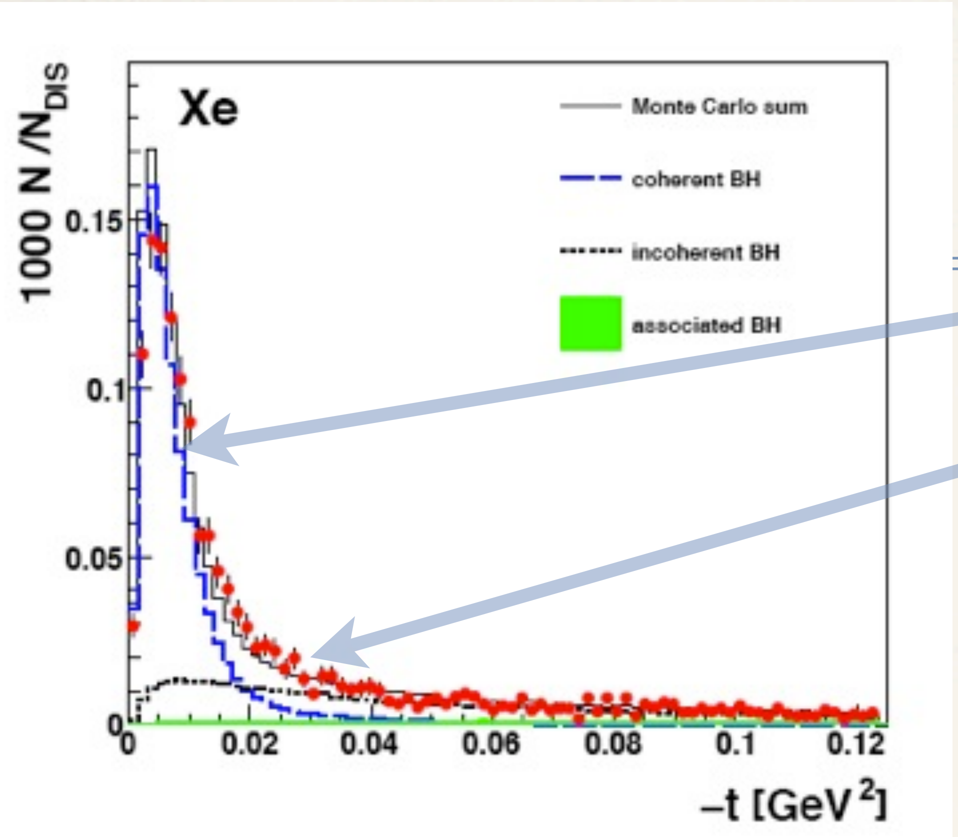

Select for each target two samples (t-cutoffs):

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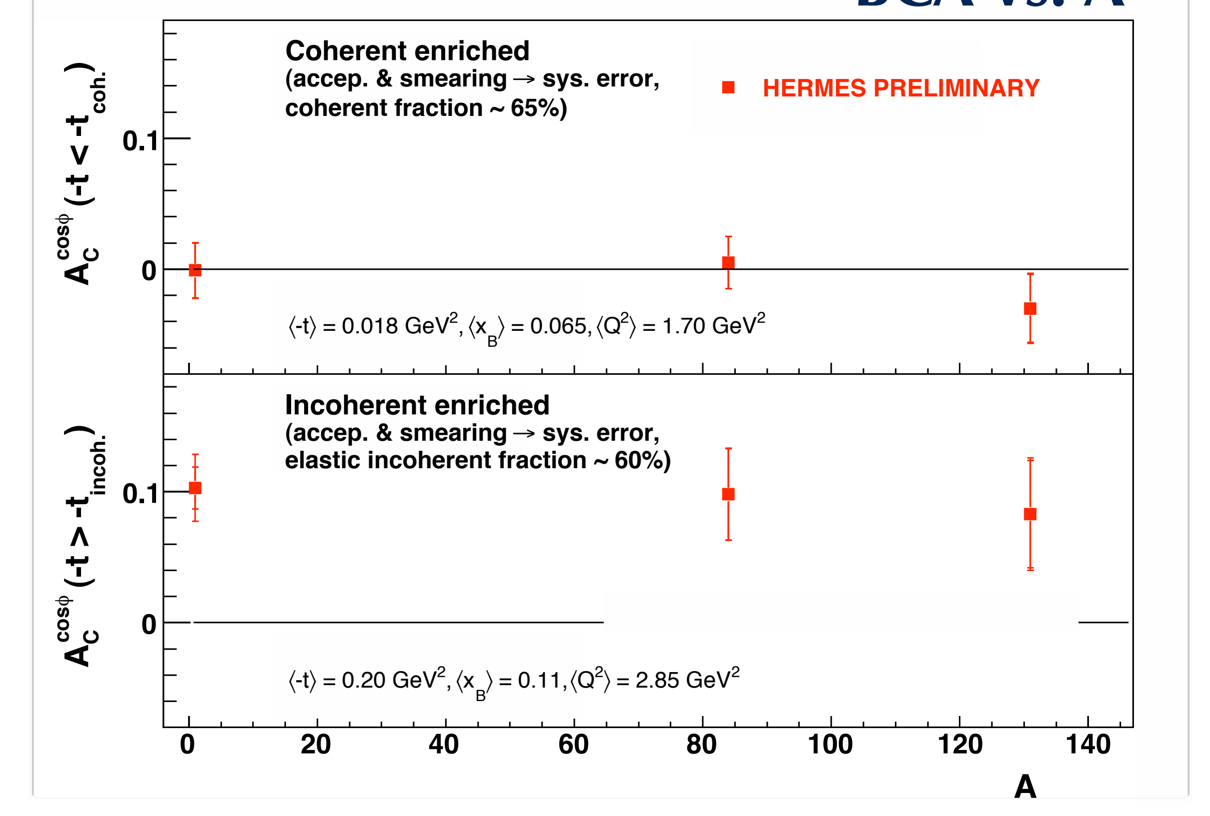
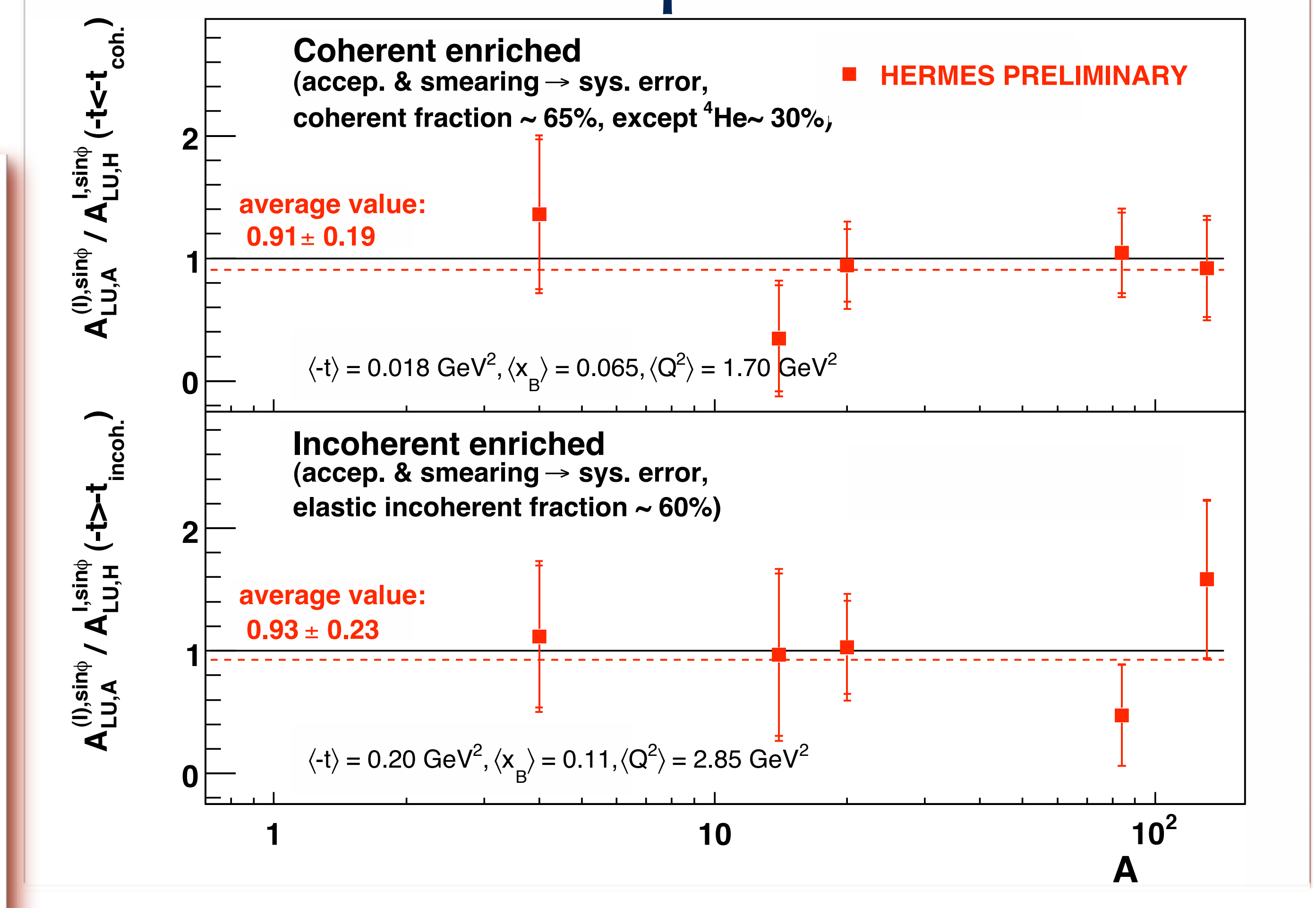
No nuclear mass dependence of BCA and BSA observed within uncertainties

⇒ no enhancement of τ_{DVCS}

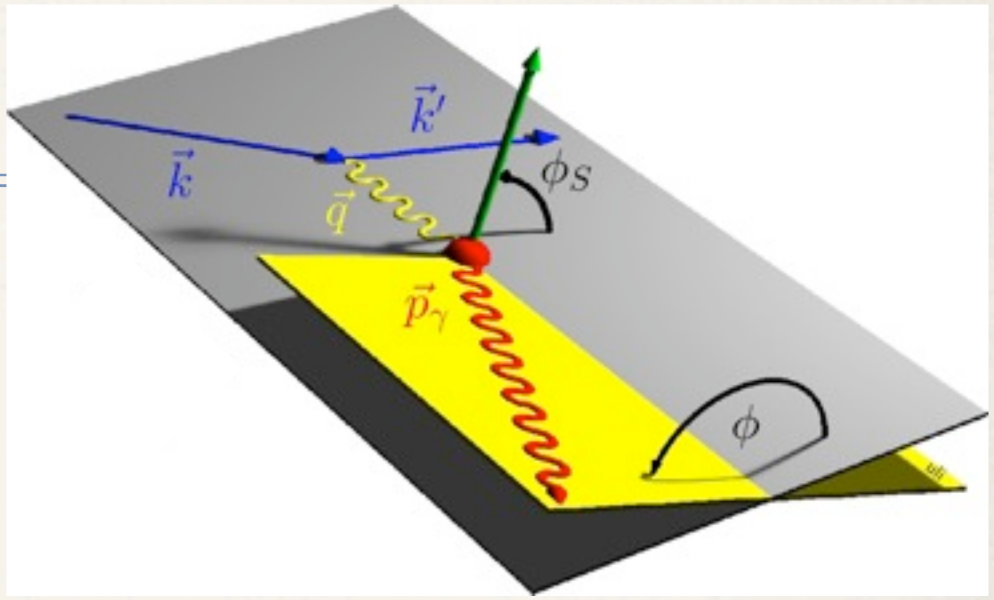
BCA vs. A



BSA ratio: nuclear / free proton vs. A



DVCS Transverse Target Spin Asymmetry $\mathcal{A}_{\mathrm{UT}}(\phi,\phi_s)$



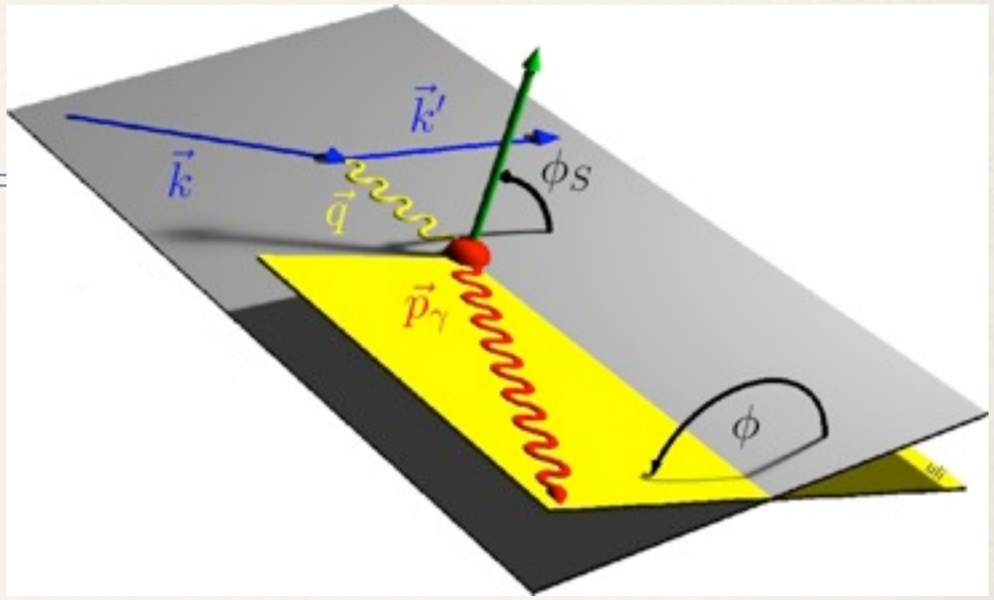
- $\mathcal{A}_{\mathrm{UT}}$: the only DVCS asymmetry on the proton for which **GPD E is not suppressed**
  (JLab Hall-A: BSA on neutron)

- **HERMES:** transversely polarized hydrogen, 170 pb^{-1}, 2 beam charges
  ➢ Separation of DVCS and interference terms possible:

$$A^{\mathcal{I}}_{\mathrm{UT}}(\phi,\phi_s) \propto \left[\mathrm{d}\sigma^+(\phi,\phi_s) - \mathrm{d}\sigma^-(\phi,\phi_s)\right] - \left[\mathrm{d}\sigma^+(\phi,\phi_s+\pi) - \mathrm{d}\sigma^-(\phi,\phi_s+\pi)\right]$$

$$\begin{aligned} A^{\mathcal{I}}_{\mathrm{UT}}(\phi,\phi_s) \quad &\propto \quad \mathrm{Im}\,(F_2\mathcal{H} - F_1\mathcal{E})\sin(\phi-\phi_s)\cos\phi \\ &+ \quad \mathrm{Im}\left(F_2\widetilde{\mathcal{H}} - (F_1+\xi F_2)\widetilde{\mathcal{E}}\right)\cos(\phi-\phi_s)\sin\phi \end{aligned}$$

DVCS Transverse Target Spin Asymmetry $\mathcal{A}_{UT}(\phi,\phi_s)$



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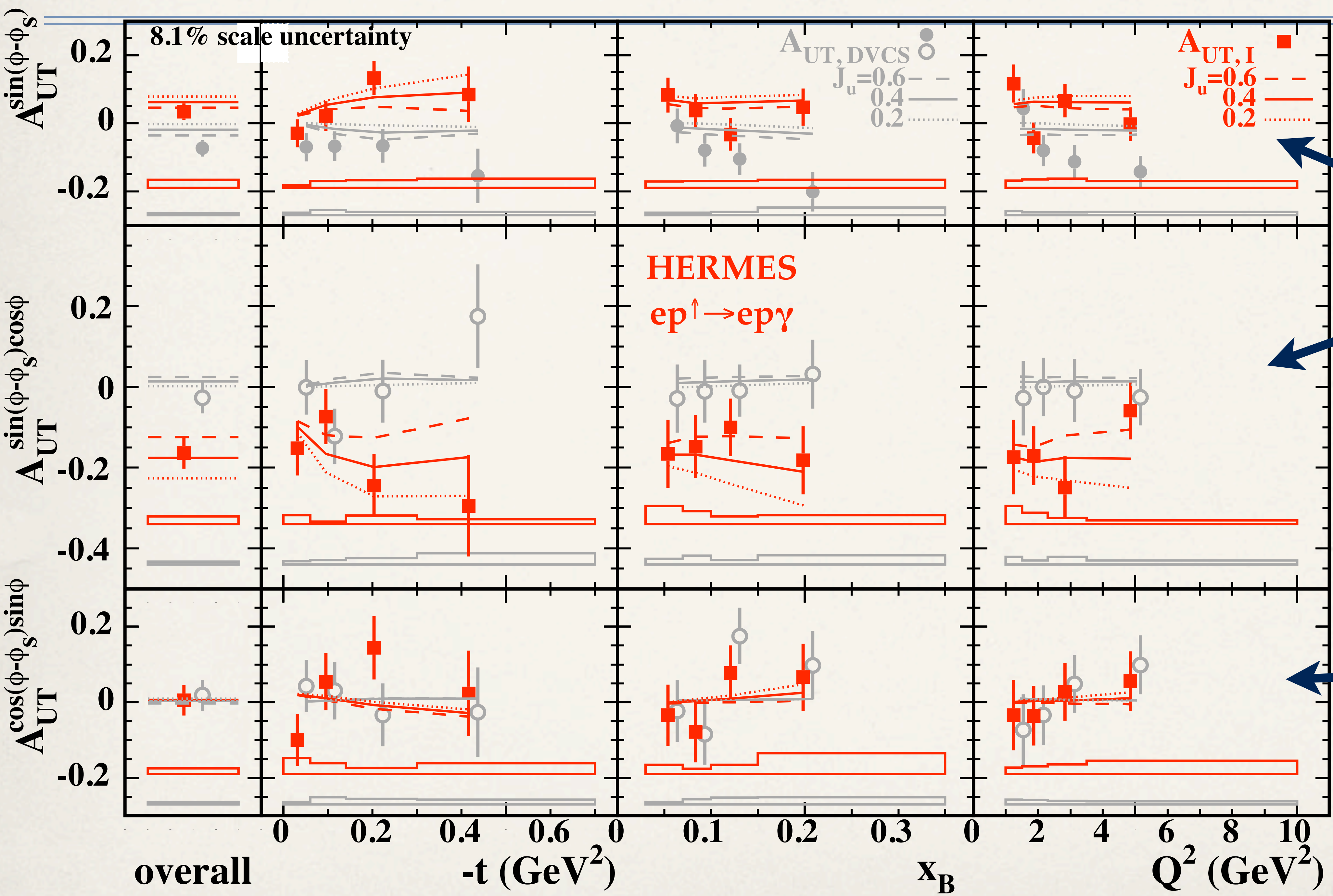
  ➢ Separation of DVCS and interference terms possible:

$A_{UT}^{DVCS}(\phi,\phi_s)$ — also sensitive to GPD E

$$A_{UT}^{\mathcal{I}}(\phi,\phi_s) \propto \left[d\sigma^{+}(\phi,\phi_s) - d\sigma^{-}(\phi,\phi_s)\right] \overset{+}{-} \left[d\sigma^{+}(\phi,\phi_s+\pi) - d\sigma^{-}(\phi,\phi_s+\pi)\right]$$

$$\begin{aligned} A_{UT}^{\mathcal{I}}(\phi,\phi_s) \quad \propto \quad & \mathrm{Im}\,(F_2\mathcal{H} - F_1\mathcal{E})\sin(\phi-\phi_s)\cos\phi \\ + \quad & \mathrm{Im}\left(F_2\widetilde{\mathcal{H}} - (F_1+\xi F_2)\widetilde{\mathcal{E}}\right)\cos(\phi-\phi_s)\sin\phi \end{aligned}$$

DVCS $\mathcal{A}_{\mathrm{UT}}$ Amplitudes



sensitive to J_u:

$\mathrm{Im}(F_2\mathcal{H} - F_1\mathcal{E}) \cdot$

$\sin(\phi - \phi_s)\cos(n\phi)$

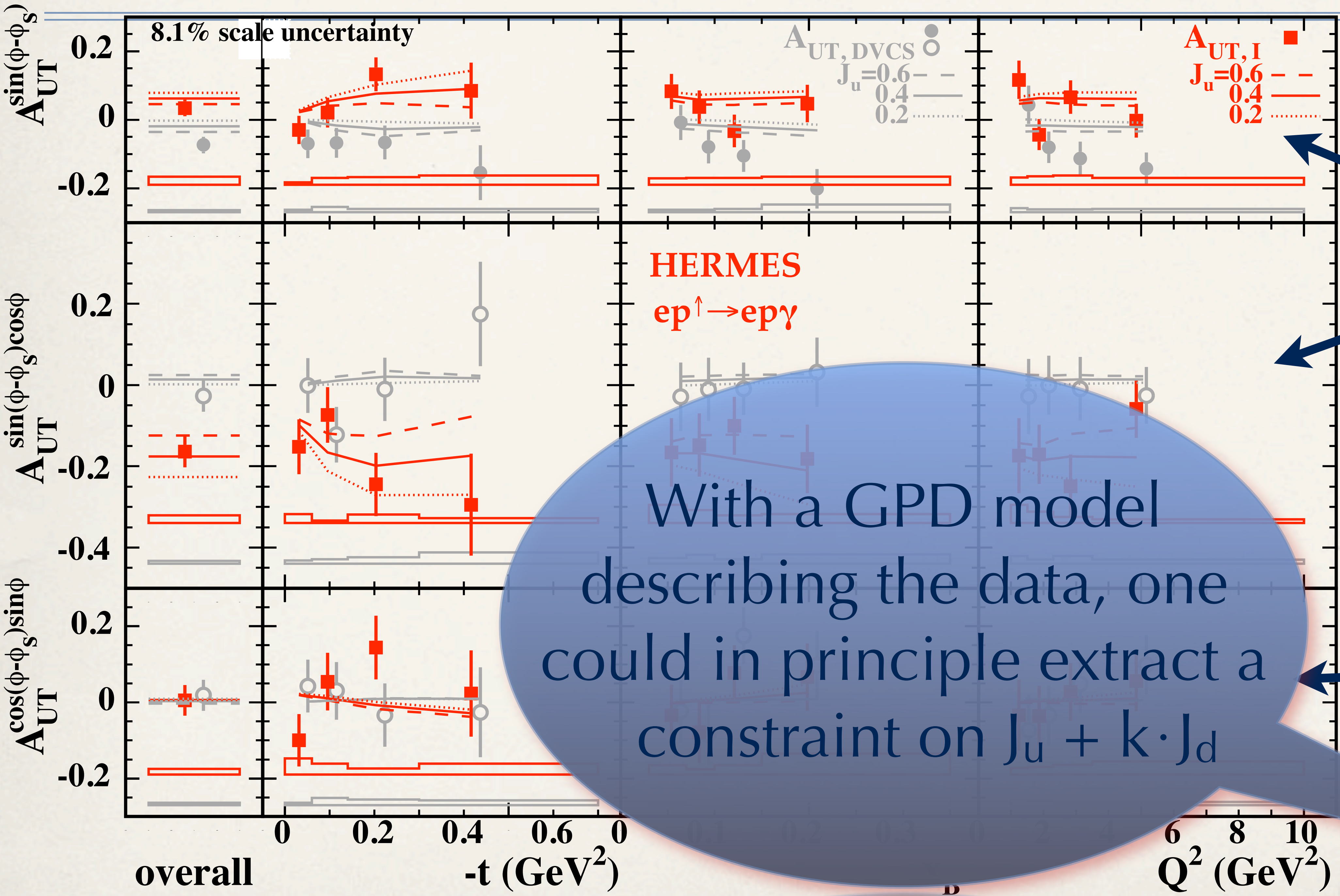
NOT sensitive to J_u:

$\mathrm{Im}\left(F_2\widetilde{\mathcal{H}} - (F_1 + \xi F_2)\widetilde{\mathcal{E}}\right) \cdot$

$\cos(\phi - \phi_s)\sin\phi$

Model: VGG with variation of J_u, while J_d=0

DVCS $\mathcal{A}_{UT}$ Amplitudes



sensitive to J_u:

$$\mathrm{Im}(F_2\mathcal{H} - F_1\mathcal{E}) \cdot \sin(\phi - \phi_s)\cos(n\phi)$$

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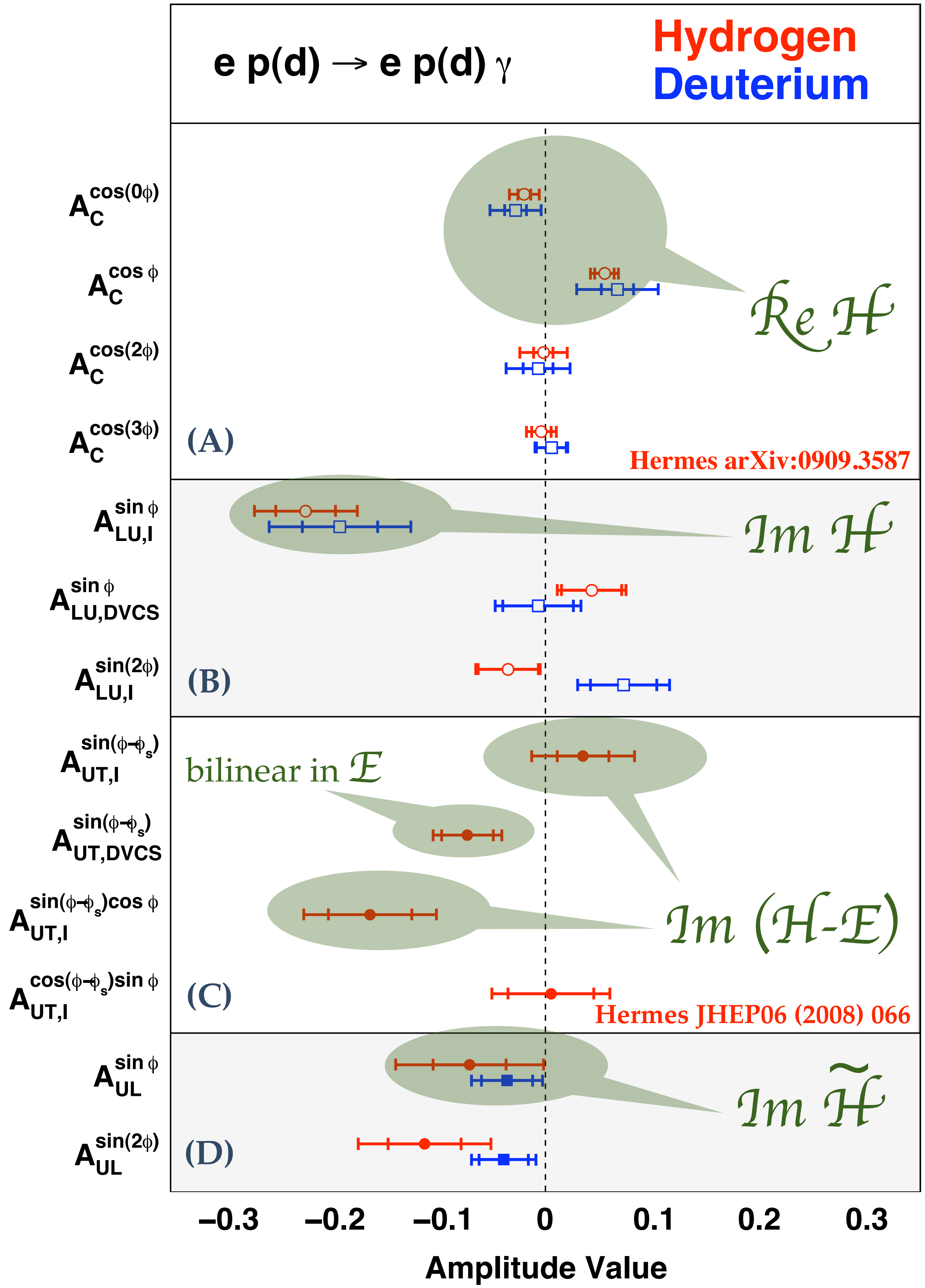
Model: VGG with variation of J_u, while J_d=0

DVCS azimuthal amplitudes

HERMES (prelim.)



(A) Beam charge asymmetry:
GPD H

(B) Beam helicity asymmetry:
GPD H

(C) Transverse target spin asymmetry:
GPD E from proton target

(D) Longitudinal target spin asymmetry:
GPD $\tilde{\text{H}}$

$\mathcal{R}e(\tau_{\text{DVCS}})$

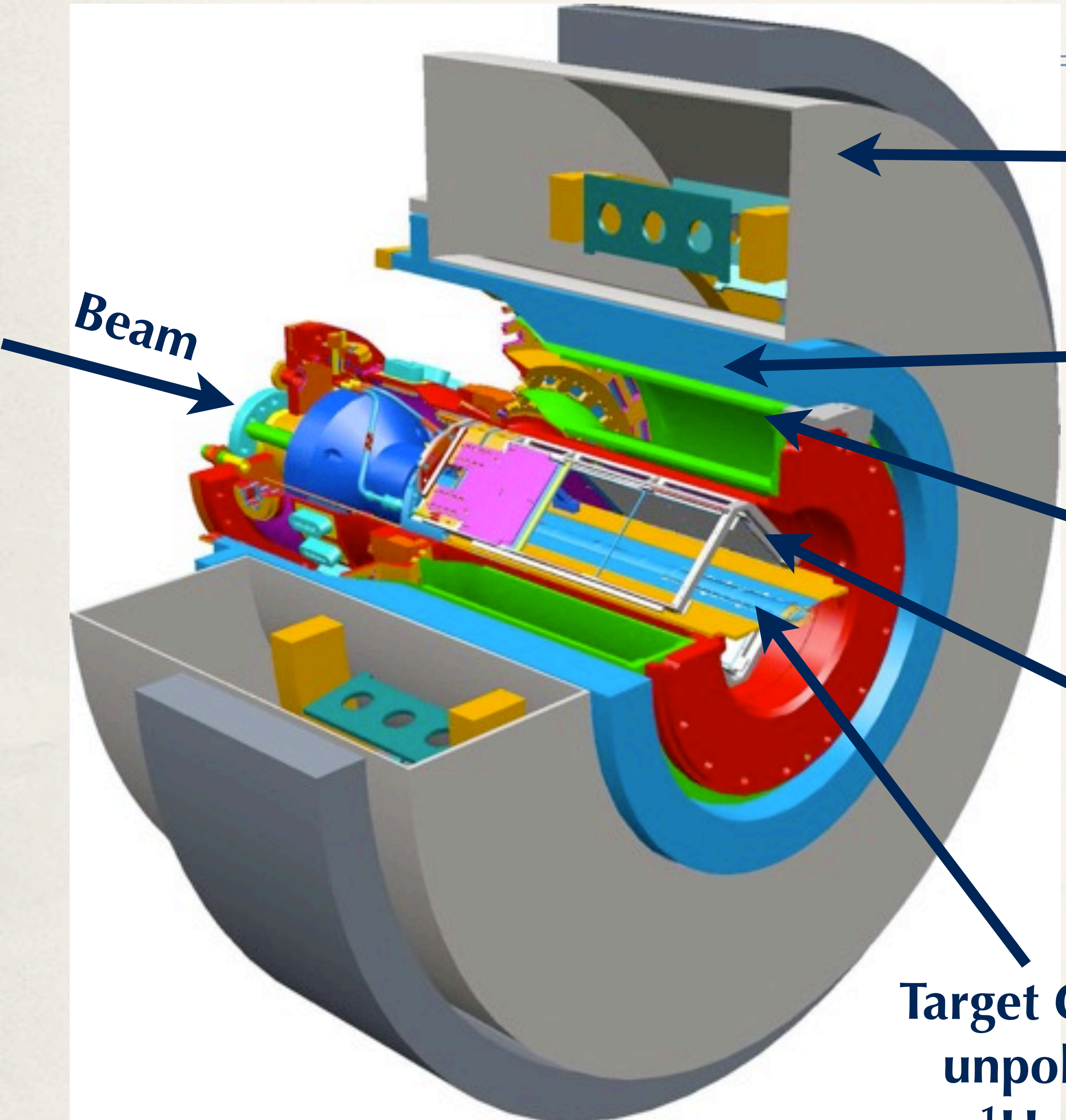
↑

Projects out

↓

$\mathcal{I}m(\tau_{\text{DVCS}})$

HERMES 2006-2007: Recoil Detector



Purpose:

★ **To tag exclusive events**

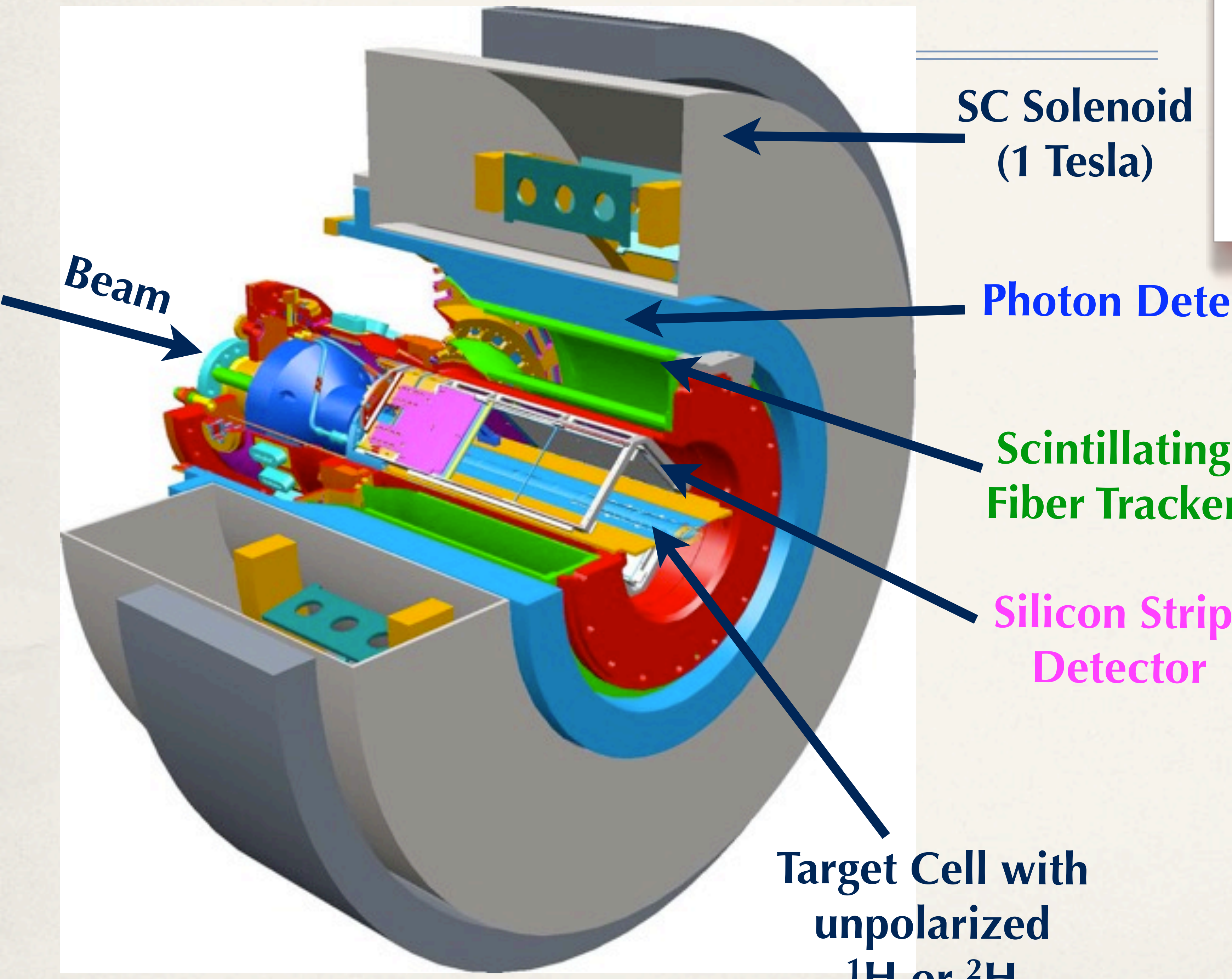
➢ Identify recoiling target proton

➢ Identify particles from background processes

^{1}H (^{2}H): factor of 1.6 (0.5) more than 1996-2005

Azimuthal coverage: 76%

HERMES 2006-2007: Recoil Detector



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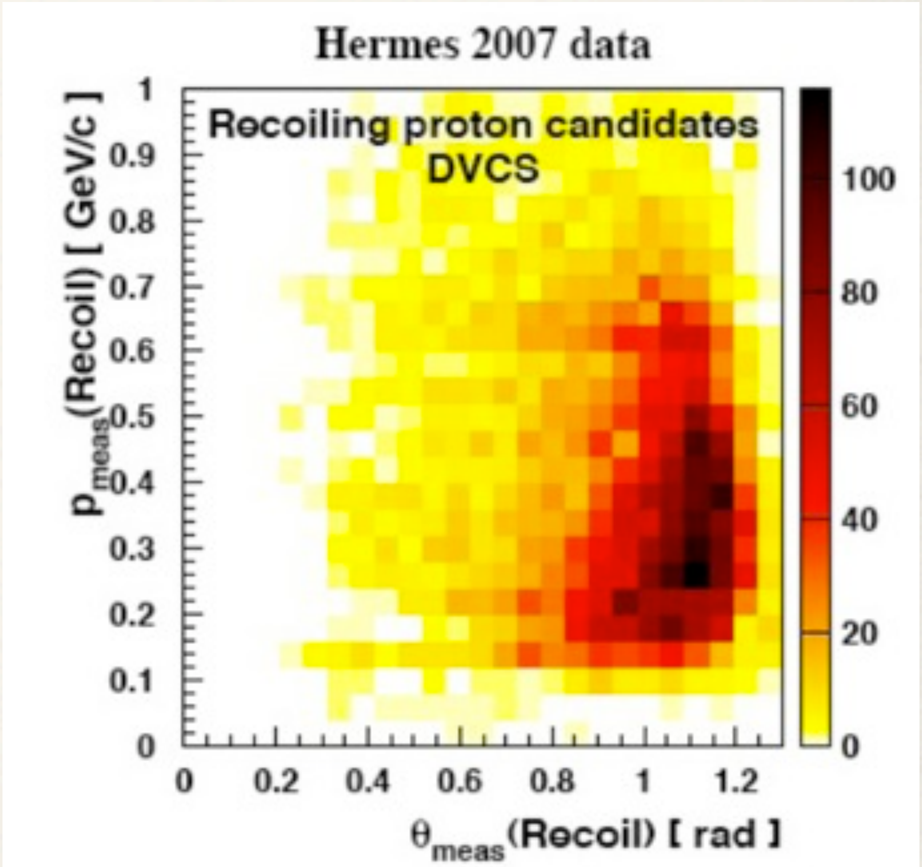

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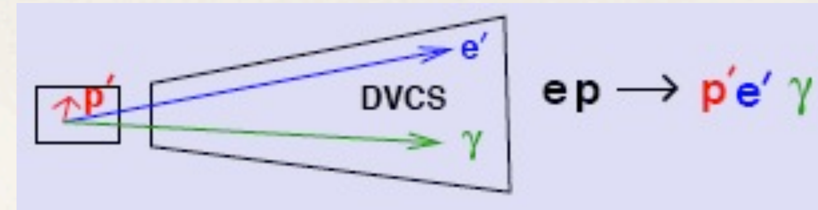
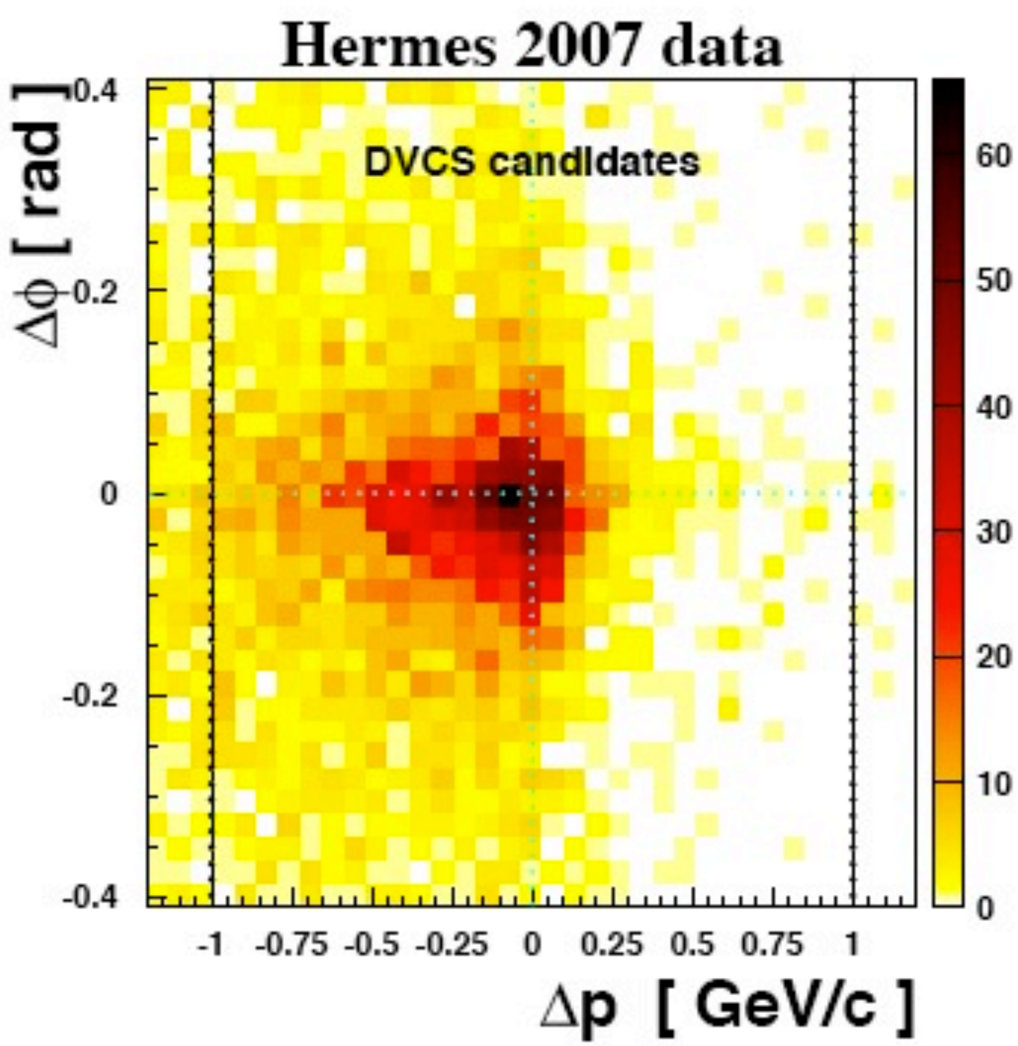
DVCS
and the Recoil

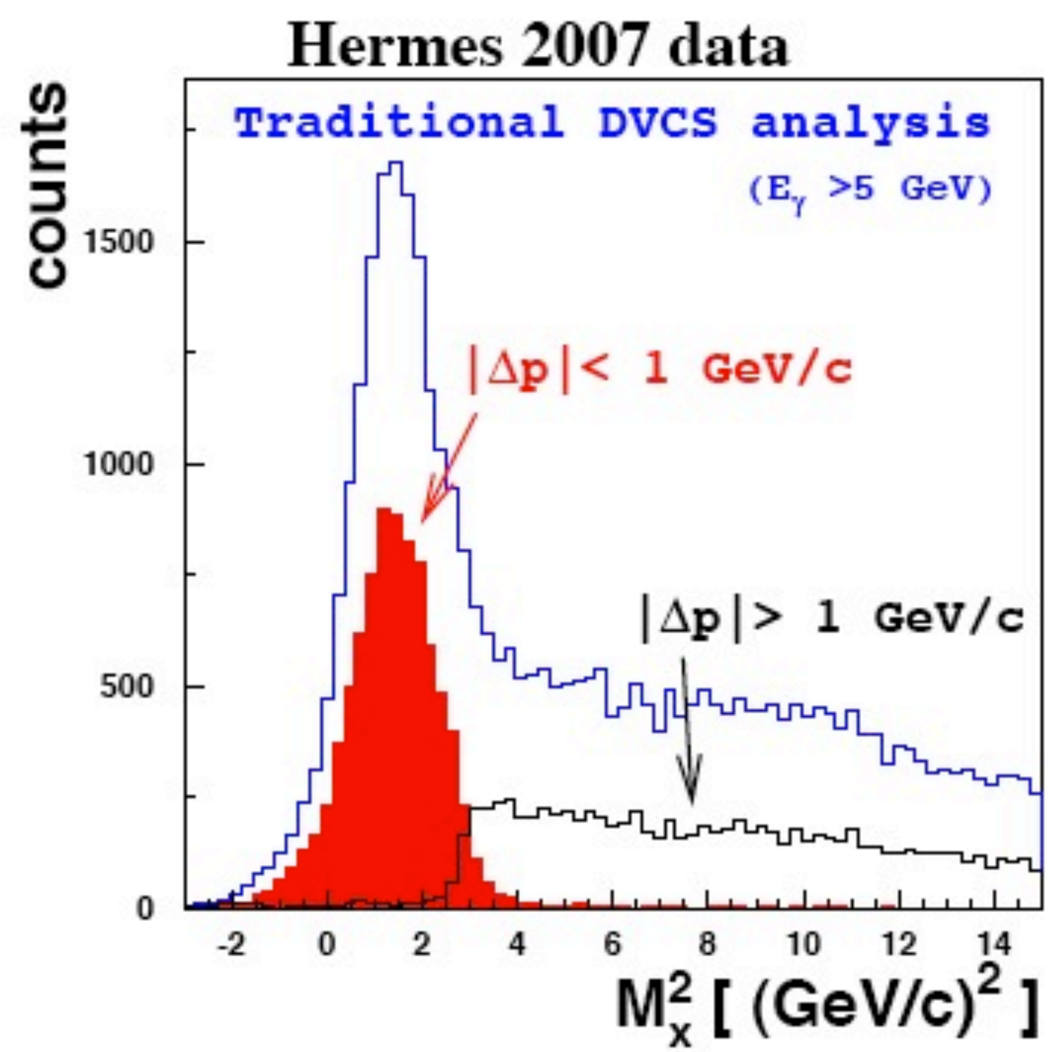


- Missing ϕ: $\Delta\phi = \phi_{\text{meas}} - \phi_{\text{calc}}$
- Missing p: $\Delta p = p_{\text{meas}} - p_{\text{calc}}$

Missing Mass ($\approx M_P^2$):

$$M_X^2 = (p + p_{\gamma^*} - p_\gamma)^2$$



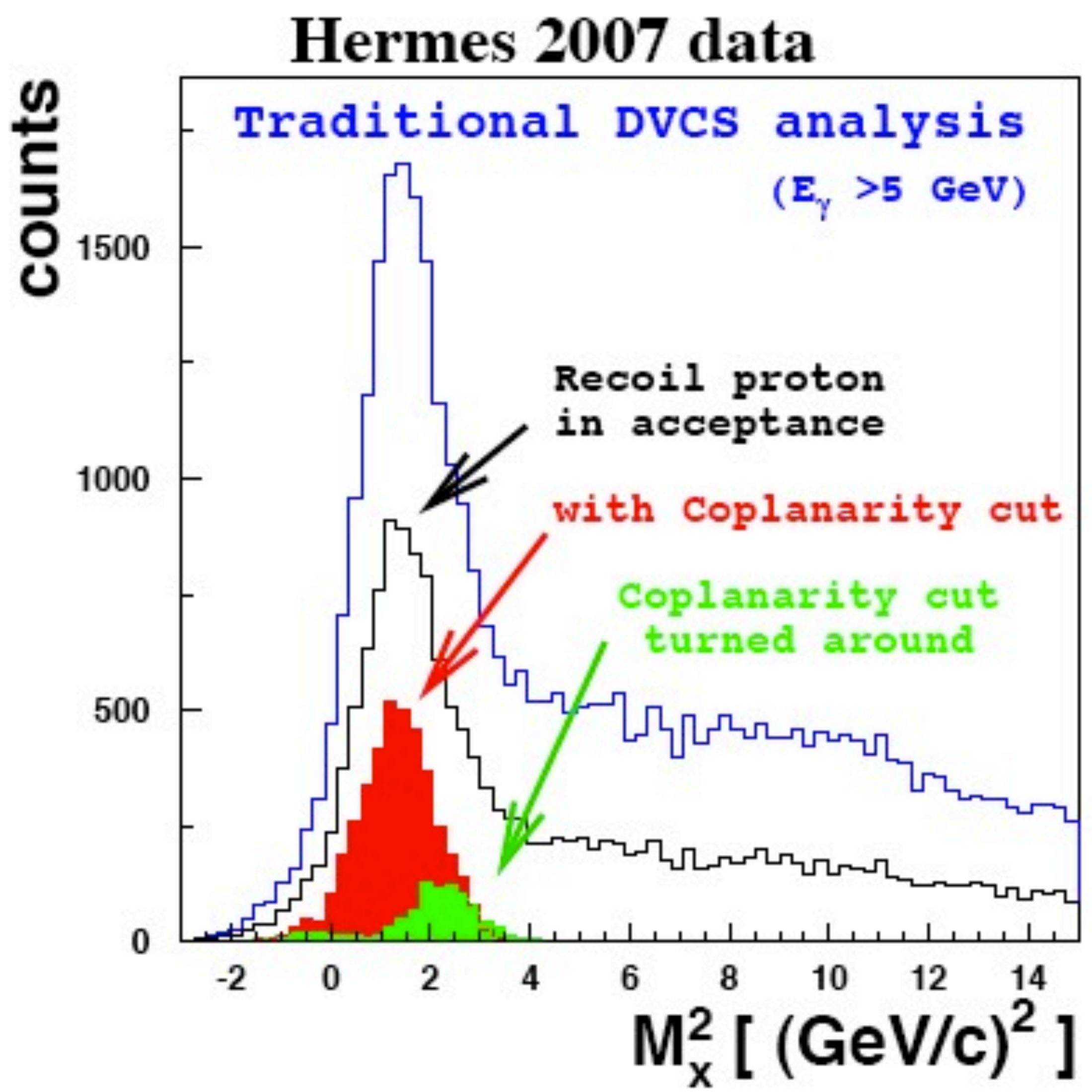


Separation of Resonant and Elastic States with the Recoil

DVCS / Bethe Heitler

- Elastic:
  - $ep \rightarrow ep\gamma$
- Resonant ('associated'):
  - $ep \rightarrow e\Delta^+\gamma$

    $$\Delta^+ \rightarrow \begin{cases} n\pi^+, & 1/3 \\ p\pi^0, & 2/3 \end{cases}$$
  - 12% of signal
- Presence of $\pi^0 \Rightarrow$ proton fails coplanarity cut
  - Select elastic:
    - $|\Delta\phi| < 0.1$ rad
    - $|p_T^{\mathrm{calc}}|/|p_T^{\mathrm{meas}}| = 0.5 \div 1.5$
  - Select resonant:
    - $|\Delta\phi| > 0.35$ rad



Summary and Outlook: DVCS at HERMES

- HERMES 1996-2005
  - Target spin asymmetry on transversely polarized H published in 2008
  - BSA and BCA on H, D and nuclear targets to be published in 2009
  - Target spin asymmetries on longitudinally polarized H and D early 2010
- HERMES 2006-2007
  - Recoil detector allows separation of resonant and elastic contributions
  - Resonant asymmetry unknown so far
  - Allows refinement of pre-Recoil data
- HERMES provides complete set of DVCS azimuthal asymmetries as input to global GPD fits
  - Limited only by statistics and acceptance