DVCS Results from HERMES

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Beam-Charge Asymmetry ($\mathcal{A}_C$)

$$\mathcal{A}_C(\phi) = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

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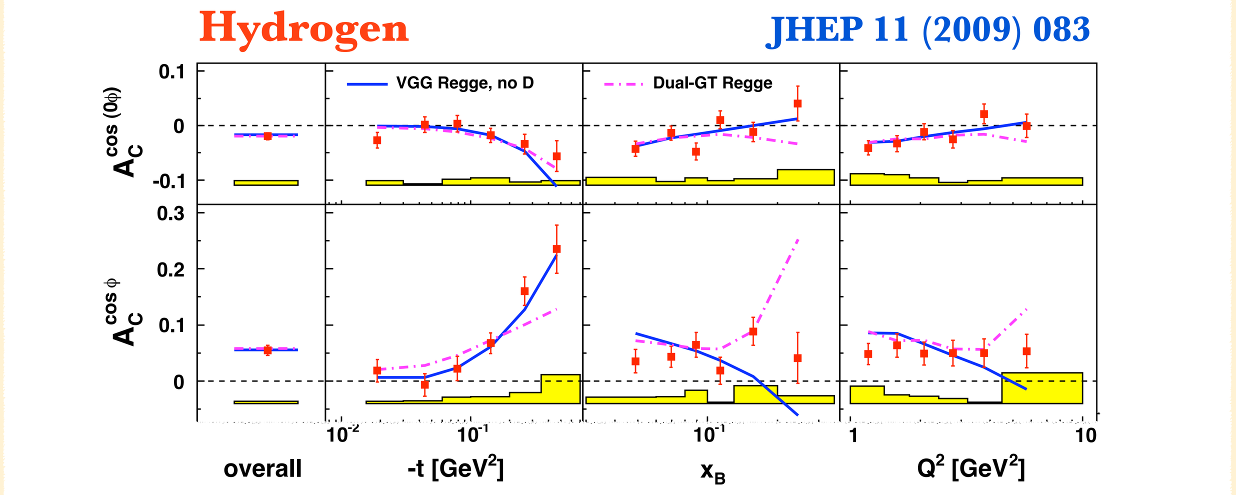

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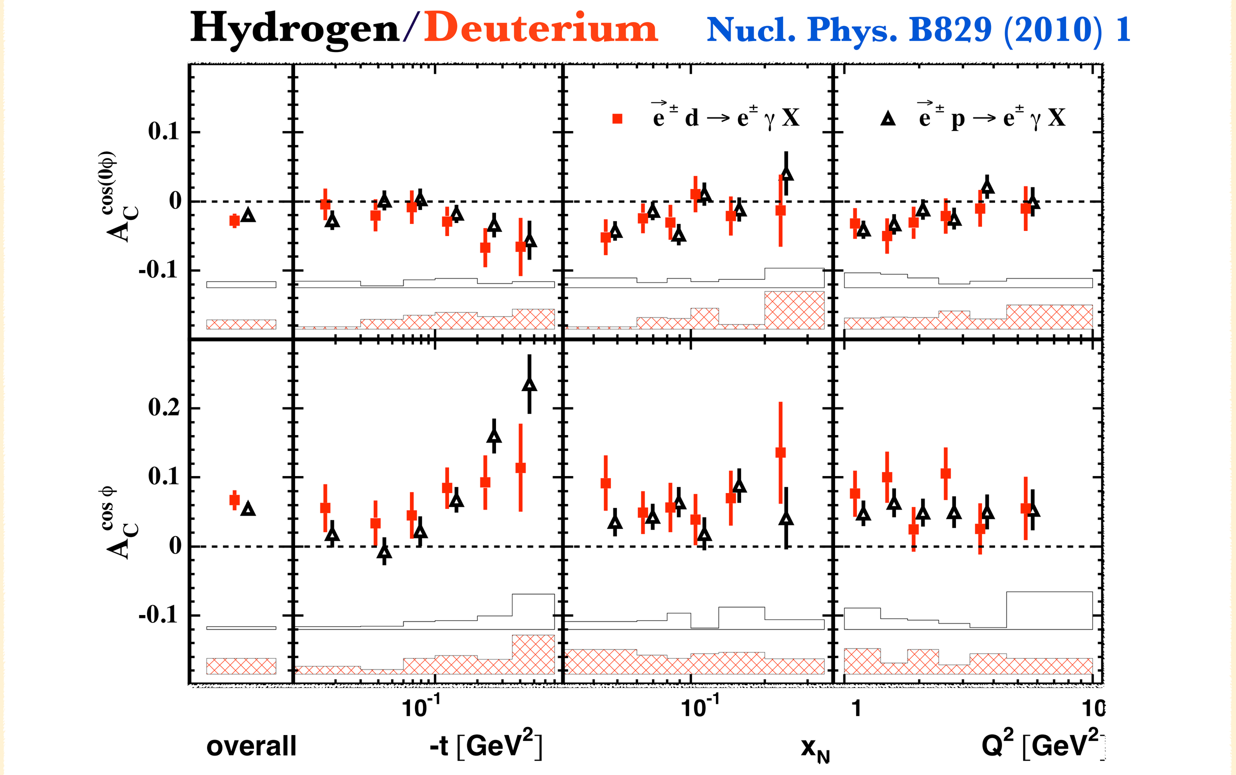

- ✦ Leading cos(ϕ) amplitude is sensitive to the real part of CFF $\mathcal{H}(\mathcal{H}_1)$.
- ✦ Results on both targets are consistent.
- ✦ No clear signature of 40% contribution from coherent scattering at low -t.
- ✦ Non-zero asymmetry amplitudes. Strong -t dependence on both targets and no significant x_B and Q^2 dependencies.
- ✦ Model predictions from M. Vanderhaeghen et.al. Phys. Rev. D(1999) 094017.

Longitudinal Target-Spin Asymmetry ($\mathcal{A}_{UL}$)

$$\mathcal{A}_{UL}(\phi) = \frac{(\sigma^{\rightarrow\Rightarrow} + \sigma^{\leftarrow\Rightarrow}) - (\sigma^{\rightarrow\Leftarrow} + \sigma^{\leftarrow\Leftarrow})}{(\sigma^{\rightarrow\Rightarrow} + \sigma^{\leftarrow\Rightarrow}) + (\sigma^{\rightarrow\Leftarrow} + \sigma^{\leftarrow\Leftarrow})}$$

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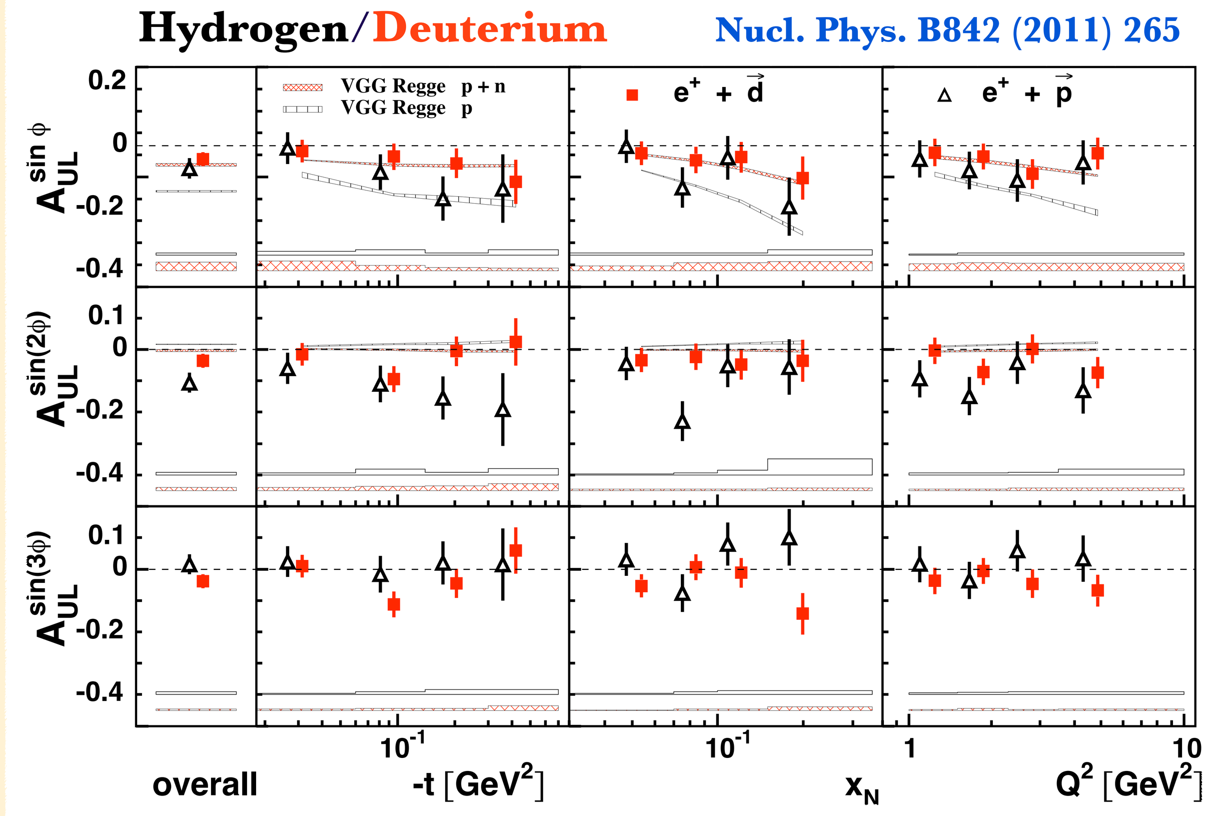

- ✦ Asymmetries measured with positron beam.
- ✦ Leading sin(ϕ) amplitude is sensitive to the imaginary part of CFF $\tilde{\mathcal{H}}(\tilde{\mathcal{H}}_1)$.
- ✦ Non-zero negative value of leading sin(ϕ) amplitude on both targets.
- ✦ Results on deuteron nither support nor disfavor large contribution from neutron, predicted by the model.
- ✦ Results on both targets are compatible.

Longitudinal Double-Spin Asymmetries ($\mathcal{A}_{LL}$)

$$\mathcal{A}_{LL}(\phi) = \frac{(\sigma^{\rightarrow\Rightarrow} + \sigma^{\leftarrow\Leftarrow}) - (\sigma^{\rightarrow\Leftarrow} + \sigma^{\leftarrow\Rightarrow})}{(\sigma^{\rightarrow\Rightarrow} + \sigma^{\leftarrow\Leftarrow}) + (\sigma^{\rightarrow\Leftarrow} + \sigma^{\leftarrow\Rightarrow})}$$

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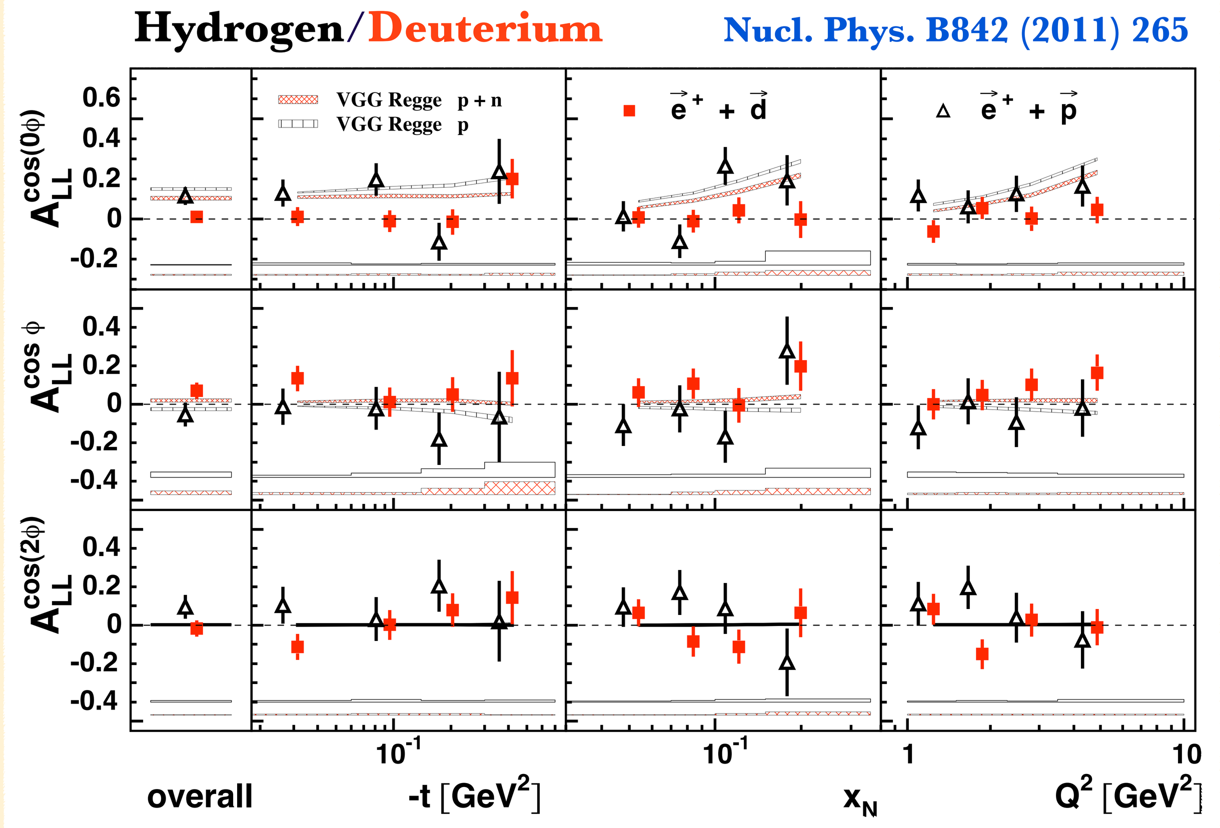
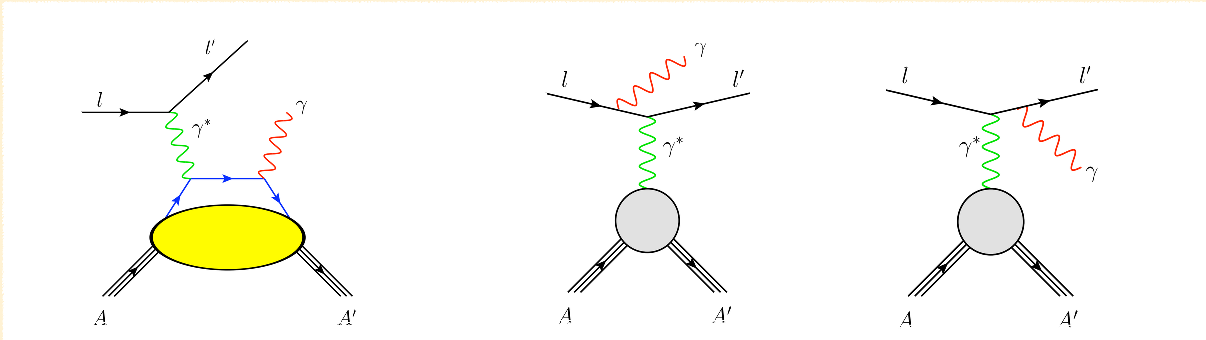


- ✦ Asymmetries measured with positron beam.
- ✦ Leading cos(ϕ) amplitude is sensitive to the real part of CFF $\tilde{\mathcal{H}}(\tilde{\mathcal{H}}_1)$.
- ✦ Leading cos(ϕ) amplitude is compatible with zero for both targets.
- ✦ Asymmetry amplitudes are attributed not only to squared DVCS or interference terms, but also to squared BH term.

DVCS at HERMES

Hard Leptoproduction of Real Photons



DVCS and **Bethe-Heitler** ⇒ Same final state ⇒ **Interference**

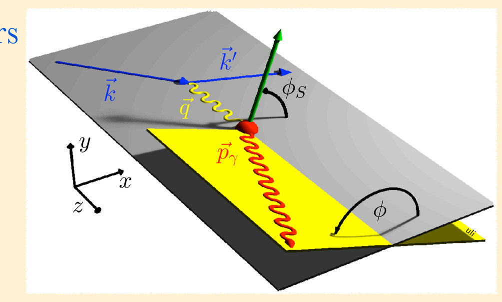
$$\frac{d\sigma}{dx_B dQ^2 d|t| d\phi d\phi_S} \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \underbrace{\mathcal{T}_{DVCS}\mathcal{T}^*_{BH} + \mathcal{T}_{BH}\mathcal{T}^*_{DVCS}}_{I}$$

At HERMES kinematics $|\mathcal{T}_{DVCS}|^2 \ll |\mathcal{T}_{BH}|^2$

Interference term leads to non-zero azimuthal asymmetries

Bethe-Heitler ⇒ Electromagnetic Form Factors

Nucleons F_1, F_2
Deuteron G_1, G_2, G_3



DVCS ⇒ Compton Form Factors (CFF) $\mathcal{F}$

Nucleons $\mathcal{H}, \mathcal{E}, \tilde{\mathcal{H}}, \tilde{\mathcal{E}}$
Deuteron $\mathcal{H}_1, \cdots \mathcal{H}_5, \tilde{\mathcal{H}}_1, \cdots \tilde{\mathcal{H}}_4$

CFFs are convolutions of hard scattering amplitude with corresponding GPDs

$$\mathcal{F}(\xi, t) = \sum_q \int_{-1}^{1} dx C_q(\xi, x) F^q(x, \xi, t)$$

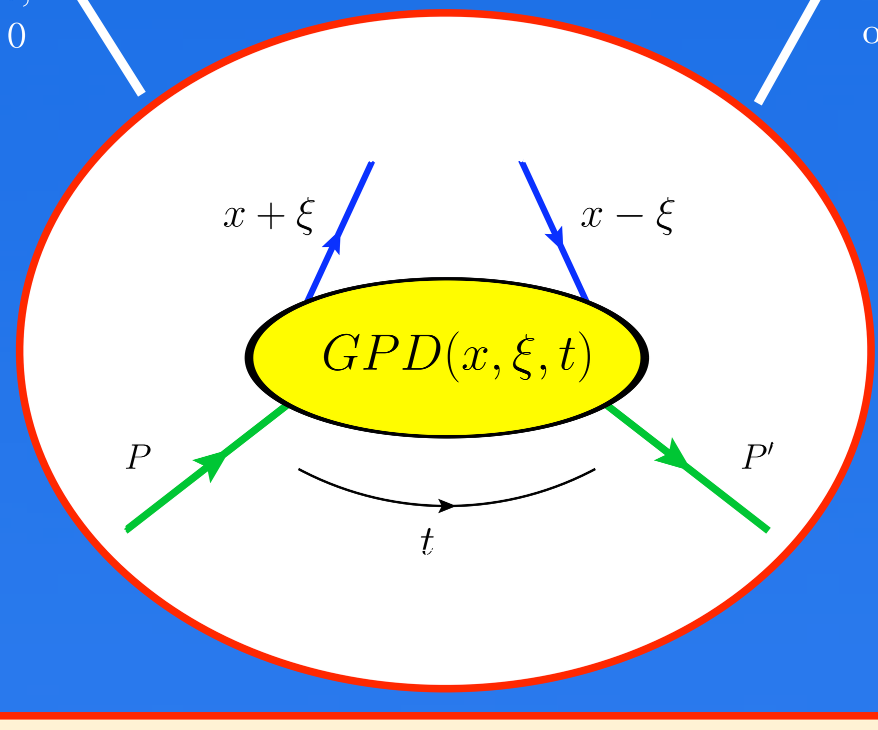
Parton Distribution Functions $f^q(x)$

Form Factors $F^q(t)$

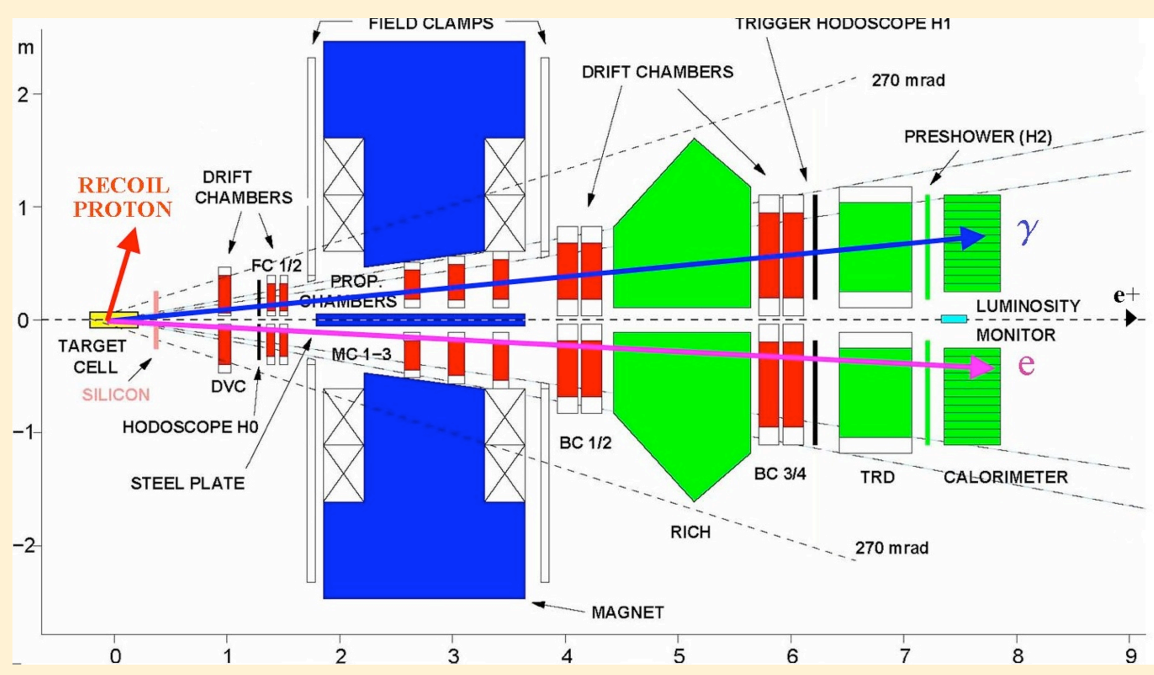
3D Structure of the Nucleon

t = 0, ξ = 0

integrate over x



DVCS Measurement



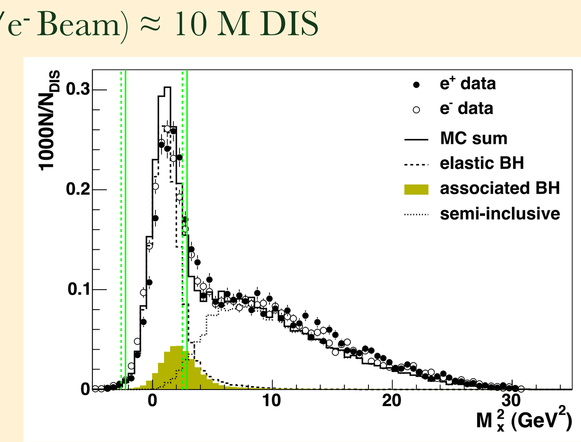
- ✦ Tracking Detectors
- ✦ Particle Identification Detectors
- ✦ Longitudinally polarized e^+/e^- Beam with energy 27.6 GeV

Data Collected 1996-2005 without Recoil Detector

- ✦ 1996-1997 Longitudinally Polarized Hydrogen (e^+ Beam) ≈ 3 M DIS
- ✦ 1998-2000 Longitudinally Polarized Deuteium (e^+/e^- Beam) ≈ 10 M DIS
- ✦ 2002-2005 Transversely Polarized Hydrogen (e^+/e^- Beam) ≈ 6 M DIS
- ✦ 1996-2005 Unpolarized Hydrogen (e^+/e^- Beam) ≈ 17 M DIS
- ✦ 1996-2005 Unpolarized Deuteium (e^+/e^- Beam) ≈ 10 M DIS

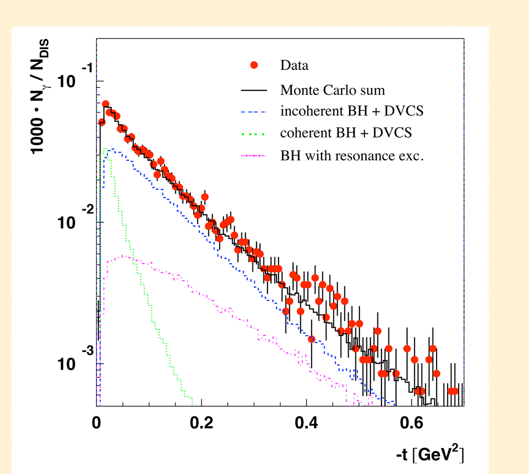
Exclusivity via Missing Mass

$$M_x^2 = (P + q - q')^2$$



Proton target
Elastic: $ep \rightarrow ep\gamma$
Associated: $ep \rightarrow e\Delta^+\gamma$
Semi-Inclusive: $ep \rightarrow e\pi^0 X$

Deuteron target
Elastic Coherent: $ed \rightarrow ed\gamma$
Elastic Incoherent: $ed \rightarrow epn\gamma$
Associated: $eN \rightarrow eN^*\gamma$
Semi-Inclusive: $eN \rightarrow e\pi^0 X$



$$W^2 > 9\,GeV^2, \quad \nu < 22\,GeV$$
$$0.03 < x_B < 0.35,\ 1 < Q^2 < 10\,GeV^2$$
$$-t < 0.7\,GeV^2, \quad E_\gamma > 5\,GeV$$
$$-2.25\,GeV^2 < M_x^2 < 2.89\,GeV^2$$

Associated process defined as a part of signal

Beam-Spin Asymmetries ($\mathcal{A}_{LU}$)

Charge-Difference Beam-Spin Asymmetry

$$\mathcal{A}^I_{LU}(\phi) = \frac{(\sigma^{+\rightarrow} - \sigma^{+\leftarrow}) - (\sigma^{-\rightarrow} - \sigma^{-\leftarrow})}{(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}) + (\sigma^{-\rightarrow} + \sigma^{-\leftarrow})}$$

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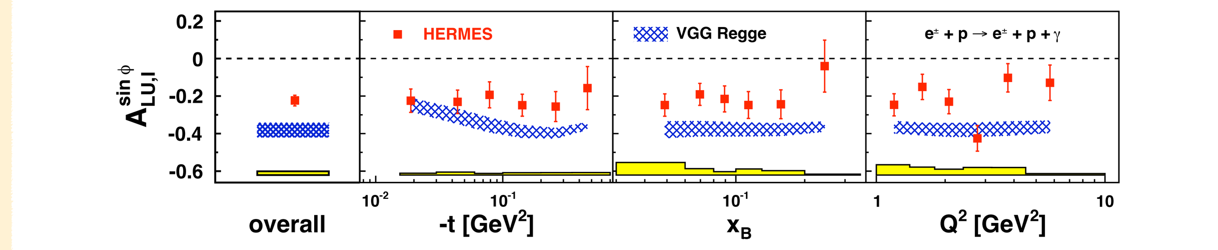

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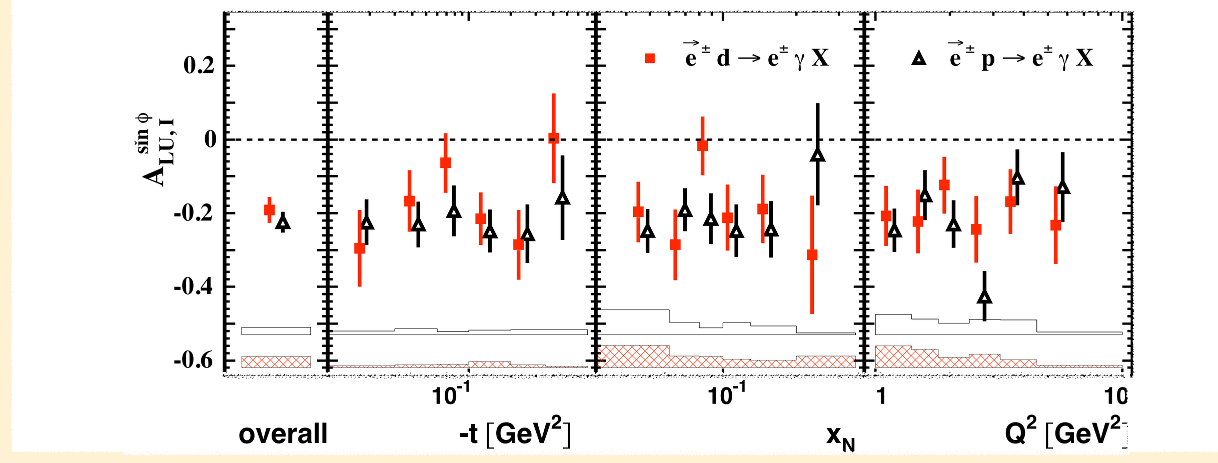
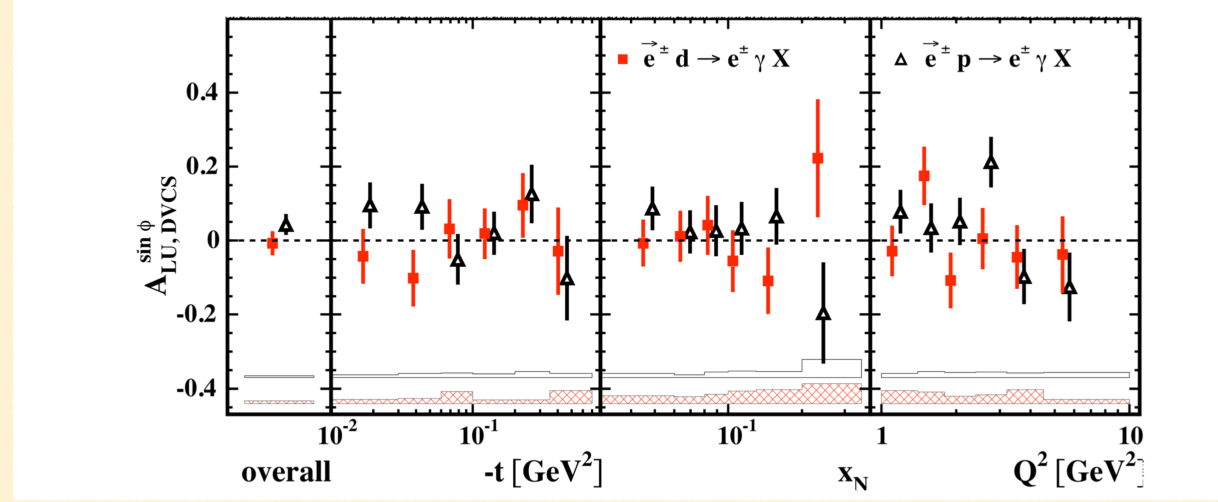


- ✦ Leading sin(ϕ) amplitude is sensitive to the imaginary part of CFF $\mathcal{H}(\mathcal{H}_1)$.
- ✦ Significantly negative sin(ϕ) amplitude on both targets.
- ✦ Results on both targets are consistent.
- ✦ No clear signature of 40% contribution from coherent scattering at low -t.
- ✦ Non-zero asymmetry amplitudes. Strong -t dependence on both targets and no significant x_B and Q^2 dependencies.

Charge-Averaged Beam-Spin Asymmetry

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



- ✦ Results on both targets are consistent with zero.

Transverse Target-Spin Asymmetries ($\mathcal{A}_{UT}$)

Charge-Difference and Charge-Averaged Target-Spin Asymmetries

$$\mathcal{A}^{I,DVCS}_{UT}(\phi, \phi_S) = \frac{(\sigma^{+\Uparrow} - \sigma^{+\Downarrow}) \pm (\sigma^{-\Uparrow} - \sigma^{-\Downarrow})}{(\sigma^{+\Uparrow} + \sigma^{+\Downarrow}) + (\sigma^{-\Uparrow} + \sigma^{-\Downarrow})}$$

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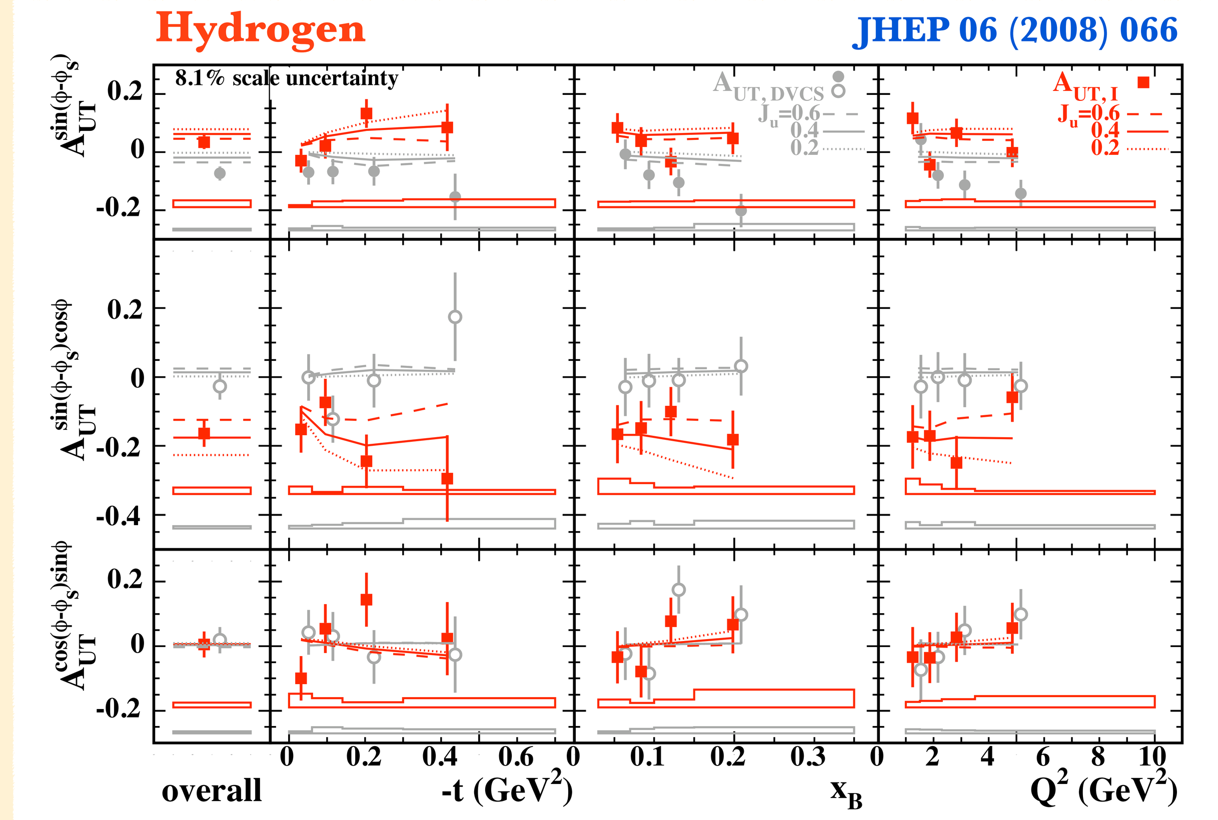

- ✦ Non-zero leading sin($\phi-\phi_S$) and sin($\phi-\phi_S$)cos(ϕ) amplitudes.
- ✦ Leading sin($\phi-\phi_S$)cos(ϕ) amplitude of charge-difference target-spin asymmetry is sensitive to the imaginary part of CFF $\mathcal{E}$. Thus it provides sensitivity to u quark total angular momenta J_u.

Transverse Double-Spin Asymmetries ($\mathcal{A}_{LT}$)

Charge-Difference and Charge-Averaged Transverse Double-Spin Asymmetries

$$\mathcal{A}^{I,BH+DVCS}_{LT}(\phi, \phi_S) = \frac{(\overrightarrow{\sigma}^{+\Uparrow} + \overleftarrow{\sigma}^{+\Downarrow} - \overrightarrow{\sigma}^{+\Downarrow} - \overleftarrow{\sigma}^{+\Uparrow}) \pm (\overrightarrow{\sigma}^{-\Uparrow} + \overleftarrow{\sigma}^{-\Downarrow} - \overrightarrow{\sigma}^{-\Downarrow} - \overleftarrow{\sigma}^{-\Uparrow})}{(\overrightarrow{\sigma}^{+\Uparrow} + \overleftarrow{\sigma}^{+\Downarrow} + \overrightarrow{\sigma}^{+\Downarrow} + \overleftarrow{\sigma}^{+\Uparrow}) + (\overrightarrow{\sigma}^{-\Uparrow} + \overleftarrow{\sigma}^{-\Downarrow} + \overrightarrow{\sigma}^{-\Downarrow} + \overleftarrow{\sigma}^{-\Uparrow})}$$

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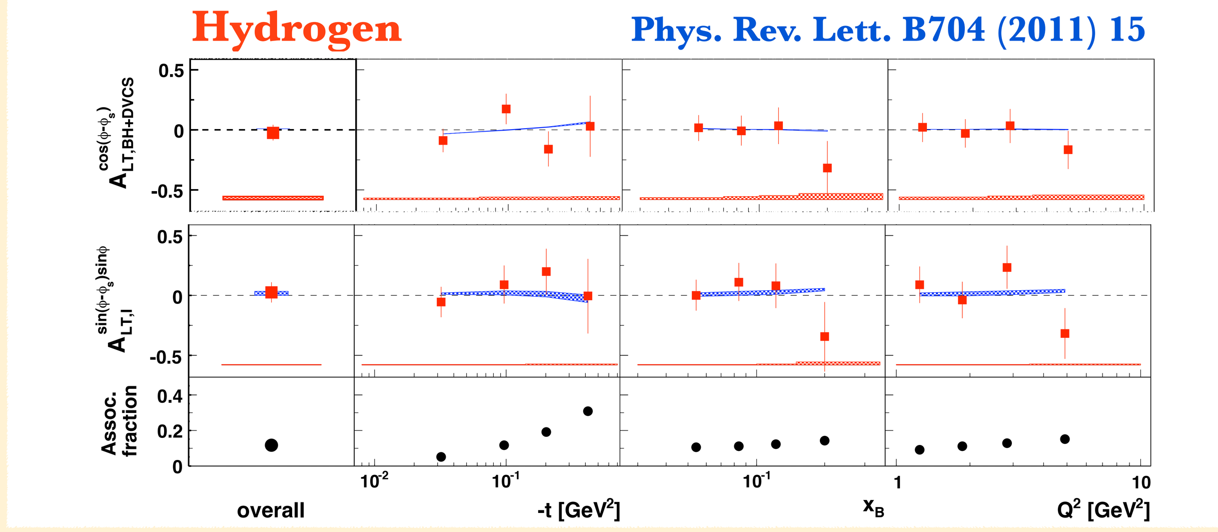

- ✦ Leading amplitudes of the asymmetries are compatible with zero.
- ✦ Leading sin($\phi-\phi_S$)sin(ϕ) amplitude of charge-difference double-spin asymmetry is sensitive to the real part of CFF $\mathcal{E}$.
- ✦ Sensitivity to the u-quark total angular momenta is suppressed by kinematic pre-factor.