DVCS at 6/12 GeV, and ideas for the EIC

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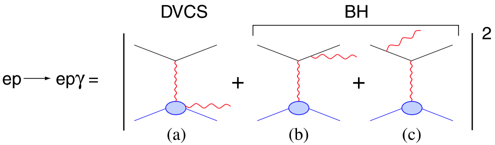
DVCS experimentally: interference with Bethe-Heitler (BH)



At leading twist:

$$d^5\overrightarrow{\sigma} - d^5\overleftarrow{\sigma} = \Im m\,(T^{BH}\cdot T^{DVCS})$$

$$d^5\overrightarrow{\sigma} + d^5\overleftarrow{\sigma} = |BH|^2 + \Re e\,(T^{BH}\cdot T^{DVCS}) + |DVCS|^2$$

$$\mathcal{T}^{DVCS} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\epsilon} + \cdots =$$

$$\underbrace{\mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}}_{\text{Access in helicity-independent cross section}} \quad - \quad \underbrace{i\pi\, H(x=\xi,\xi,t)}_{\text{Access in helicity-dependent cross-section}} \quad + \dots$$

Access in helicity-independent cross section

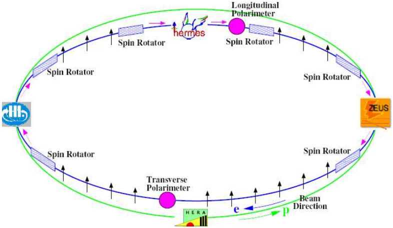
Access in helicity-dependent cross-section

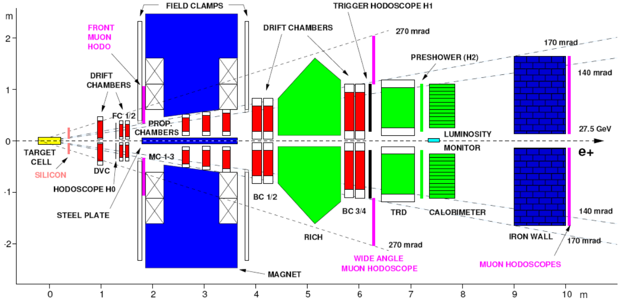
The DVCS program "worldwide"

- HERMES at DESY:
  - Beam (BSA), charge (BCA) and transverse target (TSA) asymetries published
  - Several ongoing analysis + recoil detector installed 1 year before shutdown: results to come...
- Hall A and Hall B partially overlapping, partially complementary, active programs:
  - Hall A: high accuracy, limited kinematics
  - Hall B: wide kinematic range, limited accuracy
  - Very different systematics
- COMPASS at CERN? (proposal preparation underway)
- The roadmap:
  - Early results (≈ 2001) from non-dedicated exp. (HERMES+CLAS)
  - First round of dedicated experiments in Halls A/B in 2004/5
  - Second round on 2008–2010
  - Compeling DVCS program in Halls A/B at 11 GeV (≈2013-15)

HERMES

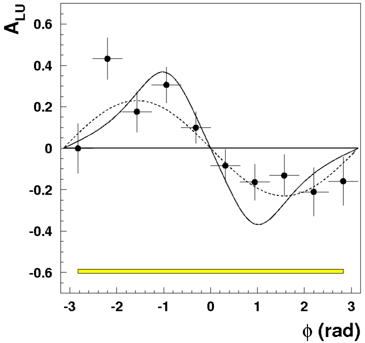
27.5 GeV polarised
e^+/e^- beam of HERA





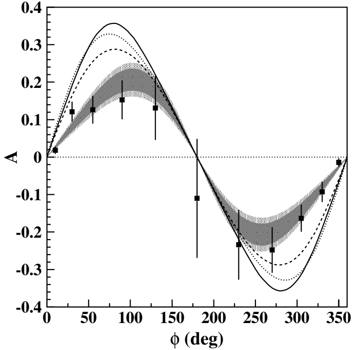
CLAS and HERMES (2001): beam spin asymmetries

A_{UL}: PRL **87**, 182001 (2001)



$\langle Q^2, x_B, -t \rangle = 2.6$ GeV^2, $0.11, 0.27$ GeV^2

A_{LU}: PRL **87**, 182002 (2001)

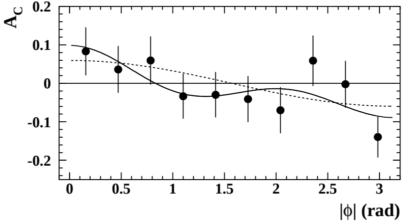


$\langle Q^2, x_B, -t \rangle = 1.25$ GeV^2, $0.19, 0.19$ GeV^2

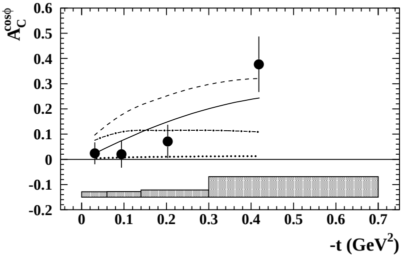
- Both results show, with a limited statistics, a $\sin\phi$ behaviour
- Not fully exclusive

Beam charge asymmetry (HERMES)

Integrated

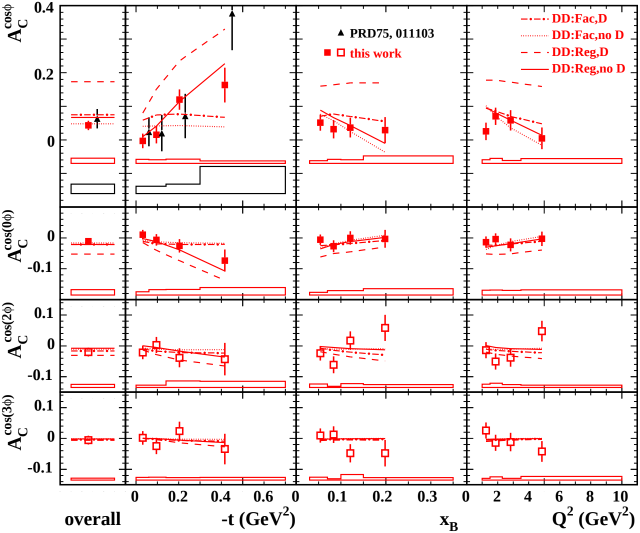


As a function of t

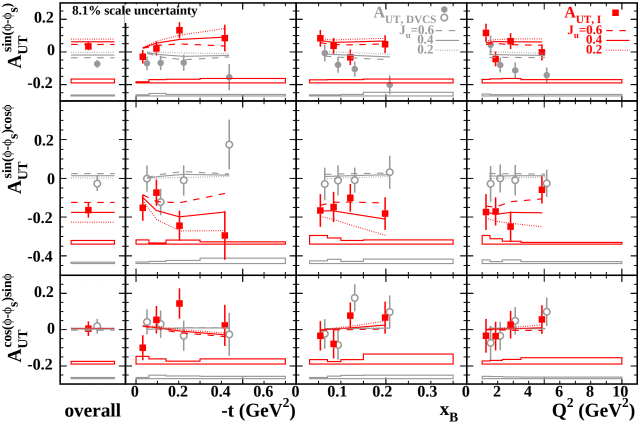


Phys. Rev. **D75**, 011103 (2007)

Beam charge asymmetry (2008)



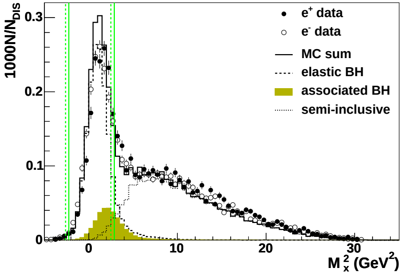
Transverse target spin asymmetry

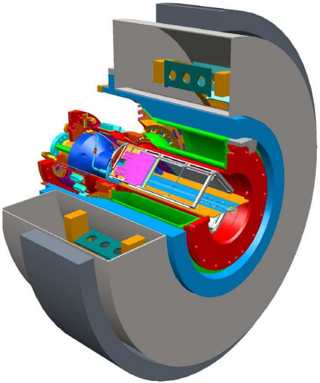


JHEP 0806, 066 (2008)

Recoil detector at HERMES

Missing mass squared $ep \to e\gamma X$

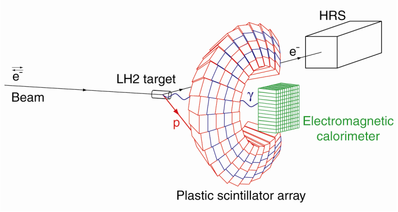




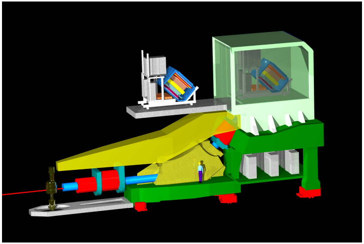
Integration window:
$-2.25 \text{ GeV}^2 < M_x^2 < 2.89 \text{ GeV}^2$

- Not fully exclusive
- Recoil detector operated during last year of data taking
- Analysis underway and results to come

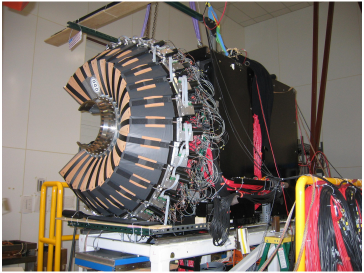
E00-110 experimental setup



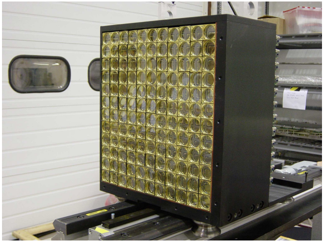
High Resolution Spectrometer



100-channel scintillator array

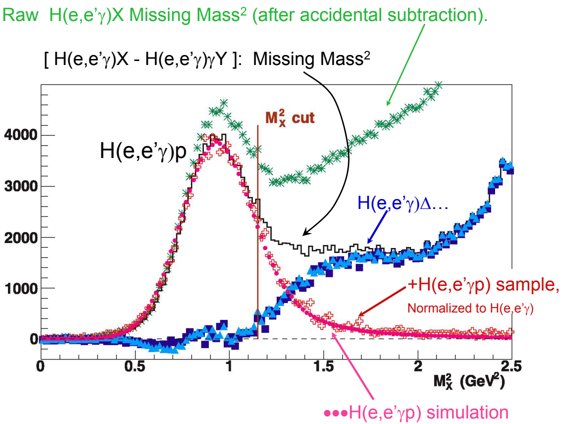


132-block PbF_2 electromagnetic calorimeter



Exclusivity

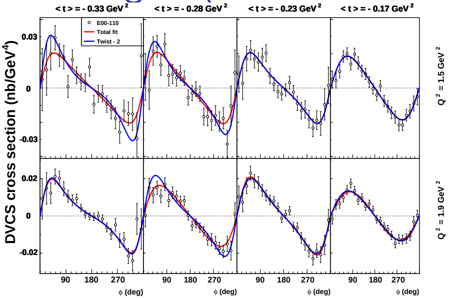
Missing mass squared $ep \to e\gamma X$ (E00-110)

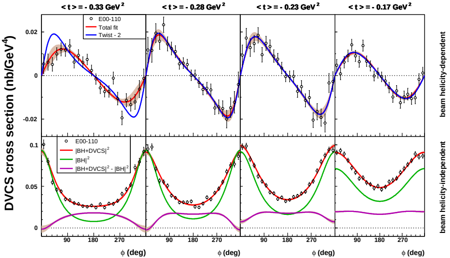


Exclusivity ensured by missing mass technique

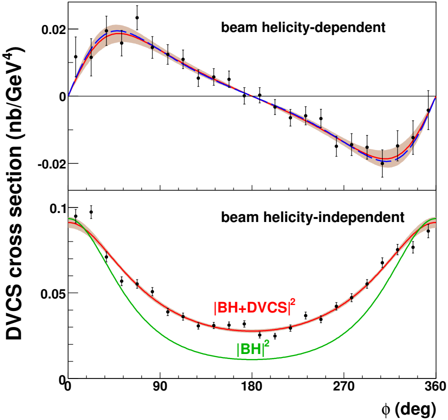
DVCS cross section in the valence region (Hall A: E00-110)

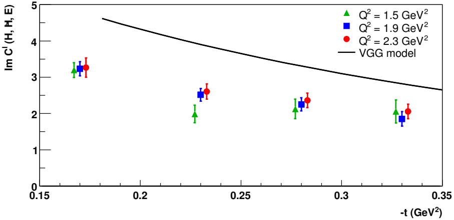
- **Helicity-dependent** cross section $(\overrightarrow{\sigma} - \overleftarrow{\sigma})$ at $Q^2 = 1.5$, 1.9 and 2.3 GeV^2.
- **Helicity-independent** cross section $(\overrightarrow{\sigma} + \overleftarrow{\sigma})$ at $Q^2 = 2.3$ GeV^2 *only*.





E00-110 results



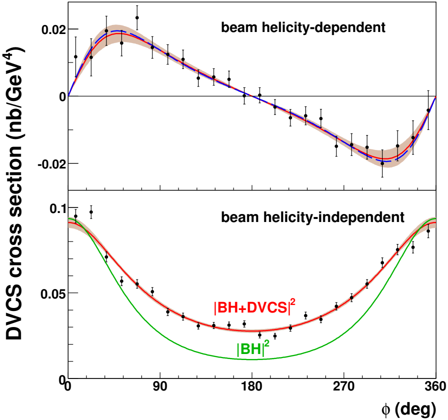


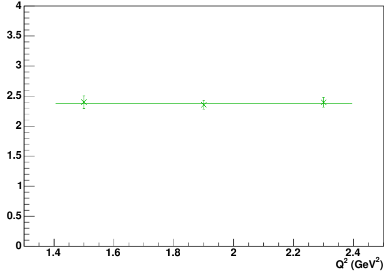
Twist-2: dominant contribution

Contributions from BH^2, DVCS^2 and BH-DVCS interference

Phys. Rev. Lett. **97**, 262002 (2006)
Physics Today, March 2007

E00-110 results





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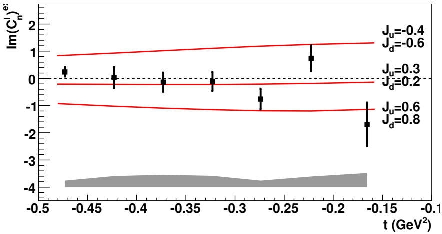
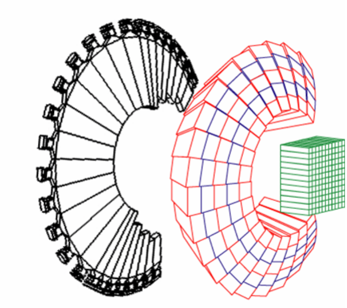
DVCS on the neutron: experiment E03-106 at JLab

LD_2 target ($F_2^n(t) \gg F_1^n(t)$!)



$$\sigma^{\rightarrow} - \sigma^{\leftarrow} = \Gamma(A \sin\varphi + \dots)$$

Charged particle veto
in front of scintillator array



$$A = F_1(t)\mathcal{H} + \frac{x_B}{2-x_B}[F_1(t)+F_2(t)]\tilde{\mathcal{H}} - \underbrace{\frac{t}{4M^2} \cdot F_2(t) \cdot \mathcal{E}}_{\text{Main contribution for neutron}}$$

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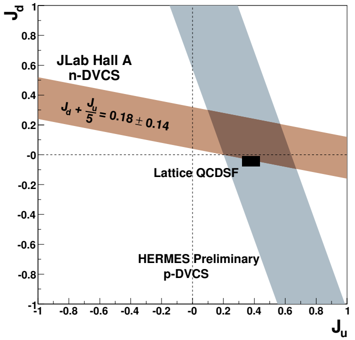

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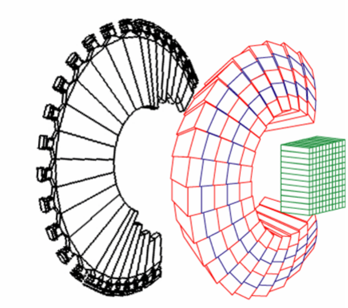

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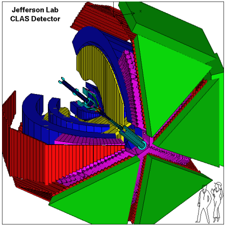
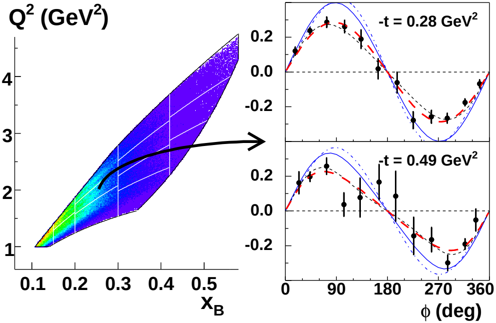
BSA in a large kinematic domain (Hall B)



$$A = \frac{\overrightarrow{\sigma} - \overleftarrow{\sigma}}{\overrightarrow{\sigma} + \overleftarrow{\sigma}} \approx \frac{\alpha \sin\phi}{1 + \beta\cos\phi}$$



Simple models do not reproduce the data

Analysis of cross sections underway

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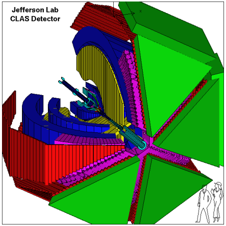

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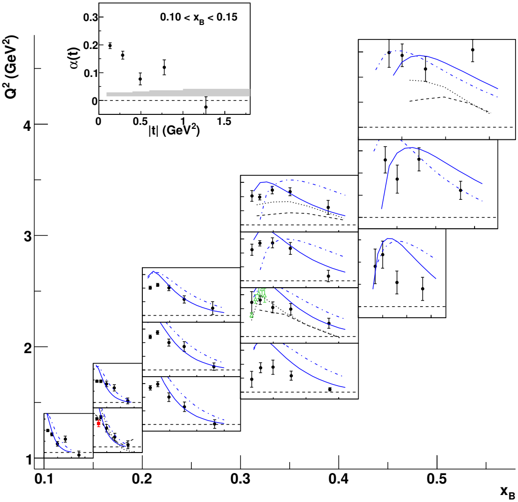
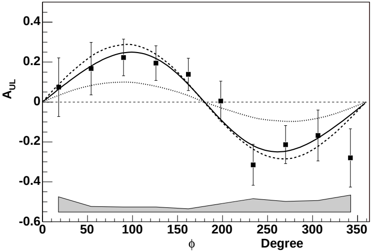


Target spin asymmetry A_{UL} (Hall B)

Not dedicated result:



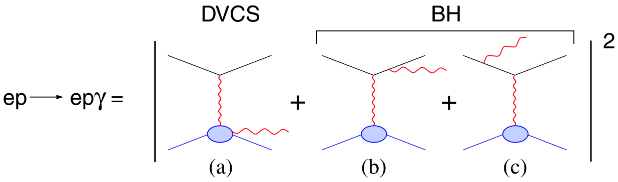
Dedicated experiment took data in Hall B earlier this year

Sensitivity to GPD $\widetilde{H}$

Other upcoming experiments (at 6 GeV):

- More DVCS on unpolarized proton
- DVCS on a transversely polarized target (conditionally approved)
- DVCS on nuclei (He^4)

E07-007 (Hall A)

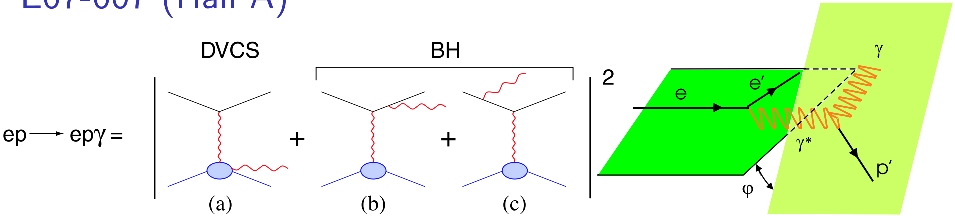


$$\sigma(ep \to ep\gamma) = \underbrace{|BH|^2}_{\text{Known to } \sim 1\%} + \underbrace{\mathcal{I}(BH \cdot DVCS)}_{\text{Linear combination of GPDs}} + \underbrace{|DVCS|^2}_{\text{Bilinear combination of GPDs}}$$

DVCS cross section has a very rich azimuthal structure:

- Azimuthal analysis allows the separation of the different contributions to $\mathcal{I}$ if DVCS^2 is negligeble.
- If DVCS^2 is important, $\mathcal{I}$ and DVCS^2 terms **MIX** in an azimuthal analysis.
- The **different energy dependence** of $\mathcal{I}$ and DVCS^2 allow a full separation.

E07-007 (Hall A)



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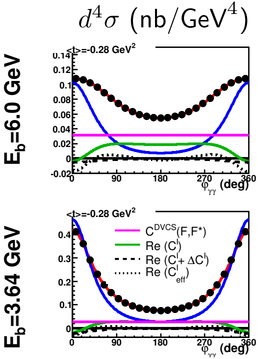
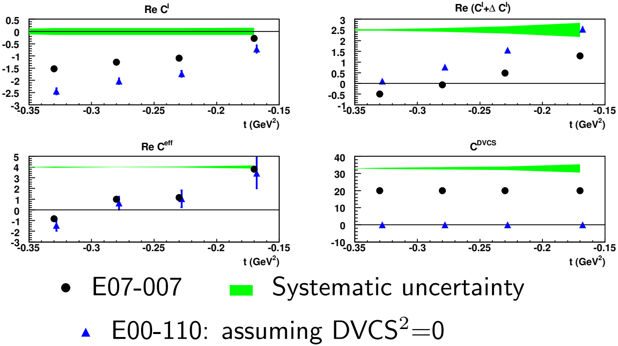
E07-007: Rosenbluth-like DVCS^2–$\mathcal{I}$ separation in Hall A

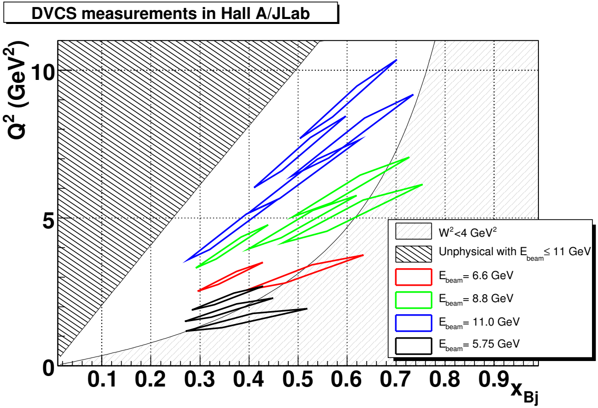
- Clean separation of BH-DVCS intereference term from pure DVCS^2
- Scaling test on the real part of the DVCS amplitude
- Rosenbluth separation of σ_L/σ_T for $ep \to ep\pi^0$





JLab Hall A at 11 GeV

JLab12 with 3, 4, 5 pass beam
(6.6, 8.8, 11.0 GeV beam energy)



Q^2 (GeV^2)	Beam time (days) x_{Bj} 0.36	0.50	0.60
3.0	3		
4.0	2		
4.55	1		
3.1		5	
4.8		4	
6.3		4	
7.2		7	
5.1			13
6.0			16
7.7			13
9.0			20
Total	6	20	62

1 GeV^2 range in $t_{min} - t$

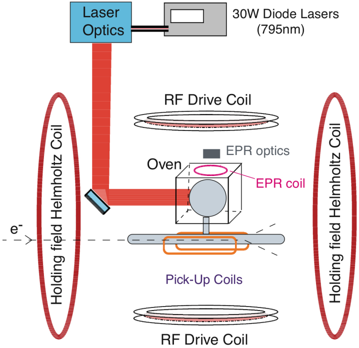
88 days
250k events/setting

1 year of operations in JLab/Hall A

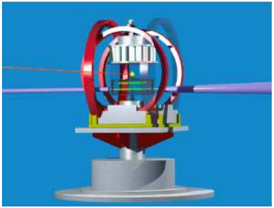
Future possibilities

- **DVCS on the neutron at 12 GeV**
  - Extention to the full kinematic domain available with JLab at 12GeV
  - Systematic uncertainties improved
- **Recoil polarimetry (R+D)**
  - A full DVCS program requires proton polarization measurements
  - Observables of proton recoil polarization in $\vec{e}p \to e\vec{p}\gamma$ are functionally equivalent to the observables $\vec{e}\vec{p} \to ep\gamma$ for polarized targets
  - Conceptual design of a large acceptance recoil polarimeter (longitudinal and transverse proton polarization) under development
- **High luminosity** ($> 10^{37}$ cm^{-2}s^{-1}) ^{3}**He target**

Polarized ^{3}He target in JLab/Hall A



- n lum. of $10^{36}/\text{cm}^2/\text{s}$ (14 atm $\times$ 40 cm)
- "Background" luminosity:
  - p in ^{3}He+entrance/exit windows
  - $10^{37}/\text{cm}^2/\text{s}$ total luminosity
- Polarization: 50%
  - Nuclear physics dilution factor 0.86 (d-state)
  - -2.8% p polarization
  - Long. & Trans.



^{3}He target upgrade conjecture

- Separate polarization and target volumes
  - Increase throughput by a factor of 10 to 100
  - Cool and/or compress ^{3}He in target area by a factor of 10 (10K at 10 atm $\times$ 20 cm)
  - Rapid cycling of ^{3}He through target
    - Reduce depolarization effect of target density, beam current, target walls
    - Replace thick glass with thin metallic walls
- Neutron luminosity of 10^{37}/cm^2/s
  - Proton luminosity $2 \cdot 10^{37}$cm^2/s
  - Endcaps $\leq 10^{37}$/cm^2/s
- Target polarization: $0.5 \cdot (0.86\ n - 0.028\ p)$

Neutron DVCS off a ^{3}He target

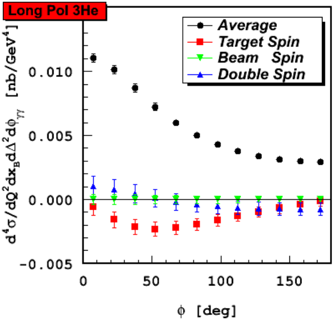
$$\vec{n}(\vec{e}, e'\gamma)n \text{ via } {}^3\vec{\text{He}}(\vec{e}, e)X$$

- Long or Trans normal polarization
- Target single spin cross sections
  - $d\sigma \sim \sin\varphi$ (twist-2): $\Im$m[BH·DVCS]
  - Unpolarized protons in ^{3}He cancel
- Target double spin
  - $d\sigma \sim c_0 + c_1 \cos\varphi$: $\Re$e[BH^2+(BH·DVCS)+DVCS^2]
  - Unpolarized protons cancel
- Transverse sideways: $\sin\varphi \to \cos\varphi$
- All other "neutron" observables (total σ, beam-spin) have large incoherent proton contributions

Cross section projections (VGG at $10^{37}\text{cm}^{-2}\text{s}^{-1}$)

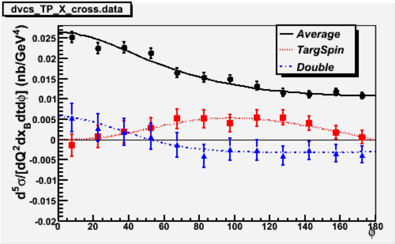
$Q^2 = 4$ GeV^2, $x_B = 0.36$, $k = 8.8$ GeV,

$t_{min} - t = 0.15$ GeV^2, 20 days

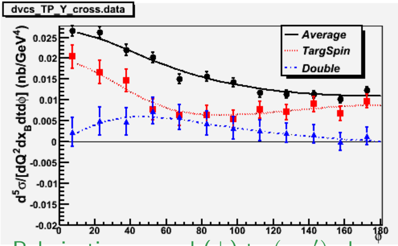


- 50%×80% polarization

$Q^2 = 2.3$ GeV^2, $x_B = 0.36$, $k = 8.8$ GeV, $t = -0.26$ GeV^2, 10 days

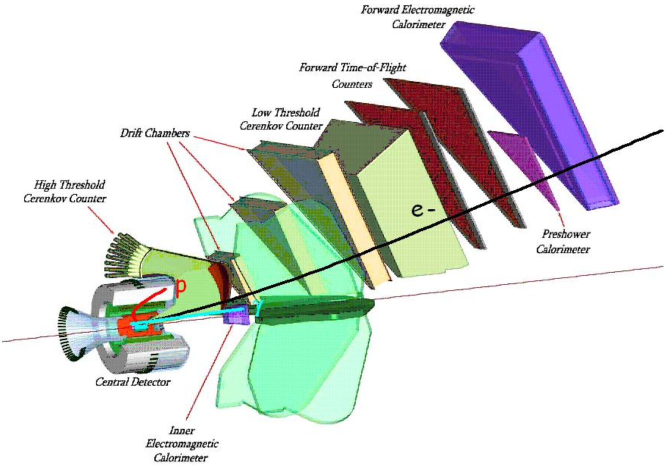


Polarization sideways (∥) to (e, e') plane

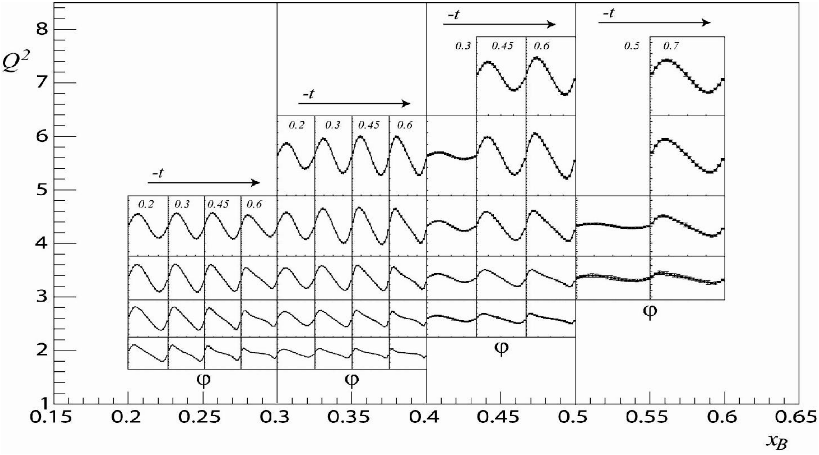


Polarization normal (⊥) to (e, e') plane

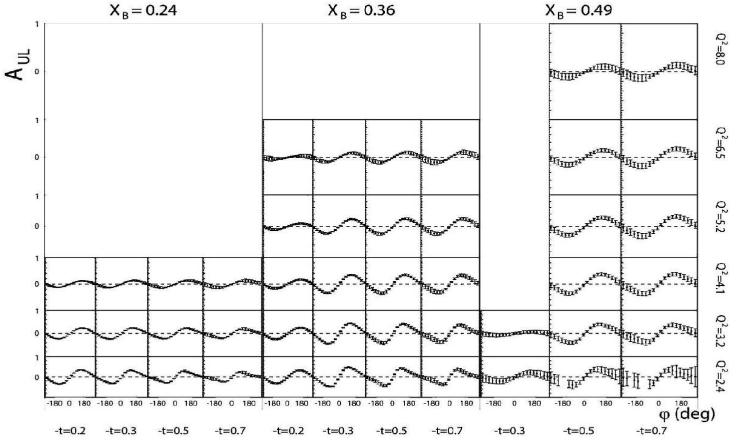
E12-06-119: DVCS with CLAS at 11 GeV



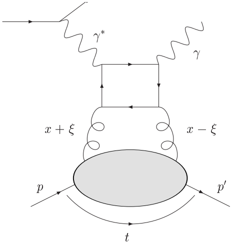
Beam spin asymmetry



Target spin asymmetry



DVCS with EIC: small x at high Q^2



- Gluon GPDs
- Sum rules (ex: orbital angular momentum)

$$\int_{-1}^{1} dx\; x\; [H(x,\xi,0) + E(x,\xi,0)] = J$$

- Dispersion relations

$$\text{Re}\; \mathcal{H}(\xi) = \text{PV} \int_{-1}^{1} dx H(x,x) \left[\frac{1}{\xi - x} - \frac{1}{\xi + x} \right] + C$$

Collider vs fixed target kinematics

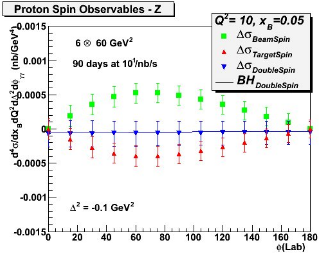
- Fixed target: q^*, q and p' are all co-linear at t_{min}
- Collider: Boost $\gamma_P \gg 1$ along the beam direction (into collider frame)
  Non-parallel boost to q, q' and p'

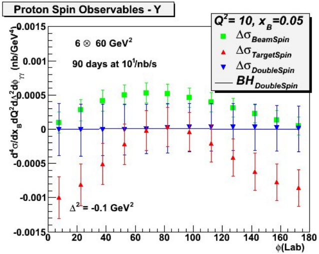
Recoil proton at very small angles: $t = -(4\xi^2 M^2 + t_\perp)/(1-2\xi)$
$\tan\theta_{p'} \simeq \frac{\sqrt{t_\perp}}{P(1-2\xi)}$

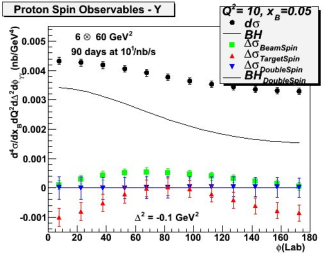
Typically, we need to detect protons at
a few mrad (~ 5) from the beamlines

Projections ($Q^2 = 10$ GeV^2, $x_B = 0.05$)

- Projections using VGG model for GPDs and $\mathcal{L} = 10^{34}$ Hz/cm^2
- Total cross-section larger than BH



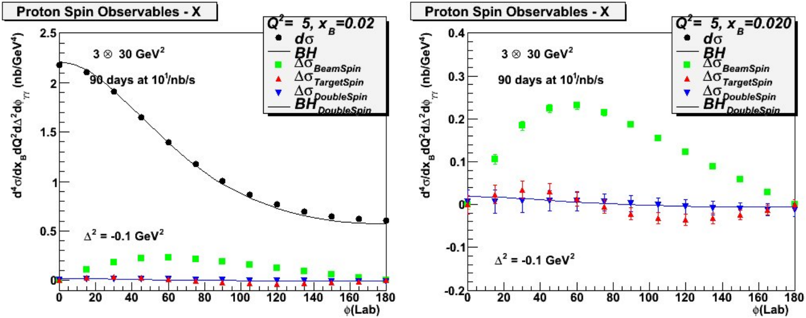




Plots by C. Hyde

Projections ($Q^2 = 5$ GeV^2, $x_B = 0.02$)

- Total cross-section dominated by BH in this kinematics
- Electron spin asymmetry particularly sensitive



Plots by C. Hyde

Summary and conclusions

JLab results:

- Twist-2 dominance at relative low Q^2 (a few GeV^2)
- Many *polarization* observables needed: both target and beam
- Different beam/collision energies needed
- Absolute cross-sections better than asymmetries

Opportunities with EIC:

- Lower x at sufficiently high Q^2
- Higher Q^2 lever arm to better understand/handle higher twists

Challenges of EIC:

- Luminosity (small cross-sections)
- Very forward recoil detection needed