The GPD experimental program at Jefferson Lab

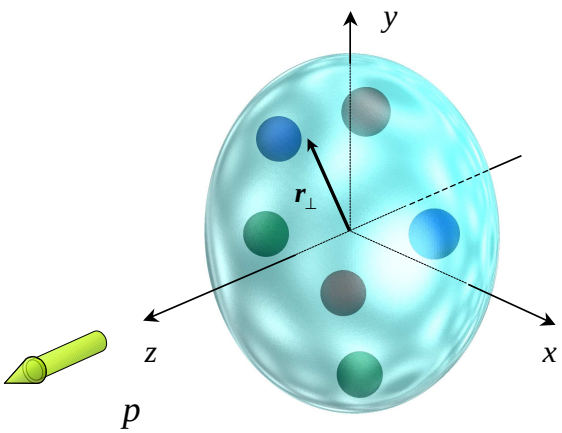
Carlos Muñoz Camacho

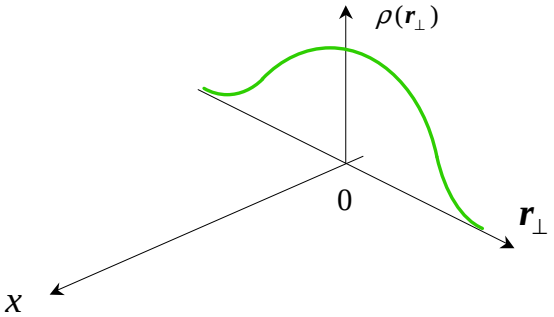
LPC Clermont-Ferrand, CNRS/IN2P3 Aubière, France

XIX International Baldin Seminar on High Energy Physics Problems
Sep 29 - Oct 4, 2008

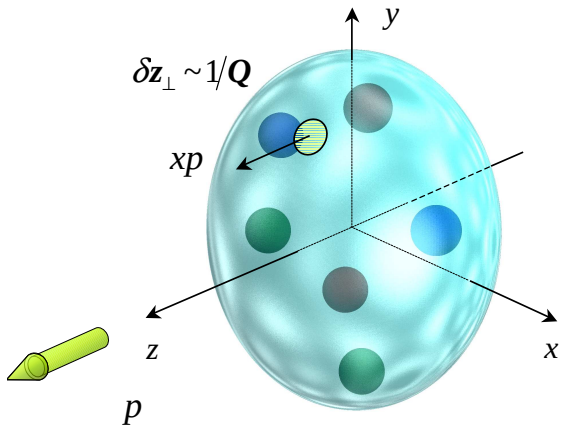
Studying the structure of the nucleon experimentally

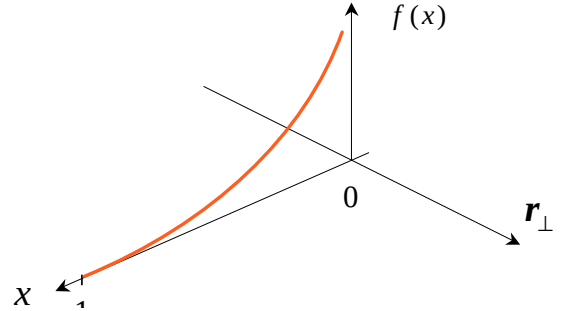
Elastic scattering





Deep inelastic scattering





Form factors

Nobel prize, 1961

Parton distributions

Nobel prize, 1969

Nobel prize, 1990

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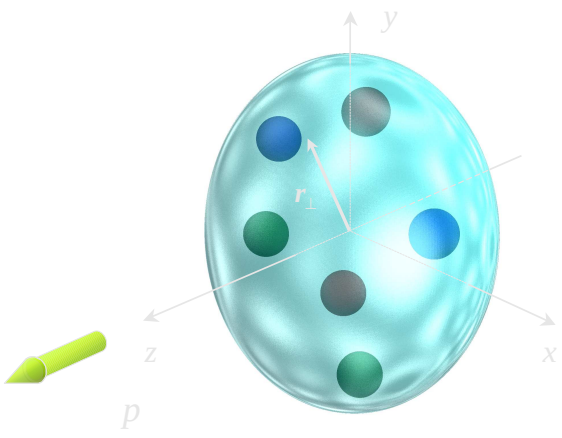
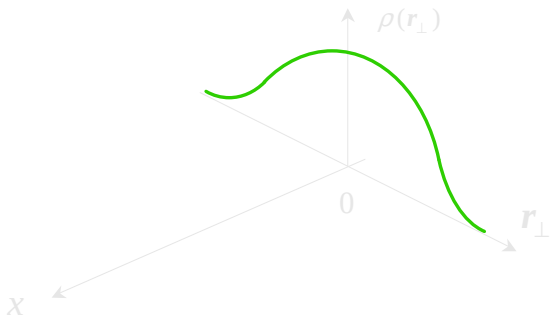
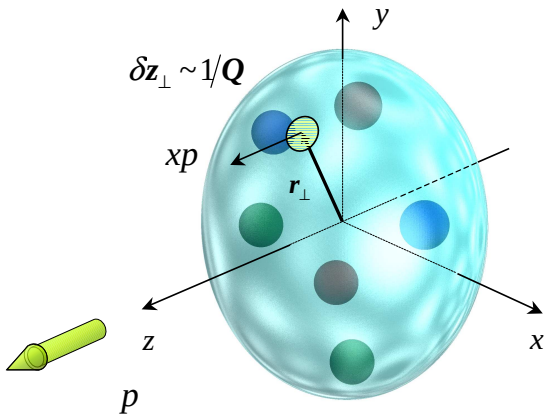


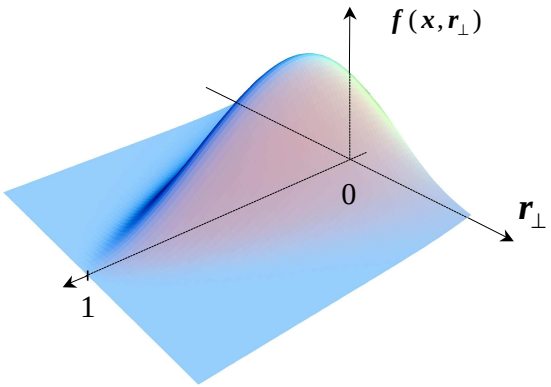


Form factors

Nobel prize, 1961

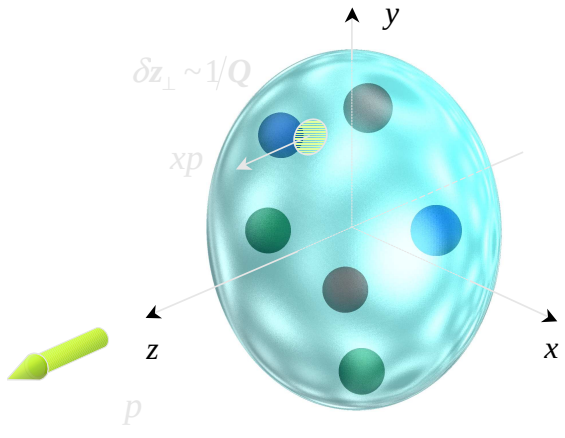
Hard exclusive processes

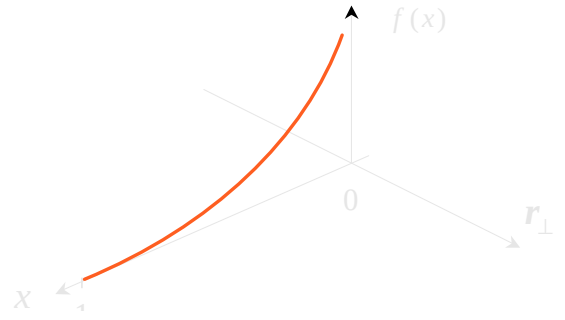




Generalized Parton Distributions (GPDs)

Deep inelastic scattering



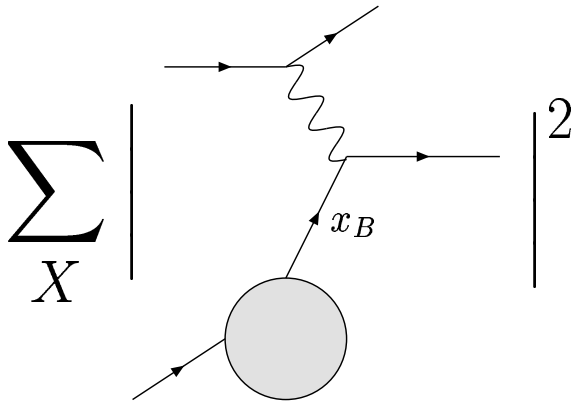


Parton distributions

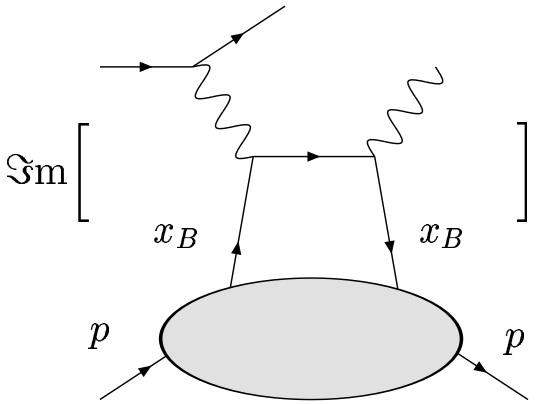
Nobel prize, 1969

Nobel prize, 1990

A step forward: from DIS to DVCS



Optical theorem

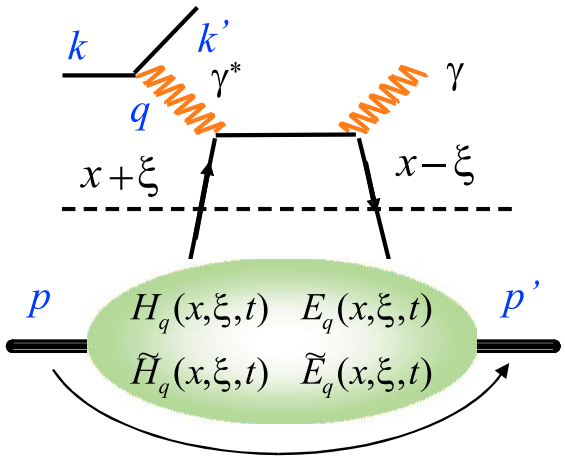


Handbag diagram

Forward Compton scattering

Deeply Virtual Compton Scattering (DVCS)

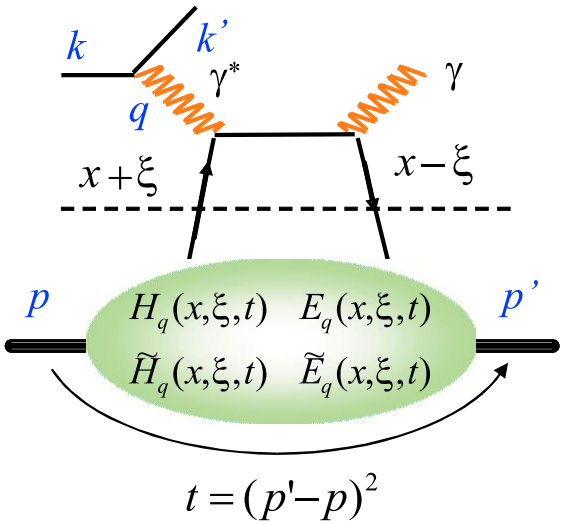
$$ep \to ep\gamma$$



$$t = (p'-p)^2$$

Off-forward Compton scattering

Generalized Parton Distributions



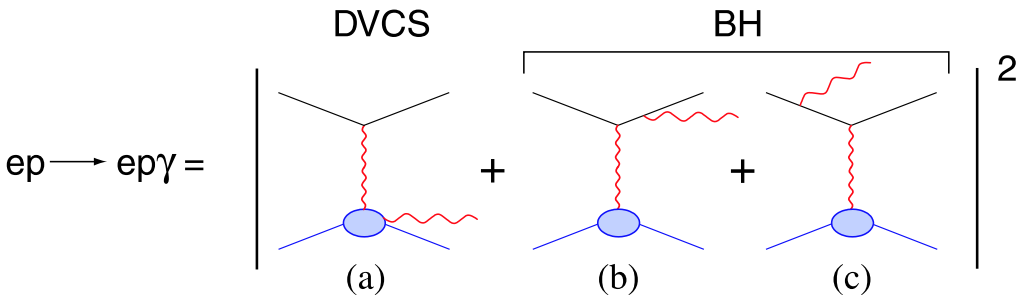
- Correlate between different partonic states
- Correlate momentum and position of partons
- Access to new fundamental properties of the nucleon

- Contribution of the **angular momentum of quarks** to proton spin:

$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma + L_z}_{J} + \Delta G \quad \Rightarrow \quad J = \frac{1}{2}\int_{-1}^{1} dx\, x[H(x,\xi,0)+E(x,\xi,0)]$$

DVCS cleanest process to access GPDs

DVCS experimentally: interference with Bethe-Heitler (BH)



At leading twist:

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

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

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

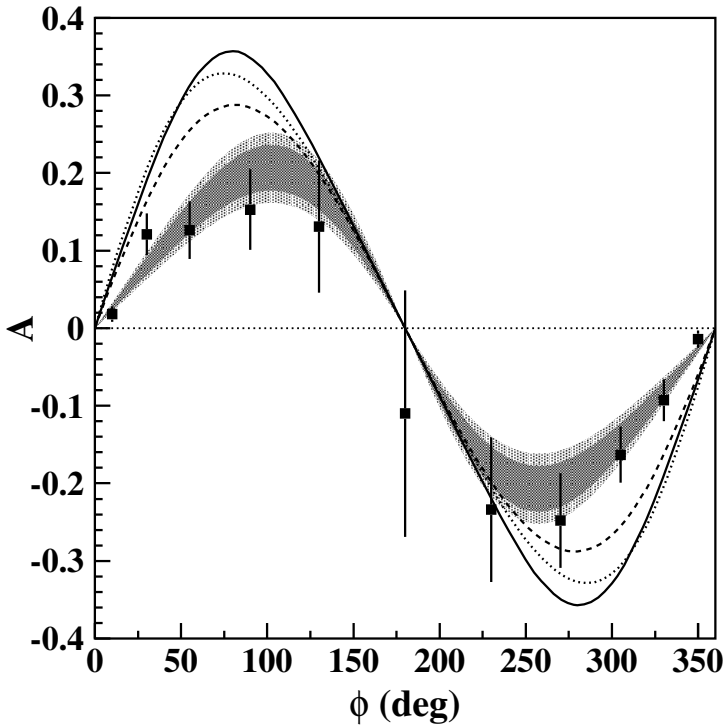
$$\underbrace{\mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}}_{\text{Access in helicity-independent cross section}} - \underbrace{i\pi\, H(x=\xi,\xi,t)}_{\text{Access in helicity-dependent cross-section}} + \ldots$$

The DVCS program at Jefferson Lab

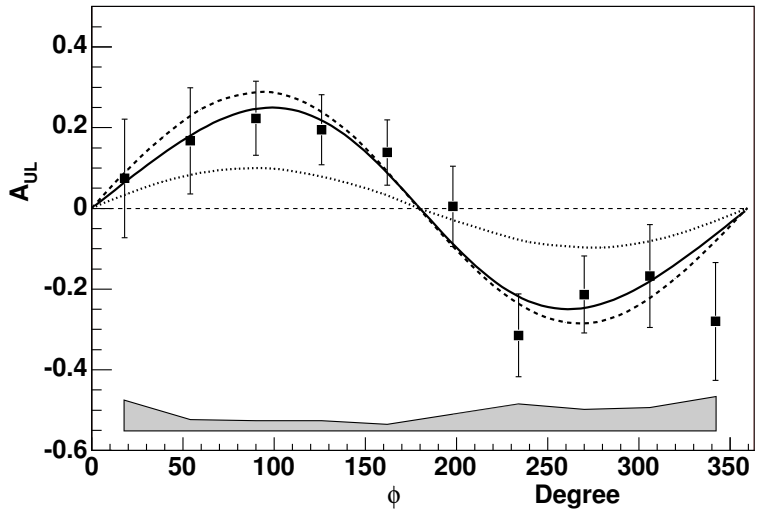
- Hall A and Hall B both have a strong DVCS program
- Partially overlapping, partially complementary:
  - Hall A: high accuracy, limited kinematics
  - Hall B: wide kinematic range, limited accuracy
  - Very different systematics
- Jefferson Lab will be the only facility with a strong emphasis on DVCS/GPDs in the future (COMPASS at CERN?)
- The roadmap:
  - Early results (≈ 2000) from non-dedicated experiments (Hall B)
  - 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)

Non-dedicated DVCS results (Hall B)

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

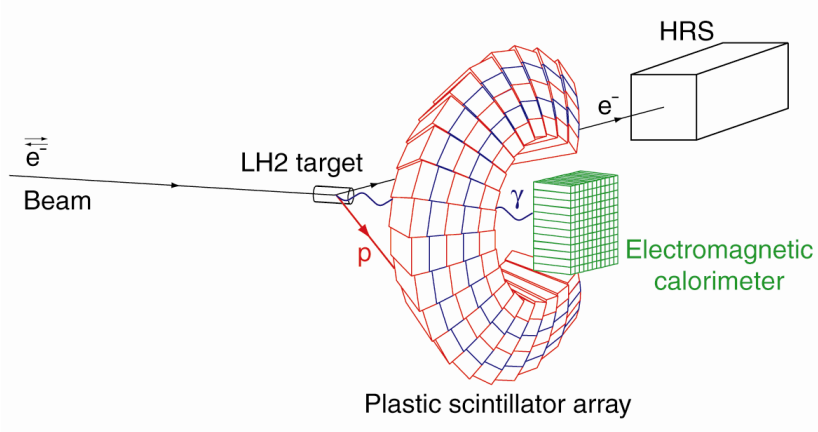


A_{UL}: PRL **97**, 072002 (2006)

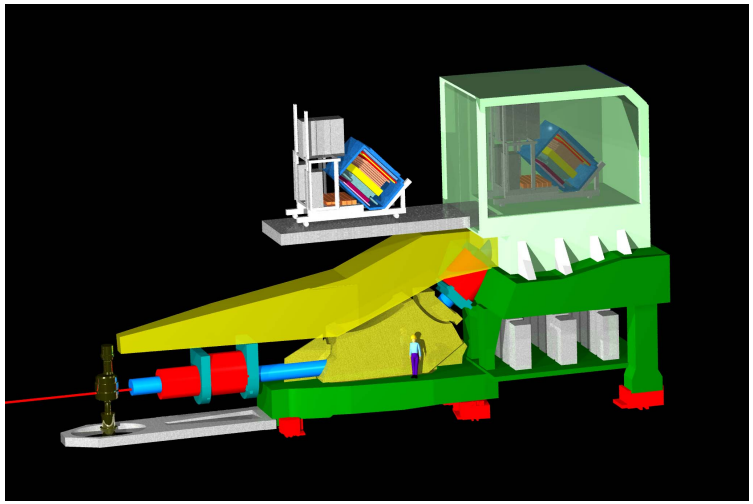


- Both results show, with a limited statistics, a $\sin\phi$ behaviour
- Not fully exclusive

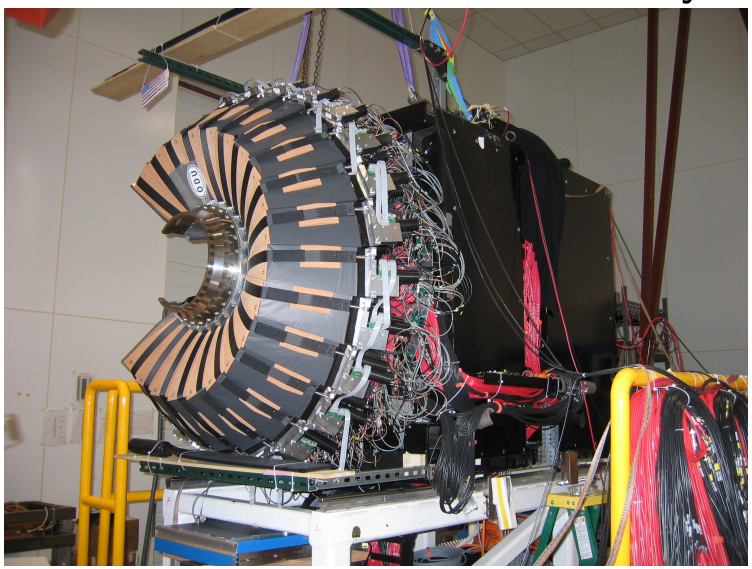
E00-110 experimental setup



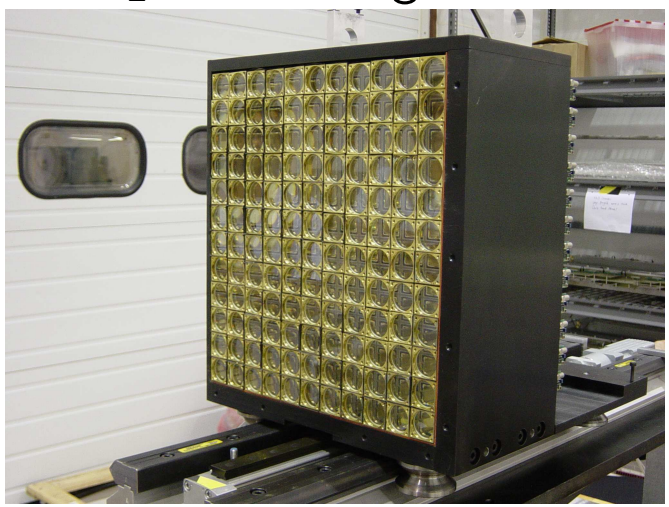
High Resolution Spectrometer



100-channel scintillator array



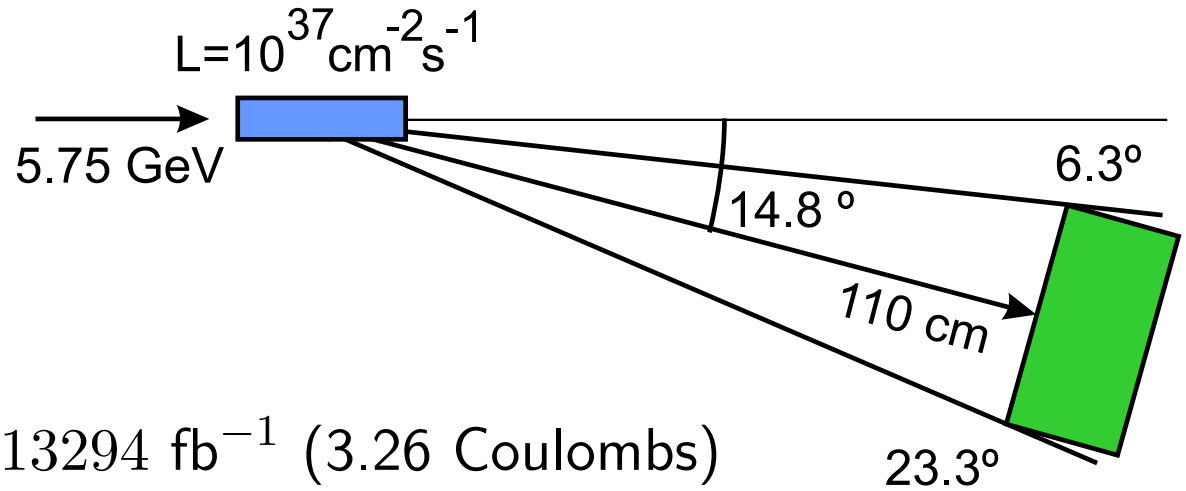
132-block PbF_2 electromagnetic calorimeter



E00-110 kinematic settings

Kin	Q^2 (GeV^2)	x_B	θ_e (deg.)	θ_{γ^*} (deg.)	P_e (GeV)
1	**1.5**	0.36	15.6	**22.3**	3.6
2	**1.9**	0.36	19.3	**18.3**	2.9
3	**2.3**	0.36	23.9	**14.8**	2.3

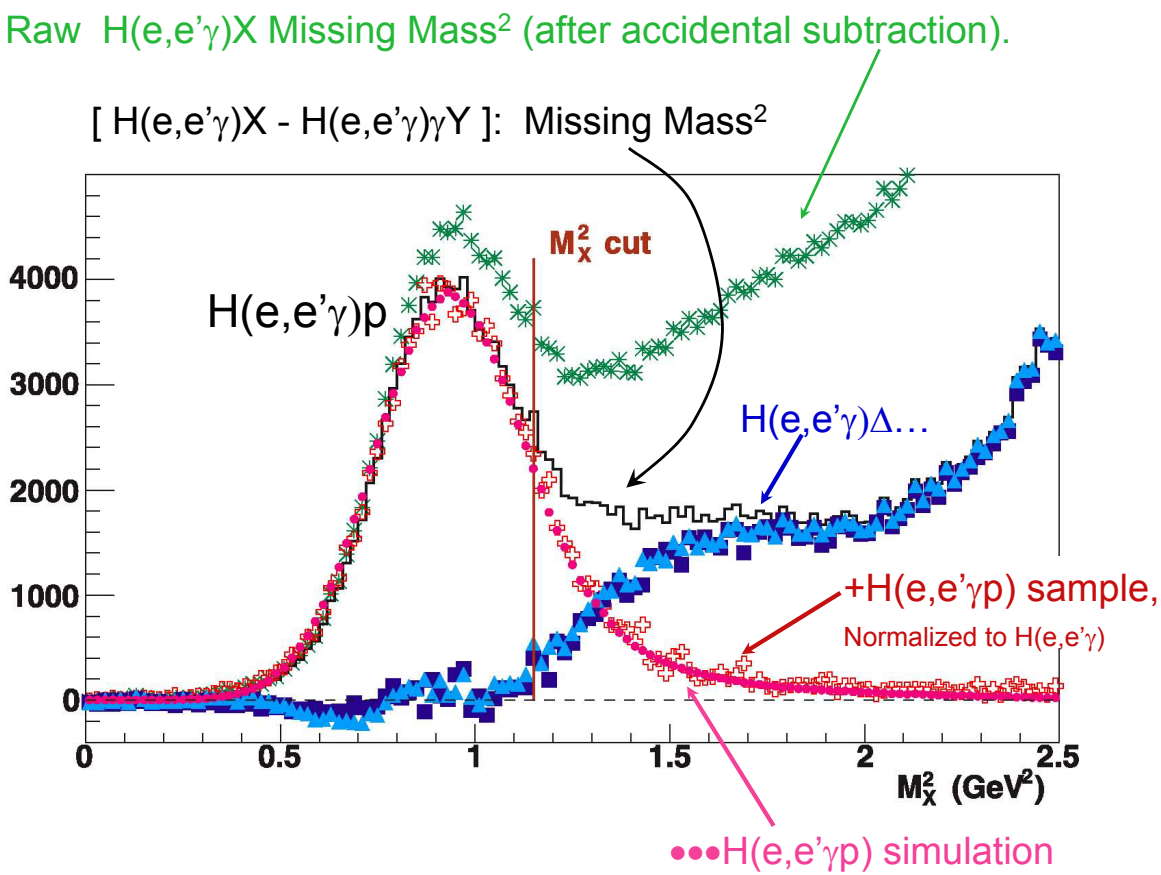
$\mathcal{P} = 75.3\%$



$\int \mathcal{L}\, dt = 13294$ fb^{-1} (3.26 Coulombs)

Exclusivity

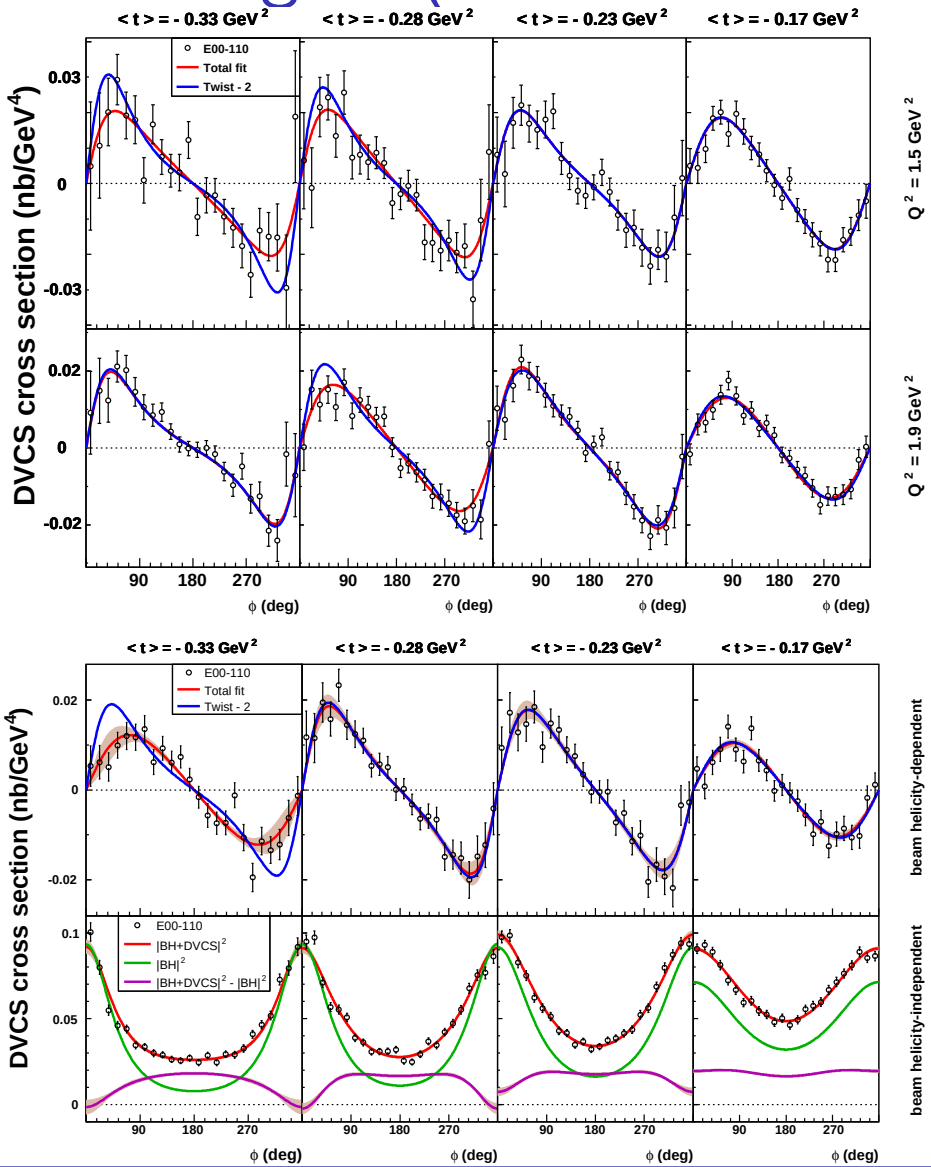
Missing mass squared $ep \rightarrow e\gamma X$ (E00-110)



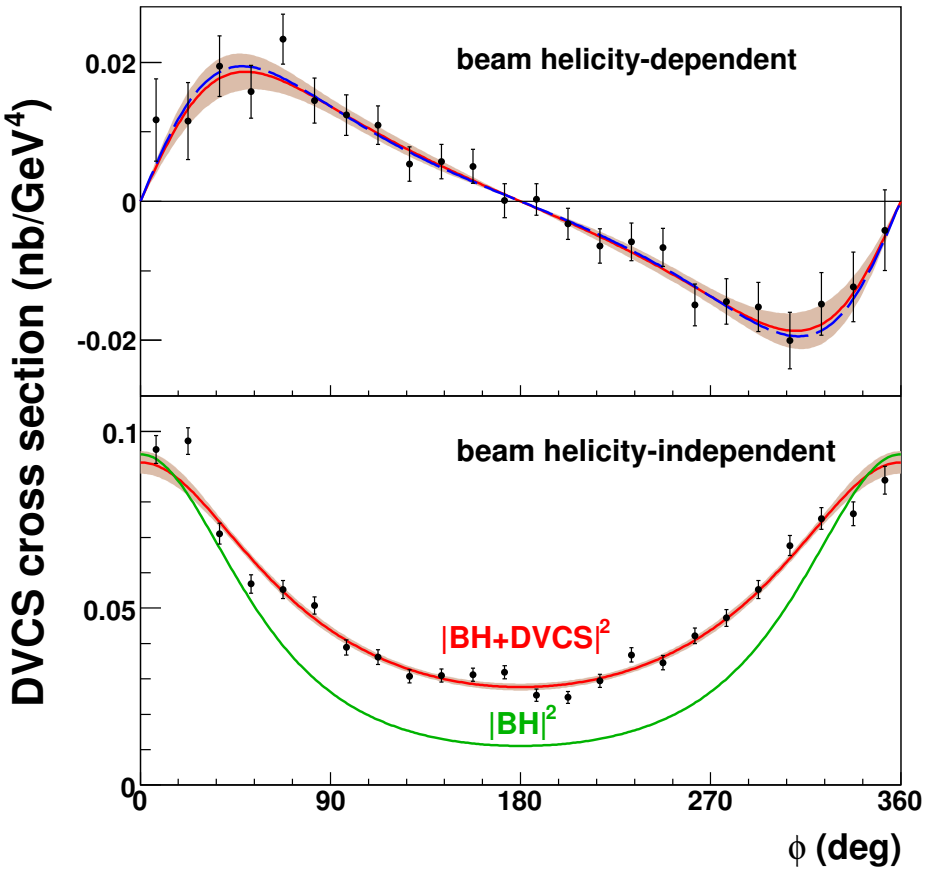
Exclusivity ensured by missing mass technique

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

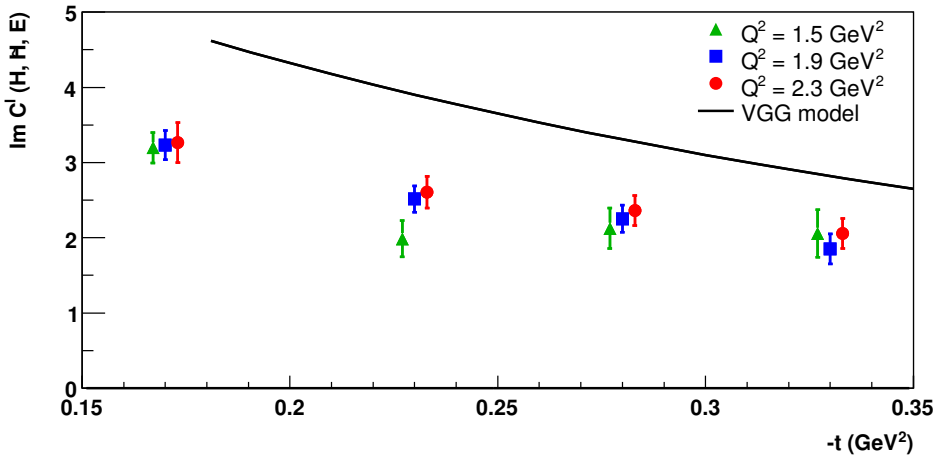
- **Helicity-dependent** cross section $(\overrightarrow{\sigma} - \overleftarrow{\sigma})$ at $Q^2 = 1.5$, 1.9 and 2.3 GeV^2.
- **Helicity-independent** cross section $(\overrightarrow{\sigma} + \overleftarrow{\sigma})$ at $Q^2 = 2.3$ GeV^2 *only*.



E00-110 results



Scaling en Q^2



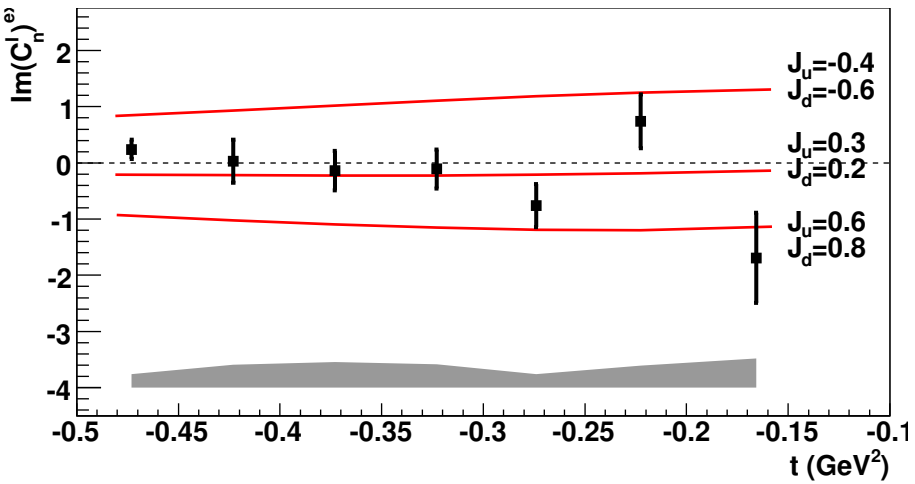
Twist-2: dominant contribution

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

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

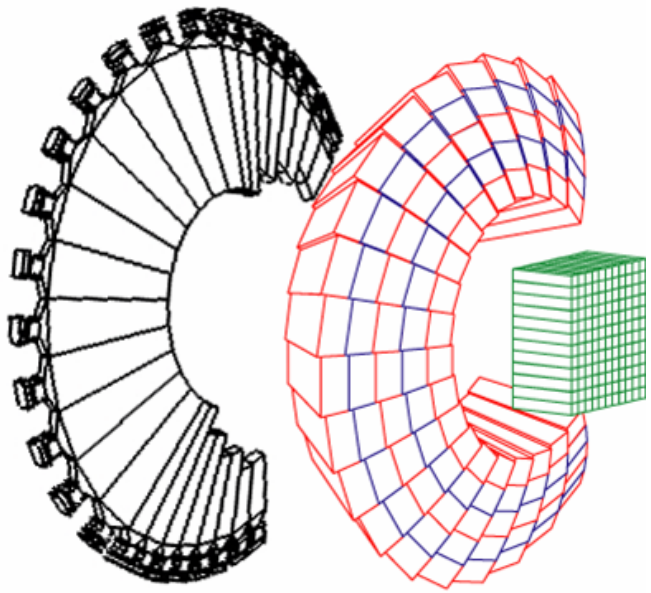
DVCS on the neutron: experiment E03-106 at JLab

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

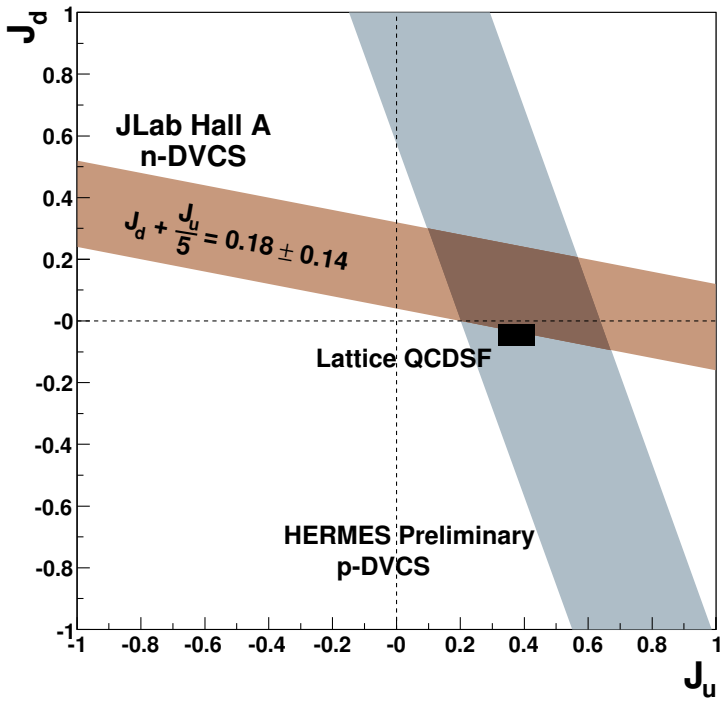


$$A = F_1(t)\mathcal{H} + \frac{x_B}{2 - x_B}[F_1(t) + F_2(t)]\tilde{\mathcal{H}} - \underbrace{\frac{t}{4M^2} \cdot F_2(t) \cdot \mathcal{E}}$$

Main contribution for neutron

DVCS on the neutron: experiment E03-106 at JLab

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



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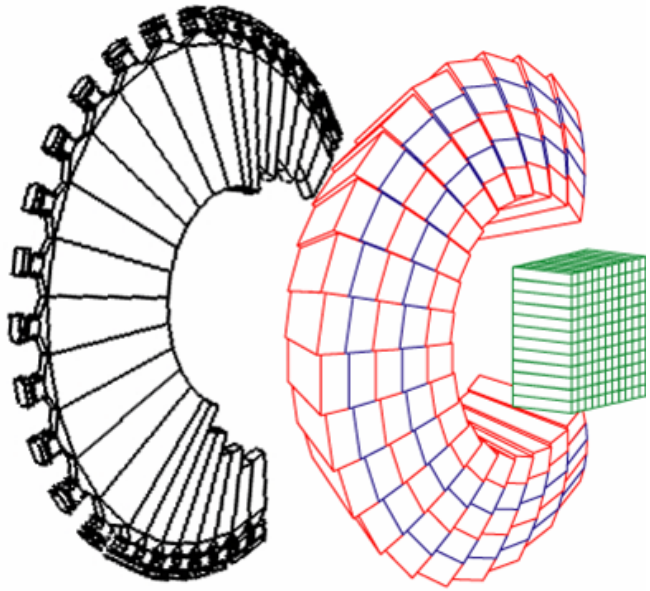

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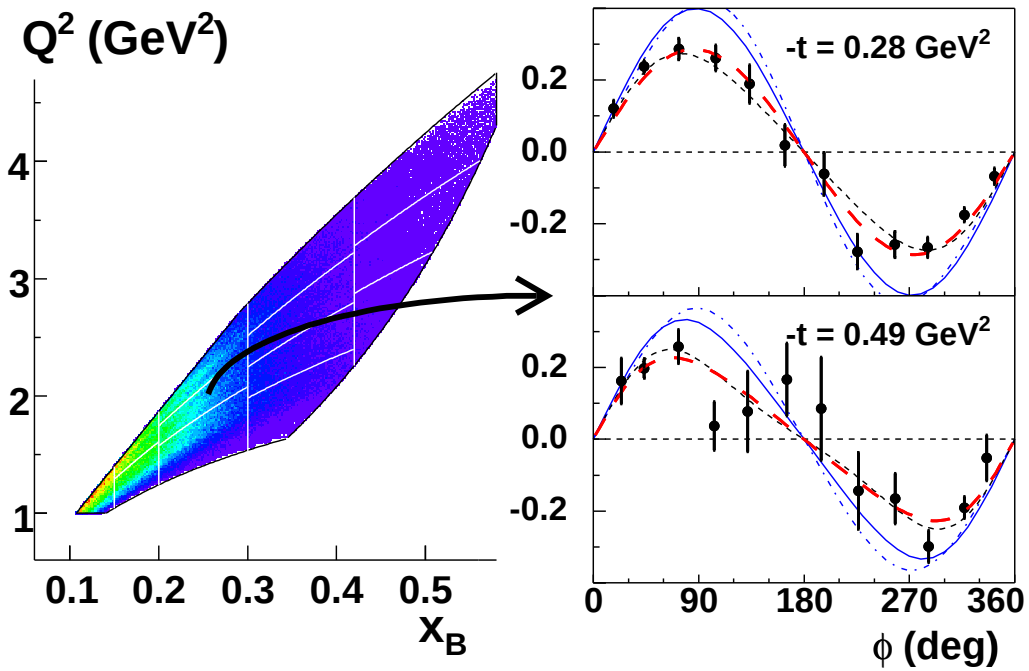
Main contribution for neutron

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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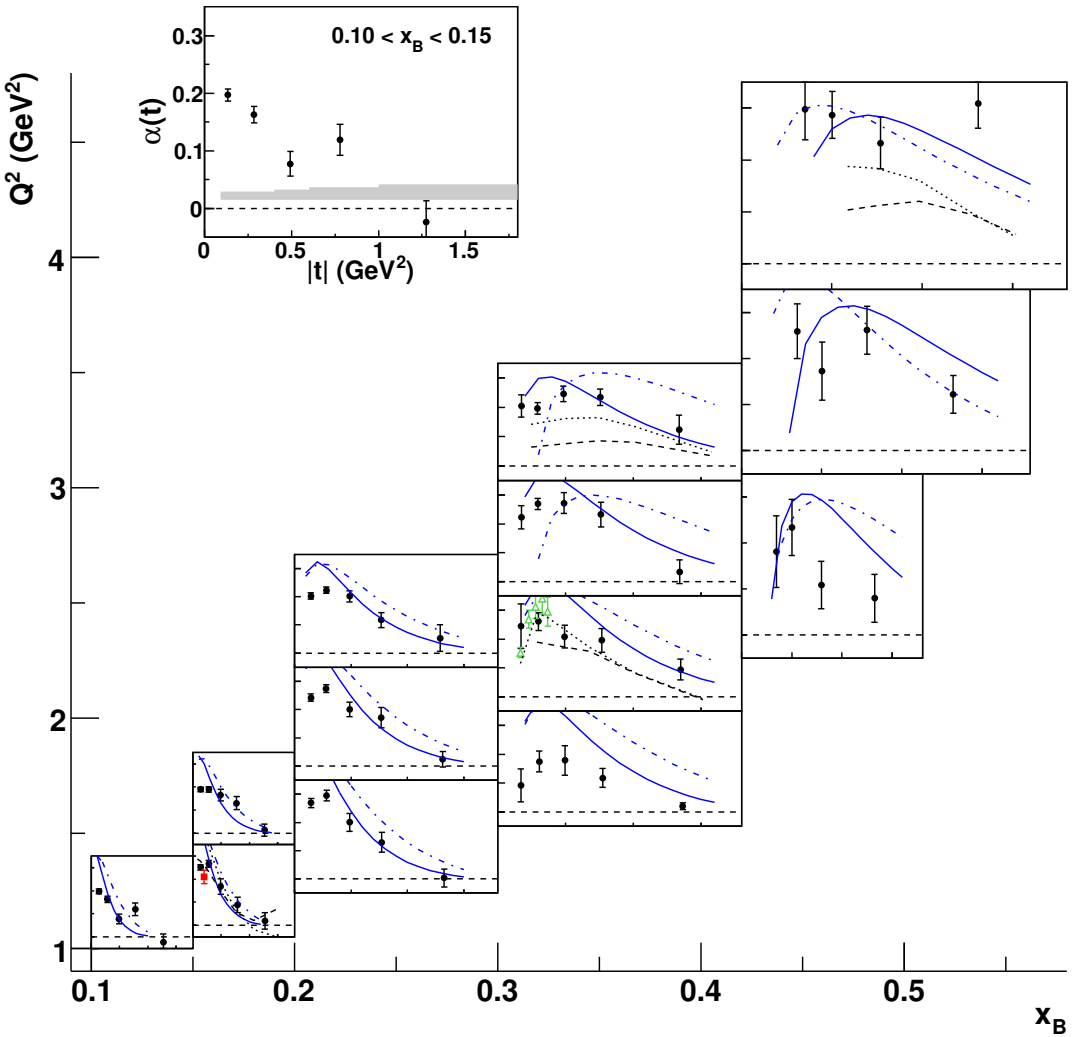
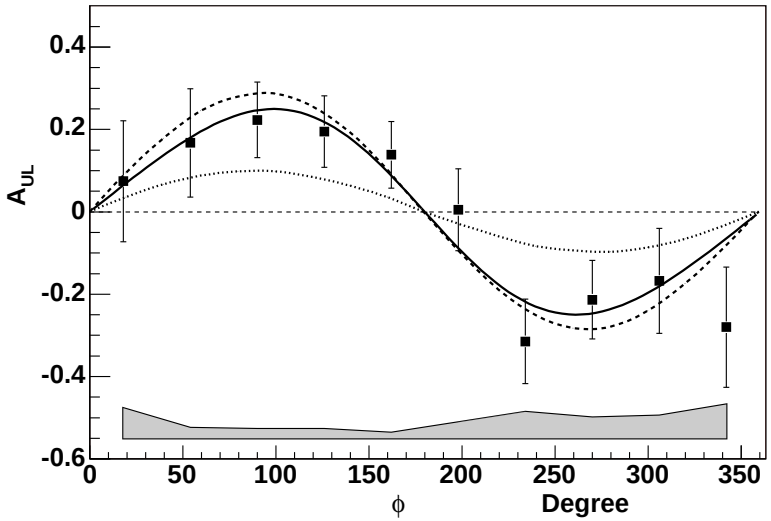


Analysis of cross sections underway

Target spin asymmetry A_{UL} (Hall B)

Not dedicated result:



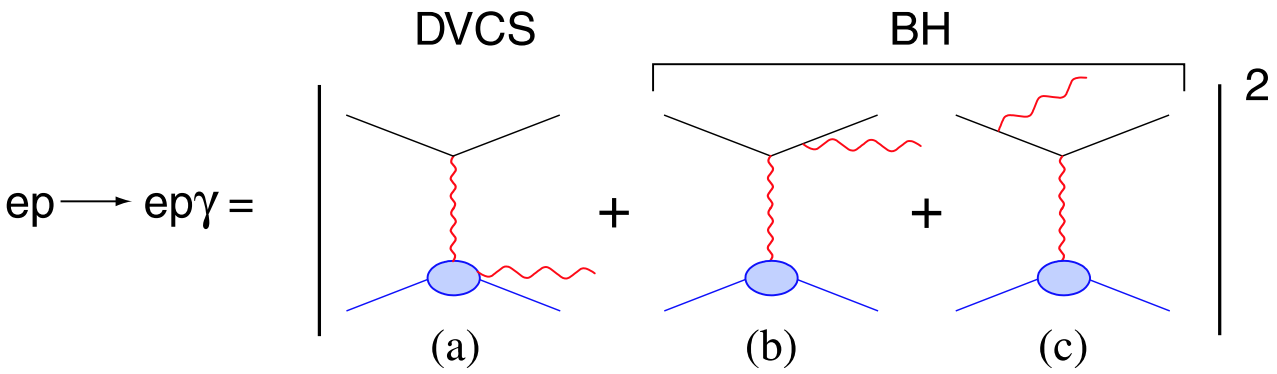
Dedicated experiment running in Hall B early next 2009

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)

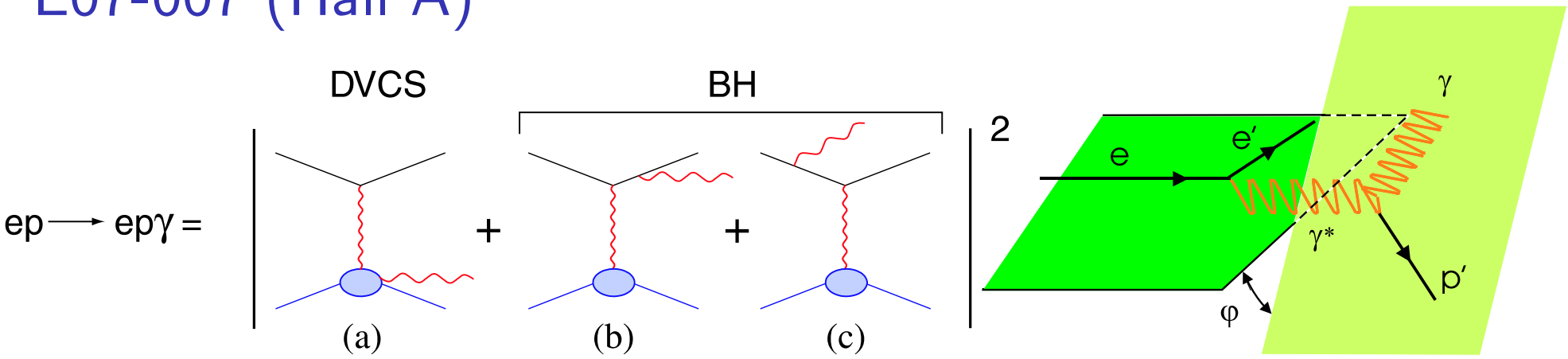


$$\sigma(ep \to ep\gamma) = \underbrace{|BH|^2}_{\text{Known to } \sim 1\%} + \underbrace{\mathcal{I}(BH \cdot DVCS)}_{\text{Linear combination of GPDs}} + \underbrace{|DVCS|^2}_{\text{Bilinear combination of GPDs}}$$

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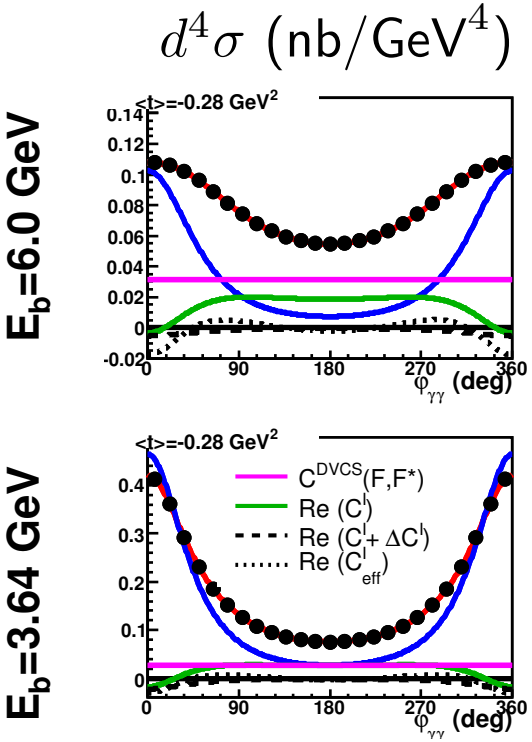
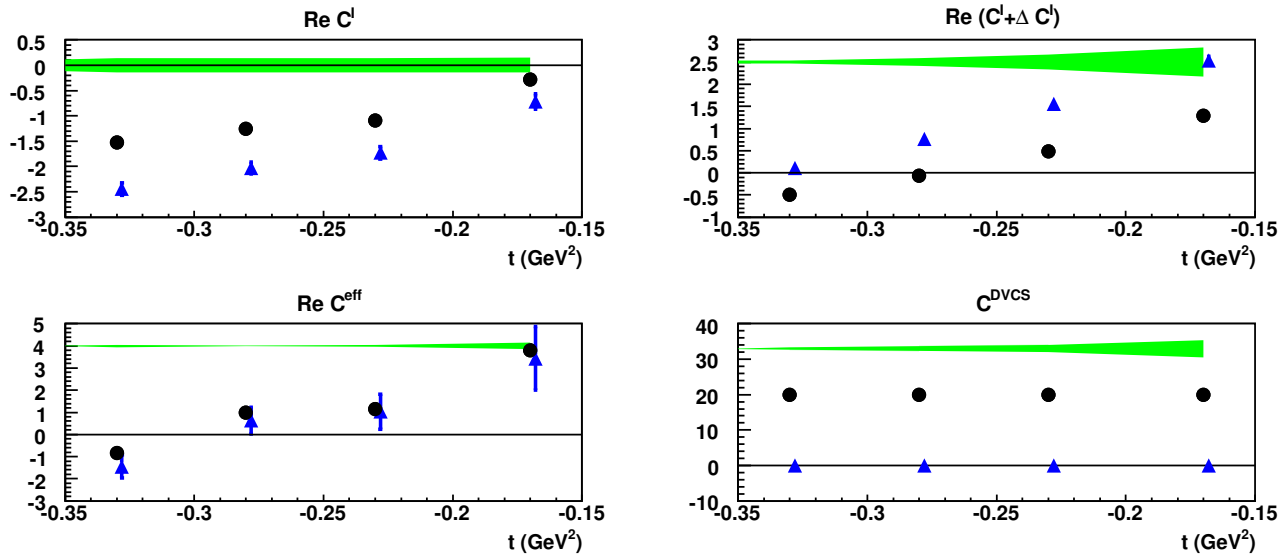
E07-007: Rosenbluth-like DVCS^2–$\mathcal{I}$ separation in Hall A

- 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 $ep \to ep\pi^0$

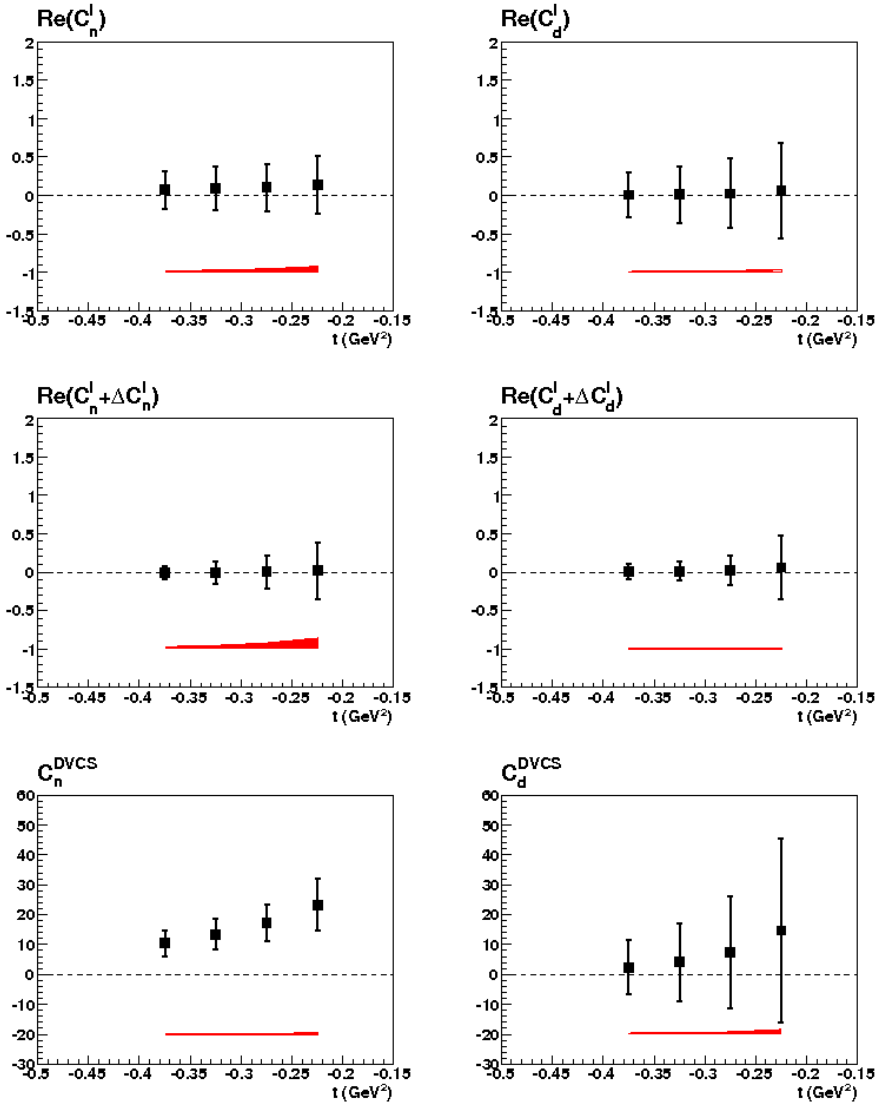




● E07-007 ▬ Systematic uncertainty

▲ E00-110: assuming DVCS^2=0

DVCS/π^0 Rosenbluth separation on the neutron/deuteron



E08-025 experiment:

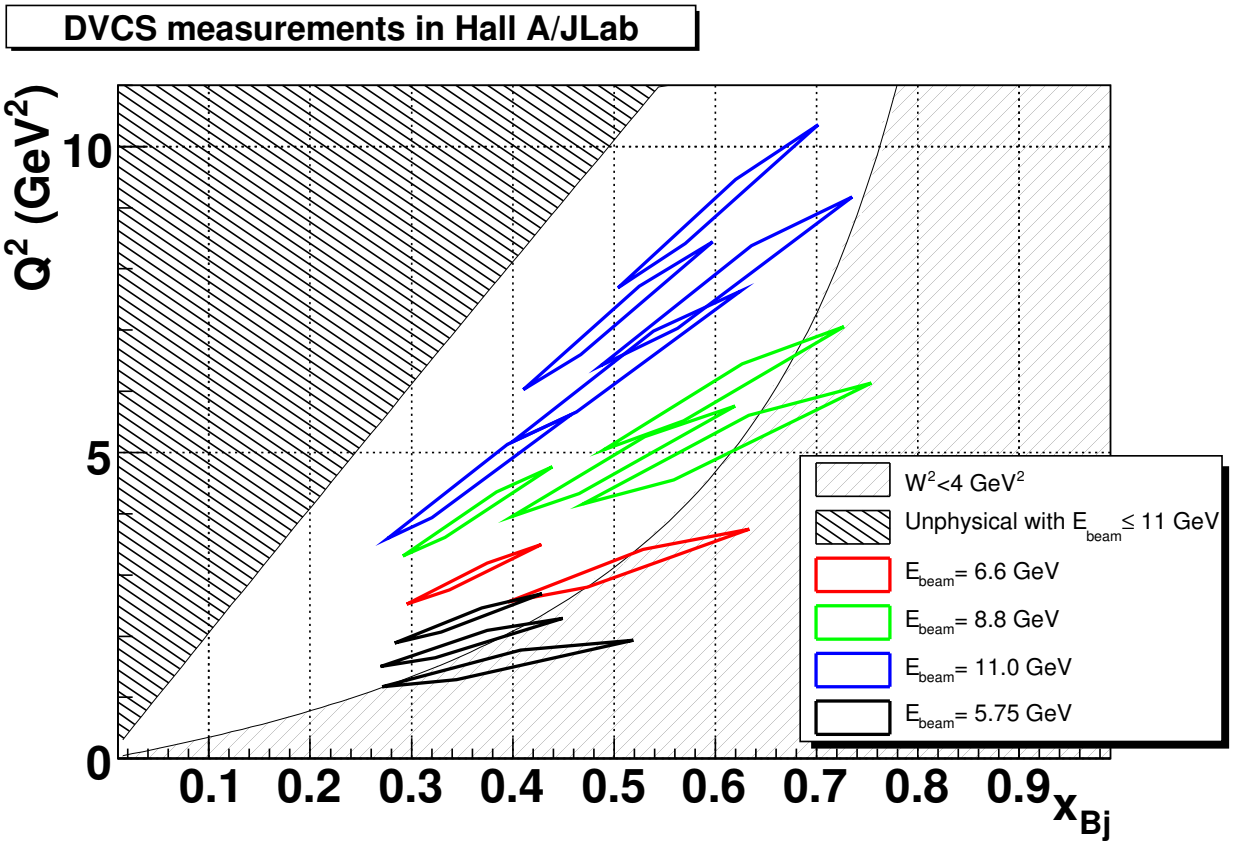
- Unpolarized cross section
- Rosenbluth separation

Recently approved to run simultaneously with E07-007

E12-06-114: JLab Hall A at 11 GeV

JLab12 with 3, 4, 5 pass beam

(6.6, 8.8, 11.0 GeV beam energy)



88 days

250k events/setting

1 year of operations in JLab/Hall A

Approved by JLab PAC-31 (2007) with A-rating

Future possibilities in Hall A

- **DVCS on the neutron at 12 GeV**
  - Extention to the full kinematic domain available with JLab at 12GeV
  - R+D underway for a high luminosity ^{3}He target
- **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

Summary and conclusions

1. DVCS BSA (Hall B/CLAS):
   - Data in a large kinematical domain to compare to models
2. DVCS cross section difference (Hall A):
   - Strong evidence of twist-2 dominance (experimental program on solid ground)
   - Upper limit to higher twist effect ($\lesssim 10\%$)
   - First model-independent extraction of a combination of GPDs
3. DVCS Unpolarized cross section (Hall A):
   - Significant contribution of *both* DVCS and BH$\Rightarrow$ New experiment approved to separate each individual contribution
4. New exciting possibilities available at 12 GeV!