

The current GPD program at JLab

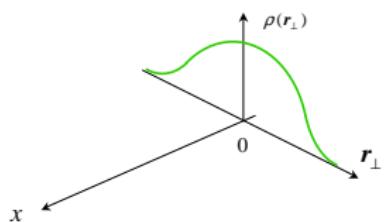
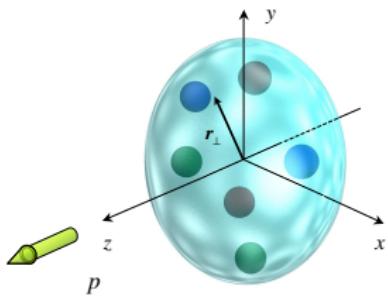
Carlos Muñoz Camacho

Los Alamos National Laboratory, Los Alamos, NM 87545

JLab Users Group Workshop and Annual Meeting
June 19, 2007

Studying the structure of the nucleon experimentally

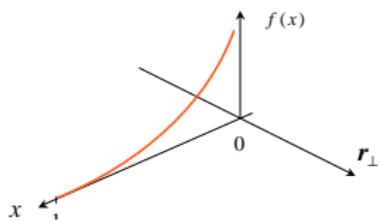
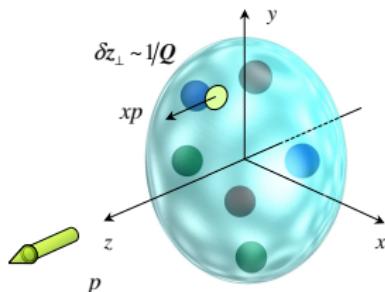
Elastic scattering



Form factors

Nobel prize, 1961

Deep inelastic scattering



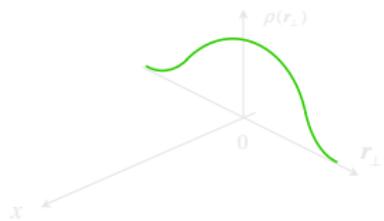
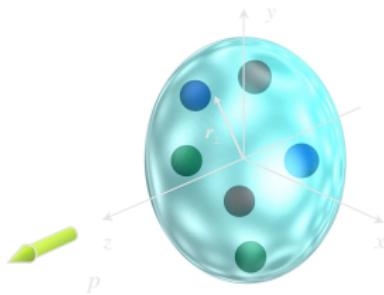
Parton distributions

Nobel prize, 1969

Nobel prize, 1990

Studying the structure of the nucleon experimentally

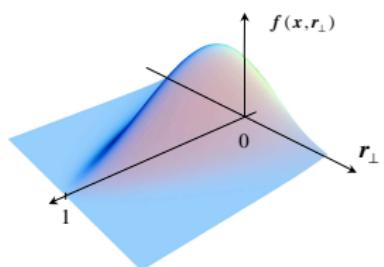
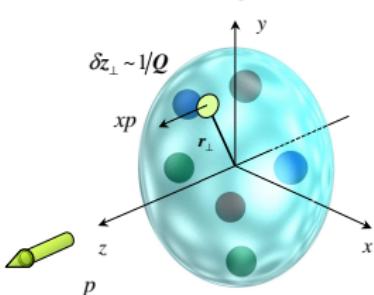
Elastic scattering



Form factors

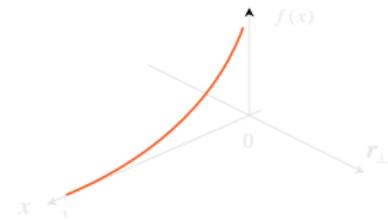
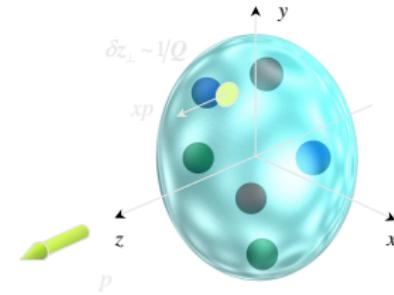
Nobel prize, 1961

Hard exclusive processes



**Generalized Parton
Distributions (GPDs)**

Deep inelastic scattering

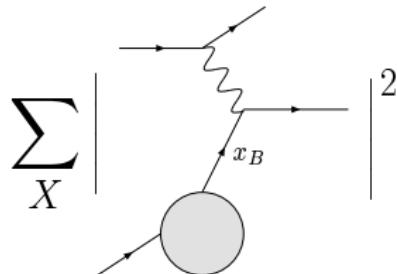


Parton distributions

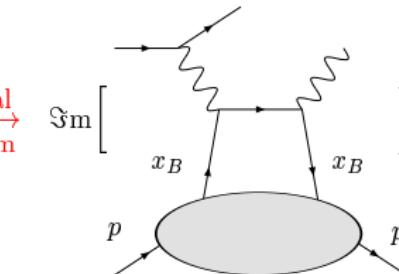
Nobel prize, 1969

Nobel prize, 1990

A step forward: from DIS to DVCS



Optical
theorem

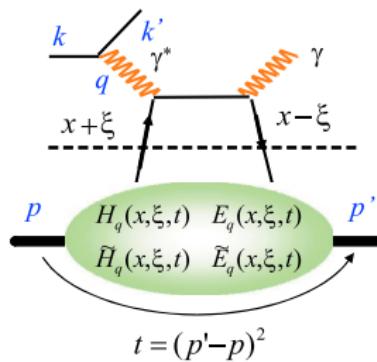


Handbag
diagram

Forward Compton scattering

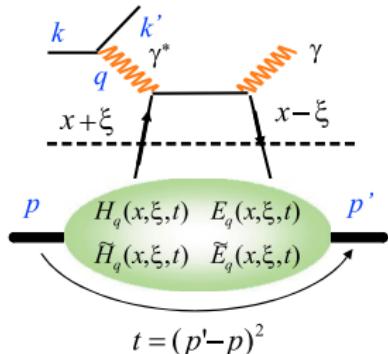
Deeply Virtual Compton Scattering (DVCS)

$$ep \rightarrow ep\gamma$$



Off-forward Compton scattering

Generalized Parton Distributions



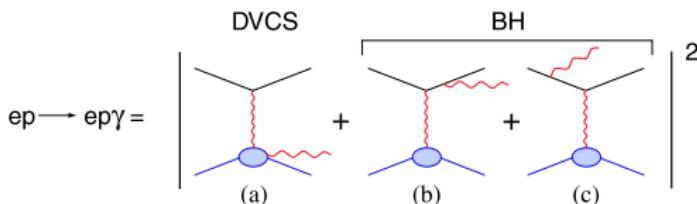
- ▶ Correlate between different partonic states
- ▶ Correlate momentum and position of partons
- ▶ Access to new fundamental properties of the nucleon

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

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

DVCS cleanest process to access GPDs

DVCS experimentally: interference with Bethe-Heitler (BH)



At leading twist:

$$d^5 \vec{\sigma} - d^5 \overleftrightarrow{\sigma} = \Im m (T^{BH} \cdot T^{DVCS})$$

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

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

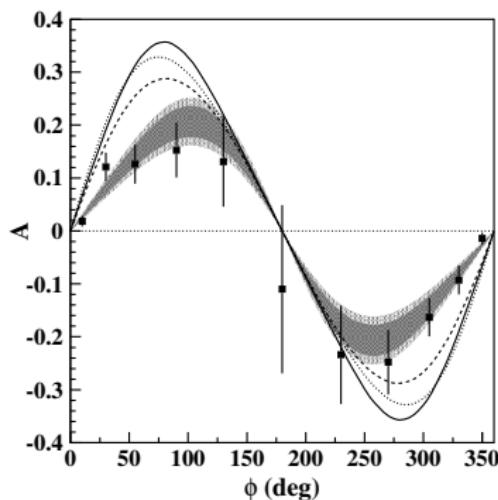
$$\underbrace{\mathcal{P} \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi}}_{\text{Access in helicity-independent cross section}} - \underbrace{i\pi H(x = \xi, \xi, t)}_{\text{Access in helicity-dependent cross-section}} + \dots$$

Access in **helicity-independent cross section**

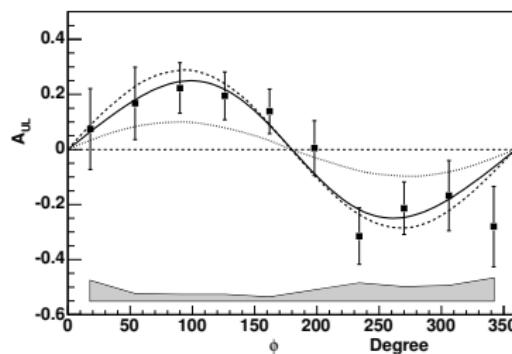
Access in **helicity-dependent cross-section**

Non-dedicated DVCS results (Hall B)

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

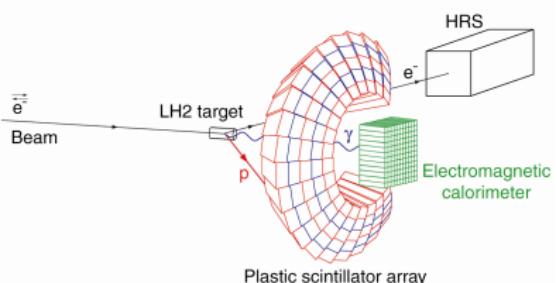


A_{UL} : PRL **97**, 072002 (2006)

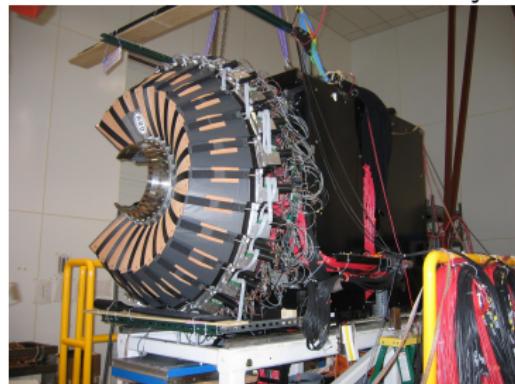


- ▶ Both results show, with a limited statistics, a $\sin \phi$ behaviour
- ▶ Not fully exclusive

E00-110 experimental setup



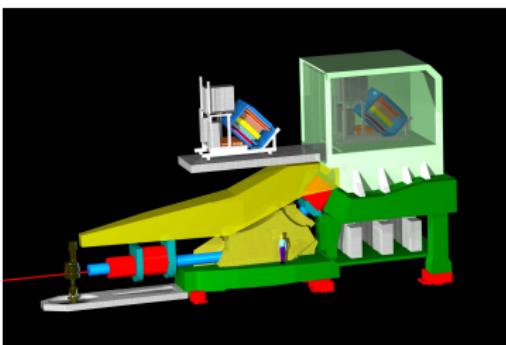
100-channel scintillator array



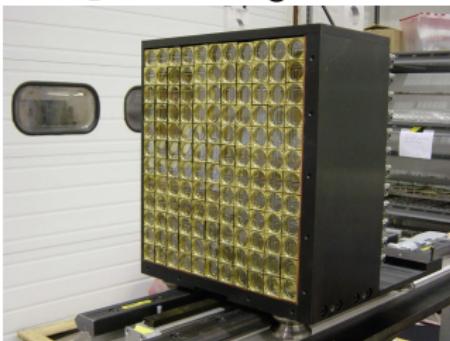
Carlos Muñoz Camacho

The current GPD program at JLab

High Resolution Spectrometer



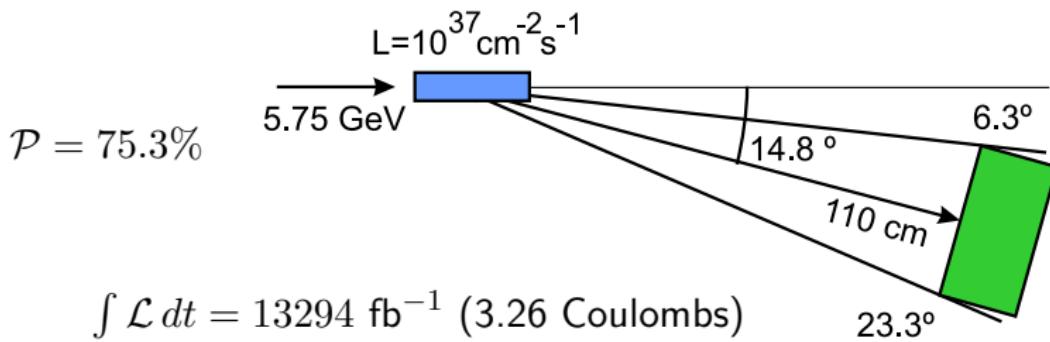
132-block PbF_2 electromagnetic calorimeter



Los Alamos National Laboratory

E00-110 kinematic settings

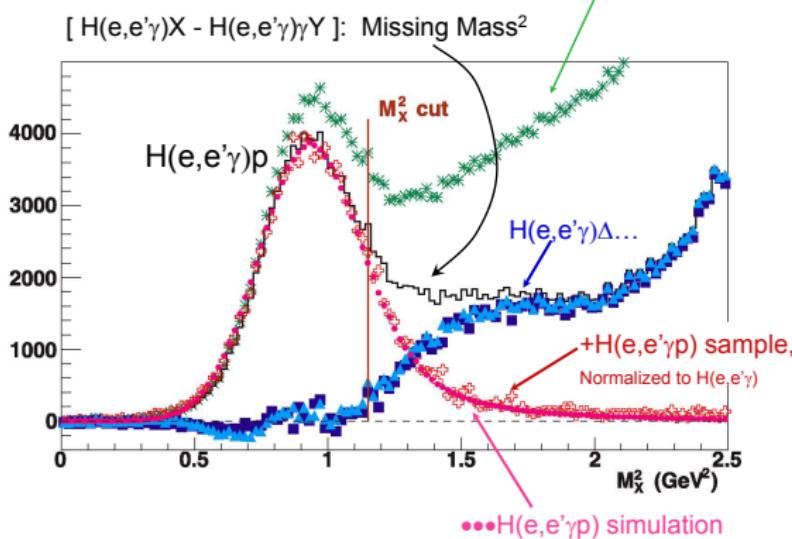
Kin	Q^2 (GeV 2)	x_B	θ_e (deg.)	θ_{γ^*} (deg.)	P_e (GeV)
1	1.5	0.36	15.6	22.3	3.6
2	1.9	0.36	19.3	18.3	2.9
3	2.3	0.36	23.9	14.8	2.3



Exclusivity

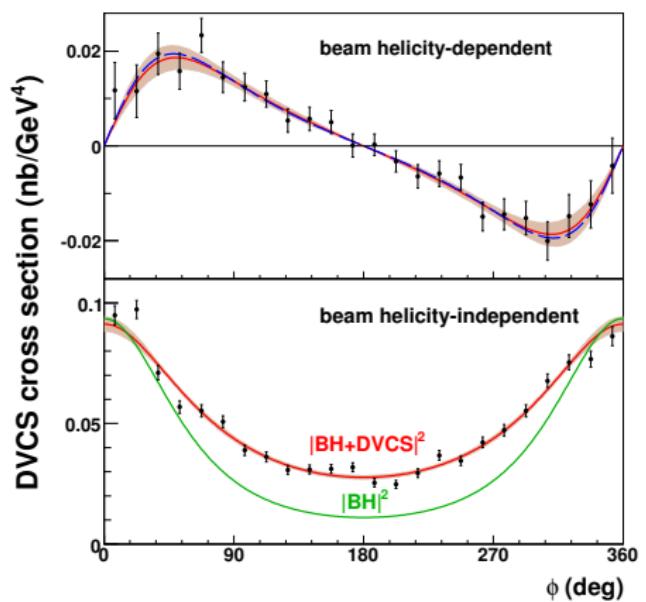
Missing mass squared $ep \rightarrow e\gamma X$ (E00-110)

Raw $H(e,e'\gamma)X$ Missing Mass² (after accidental subtraction).

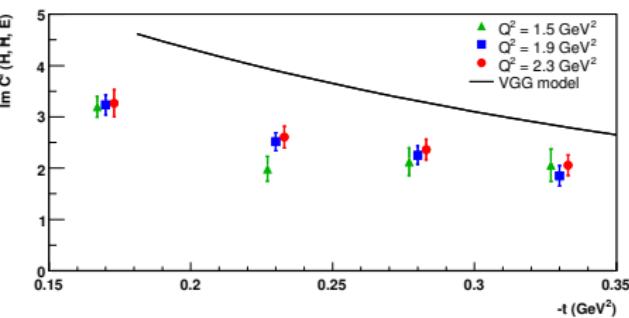


Exclusivity ensured by missing mass technique

E00-110 results



Scaling en Q^2

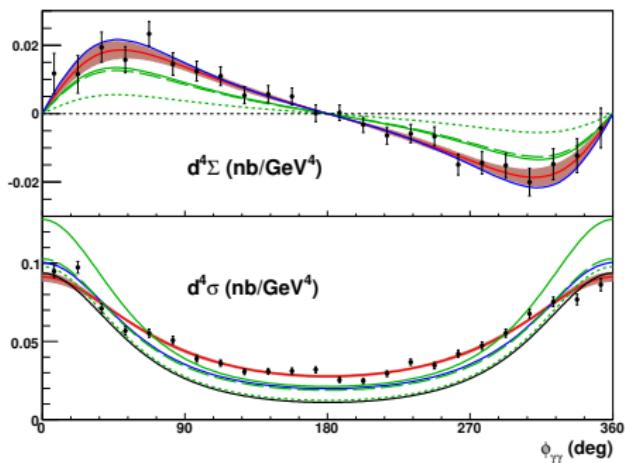
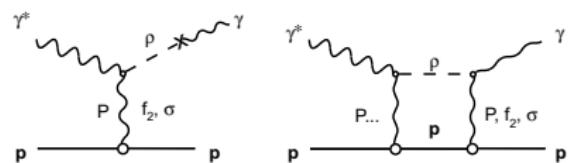


Twist-2: dominant contribution

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

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

Regge model (J.-M. Laget)



- E00-110
- Fit
- BH
- VGG (GPD-based)
- ... Laget: Regge poles + coupling to p-nucleon
- - - Laget: + coupling to all intermediate states
- Laget: + real part included

π^0 electroproduction ($ep \rightarrow ep\pi^0$)

At leading twist:

$$\frac{d\sigma_L}{dt} = \frac{1}{2}\Gamma \sum_{h_N, h_{N'}} |\mathcal{M}^L(\lambda_M = 0, h'_N, h_N)|^2 \propto \frac{1}{Q^6} \quad \sigma_T \propto \frac{1}{Q^8}$$

$$\mathcal{M}^L \propto \left[\int_0^1 dz \frac{\phi_\pi(z)}{z} \right] \int_{-1}^1 dx \left[\frac{1}{x - \xi} + \frac{1}{x + \xi} \right] \times \left\{ \Gamma_1 \tilde{H}_{\pi^0} + \Gamma_2 \tilde{E}_{\pi^0} \right\}$$

Different quark weights: flavor separation of GPDs

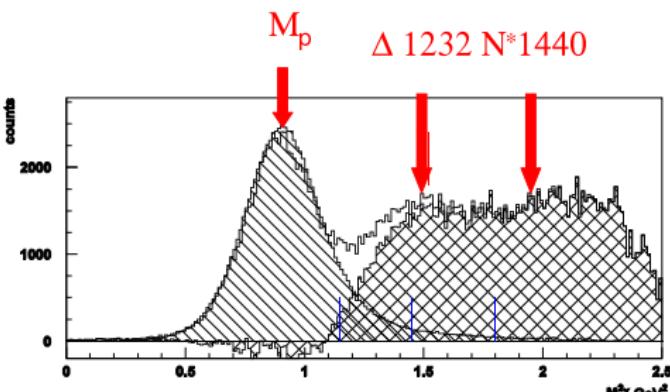
$$|\pi^0\rangle = \frac{1}{\sqrt{2}}\{|u\bar{u}\rangle - |d\bar{d}\rangle\} \quad \tilde{H}_{\pi^0} = \frac{1}{\sqrt{2}}\left\{ \frac{2}{3}\tilde{H}^u + \frac{1}{3}\tilde{H}^d \right\}$$

$$|p\rangle = |uud\rangle \quad H_{DVCS} = \frac{4}{9}H^u + \frac{1}{9}H^d$$

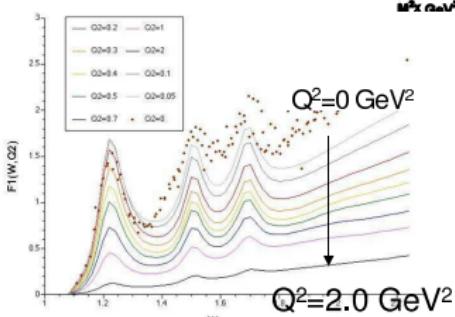
E00-110: π^0 electroproduction cross section (preliminary)

$$Q^2 = 2.3 \text{ GeV}^2, x_B = 0.36$$

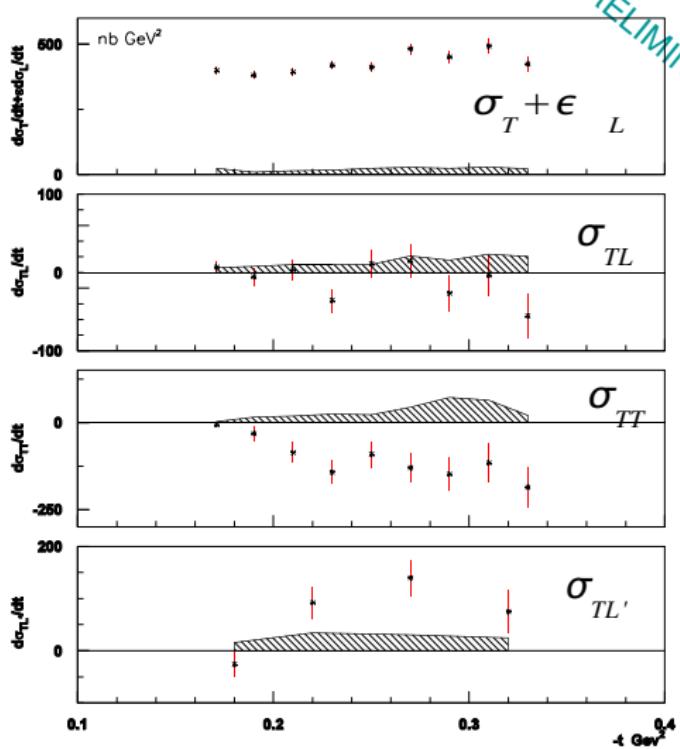
- ▶ The continuum is significant compared to the $p(e, e', \pi^0)p$
- ▶ Resonances are **washed out** into the continuum



- ▶ As seen in DIS...



E00-110: π^0 electroproduction cross section (preliminary)



PRELIMINARY

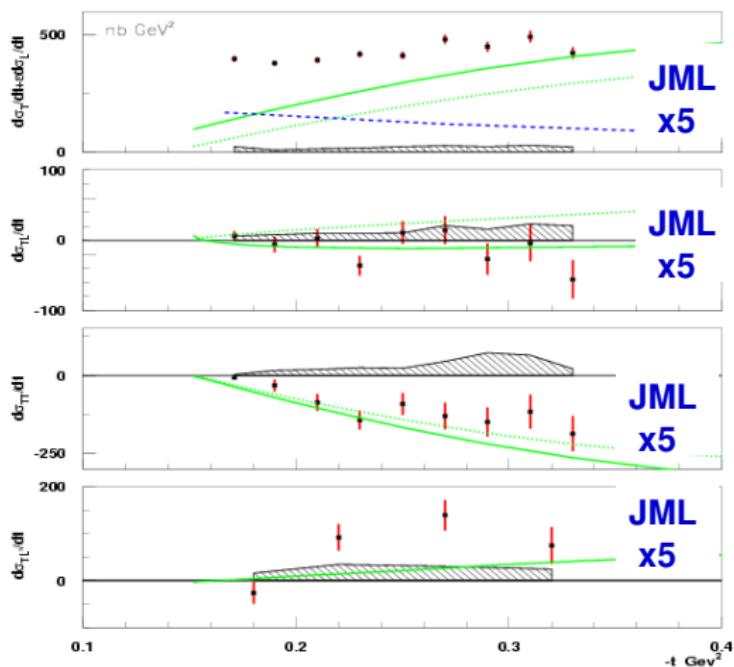
$$\frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt} +$$

$$\sqrt{2\epsilon(1+\epsilon)} \frac{d\sigma_{LT}}{dt} \cos \phi +$$

$$\epsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi +$$

$$\hbar \sqrt{2\epsilon(1-\epsilon)} \frac{d\sigma_{LT'}}{dt} \sin \phi$$

E00-110: π^0 electroproduction cross section (preliminary)



$$\frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt} +$$

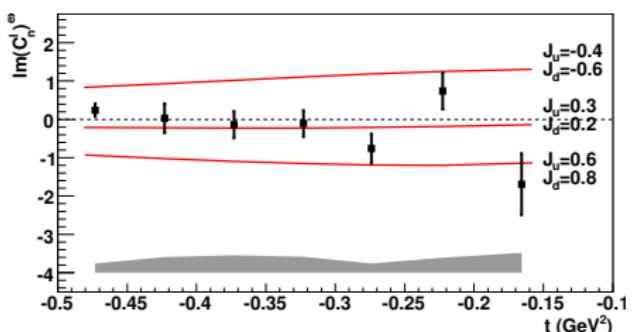
$$\sqrt{2\epsilon(1+\epsilon)} \frac{d\sigma_{LT}}{dt} \cos \phi +$$

$$\epsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi +$$

$$h \sqrt{2\epsilon(1-\epsilon)} \frac{d\sigma_{LT'}}{dt} \sin \phi$$

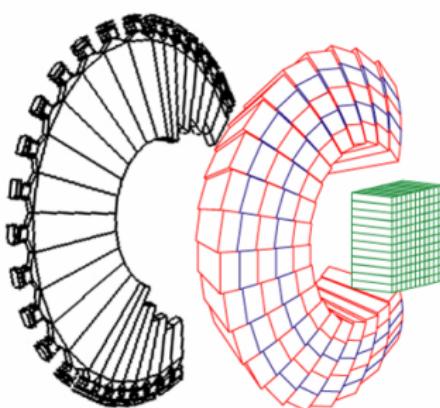
DVCS on the neutron: experiment E03-106 at JLab

LD₂ 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

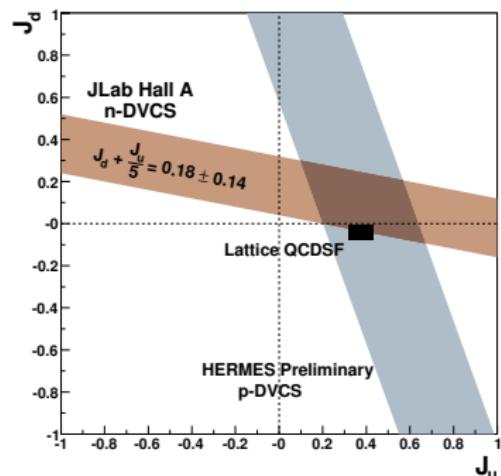


$$A = F_1(t)\mathcal{H} + \frac{x_B}{2-x_B}[F_1(t) + F_2(t)]\tilde{\mathcal{H}} - \underbrace{\frac{t}{4M^2} \cdot F_2(t) \cdot \mathcal{E}}_{\text{Main contribution for neutron}}$$

Main contribution for neutron

DVCS on the neutron: experiment E03-106 at JLab

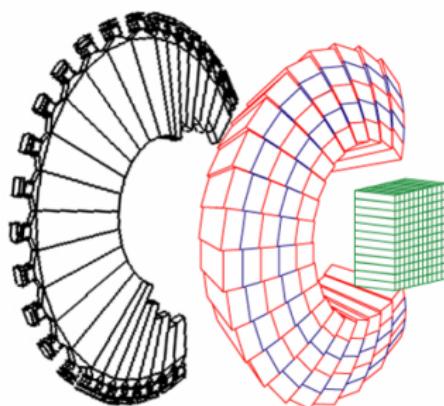
LD₂ target ($F_2^n(t) \gg F_1^n(t)$!)



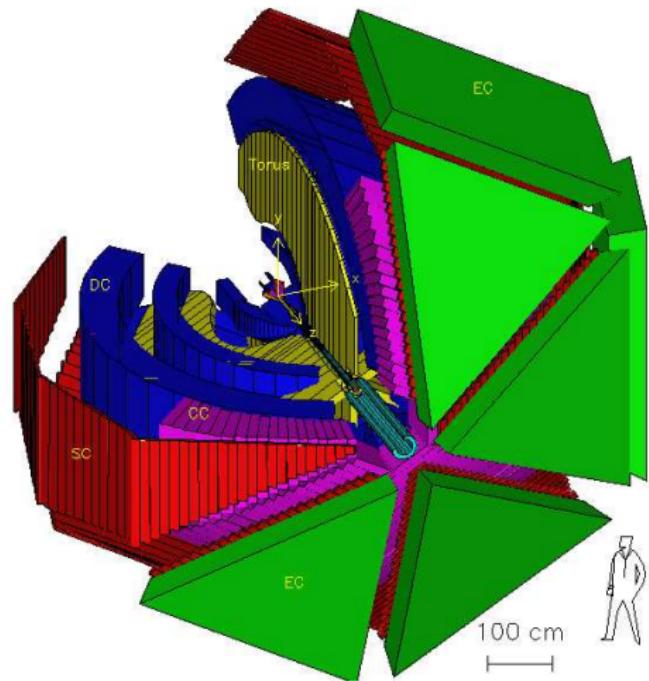
$$\sigma^{\rightarrow} - \sigma^{\leftarrow} = \Gamma(A \sin \varphi + \dots)$$

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

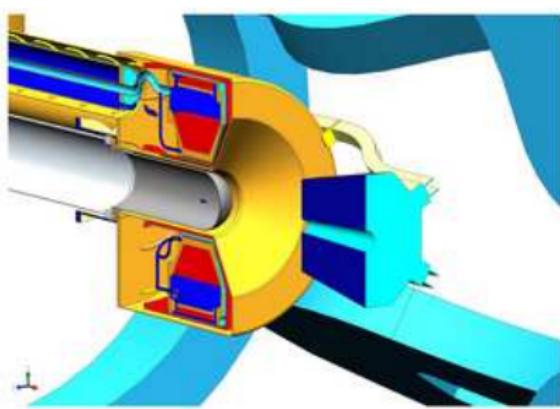
Charged particle veto
in front of scintillator array



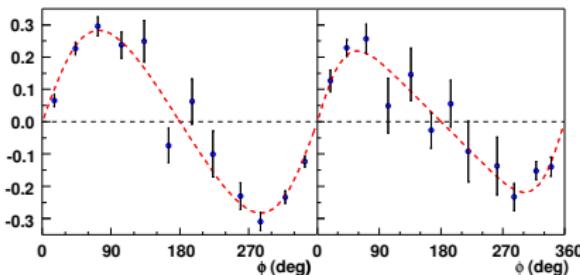
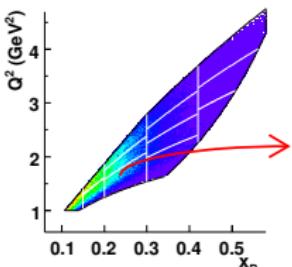
Hall B E1-DVCS



- ▶ Inner calorimeter + Møller shielding solenoid
- ▶ Integrated luminosity 45 fb^{-1}
- ▶ Ran in early 2005

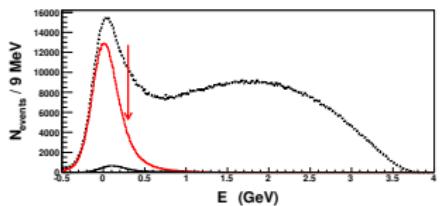
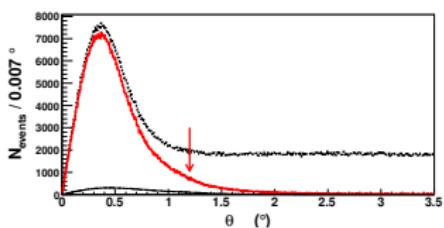


Hall B E1-DVCS preliminary results



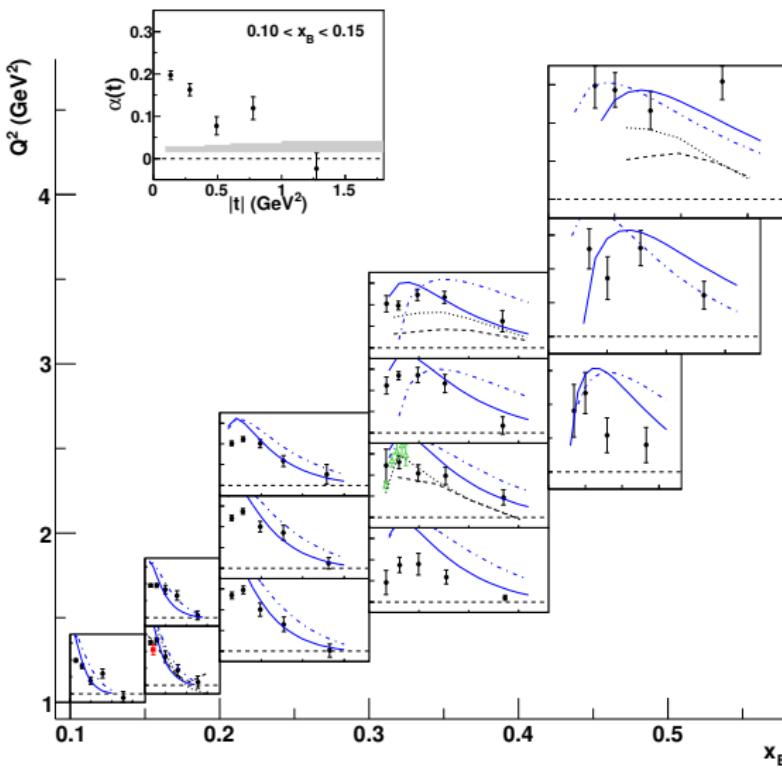
$$\langle Q^2 \rangle = 1.95 \text{ GeV}^2 \quad \langle x_B \rangle = 0.249,$$

$$\langle -t \rangle = 0.28, 0.49 \text{ GeV}^2$$



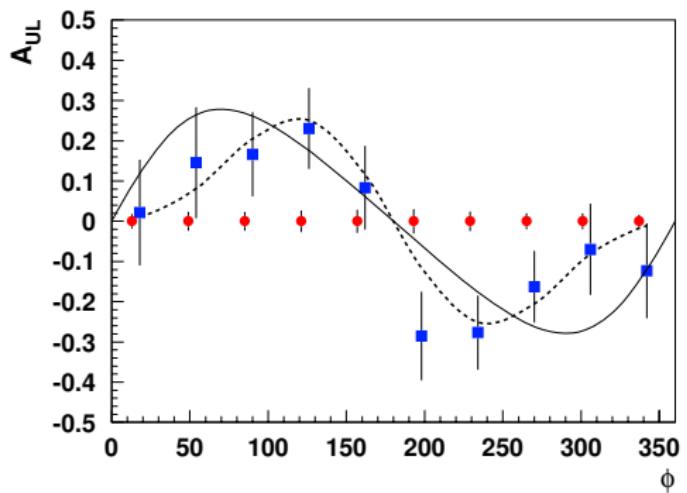
- ▶ Large kinematic coverage
- ▶ Full exclusivity
- ▶ Cross-section analysis underway
- ▶ 1/2 of the data taken:
next half soon

Kinematical dependence of A_{LU} at $\phi = 90^\circ$ (preliminary)



E05-114: Hall B A_{UL} E05-114: Hall B A_{UL}

$$A_{UL} = \frac{\Delta\sigma}{2\sigma} \quad \Delta\sigma \propto \text{Im} \left\{ F_1 \tilde{\mathcal{H}} + \xi(F_1 + F_2)(\mathcal{H} + \frac{x_B}{2}\mathcal{E}) \right\} \sin \phi$$

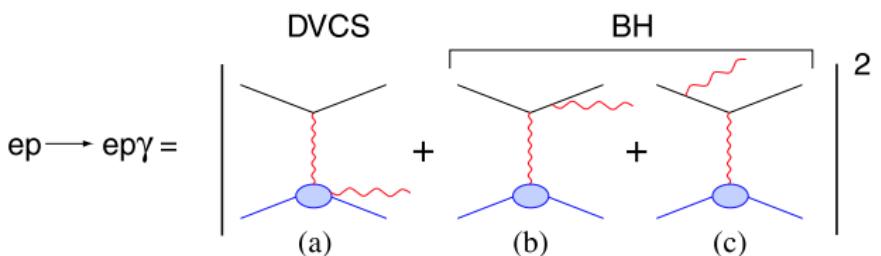


- ▶ EG1 preliminary
- ▶ E05-114 proposal

Integrated over x_B , Q^2 and t

E07-007: DVCS-BH – DVCS² separation

E07-007 (Hall A)

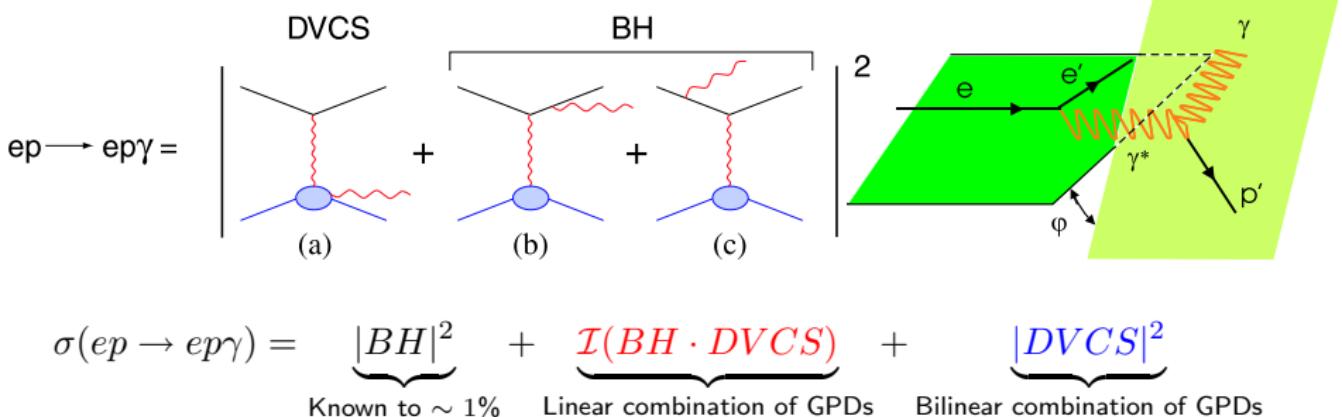


$$\sigma(ep \rightarrow ep\gamma) = \underbrace{|BH|^2}_{\text{Known to } \sim 1\%} + \underbrace{\mathcal{I}(BH \cdot DVCS)}_{\text{Linear combination of GPDs}} + \underbrace{|DVCS|^2}_{\text{Bilinear combination of GPDs}}$$

DVCS cross section has a very rich azimuthal structure:

- ▶ Azimuthal analysis allows the separation of the different contributions to \mathcal{I} if DVCS² is negligible.
- ▶ If DVCS² is important, \mathcal{I} and DVCS² terms **MIX** in an azimuthal analysis.
- ▶ The **different energy dependence** of \mathcal{I} and DVCS² allow a full separation.

E07-007 (Hall A)

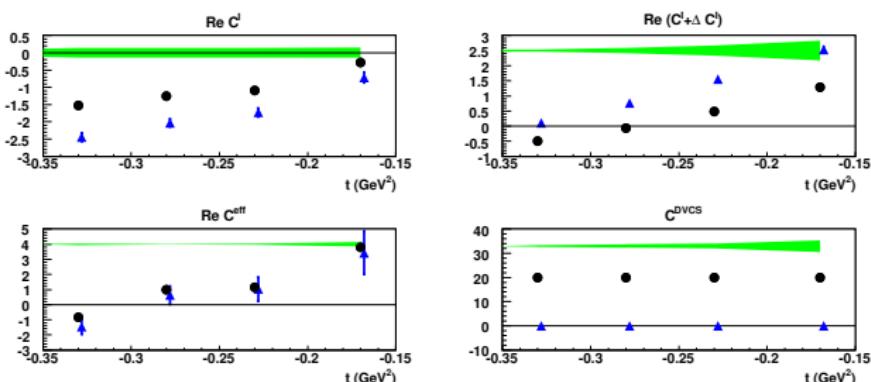
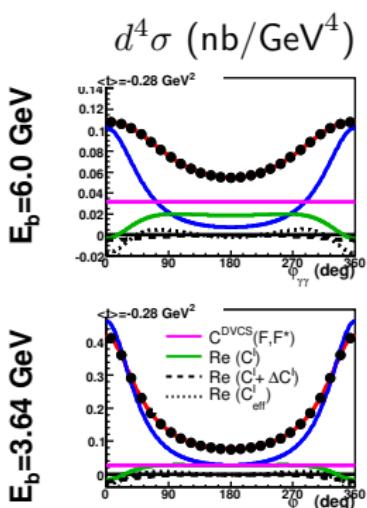


DVCS cross section has a very rich azimuthal structure:

- ▶ Azimuthal analysis allows the separation of the different contributions to \mathcal{I} if $DVCS^2$ is negligible.
- ▶ 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: Rosenbluth-like DVCS²- \mathcal{I} separation in Hall A

- ▶ Clean separation of BH-DVCS interference term from pure DVCS²
- ▶ Scaling test on the real part of the DVCS amplitude
- ▶ Rosenbluth separation of σ_L/σ_T for $ep \rightarrow ep\pi^0$



- E07-007 ■ Systematic uncertainty
- ▲ E00-110: assuming DVCS²=0

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 ⇒
New experiment approved to separate each individual contribution

4. First (preliminary) data on π^0 electroproduction (Hall A):

L/T separation needed ⇒ New experiment approved!

5. *New exciting possibilities available at 12 GeV!*

(M. Garçon's talk next)