Beam Charge Asymmetries for Deeply Virtual Compton Scattering on the proton at CLAS12

PR12+23-002 @ CLAS

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and the **CLAS Collaboration** and the **Jefferson Lab Positron Working Group**

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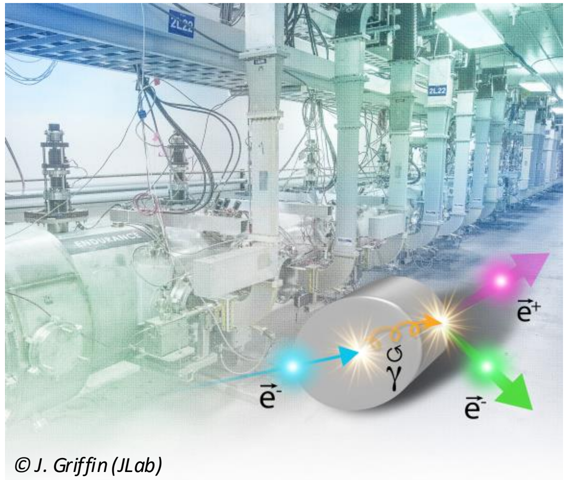
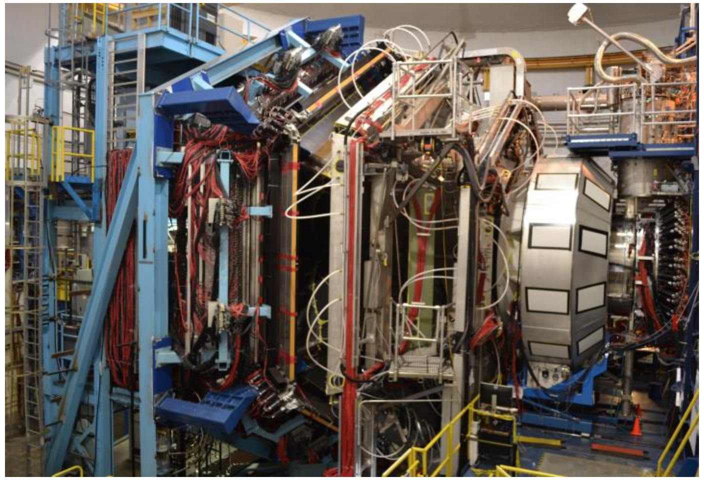




(i) Physics motivations
(ii) Proposed measurements
(iii) Activity in progress
(iv) Pending item
(v) Connected activity
(vi) Summary

Gravitational Form Factors

V.D. Burkert, L. Elouadrhiri, F.-X. Girod, C. Lorcé, P.E. Shanahan RMP 95 (2023) 041002

- The **measurement** of the **Gravitational Form Factors** (GFFs) of hadrons is the novel quest to resolve the **nucleon structure and dynamics**.
- GFFs may be **probed indirectly** in various exclusive processes: (Double) Deeply Virtual Compton Scattering, Time-Like Compton Scattering, Meson Production, J/Ψ production at threshold...

$$\langle p'|\hat{T}^q_{\mu\nu}|p\rangle = \bar{u}(p',\vec{s}')\left[\boldsymbol{M_2^q(t)}\,\frac{P_\mu P_\nu}{M} + \boldsymbol{J^q(t)}\,\frac{i(P_\mu\sigma_{\nu\alpha}+P_\nu\sigma_{\mu\alpha})\Delta^\alpha}{2M} + \boldsymbol{D^q(t)}\,\frac{\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2}{4M}\right]u(p,\vec{s})$$

Mass/energy distribution — Angular momentum distribution — Forces & pressure distribution

Mechanical properties of hadrons can be obtained from the total $D(t) = \sum_q D^q(t) + D^g(t)$ GFF and its Fourier transform in terms of their **mechanical radius** and **shear force** and **pressure** distributions.

$$D(r) = \frac{1}{(2\pi)^3}\int d^3\Delta\, e^{-i\vec{\Delta}.\vec{r}}\, D(-\vec{\Delta}^2)$$

$$r^2_{\text{mech.}} = 6\,\frac{D(0)}{\int_{-\infty}^{0} dt\, D(t)}$$

$$s(r) = -\frac{1}{4M}\, r\,\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}D(r)\right]$$

$$p(r) = \frac{1}{6M^2}\,\frac{1}{r^2}\frac{d}{dr}\left[r^2\frac{d}{dr}D(r)\right]$$

Experimental Access to D(t)

V.D. Burkert, L. Elouadrhiri, F.-X. Girod, Nature 557 (2018) 39

- GPDs are accessed through **Compton Form Factors** (CFFs) which real and imaginary parts are related by a fixed-t **dispersion relation**

$$\mathfrak{Re}[\mathcal{H}(\xi,t)] + i\,\mathfrak{Im}[\mathcal{H}(\xi,t)] = \sum_q e_q^2 \int_{-1}^{1} \left[\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon} \right] H^q(x,\xi,t)\, dx$$

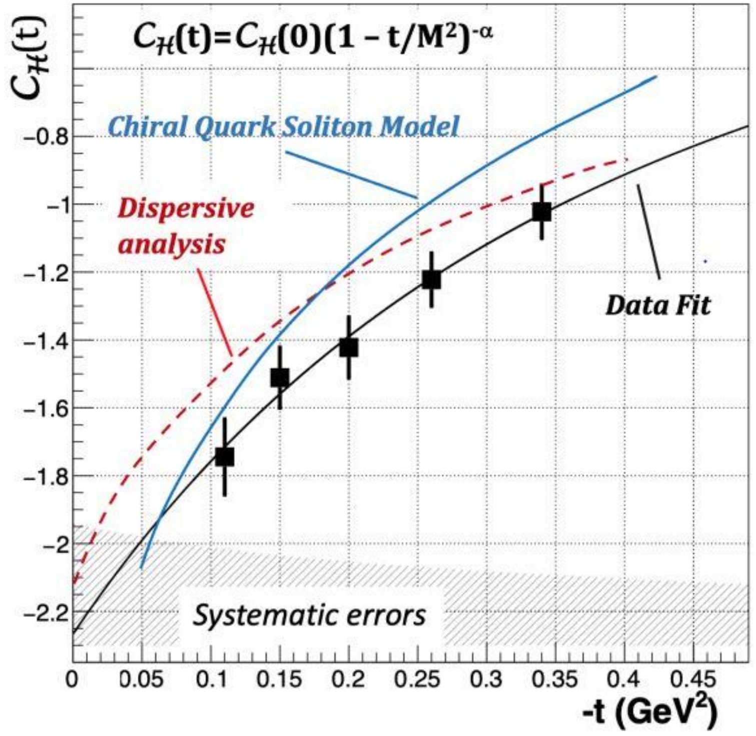
$$\mathfrak{Re}[\mathcal{H}(\xi,t)] \overset{\text{LO}}{=} C_{\mathcal{H}}(t) + \mathcal{P}\left\{ \int_{-1}^{1} \left[\frac{1}{\xi - x} - \frac{1}{\xi + x} \right] \mathfrak{Im}[\mathcal{H}(x,t)]\, dx \right\}$$

Beam Charge Asymmetry **Beam Spin Asymmetry**

$$C_{\mathcal{H}}(t) = 2 \sum_q e_q^2 \int_{-1}^{1} \frac{D^q_{\text{term}}(z,t)}{1-z}\, dz \qquad D^q_{\text{term}}(z,t) = (1-z^2) \sum_{2n+1} d_n^q(t)\, C_n^{3/2}(z)$$

$$D^q(t) = \frac{4}{5} d_1^q(t)$$

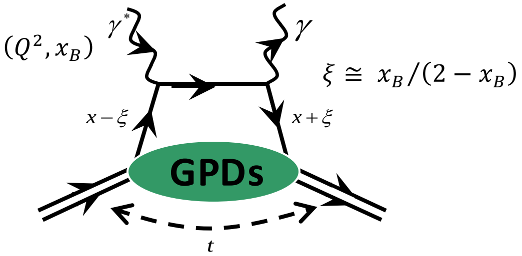
V.D. Burkert et al. RMP 95 (2023) 041002



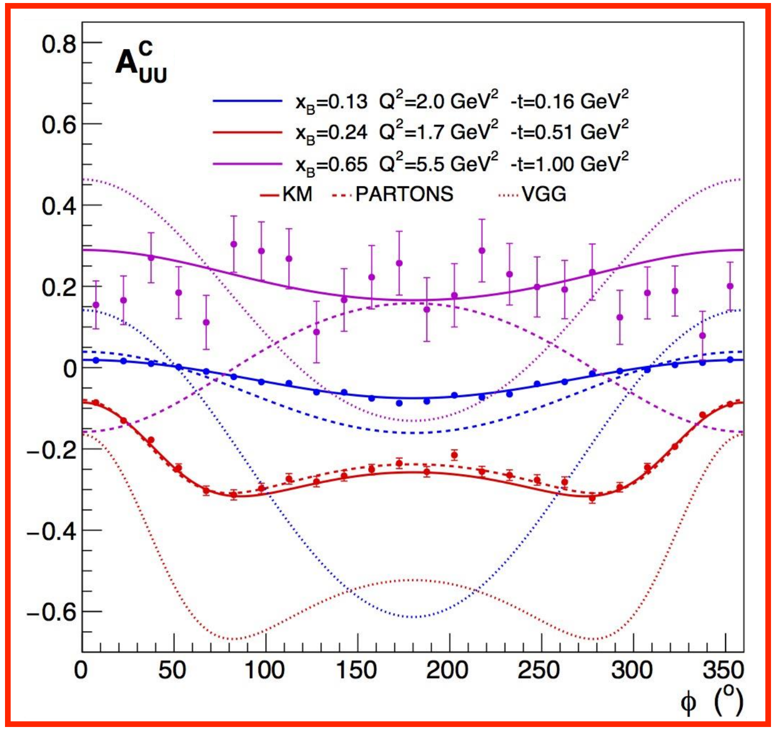
Proposed Measurements

PR12+23-002

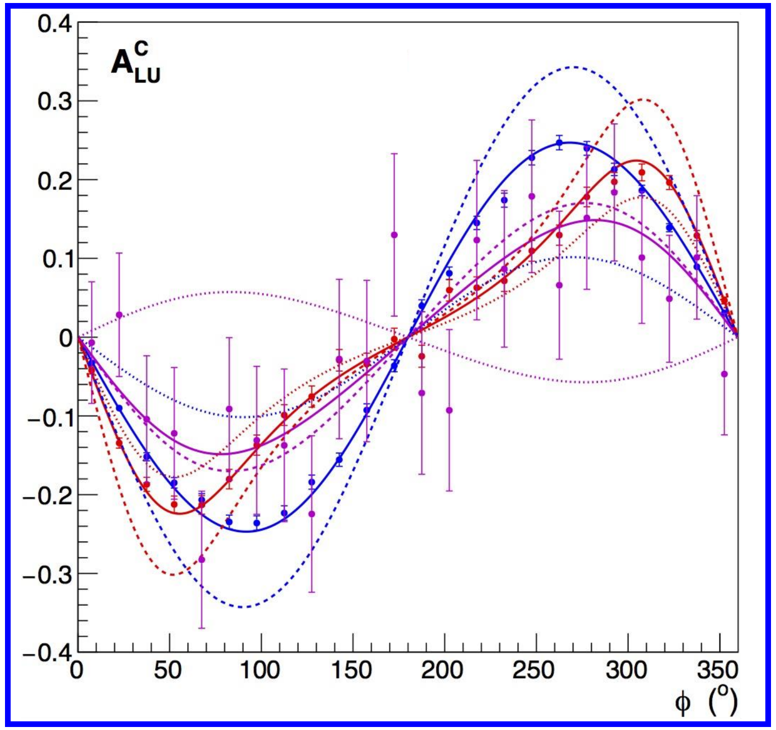
E. Voutier et al. arXiv:2309.14041



- The **comparison** between **electron**- and **positron**-induced photon production isolates the **DVCS⊗BH interference** amplitude of the **(e,epγ)** process, providing a clean access to the **real part of CFFs**.



Unpolarized beam charge asymmetry



Polarized beam charge asymmetry

$$A^C_{UU} = \frac{d^5\sigma_{INT}}{d^5\sigma_{BH} + d^5\sigma_{DVCS}} \propto \mathfrak{Re}[\mathcal{H}(\xi,t)]$$

$$A^C_{LU} = \frac{d^5\tilde{\sigma}_{INT}}{d^5\sigma_{BH} + d^5\sigma_{DVCS}} \propto \mathfrak{Im}[\mathcal{H}(x,t)]$$

$$A^0_{LU} = \frac{d^5\tilde{\sigma}_{DVCS}}{d^5\sigma_{BH} + d^5\sigma_{DVCS}} \neq 0$$

if higher-twists effects

Charge averaged beam spin asymmetry

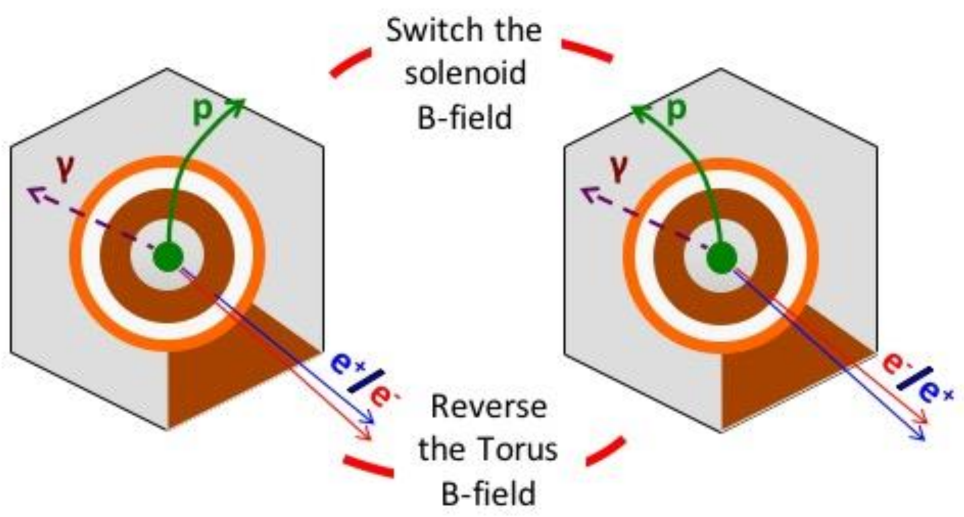
p = 11 GeV/c   P ≥ 80%   I ≥ 50 nA

Control of Systematics

J.S. Alvarado, PhD, Université Paris-Saclay (2025), in preparation

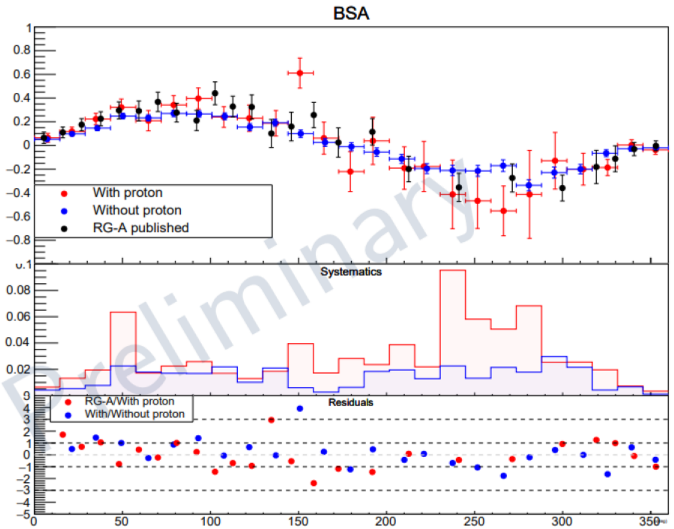
- The physics of interest is extracted from the comparison of electron and positron observables which is more challenging than the comparison of helicity dependent observables for a given beam charge.

Different : data taking period, detector, and experimental conditions.



Switching the Torus and Solenoid polarities, electrons and positrons follow the same detector path contrary to protons.

Machine learning techniques applied to DVCS events selection using a **Boosted Decision Tree** approach allows to measure BSAs within the **eγ topology**, **improving kinematic coverage**, **statistics** and **reducing systematics**.



- BSAs under CLAS collaboration review.

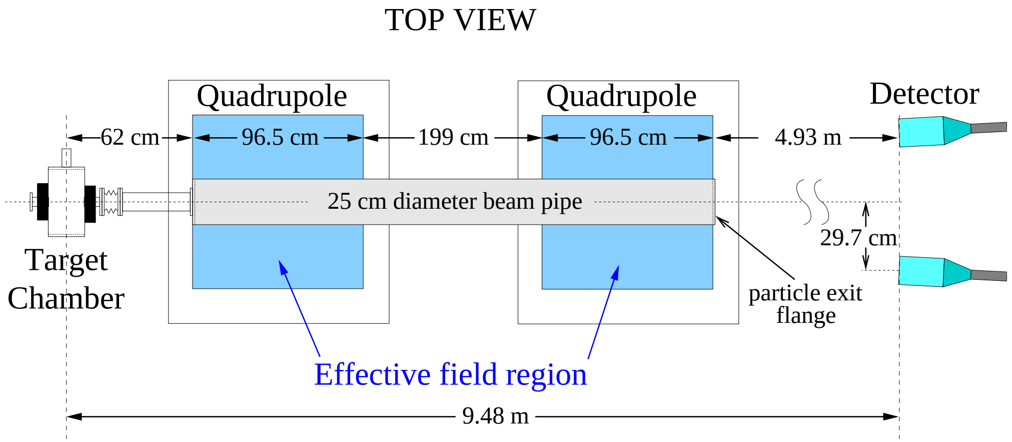
- Cross section *analysis in progress*.

J.S. Alvarado et al., CLAS Note 2024-003

E. Voutier
IJCLab Irène Joliot-Curie

Positron Polarimetry @ CLAS

- Because of similar asymmetries, the existing **Møller** polarimeter may be transformed into a **Bhabha** polarimeter to measure the positron beam polarization at high energy.
- Depending on the nature of the most appropriate solution (**double-** or **single-arm** measurements), **hardware modifications** may be required.



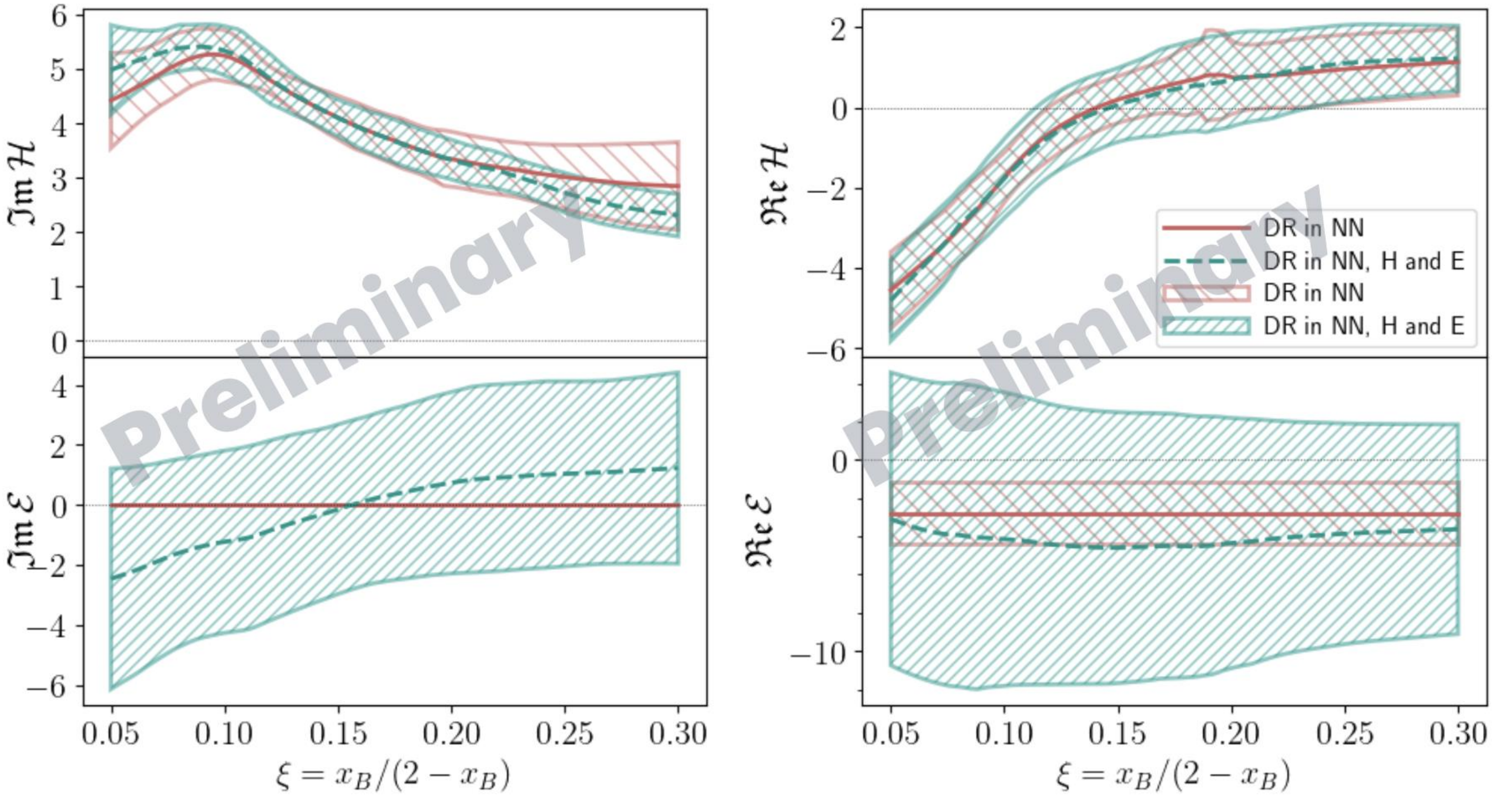
Quadrupoles are used to **deflect scattered electrons** towards the detectors while not steering the beam.

*Another option would be to implement an **annihilation polarimeter** which requires a **longitudinally polarized target** and the **detection of photons**.*

Impact Studies

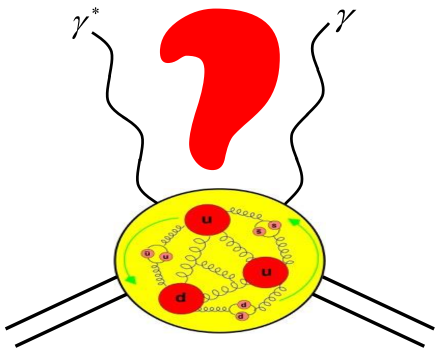
M. Higuera @ Hadron Physics 2030

- Within the LDRD project *Applications of novel computational techniques for the determination of the proton gravitational form factors and mechanical properties (A. Camsonne et al.)*, the development of new tools for the extraction of the CFFs will benefit the evaluation of the **impact of BCA measurements** at CLAS.



- Establishment of a complete DVCS data base.
- Implementation of GPD properties requirements in neural network fitting procedure.
- Implementation of lattice QCD constraints.

Summary



- Current investigations are performed with the perspectives of improving the physics reach of BCA measurements at CLAS : **enlarging experimental phase space**, **increasing statistics**, **reducing systematics**.

- Future studies will focus on **high energy positron polarimetry** at CLAS.

- Parallel developments benefit the **assesment of the physics case** of DVCS with polarized positron beams.