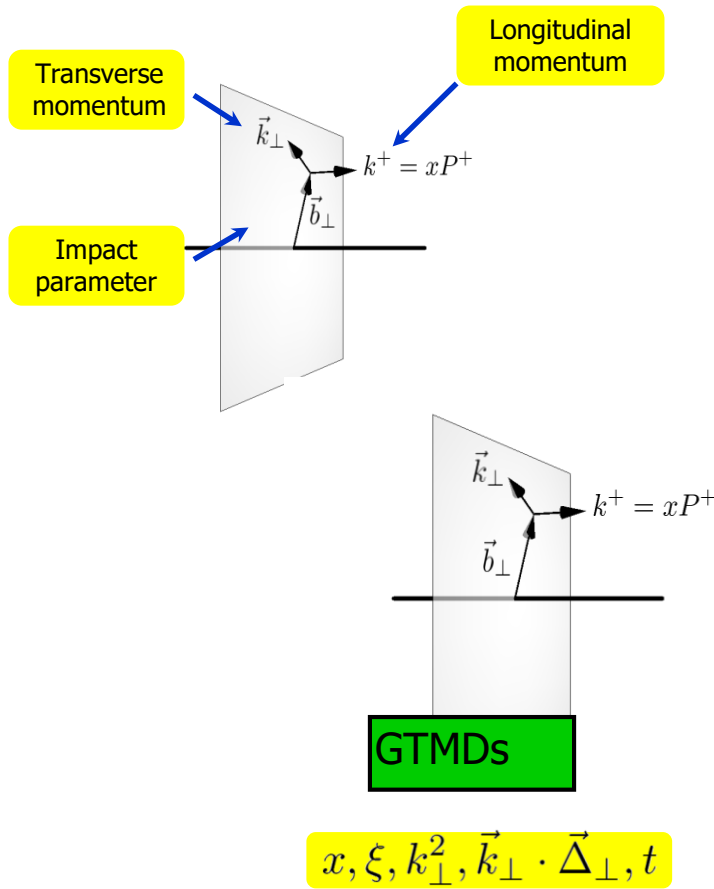


GPD measurements with a polarized positrons beam at Jefferson Lab

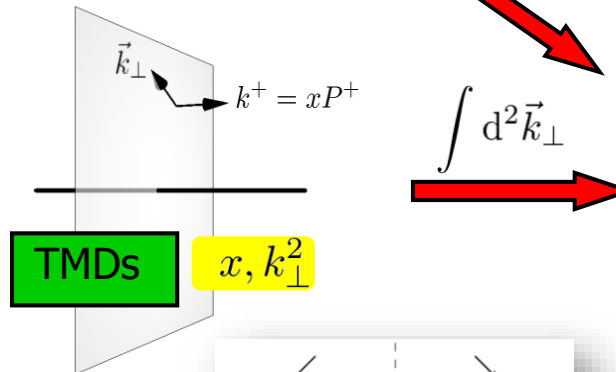
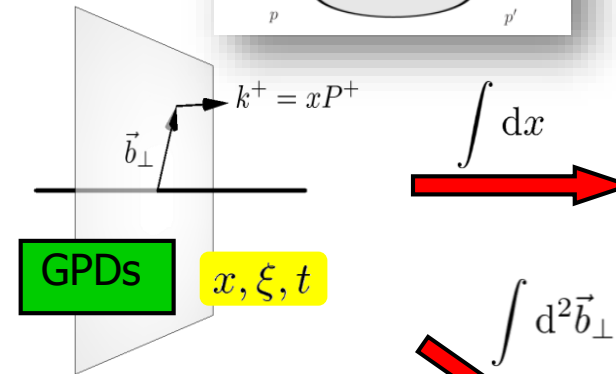
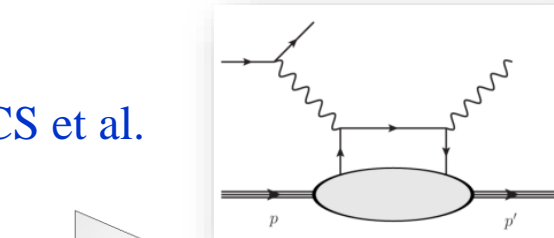
Silvia Niccolai (IJCLab Orsay)
for the Jefferson Lab Positron Working Group
DIS2022, Santiago de Compostela (Spain)
3/5/2022



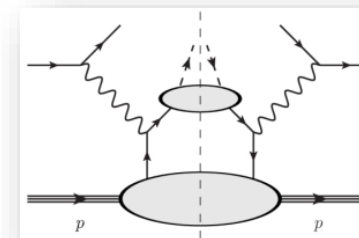
Multi-dimensional mapping of the nucleon



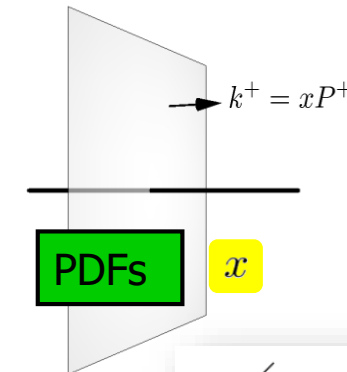
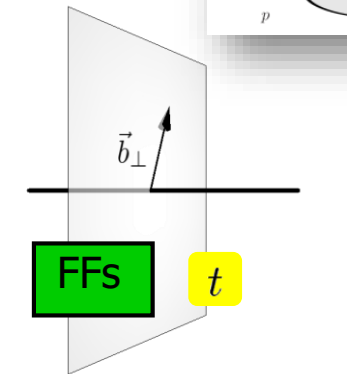
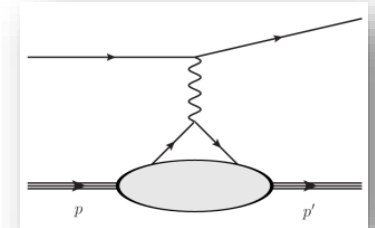
DVCS et al.



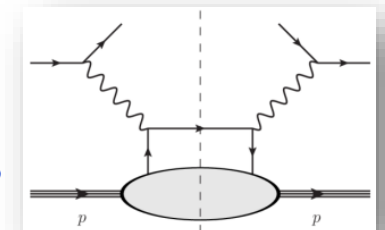
SIDIS



Elastic Scattering

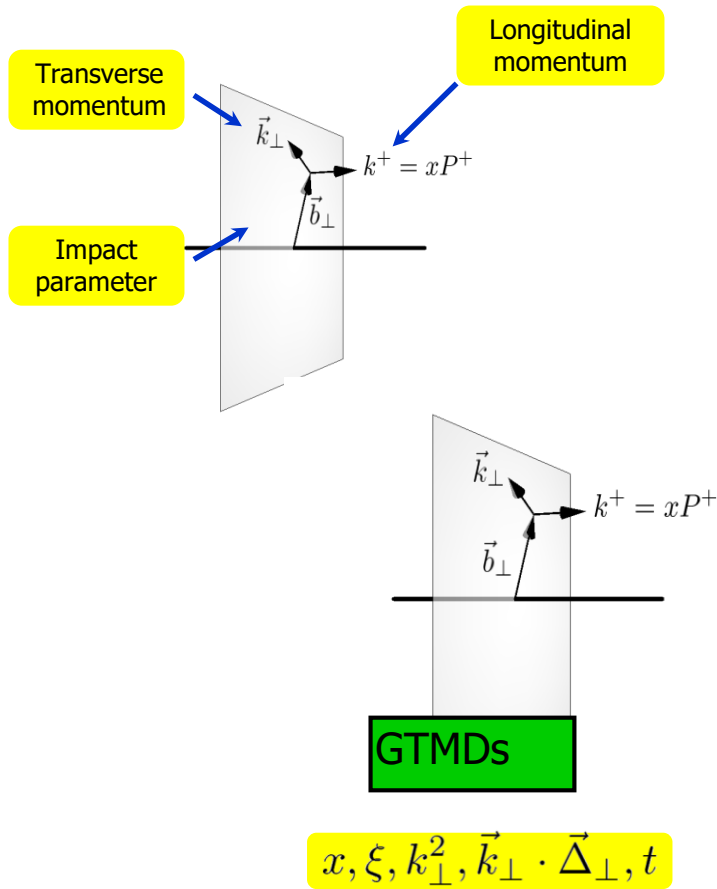


DIS

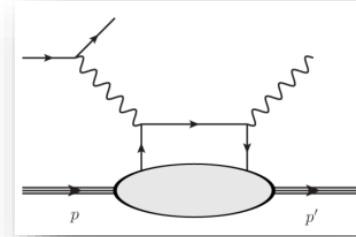


A complete picture of nucleon structure requires the measurement of all these distributions

Multi-dimensional mapping of the nucleon



DVCS et al.



Nucleon tomography

$$q(x, b_\perp) = \int_0^\infty \frac{d^2 \Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp b_\perp} H(x, 0, -\Delta_\perp^2)$$

$$\Delta q(x, b_\perp) = \int_0^\infty \frac{d^2 \Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp b_\perp} \tilde{H}(x, 0, -\Delta_\perp^2)$$

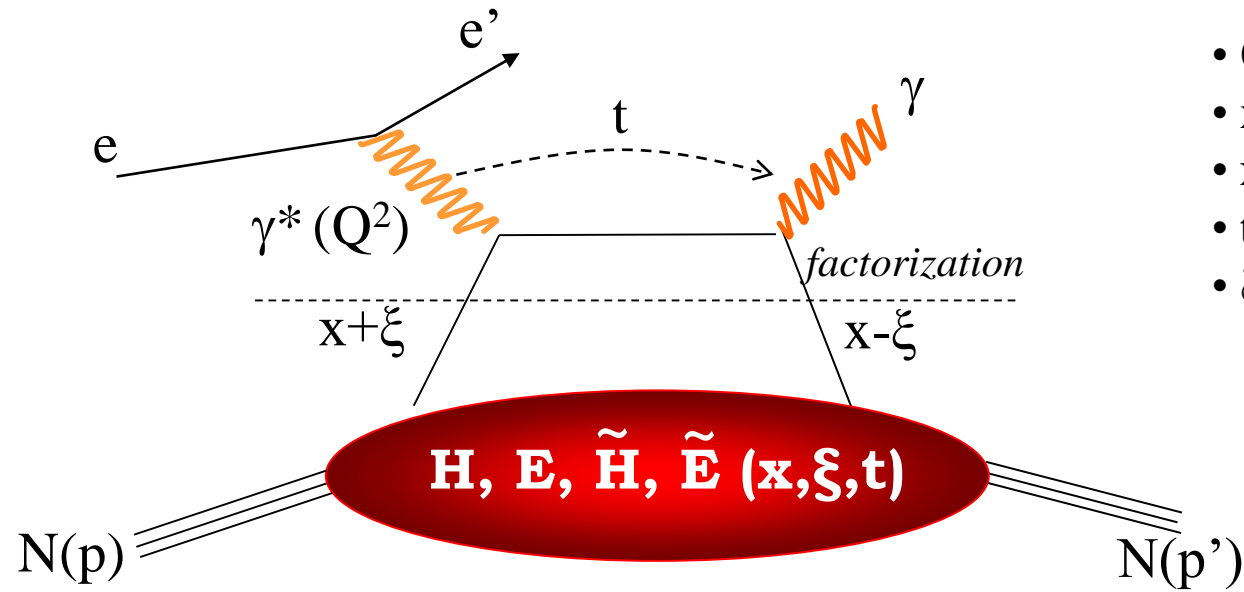
Generalized Parton Distributions:

- ✓ fully correlated parton distributions in both **coordinate** and **longitudinal momentum** space
- ✓ linked to **FFs** and **PDFs**
- ✓ **Accessible in exclusive reactions**

Quark angular momentum (Ji's sum rule)

$$\frac{1}{2} \int_{-1}^1 x dx (H(x, \xi, t=0) + E(x, \xi, t=0)) = J = \frac{1}{2} \Delta \Sigma + \Delta L$$

Deeply Virtual Compton Scattering and GPDs



- $Q^2 = -(e-e')^2$
- $x_B = Q^2/2Mv$ $v = E_e - E_{e'}$
- $x+\xi, x-\xi$ longitudinal momentum fractions
- $t = \Delta^2 = (p-p')^2$
- $\xi \cong x_B/(2-x_B)$

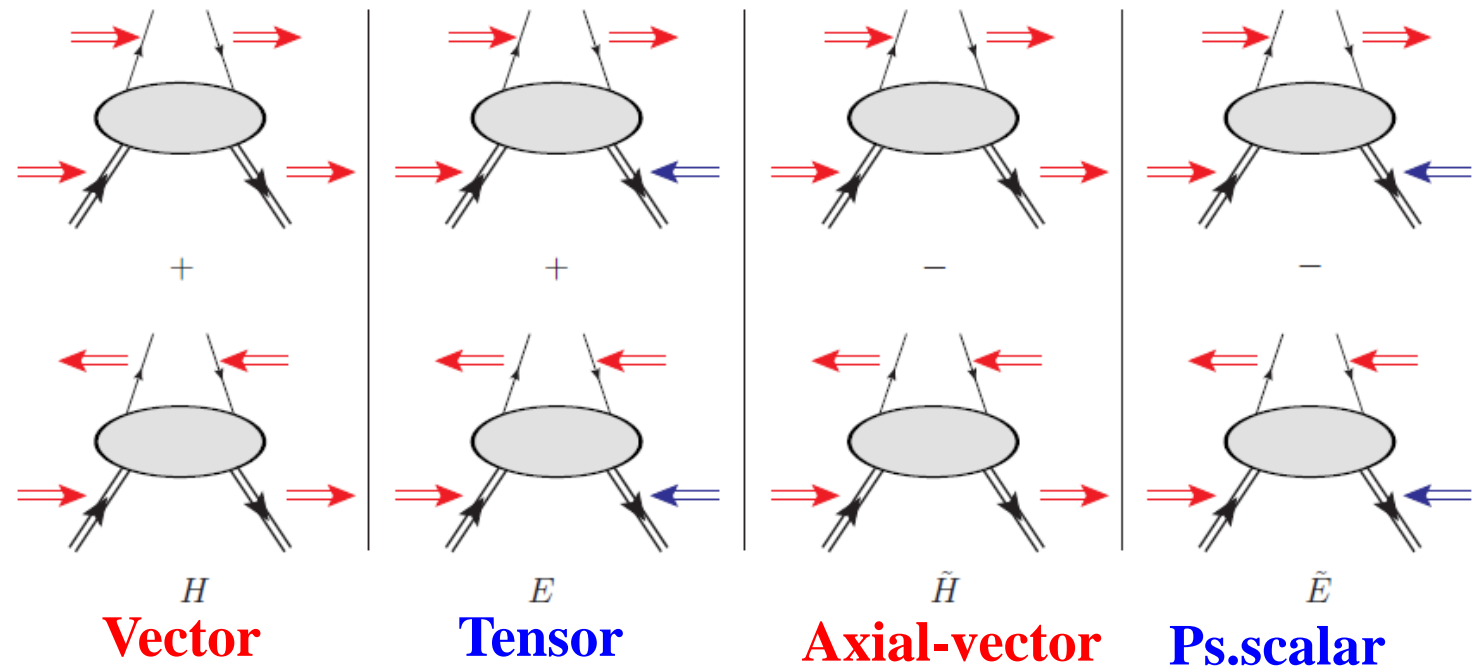
« Handbag » factorization, valid in the **Bjorken regime** (high Q^2 and v , fixed x_B), $t \ll Q^2$

GPDs: Fourier transforms of *non-local, non-diagonal* QCD operators

4 GPDs for each quark flavor
(leading-order, leading twist, quark-helicity conservation)

conserve nucleon spin

flip nucleon spin



Accessing GPDs through DVCS

$$T^{DVCS} \sim P \int_{-1}^{+1} \frac{GPDs(x, \xi, t)}{x \pm \xi} dx \pm i\pi GPDs(\pm \xi, \xi, t) + \dots$$

$$Re\mathcal{H}_q = e_q^2 P \int_0^{+1} \left(H^q(x, \xi, t) - H^q(-x, \xi, t) \right) \left[\frac{1}{\xi - x} + \frac{1}{\xi + x} \right] dx$$

$$Im\mathcal{H}_q = \pi e_q^2 \left[H^q(\xi, \xi, t) - H^q(-\xi, \xi, t) \right]$$

$$\sigma(eN \rightarrow eN\gamma) = \left| \begin{array}{c} \text{DVCS} \\ + \\ \text{Bethe-Heitler (BH)} \end{array} \right|^2$$

Polarized beam, unpolarized target:

$$\Delta\sigma_{LU} \sim \sin\phi \operatorname{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E} + \dots\}$$

Proton Neutron

$$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$$

$$Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \mathcal{E}_n\}$$

Unpolarized beam, longitudinal target:

$$\Delta\sigma_{UL} \sim \sin\phi \operatorname{Im}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E}) - \xi kF_2\tilde{\mathcal{E}}\}$$

$$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$$

$$Im\{\mathcal{H}_n, \mathcal{E}_n\}$$

Polarized beam, longitudinal target:

$$\Delta\sigma_{LL} \sim (A+B\cos\phi) \operatorname{Re}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E}) + \dots\}$$

$$Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$$

$$Re\{\mathcal{H}_n, \mathcal{E}_n\}$$

Unpolarized beam, transverse target:

$$\Delta\sigma_{UT} \sim \cos\phi \sin(\phi_s - \phi) \operatorname{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \dots\}$$

$$Im\{\mathcal{H}_p, \mathcal{E}_p\}$$

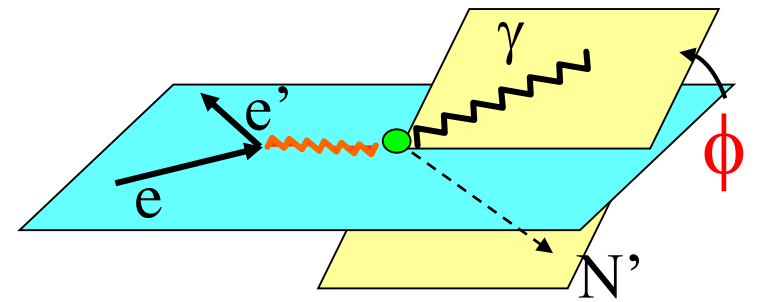
$$Im\{\mathcal{H}_n\}$$

Unpolarized beam and target, different lepton charges:

$$\Delta\sigma_C \sim \cos\phi \operatorname{Re}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E} + \dots\}$$

$$Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$$

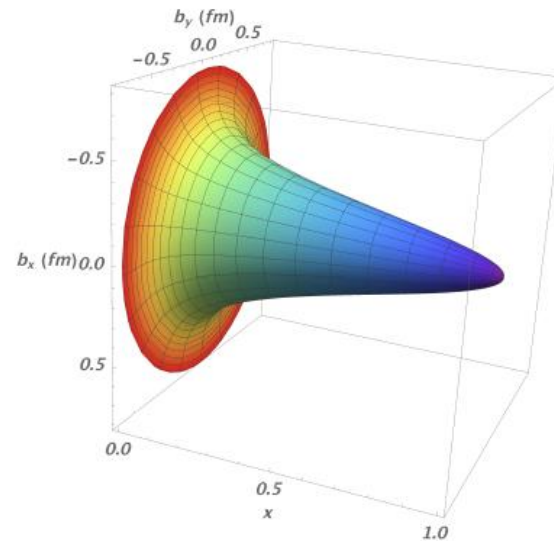
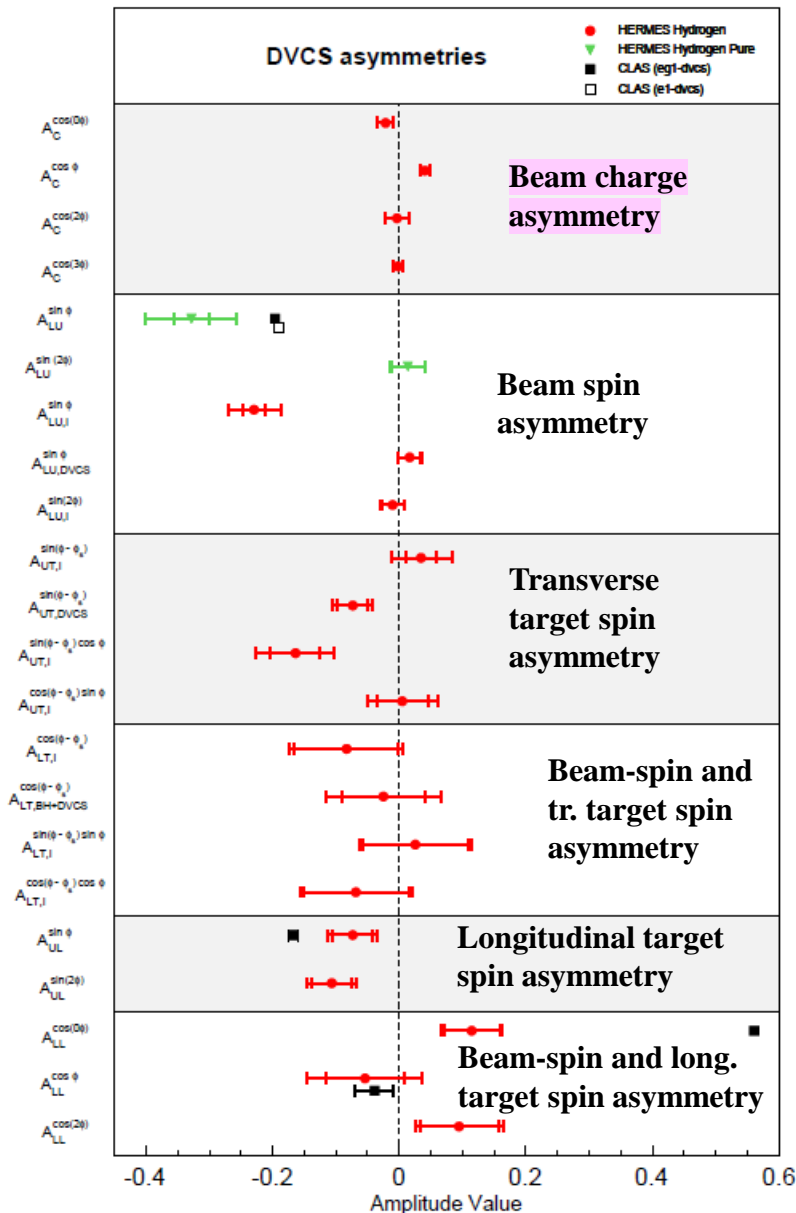
$$Re\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \mathcal{E}_n\}$$



$$\sigma \sim |T^{DVCS} + T^{BH}|^2$$

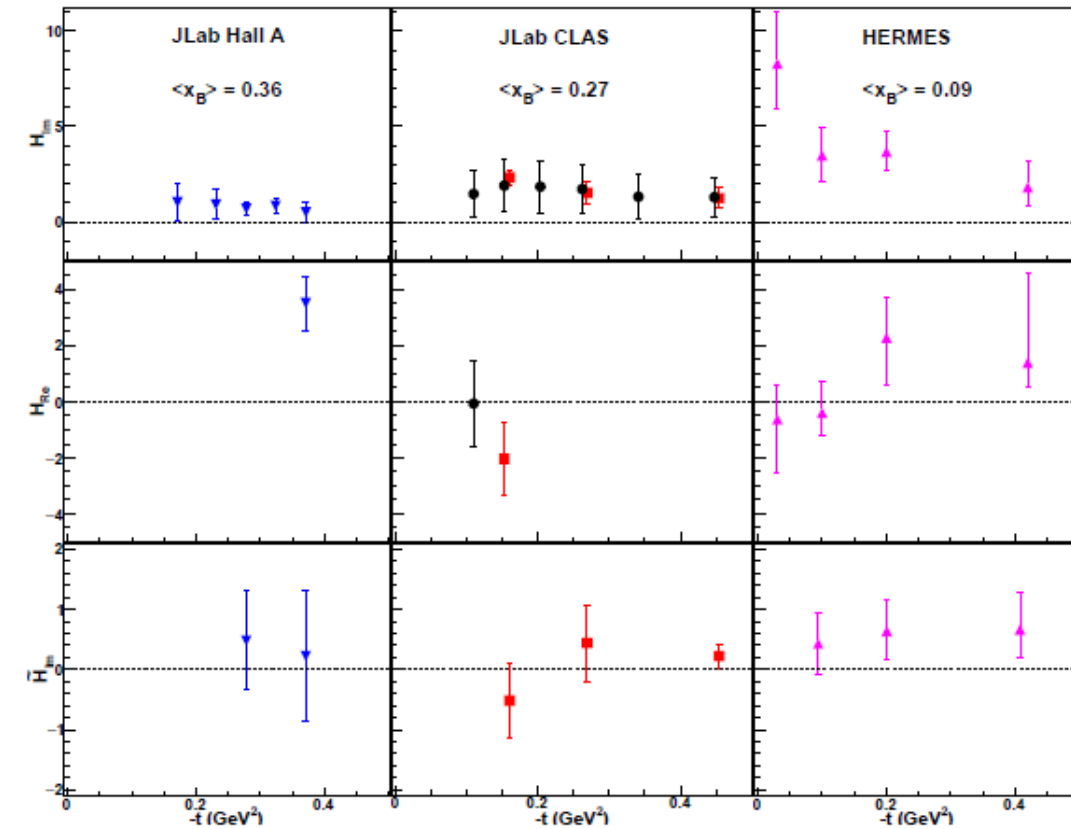
$$\Delta\sigma = \sigma^+ - \sigma^- \propto I(DVCS \cdot BH)$$

Measured p-DVCS observables and constraints on GPDs



Proton tomography
 obtained from *local fits* to
 HERMES, CLAS, and
 Hall-A data (Im \mathcal{H} + model
 dependent assumptions for
 x dependence)

R. Dupré, M. Guidal, M. Vanderhaeghen,
 PRD95, 011501 (2017)



Hall A (2015)

CLAS C.S.
CLAS C.S.
+TSA+DSA

HERMES

**Beam Charge
 Asymmetry:
 strong constraint
 for H_{Re}**

N. d'Hose, S.N., A. Rostomyan, EPJA 52, 151 (2016)

Distribution of forces in the proton

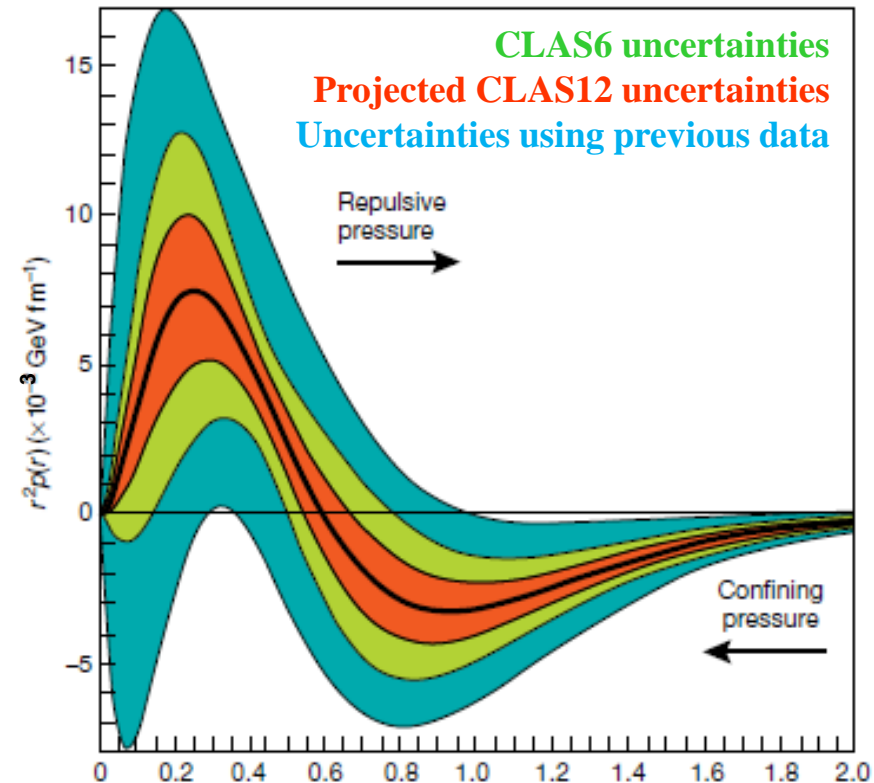
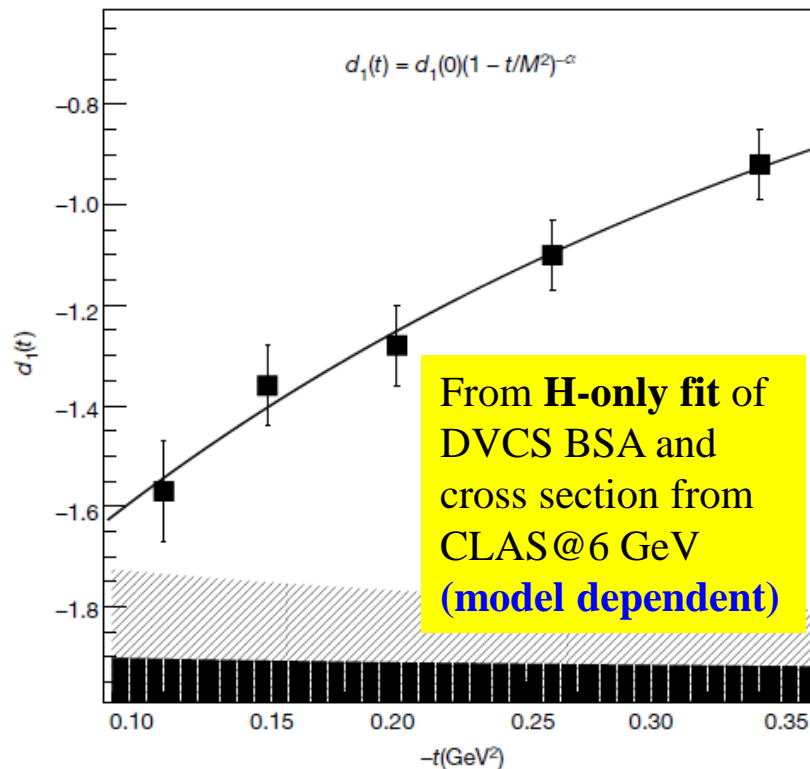
$\int x H(x, \xi, t) dx = M_2(t) + \frac{4}{5} \xi^2 d_1(t)$ Second Mellin moment of H in x: **gravitational form factor** \rightarrow shear forces and pressure (d_1)

$$\text{Re}\mathcal{H}(\xi, t) + i\text{Im}\mathcal{H}(\xi, t) = \int_{-1}^1 dx \left(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon} \right) H(x, \xi, t) \quad (1)$$

$$D(t) = \frac{1}{2} \int_{-1}^1 \frac{D(z, t)}{1-z} dz \quad D(z, t) = (1-z^2)[d_1(t)C_1^{3/2}(z) + \dots]$$

$$\text{Re}\mathcal{H}(\xi, t) \stackrel{\text{lo}}{=} D(t) + \mathcal{P} \int_{-1}^1 dx \left(\frac{1}{\xi - x} - \frac{1}{\xi + x} \right) \text{Im}\mathcal{H}(x, t)$$

$$d_1(t) \propto \int \frac{j_0(r\sqrt{-t})}{2t} p(r) d^3r$$



JLab@12 GeV DVCS program

Observable (target)	12-GeV experiments	CFF sensitivity	Status
$\sigma, \Delta\sigma_{\text{beam}}(p)$	Hall A CLAS12 Hall C	$\text{Re}\mathcal{H}(p), \text{Im}\mathcal{H}(p)$	Hall A: data taken in 2016; e-Print: 2201.03714 [hep-ph] CLAS12: data taken in 2018-2019; CS analysis in progress Hall C: experiment planned for 2023-2024
BSA(p)	CLAS12	$\text{Im}\mathcal{H}(p)$	BSA publication in Ad Hoc review stage <i>M. Defurne's talk, WG5, Tuesday 3PM</i>
lTSA(p), lDSA(p)	CLAS12	$\text{Im}\tilde{\mathcal{H}}(p), \text{Im}\mathcal{H}(p), \text{Re}\tilde{\mathcal{H}}(p), \text{Re}\mathcal{H}(p)$	Experiment will start in June 2022 (6 months)
tTSA(p)	CLAS12	$\text{Im}\mathcal{H}(p), \text{Im}\mathcal{E}(p)$	Experiment foreseen for ~2025
BSA(n)	CLAS12	$\text{Im}\mathcal{E}(n)$	Data taken in 2019-2020, BSA analysis undergoing CLAS review
lTSA(n), lDSA(n)	CLAS12	$\text{Im}\mathcal{H}(n), \text{Re}\mathcal{H}(n)$	Experiment will start in June 2022 (6 months)

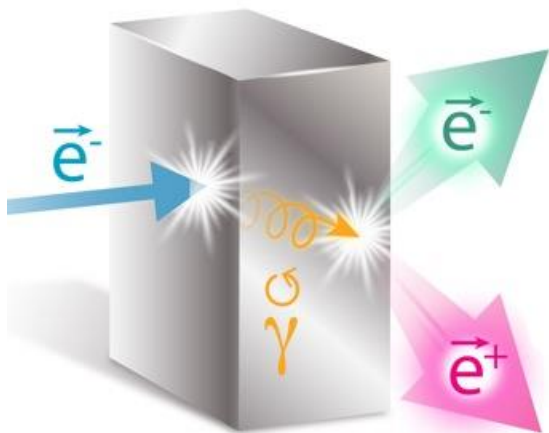
Complementarity of the experimental setups in the JLab Halls A/C and B

- Hall A/C: high luminosity \rightarrow precision, small kinematic coverage, $e\gamma$ topology
- Hall B (CLAS12): lower luminosity, large kinematic coverage, fully exclusive final state

Polarized positrons beam for Jefferson Lab

Physics Motivations:

- Two-photon physics
- **Generalized parton distributions**
- Neutral and charged current DIS
- Charm production
- Neutral electroweak coupling
- Light Dark Matter search
- Charged Lepton Flavor Violation (**X. Zheng's talk, Wed 6:10PM**)



PePPO: proof-of-principle for a polarized positron beam
PRL 116 (2016) 214801

Reza Kazimi's talk, Tuesday 10:40AM

- Publication of the **EPJ A Topical Issue about "An experimental program with positron beams at Jefferson lab"** gathering about 250 physicists from 75 institutions around a several-years-long experimental program.
- Two DVCS-based proposals were submitted to JLab PAC48 and were Conditionally Approved

An Experimental Program with Positron Beams at Jefferson Lab

A. Accardi^{1,20}, A. Altarelli²¹, I. Albayrak²², S.F. Ali²³, M. Amarian²⁴, J.R.M. Annand²⁵, J. Arrington¹¹, A. Asatryan²⁶, H. Avakian²⁷, T. Avenet²⁸, C. Ayerbe-Gonzalez²⁹, L. Baran³⁰, M. Battaglieri³¹, P. Bellini³², F. Benmokhtar³³, Y. Berdnikova³⁴, J.C. Bernauer^{35,32}, A. Bianconi^{37,45}, A. Biselli³⁸, M. Boer³⁹, M. Bondi⁴⁰, K.-T. Brinkmann⁴¹, W.J. Briscoe⁴², V. Burkert⁴³, T. Cao⁴⁴, A. Camsonne⁴⁵, R. Capobianco⁴⁶, L. Cardman⁴⁷, M. Carmignotto⁴⁸, M. Caudron⁴⁹, L. Causse⁵⁰, A. Celentano⁵¹, P. Chatagnon⁵², T. Chetry⁵³, G. Ciullo^{54,55}, E. Cline⁵⁶, P.L. Cole⁵⁷, M. Contalbrigo⁵⁸, G. Costantini^{59,60}, A. D'Angelo^{61,62}, D. Day⁶³, M. De Deurloo⁶⁴, M. De Napoli⁶⁵, A. Deur⁶⁶, R. De Vita⁶⁷, N. D'Hose⁶⁸, S. Diehl^{69,70}, M. Dieckhake⁷¹, B. Dong⁷², R. Dupre⁷³, D. Dutta⁷⁴, M. Ehardt⁷⁵, L. El-Fassi⁷⁶, L. Elouadhi⁷⁷, R. Ent⁷⁸, J. Erler^{79,80}, I.P. Fernandez⁸¹, A. Filippi⁸², D. Flay⁸³, T. Forest⁸⁴, E. Fuchey⁸⁵, S. Fucci⁸⁶, Y. Funke⁸⁷, H. Gao⁸⁸, D. Gaskell⁸⁹, A. Gasparian⁹⁰, T. Gauthier⁹¹, F.K. Gessner⁹², J. Grams⁹³, P. Guay⁹⁴, M. Guiso⁹⁵, S. Haber⁹⁶, D.J. Hamilton⁹⁷, O. Hansson⁹⁸, D. Hassler⁹⁹, M. Hattawy¹⁰⁰, D.W. Higinbotham¹⁰¹, A. Hobe¹⁰², T. Horn¹⁰³, C.E. Hyde¹⁰⁴, H. Ibrahim¹⁰⁵, A. Italiano¹⁰⁶, K. Joo¹⁰⁷, S.J. Joosten¹⁰⁸, N. Kalantar-Nia¹⁰⁹, G. Kalish¹¹⁰, D. Keller¹¹¹, C. Koppel¹¹², M. Kervin¹¹³, A. Kim¹¹⁴, J. Kim¹¹⁵, P.M. King¹¹⁶, E. Kinney¹¹⁷, V. Klimenko¹¹⁸, H.-S. Ko¹¹⁹, M. Kohl¹²⁰, V. Kozlovskiy¹²¹, V. Kubarovsky¹²², T. Kutz¹²³, L. Lanza^{124,125}, M. Leao^{126,127}, P. Lenisa^{128,129}, N. Liyanage¹³⁰, Q. Liu¹³¹, S. Liu¹³², J. Manne¹³³, S. Manly¹³⁴, D. Marchand¹³⁵, P. Markowitz¹³⁶, L. Marisciano^{137,138}, V. Mascagna^{139,140}, M. Mazouz¹⁴¹, M. McCaughan¹⁴², B. McKinnon¹⁴³, D. McNulty¹⁴⁴, W. Melnitchouk¹⁴⁵, Z.-E. Meziani¹⁴⁶, M. Mihovilev¹⁴⁷, R. Milner¹⁴⁸, A. Mertyan¹⁴⁹, H. Mertyan¹⁵⁰, A. Movsisyan¹⁵¹, M. Muoz¹⁵², C. Mulvey-Camacho¹⁵³, J. Murphy¹⁵⁴, P. Nadel-Talbot¹⁵⁵, J. Nieves¹⁵⁶, S. Nicotri¹⁵⁷, G. Niculescu¹⁵⁸, R. Novotny¹⁵⁹, M. Pacione¹⁶⁰, L. Pappalardo^{161,162}, R. Paredon¹⁶³, E. Pasyk¹⁶⁴, T. Patel¹⁶⁵, I. Pegg¹⁶⁶, C. Peng¹⁶⁷, D. Perera¹⁶⁸, M. Poeschl¹⁶⁹, K. Price¹⁷⁰, A.J.R. Puckett¹⁷¹, M. Rapp^{172,173}, N. Randazzo¹⁷⁴, M.N.H. Rashid¹⁷⁵, M. Rathnayake¹⁷⁶, B. Raue¹⁷⁷, P.E. Reimer¹⁷⁸, M. Rinaldi¹⁷⁹, H. Szumilas-Vance¹⁸⁰, V. Tadevosyan¹⁸¹, A.S. Tadeopal¹⁸², M. Tietjenback¹⁸³, R. Trott¹⁸⁴, M. Ungaro¹⁸⁵, P. Valente¹⁸⁶, L. Venturini^{187,188}, H. Voskanyan¹⁸⁹, E. Voutier¹⁹⁰, B. Wojleskhowski¹⁹¹, S. Wood¹⁹², J. Xiao¹⁹³, Z. Ye¹⁹⁴, M. Yurov¹⁹⁵, H.-G. Zaunick¹⁹⁶, S. Zhemochykhin¹⁹⁷, J. Zhang¹⁹⁸, S. Zhang¹⁹⁹, S. Zhao²⁰⁰, Z.W. Zhao²⁰¹, X. Zheng²⁰², C. Zorn²⁰³

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The ongoing **R&D** aims to identify the most appropriate implementation of **PEPPo** at **CEBAF**, taking into account the many constraints and technological challenges (**target heating, collection system, emittance filter, injection into CEBAF, radiation environment, civil construction, cost...**) towards the development of a **prototype** and a **CDR**.

DVCS with polarized positrons beam at JLab

The importance of beam-charge asymmetry for DVCS was highlighted by the pioneering HERMES experiment

Disposing of a polarized positron/electron beams at JLab → new observables = different sensitivities to GPDs

Beam Charge Asymmetries proposed to be measured at CLAS12:

- The unpolarized beam charge asymmetry A_{UU}^C , which is sensitive to the **real part of the CFF** → D-term, forces in the proton
- The polarized beam charge asymmetry A_{LU}^C , which is sensitive to the **imaginary part of the CFF**
- The neutral beam spin asymmetry A_{LU}^0 , which is sensitive to **higher-twist effects**

σ : polarization independent CS

$\tilde{\sigma}$: polarization dependent CS

New GPD Observables @ JLab

Physics goal: beam-charge asymmetry for DVCS with polarised electrons and positrons
→ separation of DVCS and DVCS-BH interference amplitudes, sensitivity to real part of GPDs

$$A_{UU}^C = \frac{(Y_+^+ + Y_-^+) - (Y_+^- + Y_-^-)}{Y_+^+ + Y_-^+ + Y_+^- + Y_-^-}$$

$$= \frac{\sigma_{INT}}{\sigma_{BH} + \sigma_{DVCS}}$$

$$A_{LU}^C = \frac{(Y_+^+ - Y_-^+) - (Y_+^- - Y_-^-)}{Y_+^+ + Y_-^+ + Y_+^- + Y_-^-}$$

$$= \frac{\tilde{\sigma}_{INT}}{\sigma_{BH} + \sigma_{DVCS}}$$

$$A_{LU}^0 = \frac{(Y_+^+ + Y_+^-) - (Y_-^+ + Y_-^-)}{Y_+^+ + Y_-^+ + Y_+^- + Y_-^-}$$

$$= \frac{\tilde{\sigma}_{DVCS}}{\sigma_{BH} + \sigma_{DVCS}}$$

$$\text{👉 } A_{LU}^C \neq A_{LU}^\pm = \frac{\pm(\tilde{\sigma}_{INT} \pm \tilde{\sigma}_{DVCS})}{\sigma_{BH} + \sigma_{DVCS} \pm \sigma_{INT}}$$

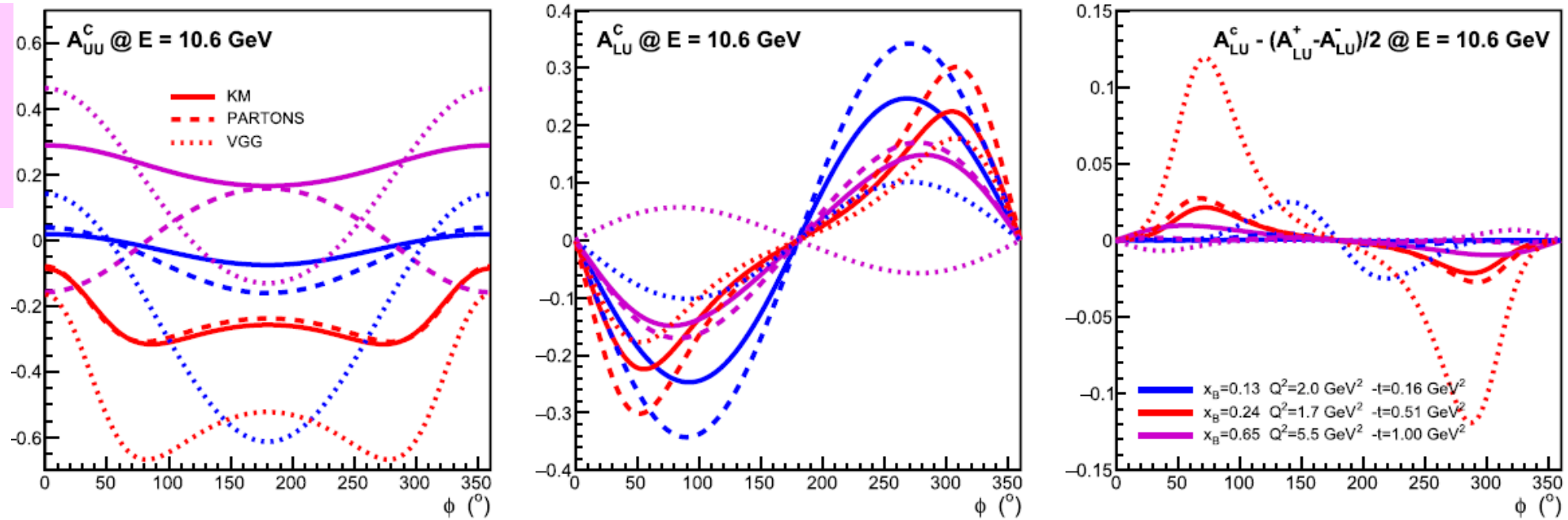
pDVCS with polarized positrons beam at CLAS12

PR12-20-009

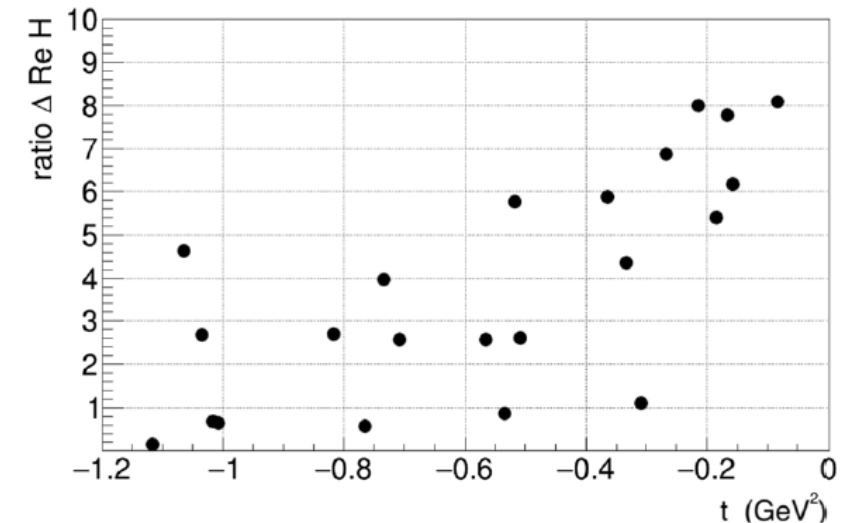
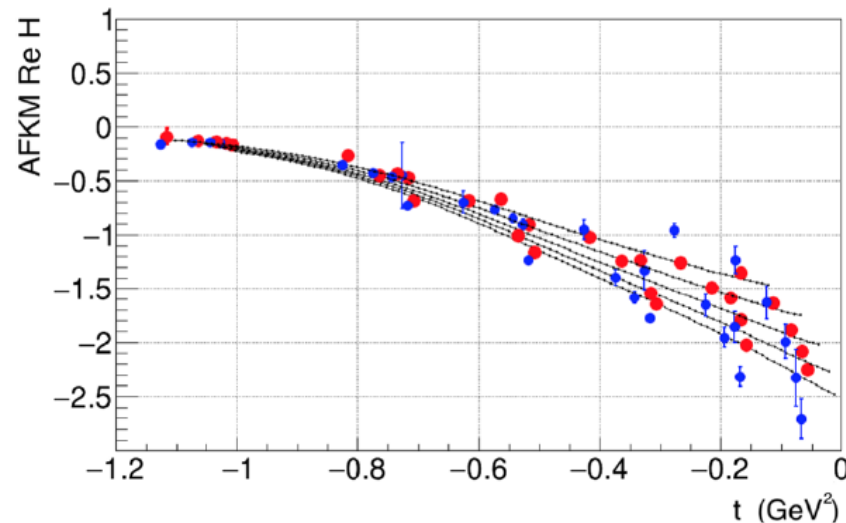
V. Burkert, L. Elouadrhiri,
F.X. Girod, S. N., E. Voutier *et al.*

Conditionally approved

Model predictions for
the three observables

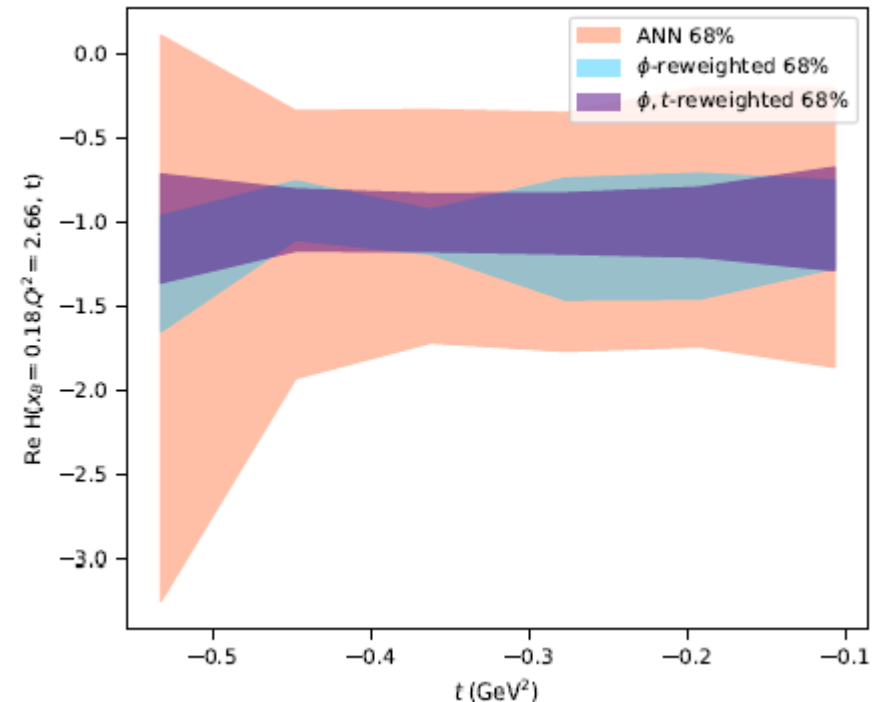
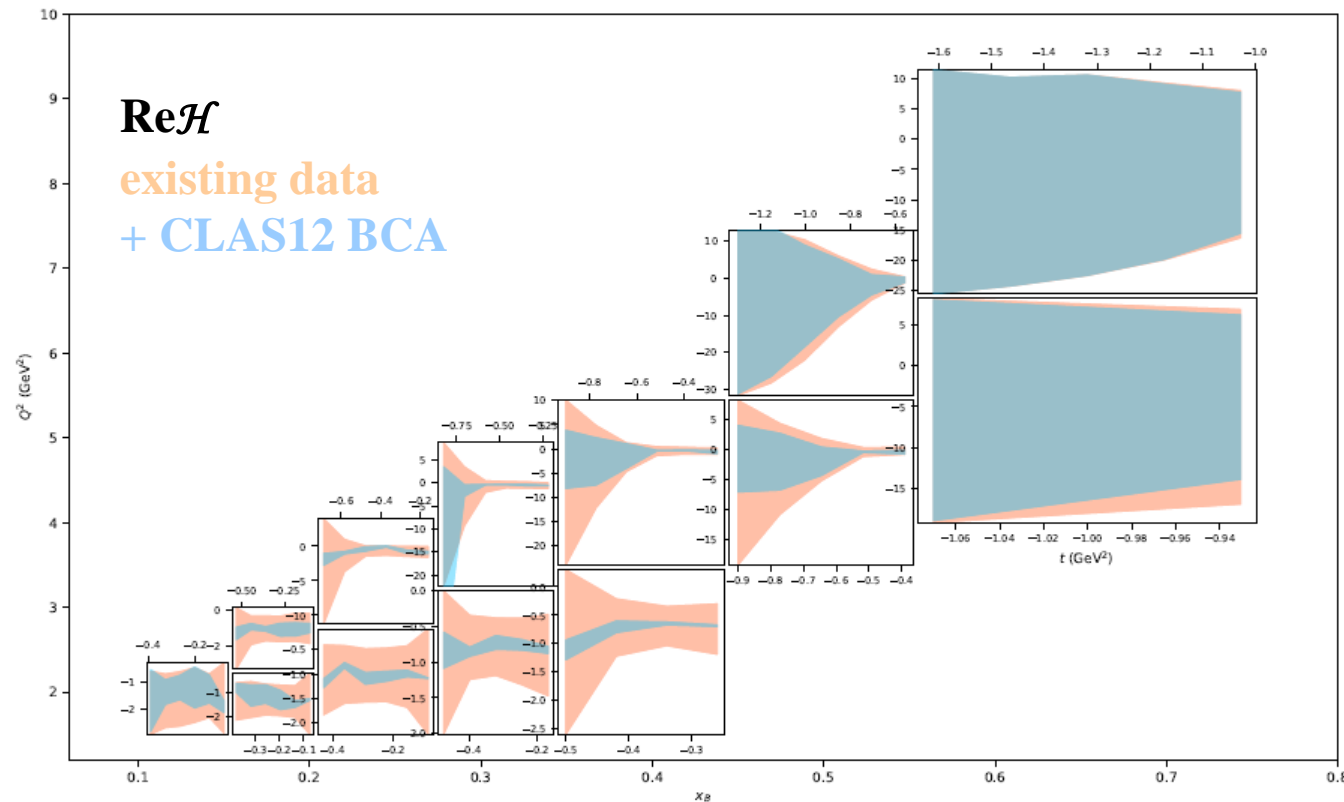


Impact of positron projected
data on the extraction of
 $Re\mathcal{H}$ via global fits, model
dependent (\mathcal{H} and $\tilde{\mathcal{H}}$ only):
→ major reduction of
relative uncertainties,
especially at low $-t$

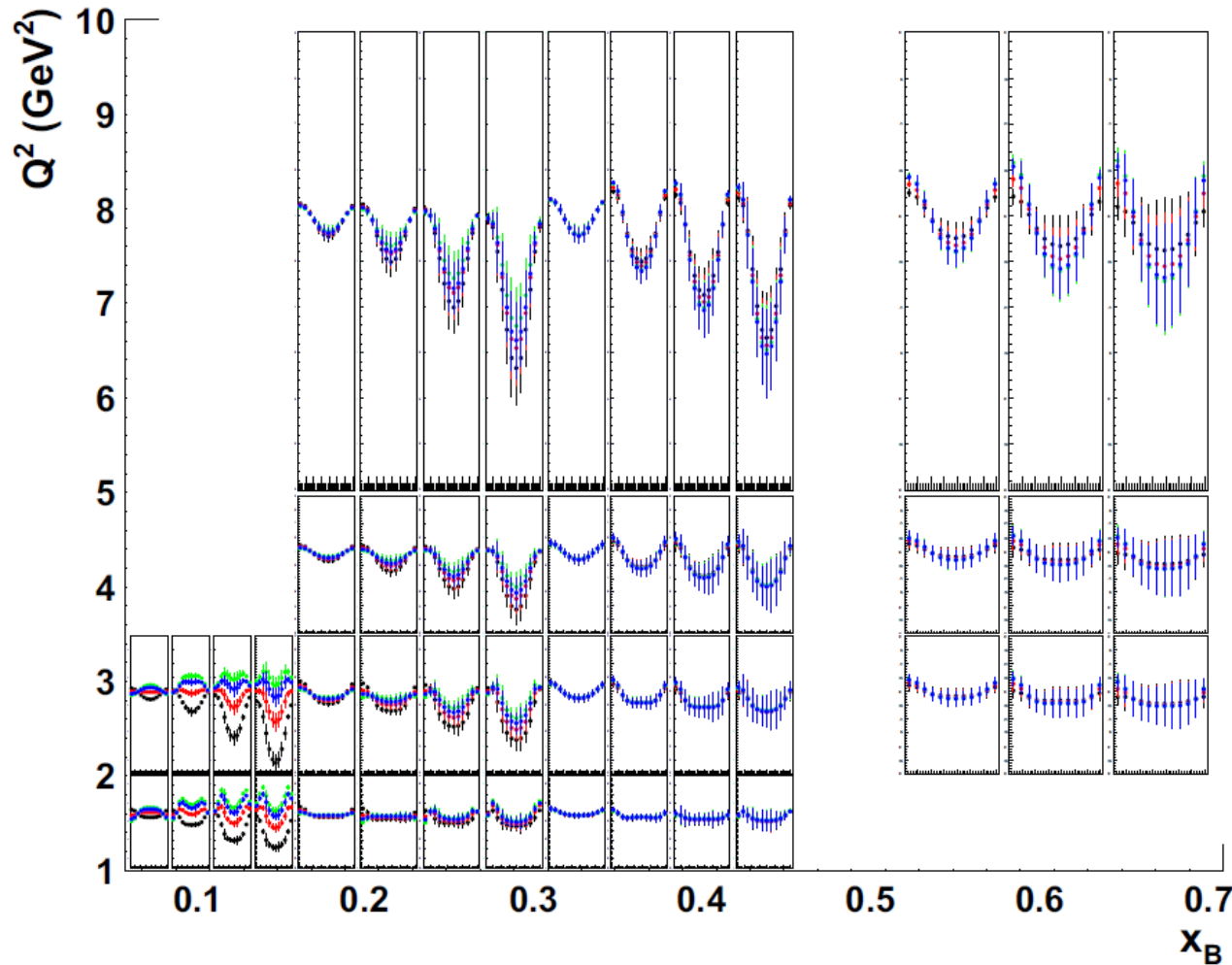


Impact study of CLAS12 pDVCS BCAs on CFF fits

- Artificial neural network (ANN)-based **extractions of DVCS CFFs in a global analysis** of experimental data collected with proton targets: ~ 30 DVCS observables measured in > 2600 kinematic points by Hall-A, CLAS, HERMES, COMPASS, ZEUS and H1, over a wide phase-space.
- Bayesian reweighting analysis** to evaluate how the projected **CLAS12 beam-charge asymmetries** would improve the determination of the CFFs obtained from the global fit with ANNs

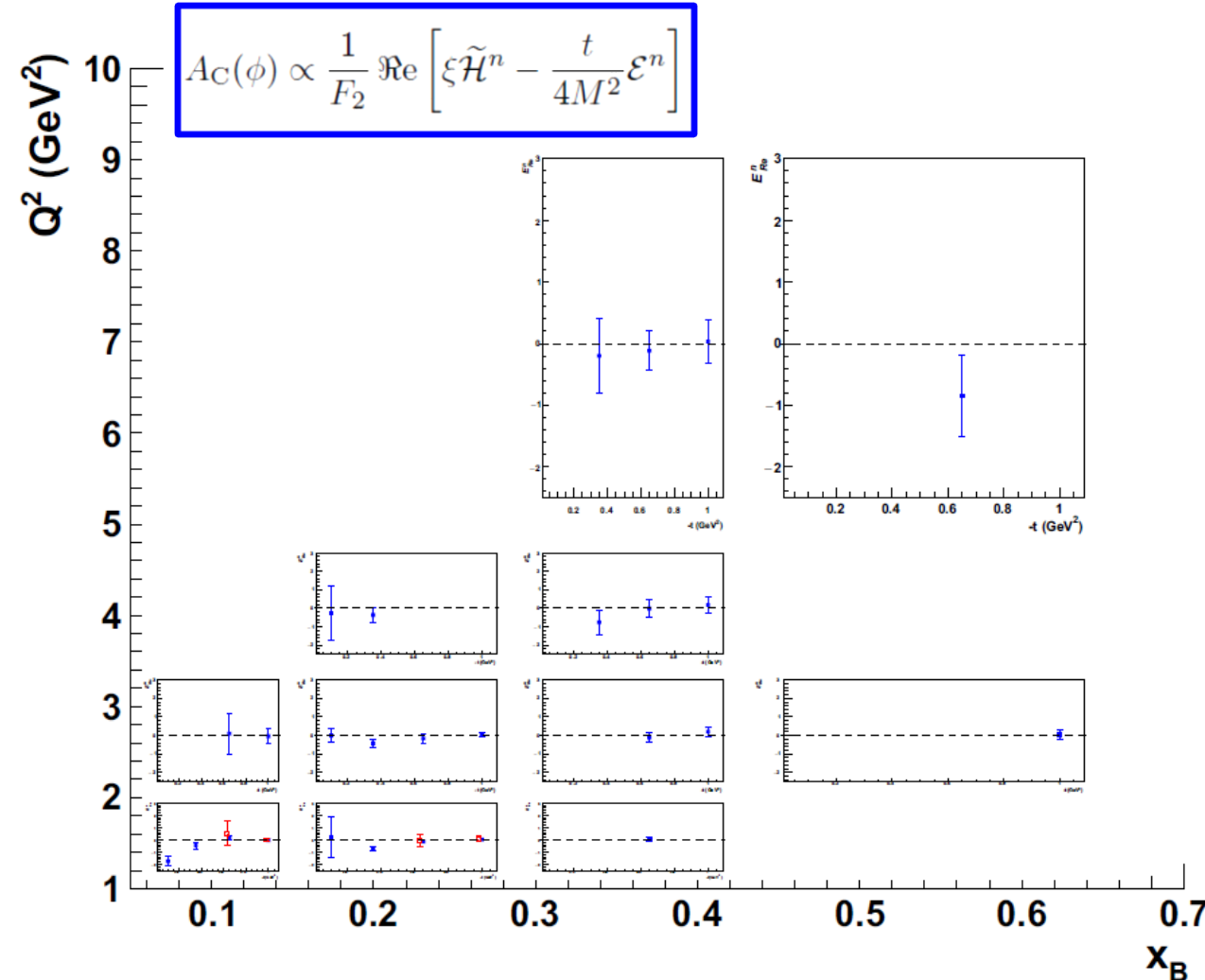


nDVCS with polarized positrons beam at CLAS12



Projections (VGG) for the BCA, for various values of J_u, J_d
 0.3, 0.1; **0.2/0.0**; **0.1/-0.1**; **0.3/-0.1**

S.N. et al, Eur. Phys. J. A (2021) 57, 226



Impact on the extraction of **ReE** using local fits, fitting
 the projections of all approved CLAS12 nDVCS
 measurements **with** and **without** BCA

pDVCS with polarized positrons beam in Hall C

Combining the HMS and the NPS spectrometers, precise DVCS cross section measurements with **unpolarized positron** beam will be performed at selected kinematics where **electron beam** data will soon be accumulated.

PR12-20-012

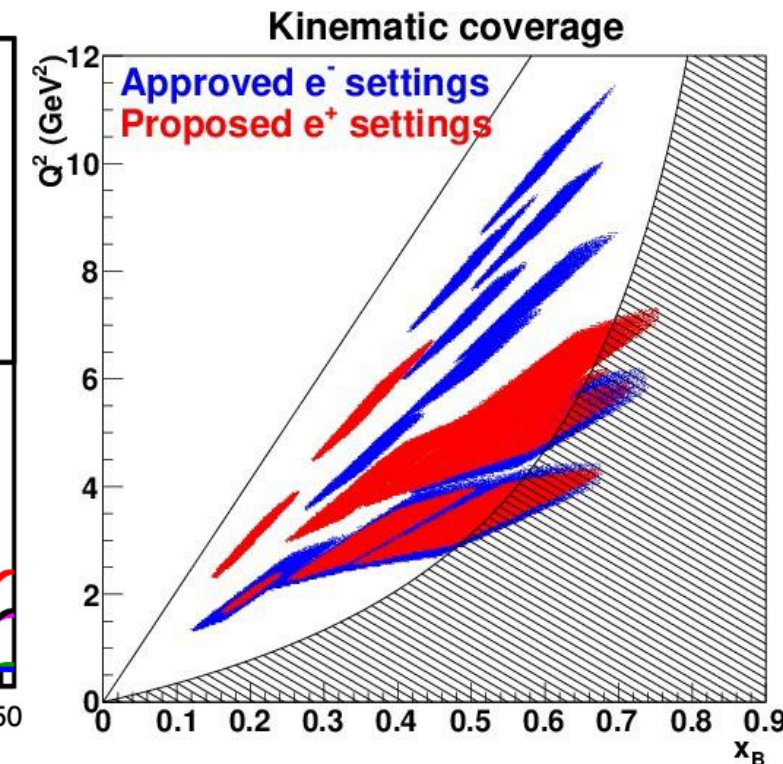
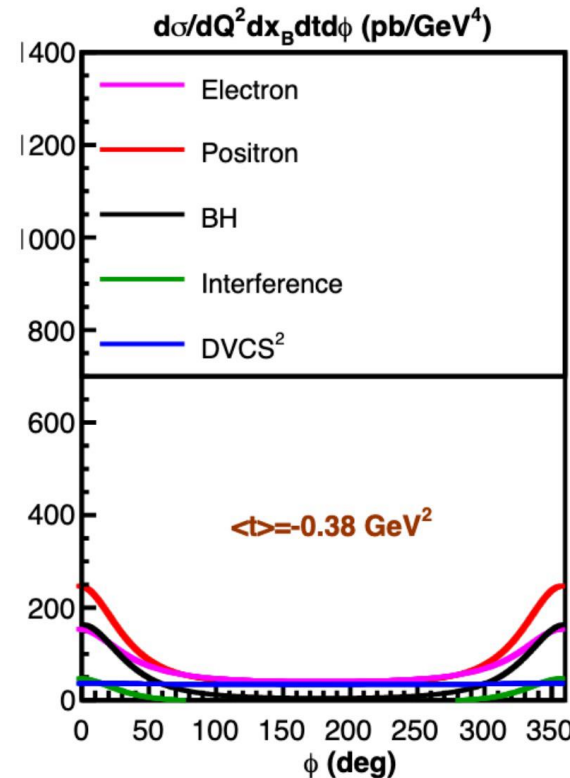
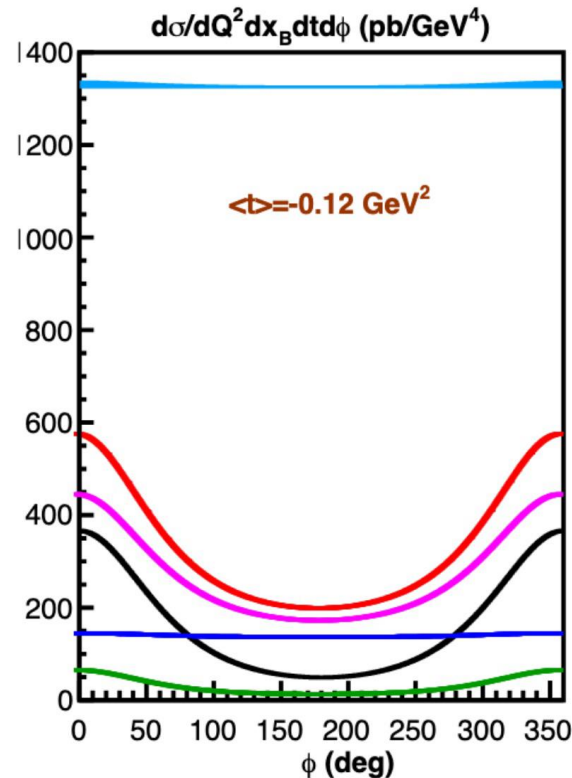
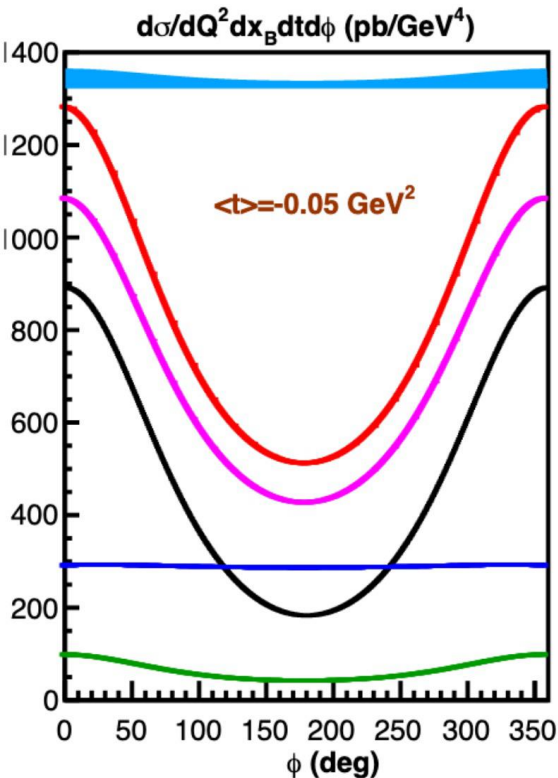
J. Grames, M. Mazouz,

C. Muñoz Camacho et al.

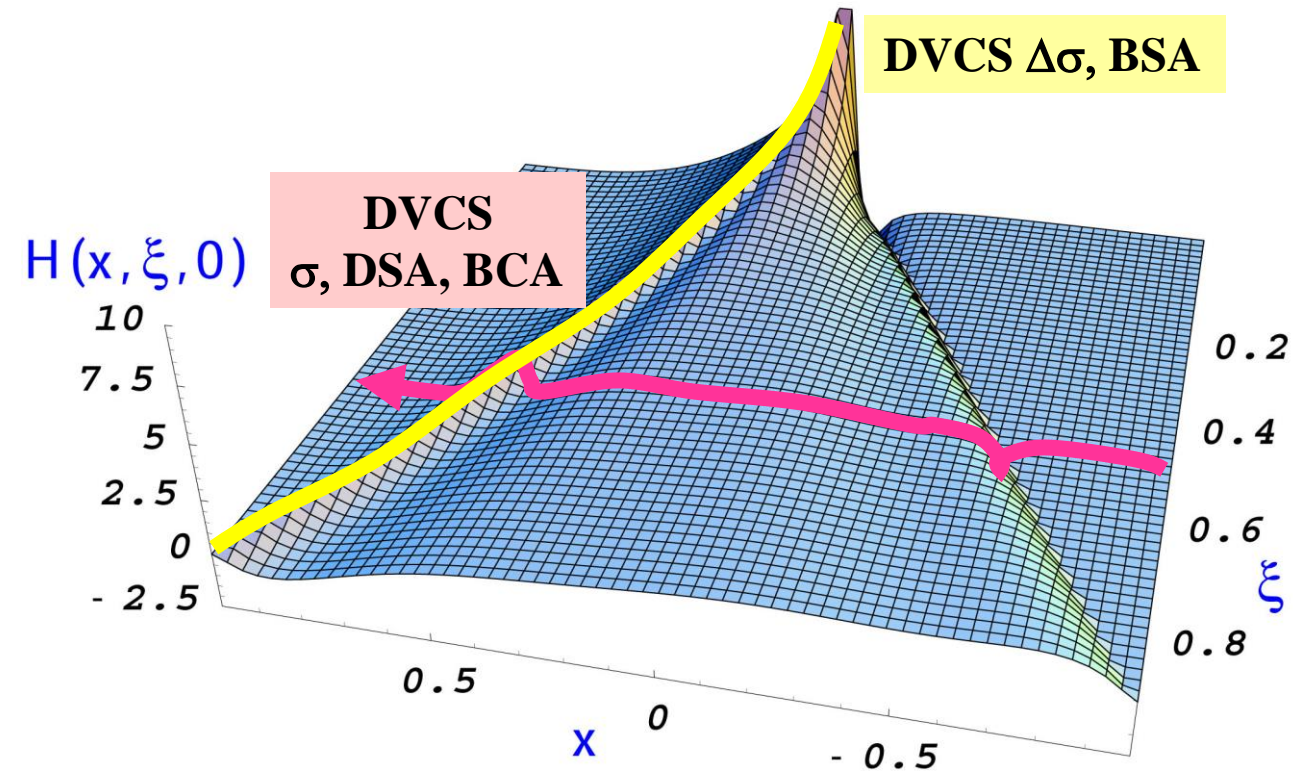
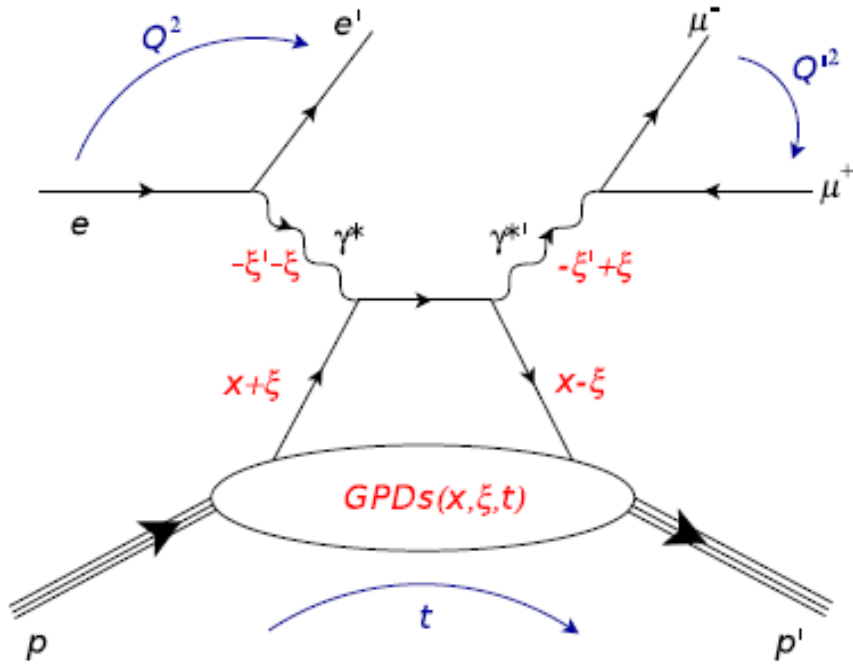
Conditionally approved

$$x_B = 0.5 \quad Q^2 = 3.4 \text{ GeV}^2$$

A. Afanasev et al, Eur. Phys. J. A 57 (2021) 10, 300



DDVCS: the gateway to the full kinematic mapping of GPDs



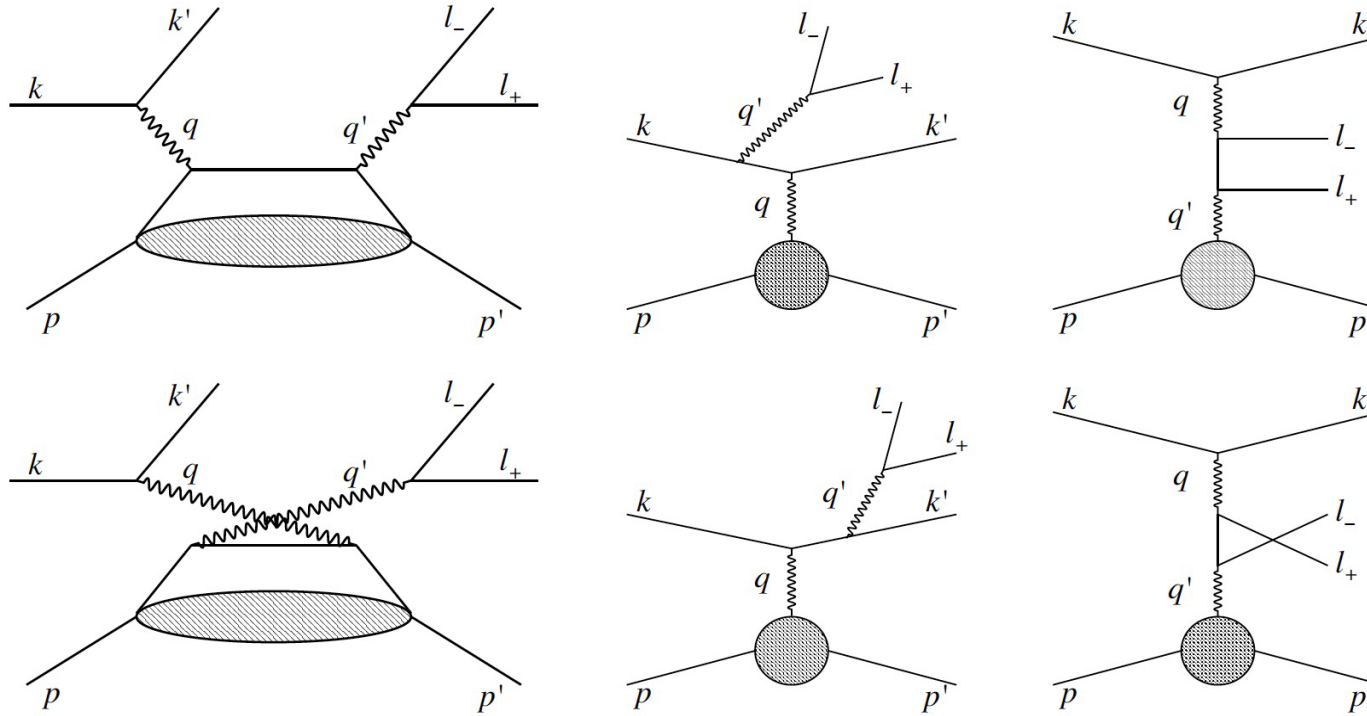
Thanks to the virtuality of the final photon, Q'^2 , **DDVCS** allows a unique direct access to GPDs at $x \neq \pm \xi$ (within $0 < 2\xi' - \xi < \xi$), which is fundamental for their modeling

Experimental challenges:

- Small cross section (300 times less than DVCS)
- Need to detect muons

$N(e,e'l^+l^-N)$ differential cross section

The lepto-production of a lepton-pair off the nucleon involves one **additional Bethe-Heitler** like mechanism. Integrating over the lepton-pair angles provides a **beam charge and polarization dependence similar to DVCS**, and INT_2 and BH_{12} terms vanish.



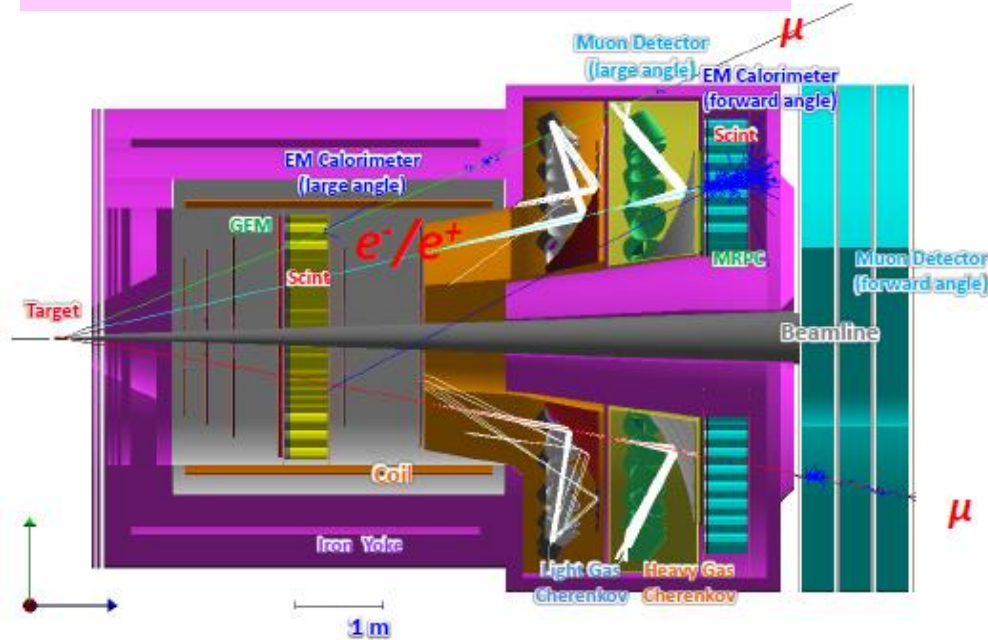
$$d^7\sigma_P^e = d^7\sigma_{BH_1} + d^7\sigma_{BH_2} + d^7\sigma_{DDVCS} + P d^7\tilde{\sigma}_{DDVCS} - e \left[d^7\sigma_{BH_{12}} + d^7\sigma_{INT_1} + P d^7\tilde{\sigma}_{INT_1} \right] + d^7\sigma_{INT_2} + P d^7\tilde{\sigma}_{INT_2}$$

$$d^5\sigma_P^e = d^5\sigma_{BH_1} + d^5\sigma_{BH_2} + d^5\sigma_{DDVCS} + P d^5\tilde{\sigma}_{DDVCS} - e \left[d^5\sigma_{INT_1} + P d^5\tilde{\sigma}_{INT_1} \right]$$

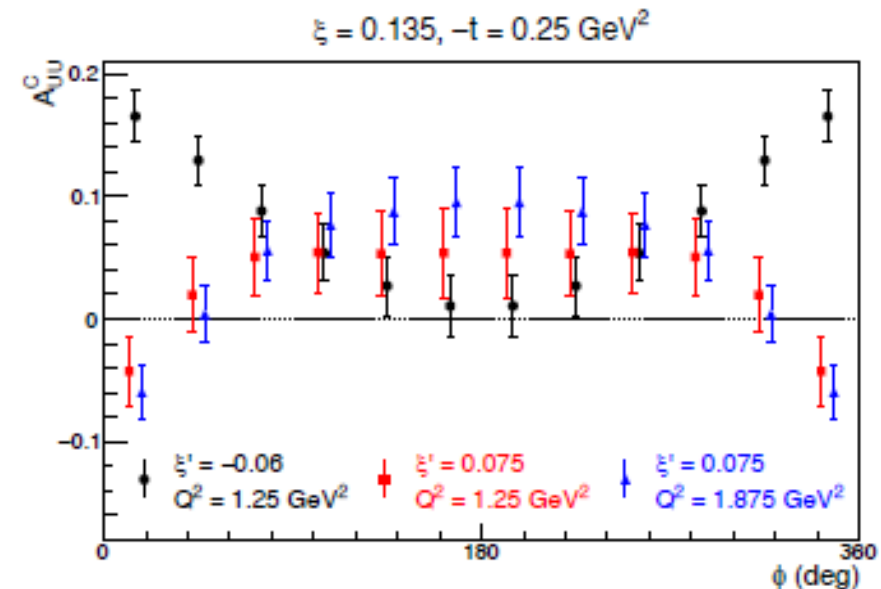
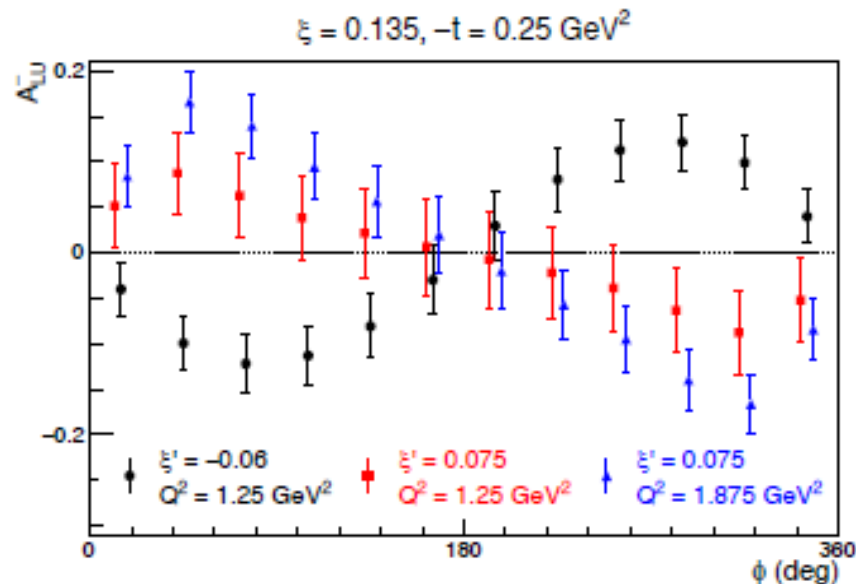
DDVCS with the SOLID detector

C. Peng's talk, WG6, Wednesday 5:50PM

S. Zhao et al., Eur. Phys. J.A 57 (2021) 7, 240



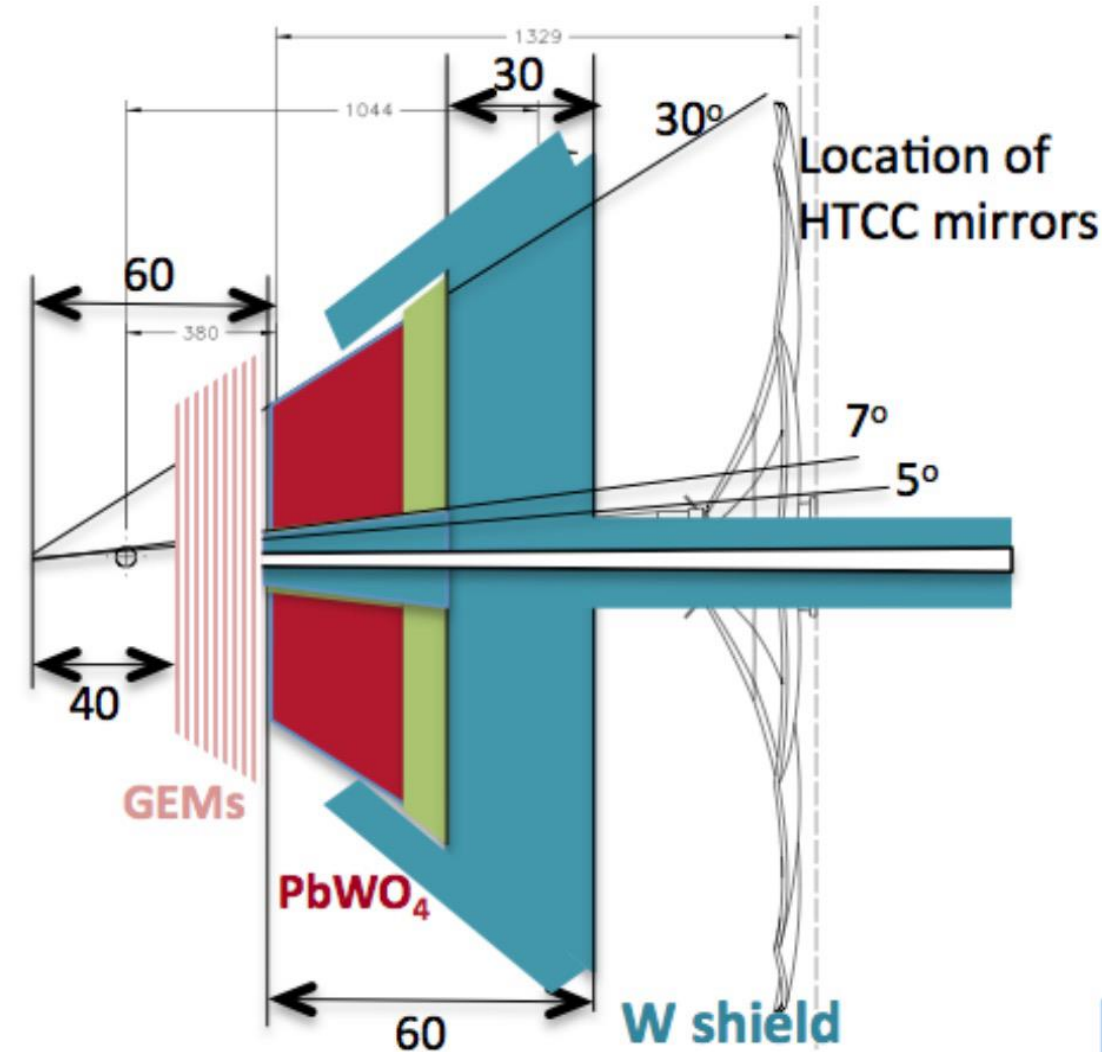
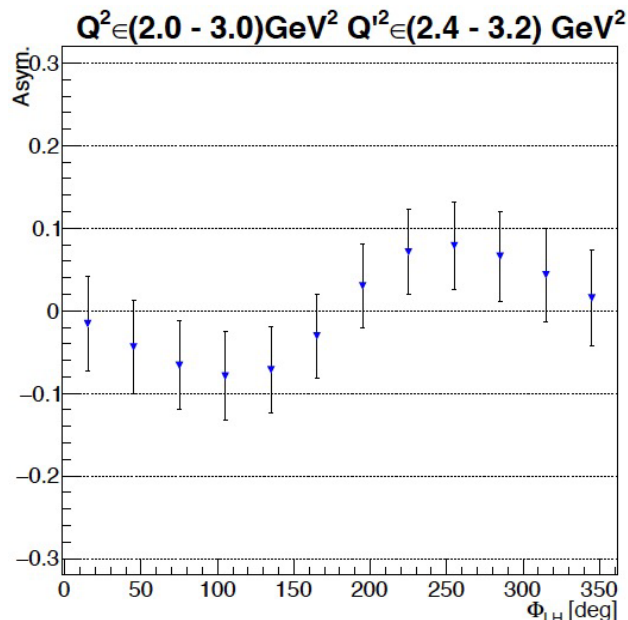
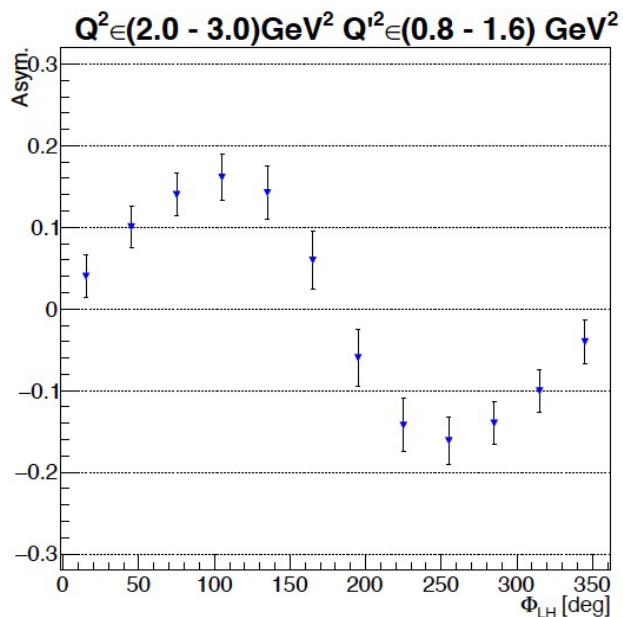
- The **SoLID** apparatus completed with **muon detectors** at large and forward angles, would allow DDVCS measurements with both polarized electron and polarized positron beams.
- The initial LoI discussed **electron BSA** measurements over a 50 days run parasitic to the J/ψ approved experiment.
- Completing this program with a 50 days positron beam run would provide **unpolarized BCA** data.



μ CLAS12 for DDVCS and J/psi (LOI12-16-004)

$ep \rightarrow e'p'\mu^+\mu^-$ at $L \sim 10^{37} \text{ cm}^{-2}\text{s}^{-1}$

- A modified CLAS12 spectrometer with a new tracker, a new calorimeter and a tungsten shield in the HTCC working volume would allow to increase CLAS12 luminosity up to $10^{37}\text{cm}^{-2} \text{ s}^{-1}$.
- The new detection system will serve electron identification.
- The CLAS12 forward detector will act as a muon detector.
- This reconfigured CLAS12 spectrometer would measure DDVCS and J/ ψ electroproduction over a 100 days run.



Conclusions

A **rich** and **high-impact experimental program** to study nucleon structure by means of Generalized Parton Distributions has been developed, requiring a **polarized-positrons beam** at JLab

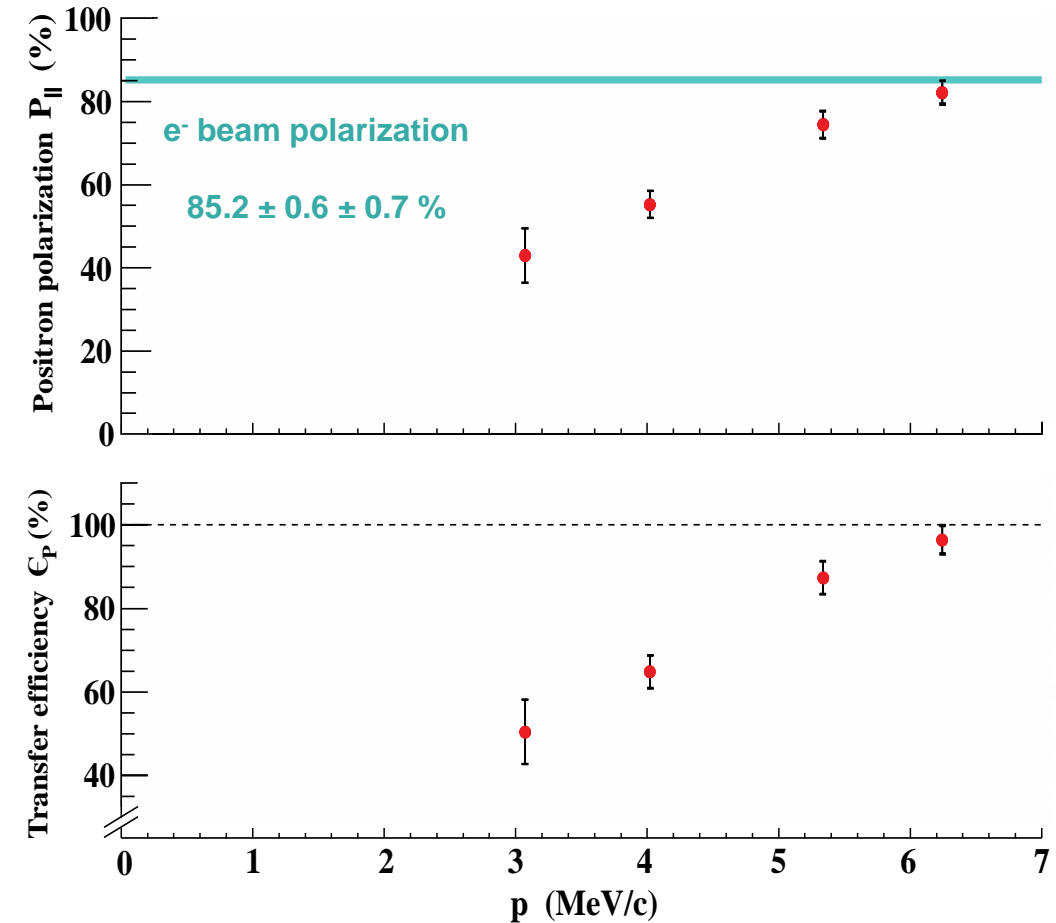
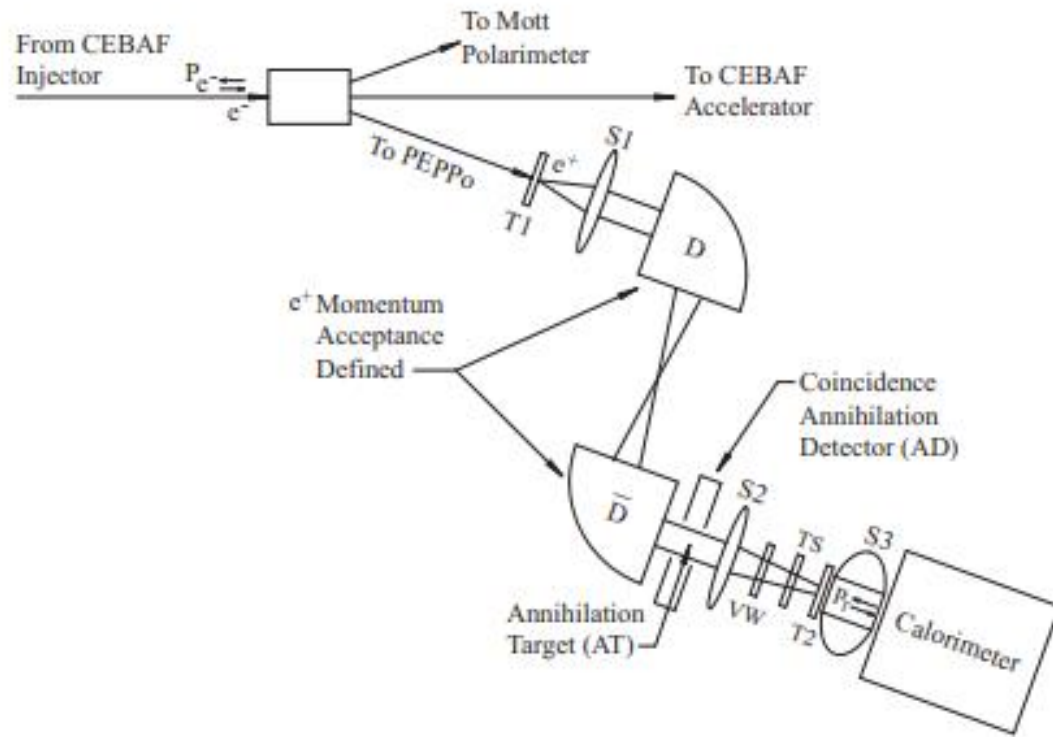
e^+ @JLab Topical Issue of EPJ A just published

- In the **DVCS** and **DDVCS** channels, **e^+** beams enable:
 - an undisputable **separation** of the **INT** amplitudes
 - a **direct access** to the **real part** of CFFs
 - a **window** to study **HT** and **NLO** effects.

Back-up slides

PEPPo: Polarized Electrons for Polarized Positrons

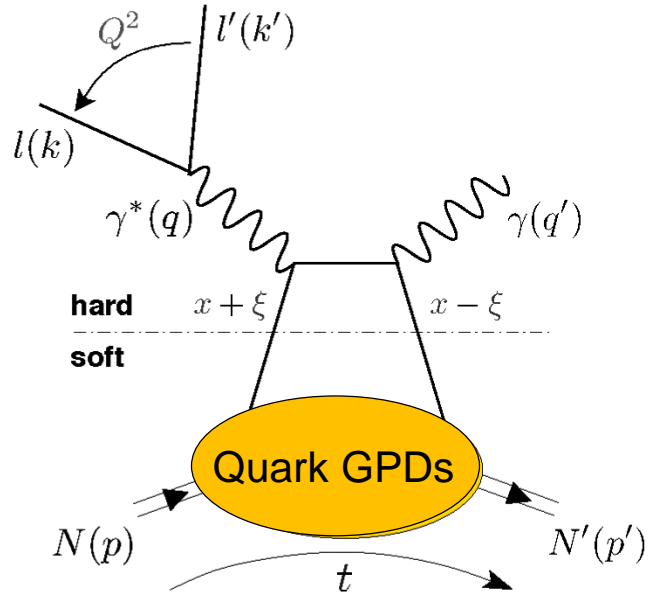
The PEPPo experiment at the CEBAF injector has shown an effective polarization transfer between electrons and positrons. It opens the possibility to produce polarized positrons with accelerators ~MeV



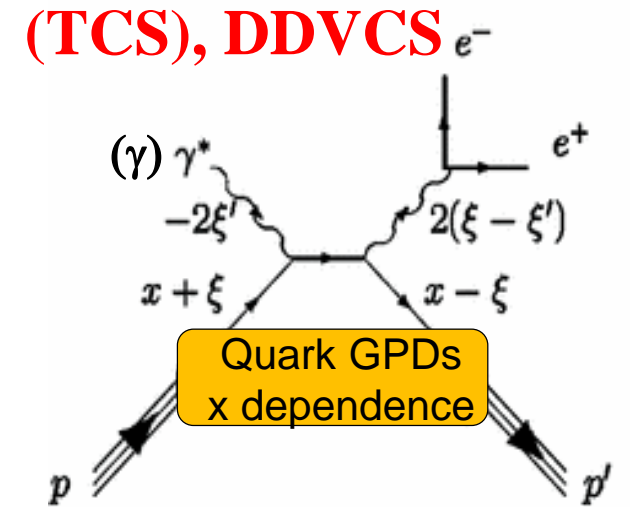
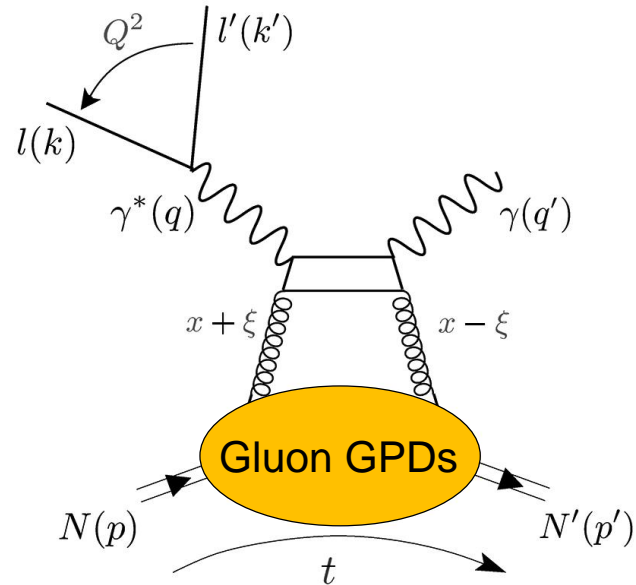
D. Abbott et al., PRL 116 (2016) 214801

Editor's choice, Physics Focus

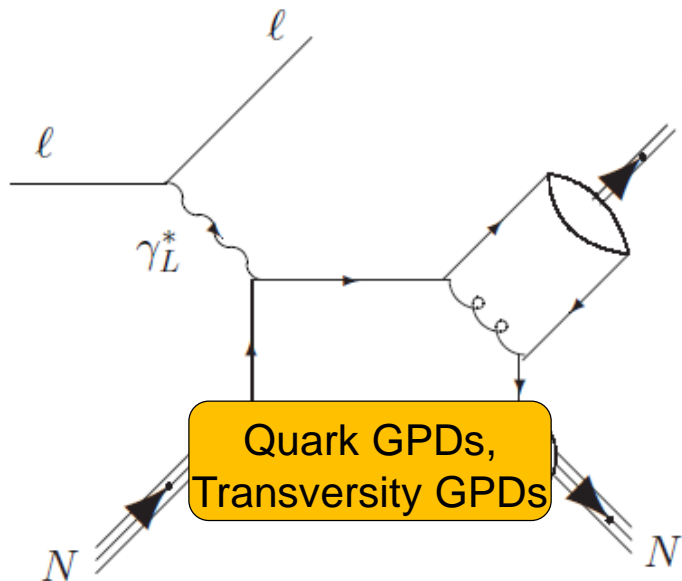
Exclusive reactions giving access to GPDs



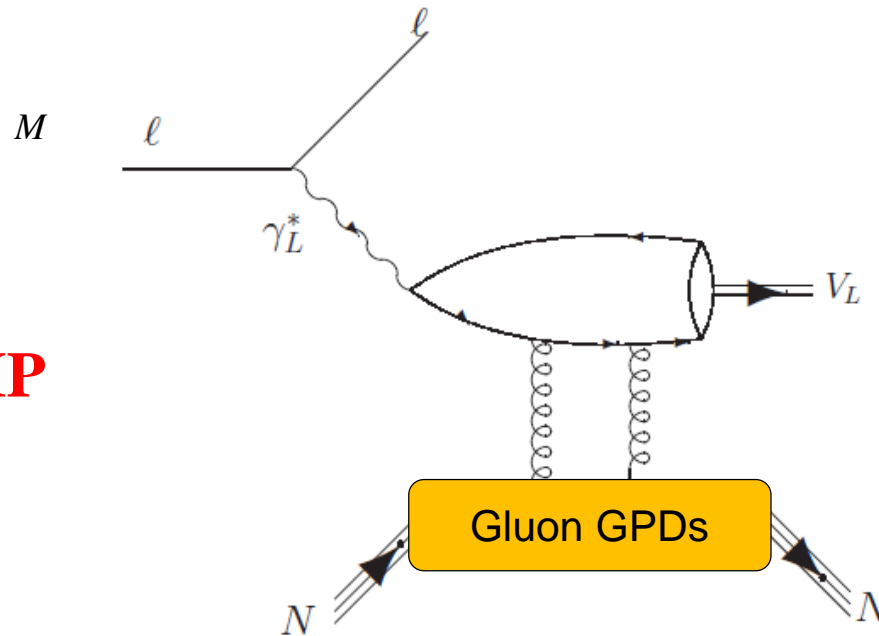
DVCS



Quark GPDs
x dependence



DVMP



Gluon GPDs