Jefferson Lab

Experimental overview of GPD results from CLAS

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Overview

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3. **Pioneering observations**
4. **Dedicated experiments**
   - e1dvcs
     - Solenoid and Inner Calorimeter
     - Flavor of analysis
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   - Towards GPDs extraction
   - Meson electroproduction
     - π^0 and η electroproduction
5. **DVCS on ^{4}He (eg6)**
   - Projected results

Physical content of GPDs :

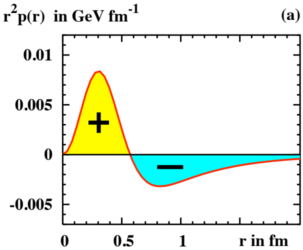
Energy-momentum tensor of q flavored quarks

$$\langle p_2 | \hat{T}^q_{\mu\nu} | p_1 \rangle = \bar{U}(p_2) \left[M_2^q(t) \frac{P_\mu P_\nu}{M} + J^q(t) \frac{\imath (P_\mu \sigma_{\nu\rho} + P_\nu \sigma_{\mu\rho}) \Delta^\rho}{2M} + d_1^q(t) \frac{\Delta_\mu \Delta_\nu - g_{\mu\nu} \Delta^2}{5M} \right] U(p_1)$$

To measure gravitational FFs : graviton scattering or GPDs identities :

$$J^q(t) = \frac{1}{2} \int_{-1}^{1} dx\, x \left[H^q(x,\xi,t) + E^q(x,\xi,t) \right] , \quad M_2^q(t) + \frac{4}{5} d_1(t) \xi^2 = \frac{1}{2} \int_{-1}^{1} dx\, x H^q(x,\xi,t)$$

(Ji's sum rule)



Stability $\Rightarrow \int_0^\infty dr\, r^2 p(r) = 0$

$r < 0.57$ fm $\Rightarrow p(r) > 0 \leftrightarrow$ repulsion (quark core)
$r > 0.57$ fm $\Rightarrow p(r) > 0 \leftrightarrow$ attraction (pion cloud)

K.Goeke,*& al*, Phys. Rev. **D75** (2007) 094021

Access to GPDs : the DVCS process

Observables in the Bjorken limit

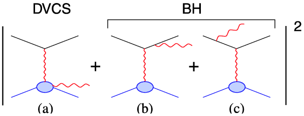
$$\gamma^* p \rightarrow \gamma p'$$

Bjorken regime :

$$Q^2 \rightarrow \infty,$$
$$\nu \rightarrow \infty,$$
$$x_B = Q^2/2M\nu \text{ fixed}$$
$$\left(\xi \rightarrow \frac{x_B}{2-x_B}\right)$$

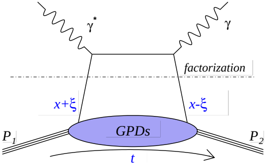
$$\vec{e}p \rightarrow ep\gamma$$

$\sigma(ep \rightarrow ep\gamma) \propto$



Diehl, Gousset, Pire, Ralston (1997)

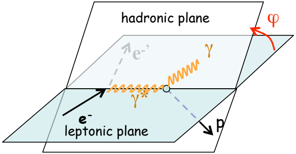
Belitsky, Müller, Kirchner (2002)



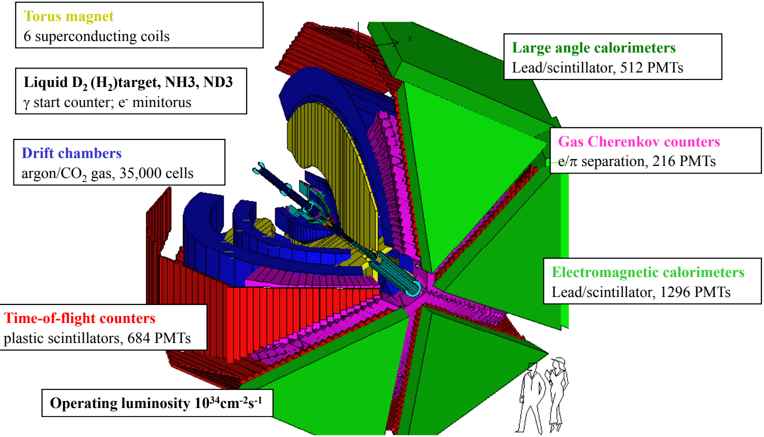
$$A_{LU} = \frac{d^4\sigma^{\rightarrow} - d^4\sigma^{\leftarrow}}{d^4\sigma^{\rightarrow} + d^4\sigma^{\leftarrow}} \overset{\text{twist-2}}{\approx} \frac{\alpha \sin\phi}{1 + \beta\cos\phi}$$

$$\alpha \propto \left(F_1 \mathcal{H} + \xi G_M \tilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E}\right)$$

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



Detector overview

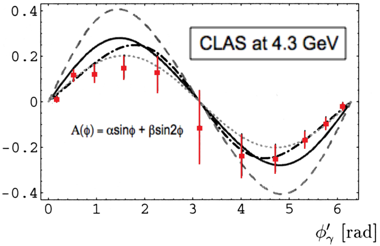


Pioneering observations

First DVCS BSA and TSA observations

A_{LU} ^{1}H target
polarisation $\approx$ 70%, $\int \mathcal{L} \approx 1.3$ fb^{-1}

$F_1 \mathcal{H} + \xi G_M \tilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E}$



$Q^2 = 1.3$ GeV^2, $x_B = 0.2$, $-t = 0.2$ GeV^2

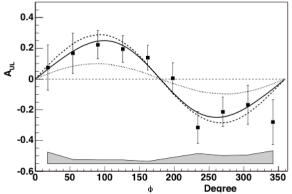
$$\begin{aligned} A(\phi) &= \alpha \sin\phi + \beta \cos(2\phi) \\ \alpha &= 0.202 \pm 0.028^{stat} \pm 0.013^{syst} \\ \beta &= -0.024 \pm 0.021^{stat} \pm 0.009^{syst} \end{aligned}$$

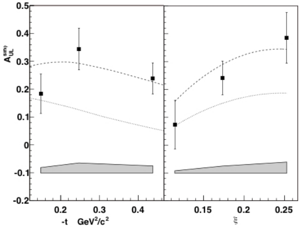
S. Stepanyan *at al.*,

PRL **87** (2001) 182002

A_{UL} $^{15}NH_3$ target, 60 to 80%
beam 5.7 GeV $\int \mathcal{L} \approx 1.3$ fb^{-1}

$F_1 \tilde{\mathcal{H}} + \xi G_M \left(\mathcal{H} + \frac{\xi}{1+\xi} \mathcal{E} \right) - \cdots$





S. Chen *et al.*,

PRL **97** (2006) 072002

Solenoid and Inner Calorimeter

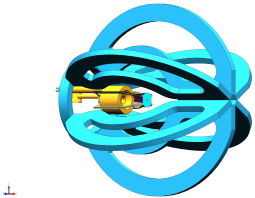
New design

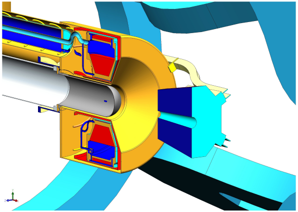
Hydrogen target, beam polarisation $\approx$ 80%, $\int \mathcal{L} \approx 45\ \text{fb}^{-1}$

- Inner Calorimeter (IC) :
  424 $PbWO_4$ crystals
  (16 cm length, 1.3 cm^2 to 1.6 cm^2)
  $X_0 = 0.9$ cm, $R_M = 2.0$ cm
  Truncated pyramidal stacking
  Light collection : APDs
  $-2\%/^\circ \Rightarrow$ temperature stabilisation
  laser monitoring system
- Move target upstream w.r.t. nominal CLAS center
- Superconductor solenoidal magnet :
  Cu+Nb/Ti alloy at 4.3 K
  Original cryogenic system
  Additional coil compensate fringe field

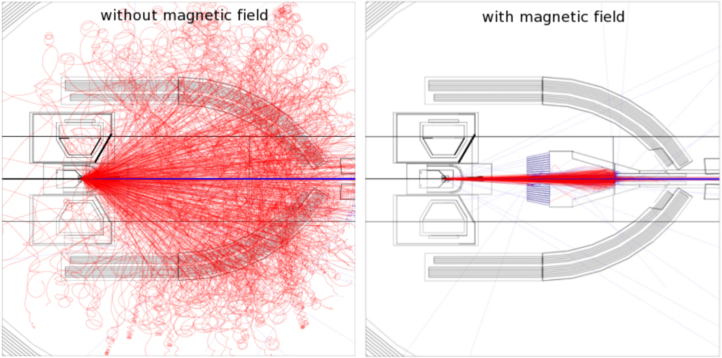
  Average field at the level of

  the target 4.5 T at 534 A



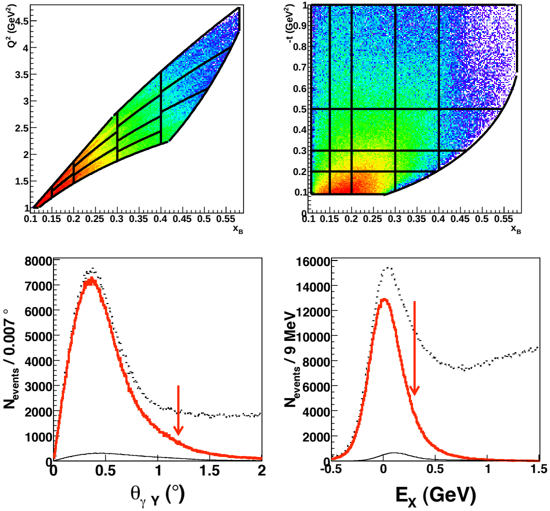


Solenoid and Inner Calorimeter
Solenoid



Flavor of analysis

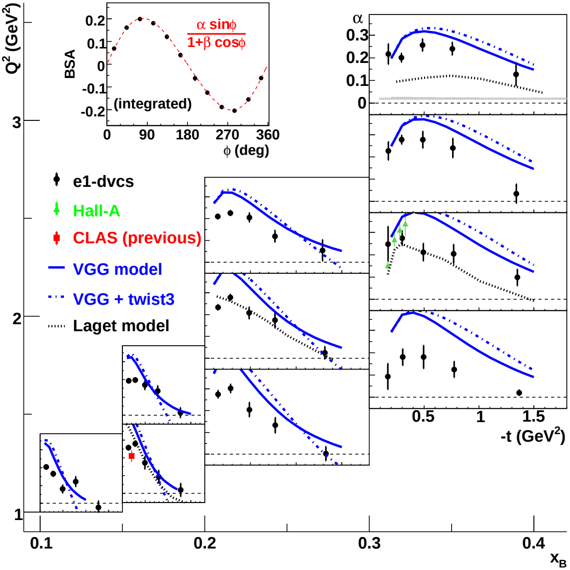
- kinematical coverage
- exclusivity cuts
- π^0 subtraction



Selected results

Proton BSA

$$F_1\mathcal{H} + \xi G_M\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}$$

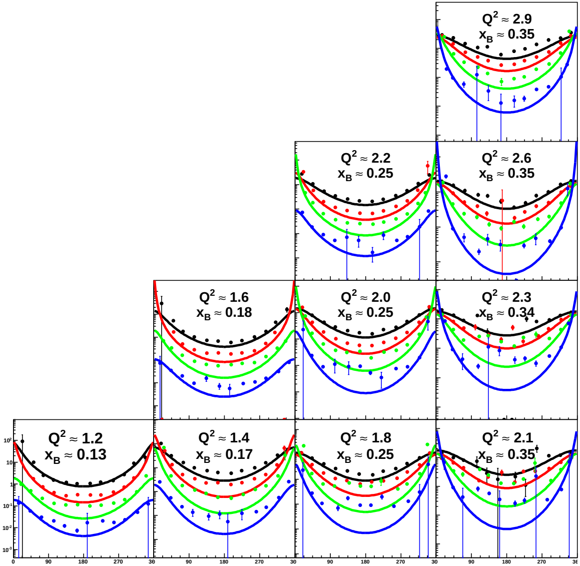


F.-X. G. *et al.*, PRL **100** (2008) 162002

Selected results

Proton cross-section (preliminary)

$F_1\mathcal{H} + \xi G_M\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}$

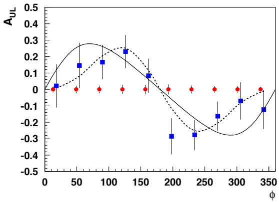


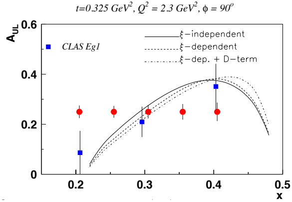
Proton DVCS

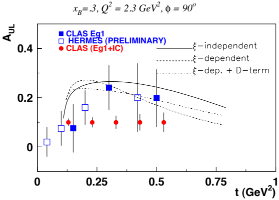
σ, BSA and TSA$_{||}$

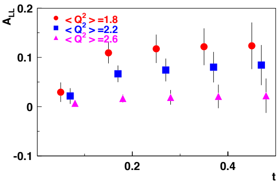
- Increase statistics with
  - better background conditions for σ and BSA
  - charged particle tagging in the Inner Calorimeter
- Dedicated experiment for TSA$_{||}$ with IC

$$F_1\tilde{\mathcal{H}} + \xi G_M\left(\mathcal{H} + \frac{\xi}{1+\xi}\mathcal{E}\right) - \cdots$$







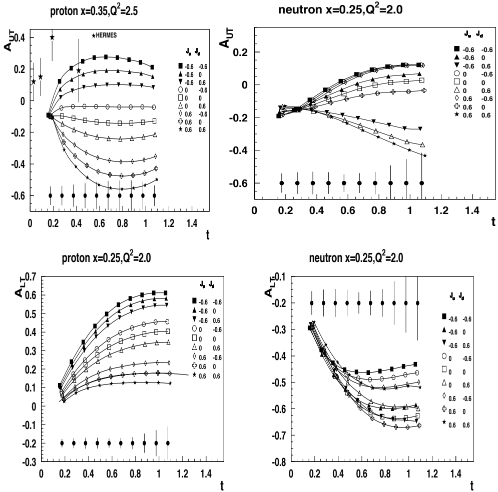


Proton/Neutron DVCS

A_{UT} and A_{LT}

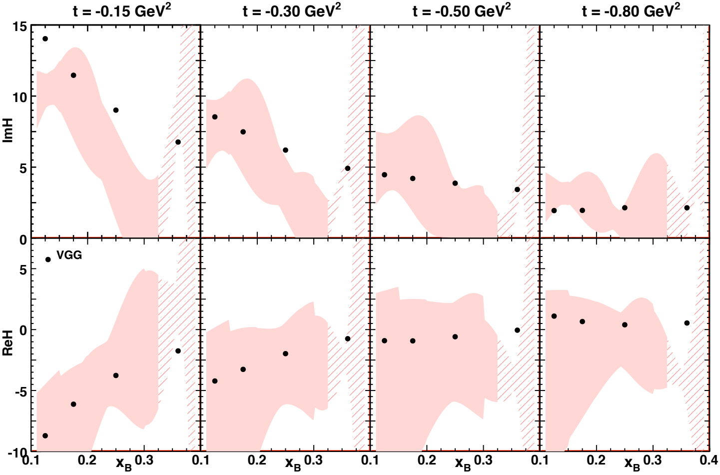
Conditionally approved experiment with HD-Ice target (2012)

$$\frac{t}{4M^2}\left(F_2\mathcal{H} - F_1\mathcal{E}\right)$$



Combined fit to all data will allow separation of $\mathcal{H}$, $\mathcal{E}$ and $\tilde{\mathcal{H}}$

Global analysis of CFFs

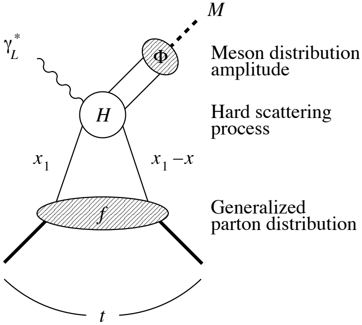


H. Moutarde, PR **D79** (2009) 094021

Meson electroproduction
Flavor decomposition

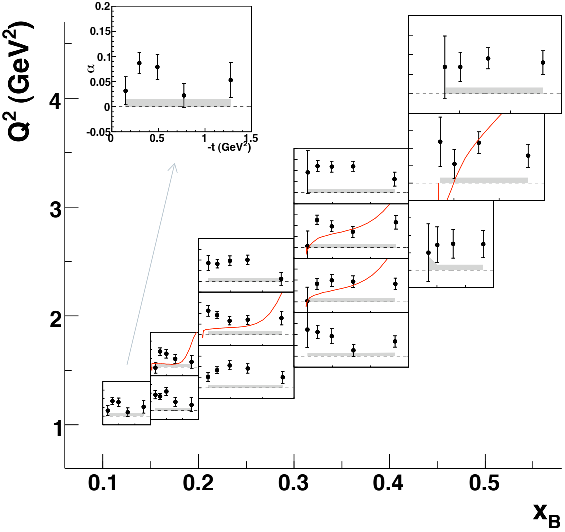
$\tilde{H}$, $\tilde{E}$	π^+	$\Delta u - \Delta d$
	π^0	$2\Delta u + \Delta d$
	η	$2\Delta u - \Delta d$
H, E	ρ^+	$u - d$
	ρ^0	$2u + d$
	ω	$2u - d$

- Factorization theorem for γ_L
- Additional gluon needed



Meson electroproduction

π^0 BSA

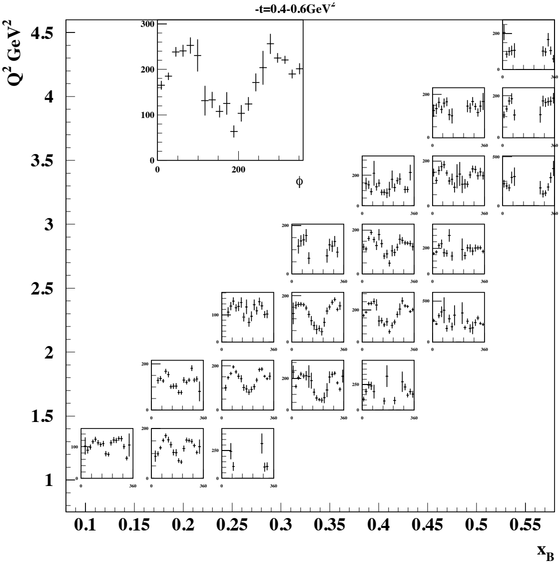


R. de Masi *et al.*, Phys. Rev. **C77** (2008) 042201

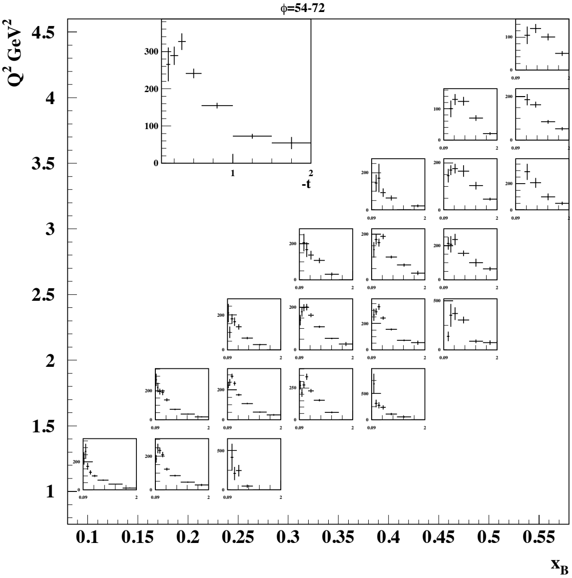
Significant LT' interferences

Meson electroproduction

π^0 cross section

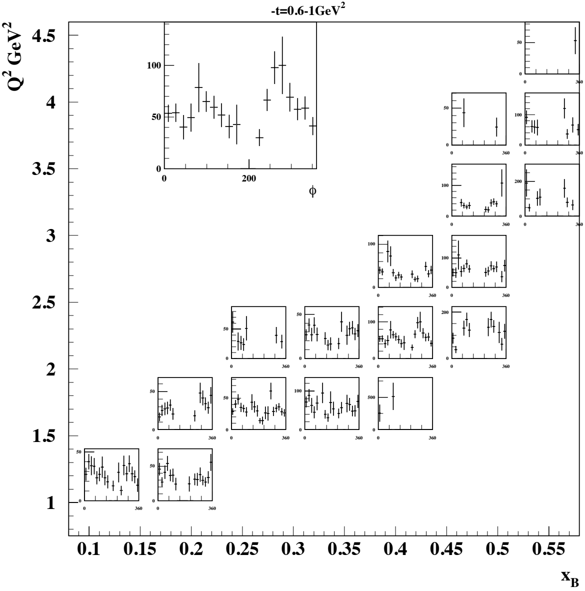


Meson electroproduction
π^0 cross section



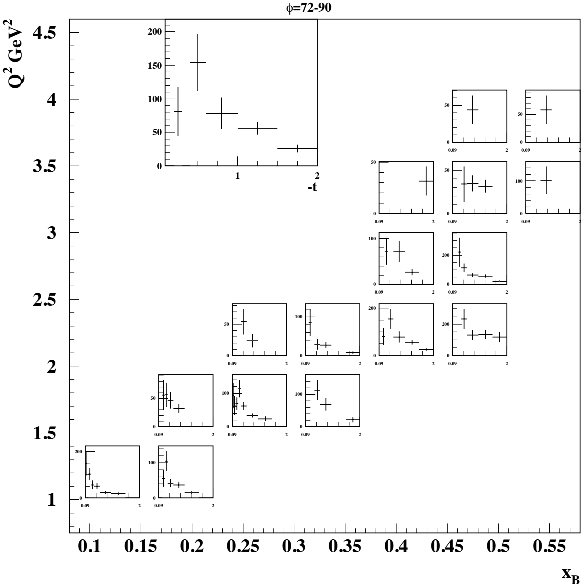
Meson electroproduction

η cross section



Meson electroproduction

η cross section



DVCS on a scalar nucleus

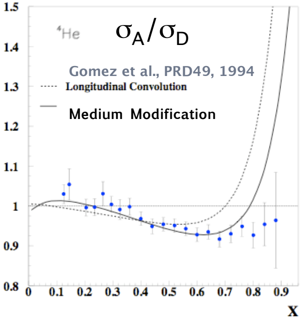
Only one twist-2 GPD, real and imaginary parts of the CFF can be fitted from the BSA simultaneously

EMC effect :

- Fermi motion ?
- Shadowing ?
- Off-shell effects ?
- . . . ?

Non-forward EMC effect provides additional constraints to the models

^{4}He is dense and simple enough for exact calculations at the proton and neutron level



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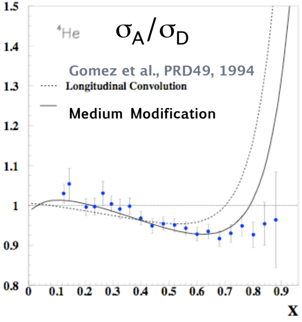
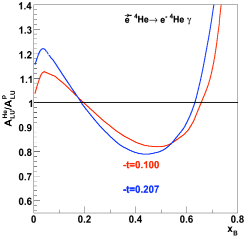
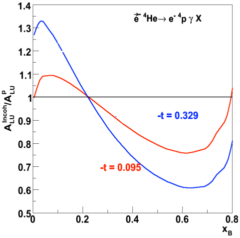
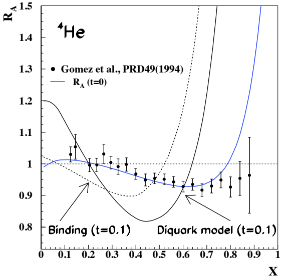
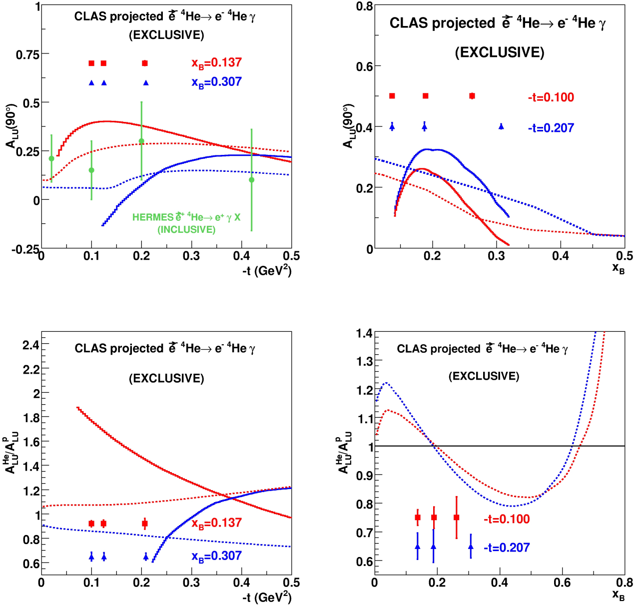








Projected results BSA and CFF



Conclusion

Summary

- 3-D imaging and spin structure of the nucleon *via* GPDs
- CLAS first expriments pioneered the way to study hadron structure with exclusive reactions
- First dedicated experiments have provided us with important insights
- Aiming at a common framework for a global analysis, with different complementary approaches
- CLAS12 will participate crucially in this program