

DVCS off ^4He : Toward the 3D Tomography of the Atomic Nuclei

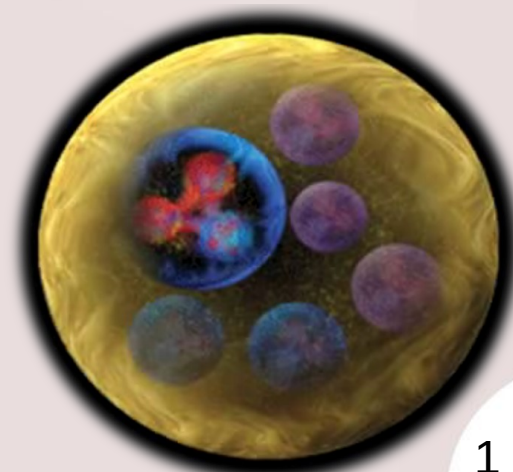
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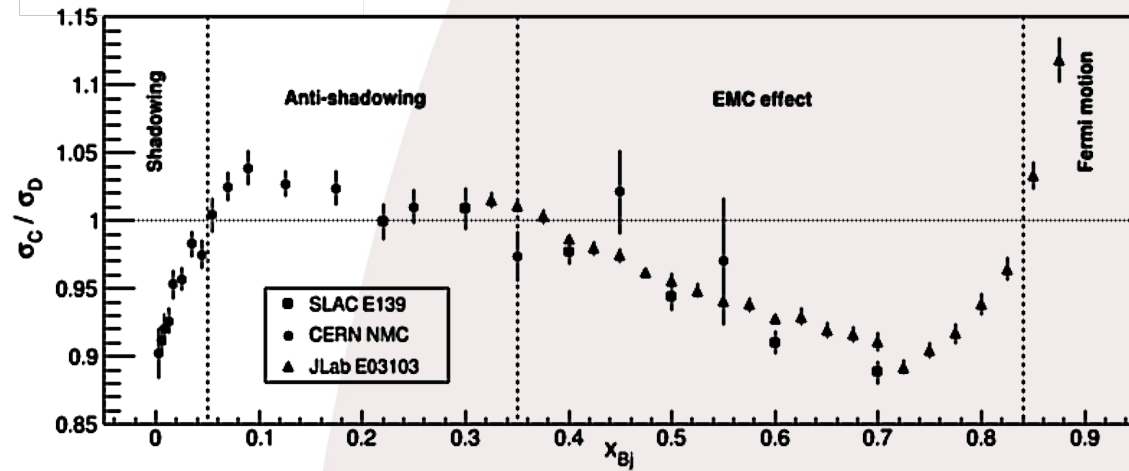
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Partonic Structure of Nuclei



- **Nuclear form factors**

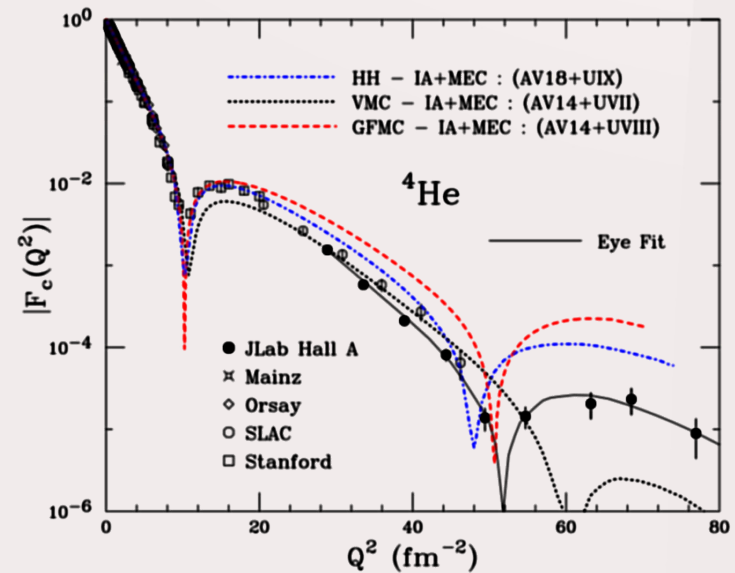
- Larger size than proton → Stronger drop in Q^2
- Reveal the structure of the nuclei
 - Mostly interpreted in term of nucleons

- **Nuclear PDFs**

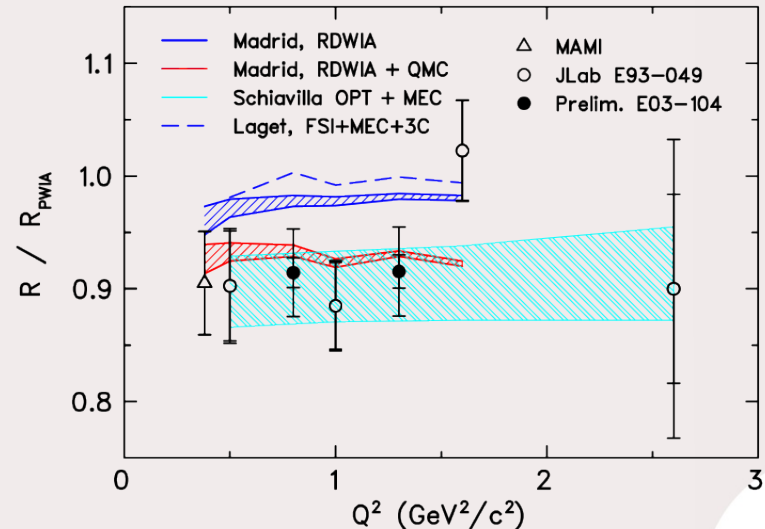
- We did not expect a significant effect
 - Binding is only at the level of MeV
- We found several: shadowing, EMC...

- **Bound nucleon FF**

- Quasi-elastic scattering on a bound nucleon
- Attempt to reveal the modification of nucleons in the nuclear medium

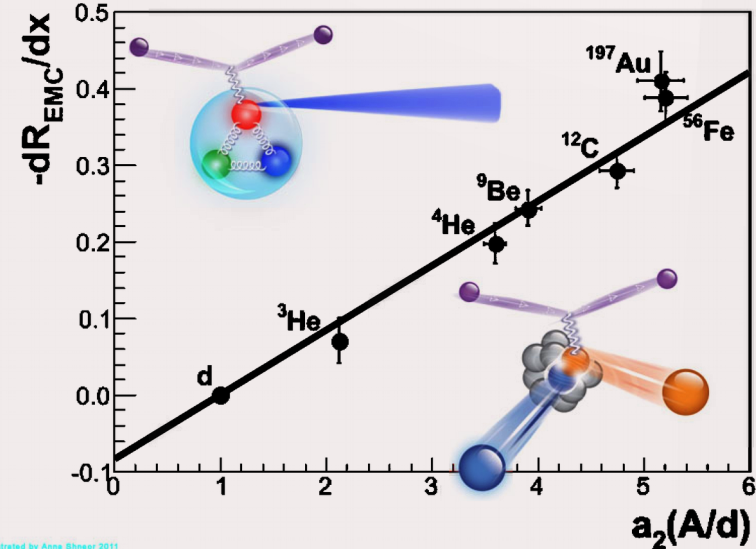
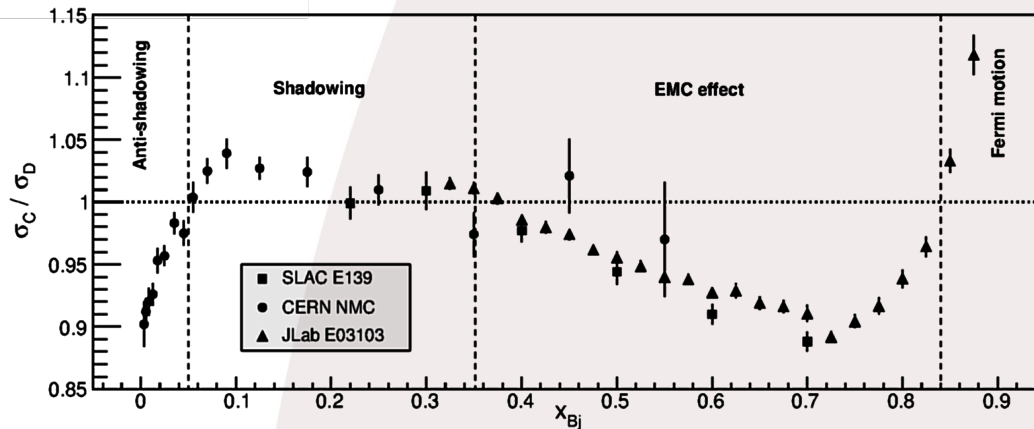


A. Camsonne et al. Phys.Rev.Lett. 112 (2014)



S. Strauch et al. Phys.Rev.Lett. 91 (2003) 052301

The EMC effect

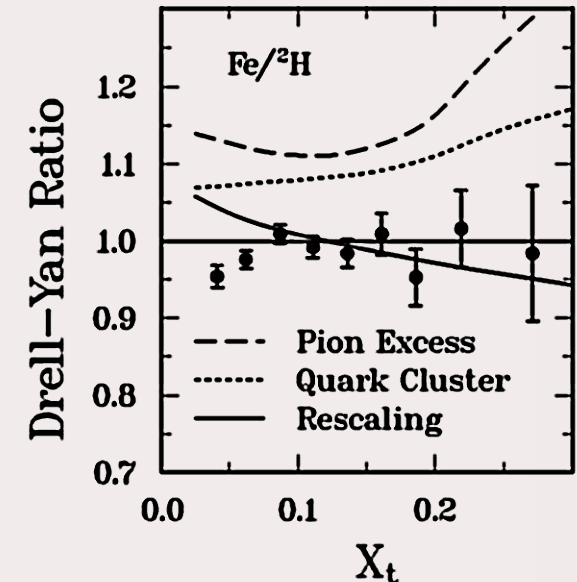


Illustrated by Anna Shearer 2011

Many models for the EMC effect

- Add the meson content induced by NN interaction
 - Drell-Yan experiment showed otherwise...
- Nucleon size might change \rightarrow bound FF
 - Difficult to account for FSI effects
- x-rescaling due to the binding energy
- Q^2 -rescaling by modifying the QCD in medium
- Short range nucleon correlations
- 6, 9, 12-quark clusters

What can the recent developments on GPDs and TMDs bring to better understand the nucleus?



D.M. Alde et al. Phys. Rev. Lett. 64, 2479 (1990)

L.B. Weinstein et al., Phys. Rev. Lett. 106, 052301 (2011)

Generalized Parton Distributions

- Generalizing the parton distributions (GPD)**

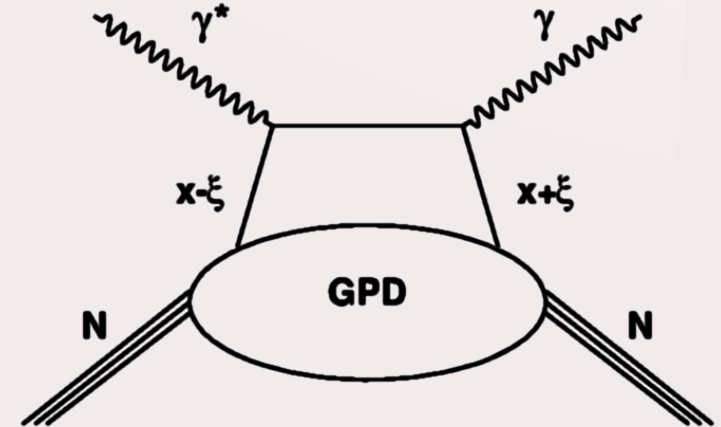
- Three dimensions: x , ξ and t
- Spin-0 \rightarrow 1 GPD /// Spin-1/2 \rightarrow 4 GPDs ///
- Spin-1 \rightarrow 9 GPDs /// ...
- Accessible through exclusive processes
 - DVCS, DVMP, TCS, DDVCS...

- Deep virtual Compton scattering (DVCS)**

- The exclusive electro-production of a photon
- The simplest access to GPDs
- x is not observable \rightarrow Compton Form Factors (CFF)

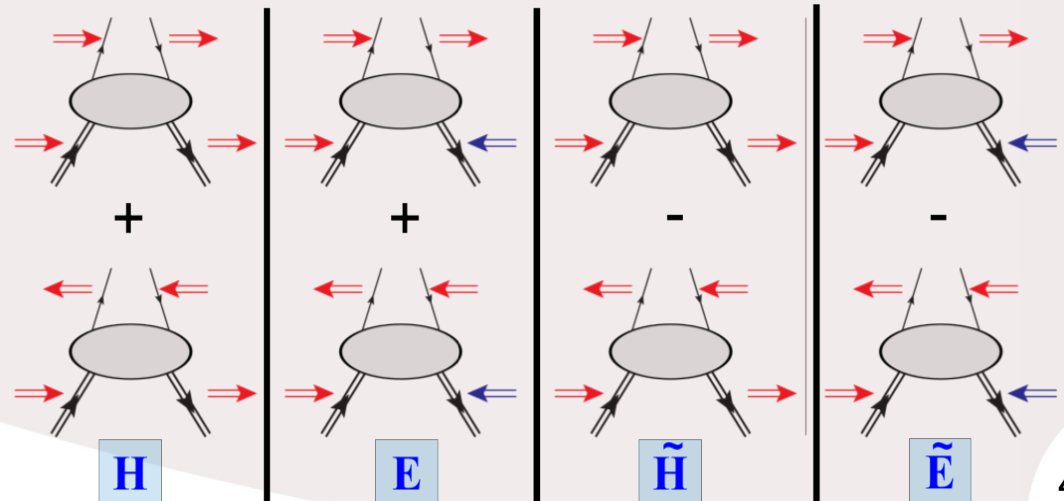
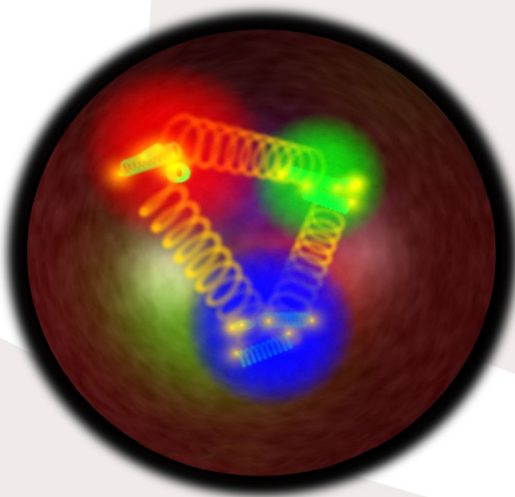
A.V. Radyushkin Phys.Rev. D56 (1997) 5524

M. Guidal et al. Rept.Prog.Phys. 76 (2013) 066202



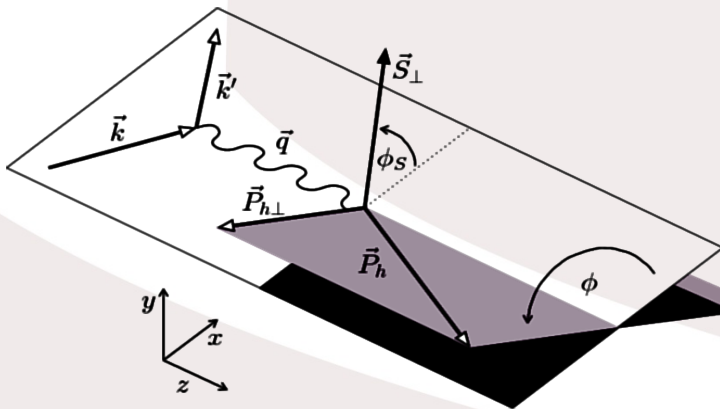
$$F_{Re}(\xi, t) = \mathcal{P} \int_{-1}^1 dx \left[\frac{1}{x - \xi} \mp \frac{1}{x + \xi} \right] F(x, \xi, t),$$

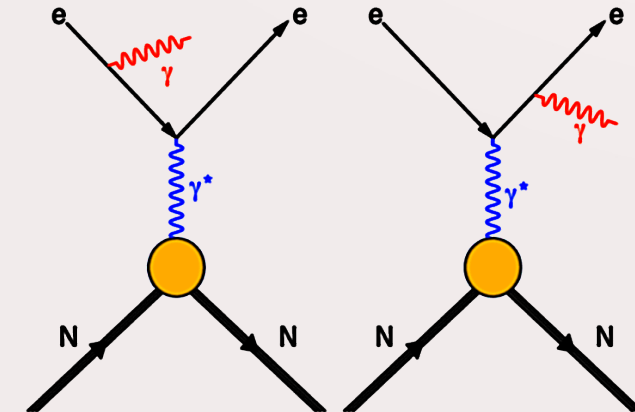
$$F_{Im}(\xi, t) = F(\xi, \xi, t) \mp F(-\xi, \xi, t).$$



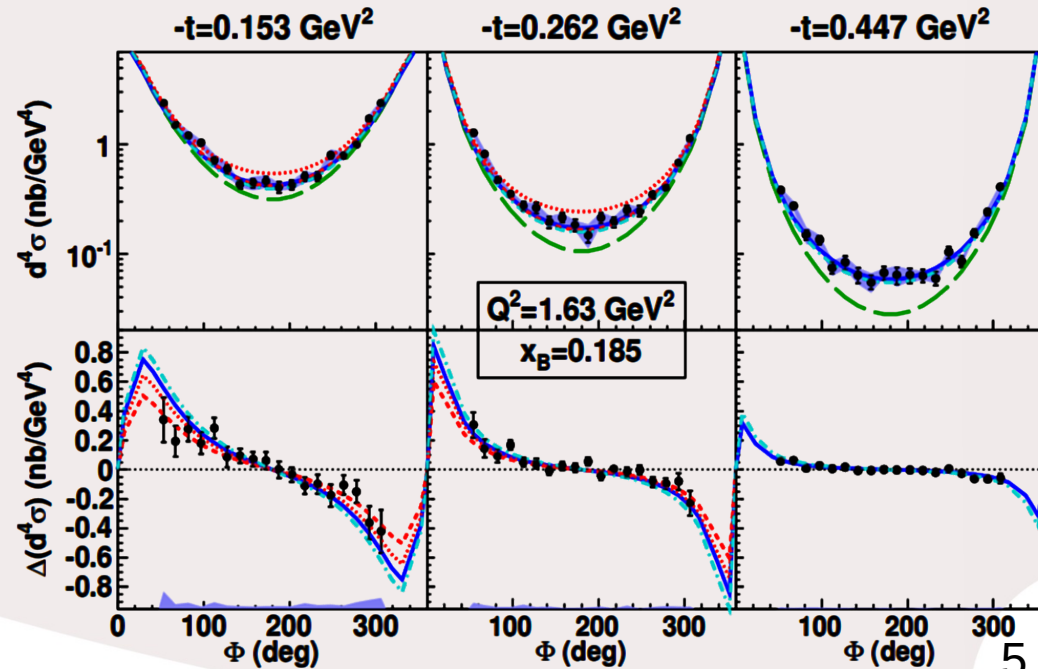
Measuring DVCS

- DVCS is not the only process to produce photons exclusively**
 - Important Bethe-Heitler contribution
 - Highly dependent on ϕ and generates asymmetries through interference
- We measure many observables**
 - Absolute cross sections
 - Spin asymmetries (beam and target)
 - Charge asymmetries
- Then, we extract the complex CFF**
 - A complete set of measurement possible
 - But rarely achieved experimentally

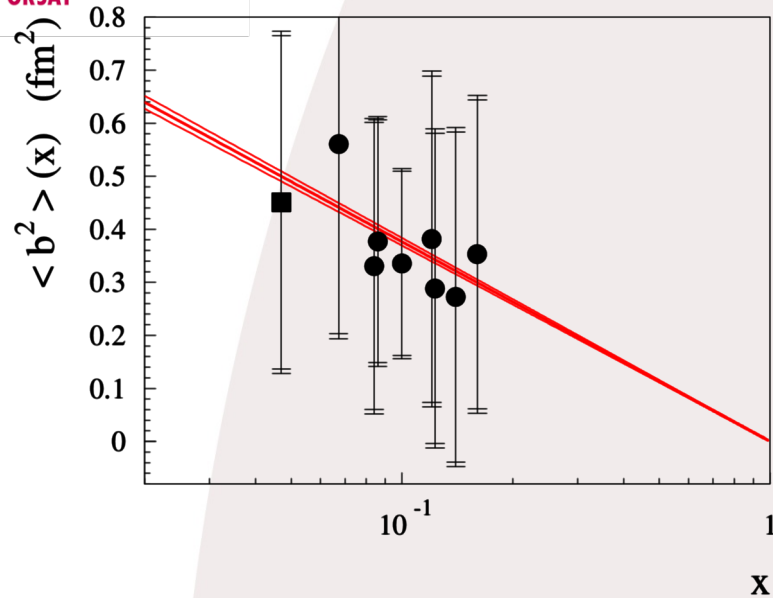




$$d\sigma \propto |\tau_{\text{BH}}|^2 + \underbrace{(\tau_{\text{DVCS}}^* \tau_{\text{BH}} + \tau_{\text{BH}}^* \tau_{\text{DVCS}})}_{\mathcal{I}} + |\tau_{\text{DVCS}}|^2$$

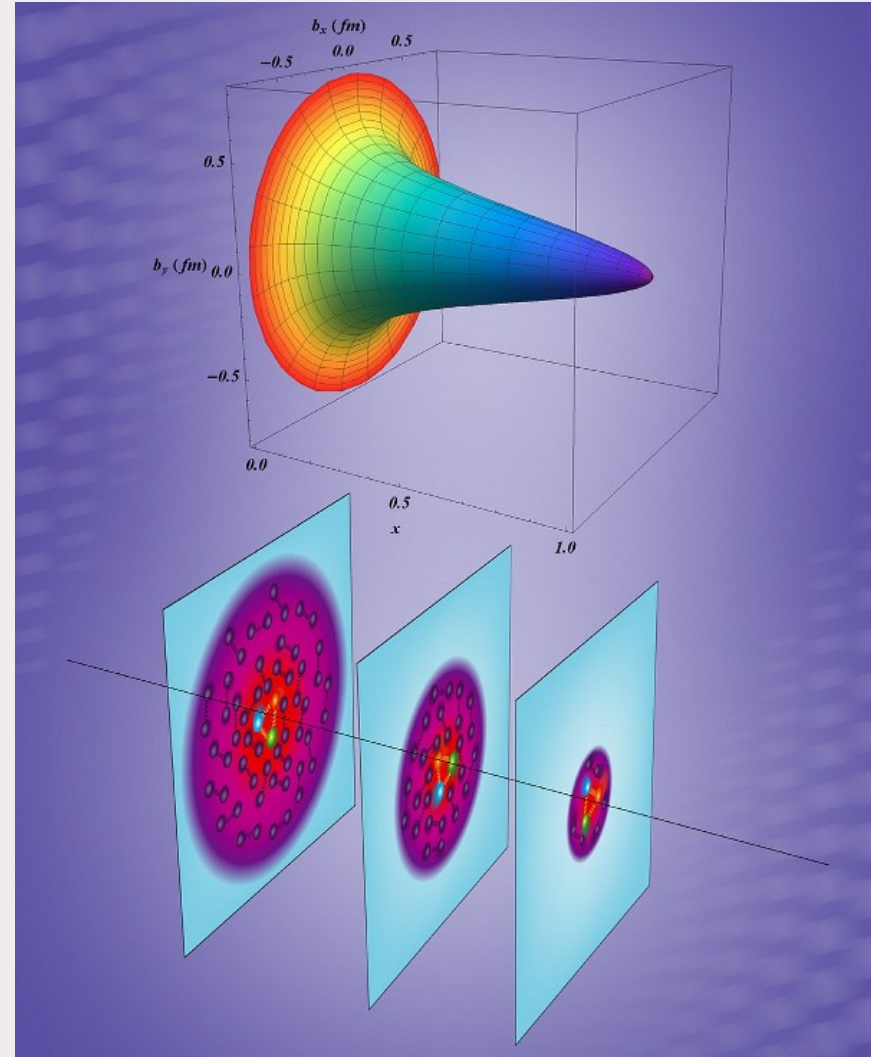


Proton Tomography



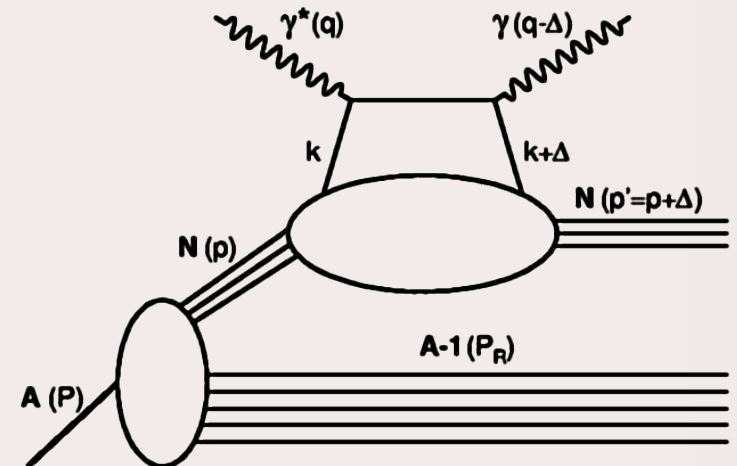
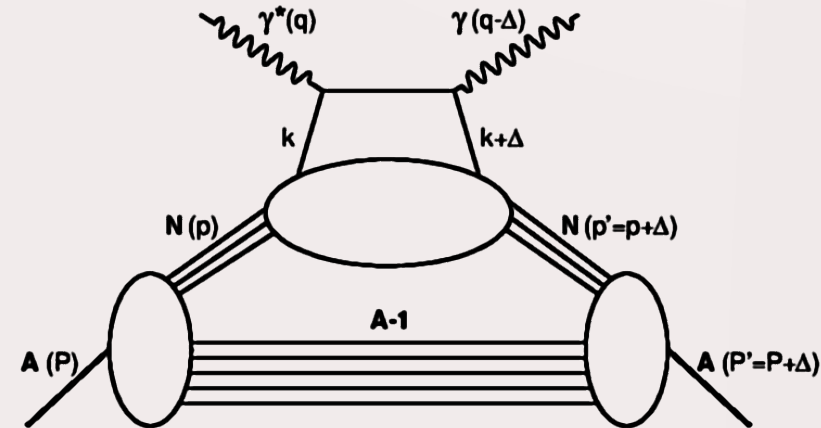
- **We can obtain the tomography of the proton**
 - Represented is the mean square charge radius of the proton for slices of x
 - Error bars reflect a factor 5 of the model used for the unconstrained CFFs
 - To flatten this distribution, one would need the unconstrained CFF with very strong opposite behavior
- **We observe the nucleon size shrinking with x**
 - Further observations will reduce the size of errors by revealing the spin structure of the proton

R. Dupré, et al. Phys.Rev. D95 (2017) no.1, 011501
and Eur.Phys.J. A53 (2017) no.8, 171



- **Coherent and incoherent channels**
 - Similarly to elastic and quasi-elastic
- **The spin simplification**
 - Only one GPD for Helium-4 \rightarrow one complex CFFs
 - Allows for a model independent extraction using only the beam-spin asymmetries of coherent DVCS
- **Perfect probe into the EMC effect**
 - Offer localization with the t dependence
 - Coherent DVCS gives access to non-nucleonic degrees of freedom
 - Incoherent DVCS gives access to the modifications of the nucleon in the nuclear medium
- **But can we measure it?**
 - Small cross section as for nucleon DVCS
 - Large energy gap between slow nuclear recoils and high energy electrons and photons

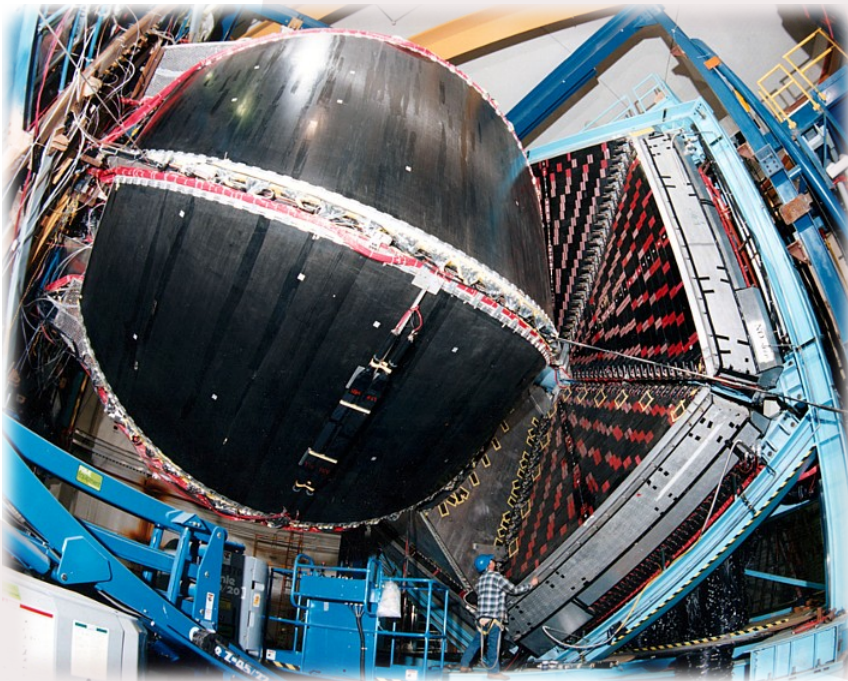
See review: R. Dupré and S. Scopetta Eur.Phys.J. A52 (2016) no.6, 159



Measuring DVCS on Helium

- **Jefferson Laboratory**

- Provides a 6 GeV electron beam (now up to 12 GeV)
- High quality beam
 - 100% duty factor
 - Around 150 μm wide
 - Intensity up to 100 μA

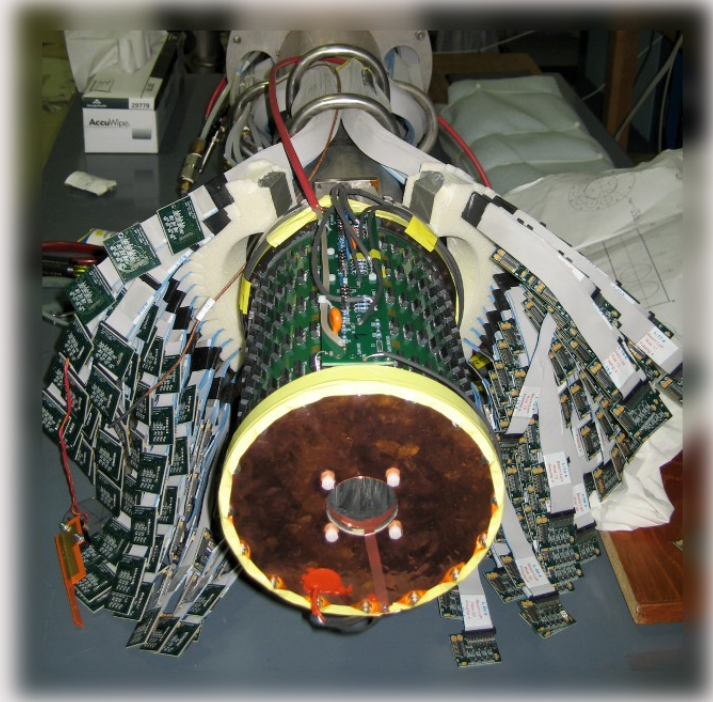
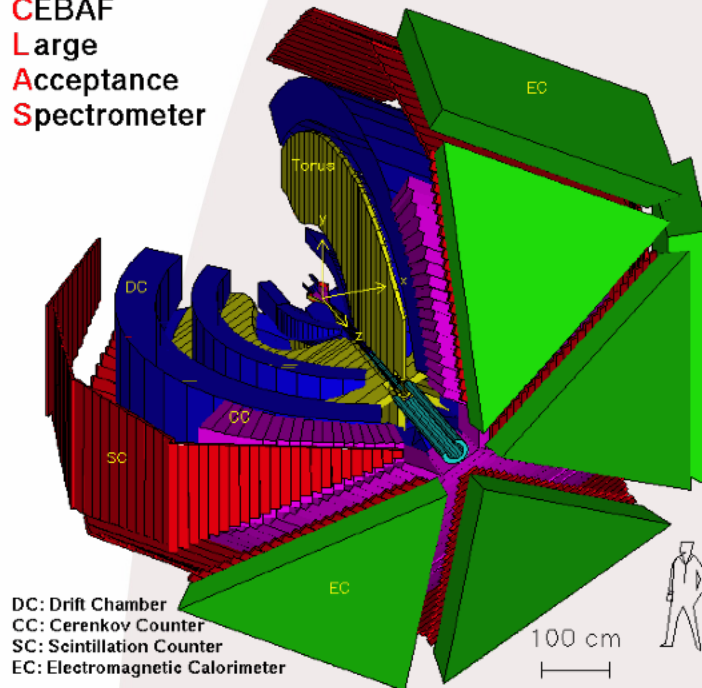


- **CEBAF Large Acceptance Spectrometer**

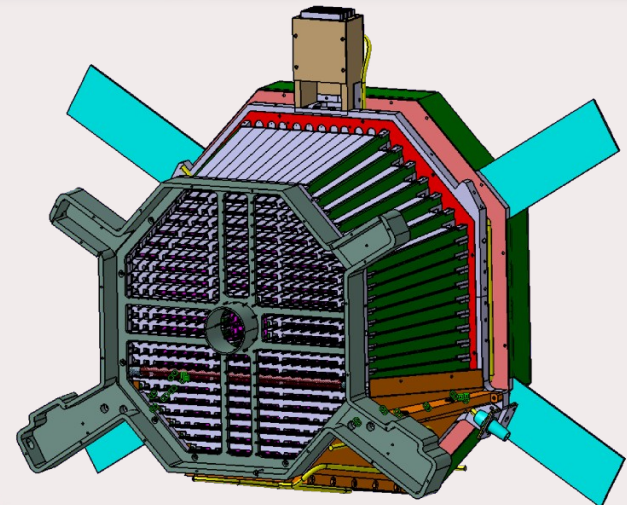
- Nearly 4π
- Offers electron and proton identification for our experiment
- Recording rates up to 8 kHz

Experimental Apparatus

CEBAF
Large
Acceptance
Spectrometer

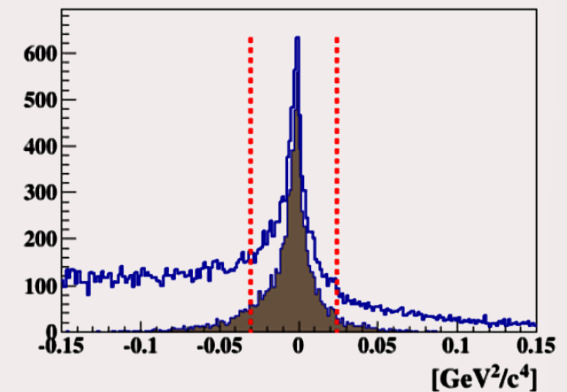
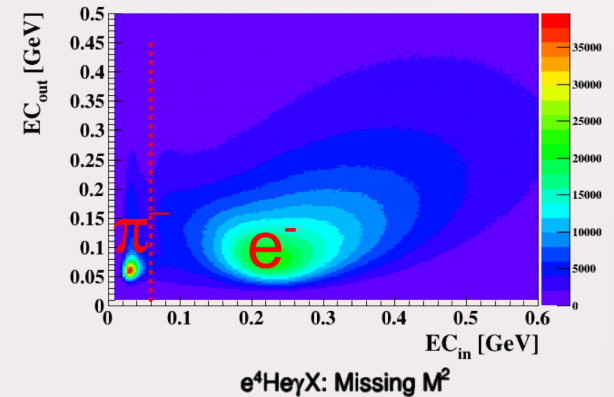


- **Experimental challenges**
 - Detecting very forward photons
 - Detecting very low energy alphas (7 MeV)
- **Inner Calorimeter**
 - Very forward electromagnetic calorimeter
- **Radial Time Projection Chamber**
 - Small TPC placed around the target

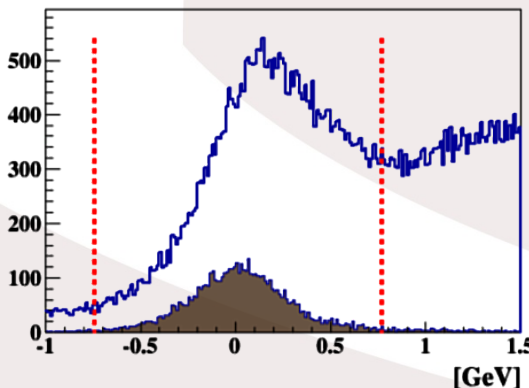


Selecting DVCS

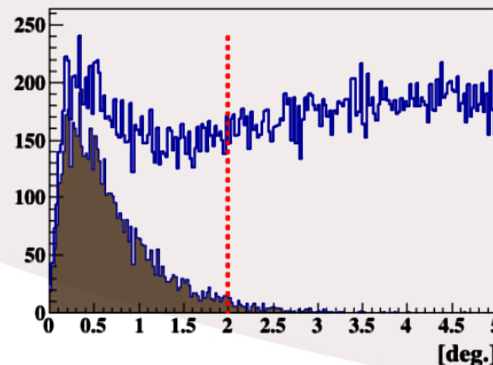
- **Identification of all particles in the detectors**
 - Identification of electron, protons, photons and helium nuclei
- **Exclusivity cuts**
 - Perform missing energy and momentum cuts to insure that we have all the products of the reaction
- **Corrections**
 - Subtract the irreducible π^0 background
 - Associated systematic errors appear much smaller than statistical errors
- **Proceed similarly for both coherent and incoherent channels**



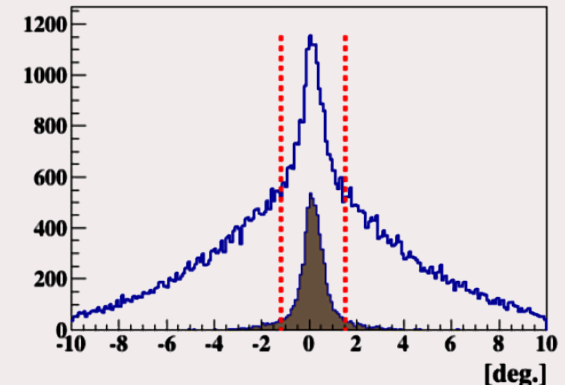
$e^4\text{He}\gamma X$: Missing E

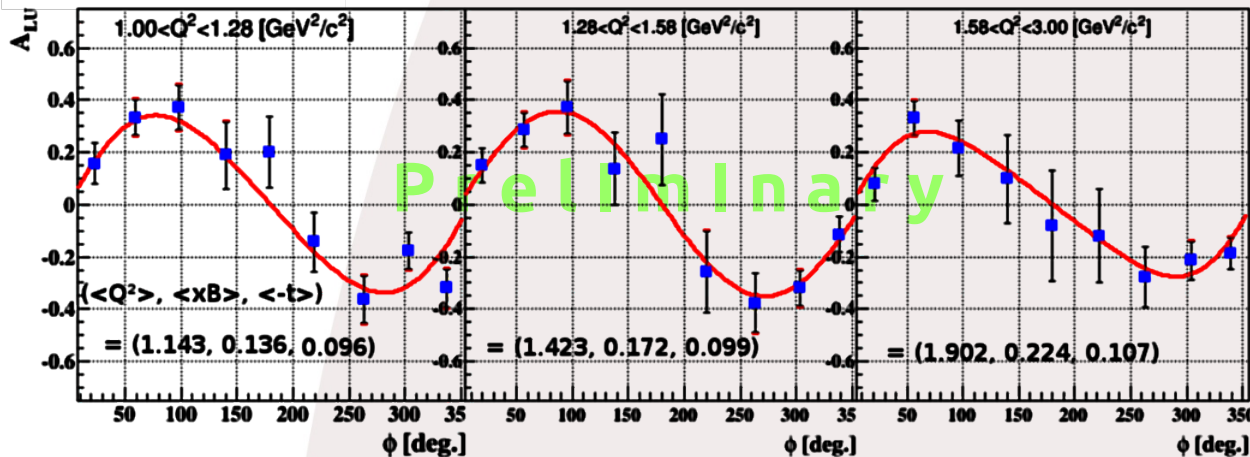


$\theta(\gamma, e^4\text{He}X)$



$(\gamma, \gamma^*): (\gamma^*, {}^4\text{He}) :: \Delta\phi$





$$A_{LU} = \frac{d^5\sigma^+ - d^5\sigma^-}{d^5\sigma^+ + d^5\sigma^-} = \frac{1}{P_B} \frac{N^+ - N^-}{N^+ + N^-}$$

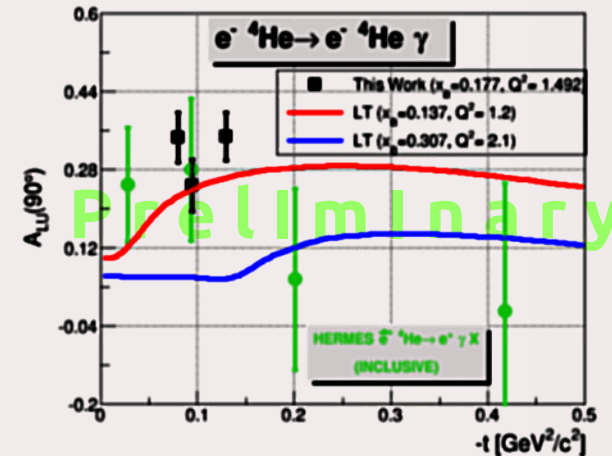
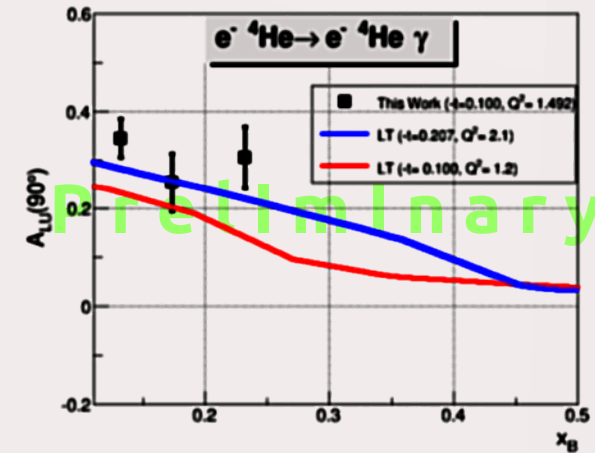
- Coherent DVCS on helium

- Shows very strong beam spin asymmetry
- Expected factor ~ 2 increase from PWIA prediction

- Interpretation

- The very strong signal proves that we are indeed probing the nuclei as a whole
- We see an even stronger signal than expected
 - Expected from theory as DVCS cross section grows with A

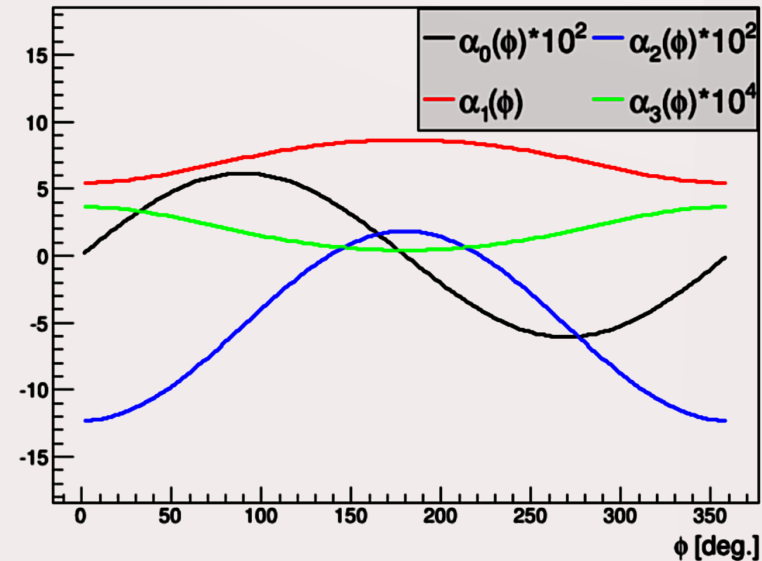
M. Hattawy et al. (CLAS Coll.) arXiv:1707.03361 to be published



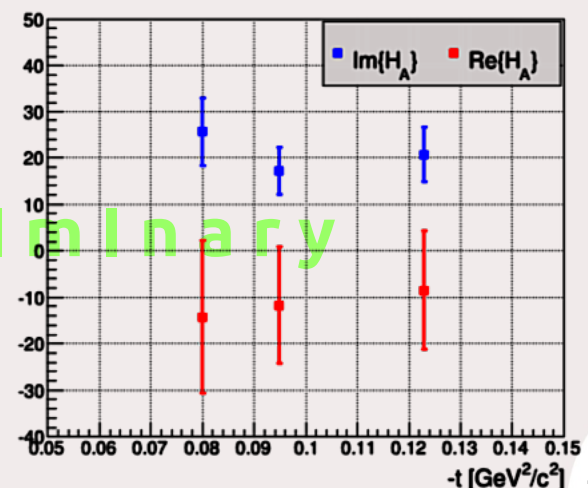
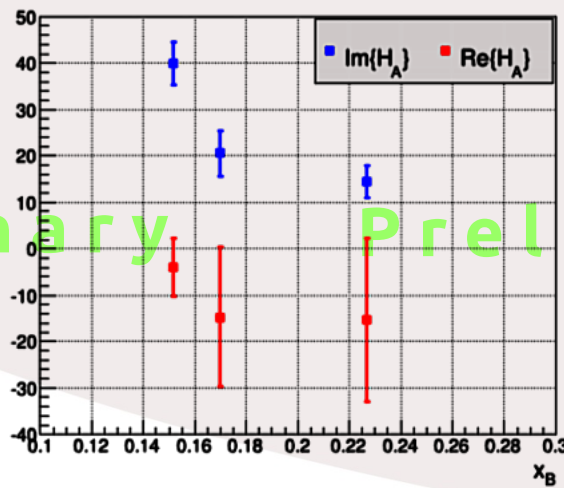
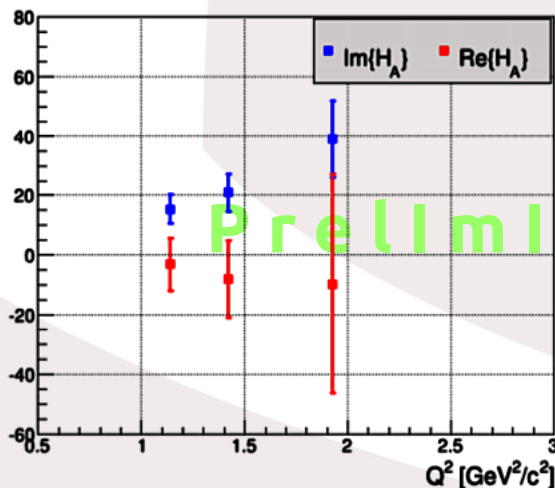
Extraction of the CFF

Simple extraction

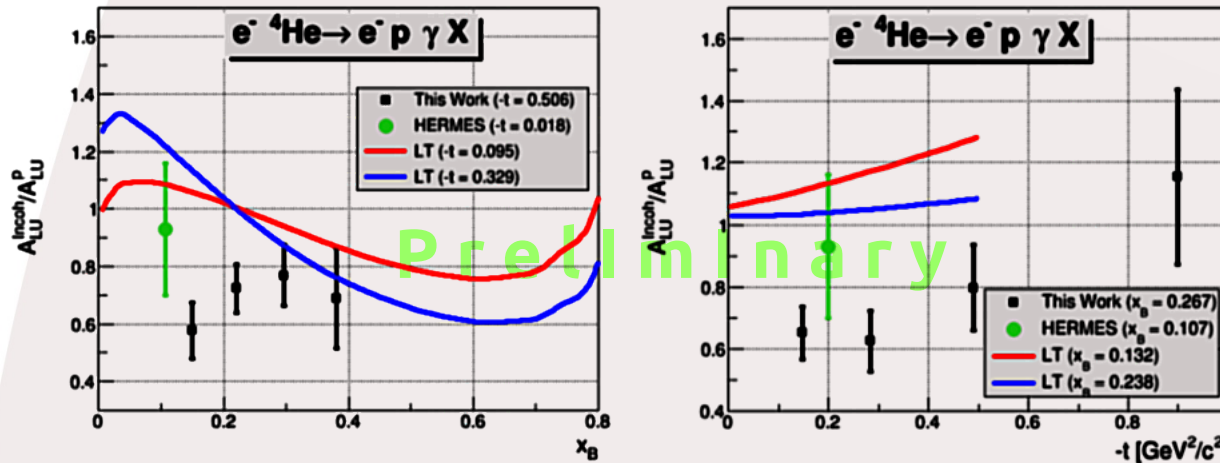
- Spin-0 \rightarrow 1 GPD \rightarrow 2 unknowns
- Their different contributions in ϕ allows to separate their contributions
- The different contributions are exactly calculable within perturbative QCD
- We are mostly sensitive at the imaginary part
- More precise measurement will be needed to extract the real part



$$A_{LU}(\phi) = \frac{\alpha_0(\phi) \Im m(\mathcal{H}_A)}{\alpha_1(\phi) + \alpha_2(\phi) \Re e(\mathcal{H}_A) + \alpha_3(\phi) (\Re e(\mathcal{H}_A)^2 + \Im m(\mathcal{H}_A)^2)}$$



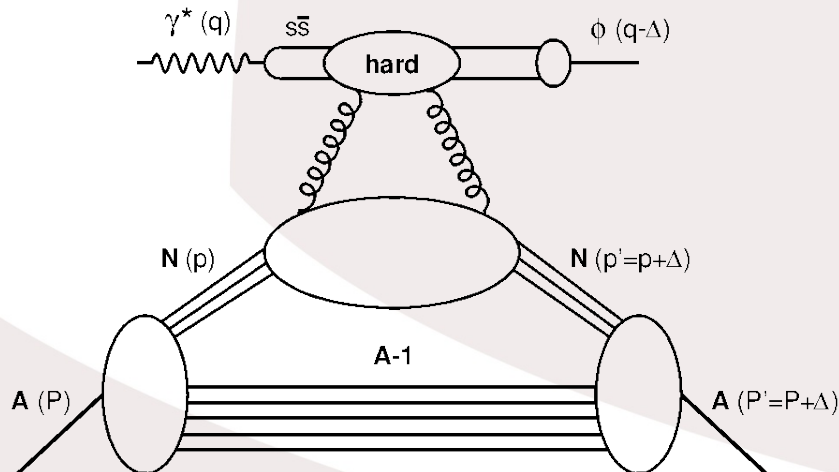
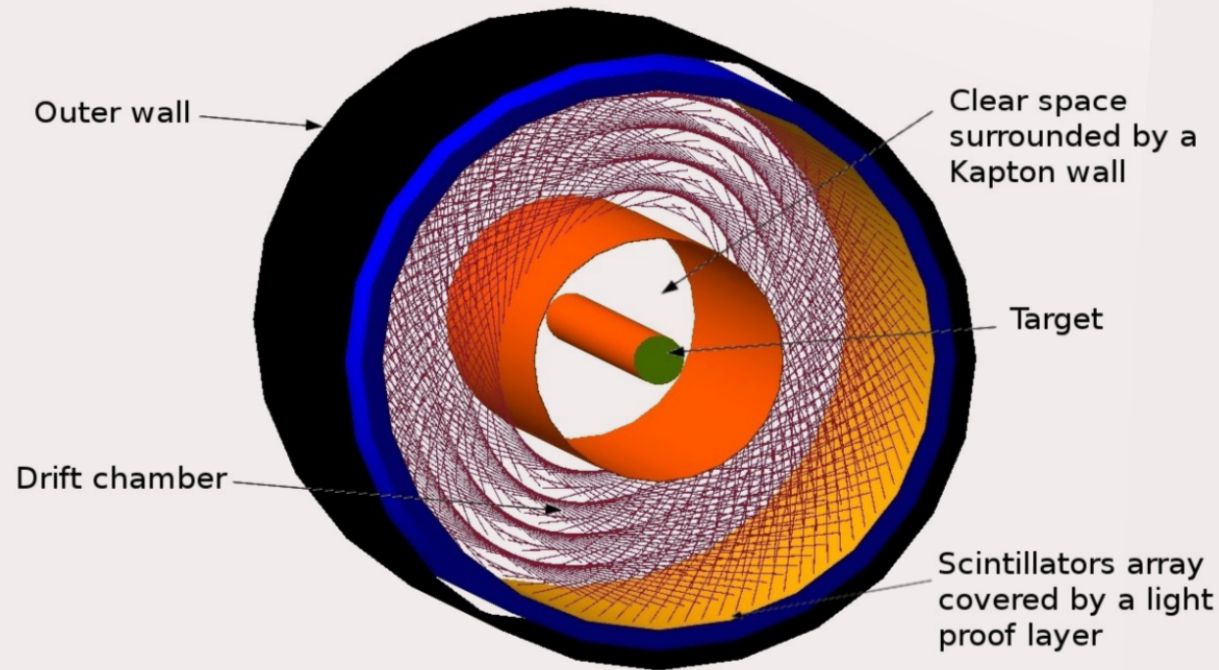
The Generalized EMC Ratio



- **Generalized EMC ratio**
 - Incoherent over free proton
 - Strongly suppressed in particular in the anti-shadowing region
 - Strange behavior compared to the binding model from
S. Liuti and S.K. Taneja Phys.Rev. C72 (2005) 032201
- **A New kind of EMC effect?**
 - We will need to exclude final state interaction possibilities before to make a claim
 - This is the plan for CLAS12 with ALERT !

Going to CLAS12

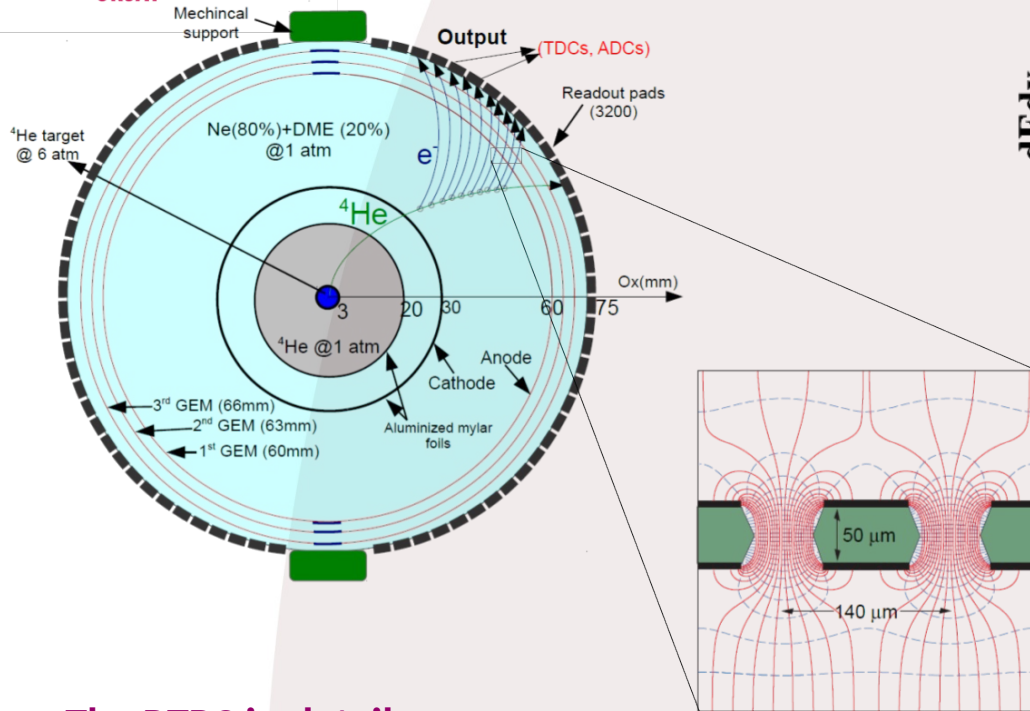
- **An extension at CLAS12**
 - For more statistics
 - And more kinematic coverage
- **Extension to DVMP**
 - To access the nuclear gluons
- **Possibility to look at other nuclei and processes**
 - DVCS on deuterium
 - Tagged DIS
 - Tagged DVCS



- **The ALERT detector**
 - Based on drift chamber & scintillators
 - Faster detectors
 - Allow integration in the trigger
 - Necessary to get maximum luminosity
- **Four proposals approved by JLab PAC**
 - A- rating for 55 days of running

- **In fifteen years of experiments at JLab, we have accumulated a wide array of data**
 - We can now extract the tomography of the nucleon from these data
 - Already the x dependence of the charge radius is visible
- **The GPD framework also applies to nuclei**
 - It is probably the best way to understand the EMC effect
 - It opens a whole new view into the nuclei beyond the simple addition of nucleons
 - A unique way to probe the non nucleonic components of the nucleus
- **We made the first exclusive measurement of nuclear DVCS**
 - Using a low energy RTPC for helium recoils
 - We achieved a fully exclusive measurement of coherent nuclear DVCS
 - We demonstrate the simplicity of extracting CFF on spin-0 target
 - These first results show several trends:
 - Large asymmetry signal for coherent DVCS (much larger than for the proton)
 - A significant suppression of asymmetries in the incoherent channel
- **Perspectives**
 - More theoretical attention will come with these new results
 - We will cover much more phase space with better accuracy at JLab 12 GeV (CLAS12)

The RTPC detector



• The RTPC in details

- 250mm long / 150mm diameter
- Drift region of 30mm (1500V)
- Amplification is obtained with 3 layers of GEM
- Signal is collected on 3200 pads in 100 ns time bins

• Solenoid

- 4.5 T to shield from Moller electrons and curve particles in the RTPC

• Calibration

- Use of Helium elastic scattering obtained with 1.2 GeV electron beam

Good tracks @ 1.2 GeV

