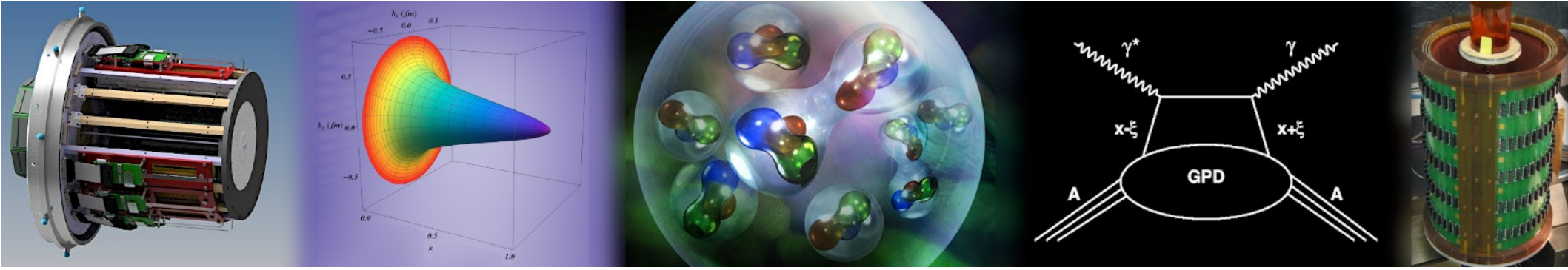
Exploring the Nucleus in 3D with GPDs and TMDs



Raphaël Dupré

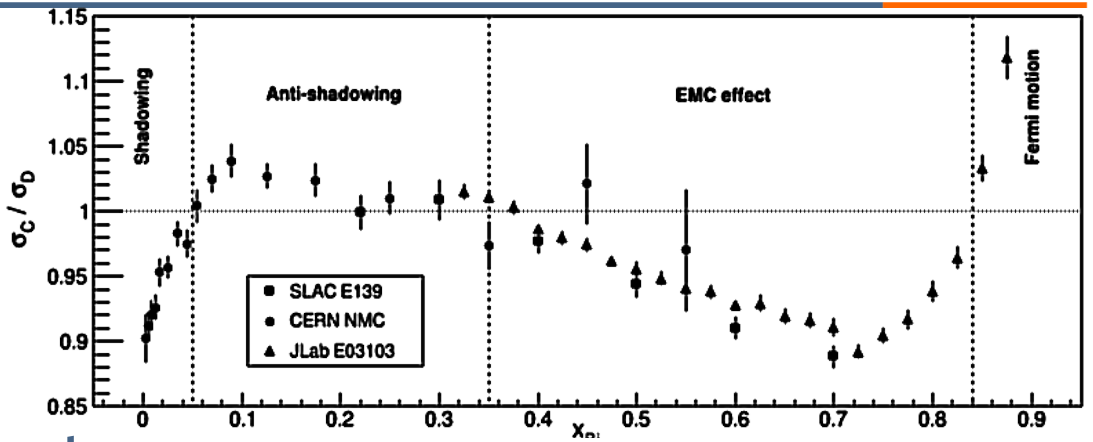
Univ. Paris-Saclay

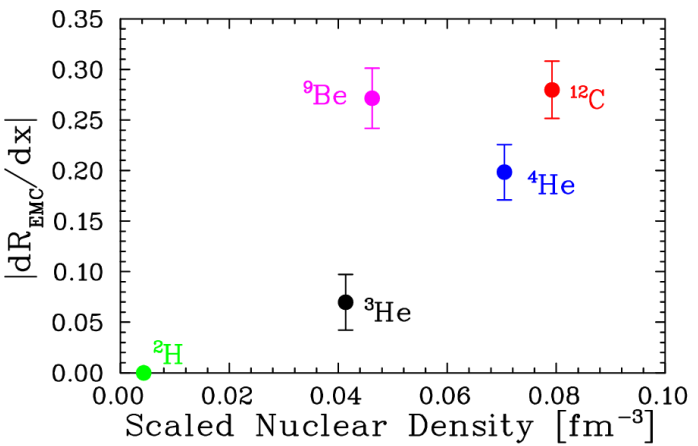
European Research Council
Established by the European Commission

The Nucleus Quark Structure

The nuclear PDFs show many suprises

- Quarks are affected by the nuclear medium
- The EMC effect at large x, the shadowing effect at lower x
- The dependence of this effect appears to have complexe dependence to nuclear density





Measuring Nuclear DVCS

Nuclei give control over the spin

- Spin-0 → 2 GPD ; Spin-1/2 → 8 GPDs ; Spin-1 → 18 GPDs
- Half of these intervene in DVCS

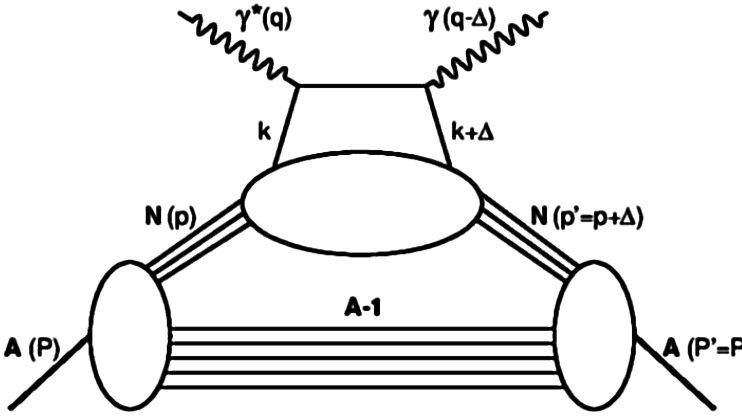
In the nucleus two processes

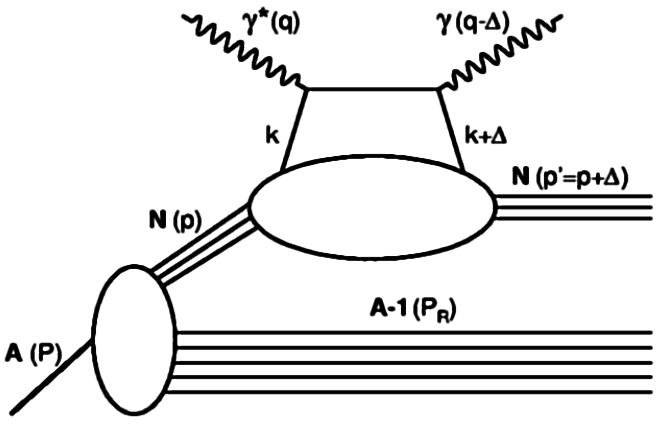
- Coherent and incoherent channels
  - **Similar to elastic and quasi-elastic**
- Probe the whole nucleus and the bound nucleons

A perfect tool to study the EMC effect

- Coherent DVCS gives access to the full nucleus
  - **Including non-nucleonic degrees of freedom**
- Incoherent DVCS gives access to the bound nucleon
  - **To test modifications of the bound nucleon structure**

R. Dupré and S. Scopetta. 3D Structure and Nuclear Targets. Eur. Phys. J., A52(6):159, 2016





HERMES Results

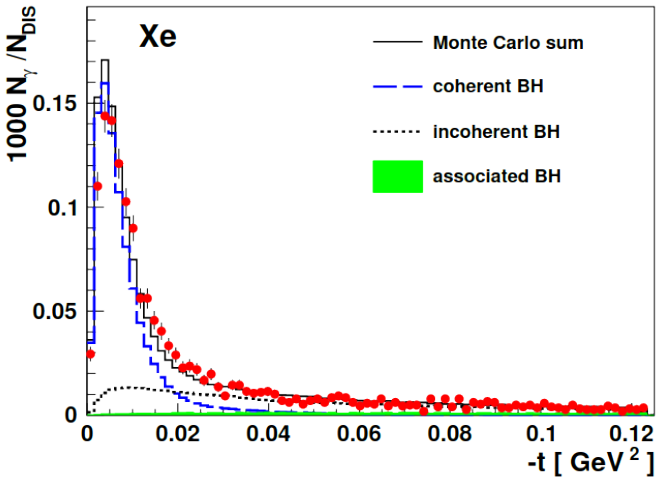
Nuclear DVCS measurement by HERMES

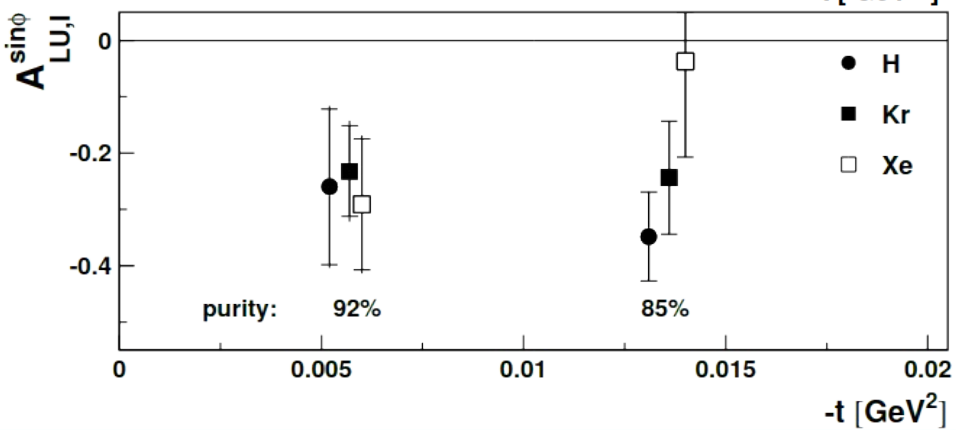
- Charge and beam-spin asymmetries
- No clear nuclear dependence
- In a rather pure coherent sample

This is a problem…

- In the coherent process we expect a significant increase
- Argument about the way coherent and incoherent are separated

Can we measure it directly ?





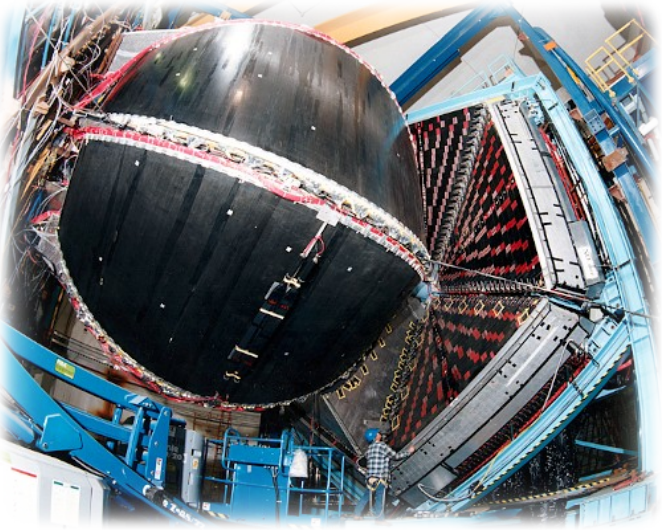
The CLAS experiment at JLab

Jefferson Laboratory

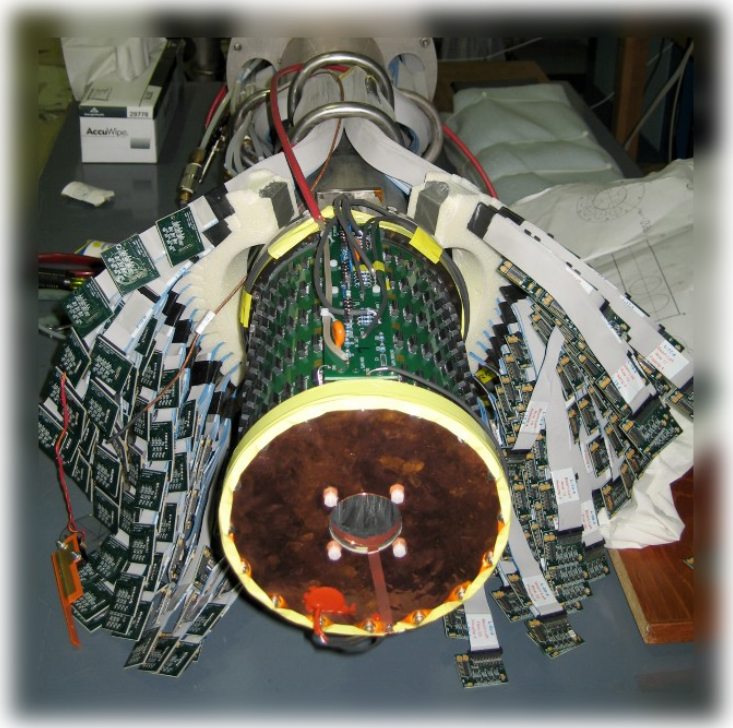
- 6 GeV electron beam (now 12 GeV)
- High stability, 100 % duty factor

The CLAS spectrometer

- 2π acceptance
- Luminosity ~10^{34} $cm^{-2}s^{-1}$
- Upgraded for DVCS measurements
  - **A Low angle calorimeter for photons**
  - **A Solenoid to protect it from secondaries**



Detecting Recoil Nuclei



Recoil nuclei are evasive

- They usually do not make it out of the target…

How to handle that ?

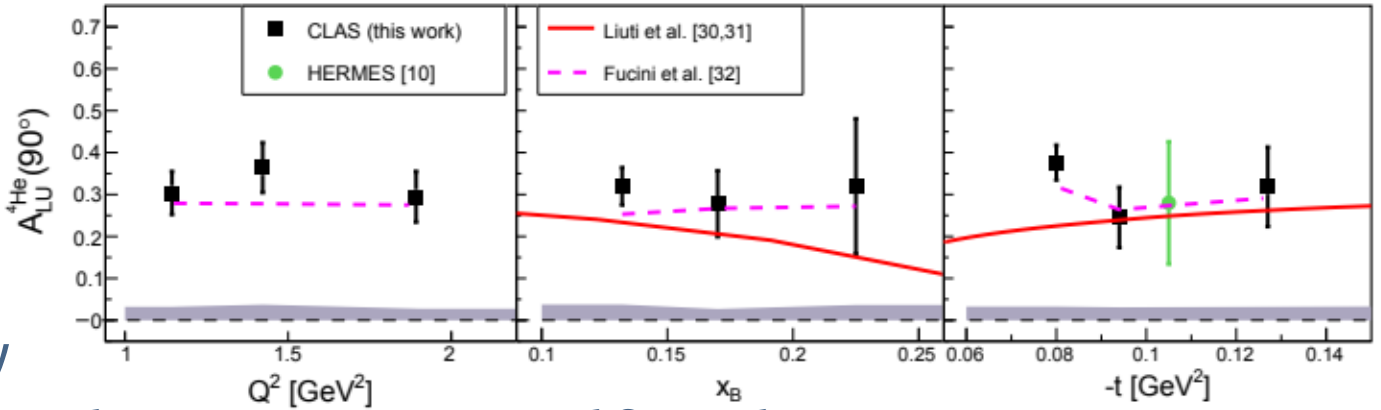
- Use a light nuclei : Helium
  - **It is also spin-0 which is nice for simplicity**
- Use a light target : a straw
  - **Filled at 5 Atm with 50 µm thick walls**
- Get very close to it : Radial TPC
  - **3 cm away from the target**

The experiment ran in 2009

The Coherent Helium DVCS

Coherent DVCS on helium

- Fully exclusive
- We observed large beam spin asymmetry
  - **About twice the one on the proton, as expected from theory**

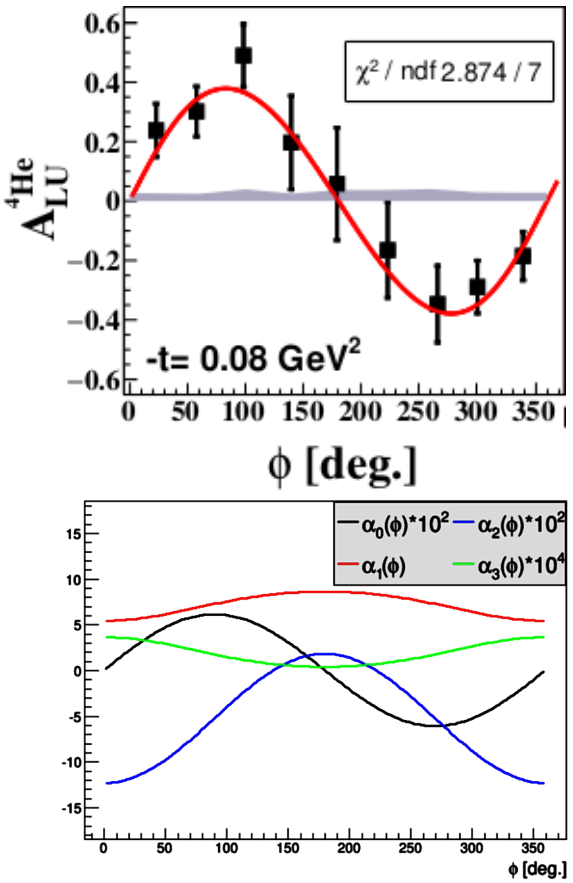


Interpretation of the results

- This strong signal shows we fully isolated coherent DVCS
- The amount of data is too little for advanced interpretation
- But enough to check if we can extract the CFF !

M. Hattawy et al. (CLAS Coll.) Phys. Rev. Lett., 119(20):202004, 2017.

Nuclear CFF Extraction



The Helium CFF extraction

- Simplified by the spin-0 (1 GPD/CFF)

This is done using the different contributions in phi

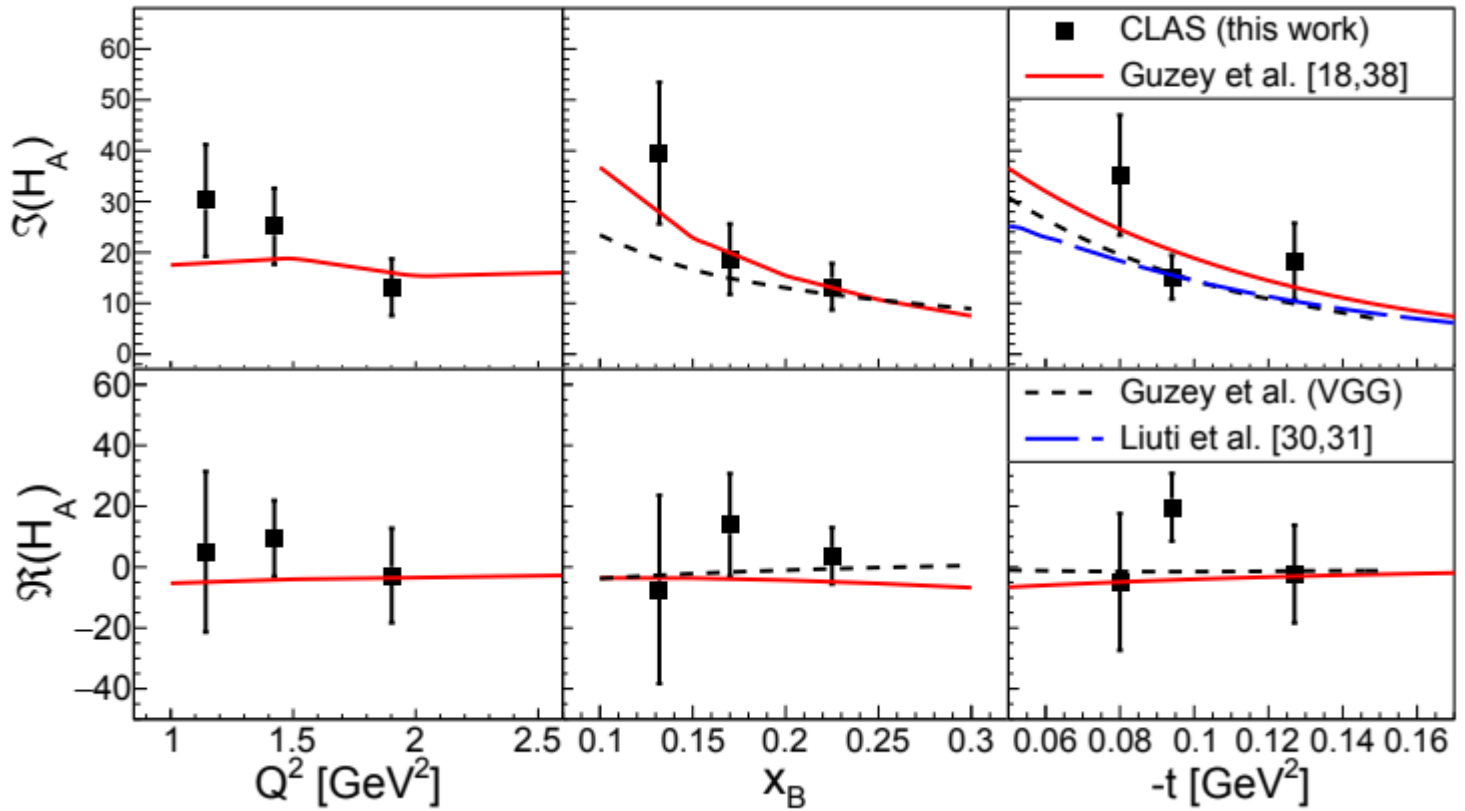
- They are calculable within pQCD

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

- The fit converges immediately

M. Hattawy et al. (CLAS Coll.) Phys. Rev. Lett., 119(20):202004, 2017.

(First) Model independent CFF extraction



Incoherent Helium DVCS

Gives a "generalized" EMC

- Strongly suppressed in particular for anti-shadowing
- Strange behavior compared to the models

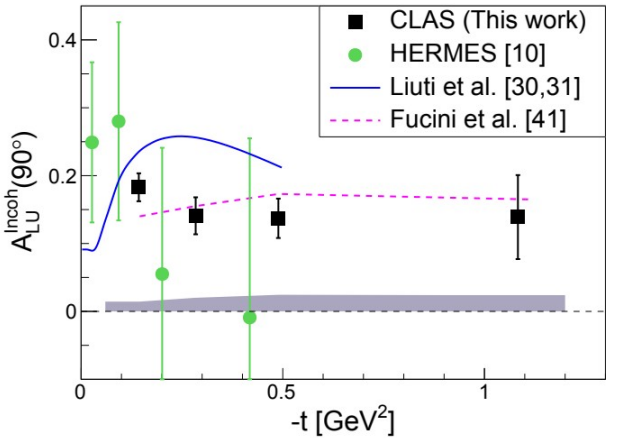
A New kind of EMC effect?

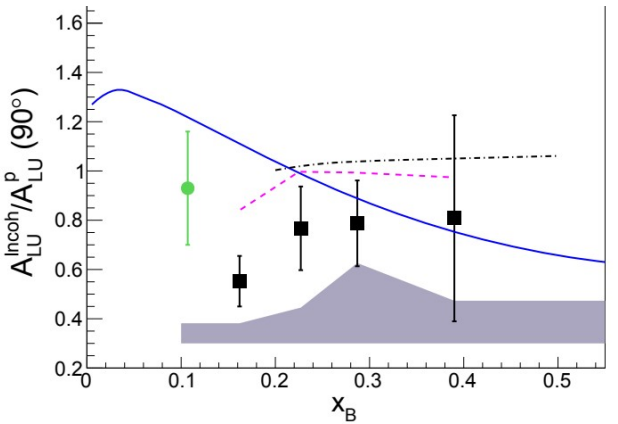
- It could be a nuclear effect
- Or it could be due to final state interactions
  - **Can be very complicated in DVCS**

M. Hattawy et al. (CLAS Coll.) Phys. Rev. Lett., 123(3):032502, 2019.

More work is ongoing on these questions

- On the theoretical side for a better description
- On the experimental side with nitrogen data





The ALERT Detector

A Low Energy Recoil Tracker

- Hyperbolic drift chamber
- Time-of-Flight array

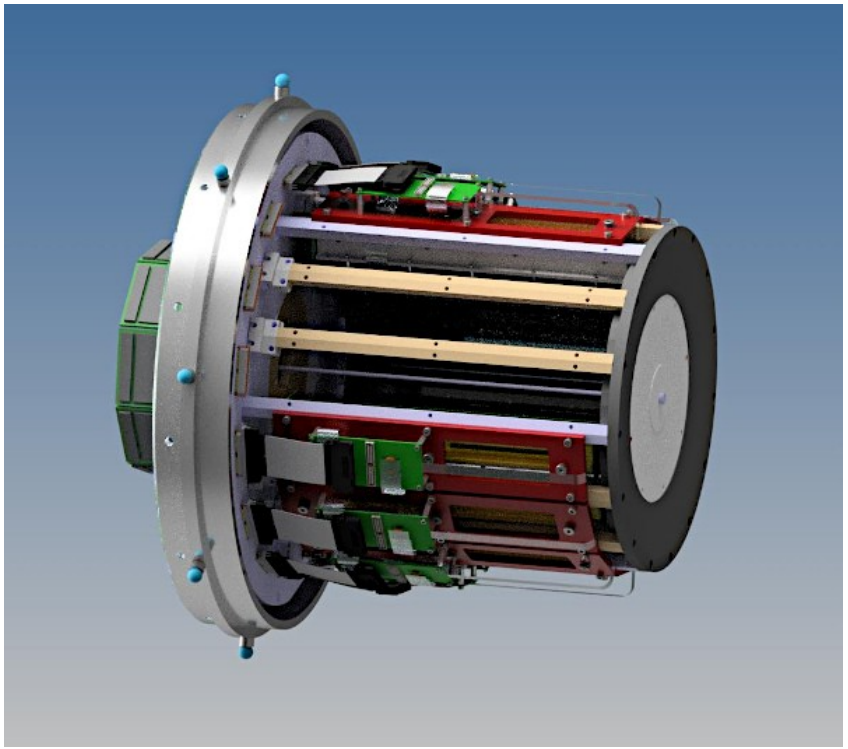
It will be used for a large array of experiments

- Nuclear DVCS, DVMP...
- Tagged processes (detailed later)

Collaborative effort within CLAS12

- ANL, IJCLab, JLab, NMSU, and Temple
- We tested a prototype with a nuclear beam in the Fall at the ALTO facility (Orsay, France)

We hope to take data in 2023 or 2024



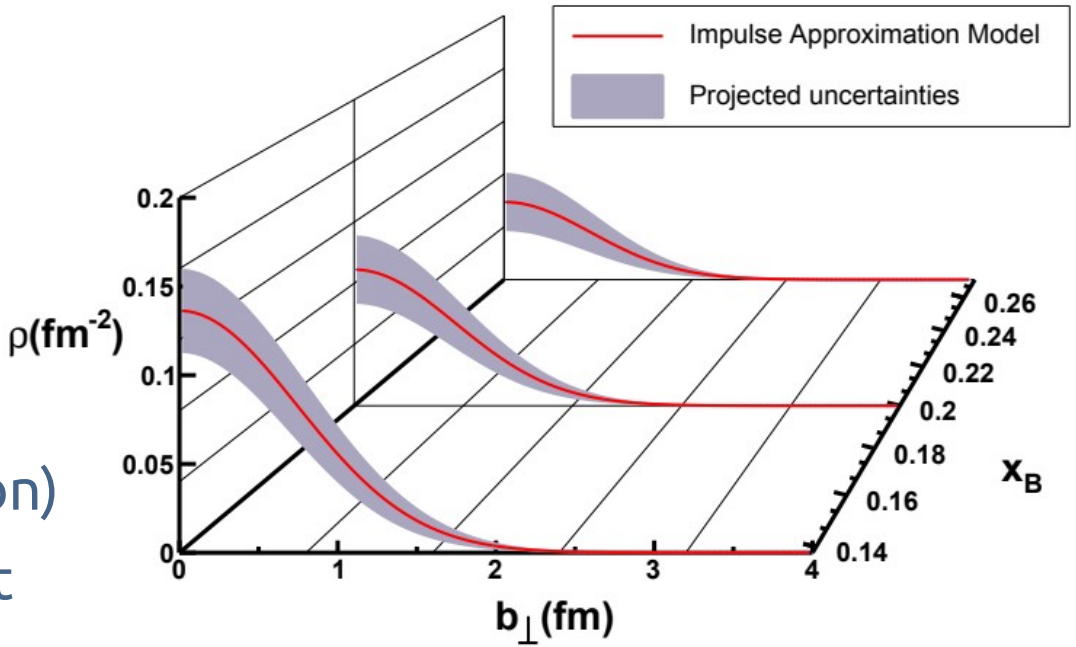
What results do we expect ?

Tomography of a nucleus

- A view into the nucleus in three dimensions
- Using the wider phase space and larger statistics

Extension to the gluons

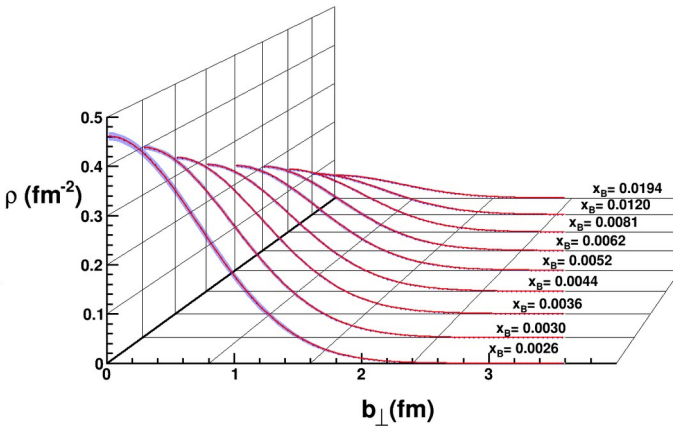
- We will measure DVMP (Phi meson)
- We hope to obtain a similar result for gluon tomography

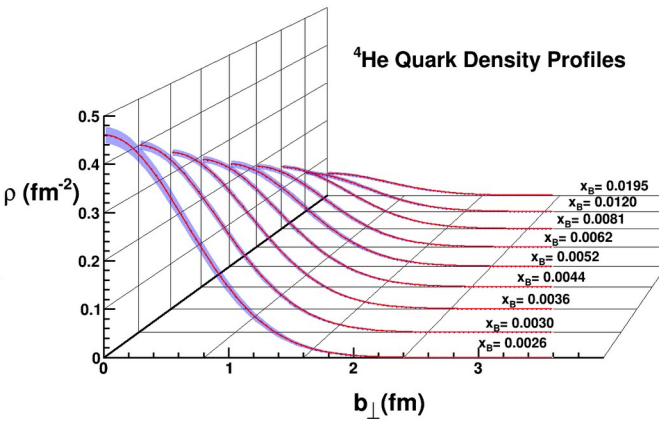


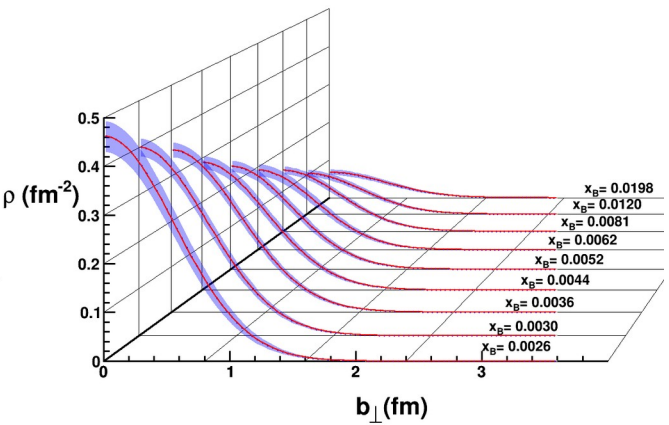
EIC Projections

We expect very nice results from the EIC

- The key detector for this is the Roman pot
- Detecting the nuclear recoil very close to the beam line
- Here we show profile extractions
  - **For transverse momentum thresholds of 0.1 (left), 0.2 (center) and 0.3 GeV (right)**







A Word About Nuclear TMDs

We will soon measure the nuclear TMDs

- Project in Jlab with CLAS12

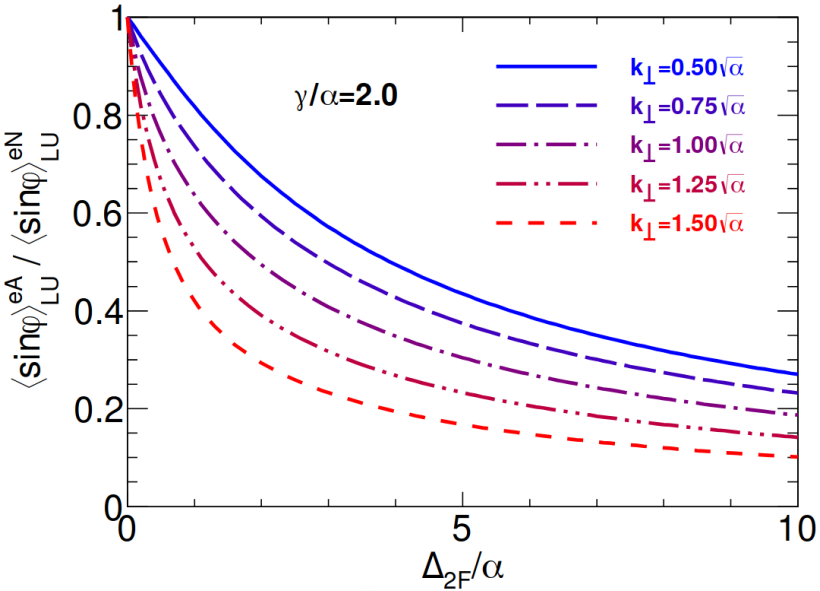
Only a bit of theory exists

- Predicting large modification of asymmetries
- Linked to the transport coefficient of the medium

Z.-T. Liang, X.-N. Wang, and J. Zhou, Phys. Rev. D77, 125010, 2008.
J.-H. Gao, Z.-t. Liang, and X.-N. Wang, Phys. Rev. C81, 065211, 2010.
Y.-K. Song, J.-h. Gao, Z.-t. Liang, and X.-N. Wang, Phys.Rev. D89, 014005, 2014.

Caveats

- These models lack full nuclear fragmentation
- We need phenomenology to make sure we will have the resolution in actual experiment



$$\Delta_{2F} = \int d\xi_N^- \hat{q}_F(\xi_N)$$

$$\hat{q}_F(\xi_N) = \frac{2\pi^2 \alpha_s}{N_c} \rho_N^A(\xi_N)[x f_g^N(x)]_{x\to 0}$$

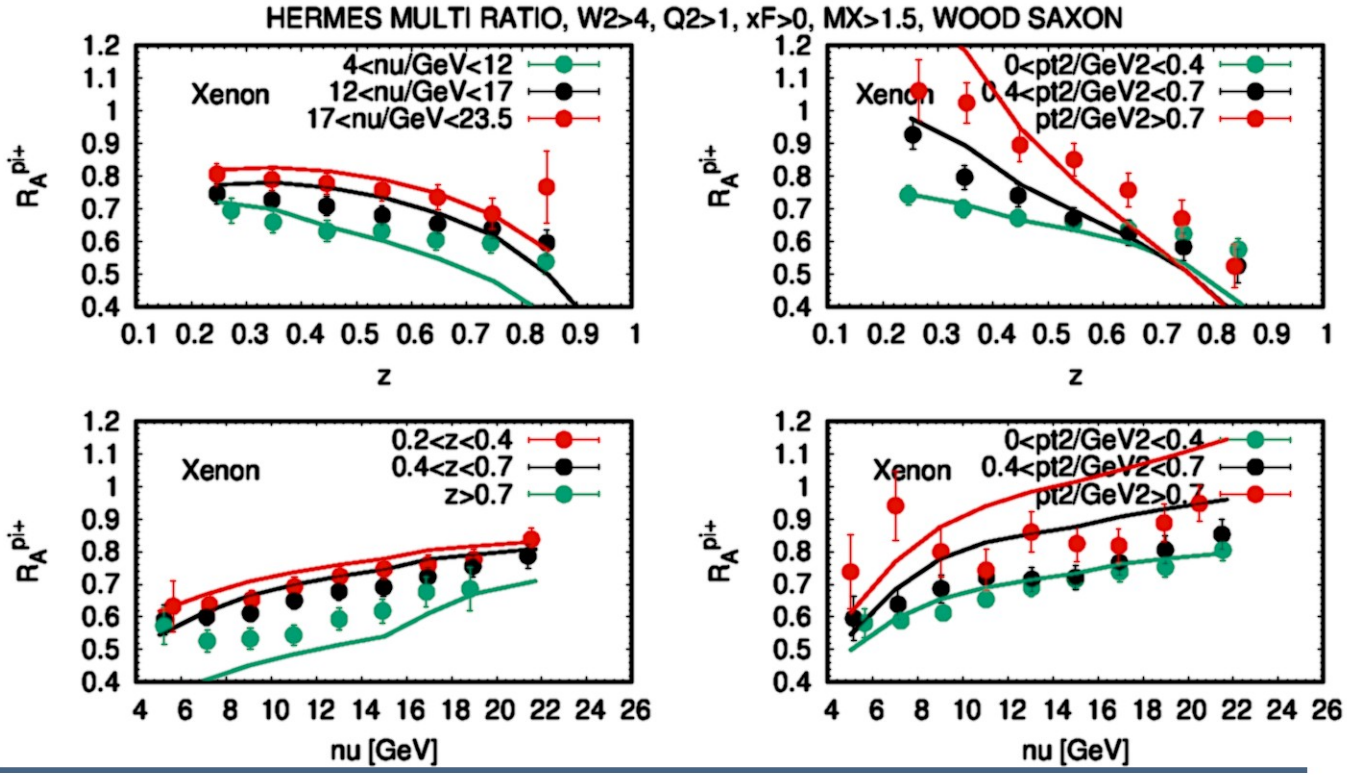
Can we understand nuclear TMDs ?

We are working on phenomenological model

- Using TMD param-etrization for the nucleons
- And applying nuclear effects

Work done with F. Ceccopieri

We hope to have results soon !



Summary

We do not understand the nucleus well within QCD

- Either we do not understand the mechanisms at play
- Or we lack a quantitative calculation to demonstrate it

There is hope in nuclear GPDs

- We measured coherent and incoherent nuclear DVCS
  - **Confirming some of our understanding and raising new questions at once**
- More measurements are coming to reach high precision

New data is coming soon to help

- Nuclear SIDIS is an important one
- But, we need to be ready to interpret it !