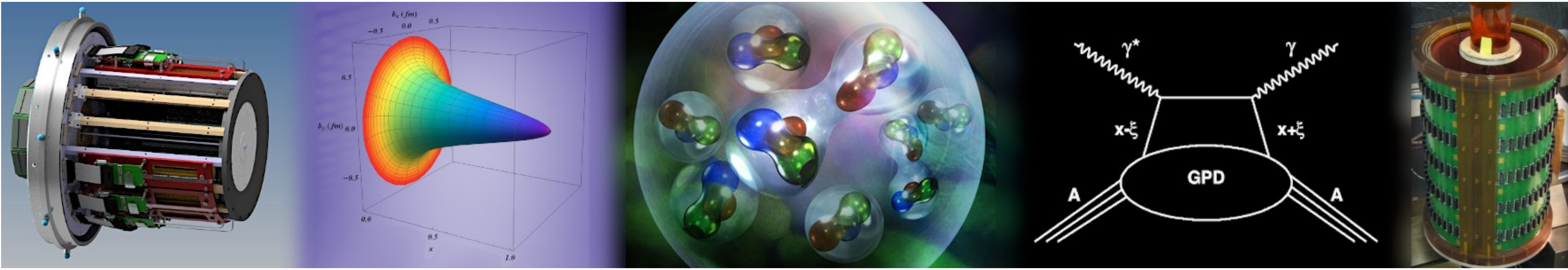
Nuclear DVCS from Jlab to EIC



Raphaël Dupré

Univ. Paris-Saclay

European Research Council
Established by the European Commission

Two Pictures of the Nucleus

Two ways to describe nuclei

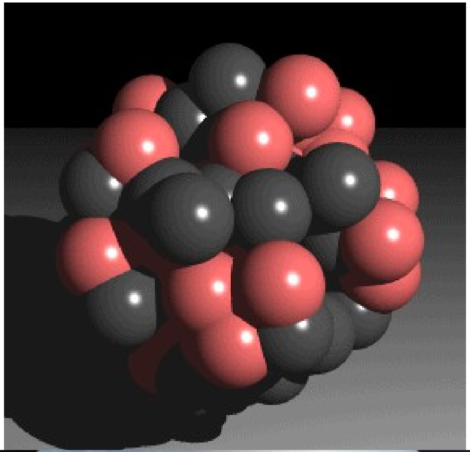
- As an ensemble of nucleons
- As an ensemble of quarks and gluons

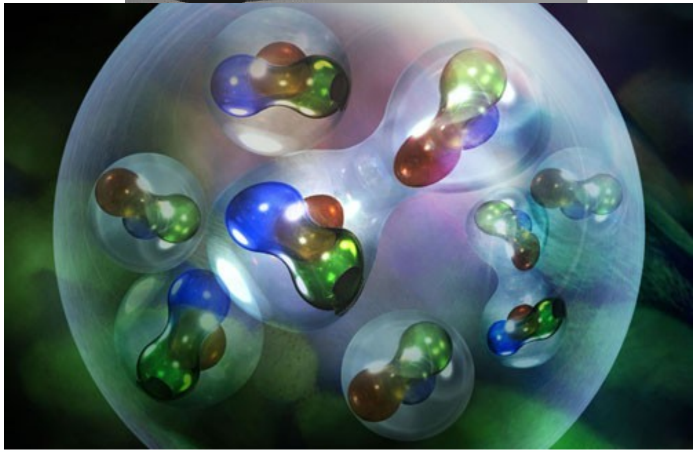
Traditional nuclear physics

- This picture is very effective
- Nuclear properties well reproduced
- Needs good NN and NNN forces

Do we need to go to quark and gluons ?

- Spoiler : we do !

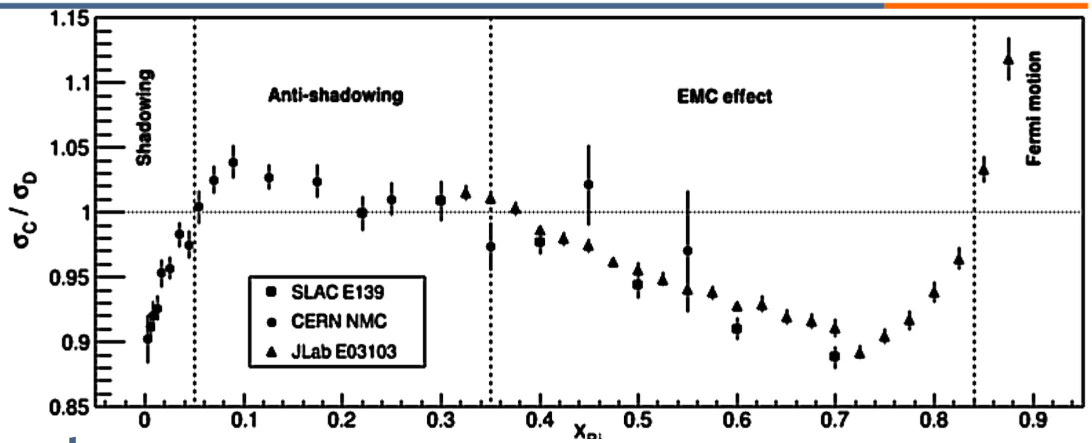


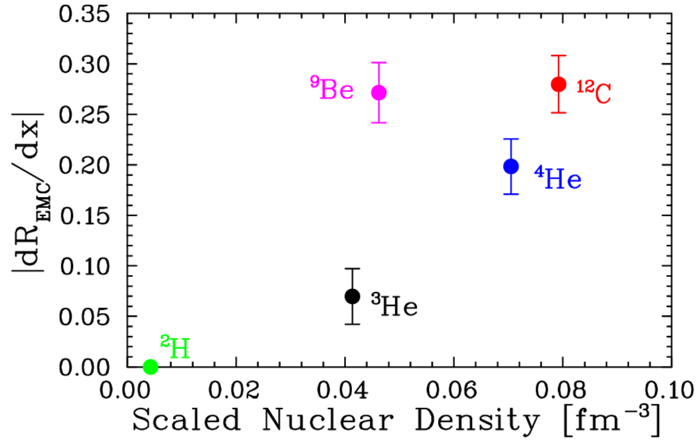


The Nucleus Quark Structure

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

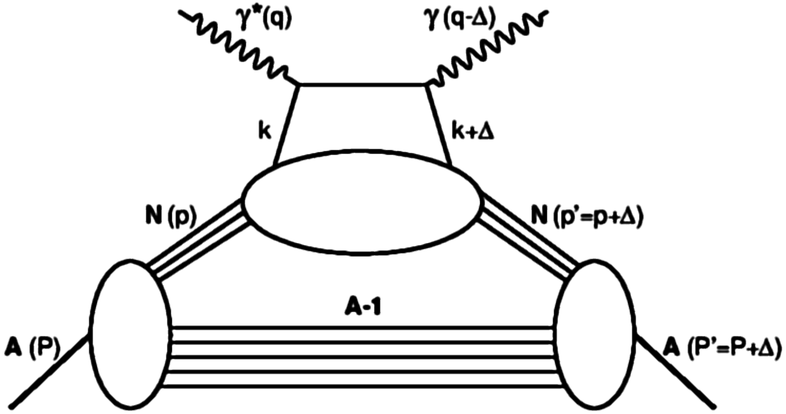
- Spin-0 → 2 GPD ; Spin-1/2 → 8 GPDs ; Spin-1 → 18 GPDs
- Half of these intervene in DVCS

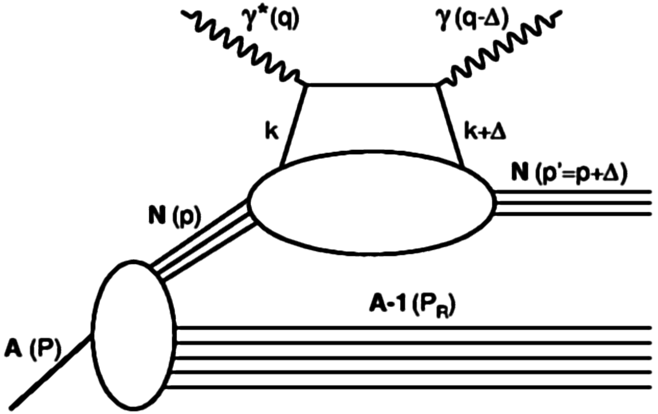
In the nucleus two processes

- 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

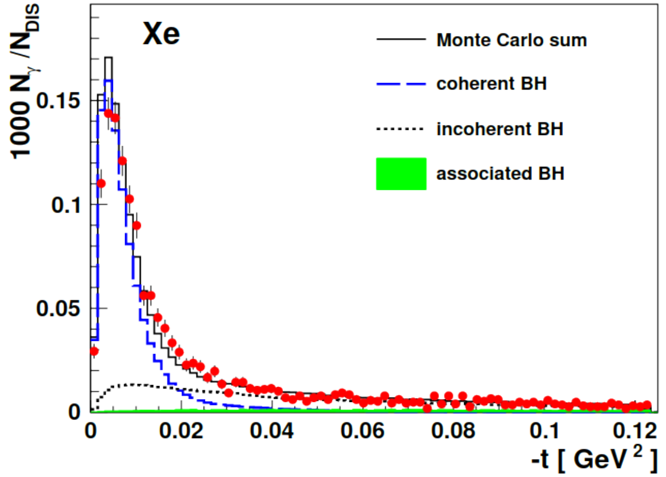
Nuclear DVCS measurement by HERMES

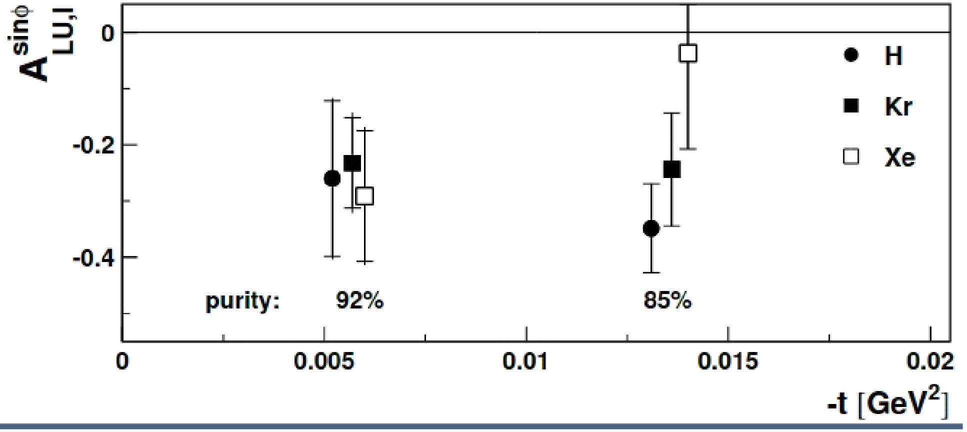
- Charge and beam-spin asymmetries
- No clear nuclear dependence
- In a rather pure coherent sample

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 ?





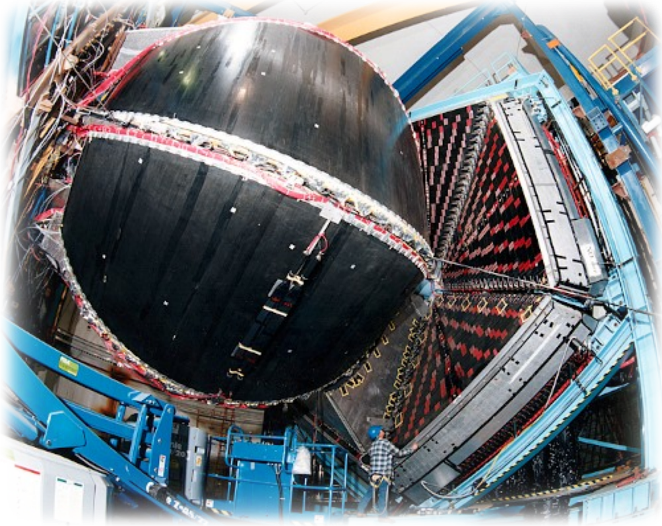
The CLAS experiment at JLab

Jefferson Laboratory

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

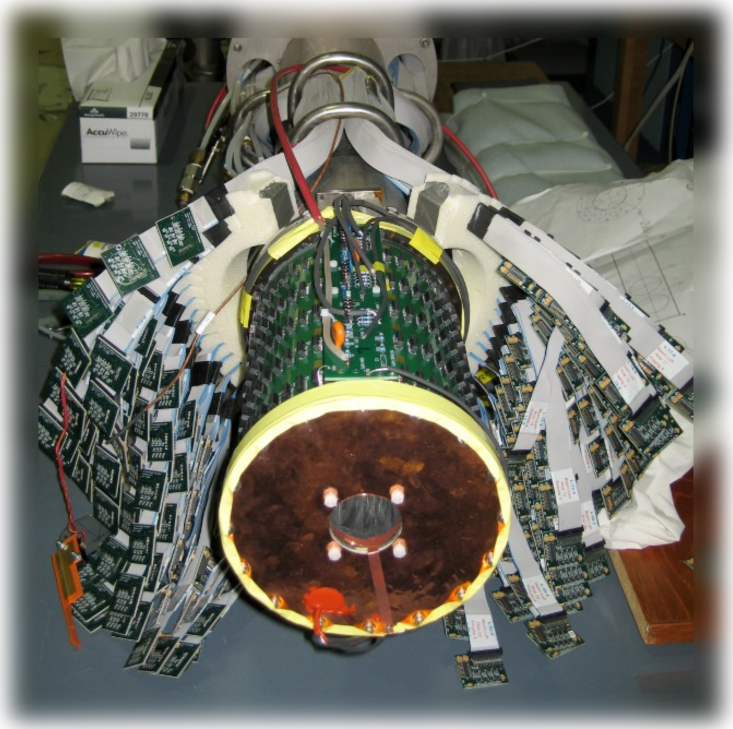
The CLAS spectrometer

- 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 ?

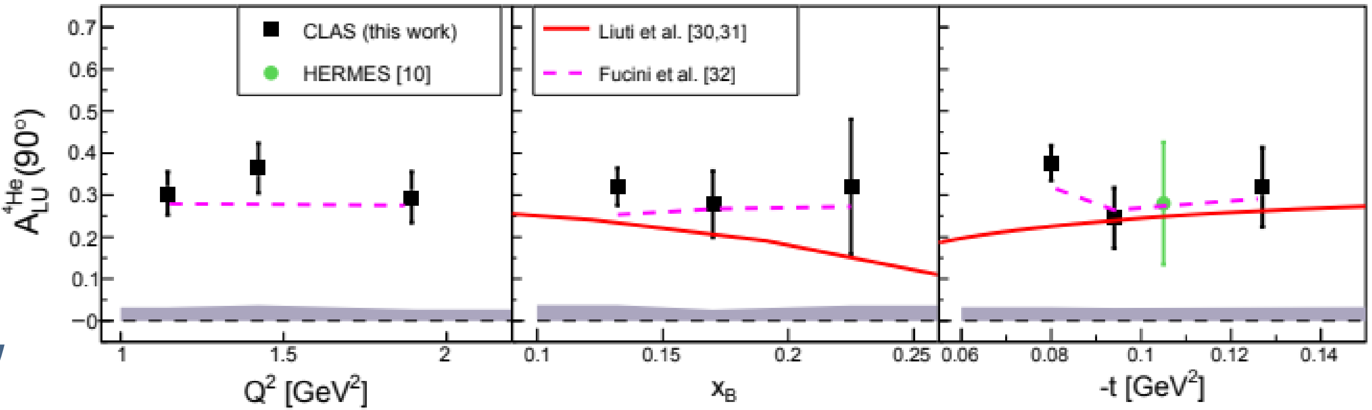
- Use a light nuclei : Helium
  - **It is also spin-0 which is nice for simplicity**
- Use a light target : a straw
  - **Filled at 5 Atm with 50 μm thick walls**
- Get very close to it : Radial TPC
  - **3 cm away from the target**

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**

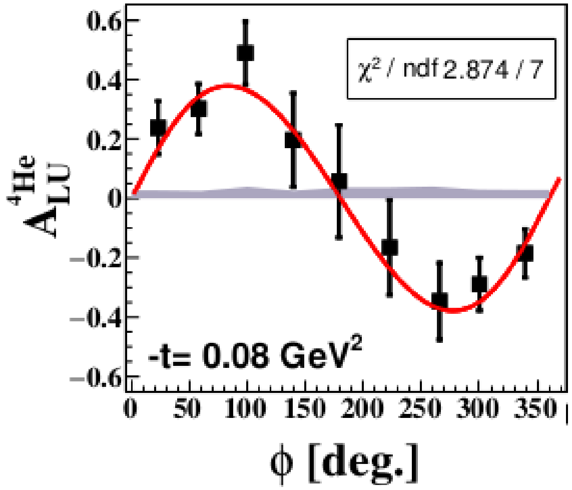


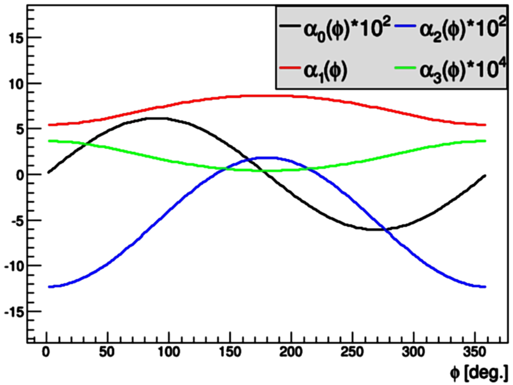
Interpretation of the results

- 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

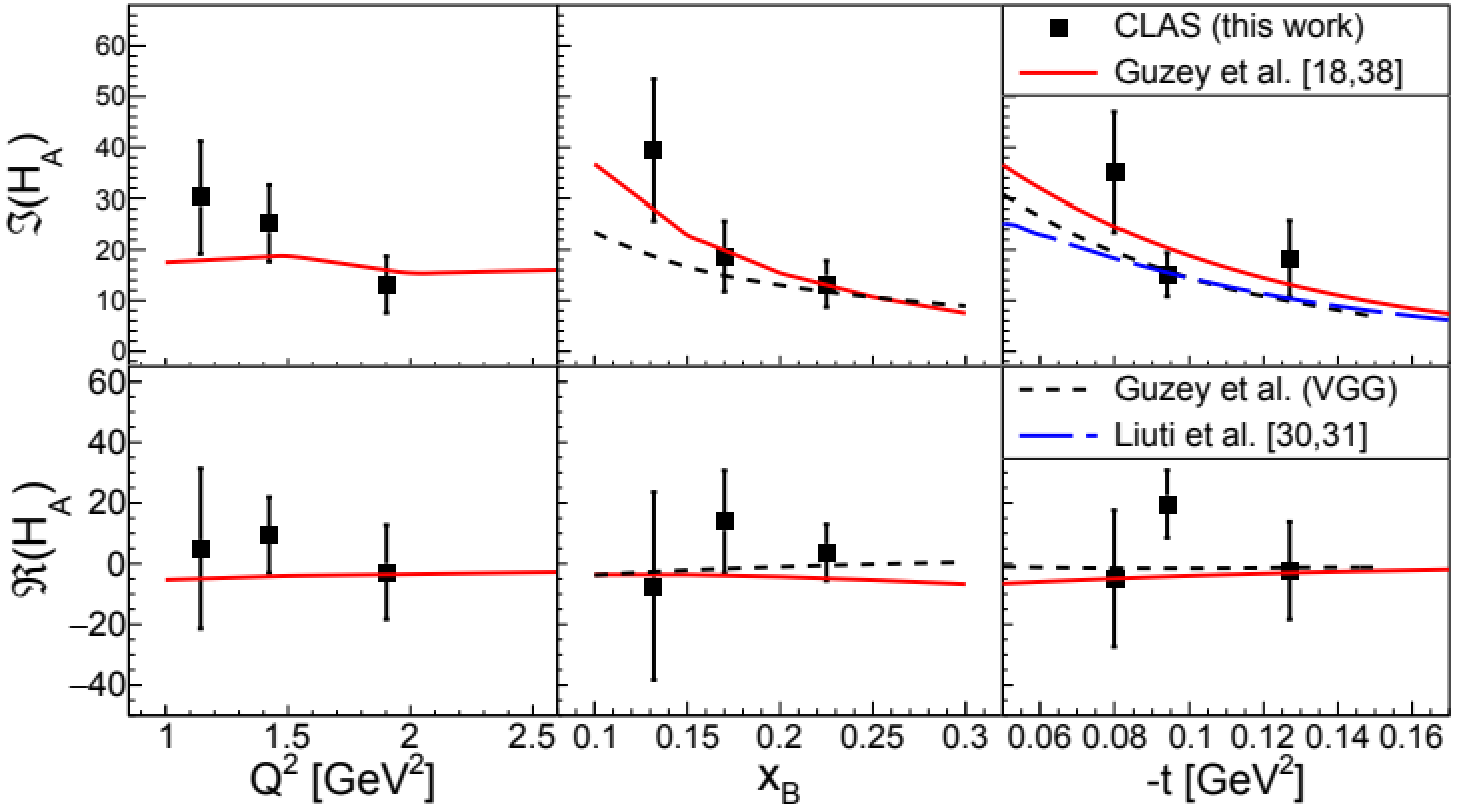
– They are calculable within pQCD

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

– 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

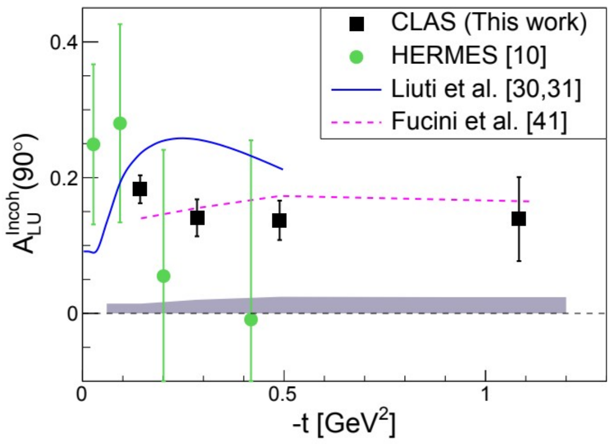
A New kind of EMC effect?

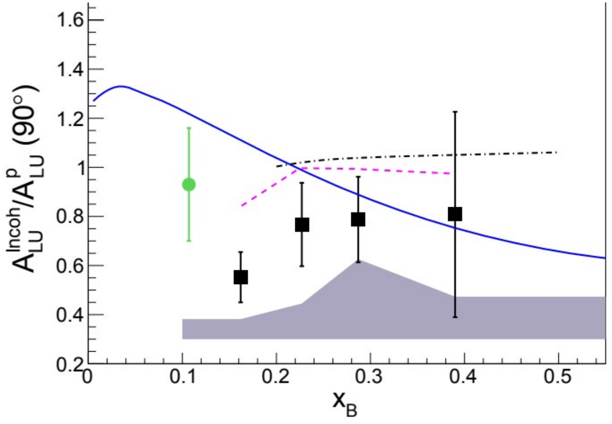
- It could be a nuclear effect
- Or it could be due to final state interactions
  - **Can be very complicated in DVCS**

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

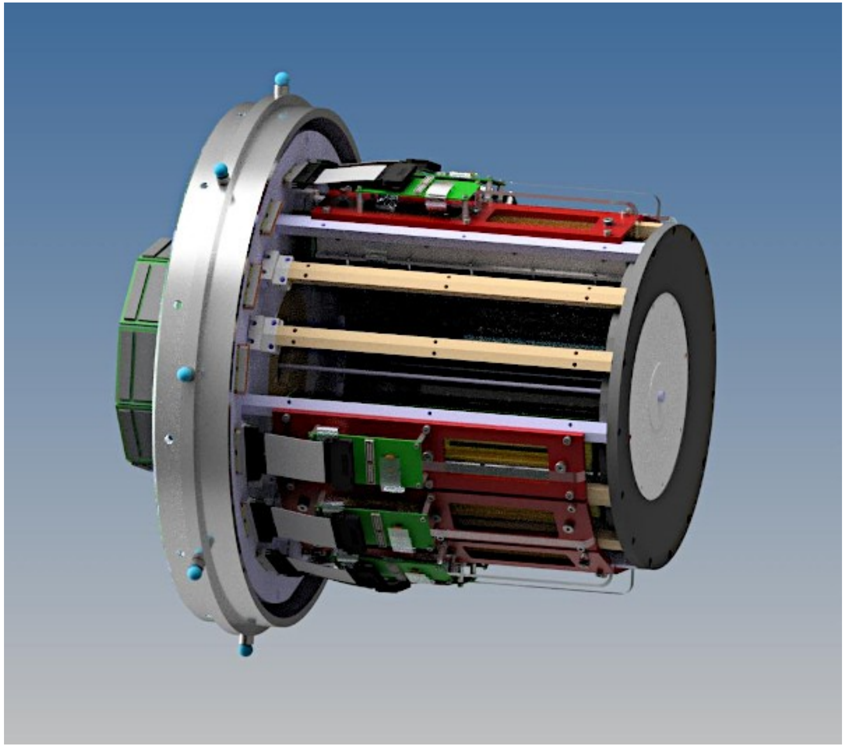
It will be used for a large array of experiments

- Nuclear DVCS, DVMP…
- Tagged processes

Collaborative effort within CLAS12

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

Scheduled for the Summer 2024



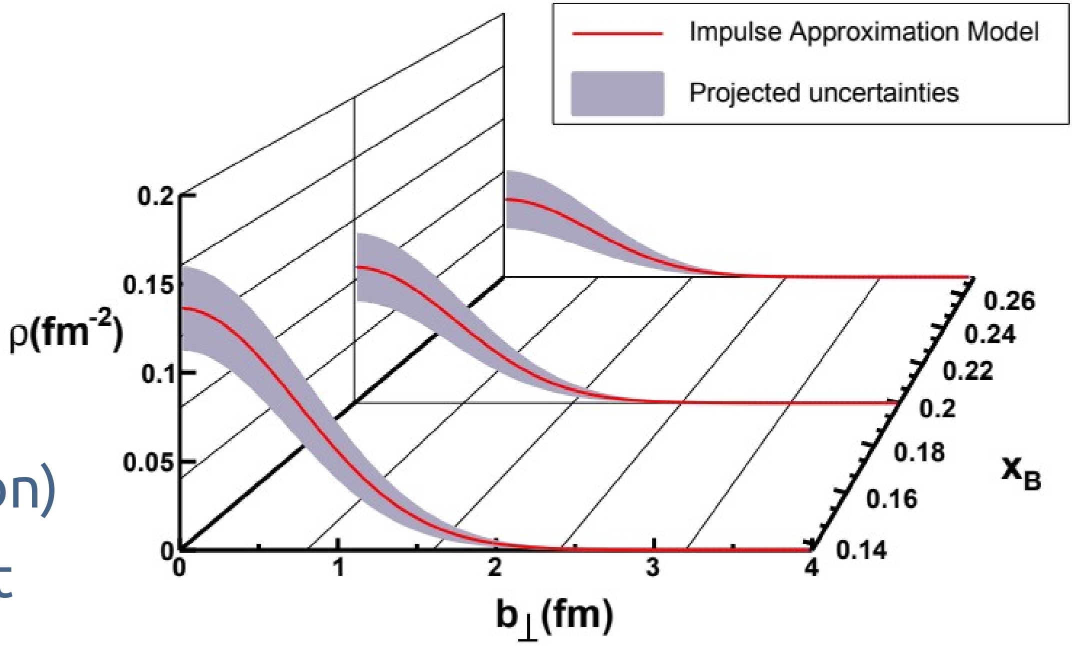
What results do we expect ?

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



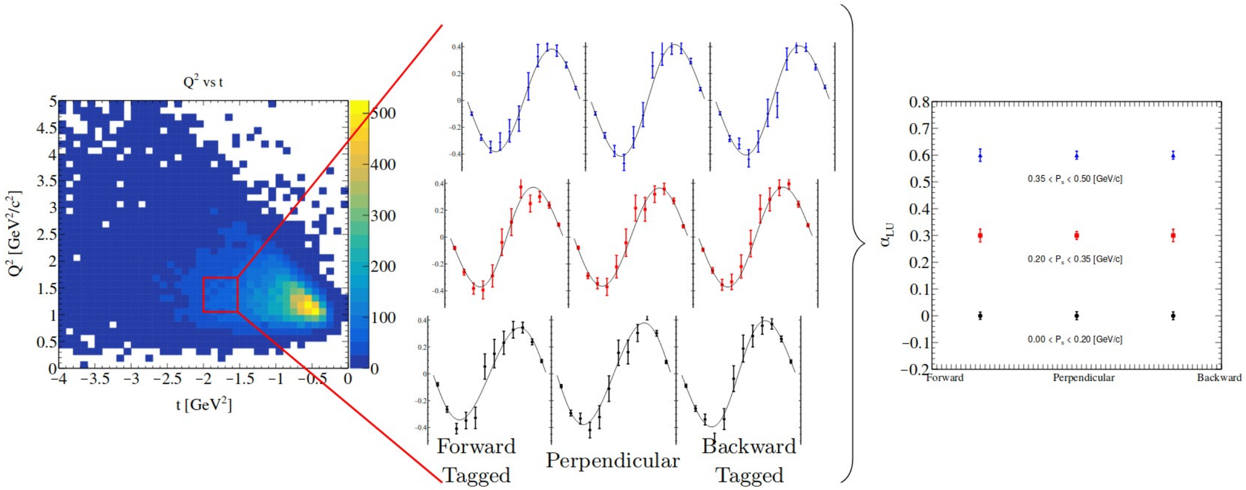
Understanding the Incoherent DVCS

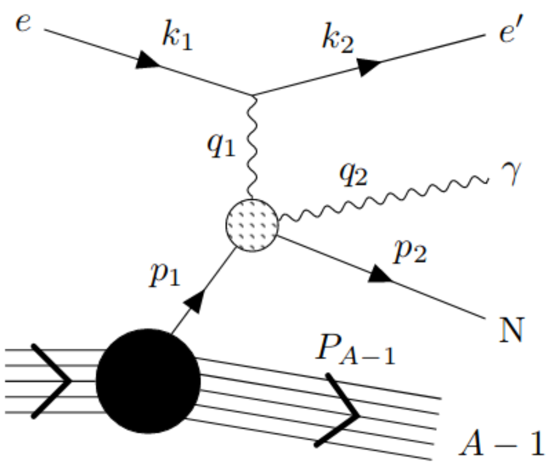
Tagging the incoherent DVCS

- A tagged measurement can pin down the origin of the strong BSA suppression in incoherent DVCS
- By better controling the initial and final states independently

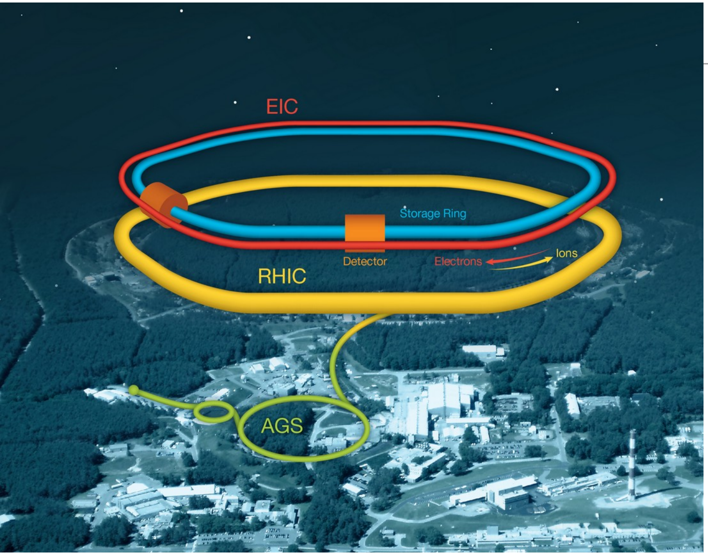
Proposed for JLab 12 GeV

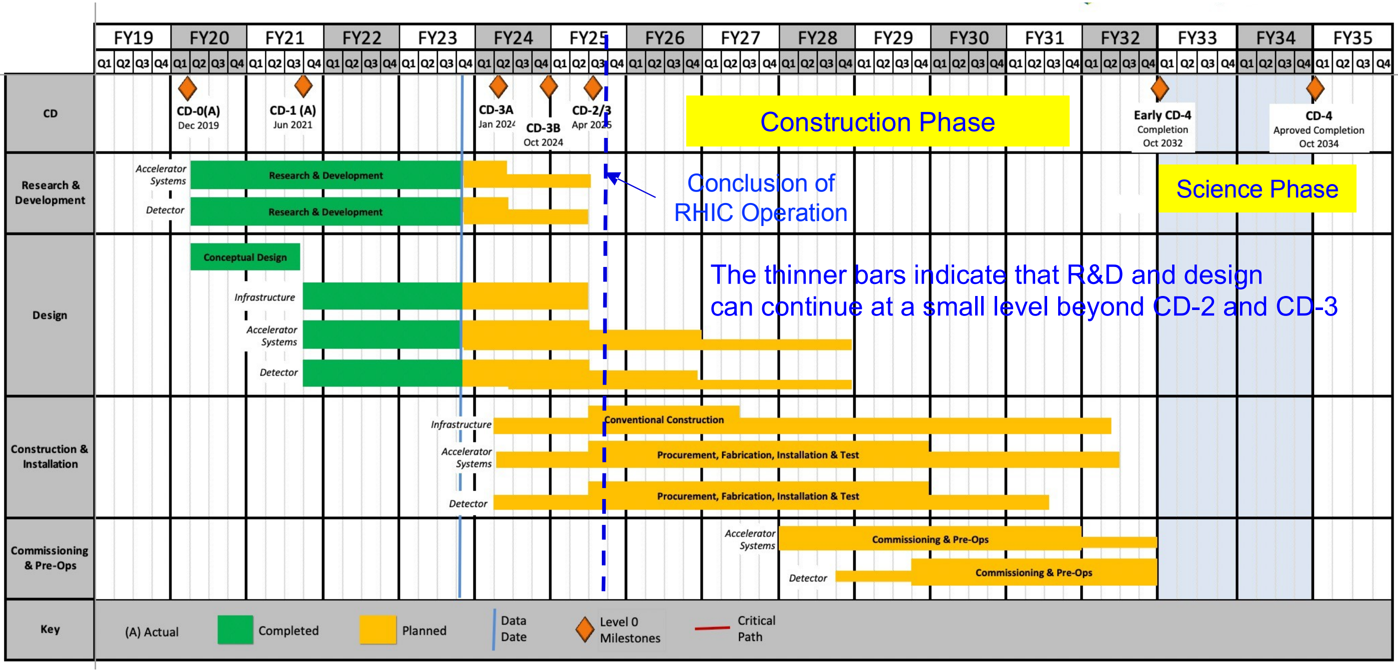
- This is probably an important addition for all incoherent processes in the future





The Future Electron Ion Collider (EIC)





First electron-ion collider

Energy CoM 20 – 141 GeV

$\mathcal{L}_{max} \Rightarrow$ 1034 cm-2 s-1

Electron, proton, and light nuclei beams all polarized.

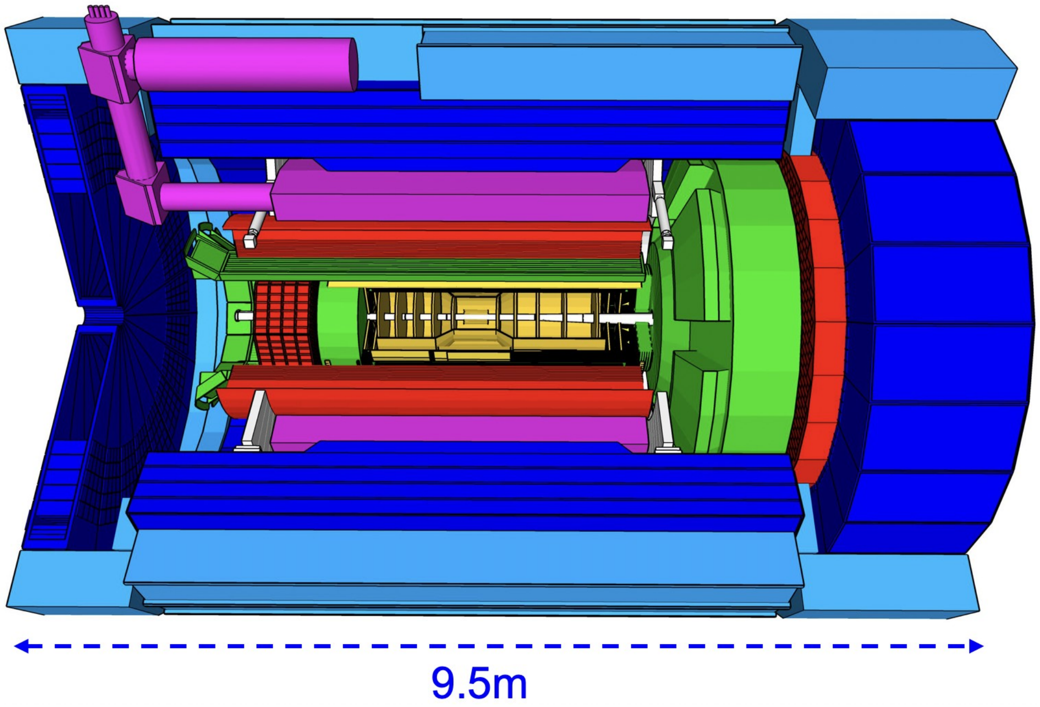
The main EIC detector : ePIC

The All Purpose Detector

- Tracking and vertexing
- New solenoid magnet
- EM and hadron calorimetry
- Important PID effort
  - **Cherenkov, DIRC…**

Collaboration ePIC

- Already working very hard



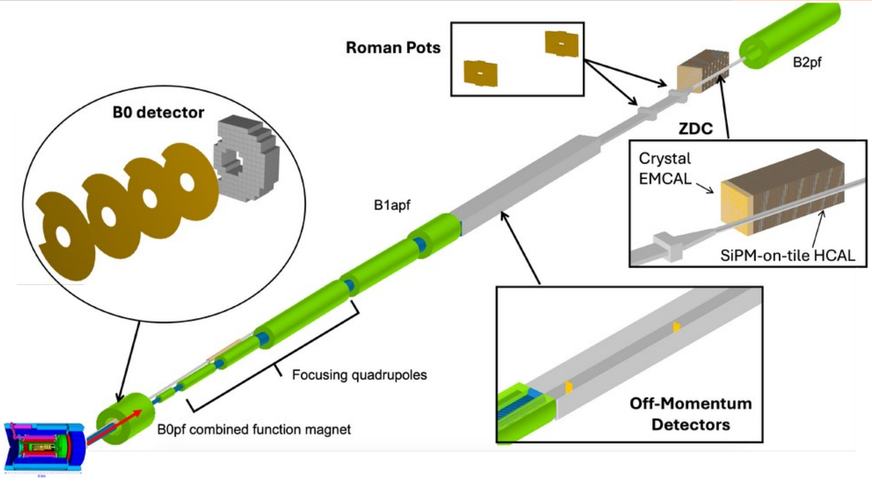
Far Forward Dedectors

ePIC includes far detectors

- To cover the smallest angles
  - **B0 calorimeter**
  - **Roman pots**
- Even down to 0
  - **ZDC and OMD**

These detectors are critical for exclusive processes

- We have a large simulation effort in the physics WG
  - **You are all welcome to join**



Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	θ < 5.5 mrad (η > 6)
Roman Pots (2 stations)	0.0* < θ < 5.0 mrad (η > 6)
Off-Momentum Detectors (2 stations)	0.0 < θ < 5.0 mrad (η > 6)
B0 Detector	5.5 < θ < 20 mrad (4.6 < η < 5.9)

EIC DVCS

EIC and ePIC ideal for exclusive reactions

- Many simulations of DVCS
- Use of all detectors

Large kinematic coverage

- Down to small x
- Need of high luminosity

Studies on-going

- Resolution in t
- Separating pi0

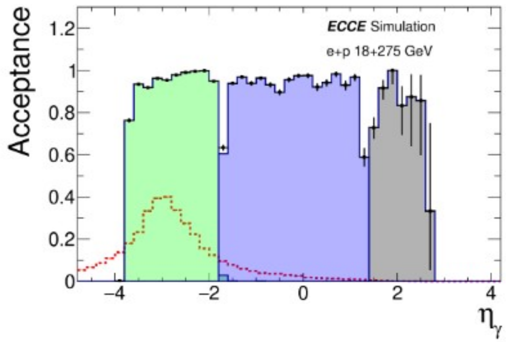


Figure 31: DVCS photon acceptance in the backward (green), barrel (blue), and forward (grey) ECAL's, as a function of pseudorapidity. The red dotted line shows the distribution of (generated) DVCS photons

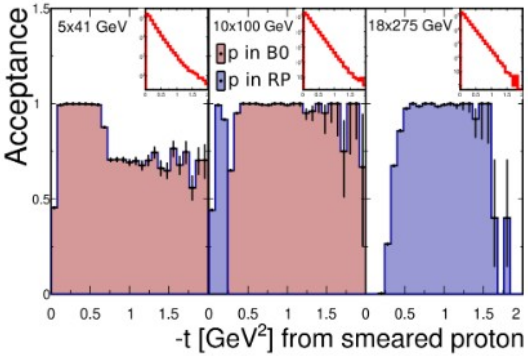


Figure 32: Acceptance for DVCS protons as a function of $-t$ in the far-forward detectors for different beam energy configurations. The inserts show the $-t$ distributions of generated events.

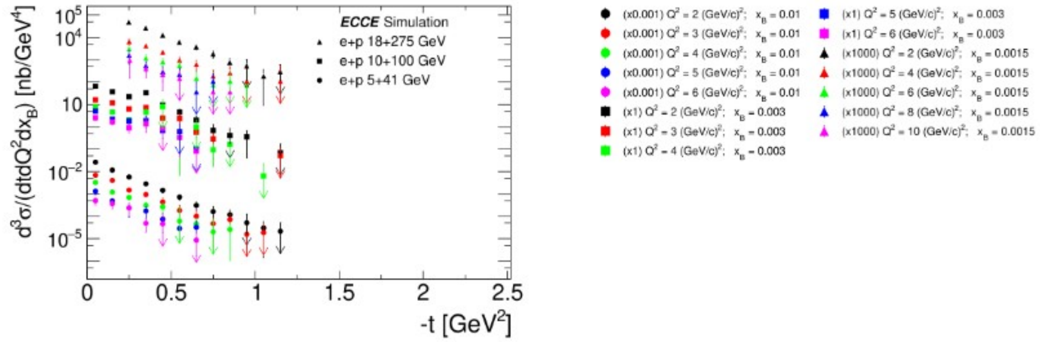


Figure 33: Projected DVCS differential cross-section measurements as a function of the momentum transfer $-t$ for different bins in Q^2 and x_B. The assumed integrated luminosity is 10 fb $^{-1}$ for each beam energy configuration.

Nuclear DVCS at the EIC

We are preparing for nuclear DVCS at the EIC

- Measuring nuclear DVCS at much lower x
- Make a 3D image of the shadowing region

We developed a Monte-Carlo Event Generator

- ROOT based event generator use the TFoam class to generate a grid and then events
- Use of a recent model tested against data

Sara Fucini, Sergio Scopetta, Michele Viviani Phys.Rev.C 98 (2018) 1, 015203

- We named it TOPEG (The Orsay Perugia Event Generator)

https://gitlab.in2p3.fr/dupre/nopeg

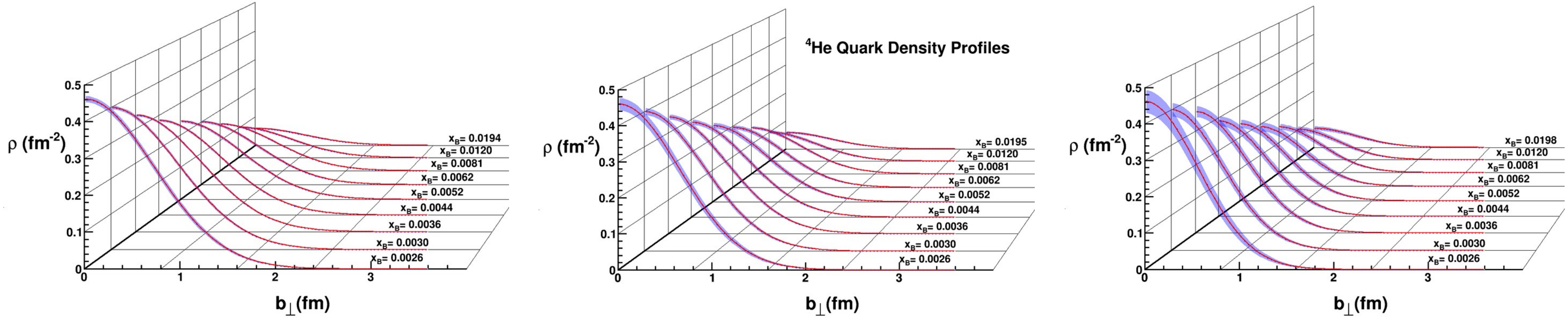
These simulations were produced for the EIC Yellow Report (2021)

- Studies prolonged for the ECCE proposal
- New models are in the work for this event generator (tagged DVCS in particular)

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)**



Much more GPD physics with exclusive meson productions

- Particularly sensitive to the gluon component

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 are many avenues, I focused here on nuclear GPDs

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

Important new elements are coming, especially with EIC

- Using tagging will open many incoherent channels and control the virtuality
- The high energy gives access to a completely new x range and gluons