## ALERT Run Group

# *Nuclear GPDs*

**Raphaël Dupré**

**On behalf of the CLAS Collaboration**

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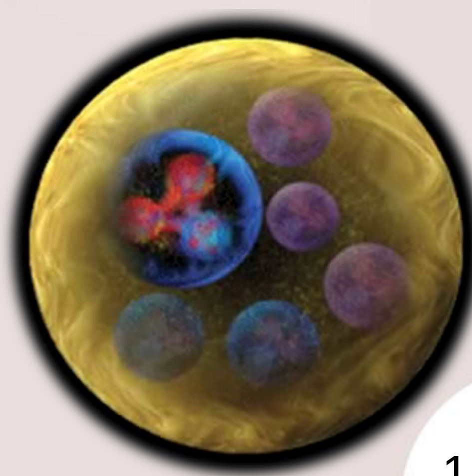

# Outline

- **Introduction**
- ALERT Detector
- GPD Measurements
- Summary & Beam Time Request

# The ALERT Run Group Program

- **We will access the nuclear structure in terms of partons**
  - We will measure together the quark and gluon GPDs (PR12-17-012)
    - GPDs will be obtained through the coherent nuclear DVCS and $\phi$ production
    - Model independent LO/LT interpretations without FSI concerns or others
    - A first glimse into gluon physics before EIC
  - We will have a full picture of $^4$He in term of both quarks and gluons
    - We will benefit fully from the spin-0 simplification
    - Unique view into the non nucleonic degrees of freedom in the nucleus
    - Allows to compare the gluon radius to the charge radius

- **We propose a comprehensive program to study nuclear effects:**
  - We will address key questions about the EMC effect (PR12-17-012A) using tagged deep inelastic scattering (DIS)
    - Is EMC due to x or $Q^2$ rescaling?
    - Is the transition from mean field to SRC regime smooth?
  - We will access Tagged DVCS in the same fashion (PR12-17-012B)
    - Is there an off-forward EMC effect ?
    - How is the nucleon profile modified in nuclei ?
  - Tagging is also a key feature of the future EIC that JLab can start to exploit right now

- **We show in PR12-17-012C that this data will be used to study many other interesting physics ($\pi^0$, deuterium GPDs, …)**
  - Relevant to this talk are propositions for studies of higher twist effects in DVCS and transversity GPDs using exclusive coherent $\pi^0$ production.

# We Need Nuclear Recoil Detection!

- **The use of a recoil detector is necessary**
  - Helium recoils produced in DVCS and Deep Virtual Meson Production (DVMP) have a low energy (from 250 MeV/c and up)
  - Tagged reactions produce fragments (p, $^{2}H$, $^{3}H$ and $^{3}He$) with recoil momenta of around 60 MeV/c and up depending on the nuclei

- **Our experimental goals**
  - Optimize detection threshold by minimizing the absorption in the target material
  - Fast detector response for high luminosity running
  - Ability to differentiate among isotopes for tagged measurements

- **We had success measuring the tagged DIS on deuterium and the coherent DVCS on $^{4}He$ with CLAS**
  - Confirmed that identification of these processes is possible
  - Also showed the limitations of the TPC technology

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# Available Detector Options

- **CLAS12 Central Detector**
  - It will not be able to detect the recoil spectators at low enough energy
- **Radial Time Projection Chamber (RTPC)**
  - RTPC has great capabilities for slow recoil detection

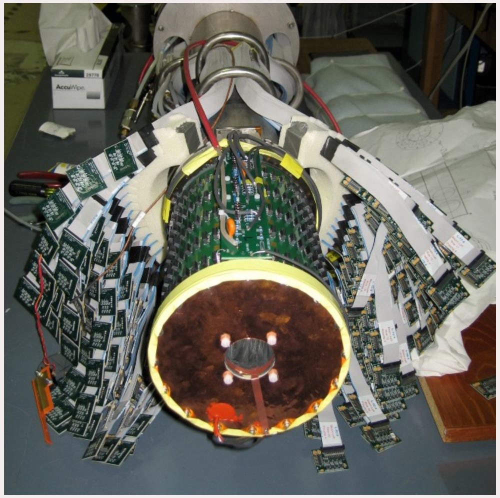
    → we built it and used it for $^4$He coherent DVCS in CLAS

    (see R. Dupré et al. arXiv:1706.10160)
  - However particle identification is limited
    - Even with improvements it cannot differentiate between $^3$He and $^3$H
  - The data acquisition rate was the limiting factor for the luminosity of this experiment
  - Because of pile-up, the time resolution (few hundreds ns) and long drift time (few µs) severely limit its performance at high luminosity

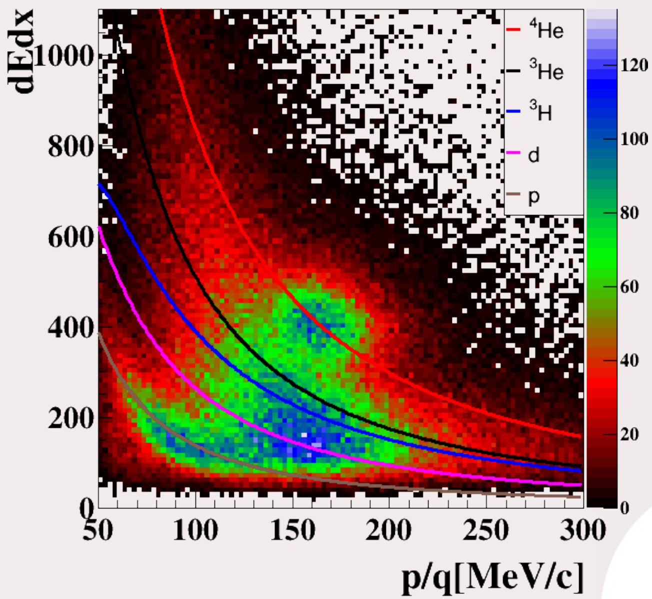
**→ We came to the conclusion that we need another detector**

- To use fully CLAS12 luminosity capabilities
- To perform tagged measurements

Nuclear DVCS RTPC



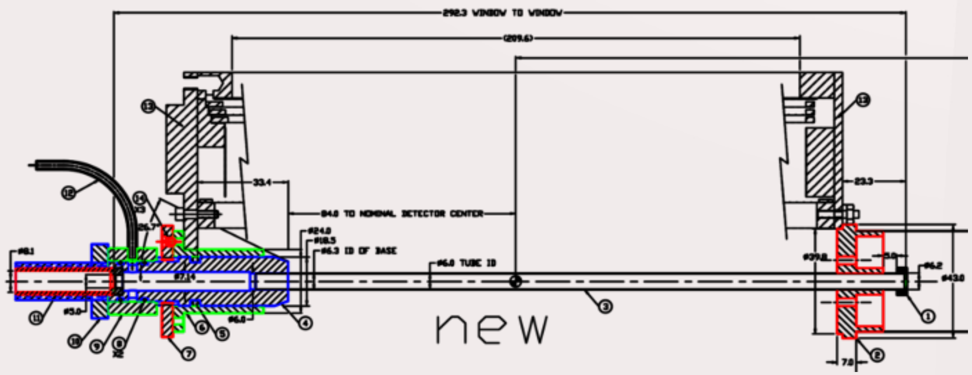
RTPC PID performance

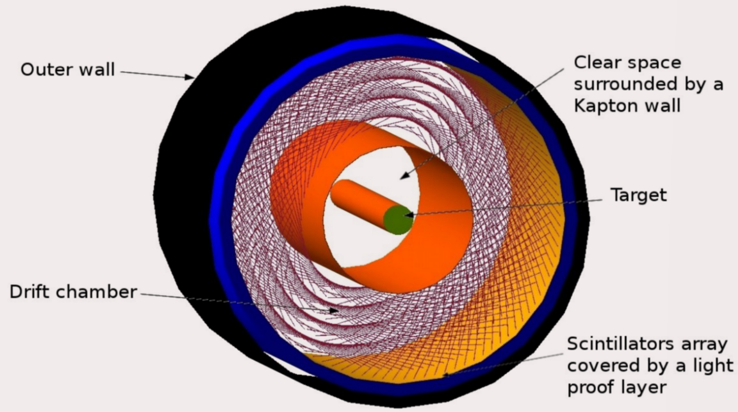


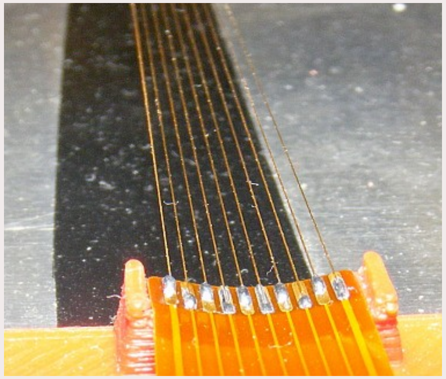
# The ALERT Detector

- **A Low Energy Recoil Tracker**
  - Replace the CLAS12 silicon vertex tracker (SVT) and the micromegas detectors
- **Hyperbolic drift chamber**
  - Stereo angles give the z-axis resolution
  - We tested electronic options
    → first prototype tested with DREAM Front-End Board
- **Scintillators for TOF and total energy measurement**
  - GEANT4 simulations have been performed to estimate energy loss in different layers
  - Path of photons have been estimated to optimize tile sizes
- **Work in Progress**
  - Some technical choices are not final
    - We present a conservative version that we are confident we can build without problems
    - We are working with prototypes to optimize different parameters (exact gas mixture, wire materials and thickness...)

      *G. Charles et al. Nucl. Instrum. Meth., A855 (2017) 154*
  - Integration of electronics and other elements
    - We use the same electronics (DREAM), but with less channels, than the CLAS12 Micromegas, so we do not expect this to be a major challenge

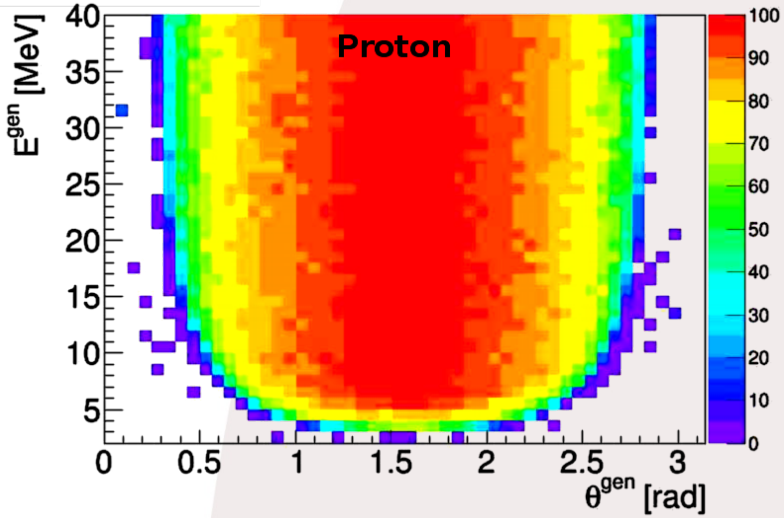


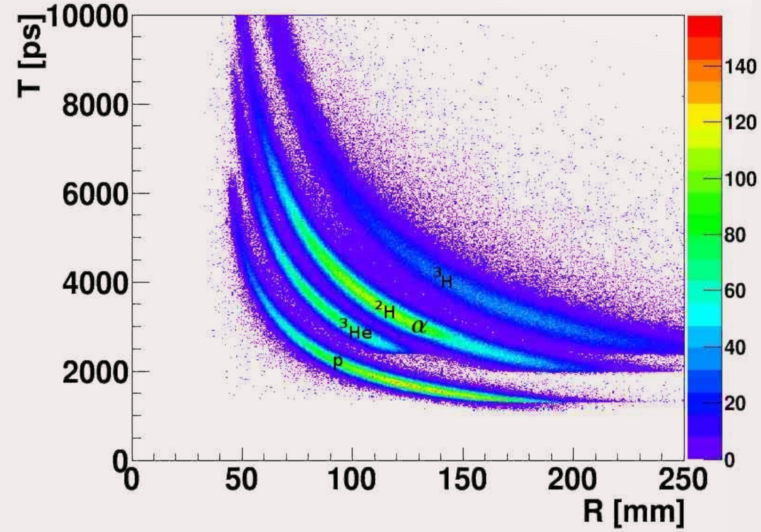



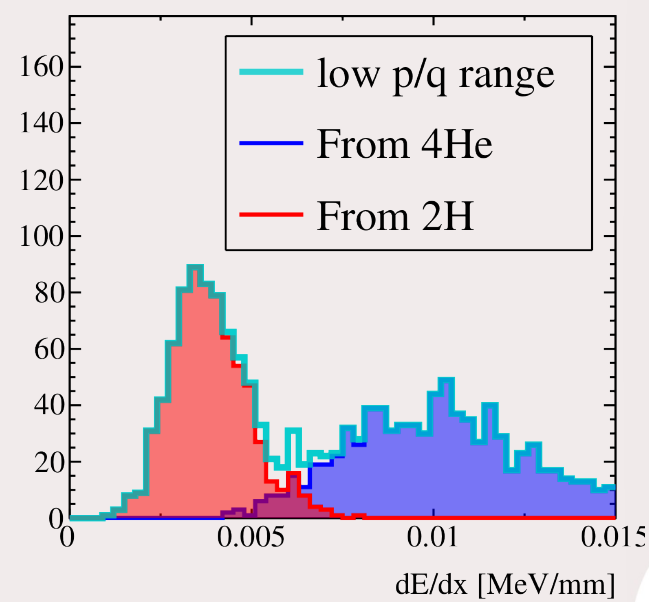
Soldering tests with a 2mm wire gap on a curved surface

# Expected Detector Performances

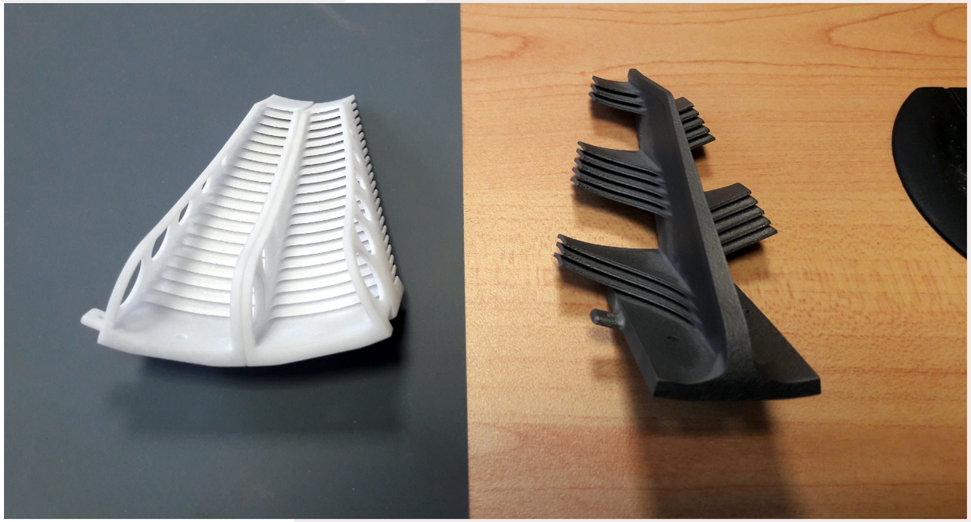


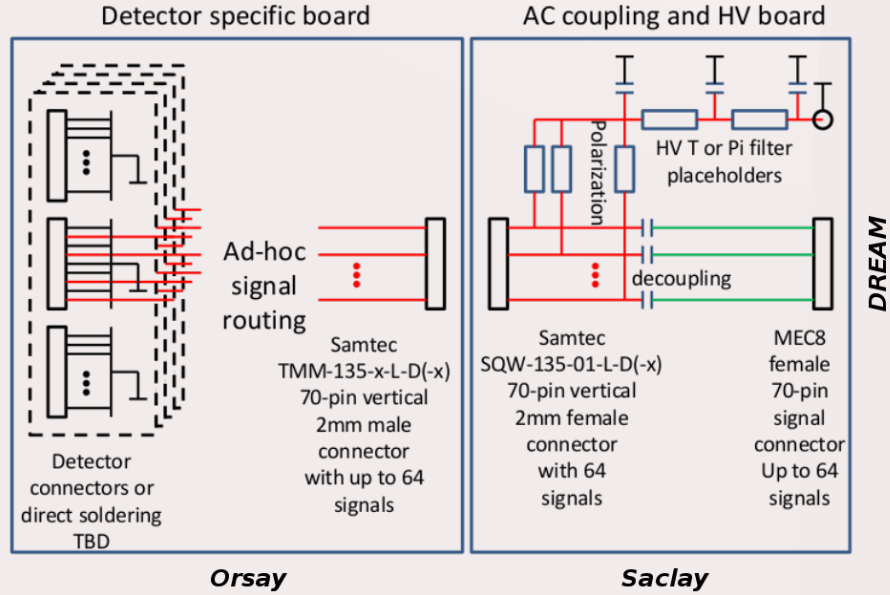




- **Capabilities for very low momentum detection**
  - As low as 70 MeV/c for protons and 240 MeV/c for $^4$He
  - Detection at large angles in forward and backward directions (25° from the beam)
  - Main limitations are due to recoils stopped in the target and are simulated with GEANT4
  - Target has 6 mm radius with 25 µm kapton walls and 3 atm pressure
- **Capabilities to handle high rates**
  - Small distance between wires leads to short drift time <250 ns (5 µs in a similar RTPC)
    - Based on MAGBOLTZ calculation
  - This translates into 20× less accidental hits
  - Allows to be integrated in the trigger for significantly reduced DAQ rate
- **Improved PID**
  - Like in the RTPC we get dE/dx
  - We have more resolution on the curvature due to the large pad size in previous RTPCs
  - We have new informations: TOF, total energy deposit…

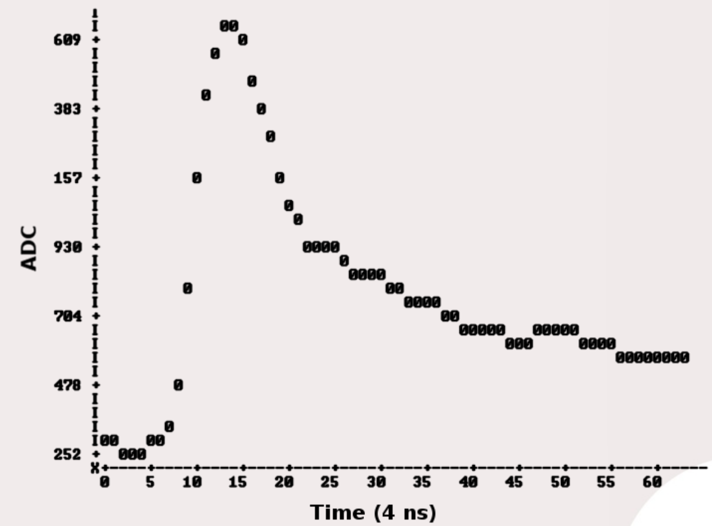


# First Prototype Tests





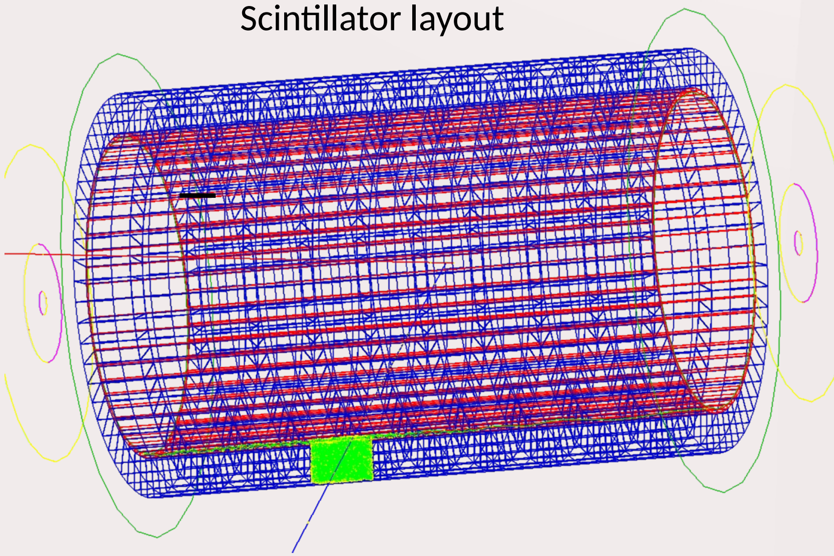

- **Mechanical structure**
  - We tested 3D printed titanium for the complex upstream pieces
  - High rigidity plastic for the forward part
- **Wire installation**
  - The 2 mm gap appears to be conservative and does not cause any issues for installation
- **Electronics test**
  - In collaboration with CEA Saclay we tested their DREAM front end chip
  - First test at Orsay has been performed with a single cell
  - Resolution appears to be well under 10 ns used in the proposal
    - Resolution will be driven by the spread of the drift electrons in the gas
    - Further studies are needed to determine precisely this resolution



# SiPM and Scintillators

- **Scintillator design**
  - Combination of a thin layer and thick tiles
    - $^{3}$He and $^{4}$He will stop in the first layer
    - p, $^{2}$H and $^{3}$H will go through and stop in the second layer
  - Optimized in GEANT 4 to match our resolution requirements
    - Thin layers will be 2mm × 9mm × 30cm with SiPM at both ends
    - Thick tiles will be 20mm × 9mm × 3cm with a SiPM in the back
- **Radiation damage**
  - We expect radiation at the level of $\lesssim$krad
  - Scintillators are significantly damaged at ~Mrad levels
  - SiPM studies based on work from Hall-D
    - Indicate that we should have only small effects
    - A more refined simulation to estimate the precise neutron rates on SiPM is in progress
  - This is not expected to be an issue for either scintillators or SiPMs

Scintillator layout



Silicon Photo-multiplier (SiPM)

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- **GPD Measurements**
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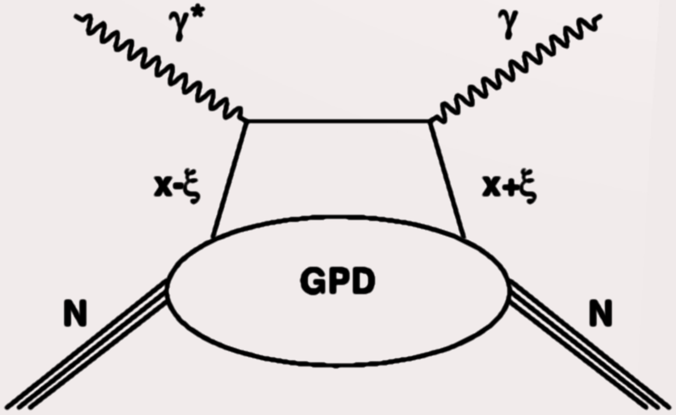
# Generalized Parton Distributions

- **Generalizing the parton distributions**
  - Three dimensions: $x$, $\xi$ and $t$
    - At leading twist, leading order DVCS is described by Spin-0 → 1 GPD / Spin-½ → 4 GPDs / Spin-1 → 9 GPDs
- **Deep virtual Compton scattering (DVCS)**
  - Using factorization gives access to GPDs
  - $x$ is not experimentally accessible → we measure Compton Form Factors (CFF)
  - Accessible through cross sections, BSA, TSA, DSA…
- **Why using $^4$He target?**
  - Spin-0 makes for much simpler extraction of GPDs
    - Allows for an immediate and simple model independent extraction of the GPD H

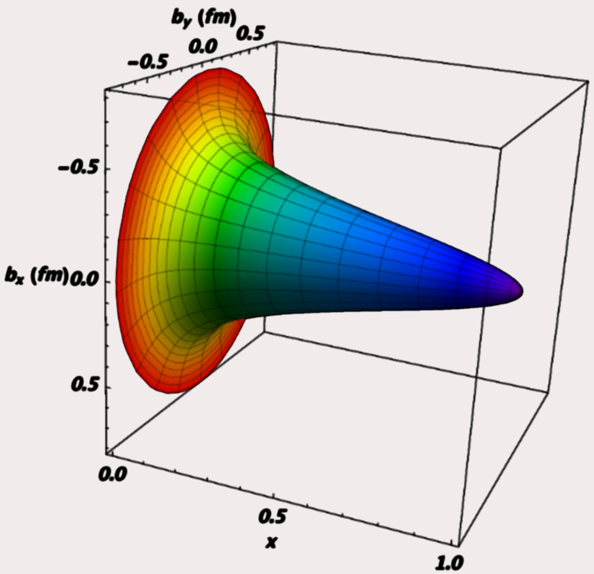
      → Using only Beam Spin Asymmetries
    - The simplification holds for all $H_q$, $H_g$ and $H_T$ !
- **A new take on nuclear physics**
  - Study nuclei beyond the sum of nucleons
    - GPDs give access to the non nucleonic degrees of freedoms in the nuclear structure
  - A direct access to quark and gluon distribution in nuclei

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




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

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



# Extracting a 3D Map

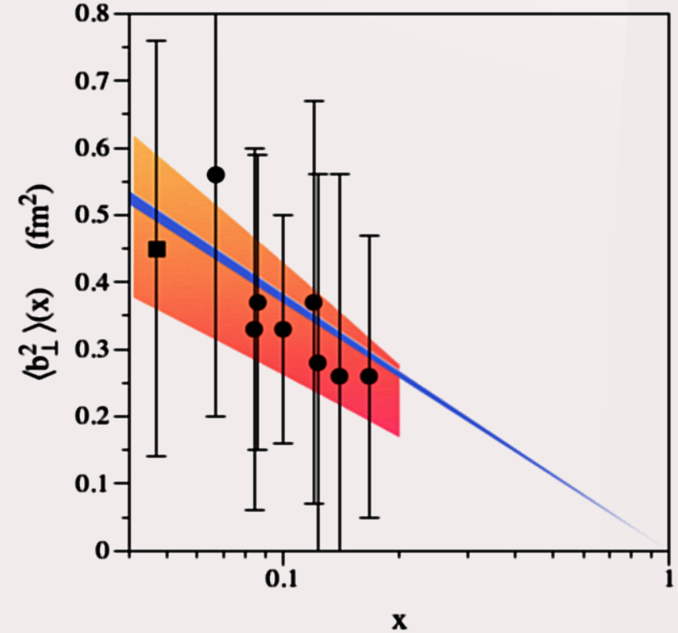
- **GPDs can be interpreted as 3D maps**
  - Fourier transform at ξ=0 gives the probability density as a function of *x* and the impact parameter

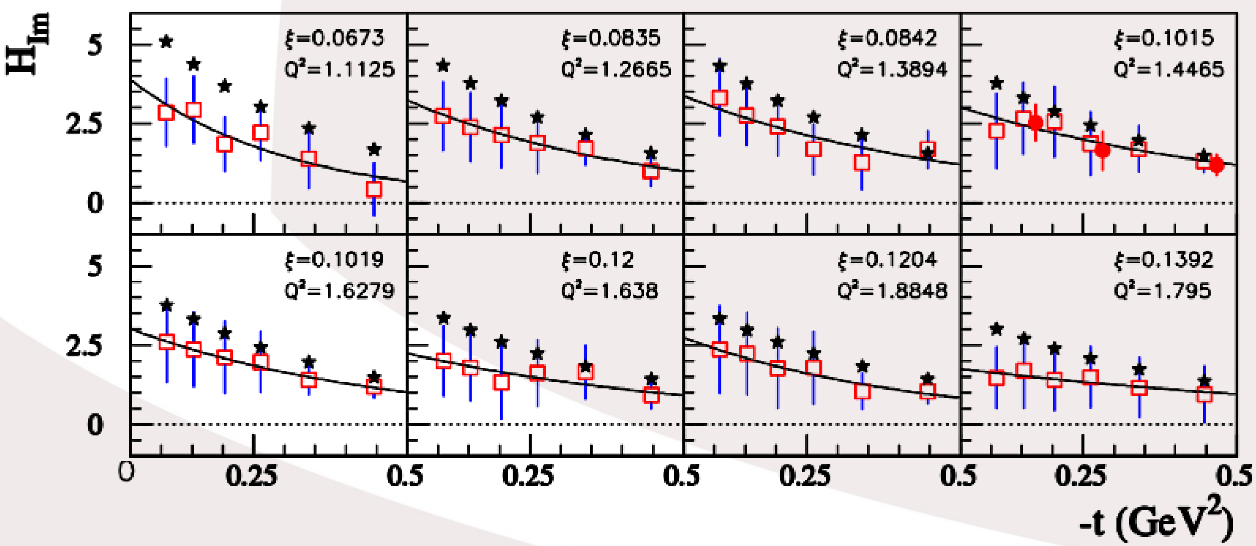
    *M. Burkardt Int.J.Mod.Phys. A18 (2003) 173-208*

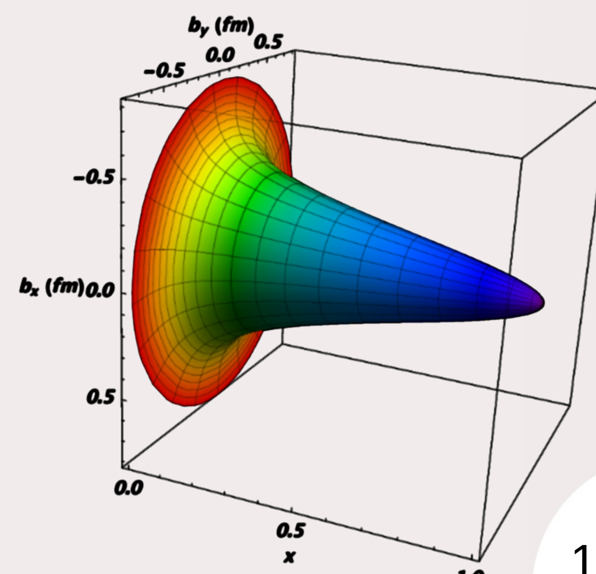
- **Fits of data**
  - Putting together cross sections and spin asymmetries
  - Global fit allows to extract the 3D map of the proton
  - Necessitate to set some limits on the sub-leading CFF

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

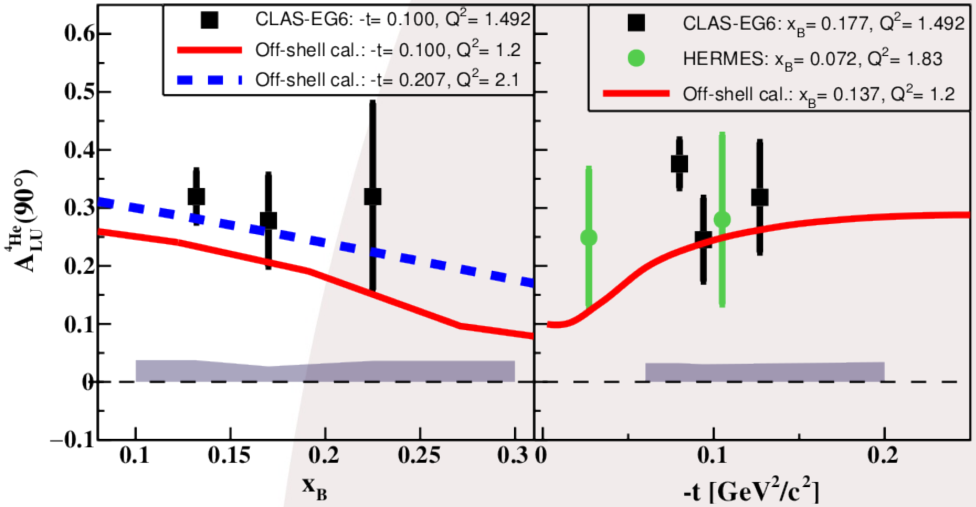
    *R. Dupré et al. Phys.Rev. D95 (2017) no.1, 011501*

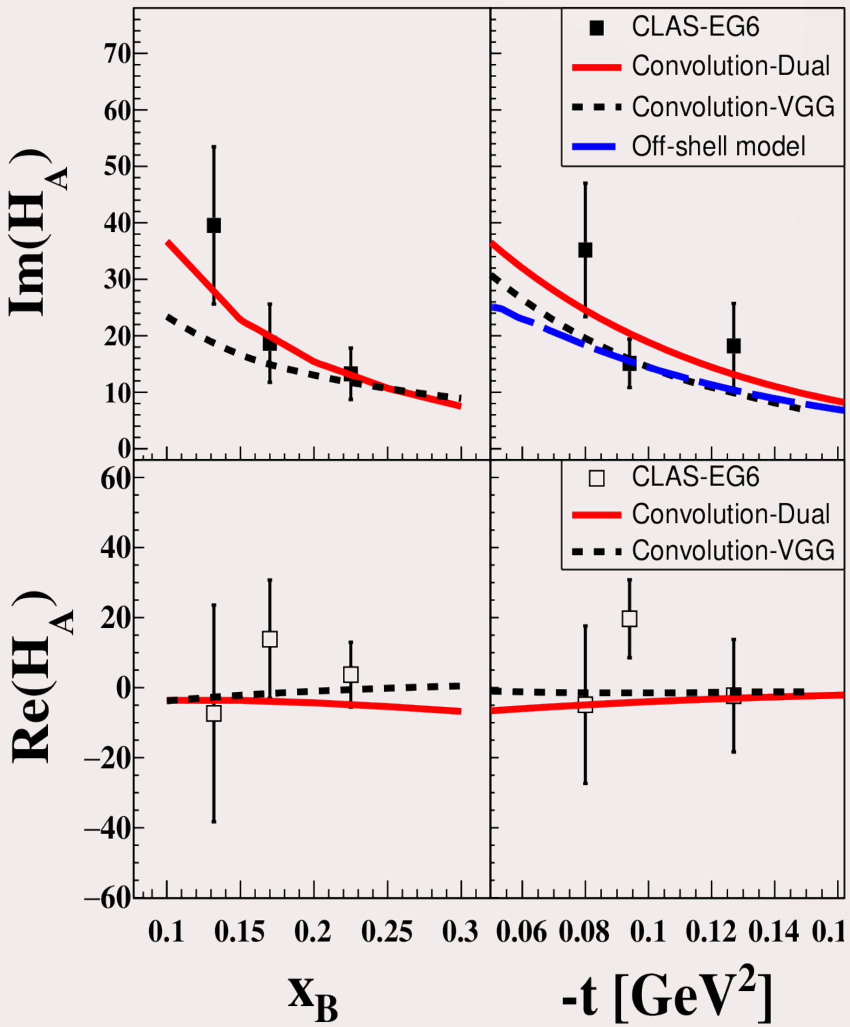


# The CLAS Measurement

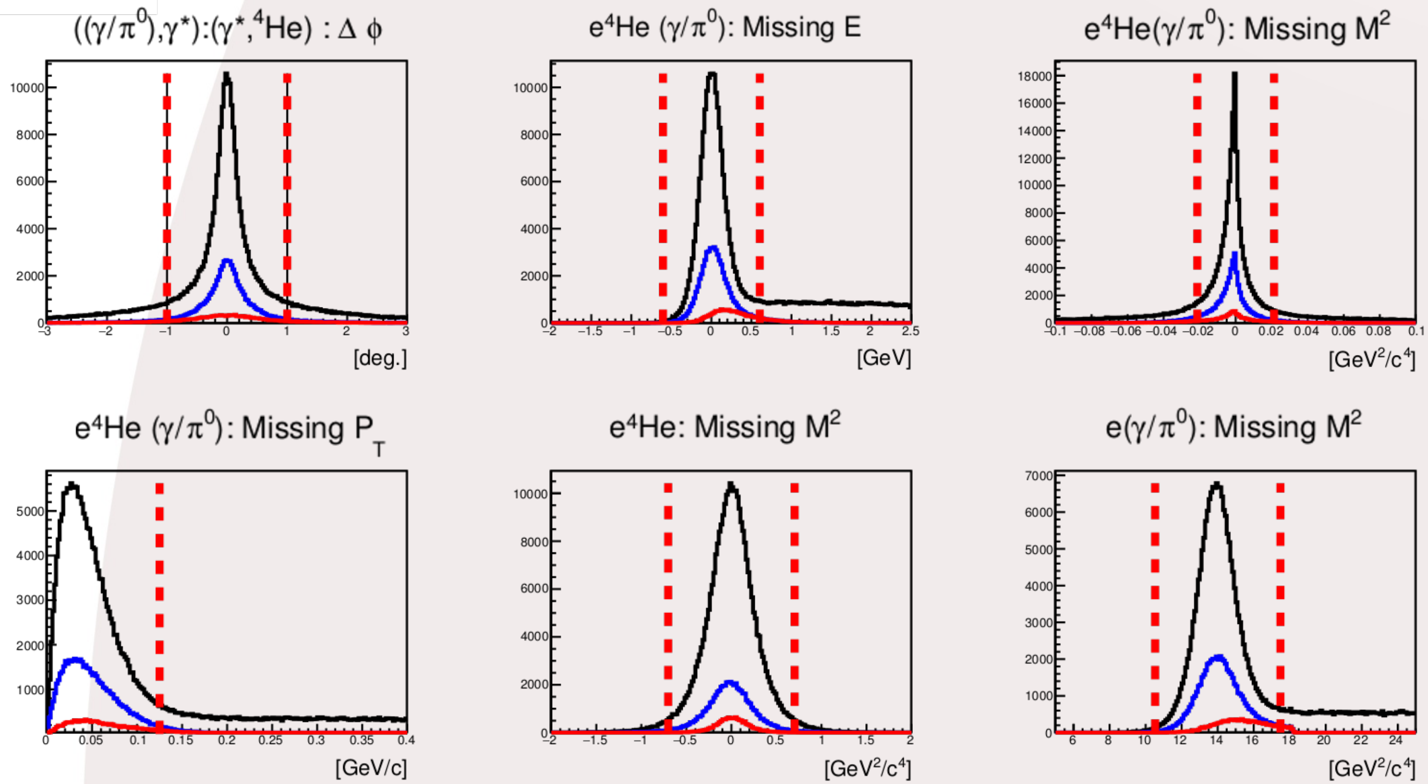



- **We have results from CLAS (E08-024) experiment**
  - First measurement of its kind
  - Larger asymmetries than for a proton target
  - Limited statistics and kinematic coverage

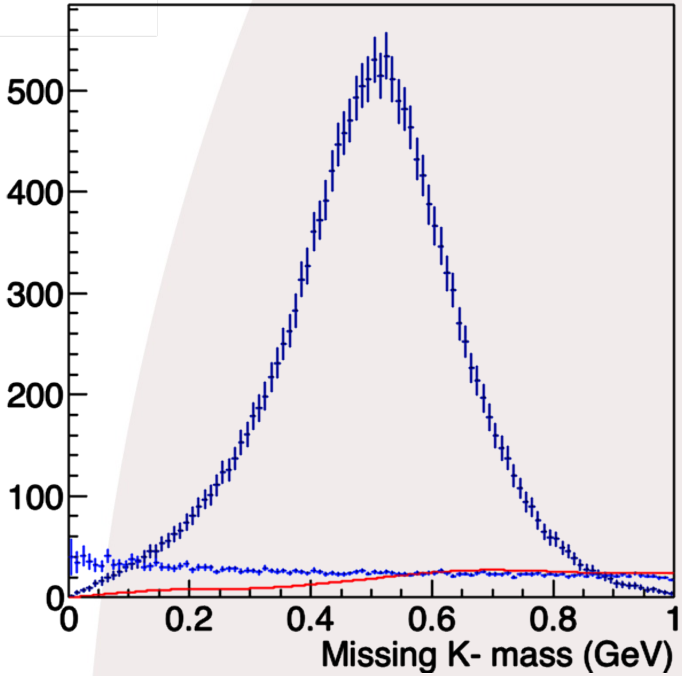
  *M. Hattawy et al. (CLAS Collab.) arXiv:1707.03361*
- **Lesson learned**
  - Higher energy will allow to get more cross section in the deeply virtual regime
  - Faster recoil detector will allow for higher luminosity

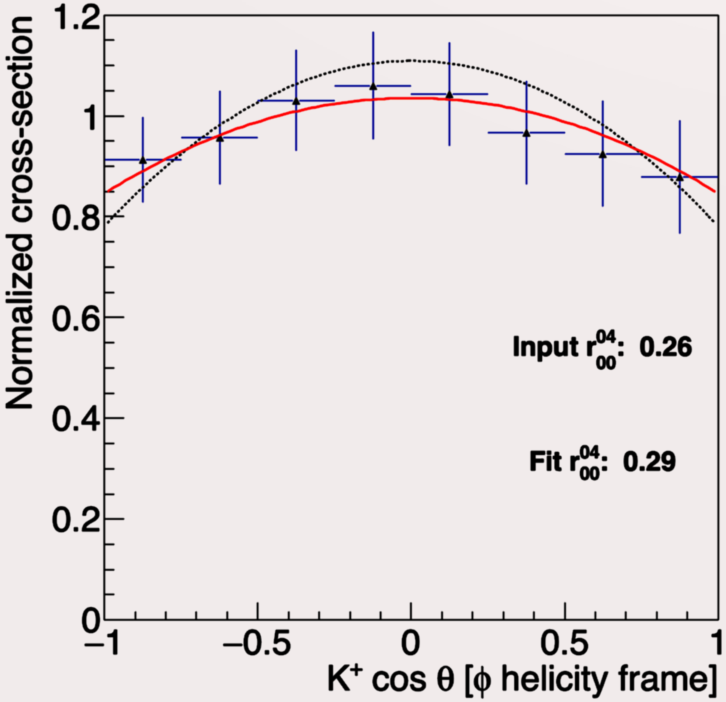
# DVCS Exclusivity




- **CLAS 12 has been designed with DVCS in mind**
  - The resolution of the detectors allows for tight exclusivity cuts necessary to get a clean DVCS sample
  - All final state particles are detected
    - Providing extra constrains to exclude backgrounds
  - The remaining $\pi^0$ background is suppressed with a well established procedure

# Deeply Virtual ϕ Production

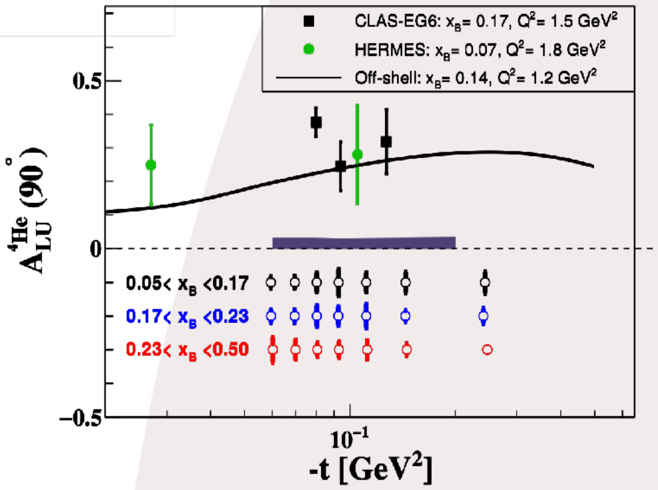


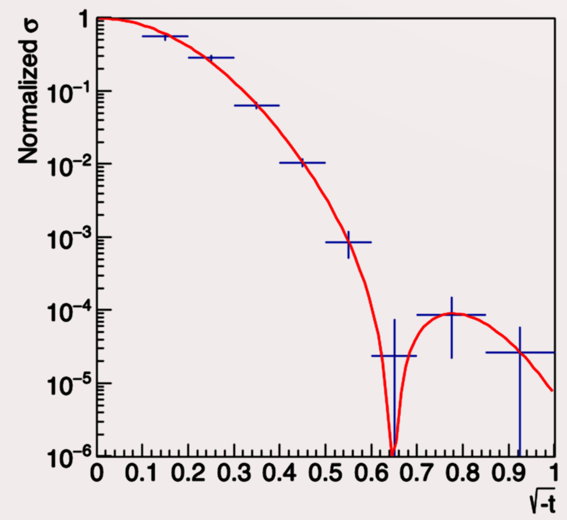



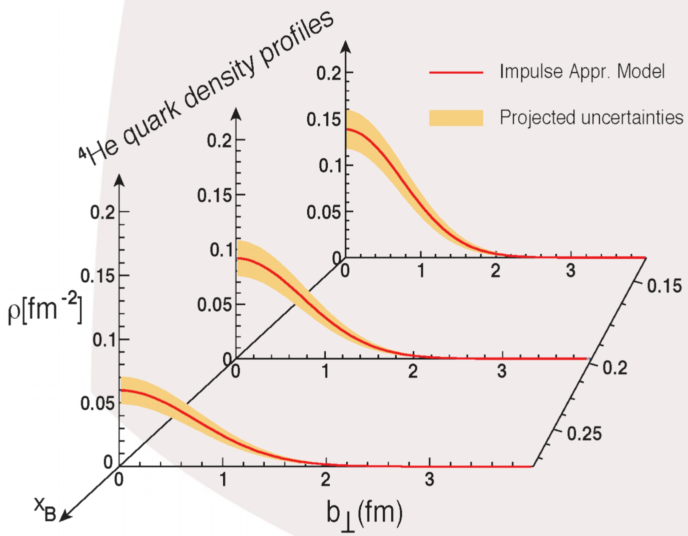

- **Exclusivity is insured by reconstructing the missing mass of a $K^-$**
  - Very sensitive to ALERT resolution
  - Background is reduced by requiring the detection of $^4$He
- **Longitudinal cross section extracted from cosθ**
  - Can then be directly related to gluon distribution

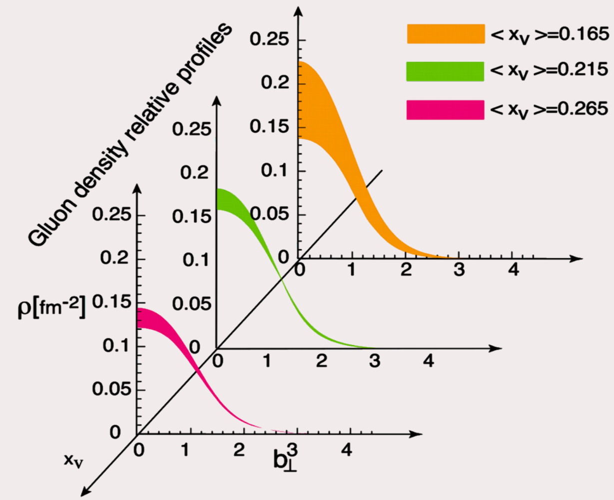
$$|\langle H_g \rangle|(t) \propto \sqrt{\frac{d\sigma_L}{dt}(t - t_{min}) \Big/ \frac{d\sigma_L}{dt}(0)}$$

# Projections




- **We will perform the tomography of the helium-4 nucleus both in term of quarks and gluons**
  - It will be a complete measurement of the leading order GPDs of helium
  - It is a unique opportunity to compare the quark and gluon distributions in the nucleus

# Outline

- Introduction
- ALERT Detector
- GPD Measurements
- **Summary**

# Beam Time Request

- **ALERT run group will need 55 days of beam time**
  - This request driven by the nuclear GPDs measurements is 35 days (commissioning and config. A & C)
  - We need a high polarization to measure beam spin asymmetries in DVCS

- **Building the ALERT detector**
  - Wire chamber project and prototyping are on-going in IPN Orsay
  - Scintillators and SiPM part of the project is on-going in ANL
  - Funding for detector construction (pending a favorable outcome for the PAC) will be pursued from France/Europe (wire chamber) and from the DOE-NP (ANL) for the scintillators and SiPM

| **Configurations** | **Proposals** | **Targets** | **Beam time request** days | **Beam current** nA | **Luminosity*** $n/cm^2/s$ |
|---|---|---|---|---|---|
| Commissioning | All† | $^1H$, $^4He$ | 5 | Various | Various |
| A | Nuclear GPDs | $^4He$ | 10 | 1000 | $6 \times 10^{34}$ |
| B | Tagged EMC & DVCS | $^2H$ | 20 | 500 | $3 \times 10^{34}$ |
| C | All† | $^4He$ | 20 | 500 | $3 \times 10^{34}$ |
| **TOTAL** | | | **55** | | |

# Summary

- **We will bring the study of the QCD structure of Nuclei to the next level**
  - With Nuclear GPDs, we are mapping the fundamental structure of nuclei
  - We will compare the quark and gluon 3D structure of the helium nucleus
  - Using a clean coherent process and benefiting from the spin-0 simplification
    - Making this measurement model independent
- **These are some of todays key questions motivating the EIC construction**
  - This proposal offers to explore some of the key elements of the EIC program
  - Using ALERT we can have the first look into these high impact physics topics

## Electron-Ion Collider: The next QCD frontier

### Understanding the glue that binds us all

A. Accardi[14,28], J.L. Albacete[16], M. Anselmino[29], N. Armesto[37], E.C. Aschenauer[3,a], A. Bacchetta[36], D. Boer[33], W.K. Brooks[38,a], T. Burton[3], N.-B. Chang[23], W.-T. Deng[13,23], A. Deshpande[25,a,b,c], M. Diehl[11,a], A. Dumitru[2], R. Dupré[7], R. Ent[28,d], S. Fazio[3], H. Gao[12,a], V. Guzey[28], H. Hakobyan[38], Y. Hao[3], D. Hasch[15], R. Holt[1,a], T. Horn[5,a], M. Huang[23], A. Hutton[28,a], C. Hyde[20], J. Jalilian-Marian[2], S. Klein[17], B. Kopeliovich[38], Y. Kovchegov[19,a], K. Kumar[25,a], K. Kumerički[40], M.A.C. Lamont[3], T. Lappi[34], J.-H. Lee[3], Y. Lee[3], E.M. Levin[26,38], F.-L. Lin[28], V. Litvinenko[3], T.W. Ludlam[3,d], C. Marquet[8], Z.-E. Meziani[27,a,b,e], R. McKeown[28,d], A. Metz[27], R. Milner[18],

### Contents

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- Theory Review
- Technical Review
- The Straw Target
- More on ALERT vs RTPC
- More on PID in ALERT
- PR12-17-012C and additional topics

# Theory Review

## PR12-17-012: *Partonic Structure of Light Nuclei*

*J. W. Van Orden*

This proposal is to measure deeply virtual Compton scattering (DVCS) and deeply virtual meson production (DVMP) from $^4$He with the final state $^4$He measured with the ALERT detector. Since $^4$He has spin 0, the number of possible structure functions is reduced to one which simplifies the analysis of the experiment. DVCS will allow the extraction of quark GPD's for $^4$He while DVMP of a $\phi$ meson allows the gluonic distribution to be accessed. There appears to be no unusual theory problems with this experiment. The production quark and gluon distributions for the nucleus rather than just a constituent nucleon eliminates the need to make any assumptions about the character of nucleons in the nucleus and would provide some very interesting results. I would recommend that this proposed experiment be approved to run as part of its associated run group.

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

# TAC Reviews

**1) One major piece of non-standard equipment is the “ALERT” system, which acts as the target and the recoil detector for the nuclear fragments. This detector has been reviewed by TAC44 and several comments and suggestions have been made.**

*We have tried to answer as many of the questions raised previously as possible in the proposals, see below for others. Note that some questions are very specific and technical, we sometimes felt that they pass the scope of a PAC proposal. The guidelines for proposals (https://www.jlab.org/exp_prog/PACpage/guidelines.html) indicate "detailed technical reviews" as one among other "subsequent steps" for the proposers, not as necessary information to be included in the proposal.*

**2) The maximum beam current has been increased to 1000nA at 11 GeV beam energy. The corresponding beam power hitting the Hall B beam stopper is 11KW. This exceeds the current design limit of 5KW. An upgrade of the beam stopper design is required.**

*This has been noted in the proposal and in the cover letter. We are hoping JLab can do this work, discussions with people of Hall-B were rather positive on this.*

**3) The effect of the wires in the drift chamber on energy loss and acceptance should be estimated. This is a momentum-dependent effect and depends on material distribution within the active volume. If not fully simulated it could affect the reach of the experiment.**

*We have certainly made estimations of these but did not fully simulated it, we should have mentioned this issue in the proposals. In fact, we found that this can cause a loss of up to 20% of the events. We have a program of R&D on carbon wires to try to reduce this number [[ see our first results in G. Charles et al. Carbon wire chamber at sub-atmospheric pressure. Nucl. Instrum. Meth., A855 :154-158, 2017 ]]. However, we believe that this loss of acceptance is acceptable for our experiments as they all involve ratios. We did not have a discussion of this topic in the proposal to avoid any confusion in the document between ideas for small improvements that some of our team members are working on and necessary features for the proposed experiments.*

# TAC Review

**4) The detector is still in the R&D phase. Even the drift chamber wires are not defined.**

*The wires will be roughly 20 μm in diameter, but obviously we still want to build a prototype to insure that this is the best we can use. Wire diameter affects mostly the amplification and the resulting gains, with very well known and calculable effect. After nearly 50 years of wire chambers history, we feel that wire thickness hardly qualifies as a R&D question. As mentioned in our answer to question 1, we considered that these kind of details are beyond the scope of the current proposal and will be fully addressed in an ensuing technical review that ensures a positive outcome of running the proposed experiment (such as the Experiment Readiness Review (ERR) organized by JLab management before any new piece of equipement is scheduled to run).*

**5) The current plan is to put the SiPMs directly on the scintillator strips. At these high luminosities (for an open detector) the gains may be affected, and if not monitored or frequently restored it may impact information on the deposited energy.**

*The SiPMs will be temperature monitored and compensated through the bias voltage. This is a common procedure and the temperature coefficients are provided in the SiPM's datasheets. The frequency at which these corrections need to be applied is currently unknown but the task is easily automated.*

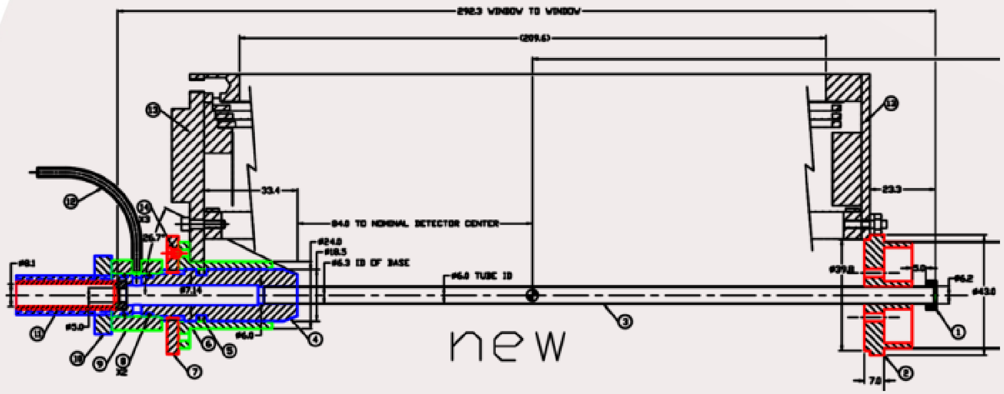
*If the reader is referring radiation damage, the SiPM gain should be unaffected by radiation. Please refer to the discussion the chapter titled "Experimental Setup", section x.3.2, in the proposals. (Note the chapter x=3 for all proposals except PR12-17-012A where x=2.)*

**6) The listing of the requested beam time has inconsistencies in all sub proposals. The Run Group as a whole appears to request a total of 55 days of beam time. However, the cover letters each contain twice the beam time, where half the time is allocated to aluminum target, which is not discussed in the text of any of the individual proposals.**

*The time requested is only partially overlapping between the proposals, this is the reason for the different requests. We refer the reviewer to page 4 of all our proposals where we included a table clarifying the request for the run group and how it breaks down between the proposals.*

*The aluminum question is clarified as a note on the same page. The aluminum represents the windows of the target, it is mentioned because it represents a significant part of the luminosity and directly impact the maximum beam current we can use. To be clear, the aluminum part of the target is not used for any physics measurements.*

# The Straw Target




| Experiments | Length | Kapton thickness | Maximum pressure |
|---|---|---|---|
| **CLAS targets** | 30 cm | 27 $\mu$m | 6 atm |
| **Bonus12 (PR12-06-113) target** | 42 cm | 30 $\mu$m | 7.5 atm |
| **JLab test target 1** | 42 cm | 30 $\mu$m | 3 atm |
| **JLab test target 2** | 42 cm | 50 $\mu$m | 4.5 atm |
| **JLab test target 3** | 42 cm | 60 $\mu$m | 6 atm |
| **Our proposed target** | 35 cm | 25 $\mu$m | 3 atm |

- **Beam scrapping issue raised by TAC (2016)**
  - It is indeed an issue and we are more conservative than BoNuS12 (PR12-06-113)
    - We use a radius of 35 cm x 6 mm instead of 42 cm x 3 mm
    - They just passed the experiment readiness review of JLab, no comments was made on the topic
- **Kapton thickness**
  - It seems that previous target pressure is not acceptable anymore and we probably will have to use slightly thicker target walls
    - This is mostly due to stricter safety standards

# Comparison between ALERT and RTPC

- **Luminosity RTPC vs ALERT**
  - The CLAS helium DVCS exp. ran at $1 \times 10^{34}$ $cm^{-2}s^{-1}$
  - Bonus12 will double this luminosity by doubling the length of the RTPC
  - However CLAS12 can go as high as $1 \times 10^{35}$ $cm^{-2}s^{-1}$
  - ALERT will be able to handle this full luminosity
- **Particle Identification**
  - $^{3}H/^{3}He$ fundamentally unresolveable with a RTPC
    - Due to the intrinsec width of the dE/dx distribution in a gas
  - ALERT has extra information with TOF, total energy deposit and segmented scintillators
    - Gives good PID for every isotopes from $^{1}H$ to $^{4}He$
- **Trigger**
  - RTPC technology is too slow to be used in the trigger
    - For inclusive CLAS triggers we had ~90% of the events with no reconstructed nuclear recoil tracks, this is a major issue when limited by the DAQ
  - ALERT will have a fast response time and will be used in coincidence with CLAS12 for trigger

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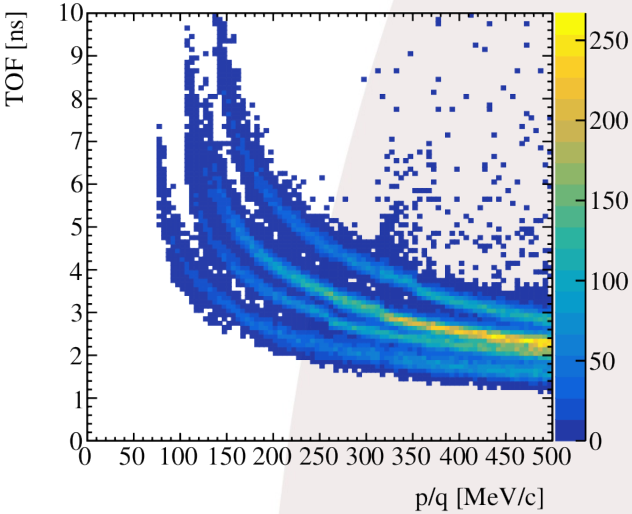
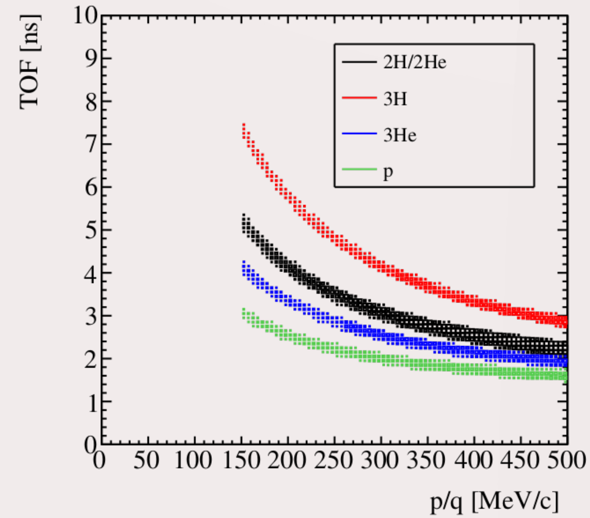
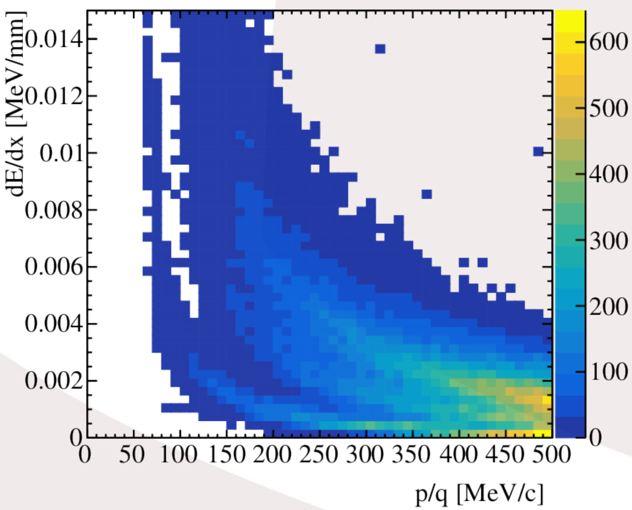
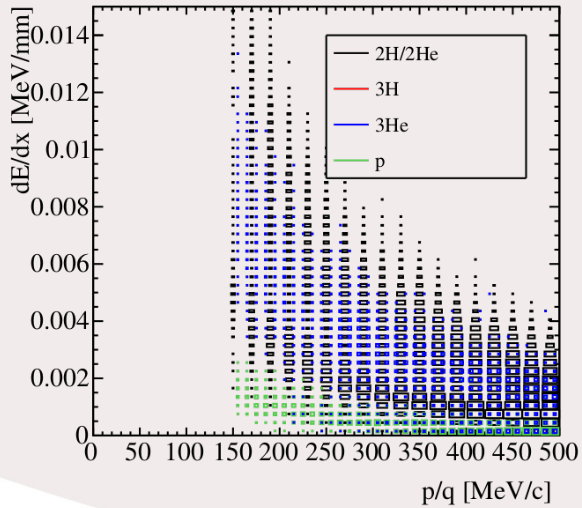
# $^{3}$H-$^{3}$He Differentiation

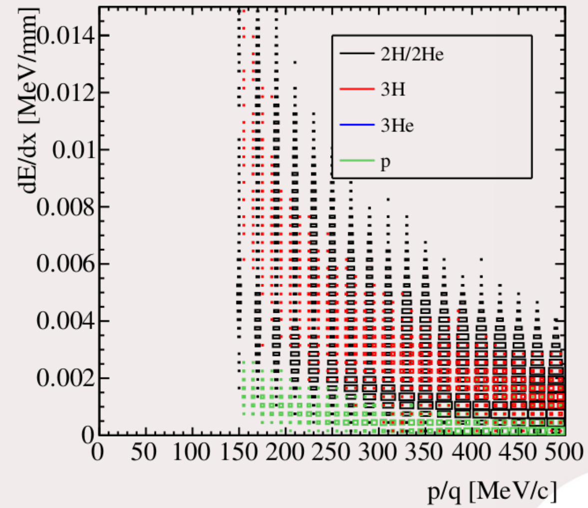



- **dE/dx is powerless**
  - Few centimeters of gas is not enough
  - Issue common to RTPC or ALERT technologies
- **The TOF information however is powerful**
  - Time difference is very easily measured between $^{3}$H and $^{3}$He



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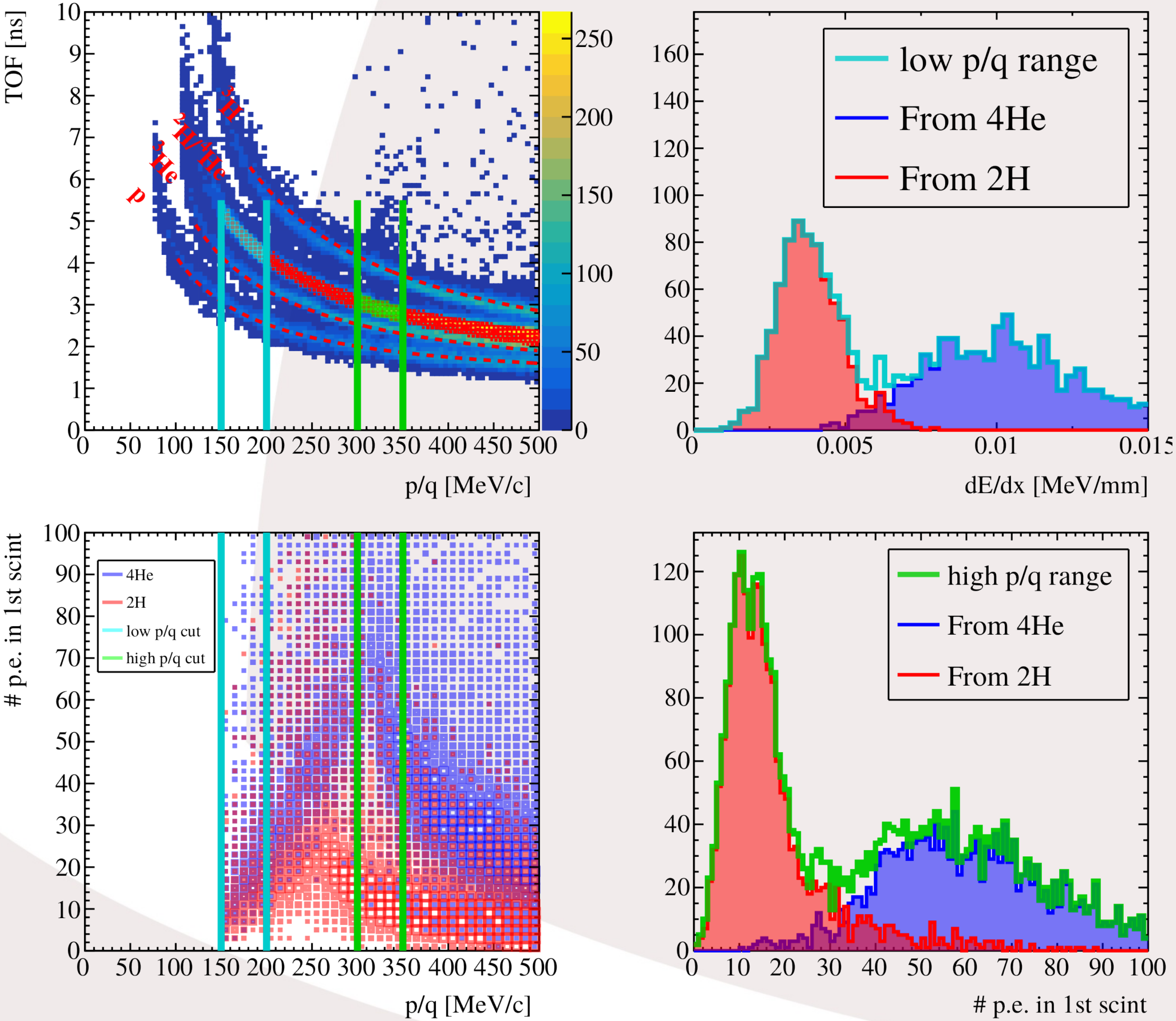
# $^{2}H$-$^{4}He$ Differentiation




- **$^{2}H$-$^{4}He$ are not differentiated at all by the TOF**
  - Complete degeneracy
  - But, we dispose of other informations
    - dE/dx and Energy deposit in scintillators
- **The dE/dx separation**
  - Most efficient for the lower momentums
- **The energy deposit in the scintillator**
  - Most efficient at higher momentum

    + extra information from the 2nd layer not displayed here
- **Together all this information gives a very nice PID in ALERT**
  - Covers all the momentum range of interest to our experiments
  - Good differentiation of all the different nucleus

# Additional Topics (PR12-17-012C)

- **We identified a number of other measurements that can be done with the data accumulated with the ALERT detector**
  - *Coherent DVCS and DVMP off deuteron*
  - *Higher twist effects and deep virtual $\pi^0$ production off $^4$He*
    - *To access transversity and higher twist GPDs*
  - *Three body break-up of $^4$He in both DIS and DVCS*
  - Semi-inclusive measurements off deuteron to study π cloud of the nucleon
  - Meson spectroscopy in $^4$He coherent production

    → Extension of E-07-009

    → Necessitate very thin forward detector window
  - Tagged Nuclear form factors
  - Role of Δs in short range correlations
  - Tagged hadronization and medium modified fragmentation functions
  - Medium modification of the transverse momentum dependent parton distributions