ALERT Run Group

N. Baltzell, on behalf of the ALERT Collaboration

CLAS Collaboration Meeting

October 4, 2017

ALERT Run Group

*Nuclear Exclusive and Semi-inclusive Measurements with **A** New CLAS12 **Low Energy Recoil Tracker***

- Comprehensive suite of studies of ^{4}He nucleus
  - nuclear partonic (inc. gluonic) structure with GPDs via coherent processes
  - nuclear models (semi-inclusive scattering)
    - Spectator mechanism, FSI, EMC effect x/Q^2 rescaling, mean-field/SRC transition
  - medium modifications, off-forward EMC effect (incoherent DVCS)
  - π^0 production on ^{4}He, deuteron-DVCS and GPDs
  - using DVCS, DVMP, SIDIS with spectator tagging
  - requires detection and identification of low energy p, ^{3}H, ^{3}He, ^{4}He recoils
    - below reach of CLAS12 Central Detector
  - spectator tagging and gluon physics are a first glimpse towards EIC program

- Four PAC-45 ALERT Proposals
  - ** Partonic Structure of Light Nuclei (PR12-17-012)*
  - ** Tagged EMC Measurements on Light Nuclei (PR12-17-012A)*
  - *Spectator-Tagged DVCS On Light Nuclei (PR12-17-012B)*
  - *Other Physics Opportunities (PR12-17-012C)*

- Experimental Setup
  - CLAS12 Forward Detectors
  - ALERT recoil detector and gas target

Primary Institutions:
- Argonne National Laboratory
- Institut de Physique Nucléaire d'Orsay
- Temple University
- Jefferson Laboratory

Run Group Contact: Z.-E.Meziani

Pre-ALERT @ 6 GeV JLab, ^{4}He DVCS

- CLAS EG6 Experiment
  - PR-07-009 and PR-08-024
  - 2nd BoNuS RTPC, optimized for ^{4}He detection
  - ^{4}He @ 6 atm target
  - 6 GeV circularly polarized e^-
  - ^{4}He DVCS beam spin asymmetries, model-independent (at LO/LT) ^{4}He Compton Form Factor, H_A GPD
  - First *fully exclusive* measurements of coherent nuclear DVCS, and incoherent ^{4}He DVCS
  - Larger coherent BSA than proton, limited statistics and kinematics (1-d binning only)
  - Incoherent DVCS allows study of predicted new off-forward EMC effects in beam spin asymmetries
  - ϕ-production on ^{4}He also under analysis
- Lessons Learned
  - faster recoil detector for higher luminosity
  - higher energy for more DVCS x-section

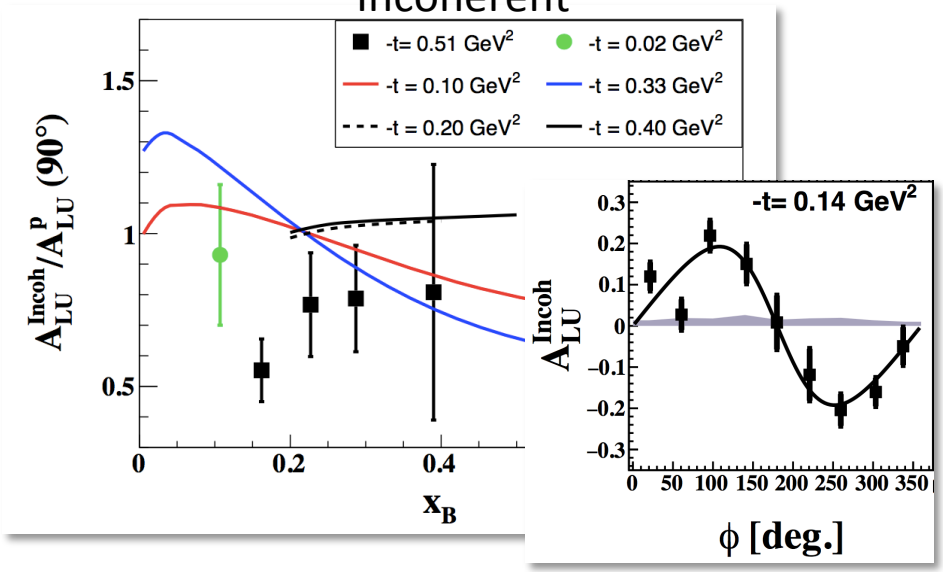
Coherent DVCS submitted to PRL in July

M. Hattawy et al. arXiv:1707.0361

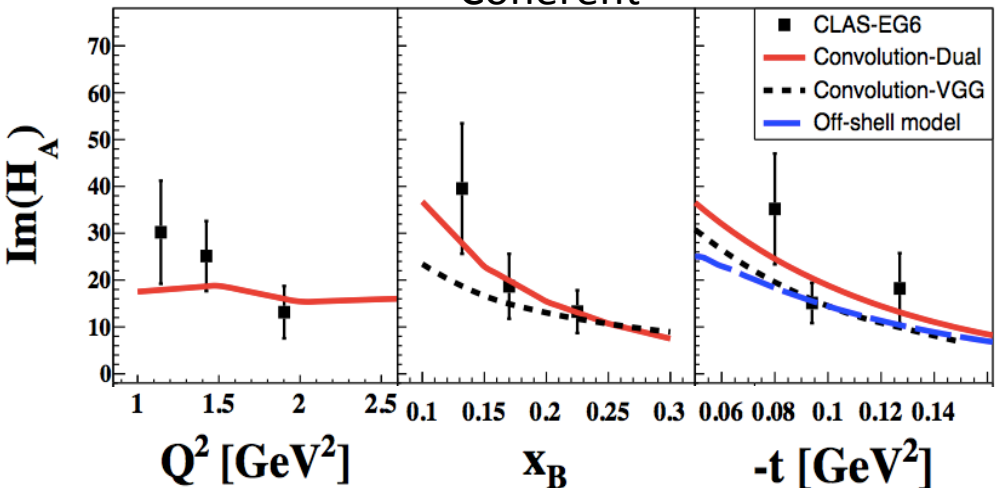
" … this experiment demonstrates perfectly the feasibility of measurement of coherent DVCS off nuclei."

" … It is very interesting to apply this method to nuclei. A study of the 3D structure of nuclei is very interesting and important as a new approach to study modifications of the nucleon GPDs in the nuclear medium. A first step in this direction is done in the present paper for the spin-0 nucleus 4-He, which is described by a single GPD and therefore simplifies the interpretation."

Incoherent

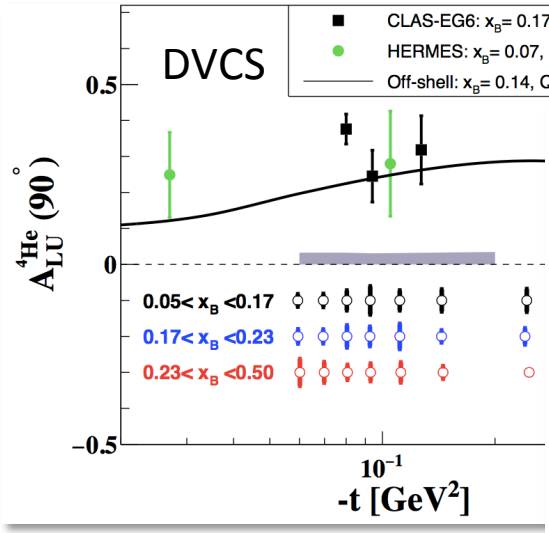


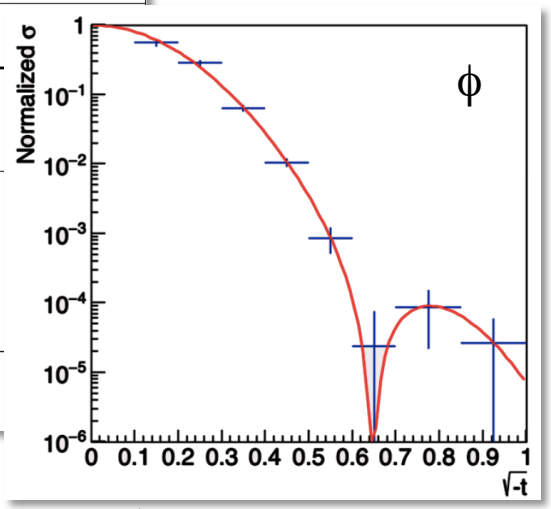
Coherent



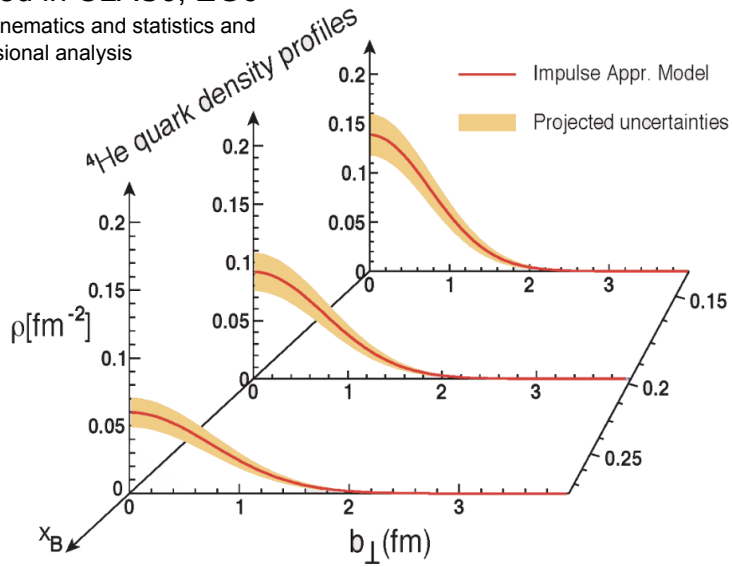
Partonic Structure of Light Nuclei (PR12-17-012)

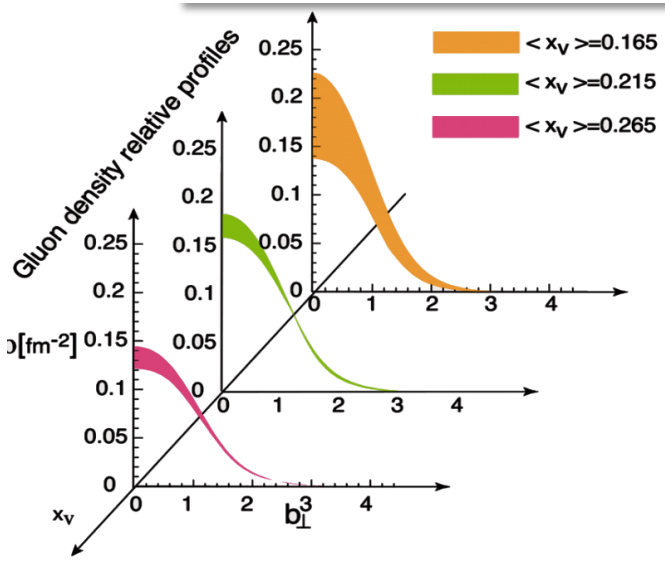
- Using nuclear GPDs to map the fundamental structure of nuclei
  - ^{4}He quark and gluon GPDs from coherent nuclear DVCS and coherent ϕ-production
- Spin-0 nucleus and allows model-independent interpertations at leading-order/twist
  - using only BSA, including extractinon of GPD H
- Complete measurement of LO GPDs in ^{4}He
  - fourier transform at ξ=0 gives probability densitiy as function of x and impact parameter
- Compare quark and gluon distributions, and cover expected location of first diffractive minumum with ϕ-production





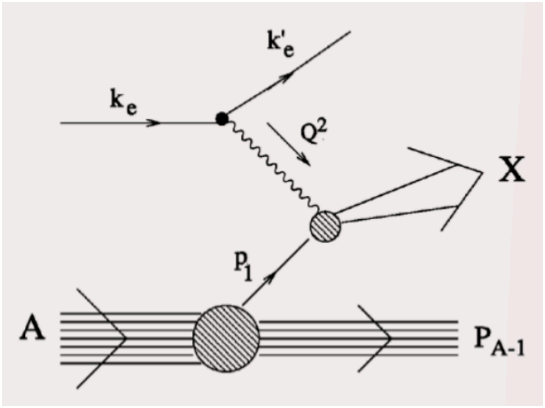
- Feasability demonstrated in CLAS6, EG6
  - ALERT greatly extends kinematics and statistics and allows for multidimensional analysis
- 30 (+5) PAC Days
  - 20 low luminosity
  - 10 high luminosity
- Contact: Z.-E. Meziani



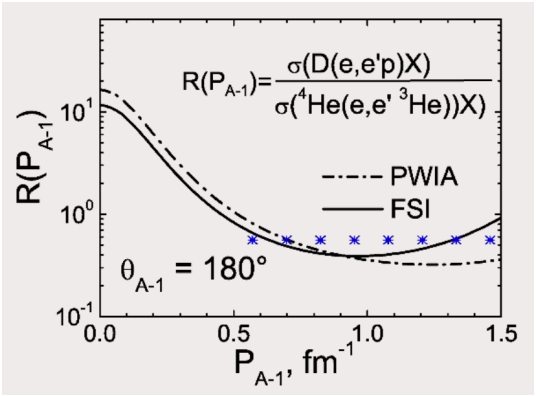


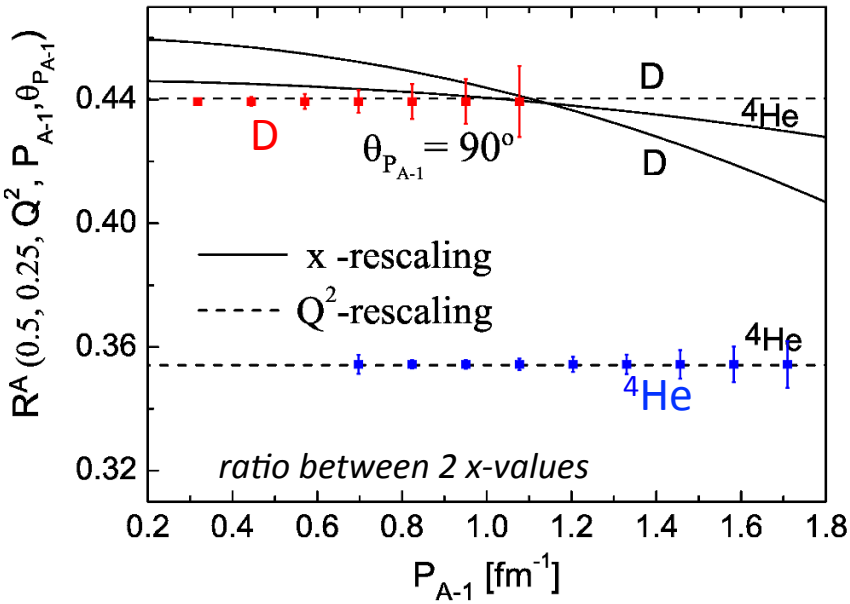
Tagged EMC Measurements on Light Nuclei (PR12-17-012A)

- Deep Inelastic scattering, with tagged spectator, provides access to new variables, and explore links between EMC effect and intranuclear dynamics
- Provides tests of
  - Spectator models, and study/minimize FSI effects
  - EMC effect models, x_B vs Q^2 rescaling of structure functions, flavor-dependent EMC effect
  - spectator virtuality dependence
  - ^{2}H vs ^{4}He comparison
    - conserves the nucleus isospin symmetry
    - ^{3}He is light, with sizeable EMC effect
    - complimentary in terms of spectator momentum coverage



- requires nuclear recoil detection and PID for all ^{4}He and H nuclides
- 40 (+5) PAC days
  - 20 on ^{4}He, 20 on D
- Contact: R. Dupre





Spectator-Tagged DVCS on Light Nuclei (PR12-17-012B)

- Probe connection between partonic and nucleonic interpretations via DVCS, using the combined benificial features of DIS and QE scattering
- Partonic interpretation and in-medium hadron tomography on nucleon
- Study of Off-Forward EMC effect in incoherent DVCS
- Bound p-DVCS
  - fully detected ep^{3}H final state, provides unique opportunity to study Final State Interactions, test PWIA, identify kinematics with small/large FSI
- n-DVCS
  - e^{3}He(n) / ep(n) final state
  - bound neutron in ^{4}He, quasi-free in ^{2}H
  - Neutron's BSA is expected very sensitive to medium modifications

$$\frac{\alpha_n^*}{\alpha_n} = \frac{\text{bound } n}{\text{quasi-free } n} = \frac{A_{LU}^{\sin\phi}(^4He)}{A_{LU}^{\sin\phi}(^2H)} \xrightarrow{\text{forward limit}} \frac{\mu_{n^*}}{\mu_n}\frac{g_1^{n^*}(x)}{g_1^n(x)}$$

$\mu_{n^*} \rightarrow$ nucleonic modification

$g_1^{n^*} \rightarrow$ partonic modification

- Need proton detection down to ~70 MeV/c, ^{3}H to ~120 MeV/c
- No additional PAC days required
- Incoherent ^{4}He DVCS feasability demonstrated in CLAS6, EG6
  - ALERT extends kinematics and statistics, provides both sides of ratio in same experiment, allows detection of full final state (inc. p, ^{3}He, ^{3}H)
- Contact: W. Armstrong

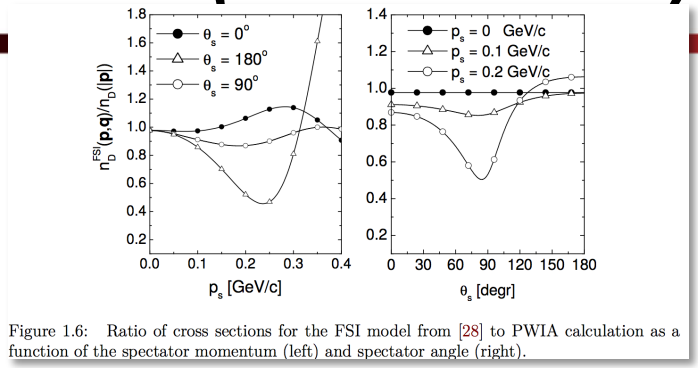
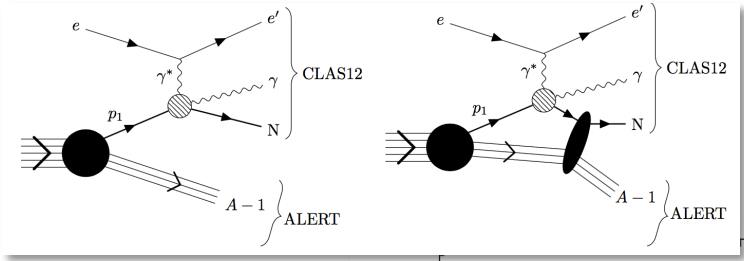
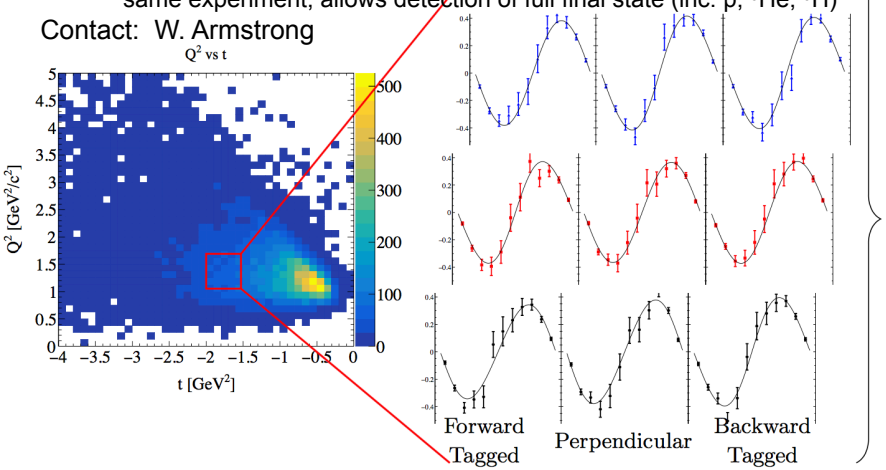
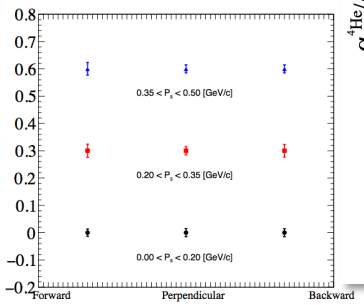
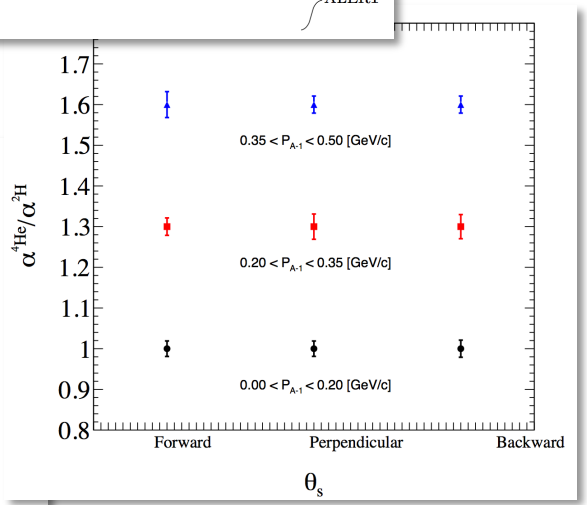


Figure 1.6: Ratio of cross sections for the FSI model from [28] to PWIA calculation as a function of the spectator momentum (left) and spectator angle (right).



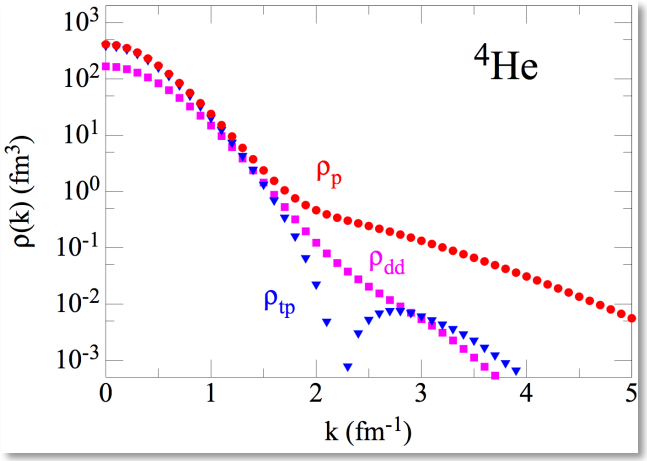


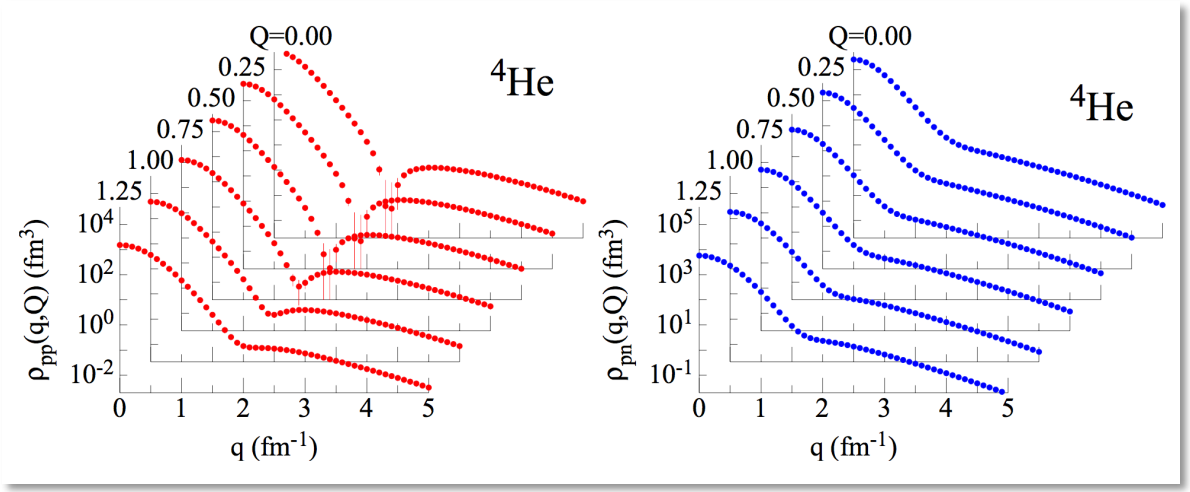




Other Physics Opportunities with ALERT (PR12-17-012C)

- π^0 production off ^{4}He
  - coherent and incoherent
  - measure beam spin asymmetries, leading to chiral-odd Compton form factor H^T_A and sensitivy to higher-twist contributions
  - also a DVCS background
- Coherent deuteron-DVCS
  - spin-1 nucleus, access to new GPDs, H_3, with relationships to dueteron charge form factors
- Three-body breakup DVCS, studying substrucure and correlations, utilizing CLAS12 CND for neutron detection
- No additional PAC days required
- Contact: K. Hafidi





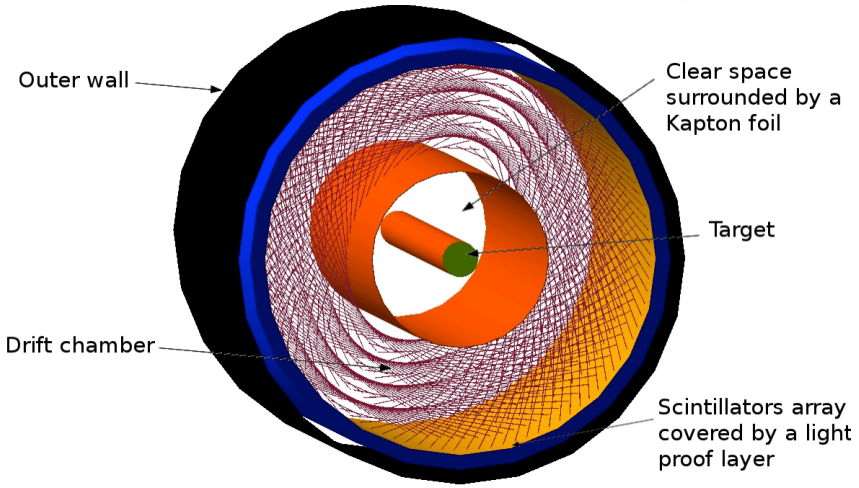
And more:

- Meson spectroscopy, coherent ^{4}He (eg6)
- Deuteron DVMP (π^0, ϕ, ω, ρ)
- Semi-inclusive pX to study pion cloud at very low proton momenta
- Tagged nuclear form factors
- Role of Δ in short-range correlations
- Role of FSI in hadronization and medium modified fragmentation functions
- Medium modification of the transverse momentum-dependent parton distributions

ALERT Detector - Overview

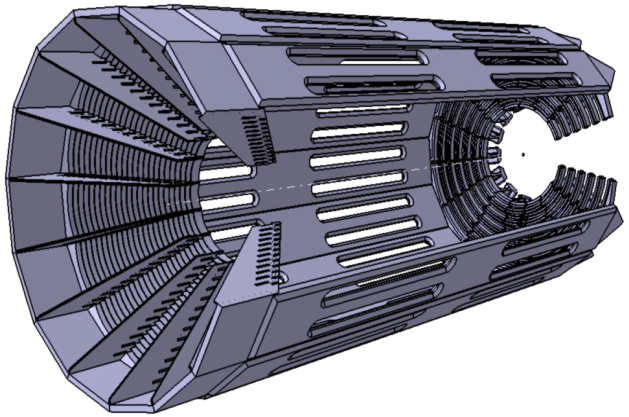
– A Low Energy Recoil Tracker
  – in place of the CLAS12 central trackers (SVT/MVT)
–Gas Target
  – 30 cm effective length, 6 mm radius, 3 atm, 25 um Kapton
– Hyperbolic drift chamber (32 < R < 85 mm)
  – 30 cm longitudinal wires with 10^{o} stereo
  – 8 ~circular layers of 2 mm hexagonal cells
  – Light gas mixture ~1 atm, insensitive to relativstics
  – <250 ns drift time
– Two Segmented Scintillator Cylinders
  – Total thickness ~20 mm, SIPMs directly attached
  – TOF (150 ps resolution) and total energy measurements

– Full GEANT 4 simulation for optimization
  – drift chamber occupancies, time and tracking resolutions, optical properties of scintillator geometry, particle identification and thresholds, …



Work in Progress

- Presented a conservative design to PAC45, one that we are confident we can build and operate
- Prototype built and tested, with electronics integration
- Some technical choices not final
  - e.g. gas mixture, wire materials & thickness
  - *G. Charles et al. Nucl. Instrum. Meth., A855 (2017) 154*

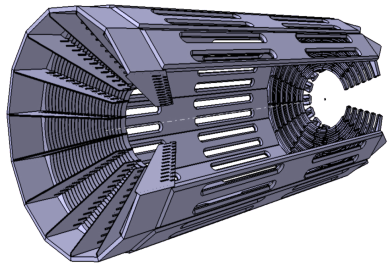


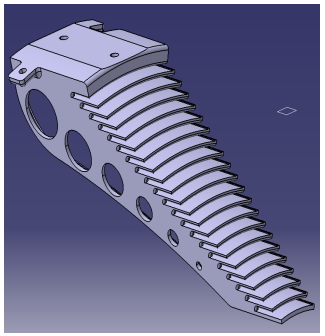
3-D printed structure, modular sectored design

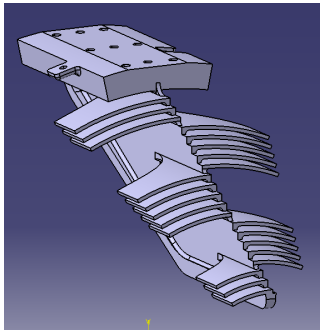
ALERT Detector - Wire Chamber

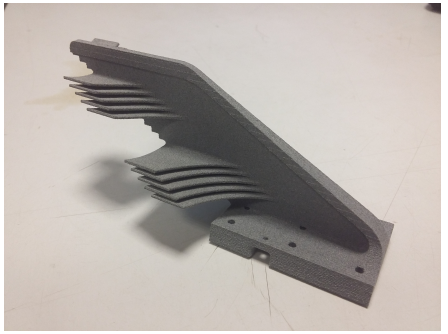
R&D at IPN Orsay

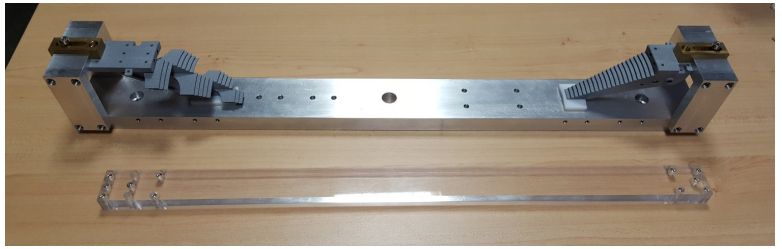
- Design structure, modularity
- Tested 3-D printing for support structures, titanium, high-rigidity plastic for forward end, wire tension and glueing/soldering with 2mm gap size
- Tested DREAM Front End chip with CEA Saclay, firsts tests at Orsay with single ALERT prototype sector
- Resolution appears to be comfortably better than the 10 ns used in the proposal





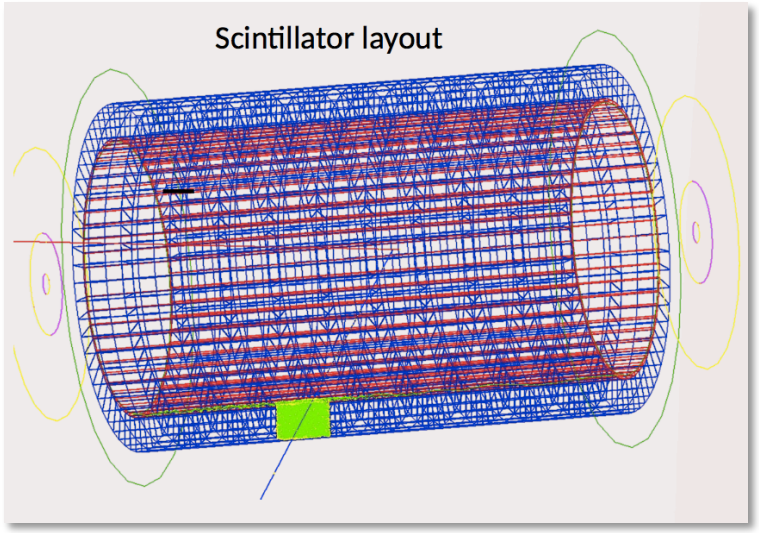


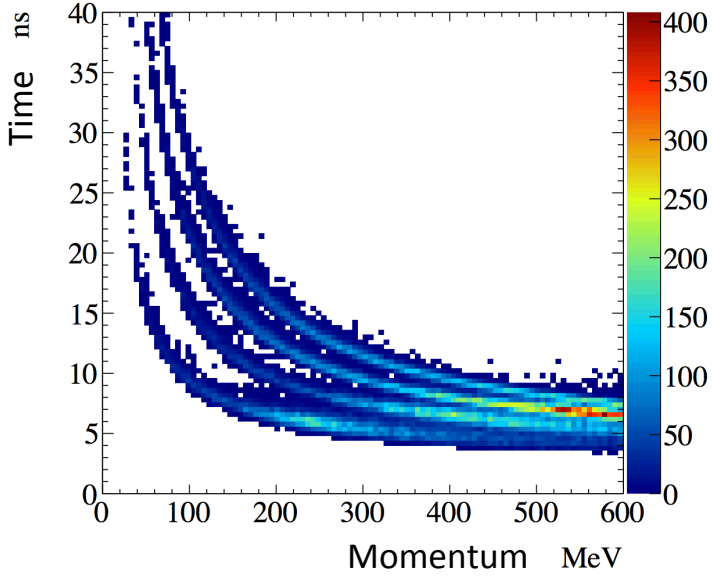




ALERT Detector - Scintillators

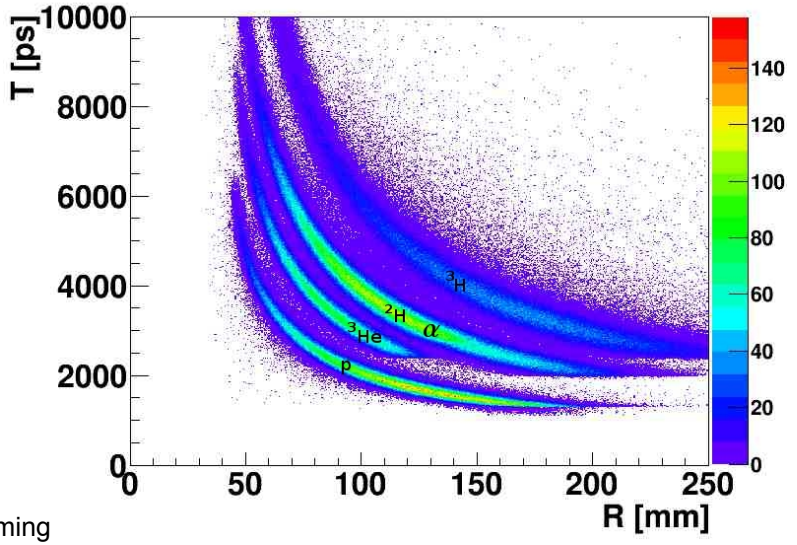
- Two concentric cylinders
  - thin (2 mm) and thick (20 mm)
  - Helium will stop in first (thin) layer
  - p/d/^{3}H will stop in the second layer
- Geometry optimized with GEANT4 for resolutions
  - thin layers 0.9 x 30 cm, with SiPM at both ends
  - thick layers 0.9 x 3 cm, one SiPM at the back
- Radiation damage
  - We expect < 1 krad, which should not be an issue for scintillators or SiPMs
    - scintillators significantly damaged ~Mrad
    - experience from Hall D suggests our SiPMs should have only small effects
    - simulation in progress for neutron rates

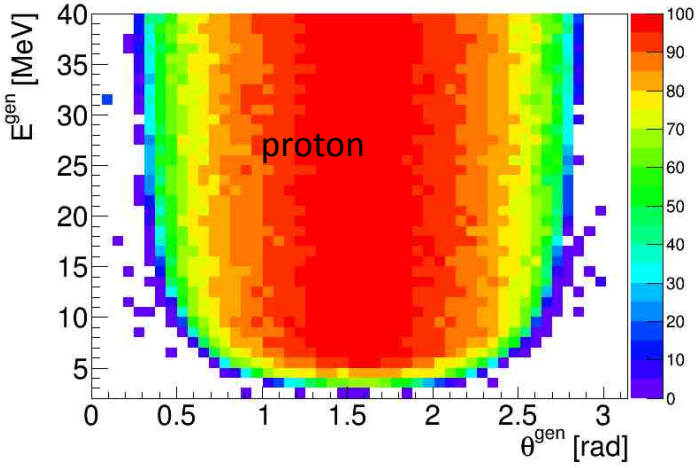


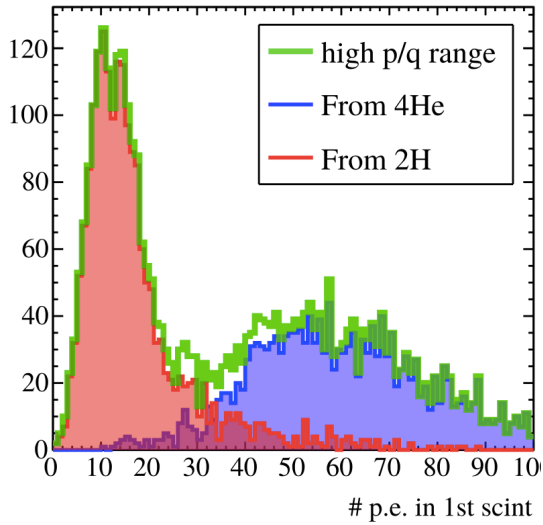


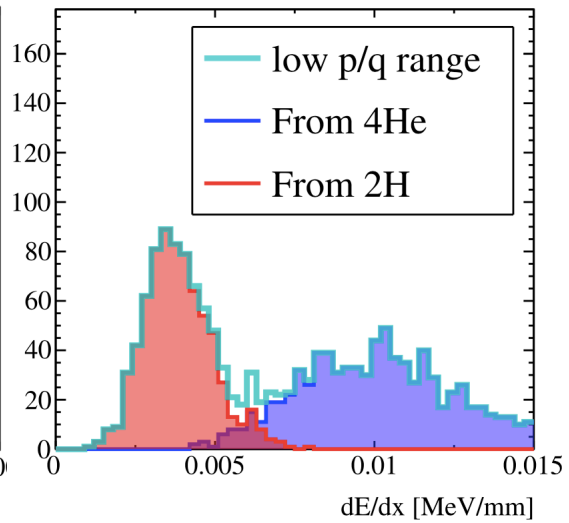
ALERT Detector - Capabilities

- Large p/theta acceptance
  - down to 70 MeV/c for protons, 240 MeV/c for ^{4}He
  - down to 25° from beamline
- Ability to handle high rates
  - Short drift time < 250 ns (few-μs in RTPC)
    - can include drift chamber in trigger
    - ~20x less accidental hits
  - Expect acceptable drift chamber occupancies at CLAS12's 10^{35}
  - For ^{4}He-only detection, can increase thresholds (luminosity)
- Particle Identification
  - Combination of tracking, energy deposition in wire chamber and scintillators, time of flight
    - sufficient to distinguish all recoil species between ^{4}He and ^{1}H
    - few-cm gas dE/dx alone cannot differentiate ^{3}He and ^{3}H, and timing powerless at separating ^{2}H and ^{4}He









ALERT Beam Time

* all 11 GeV beam with high polarization

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

Measurement	Particles detected	p range	θ range
Nuclear GPDs	^4He	$230 < p < 400 MeV/c$	$\pi/4 < \theta < \pi/2$ rad
Tagged EMC	p, ^3H, ^3He	As low as possible	As close to π as possible
Tagged DVCS	p, ^3H, ^3He	As low as possible	As close to π as possible

PAC 45 Report

We are pleased that the concept of using Run Group Additions, rather than new formal proposals, to make use of already approved beam time, is beginning to take hold. The ALERT group, for example, prepared a well developed suite of experiments to make use of a block of time in CLAS12 with a new apparatus that they will develop. We encourage the user community to seriously consider this approach for future CLAS12 and SoLID proposals, as well as any other situations where multiple physics goals can be achieved with the same beam time.

PR12-17-012

Scientific Rating: A-

Recommendation: Approve for 55 days

Title: **ALERT Run group**: Nuclear Exclusive and Semi-inclusive Measurements with a New CLAS12 Low Energy Recoil Tracker
12-17-012: Partonic Structure of Light Nuclei
12-17-012A: Tagged EMC measurements on light nuclei
12-17-012B: Spectator tagged Deeply Virtual Compton Scattering On Light Nuclei
12-16-011C: Other Physics Opportunities with the ALERT Run Group

Spokespersons: N. Baltzell, Z.-E. Meziani (Contact), K. Hafidi, M. Hattawy, R. Dupré, M. Paulone, G. Charles, W. Armstrong

PAC44 suggested that the time was ripe for a coherent plan to systematically attack the EMC effect, and to find a definitive solution. Since last year, there have been some workshops on this effort, and PAC45 considered some novel experiments, but the coherent plan we envisioned has still not materialized. We believe there is an opportunity for JLab to take the lead on this problem, and would be supportive of efforts in that direction.

PAC 45 Theory Reviews

Partonic Structure

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.

Other Physics Opportunities

would provide information on these GPDs complementary to that extracted from measurements on the nucleon. In particular, it would seem, but it is not clearly stated, that the authors will be able isolate the so-called H_3 GPD.

The last measurement deals, rather than with coherent DVCS, with DVCS resulting in a three-body breakup of ^{4}He with a final deuteron being detected along with the other recoil particles. It might be interesting to explore whether it is experimentally feasible to measure the breakup into two deuterons (rather than a deuteron and two nucleons). In a PWIA picture this would appear to be as quasi-free deuteron DVCS in ^{4}He. A comparison with the proposed measurements above could in principle shed further light on *in medio* modifications, as well as deviations from the PWIA picture.

Tagged EMC

ments alone cannot distinguish between the different scenarios. Essential progress could come from measurements in which one controls the configuration of the active nucleon during the DIS process by detecting the nuclear breakup in the final state, as is the goal of the present experiment. By

modifications and FSI. The proposed measurements could thus significanlty enhance the understanding of the EMC effect, and at the same time provide valuable information about nuclear FSI.

work that incorporates both effects. The development of such a framework requires data on nuclear breakup in DIS over a wide range of recoil momenta, as would be taken in the proposed experiment, including the measurements on the deuteron. The proposed experiment would thus enable and stimulate further theoretical research in this area. We note that DIS with detection of nuclear final states is also being studied as a next-generation measurement with a future Electron-Ion Collider, and that the theoretical development stimulated by this 12 GeV experiment would be synergistic with that effort.

Tagged DVCS

state interactions (FSI). However, I noted that the nucleon scattering amplitude (he elliptic black blob in the right Fig. 1.4 diagram) may have sizable zero momentum transfer limit which may be interpreted as final-state interaction that does not change the momenta of the tagged nucleons but can change the amplitudes and cross sections. Judging from a new Appendix A, the authors of new proposal are aware of the problem and suggest to solve it using model calculations. Based on these model calculations, the authors claim that the *significant* FSI can be identified in the experiment. At this point I do not have further questions and I think the experiment should be pursued.

Outlook

- "ALERT" Run Group approved at PAC 45 with A$^-$
  - comprehensive study of ^{4}He nucleus, including
    - partonic structure with quark and gluon GPDs from coherent DVCS/DVMP(φ)
    - EMC effect, FSI studies, from SIDIS and incoherent p/n-DVCS with tagging
    - π^0-production ^{4}He (H^T_A), deuteron GPDs from coherent d-DVCS (H_3)
  - requires new recoil detector for higher luminosity and full recoil identification

- Development on ALERT detector ongoing
  - Scintillators at ANL. Wire Chamber at IPN Orsay. Further funding for detector construction being pursued from France/Europe and DOE-NP

- ALERT can have a first look in exploring some of the key elements of the EIC program