Understanding the EMC Effect Through Tagged Processes with ALERT

CIPANP 2018

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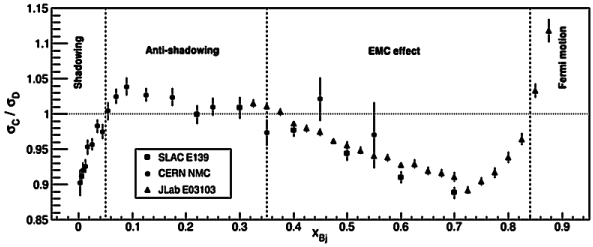
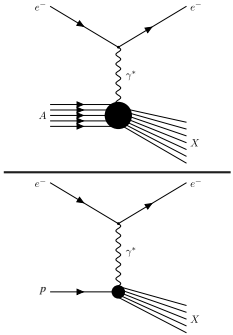
Argonne NATIONAL LABORATORY

Introduction

The EMC Effect



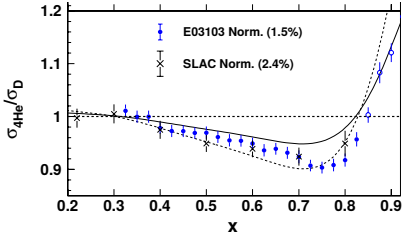


The EMC effect remains a mystery

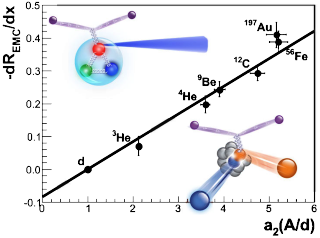
- What is the **origin** of the EMC effect?
- How is the **nucleon modified** in nuclear medium?
- How are **hadrons modified** in nuclear medium?

EMC Effect

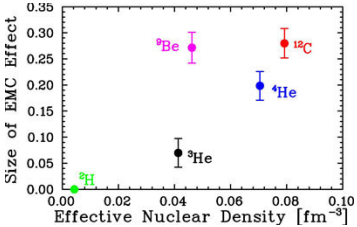
J. Seely et al. Phys.Rev.Let. 103 (2009) 202301



L.B. Weinstein et al., Phys.Rev.Let. 106, 52301 (2011)



- Is there a dependence on nucleon virtuality?
  - Hint from NN Short Range Correlations (SRC)
  - Effective nuclear density, or local density?
- x and Q^2 rescaling models produce similar results.
  - Q^2 rescaling by modifying QCD in medium
  - x rescaling due to the binding
  - "Every Model's Cool" -G. Miller



The Challenges of Nuclear Effects

A quick summary of medium modification searches

EMC Effect in DIS

Well measured but interpretation clouded by many possible explanations

Partonic interpretation

Spectator tagging will determine initial state (ID struck nucleon; separate mean field from SRC nucleons) and constrain FSIs

Polarization Transfer

Quasi-elastic nucleon knockout with induced polarization (P_y) provides a lever arm on FSIs.

Nucleonic Interpretation

but what is going on at the parton level?

see ^{2}H: B. Hu et al., PRC 73, 064004 (2006). ^{4}He: S. Dieterich et al., PLB 500, 47 (2001); S. S., et al., PRL 91, 052301 (2003); M. Paolone, et al., PRL 105, 0722001 (2010); S. Malace et al., PRL 106, 052501 (2011)

Coulomb Sum Rule

Quasi-elastic scattering

$$S_L(q) = \frac{1}{Z}\int_{\omega^+_{th}}^{\infty} d\omega \frac{R_L(q,\omega)}{|G_E^p|^2(Q^2)}$$

Nucleonic Interpretation

Observations of quenching complicated by model dependent nuclear corrections; New data coming soon

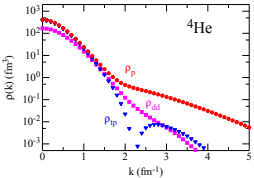
Cloet, et.al., Phys.Rev.Lett. 116 (2016)032701
Lovato, et.al., Phys.Rev.Lett. 111 (2013)092501

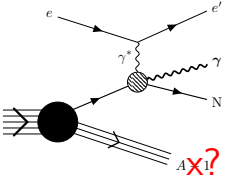
How to connect the **Partonic and Nucleonic** interpretations while systematically controlling final-state interactions?

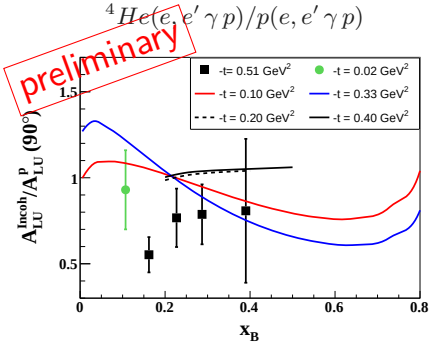
CLAS eg6 (E08-024): Incoherent DVCS on the bound proton

Off-forward EMC effect?

- Unconstrained initial state: virtual photon-nucleon CM energy unknown due to Fermi motion
- Off-forward EMC Effect calculated using denominator from previous experiment introduces extra systematics
- Interesting results, but, inconclusive interpretation: similar to untagged EMC Effect







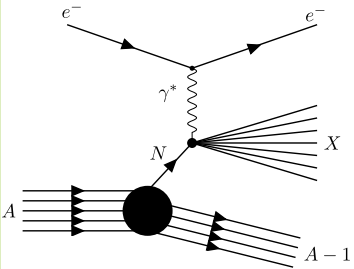
Preliminary results courtesy of M. Hattawy.

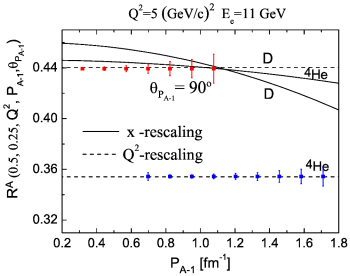
Interesting results but inconclusive (similar to regular EMC effect).

Need to tag spectator → fix kinematics

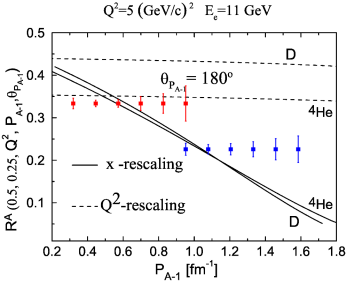
Tagged DIS and the EMC effect

- Control initial state: IA tells us which nucleon was hit
- Measure dependence on the nucleon virtuality (spectator kinematics)
- Control and constrain final state interactions
- Rescaling models behave much differently with tagged measurements



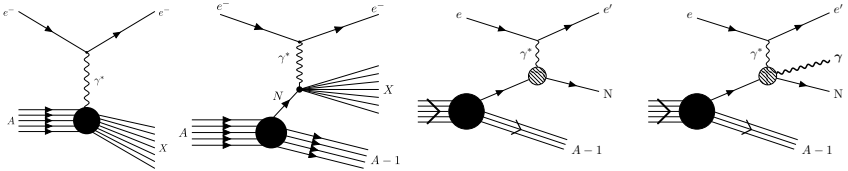


C. Ciof degli At, L. P. Kaptari, and S. Scopeta, Eur. Phys. J. A5, 191 (1999)



C. Ciof degli At et al. Phys.Rev. C76 (2007) 055206

Spectator-Tagged DVCS



A new link between the Partonic and Nucleonic

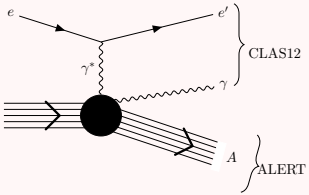
- Combines the beneficial features of **DIS and QE** scattering
- Identify struck nucleon → **separate mean field** from high momentum nucleons
- DVCS → **parton level interpretation** and in-medium hadron tomography
- DVCS on Nuclear targets → **Off-forward EMC effect**
- **Fully exclusive** measurement → Unique opportunity to study and control FSIs
- Neutron's beam-spin asymmetry ratio → extra sensitive to medium modifications

The ALERT experimental run-group

A comprehensive program to study nuclear effects

Nuclear GPDs

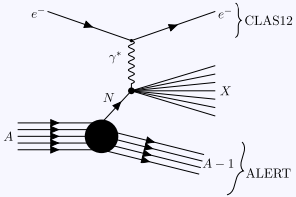
$^4\mathrm{He}(e, e'\,^4\mathrm{He}\,\gamma)$
$^4\mathrm{He}(e, e'\,^4\mathrm{He}\,\phi)$



Directly compare quark and gluon radii

Tagged EMC

$^4\mathrm{He}(e, e' + {}^3\mathrm{H}\ )X$
$^4\mathrm{He}(e, e' + {}^3\mathrm{He})X$
$^2\mathrm{H}(e, e' + p\ \ )X$



Address key questions about the EMC effect

Tagged DVCS

$^4\mathrm{He}(e, e'\gamma\, p + {}^3\mathrm{H}\ )$
$^4\mathrm{He}(e, e'\gamma\ \ + {}^3\mathrm{He})n$
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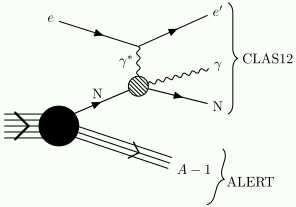
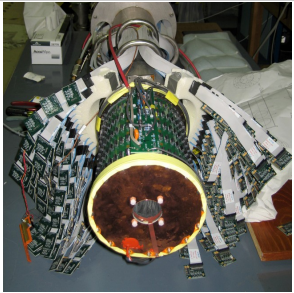


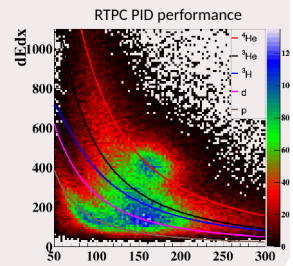
Connect partonic and nucleonic modification

A Low Energy Recoil Tracker (ALERT)

Past experiences

- Existing (eg6) and proposed (BONUS) RTPC detectors do not meet experimental needs
- eg6 RTPC was slow and lacked full PID capabilities
- BONUS12 RTPC will be similar and only detect protons



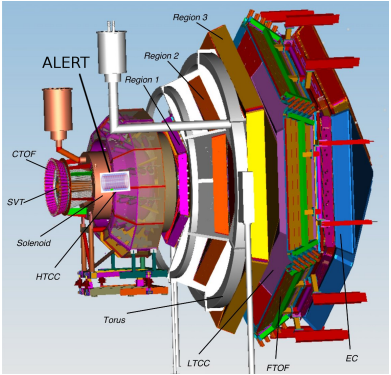


ALERT Design Requirements

- Operate in CLAS12 5 T field
- Run at **CLAS12 luminosity limit** and **Hall-B beam current limit**
- Full and independent PID of all light ions: p to $^4\mathrm{He}$
- Independent trigger (can be adjusted to operate with higher luminosities).

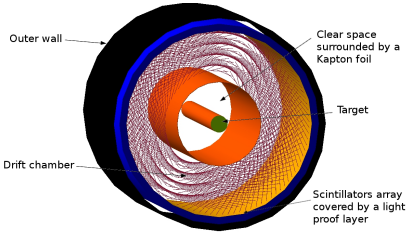
Proposed Setup: CLAS12 + ALERT

- Use CLAS12 to detect scattered electron, e', and forward scattered hadrons.
- ALERT will detect the recoiling spectator or coherently scattered nucleus



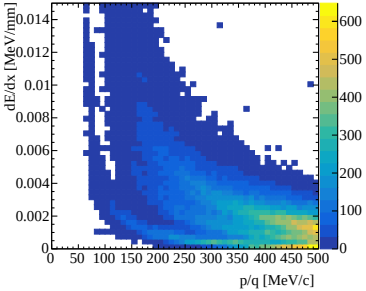
ALERT requirements

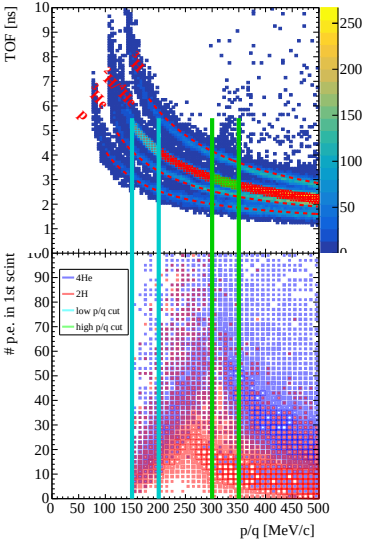
- Identify light ions: H, ^{2}H, ^{3}H, ^{3}He, and ^{4}He
- Detect the **lowest momentum** possible (close to beamline)
- Handle **high rates**
- Provide **independent trigger**
- Survive high radiation environment
  $\rightarrow$ **high luminosity**

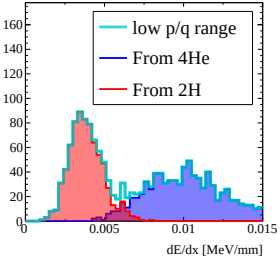


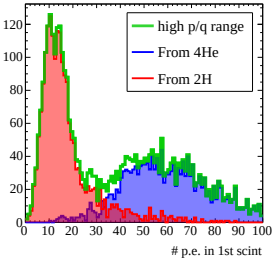
ALERT PID

- TOF is degenerate for ^{2}H and ^{4}He.
- dE/dx can separate these.
- At higher p, scintillator topology can also be used to separate.





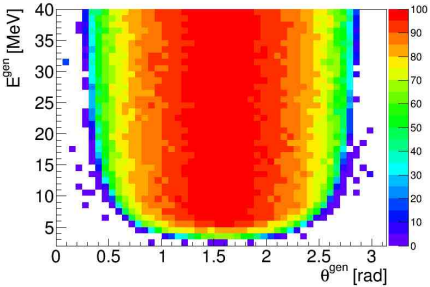


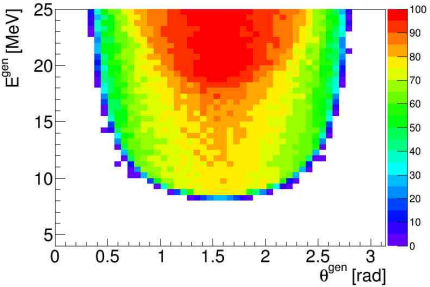


ALERT Simulation

Full Geant4 Simulation

- Minimum momentum acceptance: 70 MeV/c for protons, 240 MeV/c for ^{4}He





ALERT Simulation

Full Geant4 Simulation

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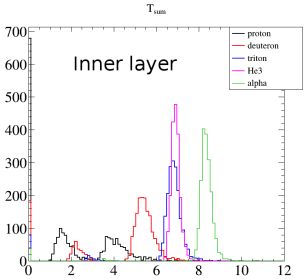
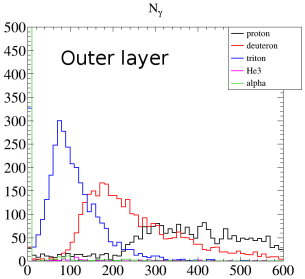
- Scintillator photon yields and timing information → optimize geometry to provide the best PID





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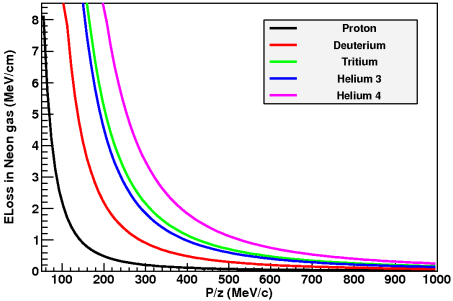

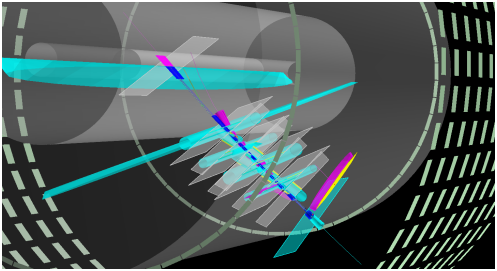

ALERT Simulation

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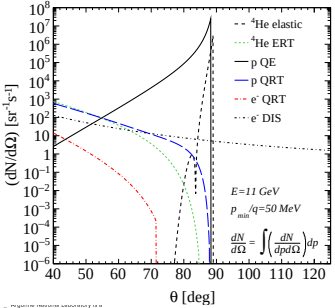
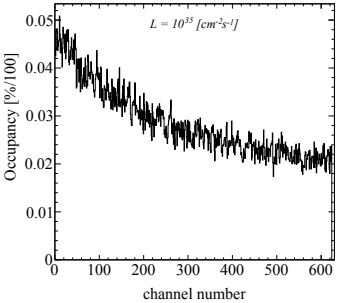
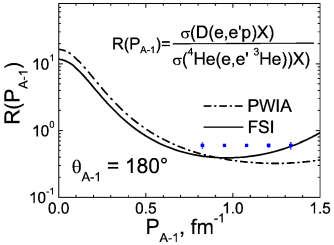
- Scintillator photon yields and timing information → optimize geometry to provide the best PID
- Kalman Filter based track reconstruction (WIP) → optimize wire layout; Get track dE/dx for PID
- DC hit occupancies simulated - can operate comfortably at nominal CLAS12 luminosity



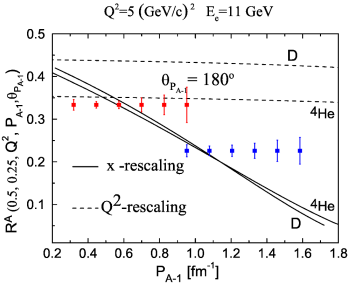


Semi-inclusive DIS: Tagged EMC

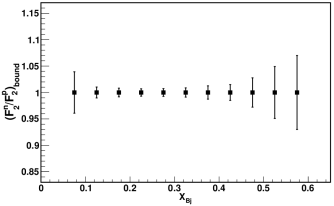


- Test FSI models for different spectator kinematics (over large momentum and angle range) with very good precision
- This measurement will provide strong constraints for theoretcal calculatons

see M. Strikman, C. Weiss, arXiv:1706.02244 - W. Cosyn, M. Sargsian, arXiv:1704.06117

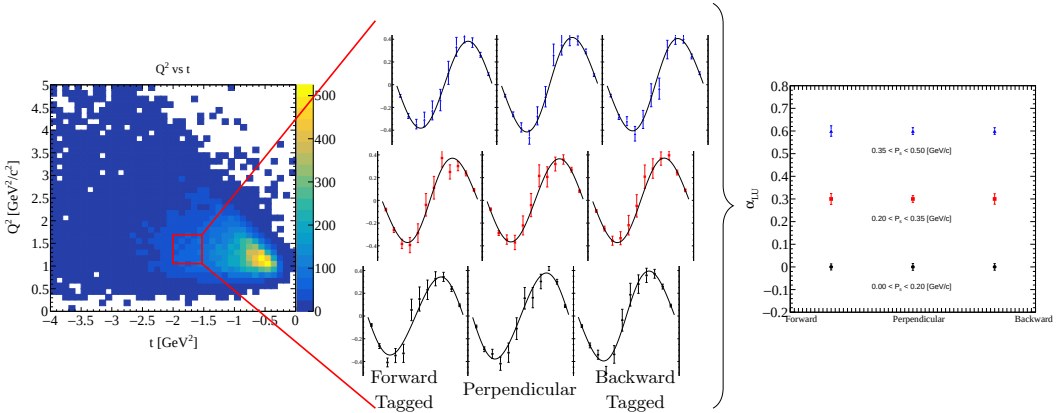


- Compare ratio of $^4\mathrm{He}$ and $^2\mathrm{H}$ to differentiate between rescaling models



- ALERT can also measure other interesting ratios as well.

Tagged DVCS: Off-forward EMC Ratio

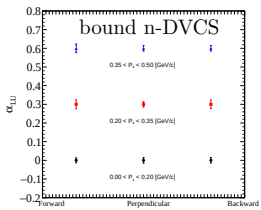


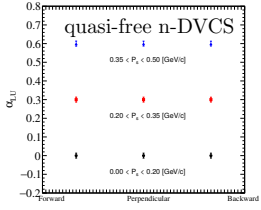
- 6 dimension binning (7 with helicity)
- Reduced to 5 after obtaining '$\sin\phi$' harmonic
- $\alpha_{LU} = \int A_{LU} \sin\phi \, d\phi$

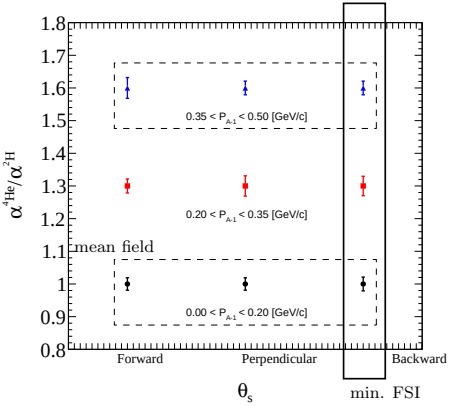
Off-forward EMC Ratio

$^4\mathrm{He}(e, e'\gamma +^3 \mathrm{He})n$

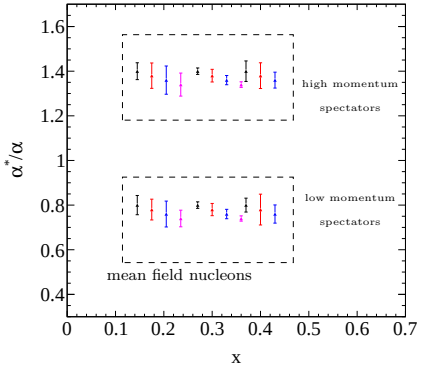
$^2\mathrm{H}(e, e'\gamma + p)n$







Off-forward EMC Ratio



Colors indicate the different t bins which are shifted horizontally for clarity

- Separated mean field nucleon Off-forward EMC Effect and high momentum nucleon Off-forward EMC Effect
- **With FSIs systematically controlled**, observed deviations from unity indicate nuclear medium modifications of nucleons at the partonic level

$$^{4}\mathrm{He} + \gamma^* \rightarrow \gamma + (n) + {}^{3}\mathrm{He}$$

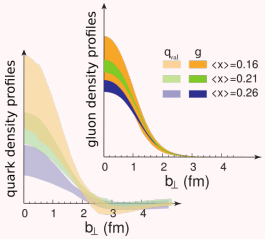
$$^{2}\mathrm{H} + \gamma^* \rightarrow \gamma + (n) + p$$

$$^{4}\mathrm{He} + \gamma^* \rightarrow \gamma + \ p \ + {}^{3}\mathrm{H}$$

ALERT Run Group

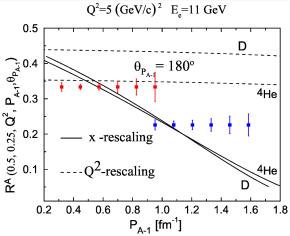
A Comprehensive Program to Study Nuclear Effects

Nuclear GPDs



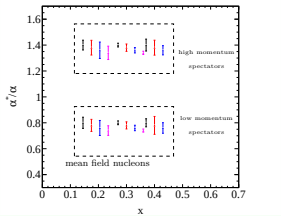
Directly compare quark and gluon radii

Tagged EMC



Address key questions about the EMC effect

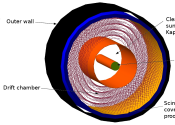
Tagged DVCS

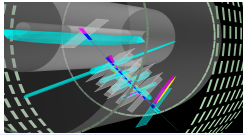


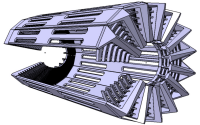
Connect partonic and nucleonic modification

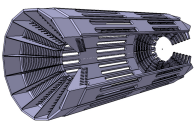
ALERT is a bridge from JLab 12 GeV physics to the Electron Ion Collider

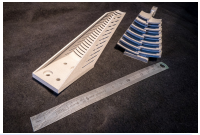
Summary



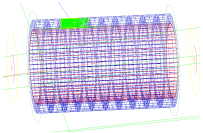


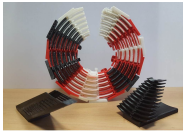


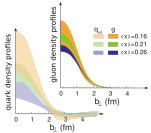


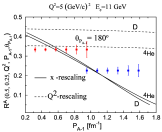


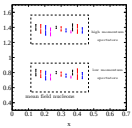
- Tagged processes will provide insight into the **origin of the EMC effect**
- Semi-inclusive DIS measurements will differentiate between rescaling models.
- Tagged DVCS will bridge the gap between **Partonic and Nucleonic interpretations** of the EMC ratio.
- Tagged measurements will better control uncertainties associated with FSIs
- ALERT run group is a comprehensive set of experiments to understand nuclear effects.











Thank you for staying... ALERT!

Neutron DVCS: A sensitive probe for medium modifications

$$A_{LU,n}^{\sin\phi} \propto \mathrm{Im}\left(F_1^n \mathcal{H}^n - \frac{t}{4M^2} F_2^n \mathcal{E}^n + \frac{x_B}{2}(F_1^n + F_2^n)\tilde{\mathcal{H}}^n\right)$$

Term by term breakdown:

1. Suppressed by neutron Dirac FF
2. Connected to Ji's sum rule and quark OAM through GPD
3. Related to Polarized EMC effect and Modified Form Factors

The Connection to Spin Structure Functions and Modified Form Factors:

The third term above is

$$\mathrm{Im}\left((F_1 + F_2)\tilde{\mathcal{H}}\right) = G_M(t) Im(\tilde{\mathcal{H}}(\xi, \xi, t))$$

Forward Limit (at leading order):

$$Im(\tilde{\mathcal{H}}(x, \xi, t)) \to \tilde{H}(x, 0, 0) = g_1(x)$$

$$G_M(t) \to \mu$$