Understanding the EMC Effect Through Tagged Processes with ALERT

Whitney R. Armstrong
Argonne National Laboratory
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CIPANP 2018
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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

- 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?

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

**Coulomb Sum Rule**
Quasi-elastic scattering

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


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

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

Need to tag spectator $\rightarrow$ fix kinematics

Preliminary results courtesy of M. Hattawy.
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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


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
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The ALERT experimental run-group
A comprehensive program to study nuclear effects

Nuclear GPDs

\[ ^4\text{He}(e, e'\quad ^4\text{He} \gamma) \]
\[ ^4\text{He}(e, e'\quad ^4\text{He} \phi) \]

Tagged EMC

\[ ^4\text{He}(e, e' + ^3\text{H} )X \]
\[ ^4\text{He}(e, e' + ^3\text{He})X \]
\[ ^2\text{H}(e, e' + p )X \]

Tagged DVCS

\[ ^4\text{He}(e, e'\gamma p + ^3\text{H} ) \]
\[ ^4\text{He}(e, e'\gamma + ^3\text{He})n \]
\[ ^2\text{H}(e, e'\gamma + p )n \]

Directly compare quark and gluon radii

Address key questions about the EMC effect

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 $^4$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
• 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

- Minimum momentum acceptance: 70 MeV/c for protons, 240 MeV/c for $^4$He
- Scintillator photon yields and timing information $\rightarrow$ optimize geometry to provide the best PID
ALERT Simulation

Full Geant4 Simulation

- Minimum momentum acceptance: 70 MeV/c for protons, 240 MeV/c for $^4$He
- Scintillator photon yields and timing information $\rightarrow$ optimize geometry to provide the best PID
- Kalman Filter based track reconstruction (WIP) $\rightarrow$ optimize wire layout; Get track $dE/dx$ for PID

<table>
<thead>
<tr>
<th>ELoss in Neon gas (MeV/cm)</th>
<th>P/z (MeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>8</td>
</tr>
<tr>
<td>Deuterium</td>
<td>7</td>
</tr>
<tr>
<td>Tritium</td>
<td>6</td>
</tr>
<tr>
<td>Helium 3</td>
<td>5</td>
</tr>
<tr>
<td>Helium 4</td>
<td>4</td>
</tr>
</tbody>
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 ALERT Simulation

Full Geant4 Simulation

- Minimum momentum acceptance: 70 MeV/c for protons, 240 MeV/c for $^4$He
- 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
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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 theoretical calculations
  

- Compare ratio of $^4$He and $^2$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

\[ ^4\text{He}(e, e'\gamma + ^3\text{He})n \]

\[ ^2\text{H}(e, e'\gamma + p)n \]
Off-forward EMC Ratio

- 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

\[ {}^4\text{He} + \gamma^* \rightarrow \gamma + (n) + {}^3\text{He} \]

\[ {}^2\text{H} + \gamma^* \rightarrow \gamma + (n) + p \]

\[ {}^4\text{He} + \gamma^* \rightarrow \gamma + p + {}^3\text{H} \]

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

\[ A_{LU,n}^{\sin \phi} \propto \text{Im} \left( \frac{F_1 H_n - \frac{t}{4M^2} F_2 E_n}{2} + \frac{x_B}{2} (F_1 + F_2) \tilde{H}_n \right) \]

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
\[ \text{Im} \left( (F_1 + F_2) \tilde{H} \right) = G_M(t) \text{Im}(\tilde{H}(\xi, \xi, t)) \]

Forward Limit (at leading order):
\[ \text{Im}(\tilde{H}(x, \xi, t)) \rightarrow \tilde{H}(x, 0, 0) = g_1(x) \]
\[ G_M(t) \rightarrow \mu \]