Tagged EMC Measurements on Light Nuclei

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An ALERT Run Group Proposal for JLab PAC 44

N. Baltzell

on behalf of the ALERT Collaboration
Nuclear Exclusive and Semi-inclusive Measurements with a New CLAS12 Low Energy Recoil Tracker

- Suite of studies of $^4$He nucleus
  - new measurements of SIDIS, DVCS, DVMP reactions
  - to study nuclear models of the EMC effect (including their treatments of off-shellness and FSI), and partonic (including gluonic) structure with GPDs
  - requiring detection of low energy p, $^3$H, $^3$He, $^4$He recoils

- 3 PAC 44 Proposals
  - Tagged EMC Measurements off Light Nuclei
  - Tagged DVCS Off Light Nuclei *
  - Partonic Structure of Light Nuclei *

- Detector System
  - CLAS12 Forward Detectors
  - ALERT Recoil Detector

* = The following talks in this session

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

Run Group Contact: K. Hafidi
ALERT Detector
New Recoil Detector Motivations

• Fast response for use in trigger
  – Only ~10% of DIS on $^4\text{He}$ or $^2\text{D}$ result in detectable recoils due to energy loss, as seen by EG6
  – BoNuS and EG6 were luminosity-limited by DAQ

• Separate all nuclear recoils up to $^4\text{He}$
  – The dE/dx resolution of a TPC alone cannot distinguish $^3\text{H}$ and $^3\text{He}$

• Minimize recoil nuclei detection threshold
  – CLAS12 central detector thresholds are too high for ALERT’s physics measurements

→ ALERT Detector designed to satisfy these goals, inside of CLAS12 solenoid and in place of the SVT and all but outermost layer of MicroMegas
ALERT Detector

- Gas Target
  - 30 cm effective length, 6 mm radius
  - 3 atm, 25 um Kapton walls
- Hyperbolic drift chamber (32 < R < 85 mm)
  - 30 cm longitudinal wires with 10° stereo
  - 8 ~circular layers of 2 mm hexagonal cells
  - Light gas mixture ~1 atm, insensitive to relativistics
- Two Segmented Scintillator Cylinders
  - TOF and total energy measurements for PID
  - Total thickness ~20 mm
  - SiPMs directly attached

- Full GEANT 4 Simulation
  - Used to optimize the detector design
  - Evaluate drift chamber occupancies, thresholds, time and tracking resolutions (used in physics projections)
- To Do
  - Evaluate/finalize electronics
  - Mechanical integration on going
• **Testing Progress:**
  – Full wire layout and support structure design, MAGBOLTZ field simulations
  – Gluing and soldering wires with 2 mm gaps on curved structure
  – 3D printed tests of 18-sector design (with one empty) for ensuring independent sector removal/replacement
  – Carbon and titanium support structures to handle the expected < 600 kg tension

• **First prototype is designed and being ordered**
• All part of a larger R&D program on drift chambers at Orsay
– Large p/theta Acceptance
  – Down to ~75 MeV/c for protons, and 25°
– Ability to handle high rates
  – Short drift time <250 ns (5 μs in RTPC) → trigger
  – Acceptable drift chamber occupancies at few $10^{34}$
    – For $^4$He-detection only running, can increase thresholds & luminosity
– Particle Identification
  – Timing and tracking resolutions sufficient to distinguish all
  – Except $^4$He and $^2$H, separable with dE/dx
Tagged EMC Measurements on Light Nuclei
The EMC Effect

- Quarks in nuclei behave differently and in a non-trivial way than quarks in a free nucleon
- EMC effect fundamentally challenged our understanding of nuclei
- Specific origins of the modification are not clearly identified yet
  - Need new observables → semi-inclusive

$F_2(x) \sim \sum_f e_f^2 q_f(x) \quad f = u, d, s$

Because nuclear binding (MeV) << energy scale of the probe, nucleon excitations (GeV)

One expects that

$F_2^A(x) \approx Z F_2^p(x) + N F_2^n(x)$

is insensitive to the details of the nuclear structure beyond Fermi motion
Models of the EMC effect

Nucleon Structure is modified in the nuclear QCD medium
- Nucleon “swelling”
- Dynamical rescaling
- Multiquark clusters (6q, 9q “bags”)

Nucleon Structure is modified due to Hadronic effects
- More detailed binding calculations: Fermi motion + binding+ N-N correlations
- Nuclear pions

Many models but no complete and accepted picture that is consistent with other data (e.g. Drell-Yan)
The Spectator Mechanism

• Plane Wave Impulse Approximation, no FSI
  • low momentum $p_1$, $A-1$

• Spectator recoil nucleon
  – Part of the nuclei that do not interact with the virtual photon and other hadronic products of the reaction
  – Necessary to control final state interactions with hadrons produced and nucleon knocked out
  – Need to select the right kinematic (usually backward and moderate momentum)
  – Used by the BoNuS experiment successfully for neutron PDF

• Spectator recoil nuclei
  – The integrity of the recoil nuclei gives an extra guarantee against FSI
  – But reduced at high momentum

\[ P_{A-1}, \text{fm}^{-1} \]
## ALERT Beam Time Request

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Particles detected</th>
<th>Targets</th>
<th>Beam time request</th>
<th>Luminosity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALERT Commissioning</td>
<td>p, d, $^4$He</td>
<td>H and He</td>
<td>5 days</td>
<td>Various</td>
</tr>
<tr>
<td>Tagged EMC</td>
<td>p, $^3$H, $^3$He</td>
<td>$^2$H and He</td>
<td>20 + 20 days</td>
<td>$3 \times 10^{34}$ cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>Tagged DVCS</td>
<td>p, $^3$H, $^3$He</td>
<td>$^2$H and He</td>
<td>20 + 20 days</td>
<td>$3 \times 10^{34}$ cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>Nuclear GPDs</td>
<td>$^4$He</td>
<td>He</td>
<td>extra 10 days on He</td>
<td>$6 \times 10^{34}$ cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>Additional Topics</td>
<td>p, d, $^3$H, $^3$He</td>
<td>$^2$H and He</td>
<td>20 + 20 + (10) days</td>
<td>$3(6) \times 10^{34}$ cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>55 days</td>
<td></td>
</tr>
</tbody>
</table>

*11 GeV*

**Expect event yield, $^3$H momentum vs $x_B$**

- **Outer wall**
- **Clear space surrounded by a Kapton foil**
- **Drift chamber**
- **Scintillators array covered by a light proof layer**

*Jefferson Lab*
Testing the Spectator Model and FSI Effects

• Can be tested on a large spectrum with very good precision

—Comparison of Helium and Deuterium targets
  — measured at same values of $x$ and $Q^2$ and recoil (A-1) momentum

—The A dependence of $R$ is entirely dominated by the A dependence of the nucleon momentum distribution, which is strong at low momenta and fairly well-known

$$R(P_{A-1}) = \frac{\sigma(D(e,e'p)X)}{\sigma(^4He(e,e'\,^3He))X}$$

$$\theta_{A-1} = 180^\circ$$

$$R(x, Q^2, |\vec{P}_{A-1}|, ^2H, ^4He) \equiv R(|\vec{P}_{A-1}|) \approx \frac{n_D^D(|\vec{P}_{A-1}|)}{n_0^4He(|\vec{P}_{A-1}|)}$$

Rescaling x or $Q^2$?

- **Rescaling models**
  - Impossible to differentiate x and $Q^2$ rescaling with inclusive measurements but gives strong signature with semi-inclusive rescaling.
  - Measure cross sections for same-A and recoil momentum, but different x.
  - Comparison of D to $^4$He is particularly interesting, no isospin issues but already strong EMC effect!
  - We will be able to give clear confirmation or exclusion for these models.

$$R(x, x', z, Q^2) = \frac{x'}{x} \frac{F_{2}^{N/A}(x / z, Q^2)}{F_{2}^{N/A}(x', z, Q^2)}$$

For x-rescaling, R depend on $P_{(A-1)}$

$$R(x, x', x', Q^2) = \frac{x'}{x} \frac{F_{2}^{N/A}(x, z, Q^2)}{F_{2}^{N/A}(x', z, Q^2)}$$

For $Q^2$-rescaling, R independent of $P_{(A-1)}$

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• **EMC effect due to local conditions and offshellness of the nucleon**
  – In this model EMC effect is due to the cancellation of much larger effects that can be separated with spectator detection
  – Slope of the ratio of structure functions is generated by the average value of the nucleon removal energy \( <E> \)
  – Separate the contribution between weakly and deeply bound nucleons
  – We will be able to give clear confirmation or exclusion for this model

Summary

• New ALERT Run Group
  – Comprehensive physics program on structure of $^4$He
  – Proposals submitted to PAC 44 covering SIDIS, DVCS, DVMP

  • Proposed Tagged-EMC measurements on $^4$He/D$_2$
    – part of next-generation studies into EMC effect, over large range of kinematics, to isolate FSI effects, offshellness, $x_B/Q^2$-rescaling

  – New ALERT Recoil Detector development in progress
    • drift chamber + scintillators for triggering, tracking, nuclear PID