Tagged EMC Measurements at EIC

Florian Hauenstein, EIC Workshop 01/23/20
Overview

- EMC-SRC Recap
- Tagged DIS-SRC
  - JLab12
  - EIC
- Status of EIC simulations
- Outlook and Summary
EMC Effect in Different Nuclei

B. Schmookler et al. (CLAS collaboration), Nature 566, 354 (2019)
SRC Recap (see talks yesterday)

https://indico.bnl.gov/event/6799/timetable/#20200122

- Nucleon pairs that are close together in the nucleus
- *high relative* and *lower c.m.* momentum compared to the Fermi momentum $k_F$

B. Schmookler et al., Nature 566, 354 (2019)

A. Schmidt et al.

from Jackson Pybus’ talk

<table>
<thead>
<tr>
<th>Missing Momentum [MeV/c]</th>
<th>Preliminary</th>
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<tbody>
<tr>
<td>400</td>
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<td>500</td>
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<td>600</td>
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<td>700</td>
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<td>800</td>
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EMC - SRC correlation

B. Schmookler et al. (CLAS collaboration), Nature 566, 354 (2019)

DIS

Quasi-Elastic

\[ \frac{\sigma_A}{A}/\frac{\sigma_D}{2} \]

\[ \frac{\sigma_A}{A}/\frac{\sigma_D}{2} \]

\[ \Delta \rightarrow EMC \text{ slope} \]

\[ \Delta \rightarrow SRC \text{ plateaus (a}_2 \) \]
EMC - SRC Correlation

- Are high-momentum nucleons responsible for the EMC effect?

Weinstein et al., PRL 106, 052301 (2011), Hen et al., PRC 85, 047301 (2012)
Tagged DIS on Deuterium

- “Tag“ interacting nucleon by measuring spectator
- How does the bound nucleon structure function depend on bound nucleon virtuality $v = p^2 - m^2$
- Explaining the EMC effect
Tagged DIS: What will be measured

- Measuring cross section ratios to minimize uncertainties

\[
\frac{F_2^{\text{bound}}(x'_\text{high}, Q_1^2, \alpha_s)}{F_2^{\text{free}}(x_{\text{high}}, Q_1^2)} = \frac{\sigma_{\text{DIS}}(x'_\text{high}, Q_1^2, \alpha_s)}{\sigma_{\text{DIS}}(x_{\text{low}}, Q_2^2, \alpha_s)} \cdot \frac{\sigma_{\text{free}}^{\text{DIS}}(x_{\text{low}}, Q_2^2)}{\sigma_{\text{free}}^{\text{DIS}}(x_{\text{high}}, Q_1^2)}
\]

- minimal FSI \( \theta_{rq} > 107^\circ \)
- \( x' = x \) for moving nucleon = \( Q^2/(2p \cdot q) \)
Tagged DIS at JLab

Hall B:
CLAS 12 + Backward Angle Neutron Detector (BAND)

• Took first data in Spring 19
• Taking more data now
Tagged DIS at JLab

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CLAS 12 + Backward Angle Neutron Detector (BAND)

- Took first data in Spring 19
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Hall C:
SHMS/HMS + Large Angle Detector (LAD)

- Experiment ready
- GEMs from PRAD experiment
- Run in 2022?
Two upcoming experiments will test the EMC-SRC connection.

Deuterium LAD

11 GeV e––

SHMS
HMS

GEMs

spectator proton

JLab Hall C

scattered electron

jet from struck quark
LAD - Refurbished CLAS6 Scintillators

- 4m long, 5 panels, 55 bars
- 6m away from the target
- coverage 90 - 157 degree
- ~200ps time resolution
LAD - BAND Comparison

BAND:

- $\sim 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ luminosity
- No tracking of neutrons
- Some regions with high material between target and BAND
- $x'$ coverage: 0.2 - 0.5
LAD - BAND Comparison

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**LAD:**
- $\sim 10^{36}$ cm$^{-2}$s$^{-1}$ luminosity
- Proton tracking with GEMs
- Low material budget between target and LAD
- $x'$ coverage: 0.2 - 0.6
LAD - BAND Comparison

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LAD wins!

$\rightarrow$ reduced (accidental) background
$\rightarrow$ higher luminosity
$\rightarrow$ higher $x'$ coverage
DIS Recoil Tagging d(e,e’N)X - Expected Results

Bound $F_2$/ Free $F_2$

Various models

No modification

$\alpha_s = (E_s - p_s^z)/m_s$

$p_s^z [\text{GeV/c}]$ → 0.4
Tagged DIS at EIC

Jefferson Labs’ LDRD project (2014/15)
``Physics potential of polarized light ions with EIC@JLab“``

Webpage: https://www.jlab.org/theory/tag/

- Polarized deuterons (vector/tensor)
- $A > 2$ nuclei
- Proton and Neutron tagging
- Exclusive processes

- Advantages at EIC
  - Detection of low momentum recoils
  - Higher $Q^2$
  - Possible detection of A-2 system

\[ e + d \rightarrow e' + p + X \]

Proton LC fraction $\alpha_p = 1.00$
1.04
1.08

JLEIC simulation
Int. luminosity 1 fb$^{-1}$
CM energy $x_N = 2000$ GeV$^2$
$x = 0.08-0.10$, $Q^2 = 50-60$ GeV$^2$

Neutron structure function $F_2$

Neutron virtuality [GeV$^2$]
Detection in Forward Ion Direction

- Detection demanding
  - need good resolutions
  - particles down to $p_T = 0$ GeV/c
  - neutral detection

- Detectors
  - roman pots
  - zero degree calorimeter
  - tracking detectors
``Tagged SRC for medium and heavy ions at EIC” (LDRD1912)

- Feasibility of tagged SRC in DIS
  - Rates
  - Resolution
  - Detector requirements (focus on forward direction)
  - Required beam energies

- Tools
  - BeAGLE - eA event generator
  - g4e - Geant4 simulation for EIC
DIS Rates for High-x

based on super-fast quark yield parametrization,
N. Fomin PRL 105, 212502 (2010)
BeAGLE - Benchmark eA Generator for LEptoproduction


Merger of
- PYTHIA 6 (hard interaction)
- Energy loss of partons: PyQM
- Nuclear environment
  - DPMJET
  - nPDF from EPS09
- Nuclear evaporation by DPMJET3+FLUKA

SRCs in BeAGLE

- SRC-DIS in development
  - scaling from deuterium
  - SRC-EMC model
- GCF-Quasielastic (QE) implemented
- (A-2)-system handled by DPMJET3+FLUKA

\[ \text{GCF-QE Generator} \quad \{e^{-}, N, N, (A-2)\} \]

Optional (BeAGLE)
- FSI
- Intranuclear cascading

\[ \text{DMPJET+FLUKA} \]
Quasi-Elastic SRC Simulations for EIC

- 5 GeV electrons and 50 GeV carbon head-on
- Interaction point crossing angle applied individually
  - 25 mrad for eRHIC
  - 50 mrad for JLEIC
- Separation of leading, recoil and evaporation nucleons

Quasi elastic selection
- $Q^2 > 3$
- $x > 1.2$ cut
QE Simulation Results (no crossing angle)
e + C (5 GeV + 50 GeV)

- Leading, recoil, evaporation nucleons well separated
- Assume similar separation of evaporation and recoil nucleons for SRC-DIS

Note: Plots without FSI and intranuclear cascading
eRHIC Interaction Point

Holger Witter talk, EIC meeting Oct 2019,
https://indico.fnal.gov/event/21416/timetable/#20191009

Central Detector

Low E Detectors

Forward Spectrometer

6 - 20 mrad

Roman pots

Neutron Detector

±4 mrad

Hadrons

Electrons

Horizontal x (cm)

Length z (m)
JLEIC Interaction Point Design

References:

- Quasi-elastic SRCs at EIC
- No FSI and Intranuclear cascading
- Nucleon Separation between Leading, Recoil and Evaporation

Published Data

- Fe to Pb / D (Norm. 1.82%)
- \( \sigma / A \) vs. \( n_e \)

Summary and Outlook

- Tagged Short Range Correlations for Published Data (JLab, SLAC)
- Goals

Labeled Short Range Correlations for Published Data (JLab, SLAC)

Implementing SRCs in BeAGLE
Forward Detection of SRCs

Separated cone in forward direction
Leading Nucleon in challenging 10 - 50 mrad detection
All neutrons detectable
Proton detection more difficult

- Recoil nucleons within magnet aperture
  - all neutrons detectable
  - proton detection more difficult
eRHIC IP: 25 mrad crossing angle

- Recoil nucleons covered by forward spectrometer and forward direction detectors
- **Ongoing:** Implementation of IP into g4e —> Detailed simulations
Summary and Outlook

- EMC-SRC correlation from electron scattering
- Tagged SRC physics possibilities at EIC
  - Recoils nucleons well separated
  - Detection of recoils in both IP designs
  - Requirements for beam energies moderate

Near term:
- GCF-QE events processed through g4e
- Simulation of DIS-SRC events
- Study of FSI and intra nuclear cascading effects
- Detector requirements
- Resolutions

Far term:
- Yellow report section
Back up slides
Quasi-elastic SRCs - Beam Rigidity

(JL)EIC e+C, 5x50 GeV², QE selection cuts

\[ \frac{\Delta p}{p} = \frac{\Delta B \rho}{B \rho_{ion}} = \frac{(Z/A)_{ion} \cdot p_f - p_{ion}}{p_{ion}} \]

- Recoils close to ion direction
- Rigidity below 0 as expected
- Rigidity for recoils smaller than for leading
- Coverage for \( \Delta p/p < -0.5 \) challenging

from V. Morozov
CFNS Summer School 2019

Quad aperture at 6T
DIS Recoil Tagging $d(e,e'n)X$ - Expected Results

$\alpha_s = (E_s - p_{sz}^z)/m_s$

$F_{2}^{p}/F_{2}^{p}$

$F_{2}^{n}/F_{2}^{n}$

$d(e,e'p)X$

LAD

BAND

No modification

Binding

Rescaling

PLC suppression

Various models

$0.2$ $0.3$ $0.4$ $0.5$ $0.6$ $0.7$ $0.8$ $0.9$ $1.0$ $1.1$

Bound $F_2$/ Free $F_2$

$0.4$ $1.0$ $1.1$ $1.2$ $1.3$ $1.4$ $1.5$ $1.6$

$p_{sz}^z$ [GeV/c]
F₂ from N. Fomin Paper and Reimplementation

N. Fomin PRL 105, 212502 (2010)
QE Simulation Results (no crossing angle)

e + C (5 GeV + 50 GeV)

- Leading, recoil, evaporation nucleons well separated
- Expecting similar separation of evaporation and recoil nucleons for DIS

Note: This results are without FSI and intranuclear cascading
LAD - Experimental Conditions

- 11 GeV electron beam
- Extended LD$_2$ target
- Approved for ~34 PAC days
- $10^{36}$ cm$^{-2}$s$^{-1}$ luminosity (10x larger than BAND in HallB)
- Low and high x’ settings in both HallC spectrometers
QE Event Handling Procedure

- GCF-QE output of electrons with \( P_e = 537 \) GeV on Carbon (fixed target)
- Process through BeAGLE and convert to ROOT-file

- **Fixed target events to collider events**
  - Boost from lab to c.m.s with fixed target kinematics \( (P_e = 537 \) GeV)
  - Boost from c.m.s to collider lab with e+C \((5\times50[40])\) beams

- **Add crossing angle via**
  - Boost along x-axis with beta = 0.025
  - Rotate along y-axis by -0.025 mrad

Check of \( Q^2 \) and \( x \) distribution
\((Q^2 > 3 \) and \( x > 1.2 \) cut)
SRC-EMC Model and Universal function

B. Schmookler et al., Nature 566, 354 (2019)

- Data driven approach
- Modification of $F_2$ by np-SRC pairs (neglect nn and pp pairs)

\[ F^A_2 = ZF^p_2 + NF^n_2 + n^A_{SRC}(\Delta F^p_2 + \Delta F^n_2) \]

Bound = “Quasi-free“ + Modified SRC

![Graph showing data points and fitted curves for $F^A_2/F_2^d$ vs $x_B$. The graph includes data from SLAC, JLab Hall C, and This work.](image)
SRC-EMC Model and Universal function (2)

B. Schmookler et al., Nature 566, 354 (2019)

- Data driven approach
- Modification of $F_2$ by np-SRC pairs (neglect nn and pp pairs)

\[
F^A_2 = ZF^p_2 + NF^n_2 + n^A_{SRC}(\Delta F^p_2 + \Delta F^n_2)
\]

Bound = "Quasi-free" + Modified SRC

$F^n_2$ not well constrained but solve by

- $F^d_2 = F^p_2 + F^n_2 + n^d_{SRC}(\Delta F^p_2 + \Delta F^n_2)$
- $a_2 = \frac{2}{N} \frac{n^A_{SRC}}{n^d_{SRC}}$
\[ n_{SRC}^d \frac{\Delta F_2^p + \Delta F_2^n}{F_2^d} = \frac{F_2^A}{F_2^d} - (Z - N) \frac{F_2^p}{F_2^d} - N \]

Universal function

Nucleus Dependent

\[ \frac{A}{2} a_2 - N \]

\[ \text{\textbf{Universal function}} \rightarrow \text{\textbf{Can be used for DIS event generators}} \]
QE Simulation Results (no crossing angle)

Neutrons from e+C JLEIC 5x50 $Q^2 > 3 \text{ GeV}^2 \times 1.2$

Protons from e+C JLEIC 5x50 $Q^2 > 3 \text{ GeV}^2 \times 1.2$