Investigating the EMC effect in highly-virtual nucleons at Jefferson Lab

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The EMC Effect in DIS Scattering

- **EMC effect still puzzles.**
- **SLAC data (1994)**
  - EMC slope: 0.32
  - $\frac{2\sigma_C}{12\sigma_d}$

**Fermi-motion**

- **J. Gomez et al., PRD 49 4348 (1994)**
- **Miller + Smith, PRC 65 015211 (2001)**

Quark distributions ($F_2$) in nucleons bound in nuclei different to distributions in free nucleons.
EMC and SRC Correlation

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

EMC slope (-dR/dx) vs. SRC pair density (a_2)

Weinstein et al., PRL 106, 052301 (2011), Hen et al., PRC 85, 047301(2012)
Short Range Correlations

- NN pair with large relative momentum and small c.m momentum
- ~20% of nucleons in nuclei
- SRC pairs dominate nucleon momentum distribution above fermi momentum $k_F$
- np dominance of SRC pairs (about ~18 more likely than pp or nn)

Duer et al. (CLAS collaboration), Nature 560, 617 (2018)
Tagged DIS on Deuterium

- "Tag" interacting nucleon by measuring spectator
- How does the bound nucleon structure function depend on nucleon virtuality $\nu = p^2 - m^2$
- Explaining the EMC effect
What will be measured

- Measuring cross section ratios to minimize uncertainties
- Choose kinematics with minimal FSI \( \theta_{rq} > 107^\circ \)

\[
\frac{\sigma_{DIS}(x'_{\text{high}}, Q^2_1, \alpha_s)}{\sigma_{DIS}(x'_{\text{low}}, Q^2_2, \alpha_s)} \cdot \frac{\sigma_{\text{free}}(x_{\text{low}}, Q^2_2)}{\sigma_{\text{free}}(x_{\text{high}}, Q^2_1)} \cdot R_{FSI} = \frac{F^\text{bound}_{2}(x'_{\text{high}}, Q^2_1, \alpha_s)}{F^\text{free}_{2}(x_{\text{high}}, Q^2_1)}
\]

- \( x' = x \) for moving nucleon = \( Q^2/(2p \cdot q) \)
- \( x'_{\text{high}} > 0.45 \)
- no EMC effect at \( 0.25 \leq x'_{\text{low}} \leq 0.35 \)
DIS Recoil Tagging $d(e,e'N)X$ - Expected Results

\[ \alpha_s = \frac{(E_s - p_s^z)}{m_s} \]

$\frac{F_2}{F_2}$ Bound / Free

$\alpha_s = \frac{(E_s - p_s^z)}{m_s}$

$\frac{p_s^z}{[\text{GeV/c}]} \rightarrow 0.4$

$d(e,e'n)X$, BAND (HallB)

$d(e,e'p)X$

LAD (HallC)
BAND in HallB

CLAS12 spectrometer

Spectator neutron

LD2

Scattered Electron

Jet from struck quark

BAND: Backward Angle Neutron Detector

3m
CLAS12 and BAND
Overview of BAND

- 5 layers thick (36cm total) with veto layer (1cm thick)
- 140 scintillator bars
- Bar resolutions < 200 ps
- 3 meters upstream of target, coverage in θ ~ 155-176°
- Design neutron efficiency ~35% and momentum resolution ~1.5%
- Laser system for calibrations
BAND Construction

Installed in the Hall
Time of Flight Distribution

All long bars in BAND, e’ from CLAS, ~3h run

with photon path length correction

\[ \sigma_{\gamma} \approx 0.3 \text{ ns} \]

\[ \frac{t_L + t_R}{2} - t_{\text{Start}} \text{ [ns]} \]

40 ns \approx 250 \text{ MeV/c}
Time of Flight Distribution

All long bars in BAND, e’ from CLAS, ~3h run

with photon path length correction

\[ \sigma_\gamma \approx 0.3 \text{ ns} \]

Photons!

Neutrons!

40 ns \( \approx \) 250 MeV/c

\[ \frac{t_L + t_R}{2} - t_{\text{Start}} \] [ns]
Time of Flight Distribution

All long bars in BAND, e’ from CLAS, ~3h run

Calibration, data processing and analysis in progress

More data in Fall 2019

$40 \text{ ns} \approx 250 \text{ MeV/c}$
Summary and Outlook

- Tagged DIS measurements to explain EMC effect
- Measurement of F2n in Hall C with LAD 2021???
- Measurement of F2p with CLAS12 plus BAND
  - Spring and fall 2019
  - Backward going neutrons clearly seen
  - Data analysis under way

\[ \frac{F_2}{\text{Free}} = \frac{(E_s - p_s^2)}{m_s} \]

- PLC suppression
- Rescaling
- Binding

Neutrons! Photons!

\[ \frac{t_L + t_R}{2} - t_{\text{start}} [\text{ns}] \]
Many thanks to the BAND crew Rey and Efrain
Back up slides
FSI in Tagged DIS

DEEPS showed little FSI at back angles.

Klimenko et al., PRC 73 035212 (2006)
BAND Experimental Conditions

- Data taking during Run Group B of CLAS12
- Approved for 180 days (90 PAC days)
- ~50% of approved beam time in spring and fall 2019
- 11 GeV electron beam
- $10^{35}$ cm$^{-2}$s$^{-1}$ luminosity
- Scattered e’ in CLAS12
Theories identify virtuality as the key to producing EMC-like modification.

- **Binding**
  - Free
  - Bound

- **Rescaling**
  - Free
  - Bound

- **Point-like Configuration Suppression**
  - Free
  - Bound

Mathematical expressions:

\[ A - 1 \]
Laser System

Used to monitor PMT stability

Laser

355nm picosecond pulsed

Mode Scrambler (SM to MM)

Mechanical Attenuator

Photodiode

Fiber Distribution System

2

10

90

1-10^{-4}

90-10 Splitter

Variable Optic Attenuator

BAND

9-10
BAND Kinematical Coverage

\[ \alpha_s = \frac{(E_s - p_s^2)}{m_s} \]

\[ x'_B = \frac{Q^2}{2[(M_d - E_s)\omega + p_s \cdot q]} \]
Time of Flight Distribution

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$\sigma_\gamma \approx 0.3$ [ns]

Photons!

Neutrons!

$40 \text{ ns} \approx 250 \text{ MeV/c}$

$\frac{t_L + t_R}{2} - t_{\text{Start}}$ [ns]
Tagged DIS at JLab

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

**Hall C:**
SHMS/HMS + Large Angle Detector (LAD)