From 12 GeV to EIC: EMC-SRC

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\approx 20\% \text{ of nucleons are part of correlated pairs.}

- Relative momentum: > 300 \text{ MeV}/c
- CoM momentum: \mathcal{O}(150 \text{ MeV}/c)
Knocked-out high-momentum nucleons come with a recoiling partner.

\[ \text{Recoil neutron momentum [GeV]} \]

\[ \cos \gamma \]

\[ \text{Recoil neutron momentum [GeV]} \]

\[ \text{Leading} \]

\[ \gamma \]

\[ \text{Recoil} \]

\( p \) scattering from Carbon:

- Always a correlated partner
- Anti-parallel momenta

E. Piasetzky et al., PRL 97 162504 (2006)
In carbon, *np*-pairs are strongly preferred.

![Graph showing SRC Pair Fraction (%)](image)

E. Piasetzky et al., PRL 97 162504 (2006)
R. Shneor et al., PRL. 99, 072501 (2007)
Indirect evidence for \( np \)-dominance in heavier asymmetric nuclei.

SRCS may play an outsized role in big open questions.

- Nuclear Matrix Elements

Kortelainen et al. PLB 647 (2007)
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- Nuclear Matrix Elements
- Neutrino-Nucleus Interactions
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- Nuclear Matrix Elements
- Neutrino-Nucleus Interactions
- Neutron Stars

The Short-Range Correlations Collaboration

Massachusetts Institute of Technology

Old Dominion University

Tel Aviv University

Universidad Técnica Federico Santa María
We study SRCs through several approaches.

- CLAS-6 Data-mining
- Dedicated SRC-pair break-up experiments
- Recoil-tagging measurements
In my talk today:

1. Pair formation and the repulsive $NN$ core
   - We’re asking sophisticated quantitative questions of our data.

2. $np$-dominance in asymmetric nuclei
   - Neutrons show saturation behavior, protons do not.

3. The EMC-SRC connection
   - New data strengthen the case for the SRC hypothesis.
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CLAS is well-suited for data mining.

- Large acceptance
- Open trigger
The CM momentum distribution of SRC pairs can tell us about pair formation.
Choose kinematics in which FSIs are confined to the pair.

- $x > 1.2$
- $Q^2 > 1.2 \text{ GeV}^2$
- $\theta_{pq} < 25^\circ$
- $M_{\text{miss}} < 1.1 \text{ GeV}$
We see saturation in the CM width.

Erez Cohen et al., under peer review
We see saturation in the CM width.
The ratio of $pp$ pairs to single protons can tell us about the $NN$-interaction.
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How often did we miss a proton we should have seen?

Simulated acceptance during EG2

Acceptance
Data-driven likelihood estimate

Data:

Longitudinal

Model:

Transverse
We use a Markov Chain MC to estimate the acceptance for recoil protons.
We use a Markov Chain MC to estimate the acceptance for recoil protons.
Prelim. results show the expected rise in $pp/p$. 

![Graph showing transparency-corrected $pp/p$ vs. $p_{miss}$ with different materials: Carbon, Aluminum, Iron, and Lead. The graph includes error bars for each data point. The contact prediction is represented by a shaded area.](image)
Much has been learned from very few events.
A new CLAS-12 proposal aims to add order of magnitude more data.
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CLAS data mining confirmed the absence of high-momentum \( pp \) pairs.

Meytal Duer has identified high-momentum neutrons for the first time.

M. Duer, CLAS collaboration, to appear in Nature
Neutrons efficiencies and resolutions were calibrated using the $d(e, e' p\pi^+\pi^-)n$ reaction.
The poor neutron resolution was studied by “smearing” protons.
The $n/p$ ratio is constant with asymmetry!
SRC fraction for neutrons saturates.

\[
\text{SRC Fraction} \equiv \frac{\sigma^A_{\text{SRC}}(e,e'N)}{\sigma^A_{\text{MF}}(e,e'N)} / \frac{\sigma^C_{\text{SRC}}(e,e'N)}{\sigma^C_{\text{MF}}(e,e'N)}
\]
SRC fraction for neutrons saturates.

\[
\text{SRC Fraction} \equiv \frac{\sigma_{A}^{\text{SRC}}(e,e'N)}{\sigma_{A}^{\text{MF}}(e,e'N)} \times \frac{\sigma_{C}^{\text{SRC}}(e,e'N)}{\sigma_{C}^{\text{MF}}(e,e'N)}
\]
$np/pp$ ratio is constant over all species.
We need experiments to disentangle nuclear size and asymmetry.

- New CLAS-12 proposal
  - Add $^{40}\text{Ca}$, $^{48}\text{Ca}$

- Recent Hall A Tritium Experiment
  - Compare $^{3}\text{H} \leftrightarrow ^{3}\text{He}$

- CaFe (E12-17-005)
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   - New data strengthen the case for the SRC hypothesis.
Could the EMC effect be stemming from heavily modified SRC pairs?
We attempted to extract $F_2$ for a single $np$-SRC pair.
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We attempted to extract $F_2$ for a single $np$-SRC pair.
We will test the SRC-EMC hypothesis with recoil-tagging experiments.

Advantages of a deuterium target:

- Minimal final-state interactions
- Spectator has *exactly* opposite momentum
- 5% of the wave-function is short-range configuration
DEEPS showed little FSI at back angles.

Klimenko et al., PRC 73 035212 (2006)
What we want to measure:

\[
\frac{F_2(x', Q^2, \alpha_s)_{\text{bound}}}{F_2(x, Q^2)_{\text{free}}} \approx \frac{\sigma_{\text{DIS}}(x', Q^2, \alpha_s)_{\text{bound}}}{\sigma_{\text{DIS}}(\text{low } x', Q^2_0, \alpha_s)_{\text{bound}}} \times \frac{\sigma_{\text{DIS}}(\text{low } x, Q^2_0)_{\text{free}}}{\sigma_{\text{DIS}}(x, Q^2)_{\text{free}}} \times R_{\text{FSI}}
\]
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Tagged DIS measurement Input \approx 1
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\]

Tagged DIS measurement Input \approx 1

At low x, the EMC effect should be small:

\[
\sigma_{\text{DIS}}(\text{low } x', Q_0^2, \alpha_s)_{\text{bound}} \approx \sigma_{\text{DIS}}(\text{low } x, Q_0^2)_{\text{free}}
\]
Different models predict different $F_2$ ratios.

BAND will detect recoiling spectator neutrons.

- **11 GeV e⁻**
- **Deuterium**
- **Spectator neutron**
- **scattered electron**
- **jet from struck quark**
BAND will surround the upstream beamline.
Experiment Details

**Experiment**
- Experiment E12-11-003A
- Approved for Run Group B
  - Installation in a few weeks!
- Extended LD$_2$ target
- 11 GeV $e^-$ beam
- $10^{35}$ cm$^{-2}$s$^{-1}$

**Backward Angle Neutron Detector**
- Finishing module assembly at MIT/ODU
- 5 rows of 21 bars
- $160^\circ$–$170^\circ$
- $\approx 60\%$ azimuthal coverage
- $\approx 40\%$ neutron efficiency
We want reach in both $x_B$ and $\alpha_s$. 
LAD will detect recoiling spectator protons.
LAD is three panels of scintillator bars, originally from the CLAS-6 ToFs.
LAD Experiment Details

Experiment
- Experiment E12-11-107
- Approved for 820 hours
- Extended LD$_2$ target
- 11 GeV $e^-$ beam
- $10^{36}$ cm$^{-2}$s$^{-1}$
- Low $x$ and high $x$ settings

Large Acceptance Detector
- 5 panels of 11 bars
- 1.5 sr at back angles
- 90°–160°
- ±18° out-of-plane
Energy deposition in LAD must match velocity.
We plan to add GEMs to assist in vertexing.
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Expected Impact

![Graph showing expected impact with PLC suppression, rescaling, and binding curves.](image-url)
Expected Impact

![Graph showing expected impact with axes labeled Bound $F_2 / \text{Free } F_2$ and $\alpha_s$. The graph includes data points for LAD and BAND, with lines representing Binding, Rescaling, and PLC suppression.](image-url)
Possibilities at the EIC

1. Tagging
   - DIS or QE
   - very forward spectator
   - “zero momentum” spectators are now detectable

2. Detection of the $A-2$ system
   - very forward residual nucleus
Small differences in initial momentum become large in the collider frame.
Spectators will be within $2^\circ$ of beamline.

\[ p_\perp = 1.0 \text{ GeV} \]
\[ p_\perp = 0.6 \text{ GeV} \]
\[ p_\perp = 0.2 \text{ GeV} \]
Recap

- Pair formation and the NN core
Recap

- Pair formation and the $NN$ core
- $np$-dominance in asymmetric nuclei

![Graph showing the ratio of $(e,e'n)/A(e,e'p)$](chart.png)
Recap

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Conclusions

- New experiments will bring an order of magnitude increase in data.

- We are entering a new *quantitative* era of SRC measurements.