Highlights and Recent Developments in Short Range Correlations

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20% of the nuclear wave function
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SRCs produce a high-momentum tail.
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![Diagram showing Fermi gas in a box and typical nucleus with high-momentum tail.](image)
SRCs impact $NN$-Matrix Elements.

Coloma et al., PRD 89 073015 (2014)
SRCs alter the eq.-of-state for neutron stars.

SRCs may play a major role in the EMC effect.

L.B. Weinstein et al., PRL 106, 052301 (2011)
O. Hen et al., PRC 85, 047301 (2012)
In my talk today:

1. Important past results
2. Recent developments
3. Future plans
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1. **Important past results**

2. Recent developments

3. Future plans
Inclusive cross sections scale for $x > 1.5$. 


Fomin et al., PRL 108, 092502 (2012)
High-$x$ kinematics restrict quasielastic scattering to high-momentum nucleons.

![Graph showing kinematics](image)
Scale factor $a_2$ is the per-nucleon density of SRC pairs.

$$\frac{3 \cdot \sigma_A}{A \cdot \sigma^{3\text{He}}}$$


Scaling constant $a_2$:

$$\sigma_A = a_2 \times \frac{A}{2} \sigma_d$$
We have learned more about SRC pairs from coincidence experiments.
All high-momentum nucleons have a correlated partner.

$p$ scattering from Carbon:

- Always a correlated partner
- Anti-parallel momenta

E. Piasetzky et al., PRL 97 162504 (2006)
Between 300–600 MeV, $np$ pairs predominate.

![Graph showing SRC pair fraction against missing momentum.](image)

E. Piasetzky et al., PRL 97 162504 (2006)
This has been verified over many nuclei.

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Recoil tagging may extend $a_2$ scaling to lower $x$. 

Nucleon momentum $x \rightarrow$ more momentum transfer

Forbidden

Nucleon momentum

$1 k_F$ $2 k_F$ $3 k_F$

0.8 1 1.2 1.4 1.6 1.8 2

Forbidden
Recoil tagging may extend $a_2$ scaling to lower $x$. 

Diagram showing recoil tagging in nuclear physics, with arrows indicating scattered electrons and struck and recoil nucleons. The graph illustrates nucleon momentum with $k_F$ values and a shaded region labeled "Forbidden."
Analyis of CLAS data suggests an extended scaling region.

B. Schmookler et al., in preparation
Analysis of CLAS data suggests an extended scaling region.

B. Schmookler et al., in preparation
We recently performed a recoil-tagging experiment at Mainz using the A1 spectrometers.
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A. Ashkenazi et al., analysis underway!
$np$ dominance comes from tensor interaction.

Scalar part of the $NN$ interaction

![Graph showing scalar part of the $NN$ interaction](image)

- Potential
- Distance
$np$ dominance comes from tensor interaction.

Scalar part of the $NN$ interaction

Potential

Distance

Tensor interaction dominates
$np$ dominance comes from tensor interaction.

We expect that the $pp$ fraction should rise with nucleon momentum.
The fraction of $pp$ pairs increases with $k$.

E. Cohen, O. Hen et al., in preparation
Which species has more kinetic energy in an asymmetric nucleus?

\[ \langle T_m \rangle < \langle T_M \rangle \]

Probability

Nucleon momentum

\[ k_F \quad 2k_F \quad 3k_F \]
Which species has more kinetic energy in an asymmetric nucleus?

\[ \langle T_m \rangle > \langle T_M \rangle \]
There are two competing forces.

Probability

Nucleon momentum
Majority
Minority

\[ \langle T_m \rangle < \langle T_M \rangle \]

Which is stronger?
Analysis of \((e, e'p)\) and \((e, e'n)\) in CLAS
Data reconfirm $np$ dominance.

![Graph showing neutron excess versus nucleon momentum](image)

Analysis by Meytal Duer

- $\frac{\sigma_A(e,e'n)/\sigma_n}{\sigma_A(e,e'p)/\sigma_p}$
- Elements: $^{12}$C, $^{27}$Al, $^{56}$Fe, $^{208}$Pb
- N/Z
- M.F.
- SRC

Probability

Nucleon momentum

Majority vs Minority

Neutron Excess [(N-Z)/Z]

PRELIMINARY
As neutron number increases, the fraction of high-momentum neutrons decreases.

\[
\text{SRC Fraction} \equiv \frac{\sigma_A^{\text{SRC}}(e,e'N)}{\sigma_A^{\text{MF}}(e,e'N)} / \frac{\sigma_C^{\text{SRC}}(e,e'N)}{\sigma_C^{\text{MF}}(e,e'N)}
\]
As neutron number increases, the fraction of high-momentum neutrons decreases.

\[
\text{SRC Fraction} \equiv \frac{\sigma_{A}^{\text{SRC}}(e,e'N)}{\sigma_{A}^{\text{MF}}(e,e'N)} / \frac{\sigma_{C}^{\text{SRC}}(e,e'N)}{\sigma_{C}^{\text{MF}}(e,e'N)}
\]

M. Duer et al., in preparation
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Some remaining questions:

- How do short-range pairs evolve with $A$ and $(N - Z)$?
- What role do SRCs play in the EMC effect?
- What happens to the remnant nucleus after hard knockout?
- Are there three-$N$ correlations?
Two upcoming \((e, e'p)\) experiments will look at asymmetric nuclei.

**SRCs in \(^3\text{H}, \(^3\text{He}\)**

E12-14-001 (Hall A)

- Hall A tritium target
- Exploit isospin symmetry
- \(^3\text{H}\) and \(^3\text{He}\) are extremely asymmetric!

**The CaFe Experiment**

E12-17-005 (Hall C)

- Disentangle asymmetry and mass number dependence
- \(^{40}\text{Ca} \rightarrow ^{48}\text{Ca} \rightarrow ^{54}\text{Fe}\)
- Pairing from different orbitals
Two upcoming experiments will test the EMC-SRC connection.

Deep inelastic scattering on deuterium, tagging a recoiling nucleon:

Deuterium

LAD

11 GeV e⁻

SHMS

GEMs

spectator proton

scattered electron

jet from struck quark

spectator neutron

Deuterium

HMS

JLab Hall C

E12-11-003A

11 GeV e⁻

jet from struck quark

11 GeV e⁻

spectator neutron

Deuterium

CLAS12

BAND

JLab Hall B

E12-11-107

scattered electron
BAND and LAD will tell us about nucleon modification and virtuality.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{plot.png}
\caption{Graph showing the relationship between \( \alpha_s \) and the ratio of bound to free \( F_2 \).}
\end{figure}
Inverse kinematics at Dubna: detecting the nuclear remnant.
We are proposing to look at SRCs with HADES at GSI.
Neutrino oscillation experiments must reconstruct $E_\nu$ event by event.
We are proposing to benchmark $\nu A$ MC codes using electron scattering.

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\[ \frac{3 \cdot \sigma_A}{A \cdot \sigma_{^3\text{He}}} \]

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Conclusions

- SRCs are 20% of the nuclear wave-function but they have far-reaching impacts.

- Our experimental program is diverse
  - Many facilities, probes, techniques

- Results are on the way!