The CaFe Experiment:

Isospin Dependence of Short Range Correlations in Nuclei

Hall C Proposal PR12-17-005

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(On the behalf of the CaFe collaboration)

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CaFe: Executive Summary

- Measure Mean-field and correlation nucleon using the \((e,e'p)\) reaction
- 4 PAC-day in Hall C using standard HMS and SHMS, \(^{40/48}\text{Ca}, \, ^{54}\text{Fe}, \, ^{12}\text{C}, \, \ldots\)

Used to extract:

- Absolute and reduce cross section \(\Rightarrow\) Distorted Spectral function
- SRC/mean-field protons ratios \(\Rightarrow\) Proton pairing probabilities
- Double ratios asym/sym nuclei \(\Rightarrow\) Pairing mechanism
What are Short Range Correlations (SRCs)?

Nucleon pairs that are close together in the nucleus.

High relative and lower c.m. momentum compared to $k_F$. 

$r$-space

$k$-space
Why SRC?

Required for a high-resolution, first principle, description of nuclear systems & processes.

- NN interaction from QCD & QCD in nuclei
- High-density systems
- High-q processes (e.g. 0νββ decay)
SRCs study using QE inclusive scattering (e,e’)

Kinematical variables:

\[
Q^2 = -(p_e - p'_e)^2 \quad \text{Resolution scale}
\]

\[
x_B = \frac{Q^2}{2m(E - E')} \quad \text{Dynamic scale}
\]
What we have learned:

- High momentum tail is universal
- $a_2 = A/D$ scaling factor ~ 4-5

Next questions:

- Do all high-momentum nucleon come in pair?
- What about c.m. momentum?
- What type of pairs?
SRCs studies from two-knock out nucleon

M. Duer et al., PRL (2019)

O. Hen, Science (2014)


Cohen et al., PRL (2018)

A. Schmidt Nature (2020)

A. Tang, PRL (2003); E. Piasetzky, PRL (2006)

Korover, PRL (2014)
SRC study using two-knock out nucleon

**Bottom Line**

- Correlated pairs are back-to-back
- C. M is lower than $k_F$
- SRCs is np dominance by factor $\sim 20$
- np dominance is observed from 4He – Pb
- np dominance due to tensor force
SRC study using two-knock out nucleon

**Bottom Line**

- Correlated pairs are back-to-back
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- SRCs is np dominance by factor $\sim 20$
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- np dominance due to tensor force

What happens to SRCs in neutron-rich nuclei?
Going to Neutron rich nuclei:

What do excess neutrons do?

don’t correlate?
correlate with each other?
correlate with core protons?
Proton “speed up” in neutron-rich nuclei

Minority nucleon moves faster than majority

M. Duer et al. (CLAS collaboration), Nature 560, 617 (2018)
More neutron more correlated proton

M. Duer et al. (CLAS collaboration), Nature 560, 617 (2018)
Absolute (e,e’) cross-section measurement

\[ \frac{d\sigma}{dE'} \text{[nb/sr/MeV]} \]

\[ \theta = 25^\circ \]
\[ \theta = 23^\circ \]
\[ \theta = 21^\circ \]

\[ ^{40}\text{Ca Models} \]

\[ ^{48}\text{Ca Models} \]

D. Nguyen et al. PRC (2020)
More pairs in $^{48}$Ca!

\frac{\sigma(48Ca)}{\sigma(40Ca)}

D. Nguyen et al., PRC(2020).
CaFe (e,e’p): Understand pairing probability

We can answer questions:

- Does $^{48}\text{Ca}$ has more Proton in SRCs?
- What is Proton high-momentum fraction?

Kinematic variables:

$$Q^2 = -(p_e - p_e')^2$$

$$x_B = \frac{Q^2}{2m(E - E')}$$

$$E_{\text{miss}} = \omega - T_p - T_{A-1}$$

$$p_{\text{miss}} = q - p' = -p_{\text{init}}$$
CaFe (e,e’p): Understand pairing probability

Cross-section:

\[ \sigma_{(e,e'p)} = k \sigma_{ep} S_p(E_{\text{miss}}, P_{\text{miss}}) T \]

Complications:
- Meson Exchange Currents (MEC).
- Delta production (i.e. IC).
- Final state interaction

Solution:
- Choosing the ‘right’ kinematics,
- Integrate over a wide \( P_{\text{miss}} \) range,
- Extract cross-section ratios.
Choosing Kinematic: Minimizing non-QE mechanisms

$X_B > 1$

$Q^2 > 2 \text{ GeV}^2$

Choosing Kinematic: Minimizing non-QE mechanisms

\( \sigma_{\text{Full}} / \sigma_{\text{PWIA}} \)

\( ^3\text{He}(e,e'p) \)

500 MeV/c

400 MeV/c

200 MeV/c

\( Q^2 > 2 \text{ GeV}^2 \)

\( X_B > 1 \)

\( \theta_{qr} < 40^\circ \)

Deuteron

\( \sigma_{\text{exp}} = k \sigma_{\text{CCL}} \)

\( \theta_{\text{eq}} = 35^\circ \)

\( \theta_{\text{eq}} = 75^\circ \)

Boeglin et al., PRL 107 (2011) 262501
## CaFe Kinematic and Acceptance

| Ebeam (GeV) | E' (GeV) | $\theta_e$ Degree | $|P_p|$ GeV | $\theta_p$ Degree | $P_m$ GeV | $Q^2_{\text{cen}}$ | $<Q^2>$ GeV$^2$ |
|------------|---------|------------------|------------|------------------|-----------|-----------------|-----------------|
| 10.6       | 8.85    | 8.3              | 1.325      | 66.4             | 0.4       | 2.1             |
| 10.6       | 8.85    | 8.3              | 1.820      | 48.3             | 0.15      | 2.1             |
CaFe Kinematic and Acceptance

Mean-field

SRC

$X_B$

$Q^2$

$P_m$ [GeV]

$X_B$

$Q^2$

$P_m$ [GeV]
Q1: Does $^{48}$Ca has more Proton in SRCs?

- Cross section ratio $^{48}$Ca/$^{40}$Ca at high missing momentum

![Graph showing $A_{1SR}(e,e'p)/A_{2SR}(e,e'p)$ as a function of $k$ [fm$^{-1}$].]
Q2: What is Proton High-momentum fraction?

- Double ratio of SRC/Mean-field Proton

\[
\frac{A_1(e, e'p)|_{SRC}}{A_1(e, e'p)|_{Mean-Field}} \div \frac{A_2(e, e'p)|_{SRC}}{A_2(e, e'p)|_{Mean-Field}}
\]
Other Potential observables

- Proton probability in SRC in light asymmetry nuclei

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<th>$n_{pB}(k)$</th>
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- Extracting absolute and reduced cross-section
  - Distorted spectral function
  - Compared to ab-initio effective theory calculation
Summary

- CaFe will do \((e,e'p)\) measurements on different nuclear targets
- 4 PAC-day experiments using standard HMS and SHMS
- Data will be used to understand SRC pairing mechanism in asymmetry nuclei
- Observables are absolute cross-section, ratio and double ratio
Plus: Or Hen, Larry Weinstein, Douglas Higinbotham, Eli Piasetzky
Back up slides