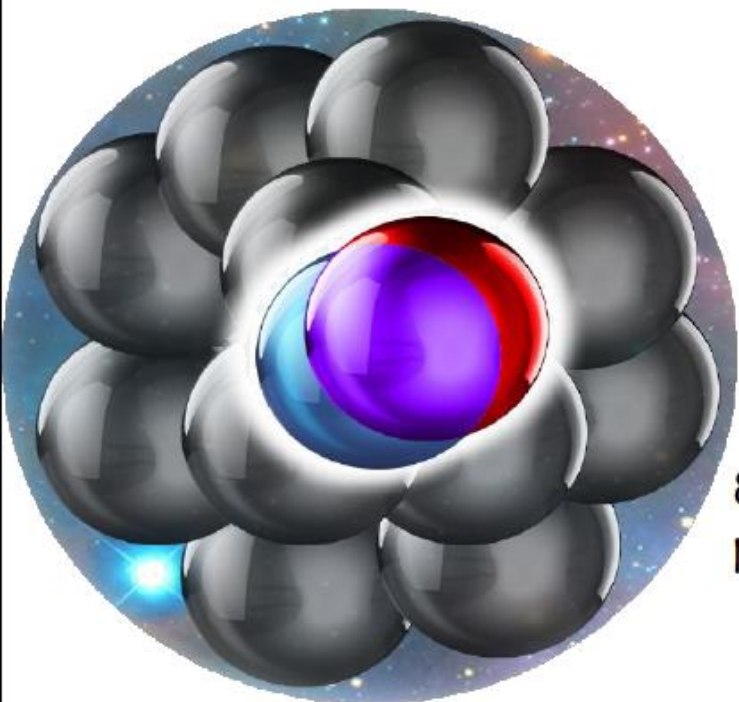# Study of NN force with SRC measurements

Igor Korover

NRCN & Tel Aviv University
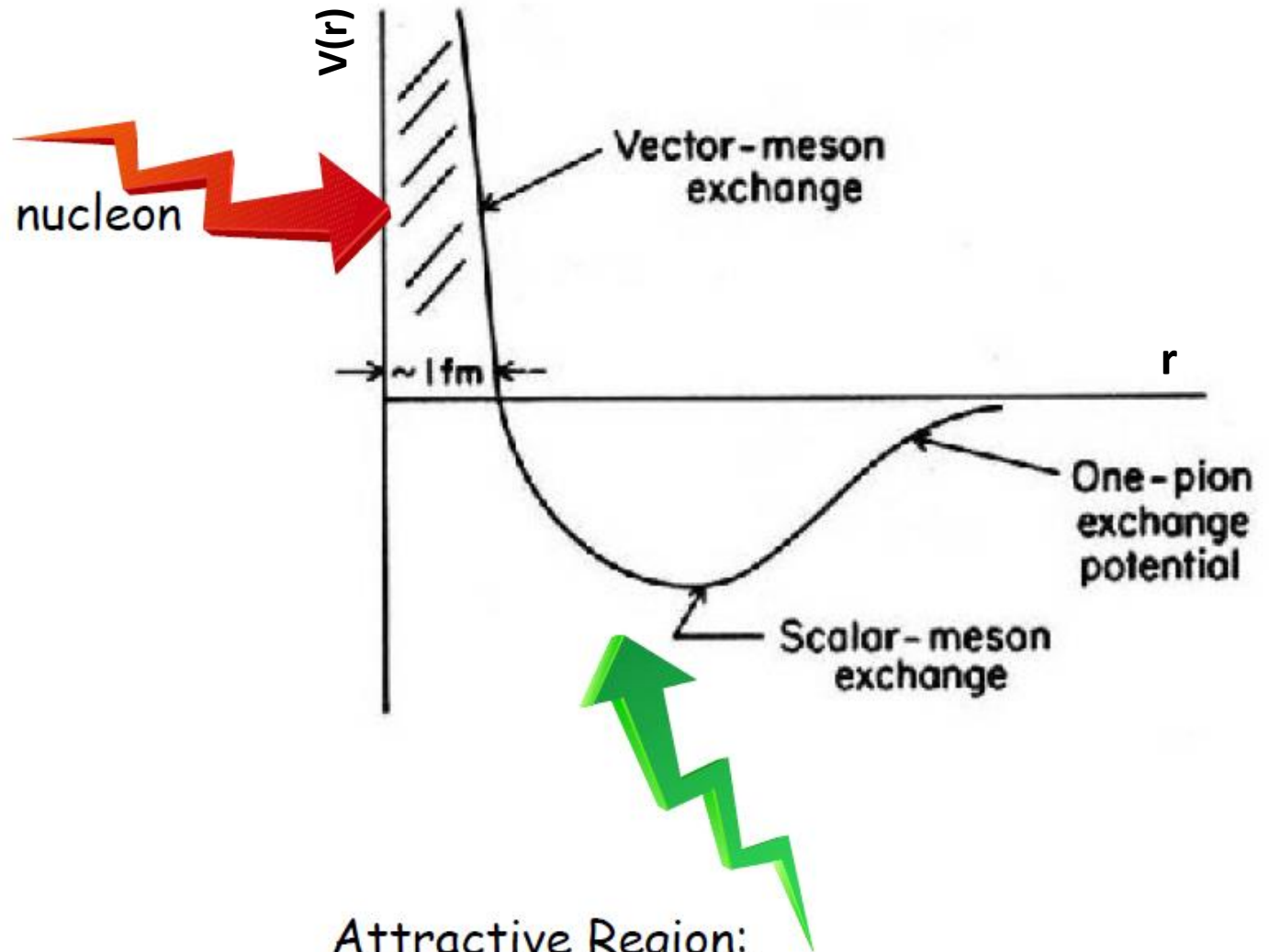Israel

8th International Conference on Quarks and Nuclear Physics 2018

Tsukuba, Ibaraki, Japan, 16 November 2018

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# General behavior of nucleon – nucleon interaction

Repulsive Core:
Scalar (?) nucleon - nucleon interaction

Attractive Region:
Scalar nucleon – nucleon interaction

V(r)

r

Vector-meson exchange

~1 fm

One-pion exchange potential

Scalar-meson exchange

General behavior of nucleon – nucleon interaction

Repulsive Core:
Scalar (?) nucleon - nucleon interaction

$V(r)$

Vector-meson exchange

r

One-pion exchange potential

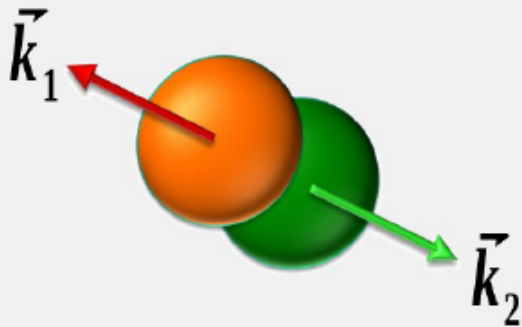Scalar-meson exchange

Attractive Region:
Scalar nucleon – nucleon interaction

3
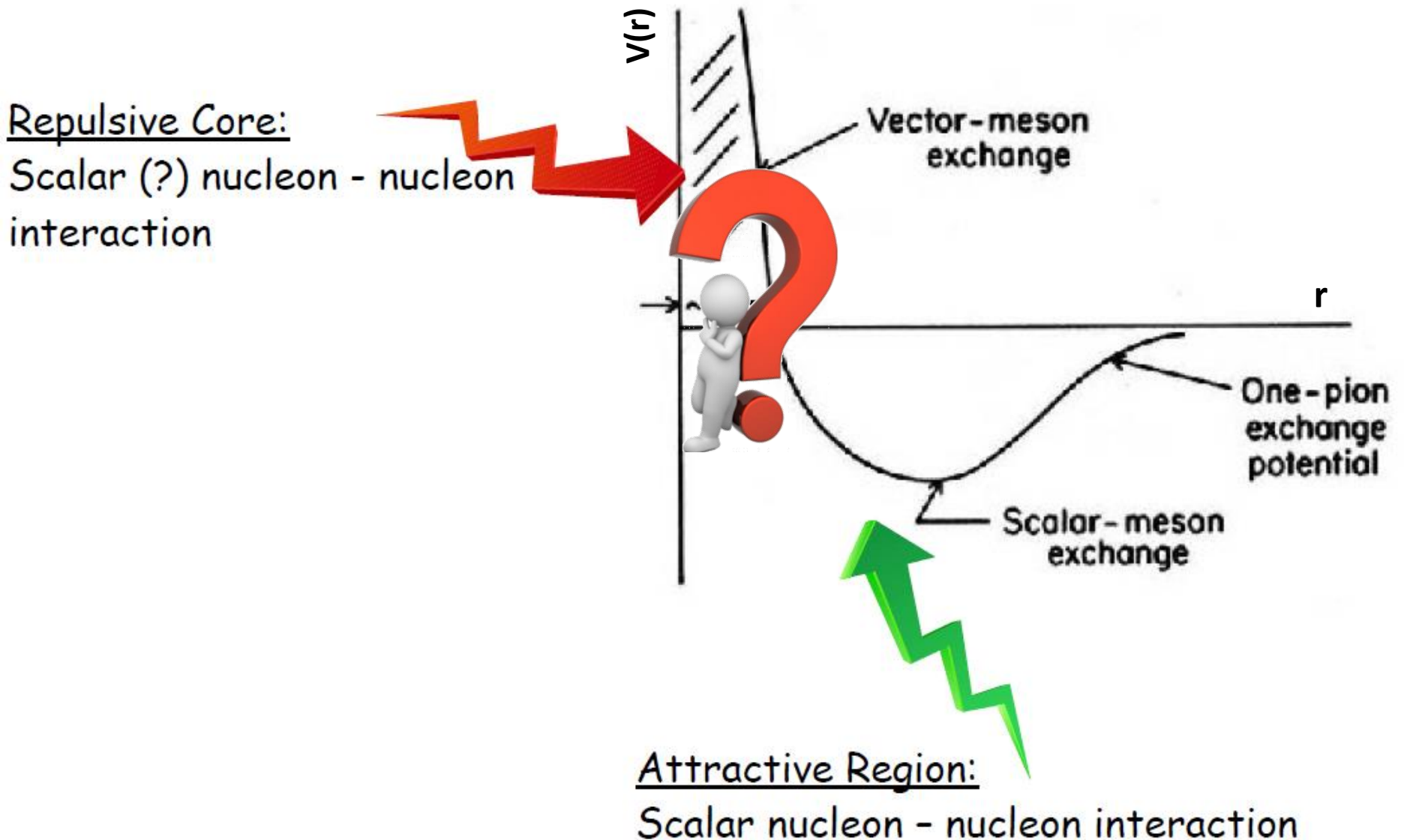
2N – Short Range Correlation (SRC)

A pair with:

Large relative momentum ($k_{rel} > k_F$)
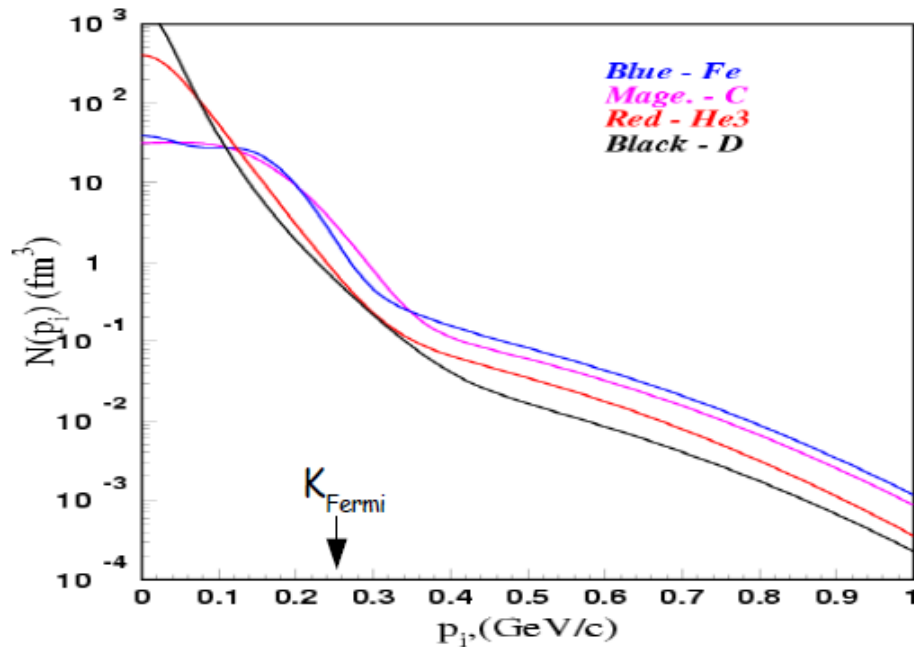
Small C.M. momentum ($k_{CM} < k_F$)

2N-SRC

~1 fm

1.7 fm

Nucleons

$\rho_o = 0.16$ GeV/fm^3

In momentum space:

$\vec{k}_1$

$\vec{k}_2$

$k_1 > k_F \quad k_2 > k_F \quad k_1 \simeq k_2$
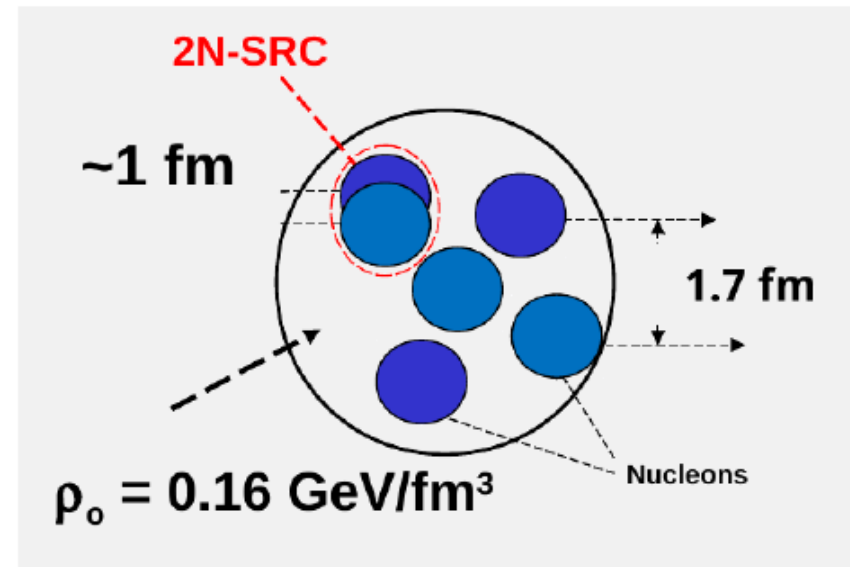
Scaling at high momentum region

Blue - Fe
Mage. - C
Red - He3
Black - D

K_{Fermi}

$N(p_i)$ (fm³)

P_i,(GeV/c)

C. Ciofi, S. Simula, Phys. Rev. C 53, 1689 (1996)

• **High momentum distributions of all nuclei have the same shape.**

• **Momentum distribution similar to momentum distribution in Deuteron**

$$n_A(k) = a_2(A, Z) \cdot n_2(k)$$
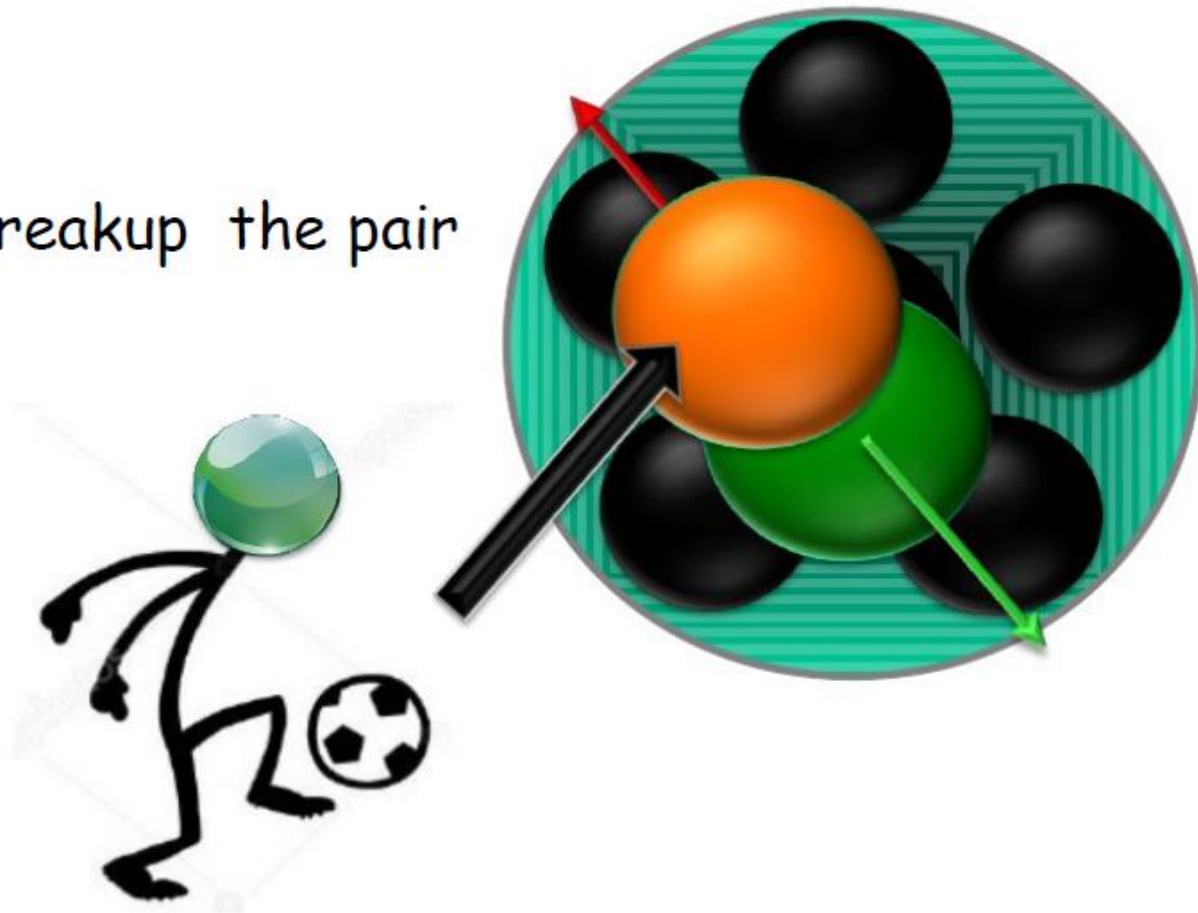
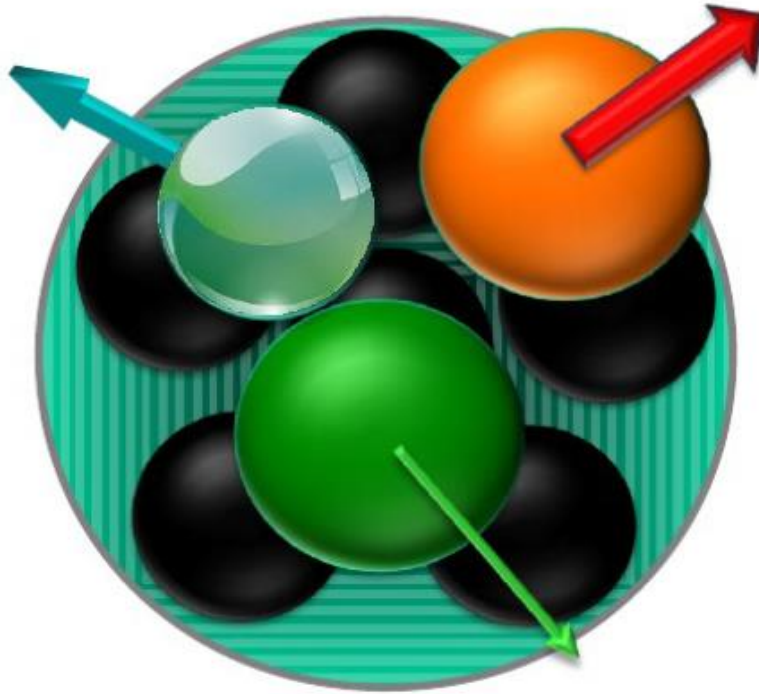$$for \quad k > k_{Fermi}$$

Scaling

Short range physics is concentrated in the

two body system (2N-SRC).

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Triple Coincidence Measurement
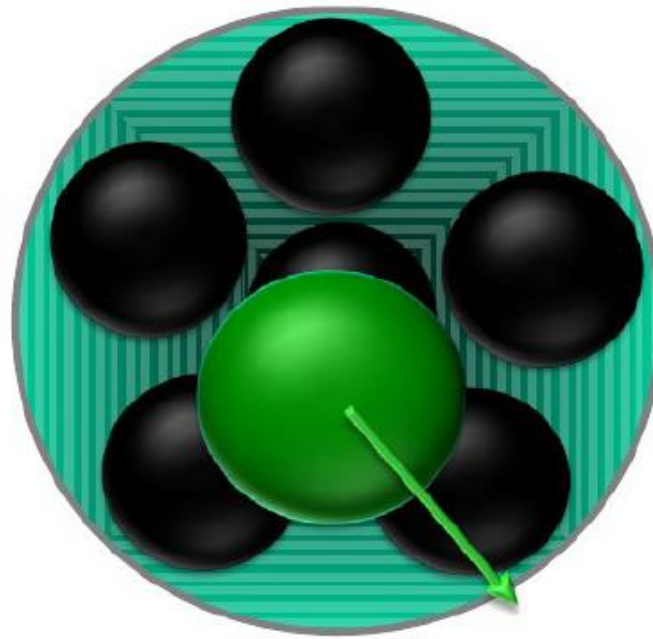
Breakup the pair

Triple Coincidence Measurement
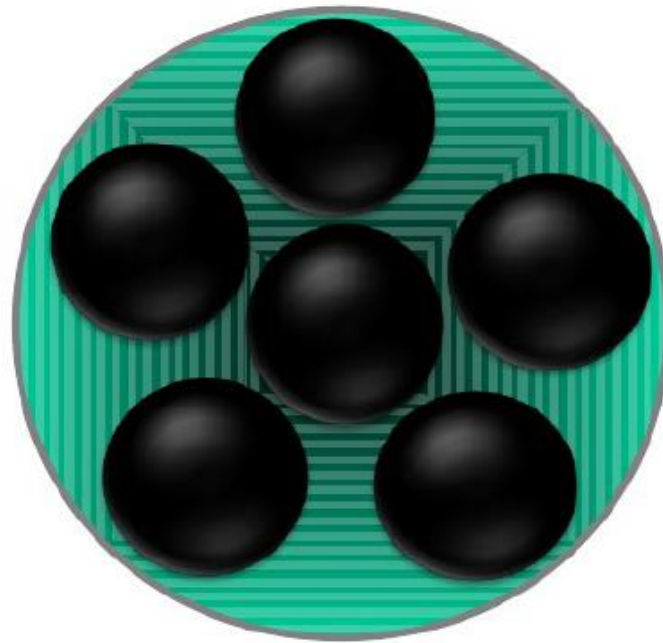
Triple Coincidence Measurement

Detect knockout nucleon

Detect Scattered Projectile

Triple Coincidence Measurement

Detect knockout nucleon
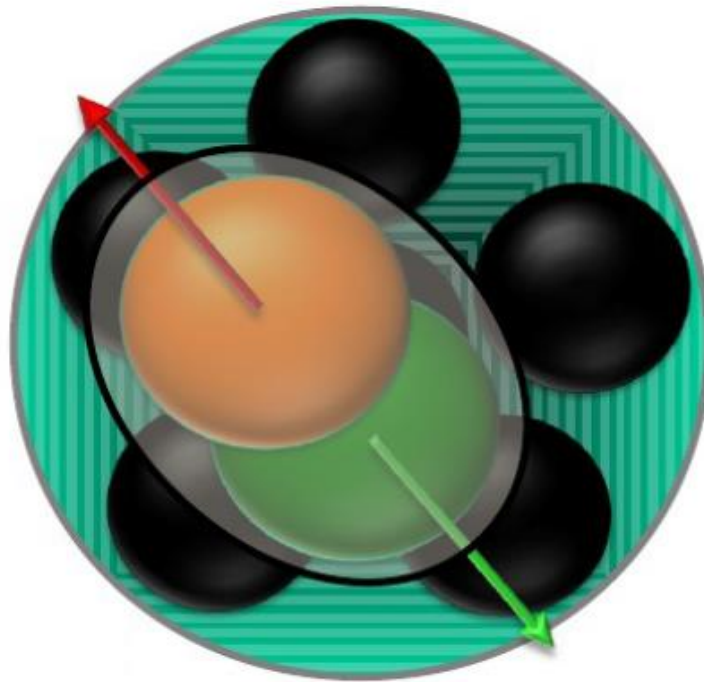
Detect Scattered Projectile

Look for Recoiling partner

Triple Coincidence Measurement

Reconstruct the 'initial' state

Detect knockout nucleon
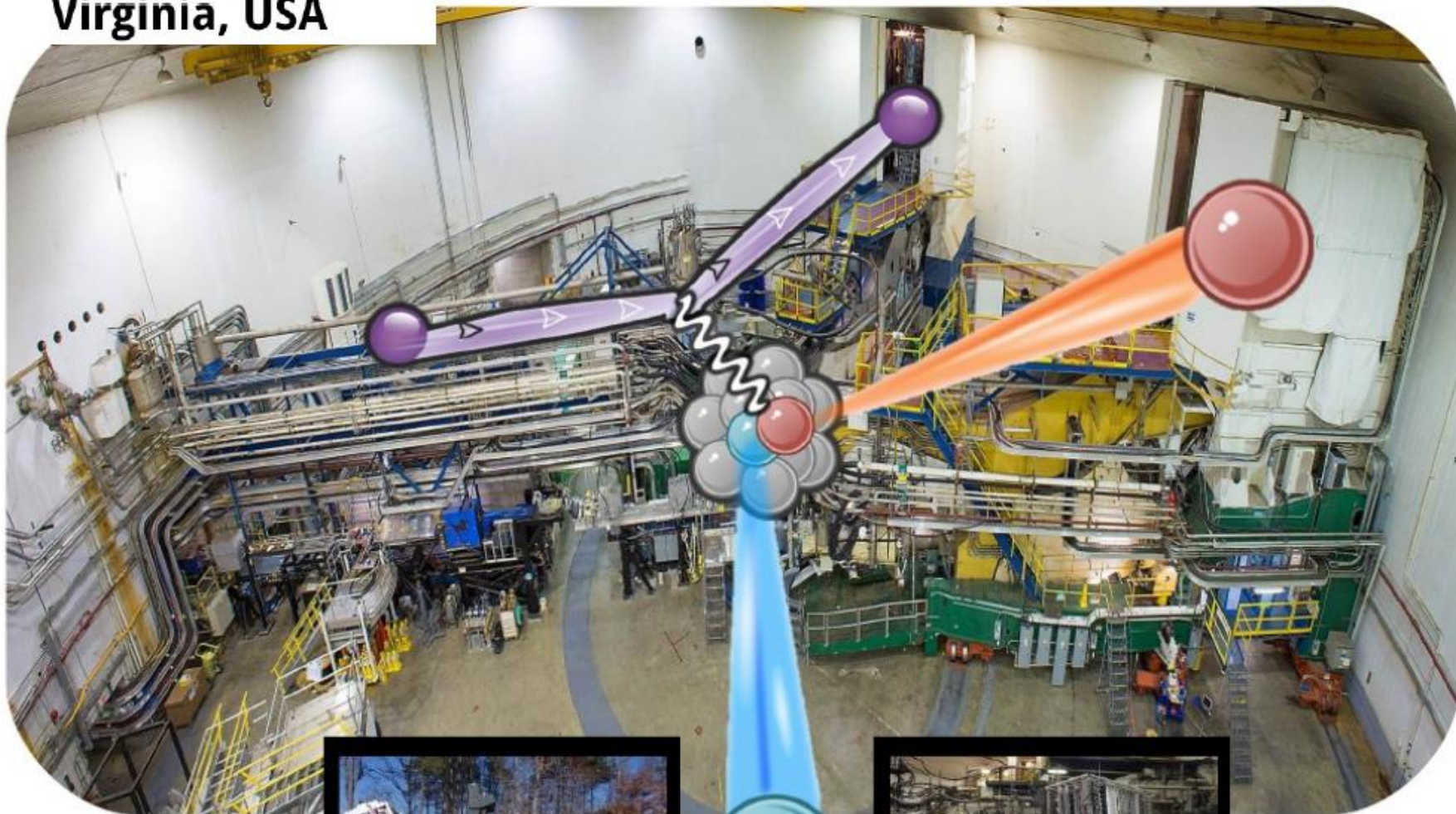
Detect Scattered Projectile

Look for Recoiling partner

Jefferson Lab
Virginia, USA

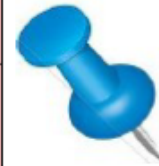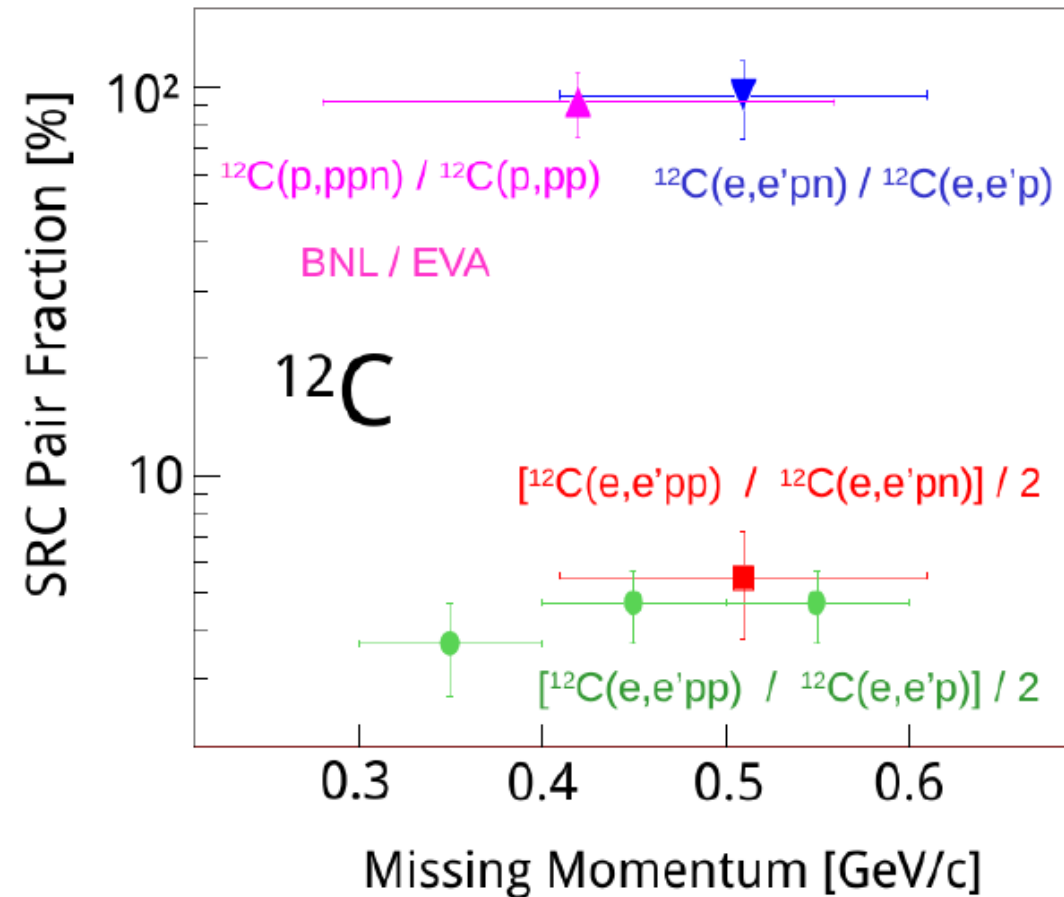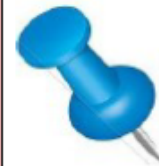Hall A: High Resolution Spectrometers

BigBite Spectrometer

Neutron Detector

What we measured:

High momentum tail is dominated by SRC pairs

np – Dominance:
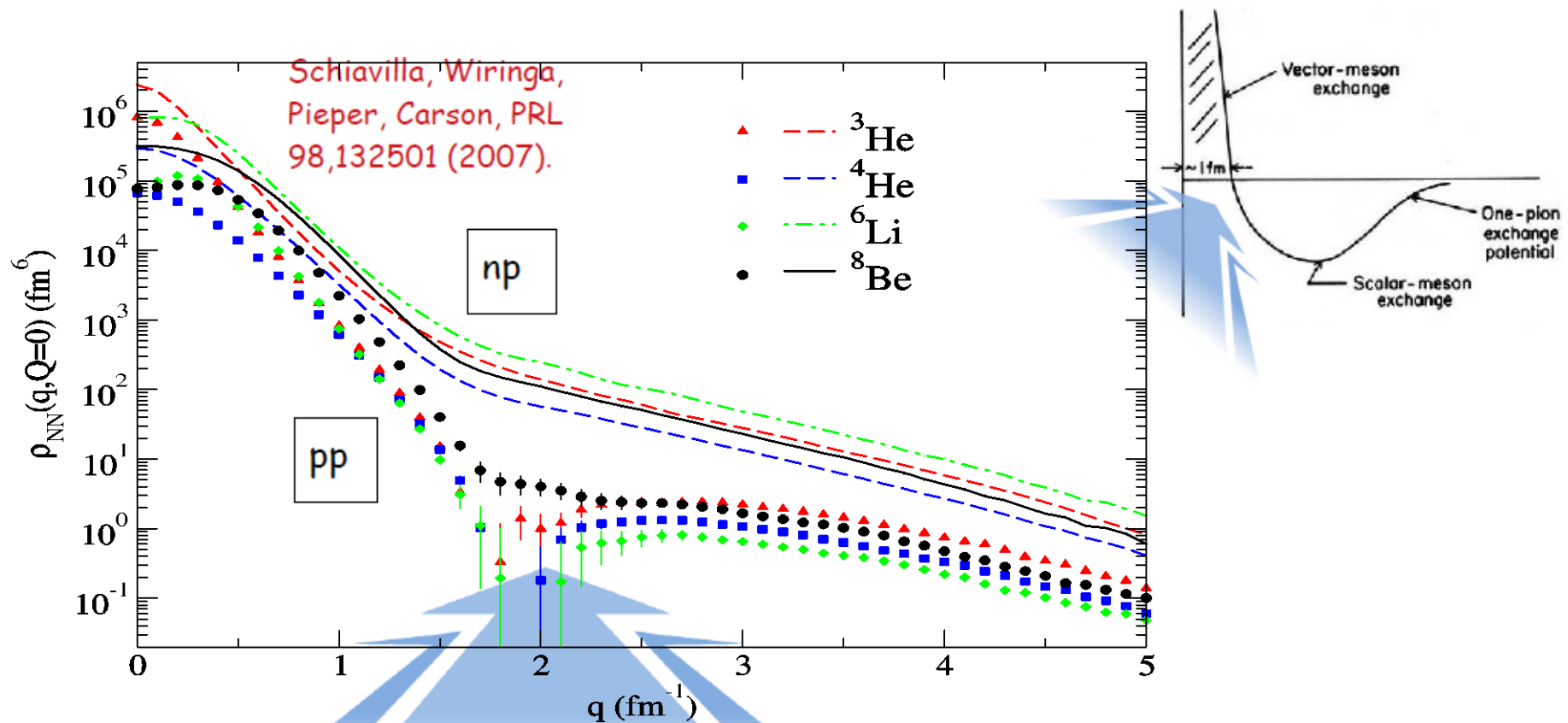
~90% np pairs
~5% pp (nn) pairs

Probing particle independence

Piasetzky et al., PRL. 97 (2006) 162504

Subedi et al., Science 320 (2008)

Shneor et al., Phys.Rev.Lett. 99 (2007) 072501

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Schiavilla, Wiringa, Pieper, Carson, PRL 98,132501 (2007).

Region dominated by Tensor part of nucleon-nucleon interaction
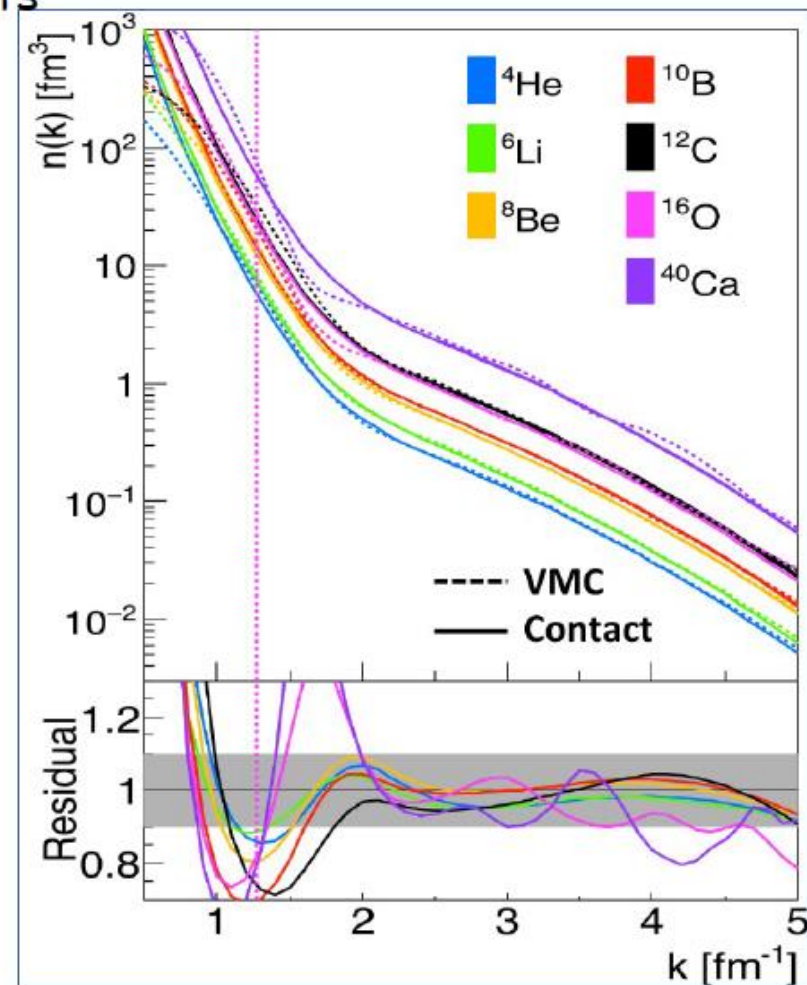
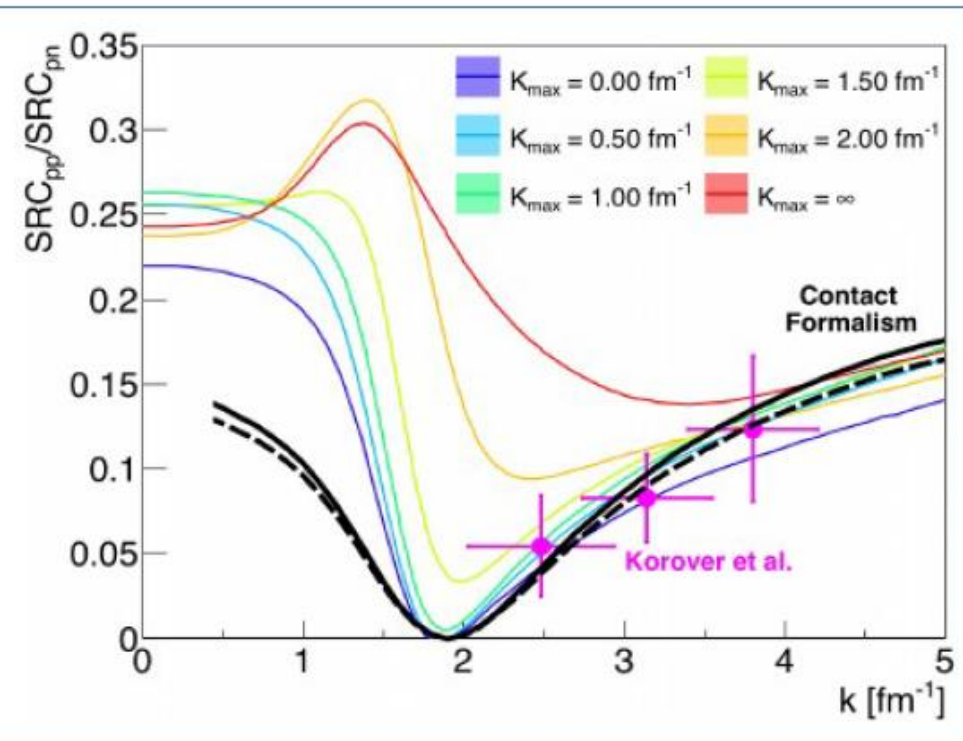Preferred spin = 1
Pairs in S or D state

Pauli principle

Many more np-SRC pairs (Deuteron like)

The nuclear Contact Formalism is an effective theory
that describes SRC by combining universal asymptotic
wavefunctions with nucleus-dependent constants

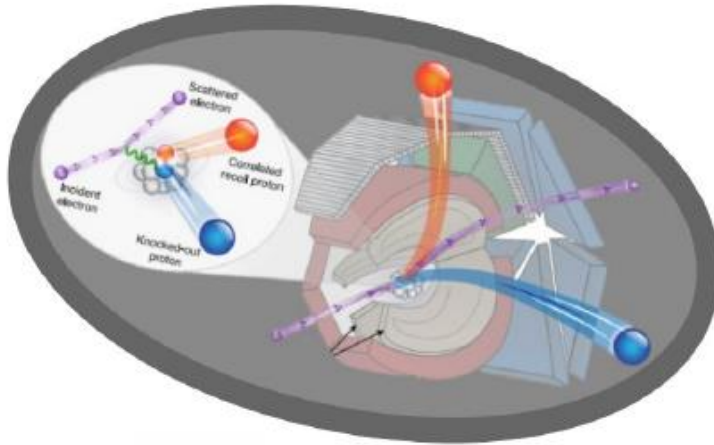$$\tilde{\rho}_2^{pp} = C_{pp}^{s=0} \left| \tilde{\varphi}_{pp}^{s=0}(k) \right|^2$$

$$\tilde{\rho}_2^{pn} = C_{pn}^{s=0} \left| \tilde{\varphi}_{pn}^{s=0}(k) \right|^2 + C_{pn}^{s=1} \left| \tilde{\varphi}_{pn}^{s=1}(k) \right|^2$$

- Weiss & Cruz-Torres et al.,
Phys.Lett. B780, 211 (2018)
- Wiringa et al., PRC 89, 024305 (2014)

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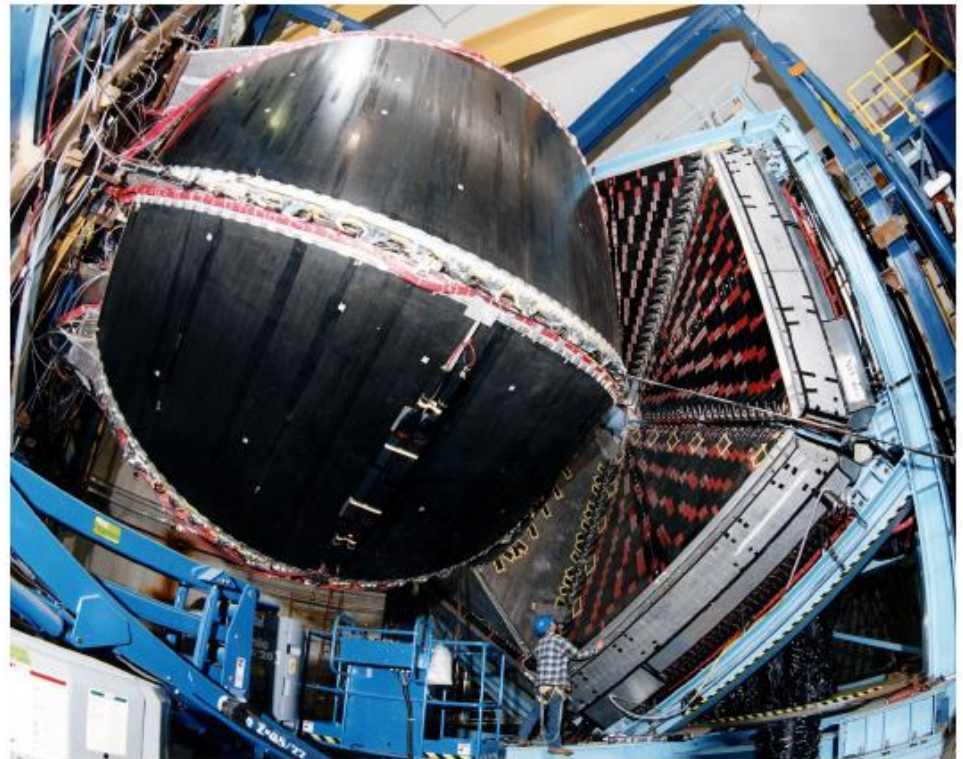**C**EBAF **L**arge **A**cceptance **S**pectrometer

Jefferson Lab

Virginia, USA

- Open (e,e'p) trigger
- Large Acceptance
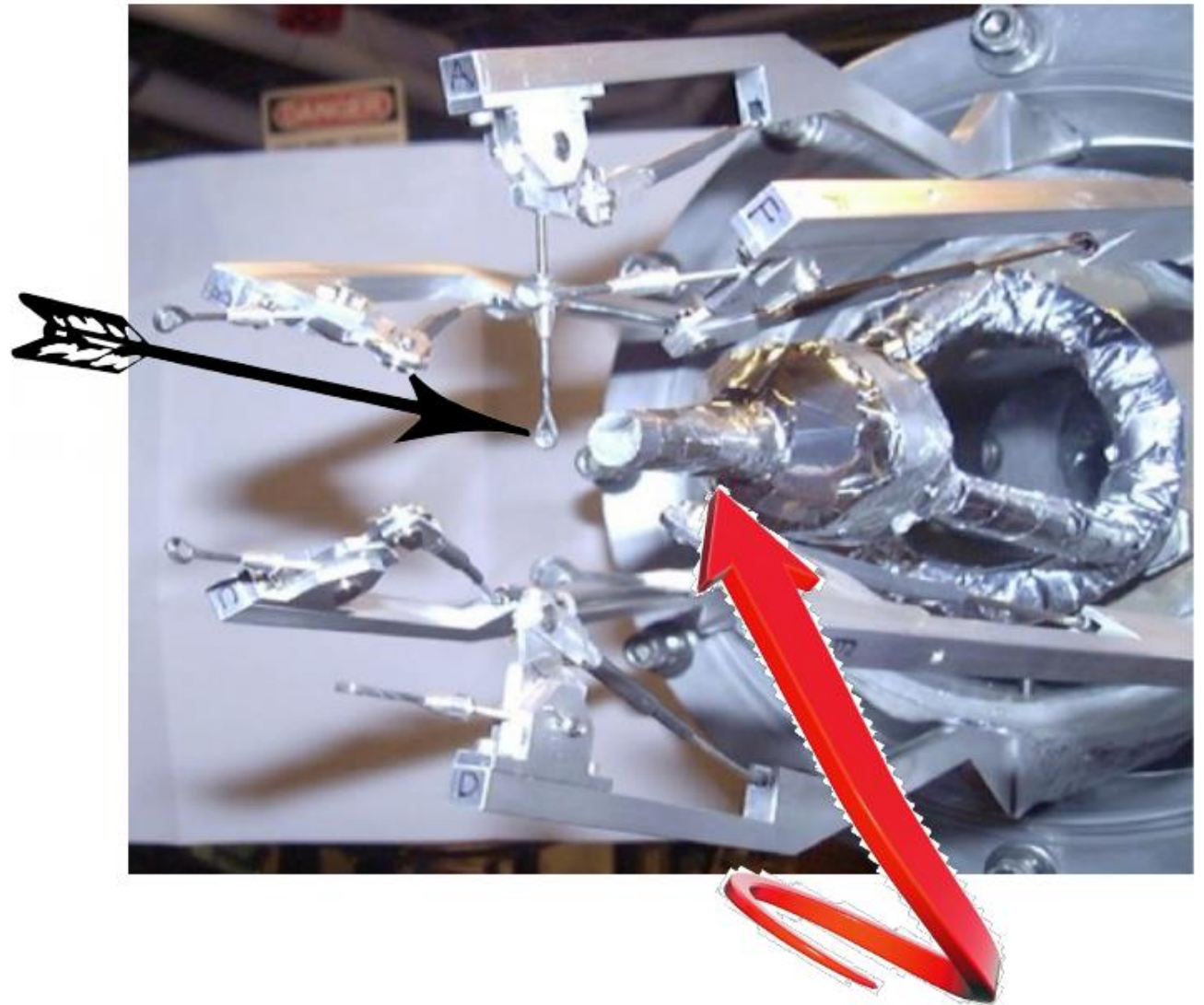- Low luminosity (~10^{34} cm^{-2} sec^{-1})
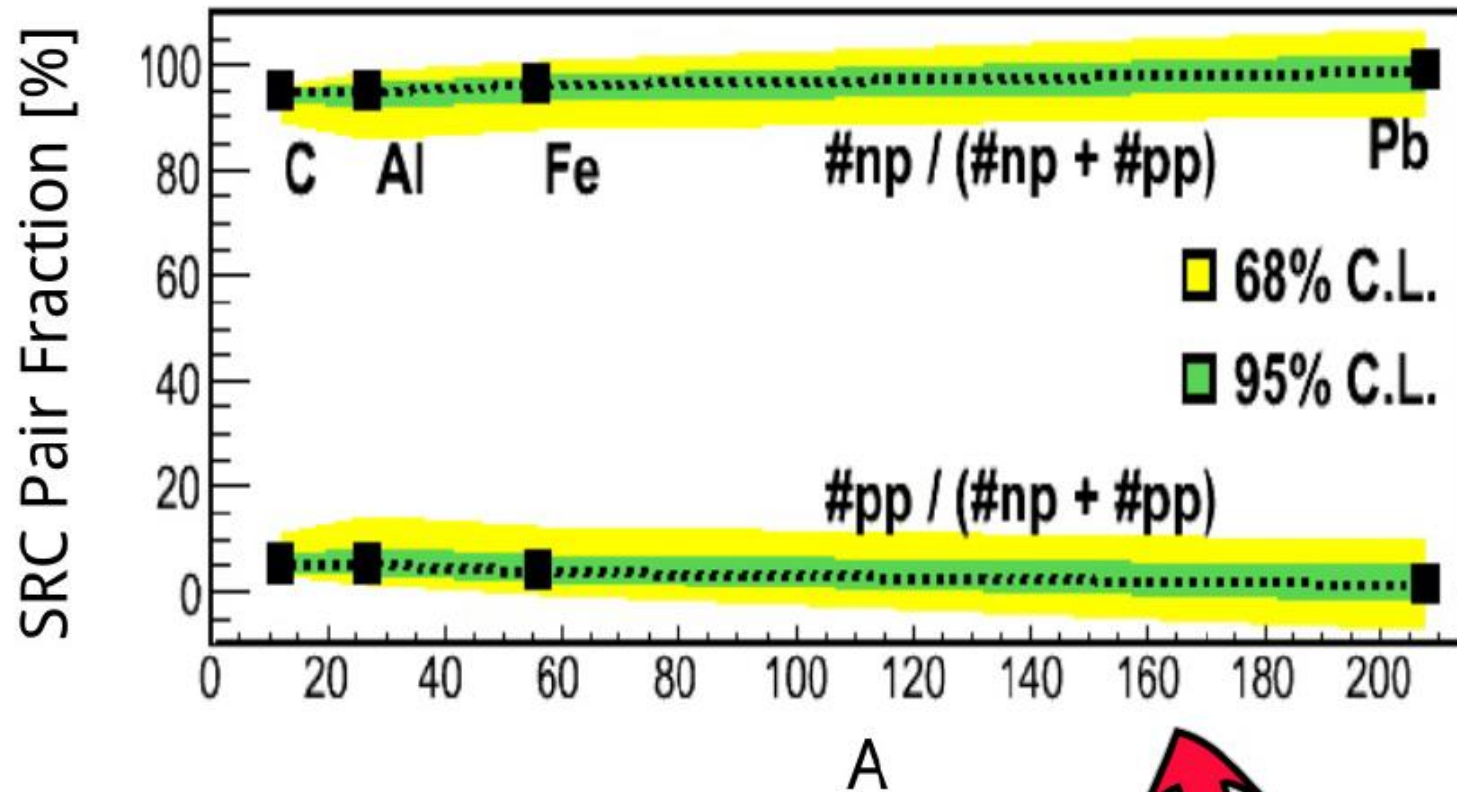
Target cell setup

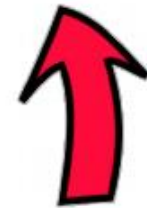Solid Targets:
→ ^{12}C
→ ^{27}Al
→ ^{56}Fe
→ ^{208}Pb

Liquid Deuterium cell

Universality of np-dominance, from light to heavy

SRC Pair Fraction [%] vs A

C   Al   Fe   #np / (#np + #pp)   Pb

□ 68% C.L.
□ 95% C.L.

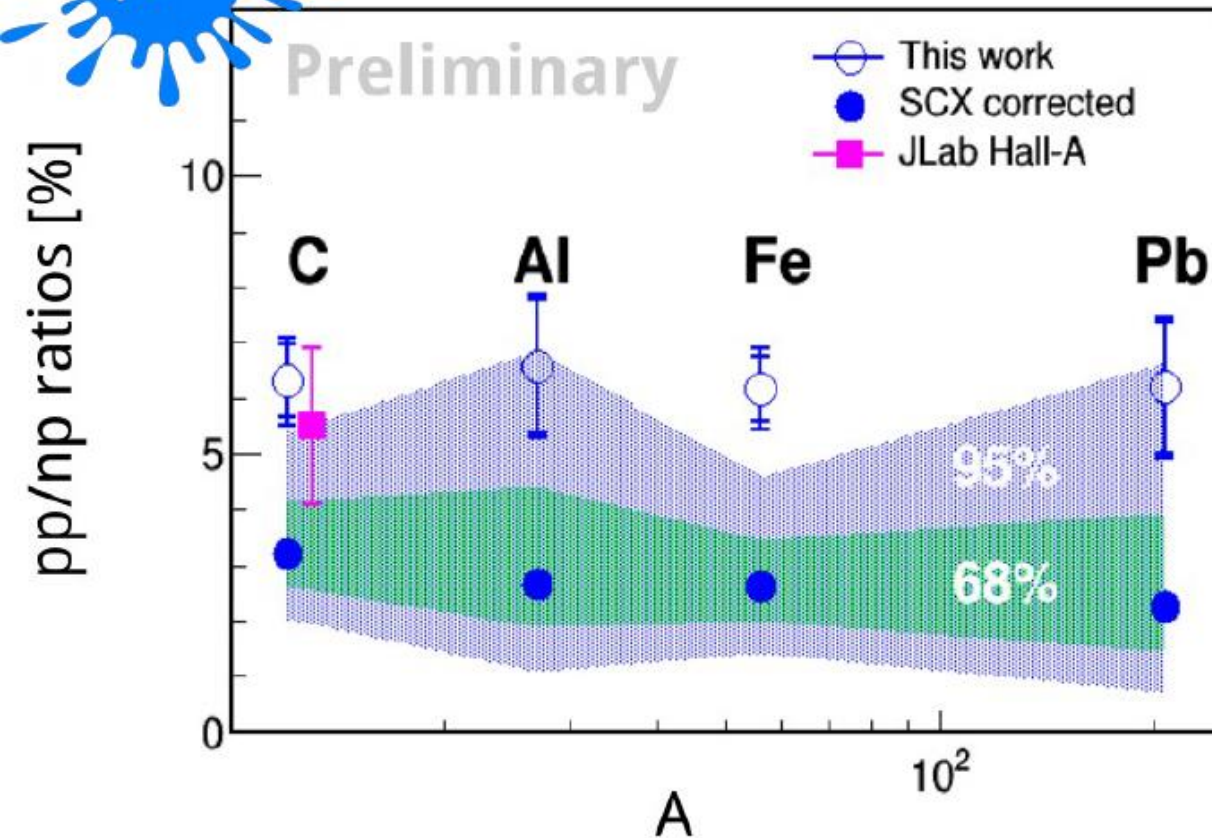#pp / (#np + #pp)

Hen *et al.*, Science 346 (2014) 614-617
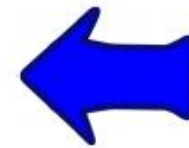
Inferred from
(e,e'p) and (e,e'pp)
measurements

Assuming every (e,e'p) event
With high momentum
has a correlated partner

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Universality of np dominance, from light to heavy
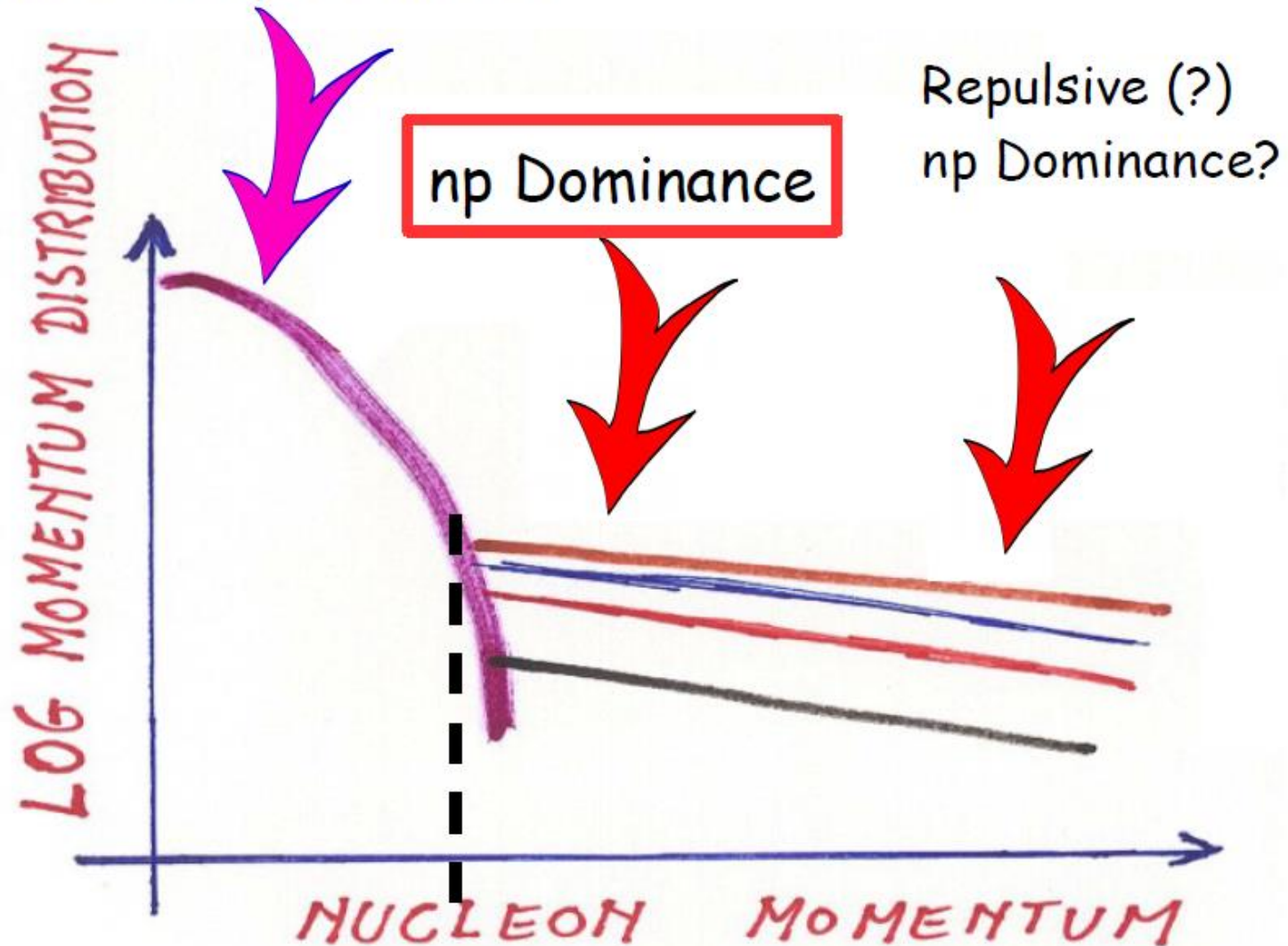

np- and pp- pairs
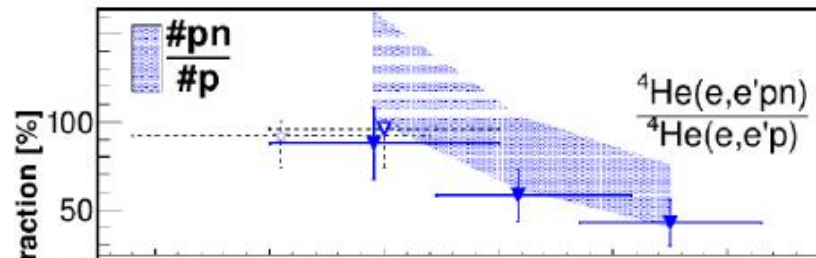where measured

- Upper limit: pp/pn < ~6%

- No A-dependence
- No neutron excess dependence

M. Duer et al.   arXiv:1810.05343

Mean Field - no np Dominance

np Dominance

Repulsive (?) np Dominance?

LOG MOMENTUM DISTRIBUTION

NUCLEON MOMENTUM

And beyond...

A (e,e'pp) / (e,e'p) [C, Al, Fe, Pb]

Contact +
AV18+UIX [VMC]

Preliminary

NEW!

np-dominance decrease with momentum increase
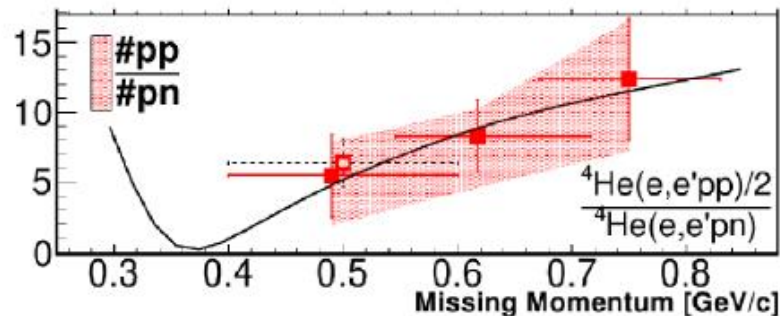
$\frac{^{4}He(e,e'pn)}{^{4}He(e,e'p)}$

$\frac{^{4}He(e,e'pp)/2}{^{4}He(e,e'pn)}$

Korover et al., PRL (2014)

Preliminary

22
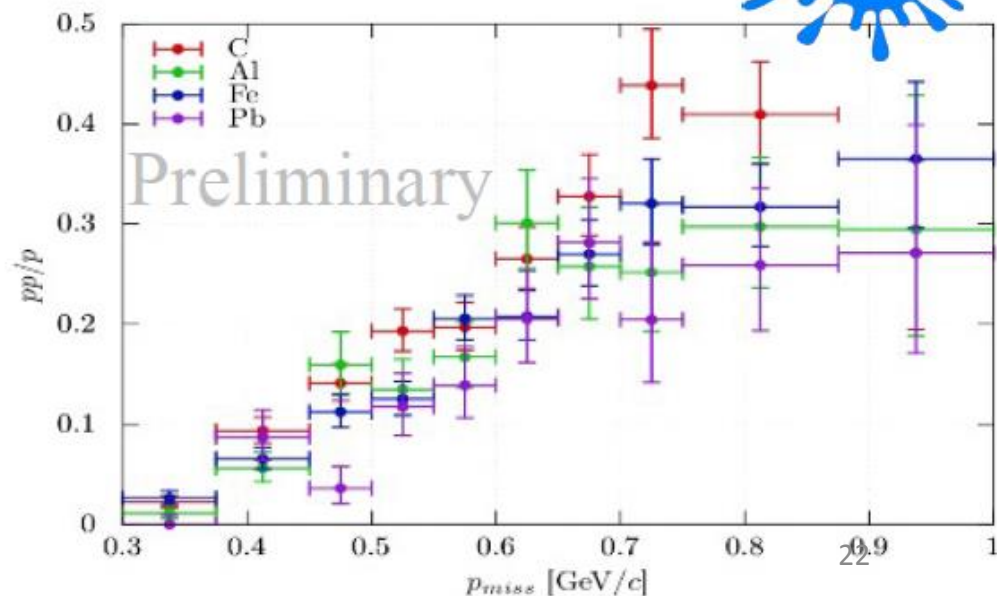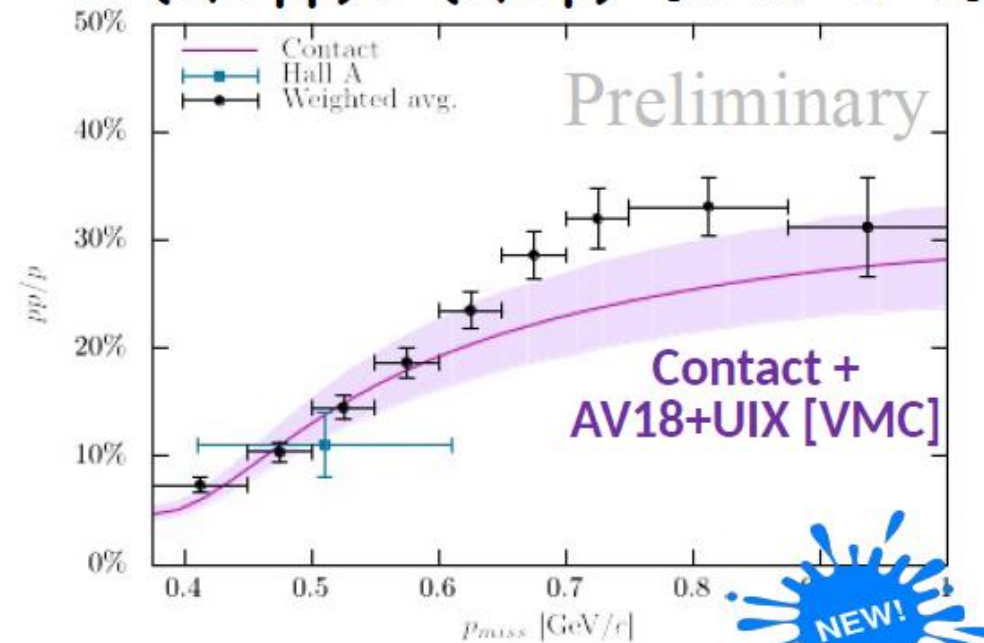
Residual A-2 system is a spectator
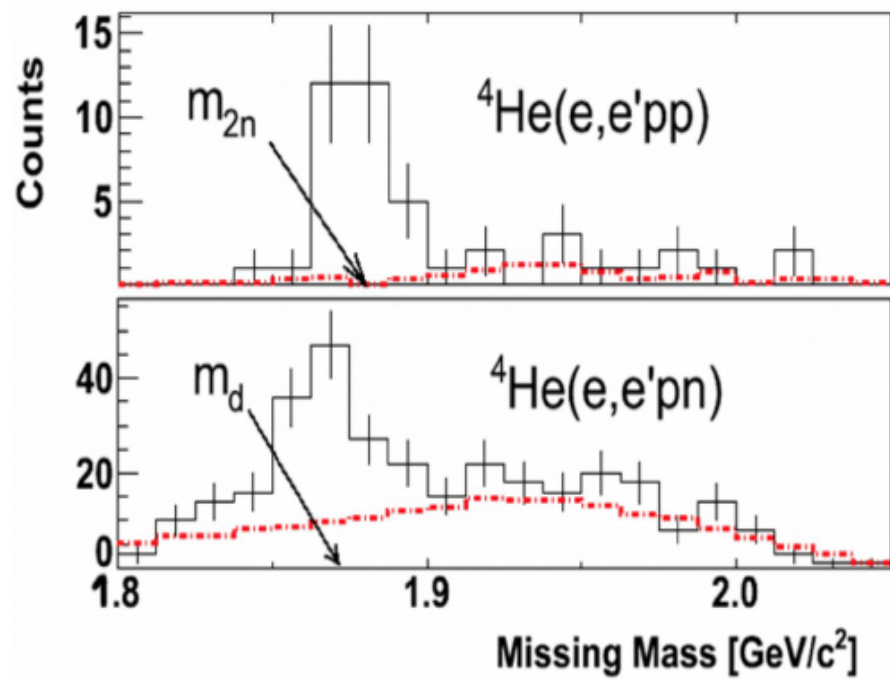
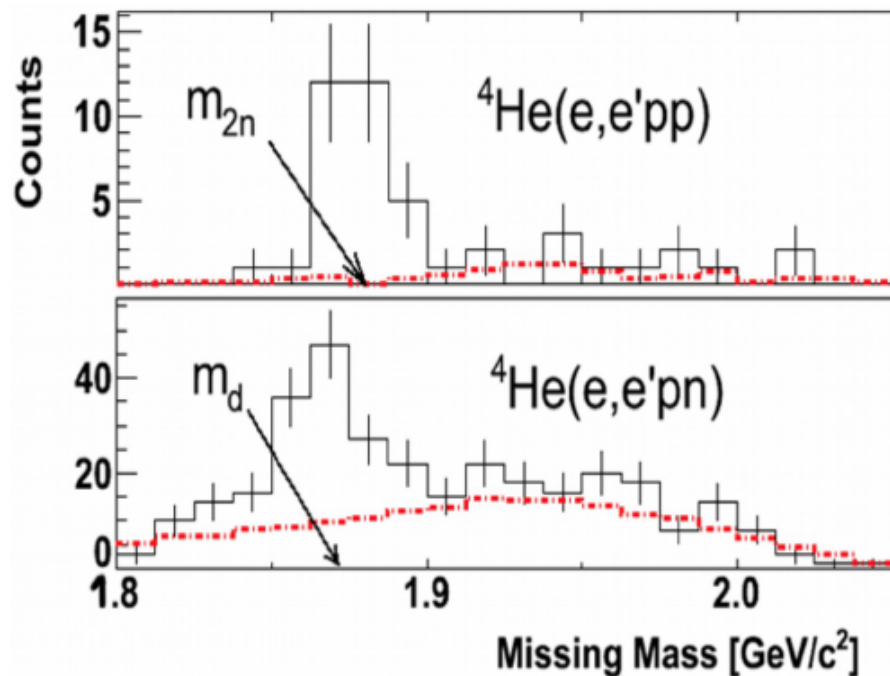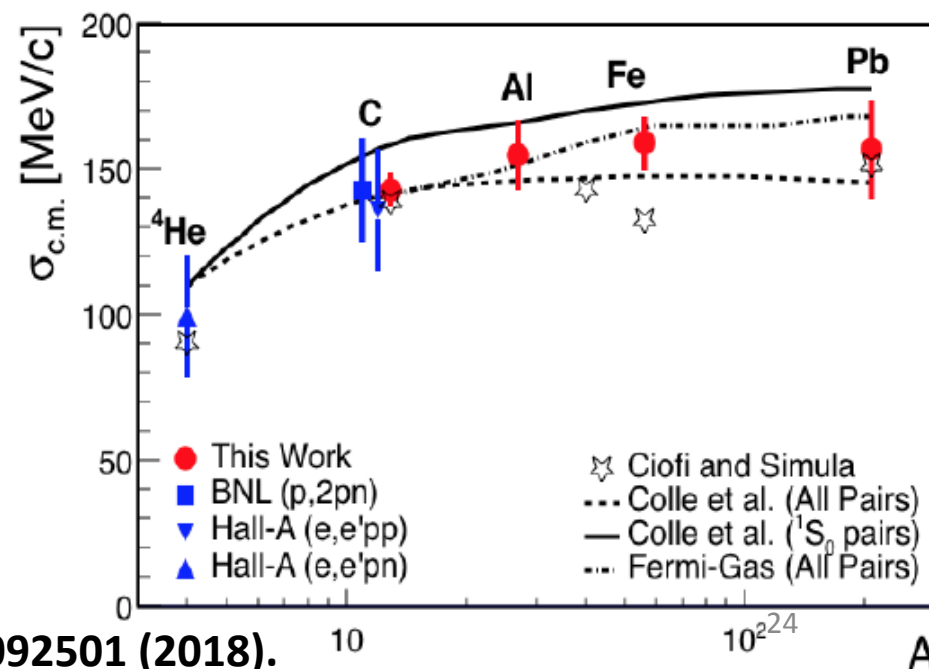Korover et al., PRL (2014)

Residual A-2 system is a spectator
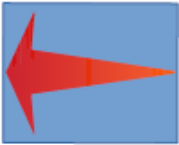

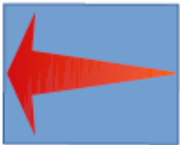Korover et al., PRL (2014)
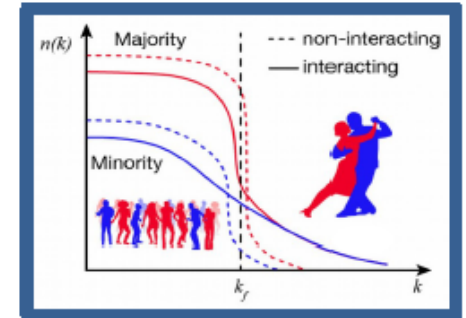
Low CM momentum of the 2N-SRC pair

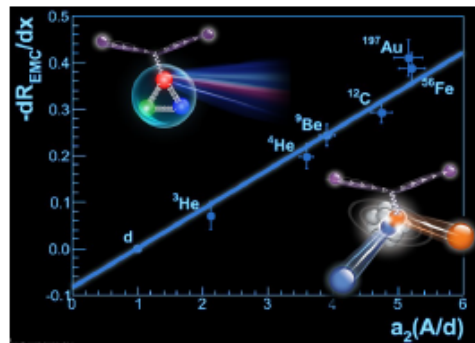**E. Cohen *et al.*,
Phys Rev. Lett. 121, 092501 (2018).**

Consequences of SRC pairs and np dominance:

Kinetic energy distribution of nucleons in asymmetric nuclei.

Nucleon structure modification in the medium.

See Eli's talk
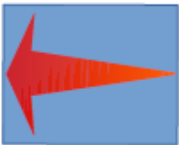
Implications to other phenomena ranging from nuclear structure to neutron stars.

Kinetic energy distribution of nucleons in asymmetric nuclei: N>Z.

Pauli principle

SRC (np-dominance)

$$\langle E_n^{kin} \rangle > \langle E_p^{kin} \rangle$$

$$\langle E_p^{kin} \rangle \overset{?}{>} \langle E_n^{kin} \rangle$$

$$\langle E_{p(n)}^{kin} \rangle = \int n_{p(n)} \cdot \frac{k^2}{2m} \cdot d^3 k$$

n(K)

neutrons
protons

$\propto n_d(k)$

~K$_F$

K

Inversion of the momentum sharing:

Protons move faster than **neutrons**

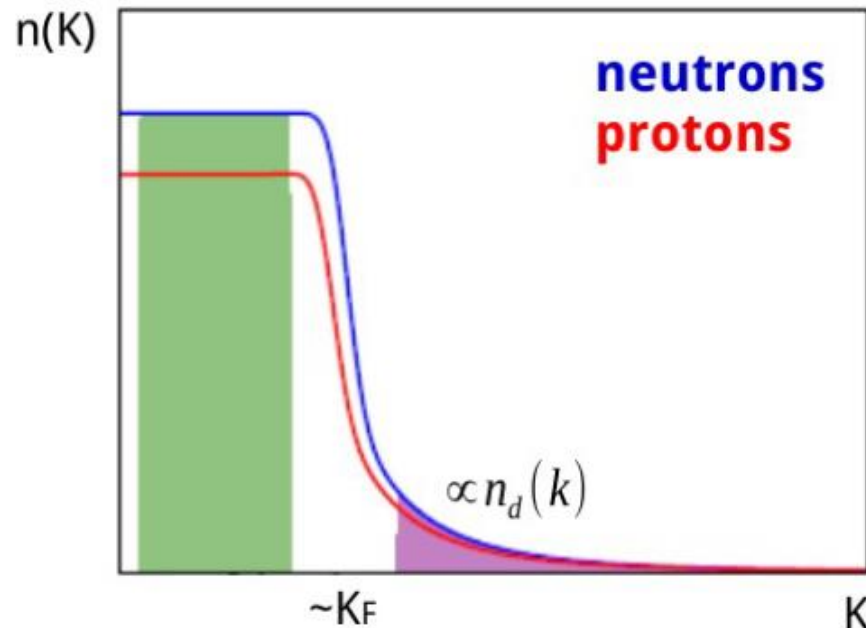$$\langle E_p^{kin} \rangle \; > \; \langle E_n^{kin} \rangle$$

Simple np-dominance model

$$n_p(k) = \begin{cases} \eta \cdot n_p^{M.F.}(k) & k < k_0 \\ \frac{A}{2Z} \cdot a_2(A/d) \cdot n_d(k) & k > k_0 \end{cases}$$

(for neutrons: $Z \rightarrow N$)

Duer *et al.*, Nature 560 (2018), 617-621
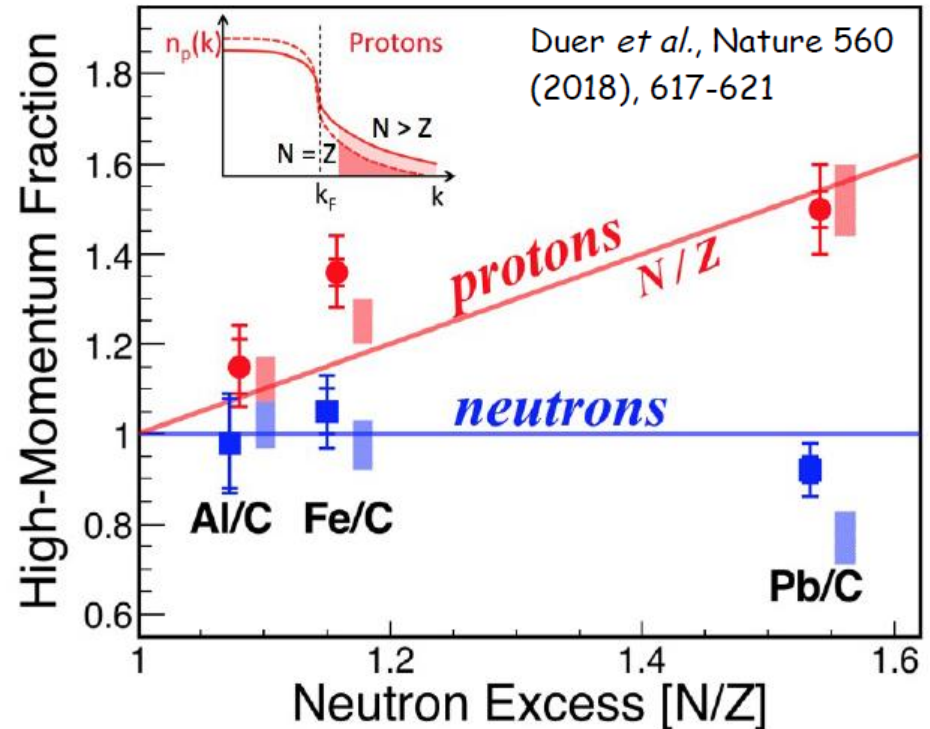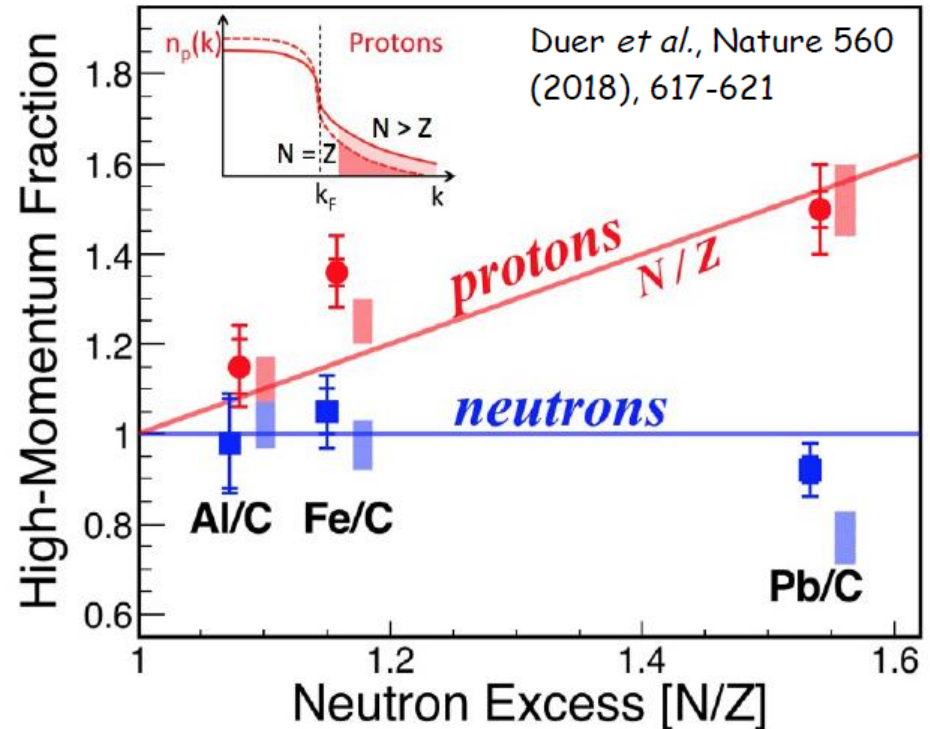
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(for neutrons: $Z \rightarrow N$)

Duer *et al.*, Nature 560 (2018), 617-621

High-Momentum Fraction

Neutron Excess [N/Z]

$\langle E_p^{kin} \rangle > \langle E_n^{kin} \rangle$

prediction

^{12}C ^{27}Al ^{56}Fe ^{208}Pb

Neutron Excess [N/Z]

Dedicated Few Body Experiment: JLab, Hall A: E12-14-001 (2018)

NEW!

Spectral Function
- CDA & Kaptari
- Benhar & Pandharipande

Momentum Density (VMC)
- AV18+UX
- N^2LO E1 (1.0 fm)
- N^2LO Eτ (1.0 fm)

Preliminary

^{3}He$(e,e'p)$ / ^{3}H $(e,e'p)$

$R_{n(p)}^{measured}$

$|\vec{p}_{miss}|$ [MeV/c]

Dedicated Few Body Experiment: JLab, Hall A: E12-14-001 (2018)

Spectral Function
- - - CDA & Kaptari
- - - Benhar & Pandharipande

Momentum Density (VMC)
— AV18+UX
— N^2LO E1 (1.0 fm)
— N^2LO Eτ (1.0 fm)

Preliminary

^{3}He(e,e'p) / ^{3}H (e,e'p)
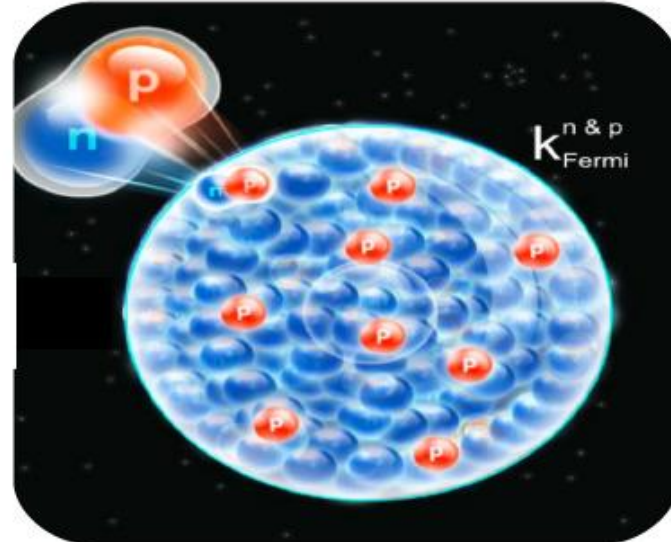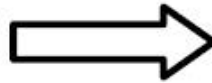
More neutrons → More correlated protons

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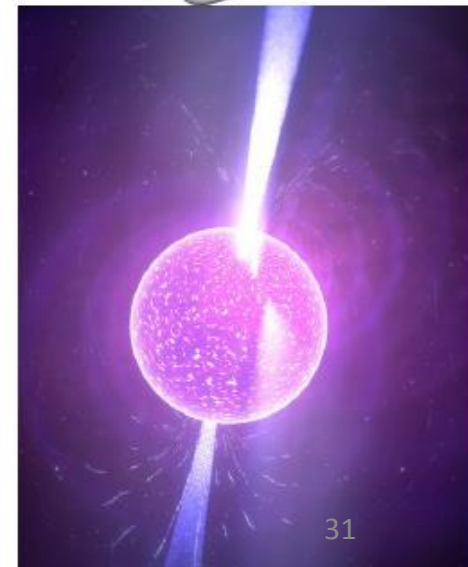
Implication for Neutron Stars
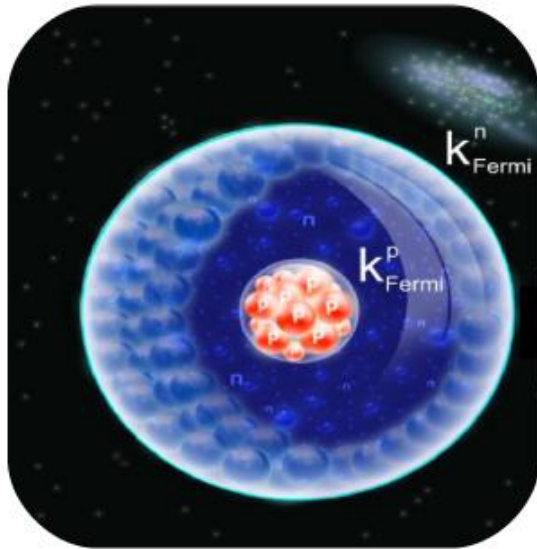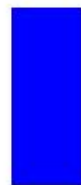

Strong SRC np interaction

The n-gas heats the p-gas

At the core of neutron stars, most accepted models assume:

~95% neutrons, ~5% protons, and ~5% electrons.

Neglecting np-SRC interaction, one can assume 3 separate Fermi gases.

~500 MeV/c

~250 MeV/c

k^n_{Fermi} k^p_{Fermi} k^e_{Fermi}

Summary

- 2N-SRC dominate the high momentum region.

- Study of SRC contribute to understanding NN interaction and high momentum tails in nuclei.

- 2N-SRC can be described by nuclear contact formalism.

- Tensor NN interaction dominate at $1.5K_F$ -$3K_F$ leading to np-dominance.

- np-dominance responsible for changing the momentum sharing between protons and neutrons in asymmetric nuclei, neutron star(?)

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Thank You