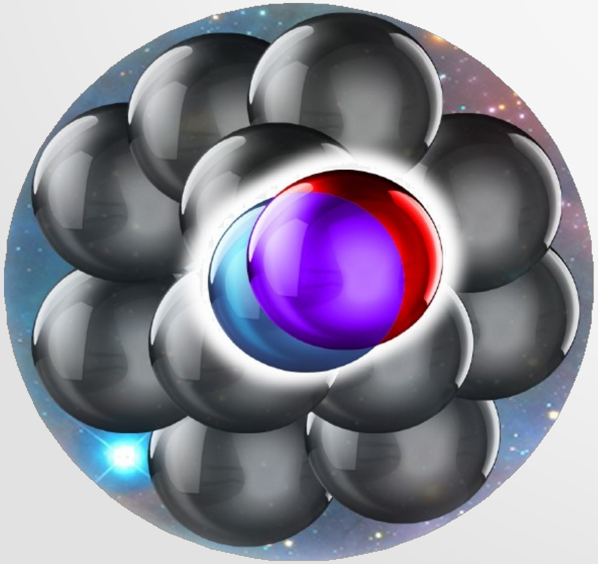
23rd International Spin symposium

Spin, Isospin and the Short Range Nucleon - Nucleon Interaction

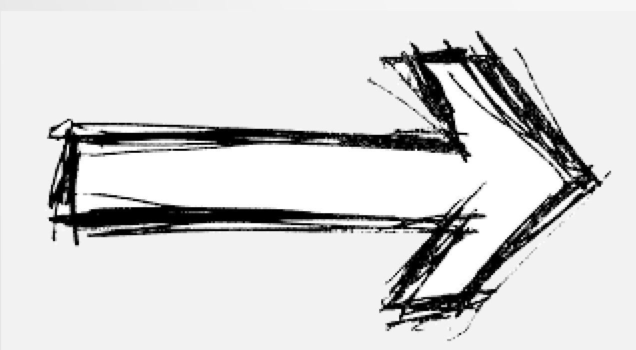


Igor Korover

NRCN, Israel

September 10, Ferrara Italy

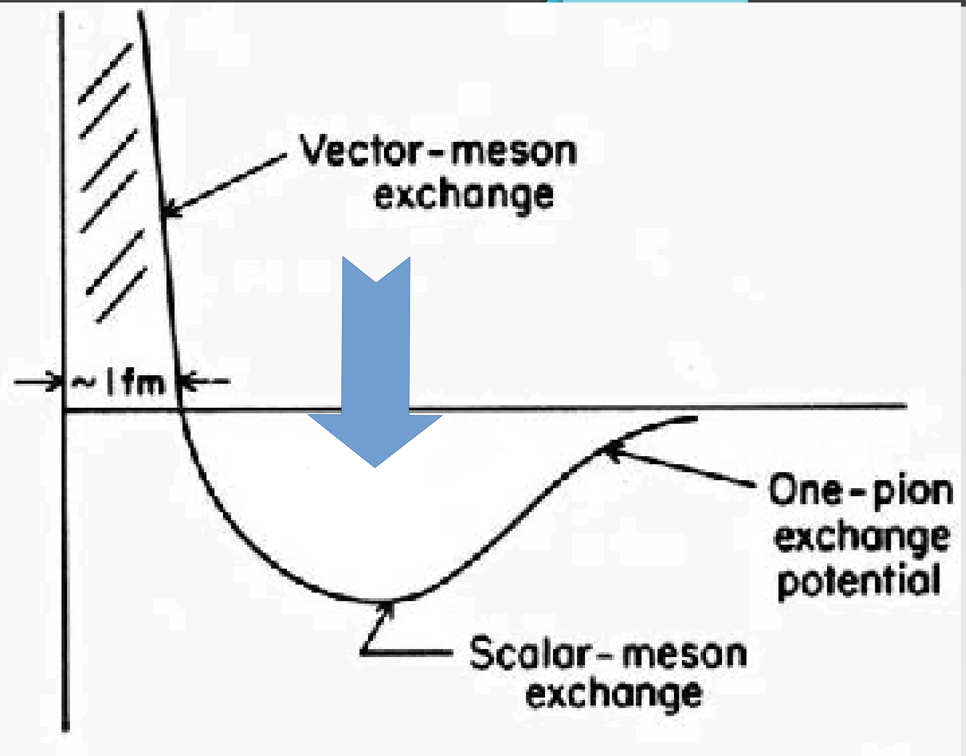
Nucleon - nucleon Interaction is dominated by **SCALAR** interaction



the Nucleon - Nucleon potential is mainly spin and isospin independent

Typical nucleon separation

Attractive

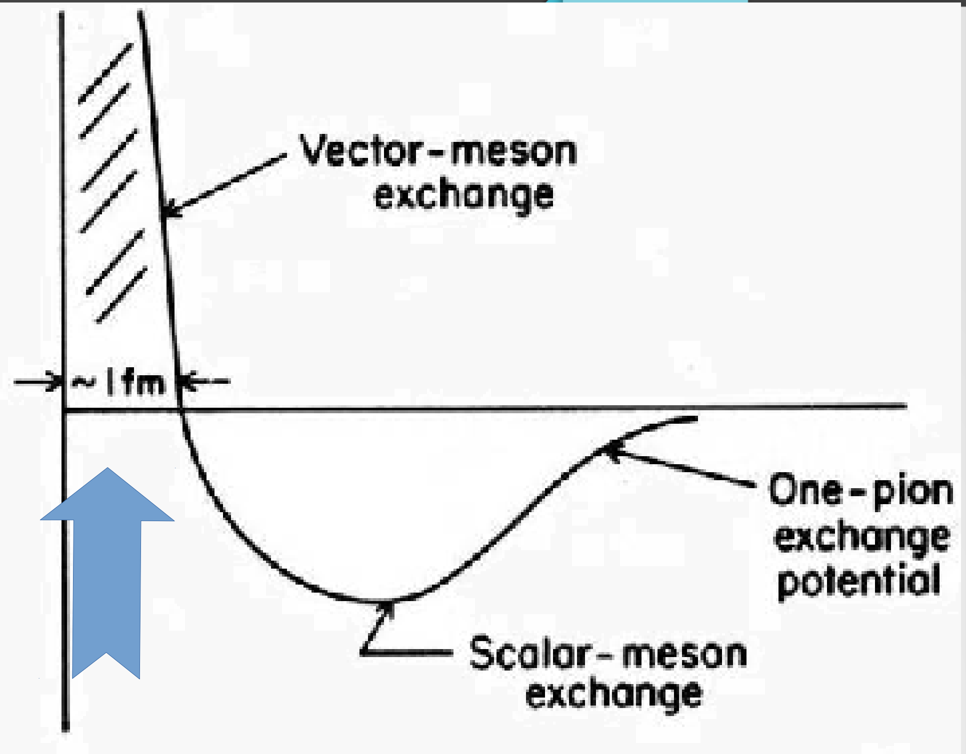


Typical nucleon separation

Attractive

At Short Distances

Repulsive

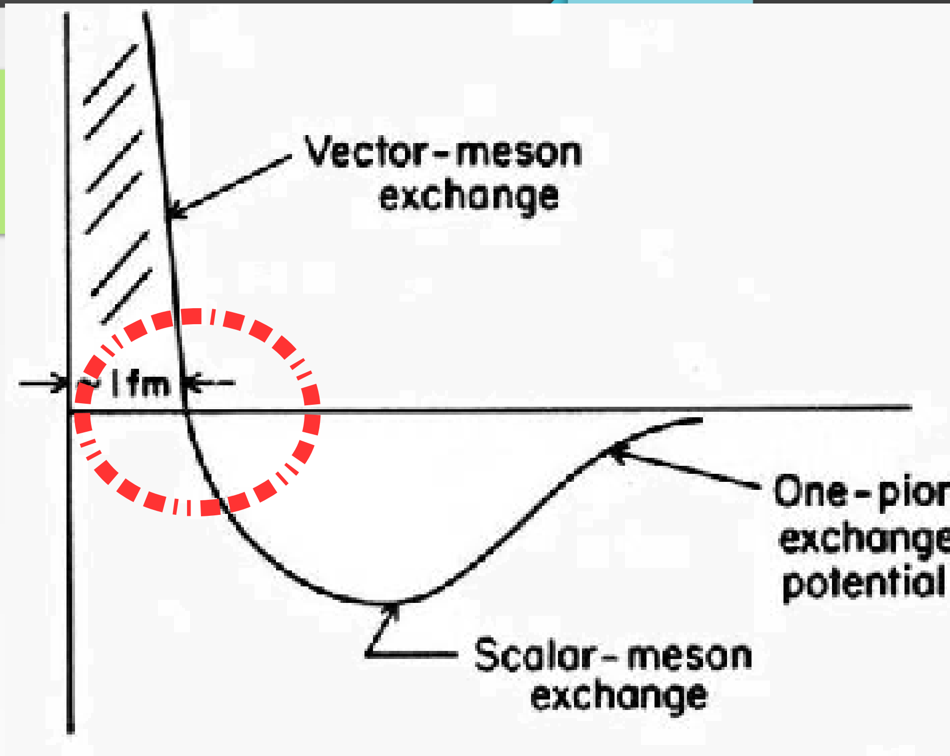


Typical nucleon separation

Attractive

At Short Distances

Repulsive



Scalar → 0

Scalar → 0

Tensor part become important

$$S_{ij}=[\frac{3}{r_{ij}^2}(\vec{\sigma}_i\cdot\vec{r}_{ij})(\vec{\sigma}_j\cdot\vec{r}_{ij})-\vec{\sigma}_i\cdot\vec{\sigma}_j]$$

Tensor part is spin **dependent**

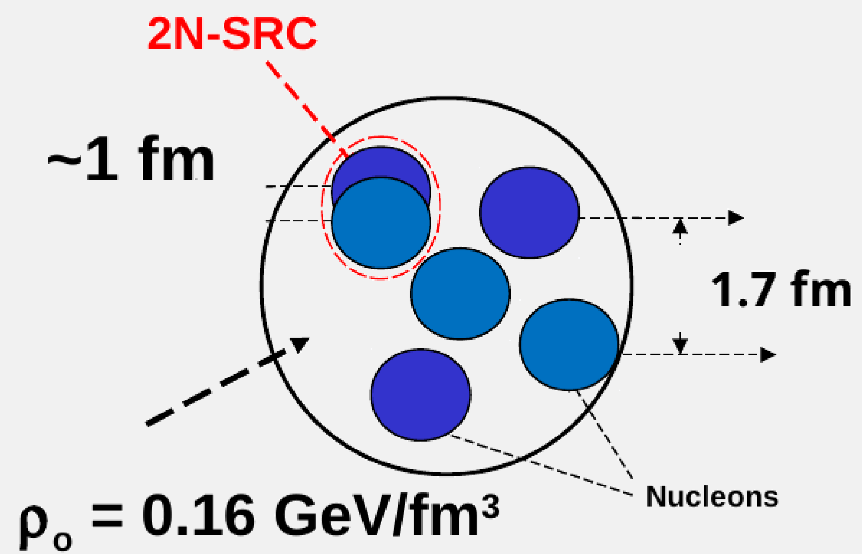
Is it possible to study this part
Experimentally in nuclei and how?

2N - Short Range Correlation (SRC)

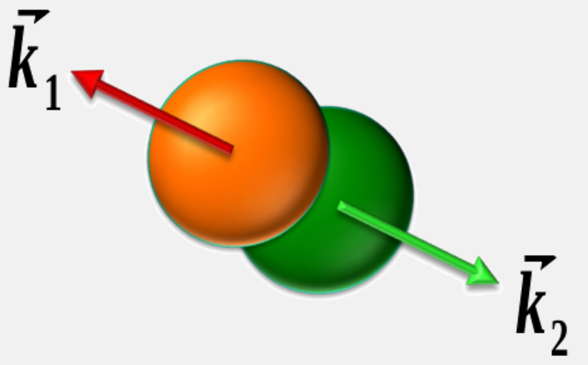
A pair with:

Large relative momentum ($k_{\rm rel} > k_{\rm F}$)

Small C.M. momentum ($k_{CM} < k_F$)



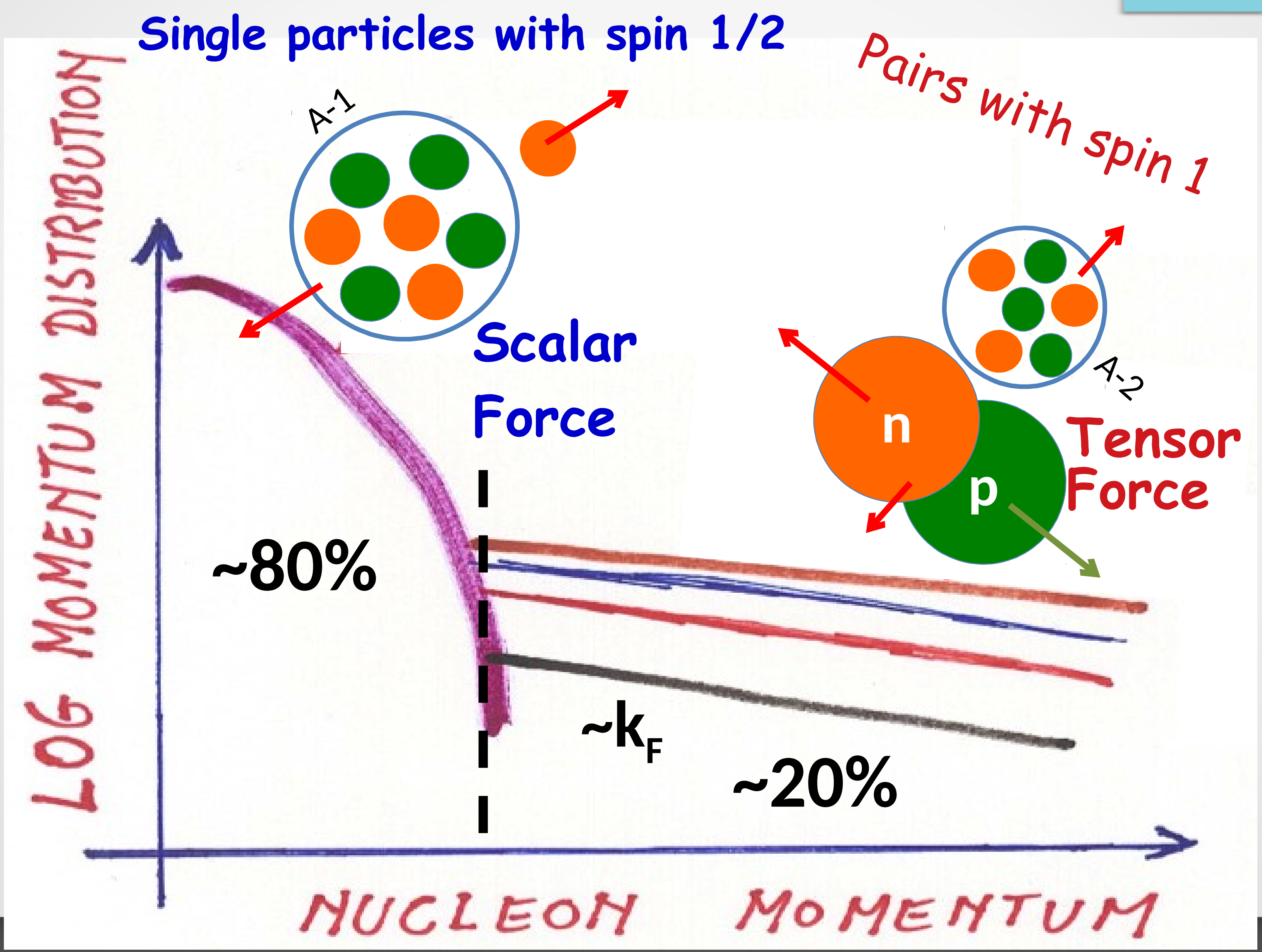
In momentum space:



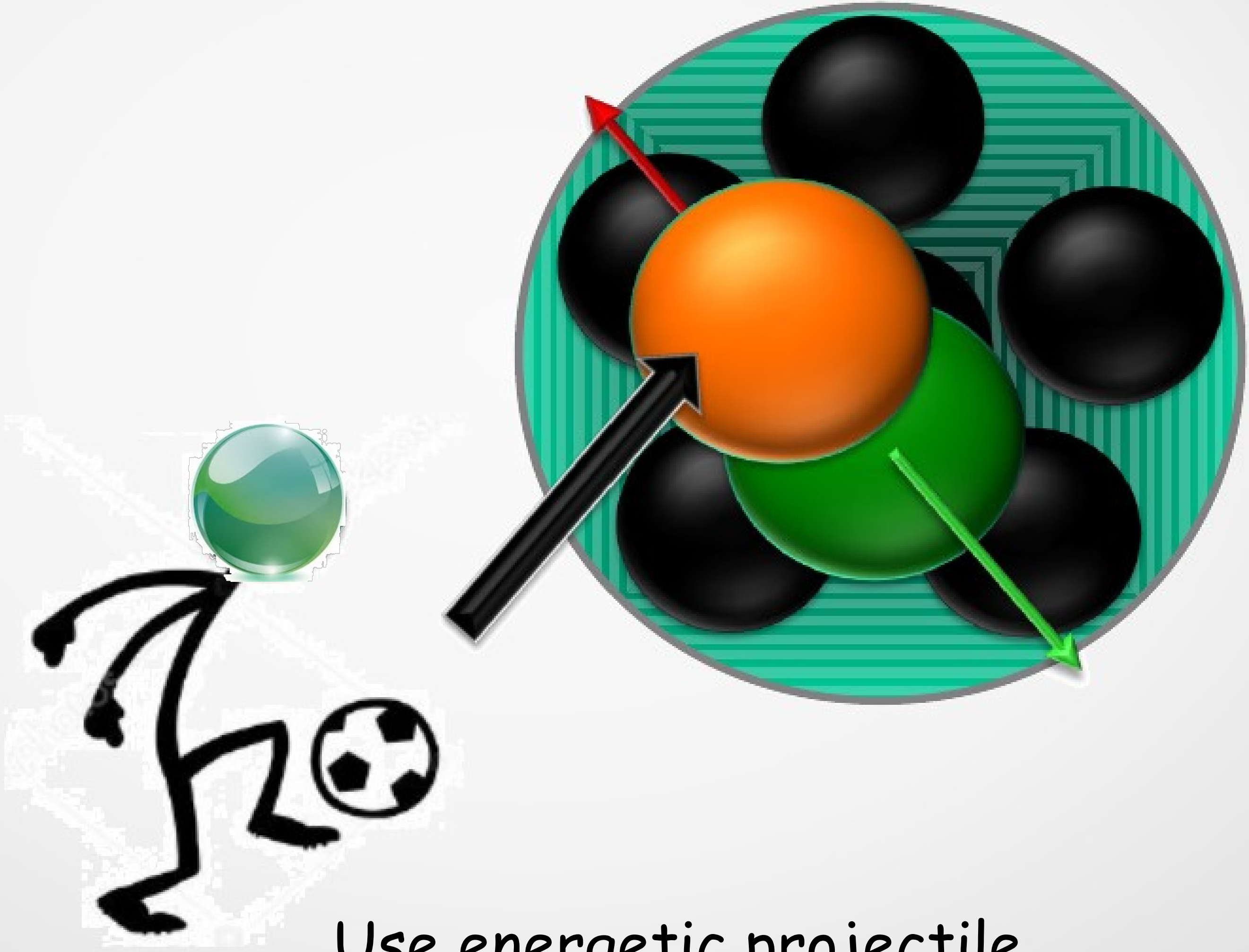
$k_1 > k_F \quad k_2 > k_F \quad k_1 \simeq k_2$

Previous knowledge:

2N – SRC dominate the high momentum

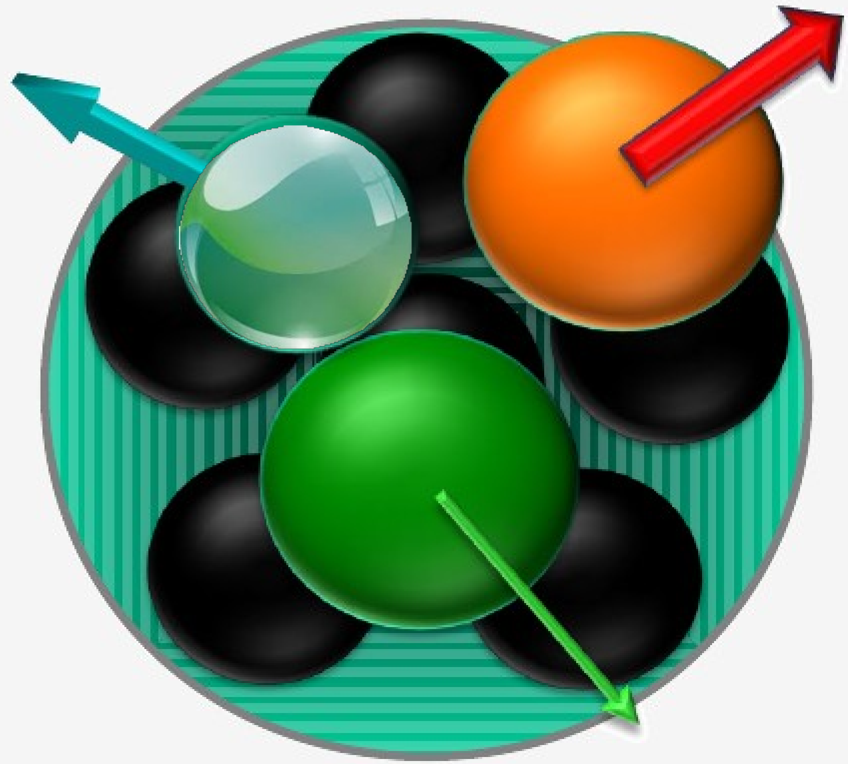


Triple Coincidence Experiment



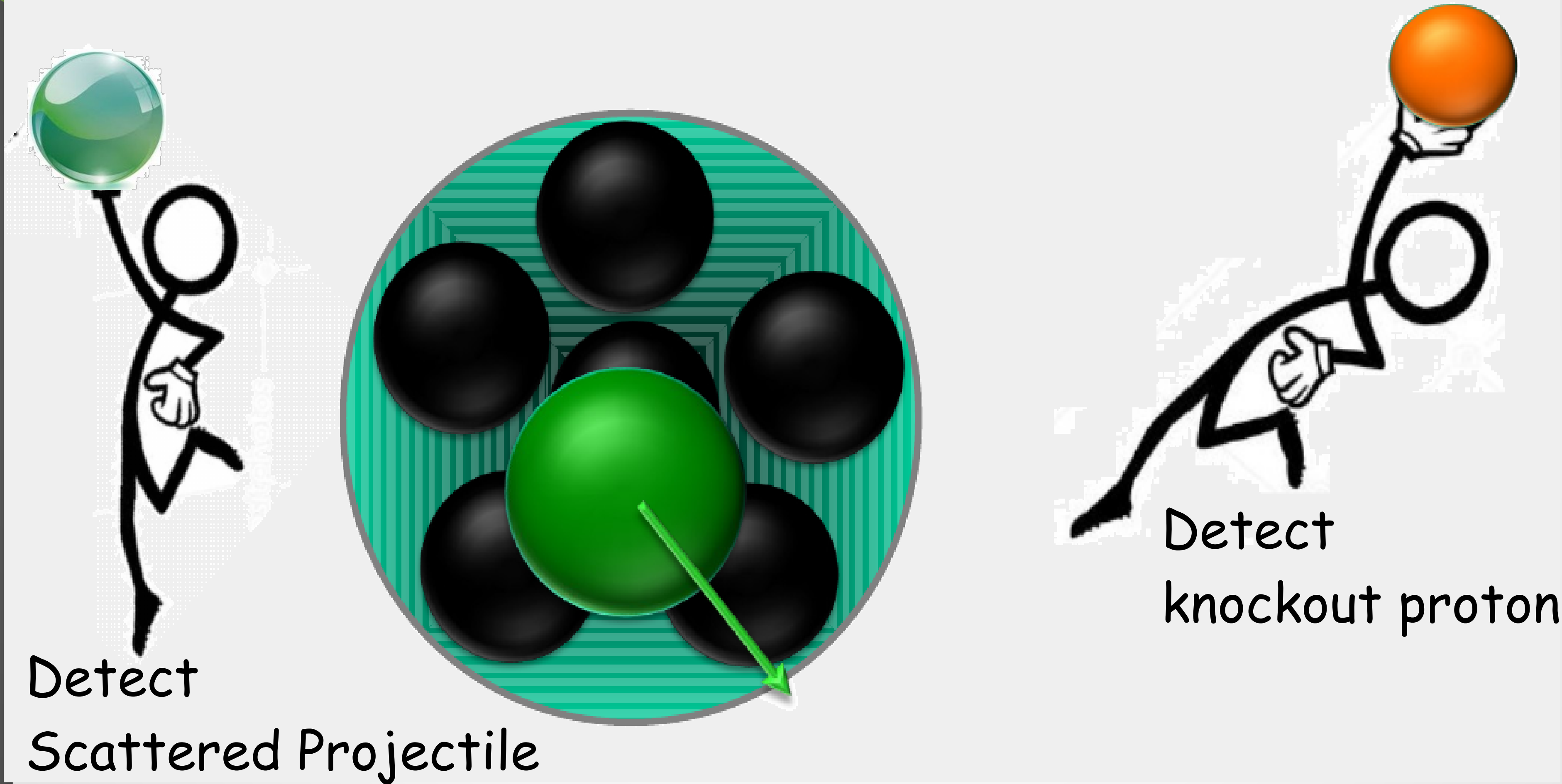
Use energetic projectile

Triple Coincidence Experiment

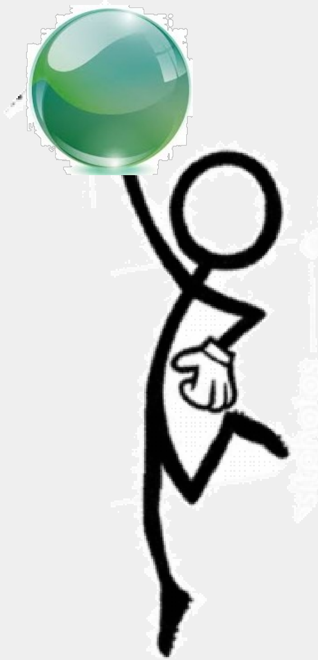


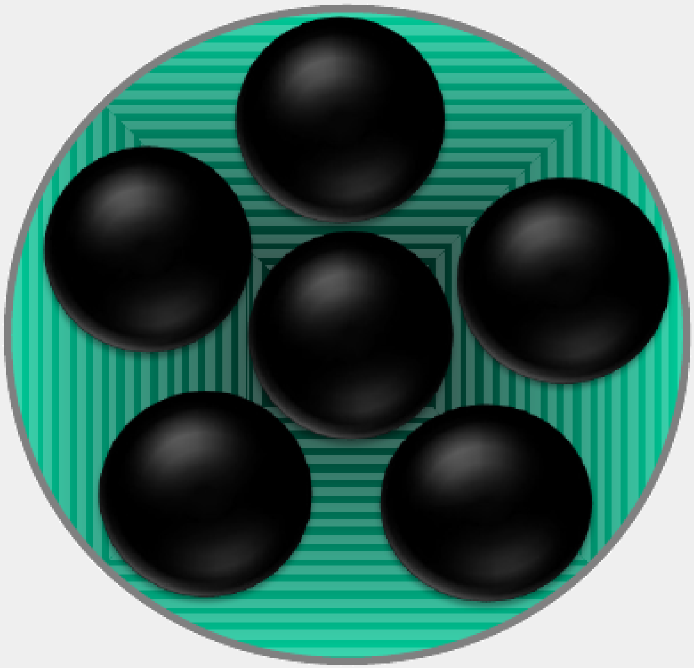
Breakup the pair

Triple Coincidence Experiment



Triple Coincidence Experiment





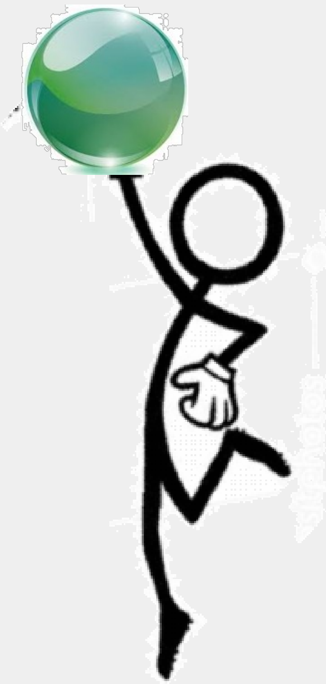
Detect
knockout proton

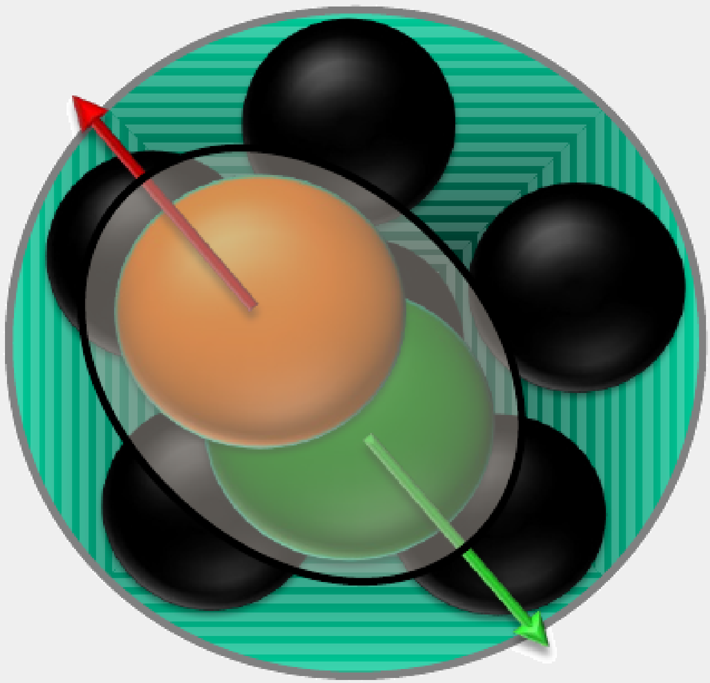
Detect
Scattered Projectile

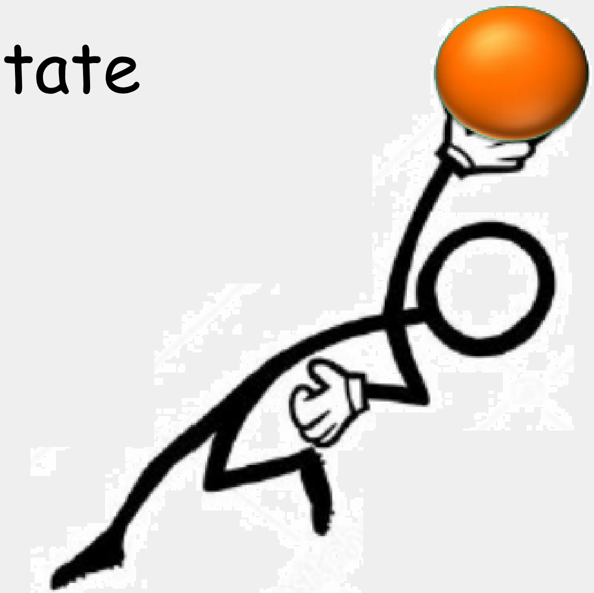
Look for Recoiling partner

Triple Coincidence Experiment

Reconstruct the 'initial' state







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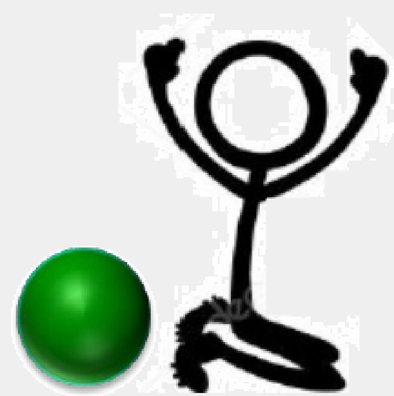
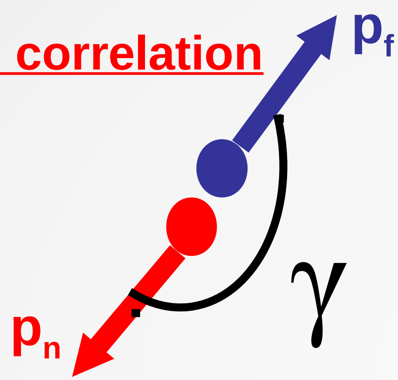


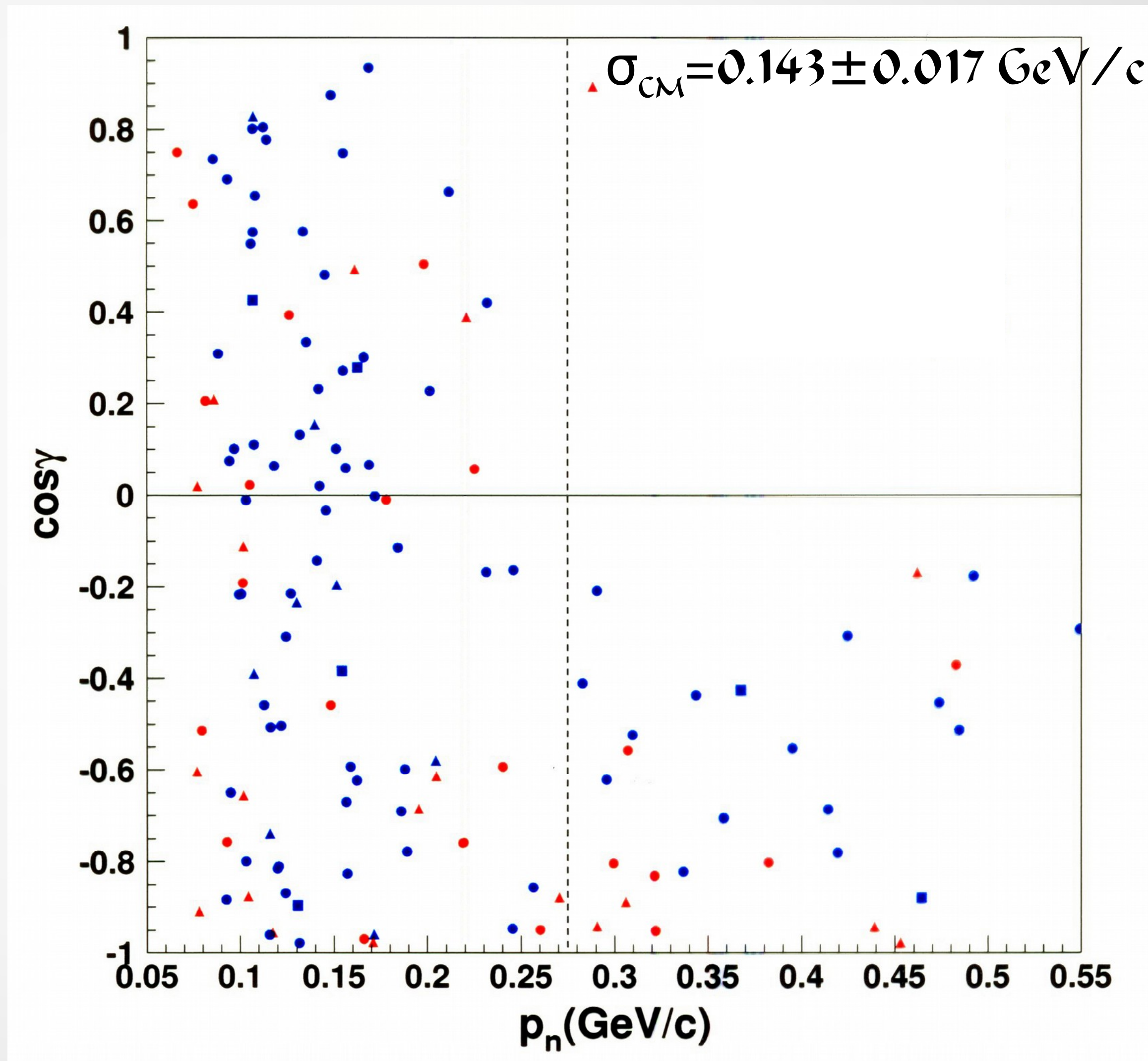
$^{12}C(p,p'pn)$ measurements at EVA / BNL

A. Tang et al. Phys. Rev. Lett. 90 ,042301 (2003)

Directional correlation

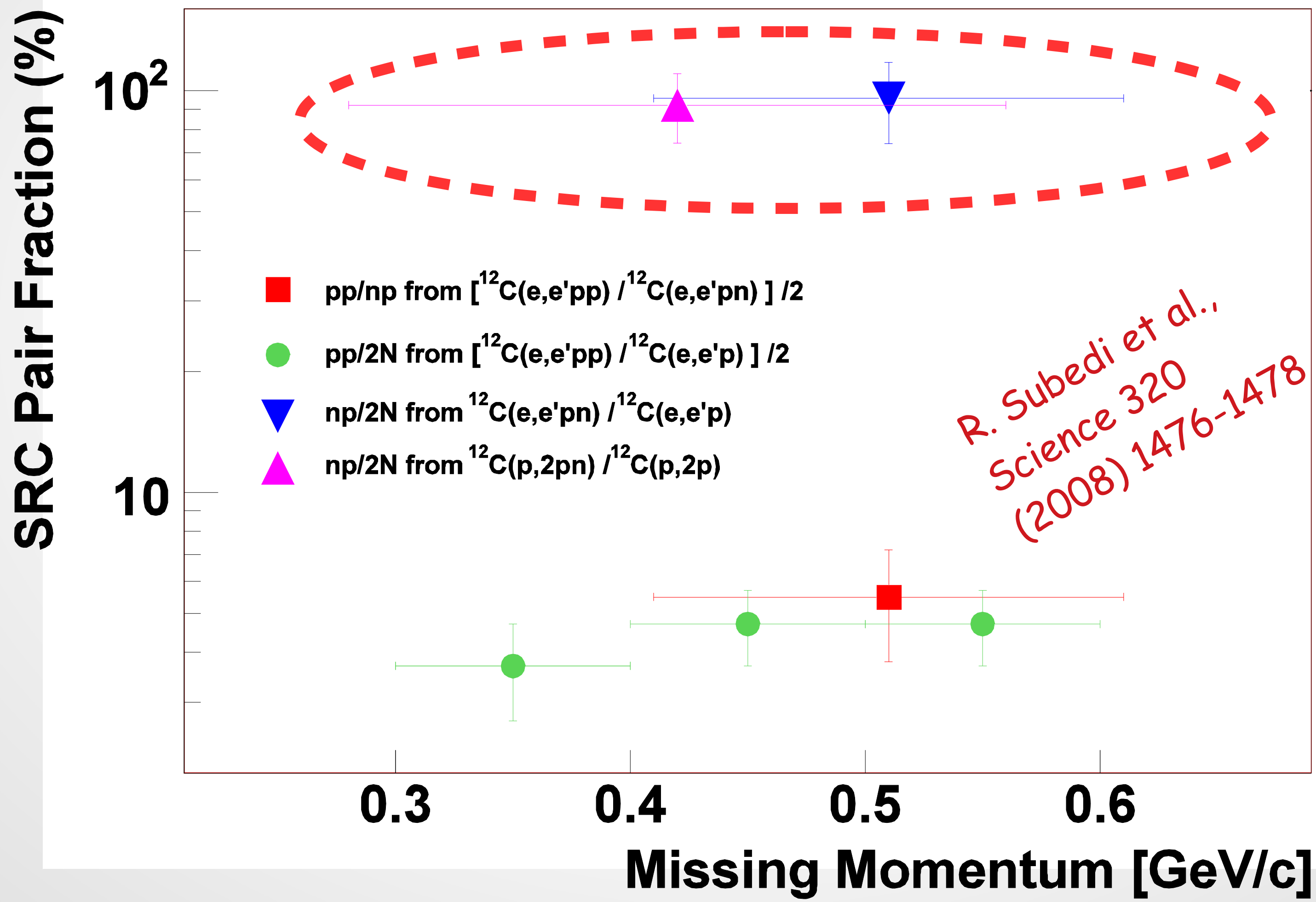


Removal of a proton with momentum above 275 MeV/c from ^{12}C is **$92\pm^{8}_{18}$ %** accompanied by the emission of a neutron with momentum equal and opposite to the missing momentum.



Piasetzky, Sargsian, Frankfurt, Strikman, Watson PRL 162504(2006).

Jefferson Lab $^{12}C(e,e'pN)$ → **np dominance**

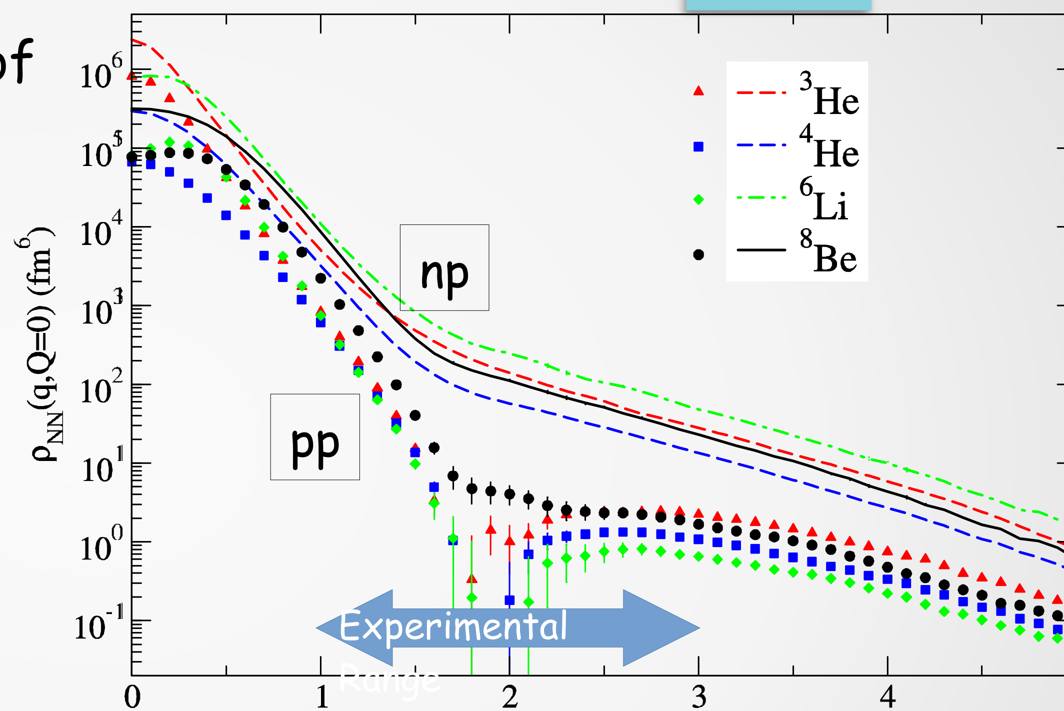


A little bit theory…

Tensor part of the nucleon-nucleon force is proportional to total Spin of the pair

Tensor force "prefer" the

<u>S = 1</u> state over the S= 0



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

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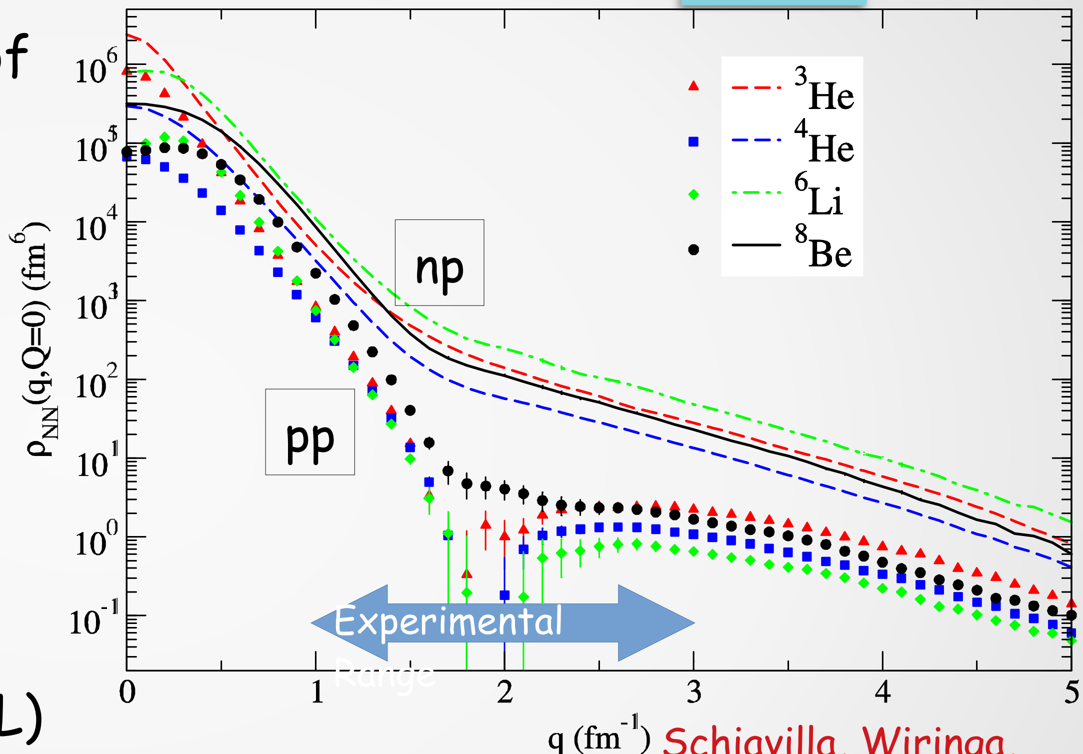
2N-SRC pairs are mainly
In the S-state or D-state (even L)



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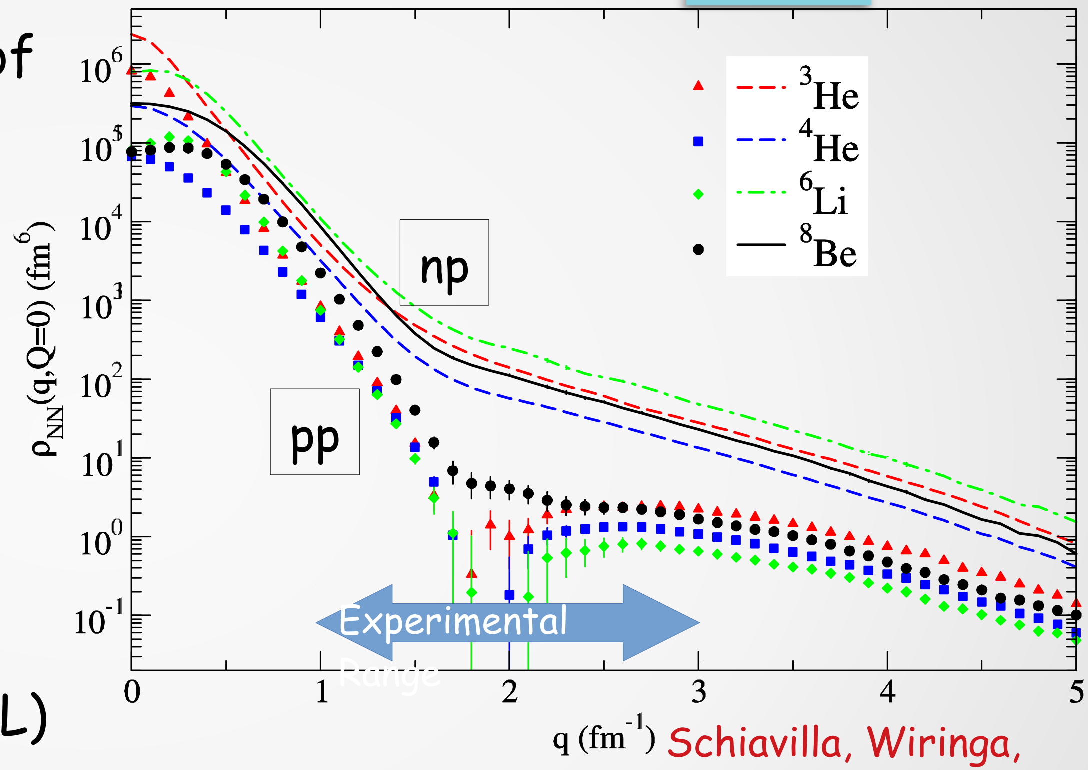
Pauli Principle

Isospin must be odd



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

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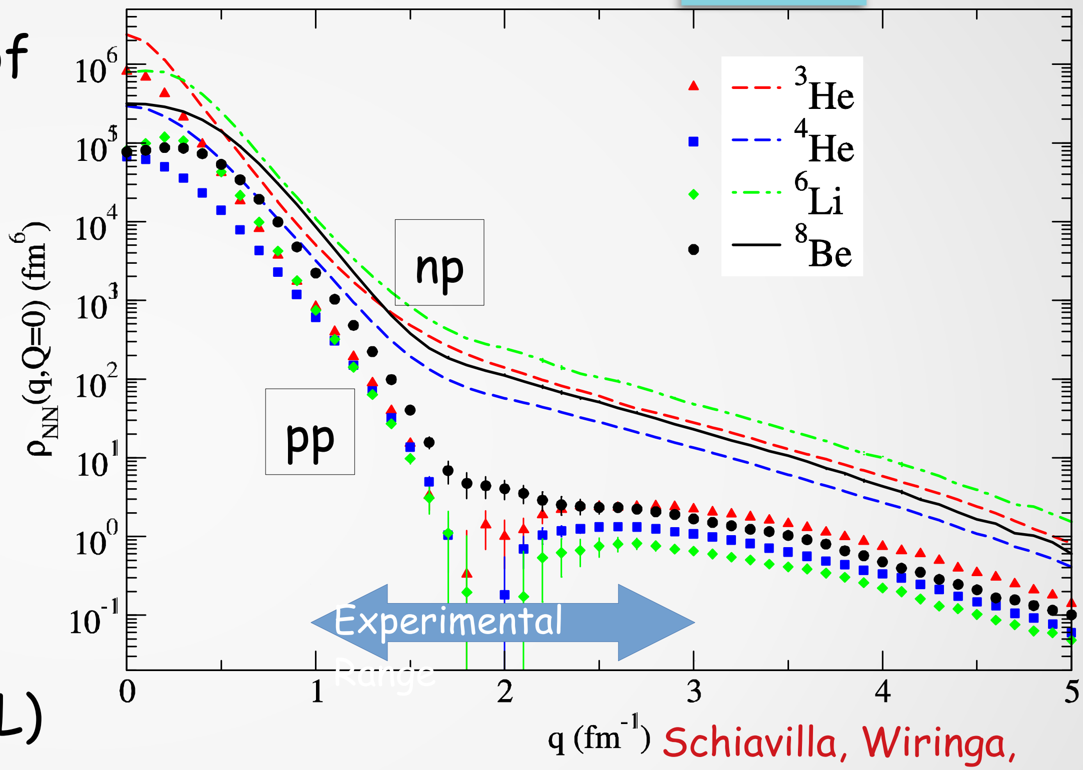

Schiavilla, Wiringa, Pieper, Carson, PRL 98,132501 (2007).

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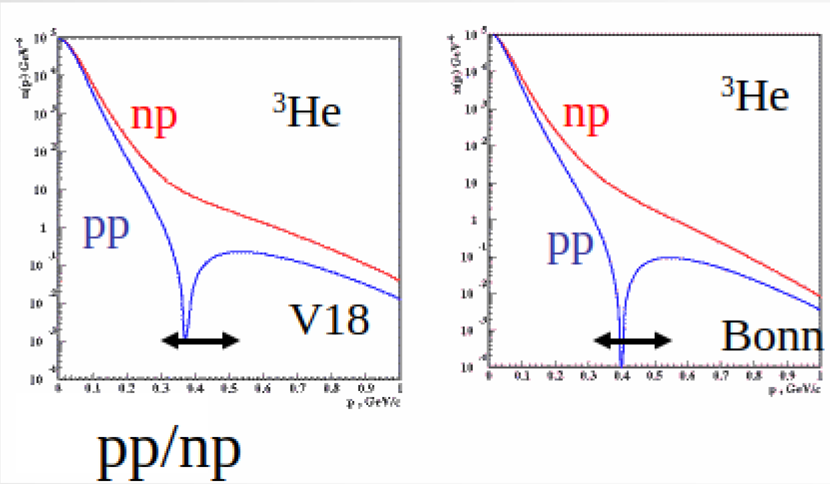
2N-SRC pairs are mainly
In the S-state or D-state (even L)

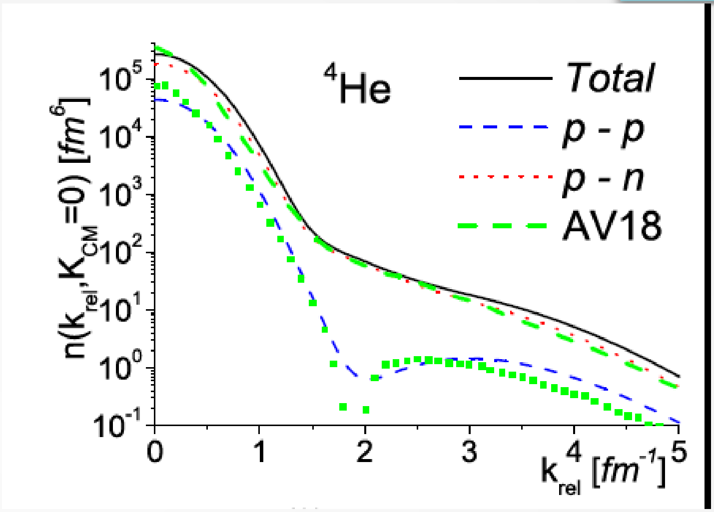
Pauli Principle

Isospin must be odd

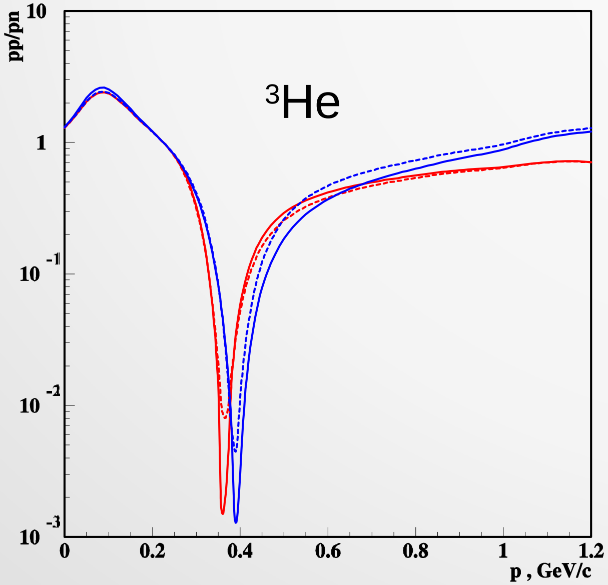
Many more np-SRC pairs (Deuteron like)

<u>Ab initio</u> Calculation of Nucleon-Nucleon Potential



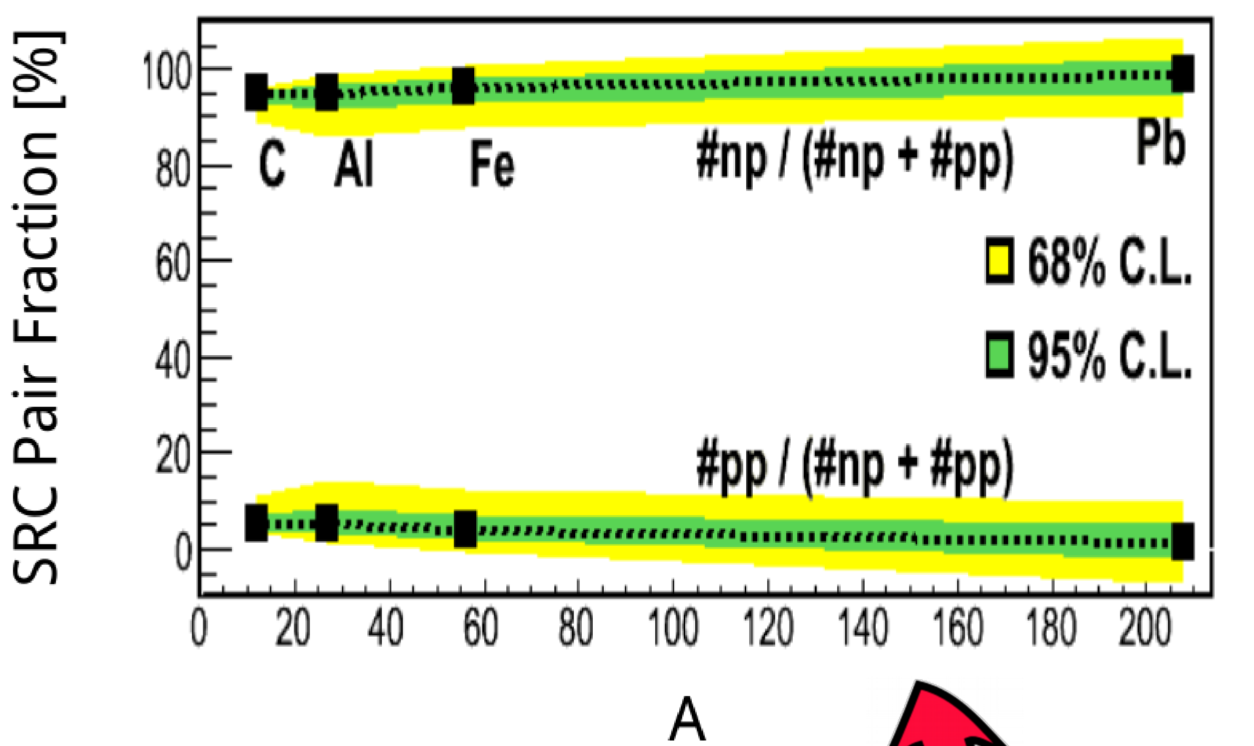


Ciofi and Alvioli
PRL 100, 162503 (2008).



Sargsian, Abrahamyan, Strikman, Frankfurt PR C71 044615 (2005).

Universality of np dominance, from light to heavy

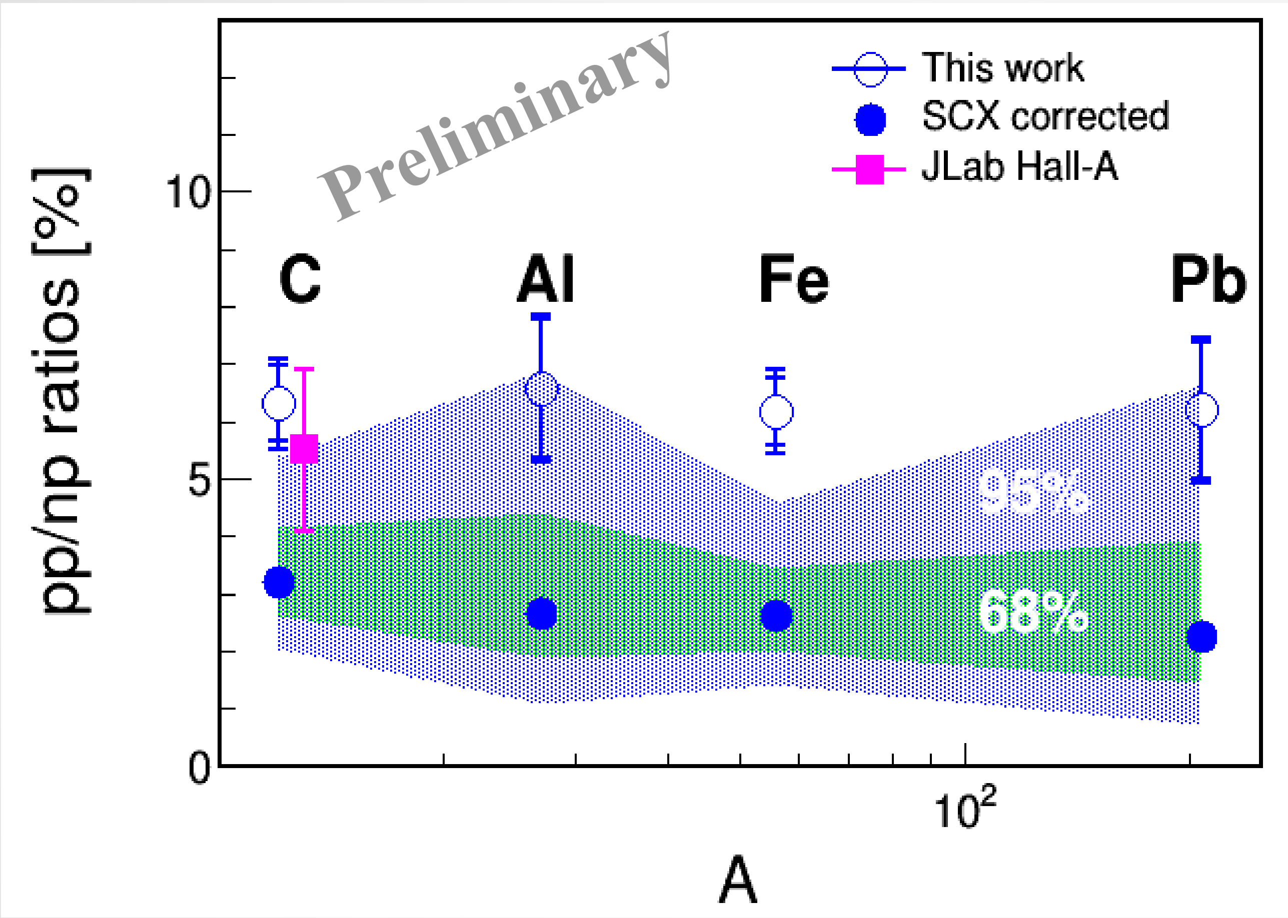


Hen *et al.*, Science 346 (2014) 614-617

Inferred from (e,e'p) and (e,e'pp) events

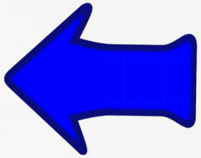
Assuming every (e,e'p) event
With high momentum
has a correlated partner

Universality of np dominance, from light to heavy

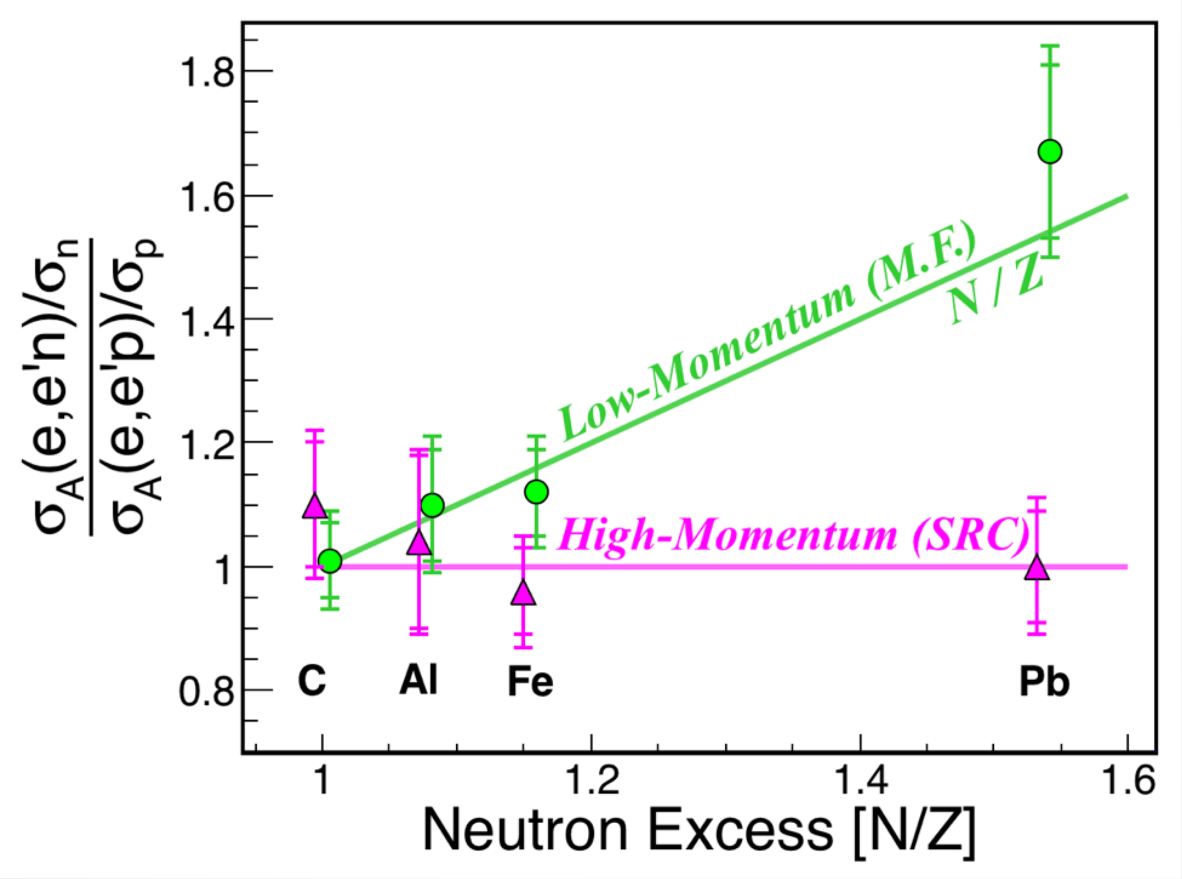


To be Submitted to PRL
Work done by Meytal Duer et al.

np and pp pairs where measured



- Upper limit: pp/pn < ~6%
- No A-dependence

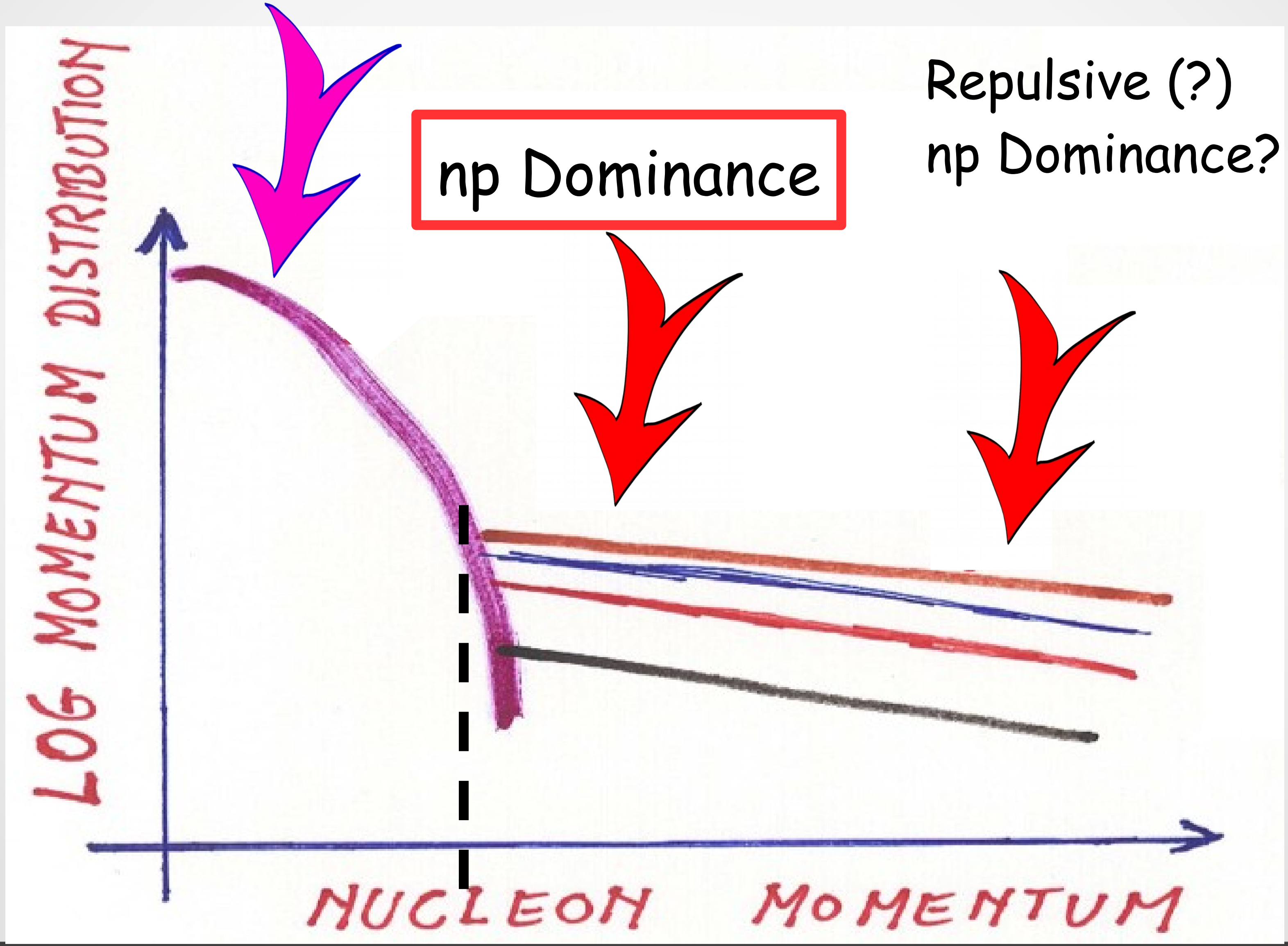


Low momentum:
n/p ~ N/Z

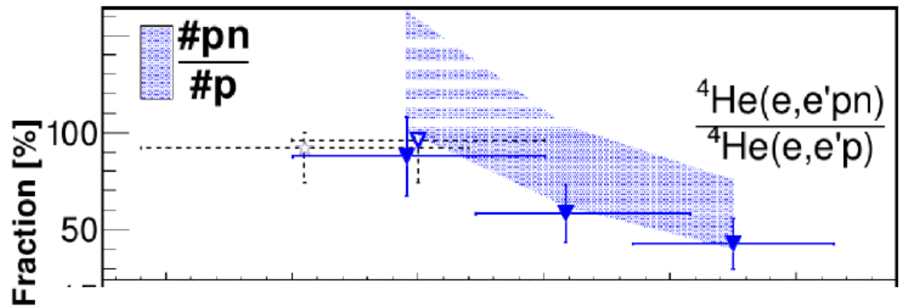
High Momentum:
#n = #p

Duer *et al.*, Nature 560 (2018) no.7720, 617-621

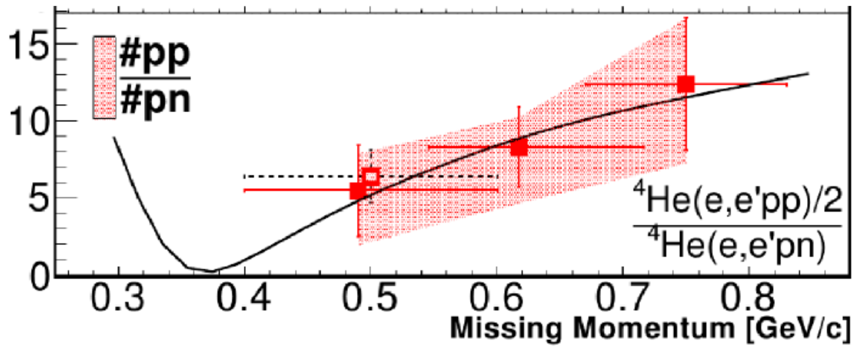
Mean Field – no np Dominance



And beyond...



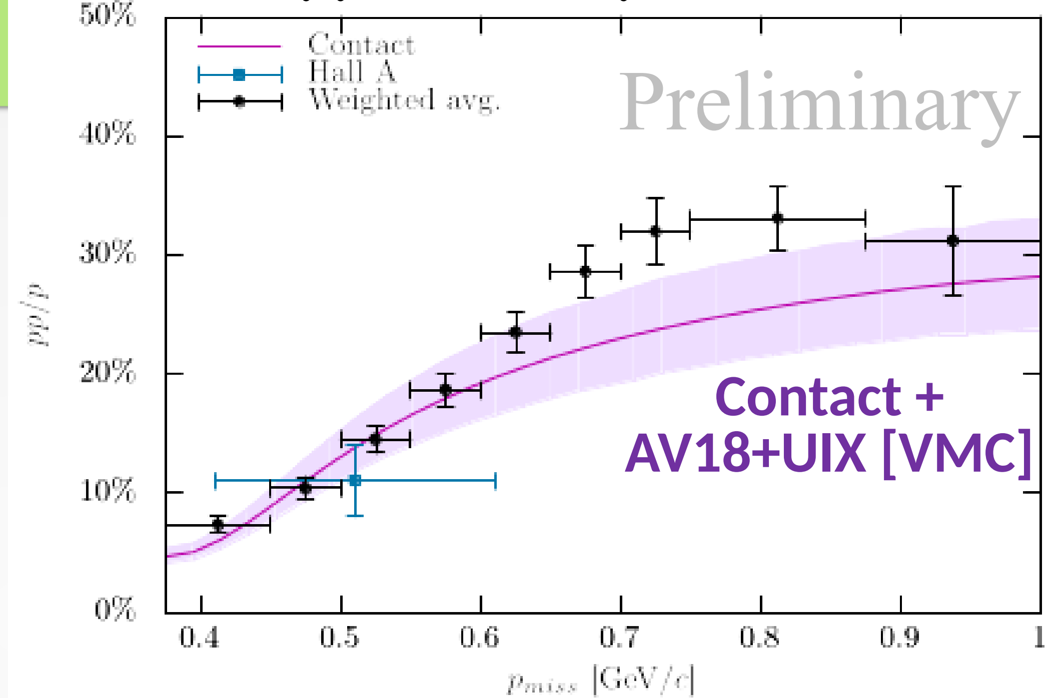
np dominance decrease with momentum increase

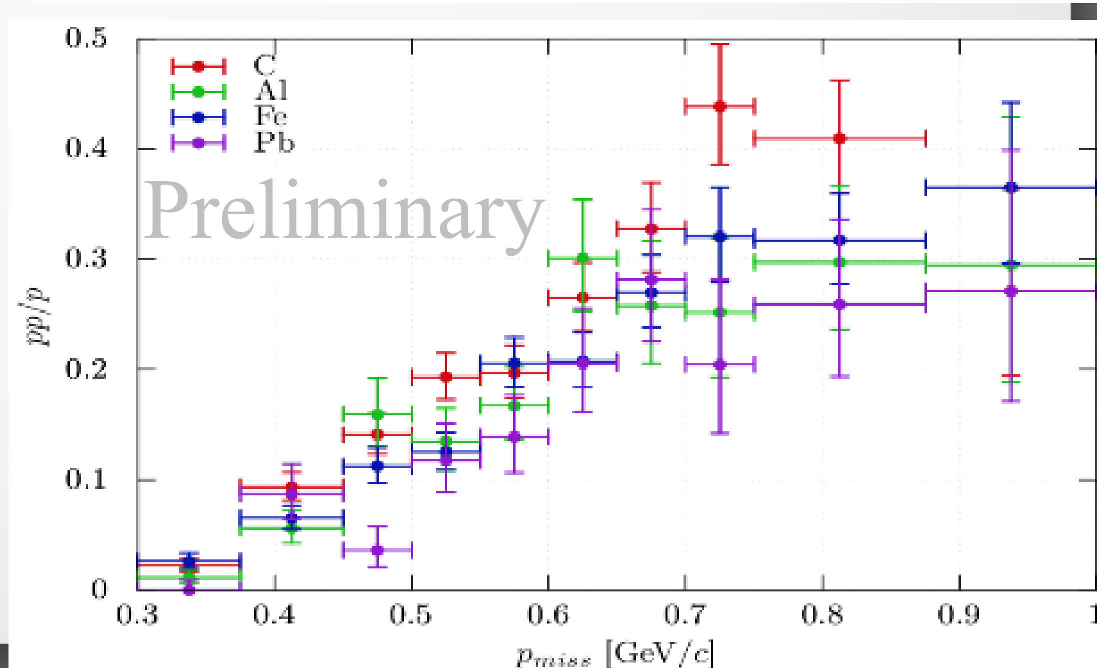


Korover et al., PRL (2014)

Schmidt et al., in preparation (2018)

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





Nucleon – Nucleon interaction depends strongly on Spin and Isospin in a "limited" momentum range

300 – 600 MeV/c

Typical $1.5 \cdot K_F - 3 \cdot K_F$

Nucleon – Nucleon interaction depends strongly on Spin and Isospin in a "limited" momentum range

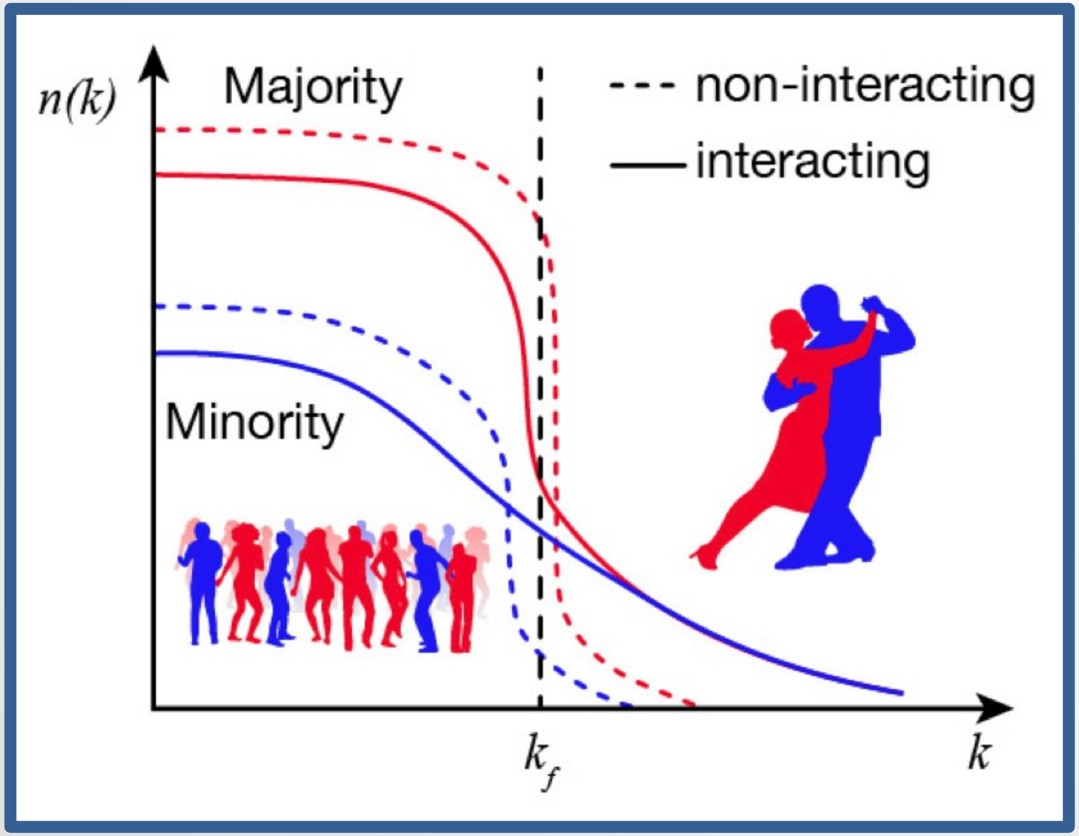
300 – 600 MeV/c

Typical $1.5 \cdot K_F - 3 \cdot K_F$

Why it is important?

The Kinetic Energy of the nucleons

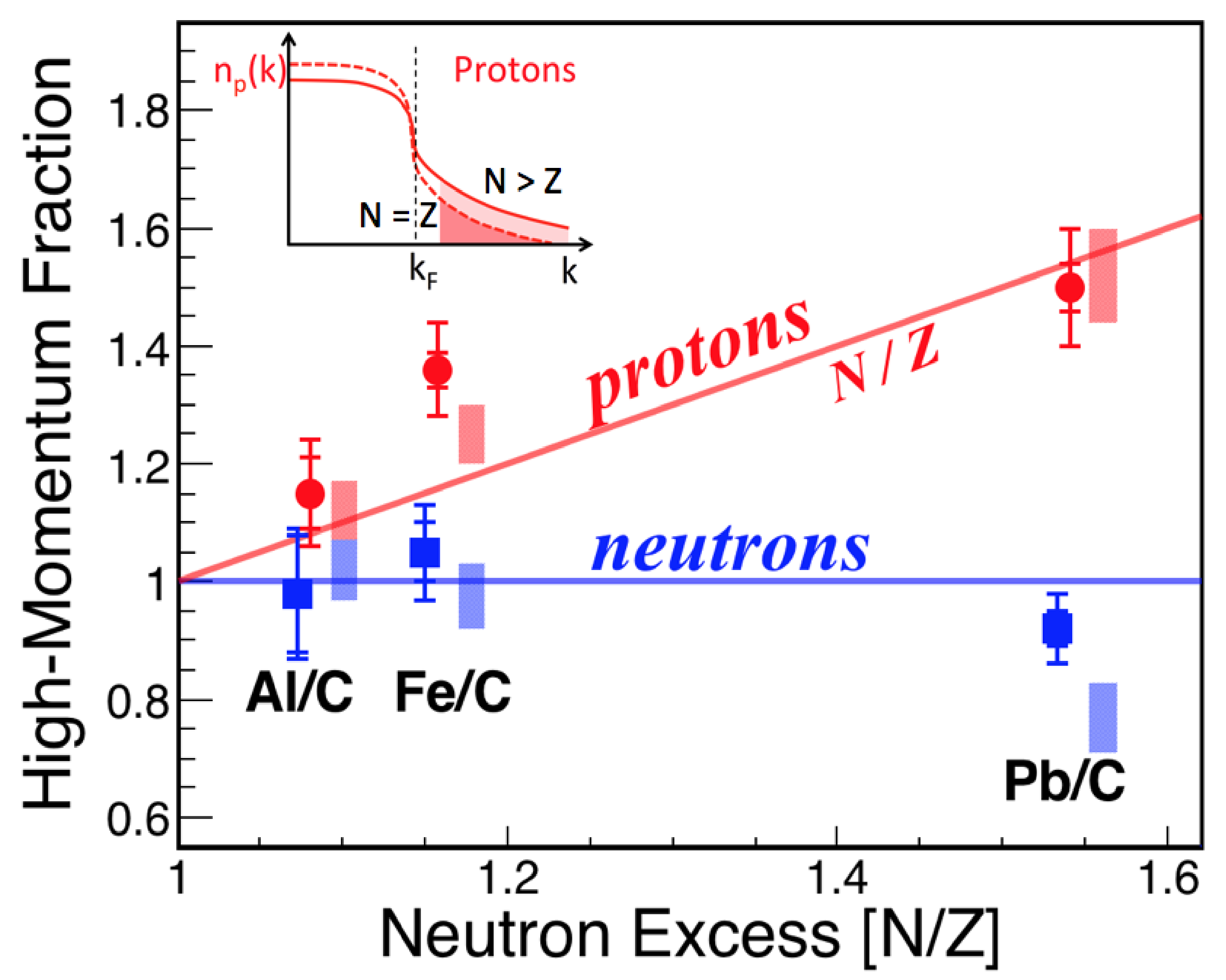
1. 20% nucleons in 2N-SRC, but ~80% of Kinetic energy
2. The average kinetic energy of "Minority" LARGER than "Majority" in asymmetric nuclei.



np-dominance affect energy distribution of nucleons in the nuclei.

Hen *et al.*, Science 346 (2014) 614-617

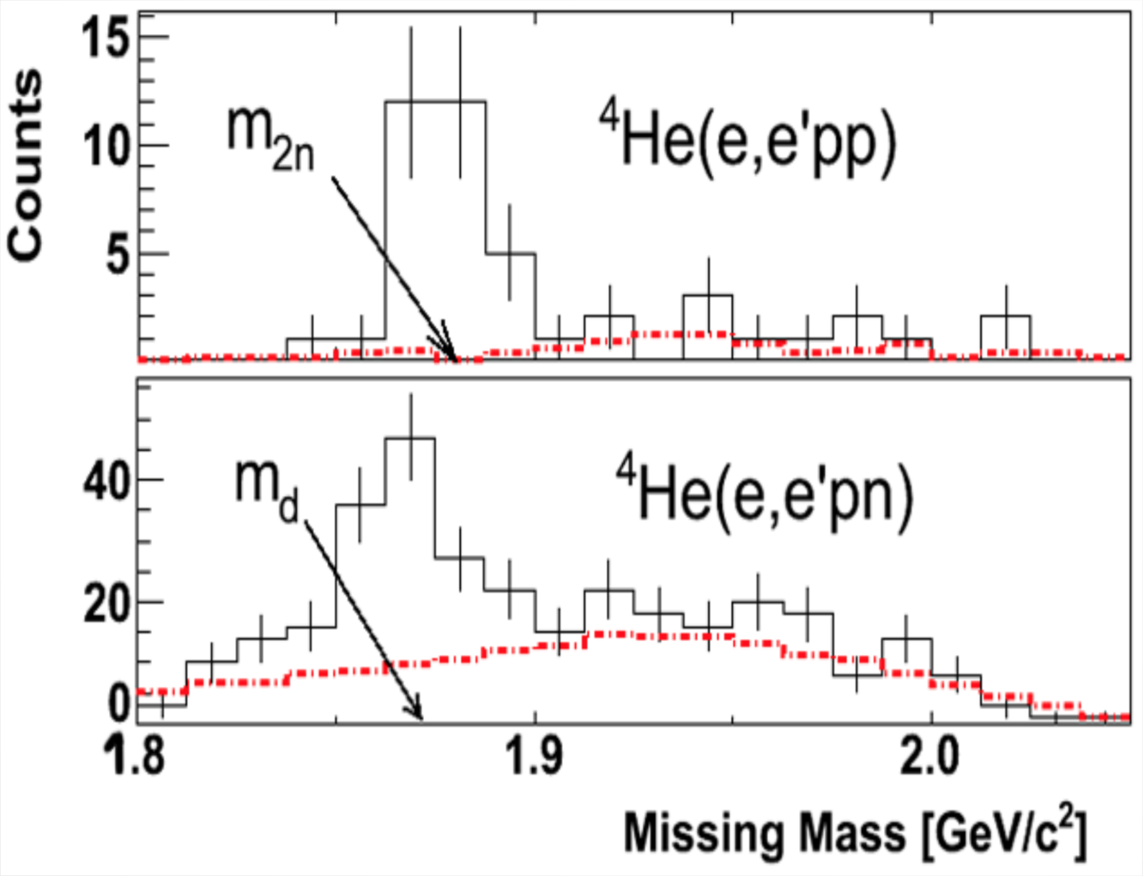
Correlation Probability:
Neutrons saturate Protons grow



Duer *et al.*, Nature 560 (2018) no.7720, 617-621

The story of the A-2 system

Residual A-2 system is a spectator

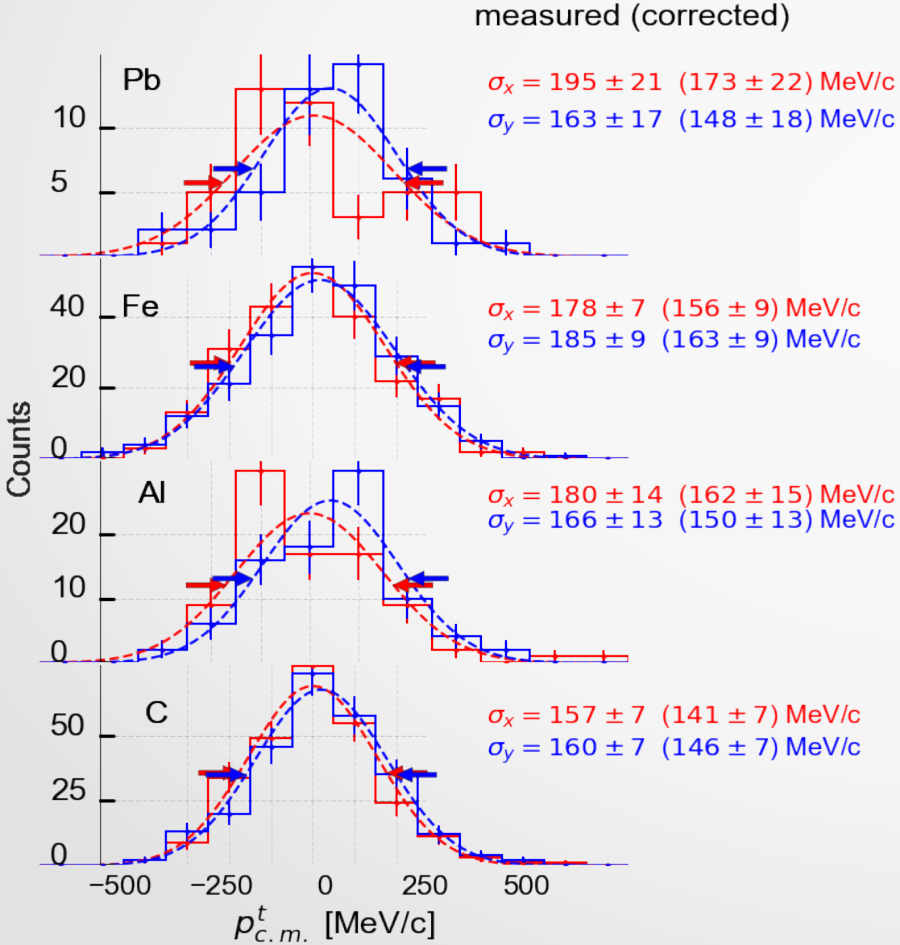


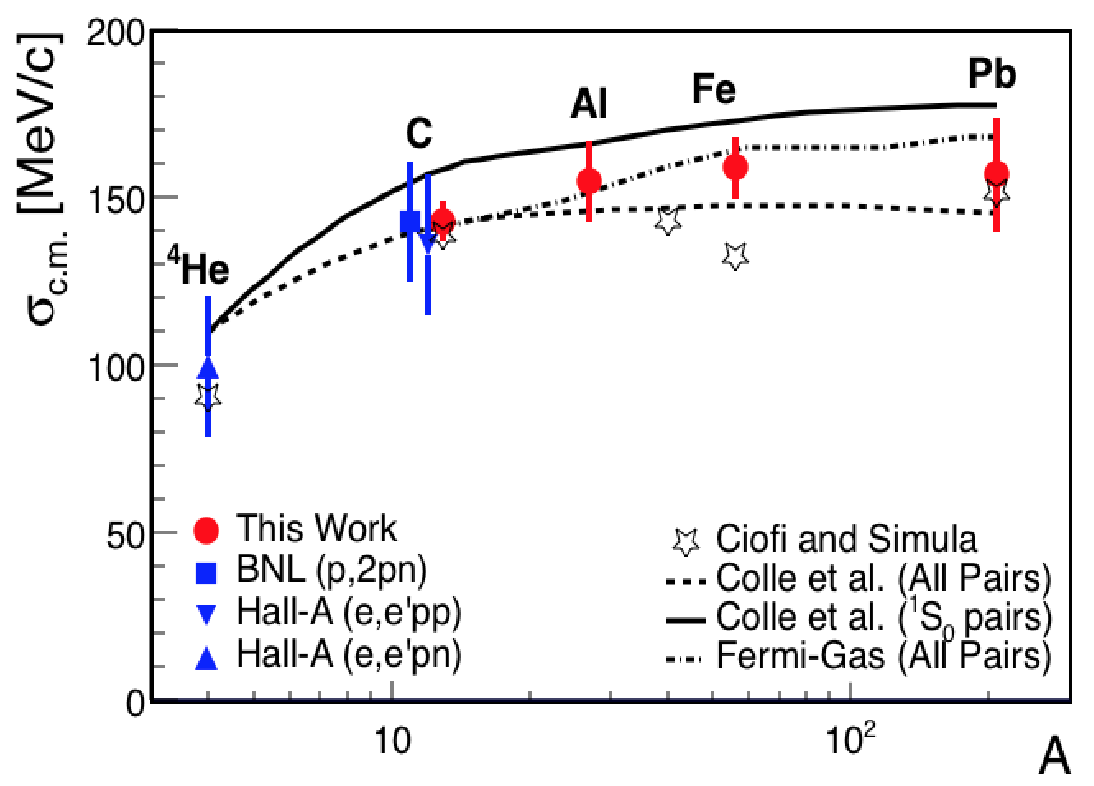
Korover et al., PRL (2014)

Reminder:

Low CM momentum of the 2N-SRC pair

Consistent with Mean-Field Calculations

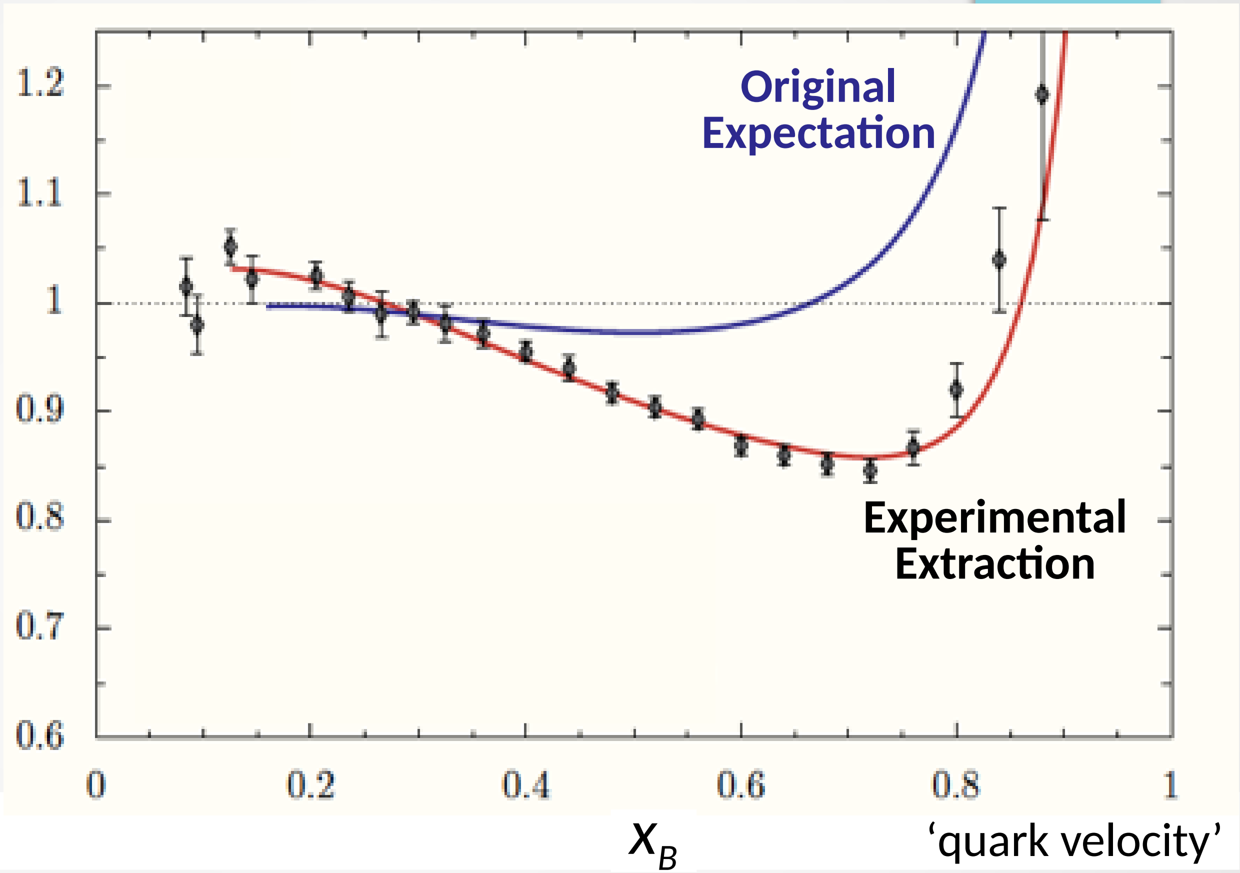




Cohen et al., Phys. Rev. Lett. 121, 092501 (2018).

EMC Effect:

Ratio of quark momentum distribution of nucleon in iron/ nucleon in Deutrerium



Aubert et al., PLB (1983); Ashman et al., PLB (1988); Arneodo et al., PLB (1988); Allasia et al., PLB (1990); Gomez et al., PRD (1994); Seely et al., PRL (2009); Schmookler et al., Submitted (2018)

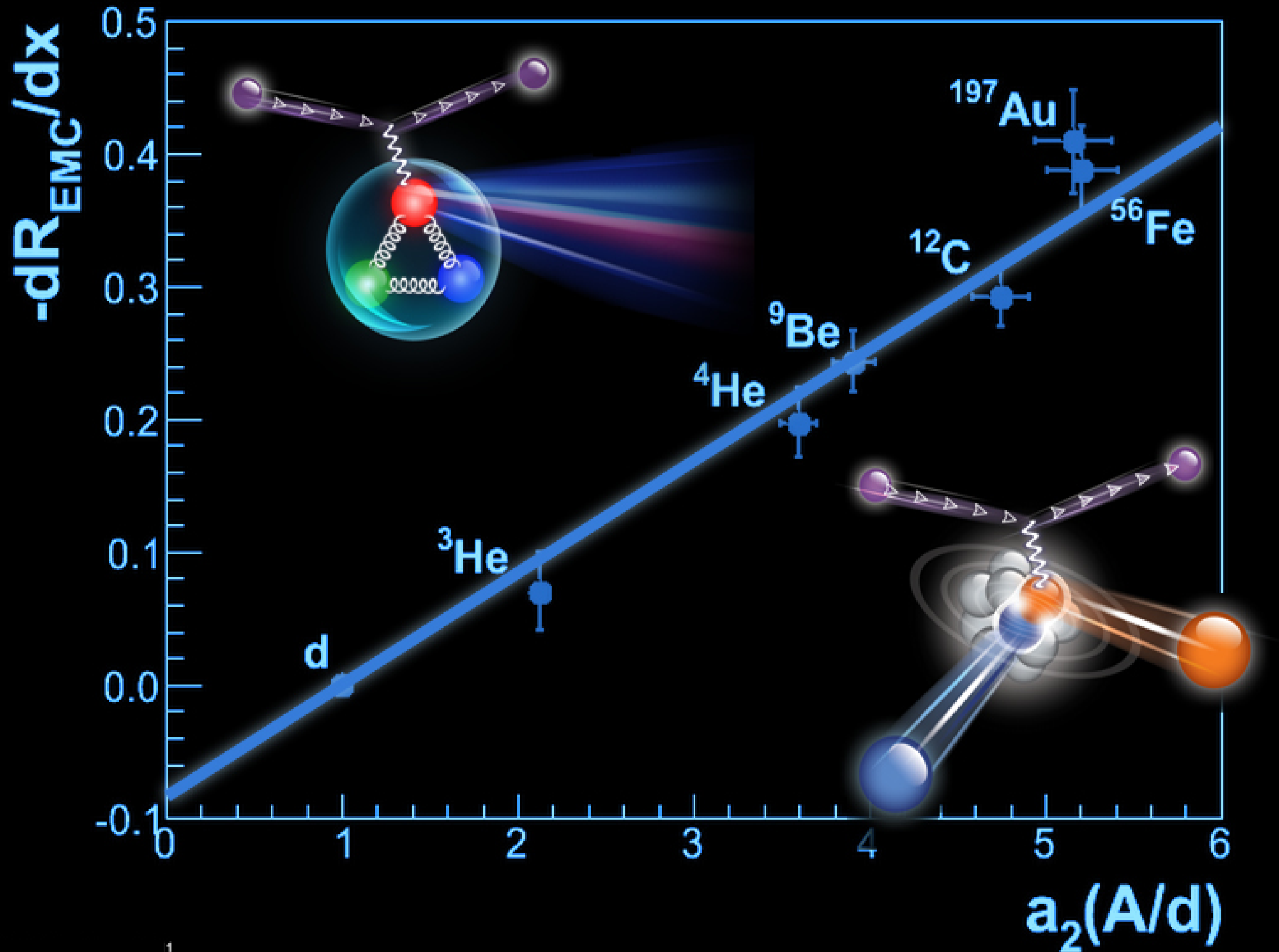
SRC may correspond to medium modification

Bound nucleon $\neq$ Free nucleon

1) All nucleons are slightly modified when bound in nuclei

2) Nucleons are unmodified most of the time, but are modified significantly when they fluctuate into SRC pairs

EMC – SRC Correlation

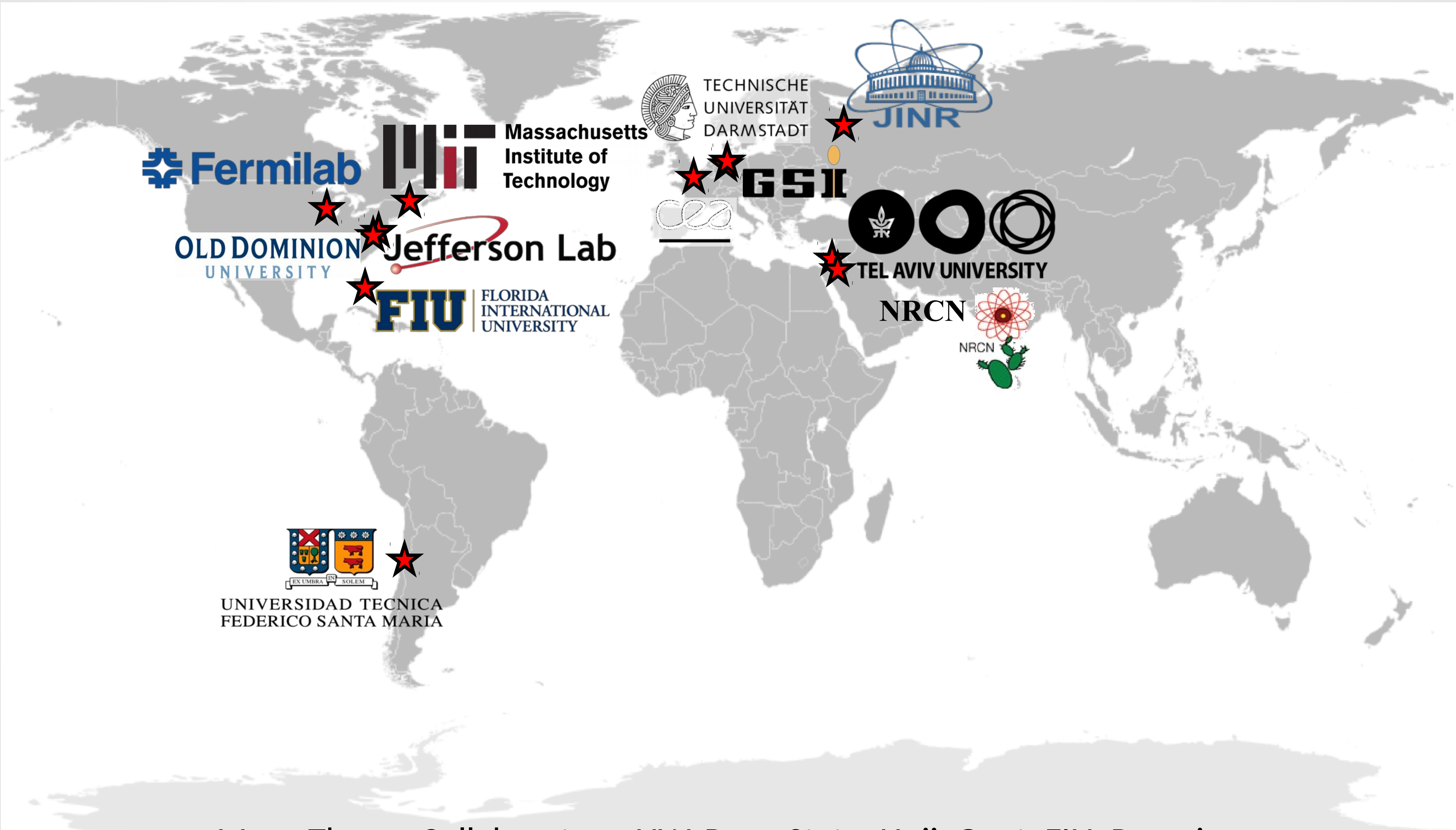


PRL (2011); PRC 85 047301 (2012); RMP 89, 04500 (2017)

Summary:

- Nucleon Nucleon interaction is mainly scalar, no spin dependence.
- Importance of the spin in "limited" nucleon momentum range where Tensor part is important.
- Spin of the 2N-SRC pair is important for np-dominance.
- Significant part of the kinetic energy of the nucleons in nuclei concentrated in SRC.
- SRC can be the reason for nucleon modifications inside the nucleus.

SRC group

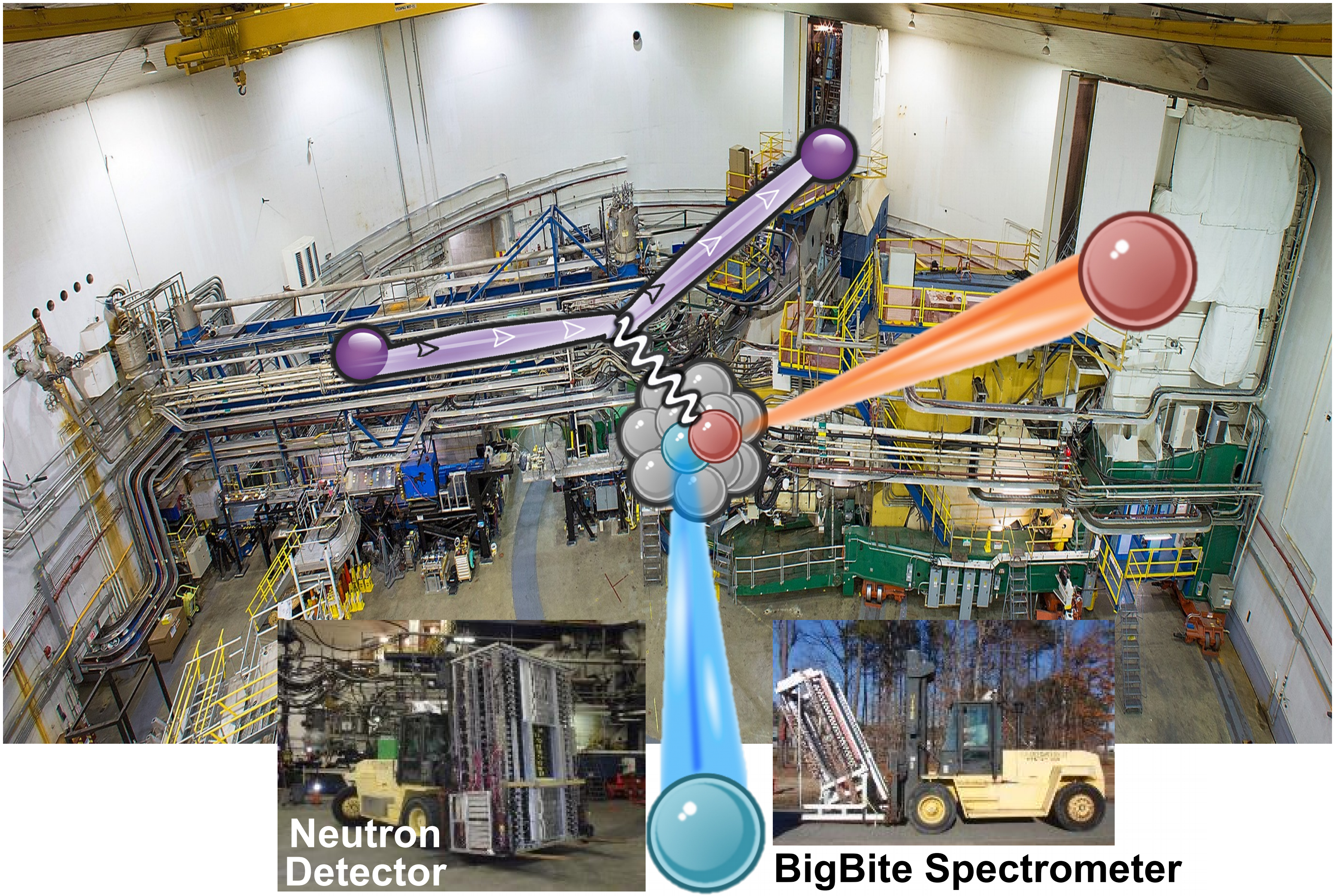


+ Many Theory Collaborators: UW, Penn State, Huji, Gent, FIU, Perugia, …

Thank You

Backup Slides

Hall-A: High-Resolution Spectrometers



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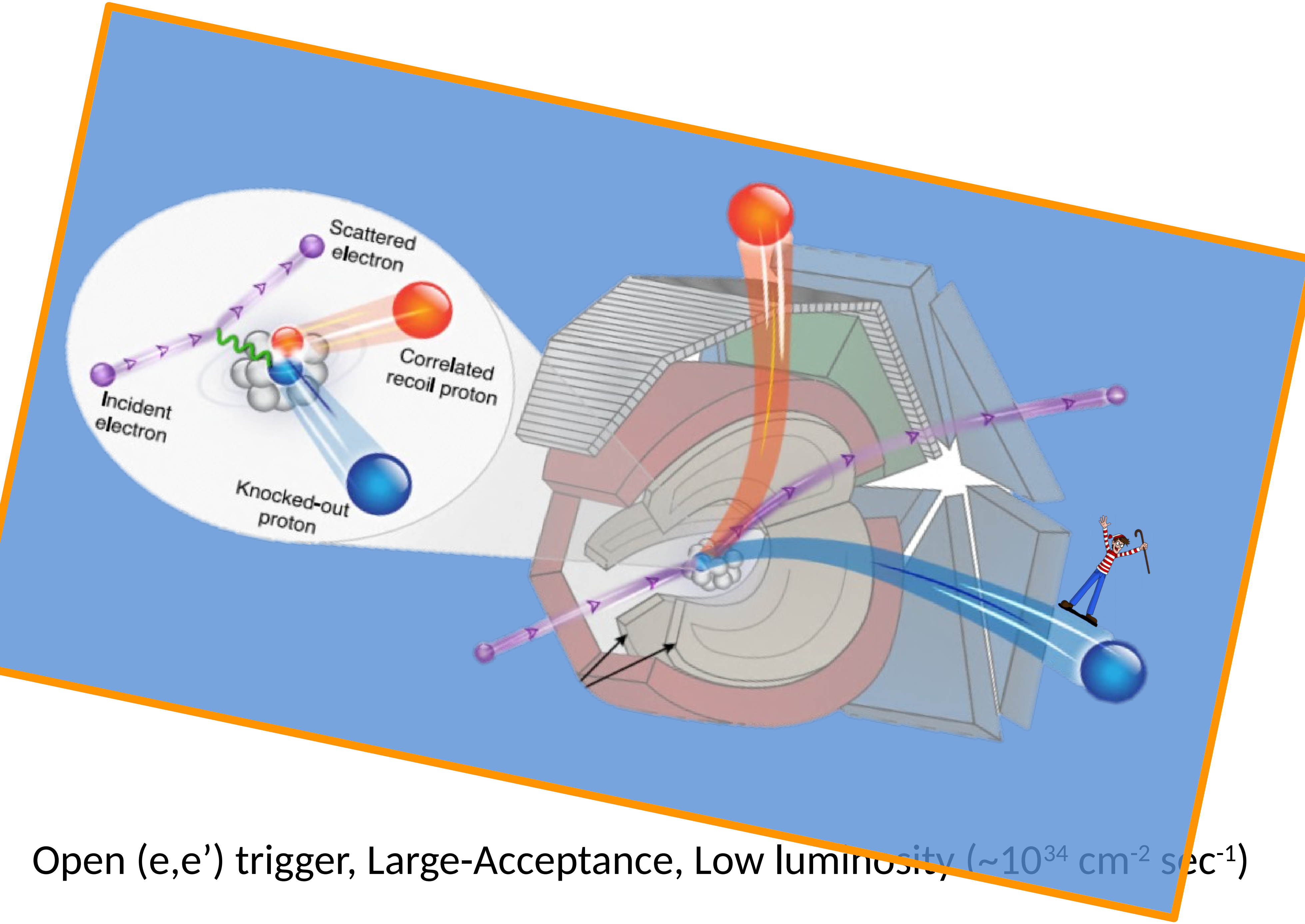
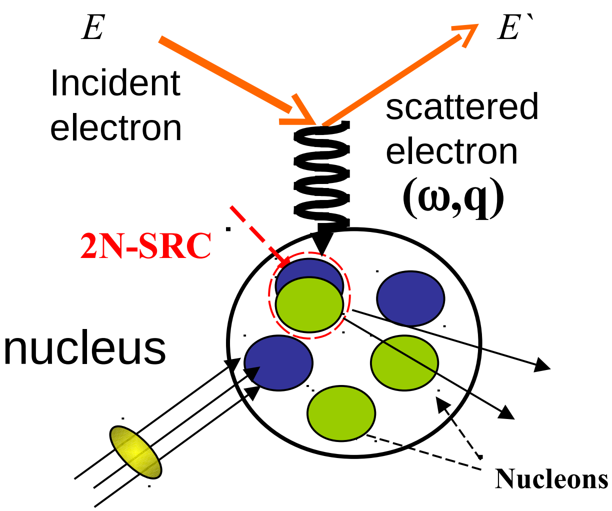
CEBAF Large Acceptance Spectrometer [CLAS]



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

A(e,e') Kinematics



$$Q^2 = -q_\mu q^\mu = q^2 - \omega^2$$

$$\omega = E' - E$$

$$x_B = \frac{Q^2}{2m\omega}$$

(just kinematics!)

DIS off a nucleon: $0 \le x_B \le 1$

HARD KNOCKOUT REACTIONS

x_B gives the fraction of the nucleon momentum carried by the struck parton

$$0 \le x_B \le A$$

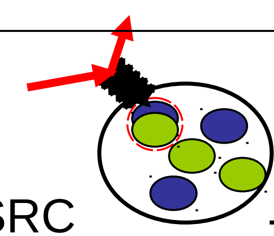
For large Q^2:

x_B counts the number of hadrons involved

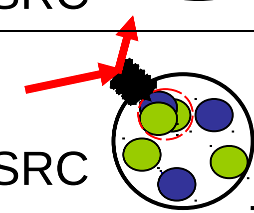
$x_B > j \Rightarrow$ at least $j+1$ nucleons

If exactly $j+1$ nucleons $\Rightarrow \frac{\sigma_A}{\sigma_{j+1}}$ scales

$x_B > 1$ 2N-SRC



$x_B > 2$ 3N-SRC

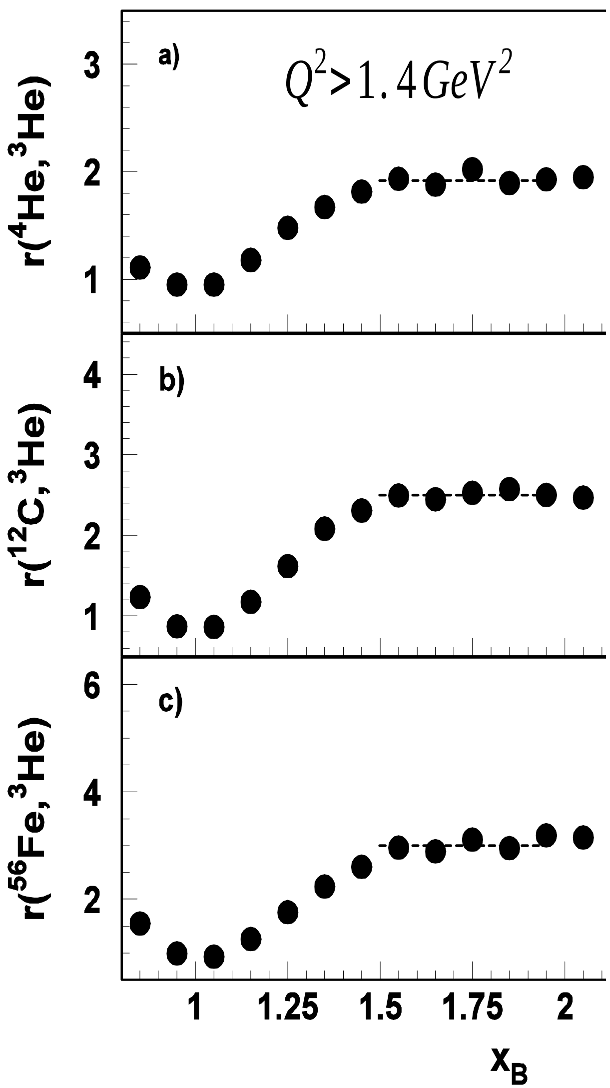


K. Sh. Egiyan et al. PRC 68, 014313 (2003)

K. Sh. Egiyan et al. PRL. 96, 082501 (2006)

SLAC D. Day et al. PRL 59,427(1987)

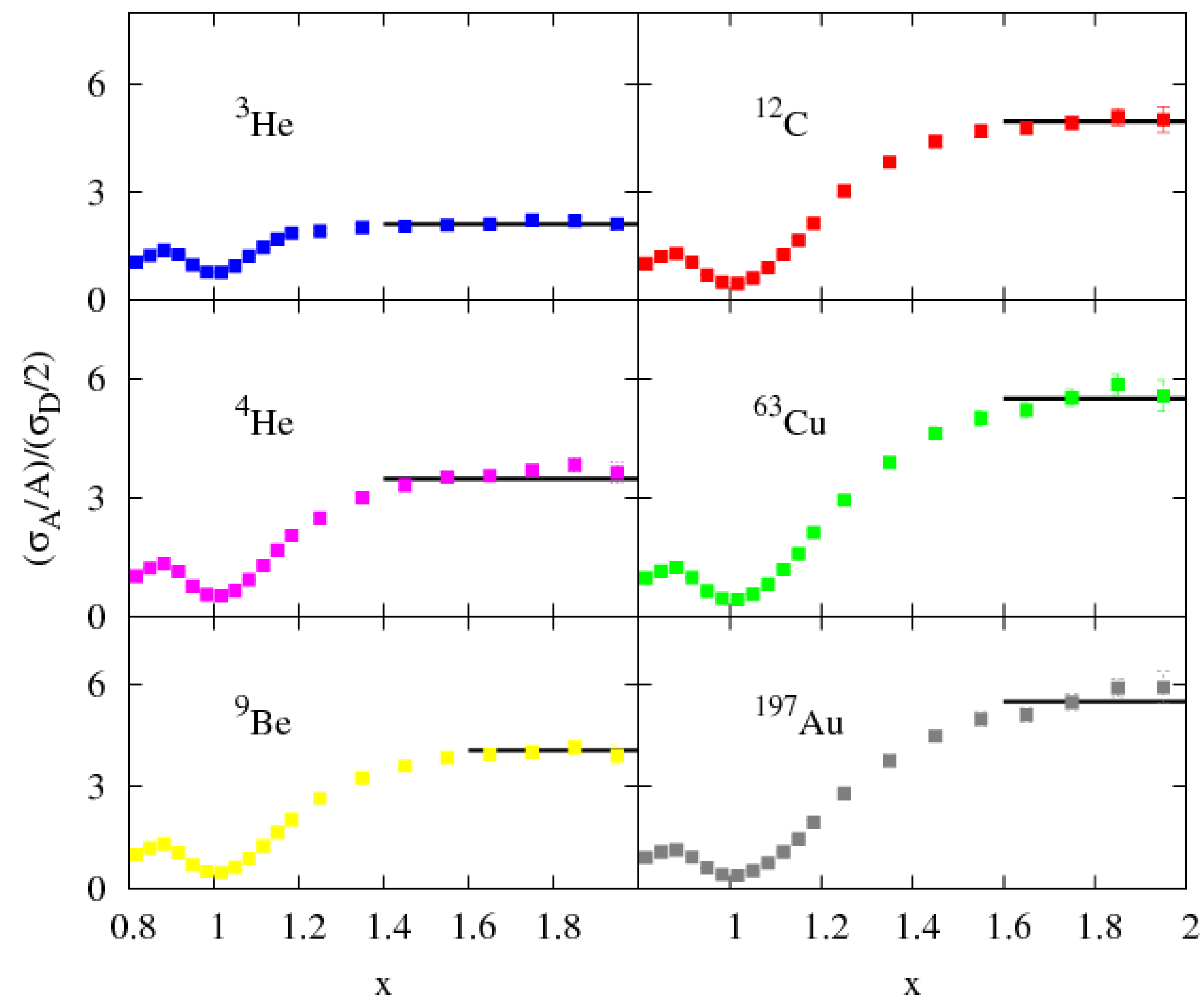
JLab, Hall B



JLab Hall C

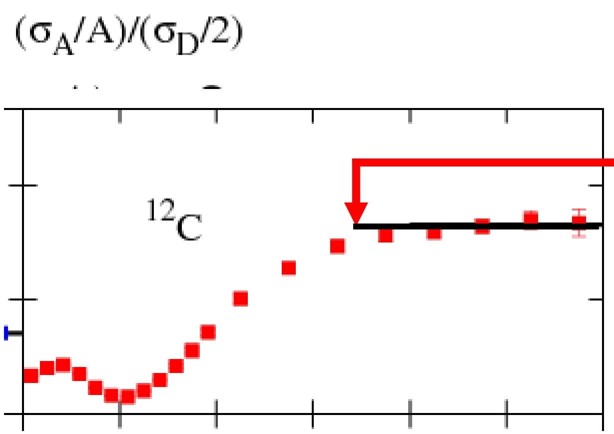
N. Fomin *et al.*, Phys.Rev.Lett. 108 (2012) 092502

Q^2=2.5GeV^2



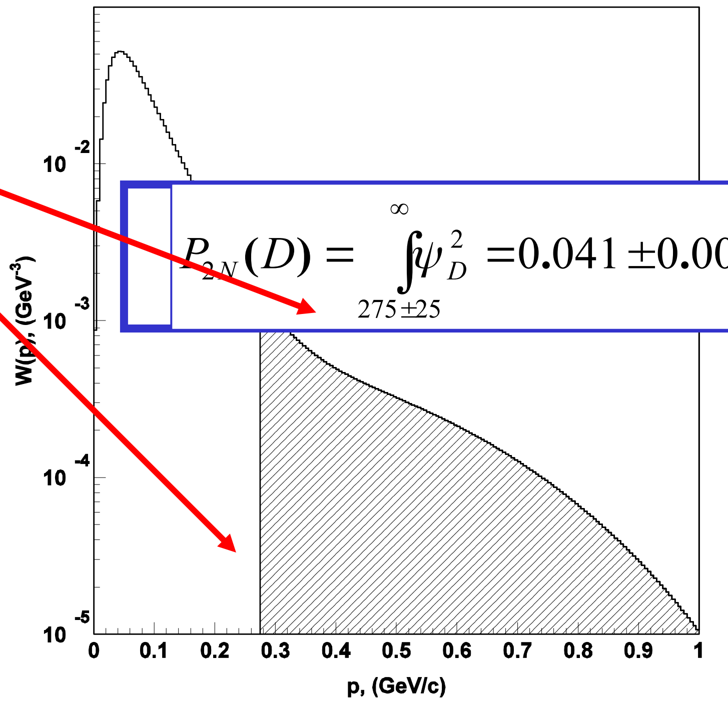
Estimate the amount of 2N-SRC in nuclei

This includes all three isotopic compositions (pn, pp, or nn) for the 2N-SRC phase in ^{12}C.



$a_{2N}(A/d)$

p_{min}



$$P_{2N}(D) = \int_{275\pm25}^{\infty} \psi_D^2 = 0.041 \pm 0.008$$

$a_{2N}(A/d)$	
^{3}He	2.08±0.01
^{4}He	3.47±0.02
Be	4.03±0.04
C	4.95±0.05
Cu	5.48±0.05
Au	5.43±0.06

$$P_{2N}(A) = a_{2N}(A/d) \cdot P_{2N}(D)$$

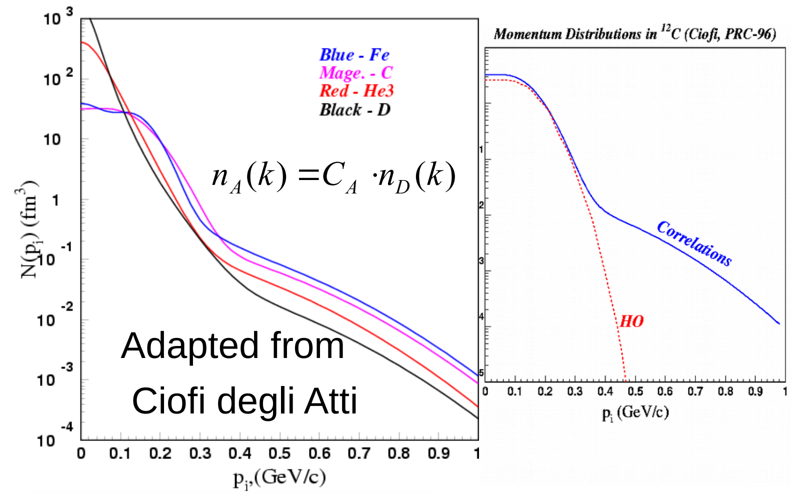
calculations

measurement

For Carbon: $P_{2N}(^{12}C) = 5 \cdot 4\% \approx 20\%$

The inclusive A(e,e') measurements

- **At high nucleon momentum distributions are similar in shape for light and heavy nuclei: SCALING.**
- **Can be explained by 2N-SRC dominance.**

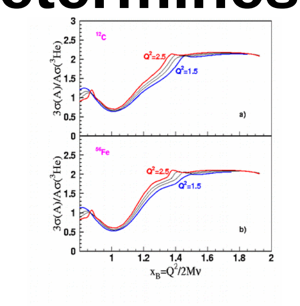


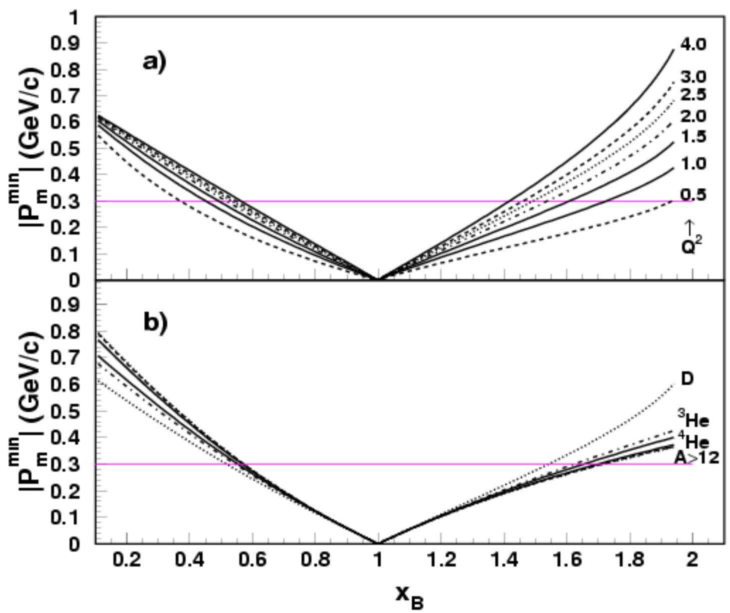
- **Within the 2N-SRC dominance picture one can get the probability of 2N-SRC in any nucleus, from the scaling factor.**

Problem: In A(e,e') the momentum of the struck proton (p_i) is unknown.

Solution: For fixed high Q^2 and $x_B>1$, x_B determines a minimum p_i

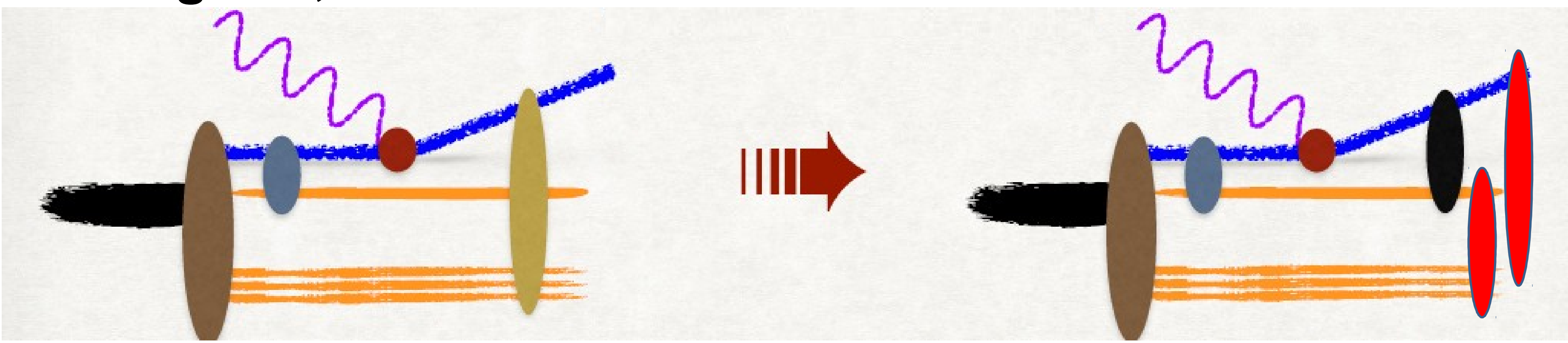
Prediction by Frankfurt, Sargsian, and Strikman:





FSI: Theory Guidance

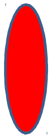
For large Q^2, x>1



$$r_{FSI} \sim \frac{1}{\Delta E v} \lesssim 1 \text{ fm}$$

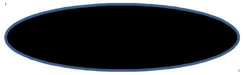
[PRC 56 1124-1137 (1997), arXiv: 0806.4412]

$$\Delta E = -q_0 - M_A + \sqrt{m^2 + (p_i + q)^2} + \sqrt{M_{A-1}^2 + p_i^2}$$



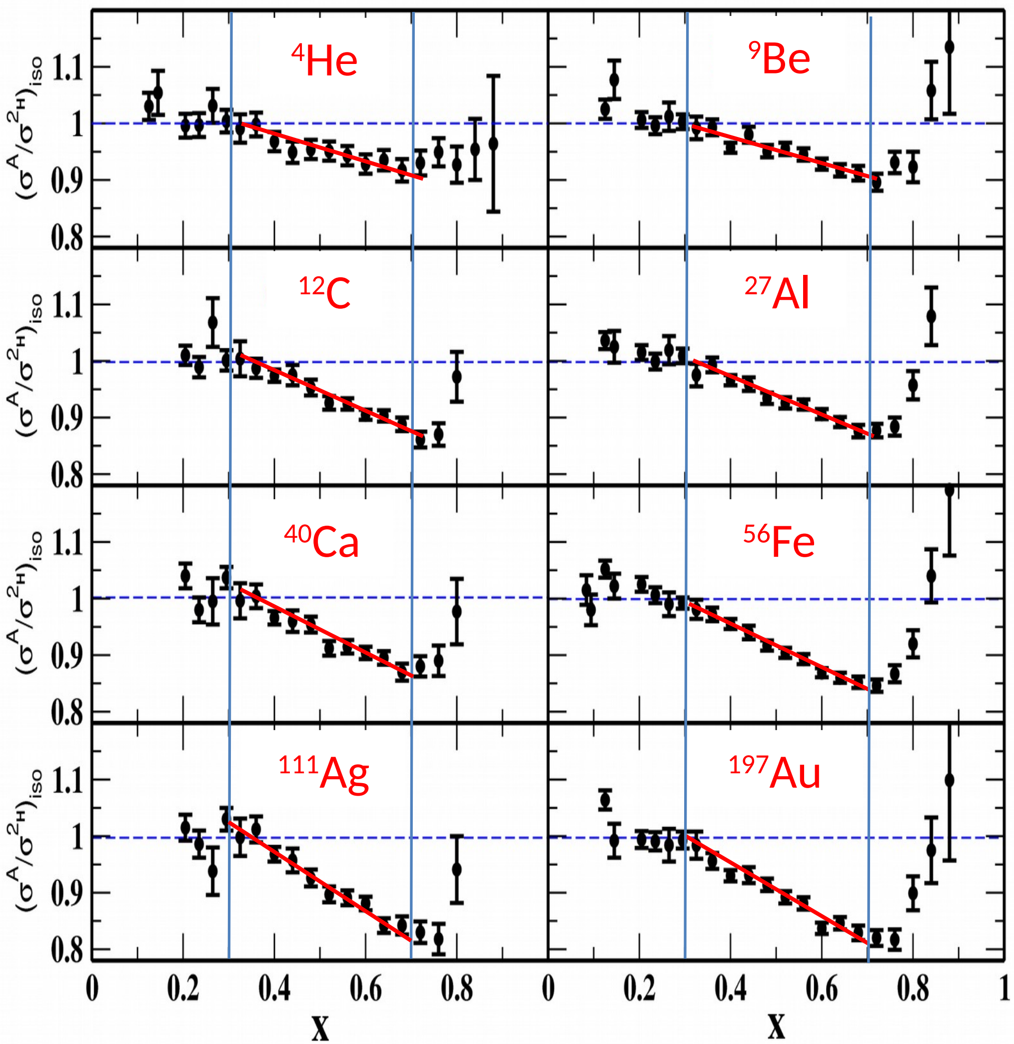
Can be approximated by Glauber (transparency)

Large but confined within the SRC pair

- **Choose kinematics to min FSI**
- **Choose observables not sensitive to** 

Rescattering do not produce 2N–SRC candidates due to high p_t

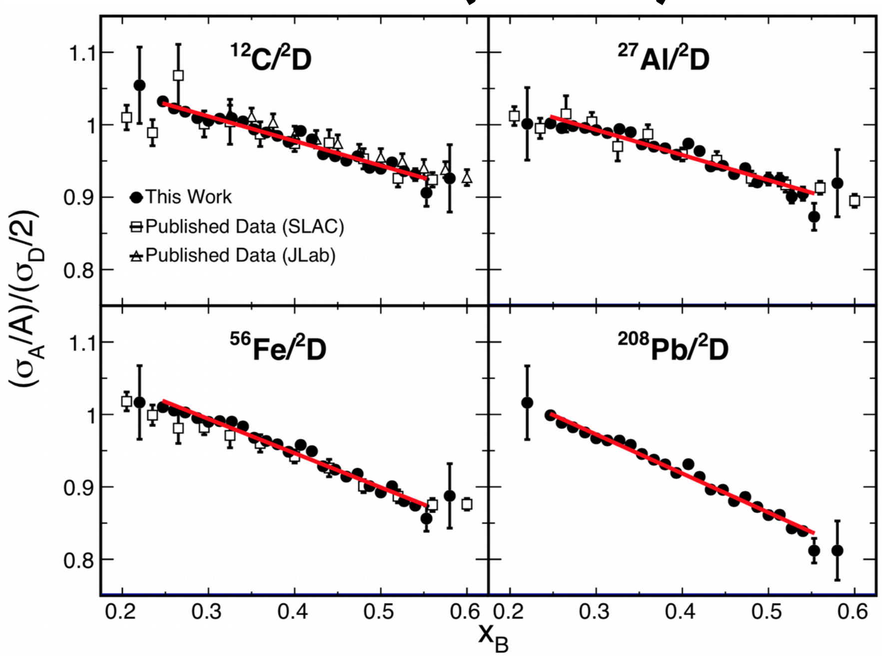
Nuclear Effect



Gomez PRD (1994)

SLAC (1994)

JLab (2018)



Schmookler, submitted (2018)