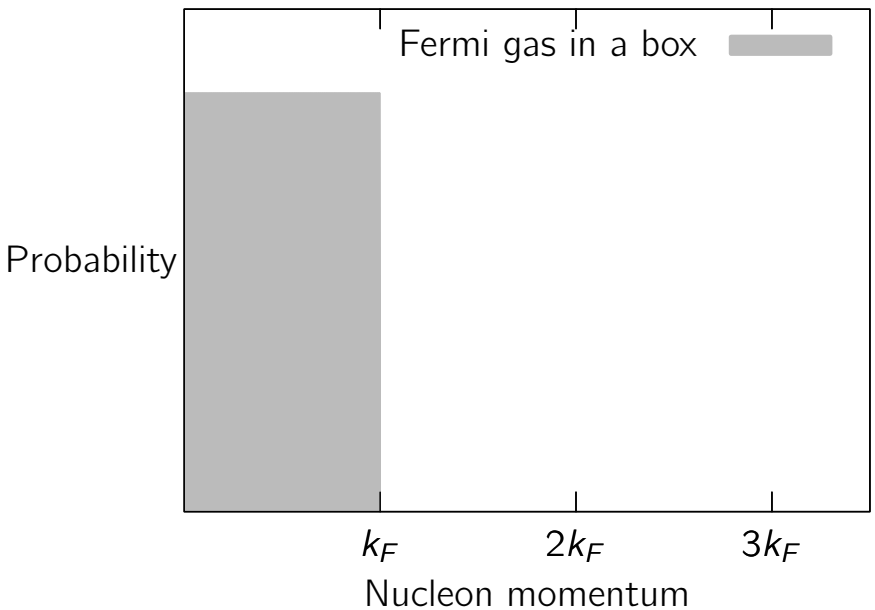
Short-range correlations in nuclei: an overview of experimental developments

Axel Schmidt

March 28, 2017

20% of nucleons in a nucleus belong to *short-range correlated pairs*.



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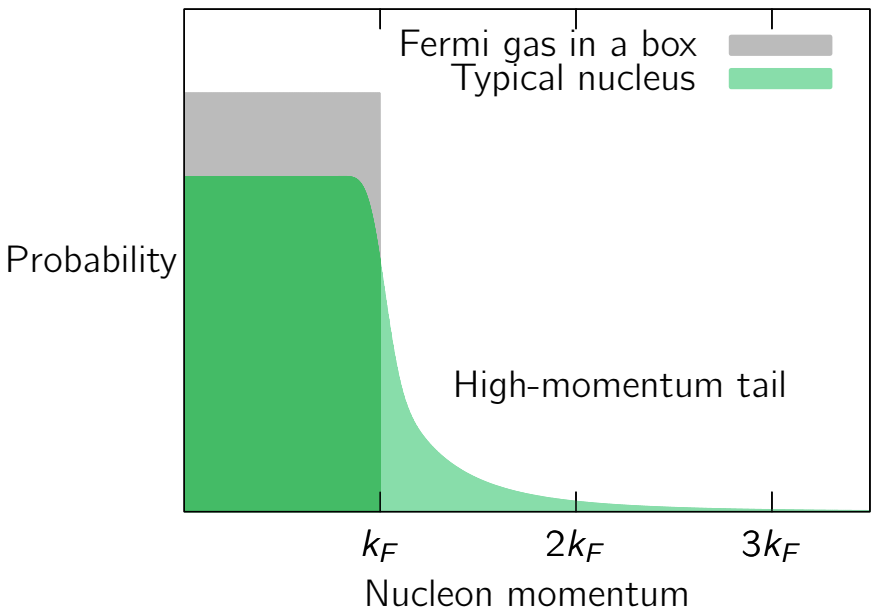
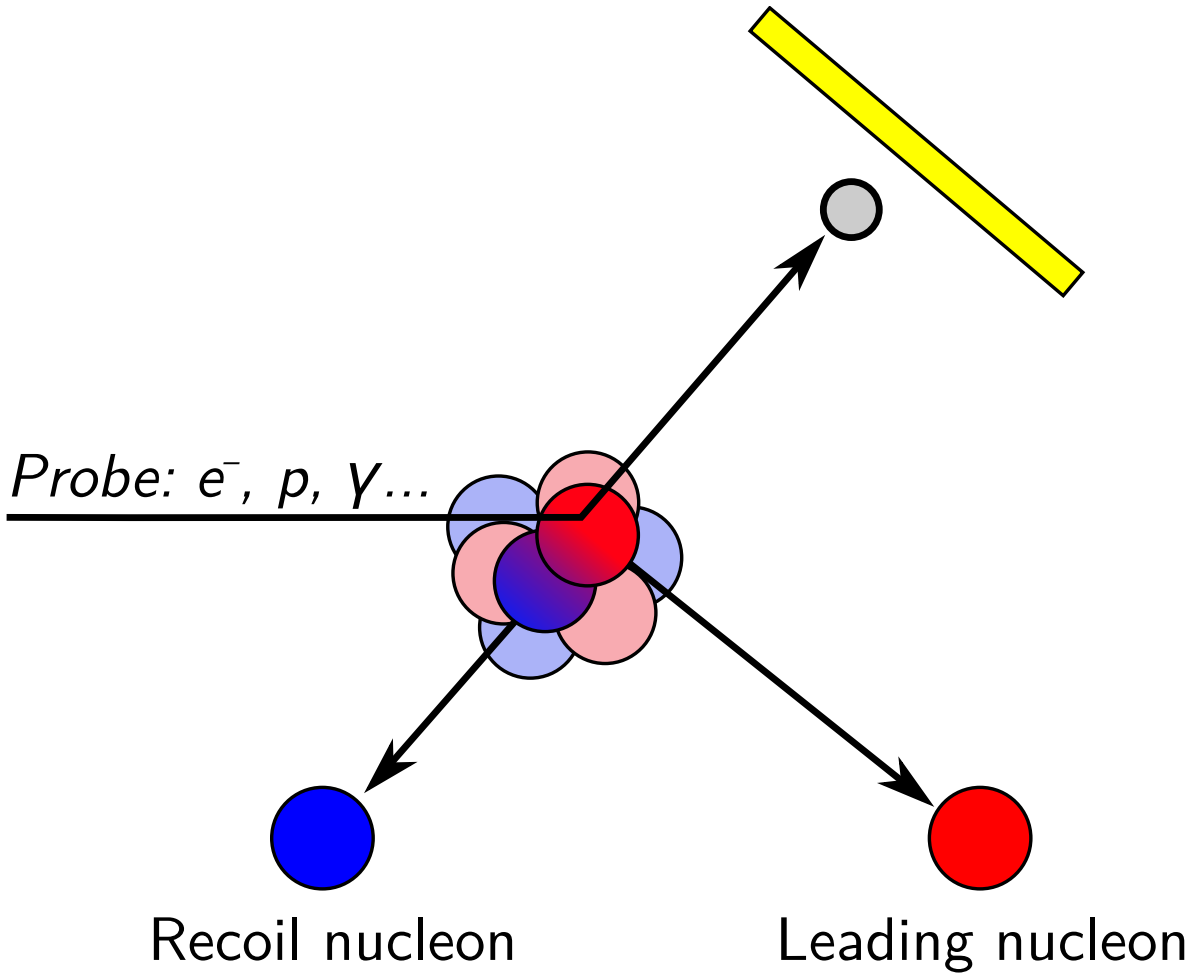


Characteristics:

- 60–70% of kinetic energy
- Correlated partner
  - High relative momentum ($> k_F$)
  - Low c.o.m momentum ($< k_F$)
  - $\approx 90\%$ np pairs for nucleons between 300–600 MeV

We can probe SRC pairs with hard knock-outs.



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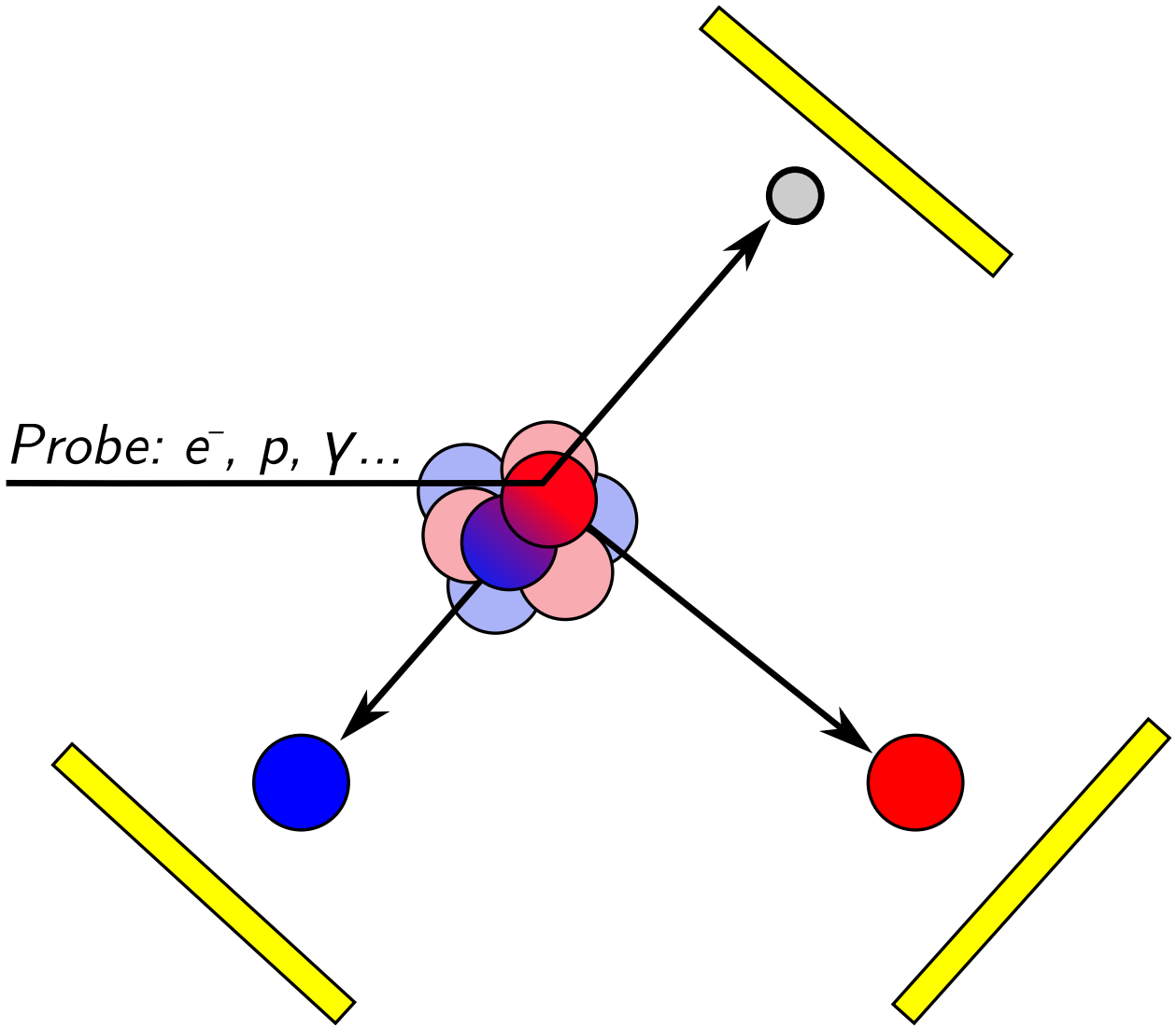
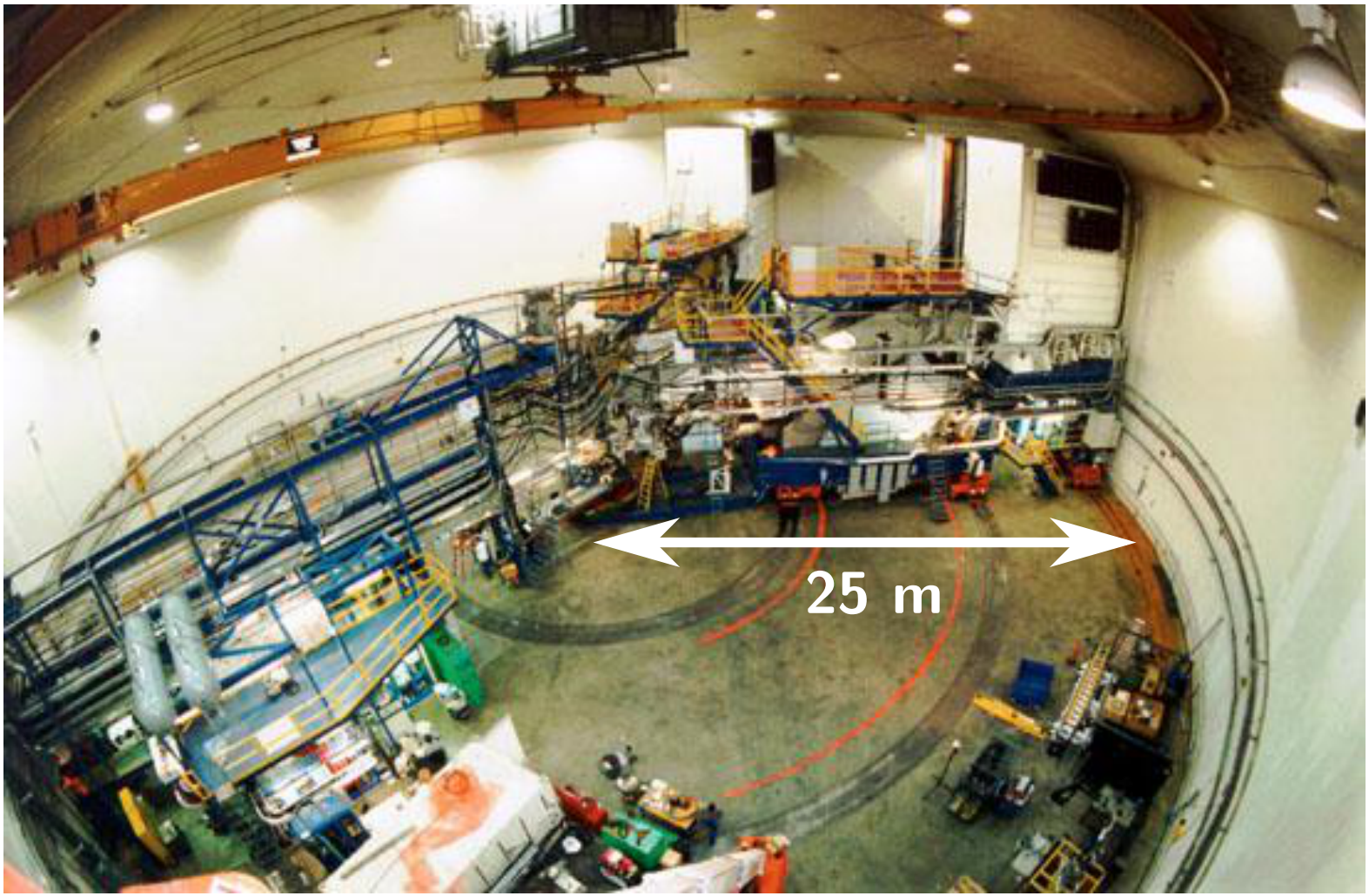


Example: high-resolution spectrometers

Jefferson Lab Hall A



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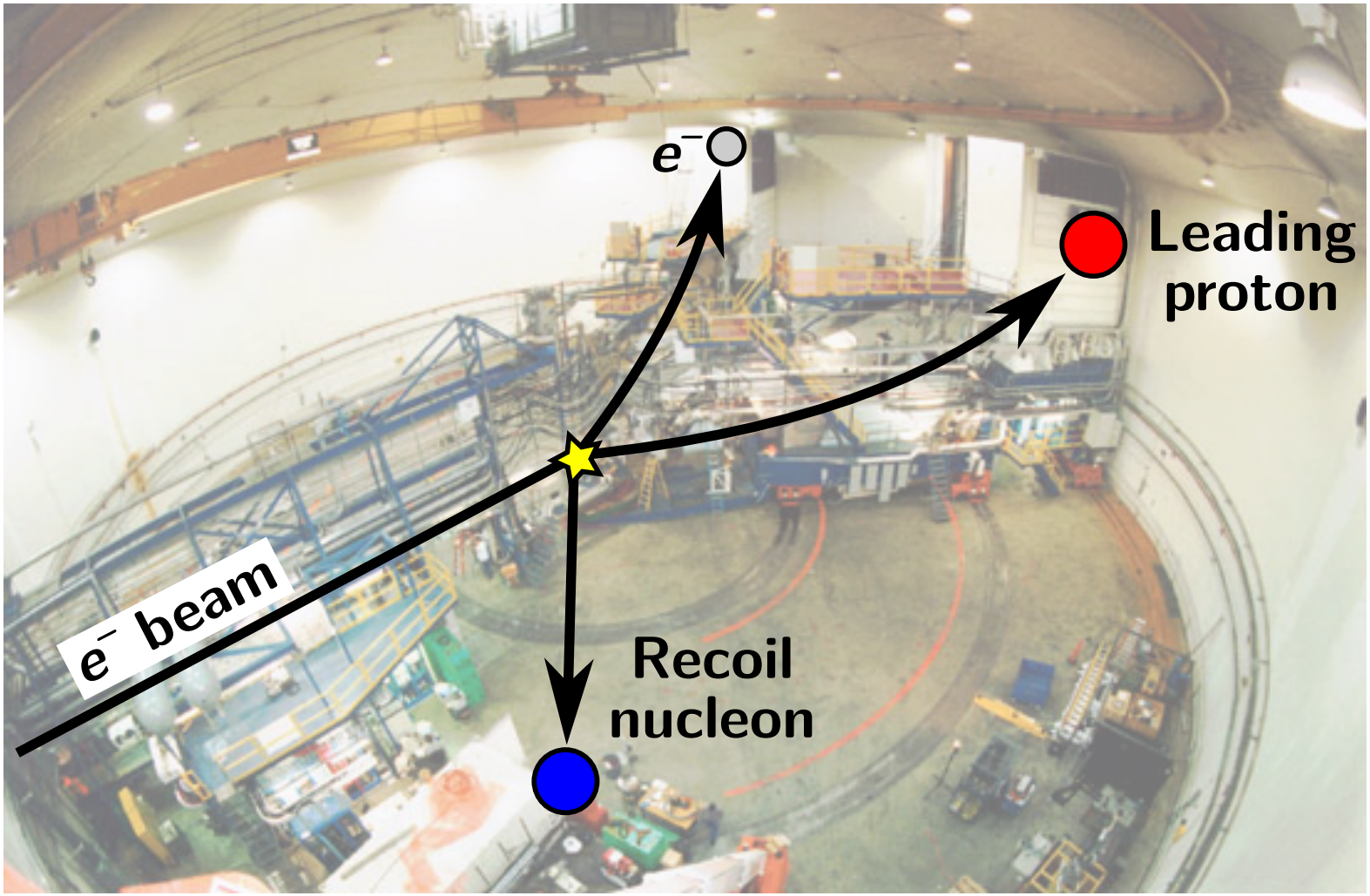
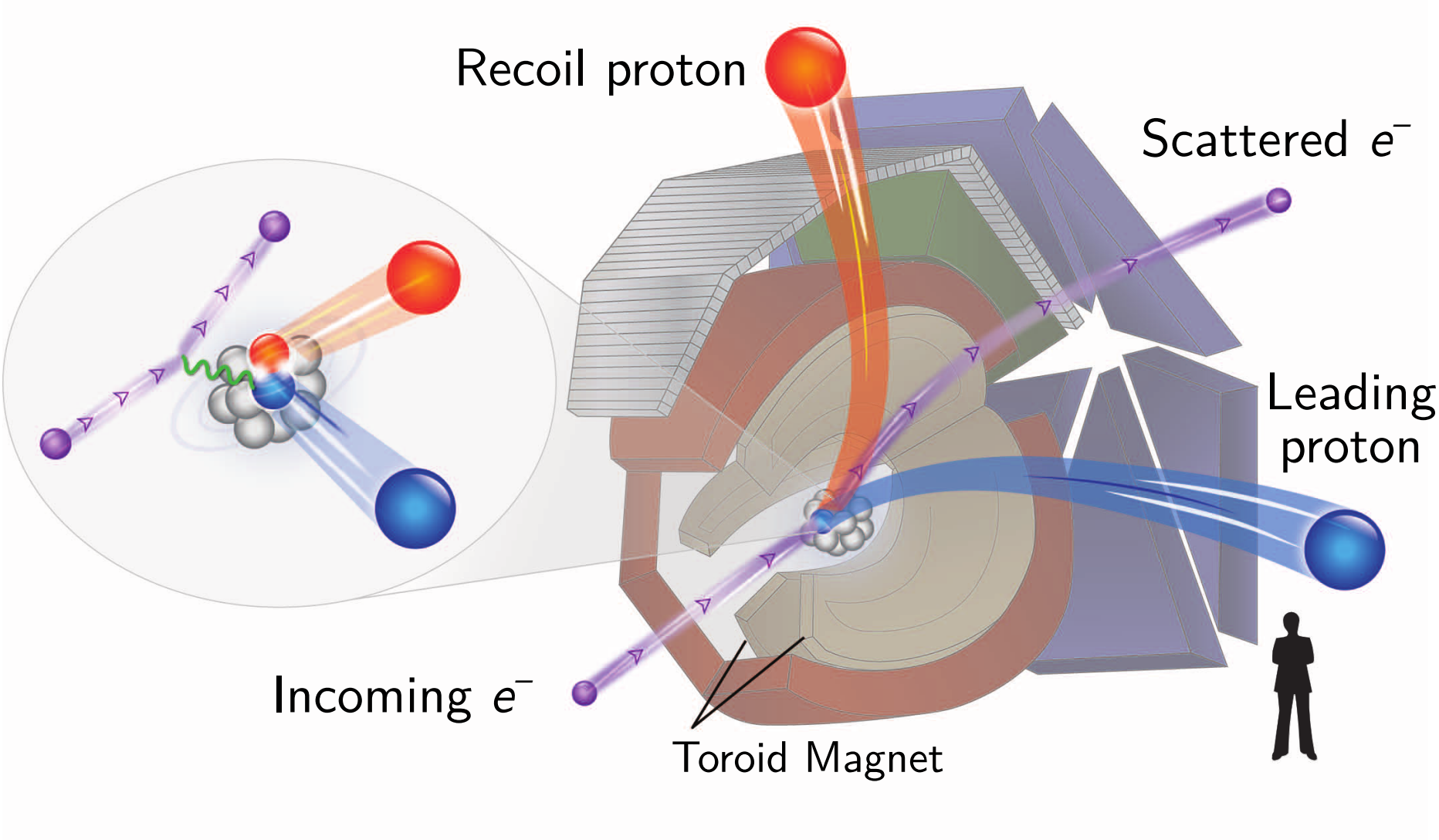


Example: large acceptance spectrometers

CLAS (Hall B)



An experimental overview of SRC pairs

1. The Past
   - Previous experiments that tell us what we know
2. The Present
   - Exciting recent developments
3. The Future
   - What questions do we want to answer?

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1. **The Past**
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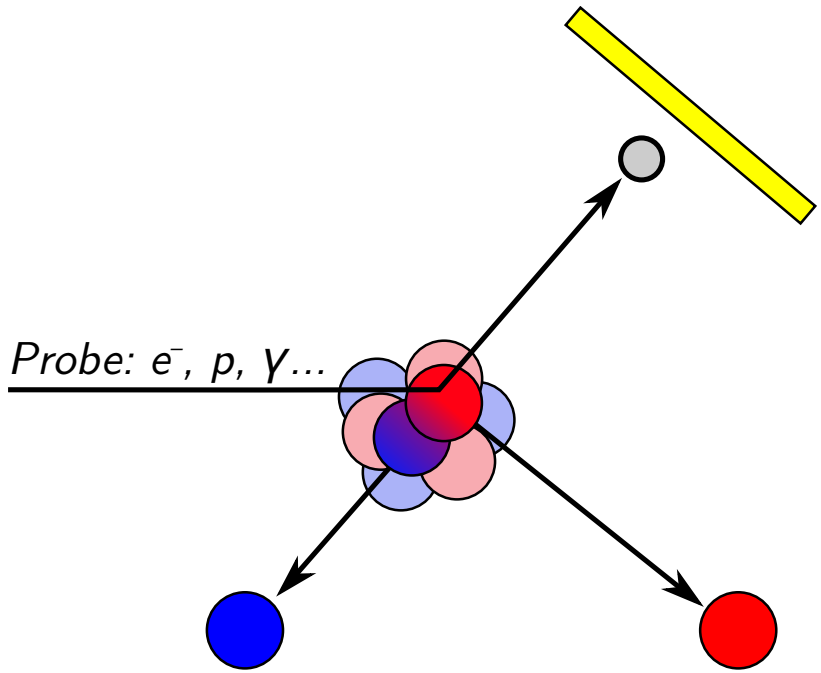
Early signs of short-range correlations came from inclusive eA scattering.



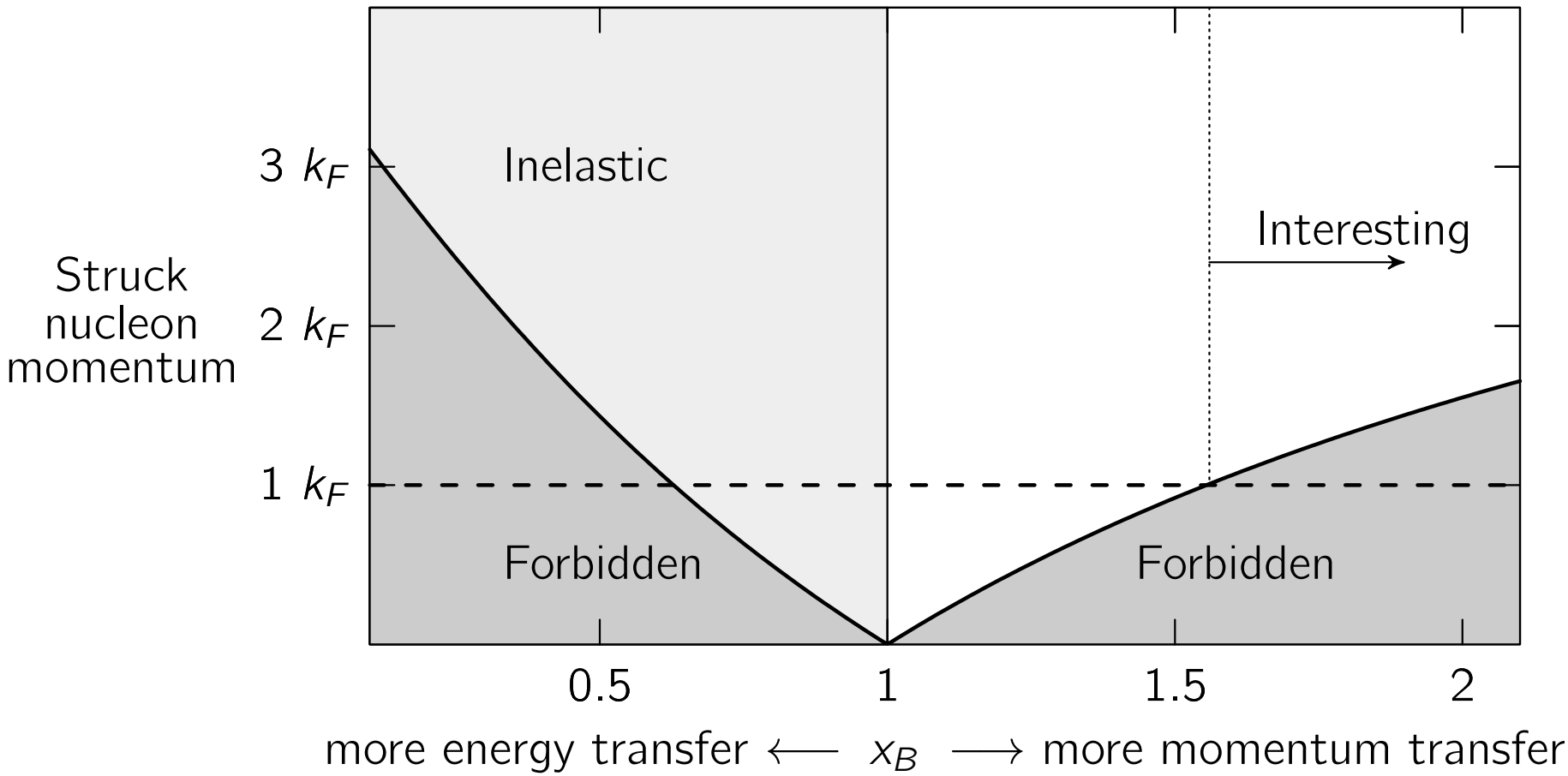
Measure:

1. Scattering angle
2. Momentum

Kinematical variables:

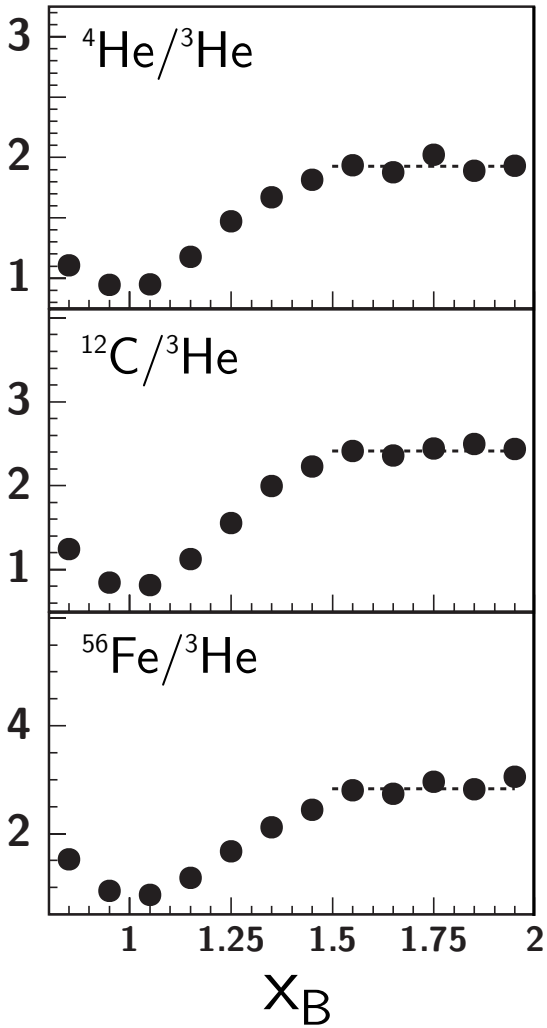
1. $Q^2 = -(p_e - p'_e)^2$: resolution scale
2. $x_B = Q^2/2m(E - E')$: dynamic scale

High-momentum nuclei can be selected by restricting only the e^- kinematics.

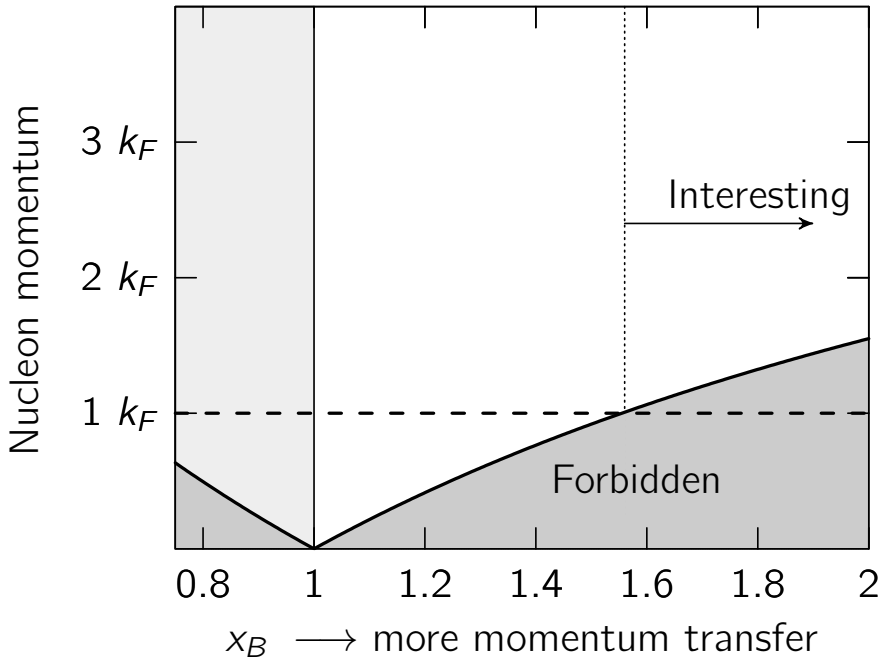


High-x_B cross sections scale!

$$\frac{3 \cdot \sigma_A}{A \cdot \sigma_{^3He}}$$



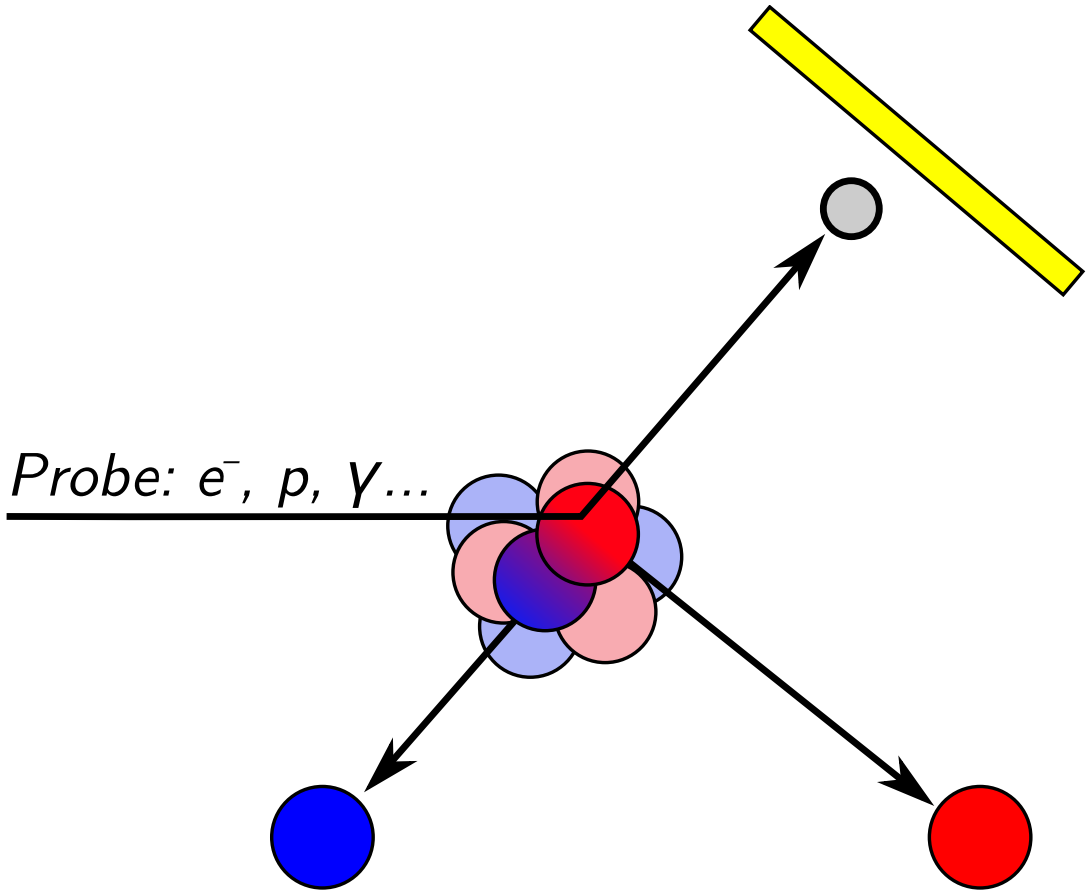
K.S. Egiyan et al. PRL 96, 082501(2006)



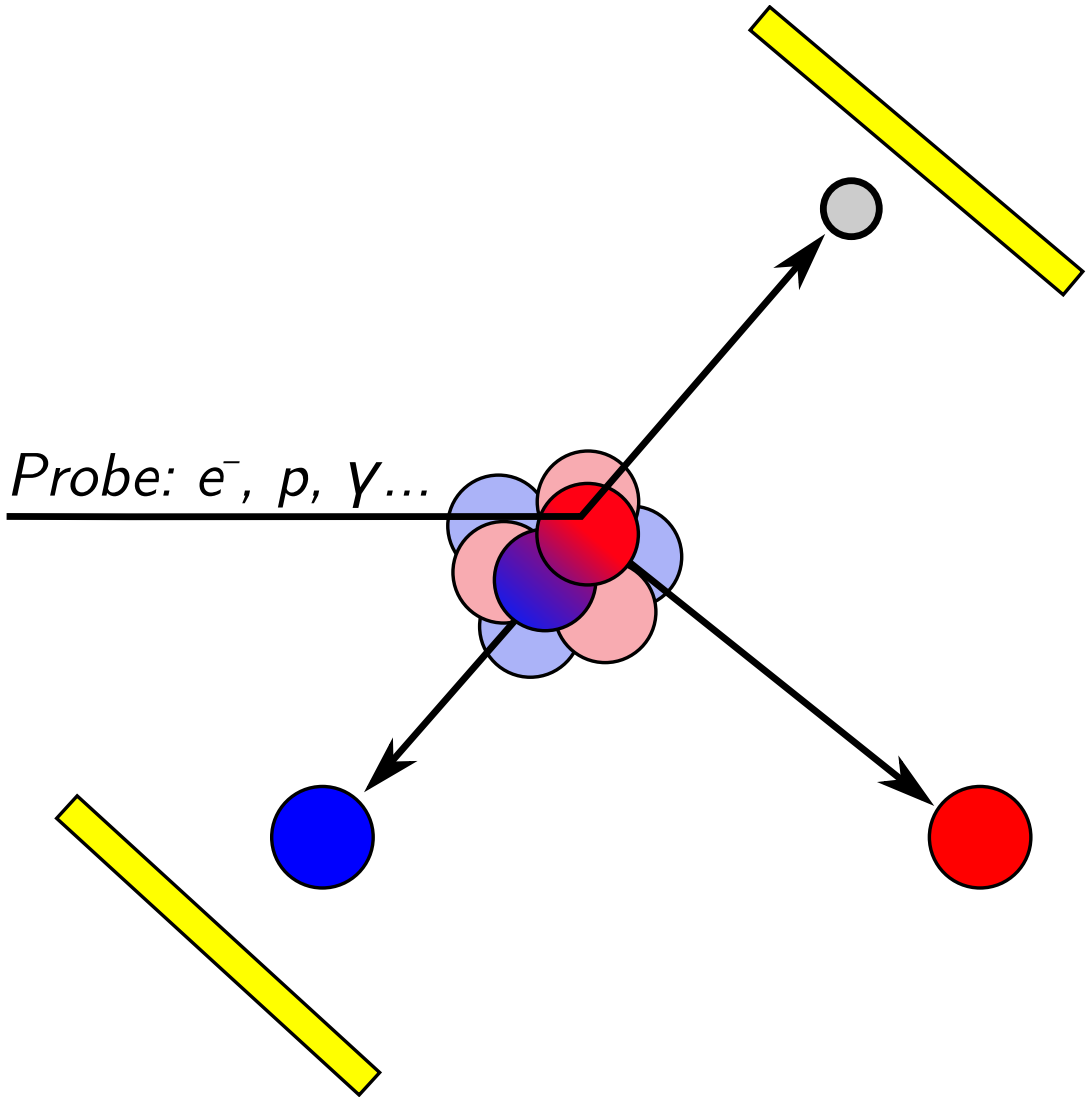
Scaling constant a_2:

$$\sigma_A = \mathbf{a_2} \times \frac{A}{2}\sigma_d$$

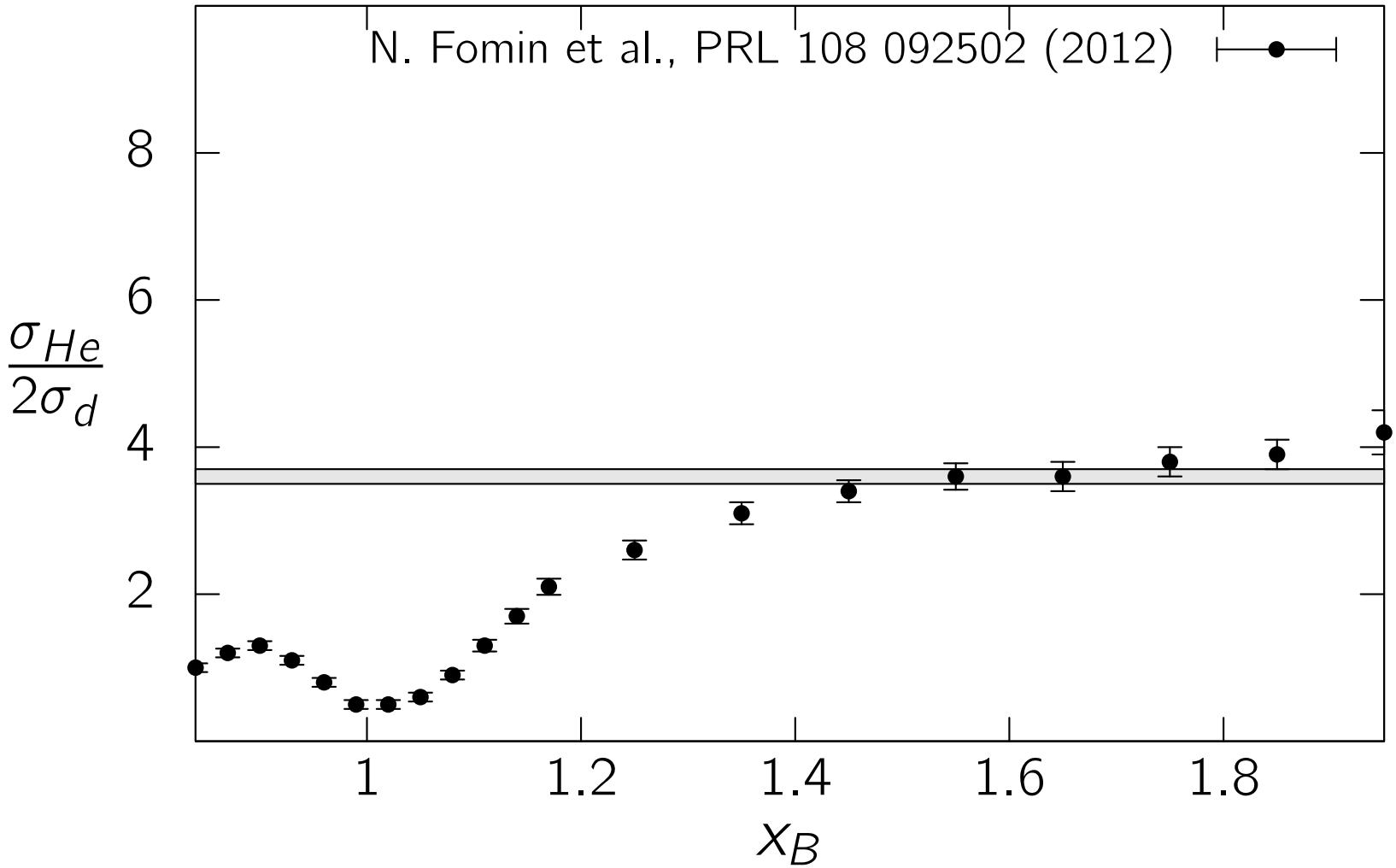
Tagging a recoil ensures high momentum.



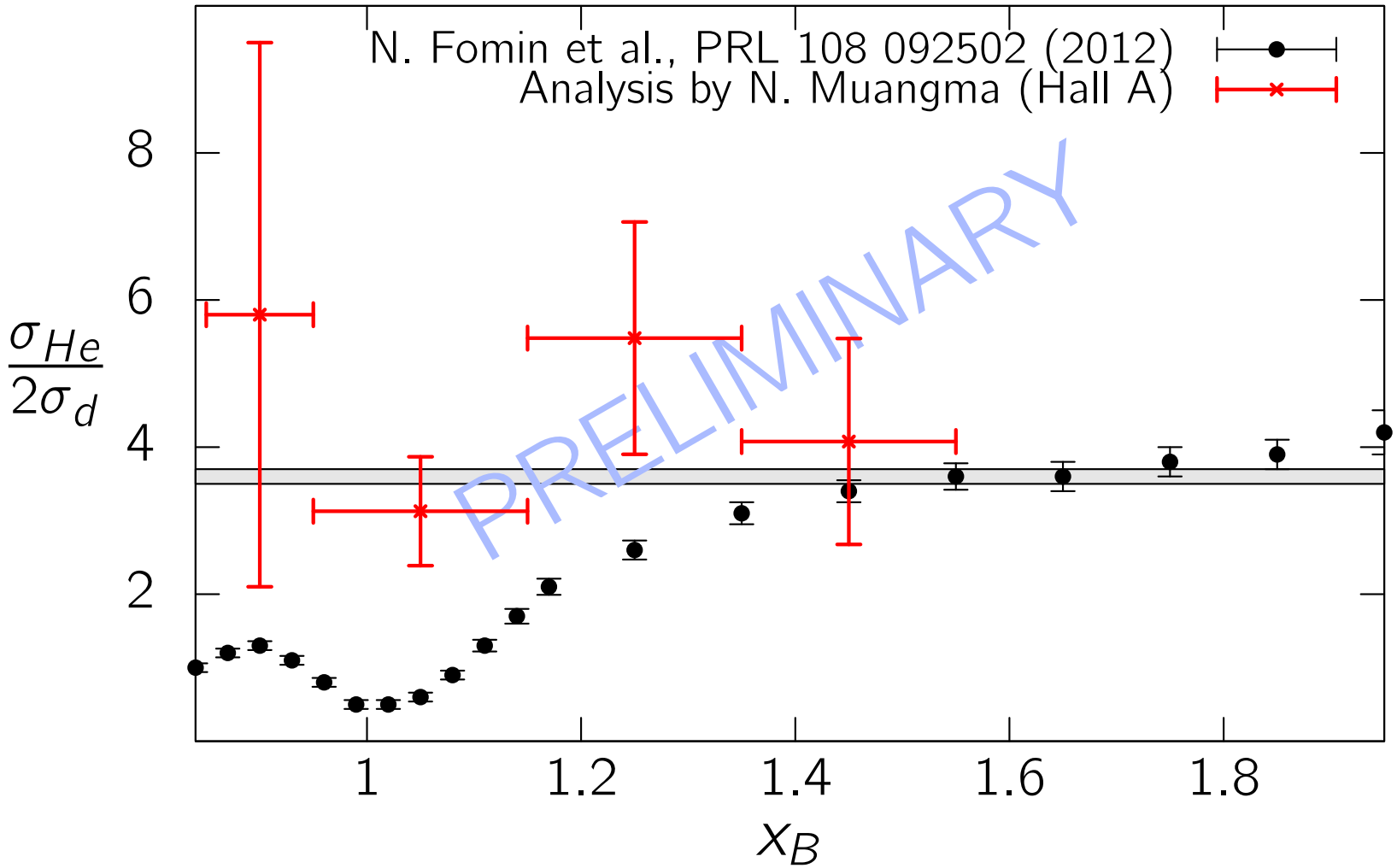
Tagging a recoil ensures high momentum.



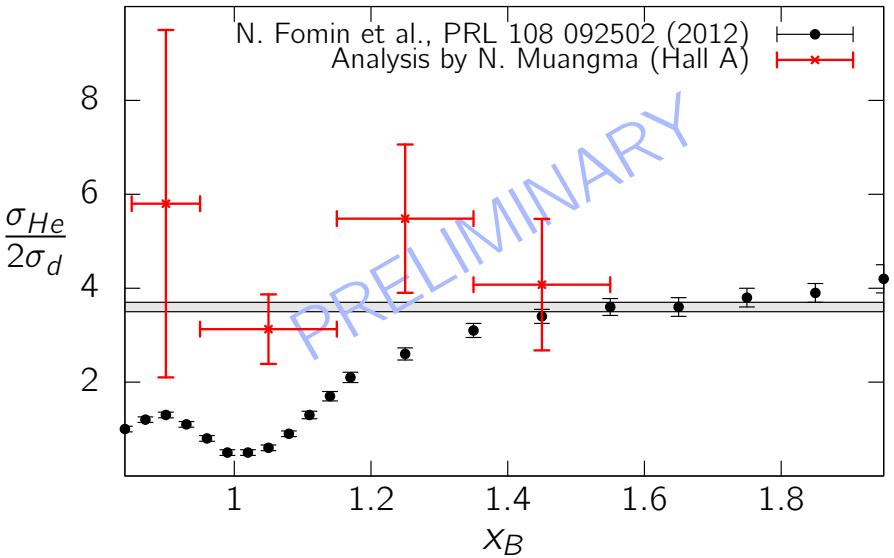
Without tagging, scaling starts at $x_B \approx 1.5$.

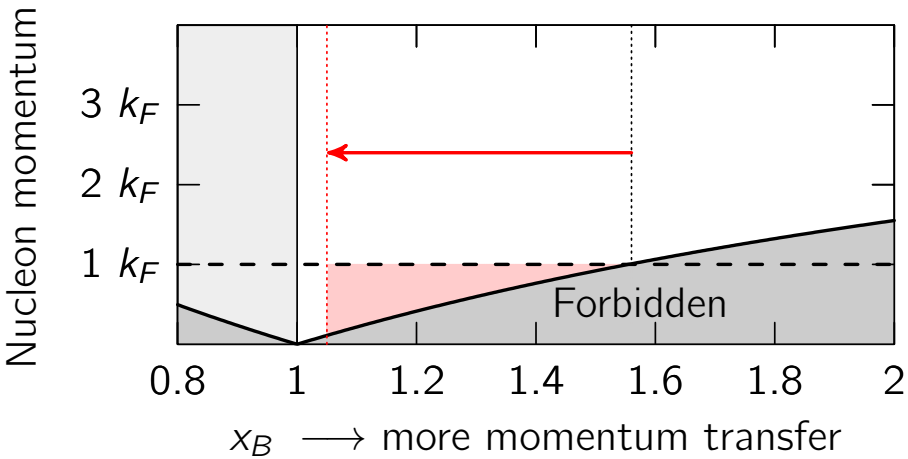


Recoil tagging can extend the scaling region!



Conclusions from inclusive scattering:

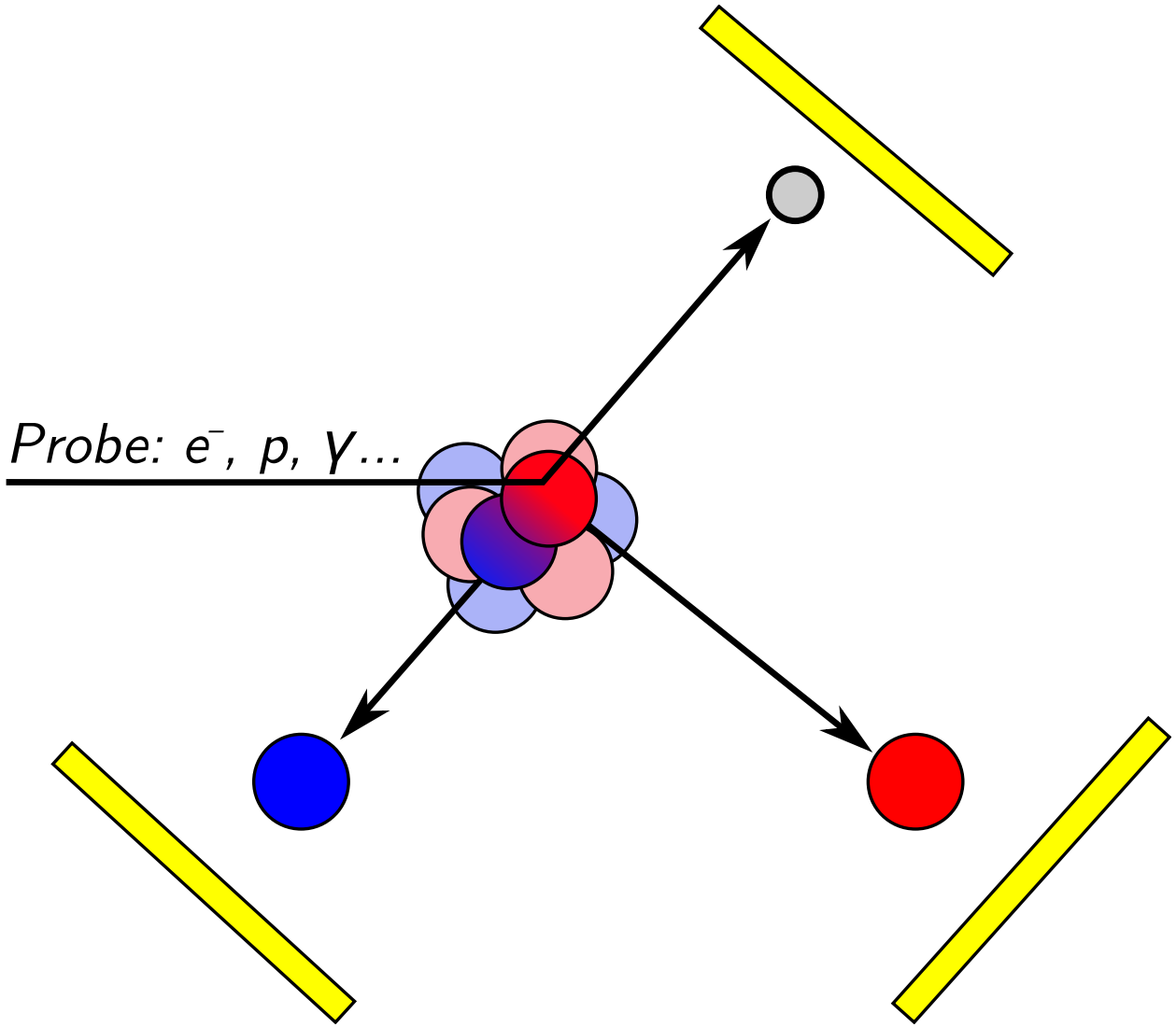




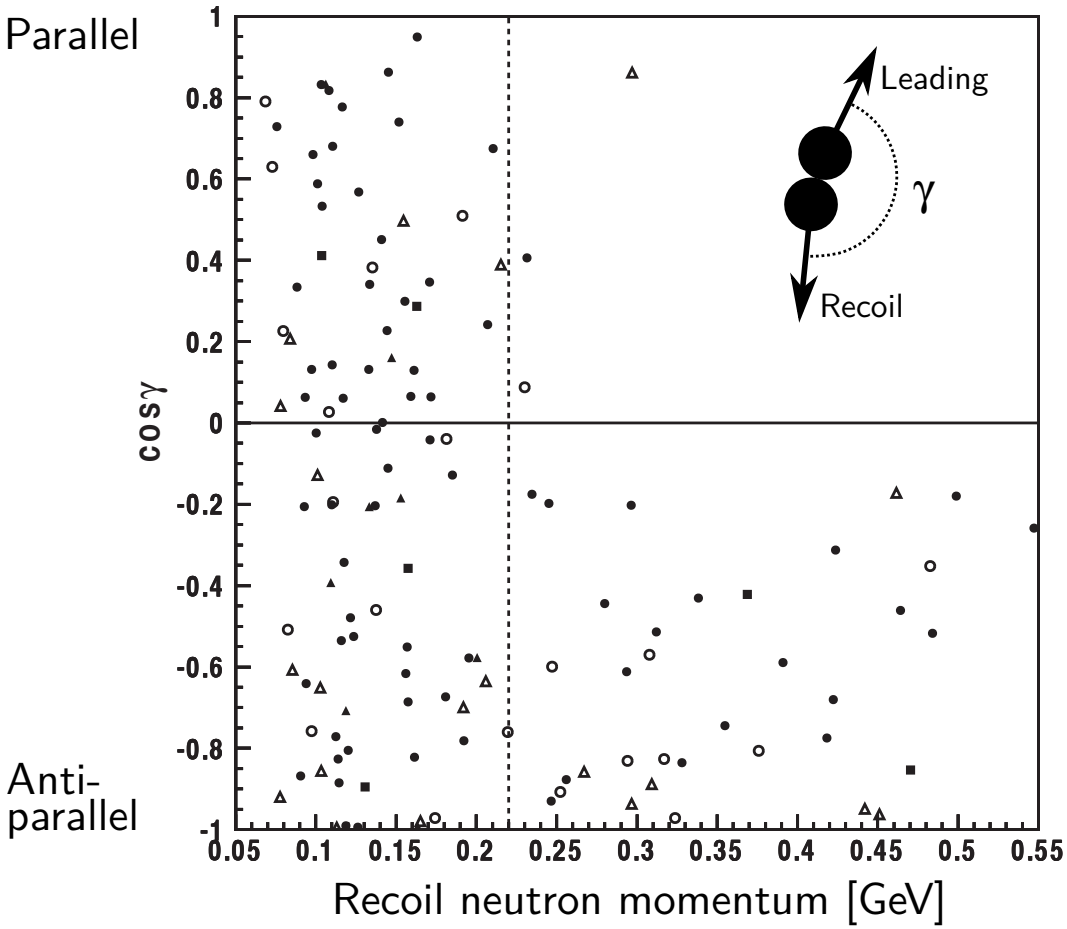
- Universal shape to high-momentum tail
- Independent of size/density
- Approximately 20% of nucleons

- Hints of correlated pairs.

Exclusive measurements show correlated pairs.



Correlated pairs are back-to-back.

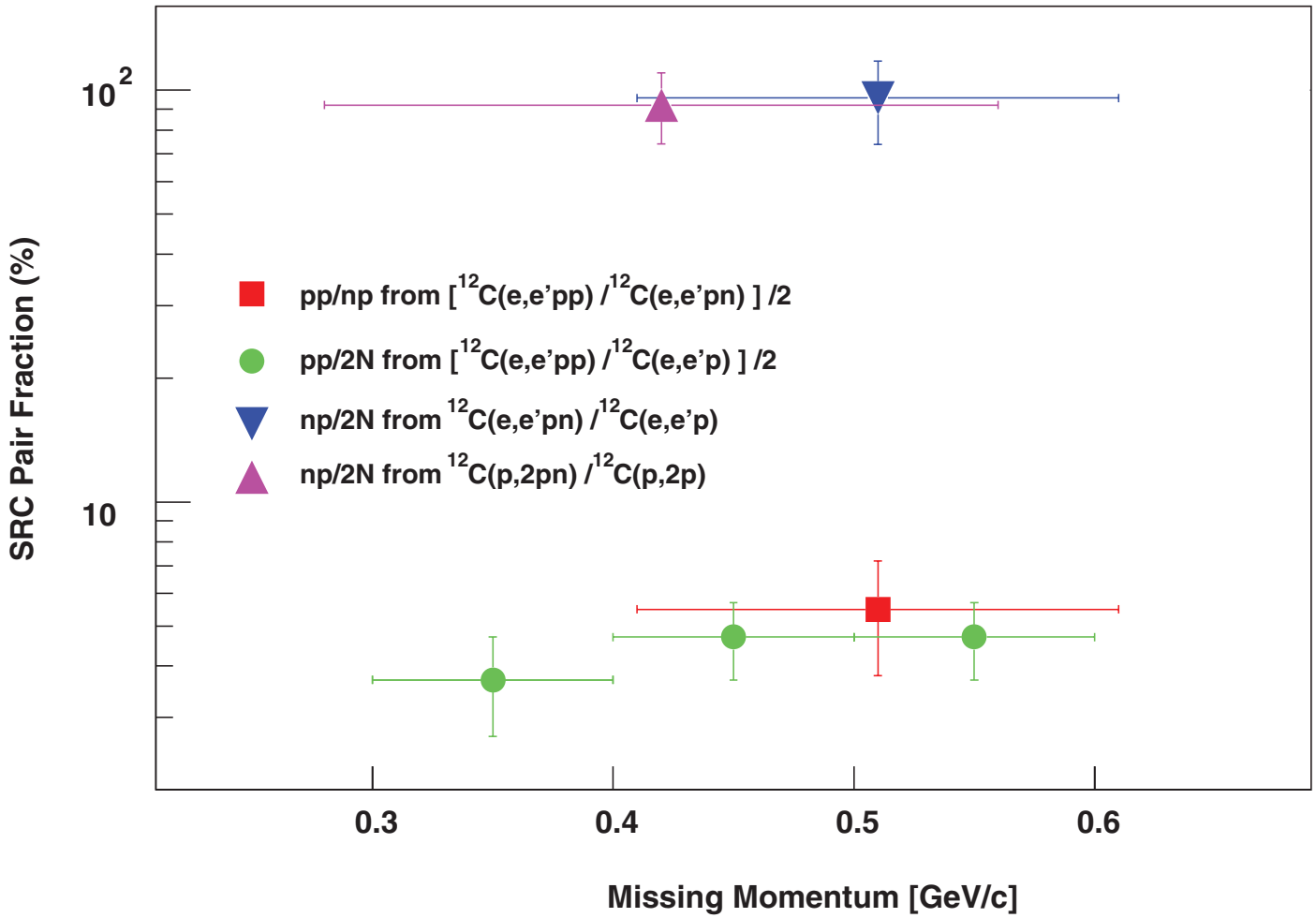


p scattering from Carbon:

- Always a correlated partner
- Anti-parallel momenta

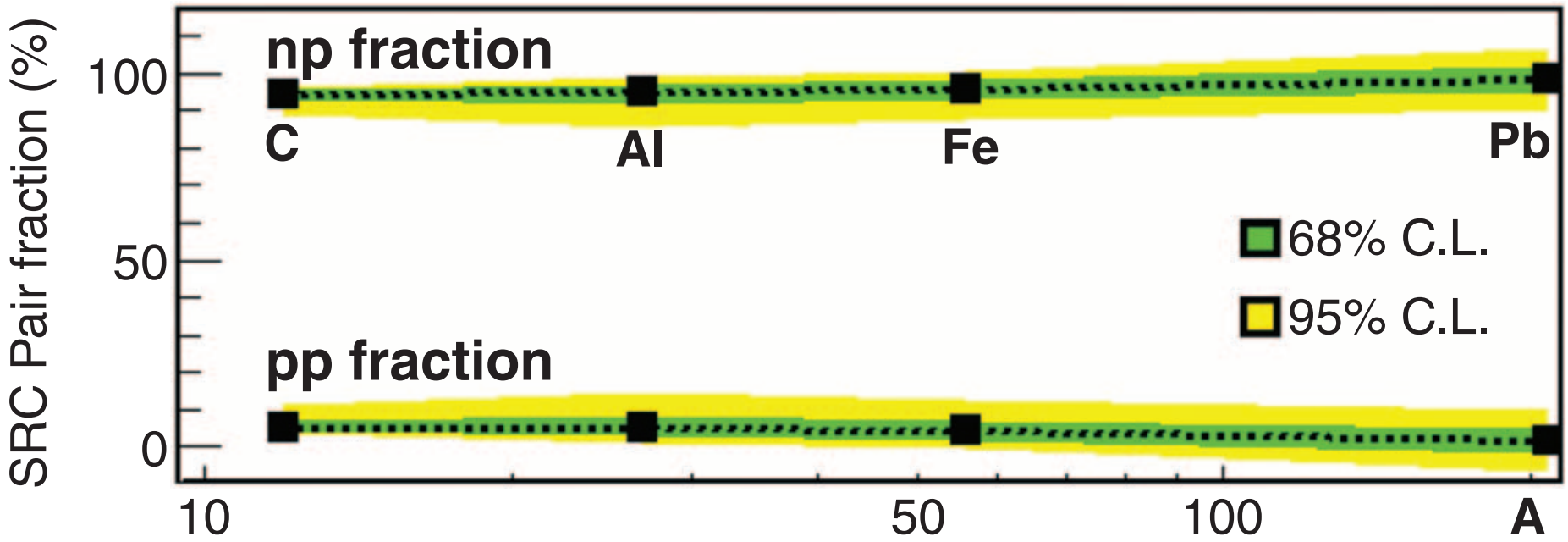
J.L.S. Aclander et al., Phys. Lett. B 453, 211 (1999)
A. Tang et al., Phys. Rev. Lett. 90, 042301 (2003)
E. Piasetzky et al., PRL 97 162504 (2006)

From $k \approx 300$–600 MeV/c, *np* pairs dominate.



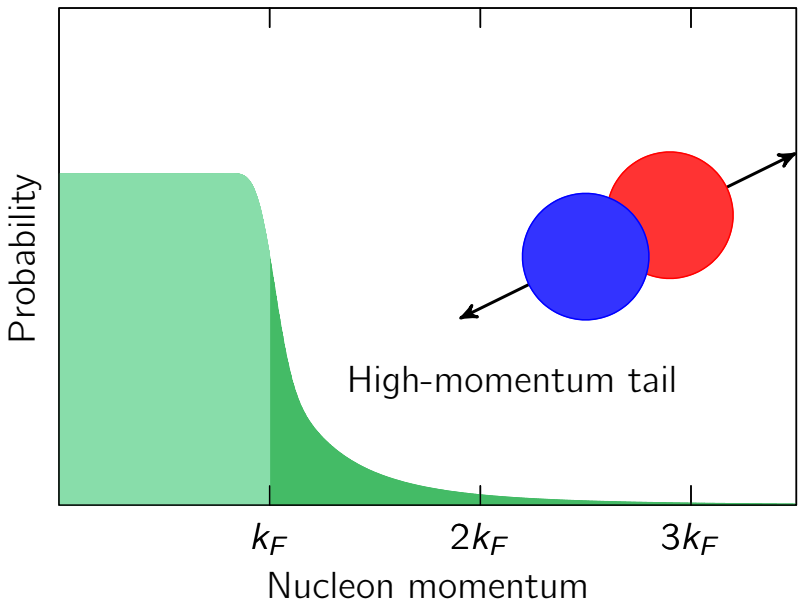
E. Piasetzky et al., PRL 97 162504 (2006)
R. Shneor et al., Phys. Rev. Lett. 99, 072501 (2007)
R. Subedi et al., Science 320, 1476 (2008)

This has been verified over many nuclei.



O. Hen et al, Science 346, 614 (2014)

A quick recap



- $\approx 20\%$ of nucleons have $k > k_F$.
- Mom. distributions scale for large k.
- High-momentum nuclei have correlated partner.
- The two momenta are back-to-back.
- 90% of pairs are neutron-proton.

An experimental overview of SRC pairs

1. The Past
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   - **Exciting recent developments**
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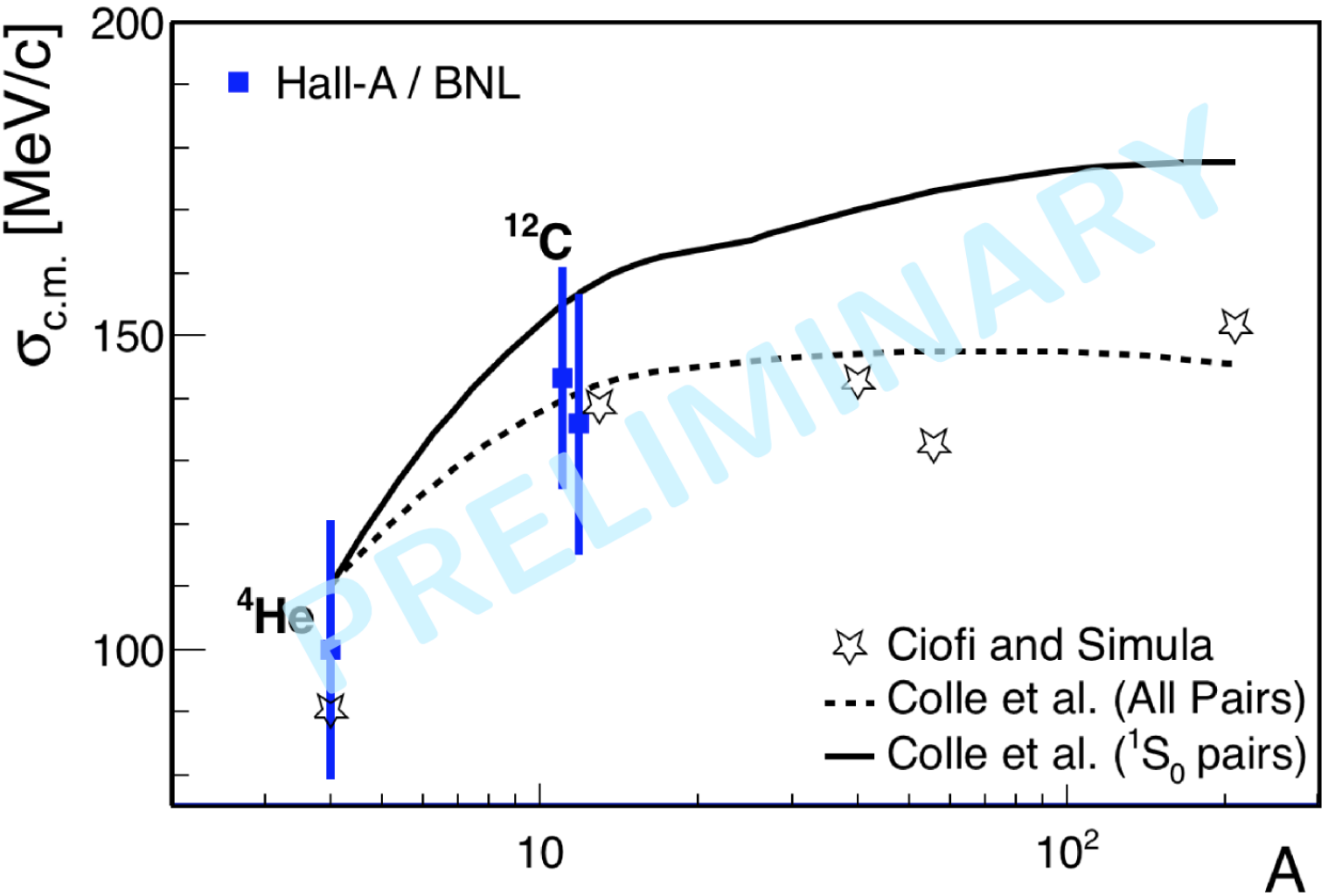
Three highlights from CLAS data mining

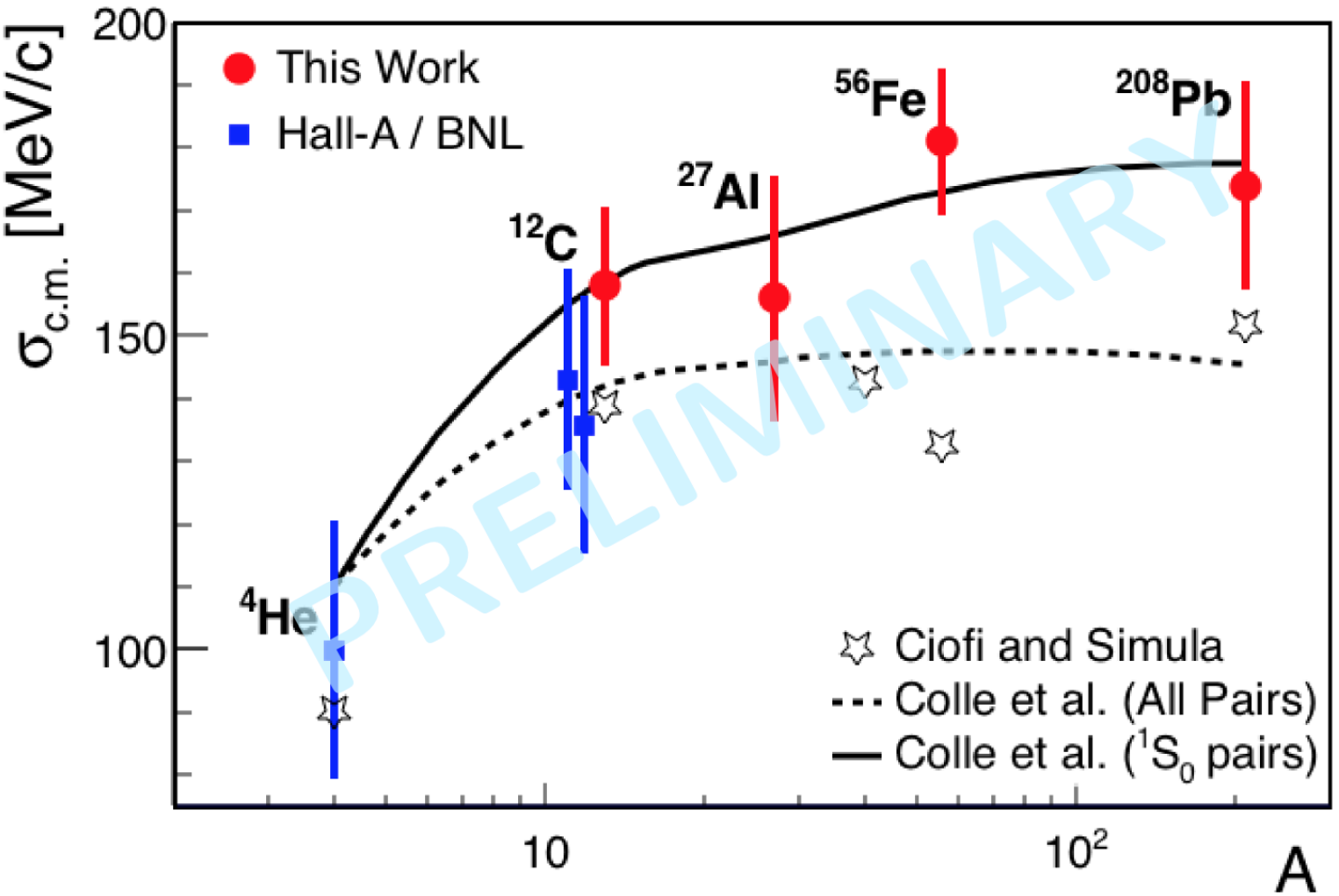
1. Center-of-mass momentum distributions of short-range pairs
   - See talk by Erez Cohen!
2. The evolution of *np* dominance with momentum
3. Kinetic energy in asymmetric nuclei
   - See talk by Meytal Duer!

Only previous data are on ^{12}C and ^{4}He.



See talk by Erez Cohen.

The C.M. width saturates for large A.



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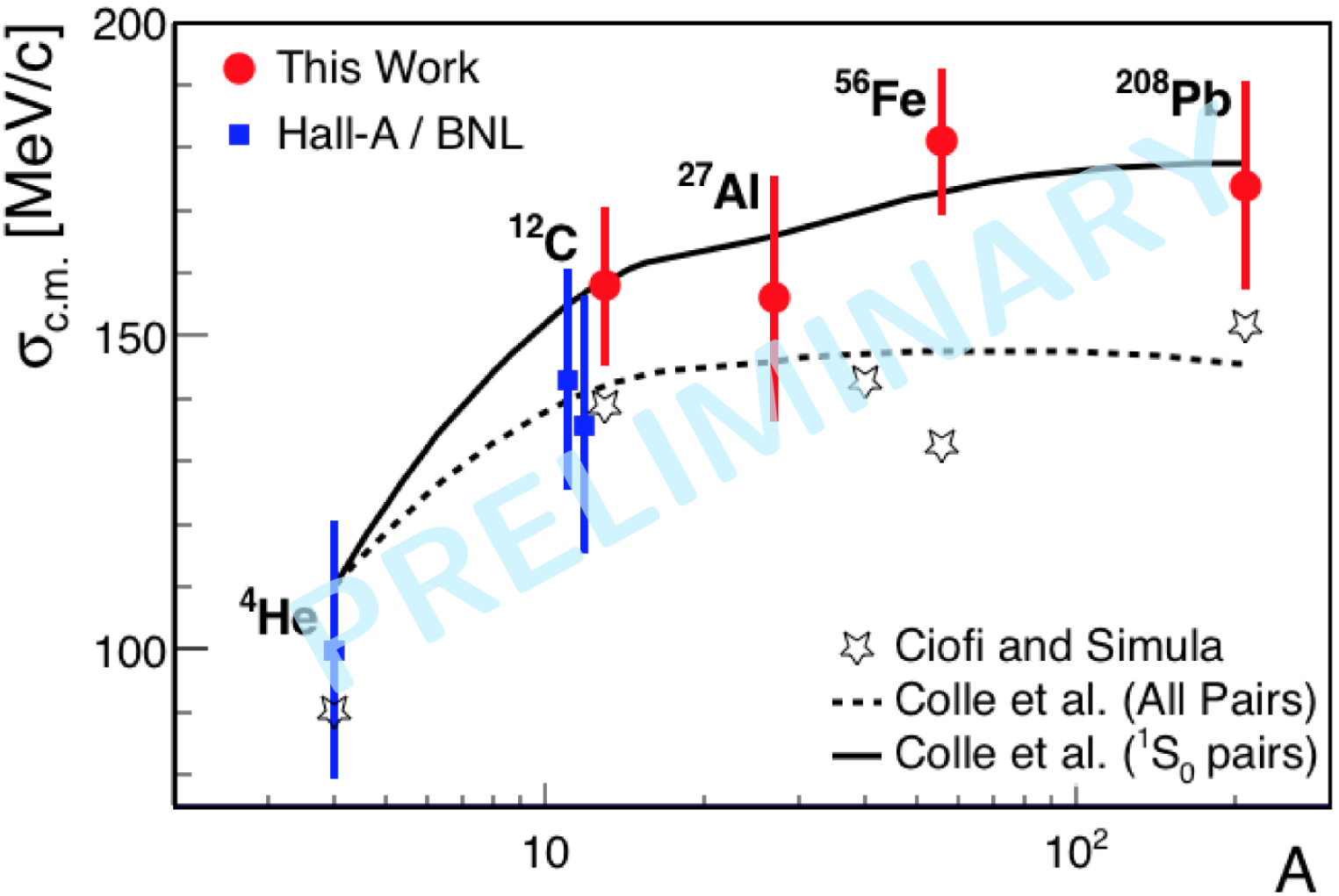
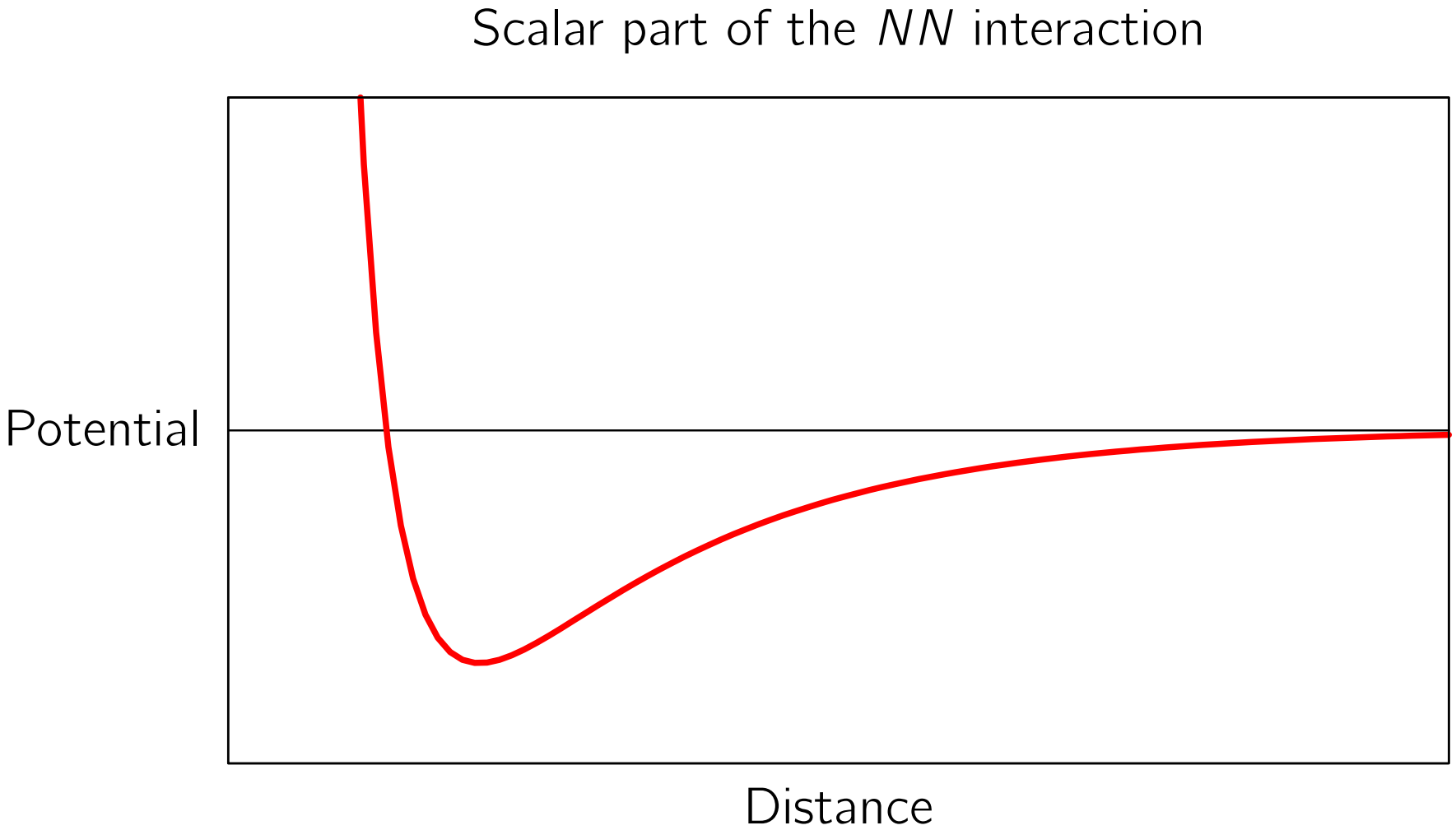


Also see talks by R. Weiss, R. Cruz Torres, C. Ciofi degli Atti

np dominance comes from tensor interaction.



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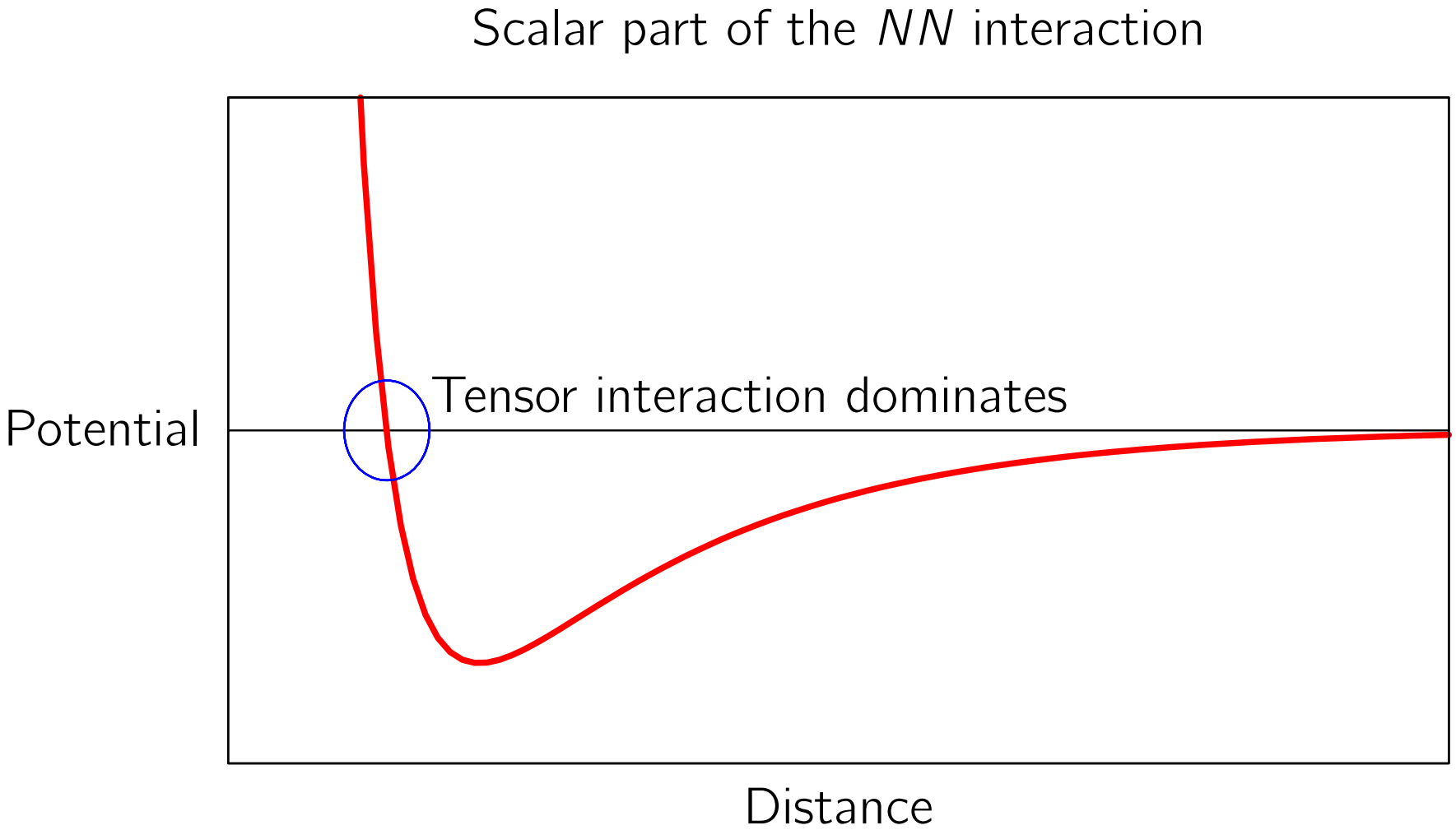

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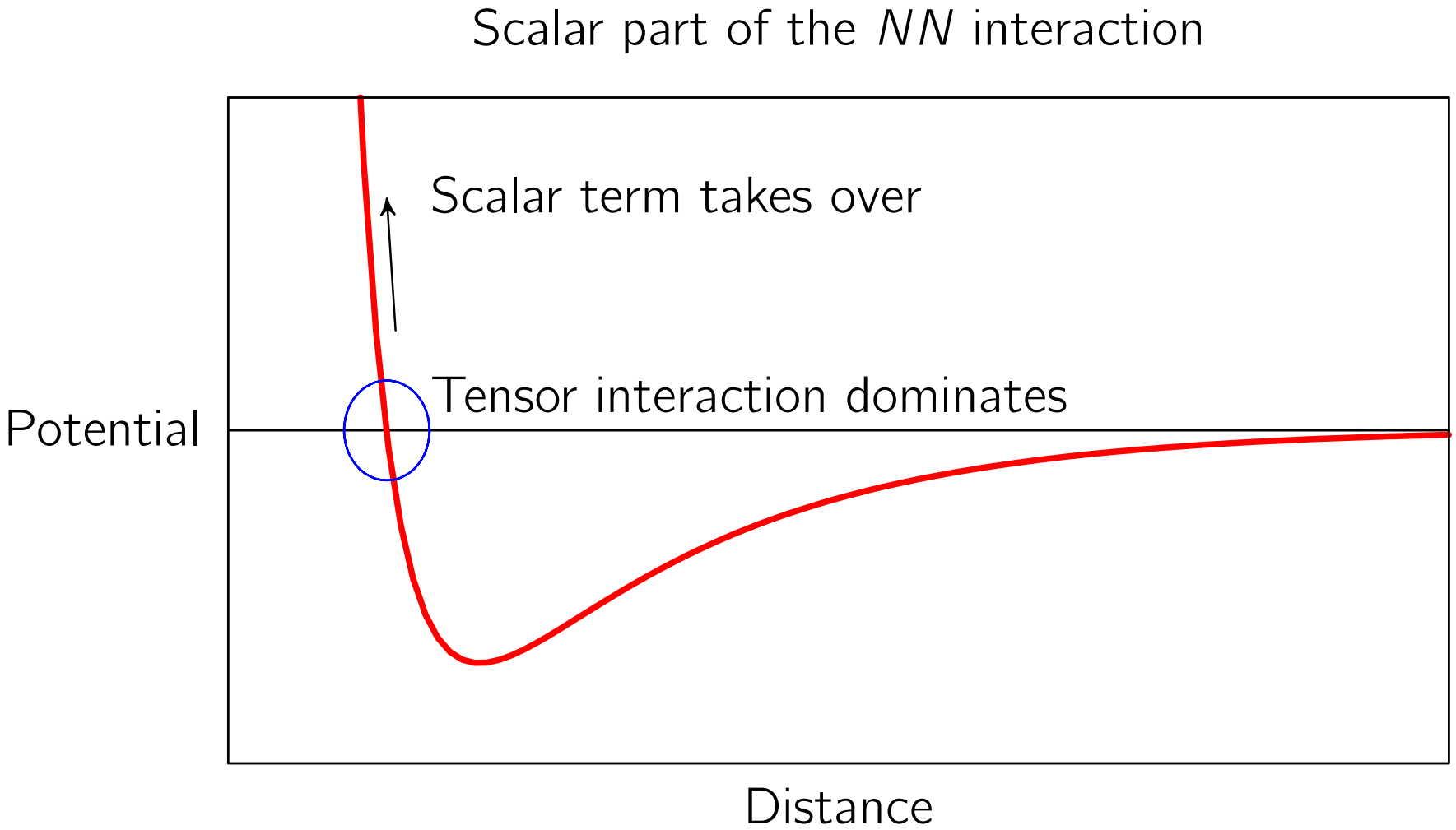
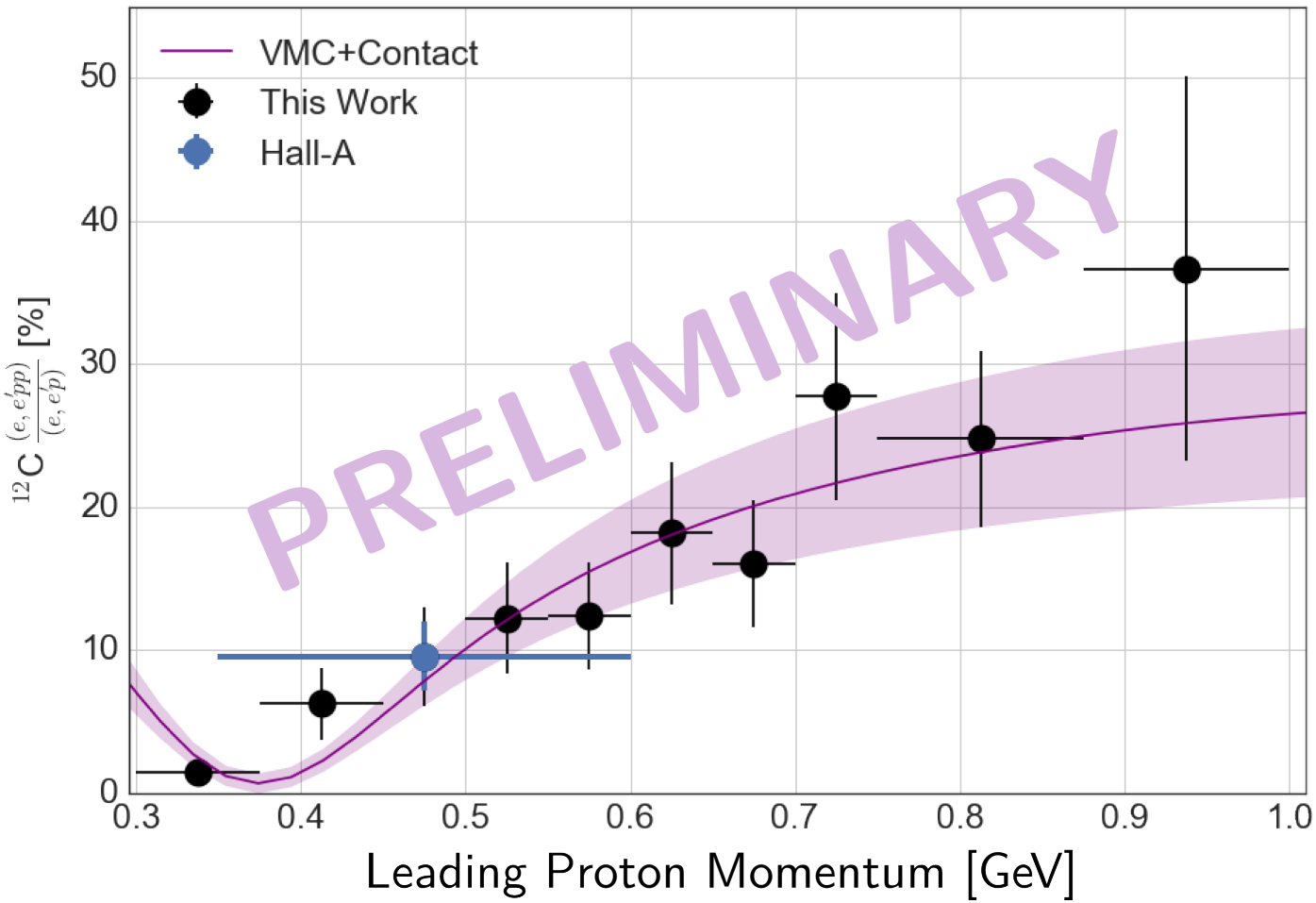


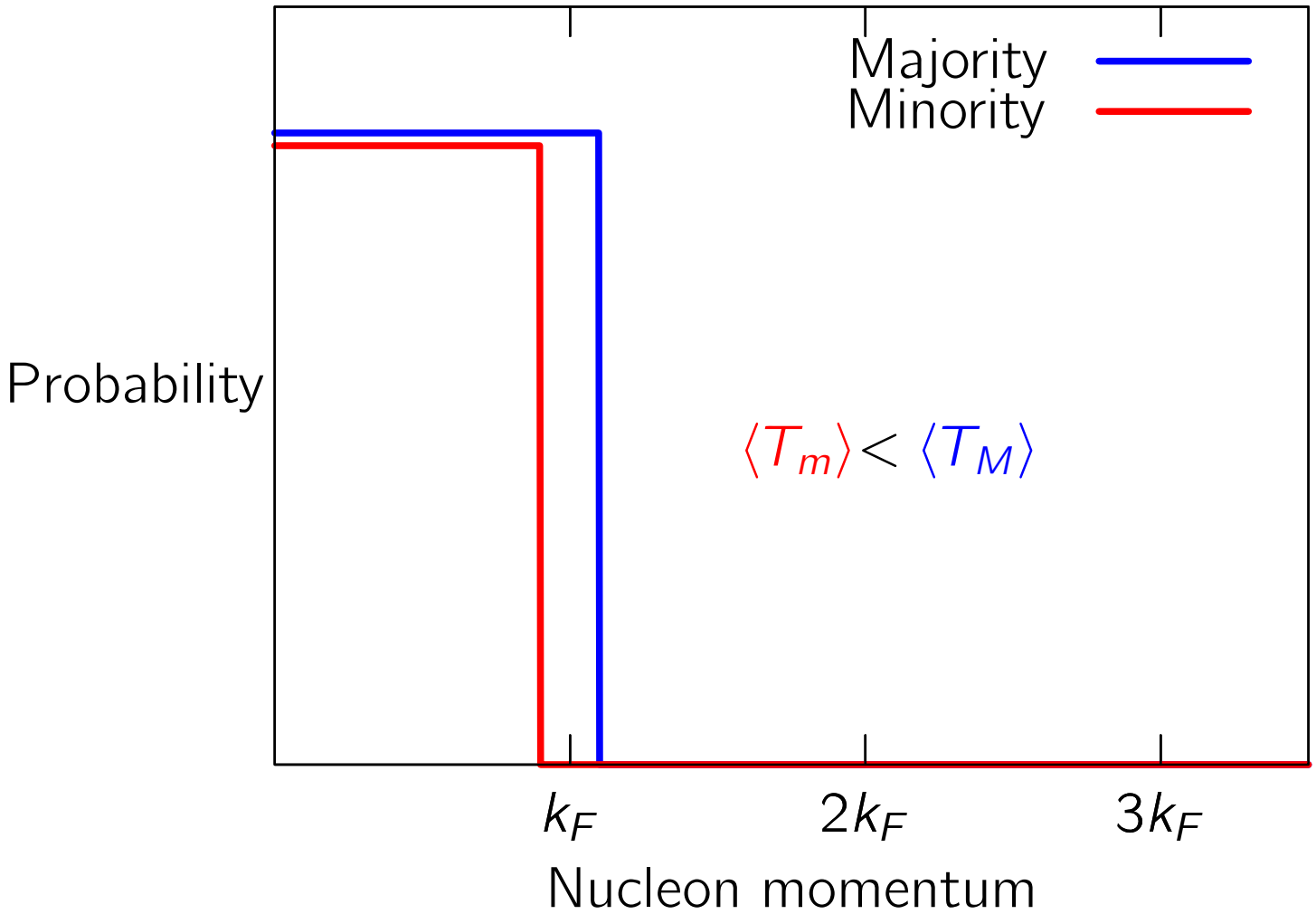
We expect that the *pp* fraction should rise with nucleon momentum.

The fraction of *pp* pairs increases with k.

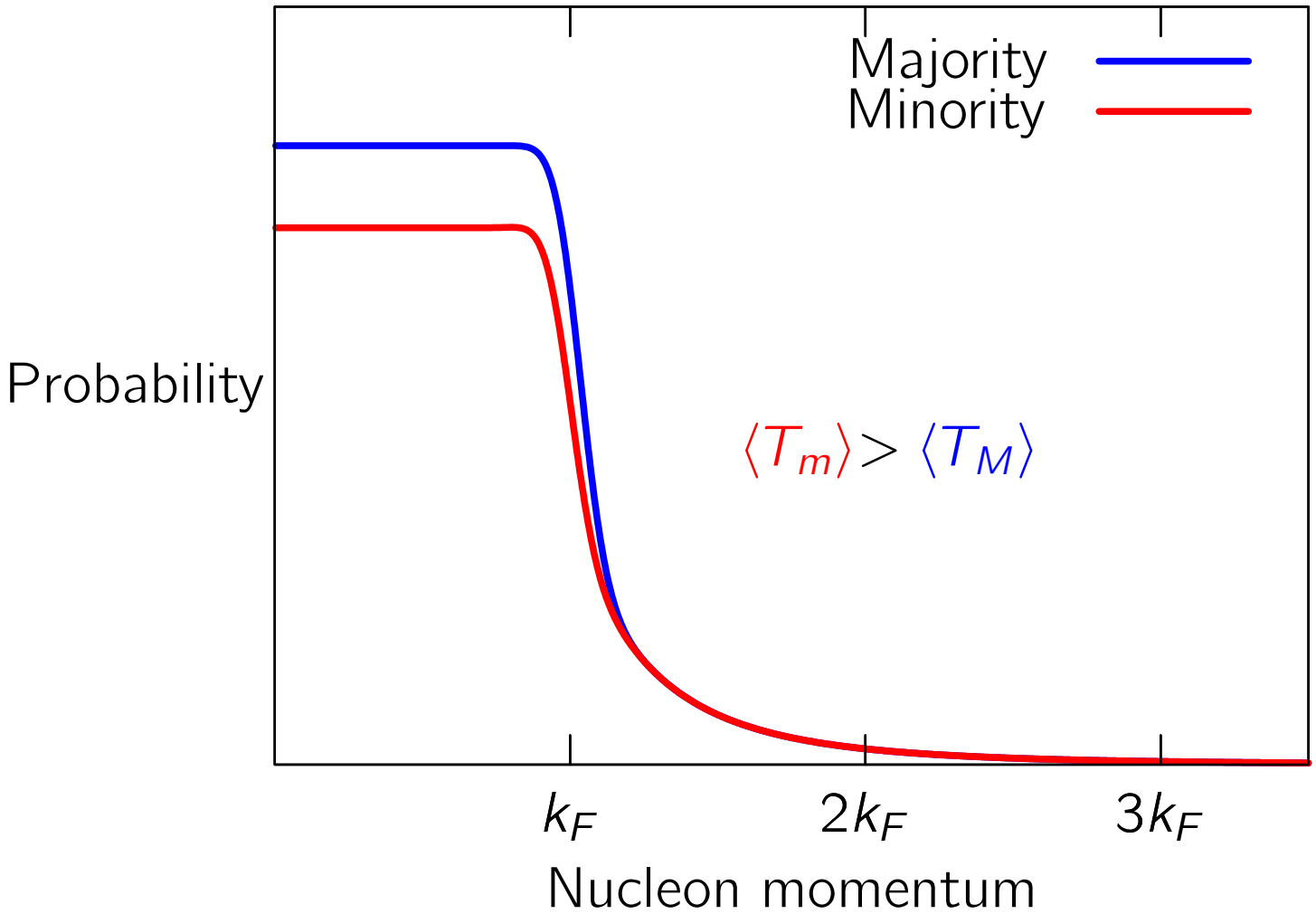


Analysis by E. Cohen, O. Hen et al.

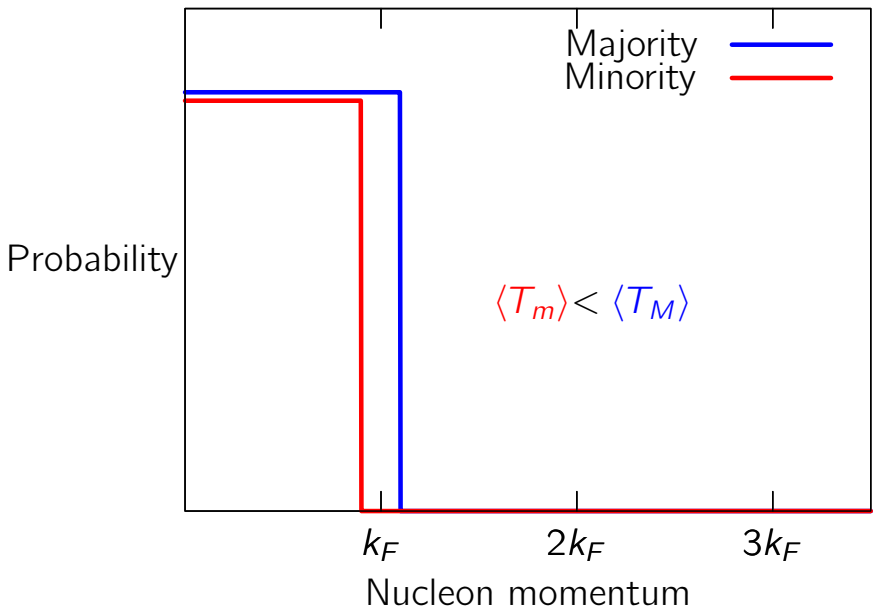
Which species has more kinetic energy in an asymmetric nucleus?

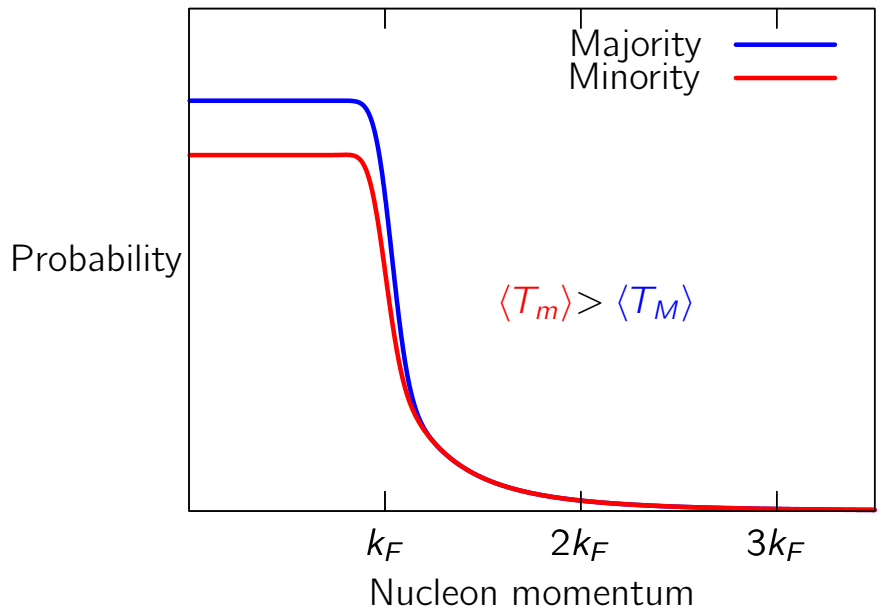


Which species has more kinetic energy in an asymmetric nucleus?



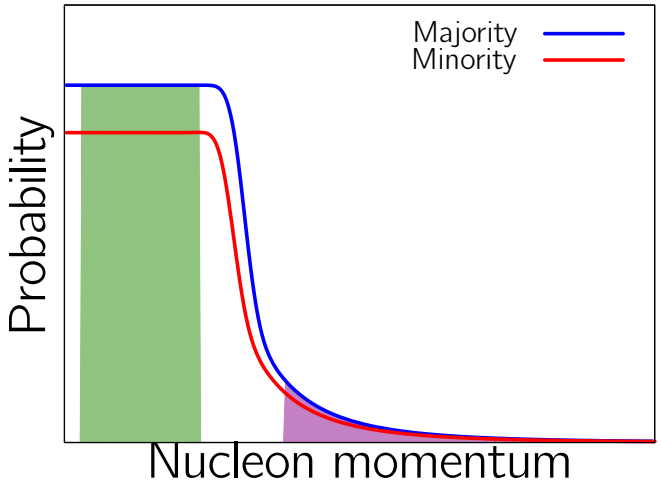
There are two competing forces.



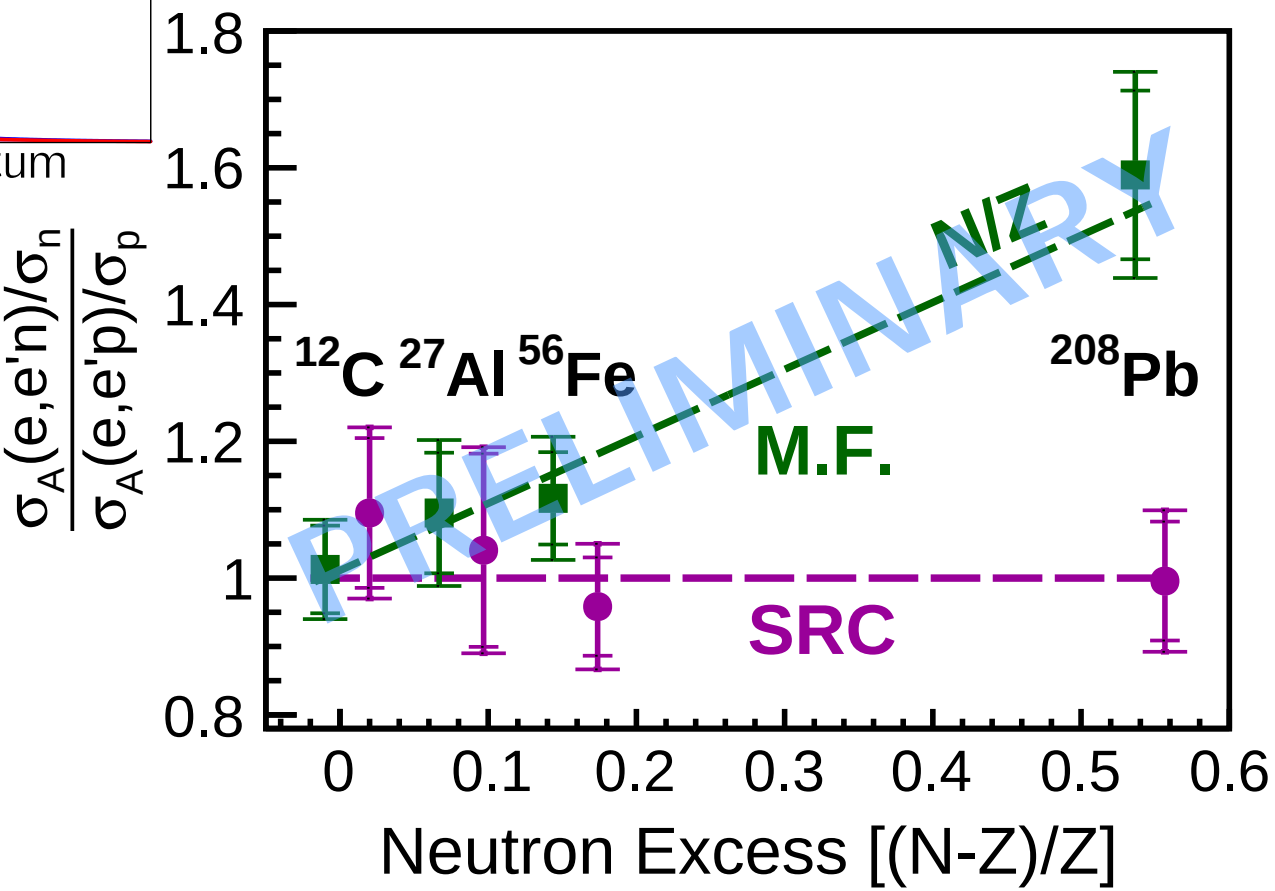


Which is stronger?

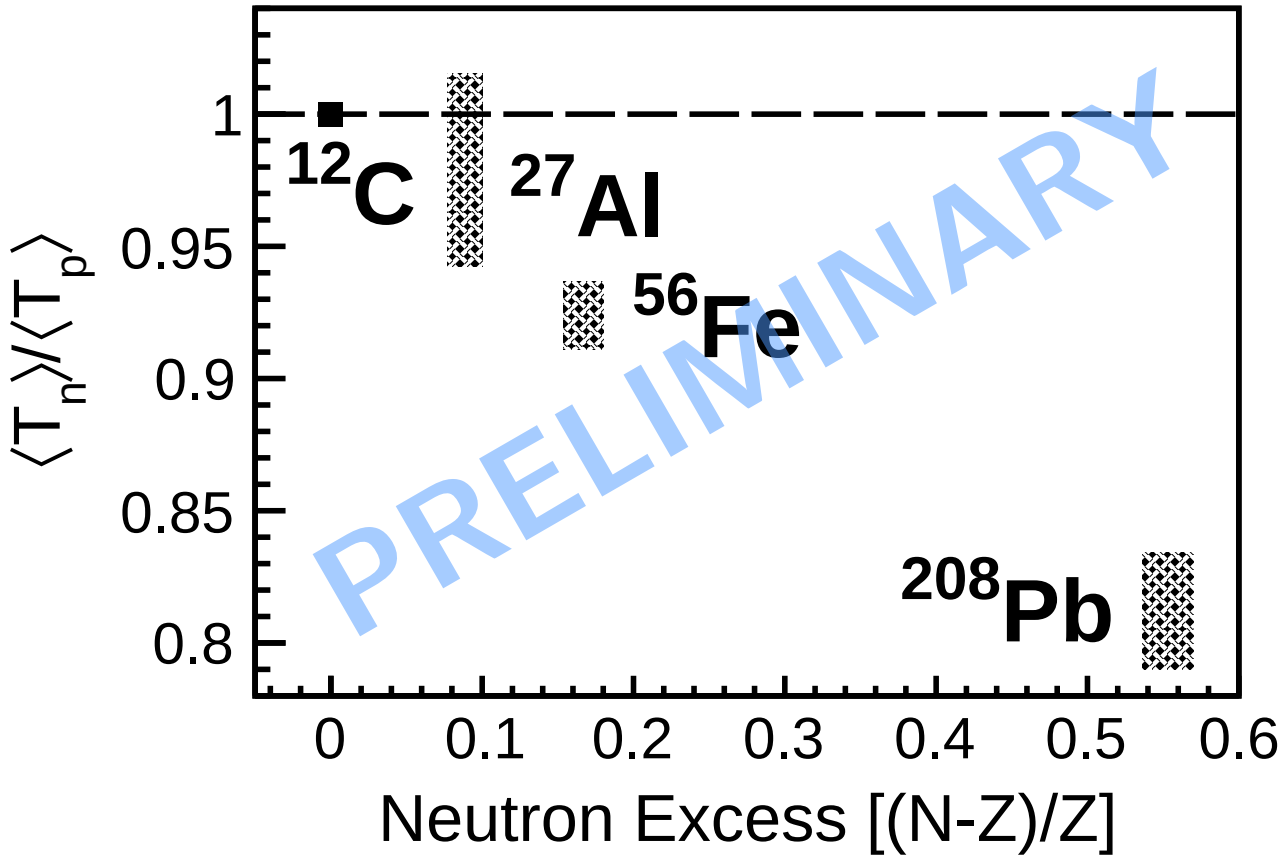
The *np* dominance model makes a prediction.



Analysis by Meytal Duer



This suggests that the minority has more energy.



See talks by Meytal Duer, Misak Sargsian, Jan Ryckebusch.

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   - Exciting recent developments
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   - **What questions do we want to answer?**

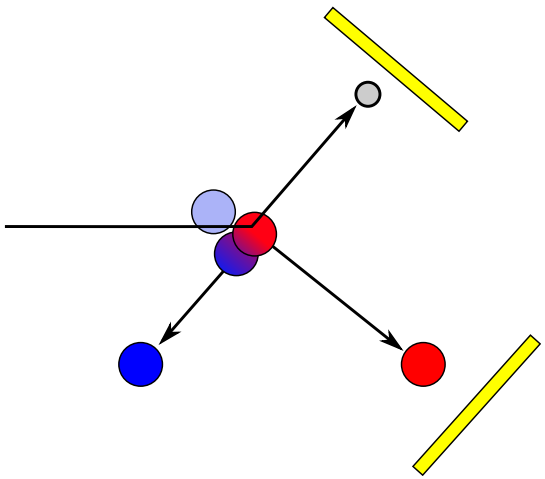
Some remaining questions:

- 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 proposals to look at asymmetric nuclei

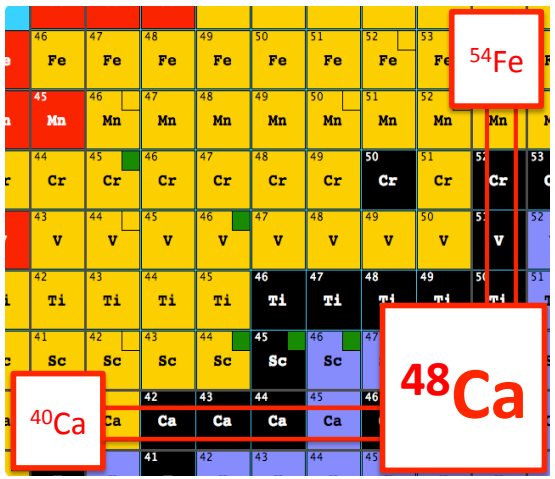
Tritium $(e, e'p)$

- Approved for JLab Hall A (E12-14-011)
- Isospin symmetry: $^3\mathrm{H} \leftrightarrow {}^3\mathrm{He}$
- See F. Hauenstein, R. Cruz Torres

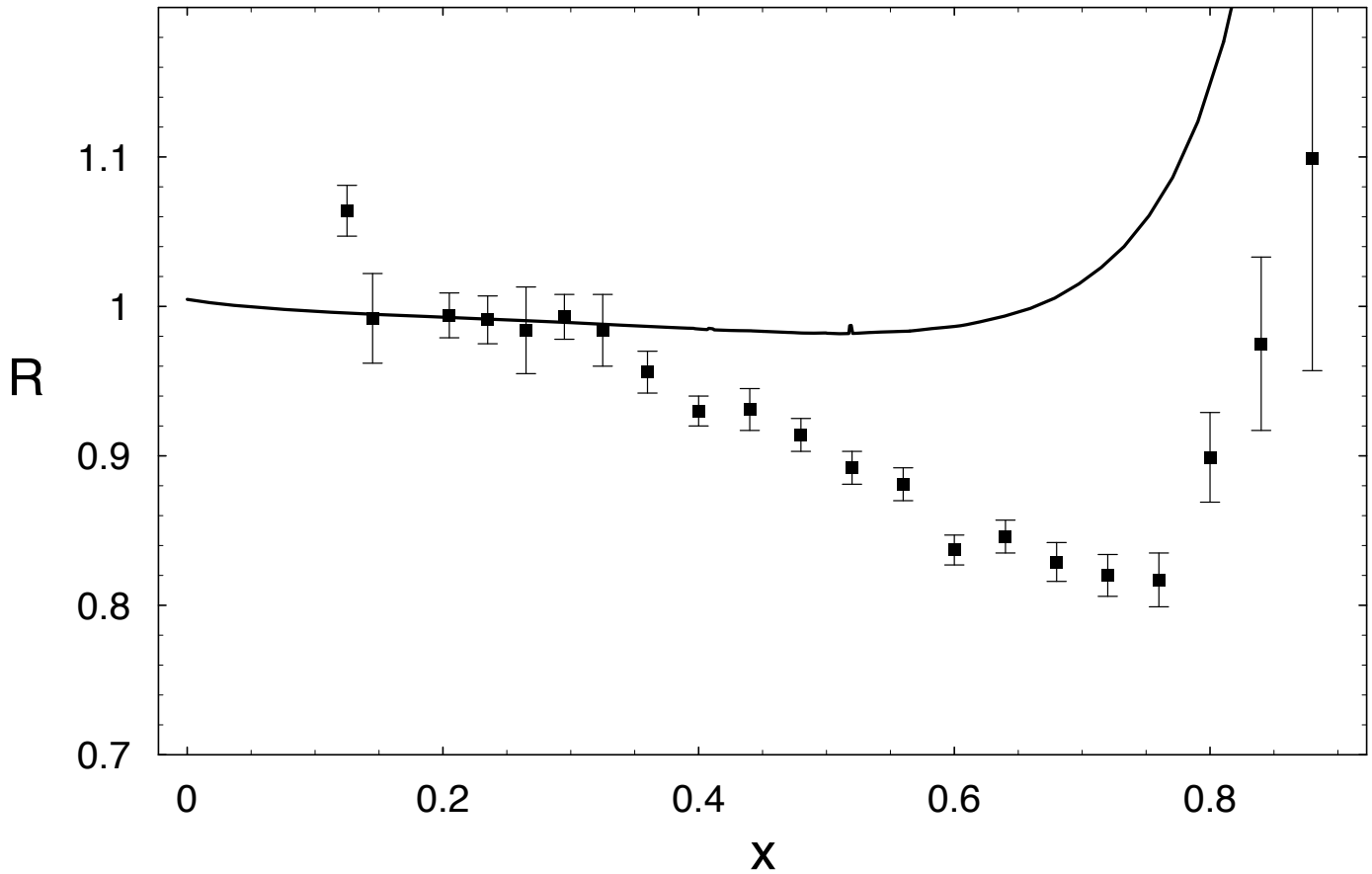


CaFe Experiment

- Proposed for JLab Hall C
- Look at dependence on mass and neutron excess
- $^{40}\mathrm{Ca} \rightarrow {}^{48}\mathrm{Ca} \rightarrow {}^{54}\mathrm{Fe}$

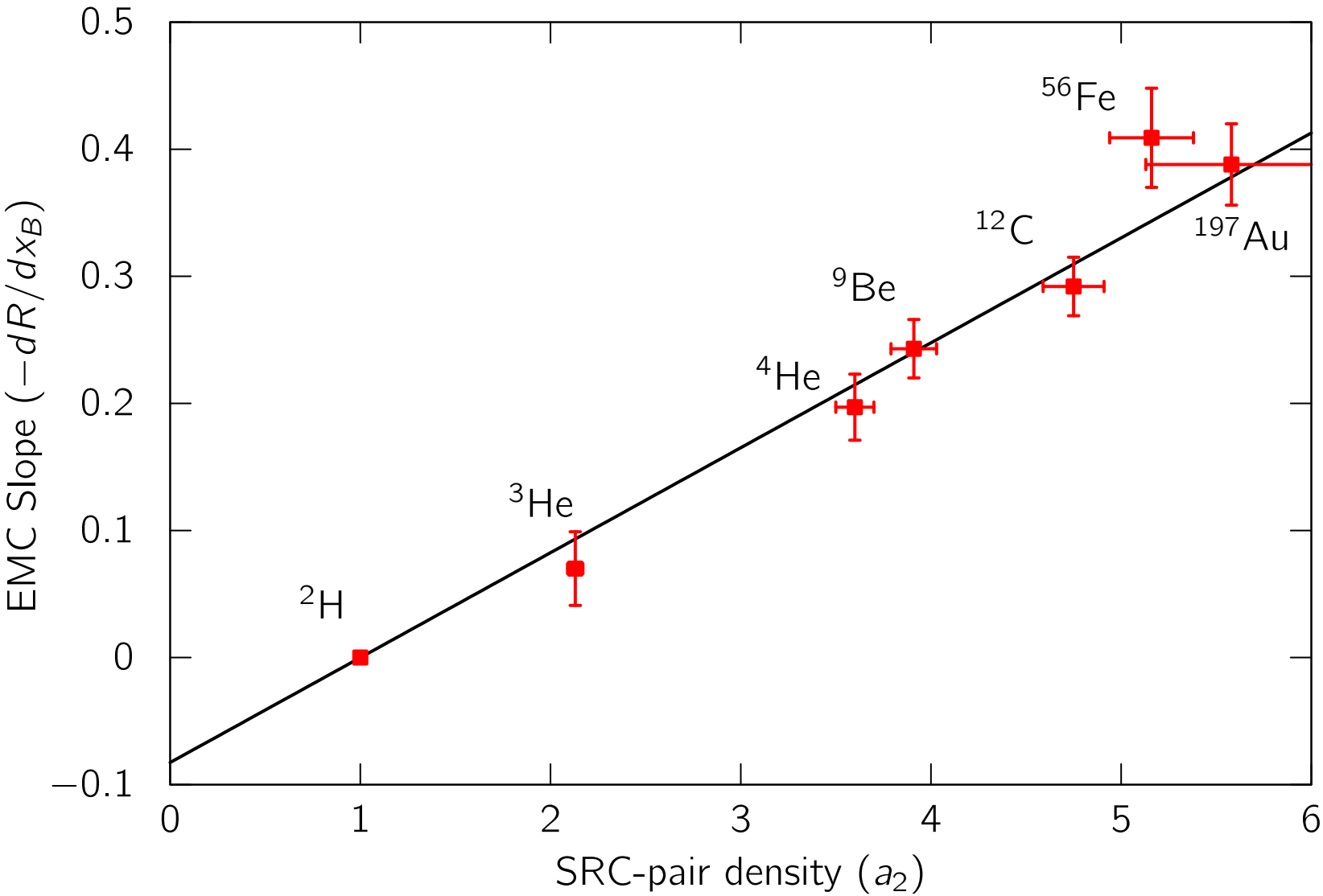


EMC Effect: nuclear medium changes quark distributions.



J. Gomez et al., Phys. Rev. D 49 4348 (1994)
J.R. Smith, G.R. Miller, Phys. Rev. C 65 055206 (2002)

There is a curious SRC/EMC correlation.



We will run two new experiments to investigate the SRC-EMC connection.

DIS on deuterium, tagging a recoil nucleon.

Large-Angle Detector (LAD)

- Approved for JLab Hall C
- e' detected in Hall C spectrometers

Backward-Angle Neutron Detector (BAND)

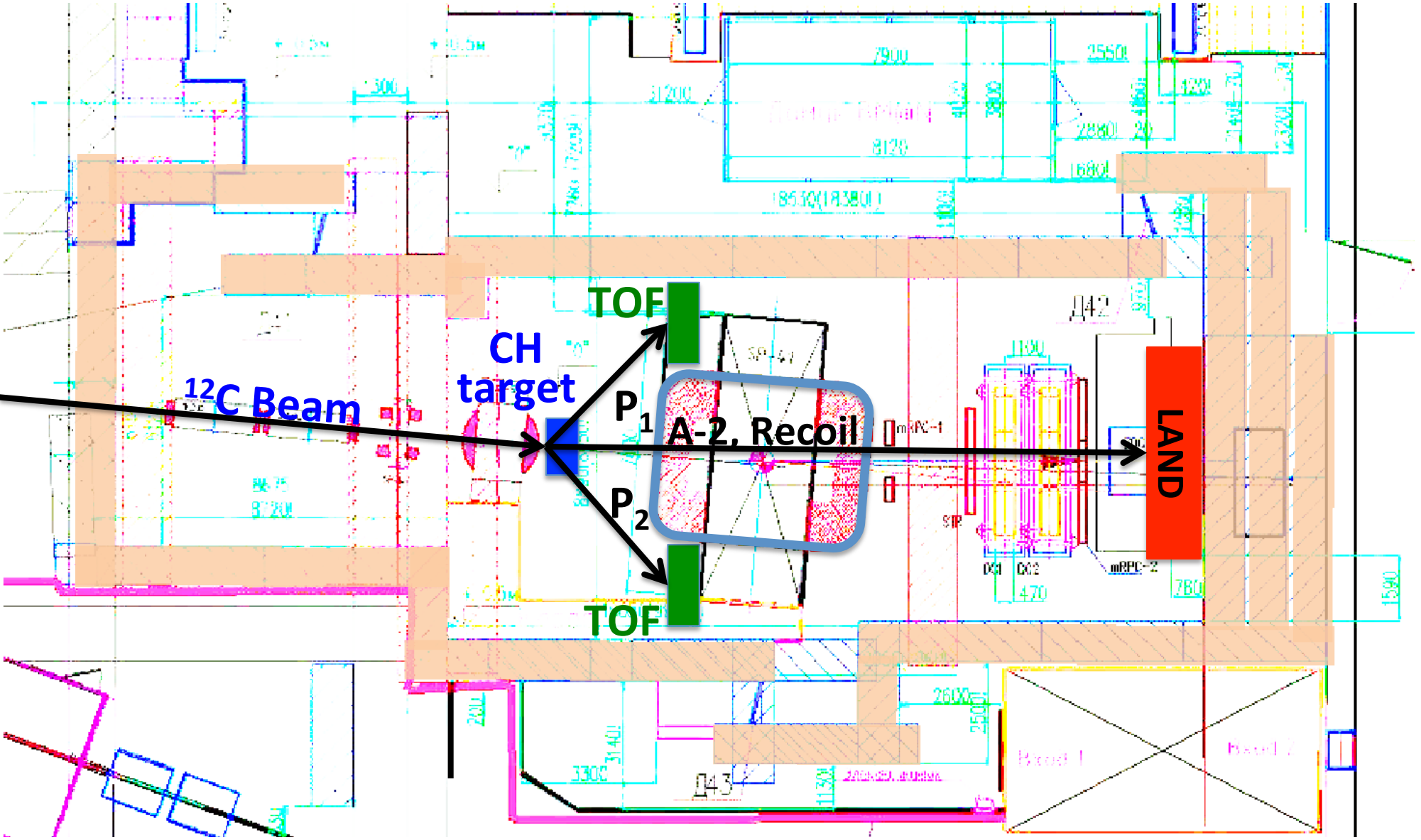
- Approved for JLab Hall B
- e' detected in CLAS-12 spectrometer

For more on medium modifications, see talks by Gerry Miller Larry Weinstein.

We want to investigate SRCs with new probes.

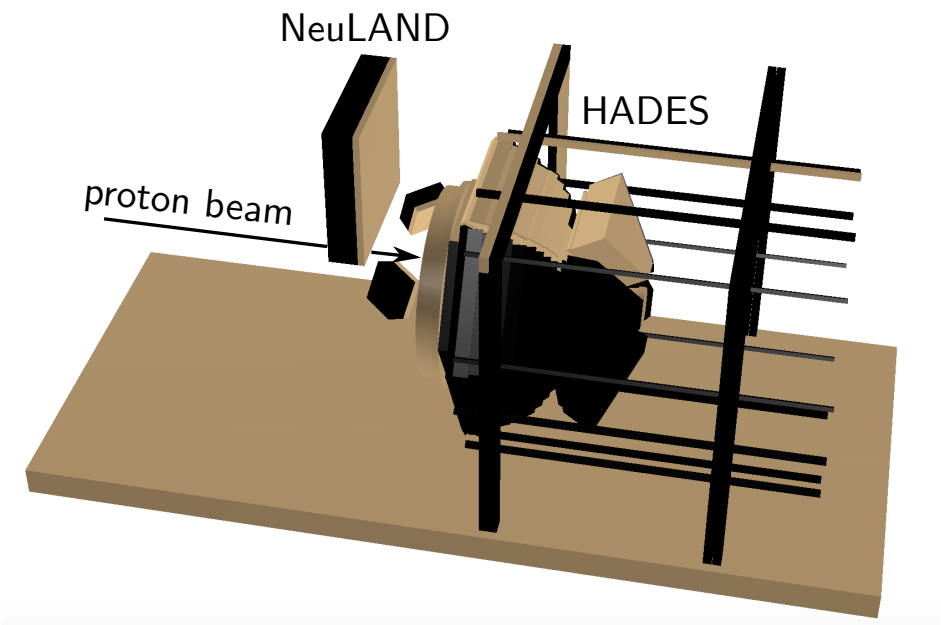
Proposals:

1. Inverse kinematics at Dubna
   - $\longrightarrow$ detect remnant nucleus
   - For related physics: see talk by Thomas Aumann
2. Protons at GSI
3. Photons at GlueX


TOF
CH
target
^{12}C Beam
P$_1$
A-2, Recoil
LAND
P$_2$
TOF

A new proton scattering experiment at GSI will be a high-statistics data set of SRC pairs.

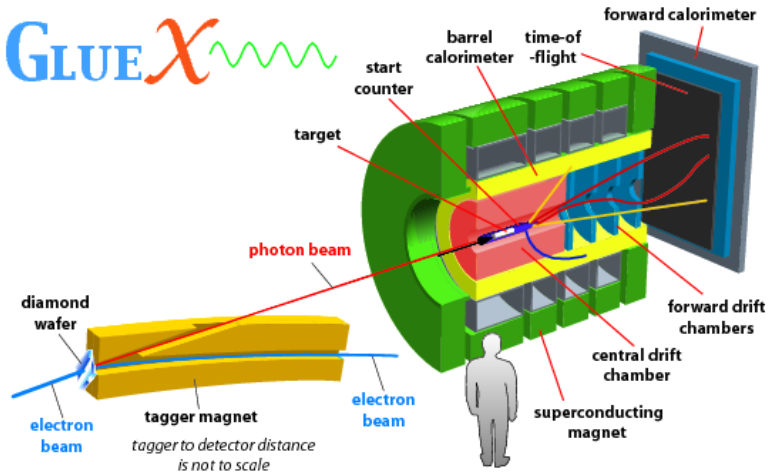
- Proton scattering enhances SRC cross section
- Use existing HADES, NeuLAND detectors
- Chance to look at 3-nucleon correlations



See my colleague, George Laskaris

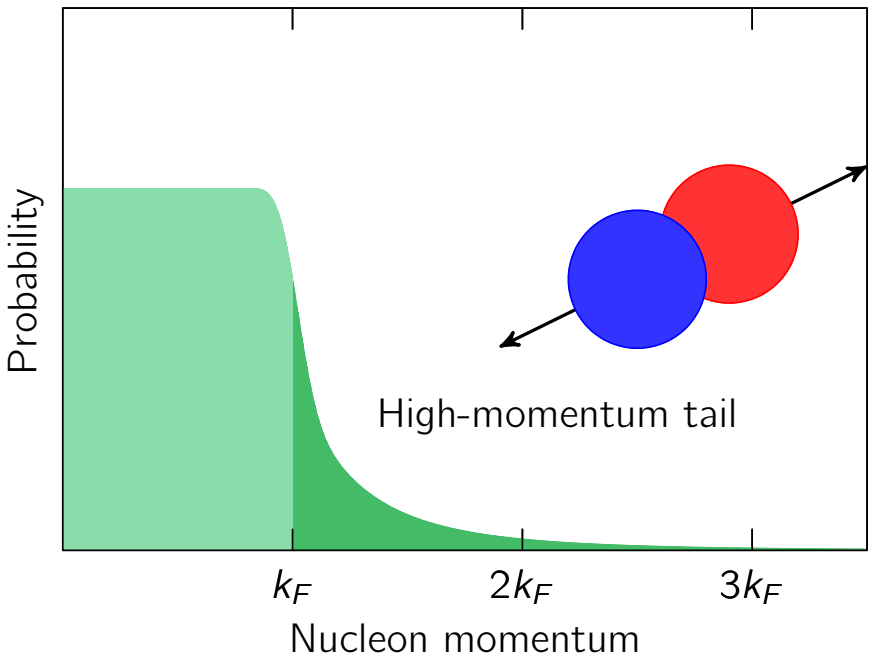
Glue-X: study SRC pairs with real photons.

- Glue-X detector at JLab Hall D
- Study neutrons with charged final states:
  - $\gamma n \longrightarrow \pi^- p$
- Tests of vector meson dominance and transparency



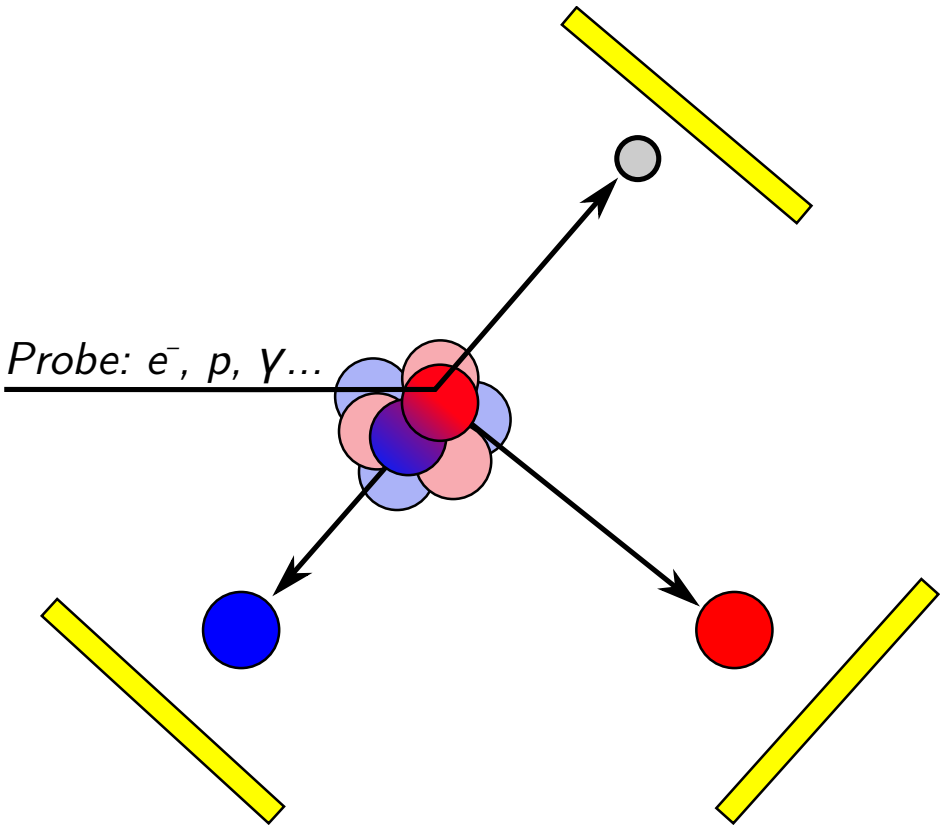
See my colleague, Maria Patsyuk

To recap:



- High momentum tail populated by short-range correlated pairs

To recap:



- High momentum tail populated by short-range correlated pairs
- Directly measured with coincidence experiments

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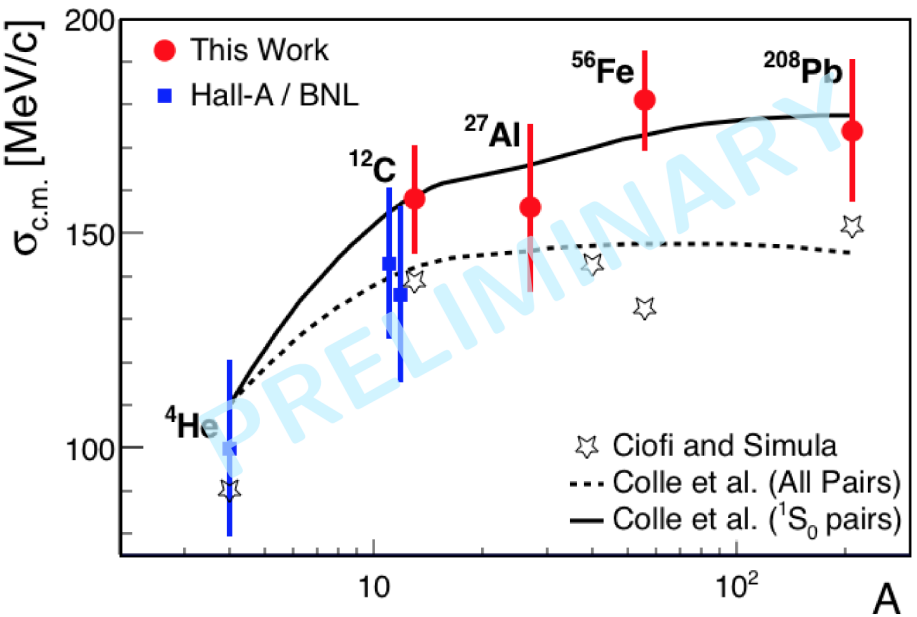

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- Directly measured with coincidence experiments
- Highlights from CLAS data mining

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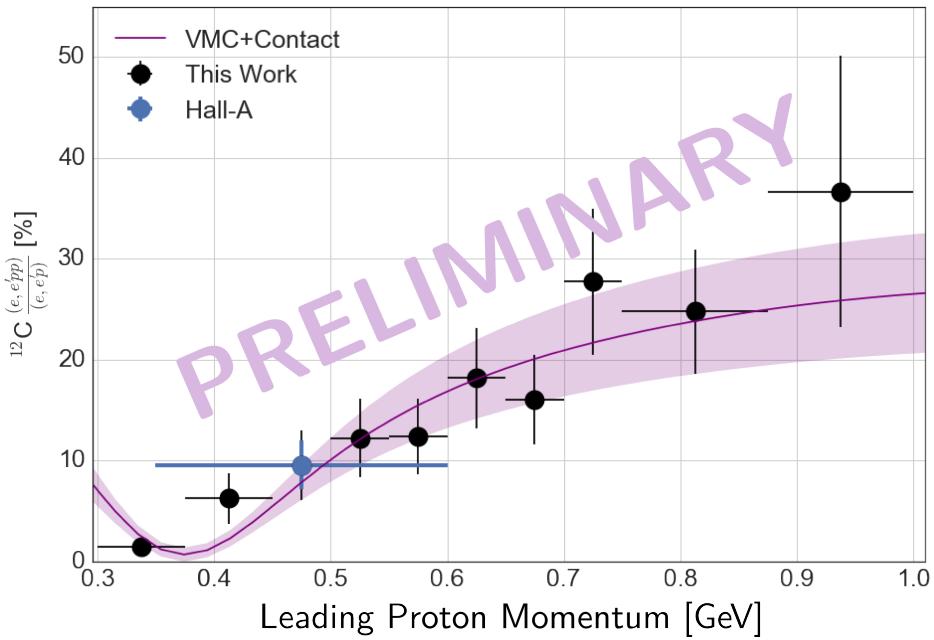

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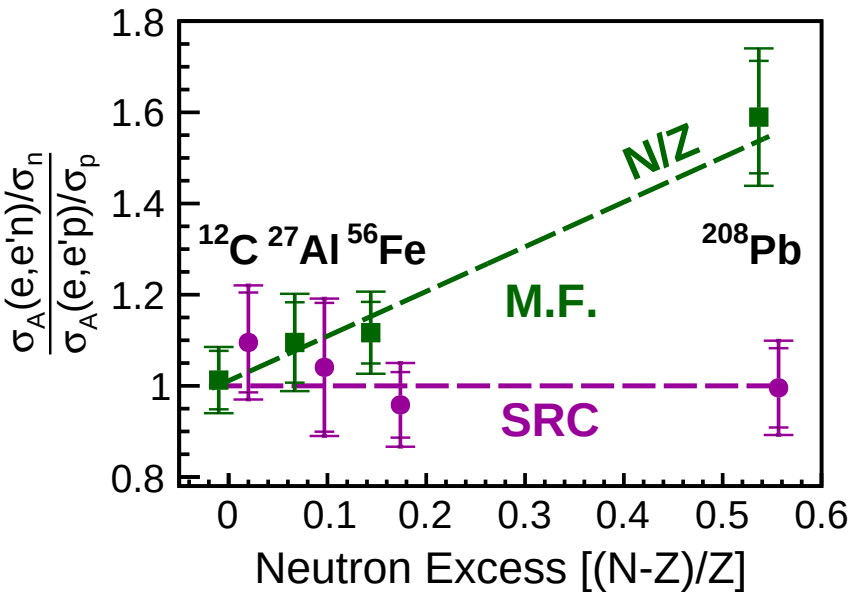
- Highlights from CLAS data mining

To recap:



- High momentum tail populated by short-range correlated pairs
- Directly measured with coincidence experiments
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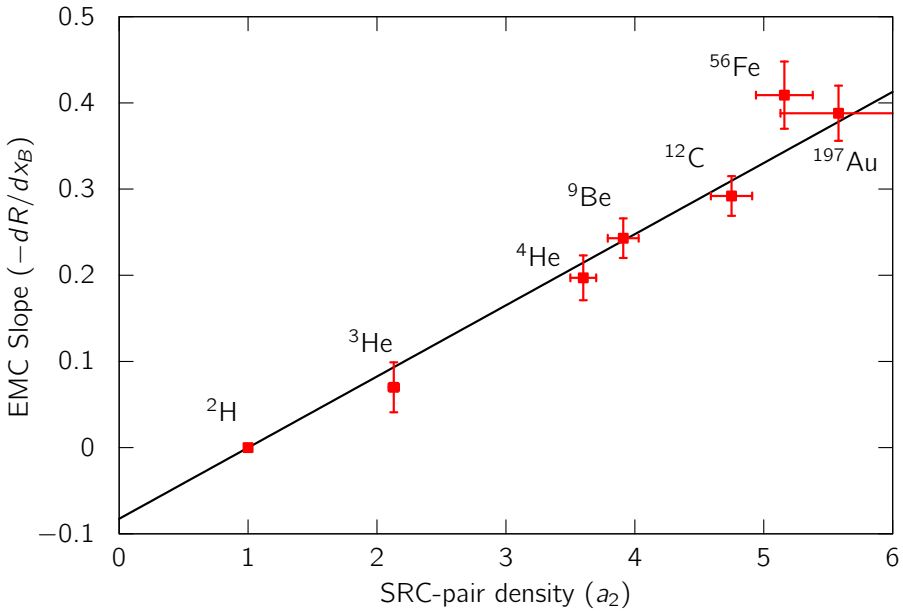

- High momentum tail populated by short-range correlated pairs
- Directly measured with coincidence experiments
- Highlights from CLAS data mining
- Remaining questions

Conclusions

- Our consistent picture of short-range correlations has come from many different probes and techniques.

- A diverse experimental program going forward is important for making progress on tough remaining problems.