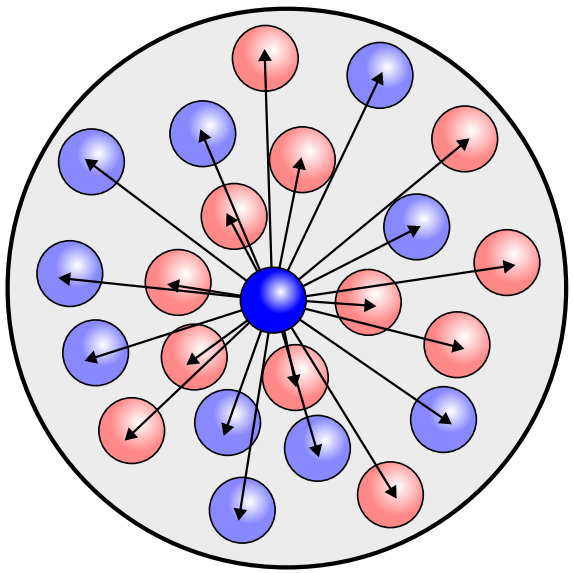
An experimental perspective on short-range correlations

Axel Schmidt

Marciana 2025 - Lepton Interactions with Nucleons and Nuclei

June 24, 2025

Simple patterns emerge in nuclear structure.



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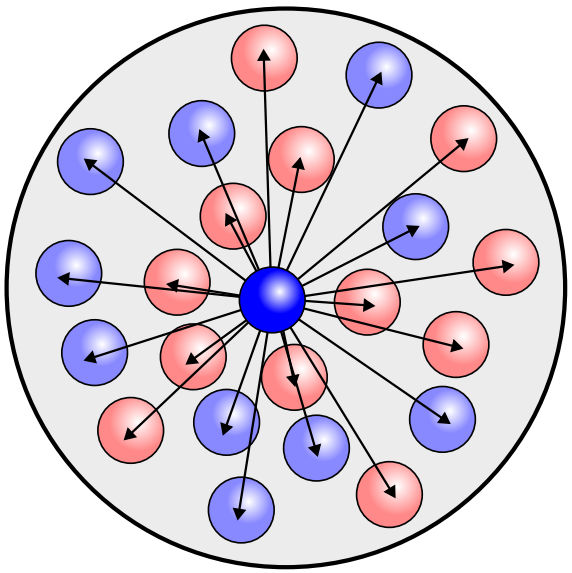

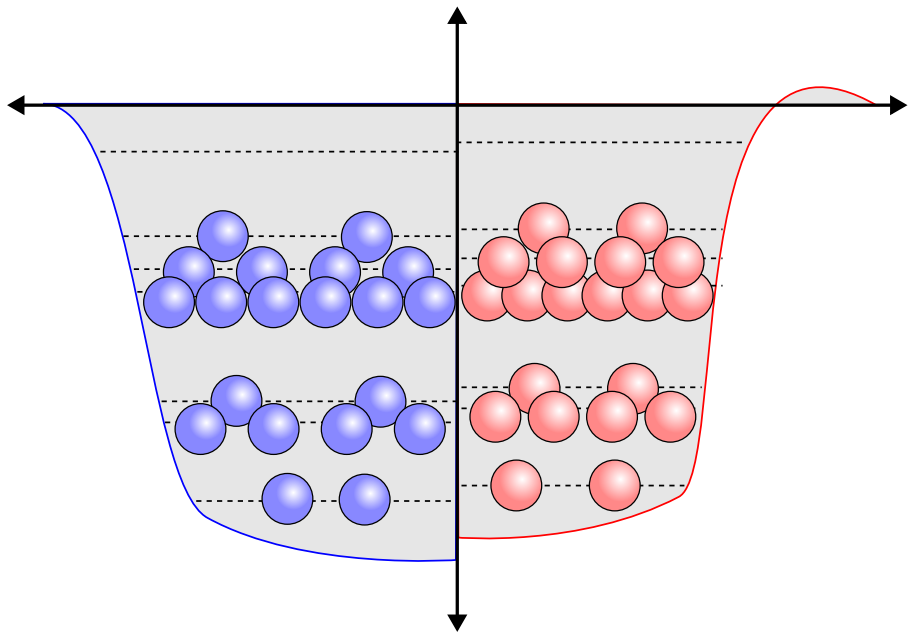

Mean-field models

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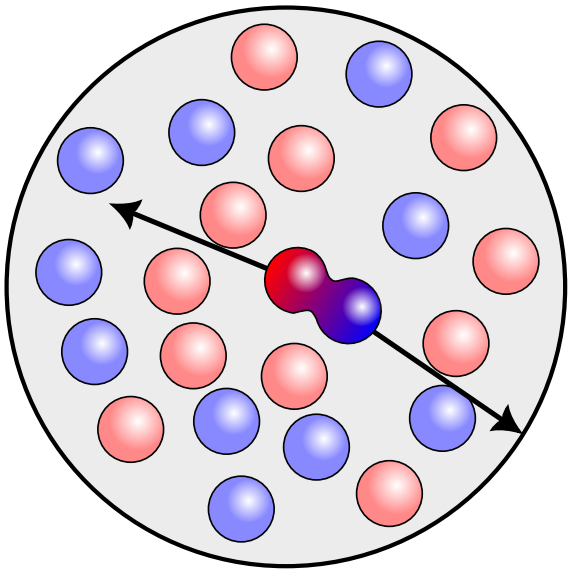
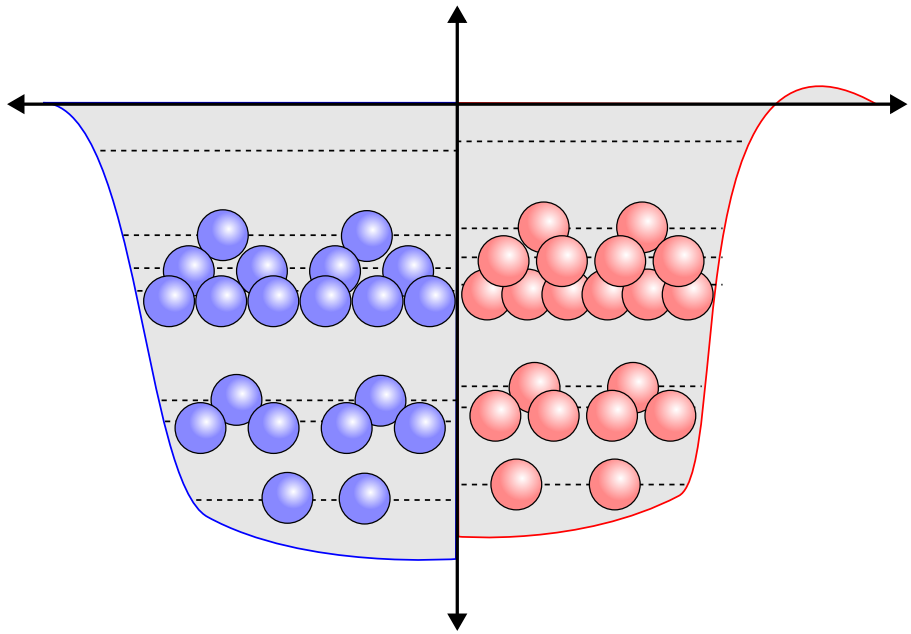
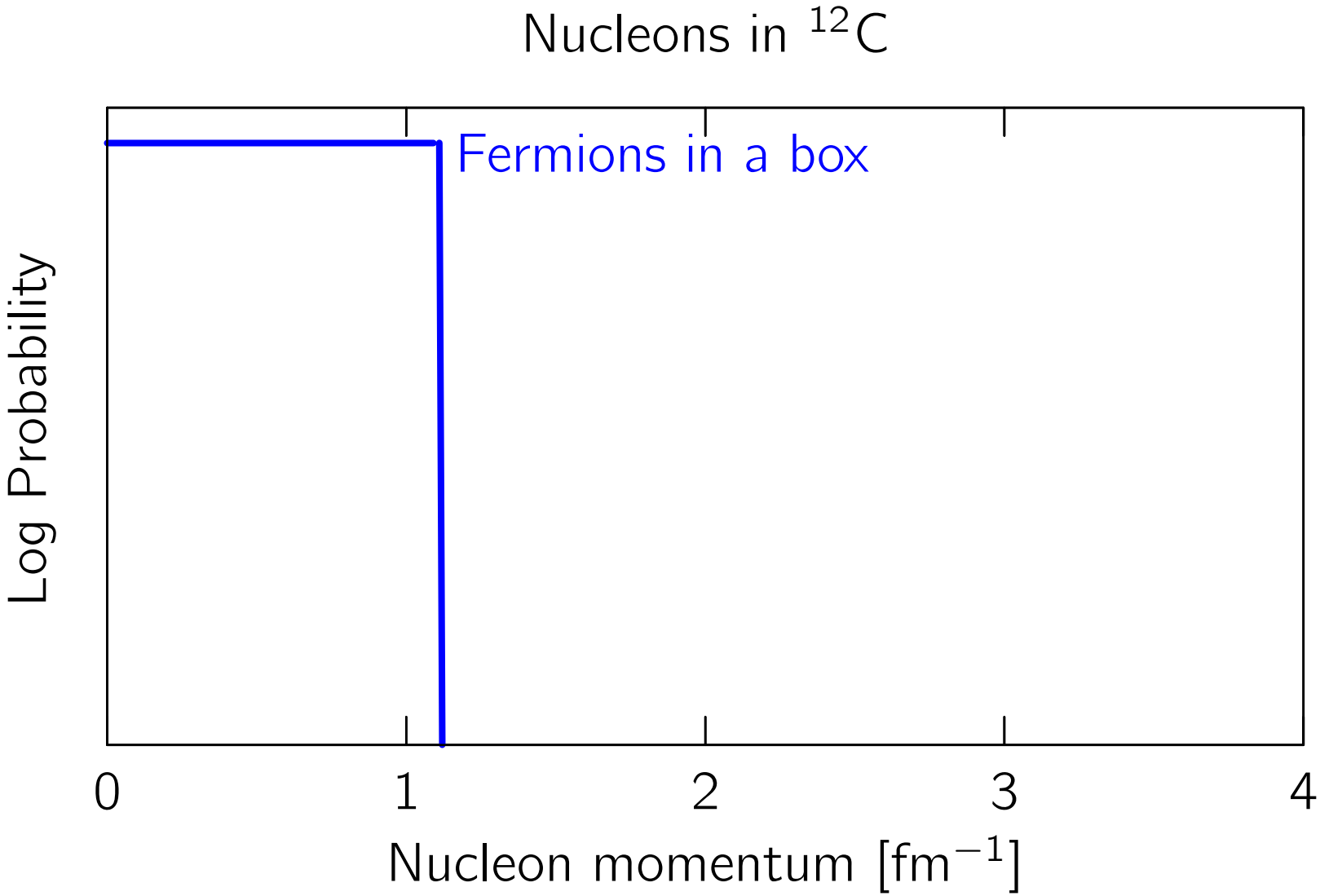




Mean-field models

SRCs manifest as very fast moving nucleons.



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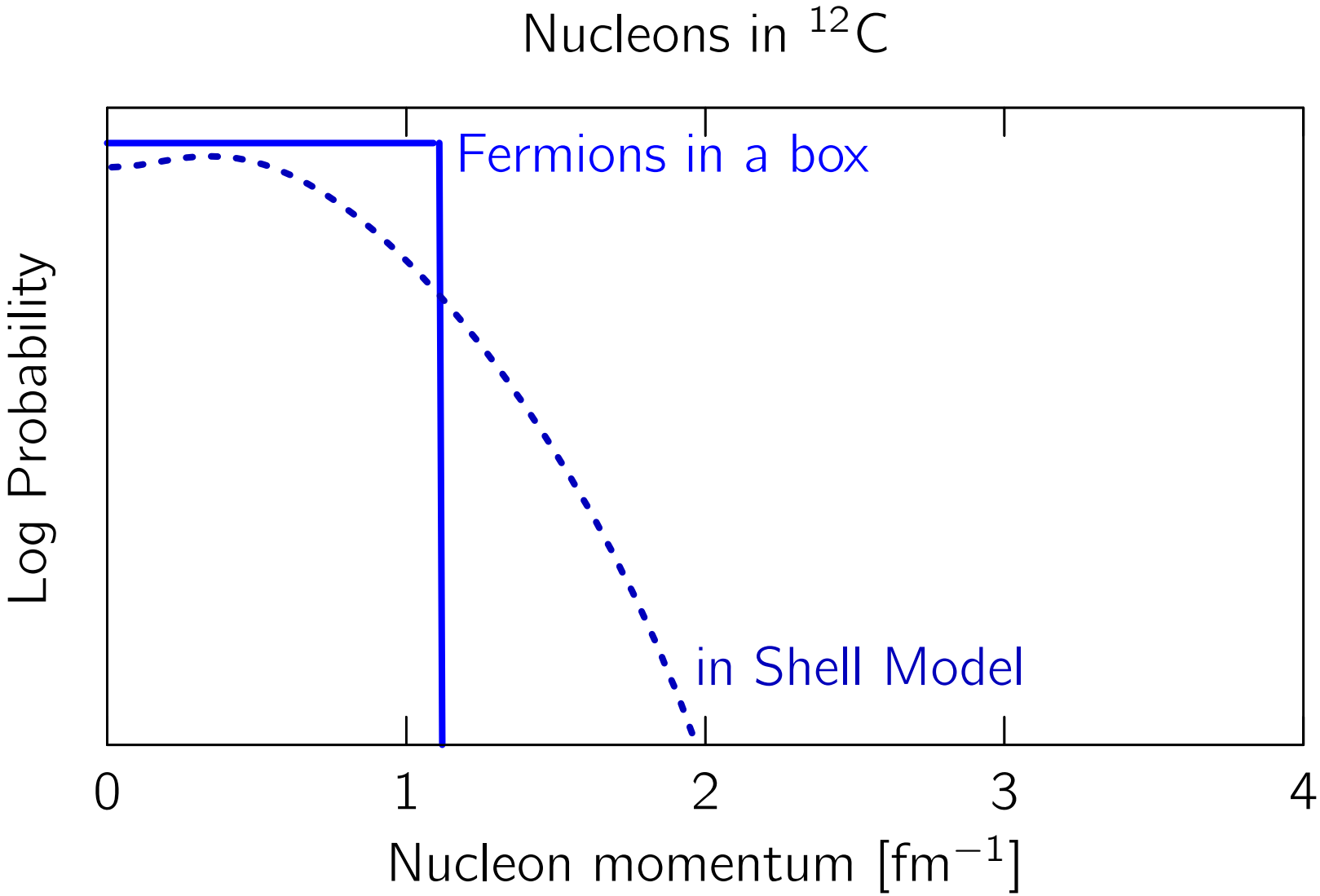

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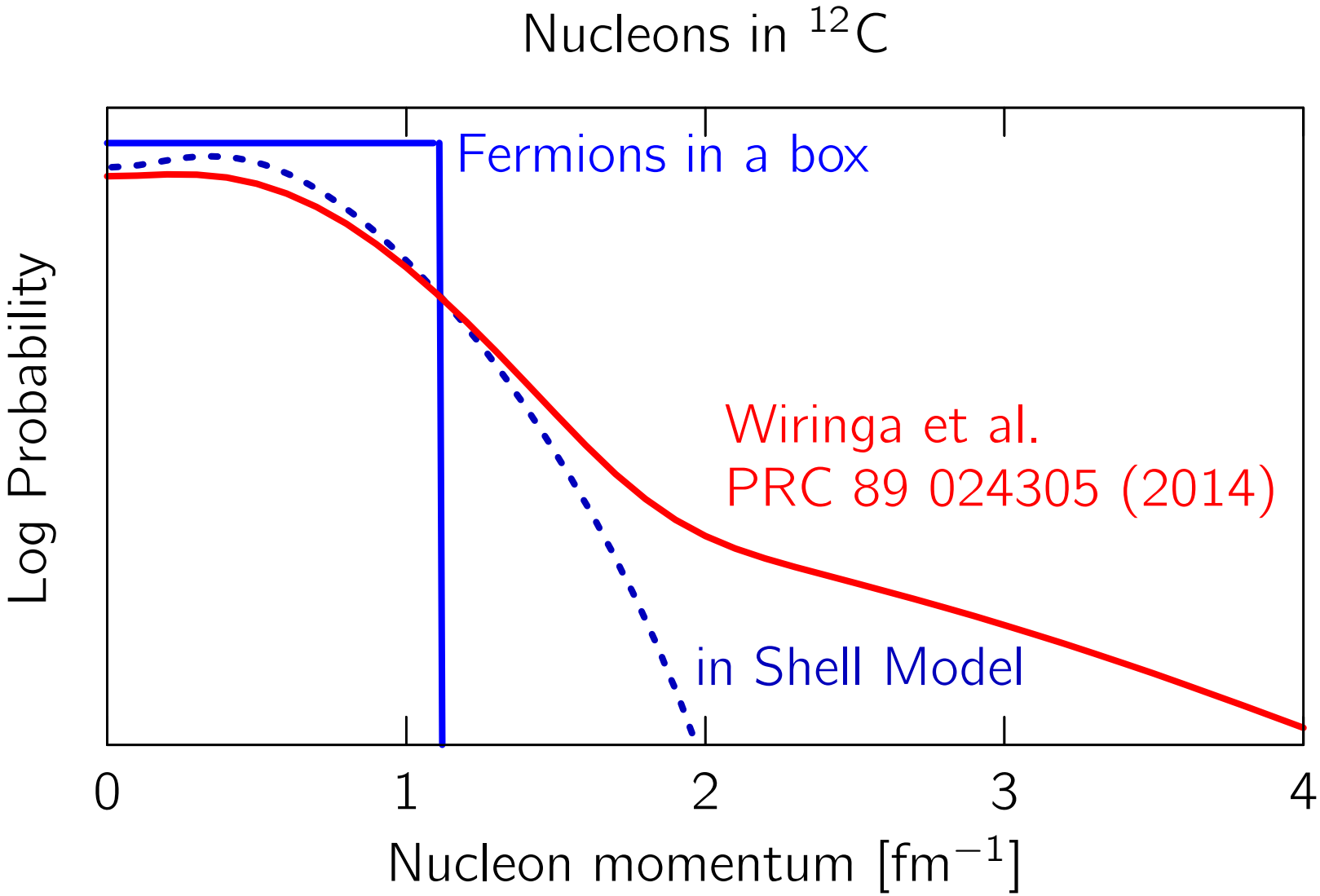

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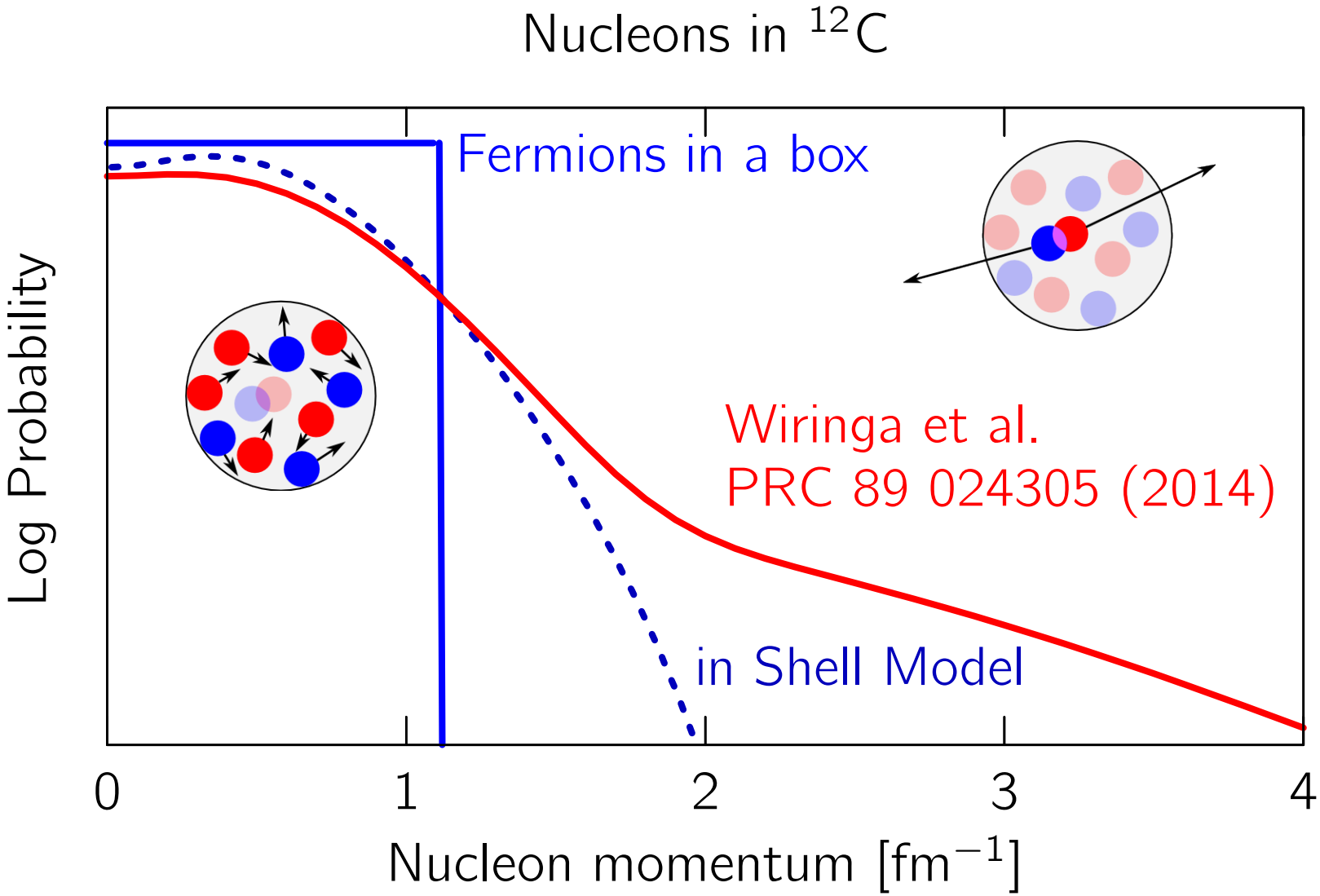
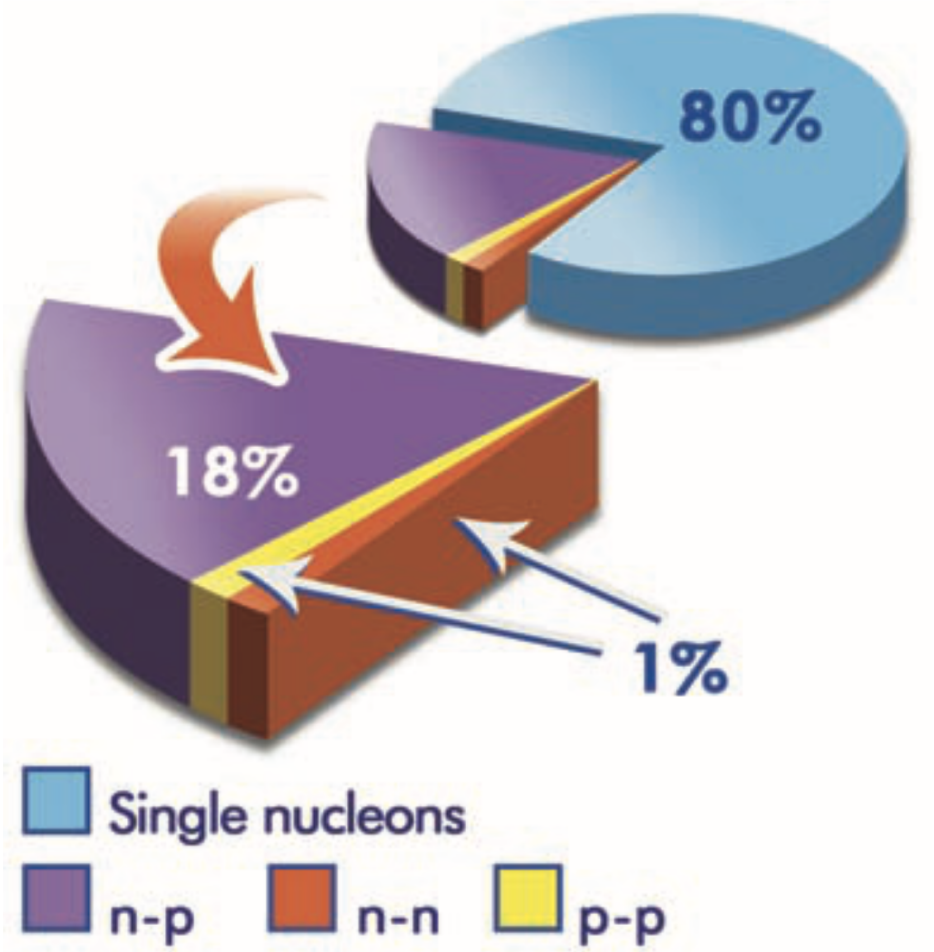


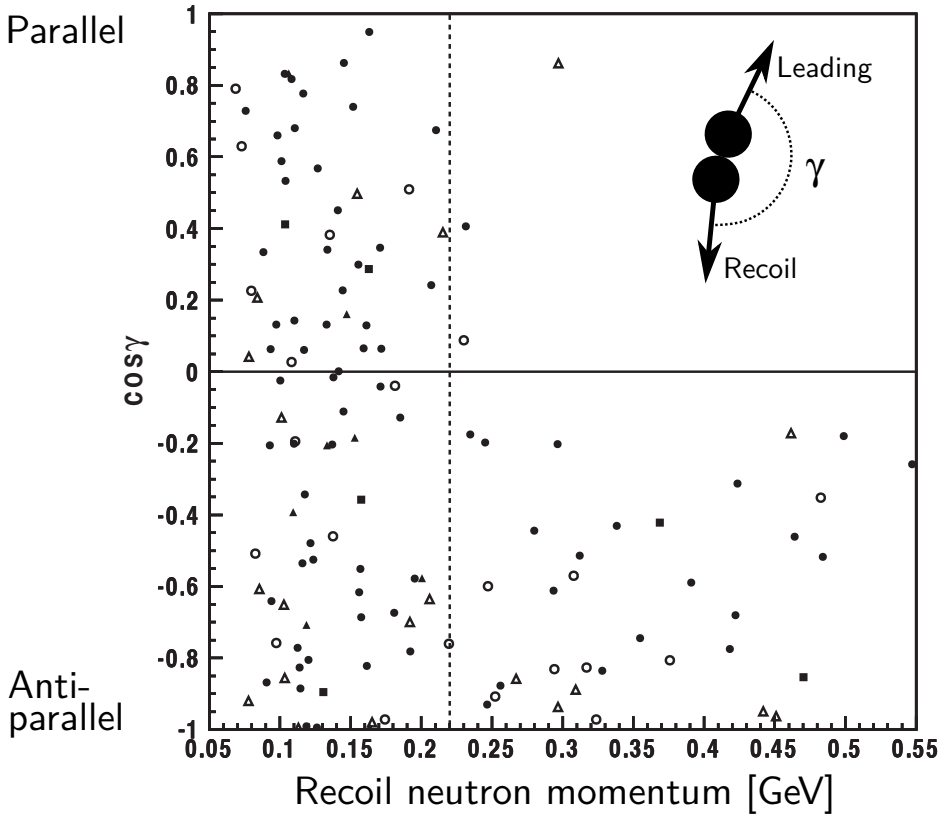
A quick primer on SRCs



R. Subedi et al., Science (2008)

- 10–20% of nucleons are correlated.

A quick primer on SRCs



E. Piasetzky et al., PRL (2006)

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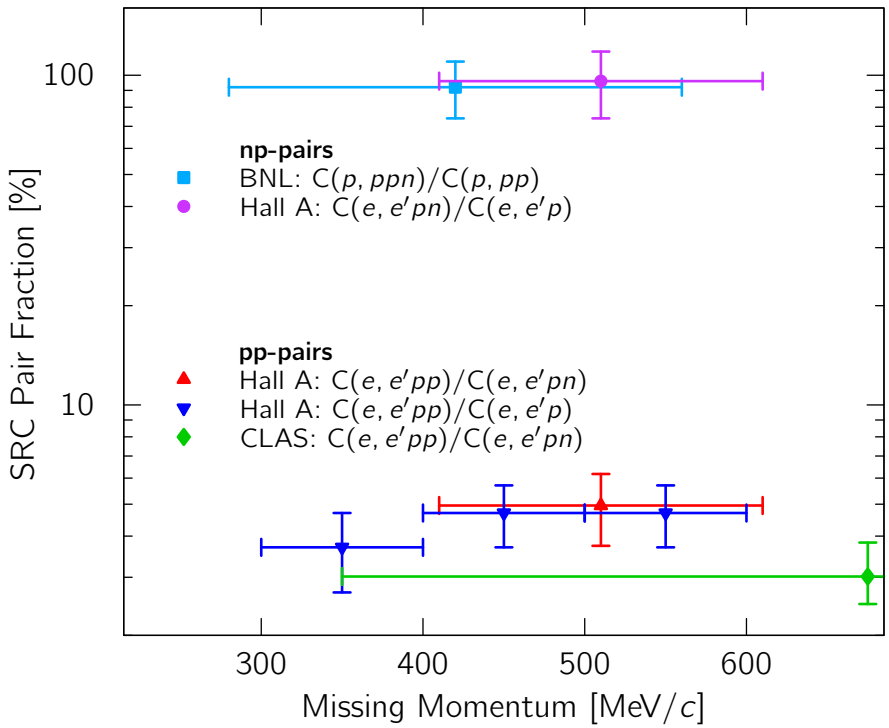
- Correlated emission of partner nucleon

A quick primer on SRCs



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- Correlated emission of partner nucleon
- Predominantly *np*-pairs due to tensor force

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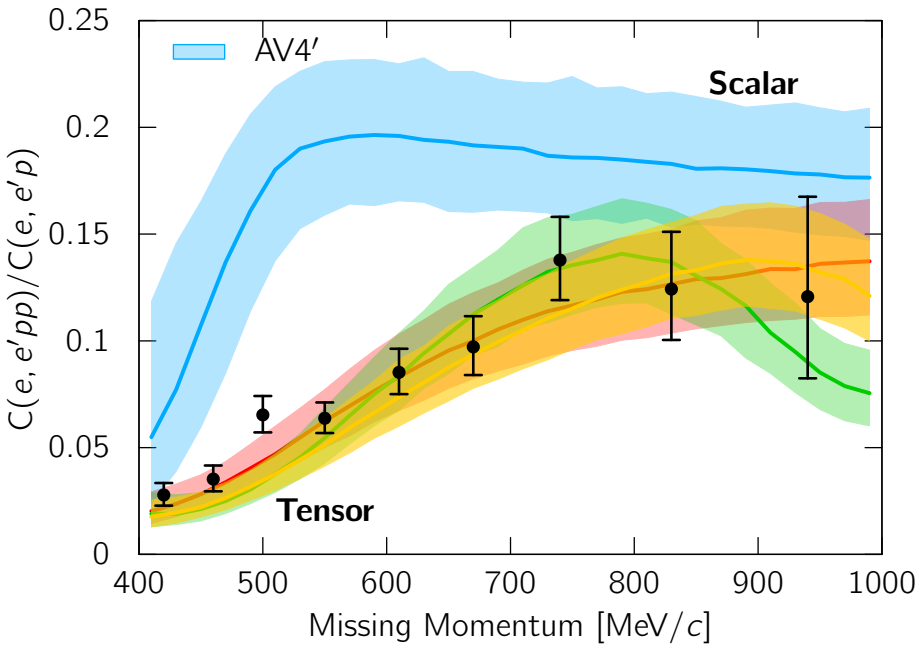
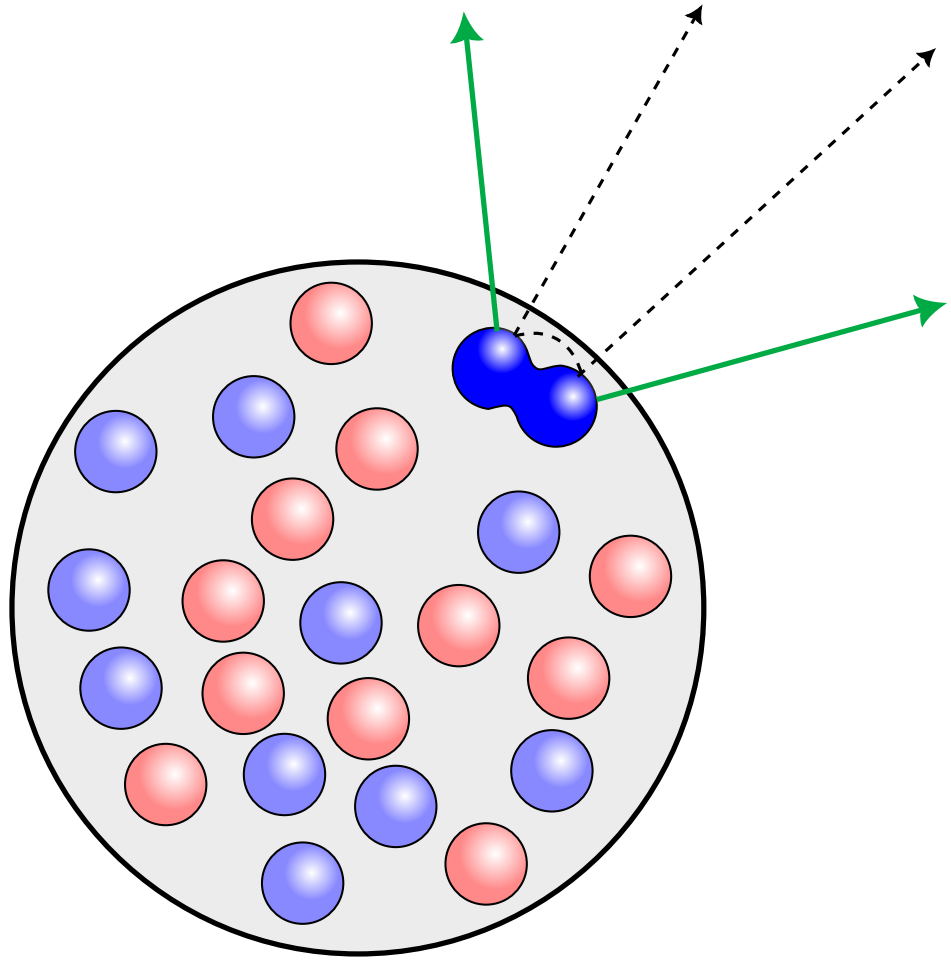


A. Schmidt et al., Nature (2020)

- 10–20% of nucleons are correlated.
- Correlated emission of partner nucleon
- Predominantly *np*-pairs due to tensor force
- *np*-dominance fades at very high momenta.

SRCs play an important role in:

- Double beta-decay matrix elements



SRCs play an important role in:

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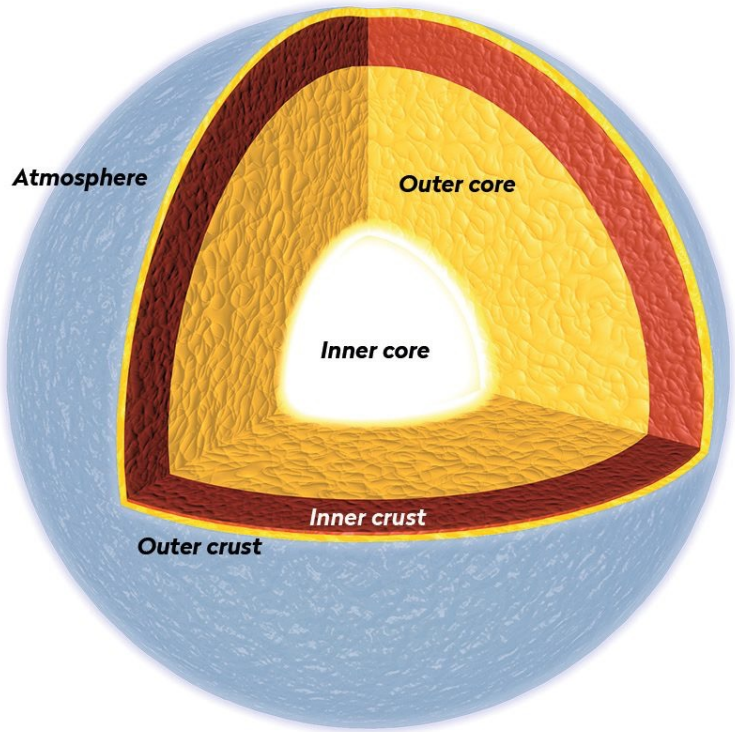
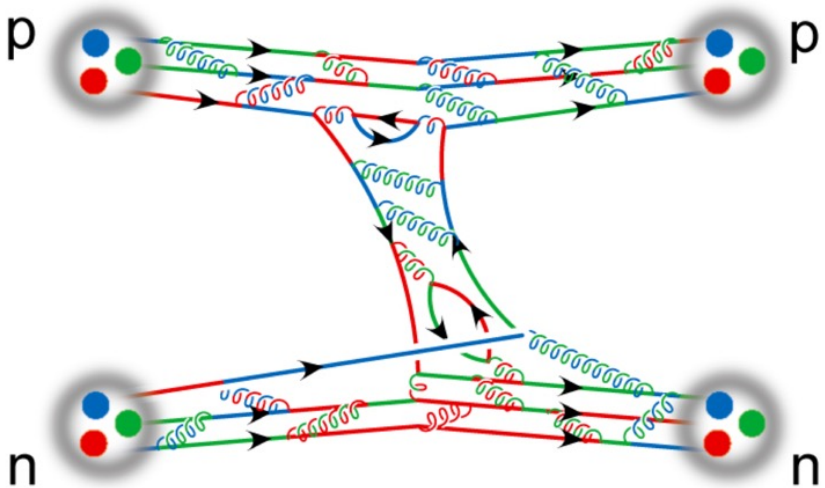
- Symmetry energy in nuclear matter E.o.S.



SRCs play an important role in:

- Double beta-decay matrix elements
- Symmetry energy in nuclear matter E.o.S.
- Partonic structure of nuclei



Big open questions

1. How universal are our findings?
   - Do they depend on probe and resolution-scale?
2. How do pairs form?
   - Which nucleons correlate?
   - Can correlations form across shells?
3. What role do SRCs play in the EMC Effect?
   - Is structure modification driven by highly virtual nucleon pairs?

Answering these questions requires a team effort.

Some of my Jefferson Lab collaborators

- Or Hen, MIT
- Tyler Kutz, Mainz
- Dien Nguyen, Tennessee
- Eli Piasetzky, Tel Aviv
- Holly Szumila-Vance, Florida Intl.
- Larry Weinstein, Old Dominion
- Jefferson Lab
  - Dave Gaskell
  - Florian Hauenstein
  - Doug Higinbotham
  - Sasha Somov

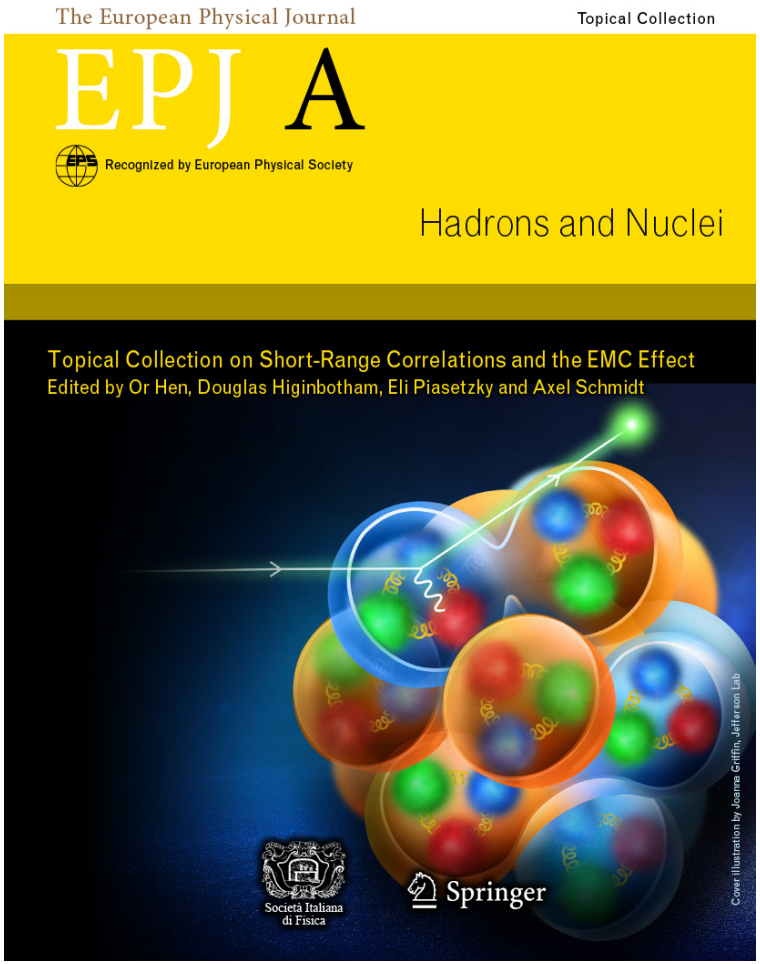
Additional JLab experiments led by:

- John Arrington, LBL
- Nadia Fomin, Tennessee
- Burcu Duran, New Mexico State

Experiments around the world

- Tom Aumann, GSI
- Maria Patsyuk, JINR
- Zhihong Ye, Tsinghua/HIAF
- Satoru Terashima, RCNP

Topical Issue on Short-Range Correlations published in Eur. Phys. J. A



May 21, 2025

Guest editors: Or Hen, Douglas Higinbotham, Eli Piasetzky, Axel Schmidt

URL: `https://link.springer.com/collections/agejehhhic`

My experimental perspective on SRCs

The first generation of SRC experiments (2000–2016) produced exciting discoveries.

- Limited kinematic reach
- Low statistics
- Data mining...

The second generation of SRC experiments in underway

- Dedicated experiments, select targets
- Novel observables, reactions
- *Entering a quantitative era*

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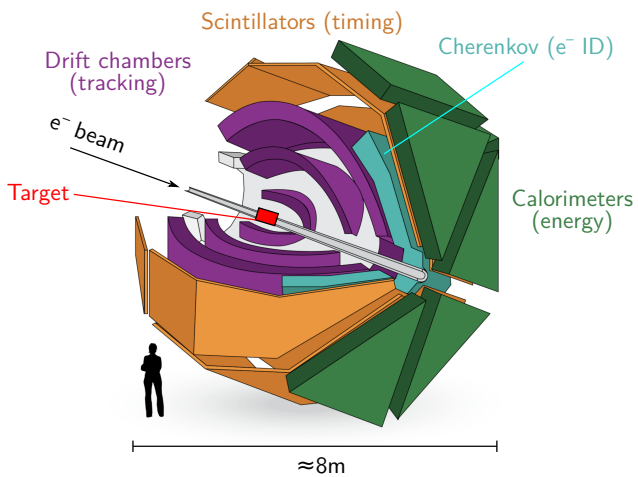
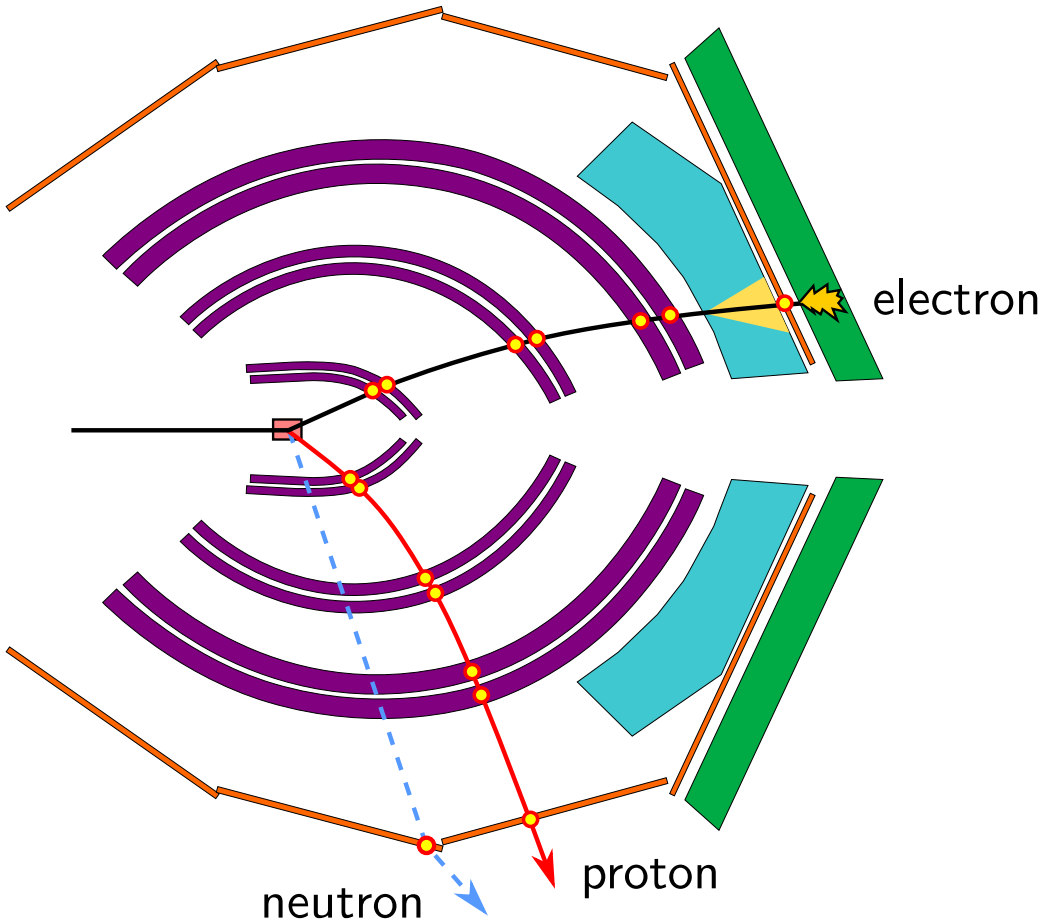
Quasi-elastic electron scattering has been a powerful tool for learning about SRCs.

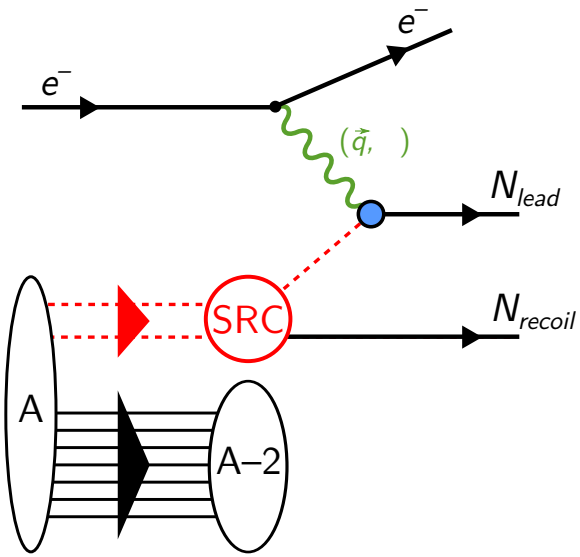
CLAS eg2 Experiment (2004)

- 5 GeV beam
- d, C, Al, Fe, Pb targets
- large acceptance spectrometer

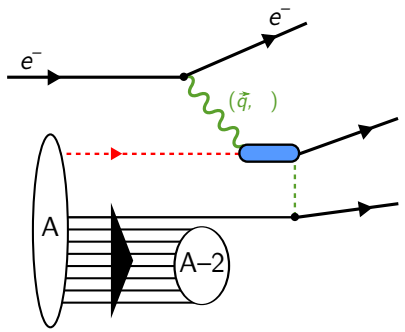




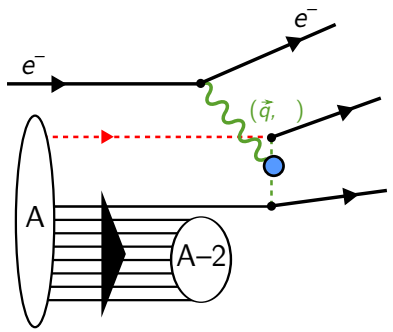
Exclusive measurements are always affected by final state interactions.



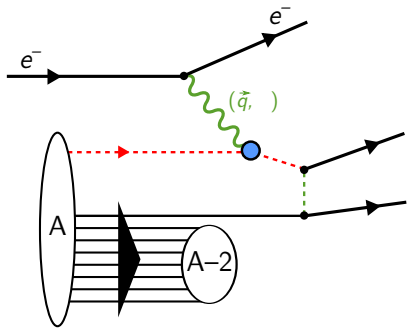
Plane-Wave



Isobar Configurations



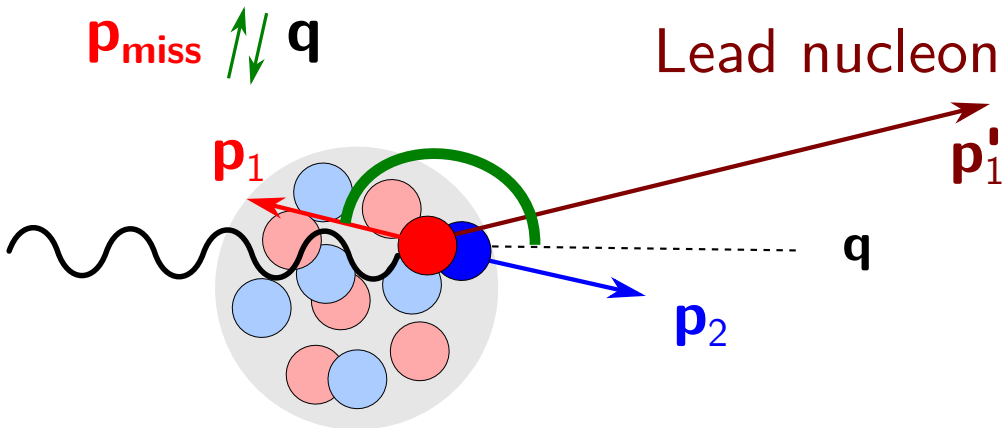
Meson-Exchange Currents



Final State interactions

Most previous SRC results come from a very narrow set of kinematics.

Missing Momentum



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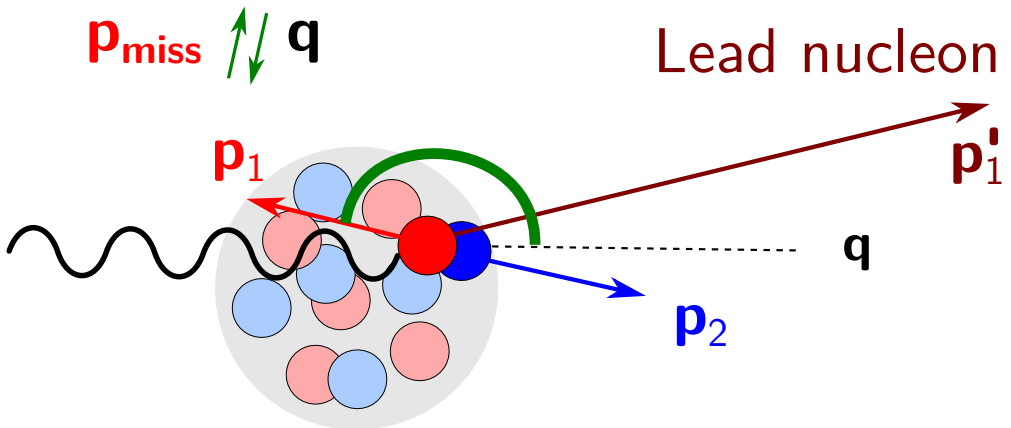

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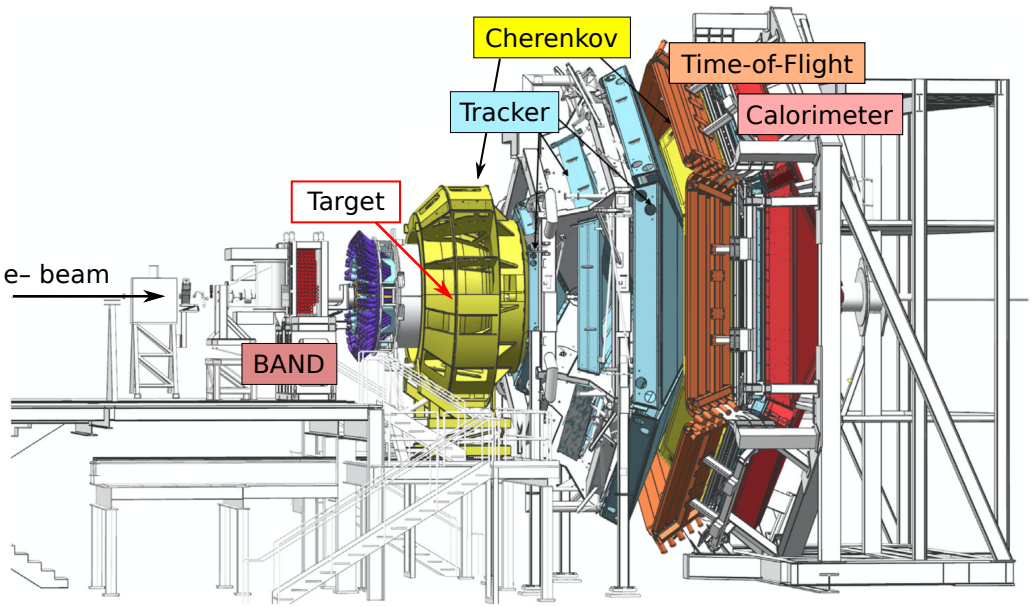
Kinematics

- $p_{\text{miss}} > 400$ MeV/c
- $x_B > 1.2$
- Large Q^2
- $\vec{p}_{\text{miss}}$ anti-parallel to $\vec{q}$

CLAS12 Run Group M is a dedicated high-statistics SRC experiment.

- Nov. 2021–Feb. 2022
- 300 fb^{-1}
  - 10× more than CLAS
- Targets: H, D, ^{4}He, ^{12}C, ^{40,48}Ca, ^{120}Sn
- 2, 4, 6, GeV beams
- CLAS12 Spectrometer



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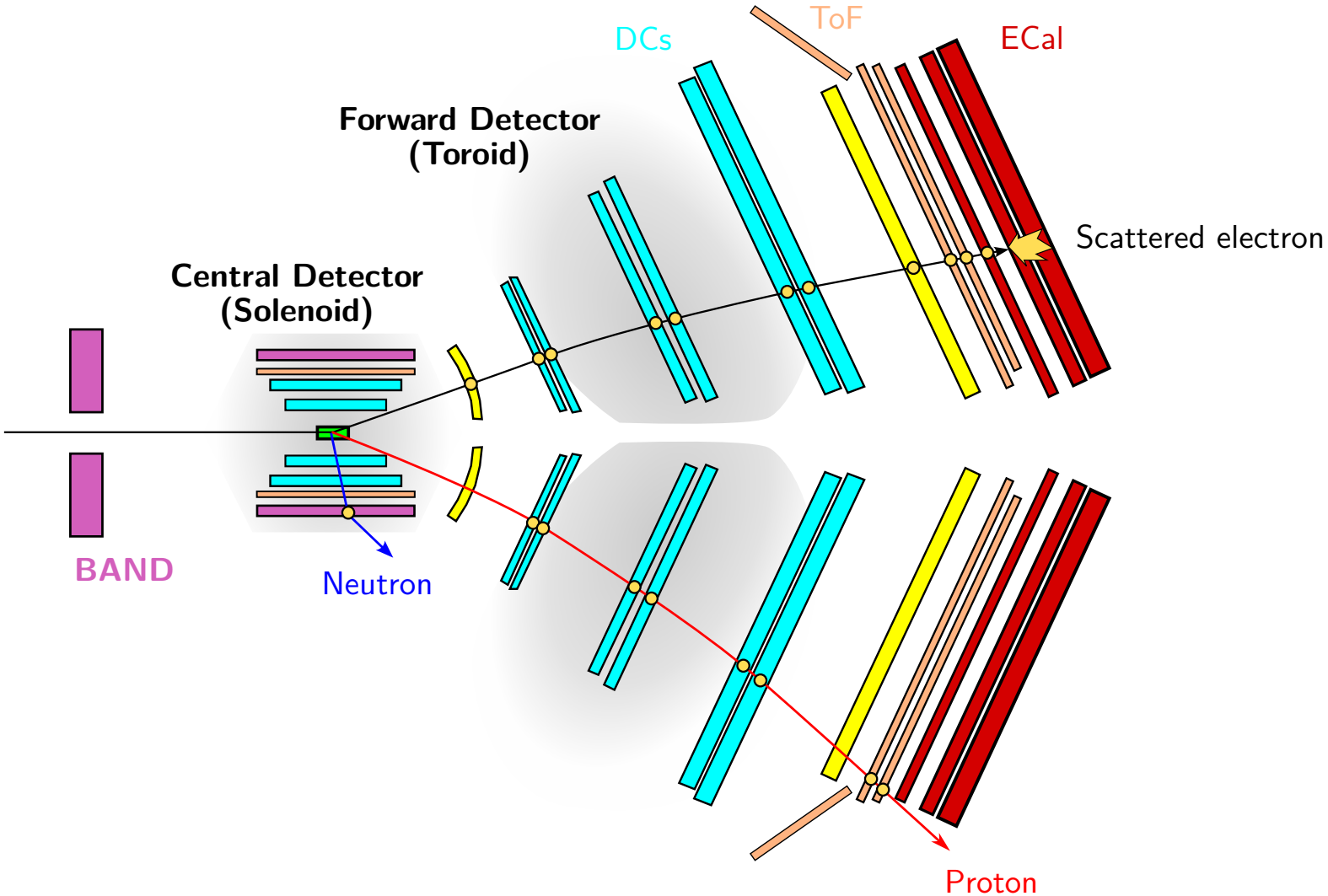
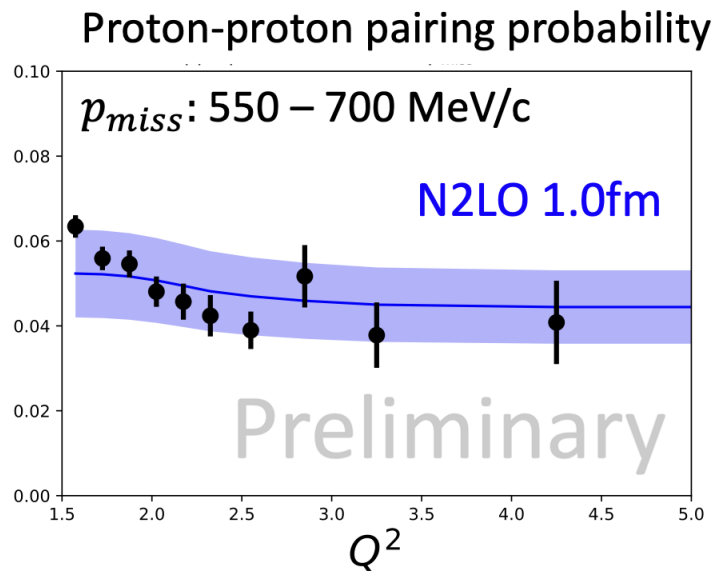
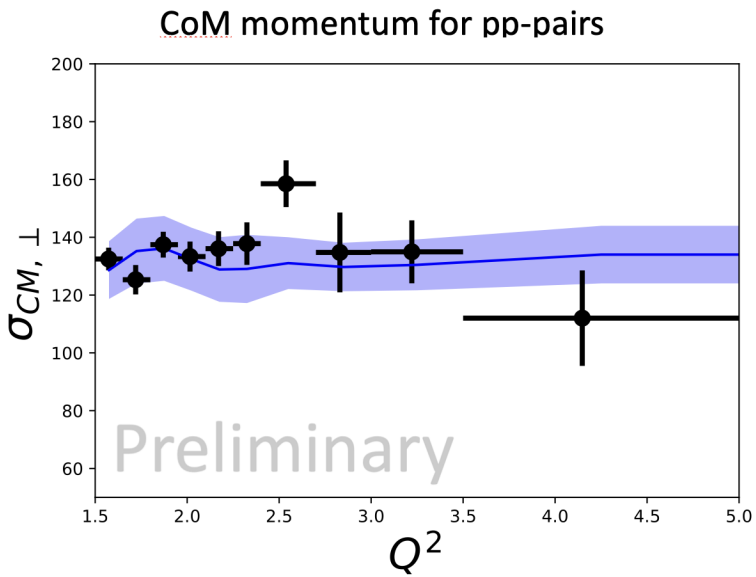


Preliminary results testing Q^2 dependence of SRC observables.

$$\frac{A(e,e'pp)}{A(e,e'p)}$$

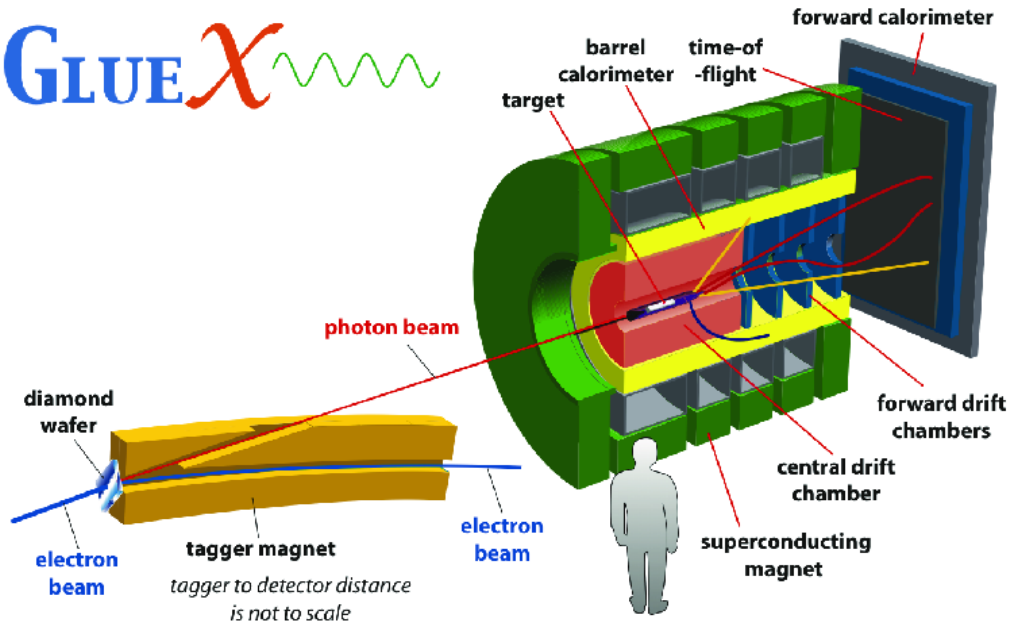




Analysis by Andrew Denniston, MIT/Tel Aviv

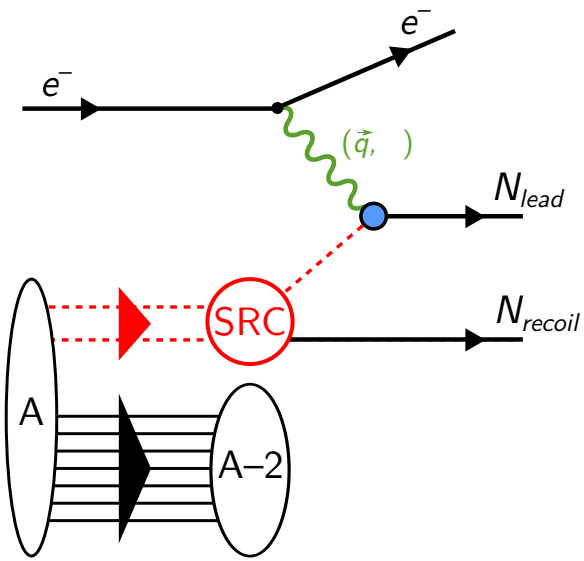
Hall D SRC/Color-Transparency Experiment: probing SRCs with photoproduction reactions

- Nov.–Dec., 2021
- $>$ 90 billion triggers
- Targets: D, ^{4}He, ^{12}C
- Peak flux at 8.5 GeV
- GlueX Spectrometer

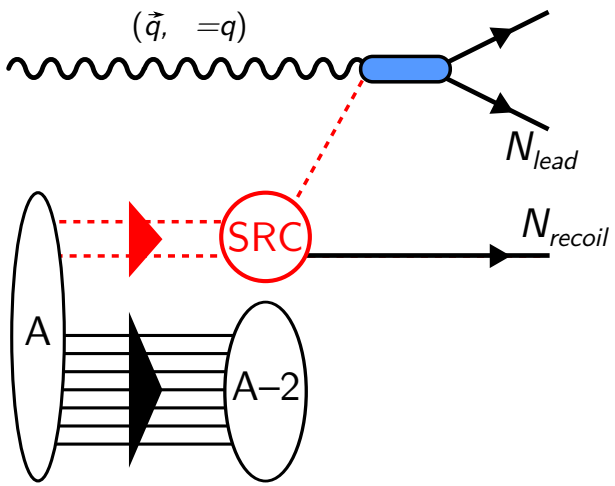


- Axion-like particle search: J. R. Pybus et al., Phys. Lett. B 855, 138790 (2024)
- Subthreshold J/ψ production: J. R. Pybus et al., Phys. Rev. Lett. 134, 201903 (2025)

Does the probe-nucleon interaction factorize from the nuclear ground state?



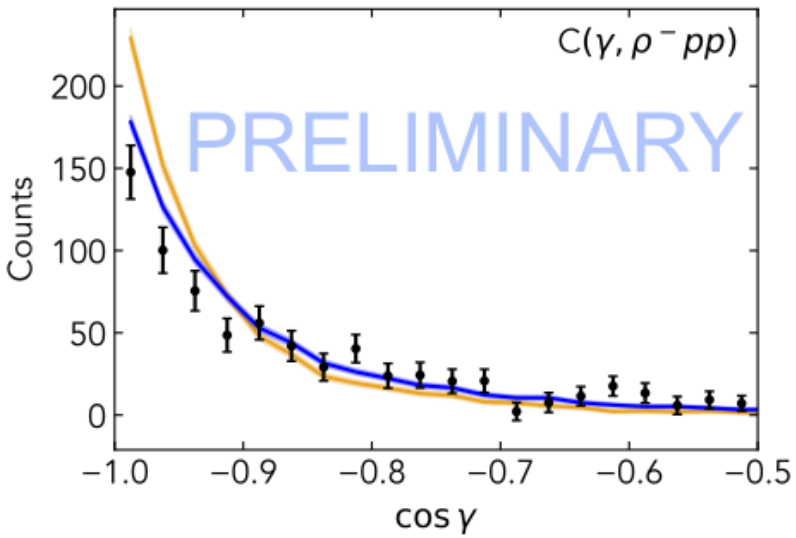
Plane wave QE scattering



Plane-wave photo-production

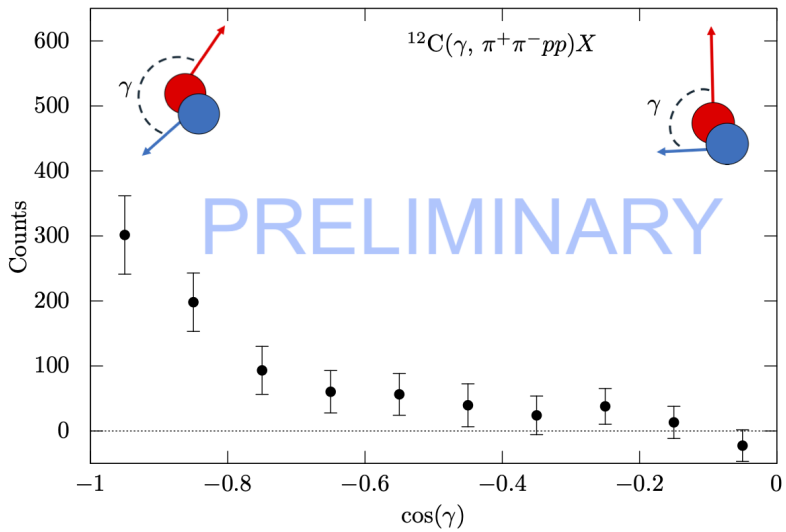
We see angular correlations in multiple reaction channels.

$\gamma n(p) \to \rho^- pp$



Credit: Jackson Pybus, MIT

$\gamma p(p) \to \rho^0 pp$



Credit: Phoebe Sharp, GW

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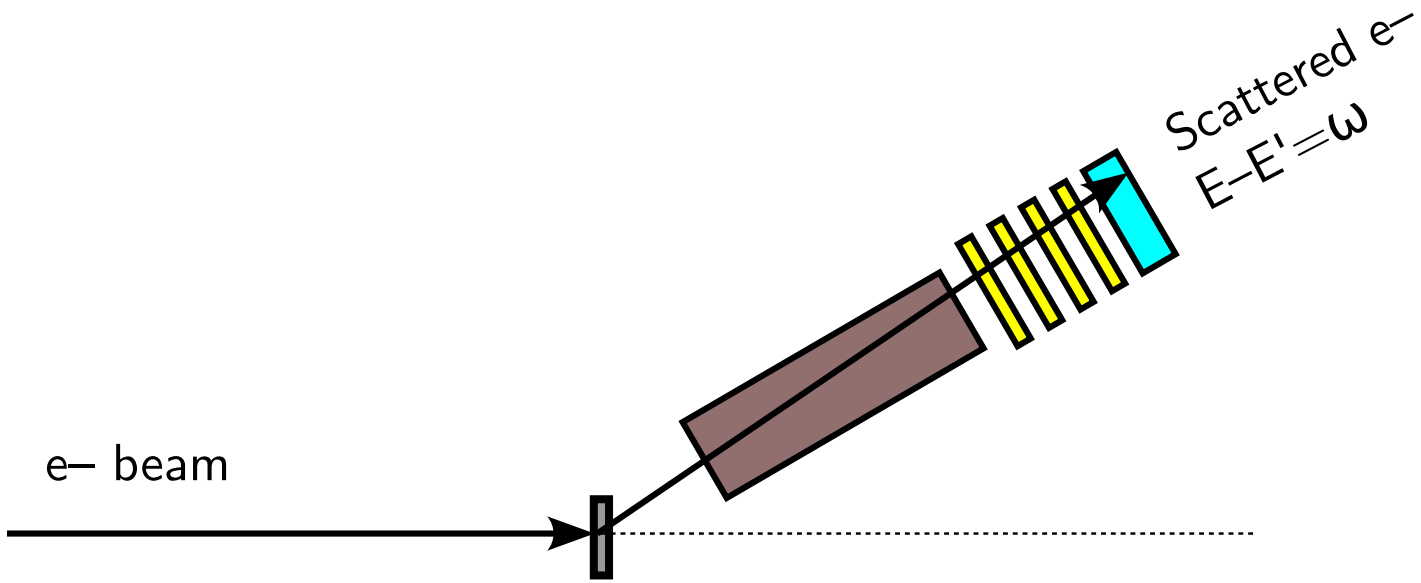
Nucleon motion can be seen in inclusive quasi-elastic scattering.



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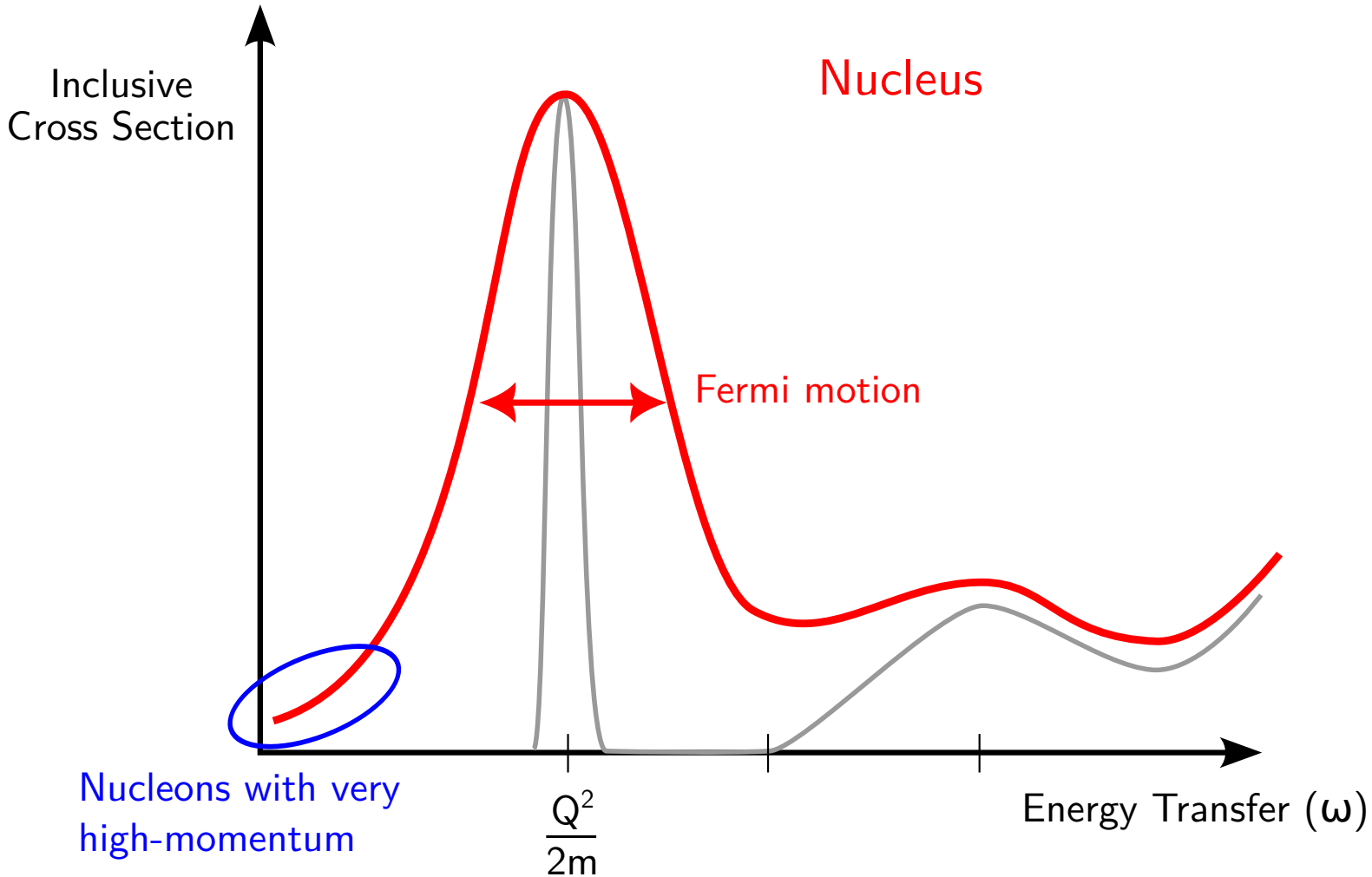

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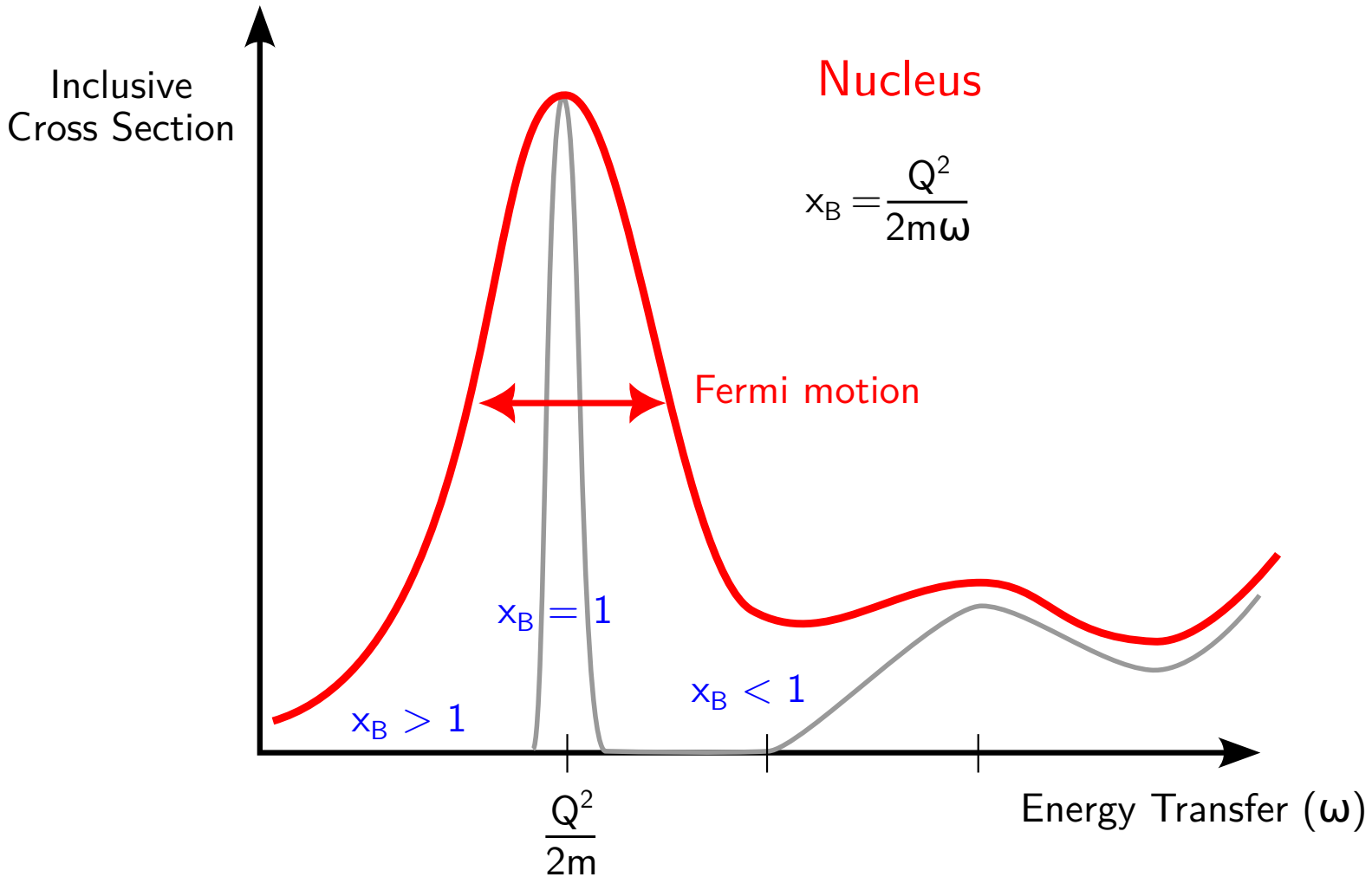

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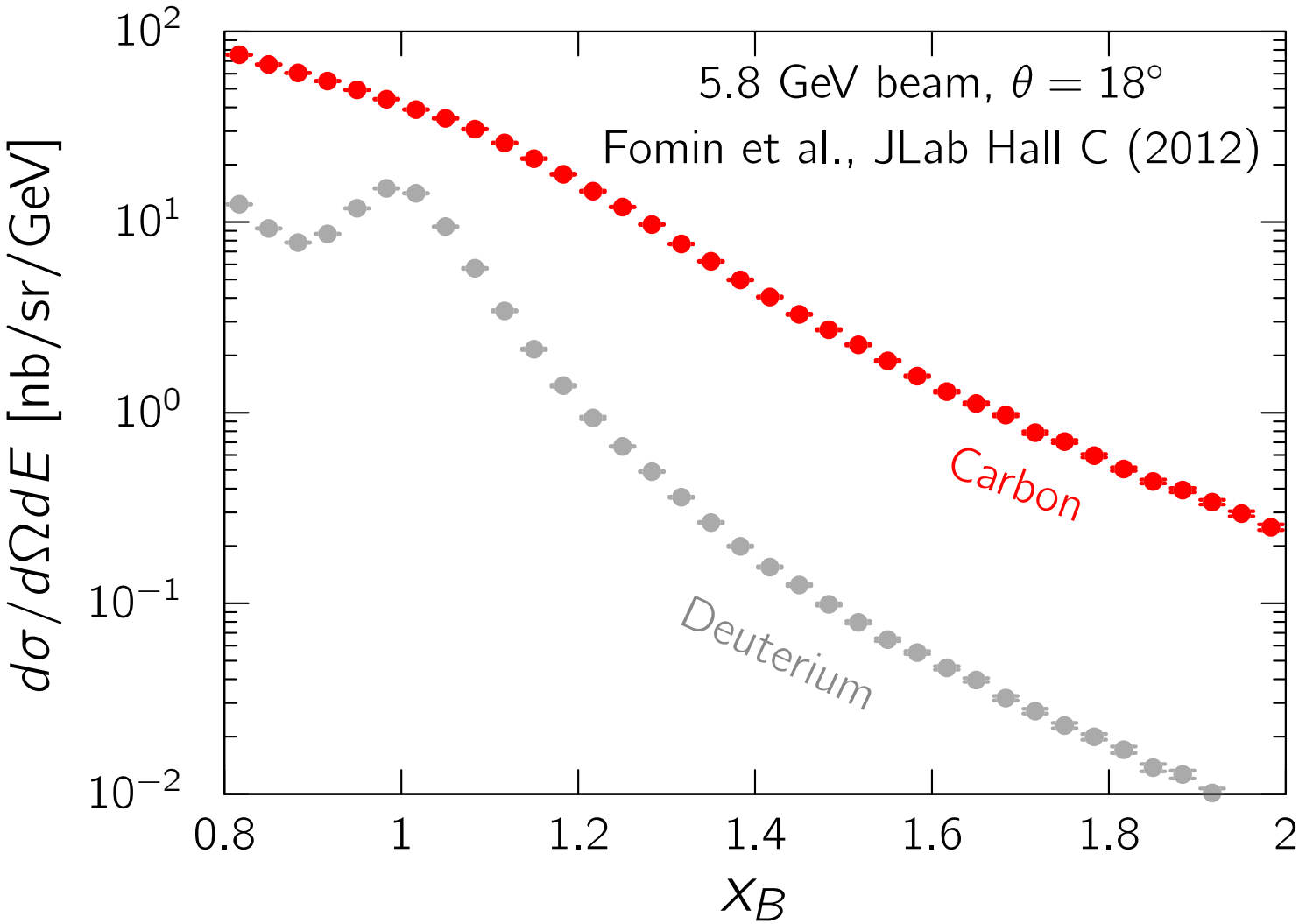
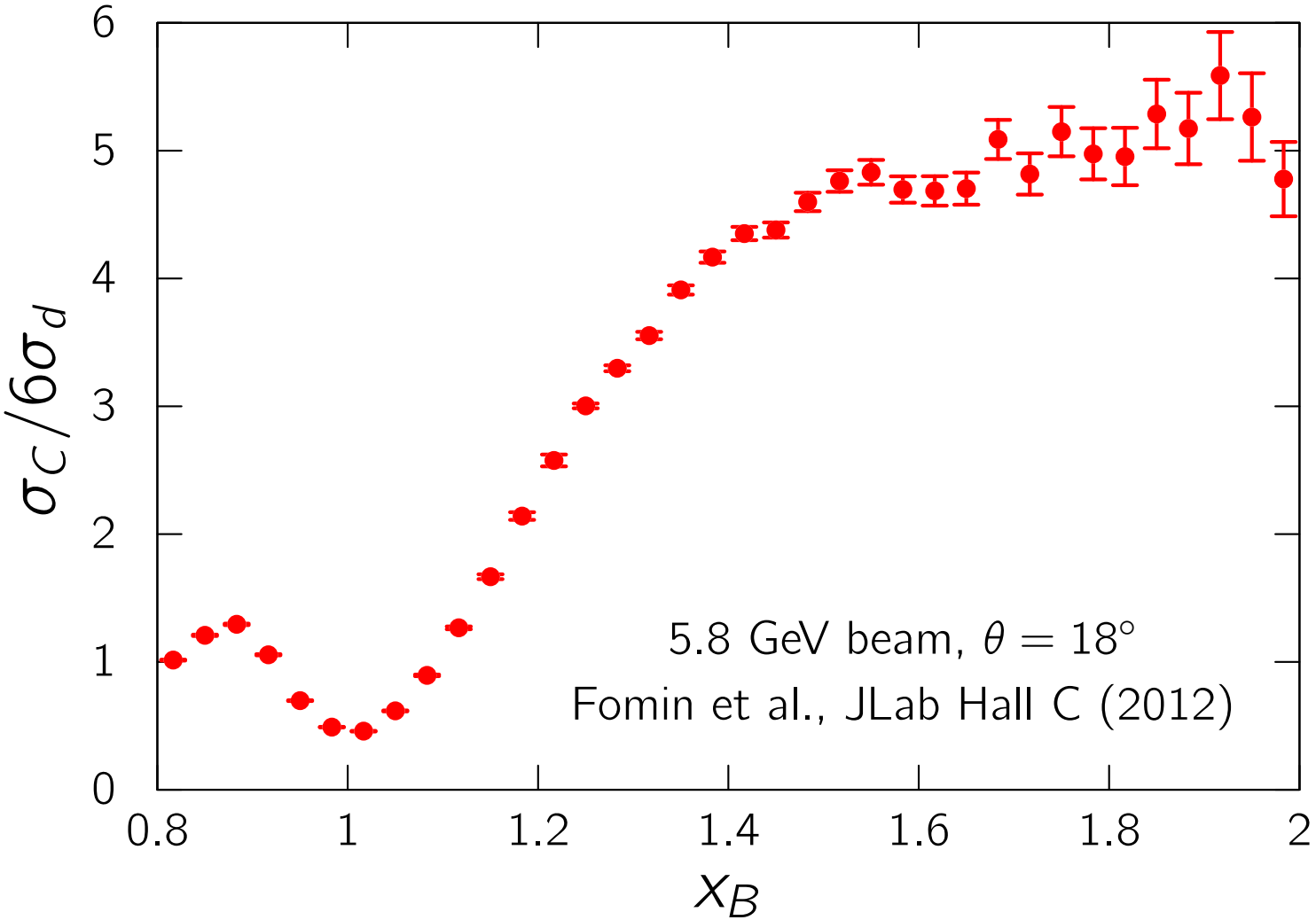
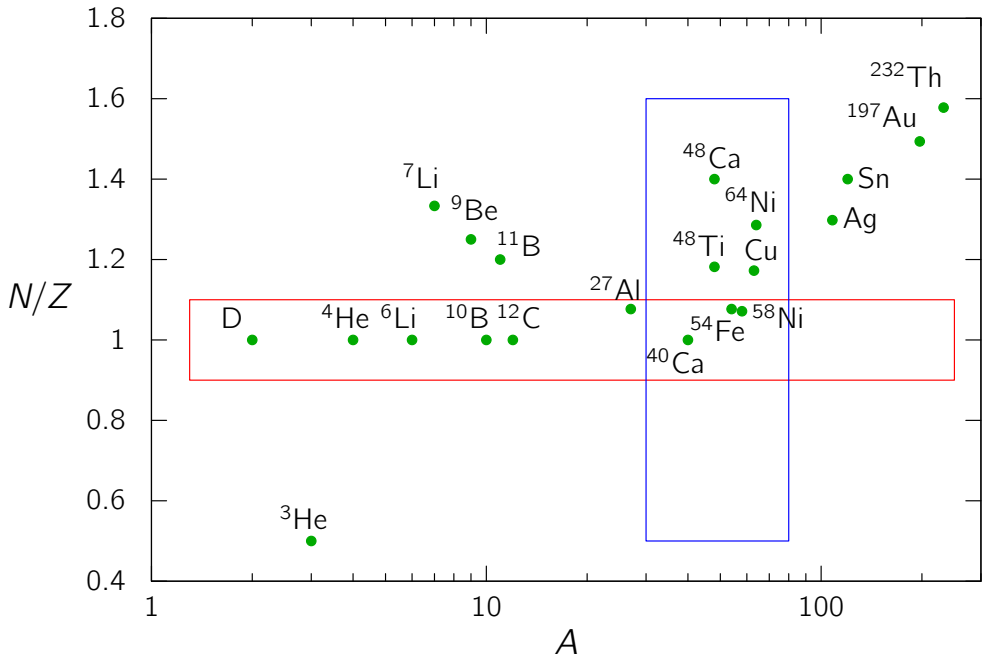


Plateau at large x_B implies 2-body physics.



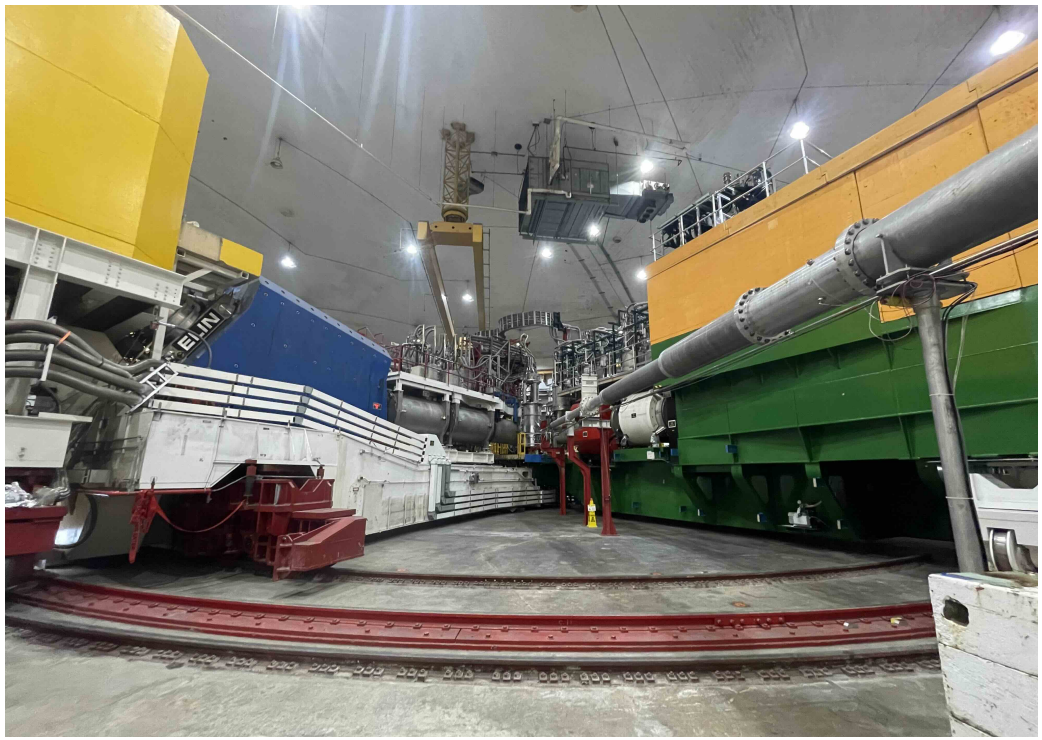
The XEM2 experiment has measured a swath of light and heavy targets.

- Spokespeople: J. Arrington, N. Fomin, D. Gaskell
- 2018, 2019, 2022–23
- Hall C HMS, SHMS
- Also covering $x_B > 2$ to look for 3N SRCs

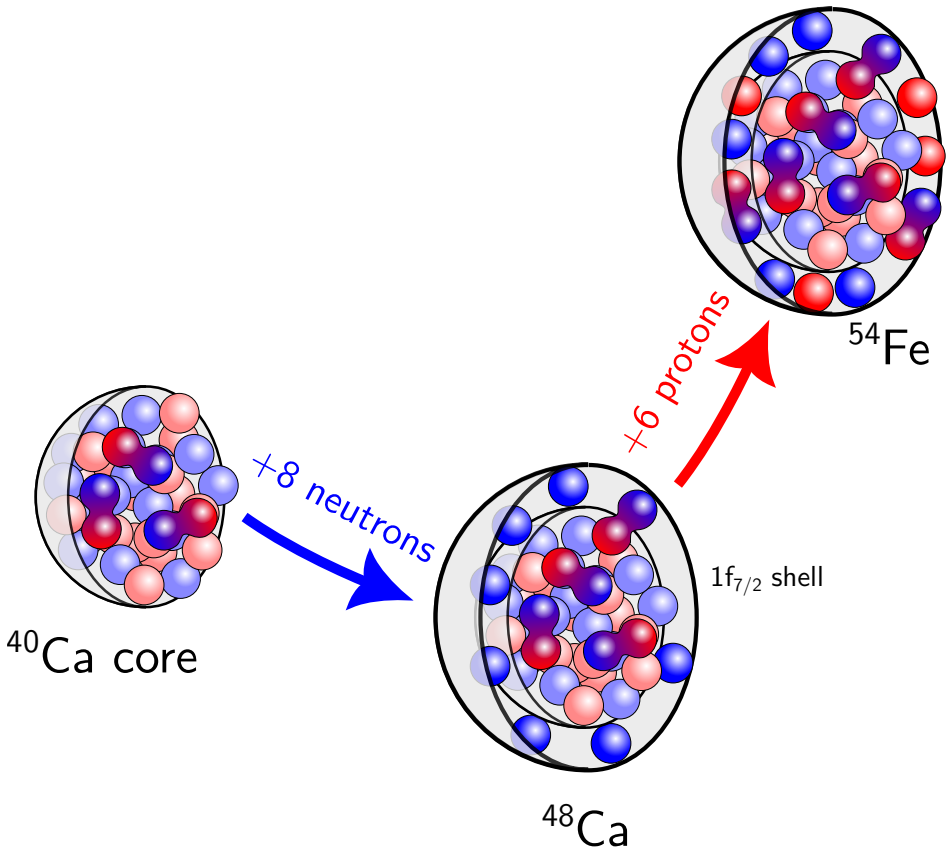


CaFe measured $(e, e'p)$ in ^{40}Ca, ^{48}Ca, and ^{54}Fe.

- Spokespeople: O. Hen, L. B. Weinstein, D. Higinbotham, F. Hauenstein
- Collected data in 2022
- SHMS+HMS in coincidence



Can pairing occur between nucleons in different orbitals?



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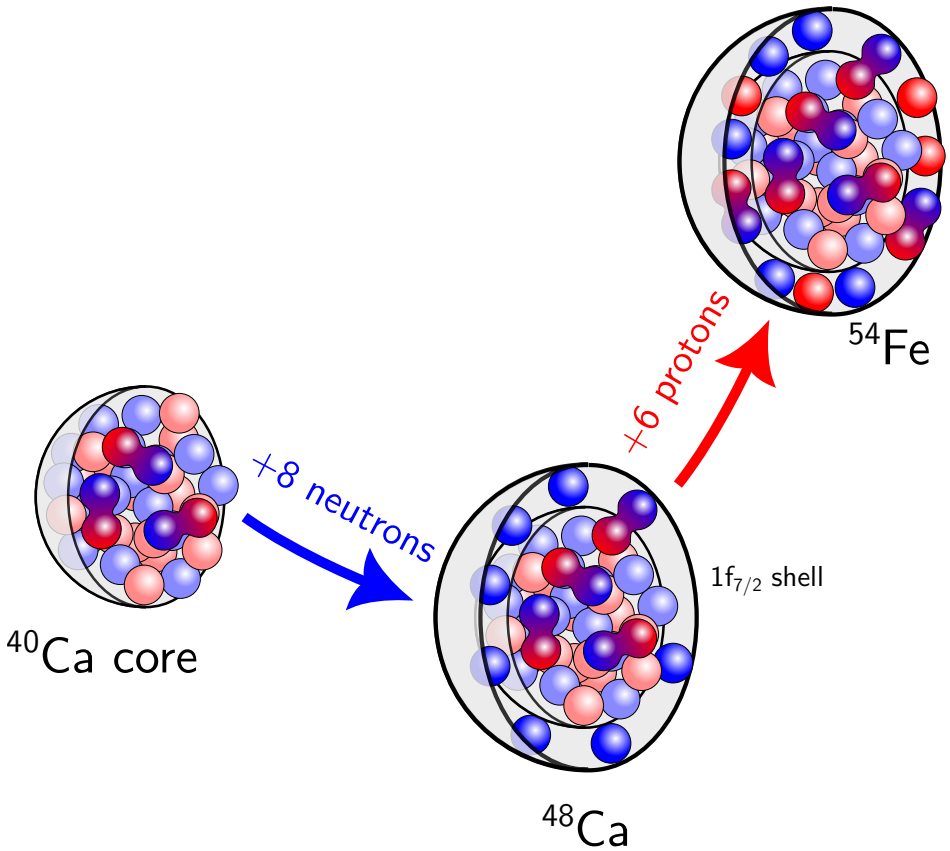
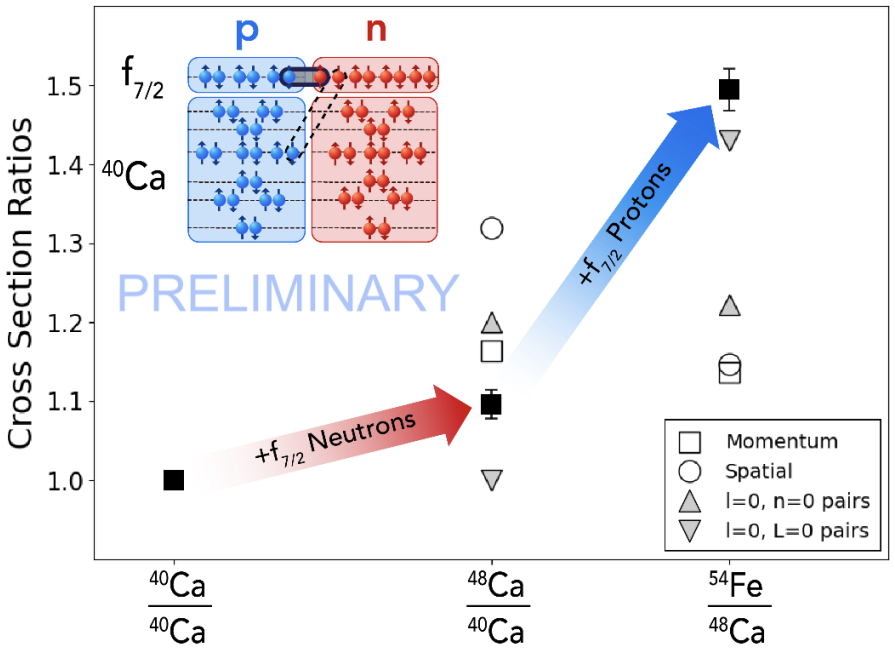


Little cross-shell pairing!



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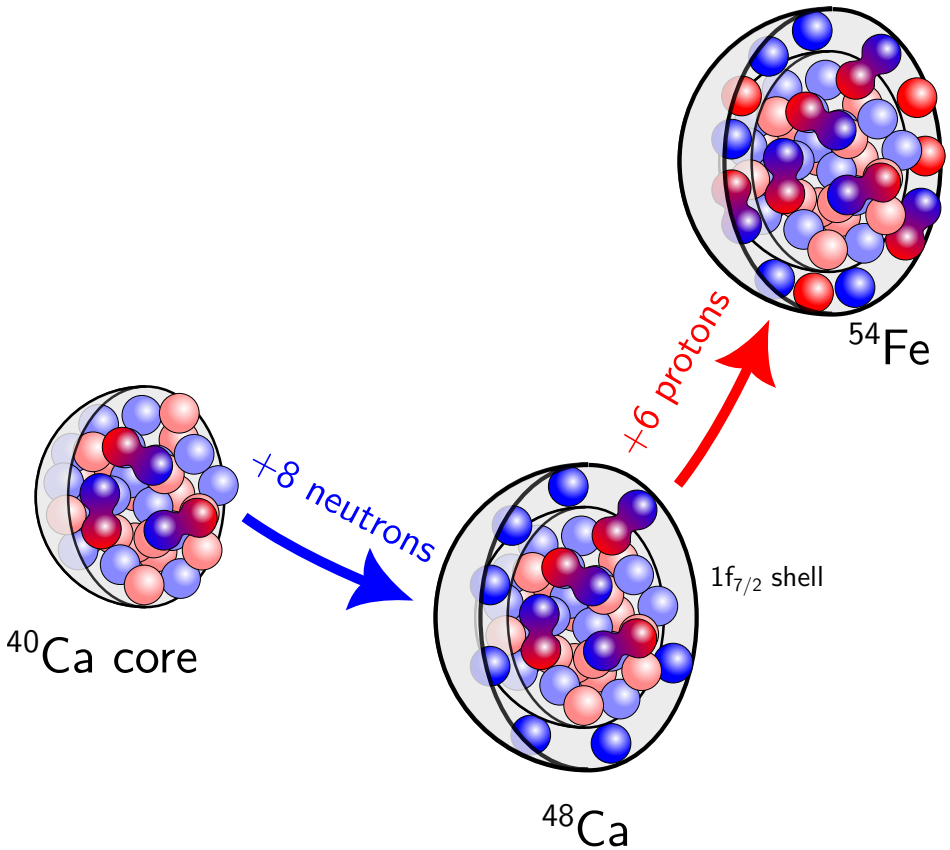

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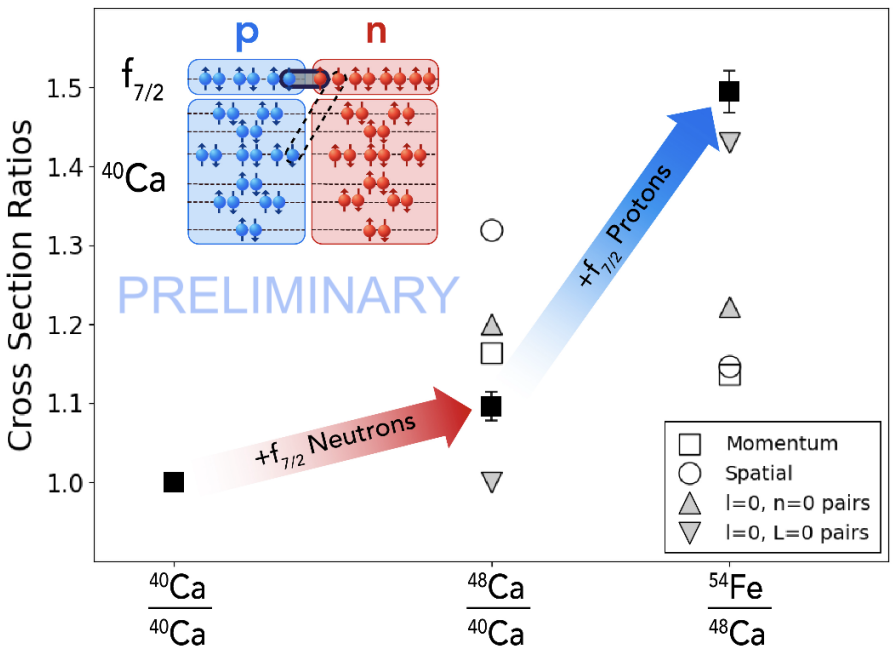
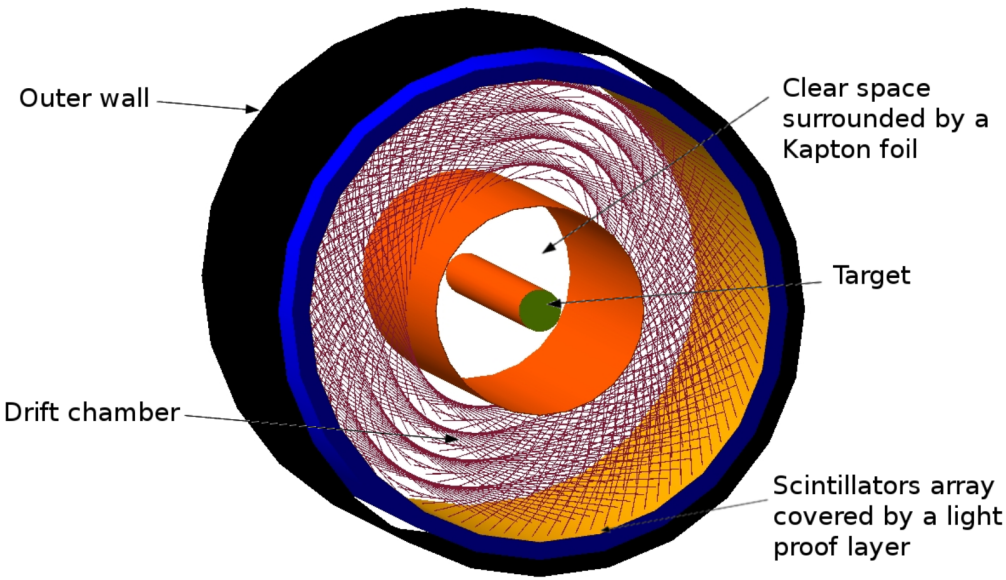


Further triangulation with XEM2, Run Group M Ca results.

ALERT can track the residual nuclear system.

- Spokespeople:
  F. Hauenstein, O. Hen,
  M. Ouillon, E. Piasetzky,
  A. Schmidt, L. B. Weinstein
- Collecting data this summer
- ALERT + CLAS12
- 6 GeV e^- on ^{4}He



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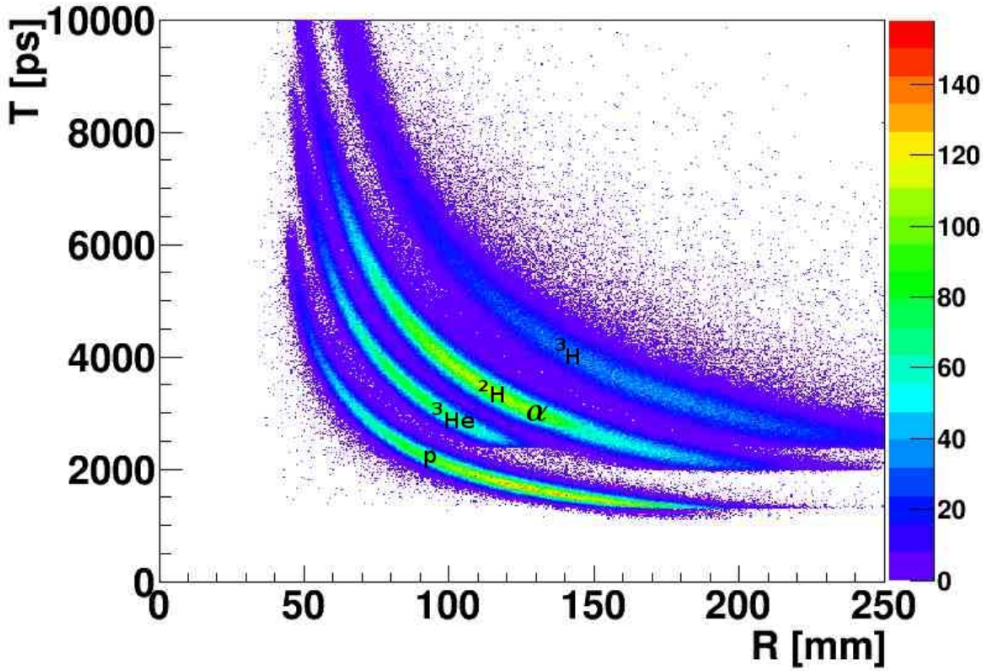
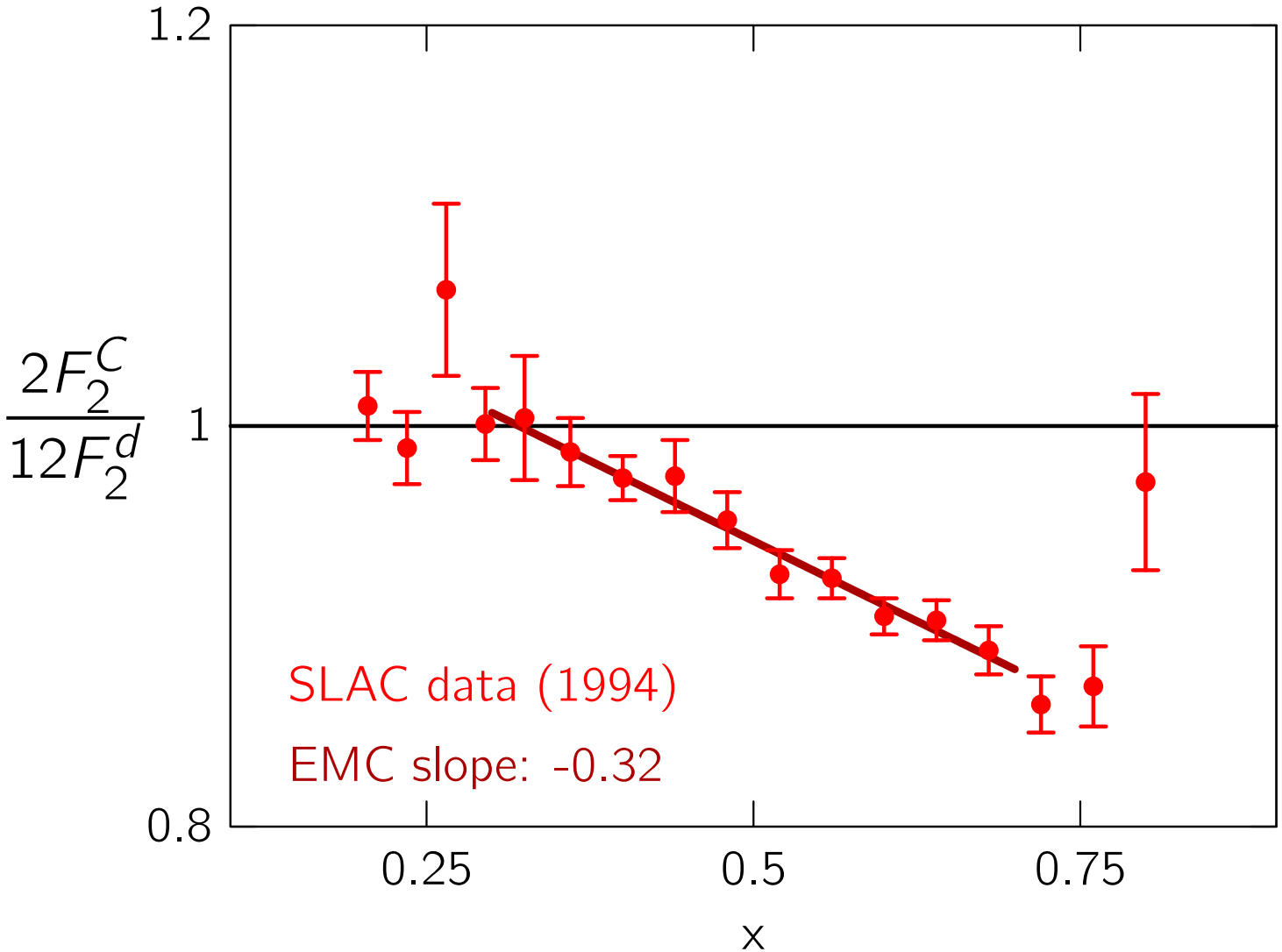
- Spokespeople:
  F. Hauenstein, O. Hen,
  M. Ouillon, E. Piasetzky,
  A. Schmidt, L. B. Weinstein
- Collecting data this summer
- ALERT + CLAS12
- 6 GeV e^- on ^{4}He



Big open questions

1. How universal are our findings?
   - Do they depend on probe and resolution-scale?
2. How do pairs form?
   - Which nucleons correlate?
   - Can correlations form across shells?
3. **What role do SRCs play in the EMC Effect?**
   - **Is structure modification driven by highly virtual nucleon pairs?**

EMC Effect: modification of bound nucleon structure



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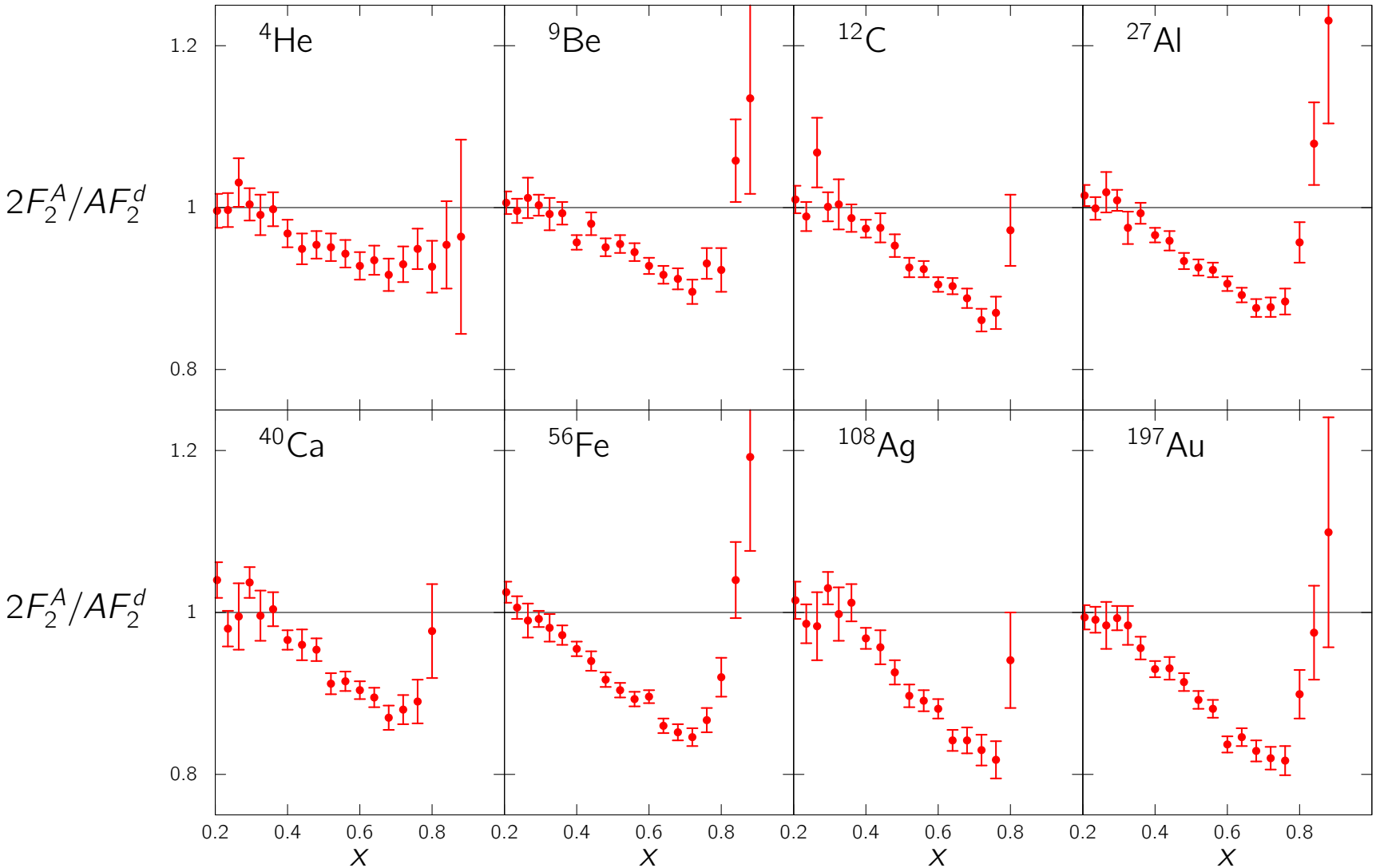
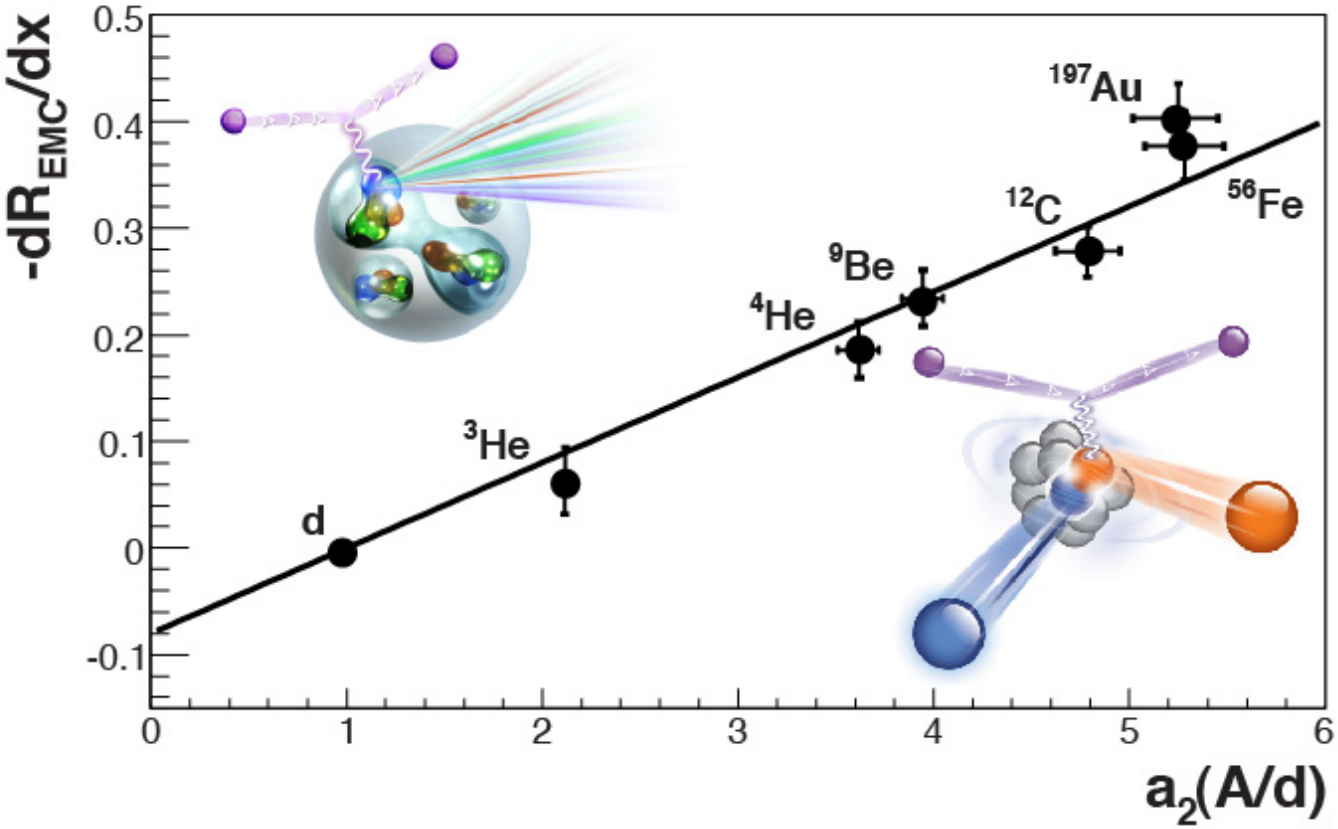


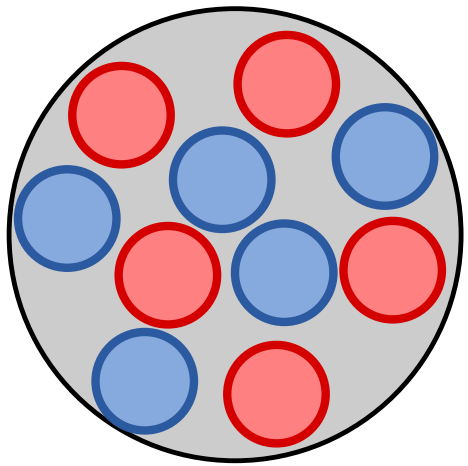
The EMC Effect correlates suspiciously with the prevalence of SRC pairs.



L. B. Weinstein et al., PRL 106, 052301 (2011)

Does binding affect all nucleons or are some nucleons affected A LOT?

Free



Medium Modification Hypothesis

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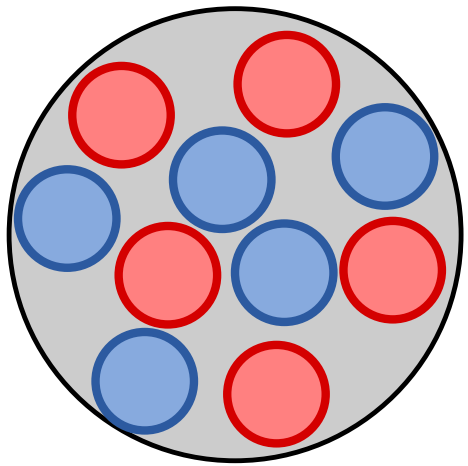

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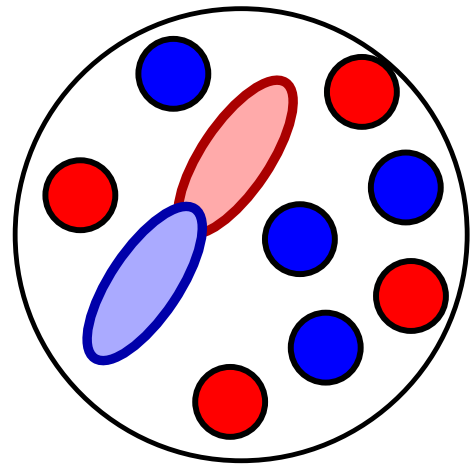
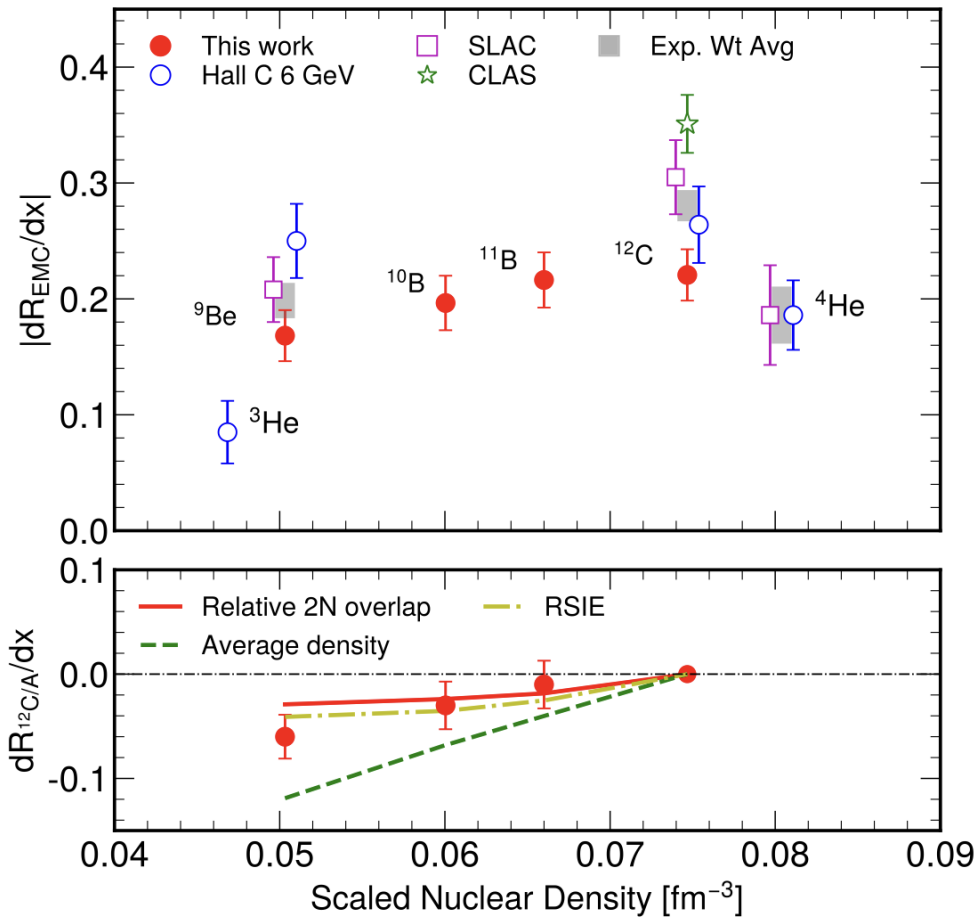


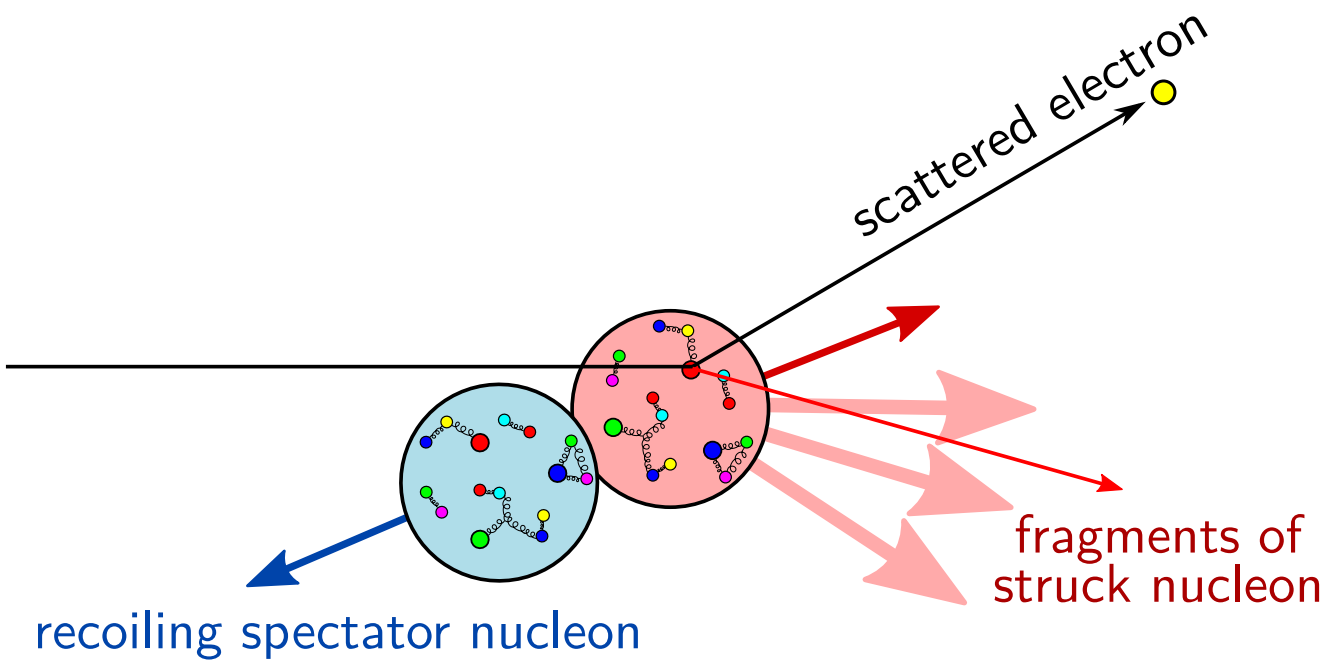
Short-Range Correlation Hypothesis

New inclusive measurements will study trends across nuclei.



A. Karki et al., Phys. Rev. C 108, 035201 (2023)

We can isolate SRC nucleons by "tagging" a correlated partner.



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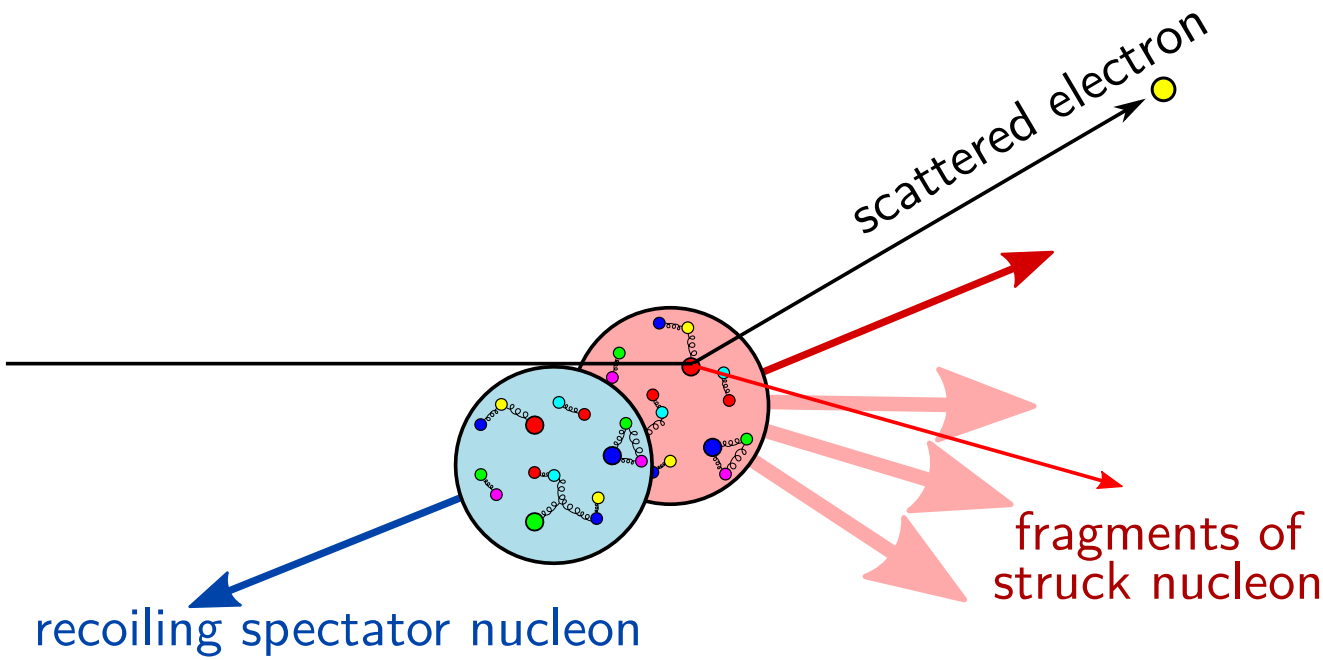

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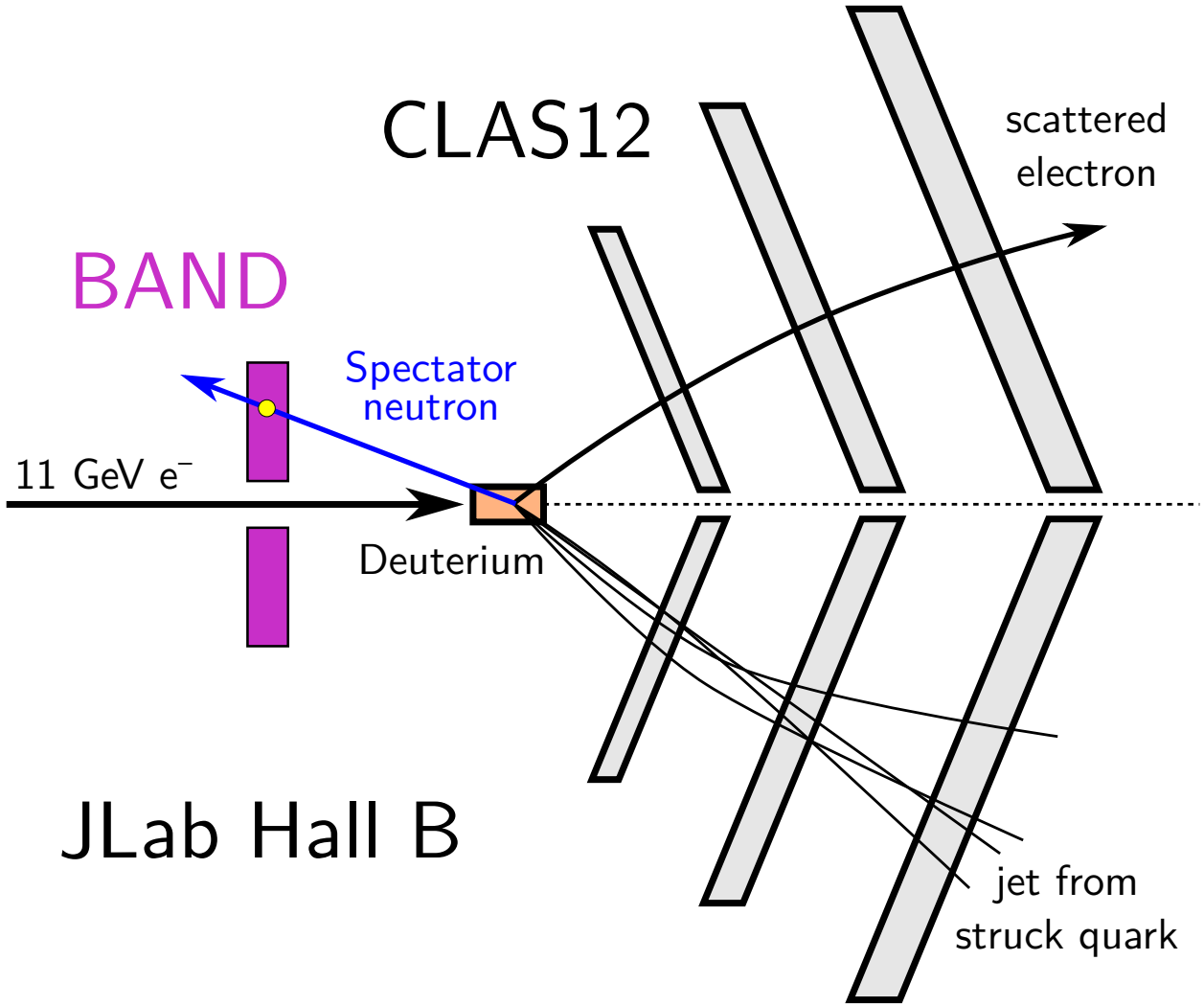
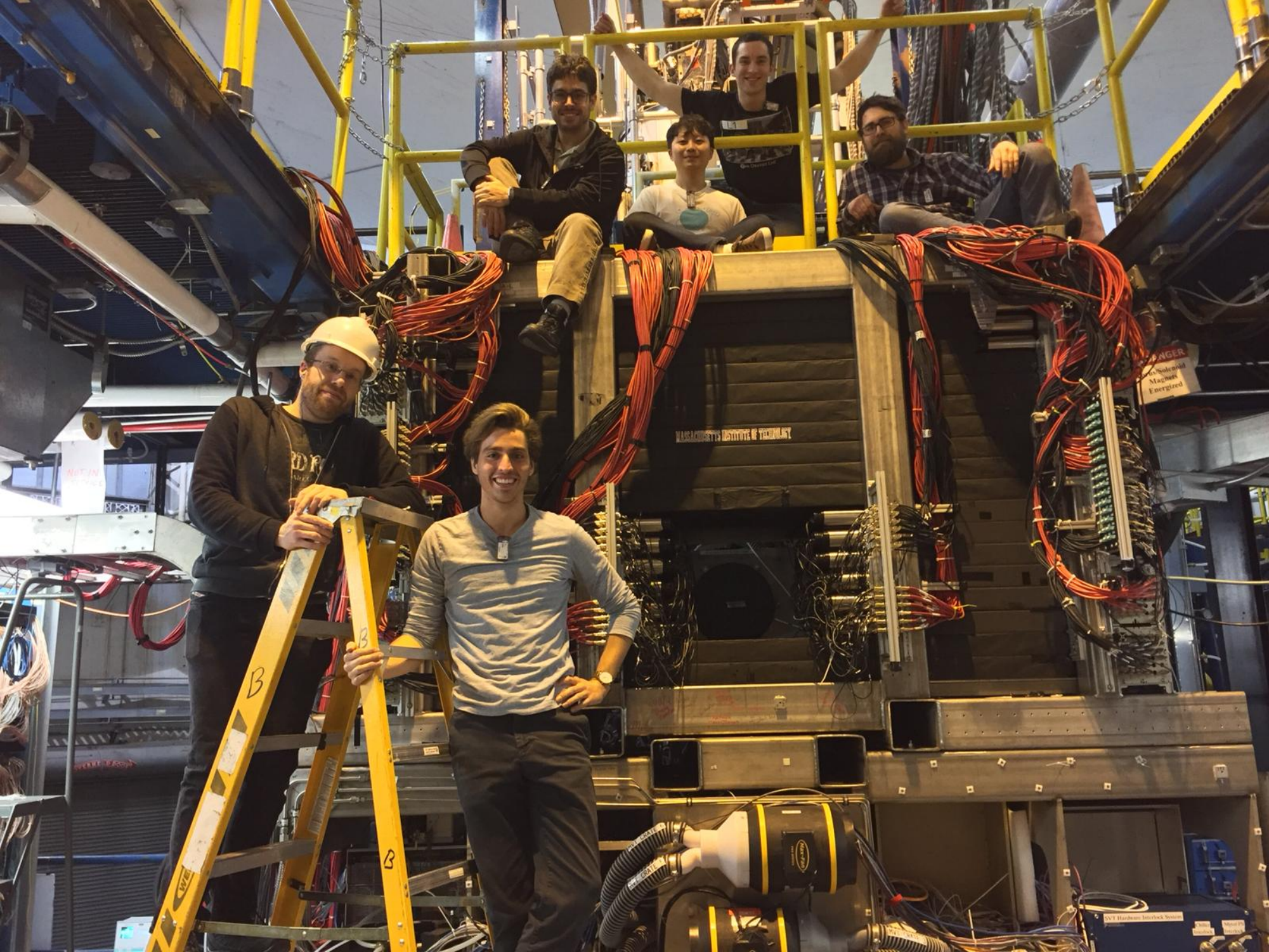
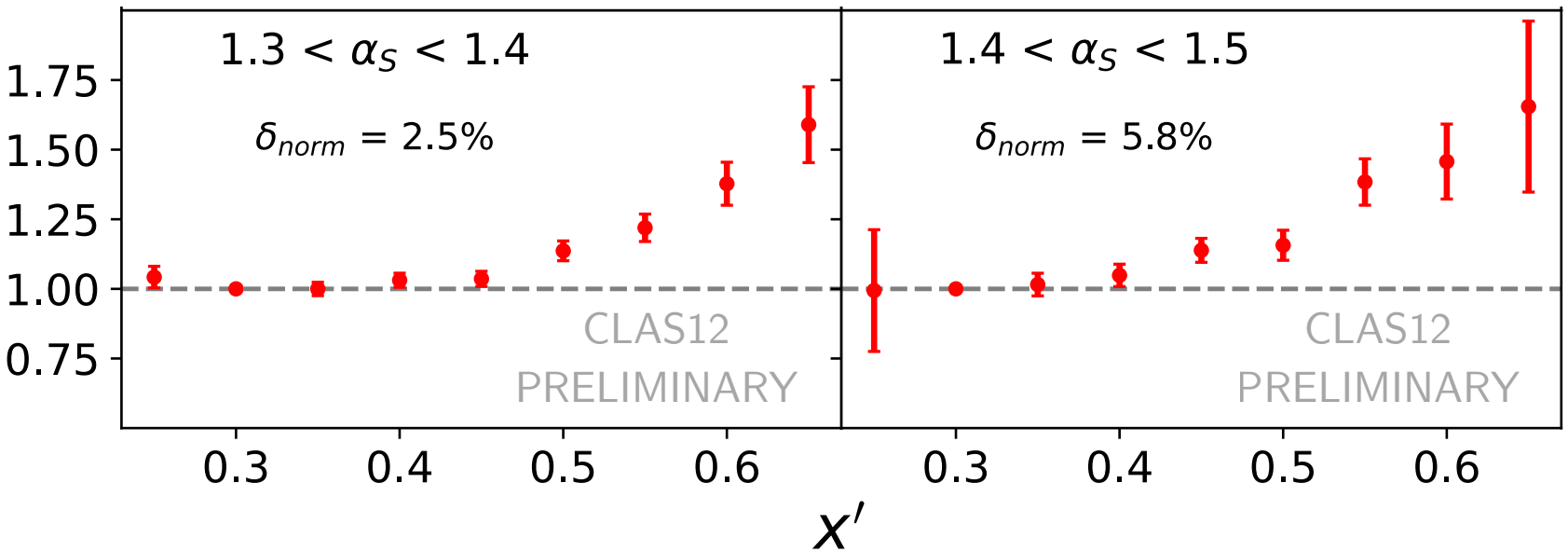
"Backward Angle Neutron Detector"
was built to detect recoiling spectator neutrons.




DANGER
Solenoid
Magnet
Energized
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SVT Hardware Interlock System

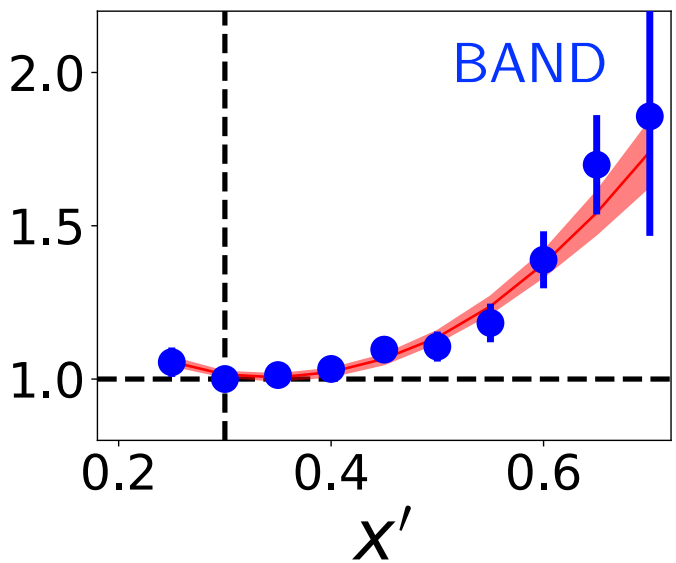
BAND preliminary results show signs of *positive* modification for high-momentum protons.

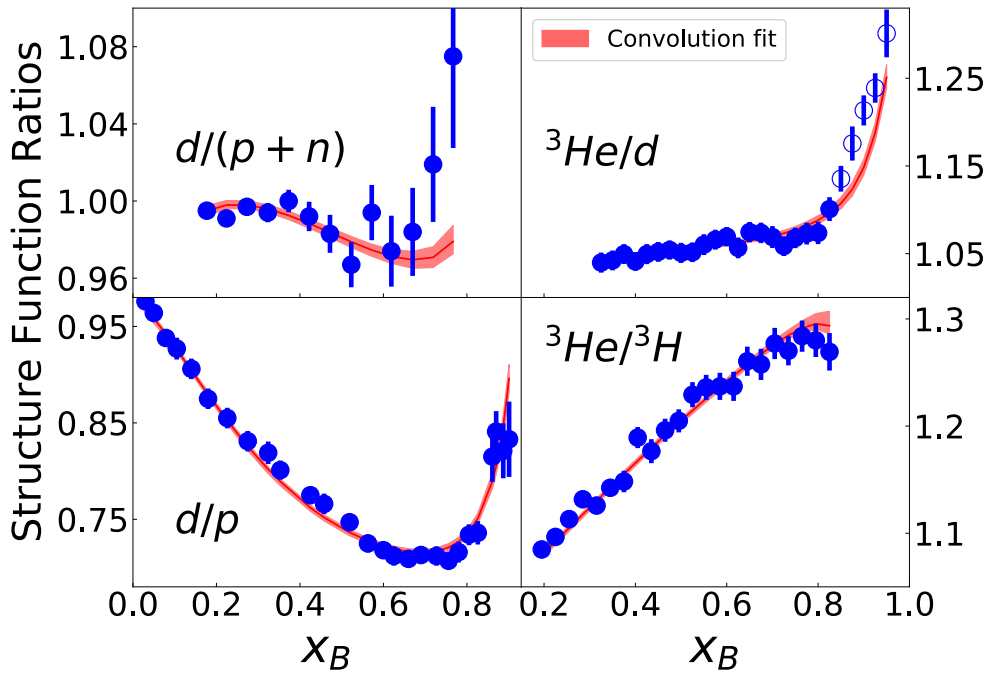
$$\mathcal{R} = \frac{\sigma^*(\alpha_S, x') \big/ \sigma(\alpha_S, x')}{\sigma^*(\alpha_S, x' = 0.3) \big/ \sigma(\alpha_S, x' = 0.3)}$$



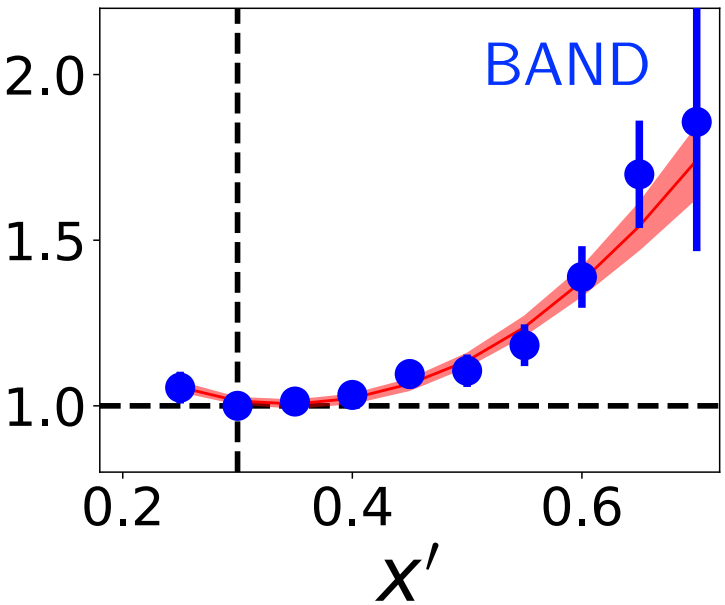
Figures courtesy of Tyler Kutz

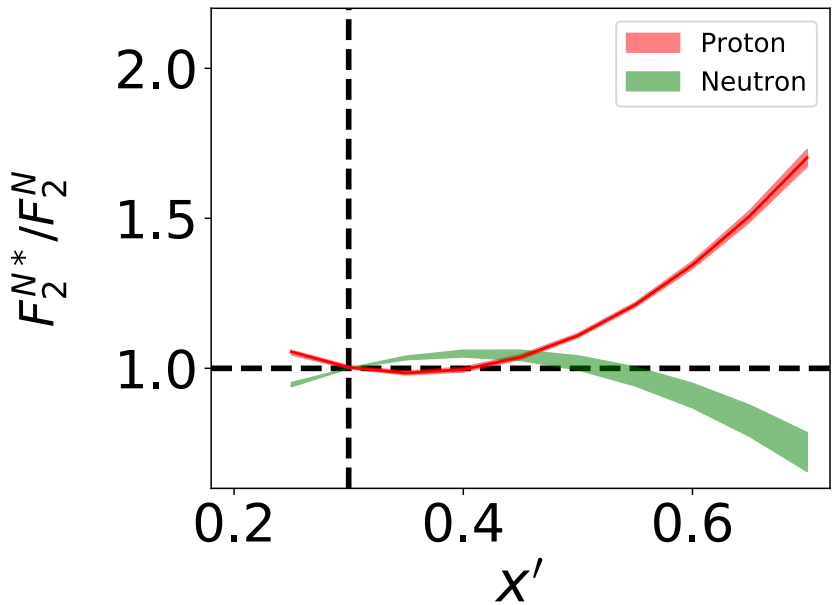
Such a modification is consistent with non-tagged DIS data on light nuclei.



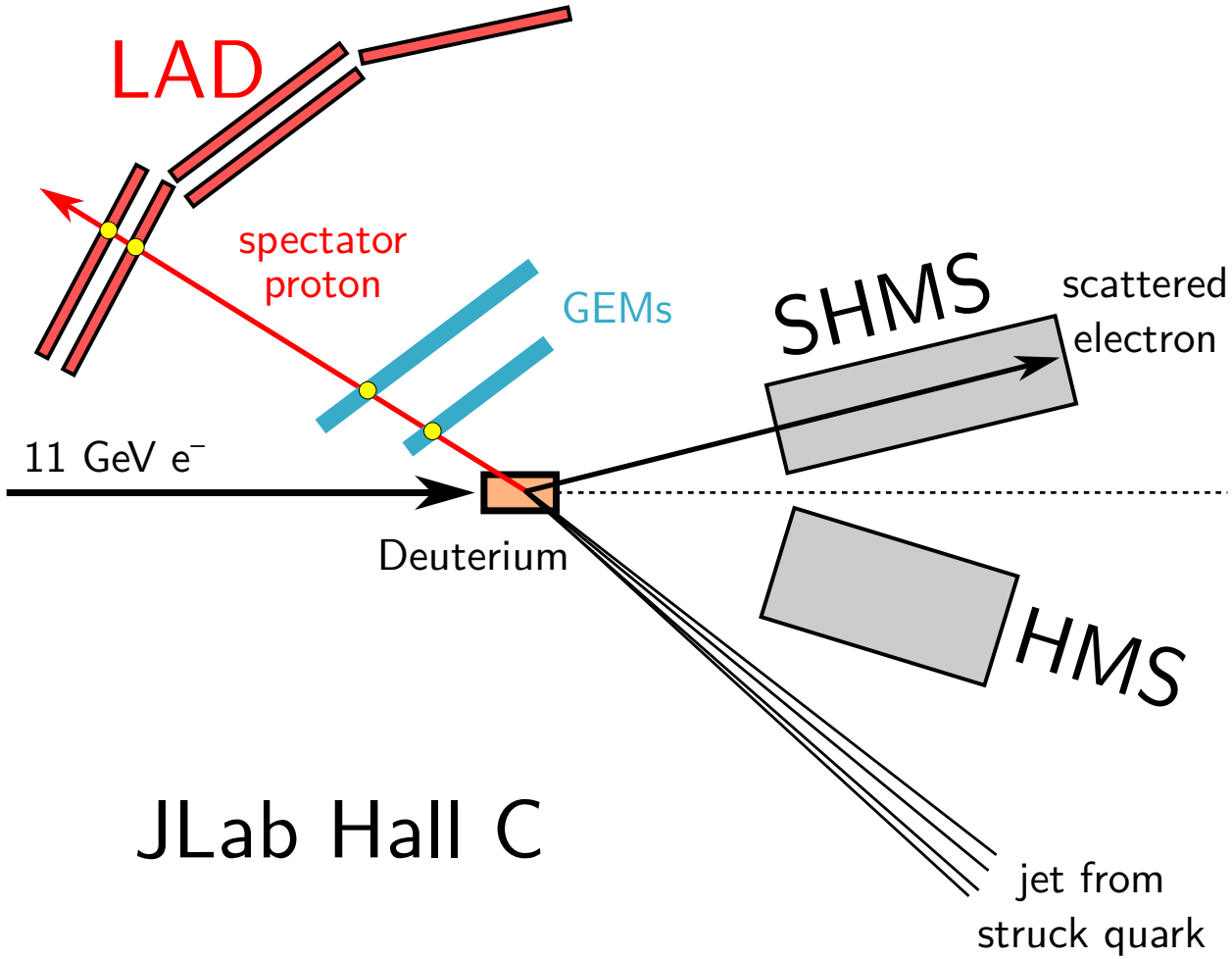


. . . but makes a very specific prediction

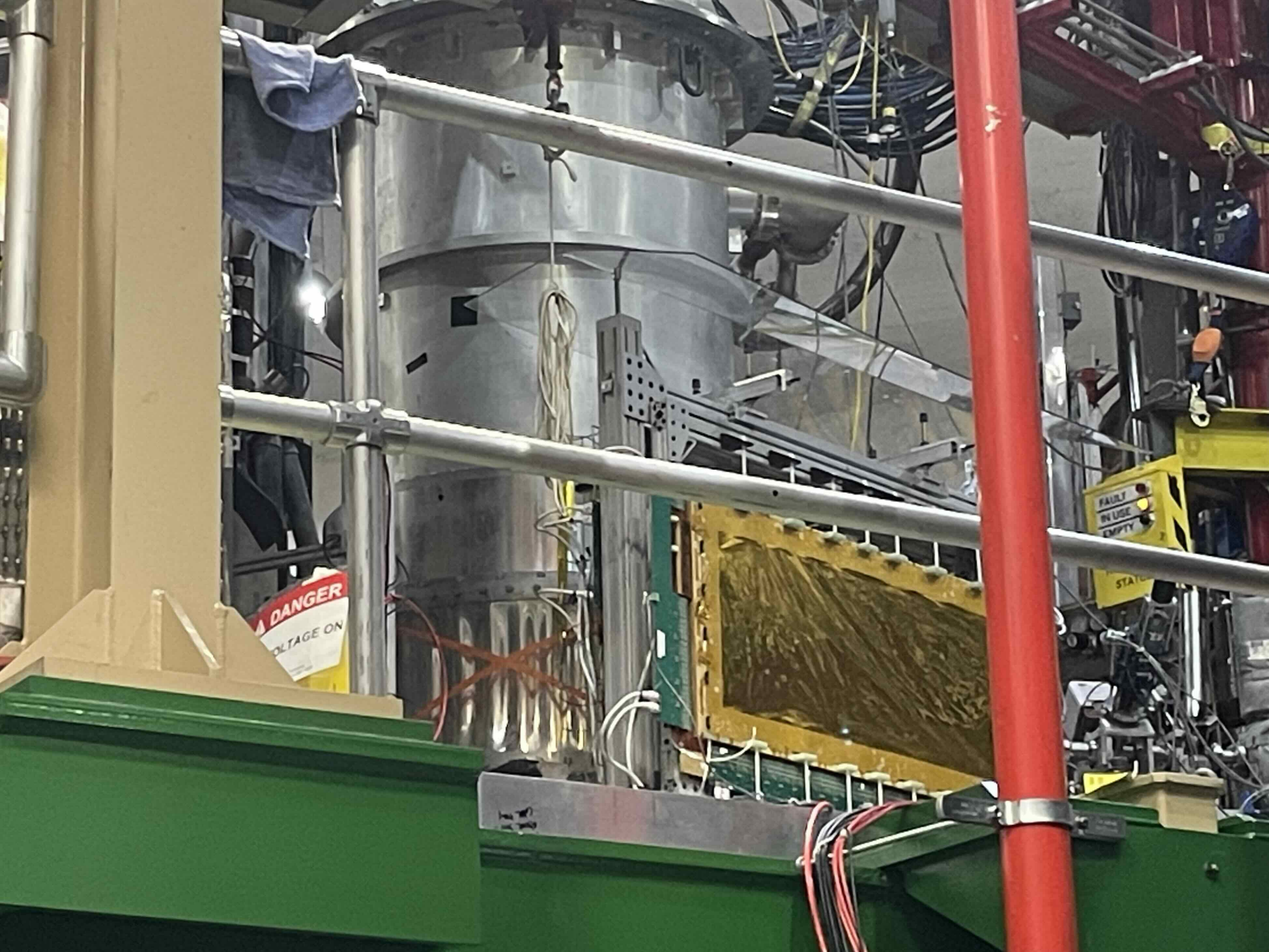




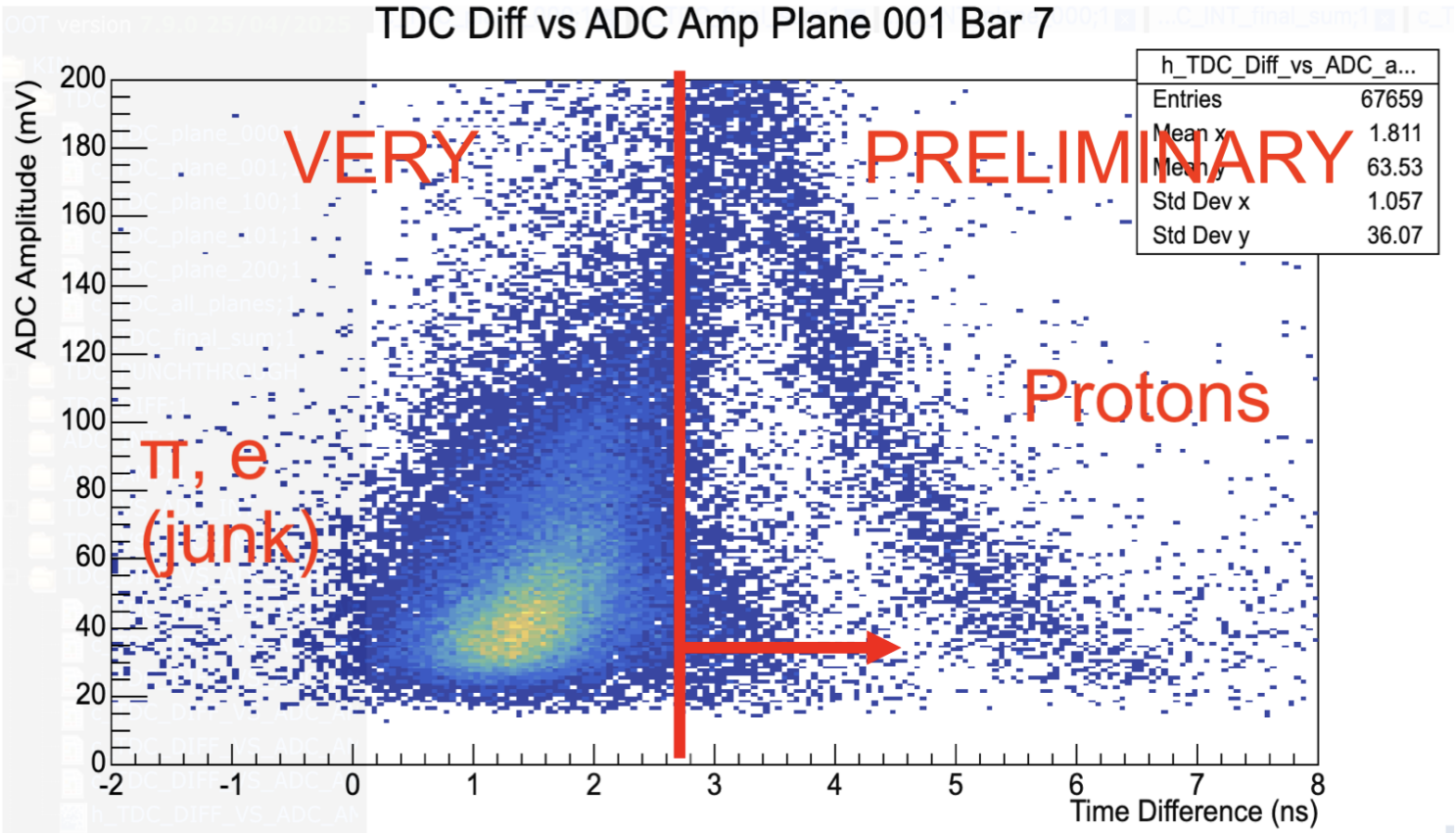
LAD is currently collecting data tagging spectator protons.




CAUTION DO NOT ENTER
CUIDADO NO ENTRE


DANGER
FAULT
IN USE
EMPTY

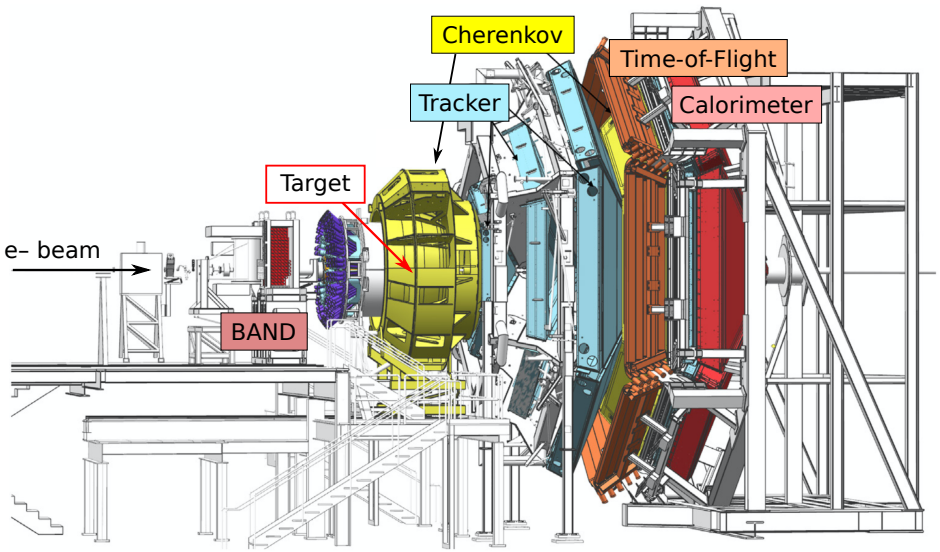
We see coincident protons in LAD!



Credit: Lucas Ehinger, MIT

To recap:

- Resolution and probe-dependence
  - RG-M: new high stats data set



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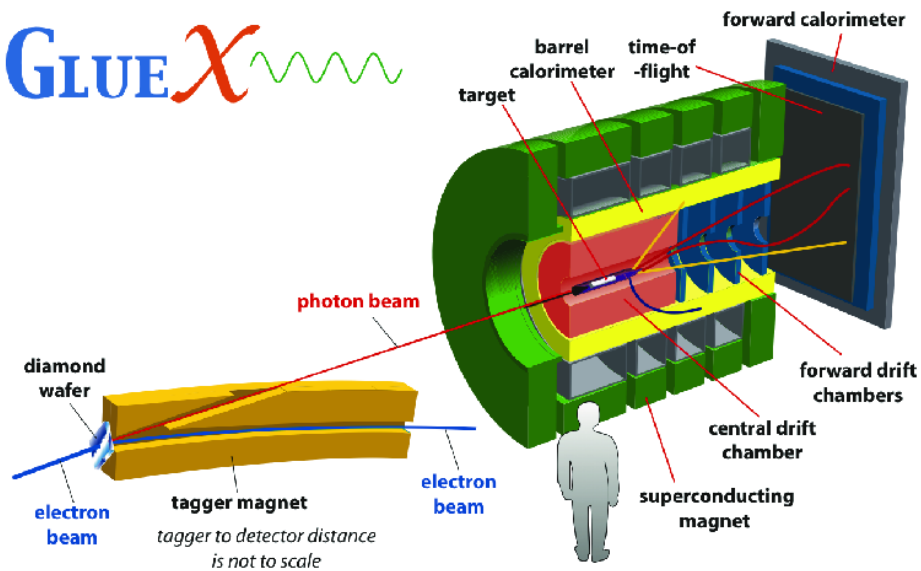

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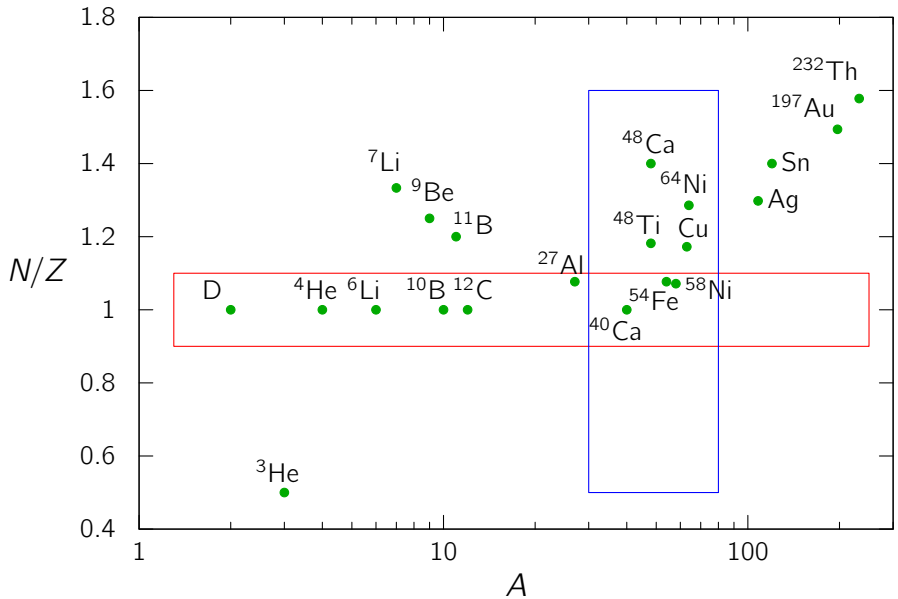
  - XEM2: inclusive survey



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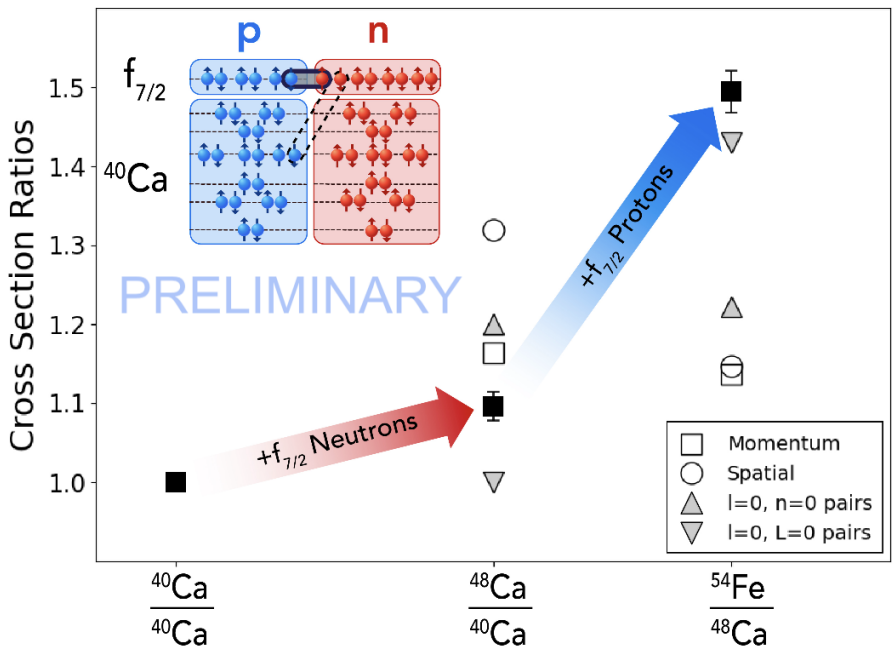

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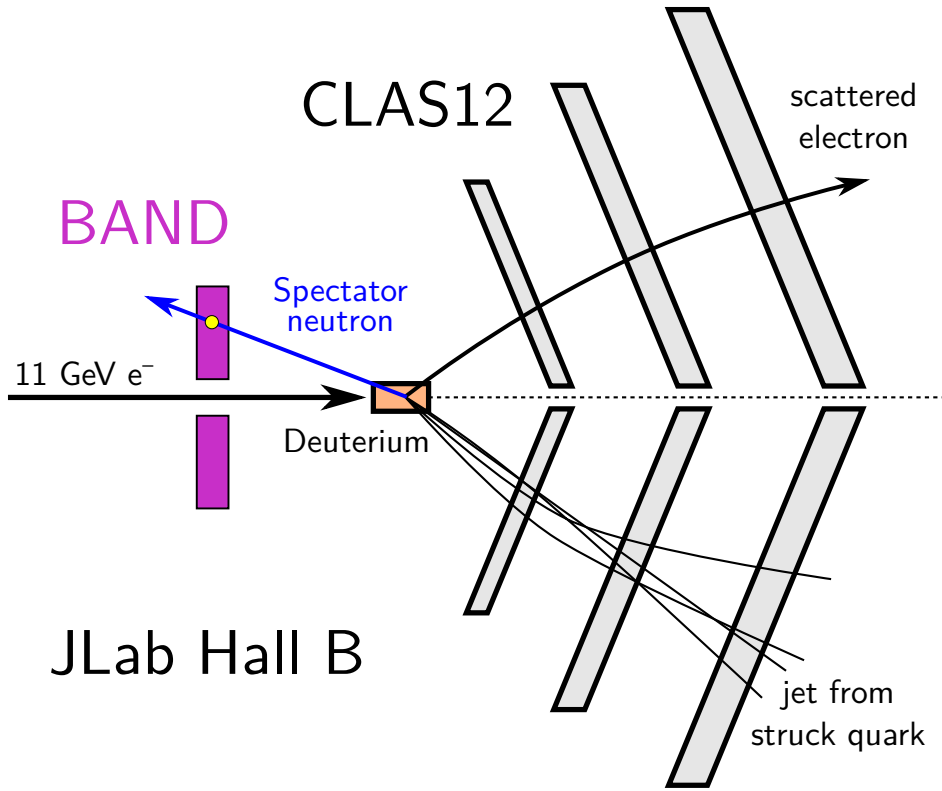
  - BAND analysis nearly complete.



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- Resolution and probe-dependence
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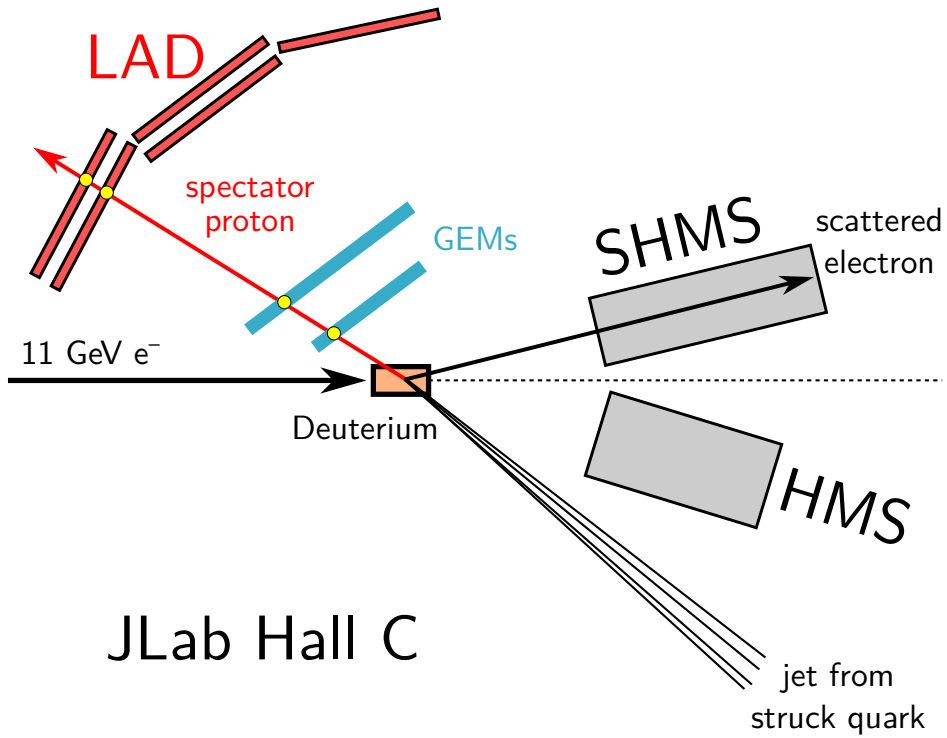
- Pair formation mechanisms
  - XEM2: inclusive survey
  - CaFe: weak cross-shell pairing
- SRCs and the EMC Effect
  - BAND analysis nearly complete.
  - LAD is underway



A second generation of SRC experiments is underway.

Stay tuned for exciting results in the coming months/years!