Short Range Correlations in $(e, e'N)$ Experiments

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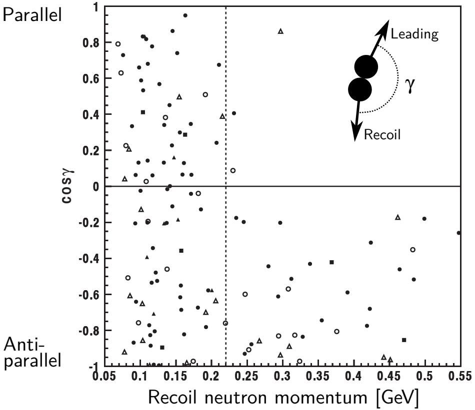
MIT

February 7, 2018

All high-momentum nucleons have a correlated partner.

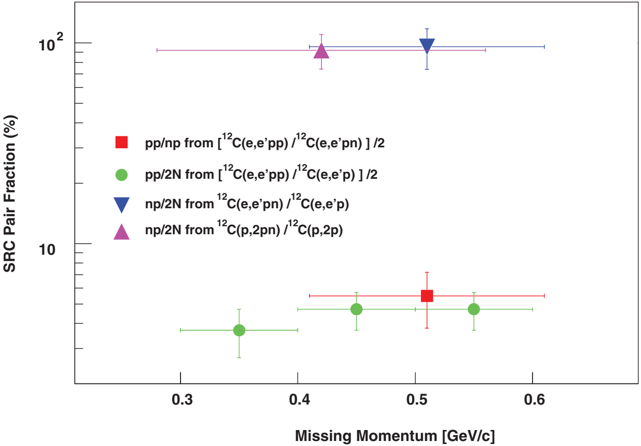


p scattering from Carbon:

- Always a correlated partner
- Anti-parallel momenta

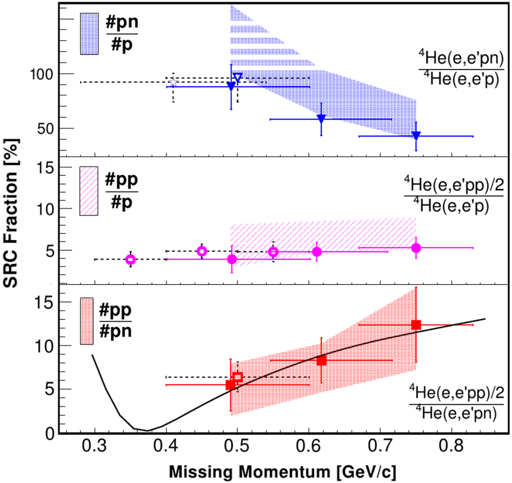
J.L.S. Aclander et al., Phys. Lett. B 453, 211 (1999)
A. Tang et al., Phys. Rev. Lett. 90, 042301 (2003)
E. Piasetzky et al., PRL 97 162504 (2006)

Between 300–600 MeV, *np* pairs predominate.



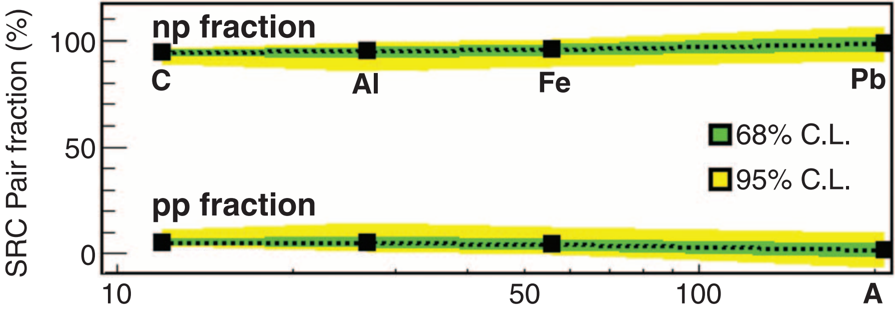
E. Piasetzky et al., PRL 97 162504 (2006)
R. Shneor et al., PRL. 99, 072501 (2007)
R. Subedi et al., Science 320, 1476 (2008)

np dominance may reduce at higher momentum.



Korover et al., PRL 113, 022501 (2014)

Data mining has been a productive source of information.



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

Open questions

1. How can we distinguish between competing reactions?
2. How does *np* dominance evolve at very high momentum?
3. How does pairing change with nuclear size/asymmetry?
4. How/where do pairs form?
5. What is the role of SRCs in the EMC effect?

Short-Range Correlations Collaboration

Today I will cover:

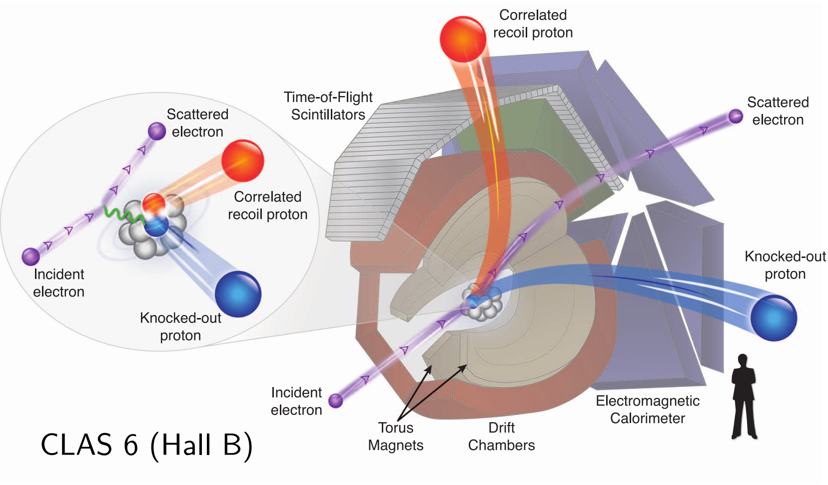
1. Where are we?
2. Where are we going?
3. Where can the EIC take us?

Today I will cover:

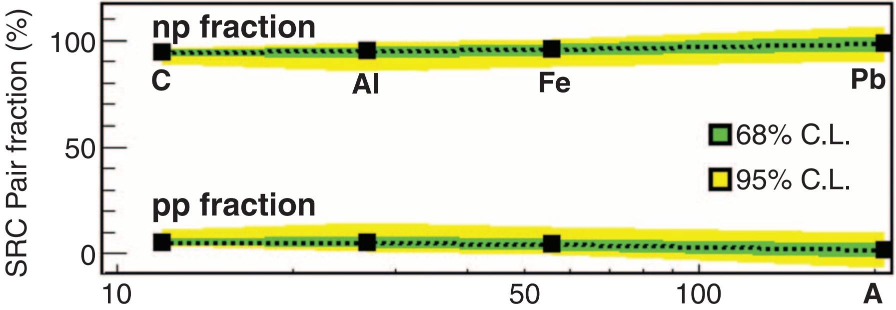
1. **Where are we?**
2. Where are we going?
3. Where can the EIC take us?

CLAS is well-suited for data mining.

- Large acceptance
- Open trigger

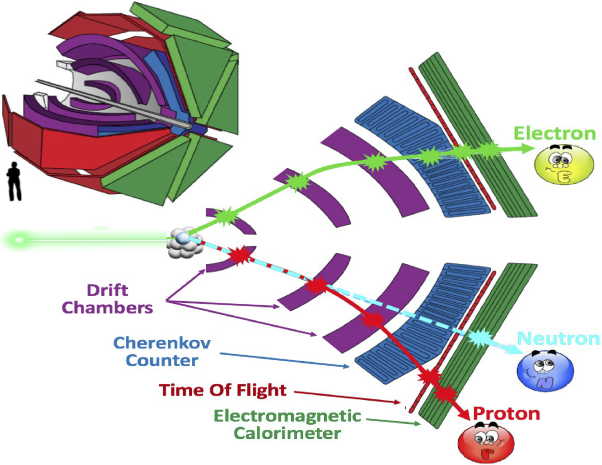


CLAS data mining confirmed the absence of high-momentum *pp* pairs.



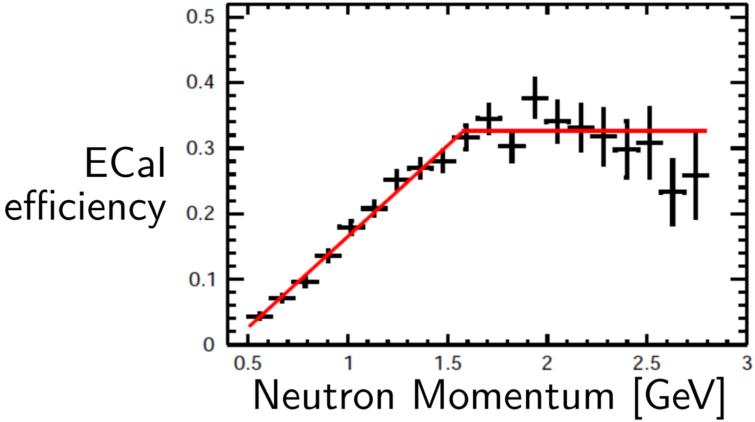
O. Hen et al, Science 346, 614 (2014)

Meytal Duer has identified high-momentum neutrons for the first time.

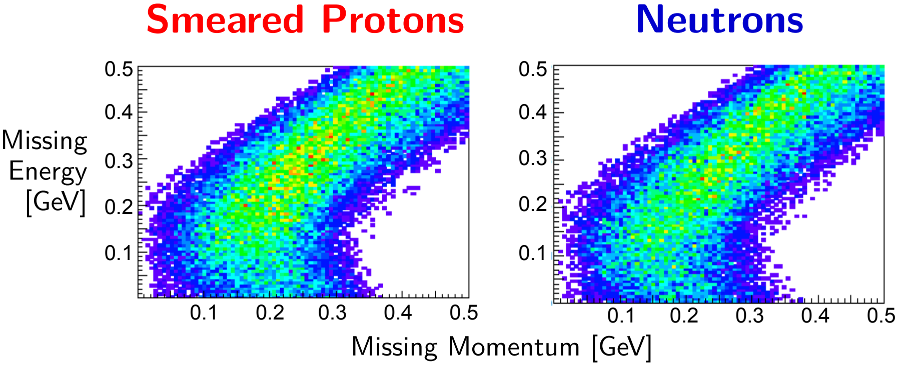


M. Duer et al., submitted to Nature

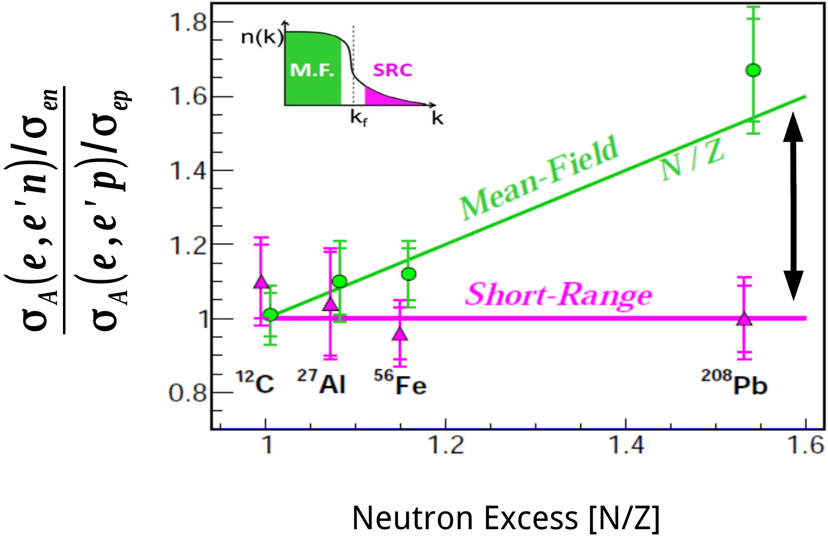
Neutrons efficiencies and resolutions were calibrated using the $d(e, e'p\pi^+\pi^-)n$ reaction.



The poor neutron resolution was studied by “smearing” protons.



n/p ratio is constant with asymmetry!



SRC fraction for neutrons saturates.

$$\text{SRC Fraction} \equiv \frac{\sigma^{A}_{\text{SRC}}(e,e'N)}{\sigma^{A}_{\text{MF}}(e,e'N)} \Big/ \frac{\sigma^{C}_{\text{SRC}}(e,e'N)}{\sigma^{C}_{\text{MF}}(e,e'N)}$$

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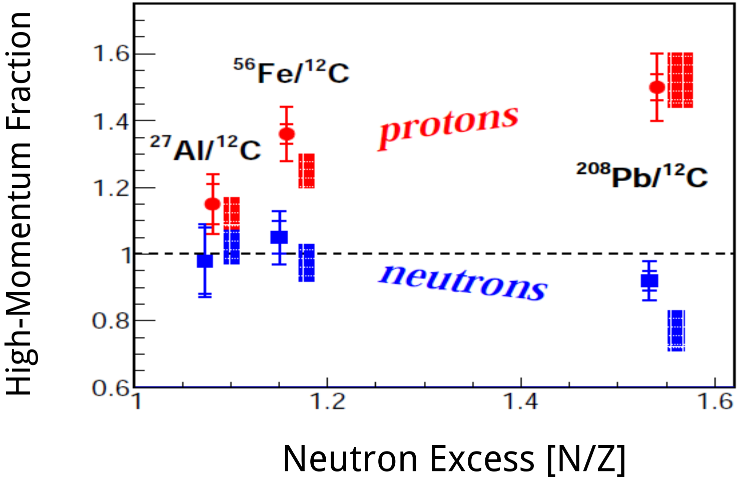
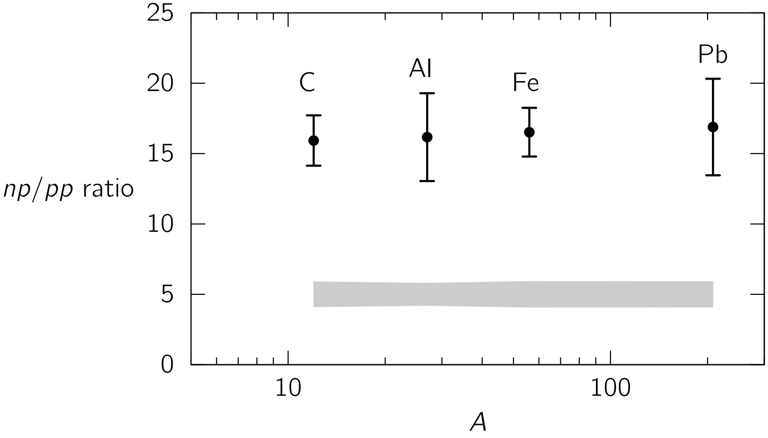


np/*pp* ratio is constant over all species.



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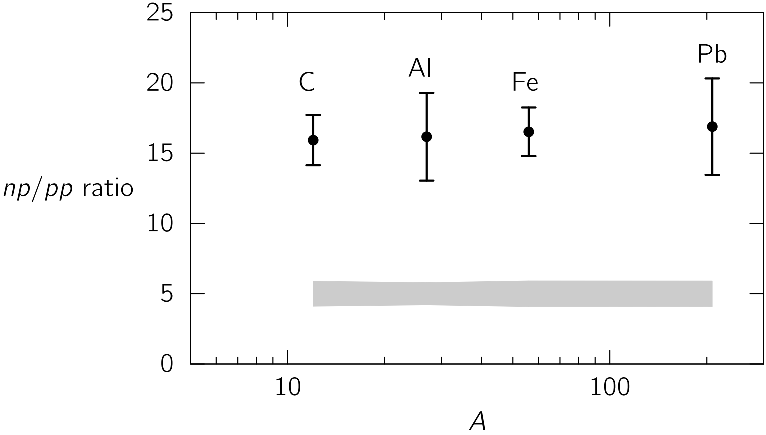
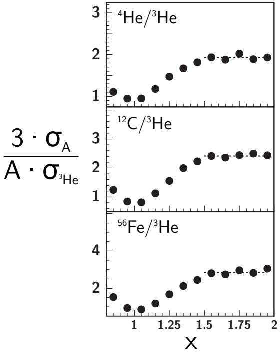
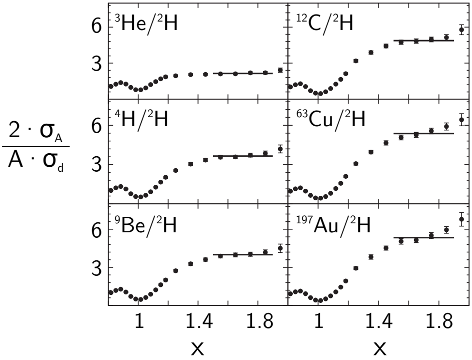


[3]He and [4]He analysis is under way.

Inclusive electron scattering can already tell us about short range interactions.

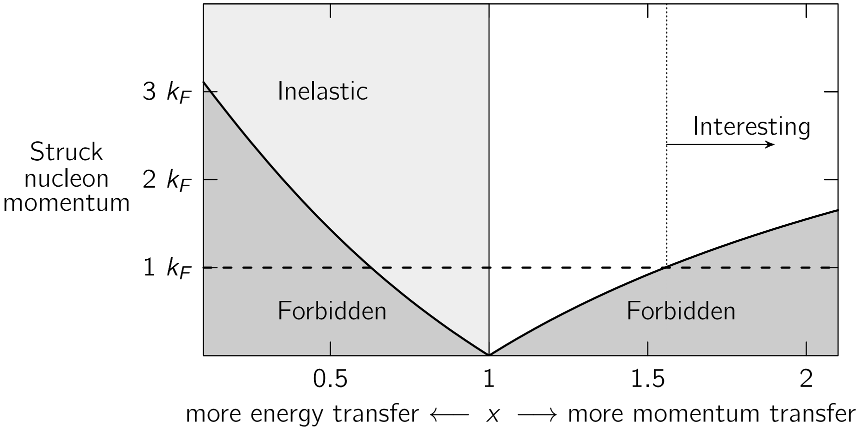


K.S. Egiyan et al. PRL 96, 082501(2006)

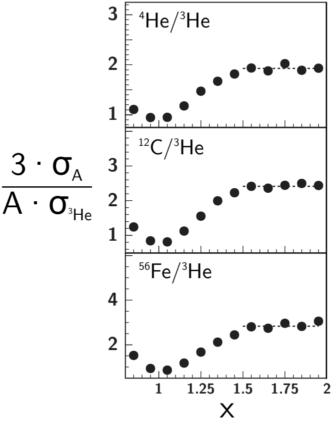


Fomin et al., PRL 108, 092502 (2012)

At high x, quasielastic scattering can only proceed from a high-momentum nucleon.



a_2 plateaus tell us that high-momentum tails are universal.



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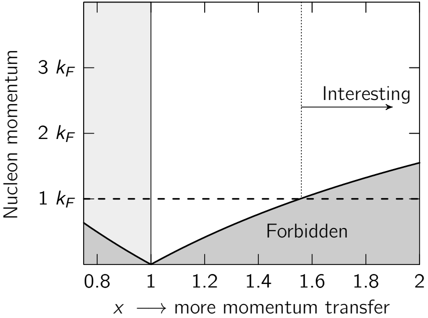
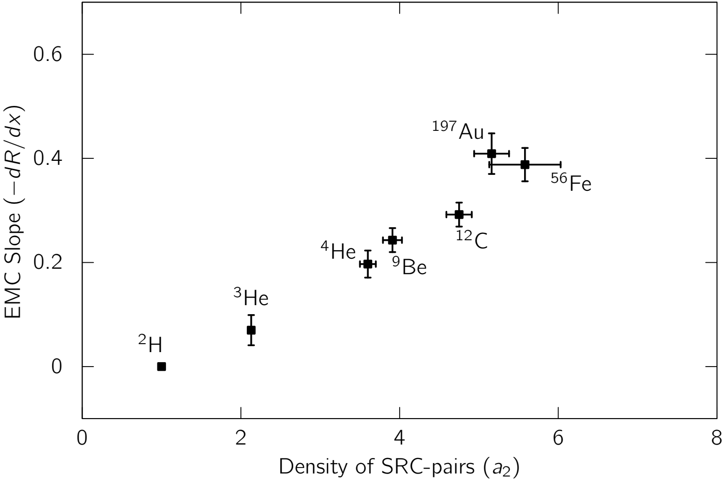


Scaling constant a_2:

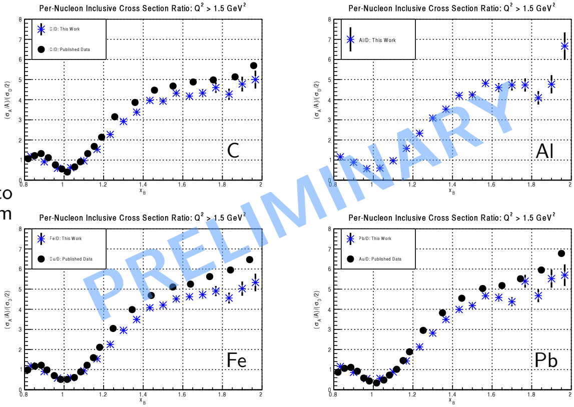
$$\sigma_A = \mathbf{a}_2 \times \frac{A}{2}\sigma_d$$

The a_2 plateau correlates with the size of the EMC effect.



New CLAS inclusive analysis on C, Al, Fe, Pb

Ratios to deuterium

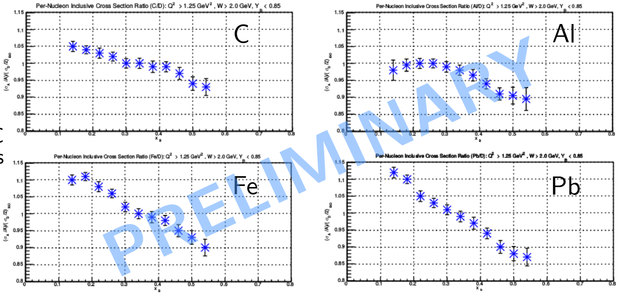


Bjorken x

Barak Schmookler et al., in preparation

New CLAS inclusive analysis on C, Al, Fe, Pb

EMC ratios



Bjorken x

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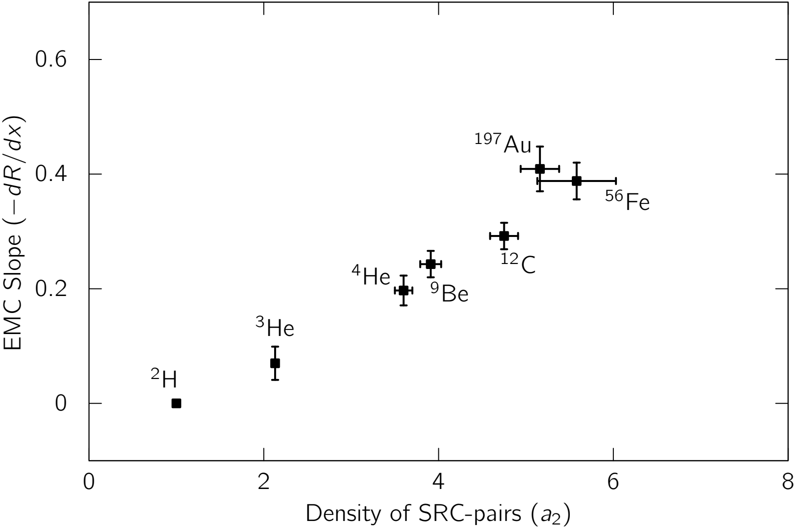
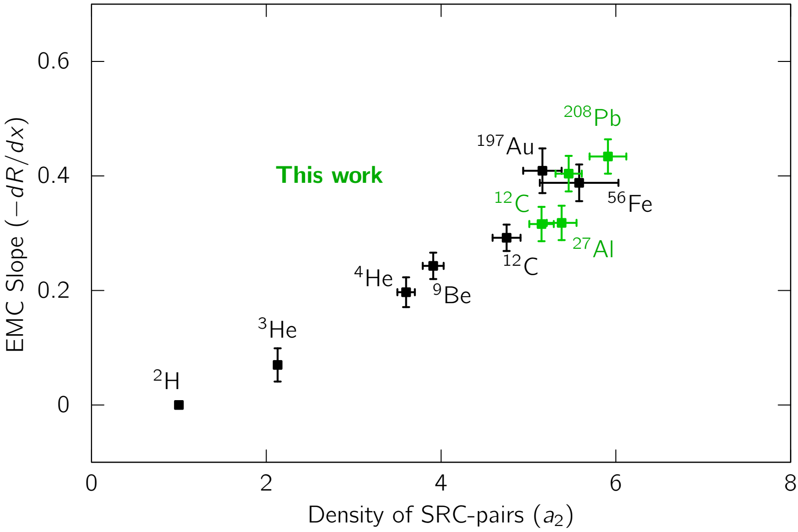
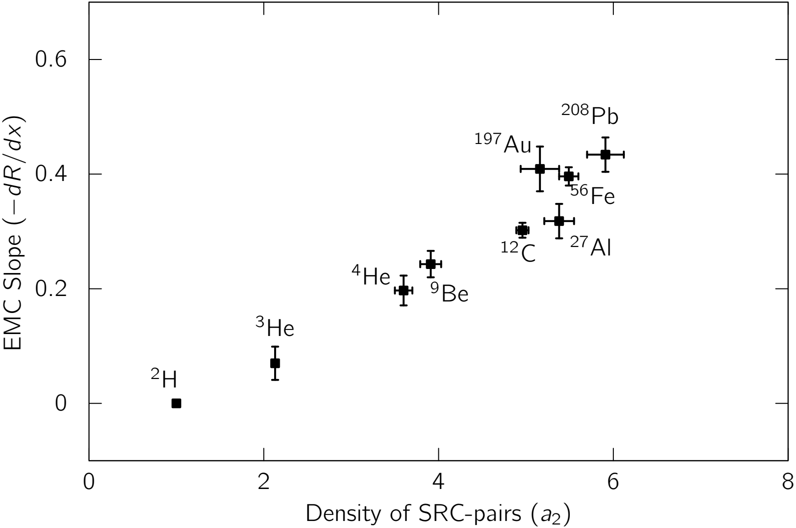
SRC-EMC correlation



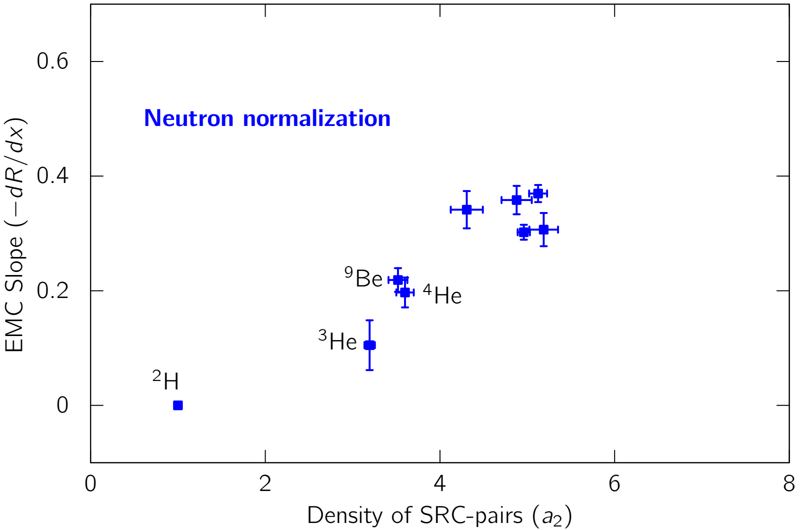
SRC-EMC correlation



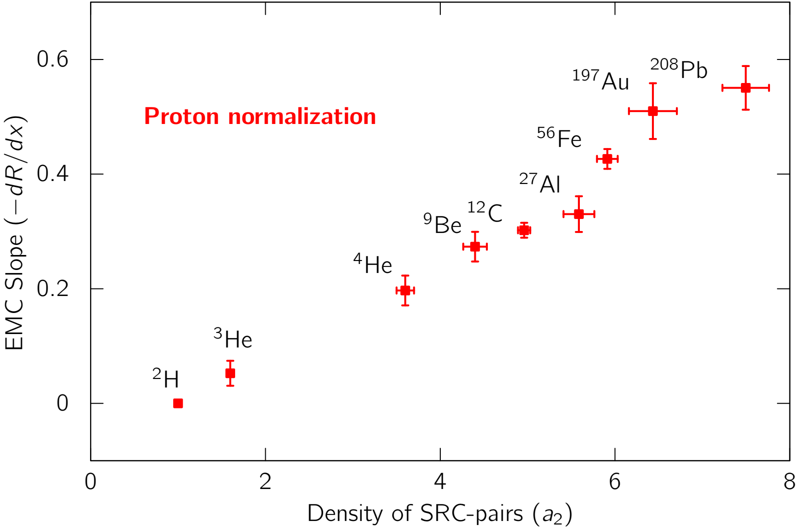
SRC-EMC correlation



Saturation with per-neutron normalization



No saturation with per-proton normalization



Other analyses underway. . .

1. Center-of-mass momentum distributions for *pp* pairs
2. ^{3}He, ^{4}He, *pp* to *p* ratio
3. Recoil-tagged inclusive scattering

Today I will cover:

1. Where are we?
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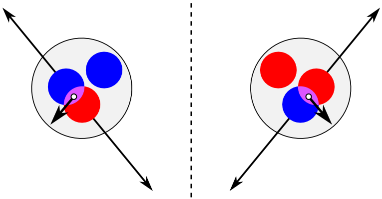
Upcoming SRC Experiments

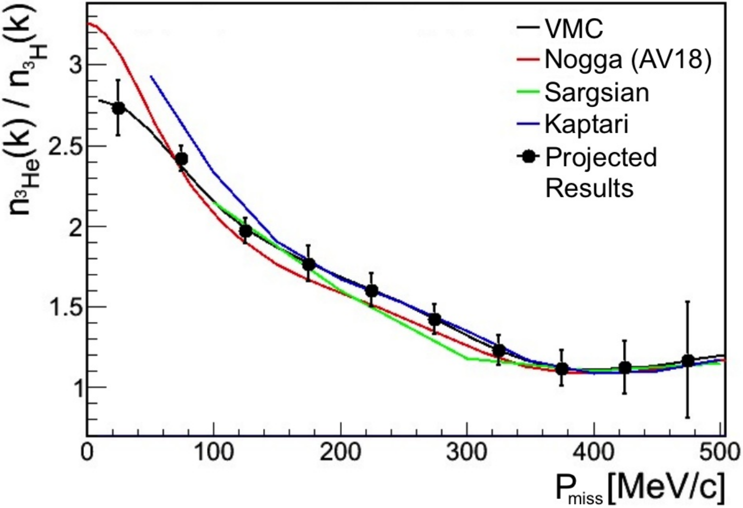
- $(e, e'p)$ in SRC kinematics
  - Tritium
  - CaFe
- Recoil-tagged DIS on deuterium
  - BAND
  - LAD

Protons in tritium tell us about neutrons in ^{3}He.

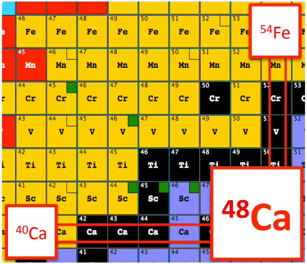


- E12-14-001 (Hall A)
- Tritium and Helium-3 gas targets
- $(e,e'p)_{^3\text{He}}/(e,e'p)_{^3\text{H}}$ as a function of p_{miss}
- 10 days of running, fall 2018

Protons in tritium tell us about neutrons in ^{3}He.

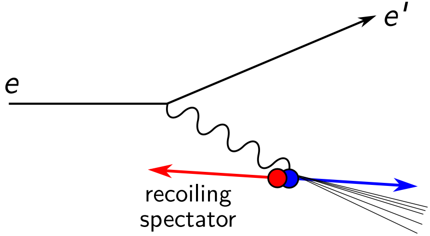


CaFe: disentangling size and asymmetry



- E12-17-005 (Hall C)
- ^{40}Ca $\longleftrightarrow$ ^{48}Ca $\longleftrightarrow$ ^{54}Fe
- Sensitive to pairing from different orbitals
- Approved for 9 days, 2017 PAC
- Measure:
    - $(e, e'p)_{\mathrm{SRC}}/(e, e'p)_{\mathrm{MF}}$
    - $(e, e'p)_{A_1}/(e, e'p)_{A_2}$
    - Double-ratios

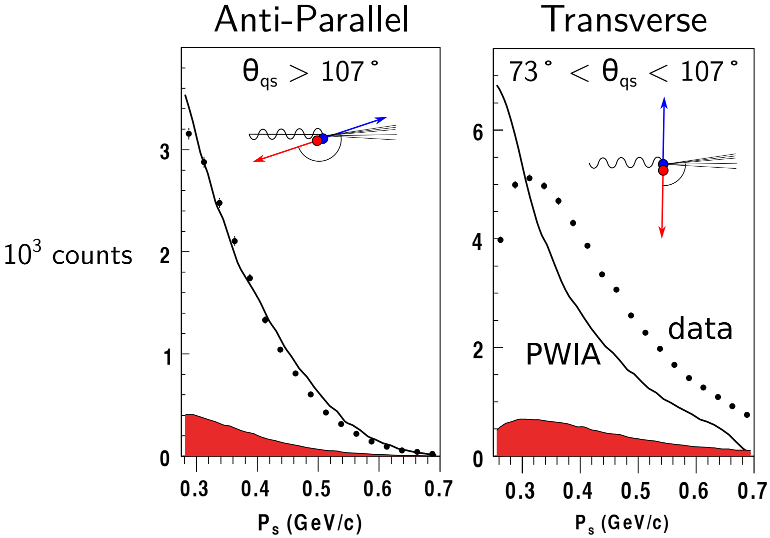
We will test the SRC-EMC hypothesis with recoil-tagging experiments.



Advantages of a deuterium target:

- Minimal final-state interactions
- Spectator has *exactly* opposite momentum
- 5% of the wave-function is short-range configuration

DEEPS showed little FSI at back angles.



Klimenko et al., PRC 73 035212 (2006)

What we want to measure:

$$\frac{F_2(x', Q^2, \alpha_s)_{\text{bound}}}{F_2(x, Q^2)_{\text{free}}} \approx \frac{\sigma_{\text{DIS}}(x', Q^2, \alpha_s)_{\text{bound}}}{\sigma_{\text{DIS}}(\text{low } x', Q_0^2, \alpha_s)_{\text{bound}}} \times \frac{\sigma_{\text{DIS}}(\text{low } x, Q_0^2)_{\text{free}}}{\sigma_{\text{DIS}}(x, Q^2)_{\text{free}}} \times R_{\text{FSI}}$$

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. Tagged DIS measurement Input ≈ 1

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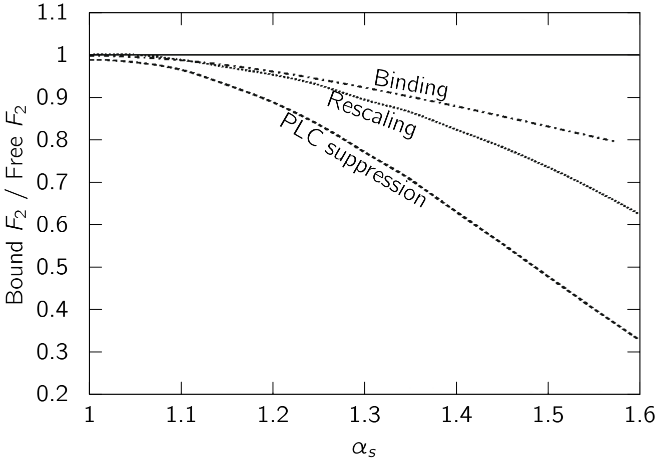
. Tagged DIS measurement Input ≈ 1

At low x, the EMC effect should be small:

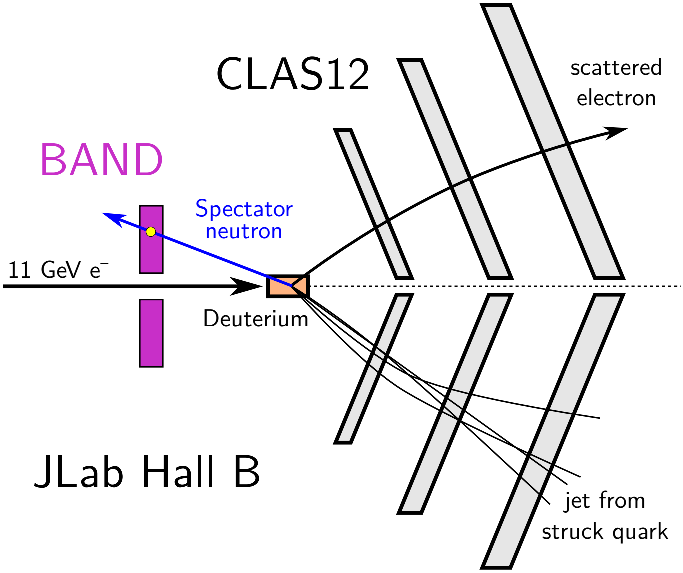
$$\sigma_{\text{DIS}}(\text{low } x', Q_0^2, \alpha_s)_{\text{bound}} \approx \sigma_{\text{DIS}}(\text{low } x, Q_0^2)_{\text{free}}$$

Different models predict different F_2 ratios.

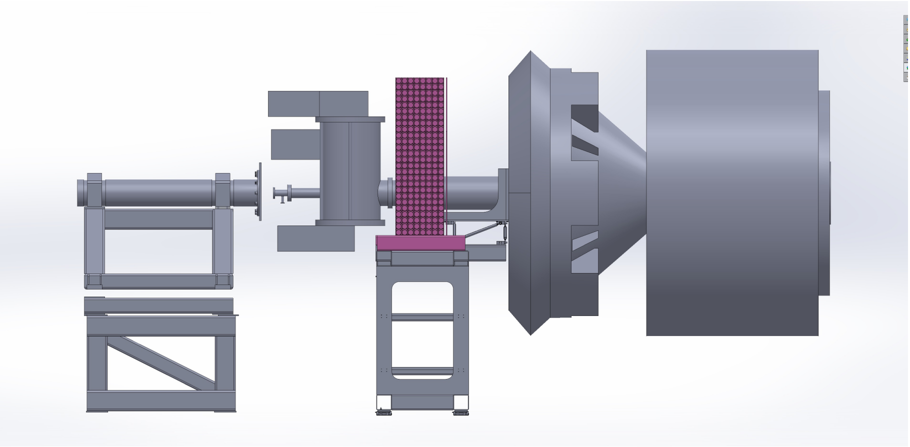


Melnitchouk, Sargsian, Strikman, Z. Phys A 359 p.99 (1997)

BAND will detect recoiling spectator neutrons.



BAND will surround the upstream beamline.



BAND Experiment Details

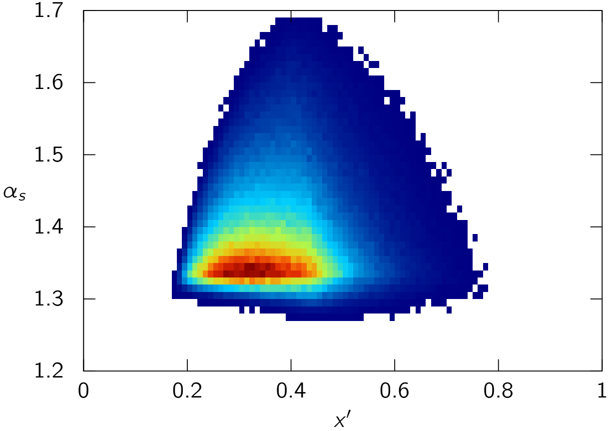
Experiment

- Experiment E12-11-003A
- Approved for 90 days
  - Run group B
  - late 2018 / early 2019
- Extended LD_2 target
- 11 GeV $e-$ beam
- 10^{35} $cm^{-2}s^{-1}$

Backward Angle Neutron Detector

- Currently being built at MIT
- 5 rows of 21 bars
- 160°–170°
- ≈ 60% azimuthal coverage

We have developed a detailed simulation of the experiment.

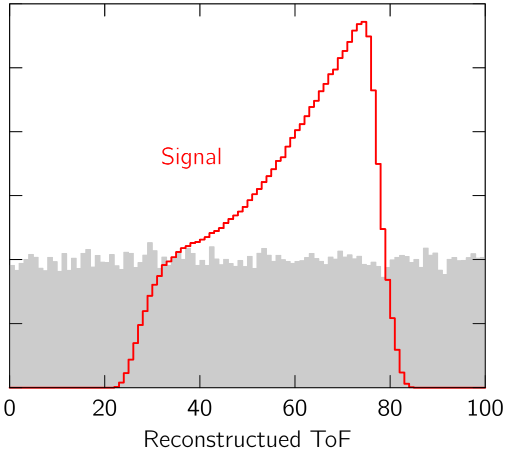


Generator by W. Cosyn

The limit will be random coincidence background.

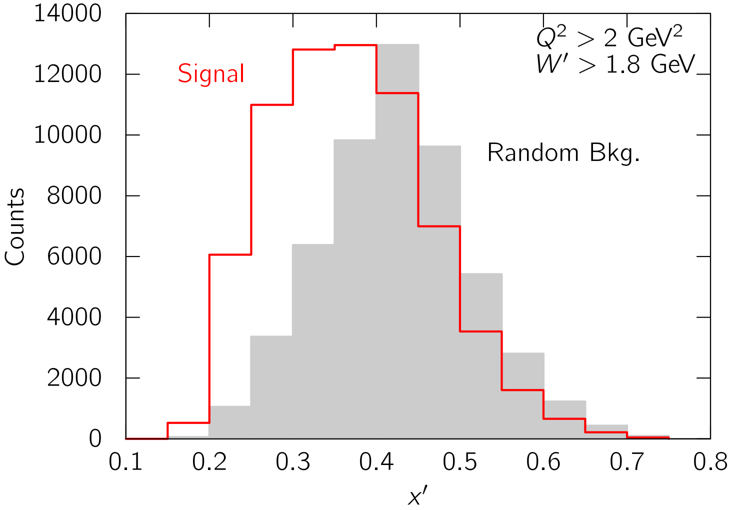
- Can be subracted using "off-time" events
- Statistical variation can drown signal

$$\frac{\delta N}{N} = \frac{\sqrt{S+B}}{S}$$

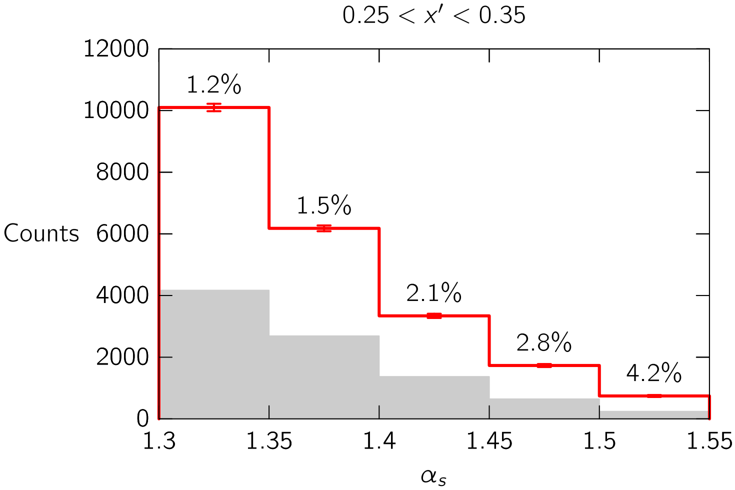


Any reduction in background buys us statistics!

Background will be higher at large x'.



Even with background, we expect good statistical precision.



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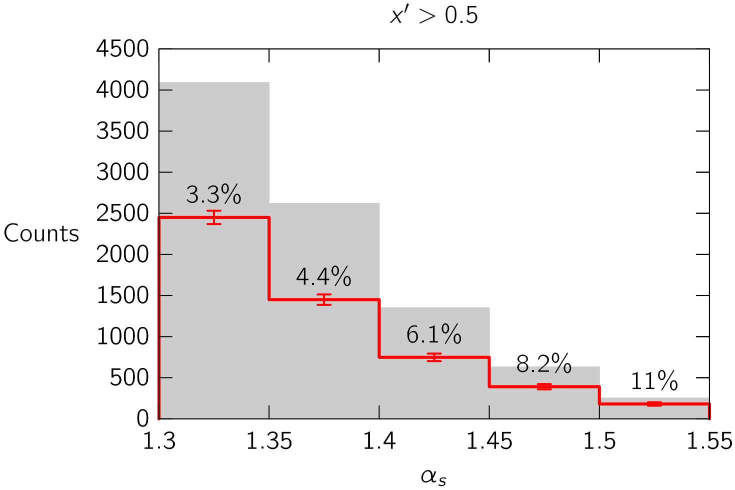
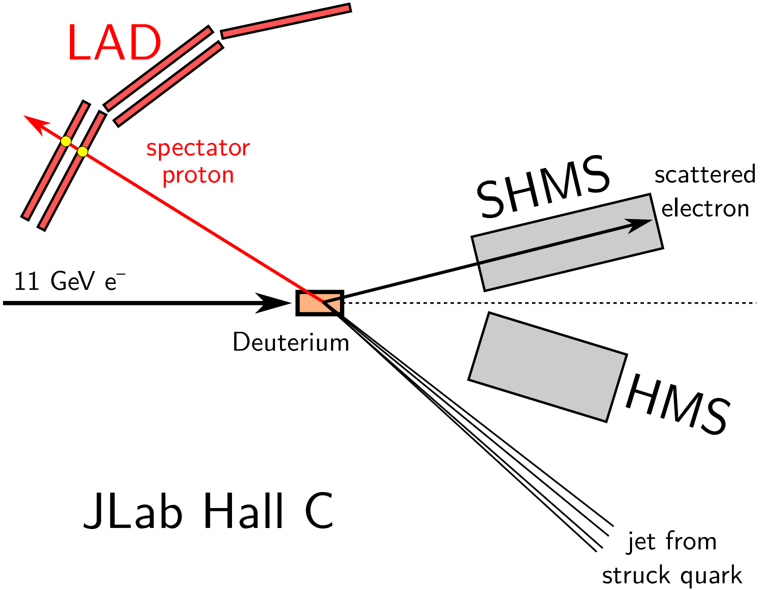
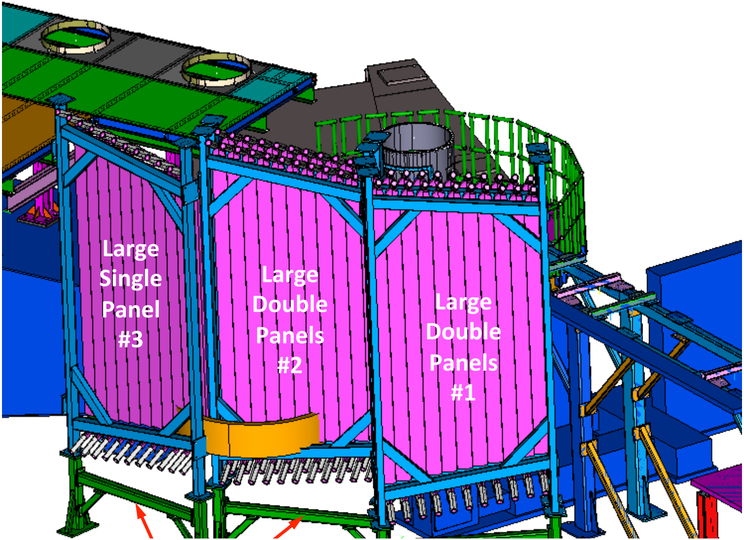
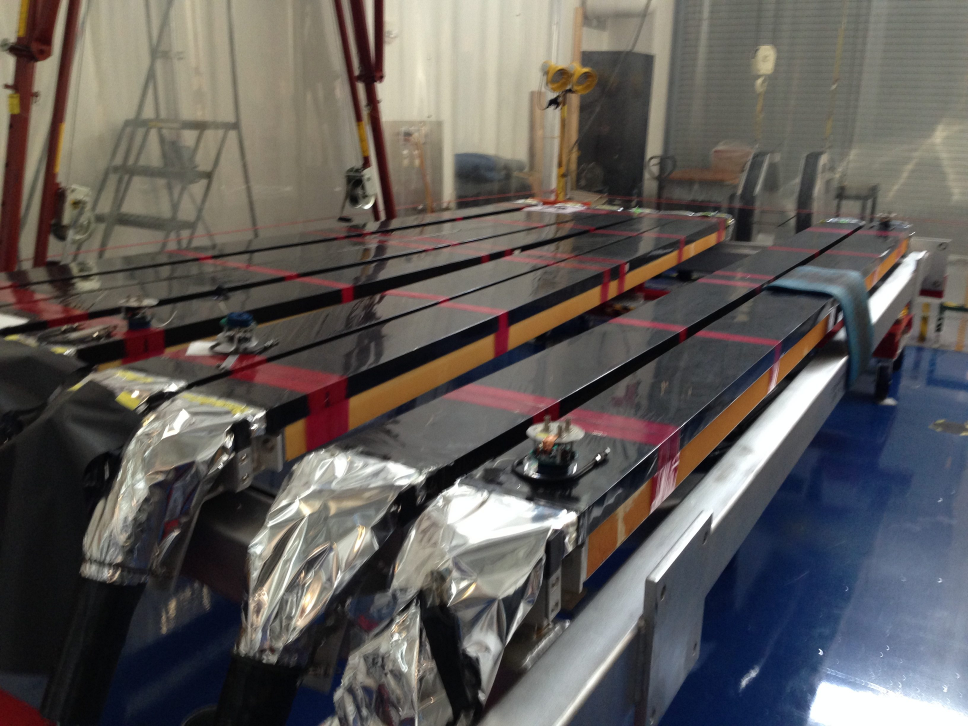


LAD will detect recoiling spectator protons.



LAD is three panels of scintillator bars, originally from the CLAS-6 ToFs.





LAD Experiment Details

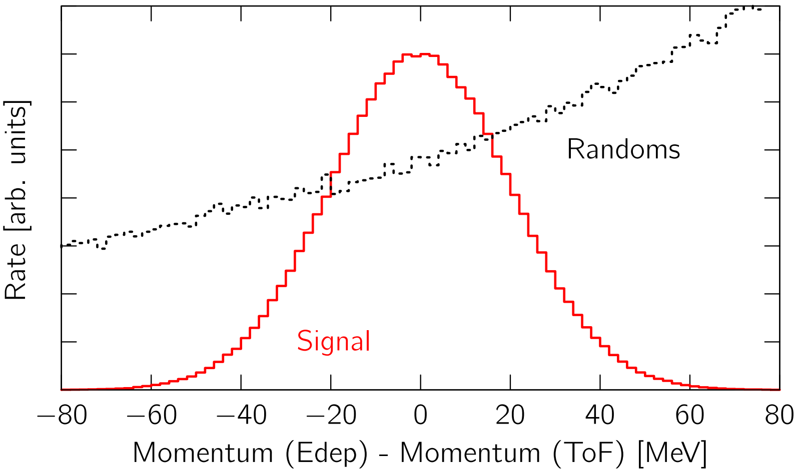
Experiment

- Experiment E12-11-107
- Approved for 820 hours
- Extended LD_2 target
- 11 GeV $e-$ beam
- 10^{36} $cm^{-2}s^{-1}$
- Low x and high x settings

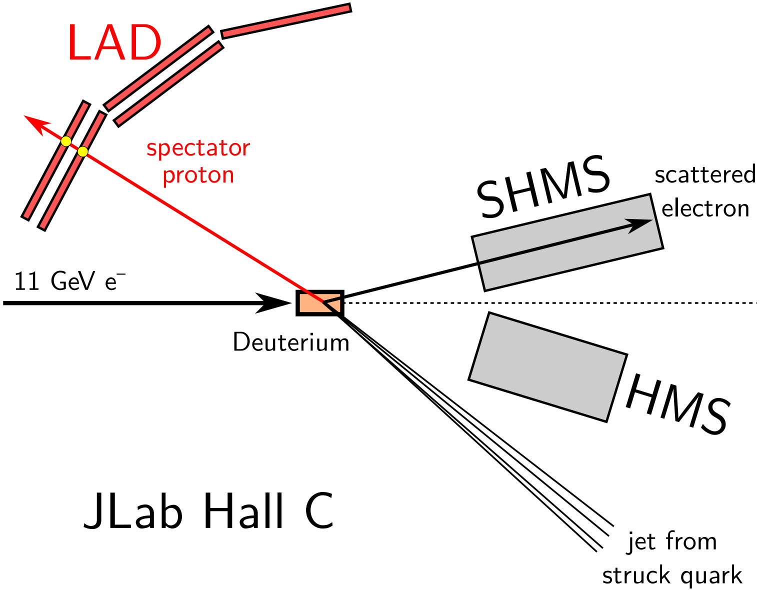
Large Acceptance Detector

- 5 panels of 11 bars
- 1.5 sr at back angles
- $90°$–$160°$
- $\pm 18°$ out-of-plane

Energy deposition in LAD must match velocity.



We plan to add GEMs to assist in vertexing.



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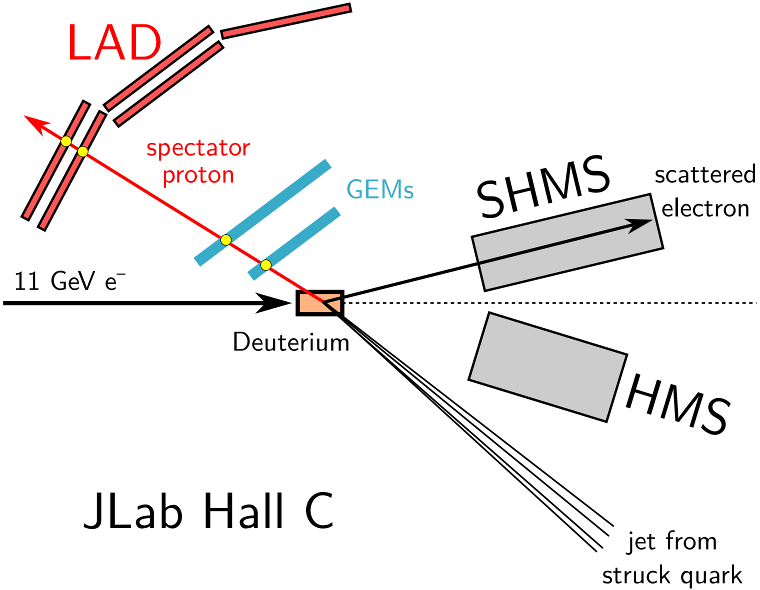
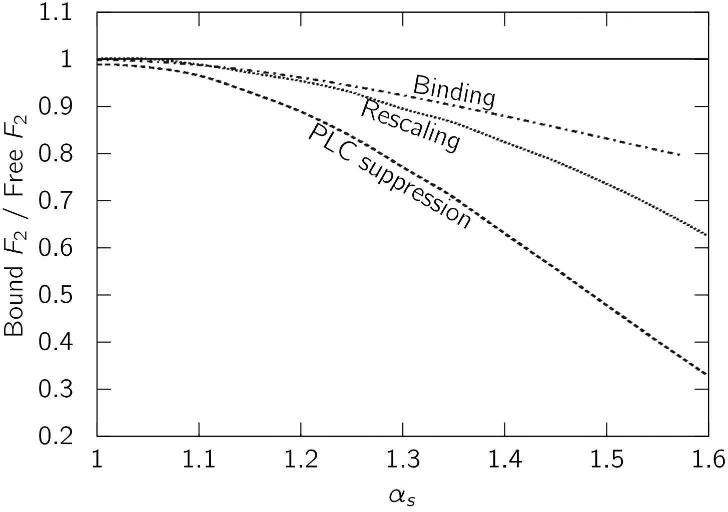


Expected Impact



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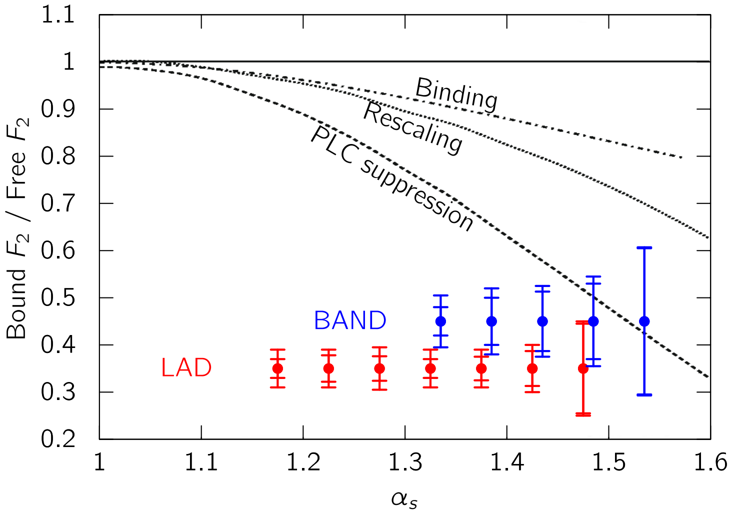


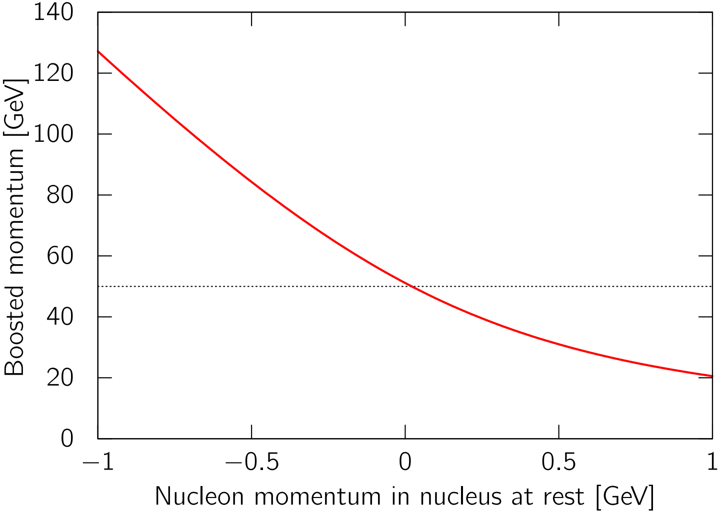
Today I will cover:

1. Where are we?
2. Where are we going?
3. **Where can the EIC take us?**

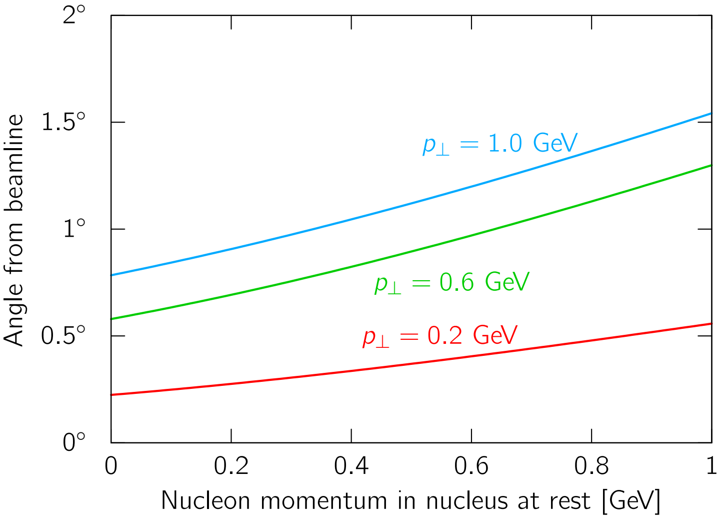
Possibilities at the EIC

1. Tagging
   - DIS or QE
   - very forward spectator
   - "zero momentum" spectators are now detectable
2. Detection of the $A-2$ system
   - very forward residual nucleus

Small differences in initial momentum become large in the collider frame.



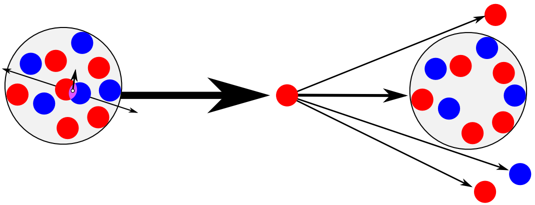
Spectators will be within 2° of beamline.

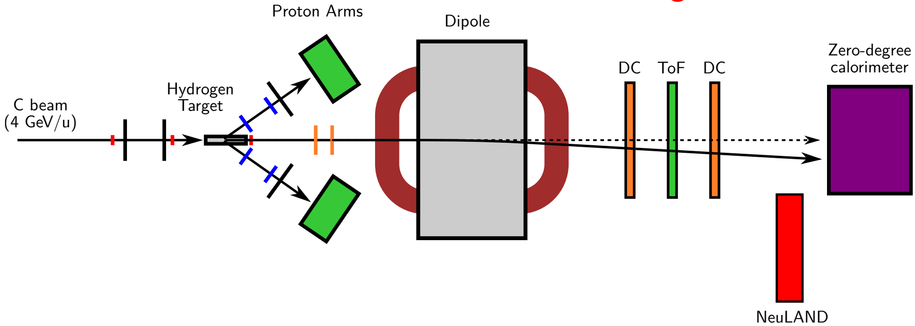


Possibilities at the EIC

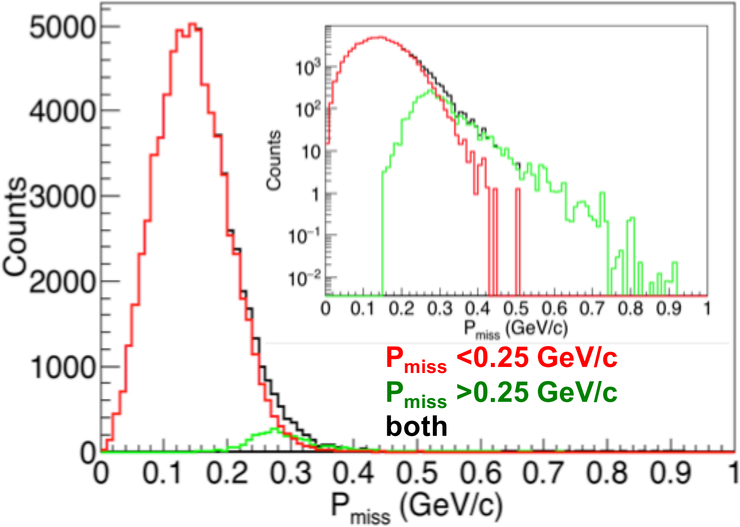
1. Tagging
   - DIS or QE
   - very forward spectator
   - "zero momentum" spectators are now detectable
2. **Detection of the $A-2$ system**
   - **very forward residual nucleus**

Inverse kinematics at Dubna: detecting the nuclear remnant.

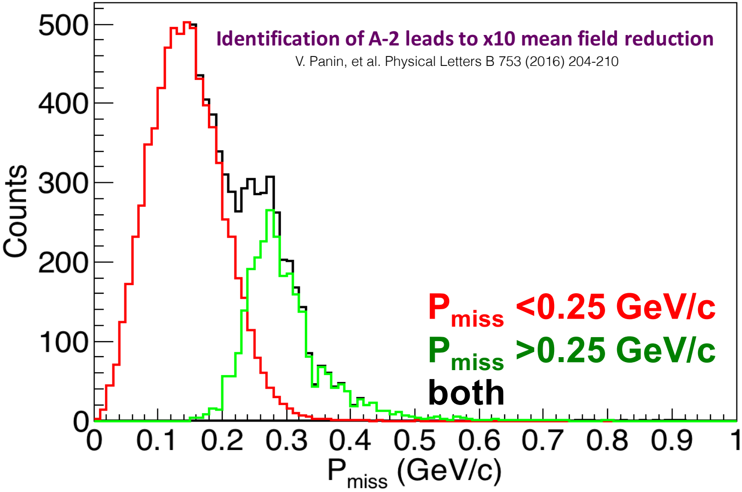




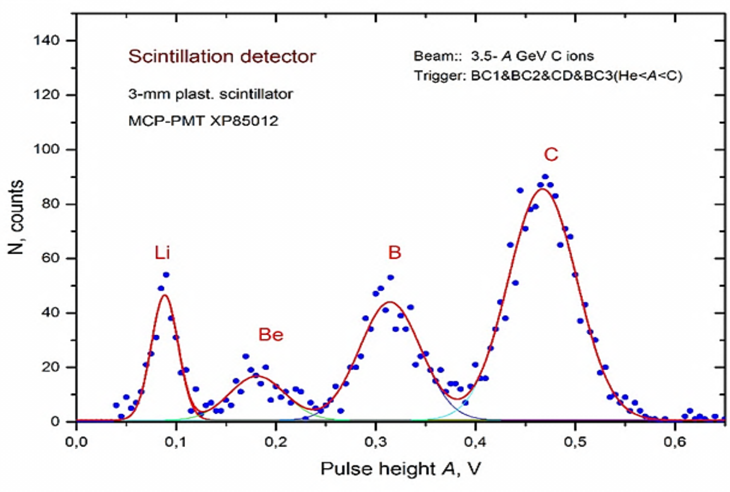
Detecting the $A - 2$ system is essential for rejecting non-SRC background.



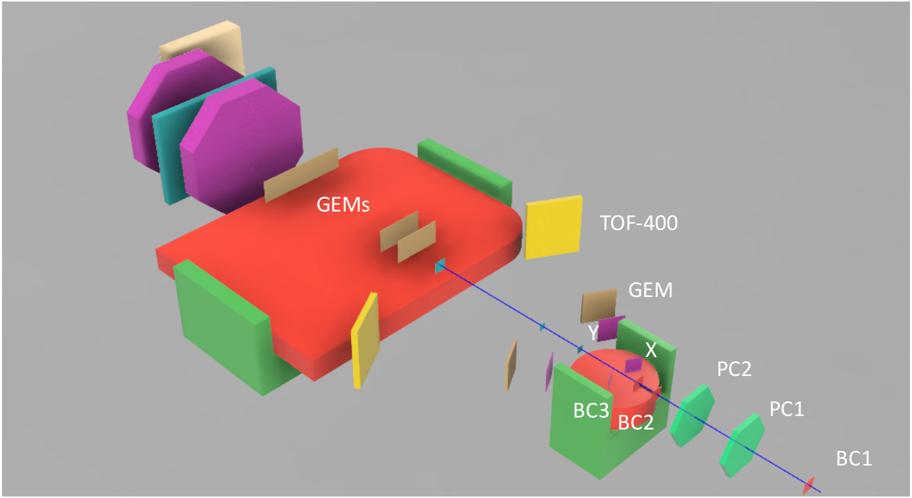
Detecting the $A-2$ system is essential for rejecting non-SRC background.



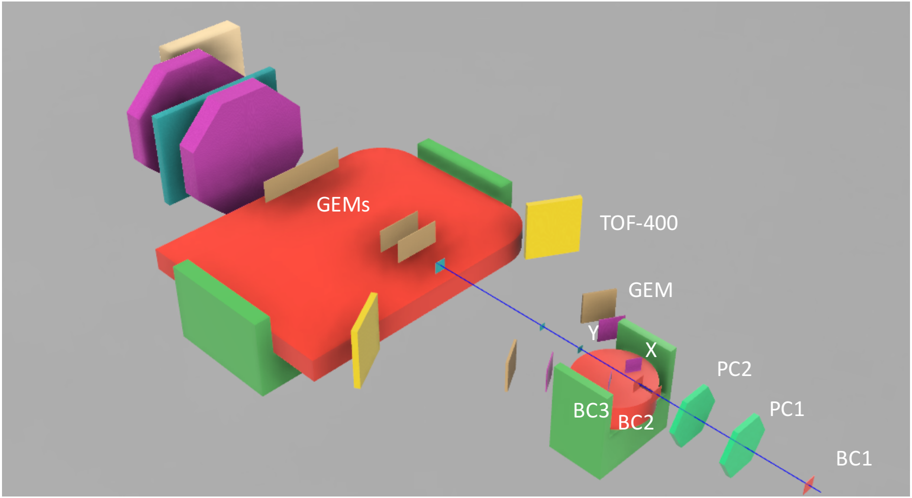
Residual nucleus can be determined from dE/dx.



This will be truly exclusive: $p(^{12}\mathrm{C},^{10}\mathrm{B}ppn)$



This will be truly exclusive: $p(^{12}\mathrm{C}, ^{10}\mathrm{B}ppn)$

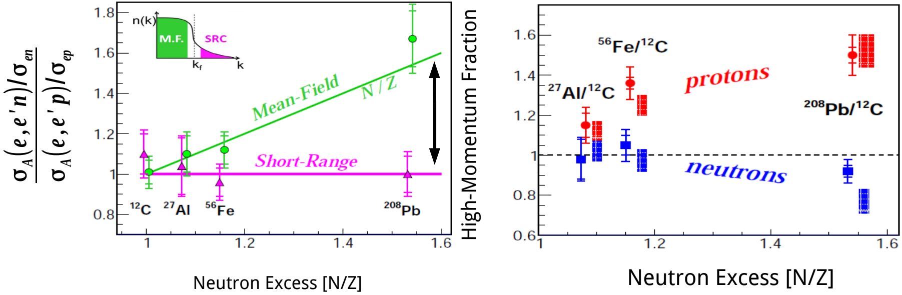


This experience will help us plan for the EIC.

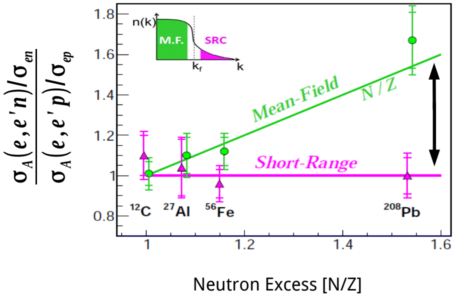
Today I will cover:

1. Where are we?
2. Where are we going?
3. Where can the EIC take us?

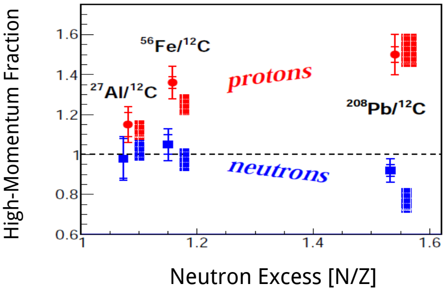
New results


σA(e,e'n)/σen / σA(e,e'p)/σep
n(k)
M.F.
SRC
kf
k
Mean-Field
N / Z
Short-Range
12C
27Al
56Fe
208Pb
Neutron Excess [N/Z]
High-Momentum Fraction
56Fe/12C
27Al/12C
208Pb/12C
protons
neutrons
Neutron Excess [N/Z]

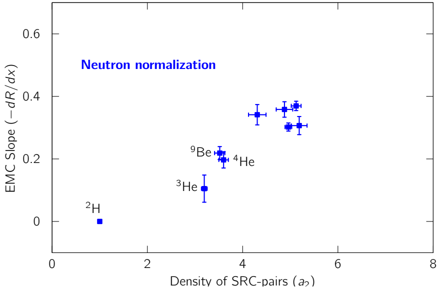
New results



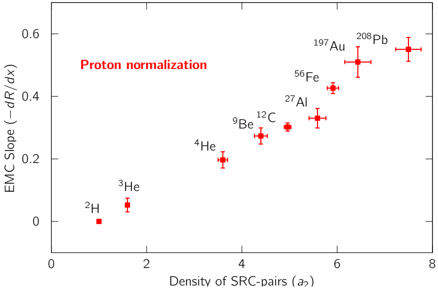
$\frac{\sigma_A(e,e'n)/\sigma_{en}}{\sigma_A(e,e'p)/\sigma_{ep}}$
n(k)
M.F.
SRC
k_f
k
Mean-Field
N / Z
Short-Range
12C
27Al
56Fe
208Pb
1.8
1.6
1.4
1.2
1
0.8
1
1.2
1.4
1.6
Neutron Excess [N/Z]



High-Momentum Fraction
56Fe/12C
27Al/12C
protons
208Pb/12C
neutrons
1.6
1.4
1.2
1
0.8
0.6
1
1.2
1.4
1.6
Neutron Excess [N/Z]

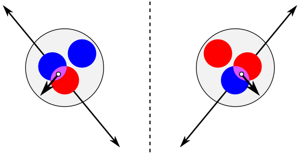


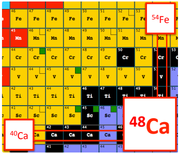
Neutron normalization
EMC Slope (−dR/dx)
9Be
4He
3He
2H
0.6
0.4
0.2
0
0
2
4
6
8
Density of SRC-pairs (a2)



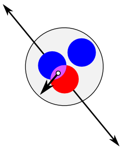
Proton normalization
EMC Slope (−dR/dx)
197Au
208Pb
56Fe
27Al
9Be
12C
4He
3He
2H
0.6
0.4
0.2
0
0
2
4
6
8
Density of SRC-pairs (a2)

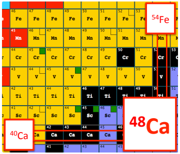
Upcoming measurements

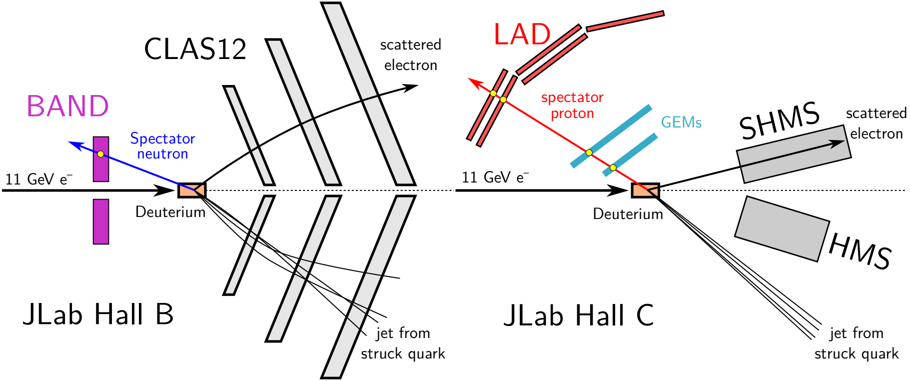




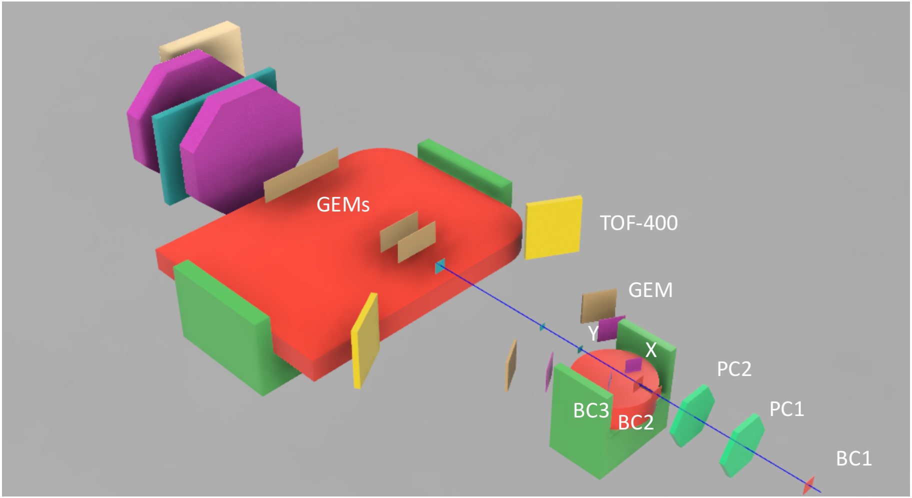
Upcoming measurements







Upcoming measurements



Conclusions

- There is still so much we don’t know about short range correlations.
- Our upcoming experiments with tagging and inverse kinematics will provide crucial experience as we plan for the EIC.