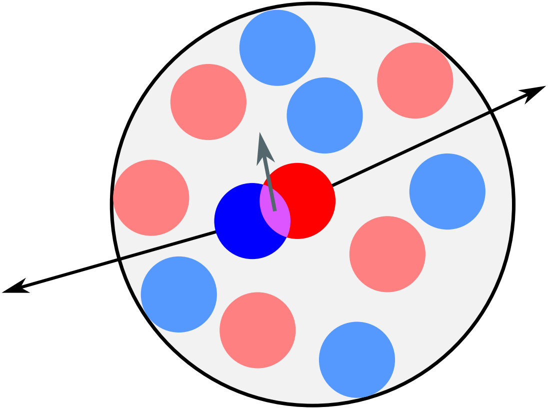
From 12 GeV to EIC: EMC-SRC

Axel Schmidt

MIT

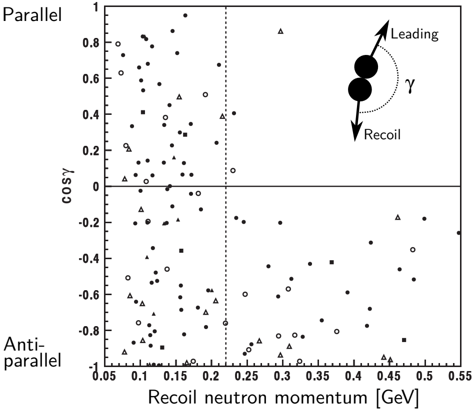
June 20, 2018

$\approx 20\%$ of nucleons are part of correlated pairs.



- Relative momentum: > 300 MeV/c
- CoM momentum: $\mathcal{O}(150$ MeV/$c)$

Knocked-out high-momentum nucleons come with a recoiling partner.

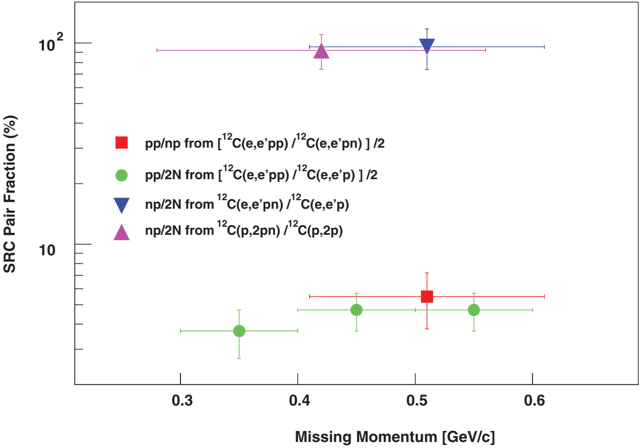


p scattering from Carbon:

- 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)

In carbon, *np*-pairs are strongly preferred.

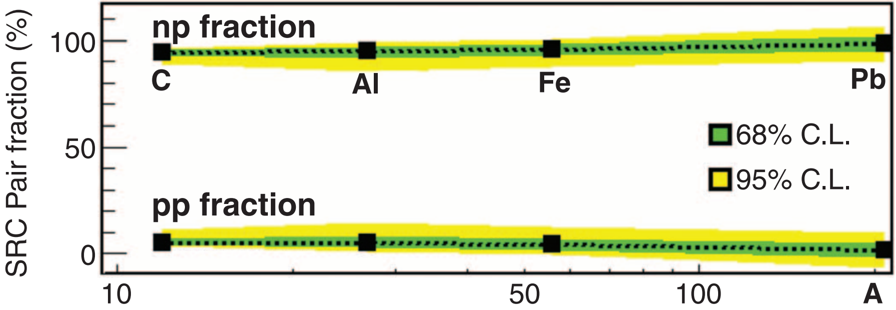


E. Piasetzky et al., PRL 97 162504 (2006)

R. Shneor et al., PRL. 99, 072501 (2007)

R. Subedi et al., Science 320, 1476 (2008)

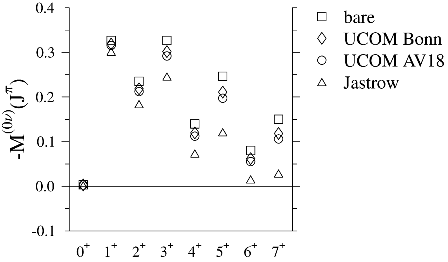
Indirect evidence for *np*-dominance in heavier asymmetric nuclei.



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

SRCs may play an outsized role in big open questions.

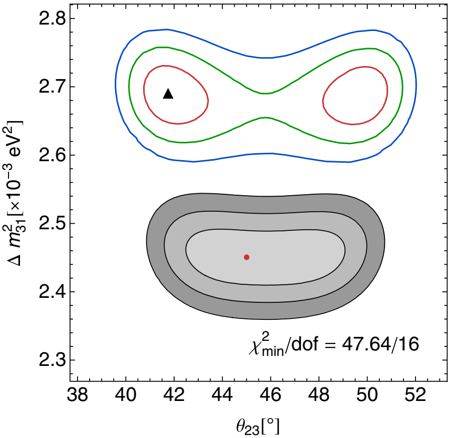
- Nuclear Matrix Elements



Kortelainen et al. PLB 647 (2007)

SRCs may play an outsized role in big open questions.

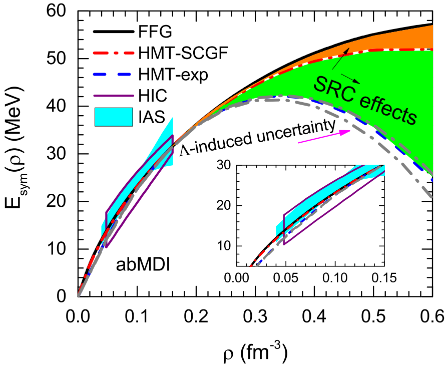
- Nuclear Matrix Elements
- Neutrino-Nucleus Interactions



Coloma et al. PRD 89 (2014)

SRCs may play an outsized role in big open questions.

- Nuclear Matrix Elements
- Neutrino-Nucleus Interactions
- Neutron Stars



B.J. Cai, B.A. Li, arXiv 1509.09290 (2016)
arXiv:1703.08743 (2017)

The Short-Range Correlations Collaboration

The Short-Range Correlations Collaboration

Massachusetts Institute of Technology

- **Prof. Or Hen**
- Dr. Shalev Gilad
- Dr. Adi Ashkenazi
- Dr. George Laskaris
- Dr. Maria Patsyuk
- Dr. Axel Schmidt
- Barak Schmookler
- Rey Cruz-Torres
- Afro Papadopoulou
- Efrain Segarra

OLD DOMINION UNIVERSITY

- **Prof. Lawrence Weinstein**
- Dr. Florian Hauenstein
- Mariana Khachatryan

TEL AVIV UNIVERSITY

- **Prof. Eli Piasetzky**
- Dr. Igor Korover
- Erez Cohen
- Meytal Duer

UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

- **Prof. Will Brooks**
- **Prof. Hayk Hakobyan**
- Iñaki Vega

We study SRCs through several approaches.

- CLAS-6 Data-mining
- Dedicated SRC-pair break-up experiments
- Recoil-tagging measurements

  ⋮

In my talk today:

1. Pair formation and the repulsive *NN* core
   - We're asking sophisticated quantitative questions of our data.
2. *np*-dominance in asymmetric nuclei
   - Neutrons show saturation behavior, protons do not.
3. The EMC-SRC connection
   - New data strengthen the case for the SRC hypothesis.

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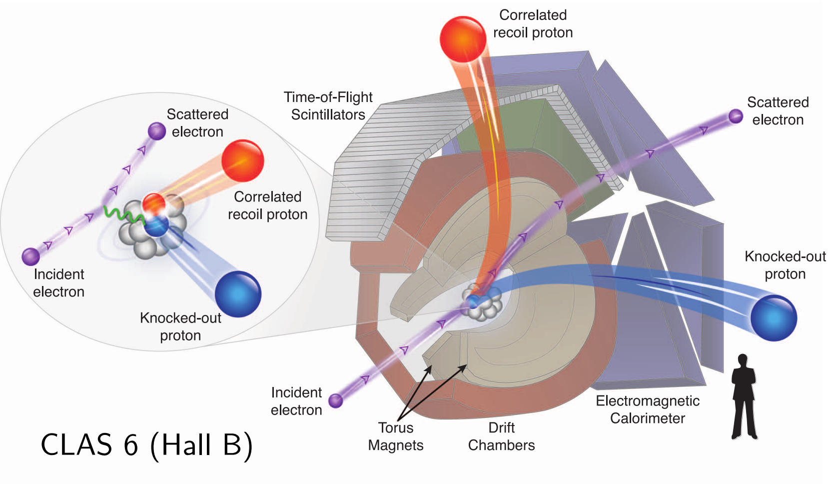
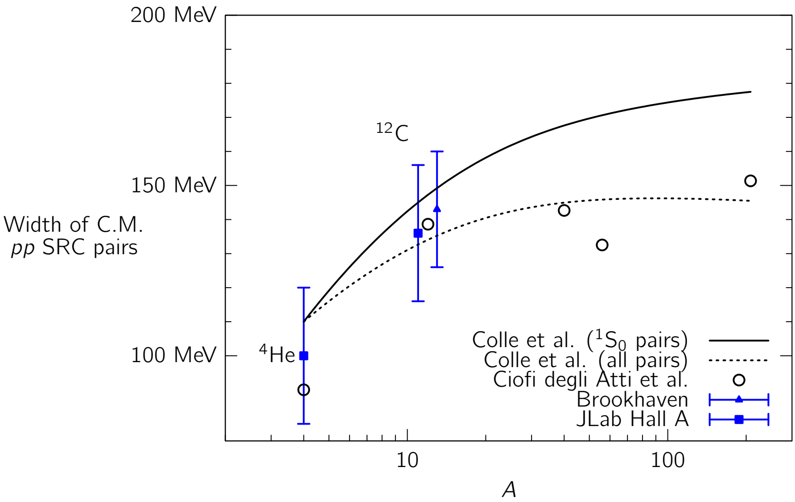
CLAS is well-suited for data mining.

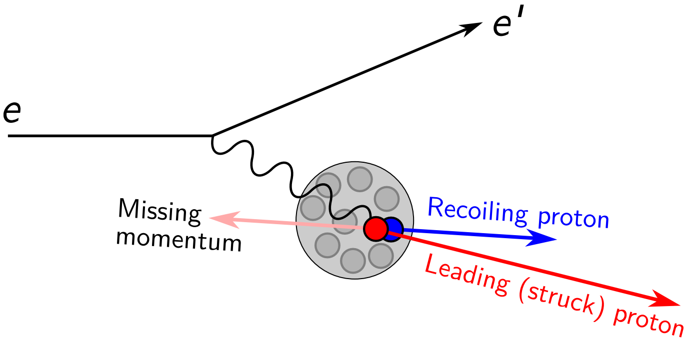
- Large acceptance
- Open trigger



The CM momentum distribution of SRC pairs can tell us about pair formation.

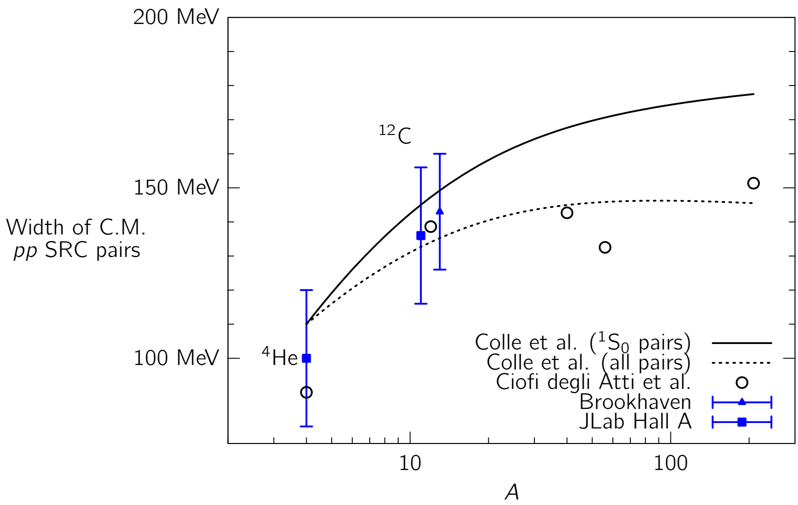


Choose kinematics in which FSIs are confined to the pair.



- $x > 1.2$
- $Q^2 > 1.2$ GeV^2
- $\theta_{pq} < 25°$
- $M_{\text{miss}} < 1.1$ GeV

We see saturation in the CM width.



Erez Cohen et al., under peer review

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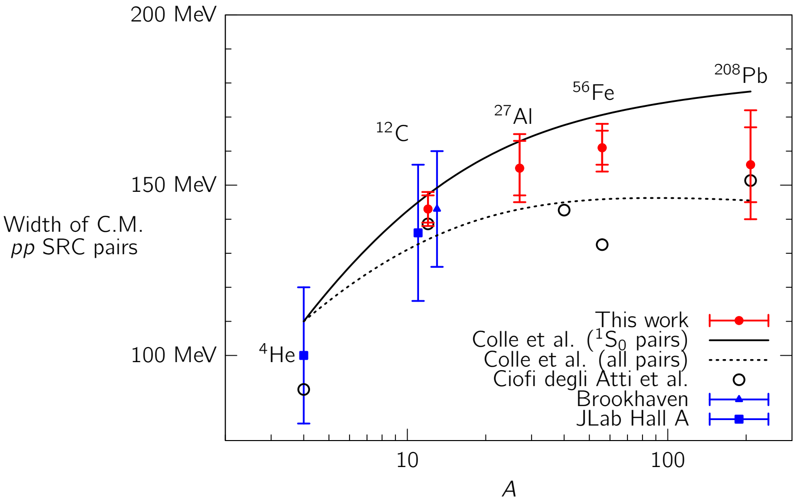
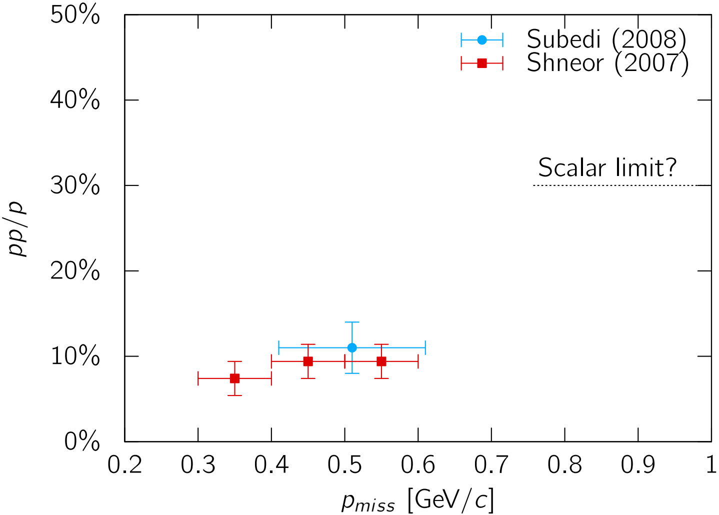
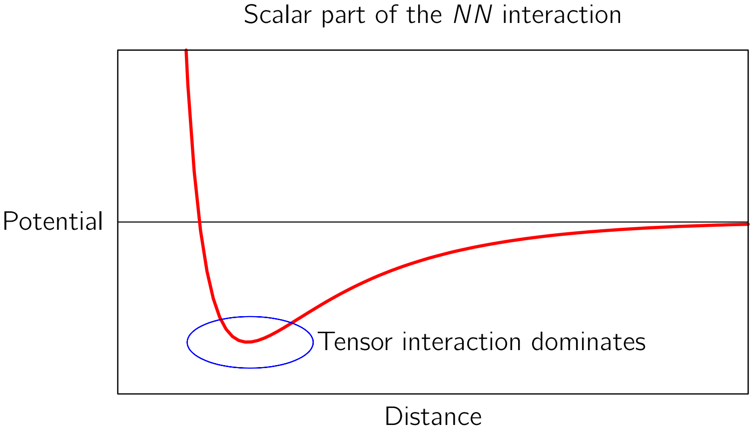


Erez Cohen et al., under peer review

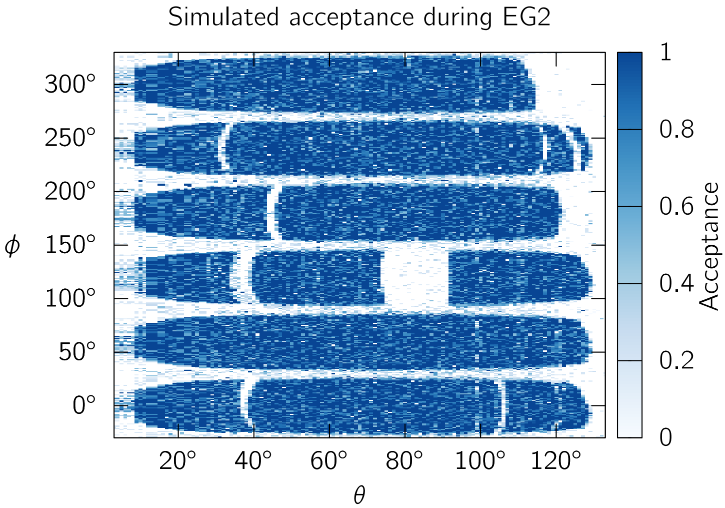
The ratio of pp pairs to single protons can tell us about the NN-interaction.



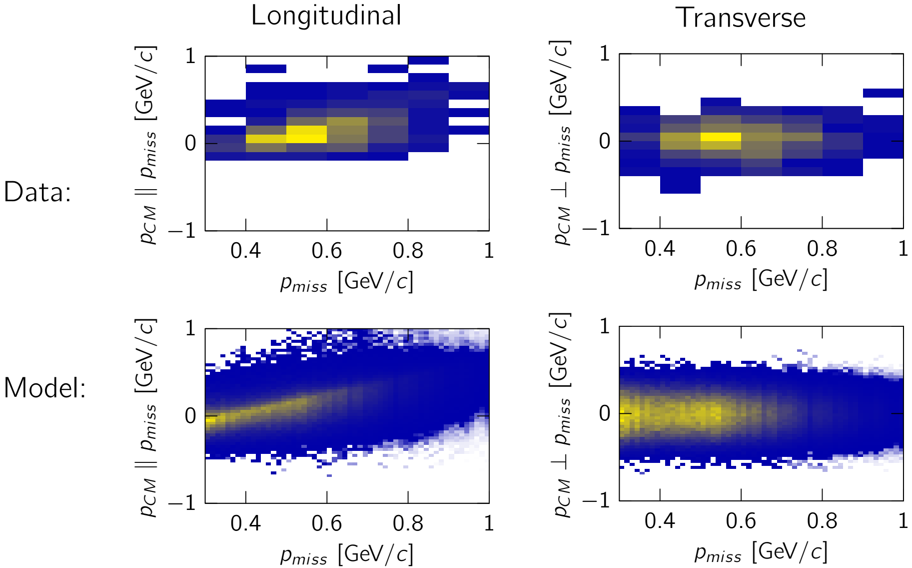
The ratio of *pp* pairs to single protons can tell us about the *NN*-interaction.



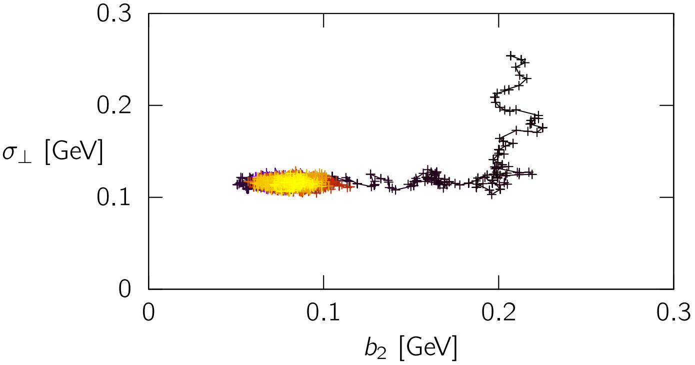
How often did we miss a proton we should have seen?



Data-driven likelihood estimate



We use a Markov Chain MC to estimate the acceptance for recoil protons.



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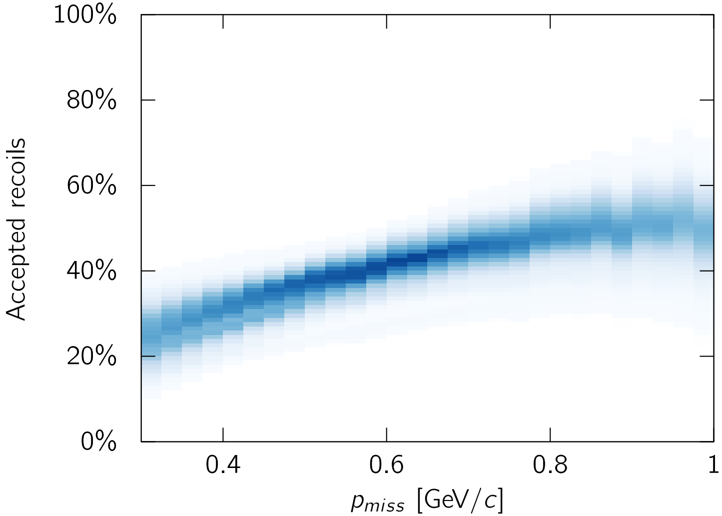
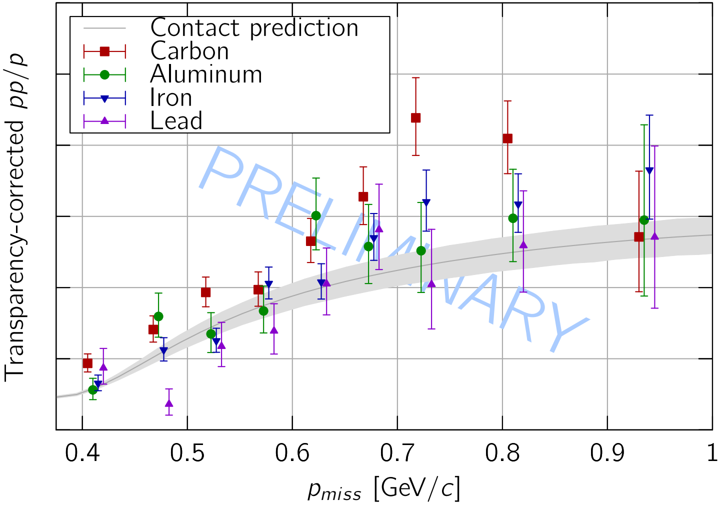
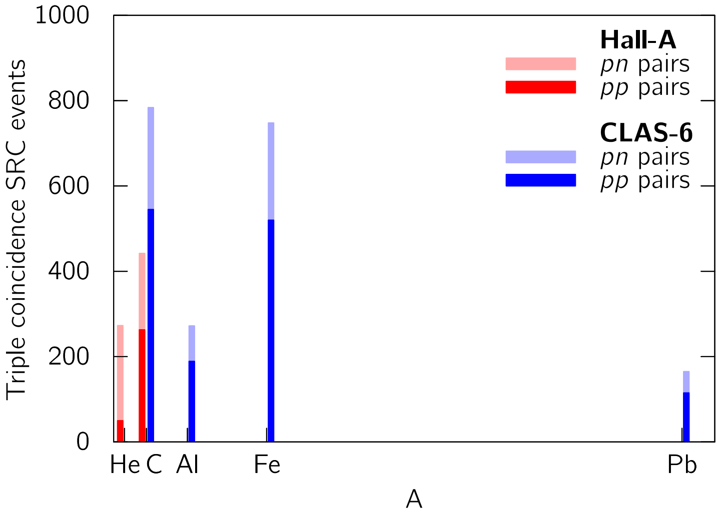


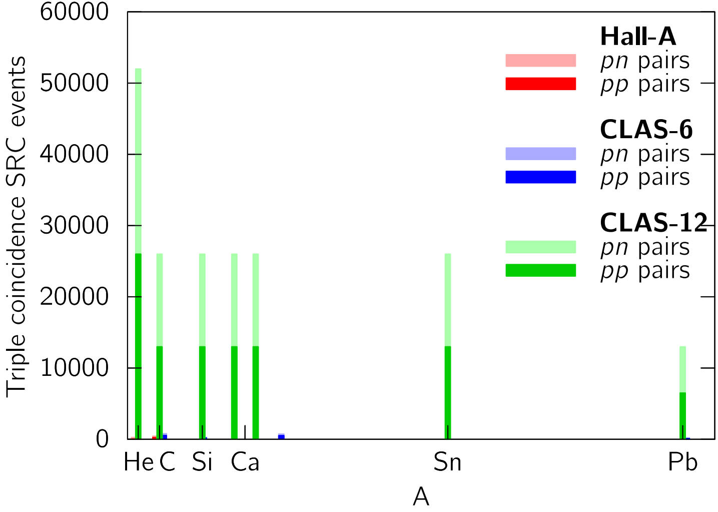
Prelim. results show the expected rise in pp/p.



Much has been learned from very few events.



A new CLAS-12 proposal aims to add order of magnitude more data.



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   - We're asking sophisticated quantitative questions of our data.
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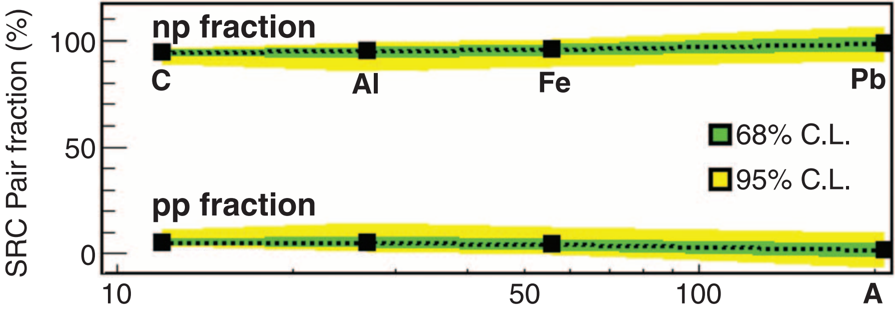
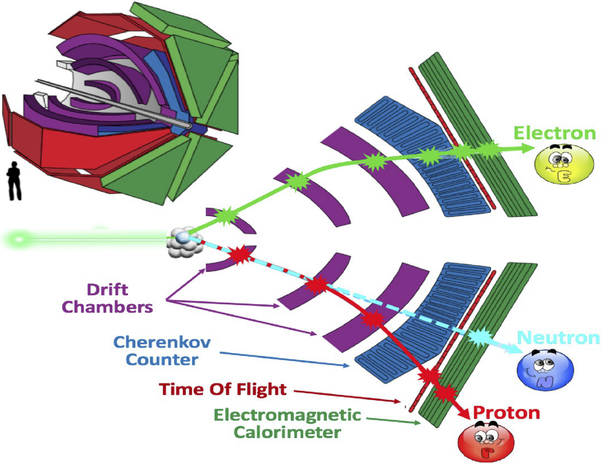
   - **Neutrons show saturation behavior, protons do not.**
3. The EMC-SRC connection
   - New data strengthen the case for the SRC hypothesis.

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



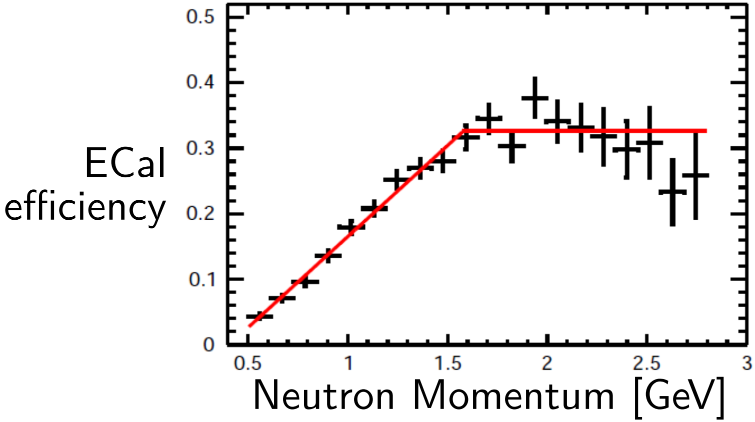
O. Hen et al, Science 346, 614 (2014)

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

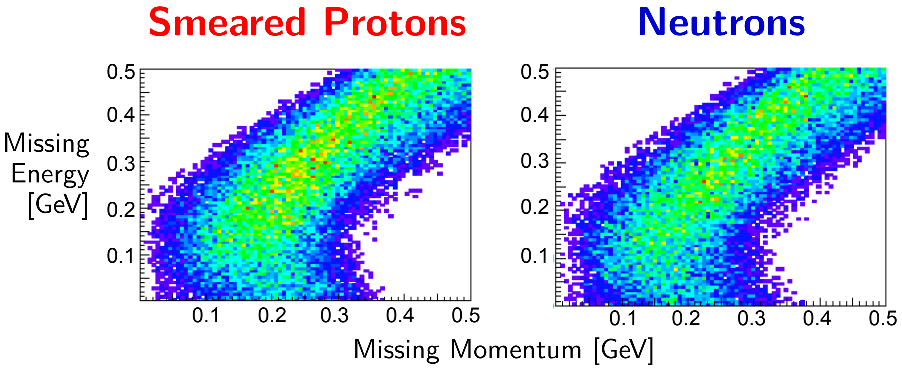


M. Duer, CLAS collaboration, to appear in Nature

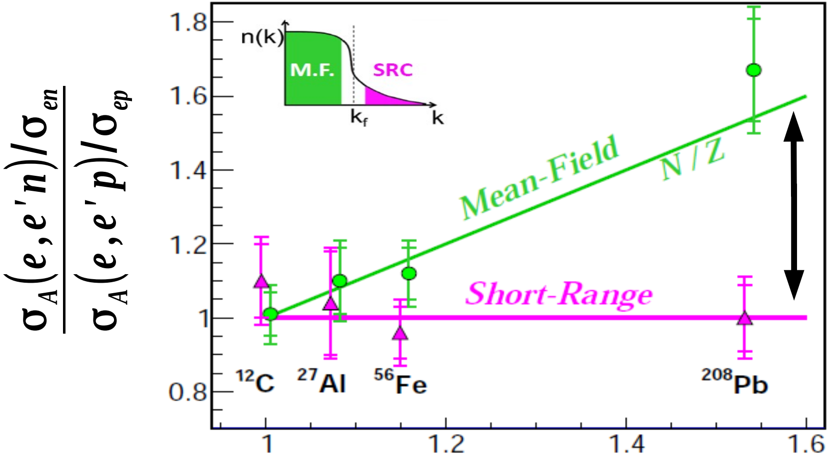
Neutrons efficiencies and resolutions were calibrated using the $d(e, e'p\pi^+\pi^-)n$ reaction.



The poor neutron resolution was studied by "smearing" protons.



n/p ratio is constant with asymmetry!



Neutron Excess [N/Z]

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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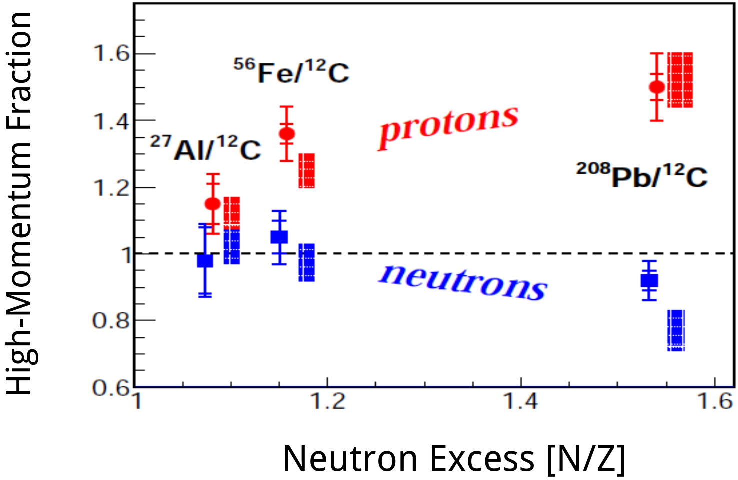
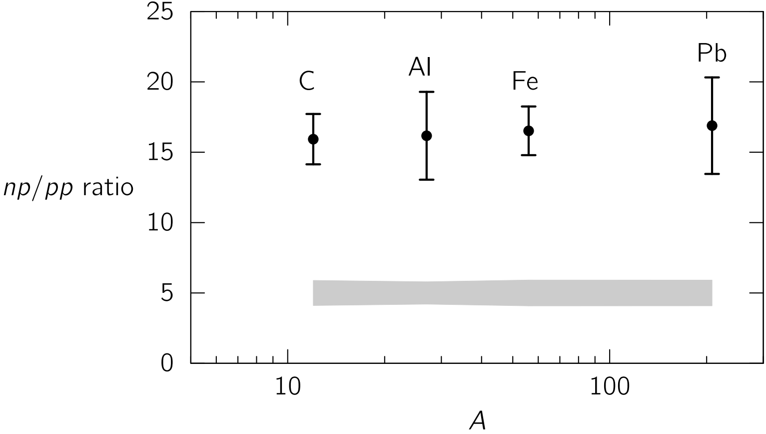
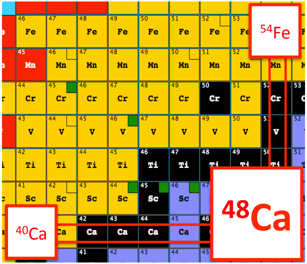


np/*pp* ratio is constant over all species.



We need experiments to disentangle nuclear size and asymmetry.

- New CLAS-12 proposal
  - Add ^{40}Ca, ^{48}Ca
- Recent Hall A Tritium Experiment
  - Compare ^{3}H $\leftrightarrow$ ^{3}He
- CaFe (E12-17-005)



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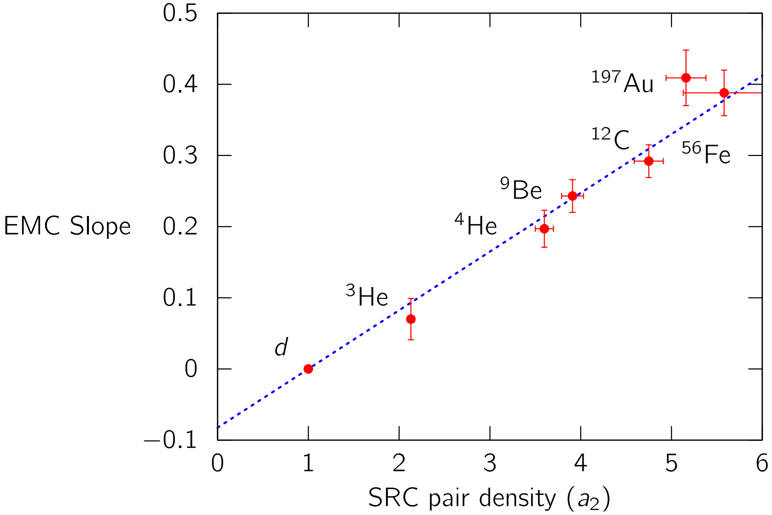
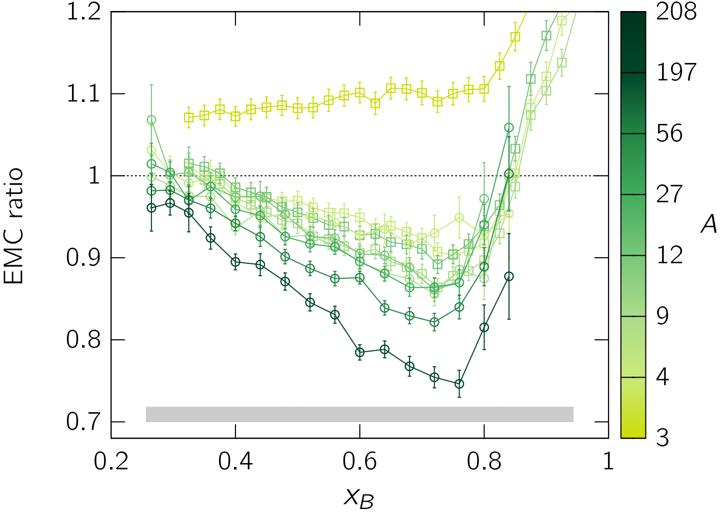
Could the EMC effect be stemming from heavily modified SRC pairs?



We attempted to extract F_2 for a single *np*-SRC pair.



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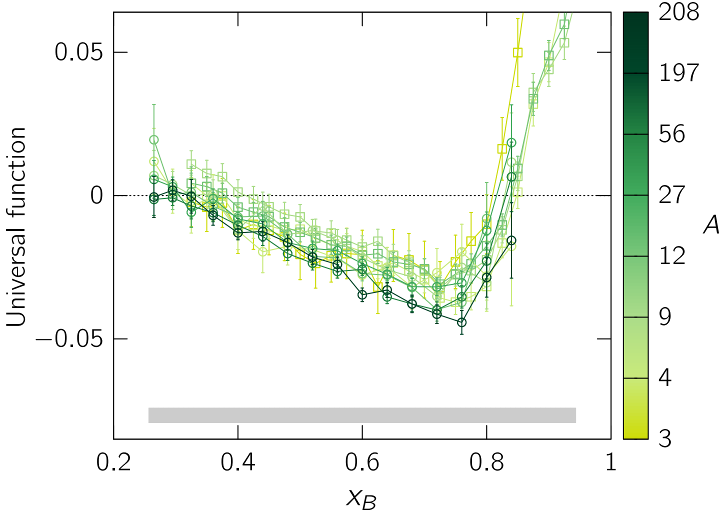

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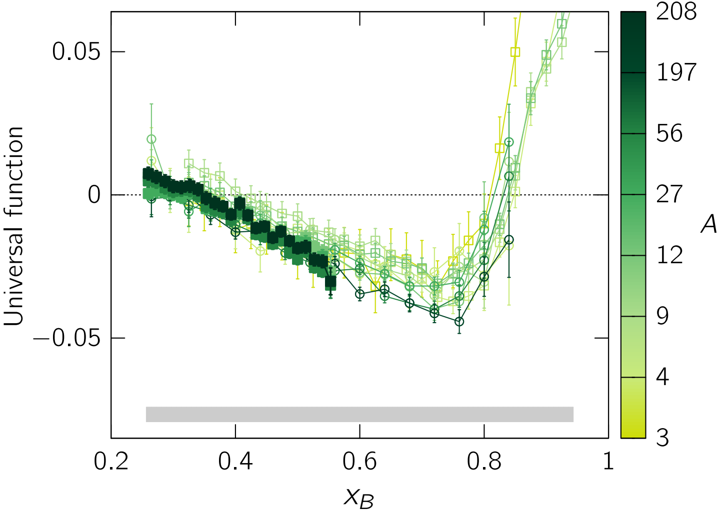
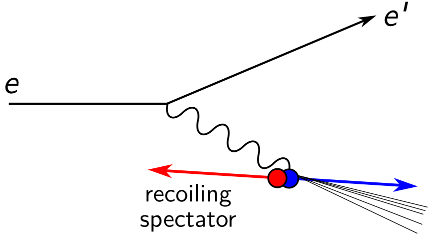


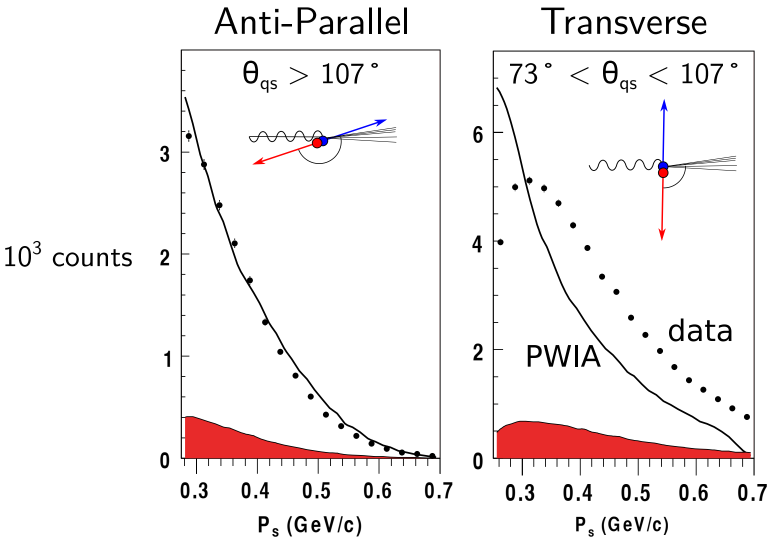
We will test the SRC-EMC hypothesis with recoil-tagging experiments.



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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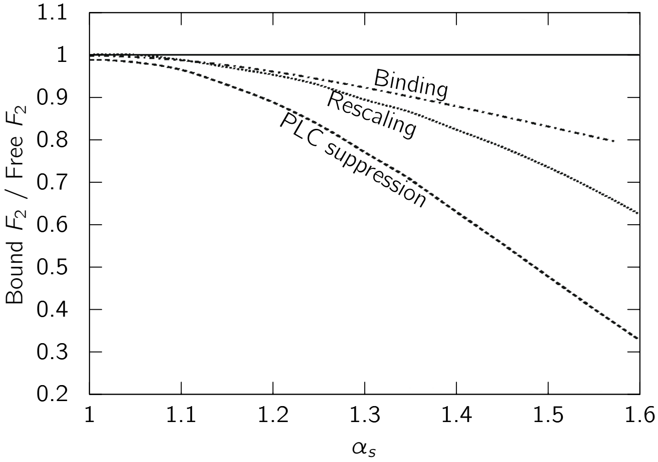
Tagged DIS measurement Input ≈ 1

At low x, the EMC effect should be small:

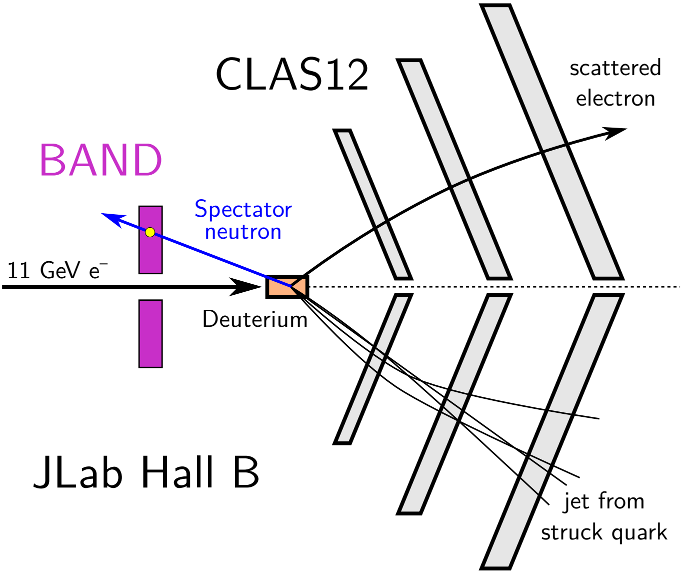
$$\sigma_{\text{DIS}}(\text{low } x', Q_0^2, \alpha_s)_{\text{bound}} \approx \sigma_{\text{DIS}}(\text{low } x, Q_0^2)_{\text{free}}$$

Different models predict different F_2 ratios.

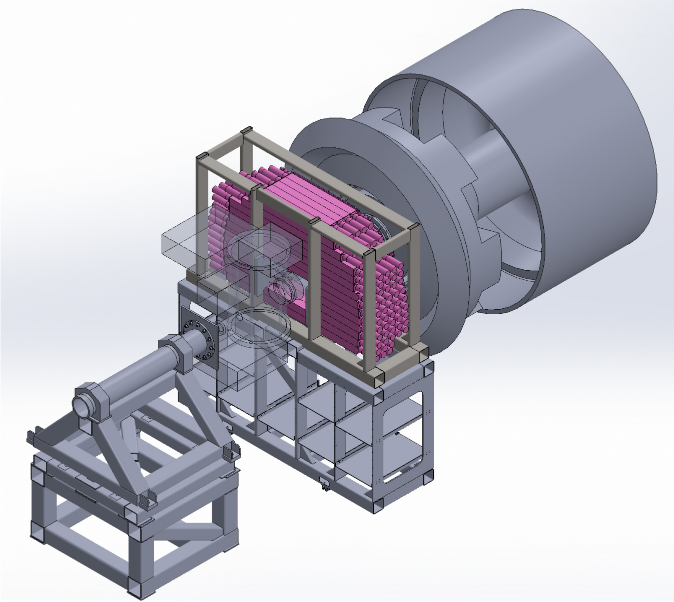


Melnitchouk, Sargsian, Strikman, Z. Phys A 359 p.99 (1997)

BAND will detect recoiling spectator neutrons.



BAND will surround the upstream beamline.



BAND Experiment Details

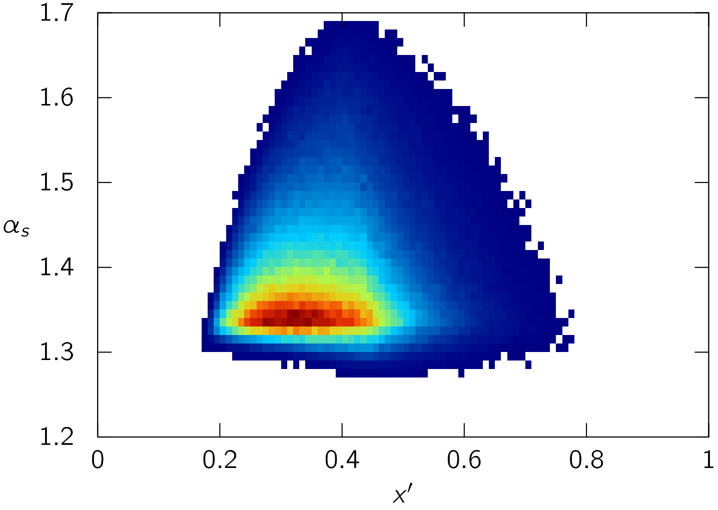
Experiment

- Experiment E12-11-003A
- Approved for Run Group B
  - Installation in a few weeks!
- Extended LD_2 target
- 11 GeV $e-$ beam
- 10^{35} cm^{-2}s^{-1}

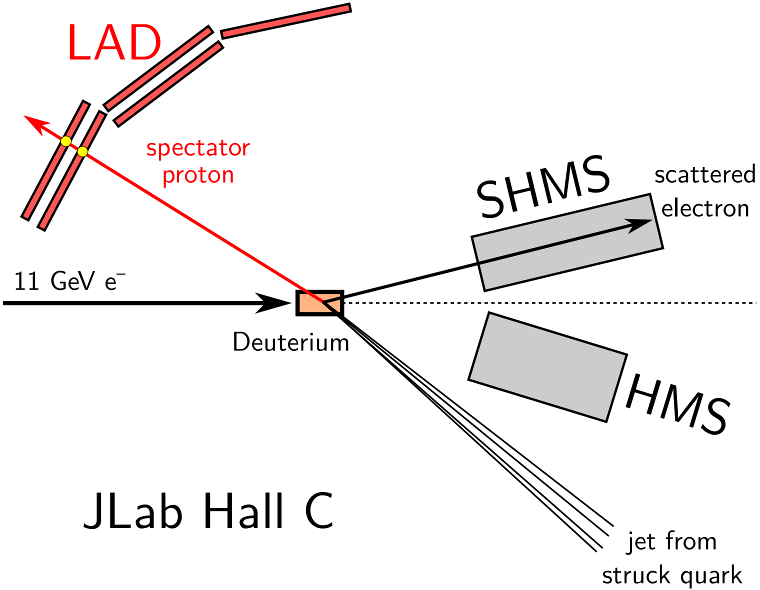
Backward Angle Neutron Detector

- Finishing module assembly at MIT/ODU
- 5 rows of 21 bars
- 160°–170°
- $\approx$ 60% azimuthal coverage
- $\approx$ 40% neutron efficiency

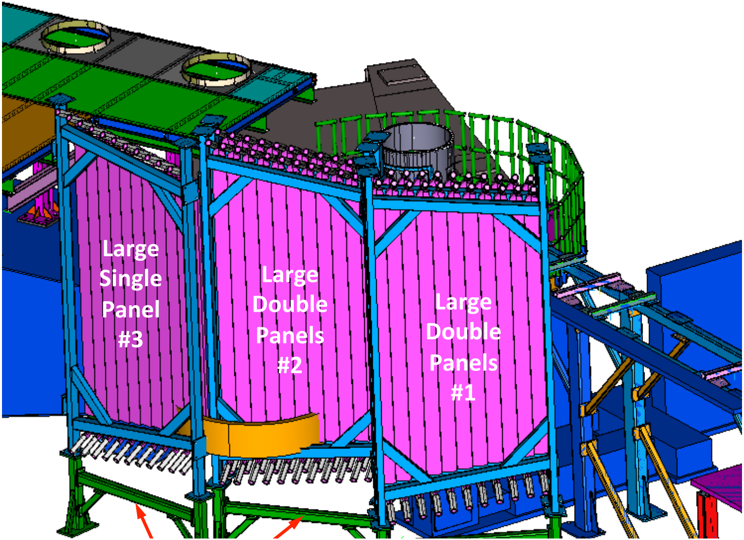
We want reach in both x_B and α_s.

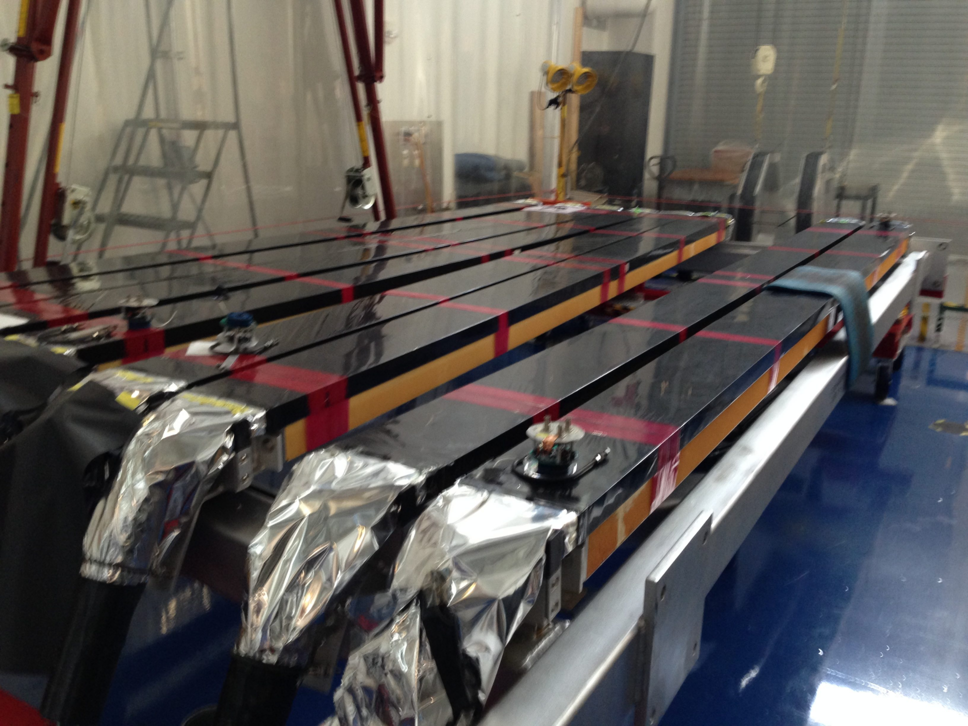


LAD will detect recoiling spectator protons.



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





LAD Experiment Details

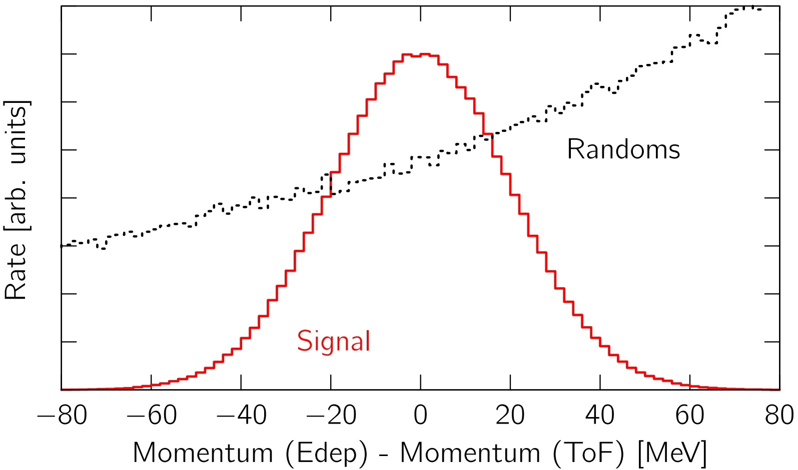
Experiment

- 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

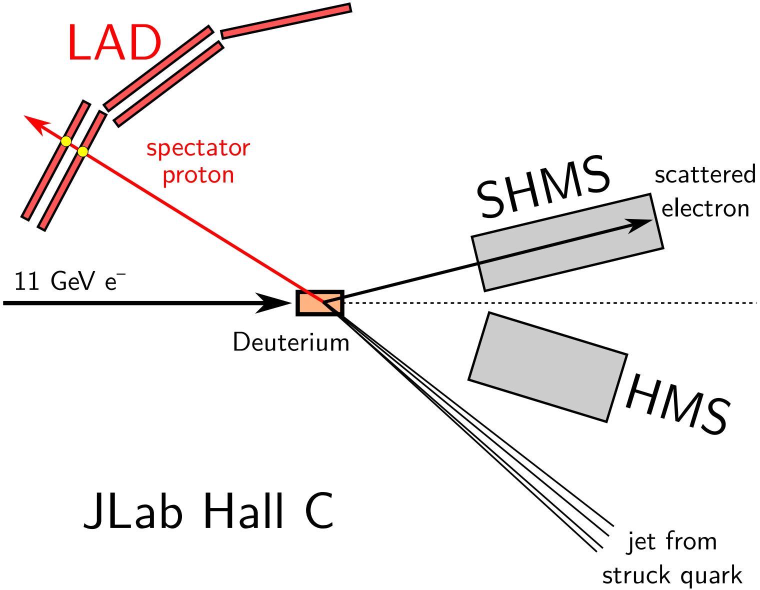
Large Acceptance Detector

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

Energy deposition in LAD must match velocity.



We plan to add GEMs to assist in vertexing.



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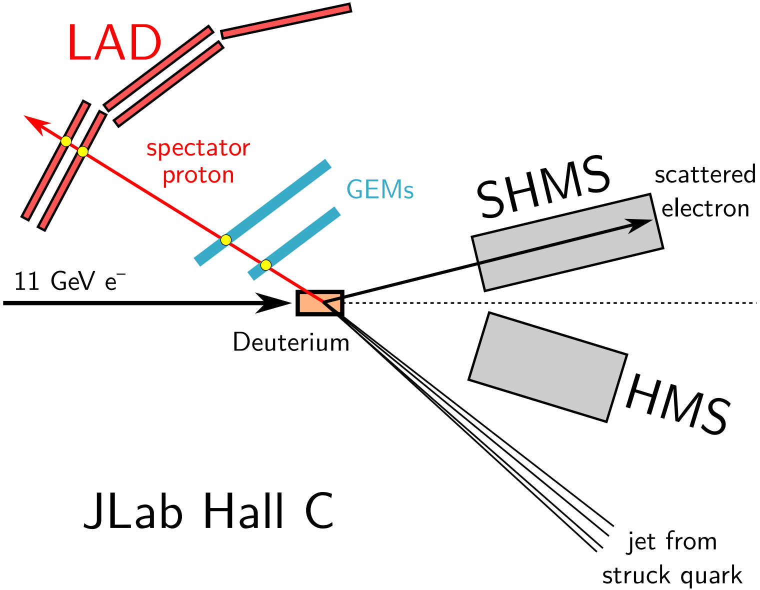
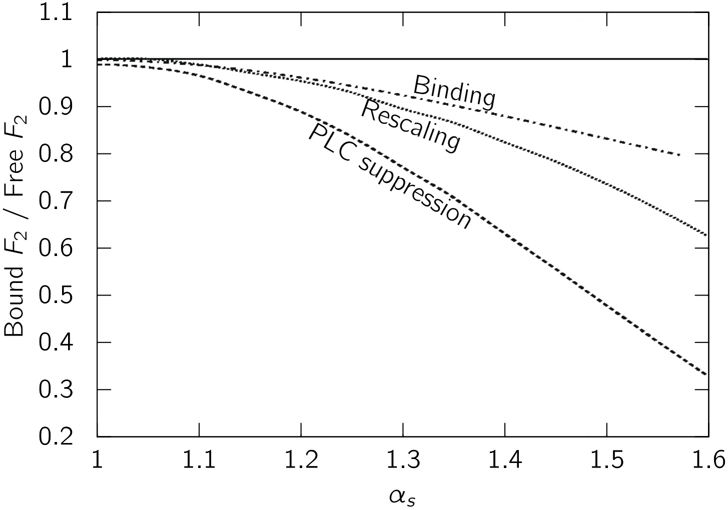


Expected Impact



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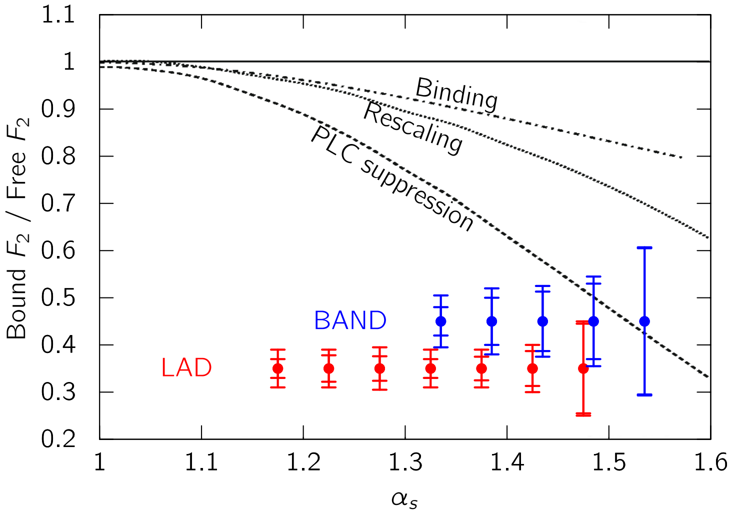
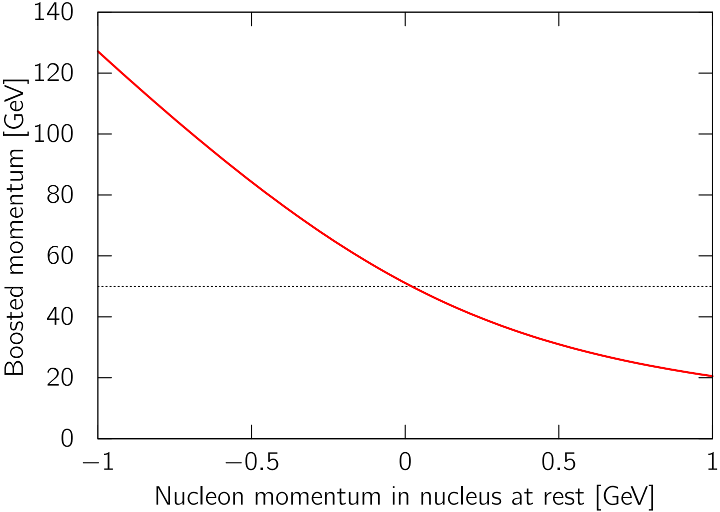


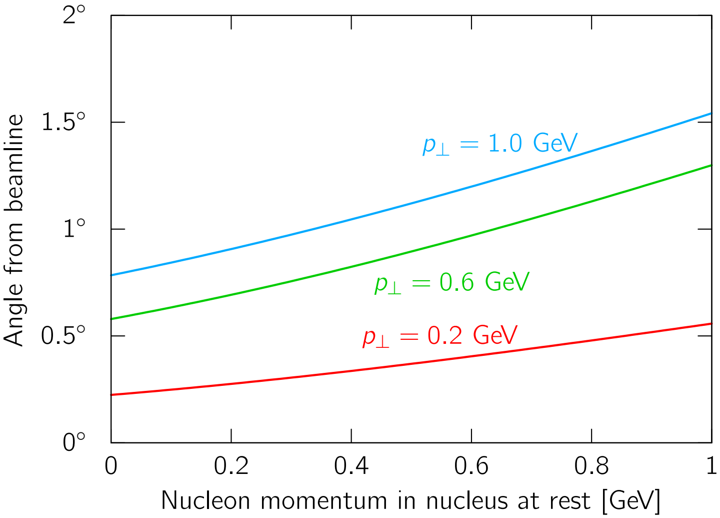
Possibilities at the EIC

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.

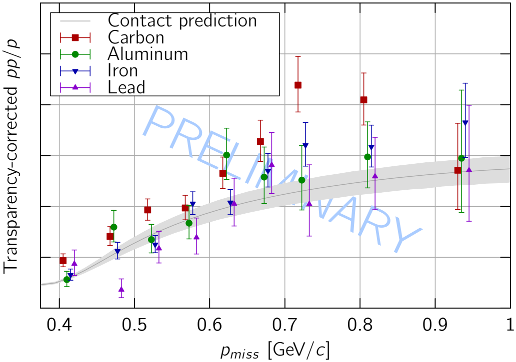


Spectators will be within 2° of beamline.



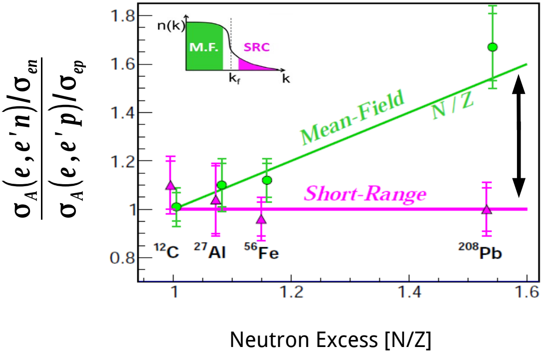
Recap

- Pair formation and the *NN* core



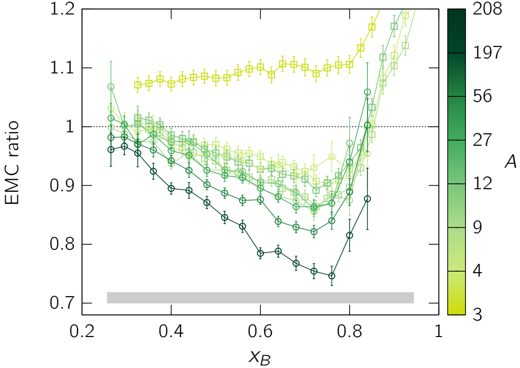
Recap

- Pair formation and the *NN* core
- *np*-dominance in asymmetric nuclei



Recap

- Pair formation and the *NN* core
- *np*-dominance in asymmetric nuclei
- SRC-EMC hypothesis



Recap

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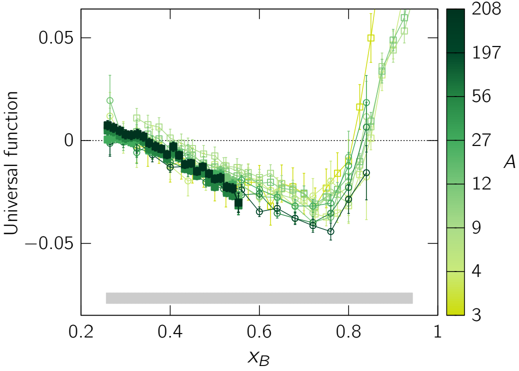

Conclusions

- New experiments will bring an order of magnitude increase in data.
- We are entering a new *quantitative* era of SRC measurements.