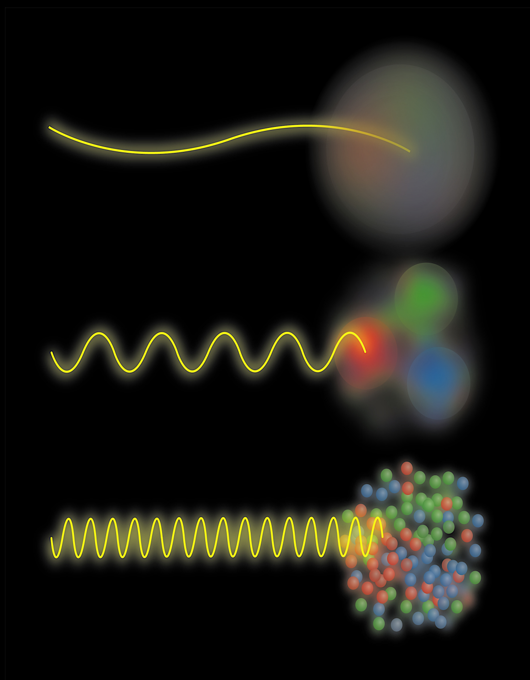
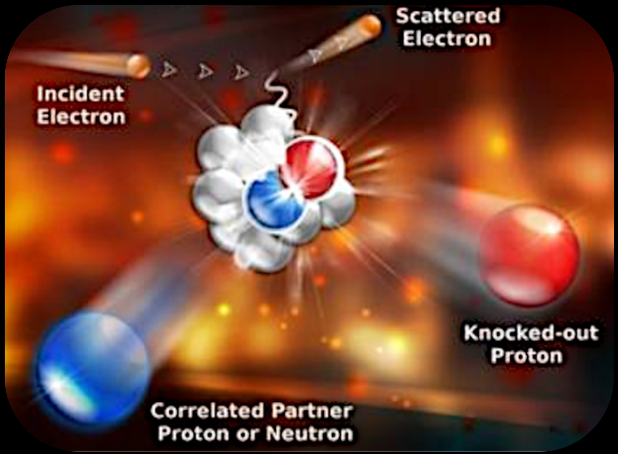
New Insights to the Origin of the EMC Effect



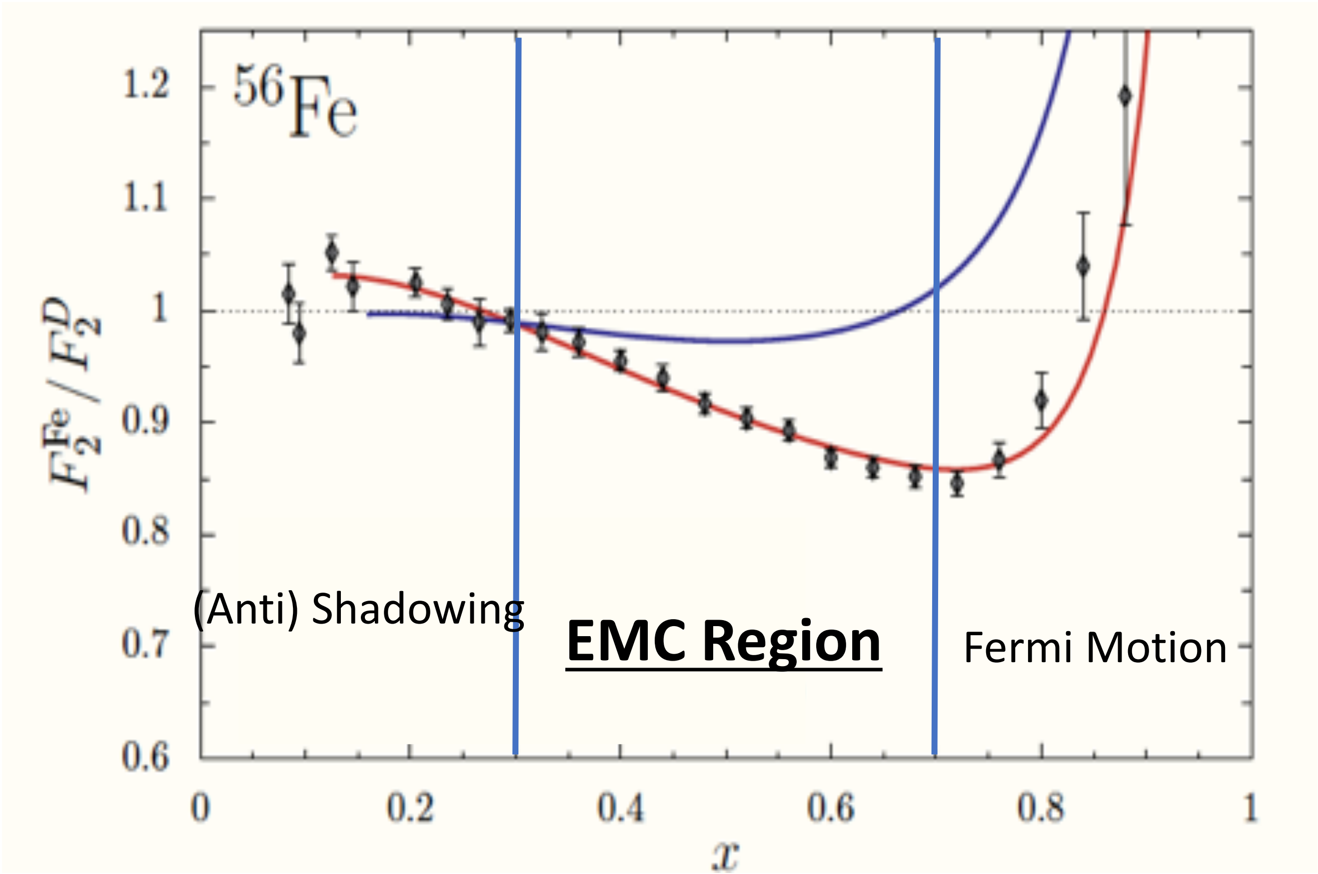
Or Hen

MIT



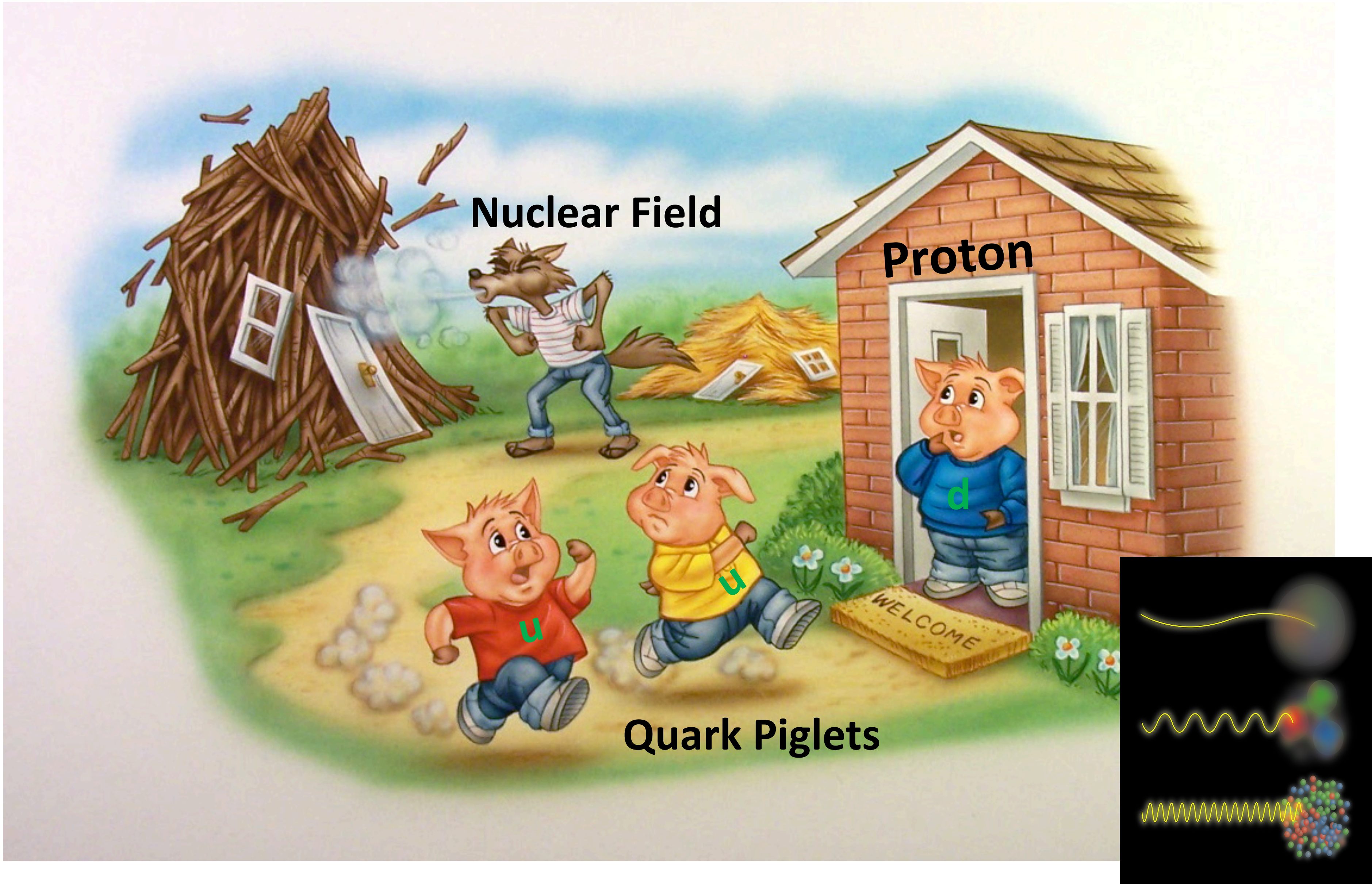
DIS-2017, April 4th, 2017, Birmingham, England.

EMC: Bound Nucleons ≠ Free Nucleons

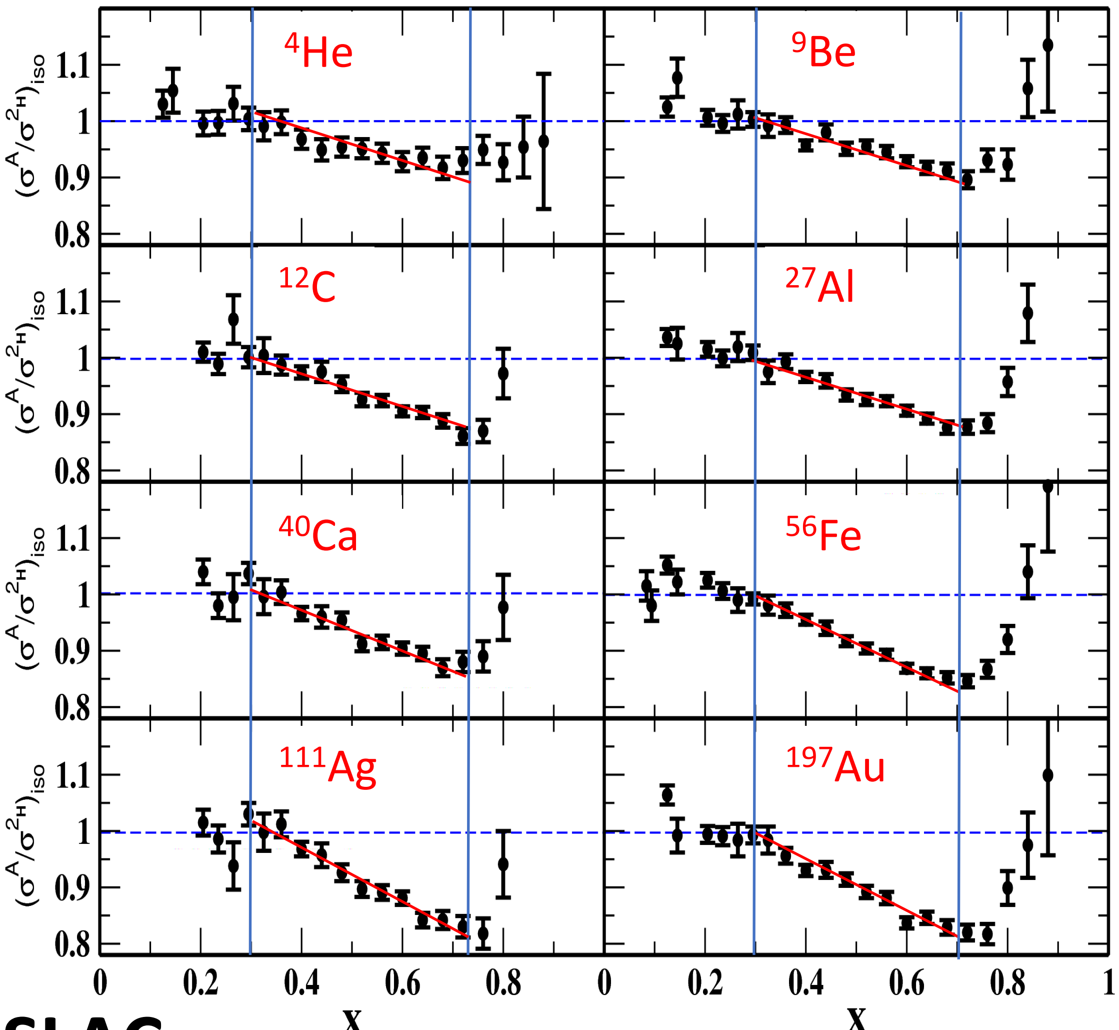


$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_A = \frac{4\alpha^2 E'^2}{Q^4}\left[2\frac{F_1}{M}\sin^2\left(\frac{\theta}{2}\right) + \frac{F_2}{\nu}\cos^2\left(\frac{\theta}{2}\right)\right] \qquad F_2\left(x,Q^2\right) = \sum_i e_i^2 \cdot x \cdot f_i(x)$$

EMC: Very Different Scales!



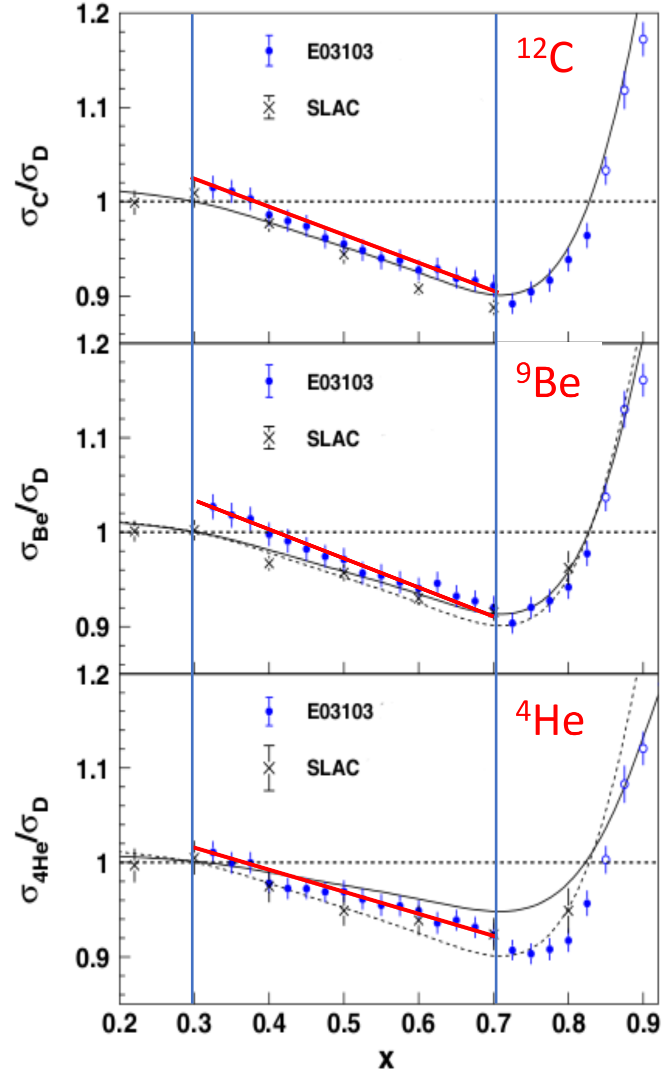
EMC: Nuclear Effect!



SLAC

J. Gomez et al., Phys. Rev. D **49**, 4348 (1994).

JLab



J. Seely et al., Phys. Rev. Lett. **103**, 202301 (2009).

Theory: 1000 papers, 3 Ideas

1. Proper treatment of 'known' nuclear effects
   [explain some of the effect, up to x≈0.5]
   - Nuclear Binding and Fermi motion, Pions, Coulomb Field.
   - **No modification of bound nucleon structure.**

2. Bound Nucleons are 'larger' than free nucleons.
   - Larger confinement volume => slower quarks.
   - Mean-Field effect.
   - Momentum Independent.
   - **Static.**

3. Short-Range Correlations
   - Beyond the mean-field.
   - Momentum dependent.
   - **Dynamical!**

EMC – Everyone's Model is Cool (G. A. Miller)

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2. P

One Model Isn’t Cool:
“Unmodified Bound-Nucleons”

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EMC – Everyone’s Model is Cool (G. A. Miller)

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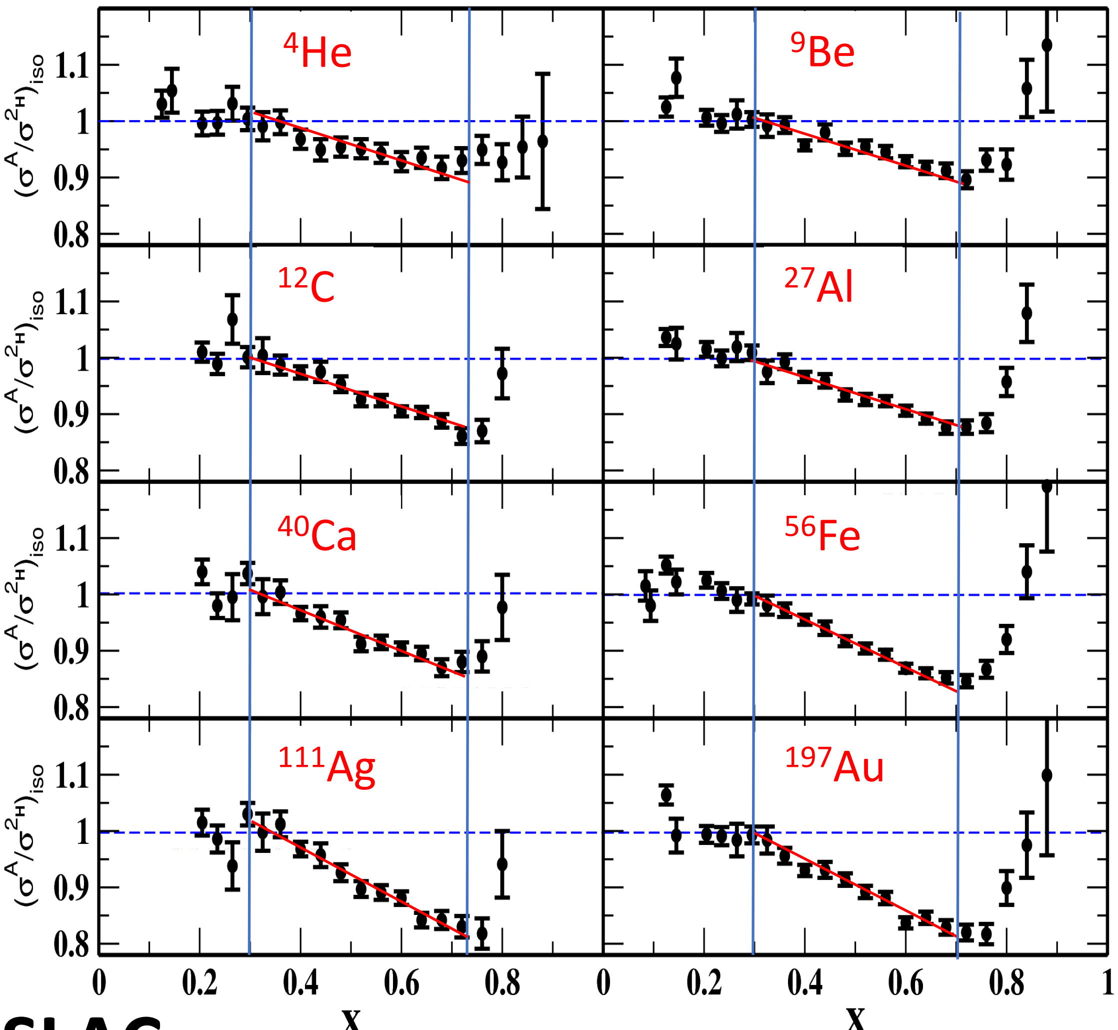
EMC – Everyone’s Model is Cool (G. A. Miller)

EMC: Nuclear Effect!



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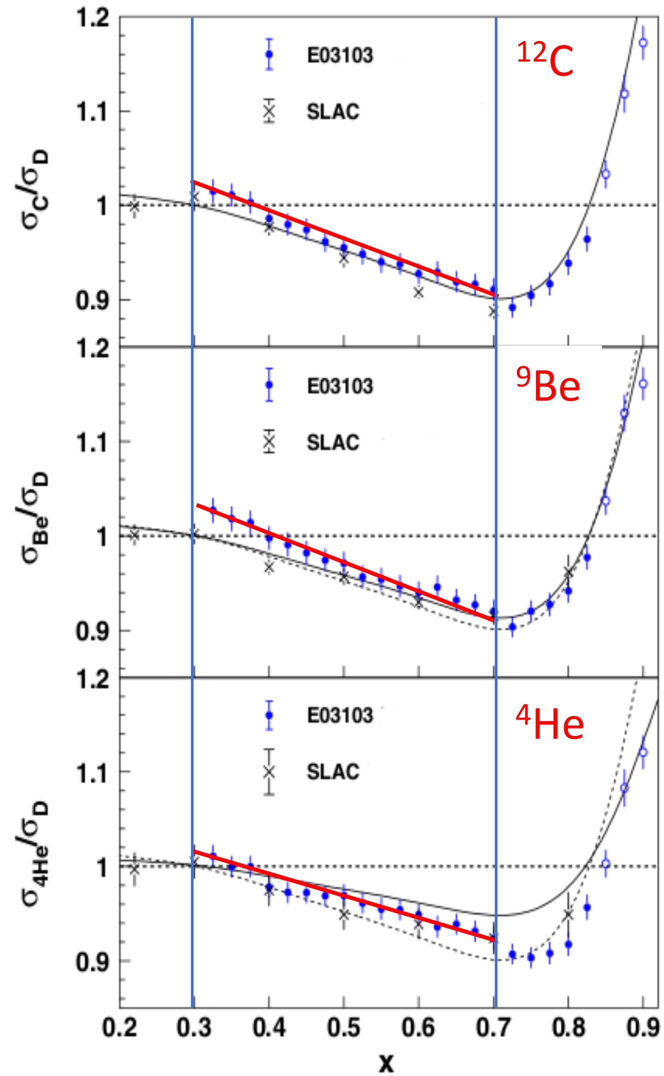
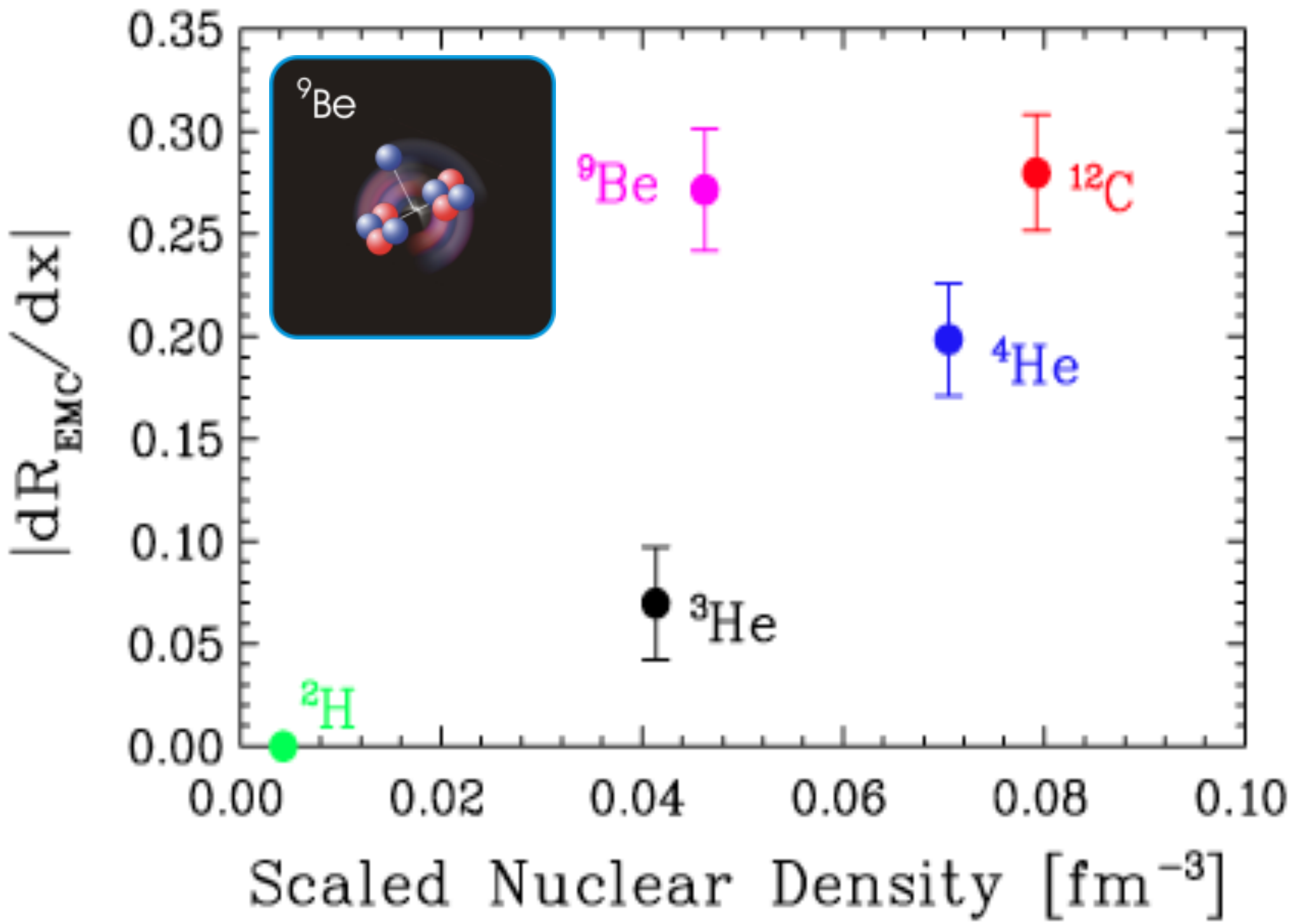


J. Seely et al., Phys. Rev. Lett. **103**, 202301 (2009).

EMC: (non-trivial) Nuclear Effect!

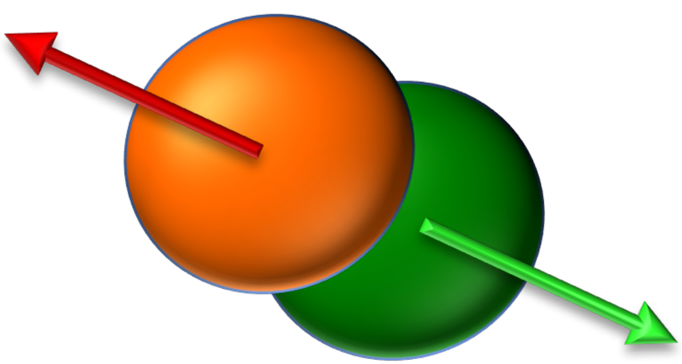


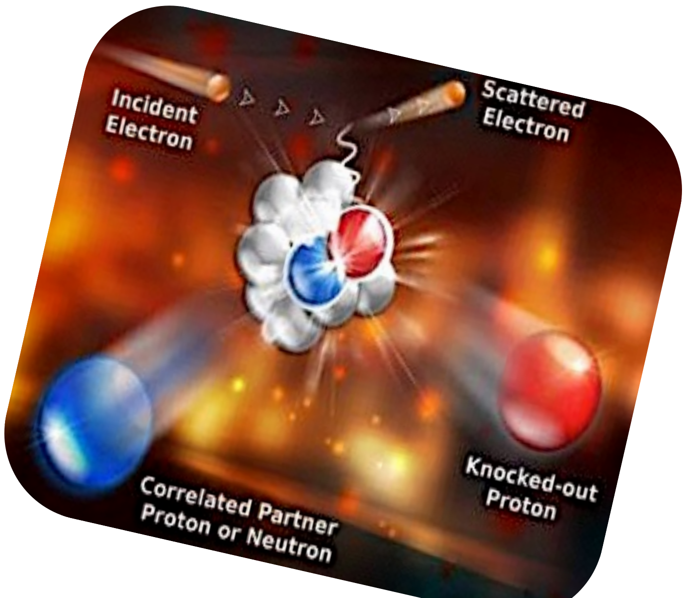
J. Seely et al., Phys. Rev. Lett. **103**, 202301 (2009).

Beyond the Mean-Field: Short-Range Correlations

Temporal fluctuations of Nucleon that are close together in the nucleus (wave functions overlap)

=> Momentum space: pairs with *high relative momentum* and *low c.m. momentum* compared to the Fermi momentum (k_F)





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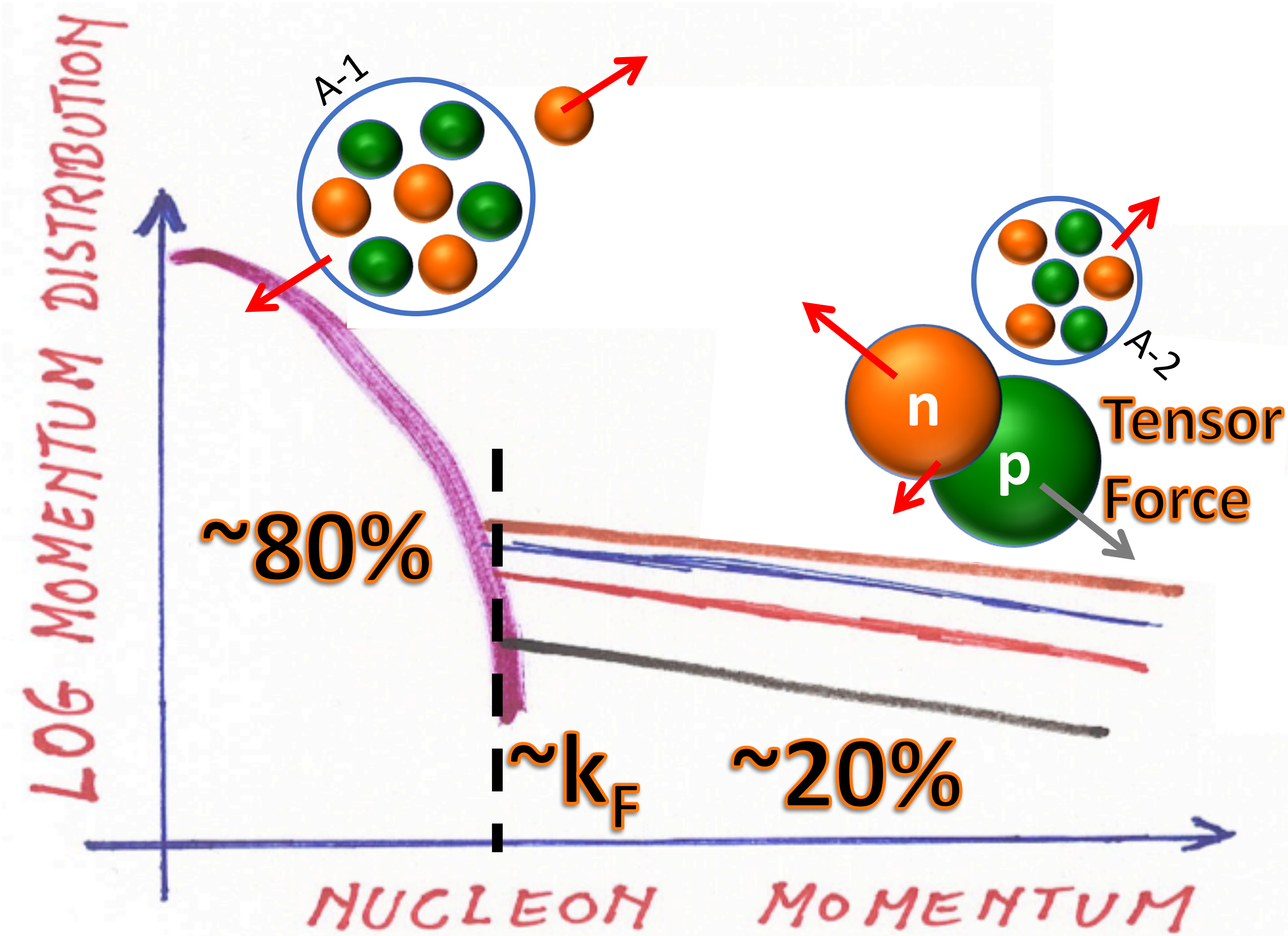
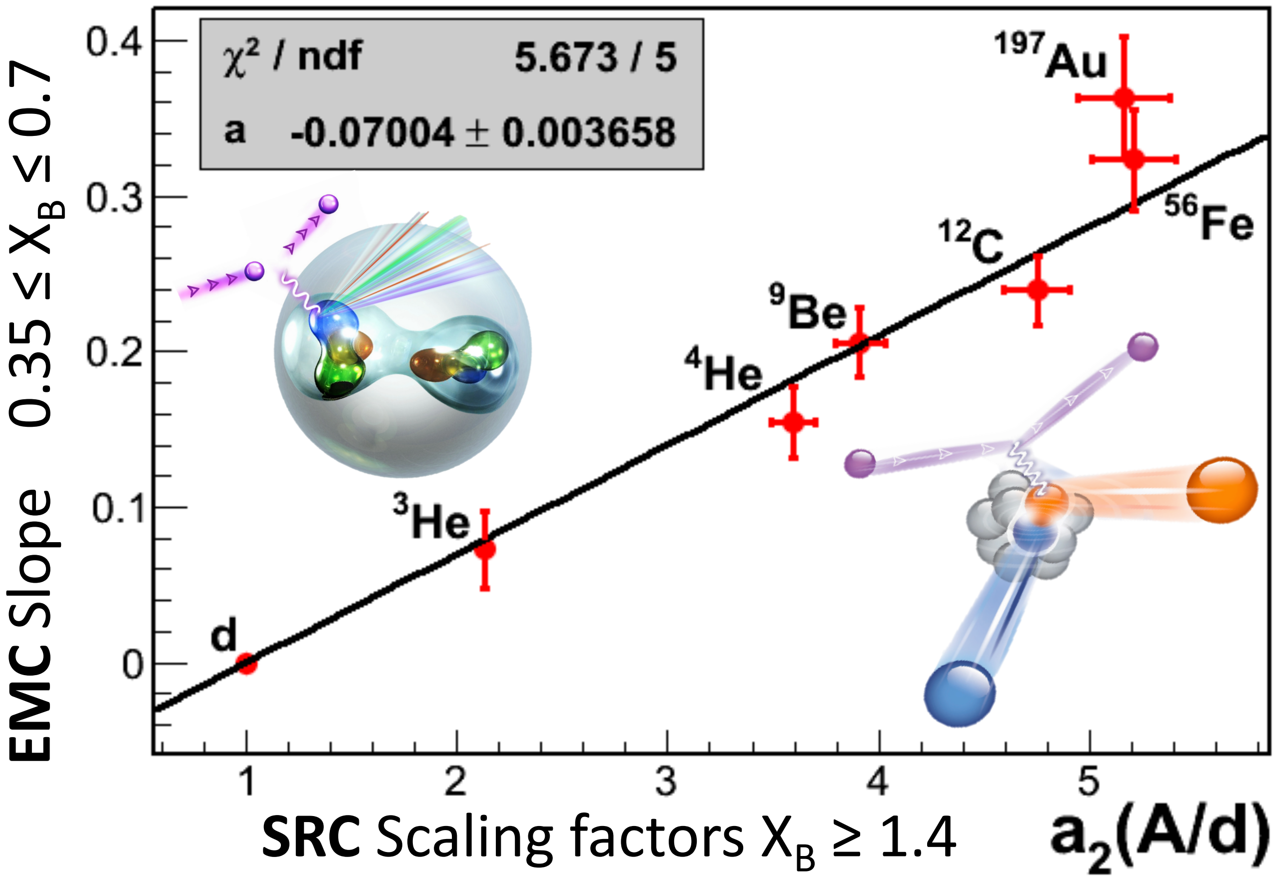


EMC and SRC are Correlated!



O. Hen et al., Int. J. Mod. Phys. E. **22**, 1330017 (2013).

O. Hen et al., Phys. Rev. C **85** (2012) 047301.

L. B. Weinstein, E. Piasetzky, D. W. Higinbotham, J. Gomez, O. Hen, R. Shneor, Phys. Rev. Lett. **106** (2011) 052301.

EMC and SRC are Correlated!

EMC Effect Predominantly Associated with High-Momentum Nucleons?

Practical Implications:

1. **NuTeV anomaly** [ask me later if interested]
2. **Free neutron structure** [Hen et al. PRC 2012]
1. **d/u ratio at large-x_B and SU(6) breaking** [Hen et al. PRD 2011]

O. Hen et al., Int. J. Mod. Phys. E. **22**, 1330017 (2013).

O. Hen et al., Phys. Rev. C **85** (2012) 047301.

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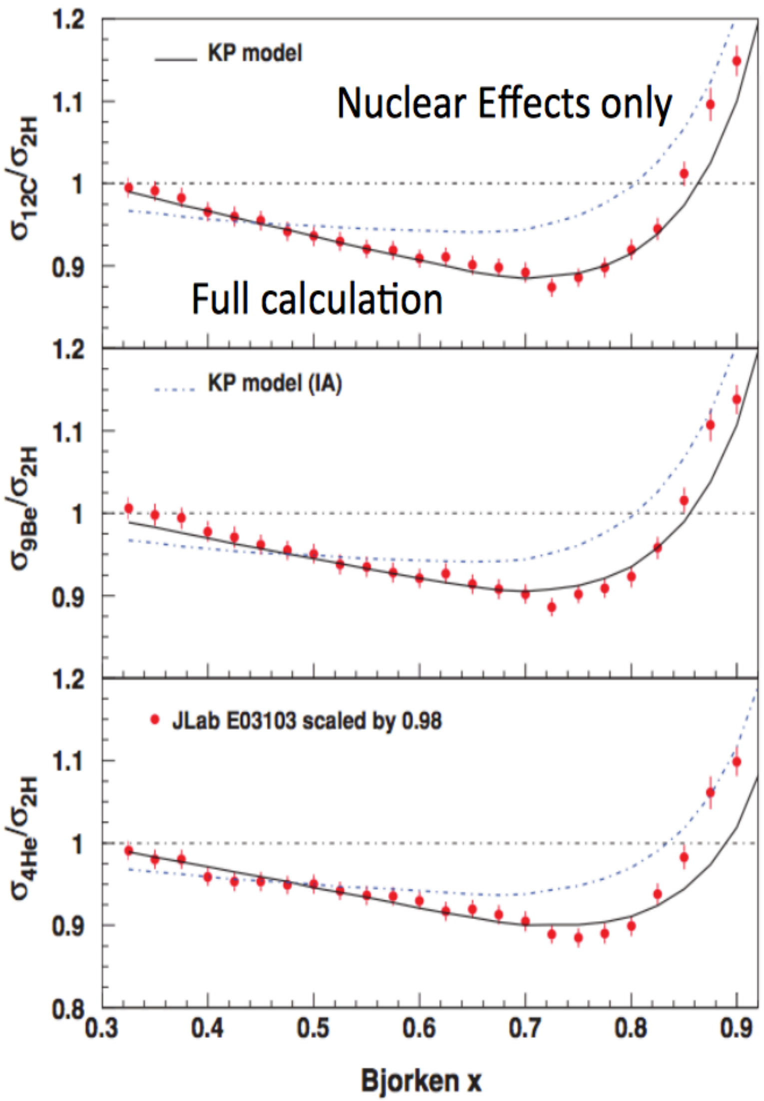
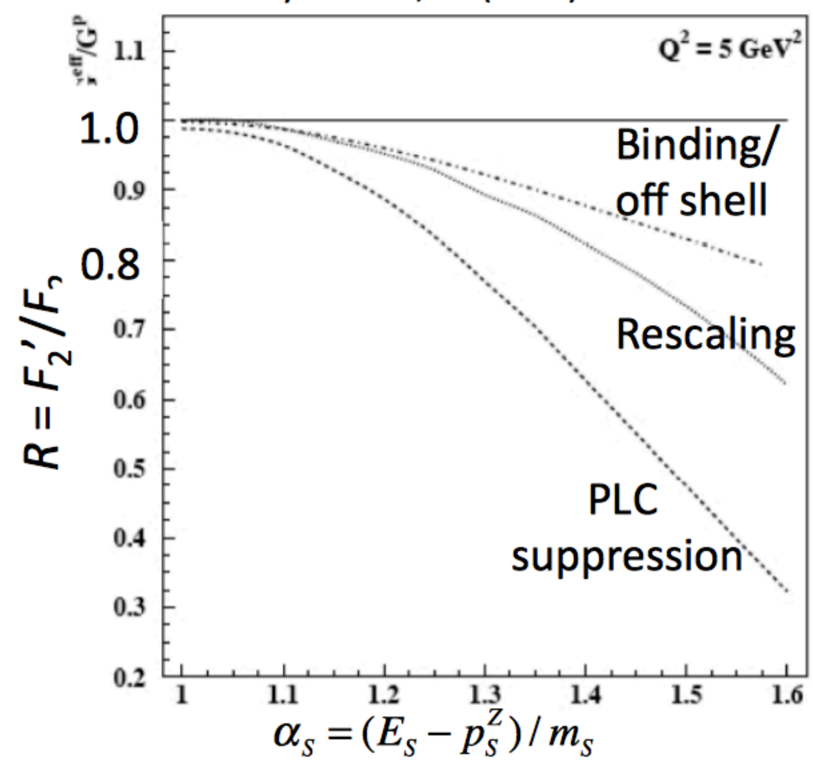
Physics Behind the Correlation?



Kulagin and PeLy, PRC 82, 054614 (2010)

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

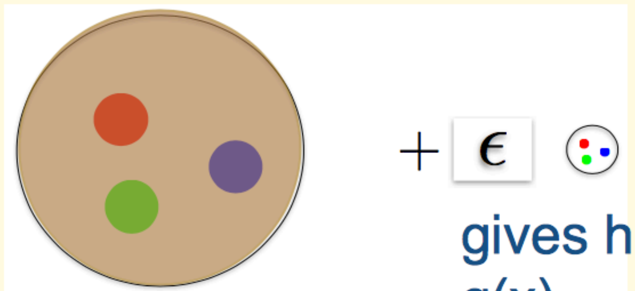


Physics Behind the Correlation?

Free nucleon

Suppression of Point Like Configurations

Frankfurt Strikman

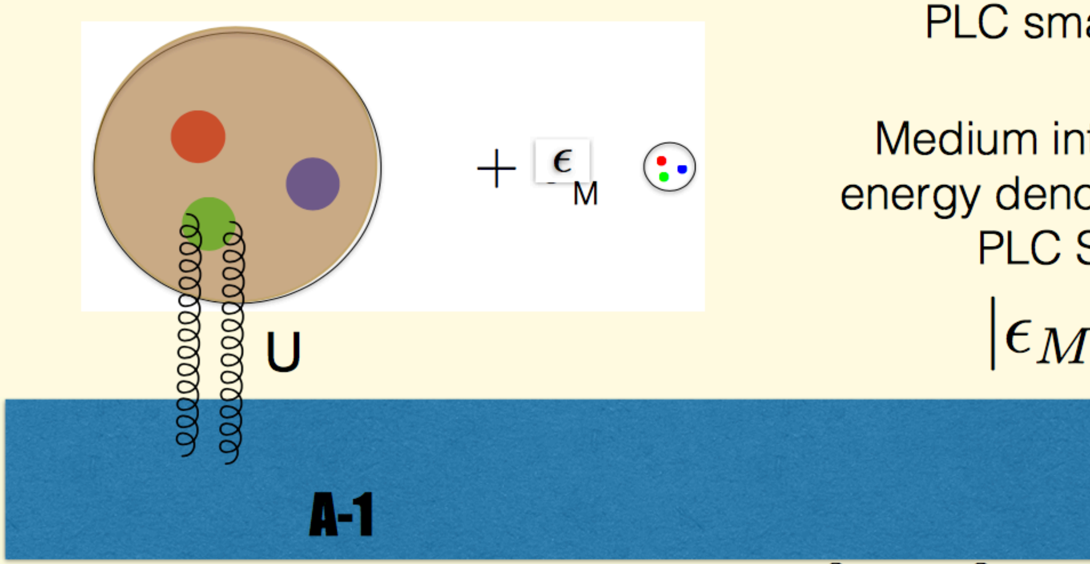


gives high x q(x)

Schematic two-component nucleon model

Blob-like config:BLC
Point-like config: PLC

Bound nucleon



PLC smaller, fewer quarks high x

Medium interacts with BLC energy denominator increases PLC Suppressed

$$|\epsilon_M| < |\epsilon|$$

$$\text{Shroedinger equation} \rightarrow U = \frac{p^2 - M^2}{2M} \equiv \frac{v}{2M}$$

G.A. Miller

Physics Behind the Correlation?

Implications of model

The two state model has a ground state $|N\rangle$ and an excited state $|N^*\rangle$

$|N\rangle_M = |N\rangle + (\epsilon_M - \epsilon)|N^*\rangle$

The nucleus contains excited states of the nucleon

non-nucleon

These configurations are the origin of high x EMC ratios

Estimate

$$\frac{\Delta q}{q}(x) = 2(\epsilon_M - \epsilon)\frac{\langle N^*|\mathcal{O}(x)|N\rangle}{\langle N|\mathcal{O}(x)|N\rangle} \approx 0.15$$

$$2(\epsilon_M - \epsilon) \sim 0.15$$

$$P_{N^*} = (\epsilon_M - \epsilon)^2 \sim 6 \times 10^{-3}$$

Previously missing in models of the EMC effect-
same model predicts some other effect

G.A. Miller

Short Range Correlations and the EMC Effect in Effective Field Theory

Jiunn-Wei Chen,[1,2,*] William Detmold,[2,†] Joel E. Lynn,[3,4,‡] and Achim Schwenk[3,4,5,§]

[1] *Department of Physics, CTS and LeCosPA, National Taiwan University, Taipei 10617, Taiwan*
[2] *Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
[3] *Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany*
[4] *ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany*
[5] *Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany*

arXiv: 1607.03065 (2016)

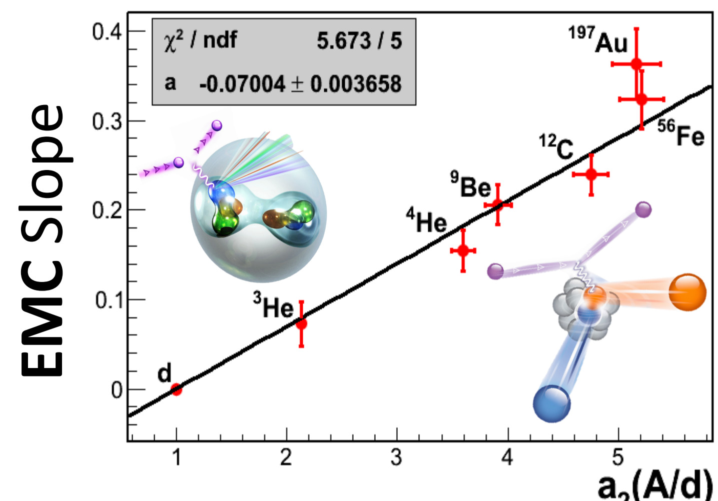
EFT description of bound nucleon structure:

$$F_2^A(x,Q^2)/A = F_2^N(x,Q^2) + g_2(A,\Lambda) f_2(x,Q^2,\Lambda).$$

$$g_2(A,\Lambda) = \underbrace{\frac{1}{A}\langle A|\left(N^\dagger N\right)^2|A\rangle_\Lambda}_{\text{SRC contact}}$$

$$a_2(A, x>1) = \frac{g_2(A,\Lambda)}{g_2(2,\Lambda)}$$

[SRC Scaling Factor]



SRC Scaling factors

RMP Review

Nucleon-Nucleon Correlations and the Quarks Within

Or Hen

Massachusetts Institute of Technology, Cambridge, MA 02139

Gerald A. Miller

Department of Physics,
University of Washington, Seattle,
WA 98195

Eli Piasetzky

School of Physics and Astronomy,
Tel Aviv University, Tel Aviv 69978,
Israel

Lawrence B. Weinstein

Department of Physics,
Old Dominion University, Norfolk,
VA 23529

(Dated: November 2, 2016)

- conventional (non-quark) nuclear physics cannot account for the EMC effect
- models need to include nucleon modification to account for the EMC effect. These models can modify the structure of either:
  - mean field nucleons, or
  - nucleons belonging to SRC pairs.
- there is a phenomenological connection between the strength of the EMC effect and the probability that a nucleon belongs to a two-nucleon SRC pair ($a_2(A)$), see Fig. 33.
- the influence of SRC pairs can account for the EMC-SRC correlation because both effects are driven by high virtuality nucleons with $p^2 \neq M^2$,
- the connection between the EMC effect and the coefficients $a_2(A)$ has been derived using two completely different theories, so that this connection is no accident
- nuclei must contain a small percentage of baryons that are not nucleons. Such baryons exist in the short-ranged correlations and are the source of the EMC effect.

Conclusions

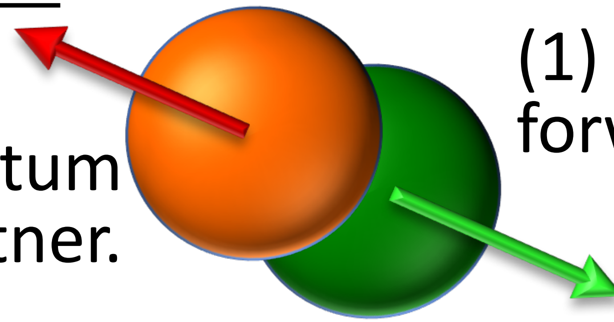
- EMC is a clear nuclear effect.
  - Can not be explained without bound nucleon structure modification.
- Temporal Short-Range Correlations exist in nuclei and lead to high virtuality nucleon.
  - Should contain a non-nucleonic component
- EMC and SRC are connected phenomenology and via several theoretical models due to their high virtuality.
  - Only (?) models that can self consistently explain all available data.
  - Effect is in the amplitude – 15% modification can come from 1% probability!
- Need an experimental test!
  - See approved JLab12 tagging program + EIC concepts.

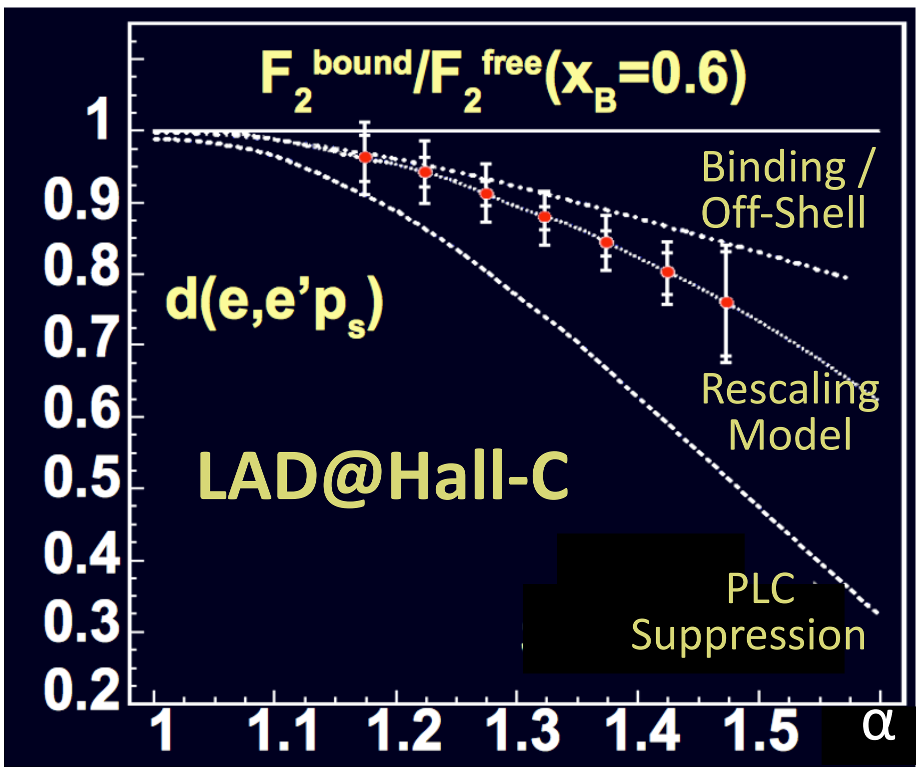
Test of Bound Nucleon Modification?

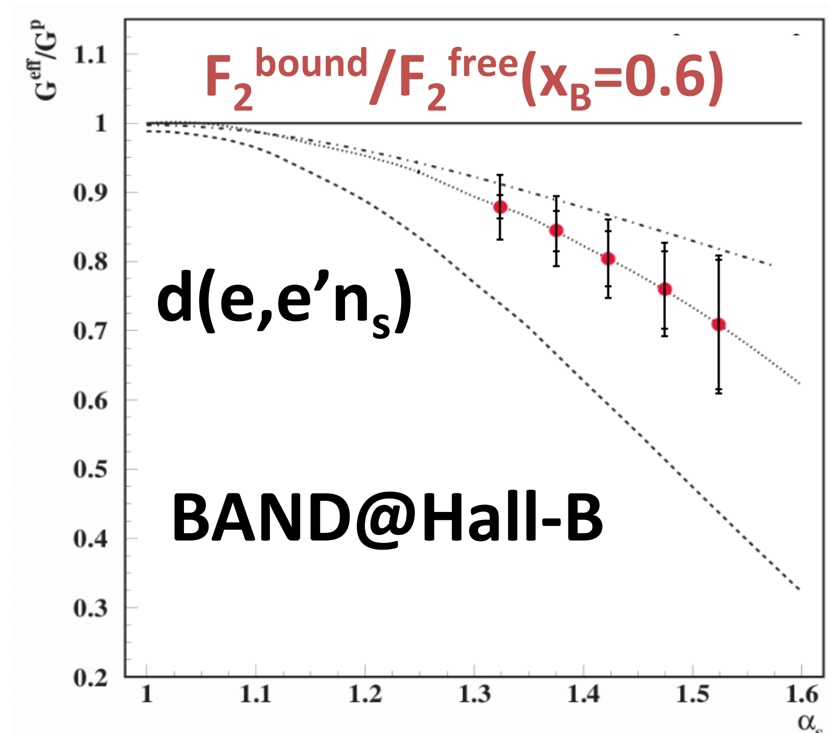
Focus on the deuteron:

(1) Perform DIS off forward going nucleon.

(2) Infer its momentum from the recoil partner.

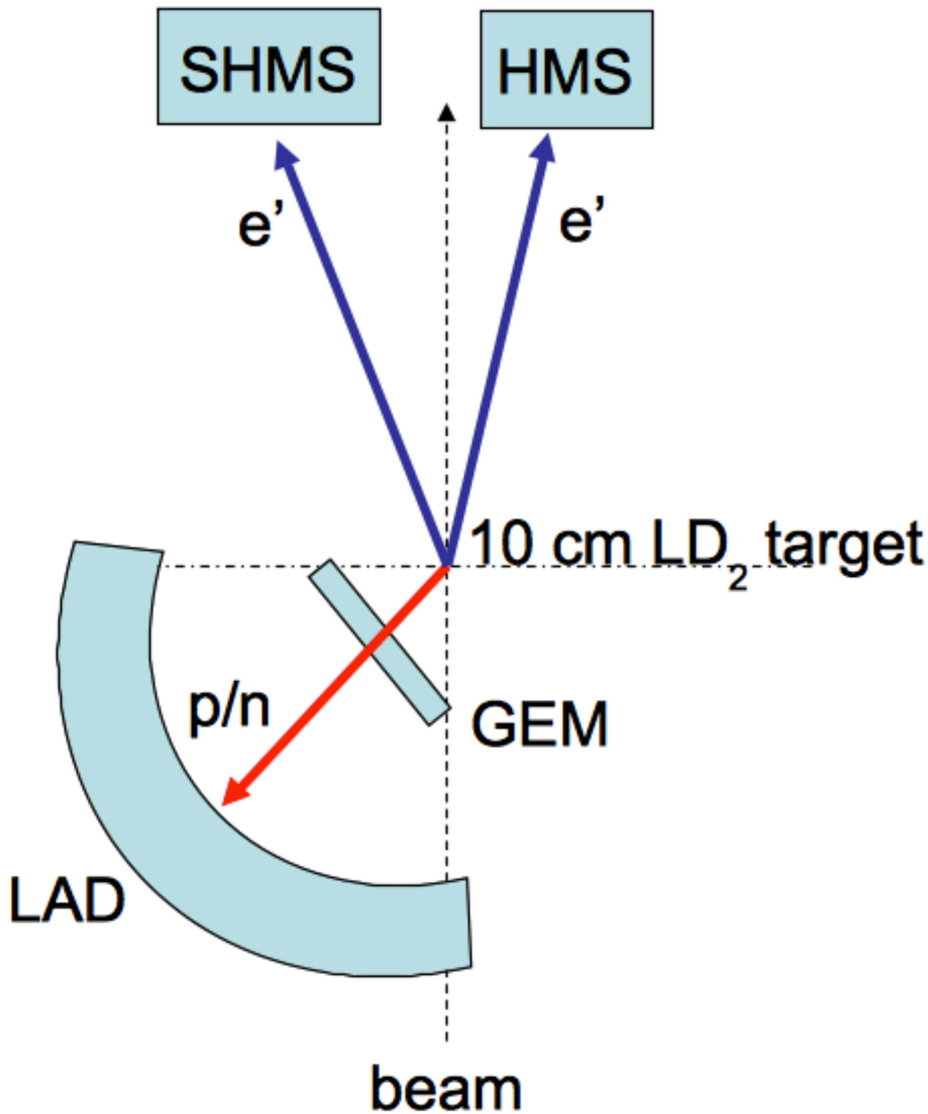






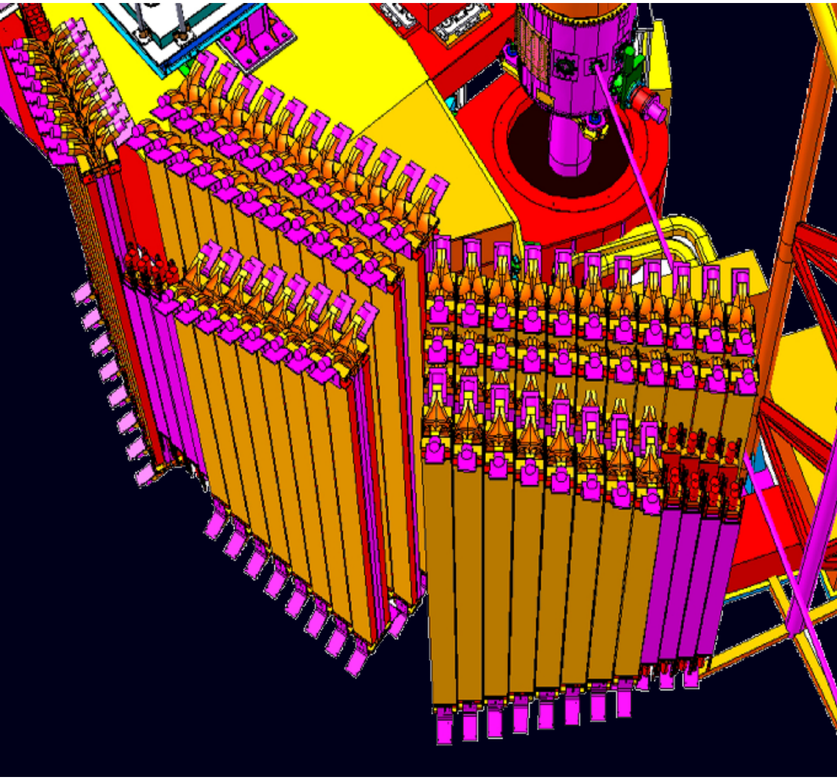
Melnitchouk et al., Z. Phys. A **359**, 99-109 (1997)

Tagging Concept d(e,e'N_{recoil})

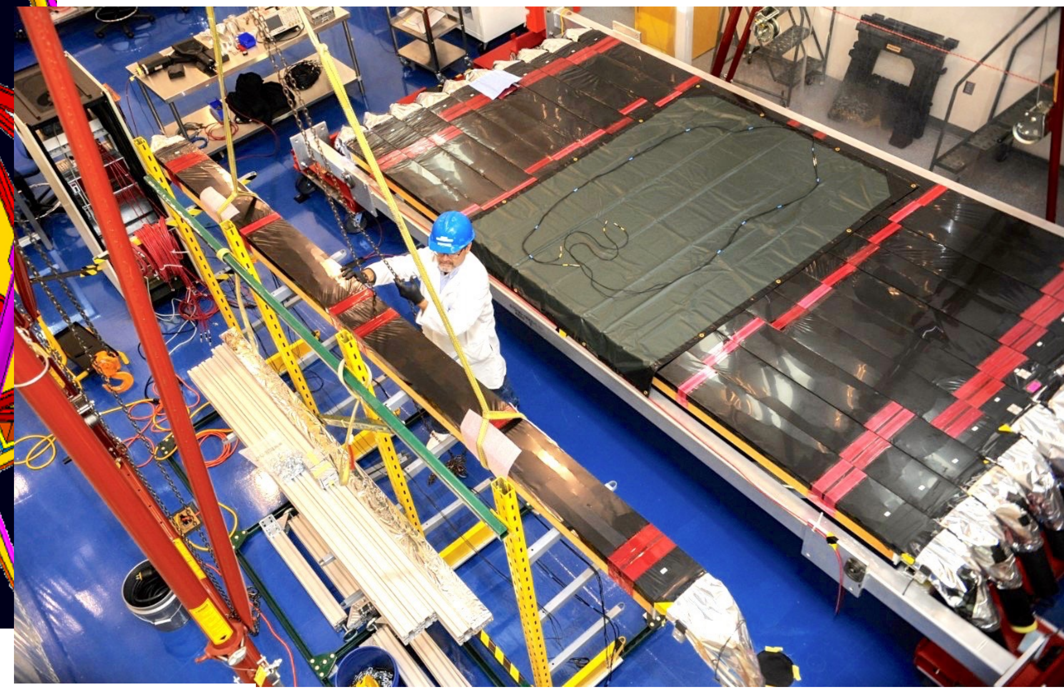


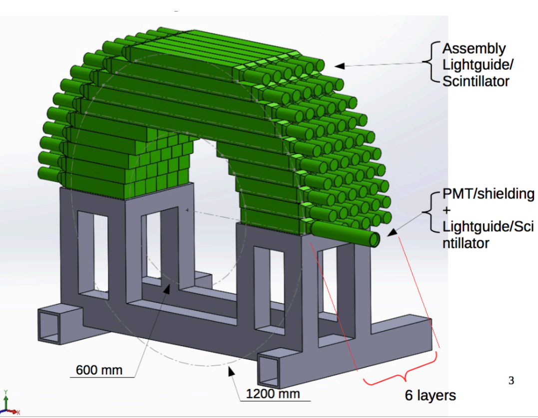
- High resolution spectrometers for (e,e') measurement in DIS kinematics
- Large acceptance recoil proton \ neutron detector
- Long target + GEM detector – reduce random coincidence

Building Large-Acceptance Detectors

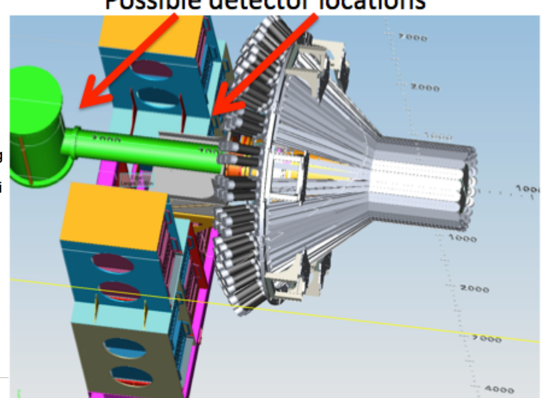


Large Acceptance Detector (LAD@Hall-C)





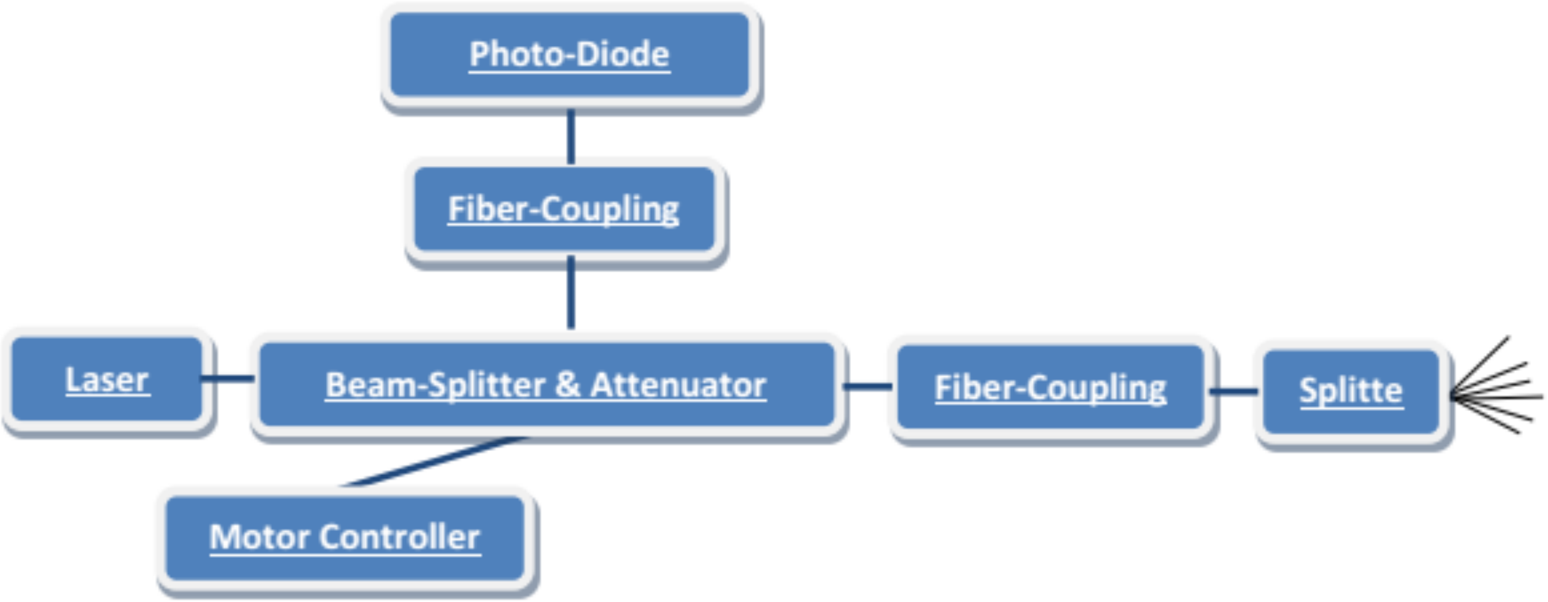
Possible detector locations

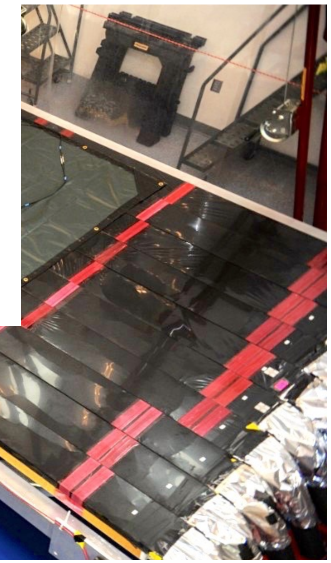


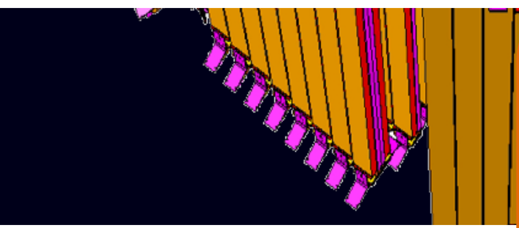
Backward Angle Neutron Detector (BAND@Hall-B)

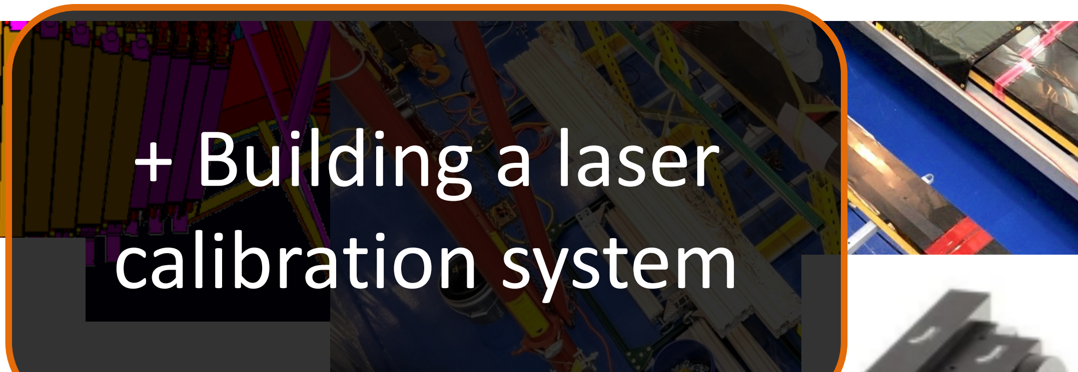
R&D @ MIT / UTSM / TAU
Construction @ BATES

ɔrs





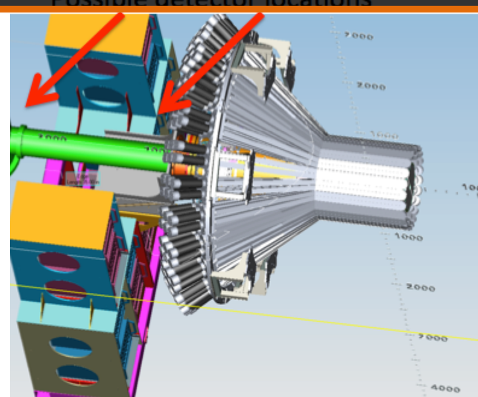




+ Building a laser calibration system

Possible detector locations

Fig 2: Standa STA-01-TH Laser



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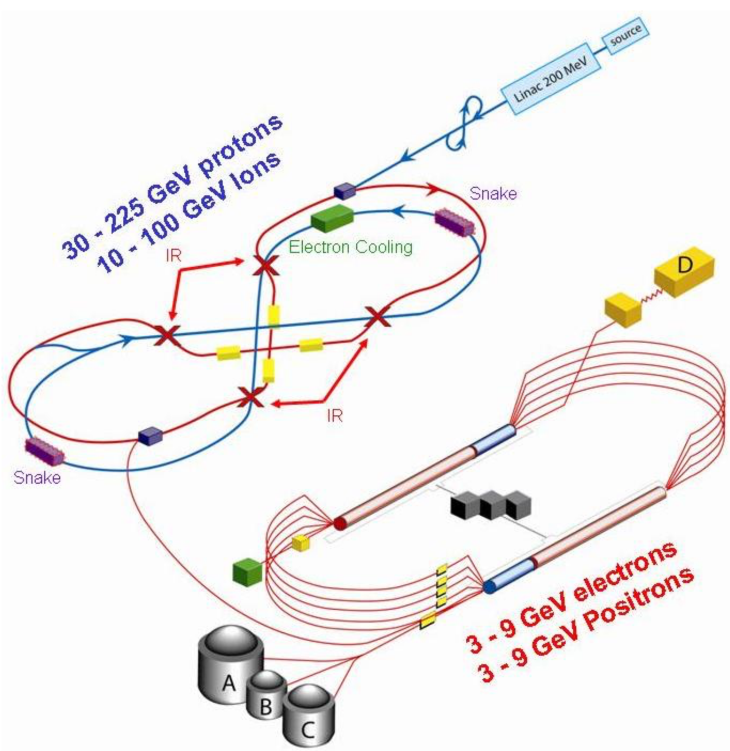
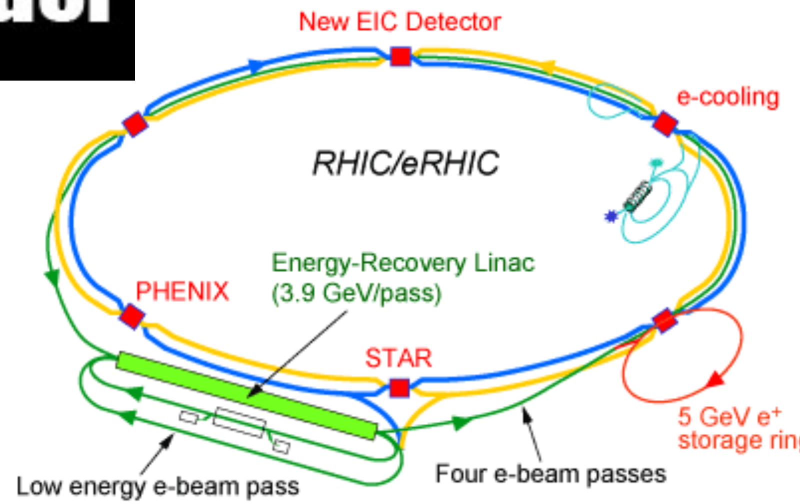
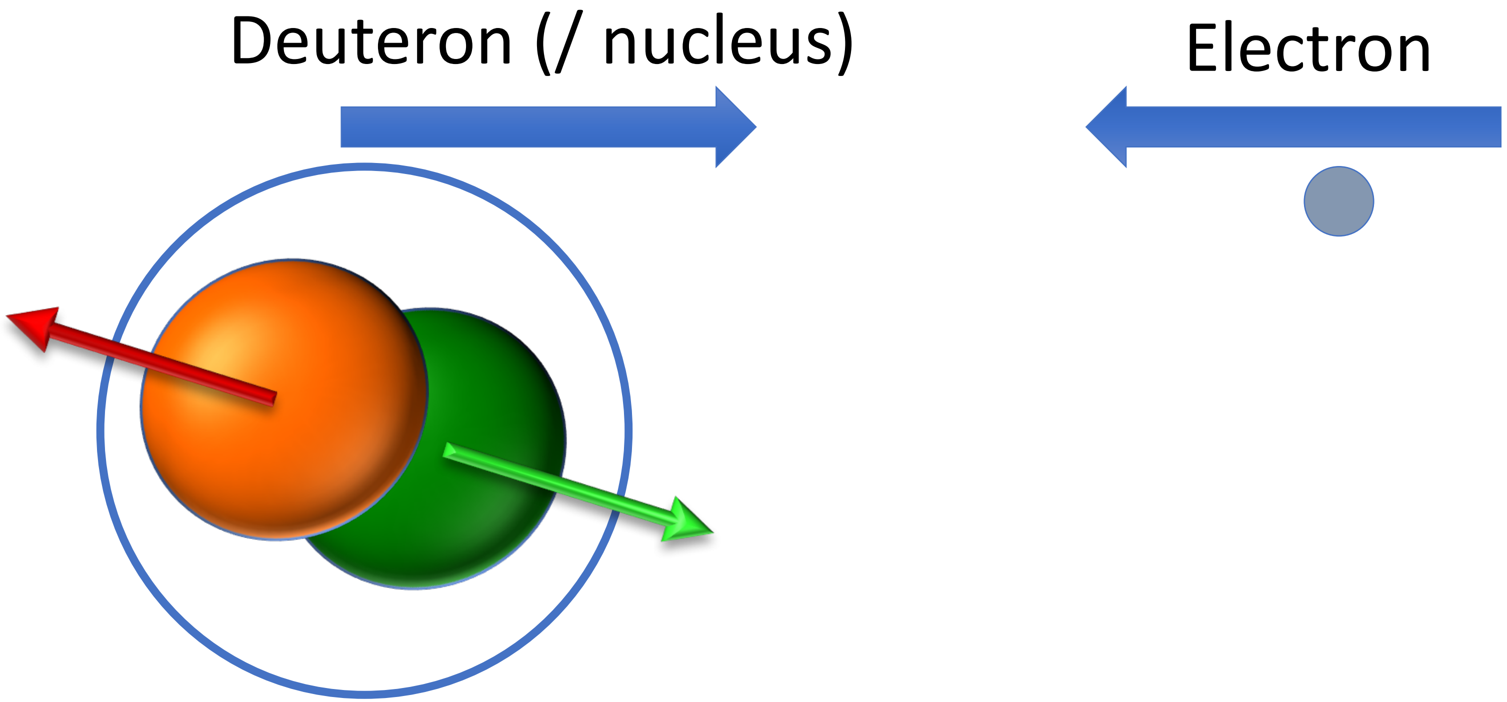
Beyond JLab12: EIC





** Your Design Here? **

Collider Concept



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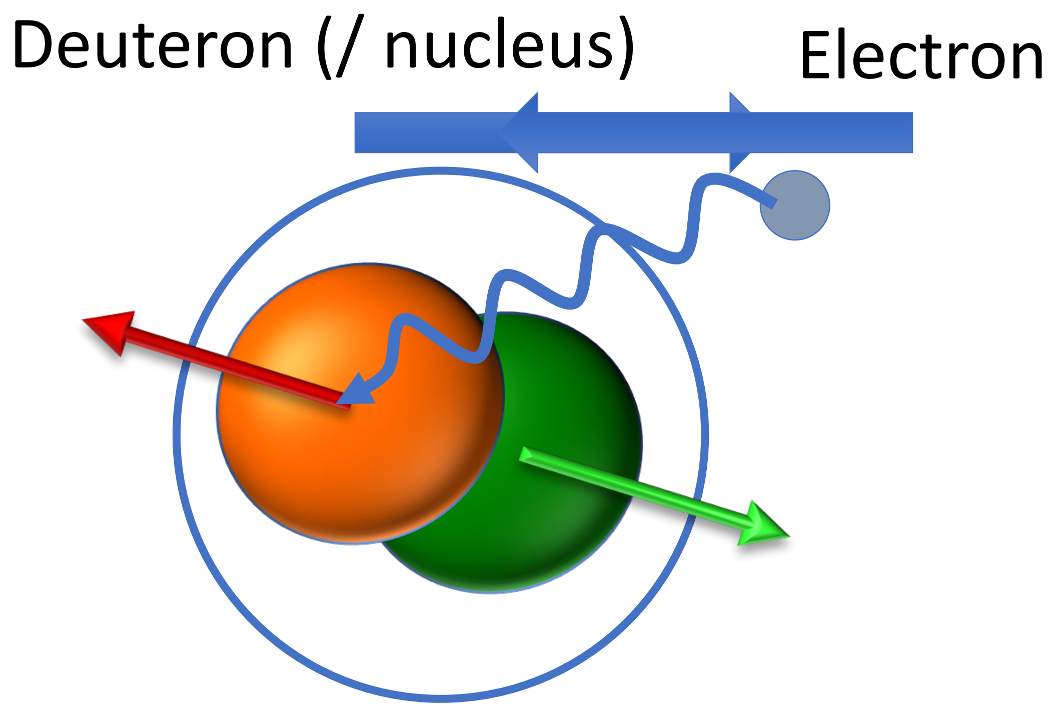

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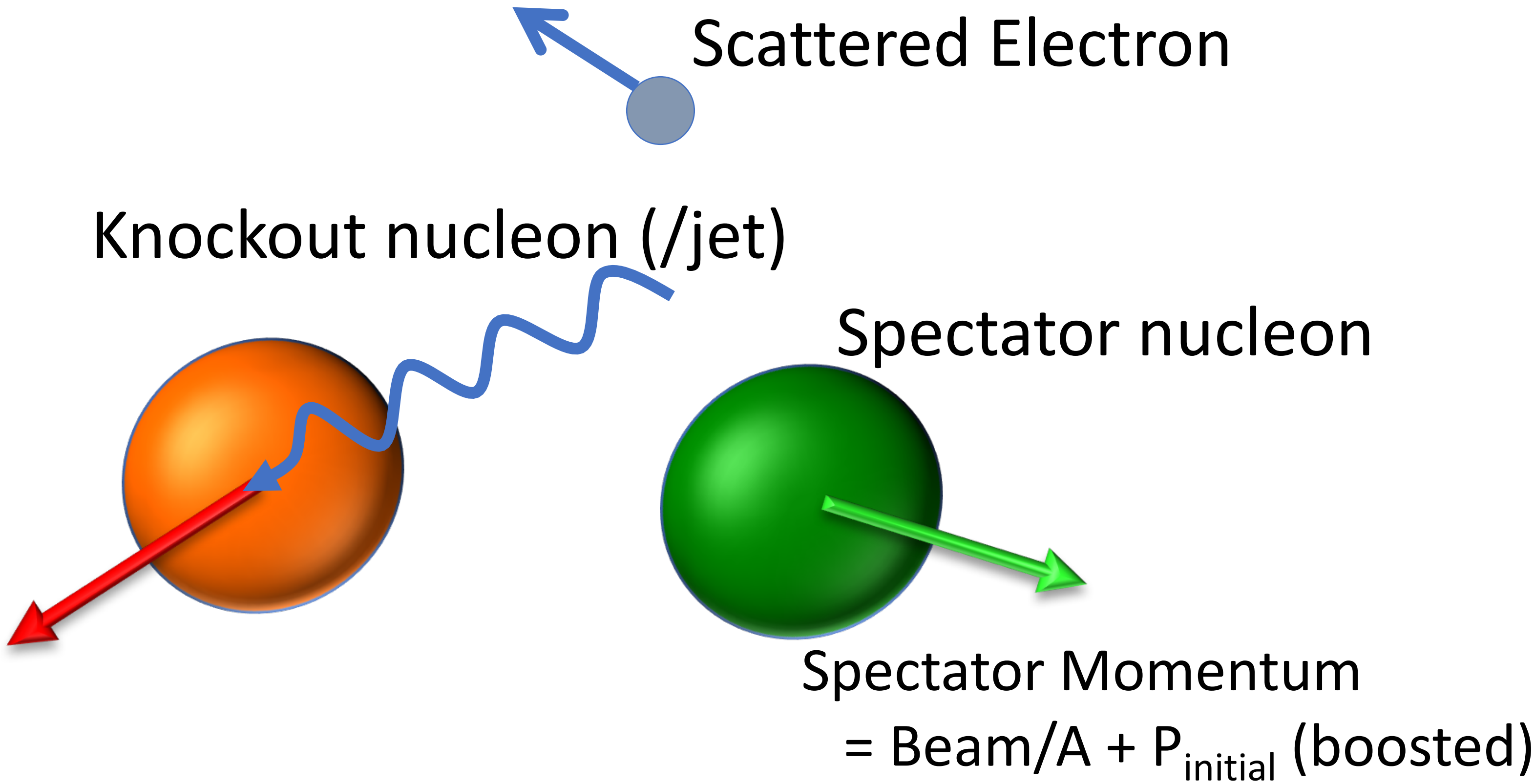
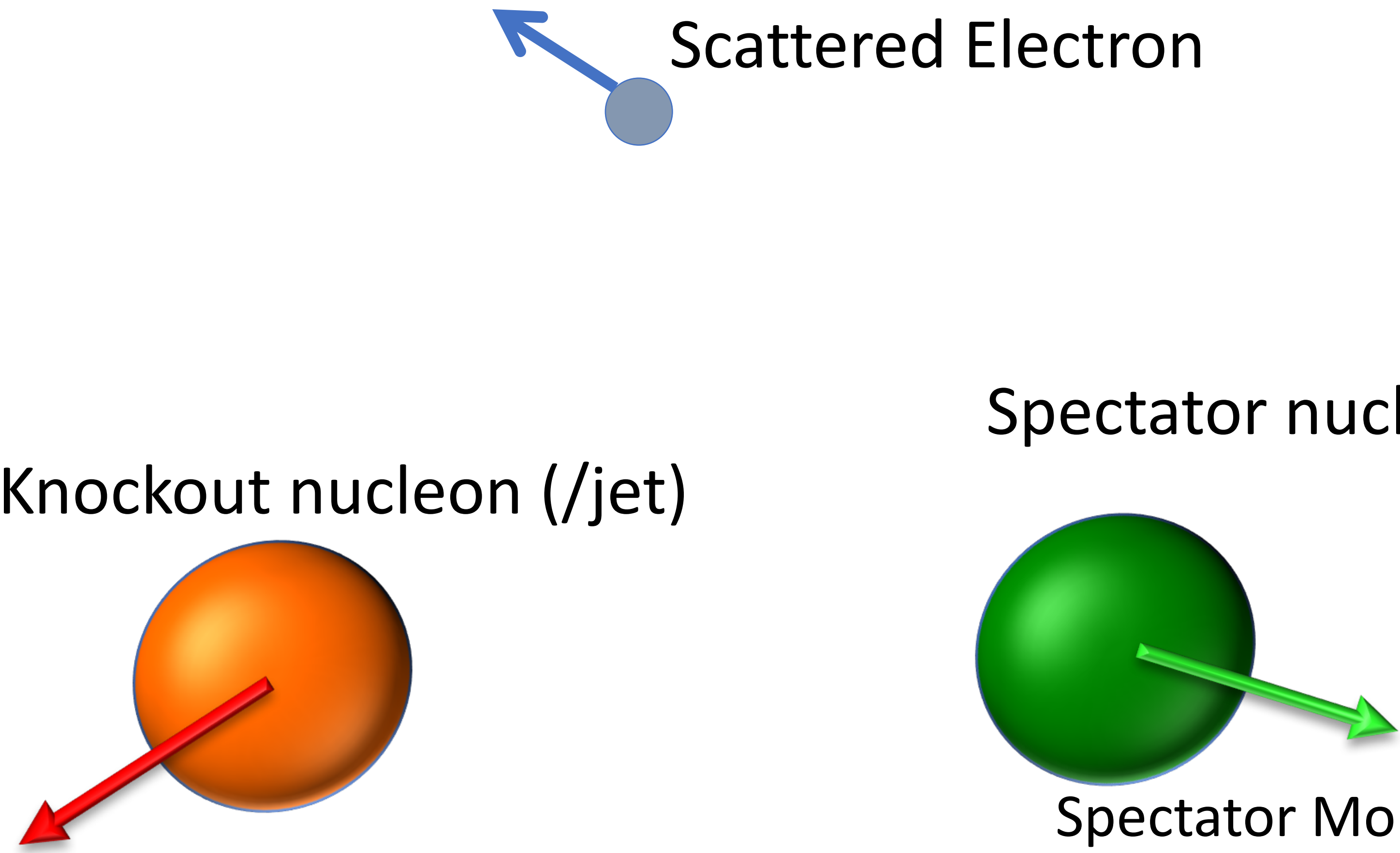


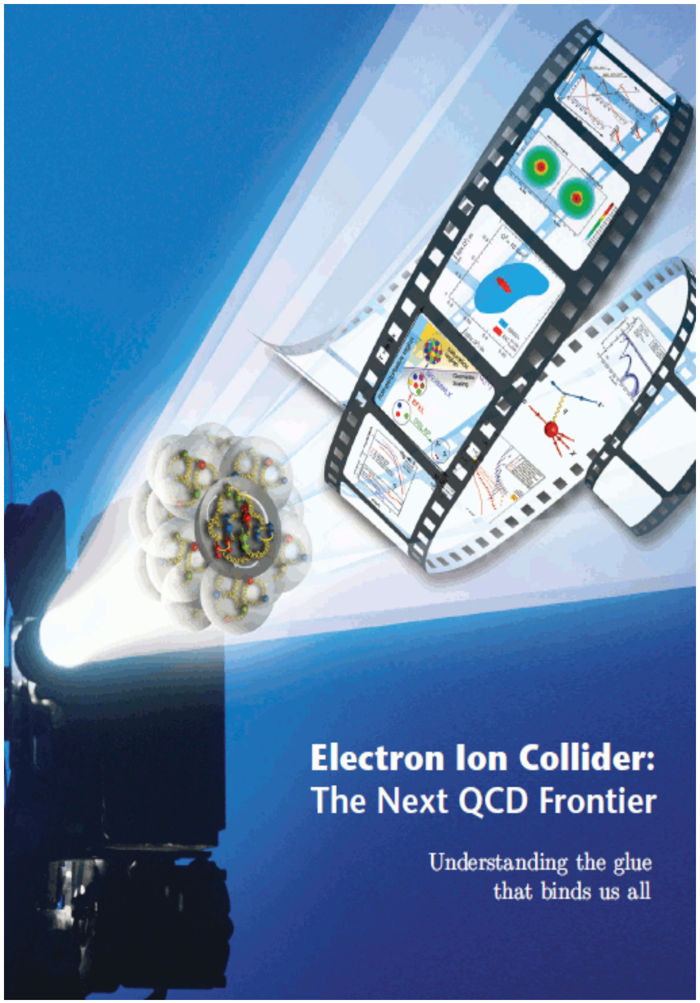
Collider Concept



Correlations Signature:

Large Spectator momentum

Collider Kinematics



Spectator Momentum

100 GeV d: $\gamma = 50$

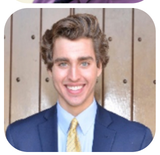
Center of Mass		Lab	
P_z (CM) GeV/c	P_{perp} (CM) GeV/c	P_z (Lab) GeV/c	θ_p (Lab)
0	0	50	0
0.2	0	41	0
0.4	0	34	0
0.6	0	28	0
0.6	0.2	29	0.007
0.6	0.6	36	0.02

The Correlations group

- **MIT (Or Hen):**


Barak Schmookler


Reynier Torres


Efrain Segarra


Afroditi Papadopoulou

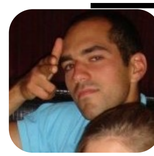

Axel Schmidt


George Laskaris


Maria Patsyuk


Taofeng Wang

- **TAU (Eli Piasetzky):**


Erez Cohen


Meytal Duer


Igor Korover


Adi Ashkenazy

- **ODU (Larry Weinstein):**


Mariana Khachatryan


Florian Hauenstein

- **Theory Collaborators (lots!)**