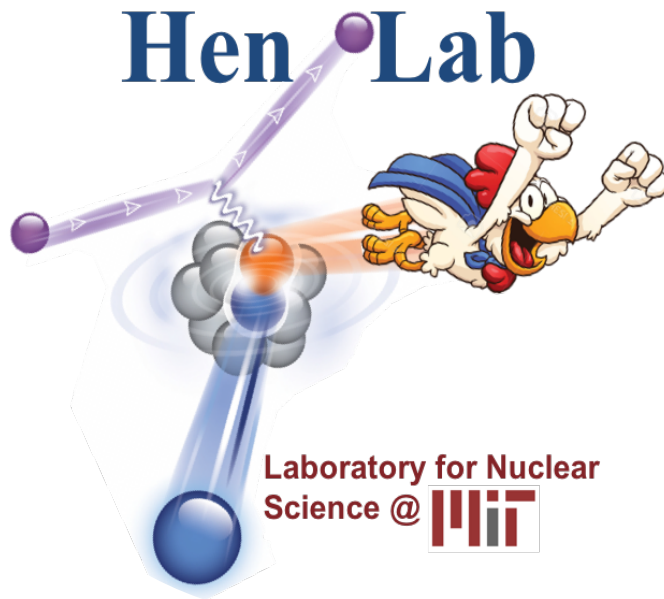


MIT Involvement and Physics Program for CLAS12

Or Hen
MIT





Background for this talk



- I recently moved from Tel-Aviv to MIT where I'm starting a new nuclear physics research group.
- While personally active in CLAS for several years, MIT and myself are not full members of CLAS.
- As we have several ongoing data-mining analysis + approved CLAS12 proposal + plans for more proposals I figured it's time to **officially join CLAS**.
- This talk is an 'official' part of the petitioning process.

Hope you will review our petition in favor!



Who Are We?



- MIT (Or Hen):



Barak Schmookler



Reynier Torres



Efrain Segarra



Afroditi Papadopoulou



Axel Schmidt



George Laskaris



Maria Patsyuk



Taofeng Wang (*visiting scientist)

- TAU (Eli Piassetzky):



Erez Cohen



Meytal Duer



Igor Korover



Adi Ashkenazy

- ODU (Larry Weinstein):



Mariana Khachatryan



Florian Hauenstein

- Theory Collaborators (lots!)



Who Are We?



- MIT (Or Hen):



Barak Schmookler



Reynier Torres



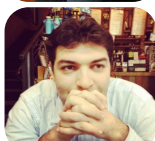
Efrain Segarra



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Axel Schmidt



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Maria Patsyuk



Taofeng Wang (*visiting scientist)

- TAU (Eli Piassetzky):



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Igor Korover



Adi Ashkenazy

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Mariana Khachatryan



Florian Hauenstein

- Theory Collaborators (lots!)

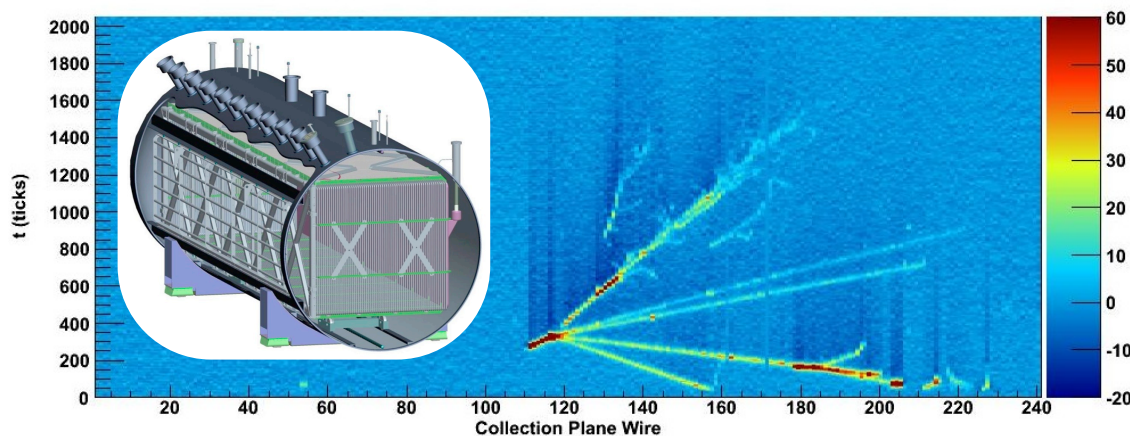
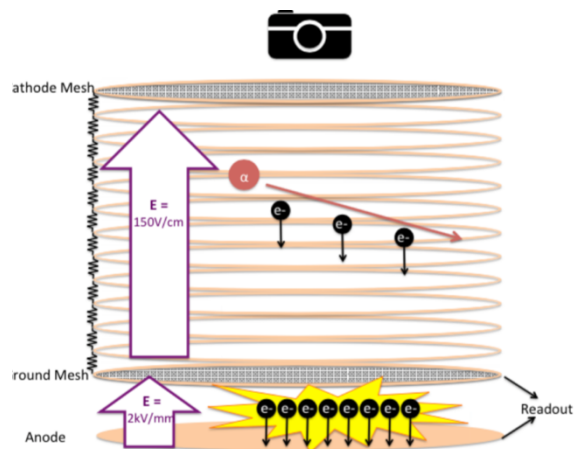
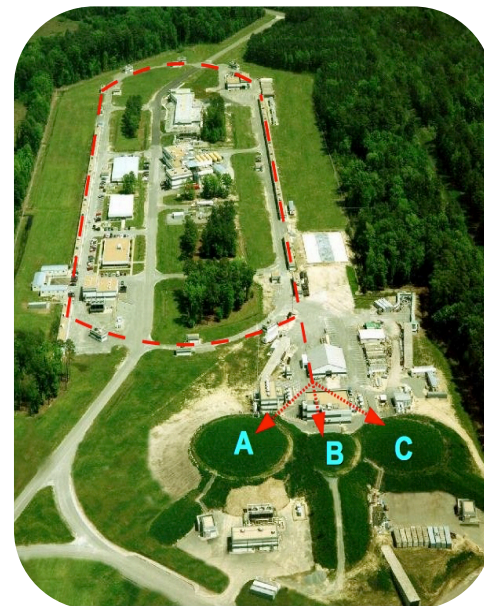
Active
in CLAS



What do we do?



1. Nuclear Structure (JLab / GSI).
+ Phenomenology.
+ Neutron Detectors.
2. Neutrino-Nucleus Interactions (Fermilab).
3. Tabletop Standard Model Tests (MIT).





What do we do?



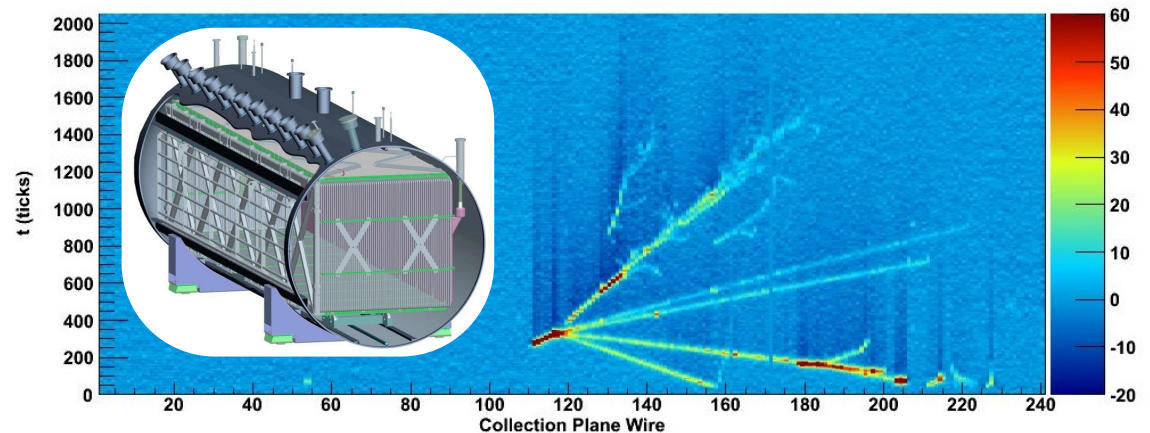
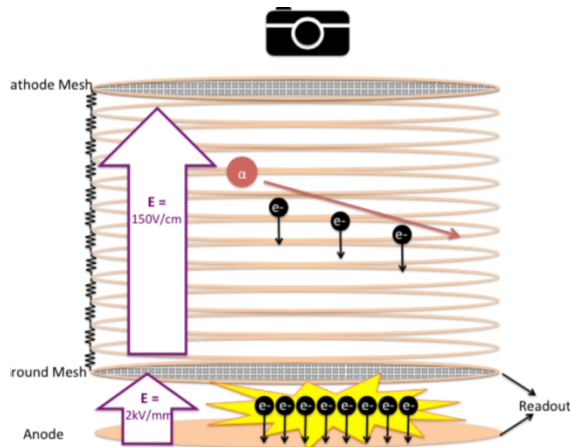
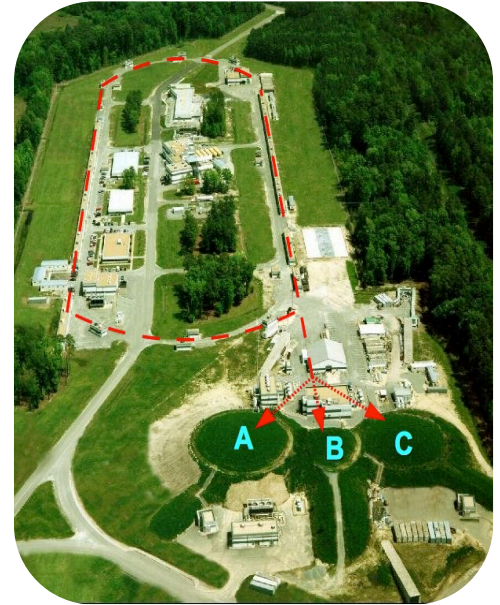
1. Nuclear Structure (JLab / GSI).

+ Phenomenology.

+ **Neutron Detectors.**

2. Neutrino-Nucleus Interactions (Fermilab).

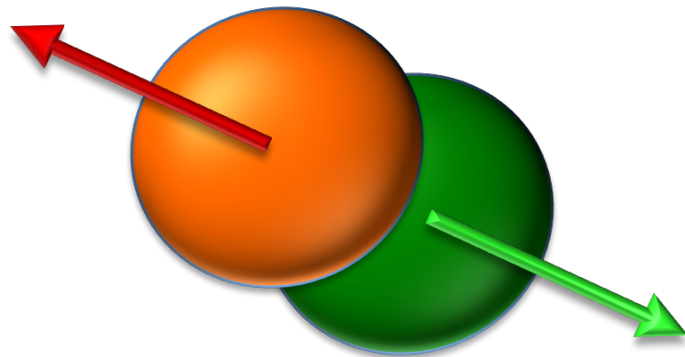
3. Tabletop Standard Model Tests (MIT).





Looking for nucleon pairs 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)



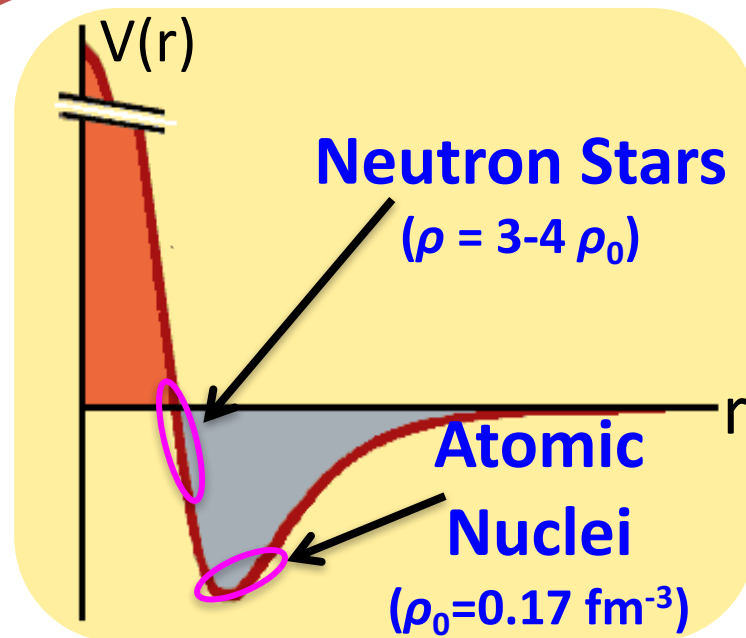


Studying High-Momentum Nucleons



Nuclear Physics

Better understanding of the nucleon-nucleon interaction and the nuclear momentum distribution



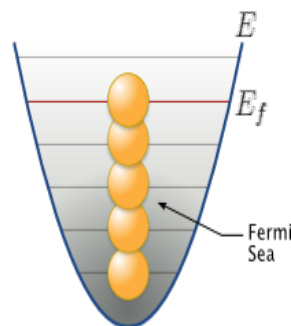


Studying High-Momentum Nucleons

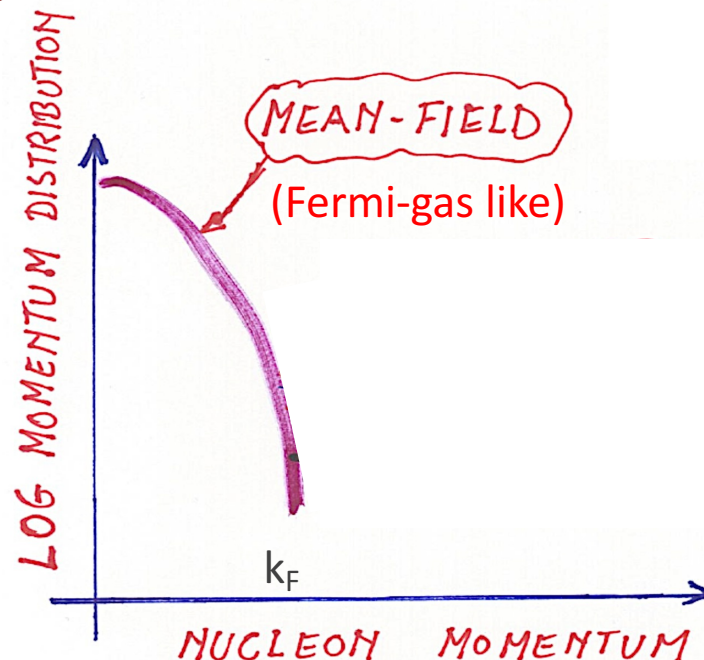


Nuclear Physics

Better understanding of the
nucleon-nucleon interaction and the
nuclear momentum distribution



Cold fermions



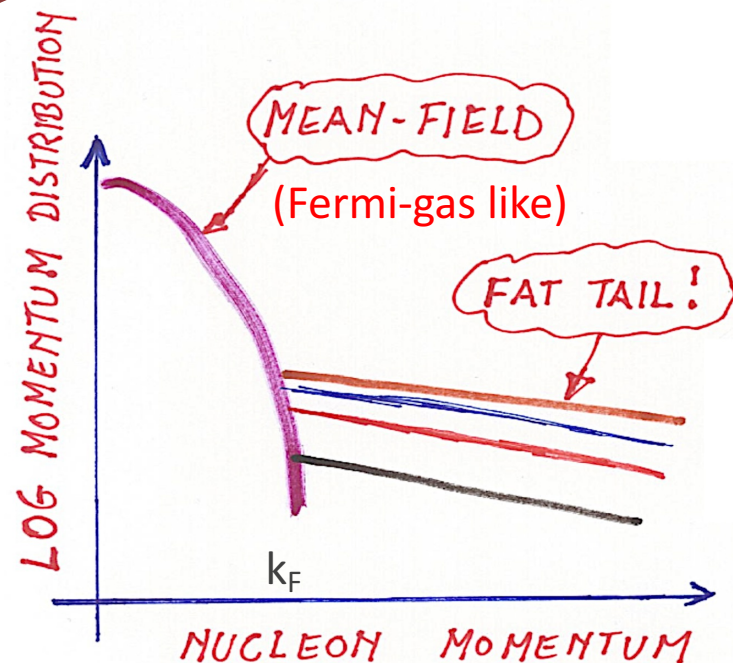
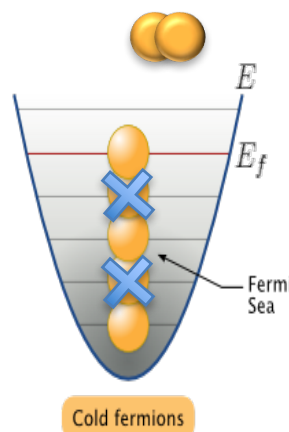


Studying High-Momentum Nucleons



Nuclear Physics

Better understanding of the
nucleon-nucleon interaction and the
nuclear momentum distribution

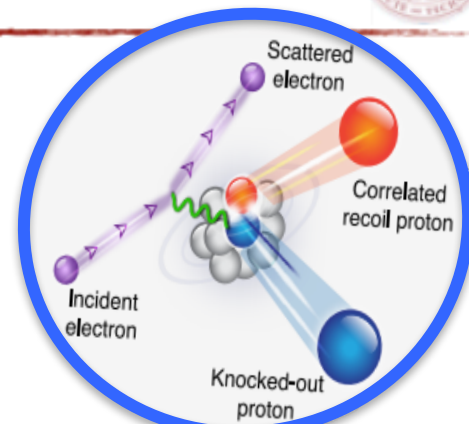




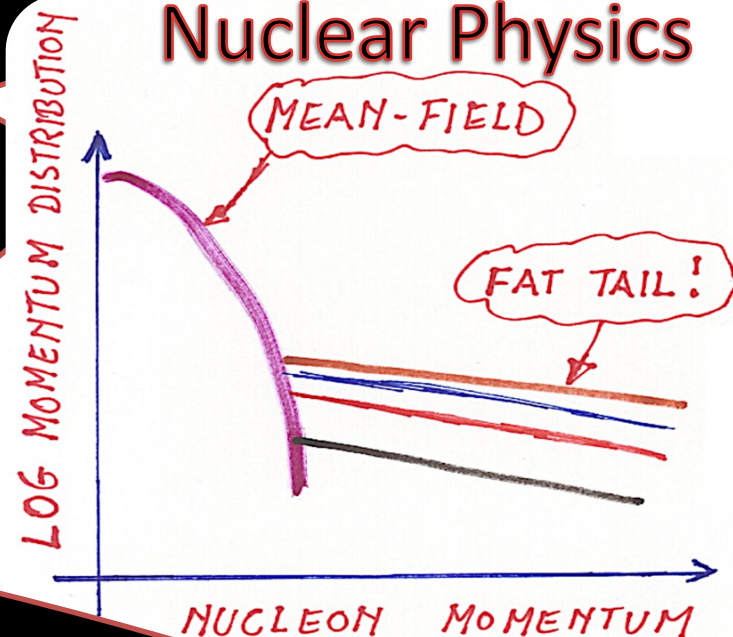
Studying High-Momentum Nucleons



Particle Physics



Nuclear Physics



The EMC Effect.
Neutrino-Nucleus Scattering.
The NuTeV Anomaly.

Astrophysics

Neutron Stars.
Nuclear Symmetry Energy.

Energy Sharing in Imbalanced Fermi Systems.
Contact Interaction in Universal Fermi Systems.

Quantum / Atomic
Physics



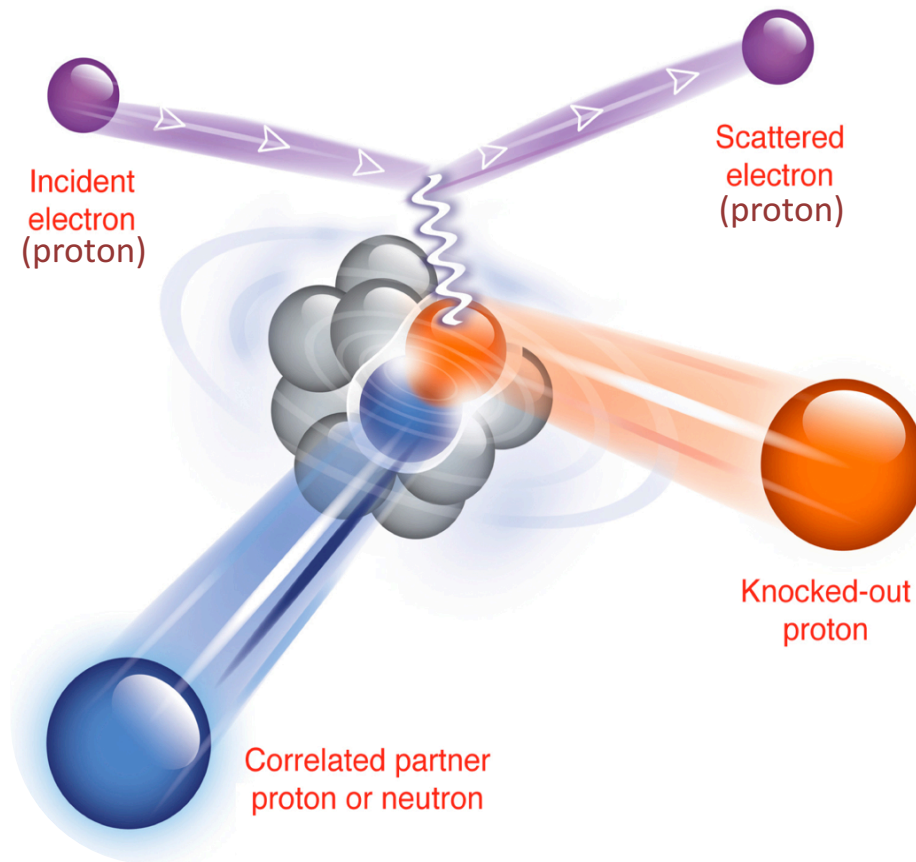
Exclusive 2N-SRC Studies



Breakup the pair =>

Detect both nucleons =>

Reconstruct 'initial' state

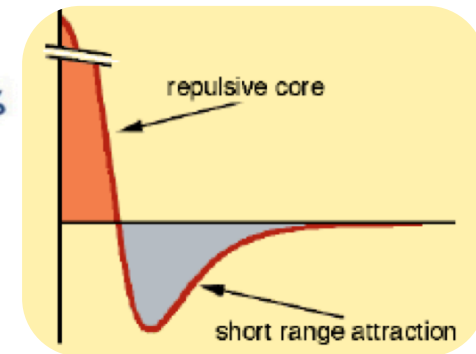
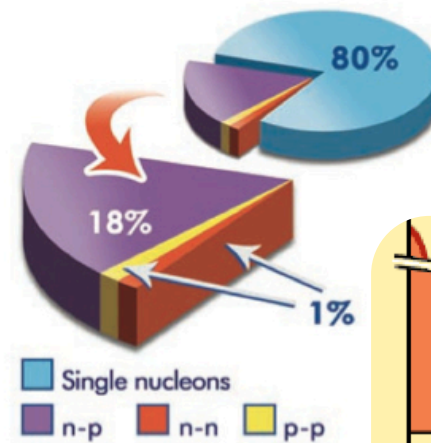
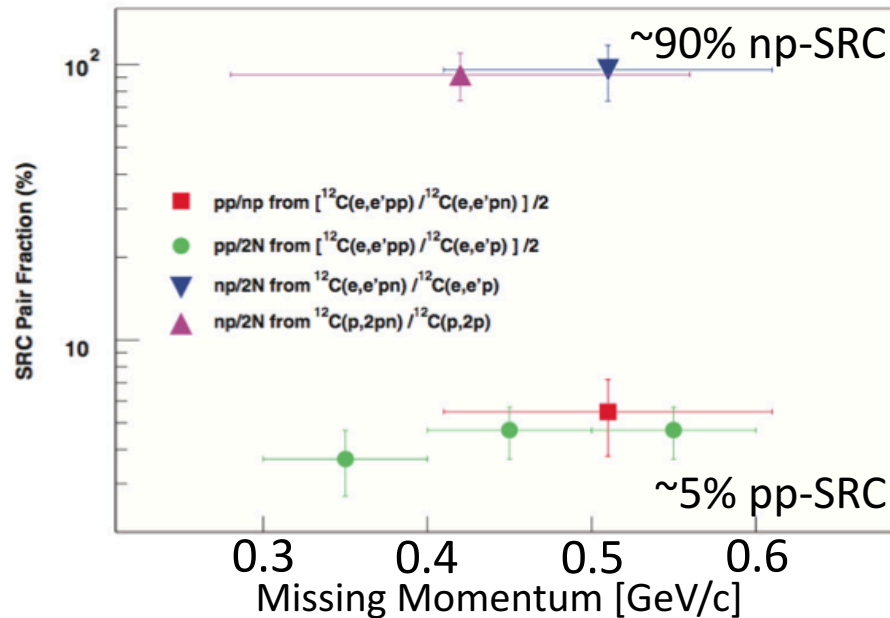




1st Gen, Hall-A / BNL (¹²C)



- Knockout high-initial-momentum proton, look for correlated nucleon partner.
- For $300 < P_{\text{miss}} < 600$ MeV/c all nucleons are part of 2N-SRC pairs: 90% np, 5% pp (nn).



A. Tang et al., Phys. Rev. Lett. 90 (2003) 042301
E. Piasetzky et al., Phys. Rev. Lett. 97 (2006) 162504

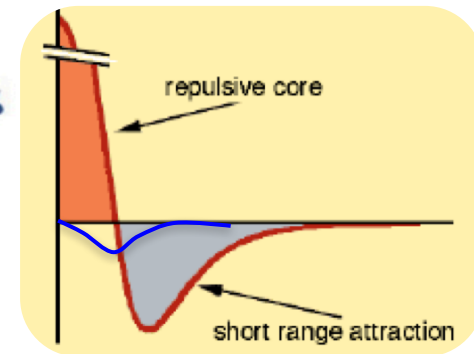
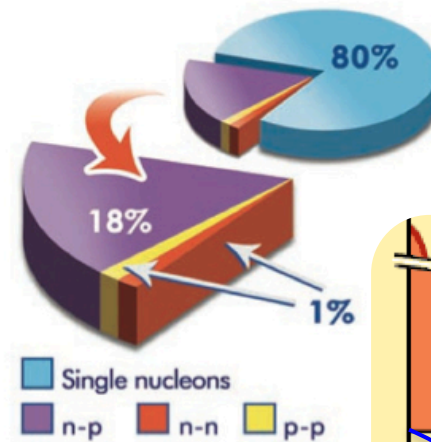
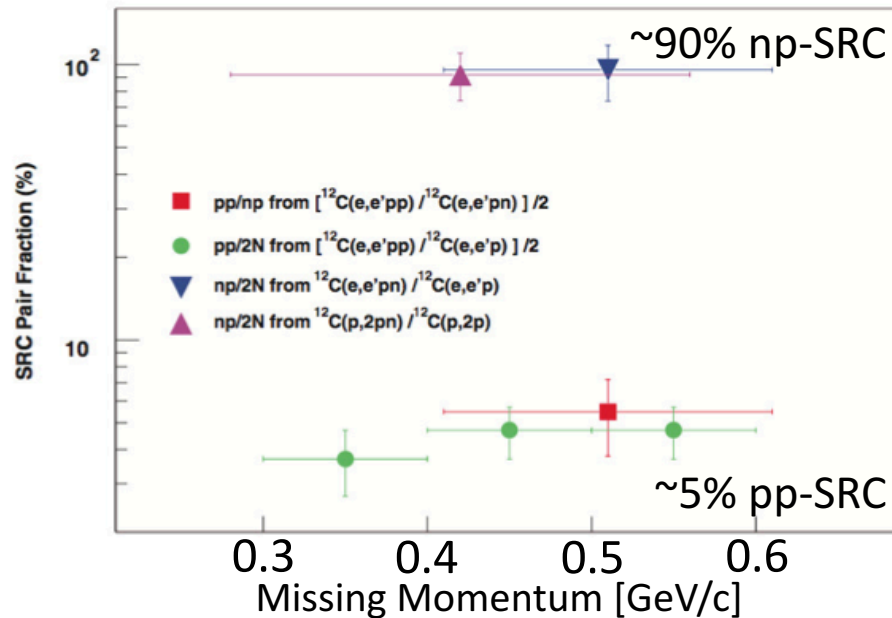
R. Shneor et al., Phys. Rev. Lett. 99 (2007) 072501
R. Subedi et al., Science 320 (2008) 1476



1st Gen, Hall-A / BNL (¹²C)



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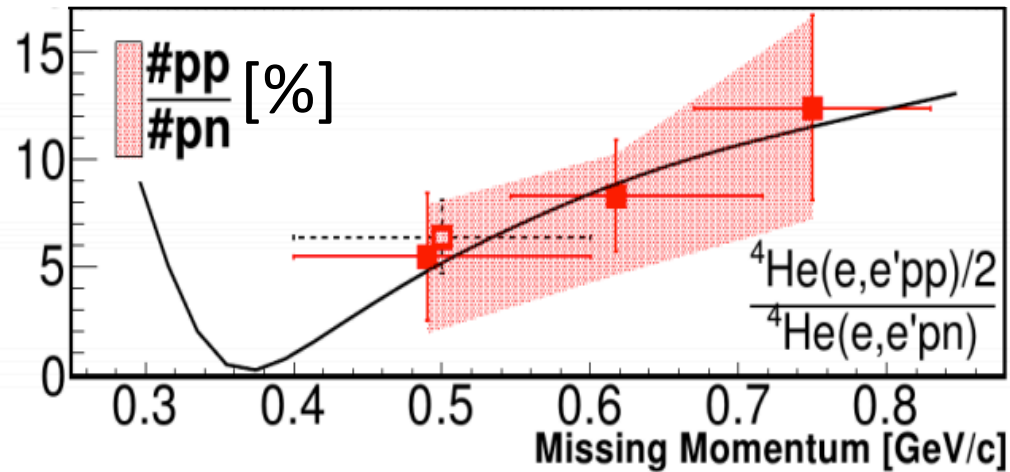


A. Tang et al., Phys. Rev. Lett. 90 (2003) 042301
E. Piasetzky et al., Phys. Rev. Lett. 97 (2006) 162504

R. Shneor et al., Phys. Rev. Lett. 99 (2007) 072501
R. Subedi et al., Science 320 (2008) 1476



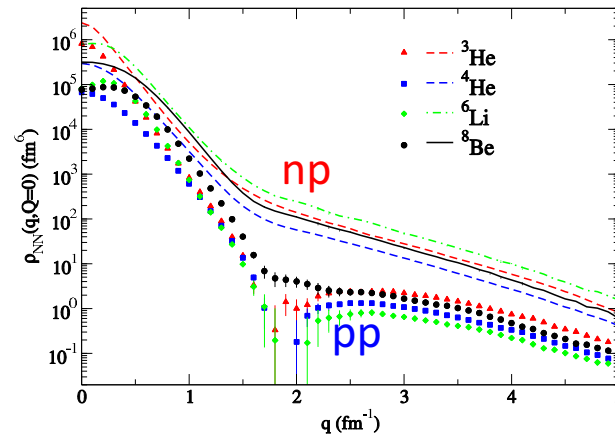
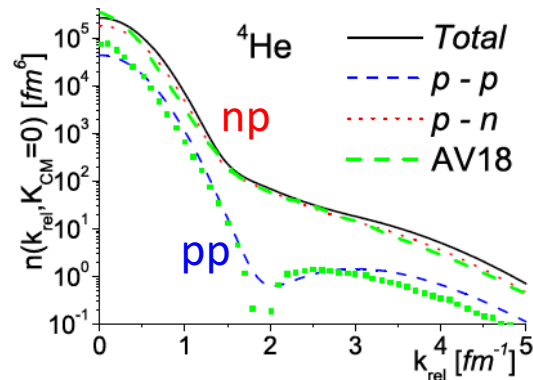
2nd Gen, Hall-A (⁴He)



I. Korover, N. Muangma, and O. Hen et al., Phys. Rev. Lett 113, 022501 (2014).

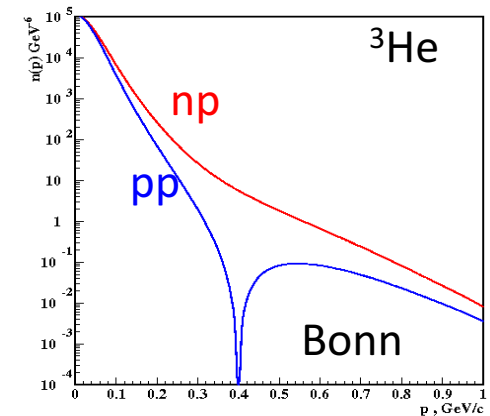
Pair density calculations:

Ciofi and Alvioli PRL 100, 162503 (2008)



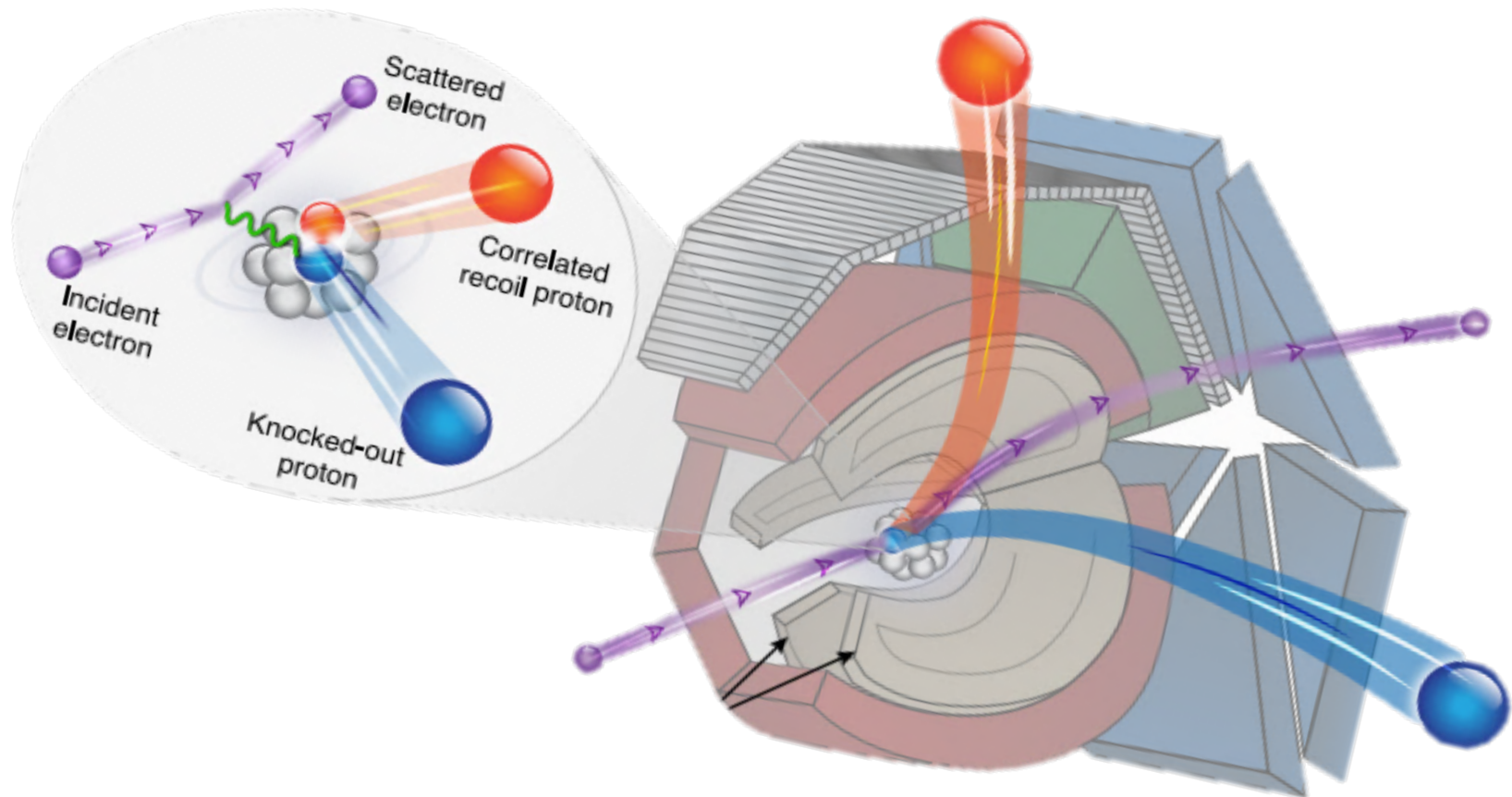
Schiavilla et al., PRL 98,132501 (2007)

Sargsian et al., PRC 71 044615 (2005)





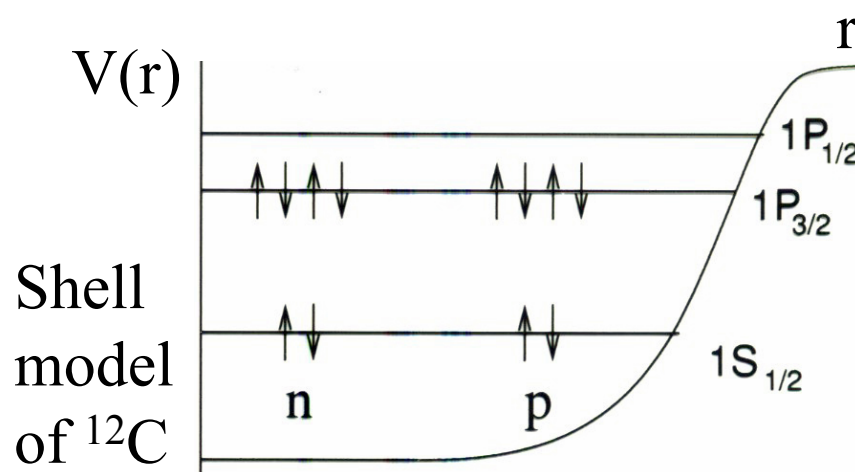
3rd Gen, Hall-B (Heavy Nuclei)





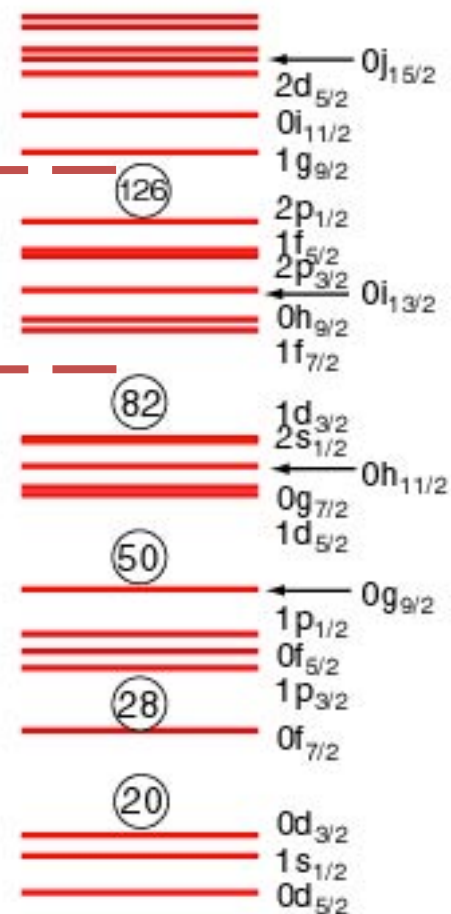
Correlations in Heavy Nuclei

- Bridging the gap between light nuclei and neutron stars?
- General properties of Fermionic systems?

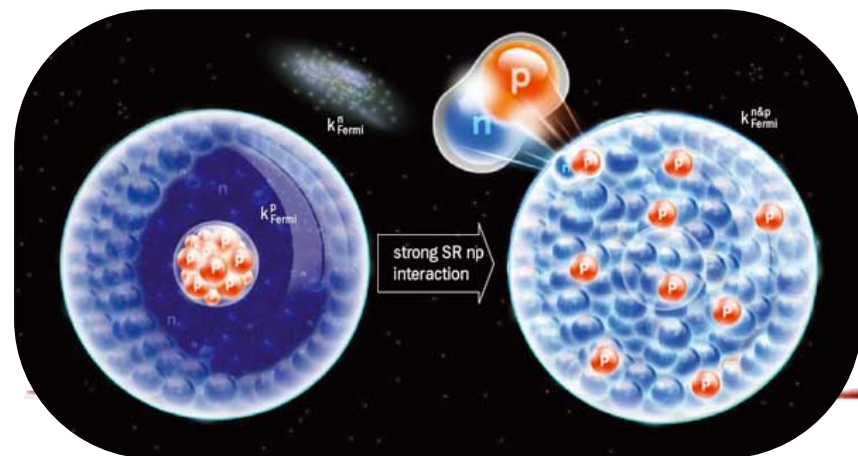
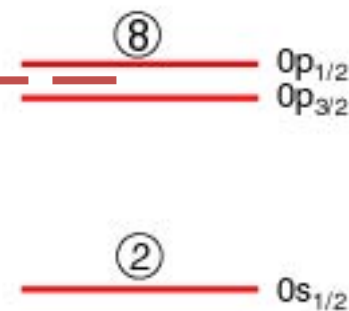


^{208}Pb (n)

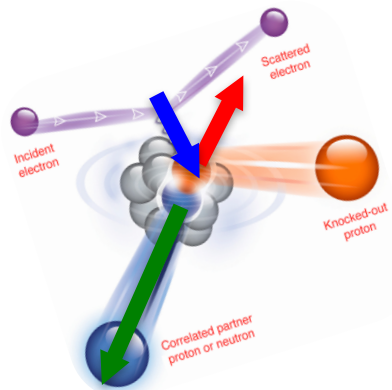
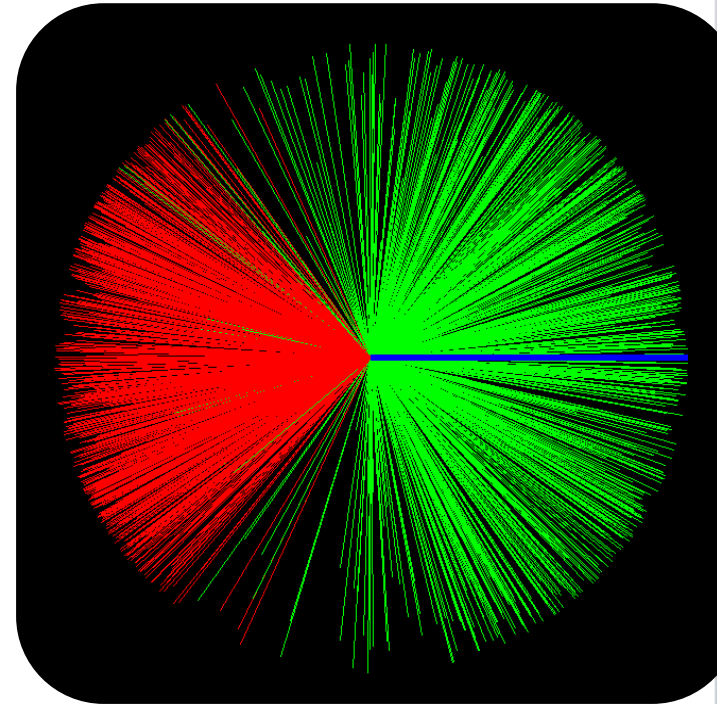
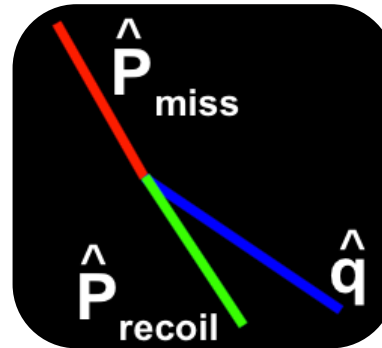
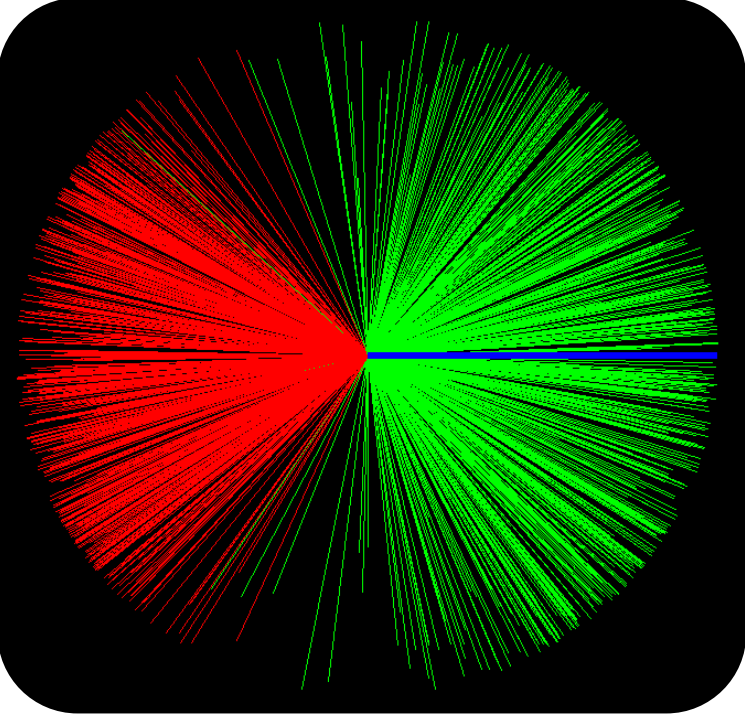
^{208}Pb (p)



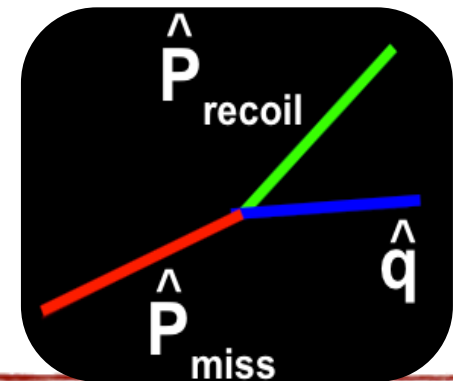
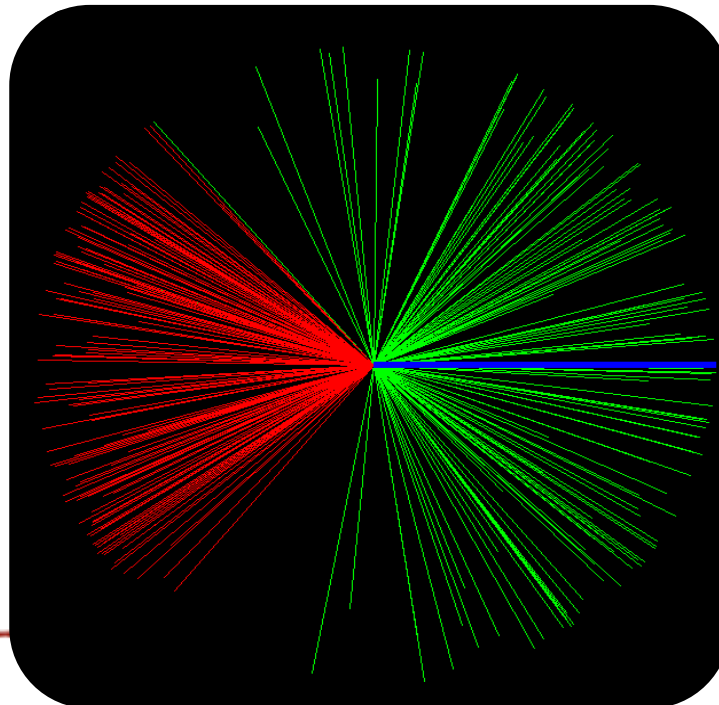
^{12}C (p,n)



3D Reconstruction

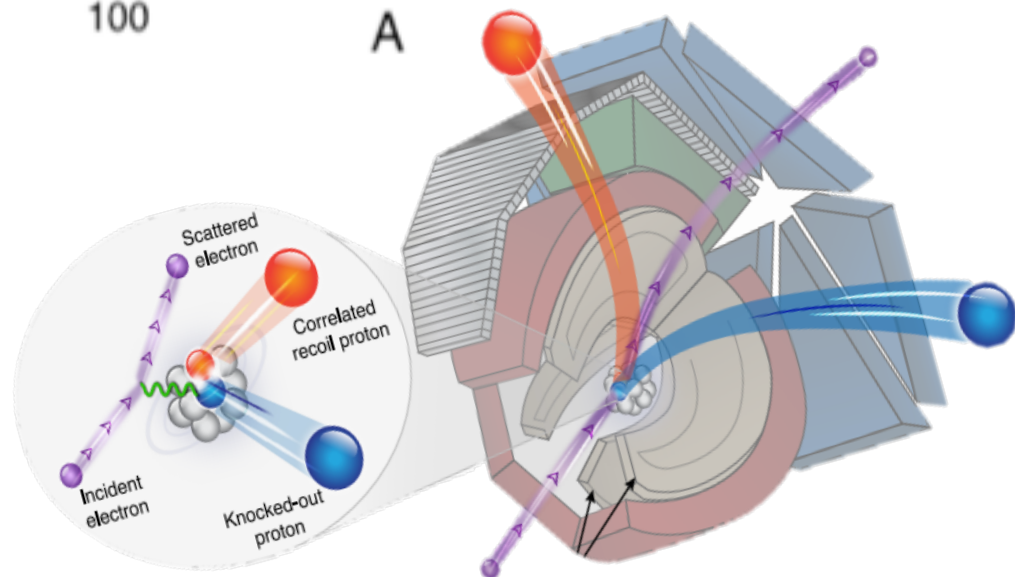
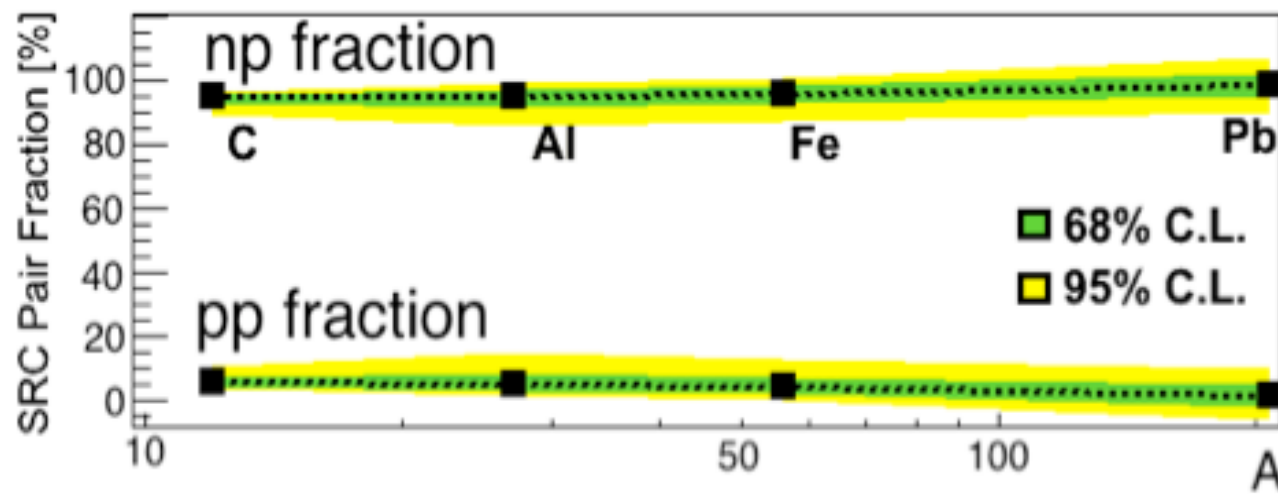


Back-to-back =
pairs!





np-SRC pair dominance in heavy nuclei



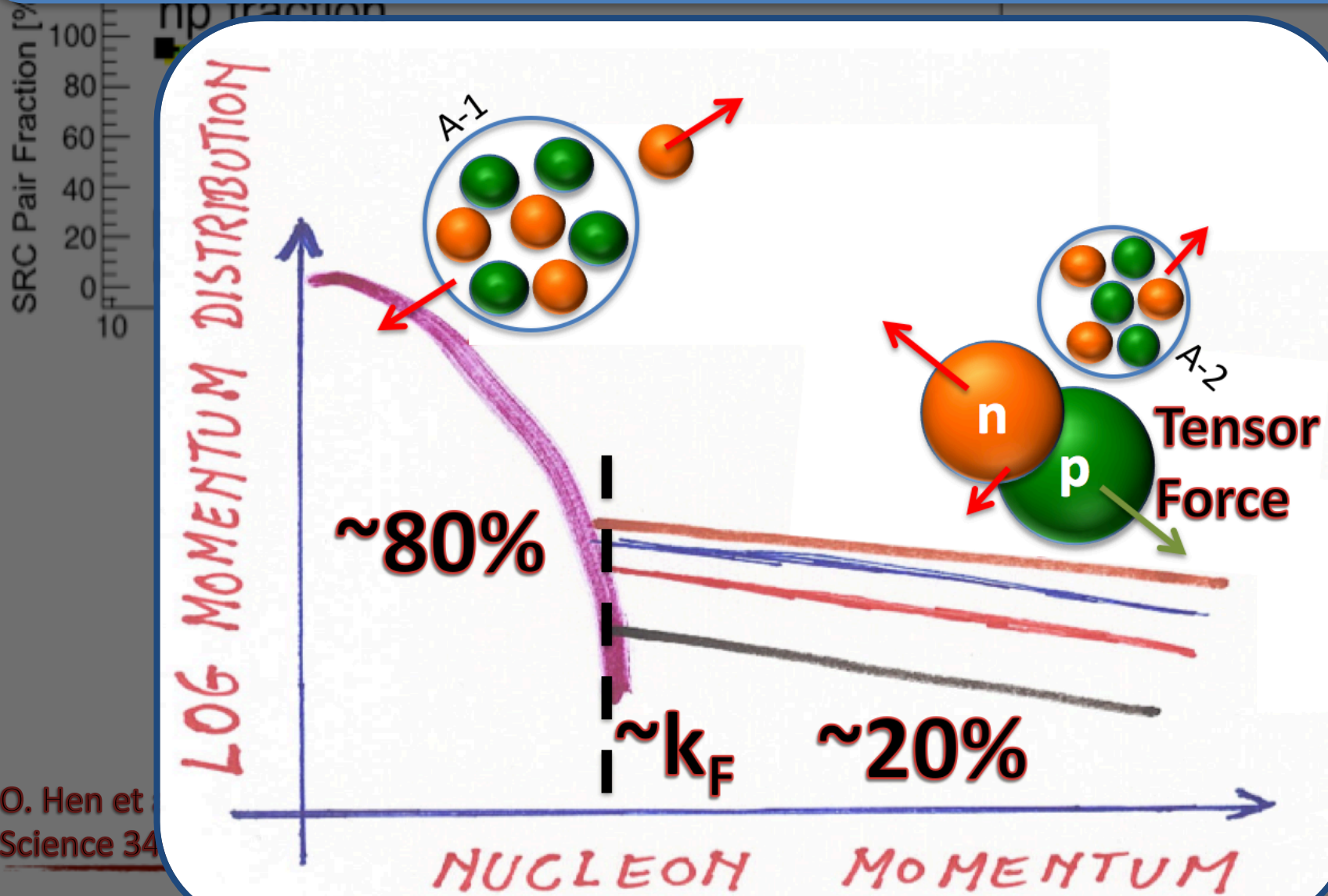
O. Hen et al. (CLAS Collaboration),
Science 346, 614 (2014)



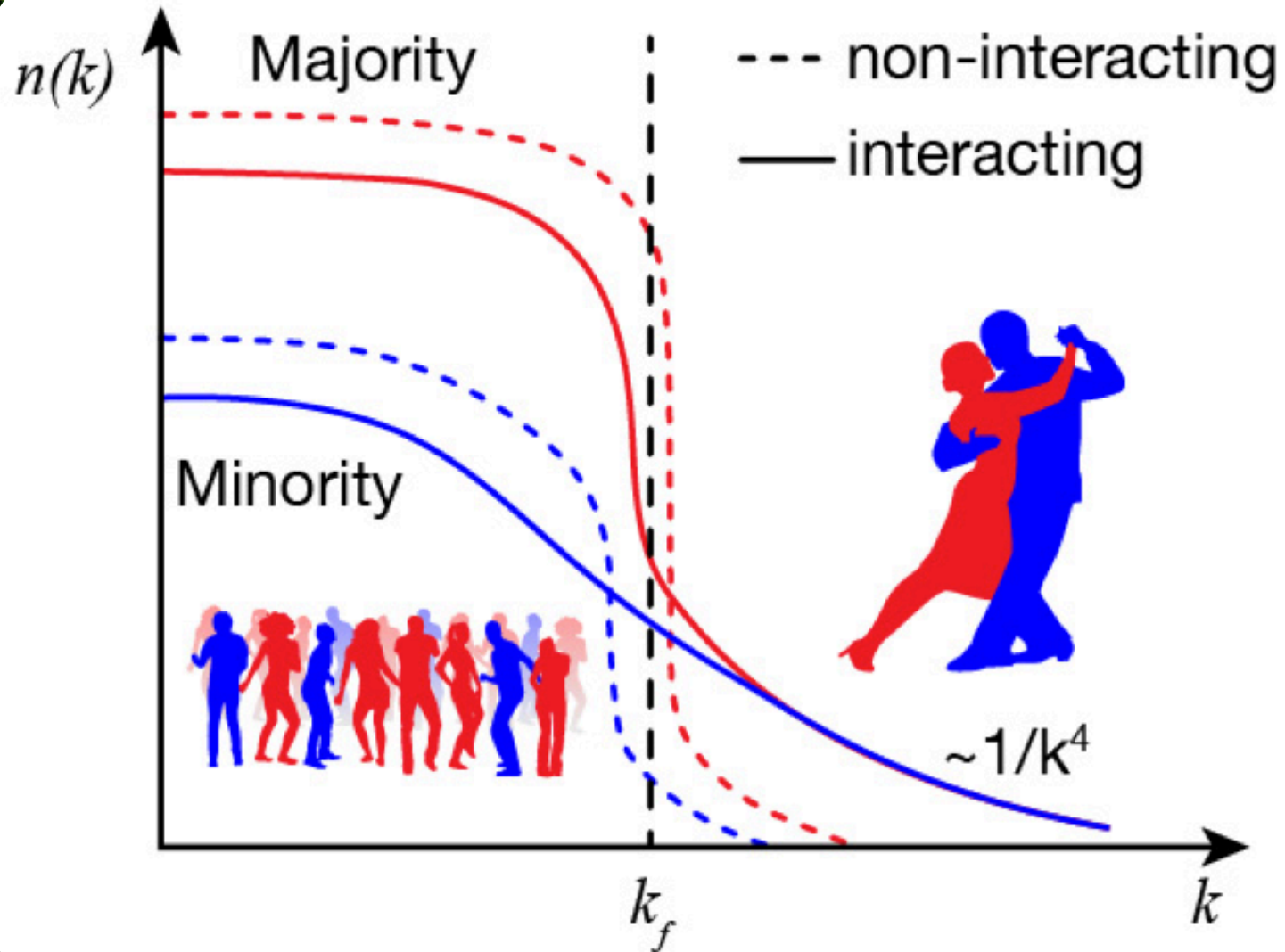
Bottom Line:

- ‘Density Fluctuations’ predominantly due to np-SRC.
- Universal character observed in $A = 4 - 208$ nuclei.
- Strong indication for Tensor force dominance at short distance

Universal structure of nuclear momentum distributions



Universal structure of nuclear momentum distributions *in asymmetric nuclei*





Data-Mining Analyses

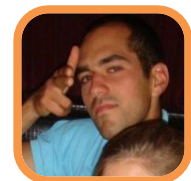


Correlation studies using high-momentum backward recoiling tagging:

- Tagging SRCs via high-momentum recoils (N. Muangma).
- Tagging the EMC Effect via high-momentum recoils (B. Schmookler).

6 - 8 papers expected in the next 3 years

Data-Miners:



Properties of SRC pairs in Nuclei:

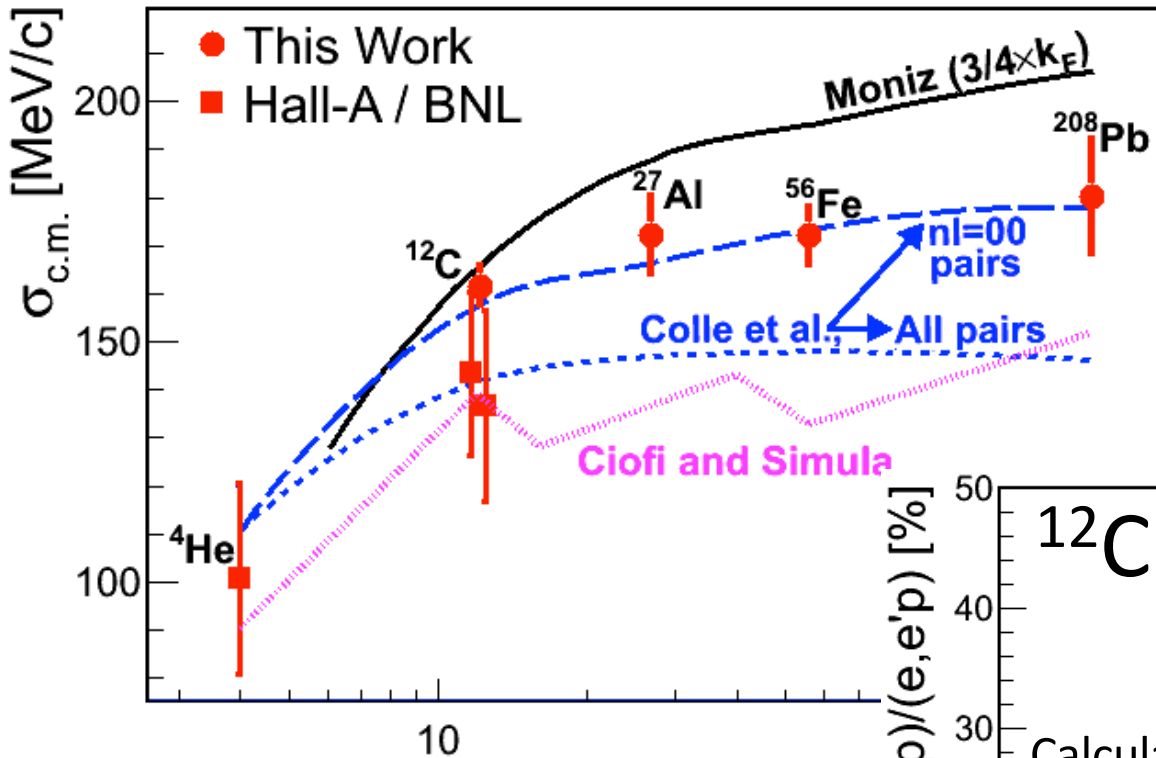
- A dependence of pp-SRC c.m. motion (E. Cohen).
- Tensor to Scalar dominance transition (E. Cohen).
- Isospin structure using leading and recoiling neutrons (M. Duer & I. Korover).
- Three-Nucleon Correlations (E. Cohen).

Energy sharing in asymmetric nuclei:

- Proton/neutron energy sharing in heavy nuclei (M. Duer).
- Proton/neutron energy sharing in ^3He and ^4He (M. Khachartyan).

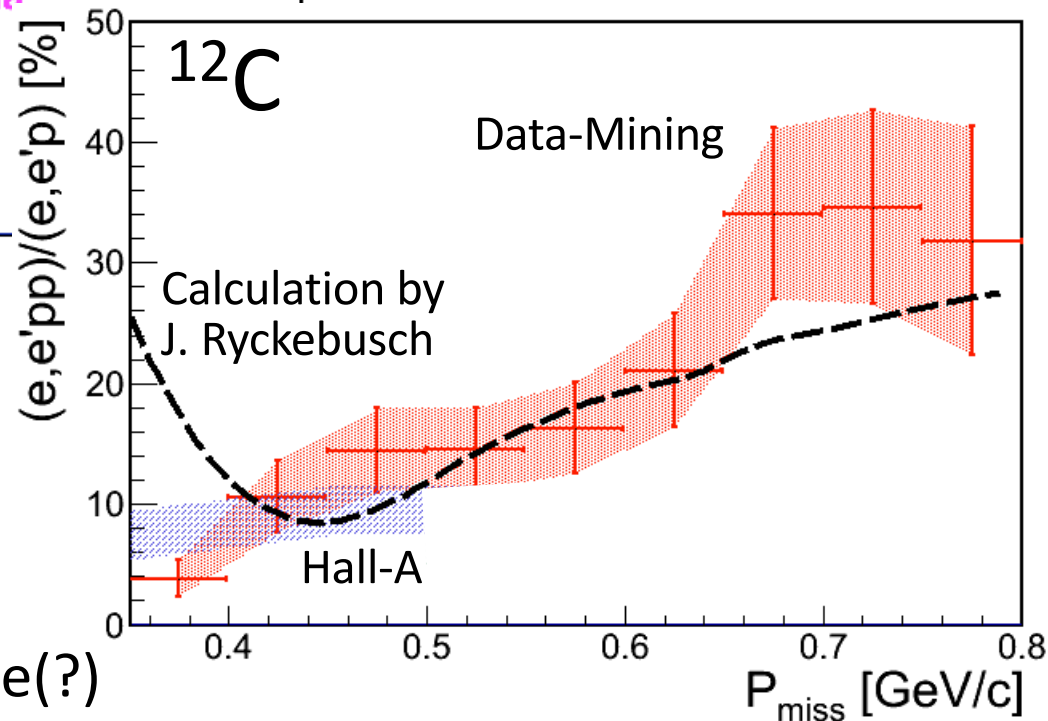


Data-Mining Example



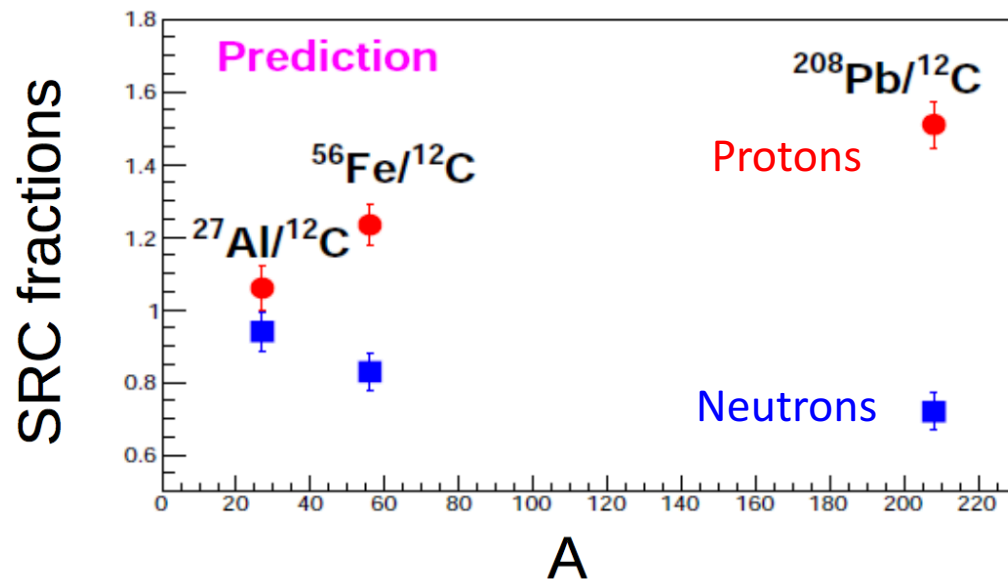
- Extraction of the c.m motion of pp-SRC pairs in nuclei.
- Comparison with calculations to constrain nuclear pairing models.

- Observed increase in the fraction of pp-SRC pairs.
- Indication of transition from Tensor and Scalar dominance(?)



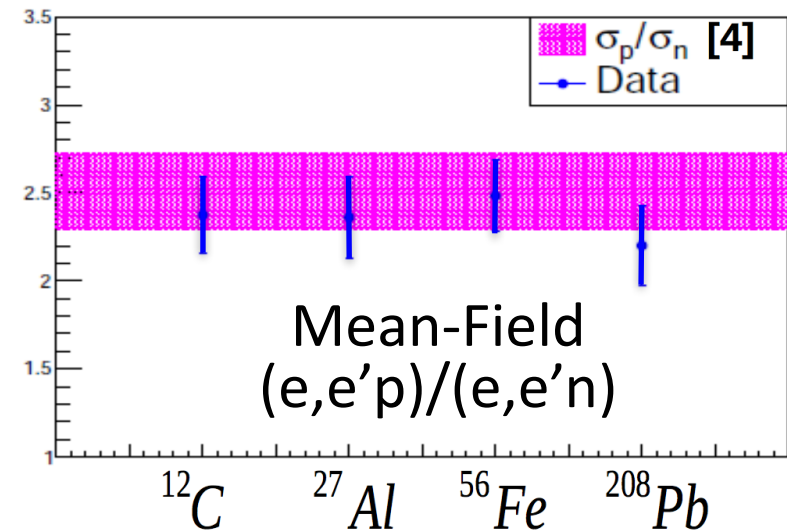
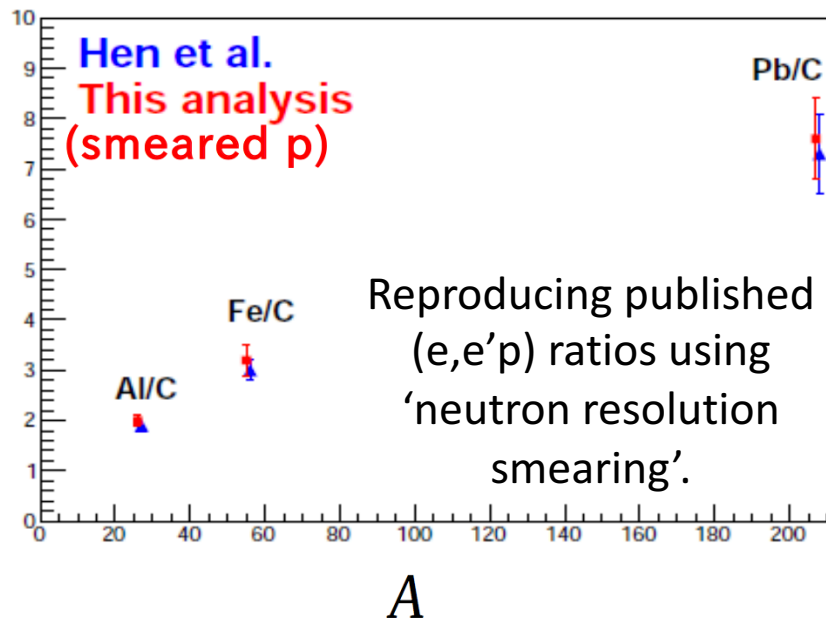


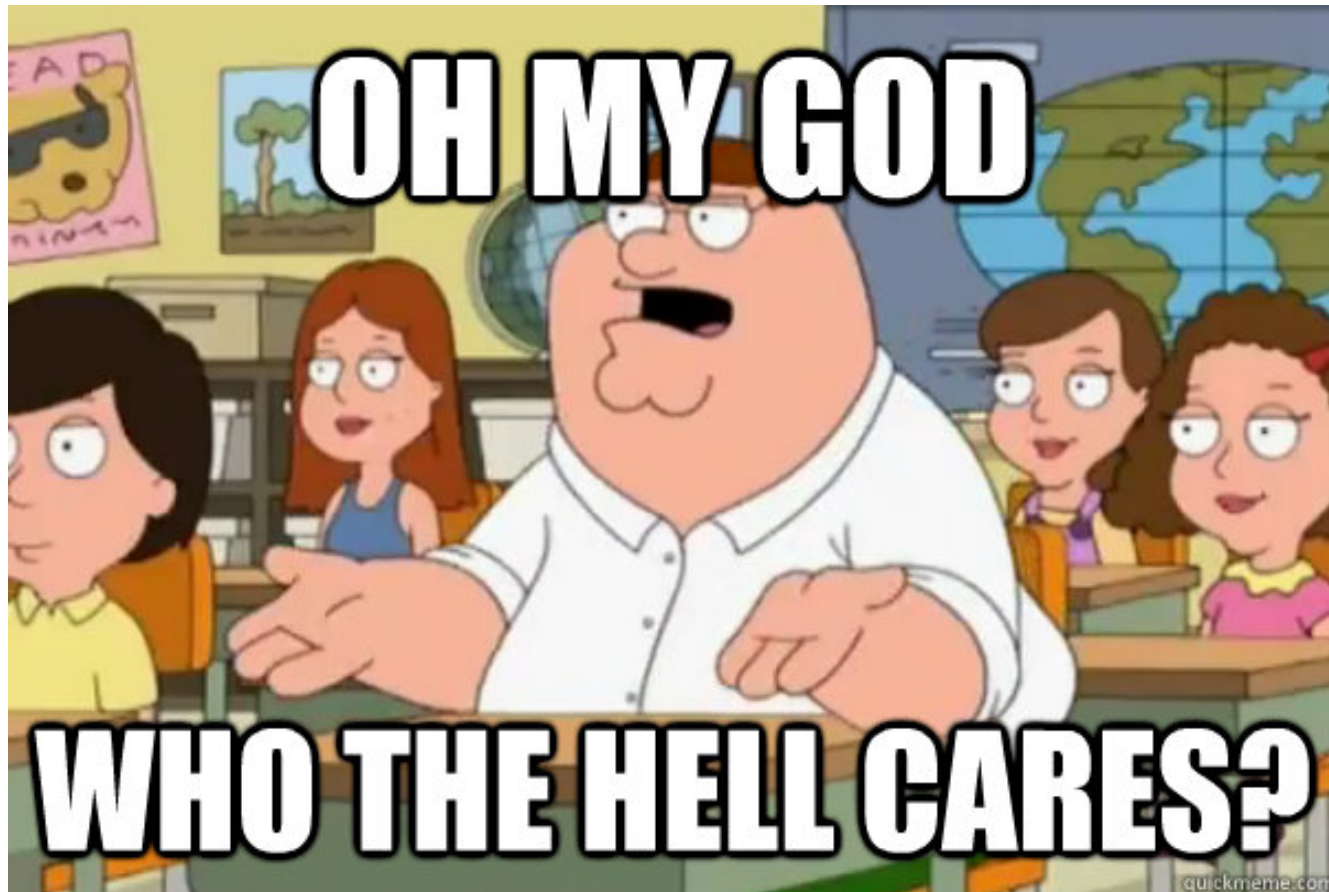
Data-Mining Example



Energy sharing in asymmetric nuclei via neutron knockout.

(Taken from M. Duer's talk yesterday at the NPWG session)

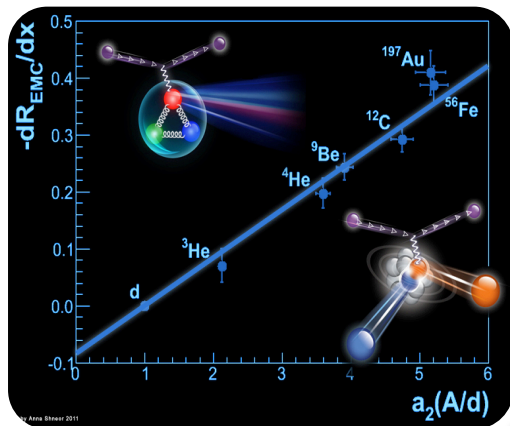




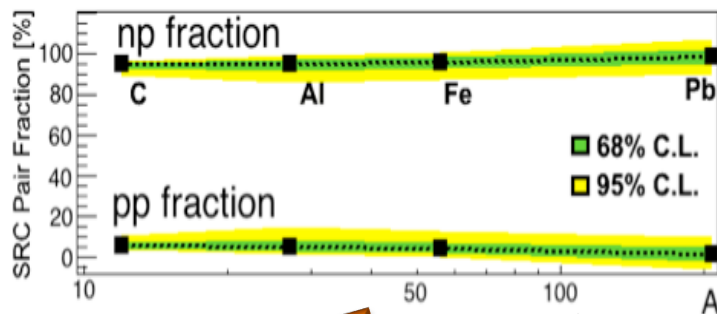
*Me at this point of the talk



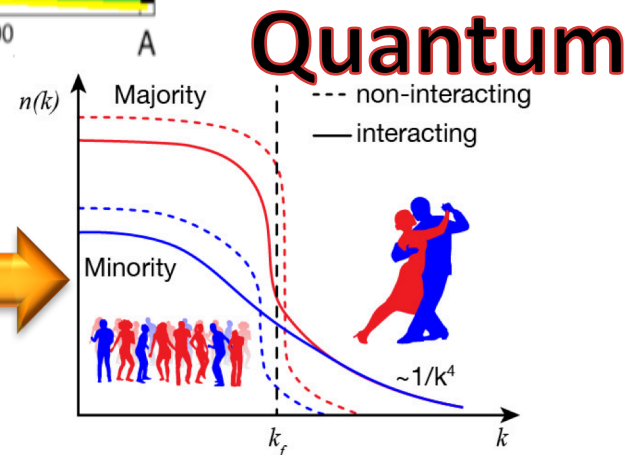
SRC Implications



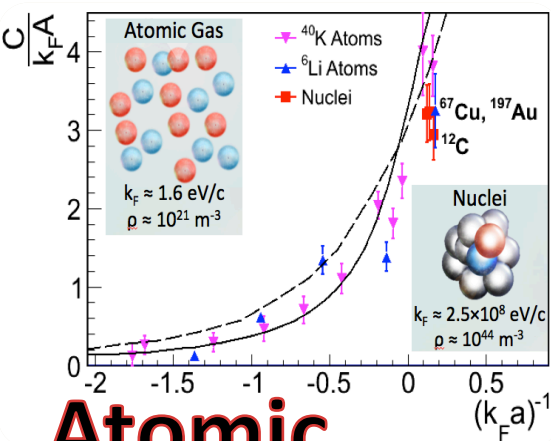
Particle



Nuclear

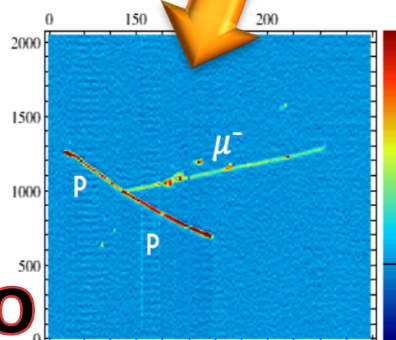


Quantum

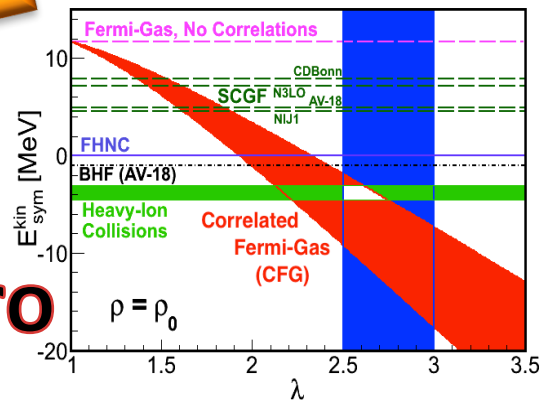


Atomic

Neutrino



Astro

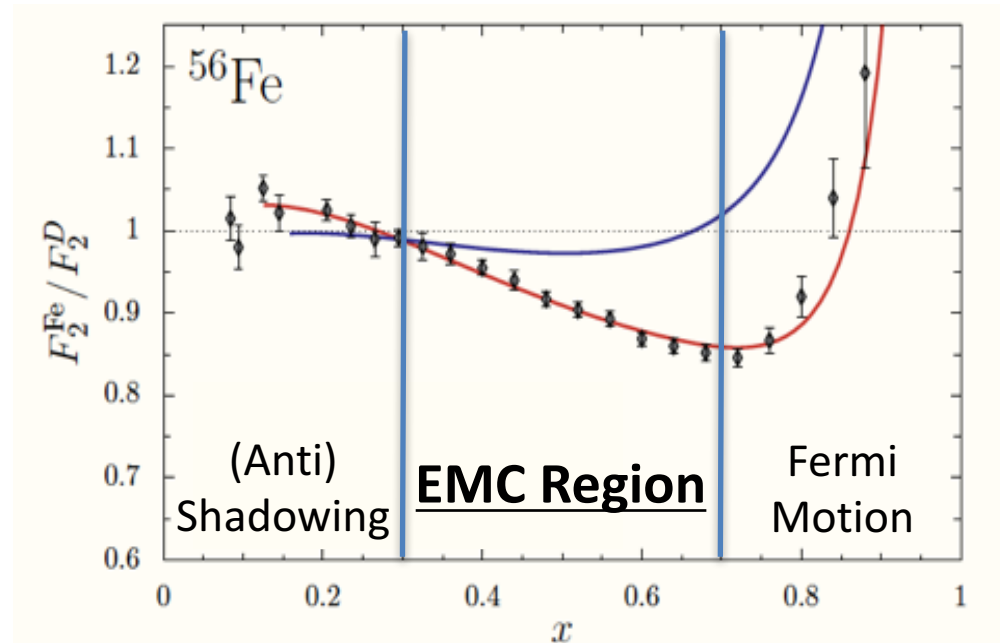




EMC Effect



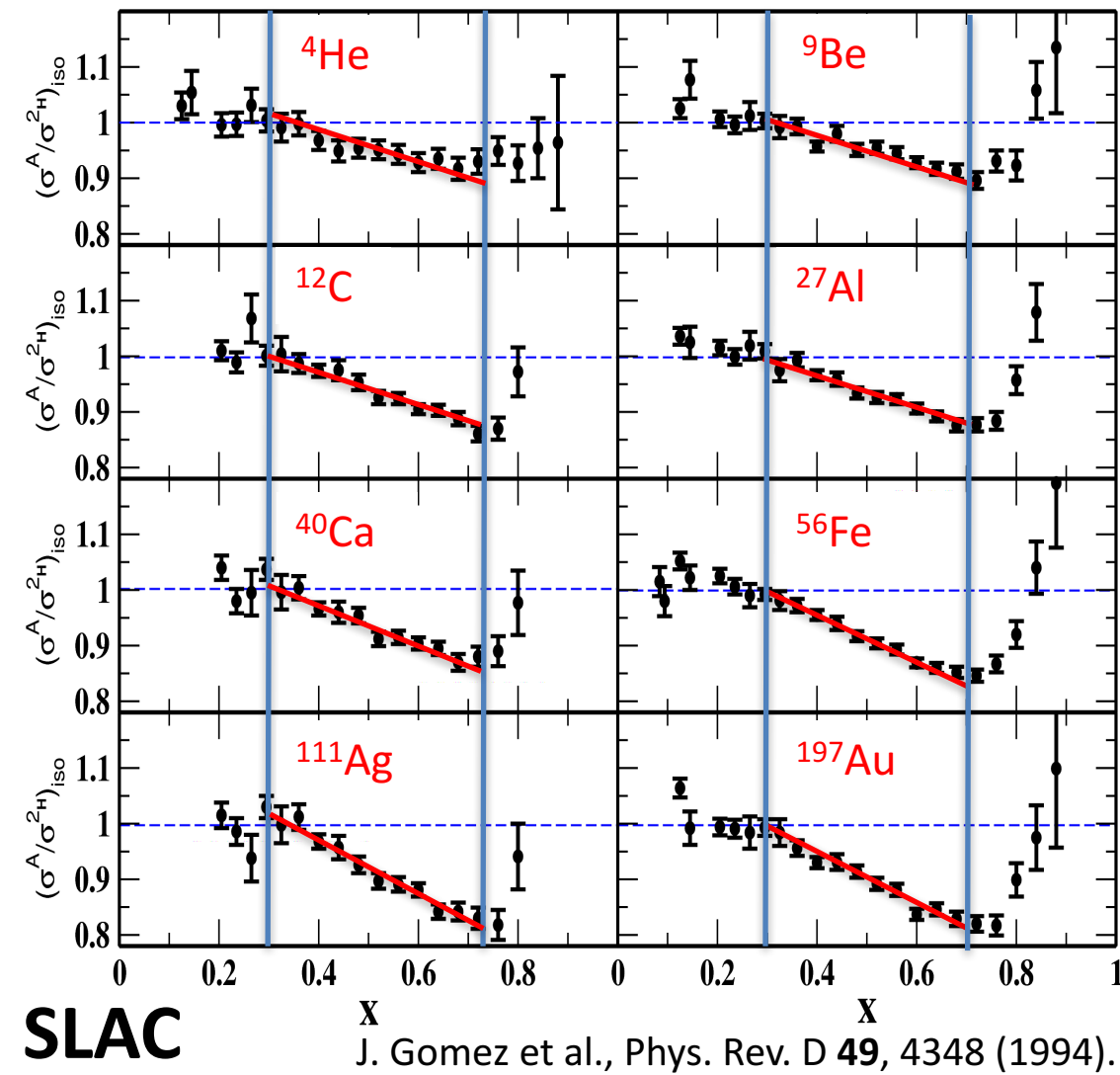
- Deviation of the per-nucleon DIS cross section ratio of nuclei relative to deuterium from unity.
- Universal shape for $0.3 < x < 0.7$ and $3 < A < 197$.
- $\sim$ Independent of Q^2 .
- Overall increasing as a function of A .
- No fully accepted theoretical explanation.



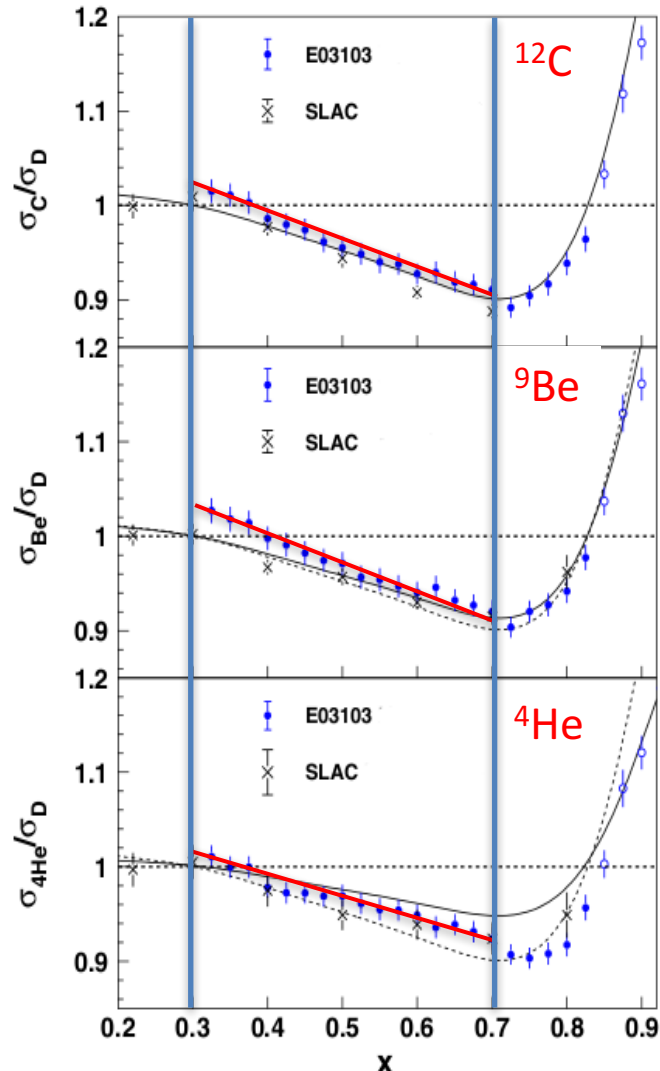
$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_A = \frac{4\alpha^2 E'^2}{Q^4} \left[2 \frac{F_1}{M} \sin^2\left(\frac{\theta}{2}\right) + \frac{F_2}{\nu} \cos^2\left(\frac{\theta}{2}\right) \right] \quad F_2(x, Q^2) = \sum_i e_i^2 \cdot x \cdot f_i(x)$$



Universality of the EMC Effect



JLab



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



EMC Challenge: 'Strength' Scales

Weak Binding

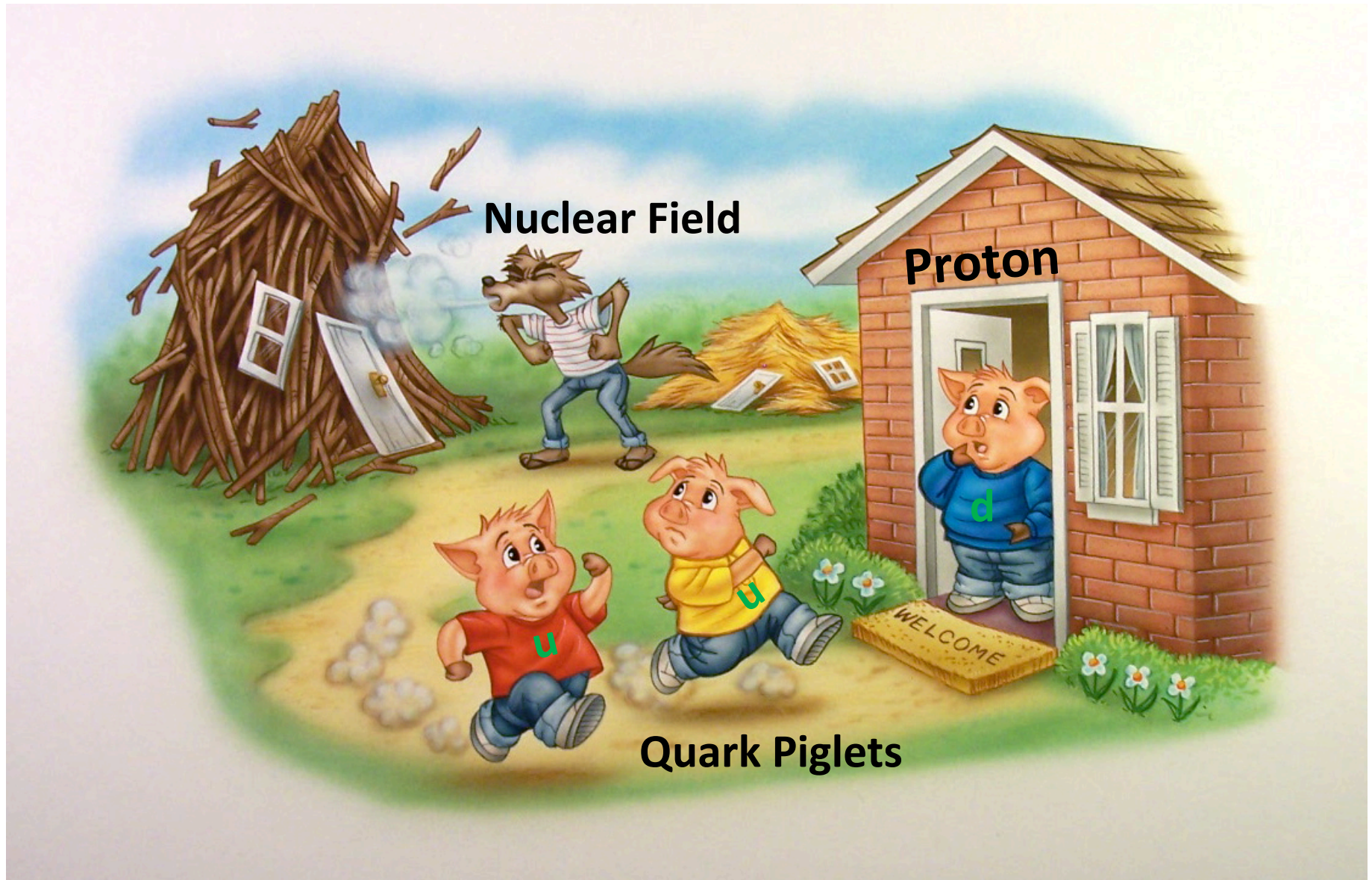
External Field

Strong Binding



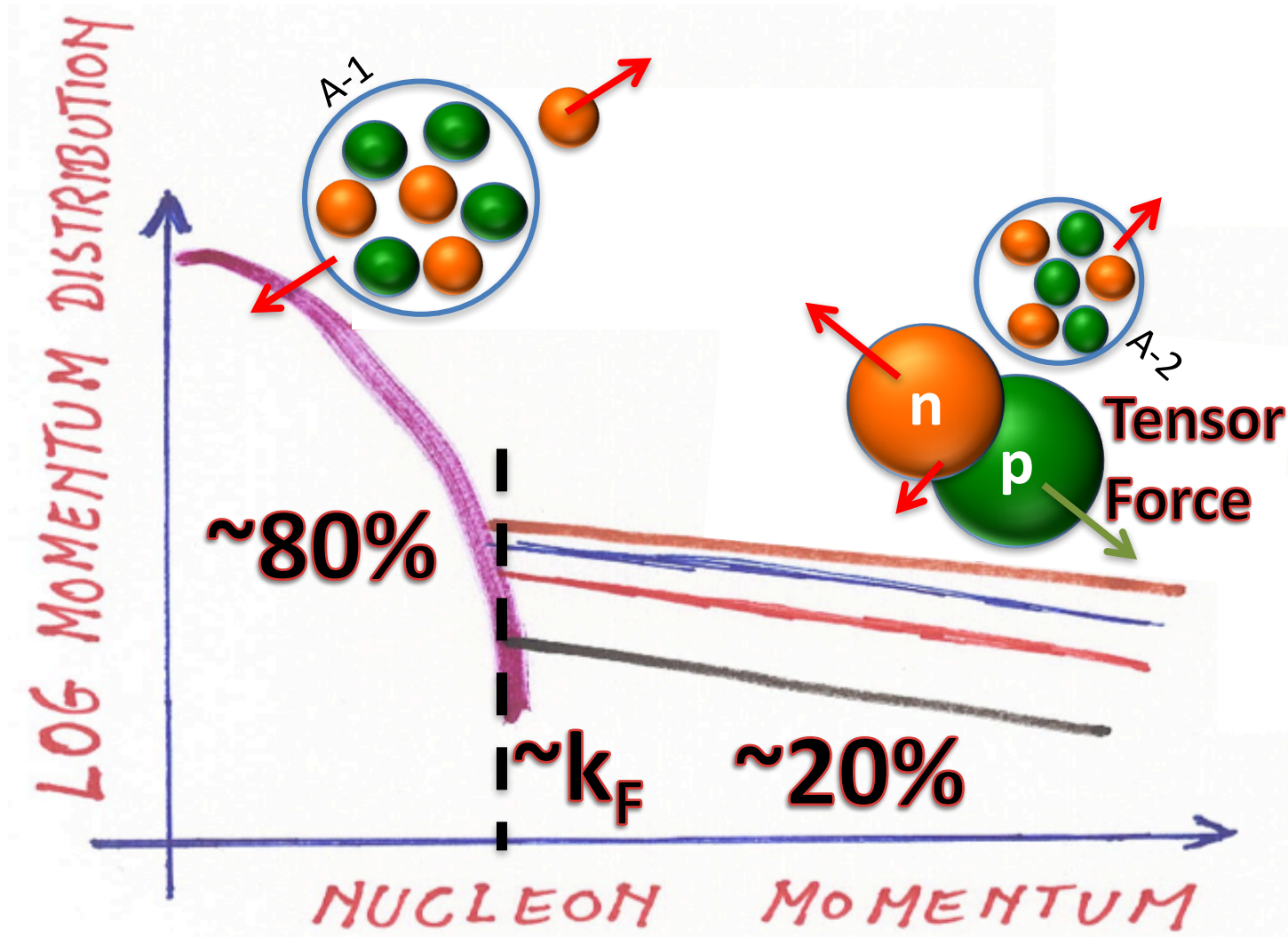


EMC Challenge: 'Strength' Scales



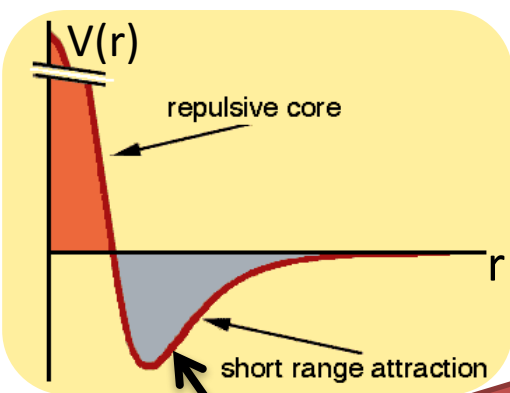


Nuclear Structure

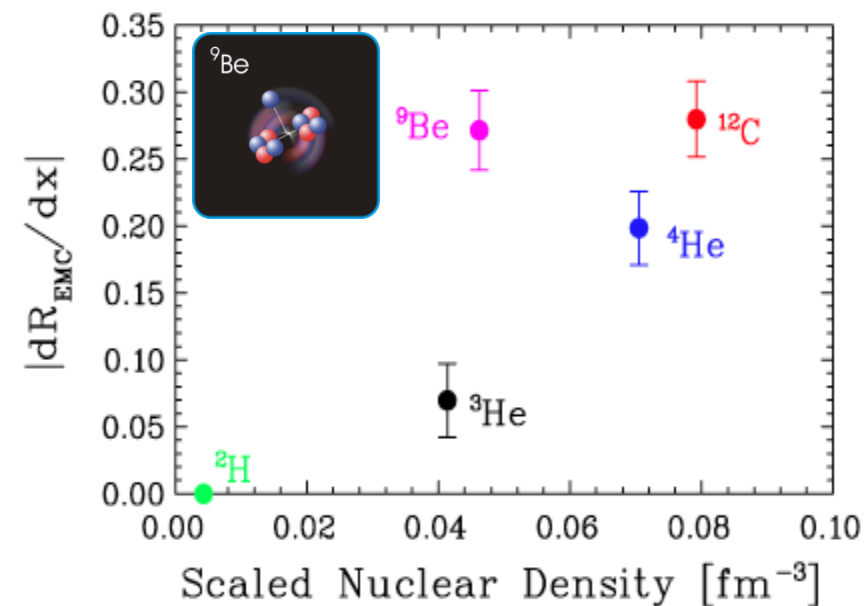
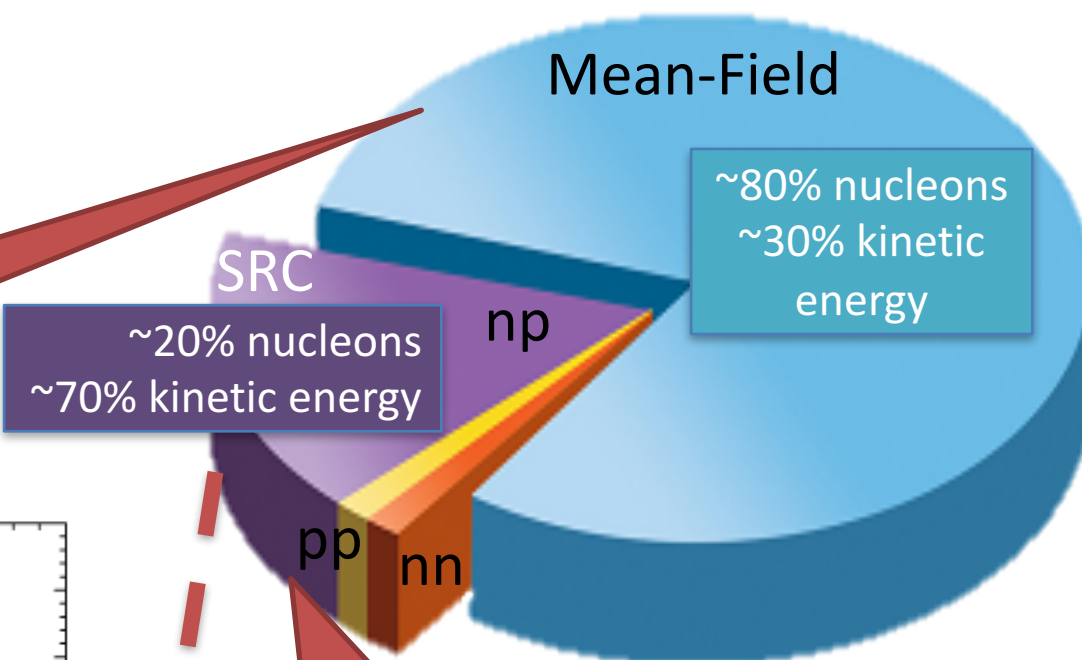




Where is the EMC Effect?



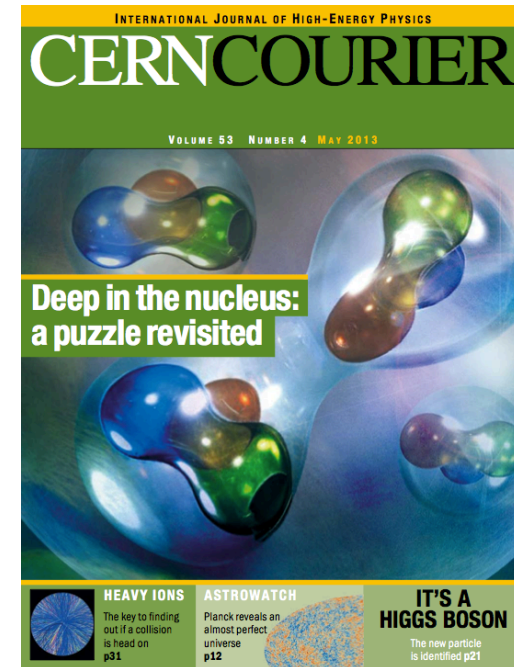
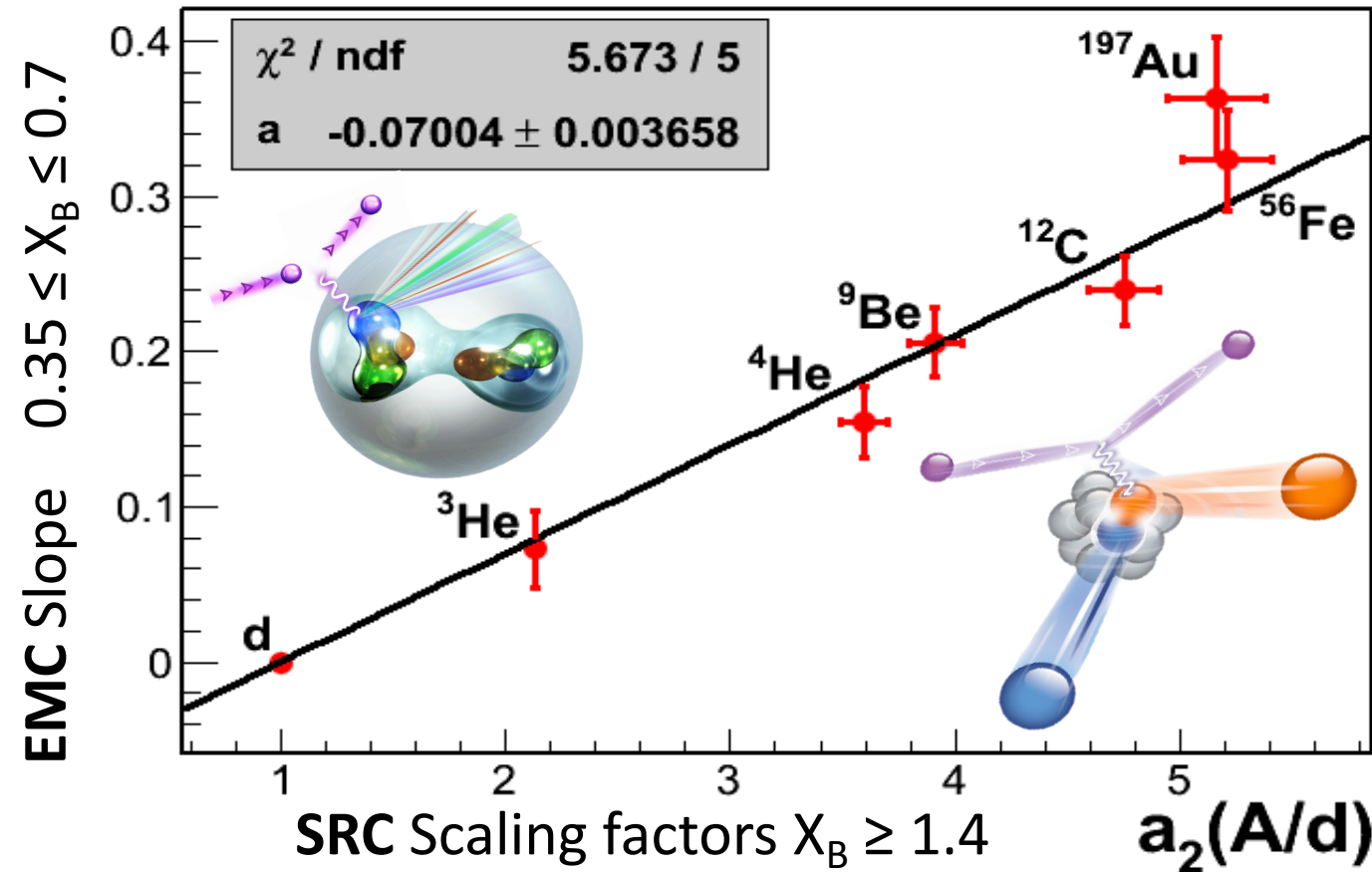
Largest attractive force



High local nuclear matter density, large momentum, large off shell, large virtuality ($v = p^{\mu 2} - m^2$)



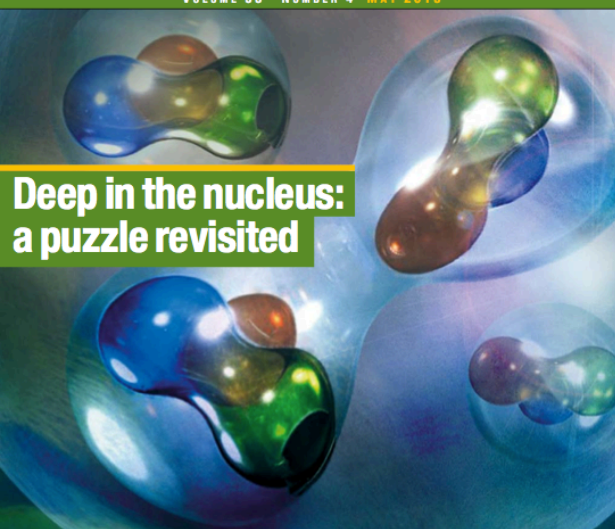
Results III: EMC-SRC Correlation



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.



Deep in the nucleus:
a puzzle revisited

HEAVY IONS ASTROWATCH
IT'S A HIGGS BOSON

52301 (2011)

PHYSICAL REVIEW LETTERS

week
4 FEBRUARY

Short Range Correlations and the EMC Effect

L. B. Weinstein,^{1,*} E. Piasetzky,² D. W. Higinbotham,³ J. Gomez,³ O. Hen,² and R. Shneor²

PHYSICAL REVIEW C 85, 047301 (2012)

The connection between short range correlations and the EMC effect

O. Hen,¹ E. Piasetzky,¹ and L. B. Weinstein²

Short range correlations and the EMC effect

E. Piasetzky^a, L.B. Weinstein^b, D.W. Higinbotham^c, J. Gomez^c, O. Hen^a, R. Shneor^a

NUCLEAR PHYSICS A

PHYSICAL REVIEW D 84, 117501 (2011)

Constraints on the large- x d/u ratio from electron-nucleus scattering at $x > 1$

O. Hen,¹ A. Accardi,^{2,3} W. Melnitchouk,³ and E. Piasetzky¹

International Journal of Modern Physics E
Vol. 22, No. 7 (2013) 1330017 (30 pages)

THE EMC EFFECT AND HIGH MOMENTUM
NUCLEONS IN NUCLEI

World Scientific
www.worldscientific.com



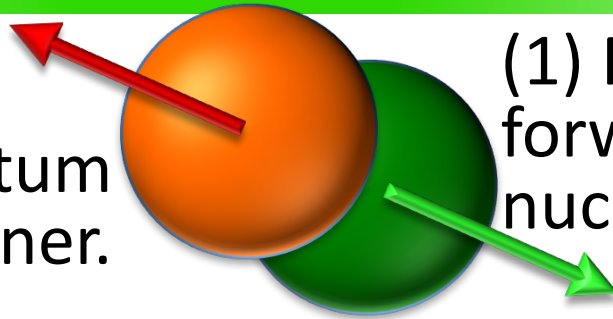
Tagged Structure Functions (JLab12)



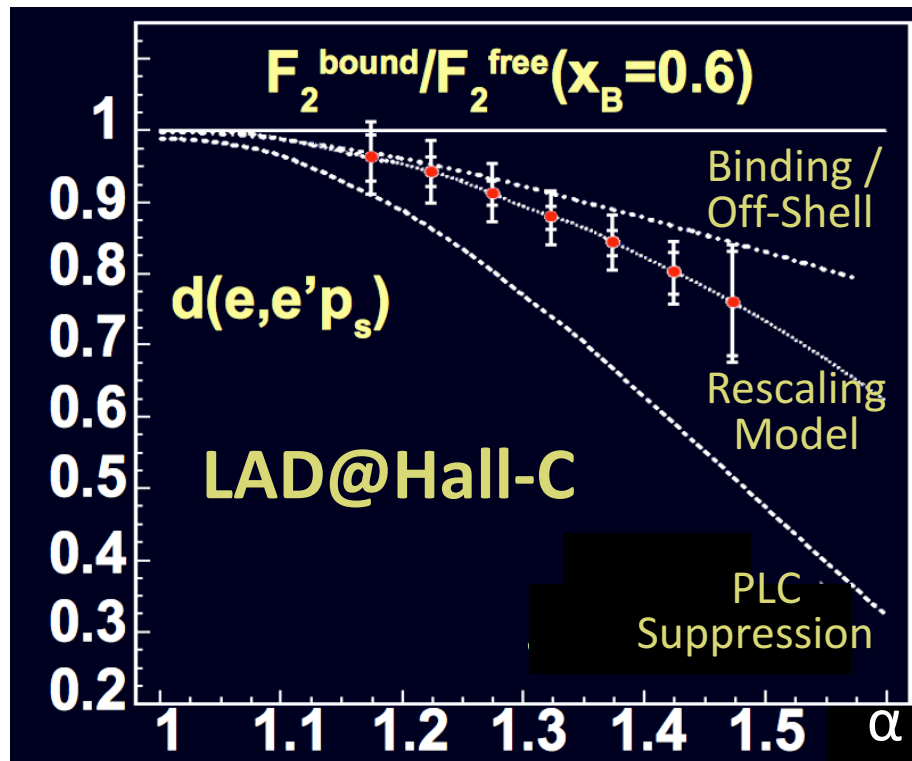
Internal structure of SRC nucleons?

Focus on the deuteron:

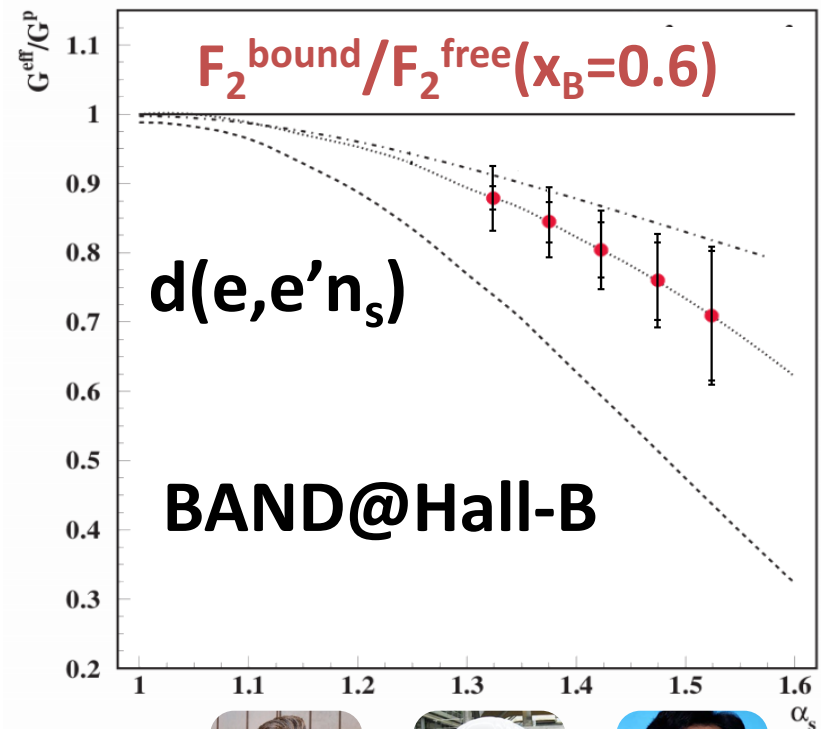
(2) Infer its momentum from the recoil partner.



(1) Perform DIS off forward going nucleon.

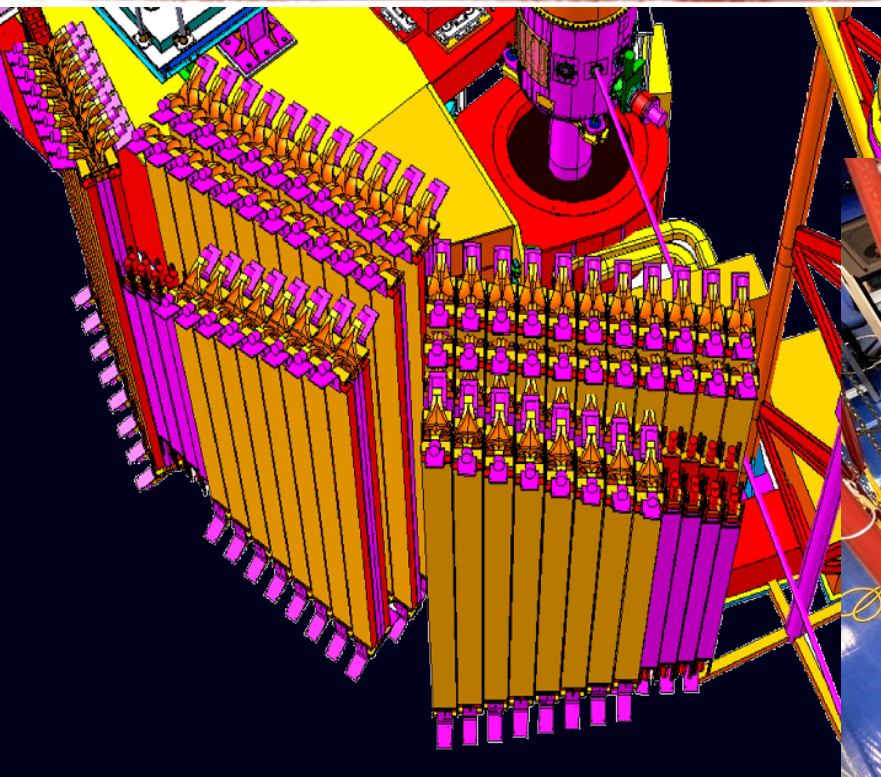


Melnitchouk et al., Z. Phys. A **359**, 99-109 (1997)

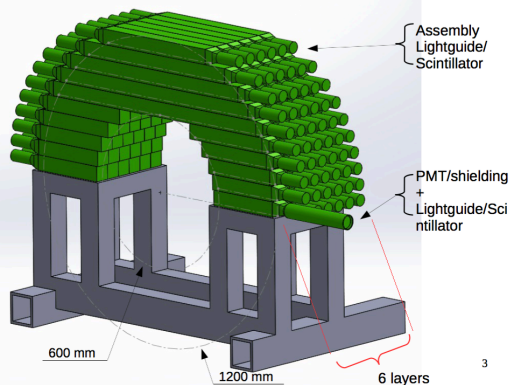




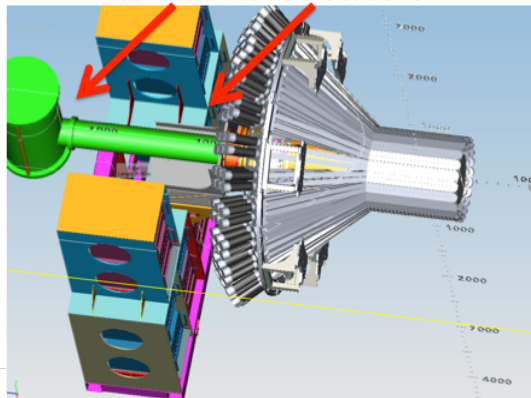
Building Large-Acceptance Detectors



Large Acceptance Detector (LAD@Hall-C)

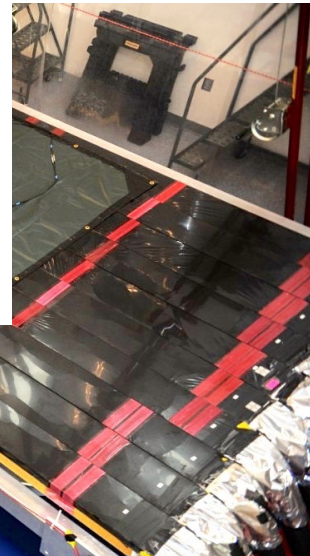
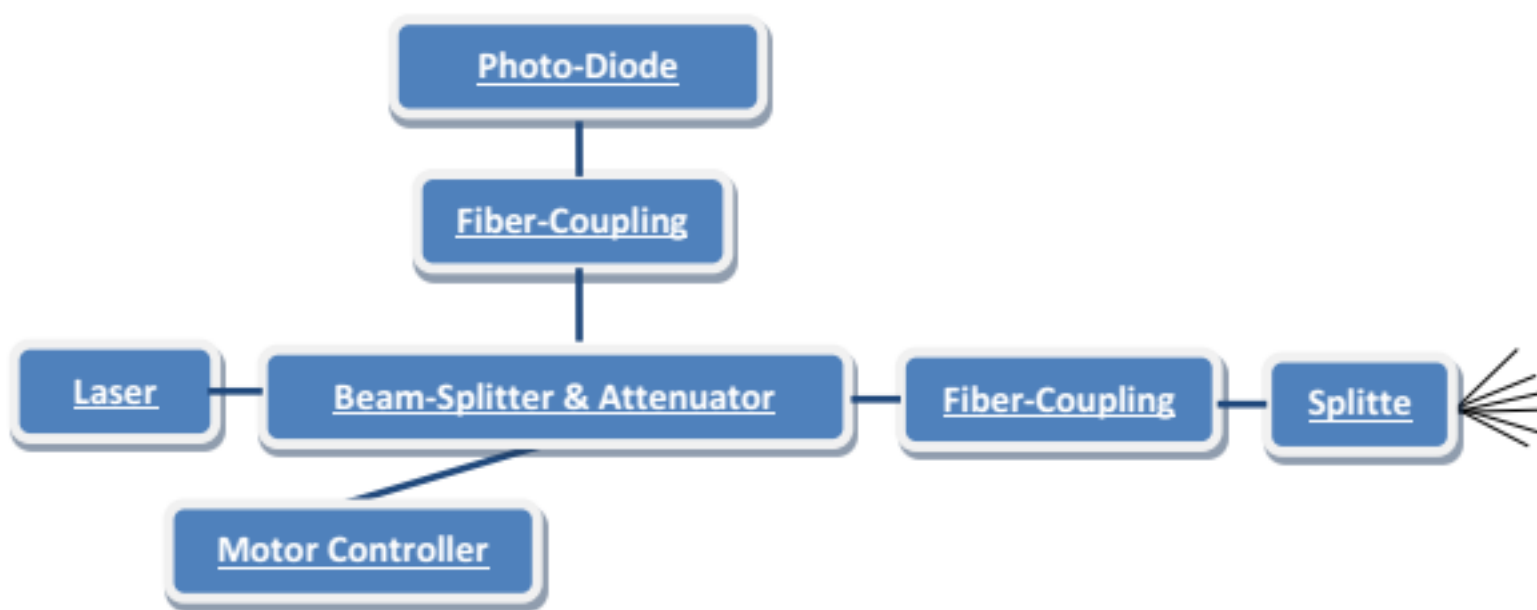


Possible detector locations



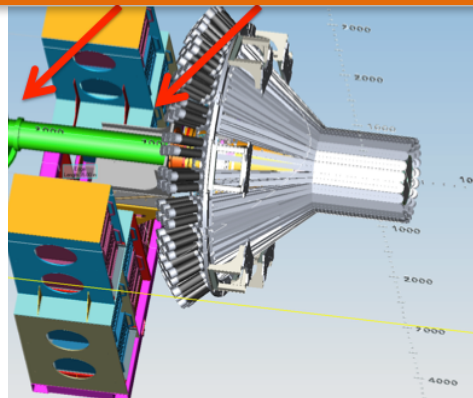
Backward Angle Neutron Detector (BAND@Hall-B)

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



+ Building a laser calibration system

Possible detector locations



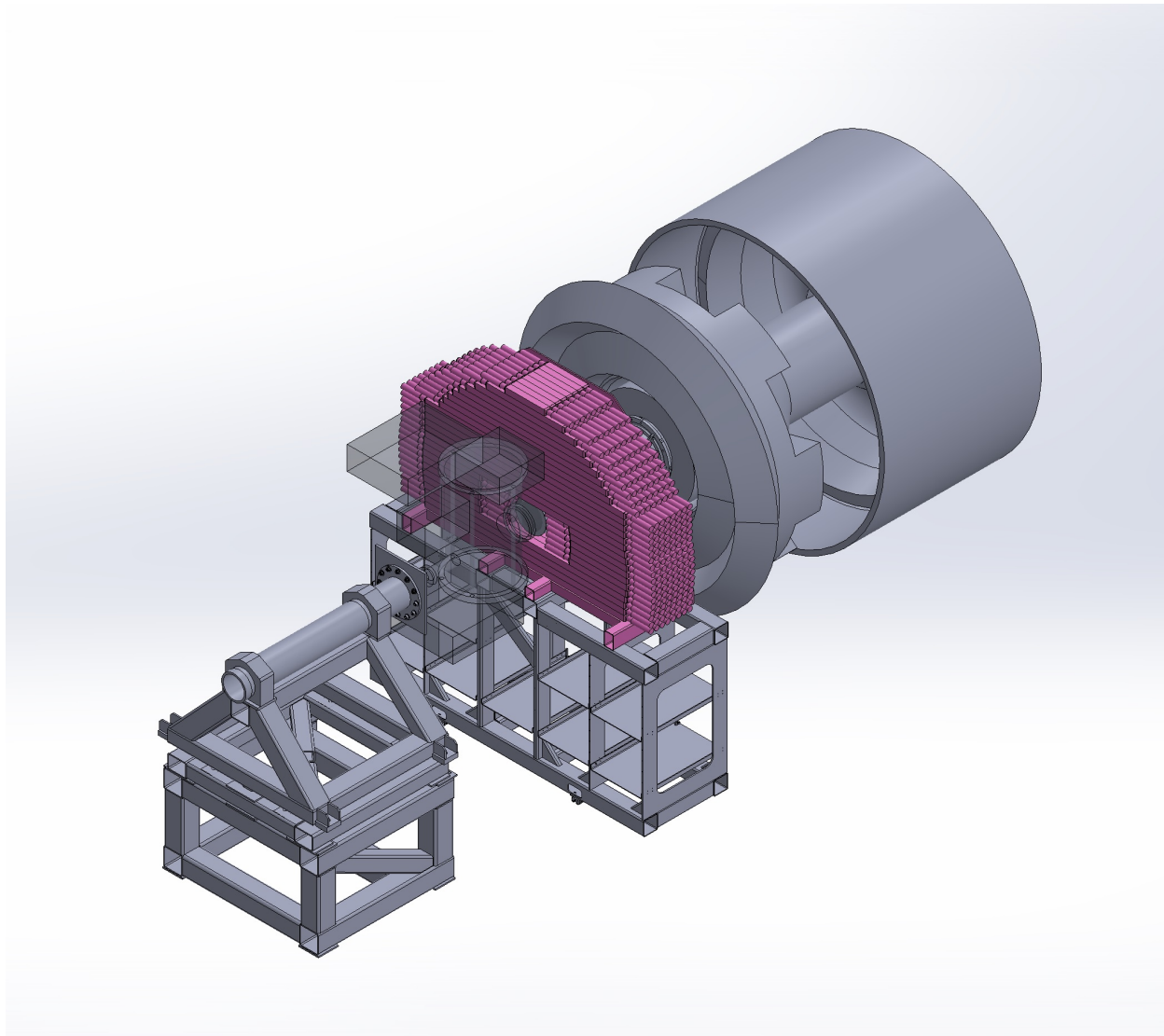
Backwa
Detecto
R&D @
Const



Fig 2: Standa STA-01-TH Laser

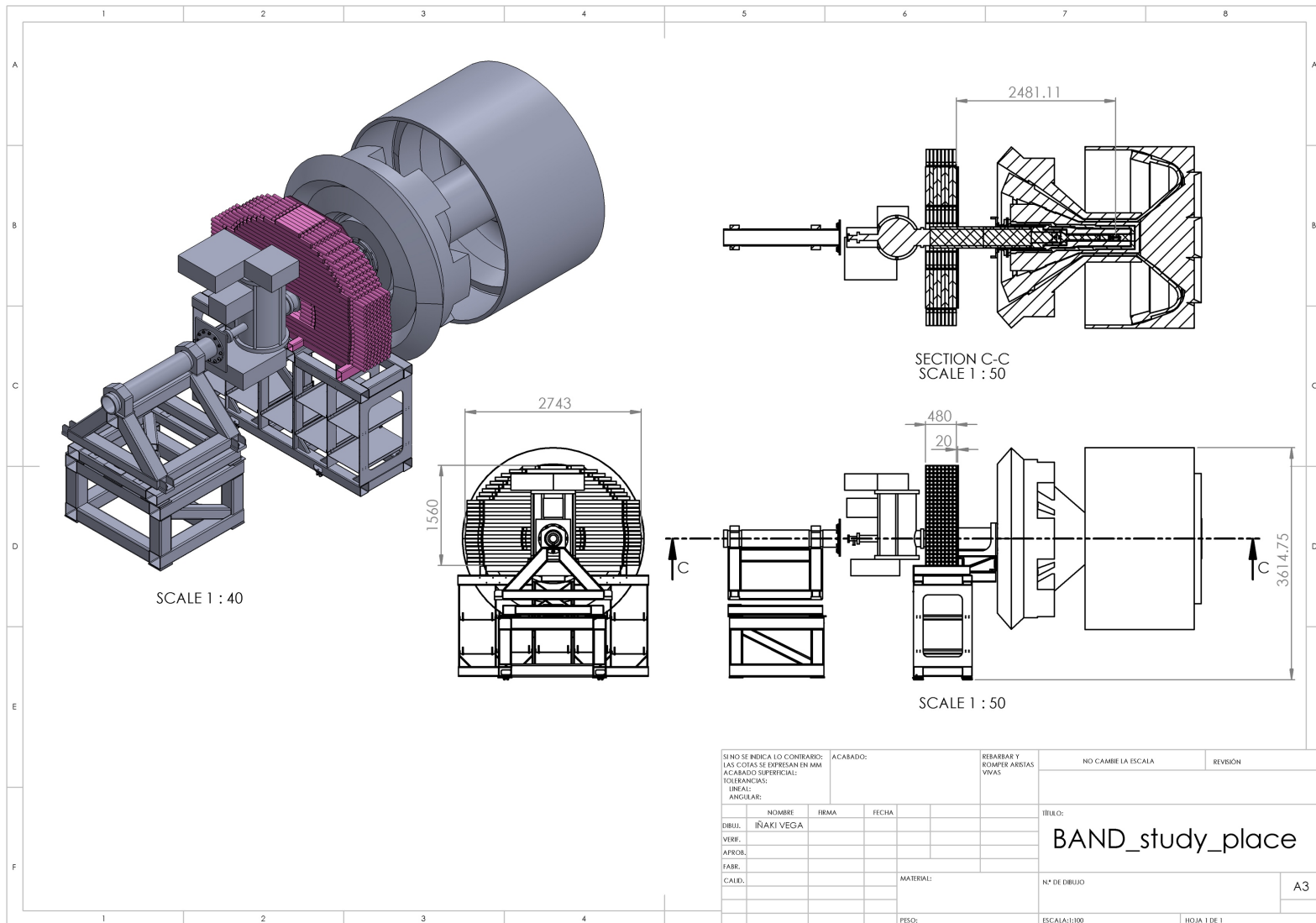


BAND R&D





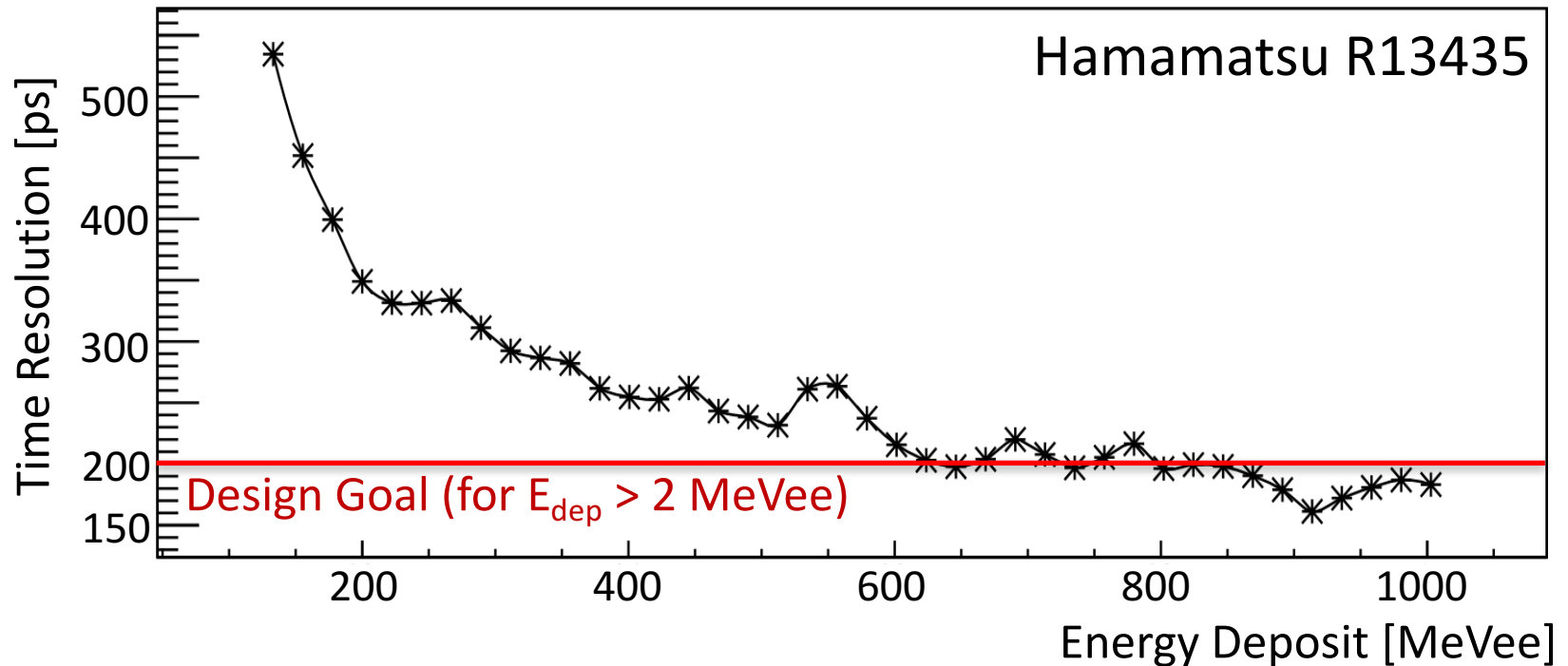
BAND R&D





Current Status:

- Finalizing mechanical design and installation plan (UTSM).
- Last stages of PMT / scintillator testing (MIT / TAU).
- Magnetic shielding tests (ODU).
- Construction during 2017 (UTSM / MIT-BATES).
- Moving to Jlab in early 2018.





Conclusions



- Do our best to be a large, active, group.
- Main interest in SRC and tagged structure functions.
- Working on 6 data-mining papers in the coming 3 years.
- Building the BAND detector for CLAS12.
- Ideas for more nuclear studies using CLAS12!

Hope to officially join CLAS! 😊

- **MIT (Or Hen):**



Barak Schmookler



Reynier Torres



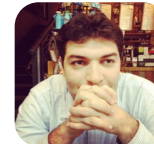
Efrain Segarra



Afroditi Papadopoulou



Axel Schmidt



George Laskaris



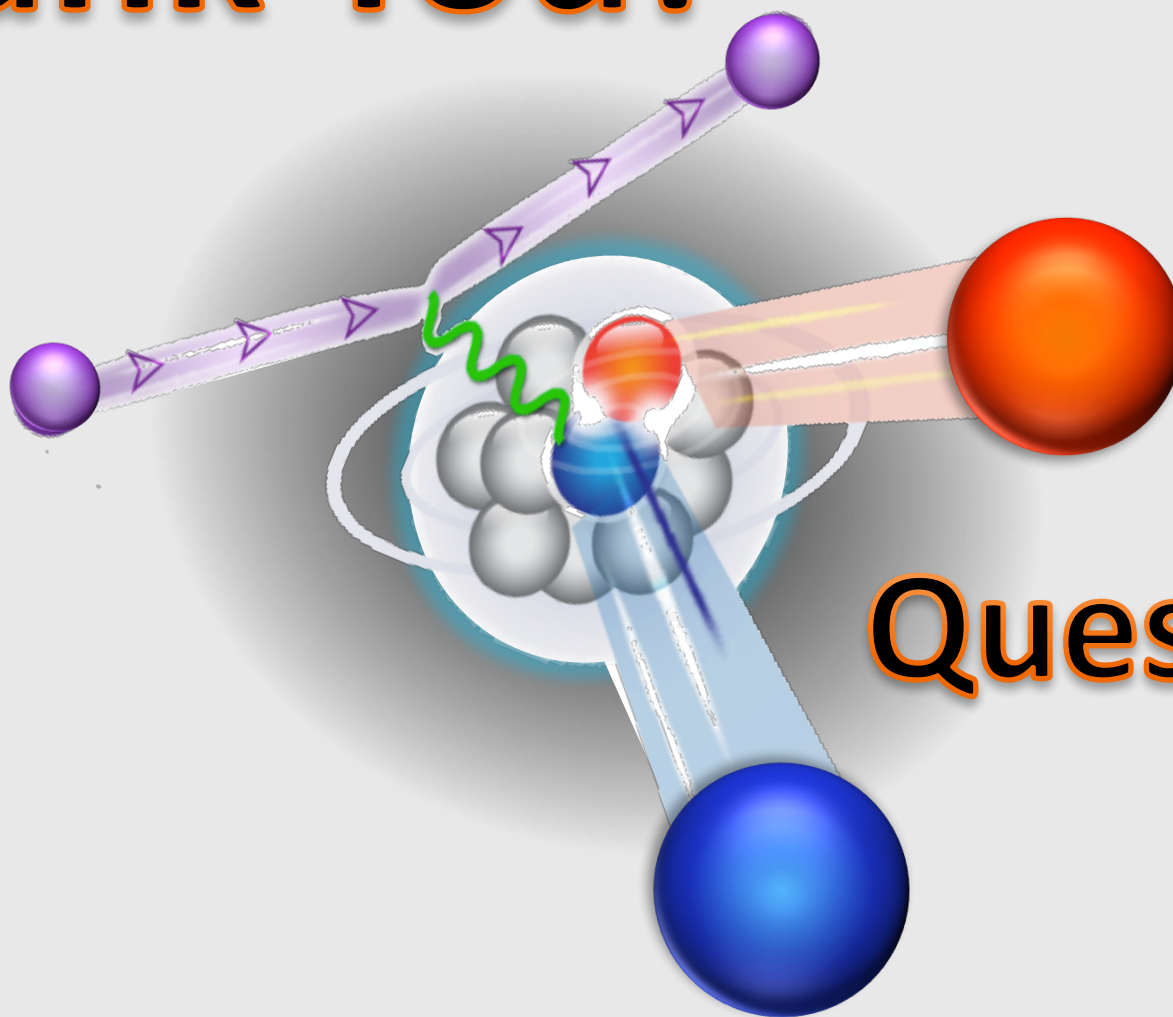
Maria Patsyuk



Taofeng Wang (*visiting scientist)



Thank You!



Questions?