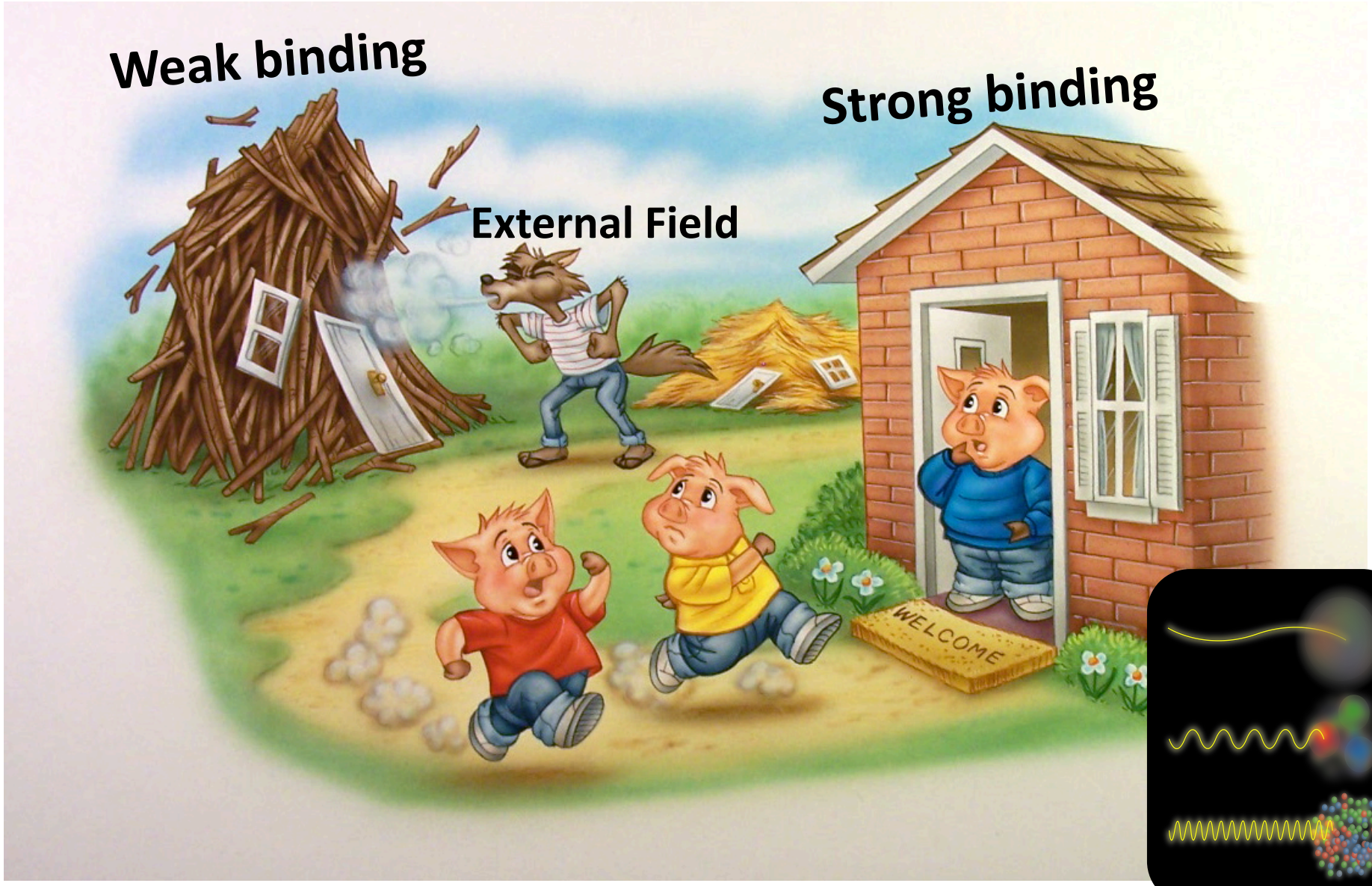
The EMC Effect and Nuclear Correlations

Or Hen (MIT)

DIS-2018, April 16th 2018.

Nuclear / Parton Scale Separation



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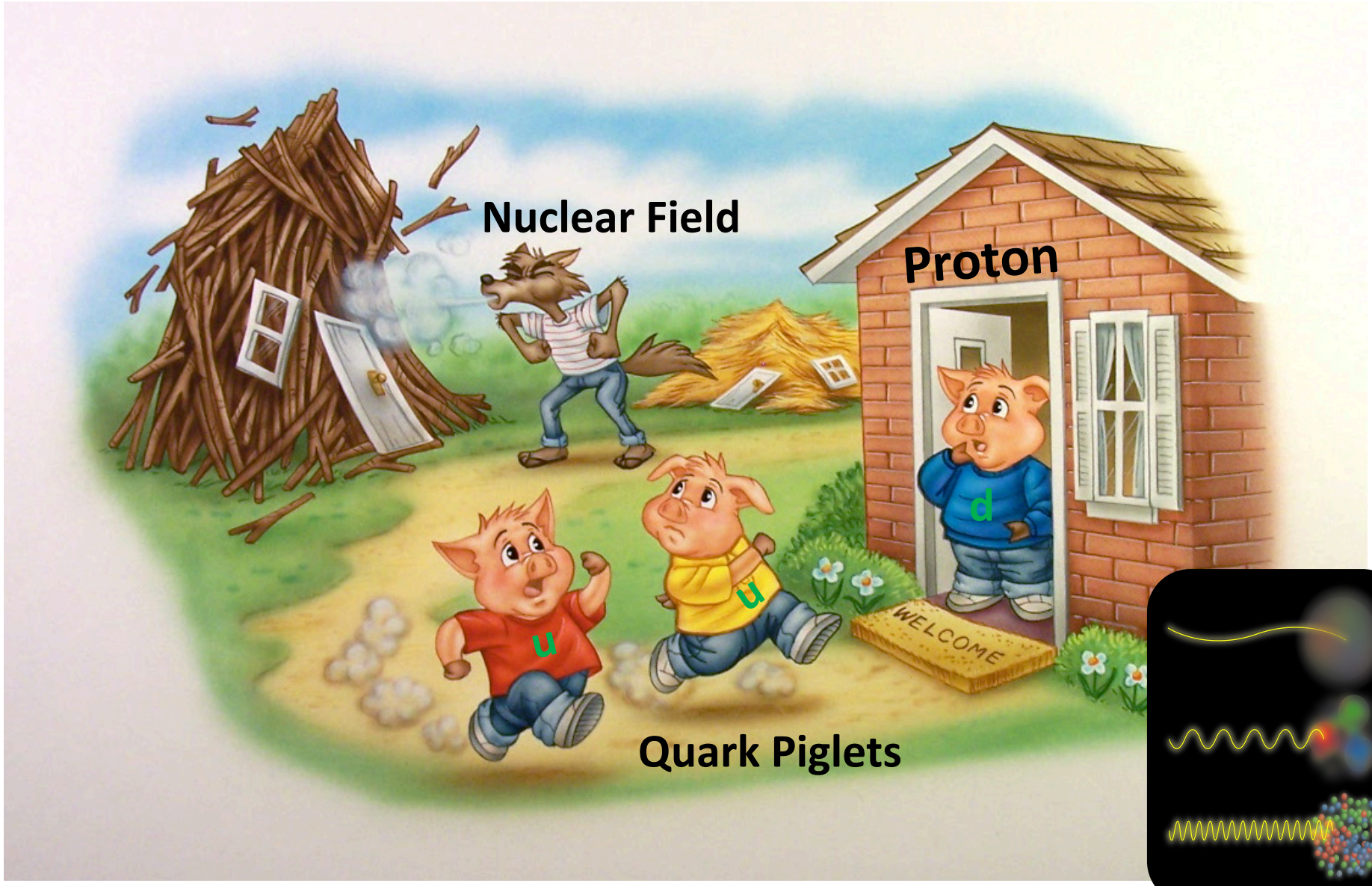
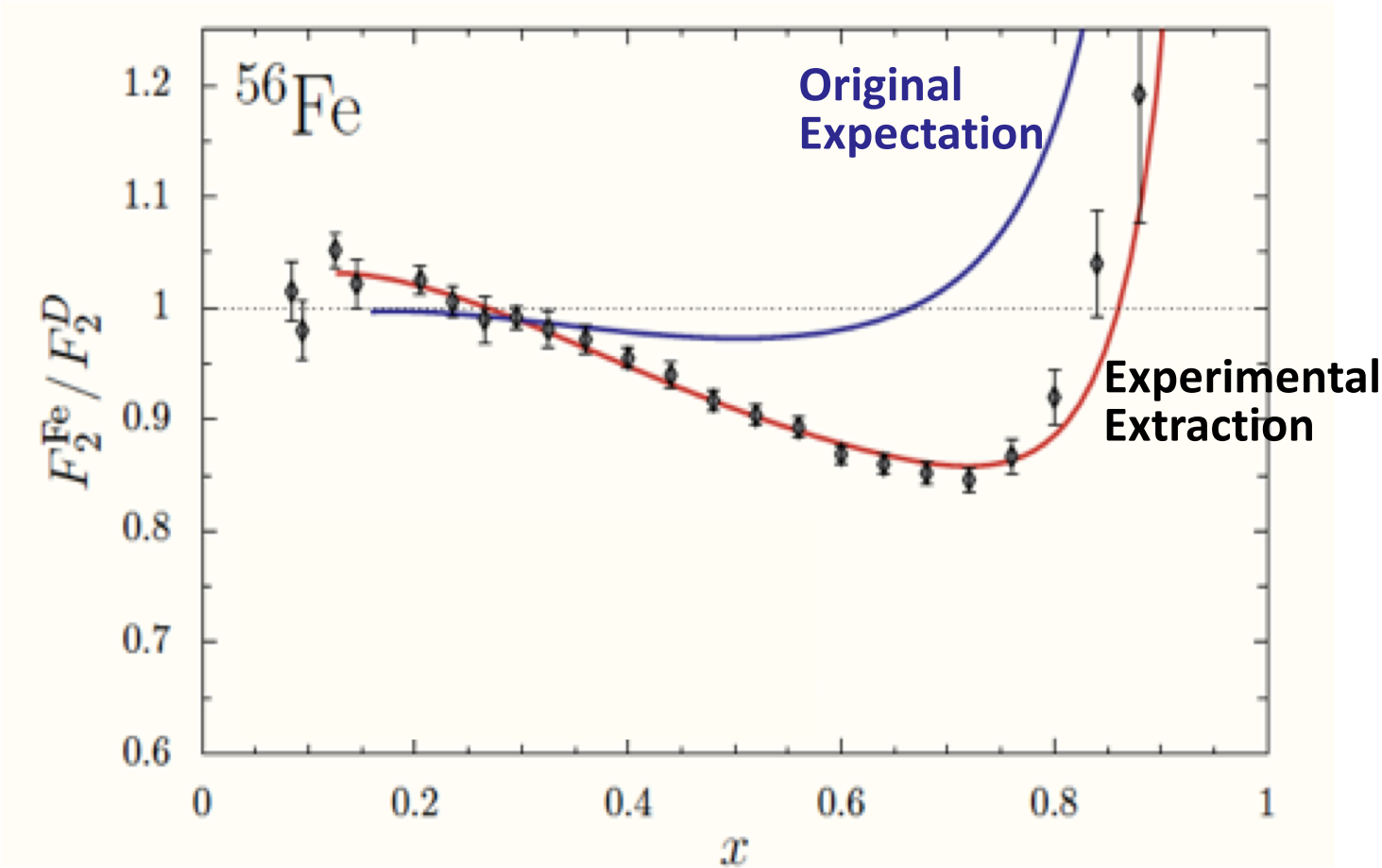


EMC Effect:
Quarks move "slower" in nuclei



Aubert et al., PLB (1983); Ashman et al., PLB (1988); Arneodo et al., PLB (1988); Allasia et al., PLB (1990); Gomez et al., PRD (1994); Seely et al., PRL (2009); Schmookler et al., Submitted (2018)

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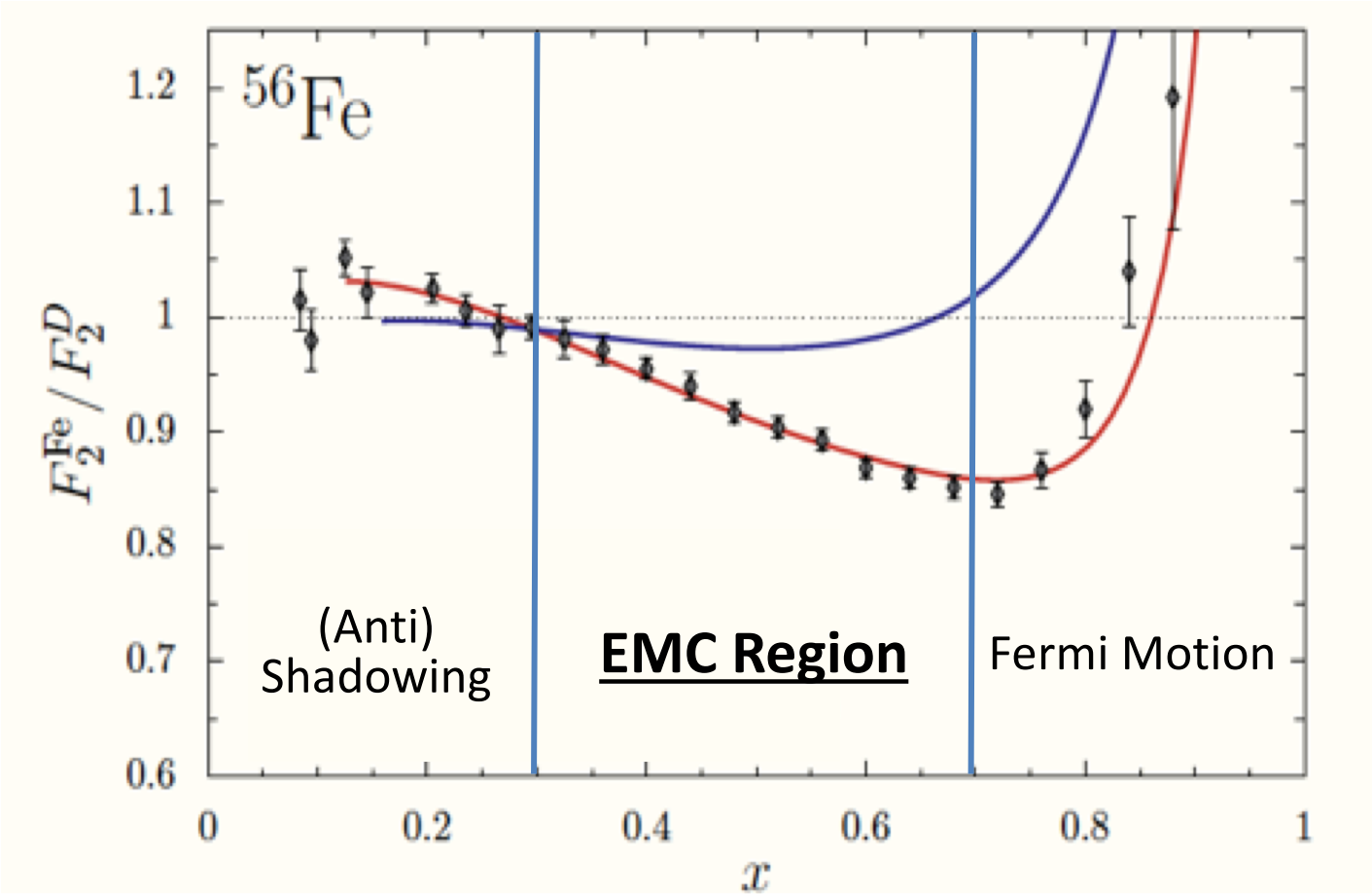

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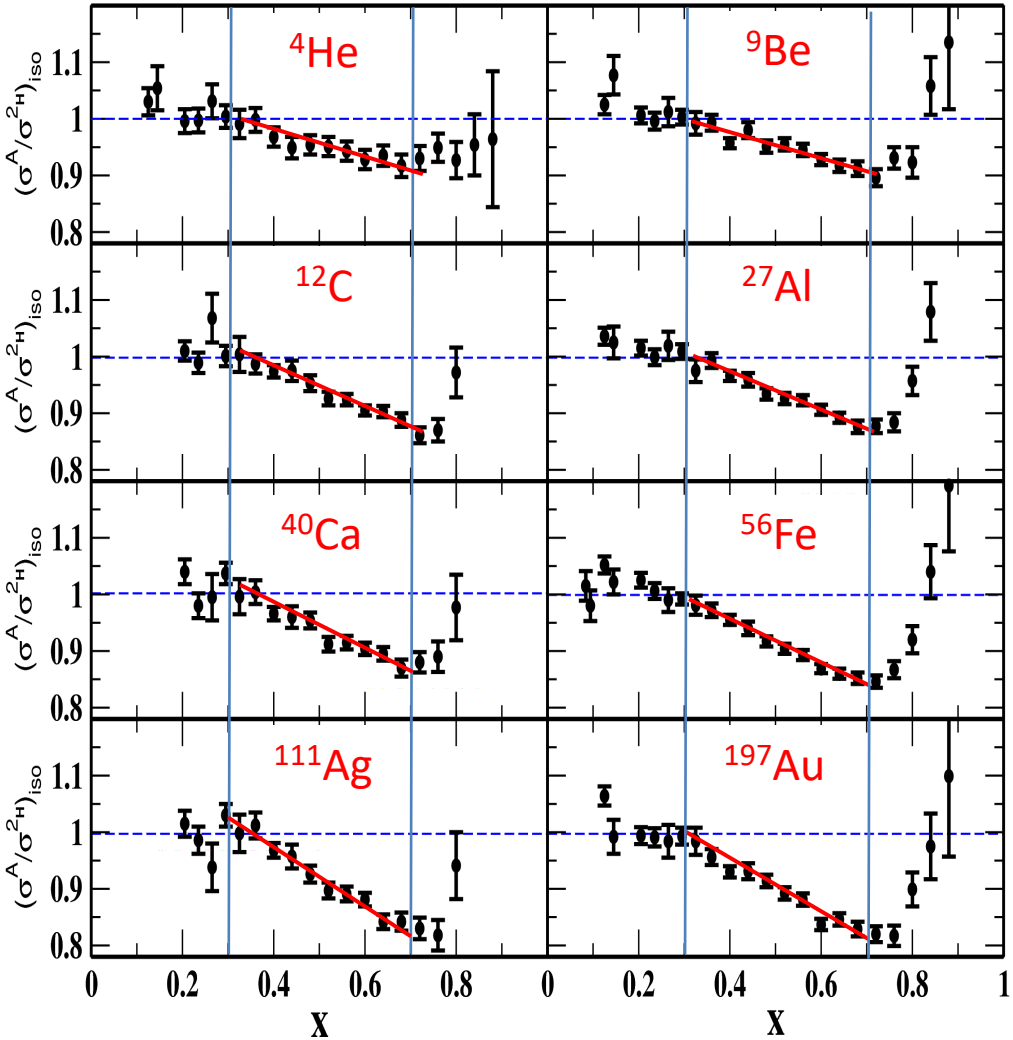
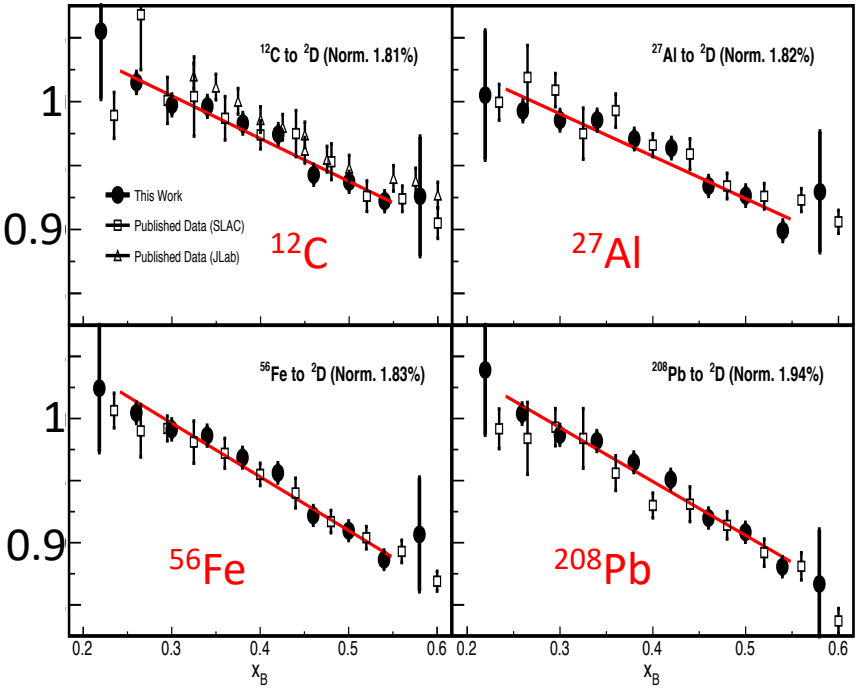
EMC Effect: Nuclear Effect



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

SLAC (1994)

JLab (2018)



Schmookler, Duer, Schmidt, and **Hen** et al., submitted (2018)

35 years, 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!**

O. Hen et al., Rev. Mod. Phys. 89, 045002 (2017)

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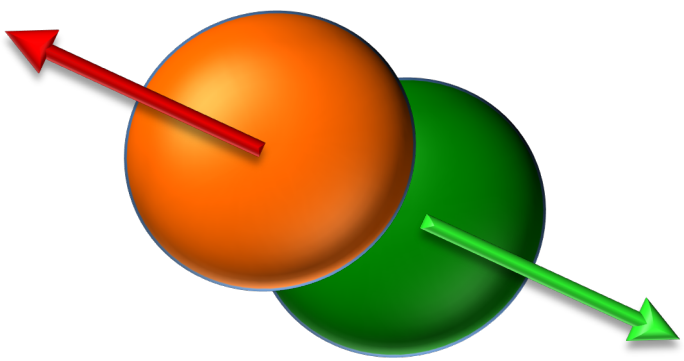
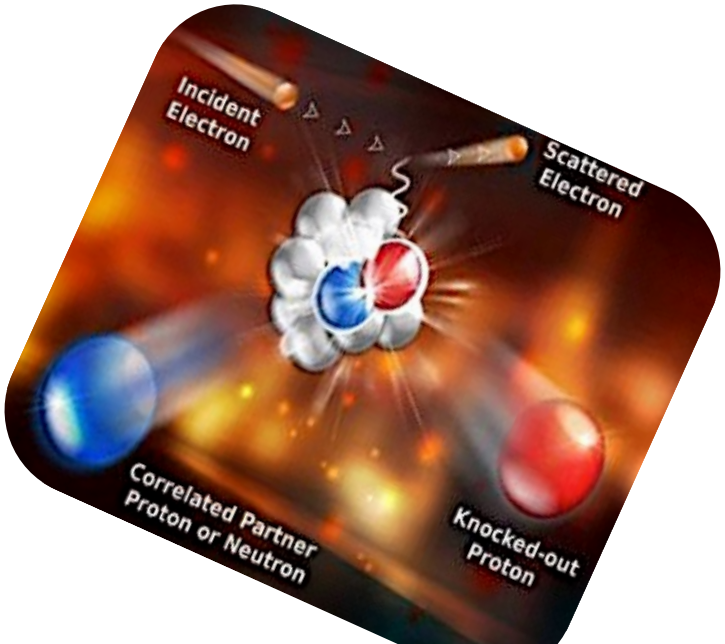
O. Hen et al., Rev. Mod. Phys. 89, 045002 (2017)

What Are SRCs?

SRCs are pairs of nucleon that are close together in the nucleus (wave functions overlap)

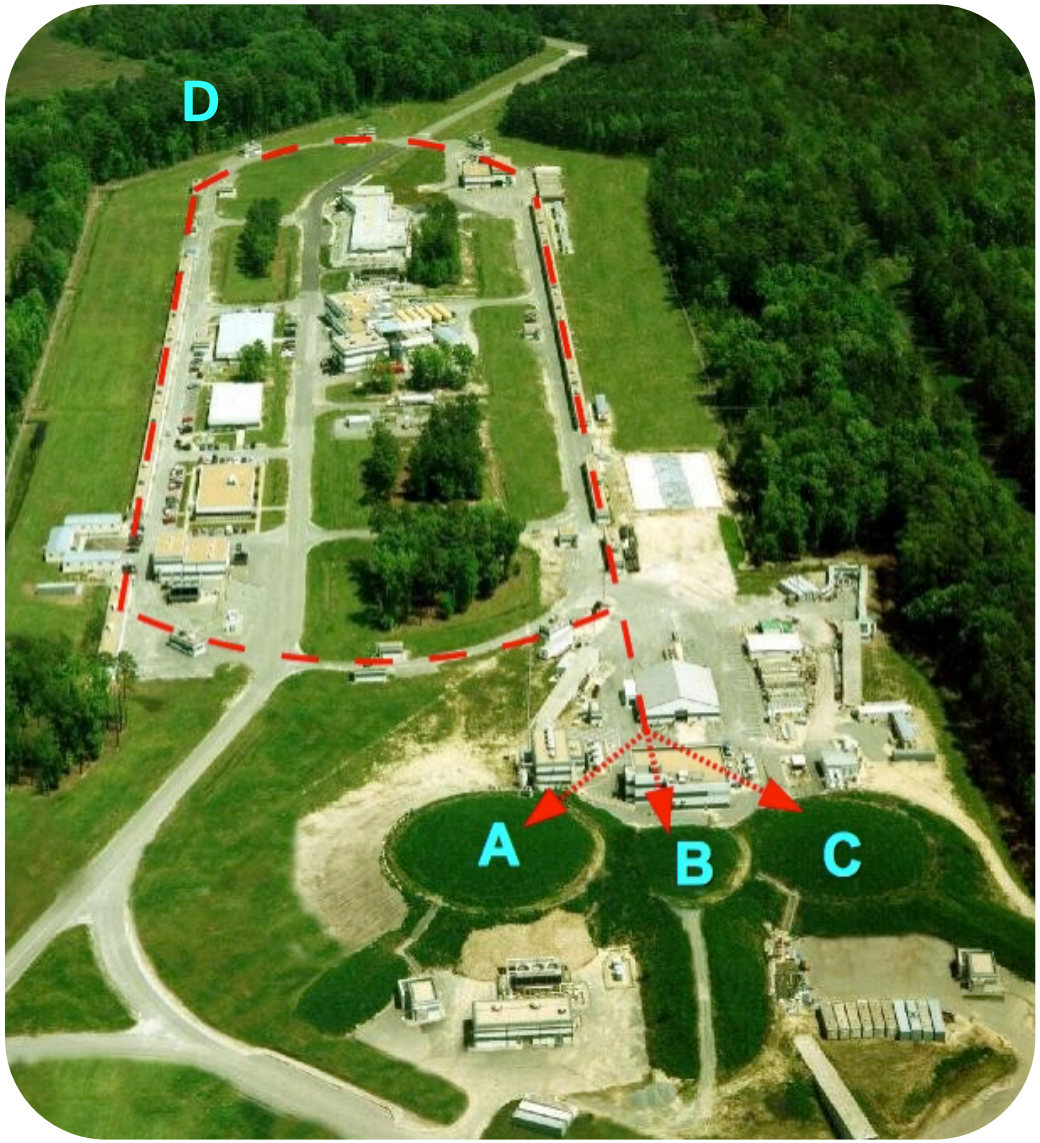
=> Momentum space: pairs with *high relative momentum* and *low c.m. momentum* compared to the Fermi momentum (k_F)



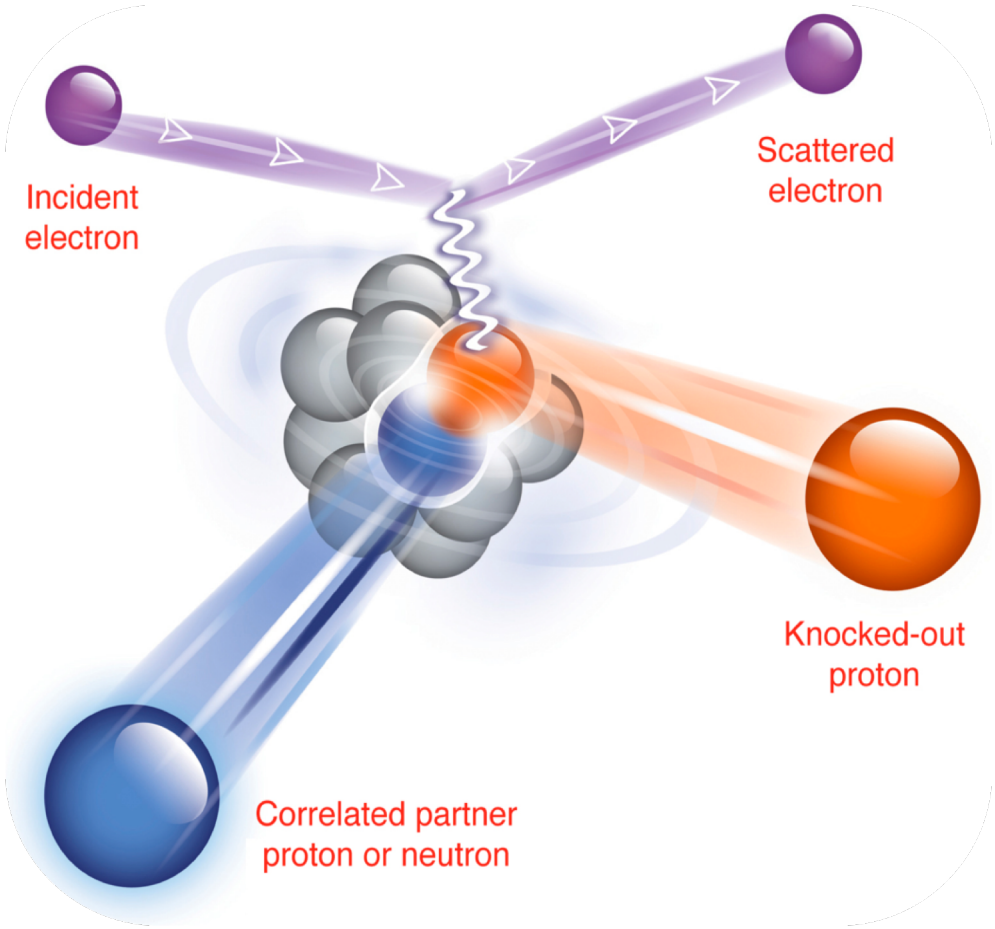


JLab: @ the nuclear–parton boundary

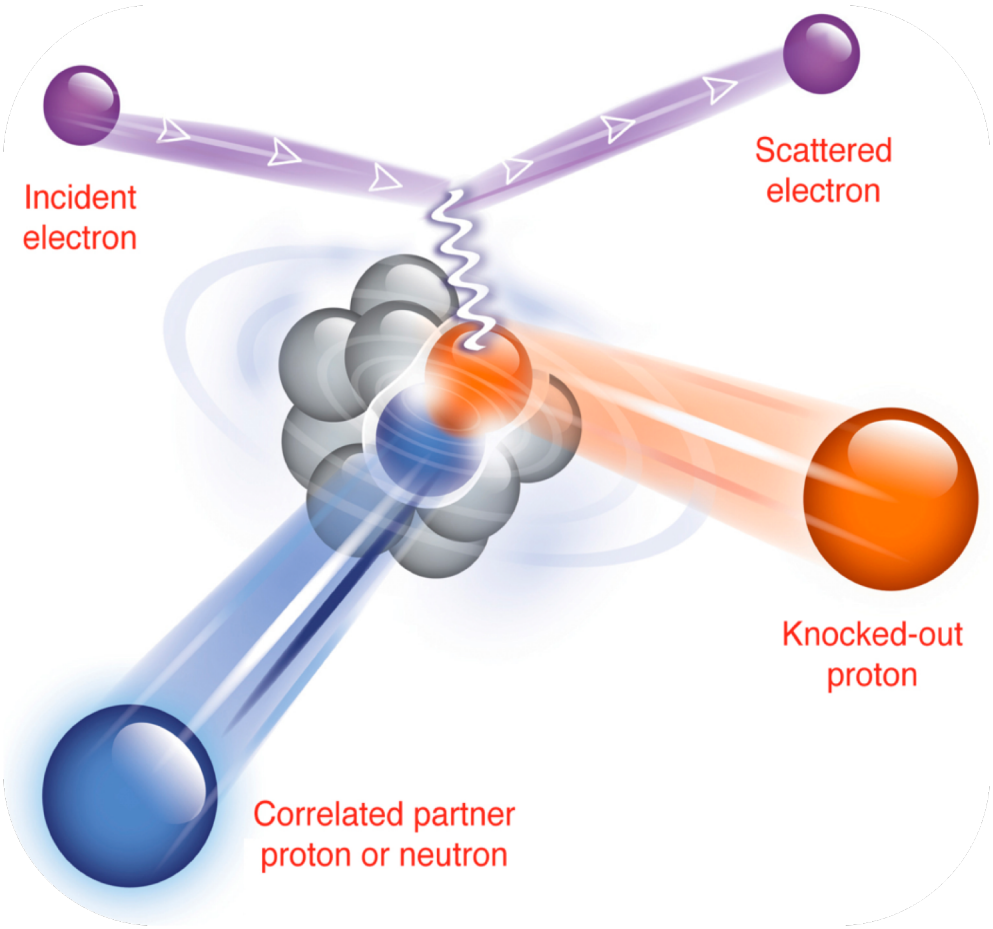
- Located in Virginia USA
- 12 GeV ~80 uA continues polarized electron beam
- Parallel operation of 4 experimental halls
- 12 GeV experiments recently started!
- Approved program for first 8 years of 12 GeV running

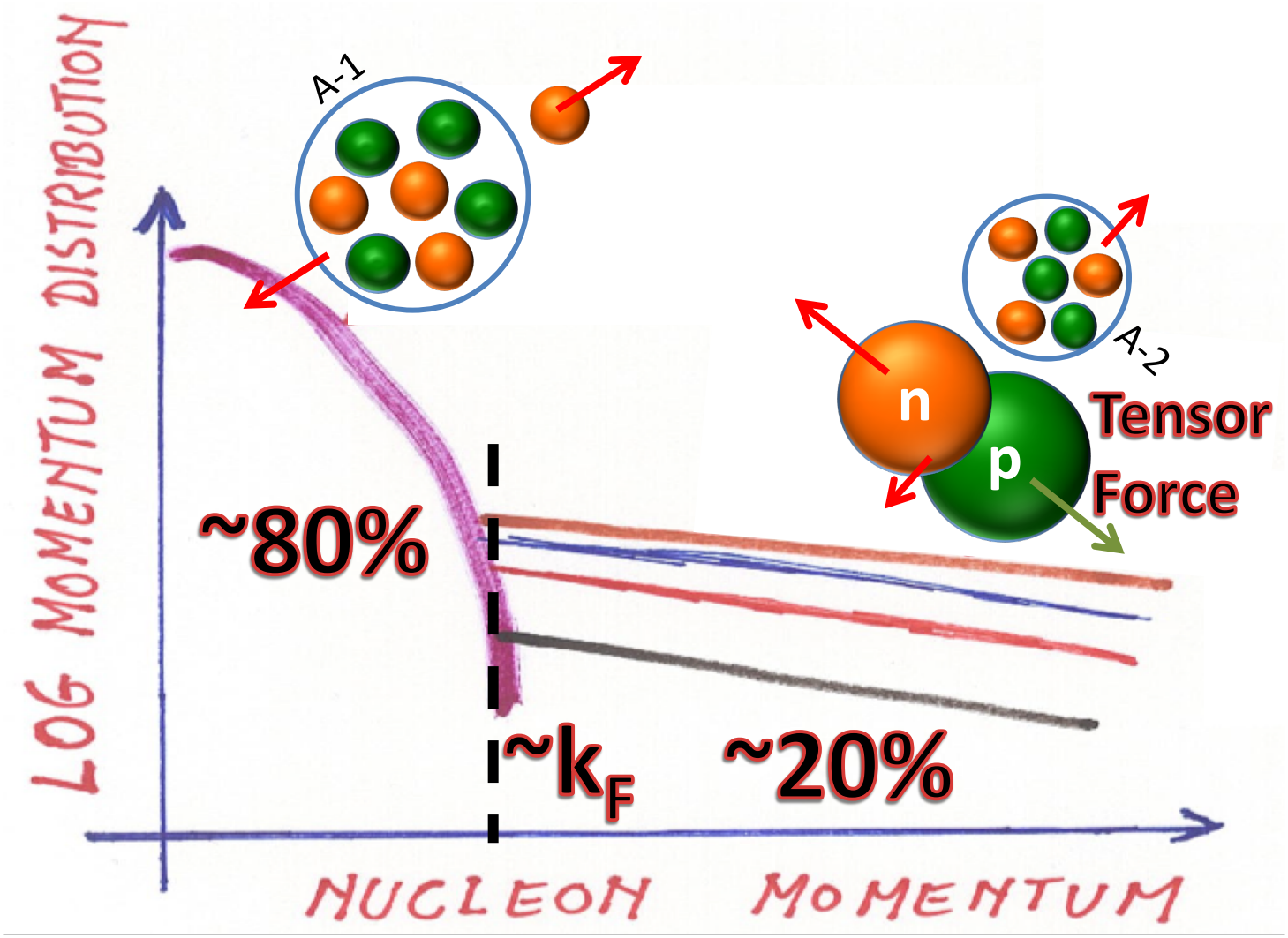


Exclusive SRC studies



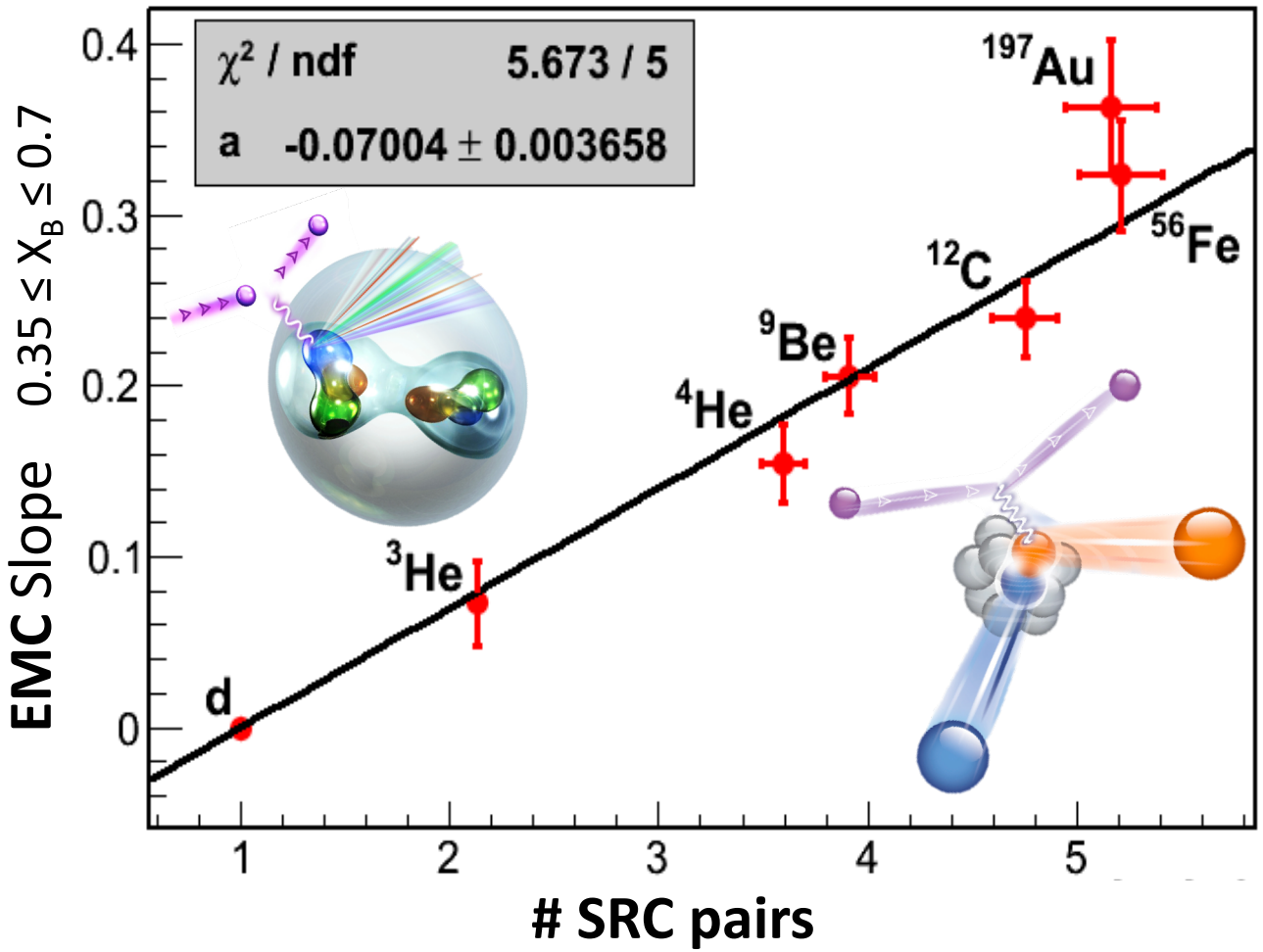
Breakup the pair =>
Detect ***both*** nucleons =>
Reconstruct 'initial' state





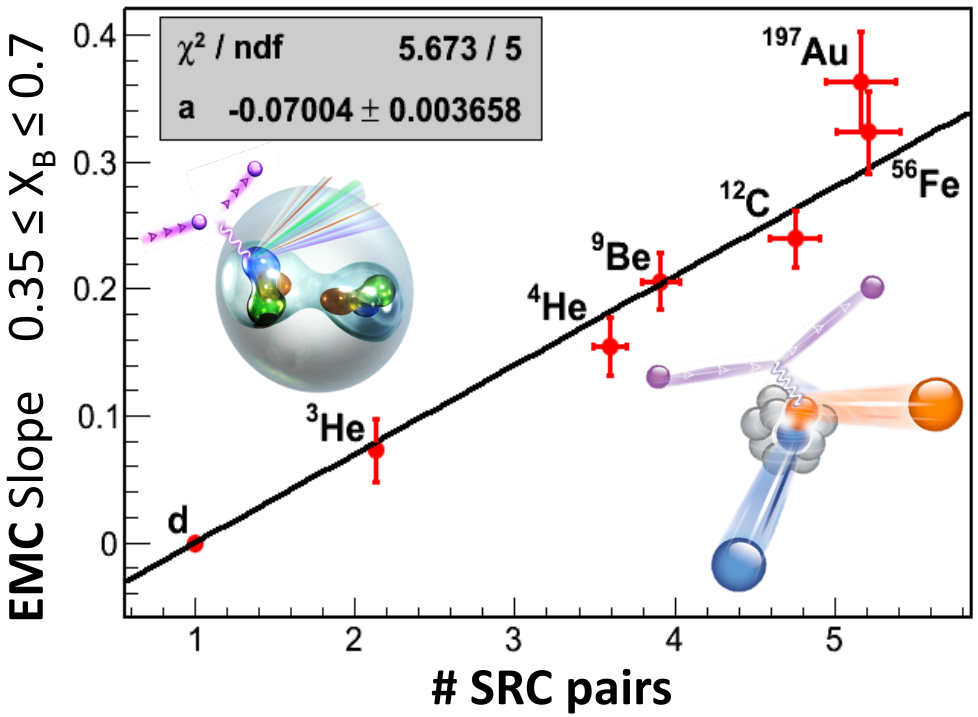
Hen et al., RMP (2017); **Hen** et al., Science (2014); **Hen** et al., PLB (2013); Korover, Muangma and **Hen** et al., PRL (2014); Fomin et al., PRL (2012); Subedi et al., Science (2008); Egiyan et al., PRL (2006);

EMC - SRC Correlation



[(e,e') ratios for $x_B \geq 1.4$]

Hen et al., RMP (2017); **Hen** et al., IJMPE (2013); **Hen** et al., PRC (2012); Weinstein, Piasetzky, Higinbotham, Gomez, **Hen**, and Shneor, PRL (2011).



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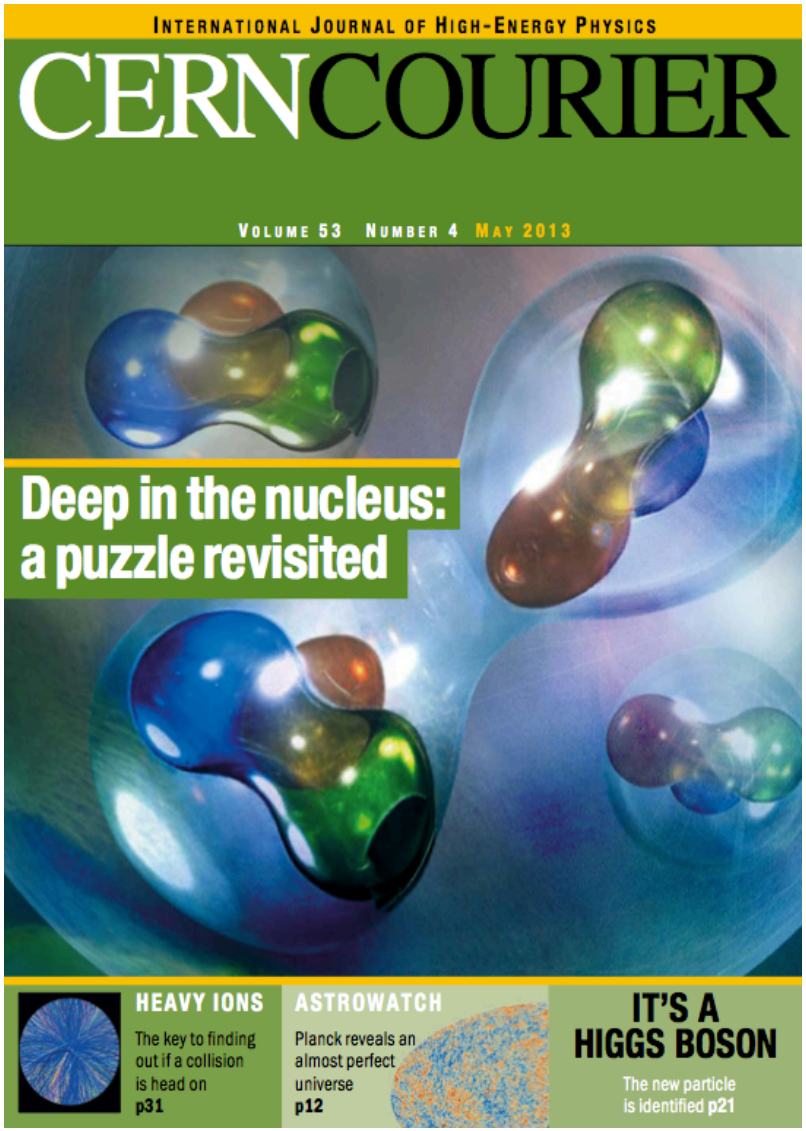
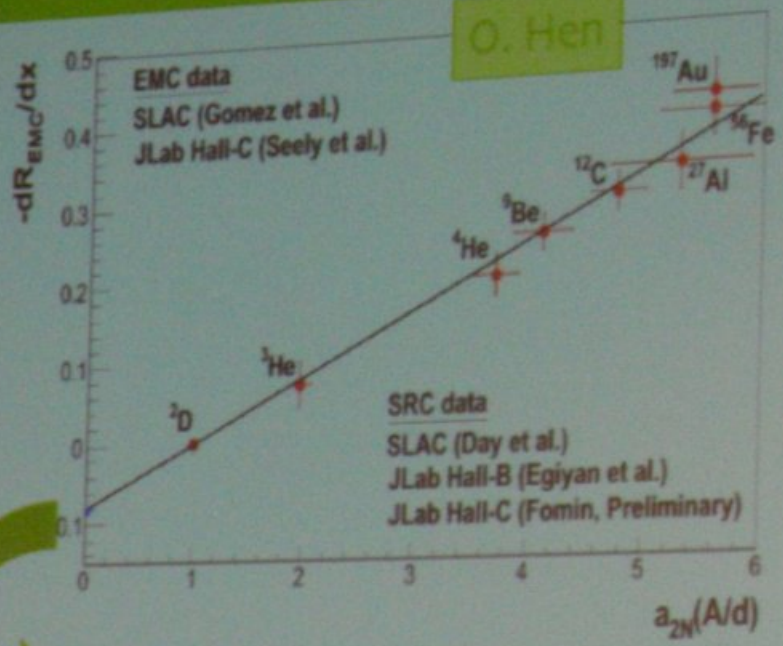


Higinbotham, Miller, **Hen**, and Rith. CERN Cour. 53N4, 35 (2013)

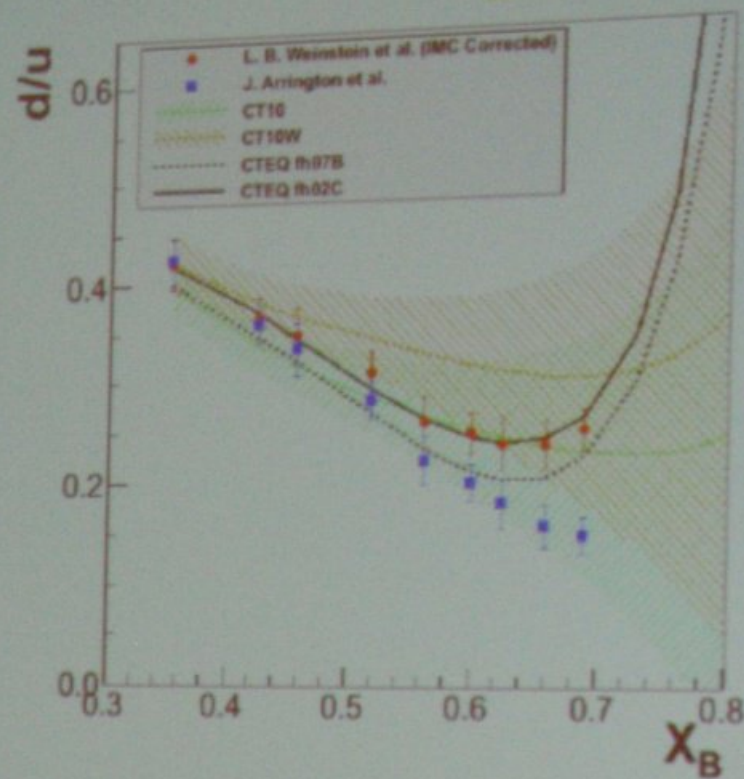
Nuclear corrections

O. Hen



Other phenomenological perspective: the EMC effect is NOT due to average medium effect but to local density effect (number of 2N-ShortRangeCorrelation)

E. Piasetzky



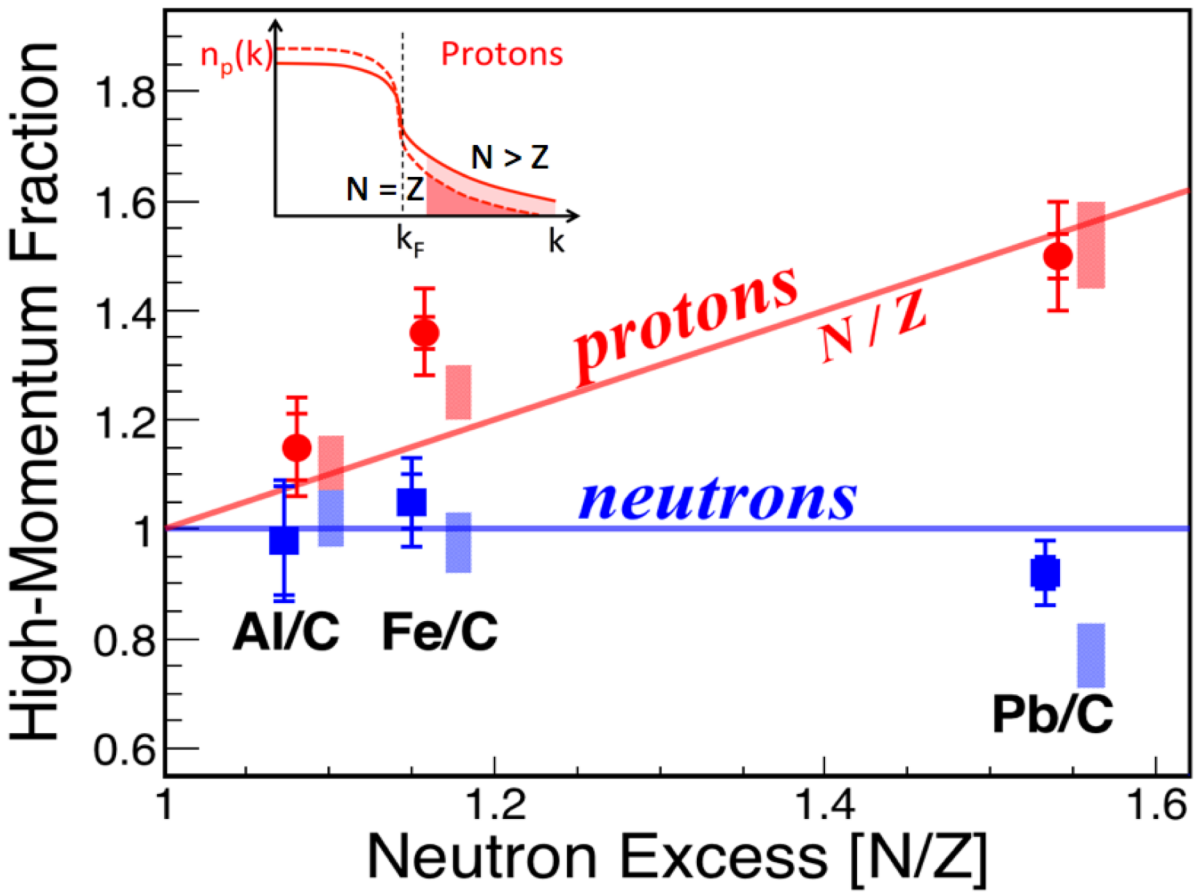
Extrapolate to free proton plus nucleon and apply correction factor to the SLAC F2n/F2p data

$$\frac{F_2^n(x_B,Q^2)}{F_2^p(x_B,Q^2)} = \frac{2F_2^d(x_B,Q^2)/F_2^p(x_B,Q^2) - [1-a(x_B-b)]}{[1-a(x_B-b)]}$$

[See also P. Solvignon talk on Coulomb effect]

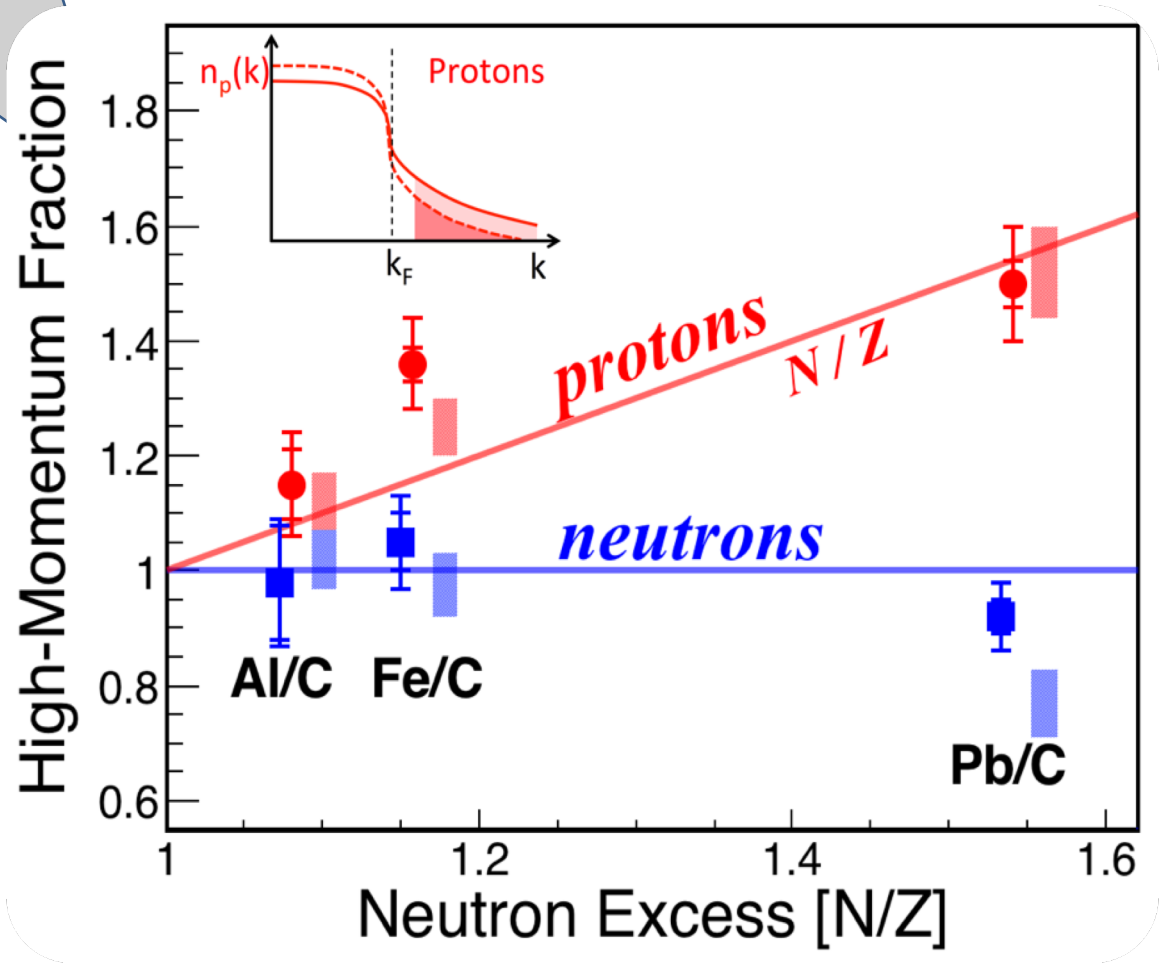
Focusing on Neutron-Rich Nuclei

Correlation Probability:
Neutrons saturate Protons grow



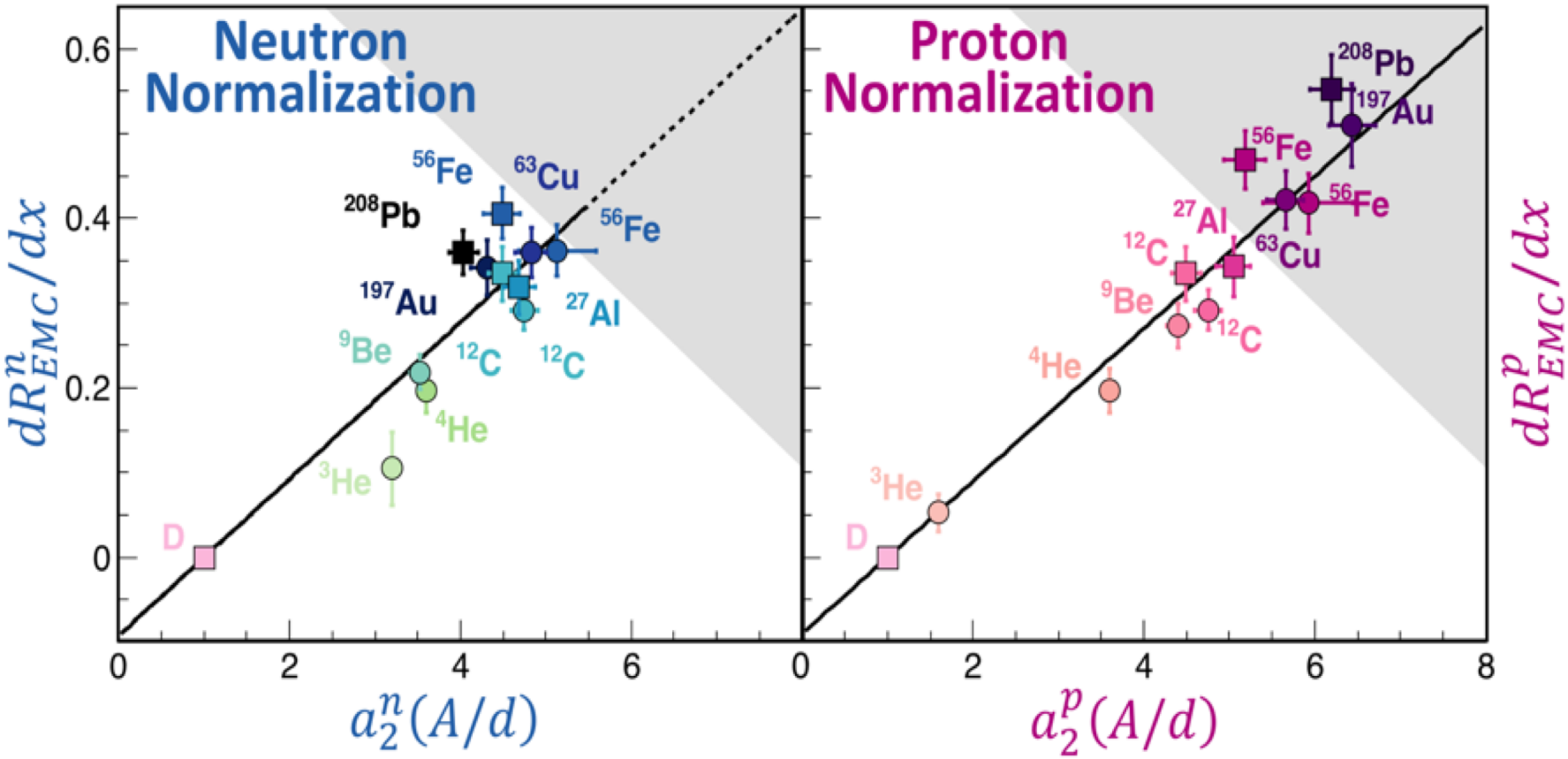
Duer and **Hen** et al. (CLAS Collaboration), submitted (2018)

’Prediction’:
EMC effect should
saturate for neutrons
and grow for protons



Neutrons Saturate, Protons Grow

B. Schmookler



Schmookler, Duer, Schmidt, and **Hen** et al., submitted (2018)

Neutrons Saturate, Protons Grow

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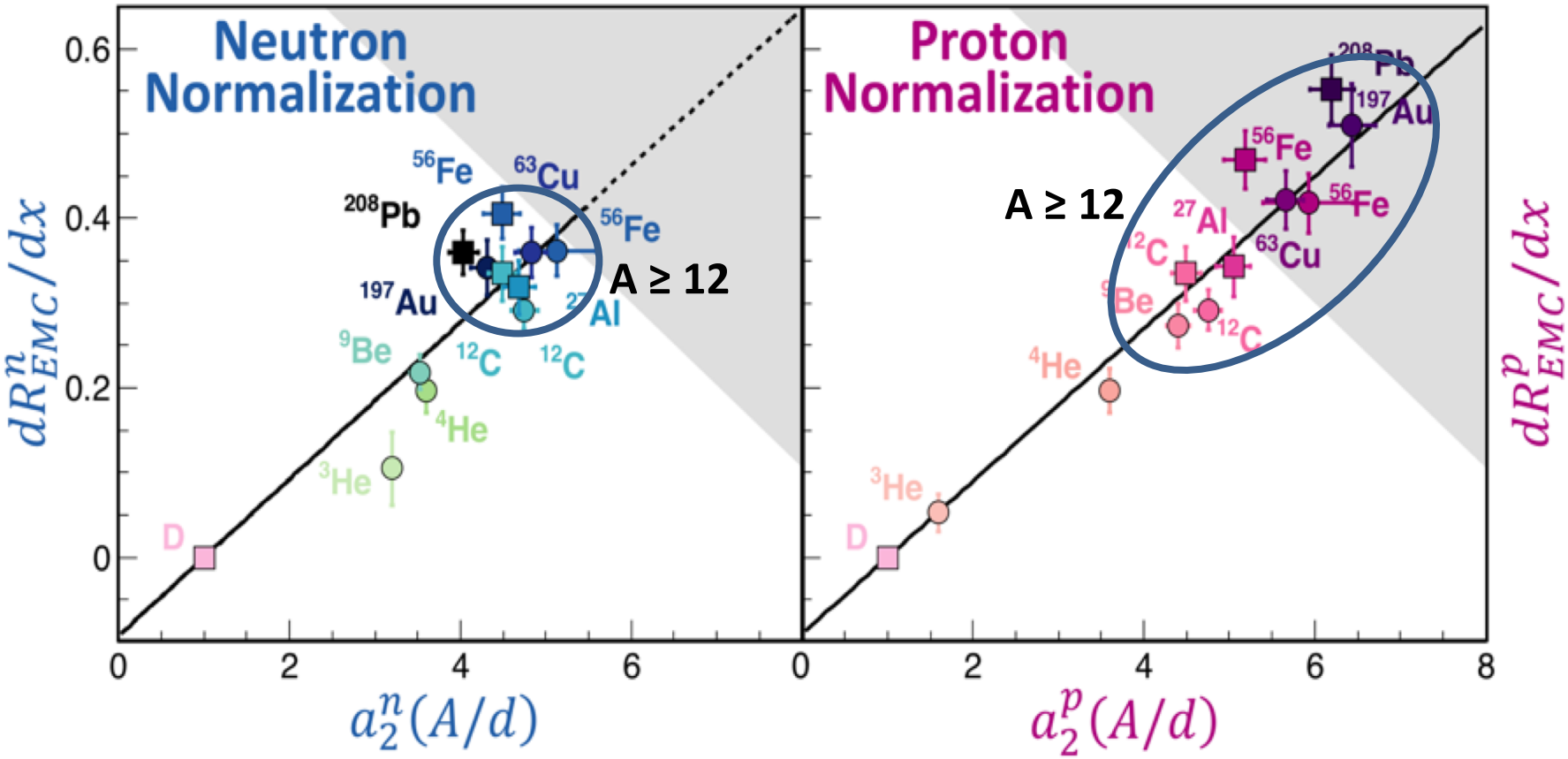
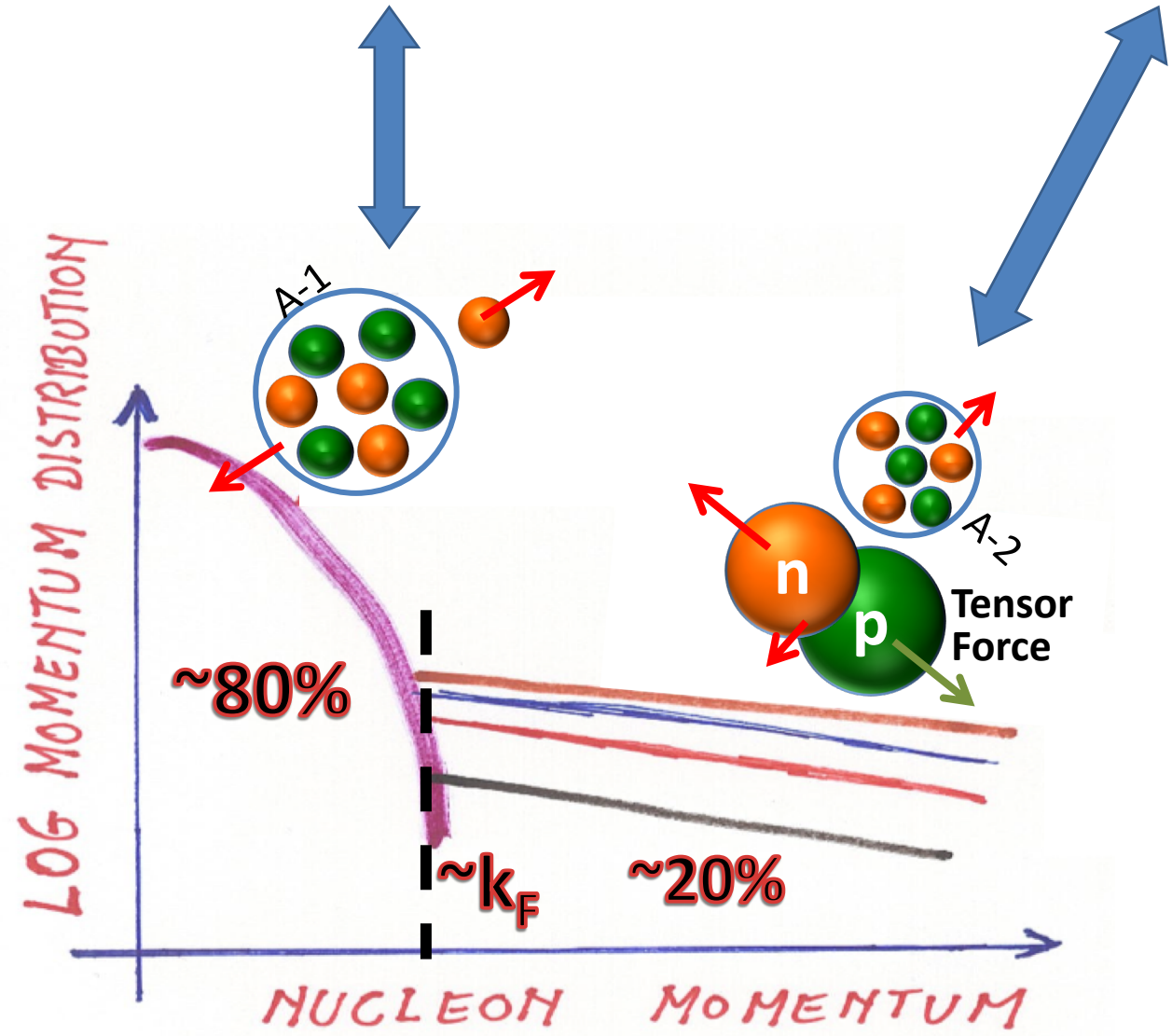


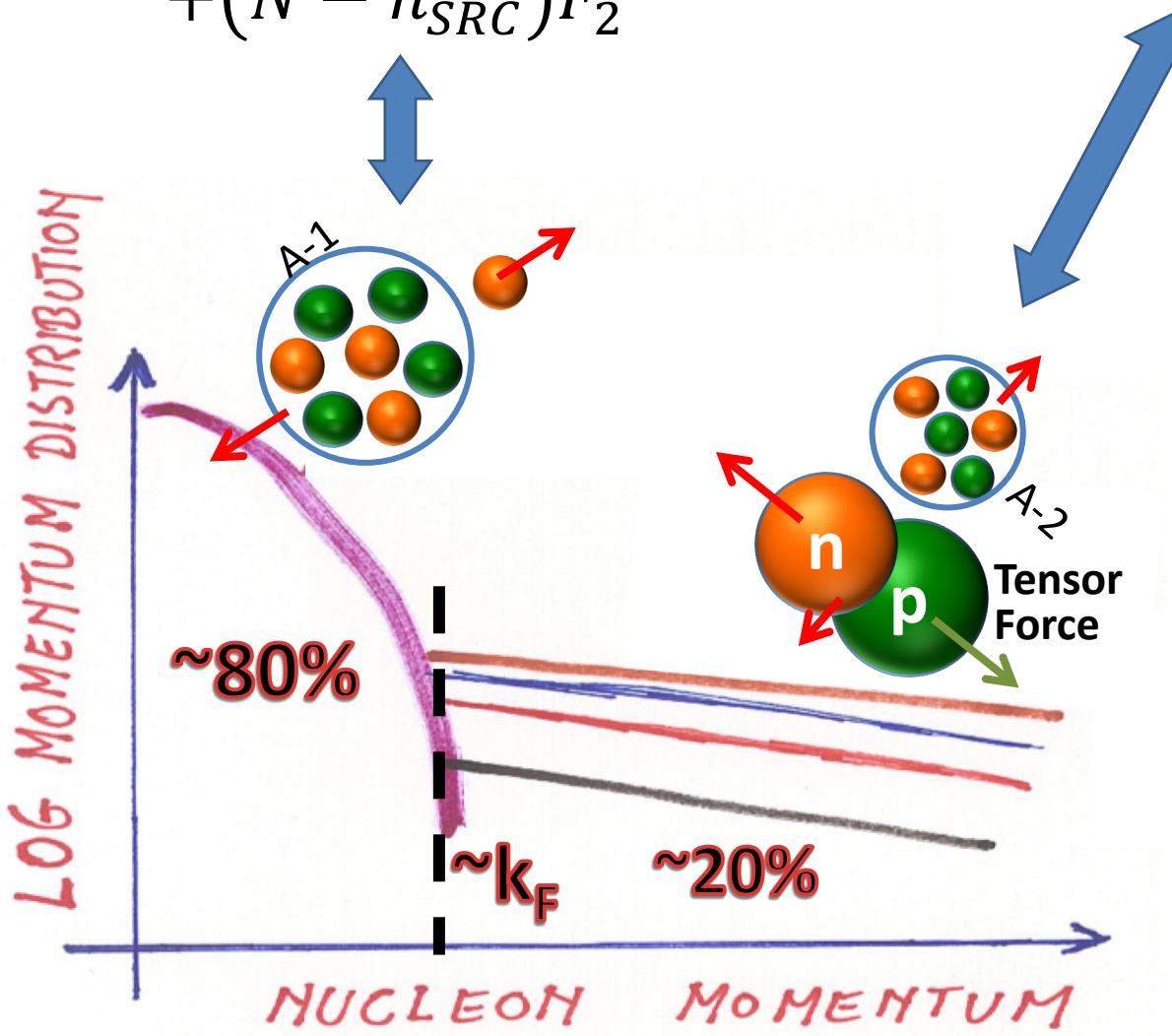
Schmookler, Duer, Schmidt, and **Hen** et al., submitted (2018)

Bound = ‘quasi Free’ + Modified SRCs



Bound = 'quasi Free' + Modified SRCs

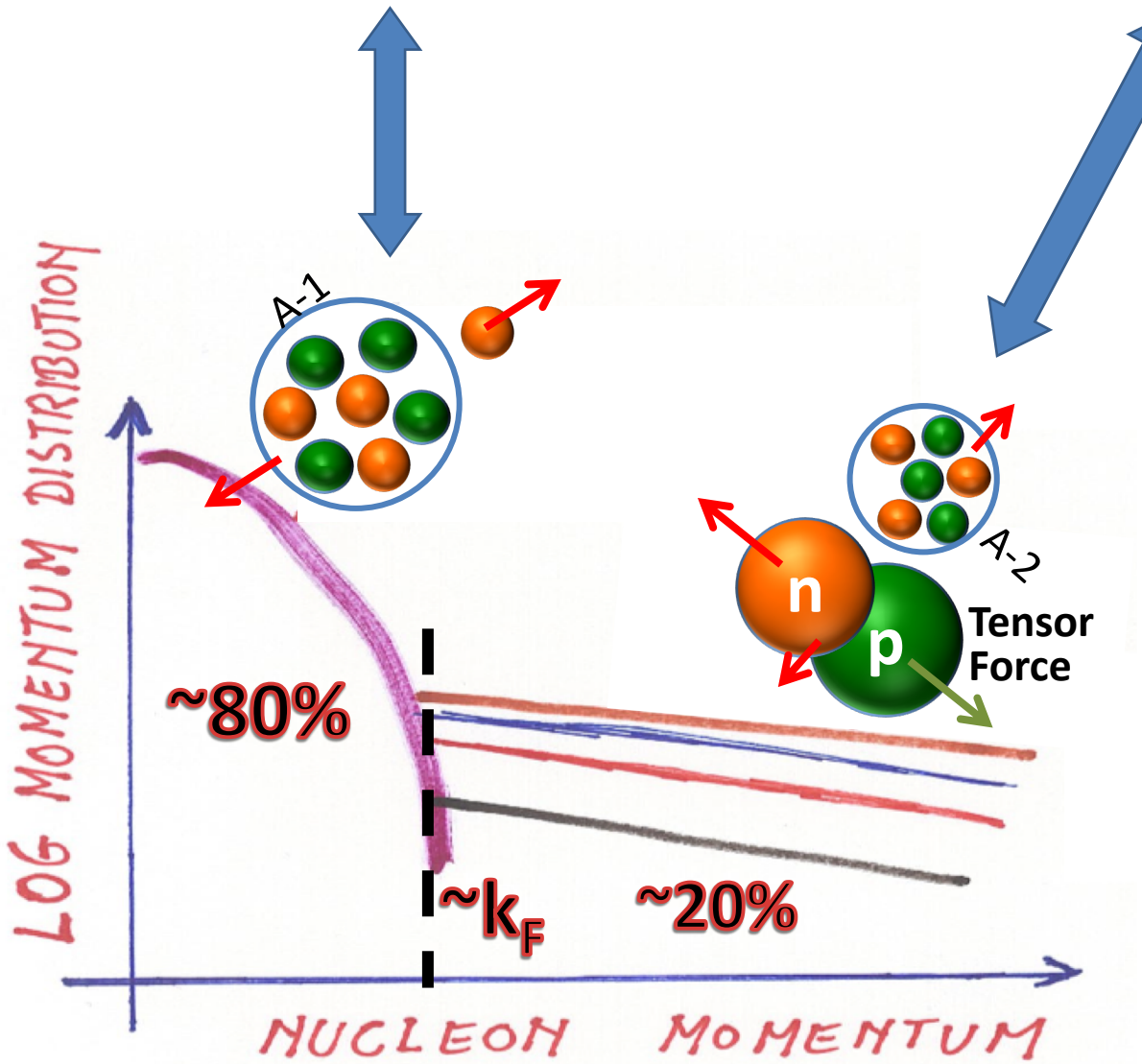
$$F_2^A = \begin{matrix}(Z - n_{SRC}^A)F_2^p \\ +(N - n_{SRC}^A)F_2^n\end{matrix} + n_{SRC}^A\left(F_2^{p*} + F_2^{n*}\right)$$



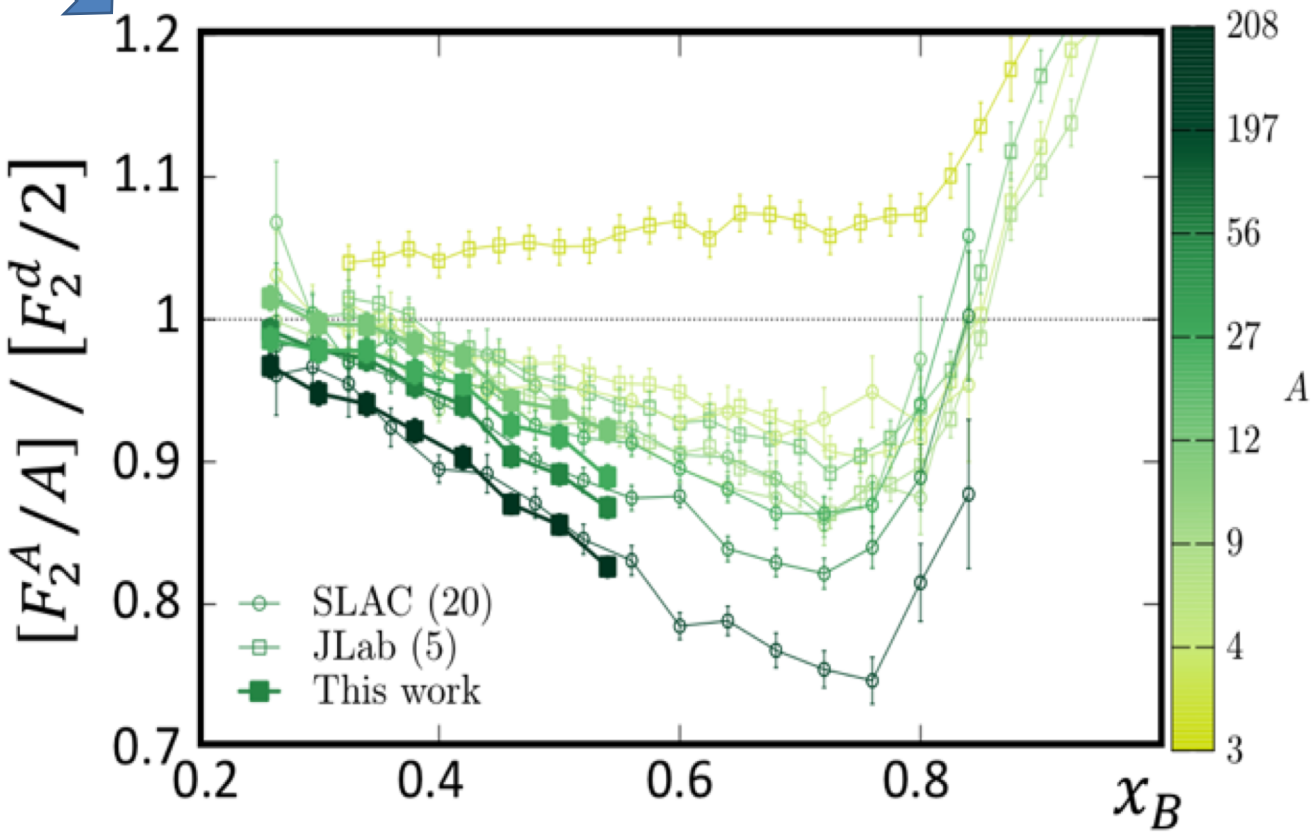
Bound = 'quasi Free' + Modified SRCs

$$F_2^A = ZF_2^p + NF_2^n + n_{SRC}^A\left(\Delta F_2^p + \Delta F_2^n\right)$$

$$\Delta F_2^N = F_2^{N*} - F_2^N$$



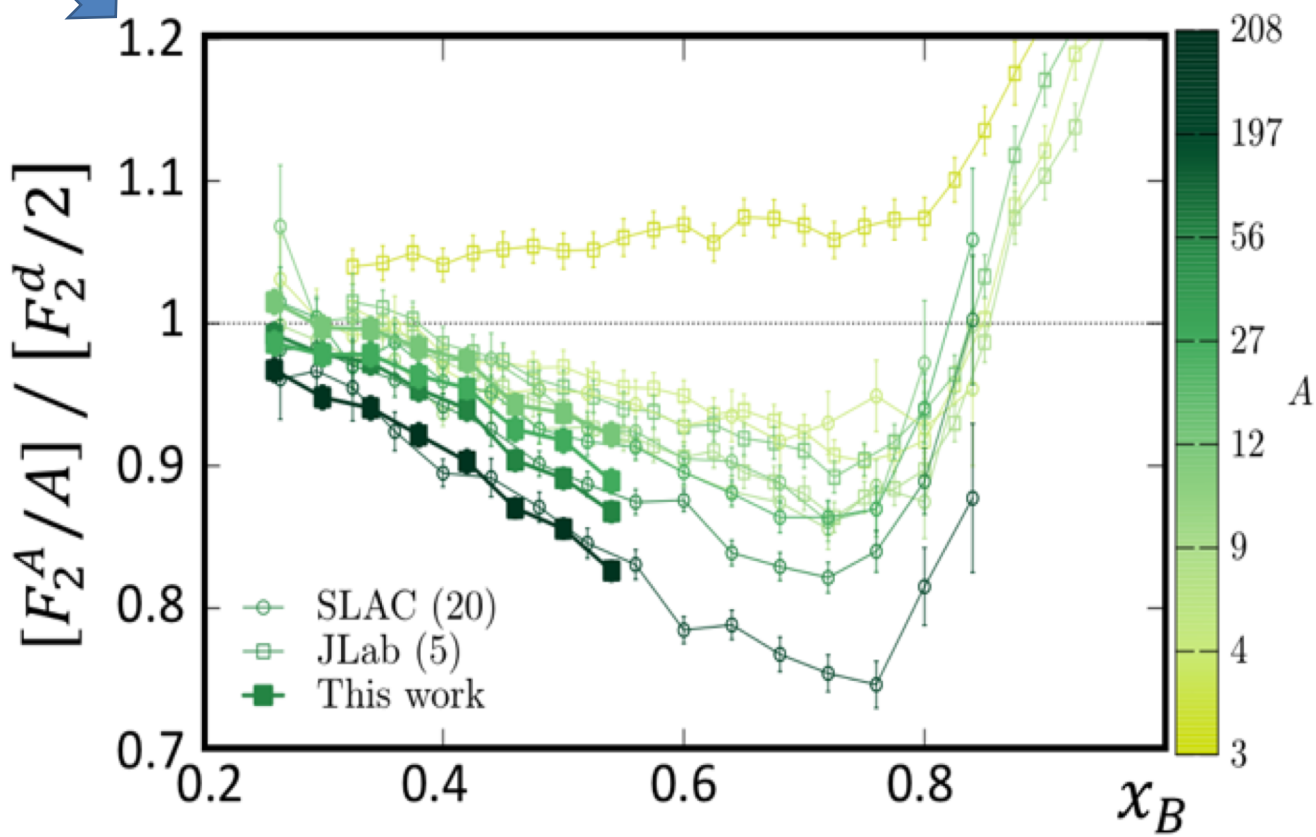
$$\frac{F_2^A}{F_2^d} = \left(n_{SRC}^A - N n_{SRC}^d\right)\frac{\Delta F_2^p + \Delta F_2^n}{F_2^d} + (Z - N)\frac{F_2^p}{F_2^d} + N$$



$$\Delta F_2^N = F_2^{N*} - F_2^N$$

Universal ?

$$\frac{F_2^A}{F_2^d} = \left(n_{SRC}^A - N n_{SRC}^d\right)\frac{\Delta F_2^p + \Delta F_2^n}{F_2^d} + (Z-N)\frac{F_2^p}{F_2^d} + N$$



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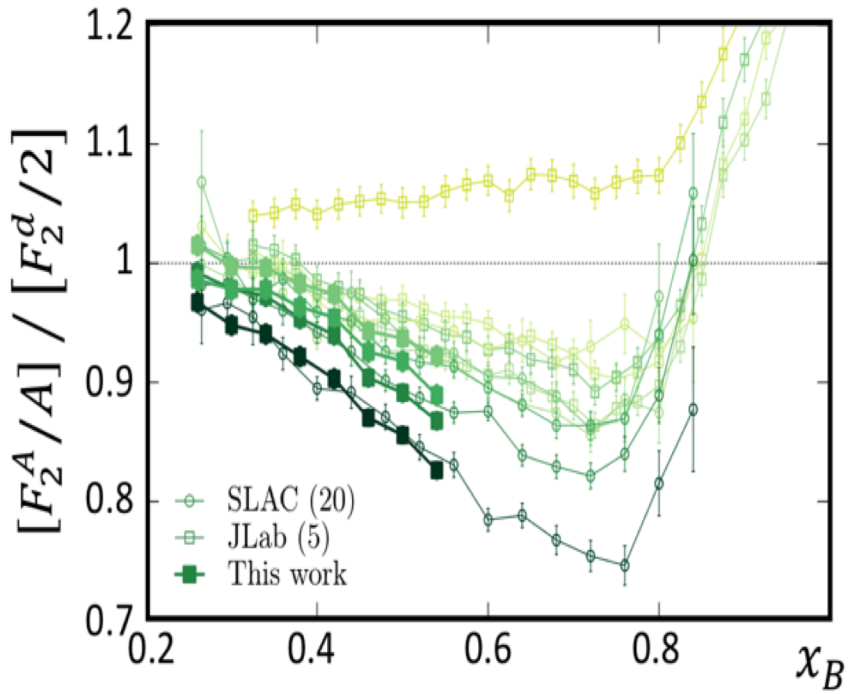
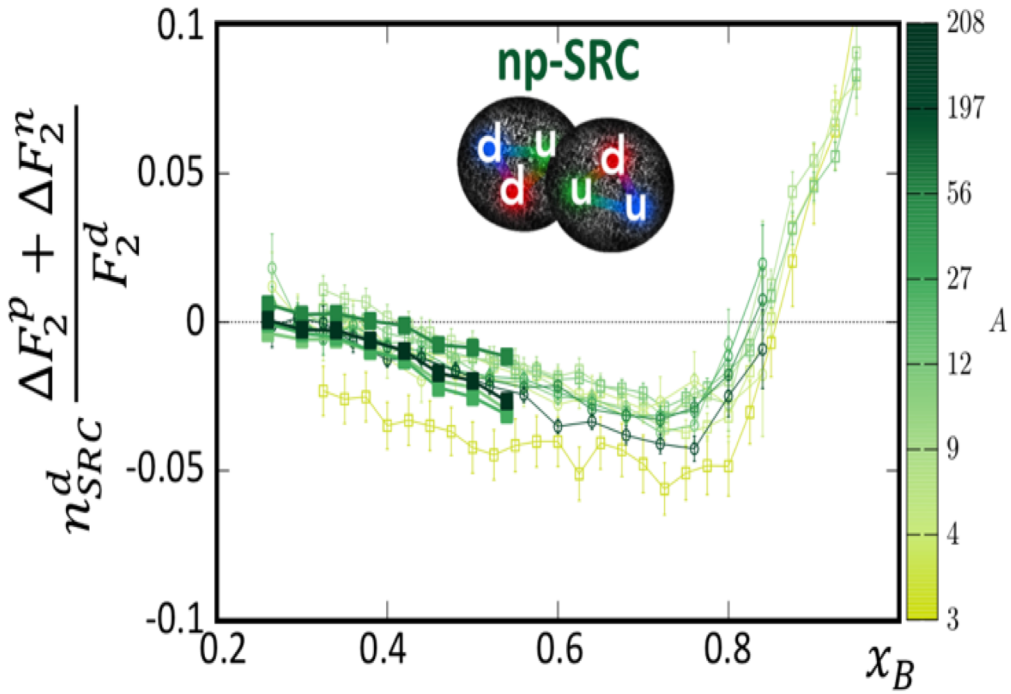
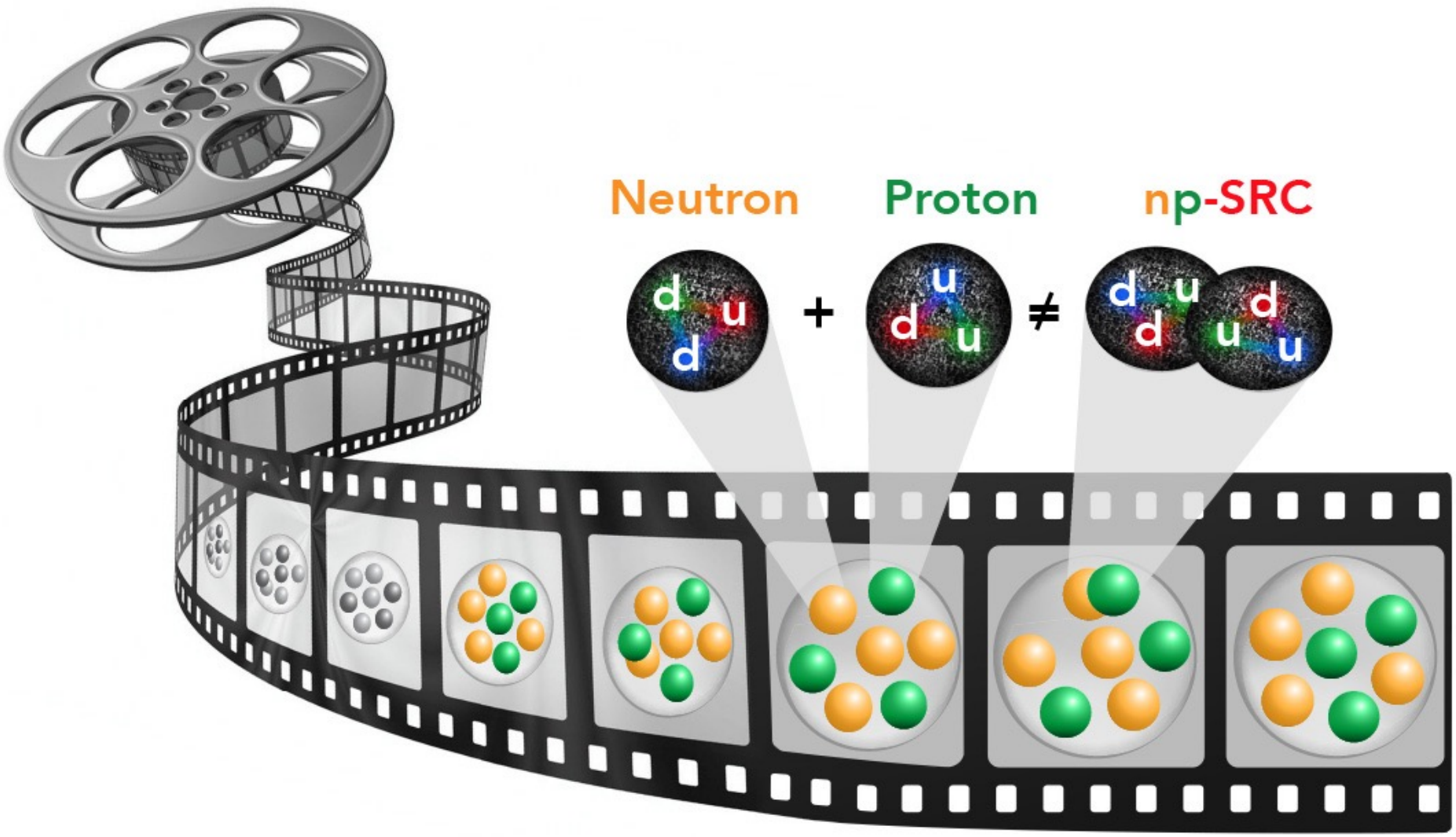




Schmookler, Duer, Schmidt, and **Hen** et al., submitted (2018)

$$\Delta F_2^N = F_2^{N*} - F_2^N$$

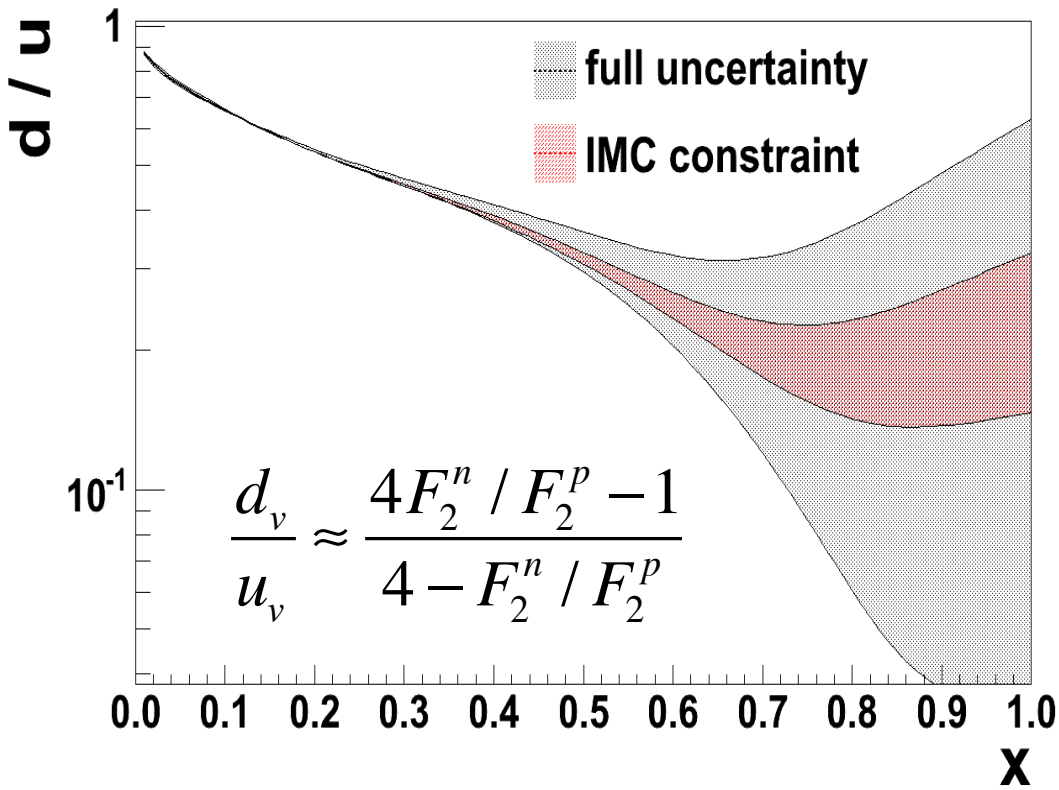
Nuclear fluctuations



Schmookler, Duer, Schmidt, and **Hen** et al., submitted (2018)

Free-Neutron Extraction

$$|p\uparrow\rangle = \frac{1}{\sqrt{2}}|u\uparrow(ud)_{S=0}\rangle + \frac{1}{\sqrt{18}}|u\uparrow(ud)_{S=1}\rangle - \frac{1}{3}|u\downarrow(ud)_{S=1}\rangle$$
$$-\frac{1}{3}|d\uparrow(uu)_{S=1}\rangle + \frac{\sqrt{2}}{3}|d\downarrow(uu)_{S=1}\rangle$$

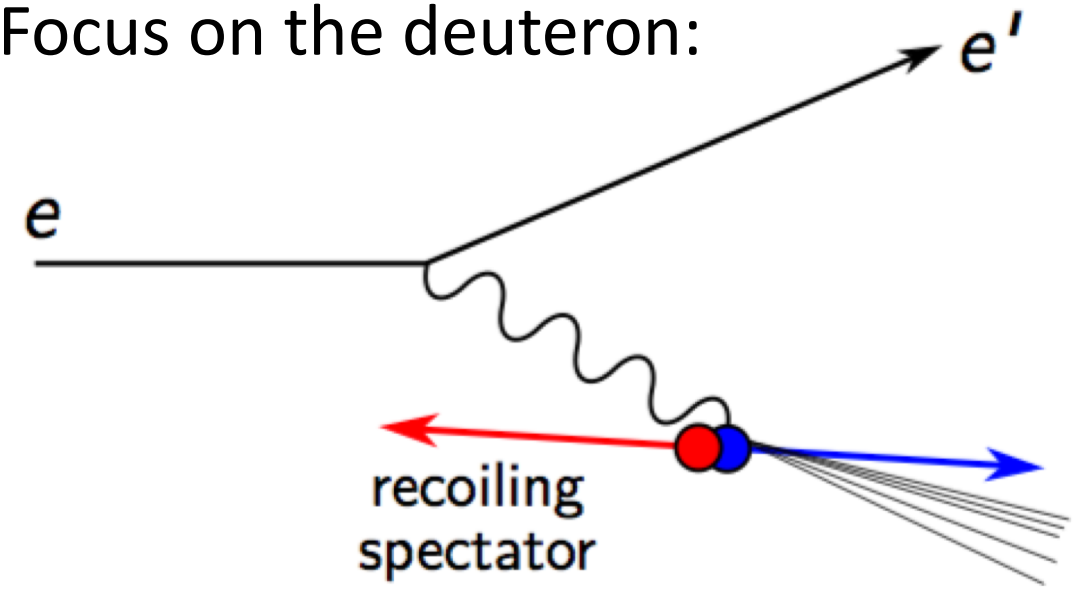


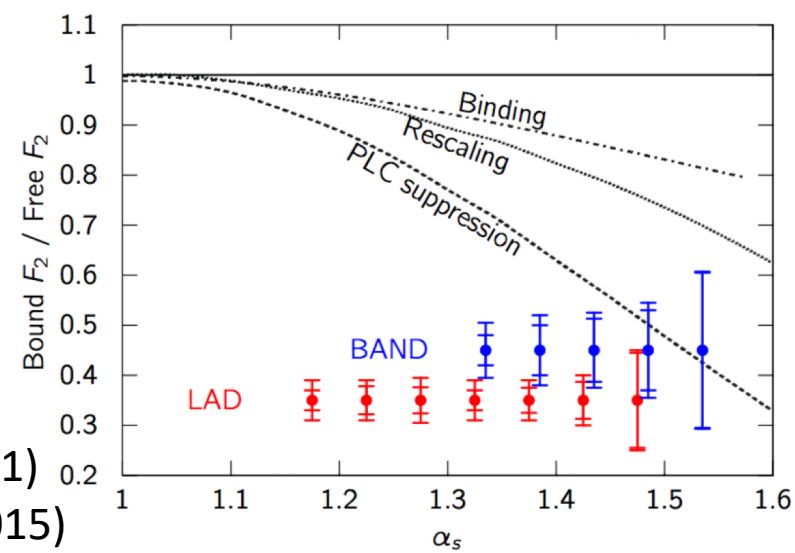
Model	F_2^n/F_2^p	d / u
SU(6)	2 / 3	0.5
pQCD (S_z=0)	3 / 7	0.2
Scalar Diquark	1 / 4	0

Hen, Accardi, Melnitchouk, and Piasetzky, PRD (2011).

JLab12: Bound Nucleon Structure

Focus on the deuteron:





Hen et al. (spokesperson), JLab Experiment E11-107 (2011)
Hen et al. (spokesperson), JLab Experiment E11-003A (2015)

JLab12: Bound Nucleon Structure

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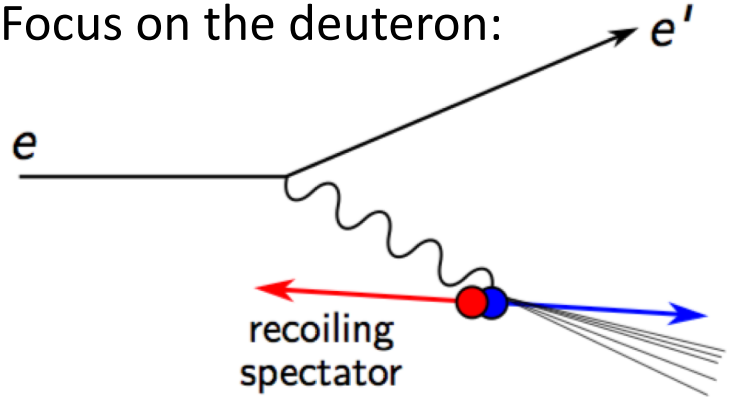
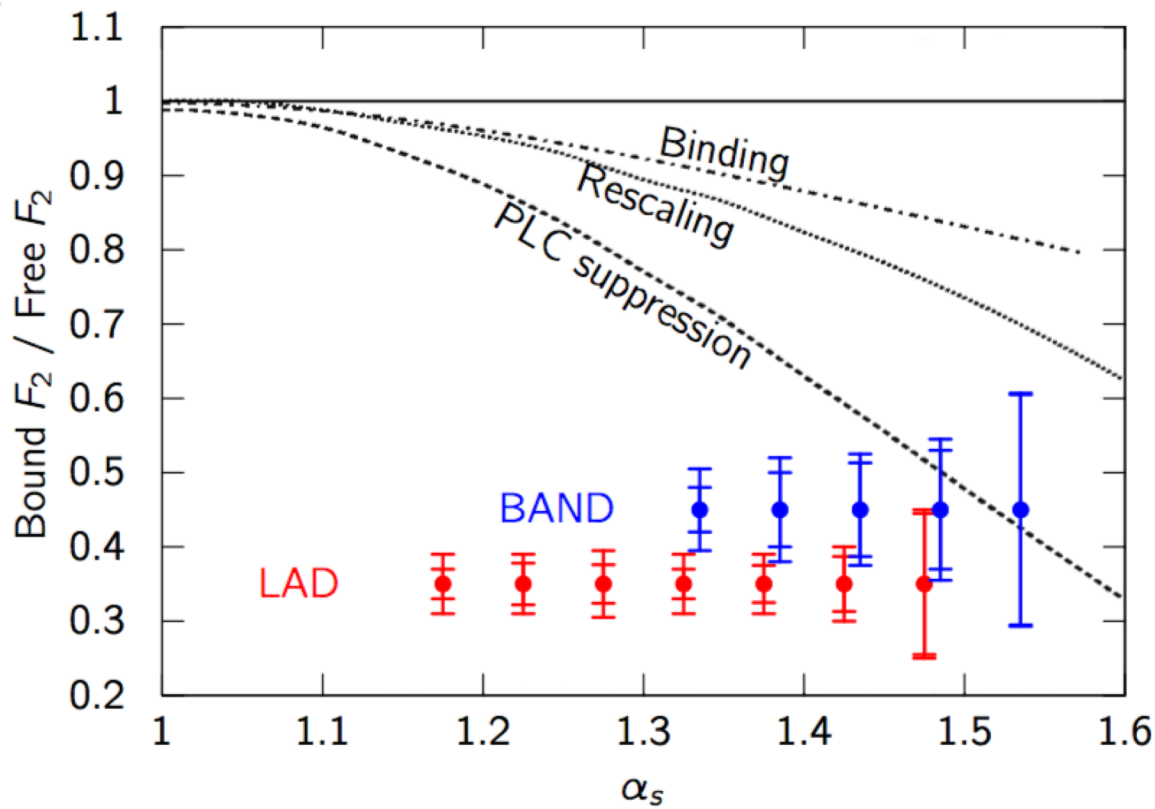
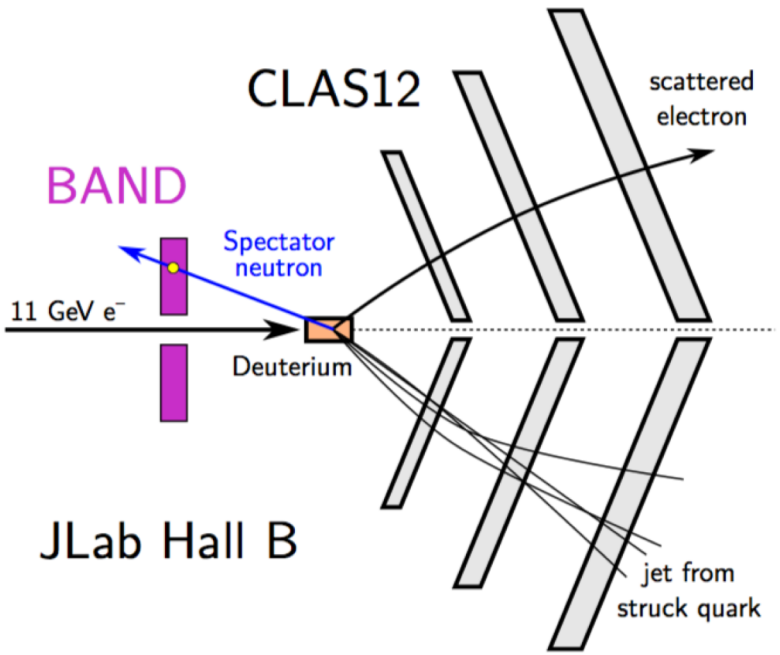


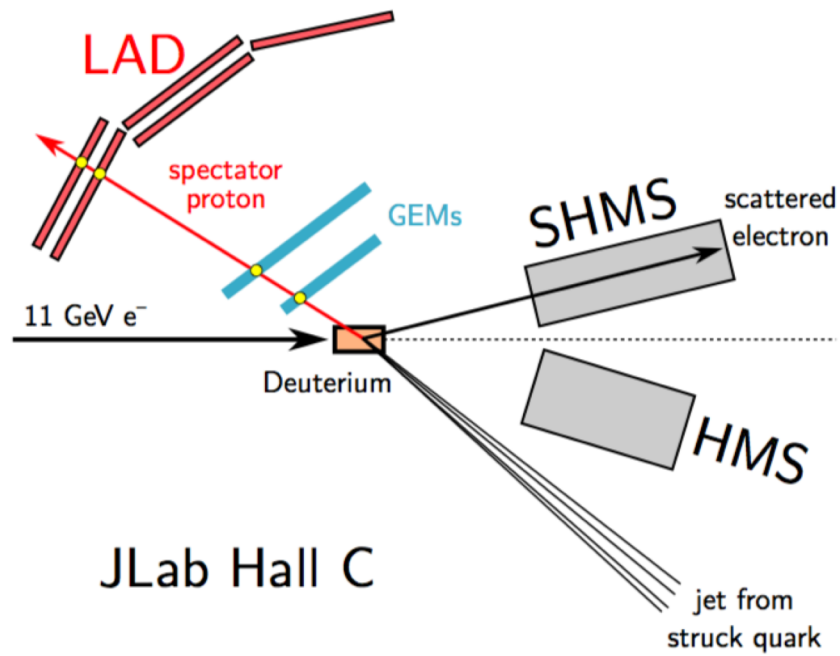


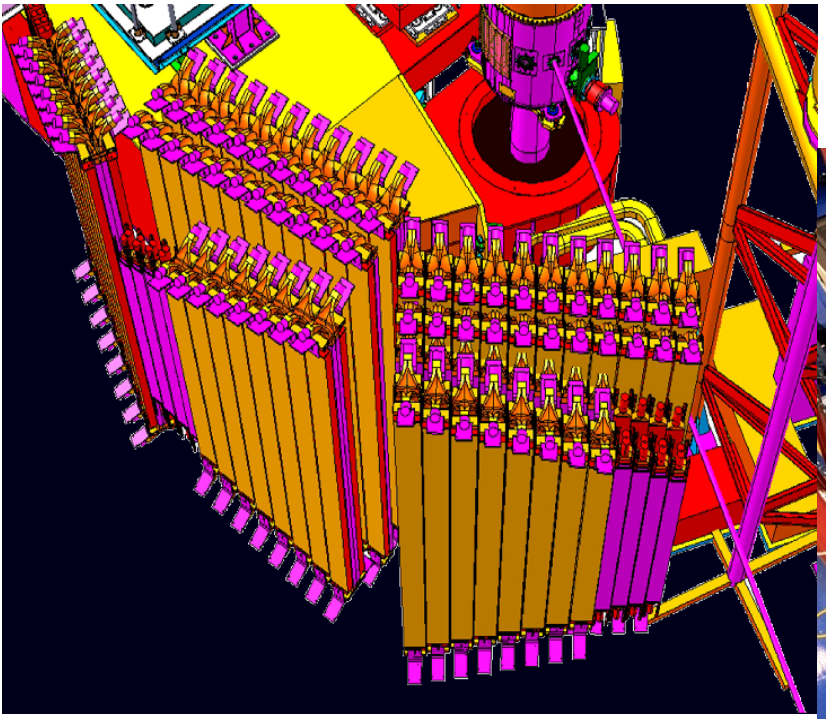
Hen et al. (spokesperson), JLab Expe

Hen et al. (spokesperson), JLab Expe

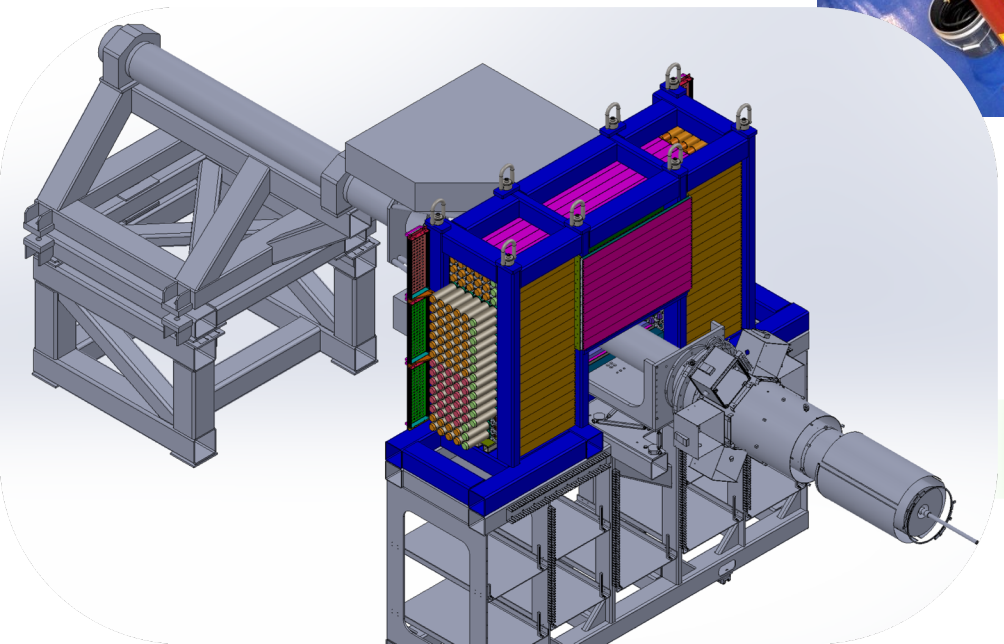
JLab12: Bound Nucleon Structure







Large Acceptance Detector (LAD@Hall-C)



Backward Angle Neutron Detector (BAND@Hall-B)

MIT / UTSM / TAU / ODU

The EMC-SRC World

Always looking to enlarge the collaboration! ☺

+ Many Theory Collaborators: UW, Penn State, Huji, Gent, FIU, Perugia, …

MIT Correlations group (Prof. O. Hen)

Barak Schmookler

Reynier Torres

Afroditi Papadopoulou

Efrain Segarra

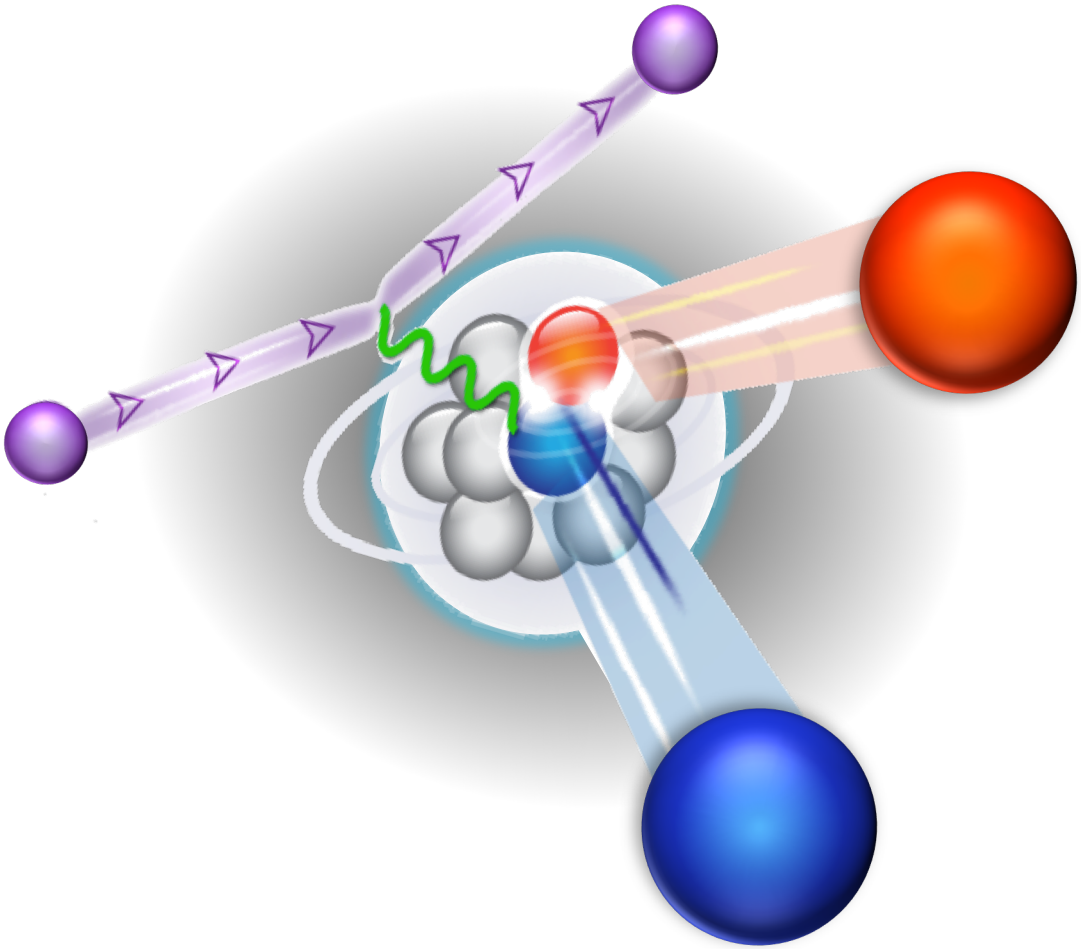
Dr. Axel Schmidt

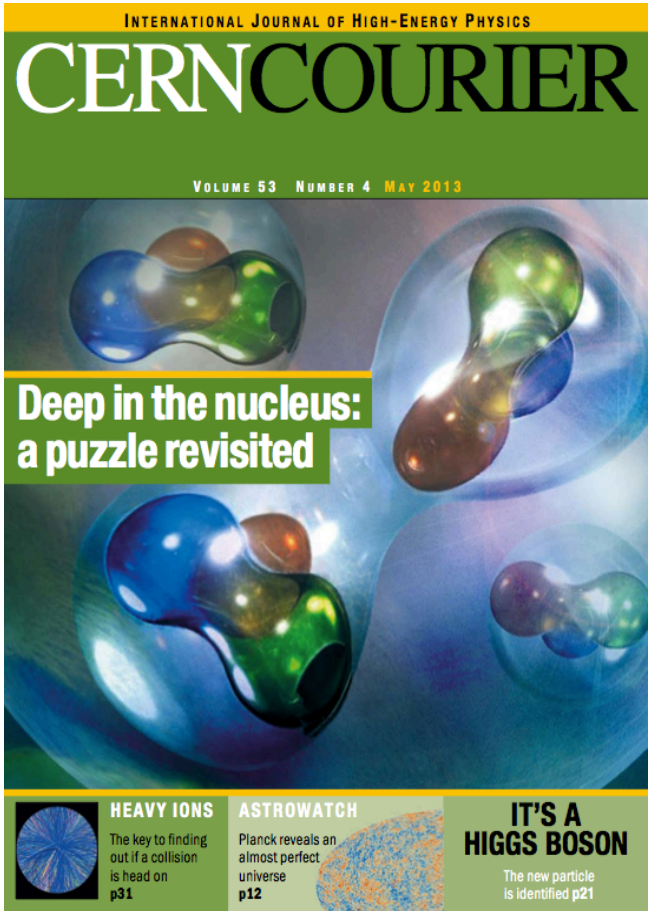
Dr. Adi Ashkenazy

Dr. Maria Patsyuk

Dr. George Laskaris

Thank You!





Hen et al., RMP (2018); Colle and **Hen** et al., PRC (2015); **Hen** et al., Science (2014); **Hen** et al., PLB (2013); Korover, Muangma and **Hen** et al., PRL (2014); **Hen** et al., IJMPE (2013); **Hen** et al., PRC (2012); **Hen** et al., PRD (2011); Weinstein, Piasetzky, Higinbotham, Gomez, **Hen**, and Shneor, PRL (2011).

+ Many works by colleagues from other groups