DIS 2013

XXI International Workshop on Deep-Inelastic Scattering and Related Subjects

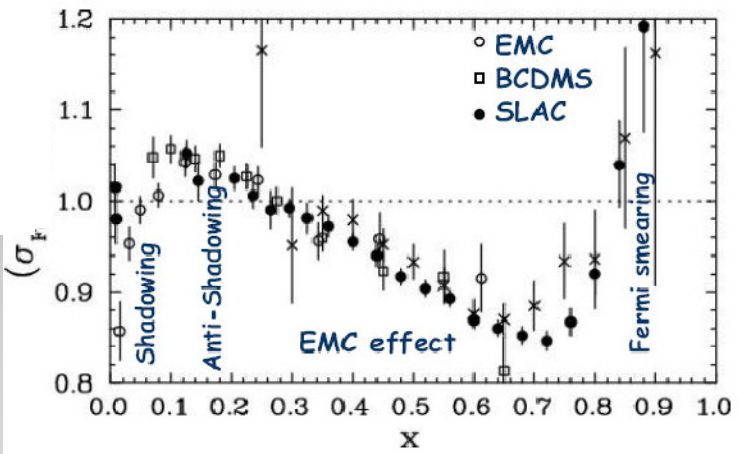
22-26 April 2013
Marseille, Parc Chanot

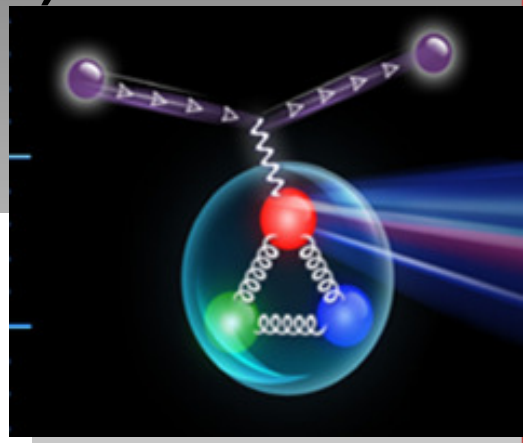
TEL AVIV UNIVERSITY

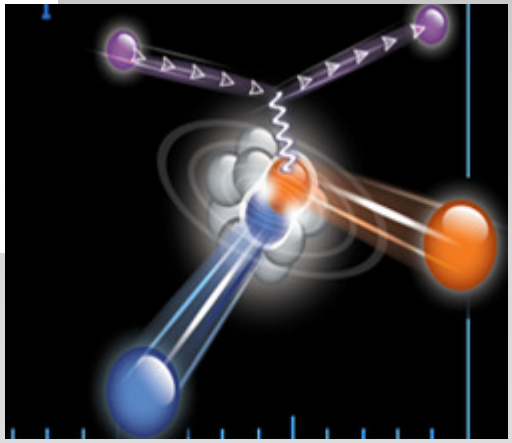
# The EMC effect and Short Range Correlation in nuclei

## (extracting the Free neutron structure function)

The EMC effect is 30 years old





**Eli Piasetzky**

**Tel Aviv University, Israel**

**Type:** Talk in Parallel Session at DIS2013
**Session:** WG1: Structure Functions
**Track:** Structure functions and Parton Densities

# Deep Inelastic Scattering (DIS)

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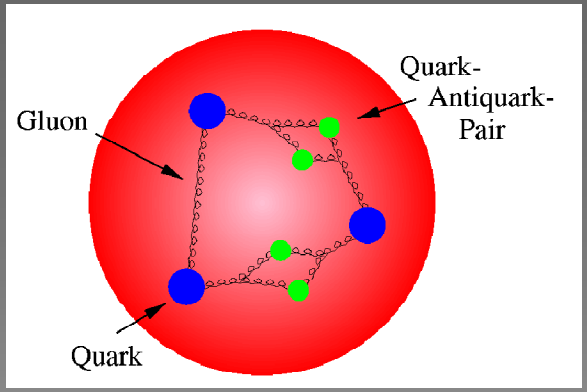
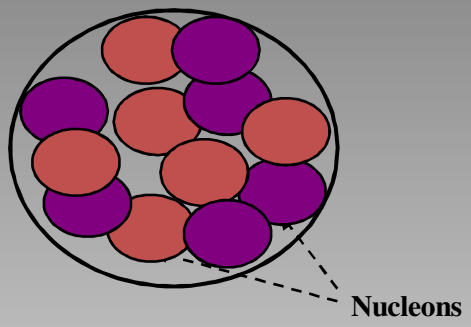
**DIS scale: several tens of GeV**

**Nucleon in nuclei are bound by ~MeV**

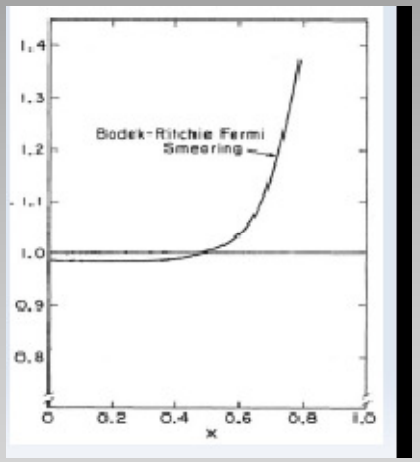


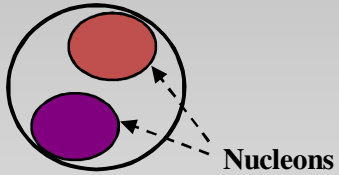




## Naive expectations :

**DIS off a bound nucleon = DIS off a free nucleon**

(Except for small Fermi momentum corrections)




**Deuteron: binding energy ~2 MeV**

**Average nucleons separation ~2 fm**

**DIS off a deuteron = DIS off a free proton neutron pair**

# The European Muon Collaboration (EMC) effect

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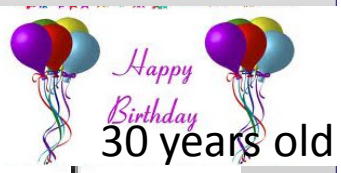
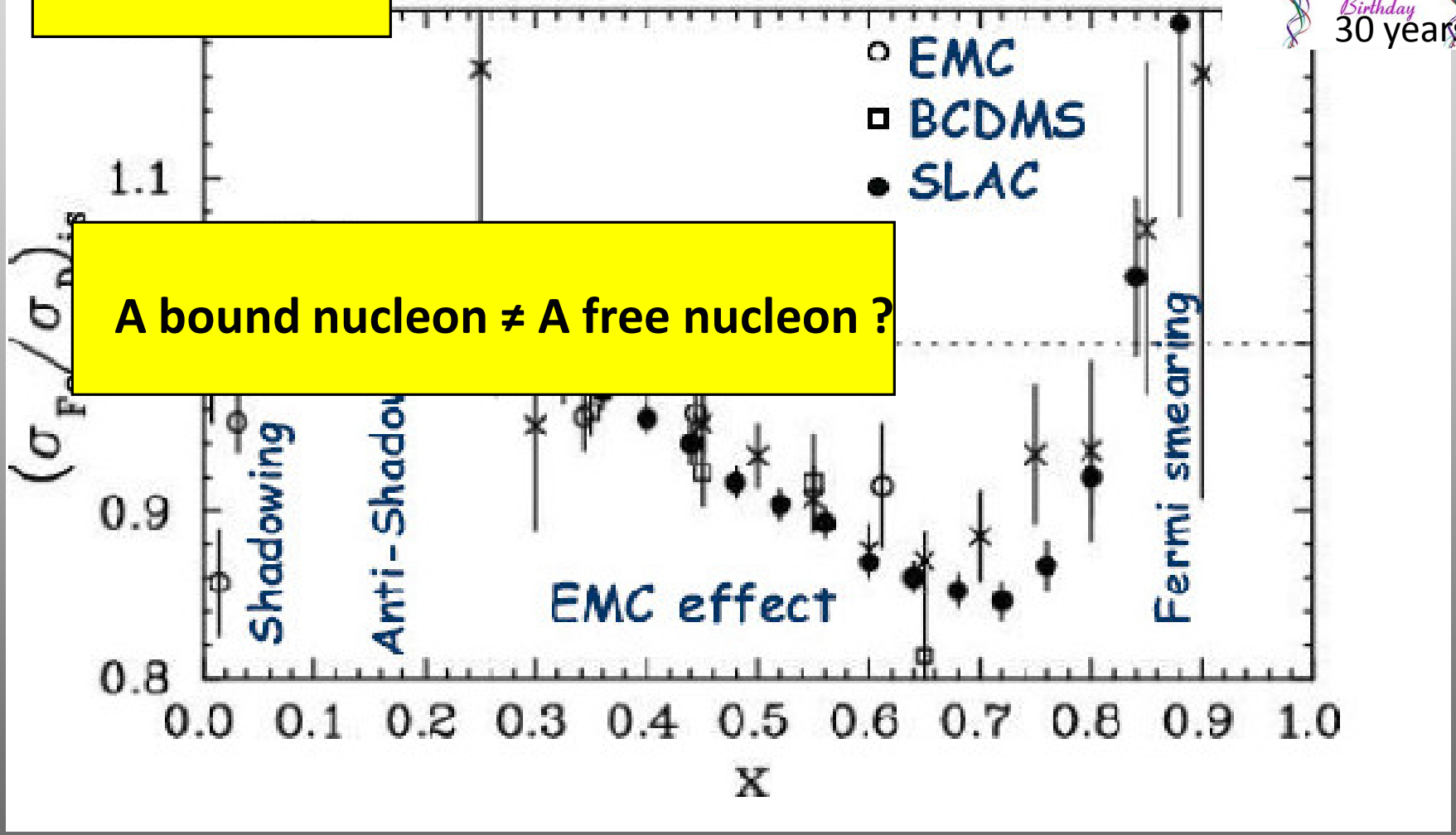



30 years old

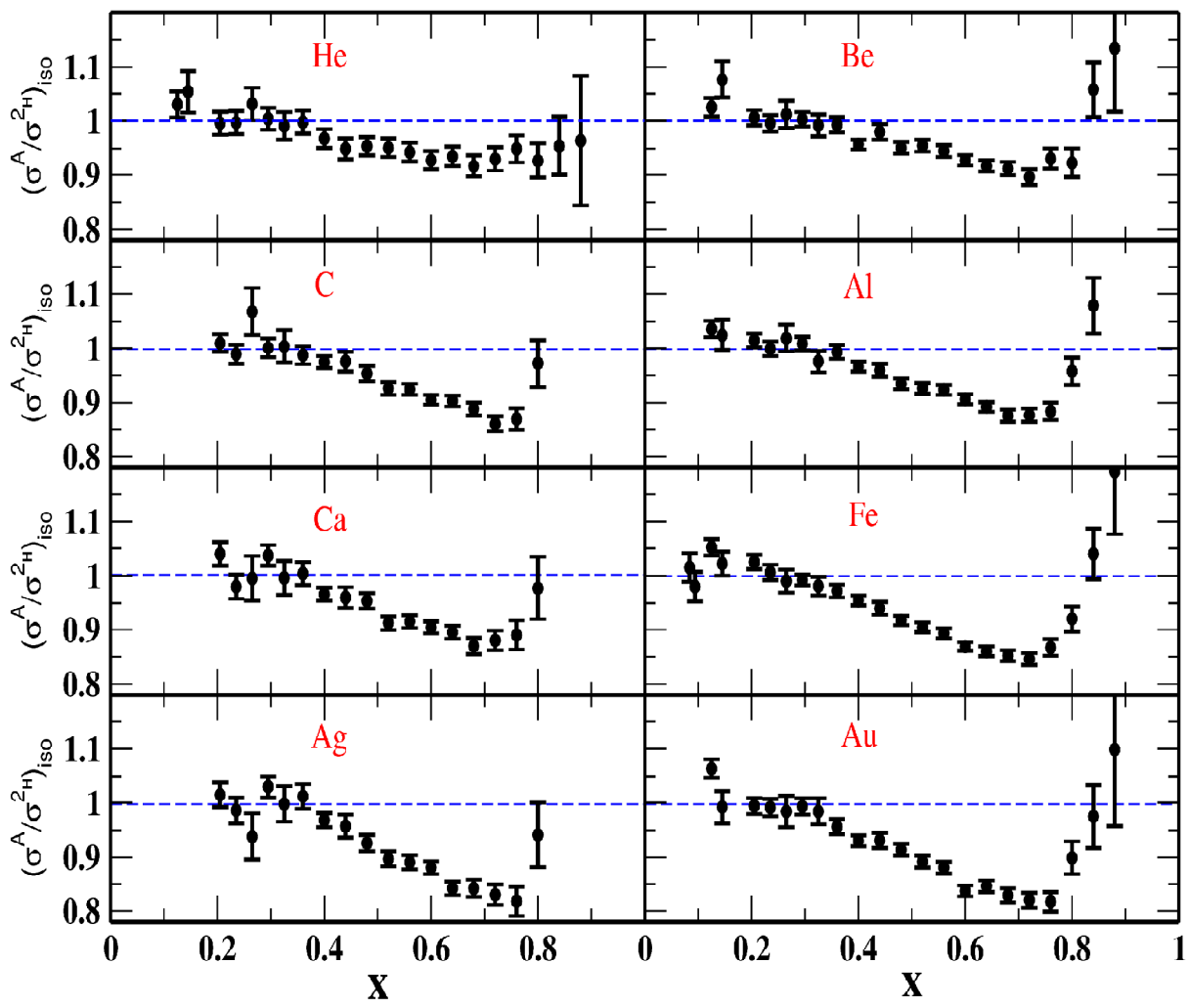
**Question :**

**A bound nucleon ≠ A free nucleon ?**




$\sigma^{DIS}$ per nucleon in nuclei ≠ $\sigma^{DIS}$ per nucleon in deuteron

## SLAC E139




universal x-dependence shape

$Q^2$ independence

magnitude varies with A

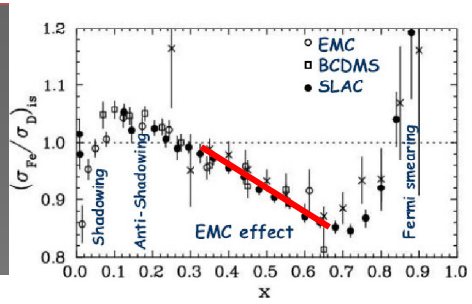
effect scale with the average nuclear density

**Data from CERN SLAC JLab**
**1983- 2009**

EMC collaboration, Aubert et al. PL B 123,275 (1983)

SLAC Gomez et al., Phys Rev. D49,4348 (1994)

A review of data collected during first decade, Arneodo, Phys. Rep. 240,301(1994)




# EMC is a not a bulk property of nuclear medium

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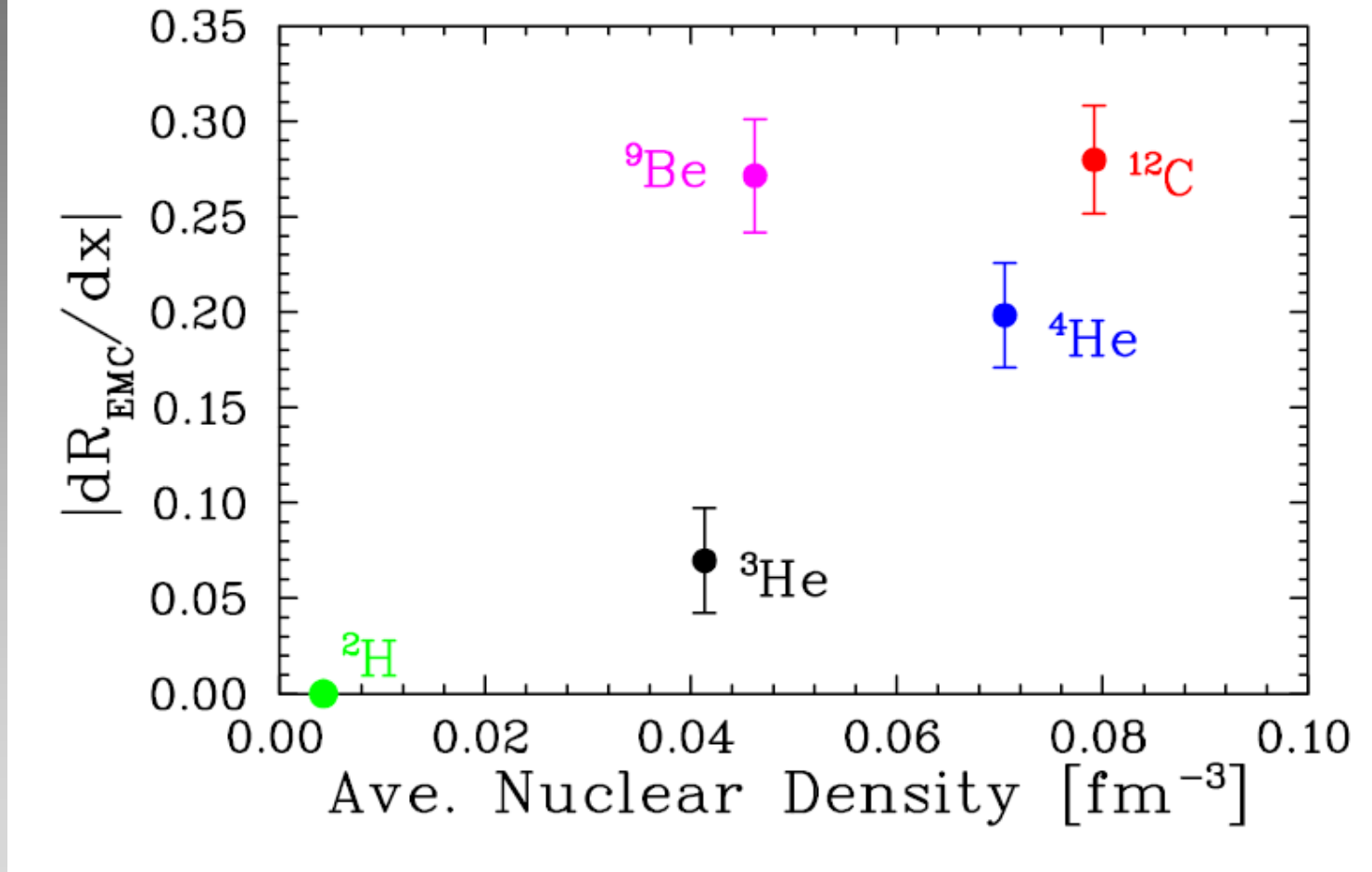


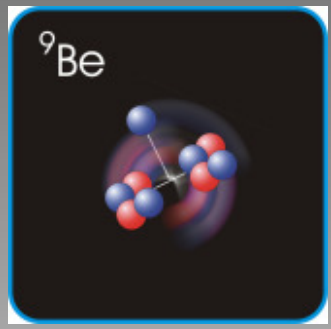


**JLab / Hall C**

. Seely et al. PRL 103, 202301 (2009)

Scaled nuclear density = *(A-1)/A* <ρ>
→ remove contribution from struck nucleon

<ρ> from ab initio few-body calculations
→ ***[S.C. Pieper and R.B. Wiringa,*** *Ann. Rev. Nucl. Part. Sci 51, 53 (2001)]*

# The European Muon Collaboration (EMC) effect

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30 years old

**Well established measured effect with no consensus as to its origin**

# Models of the EMC effect

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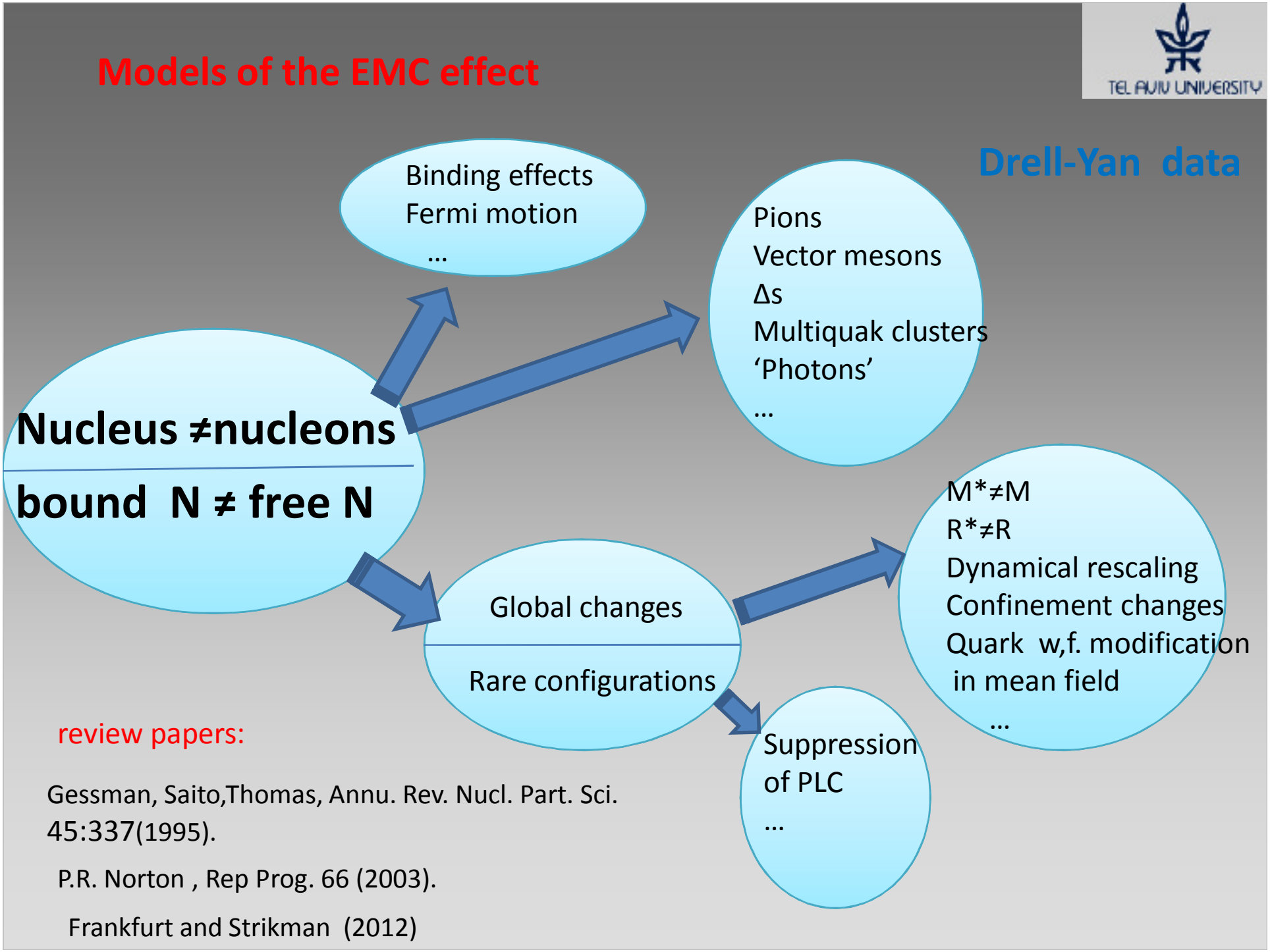


review papers:


Gessman, Saito,Thomas, Annu. Rev. Nucl. Part. Sci. 45:337(1995).

P.R. Norton , Rep Prog. 66 (2003).

Frankfurt and Strikman (2012)

# What are 2N-SRC in nuclei ?

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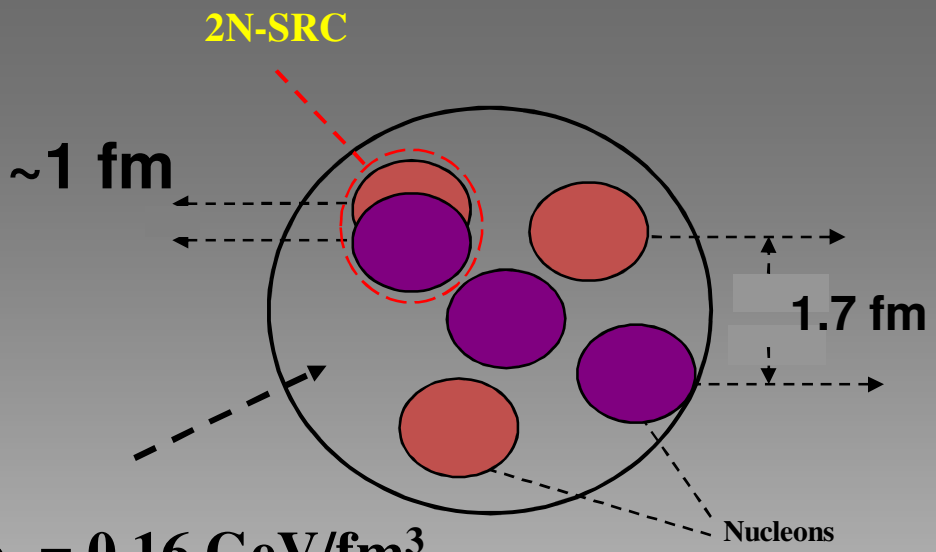
**In coordinate space:**

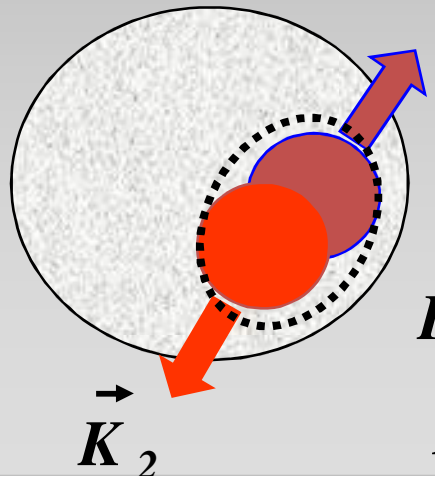
SRC ~$R_N$

LRC ~$R_A$




$\rho_o = 0.16$ GeV/fm$^3$

**In momentum space:**



$\vec{K}_1$

$\vec{K}_2$

$\vec{K}_1 \cong \vec{K}_2$

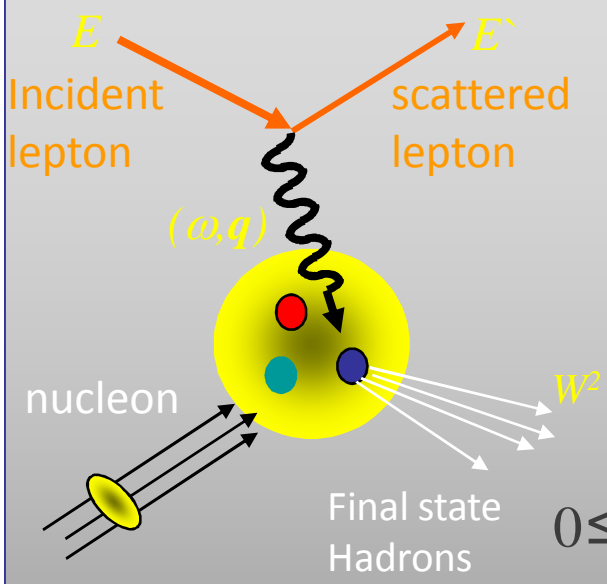
$K_1 > K_F$,

$K_2 > K_F$ $K_F$ ~250 MeV/c

**large relative momentum small CM momentum.**

# Inclusive electron scattering A(e,e')

## DIS off nucleons



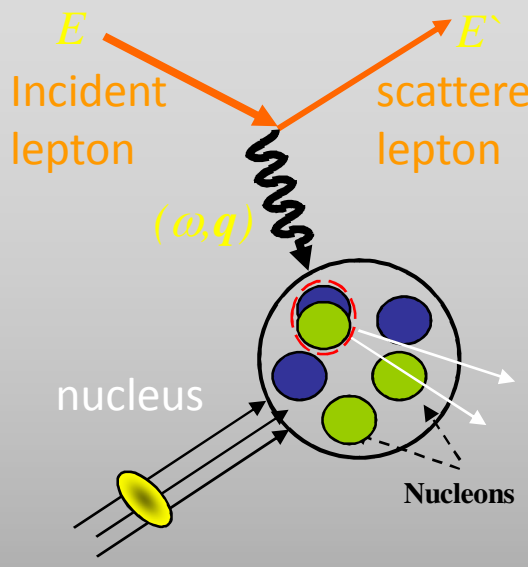

$$Q^2 = -q_\mu q^\mu = q^2 - \omega^2$$

$$\omega = E' - E$$

$$x_B = \frac{Q^2}{2m\omega} \qquad (x_B' = \frac{Q^2}{2(q \cdot p_T)})$$

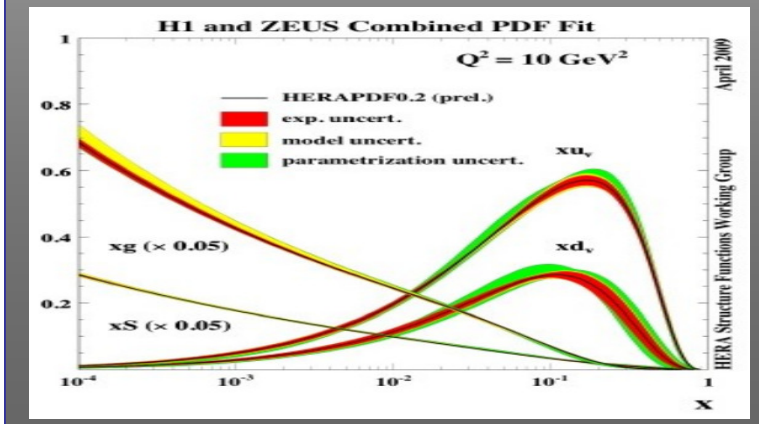
$0 \leq x_B \leq 1$

## DIS off nuclei

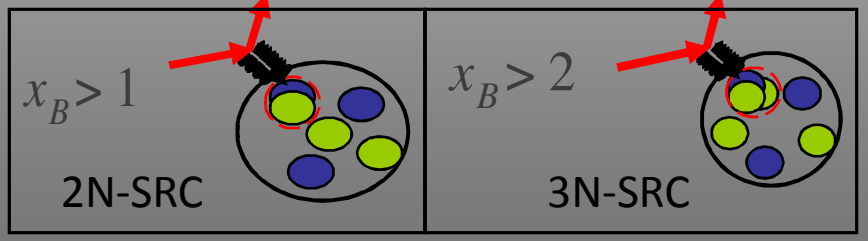



$0 \leq x_B \leq A$

**$x_B$ gives the fraction of nucleon momentum carried by the struck parton**




**$x_B$ counts the number of nucleons involved**



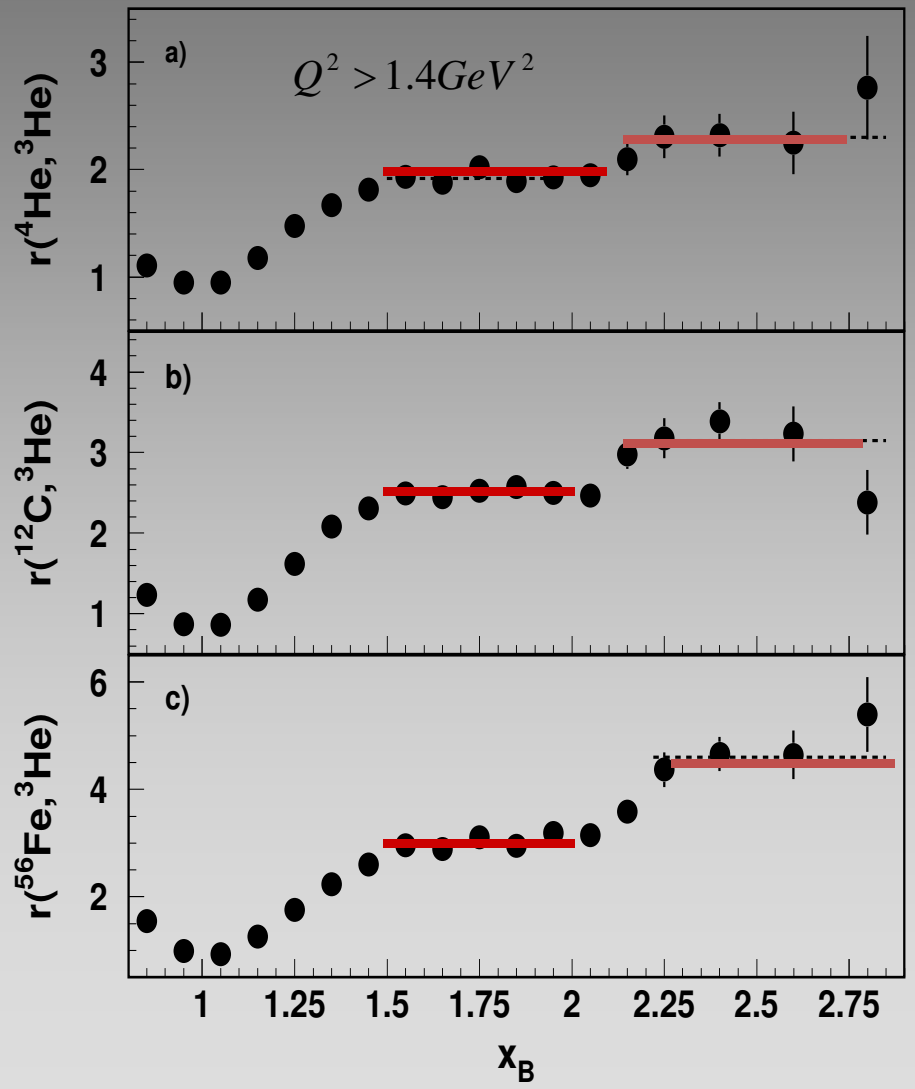

**--> scaling**

**--> Counting the number of SRC clusters in nuclei**

# JLab. CLAS A(e,e') Result

K. Sh. Egiyan et al. PRC 68, 014313 (2003)

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




**The observed "scaling" means that the electrons probe the high-momentum nucleons in the 2(3) - nucleon phase, and the scaling factors determine the per-nucleon probability of the 2(3) N-SRC phase in nuclei with A>3 relative to $^3$He.**

**For $^{12}$C 2N-SRC (np, pp, nn) = 20 ± 4.5%.**

The probabilities for 3-nucleon SRC are smaller by one order of magnitude relative to the 2N SRC.

More r(A,d) data:

SLAC D. Day et al. PRL 59,427(1987)

JLab. Hall C E02-019

N. Fomin et al. PRL 108:092502, 2012.

## Inclusive electron scattering A(e,e')

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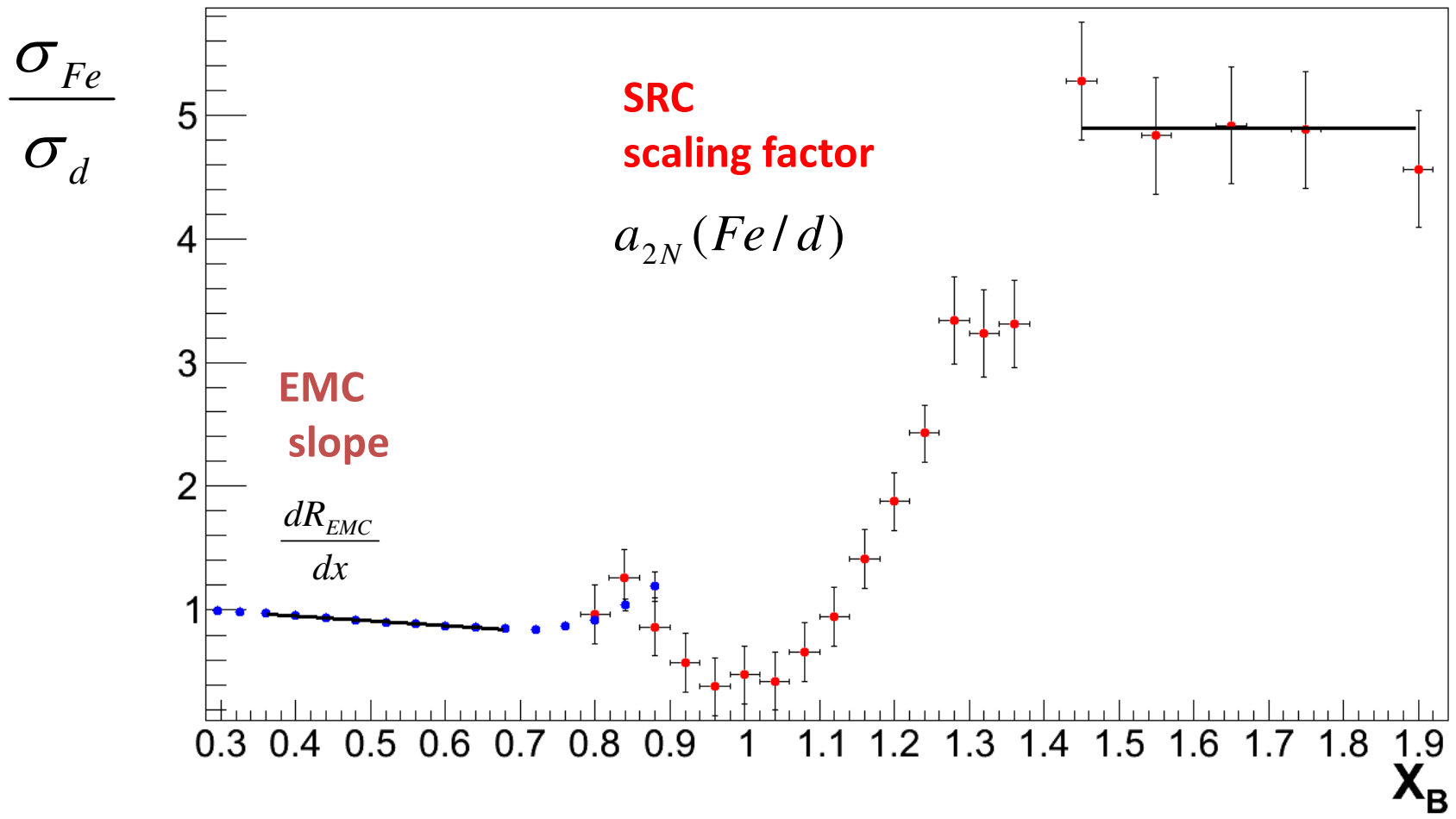
Deep Inelastic Scattering

→ Partonic (quark) Structure of **Hadrons**

Inclusive Scattering at $X_B > 1$ A(e,e')

→ Partonic (nucleon) Structure of **Nucleus**

# Comparing magnitude of EMC effect and SRC scaling factors



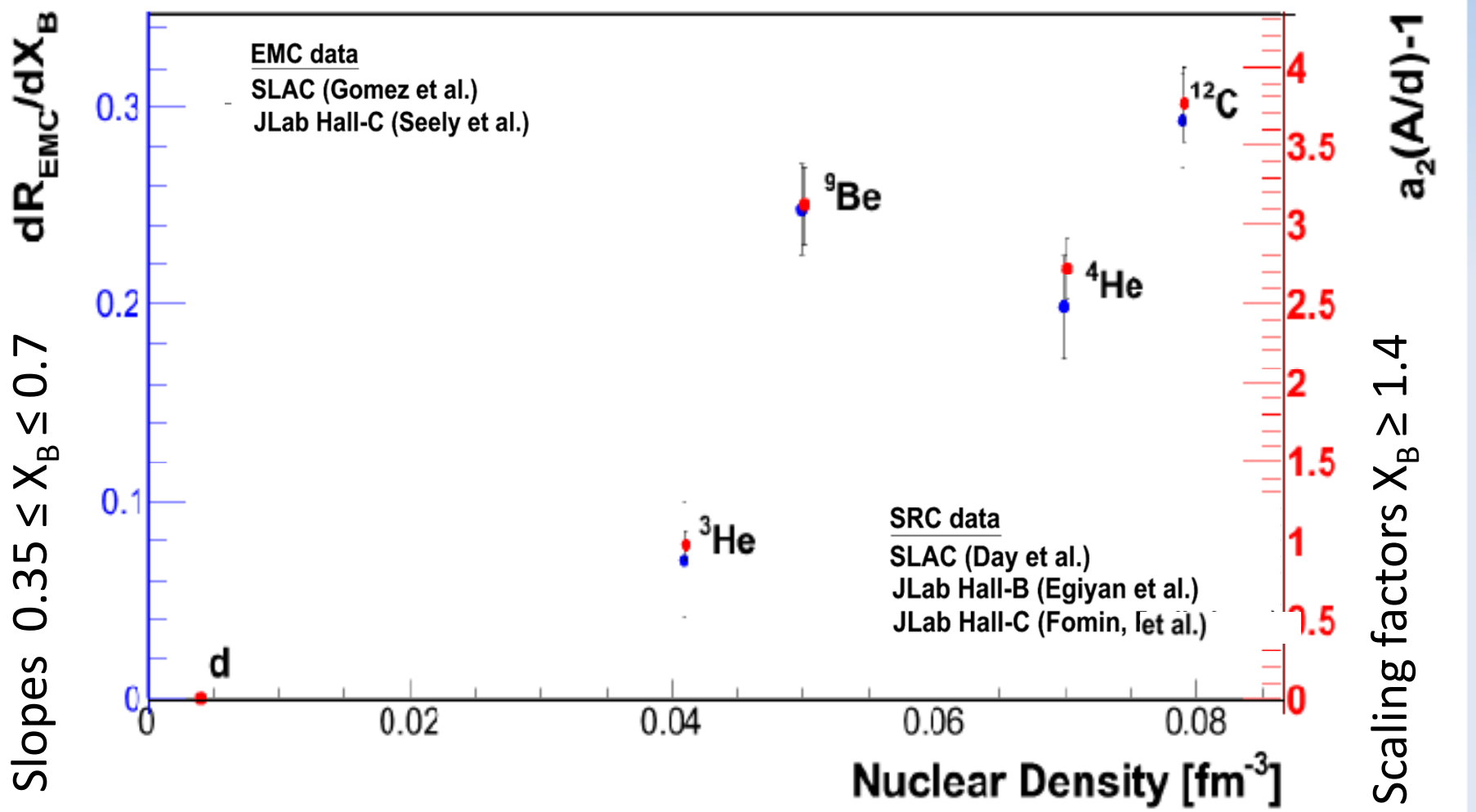

**SLAC data:**

Gomez et al., Phys. Rev. D49, 4348 (1983).

**$Q^2$=2, 5, 10, 15 GeV/$c^2$ (averaged)**

Frankfurt, Strikman, Day, Sargsyan, Phys. Rev. C48 (1993) 2451.

**$Q^2$=2.3 GeV/$c^2$**


Slopes $0.35 \le X_B \le 0.7$
$dR_{EMC}/dX_B$
EMC data
SLAC (Gomez et al.)
JLab Hall-C (Seely et al.)
SRC data
SLAC (Day et al.)
JLab Hall-B (Egiyan et al.)
JLab Hall-C (Fomin, et al.)
d
$^3$He
$^9$Be
$^4$He
$^{12}$C
0
0.1
0.2
0.3
0.02
0.04
0.06
0.08
Nuclear Density [fm$^{-3}$]
$a_2$(A/d)-1
Scaling factors $X_B \ge 1.4$
0
0.5
1
1.5
2
2.5
3
3.5
4

## PRL 106, 052301 (2011), also PRC 85 047301 (2012)

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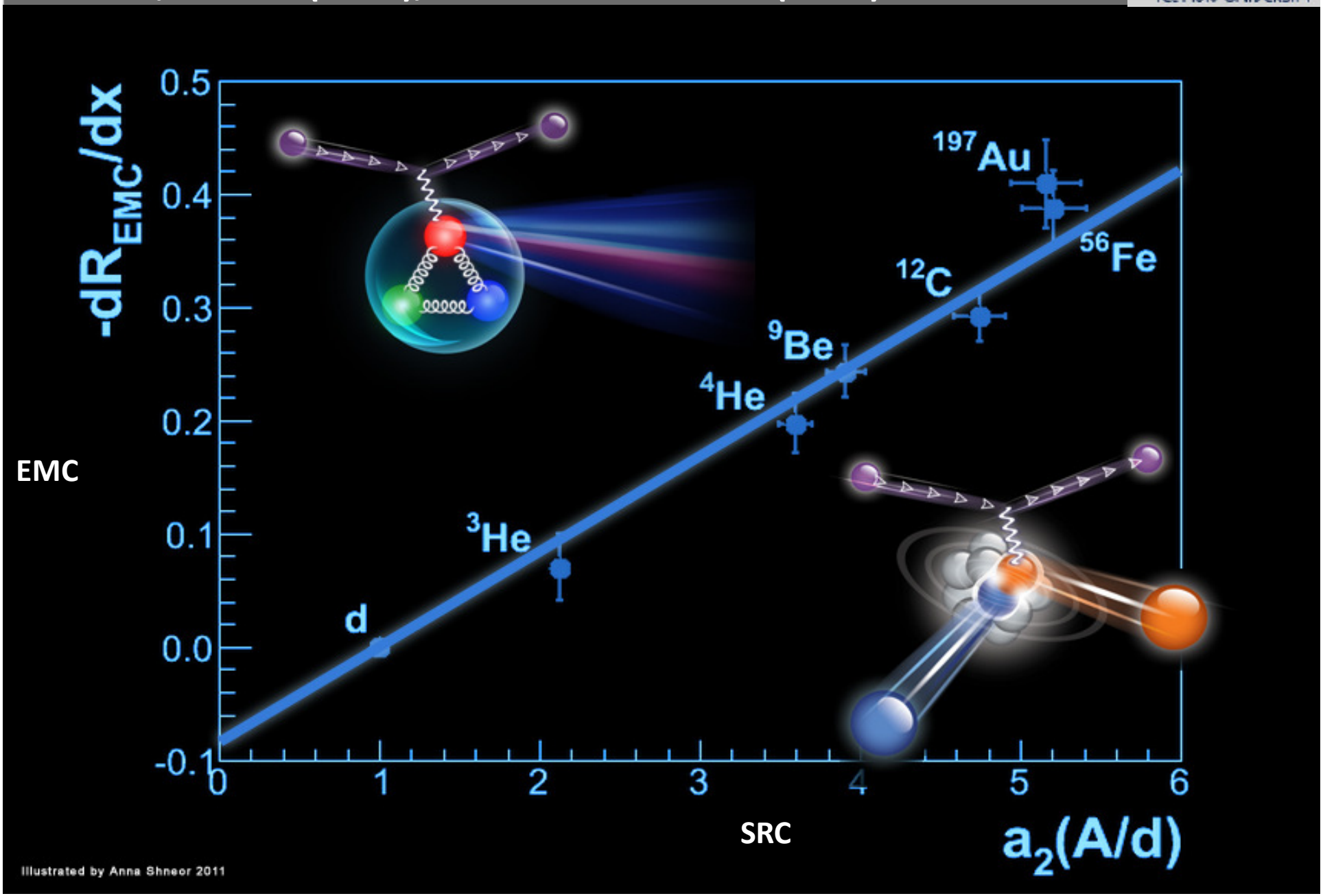
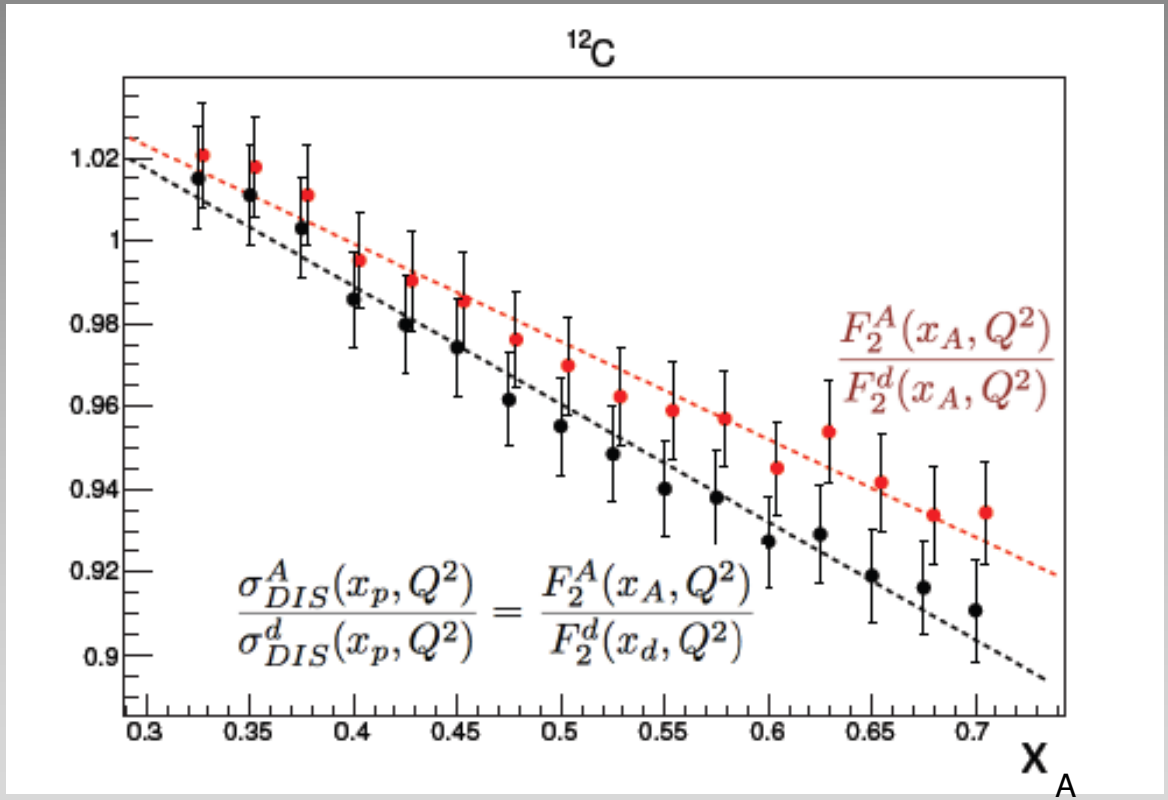


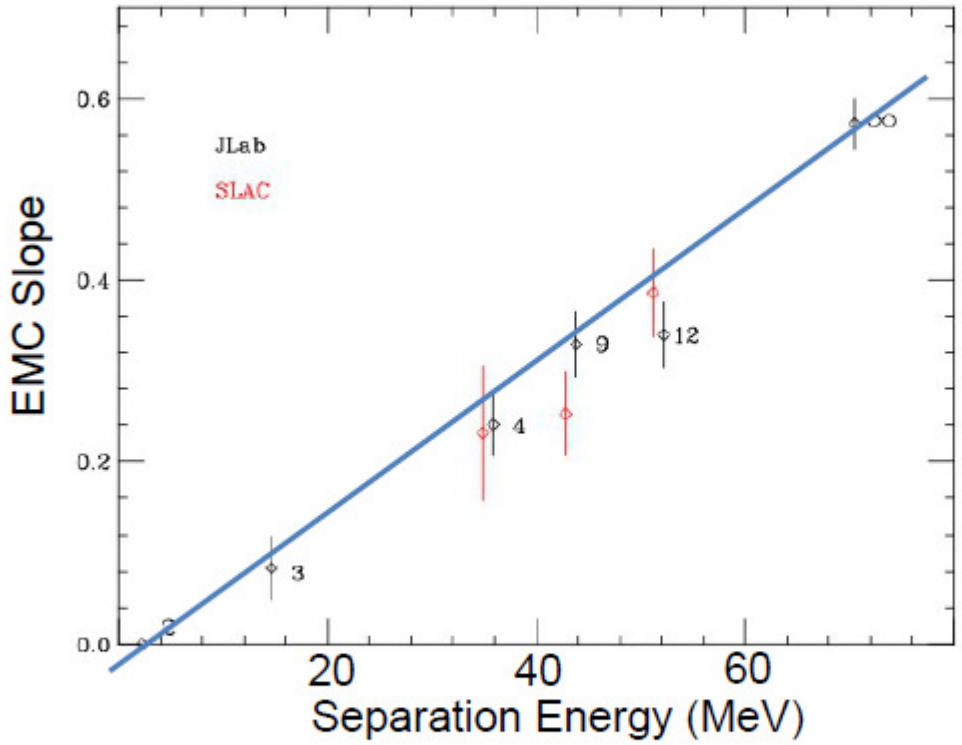
L. Frankfurt and M. Strikman, Int.J.Mod.Phys. E 21 (2012) 1230002

$$x_A = \frac{Q^2}{2q \cdot P_A/A} = \frac{AQ^2}{2\omega m_A} = x_p \cdot \frac{Am_p}{m_A}$$




**The EMC Effect and High Momentum Nucleons in Nuclei,** O. Hen, D. W. Higinbotham, G. A. Miller, E. Piasetzky, L. B. Weinstein, arXiv:1304.2813 [nucl-th]

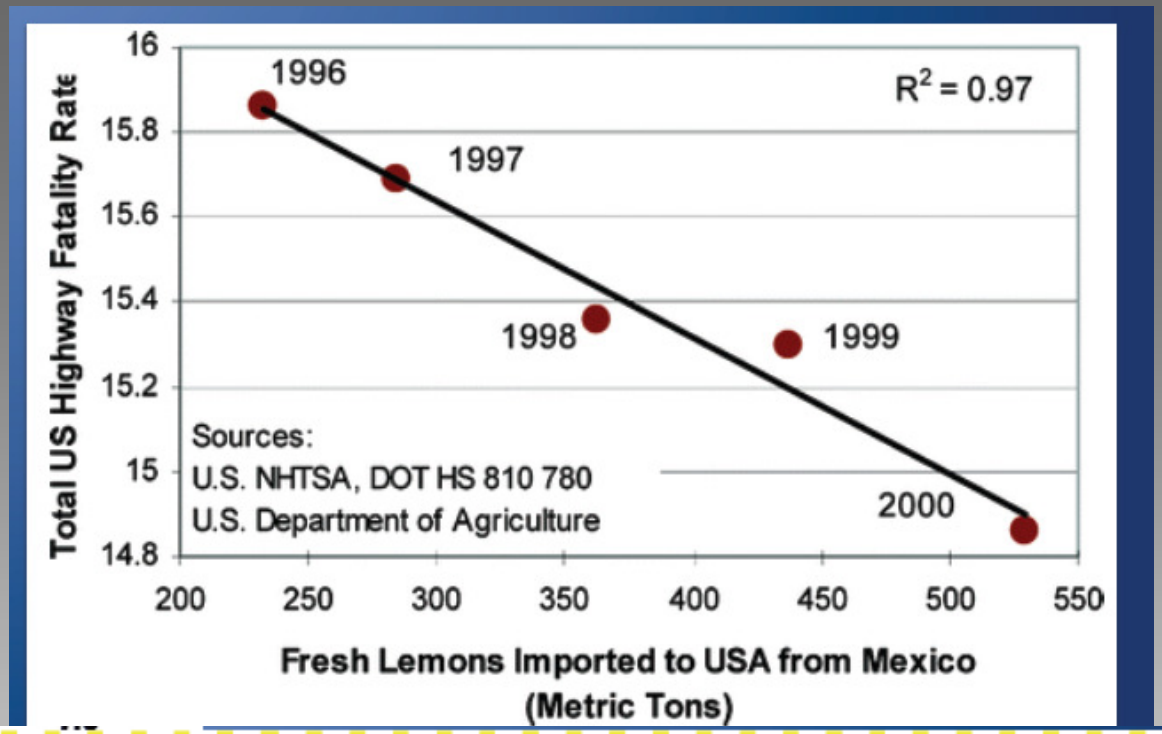
# EMC and Separation Energy




Benhar and Sick,
ArXiv 1207:4595

$$\bar{E} = \bar{T}\,\frac{A-2}{A-1} - 2\,\frac{E_0}{A}$$

- Average kinetic energy calculated using GFMC wave functions is much larger than previous calculations and\or (e,e'p) measurements.
- Not bad, but since the average separation energy is just proportional to the average nucleon virtuality.

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# Mexican Lemonade Saves Lives!

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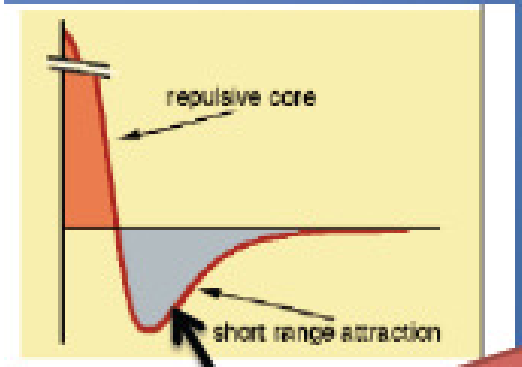
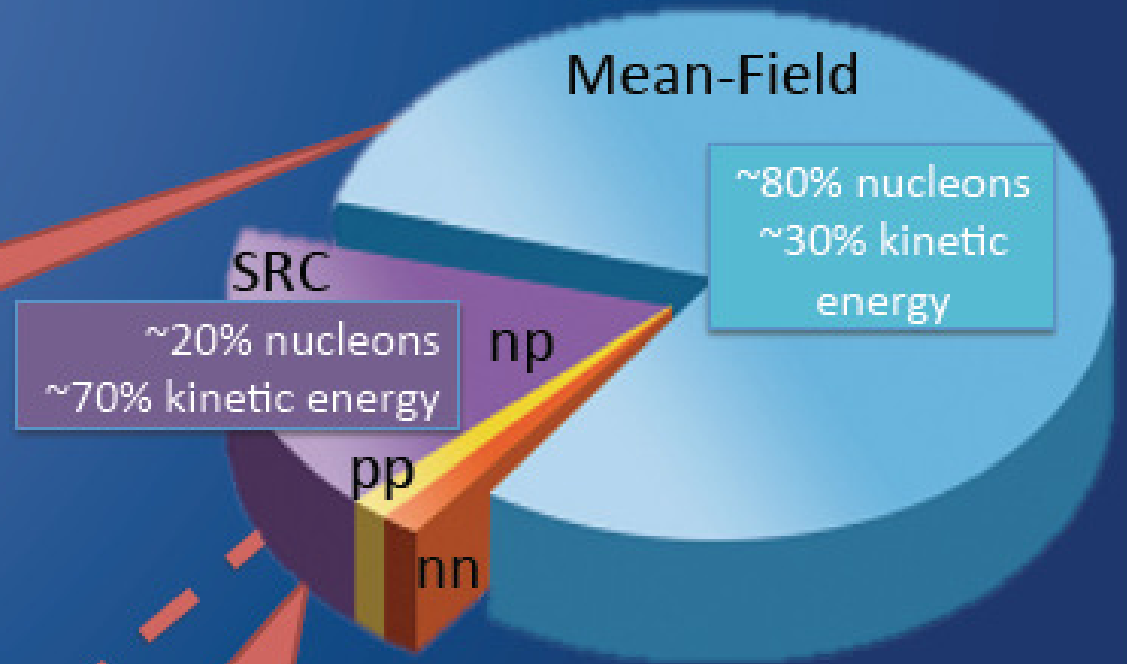
# Where is the EMC Effect?




Largest attractive force

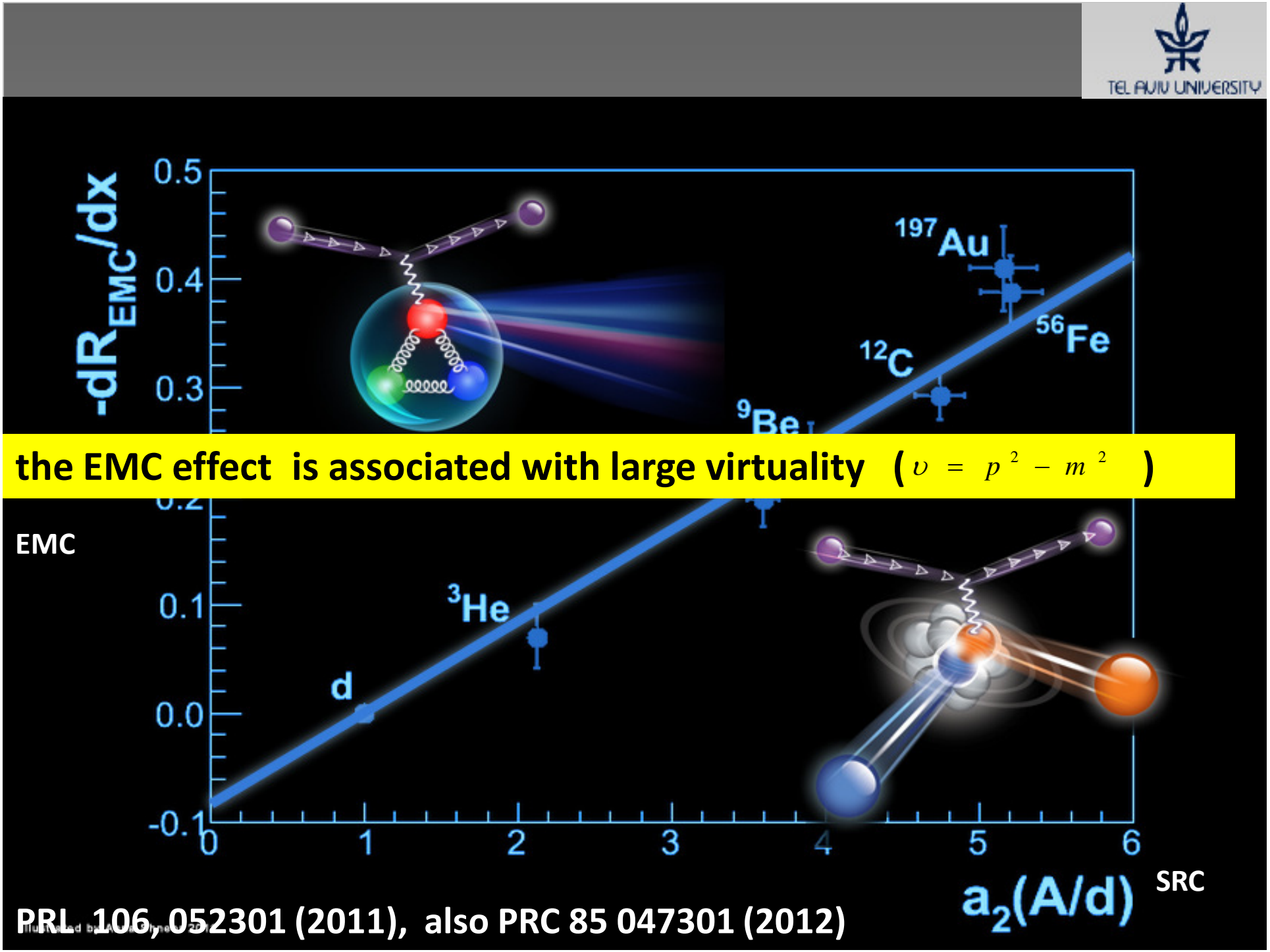



## Mean-Field

## SRC

High local nuclear matter density, large momentum, large off shell, large virtuality

$$\upsilon = p^2 - m^2$$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-dR_EMC/dx
0.5
0.4
0.3
197Au
56Fe
12C
9Be
the EMC effect is associated with large virtuality ( $\upsilon = p^2 - m^2$ )
EMC
0.1
0.0
-0.1
3He
d
0
1
2
3
4
5
6
a2(A/d)
SRC
PRL 106, 052301 (2011), also PRC 85 047301 (2012)

# Convolution Model

$$\frac{1}{A}F_2^A(x_A,Q^2) = \int_0^A \alpha\rho_A(\alpha)F_2^N(x_A/\alpha,Q^2)d\alpha,$$

Frankfurt and Strikman
PL B183 (1987) 254.

$$n_A(k) = n_A^{(0)}(k) + n_A^{(1)}(k),$$

Ciofi and Simula PRC 53 (1996) 1689.

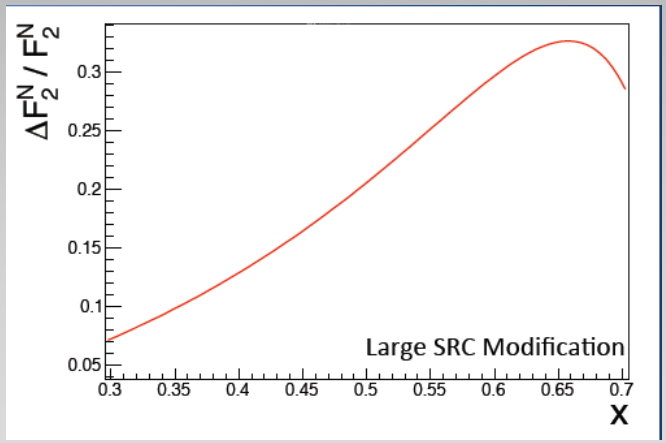
**Mean-Field Part**

$$F_2^N(x_A)$$

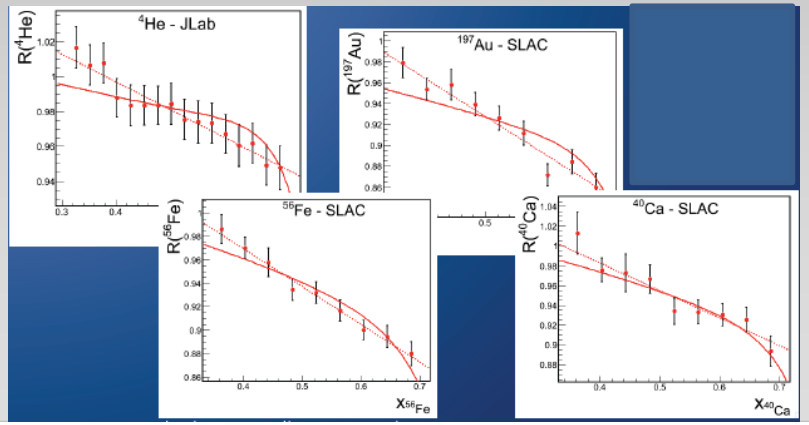
**Correlated Part**

$$\widetilde{F}_2^N(x_A)$$

$$\Delta F_2^N(x_A) = \widetilde{F}_2^N(x_A) - F_2^N(x_A).$$




**Assuming ΔF is a second order polynomial in x and fitting it to the EMC data**




**The EMC Effect and High Momentum Nucleons in Nuclei,** O. Hen, D. W. Higinbotham, G. A. Miller, E. Piasetzky, L. B. Weinstein, arXiv:1304.2813 [nucl-th]

# Hypothesis can be checked by measuring DIS off Deuteron tagged with high momentum recoil nucleon

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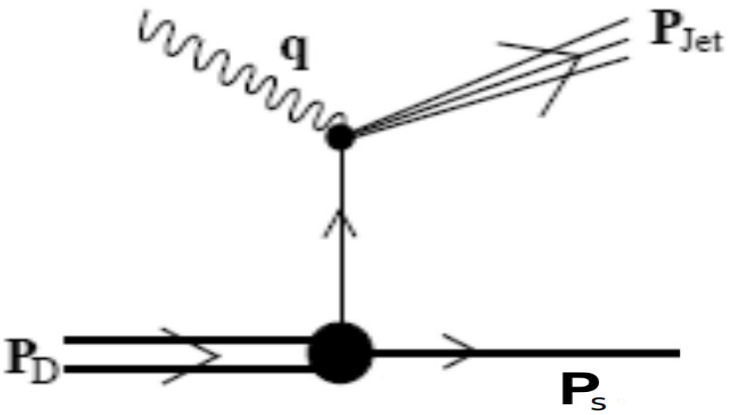
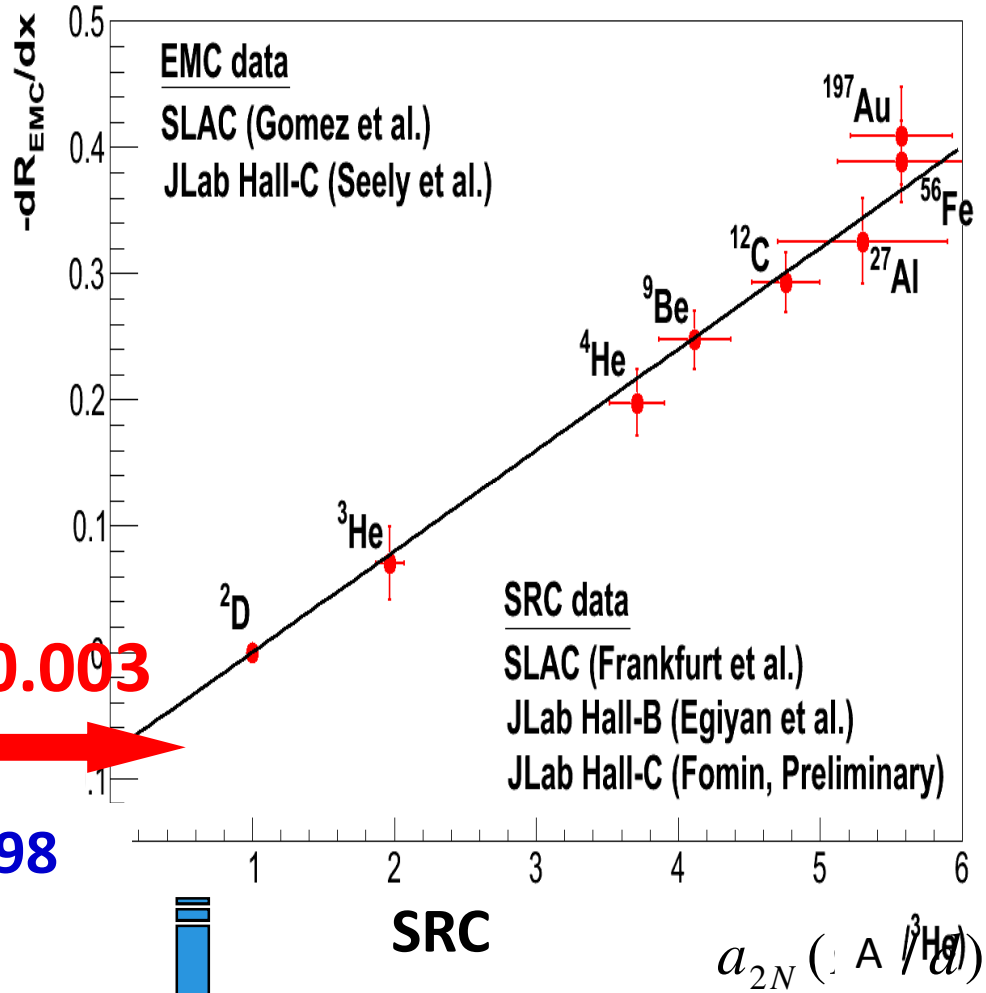
**large effect**




$$\frac{\sigma_d}{\sigma_p+\sigma_n} = 1-(0.070\pm0.003)(0.6-0.34\pm0.02) \approx 0.98$$

**0.070±0.003**

$$\frac{\sigma_p^*}{\sigma_p} \approx \frac{\sigma_n^*}{\sigma_n} \approx \frac{2-4\%}{5-10\%} \approx 30-50\%$$

**SRC=0 free nucleons**

12 GeV JLab approved Proposal PR12-11-107

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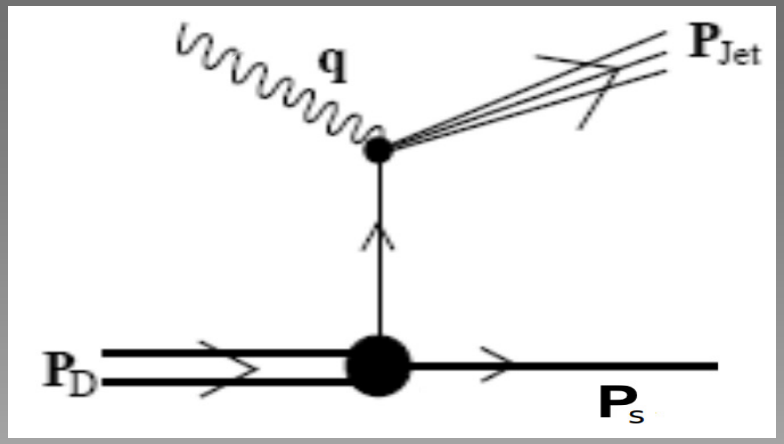
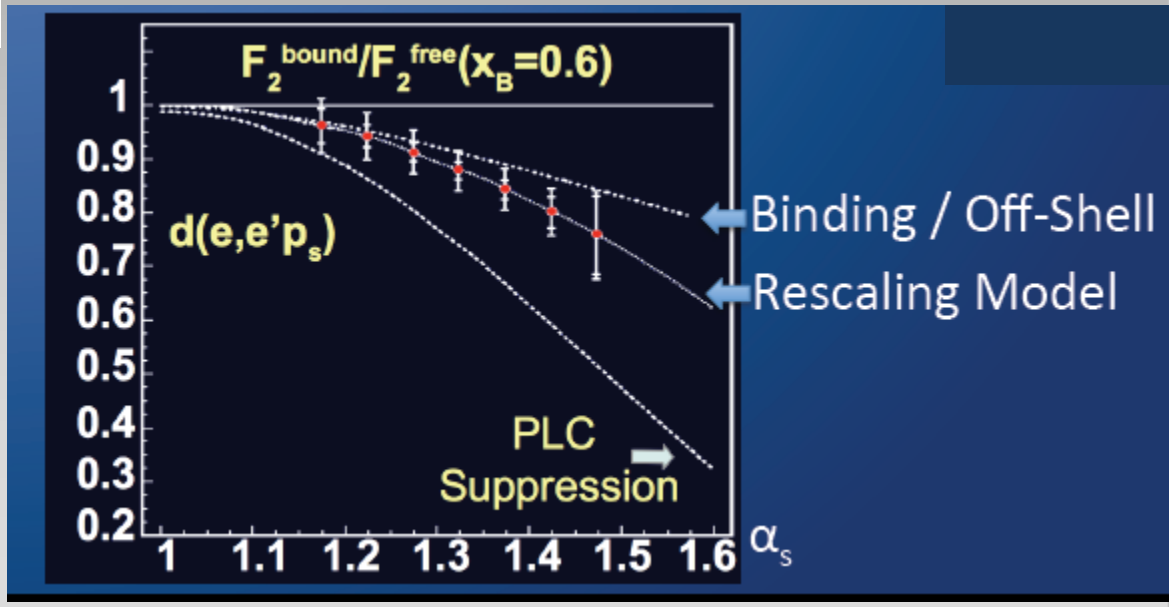
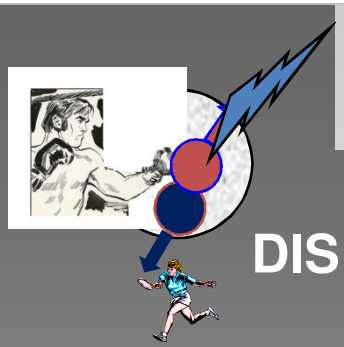
## 1. Spectator Tagging:

➔ Selects DIS off high momentum (high virtuality) nucleons





can also be study with EIC



DIS

DIS

3 GeV/c

$K_1$

$K_2$

$p_{beam}$

$k_2 \approx p_{beam} + 0.5 GeV/c$

**Study the EMC effect on SRC pair as a function of the virtiality**

**Tagged DIS with recoil nucleon with p> $p_{beam}$**

# Deuteron is not a free np pair

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$\sigma_d \neq$

$\sigma_d /$

$\sigma_p +$

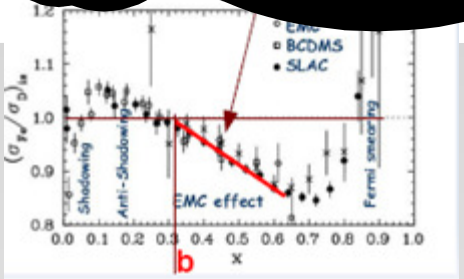
$1-(0.$

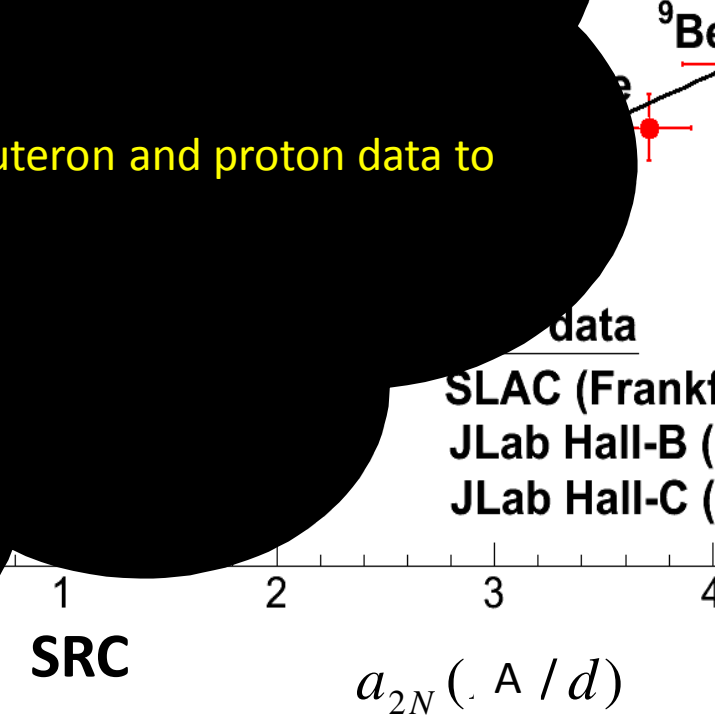
Conclusions:

(ratio to deuterium) → ratio to free (unbound) pn pair)

IMC- In-Medium Correction

One should not neglect the IMC effect using deuteron and proton data to extract free neutron properties



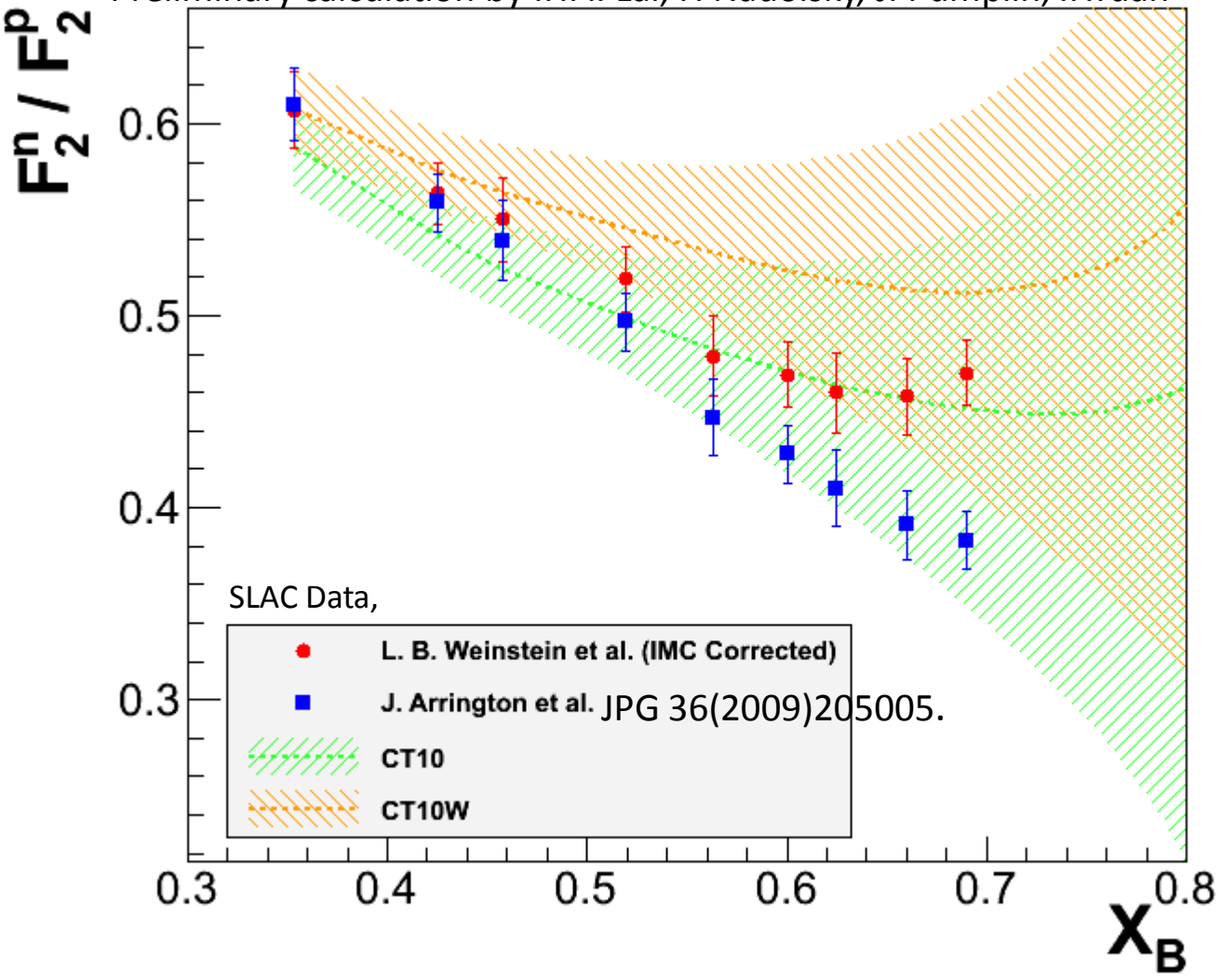




SRC=0 free nucleons

# The free neutron structure function

## Compared to CTEQ calculations

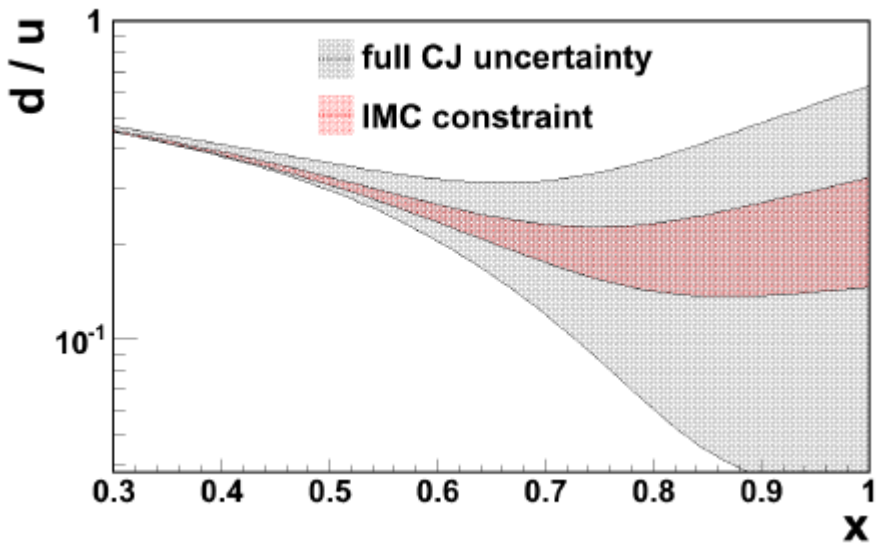
Preliminary calculation by :H. l. Lai, P. Nadolsky, J. Pumplin, .P.Yuan

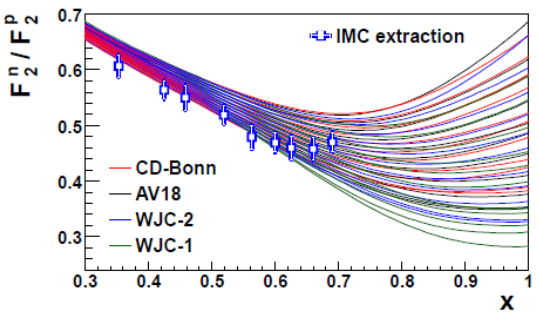



JPG 36(2009)205005.

**CT10W** - W asymmetry and W-lepton asymmetry data

# INC constrained d/u x-->1 ratio

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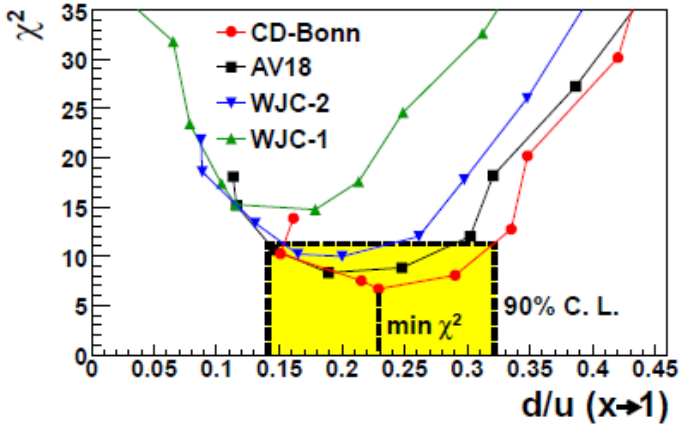



**The IMC (at a 90% C.L.):**

$$d/u \rightarrow 0.23 \pm 0.09$$

Excludes models based on
- SU(6) symmetry
- Scalar di-quark dominance

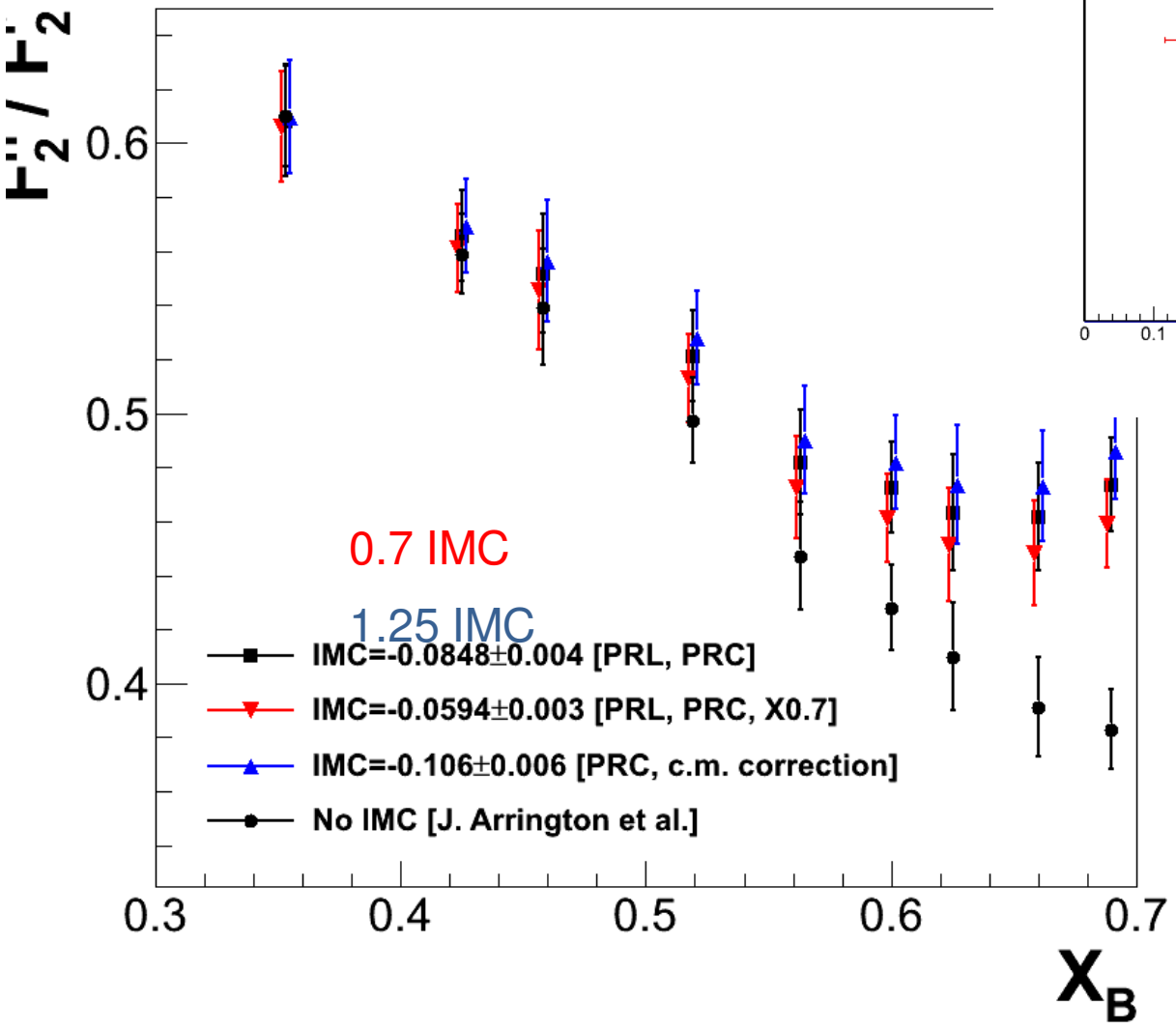
Constraints on the large-$x$ $d/u$ ratio from electron–nucleus scattering at $x > 1$

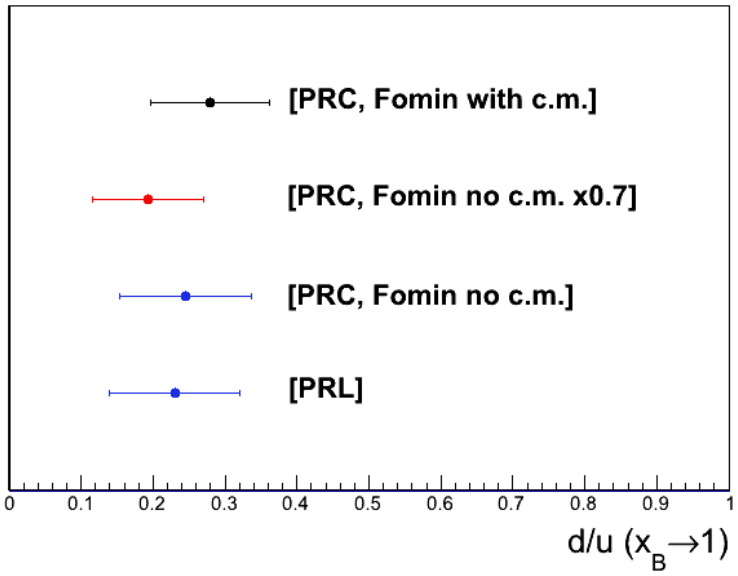
O. Hen,[1] A. Accardi,[2,3] W. Melnitchouk,[3] and E. Piasetzky[1]

**Phys. Rev. D84 117501 (2011).**

| Nucleon Model | $F_2^n/F_2^p$ | d/u |
|---|---|---|
| ~~SU(6)~~ | ~~2/3~~ | ~~1/2~~ |
| ~~Scalar diquark~~ | ~~1/4~~ | ~~0~~ |
| pQCD (p↑ q↑) | 3/7 | 1/5 |

# Robustness




| | | | |
|---|---|---|---|
| | $3.60 \pm 0.10$ | $3.3 \pm 0.5$ | $-0.197 \pm 0.026$ |
| | $3.91 \pm 0.12$ | | $-0.243 \pm 0.023$ |
| | $4.75 \pm 0.16$ | $5.0 \pm 0.5$ | $-0.292 \pm 0.023$ |
| | $5.21 \pm 0.20$ | $5.2 \pm 0.9$ | $-0.388 \pm 0.032$ |
| | $5.16 \pm 0.22$ | $4.8 \pm 0.7$ | $-0.409 \pm 0.039$ |
| 006 | $0.084 \pm 0.004$ | | |
| 006 | $1.034 \pm 0.004$ | | |
| | $4.895/5$ | | |

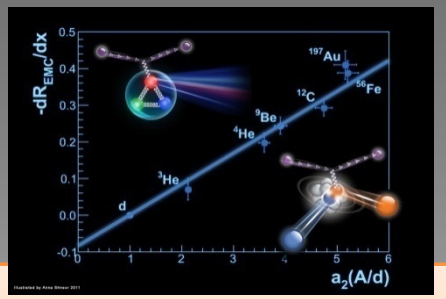
ed primarily from the calculated ratio of the
ld ($p_{thresh} = 0.275 \pm 0.025$ GeV/c).
s at different kinematics. They interpolated
measured for heavier nuclei and have larger
cluded here for completeness.

**New data strengthen the connection between Short Range Correlations and the EMC effect.**
O. Hen, E. Piasetzky, (Tel Aviv U.) , L.B. Weinstein, (Old Dominion U.) . Feb 2012.]
Phys. Rev. C85 (2012) 047301

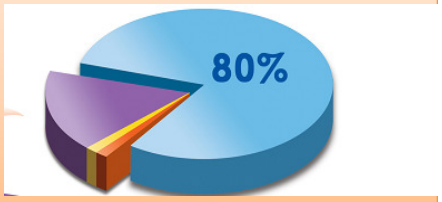
# Summary

After 30 years the EMC effect is well established measured effect with no consensus as to its origin.

SRC and EMC are linearly correlated.



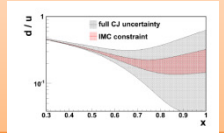

We suggest that this correlation occurs because both phenomena are related to high-momentum (large virtuality) nucleons.

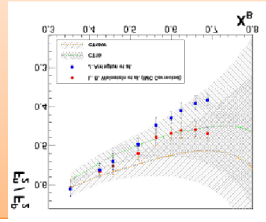



Can be verify by measuring DIS tagged by a high momentum recoil spectator.

An approved experiment at 12 GeV JLab. / EIC possibility

Based on the EMC/SRC correlation, we claim an 'EMC like' (IMC) effect also in deuteron, which impacts extraction of free neutron SF and proton d/u ratio at large x.



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Collaborators:

Or Hen, Larry Weinstein, Shalev Gilad, Doug Higinbothan, Steve Wood, John Watson

Misak Sargsian, Mark Strikman, Leonid Frankfurt, Gerald Miller

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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. Shneor[2]

**Phys. Rev. Lett. 106, 052301 (2011)**

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**The EMC Effect and High Momentum Nucleons in Nuclei,** O. Hen, D. W. Higinbotham, G. A. Miller, E. Piasetzky, L. B. Weinstein, arXiv:1304.2813 [nucl-th]

Internatlional Journal of Modern Physics E,

**Proposal: PR12-11-107**

**Title:** "In Medium Nucleon Structure Functions, SRC, and the EMC effect"

**Spokespersons:** O Hen (contact), L. Weinstein, S. Gilad, S.A. Wood