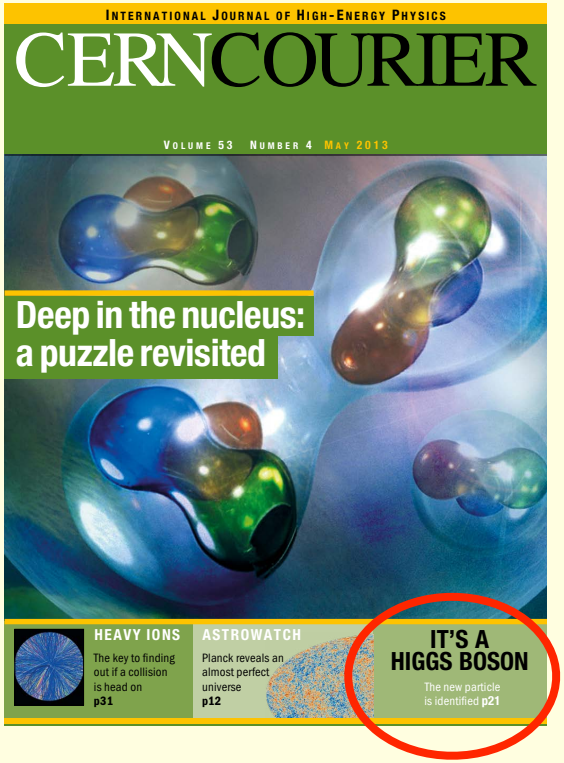
EMC Effect in 2016

Gerald A. Miller University of Washington

RMP with Or Hen, Eli Piasetzky, Larry Weinstein
RMP 89 (2017) 045002

Will focus on 0.3 <x<0.7 Remarkable experimental progress



Higinbotham, Miller,
Hen, Rith
CERN Courier 53N4('13)24

Ideas: ~1000 papers 3 ideas

- Proper treatment of known effects: binding, Fermi motion, pionic- NO nuclear modification of internal nucleon/pion quark structure
- Quark based- high momentum suppression implies larger confinement volume

a bound nucleon is larger than free one- a mean field effect

b multi-nucleon clusters - beyond the mean field

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EMC – "Everyone's Model is Cool (1985)"

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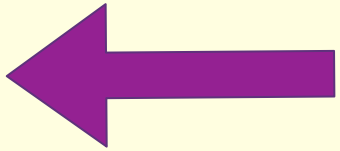

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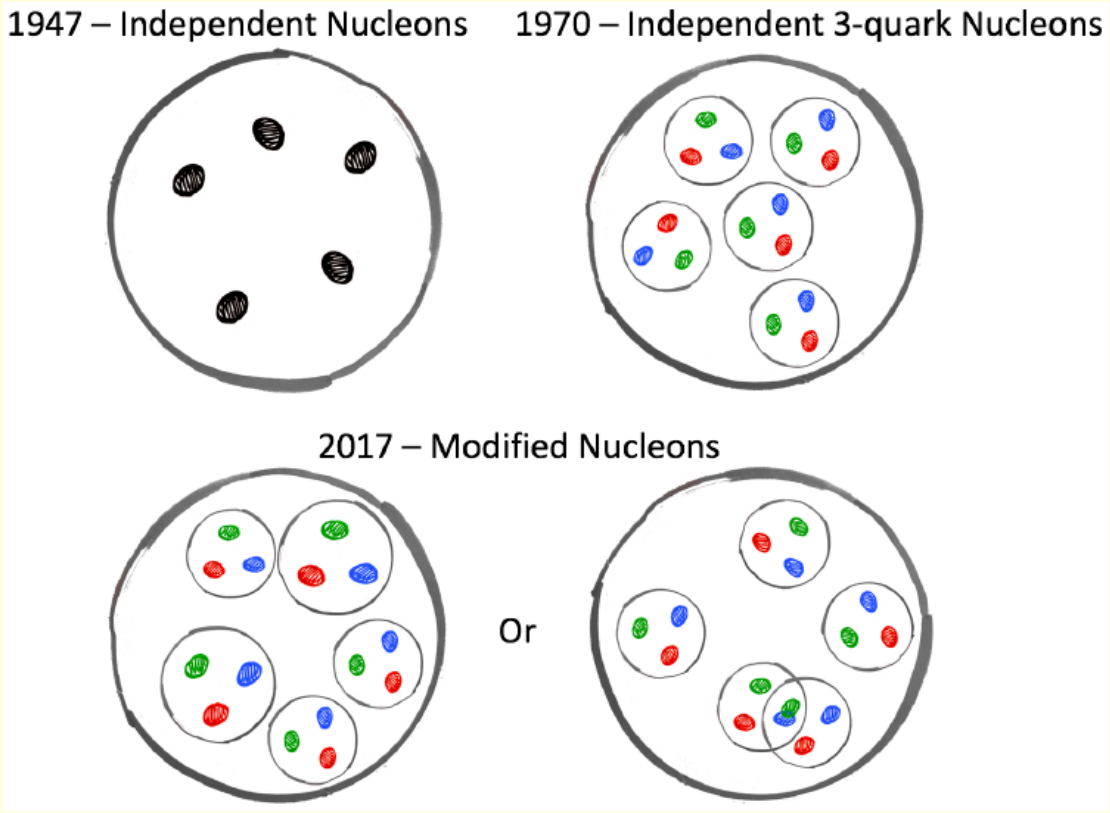
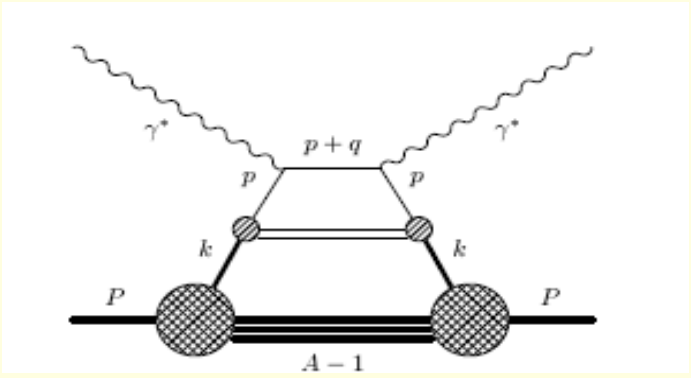
Progress in Quark Nuclear Physics

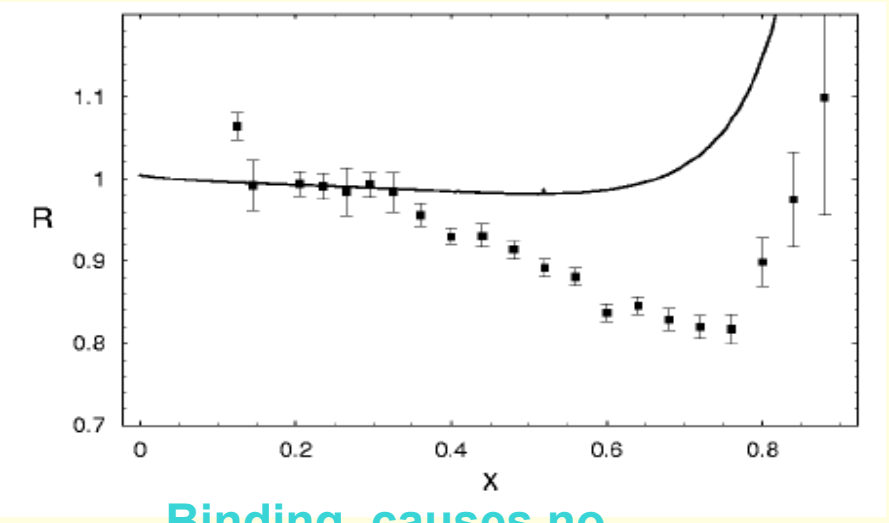


One thing I learned since ‘85

- Nucleon/pion model is not cool

Deep Inelastic scattering from nuclei- nucleons only free structure function





Binding causes no EMC effect

- **Hugenholz van Hove theorem nuclear stability implies (in rest frame) $P^+=P^-=M_A$**
- **$P^+ = A(M_N - 8\ MeV)$**
- **average nucleon k^+**

$k^+=M_N-8$ MeV, Not much spread

$F_{2A}/A \sim F_{2N}$ no EMC effect

Momentum sum rule- matrix element of energy momentum tensor

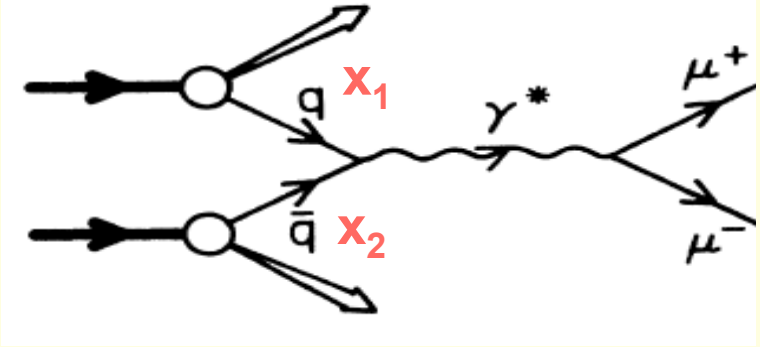
Nucleons and pions

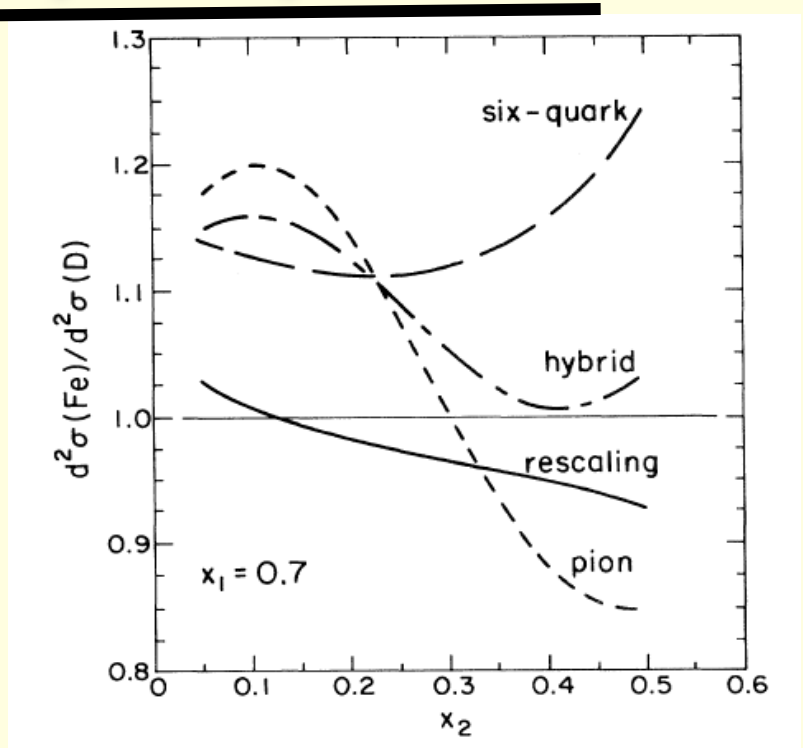
$P_A^+ = P_N^+ + P_\pi^+ = M_A$

$P_\pi^+ / M_A = .04$, explain EMC, sea enhanced

try Drell-Yan, **Bickerstaff, Birse, Miller 84**

proton(x_1) nucleus(x_2)





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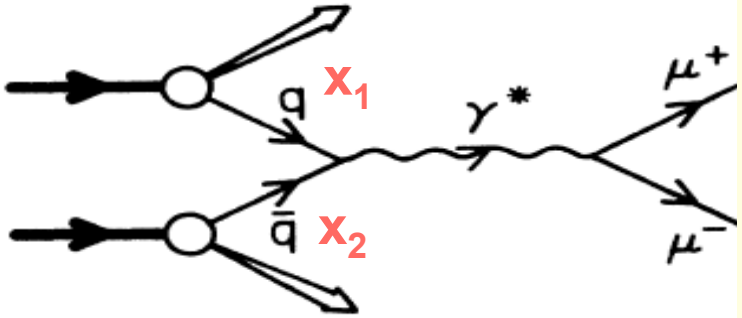
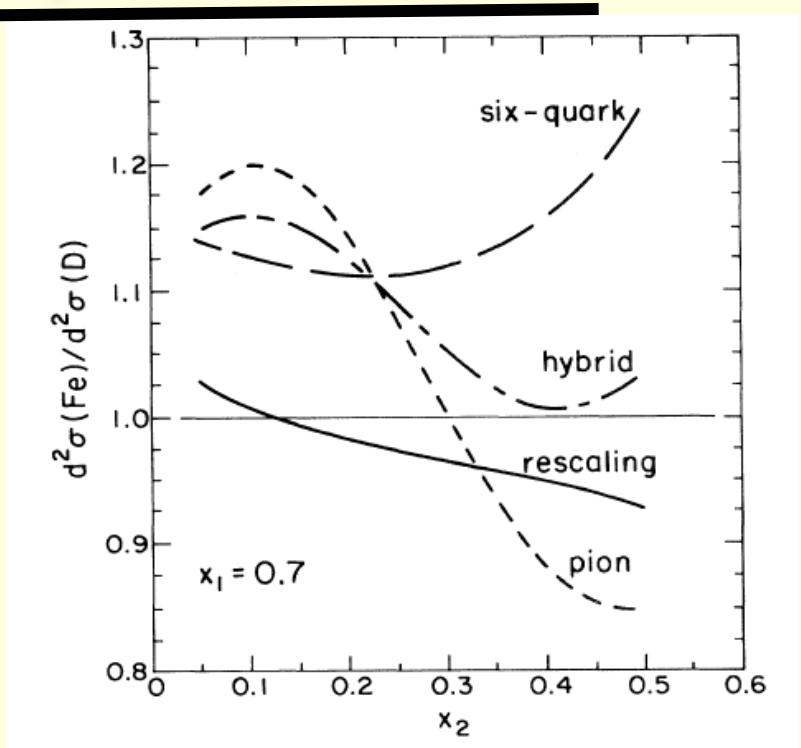
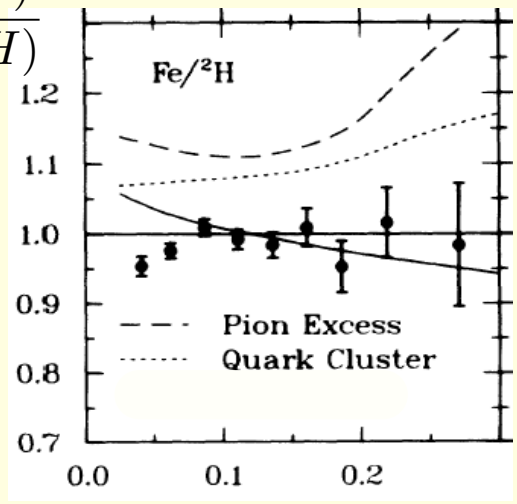




$\frac{\sigma_{DY}(\mathrm{Fe})}{\sigma_{DY}(^2H)}$



E772 PRL 69,1726 (92)

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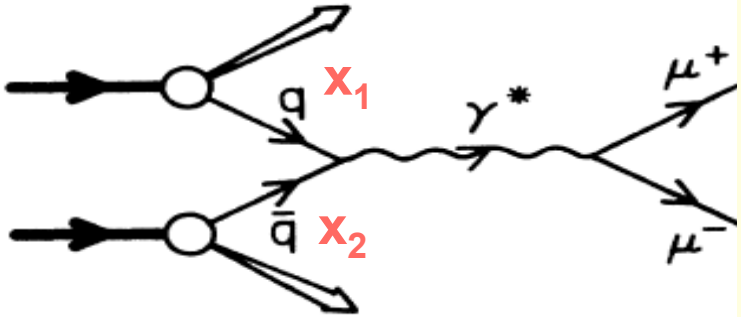

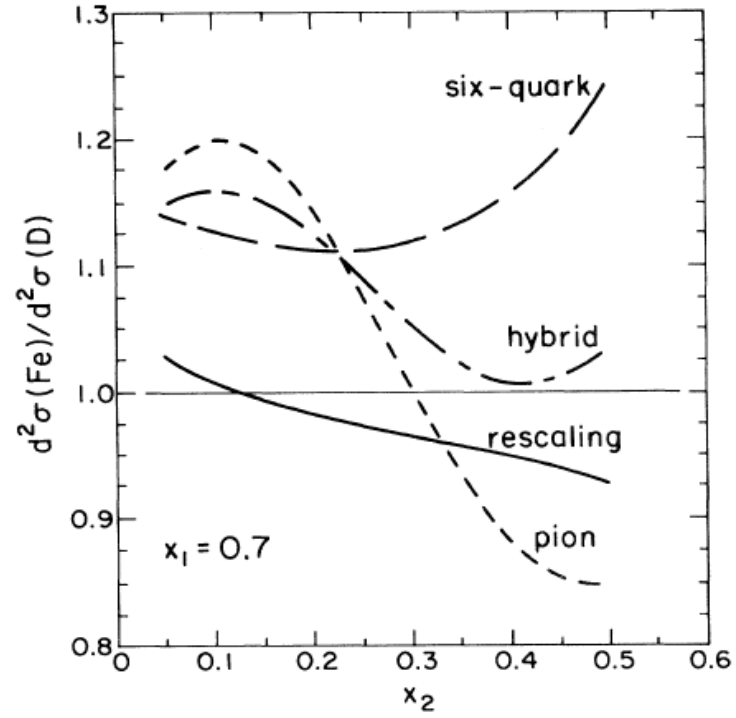

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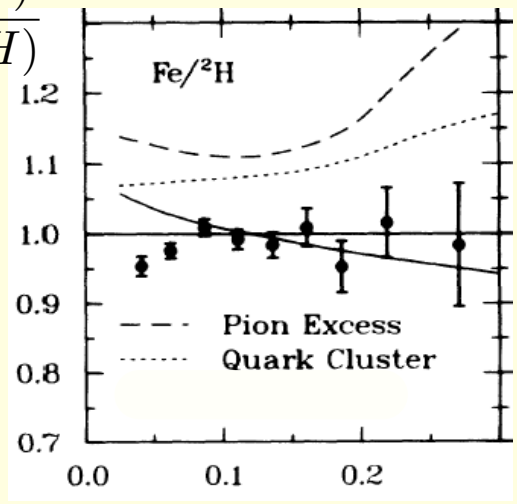

Bertsch, Frankfurt, Strikman "crisis"

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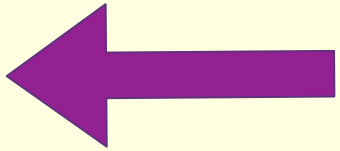
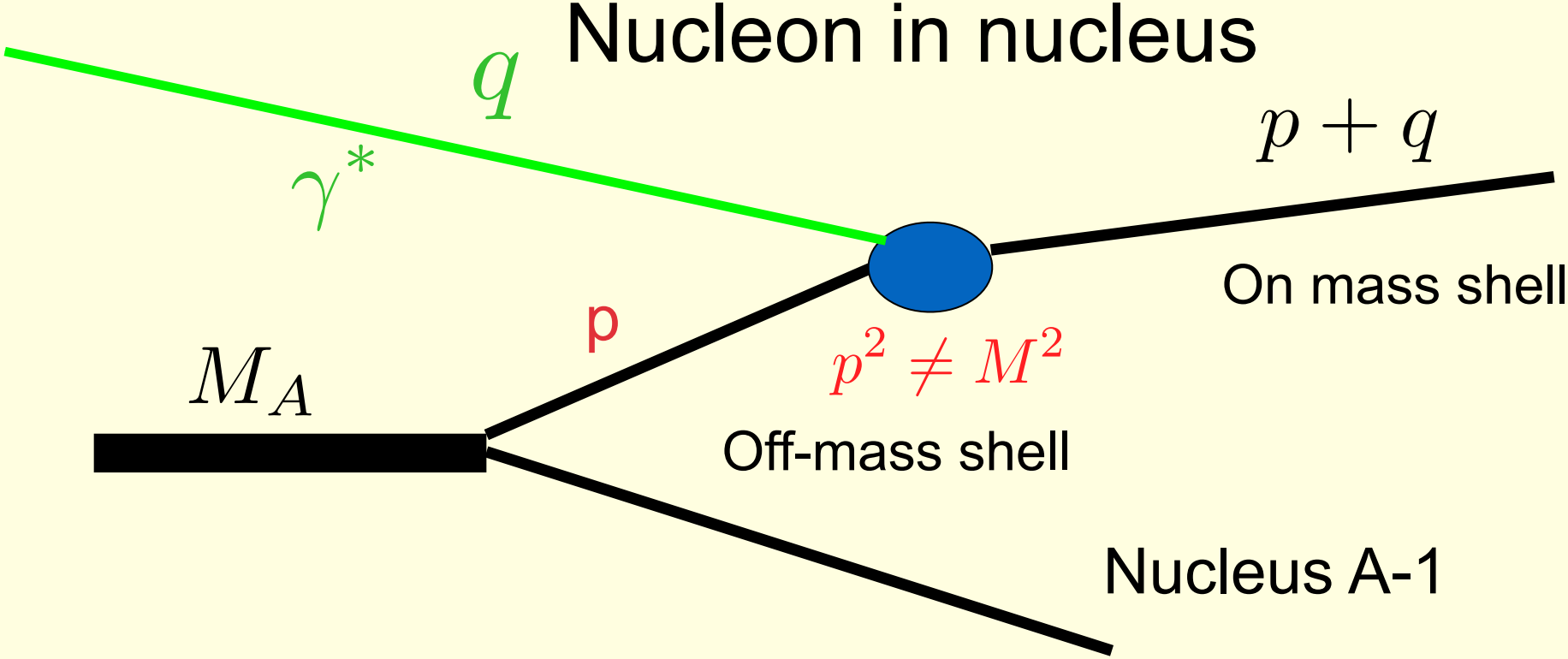
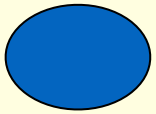


Nucleon in nucleus



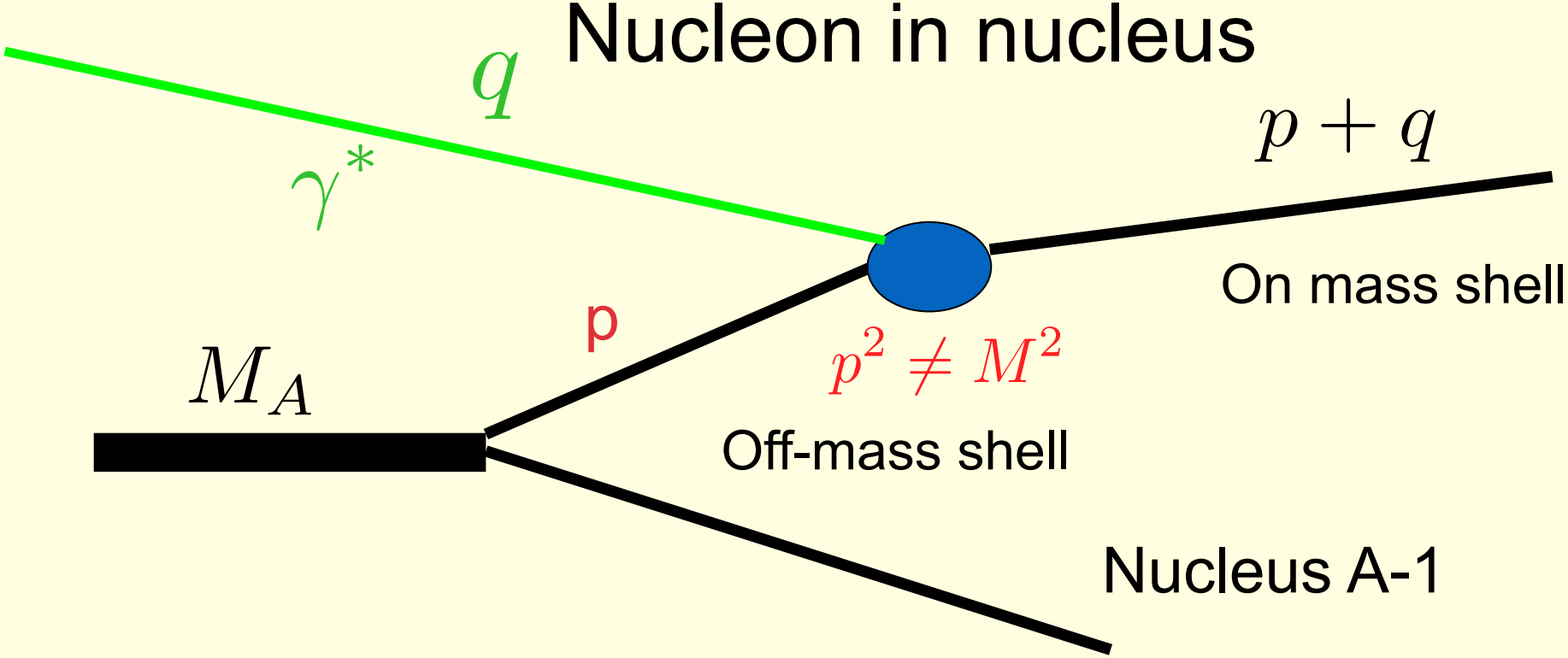
a A-1 nucleus is low-lying state  is form factor of "large" proton

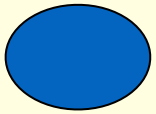
b A- 1 nucleus is 1 fast nucleon +A-2 nucleus
the struck nucleon is part of correlated pair SRC

If Nucleus A-1 is highly excited, then $p^2 - M^2$ is big

Such large virtuality occurs from two nearby correlated nucleons
Highly virtually nucleon is not a nucleon- different quark config.

Nucleon in nucleus



a A-1 nucleus is low-lying state  is form factor of "large" proton

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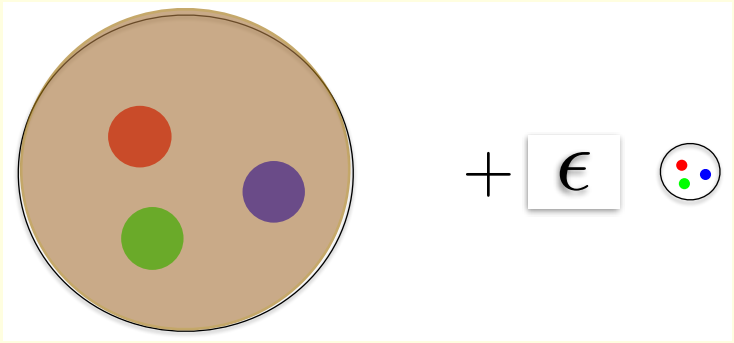
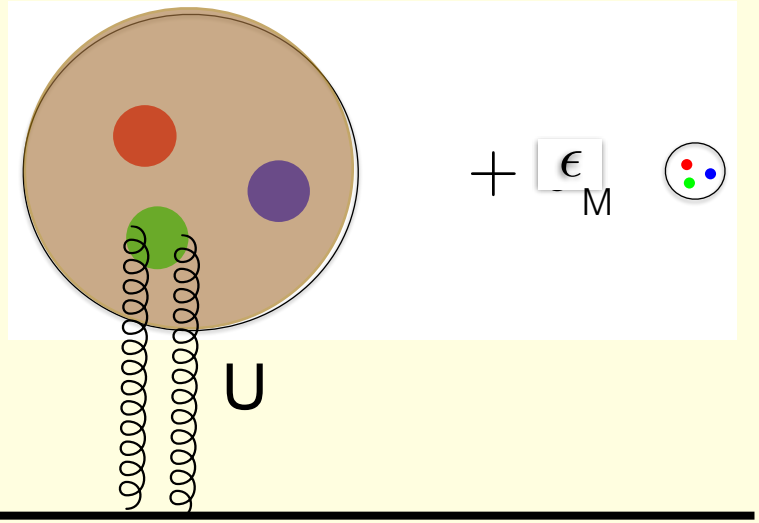
Suppression of Point Like Configurations

Frankfurt Strikman

Free nucleon



Bound nucleon



Schematic two-component nucleon model

Blob-like config:BLC

Point-like config: PLC

PLC smaller, fewer quarks high x

Medium interacts with BLC energy denominator increases PLC Suppressed

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

A-2

Quark structure of nucleon

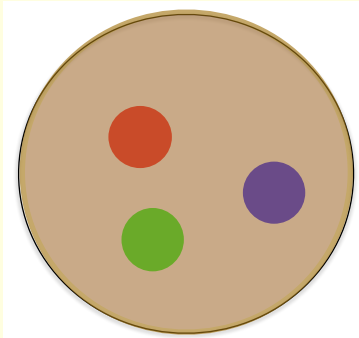
Frankfurt-Strikman

Schematic two-component nucleon model:

Blob-like config:BLC

Point-like config: PLC

BLC



PLC

$+ \epsilon$

gives high x q(x)

PLC does not interact with nucleus

$$\text{Free nucleon} : H_0 = \begin{bmatrix} E_B & V \\ V & E_P \end{bmatrix}, V > 0$$

$$|N\rangle = |B\rangle + \epsilon |P\rangle, \epsilon = \frac{V}{E_B - E_P} < 0$$

$$\text{In nucleus (M)} : H = \begin{bmatrix} E_B - |U| & V \\ V & E_P \end{bmatrix}$$

$|N\rangle_M = |B\rangle + \epsilon_M |P\rangle$, $|\epsilon_M| < |\epsilon|$, PLC suppressed, $\epsilon_M - \epsilon > 0$ amplitude effect!

$|N\rangle_M - |N\rangle \propto (\epsilon_M - \epsilon) \propto U = \frac{p^2 - m^2}{2M}$ Shroedinger eq.

$q_M(x) = q(x) + (\epsilon_M - \epsilon) f(x)\, q(x)$, $\frac{df}{dx} < 0$, $x \geq 0.3$ PLC suppression

$R = \frac{q_M}{q}$; $\boldsymbol{\frac{dR}{dx} = (\epsilon_M - \epsilon)\frac{df}{dx} < 0}$ Reproduces EMC effect - like every model

Why this model??? Large effect if $v = p^2 - m^2$ is large, it is

Cioffi degli Atti '07

A	$U = \langle v(\mathbf{p}, E)\rangle / 2M$
^{3}H	-34.59
^{4}He	-69.40
^{12}C	-82.28
^{16}O	-79.68
^{40}Ca	-84.54
^{56}Fe	-82.44
^{208}Pb	-92.20

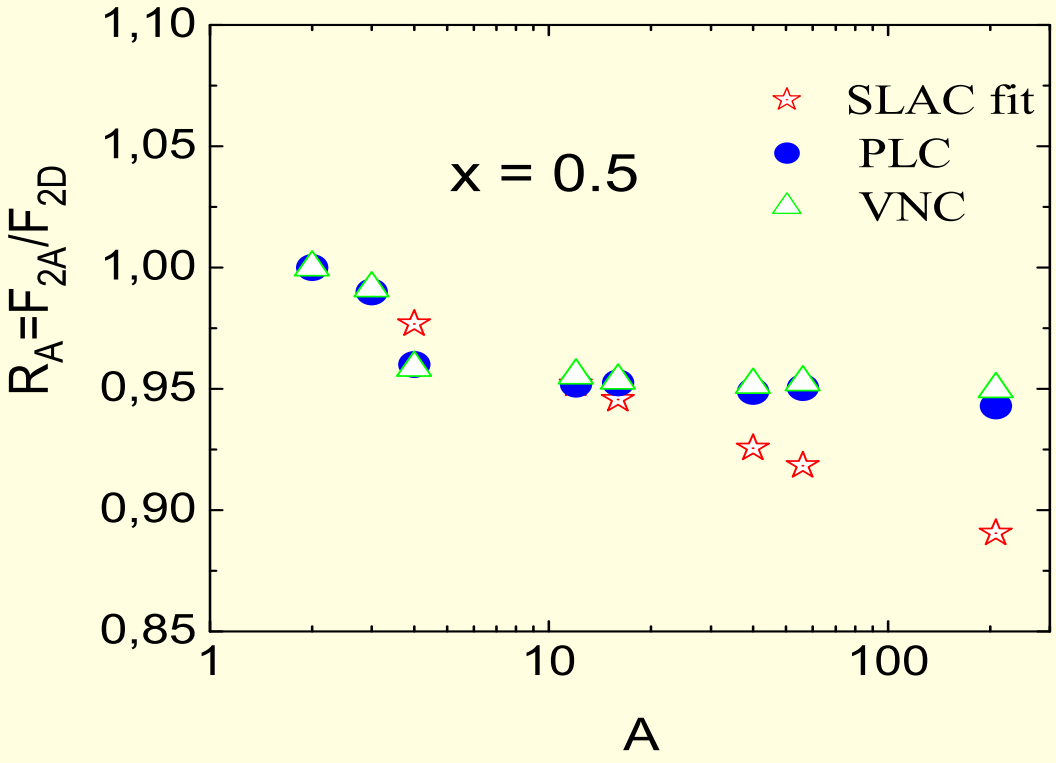
large values from two nucleon correlations Simula

EFT: Chen et al '16

Dependence of the wave function of a bound nucleon on its momentum and the EMC effect

C. Ciofi degli Atti, L. L. Frankfurt, L. P. Kaptari, and M. I. Strikman

Phys. Rev. C 76, 055206



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

These configurations are the origin of high x EMC ratios

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

A(e,e') at x>1 shows dominance of 2N SRC

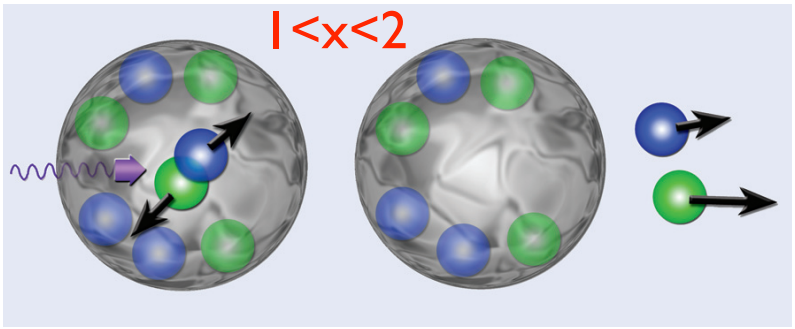
$$x = \frac{Q^2}{2M\nu}$$

x goes from 1 to A

x=1 is **exact** kinematic limit **for all Q^2** for the scattering off a free nucleon;
x=2 (x=3) is **exact** kinematic limit **for all Q^2** for the scattering off a A=2(A=3) system (up to <1% correction due to nuclear binding)

M Strikman picture

Two nucleons cluster



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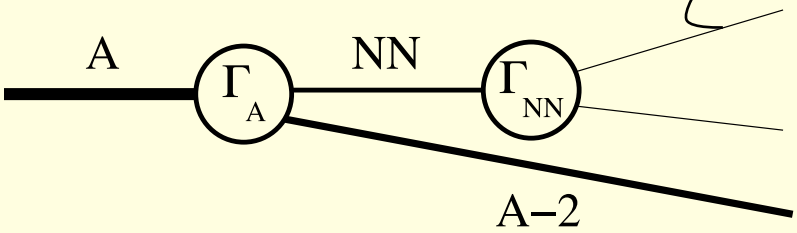
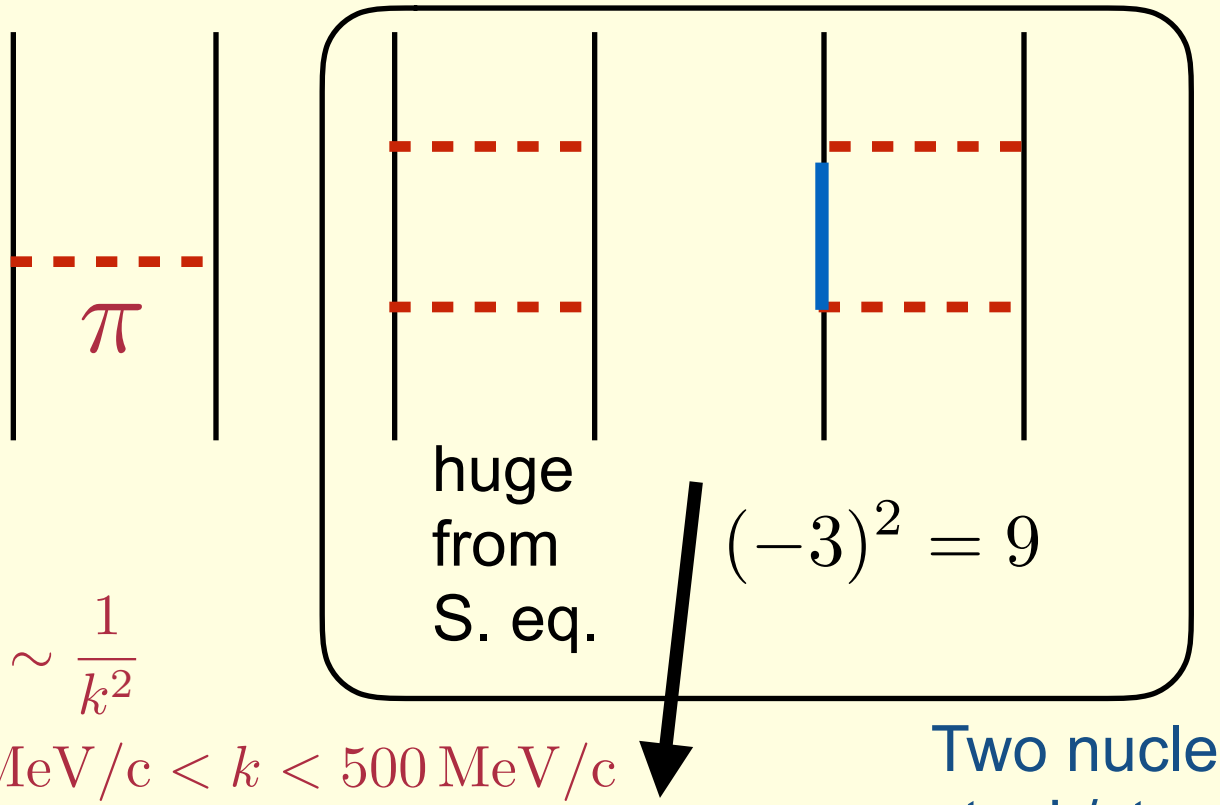


How/why nucleons in nuclei cluster

one pion exchange between n and p



$\psi(k) \sim \frac{1}{k^2}$

$300\,\mathrm{MeV/c} < k < 500\,\mathrm{MeV/c}$

Supports high momentum transfer

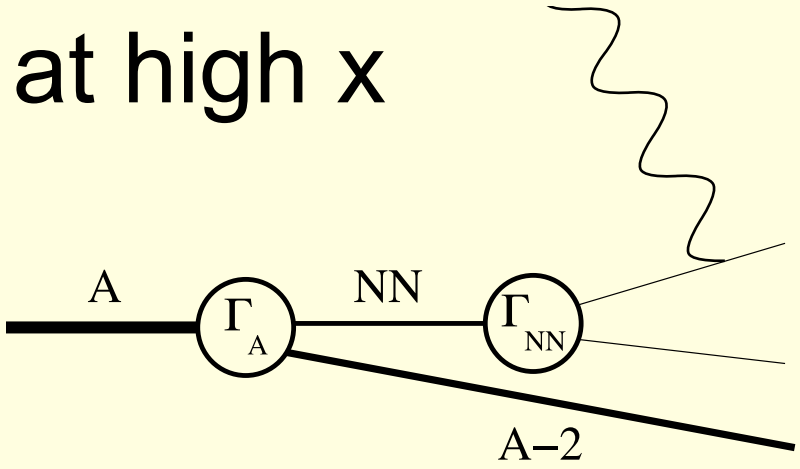
Not effective range

Two nucleons are stuck/struck together

May explain why pionless EFT works so well

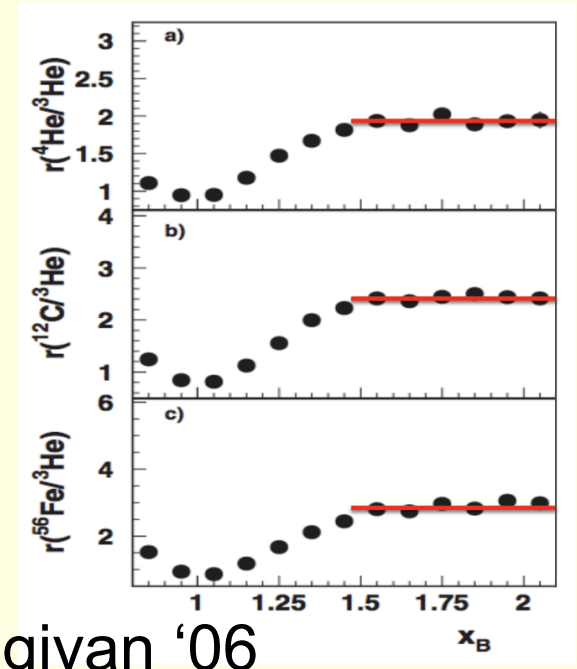
van Kolck

(e,e') at high x



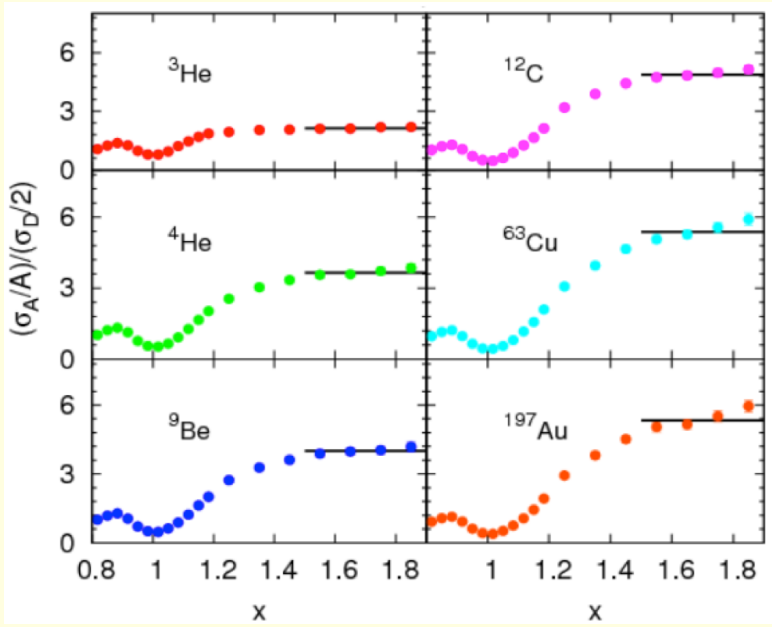
$1 < x < 2$ leading term:

$$\frac{2}{A}\sigma(x,Q^2) \approx a_2(A)\sigma_2(x,Q^2) \approx a_2(A)\sigma_D(x,Q^2)$$



a_2

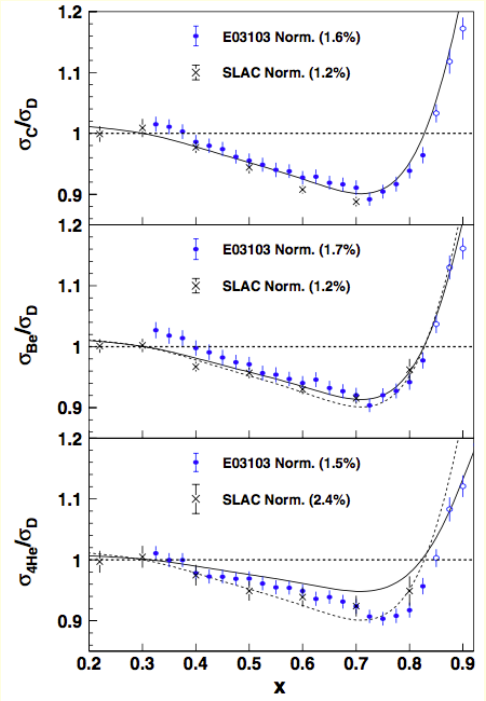
Egiyan '06



a_2

Fomin et al '11

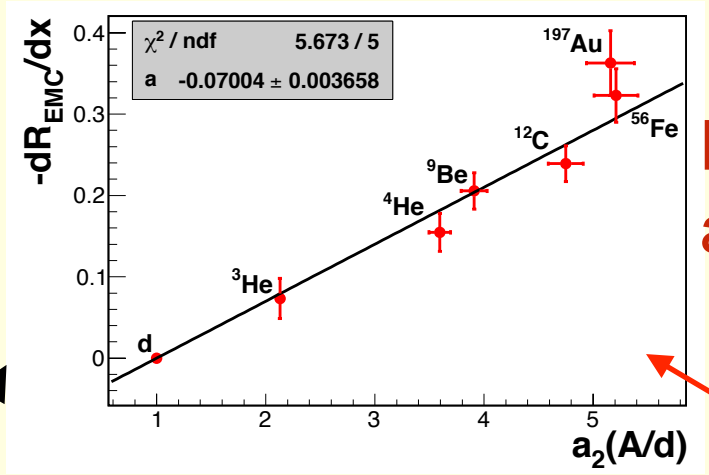
DIS



Seely et al 2009

get slope

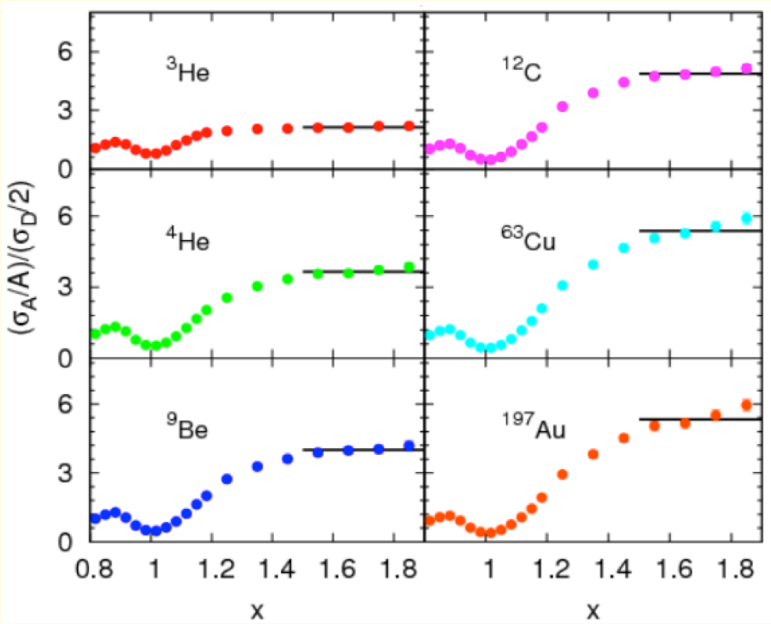
Hen et al 2013



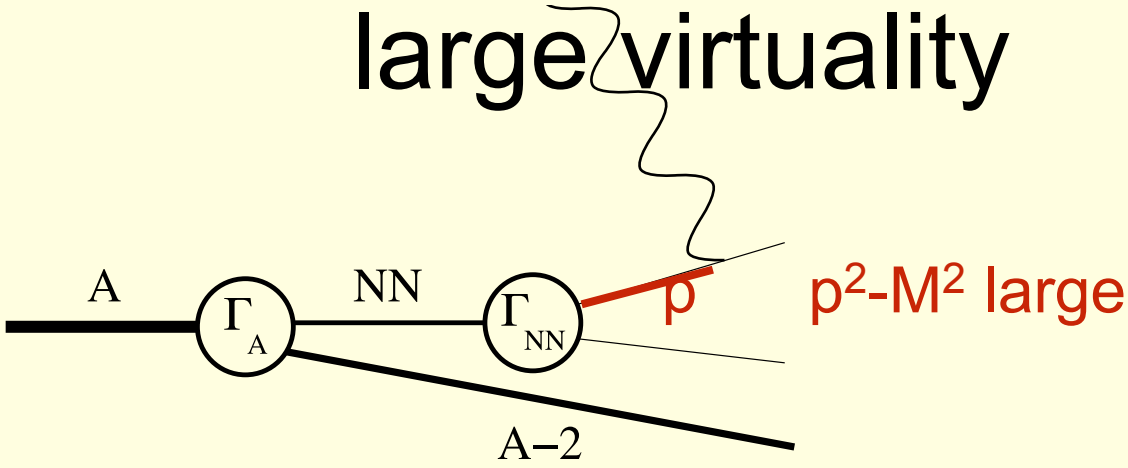
Linear relation accident?

Fomin et al 2012

a_2



Common cause of dR/dx and a_2(A): large virtuality

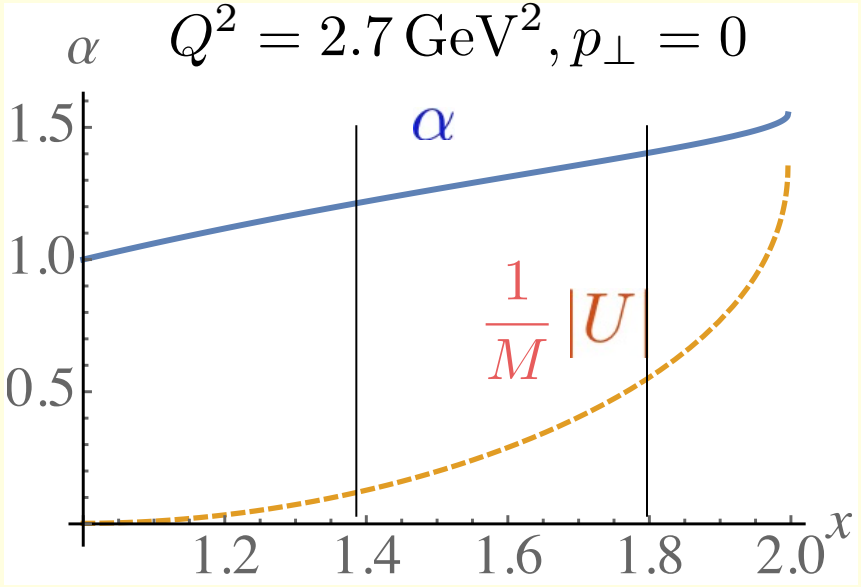


p^2-M^2 large

Given Q^2, x, $p_\perp$

U=v/(2M)

4-momentum conservation determines $2\frac{p^+}{P_D^+} \equiv \alpha$ and $v = p^2 - M^2$



Sees wave function at $\alpha \approx 1.2$

|U| is large v is large

can only get this from short range correlation

large v is responsible for both dR/dx and a_2(A)

The word both had been largely missing from models of EMC effect
many models have been ad hoc. The PLC suppression model is not.

Implications for nuclear physics

- Nucleus modifies nucleon electroweak form factors
- Nucleon excited states exist in nuclei
- Medium modifications in deuteron influence extracted neutron F_2
- spectator tagging
- …..

Logic/Summary

Data	DIS-large x	(e,e') Plateau large x	(e,e',NN)
Interpret:	valence quark momentum decrease in A	2 baryon clusters	
QCD	nucleon wf has BLC,PLC etc PLC -high x PLC suppressed		
	Large virtuality		
Short-ranged interactions		np dominance	

Logic/Summary

EMC effect and large x plateau have same cause

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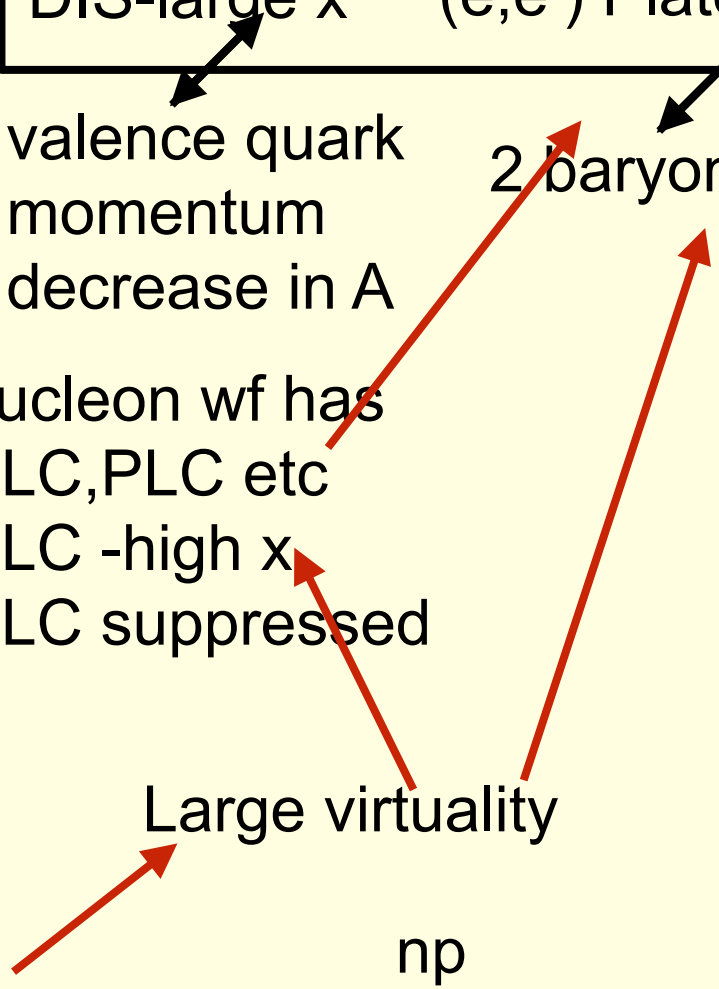

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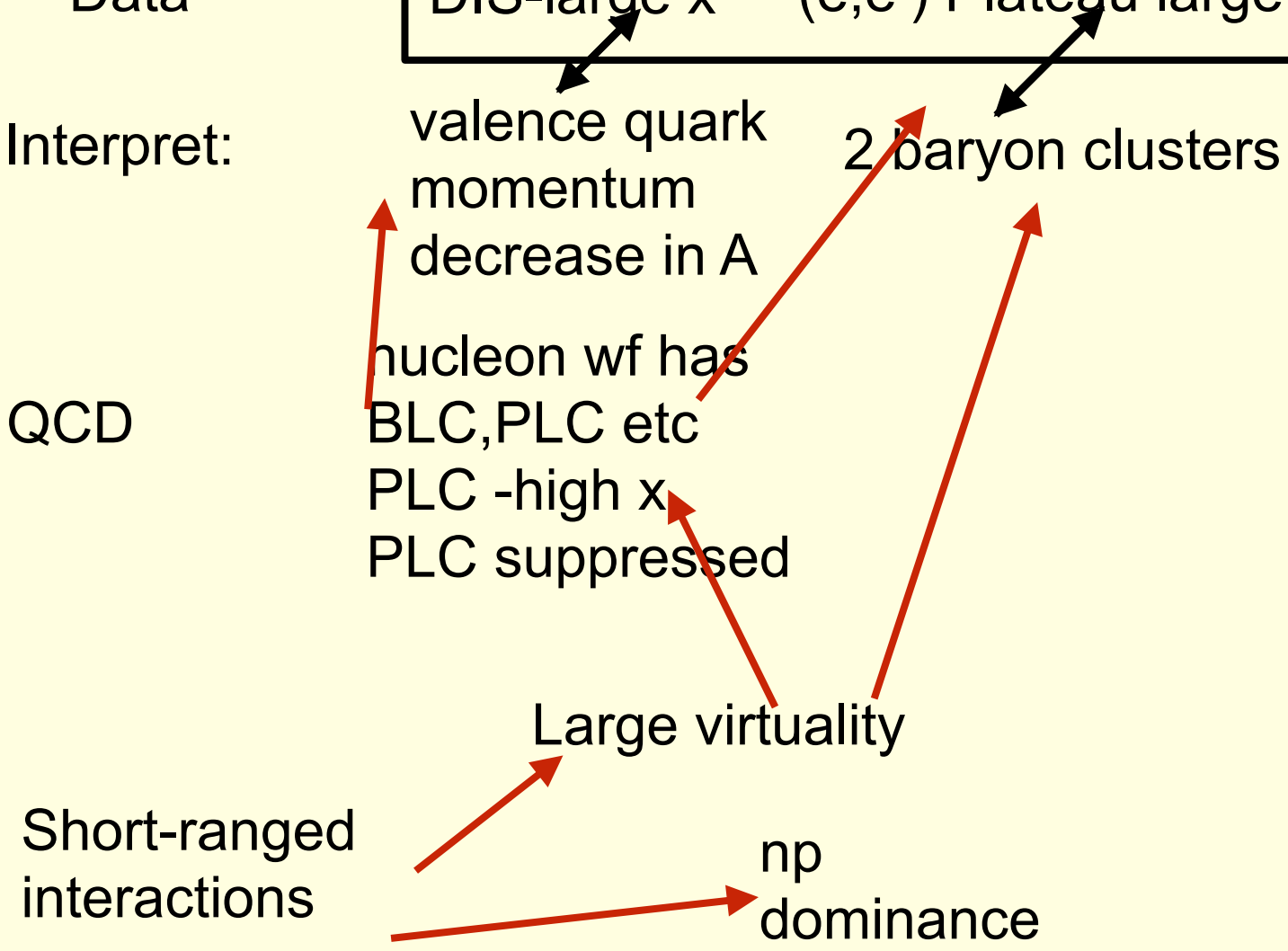

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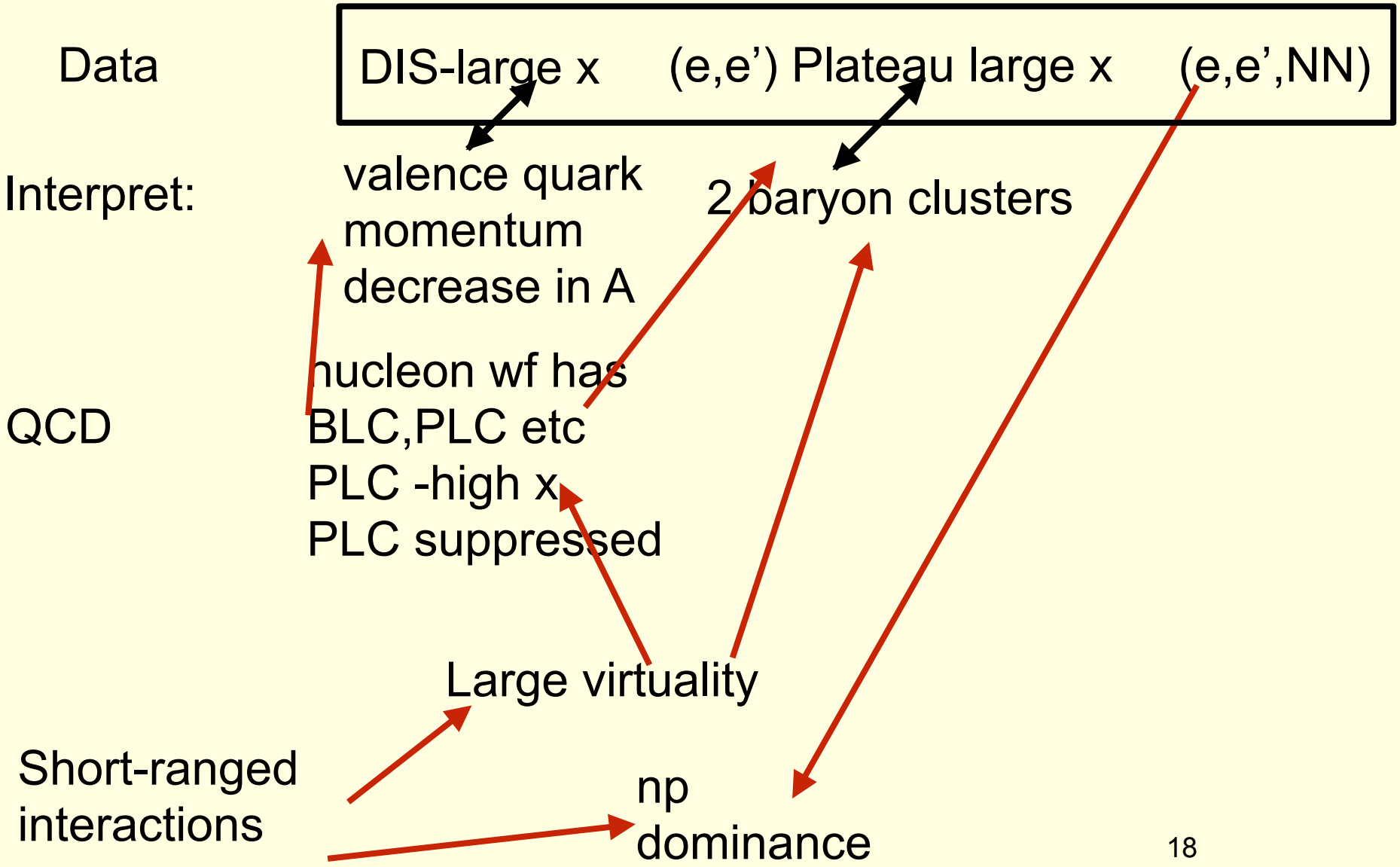

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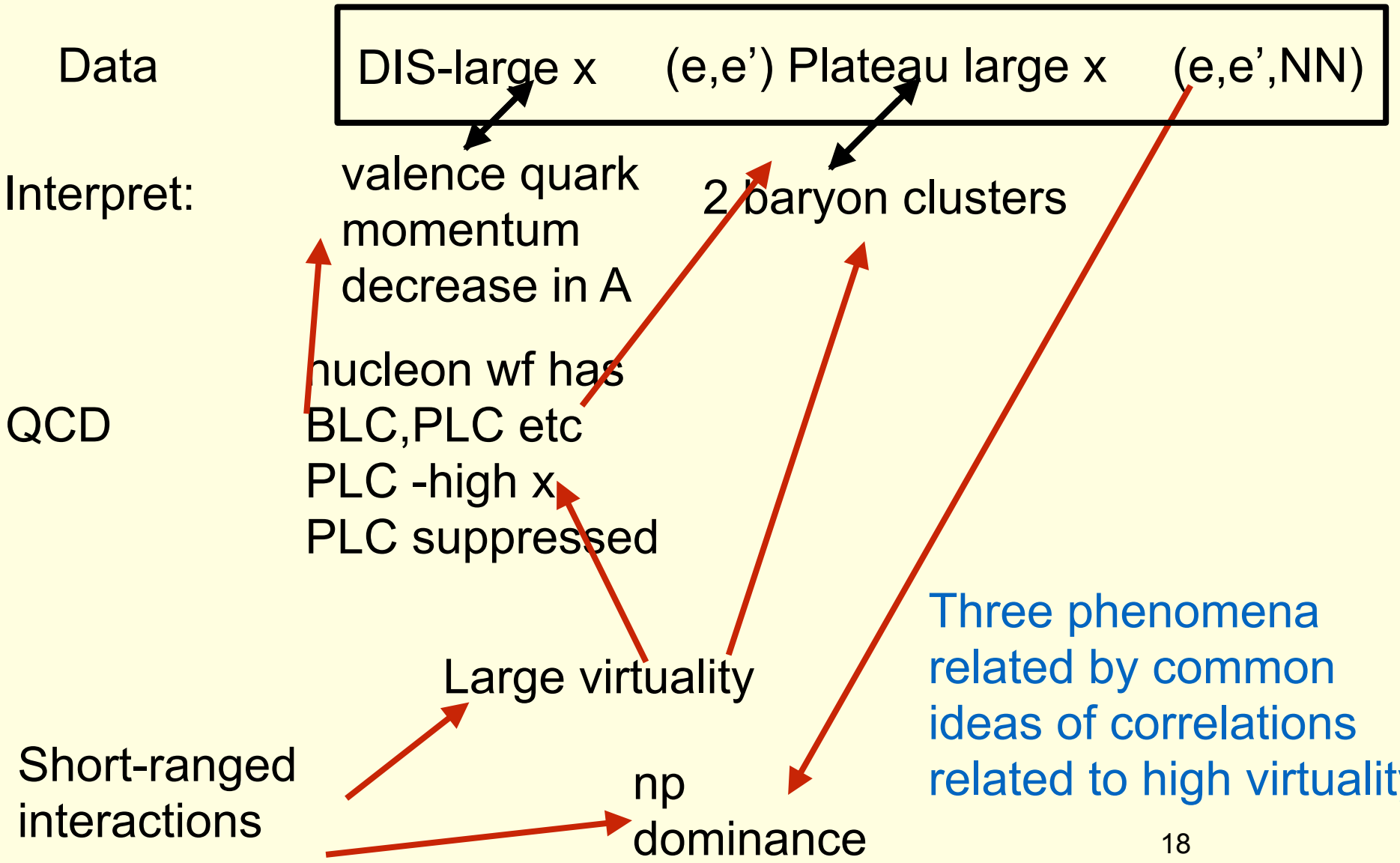

Three phenomena related by common ideas of correlations related to high virtuality