Nucleon structure: Knowns, known unknowns and unknown unknowns

Gerald A. Miller UW

- Known- proton radius -0.84 fm. Small radius
- Known unknown- why does Bloom Gilman duality occur?
- Known unknown- confinement mechanism how does QCD yield confinement
- Known unknowns- GPDs, TMDs
- Unknown unknowns- not known, but maybe stuff needed to understand confinement
- Known unknown - cause of EMC effect- nucleon structure in the nucleus THIS TALK

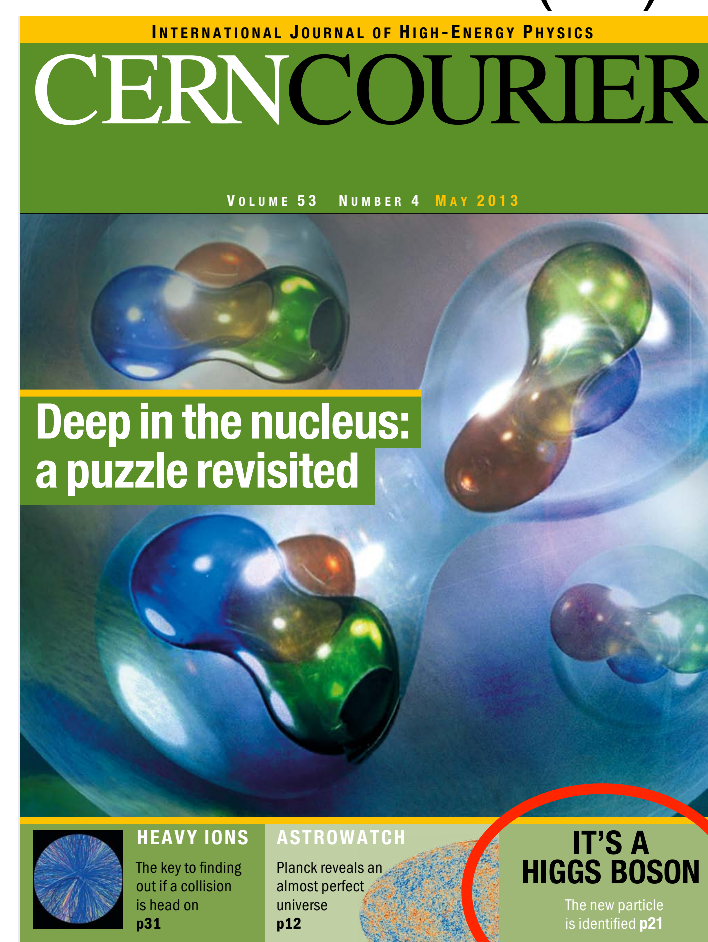
Recent thoughts on the EMC effect (1982)

Gerald A. Miller, with D N Kim U. of Washington

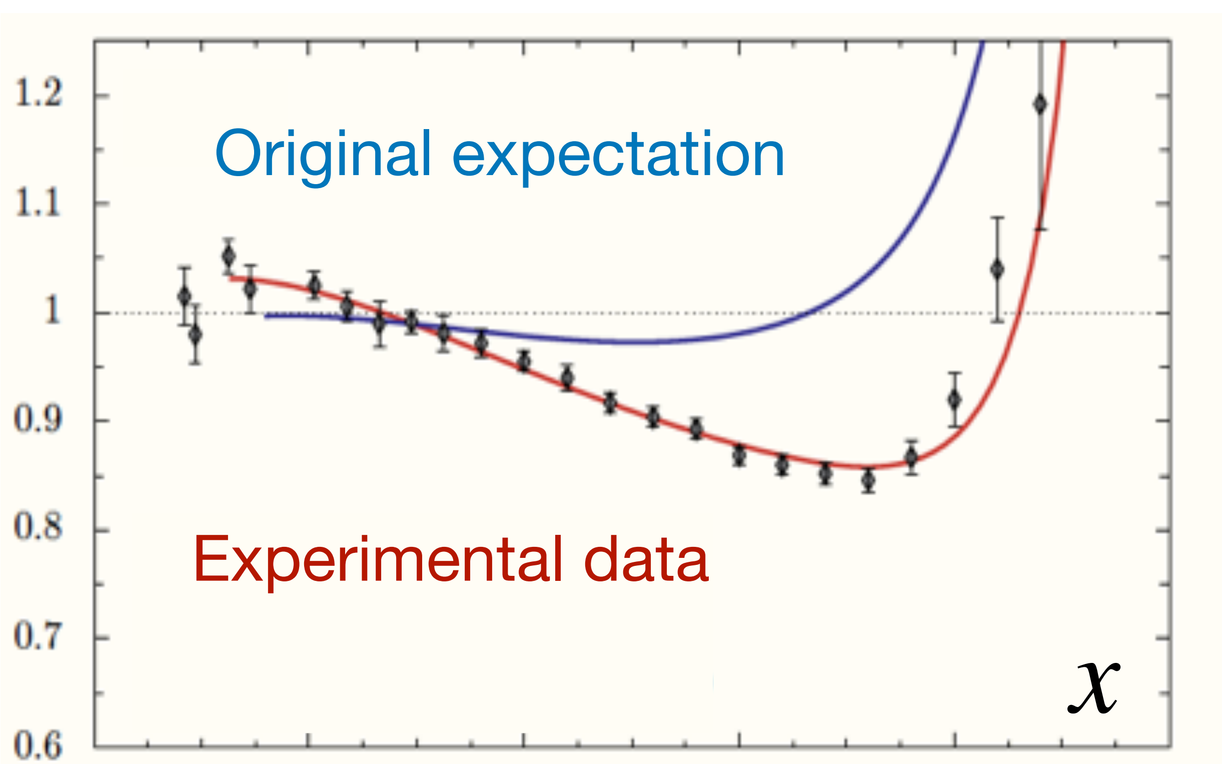
In deep inelastic scattering from nuclei

$$\frac{2}{A}\frac{\sigma_A}{\sigma_D} \neq 1$$

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



$$\frac{2}{A}\frac{\sigma_A}{\sigma_D}$$



Effect is small, for x between 0.3 and 0.7 linear decrease with x

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
- bound nucleon is larger than free one- a

a mean field effect- $p^2 - M^2$ virtuality small

- multi-nucleon clusters - beyond the mean

b field $p^2 - M^2$ virtuality large

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

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Drell-Yan Data

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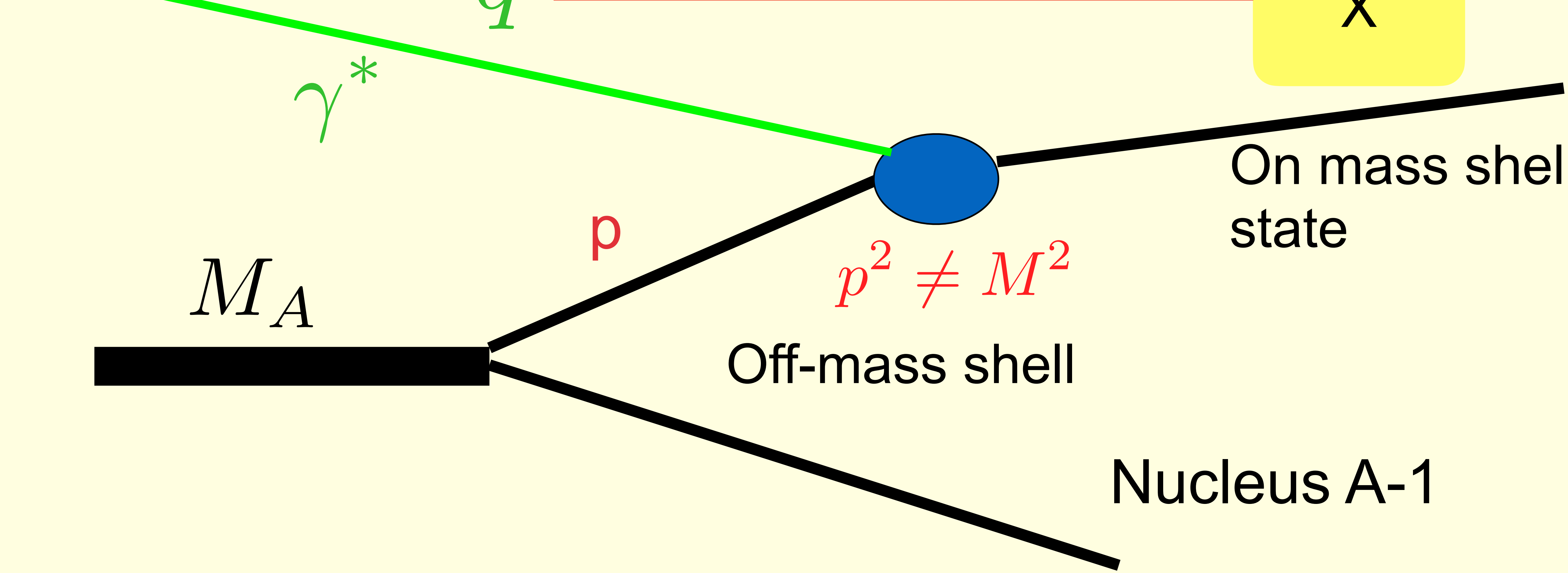
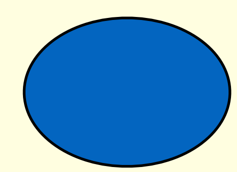
Nuclear Virtuality

X



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

b A- 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

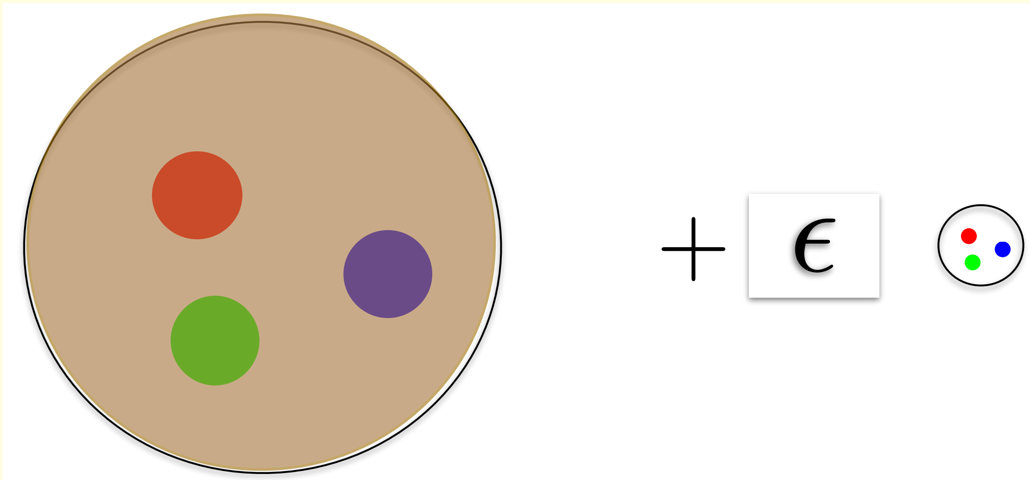
Such large virtuality occurs from two nearby correlated nucleons

Highly virtually nucleon is not a nucleon- different quark config.

Suppression of Point Like Configurations

Frankfurt Strikman

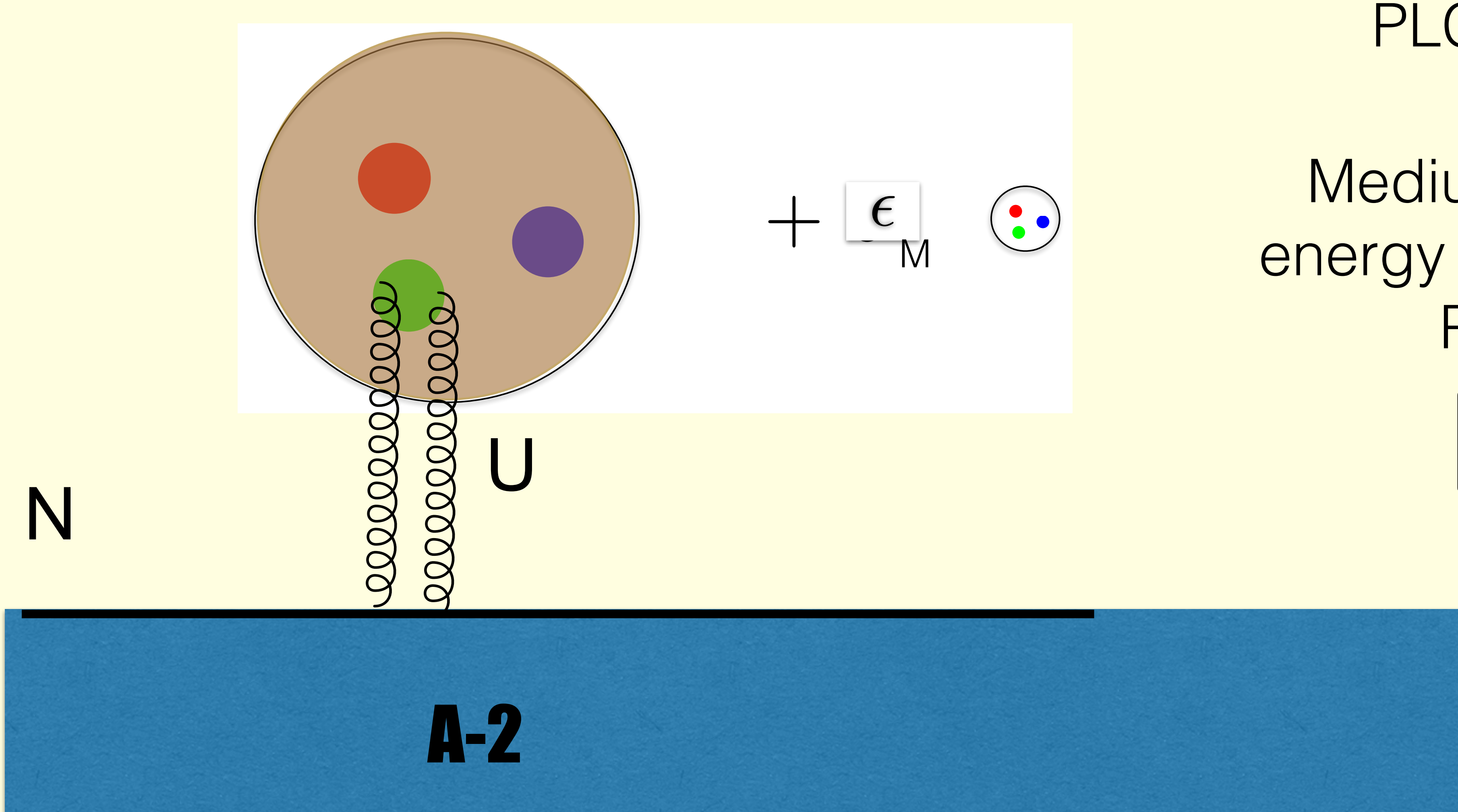
Free nucleon



Schematic two-component nucleon model

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

Bound nucleon



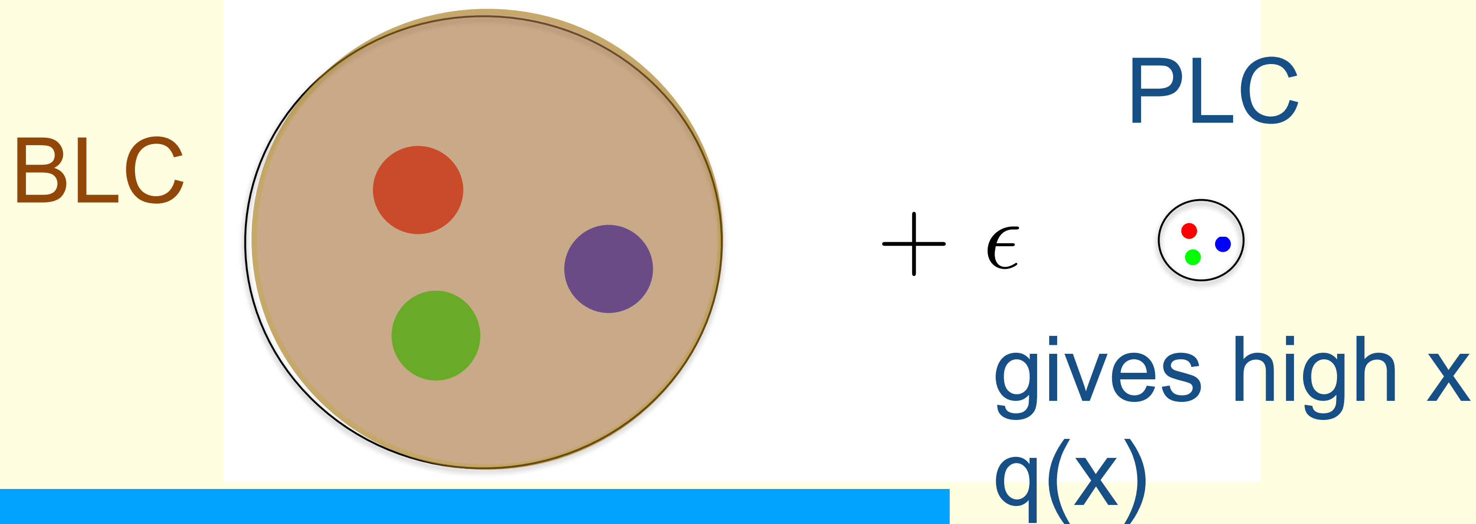
PLC smaller, fewer quarks
high x

Medium interacts with BLC
energy denominator increases
PLC Suppressed

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

Quark structure of nucleon

Frankfurt-Strikman



Schematic two-component nucleon model:
Blob-like config:BLC
Point-like config: PLC
PLC doesn't interact with nucleus

Free space $H_0 = \begin{bmatrix} E_B & V \\ V & E_P \end{bmatrix}, \ |N\rangle = \frac{1}{\sqrt{1+\epsilon^2}}(|B\rangle + \epsilon|P\rangle)$

Medium (M) $H = \begin{bmatrix} E_B - |U| & V \\ V & E_P \end{bmatrix}, \ |N\rangle_M = \frac{1}{\sqrt{1+\epsilon_M^2}}(|B\rangle + \epsilon_M|P\rangle)$

$$\epsilon_M = \epsilon \left(1 - |U|/(2\sqrt{(E_P - E_B)^2 + 4V^2}\right)$$

$$q_M = q + 1/2(\epsilon_M - \epsilon)q_B(q_P/q_B - 1) = q + 1/2 q_B(\epsilon_M - \epsilon)(f(x) - 1)$$

$$\epsilon_M < \epsilon, \frac{df}{dx} > 0, \frac{q_M}{q} = 1 + \text{function that decreases with x}$$

$$\epsilon_M - \epsilon \propto U \propto \frac{p^2 - M^2}{2M} \text{ virtuality}$$

what is $f(x)$

Previous model not complete:
Needs specific x-dependence for BLC & PLC

Physics Reports 584 (2015) 1–105

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ELSEVIER

Light-front holographic QCD and emerging confinement

Stanley J. Brodsky[a,*], Guy F. de Téramond[b], Hans Günter Dosch[c], Joshua Erlich[d]

LFQCD -good description of much data

Universality of Generalized Parton Distributions in Light-Front Holographic QCD

Guy F. de Téramond,[1] Tianbo Liu,[2,3] Raza Sabbir Sufian,[2] Hans Günter Dosch,[4] Stanley J. Brodsky,[5] and Alexandre Deur[2] PHYSICAL REVIEW LETTERS **120,** 182001 (2018)

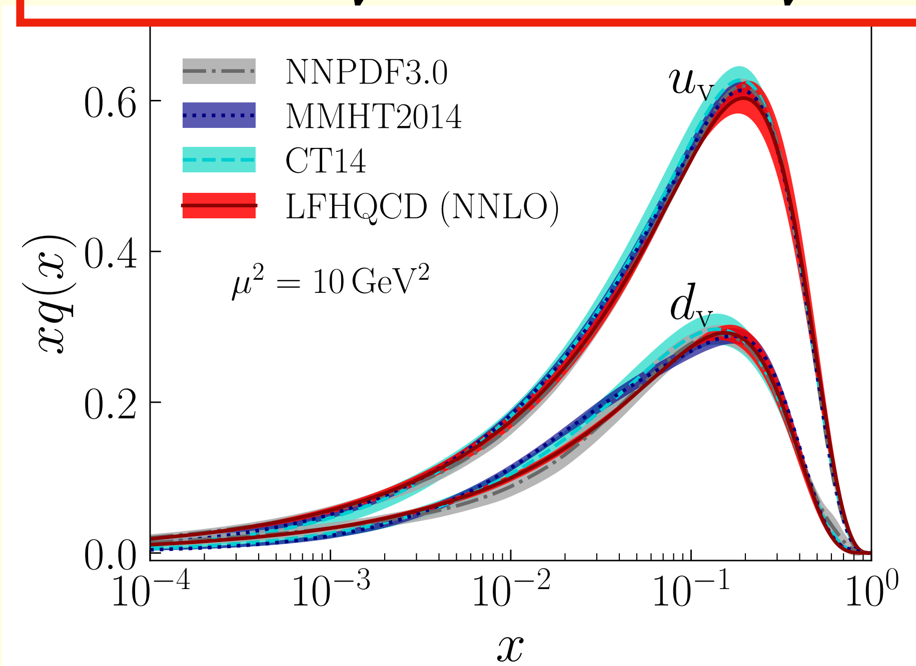
- 4 dimensional QFT equivalent to 5 dim. gravitational theory- space time is bent (Maldecena conjecture), holographic dual
- Bottom up procedure: construct four dimensional light front wave equation that has holographic dual
- Use holographic dual to compute electromagnetic form factors for systems of arbitrary spins, arbitrary number of particles
- Form factor is a Beta function, reparametrization invariance gives

$F_\tau(t) = \int H_\tau(x,t)\,dx$ in a flexible form amenable to fitting data, τ is parton number

Nucleon pdfs

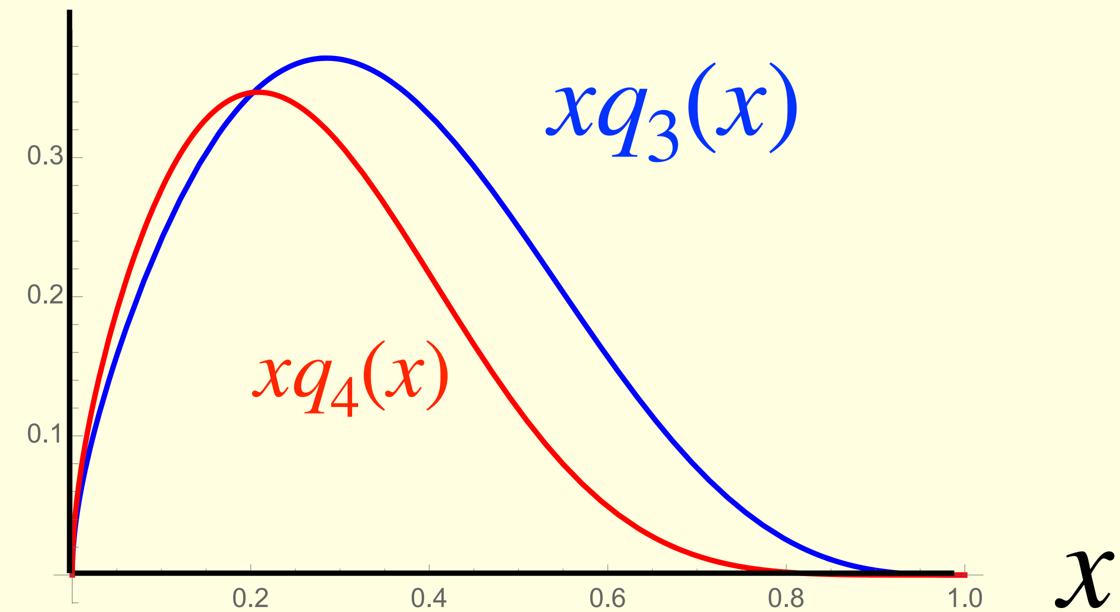
$$u_v(x) = 3/2\,q_3(x) + 1/2\,q_4(x),\ d_v(x) = q_4(x)$$

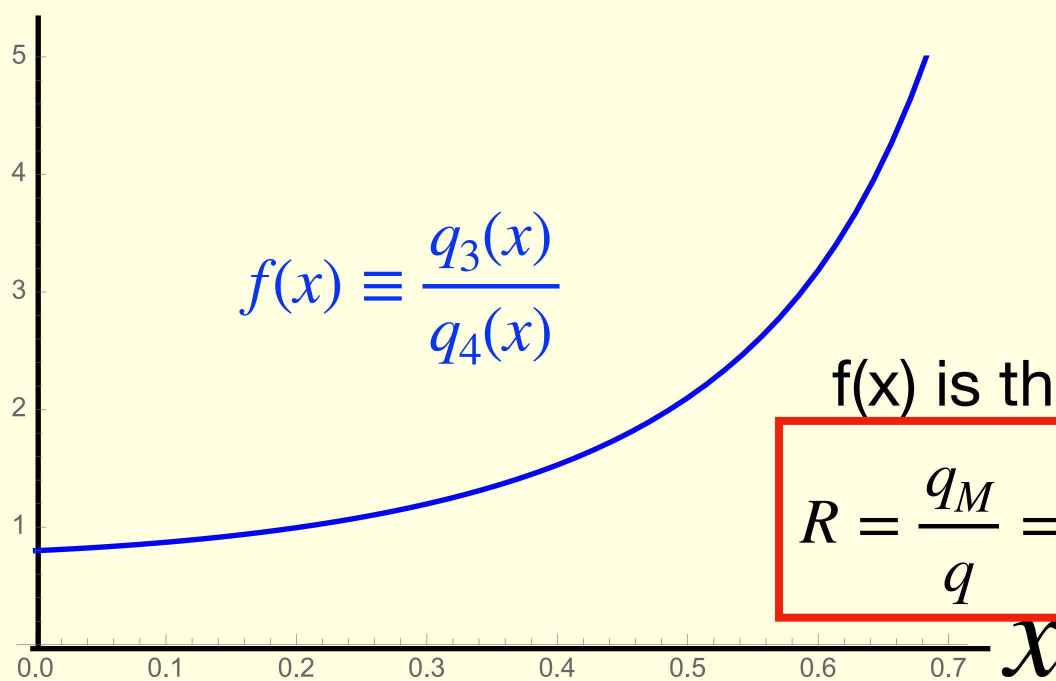
$$u_V(x) + d_V(x) = 3/2\,q_3(x) + 3/2\,q_4(x)$$



PRL 120,182001 gets good fit

3 is PLC, 4 is BLC



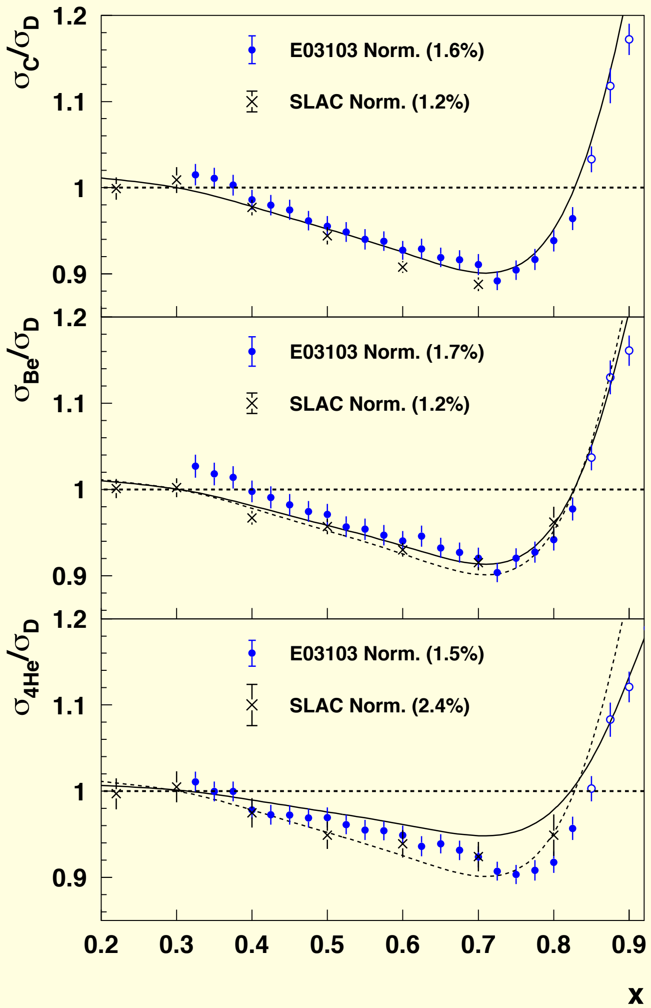


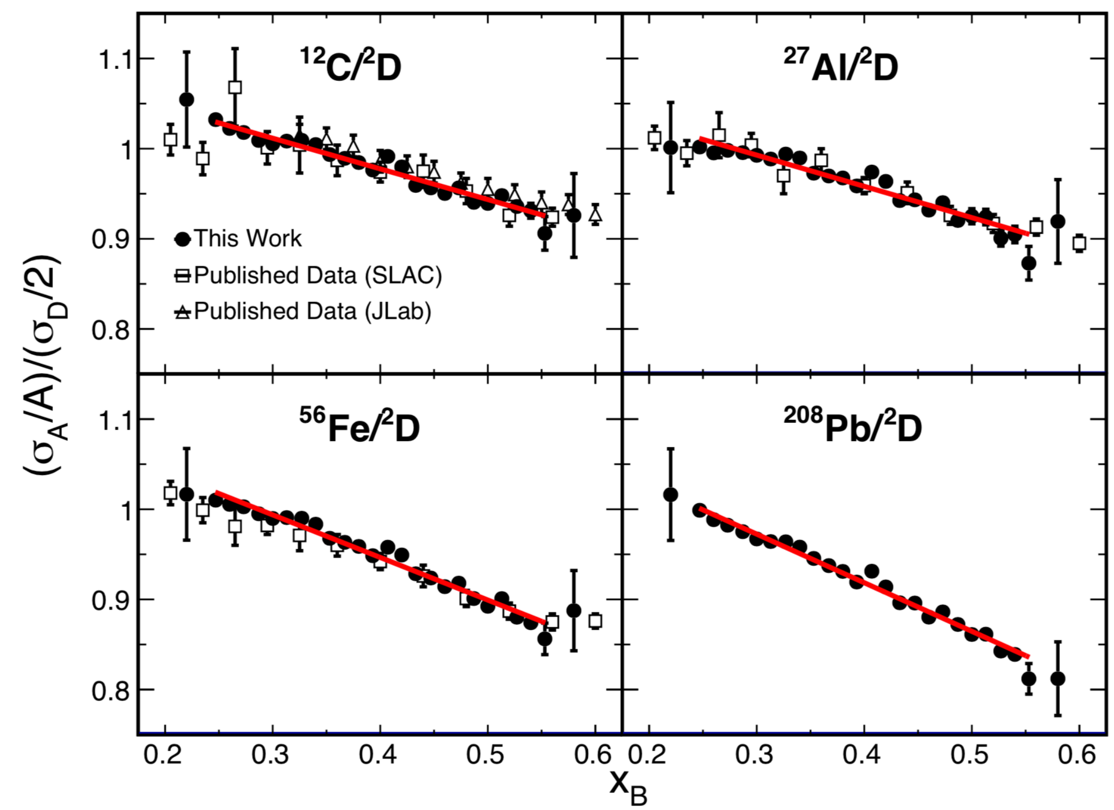
f(x) is the ratio we needed to understand the EMC effect

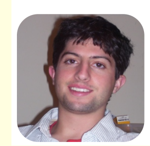
$$\boxed{R = \frac{q_M}{q} = 1 + \delta\frac{1-f}{1+f}},\ \delta = \frac{|U|}{E_P - E_B + \sqrt{(E_P - E_B)^2 + 4V^2}}$$

N=Z nuclei

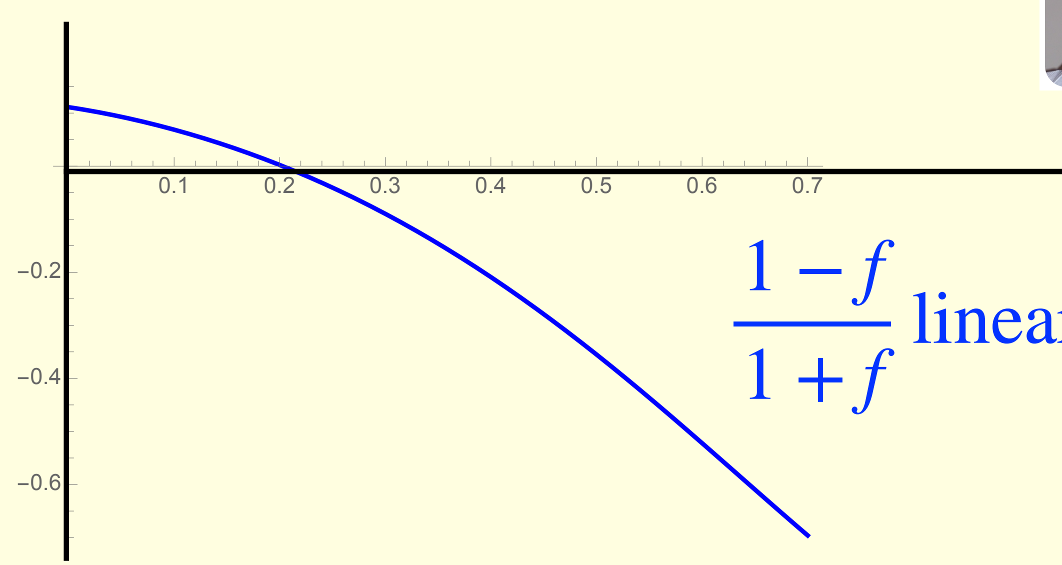
$$R = \frac{q_M}{q} = 1 + \delta\frac{1-f}{1+f}, \delta = \frac{|U|}{E_P - E_B + \sqrt{(E_P-E_B)^2 + 4V^2}}$$







Schmookler et al., Nature (2019)



$$\frac{1-f}{1+f} \text{ linear for } 0.3 \le x \le 0.7$$

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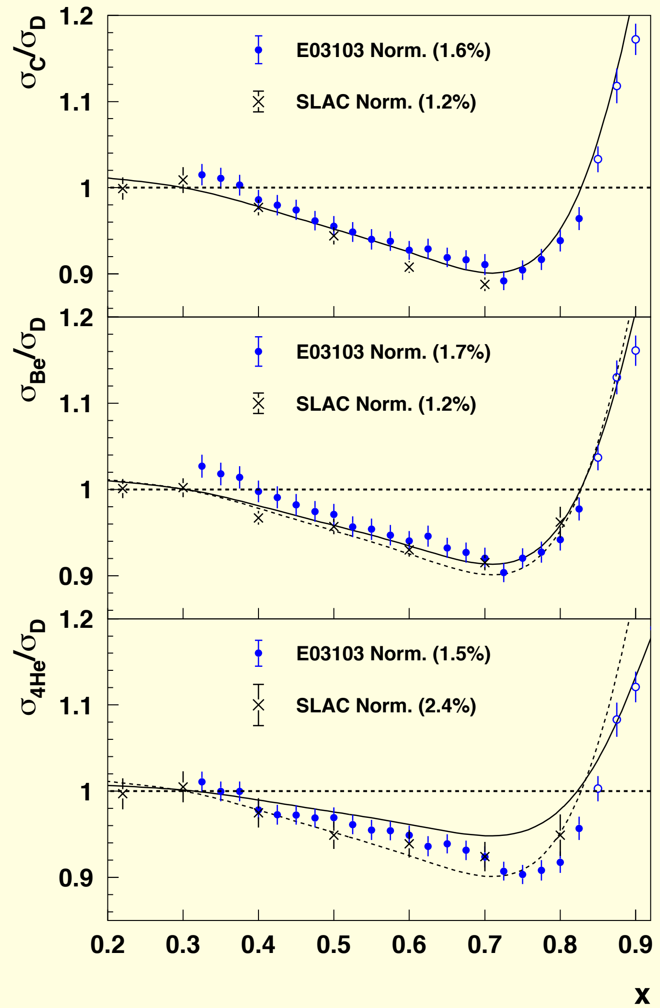

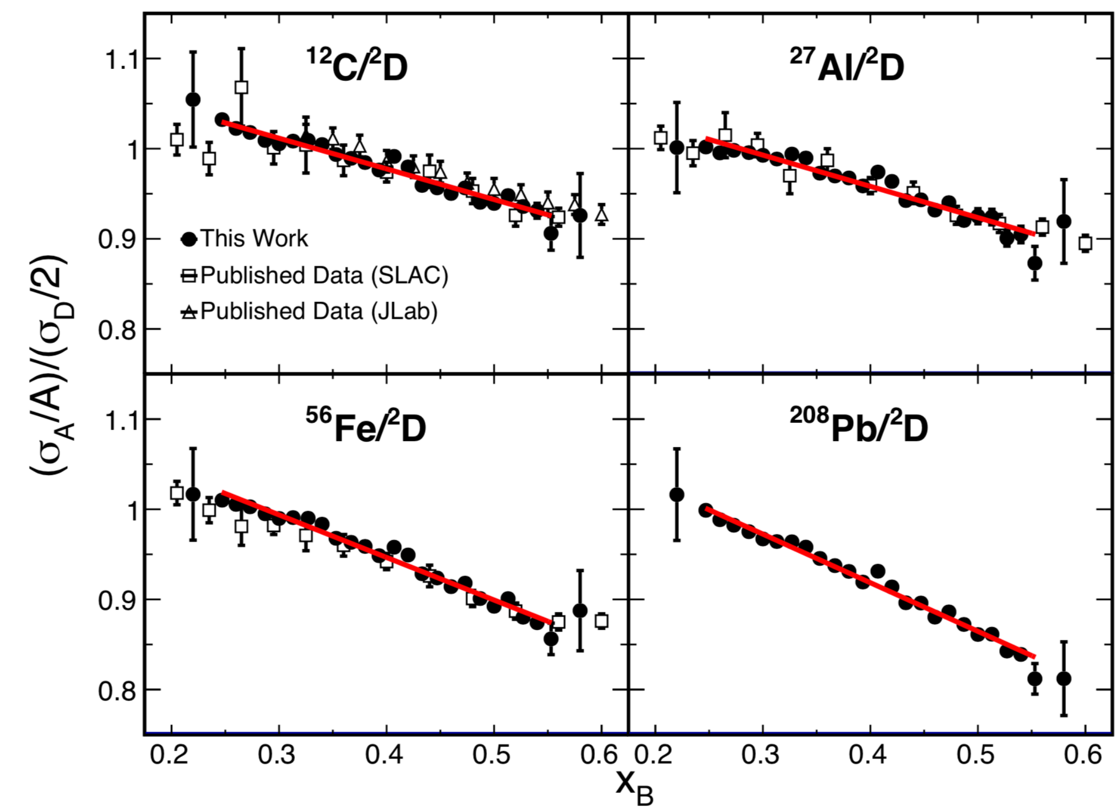

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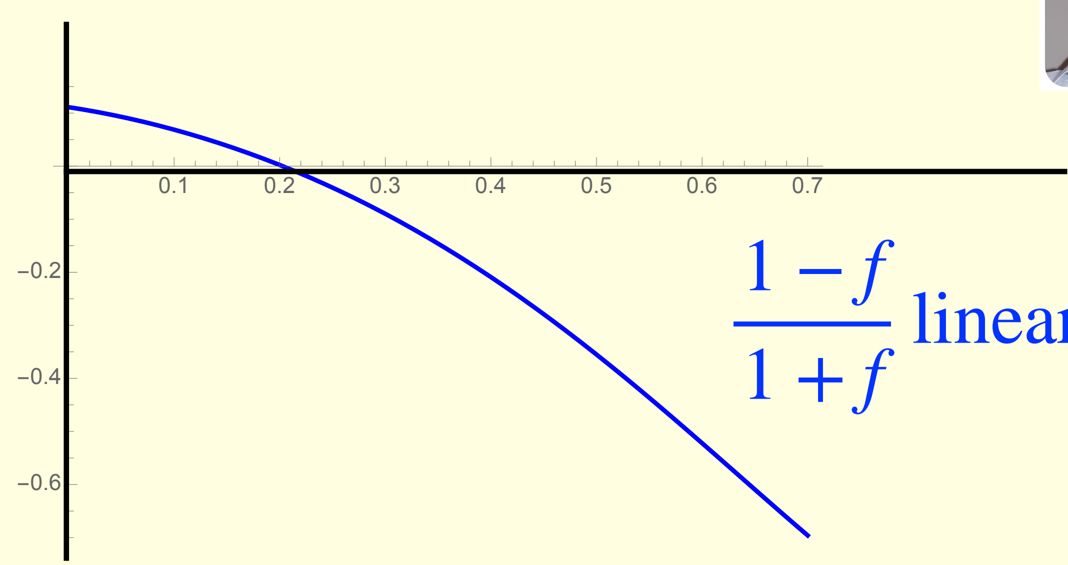
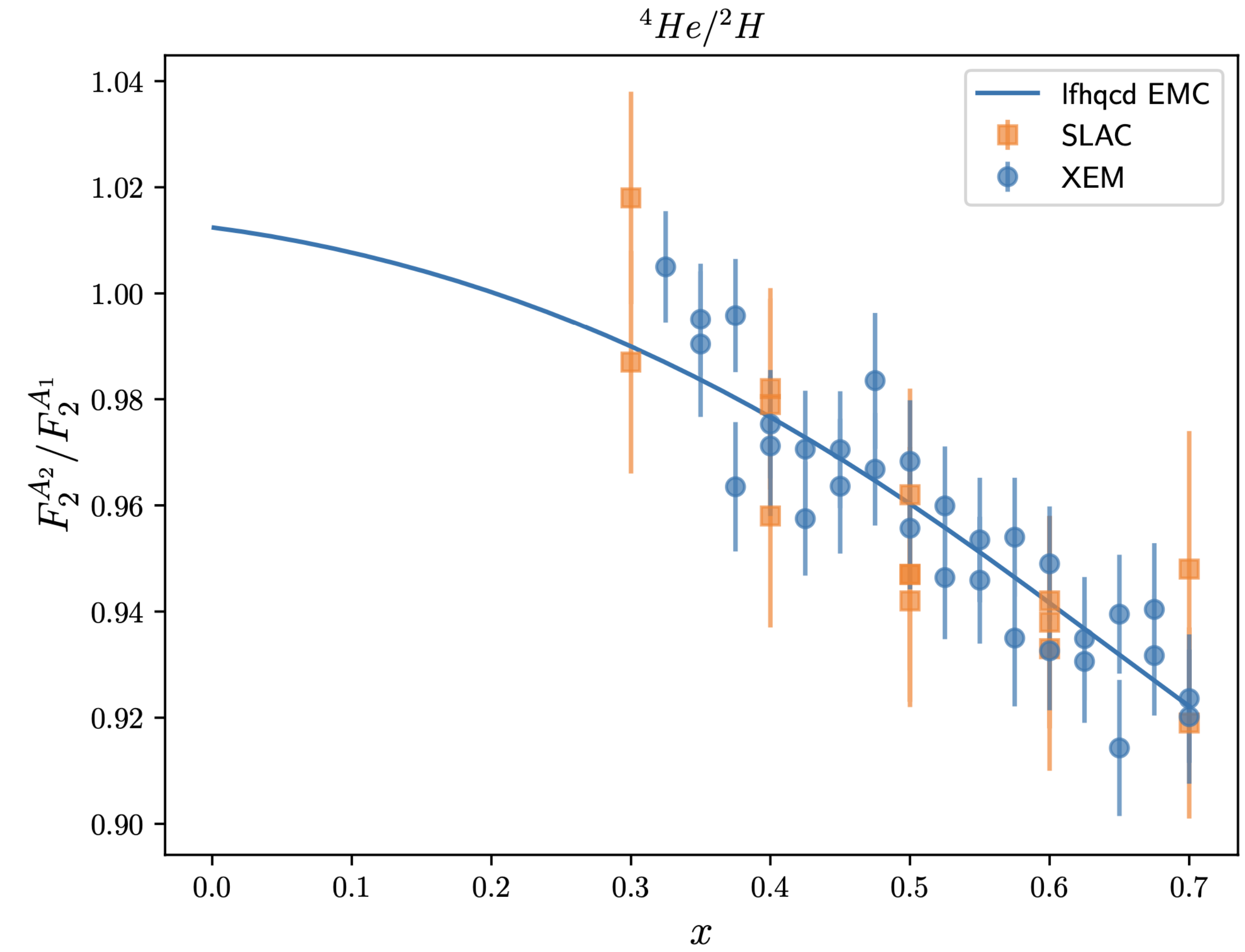
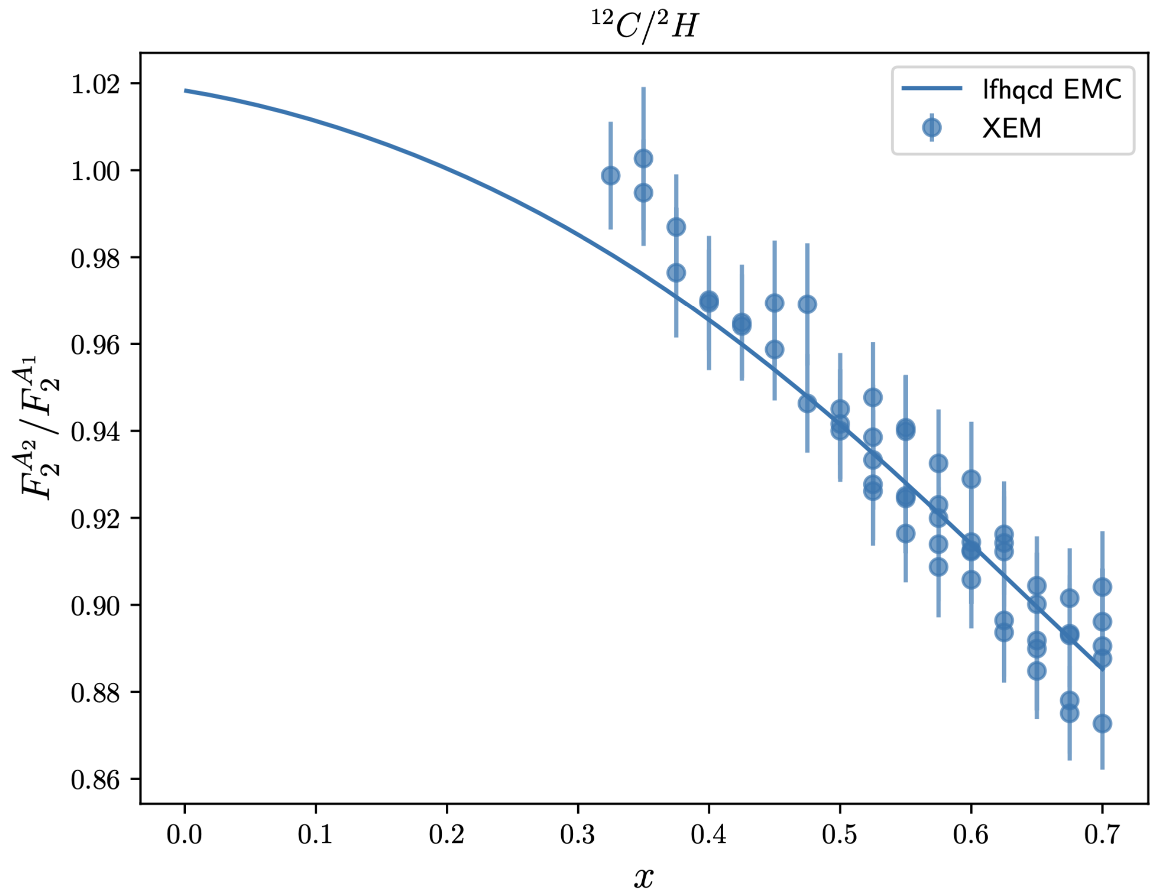


$\frac{1-f}{1+f}$ linear for $0.3 \leq x \leq 0.7$

Preliminary results





δ is large $|U| \sim 150\,\mathrm{MeV}$

Summary

- Basic model is suppression of point like configurations, PLC
- Light front holographic QCD, based duality with a gravitational theory in 5 dimensions provides distribution functions (x) for PLC and BLC components
- x dependence accounts for EMC effect
- Values of parameter δ need to describe data indicate large virtuality is needed, so SRC explanation seems favored over mean field

Dmitriy (Dima) Kim

Spares follow

Implication of model

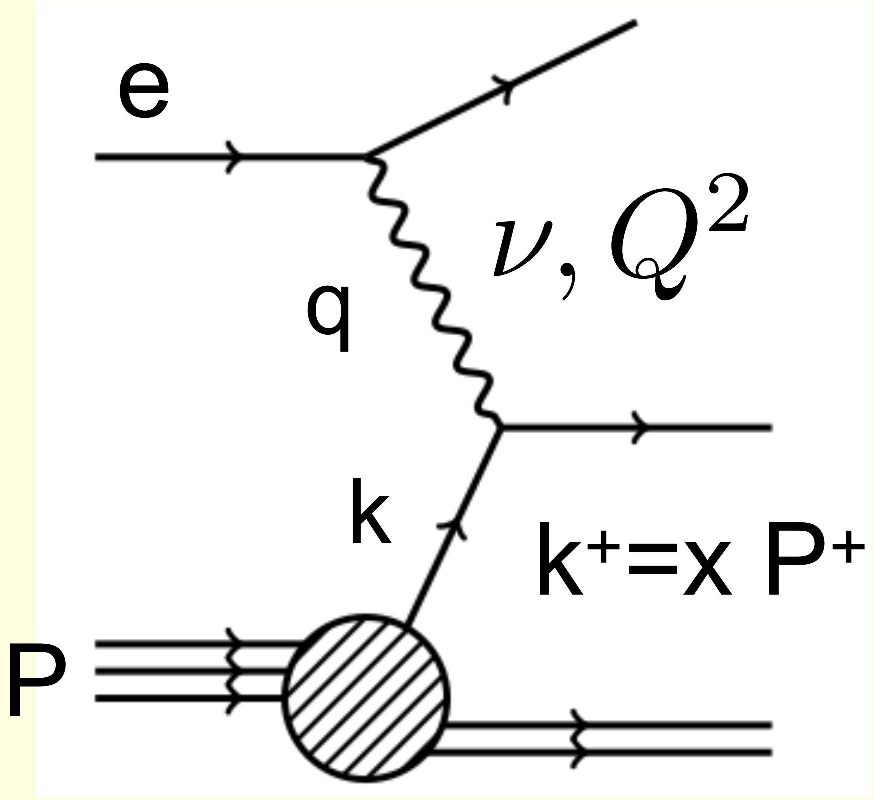
The two state model has a ground state $|N\rangle$ and an excited state $|N^*\rangle$

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

The nucleus contains excited states of the nucleon

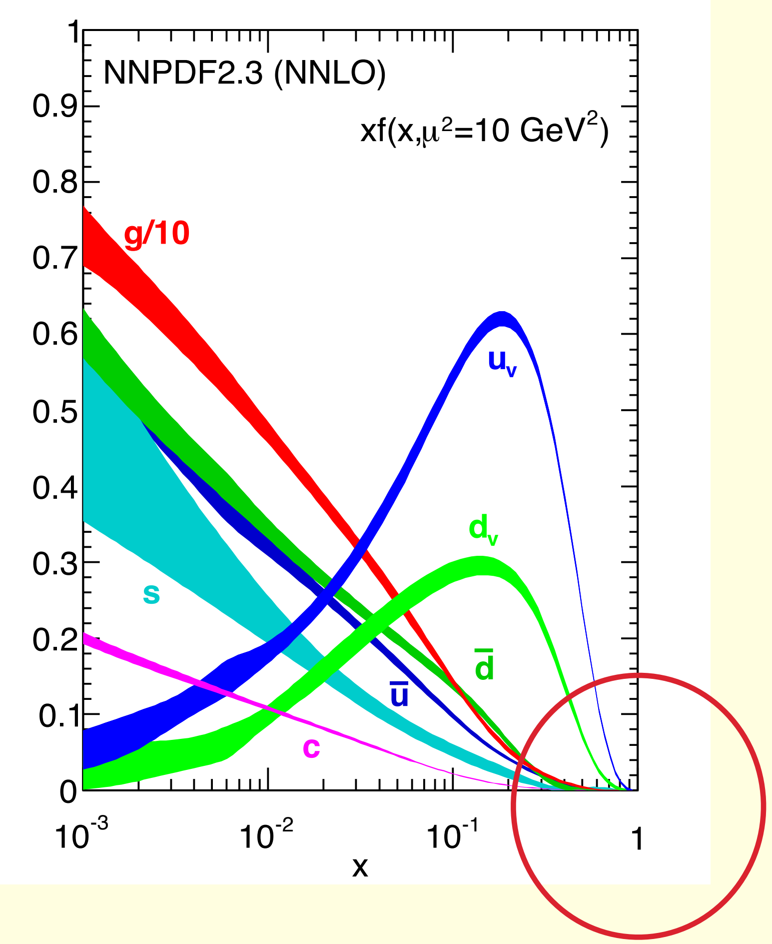
These configurations are the origin of high x EMC ratios

next topic Deep Inelastic Scattering from nuclei



$$x = \frac{Q^2}{2P\cdot q} = \frac{k^0+k^3}{P^0+P^3} = \frac{k^+}{P^+}$$

Nucleon from PDG



The 1982 EMC effect involves deep inelastic scattering from nuclei

EMC= European Muon Collaboration

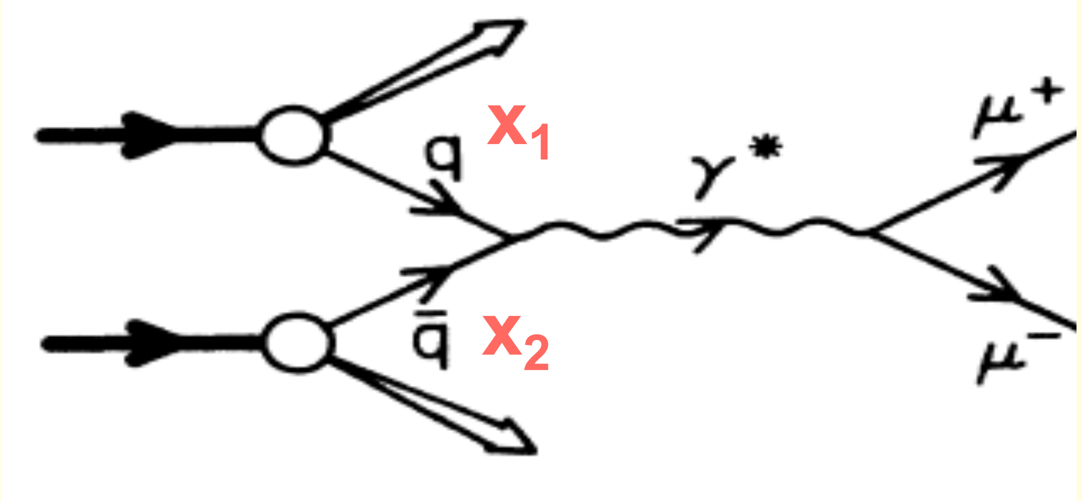
Nucleons and pions

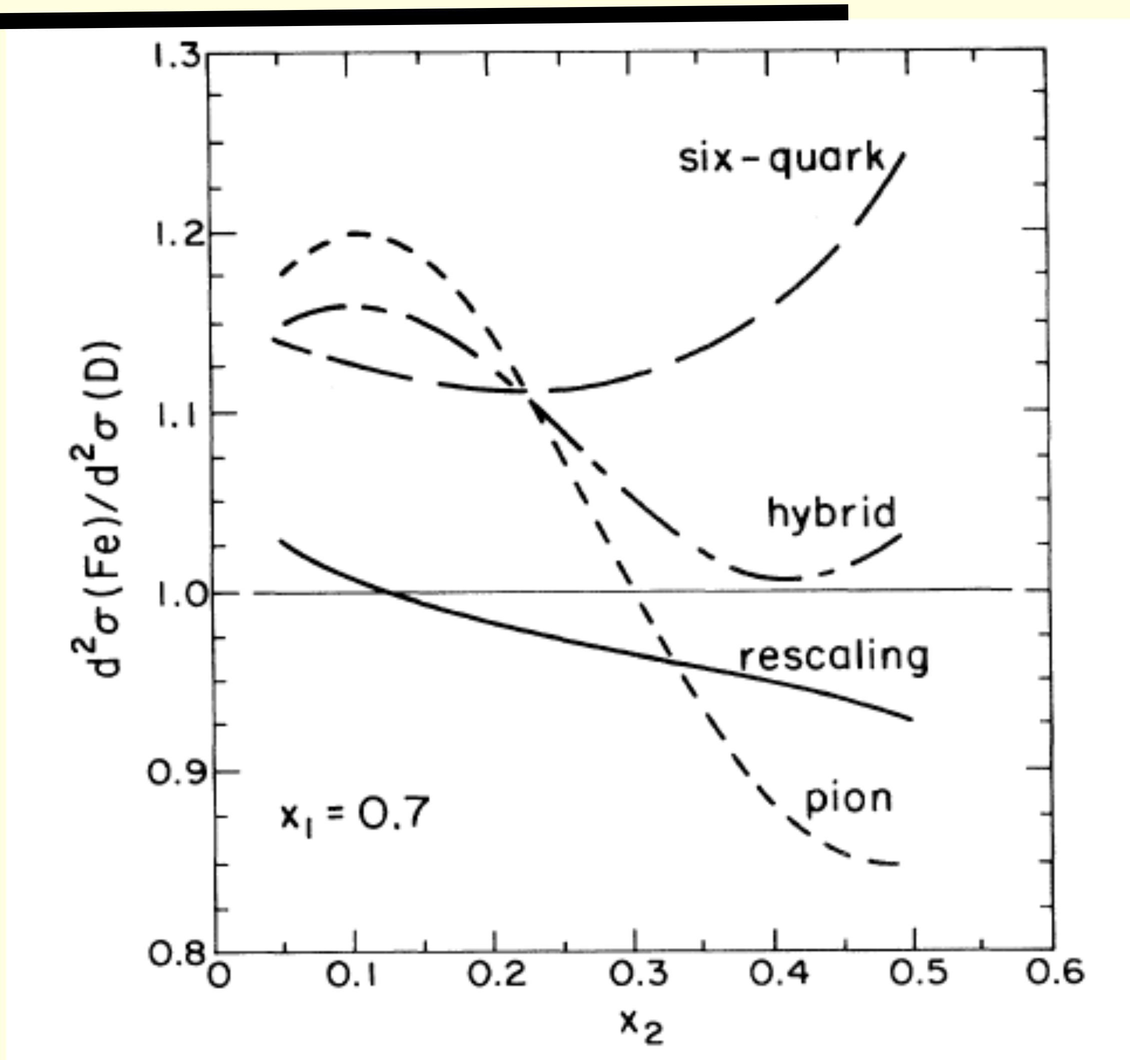
$P_A^+ = P_N^+ + P_\pi^+ = M_A$

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

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

proton(x_1) nucleus(x_2)





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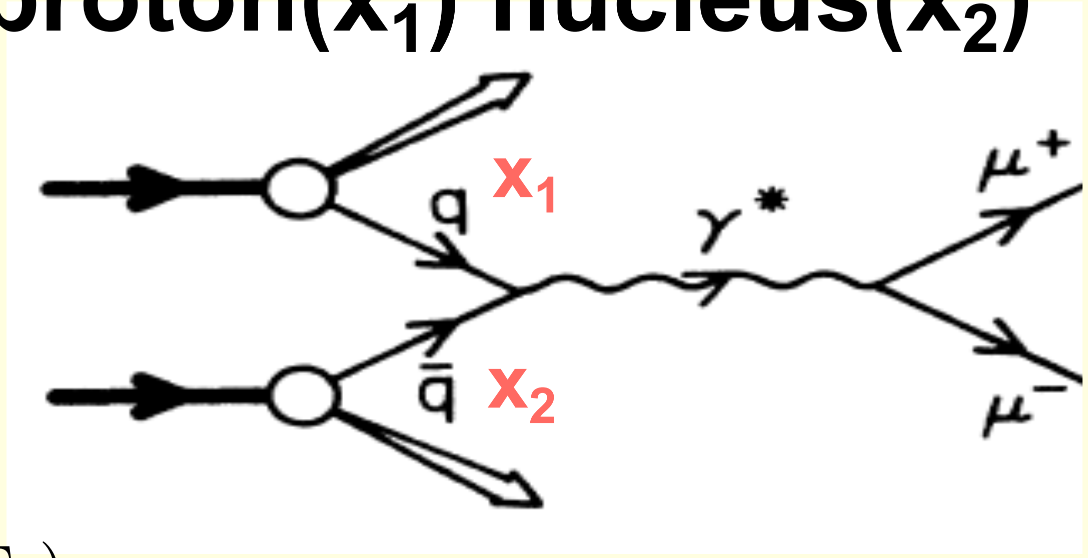
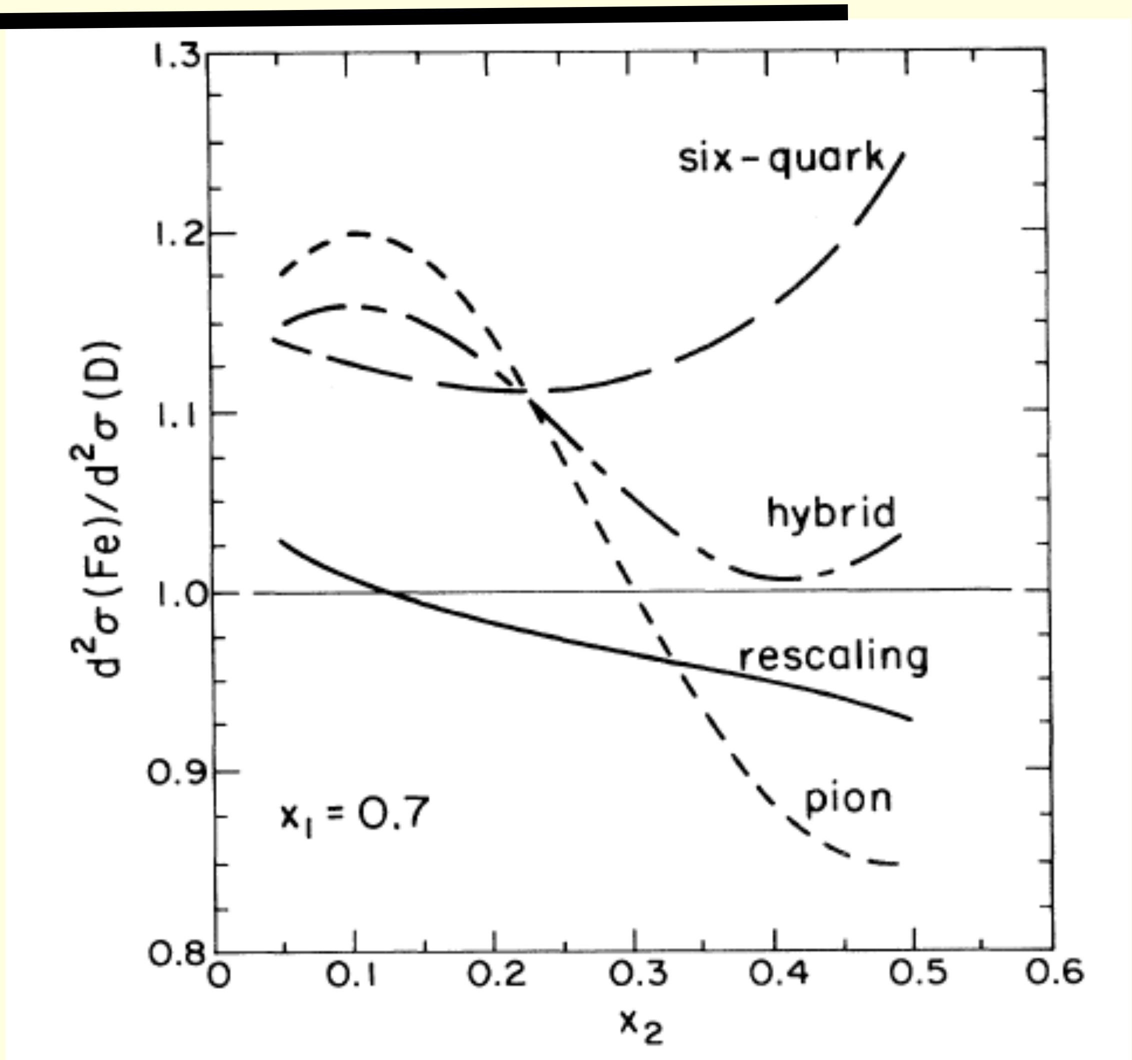
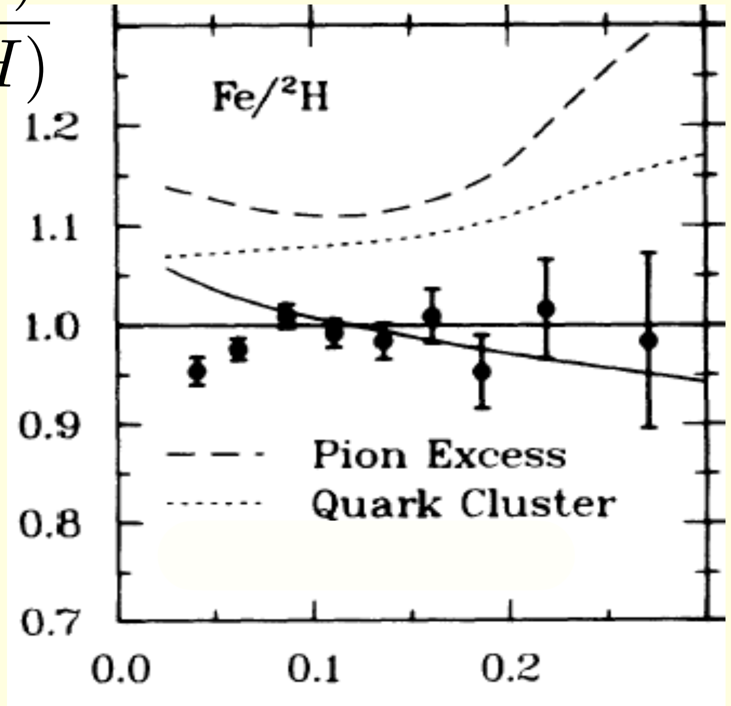




$$\frac{\sigma_{DY}(\mathrm{Fe})}{\sigma_{DY}(^2H)}$$



E772 PRL 69,1726 (92)

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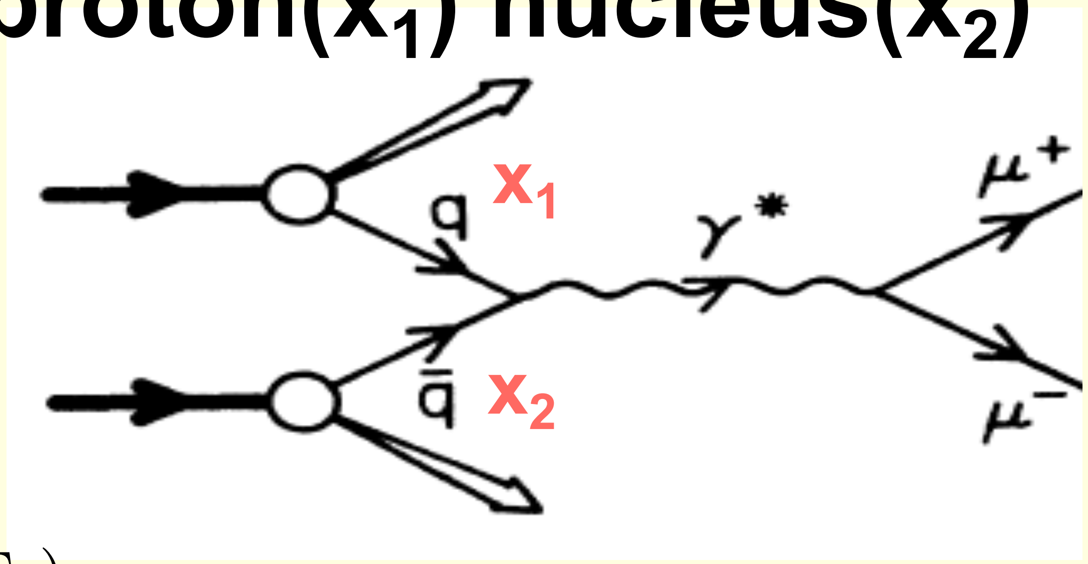

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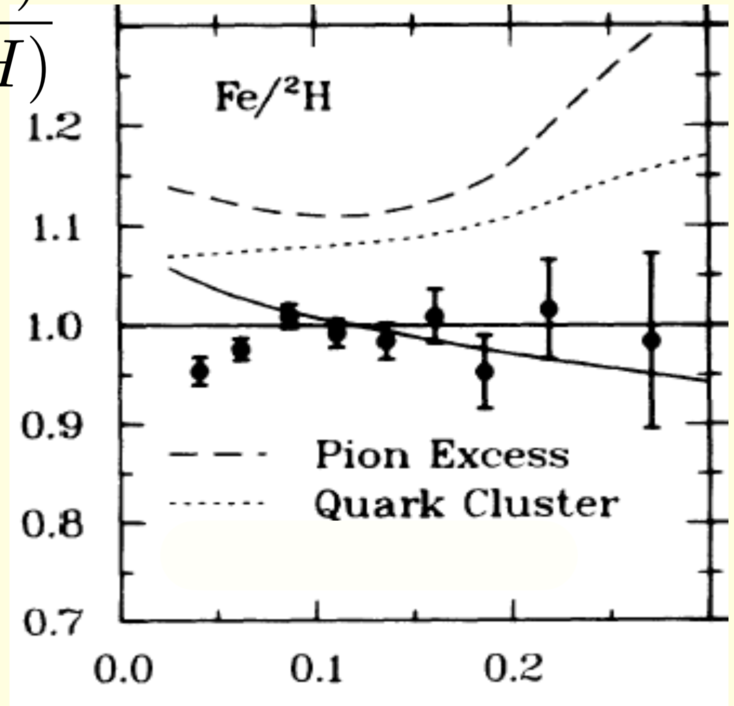

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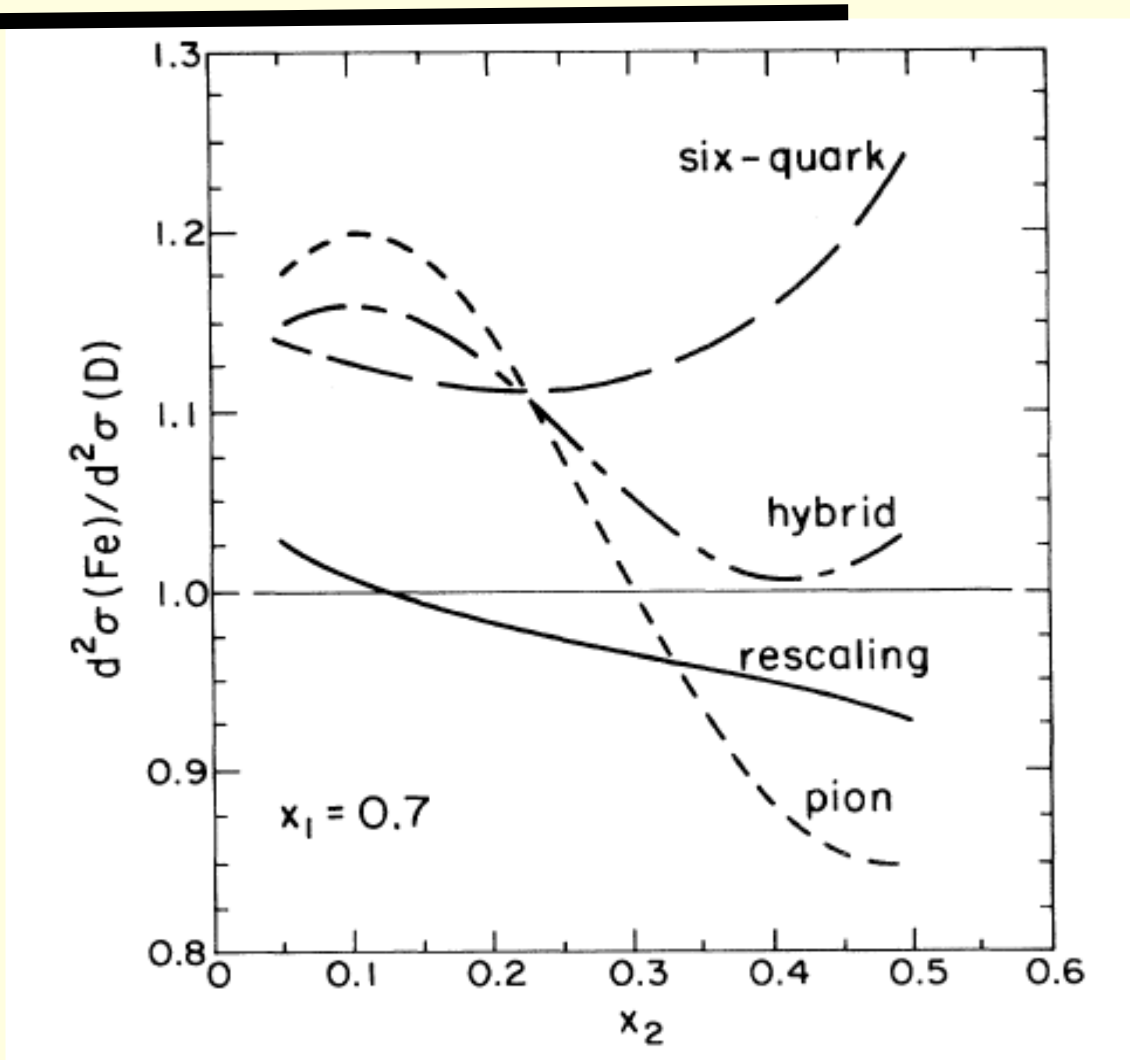
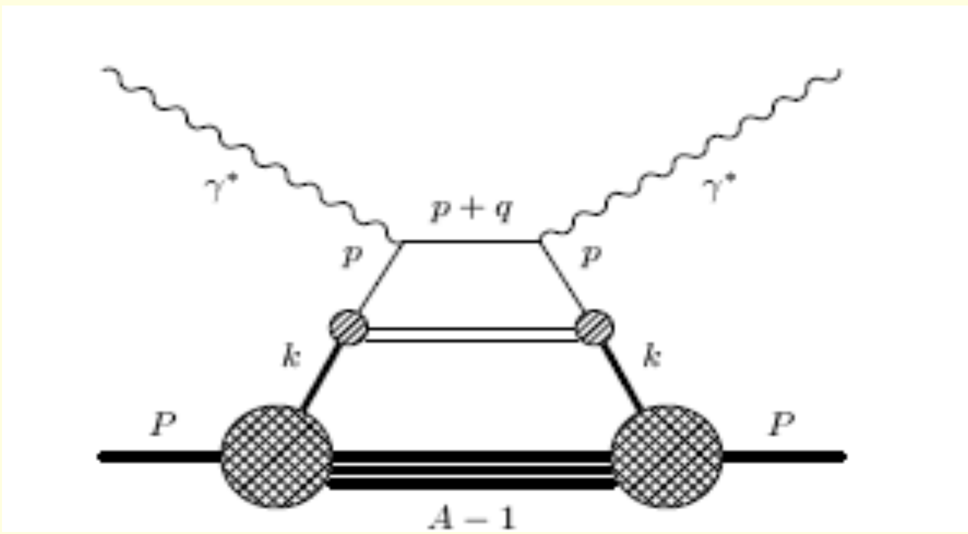


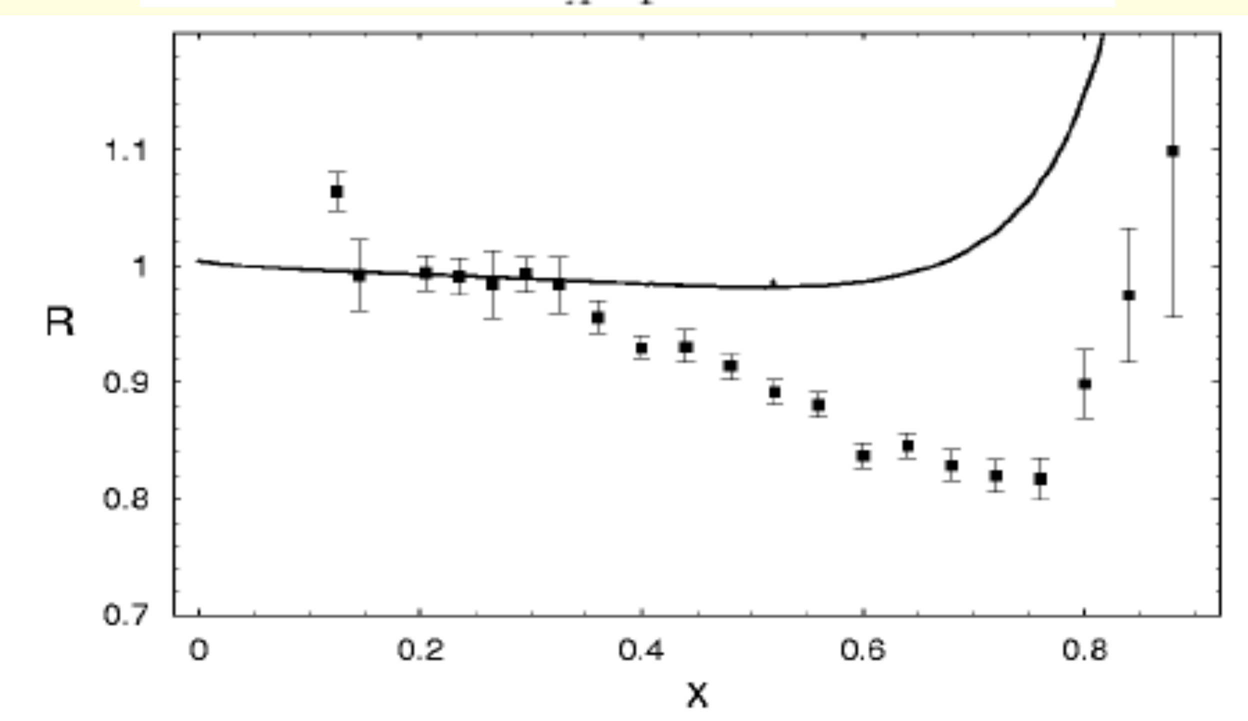
Bertsch, Frankfurt, Strikman "crisis"

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) $P^+ = P^- = M_A$**
- **$P^+ = A(M_N - 8\ \text{MeV})$**
- **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