Recent thoughts on the EMC theory (1982)

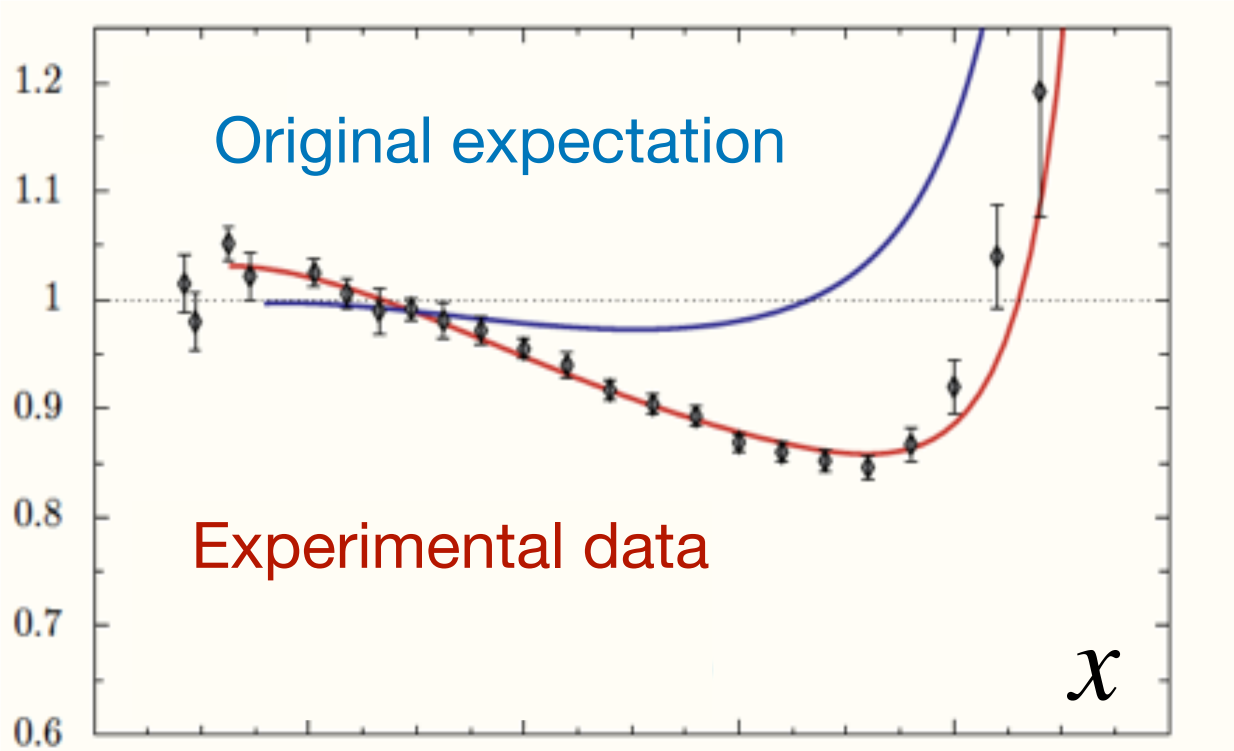
Gerald A. Miller, with D N Kim U. of Washington

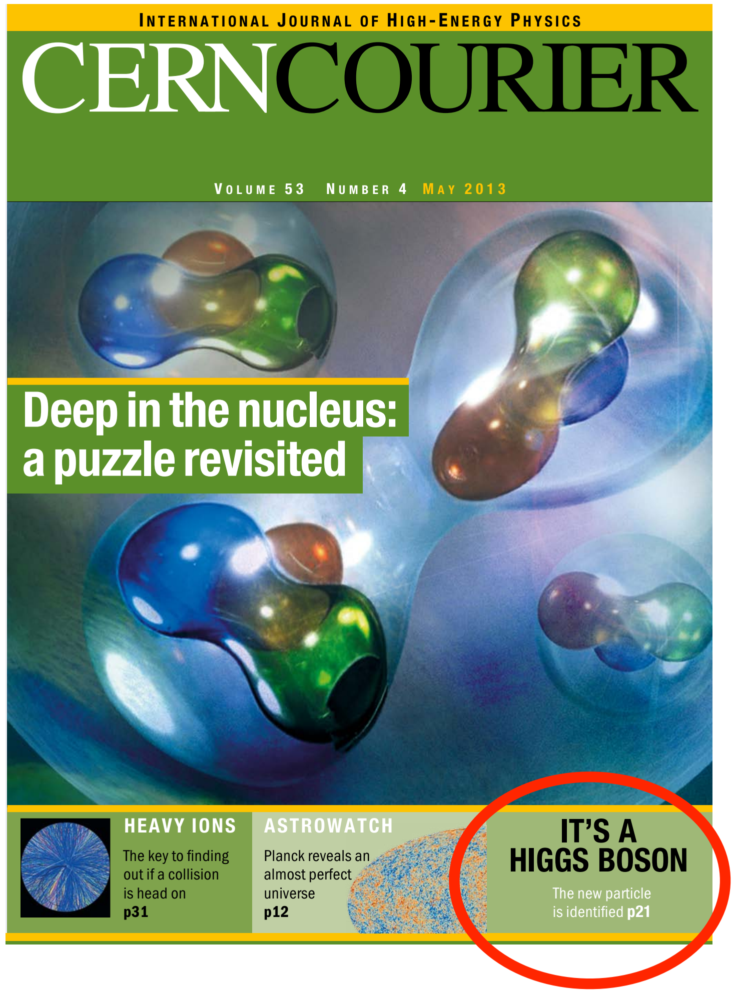
In deep inelastic scattering from nuclei   PRC 106.055202 (2023)

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

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

Drell-Yan Data

- 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

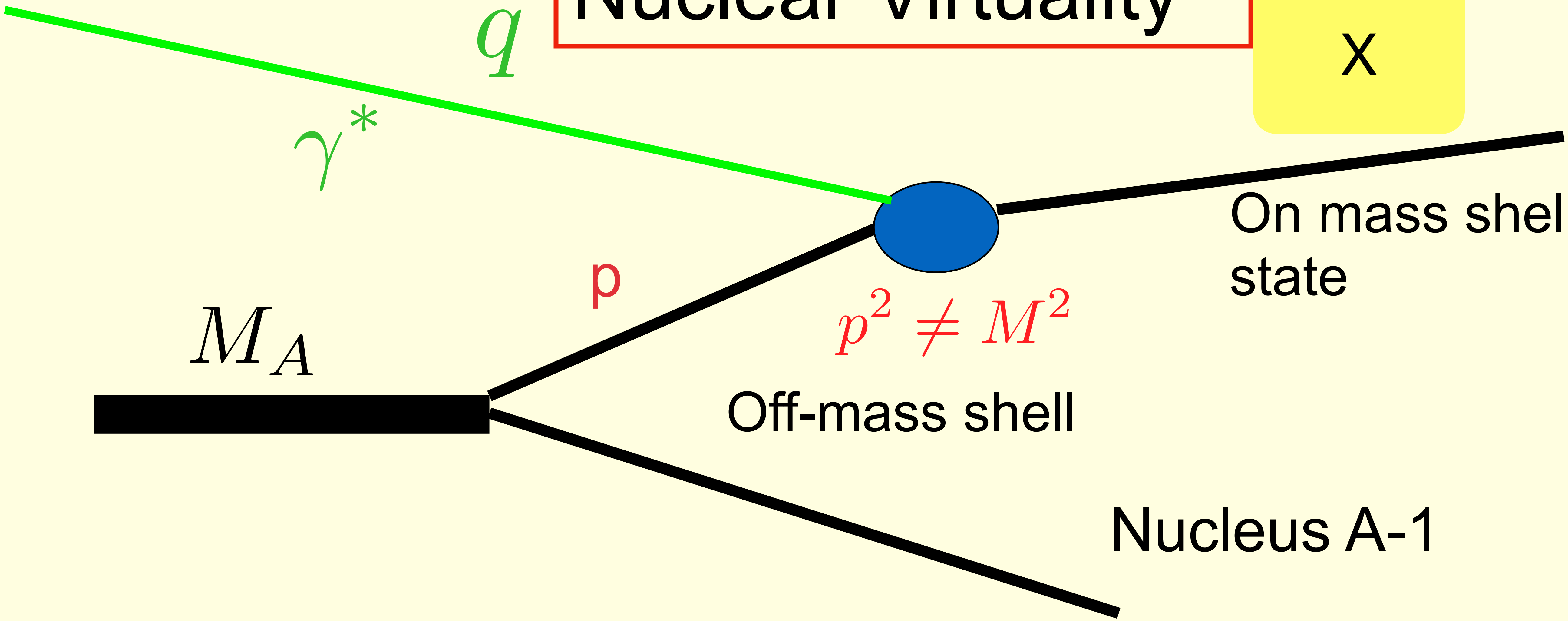
- multi-nucleon clusters - beyond the mean

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

Answer is most likely both- source of both is the same- underlying nucleon-nucleon interaction

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

Nuclear Virtuality



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

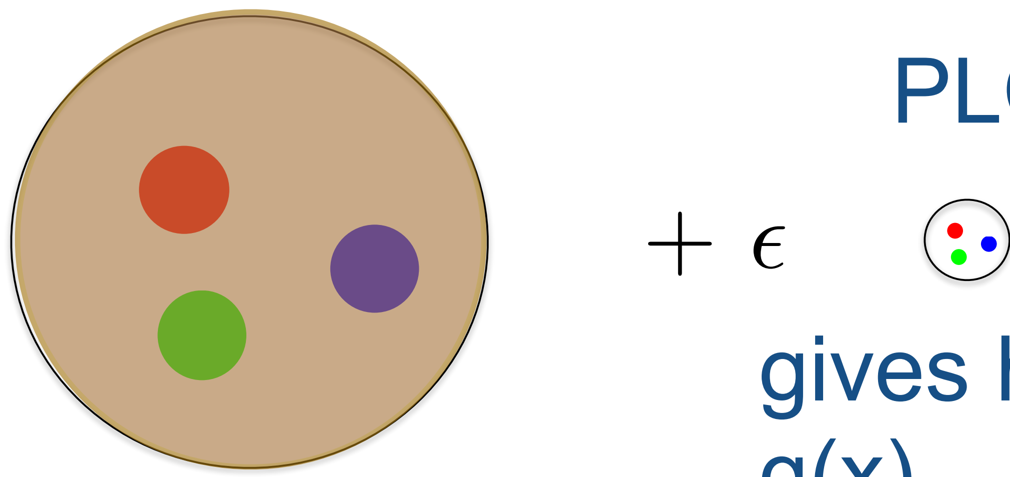
If Nucleus A-1 is highly excited, then $(M^2 - P^2)/M^2$ is big

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

Quark structure of nucleon

Frankfurt-Strikman

BLC



PLC

gives high x q(x)

Schematic two-component nucleon model:
Blob-like config:BLC
Point-like config: PLC

PLC doesn't interact with nucleus

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

$$|X\rangle = \frac{1}{\sqrt{1+\epsilon^2}}[-\epsilon\,|B\rangle + |P\rangle]$$

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

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

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

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

$$P^M_{\rm PLC} = P_{\rm PLC}\left(1 - \frac{2|U|}{\sqrt{(E_P - E_B)^2 + 4V^2}}\right)$$

Structure functions of B &P?

Reduced PLC probability → reduced q(x) at high x

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

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Light-front holographic QCD and emerging confinement

CrossMark

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

LFQCD -good description of much data

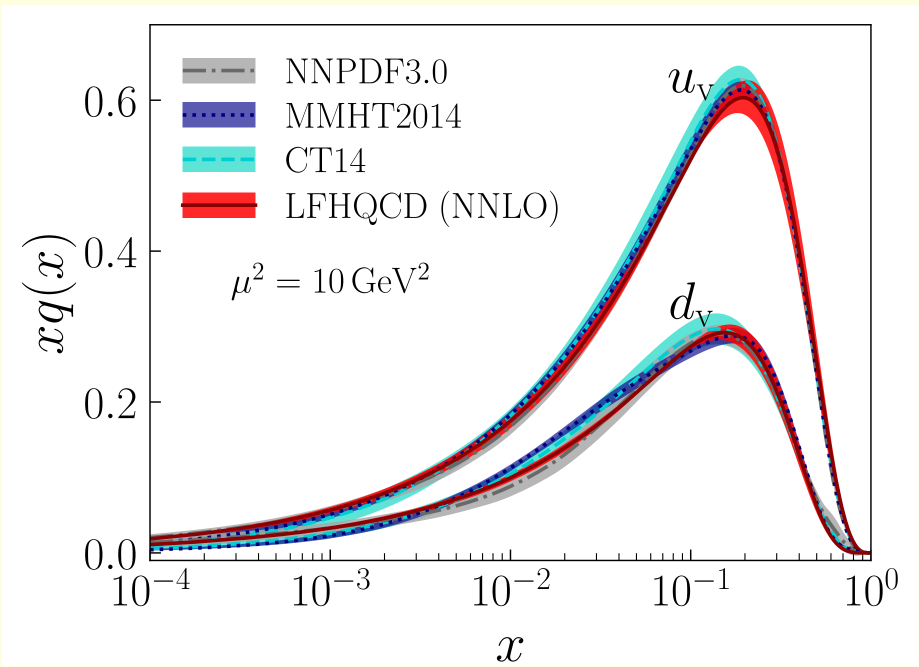
Universality of Generalized Parton Distributions in Light-Front Holographic QCD

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

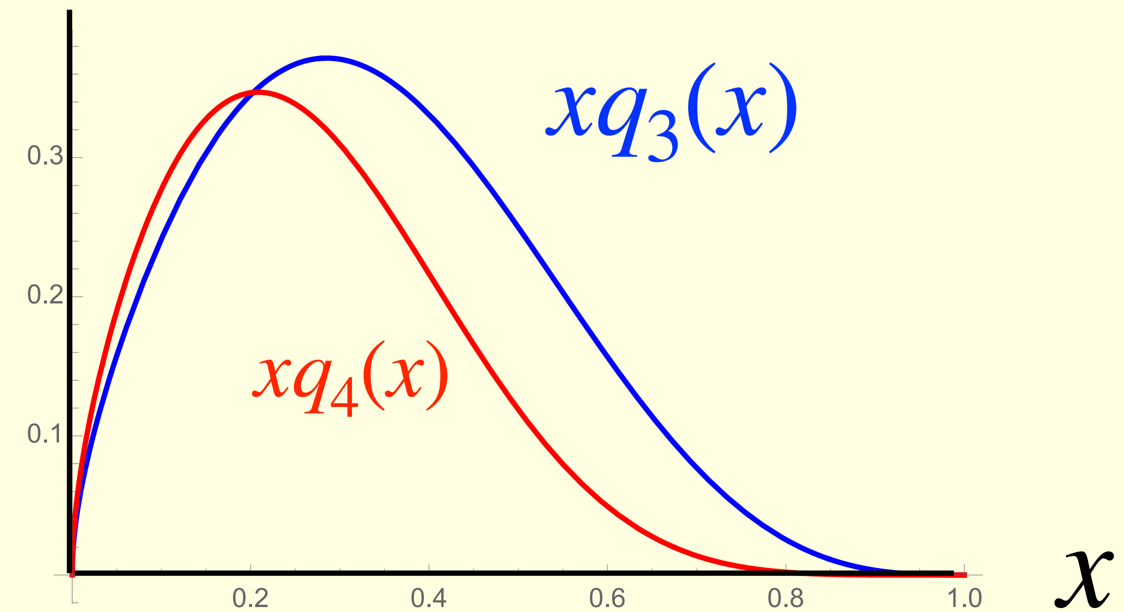
$F_\tau(t) = \int H_\tau(x,t)\,dx$ in a flexible form amenable to fitting data, τ is parton number

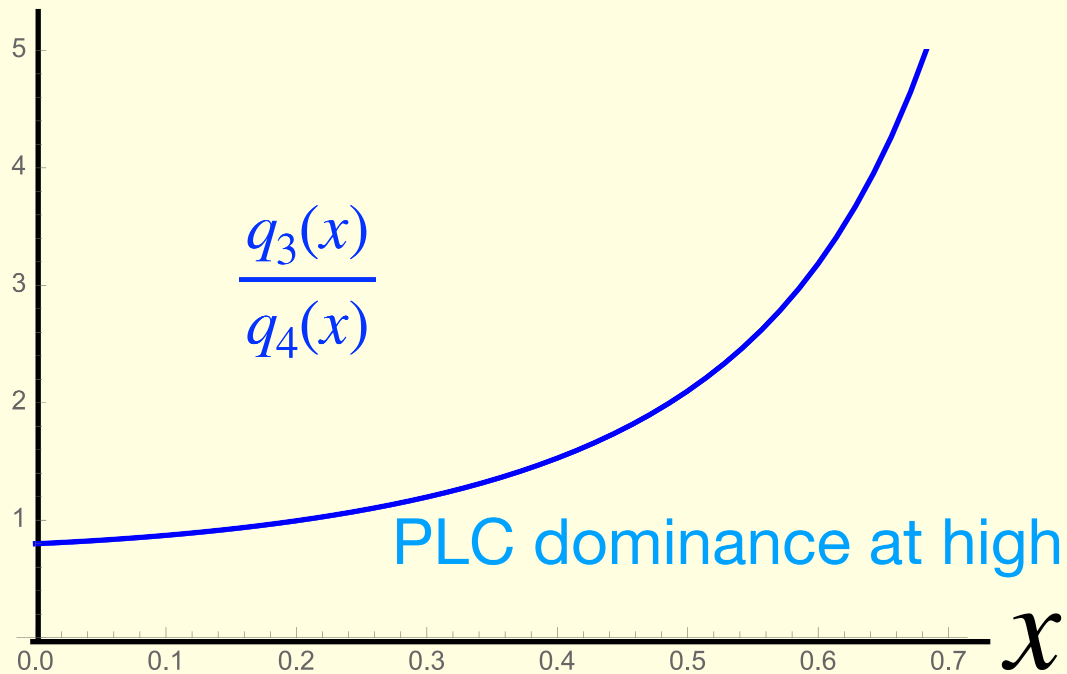
Free nucleon pdfs
Relative weighting (ϵ) of $q_{3,4}$ determined by data



PRL 120,182001 gets good fit

3 is PLC, 4 is BLC

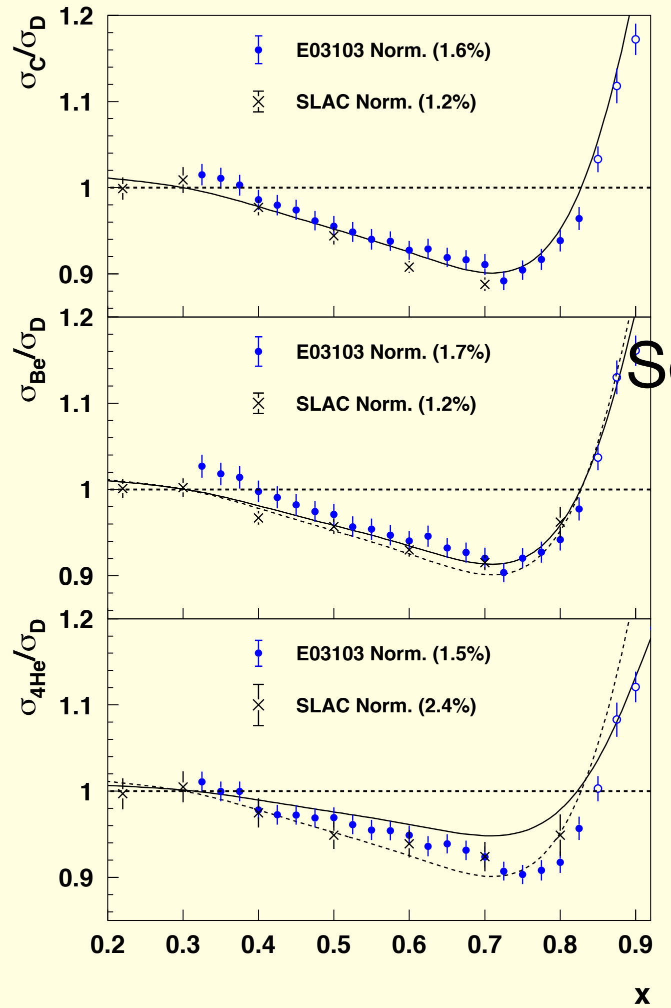




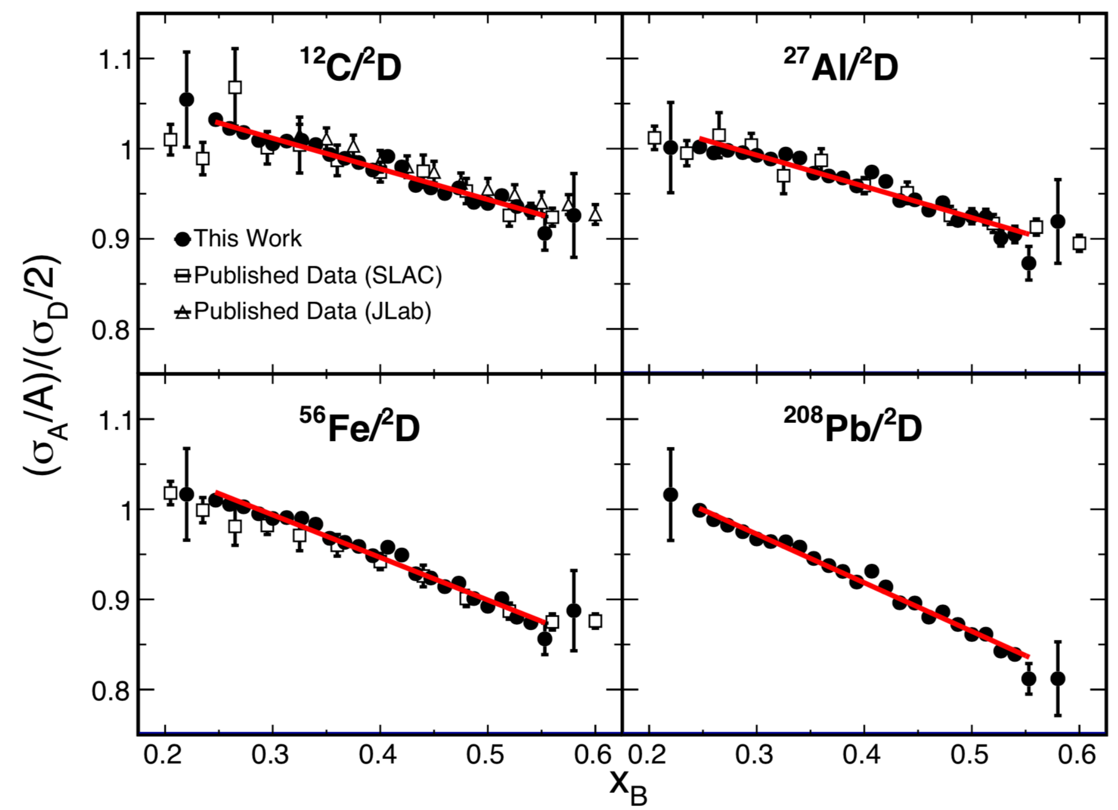
PLC dominance at high x

If N=Z

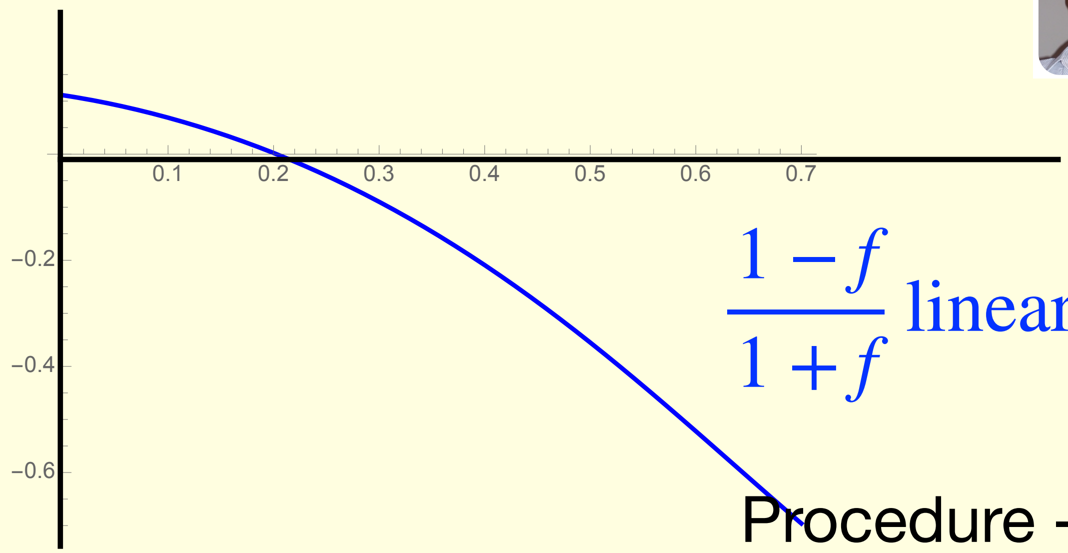
$$R = \frac{q_M}{q} = 1 + \delta\frac{1-f}{1+f}, \delta = \frac{|U|}{\sqrt{(E_P - E_B)^2 + 4V^2}}$$



Seely et al



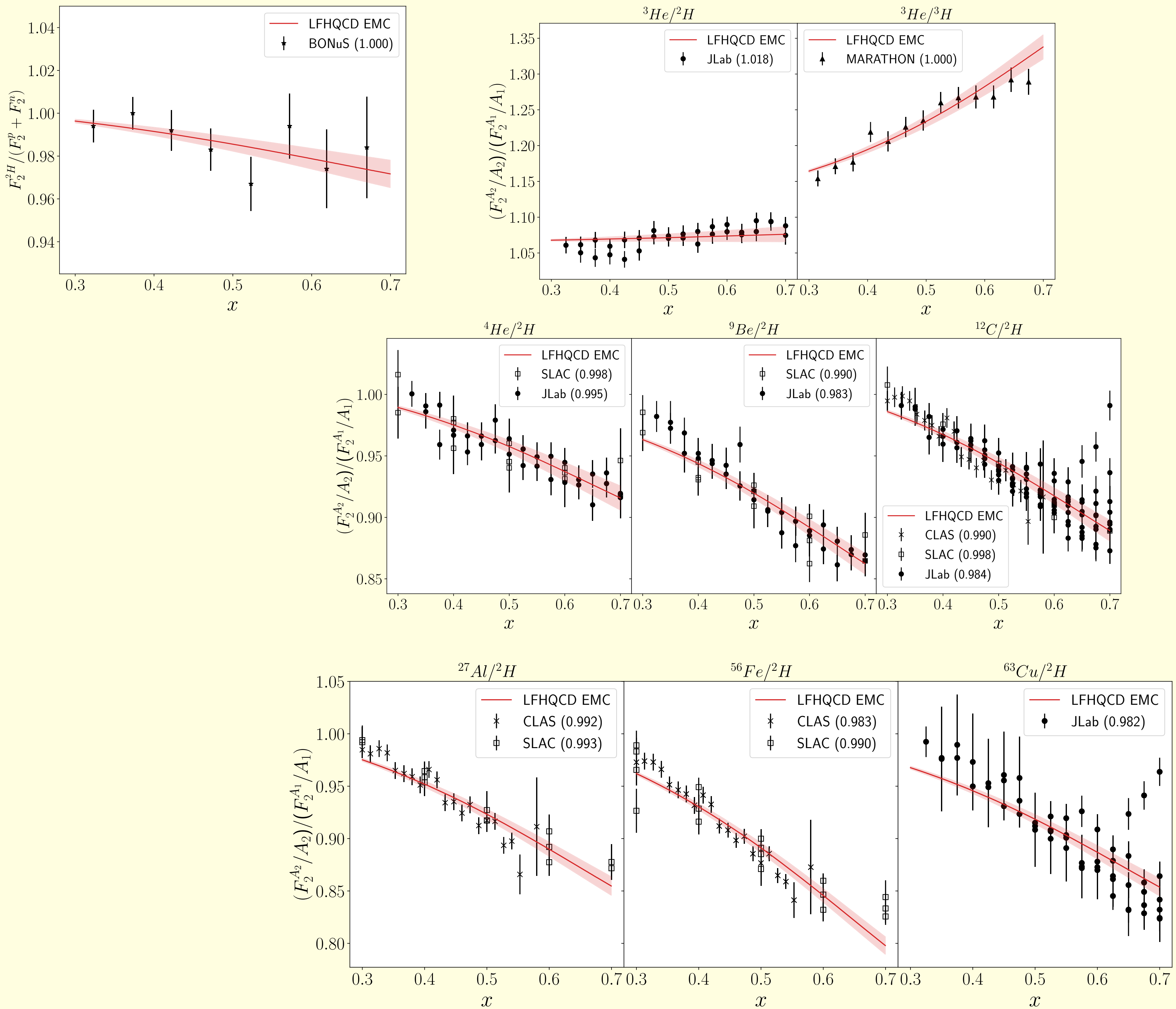
Schmookler et al., Nature (2019)



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

Procedure -fit δ to data

Published results PRC 106,055202



δ is large $|U| \sim 100$ MeV

This is an average value

Nucleon modified by nucleus

Expand in terms of free baryon

$$|N\rangle_M = \frac{1}{\sqrt{1+{\epsilon_M}^2}}[|B\rangle + \epsilon_M |P\rangle]$$

$$|N\rangle_M = \frac{1}{\sqrt{(1+\epsilon^2)(1+\epsilon_M^2)}}[(1+\epsilon_M\epsilon)|N\rangle + (\epsilon_M - \epsilon)|X\rangle]$$

$$P_X \approx \frac{(\epsilon-\epsilon_M)^2}{(1+\epsilon^2)^2} \to 1-2\,\%$$

$\epsilon_M - \epsilon \propto (p^2 - M^2)/M^2$, small

Medium modifications are small

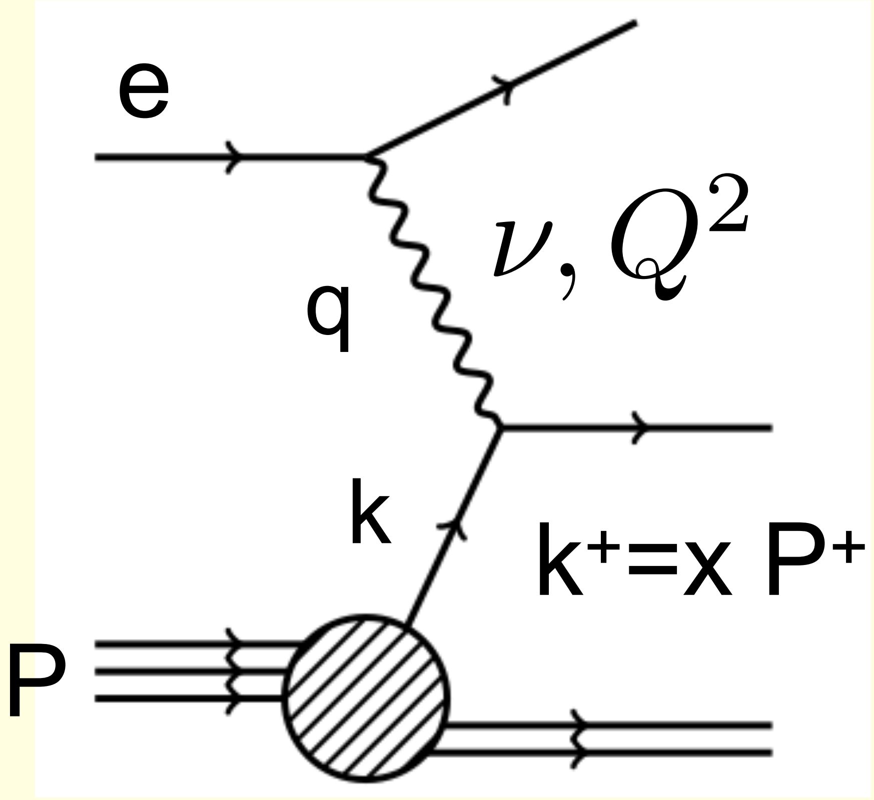
Summary

- 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 and Fermi motion

Dmitriy (Dima) Kim

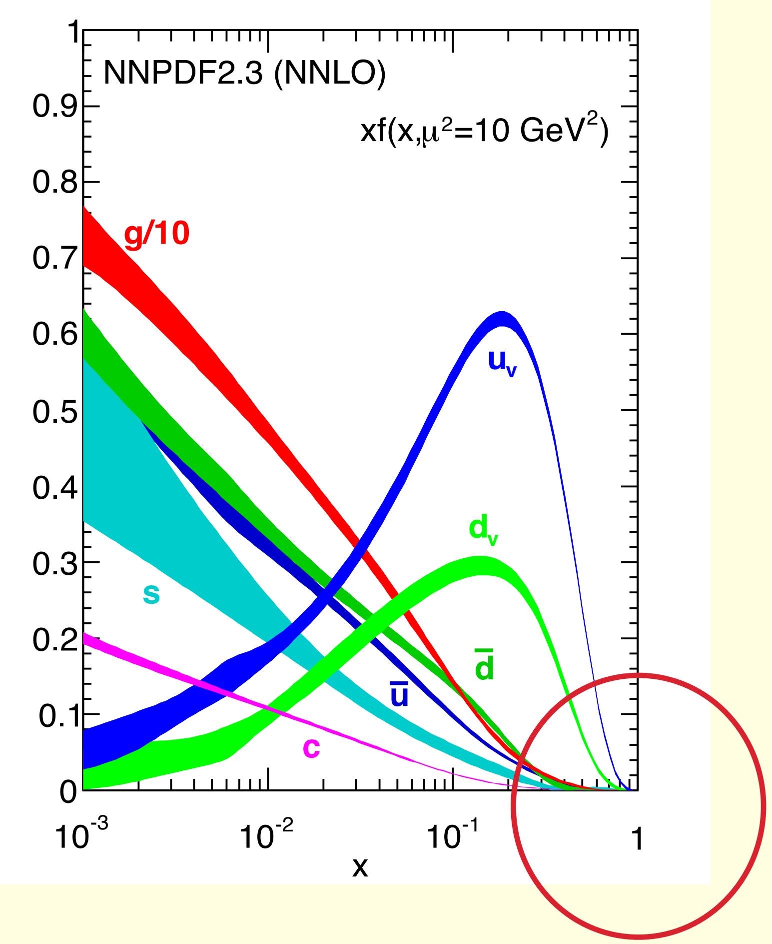
Spares follow

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

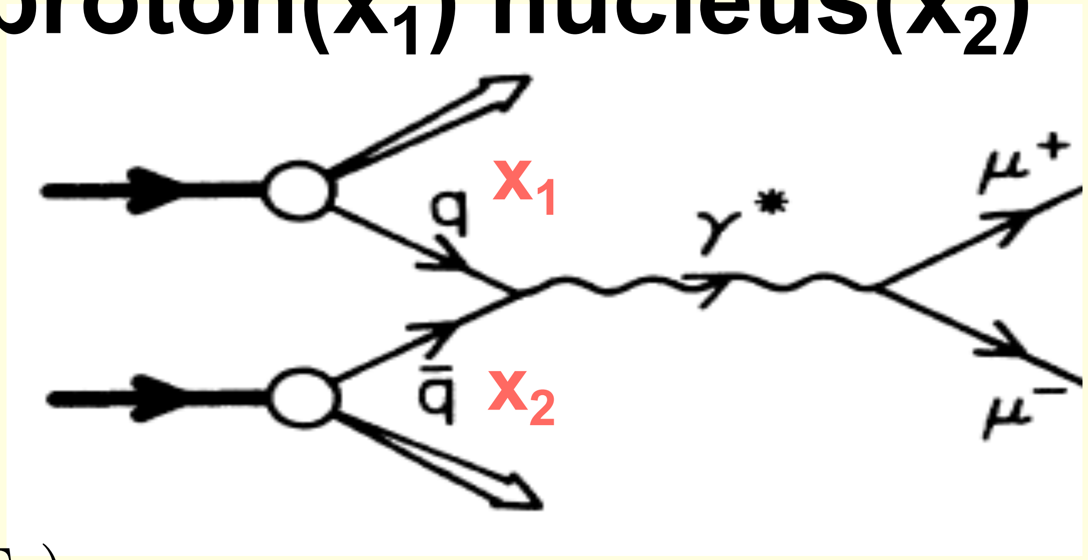
Nucleons and pions

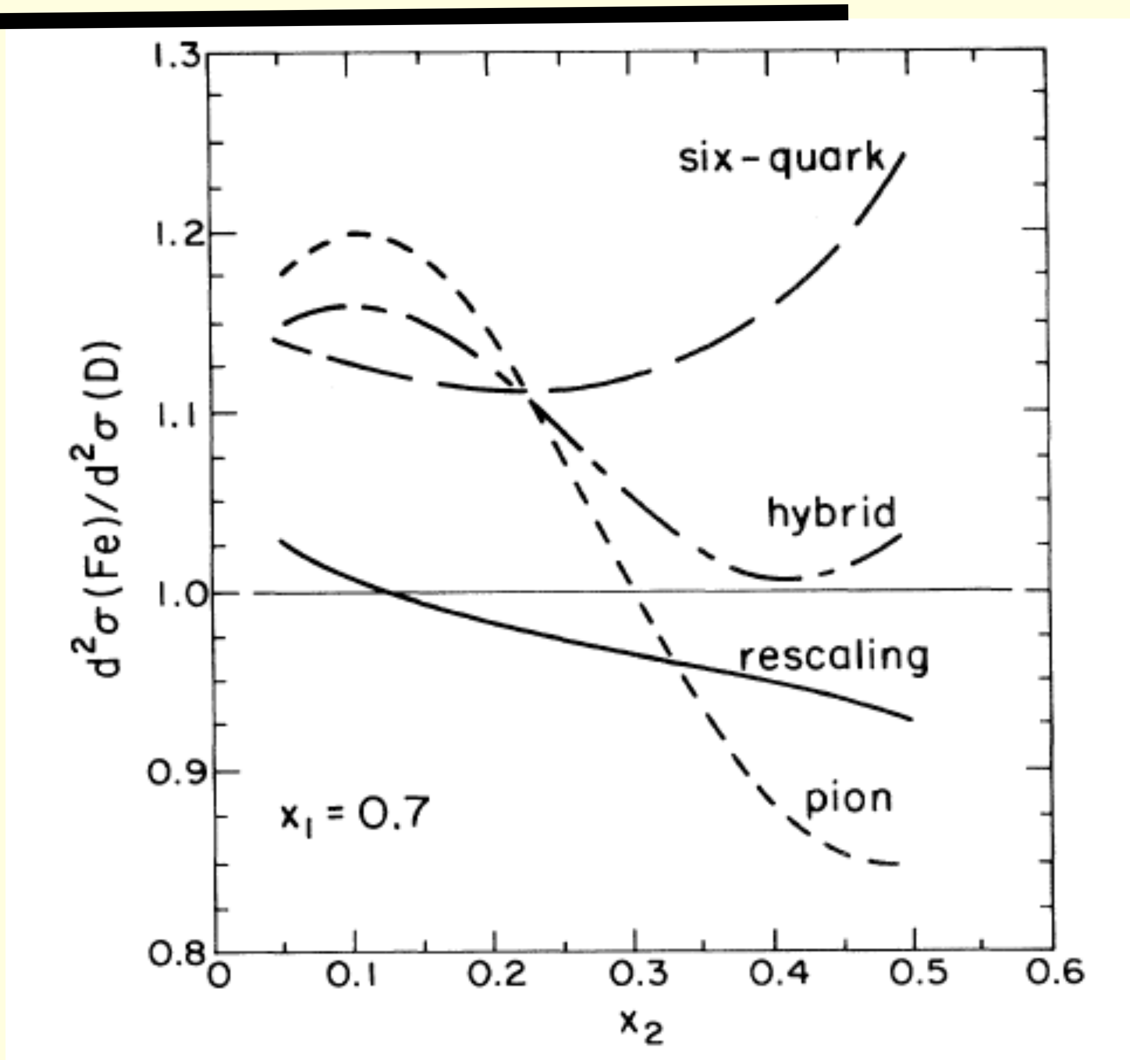
$P_A^+ = P_N^+ + P_\pi^+ = M_A$

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

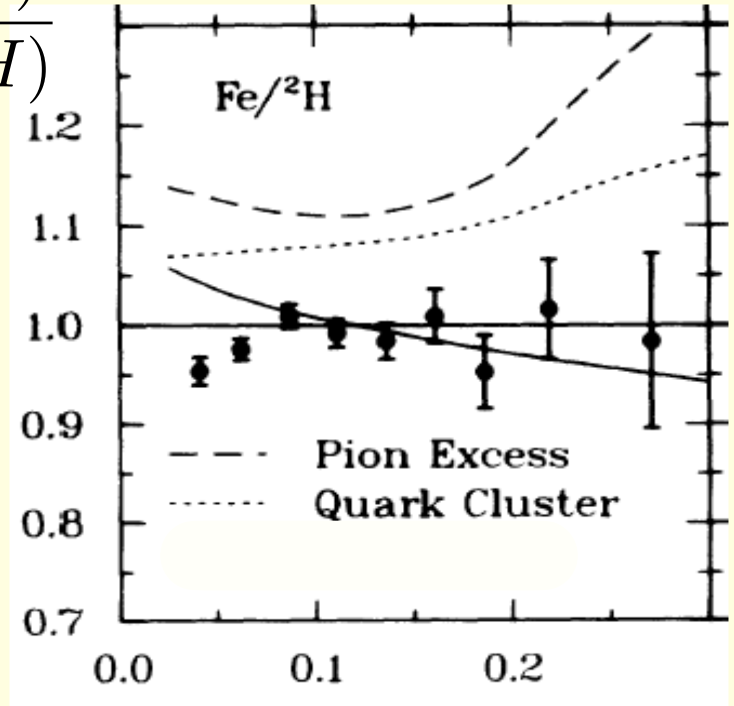
try Drell-Yan, **Bickerstaff, Birse, Miller 84**

proton(x_1) nucleus(x_2)





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



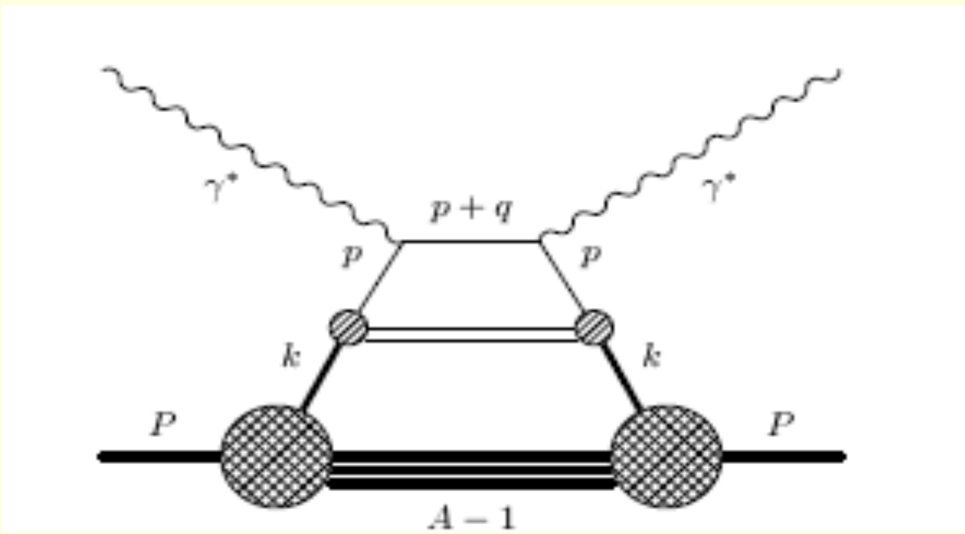
Bertsch, Frankfurt, Strikman"crisis"

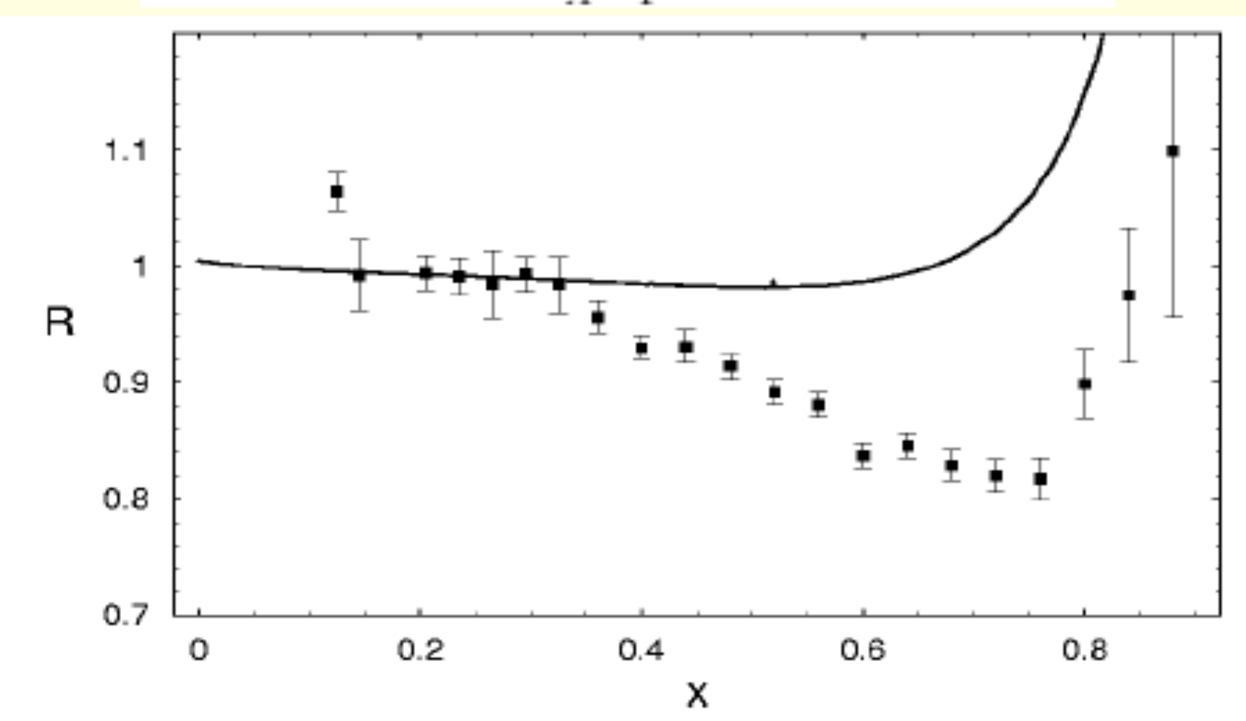
E772 PRL 69,1726 (92)

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