QCD and Nuclear Medium Effects: Theory overview

Gerald A. Miller, University of Washington

- Nucleon is composite object made of quarks, anti-quarks and gluons
- How is the nucleon structure changed in the nucleus?
- EMC effect-nuclear modification of nucleon structure function - nucleon IS modified
- Color transparency -suppression of final state interactions in coherent processes
- Relationship between EMC effect and Color Transparency?
- Can 22 GeV help? YES

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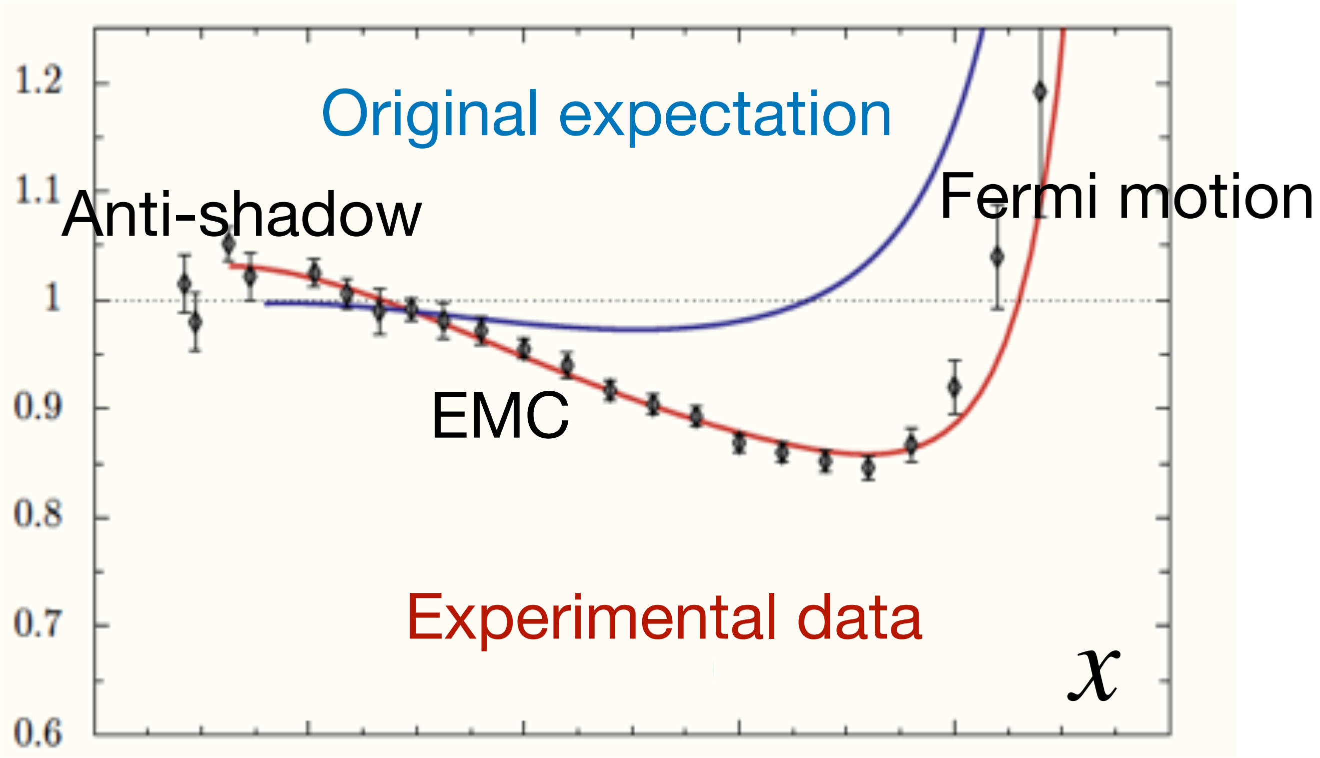
Recent thoughts on the EMC (1982) effect

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

PRC106,055202. 2209.13753 nucl-th

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



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

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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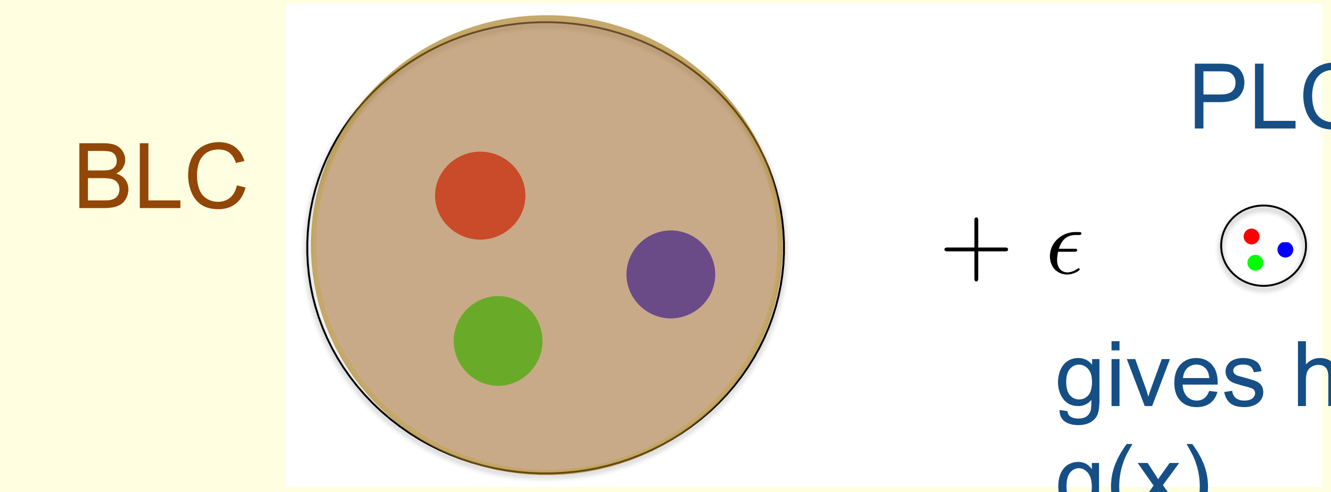
Quark structure of nucleon

Frankfurt-Strikman



gives high x q(x)

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

PLC doesn't interact with nucleus
Energy diff increased, PLC suppressed

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

$$f(x) = \frac{PLC(x)}{BLC(x)}$$

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

$$\epsilon_M - \epsilon \propto \text{virtuality}$$

Basic idea- suppression of PLC is source of EMC effect

what is $f(x)$

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

Physics Reports 584 (2015) 1–105

Contents lists available at ScienceDirect

Physics Reports

journal homepage: www.elsevier.com/locate/physrep

- 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
-

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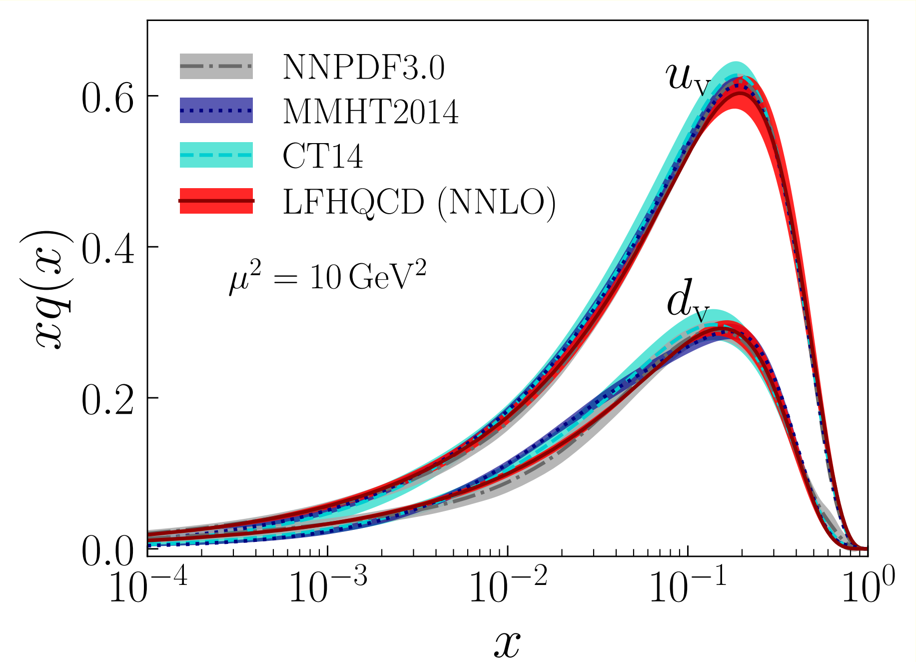
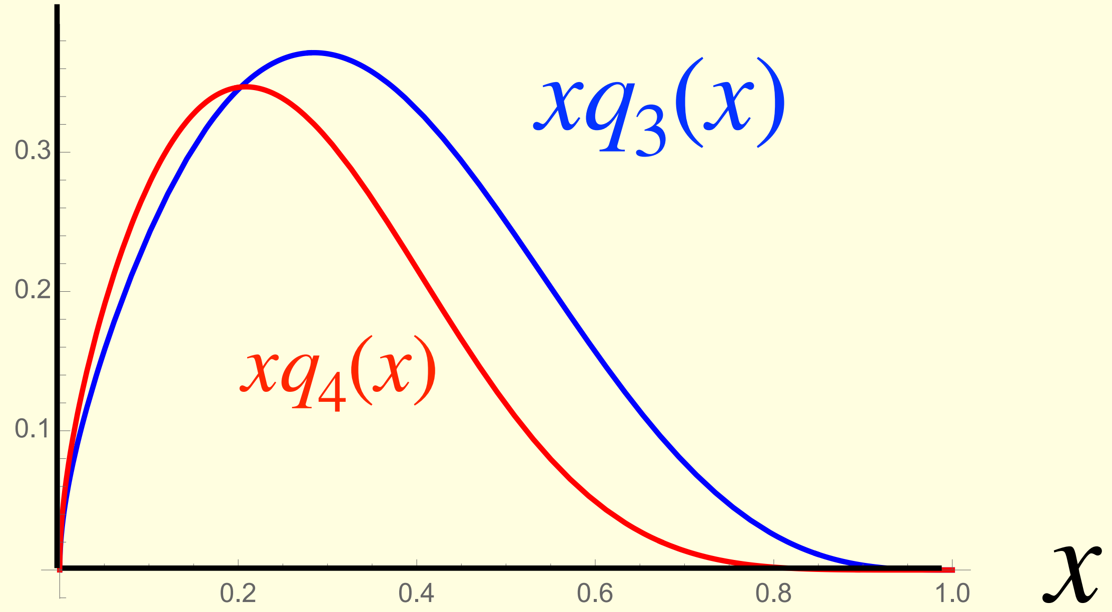
Nucleon pdf : $\Psi_N^2 = 3/2(q_3 + q_4)$

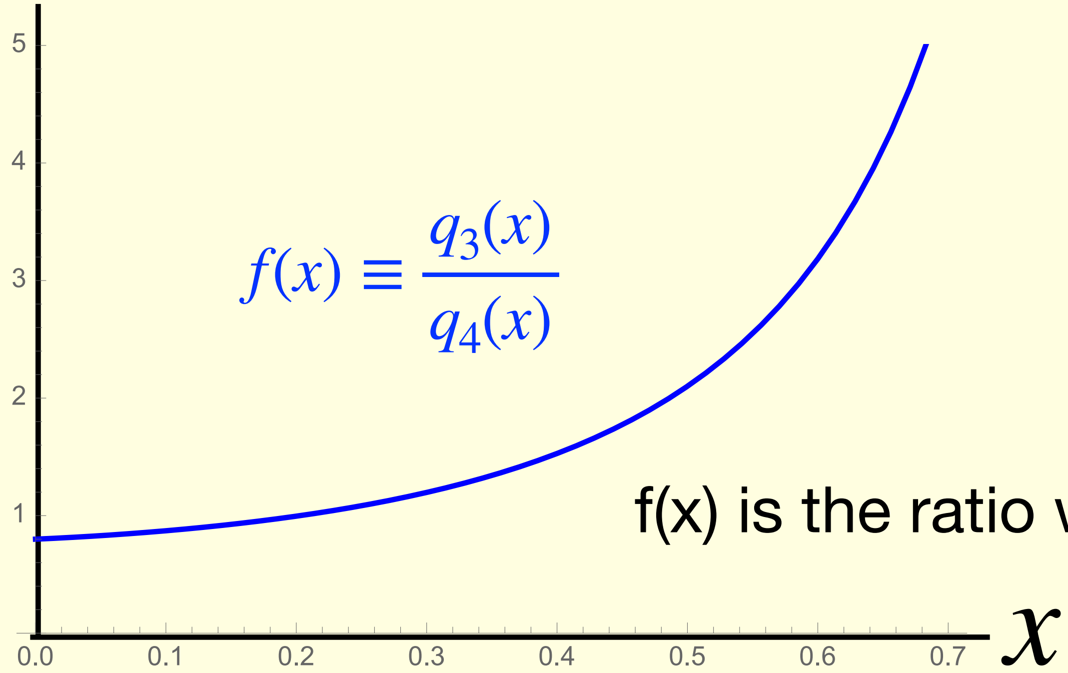
3 means 3 partons, 4 is 4 partons



PRL 120,182001 gets good fit

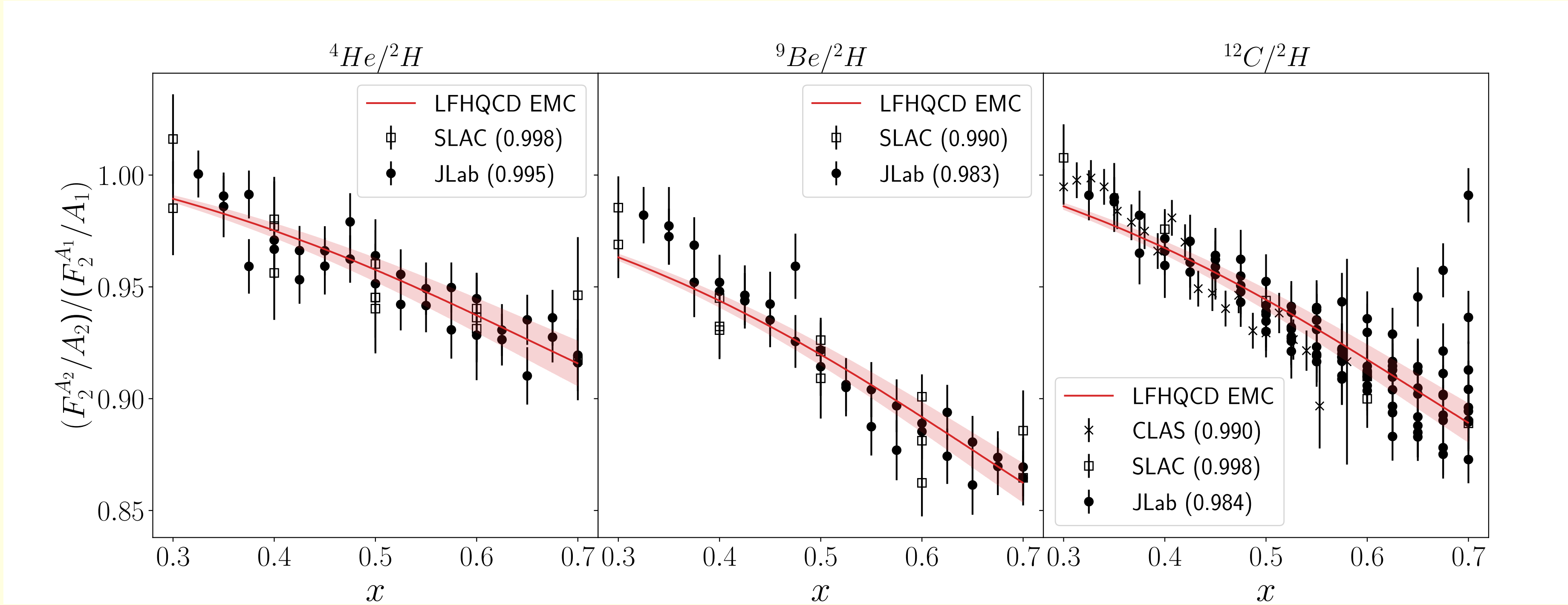
3 is PLC, 4 is BLC

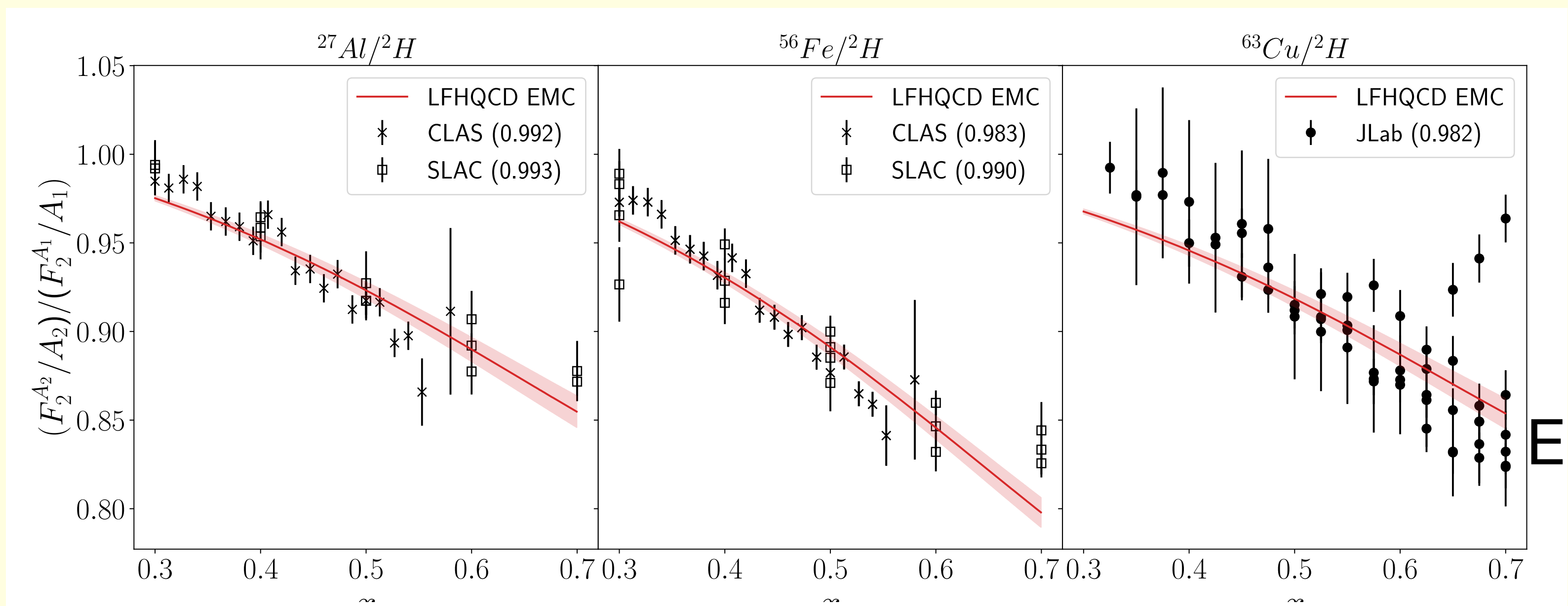


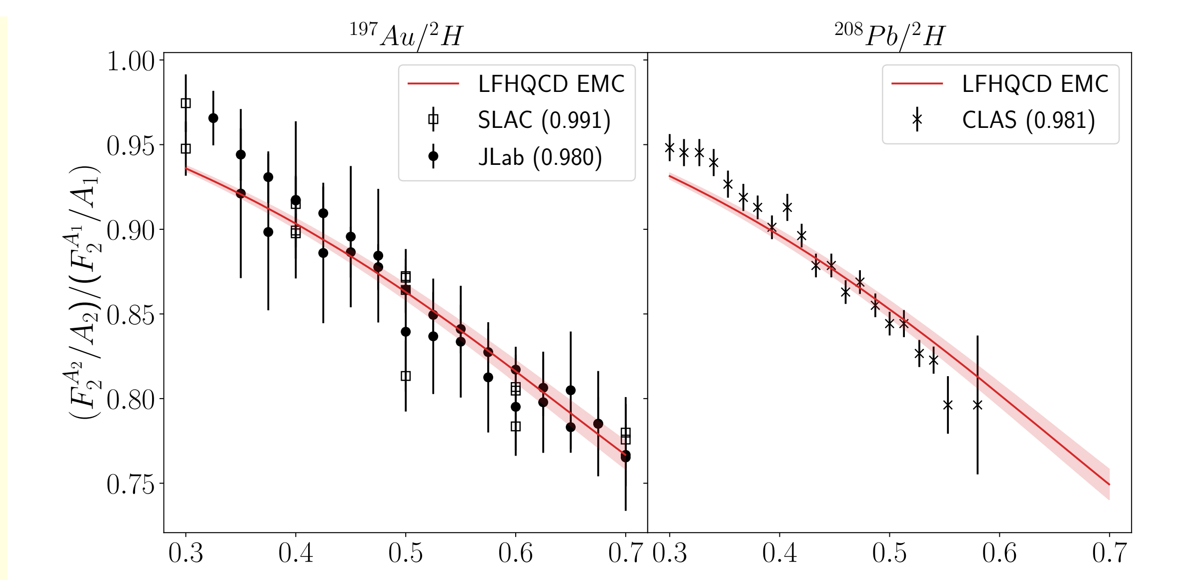


f(x) is the ratio we needed to understand the EMC effect

From PRC106,055202. 2209.13753 nucl-th

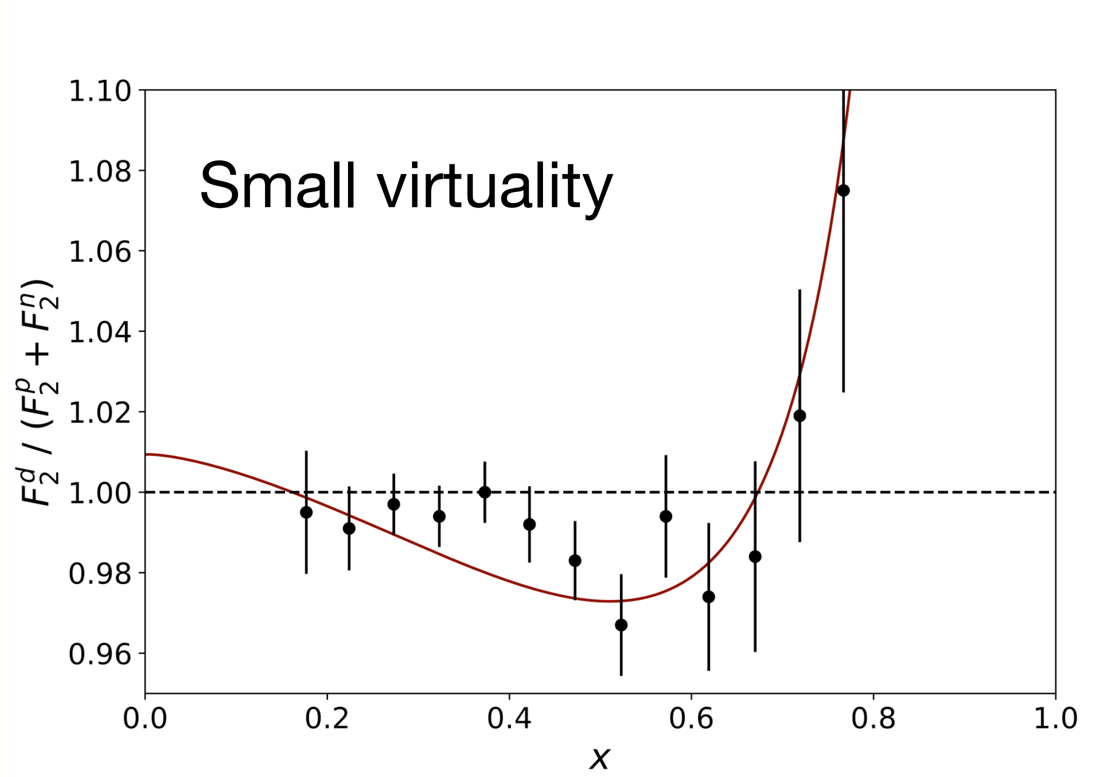


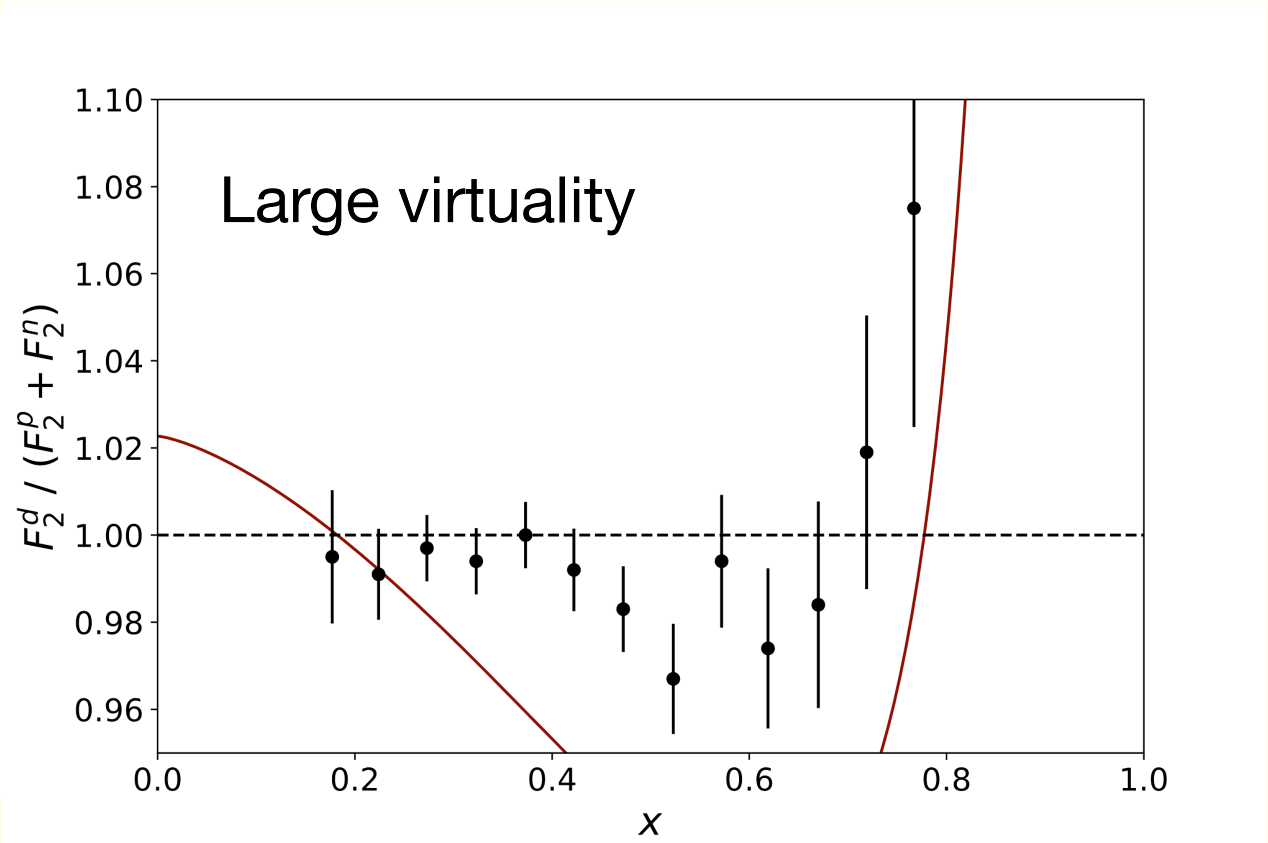




Virtuality (A)
Is large
Consistent with
EMC-SRC correlation

Anti-shadowing?





Bump at low x comes from baryon conservation- larger virtuality means larger bump at low x

22 GeV remove higher twist??

Summary of EMC

- 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- consistent with EMC-SRC correlation seen at JLab
- Anti-shadowing comes from baryon conservation

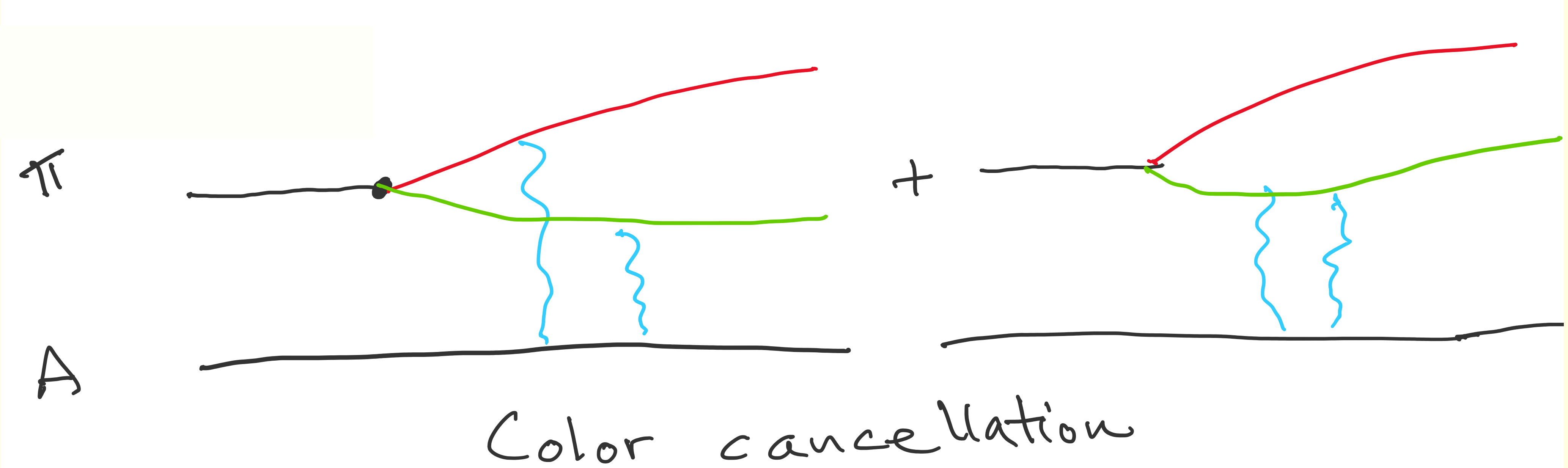
Dmitriy (Dima) Kim

Color Transparency

Color transparency- reduced initial/final state interactions in coherent reactions

1. high-momentum transfer reactions make point-like color singlet states PLC

2. Small objects have small cross sections $Im f \propto b^2$



Diffractive Dissociation

3. PLC are not eigenstates-expand as they move
Frankfurt& Strikman, Jennings & Miller

2,3 must be true, 1 is interesting ? -

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Color Transparency Idea

Why interesting?

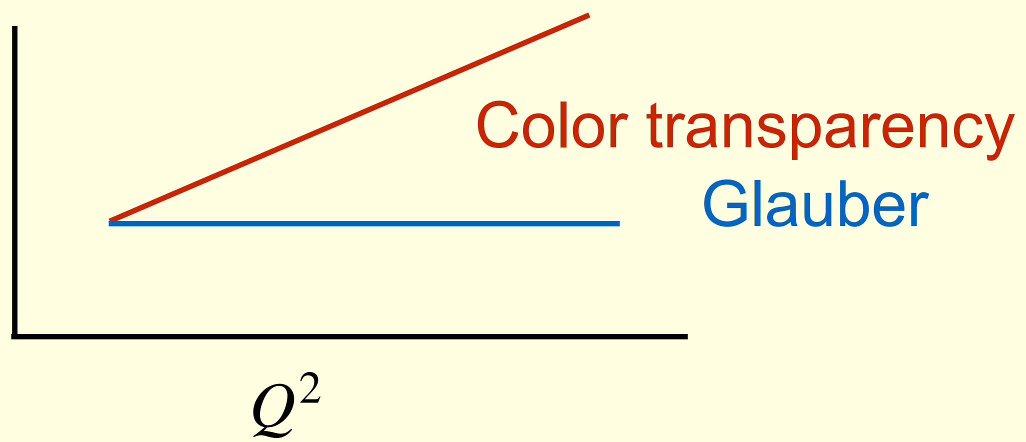
- new dynamical phenomena- turn off strong interactions
- are PLCs made? -high Q^2-exclusives
- nuclear physics implications of PLC- nucleon modified- EMC effect

Problem- expansion time- $\tau_{\text{expansion}} = \frac{2P}{\Delta M^2}$

P is momentum of outgoing particle, higher is better
JLab 22 would be a big improvement

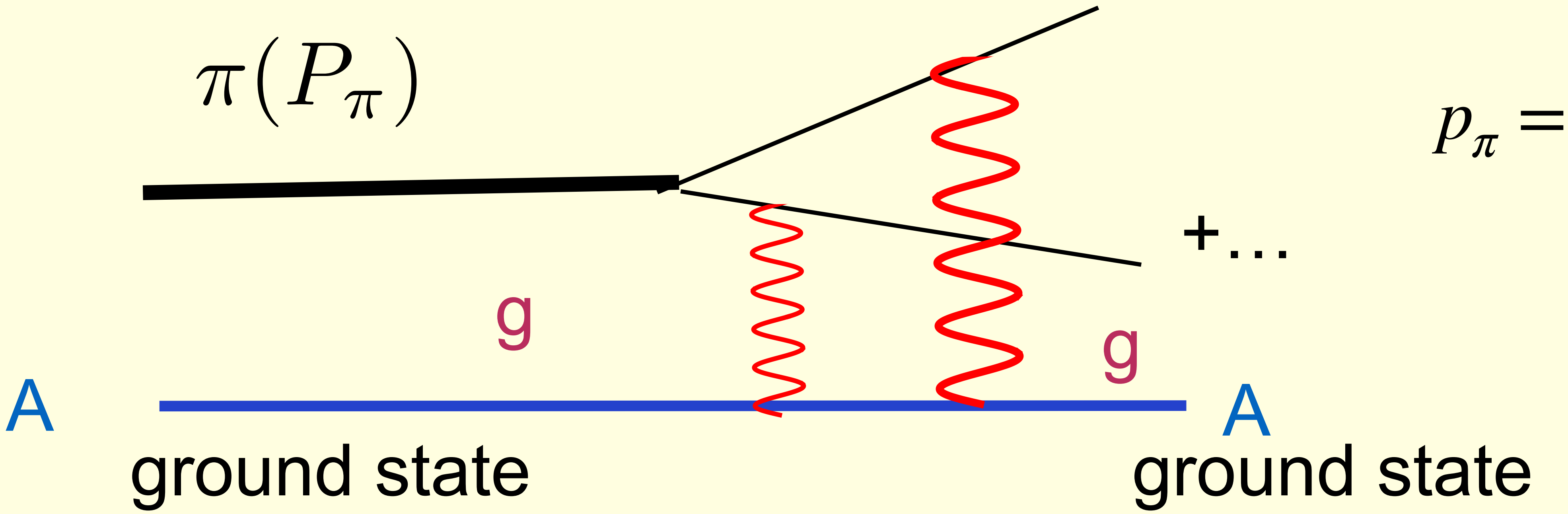
Electroproduction signature

$T = \frac{\sigma}{\sigma_{PWA}}$



$\pi + N(A) \rightarrow$ "2 high transverse momentum jets" $+ N(A)$

The one that worked   D. Ashery PRL 104, 86,4773



$p_\pi = 500\,\mathrm{GeV}$

- final state $q\bar{q}$ becomes 2 high rel. moment jets, select PLC component of pion
- $\pi \rightarrow q\bar{q}$ before hit target, no expansion
- one interaction
- Coherent process- enhanced!

FMS Phys.Lett. B304 (1993) 1

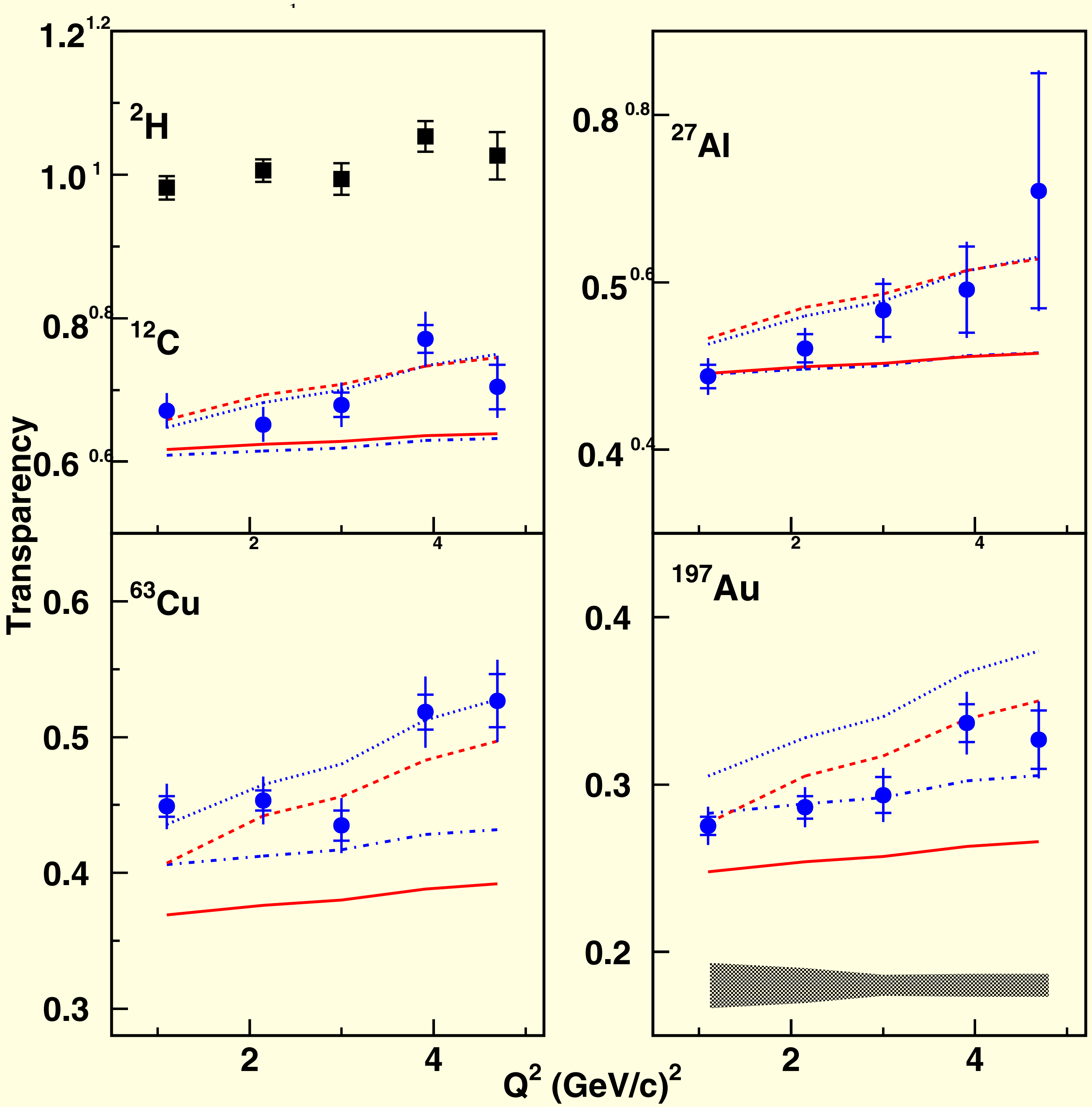
Phys. Rev D65,094015

$\mathscr{M}(\text{forward}) \propto A,\ \sigma_A \propto A^2 * A^{-2/3} = A^{4/3}$ + positive corrections

PRL 99, 242502 (2007) PHYSICAL REVIEW LETTERS week ending 14 DECEMBER 2007

Measurement of Nuclear Transparency for the $A(e, e'\pi^+)$ Reaction

B. Clasie,[1] X. Qian,[2] J. Arrington,[3] R. Asaturyan,[4] F. Benmokhtar,[5] W. Boeglin,[6] P. Bosted,[7] A. Bruell,[7] M. E. Christy,[8] E. Chudakov,[7] W. Cosyn,[9] M. M. Dalton,[10] A. Daniel,[11] D. Day,[12] D. Dutta,[13,2] L. El Fassi,[3] R. Ent,[7] H. C. Fenker,[7] J. Ferrer,[14] N. Fomin,[12] H. Gao,[1,2] K. Garrow,[15] D. Gaskell,[7] C. Gray,[10] T. Horn,[5,7] G. M. Huber,[16] M. K. Jones,[7] N. Kalantarians,[11] C. E. Keppel,[7,8] K. Kramer,[2] A. Larson,[17] Y. Li,[11] Y. Liang,[18] A. F. Lung,[7] S. Malace,[8] P. Markowitz,[6] A. Matsumura,[19] D. G. Meekins,[7] T. Mertens,[20] G. A. Miller,[17] T. Miyoshi,[11] H. Mkrtchyan,[4] R. Monson,[21] T. Navasardyan,[4] G. Niculescu,[14] I. Niculescu,[14] Y. Okayasu,[19] A. K. Opper,[18] C. Perdrisat,[22] V. Punjabi,[23] A. W. Rauf,[24] V. M. Rodriquez,[11] D. Rohe,[20] J. Ryckebusch,[9] J. Seely,[1] E. Segbefia,[8] G. R. Smith,[7] M. Strikman,[25] M. Sumihama,[19] V. Tadevosyan,[4] L. Tang,[7,8] V. Tvaskis,[7,8] A. Villano,[26] W. F. Vulcan,[7] F. R. Wesselmann,[23] S. A. Wood,[7] L. Yuan,[8] and X. C. Zheng[3]



Solid Dashed
Glauber, Glauber
+CT
LMS
prc74,018201

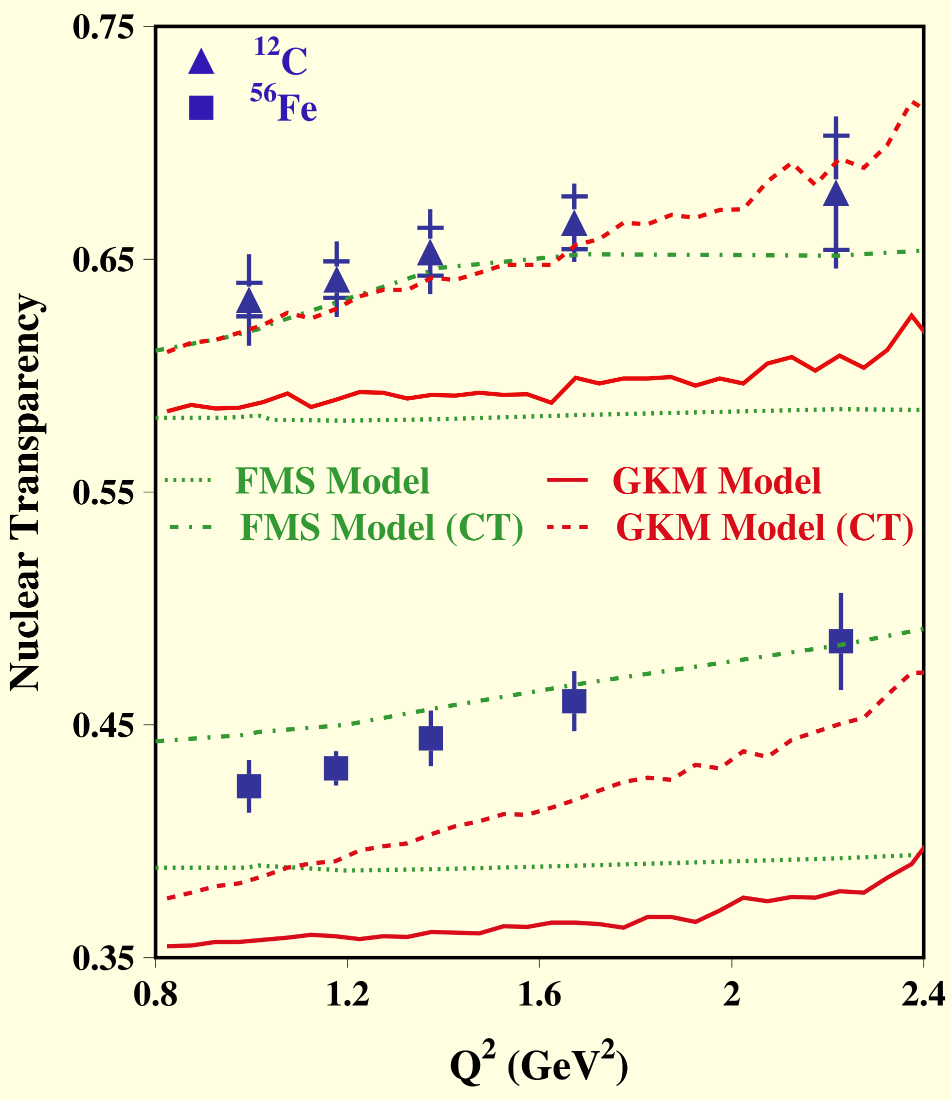
dot-dashed, dotted
CosynPRC74,062201

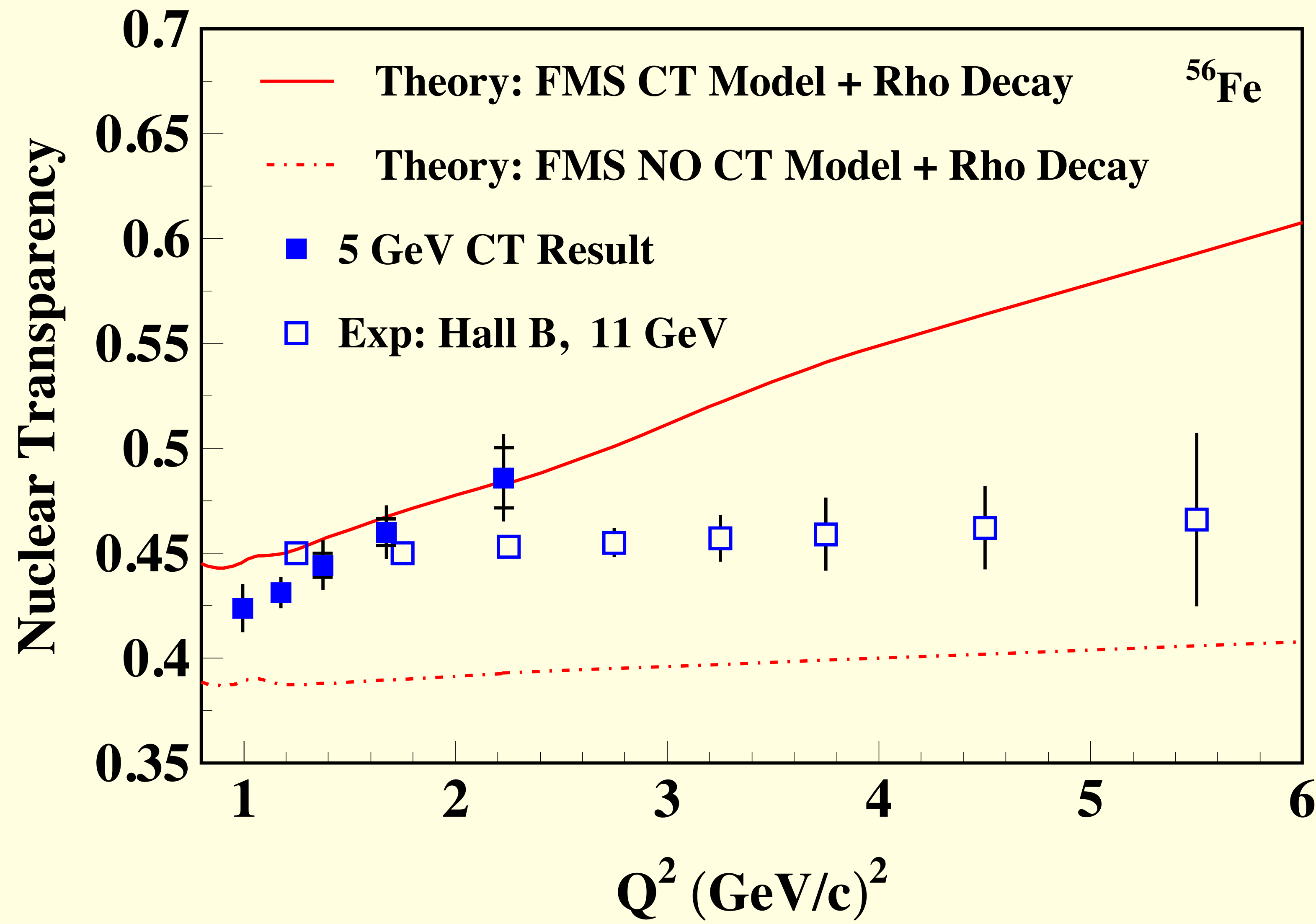
Solid-Glauber

El Fassi et al, :1201.2735

$(e, e'\rho)$ PLB 712,326

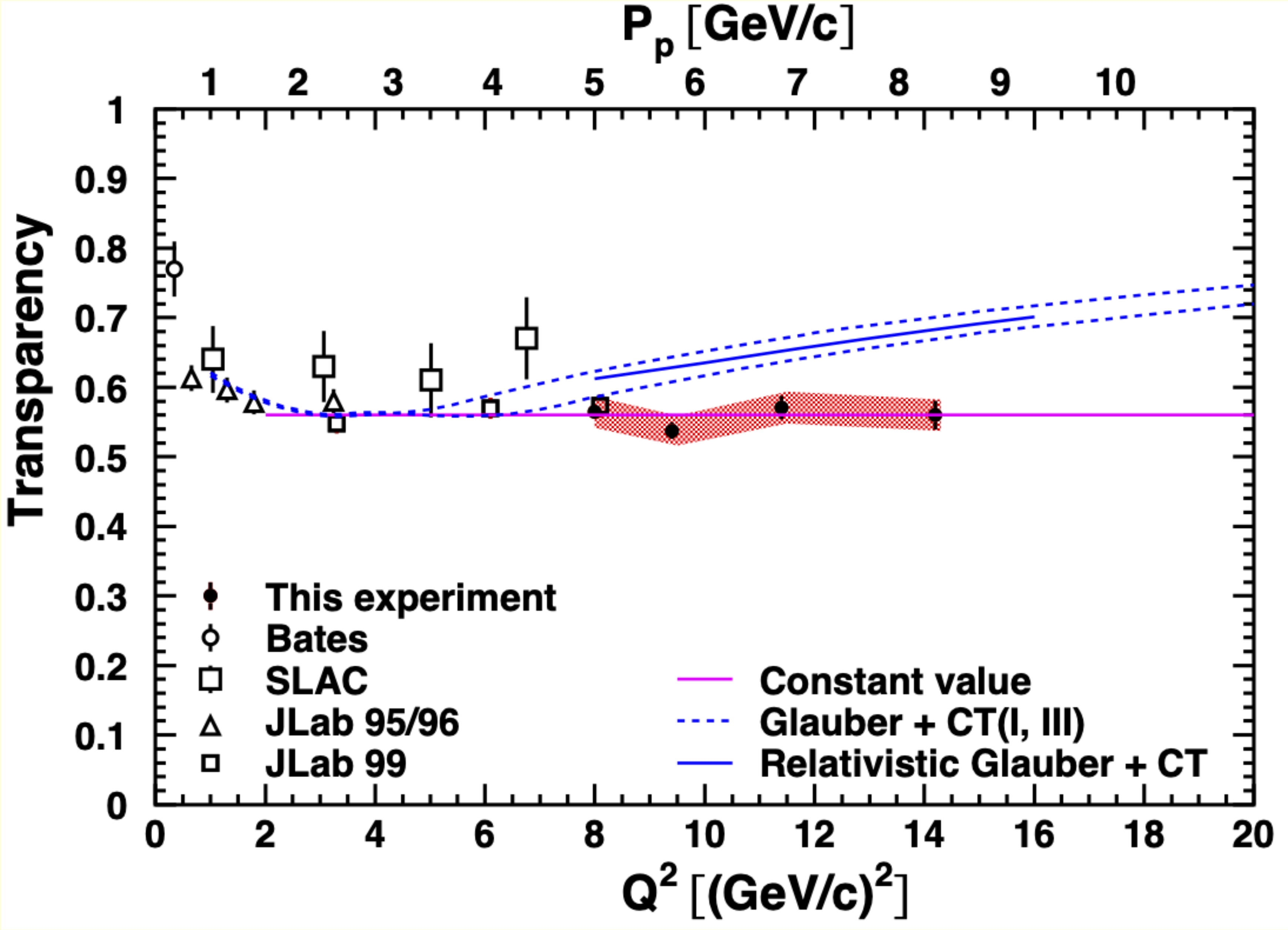
11 GeV expt





Ruling out color transparency in quasi-elastic $^{12}C(e,e'p)$ up to Q^2 of 14.2 $(GeV/c)^2$

Phys. Rev. Lett. 126, 082301



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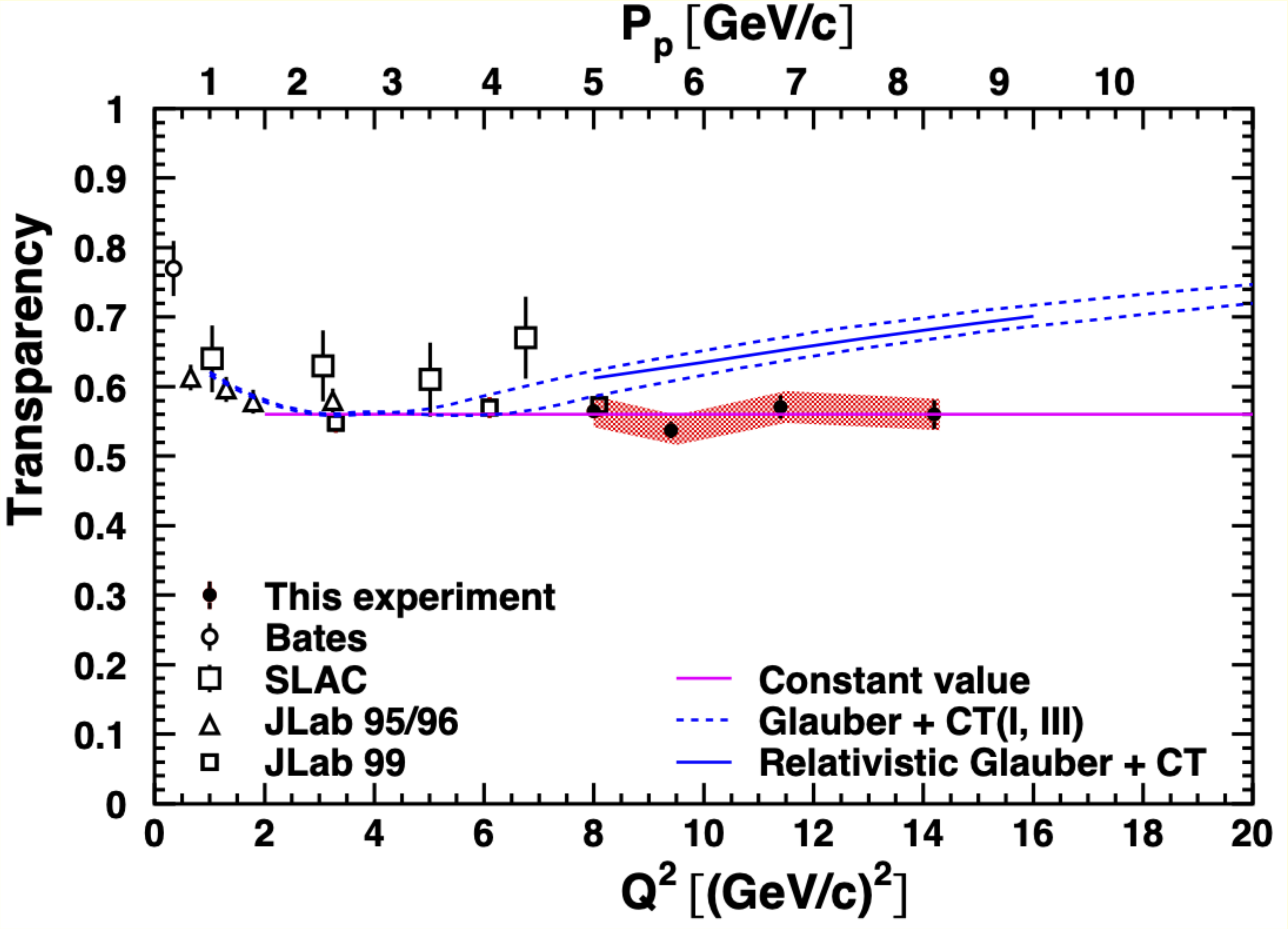

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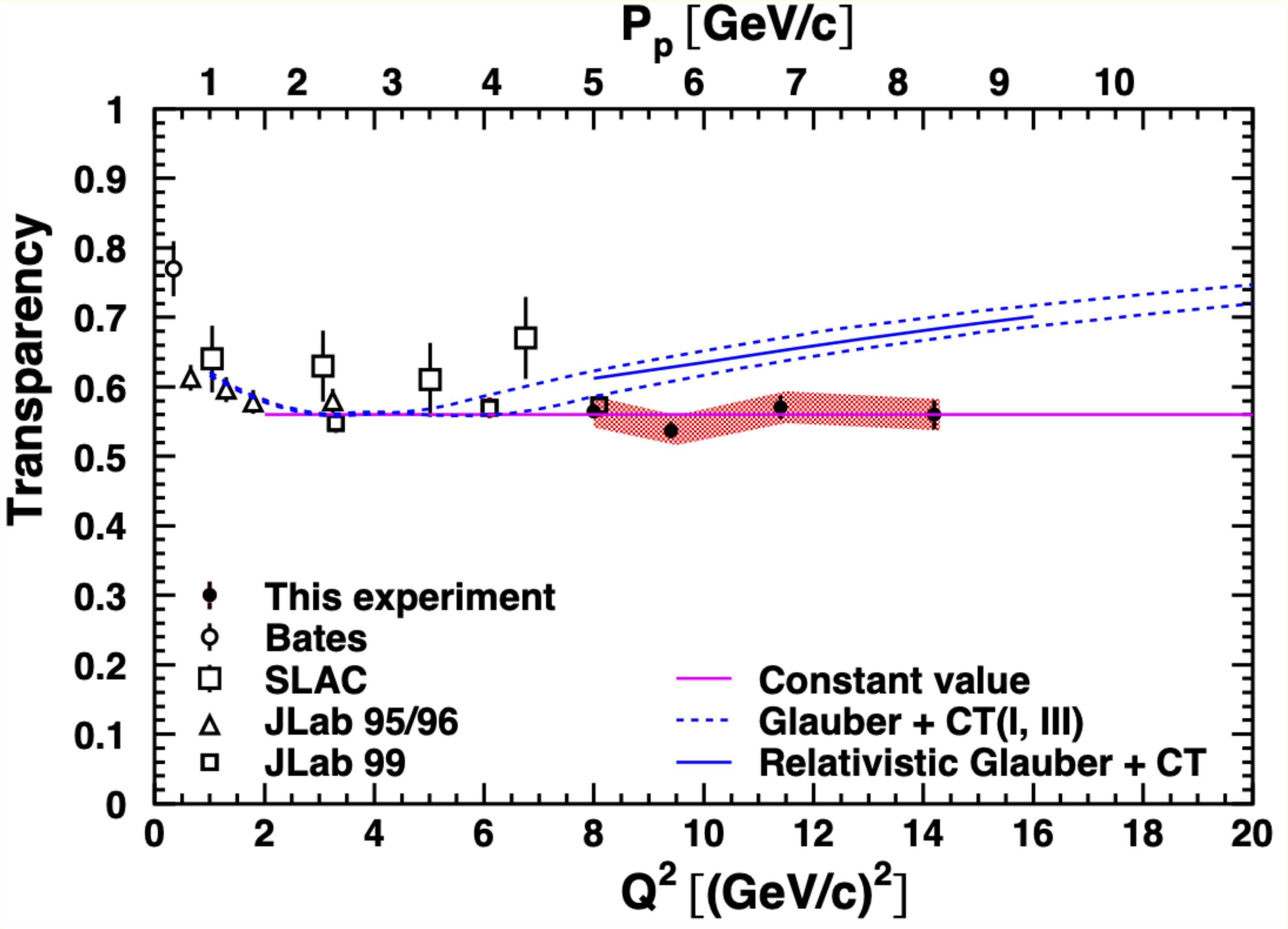


JLab: expansion is the problem

Goal: evaluate effects of expansion with new approach

Olivia Caplow-Munro, G A Miller 2104.11168 PRC104,L012201

Light front (LF) wave functions of Holographic QCD:

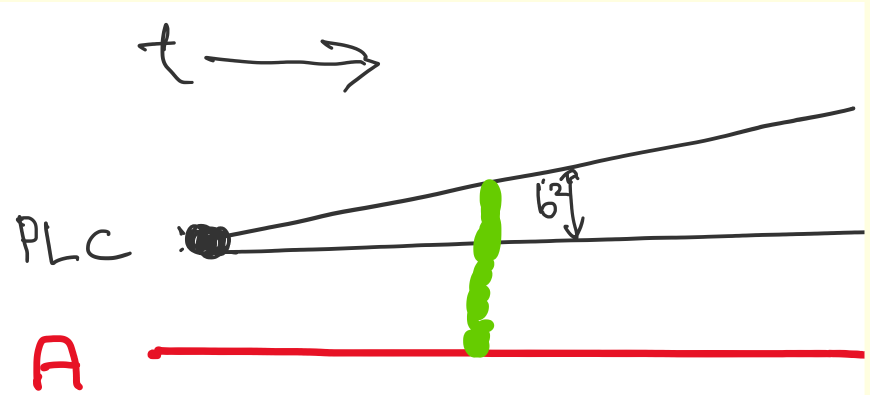
- Stanley J. Brodsky, Guy F. de Teramond, Hans Gunter Dosch, and Joshua Erlich, "Light-Front Holographic QCD and Emerging Confinement," Phys. Rept. 584, 1–105 (2015), arXiv:1407.8131 [hep-ph].

First semiclassical approximation: quantum loops & $m_q = 0$
relativistic bound-state equation reduced to effective LF Schroedinger eq.

We used holographic wave functions to compute the expansion time

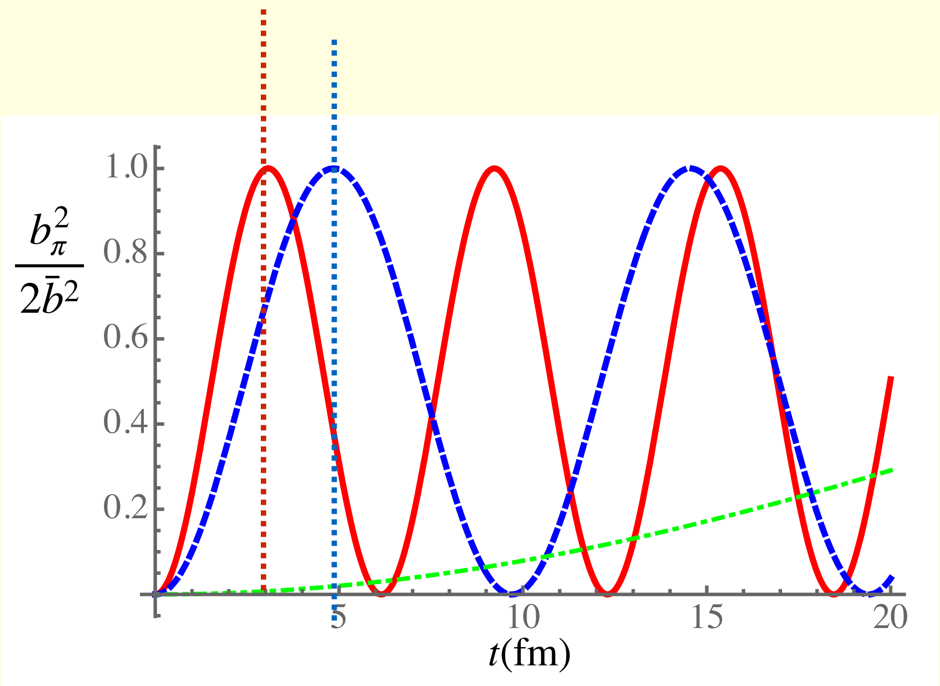
Time dependence

- Use path integral formalism to get τ development operator $K(t)$
- $b^2(t) \equiv \frac{\langle \Psi_{00} | b^2 K(t) | \mathrm{PLC} \rangle}{\langle \Psi_{00} | \mathrm{PLC} \rangle}$
- Effective size of PLC moving thru nucleus
- First-order in multiple scattering $b(0) = 0$, here



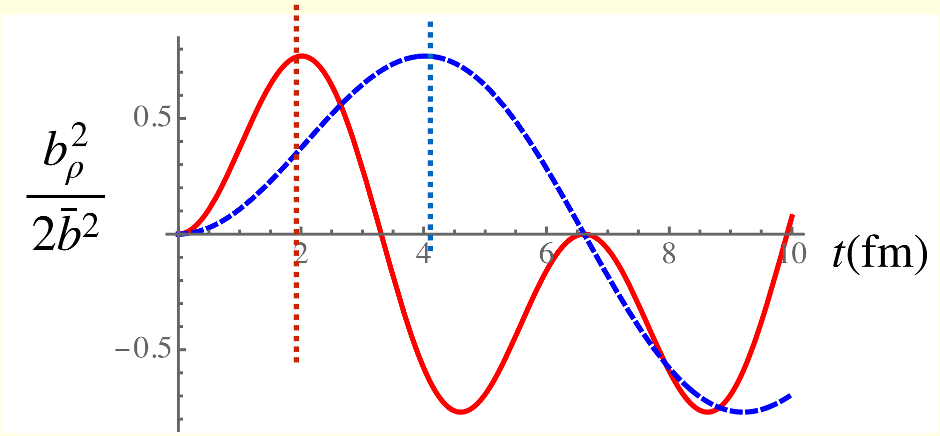
Meson results- expansion time , t_E, : vertical lines

Pion: t_E between 2 and 5 fm in exp. CT seen more Likely



Expansion does not occur for Flab Experiment

FIG. 2. $\frac{b_\pi^2}{2\bar{b}^2}$. Solid (red) $P_\pi^+ = 5.5$ GeV, Dashed (blue) $P_\pi^+ = 8.8$ GeV, Dot-dashed (green) $P_\pi^+ = 100$ GeV. t is in units of fm



Rho: t_E between 2 fm for exp. CT less likely Higher energy would see CT

FIG. 3. $\frac{b_\rho^2}{2\bar{b}^2}$. Solid (red) $P_\rho^+ = 6$ GeV, Dashed (blue) $P_\rho^+ = 12$ GeV. t is in units of fm

Proton results & Conclusion

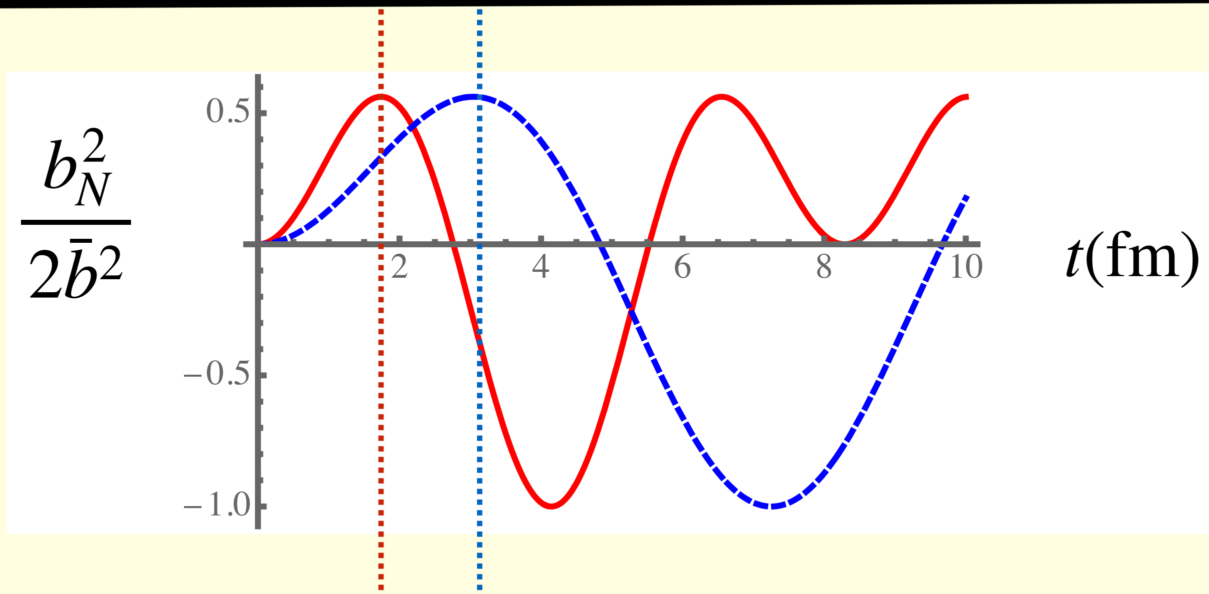


FIG. 4. $\frac{b_N^2}{2\bar{b}^2}$ Solid (red) $P_N^+ = 8$ GeV, Dashed (blue) $P_N + = 14$ GeV. t is in units of fm.

t_E ranges between 2 and 3fm . For ^{12}C CT should have seen as rise in transparency ratio

Expansion is not excuse for lack of CT in (e,e'p)
Conclude PLC is not formed
Feynman mechanism is responsible for proton em form factor at high Q^2
Best future search $(e,e'\pi)$ $(e,e'\rho)(e,e'\psi),(e,e',\psi')$
Connection with EMC in our model- PLC is not really point-like ,
High x is not directly correlated with small distance
The size of the $\tau = 3$ term not much smaller than $\tau = 4$

Spares follow

The E-791 (FNAL) data $E^{\pi}_{inc} = 500 GeV$ (D.Ashery et al, PRL 2000)

♡ Coherent peak is well resolved:

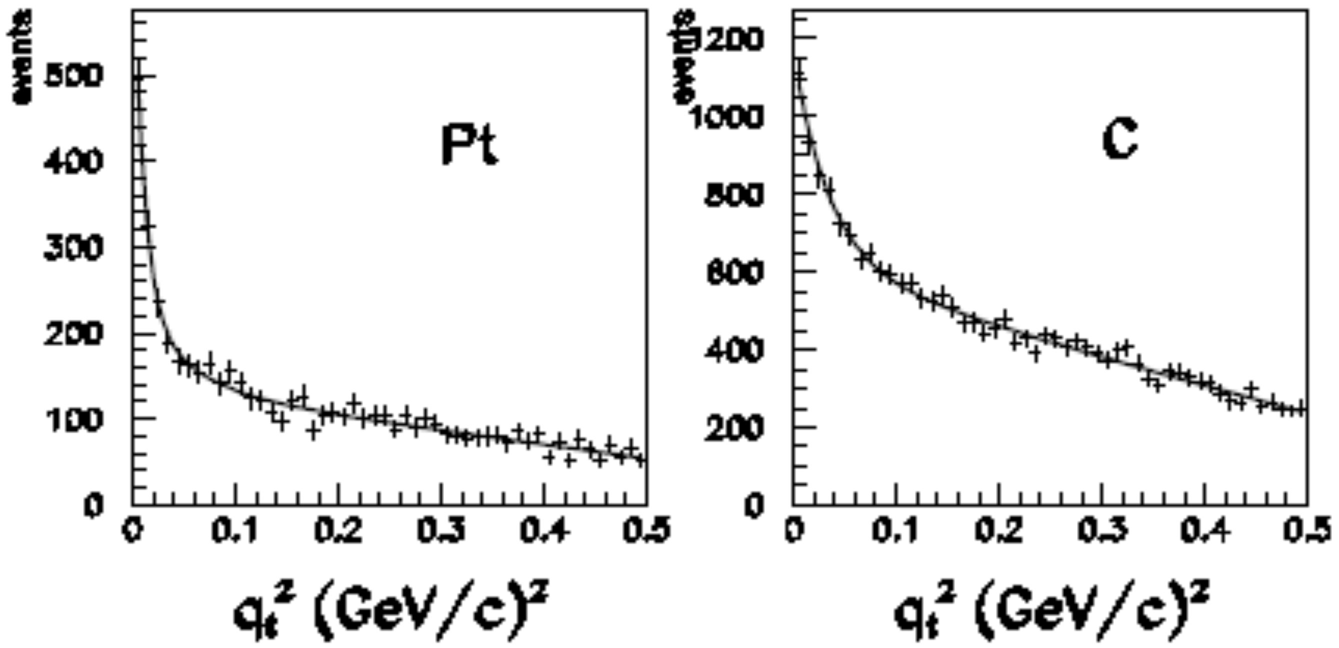


TABLE I. The exponent in $\sigma \propto A^{\alpha}$, experimental results for coherent dissociation and the color-transparency predictions.

k_t bin GeV/c	α	$\Delta\alpha_{\rm stat}$	$\Delta\alpha_{\rm sys}$	$\Delta\alpha$	α (CT)
1.25–1.5	1.64	±0.05	+0.04 −0.11	+0.06 −0.12	1.25
1.5–2.0	1.52	±0.09	±0.08	±0.12	1.45
2.0–2.5	1.55	±0.11	±0.12	±0.16	1.60

PRL 86,4773

♡♡ Observed A-dependence $A^{1.61\pm0.08}$ $[C \to Pt]$

FMS prediction $A^{1.54}$ $[C \to Pt]$ for large k_t & extra small enhancement for intermediate k_t.

For soft diffraction the Pt/C ratio is ~ 7 times smaller!!

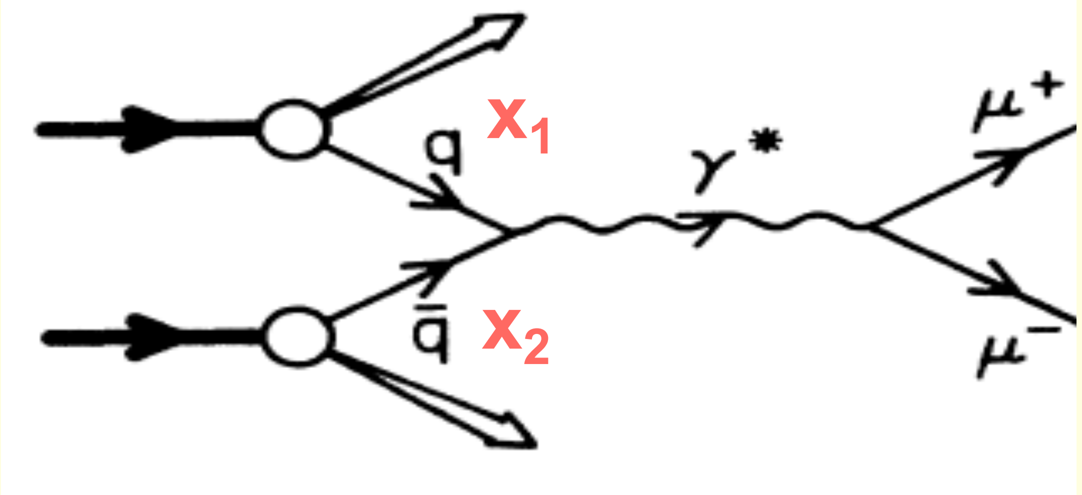
Nucleons and pions

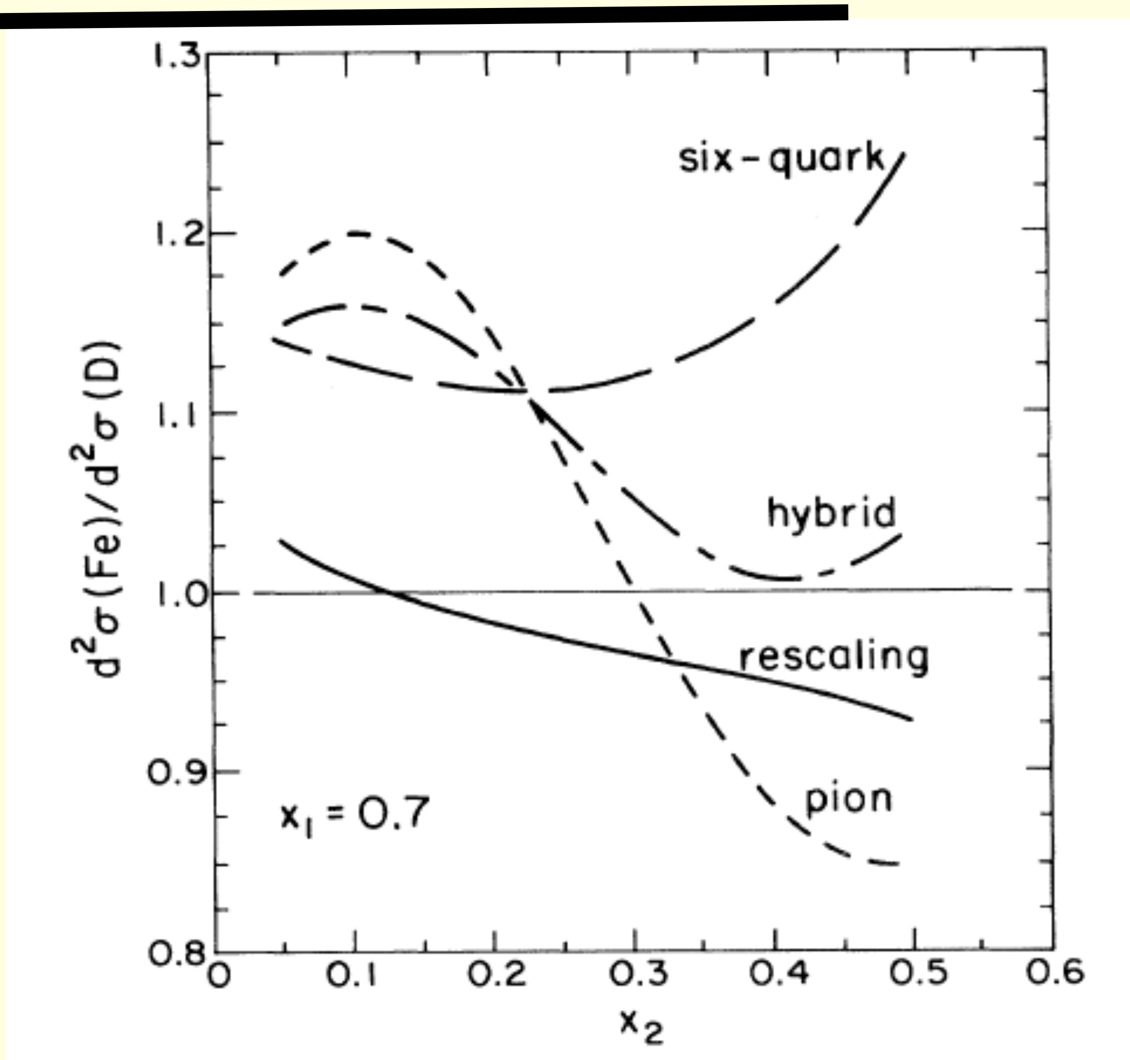
$P_A^+ = P_N^+ + P_\pi^+ = M_A$

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

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

proton(x_1) nucleus(x_2)





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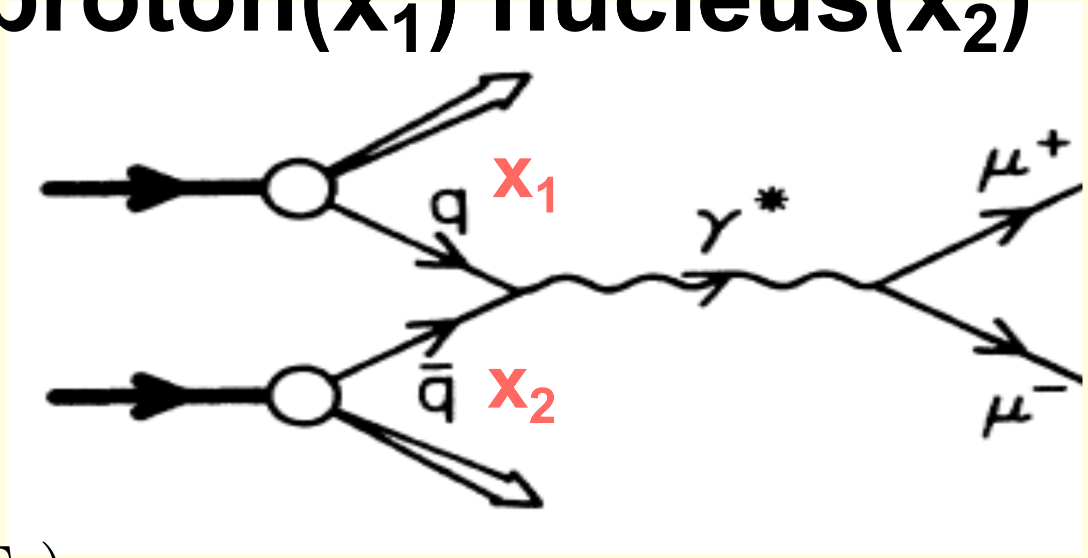
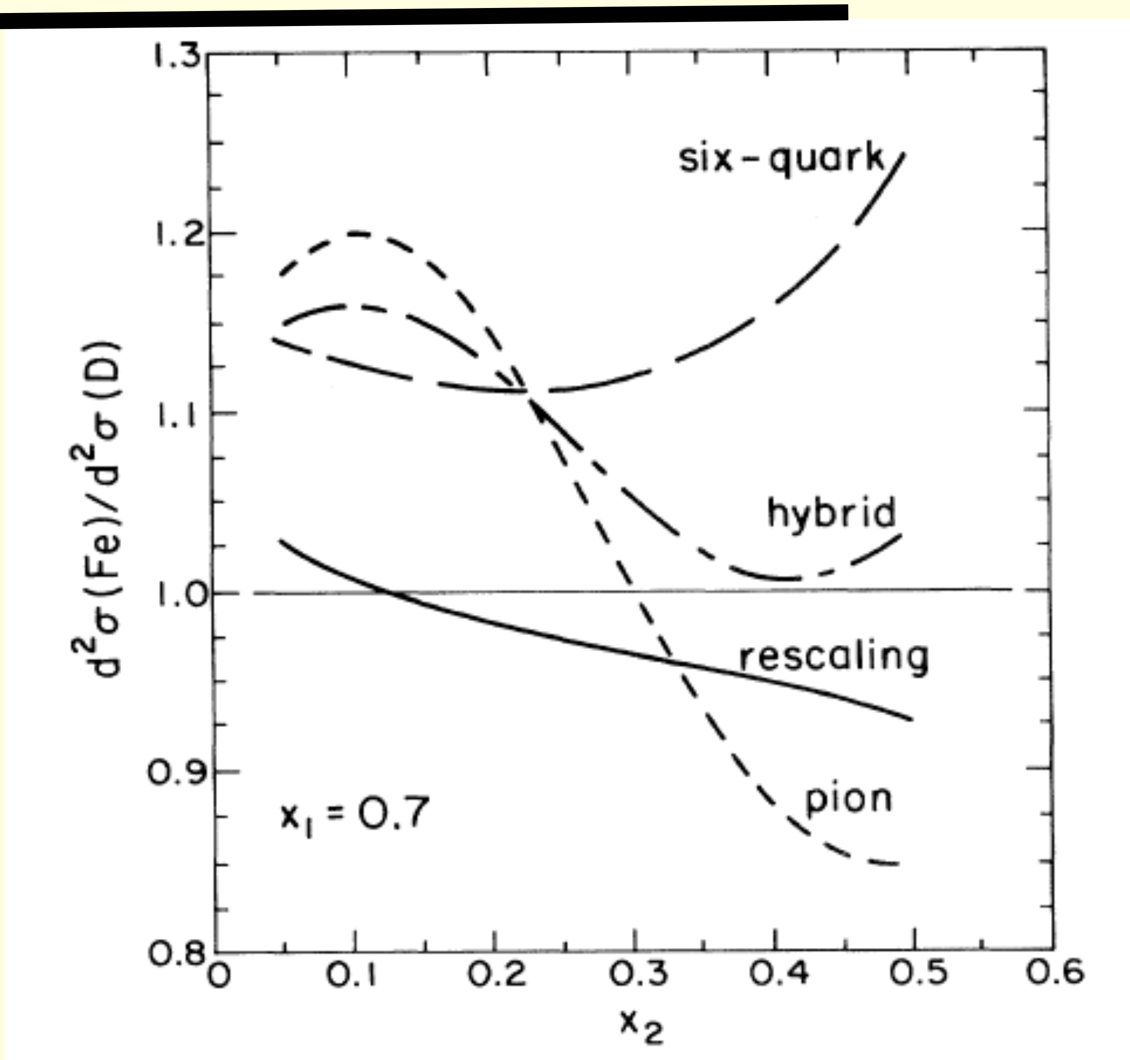
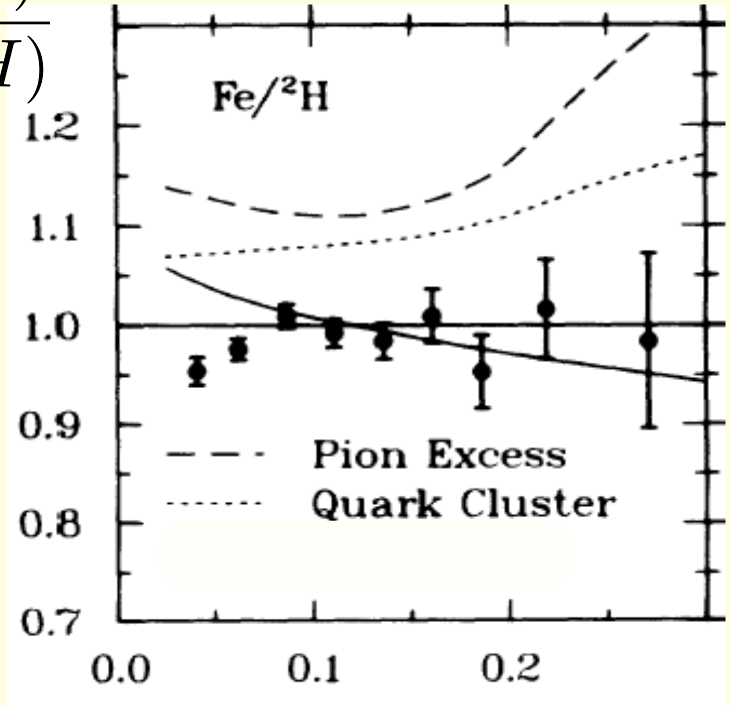




$$\frac{\sigma_{DY}(\mathrm{Fe})}{\sigma_{DY}(^2H)}$$



E772 PRL 69,1726 (92)

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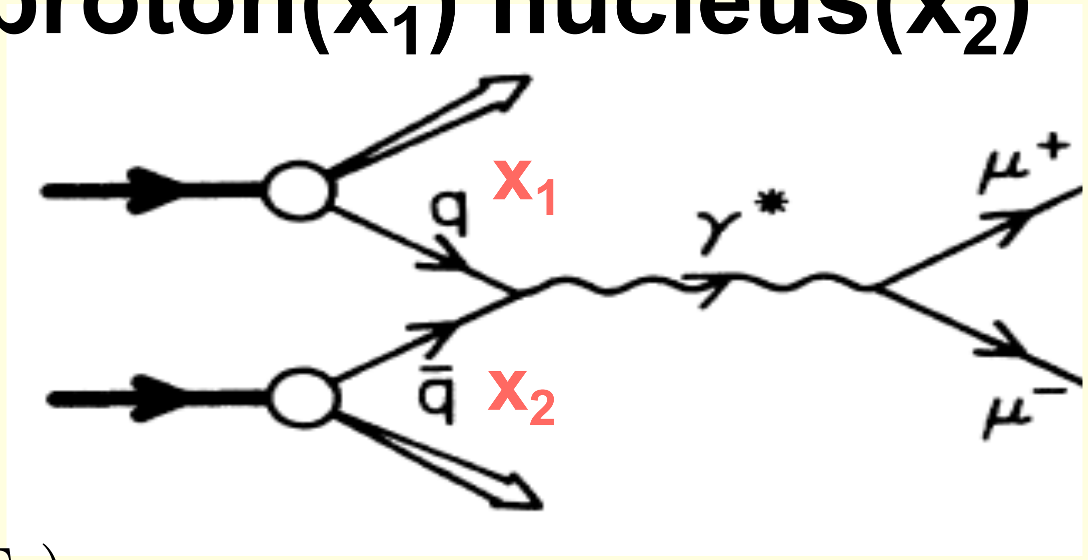

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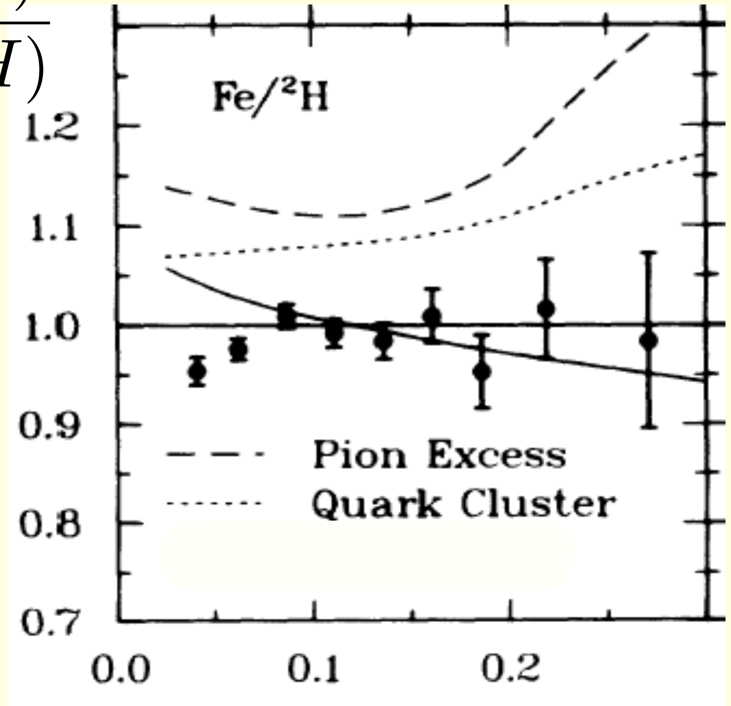
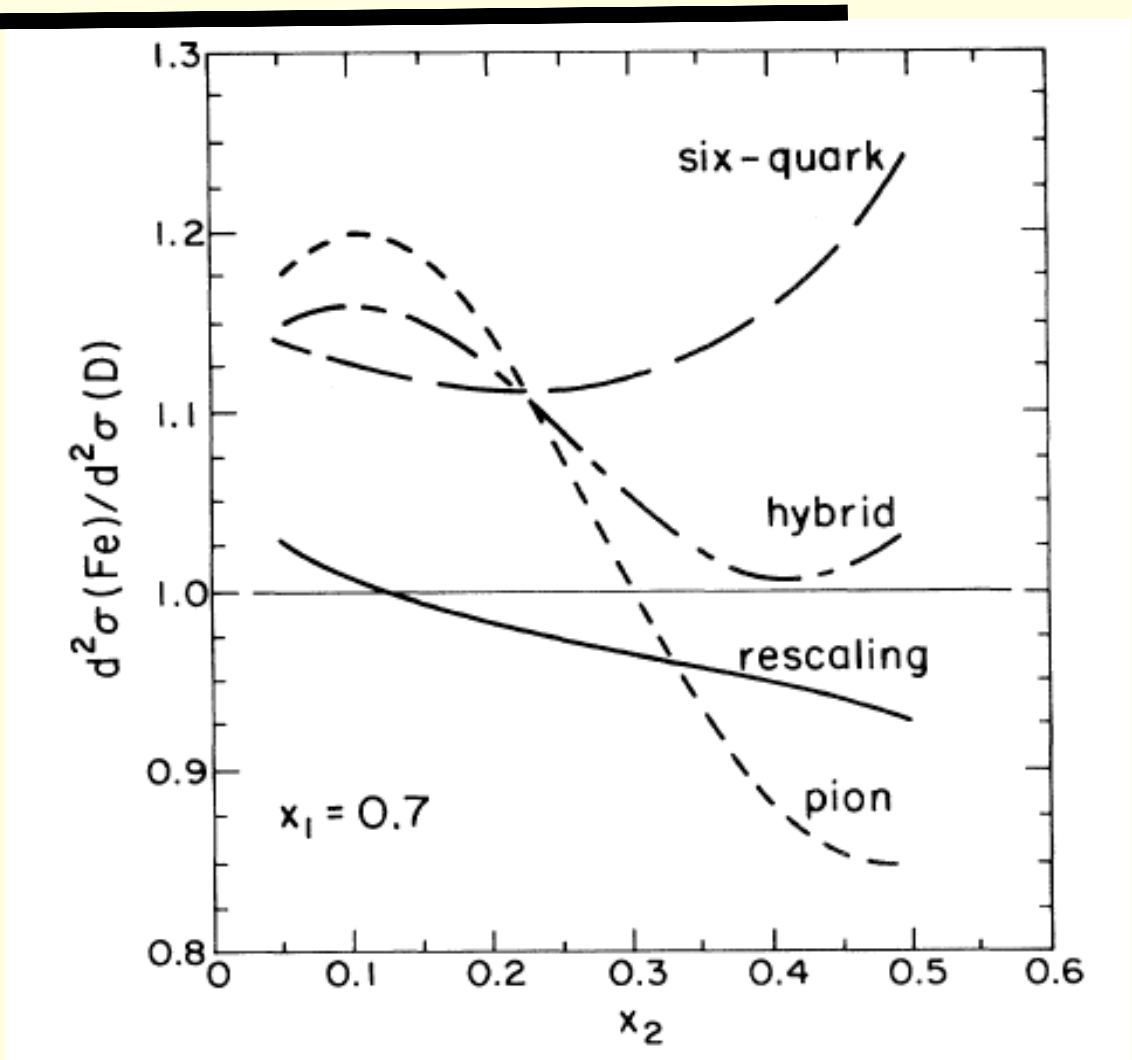




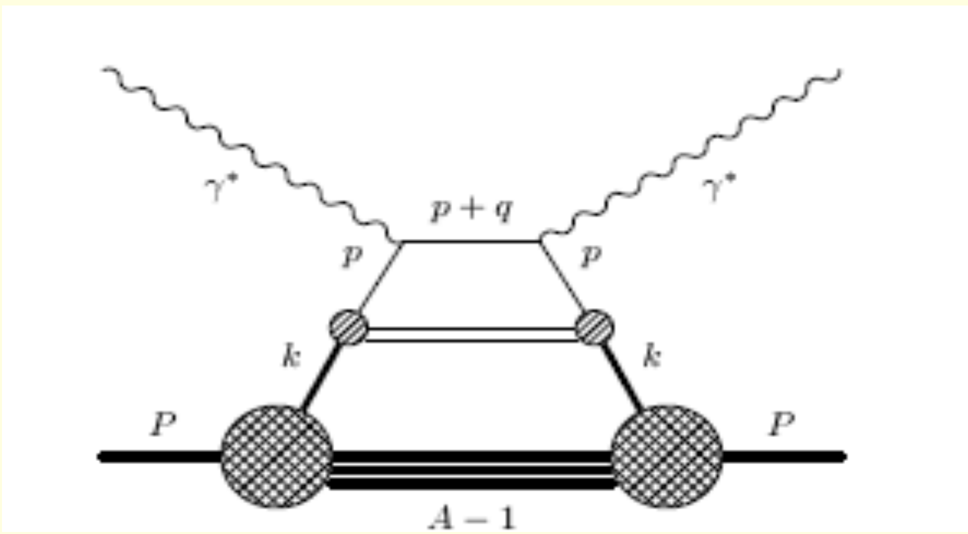
Bertsch, Frankfurt, Strikman "crisis"

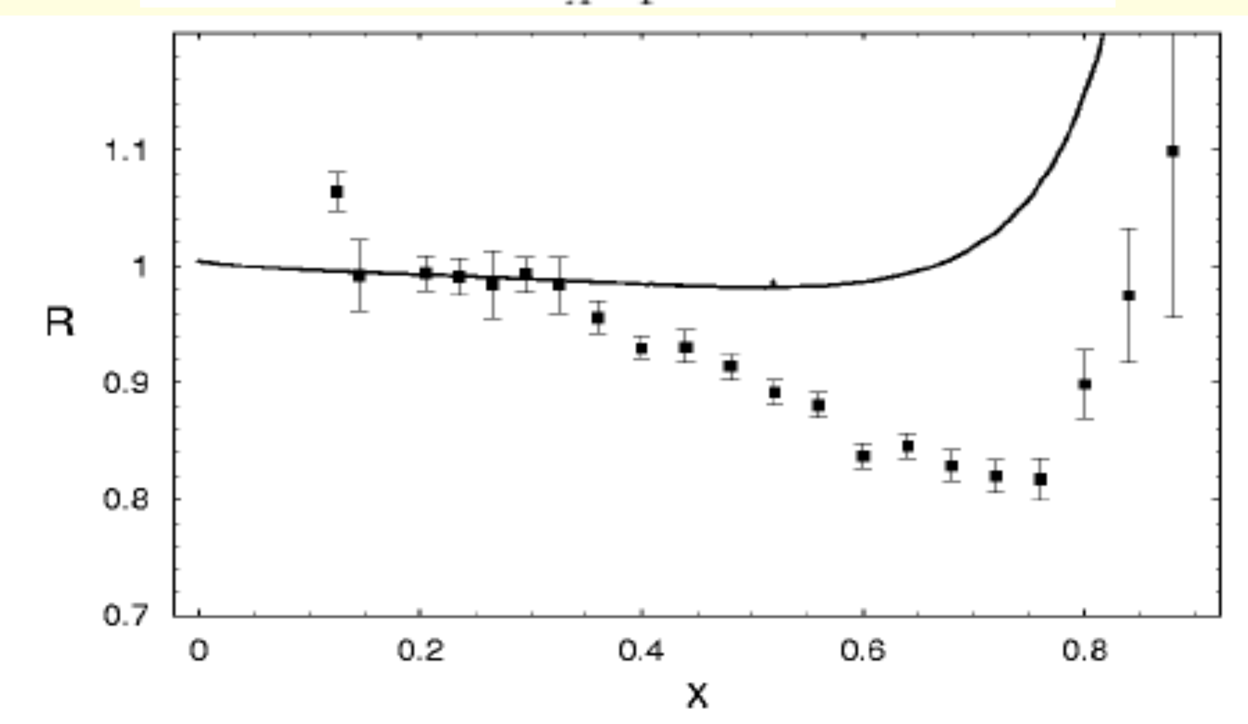
E772 PRL 69,1726 (92)

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