QCD View of the Nucleus

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JLab PN12

1-5 November 04

QCD view of Nucleus?

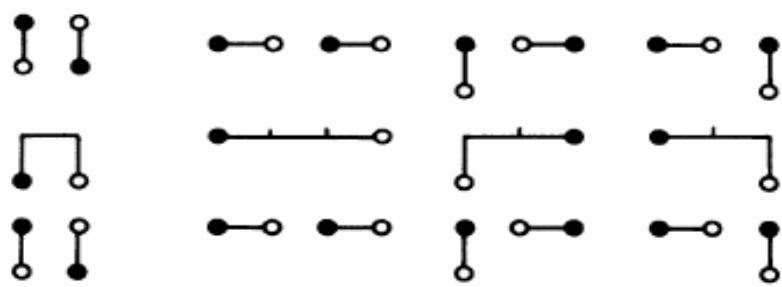
- Earliest lattice calculations

  Hamiltonian, strong coupling limit →

  confinement, flux string, color singlet clusters

  leading order: inert nucleons sit

  interactions: string break



SCQCD →

meson exchange model of nuclei, GAM PRC39,1563

quark, gluon effects hard to find, but vital

Outline

- **QCD view of nucleon**
- **Medium modifies single nucleon (what, why, how)**
- **Experiments (single nucleon)**
- **Color Transparency**
- **Nuclear glue**
- **Deuteron Photodisintegration**

QCD view of the nucleon

- nucleon is made of quarks and gluons
- color singlet of r b g quarks +… SU(3)
- many configurations
- size: sometimes small, mostly average, sometimes HUGE
- small sized configs: Point Like Configs. PLC don’t interact
- use nucleus to observe, change fluctuations

Nucleon in nucleus- kinematic distinction

- quasi-elastic, one body: single nucleon moves in nucleus
- two-body –overlapping nucleons – hidden color
- deconfinement

Single nucleon modification by nuclei

- Does it make sense?
- Neutron in nucleus is modified, lifetime changed from 17 minutes to forever
- Binding changes energy denominator, suppresses $|pe\nu\rangle$ component
- Change energy denominator change wave fun
- Strong fields polarize nucleons- analog of Stark effect, induces dipole moment of atom
- Nuclei: no direction - monopole polarization

Nuclei modify nucleons: models

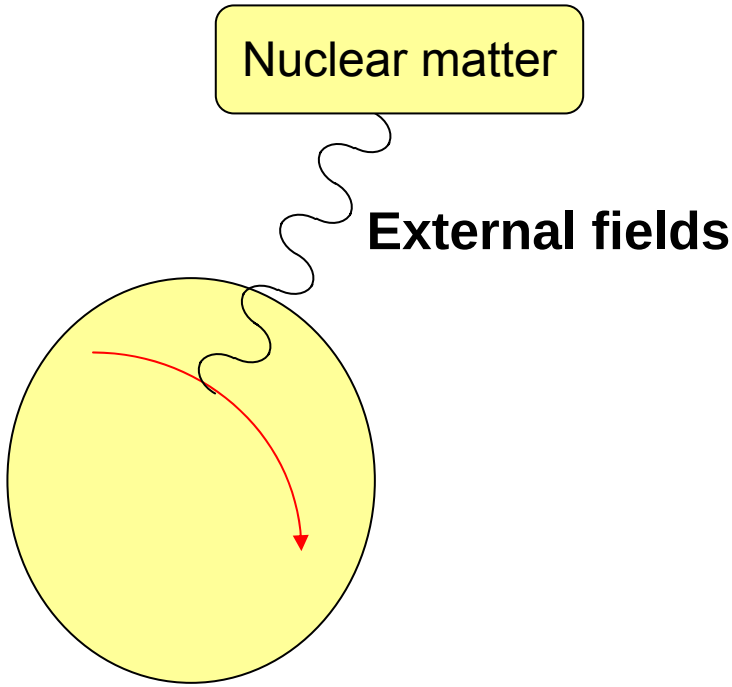
1. QMC- quarks in nucleons exchange mesons with nuclear medium - P
2. CISM- quarks in nucleons exchange infinite pairs of pions, vector mesons with nuclear medium -P
3. Suppression of point-like-configurations –D

All three well-grounded in QCD MUST BE THERE

All three poorly evaluated now

Seeing definitive evidence for any would be very interesting - big effects needed

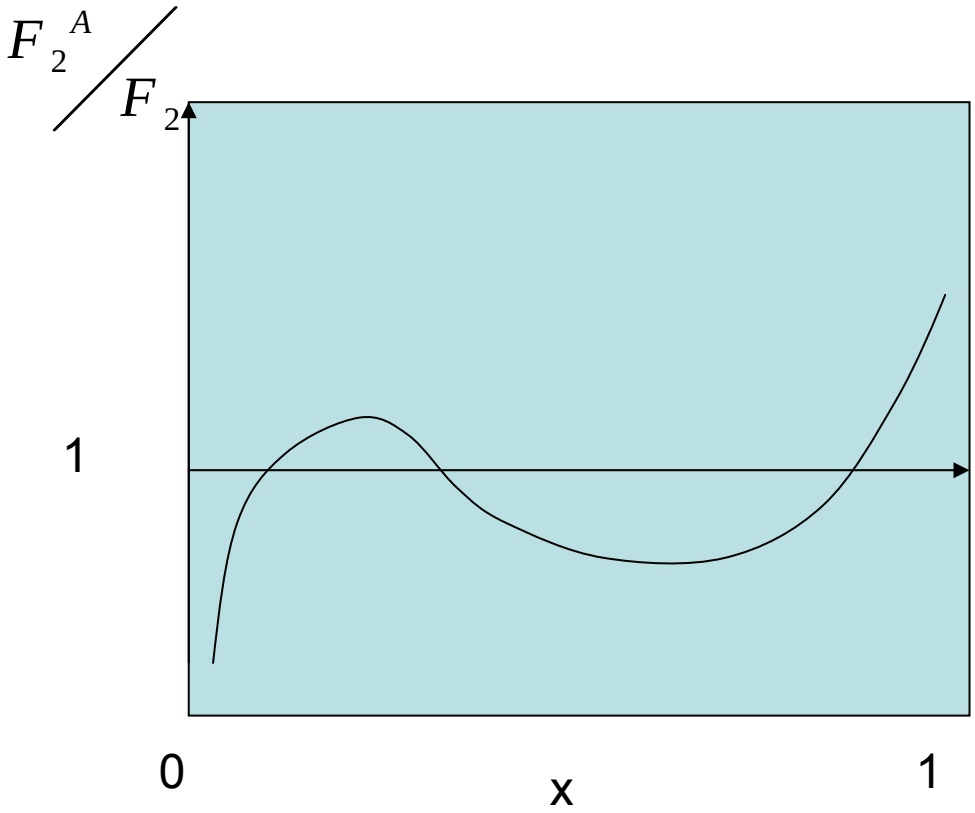
Nucleon in medium- 3 models



2 models: lower components enhanced, quark is more relativistic

Experiments

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



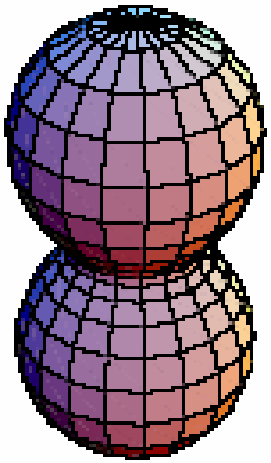
~~**Binding effect**~~

new-light nuclei, high x

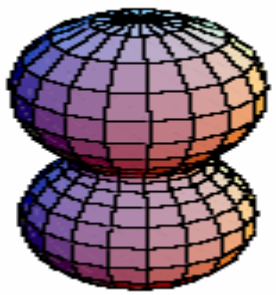
some models uncool

Closer look needed! Lower components LoC

- LoC account for QF_2/F_1
- LoC gives non-spherical shape of proton



- Medium modifies LoC
- Medium modifies shape

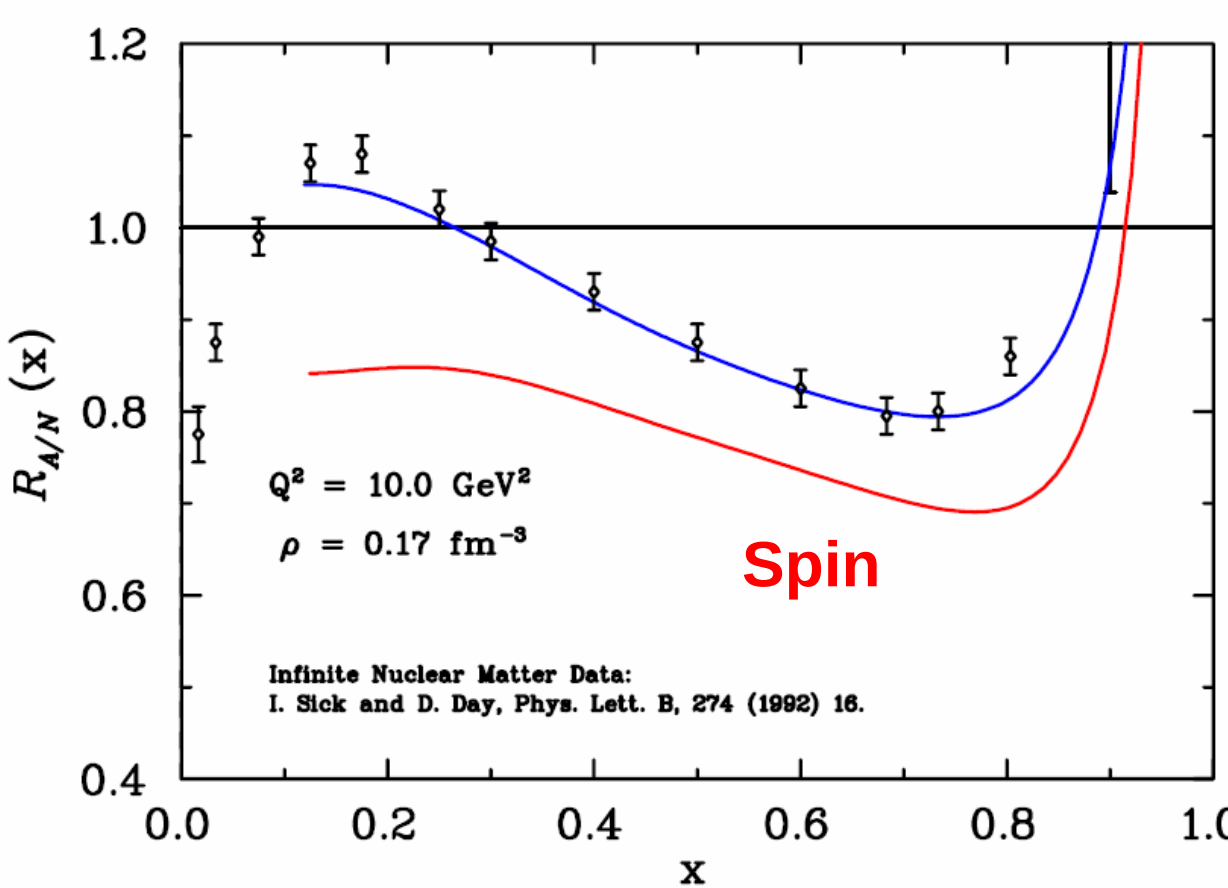


Spin experiments examine LoC

- g_{1n}, g_{1p} in nuclei

- other ways to enhance EMC

Bentz, Cloet Thomas



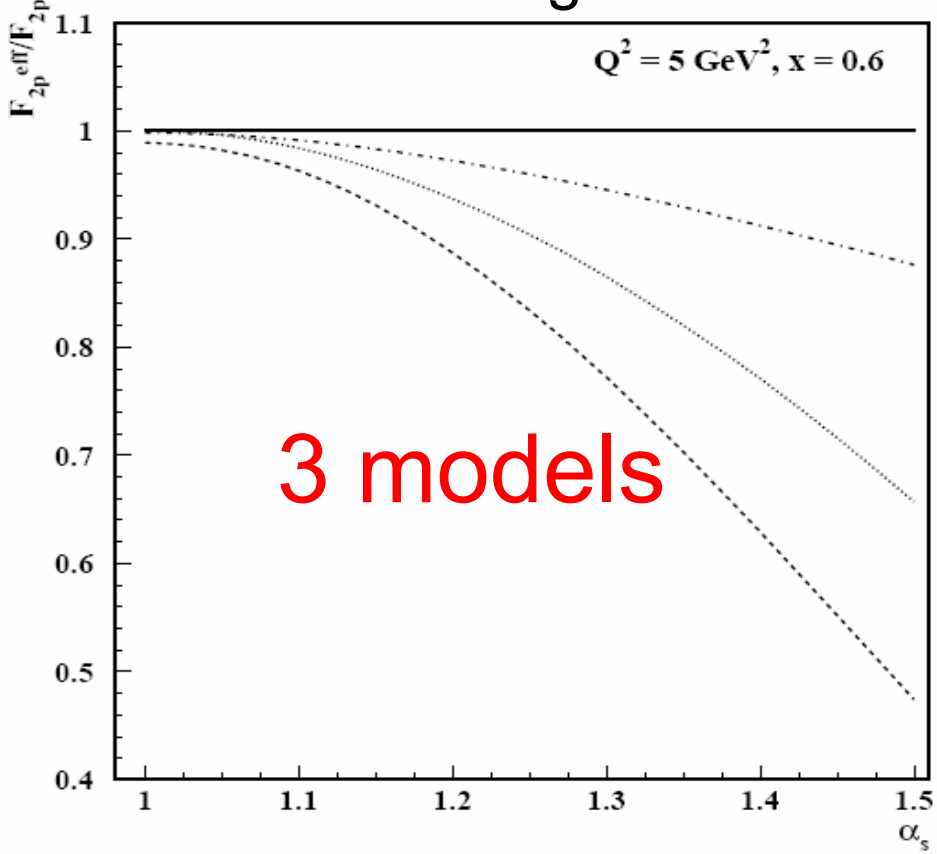
Enhancing EMC-spin independent

Tagged structure functions (measurement of a nucleon from the target fragmentation region in coincidence with the outgoing electron) with the goal of directly observing the presence of non-nucleonic degrees of freedom in droplets of superdense matter.

Ratio
bound to free F_2

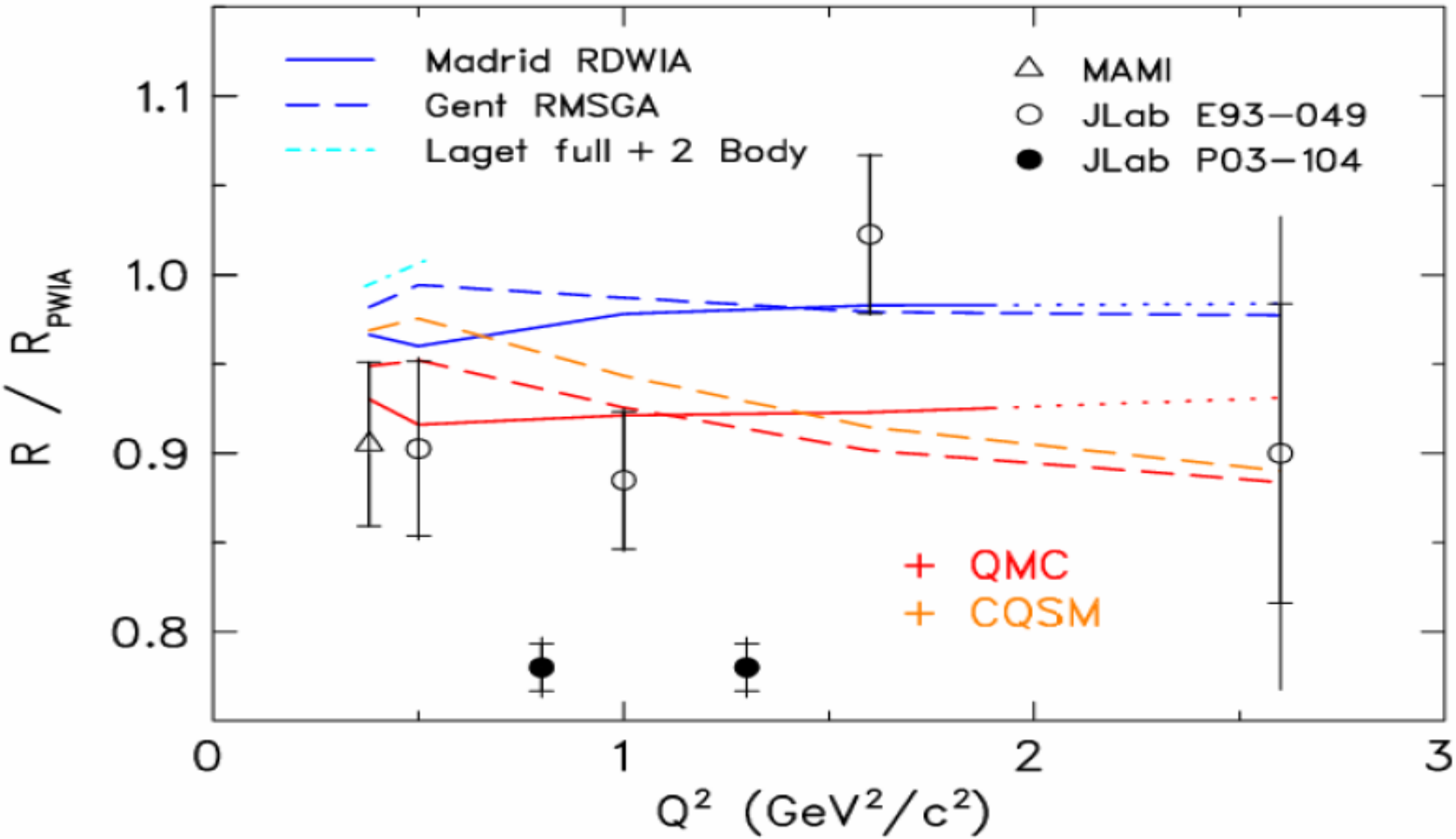
$$\alpha_s = \frac{E_s - p_z^s}{M}$$

Melnitchouk Sargsian Strikman

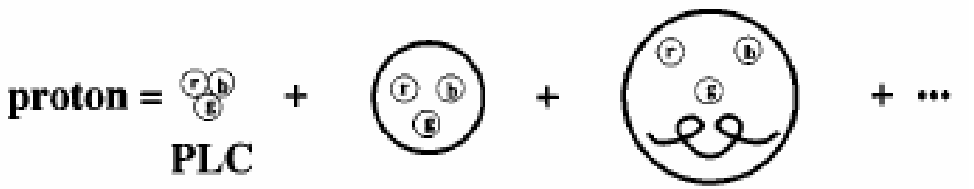


3 models

Polarization transfer in 4He(e,e'p) Nucleon form factors in medium-Strauch

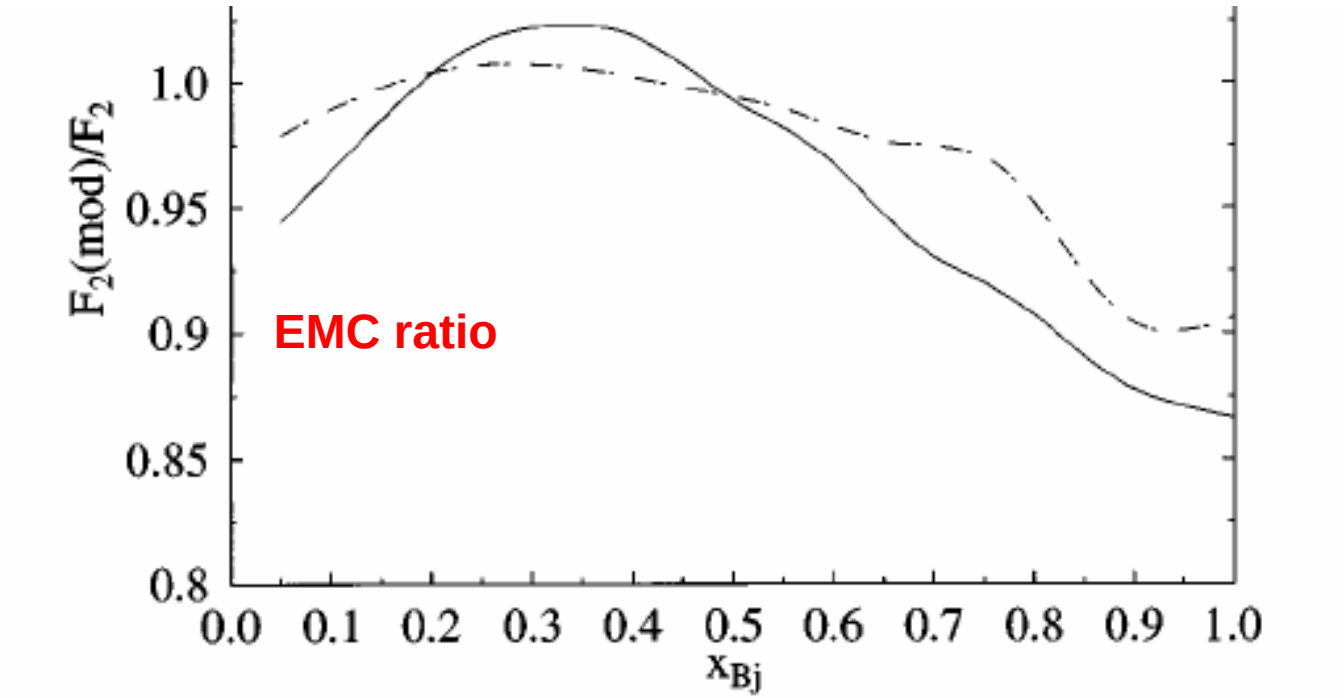


Suppression of Point Like Configurations- Frankfurt, Strikman

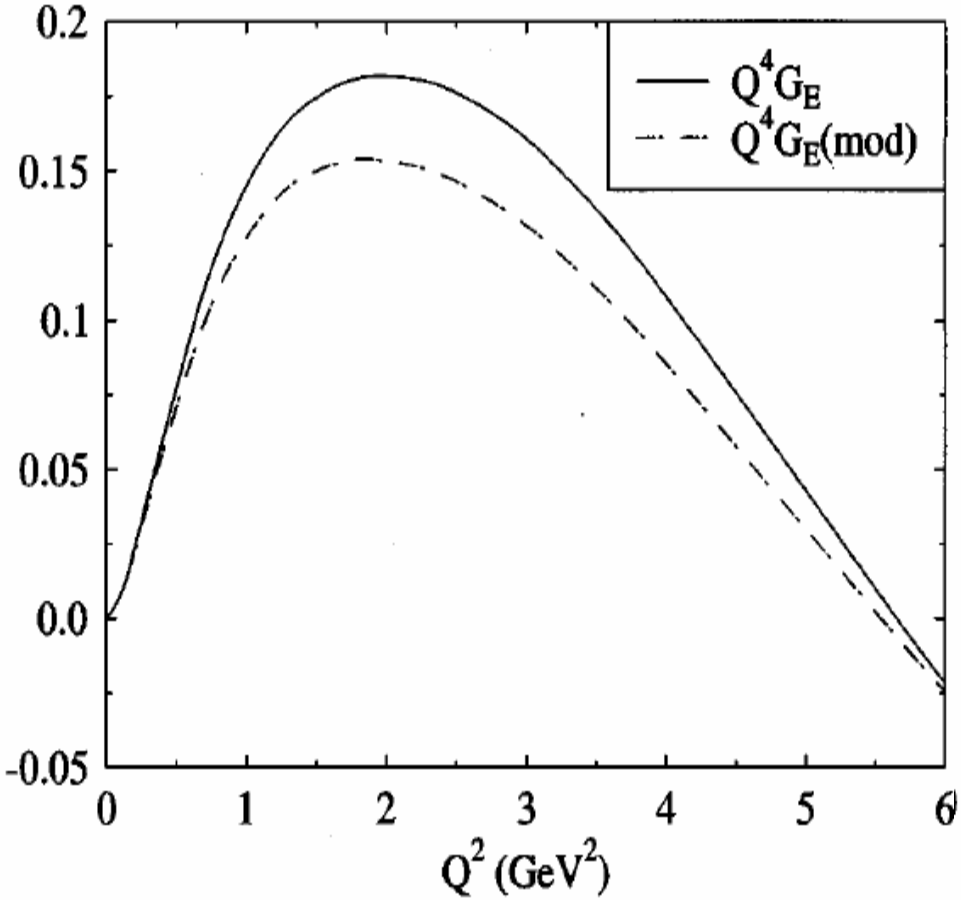


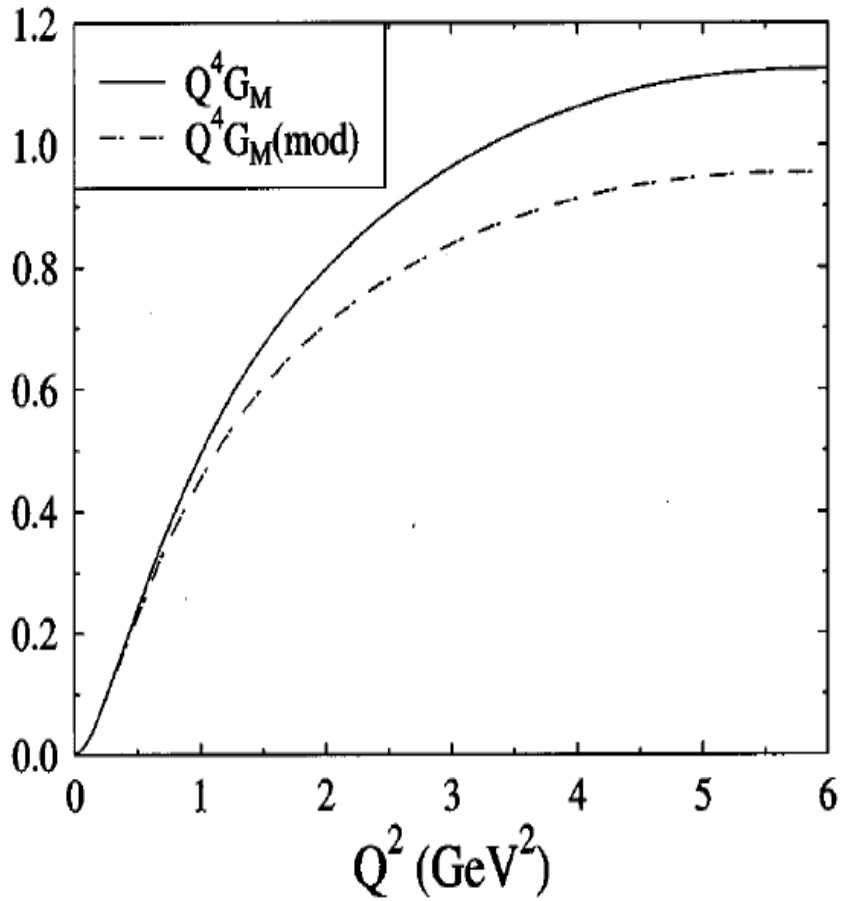
PLC has NO int. with medium

energy denominator increased



Medium modified form factors





Frank, Jennings, Miller PRC54,920

Medium modified form factors - Challenge:

- **Measure separately E,M form factors for n, p bound in nuclei**
- **Coulomb sum rule?**

Coulomb Sum Rule

G_E is the effective proton electric form factor in the nucleus.

$$S_L(k) = \frac{1}{Z}\int_{\omega_{el}^{+}}^{\infty} d\omega \frac{R_L(k,\omega)}{\left[G_{E,p}(k,\omega)\right]^2}$$

$$\equiv 1 + \rho_{LL}(k) - Z\frac{\left|F_L(k)\right|^2}{\left[G_{E,p}(k,\omega_{el})\right]^2}$$

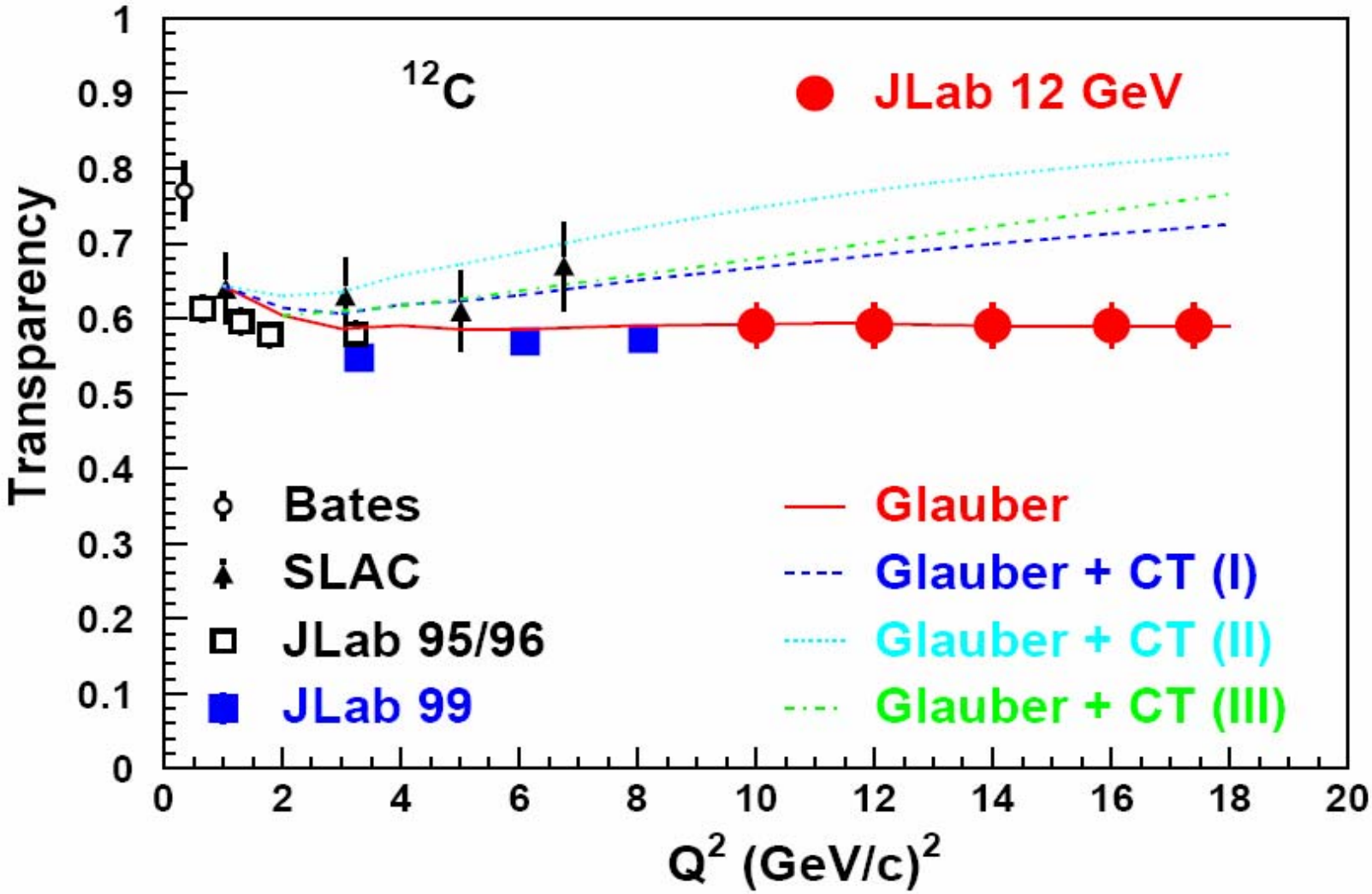
ρ_{LL} is the long.-long. dist. function and F_L is the elastic form factor.

Ransome's talk

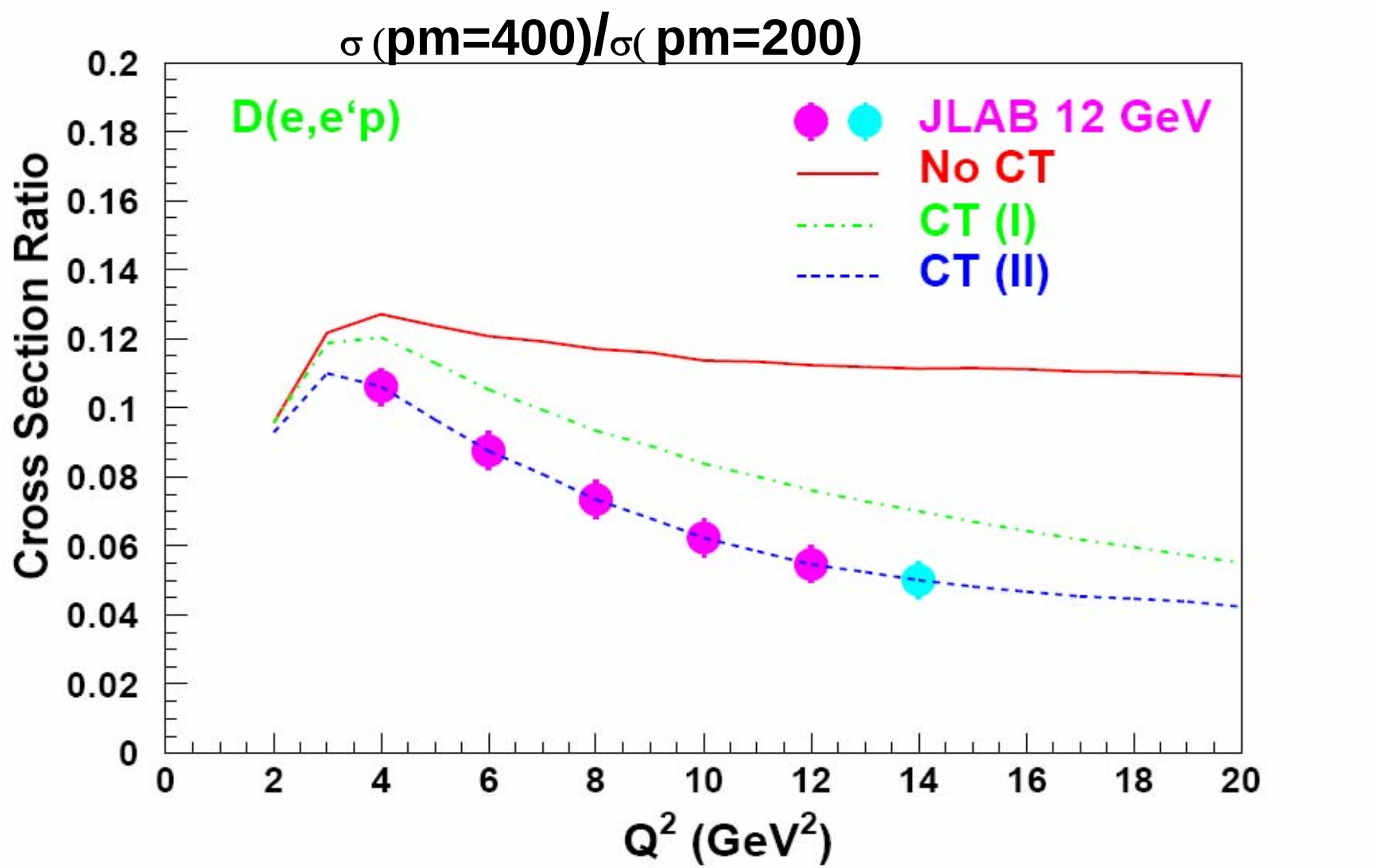
Suppression of PLC in action – Color Transparency

- high Q^2 – PLC dominates exclusive processes. Does PLC proton exist? color cancellation of r, b, g quarks a new test of color SU(3) (meson = $r\bar{r} + b\bar{b} + g\bar{g}$
- PLC doesn't interact in medium
- PLC expands as it moves- JLAB 12

Color transparency in (e,e'p) enhancement



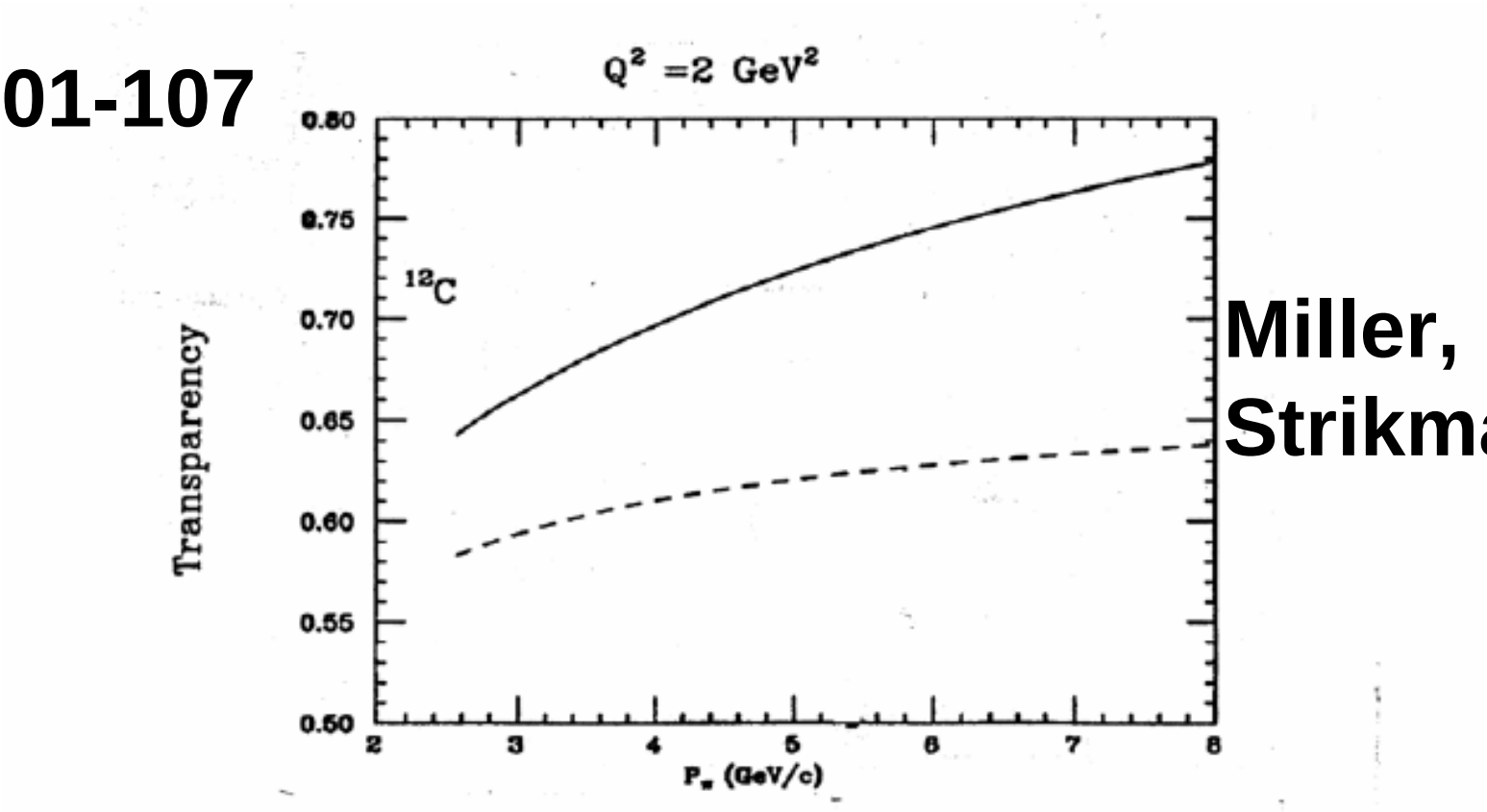
Color transparency in double scattering- suppression



Pion color transparency Jlab 6,12

- **(e,e', π): γ^* makes pion PLC (expands?)**

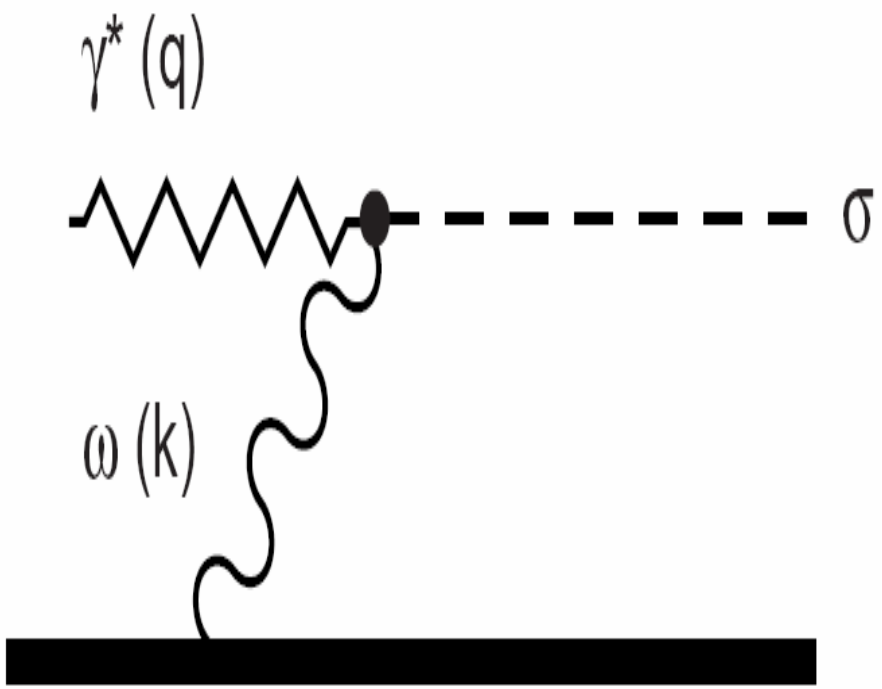
E01-107

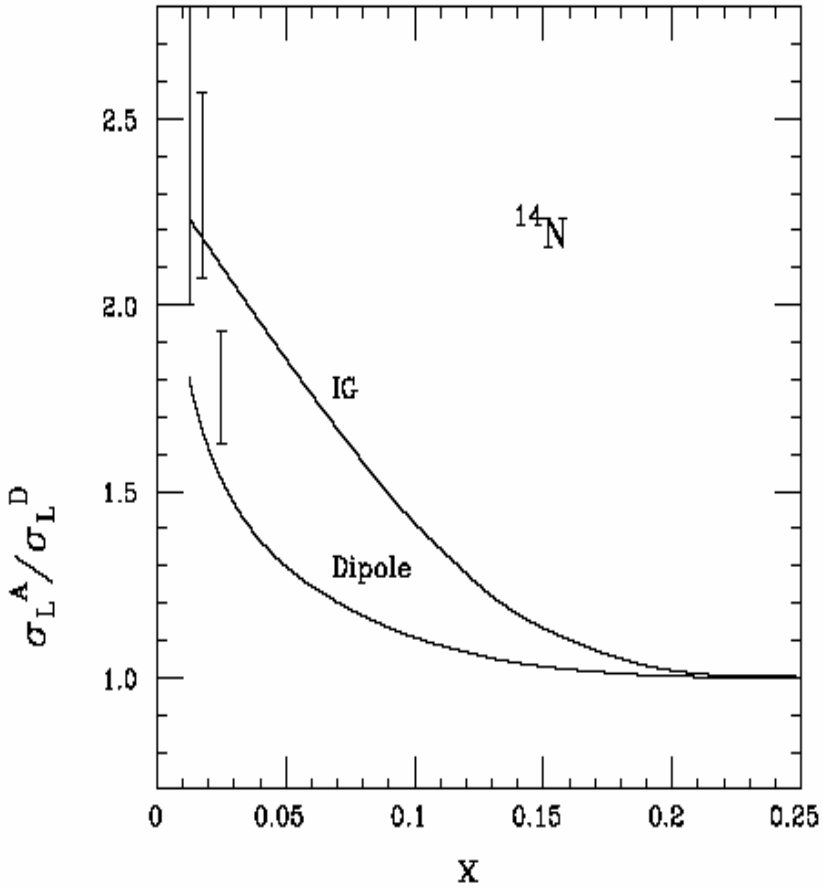


Miller, Strikman

Good at 6, better at 12

σ(L) nuclear meson Brodsky,Miller,Karliner '00





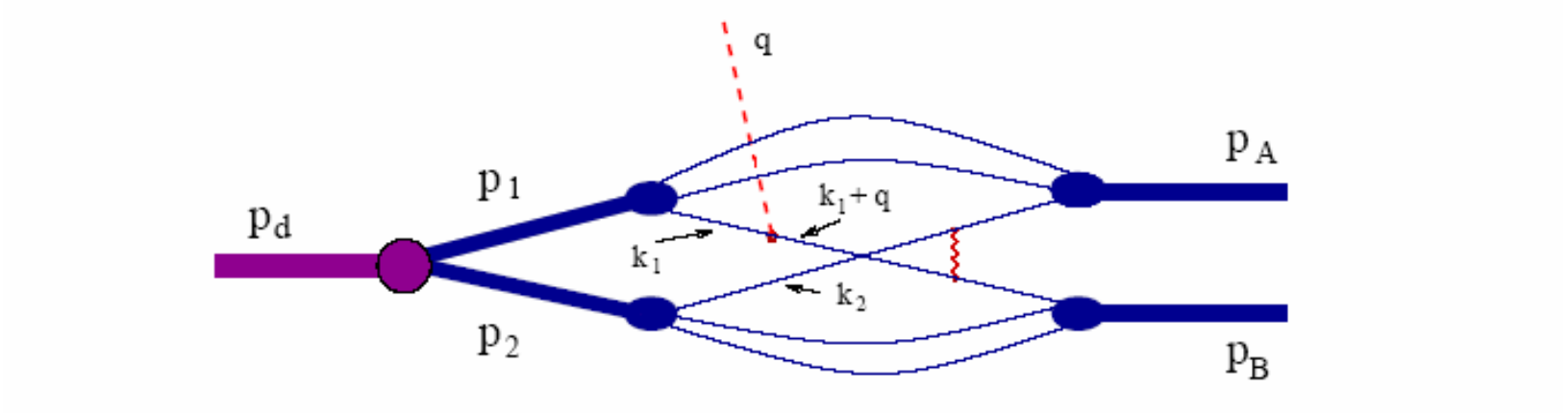
σ(L) constrain nuclear mesons? GLUONS

Nuclear glue and J/Ψ

- **Production mechanism depends on glue**
- **Interactions depend on size of system**
- **6 GeV is good, 12 GeV is better**

2 nucleon quark effects

γ d $\longrightarrow$ np

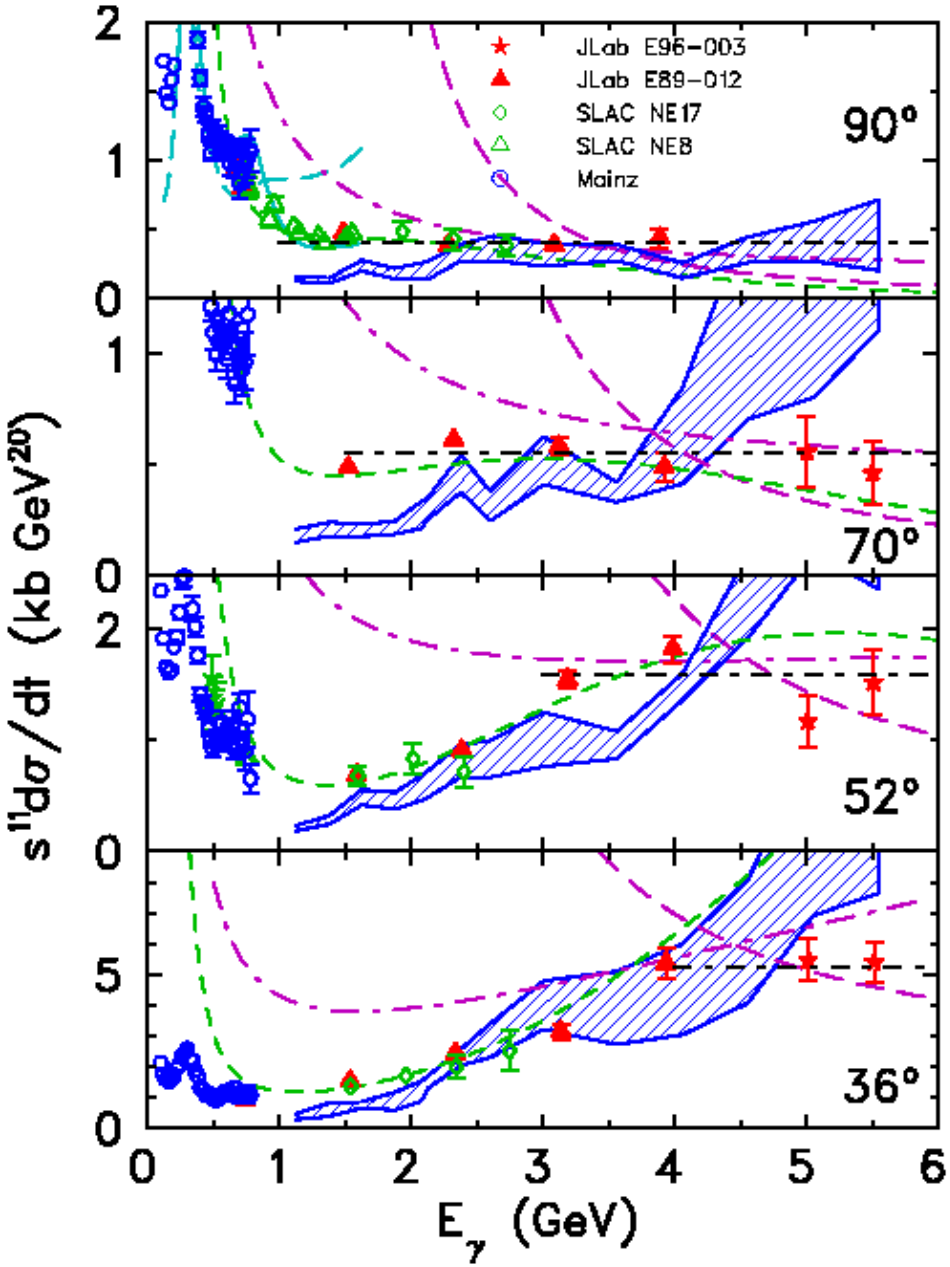


Sargsian et al

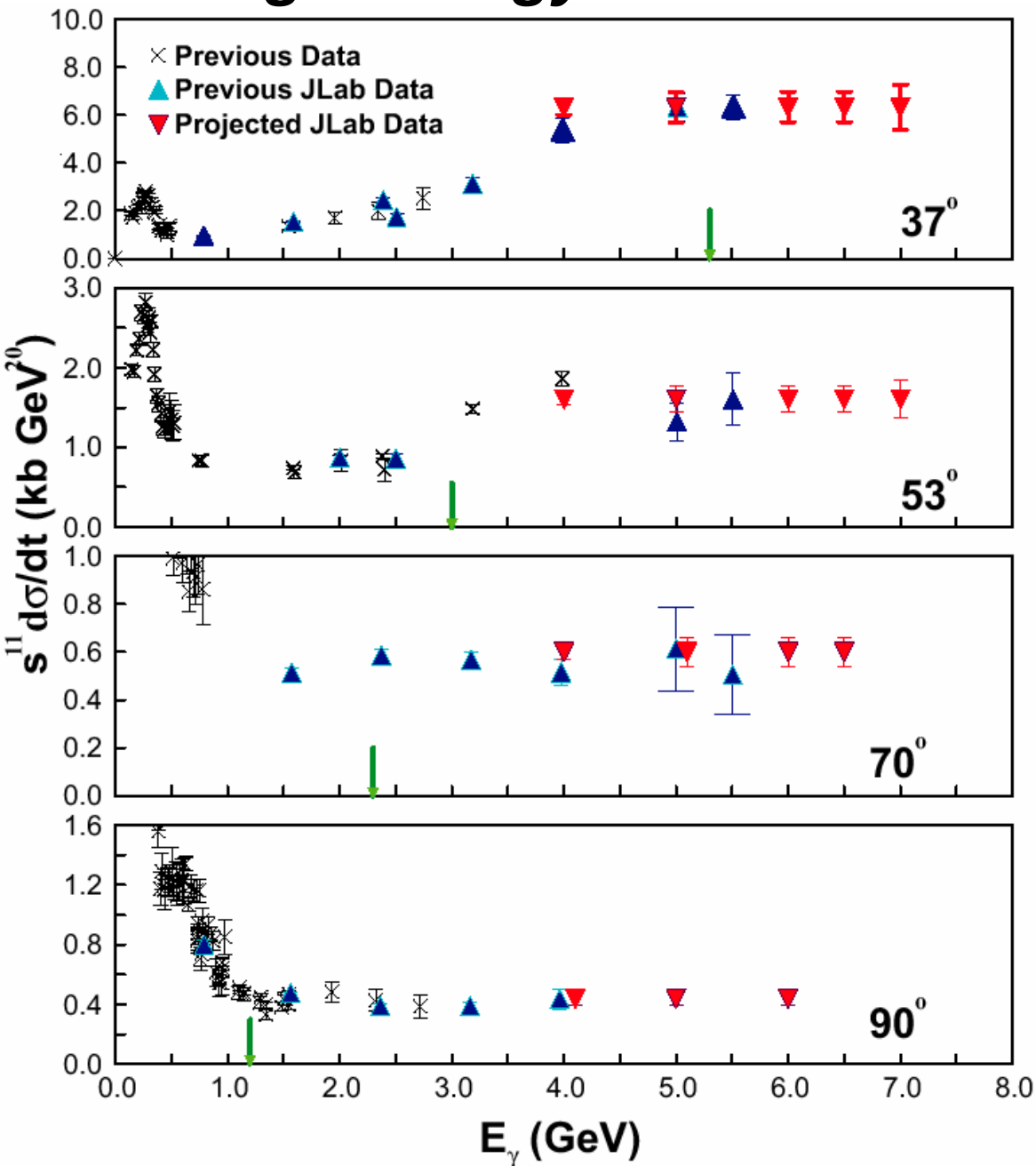
Phys.Rev.Lett.84:3045-3048,2000

$\gamma\, d \longrightarrow np$

- Highest energy data from JLab E96-003, Schulte *et al.*, PRL 87, 102302 (2001).
- The onset of "pQCD-like" scaling at all angles corresponds to PT ~ 1.3 GeV.
- Why the precocious scaling? An indication of "quark effects", even if not pQCD?



High Energy Deuteron Photodisintegration



Meaning?

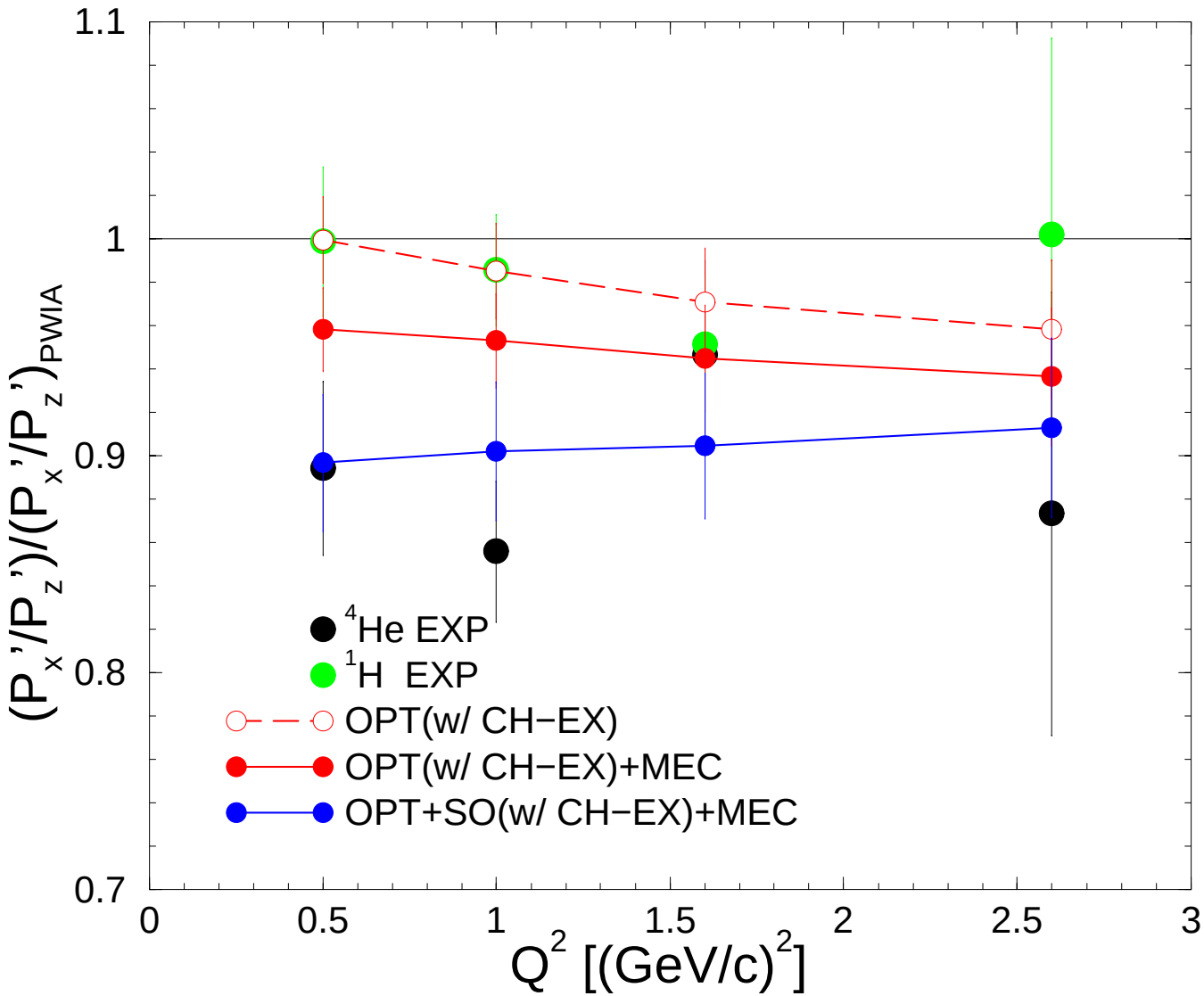
Implications?

Summary

- QCD view of nucleon informs, influences QCD view of nucleus
- Nuclear modifications of single nucleon wave function could be observed in several experiments
- Color transparency of nucleons : color SU(3)
- nuclear glue: σ(L), J/Ψ
- quark effects dominate $\gamma d \longrightarrow$ np

SPARES FOLLOW

Polarization transfer in ^{4}He(e,e'p)



R. Schiavilla

Compelling Questions

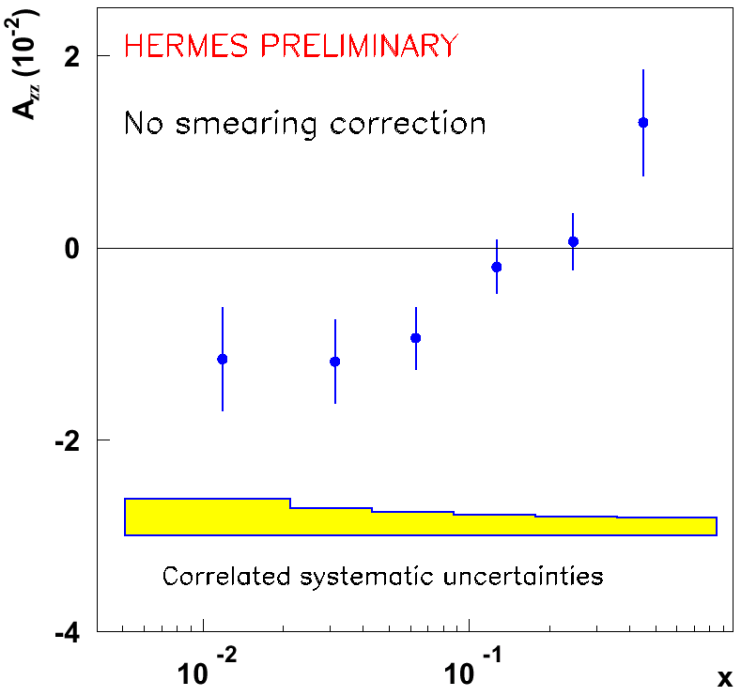
- How does the nuclear force emerge from quark and gluon physics
- Are hadronic properties, fragmentation, energy loss, … modified by the nuclear medium?
- How does the transition from hadronic physics to quark and gluon degrees of freedom occur?
- …

Coherent Themes

- Parton properties in nuclei
  - EMC effect - light nuclei, tagged EMC
  - meson or gluon excess-longitudinal structure function
  - Anti-shadowing and shadowing – DIS from aligned D target, A
  - Sivers' effect- single spin asymmetries
  - Formation times- fragmentation, parton energy loss, p_T broadening
- Hadron properties in nuclei
  - Nucleon form factors- polarization transfer, coulomb sum
  - Form factors of light nuclei- deuteron, triton, helium
  - Resonances in nuclei – R in the resonance region
  - Meson properties in nuclei- masses, widths of light quark and charm mesons
- Transition to quark-gluon d.o.f.
  - Scaling and hadron helicity conservation- Exclusive reactions for light systems – elastic form factors, photodisintegration
  - Hidden color – large angle Delta's from deuteron photodisintegration
  - Color transparency, nuclear filtering, formation times, fragmentation
  - Short range correlations - x>1, back angle tagging

Shadowing in the Deuteron

Deep inelastic scattering from aligned deuterons

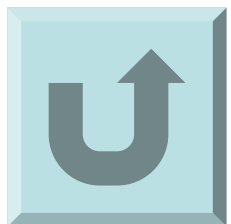


$$M_S = \pm 1$$

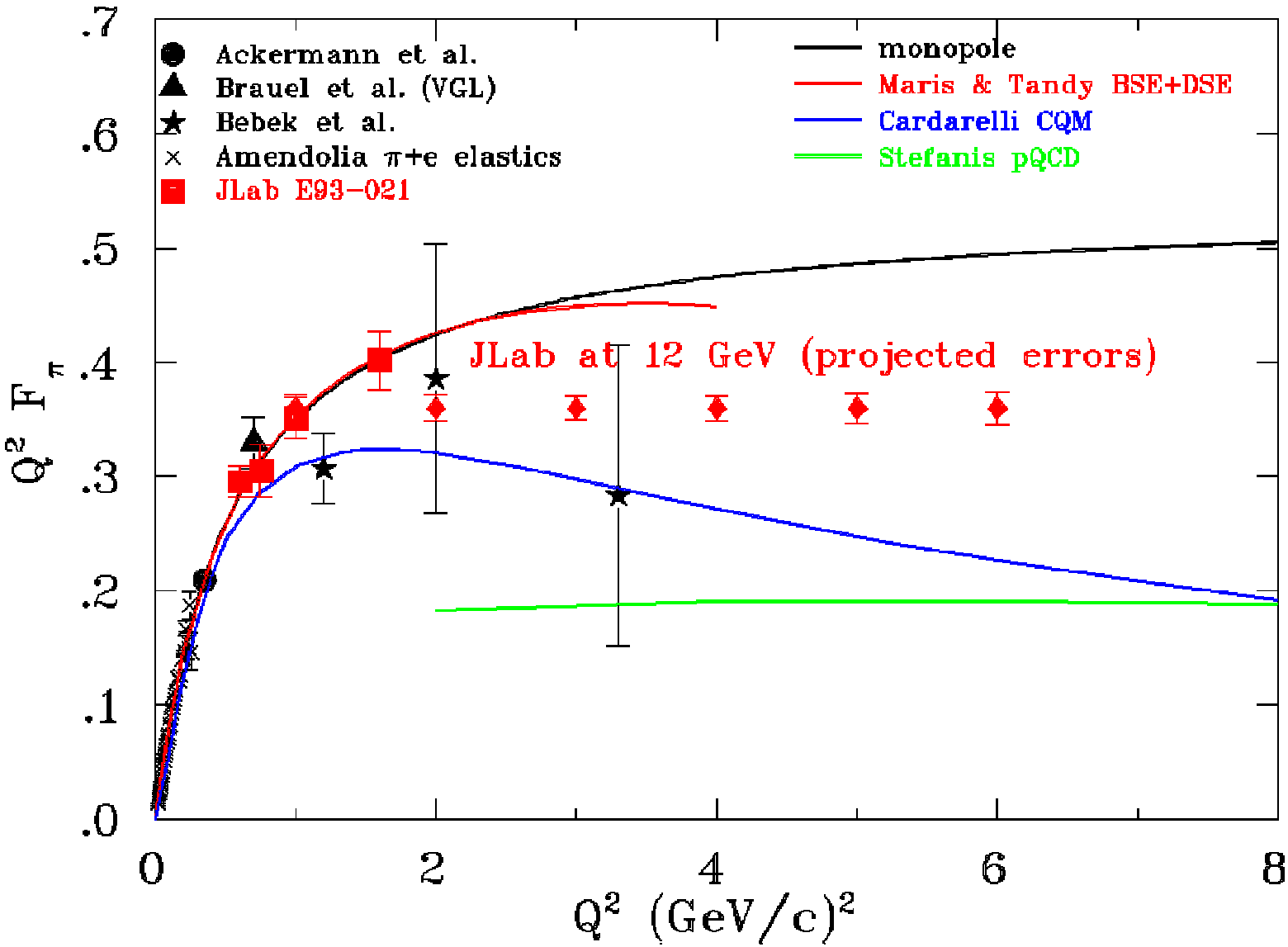
$$M_S = 0$$

$$A_{zz} = \frac{(\sigma^{+} + \sigma^{-}) - 2\sigma^{\circ}}{3\sigma}$$

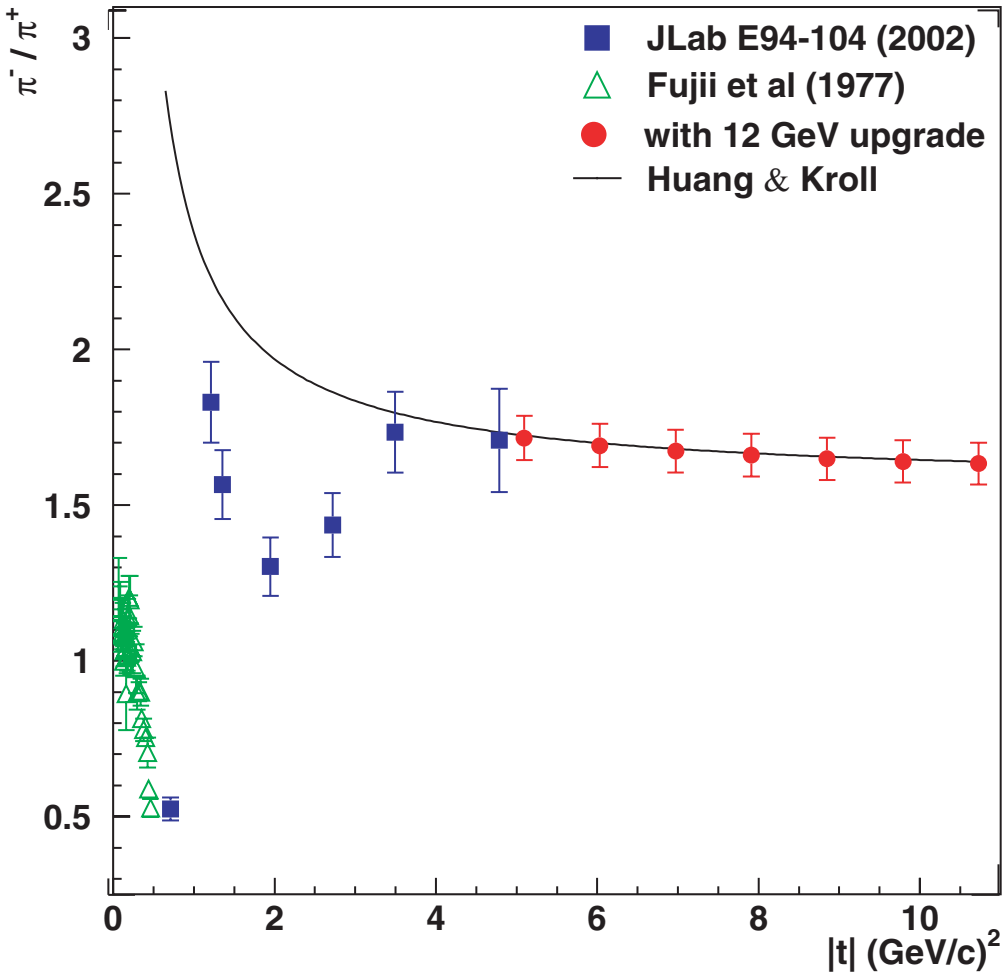
"Textbook" example of shadowing



Projected Measurements of the Pion Form Factor



π/π^+ Ratio for the $\gamma N \rightarrow \pi N$ Reaction



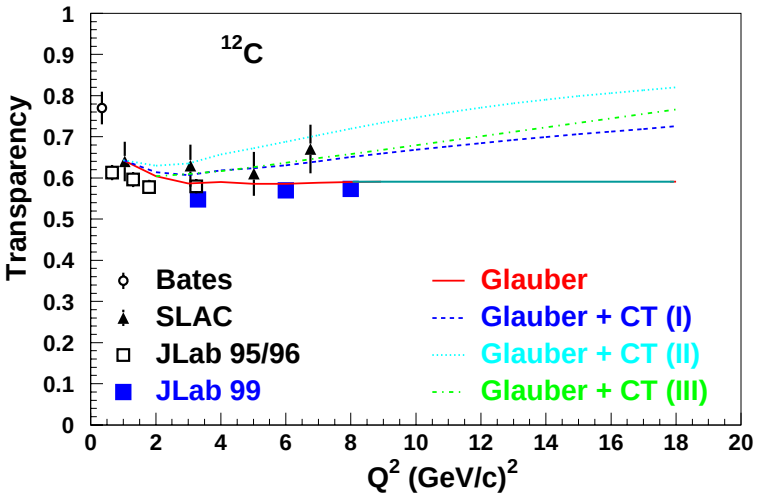
$$\frac{d\sigma(\gamma n \rightarrow \pi^- p)}{d\sigma(\gamma p \rightarrow \pi^+ n)} \approx \left(\frac{ue_d + se_u}{ue_u + se_d}\right)^2$$

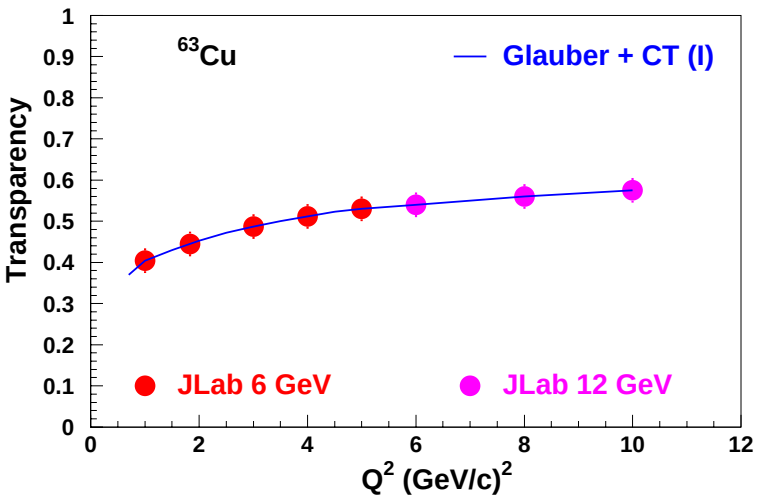
A Complementary Approach:

"Soft" Corrections partially cancel in π^-/π^+ Ratio.

E94-104 H. Gao, R. Holt
L. Zhu *et al*, PRL **91** (2003)

Color Transparency





Hall C (e,e'p) experiments at 4 and 5.5 GeV show no evidence for color transparency

JLab E91-013 D. Geesaman

JLab E94-139 R. Ent, R. Milner

K. Garrow, *et al*, PRC 66 (2002)

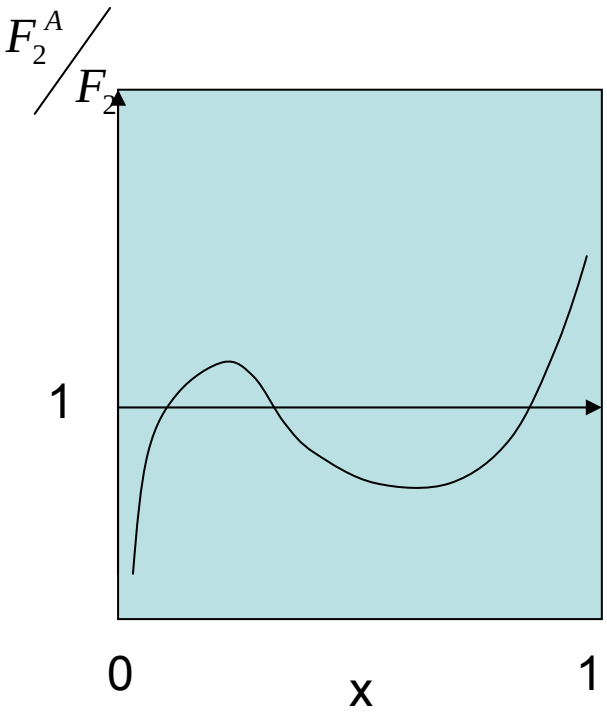
$$Transparency = \frac{\sigma_A(Q^2)}{Z\sigma_p(Q^2)}$$

Measurements in progress using the (e,e'ρ) reaction, which is expected to show color transparency at lower Q^2

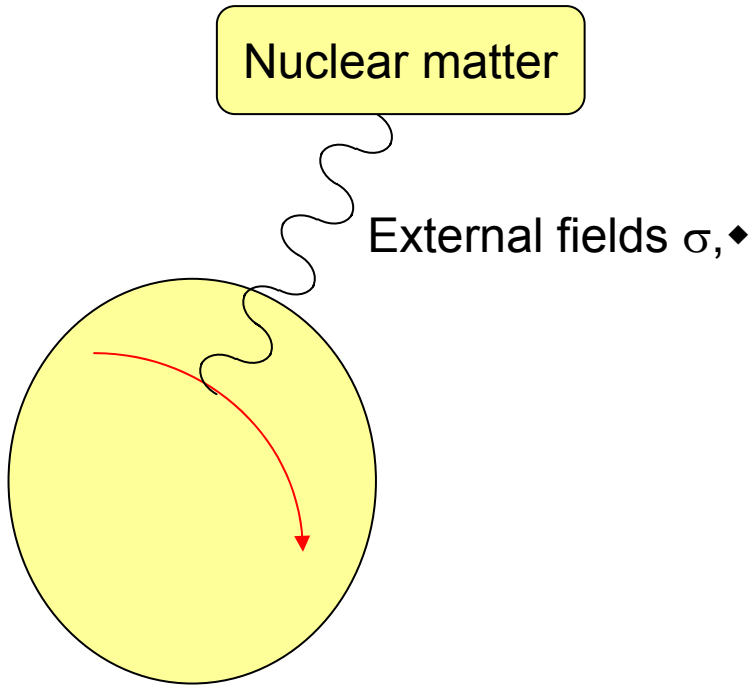
Hints from FNAL E665, E791, HERMES, and JLab E94-104.

JLab E02-110 K. Hafidi, M. Holtrap, B. Mustapha

EMC effect



A bag in matter



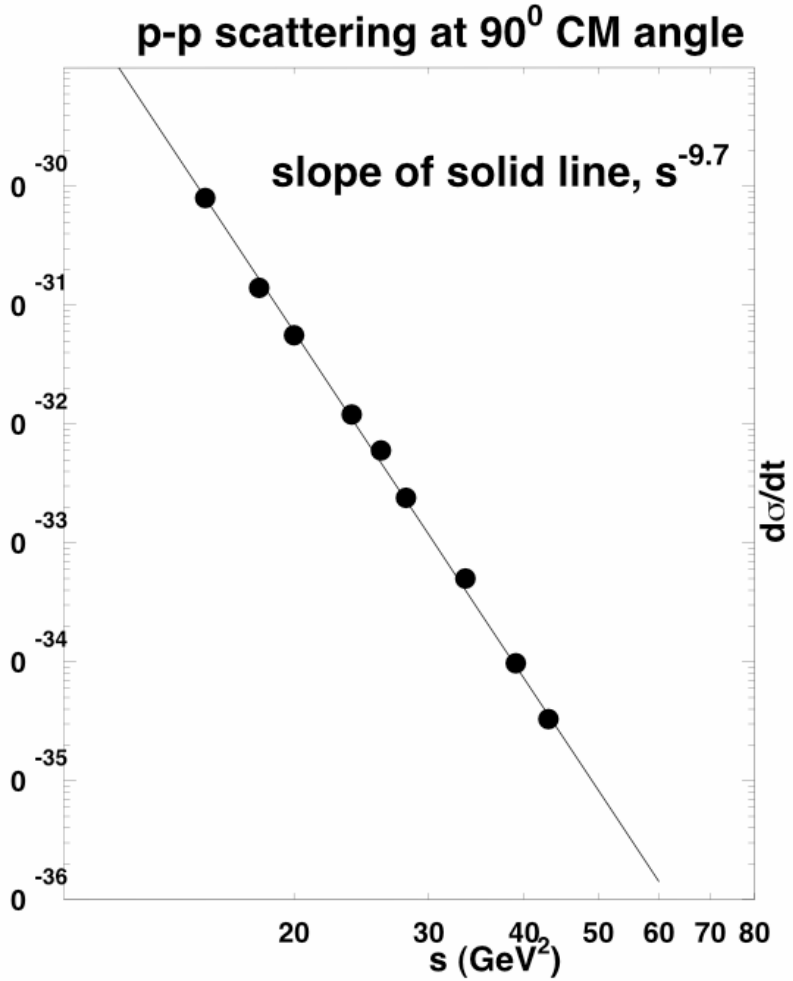
Effect of the coupling to the (constant) external fields

$$\sigma: \quad m_q \to m_q - g_\sigma^q \sigma \quad (attraction)$$

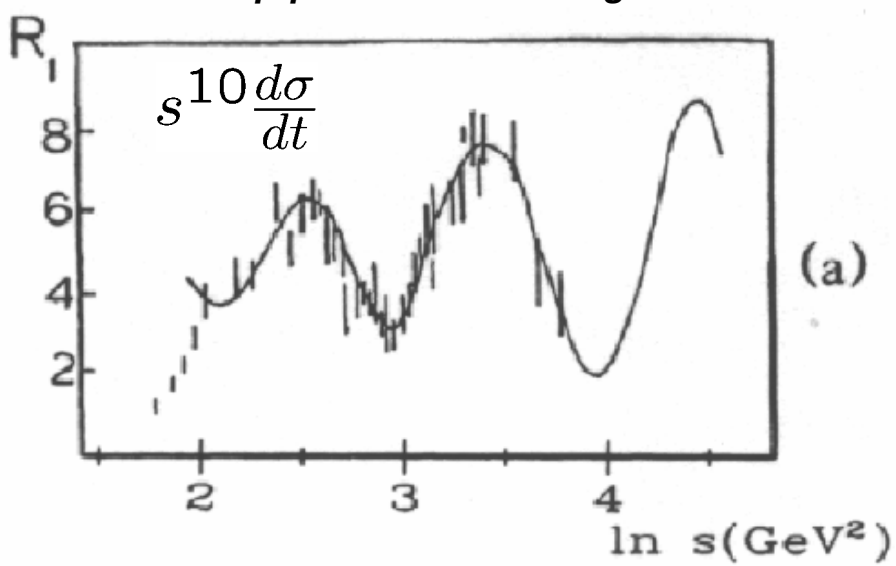
$$\omega: \quad E_q \to E_q + g_\omega^q \omega \quad (repulsion)$$

(NB: here ♦ is a chiral invariant)

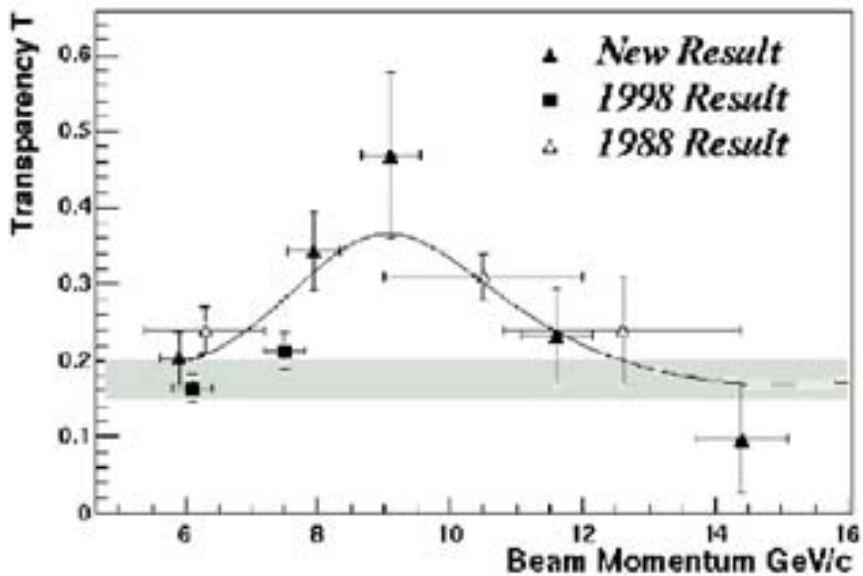
QCD Oscillations and Nuclear Filtering



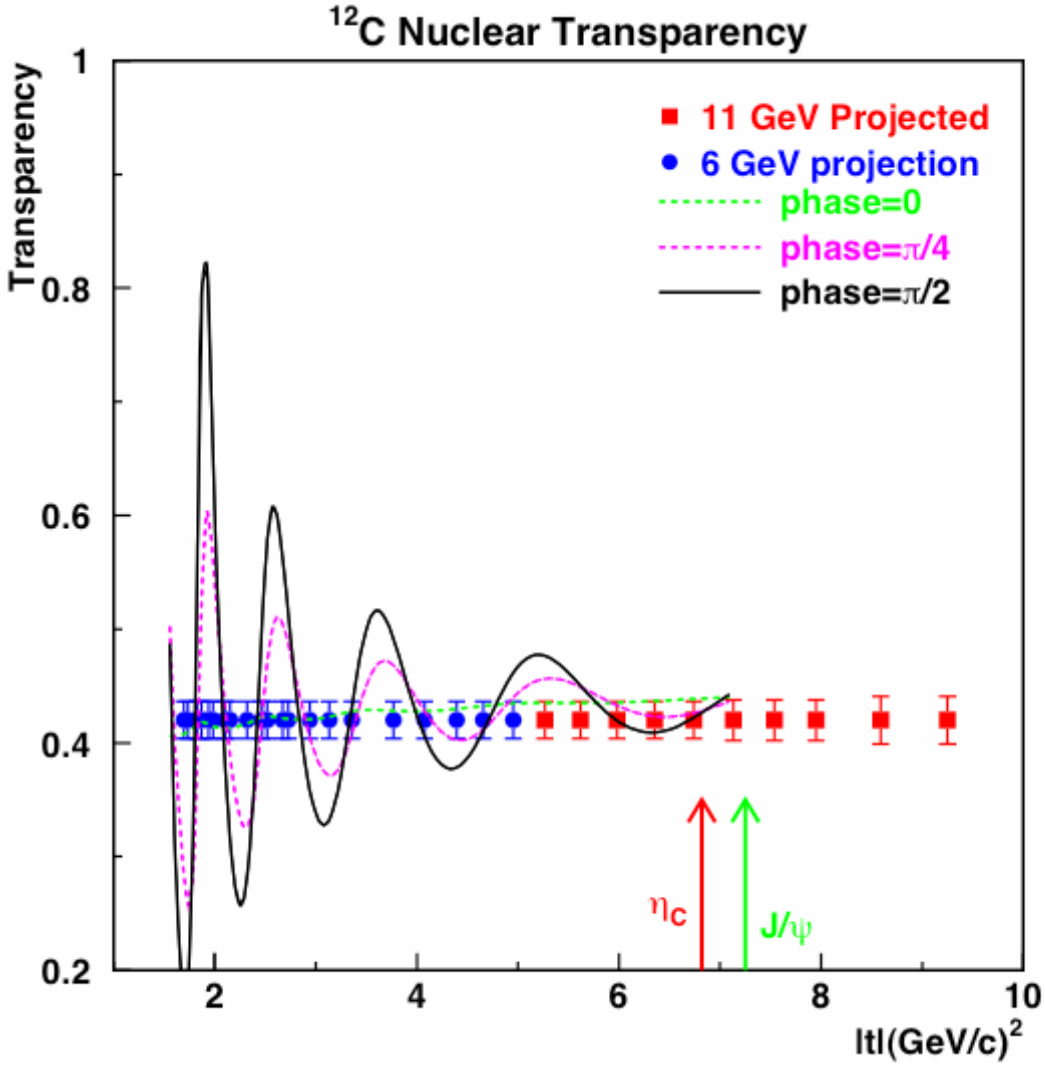
p-p elastic scattering



BNL A(p,2p)



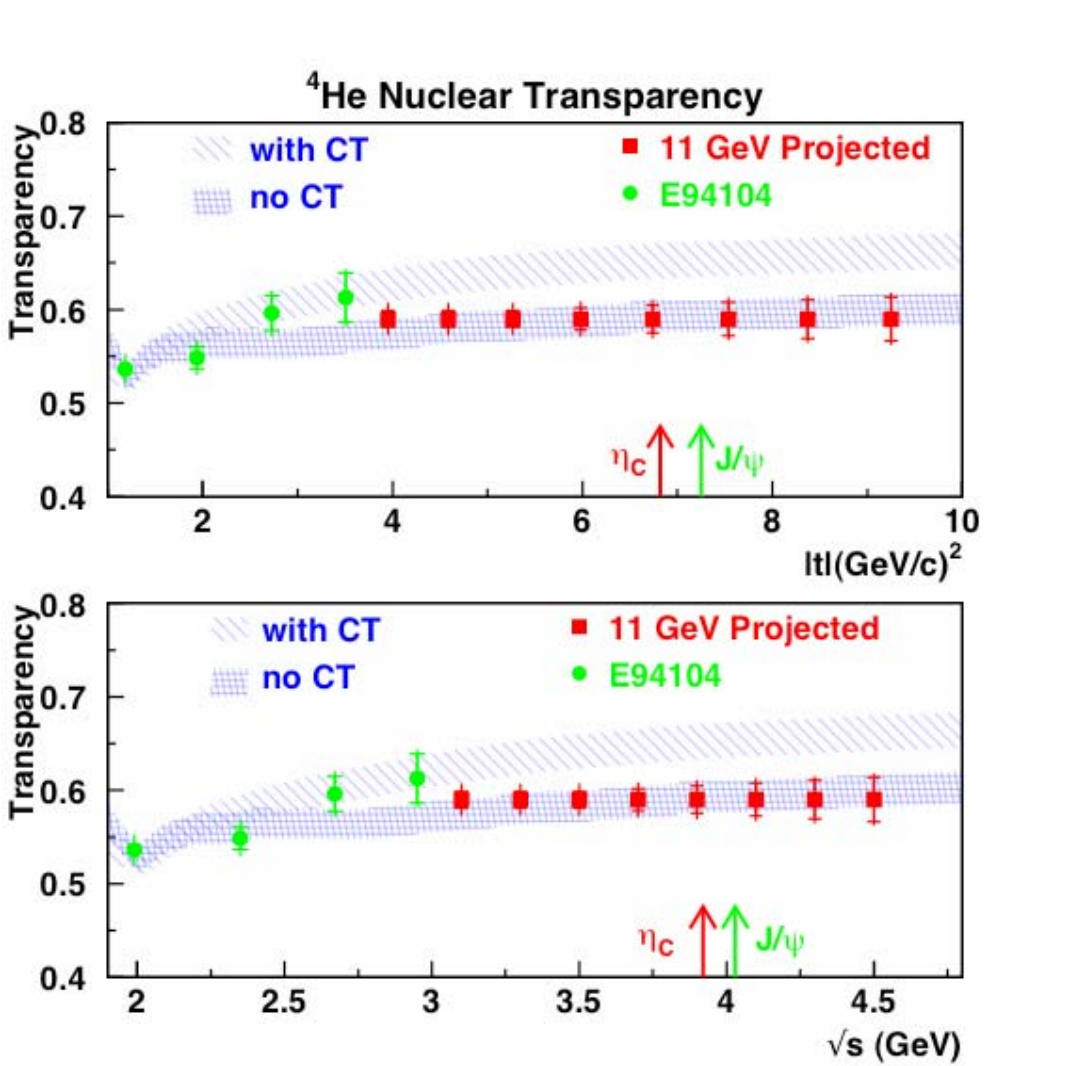
Photopion production from ^{12}C



H. Gao, D. Dutta

Up to sqrt(s) of 3.9 GeV

Photopion production from ^{4}He



Dutta *et al.* PRC68, 021001R (2003)