EMC Effect and Related Issues

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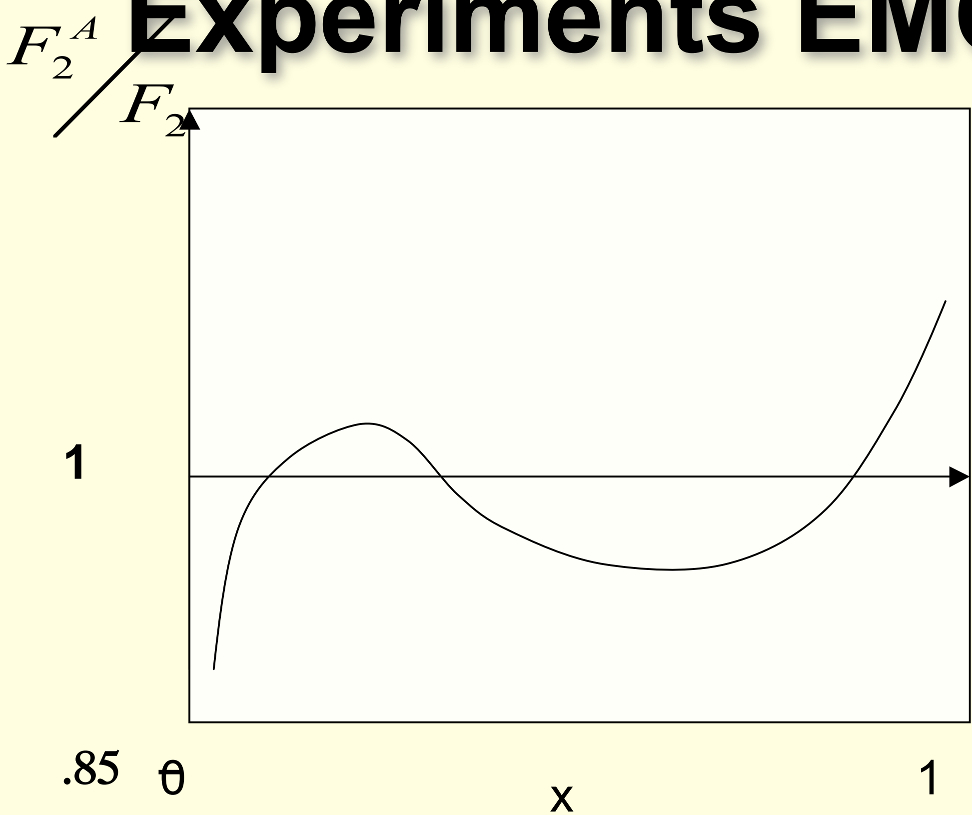
Outline

EMC effect & Drell Yan DY
Hadron dynamics fails EMC/DY
Nucleon is modified
Models and consequences
Structure and shape of the nucleon

Deep Inelastic Scattering Experiments EMC,SLAC,NMC



$$\frac{F_2^A(x)}{AF_2^N(x)} = 1 + g_{F_2}(x)\mathcal{G}(A)$$

Nucleon structure is modified: valence quark momentum depleted, sea or gluon enhanced. **How do quarks work in a nucleus?**

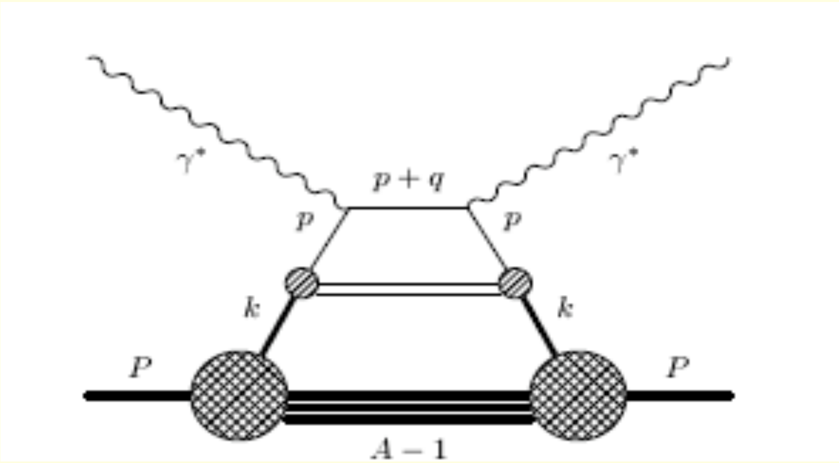
BUT EFFECTS ARE SMALL ~10%

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

One thing I learned since ‘85

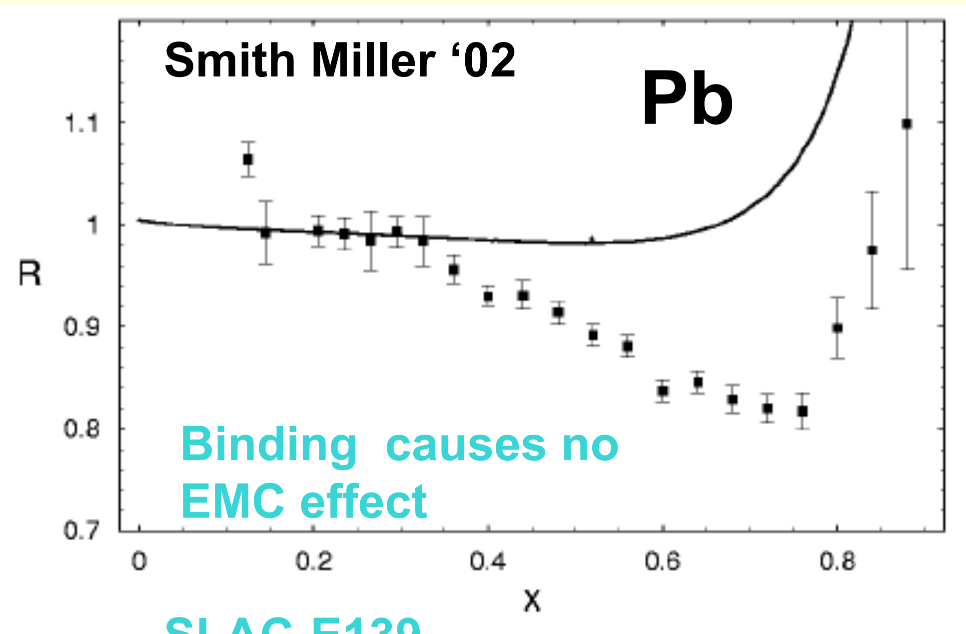
- One model is not cool

Deep Inelastic scattering from nuclei- nucleons only free structure function



$$\frac{F_{2A}(x_A)}{A} = \int_{x_A}^{A} dy f_N(y) F_{2N}(x_A/y)$$

$y=A\,k^+/P^+$



SLAC-E139

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

$p^+=M_N$-8 MeV, y → 1

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

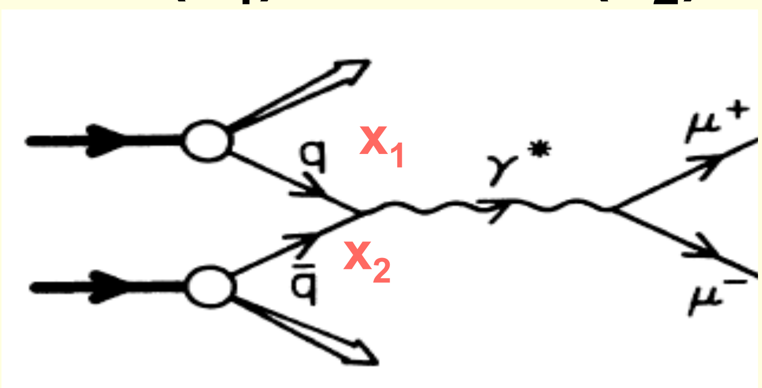
Nucleons and pions

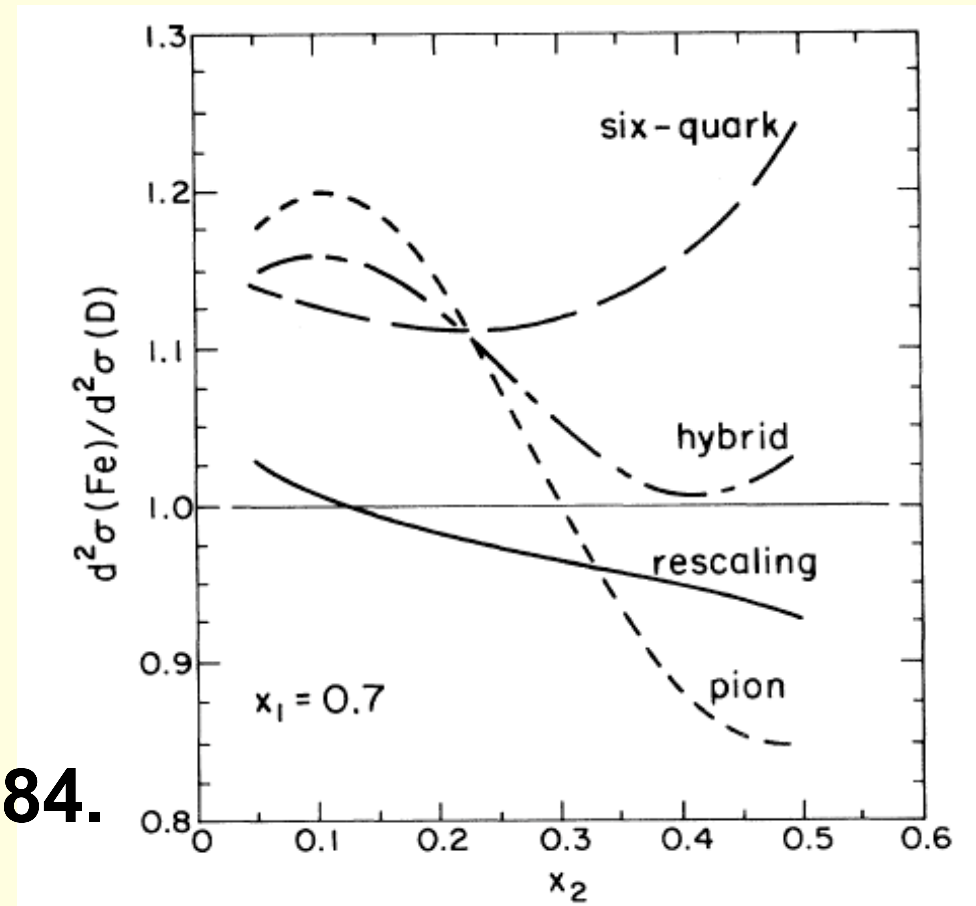
$P_A^+ = P_N^+ + P_\pi^+ = M_A$

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

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

proton(x_1) nucleus(x_2)





Phys.Rev.D33:3228,1986

Phys.Rev.Lett.53:2532,1984.

Nucleons and pions

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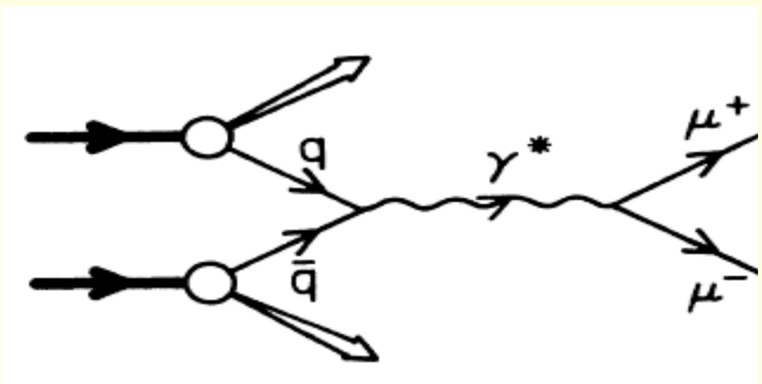
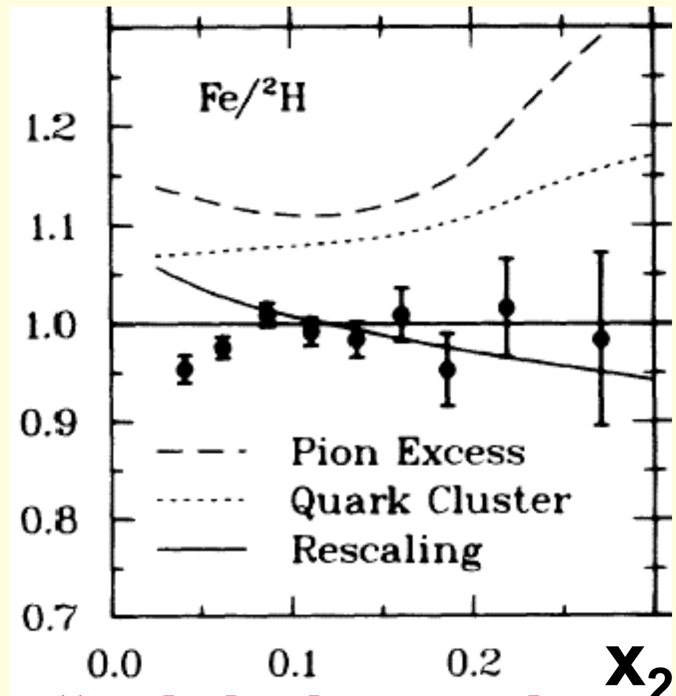
Drell-Yan, E772



No one's model is cool



π fails

Bertsch, Frankfurt, Strikman "crisis in nuclear theory" conventional physics does not work

Single nucleon modification by nuclei

- Does it make sense?
- Neutron in nucleus is modified, lifetime changed from 15 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

Medium Modification Models

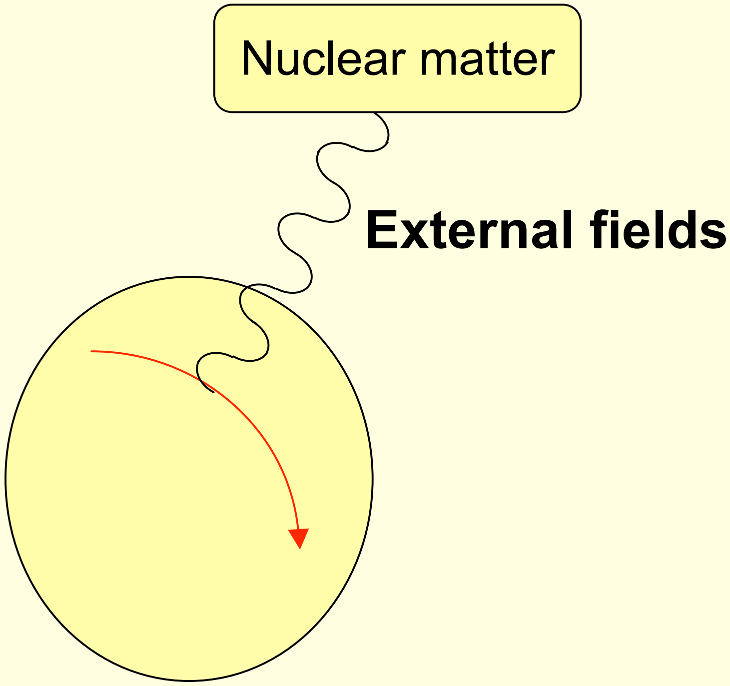
- **Chiral restoraton: m_q! m_q-g σ**
- **QCD Stark color neutrality U» $\sum_q r_q^2$**
- **Modified energy denominator**
- **Modified confinement**

- Medium Modifications-/ (p^2-m^2)¼ 2mV=U
  Cioffi, Kaptari, FS 0706.2937
- **Changes depend strongly on nucleon momentum, limits weaker**
- **Virtuality enters in all model considered here**

Requirements -Goals

- **Model the free distributions**
- **Good support**
- **Consistency with nuclear properties**
- **Describe deep inelastic and di-muon production data- valence plus sea**
- **Predict new phenomena**

Nucleon in medium- 3 models



1. **QMC- quarks in nucleons (MIT bag) exchange mesons with nuclear medium, quark mass**
2. **CQSM- quarks in nucleons (soliton) exchange infinite pairs of pions, vector mesons with nuclear medium, m_q**
3. **Suppression of point-like-configurations , polarization**

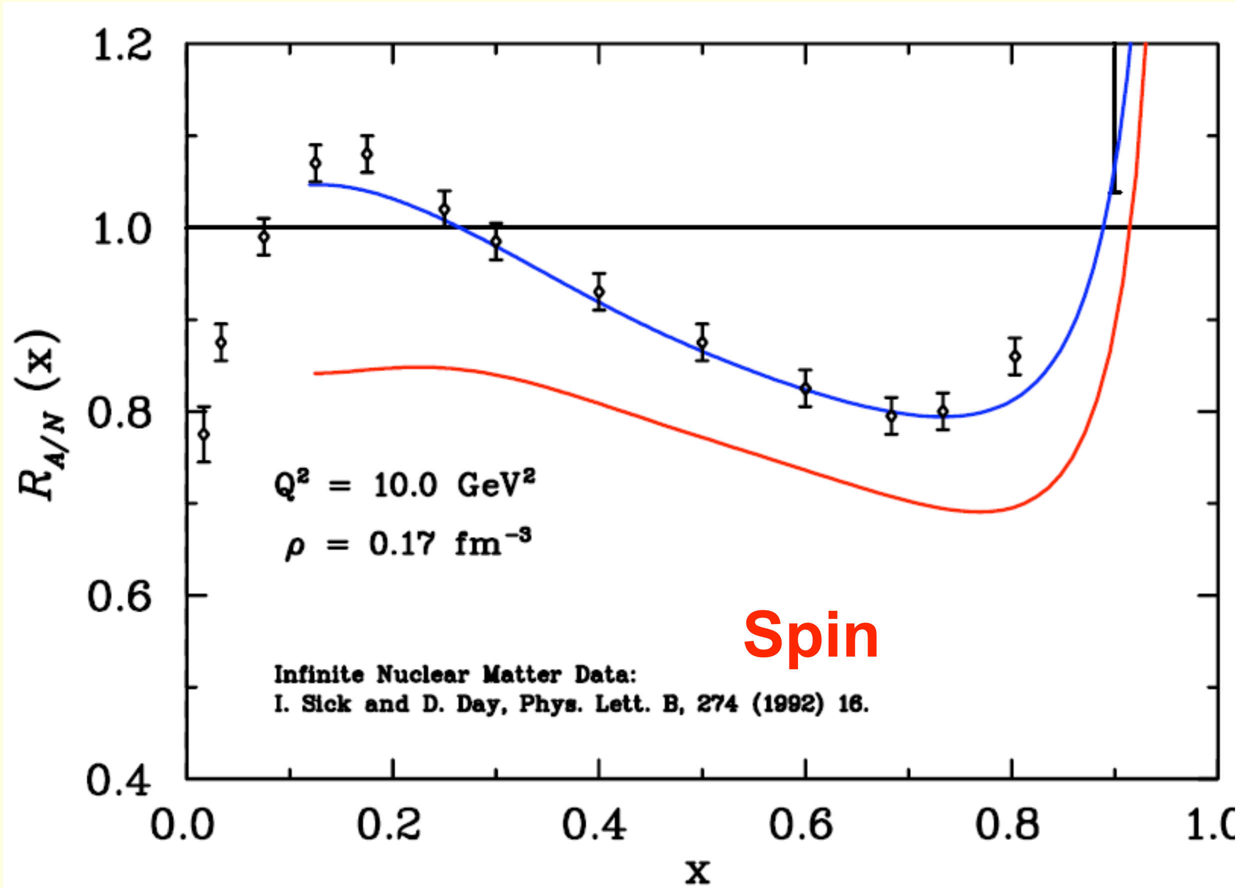
Spin experiments examine LoC

- g_{1n} , g_{1p} in nuclei — Bentz, Cloet, Thomas

- other way to enhance EMC?

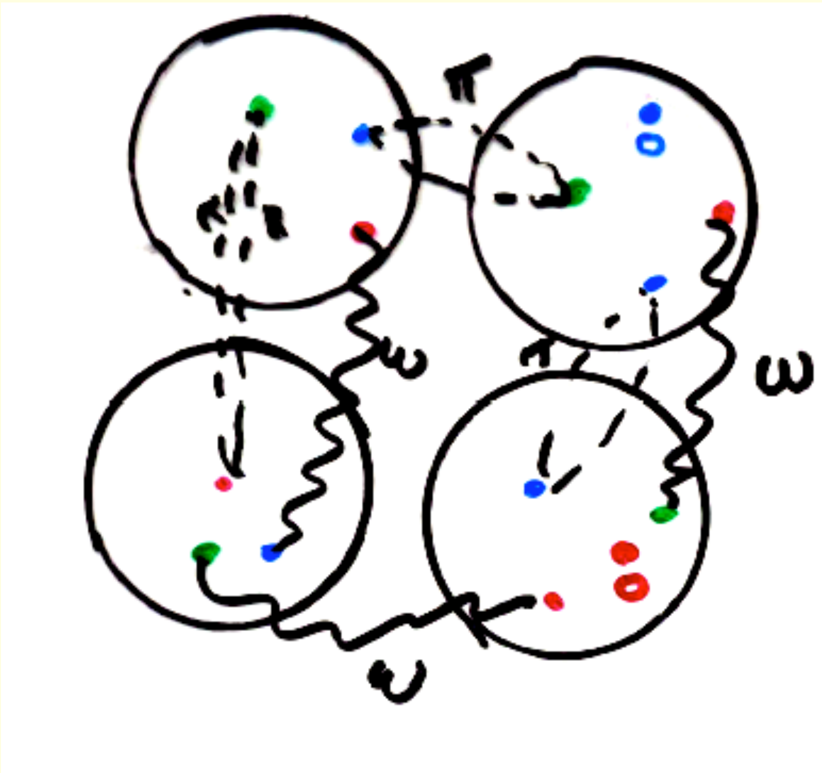
ratio of g_1 medium to free

QMC type



Chiral Quark Soliton Model of Nucleus-

Smith, Miller



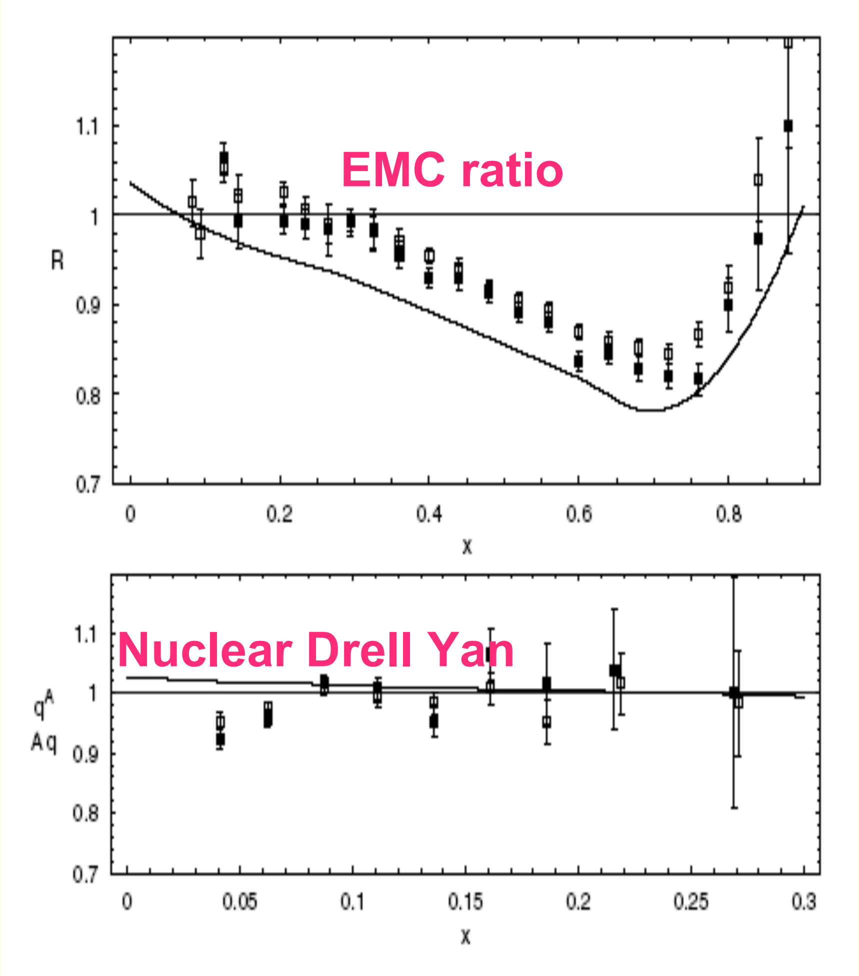
2 π exchange – attraction

ω (vector meson) exchange - repulsion

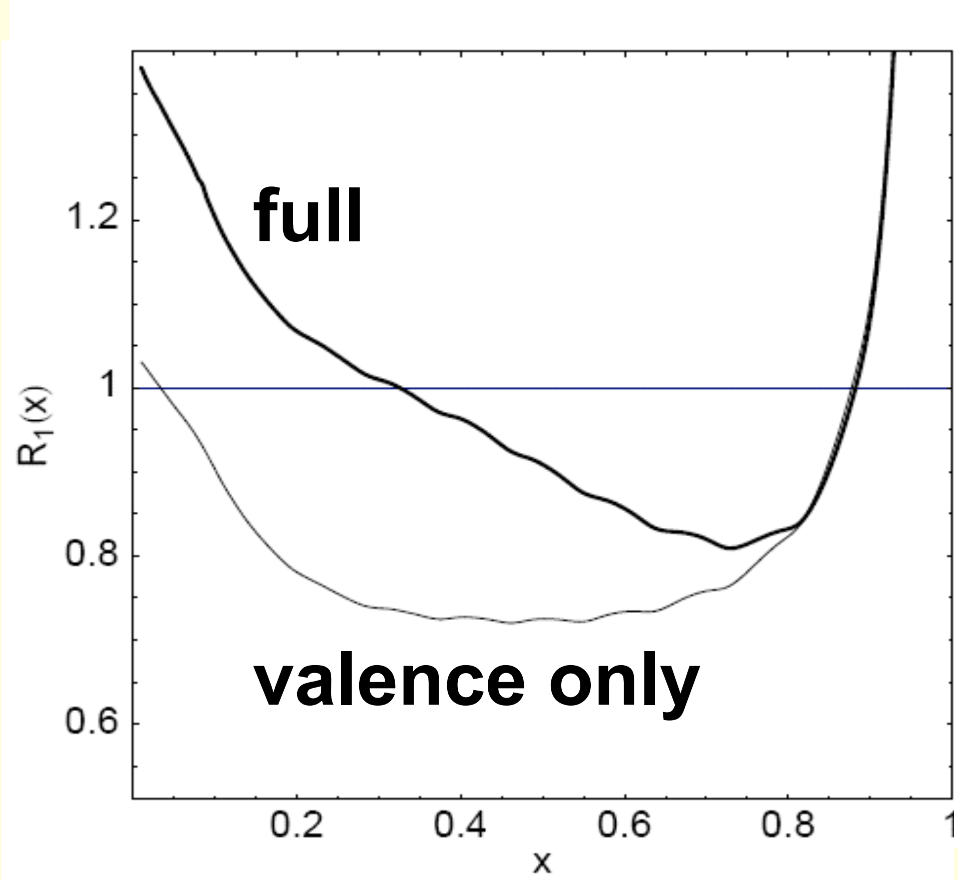
Double self consistency

profile function and k_f

Results Smith & Miller '03,04,05

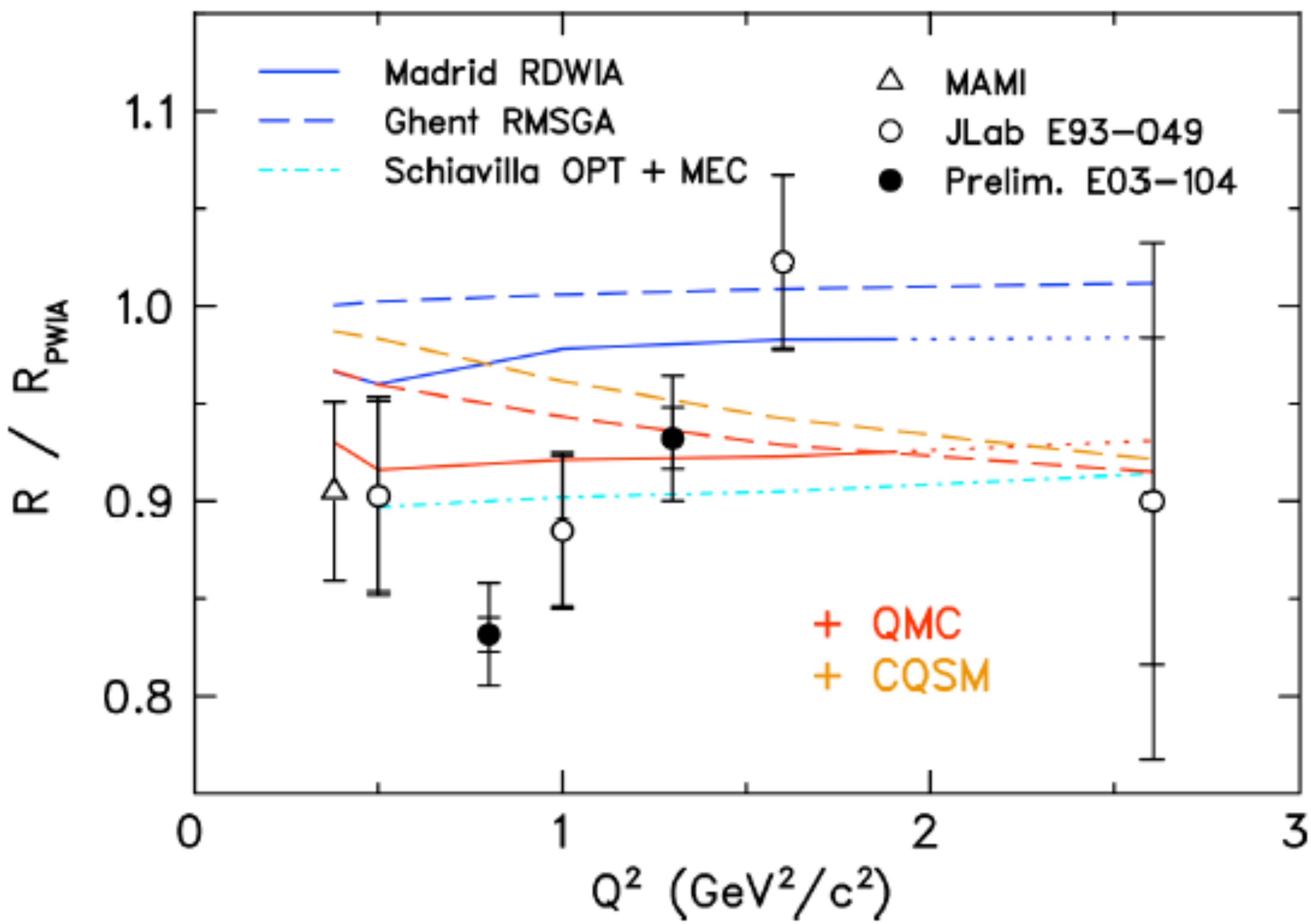


g_1 ratio



sea is not much modified

Polarization Transfer in $^4He(\vec{e},e'\vec{p})$



Strauch

June '07

Inner uncertaint
are statistical o
full analysis of
E03-104 will ha
reduced system
uncertainties

- Previous data effectively described by proton medium modified form fac
- Alternative explanation given by spin-dependent charge exchange FSI
- Neither accounts for preliminary $Q^2 = 0.8$ GeV^2 data

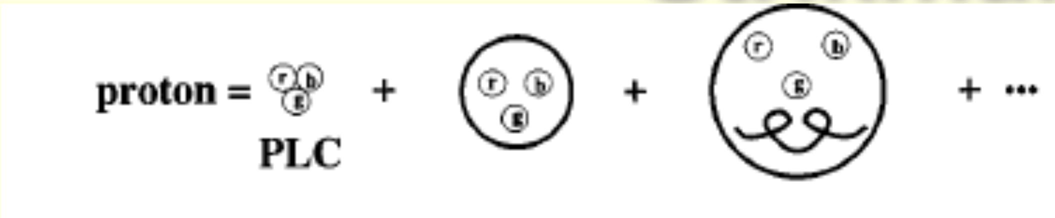
Summary

- nucleon structure is modified by nucleus
- minimum model requirements- EMC, DY, nuclear saturation
- predict new phenomena
- needed –better evaluations of models
- experimental tests –form factors

  in medium, (eA ◊e’ X N) spectator tag, nuclear gluon distribution, σ_L
- new experiments Jlab and others to find out how quarks work in a nucleus

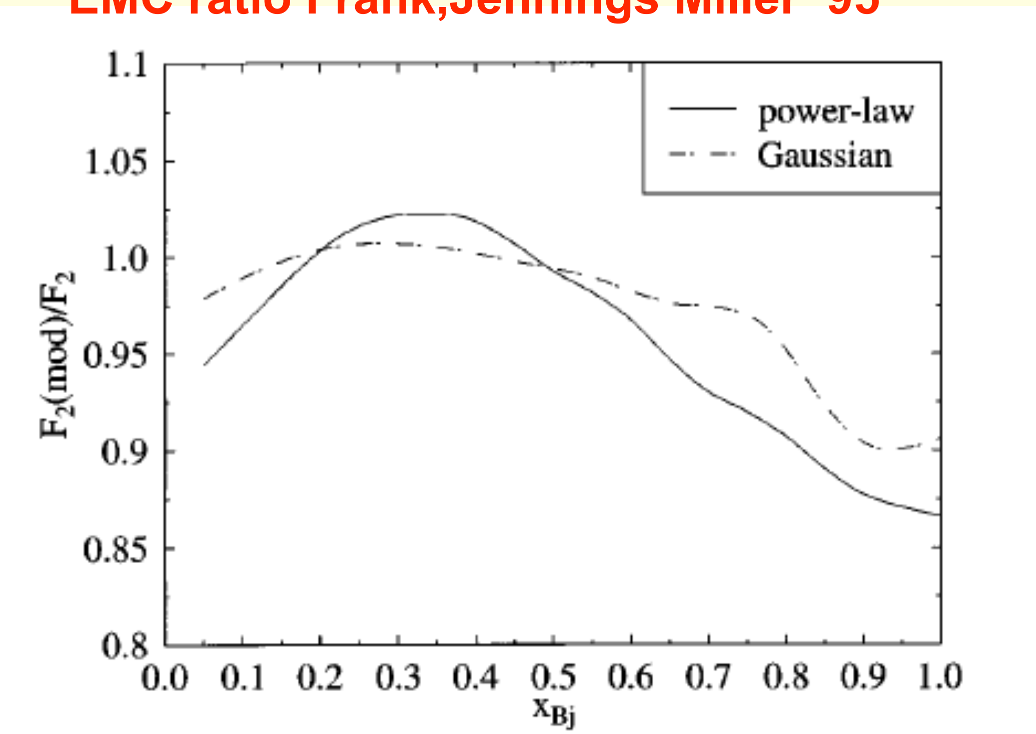
SPARES FOLLOW

Suppression of Point Like Configurations- Frankfurt, Strikman



energy denominator increased

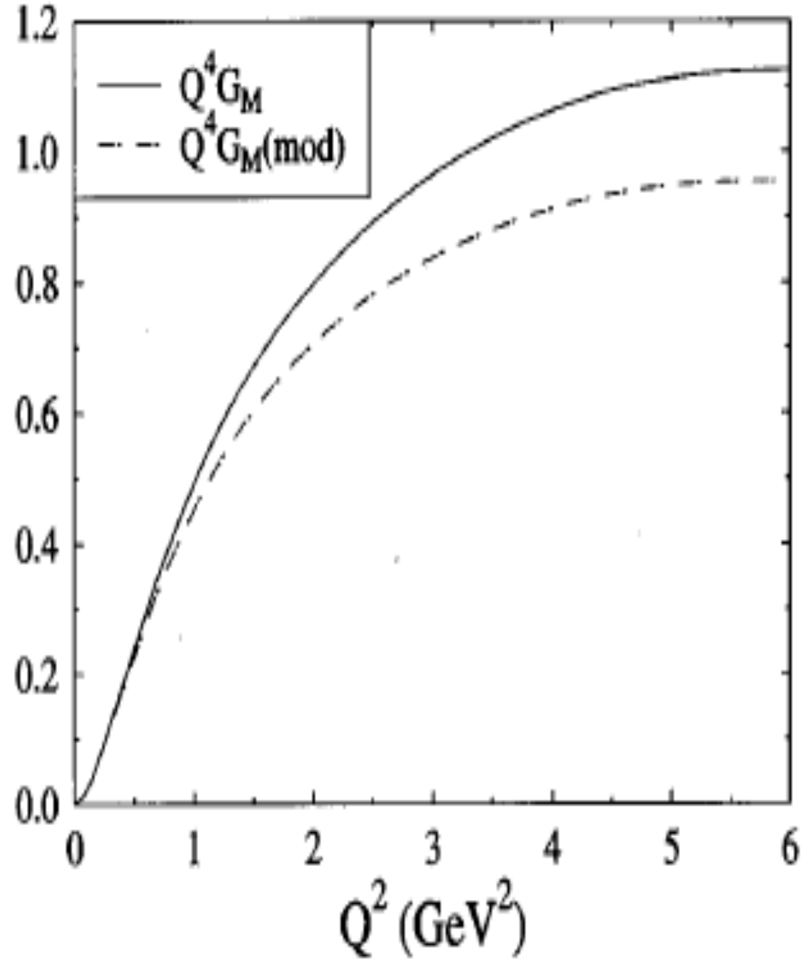
EMC ratio Frank,Jennings Miller '95

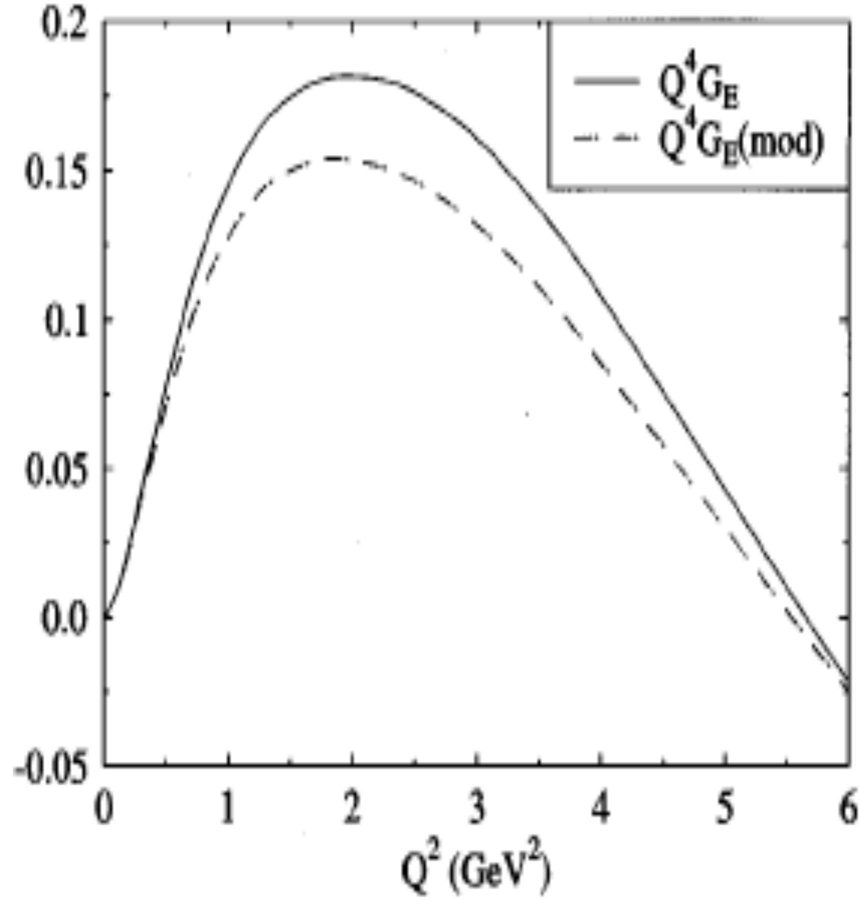


PLC has NO int. with medium

evaluated as QCD Stark, not modified energy denominator

1995 Frank, Jennings, Miller





Spin-dependent density

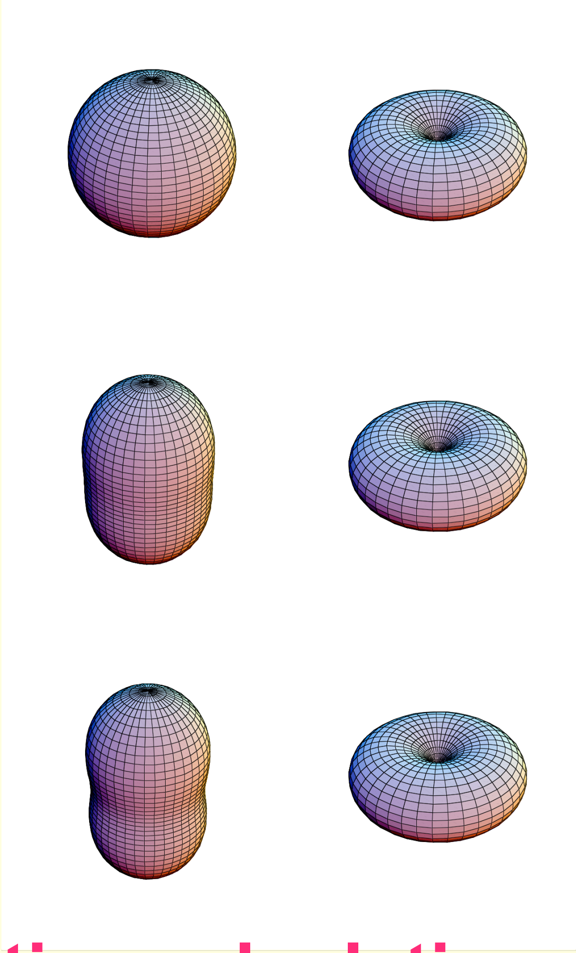
- **Spin dependent densities**
  probability that quark has given momentum K and spin in direction n

$$\hat{\rho}(\mathbf{K},\mathbf{n}) = \int \frac{d^3r}{(2\pi)^3} e^{i\mathbf{K}\cdot\mathbf{r}} \bar{\psi}(\mathbf{r}) \frac{\widehat{Q}}{e} (\gamma^0 + \boldsymbol{\gamma}\cdot\mathbf{n}\gamma_5)\psi(\mathbf{0})$$

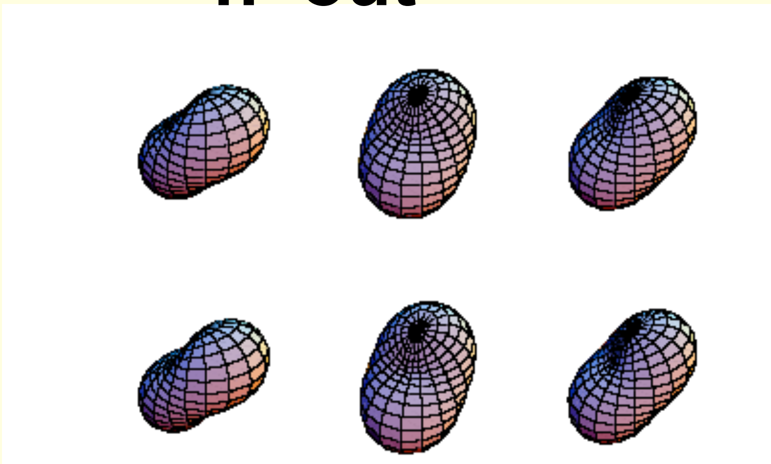
Shapes of the proton

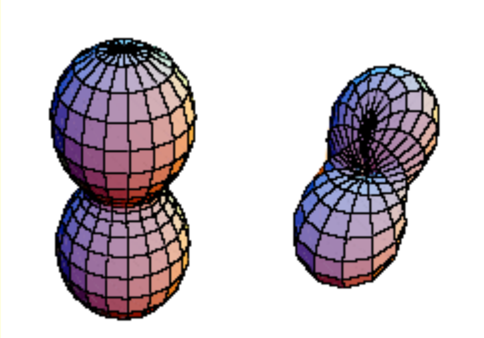
n parallel

-n parallel



n out

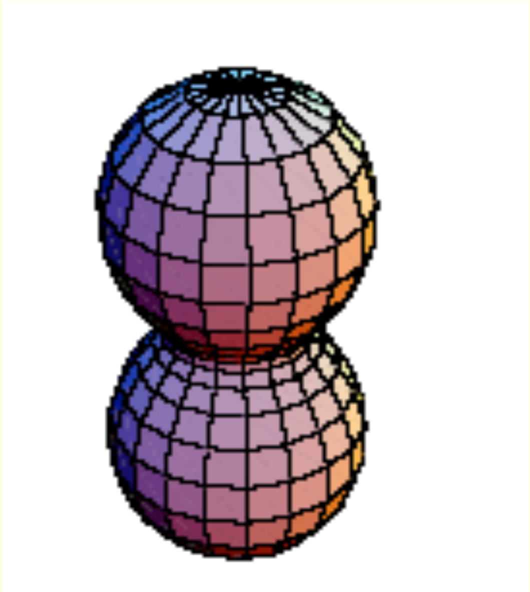




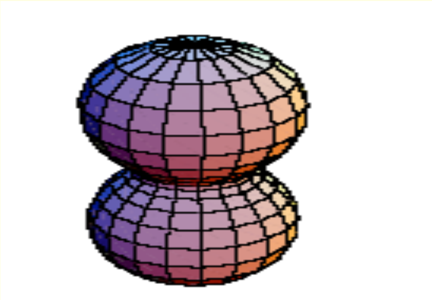
lattice calculations plus can be measured in semi-inclusive DIS arXiv:0708.2297 [nucl-th]

Closer look needed! Lower components LoC

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

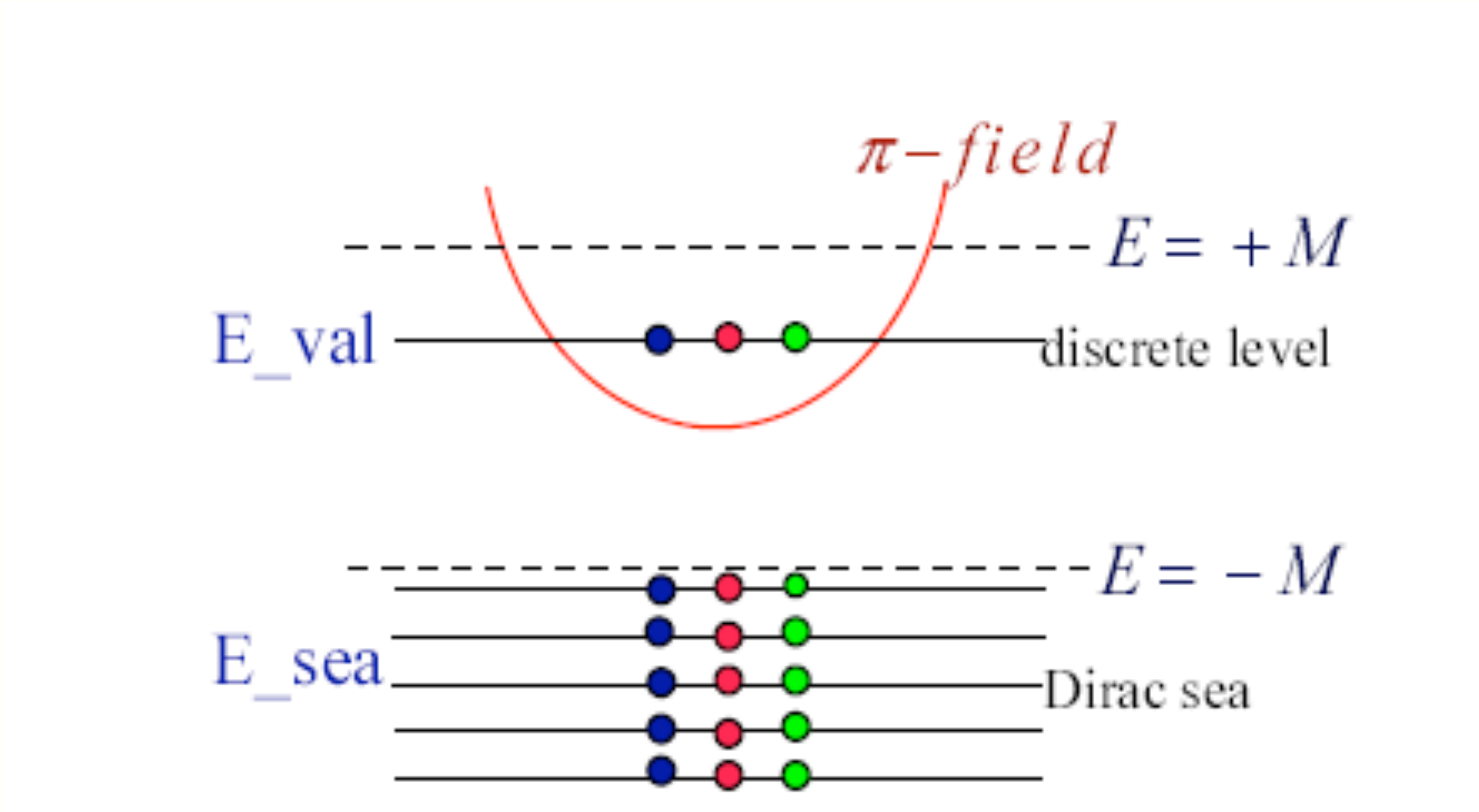


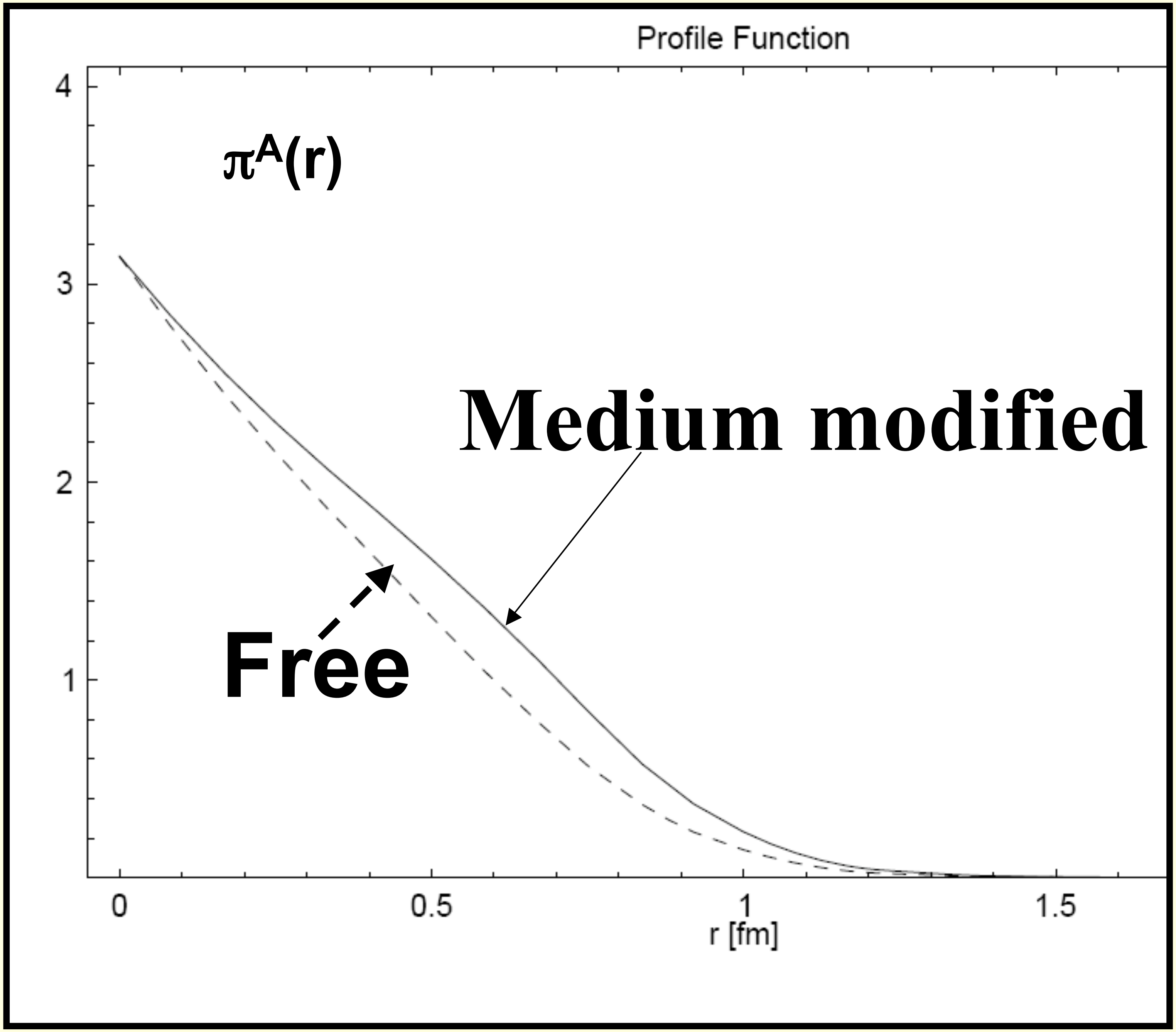
- Medium modifies LoC
- Medium modifies shape



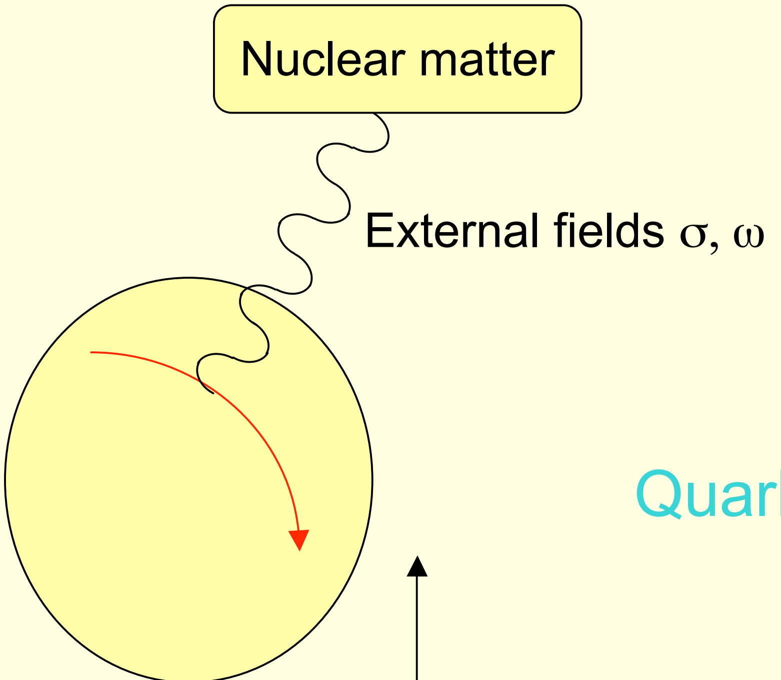
Challenge to experiment- measure either

Quark energy levels in π field




Profile Function
4
3
2
1
0
0.5
1
1.5
r [fm]
$\pi^A(r)$
Medium modified
Free

Quark Meson Coupling Model –Guichon,Thomas,Saito plus more

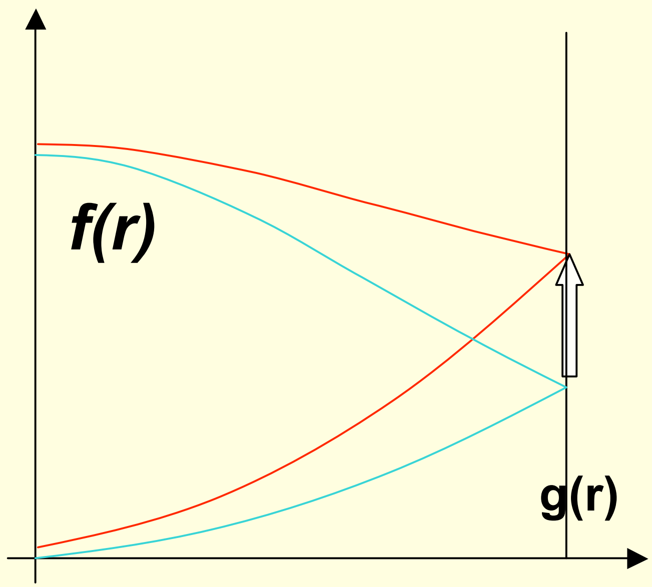


$m_q \to m_q - g_\sigma\, \sigma$ (attraction)

$E_q \to E_q + g_\omega\, \omega$ (repulsion)

Quark field

$$\psi_q(x) = e^{iE_q t} \begin{pmatrix} f(r) \\ i\vec{\sigma}.\hat{r}\, g(r) \end{pmatrix} \chi_{1/2}$$



scalar field effect, lower component loc enhanced

Chiral Quark Soliton Model –

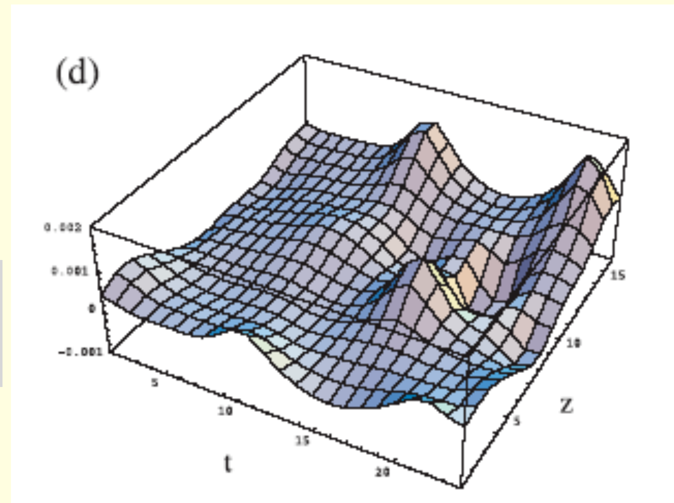
Diakonov, Petrov, Polykov, quarks couple to vacuum instantons

- Vacuum dominated by instantons
- quarks with spontaneously generated masses interact with pions

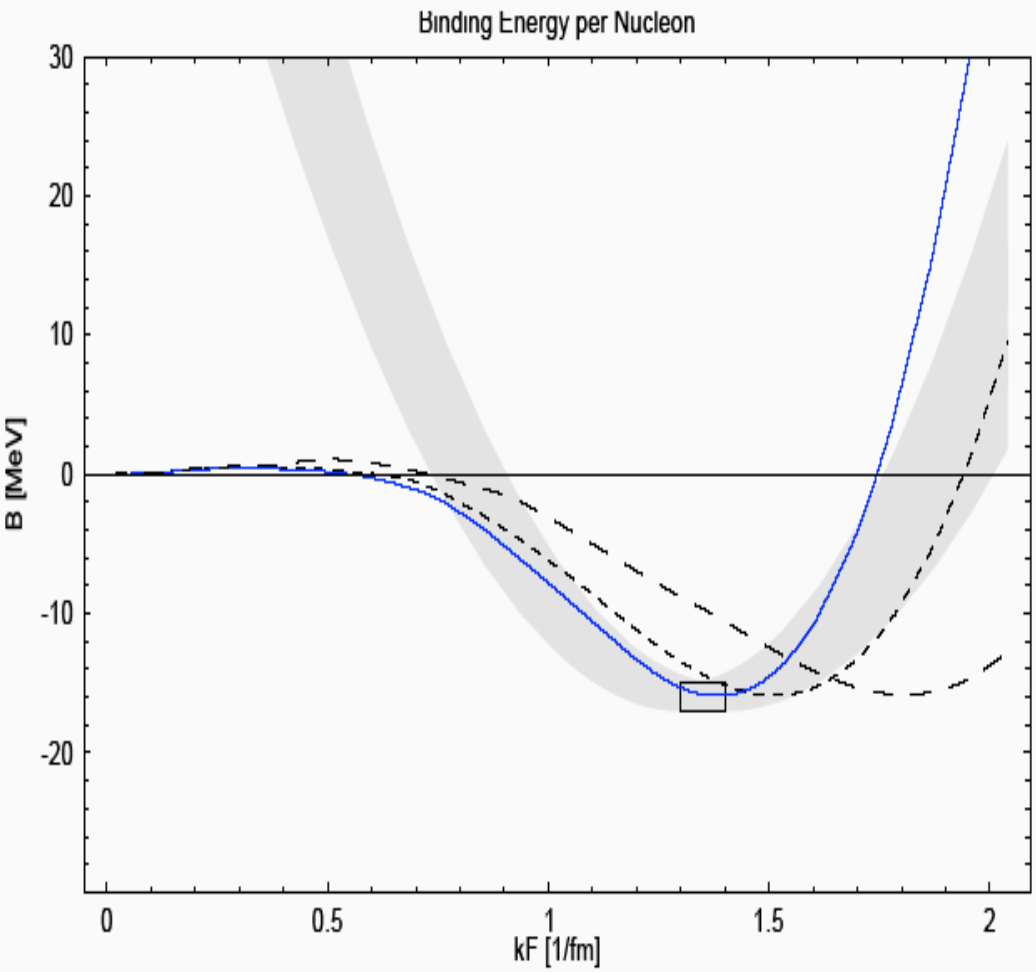
$$\mathcal{L}_{\rm eff} = \bar{q}\ \left[i\partial\!\!\!/ - M \exp(i\,\gamma_5\,\pi^A \lambda^A / F_\pi) \right]\ q,$$

- Nucleon is soliton in pion field
- M=420 MeV
- good nucleon properties

Negele et al hep-lat/9810053
topological charge density



Results –Nuclear Matter

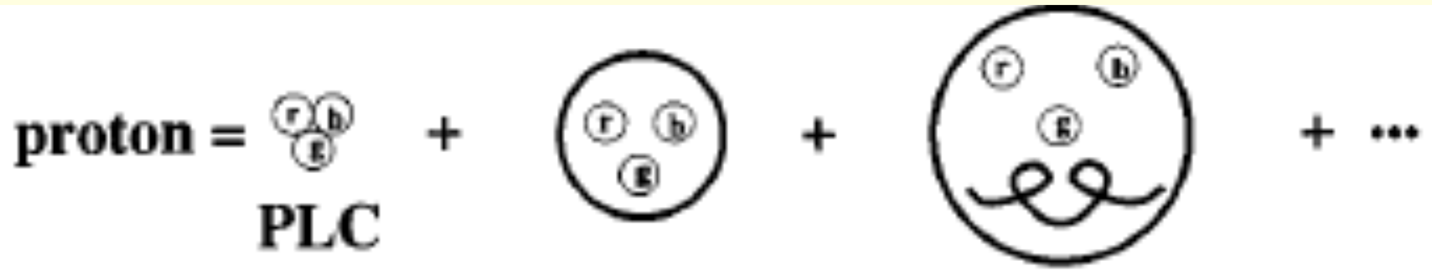


Smith-Miller

$-\langle\bar{\psi}\psi\rangle_0^{1/3}$ [MeV]	$g_v^2/4\pi$	k_F [fm^{-1}]	K [MeV]
225	7.22	1.81	291.7
210	8.96	1.51	312.5
200	10.55	1.38	348.5
-	10.47	1.42	560

Suppression of Point Like Configurations- Frankfurt, Strikman

free



place in medium:

normal size components attracted energy goes down

PLC does not interact- color screening

energy denominator increased, PLC suppressed

quarks lose momentum in medium

Need model of free nucleon wave function

- 3 quark anti-symmetric
- relative variables, frame independent
- eigenstate of spin operator- rotational invariant
- reduces to non-relativistic if $m \to \infty$

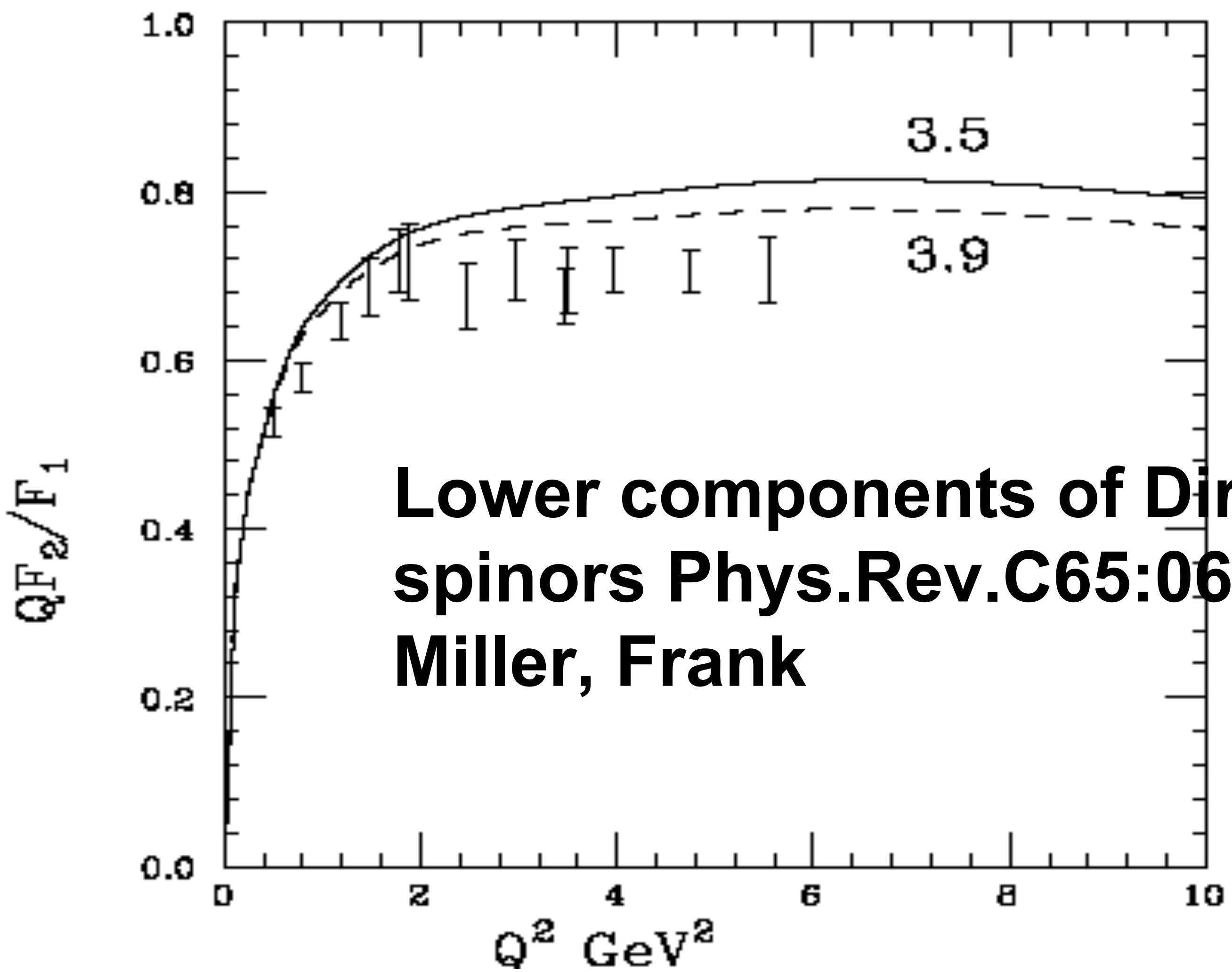
$\Psi = \Phi(M_0^2) u(p_1) u(p_2) u(p_3 = K) \psi(s_i, t_i)$ Terentev, Coester

spatial dist DIRAC SPINORS spin-ispin color amp

Schlumpf Mom space wf $\Phi(M_0) = N/(M_0^2 + \beta^2)^\gamma$

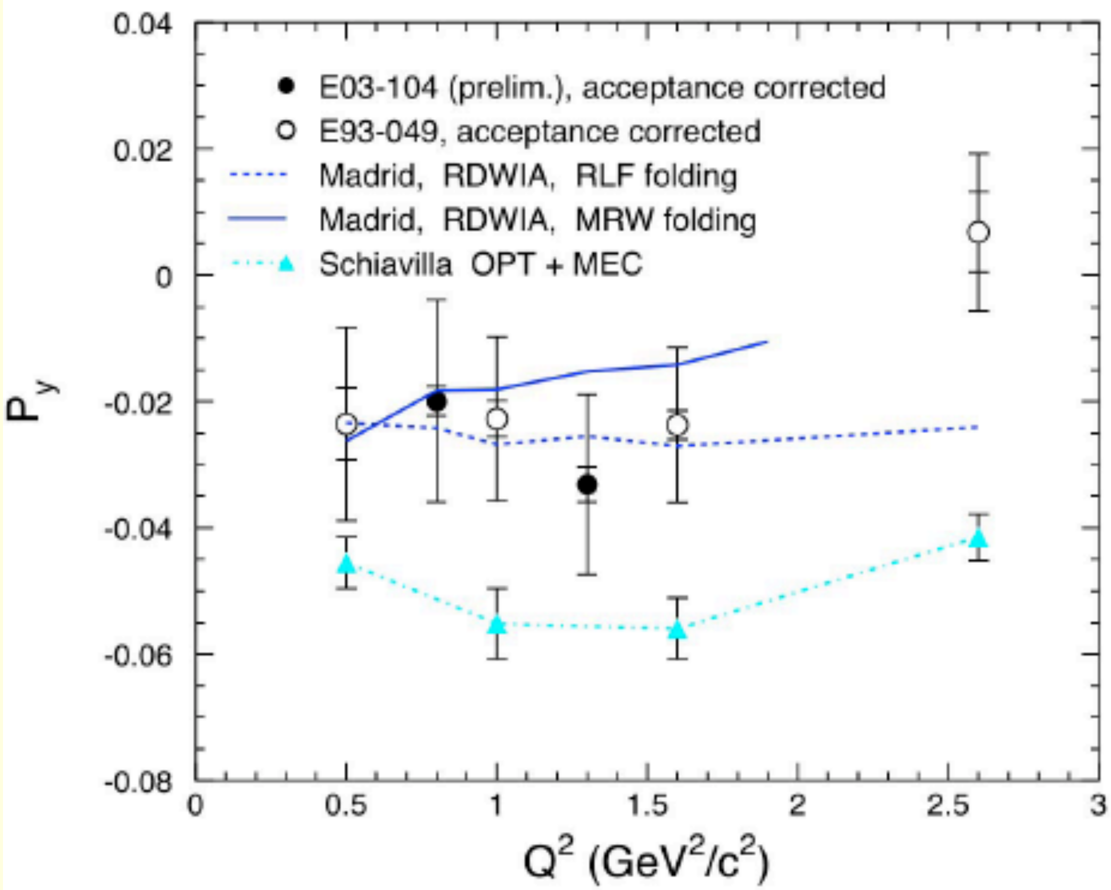
$\beta = 0.607$GeV $\gamma = 3.5$ $m = 0.267$ GeV

Ratio of Pauli to Dirac Form Factors calculation '95 data 2000



Lower components of Dirac spinors Phys.Rev.C65:065205,2002 Miller, Frank

Induced Polarization in $^{4}\mathrm{He}(e,e'\vec{p})$



- Observed final-state interaction small and with only very weak Q^2 dependence
- RDWIA results consistent with data
- Spin-dependent charge exchange terms not constrained by N-N scattering and possibly overestimated
- E03-104 took specific data that will set tight constraints on FSI

Inner uncertainties are statistical only;
full analysis of E03-104 will have reduced systematic uncertainties

Strauch June ‘07