SEMI-INCLUSIVE $\quad z = E_h/\nu$ LARGE

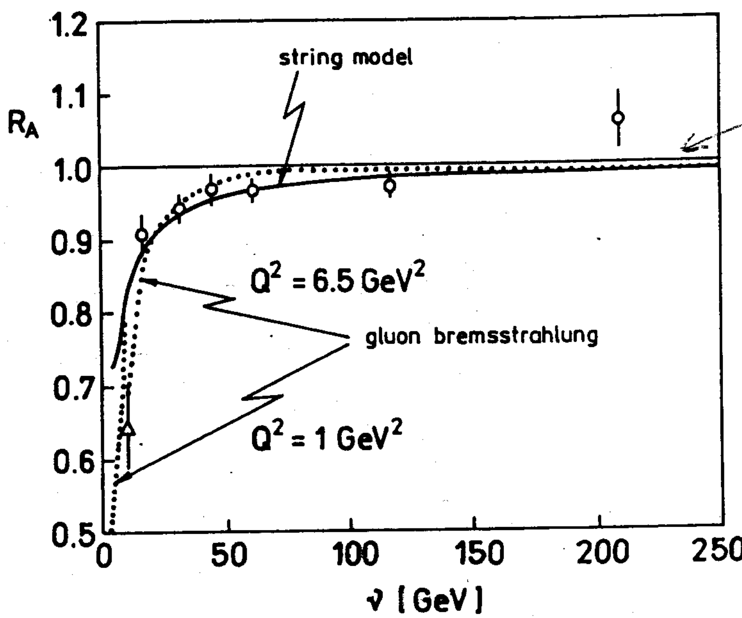
$ep \to eh \ldots \quad Q^2$ low

$$\frac{1}{\sigma_{TOT}}\frac{d\sigma}{dz} = \frac{\sum_i e_i^2 f_i(x,Q^2) D_i^h(z,Q^2)}{\sum_i e_i^2 f_i(x,Q^2)} = \frac{1}{N_e}\frac{dN^h}{dz}$$

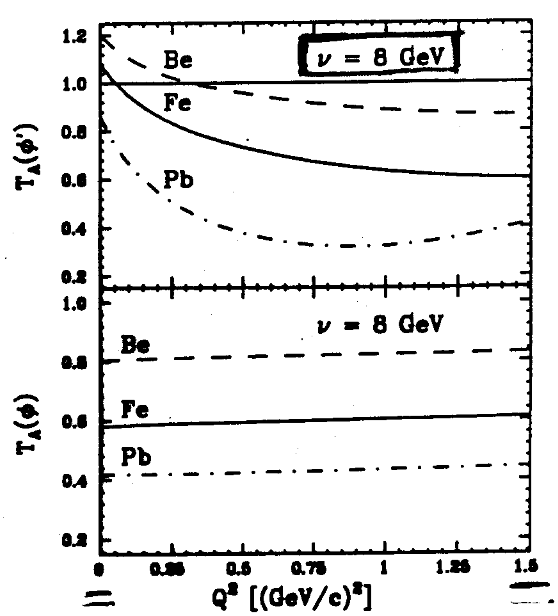
QUARK FRAGMENTATION FUNCTIONS

$$R_A = \left(\frac{1}{\sigma_A}\frac{d\sigma_A}{dz}\right) \Big/ \left(\frac{1}{\sigma_D}\frac{d\sigma_D}{dz}\right)$$

use nucleus as filter



no nuclear effects



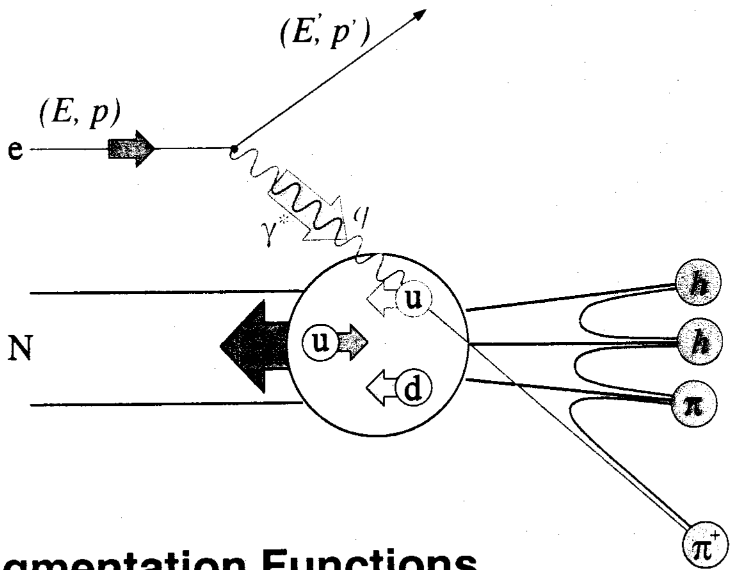
Big Effects at "small" ν

Hadron attenuation

Fragmentation Models

[illegible] → **Hadronization**

Perturbative QCD calculations — Non-perturbative models



$$z = E_h/E_q = E_h/\nu$$

Fragmentation Functions

Universal fragmentation function $D(z)$ describes the transition $(q \rightarrow hadron)$ ... "distribution of hadrons within a quark". cf. other universal function = PDF $q(x)$ ... "distribution of quarks within a hadron".

$$\frac{d\sigma}{dz}(e^+e^- \rightarrow hX) = \sum_q \sigma(e^+e^- \rightarrow q\bar{q})[D_q^h(z) + D_{\bar{q}}^h(z)]$$

$$\frac{1}{\sigma}\frac{d\sigma}{dz}(ep \rightarrow hX) = \frac{\sum_q e_q^2 q(x) D_q^h(z)}{\sum_q e_q^2 q(x)}$$

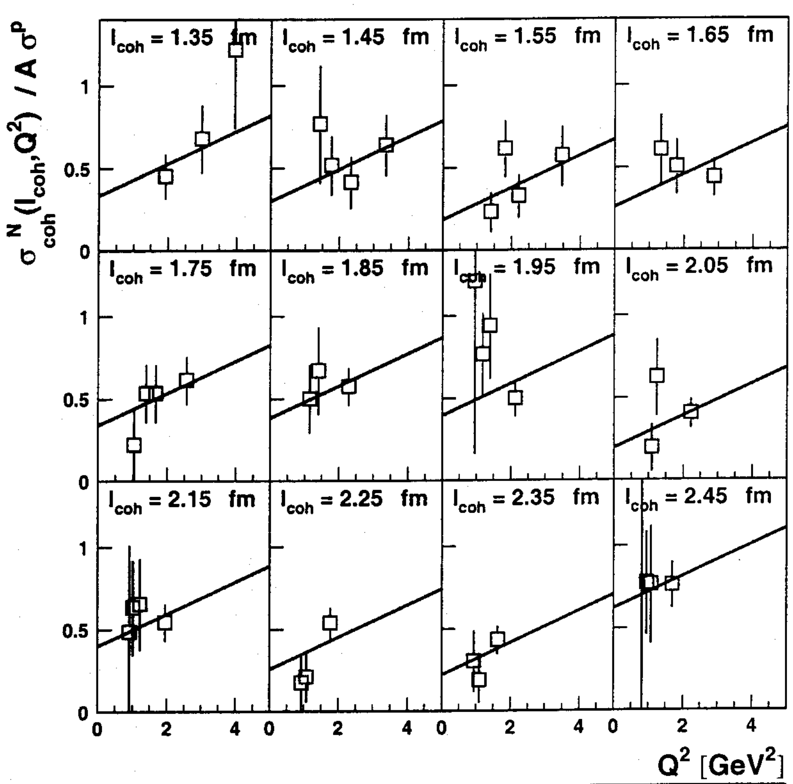
Relations

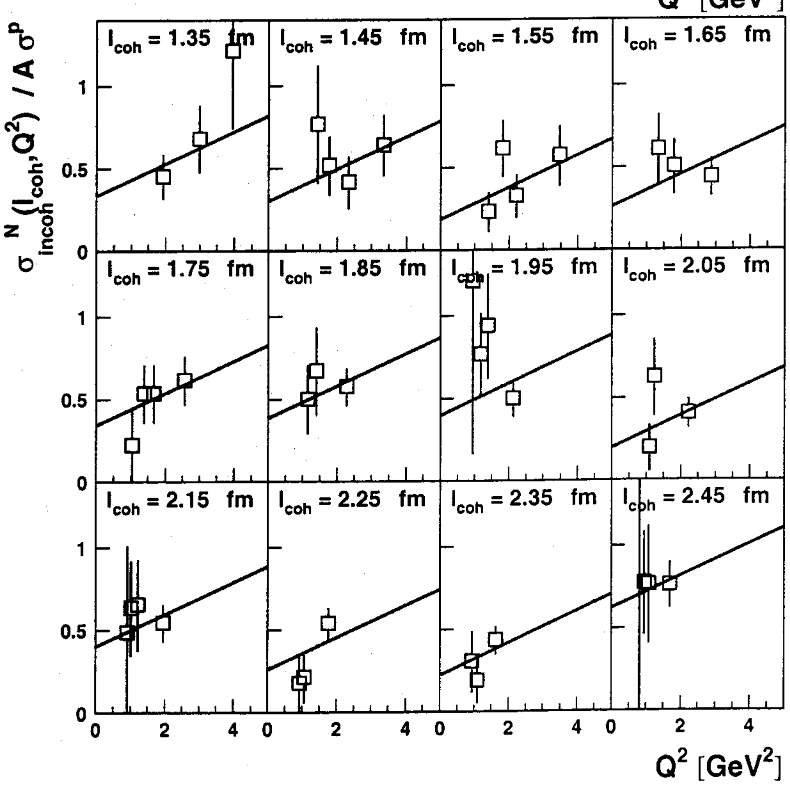
- Momentum conservation: $\sum_h \int_0^1 D_q^h(z)dz = 1$
- Probability conservation: $\sum_q \int_{z_{\min}} [D_q^h(z) + D_{\bar{q}}^h(z)]dz = n_h$ (n_h = average multiplicity)

HERMES - Fixed Coherence Length

$A(e,e'\rho^{\circ})$

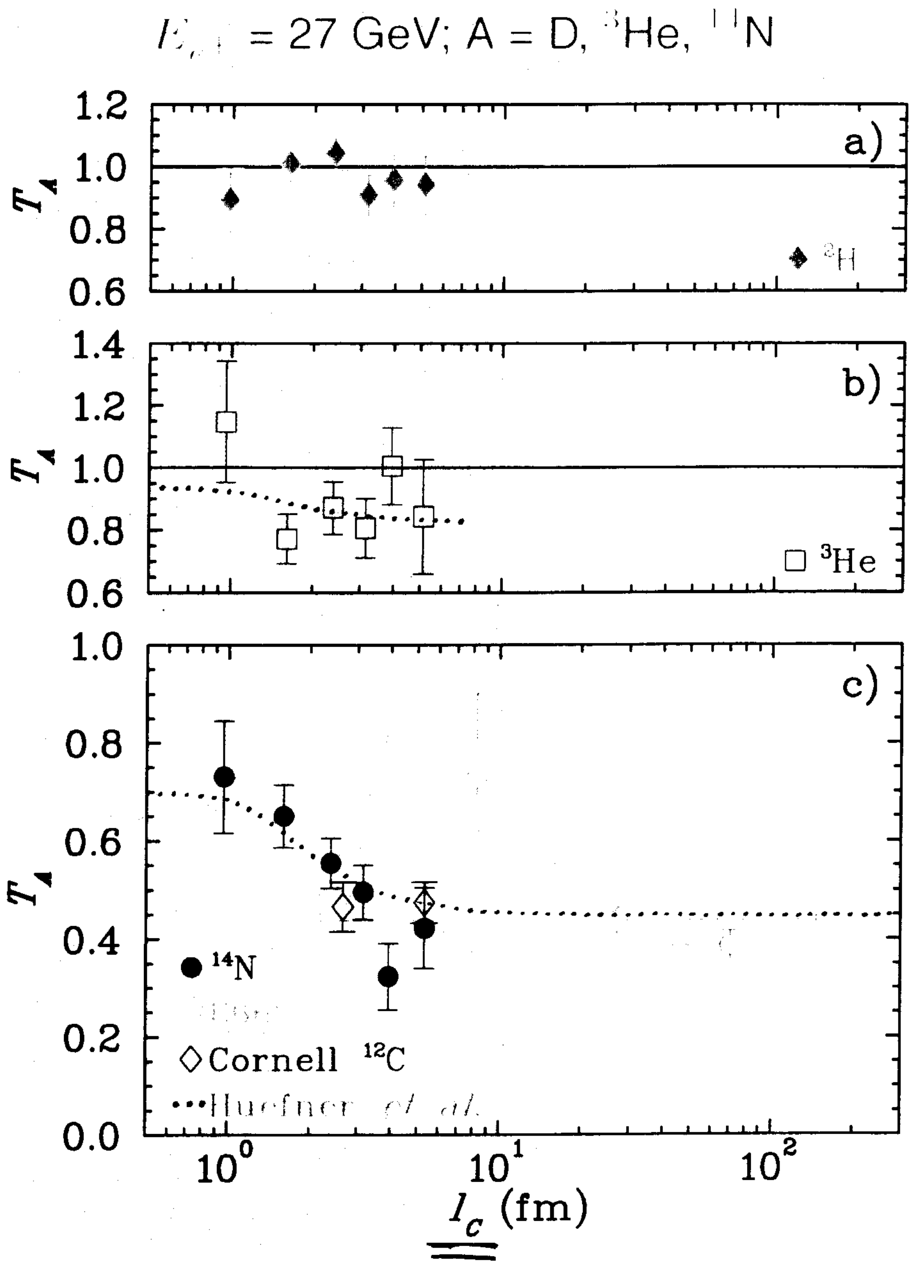
Coherent (Top) and Incoherent (Bottom) Production





Interpreted as evidence for Color Transparency

HERMES A($\mu, \mu' \rho^0$) incoherent production



NMC: 0.51 ± 0.13 (2 < l_c < 10)

HERMES, Ackerstaff et al, Phys. Rev. Lett. 82, 3025 (1999)

open circles are E665 data

Virtual photon fluctuates into a $q\bar{q}$ pair with transverse separation $\sim \frac{1}{Q}$ a distance l_c in front of the nucleus

Data interpreted as evidence for coherence length l_c effects

Confuses looking for formation length CT effects, the distance traveled before a small-size $q\bar{q}$ configuration evolves to its regular hadron size

$^{12}C(e,e'p)$ $Q^2 = 1.1$

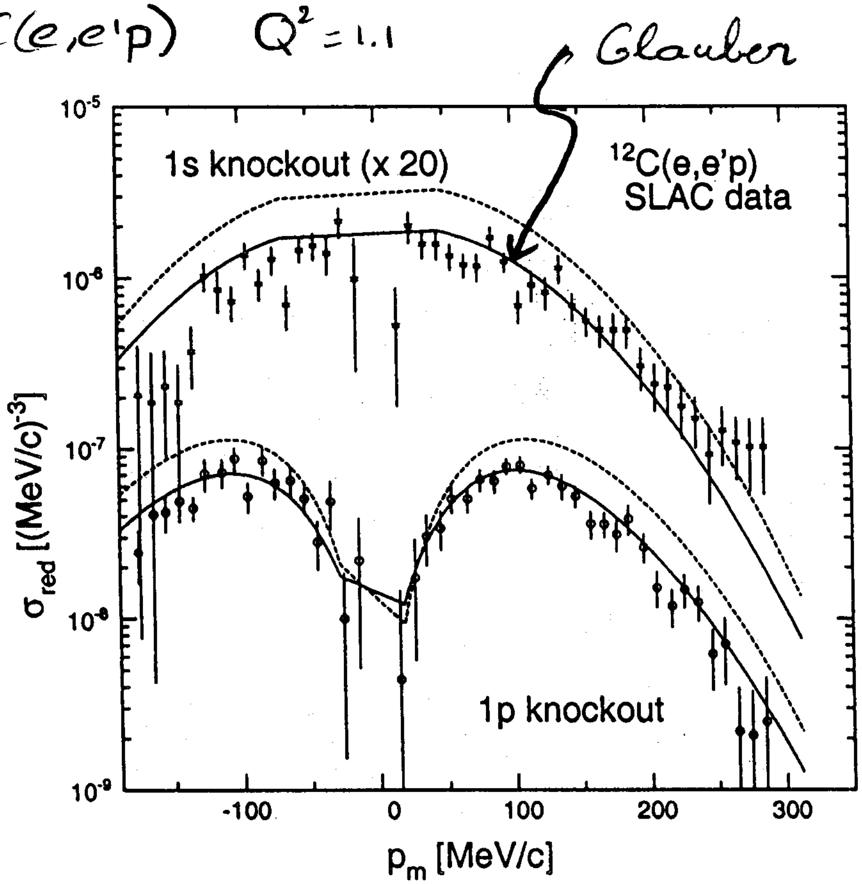


FIG. 7. Reduced cross section for $1p$ and $1s$ proton knockout in the reaction $^{12}C(e,e'p)$ as obtained in a recent SLAC experiment at $Q^2 = 1.1$ $(\mathrm{GeV}/c)^2$ (from Ref. [43]). The kinematics are given in Table I. The curves represent momentum distributions calculated in PWIA (dashed) and in the Glauber approximation (solid). For all curves the spectroscopic factors $S = 2j + 1$ were employed.

Spectroscopic Factors

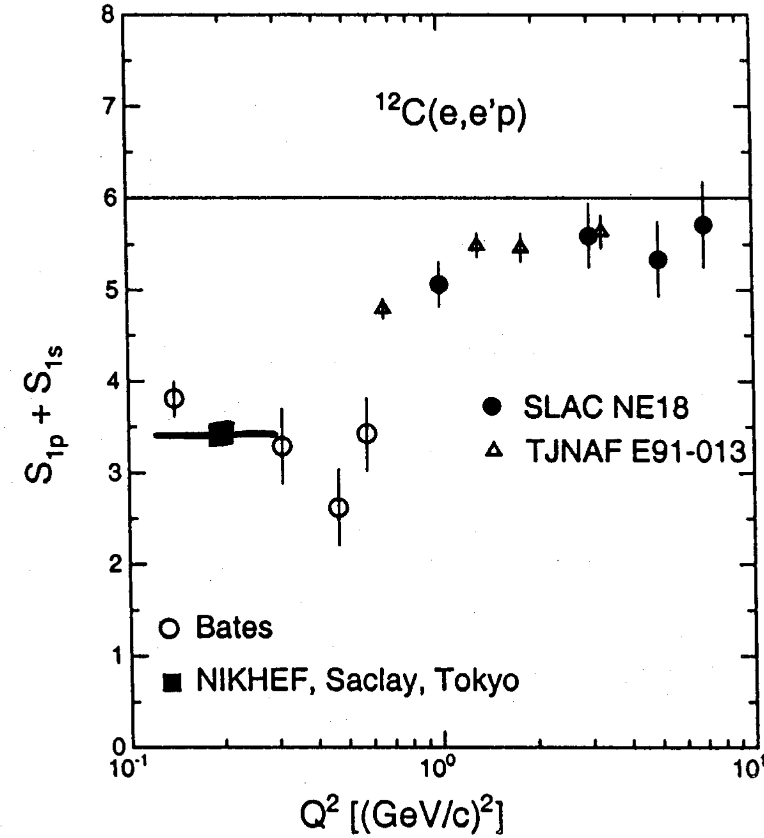


FIG. 8. Q^2 dependence of the summed spectroscopic strength $S_{1p} + S_{1s}$ for $1p$ and $1s$ proton knockout in the reaction $^{12}C(e,e'p)$ up to $E_m = 80$ MeV. The square indicates the result from the combined analysis of NIKHEF, Saclay and Tokyo data (see sections III and IV), where the horizontal bar denotes the Q^2 range of these data. Other symbols, as indicated, represent the results from experiments at Bates [22,23], SLAC [15] and TJNAF [10].

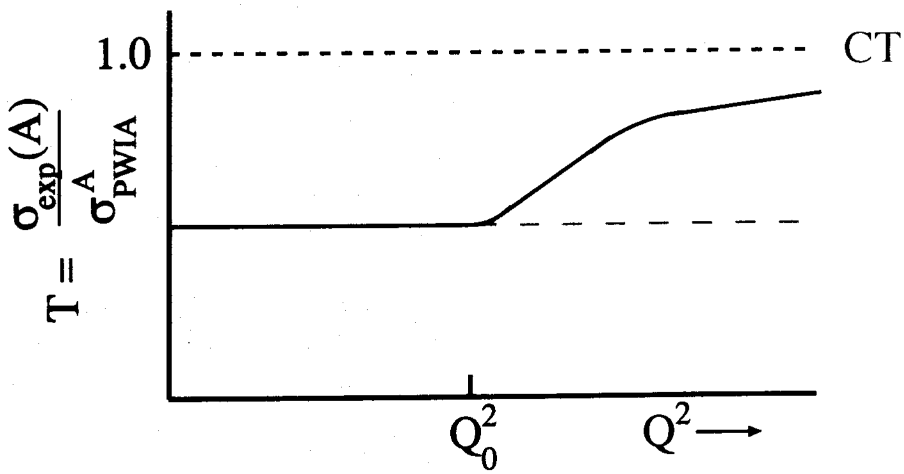
~ 60% @ low Q^2

→ 80-90% @ $Q^2 \approx 1$ $(\mathrm{GeV}/c)^2$?

JLab E94-139 Results

E94-139 Search for Color Transparency in Quasifree A(e,e′p) Scattering

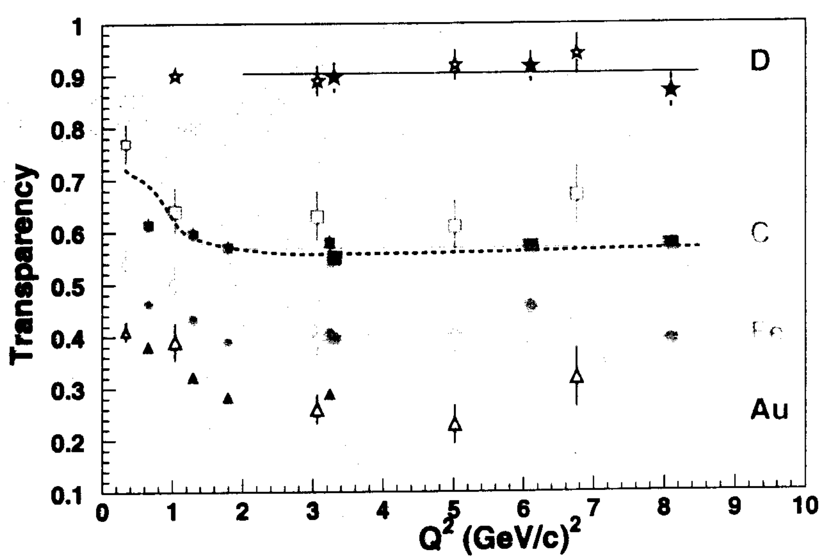
From fundamental considerations (quantum mechanics, relativity, nature of strong interaction) it is predicted (Brodsky, Mueller) that **fast** protons scattered from the nucleus will have **decreased** final state interactions



E94-139 Results (Submitted to Phys. Rev.)

C o n s t a n t Value fits for $Q^2 > 2$ (GeV/c)^2 $\rightarrow$ $\chi^2/df \approx 1$

Dashed line is correlated Glauber calculation (Pandharipande et al)



[redacted]

Polarization Transfer

- Free electron-nucleon scattering[a] $^1H(\vec{e},e'\vec{p})$

$$\frac{G_E}{G_M} = -\frac{P'_x}{P'_z} \cdot \frac{(E_i + E_f)}{2m} \tan\left(\frac{\theta_e}{2}\right)$$

- Bound nucleons → evaluation within model $^4He(\vec{e},e'\vec{p})^3H$
- Reaction mechanism effects in $A(\vec{e},e'\vec{p})B$ predicted [b] to be small and minimal for
  - Quasielastic scattering
  - Parallel kinematics
  - Low missing momentum
  - Symmetry about $\mathbf{p}_m = 0$

---

[a] R. Arnold, C. Carlson, and F. Gross, Phys. Rev. C **23**, 363 (1981)

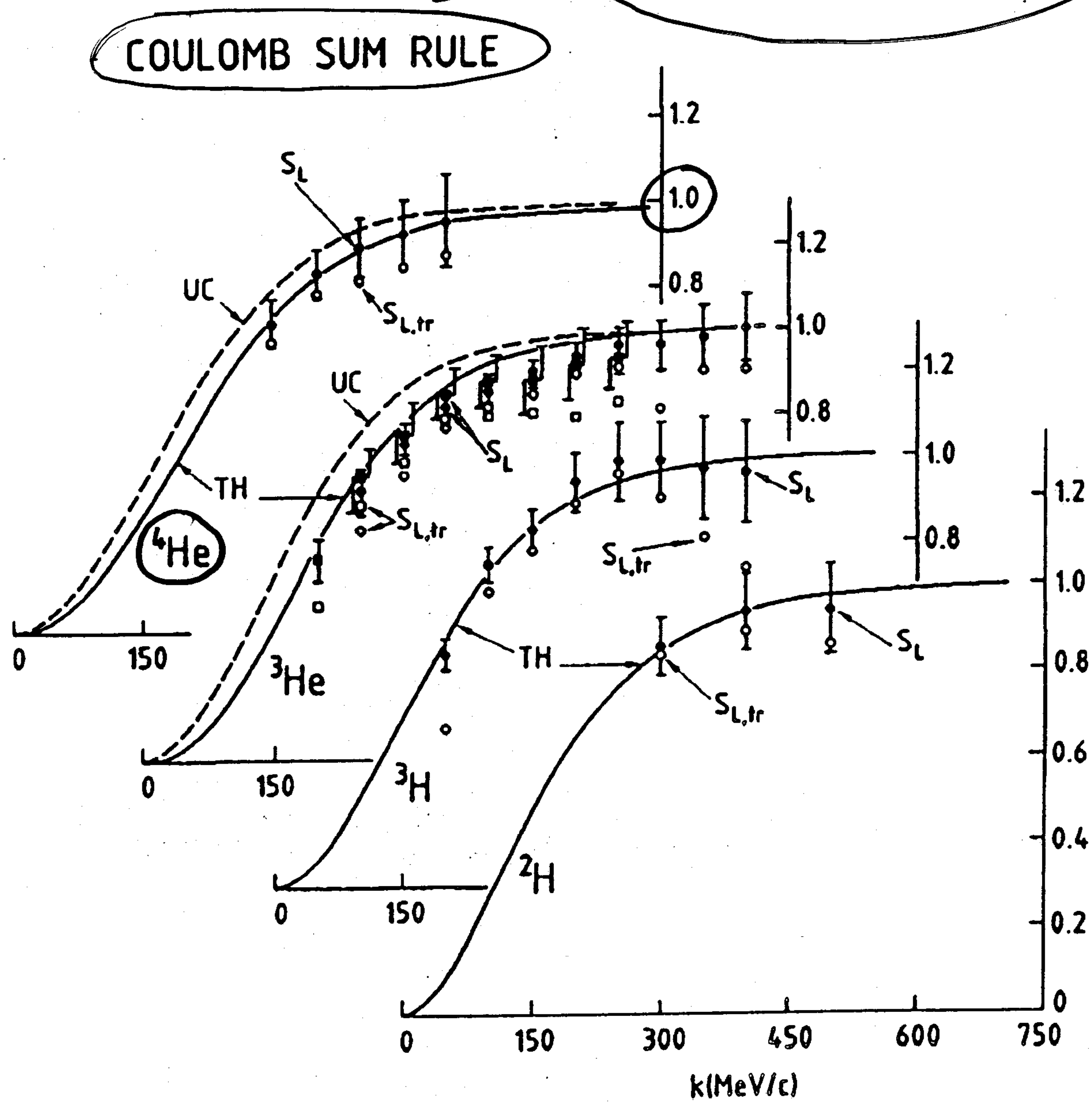
[b] E.g. J.M. Laget, Nucl. Phys. A **579**, 333 (1994), J.J. Kelly, Phys. Rev. C **59**, 3256 (1999), A. Meucci, C. Guisti, and F.D. Pacati, nucl-th/0205055

A(e,e') Quasi-Elastic Scattering

Select Longitudinal (Charge) W_L

Response Function only

$\int \frac{1}{Z}$ Integral of W_L ~ Charge Z

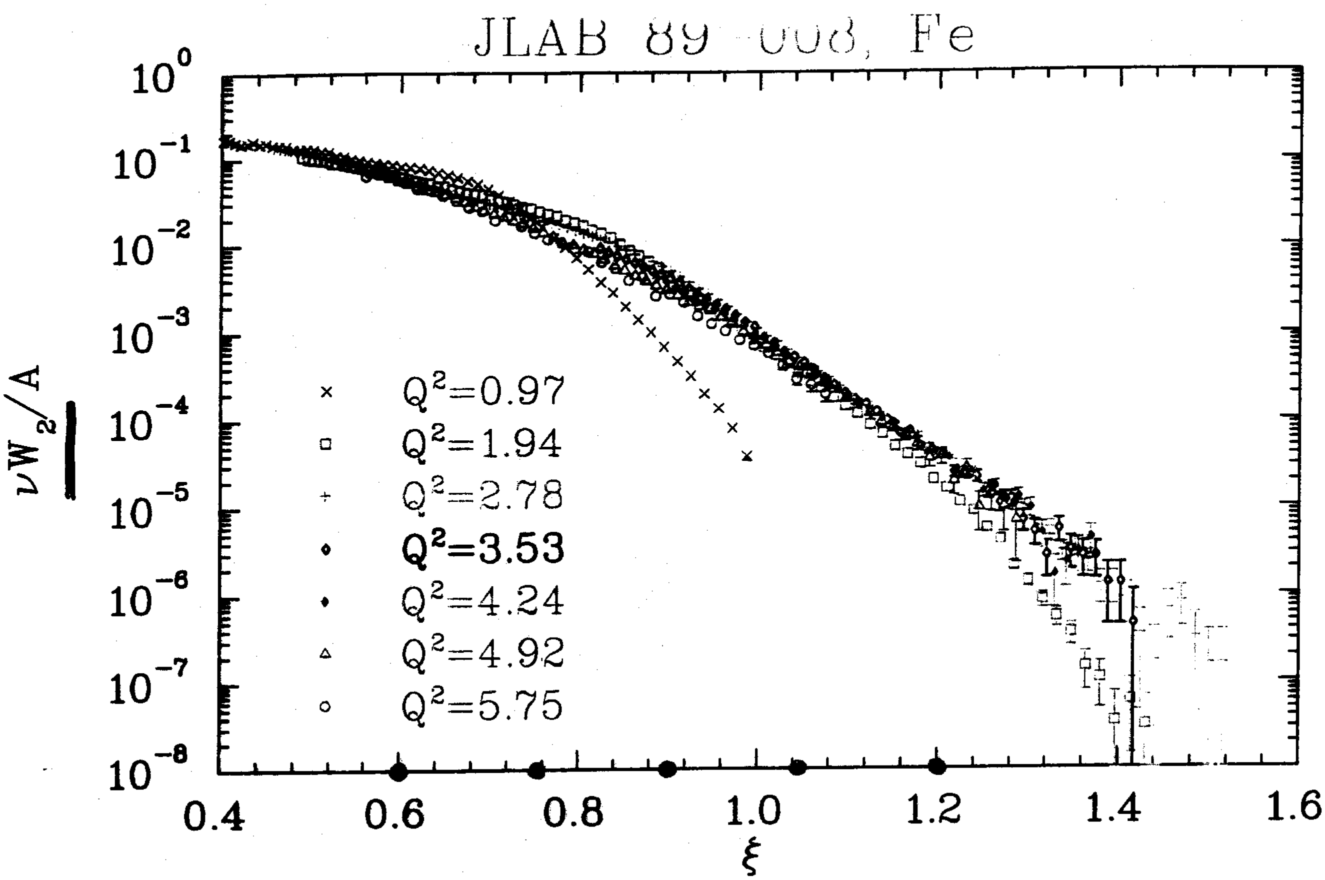


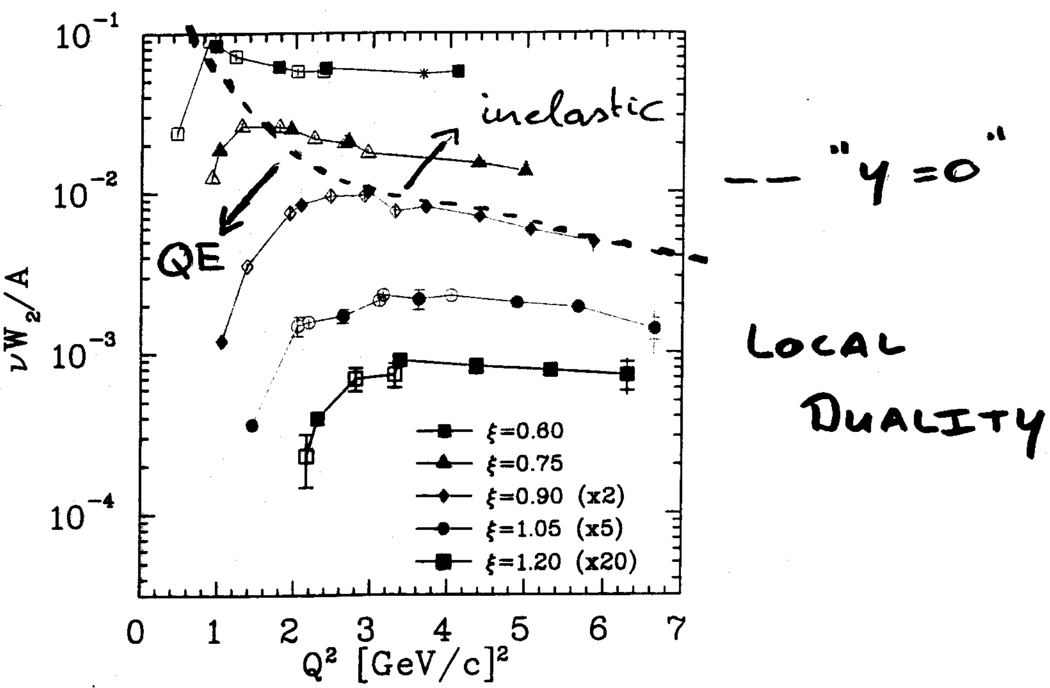
If G_E^p would be modified,

would not get 1.0

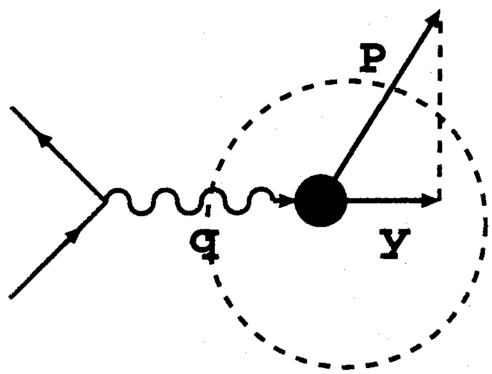
But: $$\xi = \frac{2x}{1+\sqrt{1+\frac{4M^2x^2}{Q^2}}}$$ Note: $\xi \longrightarrow x$ as $Q^2 \longrightarrow \infty$

ξ appears in the parton model as a target mass correction





A(e,e')　　　　E89-008　Day, Filippone



$x = Q^2/2M\nu > 1$

y ~ Nucleon's momentum along q

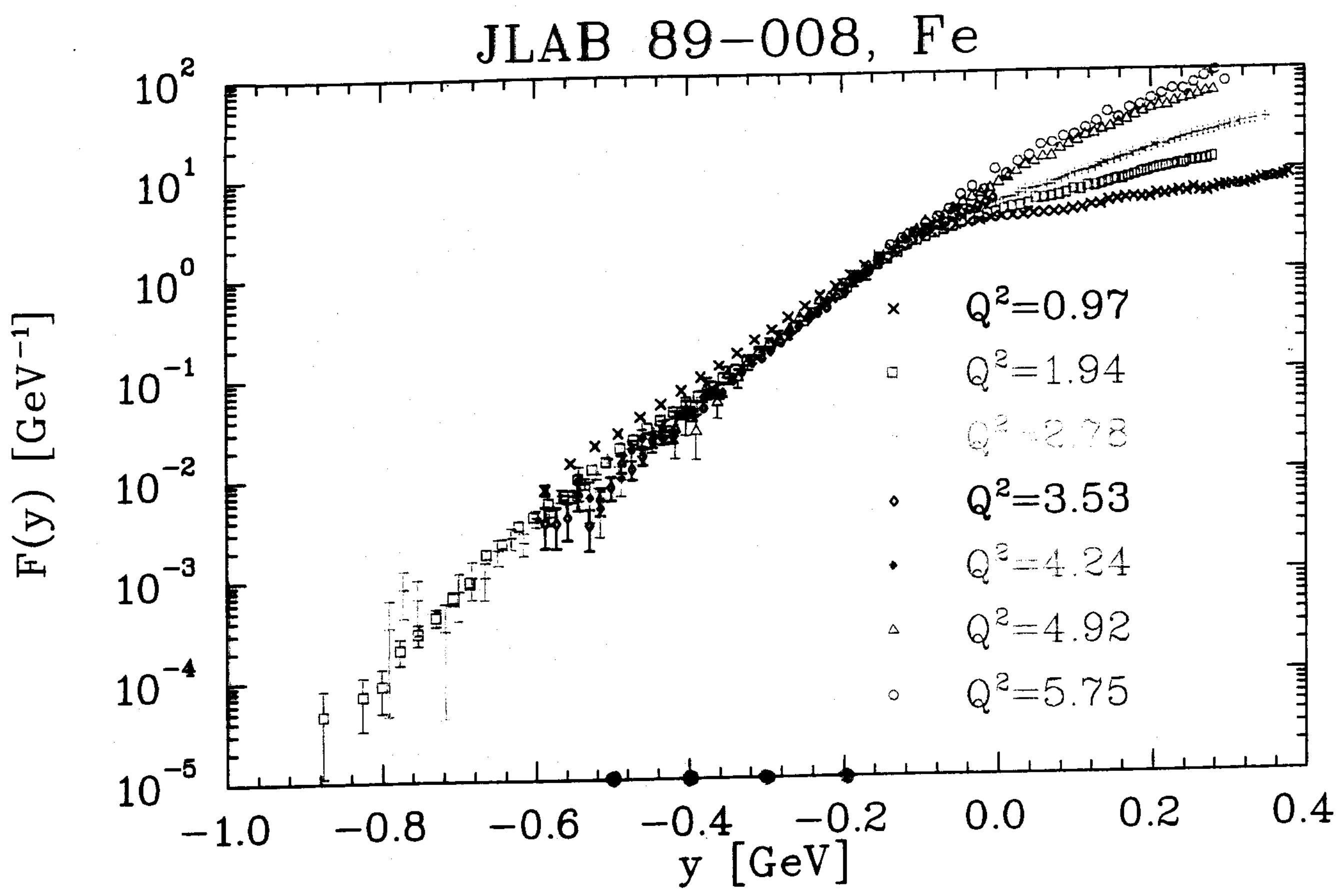
At large x and moderate Q^2, the cross section is dominated by quasielastic scattering.

In PWIA (no initial/final state interactions)

$$\frac{d^3\sigma}{d\Omega\, dE'} = \sigma_{eN} * F(y)$$

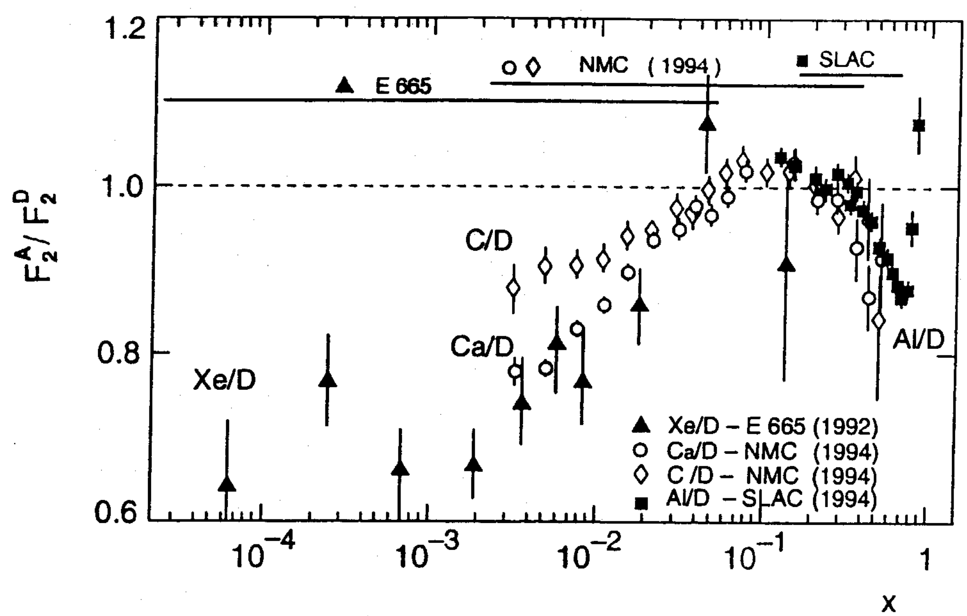
σ_{eN} → Off-shell electron-nucleon cross section

F(y) - related to momentum distribution.



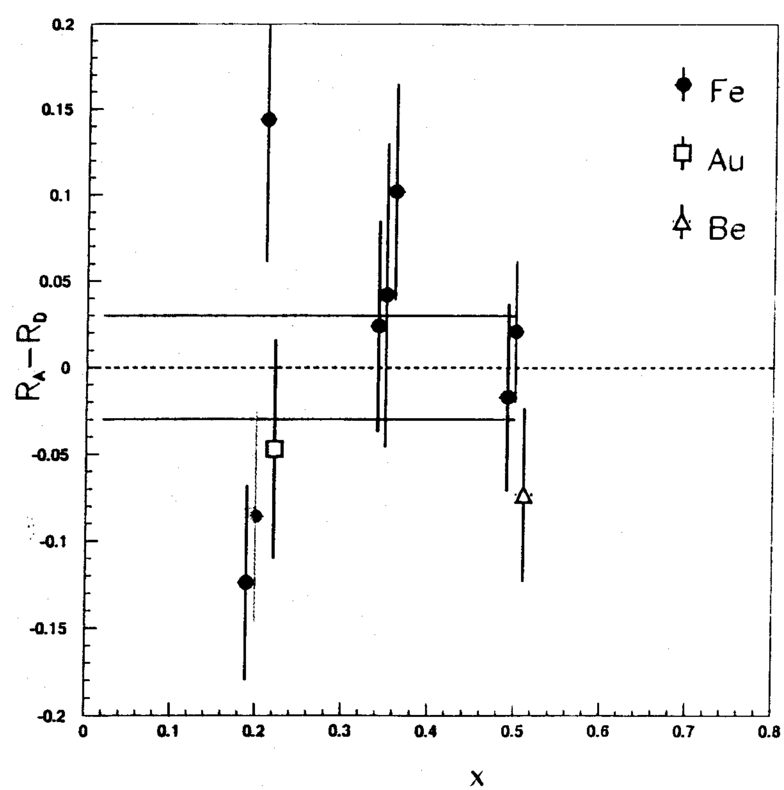
A dependence of structure functions

$\frac{F_2^A}{F_2^D}$



EMC EFFECT

$R_A - R_D$



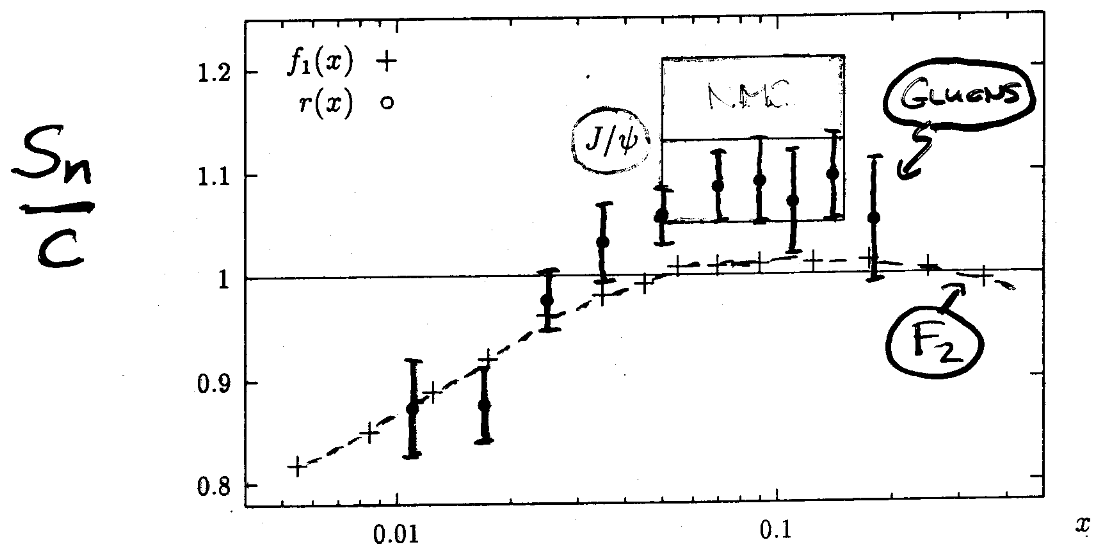
no (unambiguous) A-dependence of $R = \sigma_L/\sigma_T$ yet

GLUONS in Nuclei

- Shadowing at $x < 0.05$
- Enhancement at $x \sim 0.1$

consistent with

$$\int_0^A dx\, x\, g^A(x, Q^2) \simeq \int_0^1 dx\, x\, g^N(x, Q^2)$$



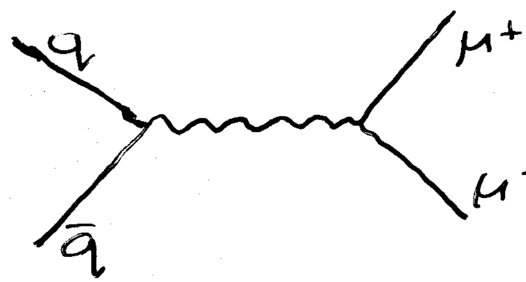
→ Glue seems to have more enhancement

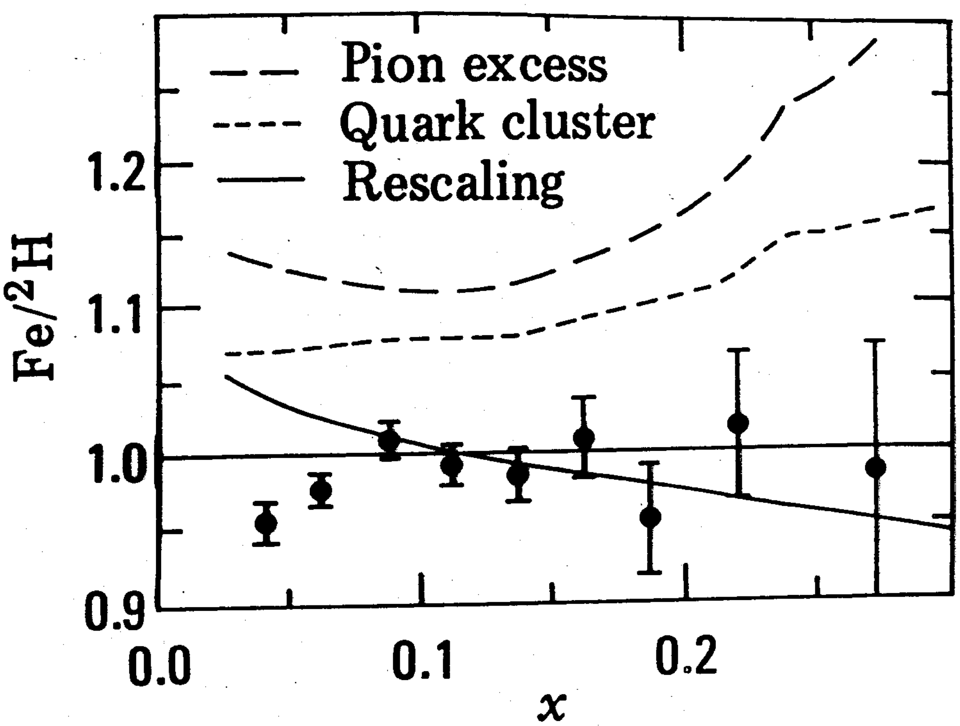
Enhancement in EMC effect?

Nuclear Binding (OPEP) $\Rightarrow \pi$ excess in Nuclei

$\Rightarrow \bar{q}$ excess in Nuclei

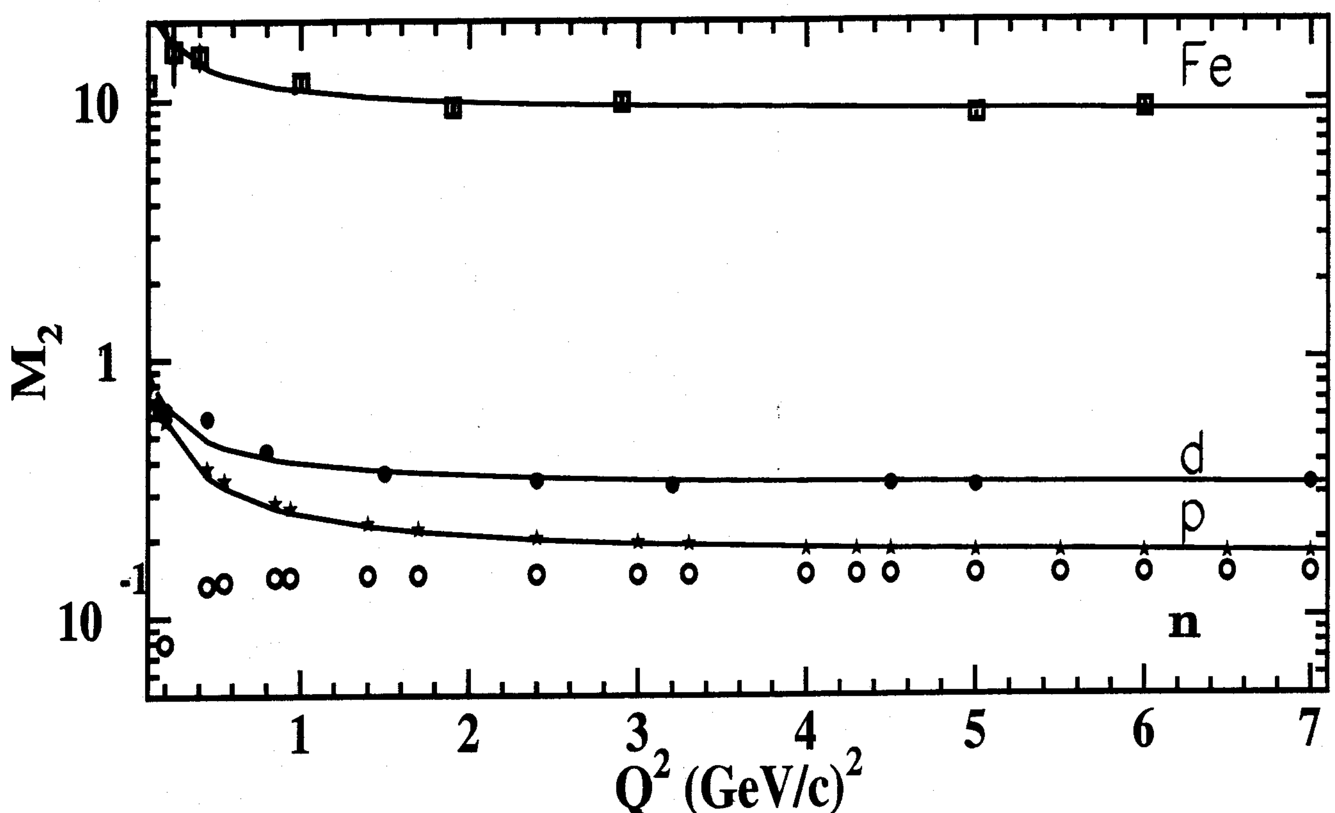
Drell-Yan



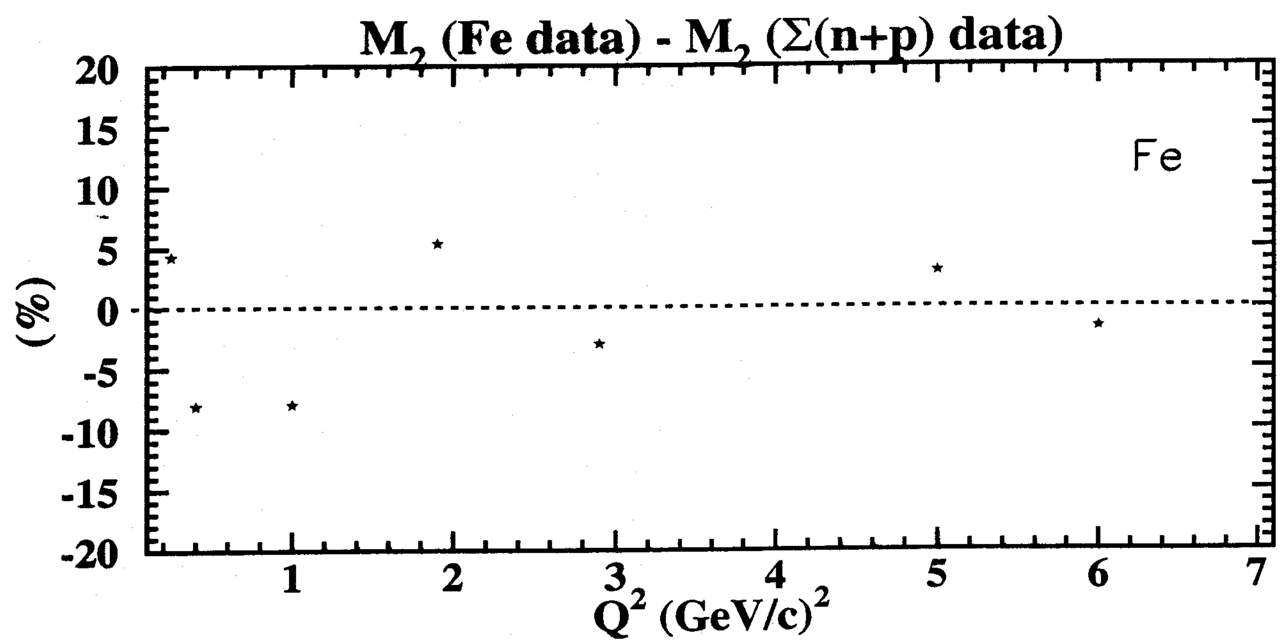


- No enhancement found
- Within 10% of regular EMC effect
- But not = ! Flavor Dependence

Energy-Momentum Sum Rule



$$M_2 = \int_0^1 dx\, F_2(x, Q^2)$$ • low Q^2: Resonances!



Present uncertainties on moments are 5% (10% at low Q^2?)

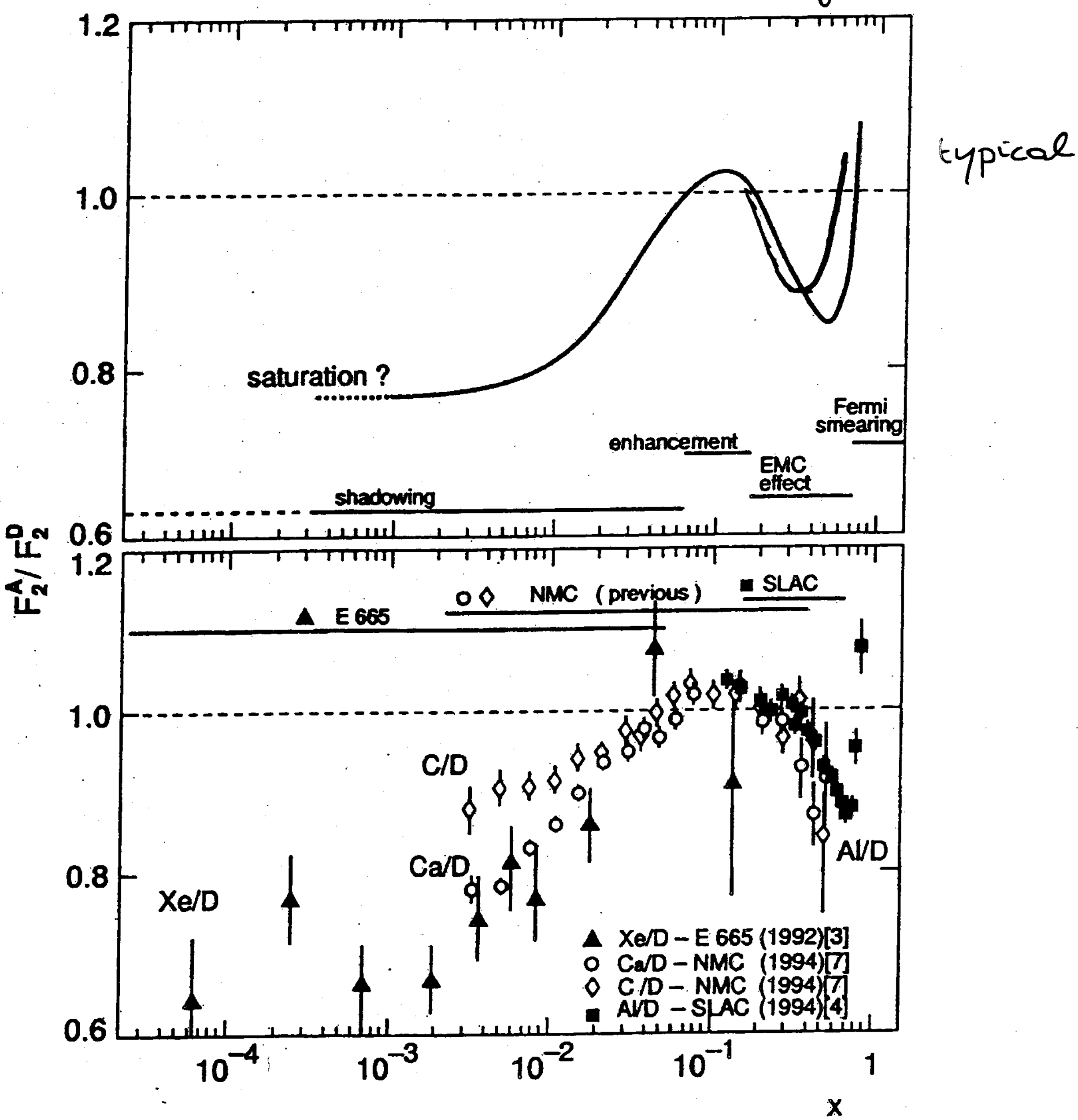
⇒ EMC effect in Resonance Region too!

EMC effect

Nuclear Binding and Fermi Motion

$$F_2^A \simeq F_2^N - \frac{\langle \varepsilon \rangle}{M} F_2^{N'} + \frac{\langle T \rangle}{3M} x^2 F_2^{N''} + 2M^2(\langle \varepsilon \rangle - \langle T \rangle) \left.\frac{\delta F_2}{\delta p^2}\right|_{p^2=M^2}$$

$\langle \varepsilon \rangle, \langle T \rangle$: mean separation, kinetic energy

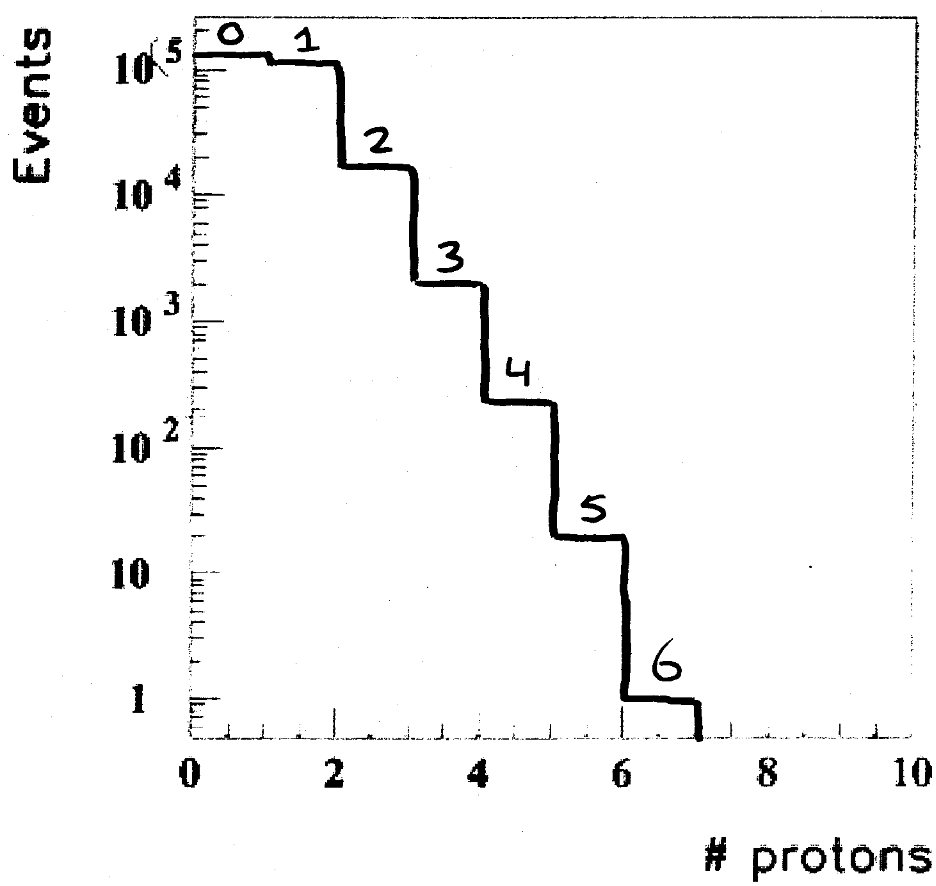


ρ or A dependence? Only real issue at $A \leq 6$

How about large x, low Q^2 region? →

$^{12}C(e,e'\#p)$ CLAS

Detect Scattered Electron + Protons



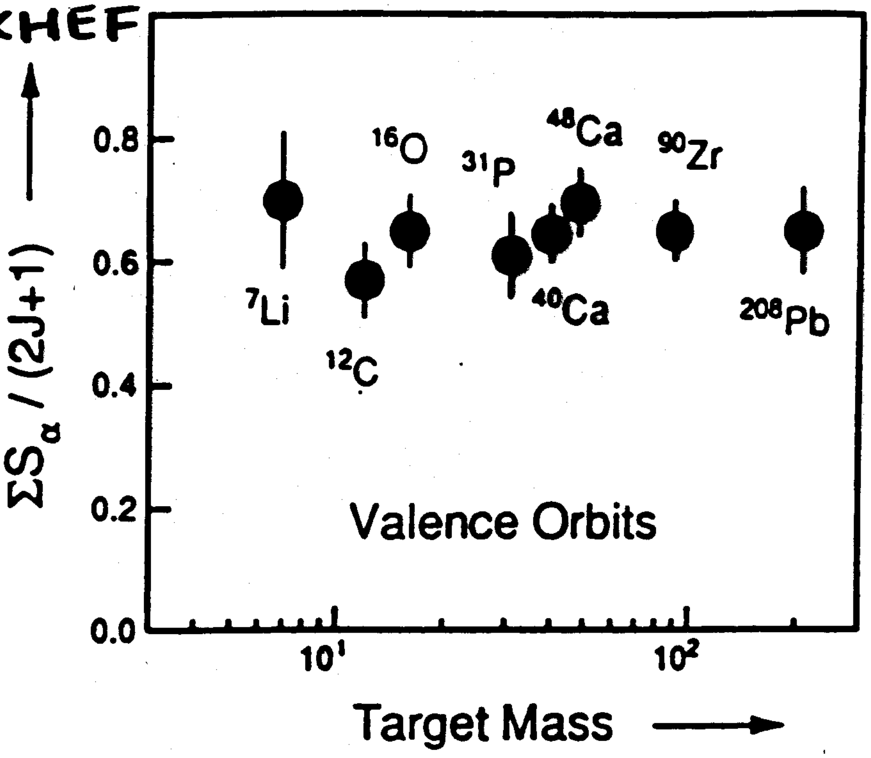
Correlations ⇒ Appreciable Fraction of > 1 protons

NIKHEF

(e,e'p)

$Q^2 \sim 0.15\ (GeV/c)^2$

~ 70 %

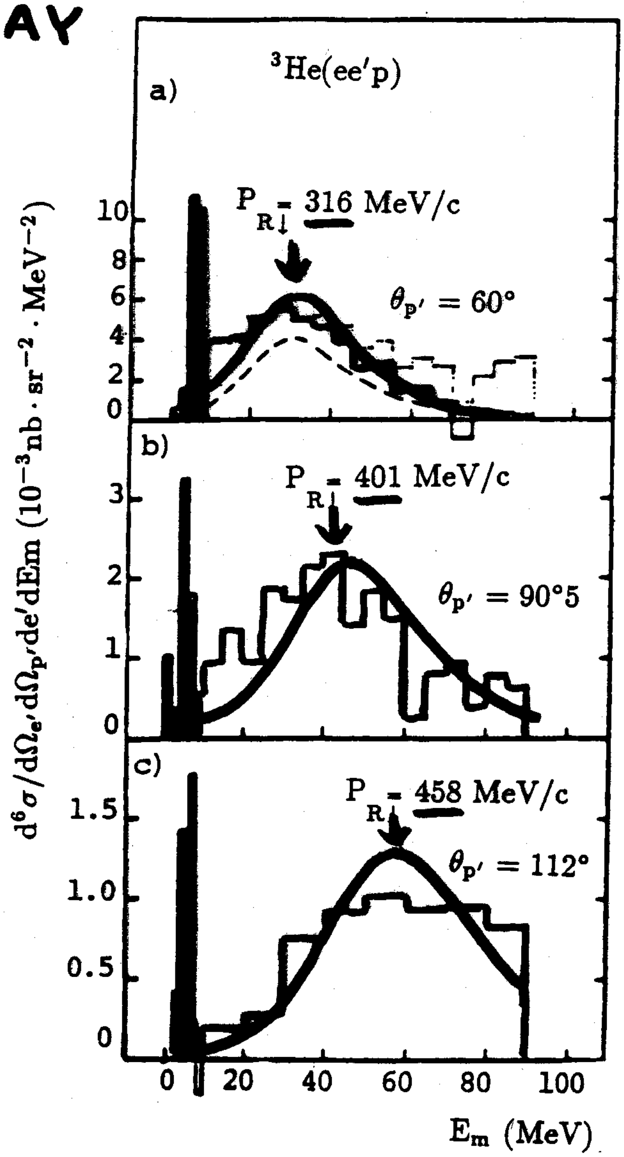


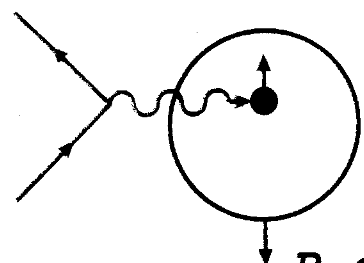
INTERPRETED AS EVIDENCE FOR CORRELATIONS

SACLAY

$^3He(e,e'p)d$

$^3He(e,e'p)pn$

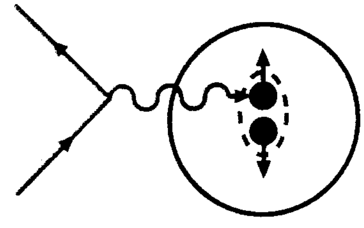




P_R or P_m

— Laget

Correlated Pair



Motivation

- Standard Model of Nuclear Physics
  - Nucleus made of Nucleons in V_{NN}
  - V_{NN} fit to NN phase shifts
  - Exchange currents[a]
  - Relativistic corrections
- Want to understand the origin and limit of the "nuclear physics approximation"

[a] Franz Gross, D.O. Riska, Phys. Rev. C **36**, 1928 (1987)

Nuclear Effects in Electron Scattering

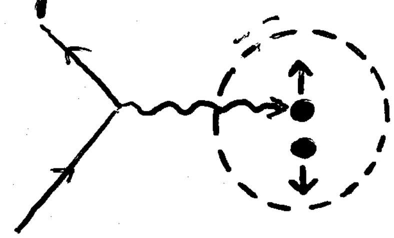
R. Ent

Will try to emphasize low Q^2, large x Region compatible w. "low" neutrino energies

I. "Standard Model" of Nuclear Physics

Beyond the Fermi Gas Model

Short-Range Structure in Nuclei



II. Medium Effects on Form Factors and Structure Functions

III. Hadron production in a Nuclear Medium