Experimental Approach to Nuclear Quark Distributions

(Rolf Ent – EIC2004 03/15/04)

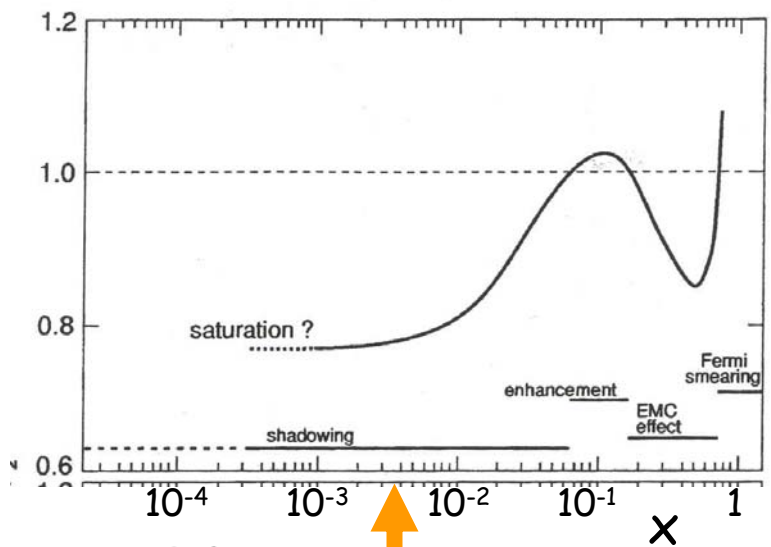
One of two tag-team presentations to show why an EIC is optimal to access nuclear pdf's, and how to do it experimentally…
Previous talk showed theoretical uncertainties in nuclear pdf's.
Next talk will emphasize access to Nuclear Gluon Distributions.

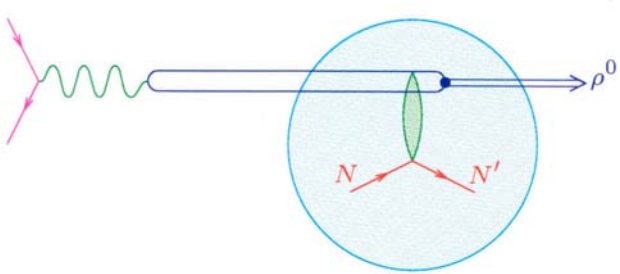
- (Nuclear) EMC Effect
- Kinematics: F_2 and F_L
- Quarks in Nuclear Physics
- Hadronization as a Tool
- Do we need π/K identification?
- Q^2 Dependence of Nuclear Ratios
  → Nuclear Gluon Distributions

Note: Present eRHIC Plans: up to Pb
Present ELIC Plans: up to Ca

The Venerable (Nuclear) EMC Effect

F_2^A/F_2^D "EMC Effect"





x < (5 times 10^{-3}) for saturation in shadowing to start?

Space-Time Structure of Photon

Nuclear Effects in R – Present Data

$$\frac{\sigma_A}{\sigma_D} = \frac{F_2^{\,A}(1+\varepsilon R_A)(1+R_D)}{F_2^{\,D}(1+R_A)(1+\varepsilon R_D)}$$

$$R = \frac{\sigma_L}{\sigma_T}$$

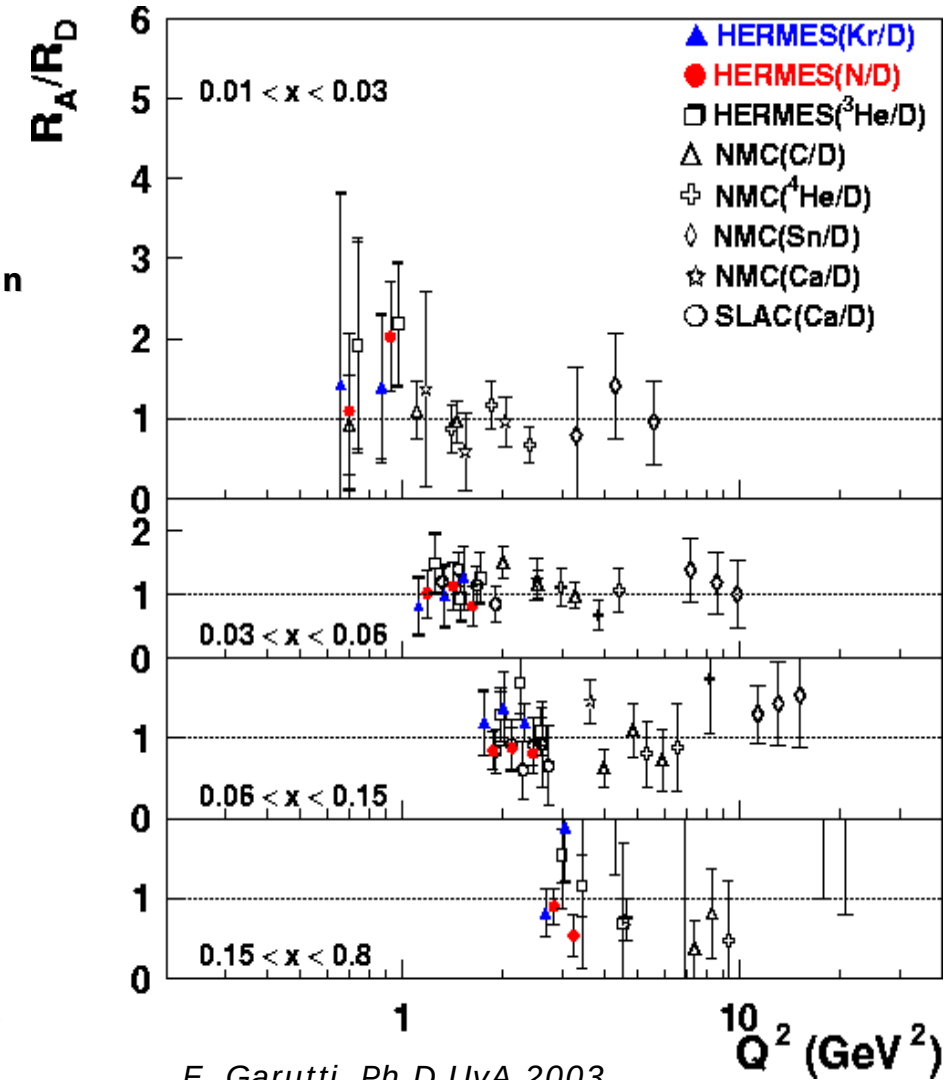
ε ≈ 1 (for high Energy) virtual photon polarization parameter

HERMES combines data from high energy experiments **ε ≈ 1** with their data at 27 (now also 12) GeV

Conclusion: $R_A = R_D$ within 25%?

Shouldn't there be an A – dependence of R at low Q^2 ?

HERMES

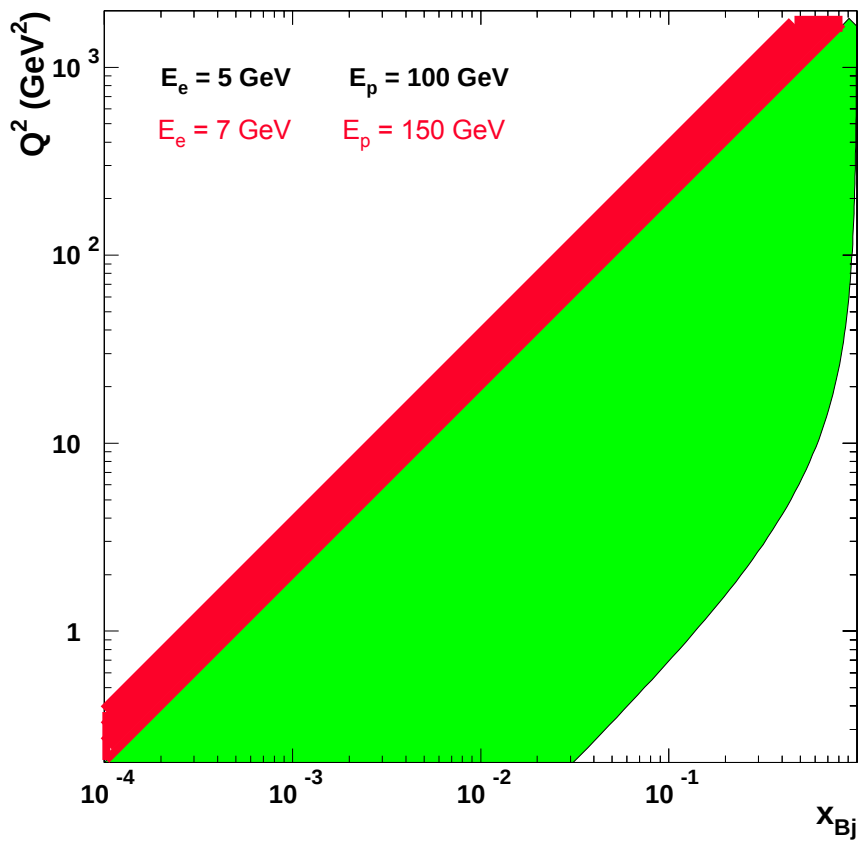


E. Garutti, Ph.D UvA 2003,

Kinematics at an Electron Ion Collider

eRHIC : up to a Center-of-Mass energy of 100 GeV
ELIC : up to a Center-of-Mass energy of 65 GeV

ELIC kinematics at E_{cm} = 45 GeV (E_{cm} = 65 GeV), and beyond the resonance region.



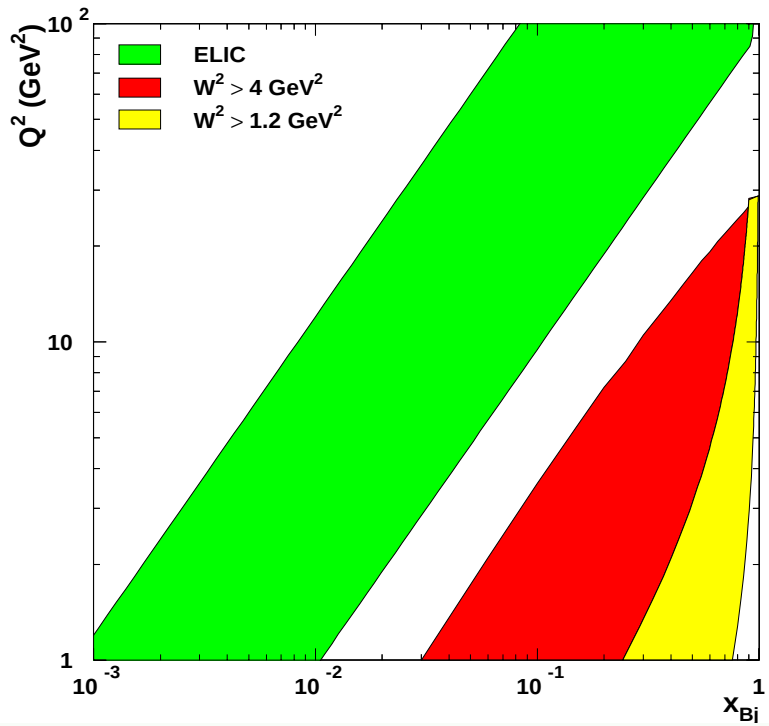
- Luminosity of up to 10^{35} cm^{-2} sec^{-1}
  - One day → 5,000 events/pb
- DIS Limit for $Q^2 > 1$ GeV^2 implies (Bjorken) x down to 5 times 10^{-4}
  - Significant results for 200 events/pb for inclusive scattering
- For $Q^2 > 10$ GeV^2 can reach x down to 5 times 10^{-3}
  - Typical cross sections still easily accessible (expect millions of DIS events!)
- Lower value of x scale as s^{-1}
  - → eRHIC option reaches x down to 2 times 10^{-4} (10^{-3}) for Q^2>1 (10)

Would like at least x ~ 5 times 10^{-3} to reach saturation region of nuclear shadowing

Kinematics for Rosenbluth Separations → F_L

No measurable nuclear effects seen in longitudinal structure functions in the DIS region to date. However, nuclear effects on gluon distributions predicted… (and sensitivity of longitudinal structure function to gluons known)

$\Delta\varepsilon > 0.3$ required



This plot for E_{cm} = 45 GeV

Can easily reach down to x < 10-3 for DIS kinematics

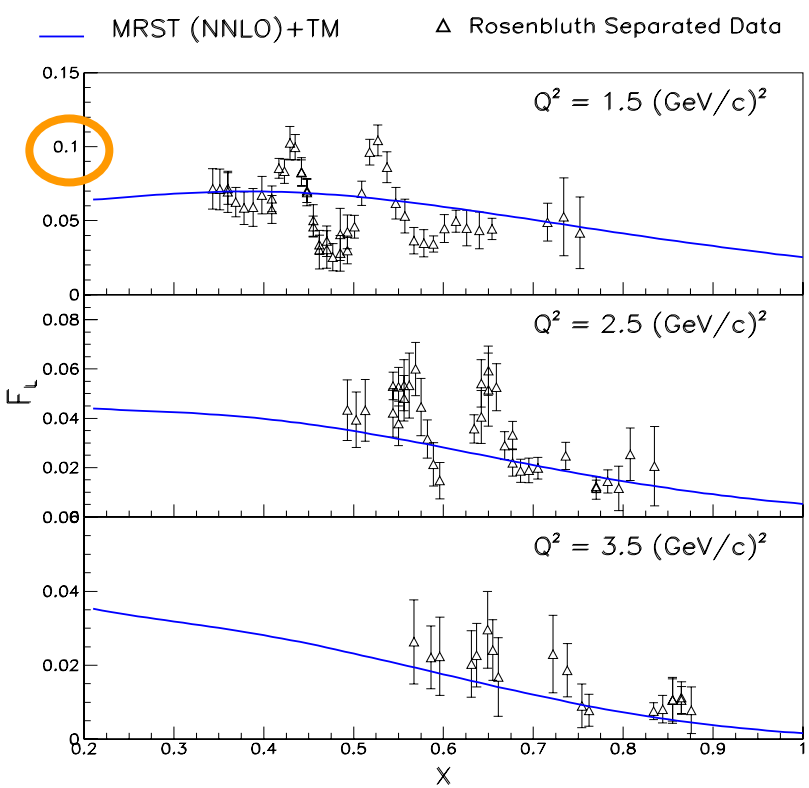
Lowest Order:

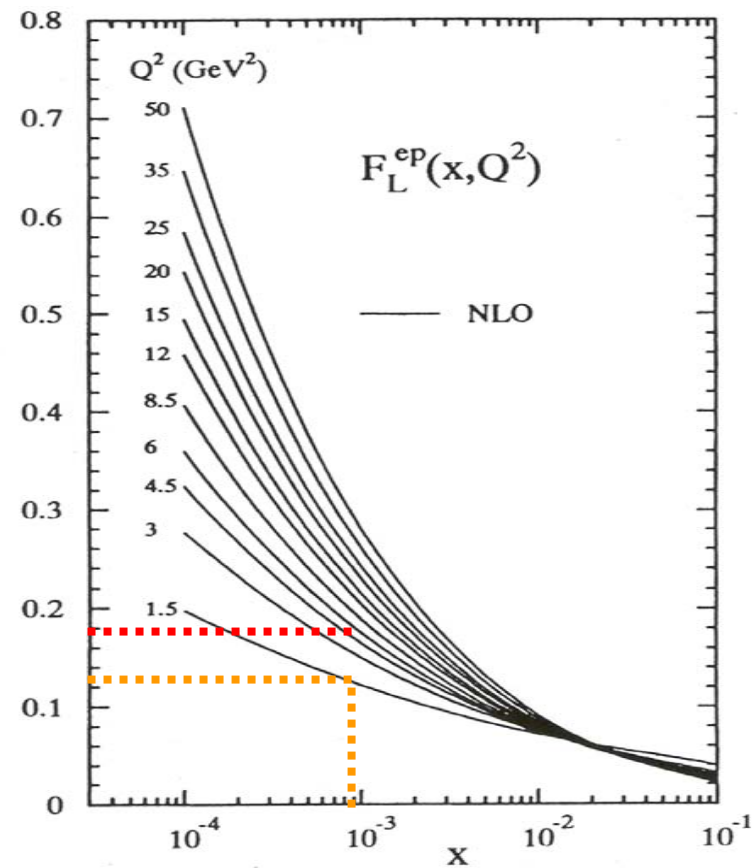
$$\int_0^1 dx F_L(x,Q^2) = \frac{\alpha_s(Q^2)}{4\pi}\left(\frac{4}{9}\int_0^1 dx F_2(x,Q^2) + \frac{2\sum e_q{}^2}{12}\int_0^1 dx\, x G(x,Q^2)\right)$$

known

Why $\Delta\varepsilon > 0.3$?

Example from 6-GeV JLab, where F_L was determined with good precision in the nucleon resonance region:





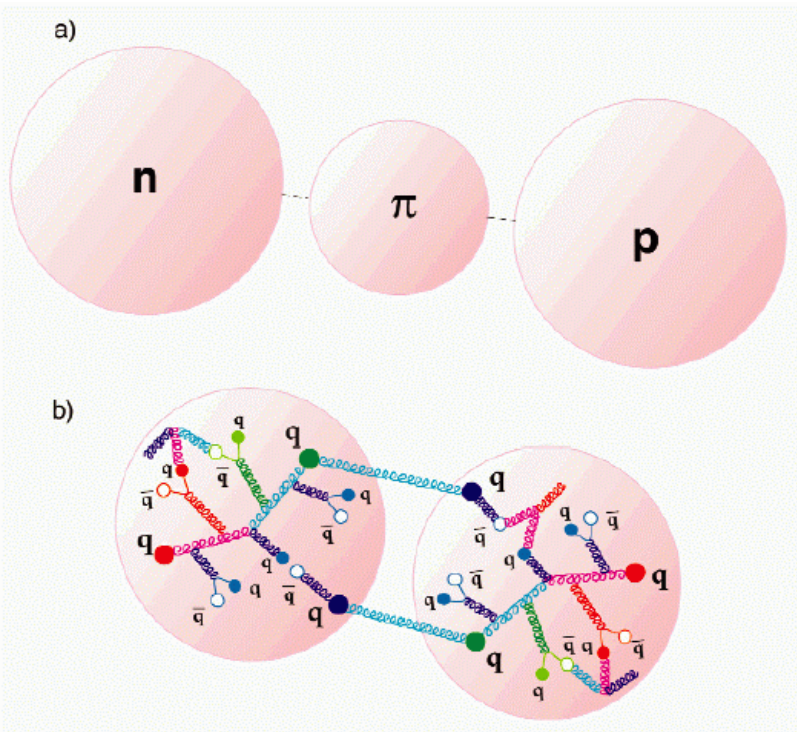
ΔF_L as small as 0.001!

F_L not small at low x, even for low Q^2 → Measurable effects?

(~10% predicted for ^{40}Ca/D at Q^2 = 4.0)

Nuclear Binding

How can one understand nuclear binding in terms of quarks and gluons?

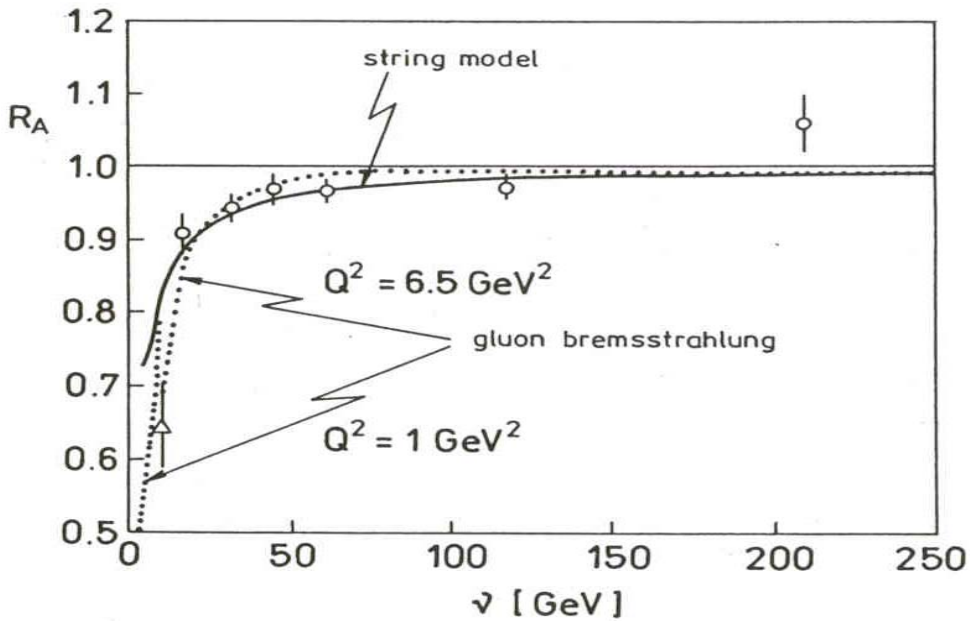


- Natural Energy Scale of QCD: O(100 MeV)
- Nuclear Binding Scale O(10 MeV)
- Does it result from a complicated detail of near cancellation of strongly attractive and repulsive terms in N-N force, or is there another explanation?

Complete spin-flavor structure of modifications to quarks and gluons in nuclear system may be best clue.

How to make progress?

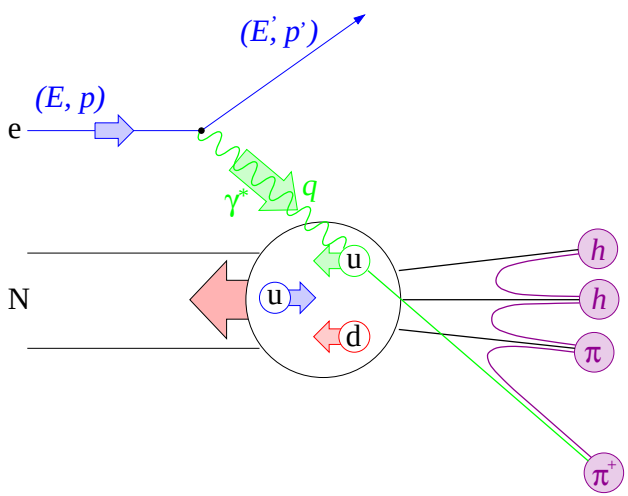
Use other well known result from EMC group:
No nuclear effects seen in semi-inclusive hadron production at large energy transfers.



Nuclear attenuation negligible for ν > 50 GeV → hadrons escape nuclear medium undisturbed

Can pick apart the spin-flavor structure of EMC effect by technique of flavor tagging, in the region where effects of the space-time structure of hadrons do not interfere (large ν!)

How Do Quarks and Gluons form Hadrons?



In semi-inclusive DIS a hadron h is detected in coincidence with the scattered lepton

Study quark-gluon substructure of

- nucleon target
  → parton distribution functions $q(x,Q^2)$
- hadron formation (or hadronization)
  → fragmentation functions $D(z,Q^2)$

Process both of interest in its own right and as a tool (see also next slide)

$$\frac{1}{\sigma}\frac{d\sigma_h}{dz} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

Hadronization as a Tool: Example from HERMES

Quark Polarization from Semi-Inclusive DIS

- Goal: Flavor Separation

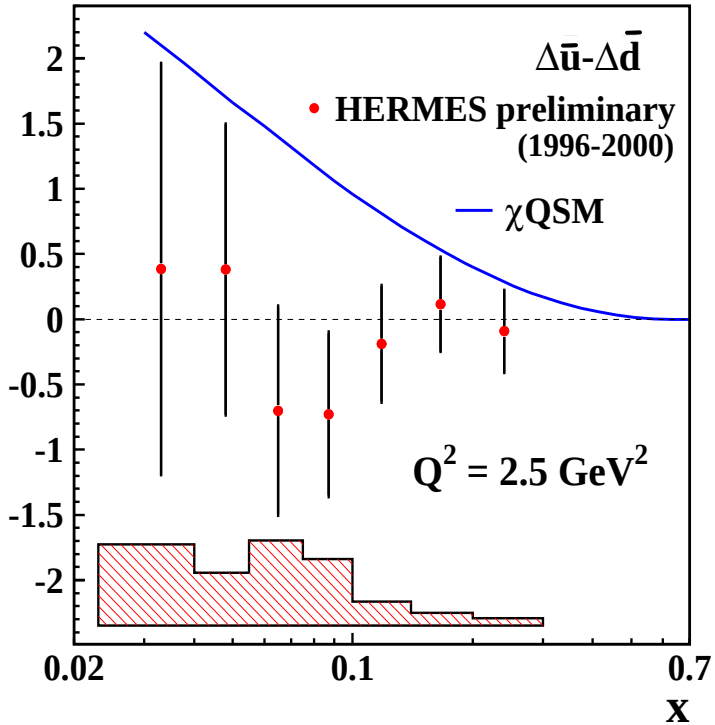
  of quark and antiquark helicity distributions

- Technique: Flavor Tagging

  The flavor content of the final state hadrons is related to the flavor of the struck quark through the agency of the fragmentation functions

$$\frac{d\sigma_h^{\uparrow\downarrow}}{dz} - \frac{d\sigma_h^{\uparrow\uparrow}}{dz} = \sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)$$

First 5-flavor fit to $\Delta q(x)$
($\Delta s(x) = \Delta\bar{s}(x)$ assumed)



Chiral-Quark Soliton Model
→Light sea quarks polarized

(Data consistent with zero)

Hadronization as a Tool: Pick Apart EMC Effect?

Strategy: Select Energy Loss ν > 50 GeV

Select hadrons with large elasticity z (=E_h/ν) to reduce space-time effect complications

Use positive and negative hadrons and fragmentation functions

to pick apart nuclear effects on u and d quarks at large x?

to pick apart nuclear effects on valence and sea quarks?

Does one benefit from π/K separation to disentangle the sea?

(or does the simple flavor tagging ansatz break down?)

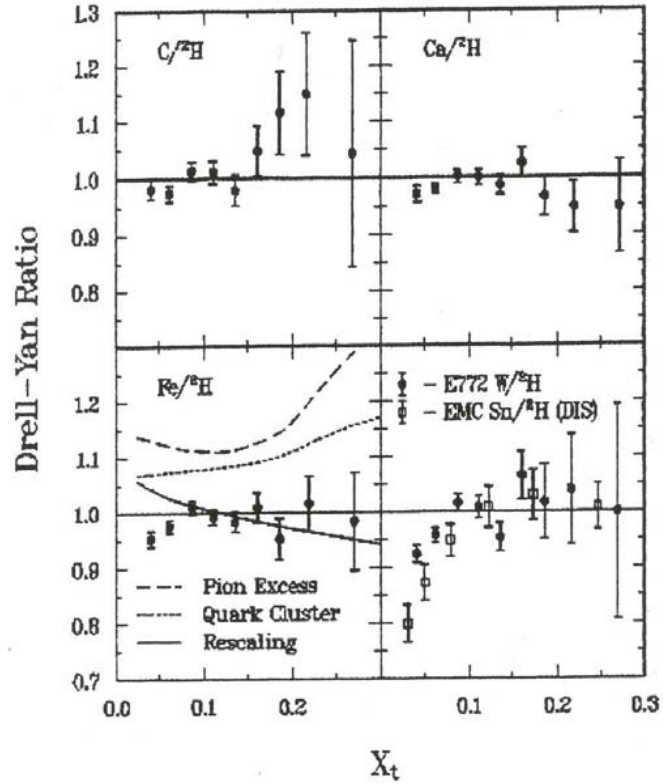
Many questions remain…

One good quality check: Drell Yan data constrain nuclear modifications to sea quarks!

Sea-Quarks in a Nucleus

Drell-Yan → No Nuclear Modifications to Sea-Quarks found at x ~ 0.1

Where is the Nuclear Binding?



Flavor tagging can also (in principle) disentangle sea-quark contributions

Gluons in a Nucleus

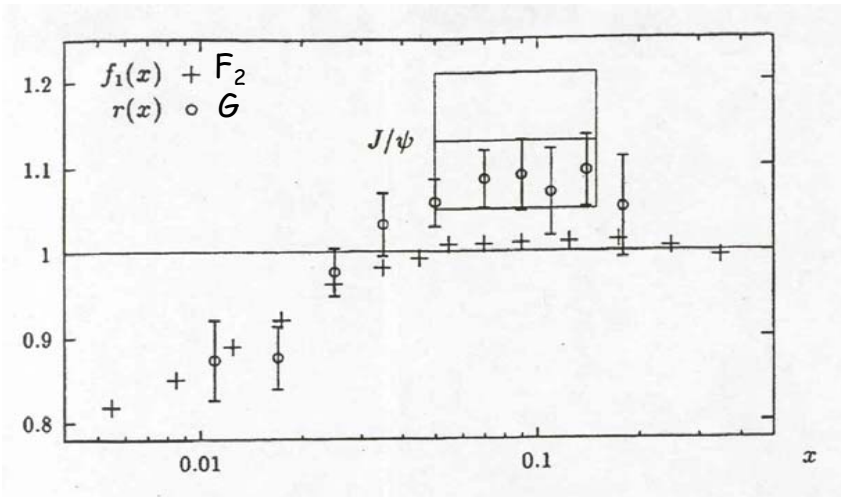
Constraints on possible nuclear modifications of glue come from

1) Q^2 evolution of nuclear ratio of F_2 in Sn/C (NMC)
2) Direct measurement of J/Psi production in nuclear targets

Antje Bruell's Presentation

No obvious technical problems for nuclear ratio measurements at the EIC:

1) Can normalize to the most precise ratios from NMC (+ now also JLab)
2) Radiative Corrections now better under control (+ can be measured or controlled with photon tags) → see next slide

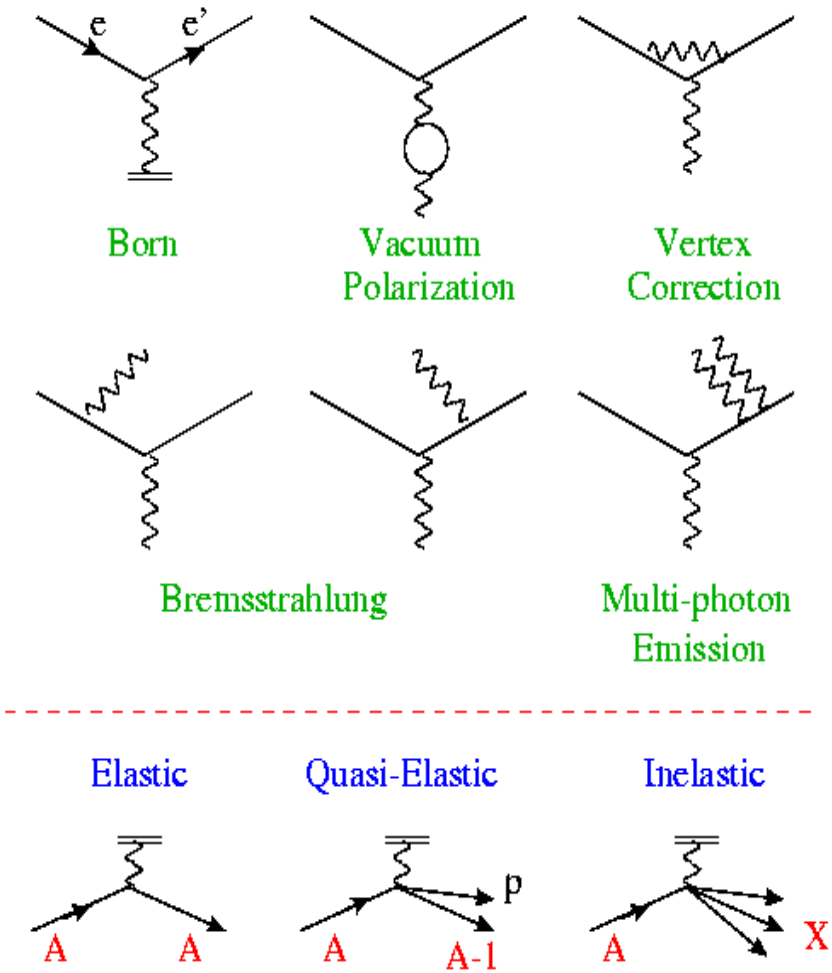


Compatible with EMC effect?

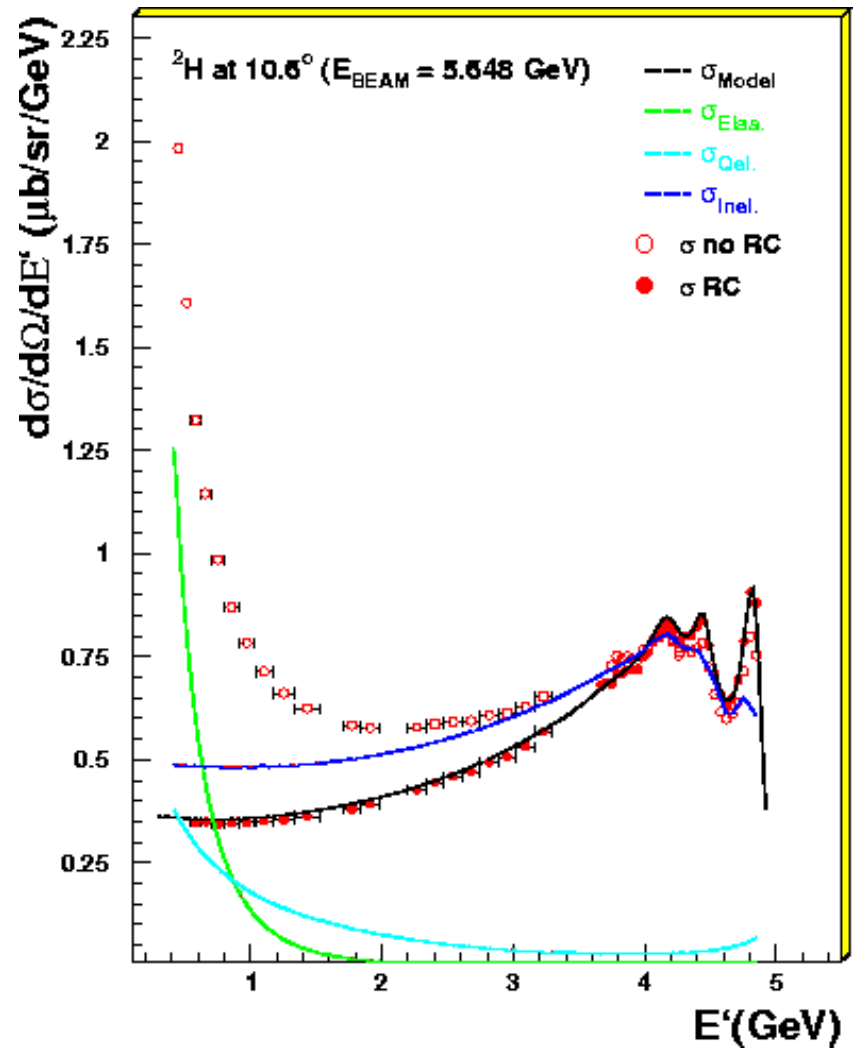
Precise measurements possible of

- Nuclear ratio of Sn/C (25 GeV)
- J/Psi production

Radiative Corrections Should be Well Under Control for EIC!



E99-118 Radiative Correction Tour de Force! (JLab-6 GeV)



Summary

- A High Energy Electron Ion Collider seems optimal to pick the Nuclear EMC effect apart (valence vs. sea, up vs. down) by using “flavor tagging”.
- The flavor tagging procedure should give results consistent with Drell Yan constraints for the sea.
- EIC kinematics allows to reach the x-region where saturation of shadowing sets in over a large range of Q^2. Statistics is not an issue for a luminosity of 10^{33} (or larger).
- Measurements of predicted 10% nuclear effects in longitudinal structure functions seem possible.
- Normalizations are well controlled by making use of the very precise ratio data (NMC) existing.
- Radiative effects should be better controlled due to present efforts at existing facilities like HERMES or JLab.

→ Should be “easy” if flavor tagging technique works!