Unique Phenomena in Nuclear High –Energy Lepton Scattering

How does the quark structure of the nucleon get modified in the nuclear medium?

- Introduction
- Review of present understanding
- What might be possible with 12 GeV Jlab?
- Some experimental considerations
- Summary

Thanks to Rolf Ent

Primer on Deep inelastic Scattering and the Parton Model

Inclusive: $F_2(x) = \Sigma_i e^2_i [q_i(x,Q^2) + \bar{q}_i(x,Q^2)]$

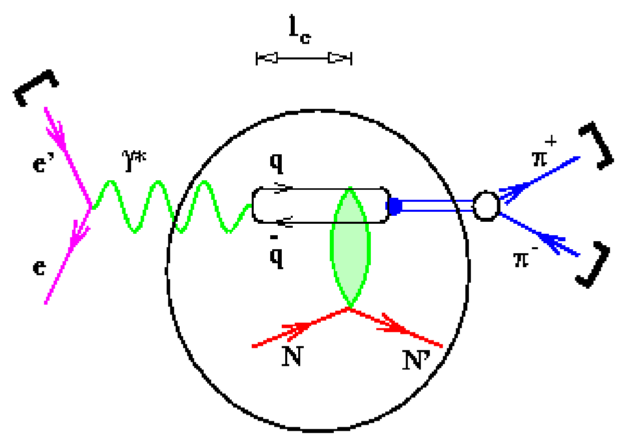
Semi-inclusive: **Factorization**

$$dN/dz \cong \Sigma_i e_i^2 [q_i(x,Q^2) D_{qi}^h(z,Q^2) + \bar{q}_i(x,Q^2) D_{qi}^h(z,Q^2)]$$

$\bar{q}_i(x,Q^2)$ – pdf, e.g. CTEQ

$D_{qi}^h(z,Q^2)$ – fragmentation function

$Z = E_h/\nu$

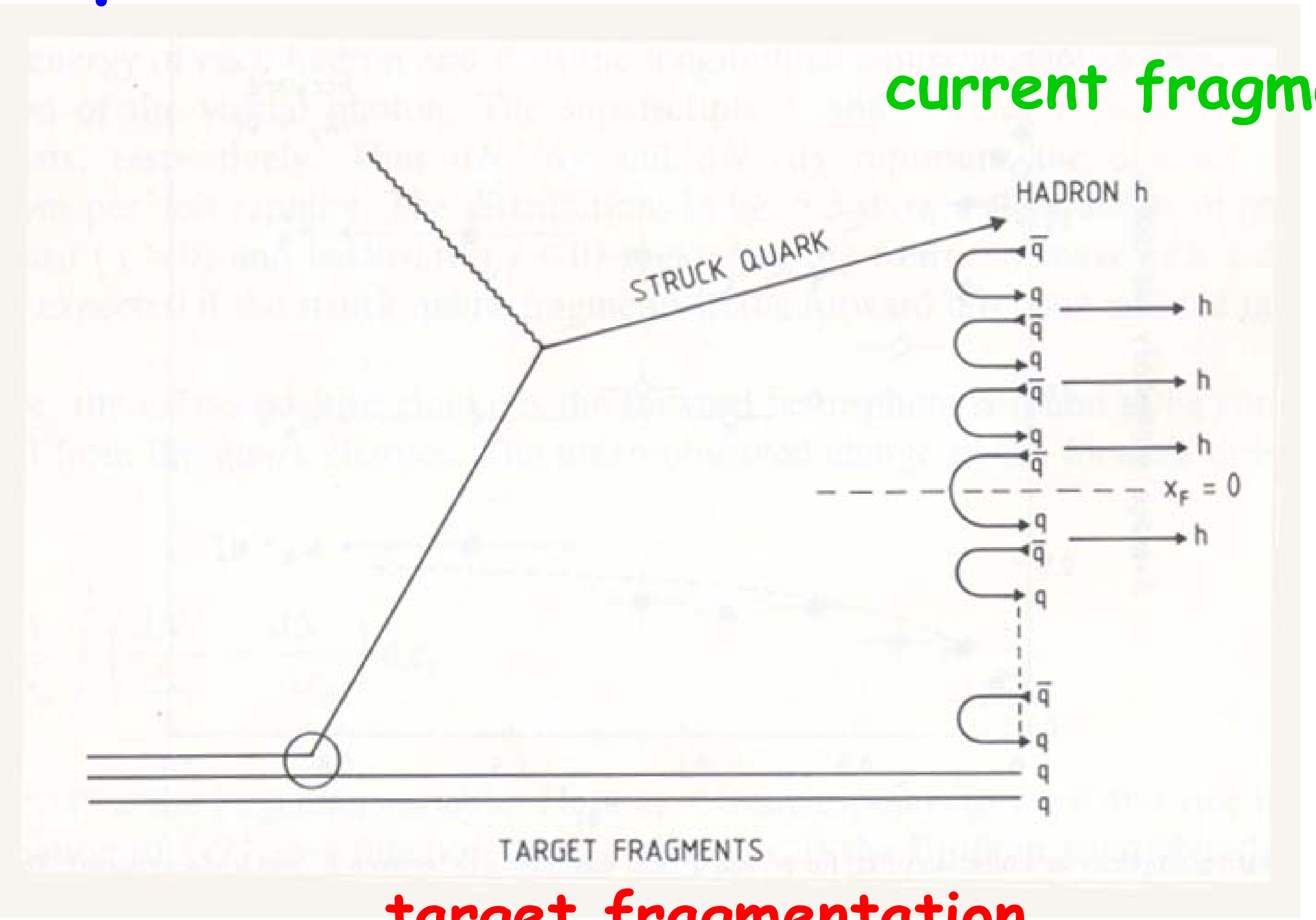


Favored FF: $zD_u^{\pi+} = 0.7\,(1-z)^{0.75}$

Unfavored FF: $zD_u^{\pi-} = (1-z)/(1+z)\, zD_u^{\pi+}$

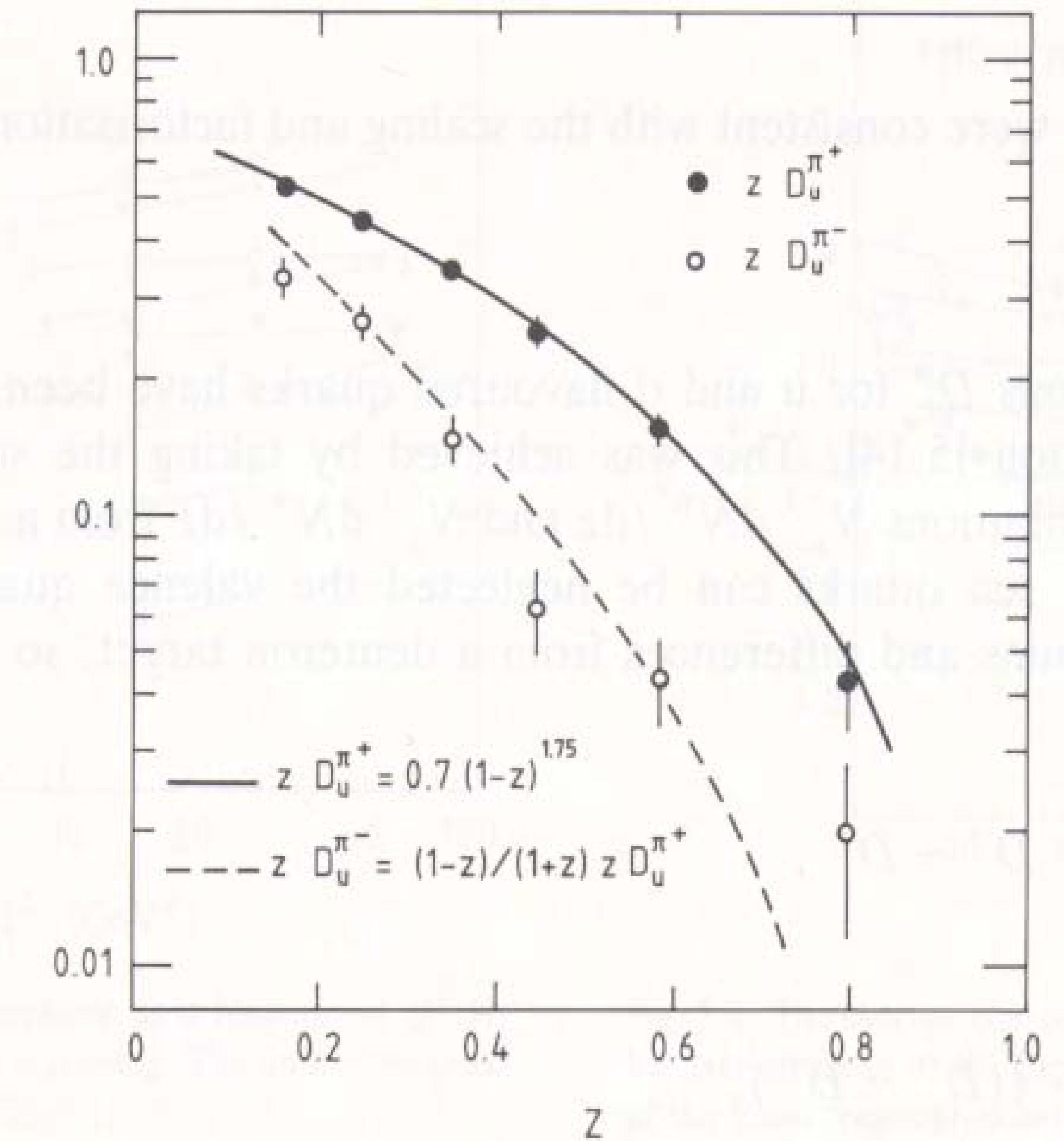
Complete hadronic final state

current fragmentation



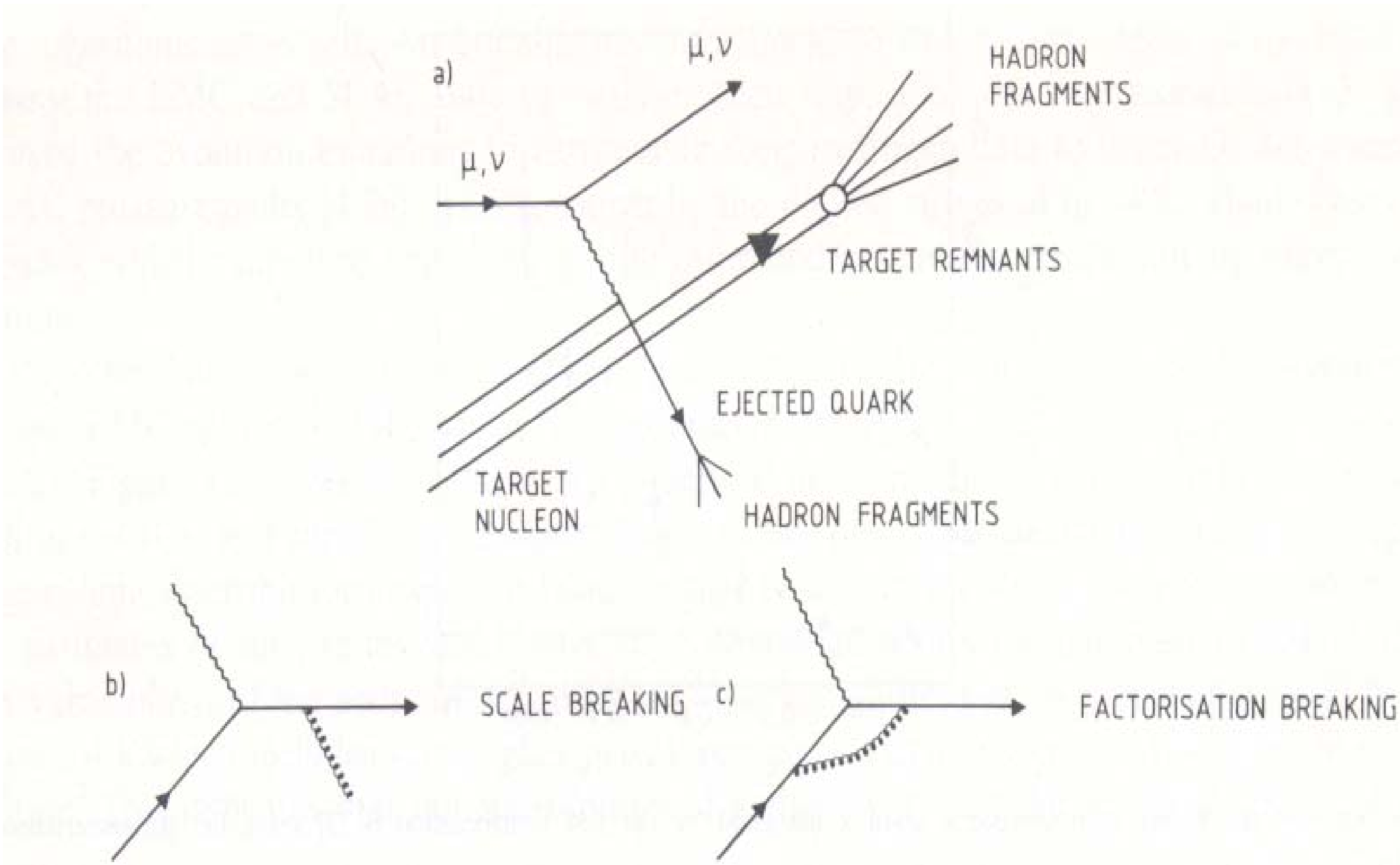
target fragmentation

Favored, unfavored fragmentation functions

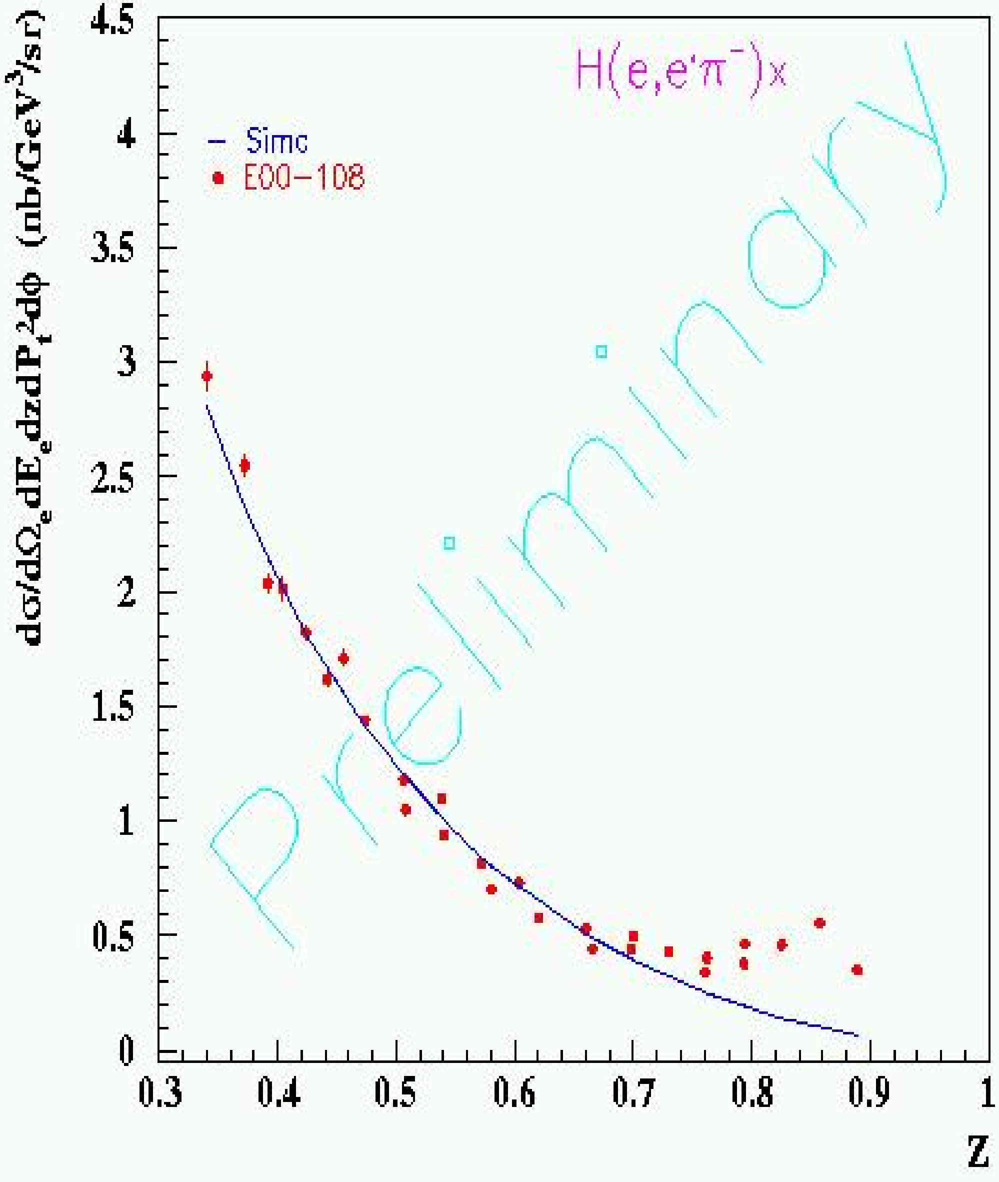


EMC data

Corrections to Impulse Approximation



Q^2 dependence



E00-108 data
E_0 =5.5 GeV

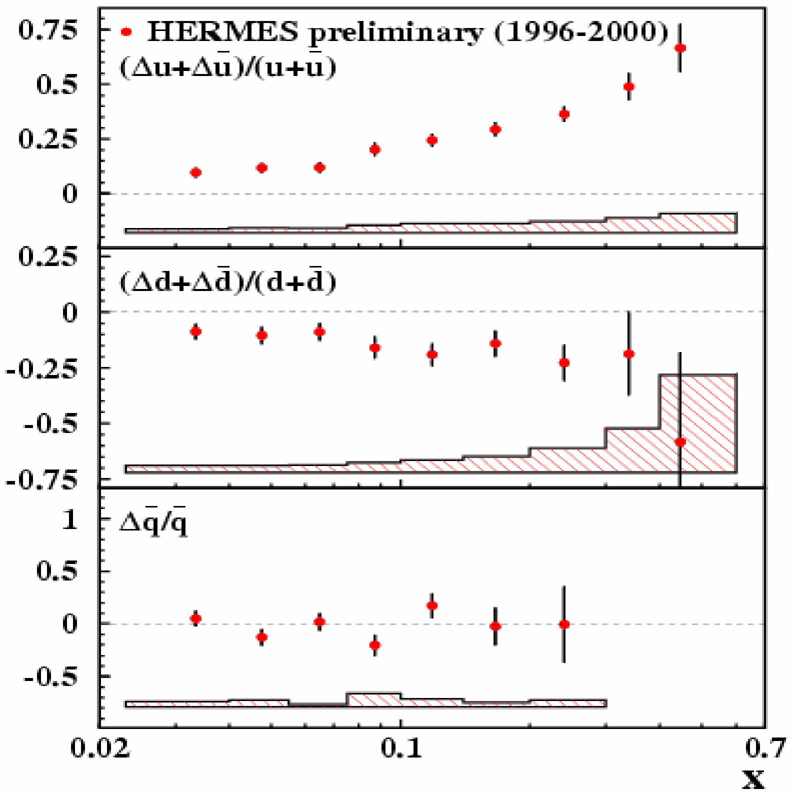
Add **fragmentation** **process to SIMC**

Input parameters:

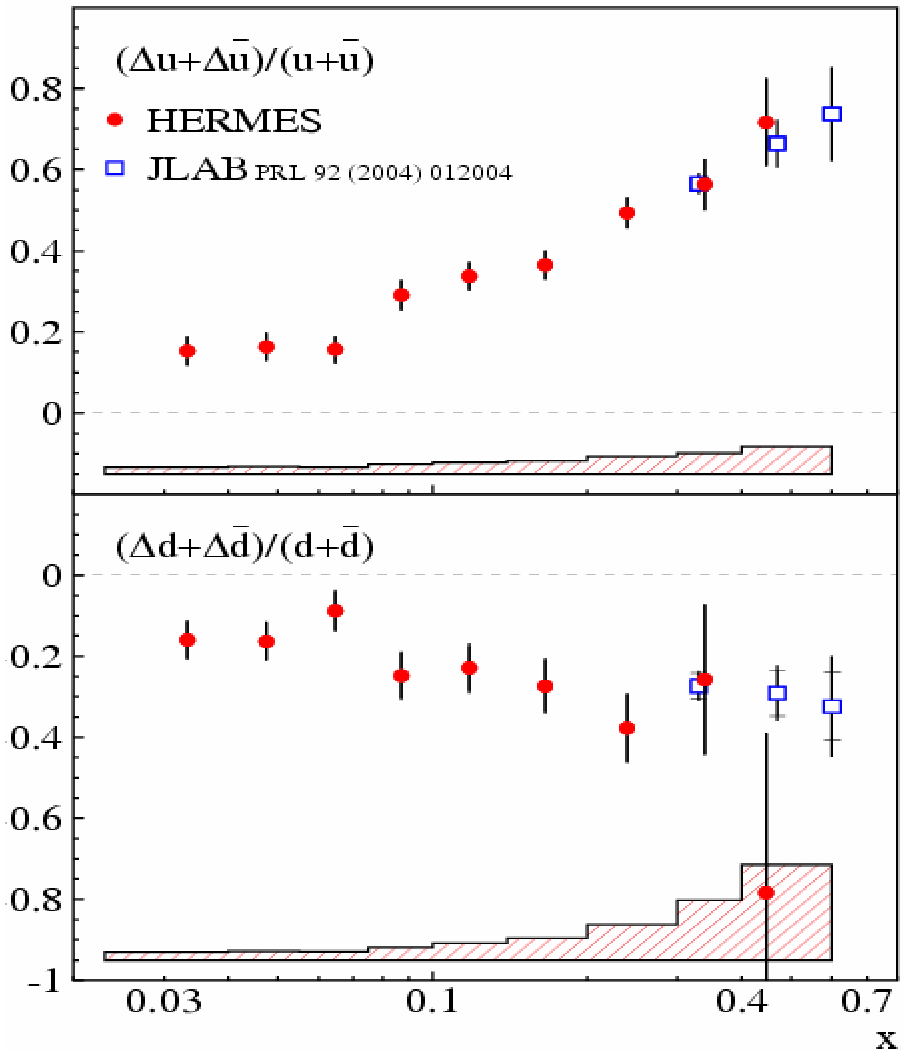
Pdf's (q_i, q_i)	: CTEQ5M
FF's (D_{qi})	: Binnewies et al., given as ($D^+ + D^-$)
D^-/D^+	: from HERMES
P_t (b)	: from HERMES
ϕ	: assume no ϕ dep.

x ~ 0.3

HERMES Semi-Inclusive Data



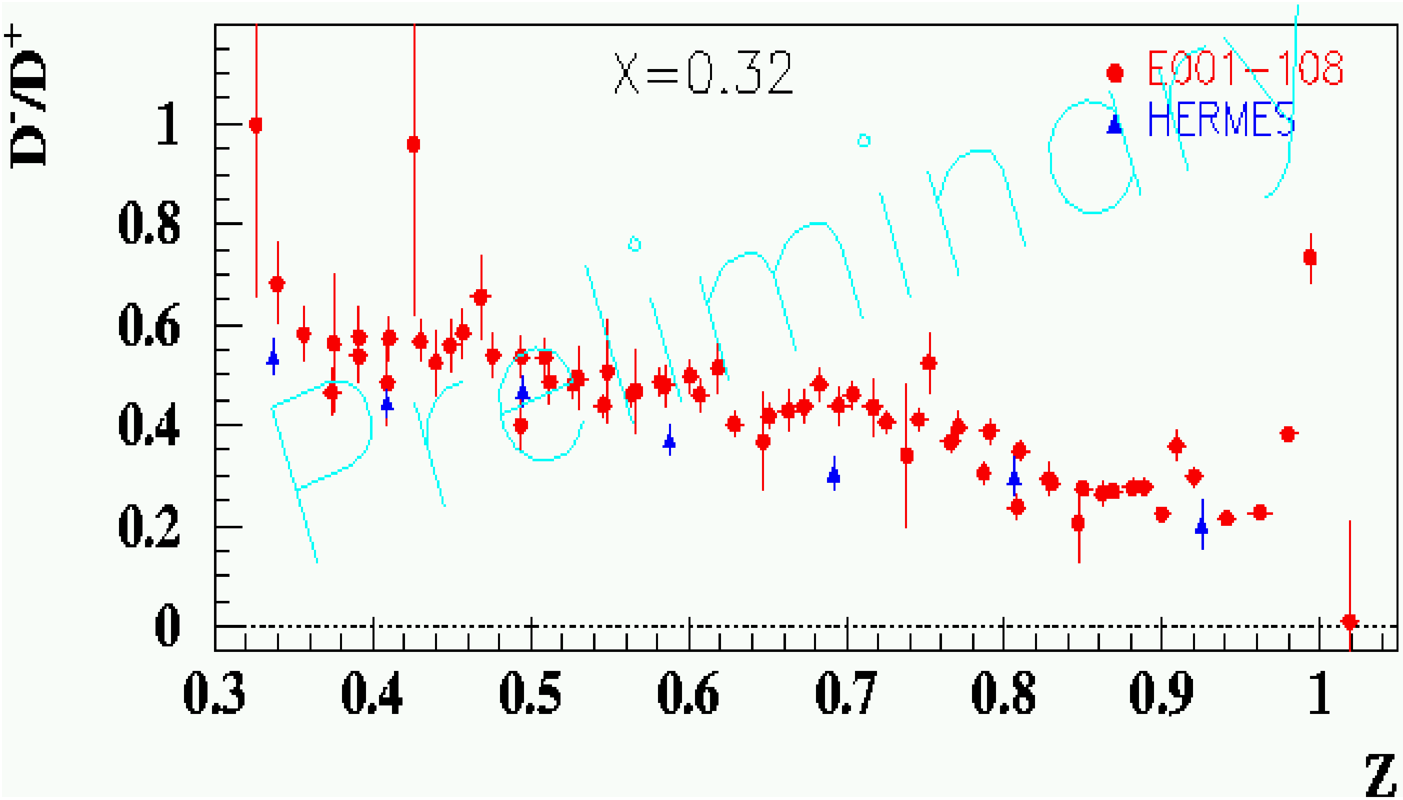
HERMES vs. Jlab data



Using inclusive A1p and A1n Jlab data

E00-108 data

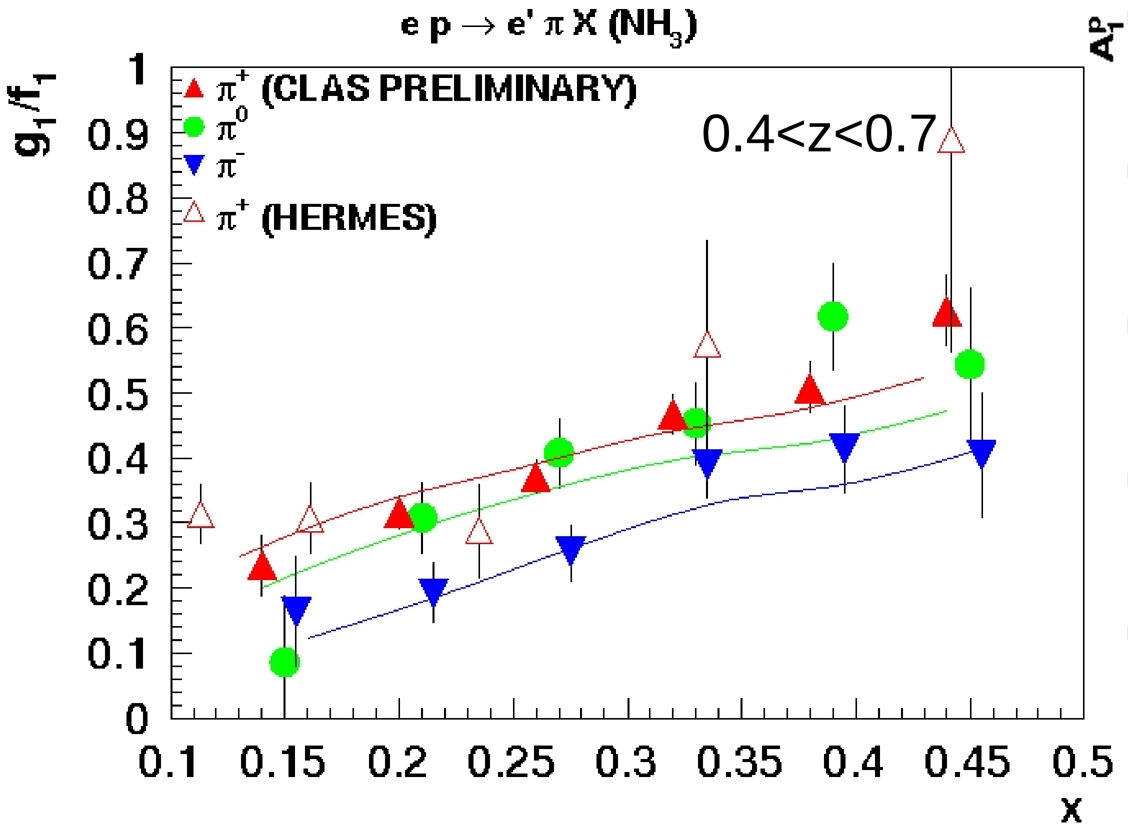
Experiment ran in August 2003
→ Only first-pass data analysis
→ No Q^2/FSI/nuclear corrections yet

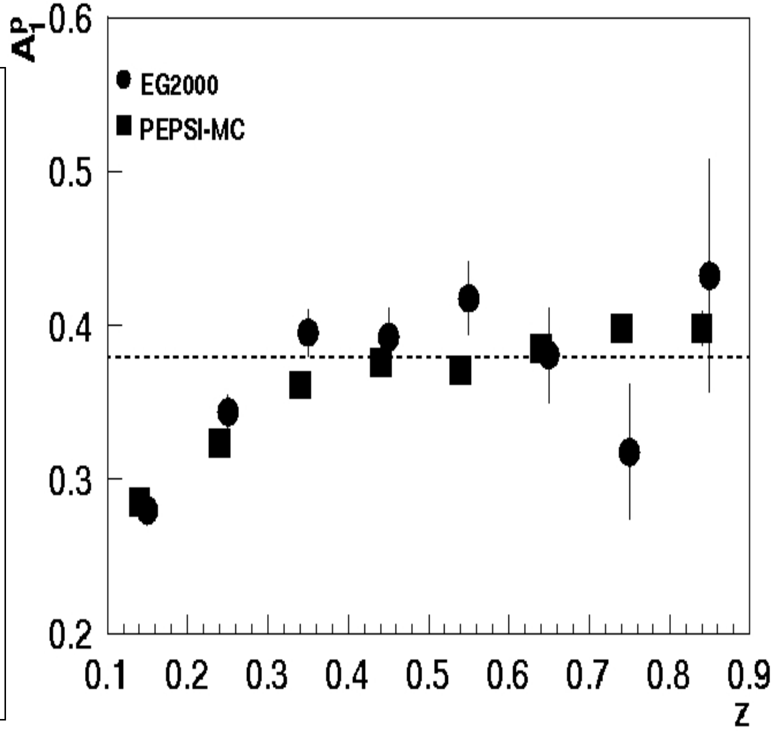


A_1^p shows no significant Q^2 and z dependence

$$A_1^p \approx \frac{1}{P_B P_T f D_{LL}(y)} \frac{N^{+-} - N^{++}}{N^{+-} + N^{++}}$$

ep $\rightarrow$ **e' π^+ X** (E_e =5.7 GeV, M_X > 1.1)

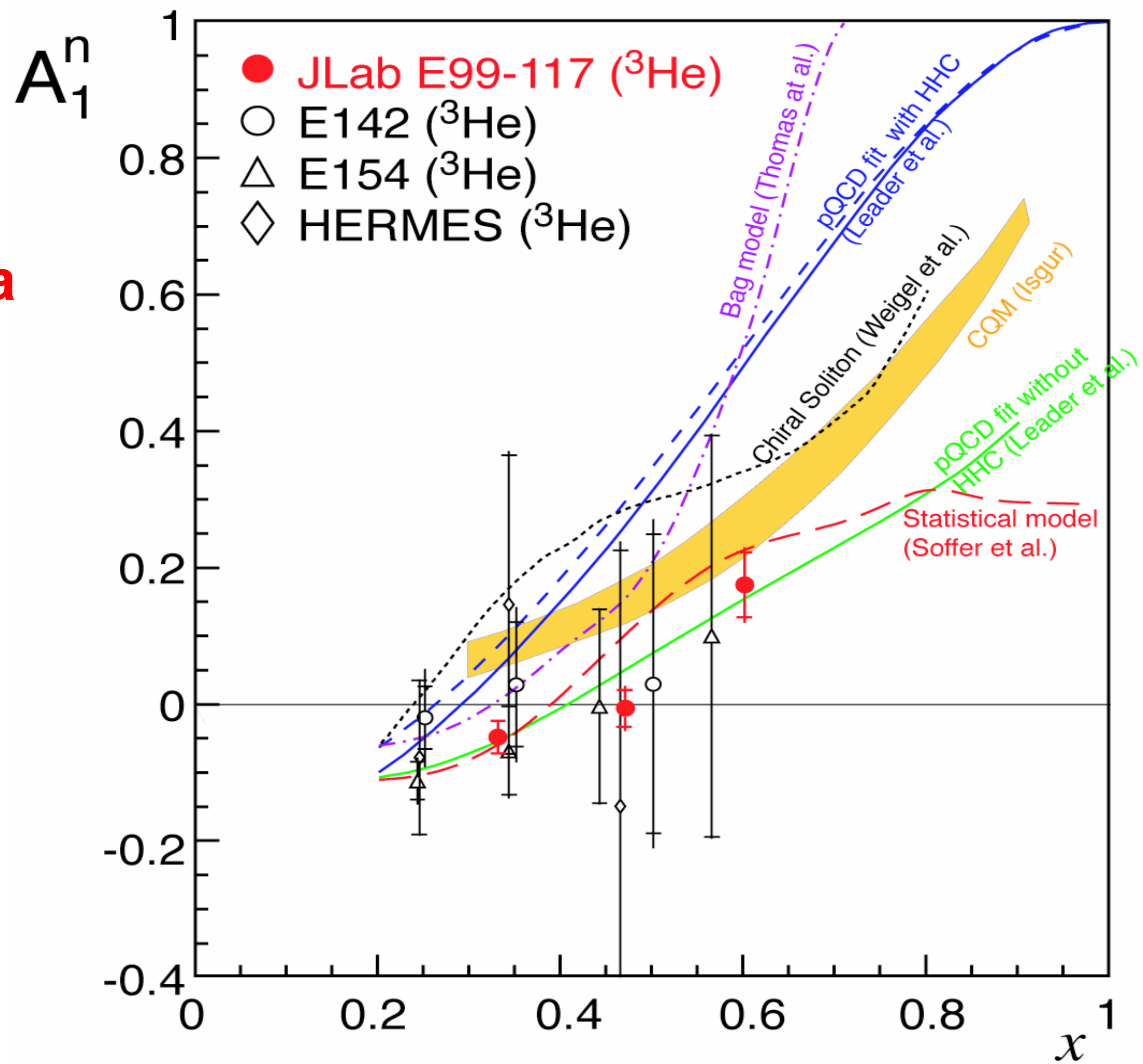




- **x** dependence of CLAS **A_1^p** (A_2=0) consistent with HERMES data and factorization.
- No z-dependence of **A_1^p** observed above z=0.4

$^3\overrightarrow{He}$ Data Support the Validity of Applying Parton Model at 6 GeV

Hall A E99-117 data



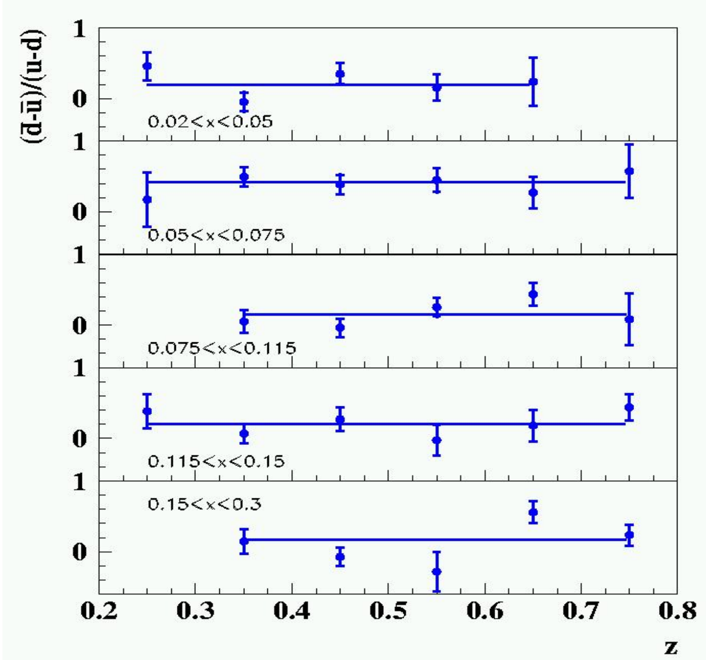
R. G. Milner

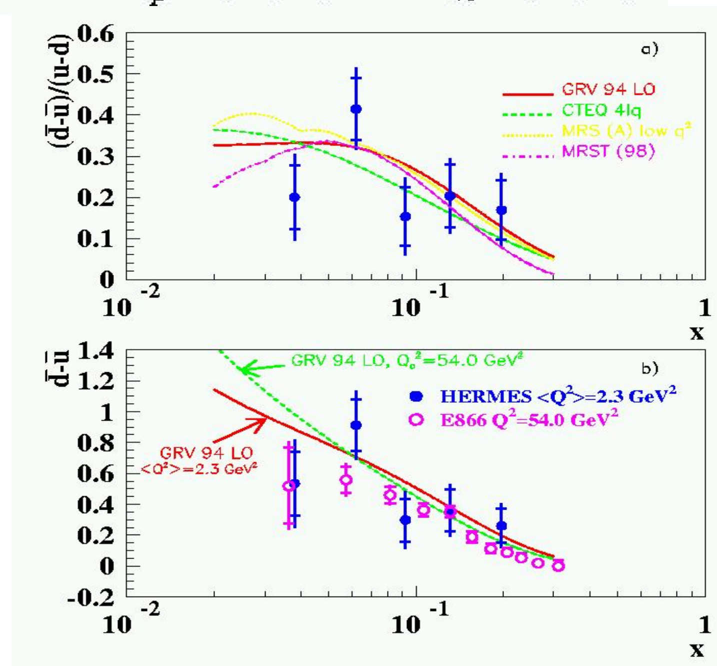
Low-Energy Factorization

HERMES Collaboration,
PRL 81, 5519 (1998)

Flavor Asymmetry of the Light Quark Sea

$$\frac{\bar{d}(x)-\bar{u}(x)}{u(x)-d(x)} \sim f(D^{+}(z)/D^{-}(z))\frac{N_p^{\pi^-}(x,z)-N_n^{\pi^-}(x,z)}{N_p^{\pi^+}(x,z)-N_n^{\pi^+}(x,z)}$$





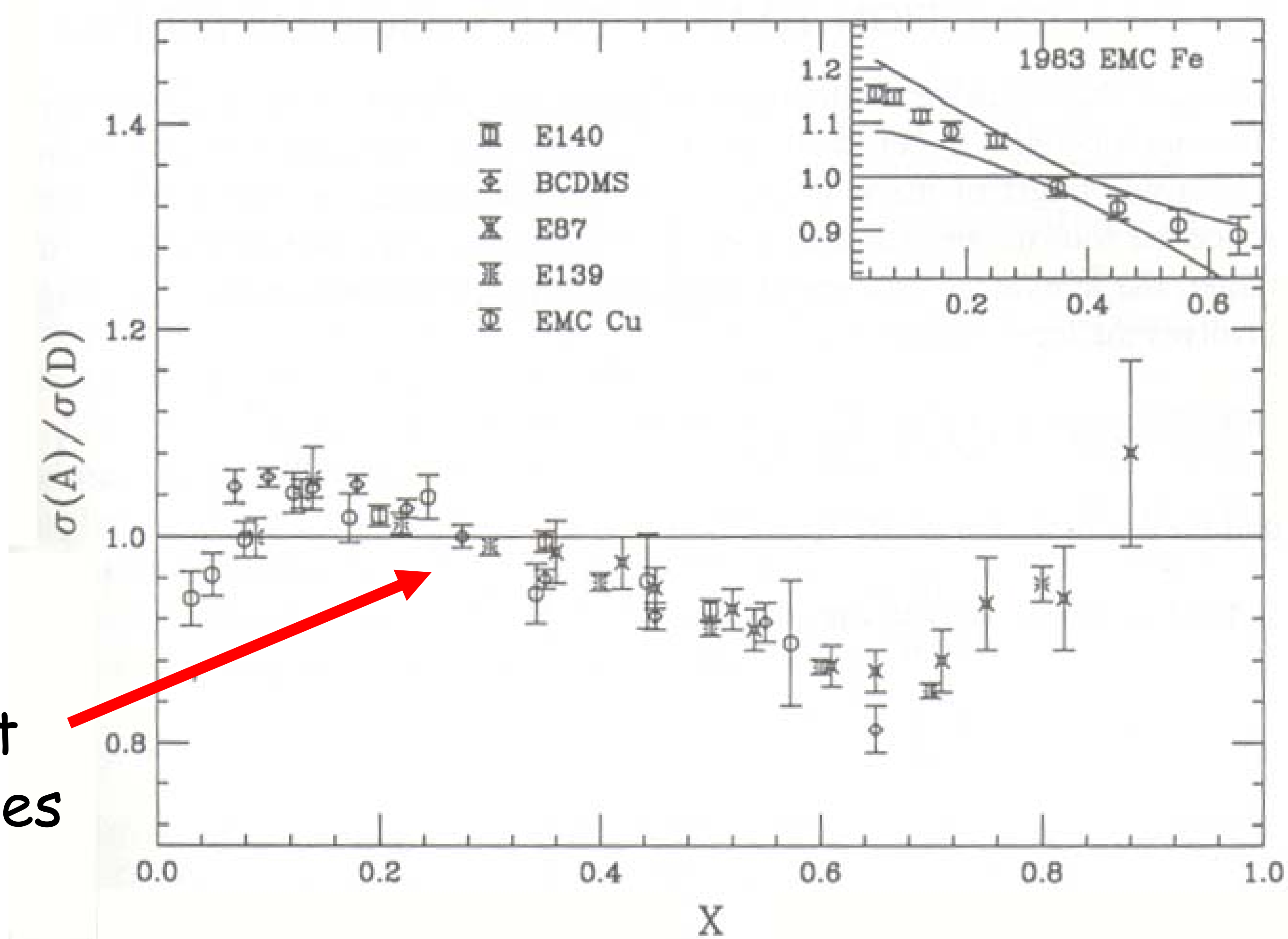
- Data do, within statistics, confirm independence of x and z dependence, for z > 0.25
- x ~ 0.1, Q^2 ~ 2.3 GeV^2 → W ~ 5 GeV
- HERMES data at Q^2 ~ 2.3 GeV^2 agree well with FNAL Drell-Yan data at Q^2 = 54 GeV^2

Conclusions

- Parton model applied to Jlab 6 GeV data works surprisingly well
  - inclusive
  - semi-inclusive
  - duality
- Encourage more extensive experimental program on nucleon
  - x, Q^2, z, x_F dependence
  - test factorization
  - measure fragmentation functions
- Establish experimentally regime where parton model can be applied successfully
- Seek understanding of parton scattering at 6 GeV with HERMES and other data at higher energies

DIS from Nuclei

Geesaman, Saito, Thomas

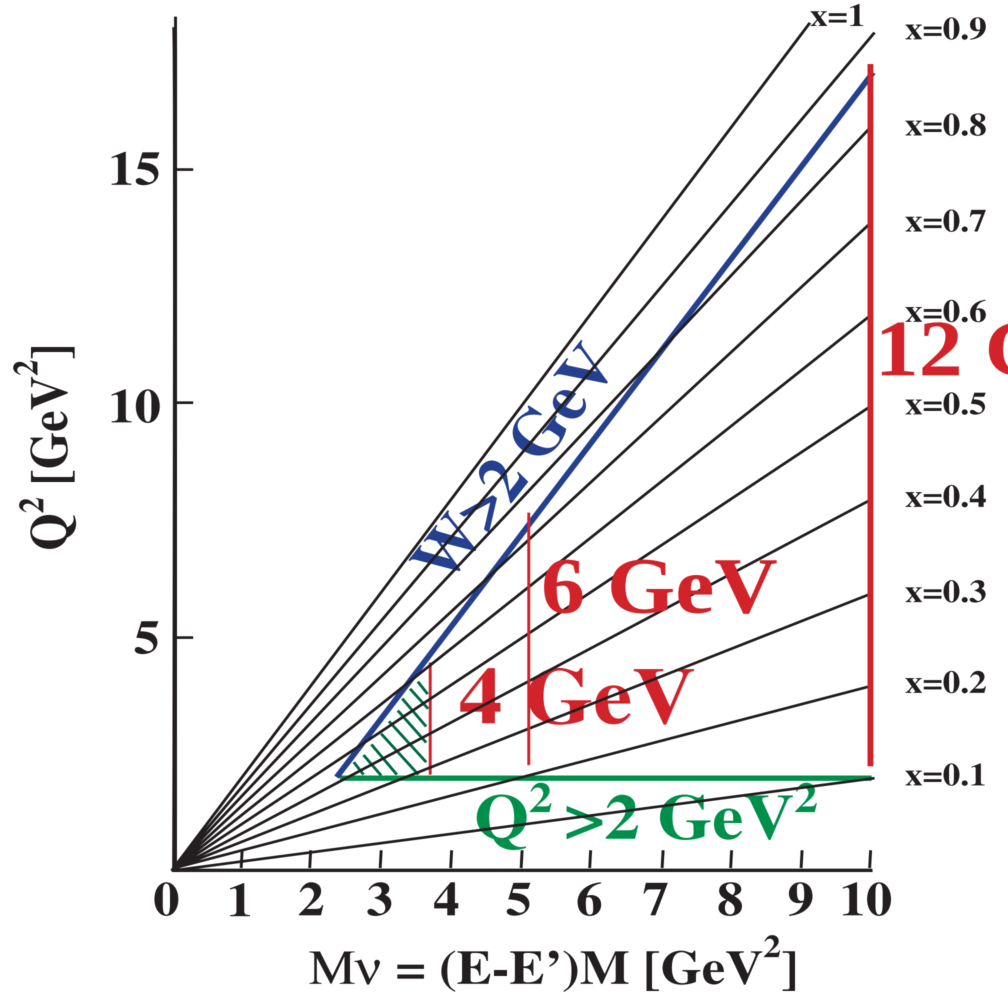


Effect vanishes

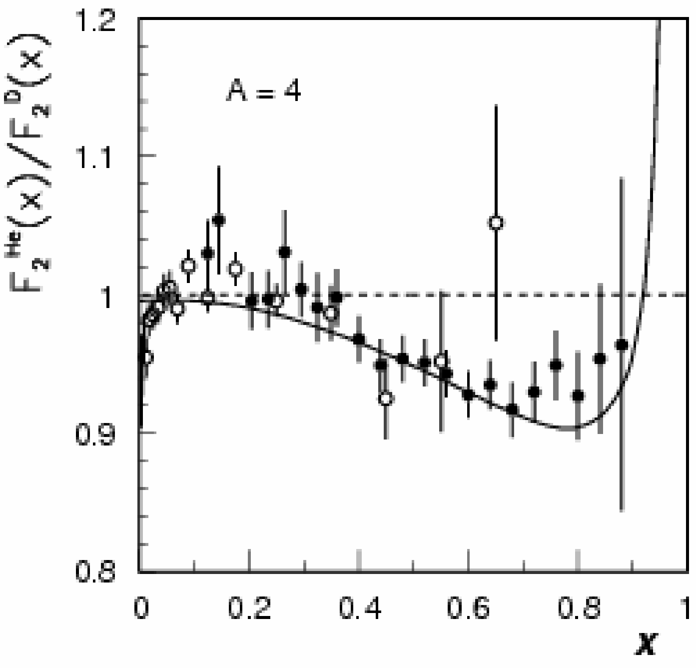
Jlab accessible
Q^2 ~ 1-10 GeV^2

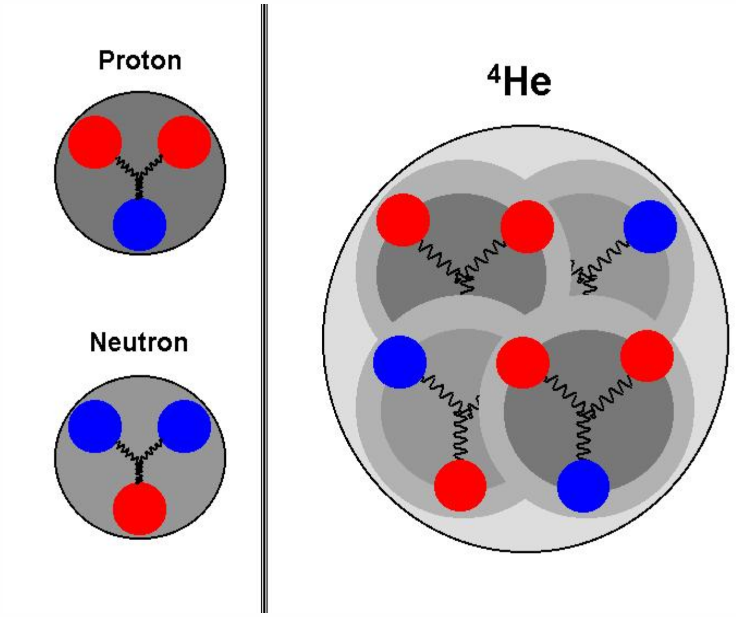
Enhanced Access to the DIS Regime With increased Energy

- 12 GeV will access quarks for x > 0.1



EMC effect significant in light nuclei



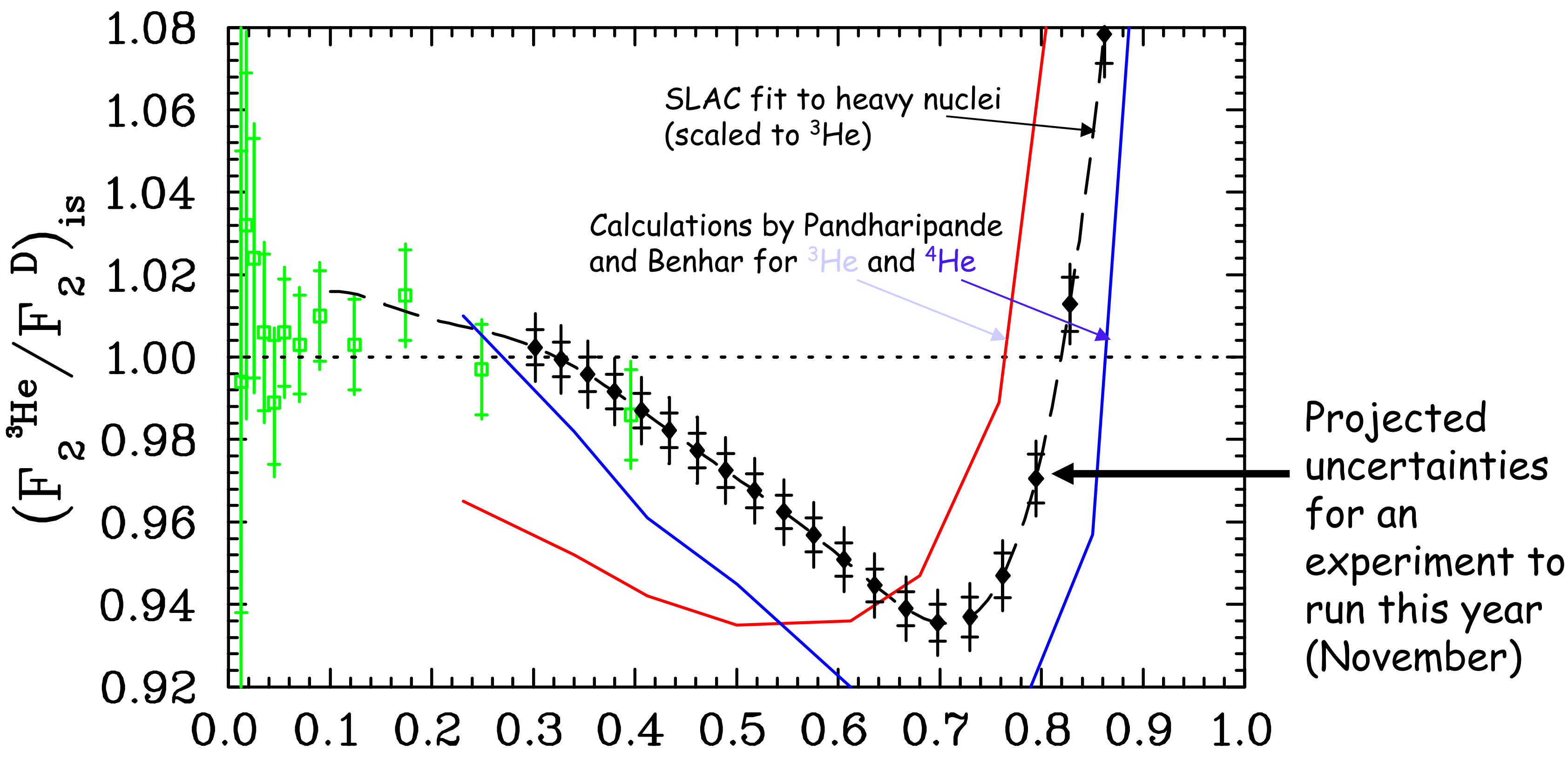


EMC Effect in ^{3}He and ^{4}He

The Nuclear EMC effect shows that quarks behave differently in nuclear systems.
It has been extensively measured in A>8 nuclei, but current data do not differentiate between models with either an A-dependence or a ρ-dependence.

→ Measure the shape in very light nuclei to distinguish

→ Test models of the EMC effect in exact few-body calculations



Theoretical considerations

- multiquark clusters
- dynamical rescaling: $Q^2 \longrightarrow \xi_A Q^2$
- nuclear binding: $\langle \varepsilon_{Fe} \rangle = -26$ MeV
- N-N correlations: SRCs important at high x
- role of virtual pions: ~5% enhancement at x=0.15

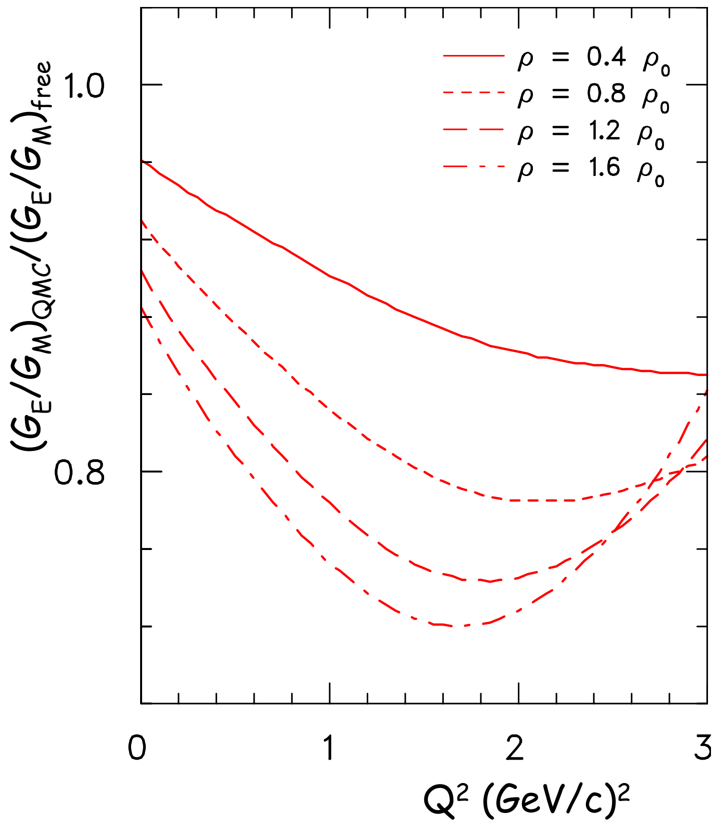
  no evidence of antiquark enhancement in nuclei

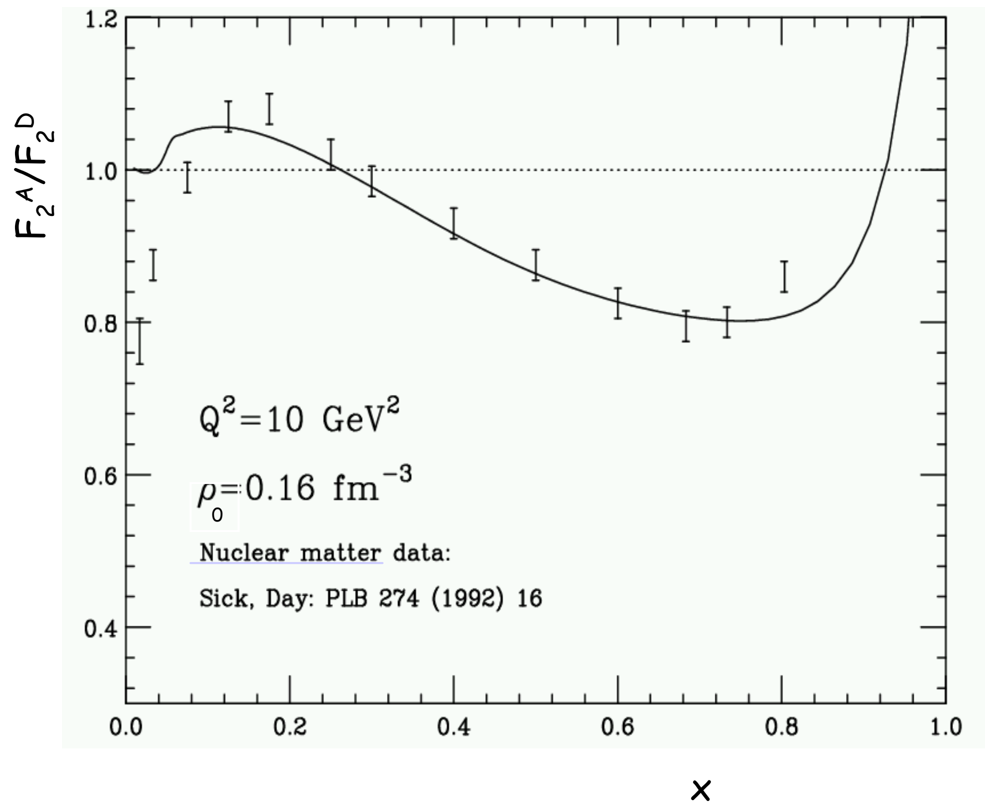
- Explanation of EMC effect relates to fundamental question of how the quark structure of nucleon is modified in the nuclear medium

- Many possibilities, no consensus

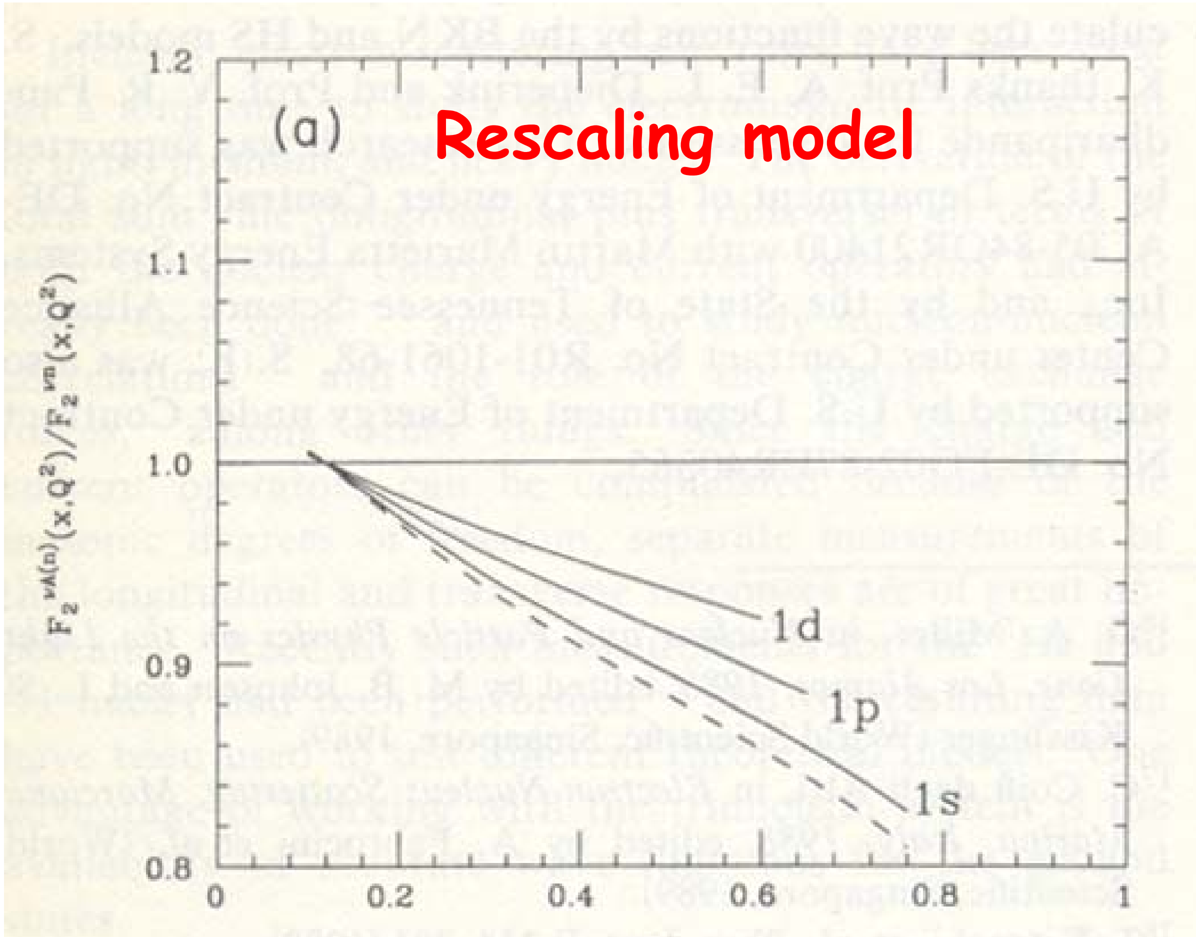
Quarks in Nuclear Physics

Quark-Meson Coupling (QMC) Model (Thomas et al.): quark's response to mean scalar and vector field (similar to quantum hadrodynamics for nucleon's response) → quark substructure of nucleon irrelevant for bulk properties of nucleus, but is relevant for form factor and structure functions





Nuclear dependence of EMC Effect

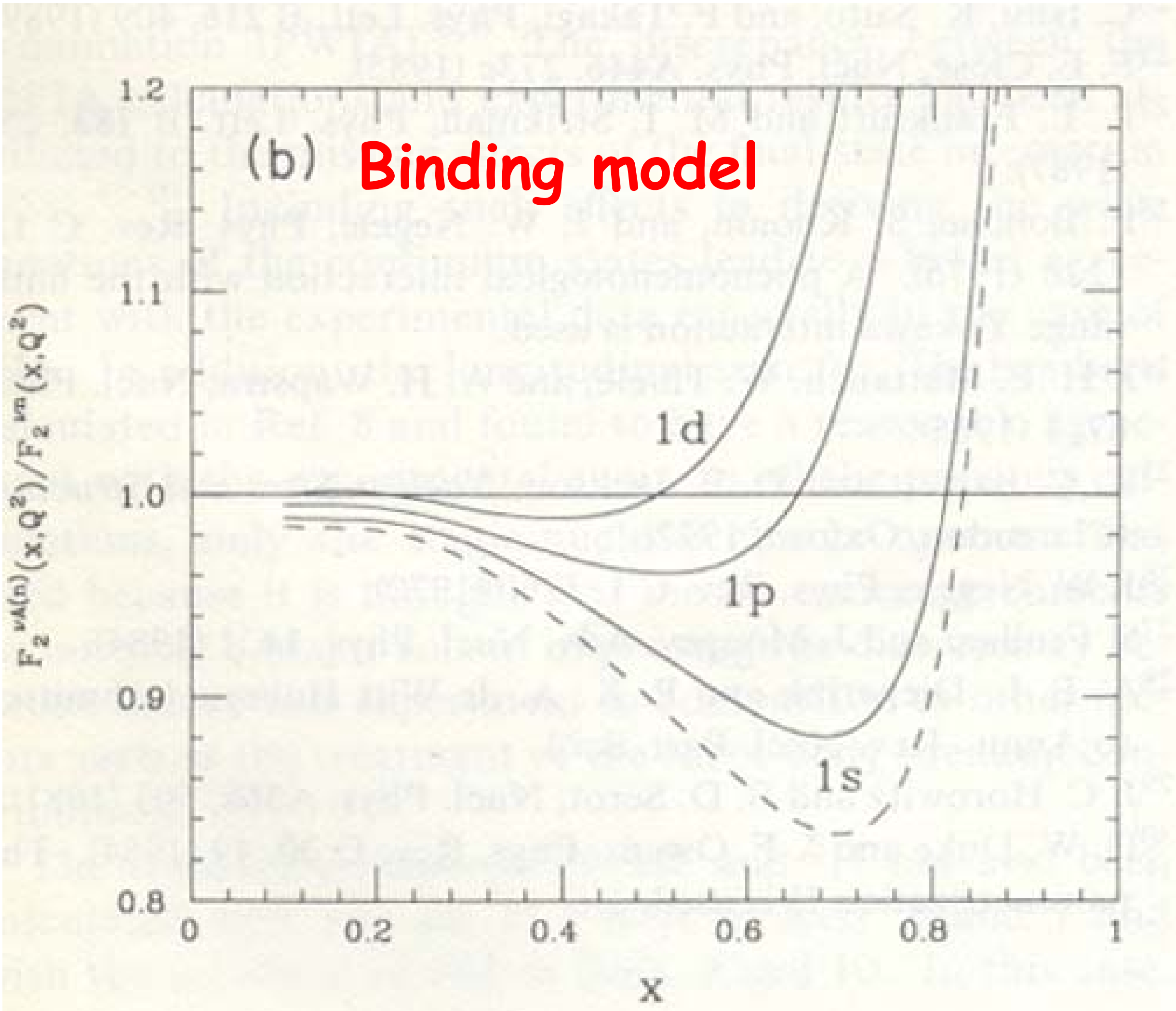


DDHF

Binding energy ~ 40 MeV for central nucleon

~ 5 MeV for surface nucleon

Kumano and Close

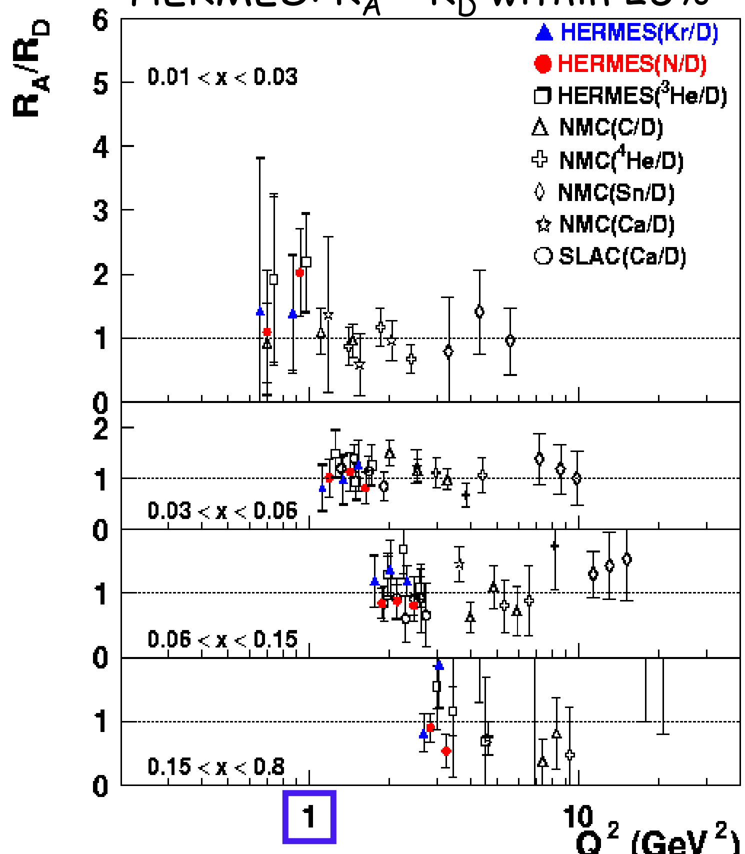


Kumano and Close

EMC Effect in R = σ_L/σ_T

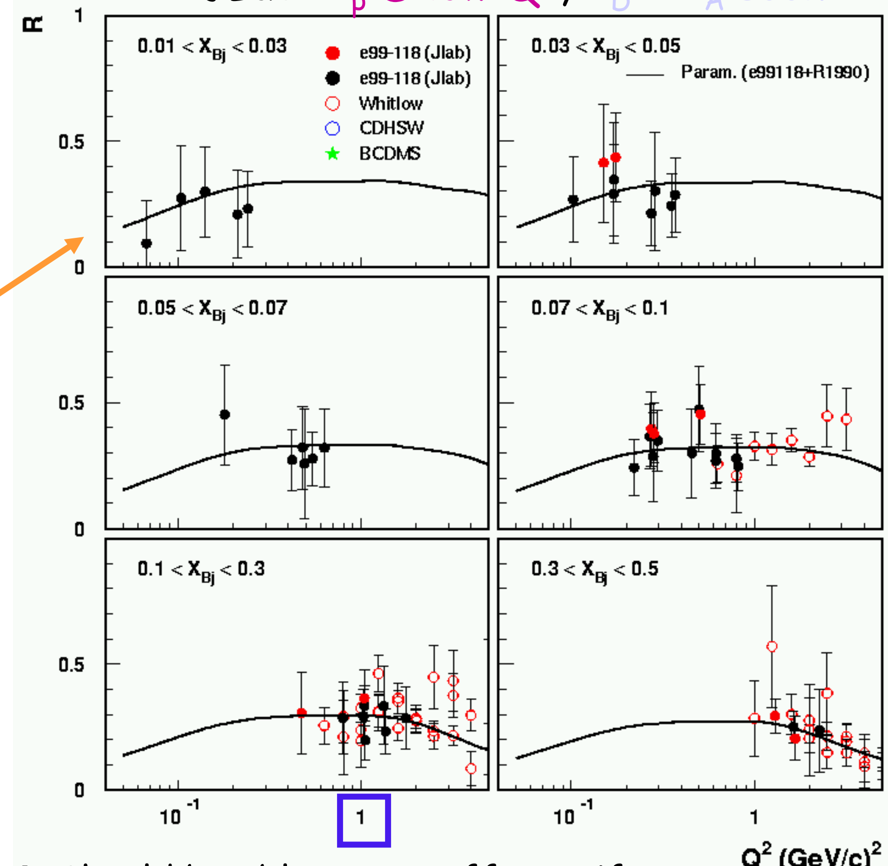
EMC Effect is measured as ratio of F_2^A/F_2^D
In Bjorken Limit: $F_2 = 2xF_1$ (transverse only)
There should be medium effects also in F_L, or in $R = \sigma_L/\sigma_T$!

HERMES: $R_A = R_D$ within 25%



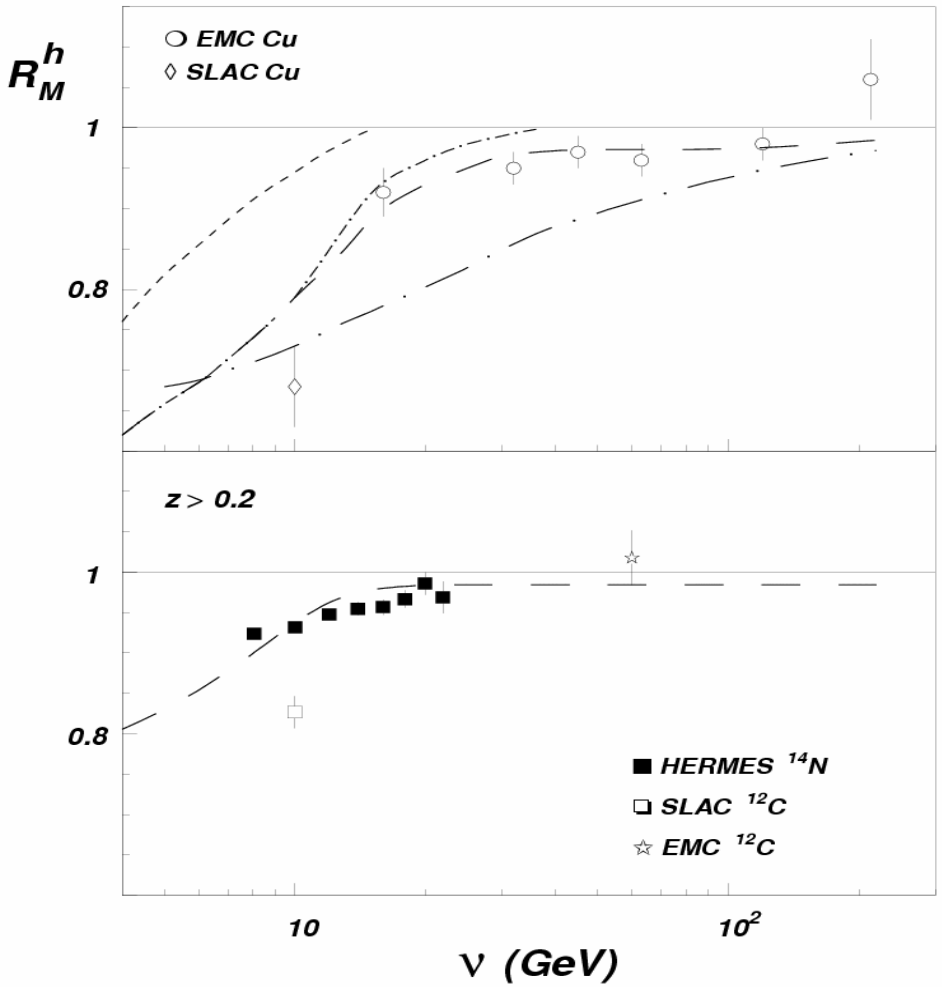
E. Garutti, Ph.D UvA 2003,

JLab: R_p @ low Q^2, $R_D + R_A$ soon



→ Should be able to see effects, if any.

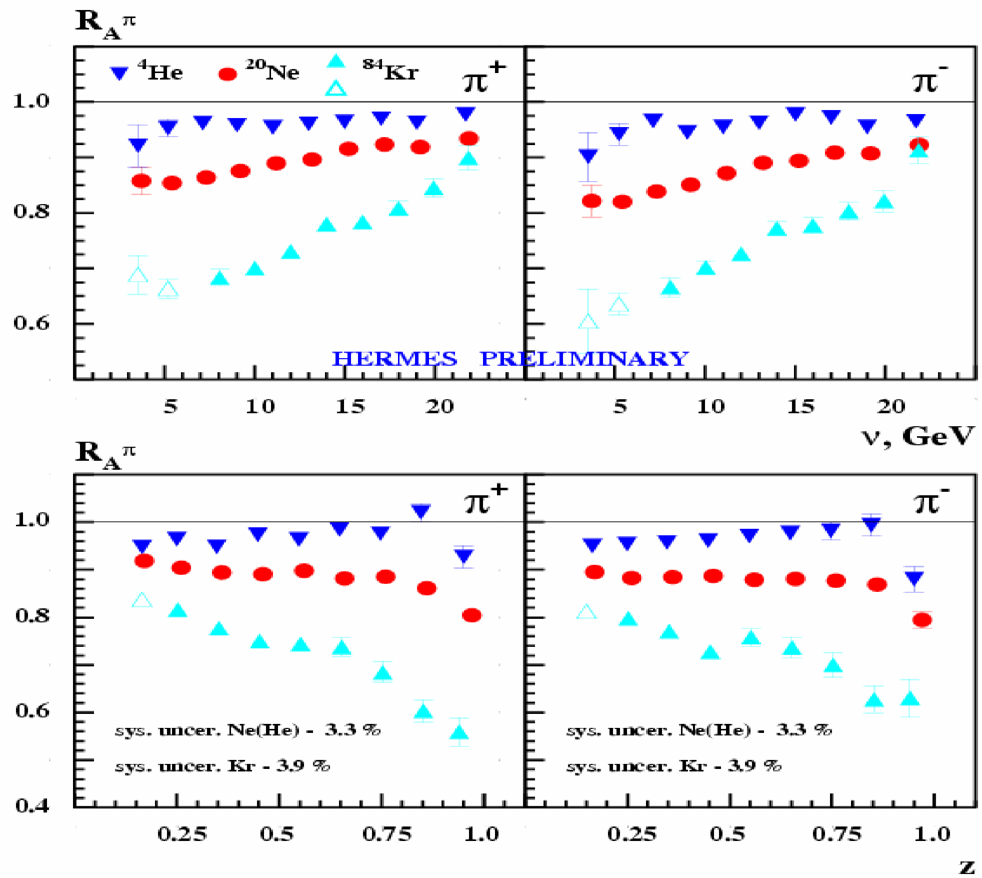
Hadron attenuation from HERMES, SLAC and EMC



HERMES data at 27 GeV on ^{4}He, ^{20}Ne, ^{84}Kr

At low ν~ 10 GeV, struck quark fragments within the target nucleus

This is the situation for JLab

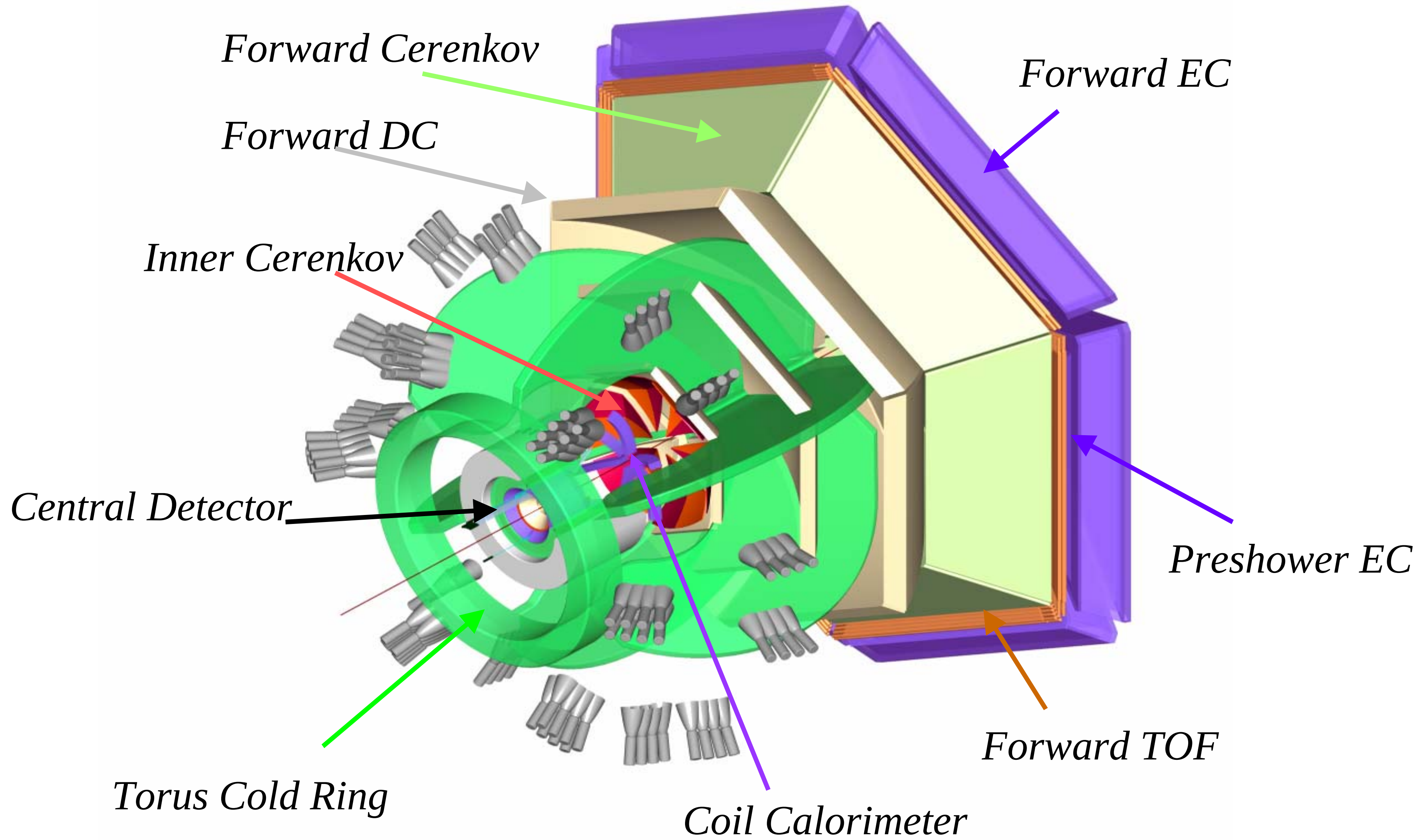


R. G. Milner

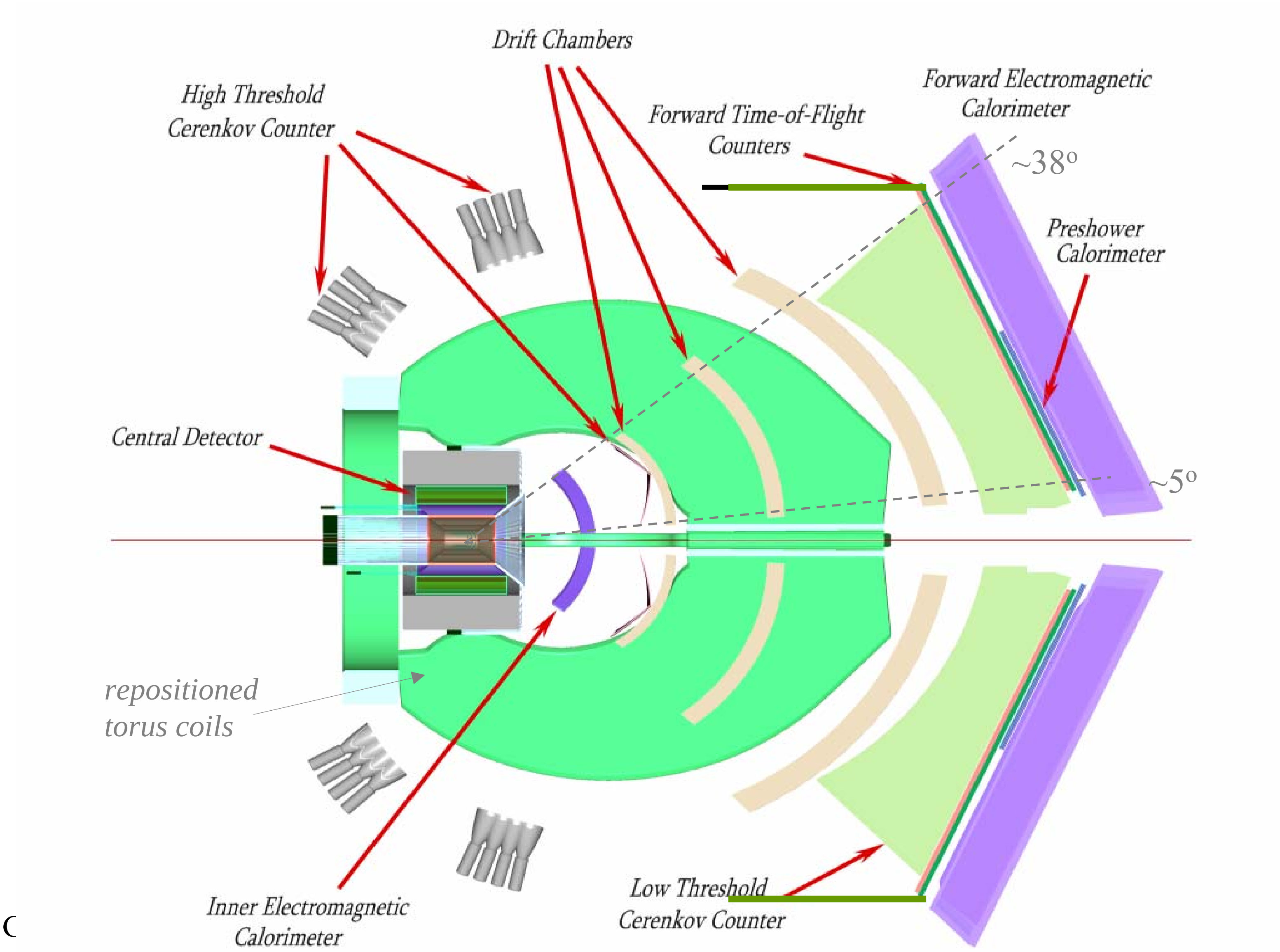
Experimental Considerations

- DIS kinematics
  CLAS^{++} looks like it is instrumented to detect scattered electron and current fragmentation region
- Detection of products in target fragmentation region
  requires tracking, particle id for low energy reaction products at large angles, e.g. BoNUS experiment
- How would one detect the complete final-state?
- Can one envisage an experiment to probe for the `local EMC' effect?
  - resolution?
  - hermiticity?

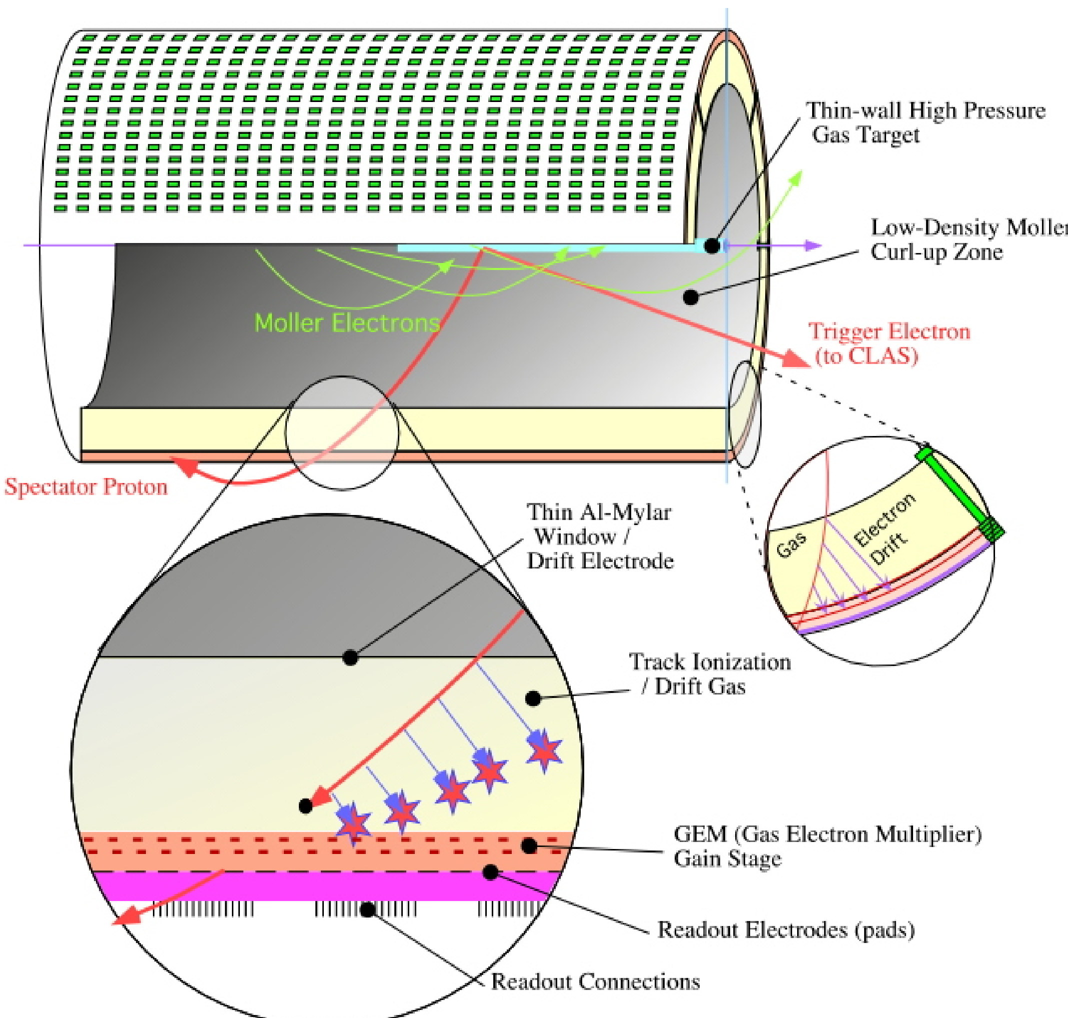
The CLAS^{++} Detector



CUT CLAS^{++} - 2D

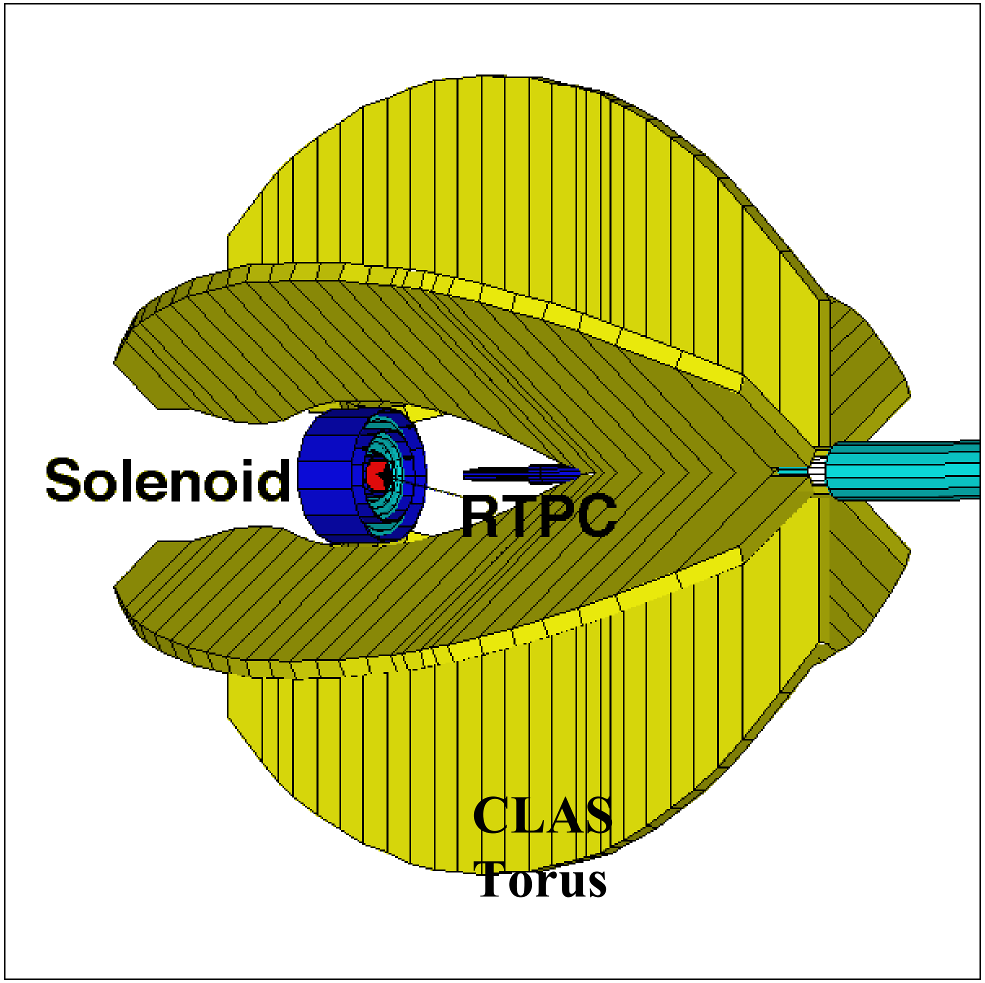

Drift Chambers
High Threshold
Cerenkov Counter
Forward Time-of-Flight
Counters
Forward Electromagnetic
Calorimeter
~38°
Preshower
Calorimeter
Central Detector
~5°
repositioned
torus coils
Inner Electromagnetic
Calorimeter
Low Threshold
Cerenkov Counter

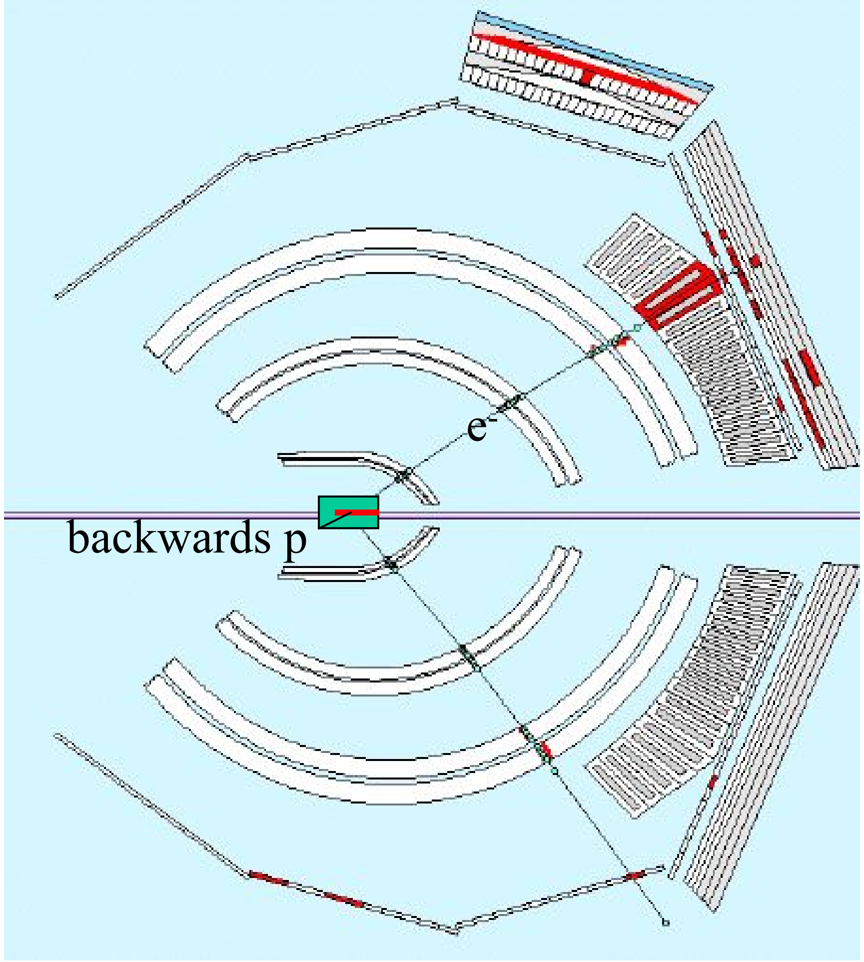
Target-detector system for slow protons



- Thin-walled gas target (7 atm., room temperature)
- **R**adial **T**ime **P**rojection **C**hamber (RTPC) with **G**aseous **E**lectron **M**ultipliers (GEMs)
- 2 Tesla longitudinal magnetic field (to suppress Möller electrons and to measure momentum)
- 3-dimensional readout of position and energy loss ("pads")

BoNuS - Experimental Setup





Summary - suggested program

1. Data from Jlab at 5-6 GeV suggest that DIS scattering from nucleon is consistent with parton model

2. It is essential to vigorously explore the validity of the parton model on the nucleon:
   - measure semi-inclusive scattering over a large kinematic range in x, Q^2, x_F, z
   - test factorization
   - determine fragmentation functions
   - make measurements in both target and current fragmentation regions

Summary (contd.)

3. Once a kinematic region in DIS where the parton model successfully describes both inclusive and semi-inclusive scattering on the nucleon, then initiate a program in scattering from nuclei, I.e. repeat 2. It may be prudent to start with light nuclei.

- Can one measure nuclear dependence of EMC effect? How does it depend on quark flavor?

The ultimate goal would be to understand why the momentum of the quarks in the nucleus is different from that in the free nucleon