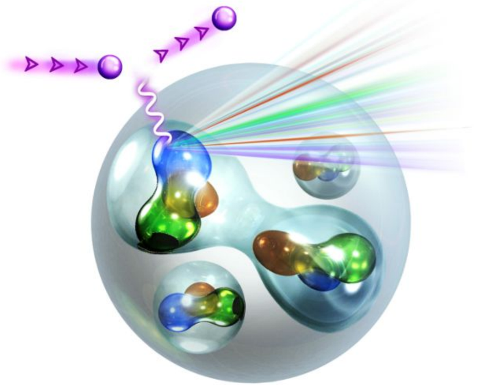
Study of superfast quarks using JLab data



March GHP, Anaheim 2025

Sebastian Moran Vasquez

On behalf of JLab E12-10-008

UCR, LBL (DE-AC02-04CH11231)

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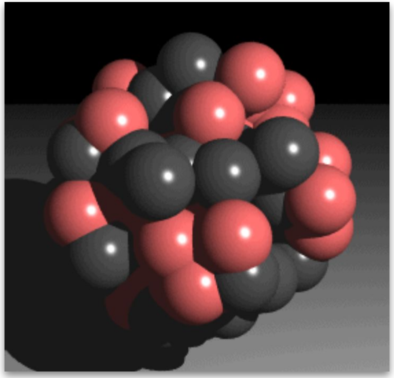
APS

How well do we understand the nucleus?

Nuclei are complex, strongly-interacting, many-body systems

Typical velocities for nucleons in nuclei are up to ~30% speed of light

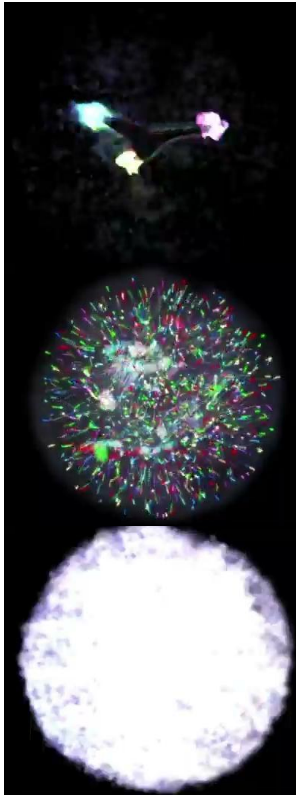


~10^{14} denser than ordinary matter

Nucleons →protons/neutrons

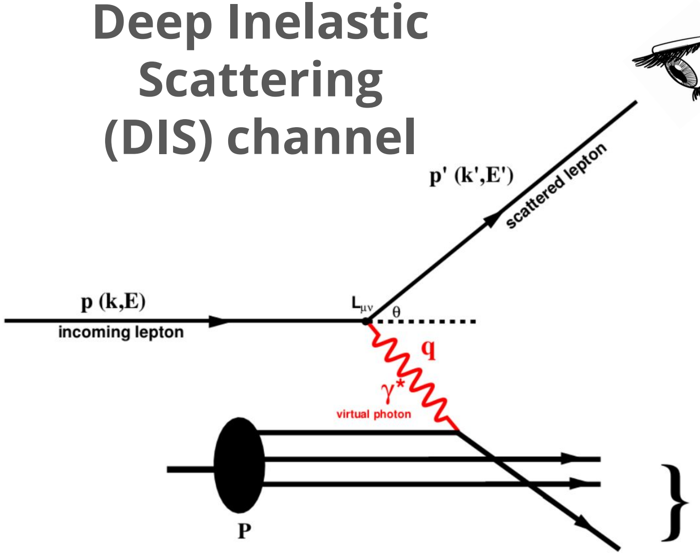
Made of 3 valence quarks bound by gluons, and the nebulous sea quarks

Partons = quarks and gluons



Inclusive Reactions

Deep Inelastic Scattering (DIS) channel



Unobserve final system

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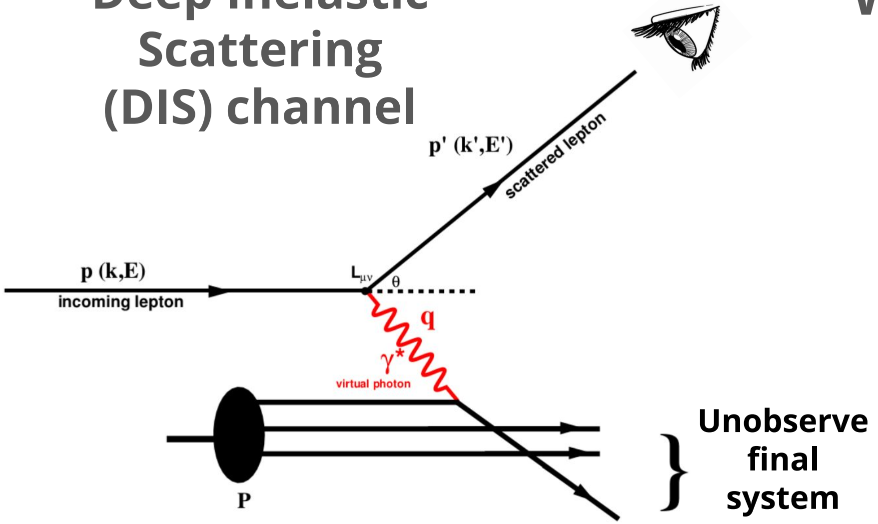

We need to define some variables:

Q^2 = squared four-momentum transfer

Bjorken x = **fraction** of the parent nucleon momentum carried by the parton

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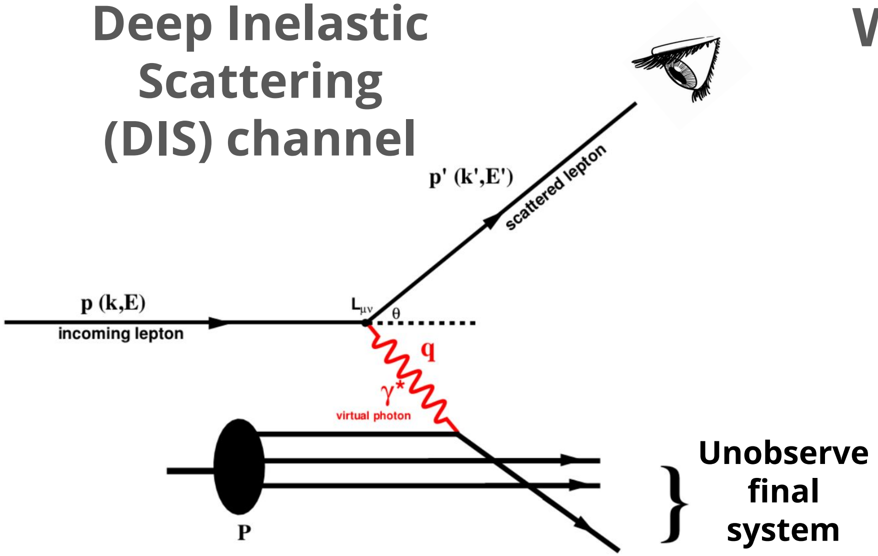

Note that x is defined as a fraction, so it can take values between 0 and 1 for **isolated** nucleons at **rest.**

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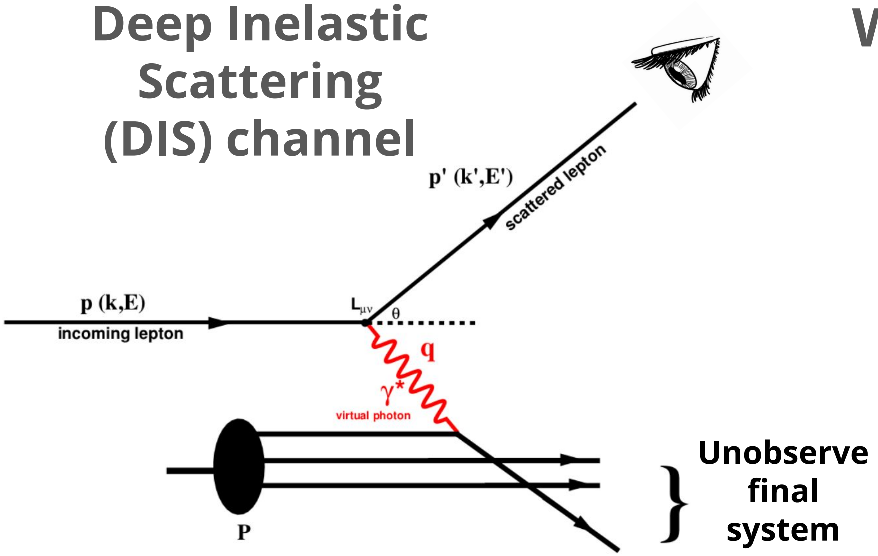

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We need to define some variables:

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At high Q2 -> Incoherent 'billiard ball' scattering from a single quark

$$F_2(x) = \sum_i^{u,d,s,\ldots} x e_i^2 q_i(x)$$

Structure Function

momentum fraction of the quark

Nuclear parton distributions
EMC Effect (1983)

Interaction electron-free nucleon -> Well known

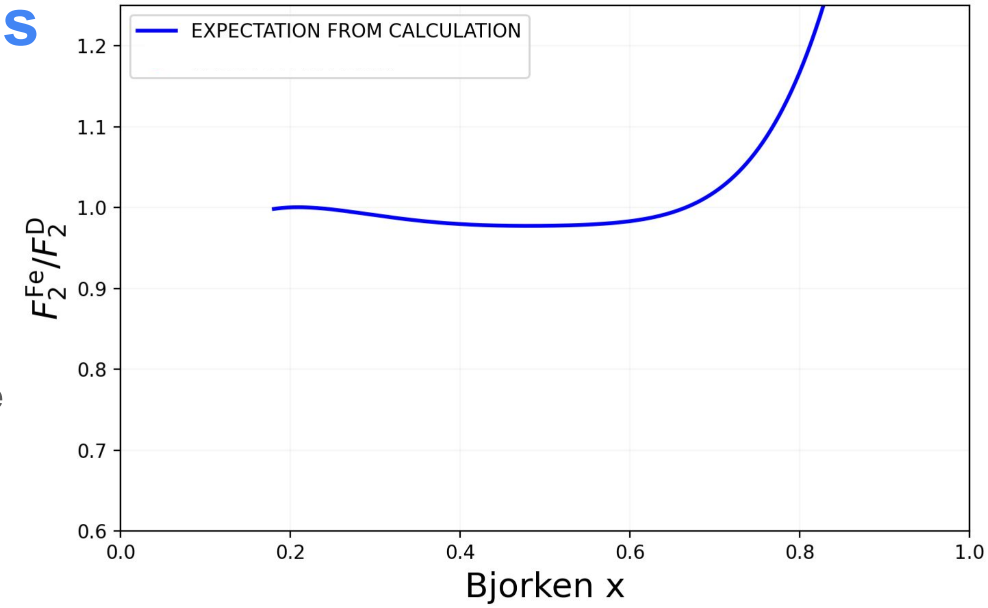
What about the nucleus?

What are the modifications of the structure of the nucleons in the nuclear medium?

Nuclear binding energy << Energy scale of the probe

Expectation (naive):

$$F_A^2(x, Q^2) = ZF_p^2(x, Q^2) + NF_n^2(x, Q^2)$$



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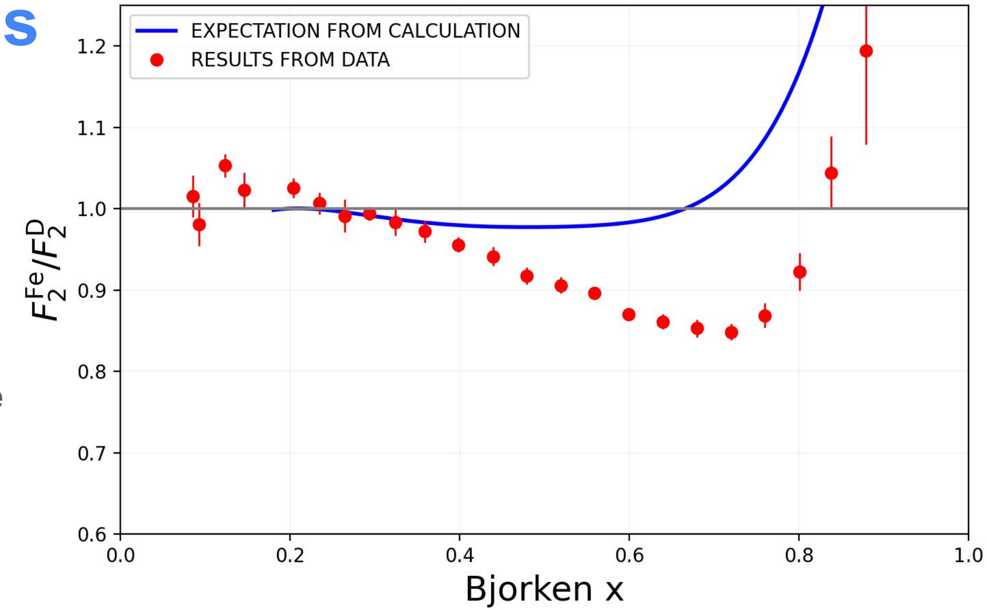

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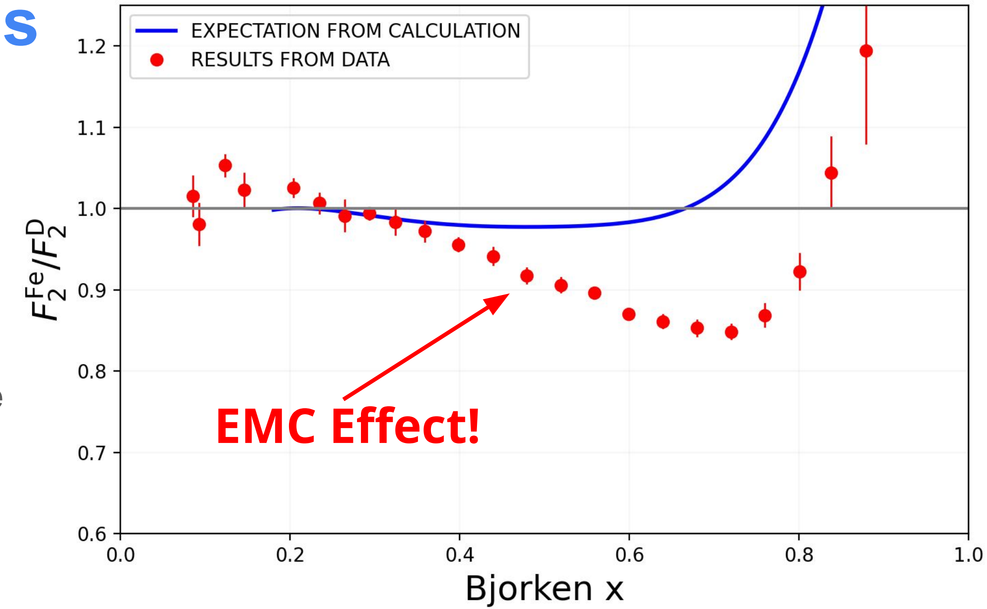

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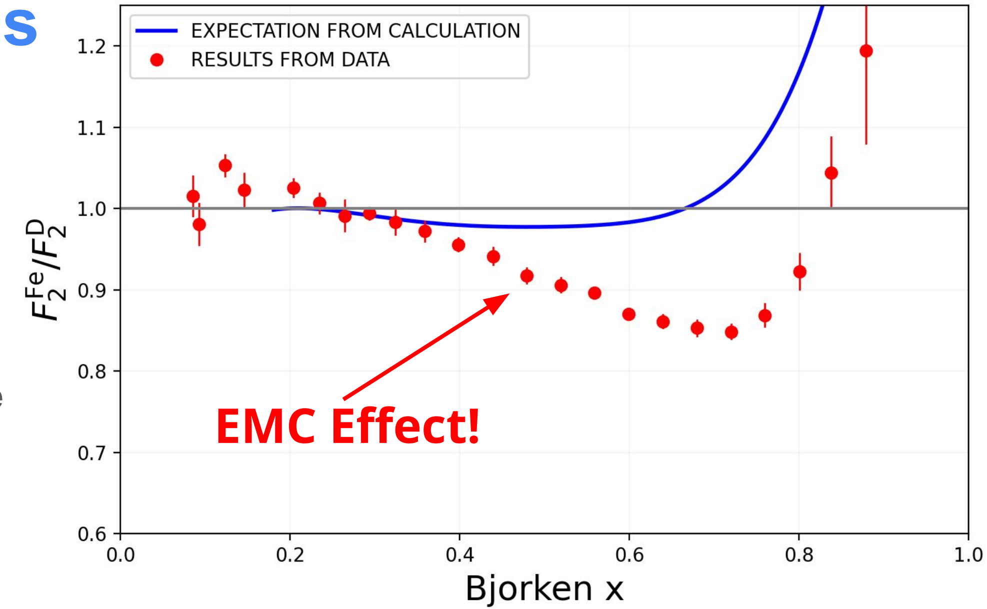

Suppression of the high momentum quarks for 0.3<x<0.7 in nuclei relative to the deuterium

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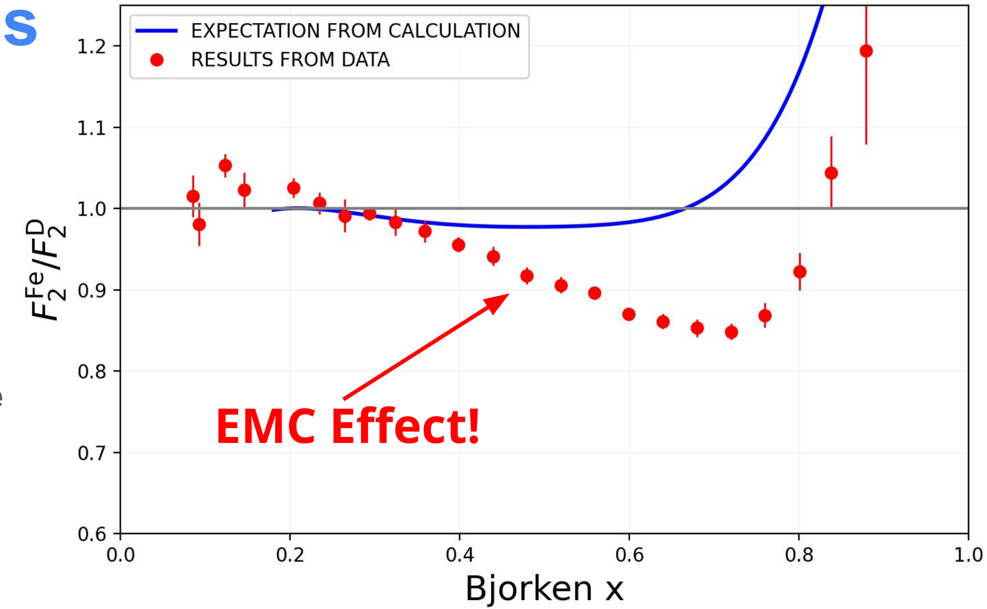

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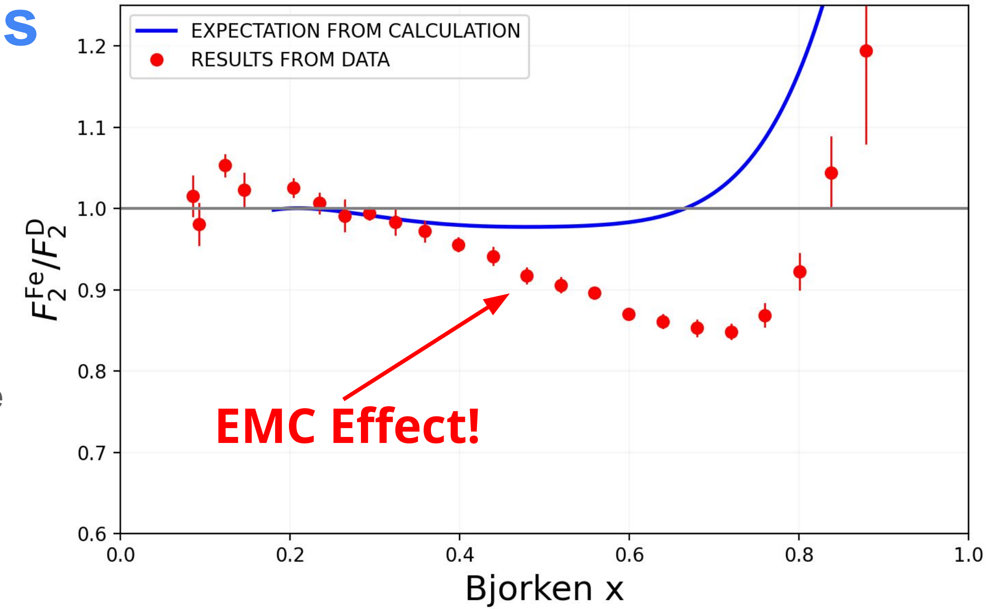


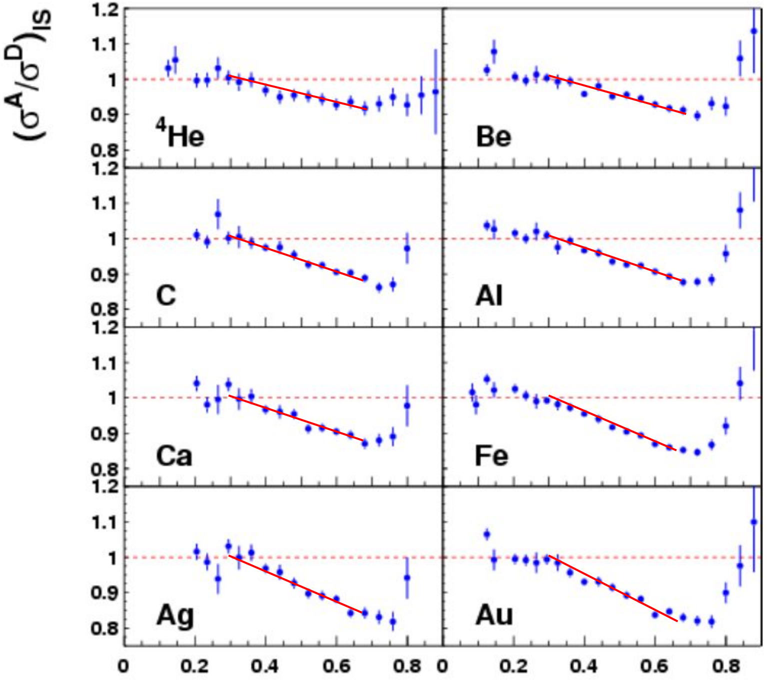
Suppression of the high momentum quarks for 0.3<x<0.7 in nuclei relative to the deuterium

"Valence quarks in nucleus carry less momentum than in a nucleon"

EMC Effect

Strength of the effect highly correlated with A and average nuclear density

SLAC *J. Gomez, et al., PRD49, 4349 (1994)*



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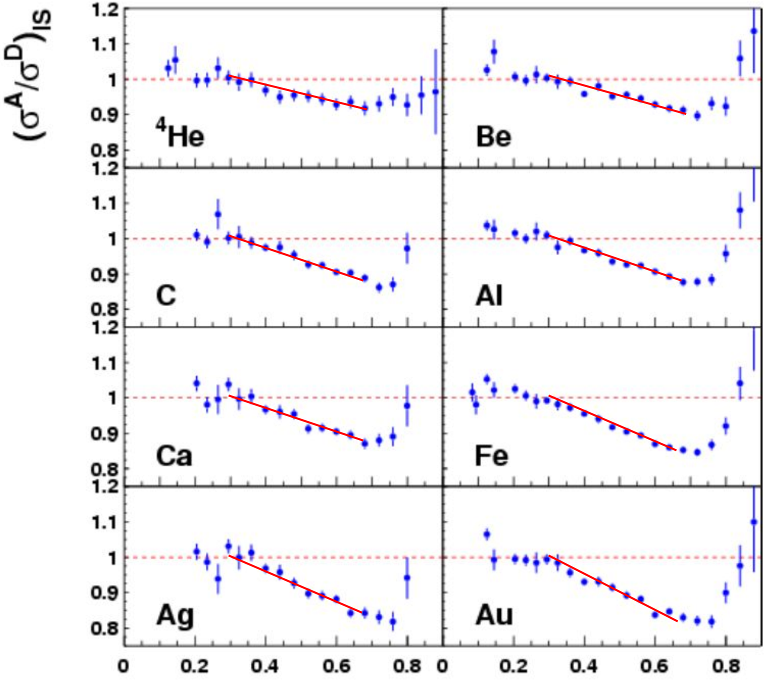
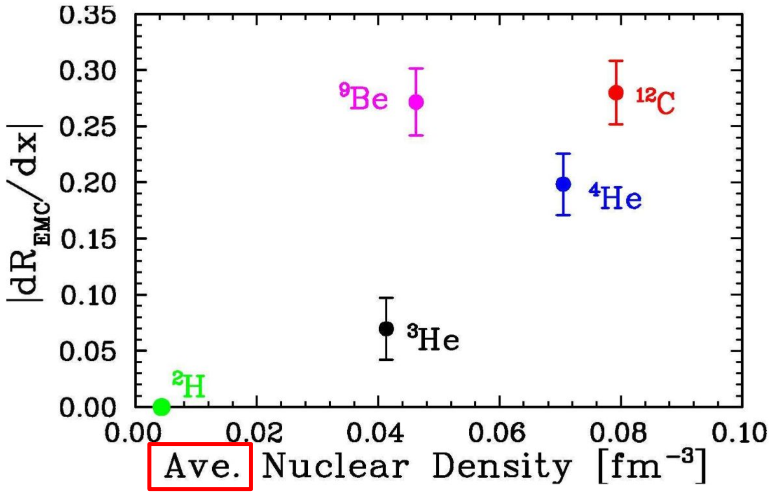


JLab E03-103 RESULTS



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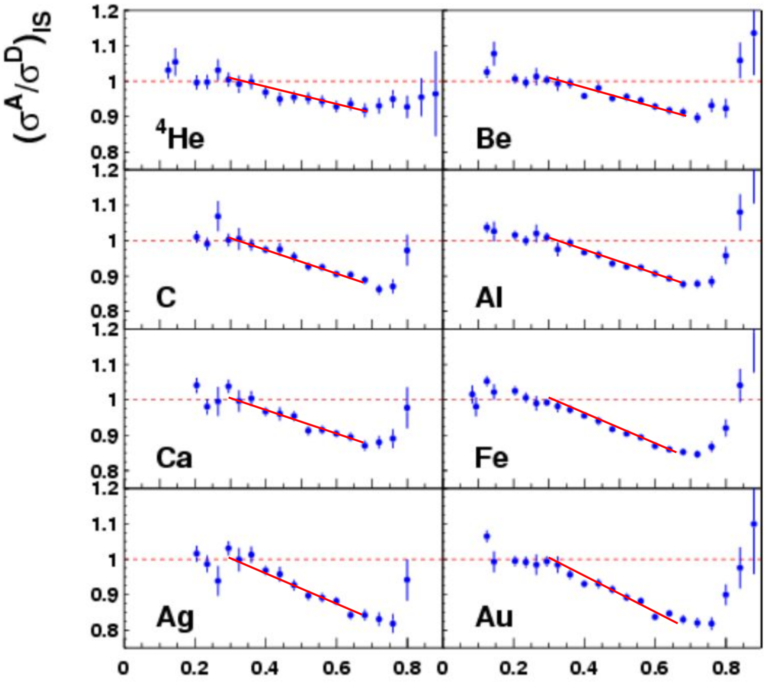

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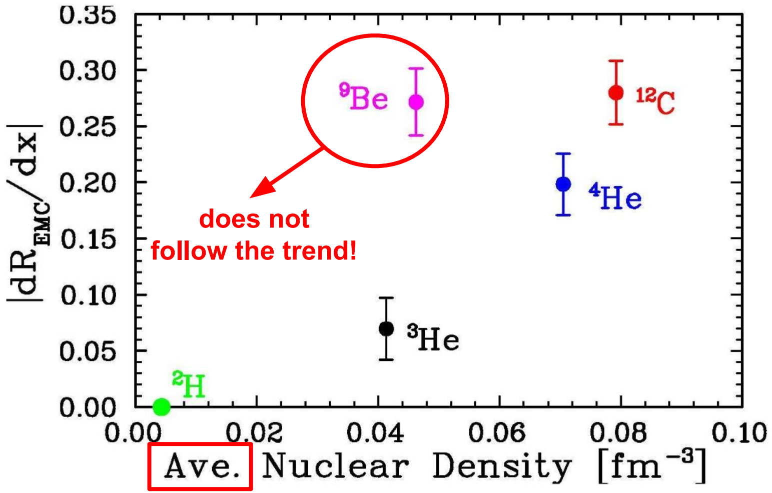

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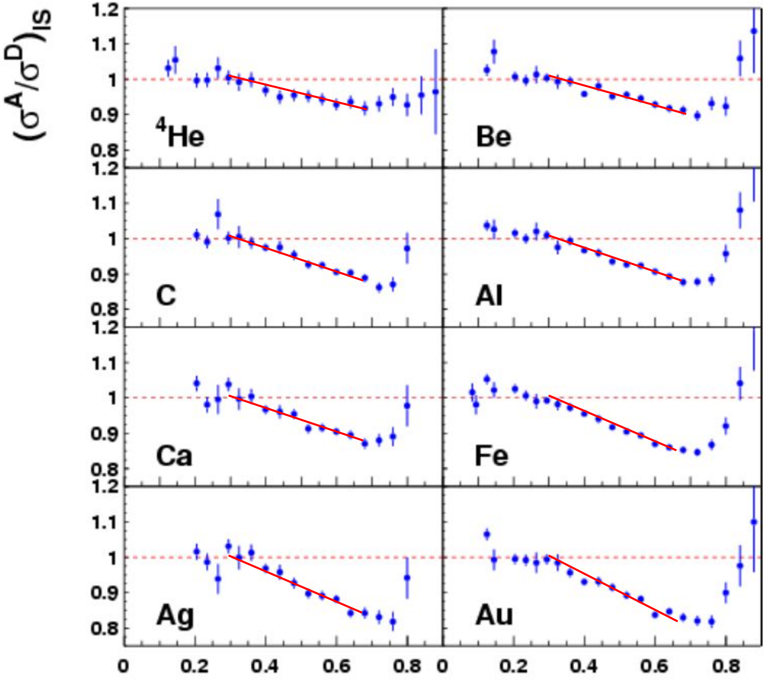

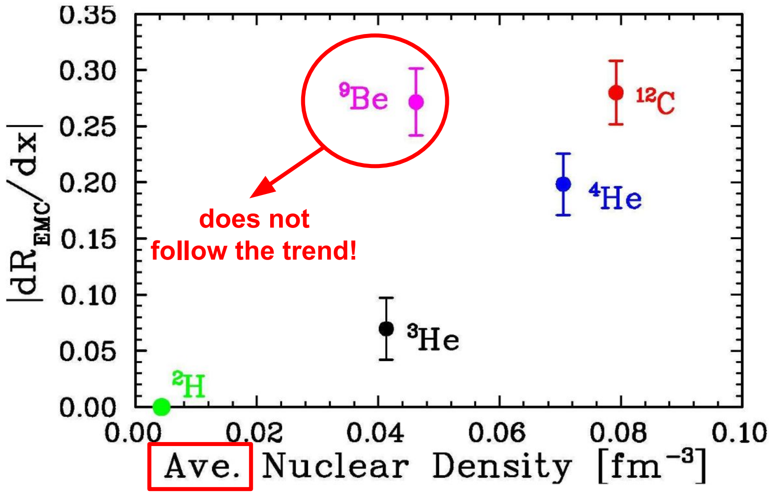

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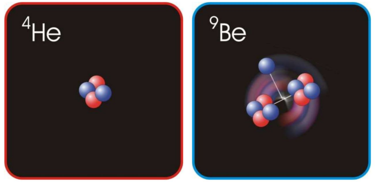

^{9}Be low average density but large 2α + n structure

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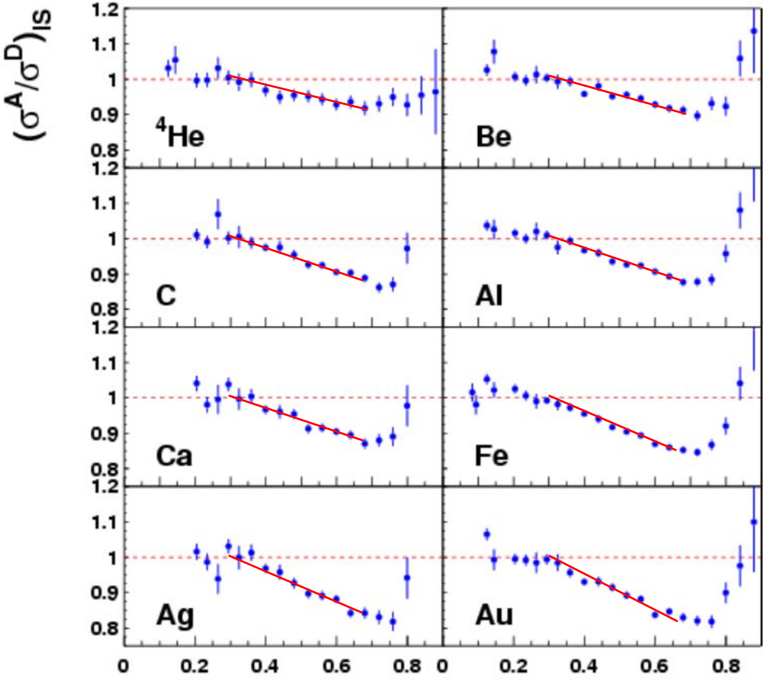

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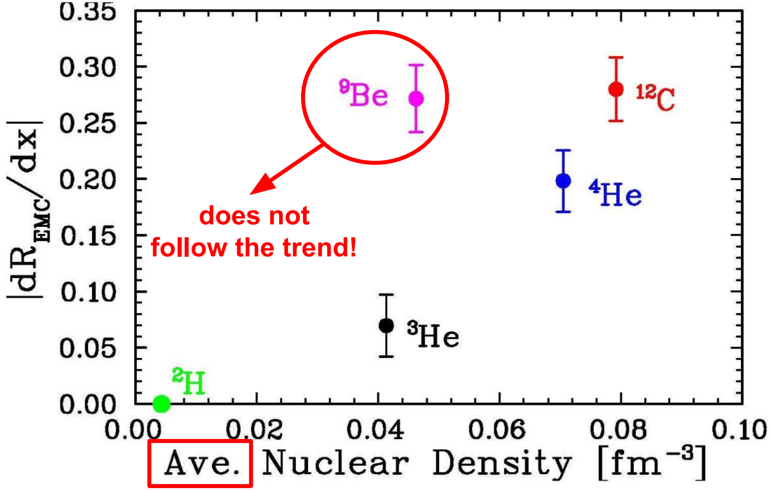

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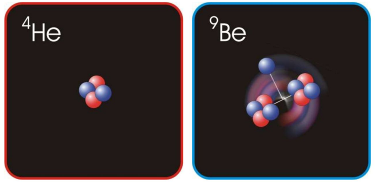


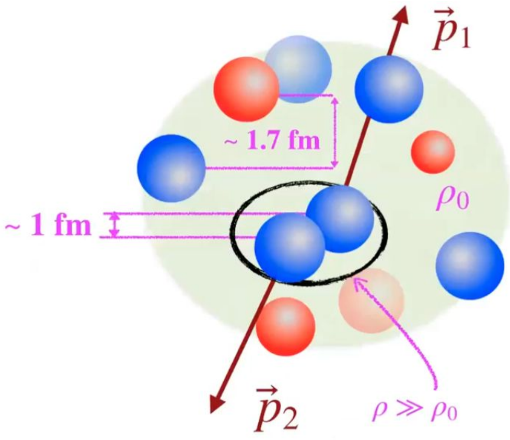
^{9}Be low average density but large 2α + n structure

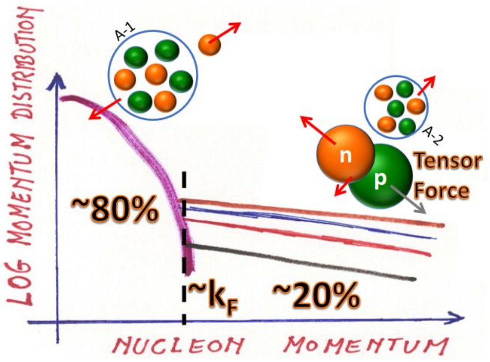
EMC effect seems to follow LOCAL density rather than average density!

How can we study local density ?

Short Range Correlations (SRC)

Pairs of nucleons with high back to back momenta





$$\vec{p}_{rel} = (\vec{p}_1 - \vec{p}_2)/2$$

$$\vec{p}_{c.m.} = \vec{p}_1 + \vec{p}_2$$

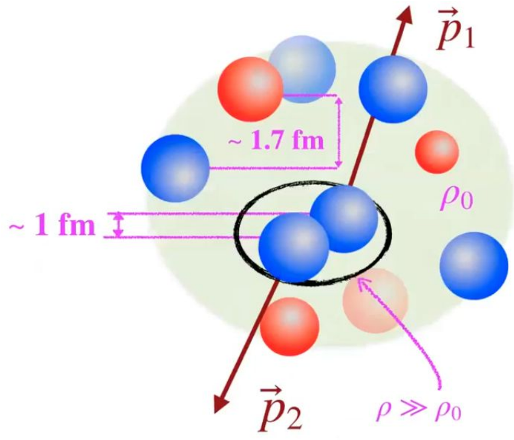
How can we study Local Density ?

Short Range Correlations (SRC)

If the high momentum nucleons in nuclei come from correlated pairs, ratio of A/D should show a plateau.

"a_2" plateau

Pairs of nucleons with high back to back momenta



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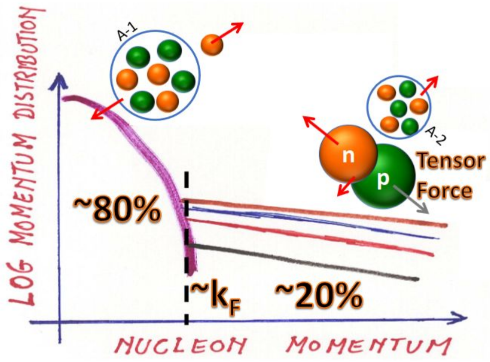
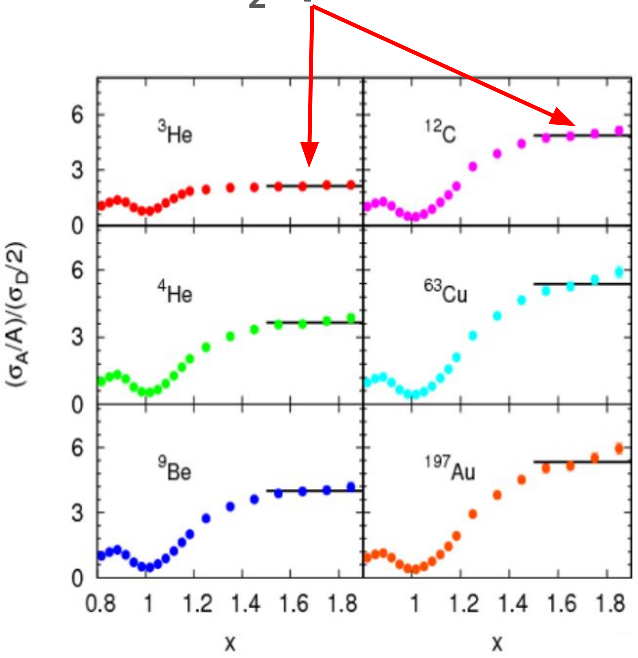
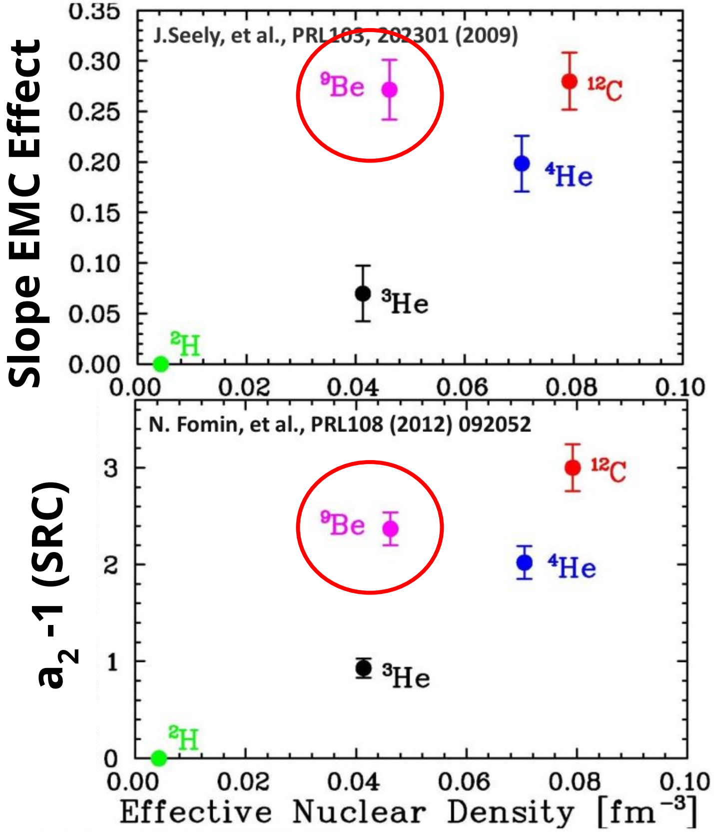




$$\frac{2}{A}\frac{\sigma_A}{\sigma_D} = a_2(A)$$

Relation between EMC and SRC



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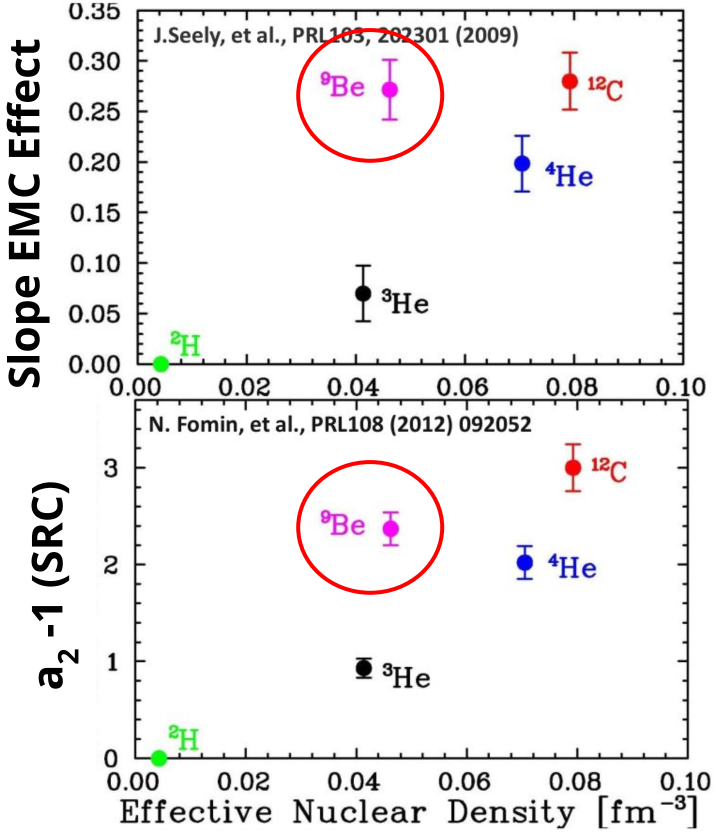
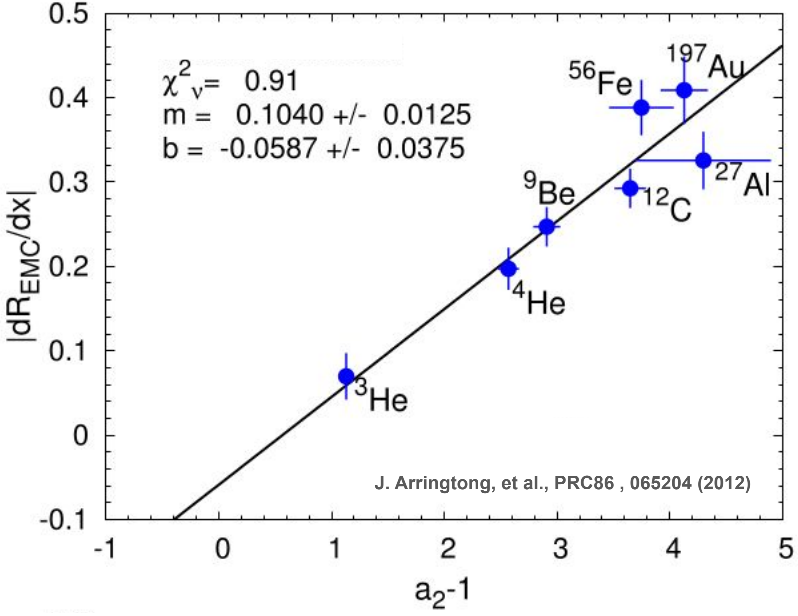


Linear correlation between the size of the EMC effect and SRC plateau



^{9}Be now does follow the trend!

How can we move forward ?

So, study of SRC (x>1) shed some light on the EMC effect (0.3<x<0.7)

Inclusive DIS sensitive to:

At high x -> Isolate high momentum **nucleons** (SRCs)
At high Q^2 -> Isolate scattering from **quarks**

Can we have access to partonic degrees of freedom at x>1? **YES!**

Now possible because we have access to higher energies (11 GeV electron beam instead of 6 GeV)

At higher Q^2 inclusive scattering is sensitive to distribution of high momentum **quarks** → **SuperFast Quarks (SFQ)**

Topic of this talk

Superfast Quarks (SFQ)

Quarks carrying a momentum greater than that of a nucleon ($x>1$)

Why do we want to study them?

Because their distribution is connected to short distance structure of nuclei

and

Quark distributions of nuclei at large x are poorly understood

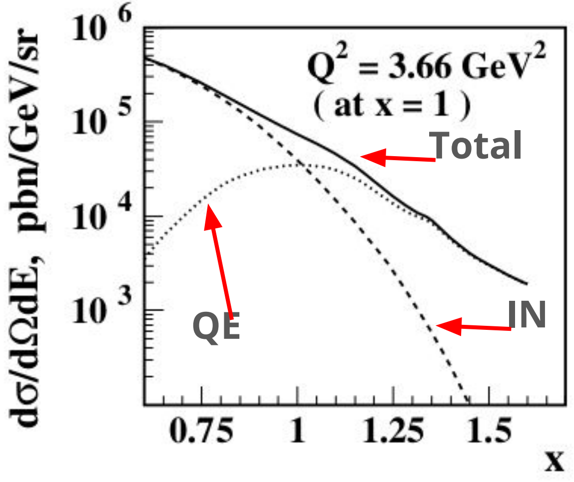
Promising region to examine for the importance of the underlying quark degrees of freedom in nuclear structure

SFQ is a new way of testing models of the EMC effect!
($1.0 \lesssim x \lesssim 1.5$)

Kinematic requirements to detect SFQ

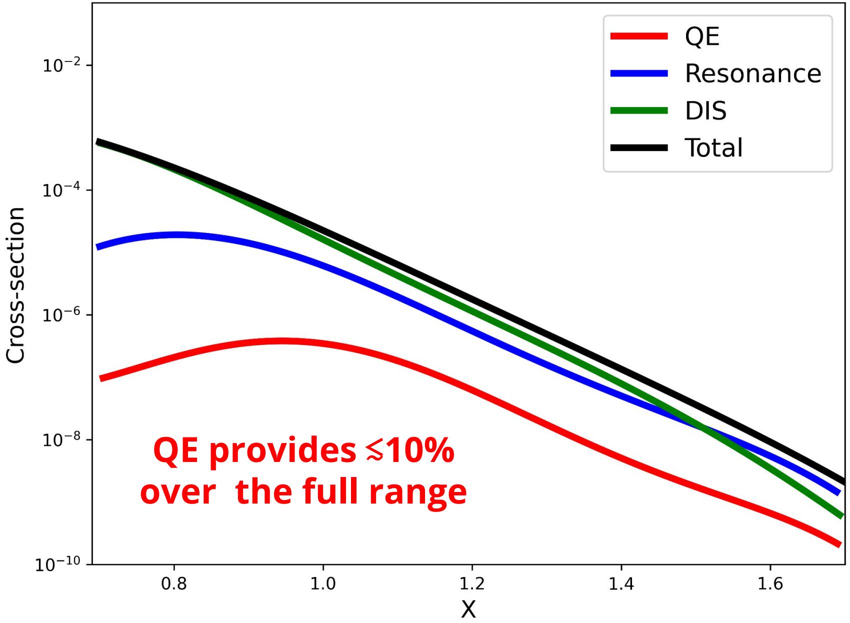
Q^2 large enough so the DIS tail overwhelm the QE contribution

Low Q^2 -> QE wins



Kinematics at 11 GeV

Breakdown of the contributions to the inclusive cross section

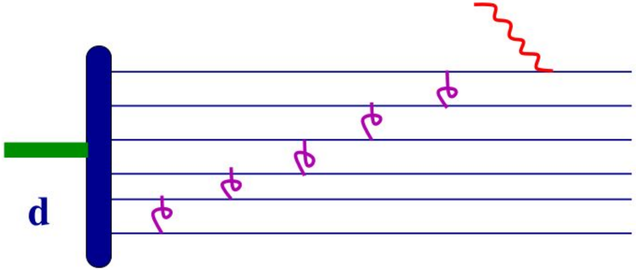


Many Theoretical Models

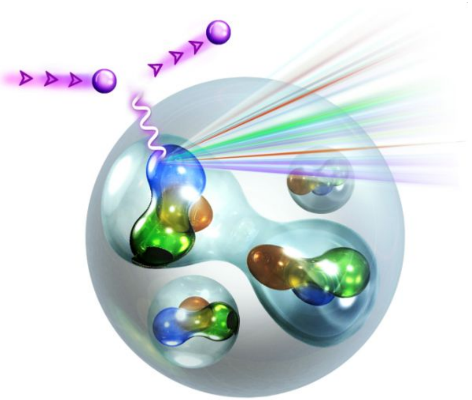
Convolution Model, Six-Quark Model, Hard-Gluon-Exchange Model and many many more ….

One example: 6-quark model:

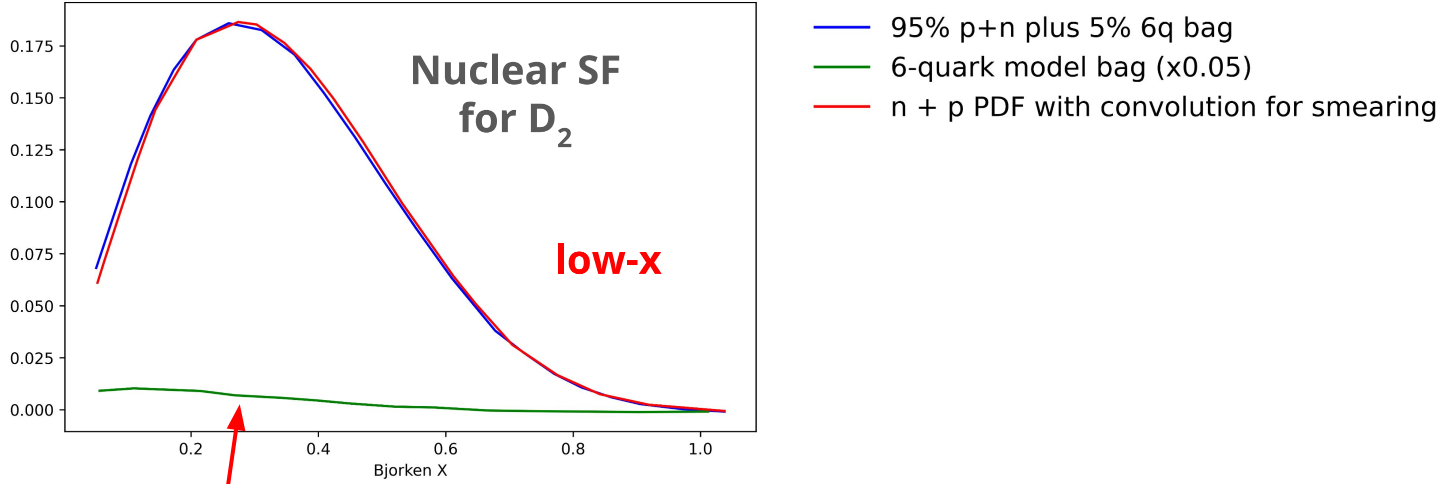
Two nucleon system collapse into 6q state



The really important feature is that we are allowing gluon exchange between the particles



So, quarks degrees of freedom in DIS at x>1



At most 2% effect in the EMC region

We would need extremely high exotic contributions to explain 10-20% suppression

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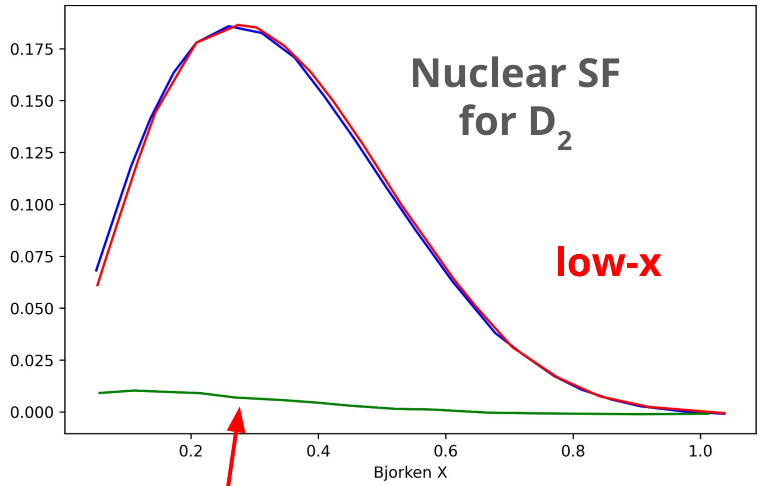

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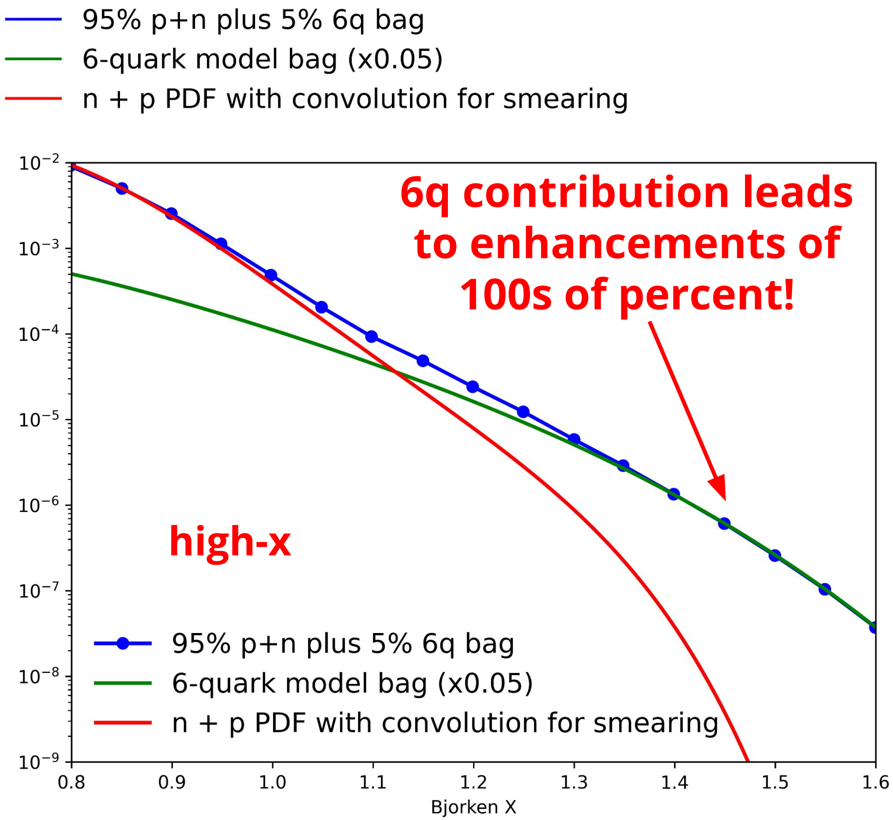
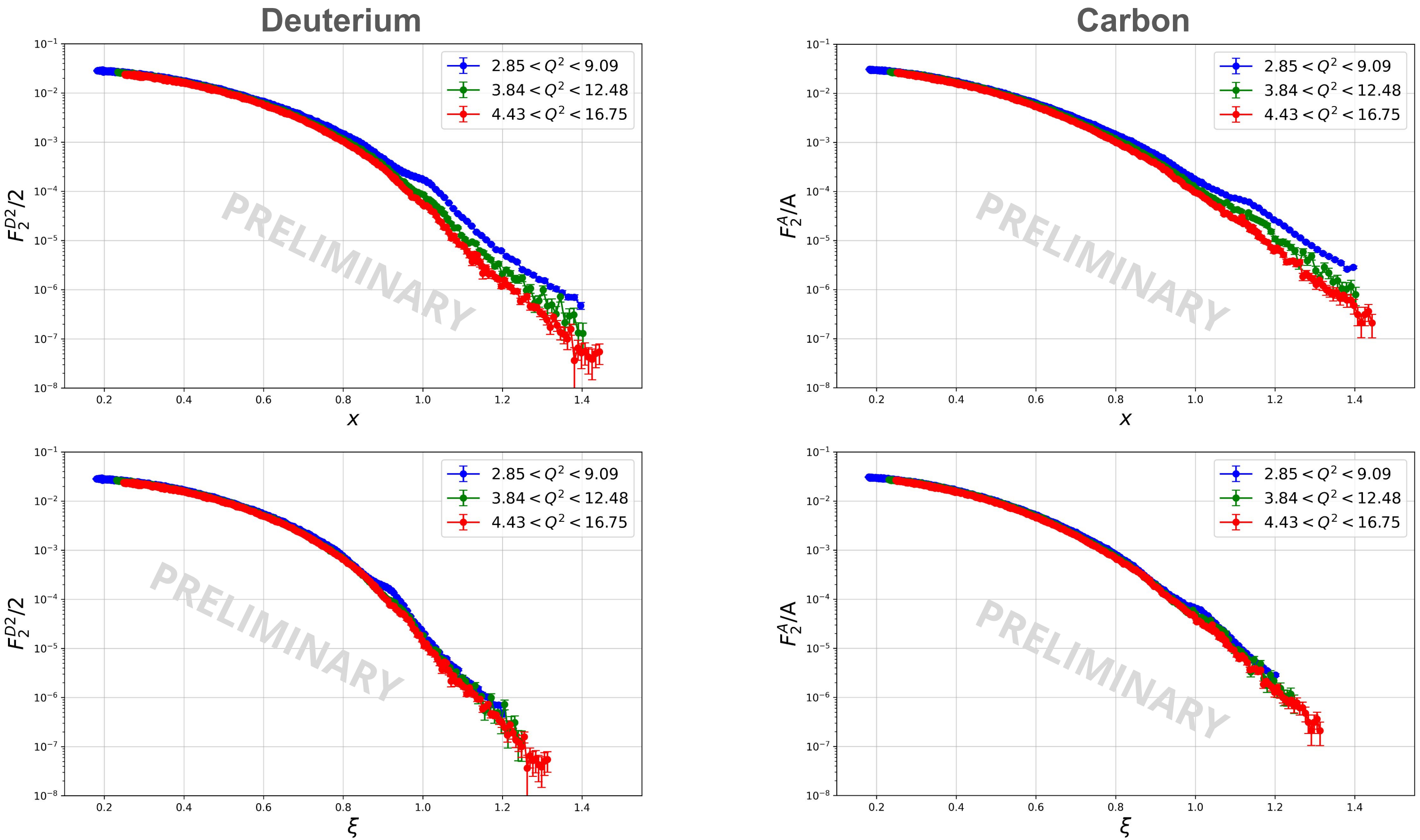


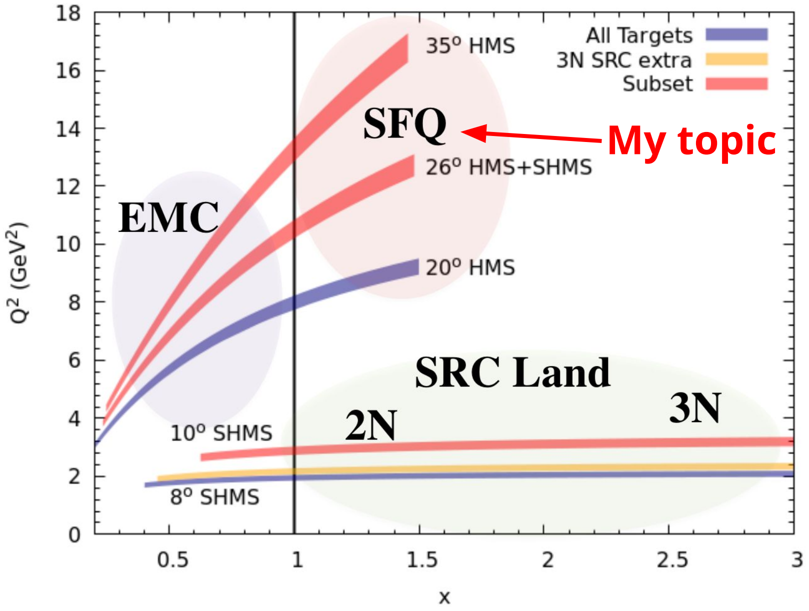


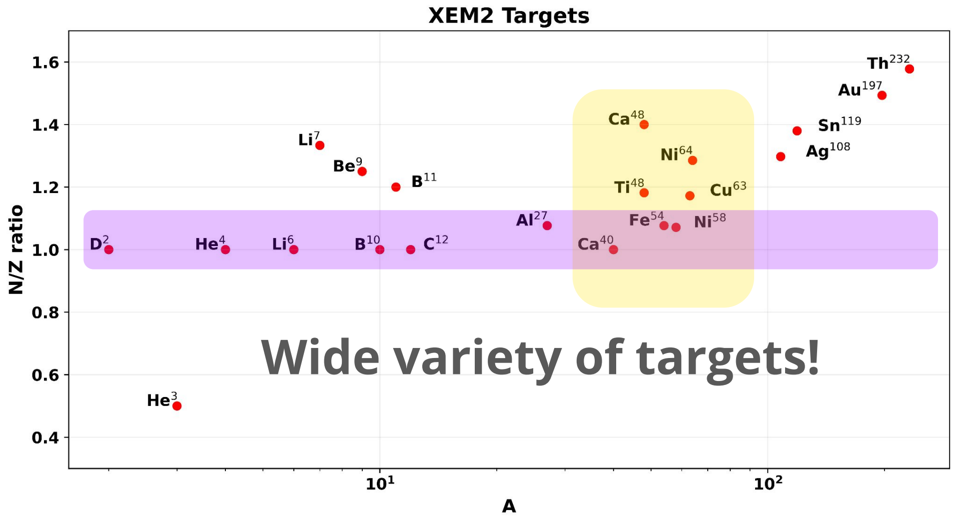
Approximate Scaling is observed

Hall C XEM2 Experiment: E12-06-105

Energy transfer as small as possible while increasing Q^2 as high as possible

For SFQ region we mainly use HMS





Data Analysis, Current Status

Detector Calibration

- Drift Chamber Calibration
- Hodoscopes Calibration
- Threshold Cherenkov Counters Calibration
- Shower Calorimeter Calibration

Corrections applied to Final Yield

- Dummy Subtraction
- Tracking Efficiency
- Calorimeter Efficiency
- Cerenkov Efficiency
- Charge Symmetry Background Correction
- Delta dependence Acceptance Correction
- BCM4A Correction
- Coulomb Corrections
- Radiative Corrections
- Ytar correction
- Delta Offset Correction
- Boiling Correction
- MC Jacobian Correction
- Cryogenic Contraction Correction
- Isoscalar Corrections

All of them applied to the cross sections already

Next Steps:

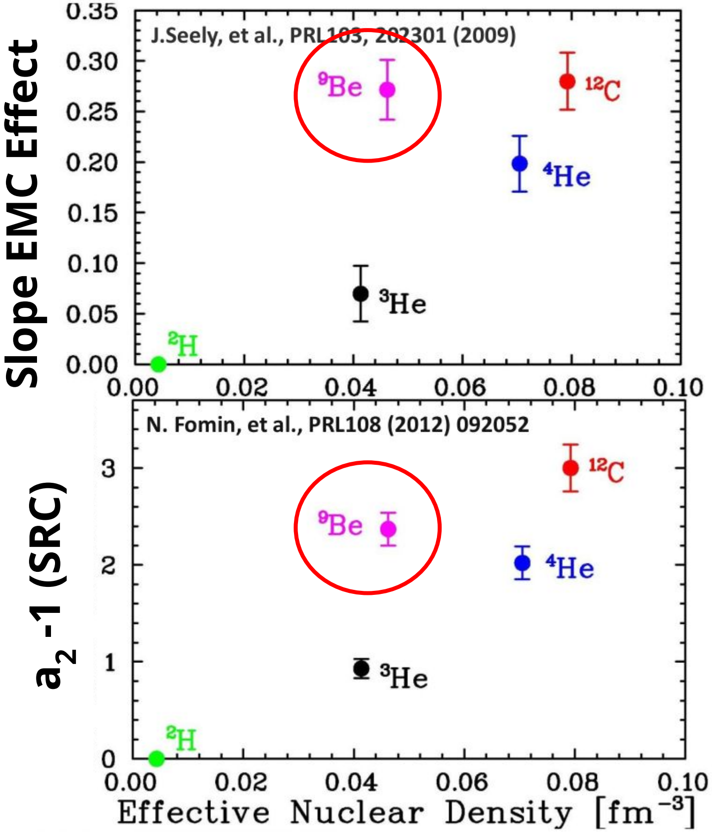
- Include systematic uncertainties
- Quantify scaling
- Compare with different models for deuterium

Some of the XEM2 members

Thank you!

BACKUP

Relation between EMC and SRC



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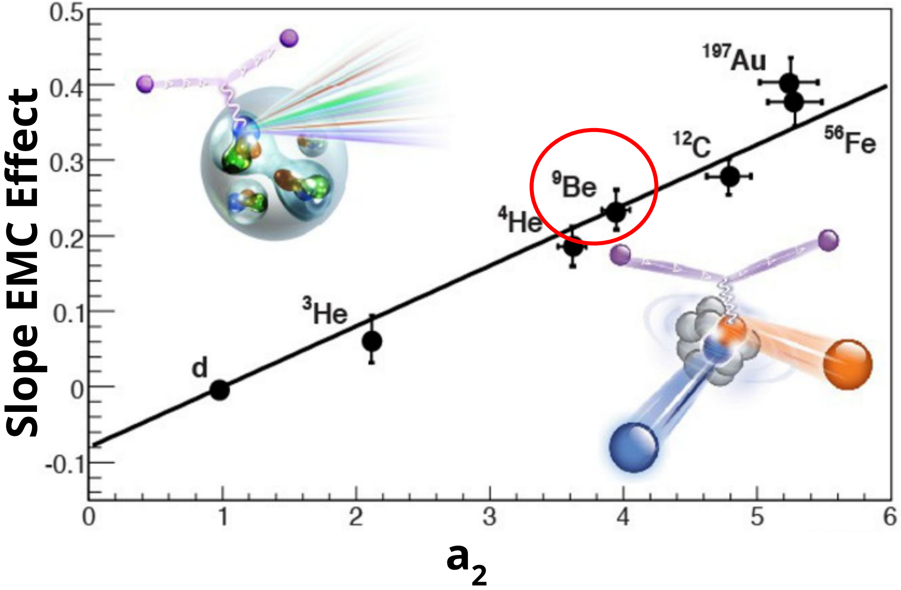
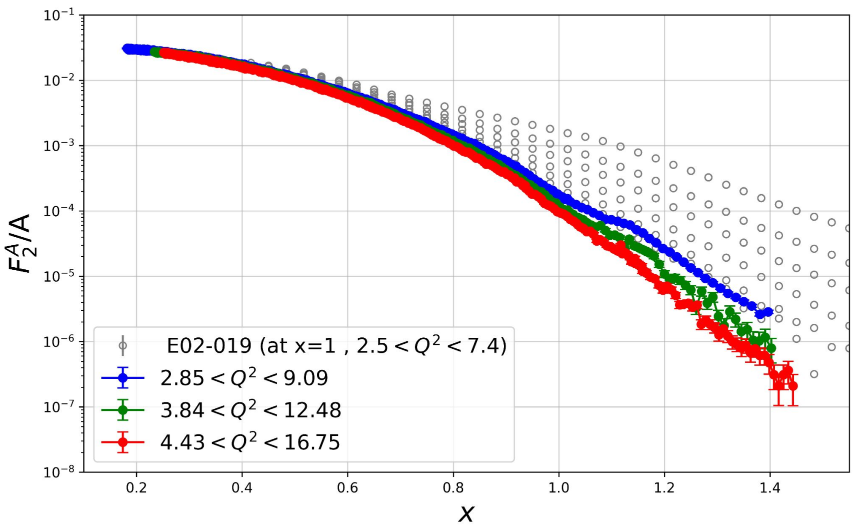
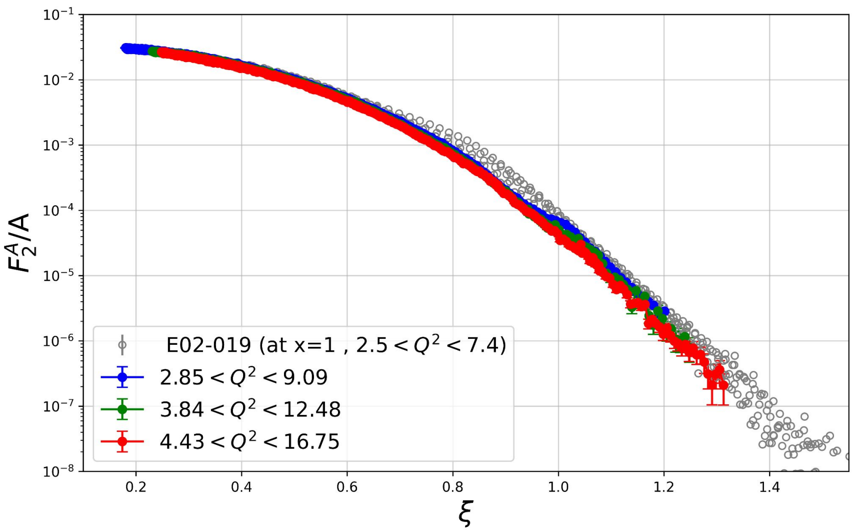


^{9}Be now does follow the trend!

Comparison with JLab 6GeV era

Carbon

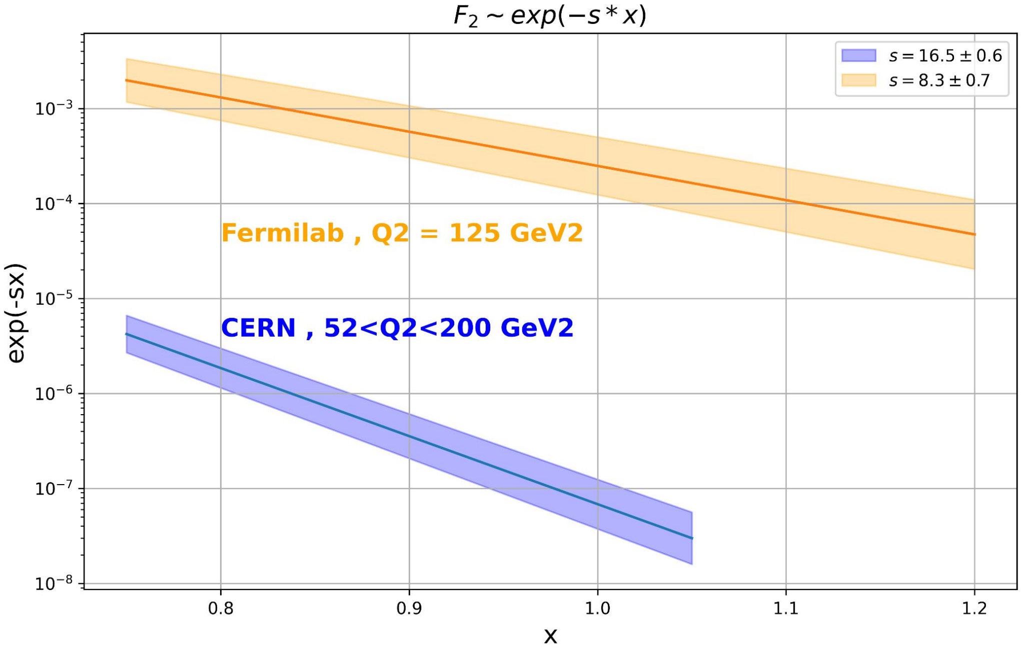




What does the distribution of SFQ look like?

Exponential fall off

Inconclusive attempts in the past:

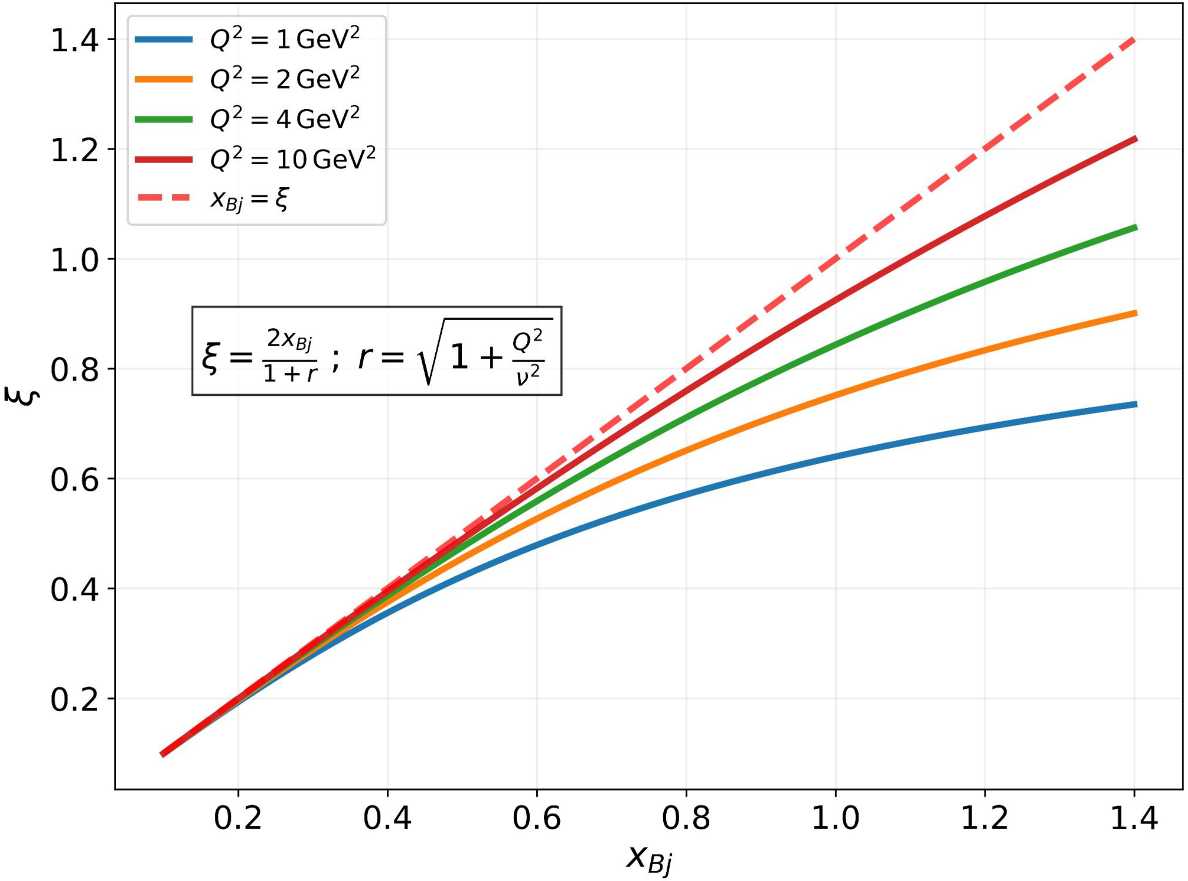


Both CERN and Fermilab fit an exponential to F_2 and extract the 'slope' of the fall off

Problems:
Fermilab has poor resolution in x
CERN has low statistics (upper limit only goes up to x=1.05)

JLab results closer to CERN , but there are many problems still, we need higher Q^2 to have a cleaner sample

Nachtman scaling variable xi



Electron-Nucleus Scattering

'LOW' ENERGY SCATTERING

As we increase Q^2 the DIS scaling region moves further up in x