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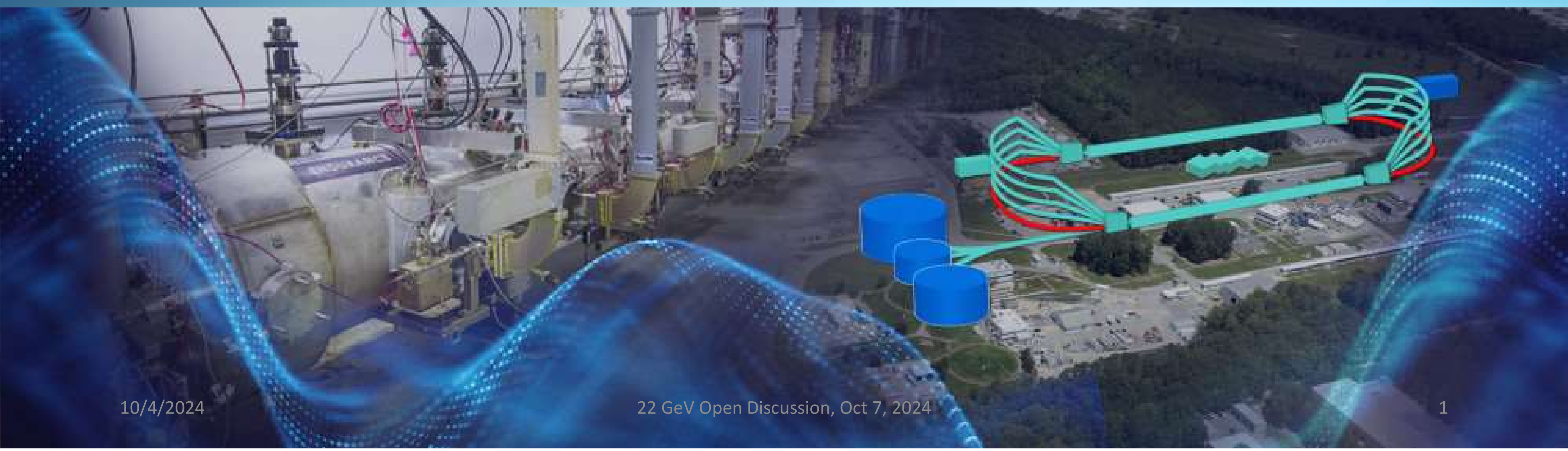
Studying nuclear pdfs in the super-fast quark regime: New insight into the EMC effect

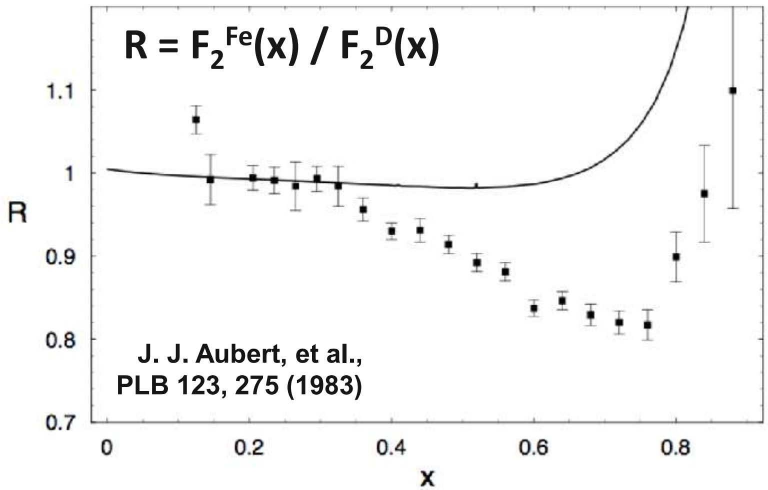
John Arrington, Lawrence Berkeley Lab

22 GeV open discussion; Jefferson Lab, Oct 7 2024



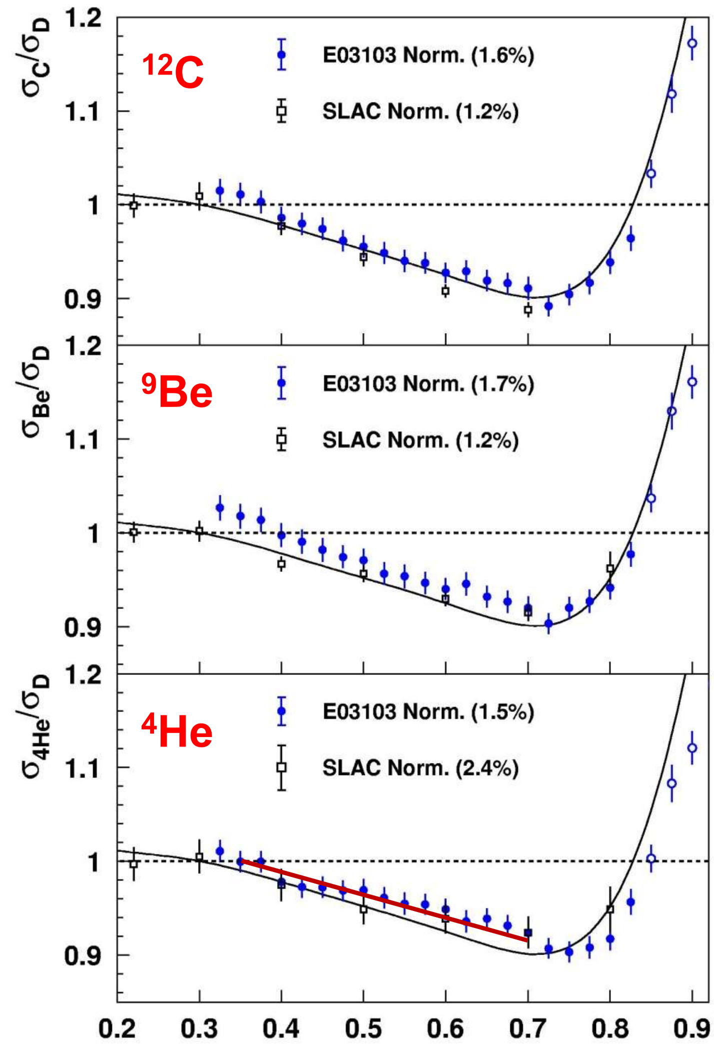
EMC effect

EMC collab measured Fe/D cross section ratios in DIS regime;
found strong suppression of nuclear pdfs in valence region
→ Significant suppression of high-x quark distribution in Fe



JLab E03-103 measured EMC effect for $^{3,4}He$, ^{9}Be, ^{12}C
Consistent shape for all nuclei (curve is SLAC ^{12}C fit)

We quantify the EMC effect using the slope in the linear region (0.35<x<0.7)



J.Seely, et al., PRL103, 202301 (2009)

EMC effect

Conventional binding/smearing can explain up to half of the effect in some models. Has much smaller impact in light-front calculations

Several more exotic explanations proposed; many can explain the conventional EMC effect, but may be excluded by other observables

<u>Insight from the Jefferson Lab program:</u>
Light nuclei measurements led to examining more detailed nuclear structure

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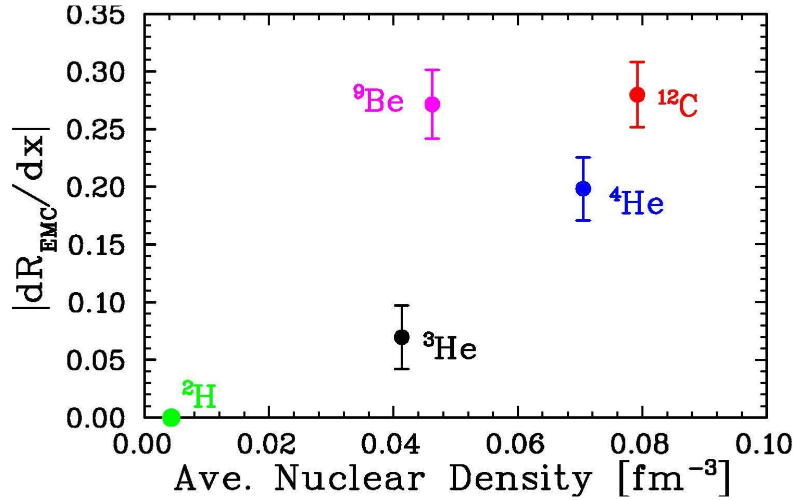

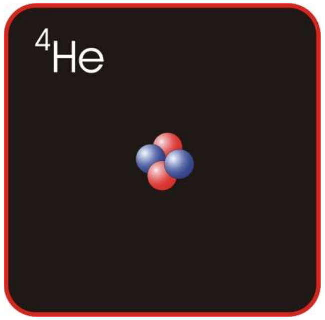

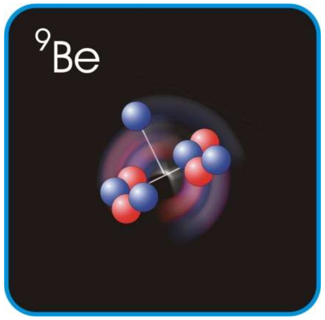

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Light nuclei measurements led to examining more detailed nuclear structure

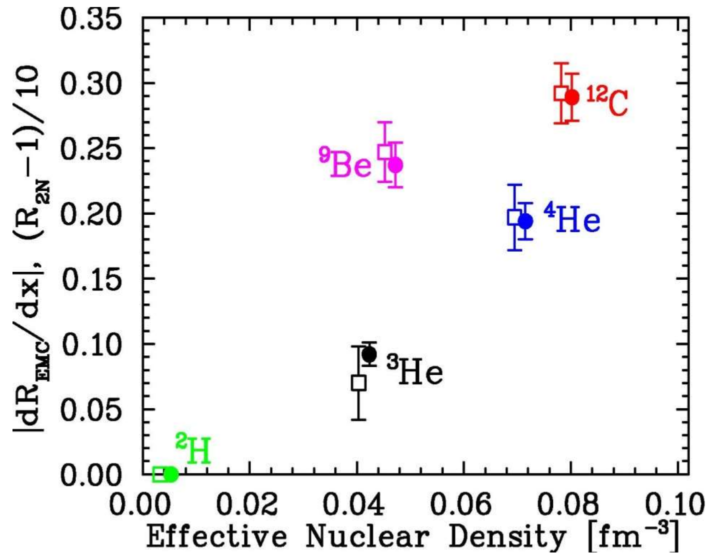
Demonstrated non-trivial EMC-SRC correlation – often explained in terms of Local-Density or High-Virtuality effects

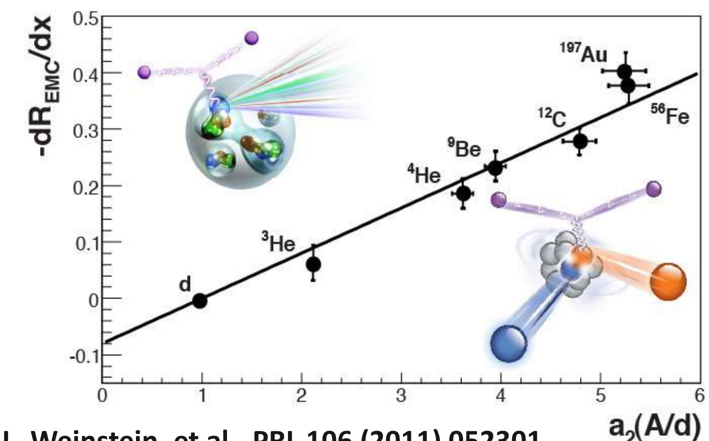
New Inclusive (12 GeV): A and N/Z dependence, flavor-dependence, spin dependence can provide tests of various models

'Tagged' measurements are latest observable, provide new information but have limitations and model dependence in the interpretation

"EMC effect" at x>1, i.e. SFQ distributions, provides entirely new test; **needs higher energy for clean interpretation**

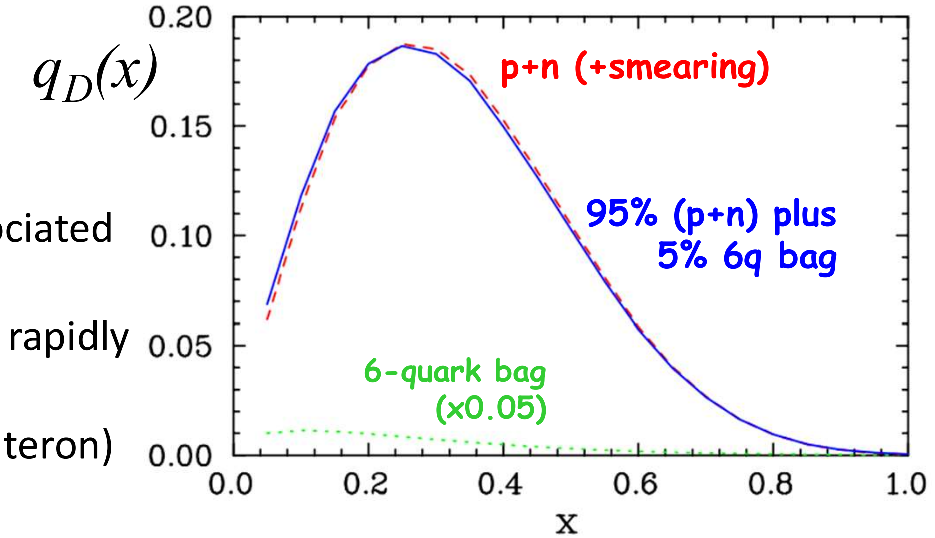
J. Arrington, et al., PRC 86 (2012) 065204





L. Weinstein, et al., PRL 106 (2011) 052301

Nuclear pdfs at x>1 (SFQs)



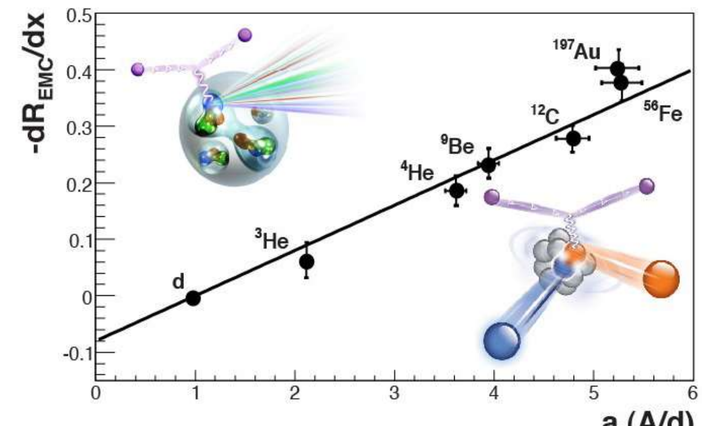
In a simple convolution model, the super-fast quarks are associated with high-x quarks in high-momentum nucleons

- Both the pdf and the nucleon momentum distribution fall rapidly at large momenta
- SFQ distribution falls rapidly at large x values (esp. for deuteron)

If conventional SFQ contribution is small, certain effects may be much easier to see

- An additive non-hadronic contribution may stand out where pdfs are small

Off-shell effects associated with very high-momentum nucleons will be amplified as x>1 selects higher momentum nucleons



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Nuclear pdfs at x>1 (SFQs)

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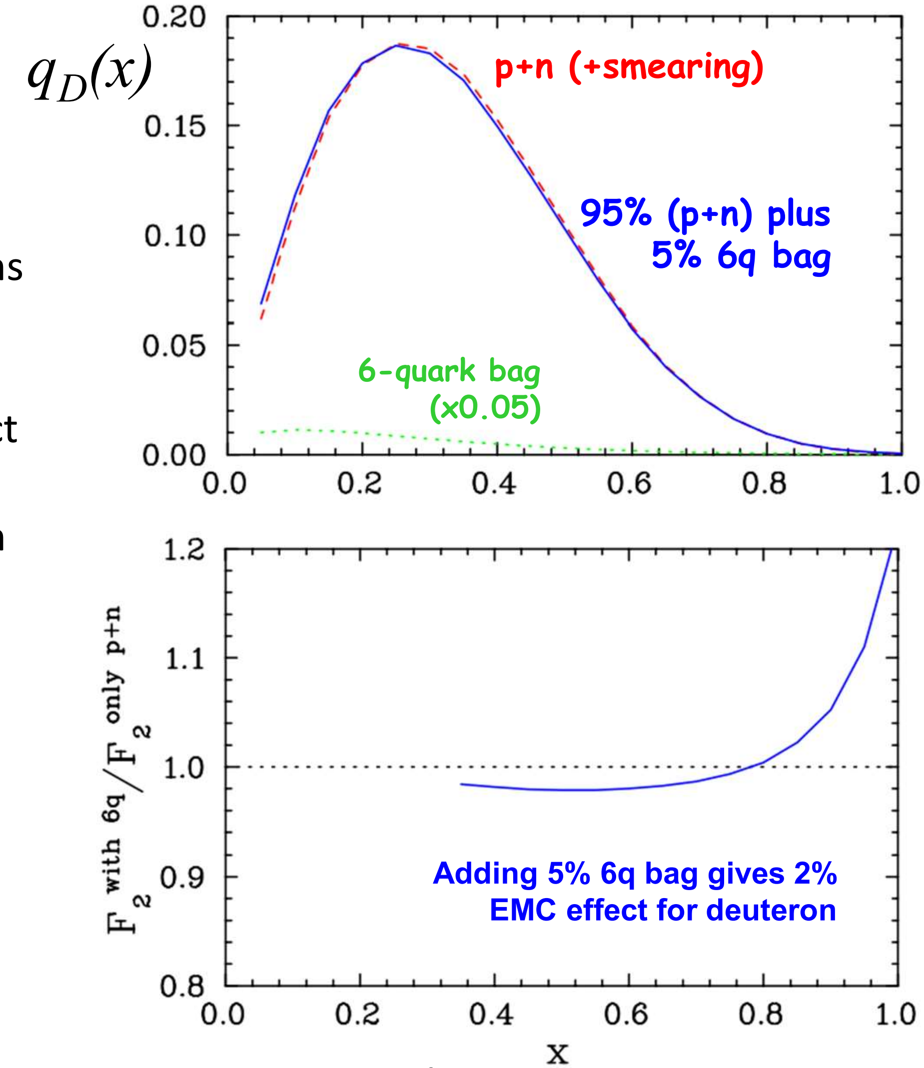
- Six-quark bag was potential explanation for the EMC effect
  - Two interacting 3q bags ≠ one 6q bag
  - Small impact EMC region, much larger in SFQ region



J. Arrington, APHA 21 (2004) 295, arXiv:hep-ph/0304213

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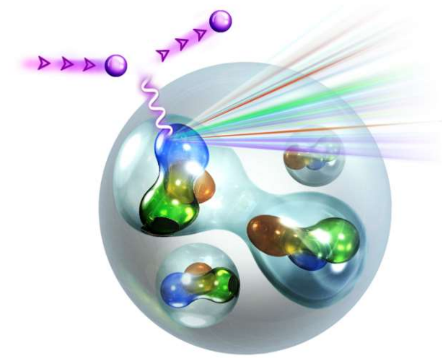

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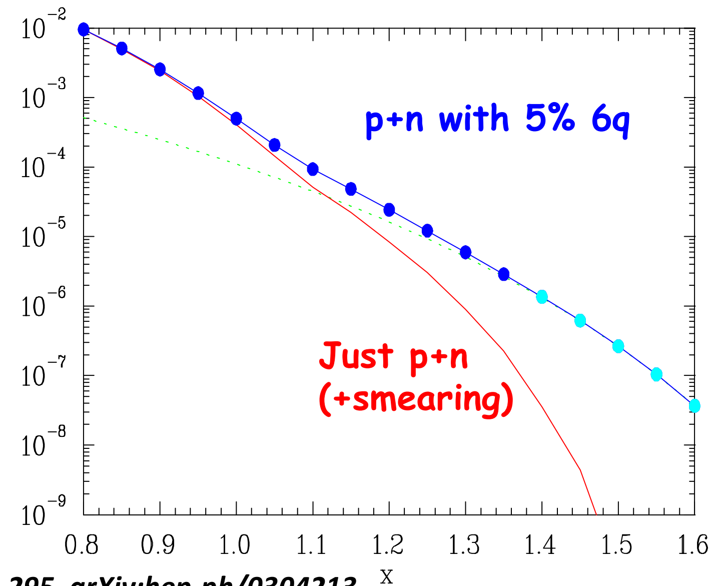
- Momentum sharing more important at largest quark momenta
  - Dramatic enhancement (potentially order of magnitude) over taking highest-x quarks in highest-momentum nucleons
- Similar for any mechanism that allows direct momentum sharing, while off-shell effects and other models suggest suppressed pdfs



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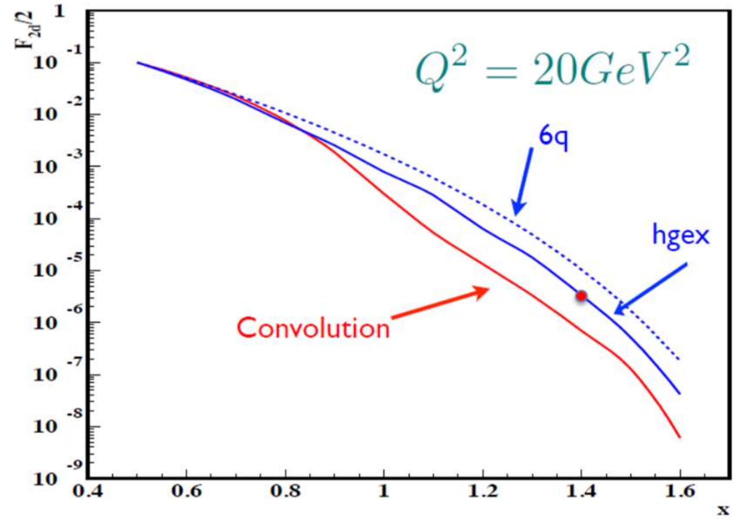
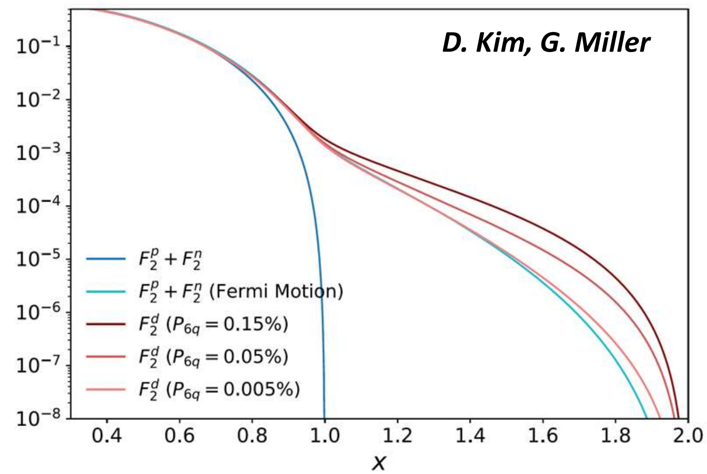
Misak M. Sargsian, NPA 782 (2007) 199

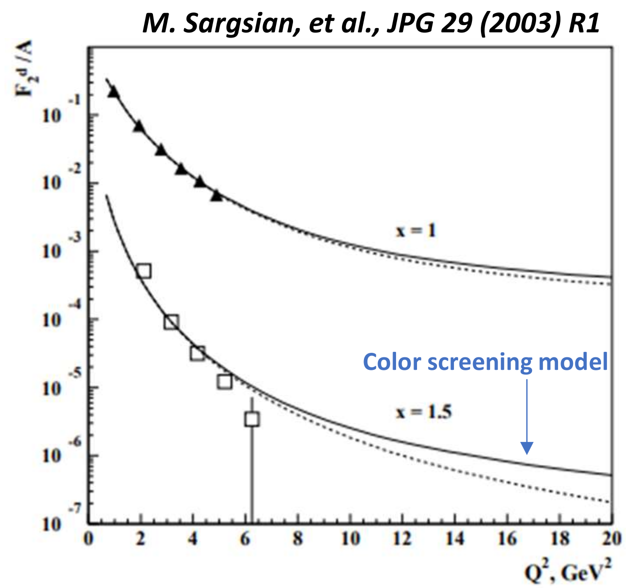


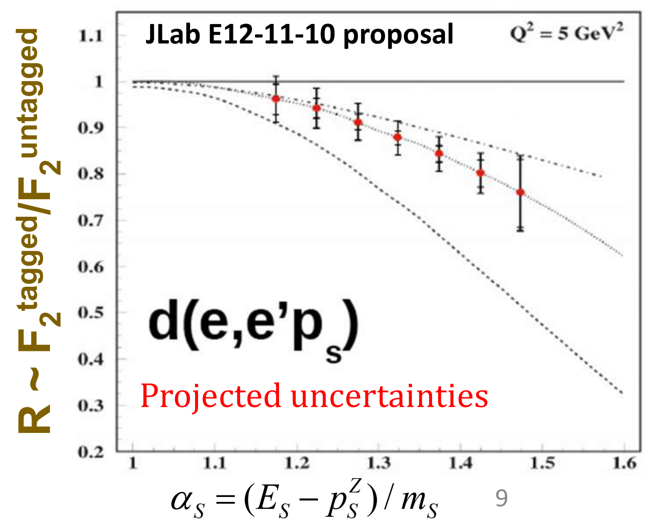


D. Kim and G. Miller, PRC 109 (2024) 045203

Other models for super-fast quarks

- Nucleon overlap/quark momentum sharing predict significant enhancement in the nuclear pdfs at x>1 (100-1000% enhancements)
- Various other models (color screening, PLC suppression, rescaling, off-shell) can yield significant suppression in this region (factors of 2ish)





Kinematic projection

Kinematic coverage for 6, 11, and 22 GeV from the 22 GeV White Paper

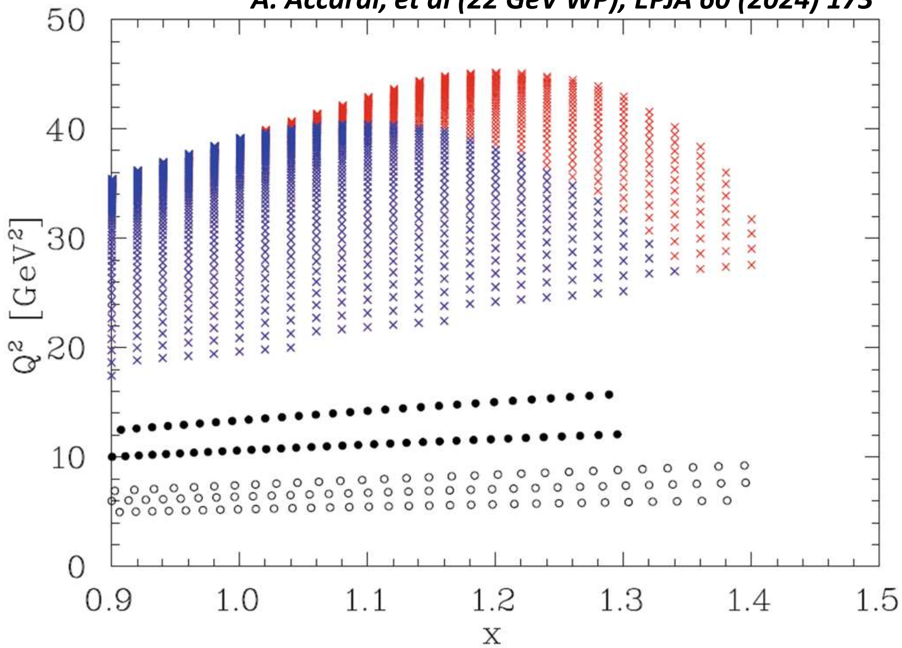
- Blue (red) shows 10 (1) counts/hour: 50uA on 2% ^{12}C target

Factor ~4 improvement in Q^2 coverage

Better to look at coverage in ξ and Q^2

- Nachtmann ξ is 'improved' version of x for finite Q^2 values
- x=1.4 gives $\xi \approx 1.2/1.3/1.35$ for 6/11/22 GeV

A. Accardi, et al (22 GeV WP), EPJA 60 (2024) 173



Theory input needed

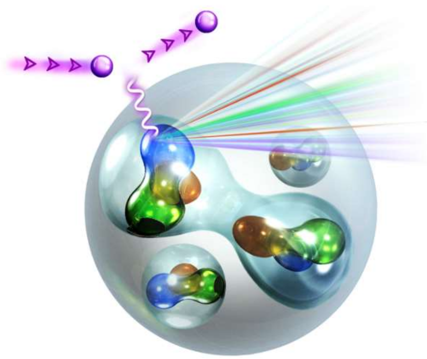
Calculations of SFQ distributions for the deuteron based on 'conventional' effects
- Determine uncertainty in the 'baseline' distributions

Evaluate models of the EMC effect in a consistent fashion
- Some calculations exist, some have been evaluated for tagged DIS but not inclusive

Examine A-dependence, Q^2 dependence
- Should be straightforward, but no systematic evaluations

Define scaling ration?
- Not well defined, but there are relatively straightforward ways to estimate and evaluate whether or not data behave like DIS
- 22 GeV is absolutely critical here.

Super-fast quarks

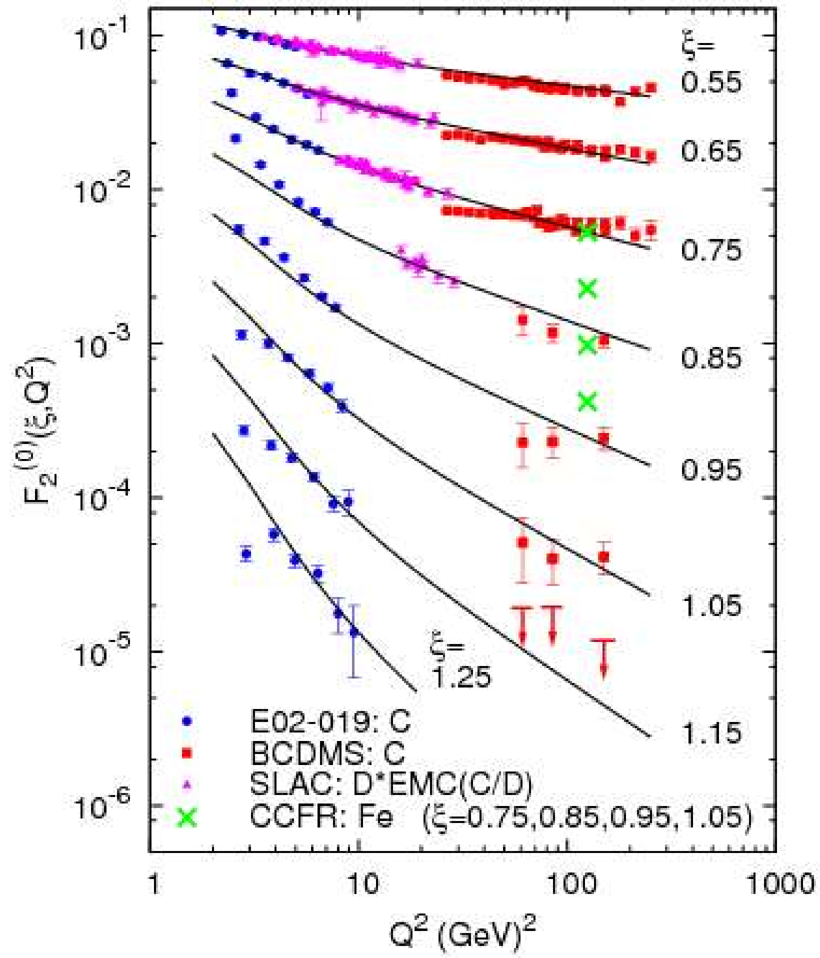


Key experimental issue is ensuring DIS to constrain pdfs

6 GeV data show ***partonic-like scaling behavior*** for x>1, despite being dominated by quasi-elastic

12 GeV experiment doubles JLab Q^2 range largely inelastic, but mainly resonance region (~10% QE): ***detailed, quantitative evaluation of scaling at large x/ξ***

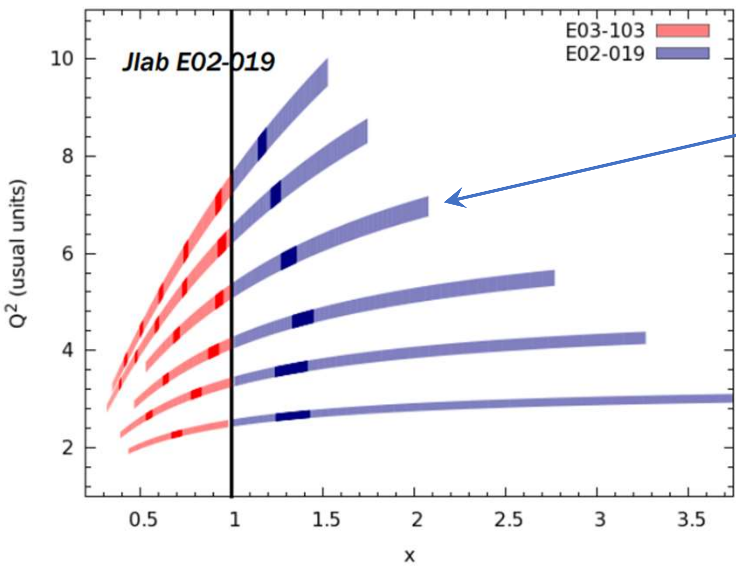
22 GeV: Dominated by DIS, small resonance and negligible QE contributions – **reliable pdf constraints**

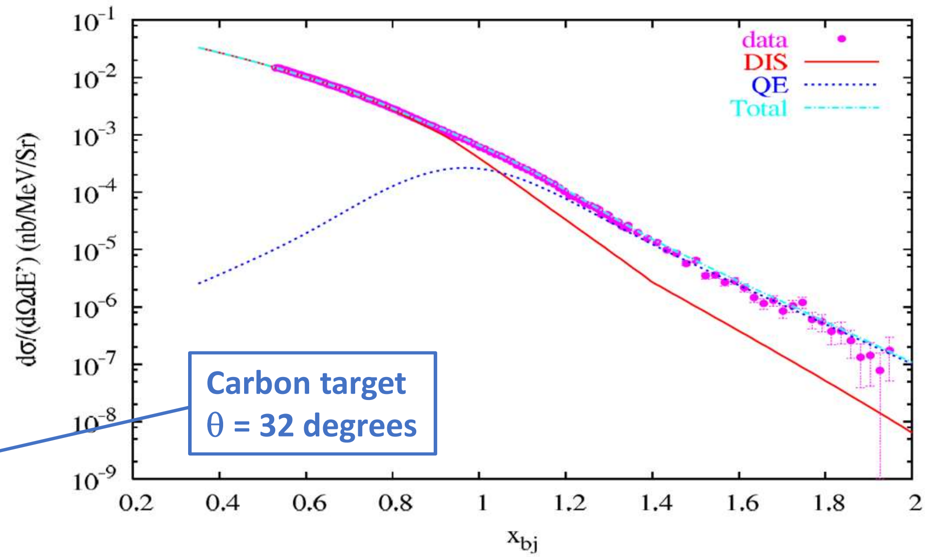


N. Fomin et al, PRL 105, 212502 (2010)

Challenges to interpreting SFQ distributions

- **High energies needed to isolate DIS at large x**
  - **6 GeV experiment limited to 8-9 GeV²**
- Cross section very small (x>1, high Q^2)
- Need reliable calculations to use as 'baseline'





QE (blue) vs Inelastic (DIS + Resonance) (red)

QE dominated for x>1.1, and inelastic has significant resonance and DIS contributions

Not at all clear that structure function would provide access to pdfs or scale like DIS

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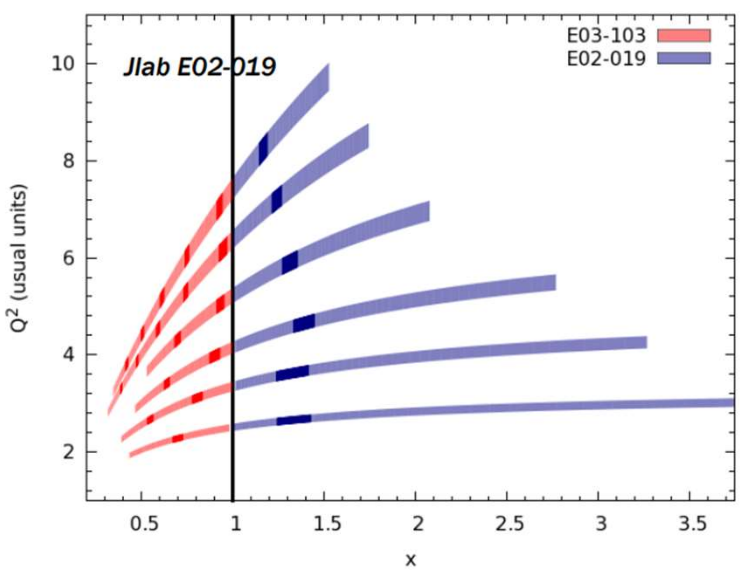
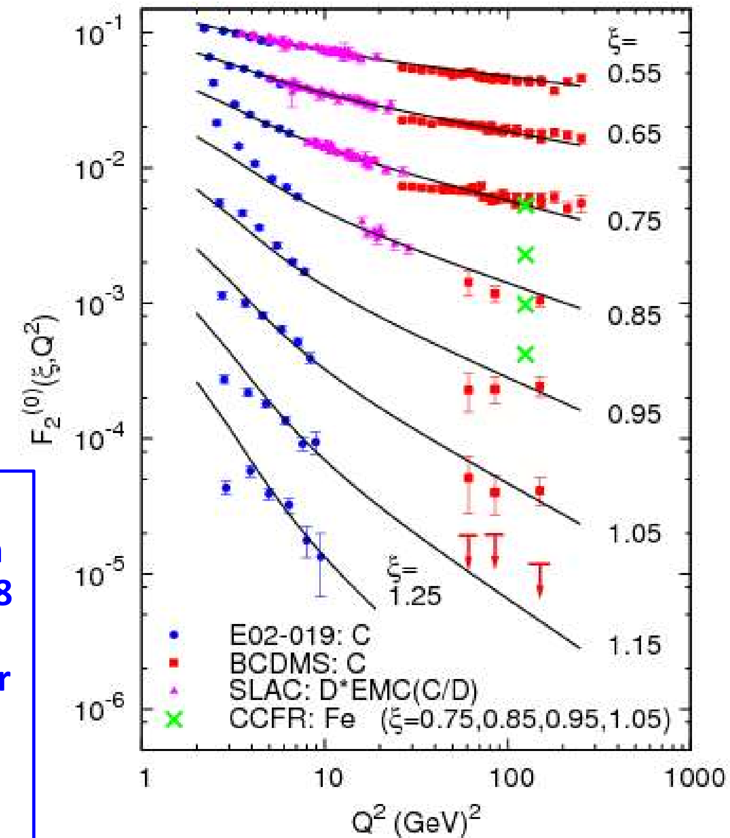


At 6 GeV, high Q^2 data consistent with DIS data up to x ≈ 0.8 and consistent with QCD scaling behavior for x>1

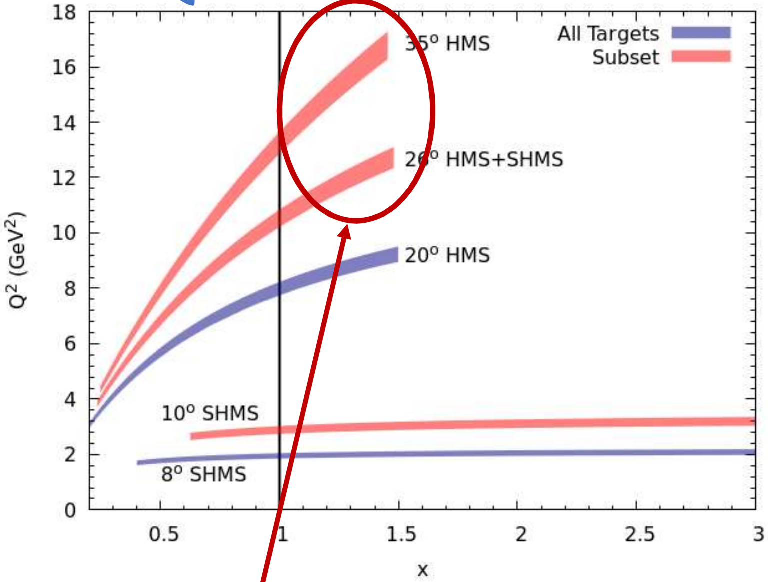
Consequence of *quark-hadron duality*

N. Fomin et al, PRL 105 (2010) 212502



JA, et al, PRC 73 (2006) 035205

SFQs at 11 GeV: New kinematics



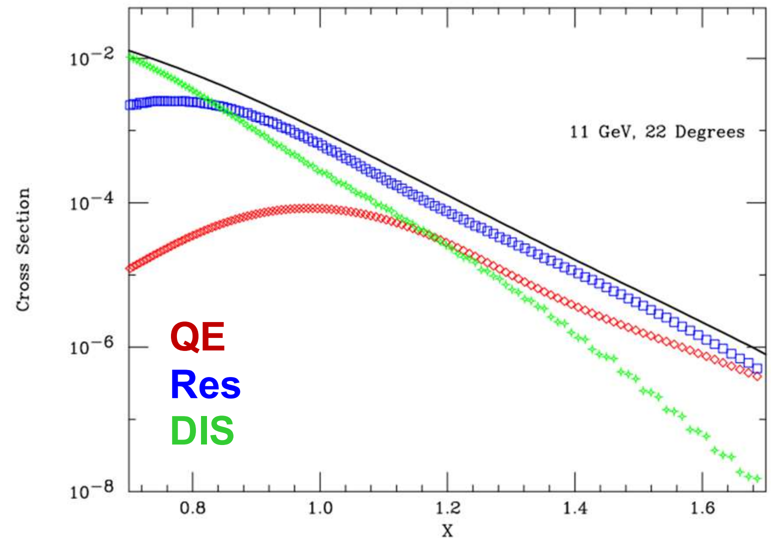
SRCs at x>1 at 12 GeV
[E06-105: JA, D. Day, N. Fomin, P. Solvignon]

Ran in Hall C with EMC effect experiment E12-10-008, 2022-2023

Inclusive scattering at x>1; push to largest Q^2 to study super-fast quark distributions

22 degrees: F_2 dominated by resonance region

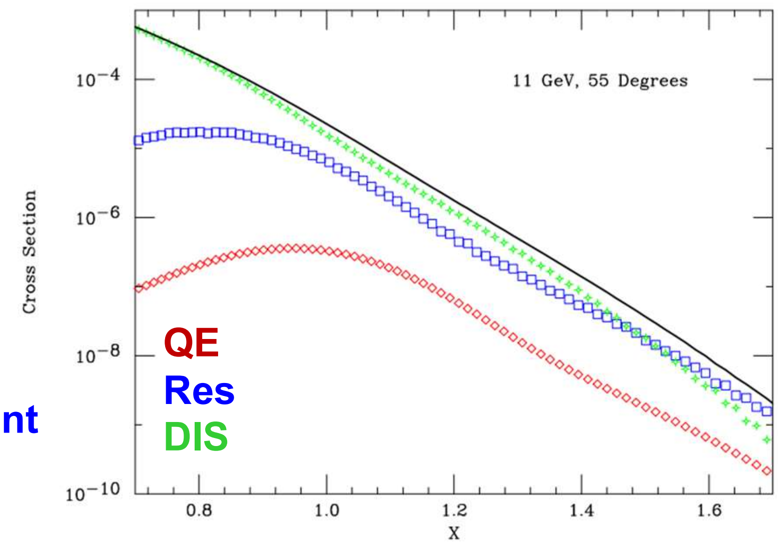
(QE & DIS small)



55 degrees: DIS dominated x<1.4

resonance important

(QE negligible)



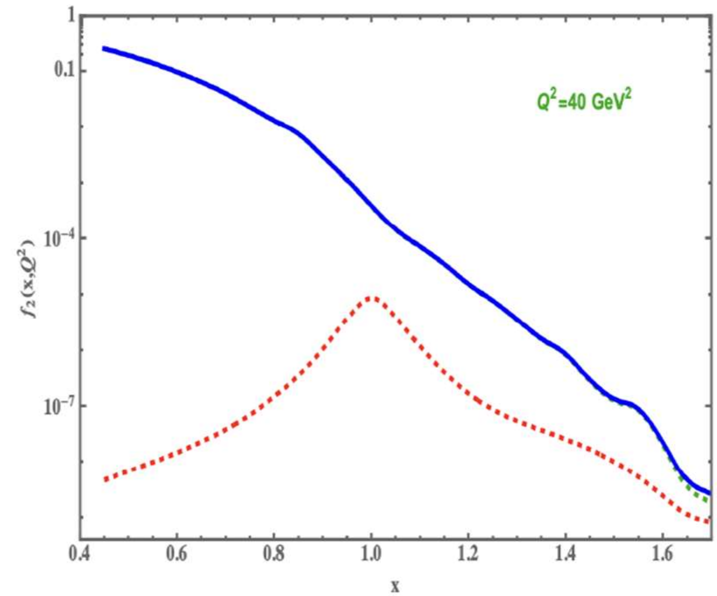
22 GeV

- 6 GeV data, Q^2<8 GeV^2: QE dominated, looks ("by eye") consistent with scaling

- 11 GeV, Q^2<16 GeV^2 : DIS comparable to resonance region; QE small
  - Not a precise measurement of pdfs; expect modest scaling violations (which can be measured)
  - Could be very compelling if very large deviations observed

- 22 GeV, $Q^2 \approx 36$ GeV^2
  - Much smaller resonance contributions
  - Better check of scaling (Q^2 dependence)
  - Push to higher x at 'lower' Q^2 – larger predicted effects
  - Real A dependence studies possible

Plot (Sargsian) illustrates small QE contribution
Need to update Resonance vs DIS estimate



Where do we go from here?

- Short-term:
  - Compare baseline convolution calculations, including TMC, HT effects
  - Extract the inclusive x>1 structure function from various models vs x, Q^2
  - Map out kinematic coverage, experimental needs for 22 GeV experiment

- 11 GeV: First test in compare of deuteron data to calculations
  - Try to quantify how well F_2 connects to pdfs at these kinematics
  - Look for potentially large increase (suppression) over baseline convolution
  - If observe large effect (relative to uncertainties associated with limit Q^2), look at A-dependence: 2H, 4He, 12C, 40Ca to see if it scales as predicted

- 22 GeV or EIC:
  - Cleaner measurement at much higher Q^2
  - JLab 22: Extend x range, where several models show rapid variation
  - EIC: Significantly higher Q^2 values
  - Examine Q^2 dependence – test/constrain HT contributions