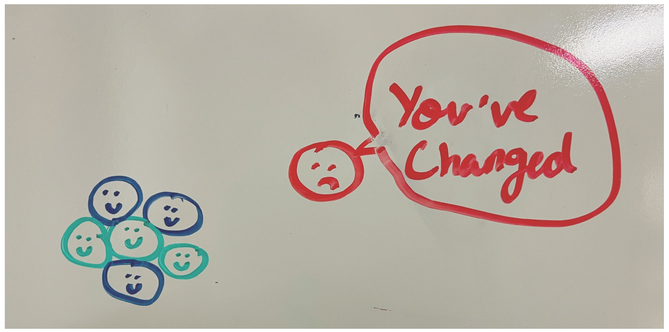
EMC Effect at 11GeV



Advisor: Professor Nadia Fomin
Abhyuday Sharda
August 8th 2024

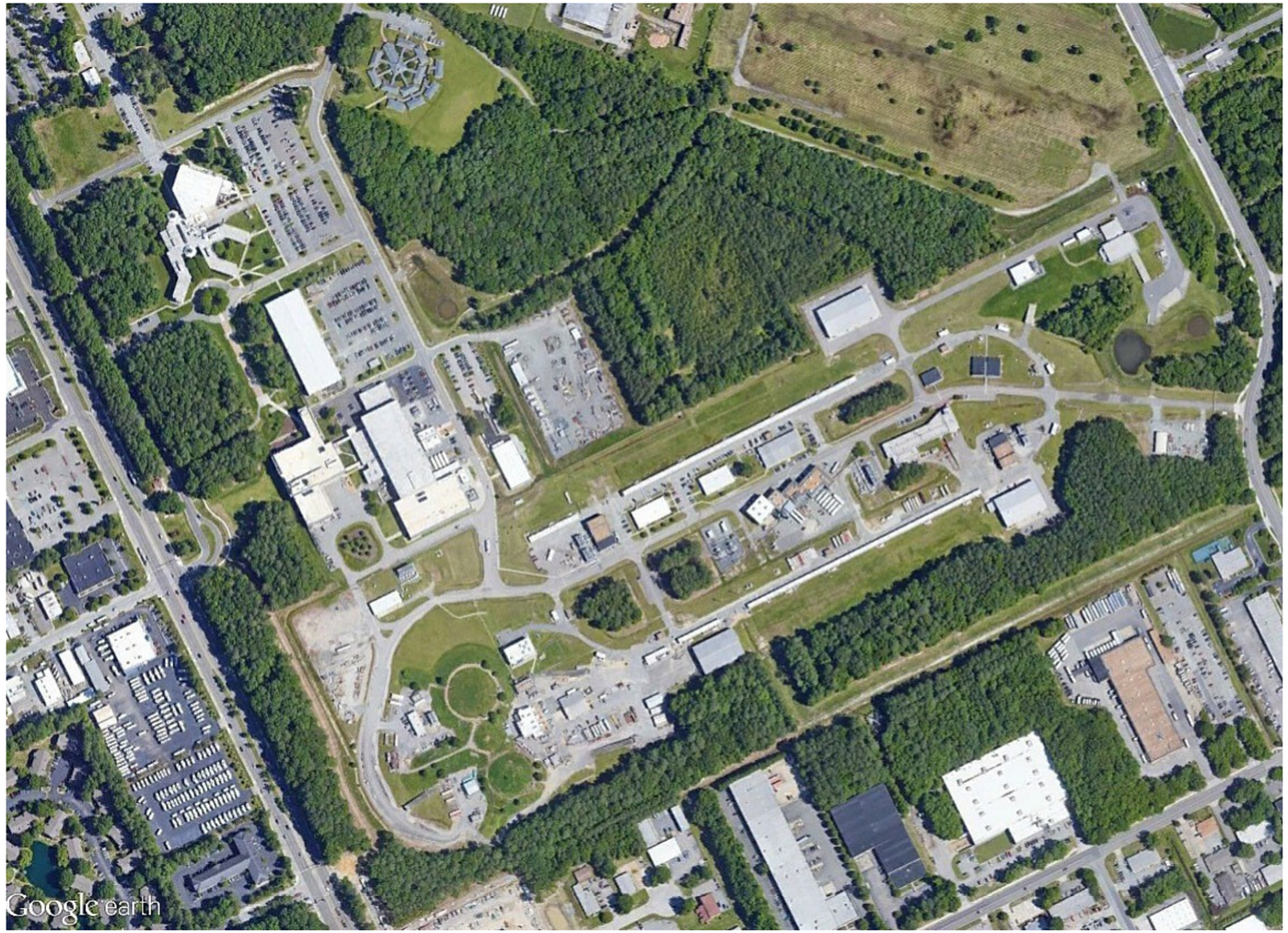
THE UNIVERSITY OF TENNESSEE KNOXVILLE

Jefferson Lab

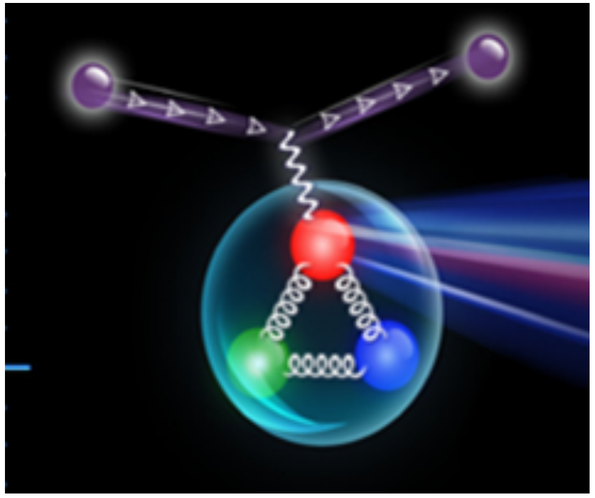
This work was supported by U.S. Department of Energy under award number: DE-SC0013615 and JSA Graduate Fellowship

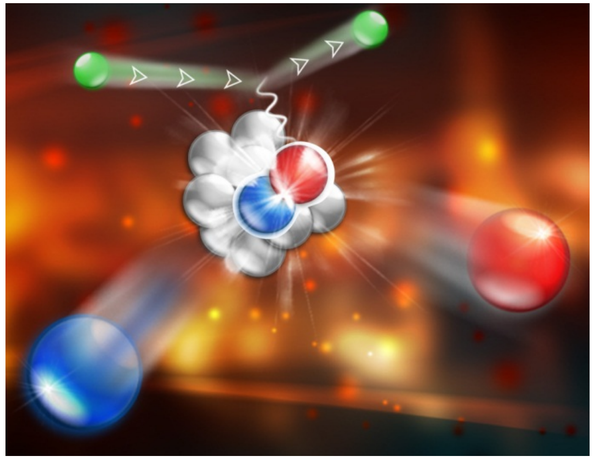
Overview

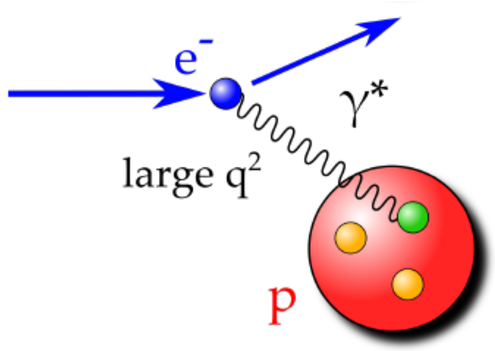
- ***Introduction & Physics motivation***
- Experimental setup and Outline
- Results
- Summary and Future

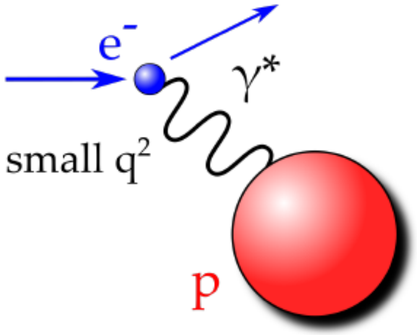


Electron scattering is our microscope









$$-q^2 = Q^2 = 4EE' \sin^2 \theta/2$$

$$\nu = E - E'$$

Find x.

- Bjorken x was defined for high energy lepton scattering from protons
- Momentum of the struck quark divided by the momentum of the constituent nucleon
- There are 3 valence quarks that make up a nucleon, so, the naïve expectation is-

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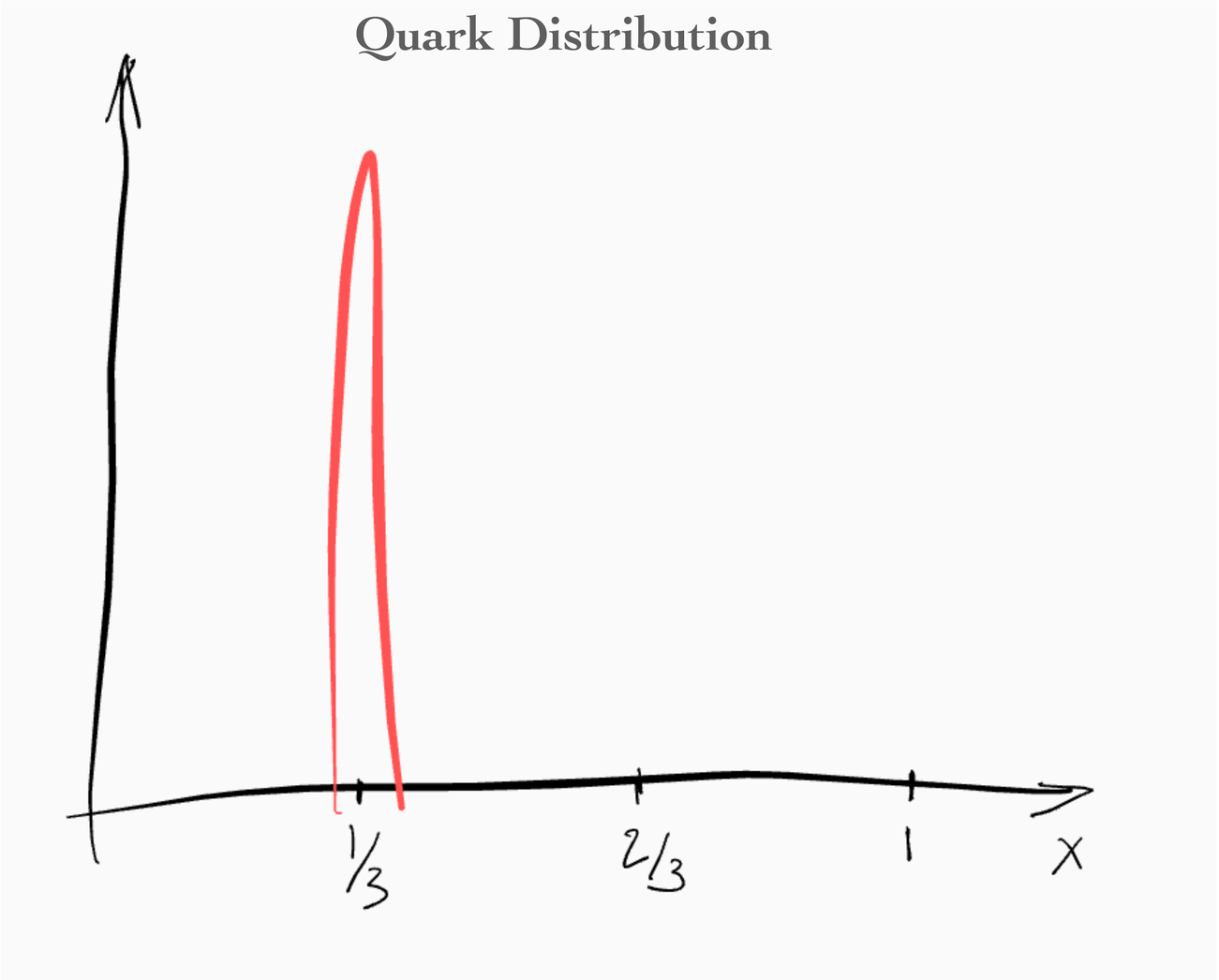

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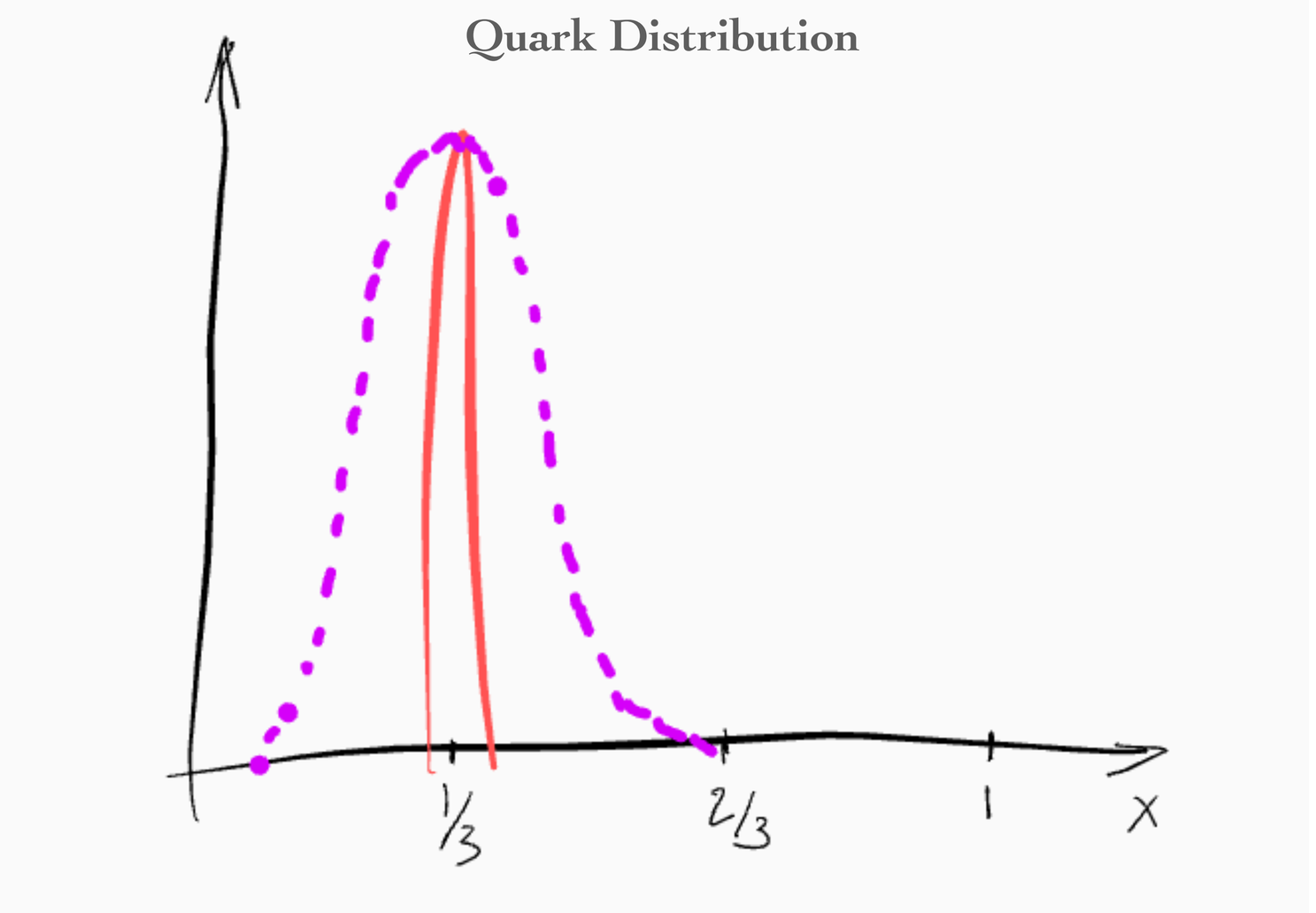
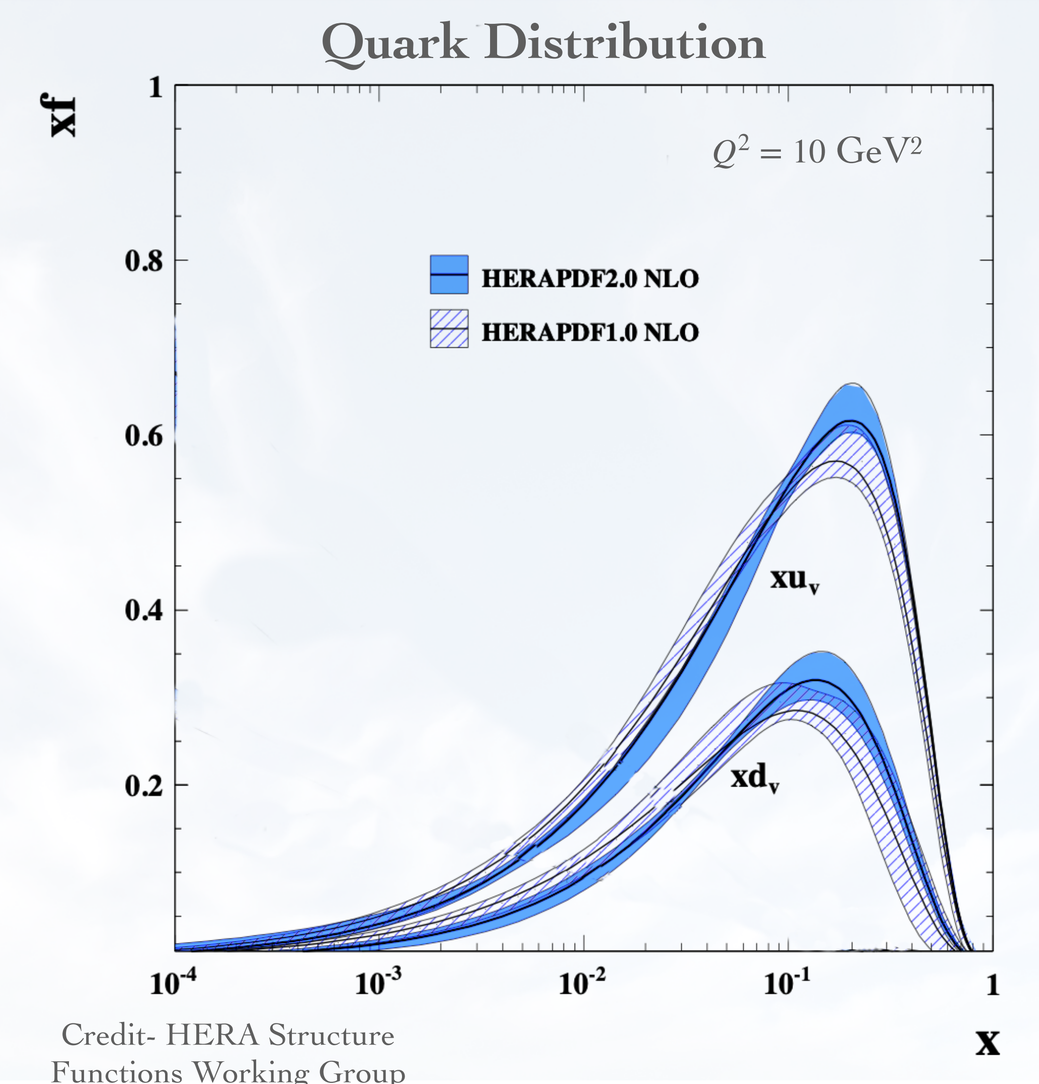
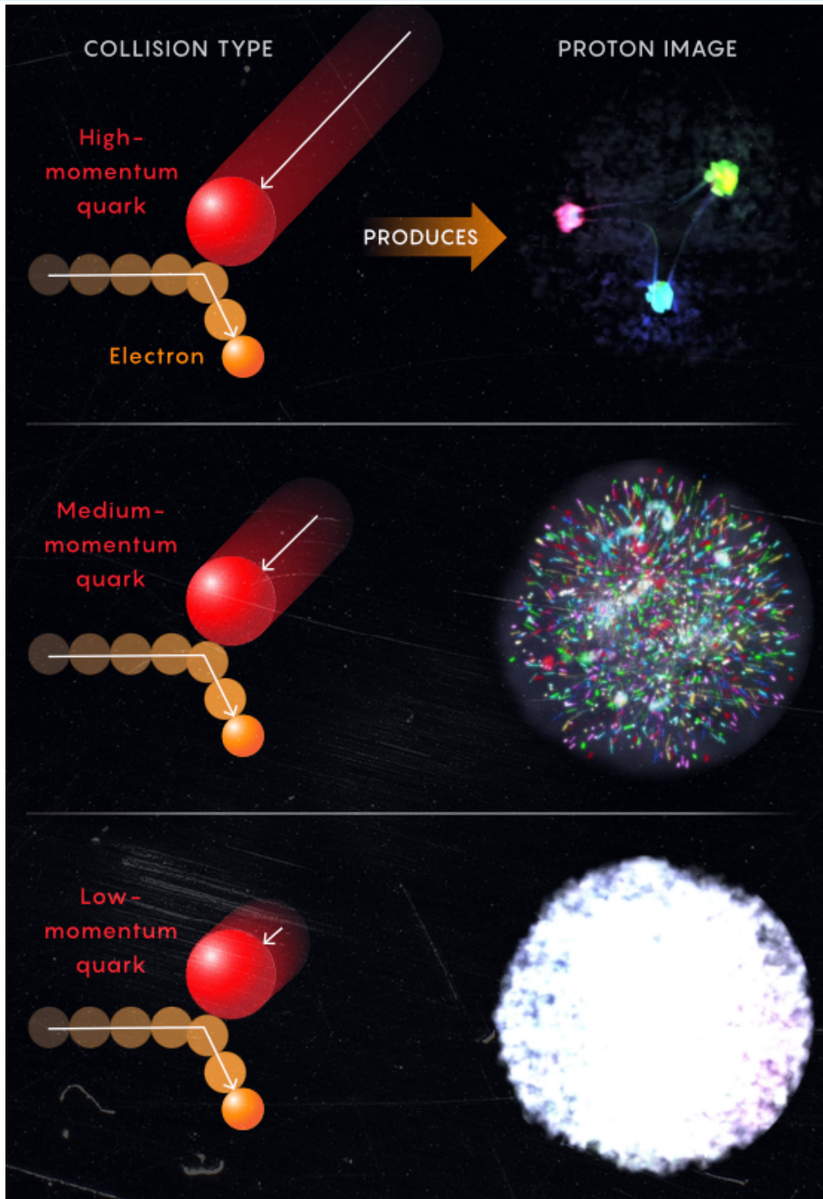


Find x.

The data-

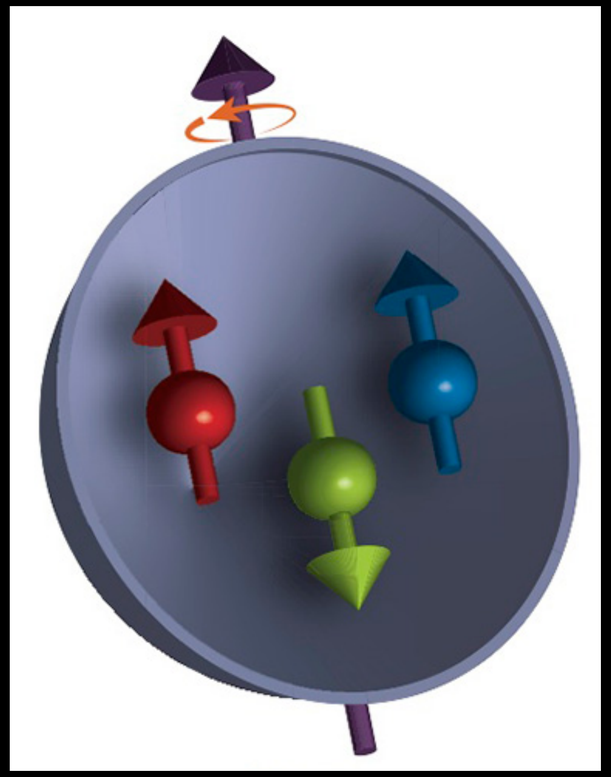


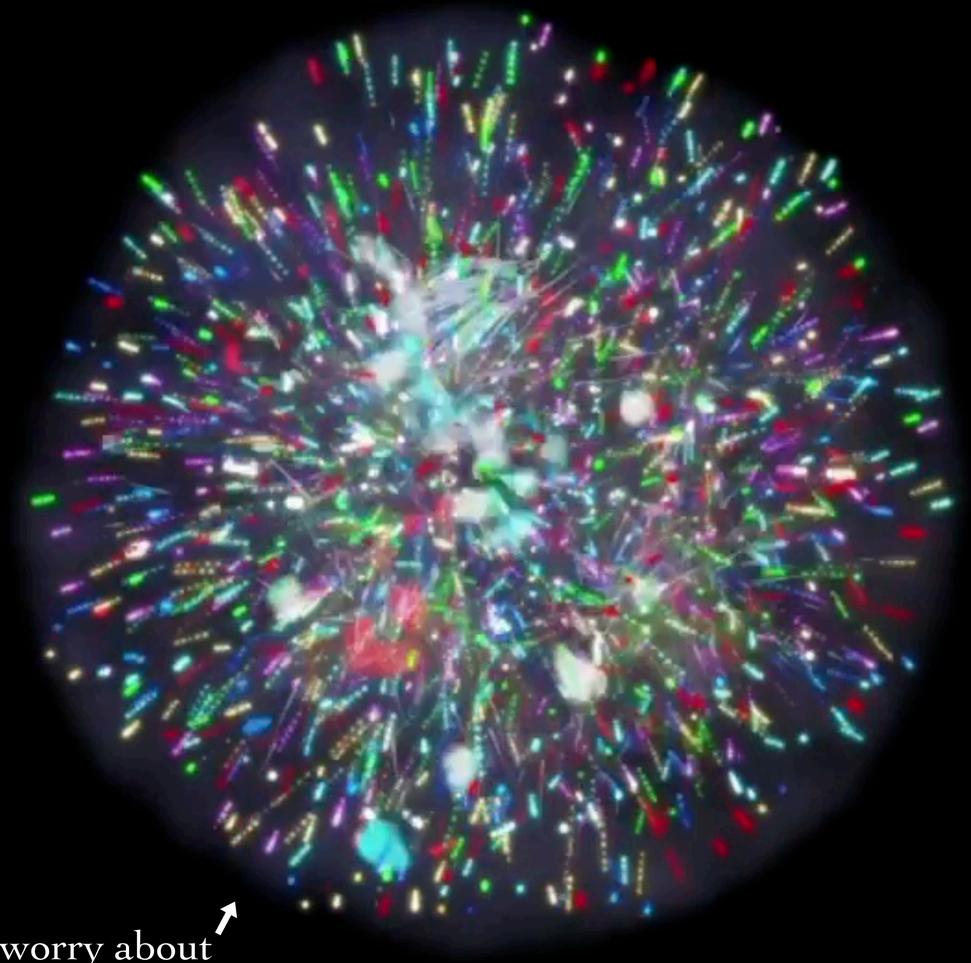
Credit- HERA Structure Functions Working Group



EMC Effect at 11GeV

‘The most complicated thing you can imagine’





You vs the nucleon she tells you not to worry about

Credit- Quanta Magazine

Why cross-sections?

- Inelastic scattering from a nuclei

$$\frac{d\sigma}{dE'd\Omega} = \frac{\alpha^2 \cos^2\left(\frac{\theta}{2}\right)}{4E^2 \sin^2\left(\frac{\theta}{2}\right)} \left[2F_1(\nu, Q^2)\tan^2\left(\frac{\theta}{2}\right) + F_2(\nu, Q^2) \right]$$

Structure Functions

- For a proton-

$$2F_1(x) = \frac{F_2(x)}{x} = \sum_i e_i^2 q_i(x) = \frac{4}{9}[u(x) + \bar{u}(x)] + \frac{1}{9}[d(x) + \bar{d}(x)] + \frac{1}{9}[s(x) + \bar{s}(x)]$$

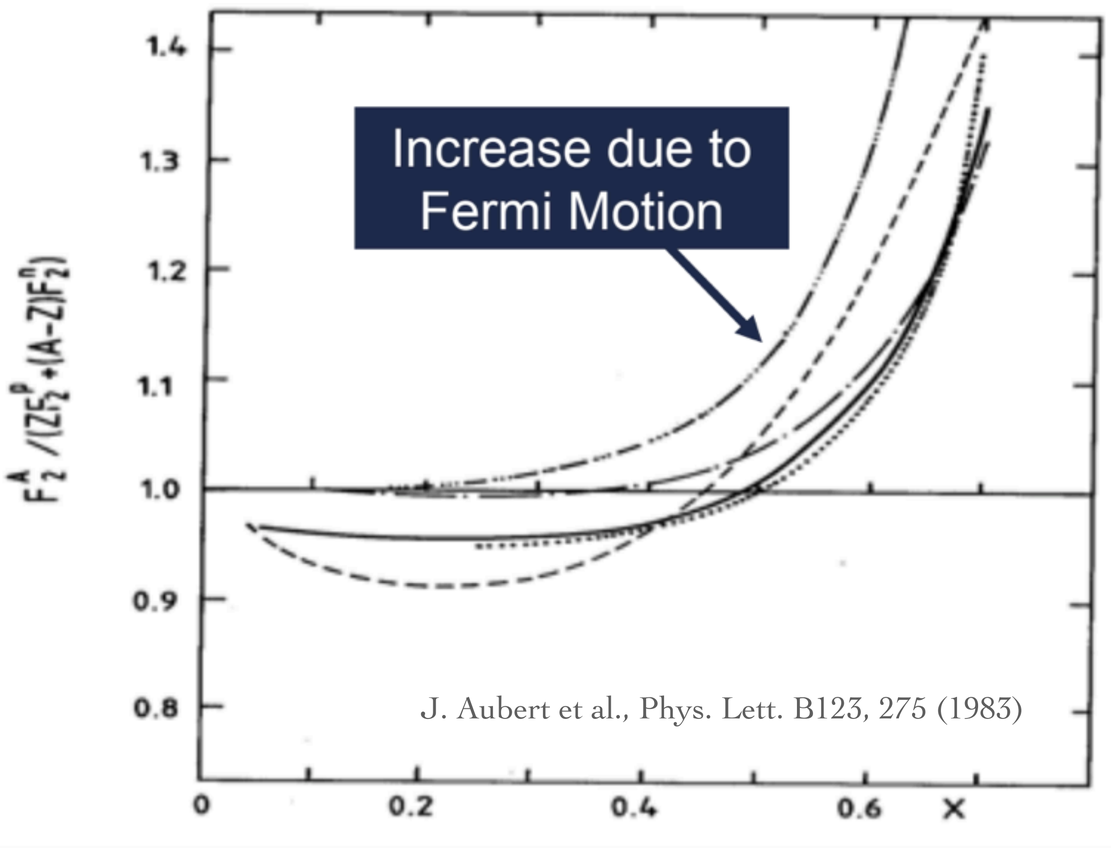
Parton Distribution Functions (PDFs)

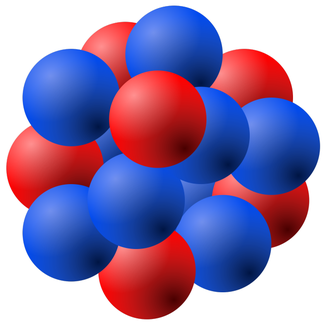
Callan-Gross relation:

$$2xF_1(x) = F_2(x)$$

What is the EMC Effect?

- $F_2^A(x) = ZF_2^p(x) + NF_2^n(x)$
- Structure function of a nuclei relative to Deuterium
- Why Deuterium? Loosely bound and assumed to be approximately a proton and neutron

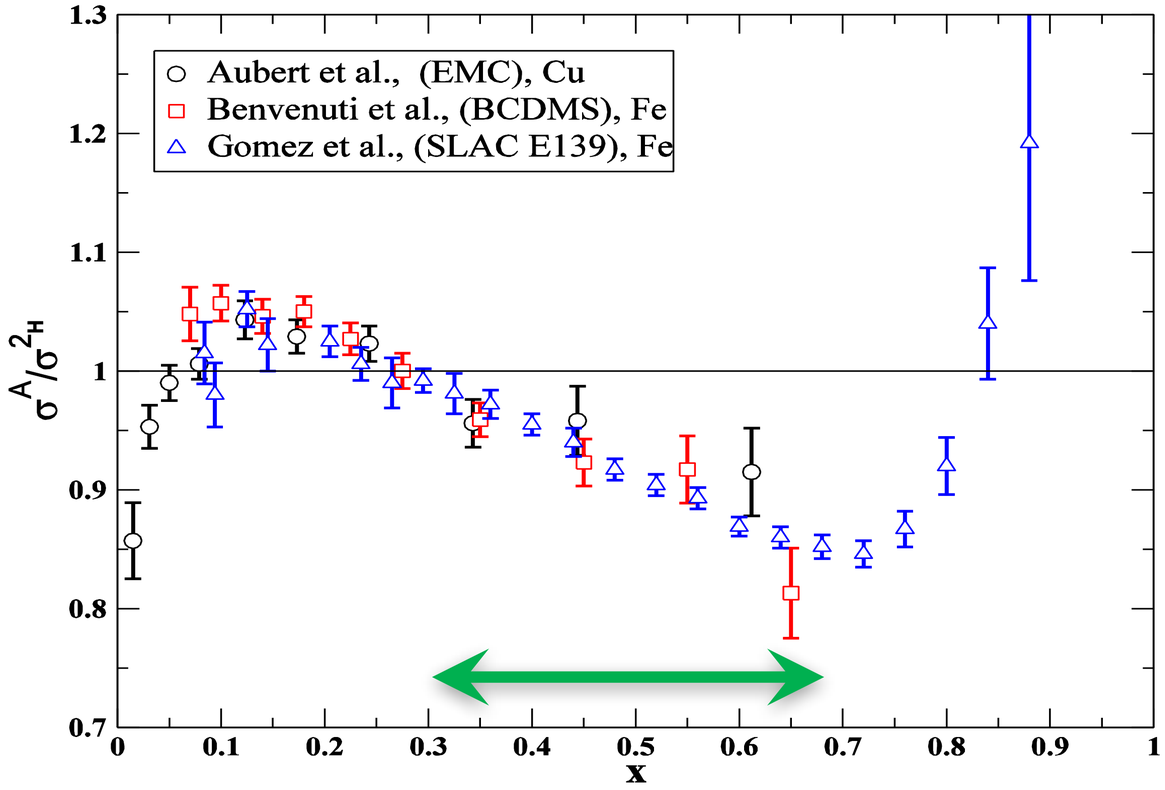


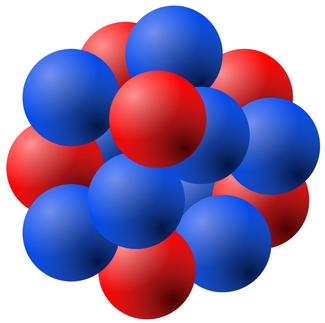


What is the EMC Effect?

- Discovered by the European Muon Collaboration in 1983

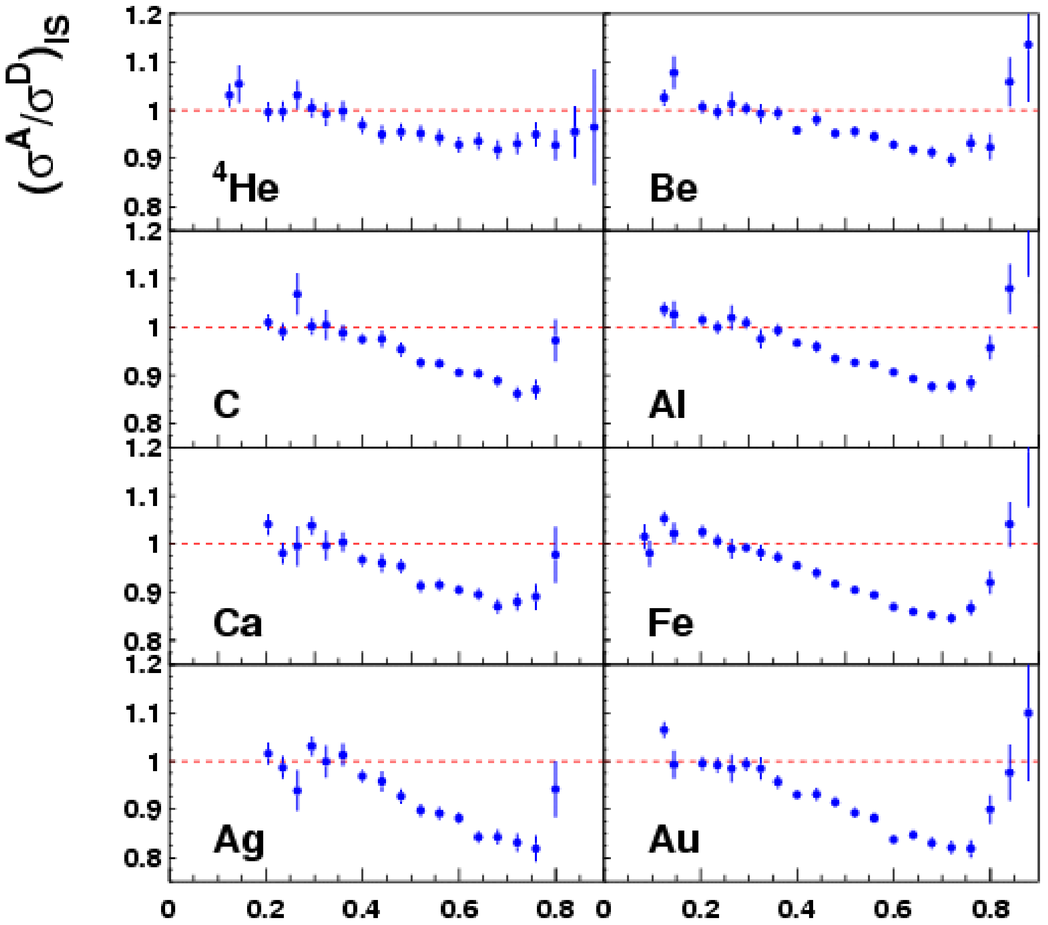
- $F_2^A(x) \neq ZF_2^p(x) + NF_2^n(x)$





What is the EMC Effect?

$$\left|\frac{dR_{EMC}}{dx}\right| \sim \text{from } 0.35 < x < 0.7$$



SLAC E139

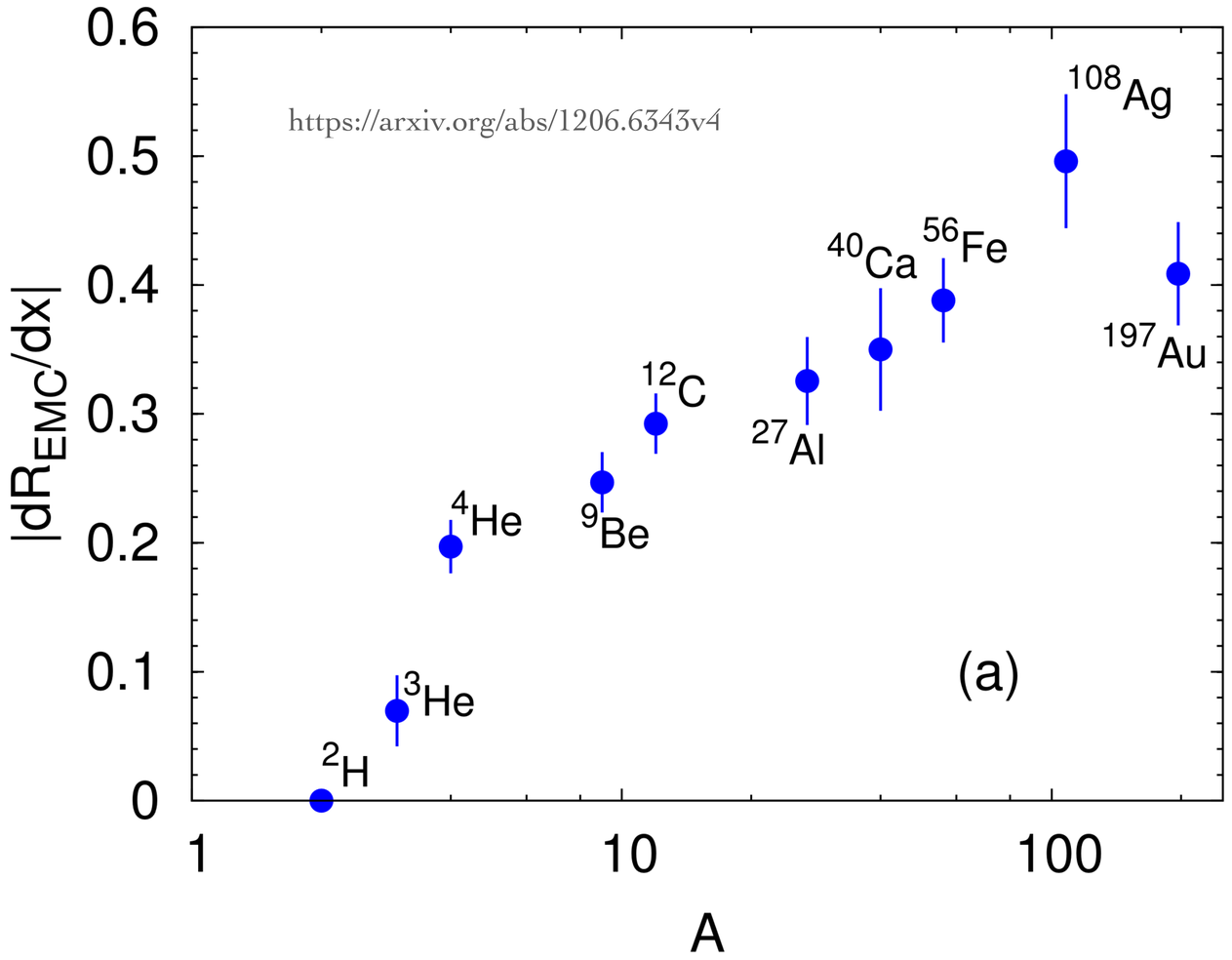
https://arxiv.org/abs/1405.1270v2

What is the EMC Effect?

- >1000s of theory papers written
- No consensus after >40 years
- Typical nuclear binding energies are insignificant compared to energies in DIS experiments (MeV vs. GeV)
- Guided by experiments, we have hints

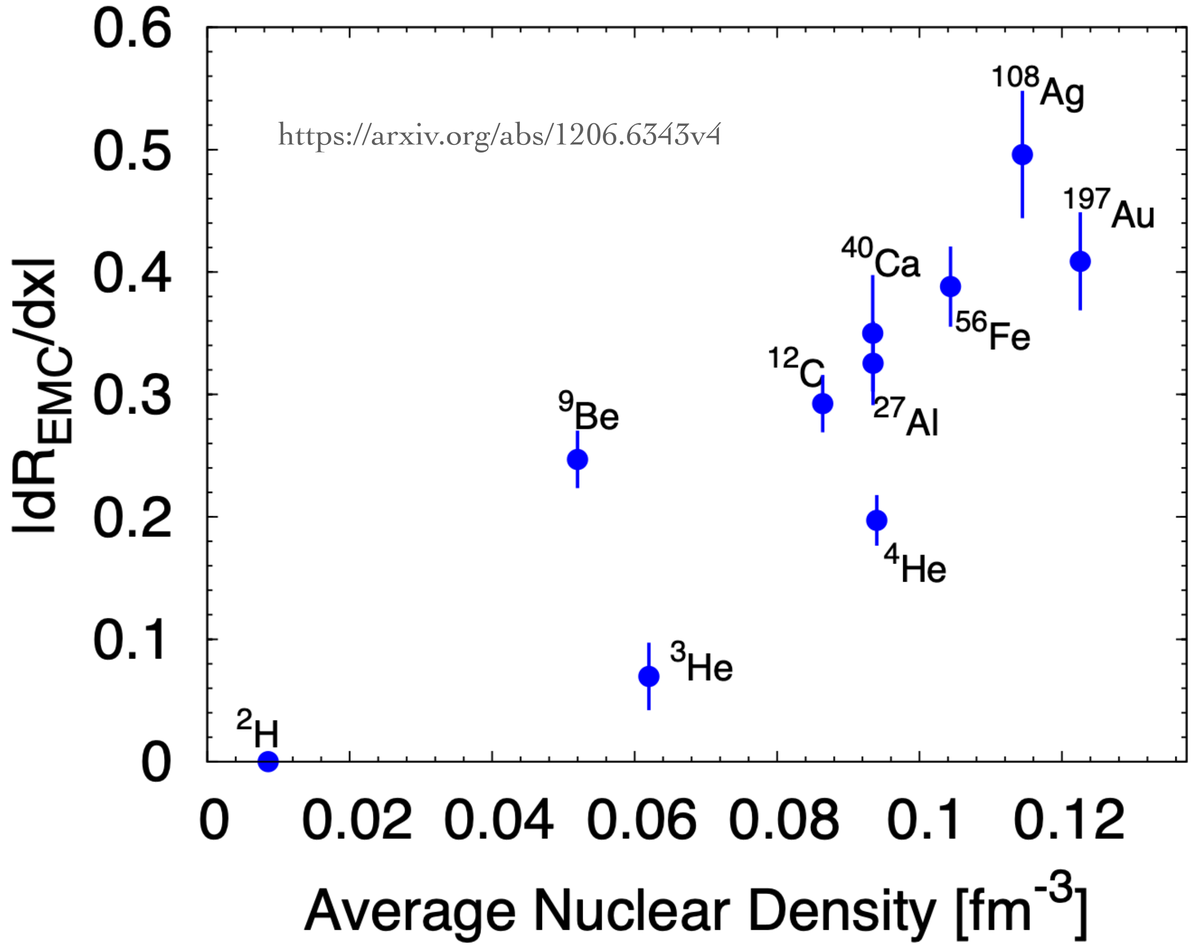
Finding Correlating Properties

- No direct relation with A

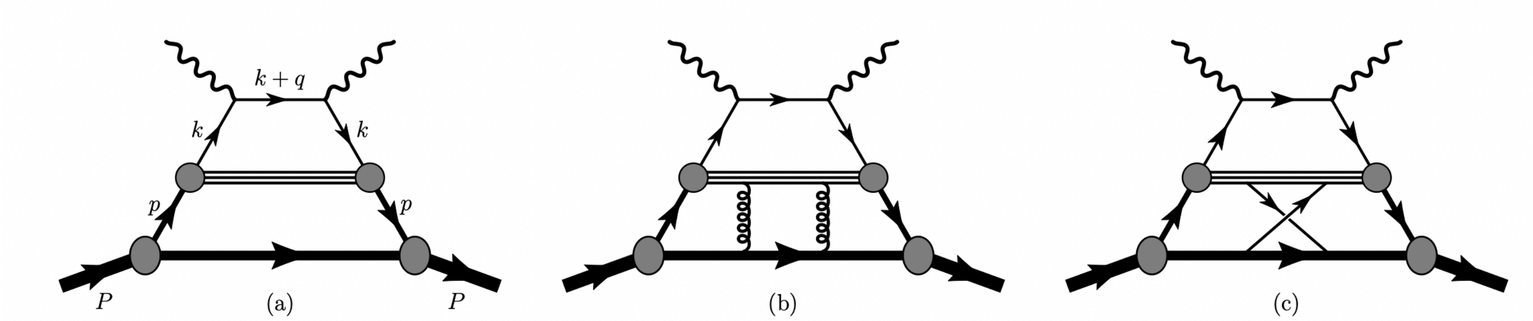


Finding Correlating Properties

- Scaling with average nuclear density is not completely satisfactory for light nuclei



Theoretical Approaches

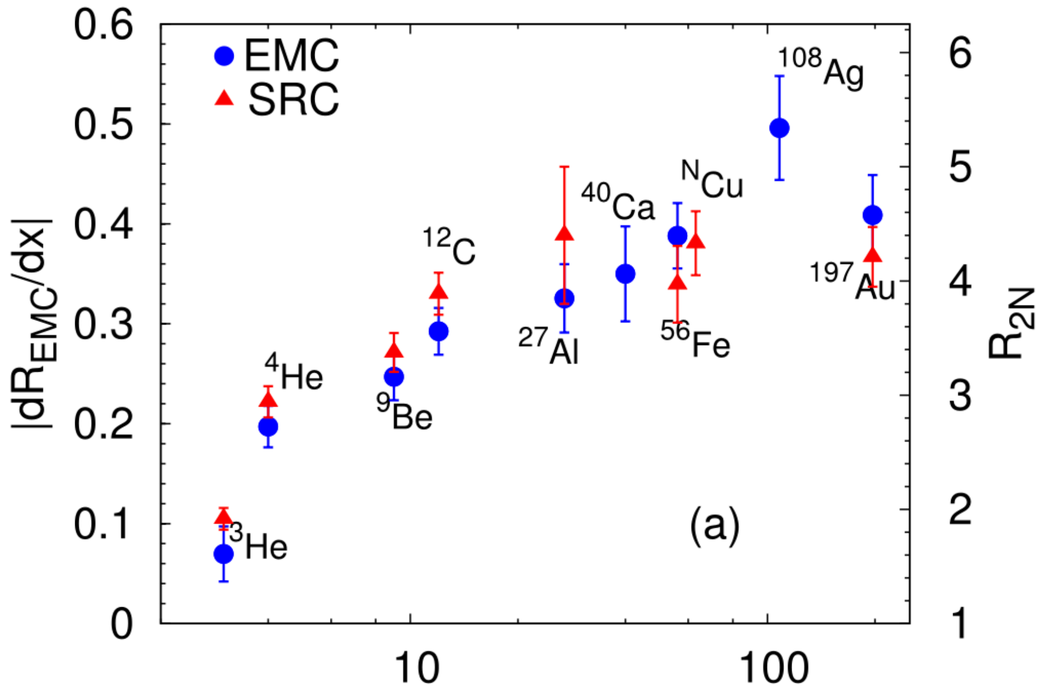


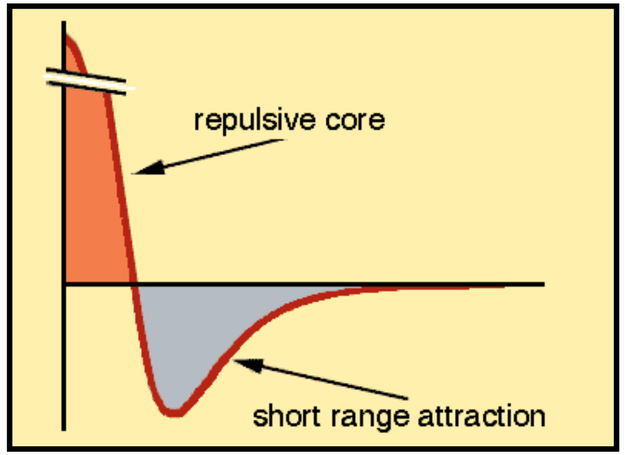
- Medium modification
- Multiquark clusters- 6 quark bag?

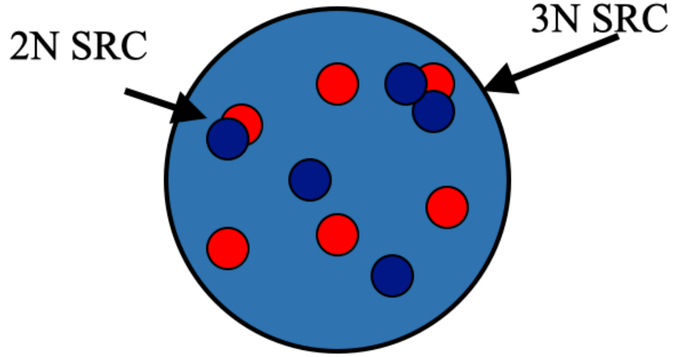
https://arxiv.org/abs/1405.1270v2

The SRC Connection

- Short-Range Correlations: Pairs of nucleons with high back-to-back momenta

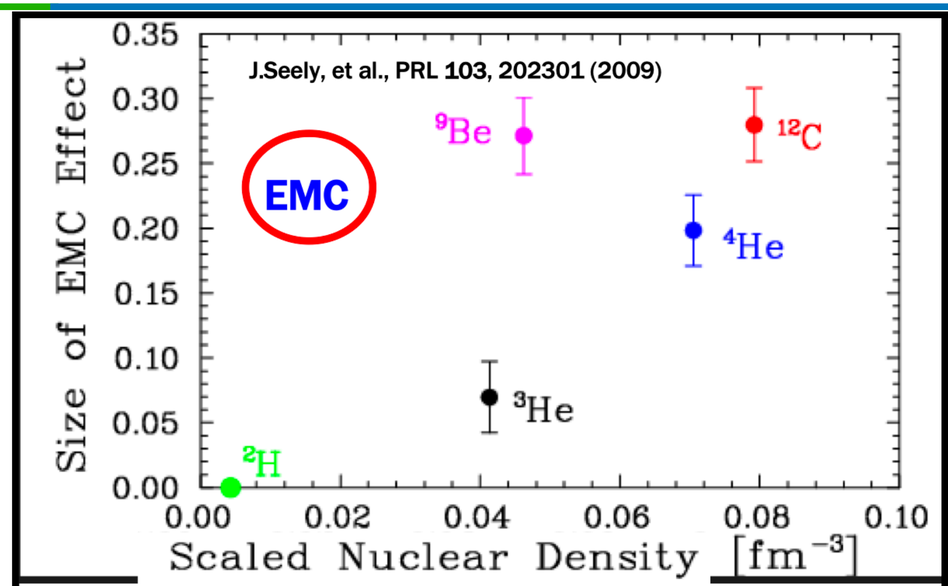


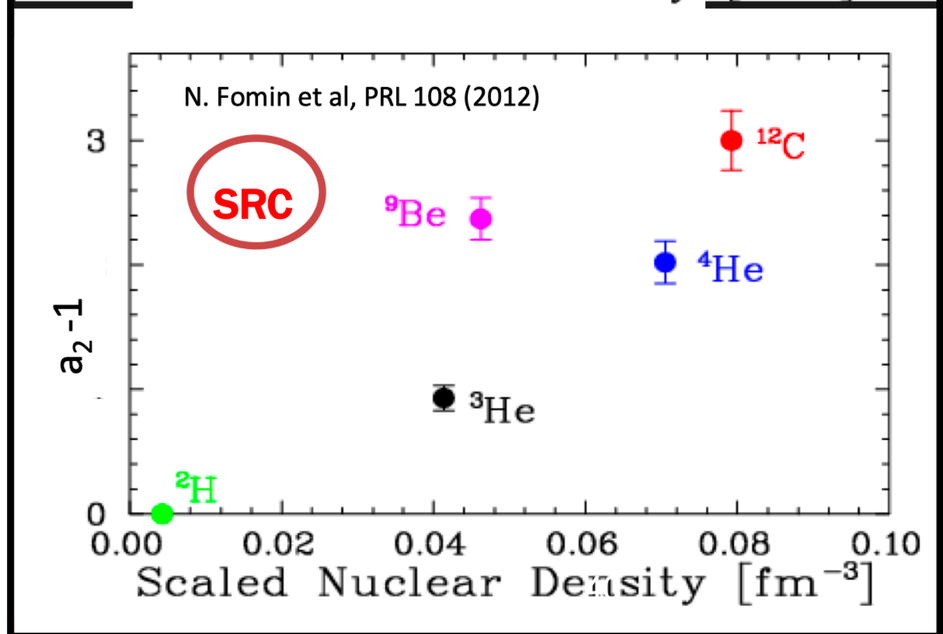




Results from the 6 GeV era

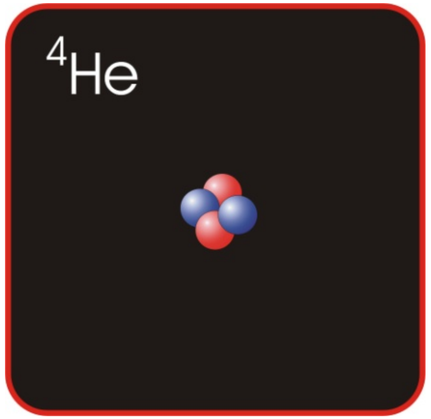
- Ran in Hall C@JLab in 2004
- EMC Effect and SRCs closely correlated
- Could they modify the nucleon structure?
- This experiment will address that

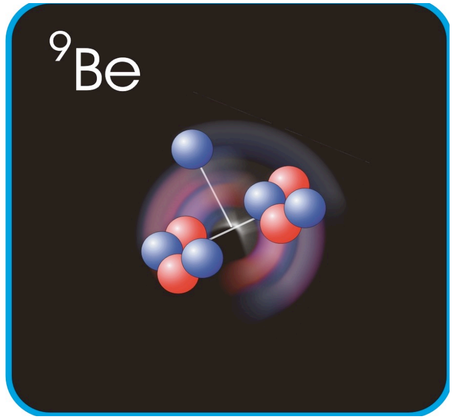


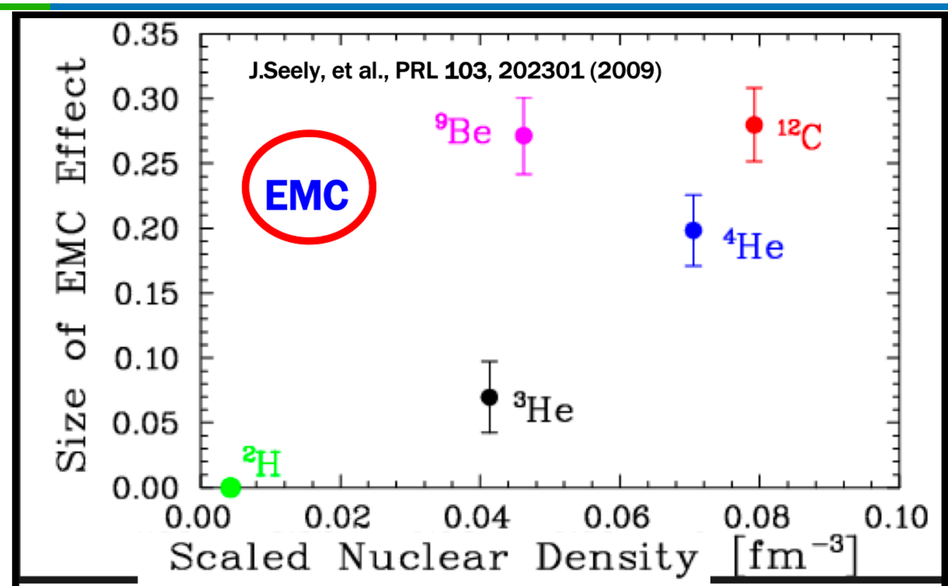


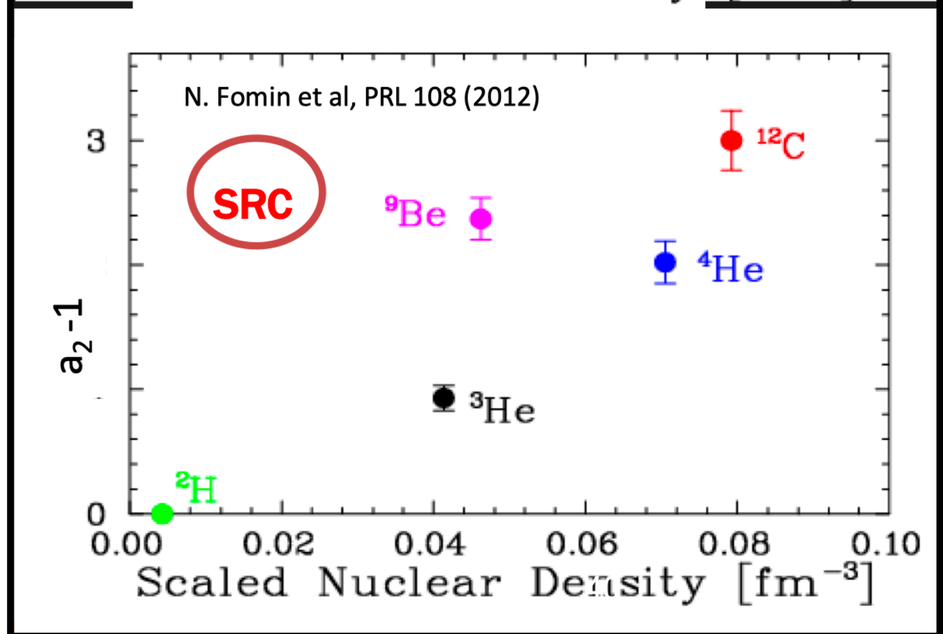
Local Density

- Seems to be a better indicator of the size of the EMC Effect
- Example: ^{9}Be vs ^{4}He









Takeaway Message

Universe: **Exists**

Physicists:

"EMC effect- Where the fast quarks at?"

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- Introduction & Physics motivation
- ***Experimental setup and outline***
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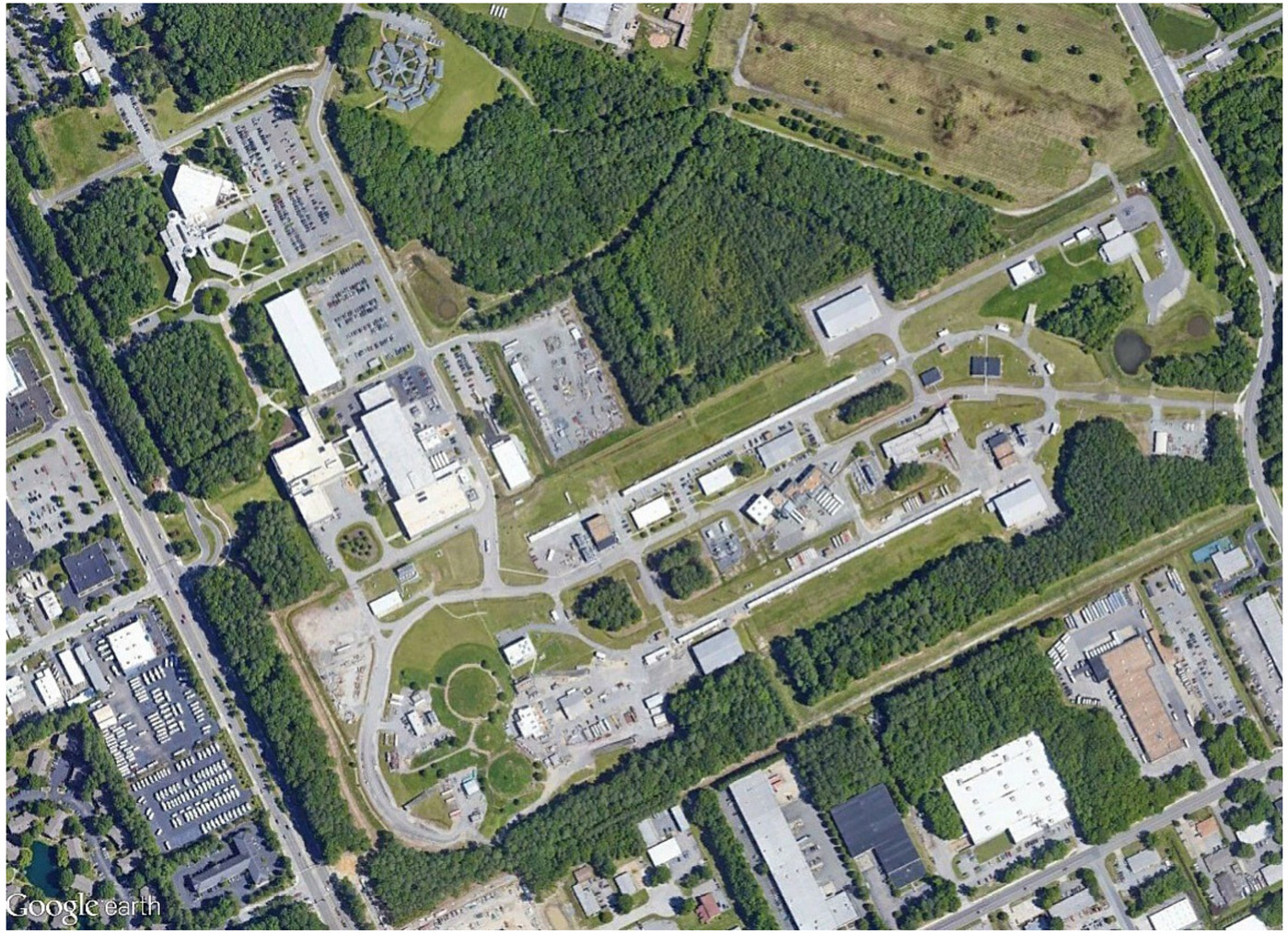
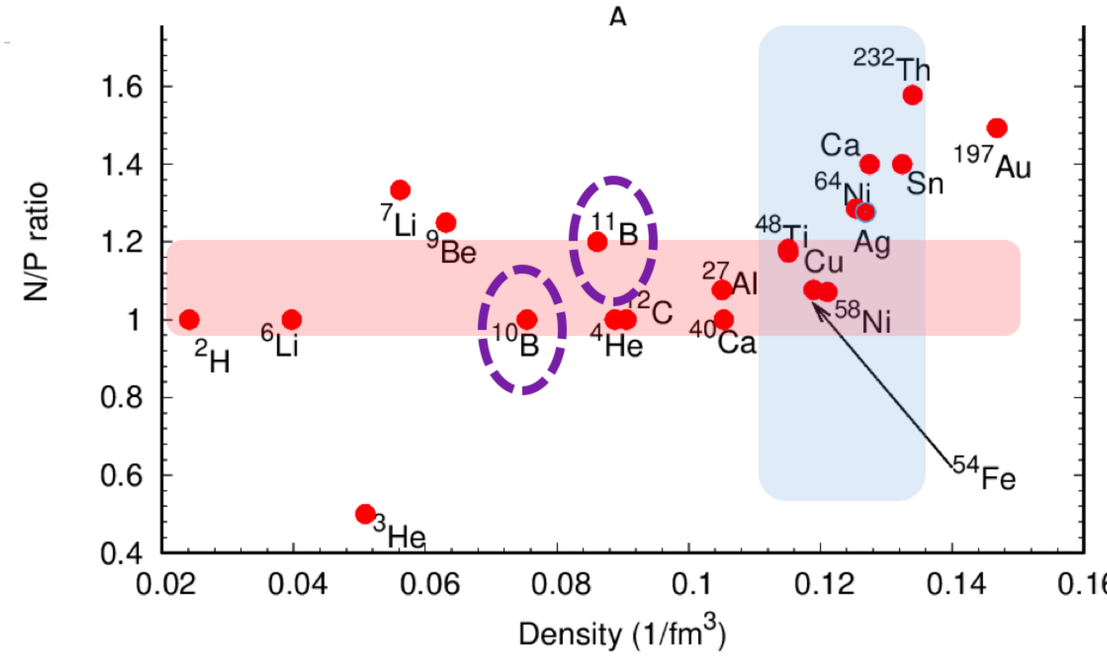


US National Labs

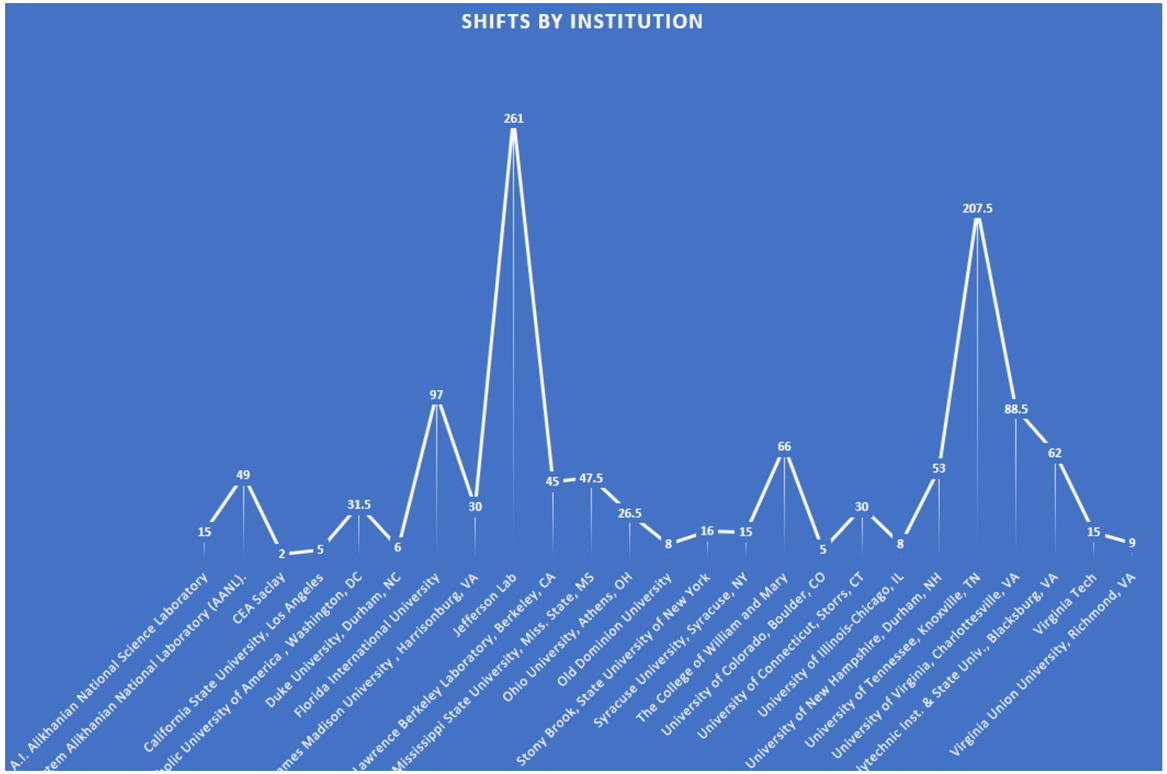
E12-10-008: Detailed studies of the nuclear dependence of F_2 in light nuclei

- Ran from Sep ’22-Feb ’23
- Investigates EMC effect in numerous nuclei from light to heavy
- Uses ^{40}Ca and ^{48}Ca which will provide insight into models predict a significant flavor dependence in the EMC effect.
- Comparisons of nuclei which differ by just one nucleon (^{11}B-^{10}B, ^{7}Li-^{6}Li, ^{12}C-^{11}B) will allow to study isospin dependence
- We measured EMC effect in several light nuclei (conducive to exact theoretical calculations)



Shifts

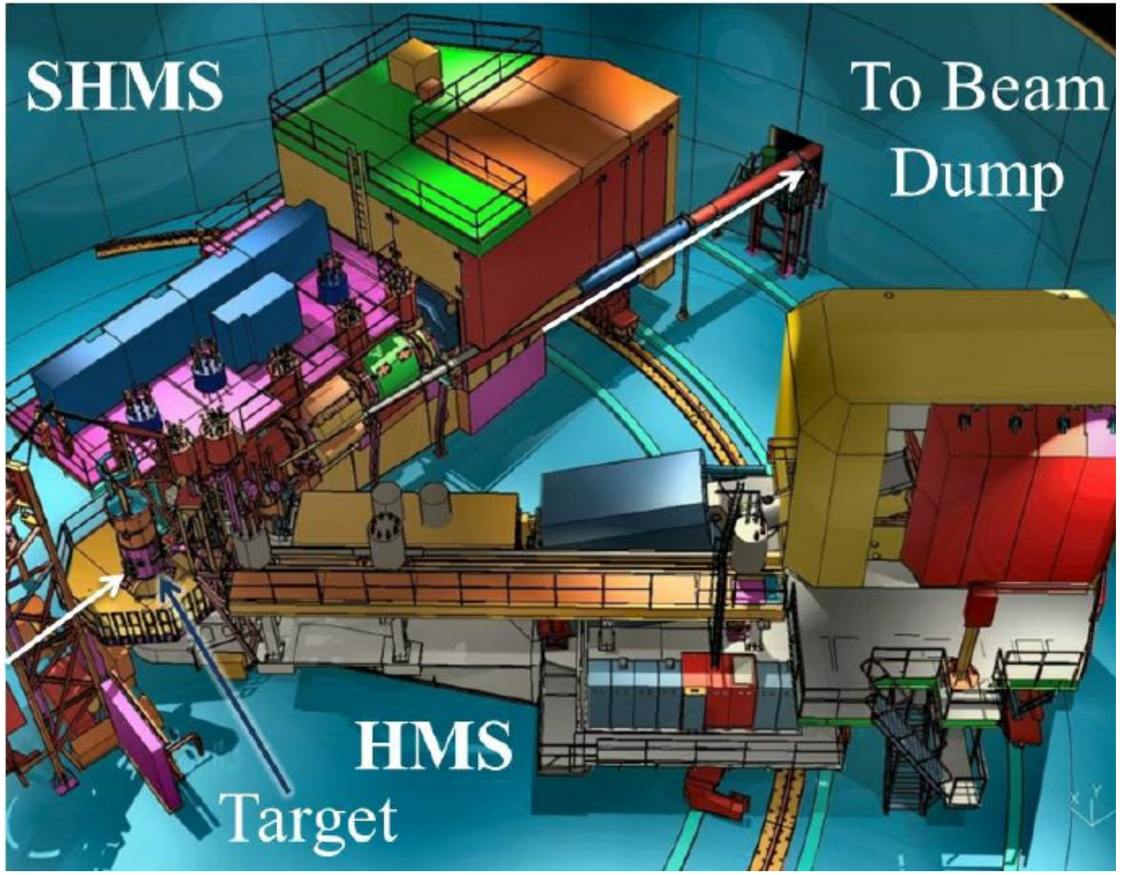
- UT folks took a lot of shifts as the lab was recovering from a dearth of grad students/users due to the pandemic



Name	Institution	Number of Shifts with weights
Abhyuday Sharda	University of Tennessee, Knoxville, TN	58
Casey Morean	University of Tennessee, Knoxville, TN	56.5
Burcu Duran	University of Tennessee, Knoxville, TN	53
Hakob Voskanyan	Artem Alikhanian National Laboratory (A	49

The ‘counting house’ where shift-taking happened

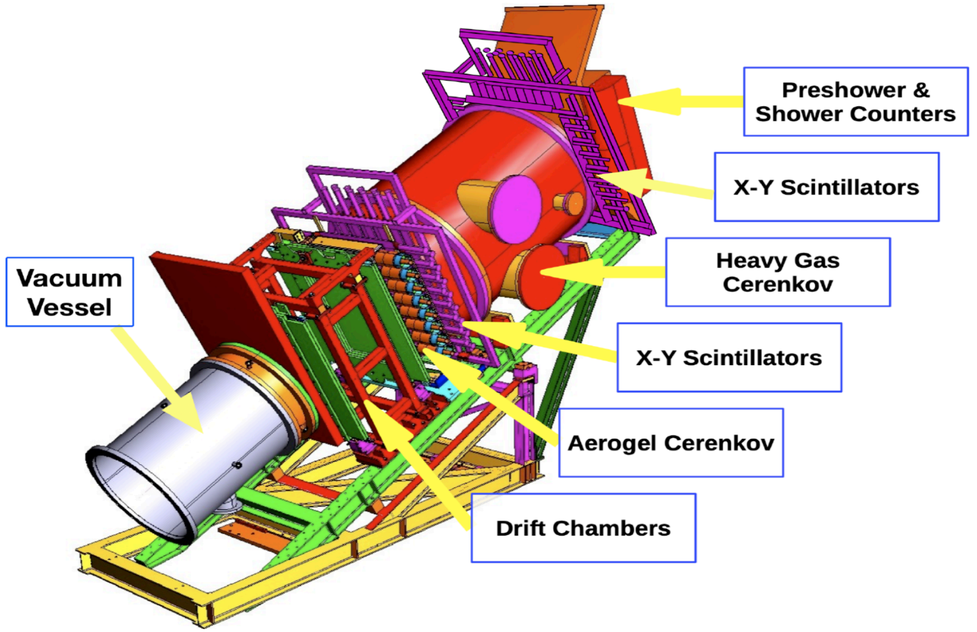
Hall C



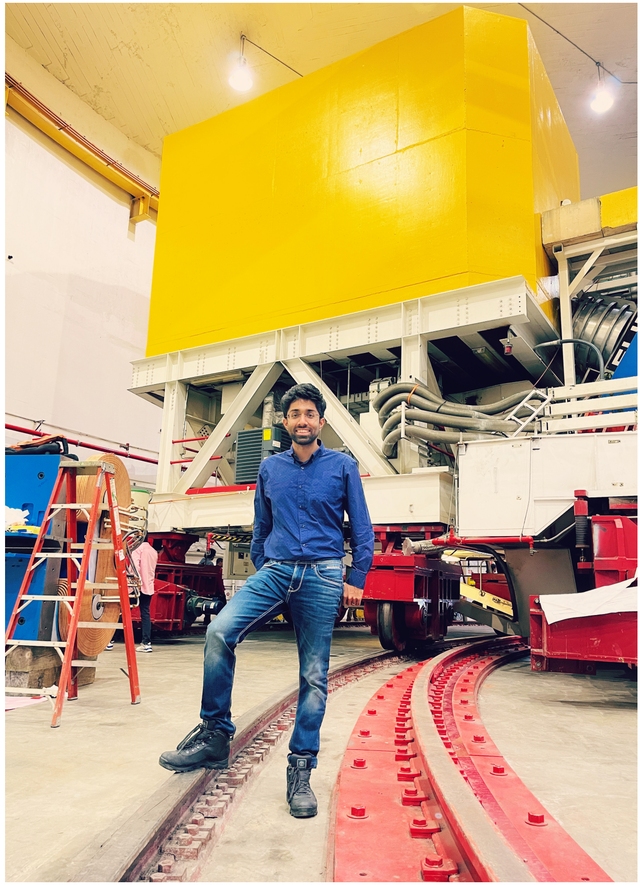
Credit- JLab Hall C Standard Equipment Manual

High Momentum Spectrometer

1. **Drift Chambers**
   - Provides tracking information
2. **Cerenkov**
   - Particle identification
3. **Hodoscopes**
   - Trigger
   - Tracking Efficiency
4. **Calorimeter**
   - Particle identification

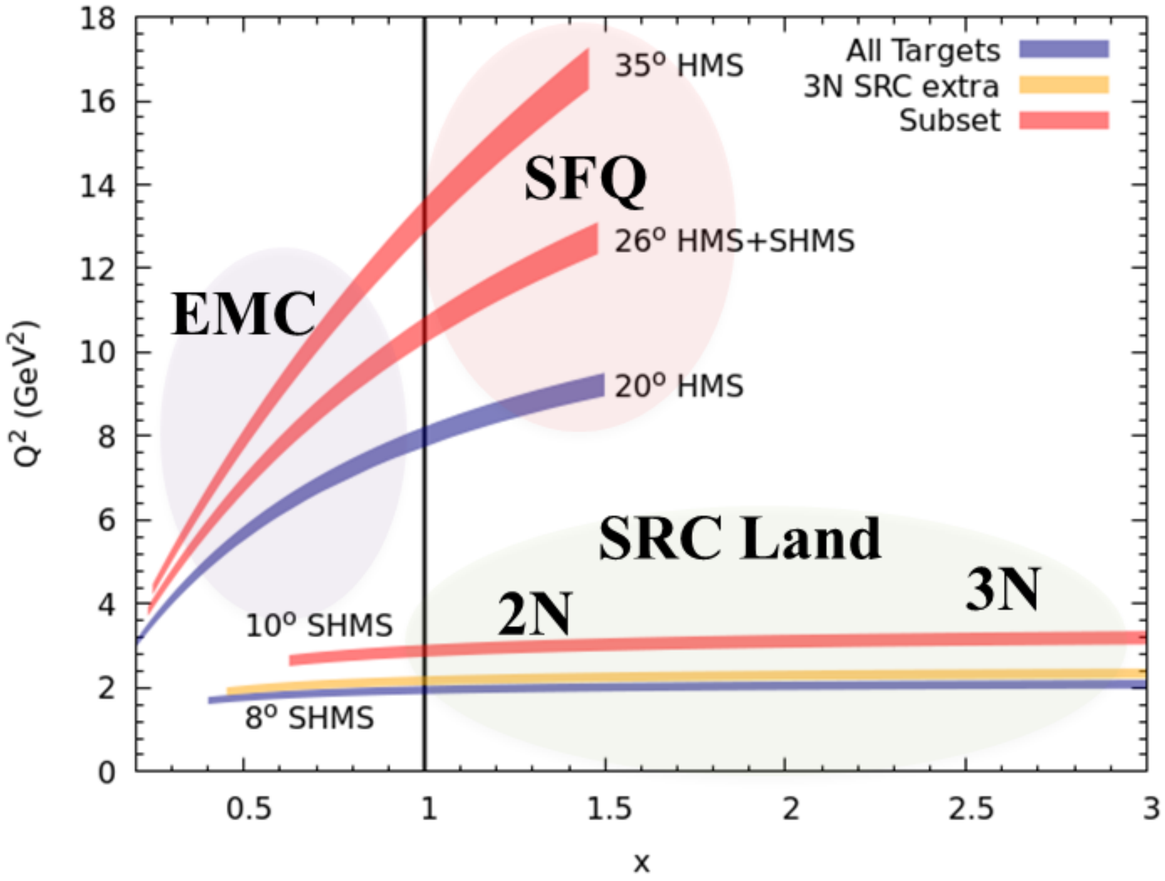


CAD Drawing of the HMS detector stack



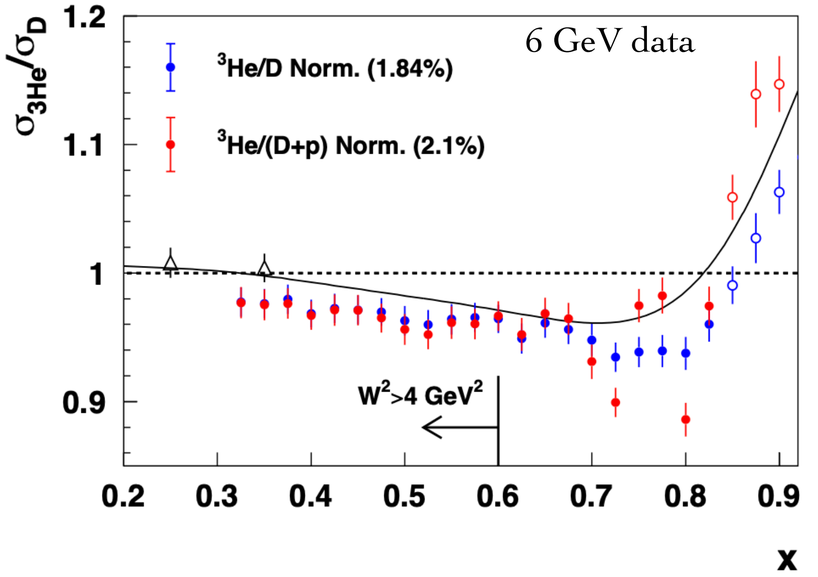
E12-10-008: Kinematic Coverage

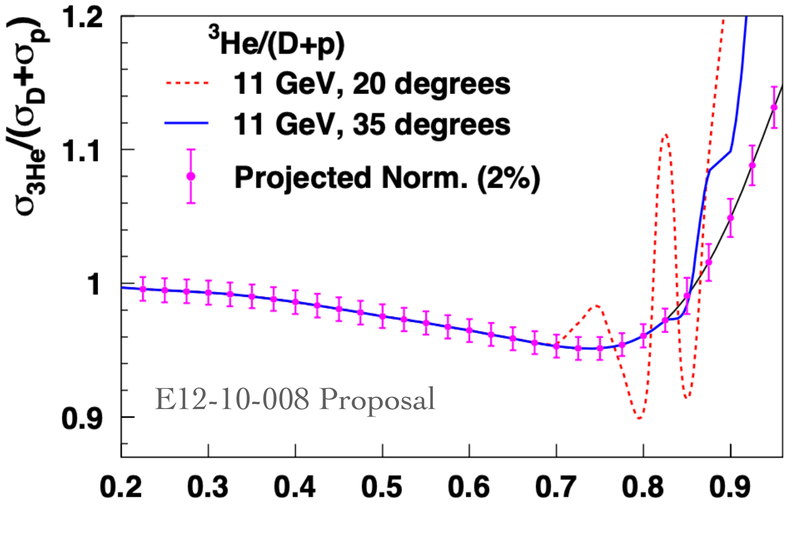
- HMS ran at high Q^2 to probe internal structure



E12-10-008: With Great Energy Comes Great Data

- Higher beam energy+ higher Q^2 allows us to skip the resonance region
- Can access higher x
- Can get $^3He/(^2H+^1H)$ without relying heavily on large isoscalar corrections
- Avoids the uncertainty associated with knowledge of the neutron structure function





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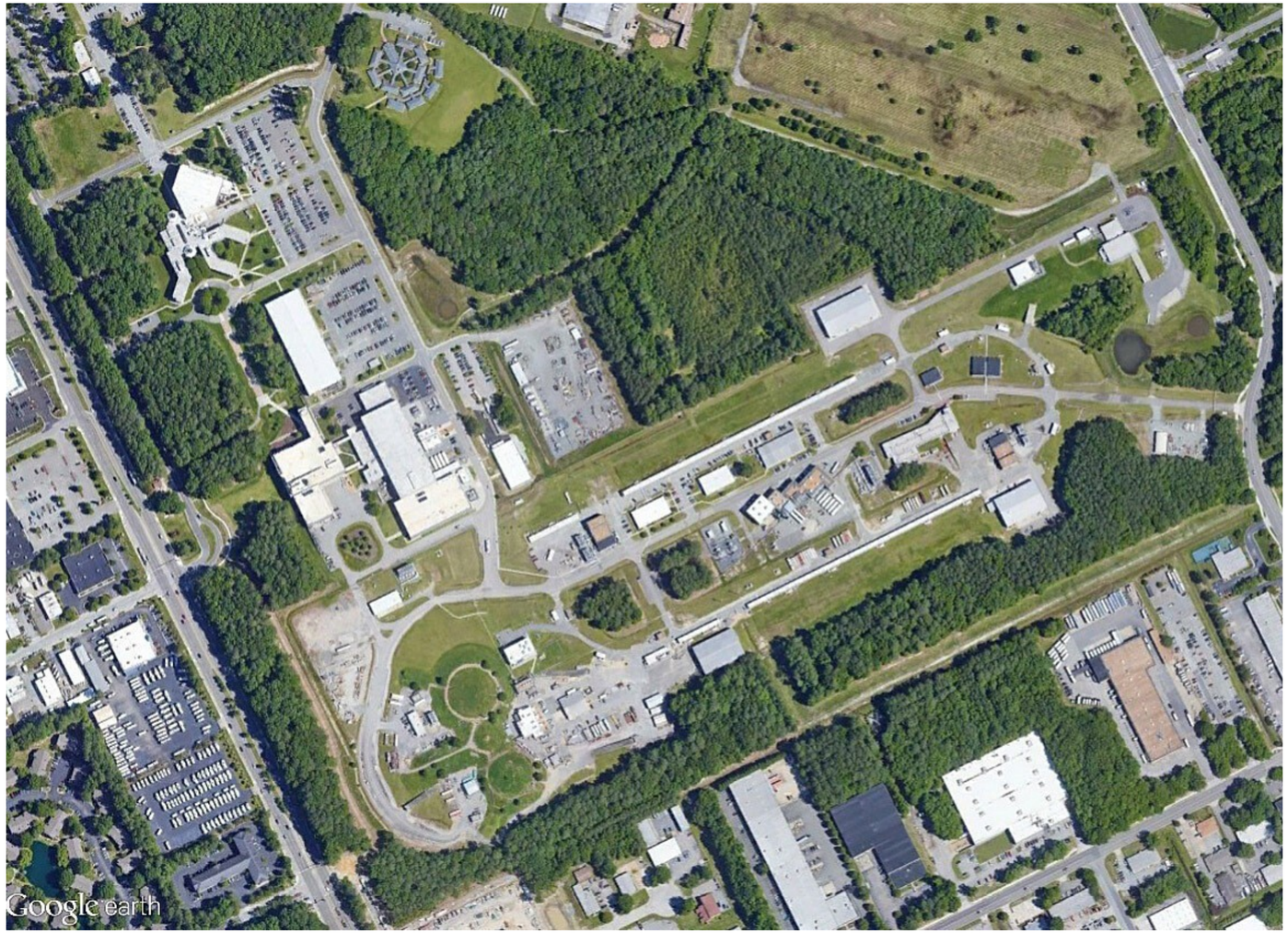
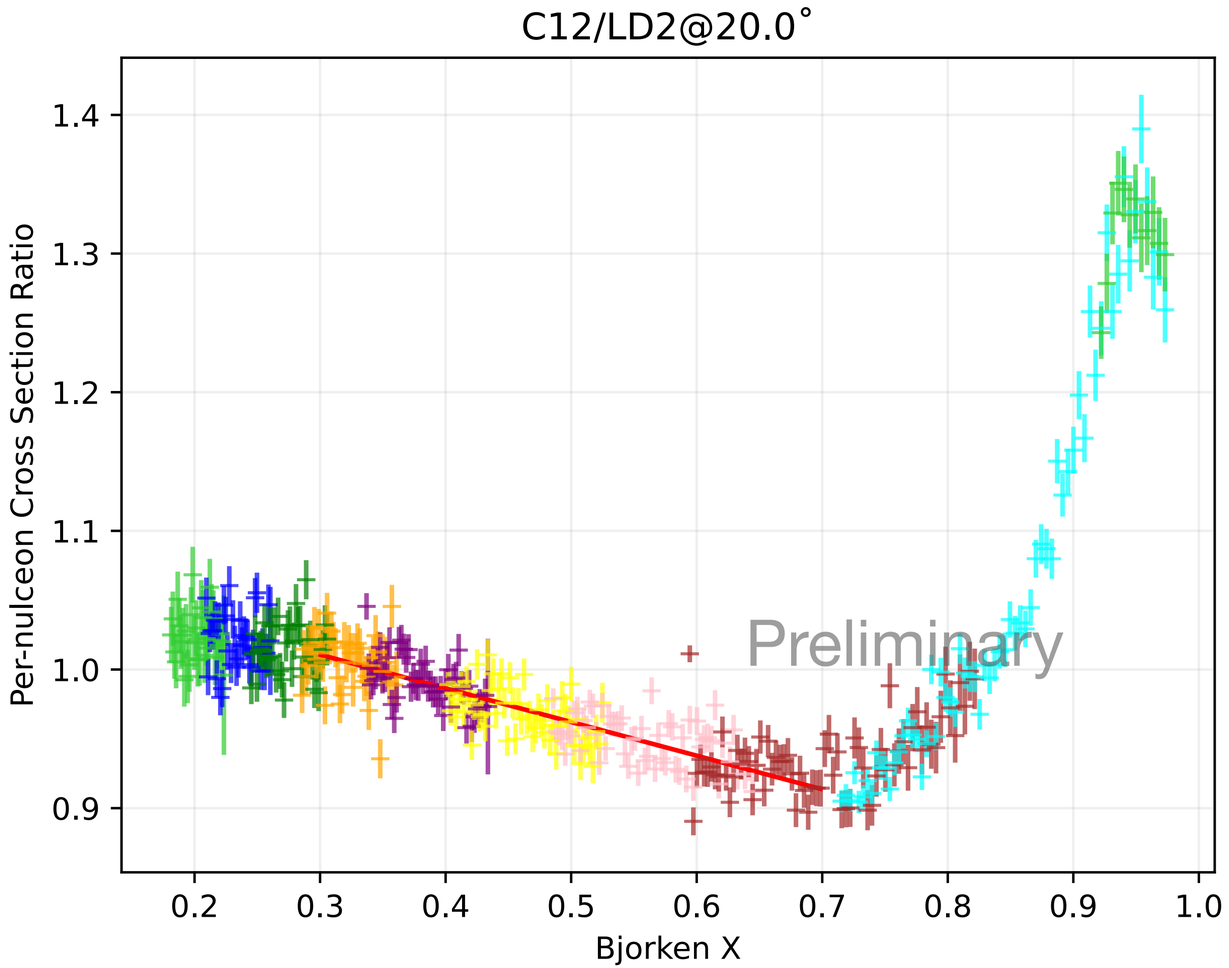


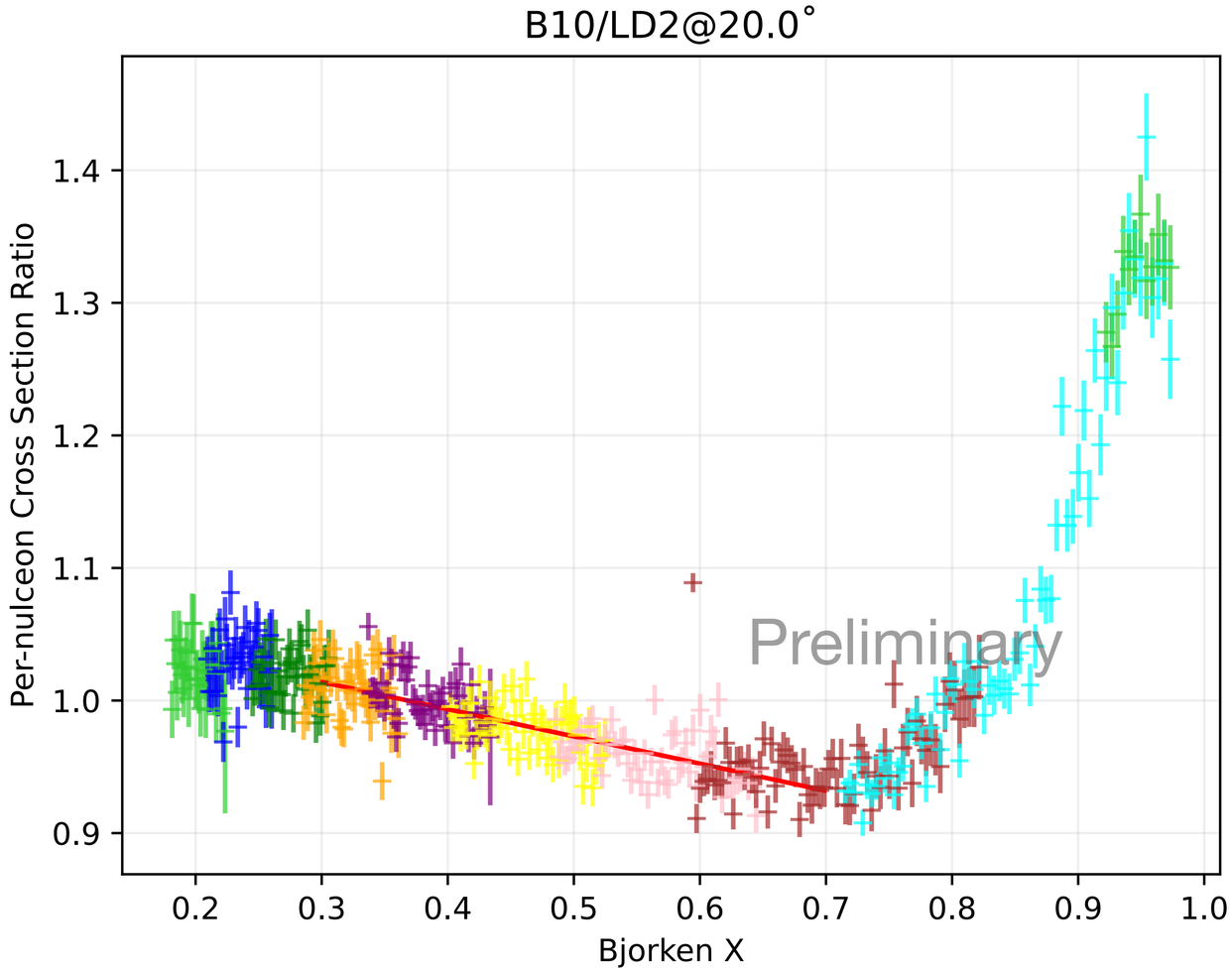
EMC effect- Carbon

- Only statistical uncertainties shown
- Each color represents data at a particular central momentum



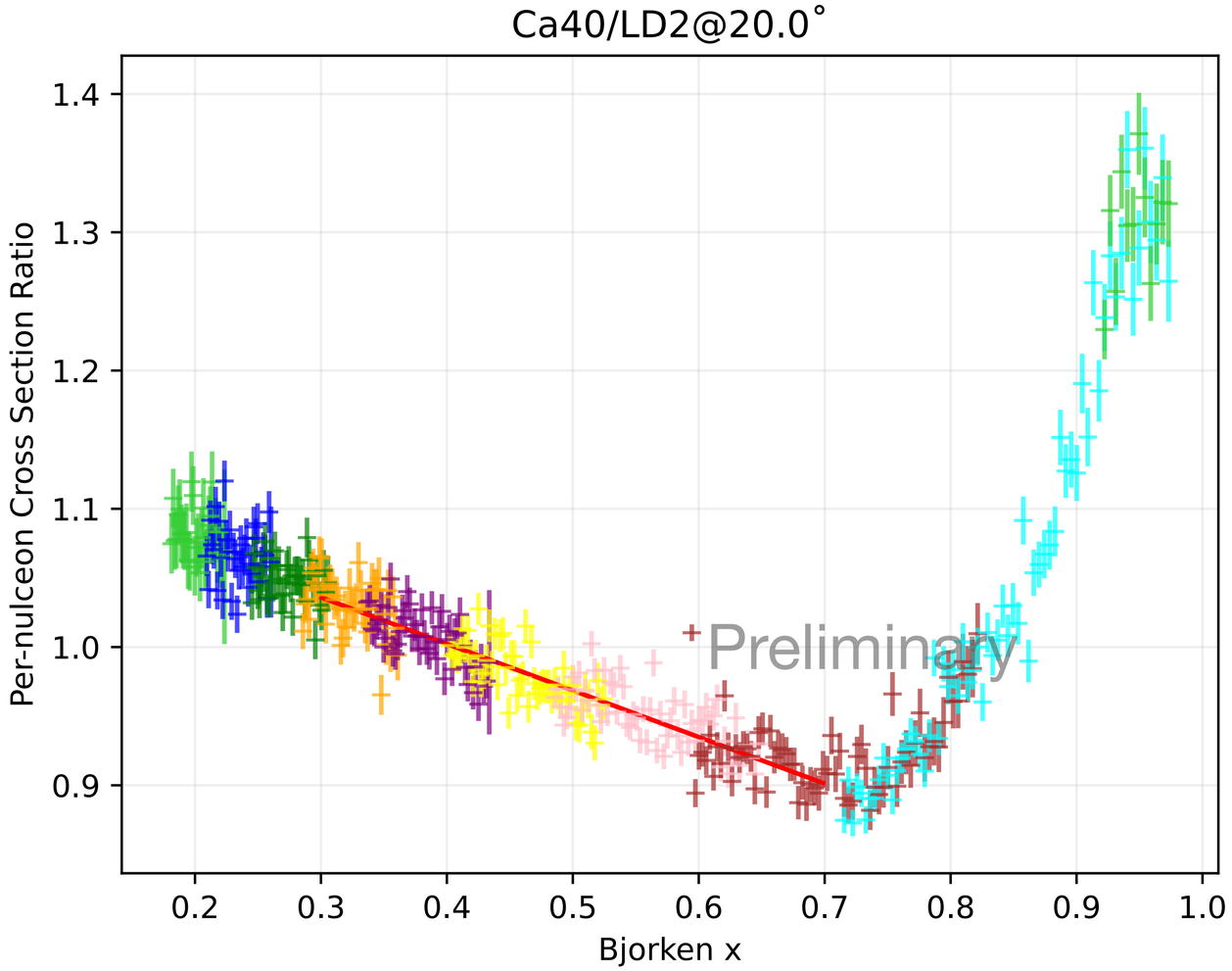
EMC effect- Boron-10

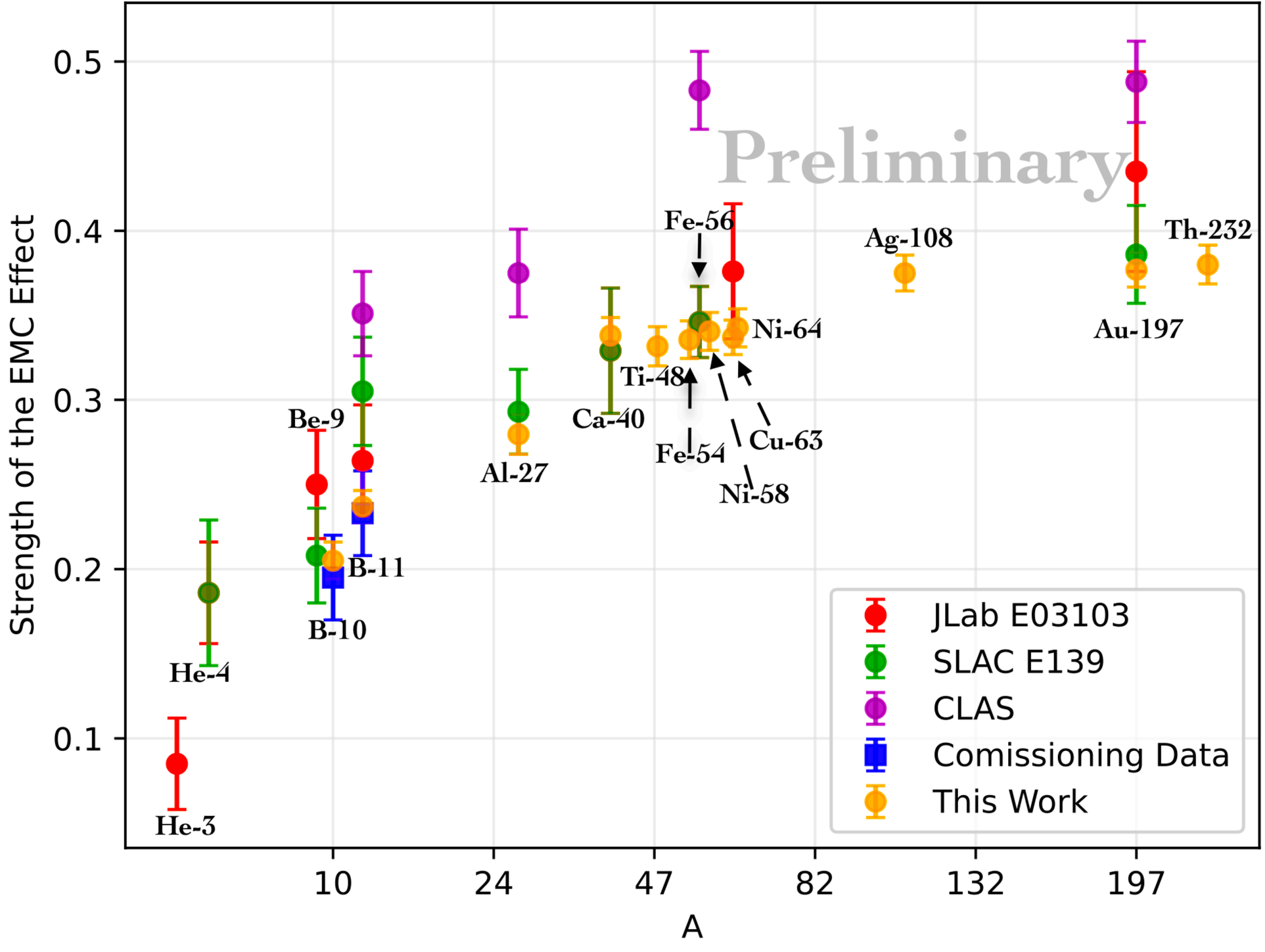
- Only statistical uncertainties shown



EMC effect- Calcium-40

- Only statistical uncertainties shown




Preliminary
Strength of the EMC Effect
0.5
0.4
0.3
0.2
0.1
10
24
47
82
132
197
A
He-3
He-4
Be-9
B-10
B-11
Al-27
Ca-40
Ti-48
Fe-54
Fe-56
Ni-58
Ni-64
Cu-63
Ag-108
Au-197
Th-232
JLab E03103
SLAC E139
CLAS
Comissioning Data
This Work

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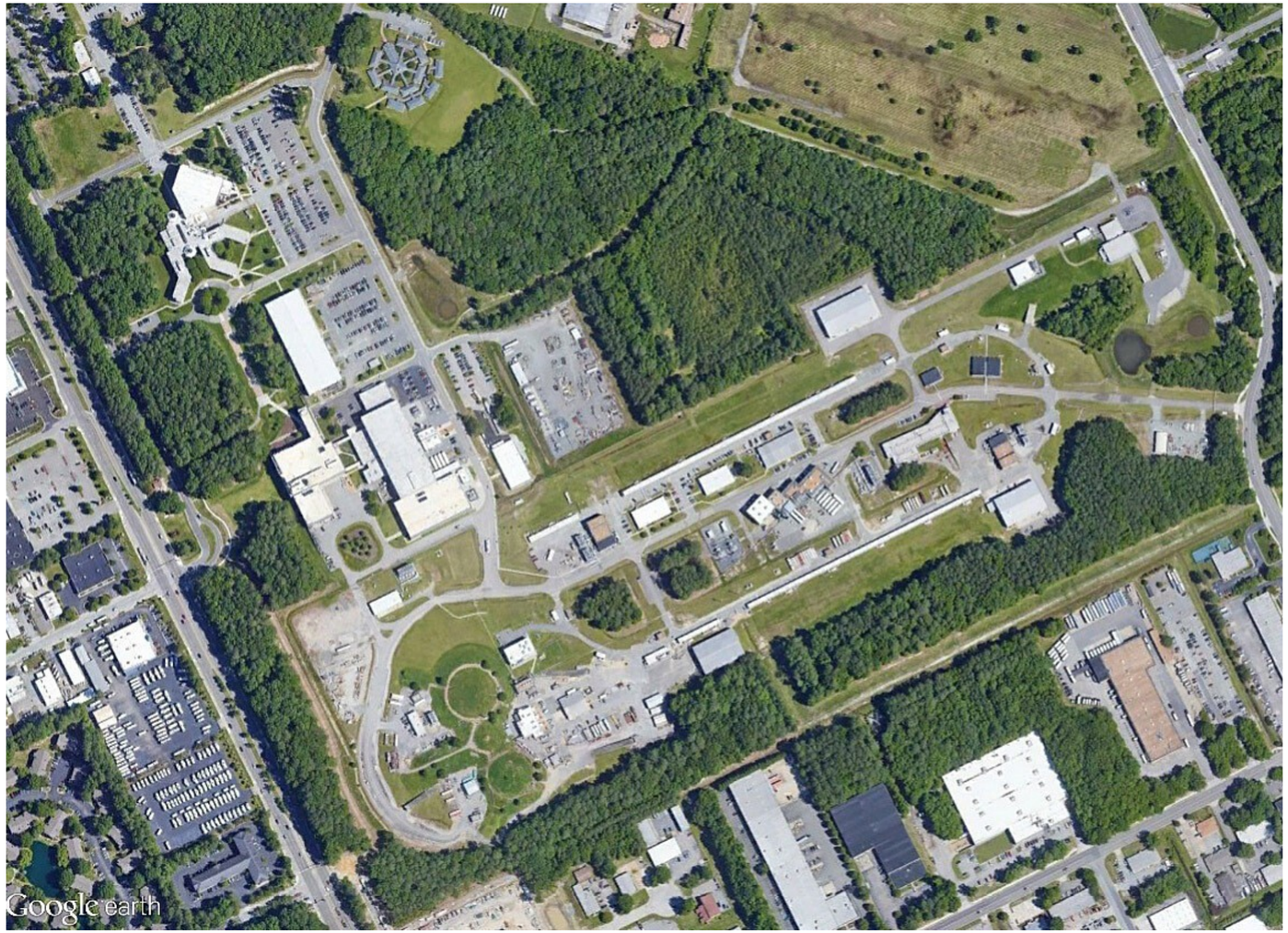


Status

- Cross-section model being iterated
-

Future

- Parity violating EMC effect- *Studies the flavor dependence of the EMC effect*
- BAND & LAD- *'EMC effect of the deuteron'*
- What other experiments?
- What other observables could be used to study the EMC effect?

Summary

- The origin of the EMC effect is still a mystery
- E12-10-008 will provide several key results:
  - Isospin dependence
  - Measurement in several light nuclei
  - More data for comparison with SRCs
  - Can get $^{3}He/(^{2}H+^{1}H)$ without relying heavily on large isoscalar corrections
- We have some results and much more to come!

Acknowledgement

Spokespeople:

John Arrington (LBL), Nadia Fomin (UTK) & Dave Gaskell (JLab)

Graduate Students:

Cameron Cotton (UVA), Abishek Karki* (MSU), Casey Morean* (UTK), Jordan O'Kronley (UTK), Ramon Ogaz (UTK), Abhyuday Sharda (UTK), Sebastian Vasquez (UCR), Zoe Wolters (UNH)

* = Graduated

Other Collaborators:

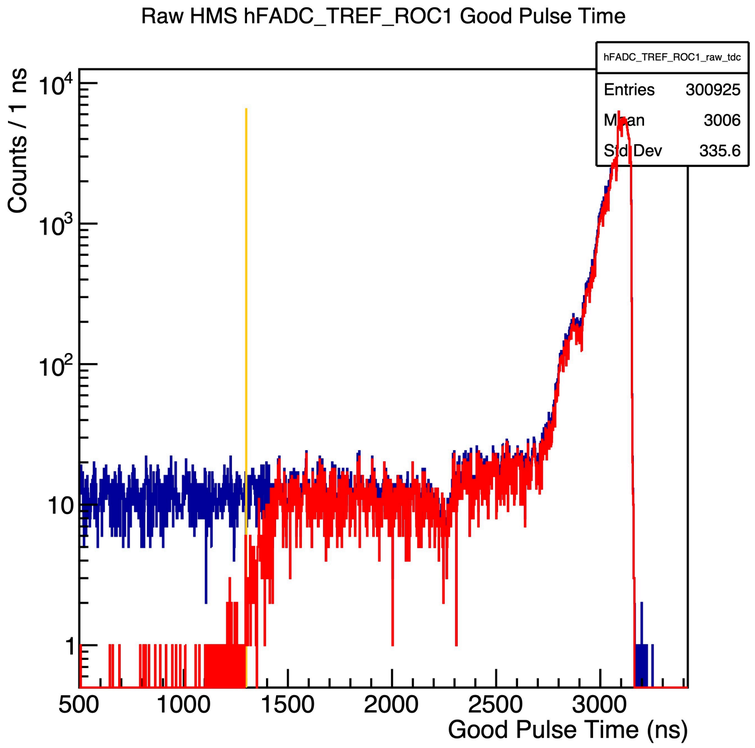
Miguel Arratia (UCR), Dipangkar Dutta (MSU), Shujie Li (LBL), Dien Nguyen (UTK),
Nathaly Santiesteban (UNH), Xiaochao Zheng (UVA),
Burcu Duran (NMSU), Tyler Hague (JLab)

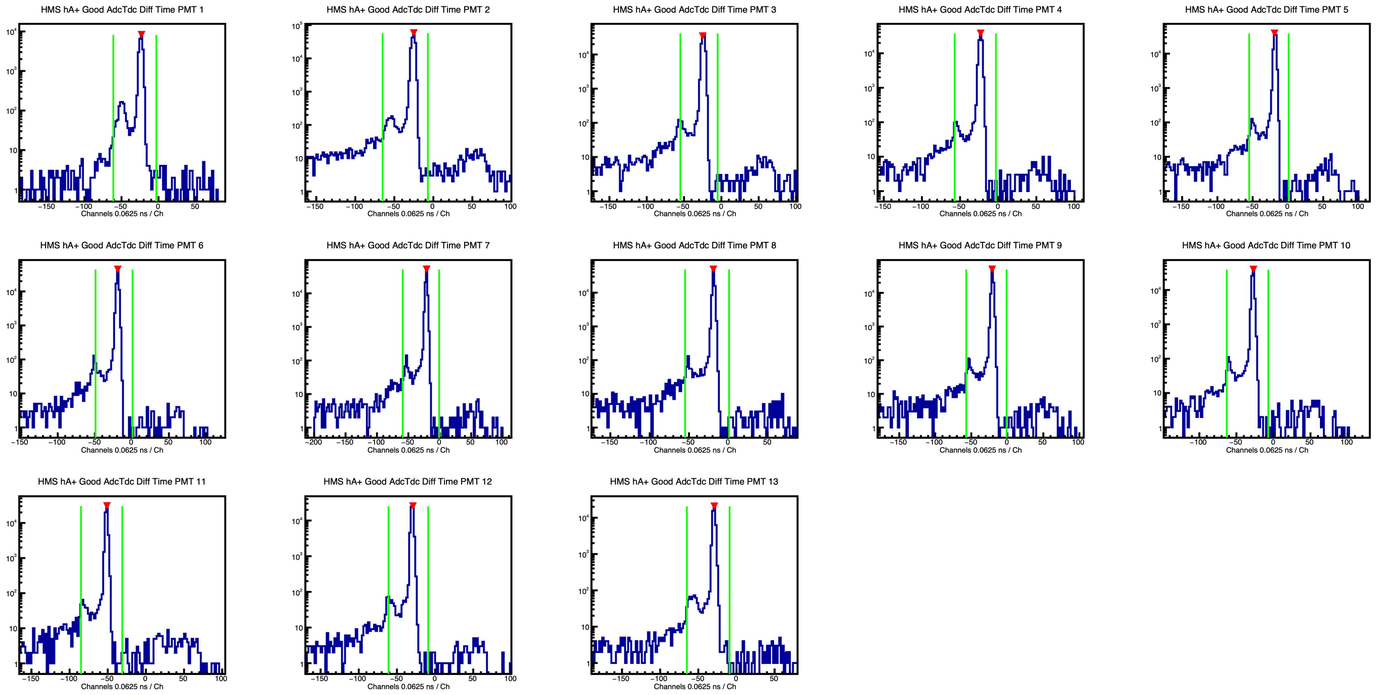
Thank you!

Backup

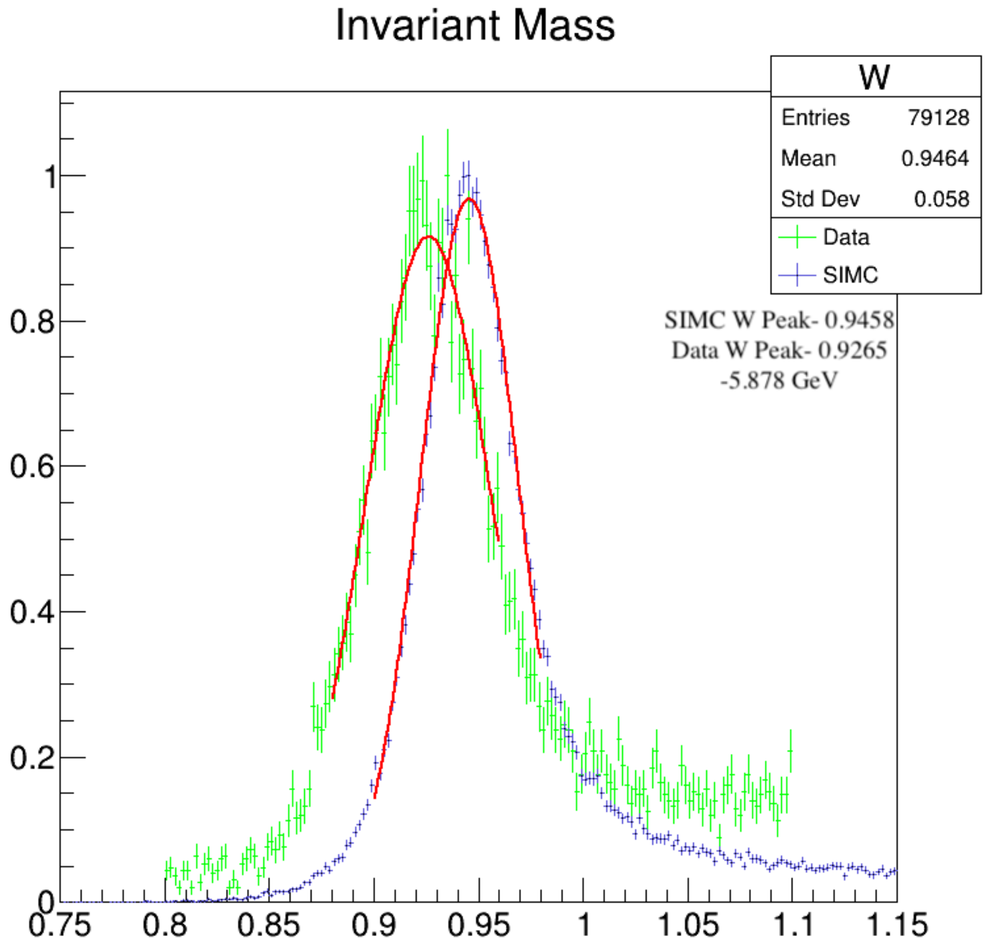
Timing Windows and Reference Time Cuts

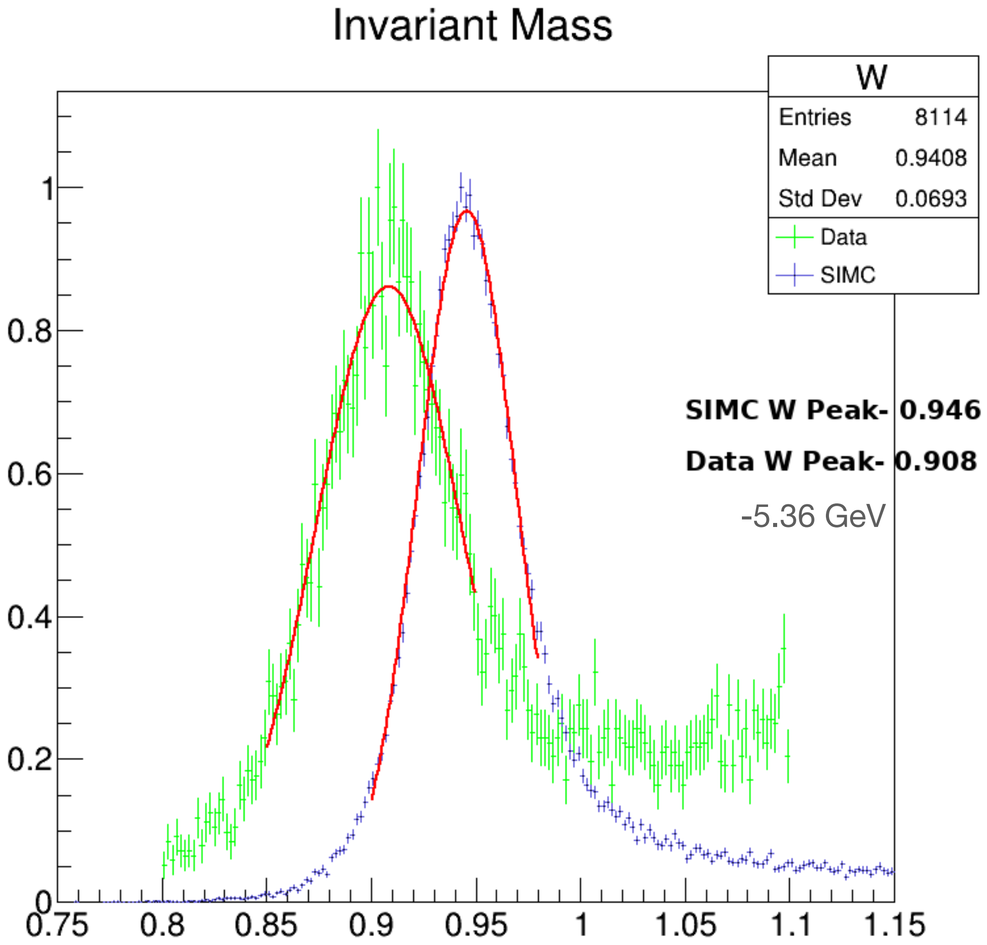
- Cuts made to exclude background events





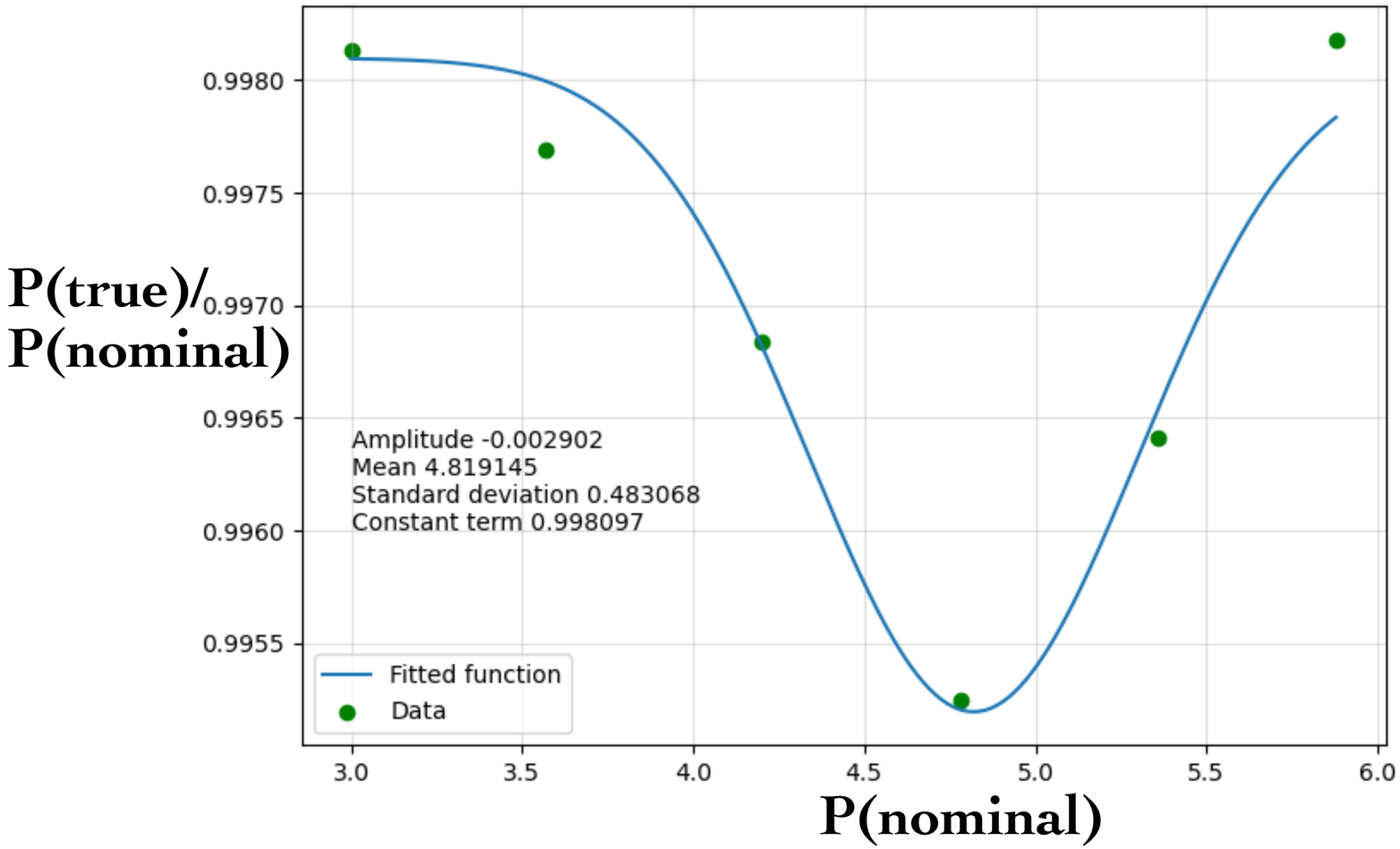
HMS Momentum offset



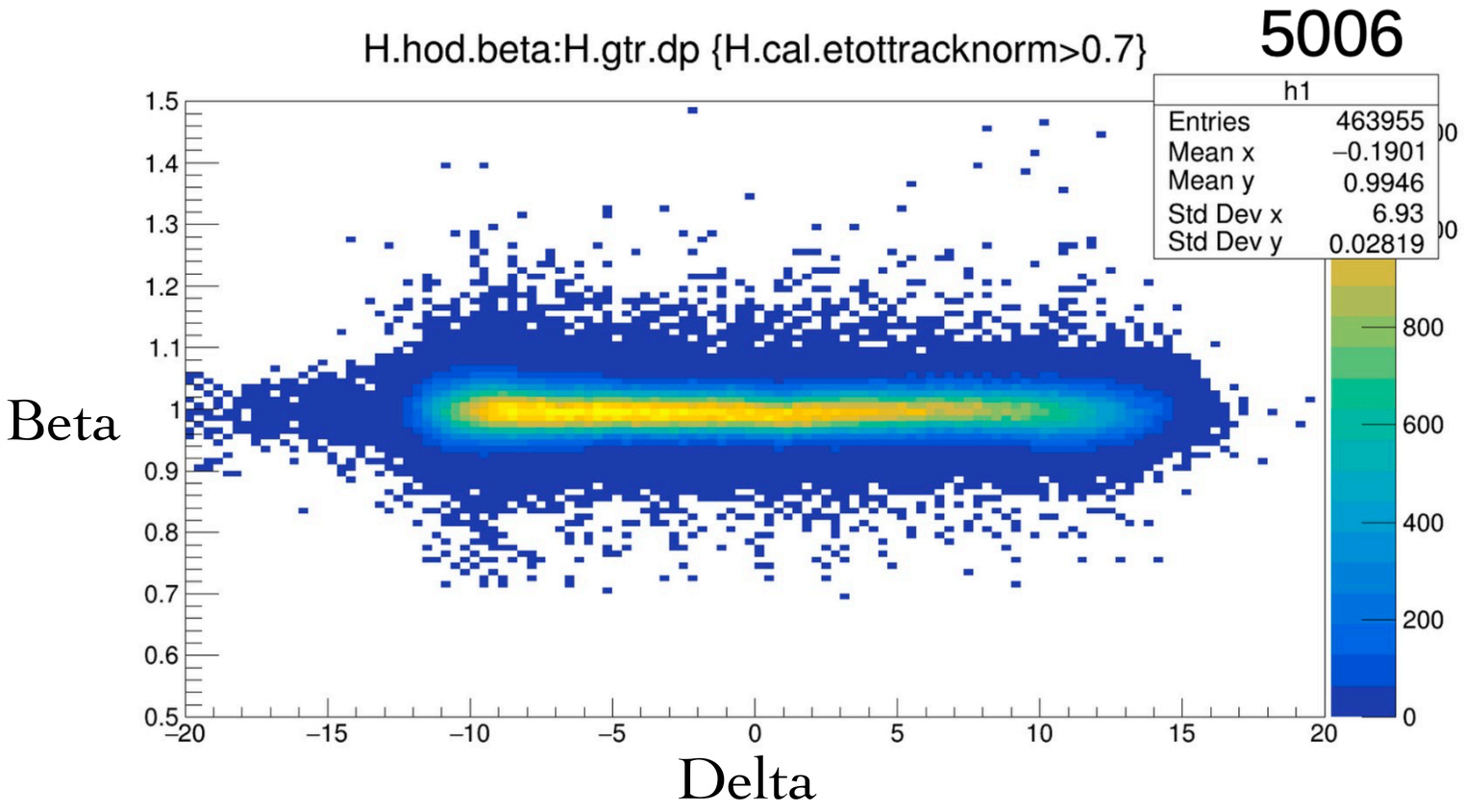


HMS Momentum offset

- Gaussian fitted

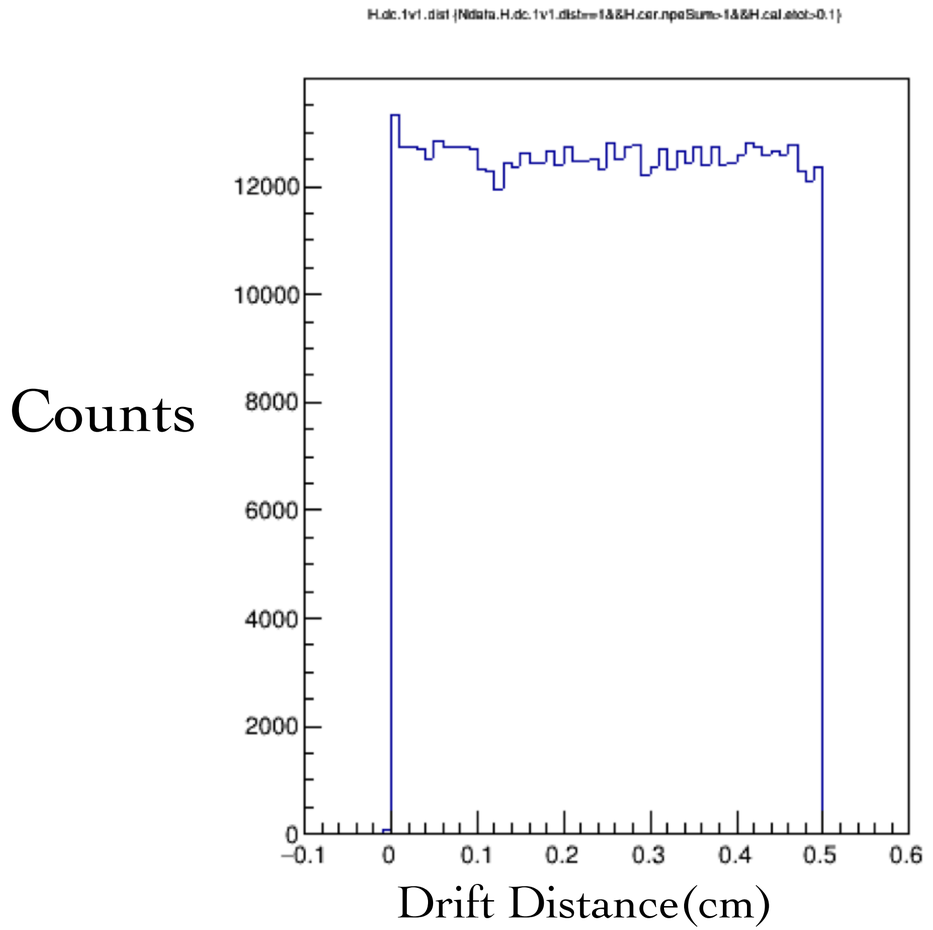


Hodoscope Calibration



Courtesy of Cameron Cotton

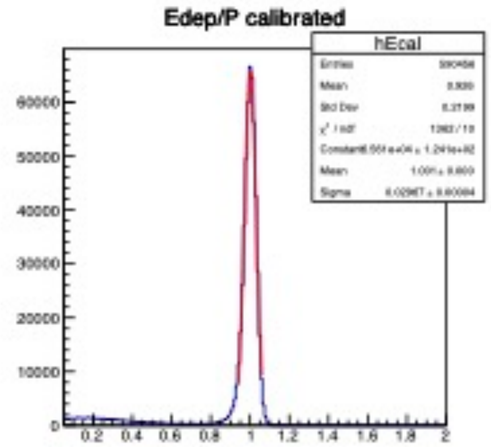
Drift Chamber Calibration

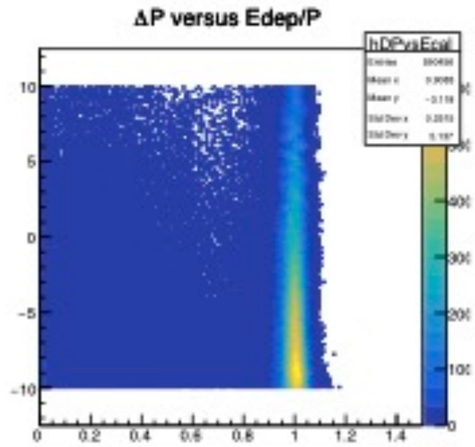


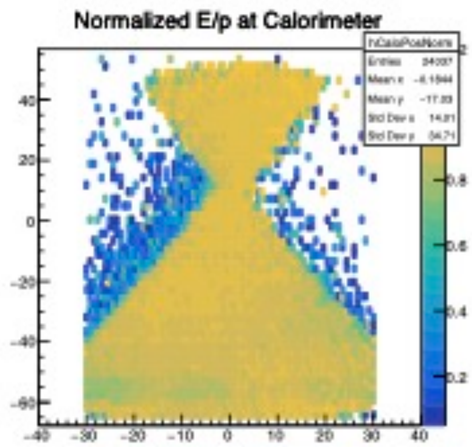
Courtesy of Cameron Cotton

HMS Calorimeter Calibration

- Calorimeter calibrated by varying gain correction for blocks to keep output signals of the same size
- The calibration produces a set of gain constants. Each corresponding to a PMT.





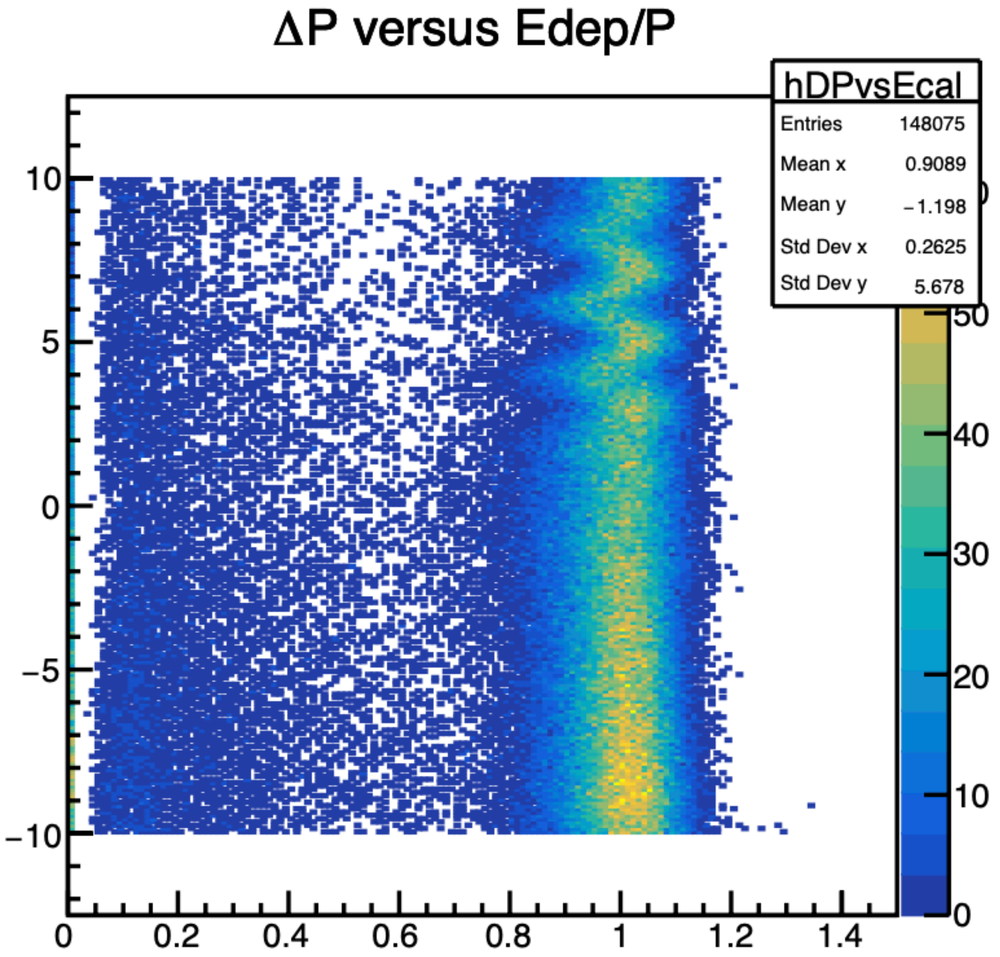



```
; Calibration constants for file hms_replay_cal_4402_-1.root, 763785 events processed

;fDeltaMin  fDeltaMax   fBetaMin fBetaMax       fLoThr  fHiThr
;-10    10      0.5     1.5     0.865631        1.03143
hcal_pos_gain_cor= 15.18,  6.41,  8.83, 10.45, 12.98, 12.76, 12.21, 12.22,  9.66, 16.29, 15.81, 13.43,  9.85,
                   10.53, 12.43,  7.86, 15.26,  8.65,  5.54,  7.19,  7.79,  8.80, 12.15, 11.31, 12.28, 12.31,
                   25.29, 14.68, 19.57, 24.81, 18.33, 21.14, 26.86, 22.31, 24.10, 26.40, 19.38, 23.02, 21.33,
                   33.98, 18.51, 22.78, 19.90, 20.27, 21.05, 23.09, 19.51, 22.85, 23.78, 20.92, 22.53, 26.62,
hcal_neg_gain_cor= 15.83, 16.03, 15.51, 12.17, 10.39, 16.17, 16.46, 21.05, 13.74, 12.15, 11.21, 12.08, 16.20,
                   14.65, 14.03, 15.65, 14.38, 16.26, 18.98, 21.23, 18.27, 18.34, 11.49, 17.01, 13.40, 10.85,
                    0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
                    0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,  0.00,
```

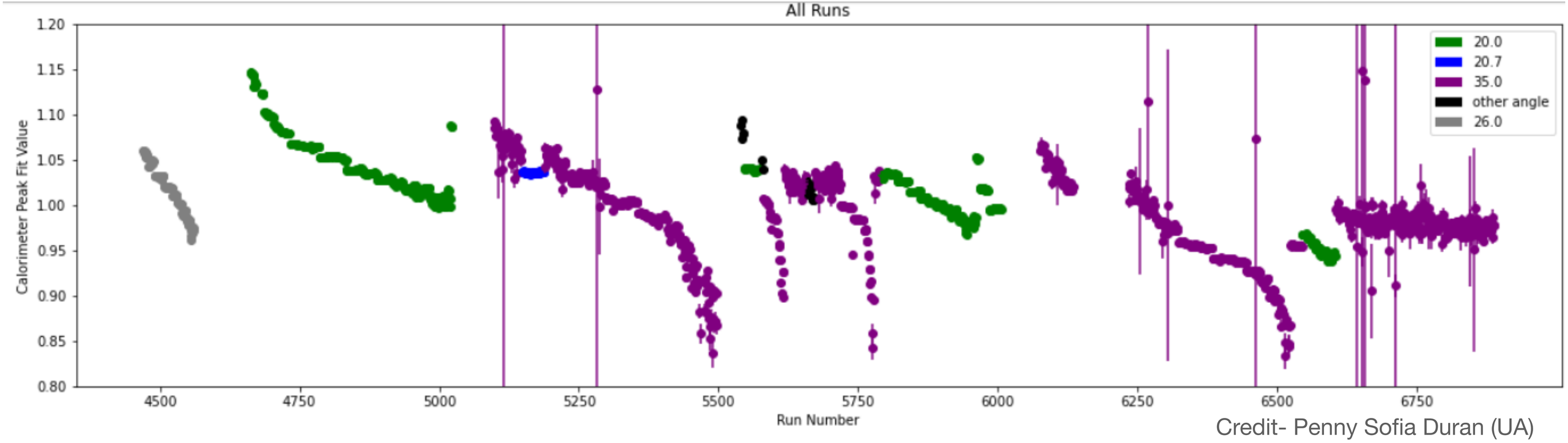
HMS Calorimeter Calibration

- Saw some wiggles
- Electron not firing the particular PMT due to the threshold voltage being too high
- Is a known issue for the HMS
- Not a big problem for our data



HMS Calorimeter Calibration

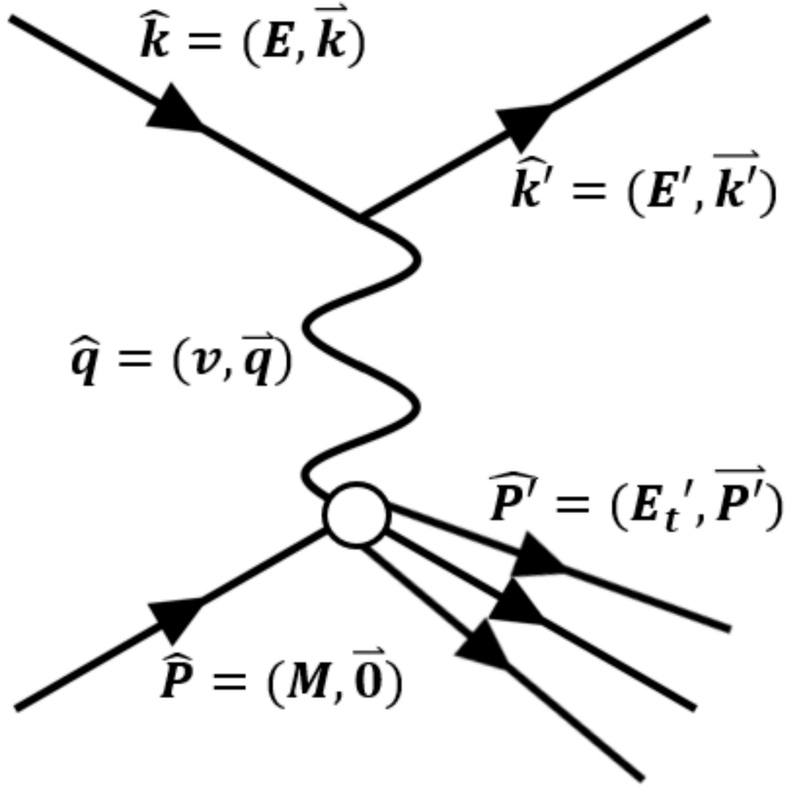
- A single set of gain constants don't work for the whole dataset
- Not obvious why



Credit- Penny Sofia Duran (UA)

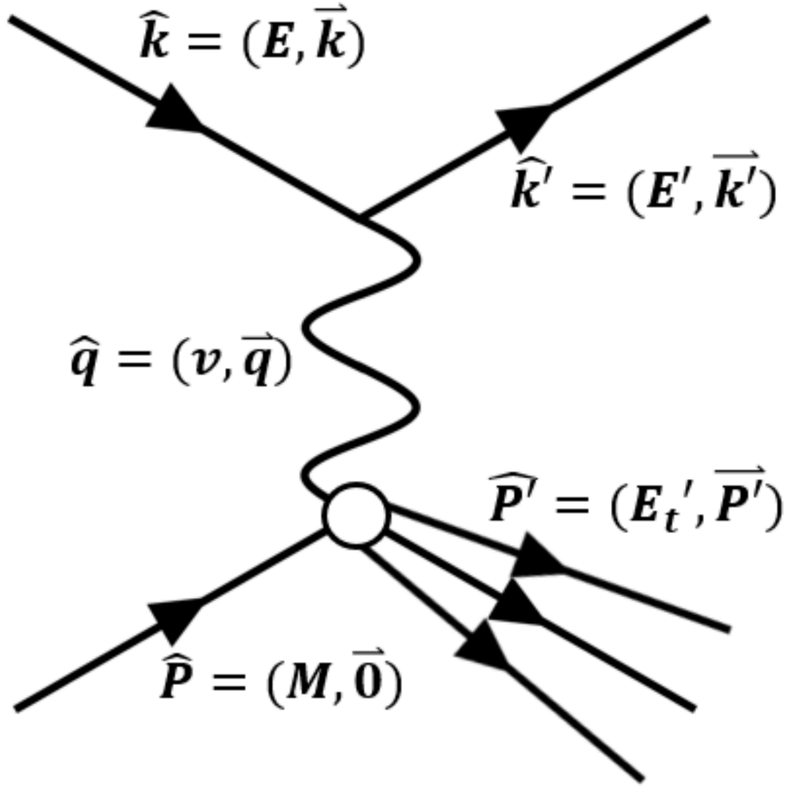
Physics Background

- In inclusive DIS, only the scattered electron's final state is measured in the spectrometer
- θ
- $\nu = E - E'$
- M



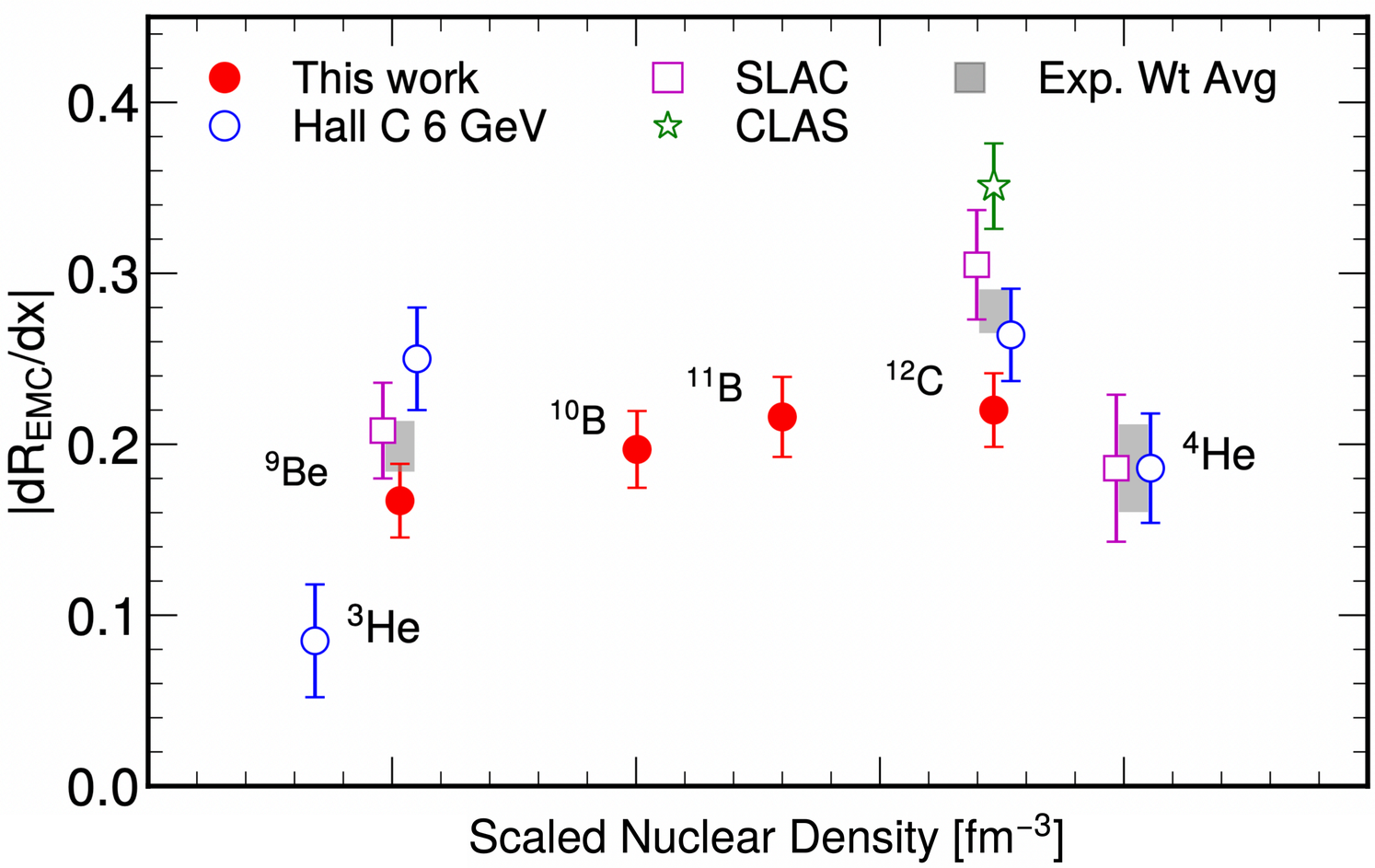
Physics Background

- $Q^2 \equiv -q^2 \simeq 4EE' \sin^2(\theta/2)$
- $W^2 = 2M\nu + M^2 - Q^2$
- $x = x_{Bj} \equiv \dfrac{Q^2}{2M\nu}$



E12-10-008: We have results

- Ran for ~2 days in February 2018
- ^{10}B & ^{11}B also thought to have alpha clustering
- Little nuclear dependence



SRC results

- Correlates with the EMC effect data!