XEM2 Studies of EMC Isospin Dependence

5th International Workshop on Quantitative Challenges in Short-Range Correlations (SRC) and the EMC-Effect Research

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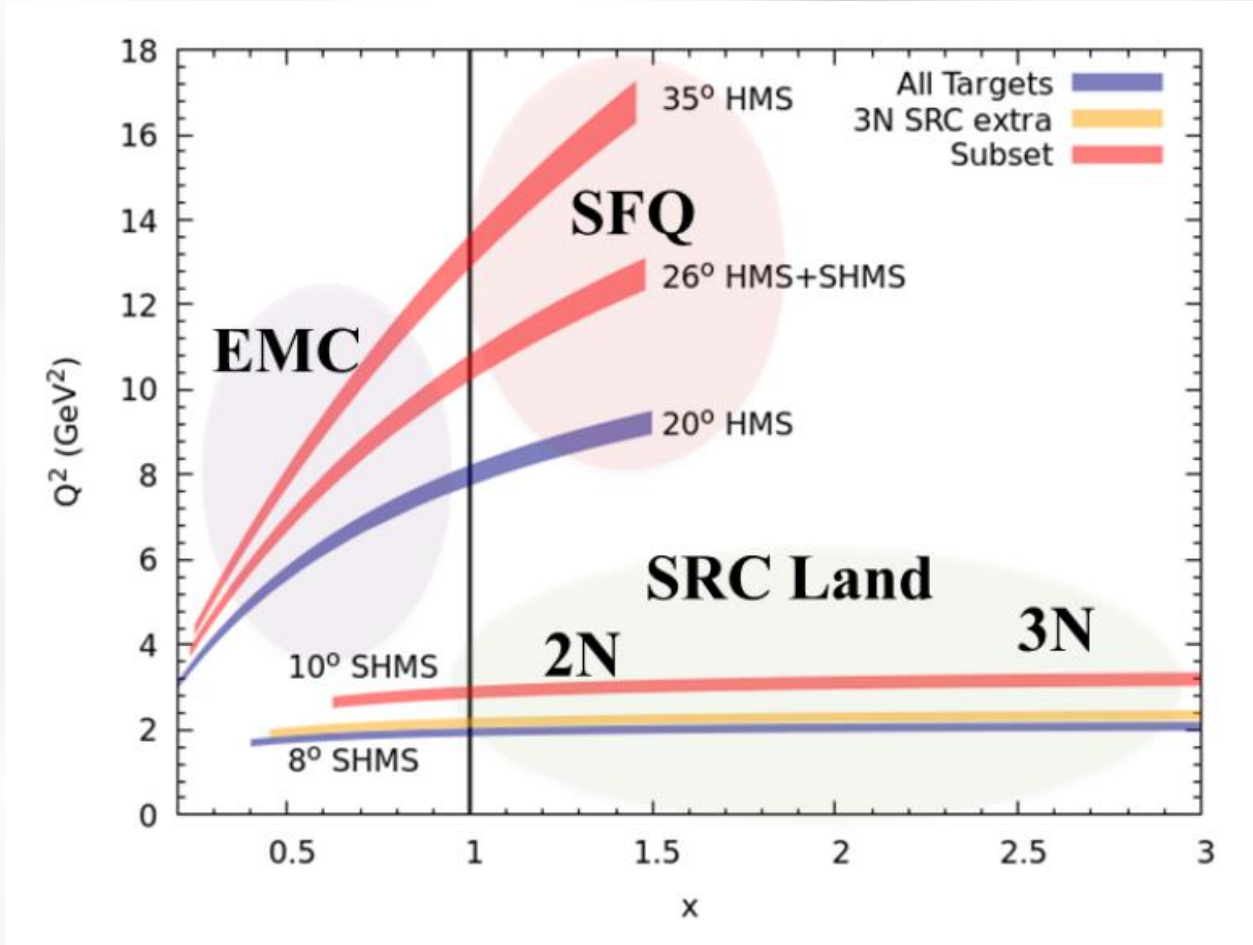
Tyler J. Hague

Jefferson Lab

U.S. Department of ENERGY

XEM2 Experiments

- E12-06-105: (SHMS)
  - Studies of Short Range Correlations (SRCs)
  - Super fast quarks
- E12-10-008: (HMS)
  - Studies of the EMC effect

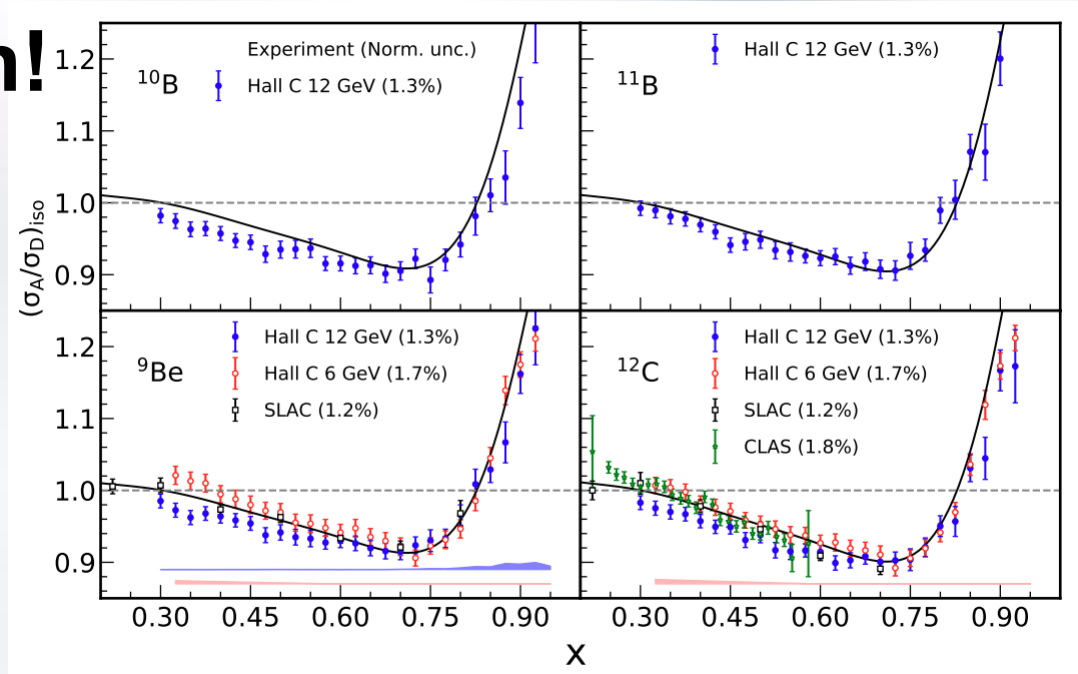


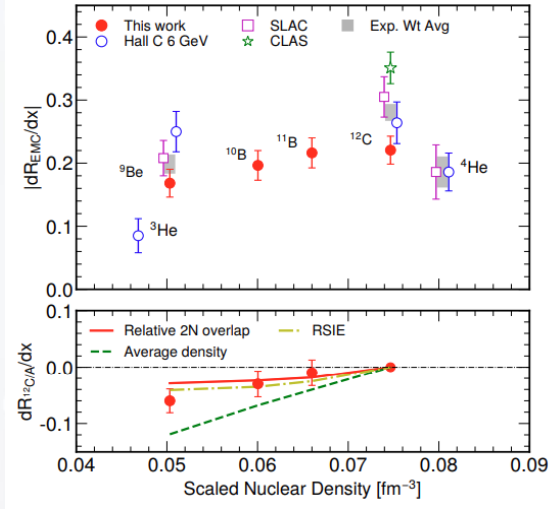
Current Status

- 4 students graduated *so far*
  - Abishek Karki
  - Casey Morean
  - Cameron Cotton
  - Abhyuday Sharda
  - *Who's next?*
- 1 Publication from commissioning data
  - A. Karki *et al.* First Measurement of the EMC Effect in ^{10}B and ^{11}B. *Phys. Rev. C* (2023).
- *Lots* of analysis underway

Commissioning Run Publication!

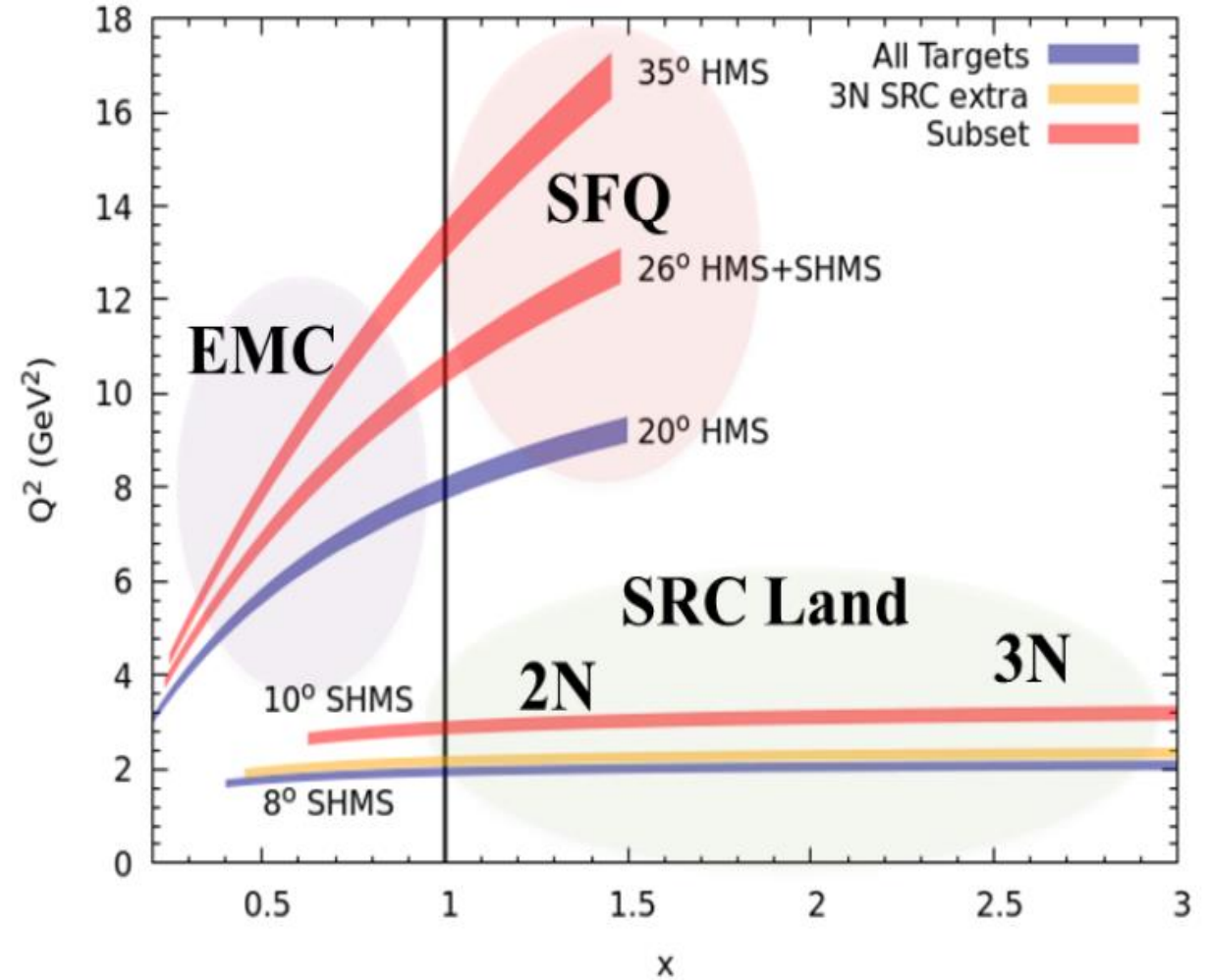
- First study of EMC effect in Boron 10 and 11
- Data recorded with SHMS at 21° with three momentum settings (3.3, 4.1, and 5.0 GeV)
- Carbon and Beryllium have approximately 2σ smaller effect than previous measurements
  - No clear cause at the moment
  - More data coming from production run
  - Beryllium difference at low x may be due to reduced radiated quasi-elastic tail contributions

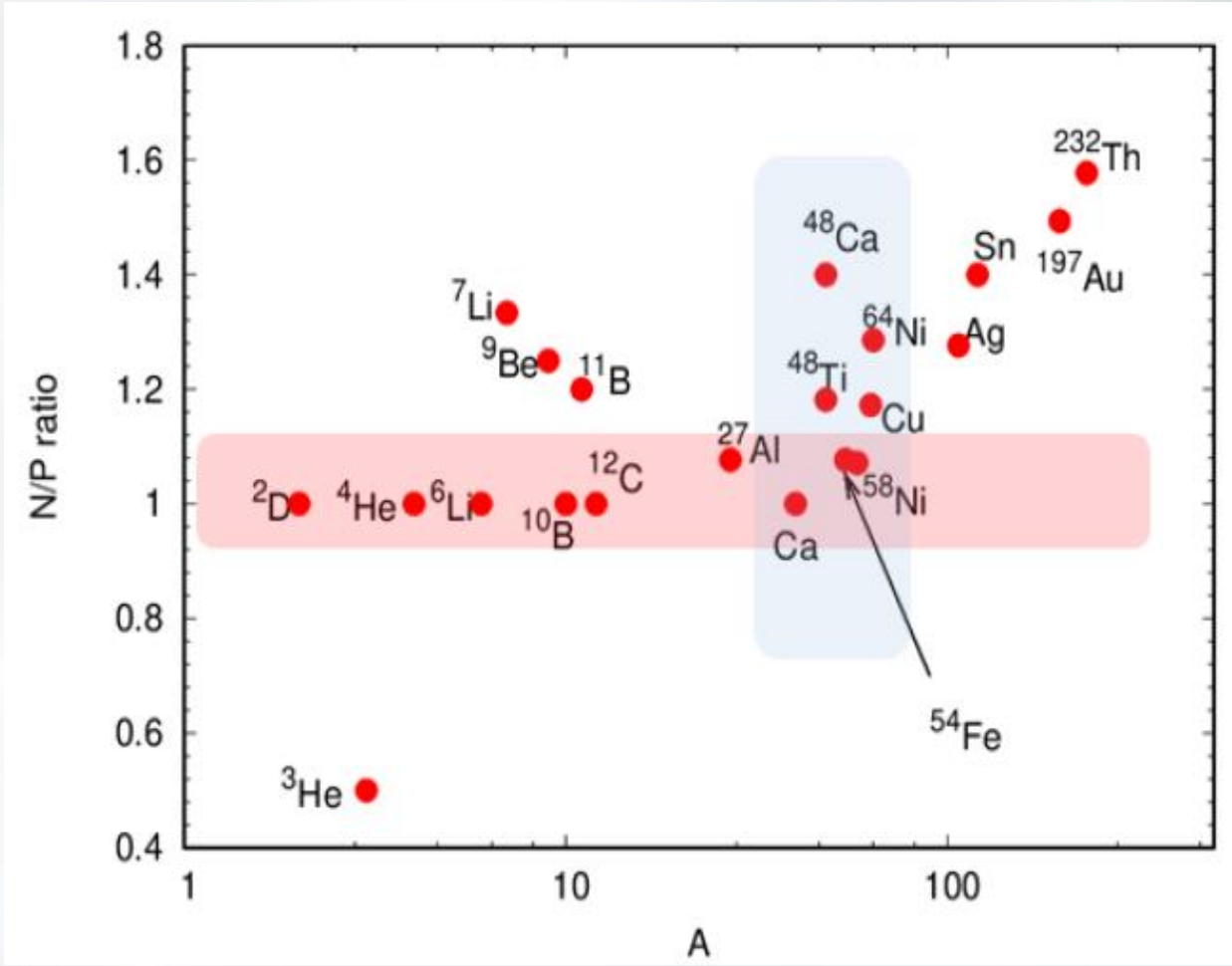




A. Karki *et al.* First Measurement of the EMC Effect in ^{10}B and ^{11}B. *Phys. Rev. C* (2023).

Experimental Landscape





What is this talk?

- Partial analysis update
  - How did we get/are we getting to results
- A conversation starter for thinking about isospin dependence of the EMC effect
- A *mostly* complete, but very preliminary, look at “medium” A nuclei
  - Our current goal is to publish this 2 months ago
- An *incomplete* look at light nuclei
  - Similar thought process to the medium nuclei, but not quite the same
- Time and session chair permitting: A *very brief* look at non-XEM2 isospin related things
  - Showing off a pet project

What classifies as *mostly* complete for medium A?

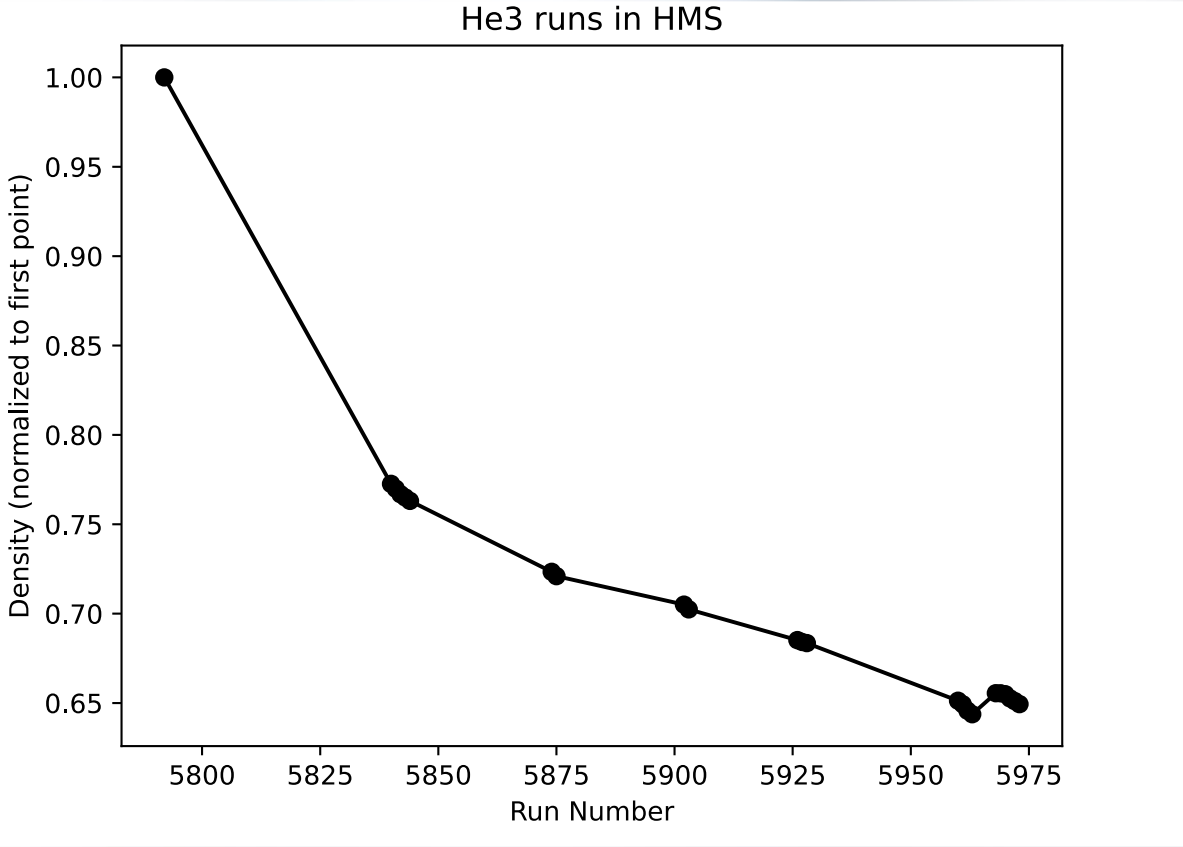
- Results are similar across a few analyses
- Crossing i's, dotting t's, checking systematic analyses
- Assessing impact of F2n/F2p fits/models
- Pondering the meaning of life and isospin

What is *incomplete* about light nuclei?

- Helium-3, Lithium-6, and Lithium-7

Helium 3 Target Leaking

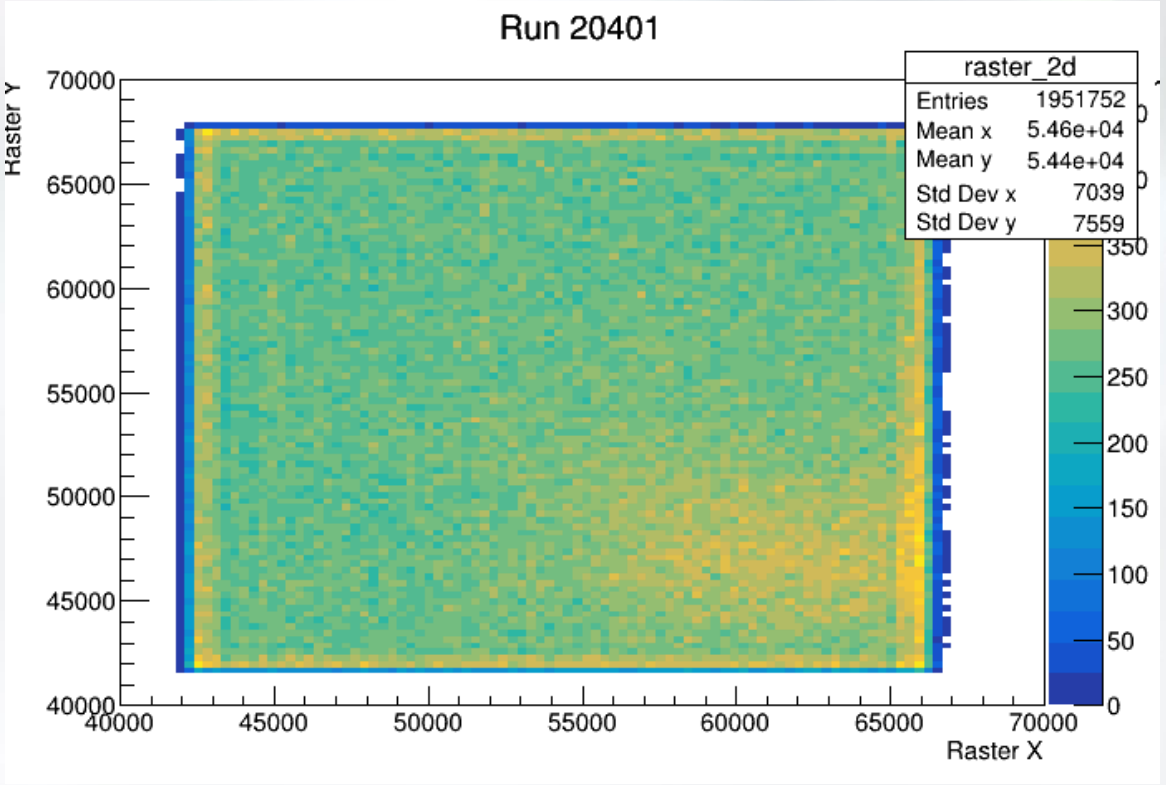
- Early after the second target ladder was installed, a leak was discovered in the ^{3}He target
- Around half of the target thickness was lost
- Abhyuday (UTK) characterized the target thickness over time
  - A non-negligible fraction of our data was taken while the target was actively leaking
  - Will lead to a time-dependent target thickness correction
  - Will require an additional systematic uncertainty to account for this correction
- On the plus side: Having multiple measurements with different densities has allowed us to assess a required offset for the target temperature probes

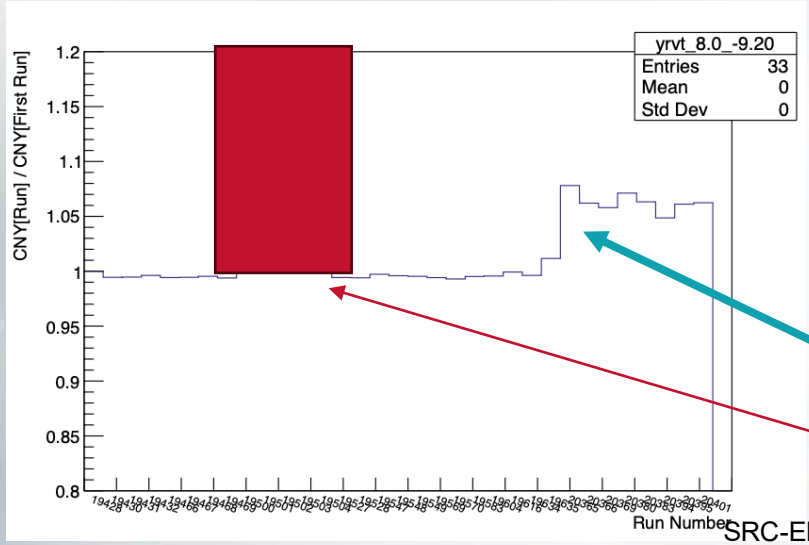


Plot courtesy of Abhyuday Sharda (UTK)

Lithium Target Melting and the Tin Disappearing Act

- Partway through the run period, a “hot spot” appeared on the ^{6}Li, ^{7}Li, and Sn targets
  - The tin target was not on the target ladder and not found after the run
- Investigation found no issues with the raster
  - That is, it is a target effect, not a beam position effect
- It seems that we partially melted the target causing a buildup of excess material forming a hot spot





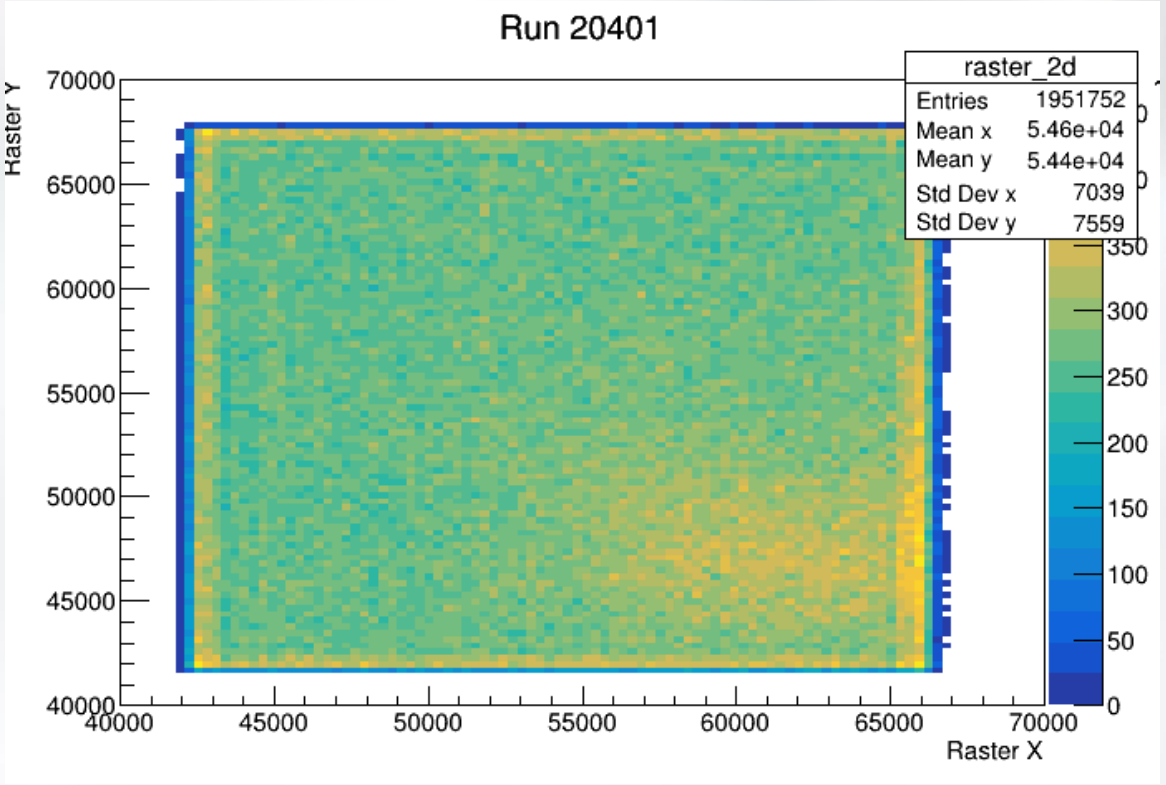
Charge Normalized Yield v. Run normalized to first run

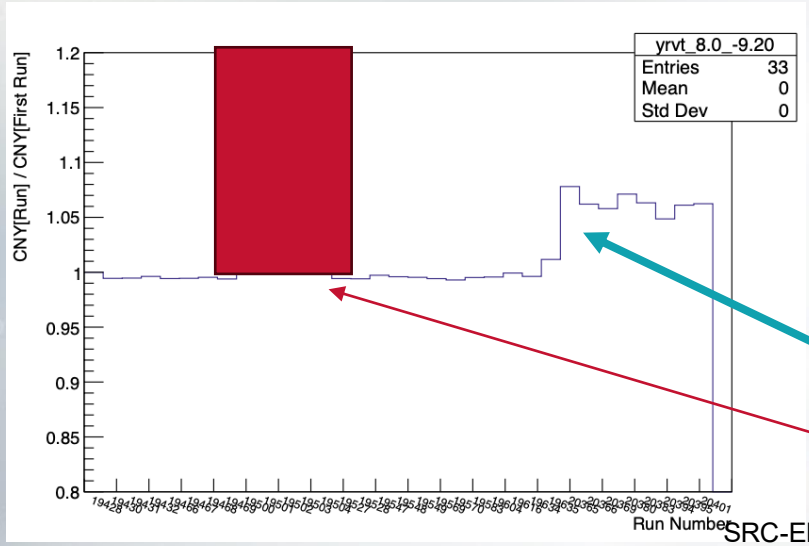
Yield jump just as hot spot appears in data!

Nothing to see here… (red herring easily explainable by configuration changes)

Lithium Target Melting and the Tin Disappearing Act

- Lara Blokland (UTK) is actively studying the lithium targets to attempt to rescue some of the data
  - The effect seems to be sudden
  - Need to verify that and determine what data is usable





Charge Normalized Yield v. Run normalized to first run

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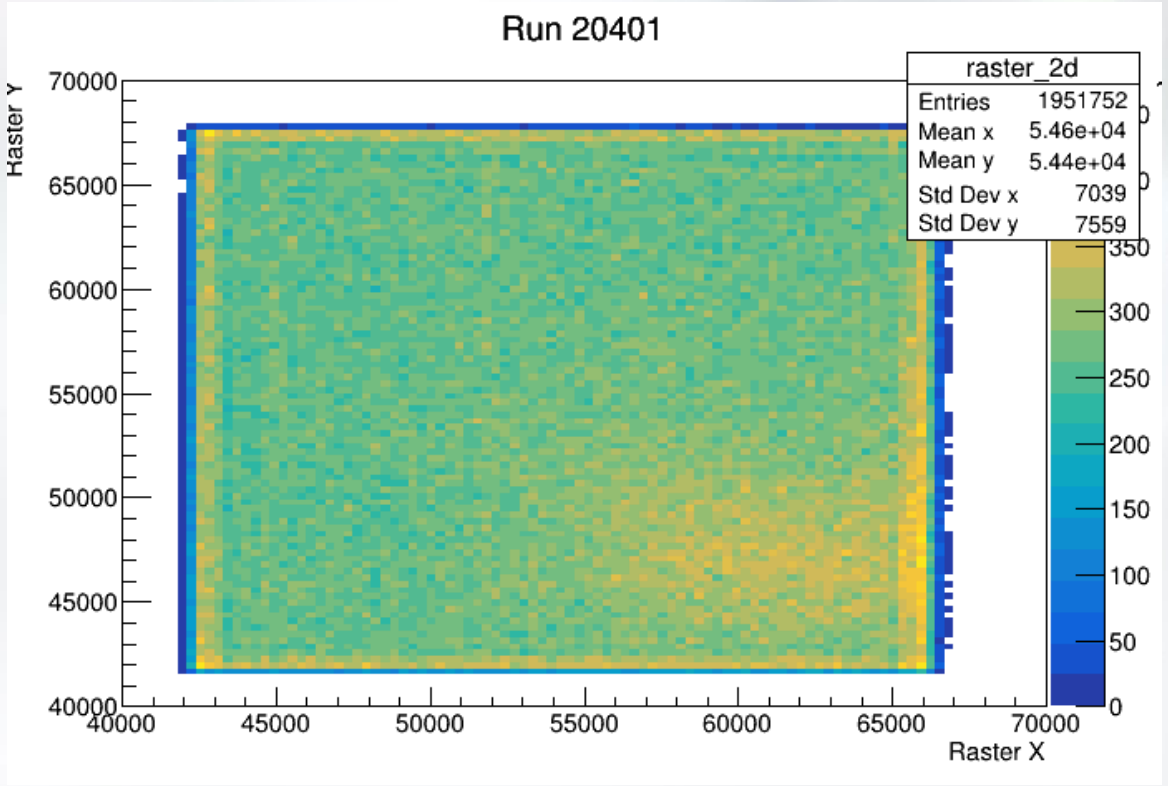
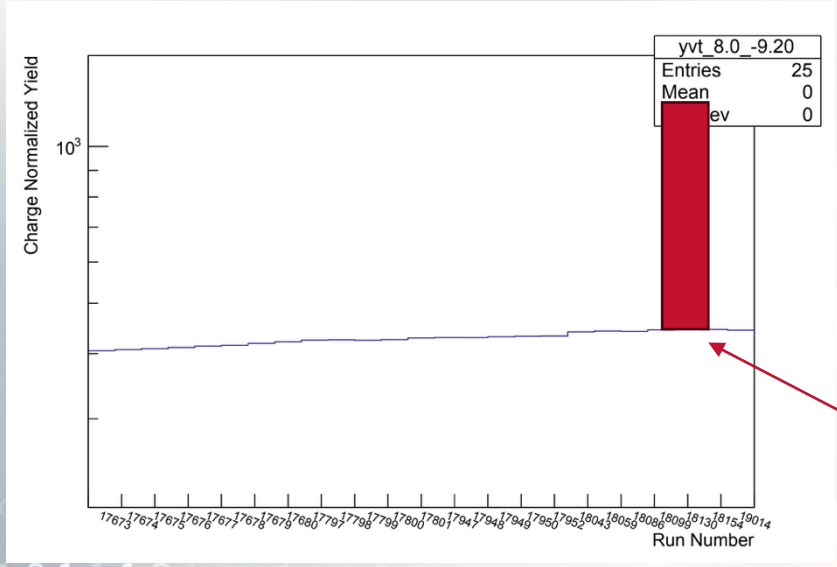
Lithium Target Melting and the Tin Disappearing Act

- Lara Blokland (UTK) is actively studying the lithium targets to attempt to rescue some of the data
  - The effect seems to be sudden
  - Need to verify that and determine what data is usable
- Tin had a constantly shifting density
  - At present, there is no expectation of saving it



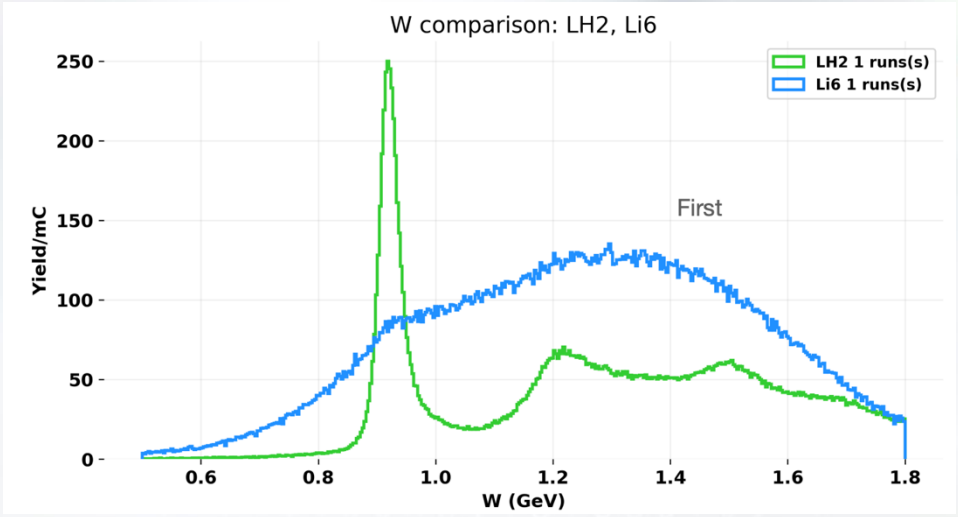
Charge Normalized Yield v. Run normalized to first run

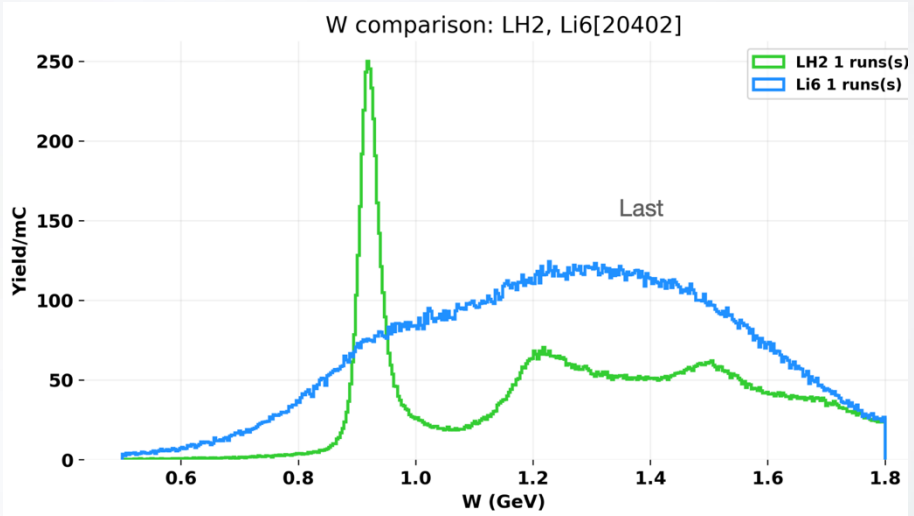


Nothing to see here… (red herring easily explainable by configuration changes)

Mineral Oil Contamination of Lithium Targets

- An enhancement has been seen in the lithium targets near the proton mass in the W spectra
- Comparing it to the hydrogen spectrum, it does appear to be in the correct location
- It appears that this is mineral oil that was used in target production that did not fully burn off
- This contaminates the data and must a subtraction procedure needs to be developed
- The mineral oil used was “white mineral oil” with a chemical structure of $C_{15}H_{16}O_6$

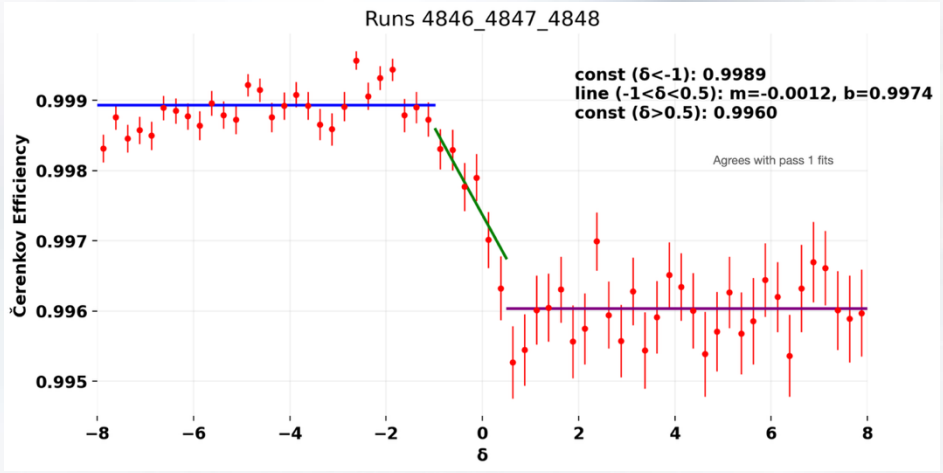




Systematics Studies

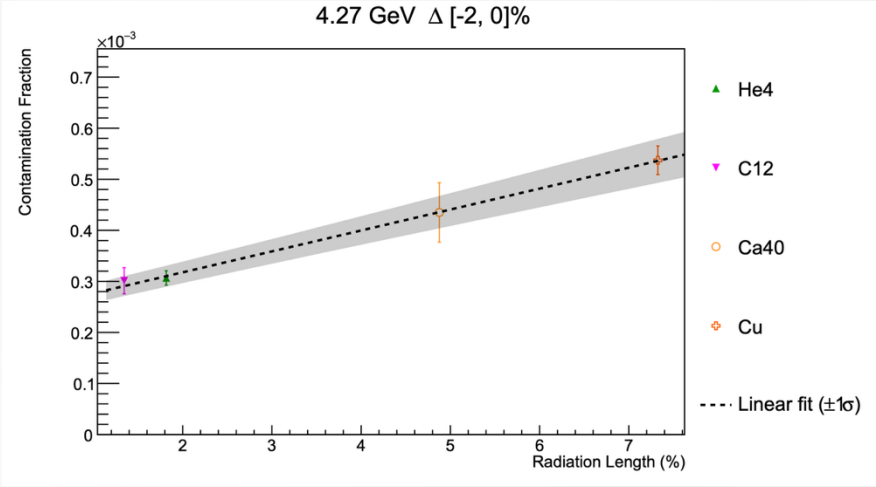
Cherenkov Efficiency

- The Cherenkov efficiency is delta dependent
- The fit is almost a step function



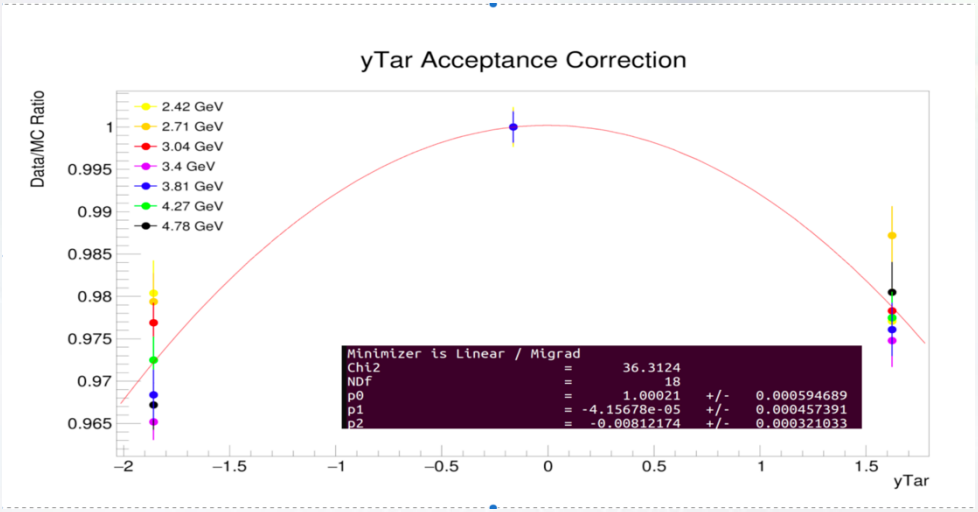
Pion Contamination

- Pion production is charge asymmetric
- We need to quantify this to ensure that the charge symmetric background is sufficient
- The relative asymmetry is at most ~0.15%
- Parametrized above threshold contamination by E' and target Radiation Length



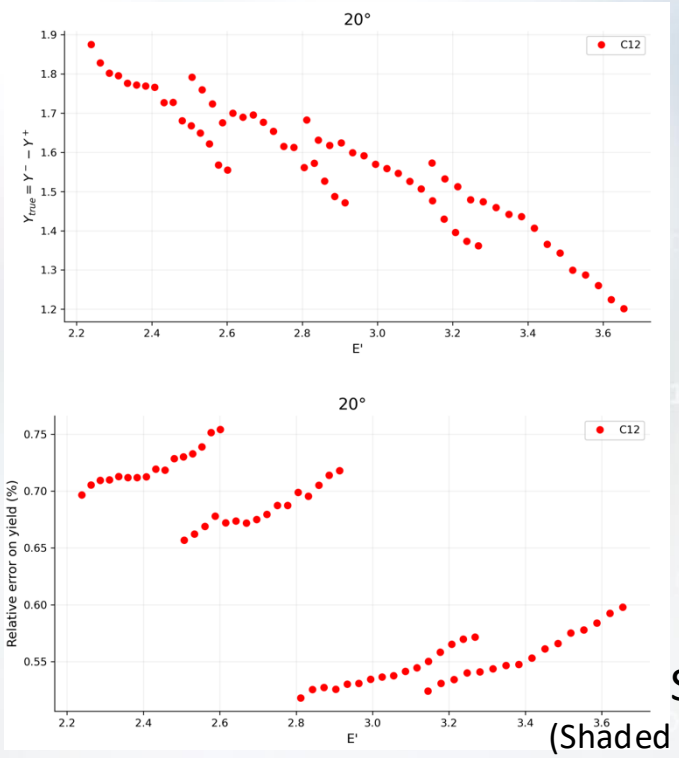
y_{tar} Acceptance Correction

- Monte Carlo simulation of the acceptance of the spectrometer is imperfect
- Best practice is to use the same target material at several ytar locations to fit a correction
- Here we use our aluminum target for a central ytar point and the two cell walls of the aluminum dummy cryo-target for the up/down-stream ytar points
- There is a clear central momentum dependence to this correction
  - Currently, we ignore this dependence
  - Studying this further is in the queue



Charge-Symmetric Background

- Reverse polarity runs used to measure charge symmetric process production
- CSB contributions grow smaller with increasing E', leading to smaller uncertainty contributions



Target Thickness

- Studies are being made into the uncertainty on target thicknesses
- Some solid target uncertainties are complicated by impurities

Deuterium Target

Error	Value	Uncertainty	drho/rho
Temperature	22 K	200 mK	0.3%
Pressure	26 psia	2 psia	0.02%
Equation of state			0.3%
Length measurement	100 mm	0.26 mm	0.26%
Target contraction	99.6%	0.1%	0.1%
Beam position	0	1 mm	0.2%
Total			0.546%

Solid Targets
(Shaded have known impurities)

Target	Relative uncertainty in thickness (%)
^{6}Li	0.356
^{7}Li	1.181
^{9}Be	0.304
^{10}B	0.463
^{11}B	0.416
^{12}C	0.315
^{27}Al	0.217
^{40}Ca	0.382
^{48}Ca	0.314
^{48}Ti	0.340
^{54}Fe	0.272
^{58}Ni	0.166
^{63}Cu	0.318
^{64}Ni	0.192
^{108}Ag	0.379
^{197}Au	0.148
^{232}Th	0.244

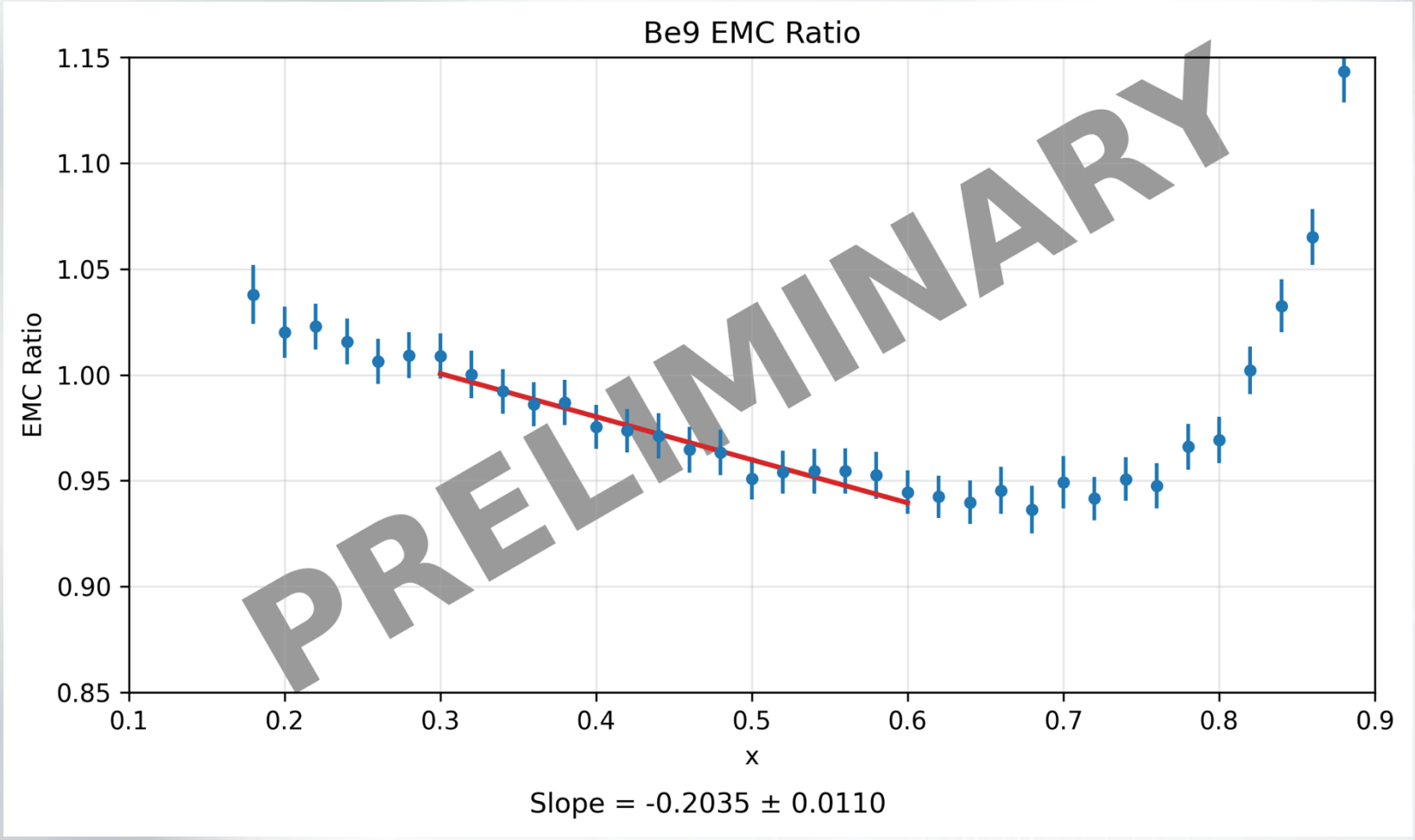
Finally, some plots

Finally, some plots

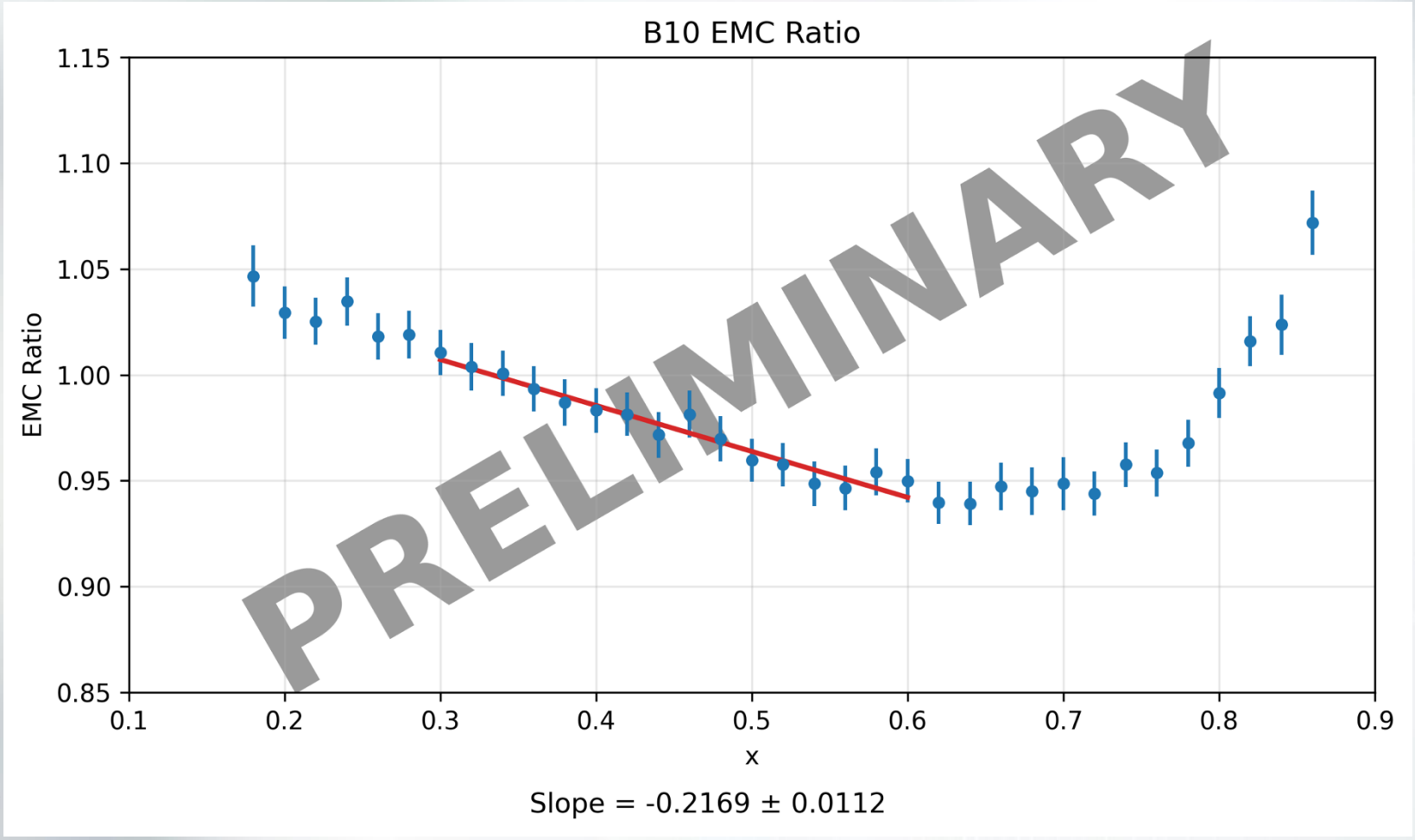
Disclaimer: I just detailed many systematic studies. Not all of them are coded up or parameterized. The following plots have correct statistical uncertainties added in quadrature with a very rough estimate of 1% systematics. 1% not the correct number but is a conservative estimate of the point-to-point systematic uncertainties. Scale and x-dependent systematics are not included or estimated.

Inclusion of these will happen later. It is not expected that they will dramatically impact the EMC slopes but will slightly increase the uncertainties.

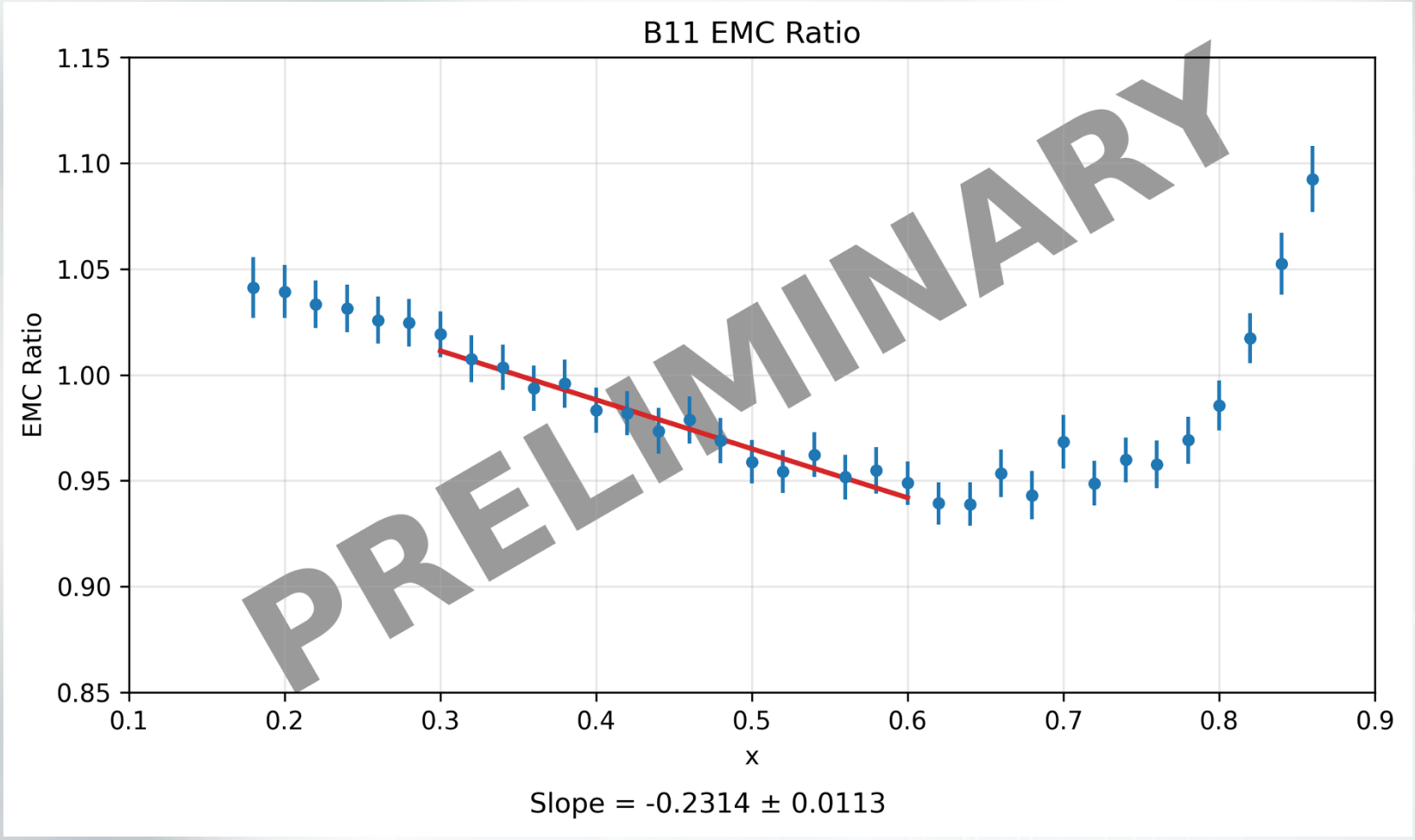
Beryllium 9


Be9 EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PRELIMINARY
Slope = -0.2035 ± 0.0110

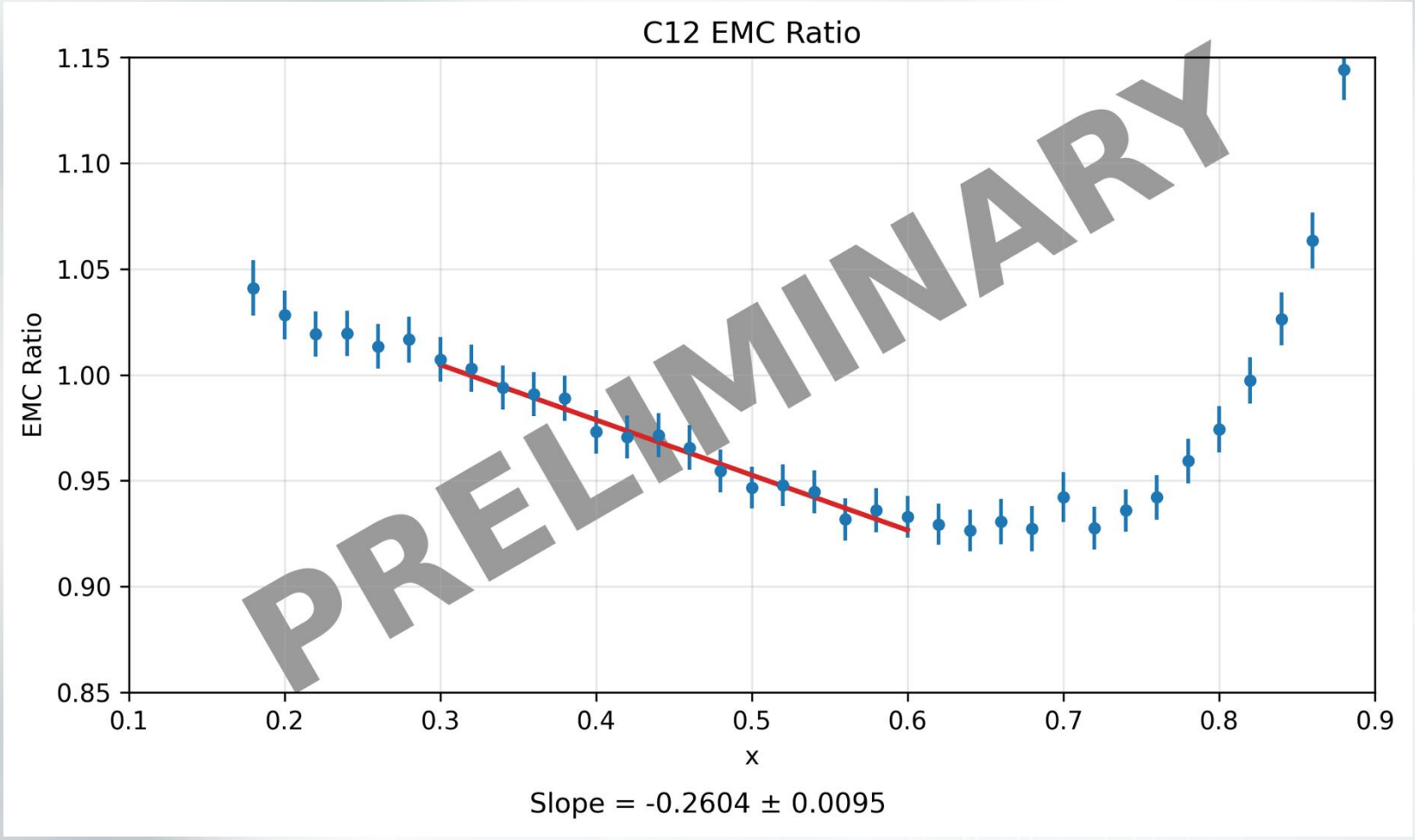
Boron 10


B10 EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PRELIMINARY
Slope = -0.2169 ± 0.0112

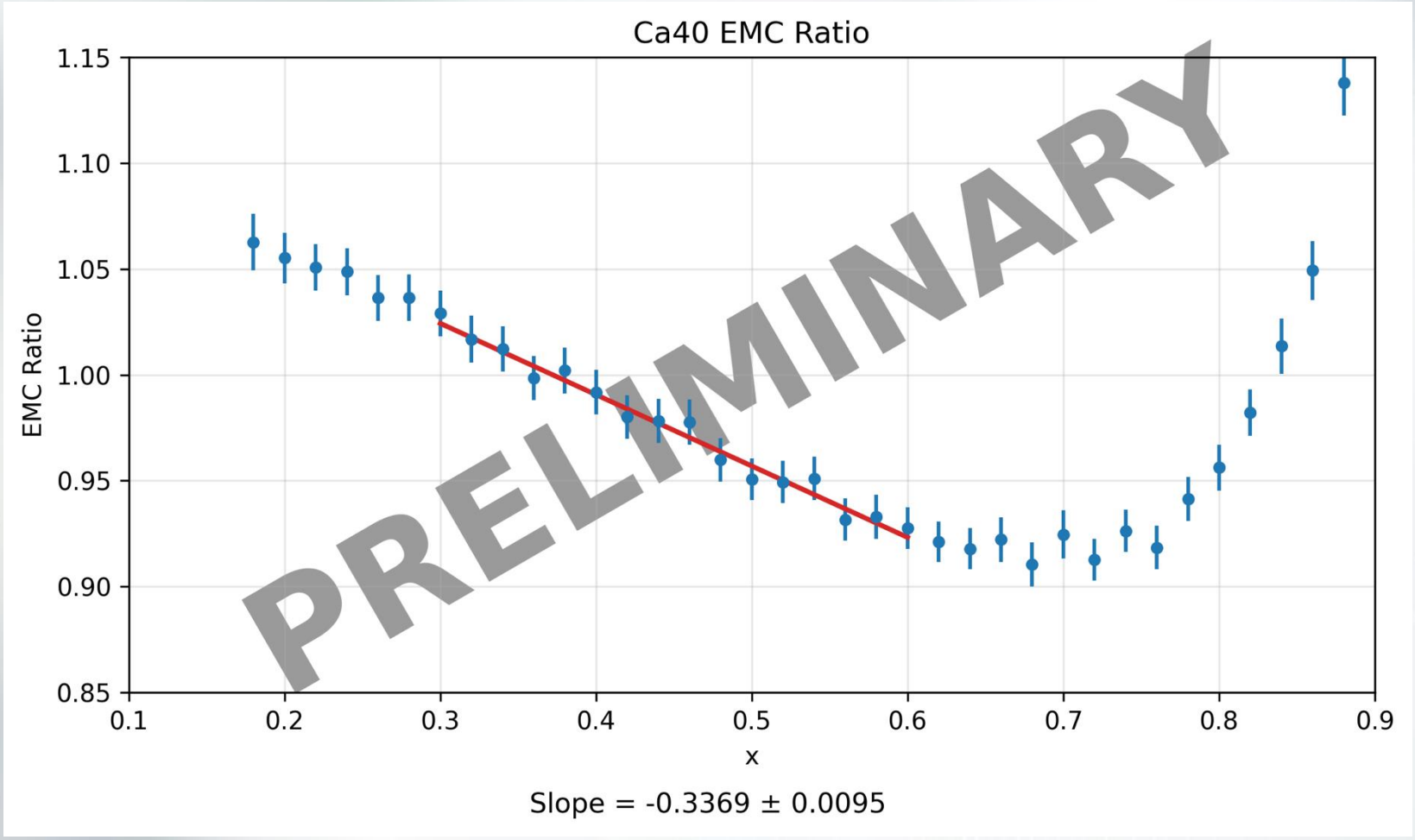
Boron 11


B11 EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PRELIMINARY
Slope = -0.2314 ± 0.0113

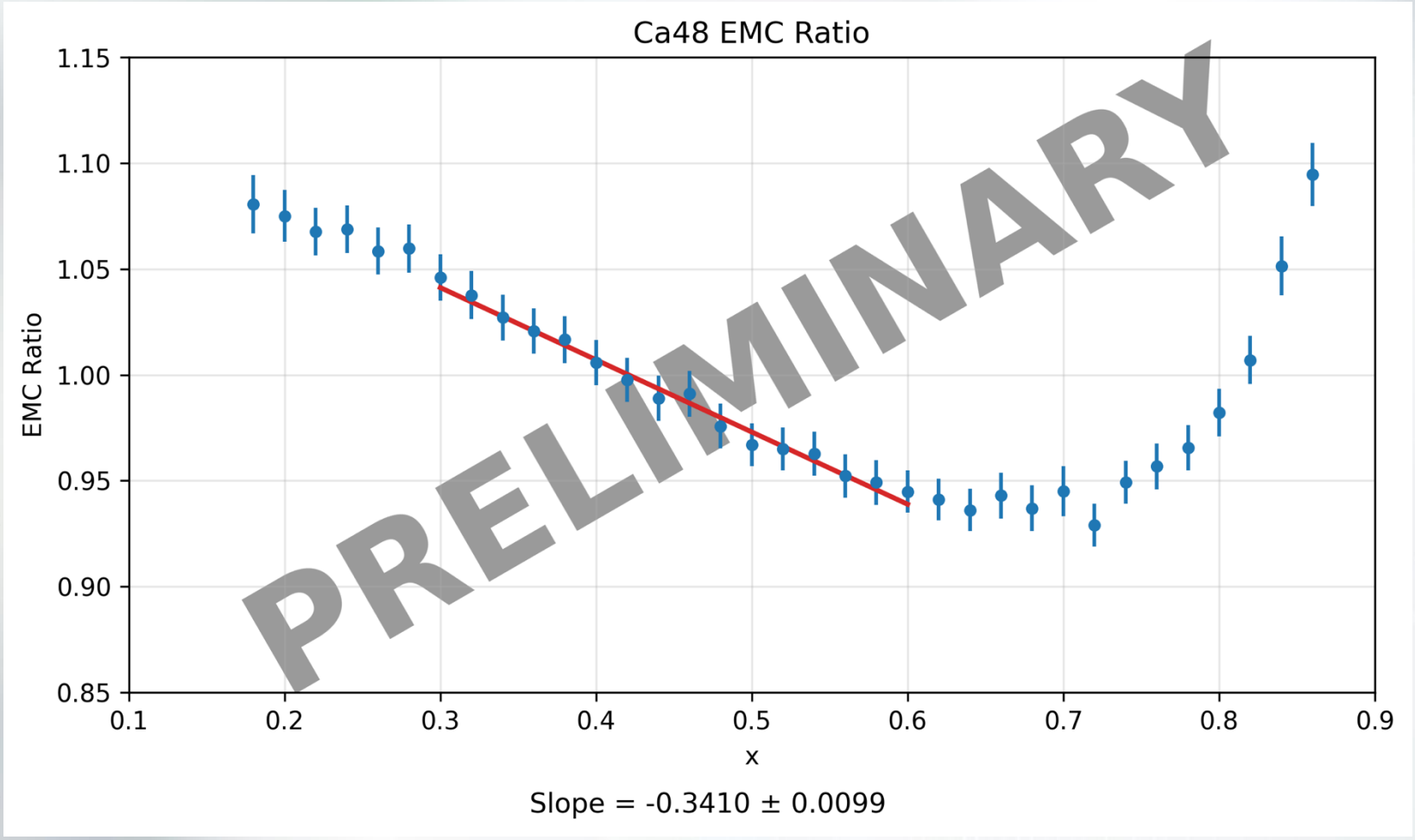
Carbon 12


C12 EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Slope = -0.2604 ± 0.0095
PRELIMINARY

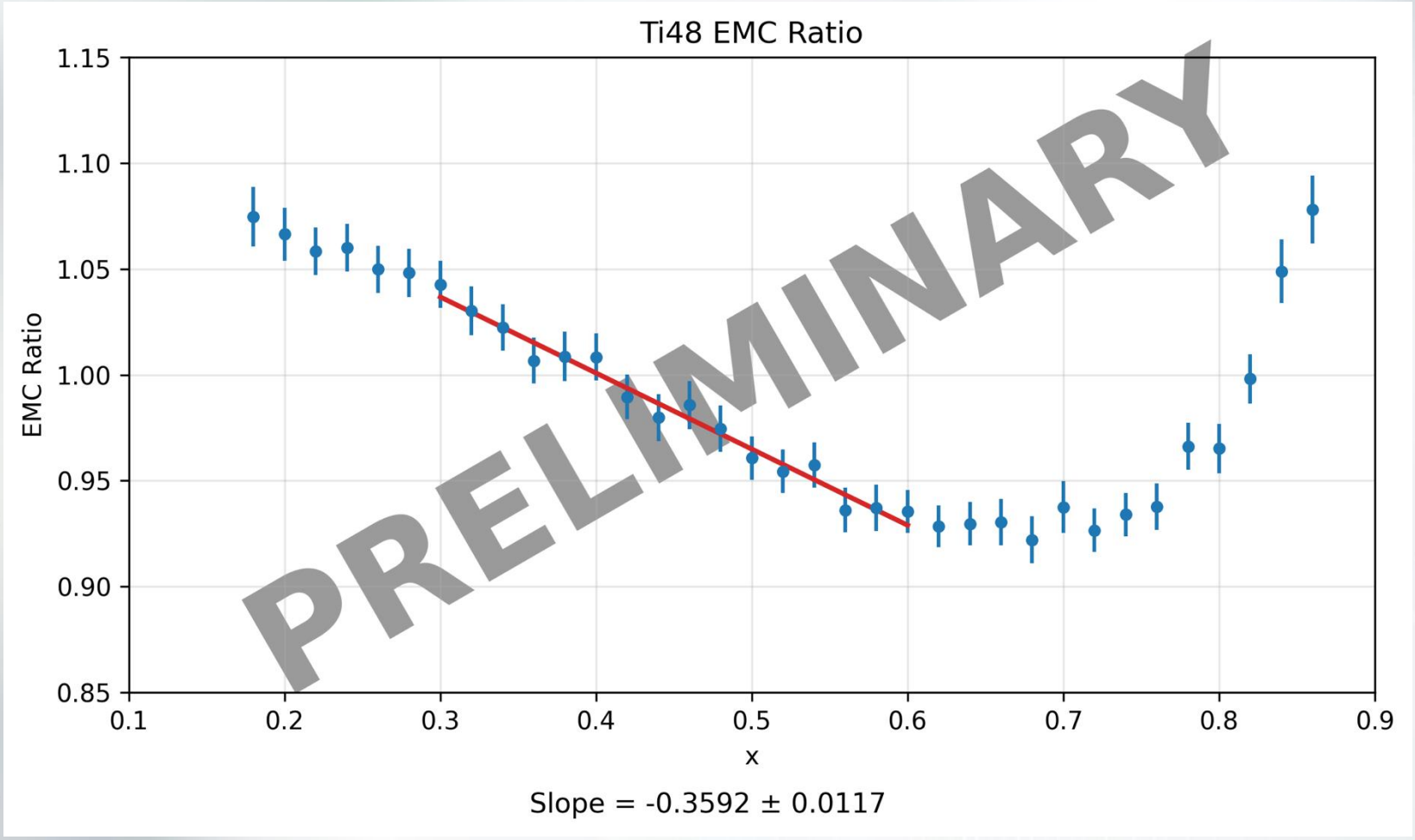
Calcium 40


Ca40 EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PRELIMINARY
Slope = -0.3369 ± 0.0095

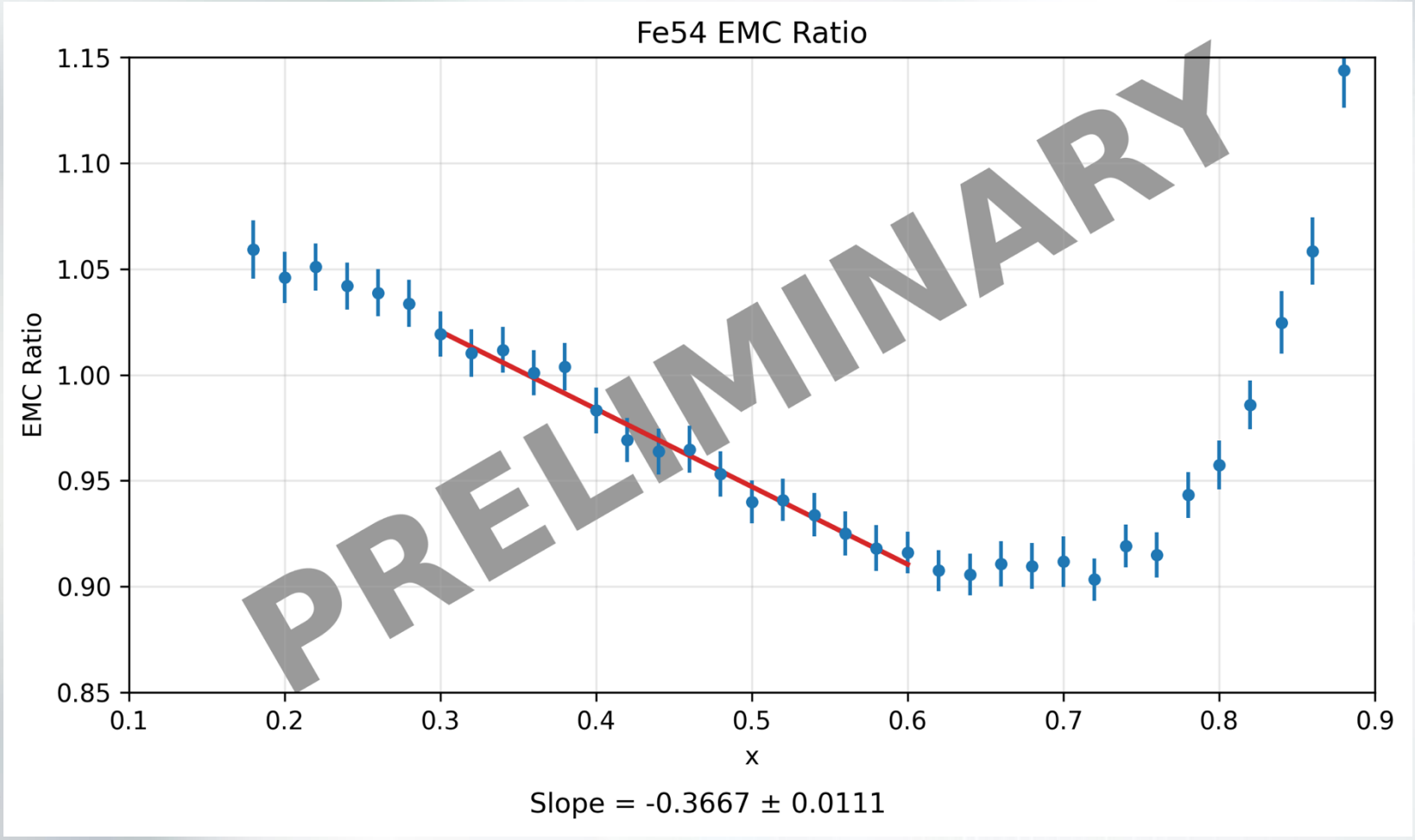
Calcium 48


Ca48 EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PRELIMINARY
Slope = -0.3410 ± 0.0099

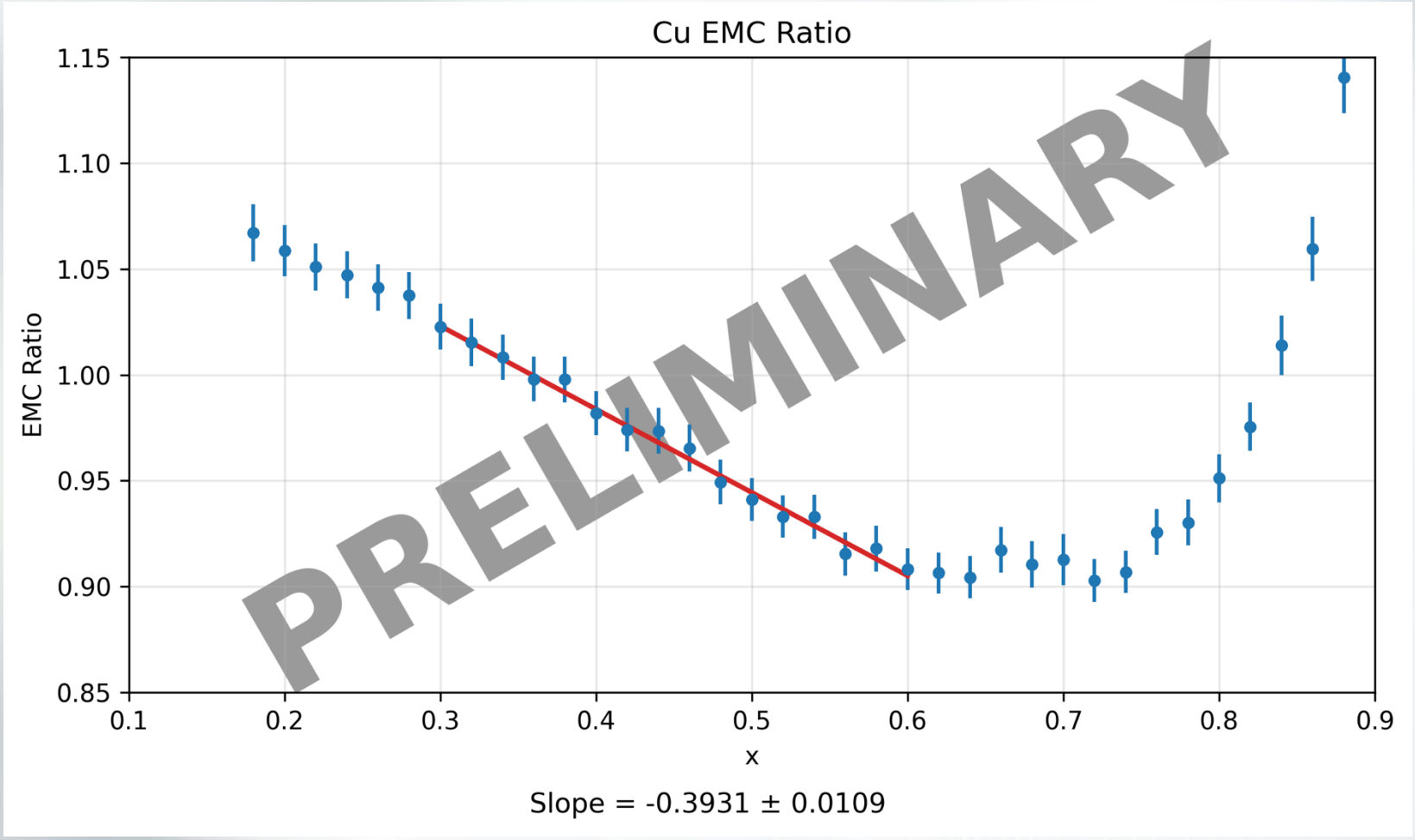
Titanium 48


Ti48 EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PRELIMINARY
Slope = -0.3592 ± 0.0117

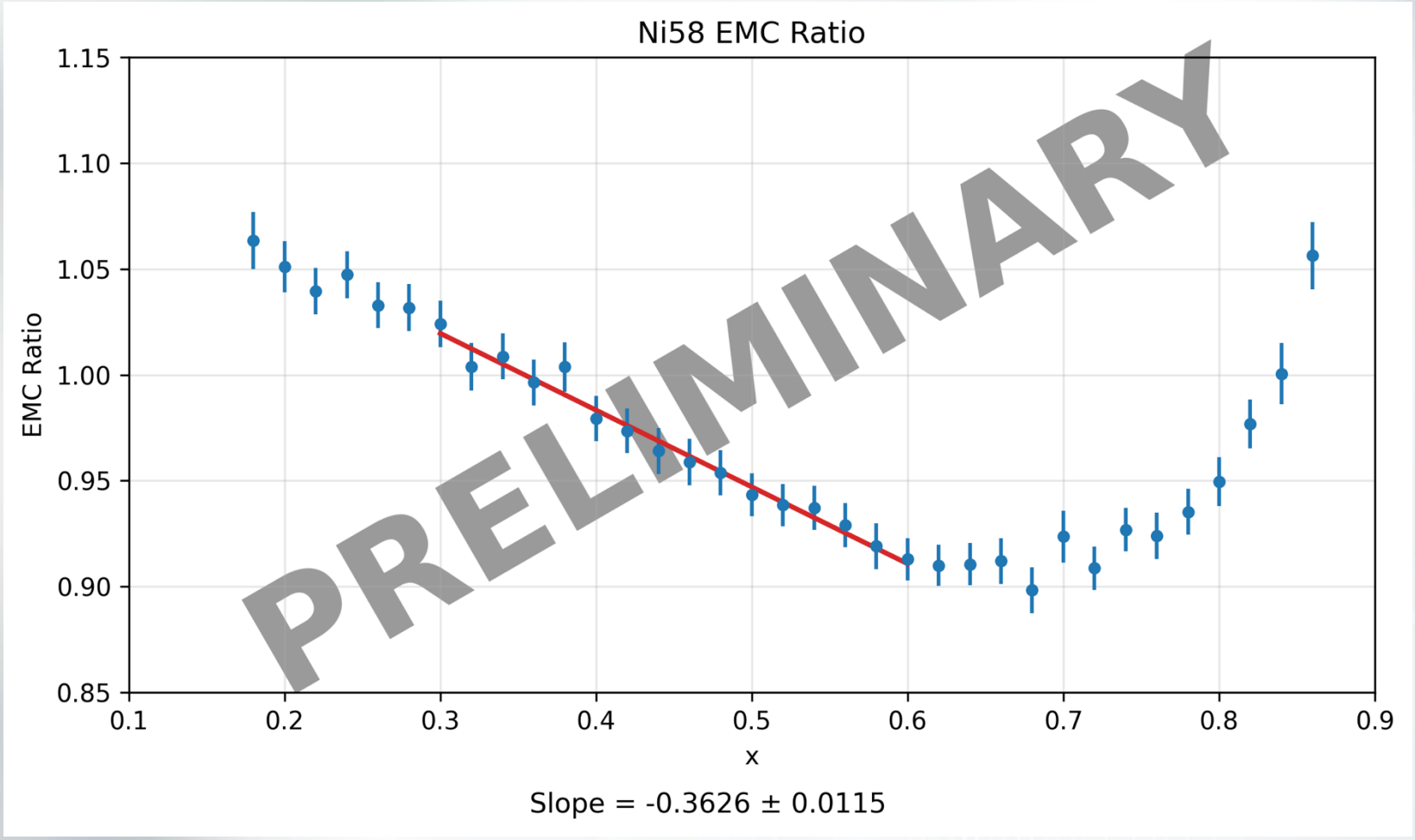
Iron 54


Fe54 EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PRELIMINARY
Slope = -0.3667 ± 0.0111

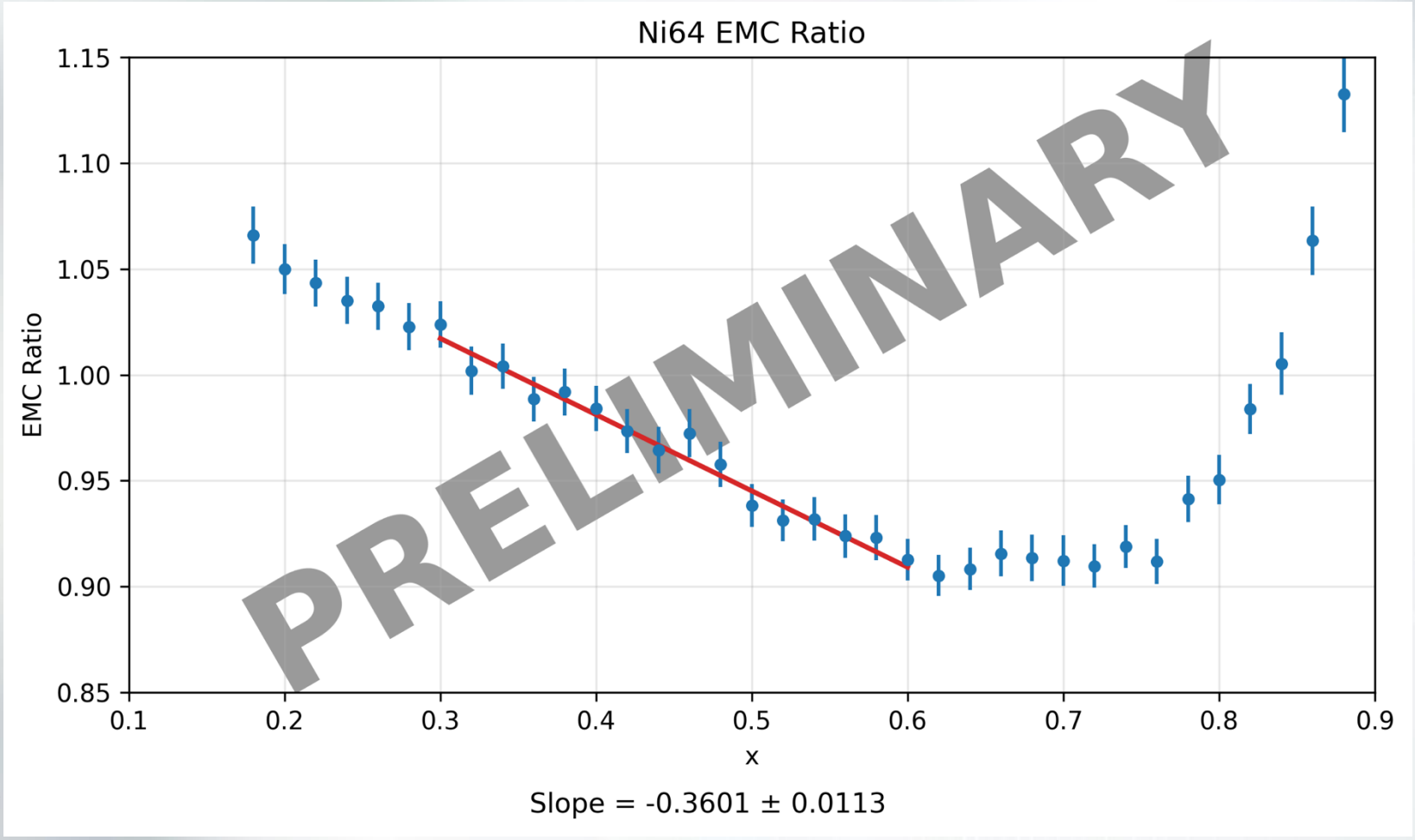
Copper 63


Cu EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PRELIMINARY
Slope = -0.3931 ± 0.0109

Nickel 58


Ni58 EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PRELIMINARY
Slope = -0.3626 ± 0.0115

Nickel 64


Ni64 EMC Ratio
EMC Ratio
x
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PRELIMINARY
Slope = -0.3601 ± 0.0113

What if we plot the slopes?

Is this isospin dependence?*

Not rhetorical

Predictions

The main prediction we know is from Cloët, Bentz, Thomas, PRL 102 (2009)

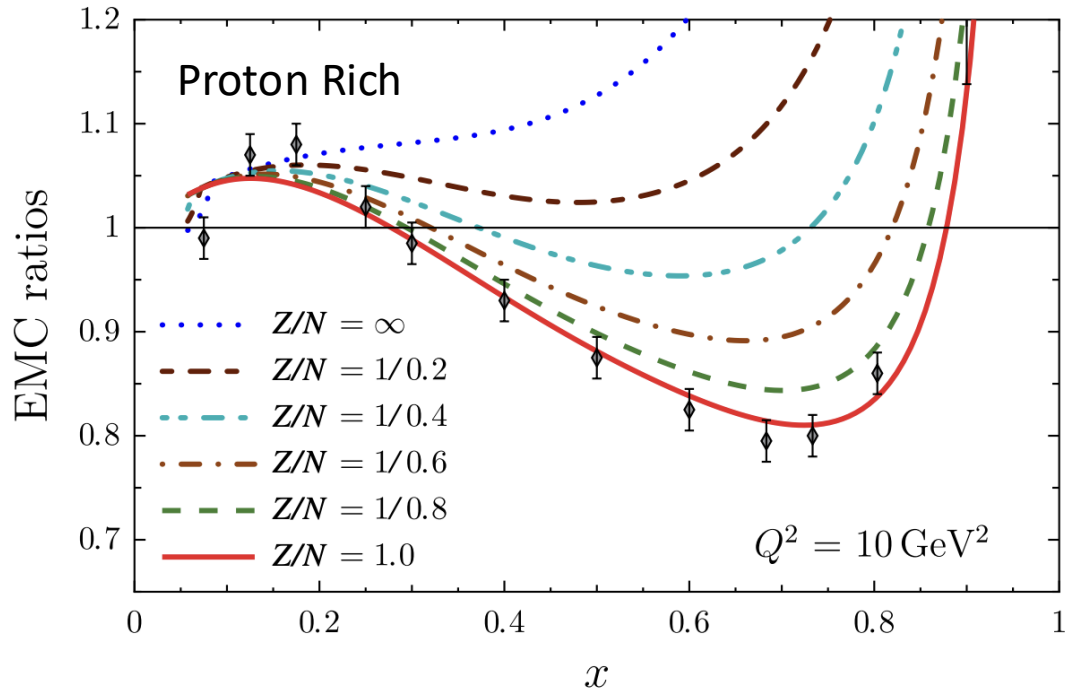
This posits that isospin dependence of the EMC effect could explain the NuTeV Anomaly

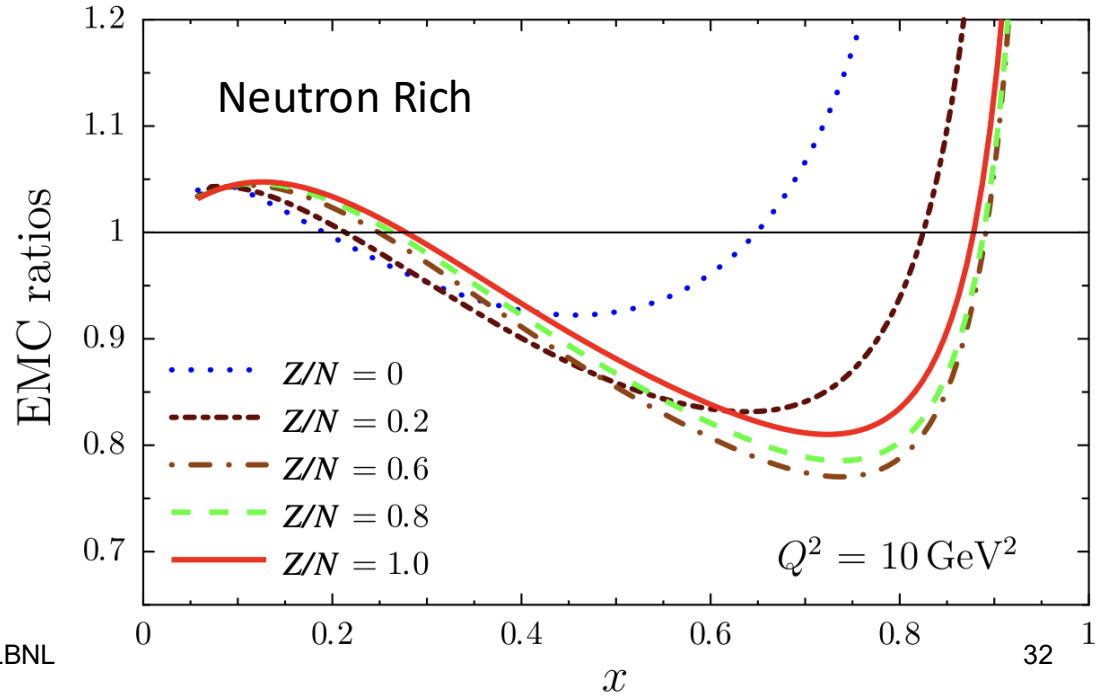
Calculations are for infinite nuclear matter, so not strictly expected to match data

It does suggest qualitative signatures

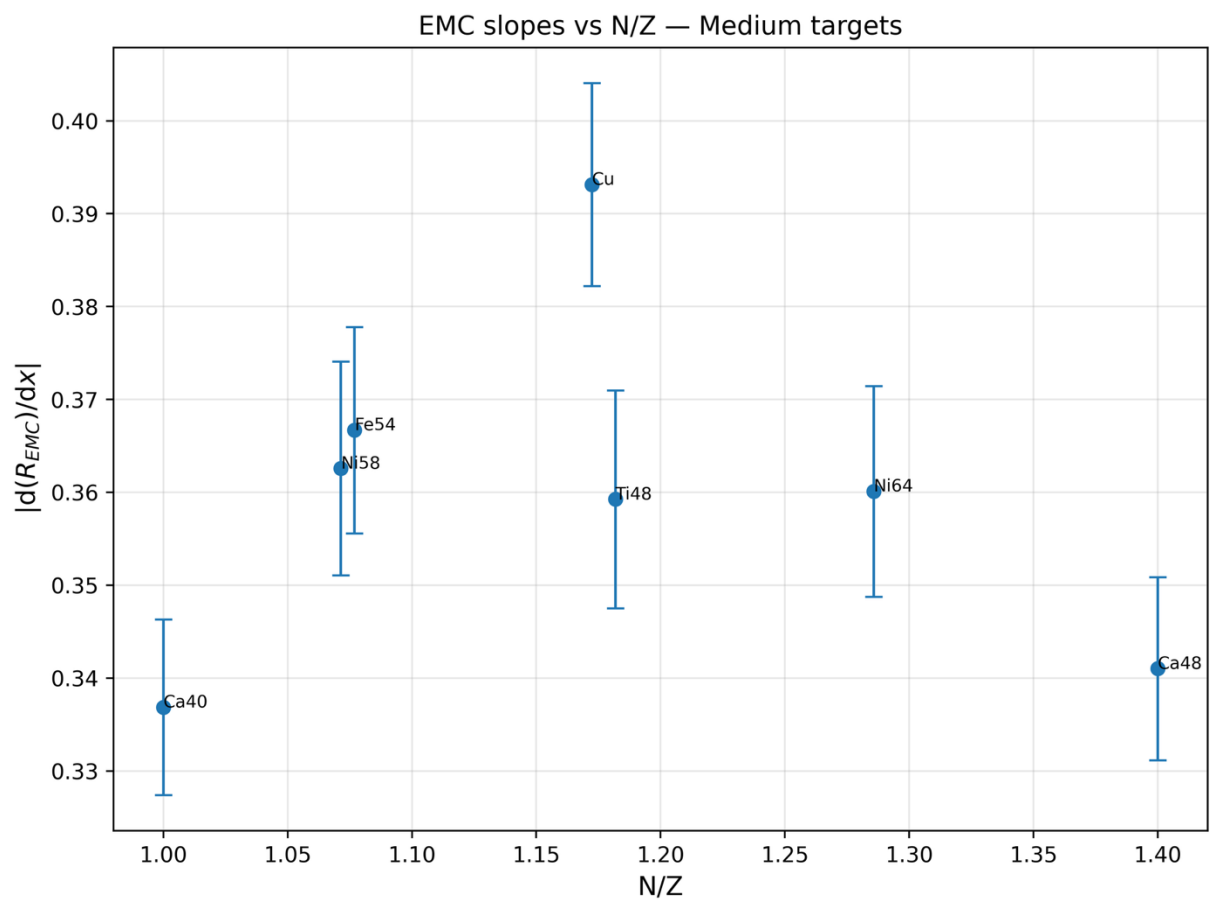
The model creates these predictions through isovector mean field effects

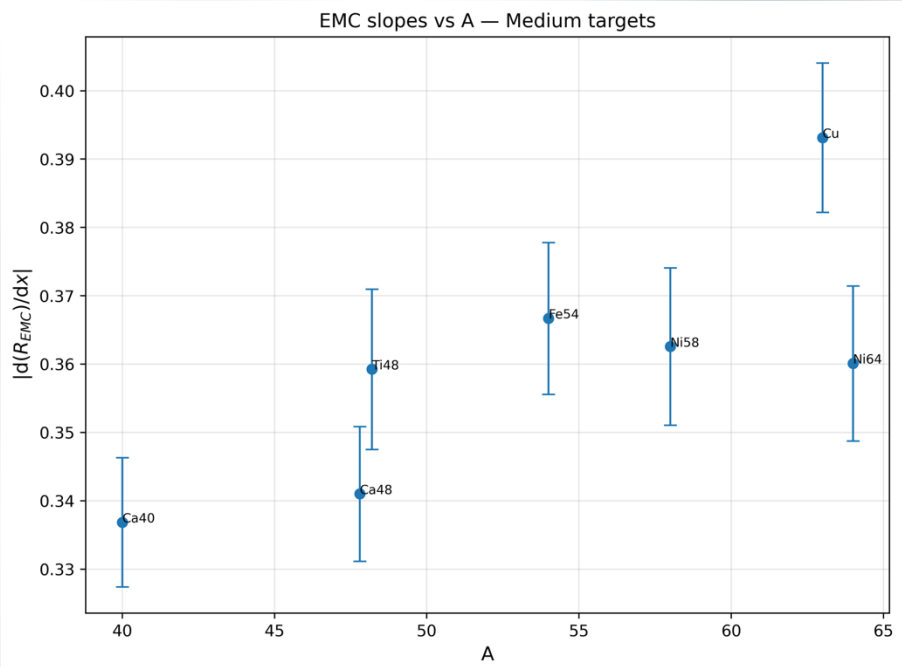
Note: Plots to the right use Z/N. Plots shown of XEM2 data use N/Z

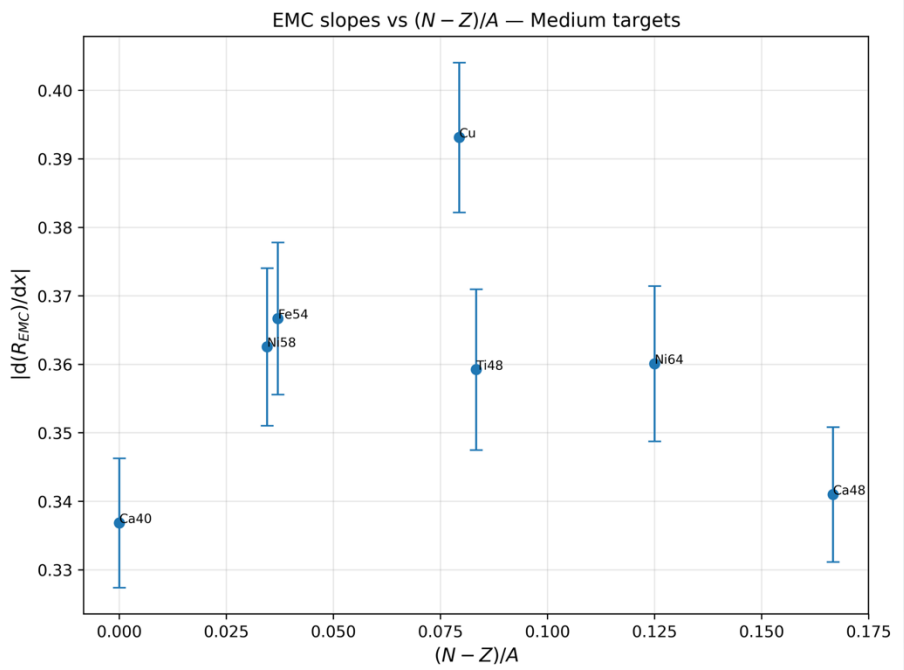




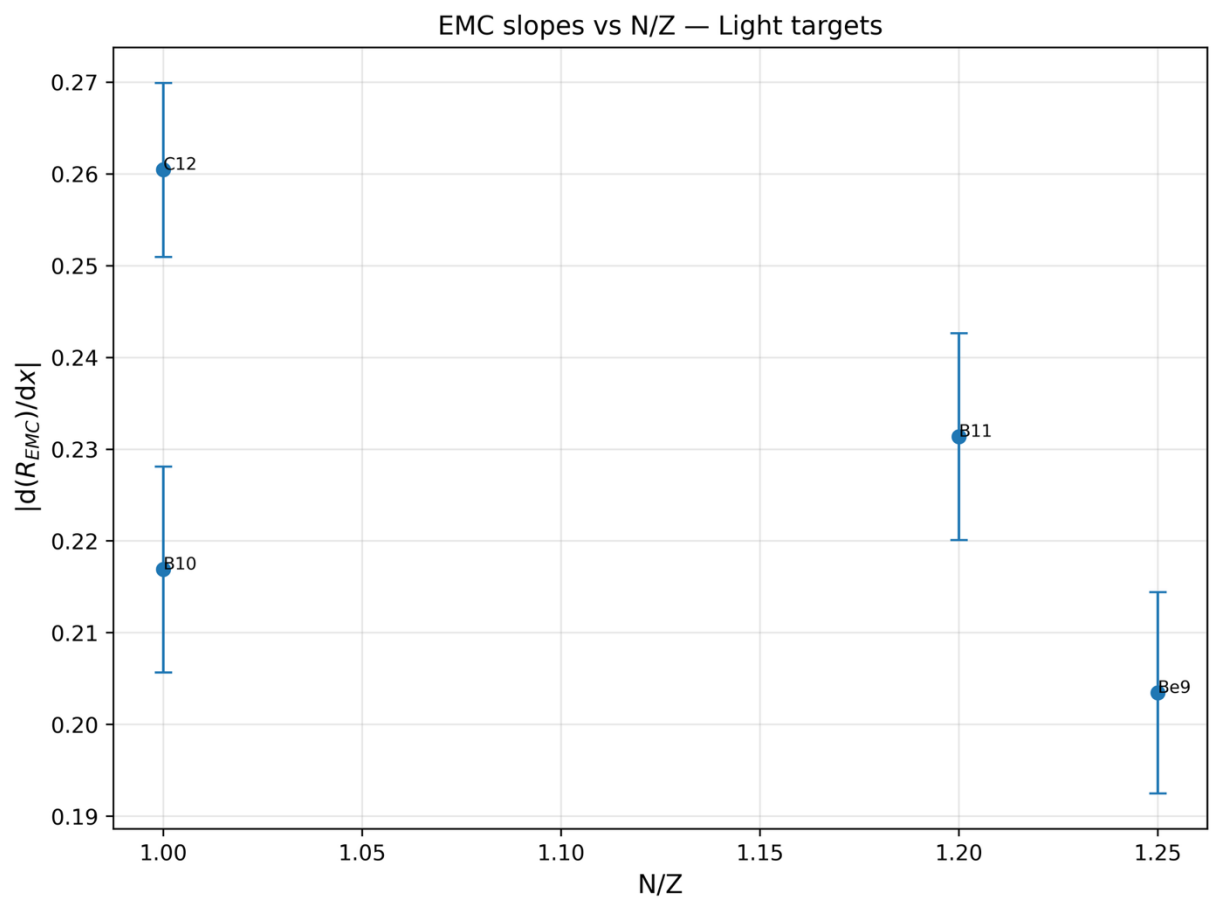
Medium A Targets

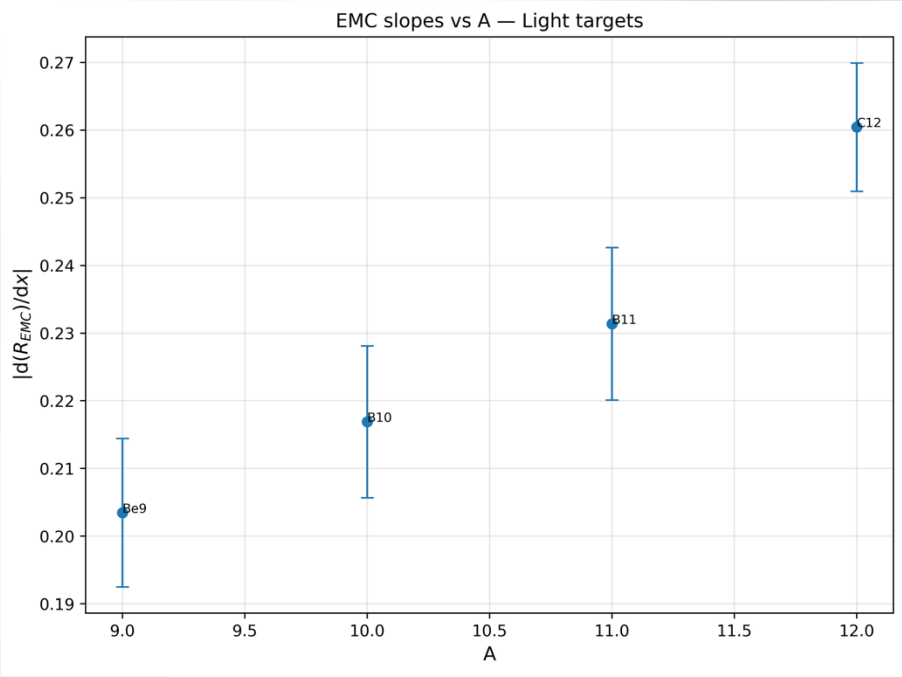


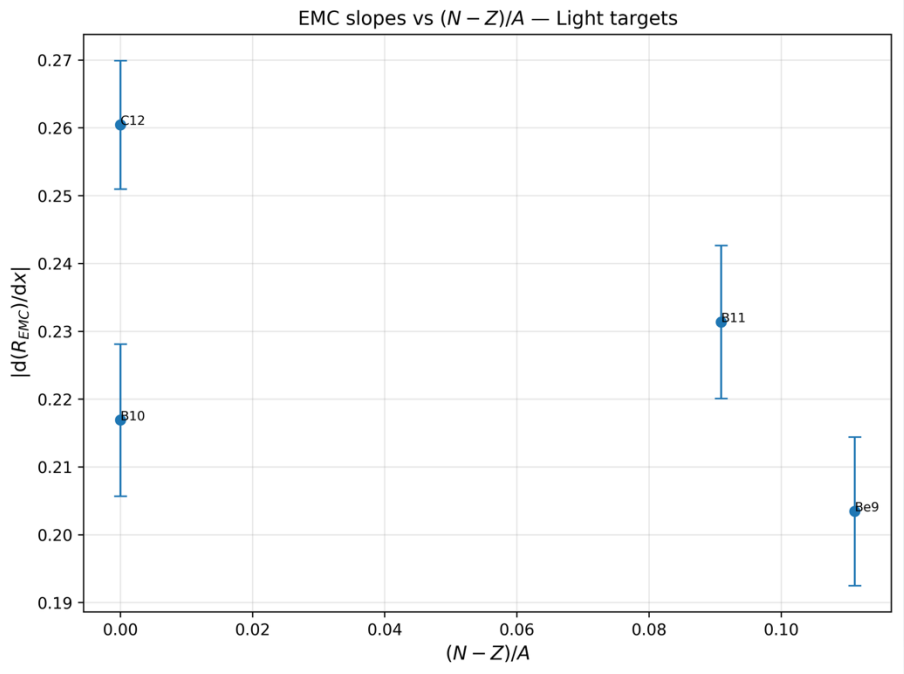




Light A Targets







Summary

- XEM2 has EMC ratios for light and medium targets
  - We also have a lot of other targets (light, medium, and heavy) that were outside the scope of this talk
  - Results made possible by the hard work of a group of fantastic students
- The medium target results might imply some isospin dependence?
- In the context of the CBT model shown before, this data shows the predicted increase in the EMC effect with increasing neutron fraction followed by a decrease in the EMC effect past a certain point
  - The data has the onset of decreasing EMC effect earlier than the model
- We're still thinking about the interpretation of this. *Please* discuss.

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/Escaped

Other Collaborators:
Dipangkar Dutta (MSU), Shujie Li (LBL), Dien Nguyen (UTK), Nathaly Santiesteban (UNH), Xiaochao Zheng (UVA), Burcu Duran (NMSU), Tyler Hague (JLab), Lara Blokland (UTK), Elle Brinkman (UTK), Penny Duran (ASU)

While I have your attention

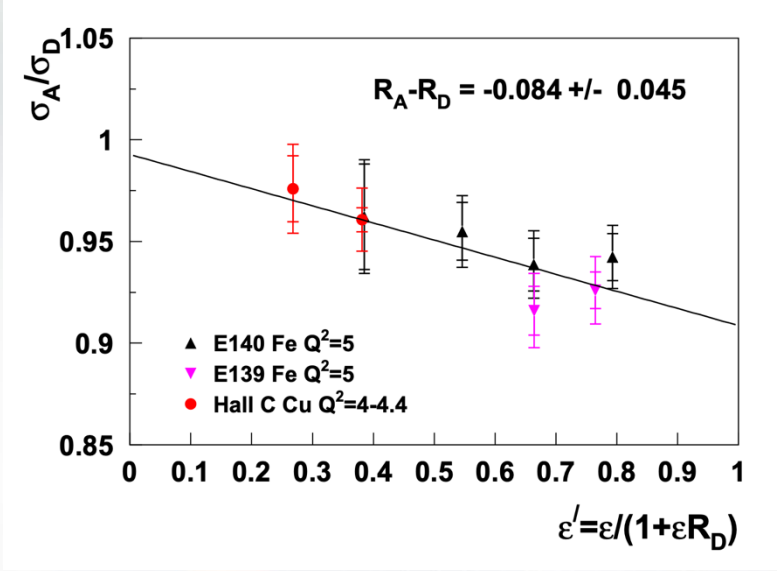
The following is not XEM2

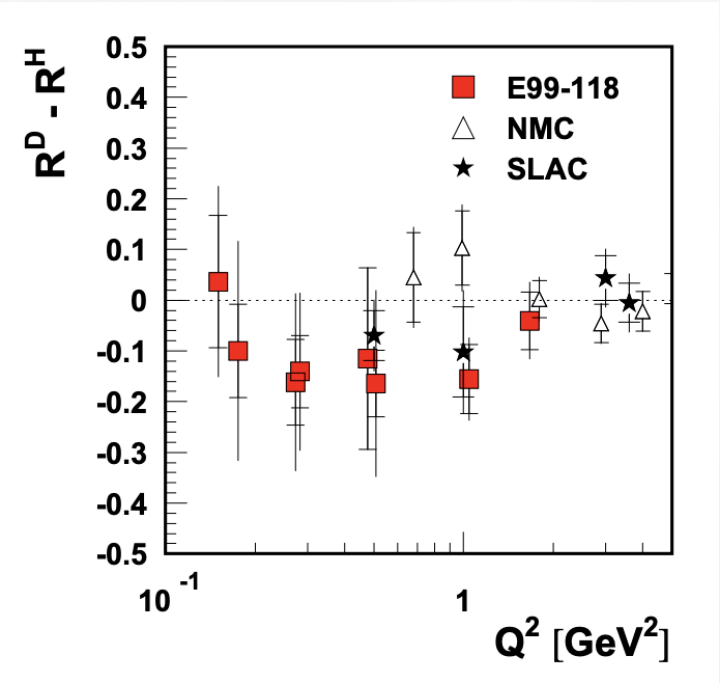
Could $R=\sigma_L/\sigma_T$ be isospin dependent?

- There are hints in data that R is smaller for the deuteron than the proton
- There are hints in data that R is smaller for iron and copper than the deuteron
- Deuteron adds a neutron over the proton
- Iron and copper have neutron excess
- What about proton excess?

$$\frac{\sigma_A}{\sigma_D} \approx \frac{F_T^A}{F_T^D}\left[1+\frac{\epsilon}{1+\epsilon R_D}\Delta R\right] = \frac{F_T^A}{F_T^D}\left[1+\epsilon'\Delta R\right]$$

A non-zero slope indicates non-zero ΔR





E12-14-002 Proposal

V. Tvaskis et al, Phys. Rev. Lett. 98, 142301 (2007)

Jefferson Lab

Caution!
The following combines data from very different experiments!
It suggests interesting physics but is not conclusive!

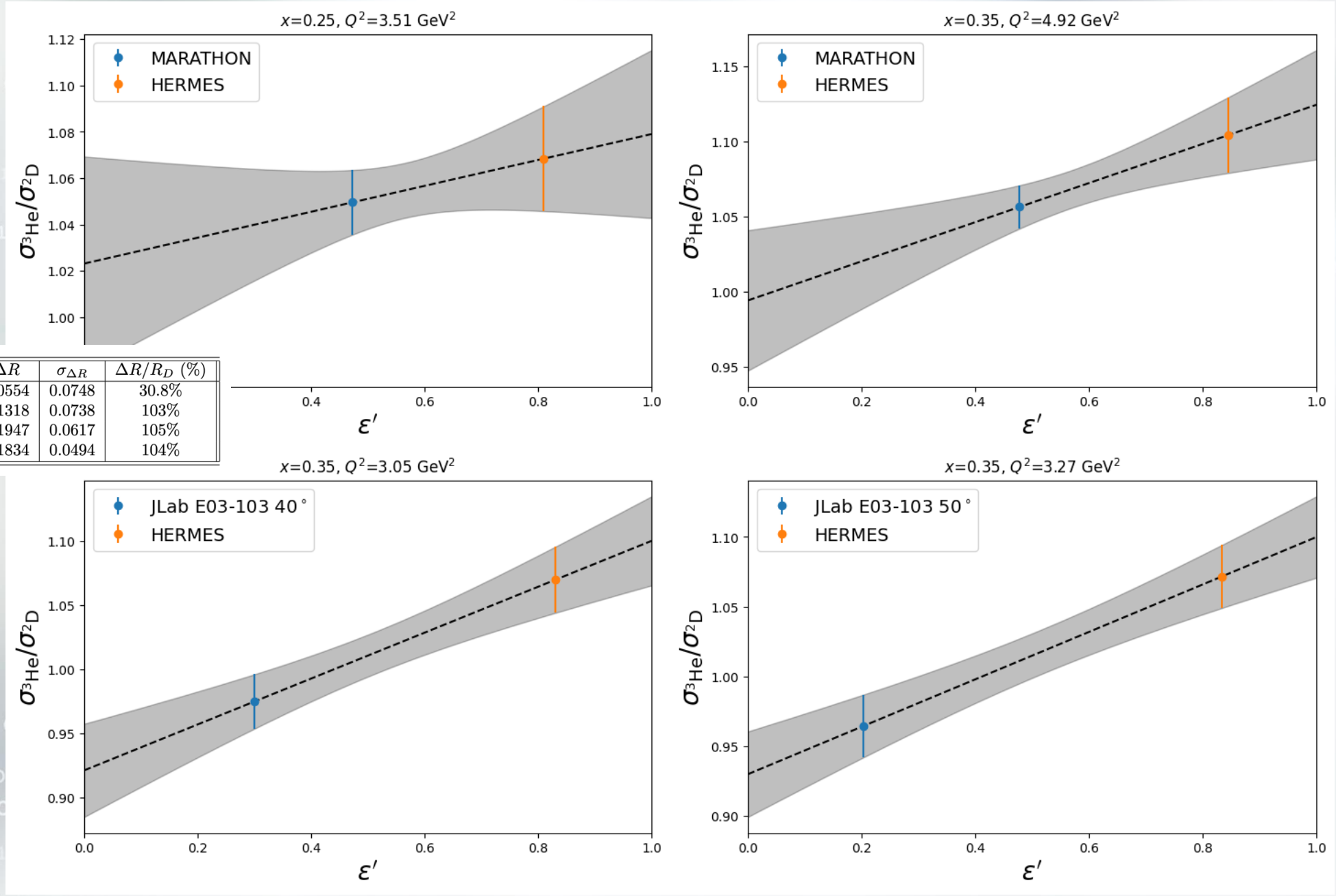
$\Delta R = R_{He3} - R_D$

Data used:

- HERMES
  - Data tables include finely binned in Q^2 which allowed matching with JLab measurements
  - Data reported with 0.9% normalization to match Helium-4 data. This has been removed
  - Data reported isoscalar corrected, removed with cited NMC extraction
- JLab E03-103
  - 6 GeV data in Hall C
- MARATHON
  - Model dependent 2.1% normalization removed

$\Delta R = R_{He3} - R_D$

Data Sets	x	Q^2	ΔR	$\sigma_{\Delta R}$	$\Delta R/R_D$ (%)
HERMES + MARATHON	0.25	3.51	0.0554	0.0748	30.8%
HERMES + MARATHON	0.35	4.92	0.1318	0.0738	103%
HERMES + E03-103	0.35	3.0456	0.1947	0.0617	105%
HERMES + E03-103	0.35	3.2663	0.1834	0.0494	104%



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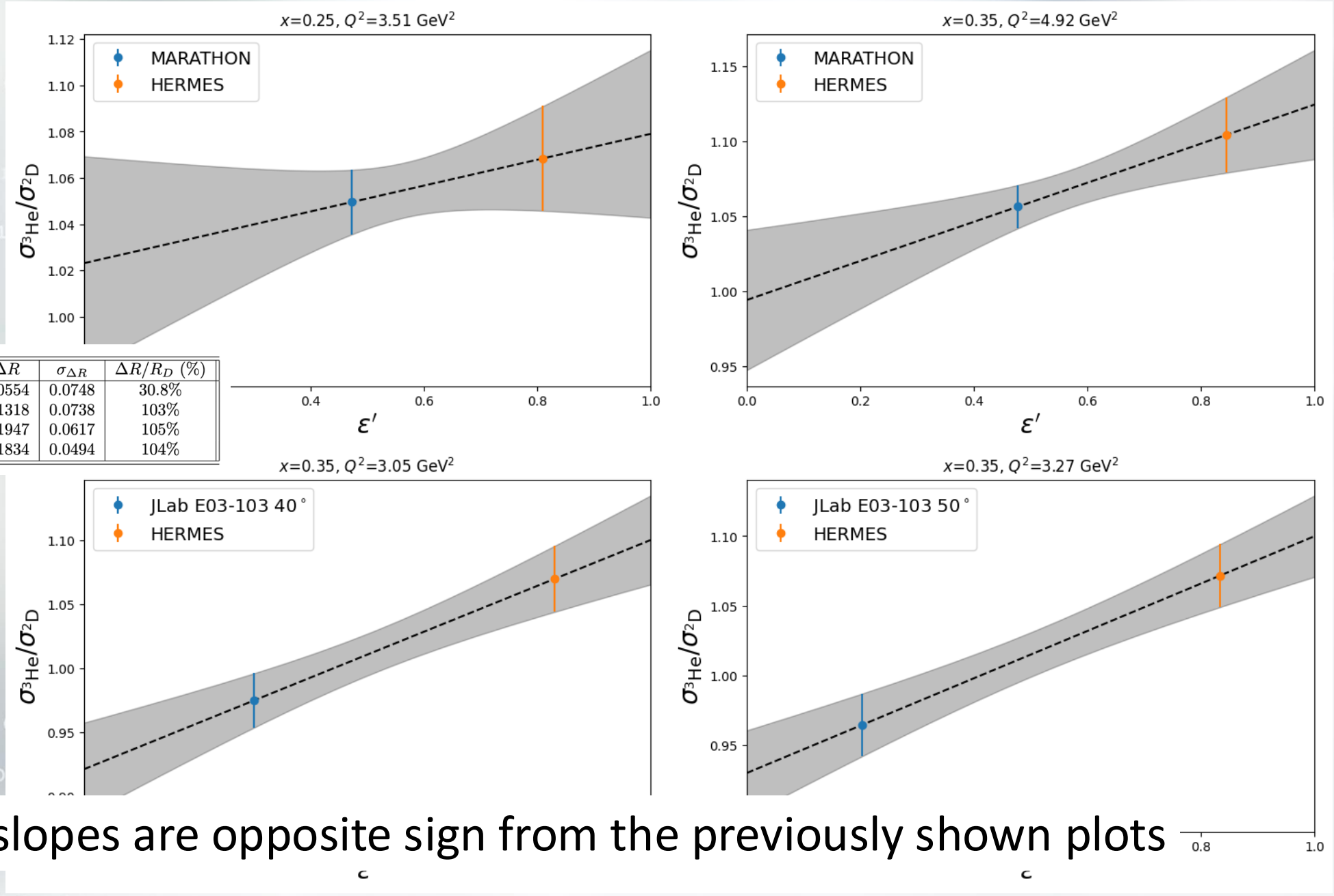

The slopes are opposite sign from the previously shown plots

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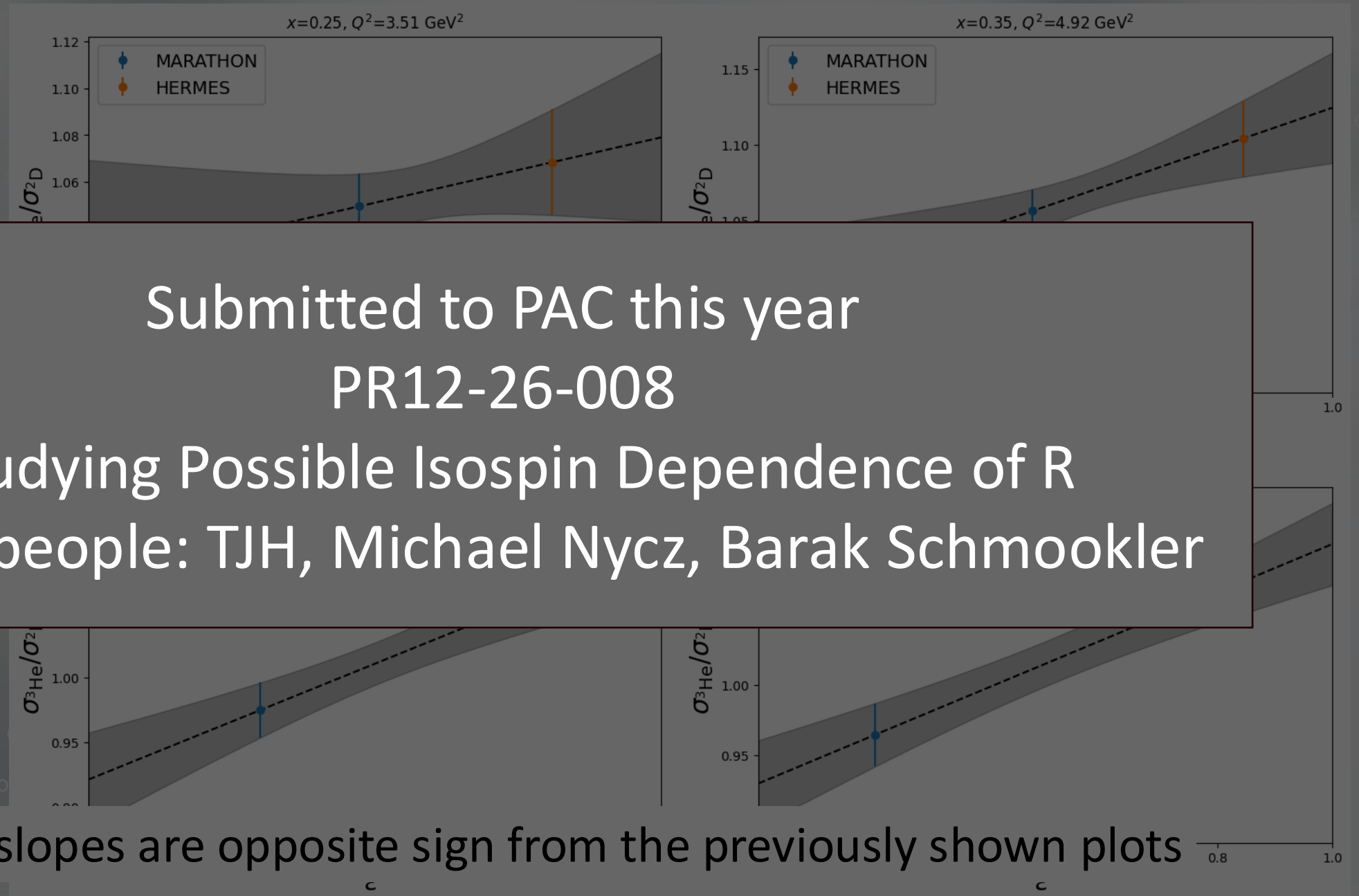
$\Delta R = R_{He3} - R_D$



Submitted to PAC this year

PR12-26-008

Studying Possible Isospin Dependence of R

Spokespeople: TJH, Michael Nycz, Barak Schmookler

The slopes are opposite sign from the previously shown plots

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QUESTIONS?

U.S. Department of ENERGY