UNDERSTANDING THE EMC-SRC CONNECTION USING EXPERIMENTAL DATA

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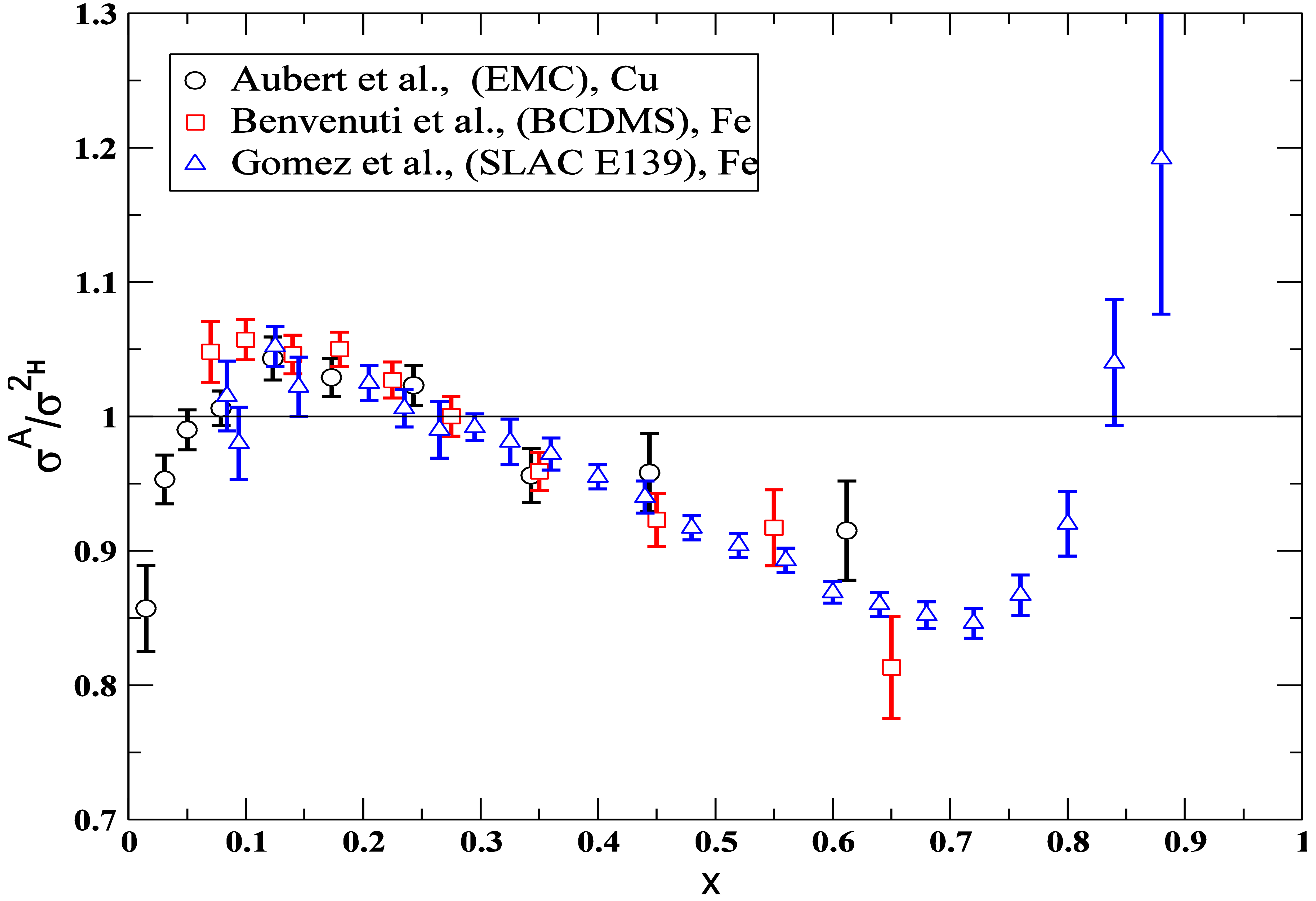
in collaboration with John Arrington and Nadia Fomin

Short-Distance Nuclear Structure and PDFs

20 July 2023 - Trento, Italy

NON-TRIVIAL STRUCTURE OF THE NUCLEUS

THE EMC EFFECT

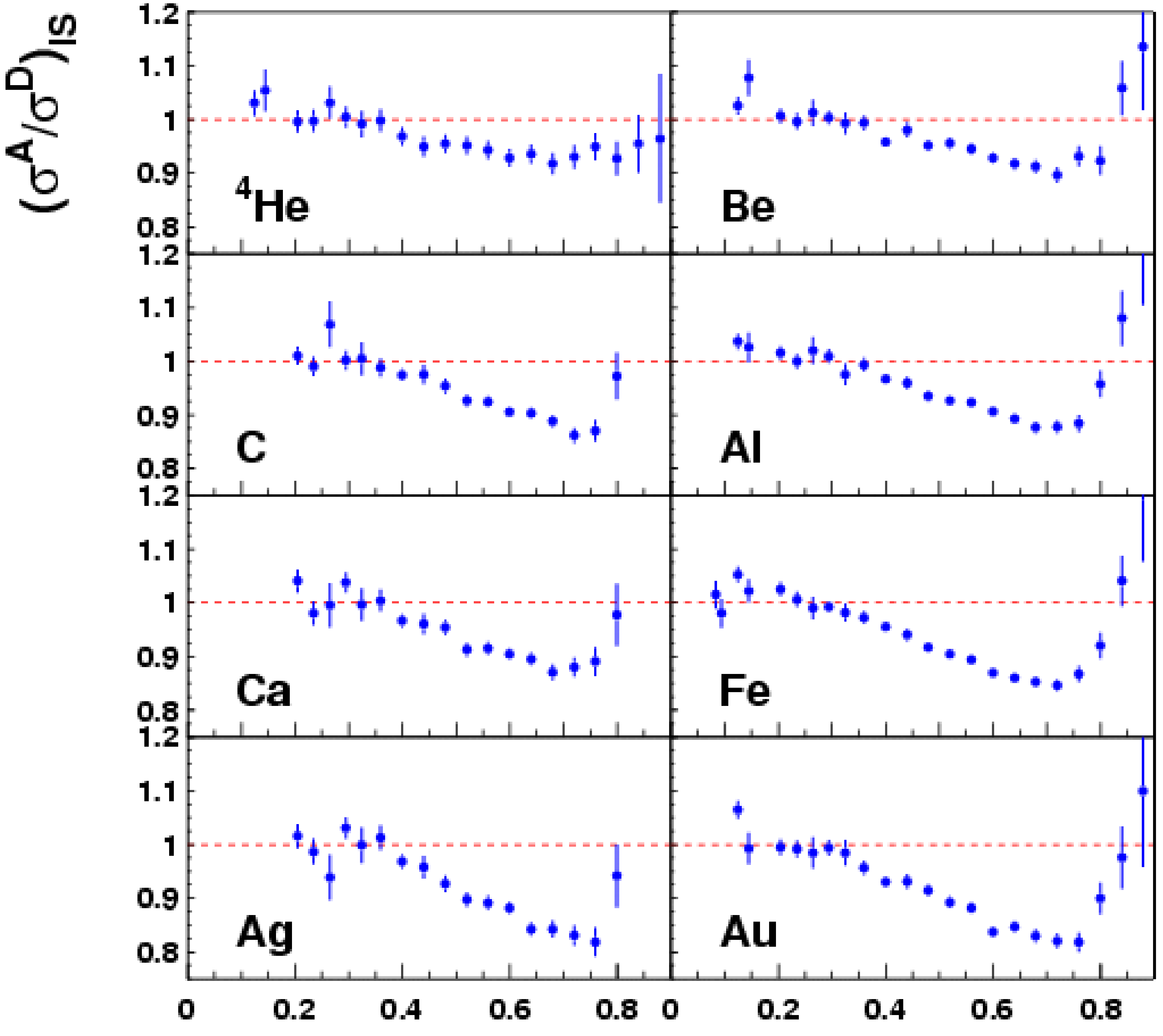


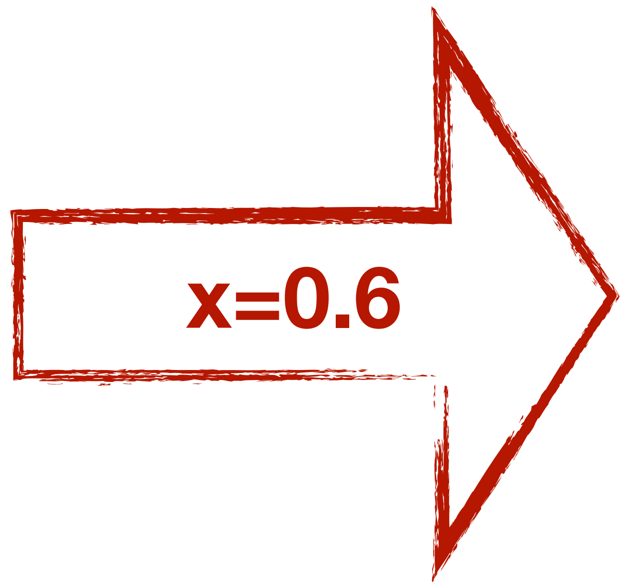
- Initial observation: per-nucleon DIS structure function for Iron significantly different than that of for deuterium. Confirmed for the several other nuclei.
- Suppression of the high momentum quarks for 0.3<x<0.7 in nuclei relative to the deuterium.
- After 40 years, no definitive explanation for the origin of the EMC effect.

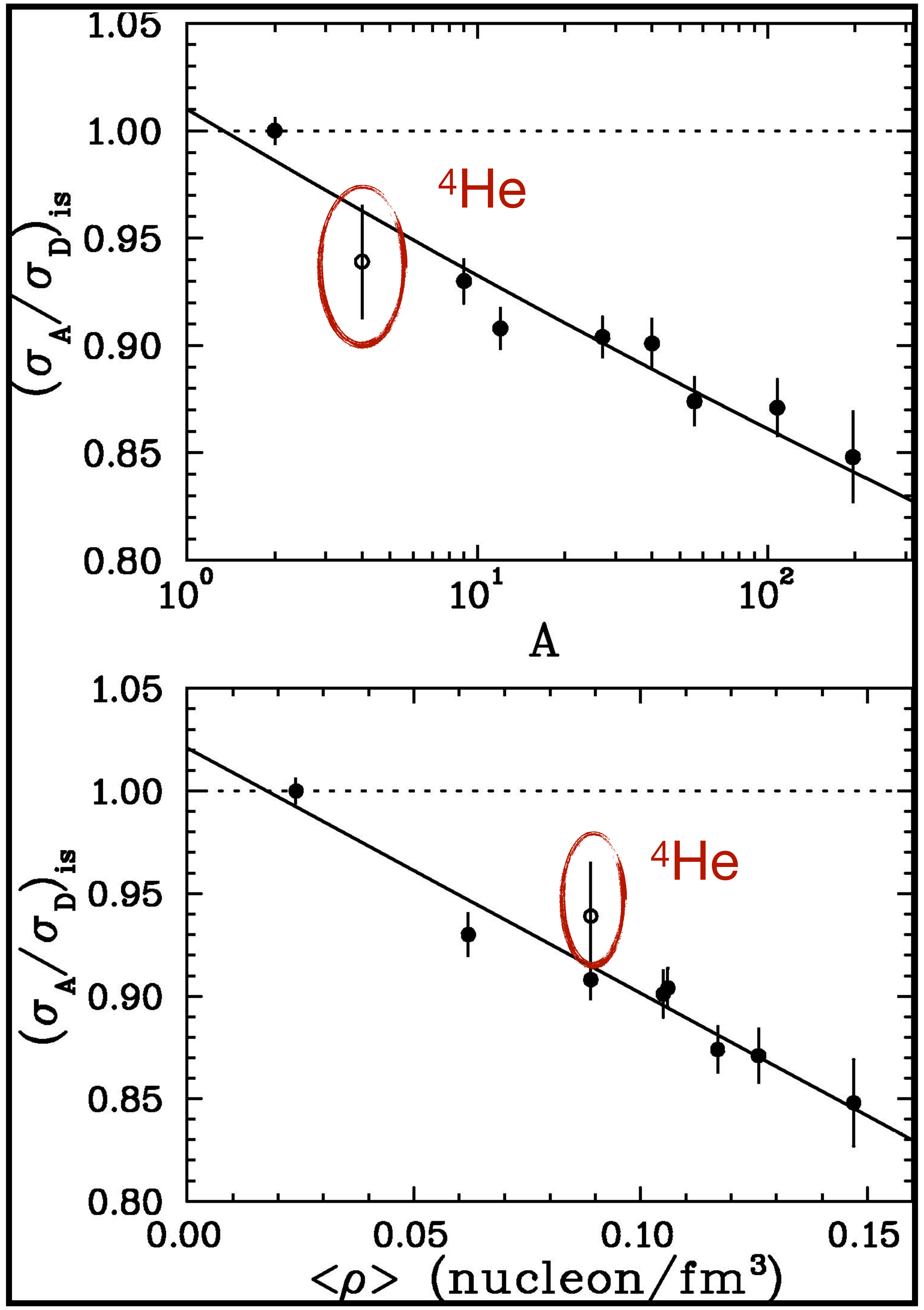
THE EMC EFFECT: DATA STATUS

- SLAC E139:

"Nuclear Dependence of the EMC Effect at Fixed x"

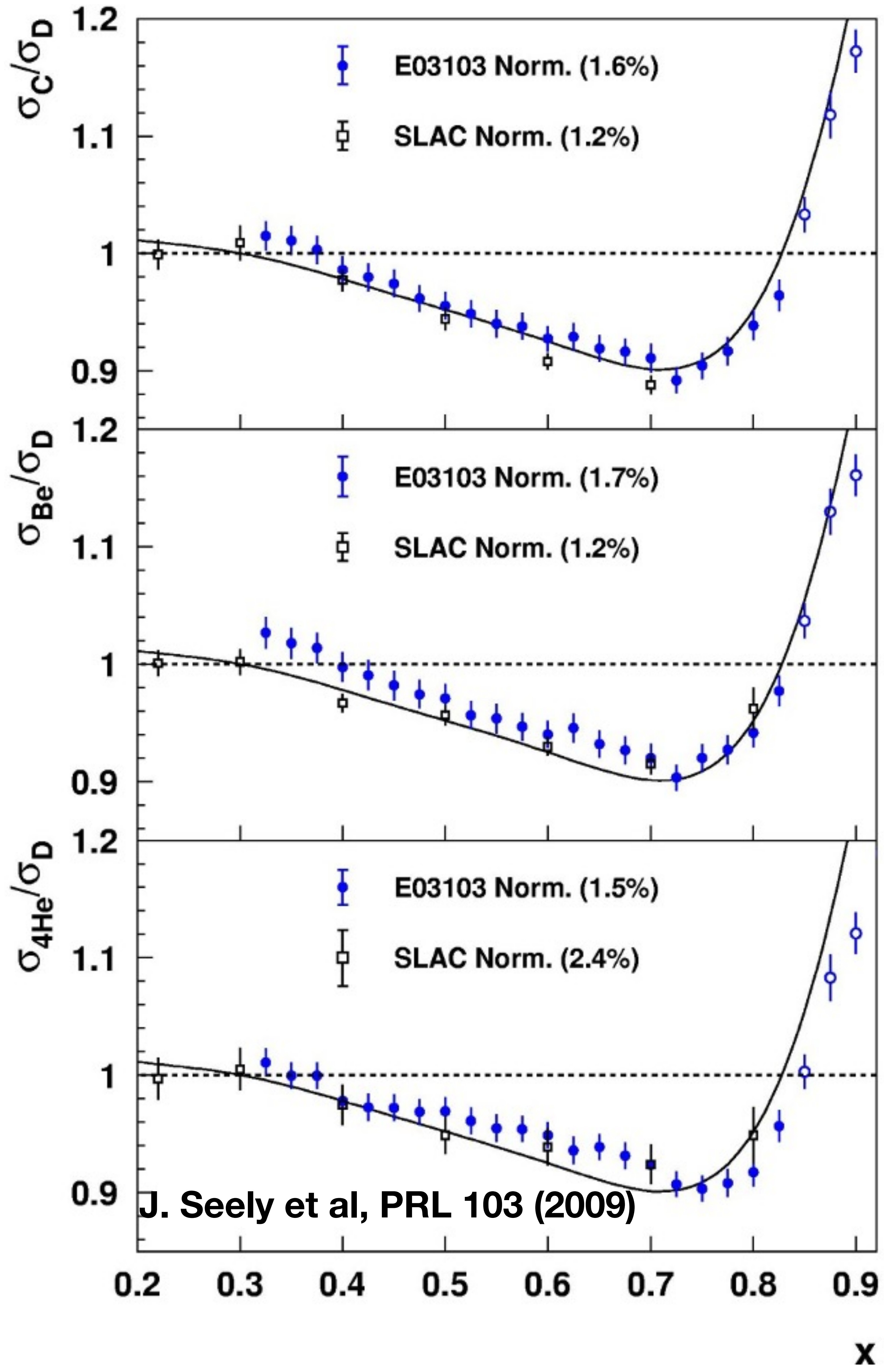






- Universal x-dependence for all the nuclei measured
- Modification scales with log(A) and average density

THE EMC EFFECT: JLab E03-103 RESULTS



Hall C E03-103: Precision Results on Light Nuclei

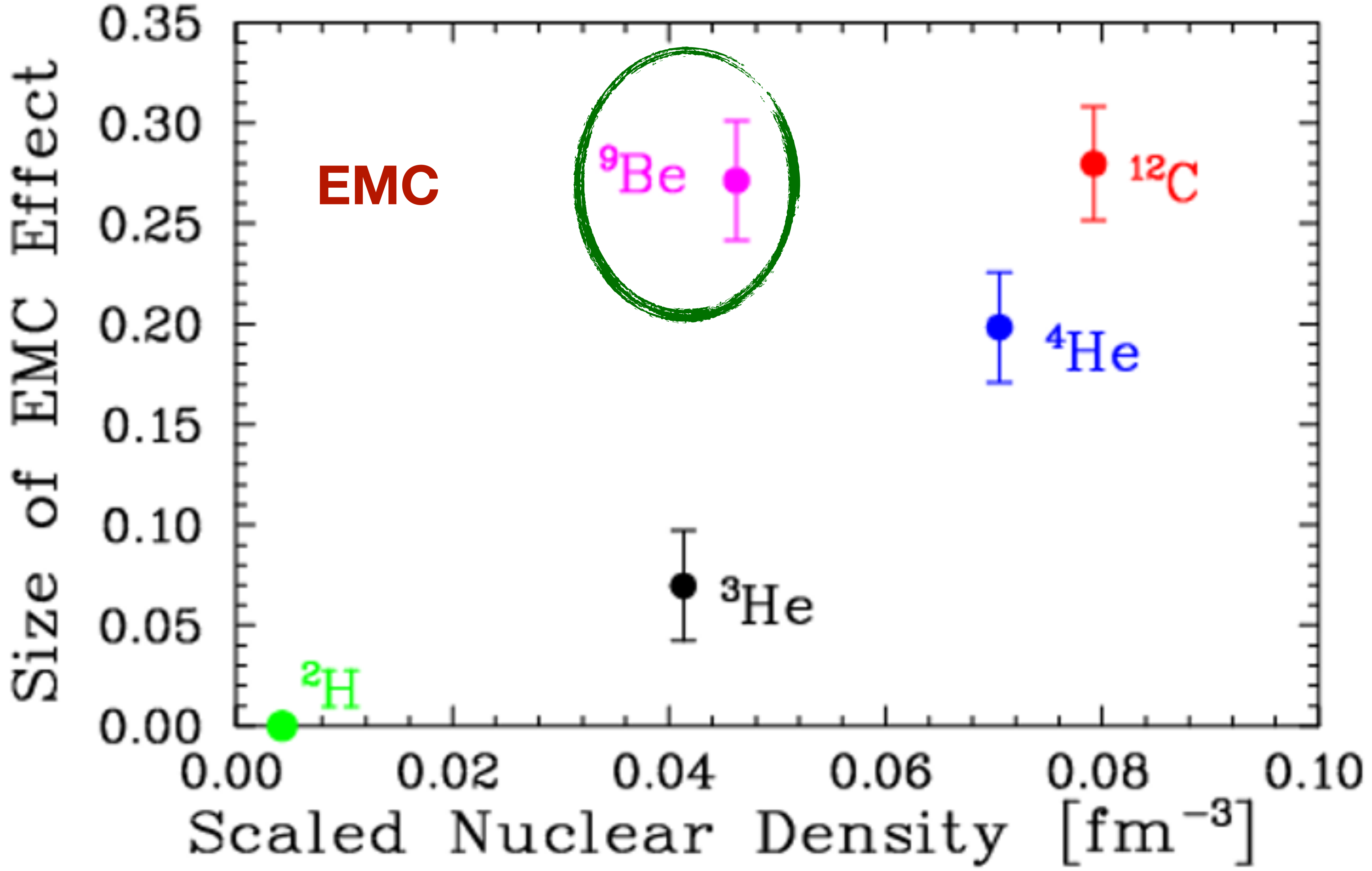
- Emphasis on light nuclei (4He, 9Be, 12C)
- Confirms the SLAC results
- Much better precision at high x
- Improved ^{4}He statistics
- Additional light nuclei measurement with ^{3}He

THE EMC EFFECT: JLab E03-103 RESULTS

^{9}Be does not fit the trend!

Hall C E03-103: Precision Results on Light Nuclei

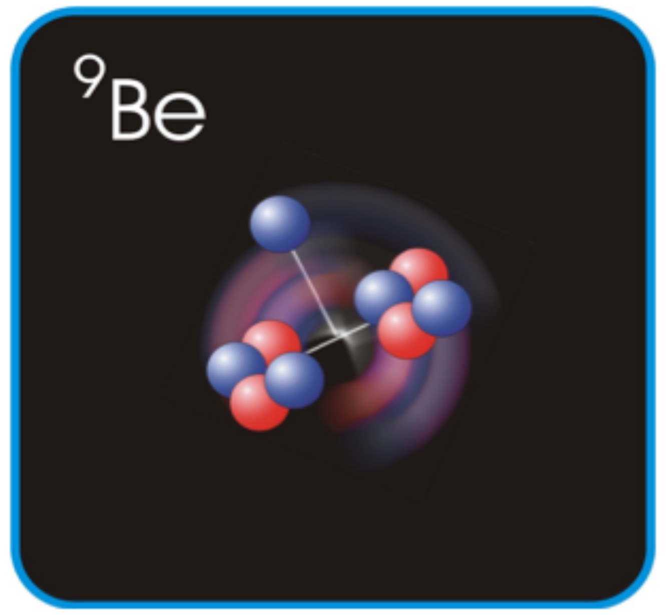
J. Seely et al, PRL 103

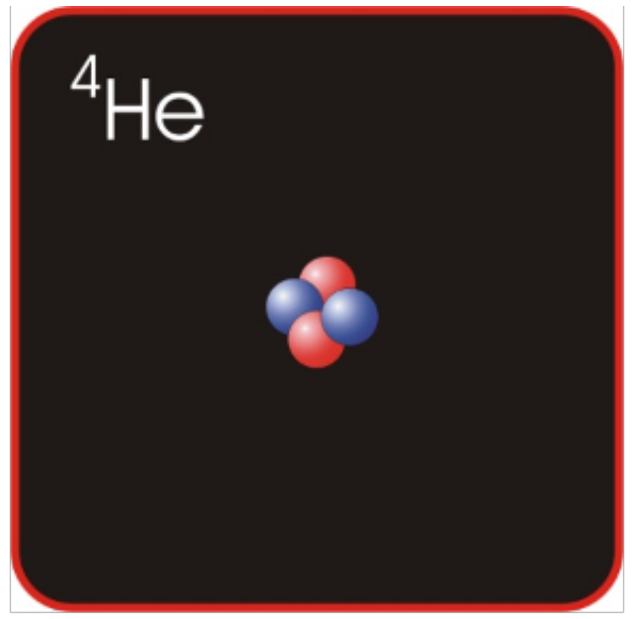


Density determined from *ab initio* few-body calculation
S.C. Pieper and R.B. Wiringa, Ann. Rev. Nucl. Part. Sci 51, 53 (2001)

^{9}Be → **strong alpha clustering**

3 body system of **2 alpha clusters** and **a neutron**

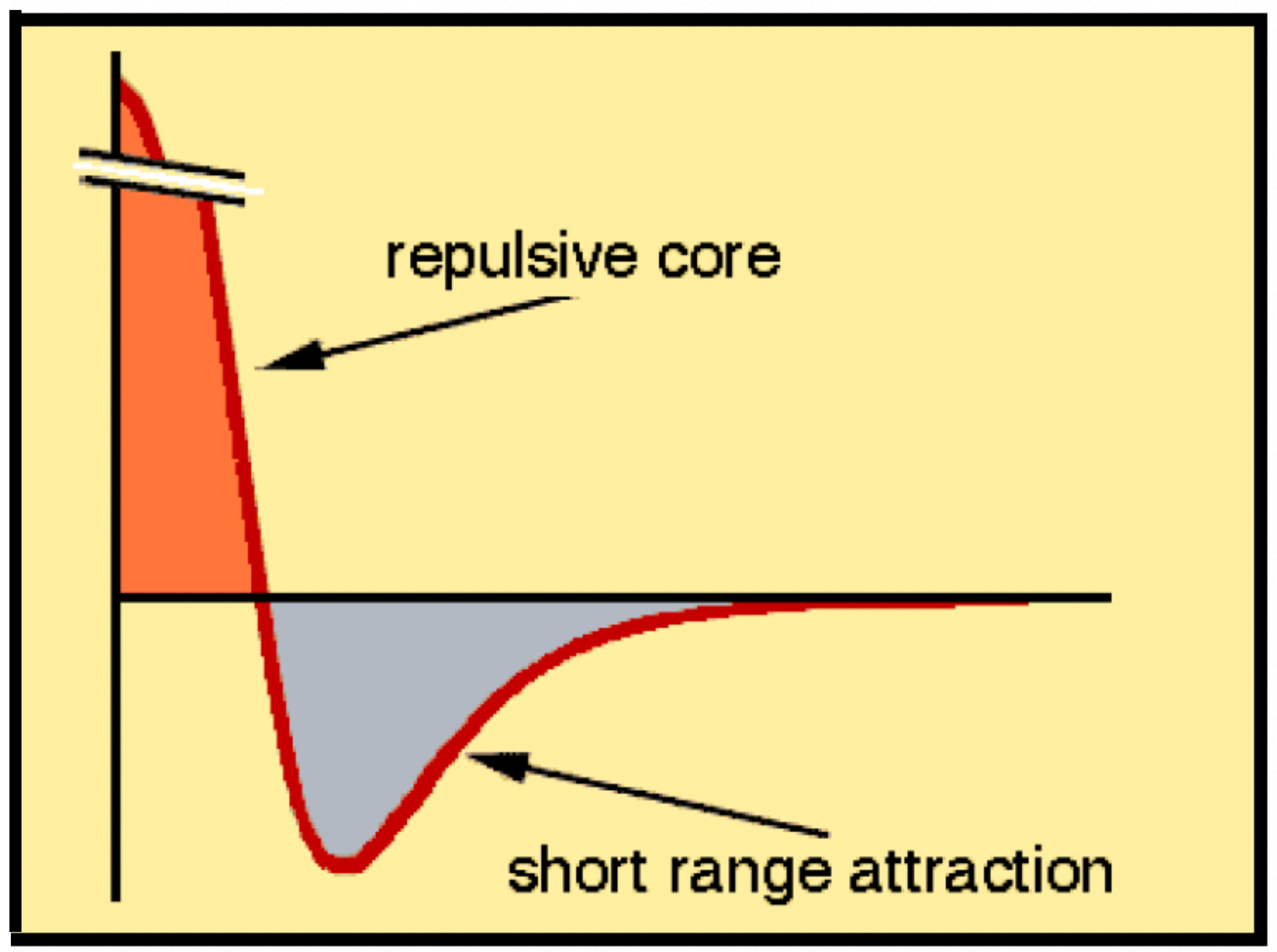


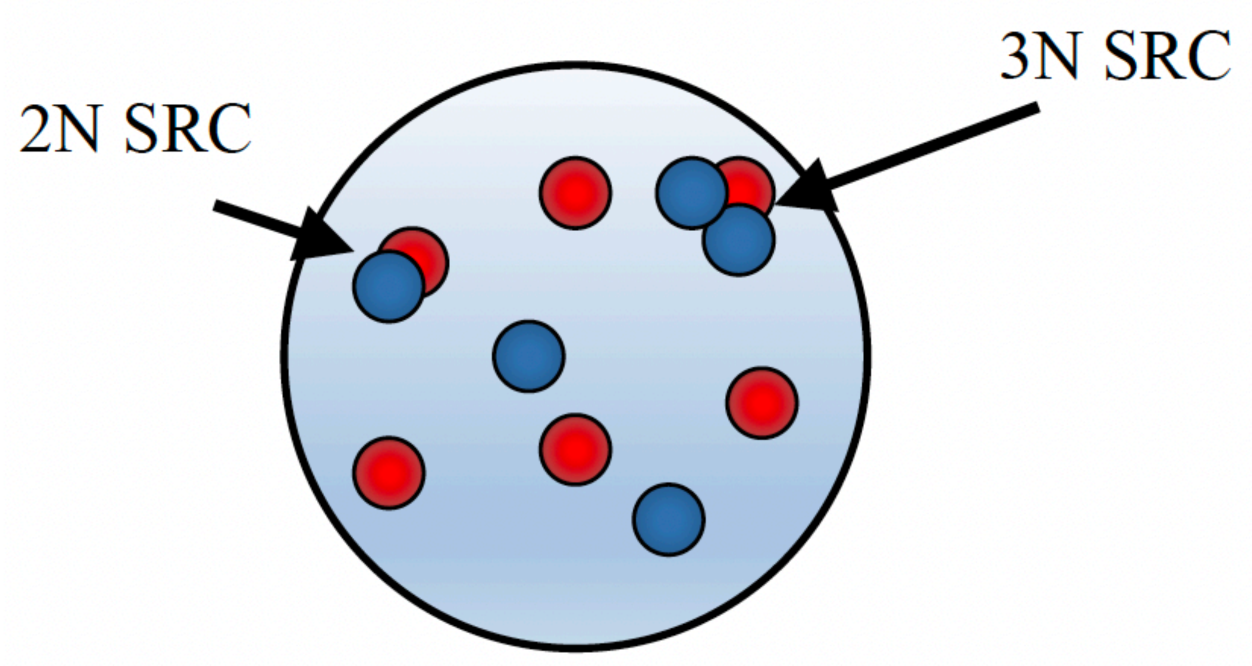


EMC effect seems to follow local density rather than average density!

**average nuclear density was scaled by a factor of (A-1)/A to remove the struck nucleon's contribution to the average nuclear density*

LOCAL DENSITY → SHORT RANGE CORRELATIONS





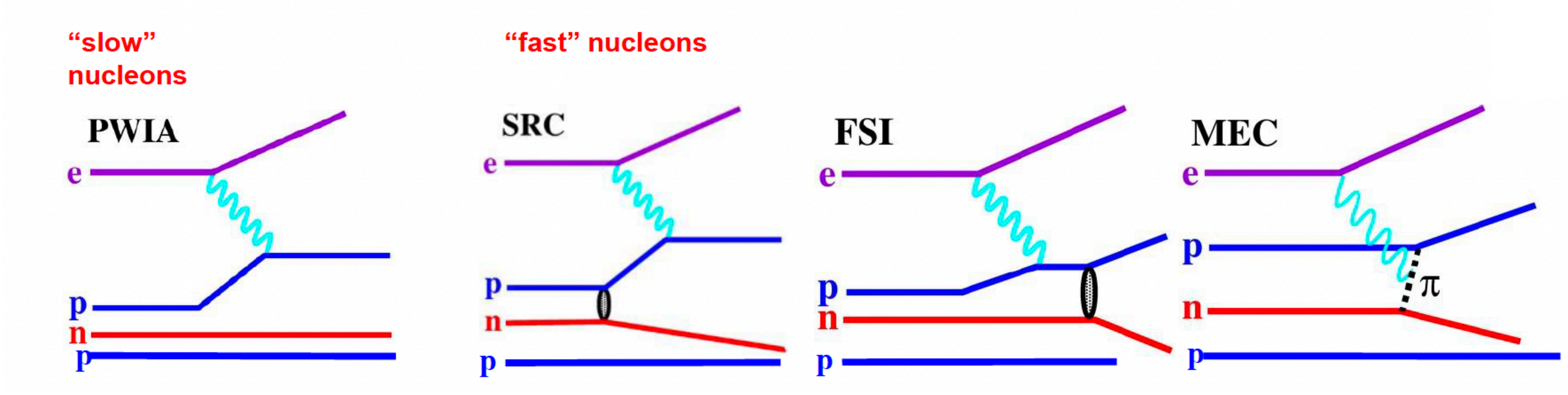
What drives high local density in the nucleus?

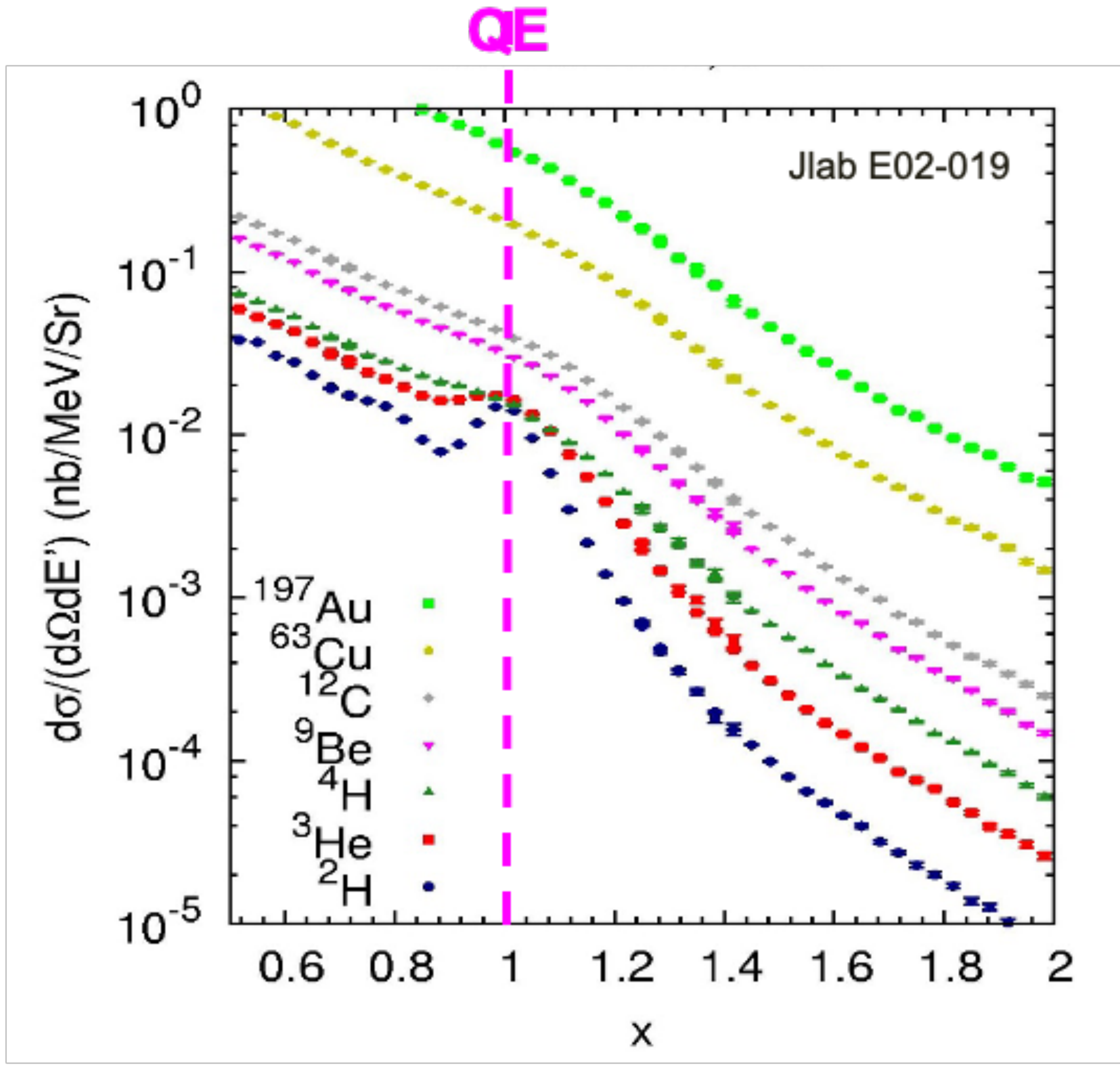
The short-distance part of the nucleon-nucleon interaction:

- **A hard short-range repulsive core + strong intermediate-range tensor attraction**
- These strong interactions between nucleons at short distance yield **high-momentum components in the nucleon momentum distributions in nuclei**
- **Pairs of nucleons with high back to back momenta: short range correlations**

MEASURING THE SHORT RANGE CORRELATIONS

- ➡ To measure the relative probability of finding a correlation, ratios of heavy to light nuclei are taken
- ➡ To experimentally probe SRCs, must be in the high-momentum region (x>1): QE scattering
- ➡ If the high momentum nucleons in nuclei come from correlated pairs, ratio of A/D should show a plateau.
- ➡ FSIs are thought to be confined to the SRCs so cancel in the cross section ratios

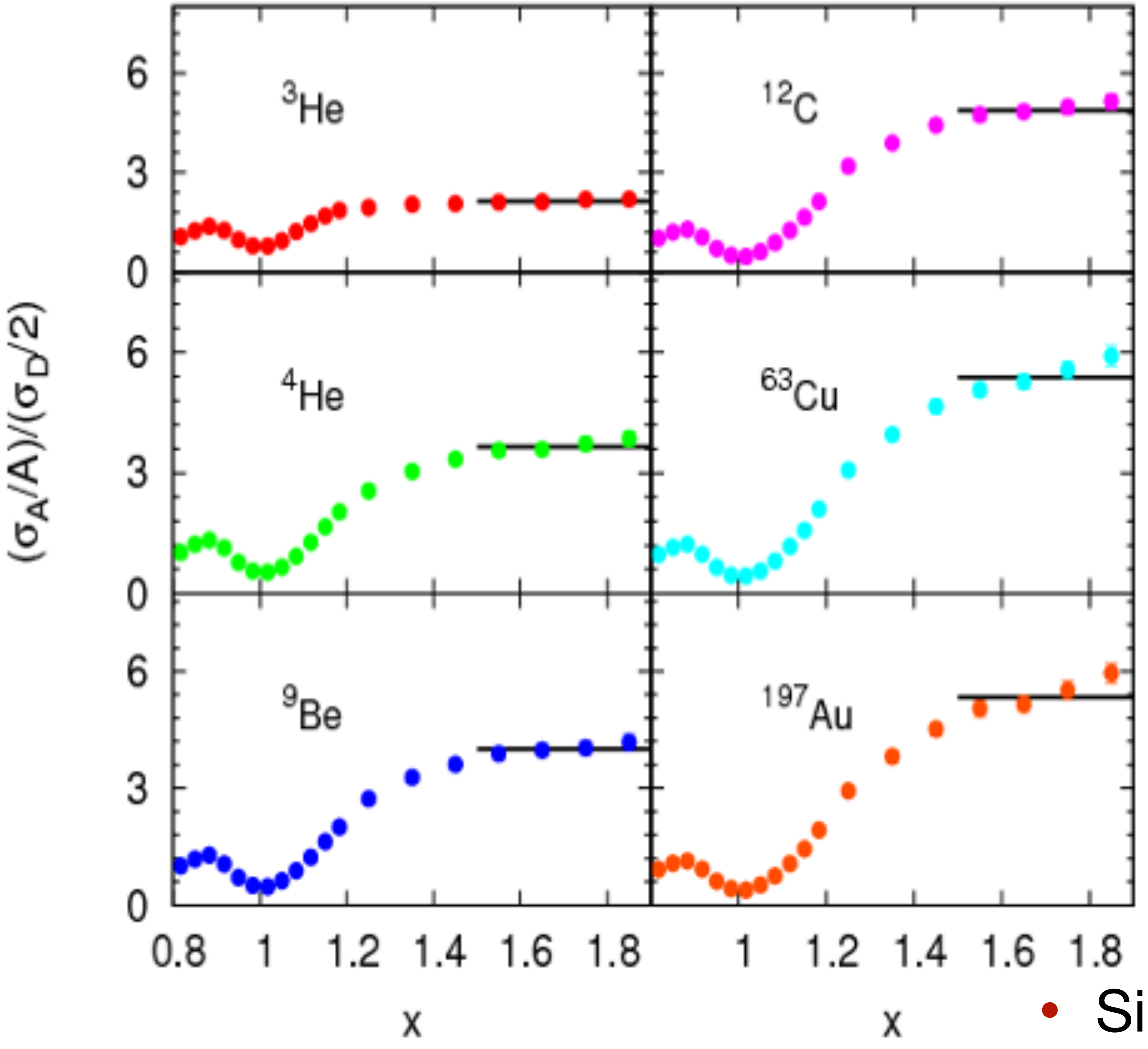


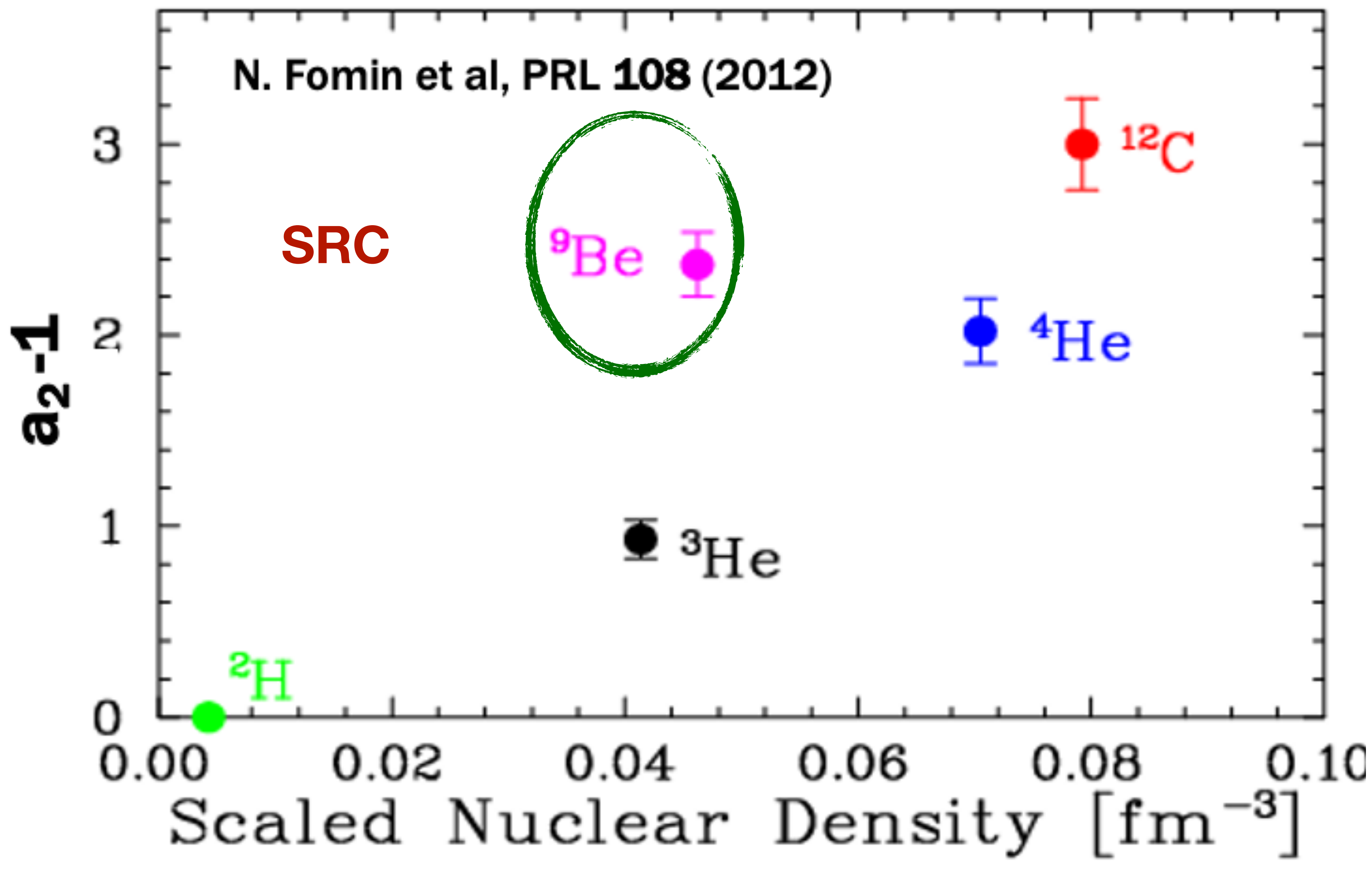


$$\frac{2}{A}\frac{\sigma_A}{\sigma_D} = a_2(A)$$

JLab HALL C 6 GeV 2N SRC RESULTS

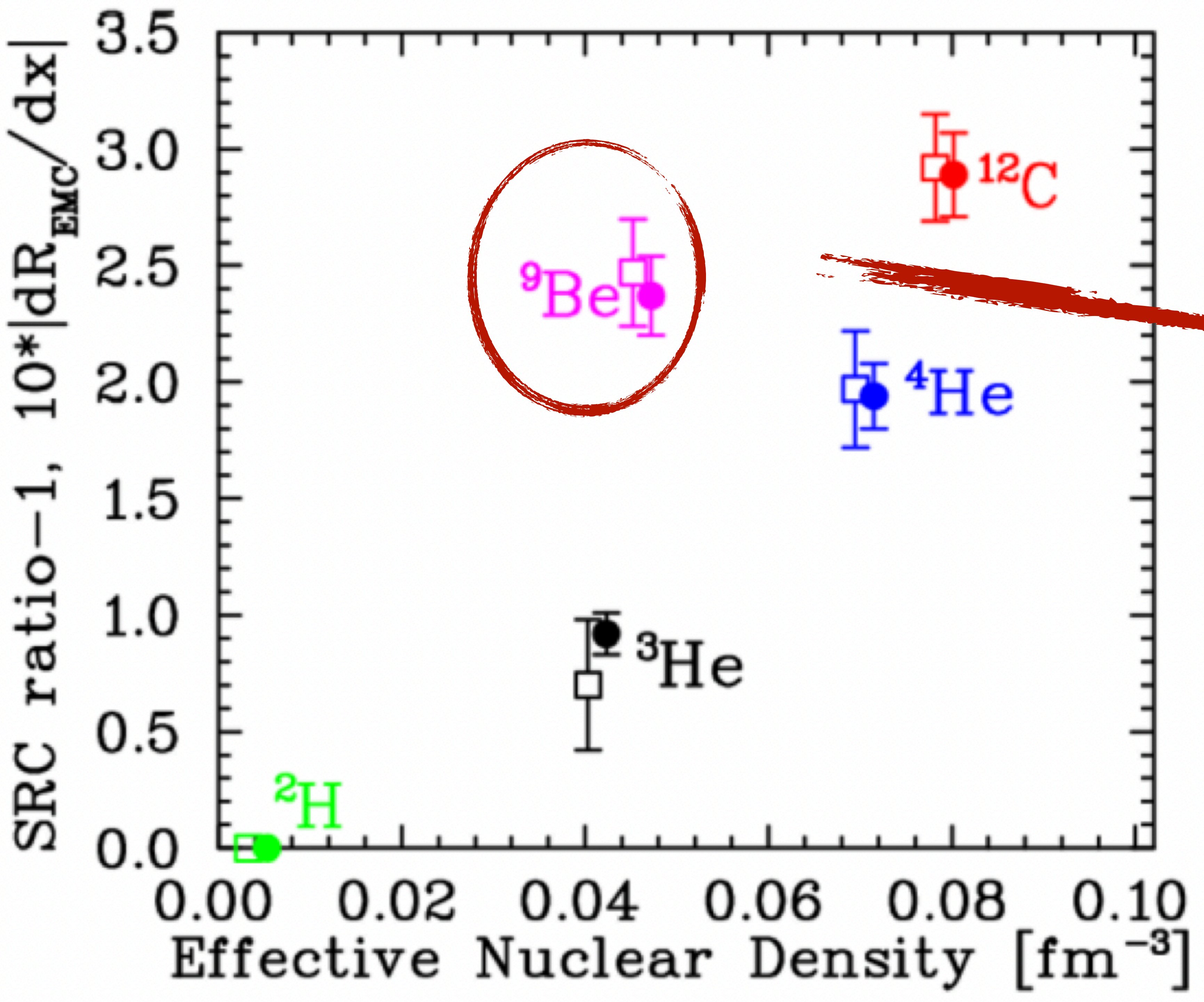
Hall C E02-019: Precision Results on Light Nuclei





- Similar pattern with the SRC measurements in light nuclei
- Suggesting a possible connection between the EMC and SRC?

EMC-SRC CORRELATION

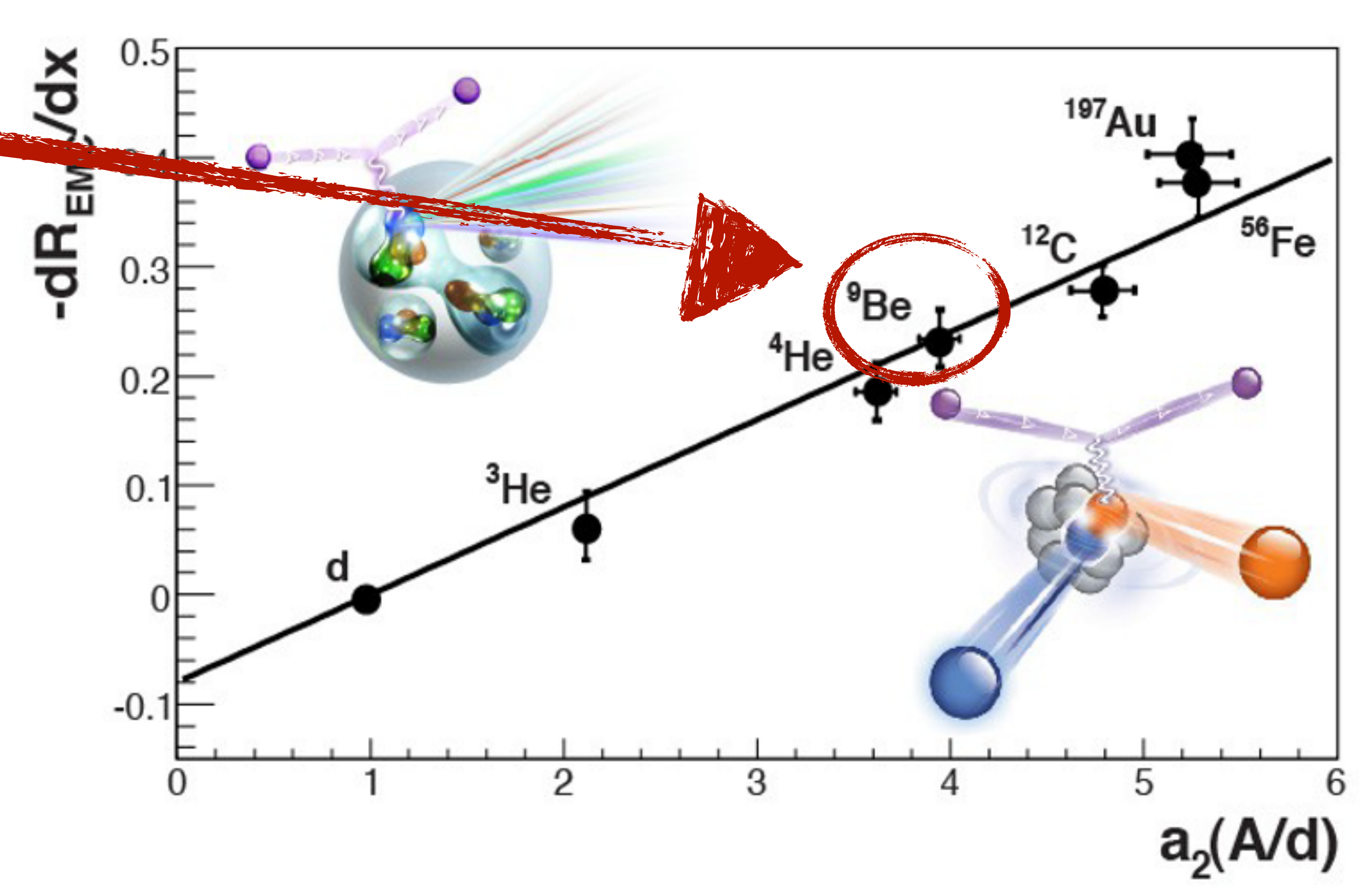


J. Seely, et al., PRL103, 202301 (2009)

N. Fomin, et al., PRL 108, 092052 (2012)

JA, A. Daniel, D. Day, N. Fomin, D. Gaskell, P. Solvignon, PRC 86, 065204 (2012)

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



O. Hen, et al, PRC 85, 047301 (2012)

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

9Be strengthens the case!

Quantitative test of level of correlation between two effects

EMC-SRC CORRELATION

High Virtuality (HV)Model

- Ø EMC effect is a result of high-momentum nucleons (off-shell effects in highly-virtual nucleons).
- Ø Only np pairs contribute to the EMC effect.
- Ø np pair contribution yields an isospin-dependent effect in non-isoscalar nuclei.

B. Schmookler et al, Nature 566, 2019

Local Density (LD) Model

- Ø Nucleons in close-proximity through quark exchange results in the EMC effect.
- Ø EMC effect is assumed to be isospin independent.
- Ø All short-distance N-N configurations contribute.

J. Arrington, N. Fomin, PRL 123, 2019

Flavor Dependence in Nuclear Behavior ?

- The dominance of the *np* pairs suggests the absolute contribution of the high momentum proton and neutrons in nuclei is nearly identical
- A different fractional contribution from the high momentum proton and neutrons in non-isoscalar nuclei

A larger fraction of the protons in neutron-rich nuclei has high momenta

↓

excess EMC Effect for the proton

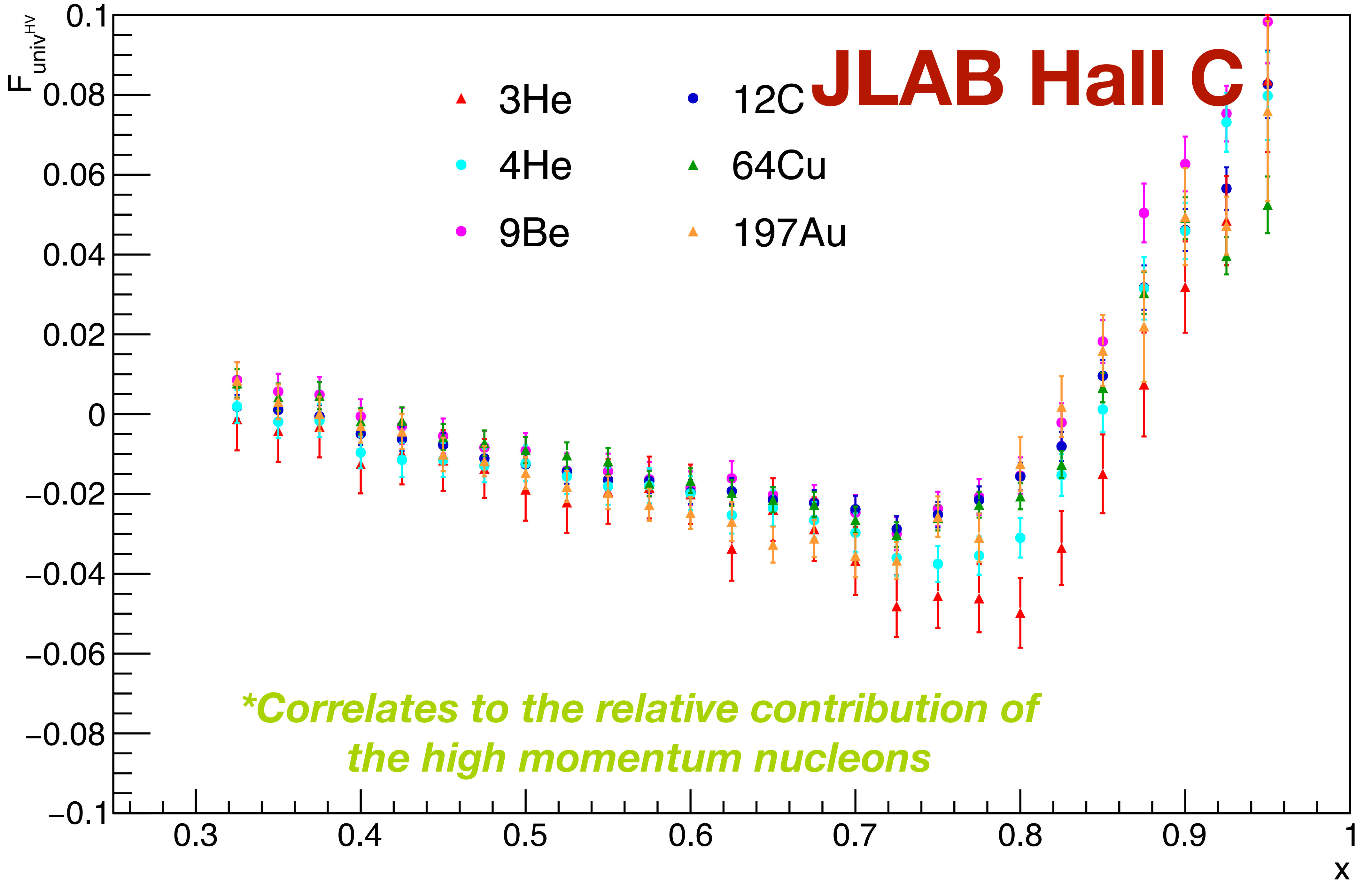
↓

flavor dependence: up quarks showing larger modification than the down quarks

UNIVERSAL EMC EFFECT FUNCTIONS

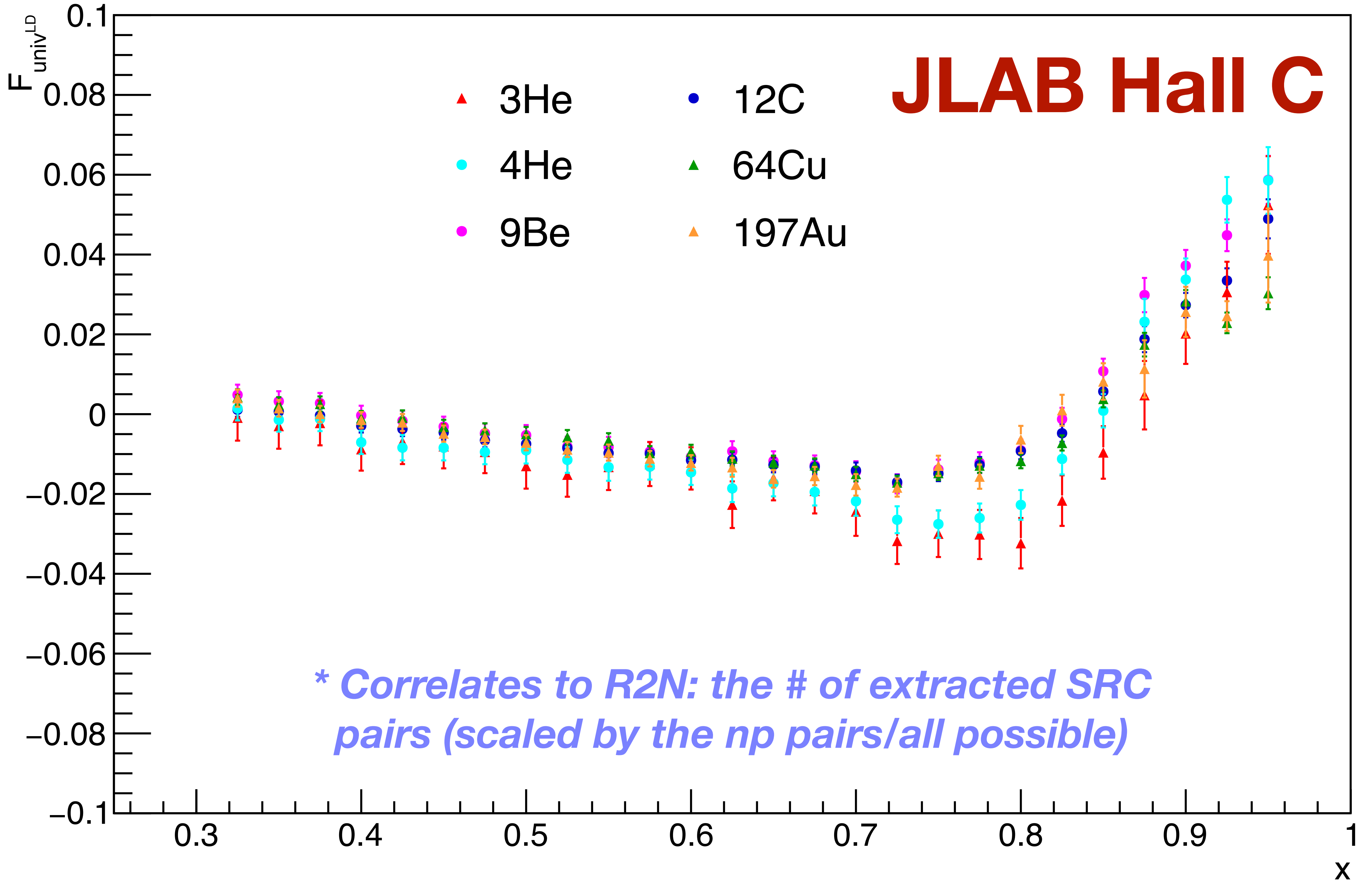
Universal EMC Effect Function via HV Model

$$F^{HV}_{univ} = \frac{(\sigma_A/\sigma_D) - (Z-N)\frac{F_2^p}{F_2^d} - N}{(A/2)a_2 - N}$$



Universal EMC Effect Function via LD Model

$$F^{LD}_{univ} = \frac{R_{EMC} - 1}{R_{2N}\frac{A(A-1)}{2ZN} - 1}$$

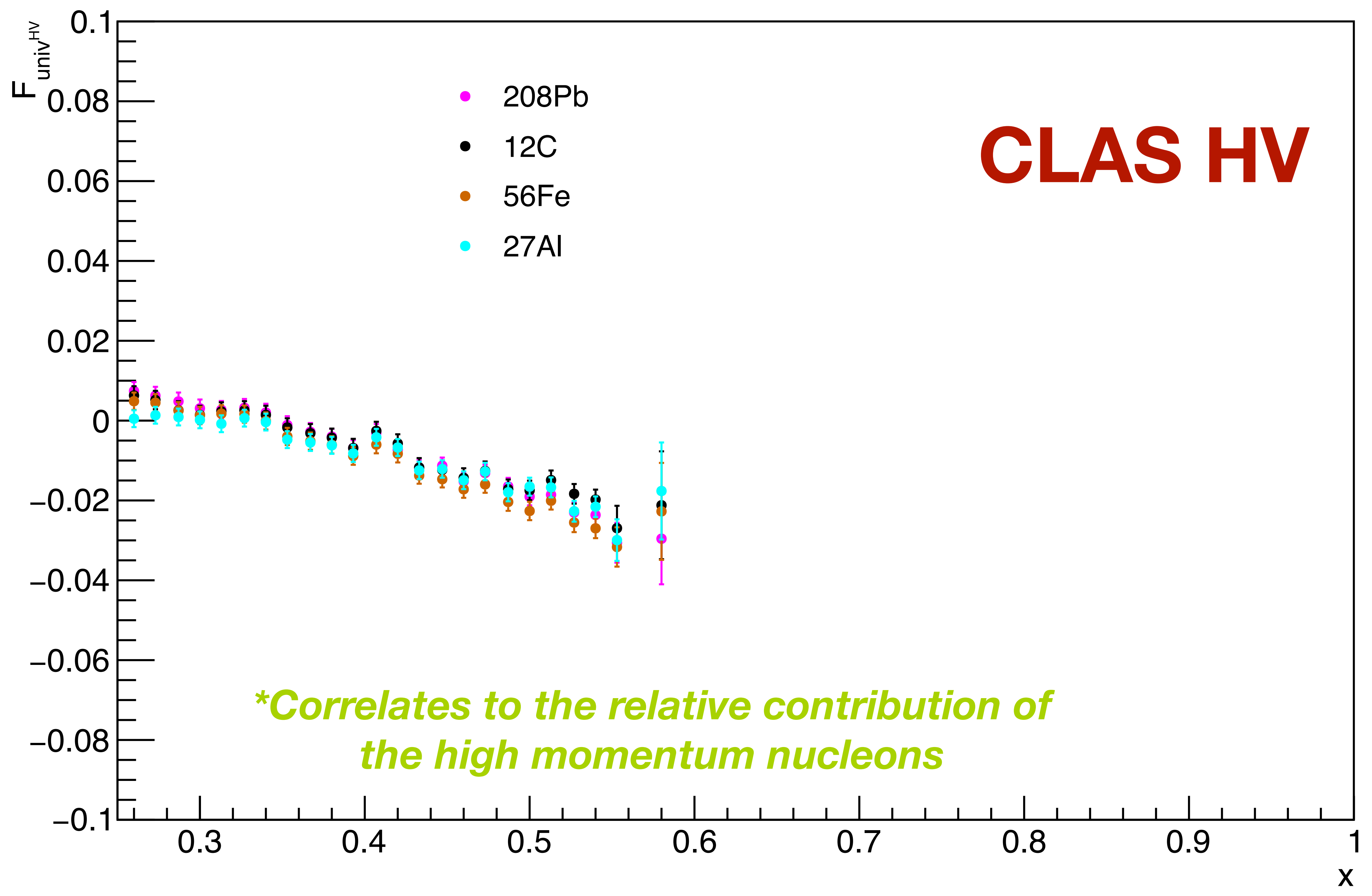


The universality of the EMC effect functions is examined by looking at the slopes for 0.3<x<0.7 as a function of A.

UNIVERSAL EMC EFFECT FUNCTIONS

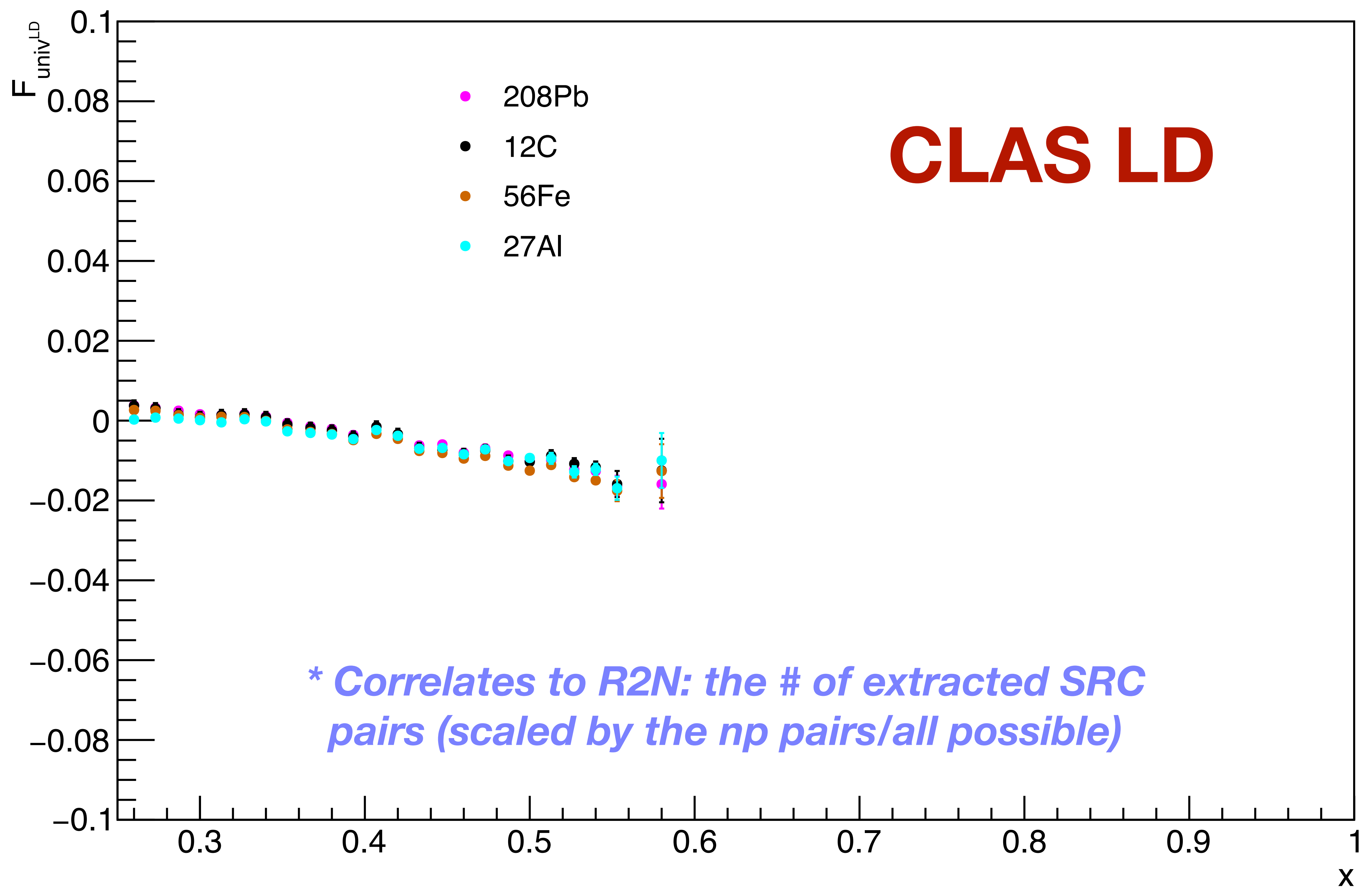
Universal EMC Effect Function via HV Model

$$F^{HV}_{univ} = \frac{(\sigma_A/\sigma_D) - (Z-N)\frac{F_2^p}{F_2^d} - N}{(A/2)a_2 - N}$$



Universal EMC Effect Function via LD Model

$$F^{LD}_{univ} = \frac{R_{EMC} - 1}{R_{2N}\frac{A(A-1)}{2ZN} - 1}$$

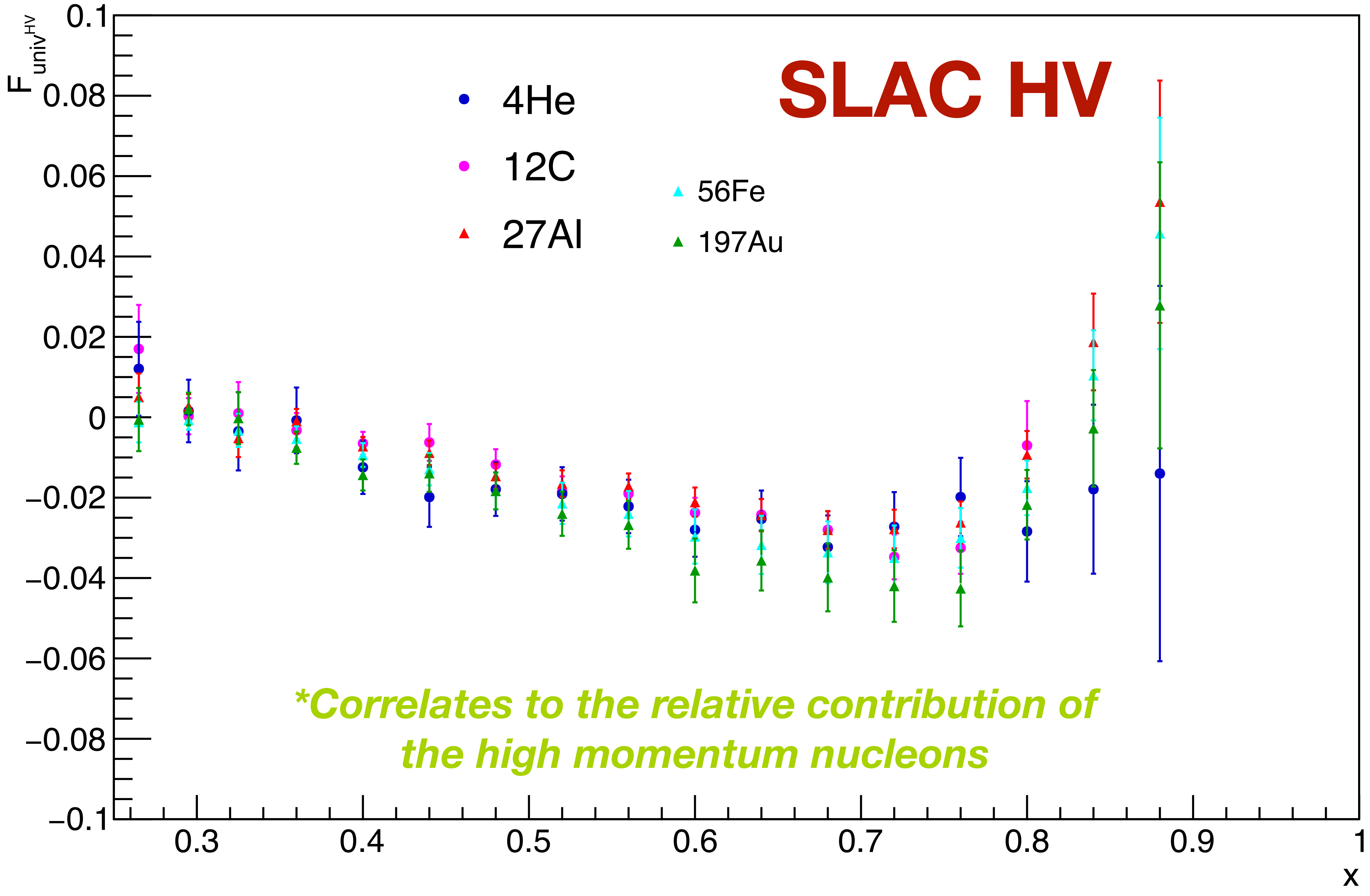


The universality of the EMC effect functions is examined by looking at the slopes for 0.3<x<0.7 as a function of A.

UNIVERSAL EMC EFFECT FUNCTIONS

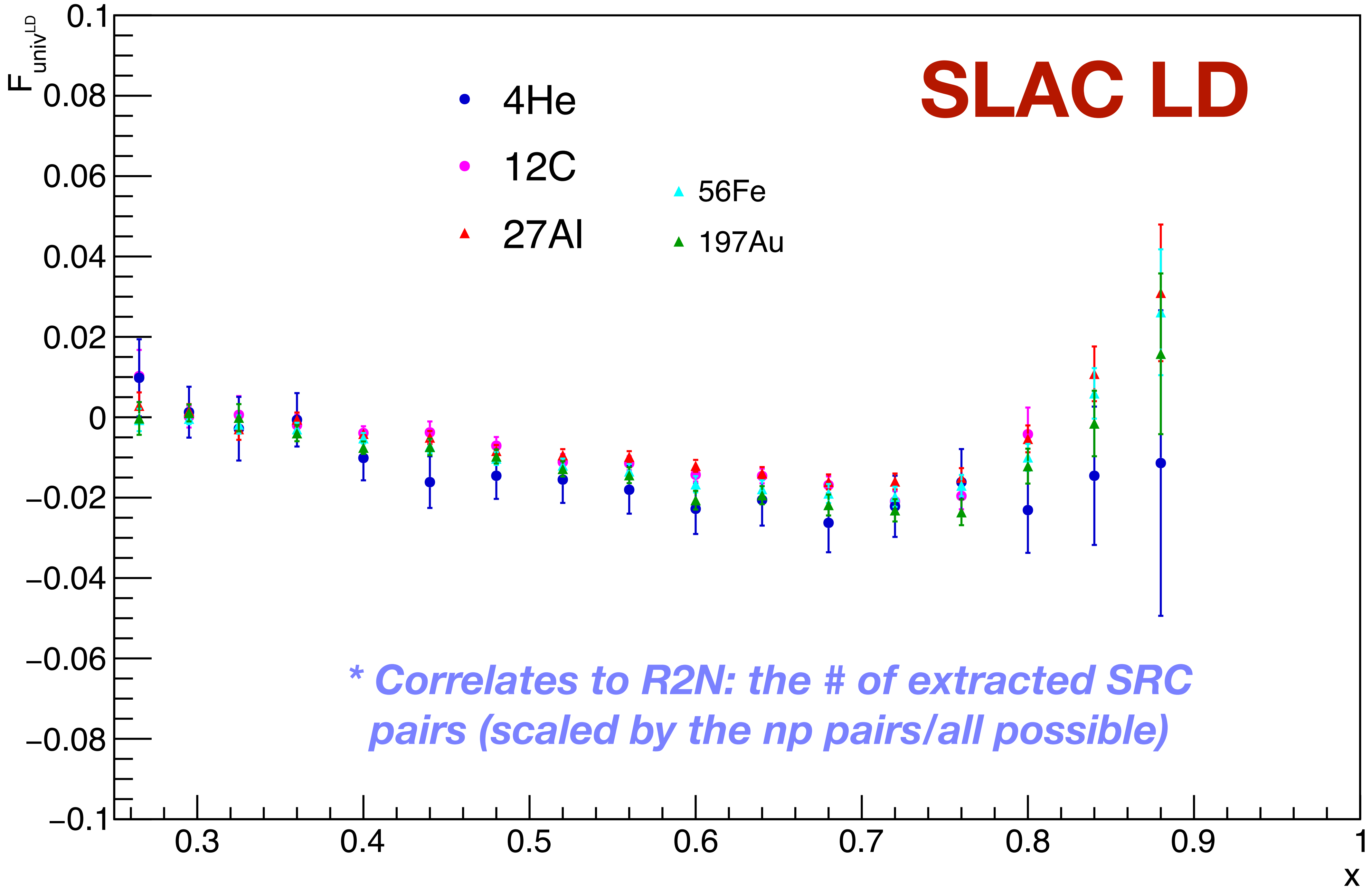
Universal EMC Effect Function via HV Model

$$F_{univ}^{HV} = \frac{(\sigma_A/\sigma_D) - (Z-N)\frac{F_2^p}{F_2^d} - N}{(A/2)a_2 - N}$$



Universal EMC Effect Function via LD Model

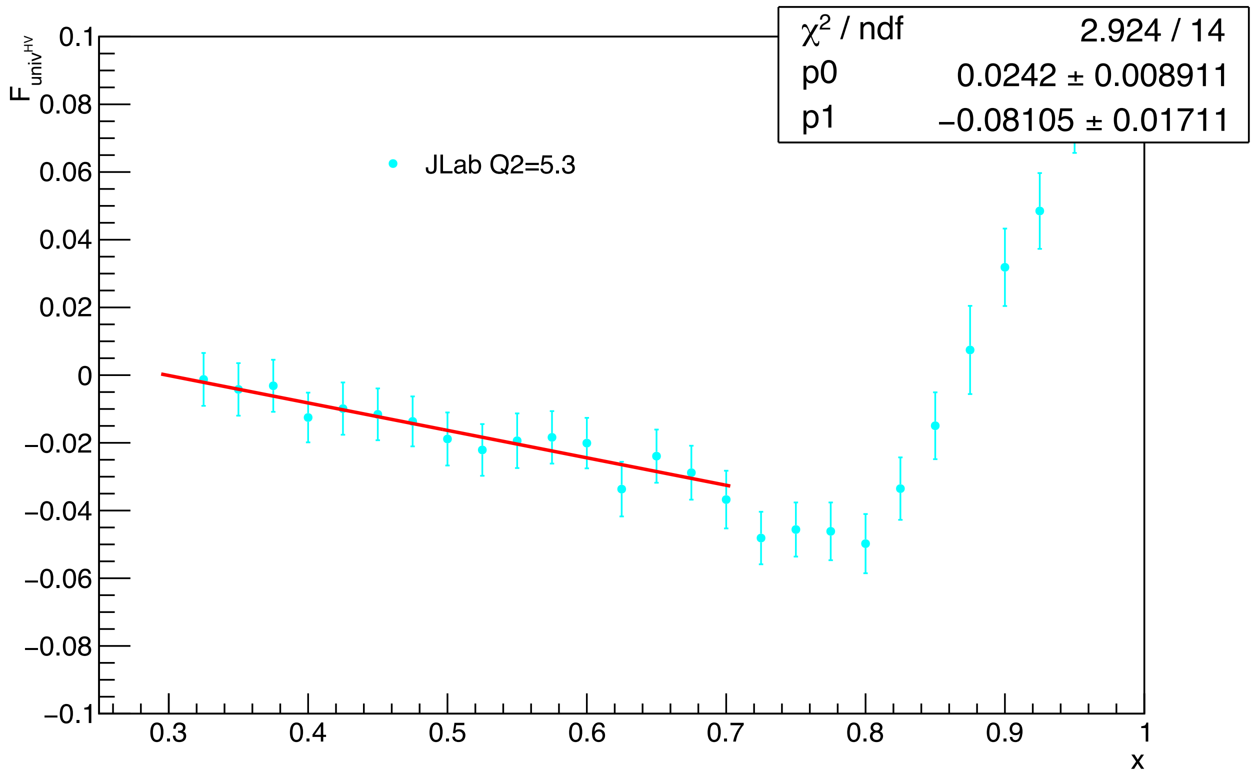
$$F_{univ}^{LD} = \frac{R_{EMC} - 1}{R_{2N}\frac{A(A-1)}{2ZN} - 1}$$



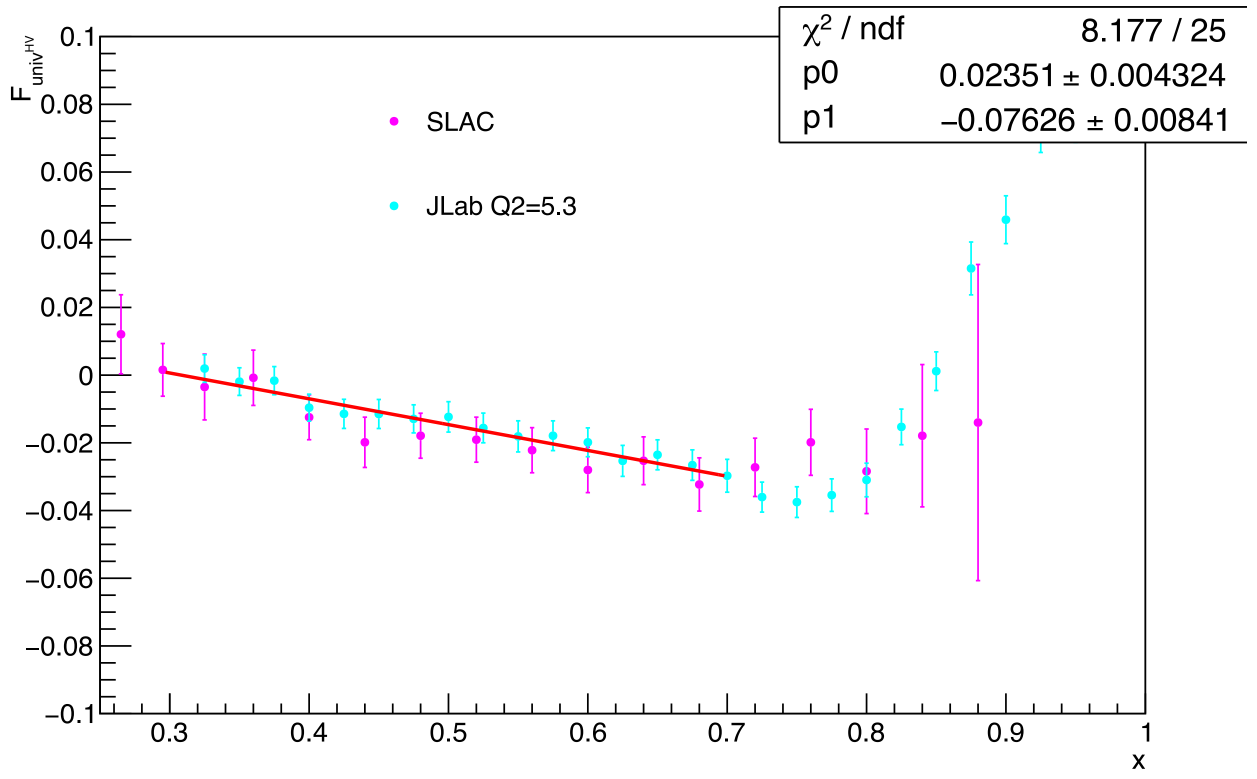
The universality of the EMC effect functions is examined by looking at the slopes for 0.3<x<0.7 as a function of A.

FITS TO THE UNIVERSAL FUNCTIONS PER TARGET

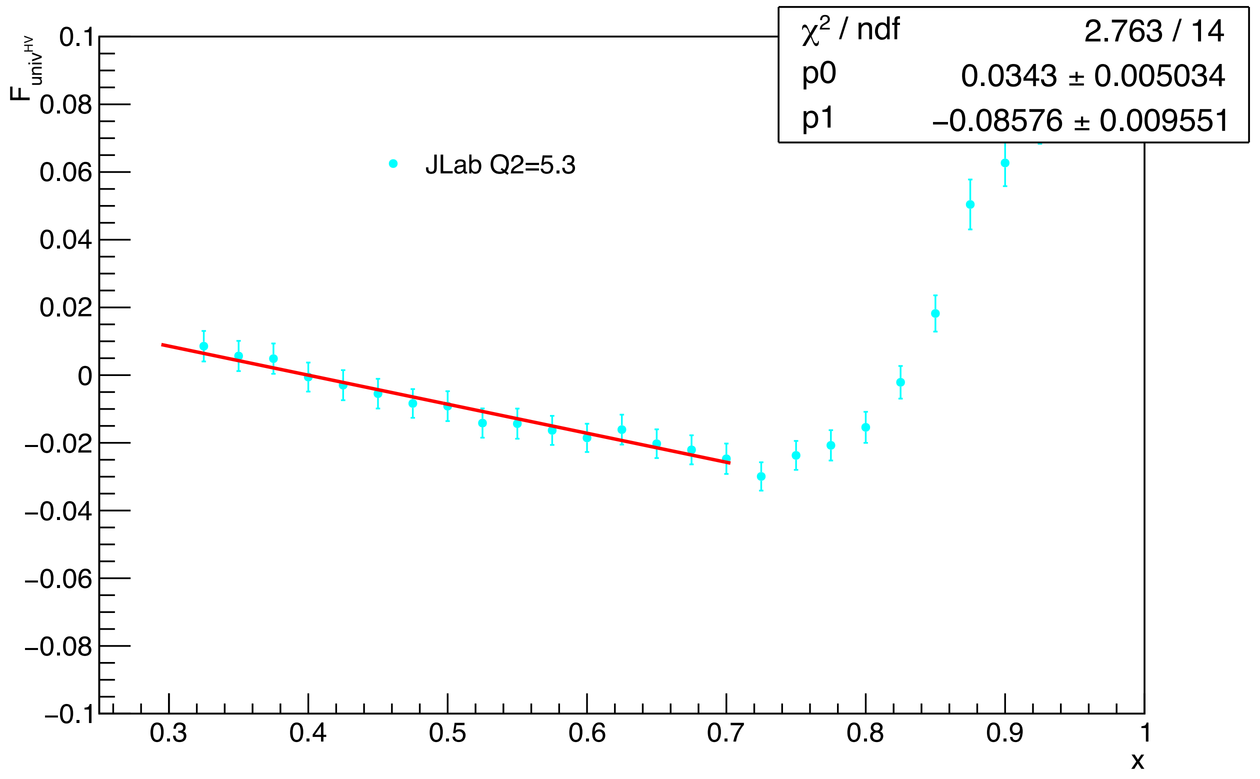
3He HV



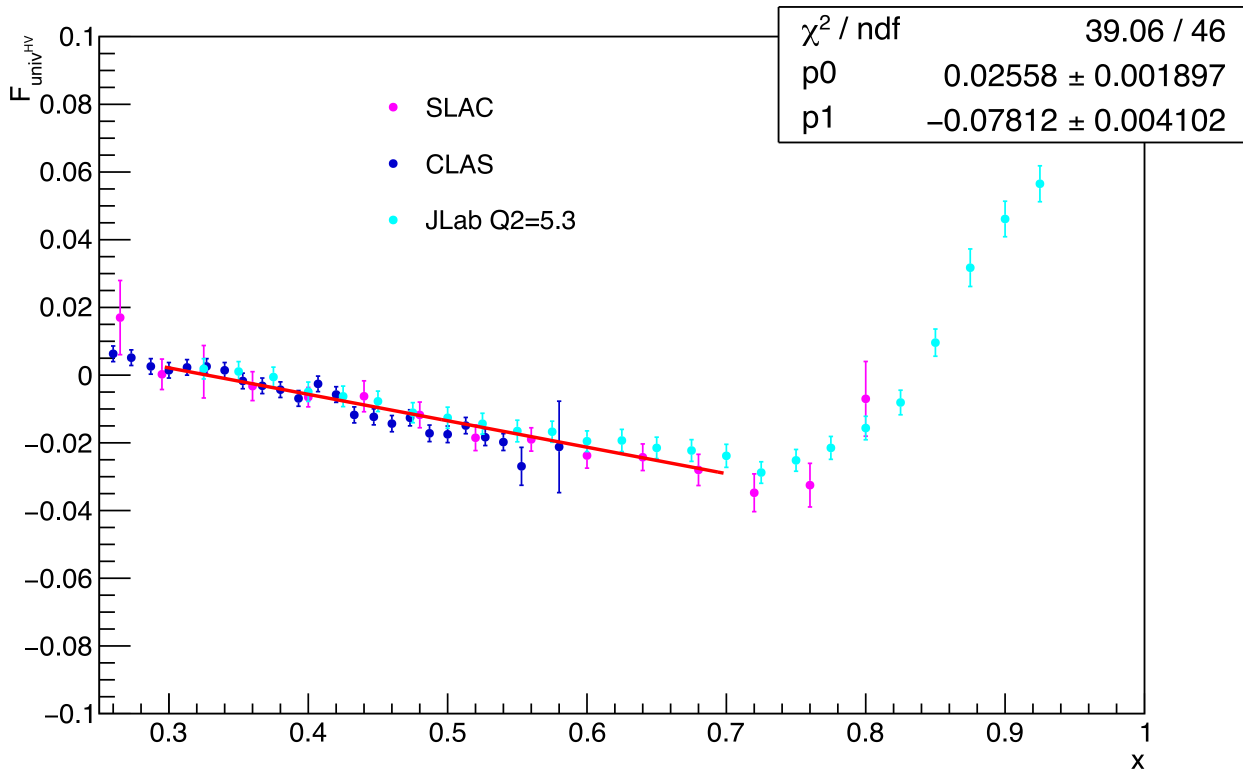
4He HV



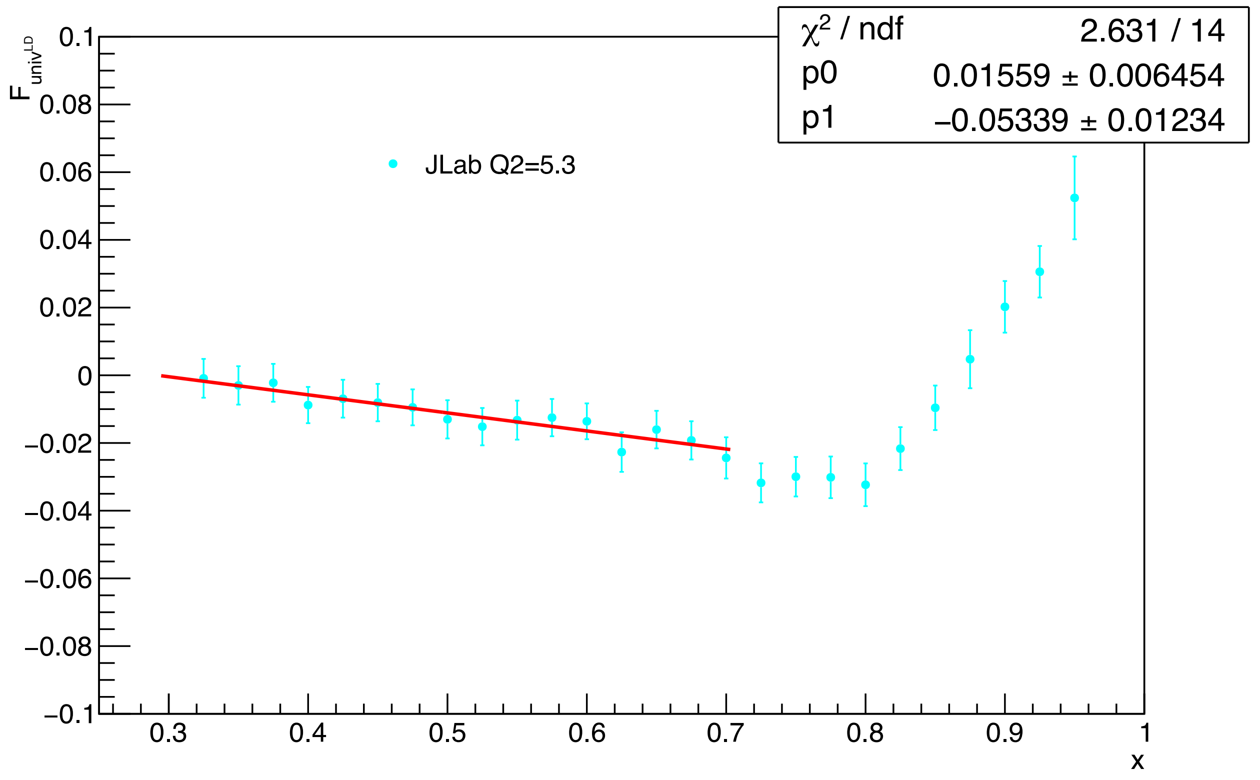
9Be HV



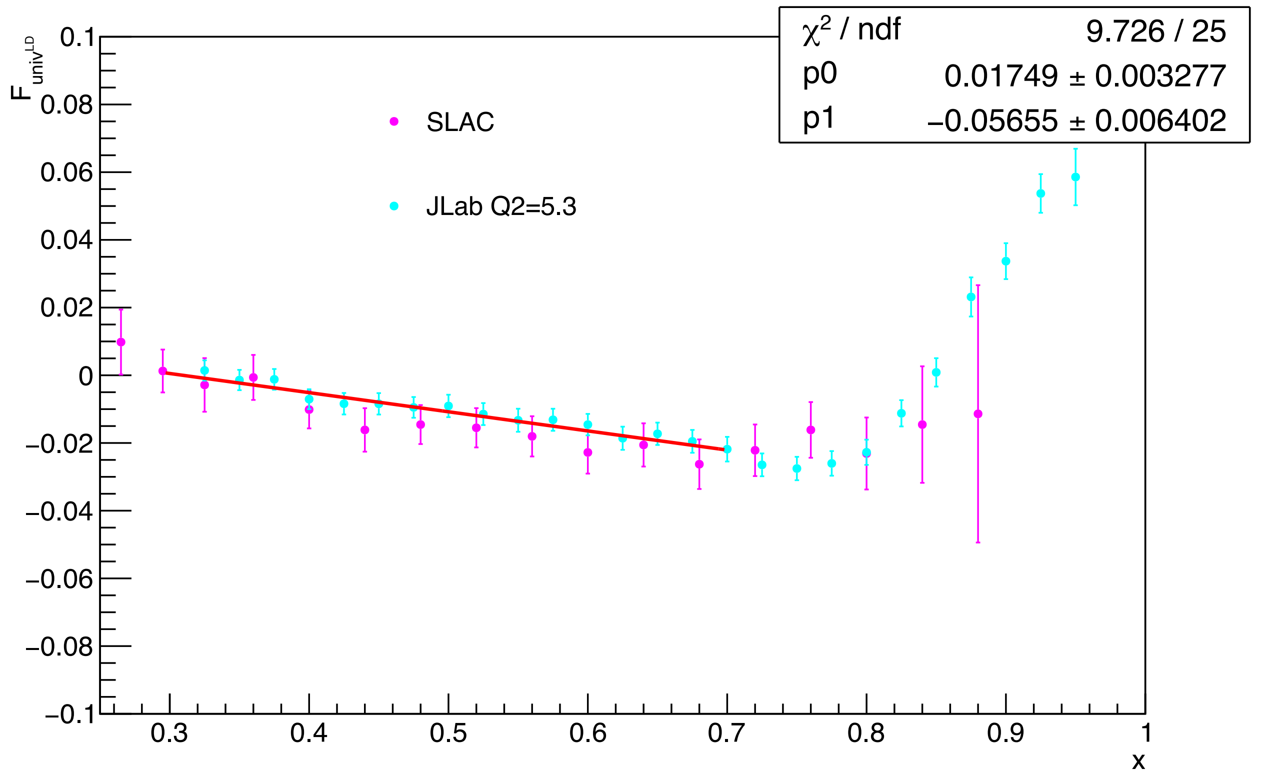
12C HV



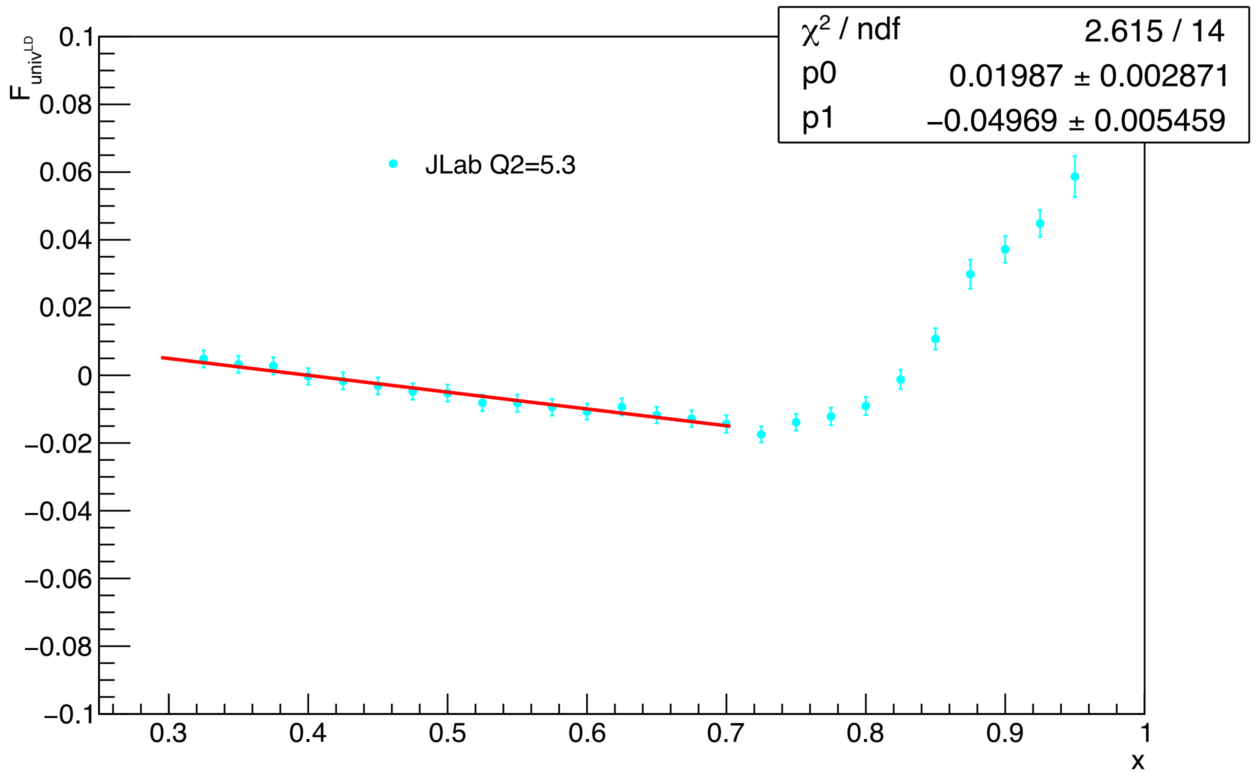
3He LD



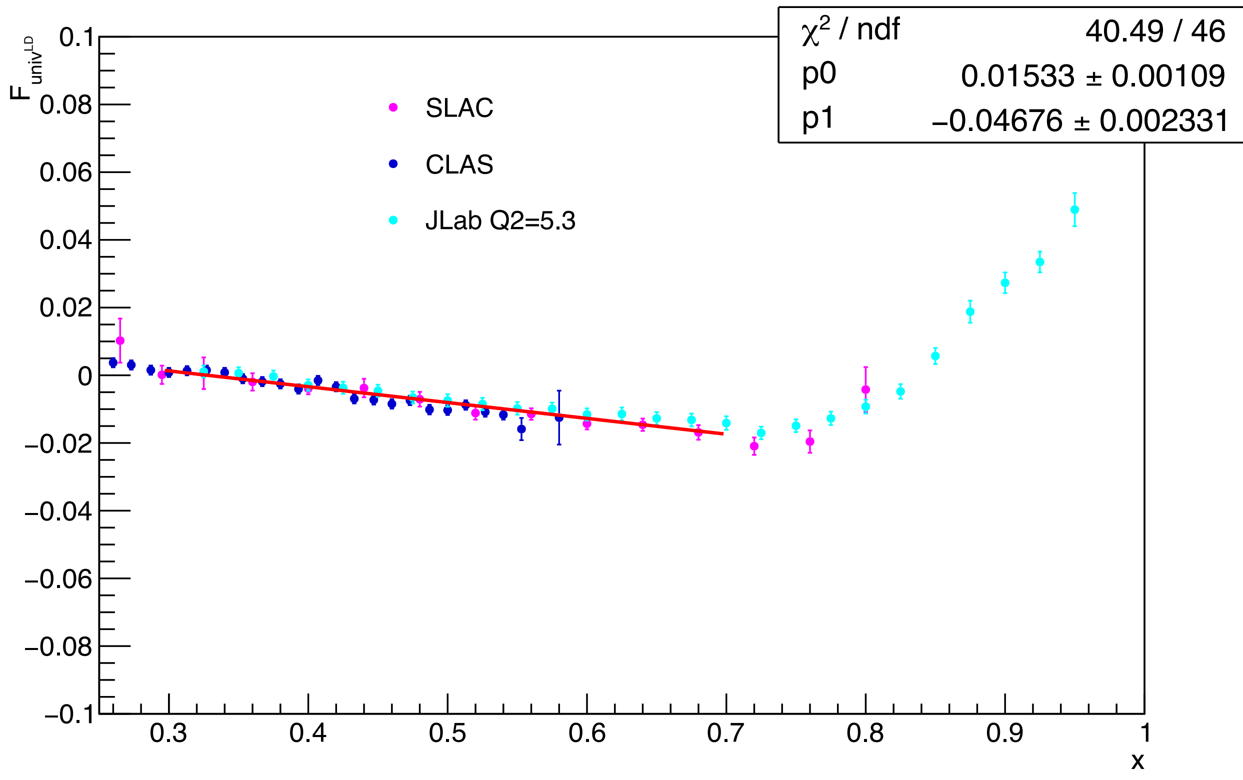
4He LD



9Be LD

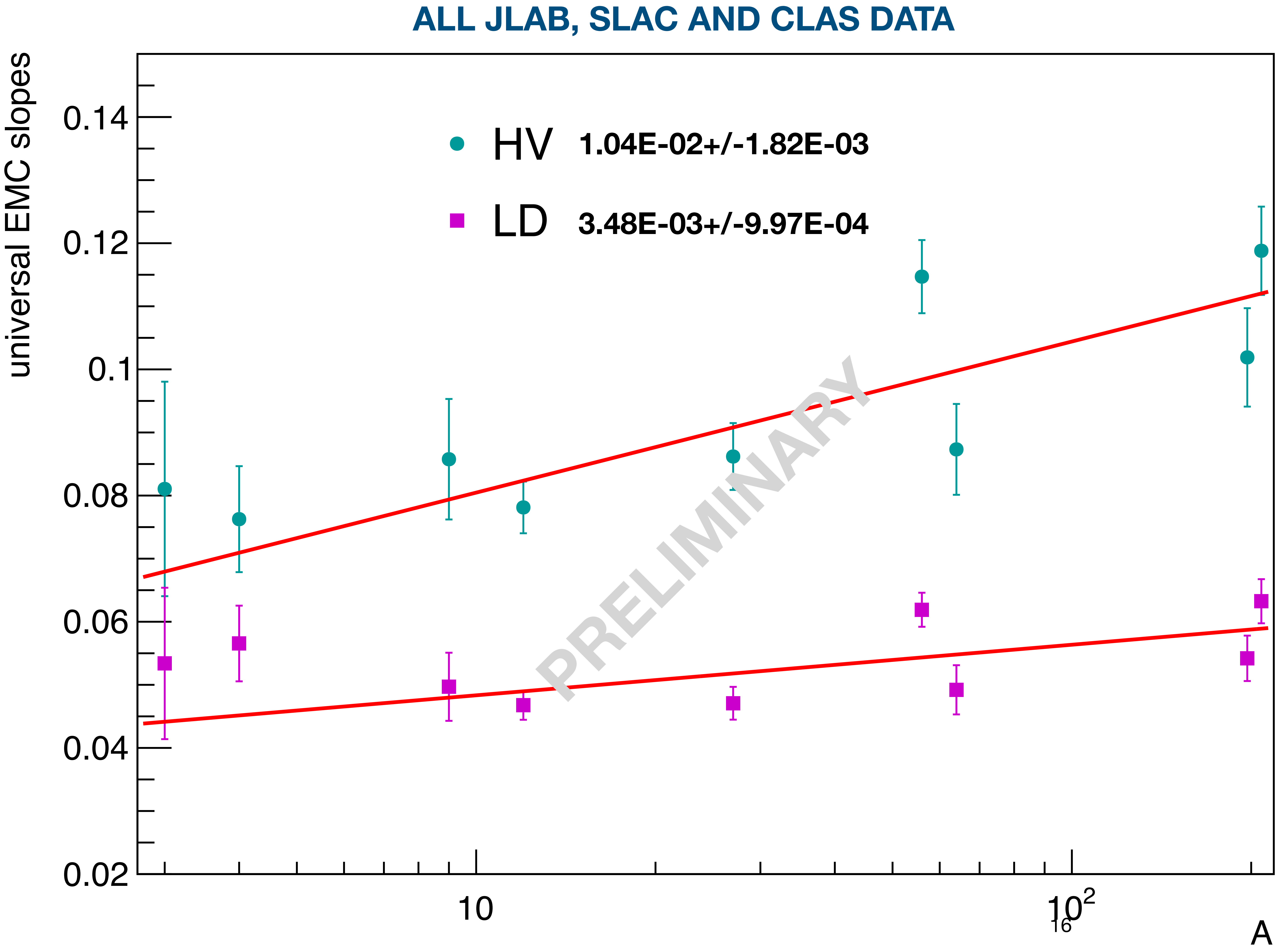


12C LD



**Only a subgroup of targets are shown for brevity*

UNIVERSAL EMC SLOPES



- Global analysis with additional published data!

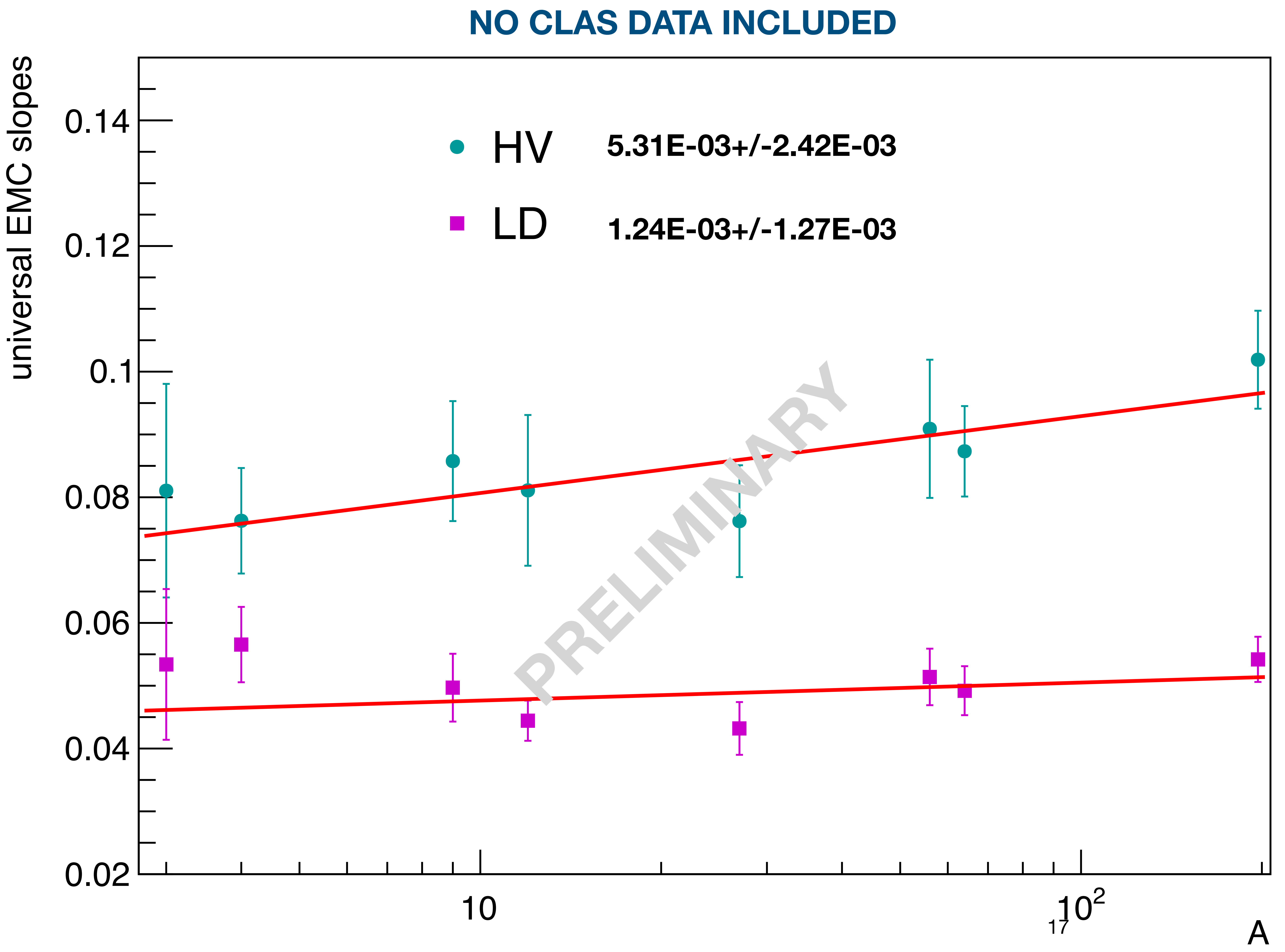
J. Arrington et al, PRC 104, 2021

B. Schmookler et al, Nature 566, 2019

- Heavy nuclei data from E03-103
- C, Al, Iron, and Lead data from CLAS

HV model: relatively modest variation with A

UNIVERSAL EMC SLOPES



- Analysis excluding the CLAS data

CONCLUSION

- Data shows weak preference for the Local Density model

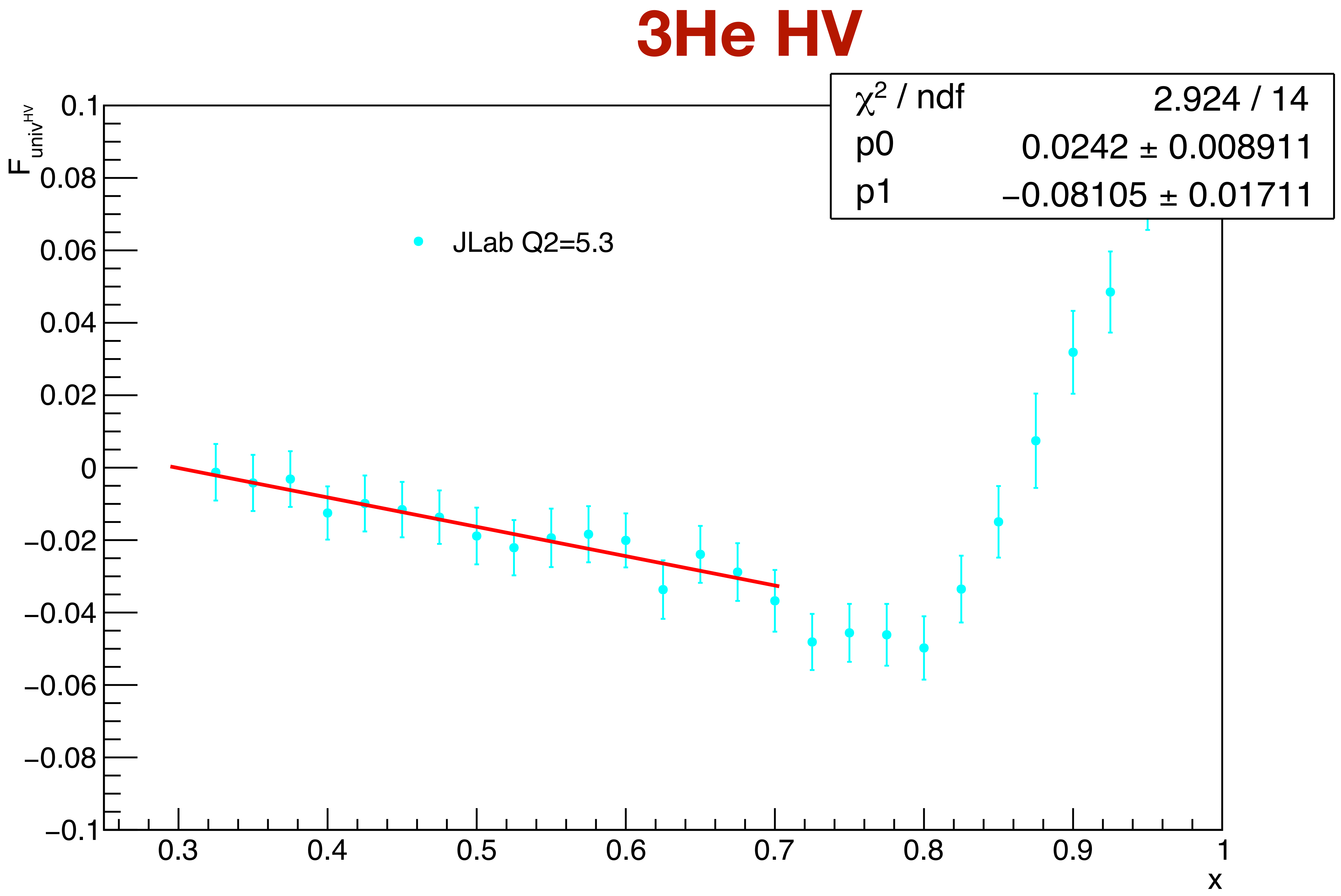
- We find no experimental evidence for the isospin dependent EMC effect

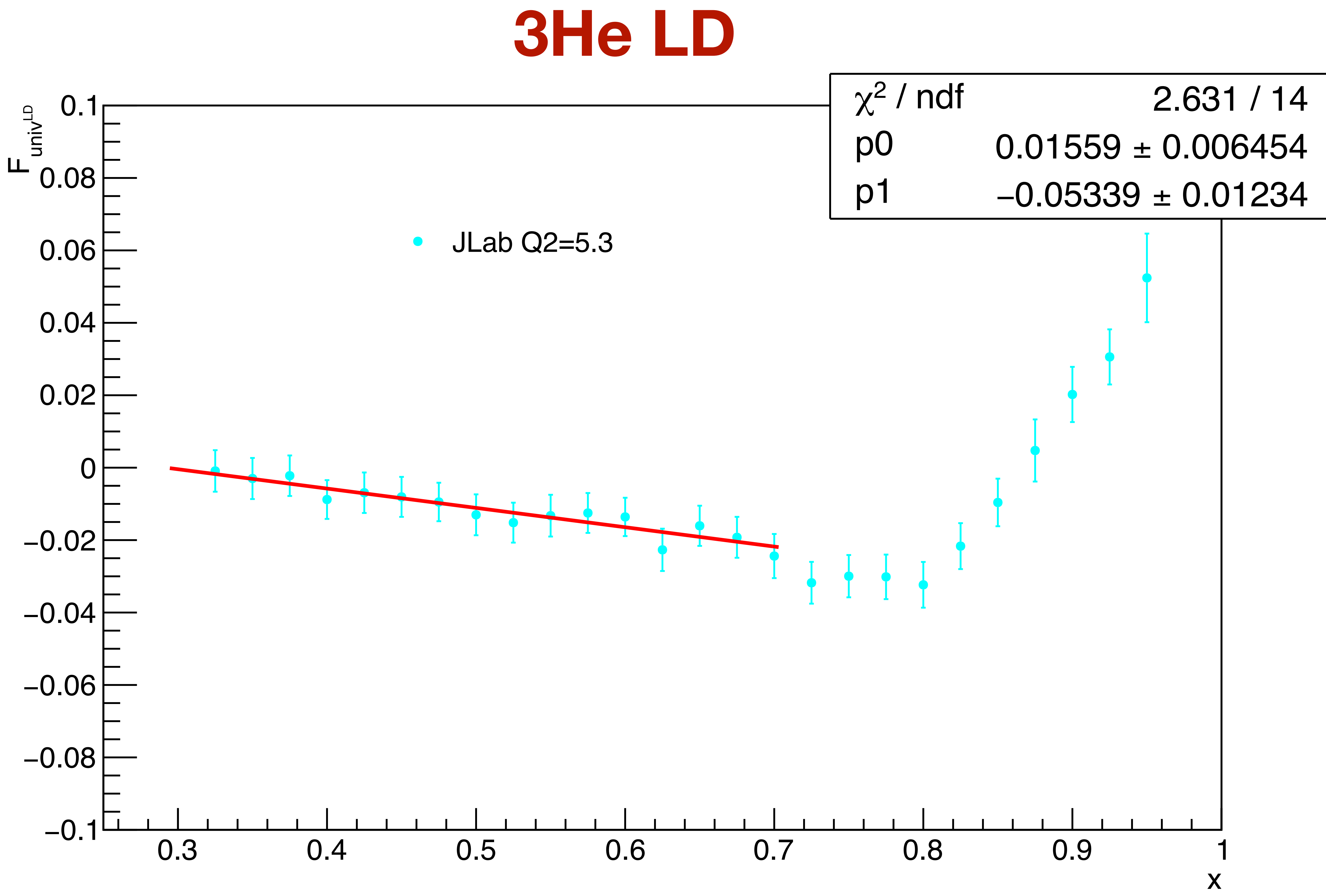
- The analysis will be expanded with the additional data including new nuclei as it becomes available

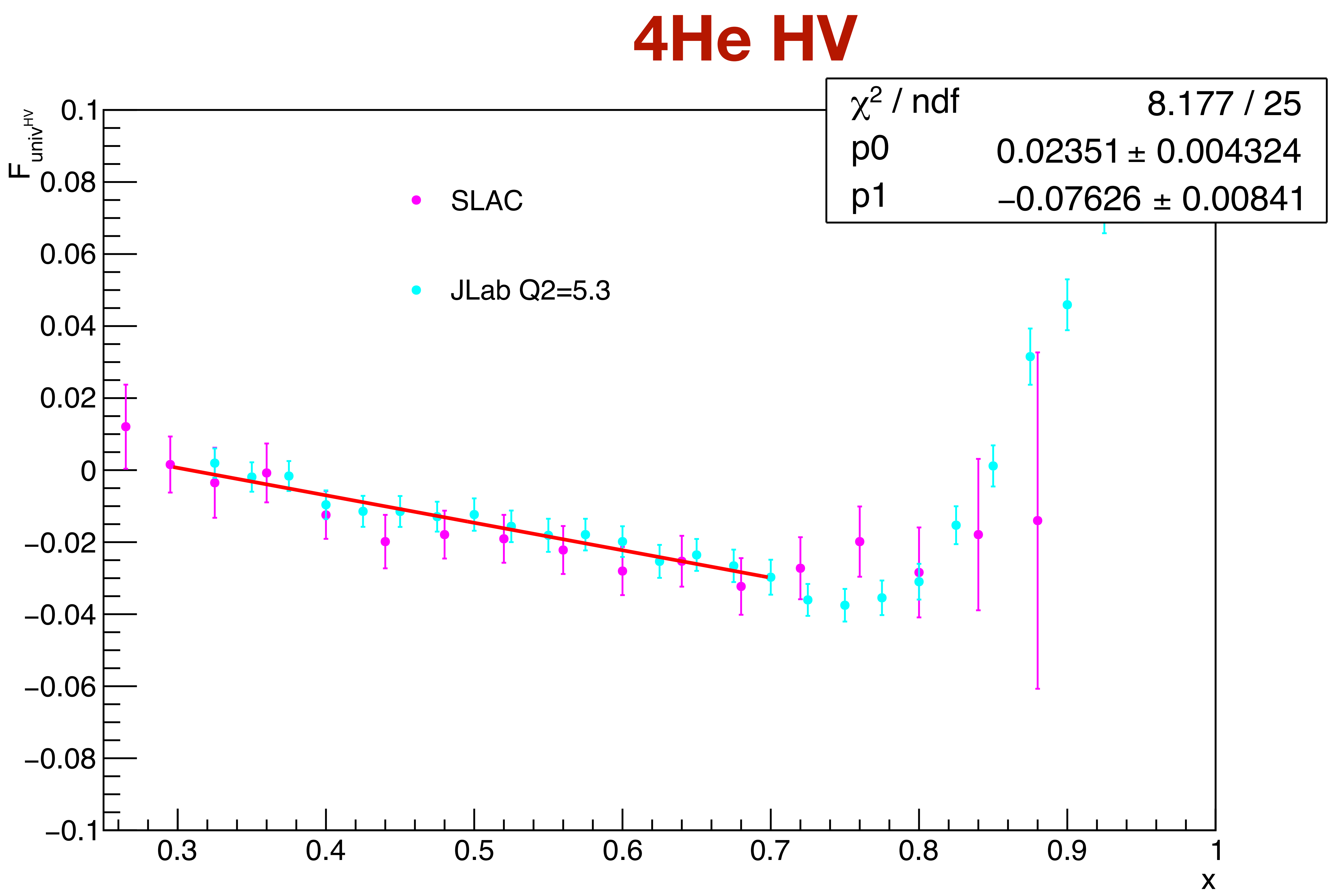
- Recent EMC effect and SRC measurements/analysis in JLab Hall C will help illuminating the potential EMC-SRC connection

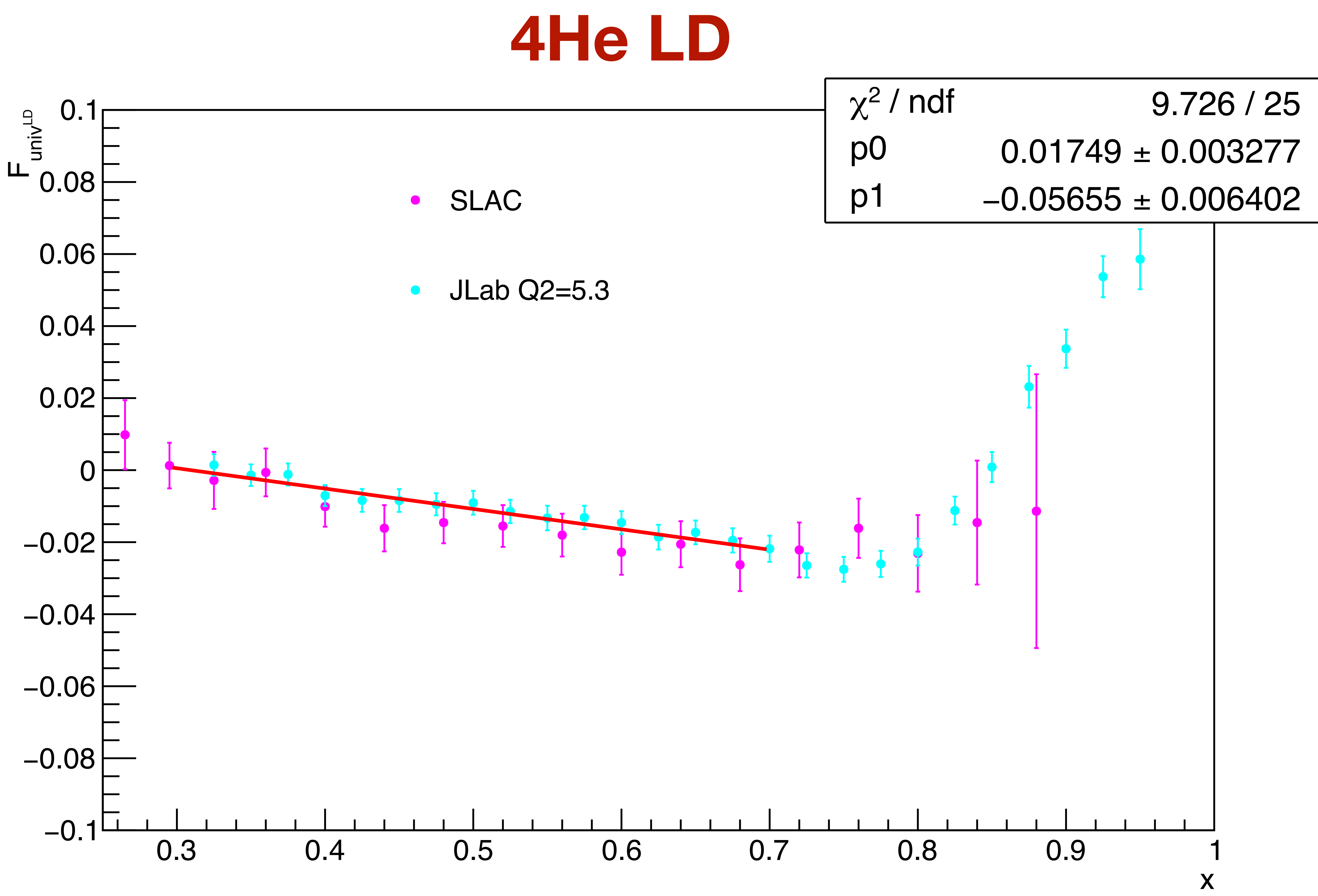
BACK UP SLIDES

HV-LD UNIV FUNCTION FITS PER TARGET

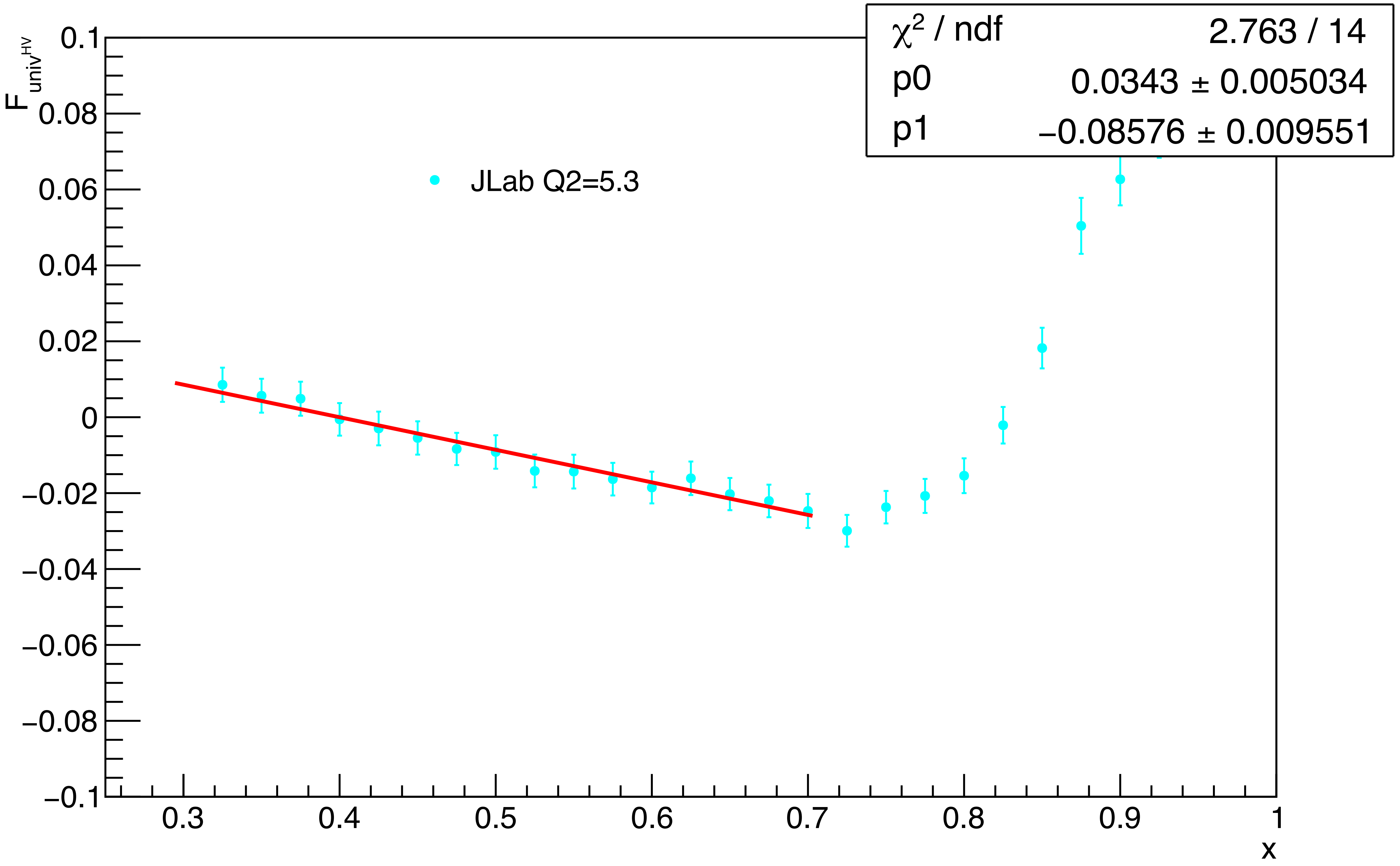

3He HV
χ2 / ndf 2.924 / 14
p0 0.0242 ± 0.008911
p1 −0.08105 ± 0.01711
JLab Q2=5.3
F_univ^HV
x


3He LD
χ2 / ndf 2.631 / 14
p0 0.01559 ± 0.006454
p1 −0.05339 ± 0.01234
JLab Q2=5.3
F_univ^LD
x


4He HV
χ² / ndf 8.177 / 25
p0 0.02351 ± 0.004324
p1 −0.07626 ± 0.00841
SLAC
JLab Q2=5.3
F_univ^HV
x

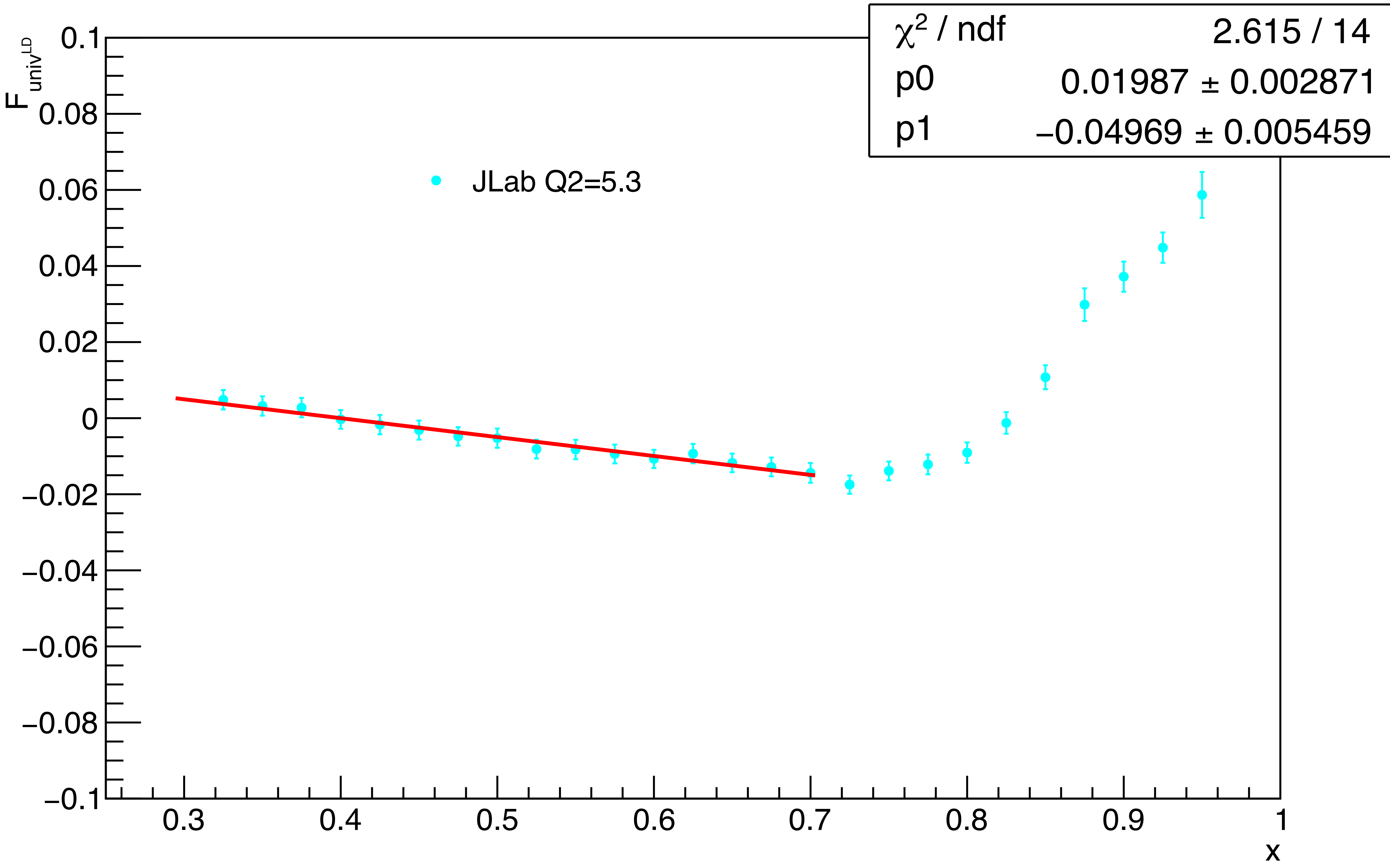

4He LD
χ² / ndf 9.726 / 25
p0 0.01749 ± 0.003277
p1 −0.05655 ± 0.006402
SLAC
JLab Q2=5.3
F_univ^LD
x

9Be HV



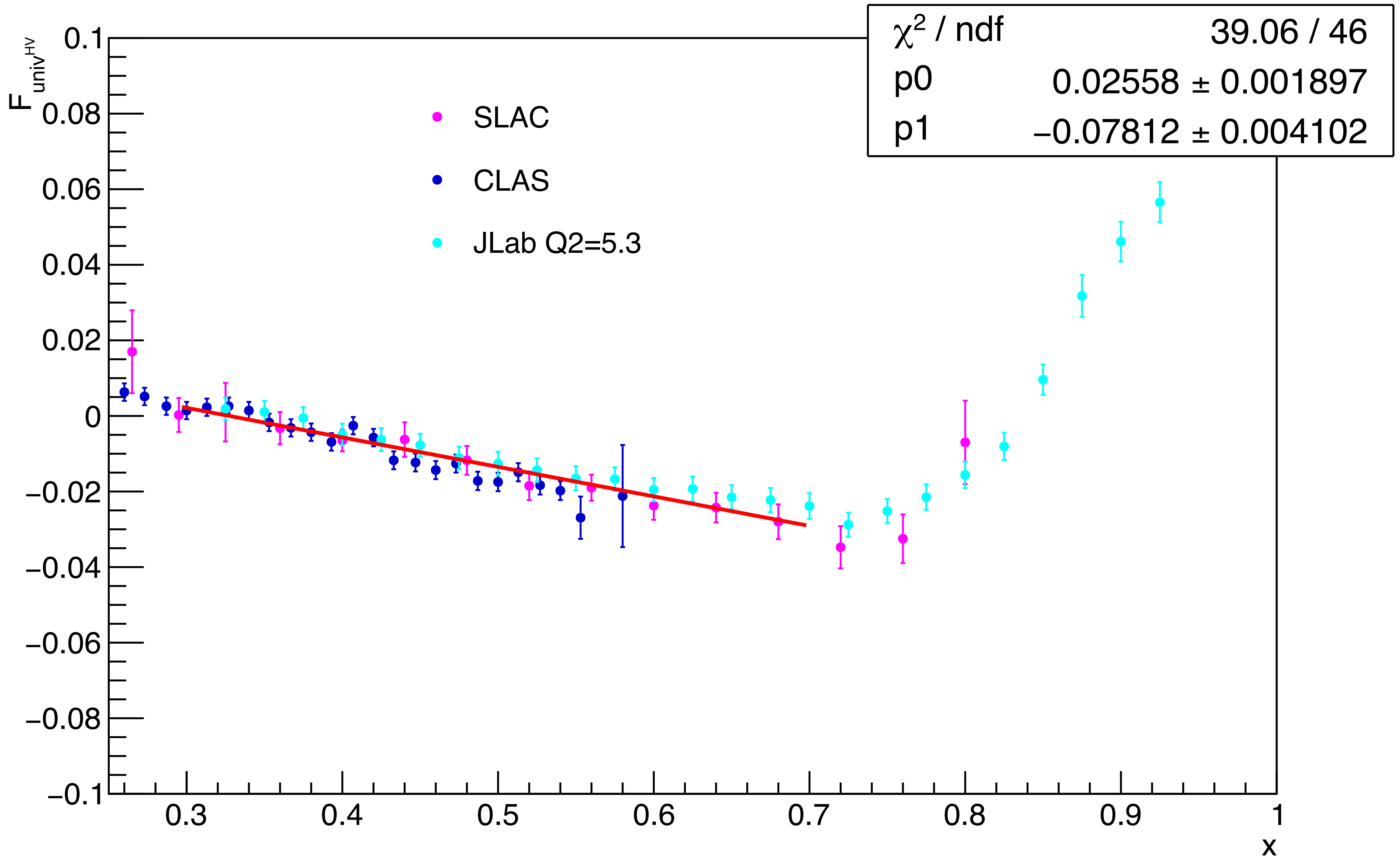
χ^2 / ndf 2.763 / 14
p0 0.0343 ± 0.005034
p1 −0.08576 ± 0.009551
JLab Q2=5.3
F_{univ}^{HV}
x

9Be LD



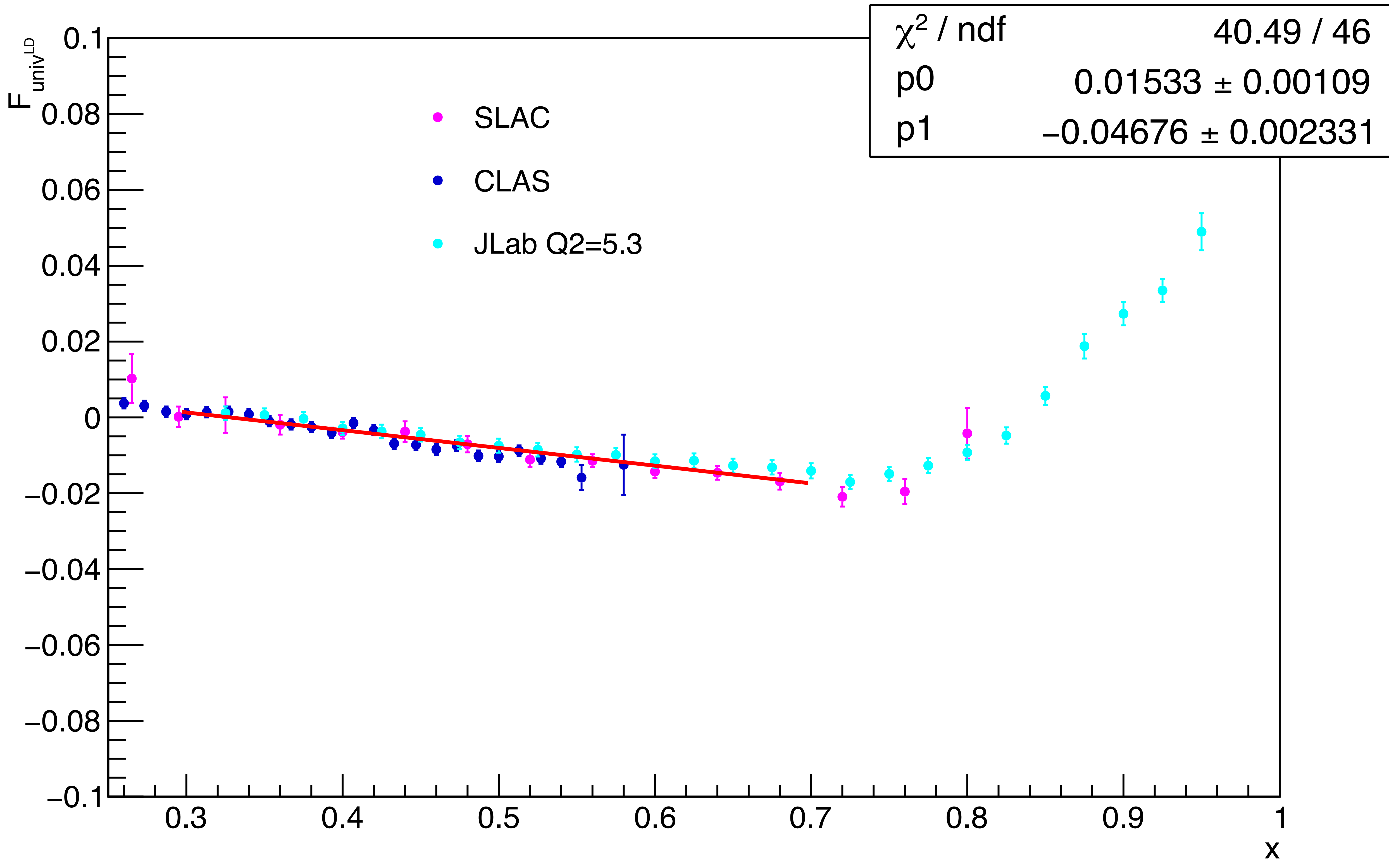
χ^2 / ndf 2.615 / 14
p0 0.01987 ± 0.002871
p1 −0.04969 ± 0.005459
JLab Q2=5.3
F_{univ}^{LD}
x

12C HV

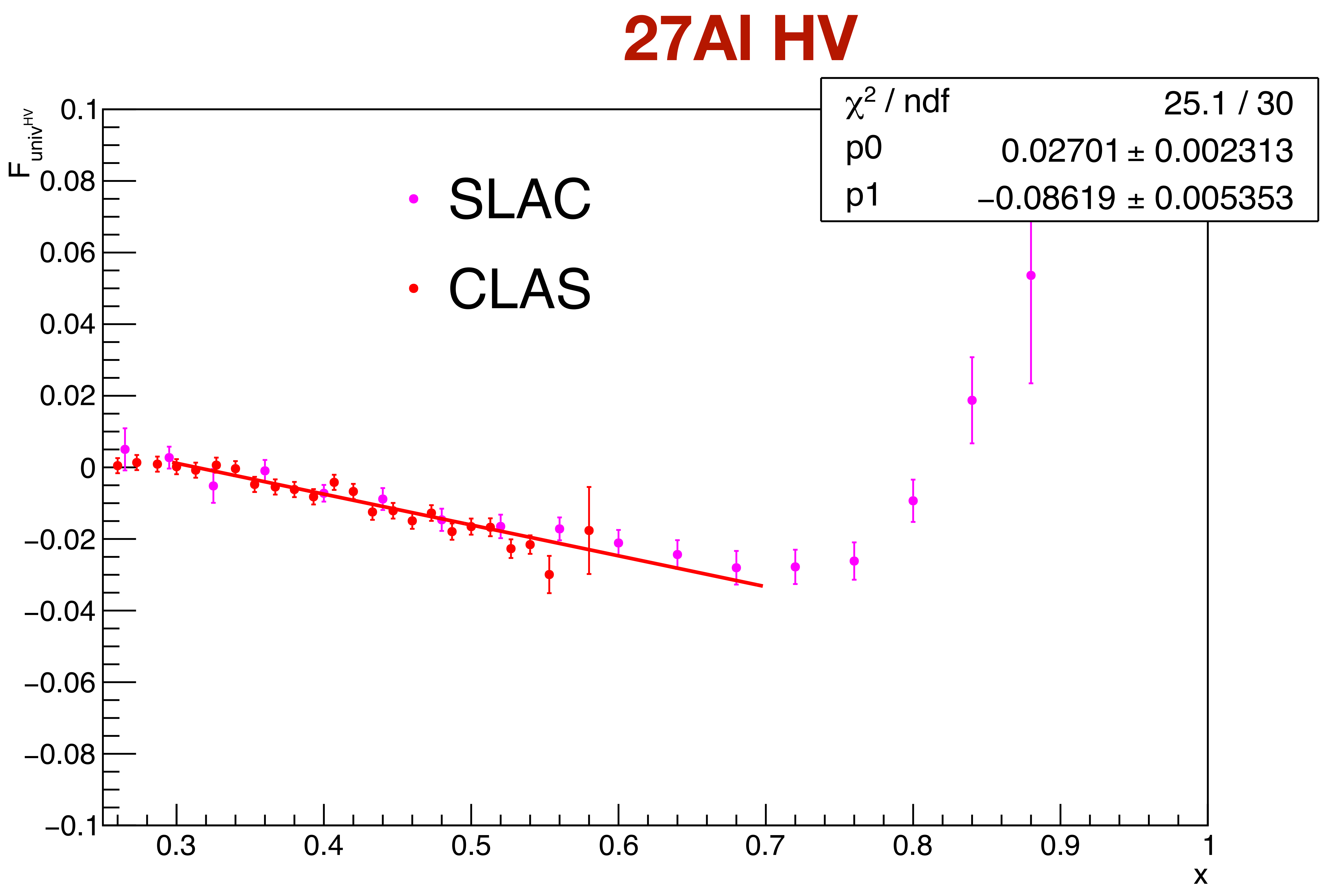


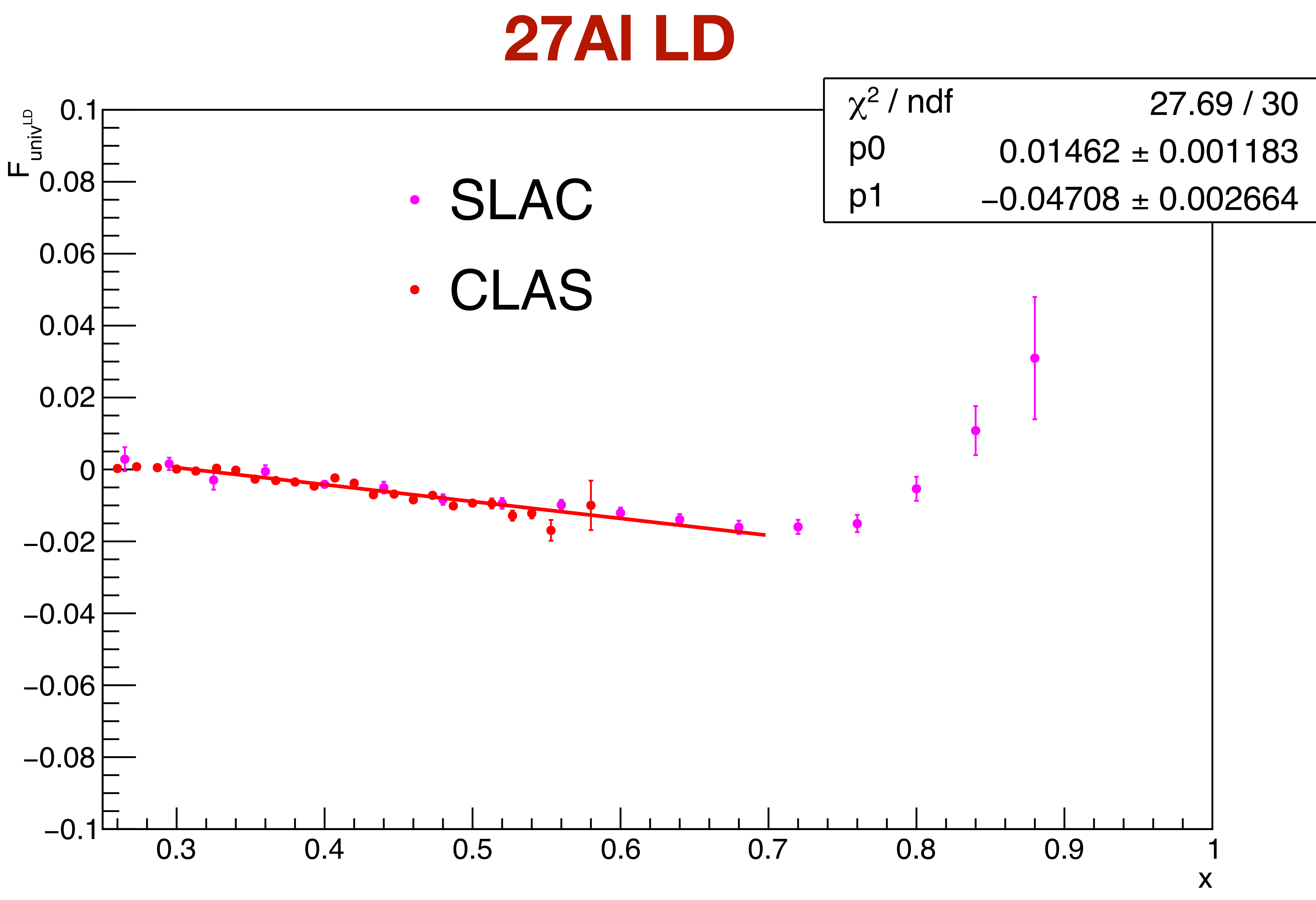
χ2 / ndf 39.06 / 46
p0 0.02558 ± 0.001897
p1 −0.07812 ± 0.004102
SLAC
CLAS
JLab Q2=5.3
F_univ^HV
x

12C LD

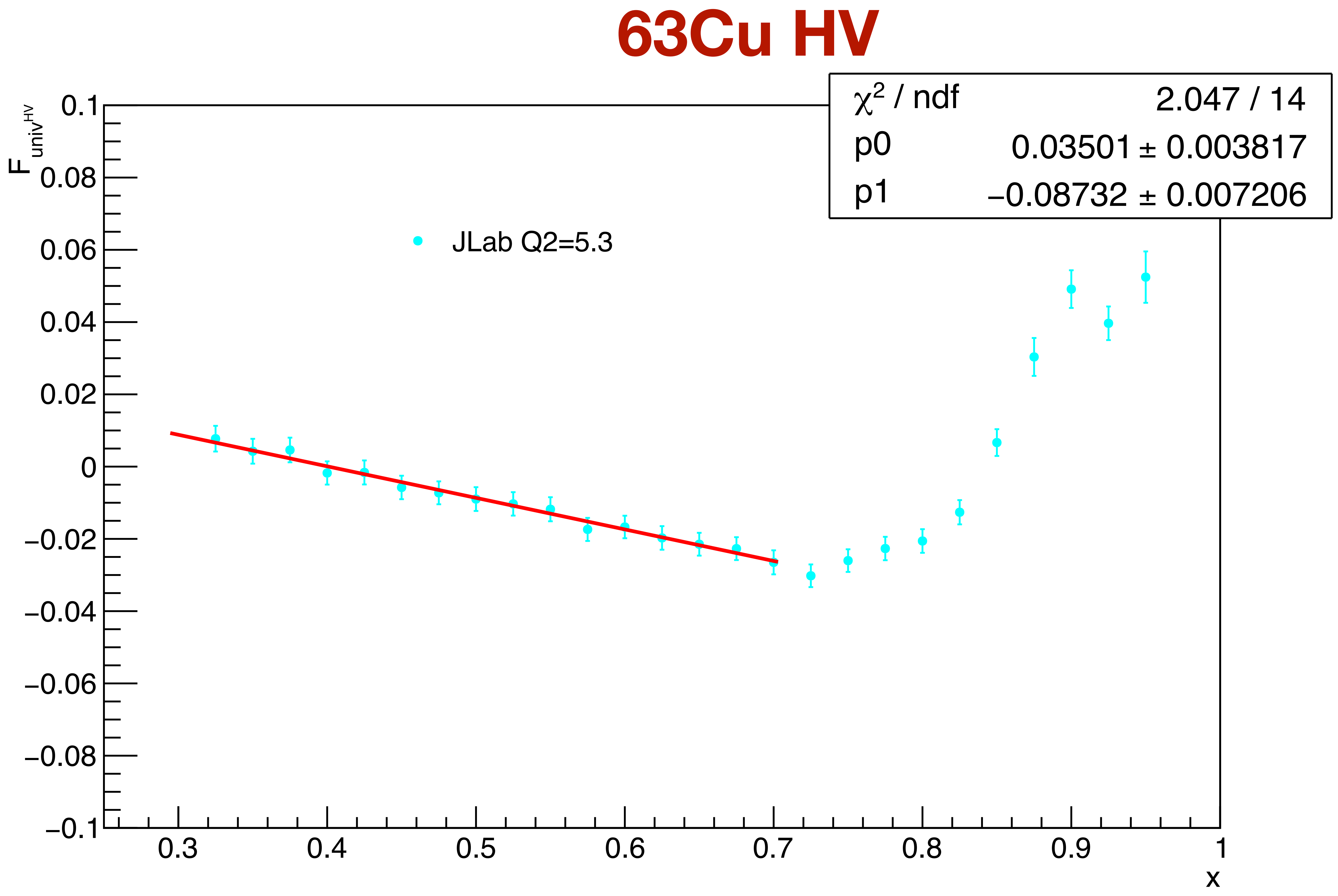


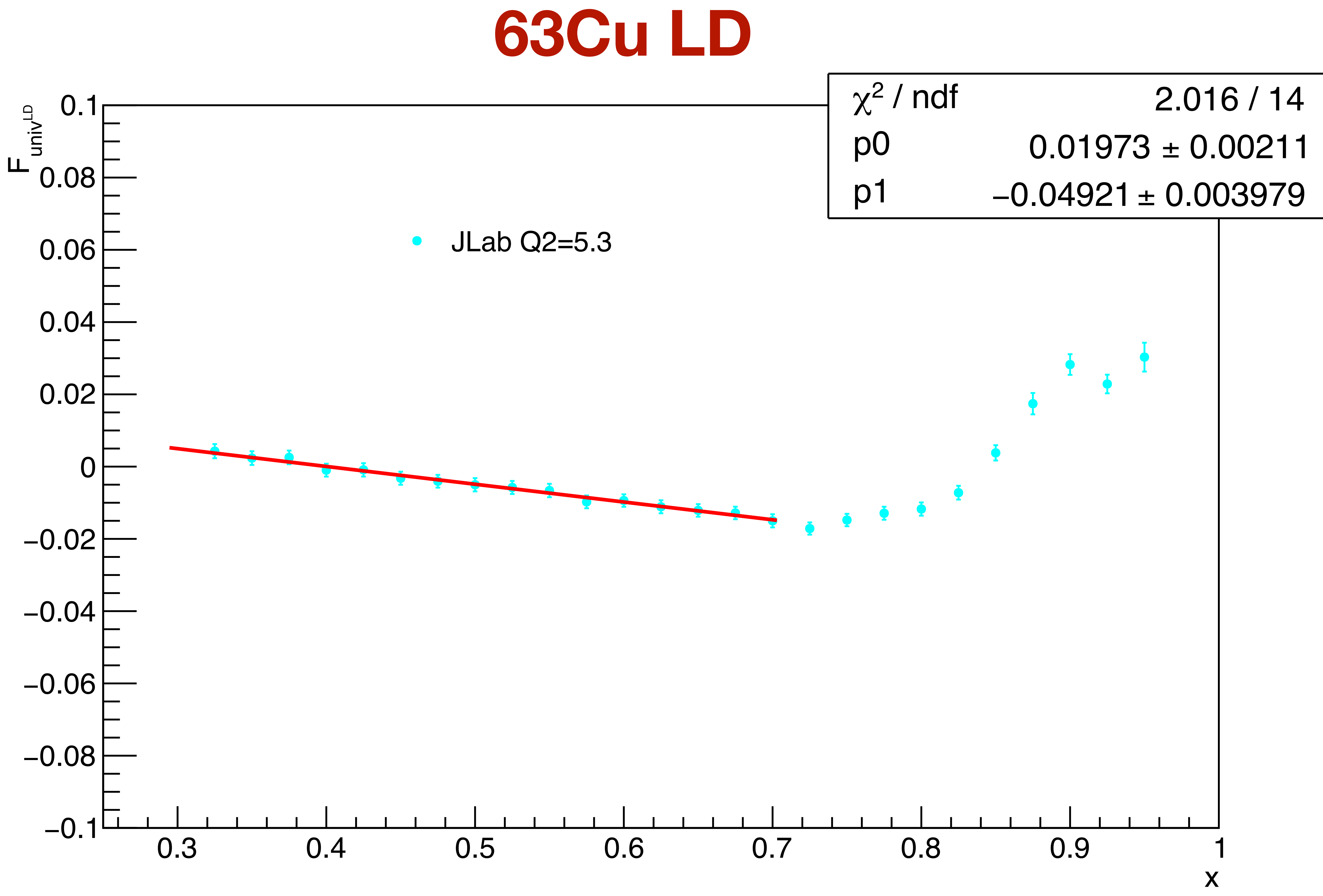
χ2 / ndf 40.49 / 46
p0 0.01533 ± 0.00109
p1 −0.04676 ± 0.002331
SLAC
CLAS
JLab Q2=5.3
F_univ^LD
x


27Al HV
χ^2 / ndf 25.1 / 30
p0 0.02701 ± 0.002313
p1 −0.08619 ± 0.005353
SLAC
CLAS
$F_{univ^{HV}}$
x

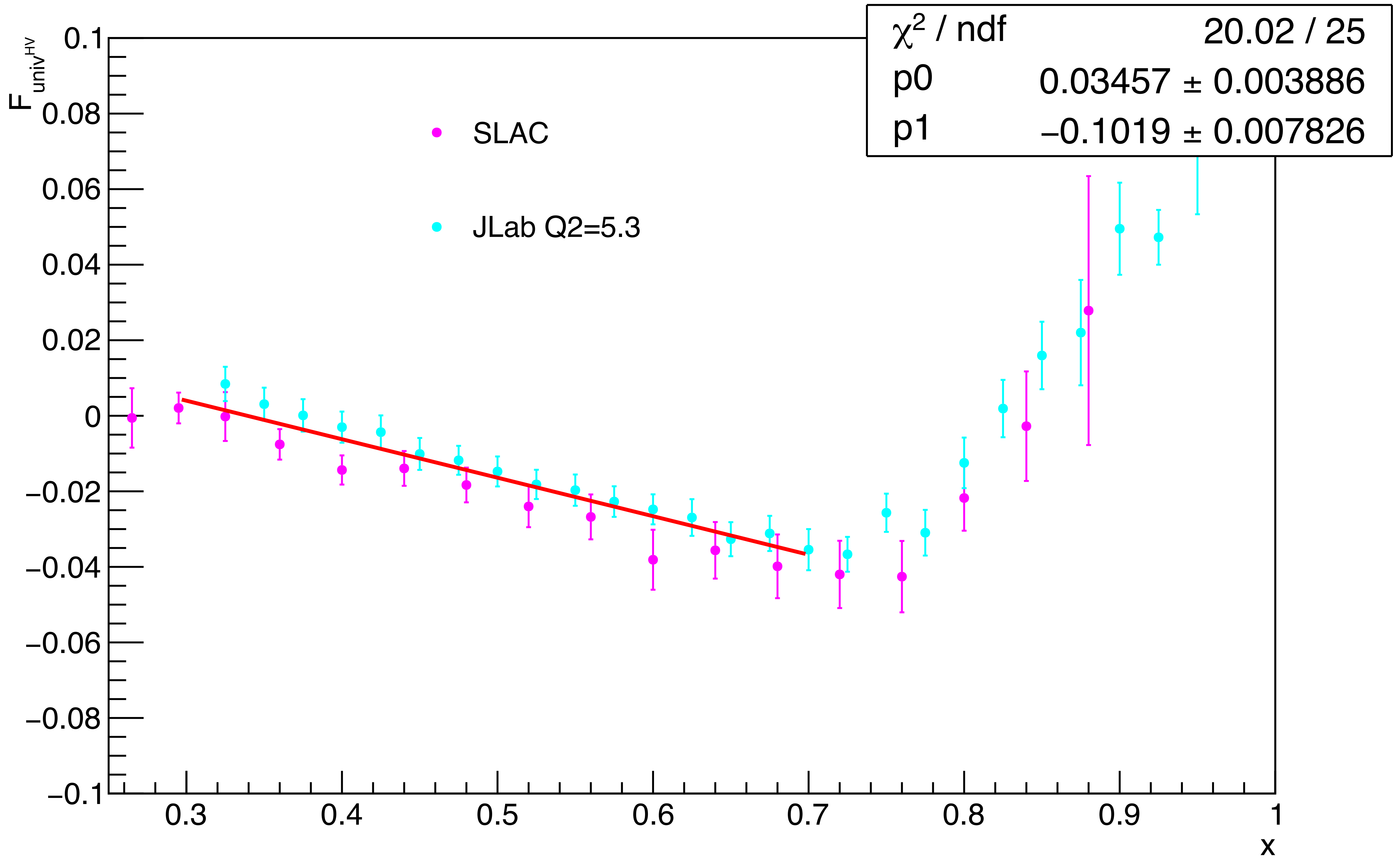

27Al LD
χ^2 / ndf 27.69 / 30
p0 0.01462 ± 0.001183
p1 −0.04708 ± 0.002664
SLAC
CLAS
$F_{univ^{LD}}$
x

56Fe HV
χ2 / ndf 18.18 / 30
p0 0.03694 ± 0.002494
p1 −0.1147 ± 0.005889
SLAC
CLAS
F_univ^HV
x
56Fe LD
χ2 / ndf 22.13 / 30
p0 0.01984 ± 0.00122
p1 −0.06197 ± 0.002788
SLAC
CLAS
F_univ^LD
x

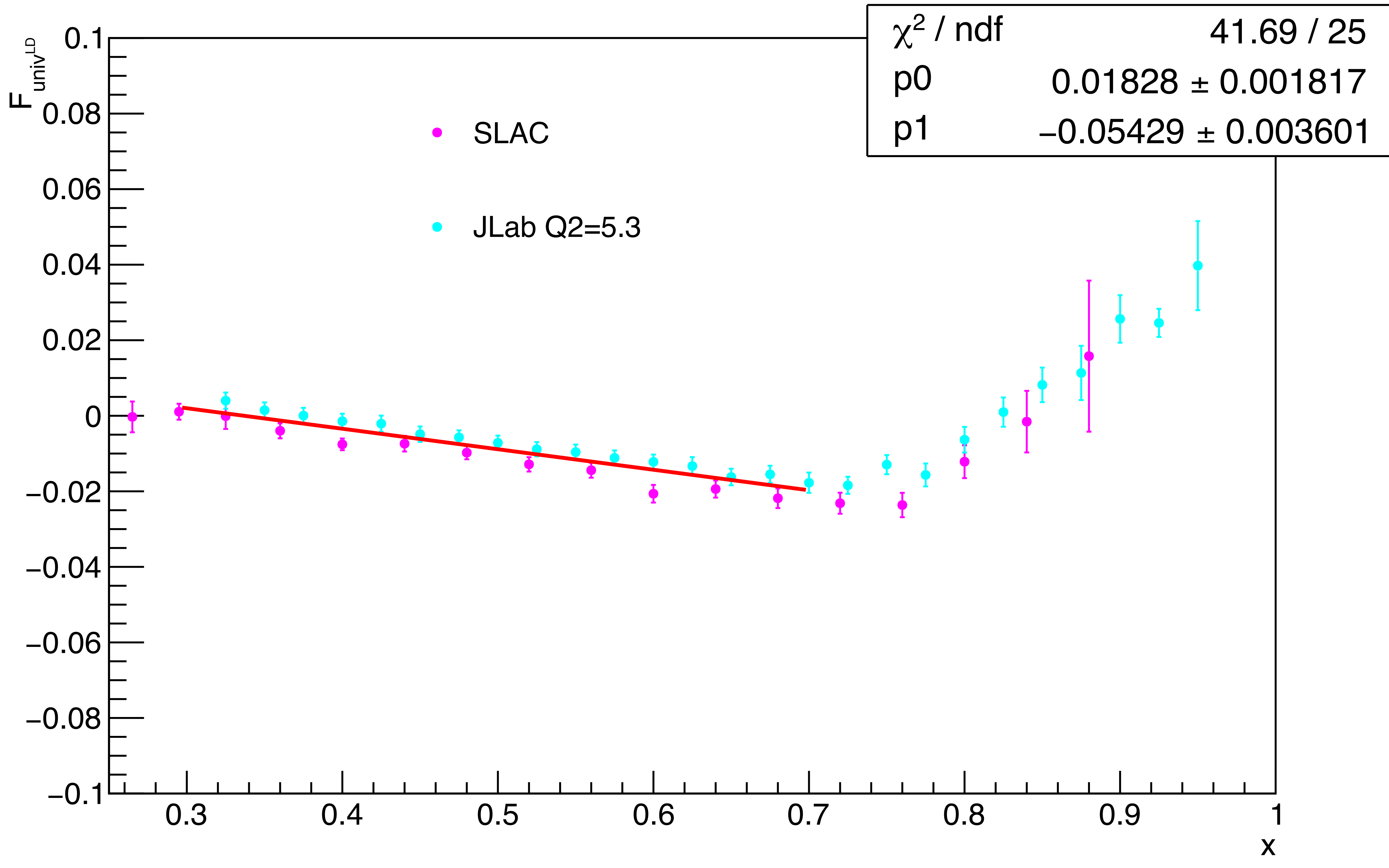

63Cu HV
χ^2 / ndf 2.047 / 14
p0 0.03501 ± 0.003817
p1 −0.08732 ± 0.007206
JLab Q2=5.3
$F_{univ^{HV}}$
x


63Cu LD
χ^2 / ndf 2.016 / 14
p0 0.01973 ± 0.00211
p1 −0.04921 ± 0.003979
JLab Q2=5.3
$F_{univ^{LD}}$
x

197Au HV

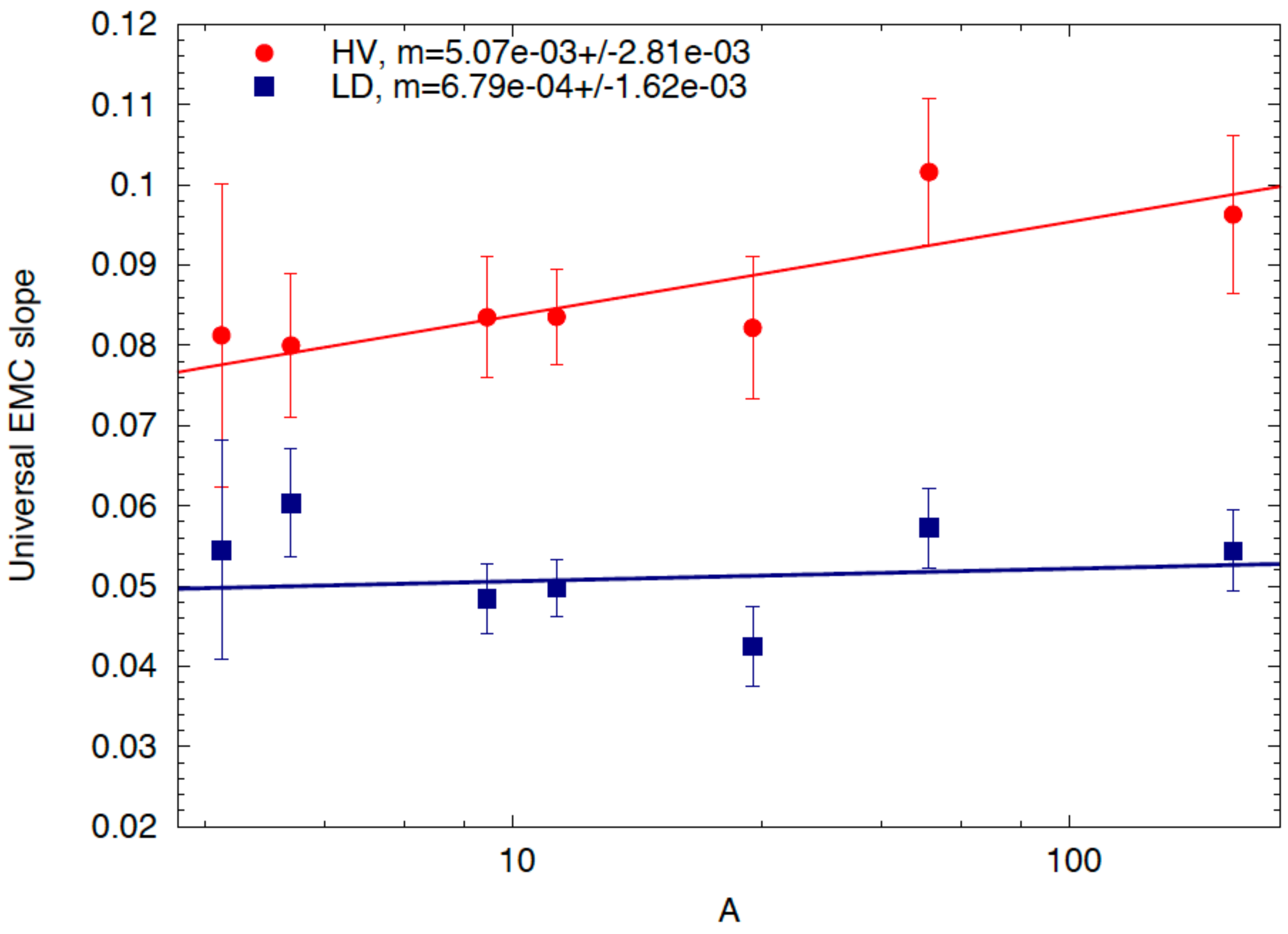


197Au LD




208Pb HV
χ2 / ndf 11.12 / 19
p0 0.04109 ± 0.00297
p1 −0.1188 ± 0.007002
CLAS
F_univ^HV
x
208Pb LD
χ2 / ndf 12.07 / 19
p0 0.02189 ± 0.00152
p1 −0.06325 ± 0.003565
CLAS
F_univ^LD
x

UNIVERSAL EMC SLOPES (2019)



J. Arrington, N. Fomin, PRL 123, 2019

- HV model: relatively modest variation with A, 2 sigma deviations from zero.

- LD model: no significant A dependence