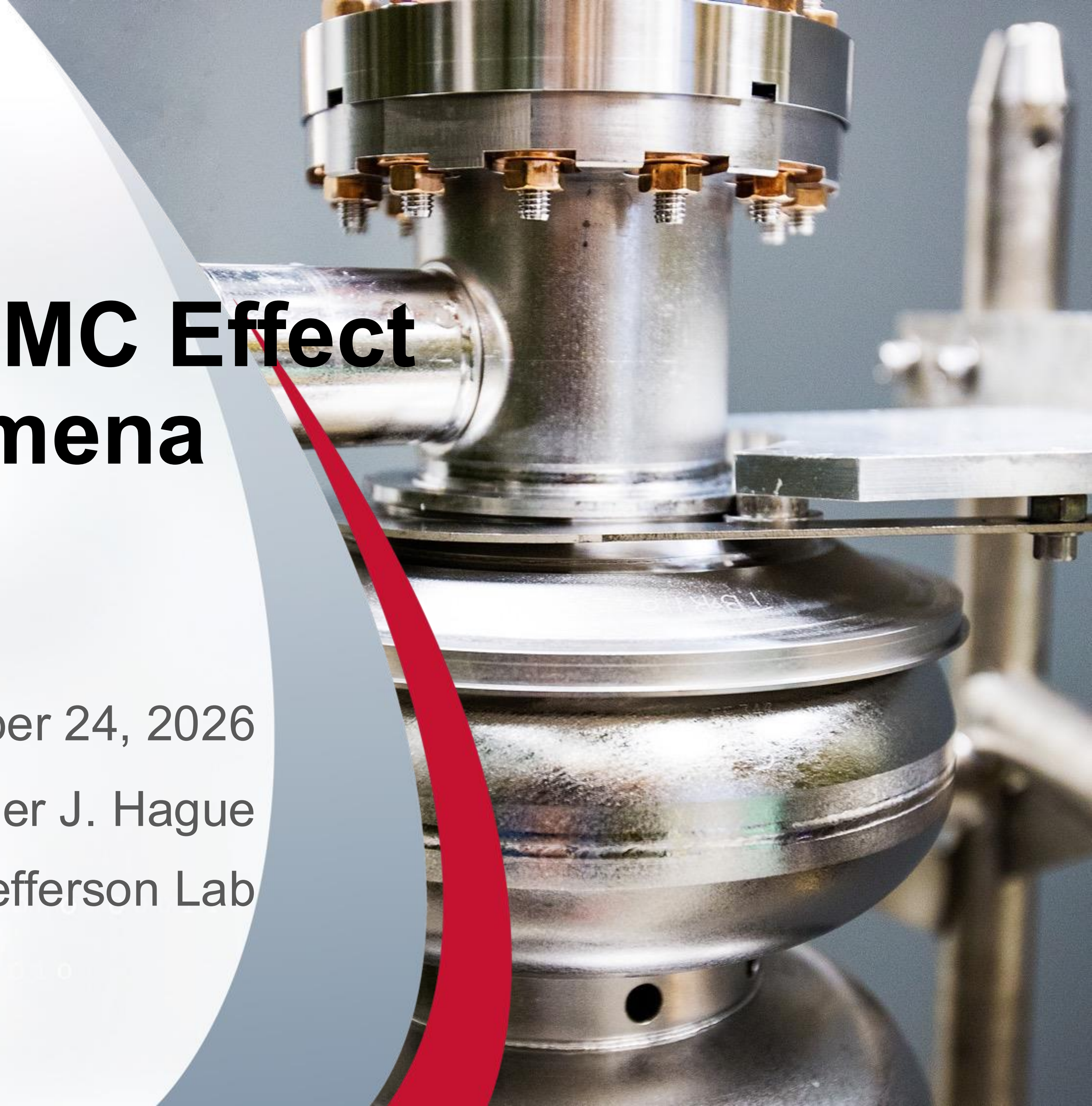
The light nuclear EMC Effect and related phenomena

Fundamental Problems in Subatomic Physics 2026



September 24, 2026

Tyler J. Hague

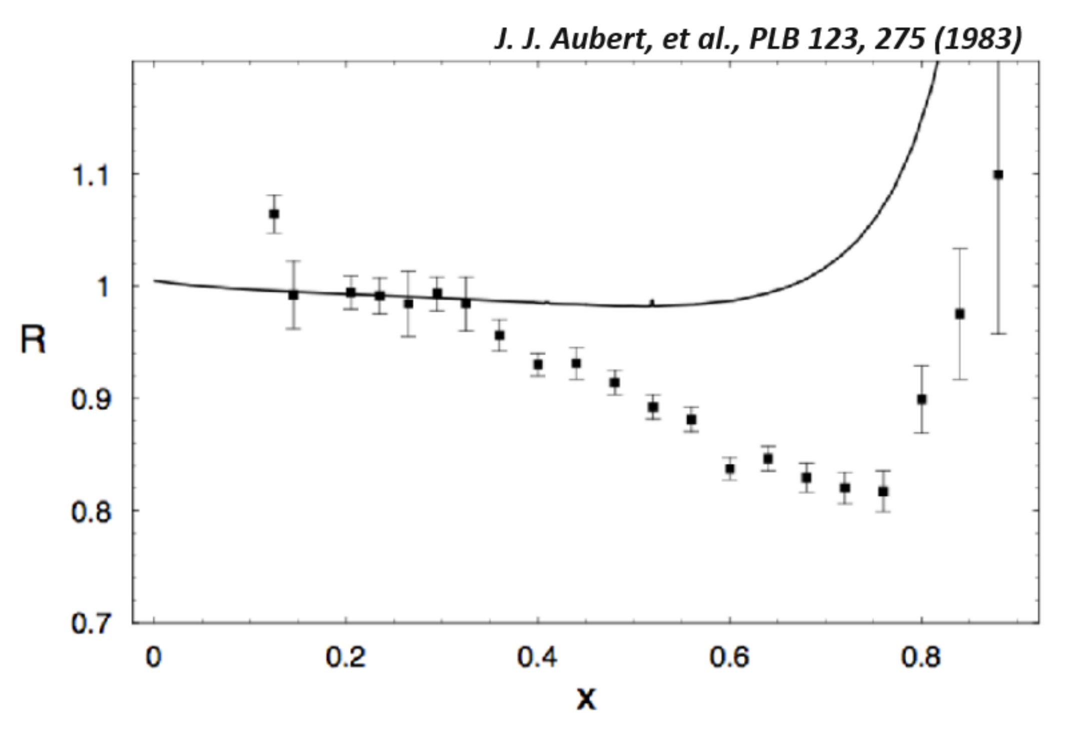
Jefferson Lab

Jefferson Lab U.S. Department of ENERGY

The EMC Effect

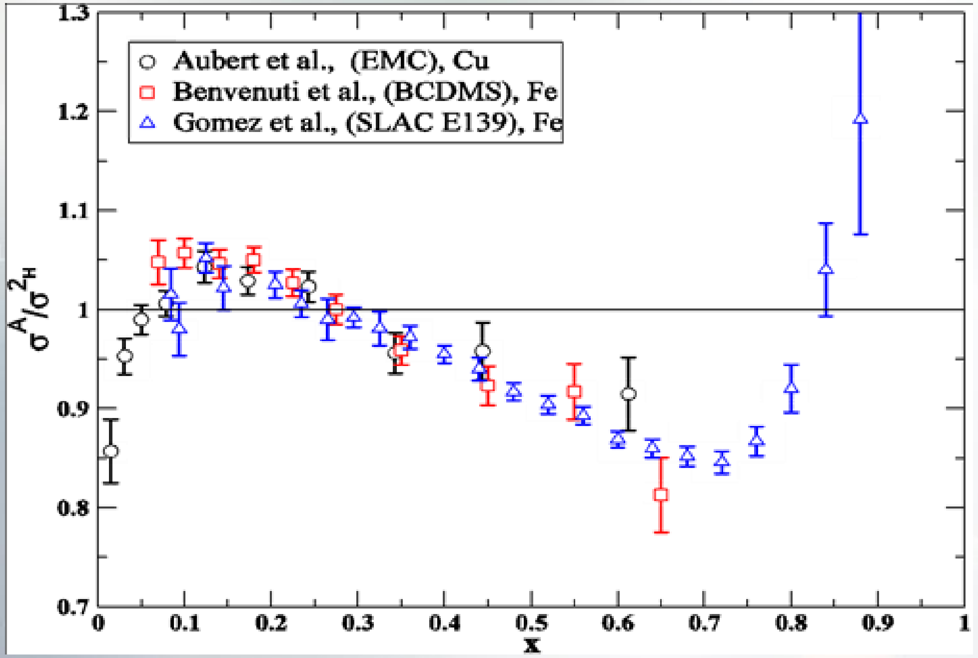
- First seen by the European Muon Collaboration (EMC)
- Partonic structure of nucleons is modified in nuclei
- Studied through ratios of nuclear F_2 structure functions to deuterium

$$\frac{\frac{d^2\sigma_A}{d\Omega dE'}}{\frac{d^2\sigma_D}{d\Omega dE'}} = \frac{\sigma_A}{\sigma_D} = \frac{F_2^A}{F_2^D}$$

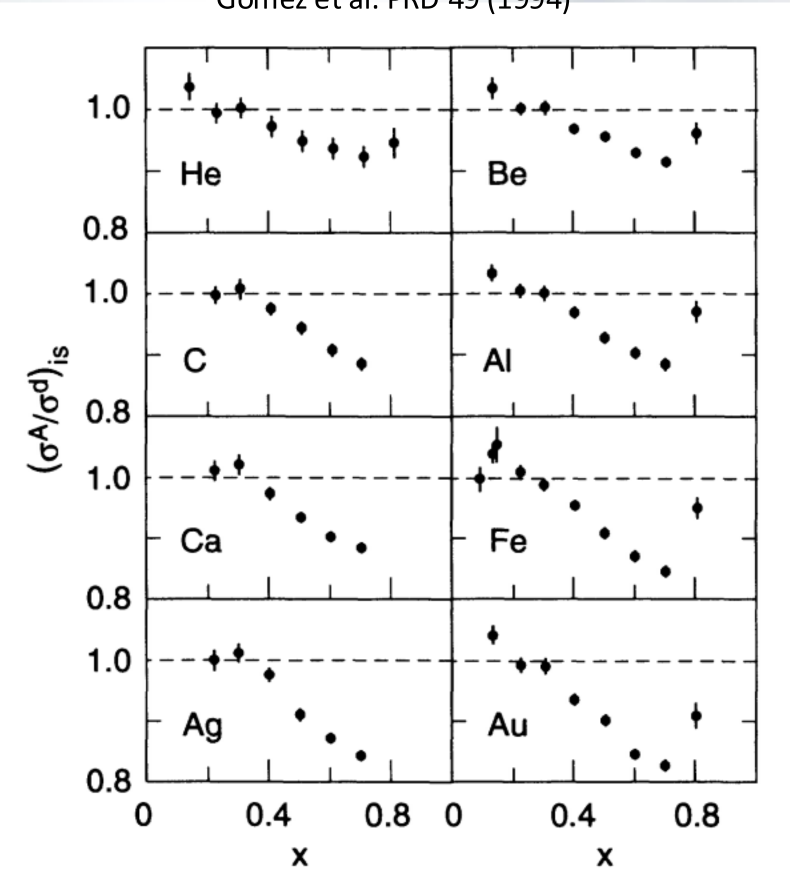


The EMC Effect

- Target ratios are generally characterized by universal features:
  - Shadowing
  - Antishadowing
  - EMC Effect
  - Fermi Smearing



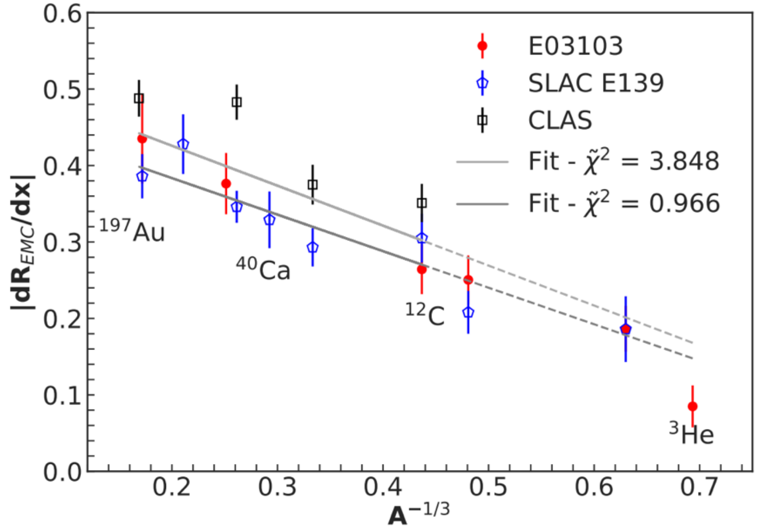
Gomez et al. PRD 49 (1994)



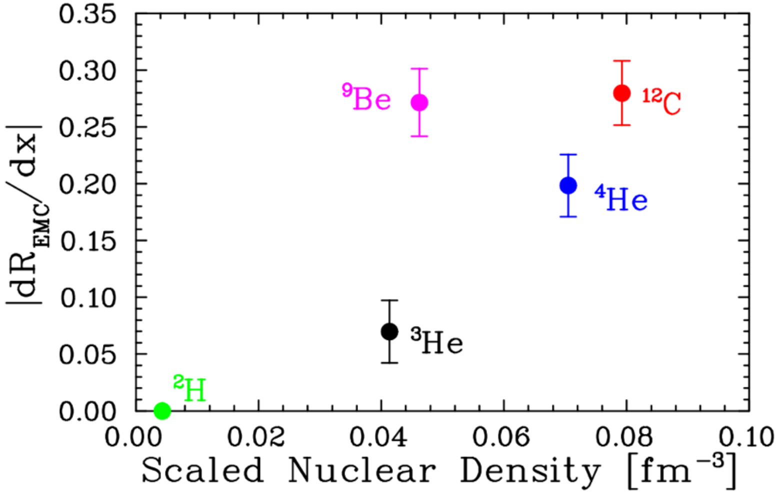
Known Properties

- Scales with mass number A
- Seems related to nuclear density
  - Inconclusive if it is mean or local density
  - Nuclei with α structure seem to have larger modification
  - Beryllium-9 data has anomalously large modification, which has low mean density but large local density (2 α + halo n)
- Correlated with the strength of Short Range Correlations (SRCs)
  - Not yet determined if this is a causal relationship or if the two effects have a common root cause

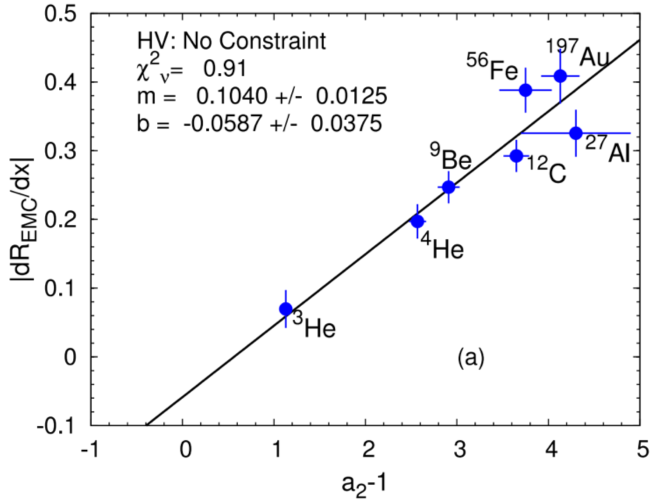
Arrington *et al.* PRC 104 (2021)



Seely *et al.* PRL 103 (2009)



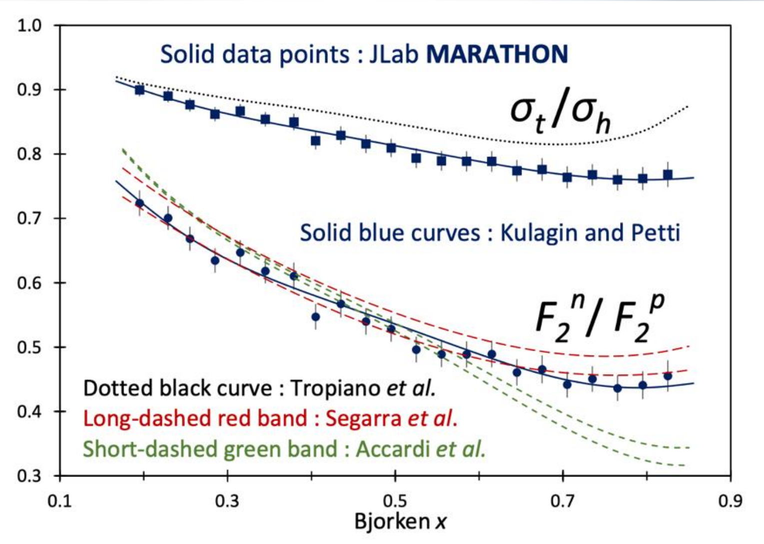
Arrington *et al.* PRC 86 (2012)

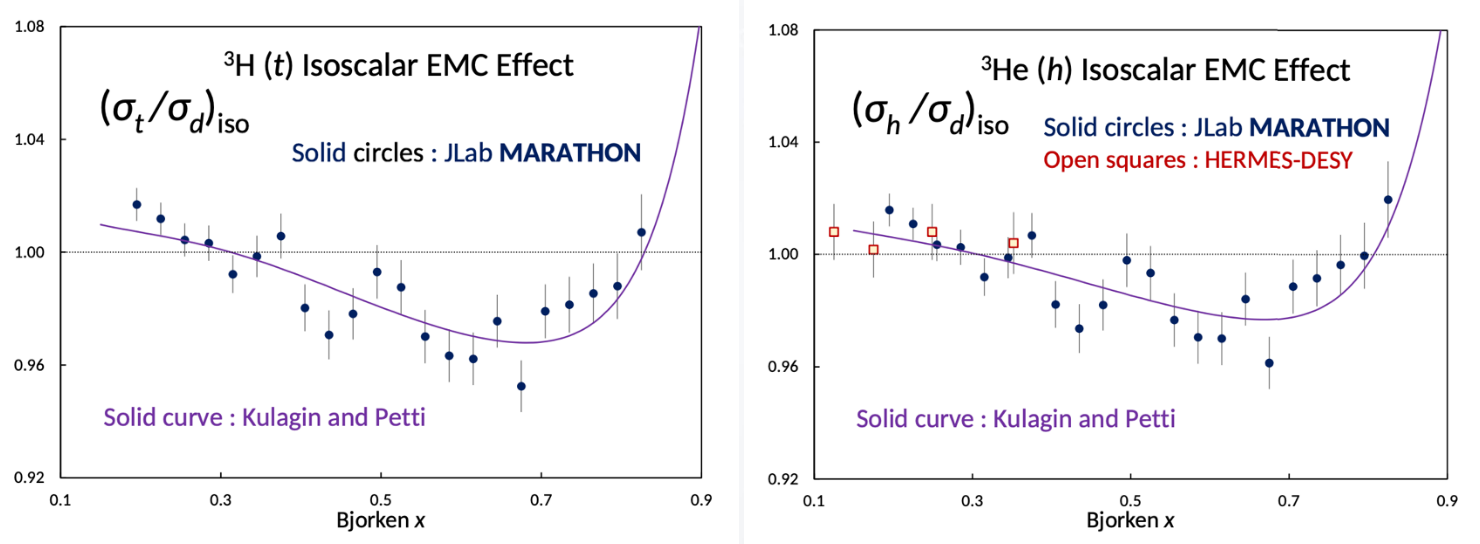


The MARATHON Experiment

- Deep Inelastic Scattering experiment in Hall A at Jefferson Lab
- Four targets
  - Hydrogen
  - Deuterium
  - Tritium
  - Helium-3
- Two main goals
  - Extract F_2^n/F_2^p from the A=3 mirror nuclei ratio
  - Study the EMC effect in the A=3 mirror nuclei

Jefferson Lab Hall A Tritium Collaboration PRL 128 (2022)



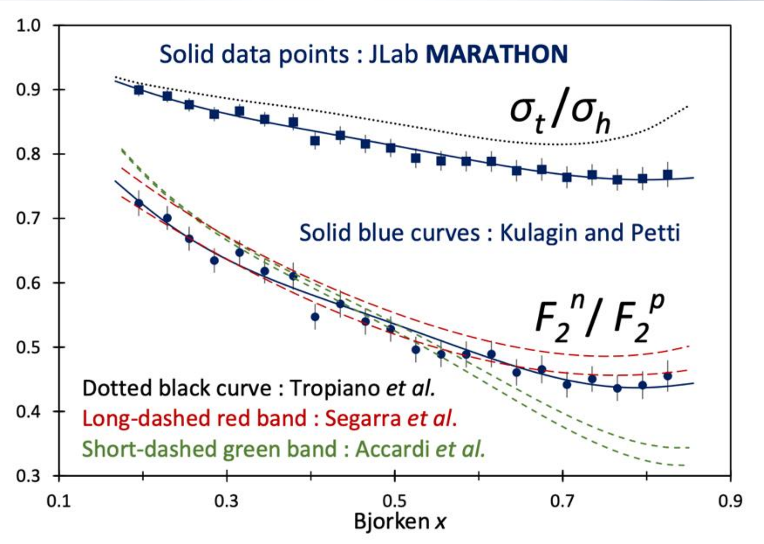


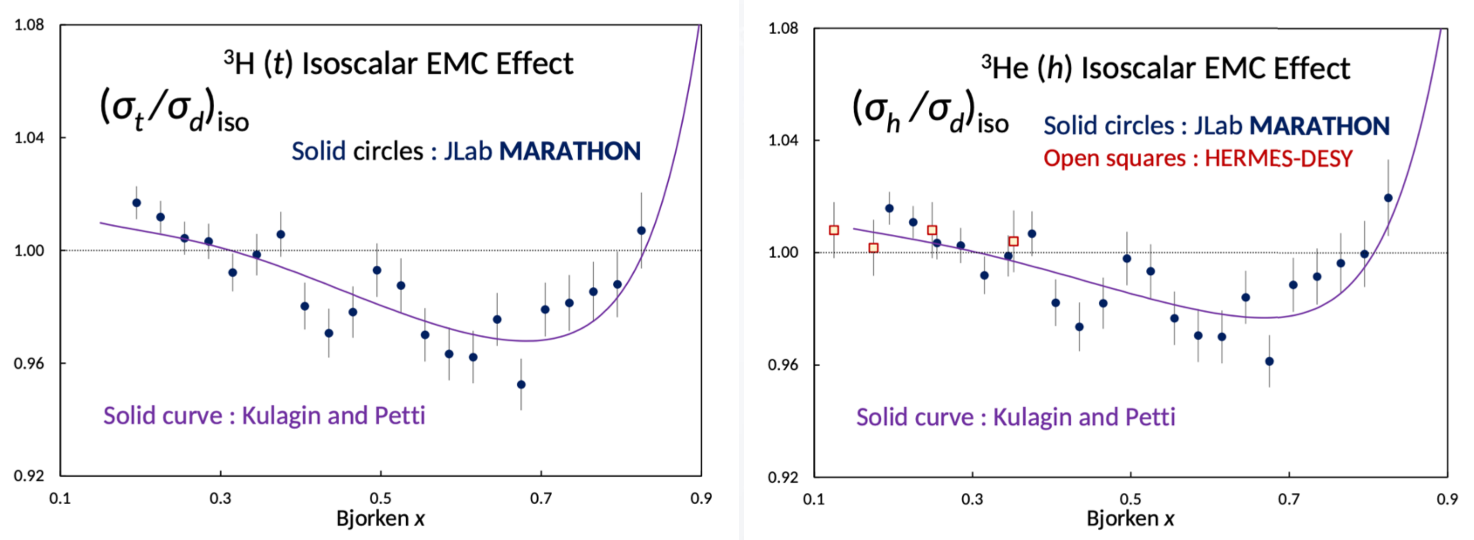
Jefferson Lab Hall A Tritium Collaboration PRL 135 (2024)

The MARATHON Experiment

- Deep Inelastic Scattering experiment in Hall A at Jefferson Lab
- Four targets
  - Hydrogen
  - Deuterium
  - Tritium
  - Helium-3
- ~~Two~~ Three main goals
  - Extract F_2^n/F_2^p from the A=3 mirror nuclei ratio
  - Study the EMC effect in the A=3 mirror nuclei
  - Give Tyler a thesis topic

Jefferson Lab Hall A Tritium Collaboration PRL 128 (2022)





Jefferson Lab Hall A Tritium Collaboration PRL 135 (2024)

The Problem of Helium-3

Helium-3 DIS Data

- There are three world data sets of DIS on Helium-3, all of which deviate from the "universal" picture

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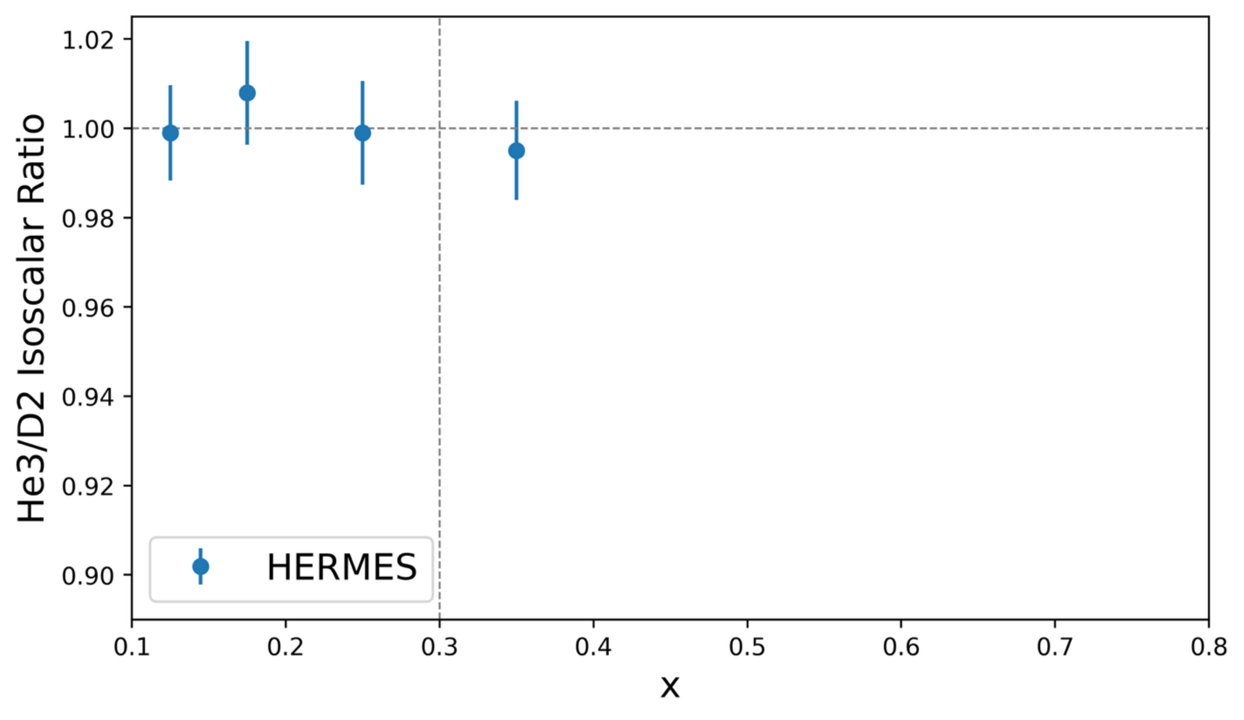
  - Once is an accident



Helium-3 DIS Data

- There are three world data sets of DIS on Helium-3, all of which deviate from the "universal" picture
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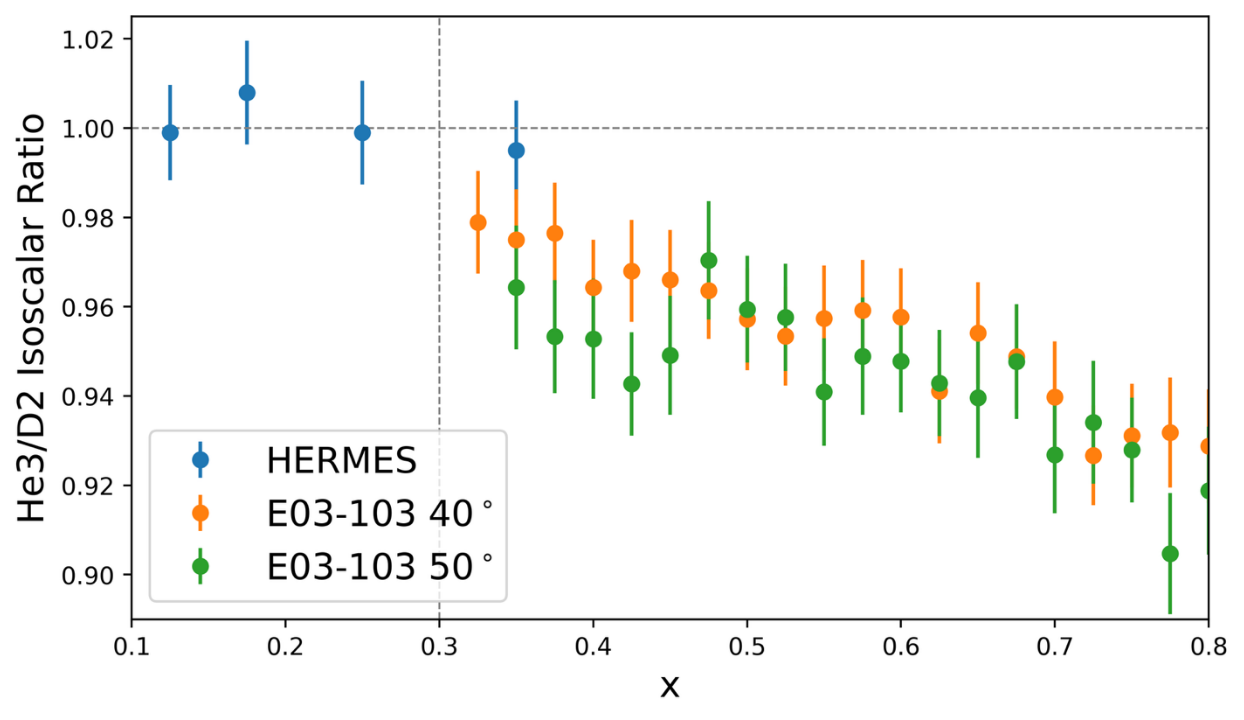
  - Twice is a coincidence



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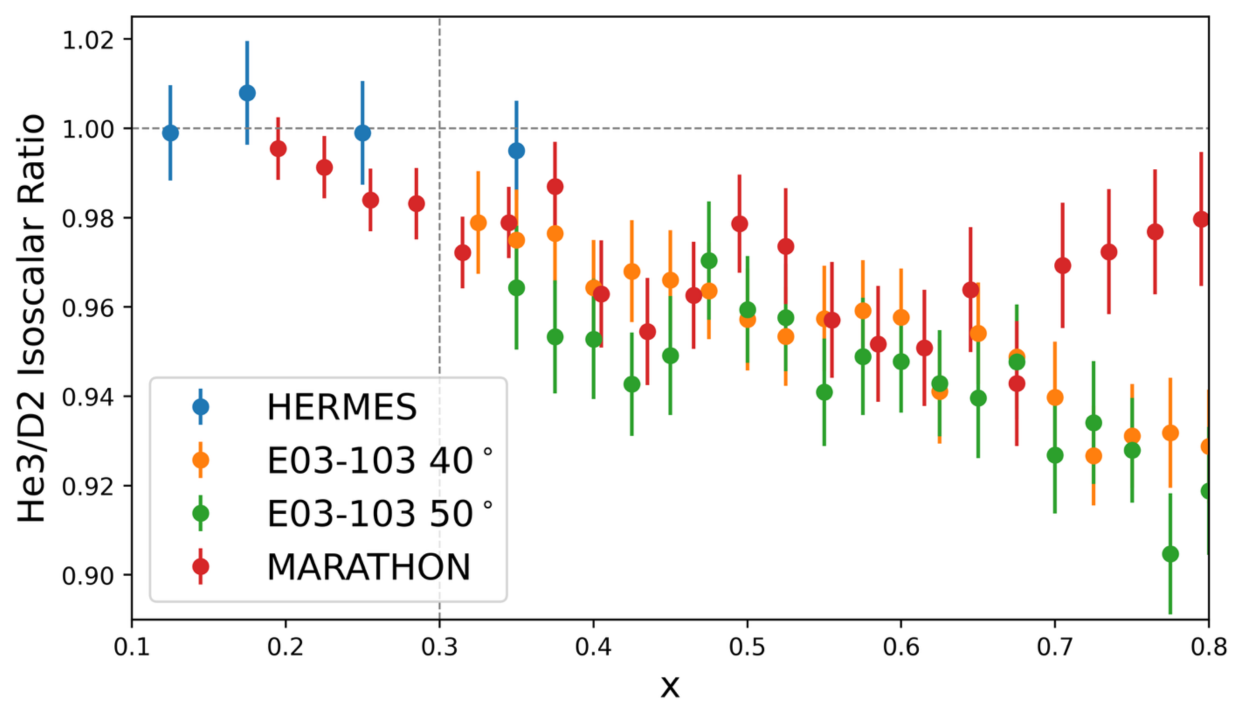
  - Thrice is a pattern



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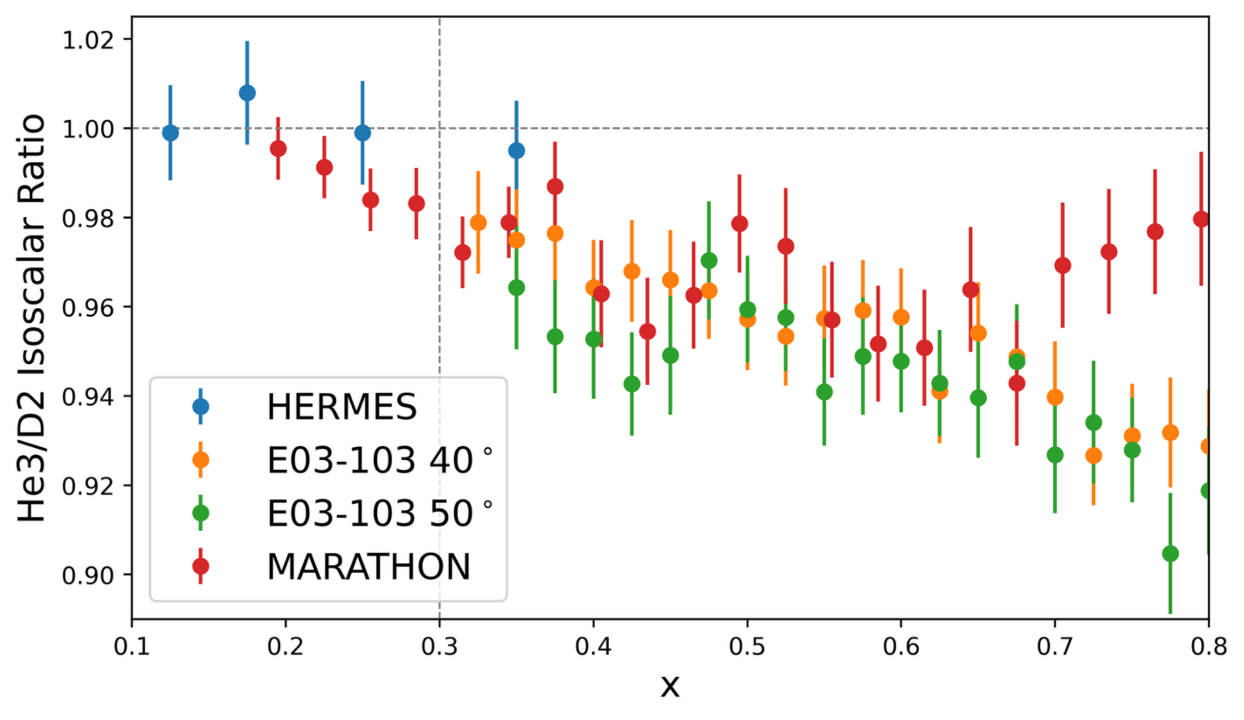


None of these data sets show the expected unity crossing at x=0.3!*

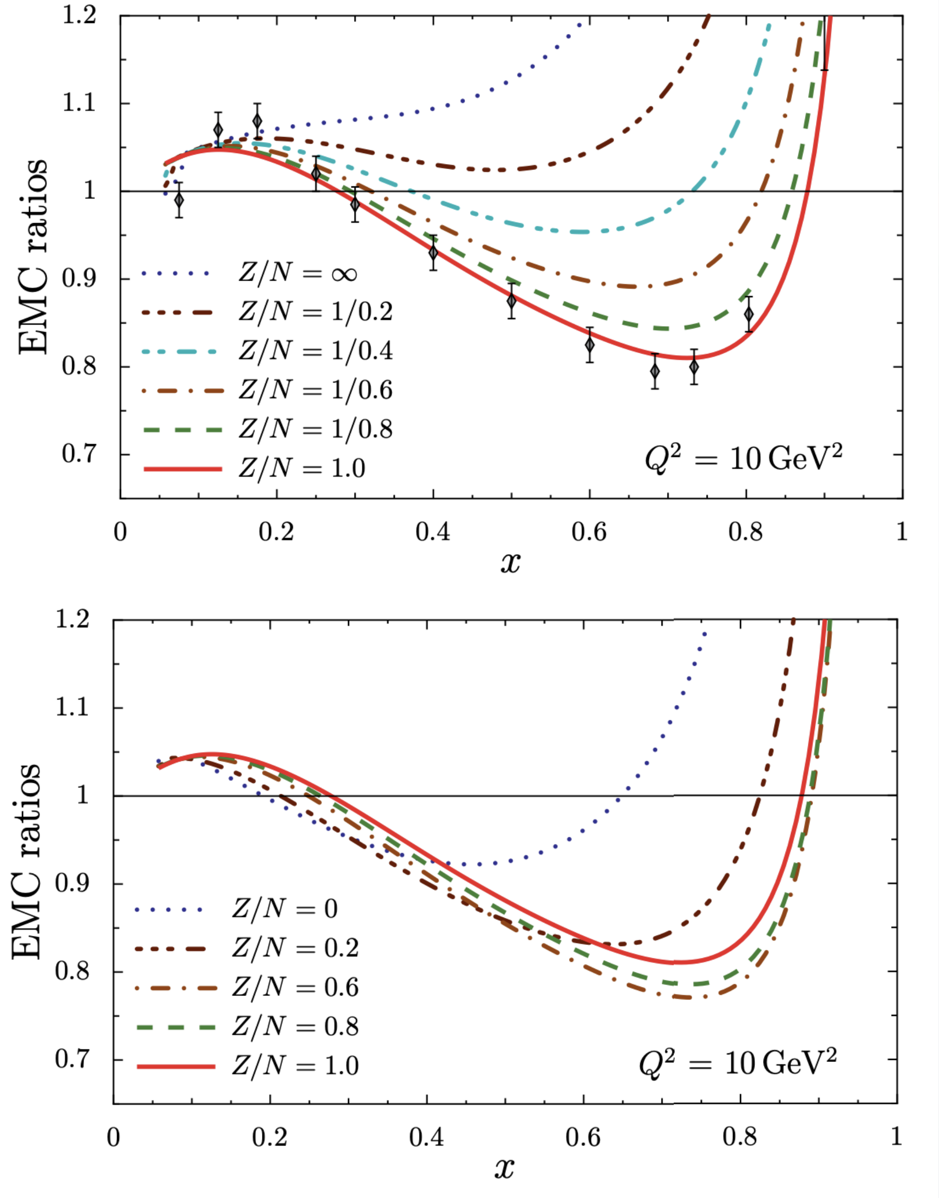
*HERMES and MARATHON were both normalized to "correct" for this. All normalizations are removed in this figure.

Is the EMC Effect Isospin Dependent?

Does N/Z impact the modification?

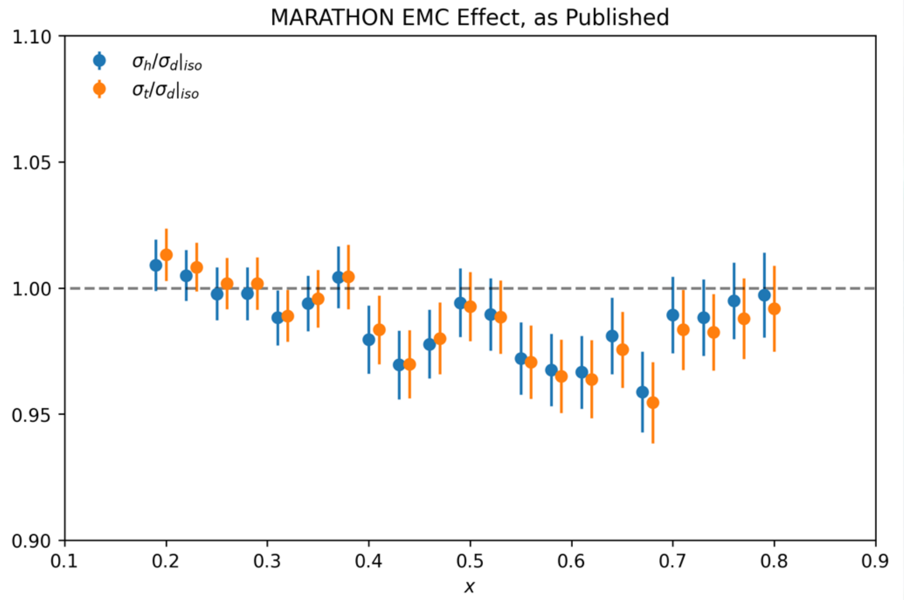
- Isospin dependence is not *strictly* distinct from isovector dependence
- However, isospin dependence is more easily studied experimentally
  - Vary N/Z with similar A
  - Tagging
- Experimentally, the studies focus on proton and neutron differences rather than quark flavor differences

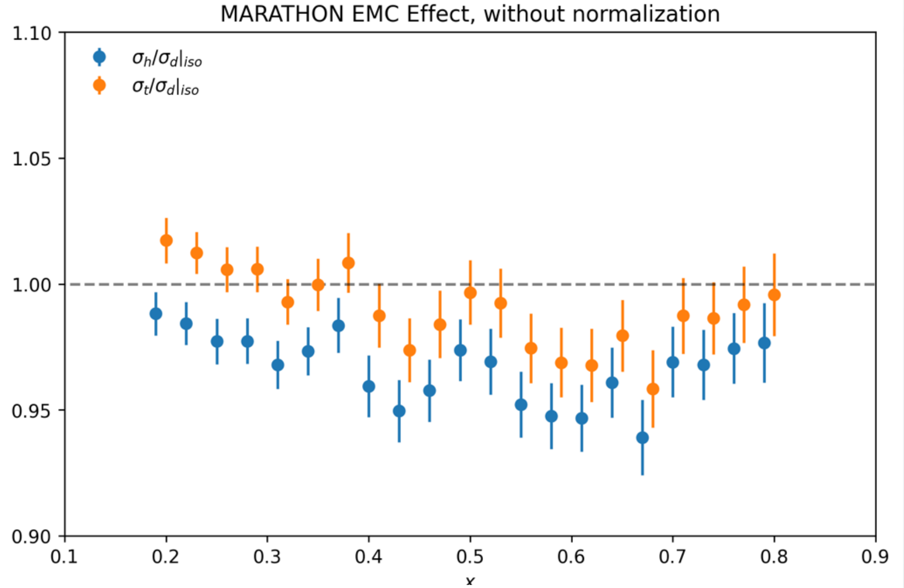
Cloët, Bentz, Thomas, PRL 102 (2009)



MARATHON

- DIS on Hydrogen, Deuterium, Tritium, and Helium-3
- Extracted F_2^n/F_2^p and the A=3 EMC Effect
- Mirror nuclei negates the impact of A-dependent effects
- Maximally isospin asymmetric
  - He3 N/Z = 1/2
  - H3 N/Z = 2
- Published data was normalized using a model that omits many isospin and isovector effects
- When the normalization is omitted, the data is more consistent with world data and suggests isospin dependent effects
- Helium-3 does not exhibit a unity crossing and has a much shallower slope

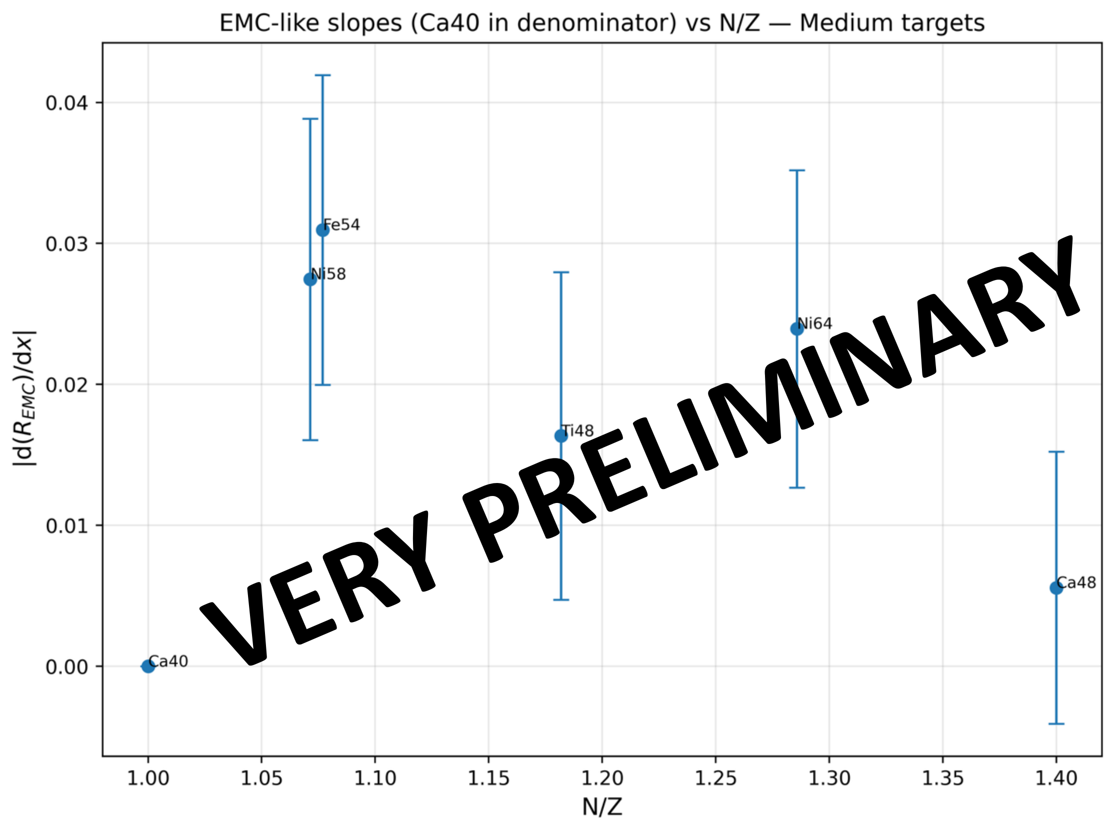




Both figures use MARATHON F_2^n/F_2^p as published for isoscalar corrections, which has the normalization built in. Consequently, the bottom figure is not *fully* free of the model assumptions

XEM2 (Very preliminary)

- Recorded DIS on a large set of nuclei from light to large
- Two main groups of nuclei for testing isospin dependence
  - Medium: Ca40, Ca48, Fe54, Ni58, Ni64
  - Light: Li6, Li7, Be9, B10, B11, C12 (←Not yet ready to show)
- Experiment also has Helium-3 data
  - Data is still being studied and is not yet ready to show



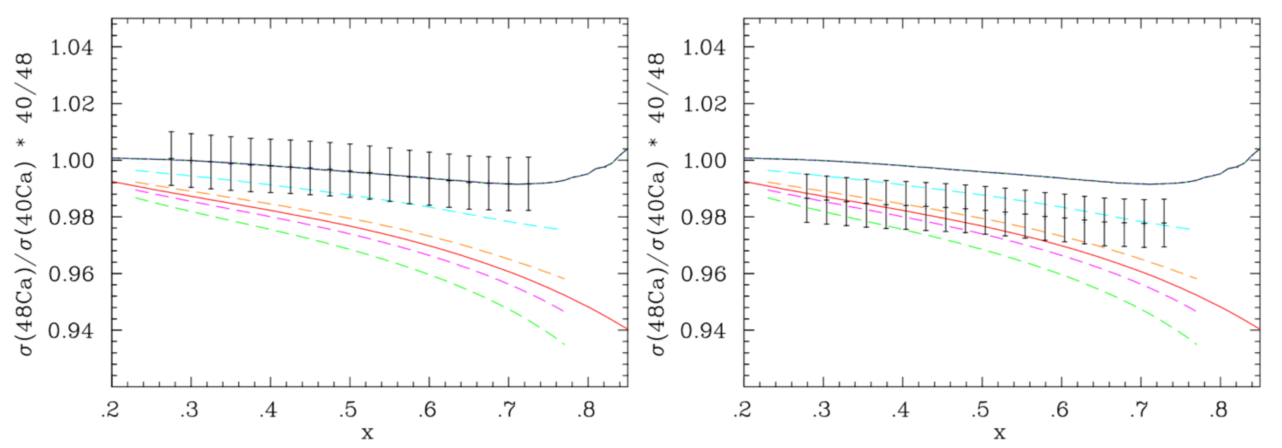
*Systematics are estimated as a few sources are still under review

Is the EMC Effect Isovector Dependent?

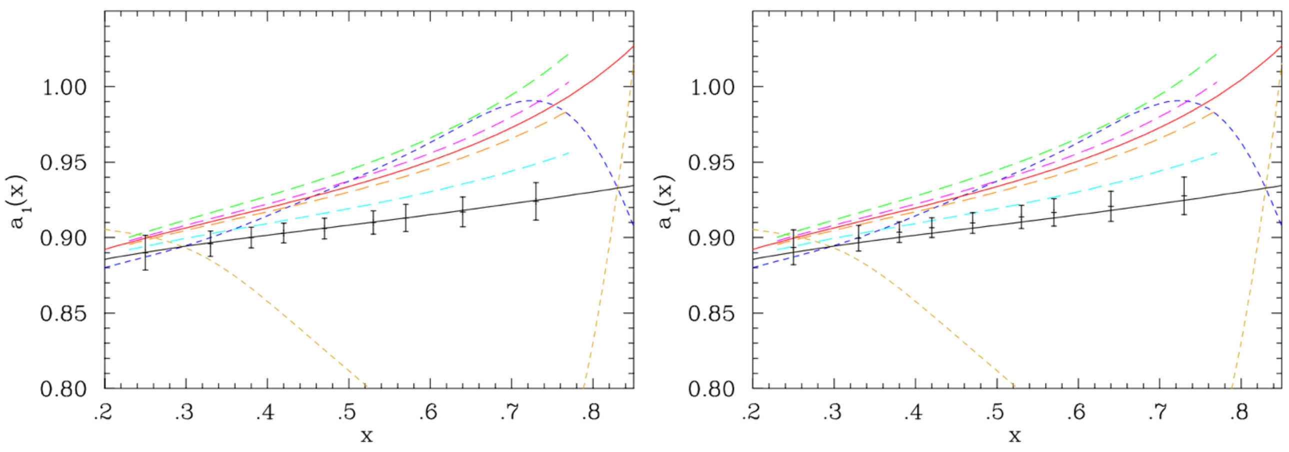
Are quark flavors modified differently?

- Focuses on differences in modification by quark flavor
- Difficult to directly* measure experimentally
  - Inclusive DIS – Can constrain, needs unrealistic uncertainties to be definitive
  - SIDIS – Can constrain, but limited by knowledge and assumptions about fragmentation functions
  - Parity Violation – Cleaner, but requires very high luminosity and/or run time

Arrington *et al.* C12-22-002 Proposal (2022)



(Above) Sensitivity of inclusive measurements to models with isovector EMC Effects
Right shows 1σ normalization shift from no-isovector baseline (solid black line)



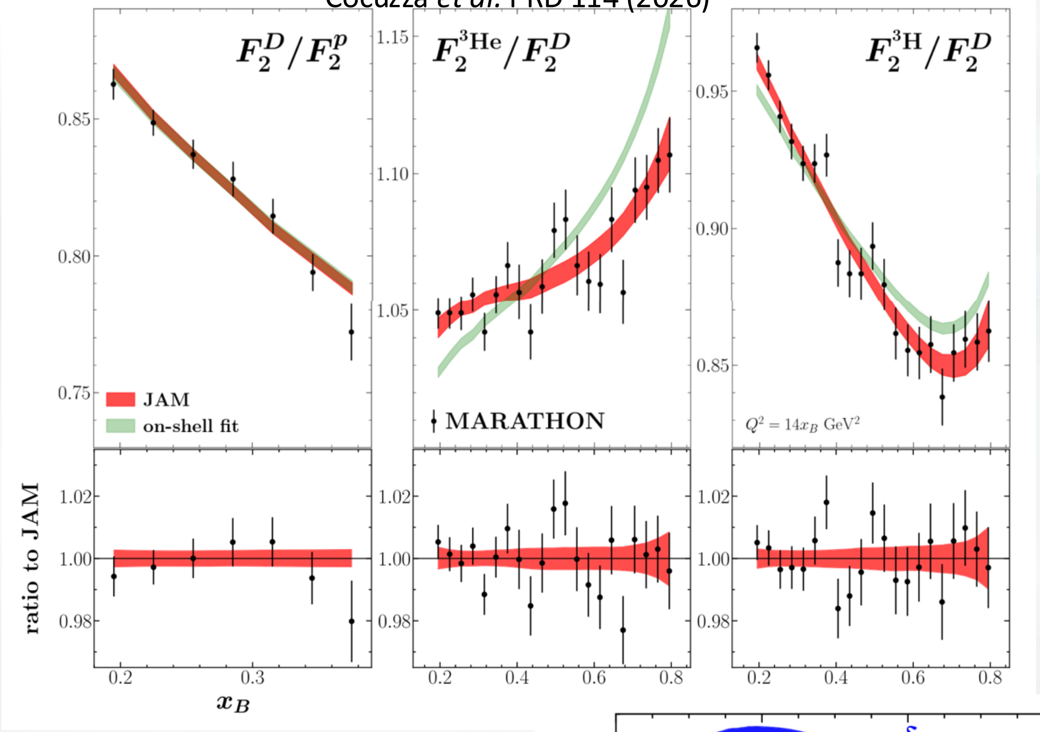
(Above) Sensitivity of proposed PVDIS measurement to models with isovector EMC Effects
Right shows 1σ normalization shift from no-isovector baseline (solid black line)

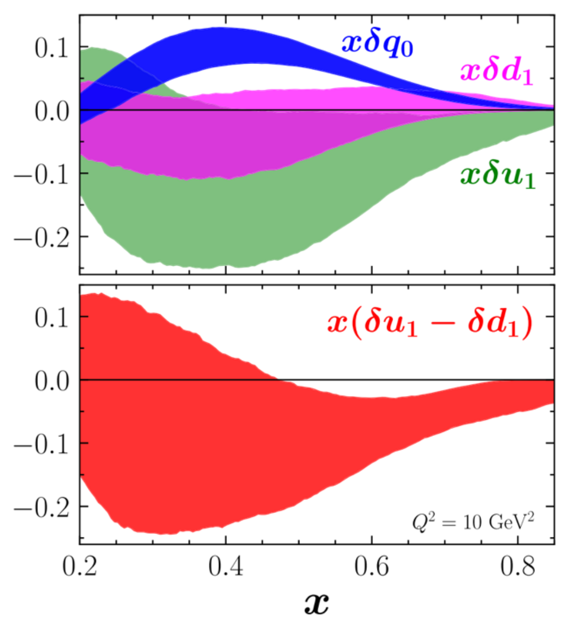
- *Directly is a simplification, as PDFs and off-shell functions are not observables

JAM 2021 & 2026

- The JAM PDF Analysis Group incorporated the MARATHON results into their global analysis of light nuclei
- Used the published data without the normalization
- Explicit purpose was to fit off-shell functions
  - Enforced flavor-symmetry in isoscalar off-shell functions
  - Did not enforce flavor-symmetry in isovector off-shell functions
  - Driven by a combination of the number of experimental constraints and physical motivation
- Found that the data requires a very large isoscalar off-shell effect
- Hints at non-zero isovector off-shell effect
- See Wally's talk from this morning for more detail

Cocuzza *et al.* PRD 114 (2026)





Is $R = \sigma_L/\sigma_T$ Universal?

Getting F_2 Ratios

- From a cross section ratio, we can see that they are equal to the F_2 ratio multiplied by a set of kinematic factors
- If, and only if, $R_A = R_D$ we can then completely cancel those terms so long as the data were taken at the same kinematics
- This is the standard assumption made

$$\frac{\frac{d^2\sigma_A}{d\Omega dE'}}{\frac{d^2\sigma_D}{d\Omega dE'}} = \frac{\sigma_A}{\sigma_D} = \frac{F_2^A\left[\frac{1}{\nu} + \frac{(1+Q^2/\nu^2)}{xM(1+R_A)}\tan^2\left(\frac{\theta}{2}\right)\right]}{F_2^D\left[\frac{1}{\nu} + \frac{(1+Q^2/\nu^2)}{xM(1+R_D)}\tan^2\left(\frac{\theta}{2}\right)\right]}$$

If $R_A = R_D$:

$$\frac{\sigma_A}{\sigma_D} = \frac{F_2^A}{F_2^D}$$

Getting F_2 Ratios

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- How well do we know it?

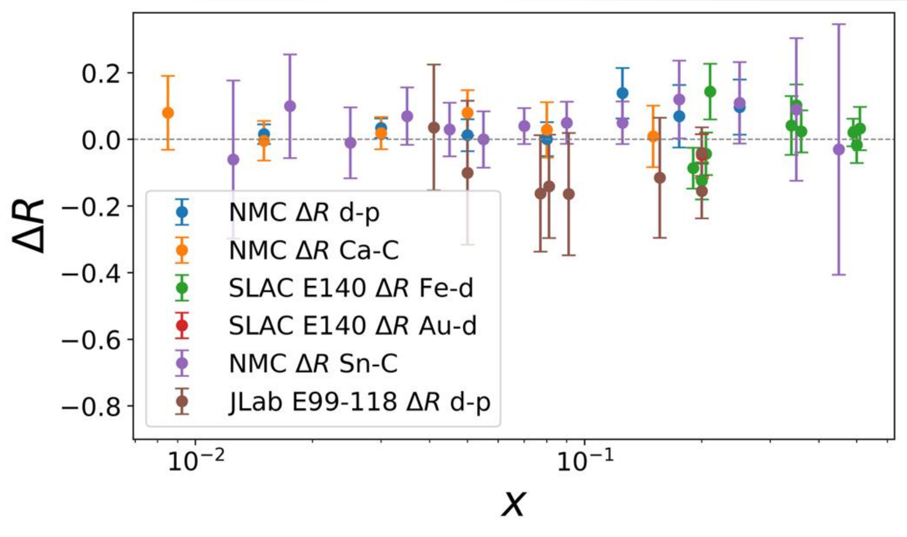
$$\frac{\frac{d^2\sigma_A}{d\Omega dE'}}{\frac{d^2\sigma_D}{d\Omega dE'}} = \frac{\sigma_A}{\sigma_D} = \frac{F_2^A\left[\frac{1}{\nu} + \frac{(1+Q^2/\nu^2)}{xM(1+R_A)}\tan^2\left(\frac{\theta}{2}\right)\right]}{F_2^D\left[\frac{1}{\nu} + \frac{(1+Q^2/\nu^2)}{xM(1+R_D)}\tan^2\left(\frac{\theta}{2}\right)\right]}$$

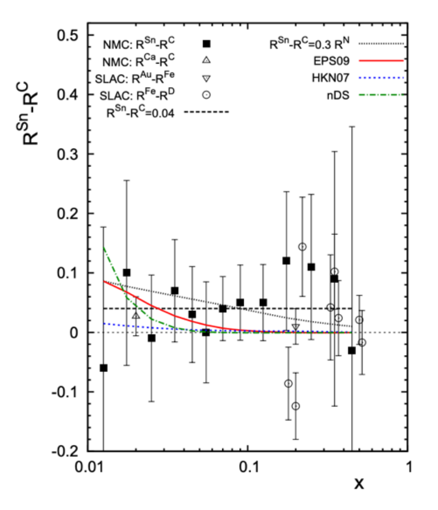
If $R_A = R_D$:

$$\frac{\sigma_A}{\sigma_D} = \frac{F_2^A}{F_2^D}$$

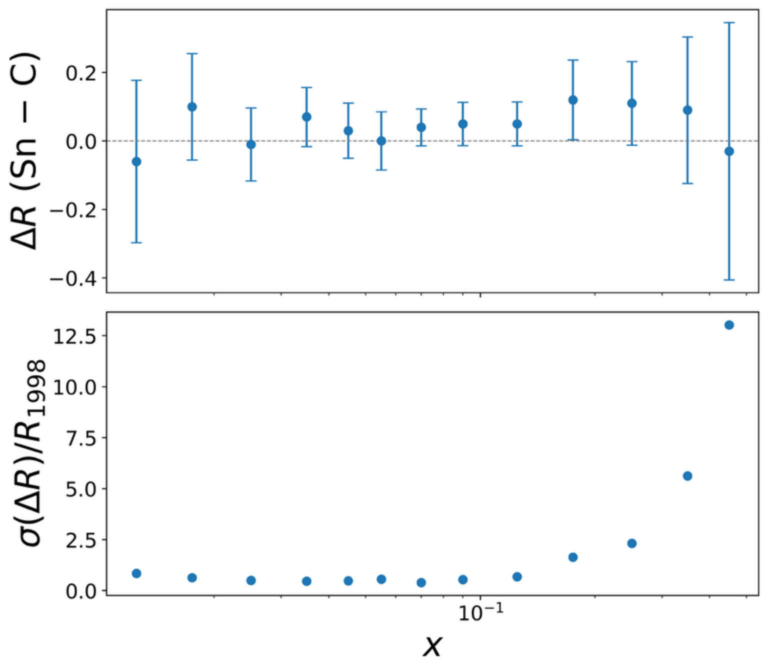
Universality of R

- In studies of the EMC effect, it is standard procedure to assume that R is universal for all nuclei
- That is, R_A=R_D which allows kinematic quantities in the ratio to cancel making the cross section ratio equal to the F_2 ratio





V. Guzey *et al,* PRC 86 (2012)

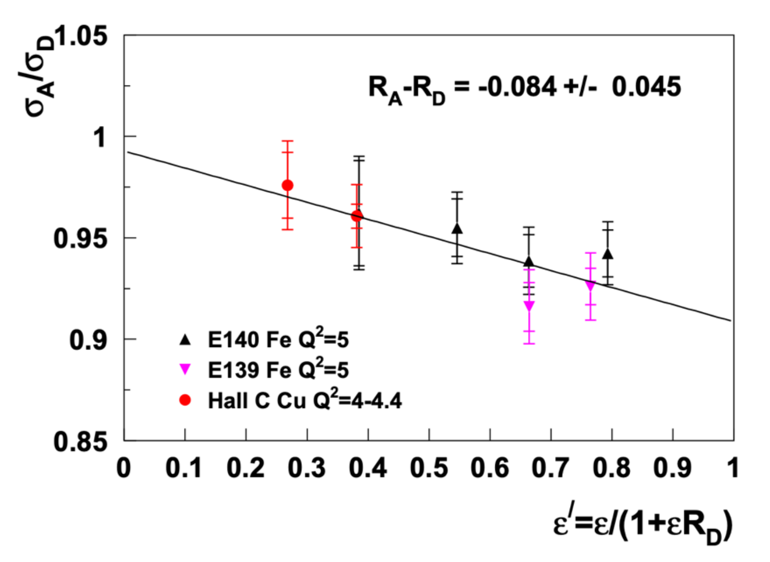


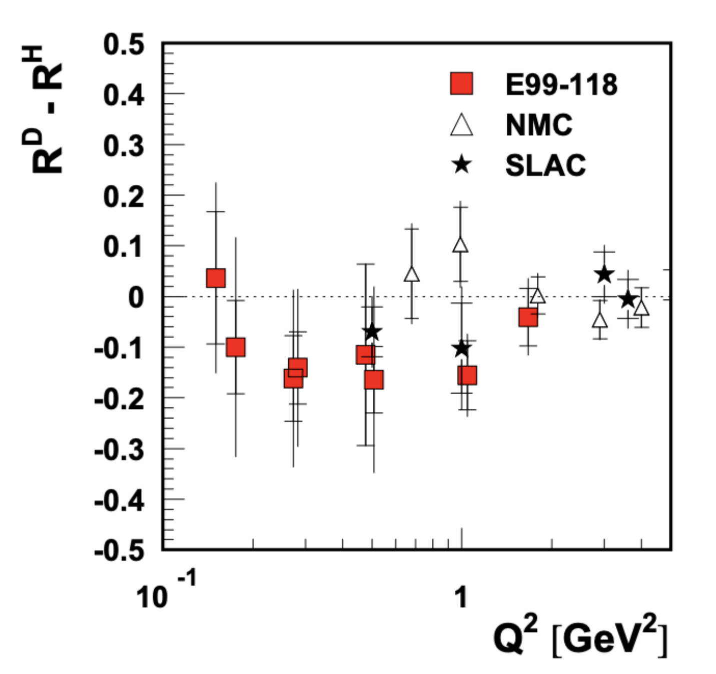
An example of precision of ΔR=0
Data from M. Arneado *et al,* NPB 481 (1996)
R1998 from K. Abe *et al,* PLB 452 (1999)

Jefferson Lab

Cracks in the Picture

- Analyses in the E12-14-002 proposal and V. Tvaskis *et al.*, PRL 98 (2007) hint that R may not be universal in the DIS regime
- Model independent analyses find that R_D trends smaller than R_p
- Model independent analyses find that R_A trends smaller than R_D
  - The nuclear targets studied are iron and copper





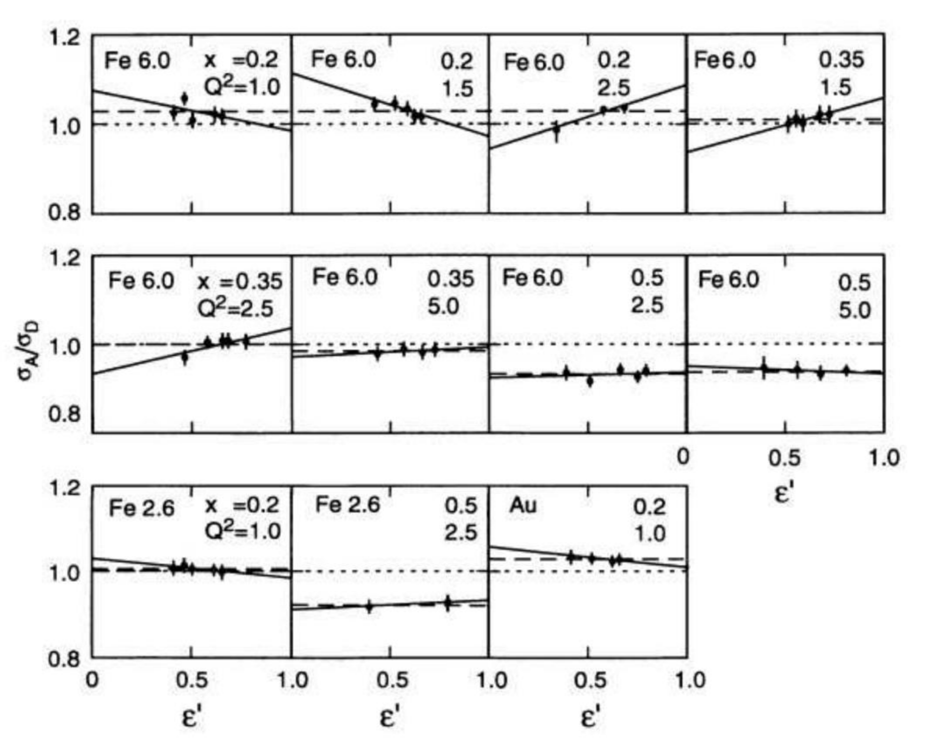
Model independent extraction of R and ΔR

- Requires an L-T separation by taking data at the same x and Q_2 with different beam energies to get a spread in ϵ (ϵ\` for ΔR)
- For cross sections, a linear fit gives σ_T for the intercept and $\sigma_T * R$ for the slope
- For cross section ratios, a linear fit gives F_1^A/F_1^D for the intercept and $\Delta R * F_1^A/F_1^D$ for the slope

$$\frac{\sigma\_A}{\sigma\_D} = \frac{F_1^A}{F_1^D}[1 + \epsilon`\Delta R]$$

$$\sigma = \Gamma\sigma_T(1 + \epsilon R)$$

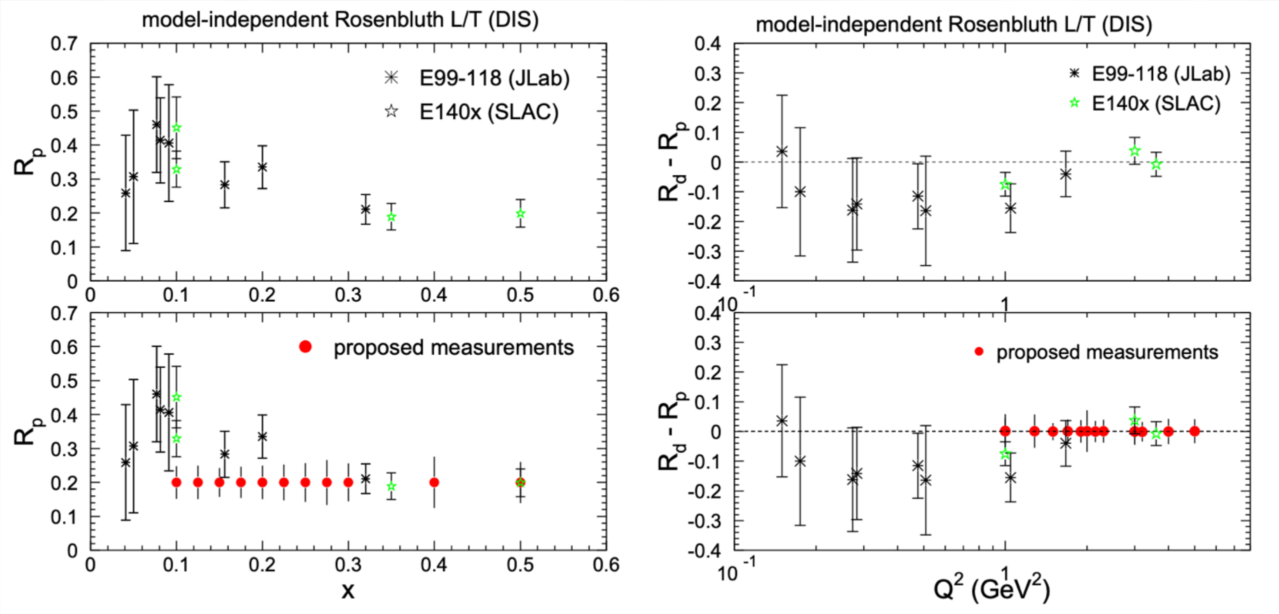
$$\Delta R = R_{numerator} - R_{denominator}$$



S. Dasu *et al.*, PRD 49 (1994)

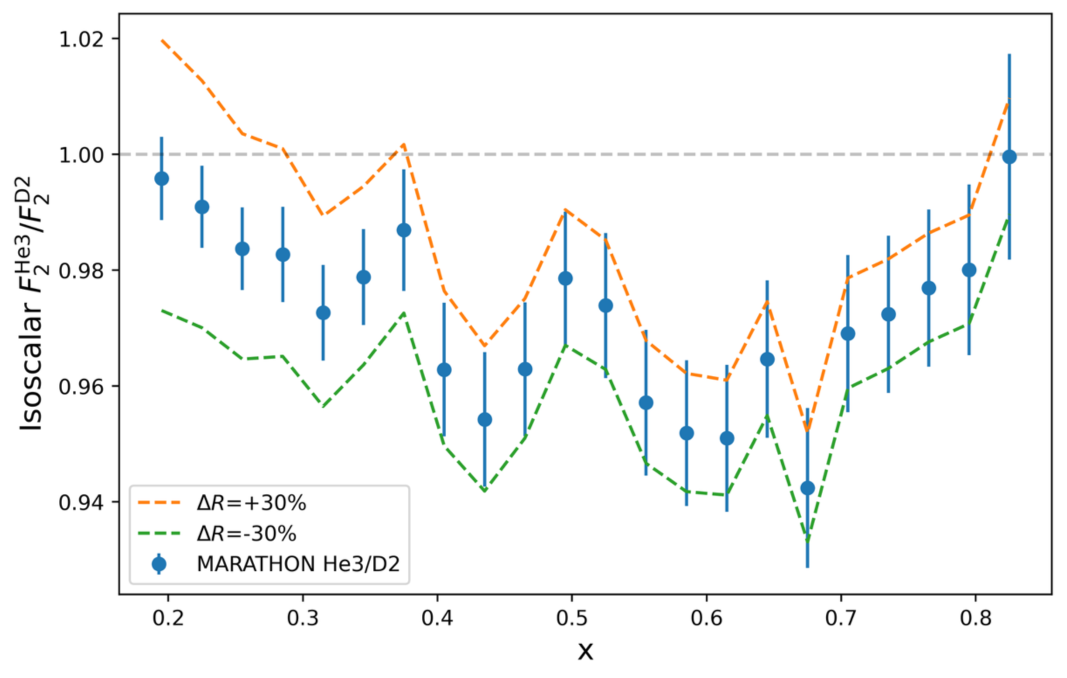
A Dependence of R (E12-14-002)

- Hall C experiment will run in 2027
- Extracting R, ΔR, F_1, F_2, and F_L on 5 target
  - Hydrogen
  - Deuterium
  - Carbon
  - Copper
  - Gold
- High-precision, model-independent test of the universality of R
- Spans $0.1 \leq x \leq 0.6$ and $1 \leq Q^2 \leq 5$



What if R is isospin dependent?

- Previously we noted that data suggests that R_D is smaller than R_p and that R_{Fe} and R_{Cu} is smaller than R_D
- Deuterium adds a neutron to proton
- Iron and copper have neutron excess
- Helium-3 has *proton* excess
- On the right is the MARATHON He3 EMC ratio, sans normalization, with a band showing the shift in the ratio if R is 30% different from deuterium, using the R1998 parameterization for R_D
- A shift of +30% (that is, larger R) is fairly close to the normalization applied



30% selected to match an example in V. Guzey *et al.* The value is well within the uncertainty at which R is measured to be universal

Can data tell us anything?

Let’s check

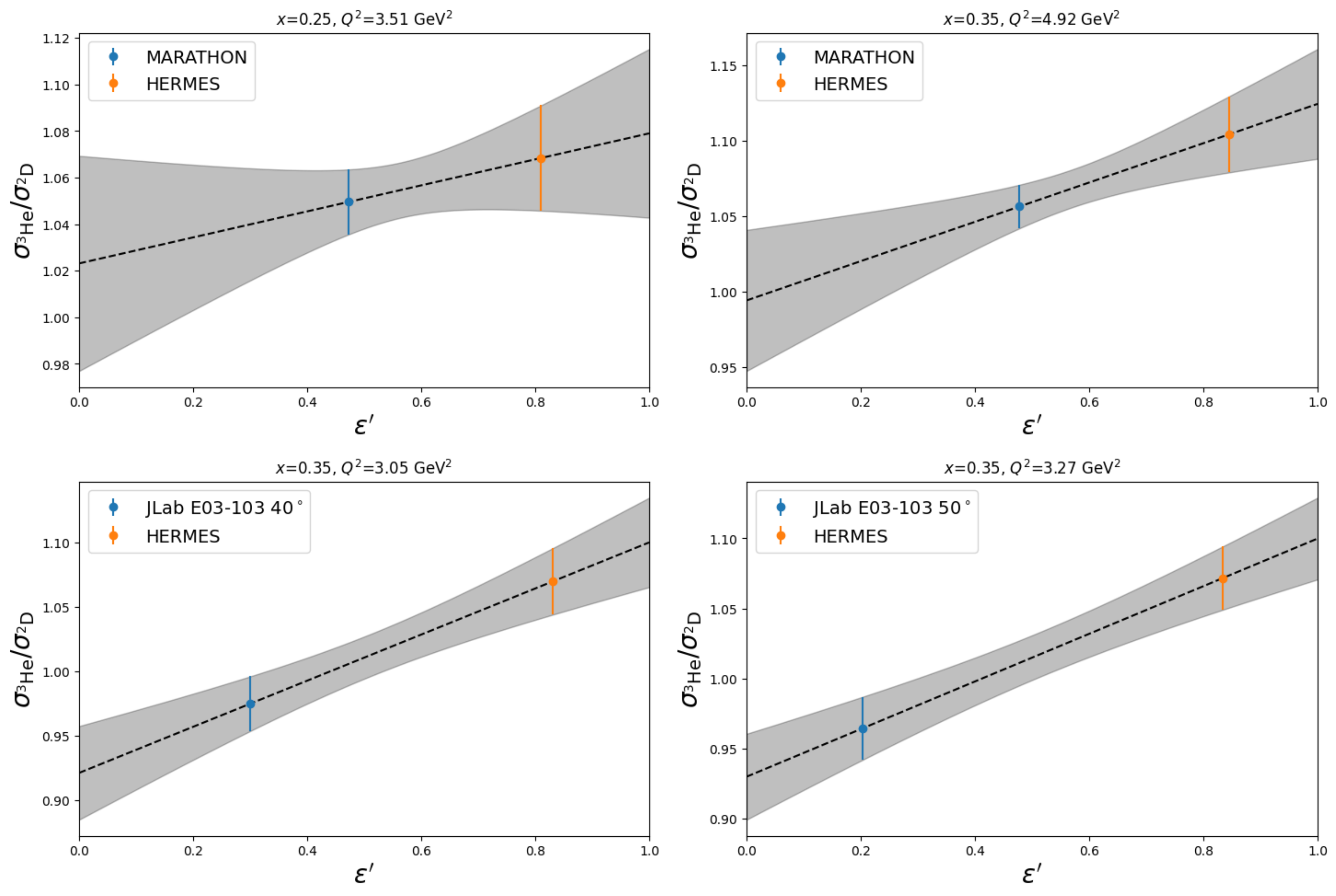
Data used

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
- Used R1998 for R_D (K. Abe *et al*, PLB 452 (1999))

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

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



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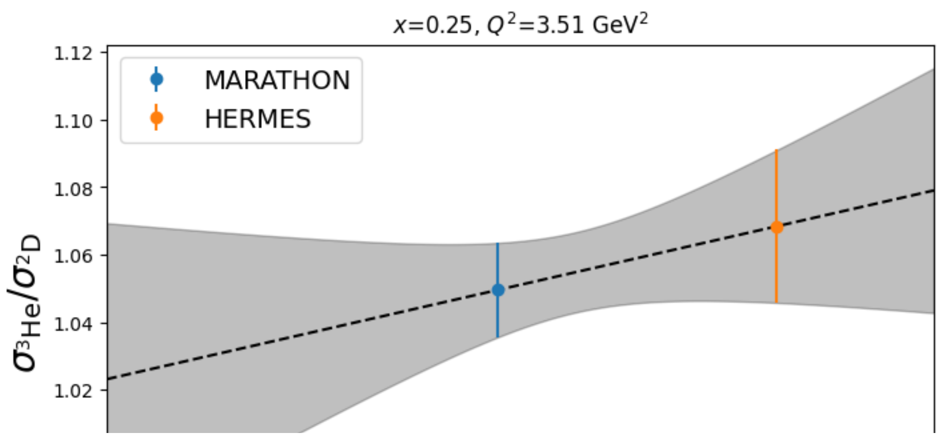
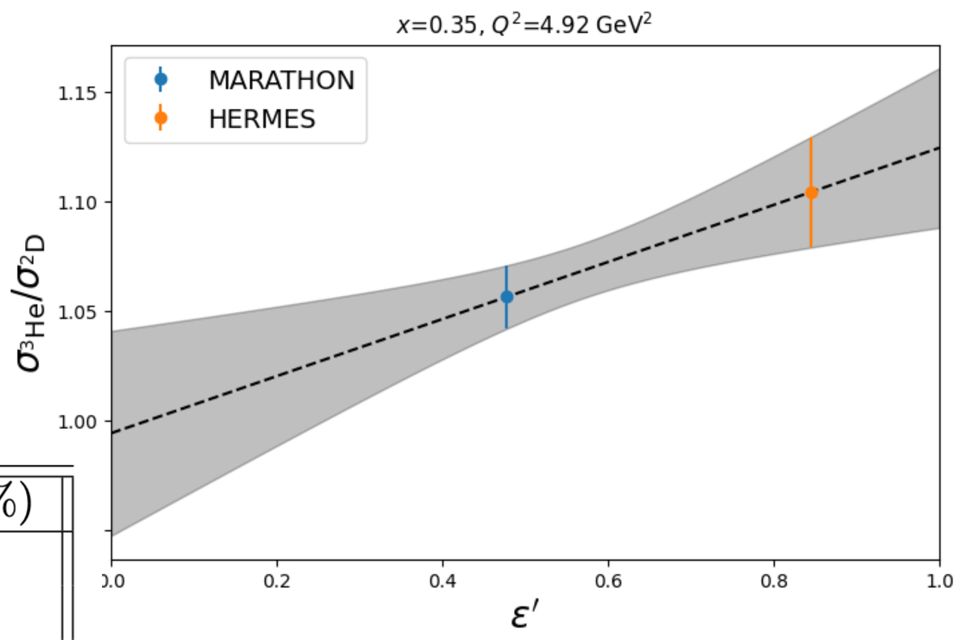
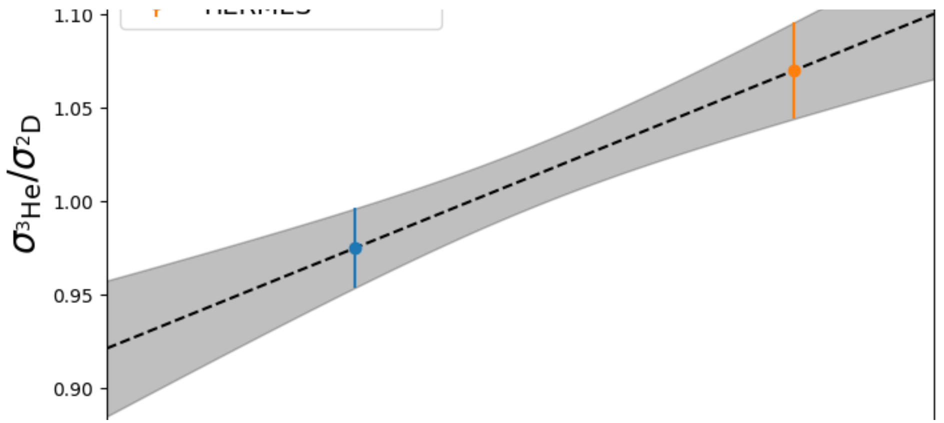
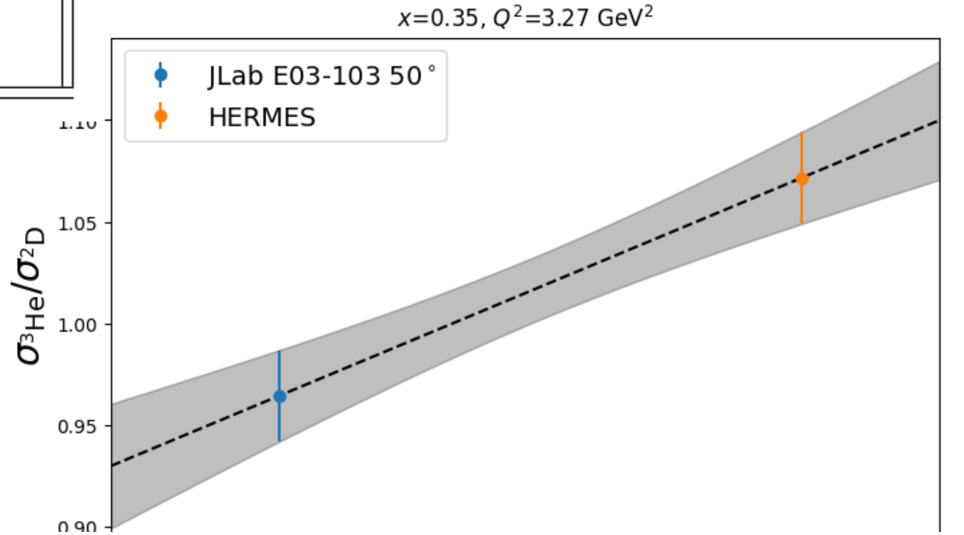




Data Sets	x	Q^2	ΔR	$\sigma_{\Delta R}$	$\Delta R/R_D$ (%)
HERMES + MARATHON	0.25	3.51	0.0554	0.0853	30.8%
HERMES + MARATHON	0.35	4.92	0.1318	0.0939	103%
HERMES + E03-103	0.35	3.0456	0.1947	0.0781	105%
HERMES + E03-103	0.35	3.2663	0.1834	0.0607	104%

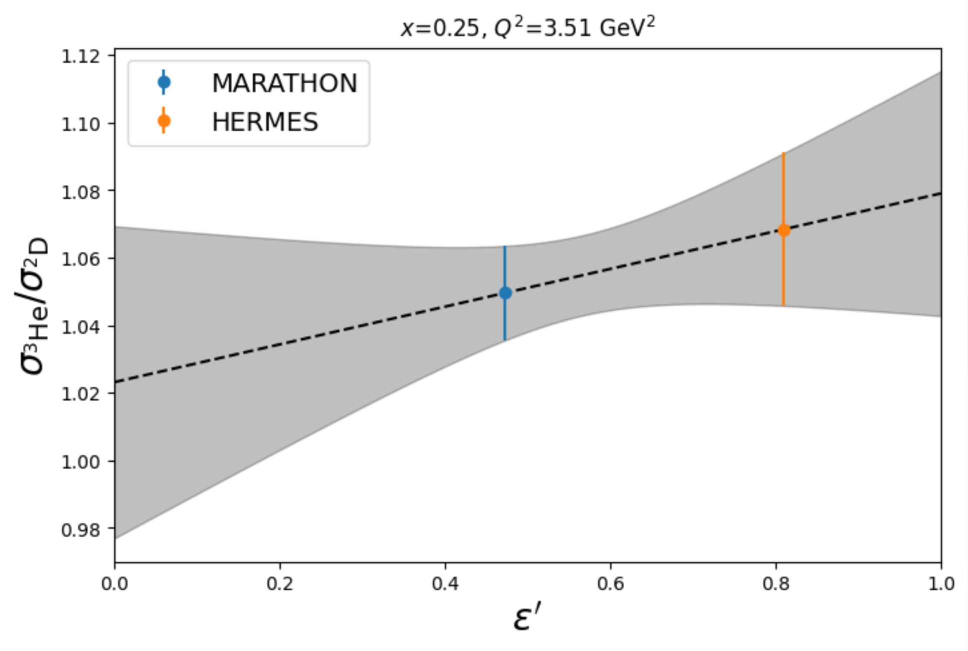


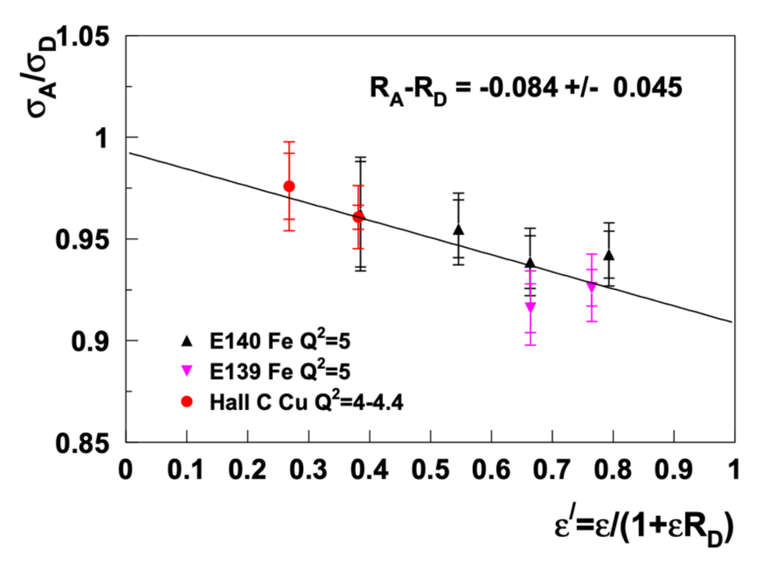


Uncertainties determined through 10,000 MC resampling trials with each experiments statistical, systematic, and scale uncertainties added in quadrature for smearing

Discussion

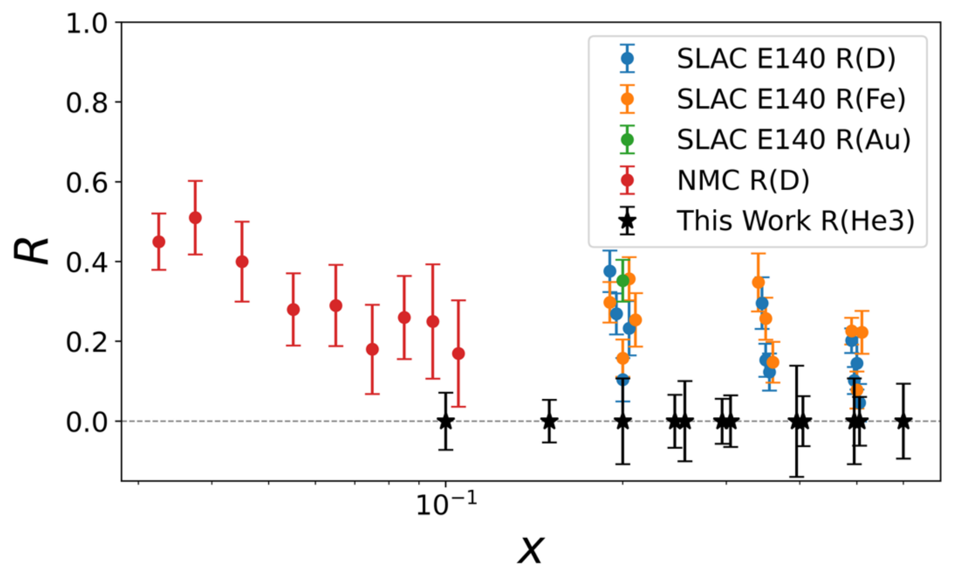
- The slope is opposite that of the previously shown ΔR plots
- The slope indicates a larger value of R for Helium-3 than Deuterium
- How can we test this?

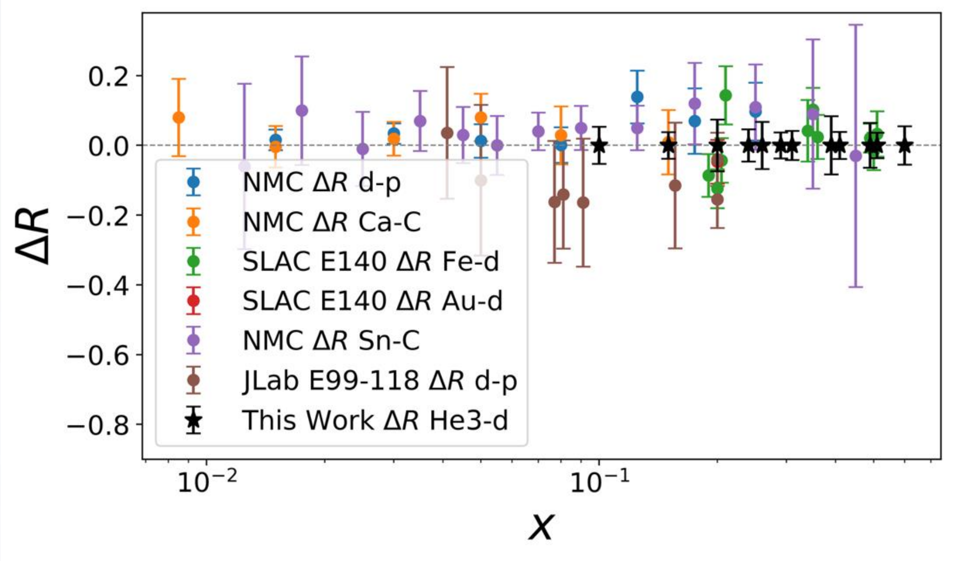




Isospin Dependence of R

- Helium-3 global analysis hints at a significant difference in the value of R for deuterium and helium-3*
- The value of ΔR from this study is opposite sign to that of the iron and copper study previously shown
- Iron and copper have neutron excess while helium-3 has proton excess, suggesting an isospin dependence to ΔR
- JLab PAC 54 (2026) approved adding a low-density Helium-3 target to the ladder for the A-dependence of R experiment to study this
  - Received 5 PAC days to cover a subset of the kinematics while maintaining broad x coverage





*Paper in development

Summary

- There are many interesting open questions remaining 40+ years on from the first measurement of the EMC effect
- Light nuclei are particularly sensitive to hypotheses about mechanisms behind the EMC effect
- A=3 nuclei have given evidence for isospin dependence, isoscalar and isovector off-shell effects, and non-universality of σ_L/σ_T
  - Many of these will be further tested in the future
- There will also be future tests of whether two-photon exchange contributes meaningfully to measurements of DIS and SIDIS and whether we correctly calculate coulomb corrections
  - See backup slides, I have too many slides for my time slot as is and needed to cut something

Summary

- There are many interesting open questions remaining 40+ years on from the first measurement of the EMC effect
- Light nuclei are particularly sensitive to hypotheses about mechanisms behind the EMC effect
- A=3 nuclei have given evidence for isospin dependence, isoscalar and isovector off-shell effects, and non-universality of σ_L/σ_T
  - Many of these will be further tested in the future
- There will also be future tests of whether two-photon exchange contributes meaningfully to measurements of DIS and SIDIS and whether we correctly calculate coulomb corrections
  - See backup slides, I have too many slides for my time slot as is and needed to cut something
- As an experimentalist at a workshop of mostly theorists… if you have ideas for how to further test any of these open questions or know of specific data that are needed to constrain models, please talk to me about them!

Backup

Two-Photon Exchange in **DIS** & SIDIS

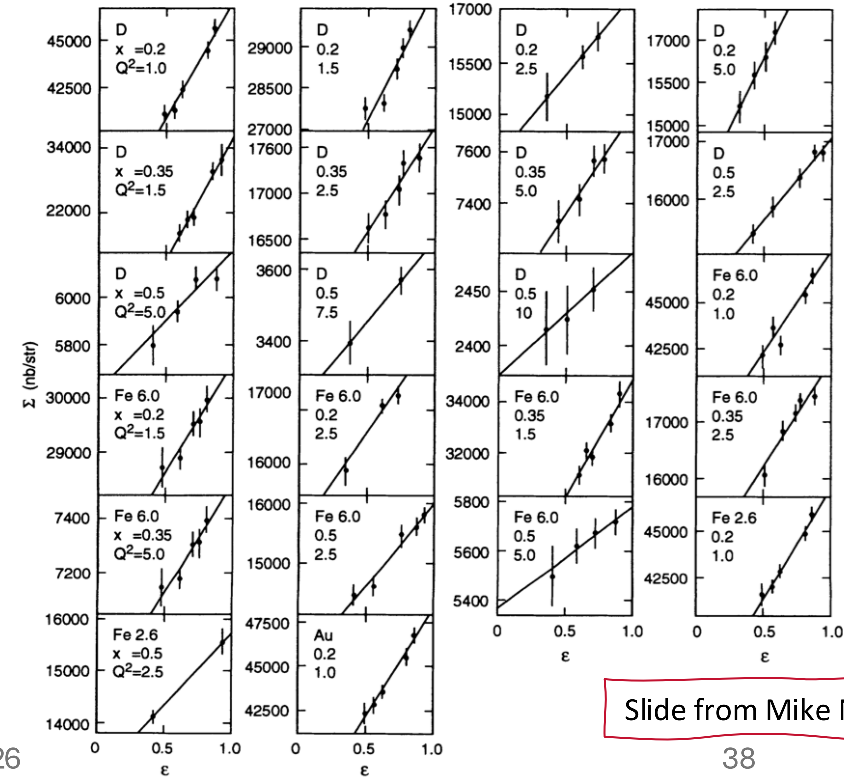
- No corollary to polarization transfer in DIS or SIDIS
- $\frac{G_E}{G_M}$ highlights the importance of understanding TPE effects in DIS
  - Small effect(s) can cause large discrepancies in measured observables
- Impact of TPE
  - L/T separations (Constant Q^2 and x bins)

$$\boxed{\frac{d^2\sigma}{d\Omega dE'} = \Gamma[\sigma_T(x, Q^2) + \varepsilon\sigma_L(x, Q^2)]}$$

$$\mathrm{R} = \frac{\sigma_L(x, Q^2)}{\sigma_T(x, Q^2)}$$

<u>TPE effects</u>

- ε dependent ?
- At large Q^2 ?



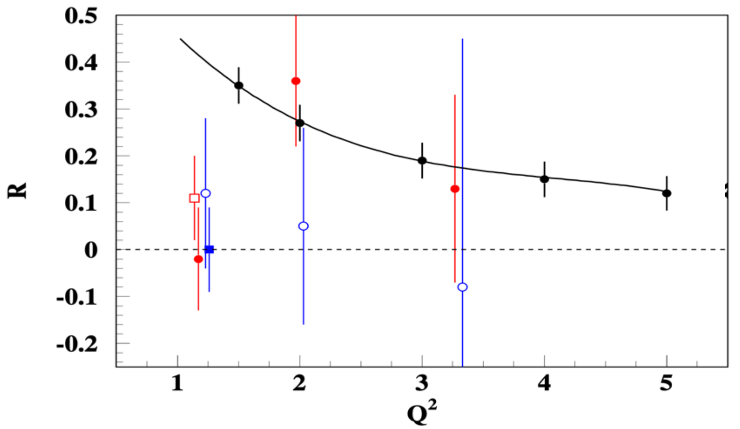
Slide from Mike Nycz

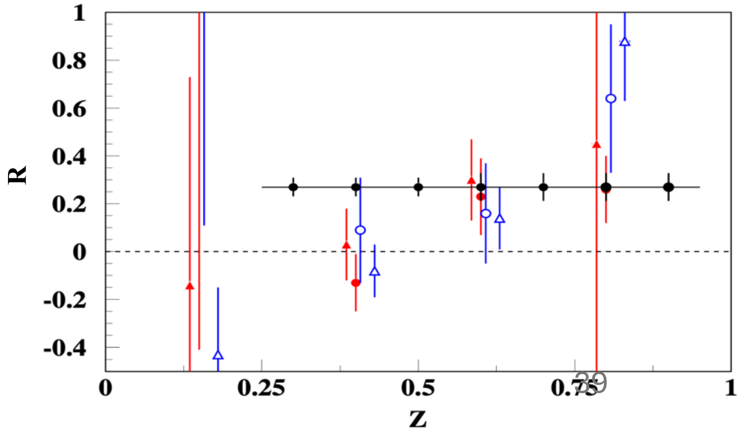
Two-Photon Exchange in DIS & **SIDIS**

Slide from Mike Nycz

- No corollary to polarization transfer in DIS or SIDIS
- Elastic measurements highlight importance of understanding TPE effects in both
  - Small effect(s) can cause large discrepancies in measured observables
- Impact of TPE
  - L/T separations: Pion electroproduction cross section

$$\frac{d^2\sigma}{d\Omega_\pi dM_x} = \frac{d\sigma_T}{d\Omega_\pi dM_x} + \varepsilon\frac{d\sigma_L}{d\Omega_\pi dM_x} + \varepsilon\frac{d\sigma_{TT}}{d\Omega_\pi dM_x}\cos 2\varphi_{pq} + \sqrt{2\varepsilon(1+\varepsilon)}\frac{d\sigma_{LT}}{d\Omega_\pi dM_x}\cos\varphi_{pq}$$



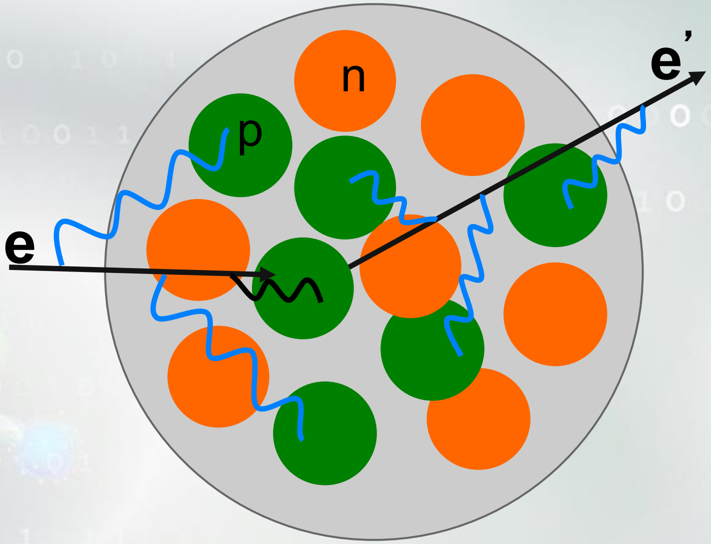


- R_{SIDIS} is assumed to be the same as R_{DIS} ($R_{SIDIS} = R_{DIS}$)
- Possible z & p_t-dependence of R_{SIDIS}?
- $R^{\pi^+}_{SIDIS} = R^{\pi^-}_{SIDIS}$?

Impact of TPE?

Coulomb Corrections

Coulomb Distortion in Heavy Nuclei



Electrons scattering from nuclei can be accelerated/decelerated in the Coulomb field of the nucleus

→ This effect is in general **NOT** included in most radiative corrections procedures

→ *Coulomb Corrections are perhaps more appropriately described in terms of multi-photon exchange, but Coulomb Corrections provide convenient shorthand*

- Well-known effect in QE scattering - relevant particularly for Coulomb sum rule
- Can be calculated in QE using DWBA → experimentalists use Effective Momentum Approximation (EMA) to apply corrections to data
- Comparisons of EMA with detailed DWBA calculations resulted in "improved EMA"

$$E_e \rightarrow E_e + V_0 \qquad E_e' \rightarrow E_e' + V_0 \quad \text{with "focusing factor"} \quad F^2 = (1+V_0/E_e)^2$$

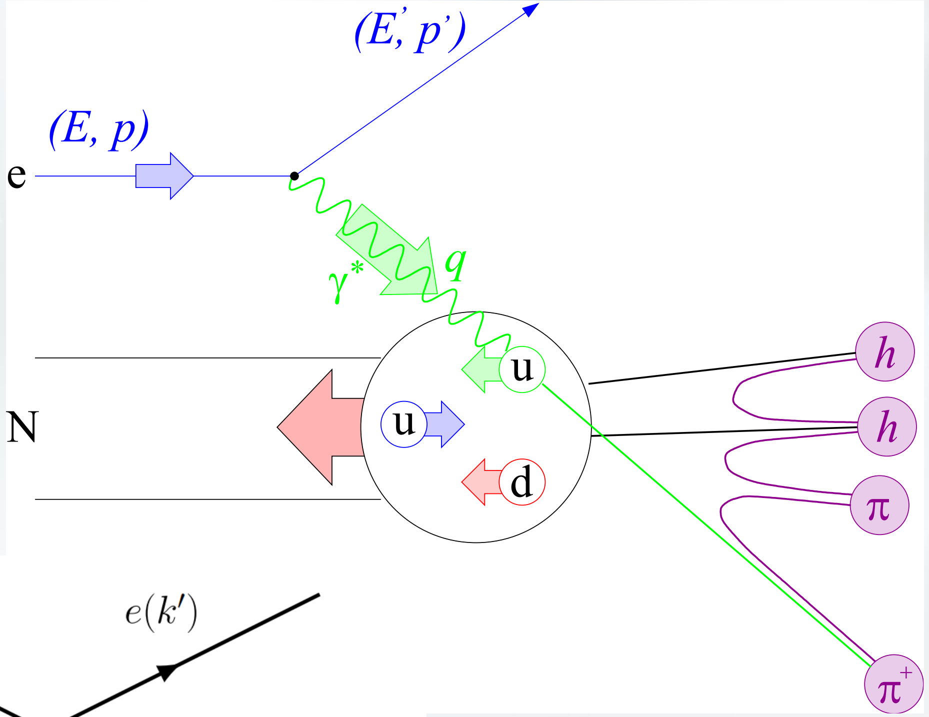
$$V_0 \rightarrow (0.7\text{-}0.8)V_0, \quad V_0=3a(Z-1)/2R$$

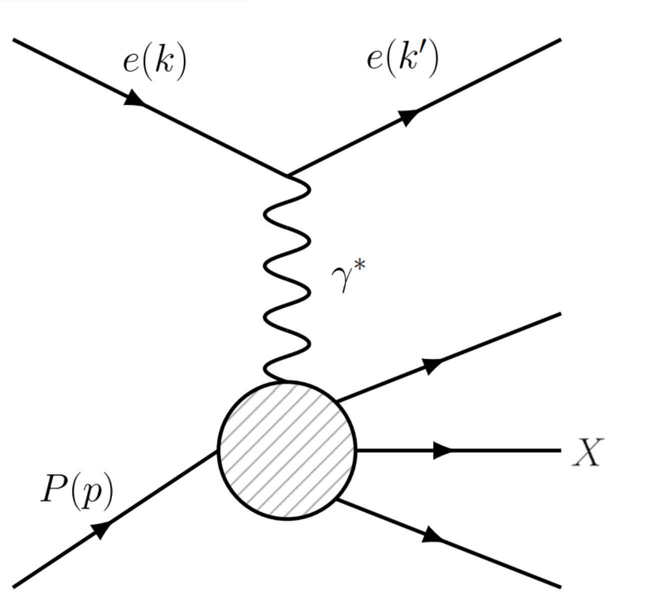
Slide from Dave Gaskell

[Aste et al, Nucl. Phys. A, 806:191-215 (2008) Eur.Phys.J.A26:167-178,2005, Europhys.Lett.67:753-759,2004]

DIS and SIDIS

- It is unclear if the EMA is applicable at DIS kinematics
  - This will be tested by E12+23-003!
- A natural extension of this question is if CCs in SIDIS are the same as DIS
  - DIS integrates over all hadronic final states
  - SIDIS selects for a subset of these for specific kinematics of a *piece* of the final state
- Does this selection impact CCs to the process?





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DIS and SIDIS

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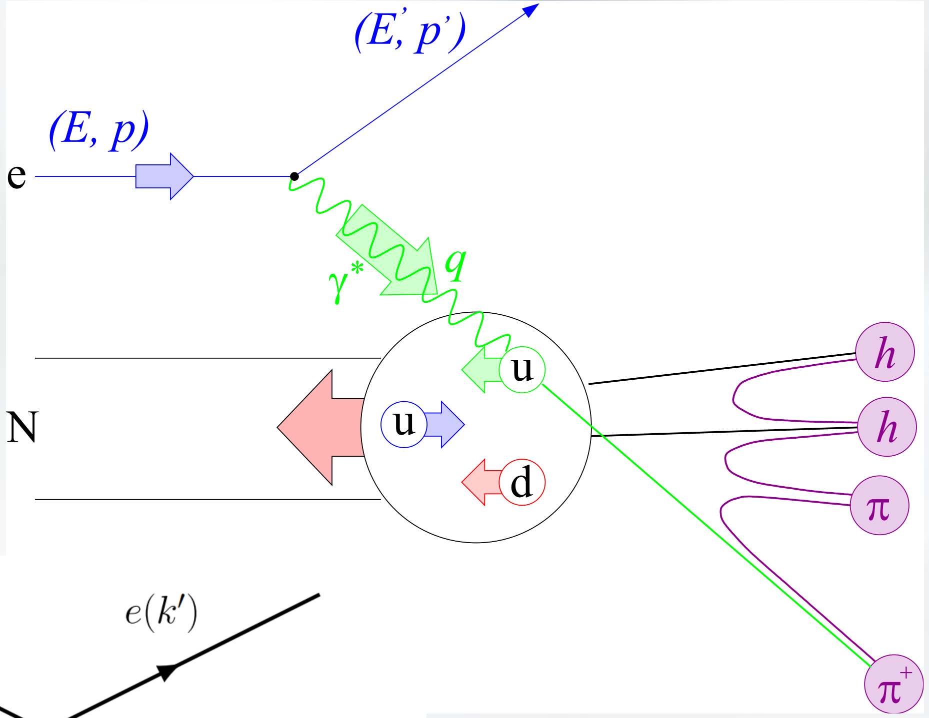
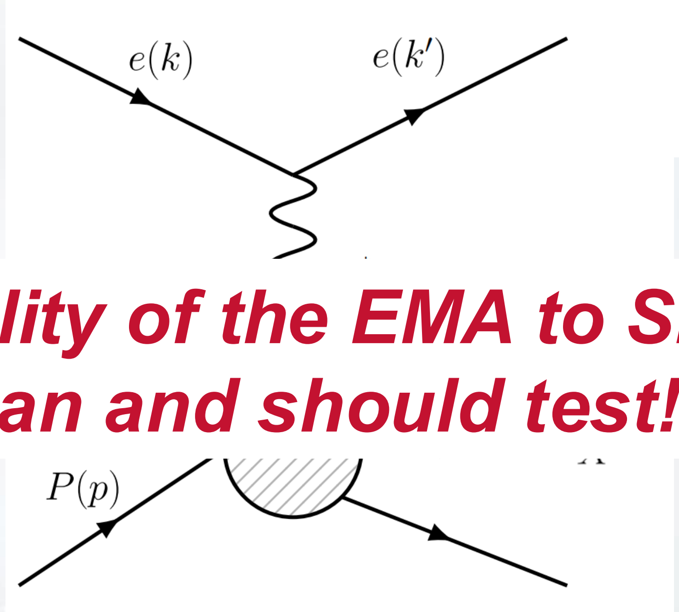
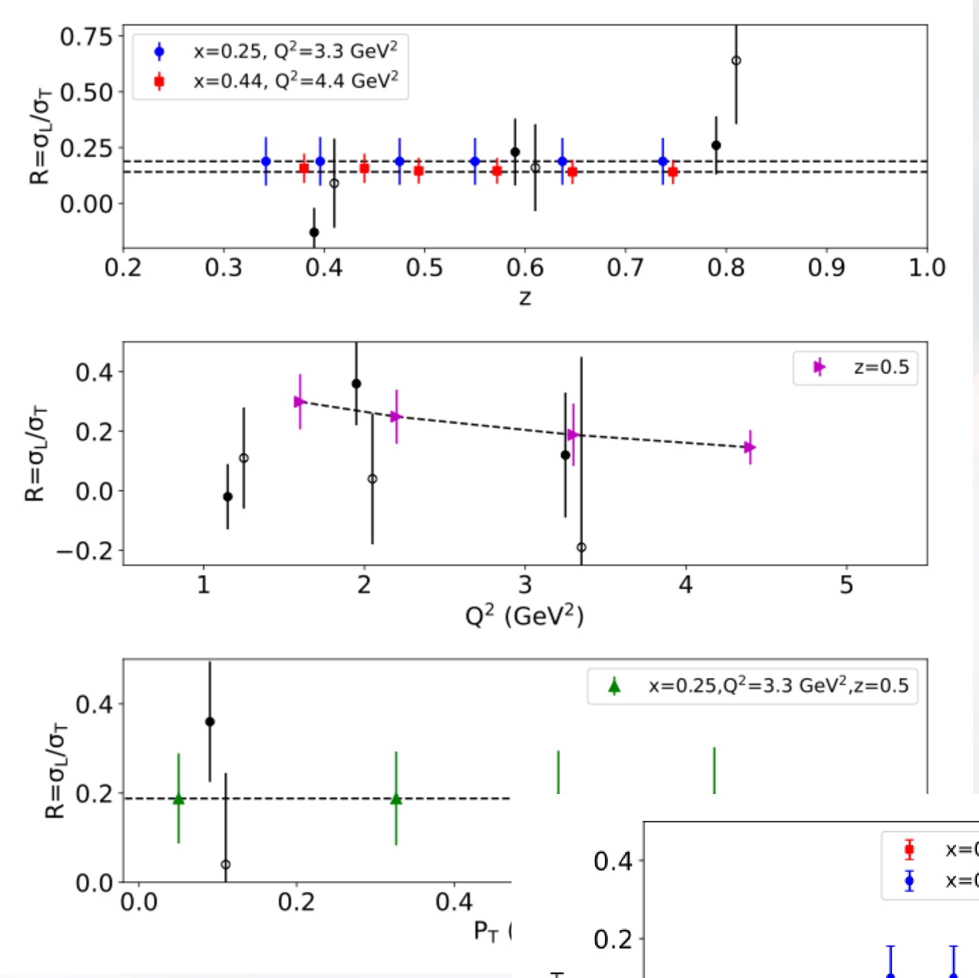


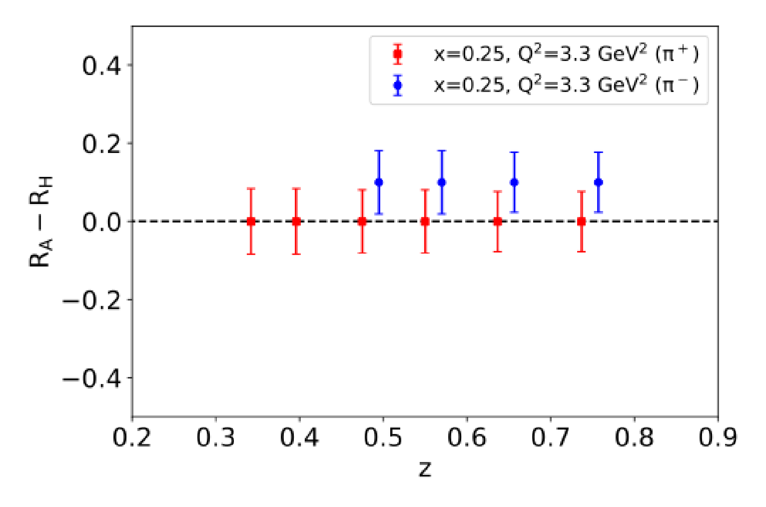


This is untested! The applicability of the EMA to SIDIS is an assumption that we can and should test!

Impact on SIDIS Data

- E12-06-104 ***(this year!)*** will extract R_LT in SIDIS data!
  - Two-photon exchange, an ε-dependent effect, will clearly impact this
- E12-24-001 formed a run group to extract R_LT in *nuclear* SIDIS data
  - Exploratory study of if R_LT is the same in SIDIS as in DIS
  - Carbon and Copper targets
  - Unclear if Coulomb Corrections will be the same in DIS and SIDIS – *No Data!*
  - Coulomb Corrections are also an ε-dependent effect, will directly impact the results
- SIDIS is a key part of JLab program
  - Important to understand and constrain corrections





CC in SIDIS

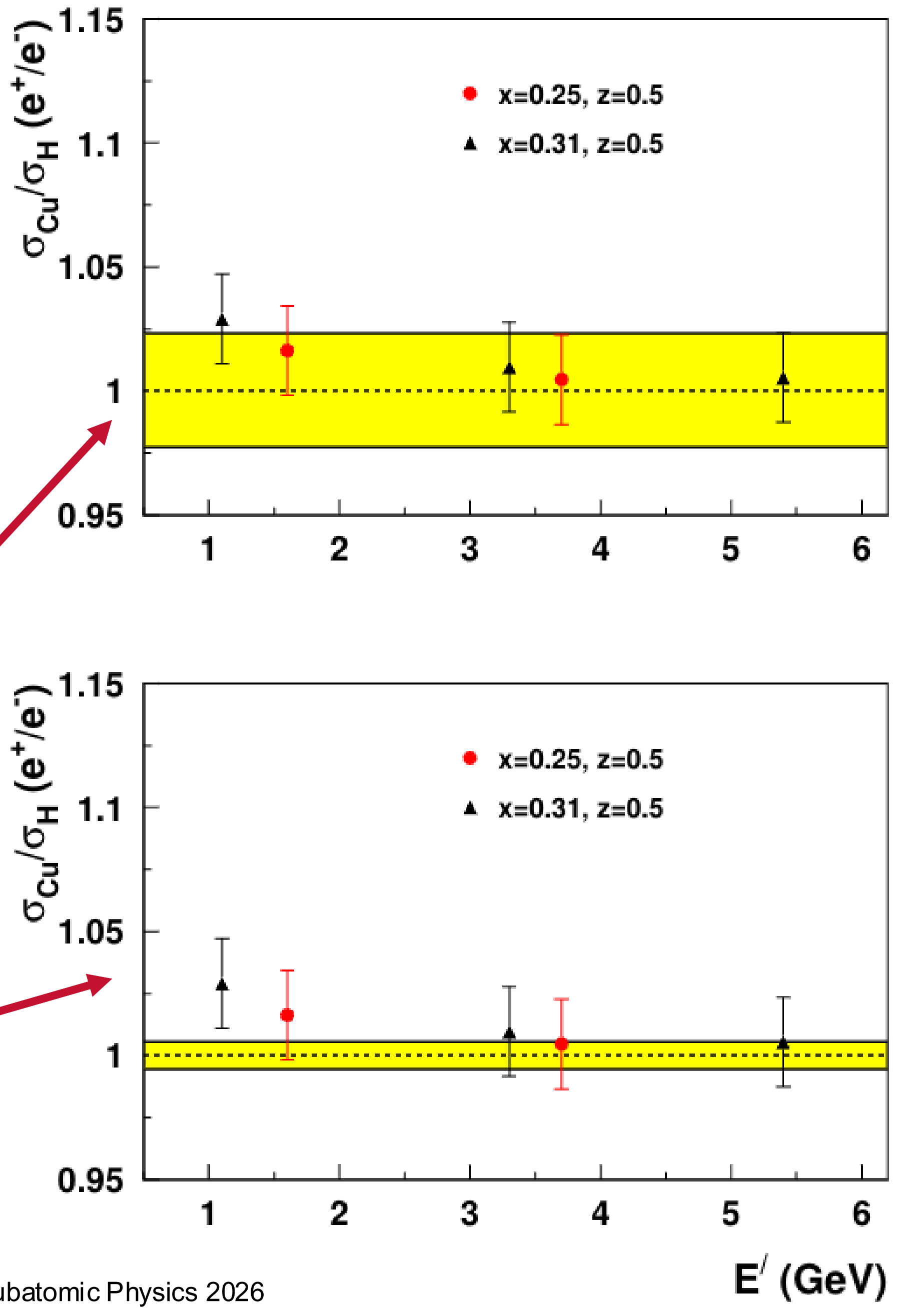
- Complementary to E12+23-003 (CC in DIS)
- Uses double ratio to extract corrections

$$R_{CC} = \frac{\left.\frac{\sigma_A}{\sigma_H}\right|_{e^+}}{\left.\frac{\sigma_A}{\sigma_H}\right|_{e^-}}$$

- Projections are based on EMA calculations

Electron data in different run period
(2.3% normalization uncertainty)

Electron data in same run period
(0.5% normalization uncertainty)



CC in SIDIS Kinematics

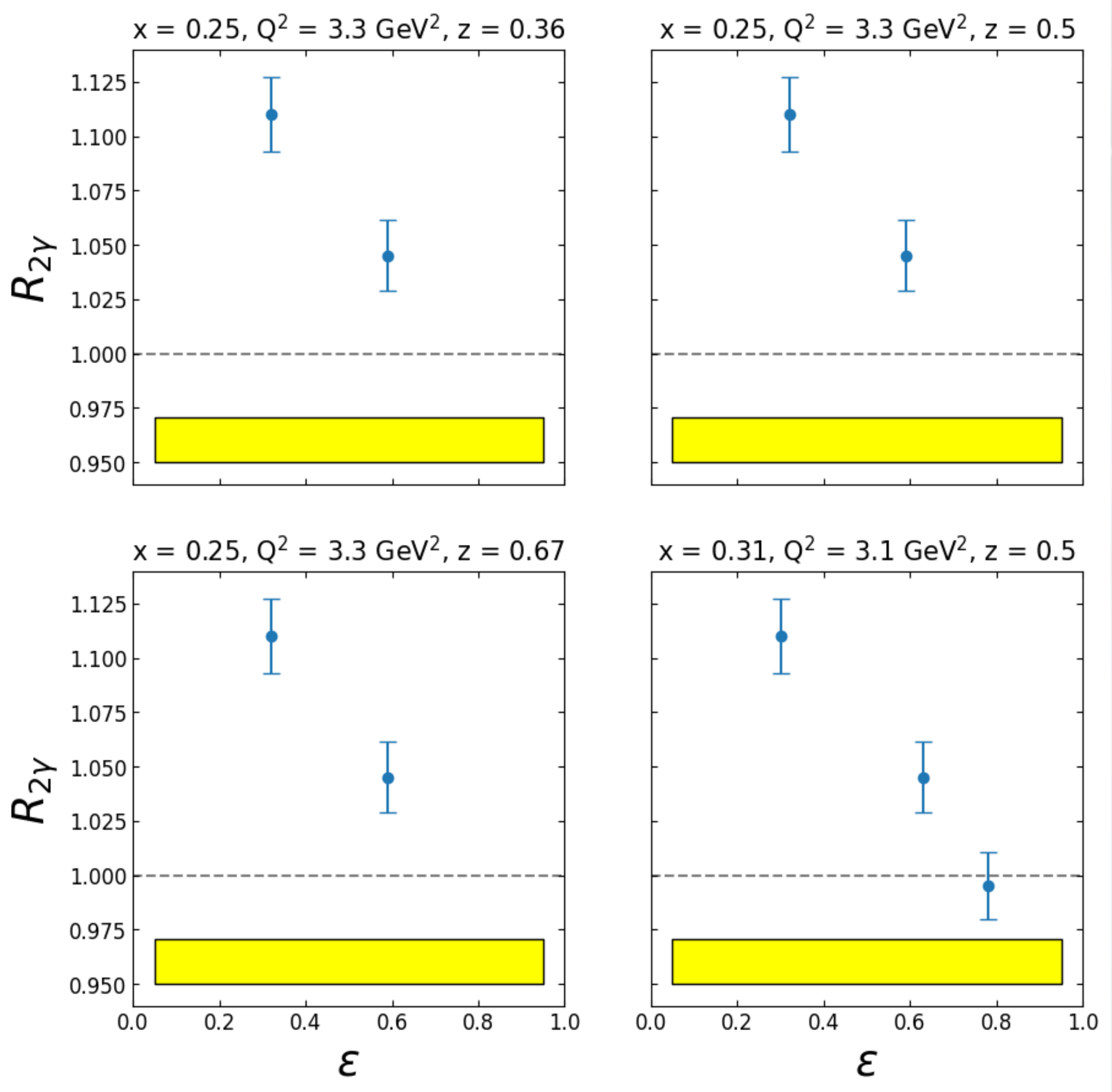
- A small number of kinematics to assess the validity of the IEMA in SIDIS
- Data recorded with π^+ final state at z=0.5
  - Higher rate than π^-
  - With no model of CC specific to SIDIS available, it is unclear how to disentangle effects from pion kinematics. Data is needed.
- Using 6% R.L. copper target
  - Though it is lower Z, it maximizes luminosity/R.L. in a rate limited scenario
  - 6% R.L. chosen to balance luminosity and radiative correction uncertainties
- Double ratio will be formed with hydrogen as opposed to deuterium
  - Make use of data already being recorded for TPE studies rather than increasing time to include another target

				Times (hrs)	
x	Q^2 (GeV^2)	E_0 (GeV)	ε	e^+	e^-
0.25	3.3	8.6	0.60	88.5	3.5
		10.7	0.33	11.5	1
0.31	3.1	6.5	0.30	252.6	10.1
		8.6	0.63	21.8	1
		10.7	0.78	5.8	1
Totals				380.2	16.6

TPE in SIDIS

- Coincident leptons in the HMS and pions in the SHMS
- We use the positron to electron ratio to extract the TPE contribution $\delta_{2\gamma}$

$$R_{2\gamma} = \frac{\sigma_{e^+}}{\sigma_{e^-}} = 1 - 2\delta_{2\gamma}$$



TPE in SIDIS Kinematics

					Times (hrs)						
x	Q^2	E_0	ε	z	π^+, e^+	π^+, e^-	Hz/μA	π^-, e^+	π^-, e^-	Hz/μA	DIS Hz/μA
0.25	3.3	8.6	0.32	0.36	49.4	2	0.056				6.11
				0.5	36.4	1.5	0.076				
				0.67	37.8	1.5	0.073				
0.25	3.3	10.7	0.59	0.36	6.3	1	3.22				19.99
				0.5	4.7	1	0.592				
				0.67	5	1	0.56				
0.31	3.1	6.5	0.3	0.5	105.8	4.2	0.026	252.5	10.1	0.011	4.47
		8.6	0.63	0.5	8.6	1	0.322	20.1	1	0.138	19.58
		10.7	0.78	0.5	2.3	1	1.23	5.3	1	0.527	44.49
Totals					256.3	14.2		277.9	12.1		

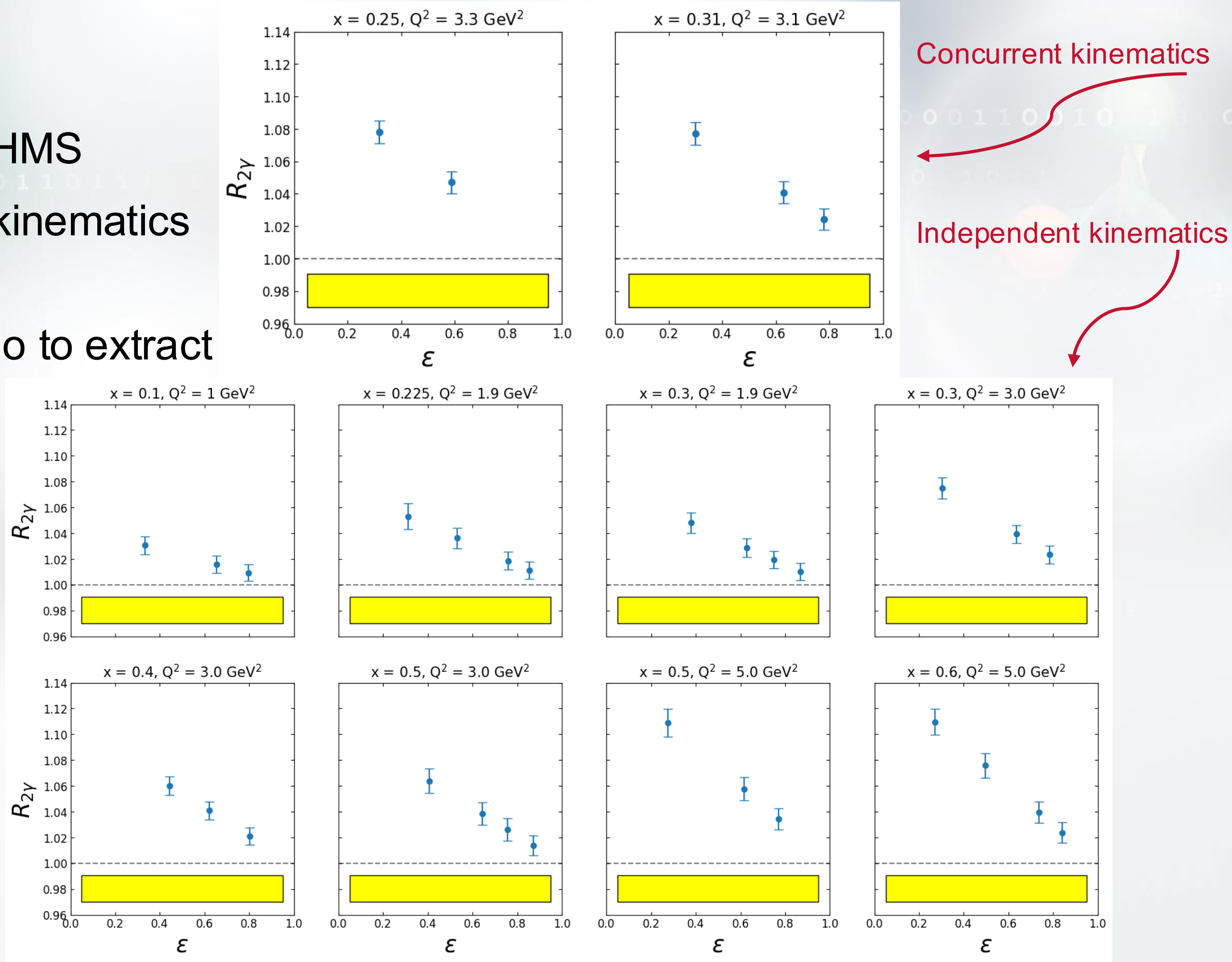
Many kinematics to test z, ε, x, and pion charge dependence
DIS physics rates are low enough for concurrent measurement (maxing out at ~1.1 kHz)

TPE in DIS

- Inclusive lepton measurements in HMS
- Including additional inclusive-only kinematics as it is higher rate
- We use the positron to electron ratio to extract the TPE contribution $\delta_{2\gamma}$

$$R_{2\gamma} = \frac{\sigma_{e^+}}{\sigma_{e^-}} = 1 - 2\delta_{2\gamma}$$

- Mapping large x range



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TPE in DIS Kinematics

- Kinematics largely mirror E12-14-002 “A dependence of R” experiment
- These kinematics were selected to cover a large range in x to map any effect and focus on high Q^2 data where the effect is expected to be largest
- All settings aim to collect at least 10k events and were then rounded up to a minimum of 1 hour per setting
- Settings are divided between SHMS and HMS such that kinematics that will be compared most directly to each other are recorded in the same spectrometer

				SHMS Time (hrs)		HMS Time (hrs)	
x	Q^2	E_0	ε	e^+	e^-	e^+	e^-
0.1	1	6.5	0.34	1	1		
		8.6	0.66	1	1		
		10.7	0.8	1	1		
0.225	1.9	5.5	0.33	1	1		
		6.5	0.55	1	1		
		8.6	0.77	1	1		
		10.7	0.87	1	1		
0.3	1.9	4.4	0.38	1	1		
		5.5	0.63	1	1		
		6.5	0.76	1	1		
		8.6	0.88	1	1		
0.3	3	6.5	0.33	1	1		
		8.6	0.66	1	1		
		10.7	0.8	1	1		
0.4	3	5.5	0.44	2	1		
		6.6	0.63	1	1		
		8.6	0.81	1	1		
		10.7	0.89	1	1		
0.5	3	4.4	0.47			5	1
		5.5	0.7			2	1
		6.6	0.8			1	1
		8.8	0.9			1	1
0.5	5	6.6	0.3			16	1
		8.8	0.64			4	1
		11	0.79			3	1
0.6	5	5.5	0.27			20	1
		6.6	0.51			6	1
		8.8	0.75			3	1
		10.7	0.85			2	1
Totals				19	18	63	11

Systematics

Source	$\delta R/R$ (%) point-to-point	$\delta R/R$ (%) scale
Spectrometer momentum	-	$< 0.1\%$
Beam energy	-	$< 0.1\%$
θ_{spec}	-	$< 0.1\%$
Charge	0.35%	-
Target Boiling	-	0.1%
Total dead time	0.15%	0.14%
Detector efficiency	0.11%	-
Charge Symmetric Background	-	-
Pion background	0.2%	-
Radiative Corrections	-	0.5%
Acceptance	0.2%	-
Cryotarget wall subtraction	-	-
Total	0.49%	0.56%

Source	$\delta R/R$ (%) point-to-point	$\delta R/R$ (%) scale
Spectrometer momentum	-	$< 0.1\%$
Beam energy	-	$< 0.1\%$
θ_{spec}	0.15-0.46%	$< 0.1\%$
Charge	0.35%	2%
Target Boiling	-	0.1%
Total dead time	0.15%	0.14%
Detector efficiency	0.11%	-
Charge Symmetric Background	-	-
Pion background	0.2%	-
Radiative Corrections	-	0.5%
Acceptance	0.1-0.14%	-
Cryotarget wall subtraction	-	-
Total	0.48-0.65%	2.07%

Coulomb Correction Double Ratio

Lower uncertainties due to cancellations in double ratio

TPE Ratios

Scale uncertainty dominated by total charge measurement

Unser does not work for low currents

2% based on past injector faraday cup measurements