Constraining Coulomb Corrections with Positrons

2023 Summer Hall A/C Meeting

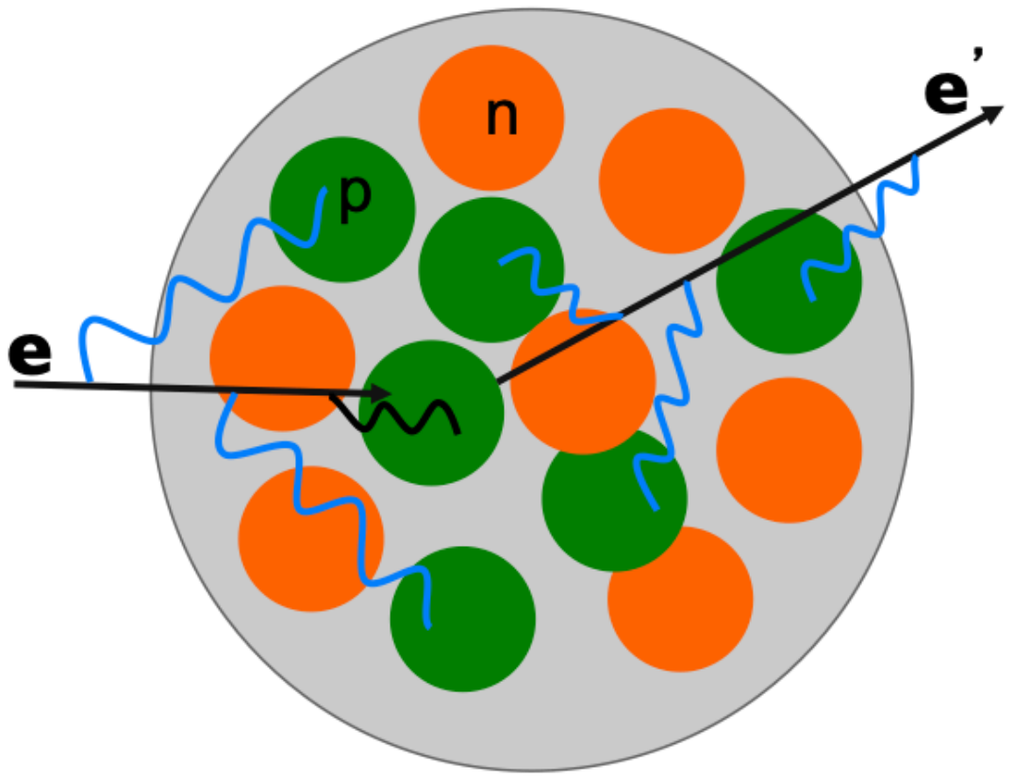
Bill Henry

June 30th, 2023

Outline

- What are Coulomb Corrections?
- Why do they matter?
- How can we better constrain them?

Heavy Nuclei and Coulomb Distortion



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

→ Important to remove/correct for apparent changes in the cross section due to Coulomb effects

In a very simple picture – Coulomb field induces a change in kinematics in the reaction

$E_e \rightarrow E_e + V_0$

$E_e' \rightarrow E_e' + V_0$

$V_0 = 3\alpha(Z-1)/2R$

↑

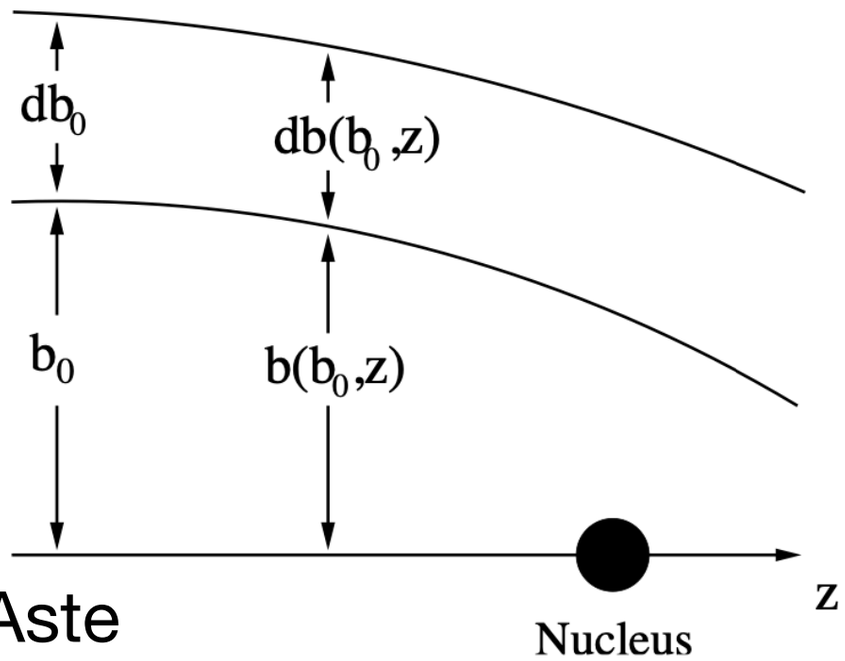
Electrostatic potential energy at center of nucleus

Slide from Dave G.

Heavy Nuclei and Coulomb Distortion

Focusing

The attractive electrostatic potential of the nucleus leads to a focusing of the electron wave in the nuclear vicinity.



credit: A. Aste

The Focusing Factor

$$F_i = \left(1 - \frac{\bar{V}}{E_e}\right)$$

$$\sigma_{CC} = F_i^2 \sigma(E_e + \bar{V}, E_e + \bar{V}).$$

Coulomb Corrections in Quasi-elastic Scattering

Coulomb Sum Rule Experiment

Seonho Choi
Seoul National University

July 24, 2014
6th Workshop on Hadron Physics in China and Opportunities in US

Major Issues of the CSR Experiments

- Coulomb Corrections
  - Effect of the nuclear Coulomb field to the incoming and outgoing electrons
  - Actual incident & scattered energy inside the nucleus are modified
  - Corrections are necessary before the comparison of elastic & quasi-elastic

- More details here

Coulomb Corrections in Quasi-elastic Scattering

- Coulomb Corrections are a well known effect in QE experiments
- A detailed Distorted-Wave Born Approximation (DWBA) can be done for QE processess but “extremely computer time consuming” for inclusive processes
- A common practice is to use the improved Effective Momentum Approximation (EMA) which is EMA “tuned” to DWBA

Andreas Aste and Jurg Jourdan. Improved effective momentum approximation for quasielastic (e,e-prime) scattering off highly charged nuclei. *EPL*, 67:753–759, 2004.

Andreas Aste, Cyrill von Arx, and Dirk Trautmann. Coulomb distortion of relativistic electrons in the nuclear electrostatic field. *Eur. Phys. J. A*, 26:167–178, 2005.

Andreas W. Aste. Coulomb distortion effects in quasi-elastic (e,e’) scattering on heavy nuclei. *Nucl. Phys. A*, 806:191–215, 2008.

Coulomb Corrections in Quasi-elastic Scattering

Question:

What V_c to use??

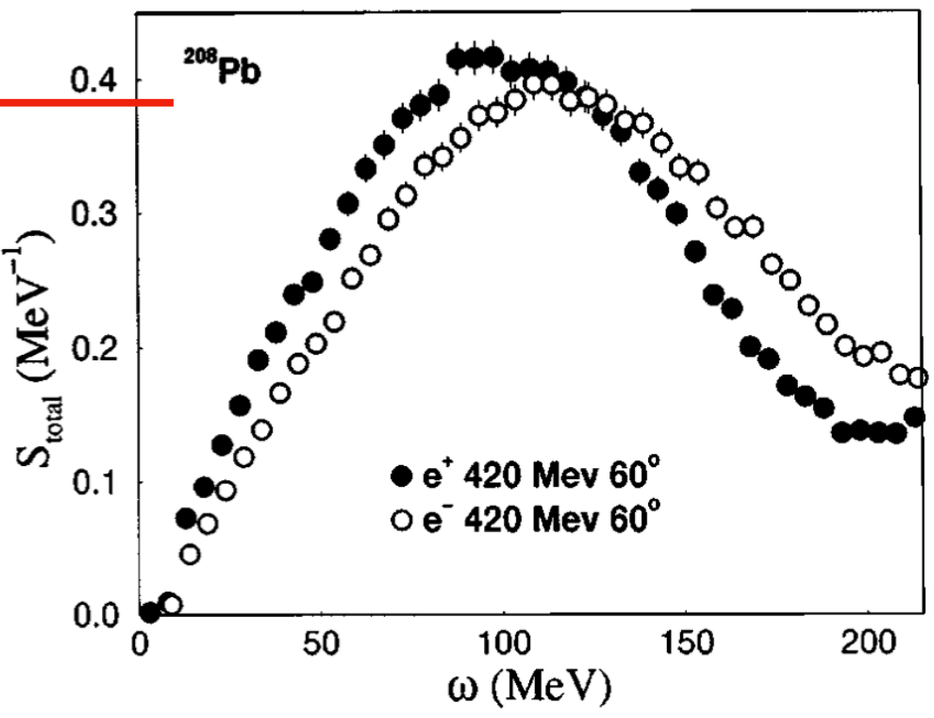
The potential at the center of the nucleus?

The average?

Nucleus	$\langle r^2\rangle^{1/2}_{\rm exp}$ (fm)	$\lvert V_C(0)\rvert$ (MeV)	$\lvert V_C\rvert$ (MeV)	$\lvert V_C\rvert_{\rm fit}$ (MeV)
^{12}C	2.464	4.6	3.3	3.1±0.25
^{40}Ca	3.450	10.5	7.9	7.4±0.6
^{48}Ca	3.451	10.4	7.9	7.4±0.6
^{56}Fe	3.714	12.5	9.5	8.9±0.7
^{90}Zr	4.258	16.7	12.8	11.9±0.9
^{154}Gd	5.124	21.8	16.9	15.9±1.2
^{208}Pb	5.503	25.9	20.1	18.9±1.5

P. GUÈYE *et al.*

Saclay (1999)



Answer:

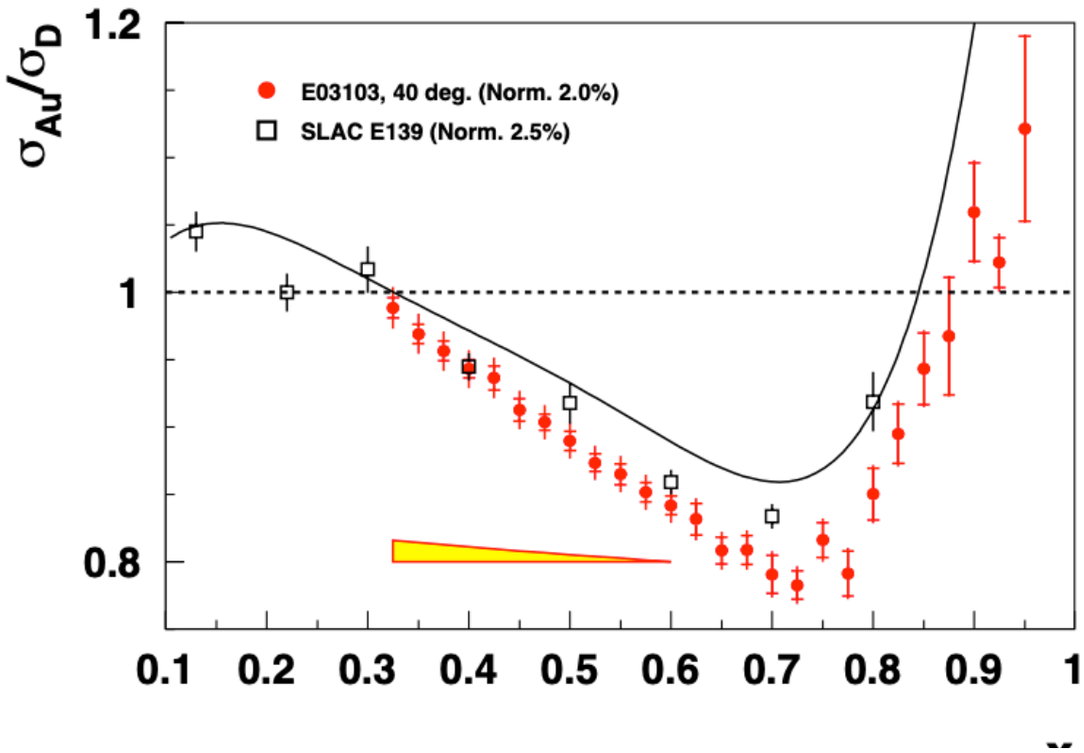
Somewhere in between.

$$|V_C| = \frac{(1.27\pm0.10)\ \ (\text{MeV fm})}{\langle r^2\rangle^{1/2}} Z,$$

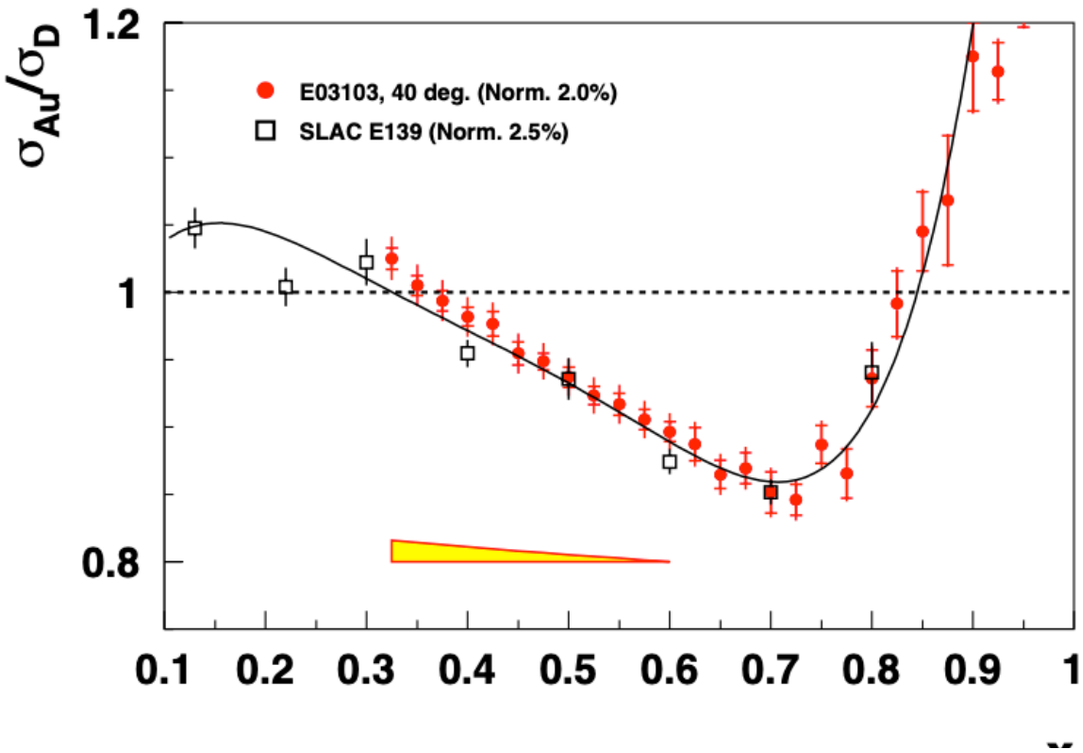
Coulomb Corrections in DIS: The EMC Effect

σ_A/σ_D for Gold
A=197 Z=79

No Coulomb Corrections



Coulomb Corrections Appled

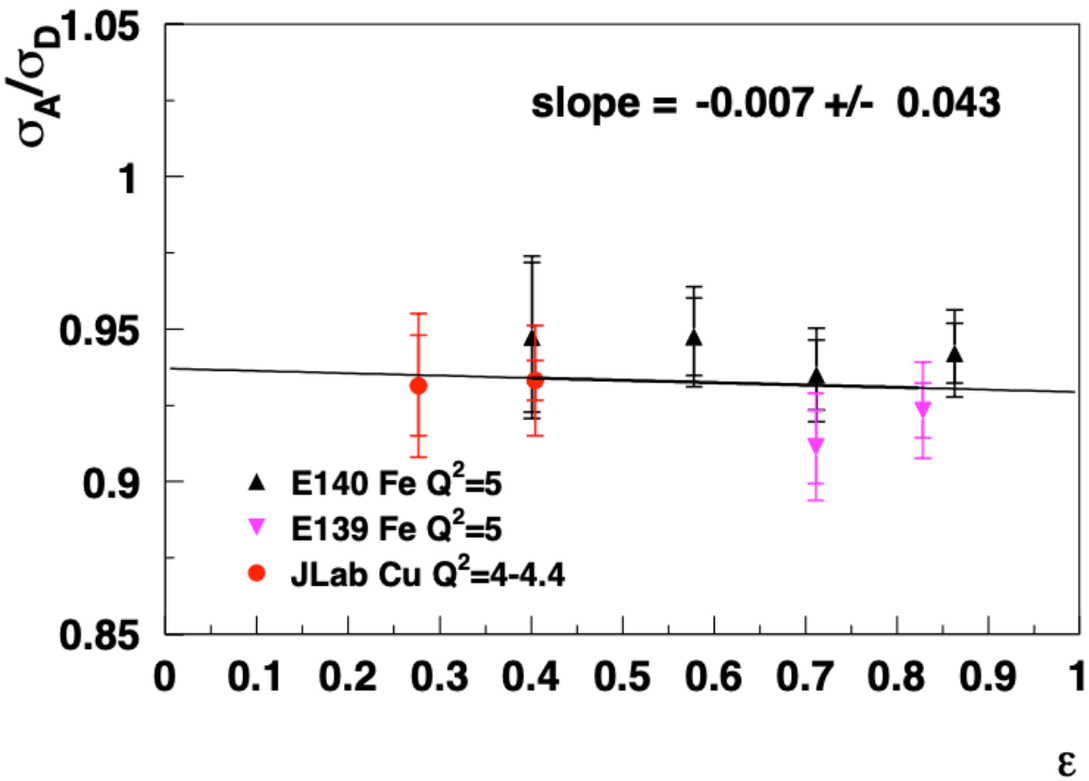


Coulomb corrections significantly larger for JLab data → 5-10%, SLAC → 1-2%

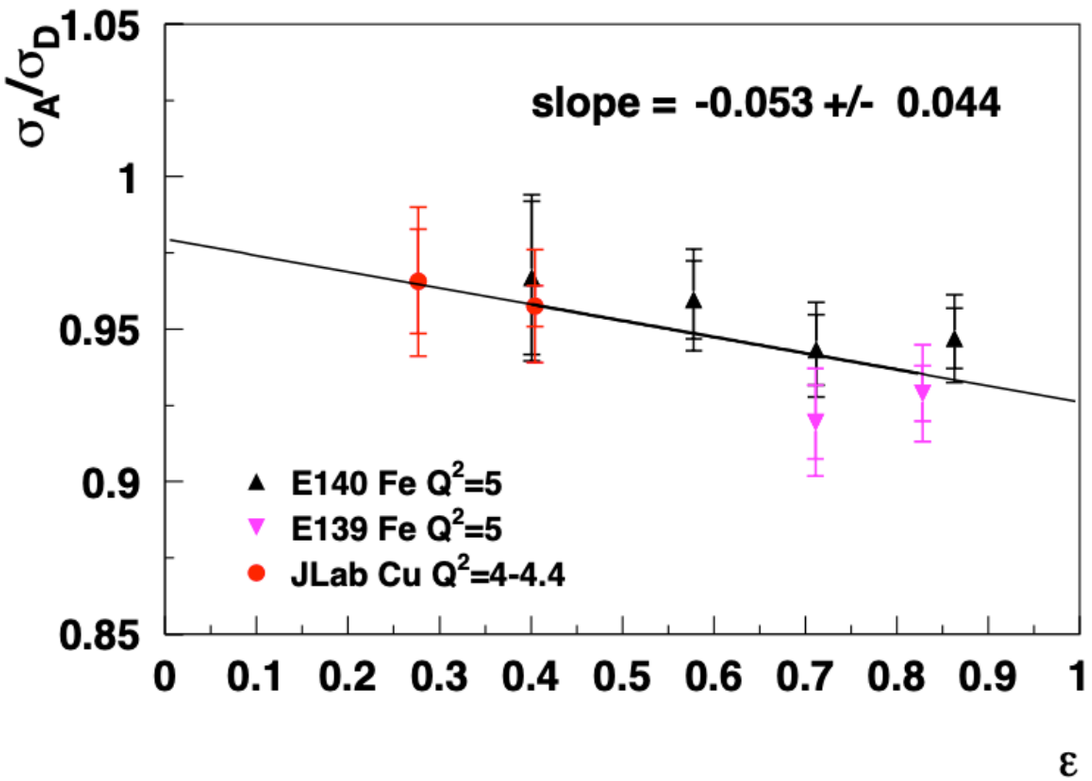
SLAC E-139	JLab E03-103
E_e ~ 8-25 GeV	E_e ~ 6 GeV
E_e' ~4-8 GeV	E_e' ~1-2 GeV

Coulomb Corrections applied to R_A-R_D

No Coulomb Corrections



Coulomb Corrections Appled



- Without CC, no slope indicates R_A=R_D
- With CC, R_A - R_D is non zero

$$\frac{\sigma_A}{\sigma_D} = \frac{\sigma_A^T}{\sigma_D^T}\left[1 + \frac{\epsilon}{1+\epsilon R_D}(R_A - R_D)\right]$$

Coulomb Corrections applied to R_A-R_D

- A common approximation when going from cross sections to structure functions to assume R_A=R_D
- The only model independent measurements of R_D-R_p hint at R_D-R_p ≠0.
- In a global analyis, Tvaskis et al. found R_D-R_p = -.054 +/- .029. https://arxiv.org/pdf/nucl-ex/0611023.pdf
- The approved E12-14-02 will measure the nuclear dependence of R at multiple x, Q^2
- Model independent approach similar to E140/E99-118
- Coulomb corrections have a large impact on the results

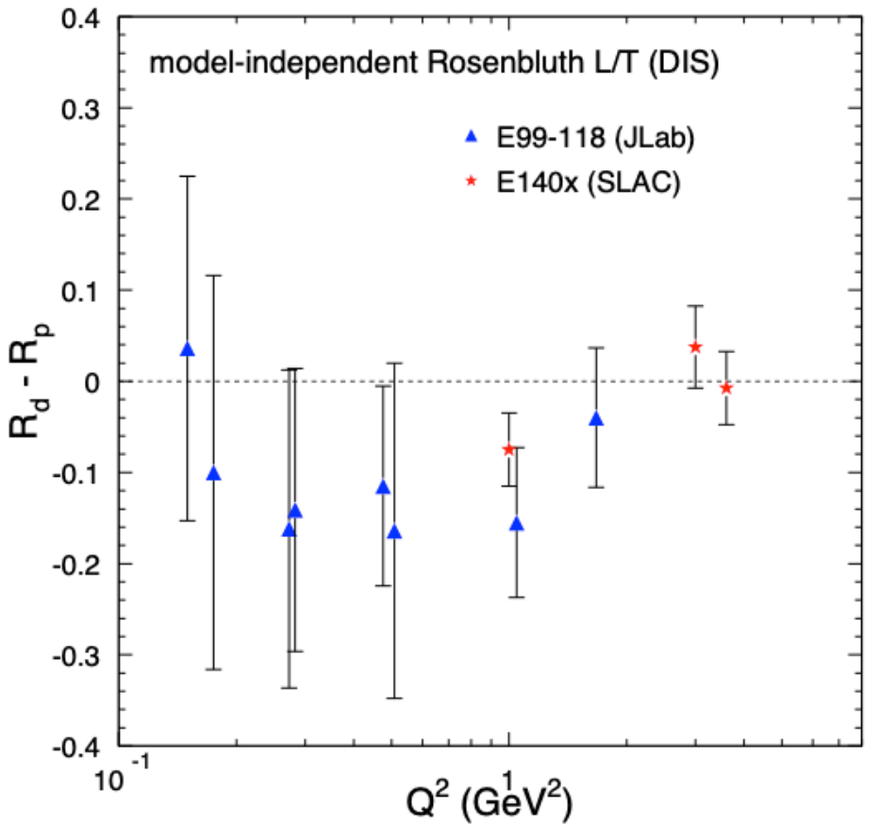
$$\frac{\sigma^A}{\sigma^D} = \frac{F_2^A}{F_2^D} \frac{(1+\epsilon R_A)(1+R_D)}{(1+R_A)(1+\epsilon R_D)},$$

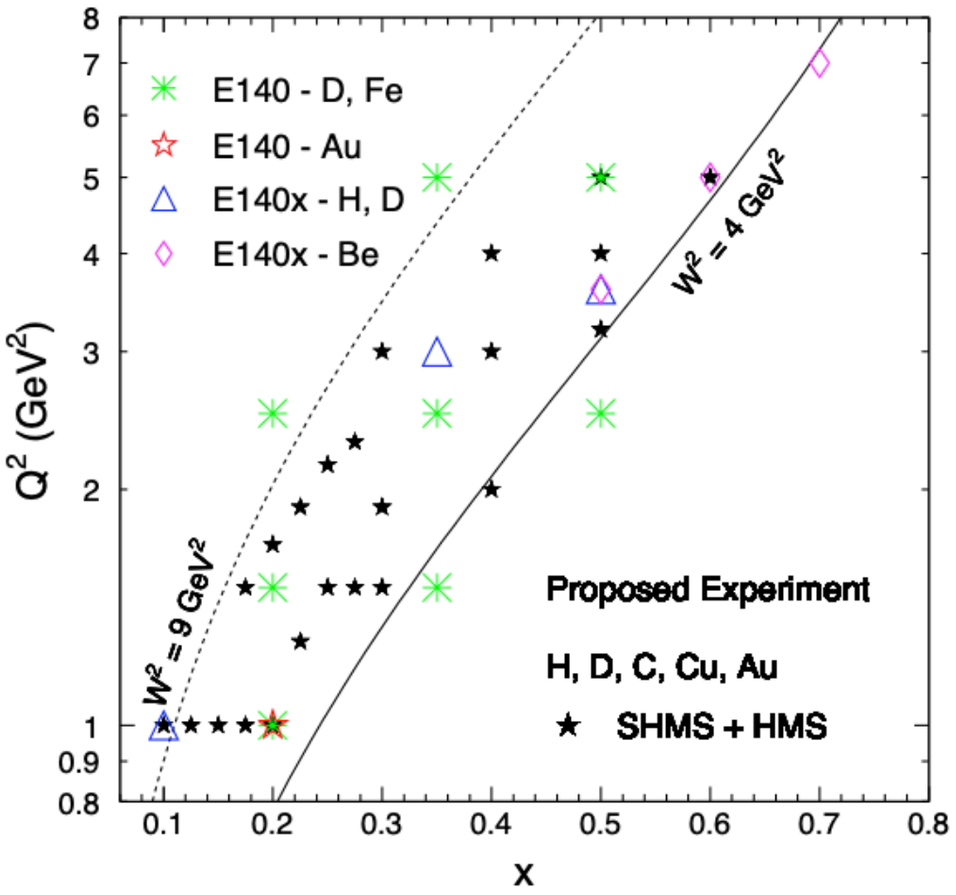
E12-14-002

Update to Precision Measurements and Studies of a Possible Nuclear Dependence of $R = \sigma_L/\sigma_T$

Spokespersons: S. Alsalmi, M. E. Christy, D. Gaskell, T. Hague, W. Henry*, S. Malace, D. Nguyen, P. Solvignon-Slifer

May 17, 2023





Testing Coulomb Corrections with electrons

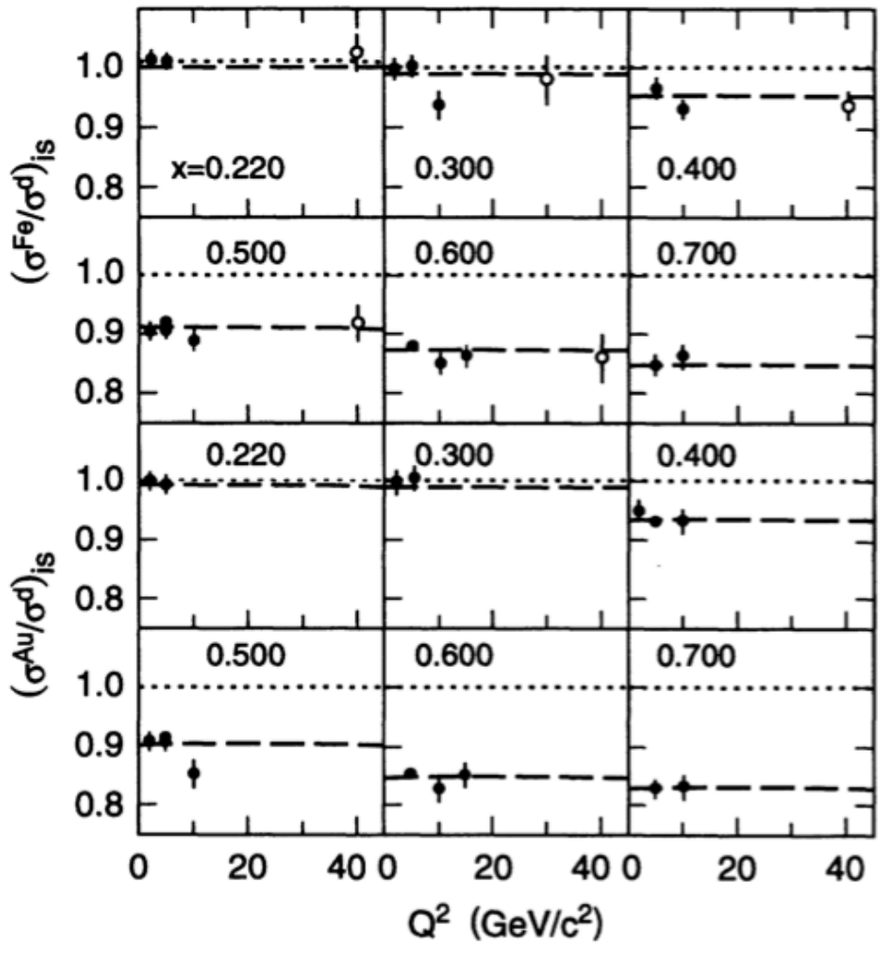
Coulomb corrections can be tested by measuring target ratios at fixed ***x*** and **ε**
→ Varying Q^2 allows us to change E/E' and hence size of CC

Fixed ***x*** required due to EMC effect

$$\frac{\sigma_A}{\sigma_D} = \frac{F_2^A(1+\epsilon R_A)(1+R_D)}{F_2^D(1+R_A)(1+\epsilon R_D)}$$

Fixed **ε** eliminates potential dependence on R_A-R_D

EMC effect measurements have shown little or no dependence on Q^2



E12-14-002 Coulomb Corr. Test

Gold target x=0.5

ε	Q^2 (GeV²)	E (GeV)	E' (GeV)	θ (deg.)	W (GeV)	$C_{Coulomb}$
0.2	3.48	4.4	0.69	64.6	2.08	11.6%
0.2	9.03	11.0	1.38	45.5	3.10	6.2%
0.7	2.15	4.4	2.11	27.9	1.74	3.5%
0.7	5.79	11.0	4.83	19.0	2.58	1.9%

CC test will measure precise Au/D ratios
→ 2 shifts (16 hours) at 60 μA

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Testing Coulomb Corrections with positrons

Measurement of Deep Inelastic Scattering from Nuclei with Electron and Positron Beams to Constrain the Impact of Coulomb Corrections in DIS

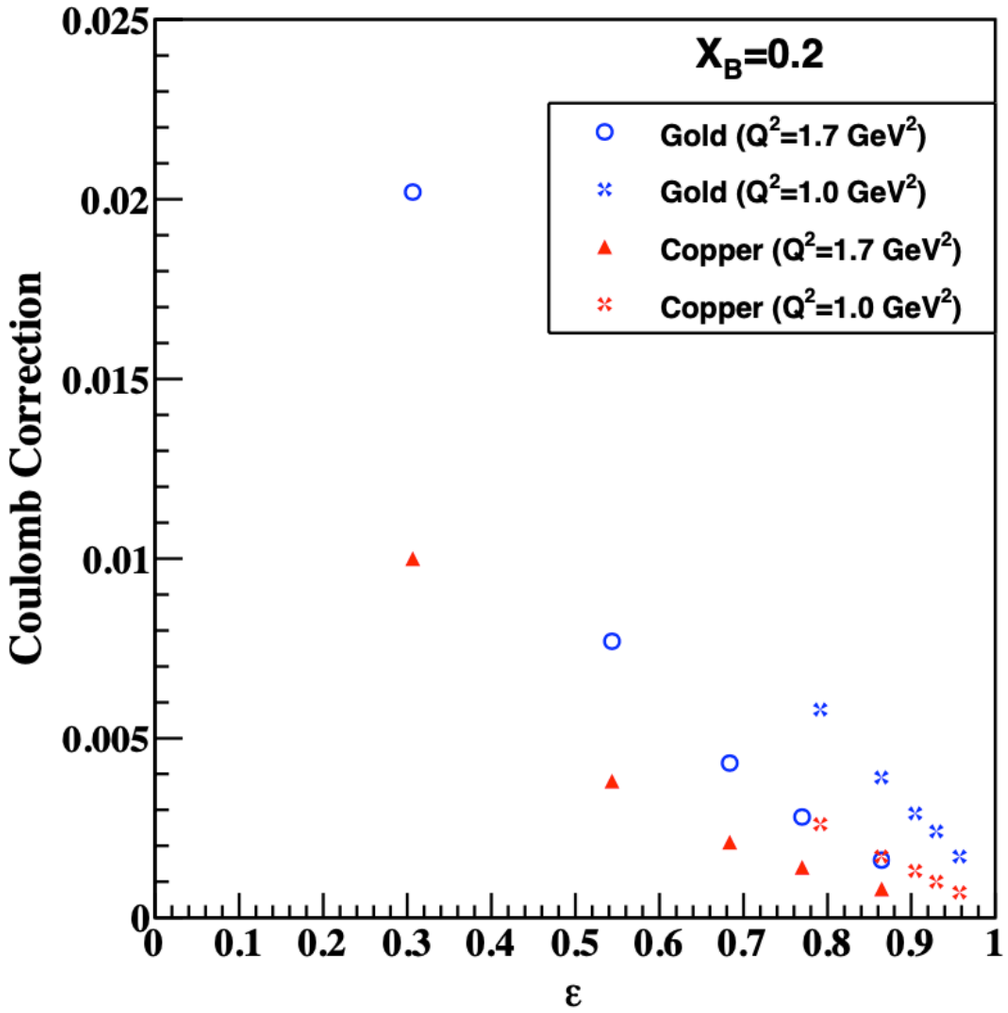
A Proposal to PAC 51

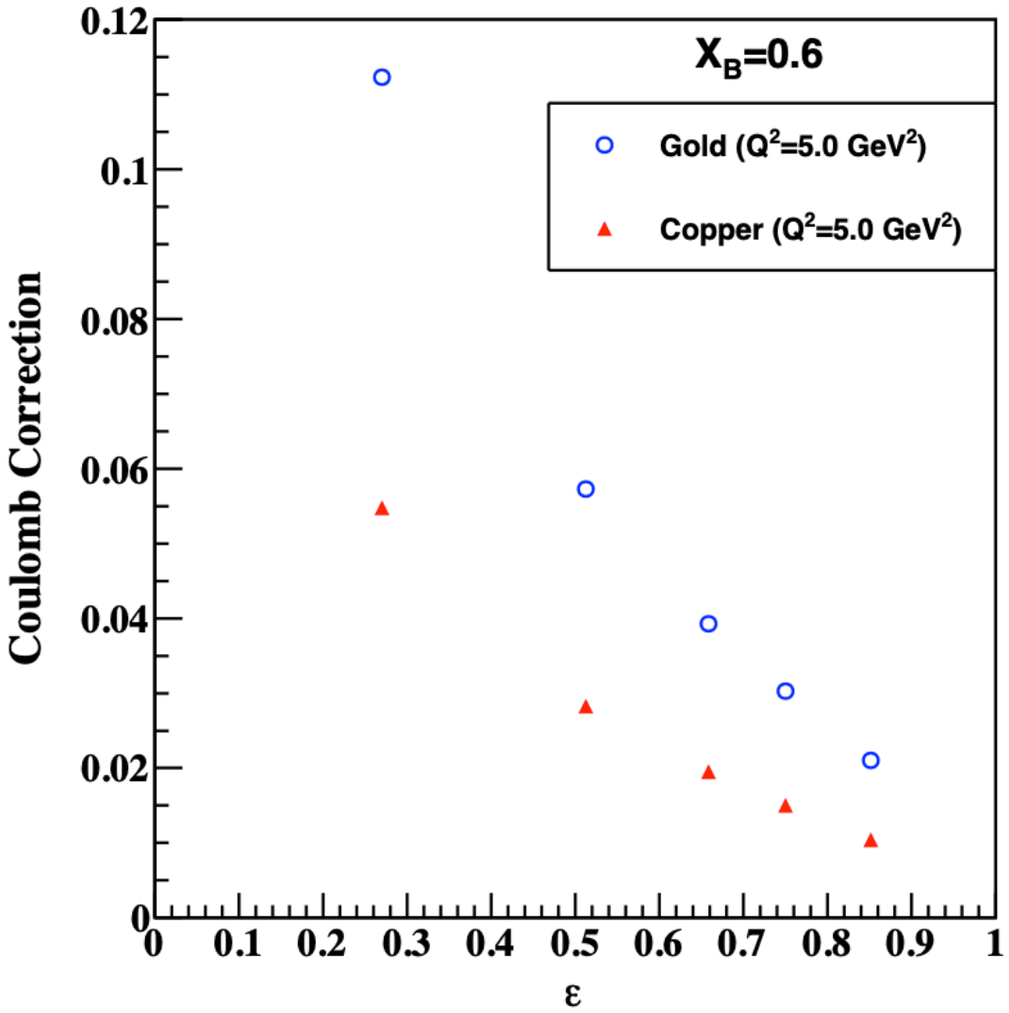
Spokespersons: N.Fomin, D. Gaskell, W. Henry

May 20, 2023

Activity	Time (hours)
Production data	159.9
Charge symmetric backgrounds	39.3
Target cell walls	9.1
Pass change	8
Kinematics and target changes	7
Total	223.3 (9.3 days)

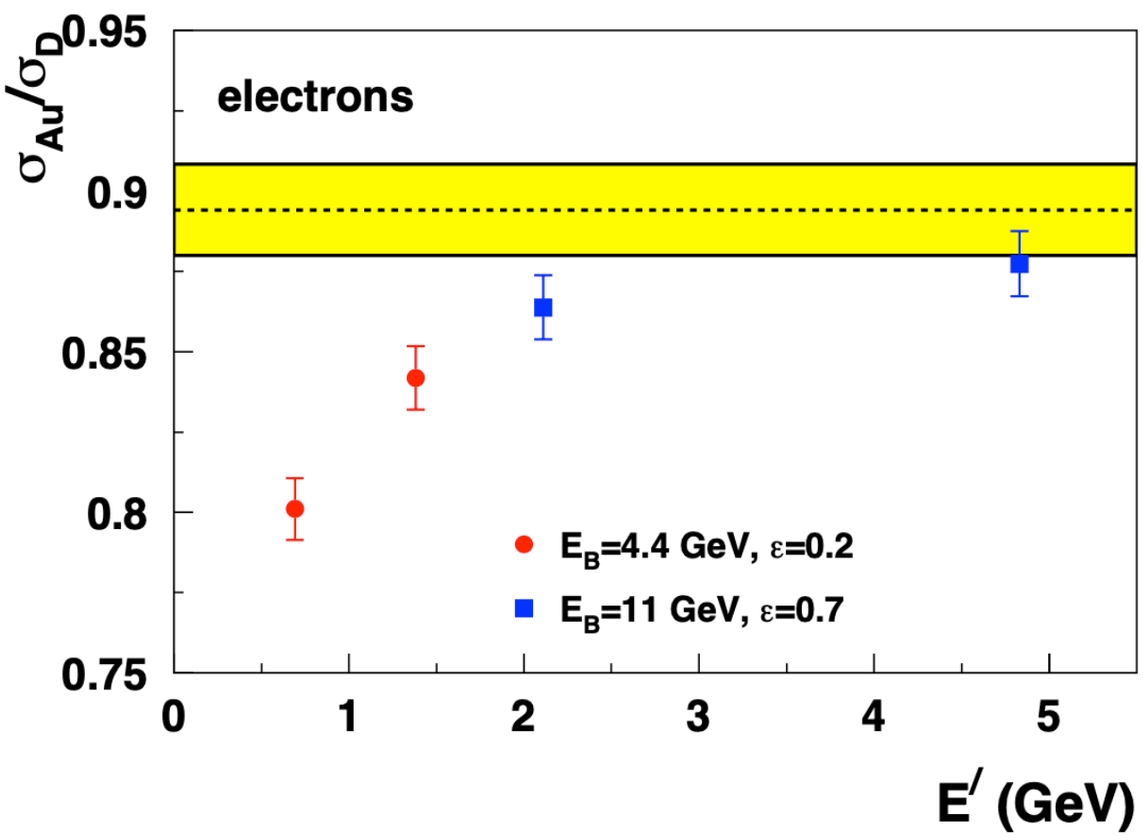
Testing Coulomb Corrections with positrons

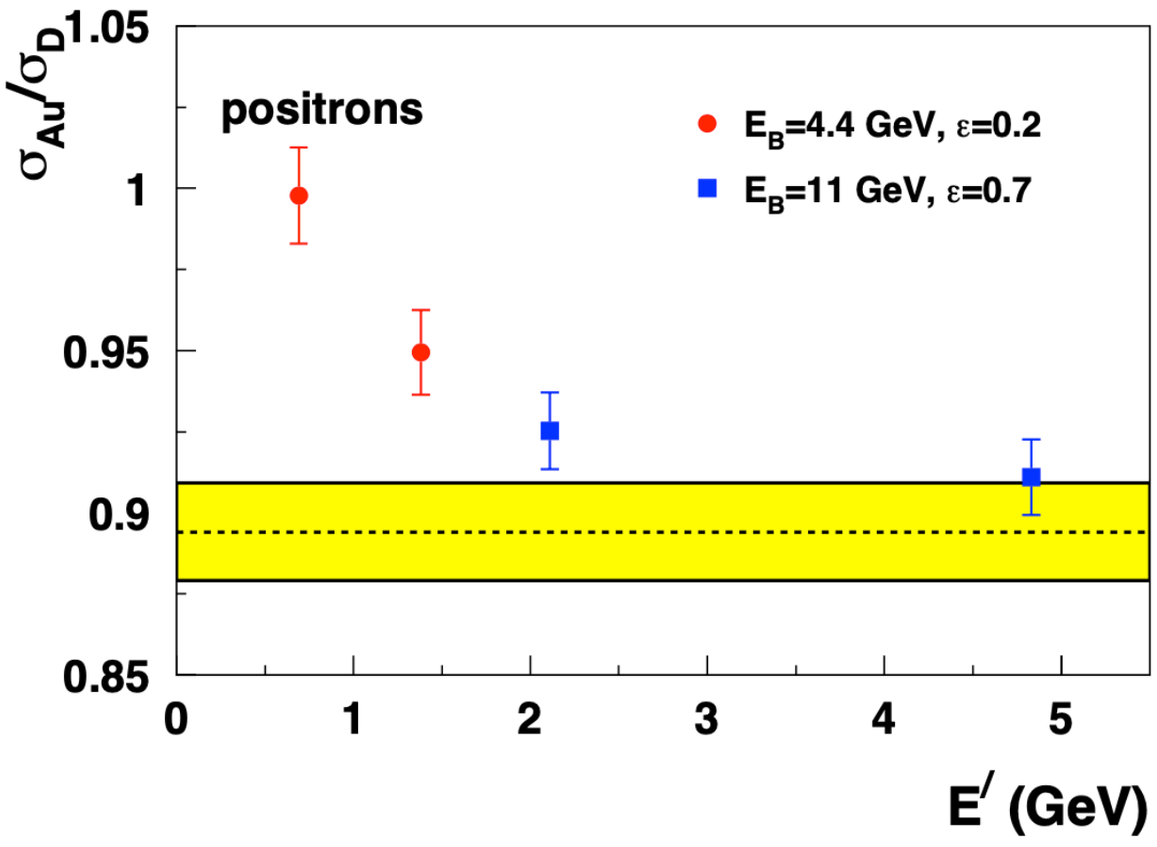




The sign of the Coulomb correction is opposite for e- and e+

Projected Results

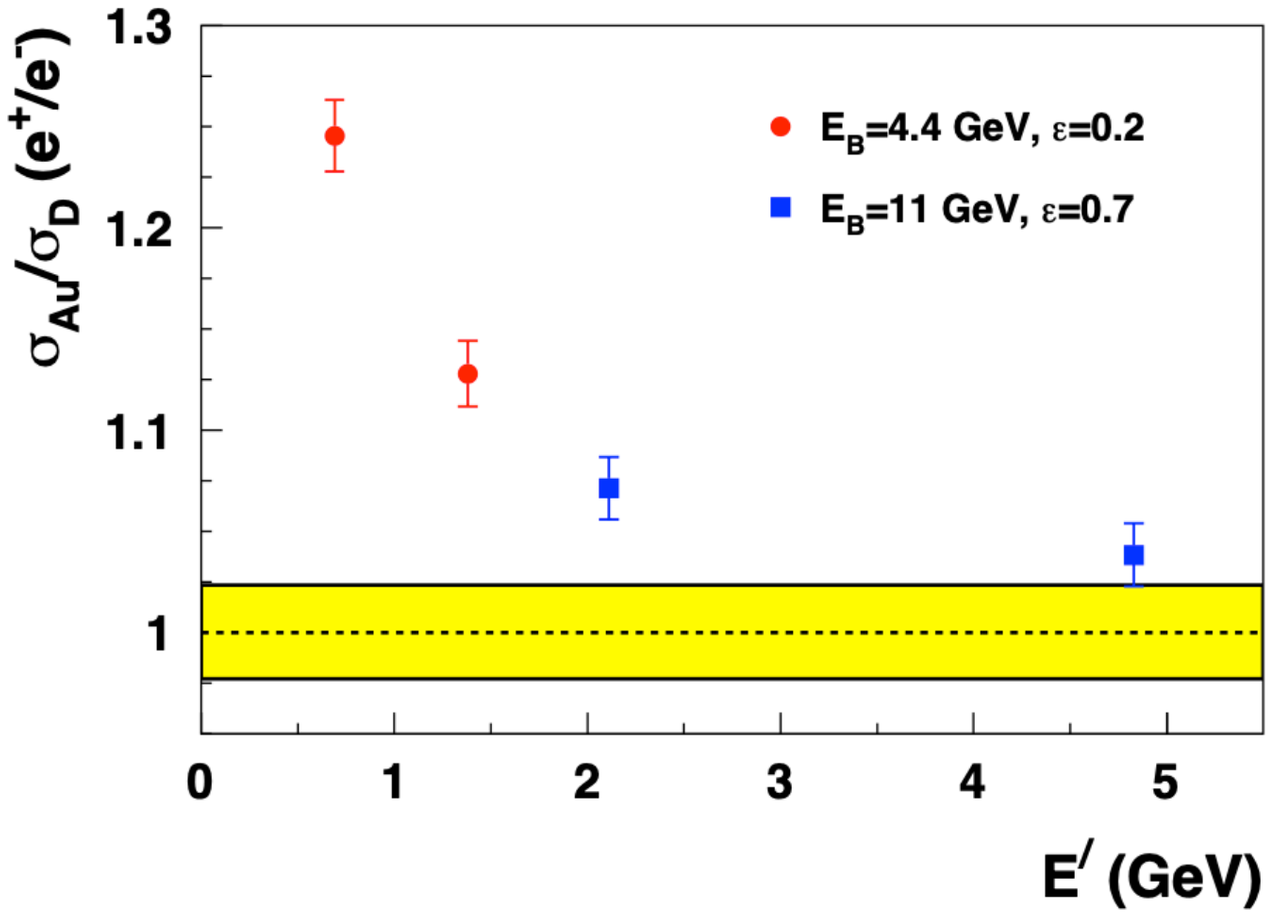




Differences in the cross section ratios between an electron beam and positron beAM will allow us directly measure the size the Coulomb corrections

Projected Results

$$R = \frac{\left(\frac{\sigma_{Au}}{\sigma_D}\right)^{e^+}}{\left(\frac{\sigma_{Au}}{\sigma_D}\right)^{e^-}}$$



- Systematics are significantly reduced by taking the super ratio

Summary

- Coulomb corrections have been extensively studied in QE processes
- Coulomb corrections are required in DIS processes as well
- It remains unclear if the effective EMA approach is suitable for DIS
- E12-14-002 will measure the nuclear dependence of R which will depend on accurate Coulomb corrections
- A positron beam at Jefferson Lab will allow for an unambiguous determination of the Coulomb effect in DIS