Precision Measurement of R_L and R_T of Quasi-Elastic Electron Scattering

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Precision ElectroWeak Interactions

Outline

- Introduction and Motivation
- JLab Proposal and Previous PACs
- Background Studies
- Coulomb Corrections
- Systematic Errors and Beam Time
- Summary

Coulomb Sum

- Response Functions in Quasi–Elastic Scattering

$$\frac{d^2\sigma}{d\Omega d\omega} = \sigma_{\text{Mott}} \left[\frac{Q^4}{q^4} R_L(q,\omega) + \frac{Q^2}{2q^2} \frac{1}{\varepsilon} R_T(q,\omega) \right]$$

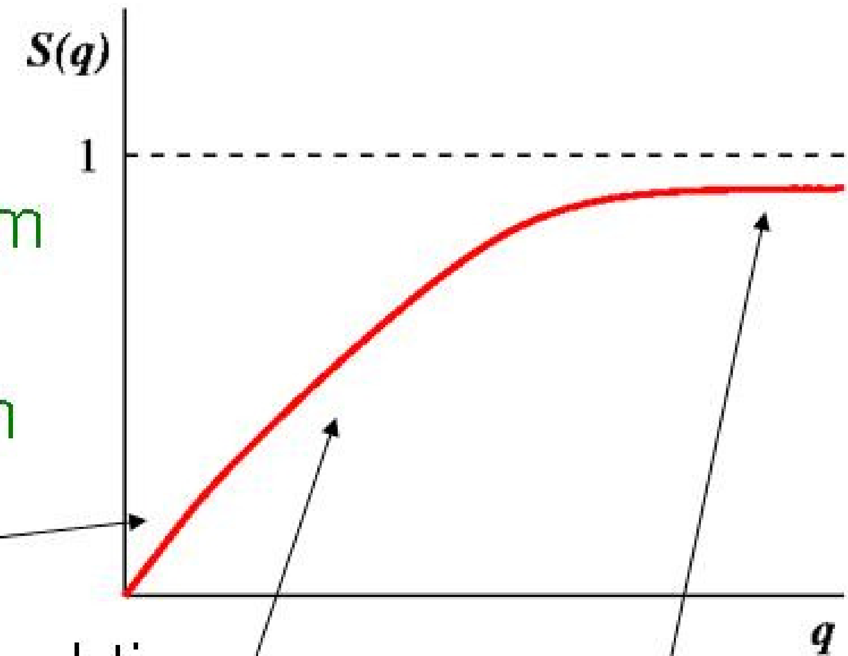
$$\varepsilon = \left[1 + \frac{2q^2}{Q^2} \tan^2 \frac{\vartheta}{2} \right]^{-1}$$

- Coulomb Sum

$$S_L(q) = \int_{\omega_{\text{el}}^+}^{\infty} d\omega \frac{R_L(q,\omega)}{Z \tilde{G}_E^{\,2}(Q^2)}$$

$$\tilde{G}_E^{\,2}(Q^2) = \left([G_E^p(Q^2)]^2 + (N/Z)[G_E^n(Q^2)]^2 \right) \frac{1 + Q^2/4M^2}{1 + Q^2/2M^2}$$

Saturation/Quenching of the Coulomb Sum



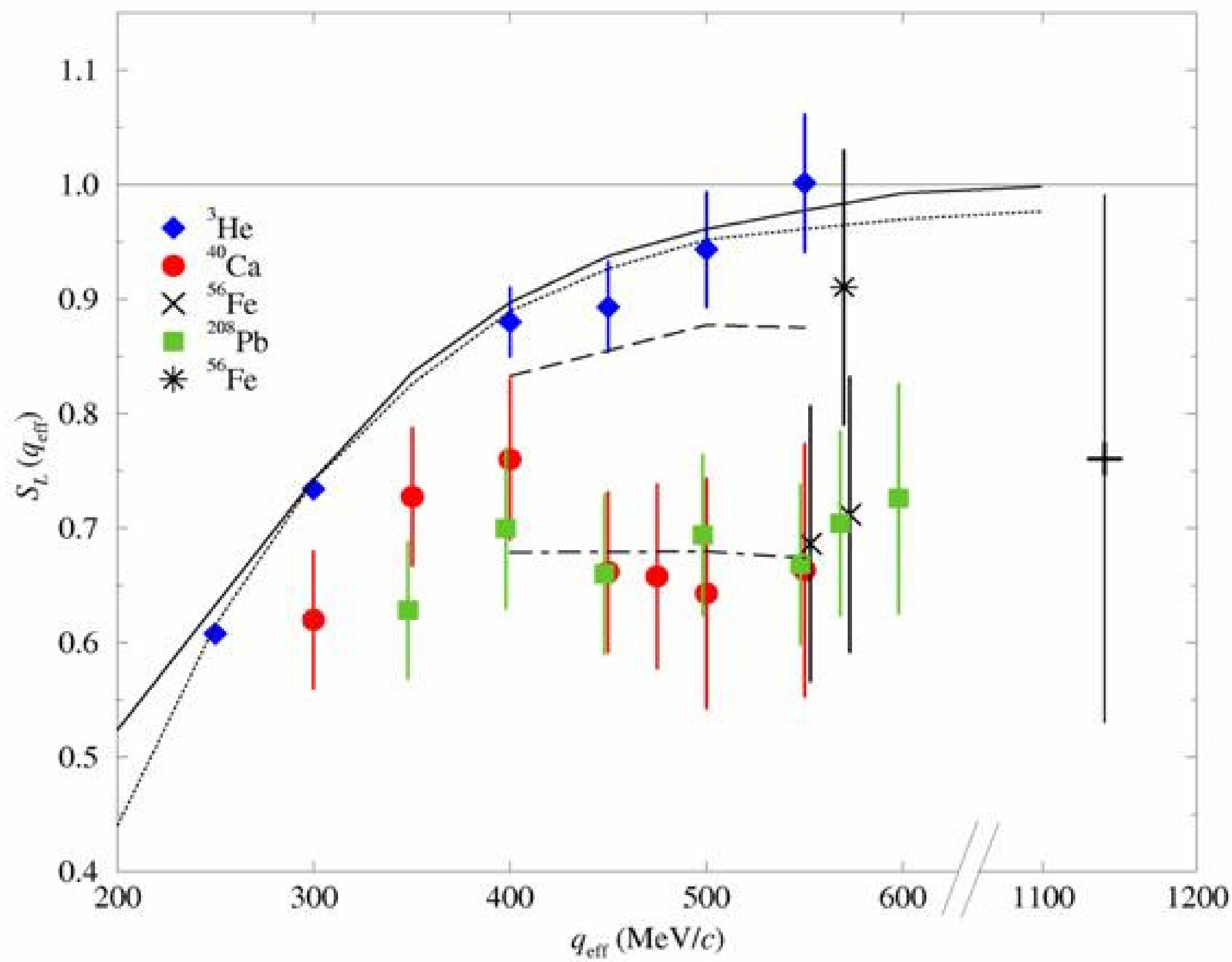
- Saturation of the Coulomb Sum
  - $S_L(q) \rightarrow 1$ at sufficiently large q
- Deviation of the Coulomb Sum
  - at small q
    - Pauli blocking
    - Nucleon–nucleon long-range correlations
  - at large q
    - Short range correlations
    - Modification of the free nucleon electromagnetic properties inside the nuclear medium
- One of the long lasting questions in physics

Overview

- Comprehensive measurements of the Coulomb sum at various labs for over 20 years
  - Limited range in q and ω
  - Saturation/Quenching of the Coulomb sum still controversial
- Proposed experiment (ex–E01–016) at JLab
  - Covers a region up to $q = 900$ MeV/c
    - Free of long range correlations/Pauli blocking
    - Effect of short range correlations, at most 10%
  - Largest lever arm for Rosenbluth separation in a single experiment
  - Better control of systematic uncertainties
  - Better control of experimental backgrounds

Previous Measurements

- For the past twenty years, a large experimental program at Bates, Saclay and SLAC
- Limited kinematic coverage in q and ω due to machine limitations



JLab Proposal at PAC19 (Jan. 2001)

- Approved for 26 days in Hall A with rating A−
- The PAC recognized the importance of performing a definitive study of the Coulomb sum rule at JLab
- Recommendations, suggestions
  - careful study of experimental backgrounds
  - close cooperation with theorists for Coulomb distortions

Jeopardy Return at PAC25 (Jan. 2004)

- On the motivation, PAC agrees that
  - Clear evidence for such effects would be of great interest in attempting to define the limits of a baryon–meson picture of the nucleus
- But PAC raises a major concern on Coulomb Corrections
- Deferred

Proposed Experiment at JLab

- Scattering Angles 15, 60, 90, 120
  - compromise between counting rates and lowest momentum setting
  - two more angles at ~ equally spaced e – improved systematic uncertainties
- Beam Energy 0.4 to 3.6 GeV
- Range of q 550 MeV/c to 900 MeV/c
- Targets ^{4}He, ^{12}C, ^{56}Fe, ^{208}Pb
  - study A or density dependent effect
  - Coulomb corrections (small for ^{4}He or ^{12}C, but large for 208Pb)
- Scattered energy Covers complete range of QE peak and beyond

Study of the Spectrometer Background

- Major concern: background originating inside the spectrometer
- Combination of SNAKE (ray tracing) and GEANT (physics)
- Electrons hitting Dipole or Q3
  - Rescattering or secondary particles by GEANT
  - Re-insertion into SNAKE
- Rescattering from the Dipole
  - Mostly from the elastic events
  - negligible (1.5×10^{-4} of the elastic yield)
- Some background events from the Q3
  - about 2% of the clean events
  - Reconstructed energy $\neq$ true energy

Cleaning up the background

- Reduction of background events from Q3
  - Different position/angle distributions for clean and un-clean events
  - Cut on the position/angle at the Q3 Exit
  - Geometric cut reduces the background by factor 10
    - After cut, background is only 0.2% of the clean events
- Further reduction using calorimeter
  - DVCS calorimeter (132 blocks)
  - 3 x 3 cm2 arranged in 3 x 44 array
  - cover central region of the focal plane
  - In situ calibration of the simulation for each spectrometer configuration
  - Energy resolution: $3\%/\sqrt{E}$

Coulomb Corrections

- Need to take into account the effect of the nucleus Coulomb field to the incoming/outgoing electrons
- Approximate corrections via Effective Momentum Approximation (EMA)
- Full treatment of Coulomb corrections via Distorted Wave Born Approximation (DWBA)
- Another approximation: Local Effective Momentum Approximation (LEMA)
- Disagreement between EMA & LEMA

Workshop on Coulomb Distortions

- First workshop on this issue
- Presentations and round-table discussions with 4 different theory groups
  - L. Wright (Ohio), J. Tjon (JLab & Maryland), A. Aste (Basel), J. Udias (Madrid)
- Some conclusions from the workshop
  - All agreed that the issue can be resolved with a coordinated effort
  - All agreed to work on the issue until reaching a consensus
- http://www.jlab.org/~choi/CSR/workshop

L. Wright's Conclusions

- Using "plane–wave–like" approach we have a very good approximate DW for potential for use in (e,e'p). It does require finding at least two Coulomb phases, and is not amenable to an expansion in Spherical Harmonics.
- For (e,e') reactions we developed a further *ad–hoc* treatment that does permit expansion in Spherical Harmonics.
- Both approximations work very well for lepton energies above 300 MeV and for 3–momentum transfers above about 250 MeV/c
- Let the Experiments Continue!

Conclusions from the mini-workshop

- J. Tjon's concluding remark: (with Eikonal's expansion)
  - *Results indicate that simple approximations are possible to account for Coulomb distortion*
- Aste's conclusion:
  - *Probably both effects (focusing and change of momentum) can be described quite accurately by a common parameter, such that EMA is a viable method to calculate Coulomb corrections*
- J. Udias agrees with the other conclusions, will do calculations to confirm.

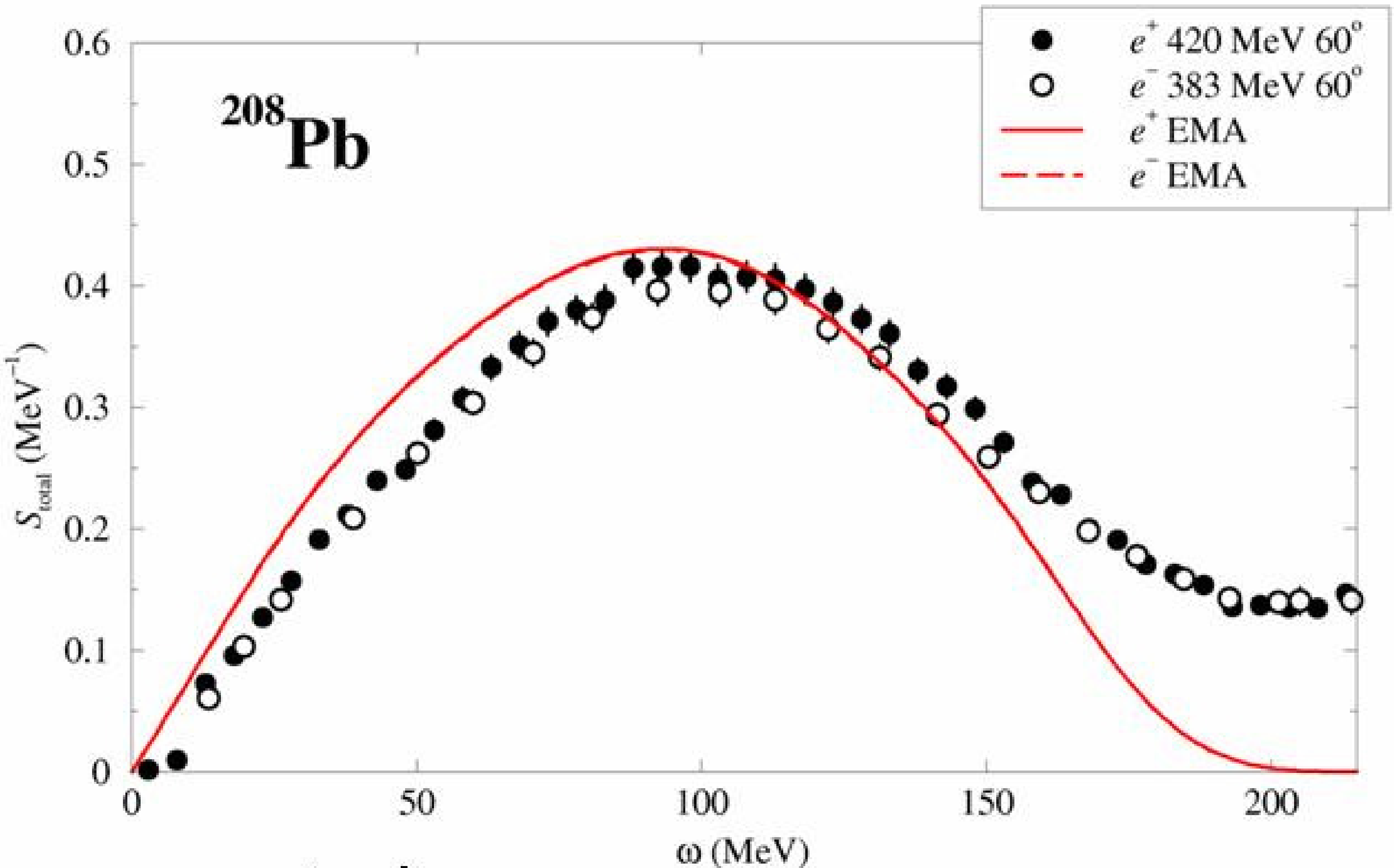
After the Workshop

- New calculations in progress
  - e.g. from A. Aste
    - *It is still interesting to observe that the exact calculations (his) agree so well with EMA, although the two approaches are completely unrelated from the calculational point of view.* (June 18)
    - *I feel very convinced that EMA is a very effective method for the description of CC.* (June 24)
    - See A. Aste *et al.*, nucl-th/0502074
- A session on Coulomb Corrections during JLab/INT workshop at W&M in August

Wright's new paper

- Nucl–th/0505032:
  - EMA–f getting better at higher E_{in}, perh aps can be used as a basic analysis too l
  - Proposed D_L, D_T to take into account Coulomb Correction;
  - at $E_{in} > 600$ MeV, good to < 5%.

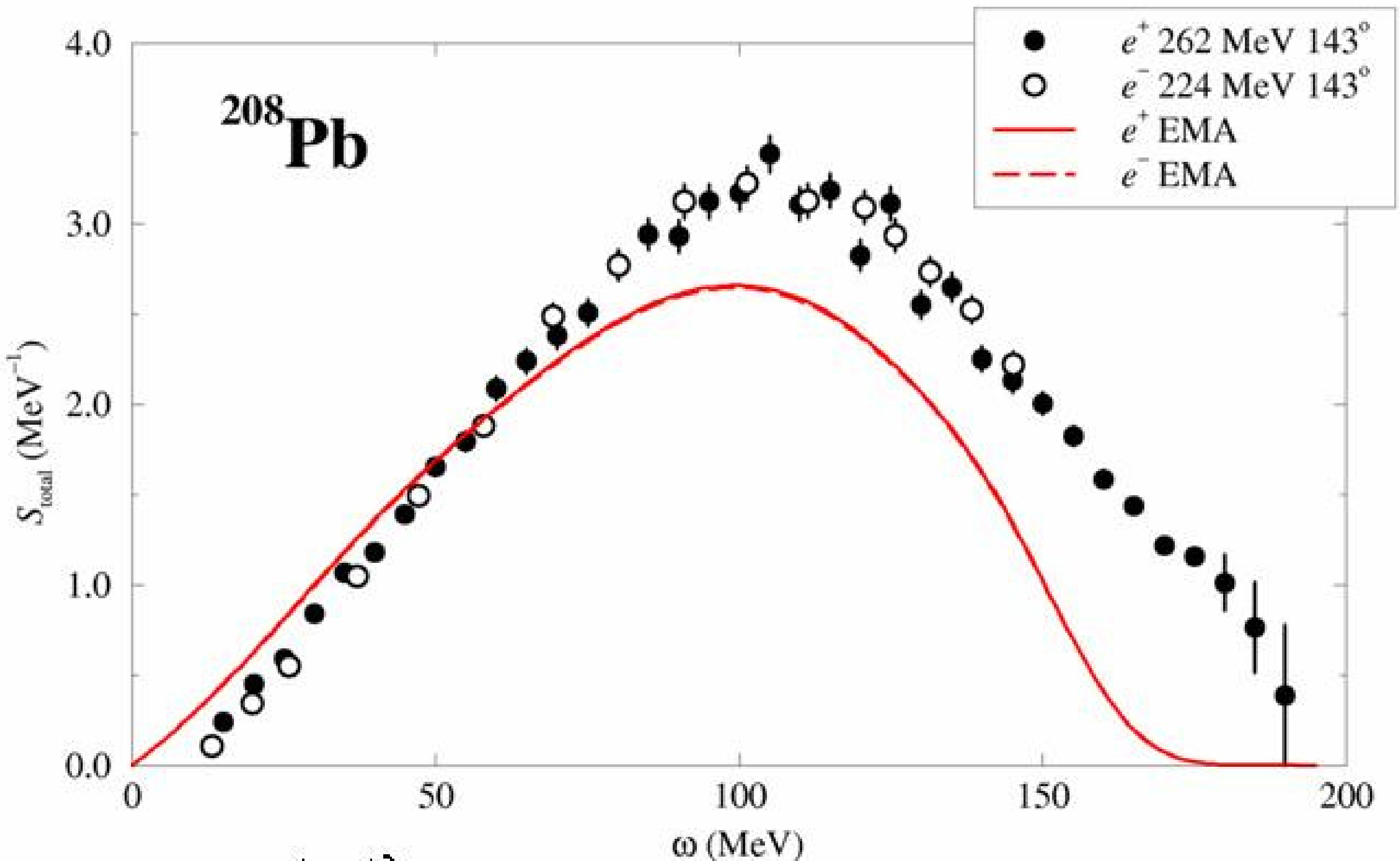
Data & EMA at Forward Angle



In EMA, $\left.\begin{array}{c} E \rightarrow E - \left|\overline{V_C}\right| \\ \hline E' \rightarrow E' - \left|\overline{V_C}\right| \end{array}\right\} \rightarrow q_{eff}, Q^2_{eff}$ with $\left|\overline{V_C}\right| = 19.0 \pm 1.5$ MeV for ^{208}Pb

P. Gueye *et al.*, Physical Review C 60 044308 (1999)

Data & EMA at Backward Angle



In EMA, $\left.\begin{array}{c} E \rightarrow E - \left|\overline{V_C}\right| \\ E' \rightarrow E' - \left|\overline{V_C}\right| \end{array}\right\} \rightarrow q_{eff}, Q^2_{eff}$ with $\left|\overline{V_C}\right| = 19.0 \pm 1.5$ MeV for ^{208}Pb

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Systematic Error Estimate on R_L

Source	Solid Target	Gas Target
Beam Energy (4×10^{-4})	< 0.3%	< 0.3%
Momentum Reconstruction	< 0.3%	< 0.3%
Detector Inefficiency	< 0.3%	< 0.3%
Dead Time Corrections	< 0.3%	< 0.3%
Interpolation	< 0.3%	< 0.3%
Beam Current	0.3%	0.3%
Scattering Angle (0.2mrad)	0.5%	0.5%
Background	0.5%	0.5%
Target Density	0.5%	1.0%
Radiative Corrections	1.0%	1.0%
Acceptance[1)]	1.0%	1.0%
Total [2)]	**1.7%**	**2.2%**

1) Contributions from the relative change between forward and backward angles

2) Conservative limit

Counting Rates and Required Time

Ebeam (MeV)	Θ	No of Pref	Time(Hour)	Sub Total (Hour)
400,0	90	17	11,3	22,3
	120	16	10,9	
500,0	90	20	13,9	30,0
	120	18	16,1	
600,0	60	16	10,7	48,9
	90	17	15,6	
	120	18	22,7	
700,0	60	13	8,8	57,6
	90	14	20,6	
	120	15	28,2	
800,0	60	11	8,5	46,8
	90	13	23,1	
	120	9	15,2	
900,0	60	10	10,7	24,9
	90	7	14,2	
1000,0	60	9	15,3	15,3
1100,0	60	9	18,4	18,4
1600,0	15	4	2,7	2,7
2000,0	15	3	2,0	2,0
2400,0	15	3	2,0	2,0
2800,0	15	3	2,0	2,0
3200,0	15	3	2,2	2,2
3600,0	15	1	0,9	0,9
Total Time (hours)				276
With 2 Spectrometers				193

Overhead

Item	Time (Hour)
Linac Energy Change	$6 \times 16 = 96$
Pass Change	$7 \times 8 = 56$
Beam Energy Measurement	$14 \times 2 = 28$
Beam Current Calibration	$4 \times 1 = 4$
Acceptance Calibration	$24 \times \frac{3}{4} = 18$
Spectrometer Change	$255 \times \frac{1}{2} \times 0.7 = 89$
Target Change	$128 \times 5 \times 1/12 = 53$
Set-up and Test	$3 \times 24 = 72$
Total Overhead	416 (=17.3 days)

Total time needed for the experiment : 610 hours (= **26 days**)

Summary

- Precision measurement of R_L and R_T over the QE scattering range
  - Momentum transfer: 550 MeV/$c \leq q \leq$ 900 MeV/c
  - On four nuclei: ^{4}He, ^{12}C, ^{56}Fe and ^{208}Pb
- Spectrometer background well under control
- Progress in Coulomb Correction Studies
- Study the evolution of the Coulomb Sum in a clear region
- Shed light on nucleon property inside the nuclear medium

26 days of beam time

Expected Uncertainty on Coulomb Sum