Measuring the Coulomb Sum Rule at JLab

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Abstract. In order to determine the Coulomb sum in nuclei, a precision measurement of inclusive electron scattering cross sections in the quasi-elastic region was performed at Jefferson Lab. Incident electrons with energies ranging from 0.4 GeV to 4 GeV scattered from ^{4}He,^{12}C,^{56}Fe and ^{208}Pb nuclei at four scattering angles $(15°, 60°, 90°, 120°)$ and scattered energies ranging from 0.1 GeV to 4 GeV. The Rosenbluth separation method is used to extract the transverse and longitudinal response functions at three-momentum transfers in the range 0.55 GeV/c $\leq$ $|\mathbf{q}|$ $\leq$ 1.0 GeV/c. The impact of a similar positron beam measurement, and its importance in testing coulomb corrections used to extract the Born cross-section, will be discussed.

PHYSICS MOTIVATION

The question of how and by how much the structure of constituent nucleons bound in a nucleus are modified has intrigued the nuclear physics community for many decades now. One experimental method of testing medium modifications of the electric Sachs form-factor of bound nucleons involves testing the Coulomb Sum Rule (CSR) through inclusive quasi-elastics lepton scattering off of nuclear targets. The CSR is defined as the integral of the longitudinal response divided by the charge-weighted electric form-factor for a fixed virtual photon momentum $|q|$ over all possible virtual photon energies ω, see Equation 1. At momentum transfer well above the fermi-momentum one would expect the CSR to be unity in the absence of short-range correlations, relativistic effects, and medium modified nucleon structure. In the kinematic regime where short-range correlations and relativistic effects are expected to be small, then any significant deviation of the CSR from unity would be evidence of a modified electric form-factor.

$$S_L(|\mathbf{q}|) = \frac{1}{Z}\int_{\omega^+}^{|\mathbf{q}|} \frac{R_L(\omega, |\mathbf{q}|)}{\tilde{G}_E^2} d\omega \tag{1}$$

E05-110 EXPERIMENTAL DESIGN

Jefferson Lab Hall-A experiment E05-110 [1] ran from October 23rd 2007 to January 16th 2008. It used an electron beam at energies between 0.4 and 4.0 GeV incident on targets ^{4}He, ^{12}C, ^{56}Fe, and ^{208}Pb. Data was collected in two spectrometer arms, independently, and at scattering angles of 15°, 60°, 90°, and 120° to allow for a high precision extraction of the longitudinal response function through the Rosenbluth separation method. A large range of beam energies and scattered-electron momenta were used to allow for interpolation of cross-sections over a range of constant-$|q|$ between 550 to 1000 MeV/c.

COULOMB DISTORTIONS AND THE EFFECTIVE MOMENTUM APPROXIMATION

One complication in extracting a clean CSR measurement is correctly accounting for the coulomb screening and focusing that is known to occur when an incident electron approaches a highly charged nucleus. The scattering result can be calculated, quite tediously, through solving the Dirac equation radially for each term in a partial wave expansion of the nuclear field. A complete calculation for each scattering event becomes unrealistic for large data samples such as those found in E05-110. Instead, an effective momentum approximation (EMA) is used, which applies a correction to the virtual photon momentum (q_{eff}), based on a mean potential calculated from the radius and charge of the nucleus, see Equation 2.

$$V_0 = \frac{3\alpha Z}{2r_c} \quad (2)$$

$$Q^2_{eff} = 4(k_i - \kappa_A V_0/c)(k_f - \kappa_A V_0/c)\sin^2(\theta/2) \quad (3)$$

$$q_{eff} = \sqrt{\omega^2 + Q^2_{eff}} \quad (4)$$

The potential is then tuned against full Dirac calculations (using κ_A in Eq. 3)[2]. EMAs have been widely used on many nuclear scattering experiments and methods have been cross-checked between different theoretical groups [3]. All CSR data is corrected using the EMA. The corrections are largest with the heaviest nuclei and lowest momentum-transfer. For E05-110, the 120° data on ^{208}Pb have the largest coulomb corrections, which result in corrections to the cross-section above ≈ 10%, see Fig. 1.

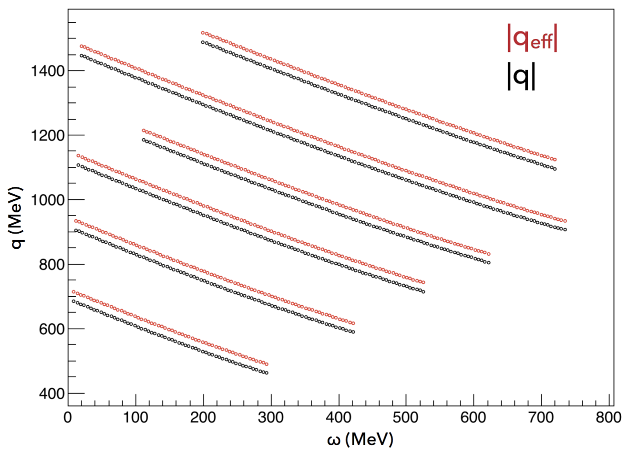

FIGURE 1. The adjustment to the $|q|$-ω phasespace from the expected EMA correction on ^{208}Pb 120° data from E05-110.

EXISTING VERIFICATION OF THE EMA

The most straight-forward way to test the validity of EMA is through comparing positron to electron scattering off of heavy nuclei. By keeping the same beam energy and angle, one can see the direct result of the coulomb field on the scattering process. Such an analysis has been performed by Gueye *et. al.* at Saclay [4]. For positron and electron beams at 420 MeV incident on lead targets, the scattered lepton was detected at 60°. A comparison of the reduced cross-sections show a clear difference between the data. Furthermore, after applying the expected EMA correction to the positron data, both cross-sections come into agreement, see Fig. 2.

CSR AND FUTURE POSSIBILITIES WITH POSITRON BEAMS

Although coulomb corrections are largest at low beam energies on heavier targets, the correction is applied to all data when calculating the CSR. At larger momentum transfer, there is no existing positron data to confirm EMA. It is important to test the validity of the EMA corrections in this regime, especially in kinematic regions where the slope of the Rosenbluth fit may be susceptible to slight changes in the cross-section. For this reason, collecting inclusive positron scattering data at large momentum transfer would be invaluable to validate the currently used EMA corrections.

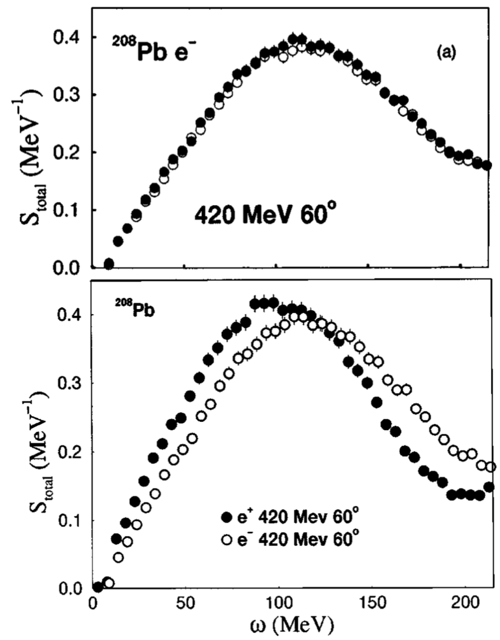

FIGURE 2. Figures are from Gueye *et. al.* [4], 420 MeV beam energy incident on ^{208}Pb target with scattered lepton detected at 60°. Top plot: Positron and electron beam cross-section comparison after EMA corrections on positron data ($E_{e-} = E_{e+} - 2|V_C|$). Bottom plot: Positron and electron cross-sections before EMA correction.

ACKNOWLEDGMENTS

This work is supported in part by the U.S. Department of Energy Grant Award DE-FG02-94ER4084.

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