

# ARE RECOIL POLARIZATION MEASUREMENTS OF $G_E^P/G_M^P$ CONSISTENT WITH ROSENBLUTH SEPARATION DATA?

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Recent recoil polarization measurements in Hall A at Jefferson Lab show that the ratio of the electric to magnetic form factors for the proton decreases significantly with increasing  $Q^2$ . This contradicts previous Rosenbluth measurements which indicate approximate scaling of the form factors ( $\mu_p G_E^p(Q^2)/G_M^p(Q^2) \approx 1$ ). The cross section measurements were reanalyzed to try and understand the source of this discrepancy. We find that the Rosenbluth measurements are consistent when normalization uncertainties are taken into account, and that the discrepancy cannot come from errors in one or two data sets. If there is a problem in the Rosenbluth data, it must be a systematic,  $\epsilon$ -dependent uncertainty affecting several experiments.

The structure of the proton is a matter of universal interest in nuclear and particle physics. The electromagnetic structure of the proton can be parameterized in terms of the electric and magnetic form factors,  $G_E(Q^2)$  and  $G_M(Q^2)$ , which can be measured in elastic electron-proton scattering. The electric and magnetic form factors can be separated using the Rosenbluth technique<sup>1</sup>, or by measurements of the recoil polarization of the struck nucleon<sup>2</sup>. Figure 1 shows the ratio of  $\mu_p G_E/G_M$  as a function of  $Q^2$  for the Jefferson Lab recoil polarization measurements<sup>3</sup> and from a global Rosenbluth analysis of the cross section measurements<sup>4</sup>. Clearly we must understand this discrepancy if we want to be confident in our knowledge of the proton form factors.

While it is possible that there is a fundamental problem with one of these techniques, we first want to understand if we can explain the difference in terms of less fundamental problems (*e.g.* experimental errors or analysis procedures). The Rosenbluth measurements are more sensitive to experimental uncertainties as  $Q^2$  increases, and extractions that involve combining multiple data sets are sensitive to their relative normalization factors. Thus, we wish to examine both the individual cross section measurements and the analysis procedures to see if there could be problems that would explain the discrepancy between the two techniques.

In the global analysis shown in fig. 1, many data sets are combined, and a global fit is performed to extract the relative normalization of the experiments as well as the value of  $G_E$  and  $G_M$  at several  $Q^2$  values. Errors in one or more of the experiments or improper normalization procedures for experi-

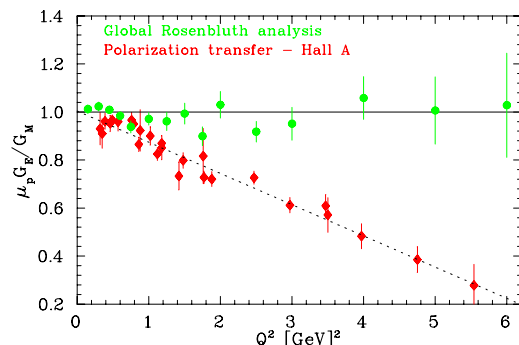


Figure 1. Ratio of electric to magnetic form factor from a global analysis of cross section data (circles) and from the JLab measurements of recoil polarization (diamonds).

ments which combine multiple measurements could cause such a global fit to give an incorrect result. In addition, because relative normalization factors are being fit, it is possible that one could vary the normalization factors for one or more experiments by an amount that is within the experimental uncertainty in such a way that the ratio of  $G_E/G_M$  changes significantly, while the overall  $\chi^2$  of the fit is not significantly increased (*i.e.* the global minimum might give the results shown in fig. 1, but a local minimum may give a global fit that is almost as good in which the ratio of  $G_E/G_M$  falls with  $Q^2$ ).

A new global fit was performed in order to investigate possible problems in the previous data or analyses. Experiments where multiple detectors were used to take portions of the data were broken up, so that there were 16 data sets (and 16 normalization parameters) for the 13 experiments included. As this analysis was focussed on the discrepancy at larger  $Q^2$ , data below  $Q^2 = 0.3 \text{ GeV}^2$  were excluded. The small angle data ( $\theta < 15^\circ$ ) from the Walker measurement were also excluded, because a later SLAC experiment found corrections that had been neglected in the analysis<sup>5</sup>. The new fit gives results that were similar to the global analysis by Walker, and no data set had an anomalously large contribution to the  $\chi^2$ . Additional fits were performed with individual data sets left out, to see if the result might be driven by a single (potentially bad) data set. No single experiment had a large impact on the overall fit, and even removing the three data sets that had the largest effect only gave a decrease of  $\sim 10\%$  in the ratio.

While improvement to the global analysis and removal of data sets did not allow for agreement between the two techniques, there is still the question as

to whether a different solution for the relative normalizations could be found which brings the experiments into agreement without significantly decreasing the quality of the fit. This was tested in two different ways. First,  $G_M$  was fit to the data, with the ratio of  $G_E/G_M$  determined from a parameterization of the recoil polarization data ( $\mu_p G_E/G_M = 1 - 0.13Q^2$ ). This gave a much worse fit, increasing the total  $\chi^2$  by 69 for the fit to 301 cross section data points. The Rosenbluth data do not reproduce the recoil polarization data with only minor adjustments to the relative normalization factors. Fixing the ratio of  $G_E/G_M$  to match the recoil polarization measurements gives these data more impact on the fitting than they should have and ignores their uncertainties, so this test likely overestimates the inconsistency. A global analysis including both the cross section data and the  $G_E/G_M$  polarization measurements from fig. 1 (including their statistical and systematic errors) also gives a significantly worse overall fit, though not as bad as when the ratio is fixed in the fit (16 data points are added to the fit and the total  $\chi^2$  increases by 49).

Finally, it has been noted that individual extractions of  $G_E/G_M$  from recoil polarization measurements are inconsistent. However, these extractions often involve combining two or three data sets that cover different  $\epsilon$  ranges, which requires determining the cross-normalization between experiments. While various procedures have been used to determine these normalization factors, the uncertainty in the normalization is often not taken into account in extracting  $G_E$  and  $G_M$ . Thus, it is difficult to verify the consistency of the underlying cross section data based on these extractions. If one examines only experiments where a single detector covered an adequate range of  $\epsilon$  to perform a Rosenbluth separation, these experiments are consistent with each other and give results similar to the previous global fits (although with significantly reduced precision). One can increase the amount of data available by including experiments where multiple detectors were used, but where direct cross-calibrations were possible within the experiment. Again, this set of experiments give consistent results, and are in good agreement with the cross section global analysis. The inconsistency of the Rosenbluth extractions appears to come from the assumptions made when combining data sets at different  $\epsilon$  values, and does not indicate a fundamental inconsistency between the different measurements.

Even if the recoil polarization result is correct, and the problem lies with the cross section data, we must still understand the problem with the Rosenbluth measurements. If the recoil polarization data is correct, this implies that there is a problem in the cross section measurements that introduces a systematic  $\epsilon$ -dependence in multiple data sets. Even with perfect knowl-

edge of  $G_E/G_M$ , we need these cross sections to extract the absolute values of  $G_E$  and  $G_M$ , and we cannot extract precise and accurate values for the form factors if we do not know what the problem is with the cross section measurement.

In conclusion, the disagreement between the recoil polarization and Rosenbluth measurements cannot be explained by assuming that there is a problem with one or two data sets, nor can they be made to agree by simply adjusting the relative normalization factors in a global analysis (without significantly worsening the quality of the fit). There is no evidence of problems within any of the data sets (with the exception of the low angle Walker data), and the existing Rosenbluth measurements are completely consistent. The extractions of  $G_E$  from these data are only inconsistent when one includes analyses that combine different data sets without properly taking into account the uncertainties in the relative normalizations. Thus, there is no experimental evidence to tell us which of these techniques is failing. It is important to determine which is correct not only because we want to know the form factors of the proton, but also because these techniques are used in other measurements, and a fundamental problem with either technique could affect other measurements. Future measurements at JLab including a high precision Rosenbluth<sup>6</sup> separation and a new recoil polarization measurement<sup>7</sup> (using a different experimental setup) will help us understand the discrepancy and determine if it is a fundamental problem with one of the techniques or a problem with the existing data.

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