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Workshop summary

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Abstract. This latest in a series of workshops on parity-violating electron scattering comes at a momentous time in the history of this subject. The first experiments to determine strange form factors of the nucleon have produced intriguing final results, and several powerful new experiments are now producing data. In addition, the precision of the technique has been improving and new experiments testing the electroweak theory have reported remarkably precise data. There has also been a great deal of progress on both the theory of strange form factors and interpretation of electroweak symmetry tests.

PACS. 01.30.Cc Conference proceedings – 25.30.Bf Elastic electron scattering – 11.30.Er Charge conjugation, parity, time reversal, and other discrete symmetries

1 Introduction

It has been 15 years since the first papers [1,2,3] proposing to study strange quark contributions to nucleon electroweak form factors gave new impetus to the field of parity-violating electron scattering. Indeed shortly after those papers in February of 1990, the first of these workshops [4] was held in Pasadena, California. The warm and sunny winter weather seemed to portend a bright future (we didn't know the workshop should have been called PAVI-90!) and provided additional motivation for participants from colder climes in the US, Canada, and Germany to attend. That workshop certainly reaffirmed the motivation for planning a program of parity-violating electron scattering experiments to explore the strangeness in the nucleon. But it also served to highlight many concerns on both the theoretical and experimental sides, which have fortunately all been mitigated through diligent and clever efforts in the subsequent years.

Since that time, we have seen truly remarkable progress in this field with great strides made by theorists as well as experimentalists. This workshop was an excellent opportunity to take stock and chart a new course for the future. The organizers should be commended for providing a stimulating program and delightful environment, and I certainly hope that their plans to continue this tradition are fruitful.

2 Strange form factors

The first proposed experiment to study the strangeness in the nucleon using parity-violating electron scattering was the SAMPLE [5] experiment at MIT/Bates. As reported at this workshop by D. Spayde, the SAMPLE experiment has measured the strange magnetic form factor for the first time, with the result [6]

$$G_M^s(Q^2 = 0.1(\mathrm{GeV/c})^2) = 0.37 \pm 0.20 \pm 0.26 \pm 0.07\,. \quad (1)$$

Although this result is consistent with zero strangeness, it is not consistent with the prevailing theoretical view as presented in Fig. 1. Most theoretical predictions favor a substantially negative strange magnetic moment, whereas the SAMPLE result indicates $\mu_s \geq 0$.

Figure 1 also indicates the level of interest in the quantity μ_s among theorists in this field. There have been a great number of studies, and this has made for very pleasant and productive interactions between theorists and experimentalists. What is difficult to tell from Fig. 1 is that we have actually learned something from this discourse. Early models with simplistic treatments of vector meson dominance or lowest order $K - \Lambda$ loops are known to be inadequate to reproduce the the experimental result, have well-studied theoretical shortcomings, and so are no longer used in modern calculations. Unfortunately, as reported in this conference by Kubis and Ramsey-Musolf, effective field theory is not very effective for these observables as there are too many unknown counterterms and the convergence of the series is, at best, very slow. It now appears that the remaining theoretical treatments that are consistent with the data are the chiral soliton model [9] (as discussed by Silva at this workshop) and the lattice-based treatment [10] as discussed by Leinweber. The prediction of the chiral soliton model for the SAMPLE result is shown as the black diamond at entry 25 in Fig. 1, one of the few results with $G_M^s > 0$. The Leinweber *et. al.* result is shown as the last magenta star (entry 27), and represents a bold and precise prediction

$$\mu_s = -0.051 \pm 0.021 \quad (2)$$

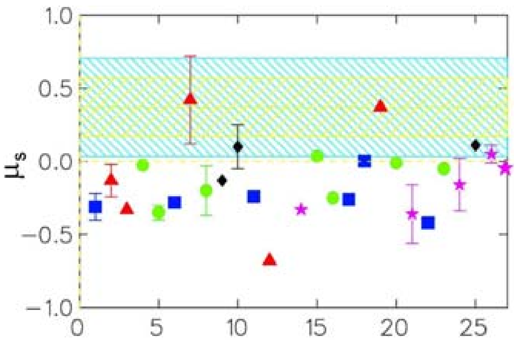

Fig. 1. Theoretical predictions for μ_s are shown as symbols, with the SAMPLE experimental result indicated by the hatched region, statistical uncertainty (*inner*) and total uncertainty (*outer*). The theoretical results are compiled and discussed in [7,8]

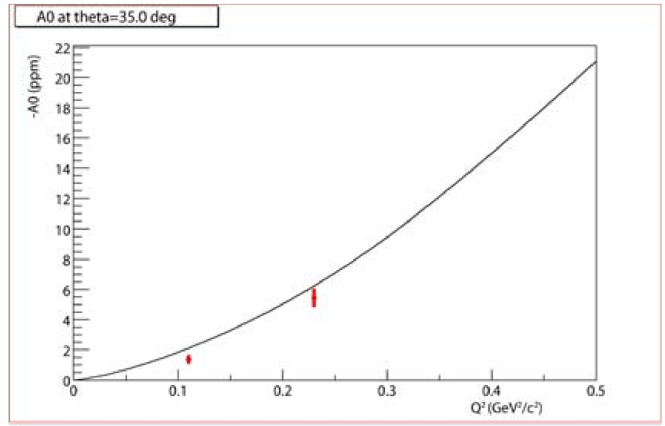

Fig. 2. Results reported at this workshop by the A4 collaboration. The *solid line* is the prediction for the case where both strange form factors vanish

that lies just outside the 1σ error bar of the experiment. There was much discussion about the justification for the very small quoted theoretical error, and I am sure that this discussion will continue at many additional conferences and workshops.

Of course during the last few years we have also seen the remarkably precise data [11] from HAPPEX. This experiment has the notable distinction of being the first parity-violation experiment to use a high polarization beam from a strained GaAs crystal. They obtain a result for the combination of form factors at $Q^2 = 0.477$ (GeV/c)^2:

$$\frac{G_E^s + 0.392 G_M^s}{G_M^p/\mu_p} = 0.091 \pm 0.054 \pm 0.039 \qquad (3)$$

which also can be used to rule out many models. Future planned running of HAPPEX involves lower $Q^2 = 0.1$ (GeV/c)^2 measurements of elastic asymmetries for Helium as well as Hydrogen targets.

And the major news at this conference are the new results from the Mainz A4 collaboration. They report asymmetries at $\theta = 35°$ at two Q^2 values, as shown in Fig. 2. These are very interesting results that may indicate a non-vanishing strange quark contribution, and the A4 collaboration has plans for many more measurements including backward angles.

In addition, we heard that the G^0 experiment has completed its production run at forward angles. The data are under analysis and will hopefully be available in the very near future. Clearly, many years of planning, systematic studies, and equipment construction are now yielding an impressive data set that will surely provide us with a clearer picture of strangeness in the nucleon.

The broader context of strangeness in the nucleon was also discussed at the workshop. M. Sainio updated the situation regarding the sigma term. And J. Ellis presented an overview discussing the relation to the spin of the nucleon, the possible connection with exotic baryon states, and ideas for evading the OZI-rule. It is intriguing to note that the chiral soliton model, which is uniquely successful in producing a result for G_M^s that quantitatively agrees with the SAMPLE experimental data, is also achieving significant notoriety for it's recent predictions of pentaquark states (for which there is increasingly substantial, but also controversial, experimental evidence).

3 Transverse spin asymmetries

The subject of transverse spin asymmetries is receiving increased attention in the last year or so. Due to the fact that it is higher order in the fine structure constant (i.e., 2 photon exchange) and it is further suppressed by the lorentz factor $1/\gamma$, there was not much previous interest in this subject. The existence of recent data from the SAMPLE experiment [12] demonstrated the feasibility of the method for measuring the small asymmetries (although larger than parity-violation asymmetries). In addition, there has been increased recent interest due to the apparently significant 2 photon exchange effects in the interpretation of proton form factor measurements at high Q^2 (see Sect. 4). At this workshop, we heard presentations of the SAMPLE data by D. Spayde as well as new data from A4 by S. Baunack. In addition, high energy data from SLAC E158 will be available soon.

The A4 collaboration measures transverse asymmetries with their luminosity monitors, or "Lumis" (mostly Møller scattering), as well as with their detectors for elastic scattering off protons. The Lumi data are quite precise (5%), but disagree with the NLO calculations for Møller scattering by 2-5 σ. This is not understood.

The theoretical interpretation of the transverse asymmetries in elastic *e-p* scattering was discussed by Pasquini and by Ramsey-Musolf. Pasquini *et al.* use the MAID description of photon couplings to the nucleon and the continuum. This prescription results in qualitatively correct behavior, but misses all the data by about 2 σ (they *underpredict* the magnitude of the SAMPLE asymmetry but *overpredict* the magnitude of the A4 asymmetries). Ramsey-Musolf presented calculations [13] in the framework of effective field theory. They obtain reasonable agreement with the SAMPLE data, but it seems that the A4 data are at too high a Q^2 for this treatment to be valid.

4 Other form factors

K. DeJager presented a thorough review of the situation with the elastic electromagnetic form factors of the nucleon. There are recent G_E^n data that are beginning to map out the Q^2 dependence of this elusive form factor with impressive precision. This form factor is an important constraint on nucleon structure as well as an important input in the interpretation of parity-violation experiments. Another major topic of current interest relates to the controversy regarding the G_E^p/G_M^p data from recoil polarization measurements [14] at $Q^2 > 1$ GeV^2. The form factor ratio extracted from these measurements disagrees with the results determined previously by Rosenbluth separation. More recently, new Rosenbluth separation data [15] taken by detection of the recoil proton (to reduce systematic errors and radiative corrections) give strong support for the earlier Rosenbluth separation data.

This conundrum appears to be resolvable by consideration of 2 photon exchange effects [16]. Guichon presented their analysis at this workshop, and it appears that quantitative agreement with the two data sets is possible although additional free parameters must be employed. Their analysis indicates that $2-3\%$ two photon exchange contributions with reasonable magnitudes can distort the Rosenbluth plots by about the amount necessary to resolve the discrepancy. Clearly further measurements are desirable, including comparison of positron and electron scattering cross sections to test the model quantitatively. If this explanation is correct, then it would seem prudent to revisit all cases where delicate Rosenbluth separations have been performed to extract small amplitudes (e.g. the famous $R = \sigma_L/\sigma_T$ in deep inelastic scattering).

E. Beise discussed a recent reanalysis [17] of the Q^2 dependence of the axial form factor of the nucleon as determined in quasielastic neutrino charged current interactions. That work produced a slightly smaller value of the axial mass as compared to previous studies: $M_A = 1.001 \pm 0.020$ GeV. This quantity is relevant to the interpretation of backward angle parity-violation experiments such as future planned measurements by G^0 and A4. These collaborations also plan to run with deuterium, which allows separation of the axial term (as was done for SAMPLE [18]).

5 Electroweak tests

The birth of parity-violating electron scattering was marked by the famous Prescott experiment at SLAC [19], which had the distinction to provide the first quantitative evidence for violation of parity in the neutral current as predicted by the standard model. Other early experiments in parity-violating electron scattering also were attempts at testing the standard electroweak theory, notably the Mainz ^{9}Be experiment and the Bates ^{12}C experiment. The advances in experimental techniques that have been achieved in the pursuit of strange quark form factors during the last decade have also motivated new higher precision experiments to test the standard electroweak model. At this workshop we heard a report by A. Vacheret on the SLAC E158 experiment, which measures parity-violating Møller scattering and a presentation of the plans for Qweak at JLab by G. Smith.

In a fundamental sense, the parity-violating effect in electron scattering relates to the weak neutral couplings to the electrons and quarks. At tree-level, these couplings depend on one parameter, the weak mixing angle θ_W. Thus the various precision parity-violating electron scattering experiments aim to constrain $\sin^2\theta_W$ and compare with the very precise value measured at the Z-pole in e^+-e^- scattering. Due to radiative corrections, the value of $\sin^2\theta_W$ "runs" with Q^2 in a predictable fashion according to the standard model. Thus these experiments test for new particles in loops and exchanges associated with these radiative corrections to search for evidence of new physics beyond the standard model.

Another method to precisely determine $\sin^2\theta_W$ at low Q^2 is via neutral current neutrino scattering. Recently, the NuTeV experiment at Fermilab has reported a measurement [20] of ratios of neutral current to charged current cross sections for both neutrinos and antineutrinos. They observe a substantial effect in the neutrino ratio, which they interpret as an anomalous value of ("on-shell" scheme)

$$\sin^2\theta_W = 0.2277 \pm 0.0013 \pm 0.0009 \quad (4)$$

which is 3σ from the standard model prediction of 0.2227 ± 0.00037. K. McFarland presented these results and discussed many alternate explanations for the discrepancy. It appears that relatively large isospin violation in the parton distribution functions could generate the observed effect and would be consistent with all other experiments. The cause of the NuTeV anomaly remains a subject of much active study.

The recently published E158 results [21] are based on the data from the first of three data runs. The results reported at this workshop included the first and second data sets:

$$\sin^2\theta_W = 0.2379 \pm 0.0016 \pm 0.0013 \quad (5)$$

which agrees well with the standard model prediction of 0.2386 ± 0.0006. (Note that E158 uses a different renormalization scheme to quote $\sin^2\theta_W$). The situation is shown graphically in Fig. 3.

The Qweak proposal [23] to JLab is to measure parity-violating elastic electron-proton scattering at very forward angles ($\theta \sim 8°$) to achieve a low $Q^2 = 0.028$ GeV^2. This will ensure that the strange quark effects in the electric form factor are small enough to be manageable. The high statistics will be achieved by using 180μA of electron beam from strained GaAs with high polarization. The 35 cm long liquid hydrogen target must absorb 2.5kW of beam power without boiling effects. (Previous high power targets at SAMPLE and E158 achieved 500W and maintained excellent thermal stability.) The goal is to measure

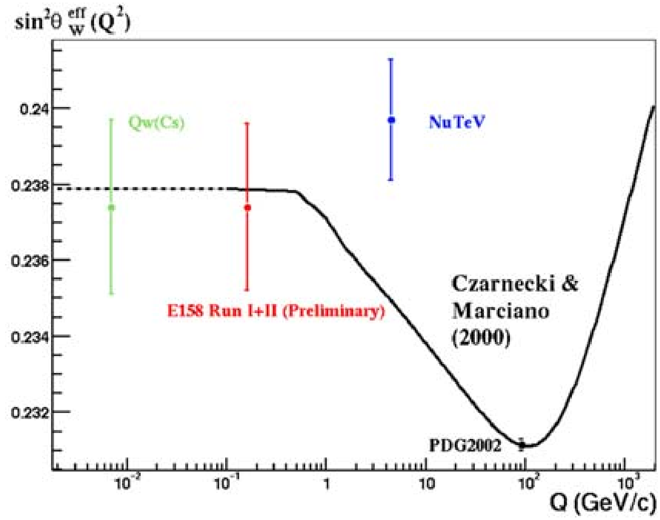

Fig. 3. Plot of effective $\sin^2\theta_W$ vs Q^2 showing the E158 result, NuTeV result, Z-pole value, and Cs atomic parity-violation. The theoretical curve is from [22]

$\sin^2\theta_W$ to a precision of ± 0.0007 (compared to the ultimate precision of E158 of $\sim \pm 0.0012$). It is hoped that this ambitious experiment could be mounted in 2007 and begin commissioning studies shortly thereafter. One should keep in mind that this is the time scale for LHC to start, and the future of such experiments in the post-LHC era is far from clear.

6 Outlook

The field of parity-violating electron scattering has entered an extremely productive phase. Over the next 3-5 years we should have in hand a definitive dataset mapping out the role of strange quarks in the electroweak form factors of the nucleon. It is difficult to judge how that will turn out and how the theoretical interpretation will develop in response to the data. Perhaps a round of higher precision experiments will be indicated. Already we see that if one takes the Leinweber, *et al.* prediction seriously, one could justify building a super-SAMPLE experiment with high polarization CW beam to achieve precision on μ_s comparable to this theoretical prediction.

Perhaps we will even have new data from Qweak in this time frame to further test the standard electroweak theory. And it might even be worth revisiting the method of elastic scattering from a spinless nucleus like ^{12}C to perform other high precision tests.

In the shorter term, it seems that the methods developed for parity-violation experiments can be used to obtain more data on transverse asymmetries to explore the 2 photon exchange process in more detail. At high Q^2 there could be a useful connection with the Generalized Parton Distributions (see the talk by M. Gorshteyn) and at low Q^2 there could be a connection with the nucleon polarizabilities. Clearly there is a great deal of experimental and theoretical work to do in this area, and we are just seeing the beginning of that endeavor.

So it seems that at least one more workshop on this topic is well-justified, and if the organizers can find a location that is of comparable quality to the Grenoble workshop I am sure we (and many new younger people) will be there to hear of the exciting developments that are sure to come.

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