Eur. Phys. J. A (2007)
DOI 10.1140/epja/i2006-10207-5

THE EUROPEAN PHYSICAL JOURNAL A

Special Article – QNP 2006

Strange quarks in the nucleon sea

Results from HAPPEX II

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Received: 25 October 2006
Published online: 23 February 2007 –

Abstract. The HAPPEX Collaboration measured parity-violating electron scattering from ^{4}He(e,e) and H(e,e) in 2004 and 2005 for $Q^2 \leq 0.11\,\mathrm{GeV}^2$. Results for the strange-quark contributions to the electromagnetic form factors of the nucleon from the 2004 data will be reviewed. Preliminary results from the 2005 data, which have significantly greater statistical precision, are $G_E^s = 0.004 \pm 0.014_{stat} \pm 0.013_{syst}$ for $Q^2 = 0.0772\,\mathrm{GeV}^2$ from the helium data and $G_E^s + 0.088 G_M^s = 0.004 \pm 0.011_{stat} \pm 0.005_{syst} \pm 0.004_{FF}$ for $Q^2 = 0.1089\,\mathrm{GeV}^2$ from the hydrogen data.

PACS. 14.20.Dh Protons and neutrons – 13.40.Gp Electromagnetic form factors

1 Introduction

The structure of the nucleon is of fundamental interest. Almost all the non-dark-matter mass in the Universe is contained within the nucleon. The nucleon is unique among systems of ordinary matter in that most of its mass is not due to the masses of its constituents. For example, QCD calculations of nucleon mass [1] propose that most of the nucleon's mass is due to the energy in the gluon fields. Such strong gluon fields are expected to give rise to significant numbers of virtual quark and antiquark pairs. Indeed, the importance of this sea of $q\bar{q}$ pairs has been demonstrated [2] in the analysis of νN scattering. Since the nucleon contains no net strangeness, any effect of strange quarks on the structure of the nucleon should be attributable to the strange-quark sea. Hints of the importance of the strange quark sea to the mass of the nucleon [3] or to the spin structure of the nucleon [4] raise the question of whether static properties of the nucleon ground state, such as the electromagnetic form factors, also depend on the strength of the strange-quark sea.

2 Parity-violating electron scattering

Measurements of the electromagnetic form factors of the proton and neutron provide two pieces of data, as a function of Q^2, from which a two-component quark flavor separation is possible. If, however, a third quark flavor, that is strangeness, needs to be extracted, additional experimental data are needed. This third piece of data can be provided by parity-violating electron scattering [5]. Interference between photon and Z^0 exchange gives rise to a helicity-dependent asymmetry in the elastic scattering cross-section. For the Q^2 range, $0.01\,\mathrm{GeV}^2 \leq Q^2 \leq 1\,\mathrm{GeV}^2$ the experimentally measured asymmetry A_{PV} is expected to lie between 10^{-7} and 10^{-4}, where $A_{PV} = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$, and σ_+ and σ_- refer to positive and negative electron helicity states. In these experiments one measures G_E^s, and G_M^s, the strangeness analogs of the usual Sachs form factors. For the spin zero ^{4}He target the asymmetry is sensitive to G_E^s, whereas for hydrogen one extracts a linear combination of G_E^s and G_M^s. The asymmetry has been exploited by several other groups (G0) [6],(A4) [7], (SAMPLE) [8] besides HAPPEX to obtain nucleon strange-quark electromagnetic form factors. Given the experimentally challengingly small asymmetries it has been a boon that different groups with different techniques have attacked the same question in overlapping Q^2 regions.

2.1 HAPPEX II, 2004 results

We have measured [9] the parity-violating electroweak asymmetry in the elastic scattering of polarized electrons from ^{4}He at an average scattering angle $\theta_{lab} = 5.7°$ and a four-momentum transfer $Q^2 = 0.091\,\mathrm{GeV}^2$. From these data, for the first time, the strange electric form factor of the nucleon G_E^s has been isolated. The measured asymmetry of $A_{PV} = 6.72 \pm 0.84_{stat} \pm 0.21_{syst} \times 10^{-6}$ yields a value of $G_E^s = -0.038 \pm 0.042_{stat} \pm 0.010_{syst}$, consistent with zero. This data set consists of about 3 million helicity window pairs. A helicity window is 33.3 ms long. A

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pair consists of opposite helicity windows, with the helicity of the first window in each pair chosen at random. The details of the measurement are described in the paper [9].

We report [10] the most precise measurement to date of a parity-violating asymmetry in elastic electron-proton scattering. The measurement was carried out with a beam energy of 3.03 GeV and a scattering angle $\theta_{lab} = 6°$, with the result $A_{PV} = -1.14 \pm 0.24_{stat} \pm 0.06_{syst} \times 10^{-6}$. From this we extract, at $Q^2 = 0.099\,\mathrm{GeV}^2$, the strange form factor combination $G_E^s + 0.080 G_M^s = 0.030 \pm 0.025_{stat} \pm 0.006_{syst} \pm 0.012_{FF}$, where the first two errors are experimental and the last error is due to the uncertainty in the neutron electromagnetic form factor. This result significantly improves current knowledge of G_E^s and G_M^s at $Q^2 \approx 0.1\,\mathrm{GeV}^2$. A consistent picture emerges when several measurements at about the same Q^2 value are combined: G_E^s is consistent with zero while G_M^s prefers positive values though $G_E^s = G_M^s = 0$ is compatible with the data at 95% C.L. This data set consists of about 9 million helicity window pairs.

2.2 HAPPEX II, 2005 preliminary results

The 2005 experimental procedure was the same as that in 2004 except for some improvements to the shielding of the septa magnets that allow us to go to 6°. In 2005 we recorded 35 million helicity window pairs for the ^{4}He data, and 25 million window pairs for the hydrogen data. Our preliminary results from the 2005 data sets are: $G_E^s = 0.004 \pm 0.014_{stat} \pm 0.013_{syst}$ for $Q^2 = 0.0772\,\mathrm{GeV}^2$ from the helium data and $G_E^s + 0.088 G_M^s = 0.004 \pm 0.011_{stat} \pm 0.005_{syst} \pm 0.004_{FF}$ for $Q^2 = 0.1089\,\mathrm{GeV}^2$ from the hydrogen data.

3 Comparison of HAPPEX and world data

In fig. 1 we show a comparison of the HAPPEX 2005 preliminary results to the combined world's data for $Q^2 \approx 0.1\,\mathrm{GeV}^2$. The outer two ovals show the 68% and 95% probability contours. The HAPPEX 2004 data are included in the probability contours calculation.

We show in fig. 2 a comparison of the HAPPEX data with the world's data over a range of Q^2. For Q^2 around $0.1\,\mathrm{GeV}^2$ data from G0 and A4 indicate a non-zero value for the combined form factors of the nucleon. The HAPPEX 2004 results are consistent with these data but also with zero. The preliminary HAPPEX 2005 data favor a value much closer to zero. A value of zero would eliminate the need to explain the otherwise seeming cancellation of terms to produce a zero in the result for $Q^2 = 0.2\,\mathrm{GeV}^2$. A value of zero at $Q^2 = 0.1\,\mathrm{GeV}^2$ is also consistent with an empirical global fit [11] of the world's data for $Q^2 \leq 0.3\,\mathrm{GeV}^2$. These authors parameterized the form factors as: $G_E^s = \rho_s Q^2$ and $G_M^s = \mu_s$. With $\rho_s = -0.06 \pm 0.41\,\mathrm{GeV}^{-2}$ and $\mu_s = 0.12 \pm 0.55 \pm 0.07$. This fit includes the data from G0, A4, SAMPLE and HAPPEX II-2004. A recent lattice calculation [12] also

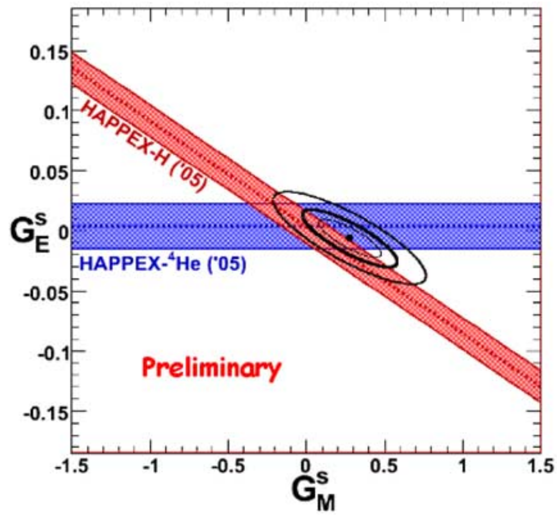

Fig. 1. A comparison of the HAPPEX II 2005 preliminary results with the world's data. The world's data includes HAPPEX II 2004 data. The second and third ovals are the 68% and 95% probability contours.

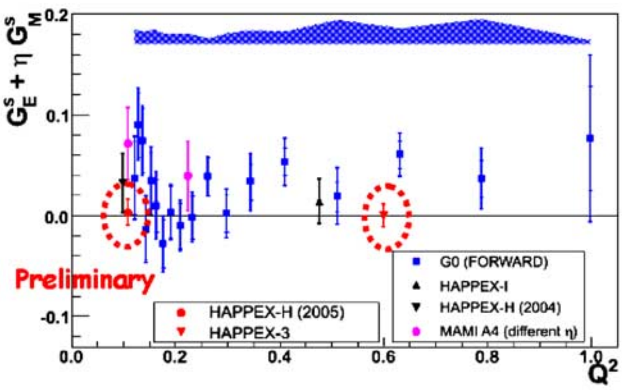

Fig. 2. A comparison of the HAPPEX data with the world's data. The future HAPPEX 3 data point is an estimate of the expected error. The band at the top of the figure represents correlated systematic uncertainty in the G0 (FORWARD) data.

predicts a very small value for the strange magnetic moment, $G_M^s = -0.046 \pm 0.19\ \mu_N$, consistent with the preliminary HAPPEX II 2005 result.

The G0 results in fig. 2 indicate that the combined strange electromagnetic form factors for the nucleon are positive for larger Q^2. The HAPPEX Collaboration has been approved to extend the measurements to $Q^2 = 0.6\,\mathrm{GeV}^2$. This is an important check on the G0 results. The future point is placed on zero in the figure and shows the expected error bar. We expect to be able to make the measurement in 2008.

References

1. X. Ji, Phys. Rev. Lett. **74**, 1071 (1995).
2. A.D. Martin, R.G. Roberts, W.J. Stirling, R.S. Thorne, Phys. Lett. B **604**, 61 (2004).

3. J. Gasser, H. Leutwyler, M.E. Sainio, Phys. Lett. B **253**, 252 (1991).
4. B. Adeva *et al.*, Phys. Rev. Lett. **71**, 959 (1993).
5. R.D. McKeown, Phys. Lett. B **219**, 140 (1989).
6. D. Armstrong *et al.*, Phys. Rev. Lett. **95**, 092001 (2005).
7. F.E. Maas *et al.*, Phys. Rev. Lett. **94**, 152001 (2005).
8. T.M. Ito *et al.*, Phys. Rev. Lett. **92**, 102003 (2004).
9. K.A. Aniol *et al.*, Phys. Rev. Lett. **96**, 022003 (2006).
10. K.A. Aniol *et al.*, Phys. Lett. B **265**, 275 (2006).
11. R.D. Young *et al.*, Phys. Rev. Lett. **97**, 102002 (2006).
12. D.B. Leinweber *et al.*, Phys. Rev. Lett. **94**, 212001 (2005).