Strange Quark Contribution to the Proton Spin, from Elastic $\vec{e}p$ and $\nu p$ Scattering

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Abstract. The strangeness contribution to the vector and axial form factors of the proton is presented for momentum transfers in the range $0.45 < Q^2 < 1.0$ GeV$^2$. The results are obtained via a combined analysis of forward-scattering parity-violating elastic $\vec{e}p$ asymmetry data from the $G^0$ and HAPPEX experiments at Jefferson Lab, and elastic $\nu p$ and $\bar{\nu} p$ scattering data from Experiment 734 at Brookhaven National Laboratory. The combination of the two data sets allows for the simultaneous extraction of $G^s_E$, $G^s_M$, and $G^s_A$ over a significant range of $Q^2$ for the very first time. Determination of the strange axial form factor $G^s_A$ is vital to an understanding of the strange quark contribution to the proton spin.

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The strange quark contribution to the proton spin has been a subject of investigation ever since the first polarized inclusive deep-inelastic measurements of the spin-dependent structure function $g_1(x)$ by EMC \cite{1} demonstrated that the Ellis-Jaffe sum rule \cite{2, 3} did not hold true. Subsequent measurements at CERN and SLAC supported the initial EMC measurements, and a global analysis \cite{4} of these data suggested $\Delta s \approx -0.15$. This analysis carries with it an unknown theoretical uncertainty because the deep-inelastic data must be extrapolated to $x = 0$ and an assumption of SU(3)-flavor symmetry\cite{1} must be invoked.

In the meantime, the E734 experiment \cite{5} at Brookhaven measured the $\nu p$ and $\bar{\nu} p$ elastic scattering cross sections in the momentum-transfer range $0.45 < Q^2 < 1.05$ GeV$^2$. These cross sections are very sensitive to the strange axial form factor of the proton, $G^s_A(Q^2)$, which is related to the strange quark contribution to the proton spin: $G^s_A(Q^2 = 0) = \Delta s$. Assuming the strange axial form factor had the same $Q^2$-dependence as the isovector axial form factor, E734 also extracted a negative value for $\Delta s$. However, this determination was hampered by the large systematic uncertainties in the cross section measurement, as well as a lack of knowledge of the strange vector form factors, and no definitive determination of $\Delta s$ was possible — this conclusion was confirmed by subsequent reanalyses of these data \cite{6, 7}.

The HERMES\cite{8} experiment measured the helicity distribution of strange quarks, $\Delta s(x)$, using polarized semi-inclusive deep-inelastic scattering and a leading order “purity” analysis, and found $\Delta s(x) \approx 0$ in the range $0.03 < x < 0.3$. This seems to disagree with the analysis of the inclusive deep-inelastic data. This disagreement could be due to

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1 See talk by T. Yamanishi on SU(3)-symmetry-breaking effects.
2 See talk by H. Jackson.
a failure of one or more of the assumptions made in the analysis of the inclusive and/or the semi-inclusive data, or it could be due to a more exotic physics mechanism such as a “polarized condensate” at $x = 0$ not observable in deep-inelastic scattering [9].

On account of the apparent discrepancy between the two kinds of deep-inelastic data, another method is needed to shed light on the strange quark contribution to the proton spin. Recently [10] it has become possible to determine the strange vector and axial form factors of the proton by combining data from elastic parity-violating $\vec{e}p$ scattering experiments at Jefferson Lab with the $\nu p$ and $\bar{\nu}p$ elastic scattering data from E734. The parity-violating $\vec{e}p$ data place constraints on the strange vector form factors that were not available for previous analyses of E734 data.

Several experiments[3] have now produced data on forward parity-violating $\vec{e}p$ elastic scattering [11, 12, 13, 14, 15, 16]. Of most interest here are measurements that lie in the same $Q^2$ range as the BNL E734 experiment, which are the original HAPPEX measurement [11] at $Q^2 = 0.477$ GeV$^2$ and four points in the recent $G^0$ data [14]. These forward scattering data are most sensitive to $G_E^s$, somewhat less sensitive to $G_M^s$, and almost completely insensitive to the axial form factors due to suppression by both the weak vector electron charge $(1 - 4\sin^2\theta_W)$ and by a kinematic factor that approaches 0 at forward angles.

The basic technique for combining the $\vec{e}p$, $\nu p$, and $\bar{\nu}p$ data sets has already been described [10] and the details of the present analysis will be published [17]. The results are displayed in Figure 1. The uncertainties in all three form factors are dominated by the large uncertainties in the neutrino cross section data. Since those data are somewhat insensitive to $G_E^s$ and $G_M^s$ then the uncertainties in those two form factors are generally very large. However the results for the strange axial form factor are of sufficient precision to give a hint of the $Q^2$-dependence of this important form factor for the very first time. There is a strong indication from this $Q^2$-dependence that $\Delta s < 0$, i.e. that the strange quark contribution to the proton spin is negative. However the data are not of sufficient quality to permit an extrapolation to $Q^2 = 0$, so no quantitative evaluation of $\Delta s$ from these data can be made at this time.

It is interesting to compare these results with models that can calculate a $Q^2$-dependence for these form factors. Silva, Kim, Urbano and Goeke [18, 19, 20] have used the chiral quark soliton model ($\chi$QSM) to calculate $G_{E,M,A}^s(Q^2)$ in the range $0.0 < Q^2 < 1.0$ GeV$^2$. The $\chi$QSM has been very successful in reproducing other properties of light baryons using only a few parameters which are fixed by other data. In Figure 1 their calculation is shown as the solid line; it is seen to be in reasonable agreement with the available data, although the HAPPEX $G_E^s$ point at $Q^2 = 0.1$ GeV$^2$ disfavors this calculation. Riska, An, and Zou [21, 22, 23] have explored the stangeness content of the proton by writing all possible $uuds\bar{s}$ configurations and considering their contributions to $G_{E,M,A}^s(Q^2)$. They find that a unique $uuds\bar{s}$ configuration, with the $s$ quark in a $P$ state and the $\bar{s}$ in an $S$ state, gives the best fit to the data for these form factors; see the small-dotted curves in Figure 1. Bijker [24] uses a two-component model of the nucleon to calculate $G_{E,M}^s(Q^2)$; the two components are an intrinsic three-quark structure and

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3 See talks by R. Michaels and K. Nakahara.
FIGURE 1. Results of this analysis for the strange vector and axial form factors of the proton. Open circles are from a combination of HAPPEx and E734 data, while the closed circles are from a combination of $G^0$ and E734 data. [Open squares are from Ref. [16] and involve parity-violating $\vec{ep}$ data only.] The theoretical curves are from Ref. [18, 19, 20] (solid line), Ref. [23] (small-dotted line), and Ref. [24] (big-dotted line). There is not any calculation of $G^s_A$ from Ref. [24].

a vector-meson ($\rho$, $\omega$, and $\phi$) cloud; the strange quark content comes from the meson cloud component. The values of $G^s_{E,M}(Q^2)$ are in good agreement with the data, see the big-dotted line in Figure[1]. In the near future, the $G^0$ experiment will provided additional data on $G^s_{E,M}(Q^2)$ at 0.23 abd 0.63 GeV$^2$ which will help to discriminate between the $\chi$QSM and the models of Bijker and of Riska et al.

To provide a useful determination of $\Delta s$, better data are needed for both the form factors and the polarized parton distribution functions. Two new experiments have been proposed to provide improved neutrino data for the determination of the strange axial form factor. FINeSSE [25] proposes to measure the ratio of the neutral-current to the charged-current $\nu N$ and $\bar{\nu} N$ processes. A measurement of $R_{NC/CC} = \sigma(\nu p \rightarrow \nu p)/\sigma(\nu n \rightarrow \mu^- p)$ and $\bar{R}_{NC/CC} = \sigma(\bar{\nu} p \rightarrow \bar{\nu} p)/\sigma(\bar{\nu} p \rightarrow \mu^+ n)$ combined with the world’s data on forward-scattering PV ep data can produce a dense set of data points for $G^s_A$ in the range $0.25 < Q^2 < 0.75$ GeV$^2$ with an uncertainty at each point of about $\pm 0.02$. Another ex-
periment with similar physics goals, called NeuSpin, is being proposed for the new J-PARC facility in Japan. It is also important to extend the semi-inclusive deep-inelastic data to smaller $x$ and higher $Q^2$ so that the determination of the polarized strange quark distribution $\Delta s(x)$ can be improved. A measurement of this type is envisioned [26, 27] for the proposed electron-ion collider facility. It is only with these improved data sets that we will be able to arrive at an understanding of the strange quark contribution to the proton spin.

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4 See talk by Y. Miyachi.