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The A4 experiment

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Summary. — The A4 Collaboration at the electron accelerator facility MAMI measures parity-violating asymmetries in (quasi-)elastic electron scattering off hydrogen or deuterium to determine the strangeness contribution to the vector form factors of the proton. The control of systematic effects like helicity correlated beam fluctuations and the determination of the electron beam polarization are crucial issues. Recently, backward angle measurements at $Q^2 = 0.23\,\mathrm{GeV}^2$ with a deuterium target and forward angle measurements with a hydrogen target at $Q^2 = 0.62\,\mathrm{GeV}^2$ have been analyzed. The preliminary results are presented here.

PACS 12.15.-y – Electroweak interactions.
PACS 11.30.Er – Charge conjugation, parity, time reversal, and other discrete symmetries.
PACS 13.40.Gp – Electromagnetic form factors.
PACS 14.20.Dh – Protons and neutrons.

1. – Introduction

Sea quark contributions, and in particular strange quark contributions, to the properties of the nucleon are subject of investigations for two decades now. Assuming charge symmetry, parity-violating asymmetries in elastic electron-proton scattering can be used to extract the strange quark contributions to the vector form factors of the nucleon, expressed by the strange form factors G_E^s and G_M^s [1,2]. A few experiments were designed to measure these asymmetries, among them the A4 experiment [3-5] at the MAMI accelerator facility in Mainz. We present shortly the experimental setup with the focus on the helicity correlated beam fluctuations and the Compton backscatter polarimeter, then the most recent results obtained at backward angle scattering off deuterium ("A4-II") at the momentum transfer $Q^2 = 0.23\,\mathrm{GeV}^2$ and at forward angle scattering off hydrogen ("A4-III") at $Q^2 = 0.62\,\mathrm{GeV}^2$, and finally we give an outlook on the new, ongoing measurements at low momentum transfer $Q^2 = 0.1\,\mathrm{GeV}^2$.

2. – The A4 experimental setup

The A4 experimental concept is a single arm calorimetric measurement. The scattered electrons are detected by a fully absorbing, segmented electromagnetic calorimeter [6]. It consists of 1022 lead fluoride (Pb_2) crystals arranged in 146 frames and 7 rings. It covers polar scattering angles between 30° and 40° in forward angle configuration or between 140° and 150° in backward angle configuration. PbF_2 is a pure Cherenkov radiator and hence intrinsically fast. The processing of one event takes only 20 ns. A total rate of 100 MHz can be processed without substantial dead time losses. The separation of the elastic events from inelastic events is done via cuts in the measured energy spectra. At forward angles, this separation is sufficient. At backward angles there are background events with almost the same energy as the elastically scattered electrons, which come from the decay photons from π^0. These photons are not distinguishable from charged particles by the calorimeter. Therefore an additional scintillator system is installed between target and calorimeter at backward angle measurements in order to separate charged from neutral particles. The A4 experiment is a counting experiment and stores single counts into histograms.

Several corrections have to be applied to the measured asymmetry. The polarization degree of the electron beam enters directly into the measured count rate asymmetry. Helicity correlated beam fluctuations generate trivial, so called false asymmetries. In order to extract the parity violating asymmetry A_{PV} we correct the measured asymmetry A_{meas} using the ansatz

$$A_{meas} = P \cdot A_{PV} + \sum_{i=1}^{6} a_i \cdot X_i \tag{1}$$

with P the electron beam polarization, X_i the helicity correlated beam differences and a_i the correlation coefficients which are determined by a multiple linear regression analysis from the natural beam jitter. In order to minimize the beam fluctuations, several stabilization systems are installed in the accelerator among the way of the electrons from the source to the target. During ten years of operation of the A4 experiment it was possible to improve the performance of these systems. As an example, fig. 1 demonstrates the improvement in the horizontal position of the electron beam measured by a position monitor (XYMO27). Each 20 ms the position of the beam is measured.

The point-to-point differences in the position measured in ADC units are histogrammed for each five-minute run. The quantity shown is the root mean square of this distribution which is an appropiate measure for the position fluctuations. An improvement over the years is clearly visible.

For the monitoring of the degree of polarization of the electron beam, the A4 Collaboration has developed a Compton Backscatter polarimeter [7]. The asymmetry in the cross section of Compton scattering of polarized photons from a laser off the polarized beam electrons is proportional to the electron beam polarization P. See the contribution of Y. Imai within these proceedings for details. Figure 2 shows as an example a measured energy spectra of the backscattered photons, one for positive electron helicity (blue) and one for negative electron helicity (red), measured for a five minute run with an electron energy of 1.5 GeV. One can directly recognize the asymmetry in the cross section. For the beam energy of 1.5 GeV, a statistical precision of less than 1% can be achieved within 24 h of data taking. The systematic uncertainty is still subject of investigations. 1% is expected from the analysis of the backscattered photon spectra, another 1% from the determination of the degree of polarization of the laser beam.

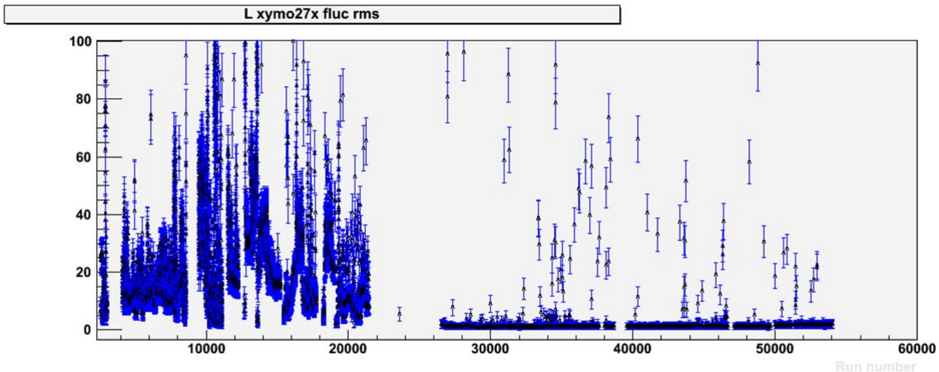

Fig. 1. – Position stability of the electron beam *vs.* run number. The run numbers which are shown represent nearly 10 years of data taking in the A4 experiment. See text for further explanations.

3. – Backward angle scattering off deuterium at $Q^2 = 0.23\,\mathbf{GeV^2}$

In order to obtain the strange form factors G_E^s and G_M^s, the axial form factor G_A^p of the proton must also be known. So far the A4 experiment used G_A^p as an input parameter from a theoretical calculation [8] with a dipole evolution. At backward angles, a measurement with a proton target is mainly sensitive to a linear combination of G_M^s and G_A^p. A measurement with a deuterium target at the same momentum transfer yields a different linear combination of these two form factors and allows a determination of G_A^p out of the experiment. About 1100 h of data were taken with a deuterium target at

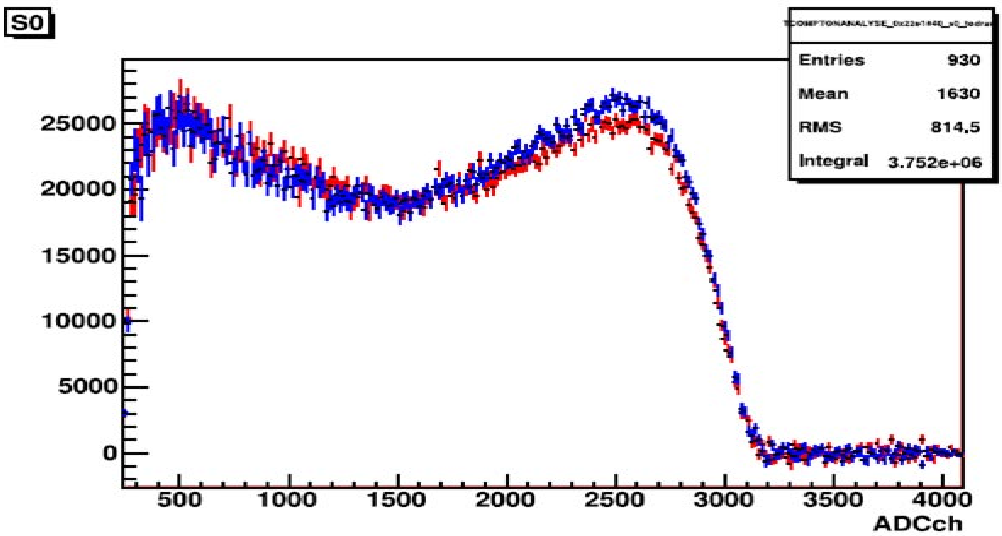

Fig. 2. – Energy spectra of the backscattered photons from the A4 Compton backscatter polarimeter. The two colors represent different electron beam helicities. The measurement was done for a five-minute run with a beam energy of 1.5 GeV. The asymmetry in the Compton cross section can be directly observed.

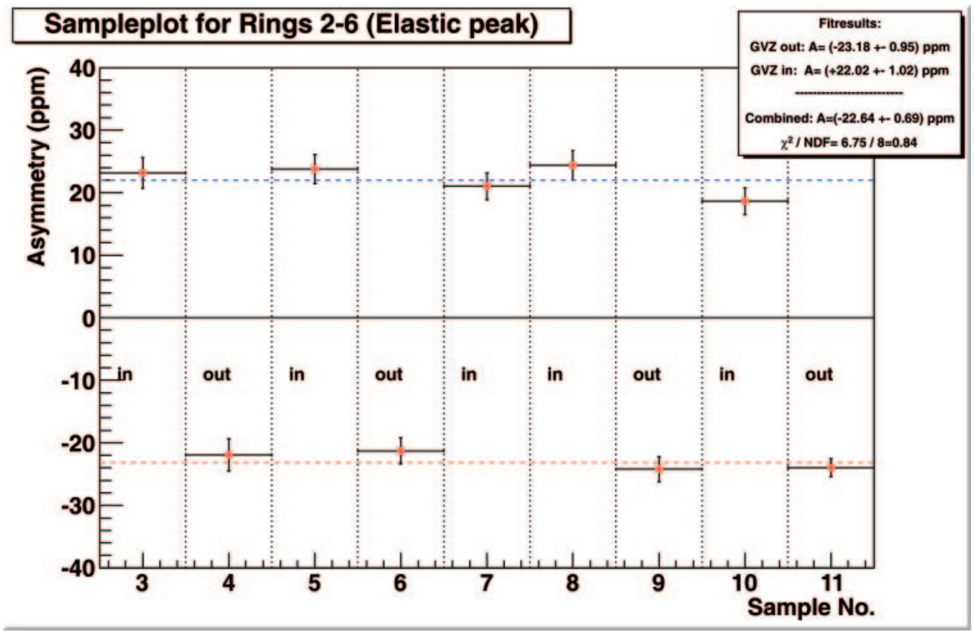

Fig. 3. – Asymmetries in elastic *ep*-scattering at the momentum transfer of $0.62\,\mathrm{GeV}^2$. Each point represents a measurement with either a positive or negative electron beam polarization (halfwave plate at the source in or out). The sign flip of the measured asymmetries can be well observed.

the momentum transfer of $Q^2 = 0.23\,\mathrm{GeV}^2$. The analysis of the data is more demanding compared to the hydrogen data for two reasons. Firstly, the peak of the quasielastic scattered electrons is broader due to the Fermi motion of the nucleons within the nucleus. Secondly, while the rate of charged particles increases by a factor of 1.5, the rate of decay photons increases by a factor of 2 which requires a careful study of the background subtraction procedure. We obtain a preliminary value for the asymmetry in quasielastic *ed* scattering of $A_d = (-20.02 \pm 0.84_{\text{stat.}} \pm 1.25_{\text{syst.}}) \cdot 10^{-6}$. Adding these uncertainty in quadrature, we get for the form factors a linear combination of $G_A + 0.61\ G_M^s = -0.55 \pm 0.35$. For G_A^p alone, we obtain the preliminary value of $G_A^p = -0.47 \pm 0.31$ which is smaller than the value taken from the calculation [8], but in good agreement with the result from the G0 Collaboration at the same momentum transfer [9].

4. – Forward angle scattering off hydrogen at $Q^2 = 0.62\,\mathrm{GeV}^2$

The measurement with a proton target at high momentum transfer was carried out at the MAMI-C beam energy of 1508 MeV. The resulting momentum transfer is $Q^2 = 0.62\,\mathrm{GeV}^2$. In this momentum transfer region the results of the G0 forward angle measurements suggested nonvanishing strange quark contributions to the vector form factors of the proton [10]. 600 h of data were taken for this measurement. The average beam polarization was 85%. The asymmetry could be measured with an relative uncertainty of $\Delta A/A \approx 5\%$. Figure 3 shows the preliminary results with respect to the sign of the electron beam polarization (halfwave plate at the source in or out). We obtain a preliminary result for the linear combination of the strange form factors of $G_E^s + 0.628\ G_M^s = 0.067 \pm 0.030$, where all errors have been added in quadrature.

5. – Summary and outlook

After some years of operation, the A4 experiment measures routinely parity-violating asymmetries in elastic electron scattering of the order of 10^{-6}. So far, no significant strange quark contribution to the vector form factor of the nucleon could be observed. From the deuterium measurement, an experimental value for the axial form factor G_A^p could be obtained. Currently, there is a new experimental program ongoing at the low momentum transfer of $0.1\,\mathrm{GeV}^2$. Measurements both with hydrogen and deuterium are projected. So far, the statistical precision of the hydrogen result from the SAMPLE Collaboration [11, 12] could be achieved. We plan to reduce the uncertainty by a factor of 2 for the hydrogen and the deuterium measurement. These measurements will help to reduce the hadronic uncertainties for a new generation of parity violation experiments that aim to measure the weak charge of the proton.

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