The G^0 parity violation experiment at JLab.

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Abstract
The goal of the G^0 experiment is to separate the s quark contributions - $G_E^s(Q^2)$ and $G_M^s(Q^2)$ - from the overall charge and magnetization densities of the proton, by means of parity violation asymmetry measurements in elastic electron scattering from hydrogen and deuterium. The dedicated apparatus under completion at JLab[1]/Hall-C will be presented in its current status.

Key-words: asymmetry, experiment, parity violation, strange form-factors.

Introduction

The amplitude of strange quark component in the proton description still have to be established. It cannot be accessed by electromagnetic interaction only sensitive to u and d quark components but it can be revealed in the electroweak interaction. This process is orders of magnitude smaller than the former one and requires a special technique to be isolated. It is the parity violation characteristic of the electroweak interaction that will make the experiment possible. Observables will be obtained with asymmetry measurements for which many cancellations of experimental parameters allow to access a signal at the 10^{-7} level. A special set-up is to be completed in the Hall-C of the Jefferson Laboratory [1] to detected asymmetries in elastic electron scattering from hydrogen and from deuterium at various angles to separate three new important quantities: the strange electric form-factor $G_E^s(Q^2)$, the strange magnetic form-factor $G_M^s(Q^2)$ and the axial form-factor $G_A^e(Q^2)$. In addition the N-Δ axial transition form-factor will extracted from the back angle measurements[2].

This paper will briefly describe the method to be used, the overall equipment required, the status of each subsystems and will conclude with the agenda.

1 Physics issues

1.1 Notations

Parity violation in elastic electron scattering arises at main order through the interference of γ or Z^0 exchange processes shown in Fig1. The asymmetry of the reaction for

*http://www.npl.uiuc.edu/exp/G0/G0Main.html
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Figure 1: Diagram for electromagnetic and electroweak interactions.

the two helicity states of the beam, can be expressed as:

$$A = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha} \frac{\varepsilon G_E^\gamma G_E^Z + \tau G_M^\gamma G_M^Z - (1 - 4\sin^2\theta_W)\varepsilon' G_M^\gamma G_A^e}{\varepsilon (G_E^\gamma)^2 + \tau (G_M^\gamma)^2} \tag{1}$$

where : G_E^γ and G_M^γ are the electromagnetic form-factors, G_E^Z and G_M^Z are the electroweak form-factors and G_A^e is the axial form-factor of the proton. From the measurements of G_E^Z, G_M^Z and G_A^e, combined with the knowledge of the electromagnetic form-factors of the proton and the neutron, it is possible to extract the s quark contribution (G_E^s and G_M^s) to the overall nucleon structure. This decomposition only relies on SU(3) and on charge symmetry of the nucleon. Finally the measured asymmetry can be directly expressed in terms of strange form-factors :

$$A = \eta + \xi G_E^s + \chi G_M^s + \phi G_A^e \tag{2}$$

where η is the asymmetry known from neutron and proton form-factors (for the G^0 experiment, η ranges between -1 and -35 $\times 10^{-6}$). How to measure the other parts?

1.2 The G^0 program and other parity violation experiments.

Three asymmetry measurements are necessary to extract G_E^Z, G_M^Z and G_A^e and from them the strange form-factors are deduced. The Table 1 shows the kinematics used in different experiments. Two of them, SAMPLE[3] and HAPPEX[4] measure asymmetries at a given angle from two different targets, hydrogen and deuterium, and take advantage of the kinematic suppression of one of the observables (respectivly G_E^s and G_A^e). On the opposite the G^0 program[1] will give separate values of G_E^Z, G_M^Z and G_A^e. Asymmetries will be measured at one incident energy with hydrogen target at forward electron angle (7°) [protons will be detected] and with hydrogen and deuterium targets at backward electron angles (110°)[electrons will be detected] for three different ingoing energies.

The G^0 experiment will therefore measure the evolution of those observables for different momentum transfers Q^2 between 0.1 and 1.0 fm^2. The Fig.2 shows the expected total errors of the G^0 measurements compared to the predictions of different models : Chiral Perturbation Theory[6] and Lattice QCD[7] for the strange form-factors and an estimate of $G_A^e(Q^2)$ from electroweak radiative corrections[8] for which the calculation at $Q^2 = 0$ has been extended using the standard dipole form for G_A measured in neutrino scattering. A discussion of $G_A^e(Q^2)$can be found in these proceedings[9] and more focus will be here on the strange form-factors $G_M^s(Q^2)$ and $G_E^s(Q^2)$.

SAMPLE [3] (MIT-Bates)	p d	146 146	0.1 0.1	$G_M^s = 0.14 \pm 0.29 \pm 0.31$ $G_A^e = 0.22 \pm 0.45 \pm 0.39$
HAPPEX[4] (JLab)	p	12.3	0.47	$G_E^s + 0.392 G_M^s =$ $0.025 \pm 0.020 \pm 0.014$
SAMPLE'01	d	146	0.04	$G_M^s + 3.8 G_A^e$
HAPPEX II	p He^4	6 6	0.1 0.1	$G_E^s + 0.1 G_M^s$ G_E^s
PV-A4[5] (MAMI)	p p	35 35	0.23 0.1	$G_E^s + 0.2 G_M^s$ $G_E^s + 0.1 G_M^s$
G^0[1] (JLab)	p p d	7 110 110	0.1 ... 1.0 0.3, 0.5, 0.8 0.3, 0.5, 0.8	G_E^s , G_M^s, G_A^e

Table 1: Comparison of experiments measuring the strange form-factors.

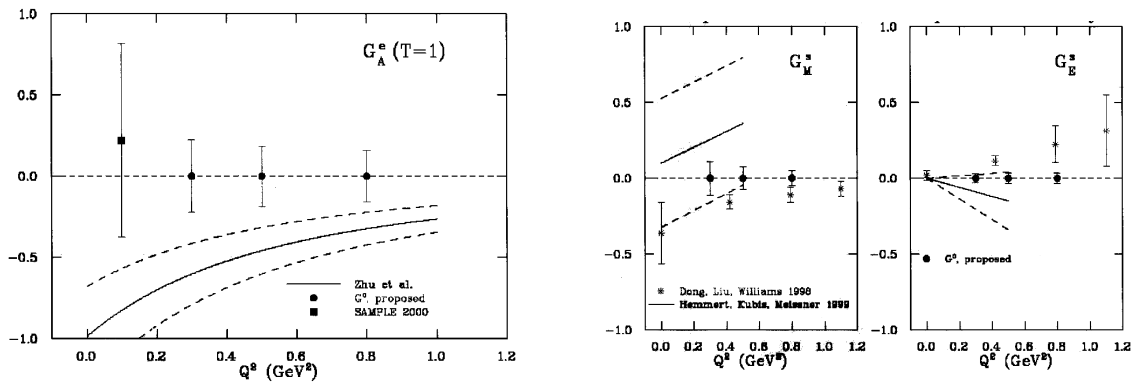

Figure 2: Expected errors for g0 measurements and comparison with theory.

For these quantities both models agree with the zero-compatible published results of SAMPLE and HAPPEX experiments [2] but they predict non-zero individual values for $G_E^s(Q^2)$ and $G_M^s(Q^2)$ and the evolution with Q^2 which can be investigated with the given accuracy of the experiment. The projected errors presented here include the statistical uncertainty of the measurements ($\Delta A/A = 5\%$), the systematic precision and the possible errors from the knowledge of the electromagnetic form-factors of the proton and the neutron. Despite of a specific design of the experimental apparatus the G^0 overall errors will be dominated by statistics.

2 General set-up

As an experiment to be achieved after measurement periods spanning several years G^0 had to be installed in the Hall-C of Jlab, in a place and in a manner that would make it temporarily removable for compatibility with other experiments (see Fig. 3). To reduced the data taking time at it was designed a large solid angle apparatus (0.5-0.9 str), able to handle a large luminosity (2×10^{38} cm^{-2} s^{-1}).
The choice was of a toroidal magnet associated with scintillators and photo-multiplier

[2] In fact the Chiral model actually uses the SAMPLE and the HAPPEX results to fix two of its perturbative constants.

tubes [PMTs] able to stand very high counting rates.

At forward angle the recoil protons, emitted at a more reasonable angle, will be detected wheras at backward angles the electrons will be directly detected. Particle identification will rely on time of flight measurements.

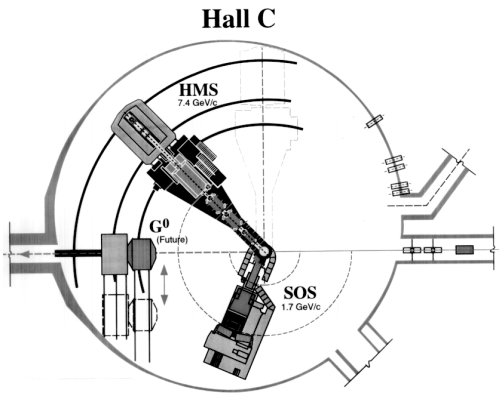

Figure 3: Position of G0 set-up in Hall-C

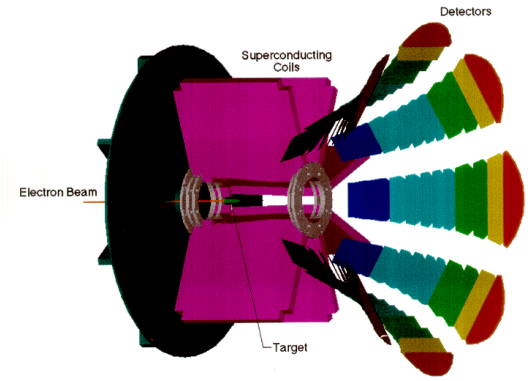

Figure 4: Scheme of the detection.

The sketch of Fig.4 shows the Superconducting Magnet System [SMS] and a view of the sensitive regions to be covered by detectors for the forward angle set-up. There is a symmetry of 8 corresponding to the number of coils. Accordingly the detection is made of 8 octant groups, 4 built by an North Americain collaboration and 4 made by a French collaboration of the ISN of Grenoble and the IPN from Orsay. The special design of the magnet gives a focussing of proton such as a Q^2 separation, (see Fig.5) is directly done at the detection level on 16 pairs of scintallators [FPD](see Fig.6) .

For backward angle measurements the experimental setup is flipped. New detectors[CED] must be installed at the exit of the cryostat to identify electron by the Time of Flight with FPD. Good separation of elastic and inelastic events will make possible the study of the form-factors in the N-Δ region [2]. For measurements on deuterium target the contamination from pions has to be rejected and this will be done by means of additionnal Cerenkov counters[1].

To reach the high luminosity and the extreme control of stability special requirements are made on the source, the beam qualities and the cryotarget. To handle the resulting counting rates electronics, acquistion and analysis have been developped in specific ways. This will be exposed in the following section.

3 Subsystems and status

3.1 Source

The experiment will required a new source system to deliver a beam pulsed at 31.25 MHz instead of the 499 MHz of regular Cebaf operating mode, and still deliver a 40μA intensity with high polarization [70%] and will reverse helicity periodically for asymmetry measurements. A new laser has been ordered for this purpose.

3.2 Beam

The beam will be focused in a specific target point and new control systems (girders and raster) will be adapted for the experiments. The required characteristics are the following: an energy of 3 GeV and an intensity of 40 μA and helicity correlated variations in 30 days better than 2.5x10^{-8} for the energy, 1ppm for the intensity, 20 nm for the position and 2 nrad for the angle[3].

3.3 Target

A cryogenic target for liquid hydrogen and deuterium has been build, 20 cm long and with a high cooling power to resist the high energy deposit from the electron, 250 watts. A high circulation rate is necessary to minimize the target density fluctuations. Special pump motors have been ordered to face the deuterium case.

3.4 Magnet

A special super-conducting toroidal spectrometer with azimuthally symmetrical angular acceptance has been built, with eight sectors and a maximum current of 5000 Ampers. A situation of zero-magnification of the target will focus on the same detector all protons

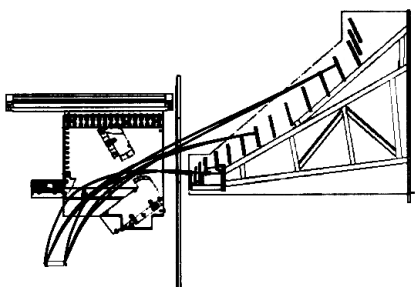

Figure 5: Q^2 - selection

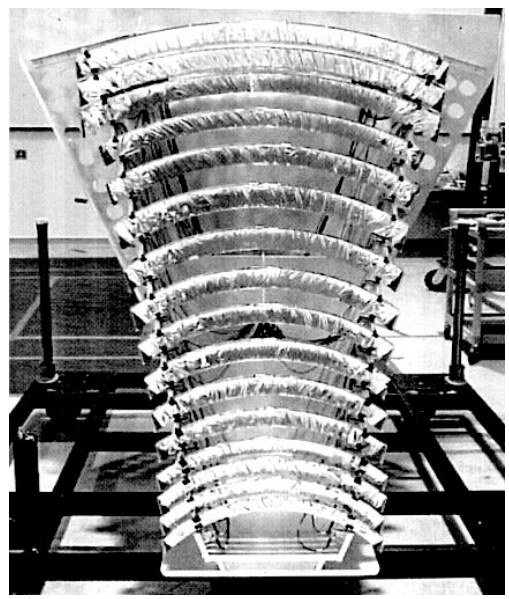

Figure 6: Front view of Detectors

emitted from target with the same Q^2 . A line-of-sight shielding is possible because the bending angle is larger than 35°. The angle of detection is 70° at forward direction and 110° at backward angle. The angular apertures are 20° in both direction. All the tests have to be done these summer and fall at Jlab.

[3] this was achieved in 1999 for HAPPEX with a strained GaAs source

3.5 Detectors

The shapes of the scintillators for the FPDs have been adapted to the results of simulations with the magnet model, to optimize counting rates and backgrounds. There is 16 detectors of different sizes and locations (see Fig. 6). Each detector is made of 2 scintillators (see Fig. 7) spaced by aluminium [French option] or plastic [NA option] and put in coincidence to reduce the background. Each scintillator is read at both ends. The bases for PMTs include an amplifier [French option] or will be followed by an amplifier [NA option] to work at lower voltage and stand for higher counting rates and/or last longer.

3.6 Electronics

The electronics for NA detectors and French ones are similar but the French one is more integrated than the NA one which relies on commercial modules.

Figure 7: FPD stack

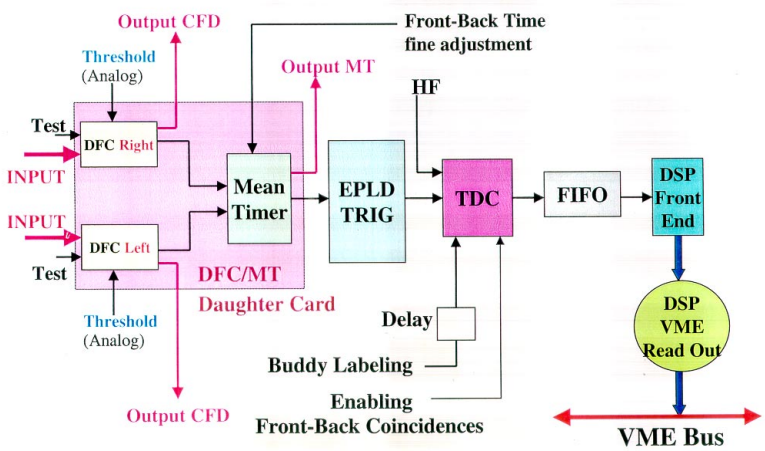

Figure 8: Architecture of one DMCH channel

Let us briefly discribe the French DMCH-16X module , the name of which means: Dicriminator, Mean-timers, Converter, Histogramming for 16 channels in vXi standard crate. The Fig.8 illustrates one channel, with a daughter board for CFDs and MT for each channel, then a common EPLD-Trig - a logical device externally programmable to fit the experiment requirements, an integrated TDC, common for 8 channels, and DSPs (Digital System Processors) for processing data to main Acquisition system through the VXI backplane bus. The Fig. 9 and 10 are photographs of the module.

The front panel view shows the outputs for the internal scalers, from a daughter board, for CFDs and MTs independent counting rates and the PMT input signals coming from splitters as the signals also go to fastbus ADCs for slow monitoring. The MT signals are also sent to fastbus TDC's for slow monitoring and cross-checks with the internal time histogramming. For the Frnch detection eight of these modules are sitting in the VXI crate with and Interface Box to coordinate them, an Trigger interface box and of course the Central Progamming Unit, run under VxWorks. The system is very compact, flexible and computer driven and will allow to work in different configurtions for tunig, checking and commissionning. The acquisition will be done with the Jlab standard CODA system.

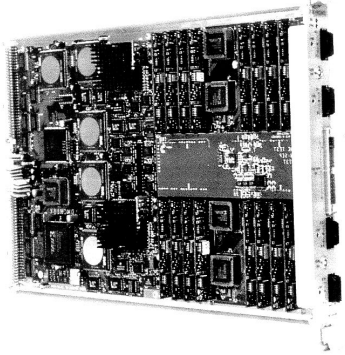

Figure 9: DMCH module

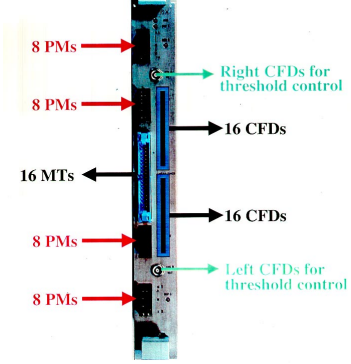

Figure 10: Front panel

4 Anticipated issues

4.1 Dead time control

If the intensity and counting rates are identical in both helicity states the dead time correction should cancel in asymmetry computation but however it is necessary to control the electronic behavior according to counting rates. Two specific methods are used to estimate and control the deadtime. First: introducing a fix and known deadtime in the electronics by a Next Pulse Neutralisation whenever a channel is hit. Second: a parallel counting, on each channel, of coincidences with the symmetric channel [buddy] which must reflect the loss dues to deadtime (i.e. busy channel). Simulations have been carried out for the French electronics with generators and/or with β sources showing that the deadtime can be corrected within the expected accuracy.

4.2 Asymmetry measurements

Similarly long time measurements have been done with either radioactive sources or unpolarized background from beam to check that the 0.0 asymmetry was correctly extracted from the data supposing any kind of helicity sequences and to determine the best way to run the real experiment. The results are in favor of quartet of helicity.

4.3 Stability

The measurement of asymmetry requires an excellent stability on beam postion an beam energy values that will be continously monitored and used in automatic feedback systems in the accelerator to prevent or correct the false asymmetry. The helicity is to be flipped every MPS (Macro Pulse Signal i.e. 32msec) and asymmetries to be measured accordingly but quartets will be used, to reduced by cancelling any possible time dependent slow evolution, and the asymmetry will be calculated after 4 MPS with helicities [+ - - +] or [- + + -] delivered randomly.

Summary and agenda

The g0 experiments is now almost ready to measure elastic polarized electron scaterring from hydrogen target. The full expriment will consist of one measurement at forward angle, done in measuring the recoiling proton and covering a large range of Q^2, to be complemented by three measurements at backward angle, at three different energies to have 3 different Q^2 for electrons. If the axial form-factor was negligible it would be enough but from the results of the SAMPLE experiment it is proven not to be. So three additionnal measurements on deuterium target at backward angles will be necessary to disantengle completly the three form-factors of interest: $G_E^s(Q^2)$, $G_M^s(Q^2)$ and $G_A^e(Q^2)$ and to provide the shape of the Q^2 dependence.

At the present stage of realization the schedule is the following : summer and fall of 2002 will be used for the commissionning of all the different parts. It will last untill mid january of 2003. Then the fall of 2003 should be the real data taking campaign, followed in 2004, 2005 and 2006 by the backward angle measurements and therefore the Q^2 dependence should be etablished by the end of 2007.

Complementary and updated informations can always be found on the G^0 web page : *http://www.npl.uiuc.edu/exp/G0/G0Main.html*.

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