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RECENT MEASUREMENTS FROM THE G0 PARITY VIOLATION EXPERIMENT CARRIED OUT AT JEFFERSON LABORATORY

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Abstract

The measurements were made at the Thomas Jefferson National Accelerator Facility (JLab.), Newport News, VA (USA) in the backward angle configuration set-up. A toroïdal spectrometer, associated with particle detectors, is used to count electrons and pions from a liquid hydrogen or deuterium target. Parity-violating asymmetries in elastic electron-proton scattering are determined for momentum transfers of $Q^2 = 0.62$ and 0.23 $(GeV/c)^2$. Combined with previous results obtained with the forward angle configuration setup, these measurements give access to the separation of the values of electric and magnetic strange form factors of the proton. More results may be extracted from the asymmetries for inelastically scattered electrons and for produced pions.

Keywords: *Experiment, asymmetry, parity violation, strange form factors.*

INTRODUCTION

The amplitude of the strange quark component in the description of the proton still has to be established. It cannot be evaluated from the electromagnetic interaction alone, but it can be accessed through electro-weak processes. The electro-weak interaction is smaller than the former one by orders of magnitude and requires special techniques to be observed and isolated. Parity violation is specific to the electro-weak interaction and forms the basis of the G0 experiment. The observables, the strange form factors of the proton, are extracted from asymmetry measurements for which many cancellations of experimental parameters permit access to a signal at the 10^{-6} level.

Several experiments are based on parity violation to determine the strange component of the nucleon: HAPPEX [**1**], PVA4 [**2**] and SAMPLE [**3**], but G0 [**4**] is the largest investigation with both forward and backward angle measurements providing values of three form factors at three different Q^2. At the present stage of the experiment the results from the forward mode of detection are published [**5**] and the data from the backward mode are under analysis.

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[1] (see http://www.npl.uiuc.edu/exp/G0/)

At Nuppac’03, I gave a detailed presentation [**6**] of the set-up and the commissioning and at Nuppac’05, I presented the results from the first part of the experiment [**7**] referred to as the *forward angle* configuration. For Nuppac’07 I will speak of the status of the second part of this experiment, referred to as the *backward angle* configuration, giving reminders of the physics and of the experimental approach. This will include the description of the crucial parts of the data taking and of the analysis procedure as well as the technical developments required for the measurements.

1. PHYSICS GOALS

Parity violation in elastic electron scattering arises at leading order from the interference of the γ and Z^0 exchange processes shown in Figure 1.

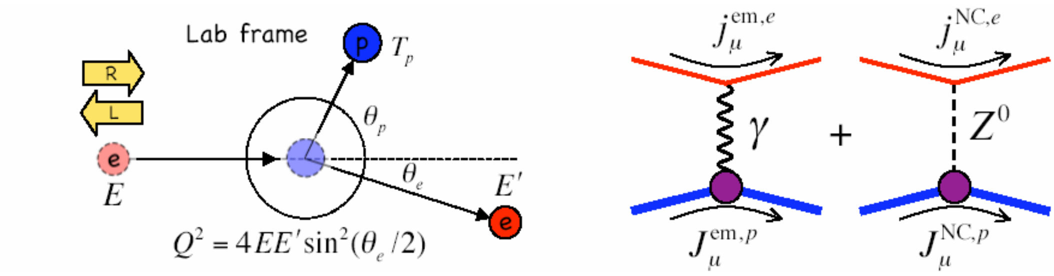


Figure 1. Diagrams for electron elastic scattering.
Left diagram summarizes the kinematics and right diagram represents the electromagnetic and electro-weak interactions, the interference of which makes the experiment possible.

The asymmetry of the reaction for the two helicity states of the beam can be expressed as:

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

where:

$$\tau = \frac{Q^2}{4M_p^2},\quad \varepsilon = \left(1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right)^{-1},\quad \text{and } \varepsilon' = \sqrt{\tau(1+\tau)(1-\varepsilon^2)}.$$

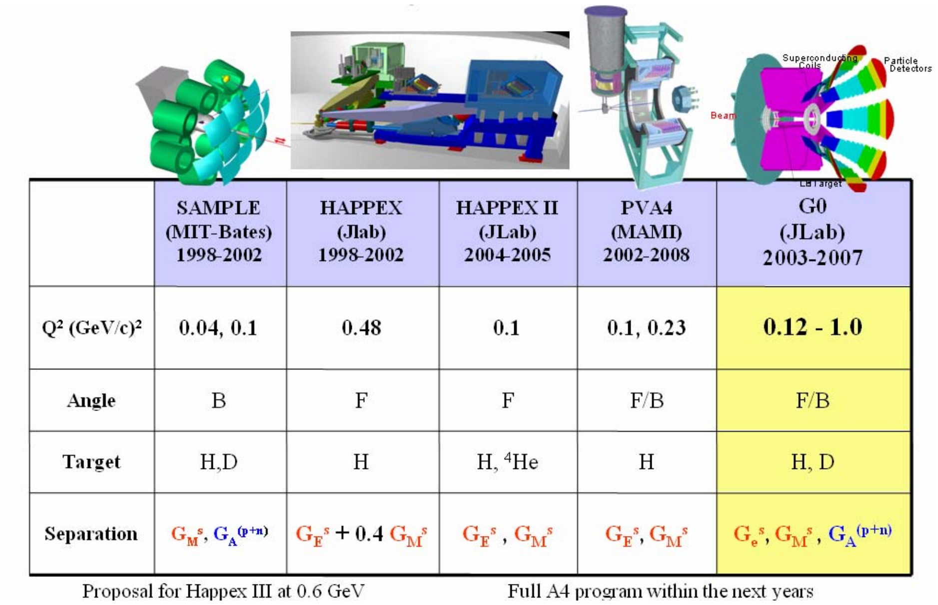
Q^2 is the squared four-momentum transfer ($Q^2 > 0$), G_F and α the usual weak and electromagnetic couplings, M_p the proton mass and θ the laboratory electron scattering angle. G^γ_E and G^γ_M are the electromagnetic form-factors, G^z_E and G^z_M are the electroweak form-factors and G^e_A is the effective axial form-factor of the proton seen in parity-violating electron scattering. From the measurements of G^z_E, G^z_M and G^e_A and the knowledge of the electromagnetic form-factors of the proton and the neutron, it is possible to extract the ***s*** quark contribution (G^s_E and G^s_M) to the nucleon structure. This decomposition only relies on charge symmetry of the nucleon and on the assumption that only the light quark flavours contribute to these form factors. Finally the measured asymmetry can be expressed in terms of strange form factors:

$$A = \eta + \xi G^s_E + \chi G^s_M + \phi\, G^e_A$$

where η is the asymmetry known from neutron and proton form factors (for the G0 experiment η varies between -1 and -35 x10^{-6}).

Three asymmetry measurements are necessary to extract G^z_E, G^z_M and G^e_A - from which the strange form-factors can be deduced [**8**]. Several experiments have been devoted to the measurement of these observables, the main characteristics of which are given in Table 1.

Table 1. Complementary experiments on parity violation.
G0 is covering a wide range in Q. B and F are used for Backward or Forward detection of the scattered electron. Hydrogen, Deuterium or ^{4}He target are used. Different combinations of form factors are measured in each experiment.



	SAMPLE (MIT-Bates) 1998-2002	HAPPEX (Jlab) 1998-2002	HAPPEX II (JLab) 2004-2005	PVA4 (MAMI) 2002-2008	G0 (JLab) 2003-2007
Q^2 (GeV/c)^2	0.04, 0.1	0.48	0.1	0.1, 0.23	**0.12 - 1.0**
Angle	B	F	F	F/B	F/B
Target	H,D	H	H, ^{4}He	H	H, D
Separation	G_M^s, $G_A^{(p+n)}$	$G_E^s + 0.4\, G_M^s$	G_E^s , G_M^s	G_E^s, G_M^s	G_e^s, G_M^s , $G_A^{(p+n)}$

Proposal for Happex III at 0.6 GeV

Full A4 program within the next years

The results already extracted of these measurements are presented and combined in Figure 2.

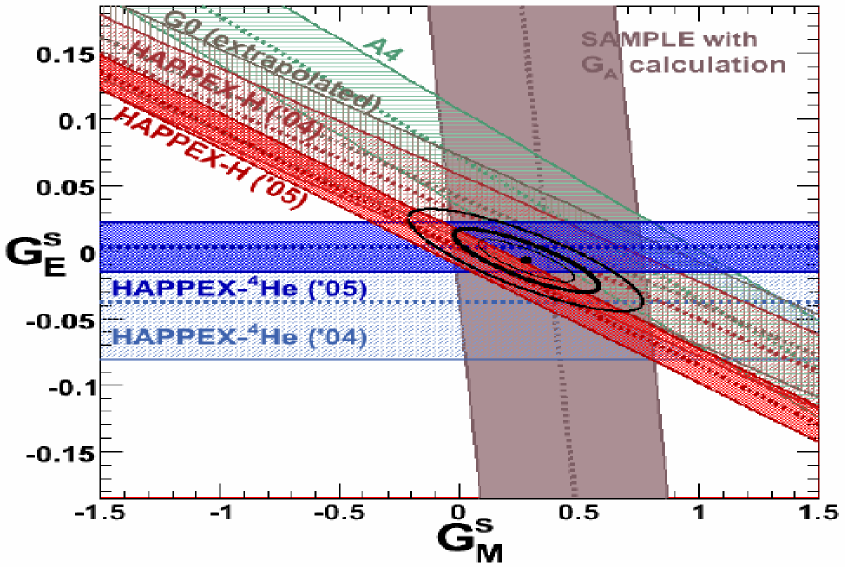


Figure 2. G^s_E and G^s_M determination form current world data, at Q^2=0.1(GeV/c)^2
G^s_E =-0.006 +/- 0.016 and G^s_M = 0.28 +/- 0.20 corresponding respectively to approximatively 0.2% and 3% of the proton electric and magnetic moments [**9**].

2. EXPERIMENTAL SET-UP

To undertake the experiment a specialized instrumentation apparatus has been set up in Hall C of Jefferson Laboratory, Newport News, Virginia, USA. The forward angle configuration was described in detail in previous contributions to NUPPAC [**6,7**]. The backward angle configuration corresponding to the recent measurements is shown in Figure 3.

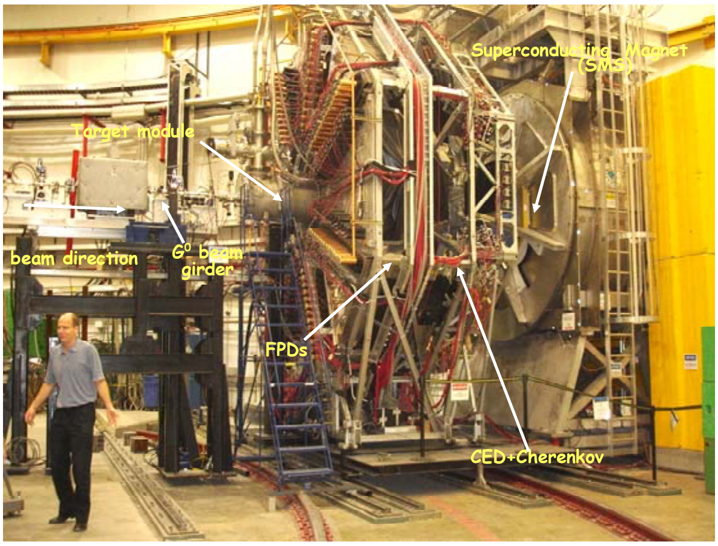


Figure 3. General view of the G0 back angle configuration set-up in Hall C.
The detection system is removed from beam line to allow other experiments in the same hall.

2.1. Targets

As for the forward angle measurements the target as been specially built to survive the intense beams necessary for parity violation experiment, of the order of 60μA on liquid hydrogen target. For the numerous background and contamination studies required for this experiment the target lift was equipped and surrounded by several devices shown in Figure 4. The available targets were:

- 20 cm liquid H2 or D2 (20 cm gaseous H2, D2 or He for a different operating conditions)
- 5 mm C (3.2 mm Al)
- 5.6 mm diameter hole
- 0.085 mm W upstream of the target cell (radiator)
- removable 0.76 mm thick Al foil, downstream of the target cell (flyswatter)
- a position with everything out of beam

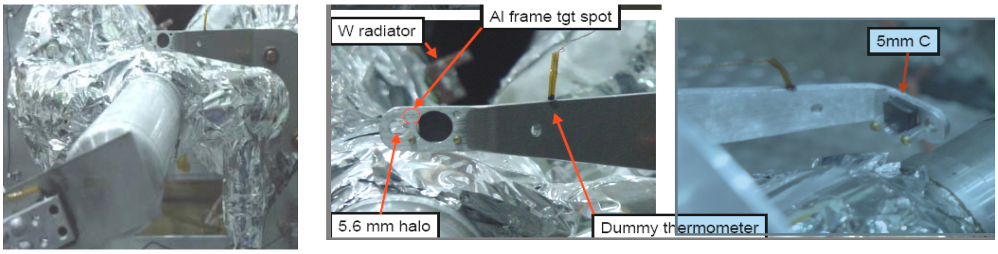


Figure 4. Details of the target apparatus.

From left to right: Flyswatter put in beam downstream of the visible targe cellt, Dummy target made of 5mm of Carbon with small hole on the side to monitor halo size and a W radiator to simulate photon production effects in target and finally another view of the dummy.

2.2. Magnet and Detectors

Major changes have been done compare with the forward angle configuration [**7**]. The toroid has been rotated by 180°. The Ferris wheel equipped with the FPDs (focal plane detectors) has been moved apart of the magnet and an additional structure, mini Ferris wheel, holding the Cherenkov and the CEDs (cryostat exit detectors), has been put in the gap. The detection of the particles is still based on the use of light emitting material associated with photomultiplier tubes but now it combines scintillation (FPDs and CEDs) and Cherenkov effects allowing a separation of pions from electrons. The set-up is presented in Figure 6.

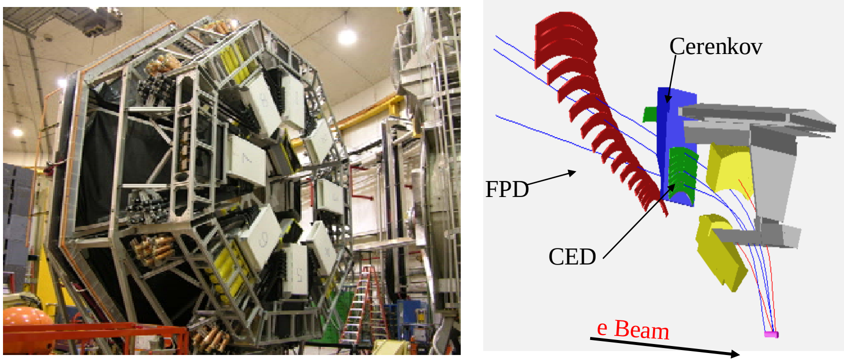


Figure 5. Detector assembly

On the right is a schematic view of the detection and on the left a picture of the mounting with the detectors moved far away of the SMS partly visible on the right edge.

2.3. Beam monitors

To verify the beam quality during the data taking several monitoring systems have been installed. A specific G0 girder, visible on Figure 3, was devoted to intensity and alignment measurements. Special detectors associated with a hole in Aluminium plate put in the beam line were used to check the reasonable size of the halo whereas another set of detectors allowed a survey of luminosity and charge and position asymmetries of the delivered beam.

3. ELECTRONICS AND DAQ

3.1. Electronics Chain

For the forward angle measurements the recoiling proton was detected and the particle identification was based on time of flight. For the backward angle measurements the electrons are detected and they covered a specific place in the focal plane. The particle identification comes from the location in space. Using Cherenkov detectors the separation of pions from electron is possible as illustrated in Figure 6. The electronics chains are composed of splitters, discriminators, mean-timers, coincidences modules and scalers from which the matrix are built for electrons or pions according to Cherenkov signal.

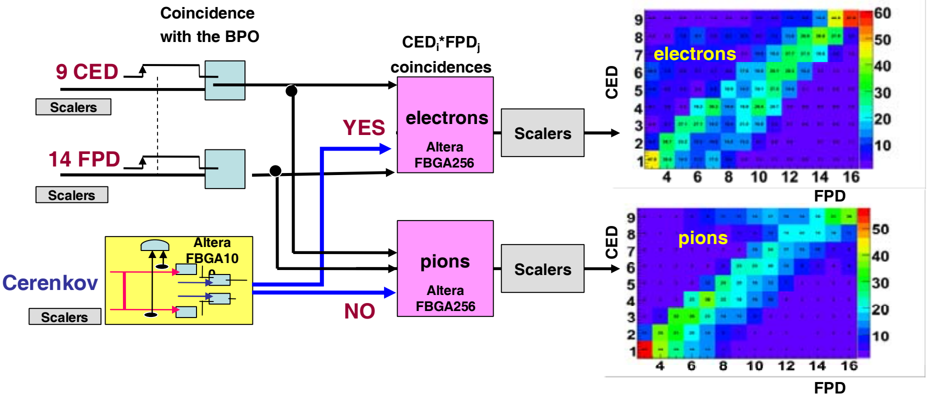


Figure 6. Electronics chains
Only electrons give a Cherenkov signal

Using the 2 sets of detectors, CEDsc and FPDs, and building the matrix of coincidences different type of events can be separated, corresponding either to elastic scattering or inelastic scattering or background (Dalitz or super-elastic) and this for electrons and pions. Examples are presented on Figure 7 for electrons at the 2 different beam energies.

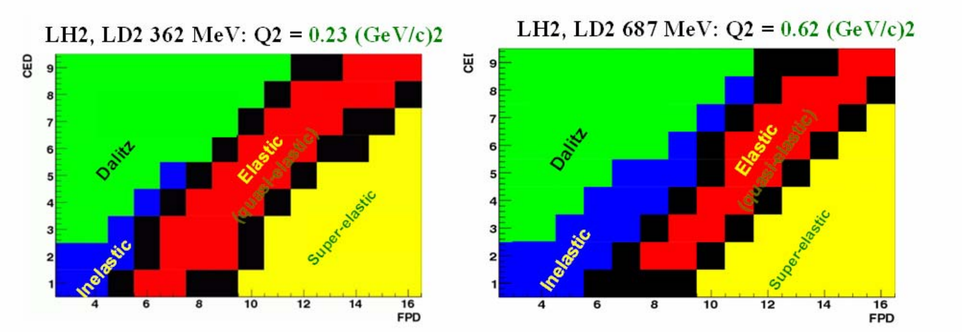


Figure 7. Localisations of electrons from different processes.
Elastic *or* ***Quasi-elastic*** *for* e + p → e + p *or* e + n → e + n
Inelastic *for e + p → e +* Δ, ***Dalitz*** *for e + p →* π° + p → 2γ --> e+e- *and similar,*
and ***Super elastic*** *with no physical origin but background*

The pion matrix is build in case of absence of the Cherenkov signal but the same channel in acquisition is sometimes used, with different settings to measure the accidental rate in electron detection in what is referred to later as random, allowing a direct estimation of the contamination and the resulting dilution factor

A monitoring of the detector response and tuning is made with an additional electronics system, using fastbus ADC and TDC modules and working at low rate but in an event-by-event mode which enables correlation studies and checks on thresholds, amplifications and timing of the full experiment (see [**10**] for details).

3.2. Data Acquisition and On-line Control

The acquisition system and on-line control are very similar to what they were for the forward angle configuration [**10**] except for the lack of time of flight measurement. The monitoring made with fastbus elements is almost identical but covers now FPDs and CEDs. The data for asymmetries determinations is only the scaler content. The principle is presented in Figure8.

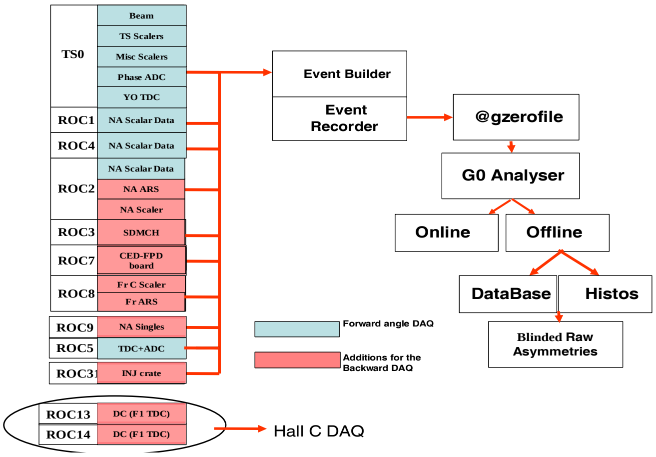


Figure 8. Chart for data acquisition and analysis.
The event builder collects all information from detectors (G0 DAQ) whereas the beam related quantities are recorded using a second system (Hall C DAQ). Raw events are recorded. A few events are analyzed on line to insure integrity of the measurements.

A different colour is used for the additional part needed for the backward angle measurements. It corresponds to the treatments of coincidences between couple of CEDs and FPDs to produce events matrix and to the processing of the Cherenkov information to built pions events differently from electron event.

4. DATA TAKING AND ANALYSIS

4.1. Operating Conditions

4.1.1 Beam

The beam properties have been carefully maintained within the required values during the whole experiment. Comparison of the experimental conditions with the specifications mandatory for a meaningful measurement is presented in Table 2. All the specifications required by the experiment were successfully met.

Table 2. Beam properties.

Beam Parameter	**Achieved (IN-OUT)/2**	**“Specs”**
Charge asymmetry	0.09 +/- 0.08	2 ppm
x position difference	-19 +/- 3	40 nm
y position difference	-17 +/- 2	40 nm
x angle difference	-0.8 +/- 0.2	4 nrad
y angle difference	0.0 +/- 0.1	4 nrad
Energy difference	2.5 +/- 0.5	34 eV
Beam halo (out 6 mm)	< 0.3 x 10-6	10-6

4.1.2 Beam Polarization

The beam polarization is an important factor for these measurements. The asymmetry signal depends on polarization. The figure of merit depends on the square of the polarisation. The proposals were made with an estimation of 74% but the measurements, made with a constrained AsGa source, were constantly close to 84%. The increase in polarisation was unfortunately more than offset by reduced beam current and running time (see Table 3).

To prevent the data from systematic error coming from helicity change the beam was delivered on target following the same quartet structure (+--+,-++-) as for forward angle measurement [5]

4.1.3 Target and Charge

The experiment with backward angle configuration was planned for two different energies of the electron beam (687 MeV and 362 MeV) on two complementary targets (liquid Hydrogen and liquid Deuterium) in order to allow a separation of individual form factors when combined with the forward angles results at 2 different values of Q^2 (0.62 and 0.23 $(GeV/c)^2$). In Table 3 is presented a summary of total charge delivered per measurement.

Table 3. Total charge (both helicity states) of delivered beam
Initial proposal was for a total charge of 170C with 74% polarisation. The real measurements were done with 84% polarisation and the total charge per setting is given below.

	362 MeV	687 MeV
Hydrogen	90C	100C
Deuterium	65C	45C

In addition to this part concerning the physics case it was necessary to make a systematic study of factors which may have biased the results and several measurements have been carried out to allow a precise evaluation of the background and the contamination during data taking. A list is given in Table 4.

Table 4. Side measurements for background and contamination
Initial proposal was for a total charge of 170C with 74% polarisation.
The real measurements

	LH2 (687)	LH2(362)	LD2(687)	LD2(362)
Field scan	Yes	Yes	Yes	Yes
31 MHz	Yes	Yes	Yes	Yes
Transverse	Yes	Yes	Yes	Yes
Reversed pol	Yes	No	Yes	Yes
Target windows	Yes	Yes	No	Yes

All the targets quoted previously have been useful but also beam characteristics and experimental conditions have been scanned around the nominal value to evaluate the hidden part of the signal. The effects observed are being globally reflected in a dilution factor estimated cell by cell before computing the final asymmetry.

4.2. Analysis Procedure

The analysis procedure is identical to the one used for forward angle measurement; a blinding factor is introduce to prevent distortion in the analysis from any expectation. After rejecting all quartets including bad events, the raw asymmetries are calculated from which we can verify the data quality. Then corrections coming from beam quality and instrumental effects are apply, follow by all the corrections coming from background contamination. The analysis is currently in this stage of progress. Then it will be unblinded to allow combination with other world results, starting with the G0 forward angle measurements to enable the determination of individual strange and axial form factors. This is summarized in Figure 9.

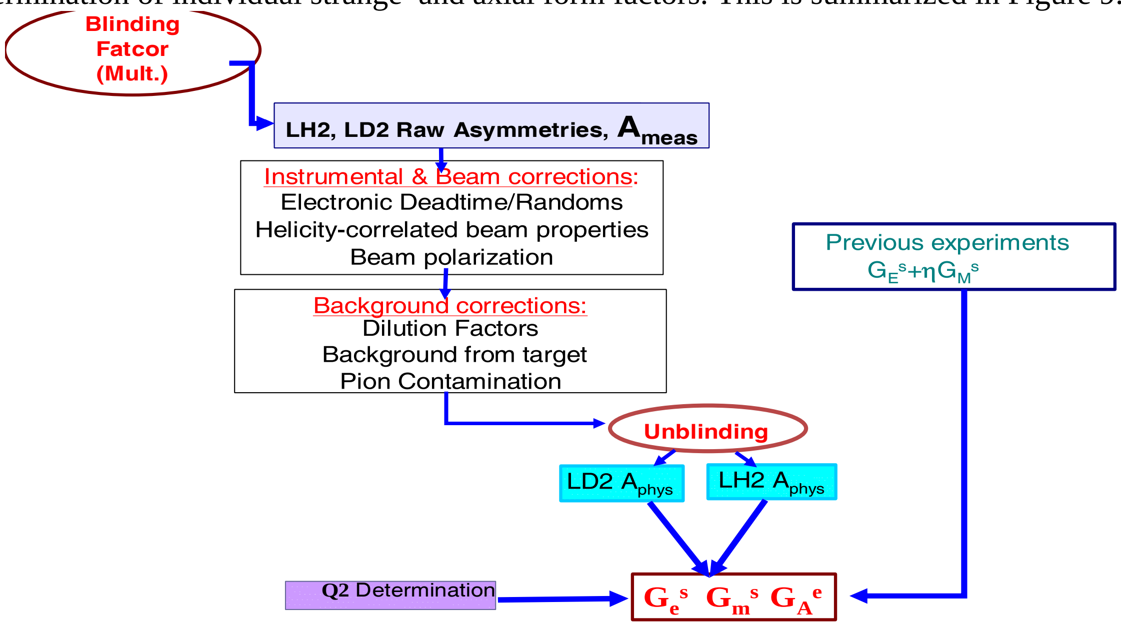


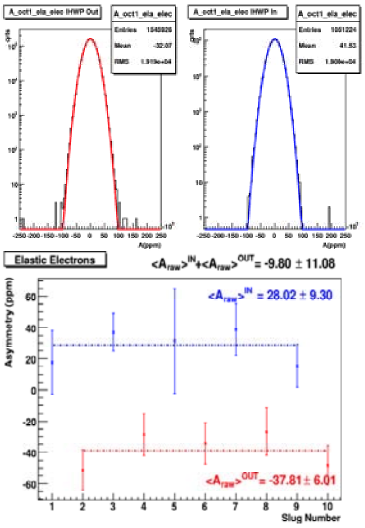
Figure 9. Scheme of the analysis procedure

5. CURRENT STATUS

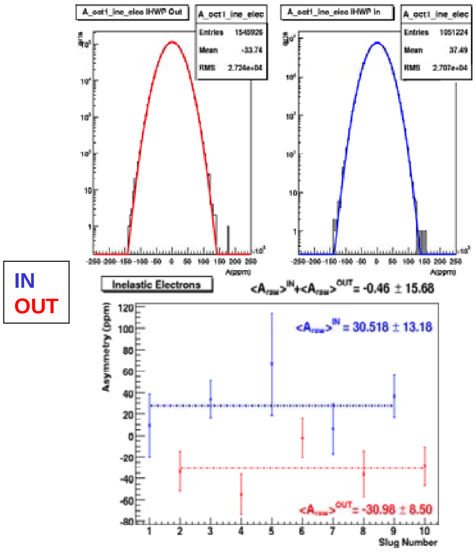
5.1. Raw Results

Still in progress and in its blinded stage the analysis is covering the full set of data. Final conclusions cannot be drawn, but the following Figures 10 -12 gives a glimpse on data quality and expectations on accurate values to be extracted from the experiment.

Figure 10 is a plot of raw asymmetries reflecting the good control of all parameter during data taking. Figure 11 gives preliminary results on the measured asymmetries for the elastically scattered electrons in four cases longitudinal polarisation of the electron beam and Figure 12 shows results on pions production.



Elastic electrons



Inelastic electrons

Figure 10. Asymmetry quality data

For five orders of magnitude the asymmetries follow the statistical law for the both helicity states obtained with or ½ wave length plate inserted or no in beam at low energy to reverse polarization (measurement on LH_2 target at 687 MeV).

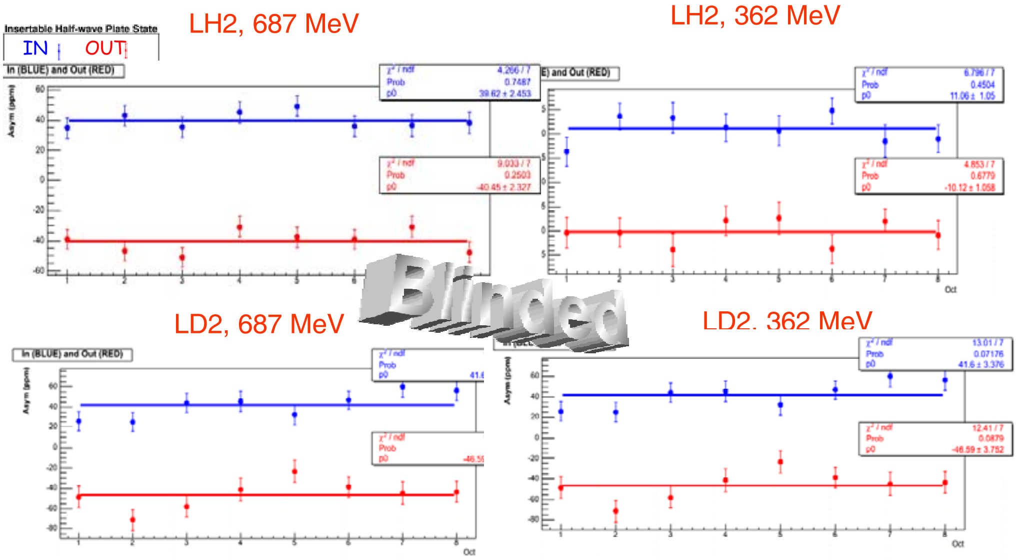


Figure 11. Asymmetries for elastic electrons.

Presented by octant and for the 2 opposite helicity measurements

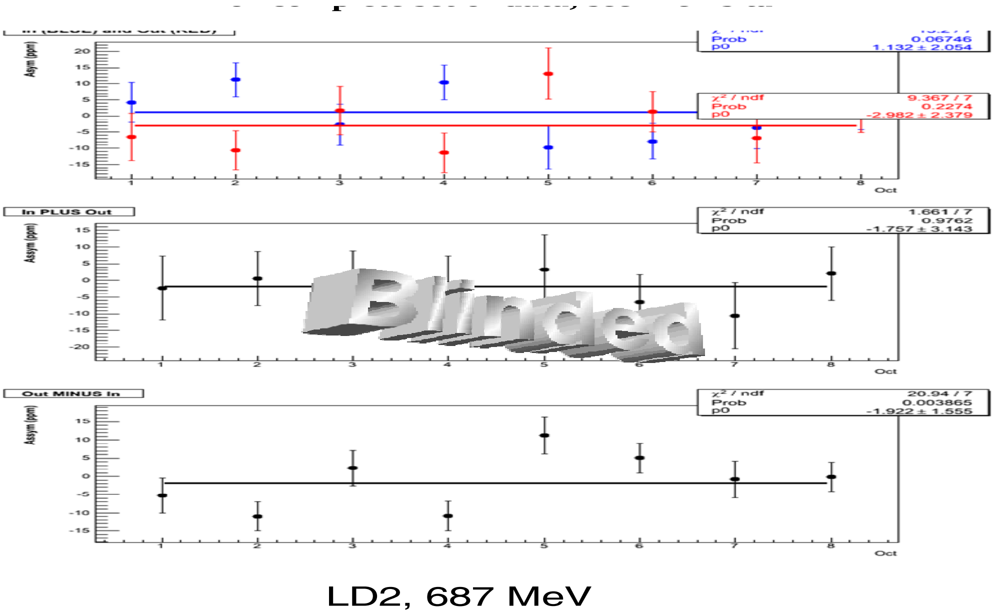


Figure 12. Preliminary pion raw inelastics asymmetries

Presented by octant and for the 2 opposite helicity measurements

5.2. Corrections to be Applied

These raw results coming from a first pass analysis must now be corrected from several effects listed below:

- Deadtime and randoms corrections
- Pion/electron contaminations and efficiencies
- Physics contamination

- Transverse polarization contamination
- Target windows contribution studied with flyswatter, Al frame and W radiator the amount of which is of the order of 3 to 5%
- Leakage from other beams
- Radiative corrections

Each item is subject to special studies by replay or analysis of dedicated measurements or by simulation. Leakage current does not affect these measurements as it did for the forward measurements and was measured to be small in any case. Two other examples of these corrections are illustrated on Figure 13 for the deadtime and Figure14 for the randoms.

Deadtime

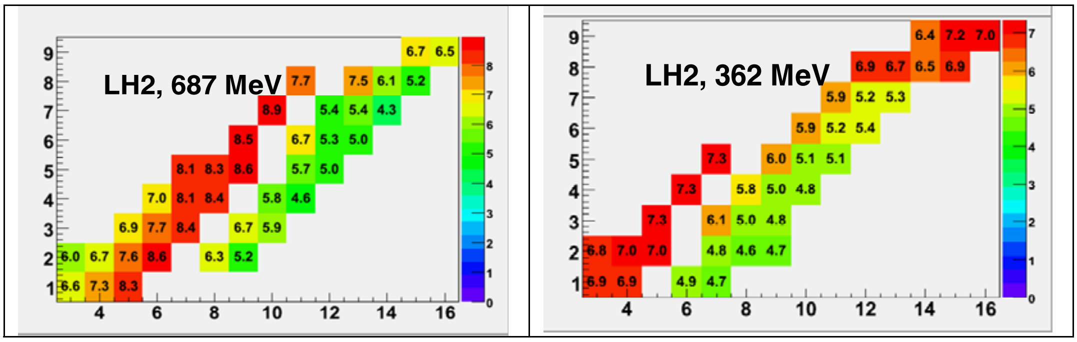


Figure 13. Deadtime estimations
Using a simulation of the electronics chain, loss by deadtime is estimated here for the hydrogen target case at 687 and 362 MeV, for each cell independently. The values vary from 4.3 to 8.9.

The calculation have shown that for the LH2 at 687 MeV with 60 µA the loss from dead time was of the order of 7% and 6% at 362 MeV with the same intensity. With the LD2 however it becomes more important and for reduced intensities of 30 µA and 35 µA respectively at 687 and 362 MeV the values go to 9% and 13% respectively.

Randoms

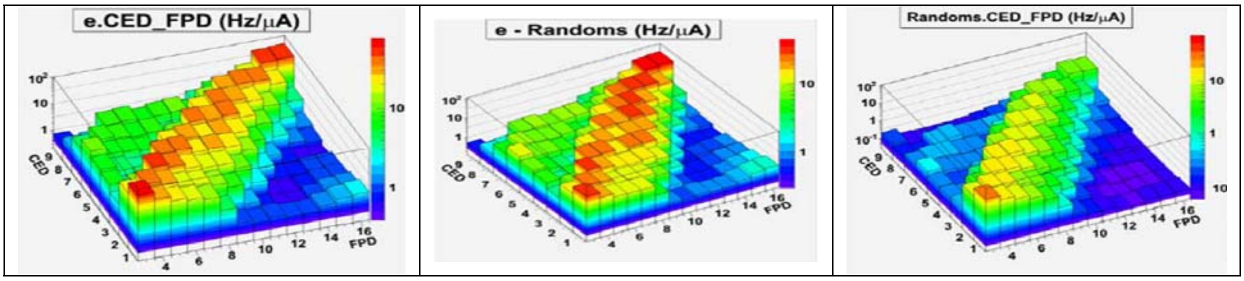


Figure 14. Randoms studies
A special timing of the experiment allows a direct measurements of the random rates compared in the figure with the coincidences rates. The contamination of data is thus measurable.

From these studies it was observed that the random contamination was small for the measurements made with liquid hydrogen target but became important when the liquid deuterium is used.

SUMMARY

Data have been collected for two backward angle parity violation asymmetry measurements at Q^2 of 0.23 and 0.62 $(Gev/c)^2$ on hydrogen and deuterium targets. With the previously published G*0* forward angle measurements, this data will allow extraction of G^s_E , G^s_M, and G^e_A, providing a further glimpse at the Q^2 behavior of these form factors. Simultaneously the asymmetry of inelastic electrons from N-Δ transition was measured and asymmetries for pion production as well. Additional measurements were taken with normal beam spin, to measure the beam normal single spin asymmetry on hydrogen and deuterium at backward angles at the beam energies of 362 MeV and 687 MeV.

The analysis is in progress. At the present stage the good quality of the data is certified but the final values of the individual form factors are not available. Other new data on parity violation will soon complement these studies leading to good knowledge of hadronic effects at low Q^2. The next challenge for the parity-violating electron scattering is the search of physics beyond the Standard Model, part for example, of the already planned Qweak experiment at Jlab.

ACKNOWLEDGEMENTS

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