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Description and Performances of the Electrical Test Benches for Readout Electrodes of the ATLAS EM Calorimeter

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Abstract

This note describes the different benches proposed by the LPNHE-Paris group to test the electrical properties of ATLAS Liquid Argon calorimeter electrodes. Two types of tests have been performed on electrode pre-prototypes since October 1997 to evaluate the benches performances. The first tests are done on flat electrodes, and the latter ones on the same electrodes after bending. At the production step, flat electrodes tests will be done in the factories and bent electrodes tests in the laboratories. Examples of results on benches performances (capacitances, resistances and leakage current measurements) are presented in this note.

1 Introduction

Since August 1997, various pre-prototype[1] electrodes of the Liquid Argon electromagnetic calorimeter have been tested before and after bending. These tests have all been done in the laboratory. These pre-prototypes allowed to test the different manufacturing steps and the tools used to control and qualify the product. During production, read-out electrodes quality control is mandatory to :

- **meet acceptance criteria** at the production level in the factory, before delivering electrodes. During the production, these tests on the flat electrodes will be done in the factory.
- **compare measurements before and after bending :** This ensures quality control of the product before assembling calorimeter modules. For example, potentially dangerous micro-fissures could appear in resistive pads during bending, and can be detected because they modify resistance values.
- **keep track of the different elements in the calorimeter.** In this way, a data-base containing electrical test measurements of the electrodes before and after bending will be built.

2 Description of the different types of electrodes

There are four types of electrodes depending on their position in the calorimeter. Electrodes description can be found in [1]. Geometry and cell design are different for each type of electrode : therefore, specific configuration benches are used in each case. As an example, one type of electrode is presented on figures 1 and 2.

2.1 Electrodes of the barrel calorimeter (electrodes A and B)

The type A electrode covers the η range [0-0.8] in the calorimeter. It includes 303 signal cells (255 in sampling one, 32 in sampling two and 16 in sampling three). Its dimensions are 1750 mm x 780 mm. It is shown on figure 1 in flat configuration, and on figure 2 in bent configuration.
The second electrode (electrode B) covers the η range [0.8-1.45]. It includes 231 signal cells (195 in sampling one, 25 in sampling two and 11 in sampling three). Its dimensions are 1840 mm x 780 mm.

[1] The term "pre-prototype" is used for a product which is not intended to be used in the calorimeter, but which allows to exercise different steps at the production and to perform electrical test benches.

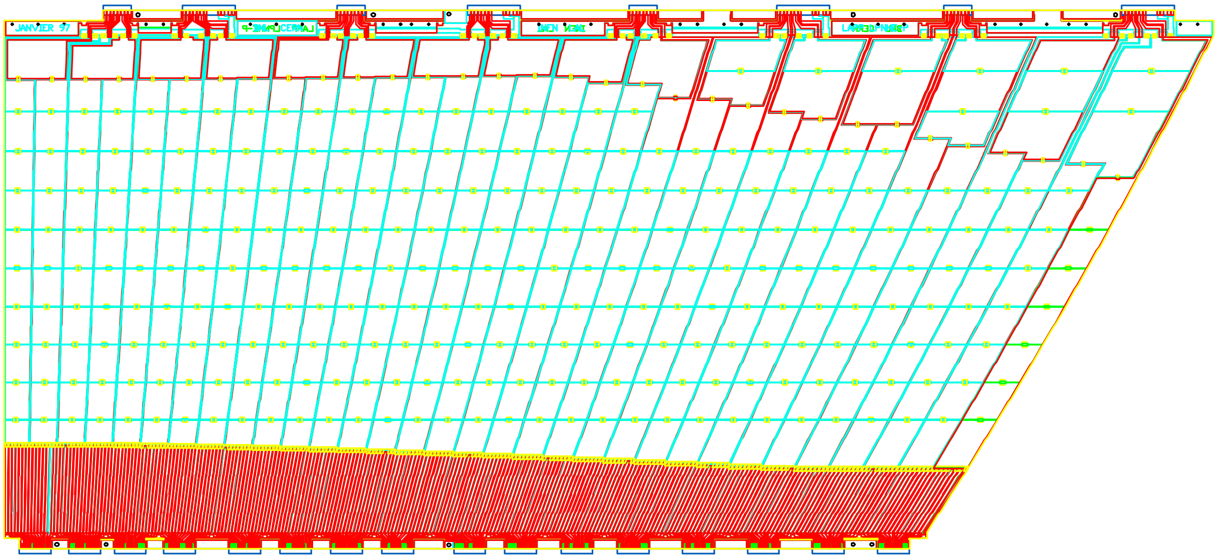

Figure 1: *Electrode A in flat configuration. See the text for the description*

2.2 Electrodes of the end-cap calorimeter (electrodes C and D)

Electrode C covers the η range [2.5-3.1] (inner wheel), and include 14 signal cells. Its dimensions are 930 mm x 565 mm. Electrode C is the smallest electrode.
Electrode D is the most complicated one because of its specific geometry without any right angle and a high density of connectors. It covers the η range [1.47-2.5] (outer wheel). It includes 284 signal cells (208 in sampling one, 44 in sampling two and 20 in sampling three). Its dimensions are 1580 mm x 985 mm.

Following table summarises these characteristics:

Electrode type	A	B	C	D
η Range	[0-0.8]	[0.8-1.45]	[2.5-3.1]	[1.47-2.5]
Dimensions (mm)	1750 x 780	1840x 780	930 x 565	1580 x 985
# signal cells S1	255	195	7	208
# signal cells S2	32	25	7	44
# signal cells S3	16	11	0	20

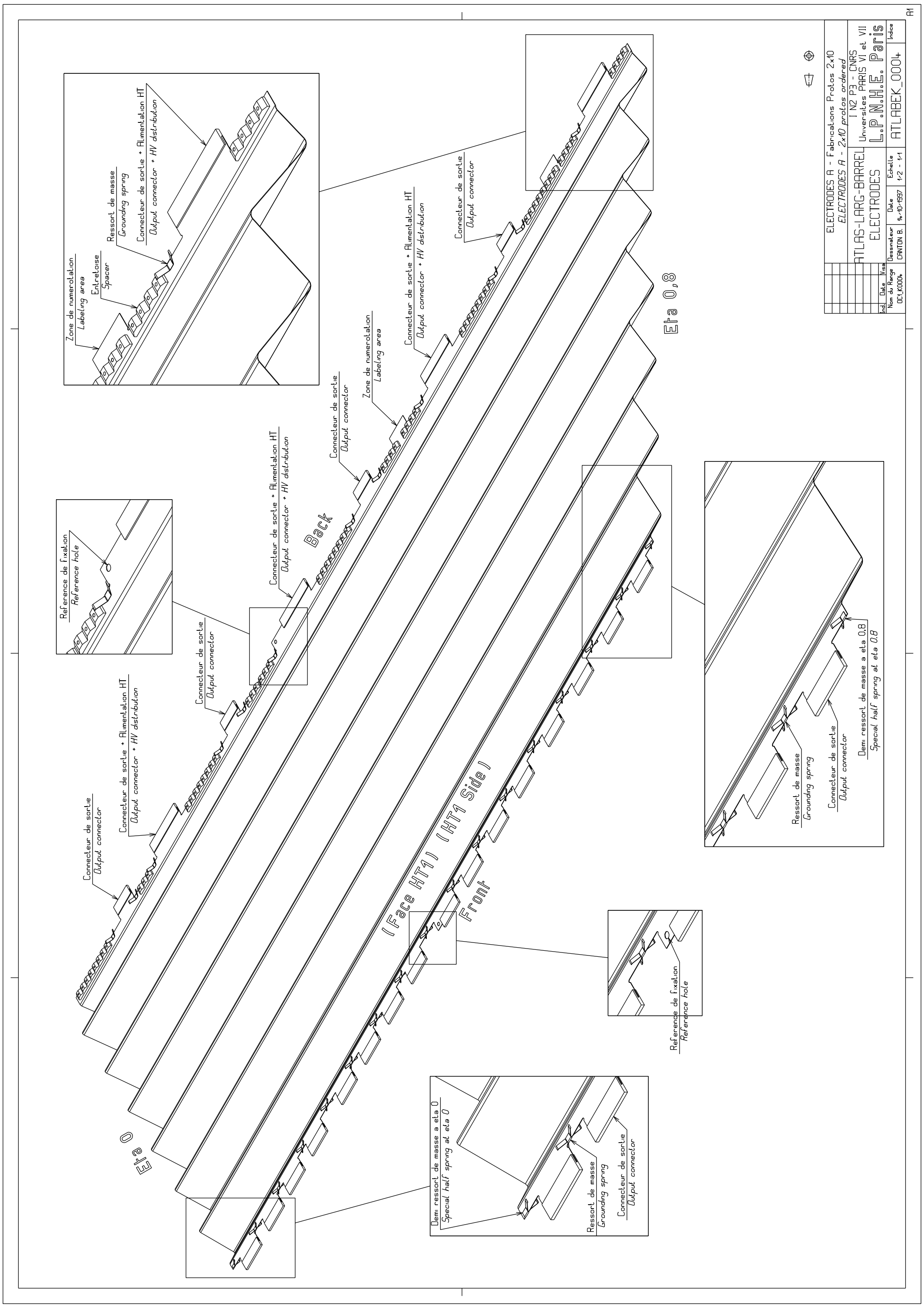

Figure 2: *Electrode A in bent configuration. Different elements are shown on this picture : Output connector, reference hole, HV distribution, grounding spring, spacer*

3 Electrical test benches

These tests are required to know electrode quality before delivery (for flat electrodes), and before calorimeter module assembling (for bent electrodes). Results of these two tests allow to compare measurements before and after bending, and to detect possible fabrication and handling damages. These two tests are presented in the following sections along with measurements on flat electrodes showing benches performances.

3.1 General description

The principle of measurements is the same for flat and bent electrodes. Two types of measurements are done : the low voltage test for resistances and capacitances measurement, the high voltage test for the leakage current measurement.

All data are stored in a database to be analyzed in detail for the pre-production. For electrodes of the standard production, an on-line analyzer gives a diagnostic for each electrode, and allows to reject or if possible to repair the faulty ones.

The following list presents different benches available in different test configurations[2] :

- 1. Flat electrode A (laboratory) : full test to validate fabrication process on prototype electrodes.
- 2. Flat electrode D (laboratory) : full test to validate fabrication process on prototype electrodes.
- 3. Bent electrode A (laboratory) : full test to validate fabrication process and quality of each electrode before assembling.
- 4. Bent electrode C and D (laboratory) : full test to validate fabrication process and the quality of each electrode before assembling.
- 5. Flat electrodes A/B (industry) : fast test to validate the product before leaving the industry.
- 6. Flat electrodes C/D (industry) : fast test to validate the product before leaving the industry.

[2]The High Voltage part of A/B and C/D tests in industry is done by INFN Milano laboratory. Bent electrodes B tests are also done by INFN Milano laboratory [2]

Figure 3 shows the benches for flat electrodes in the final configuration (benches # 5 and # 6). The top level of the bench is the A/B electrode part and the bottom level is the C/D electrodes part. Bench # 4 (bent electrode C) is presented on figure 6.

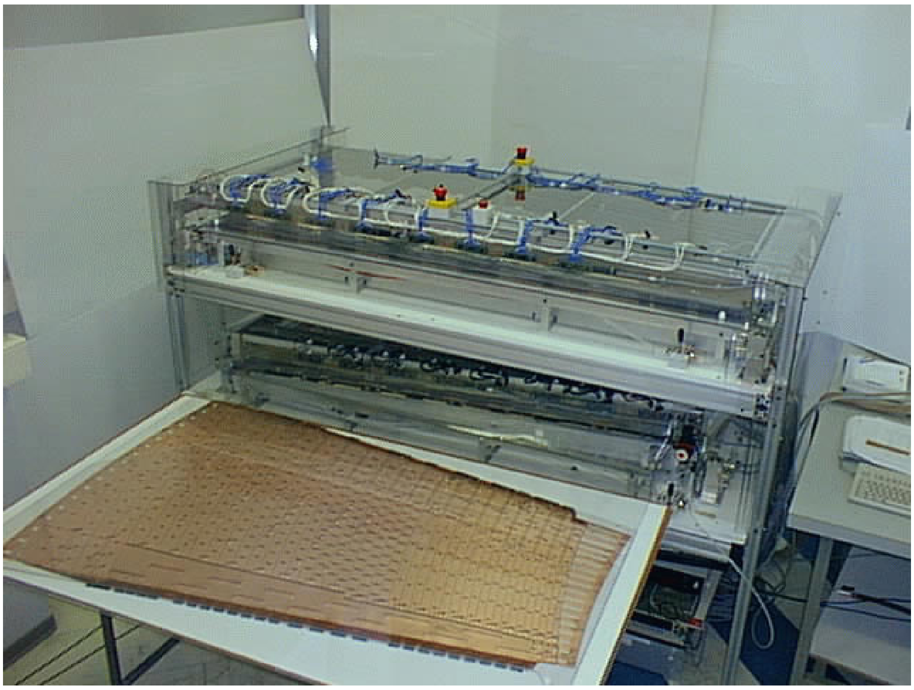

Figure 3: *Bench used in the companies to test the flat electrodes : Top level of the bench is the A/B electrode part and the bottom level is the C/D electrode part.*

3.2 Low voltage test : resistance and capacitance

3.2.1 Requirements

- Measurements of capacitances between signal layer and HV layer allow to detect any interruption in the inner Cu layer of the cell, in the signal fan-out and in the crimped connectors.
- Resistances measurements allow to check electrical continuity. These measurement are compared to the nominal resistivity value which is 1 MΩ per square. The acceptable range of the resistance is 100 KΩ to few MΩ [3] [5].

3.2.2 Measurements

Measurements are done with probes contacting with the different electrode cells. Probe extremities have an optimized shape flat or convex to follow the electrode shape and to get an optimal contact between probes and electrode. The applied force on the probes is about 10 Newtons. A schematic view of

these probes is presented on figure 4. Mechanical alignment of these probes is a crucial point of the benches mechanical structure. This alignment is obtained after fine tuning.
The level one multiplexing is done directly on the mechanical support for 32 channels (see figure 7). A second multiplexer connects electronic where measurements are done.

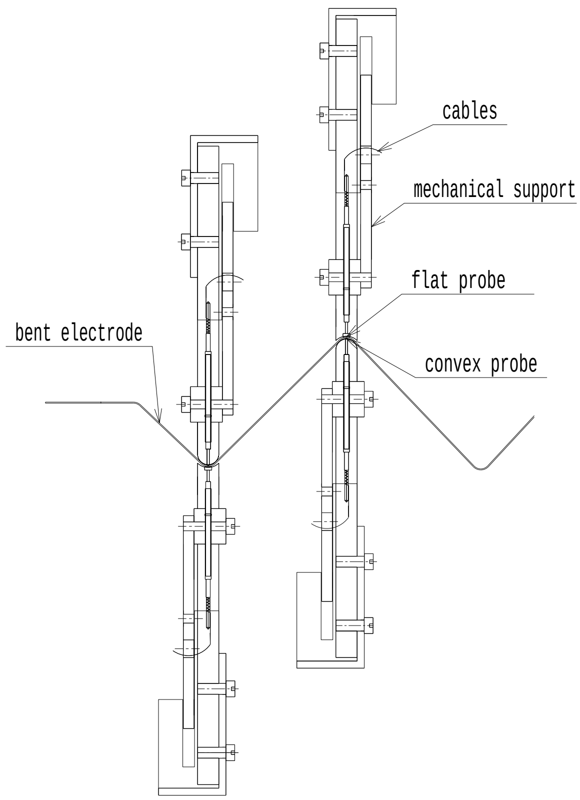

Figure 4: *Schematic view of the test probes used for RC measurement : on this figure a part of a bent electrode is tested. Two probes are shown with cables, mechanical supports, flat and convex probes*

Figure 5 shows details of a bench for bent electrodes : test probes and mechanical supports can be seen on this picture. The high density of probes in sampling one makes the alignment tuning rather delicate.

Resistances are measured with an electro-meter, and capacitances are measured with a RLC bridge (see figure 7). In a first step, resistances were measured with a RLC bridge for resistances value around 100 KOhms (UVGEM prototype used in RD3 tests). With present values between 200 KOhms to 10 MOhms, the RLC bridge is not adequate due to its frequency measurement giving an impedance of the same order as the measured resistance. Therefore, we use the electro-meter with continuous measurement.

The silk screen resistances are located on the external faces of the electrodes. The measurements are done by selecting two probes with the multi-

plexer. A map of all resistance electronic addresses which have to be measured is recorded in the computer. With this map, only one run with a Labview program is needed to test automatically all the resistances one by one.
Following measurements are perfomed:

- **C1** : Sampling 1 cell capacitance between HV layer and signal layer.
- **C2** : Sampling 2 cell capacitance between HV layer and signal layer.
- **C3** : Sampling 3 cell capacitance between HV layer and signal layer.
- **R1** : Individual resistances connecting sampling 1 to sampling 2.
- **R2** : Resistances in series from the front of the sampling 2 to the HT connection.
- **R3** : Resistances in series from the front of the sampling 3 to the HT connection.
- **R4** : Resistances in series from the front of the sampling 2 to the back of the sampling 2.
- **R5** : Individual resistances in the sampling 3 (in parallel with other resistances).
- **R6** : Individual resistances connecting sampling 2 to sampling 3 (in parallel with other resistances).
- **R7** : Isolation between contiguous cells (e.g. due to bad etching) on the various layers
- **R8** (bent electrode only) : Individual resistances in sampling 2

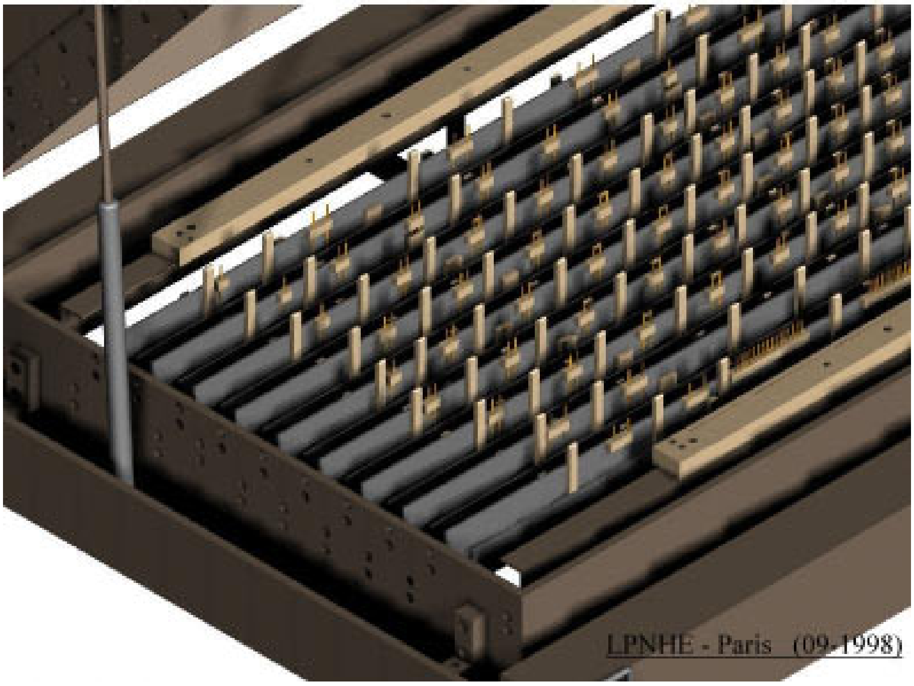

Figure 5: *Details of one bench for the bent electrodes : Test probes and mechanical supports can be seen on this picture*

Figure 6: *Bench for the bent electrodes C : Mechanical support keep the tested electrode in shape*

Capacitance measurements are done between the external and internal layer. For each capacitance, one probe and one output connector are used. As for resistances, a map of all capacitances to be measured is recorded, and all measurements of one electrode are done in the same run.

An electrode identifier is read automatically using an optical pen, and stored in the data-base. This identifier contains information such as the company, date of production, type of electrodes, batch number etc... This allows to keep track of each electrode tested.

A very detailed automatic test of prototype and pre-series electrodes is composed of 1500 measurements on A and D flat or bent electrodes. Duration of this test is 30 minutes per electrode.
In production configuration, the test achieved in factories consist of 1000 measurements for A/B and C/D flat electrodes. The duration is 20 minutes per test.

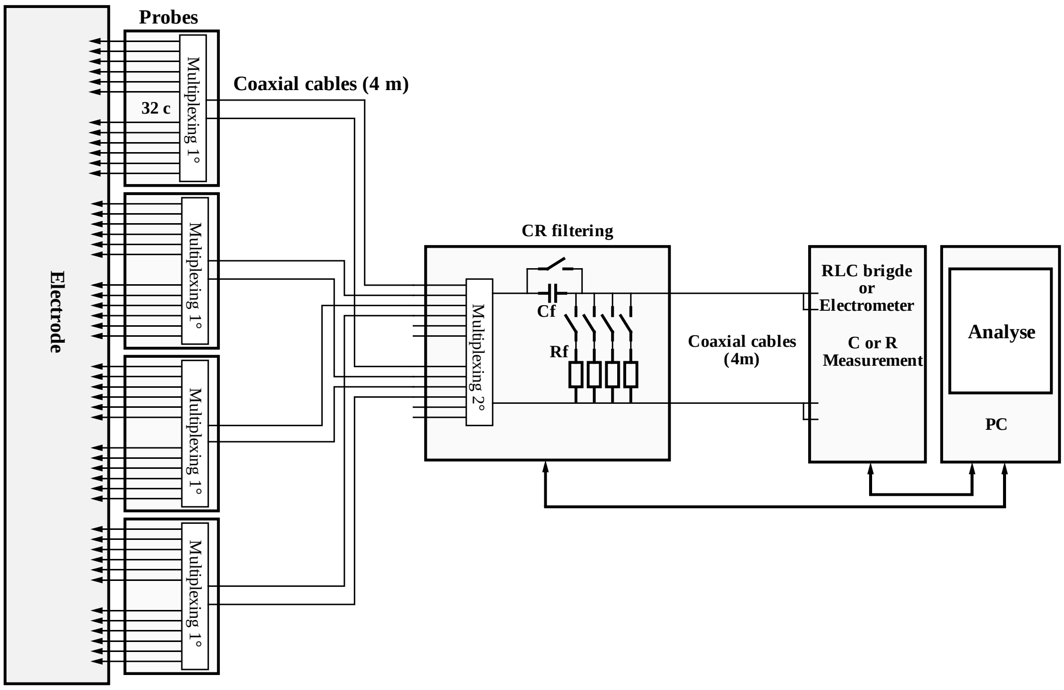

Figure 7: *Capacitance and resistance measurement - The RC filter was used only for UVGEM prototypes*

3.2.3 Capacitance measurement results

As an example, in figure 8, we show the capacitances measured for one electrode of D type.

Mean values obtained are different for each side : 203 pF for the HV1 side and 227 pF for HV2 side. This feature is due to the difference of thickness of the "dielectric" making up the capacitor on each side : while HV1 side goes over 25 μm of glue (plus 50 μm Kapton and other 15 μm glue), the HV2 has the capacitance over the glue within the double sided Cu-polyimide laminate, 15 μm of glue.

The correlation between capacitances values measured on the HV1 and the HV2 sides has been studied systematically. We obtain a mean value for the ratio equal to 0.86 (obtained with a gaussian fit). From the thicknesses mentioned above we expect 0.89.

A few channels have a capacitance value equal to 0 pF. This is due to a broken connection. Capacitance distributions versus cell number of both sides are shown on the bottom of figure 8. The pattern of these distributions comes from the cell surface variations. Broken connections are well seen and can be associated with the faulty cell number. More results can be found in [4]

3.2.4 Resistance measurement results

Figure 9 shows the resistances distributions of one flat electrode D measured on both HV1 and HV2 faces. In the distributions versus cell numbers we see different values due to different patterns on the various sections.

We see that the mean value of resistance is different between the two faces HV1 and HV2. This is reproduced in all electrodes of both firms. We suspect this feature could be due to the fact that the serigraphic process starts on one face and thus we obtain an asymmetric number of drying steps between the two faces. This problem is under investigation.

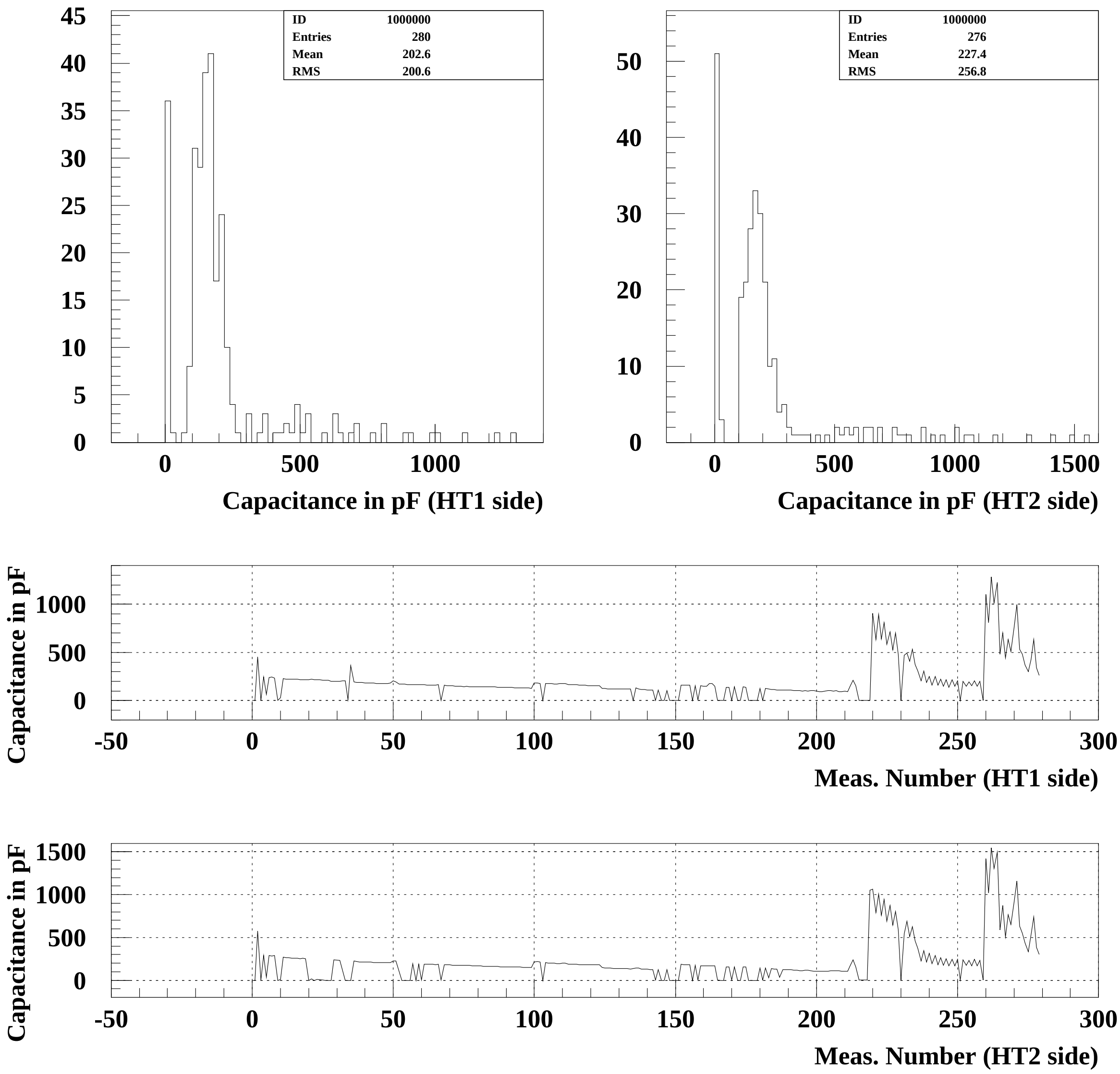

Figure 8: *Top left : HT1 capacitances distribution. Top right : HT2 capacitances distribution. Middle : HT1 capacitances versus cell number. Bottom : HT2 capacitances versus cell number.*

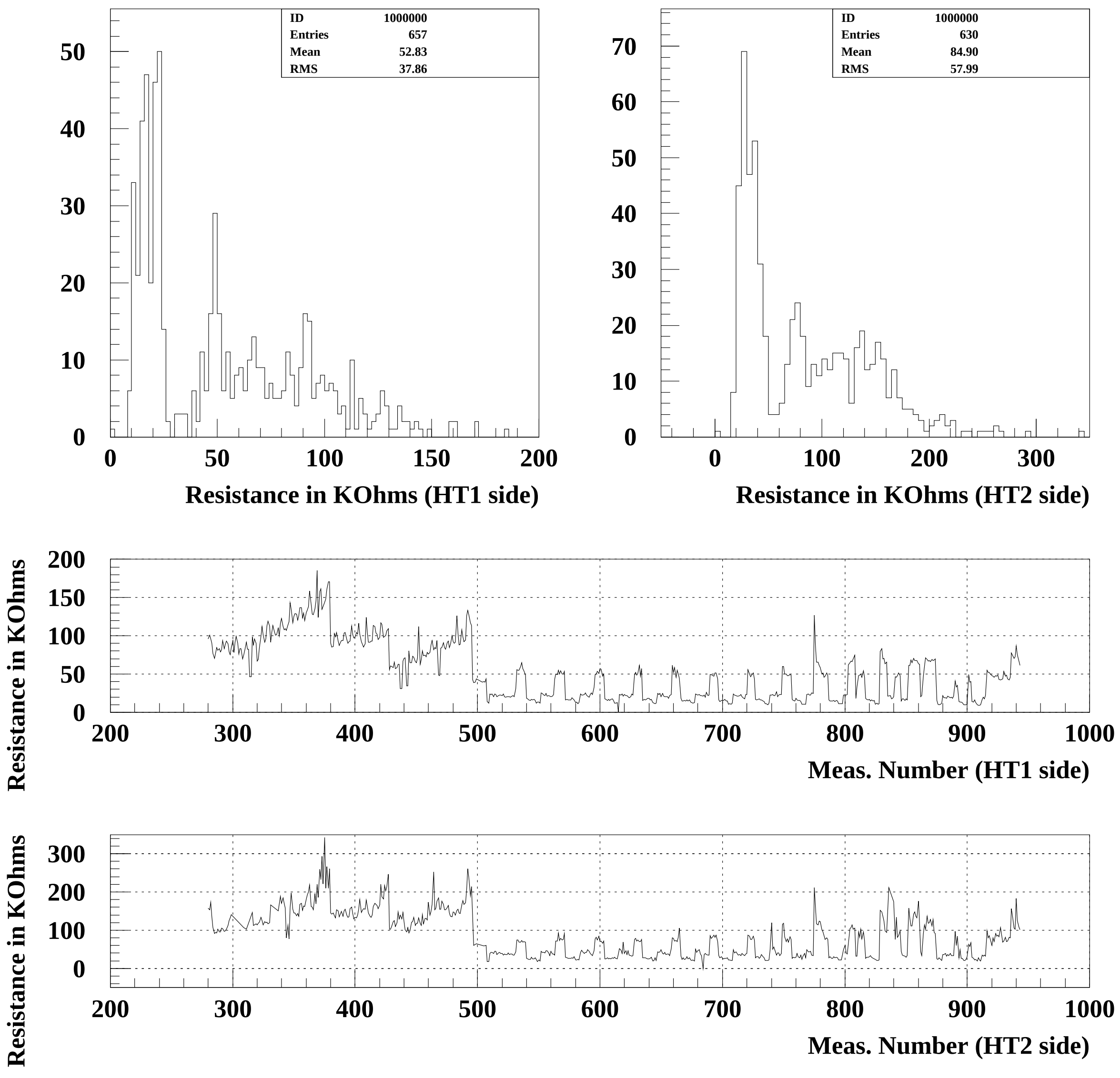

Figure 9: *Top left : HT1 resistances distribution. Top right : HT2 resistances distribution. Middle : HT1 resistances versus cell number. Bottom : HT2 resistances versus cell number.*

3.3 Leakage currents

3.3.1 Requirements

The H.V behavior is tested to detect any failure in the H.V insulation provided by the dielectric which could degrade a fraction of the sensitive volume of the calorimeter. The leakage current could contribute to the electronic noise of the front-end electronic. Its value has to be limited.

3.3.2 Measurements

Using a High Voltage power supply CAEN system, 2000 Volts is applied between the two HV layers and the signal layer, the cells of which are clamped to ground. The H.V. ramp-up is about 10 Volts/second. All tests are done in a room with controlled relative humidity below 40 % to reduce the risk of surface current leaking and sparking.
The current value is measured using the current monitor of the HV system. The resolution is about 10 nA. The asymptotical decrease of the current is presented on figure 10. About 3000 measurements are recorded during one hour. The mean value of the 100 last measurements gives the leakage current value (see bottom of figure 10). In this example, the leakage current is equal to 14.9 nA.
Figure 11 shows the current value evolution as a function of time when succesively 1900, 1950 and 2000 Volts high voltage is applied for both sides. The top curve shows the evolution on HT1 side, the bottom curve shows the evolution on HT2 side. In this case, no flashes effect are recorded, and the high voltage behavior is correct.

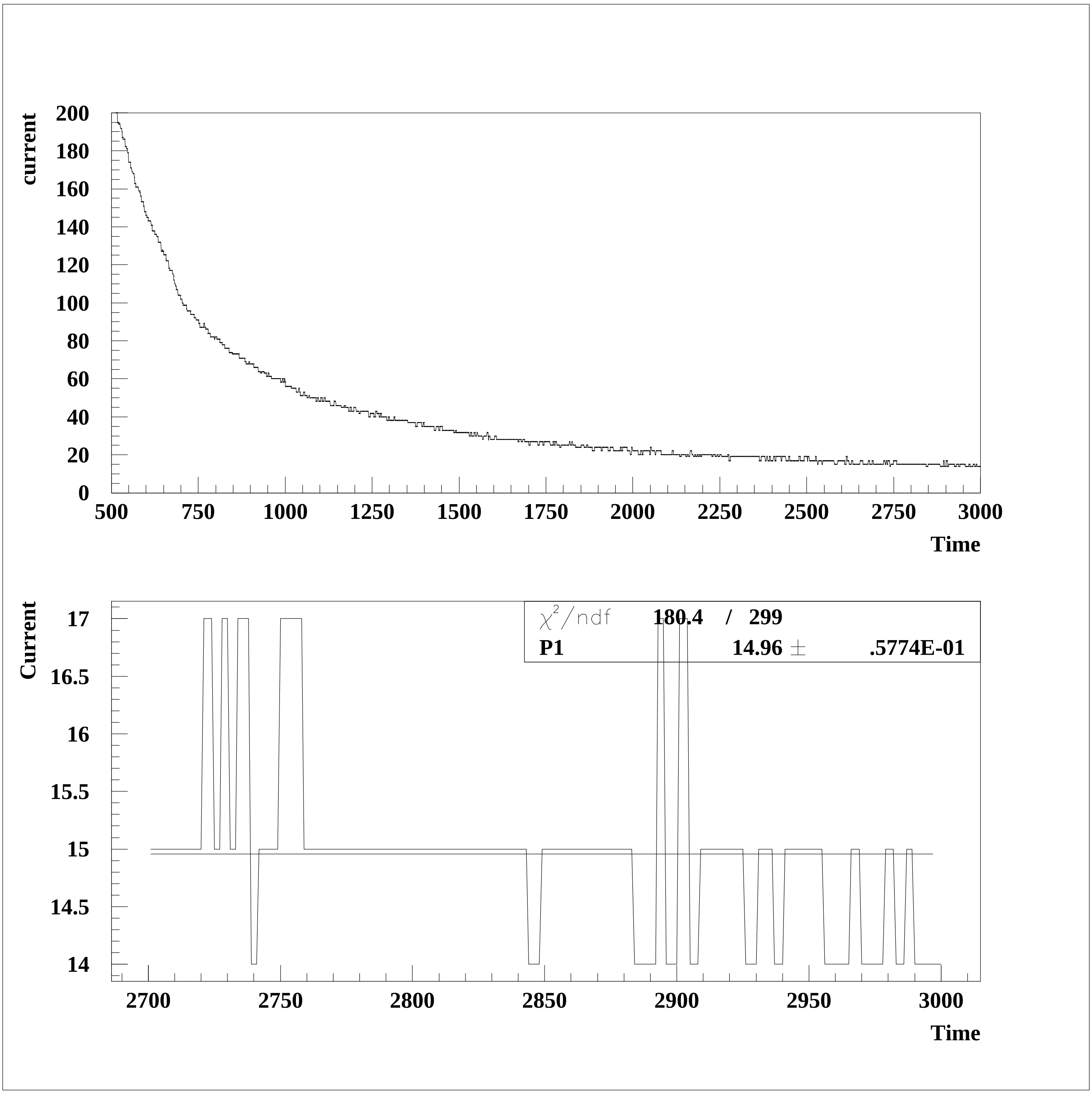

Figure 10: *Top : decrease of the current. Bottom : leakage current measurement using the 100 last points of the previous distribution - A linear fit gives the leakage current value.*

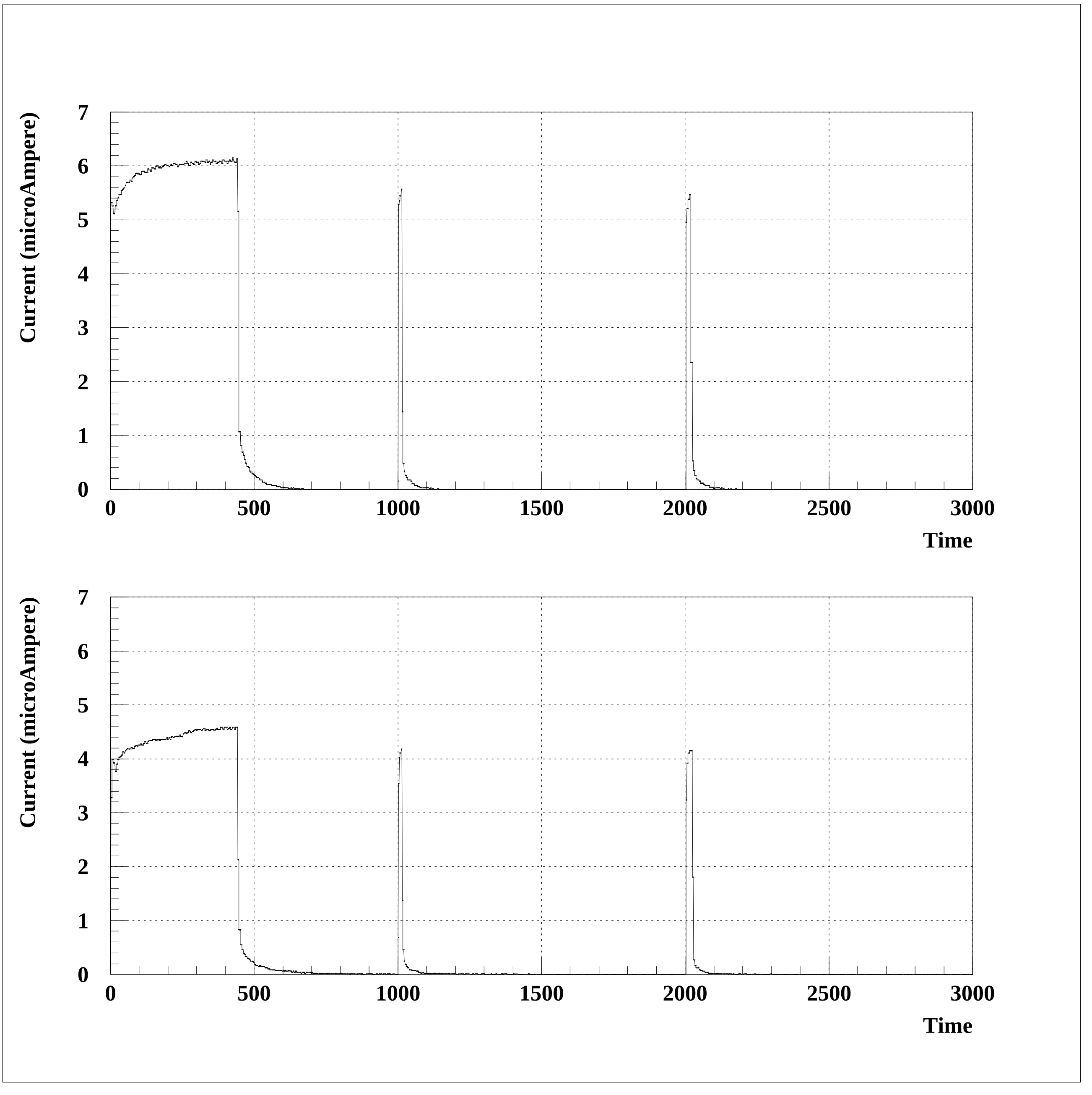

Figure 11: *Current versus Time for both side of one electrode when 1900, 1950 and 2000 volts are applied. The top curve shows the evolution on HT1 side, the bottom curve shows the evolution on HT2 side.*

4 Conclusion

The set of tests presented in this note shows that the station is operative and adequate to qualify electrodes. The different types of benches allow a very detailled control and check of the electrodes to assure a good quality of the product for the liquid argon calorimeter and a good knowledge of its characteristics.

References

[1] ATLAS collaboration : **Liquid Argon Calorimeter : Technical Design Report**

[2] W. Bonivento, G. Costa, M. Mazzanti : **The electrode test setup developed in Milano : experience with RD3 and ATLAS prototype**

[3] W. Bonivento, G. Costa, M. Mazzanti : **Impact of resistor quality of the readout electrodes on e.m. calorimeter performance**

[4] L. Hervás et al : **Summary of measurement on preseries electrodes for the ATLAS EM Calorimeter**

[5] W. Bonivento, D. Lacour : **Acceptable Values of Resistances on Electrodes of the ATLAS EM Calorimeter** (note in preparation)

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