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ATLAS Note

Evaporating short-circuits in the ATLAS liquid argon barrel presampler

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Abstract

A technique to eliminate or limit the implications of short-circuits in the ATLAS barrel presampler is described. A high voltage capacitor with a large capacity is charged at different high voltages and discharged through the short-circuit which allows either to disintegrate the dust being the origin of the short-circuit, or to burn away a thin etched copper strip which acts as a fuse on the corresponding presampler anode. This effect is possible even in the presence of a resistive HV cable (10 to 30 Ω) in series which dampens the pulse.

1 Introduction

The liquid argon barrel presampler is a detector placed in front of the electromagnetic calorimeter [1] inside the same cryostat. A thin active sampling layer (11 mm of liquid argon) allows to estimate the energy lost by incident particles in preshower formation before they reach the calorimeter. The purpose is to improve the energy resolution of the barrel calorimeter.

The presampler is composed of sixty four sectors which consist of 8 different types of modules (fig 1). The modules are made of interleaved cathodes and anodes, glued between FR4 plates. The anodes are 3-layered printed circuit boards: a high voltage of +2 kV is applied to the outer layers and the signal is read out through capacitive coupling using the central anode layer. The cathodes are double sided boards, where the two copper layers are connected to ground. The gap between anodes and cathodes is approximately 2 mm for all types of modules. To obtain an electric field of 10 kV/cm an electrical potential of 2 kV is therefore applied bewteen anodes and cathodes. The volume between these two types of electrodes is filled with active liquid argon.

The two outer copper (Cu) layers of an anode are divided into 2 parts (fig 2), thus defining 2 equal regions on each side of the anode. These 4 Cu areas are connected to 2 high voltage buses via a thin etched Cu strip and a 1 MΩ protective decoupling resistor soldered on the anode. The surface mounted 1 MΩ decoupling resistor, type 0805, is 2 mm long and 1.25 mm wide. The number of anodes connected to one high voltage bus varies between 120 (modules 1 and 2) and 214 (modules 7 and 8). In average, the associated capacitance is of the order of 70 nF.

Numerous high voltage tests, during at least 24 h each, have been performed: 1- on the modules just after their production in dry nitrogen gas at 2 kV; 2- on the complete sectors in dry nitrogen gas at 1 kV; 3- on the complete sectors in liquid nitrogen at 2 kV. During the sector assembly into two wheels, each sector has been tested again at 1.4 kV for at least half an hour in air. Subsequently, after insertion of the 2 wheels in the barrel cryostat, the sectors have been tested at 1.4 kV during about 2 hours. Nevertheless a fair number of short-circuits appeared just after filling the barrel with liquid argon and at very low voltage: ∼50 V. The origin of these short-circuits is not well understood, for instance, it could be due to the presence of "conductive dust" in the liquid argon which enters into the space between anode and cathode even deep inside the sector far away from its ends. One should note that the presampler does not, contrary to the barrel electromagnetic calorimeter, have any honeycomb spacer between anodes and cathodes. After removing the liquid argon from the barrel, all the short-circuits disappeared.

In this note, a study of a technique for burning away the short-circuits is reported.

2 A technique for burning away the short-circuits

The first solution studied was to burn away the 1 MΩ decoupling resistor soldered on the anode. By applying a potential difference of a few kV between the ends of the resistor, it is possible to get a large current which can bypass the resistor through sparks or an electrical arc. This current was found to even be able to burn the insulator material, FR4 prepreg, of the anode, but unfortunately without burning away the resistor itself. Actually the resistor value tends to decrease rather than increase.

The second solution was to inject a high voltage pulse by discharging a capacitor. The thin Cu line etched on the anode (fig 2), 17 μm thick, 300 μm wide and about 5 mm long, can act as a fuse. This technique is possible because the current, due to an electric arc, can jump across the decoupling resistor without limiting the power dissipated in the thin copper strip, even in liquid nitrogen or liquid argon. To fuse one of these Cu lines results in the loss of $1/(678 \times 4 \times 64) = 5.7 \times 10^{-6}$ of the total detection surface of the presampler which is small enough to be acceptable.

A schematic view of the experimental set-up is shown in figure 3.

A large number of tests have been performed with simple anodes, pieces of modules, modules with their mother-boards, complete sectors; in the air, liquid nitrogen and liquid argon; with different capacitors and different values of the applied high voltage. Only the main results will be reported here.

Usually the short-circuits have been simulated by introducing a piece of conductive solder-wick between an anode and a cathode (2 mm gap). After a positive result, i.e. succesfully burn away the thin Cu line, the anode or the module was systematically tested to withstand the nominal value of 2 kV with negligible leakage current. No large conductive pieces of Cu line were ever found after burning away short-circuits or Cu lines.

3 Results and comments

The first sets of tests were made with copper cables, i.e. low resistance, from the capacitor to the presampler. In the real ATLAS barrel constantan wires are used from the cryostat feedthroughs to the presampler resulting in a series resistance between $\sim$9.5 and $\sim$31.5 Ω. Tests were made with single anodes where one of the regions of the two outer Cu layers was short-circuited to ground, or small pieces of modules without mother-boards or on complete modules including mother-boards with their calibration distribution network.

3.1 Tests in liquid nitrogen without resistive cable in series

These tests were performed with a 2.2 μF capacitor and a high voltage value between 1.8 and 2.5 kV. The described technique works well, but due to the shock wave it has been observed with single anodes that the 1 MΩ decoupling resistors can fall off the anodes. With pieces of modules, i.e. several anodes and cathodes glued to FR4 plates, this happened very rarely.

3.2 Tests in liquid argon without resistive cable in series

These tests were similar to the previous ones, though with single anodes, the 1 MΩ decoupling resistors were more frequently lost due to the shock wave. Here this phenomenon also happened fairly often with pieces of modules.

3.3 Tests of a module equipped with mother-board but without resistive cable in series

Tests of a module of type 1 equipped with its mother-board have been performed in different media: air, liquid nitrogen (LN_2) and liquid argon (LAr). The calibration and signal cables from the module were terminated by 50 Ω resistors. Table 1 shows the main results. No change ($\geq$1/1000) in the resistance values of the calibration resistors soldered on the mother-board was observed after burning away the short-circuits.

Table 1: Tests of a module equipped with its mother-board

Test performed in	C (μF)	HV (kV)	Succesful burning	Number of missing 1 MΩ resistors
air	2.2	2.4	O.K.	0
LN_2	2.2	2.4	O.K.	1
LAr	2.2	2.0	O.K.	0
LAr	2.2	1.8	O.K.	0

3.4 Tests on complete presampler sectors

Tests have been performed in liquid argon in two cases where a short circuit has occured:

1. one of the presampler sectors installed in the test beam cryostat. A capacitor of 2.2 μF charged to 2.2 kV has been used.

2. one of the presampler sectors installed in the barrel cryostat of the ATLAS electromagnetic calorimeter. Two capacitors of 2.2 μF each in parallel, charged to 2.0 kV, were necessary.

In both cases, the short-circuits have disappeared. Moreover, using a test bench specially designed for the purpose[1], it was possible to see in both cases that no electrical connection to the anodes was missing and therefore only the "dust" had been burnt away.
The sector in the test beam cryostat was subsequently able to detect particles during several months without any problem.

3.5 Tests in liquid nitrogen with a resistive cable in series

In the real barrel cryostat the HV lines of the presampler sectors are connected to the cryostat feedthroughs via constantan wires which are bad thermal conductors but also electrically resistive (~3.8 Ω/m). The length of these wires varies from 2.5 m (~9.5 Ω) up to 8.3 m (~31.5 Ω). Unfortunately this additional resistance limits the current intensity of the HV pulses through the thin lines on the anode or the dust. This explains, for instance, why a capacitor of 2.2 μF was not sufficient in the case of the sector in the final cryostat while it worked fine for the sector in the test beam cryostat where the cables are not resistive. Tests have shown that the capacitance value has to be increased with more than an order of magnitude to assure that the Cu line on the anodes can be burnt away in the presence of the series resistor.

Our results are reported in table 2. The length of the resistive cable, the capacitance used and the high voltage are indicated in the first, second and third column, respectively. None of the 1 MΩ resistors was missing after the tests, even in the case where L=2 m, C=50 μF and HT=3 kV. This is due to the fact that the resistive cable considerably dampens the HV pulse. The audible noise coming from the shock wave is substantially reduced.

It can be noticed that for 2 m of resistive cable, a 12 μF capacitor charged to 2 kV is not sufficient to burn away the anode strip; but at 2.2 kV the test becomes positive. Again, at 2 kV for 5 m of resistive cable, a 21.3 μF capacitor is not sufficient, while 25.7 μF is. For 9 m of resistive cable, we had to used our largest capacitor (i.e. 50 μF). Finally, one should note that it is always possible

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[1] Measurement of the signal response to a low amplitude (10 V) and low frequency (10 kHz) sinusoidal signal injected in the module high voltage lines.

to burn away the Cu line etched on the anode and therefore to eliminate the short-circuit.

Table 2: Tests in liquid nitrogen with a resistive cable (see text).

L (m)	C (μF)	HV (kV)	Succesful burning	Number of missing 1 MΩ resistors
2	12	2	No	0
2	12	2.2	O.K.	0
2	50	2	O.K.	0
2	50	3	O.K.	0
3	12	3	O.K.	0
3	21.3	2.2	O.K.	0
3	11.3	2.1	O.K.	0
3	11.3	2.0	No	0
5	11.3	2.1	No	0
5	11.3	2.2	No	0
5	11.3	2.3	No	0
5	21.3	2	No	0
5	21.3	2.1	O.K.	0
5	21.3	2.2	O.K.	0
5	25.7	2	O.K.	0
7.37	12	3	No	0
7.37	50	2	O.K.	0
9	50	2	O.K.	0

3.6 Tests in liquid nitrogen of a module equipped with mother-board and with a resistive cable in series

The results are reported in table 3. As mentioned previously, the resistive cable length, the capacitor value and the high voltage are indicated in the first, second and third column, respectively. The calibration and signal cables from the module were terminated by 50 Ω resistors. No change in resistance ($\geq$1/1000) of the calibraton resistors soldered on the mother-board was observed after burning away the short-circuits.

Table 3: Tests in liquid nitrogen with a resistive cable in series (see text).

L (m)	C (μF)	HV (kV)	Succesful burning	Number of missing 1 MΩ resistors
2	14.7	2.2	O.K.	0
2	50	2.7	O.K.	0
2	50	3.0	O.K.	0

3.7 Tests in liquid argon of a module equipped with mother-board and with resistive cable in series

Similar tests have been performed in liquid argon. Our results are reported in table 4. As before, the calibration and signal cables from the module were terminated by 50 Ω resistors. No change ($\geq$1/1000) of the calibration resistors soldered on the mother-board was observed after burning away the short-circuits. One can notice that there is no missing resistor after all the burnings when a series resistive cables was used. This technique allows to burn away the short-circuits even if the resistive cable is 9 m long (i.e. a little more than the maximum value of 8.3 m). The worst case in view of possible damage, L = 2.5 m, C = 50 μF, HV = 3 kV, does not lead to a change of the calibration resistor values, and furthermore, no HV protective resistor was missing after the test.

Table 4: Tests in liquid argon with a resistive cable (see text).

L (m)	C (μF)	HV (kV)	Succesful burning	Number of missing 1 MΩ resistors
2.5	50	2.2	O.K.	0
2.5	50	3.0	O.K.	0
5	10	2.0	No	0
5	21.3	2.0	No	0
5	25.7	2.2	O.K.	0
5	50	2.0	O.K.	0
9	50	1.8	No	0
9	50	1.9	O.K.	0
9	50	2.0	O.K.	0

Unfortunately, the sequence of tries during these tests, seems not to be without consequences. For instance, with 5 m of resistive cable, if we start to burn away the strip with a capacitor of 21.3 μF charged to 2 kV, the detector resistance becomes infinite as measured with an ohm-meter. Though when applying the nominal high voltage value (2 kV), the short-circuit is still visible. This probably means that the cut in the Cu strip is not large enough to assure a good electrical insulation at high voltage. Furthermore, it then becomes impossible to burn away the strip with a slightly larger capacitor[2], e.g. 25.7 μF at 2 kV (see table 2). However, when we directly started the test with the slightly larger capacitor (25.7 μF and 2.2 kV) the result was positive, i.e. the detector resistance stays infinite even at 2 kV.

4 Shape of the HV pulse

The pulse corresponding to the discharge of the capacitor has been recorded using a HV probe connected to a digital oscilloscope (see fig. 3). Only a piece, 1/3, of a presampler module type 1 was used in these measurements. The corresponding capacitance was estimated to about 10 nF per HV line, Figure 4 shows two measurements performed in liquid nitrogen:

1. with a capacitor of 21.3$\pm$10% μF (21.14 μF measured) which was charged to 2.2 kV. The length of the resistive cable was about 3 m, giving a resistance of 11.4 Ω.
2. with a capacitor of 21.3$\pm$10% μF (21.14 μF measured) which was charged to 2.2 kV. The length of the resistive cable was about 5 m, giving a resistance of 18.9 Ω.

The ratio of the capacitances of the module piece and the discharge capacitor was thus $\sim 2.10^{-3}$ in both measurements.

Both pulses are quite similar: an exponential decrease at the beginning up to a minimum and then a slight increase. Actually, such a behaviour was systematically observed. The RC value can be estimated from an exponential fit but the analysis shows that this value depends on the fitting interval: the further it is from the pulse start, the smaller is the value of the RC product. The estimated cable resistance is slightly smaller than the nominal value determined with an ohmmeter, the curvature tending to slightly reduce the value.

The RC product can also be evaluated from the tangent at the origin, i.e. the pulse start. In that case, the resistance which can be deduced is slightly larger than the nominal cable resistance.

The increase of the capacitor voltage which follows the minimum, is probably due to the "dielectric absorption" effect, i.e. re-polarization of the dielectric dipoles.

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[2] At 2 kV, the 50 μF capacitor always allowed to produce the expected burning of the remainder of the strip.

After about 1 minute, the residual voltage is typically of the order of 100 V up to 250 V.

The HV probe has also been connected to the module HV lines and thus has allowed to follow what happens at the anode. Tests have been performed in liquid nitrogen with a 25.7 μF capacitor (25.6 μF measured), charged to 2.2 kV and with a 2.5 m resistive cable in series during the discharge. The upper part (a.) of figure 5 shows the voltage value at the module HV line. It stays zero until the discharge switch is operated. Then the voltage rises to a value of 2.2 kV and stays at this level during 570 ms after which it rapidly drops probably when the electrical arc bypasses the 1 MΩ protective resistor. Another test performed under the same conditions has led to a plateau width of 380 ms instead of 572 ms. Humidity at the 1 MΩ resistor could play an important role, delaying the electrical arc. The lower part (b.) of figure 5 shows that the fall time is quite short, leading to oscillations before reaching a value close to zero.

5 Conclusion

Despite the presence of resistive cables, it was found to be always possible to burn away the short-circuit or the thin copper strip from the decoupling resistor on the anode in the barrel presampler, without deteriorating the precision of the calibration resistors and losing the protective resistors soldered on the anodes. Nevertheless, high voltage and capacity values have to be chosen lower than the values used in this work in order to preferably burn away the "dust" instead of the Cu lines.

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References

[1] M.L. Andrieux et al., Nucl. Instr. and Meth. A 479 (2002) 316.

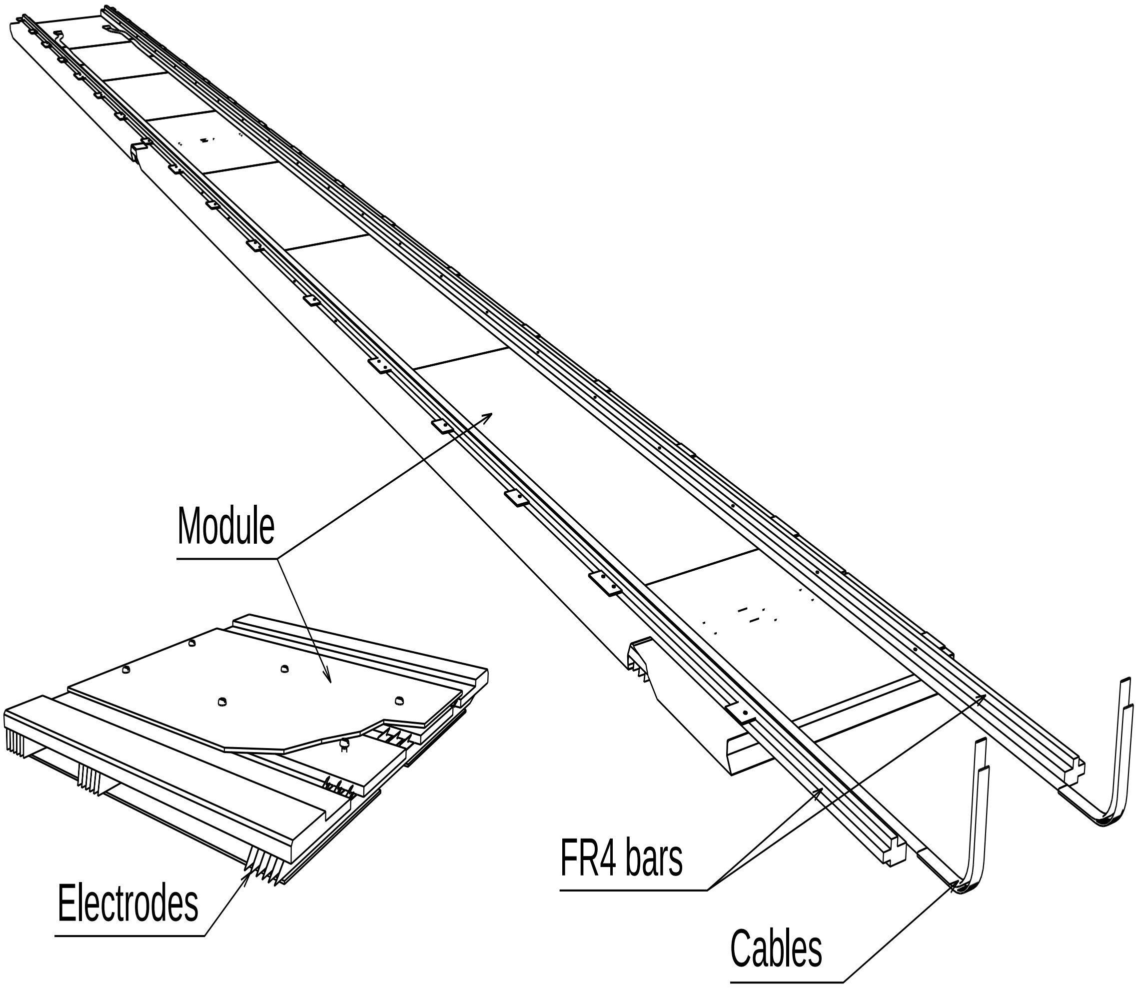

Figure 1: Perspective view of a presampler sector.

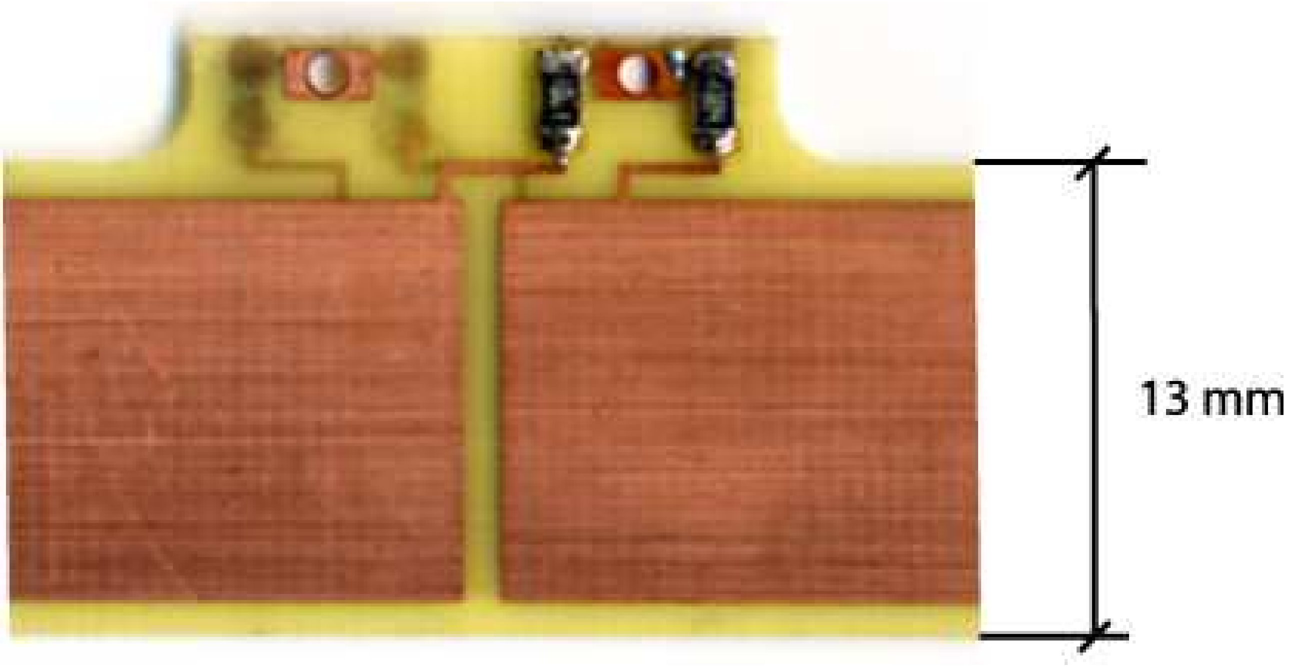

Figure 2: Photograph of the central part of an anode (see text).

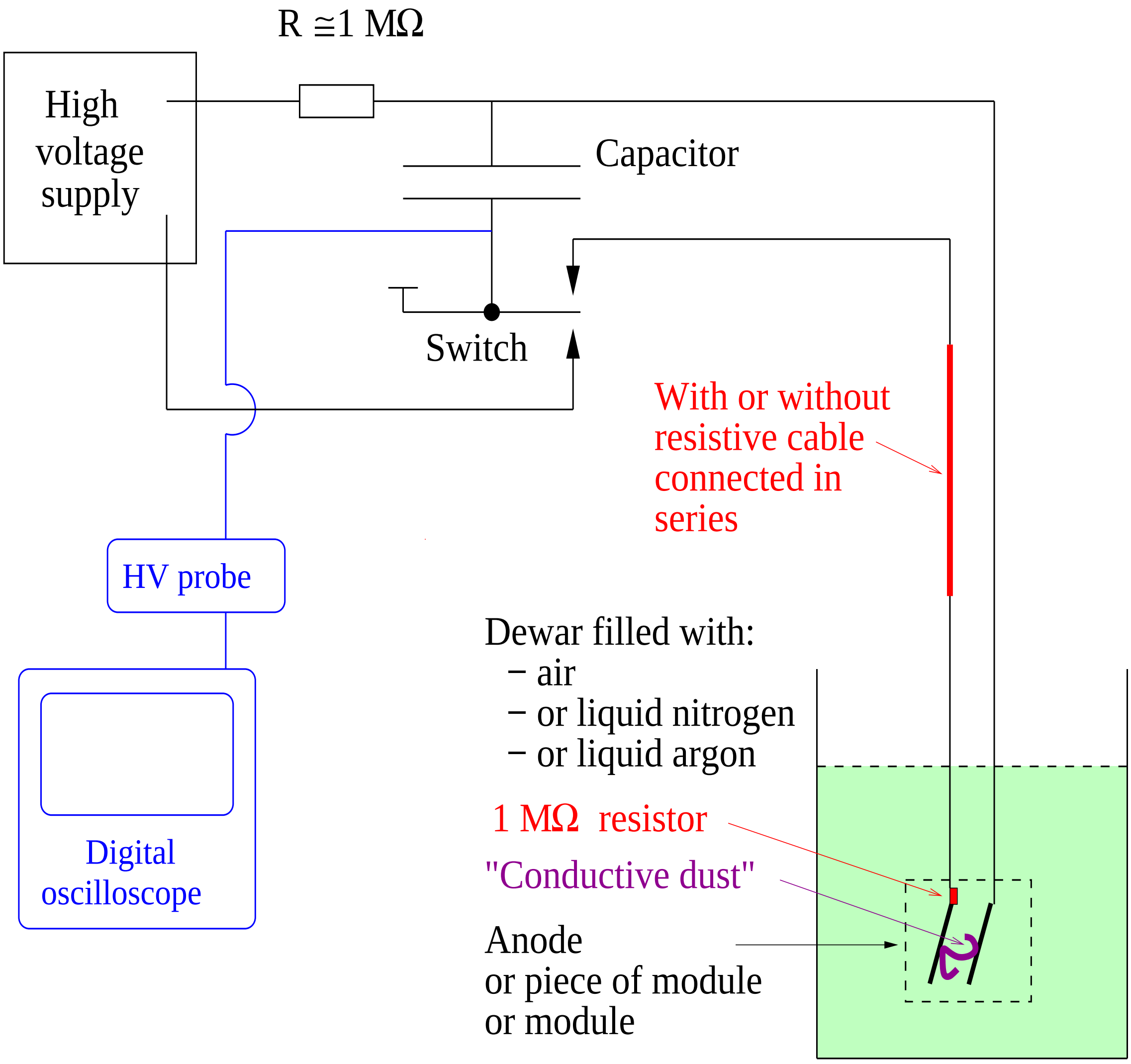

Figure 3: Schematic view of the experimental set-up.

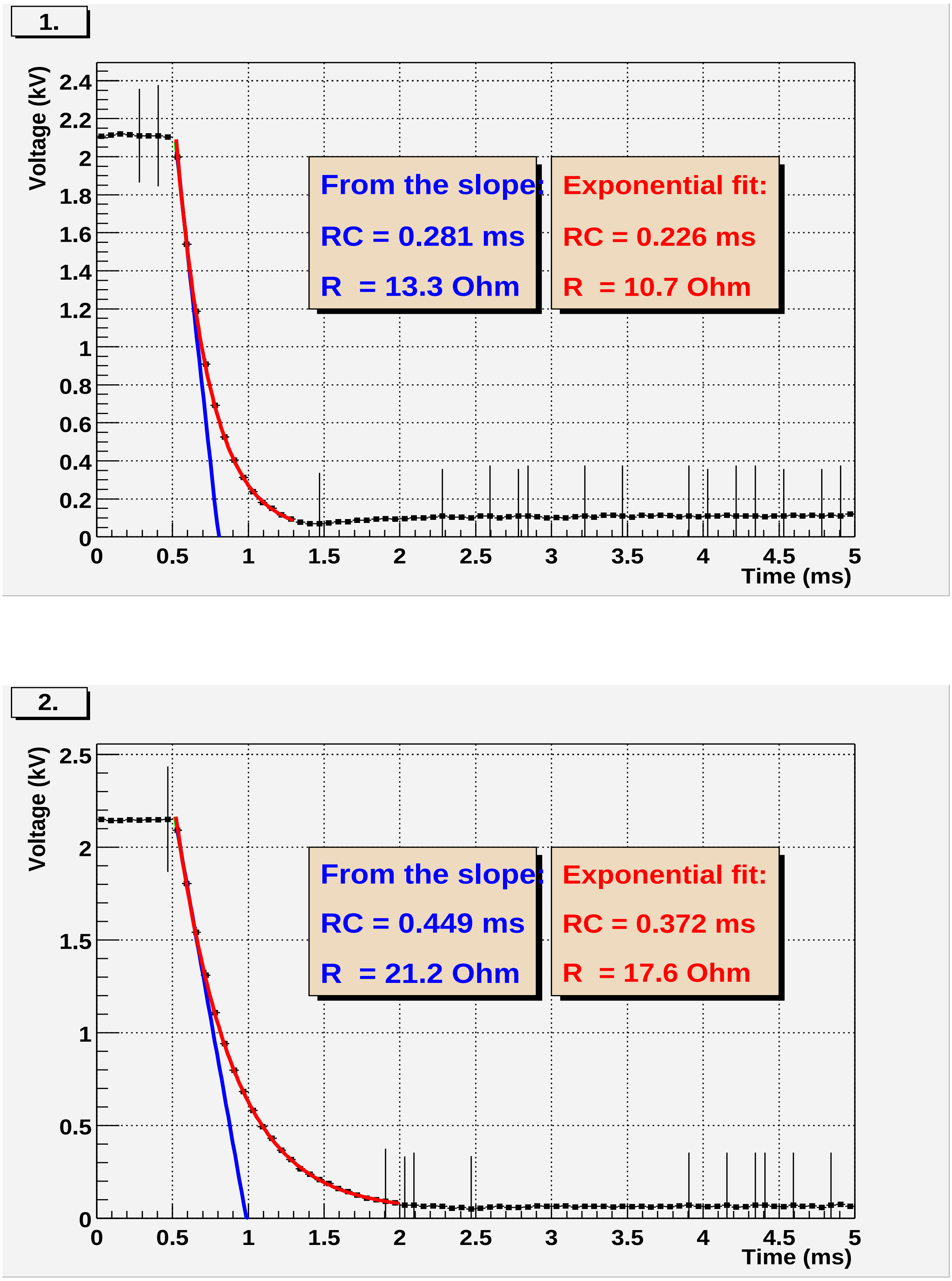

Figure 4: Shape of the HV pulse (see text).

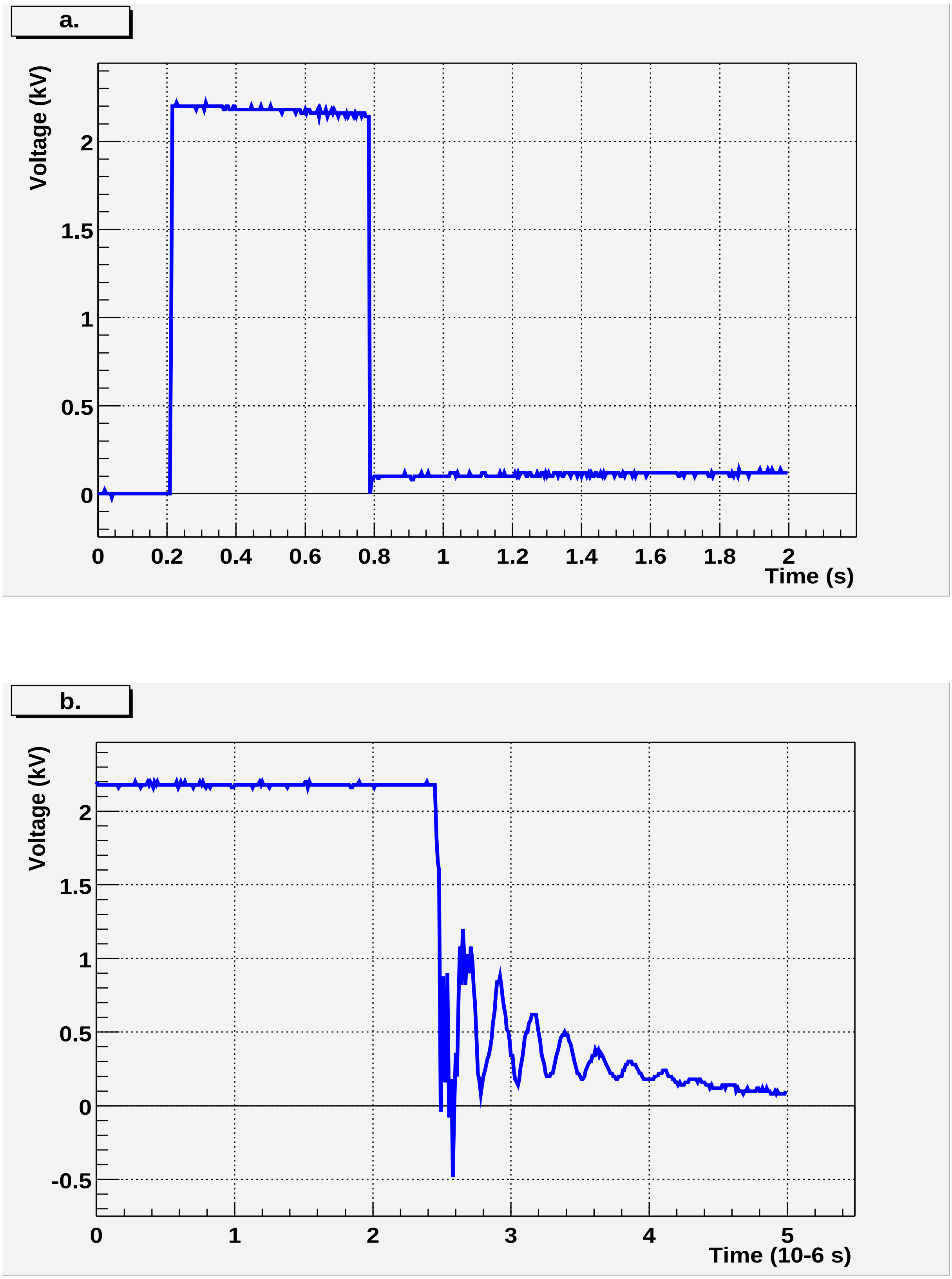

Figure 5: Voltage measurement on the module HV lines during discharge. The voltage drop at 0.8 s and 2.5 μs respectively are due to the 1 MΩ resistor being bypassed by an electrical arc.