HV Training as a Cure for the Ageing in the Outer Tracker

March 5, 2010

Abstract

The straw-tubes modules of the Outer Tracker detector suffer from gain loss under irradiation at moderate intensities. High voltage training beyond the proportional regime, producing large dark currents, has been shown to repair the gain loss in most cases, and even prevent future radiation damage until certain irradiation doses. This note summarizes the HV training studies and their results and proposes a recipe for application in situ at LHCb.

LHCb Note

Reference	LHCb-PUB-2010-010
	LHCb-INT-2010-009
Last Modified	March 5, 2010

Prepared by N.Tuning, M.Blom, D.van Eijk, I.Mous, A.Pellegrino, B.Storaci E.Visser

Nikhef, Amsterdam, The Netherlands

Contents

List of Figures

1 Introduction

The Outer Tracker (OT) detector of the LHCb Experiment has shown to suffer from gain loss under irradiation at moderate intensities (few nanoamperes per centimeter). Under the influence of irradiation, a small insulating layer of hydrocarbure-containing substance is deposited on the anode wire, thereby reducing the signal response of the detector. The detector modules were constructed with the two-component epoxy Araldite AY103-1, and the plastifier di-isopropyl-naphthalene was shown to be the culprit of the gain loss [1, 2].

The harmful effects of the plastifier di-isopropyl-naphthalene were identified only after the completion of module production [1]. A number of beneficial effects have been devised to reduce the deterioration of the detector response:

- heating the modules for 2 weeks at 40^oC to increase the outgassing rate;
- the addition of a few percent of oxygen to the counting gas decreases the ageing rate, through the enhancement of ozone formation in the avalanche;
- lowering the gas flow decreases the ageing rate, presumably because it reduces efficient removal of the ozone formed in the avalanche.

In addition to these preventive measures, a treatment has been devised to removes the insulating deposits on the anode wire, consisting in the application of large high voltage values that take the OT drift-tubes in the discharges regime and produce high dark currents, and henceforth referred to as **high voltage training** [9].

The HV training procedure has proven to repair previous gain losses, and, to some extent, even to prevent future irradiation damages up to a certain irradiation dose [3]. Analogous observations have also been reported in the literature [5, 6].

The HV training procedure is illustrated in Section 2. Its effects are shown in Section 3 and the results of a wire inspection after HV training are presented in Section 4. Finally, some results from a first application of the HV training procedure in situ are shown in Section 5 and a proposal is formulated for the application of the HV training procedure to the entire OT detector prior to any significant exposure to beam radiation, as a preventive action.

2 High Voltage Training Procedure

The OT detector will operate with a gas mixture of Ar/CO_2/O_2 70/28.5/1.5 at a nominal high voltage of 1550 V, corresponding to a gain of approximately 5×10^4 [4]. Typically, the gain doubles every 70 V increase of the high voltage. The proportional regime in a Ar/CO_2 70/30 gas mixture ranges approximately from 1540 V to 1800 V [7]. Above 1800 V, the dark current rises sharply from approximately 10 nA per straw at 1850V to typically 10μA per straw at 1900V (the actual current value strongly depends on the wire quality, the gas cleanliness, the processing time at that HV value, etc.)

An example of the current (integrated over 32 wires) as a function of the high voltage is shown in Fig. 1: a strong increase in current is observed between 1840V and 1870V (top panels); subsequently, the current drops from 200 μA to 7 μA in a period of 19 hours at 1870 V (lower panel). After this procedure, the currents for the same high voltage are lower, as is shown in Fig. 2 by measurements performed two days later: this time, a current of 200 μA is reached at a value of 1910V. After a period of 19 hours at 1910V, the current dropped to 90μA. This behavior can be considered rather typical of the OT modules, as it has been observed for four modules (M002, M003, M030, and S3U099) in the laboratory, and one module (S1L121) in situ.

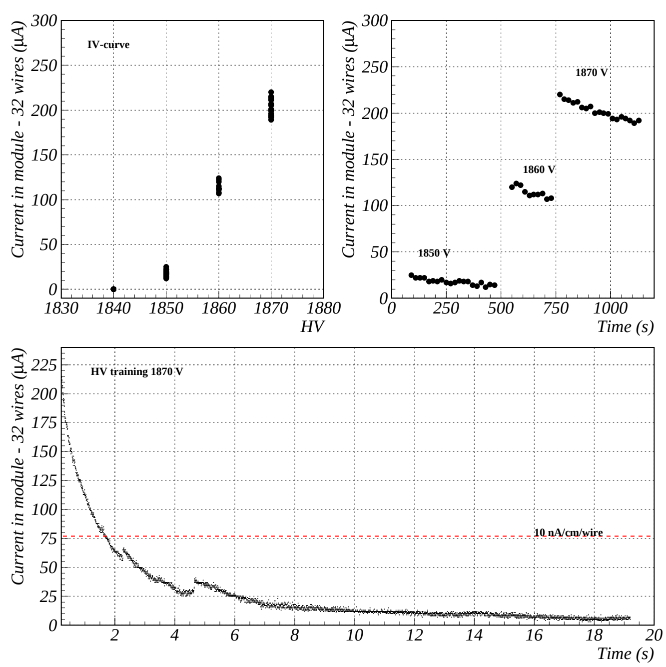

Figure 1: *Current as a function of HV and time.* [17/8/06, mod3A]

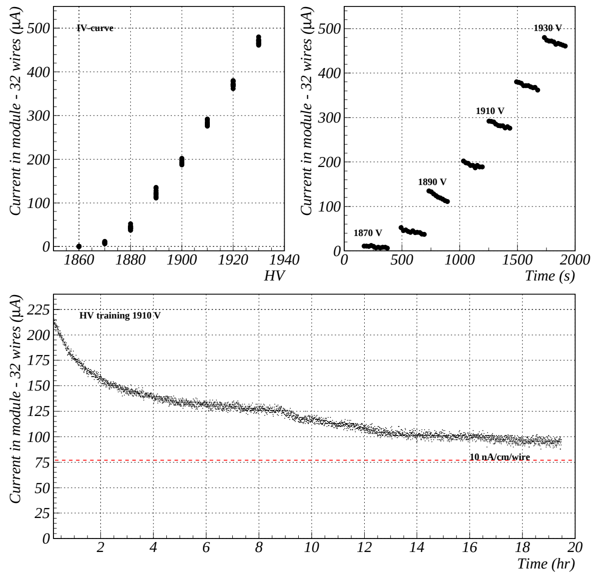

Figure 2: *Current as a function of HV and time.* [19/8/2006, mod3A]

In the LHCb experiment, the HV is applied to groups of 32 wires (grouped through a PCB hosting the 330 pF capacitors decoupling the HV from the small hit signals from the anode wires) and one channel of the HV power supplies is connected to 8 such groups through a patch panel. From the production data, we know that, up to values of the order of 1600 V, the dark current is very uniformly distributed over the many thousands of wires of the OT modules. From a few experiments performed in the lab and in situ, we believe this to be the case also at the higher HV values required by the HV training procedure, as illustrated in Fig. 3.

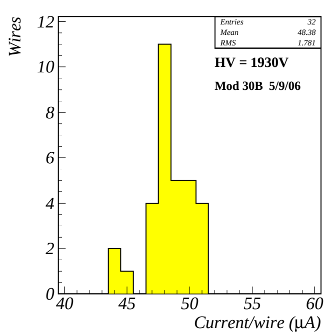

Figure 3: *The current per wire at 1930V shows that the current is rather uniformly distributed over the 32 wires.* [5/9/2006, mod30B]

3 Effects of HV training: Cure and Prevention of Irradiation Damage

It has been observed that the irradiation-induced gain loss is recovered through the HV training procedure described in Section 2 (notice that in some cases, though, the gain loss was only partially recovered). Various parameters have been varied to optimize the gain recovery: HV training campaigns at various currents, and for extended periods have been tried, as well as the addition of oxygen and humidity to the gas mixture. The results of the studies performed on five OT modules to optimize the HV training procedure are summarized in this section. It can already be anticipated that, remarkably, in most cases the HV training does not only recover the gain loss induced by irradiation, but in addition provides a certain "immunity" against gain loss by further irradiation.

These two aspects, recovery and immunity, are illustrated by Fig. 4. In the top row (Fig. 4-a), the effects of HV training at 1870 V are shown; from left to right, the four panels show:

1) ^{90}Sr scan showing previously induced irradiation damages around 230 cm;

2) ^{90}Sr scan taken after 19 hours of HV training at 1870 V applied to the upper half of the module (channels 33-64), showing the gain recovery of the previously damaged wires in the trained half;

3) the ratio of the two previous scans, indicating the relative gain increase of the damaged spot in the trained half;

4) the ratio between the previous scan and a newer one obtained after 20 hours of irradiation with a 2mC source: while gain losses are observed on the untrained half of the module, no gain loss is observed on the trained one.

A second HV training procedure at 1910 V was then applied to complete the curing, followed by 206 hours of irradiation demonstrating the prevention effect. This is shown in the second row, Fig. 4-b. After further 340 hours of irradiation, the procedure is repeated as shown in the third row, Fig. 4-c): the HV training is performed, followed by 236 hours of irradiation. After further 350 hours of irradiation, the procedure was again repeated, as shown in the fourth row, Fig. 4-c): the HV training is performed, followed by 96 hours of irradiation.

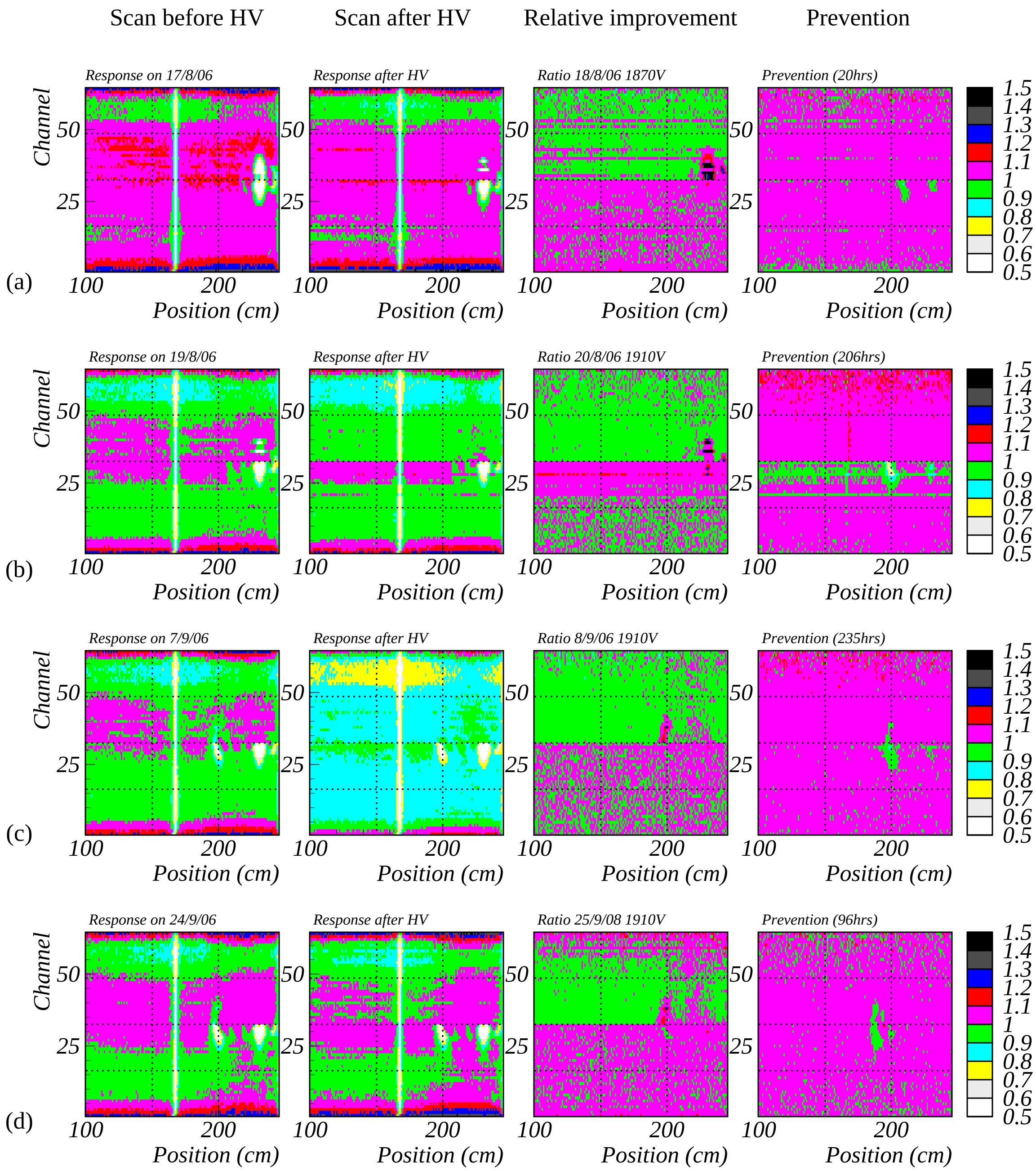

Figure 4: *The results of four HV trainings applied to the upper half (wires 33-64) of the "A" monolayer of module M003: (a) The first HV training at 1870 V cured about half of the damaged area. (b) A second HV training at 1910 V cured the rest of the damage; furthermore, no damage appeared after 206 hours of irradiation. (c) After further 340 hours of irradiation, the procedure was repeated: the HV training cured the damage, and only little damage appeared after 236 hours of irradiation. (d) After further 350 hours of irradiation, the procedure was repeated again: the HV training cured the damage, but this time some damage appeared after 96 hours of irradiation.* [Fall 2006, mod3A]

The findings of these last two irradiations and HV trainings are best summarized in Fig. 5 in terms of gain loss as a function of irradiation time: the figure illustrates both the gain recoveries obtained through the HV trainings, as well as the preventive action of the HV trainings, shown by the fact that no gain loss is observed in the trained half for the first 200 hours of irradiation following the HV training. The detailed mechanism behind the immunity period subsequent to the HV training is at the moment not understood; possibly the HV training "cleans" the anode wire surface rendering the plastifier deposit more difficult[1].

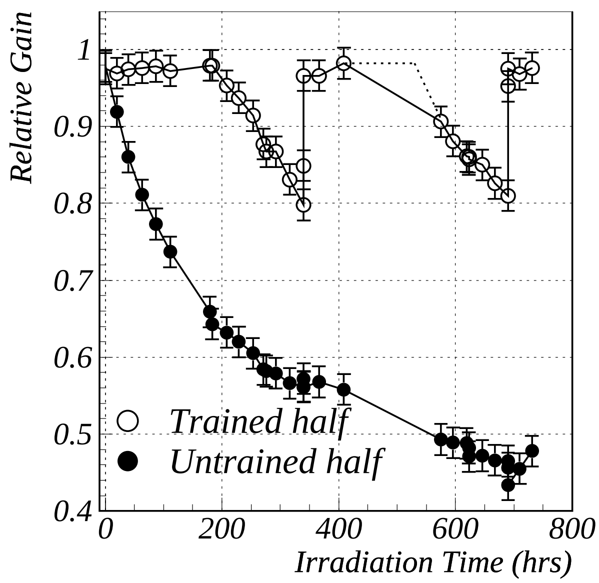

Figure 5: *The relative gain is deteriorating as a function of irradiation time. However, the HV-trained half of the module recovers the gain. Furthermore, the three HV training procedures (at 0, 300, and 700 hours, respectively) all show a prevention of further gain loss.* *[Fall 2006, mod3A]*

Similar studies were performed in the laboratory with four other modules, namely M030, S1L121, S3U099 and M002. The results are shown in Figs. 6-12.

In particular, module M030 was irradiated with a 10-fold more intense 20 mCi source, but its HV training (Fig. 6) confirmed the efficient gain recovery observed in module M003. The prevention effect was also observed on the

[1]It has also been speculated that the HV training smoothens the gold surface of the anode wire, thereby reducing the catalytic effect of gold of the process $CO + O \rightarrow CO_2$. As a result, a larger concentration of atomic oxygen can then reduce the deposits of di-isopropyl-naphthalene on the wire.

trained half of the module. Notice that a small spot at 435 cm was not fully cured after two HV training procedures at 1930 V and 1910 V (Figs. 6c-d). However, two years later the same module was tested again and the results in Fig. 7 show that the small spot at 435 cm could then be cured. Moreover, no less than 14 other spots with previous irradiation damages were fully cured (Fig. 7b). The currents recorded during these studies are shown as a function of high voltage in Fig. 8. The details of the time evolution of the gain recovery of the 14 spots can be seen in Fig. 9: after 24 hours of HV training, all gain loss is fully recovered.

The HV trainings of the 2.5 m modules S1L121 and S3U099 were HV performed with a small percentages of O_2, ranging from 1% to 2.5%, added to the gas mixture and the results did not exhibit significant differences due to the addition of O_2 (see Fig. 10).

Various attempts made to cure the irradiation damages on module M002 sorted only limited success. In Fig. 11 only in the first hour at 1905 V some recovery is observed. Further more aggressive trainings up to 1945 V for 136 hrs, yielding total currents of about 500 μA for 32 wires, did not produce significant improvements. The insertion of H_2O (up to 40,000 ppm) into the gas volume was also tried, but had no significant impact (see Fig. 12).

An overview of the various tests performed in the laboratory is given in Table 1.

3.1 Conclusion from laboratory studies

Based on the studies presented in this section, three main effects of the HV training procedure have been identified:

1) **Cure**
   In most cases, an HV training procedure of approximately 15 hours restores the gain lost by irradiation. Occasionally the procedure may not be successful. This might be caused by the fact that the large currents do not appear uniformly along the wire (it has been shown, but is not presented in this manuscript, that all deposits can be efficiently removed by illuminating the damaged surface with a radioactive source, thus ensuring that the large currents are located at the desired positions).

2) **Prevention**
   After the HV training procedure, the detector exhibits a temporary immunity to radiation damage. The mechanism of this preventive effect is not understood, but it can be speculated that it is due to the

removal from the wire surface of traces of glue vapors, which in turn could facilitate the growth of deposits on the wire (however, such traces have not been observed in the SEM/EDX analyses performed on wire samples extracted from irradiated module).

3) **Overall signal response**
Immediately following the HV training procedure, the global response along the entire length of the trained wires is affected. After a few hours of flushing, the module response goes back to the original value, indicating in our opinion that the HV training temporarily affected the gas composition (it can be speculated that the HV training creates short-living radicals that either react, or are flushed out of the module).

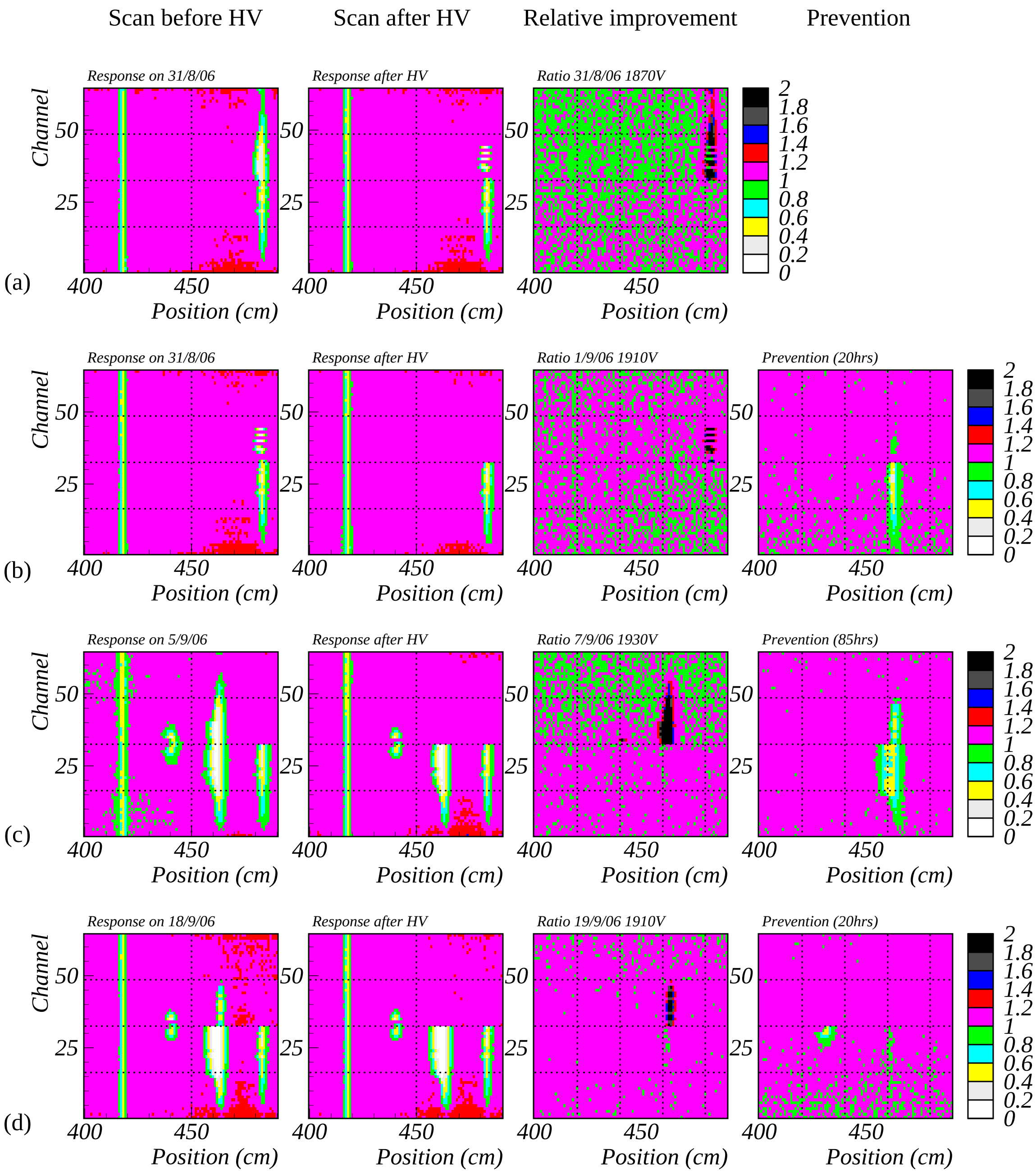

Figure 6: *The results of four HV trainings applied to the upper half (wires 33-64) of the "B" monolayer of module M030: (a) the first HV training cures half of the damaged area; (b) the rest of the damage is cured by a second HV training. (c) A large damage induced by the 20 mCi line-source is fully repaired, whereas the damage due to the smaller 2 mCi point source is not; (d) same as (c) after additional 85 hours of irradiation with the 20 mCi line-source.* [Fall 2006, mod30B]

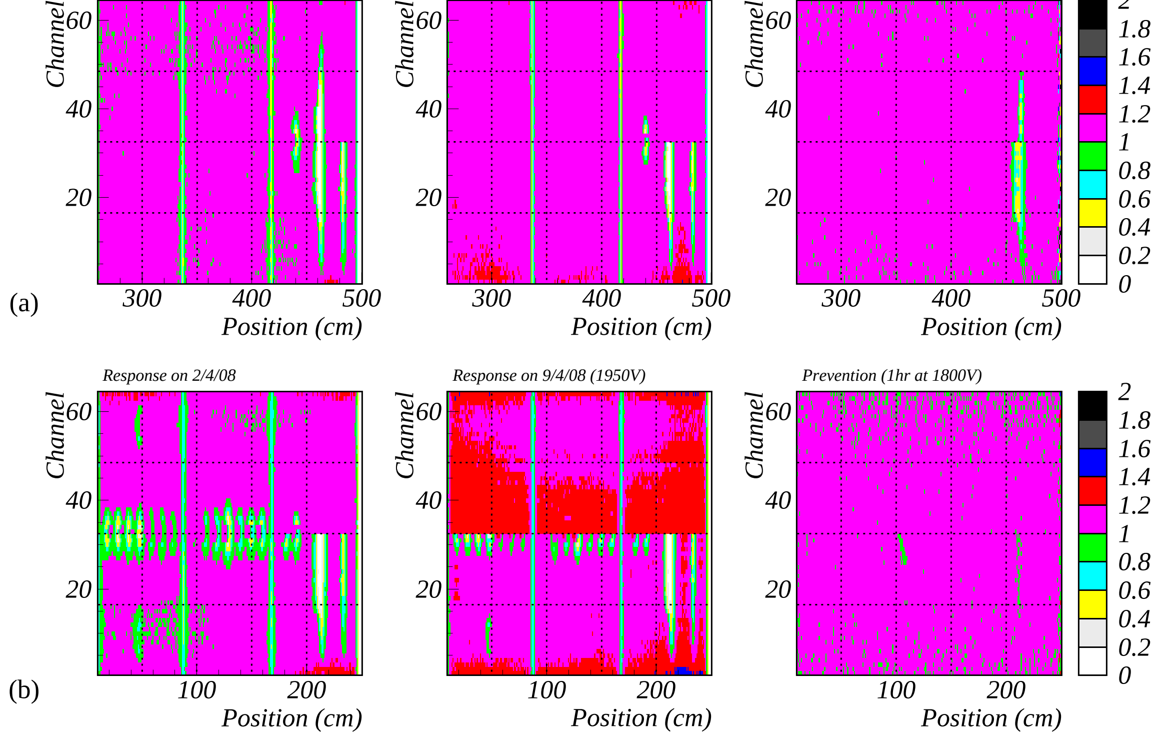

Figure 7: *In 2008, new HV trainings studies were performed on the upper half (wires 33-64) of the "B" monolayer. (a) Previous HV trainings (2006) had not cured the spot at 440 cm (see also Fig. 6c-d). (b) In the new HV training session, all damages could be cured, including the spot that was remaining from 2006 (note that this spot is now located at 190 cm, because in 2008 the scans were performed with a different setup scanning only one module half).* *[2006& 2008 mod30B]*

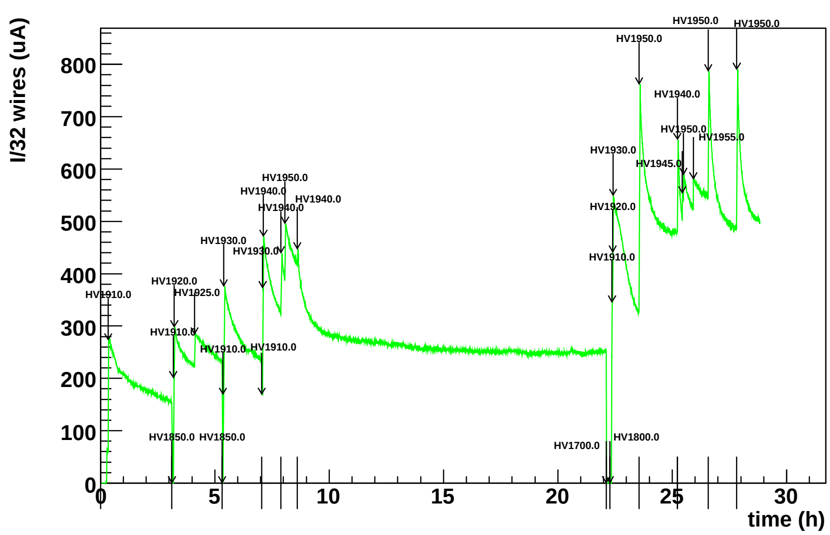

Figure 8: *The time evolution of the total current of 32 wires during the HV training of module M030.* *[3/4/2008, 9/4/2008, mod30B]*

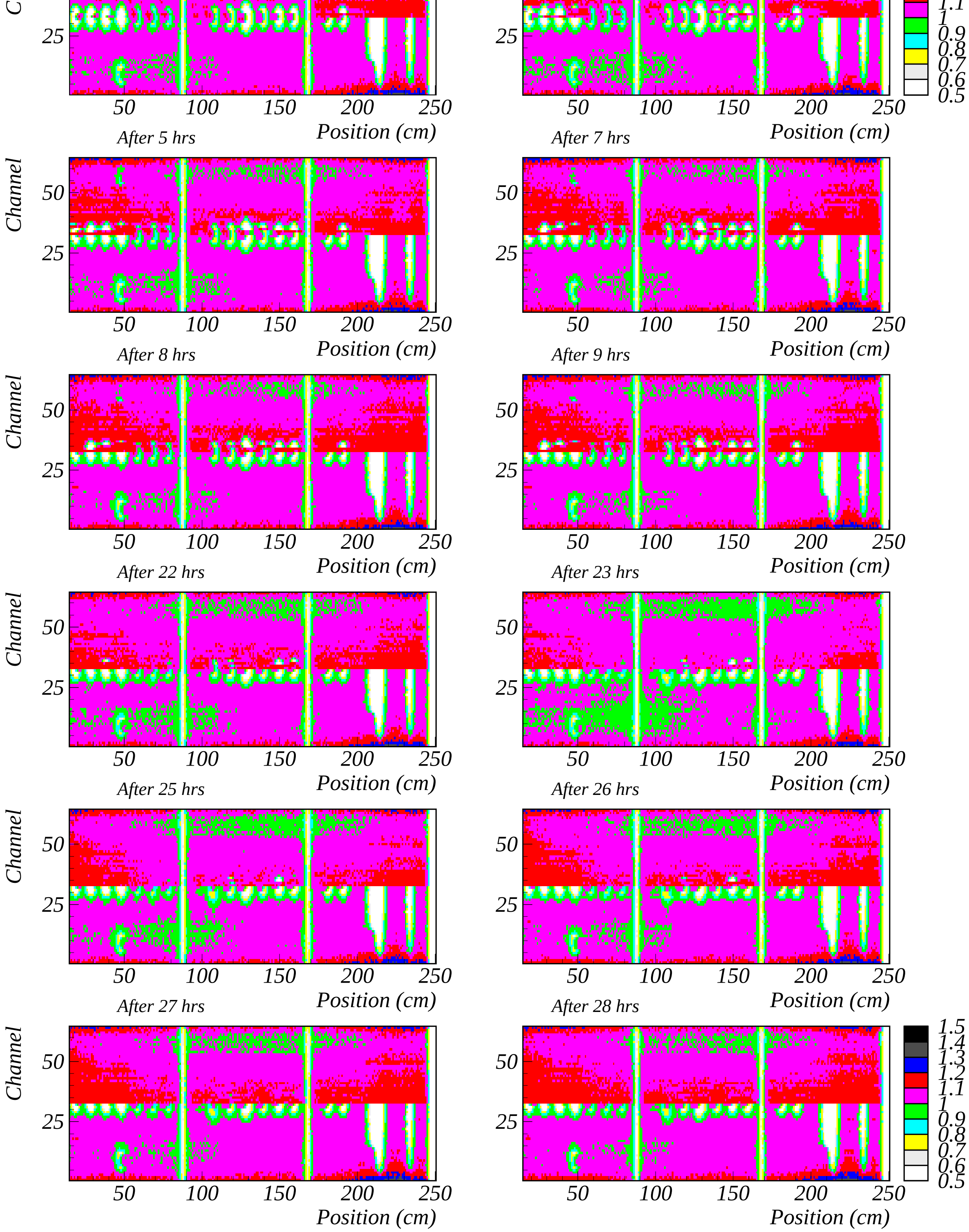

Figure 9: *The time evolution of the curing process from the HV training of the upper half (wires 33-64) of the "B" monolayer of module M030 (see Figs 7,8). From top to bottom, the gradual curing is illustrated by scans taken every few hours.* *[3/4/2008, 9/4/2008, mod30B]*

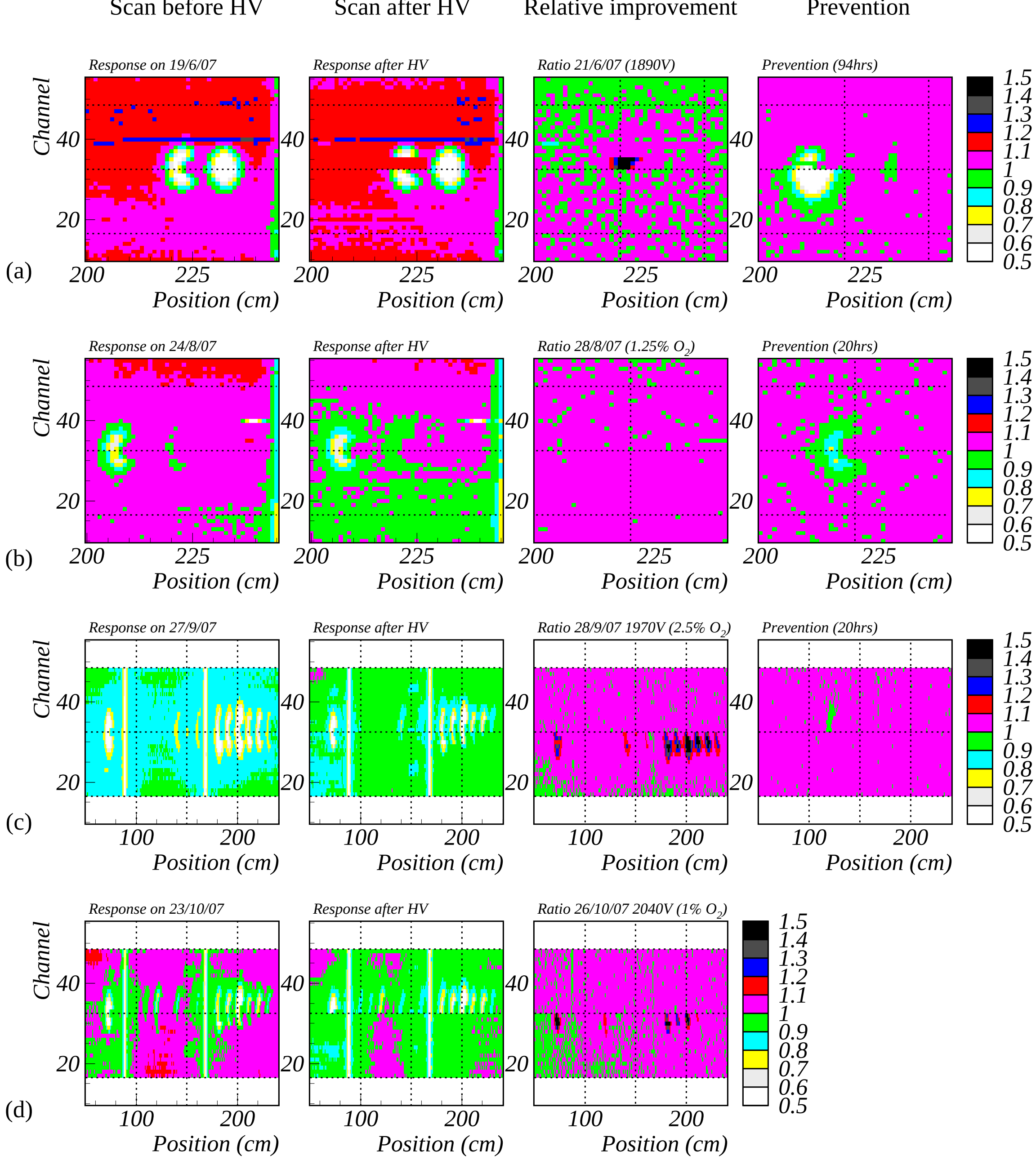

Figure 10: *HV trainings performed in 2007 on S-modules.*
(a) The HV training of the "A" monolayer of module S1L121 only recovered part of one damaged area. Remarkably, the subsequent prevention is mainly seen in the same wires where the damage was repaired.
(b) The "B" monolayer of module S1L121 was trained with rather moderate currents, mostly below 500 nA per wire (1.25% O_2 added to the counting gas). No cure, nor prevention observed.
(c) Half of the damaged spots on the "A" monolayer of module S3U099 recovered with an HV training at 1970 V (2.5% O_2 added to the counting gas).
(d) The rest of the damaged spots on the "A" monolayer of module S3U099 cured at 2040 V (1.0% O_2 added to the counting gas).

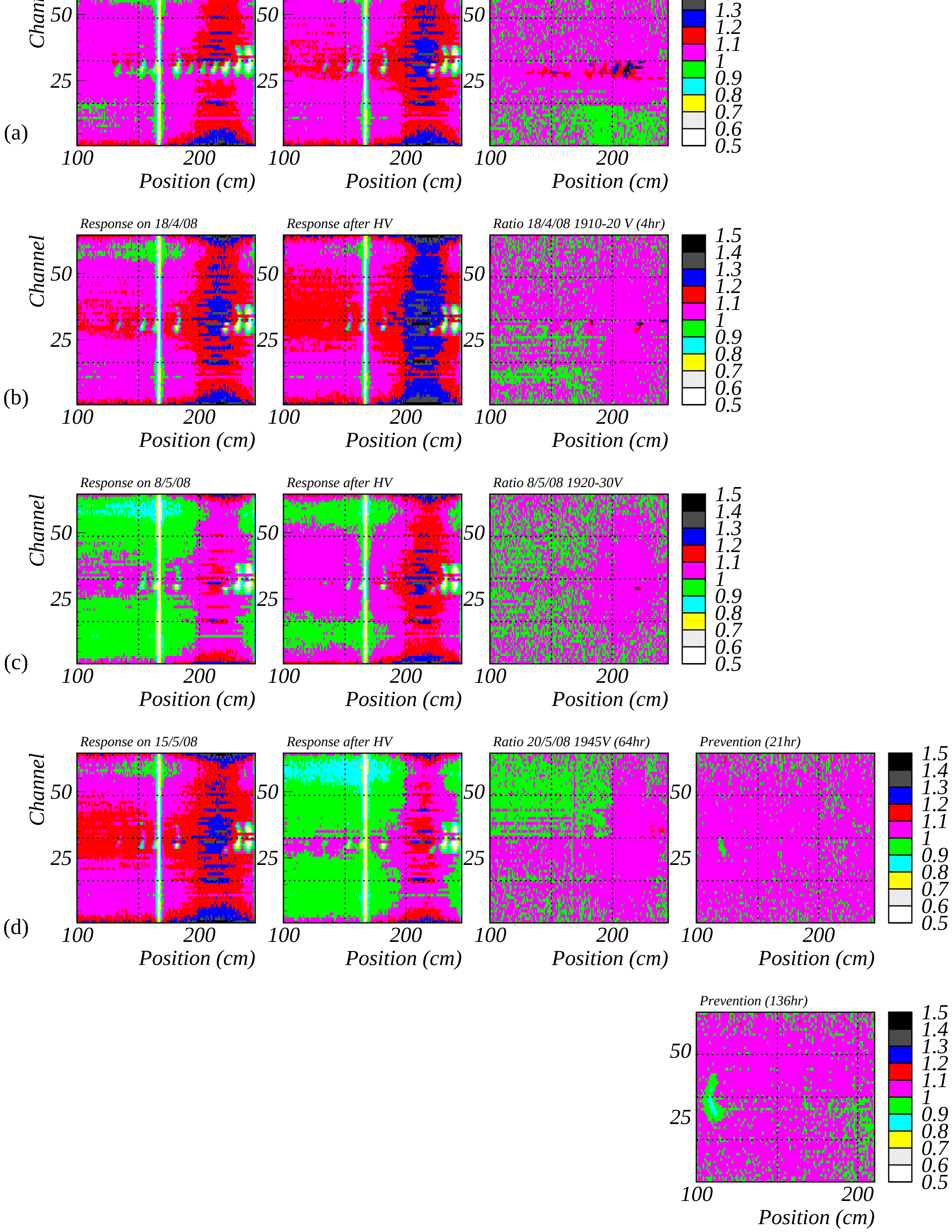

Figure 11: *Four HV trainings performed in 2008 on the "A" monolayer of module M002. (a) During a HV training of only 1 hour at 1905 V four damaged areas recovered partially.*
(b,c) Subsequent HV trainings at varying values of the high voltage between 1910 and 1930 V, no improvement is seen.
(d) A long HV training of 64 hours at 1945 V on the "B" monolayer of the module does not show any curing of the damaged areas. Small prevention is observed after an irradiation of 136 hours.

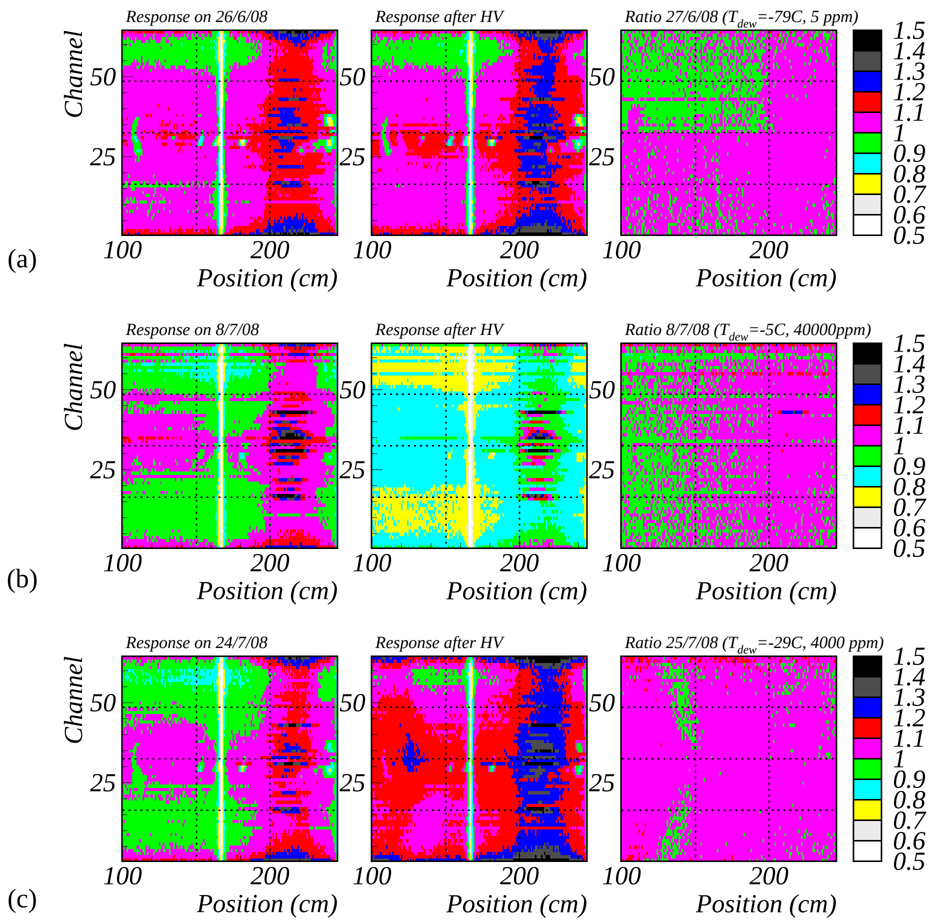

Figure 12: *Three HV trainings performed in 2008 on the "A" monolayer of module M002. The humidity in the module was varied from 5 ppm (a), to 40,000 ppm (b), to 4,000 ppm (c), but no beneficial effect from HV training was observed.*

Mod	Date	HV (V)	I (μA)	HV time (hrs)	Ch	Flush time (days)	Effect on irr. spots		Lab	Comment
							Cure	Prevention		
3A	17/8/06	1870	200 $\searrow$ 7	20	1-32	32	half spot	<20 hrs	H040	
3A	19/8/06	1910	250 $\searrow$ 90	26	1-32	34	whole spot	~206 hrs	H040	
3A	7/9/06	1910	400 $\searrow$ 80	20	1-32	53	spot after 340hrs	~235 hrs	H040	
3A	24/9/06	1910	400 $\searrow$ 80	20	1-32	53	spot after 350hrs	<96 hrs	H040	
30B	31/8/06	1870	180 $\searrow$ 80	10	1-32	2	half spot	-	Cl.room	
30B	31/8/06	1930	730 $\searrow$ 445	15	1-32	2	whole spot	<20 hrs	Cl.room	
30B	5/9/06	1930-50	800 $\searrow$ 475	16+16	1-32	7	only big spot	<85 hrs	Cl.room	
30B	18/9/06	1910	520 $\searrow$ 320	14	1-32	20	only (same) big spot	>20 hrs	Cl.room	
30B	3/4/08	1910-55	970 $\searrow$ 420	23+14+8	1-32	29	also all small spots	-	H040	
S1L121A	20/6/07	1890	250 $\searrow$ 130	20	1-32	6	only half of 1 spot	same wires	H040	
S1L121B	27/8/07	1890	< 1	20	1-32	10	no	no	H040	1.25% O_2
S3U99A	27/ 9/07	1970	200 $\searrow$ 9	18	1-16	23	half	>20 hrs	H040	2.5% O_2
S3U99A	25/10/07	2040	200 $\searrow$ 70 $\nearrow$ 150	18	1-16	51	all	-	H040	1.0% O_2
2A	18/4/08	1905	600 $\nearrow$	1	33-64	8	some	-	H040	
2A	18/4/08	1910-20	600 $\nearrow$	4	33-64	8	no	-	H040	
2A	8/5/08	1920-30	800 $\nearrow$	5	1-64	28	no	-	H040	
2A	16/5/08	1945	580 $\searrow$ 430	64	1-32	36	no	>21 hrs	H040	
2A	26/6/08	1930	740 $\searrow$ 600	15	1-32	77	no	-	H040	5 ppm H_2O
2A	9/7/08	1930	300 $\nearrow$	7	1-32	12	no	-	H040	40,000ppm H
2A	24/7/08	1910	330 $\rightarrow$ 330	16	1-32	27	no	-	H040	4,000 ppm H

Table 1: *The results of various HV training procedures.*

4 Wire Inspection after HV training

With large dark currents up to 20μA per wire, the HV training procedure is rather more aggressive than normal OT detector operation. One of the main worries is that unknown chemical or physical reaction might occur on the wire surface or in the gas mixture, that in turn may damage the wire surface or lead to the formation of deposits.

To assess these risks, aggressive HV trainings were performed on 4 wires inside an openable test-module from which wire samples can easily be extracted. Subsequently, wire samples were inspected under a scanning electron-microscope (SEM) and analyzed with energy dispersion X-ray spectroscopy (EDX)[8]. Four wires (previously damaged by irradiation) were trained in two sessions of one night each, at 1870 V and 1880 V, respectively; the total currents were above 200 μA, so around 50 μA per wire (see Fig. 13). This is about five times higher than what was proved to be sufficient to cure a wire from radiation damage. Scans were also taken to check that the HV training cured the previously induced gain loss (see Fig. 14).

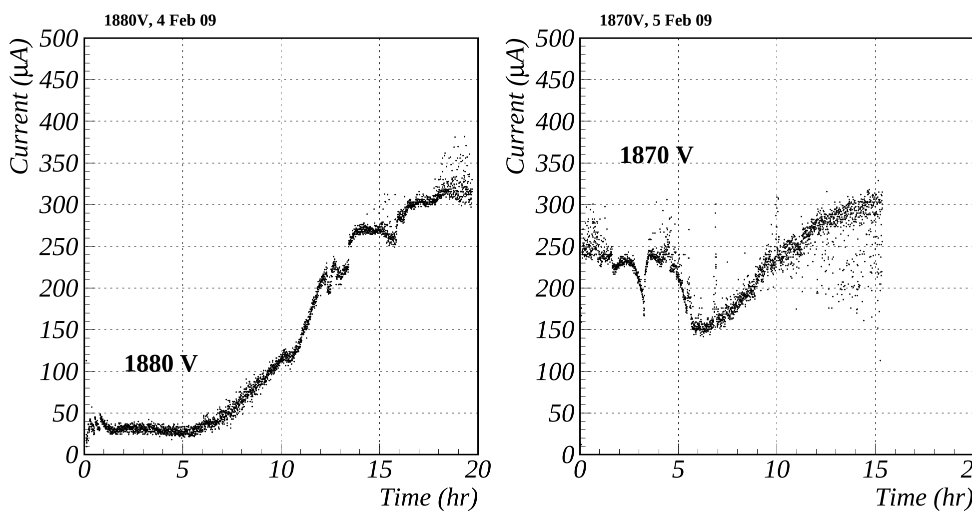

Figure 13: *Time evolution of the total current of 4 wires trained in the openable test-module: (left) first HV training of 19 hours at 1880 V; (right) second HV training of 15 hours at 1870 V.*

Various different wire samples were extracted from the openable chamber, of which five were investigated in detail. These five samples originate at physically different locations on three different wires: one wire that did not undergo HV training (channel 38), one wire that did undergo the HV training

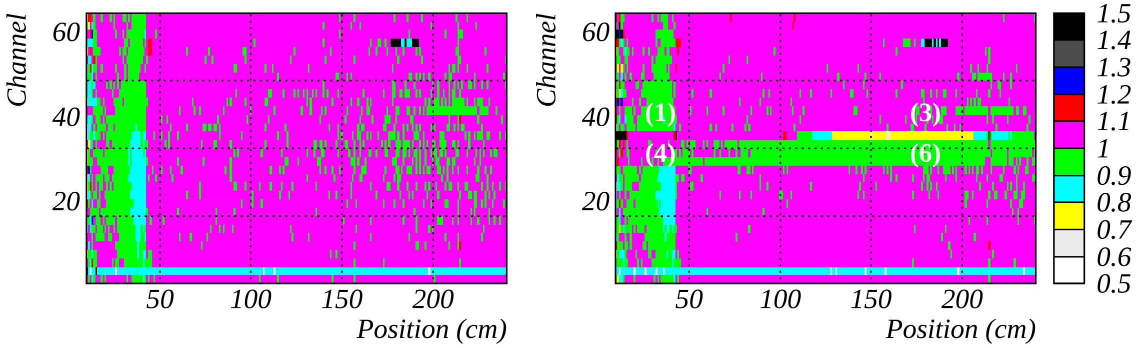

Figure 14: *(Left) Ratio plot showing the radiation damage suffered by the openable test-module at 40 cm. (Right) Ratio plot demonstrating the recovery of the four HV-trained wires in the module center. The smaller signal between 100 and 200 cm disappeared after 12 hours of flushing.*

(channel 36) and one new wire that was never used in a module. The five samples and their characteristics are listed in Table 2.

Sample	Wire	Position (cm)	Treatment
1	38	37	Irradiation damage
3	38	180	No damage
4	36	37	Damage + HV training
6	36	180	No damage+ HV training
7	-	-	New from spool

Table 2: *These five wire samples were analyzed with the scanning electron microscope. See Fig. 14 for the location of the samples in the module.*

Four of these samples were analyzed with SEM/EDX. The SEM results are shown in Fig. 15. From these pictures a few conclusions can be drawn:

- Sample No. (3) acted as a reference, since it came from the same wire (wire 38) as Sample No. (1), but from a spot that had not been irradiated.
- Sample No. (1) came from a spot that had been irradiated and had shown gain losses in the ^{90}Sr scan. In the SEM picture, the clearer rectangular area is due to an SEM zoom, which indicates that deposits previously present on the wire surface were partly sputtered off by the SEM electron beam itself.

- Sample No. (4) (wire 36) came from a spot that was damaged by irradiation, but recovered after the HV training. The SEM zoom this time gave rise to a darker rectangular area, which indicates that deposits were *created* by the SEM electron beam, mainly due to polluted vacuum in the apparatus (this is supported by the observation that also the sample of new wire exhibits a darker rectangular area in correspondance of an SEM zoom, as shown in Fig. 16). The comparison between the two irradiated samples No. (1) and No. (3) leads us to believe that the surface of a trained wire contains less deposits than that of an untrained one, consistent with the recovery pattern exhibited in the ^{90}Sr scans. Also notice that sample No. (4) shows **no evidence of mechanical damage to the gold surface due to the aggressive HV training**.
- Sample No. (6) came from the same physical wire (wire 36) as sample No. (4), but from a spot that had not been irradiated. As the rest of wire 36, also this sample had undergone the HV training. This sample does not show any particular feature, with the noticeable exception of a thin and long dark "valley". We do not attribute this feature to possible carbon deposits from the HV training, first of all because no significant carbon peak appeared in the EDX analysis (at least not beyond the level which is physiological in areas closely bombarded by SEM beams), and secondly because this feature is not too dissimilar from the one also observed on the reference sample No. (3) from an untrained wire. Possibly both are due to mechanical damages suffered by the wires during the process of extraction from the test vessel, when passing through the wire locators.

Given the results outlined above, we concluded that HV training procedures with currents up to around 50μA per wire for a period of 35 hours induced no mechanical damage to the gold plating of the anode wire and produced no extra depositions on the wire surface.

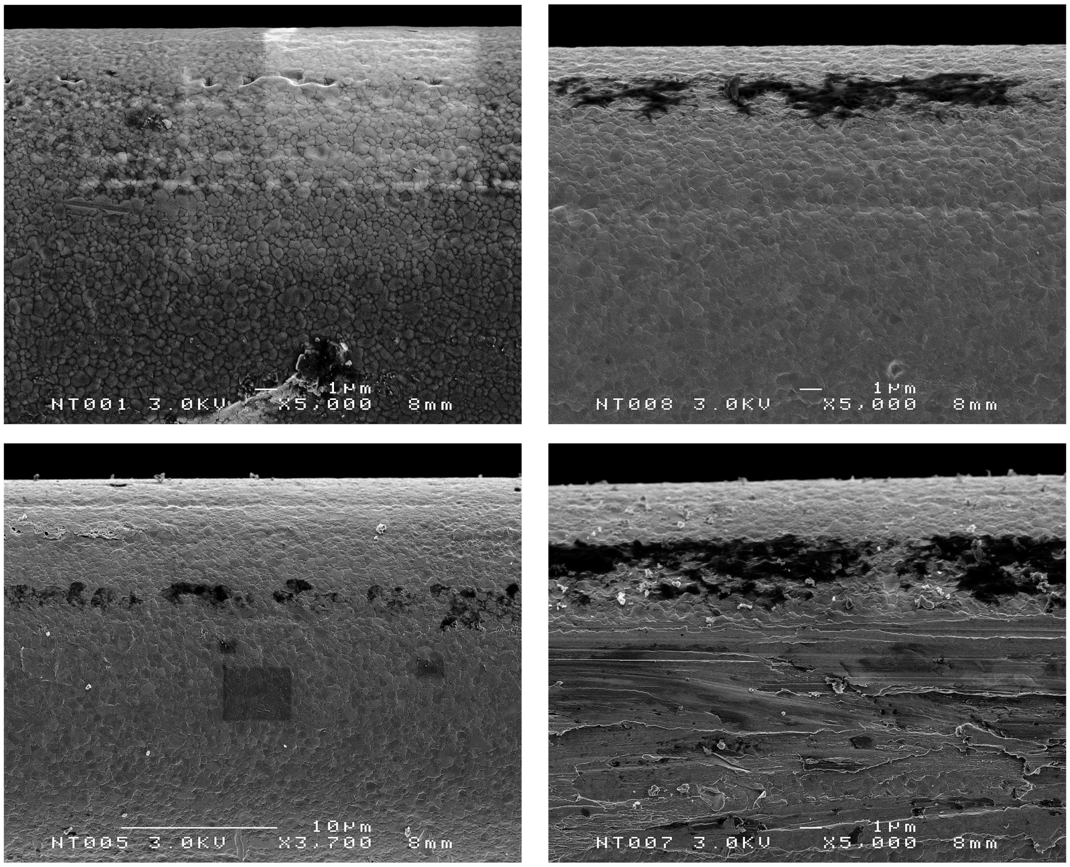

Figure 15: *SEM pictures of the four wire samples from the test-module.*

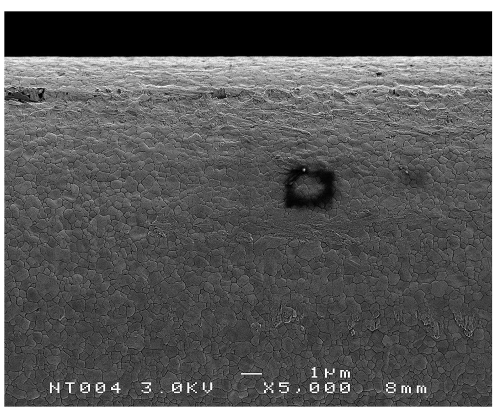

Figure 16: *SEM picture of the new wire sample. The darker rectangular spot is due to an SEM zoom and indicates a polluted vacuum of the apparatus.*

5 HV training in situ

The HV training procedure has been tried in situ on module S1L121, located in position 8 of the L0 layer (X) of the C-frame T2-Q13-XU. The CAEN A1733BPLC HV Boards of the OT HV system were used to bias one group of 32 wires (half of the “B” monolayer of the S1L121 module) selected by the appropriate jumper combination in the HV patch panel. The nominal OT gas mixture $Ar/CO_2/O_2$ 70/28.5/1.5 was used. As observed in the lab, large dark currents started to set in around 1850 V; then they dropped quickly and, after about 30 minutes, we could set the HV at 1900V for one hour, and subsequently at 1950 V for two periods of 1.5 and 13.5 hours, respectively. Currents dropped quickly from approximately 500 μA to below 200 μA in about 2 minutes, and finally to about 22 μA during the remainder of the HV training.

Time	HV	Current (μA)
14:50	1850	193
14:51	1830	14
14:52	1850	150
14:58	1850	73
14:59	1870	290
15:14	1870	74
15:15	1900	341
15:18	1900	145
16:07	1900	54

Table 3: *Initially, large dark currents are observed around a high voltage of 1850 V. The currents drop quickly, allowing to set the HV at 1900 V after approximately 30 minutes.*

The effect of the HV training is summarized in Fig. 18. The initial scan (top left) exhibits two damages around 40 cm and 100 cm, respectively. The scan taken after the HV training (top right) shows that the gain is recovered in the trained channels 33-64. The relative improvement can be seen in the ratio plot (bottom left). Subsequently, a new irradiation was performed at 120 cm and the ratio plot (bottom right) shows a small gain loss of about 7% only in the untrained half of the module. We also observed the behavior already exhibited in the lab immediately after the HV training: the signal response of the trained half decreased by approximately 5%, but, after a few hours of flushing the normal response was recovered (see Fig. 19).

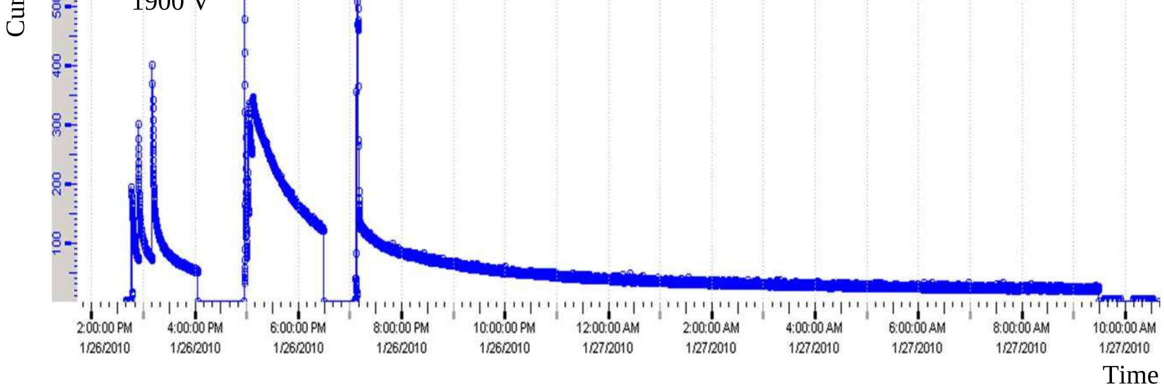

Figure 17: *Time evolution of the total current of 32 wires during the first HV training in situ: large dark currents appear around 1850 V, then quickly drop; after 30 minutes at 1850 V and 1870 V, the HV was set to 1900 V for 1 hour, during which the current dropped from 341 μA to 54 μA. In subsequent HV trainings at l950 V, the current dropped from 500 μA to below 200 μA in about 2 minutes, and then to 22 μA in 13 hours.*

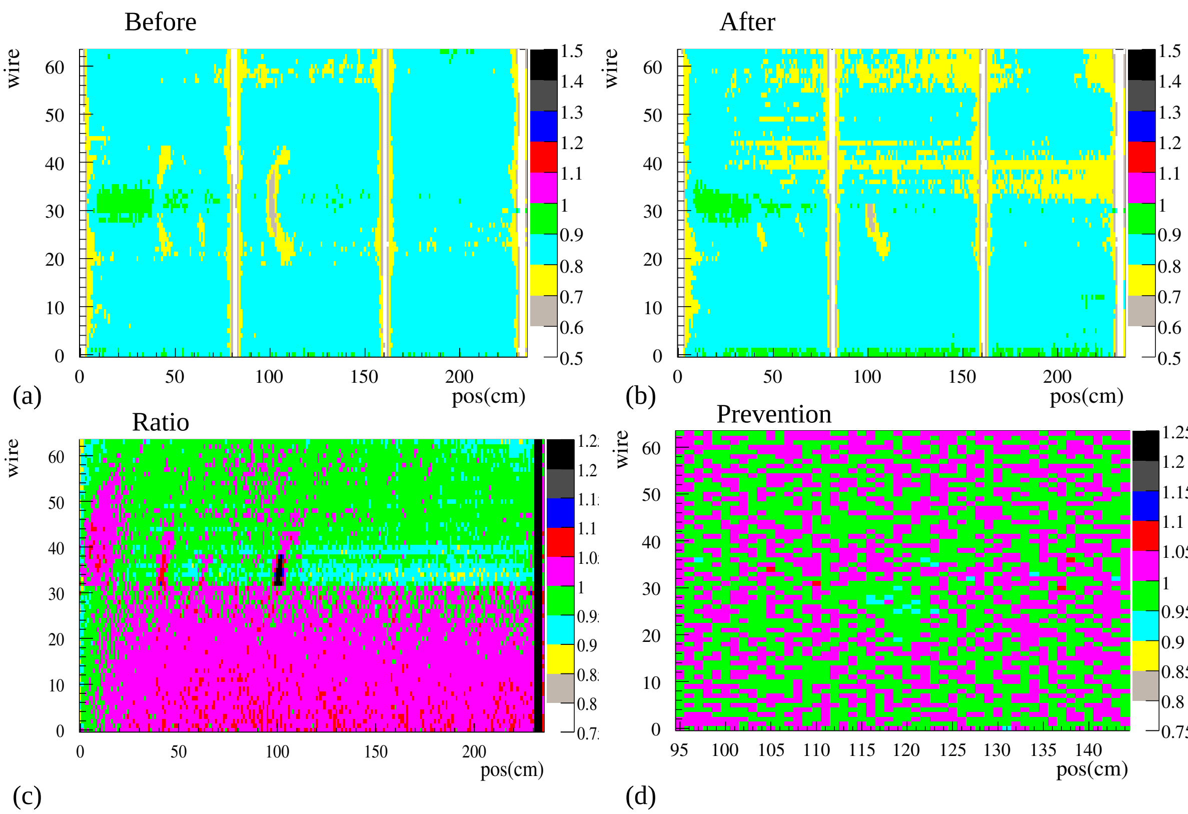

Figure 18: *HV training in situ. The top panels show the ^{90}Sr scans before (a) and after (b) HV training, respectively. The bottom left panel (c) shows the gain recovery of the trained half at 40, 60 and most notably at 100 cm. (d) A subsequent irradiation at 120 cm shows a small gain loss only in the untrained half.*

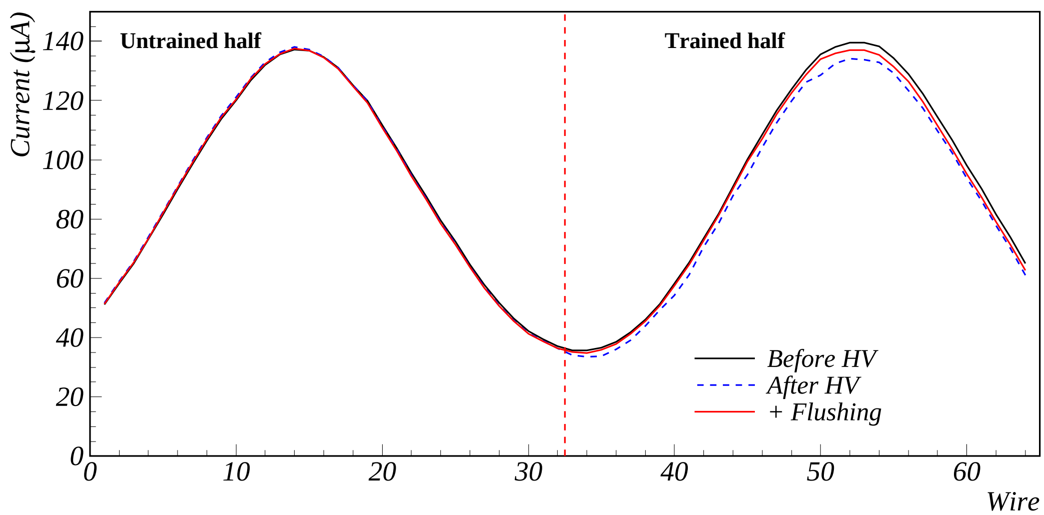

Figure 19: *The current profile produced in the 64 wires of the "B" monolayer of S1L121 by the ^{90}Sr scanning source. Immediately after the HV training, the signal response (denoted by the blue dashed curve) decreases in the trained half. After few hours of flushing, the signal response (denoted by the continuous red curve) is almost fully recoverd.*

6 Proposed Recipe for HV Training in situ

In view of the results described in this note, we propose the following recipe for the application of the HV training procedure in situ:

1) **Ramp.** Raise the high voltage from the nominal 1550 V to 1800 V in steps of 50 V. At each step the current is monitored.

   – If the dark currents are negligible (as expected) then proceed until 1800V.

   – If the current rises above 80 μA, stay at that HV value (conventional HV training).

   – If the current causes a trip of the power supply, then the procedure cannot be applied to this group of wires.

2) **Short HV training.** Raise the high voltage in steps of 10 V from 1800 V until an HV value where large dark currents appear of about 1,600 μA per HV channel (256 wires). These large dark currents are expected above 1850V.

   – If current rises, lower the high voltage by 10 V.

   – If current decreases, wait until current is below 200 μA (expected in approximately 30 minutes).

3) **Long HV training.** Raise the high voltage in steps of 10 V until again a current of about 1,600 μA per HV channel (256 wires) is reached. These large dark currents are expected between 1870 V and 1950 V.

   – If current rises, lower the high voltage by 10V.

   – If current decreases, keep this HV value for 15 hrs.

We propose to devise an implementation of this procedure in the experimental control system. During the development, we should limit ourselves to a single group of 32 wires appropriately selected via the HV patch panel. Once the automatic procedure is developed, we can apply to single HV channels (groups of 256 wires), then finally propose a roadmap for its application to the entire OT detector. At any rate, we propose that, before scaling the procedure to the entire detector, we test our abilities to closely monitor the OT performance during nominal LHC operation. Last but not least, careful consideration should be given to the possibility of applying the HV training procedure as a “preventive” action, thus even prior to any radiation damage observation.

7 Conclusion

The Outer Tracker detector modules have been shown to suffer from gain loss under irradiation at moderate intensities. High voltage training producing large dark currents have been shown to repair the gain loss in most cases, and even to prevent future radiation damage until a certain irradiation dose. This note presented the effects of the HV training and proposed a recipe for its application in situ in the LHCb experiment.

References

[1] N.Tuning et al., *Ageing in the LHCb Outer Tracker: Phenomenon, Culprit and Effect of Oxygen* Nucl.Instrum.Meth., to be published, DOI: `http://dx.doi.org/10.1016/j.nima.2009.10.049`

[2] T.Haas et al.,*Aging phenomena in the LHCb outer tracker*, Nucl.Instrum.Meth.A581:164-166,2007.

[3] G.van Apeldoorn and N.Tuning *Ageing Results from NIKHEF*, LHCb week Sep. 2006, Heidelberg, `http://indico.cern.ch/conferenceDisplay.py?confId=3886`

[4] G.W. van Apeldoorn *et al.*, *Outer Tracker Module Production at NIKHEF - Quality Assurance*, LHCb-2004-078, Oct. 2004.

[5] R.Openshaw et al., *Etching of anode wire deposits with* CF_4*/isobutane (80:20) avalanches*, Nucl.Instrum.Meth.A307:298-308, 1991.

[6] J.Va'vra, *Wire ageing with the TEA photocathode*, Nucl.Instrum.Meth.A387:183-185, 1997.

[7] V.Suvorov, G.W. van Apeldoorn, I.Gouz, T.Sluijk, *Avalanche and streamer production in* Ar/CO_2 *mixtures*, LHCb-2005-038, Jul. 2005.

[8] N.Tuning *HV Training*, LHCb week Feb. 2009, Cern, `http://indico.cern.ch/conferenceDisplay.py?confId=53080`

[9] I. Mous, *Aging in the LHCb Outer Tracker*, CERN-THESIS-2008-005, Master Thesis, Free University Amsterdam, Nov. 2007.
M. Blom, *Aging of the LHCb Outer Tracker*, CERN-THESIS-2009-089, Master Thesis, Free University Amsterdam, Jun. 2009.
T. Haas, *Alterungsstudien und Studium der Betriebseigenschaften des Outer Trackers des LHCb Detektors*, PhD Thesis, Physikalisches Institut Heidelberg, Nov. 2007.