FM Proton Irradiation Tests High & Low Stress Modules I : Glitch Effects & Curing

PICC-KL-TN-022

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Table of Contents

1 Introduction

One high and one low stress modules of PACS spectrometer detectors were tested under proton irradiation at the cyclotron of Louvain-la-Neuve in Belgium (UCL). This happened under representative FIR flux, on 7 & 8 April 2005 for the high stress (HS) module and 4 & 5 October 2005 for the low stress (LS). The aim of this document is to report on the various ways the proton irradiation affects the outcoming signal and how this can be handled in the data analysis.

2 Reference Documents

RD01 PACS-ME-TP-009 version 2.2 Test plan and procedure for investigation of glitch event rate during proton irradiation (2nd test phase)

RD02 PACS-ME-TP-009 version 3.1 Test plan and procedure for investigation of glitch event rate during proton irradiation (3rd test phase)

RD03 PICC-KL-TN-011 CQM Proton irradiation test analysis

RD04 PICC-KL-TN-021 FM Proton Irradiation Test : responsivity or dark current

3 Data

A description of the test setup, test procedure and resulting data for both FM test campains can be found in RD01 & RD02. It suffices here to say that there were 2 test campains, one for a LS and one for a HS module. Two proton fluxes were used. Typically a low flux, being ~ 10 p/cm^2/s, and a higher flux, simulating a solar flare, being ~400 p/cm^2/s. The modules were operated in a nominal way during the tests, under representative FIR background. In both test campains, a FIR filter representative of that in the PACS instrument was also placed in front of 'lower' 8 detectors (in terms of numerotation). Hence, detectors 1 to 8 received a smaller flux than detectors 9 to 16.

We will here refer to the data files by abbreviated names refering either to HS or LS data, and starting with the letter N, L and H for No, Low and High proton flux respectively, and following the same numerotation than RD01 and RD02. So, for instance, T25b80d10t025c04n256_N_33.dat of RD02 becomes HS_N33, or N33 if there is no ambiguity on which module we are talking about. The detector setup parameters can be obtained directly from the filename in RD01 or RD02.

4 Increase of responsivity

When these are exposed to proton irradiation, the responsivity of PACS spectrometer Ge:Ga photoconductors is steadily increasing (see RD03, RD04 and figure 1). In absence of dedicated curing, the processus goes on until a high responsivity plateau is reached.

The time after which this plateau is reached varies from minutes under high proton flux to hours under low proton flux. In a similar way, the responsivity at this plateau varies between ~4-5 (low proton flux) and ~15-20 (high proton flux) times the responsivity at rest (no proton beam; detectors cured). It is likely that the latter dependency finds its origin in the self curing of the detectors between the events, due to the FIR background applied during the tests. Indeed, the higher the flux, the less self-curing, the higher the responsivity at the plateau.

The classical interpretation of the responsivity increase is that more and more electrons from the valence band get captured in the discrete/localised shallow levels, hence freeing more and more holes. This occupation of the localised states induces an increased probability for the next charge carriers to make it through the detectors to the electrical contacts, i.e. finally be measured without recombining underway.

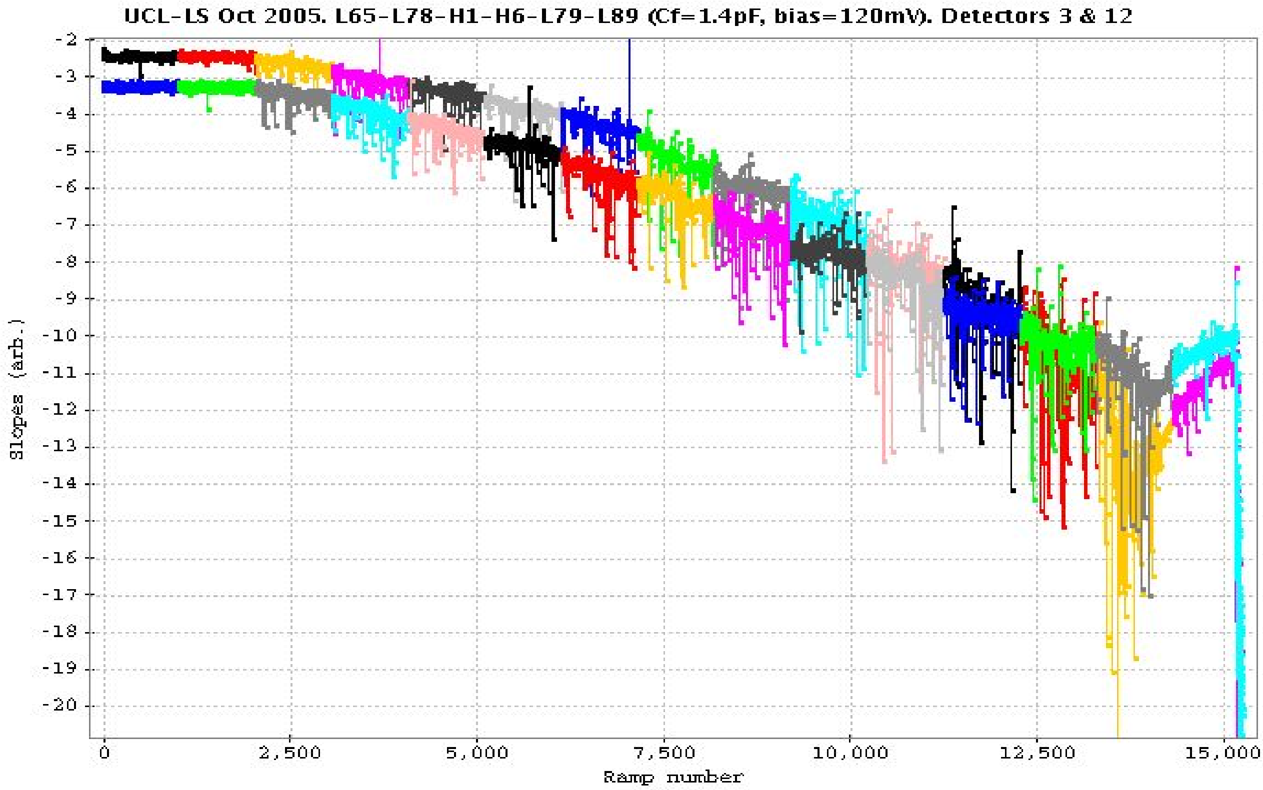

Figure 1 : LS-L65 to L78 & H1 (one color per file). Detectors 3 (top curve) & 12. From the 3^{rd} data file on (when the proton beam is turned on), the responsivity increase is very clear. The effect of many glitches on the fitted slopes is also obvious. Around ramp 14000, the proton beam is switched off for a while, and the self curing of the detectors exposed to FIR light is visible. Then the proton beam is restarted, with a much higher flux (400 p/cm^2/s instead of 10), and the responsivity increases extremely fast from then on.

5 Curing

Three methods of curing were investigated, namely bias boost, FIR light flash, and heating the detectors. All of them correspond to flooding the detectors with a very large amount of free charges.

5.1High Stress Module

Figure 2, 3 and 4 show the result of the application of the 3 curing methods in various cases. In all 3, the first data files are reference, pre-beam data, showing in a sense the responsivity to which the detectors should return after a succesful curing.

In figure 2, the files directly following the reference data were obtained some time *after* a solar flare simulation (high proton flux), when the self curing had brought the responsivity back to a quasi-stable level, hence suited for curing investigations. The first curing tried was a **bias boost** (2.5V, max possible current, applied for 2x60 sec, with 60 sec in between). This **curing** is obviously **very partial**. Right after, the flasher was used (3 x 60 sec first, 3 x 20 sec after, each time with a supply current of 4mA). From the first time already, the **flasher** achieves very **good curing**.

As just said, the flasher was used in sequences. Although most of the curing is achieved after the first flasher ignition already, the subsequents ones still do bring something (see figure 2 around ramp 7500: perfect curing is reached after the 3^{rd} flasher ignition).

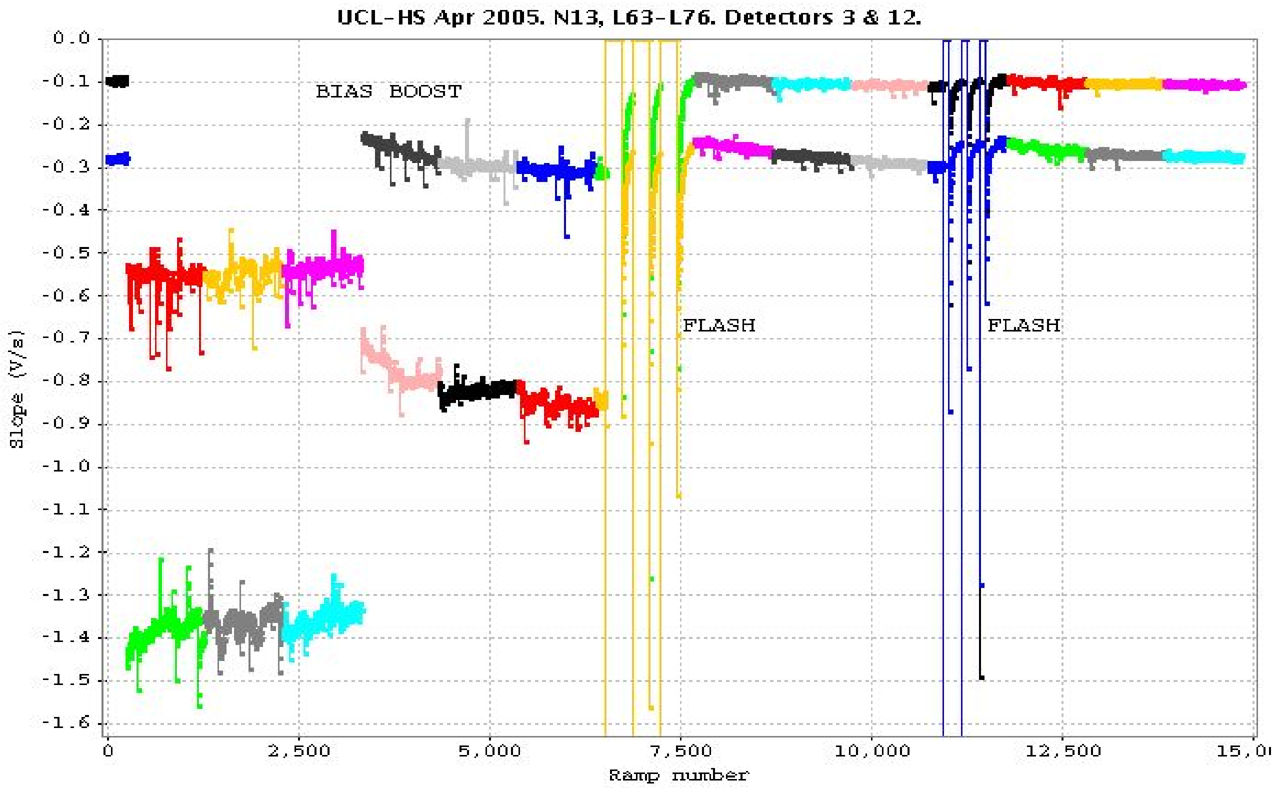

Figure 2 : HS-N13 and L63 to L76. N13 is used as pre-beam reference level. L63 to L65 were obtained after a 'solar flare simulation' (high proton flux), after some time of self-curing (the responsivity is almost stable there). Between L65 and L66, a Bias Boost was applied to the detectors (2x60s 2.5V with the CREs deselected). This doesn't bring the responsivity back very close to the original value. Then the FIR flasher is used (3x60s, then 3x20s, twice with 40mA current through it), and this time the curing is succesful.

Figure 3 & 4 show further investigations on the curing of HS detectors after a solar flare event, here simulated by a high proton flux. The bias boost isn't tried anymore, but the test proves the FIR flash as well as **heating the detectors** up to ~5.8-6K to be **efficient** methods of **curing**. In this test, the flasher was operated with a supply current of 4mA during 3 x 60 sec (gaps of 30 sec), and the heater was operated twice. Each time, the detector module was brought close to 6K for 1 minute. The first time, the cool-down time was measured : it took about 2 minutes for the detector module to come back to its nominal working temperature of 1.9K.

5.2Low Stress Module

For the low stress, as for the high stress module, the curing by FIR flash proved efficient, as shown in detail in figures 5 to 7.

The two other curing methods were also tried, as shown in figures 8 & 9.

Heating the detectors leads to efficient curing. The novelty here wrt HS detectors, is that bias boost is also efficient in curing some of the detectors (e.g. detectors 3 & 13). For other detectors (e.g. detectors 5 & 12), and though it makes an acceptable job, the curing by bias boost is not perfect. The critical parameter making the difference between those detectors for which the bias boost does work and those for which it doesn't is unclear.

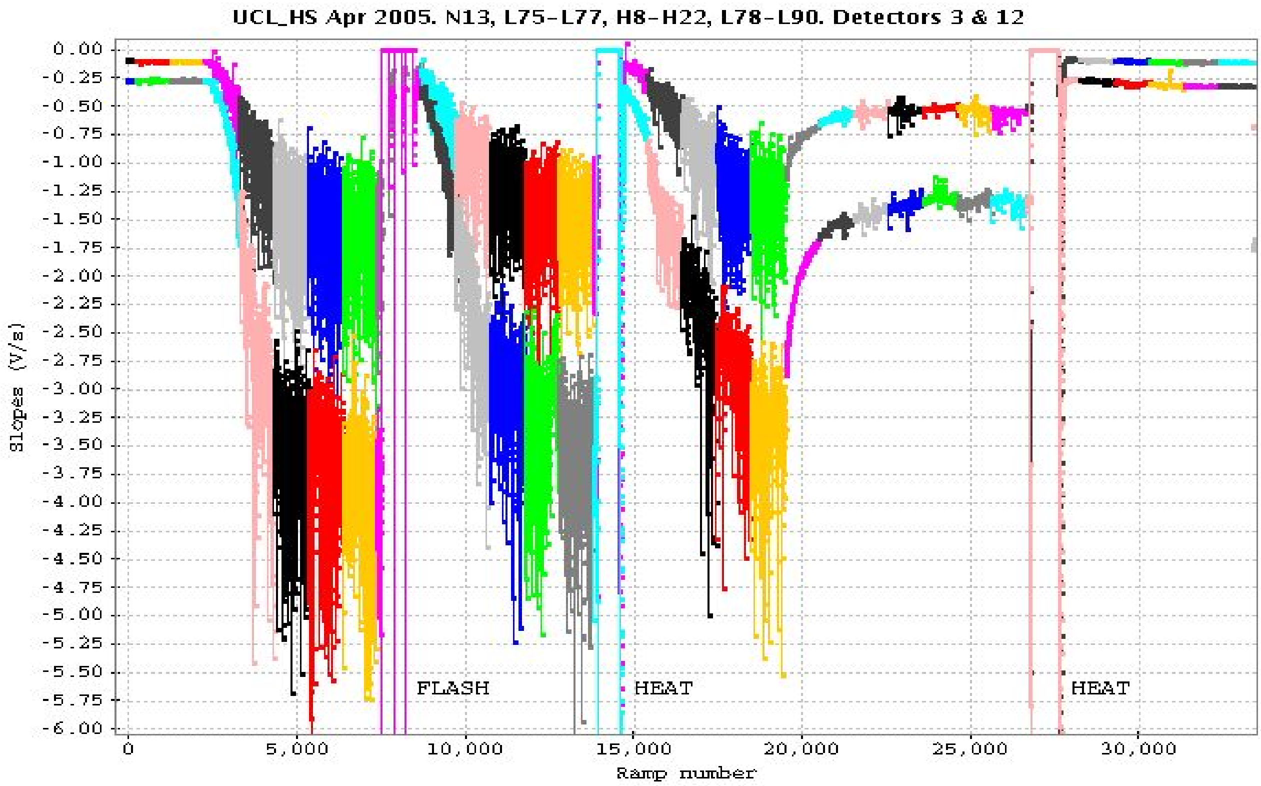

Figure 3. HS detectors 3 & 12. High proton flux and curing via FIR flash or detector heating.

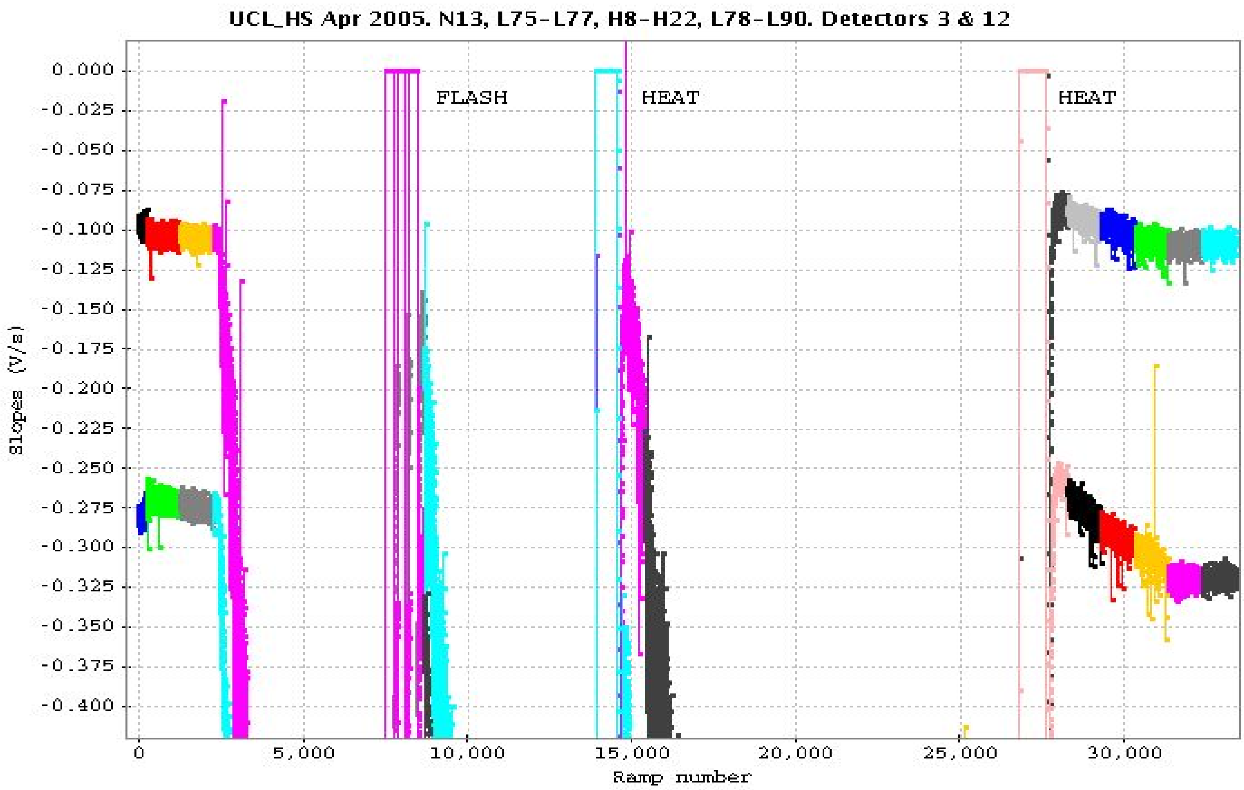

Figure 4. As figure 3, zoomed on the low responsivity levels, showing the efficiency of both curing methods investigated here.

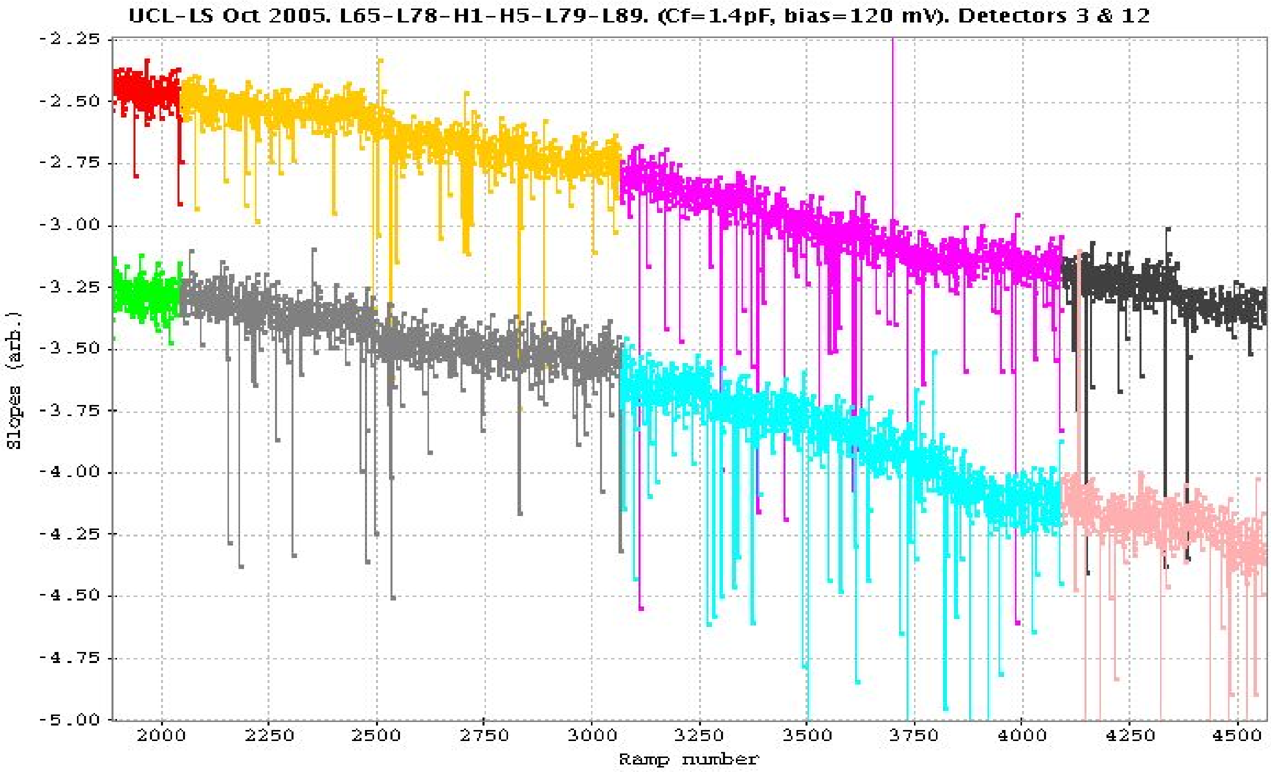

Figure 5. Slopes of files LS_L67 & L68. These data were obtained right at the start of the proton beam. (see figure 1).

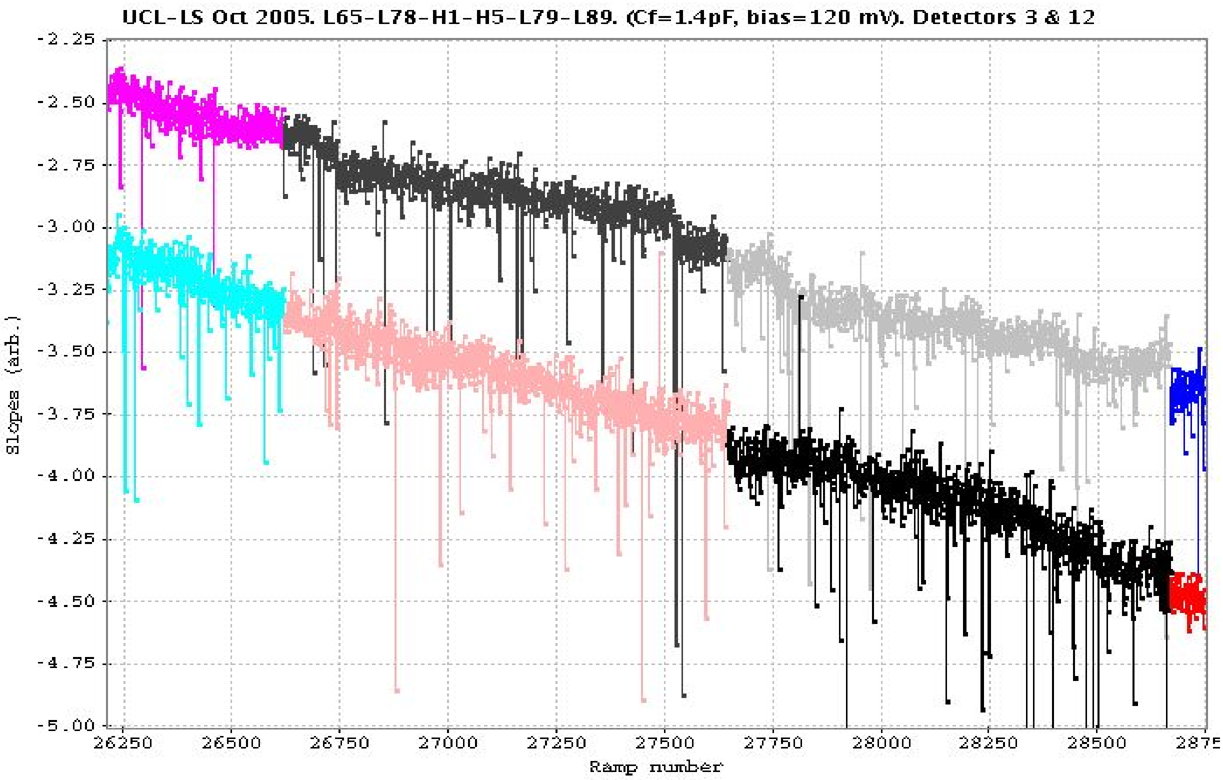

Figure 6. Slopes of files LS_L_85 & L_86, obtained right after flasher curing. Comparison with figure 5 demonstrates the efficiency of the curing (y-units, though "arbitrary", are the same).

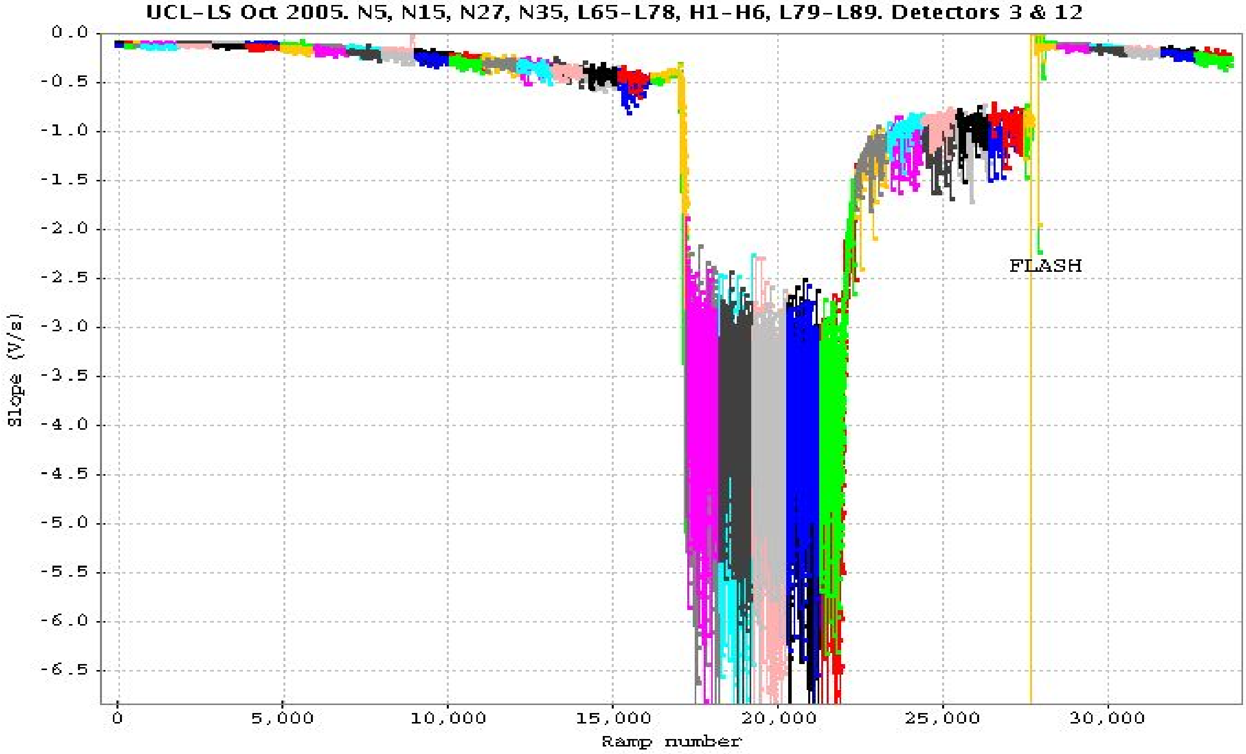

Fig.7. The whole test sequence from which figure 5 & 6 were extracted. The first 15000 ramps are better visible in fig. 1

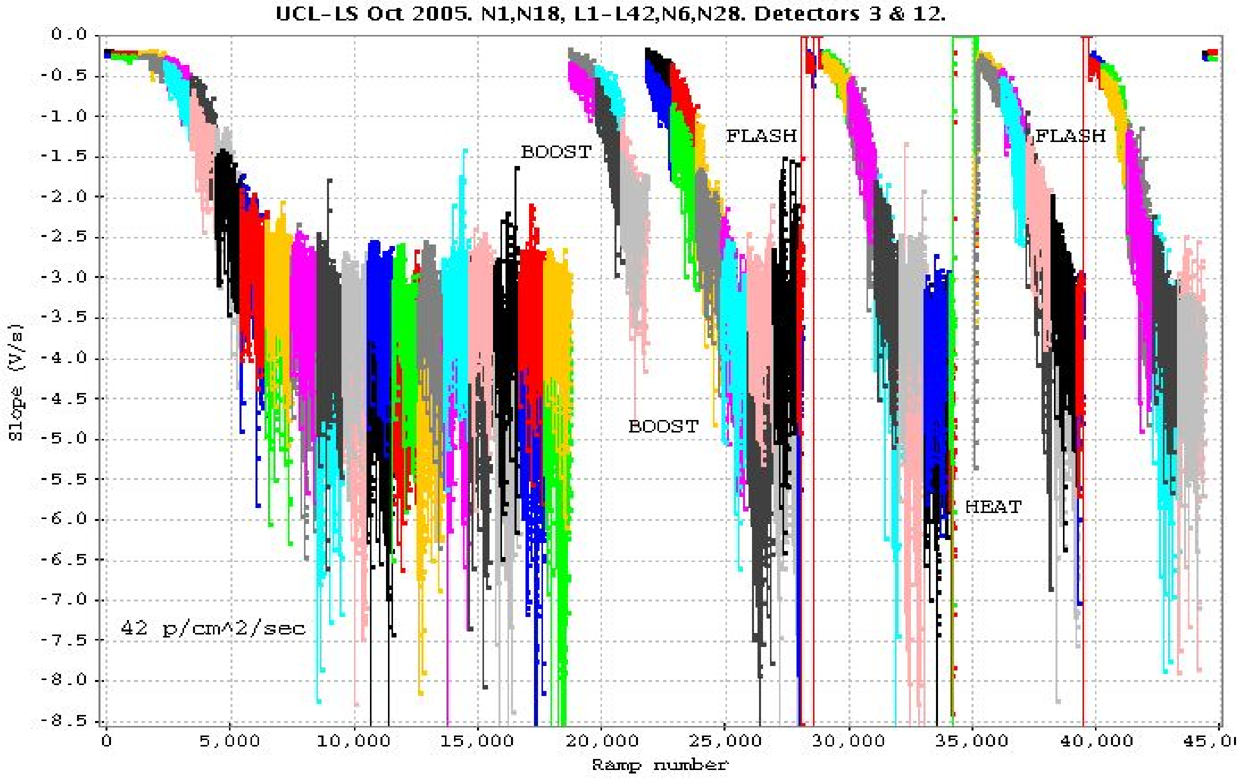

Figure 8 : LS data of the first test day (42 p/cm2/s). Zooms in this figure (e.g. figure 9) show that all curings are efficient, although bias boost is only efficient for some detectors, not all!

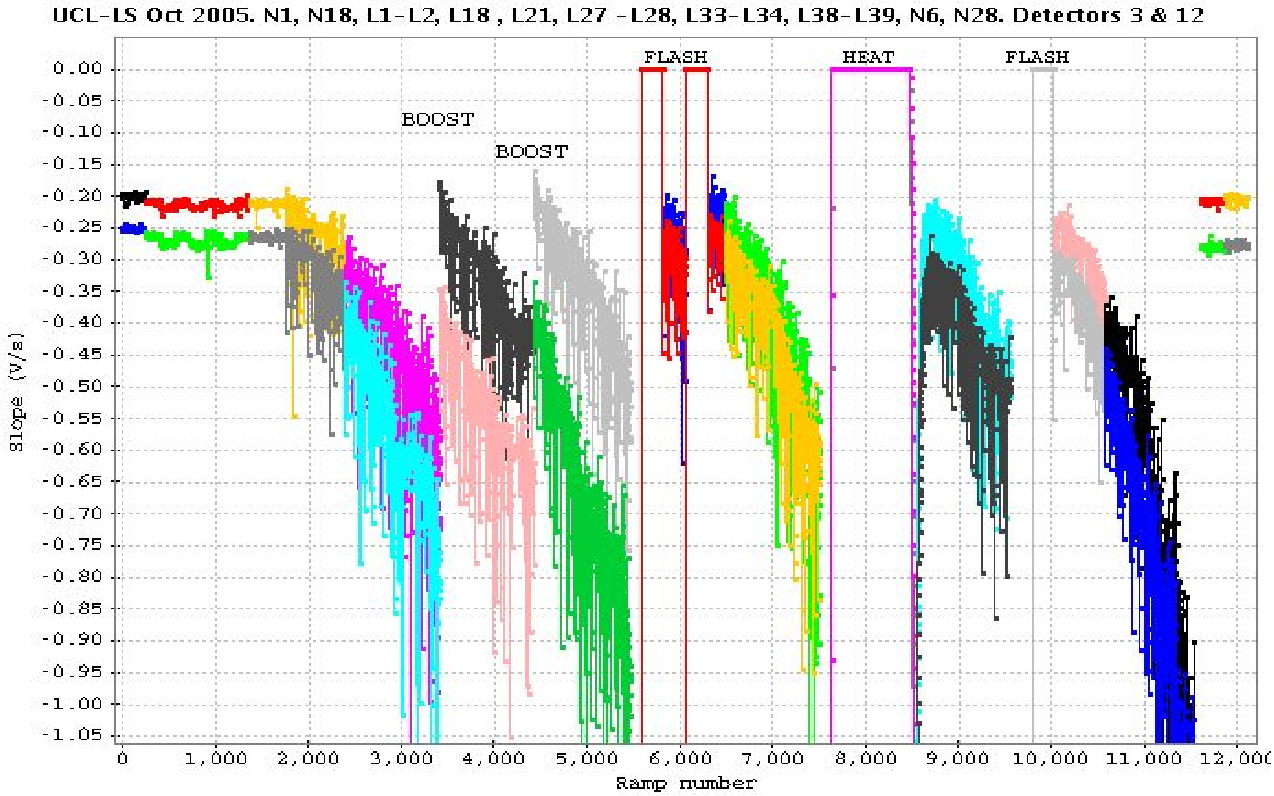

Figure 9. As figure 8, where only the data files related to application of curing methods were selected. The bias boost shows good curing of detector 3 (upper curve), not of detector 12.

6 Close-up on Glitch (& other) effects

6.1One glitch, no effects. No (visible) glitch, some effect

Figure 10. shows a chronological sequence of slopes. One of the ramps is affected by a glitch (nr 729). This is of course directly visible in its slope. Nevertheless, this glitch has no effect on the subsequent slopes, which remain very similar to those obtained before the glitch.

Similar cases occur where no glitch can be detected whereas the responsivity is affected. Figure 11 shows the raw ramps around such an event. Whereas no glitch is visible, the responsivity is obviously and suddenly increased. In such cases, we suspect that the glitch happens during the reset time. The correspondance between responsivity jumps and glitches can be checked on a statistical basis once appropriate methods for detecting both kinds of events are defined.

6.2Increasing the responsivity

As noted in section 4, after a curing, the main irradiation effect is an increase in responsivity. Figure 12 shows that this general trend is made of discrete steps. Each of these correspond to a glitch.

6.3Decreasing the responsivity

An appreciable amount of glitches do in fact provoque the exact counter effect : a decrease in responsivity, similar to curing. Figure 13 & 14 each show two examples of this. In the black curve of figure 13, ramp 607 suffers from a glitch modifiying the slope of the end of the ramp sufficiently for the overall slope to look rather normal (this is of course easier to achieve when the glitch occurs early in the ramp). In the red curve, ramp 615 is affected by a very strong glitch. It is worth to note that, despite the very different strength of these two glitches, and of their effects on the responsivity, the transient seems to have about the same time constant. This should be confirmed on a wider number of events.

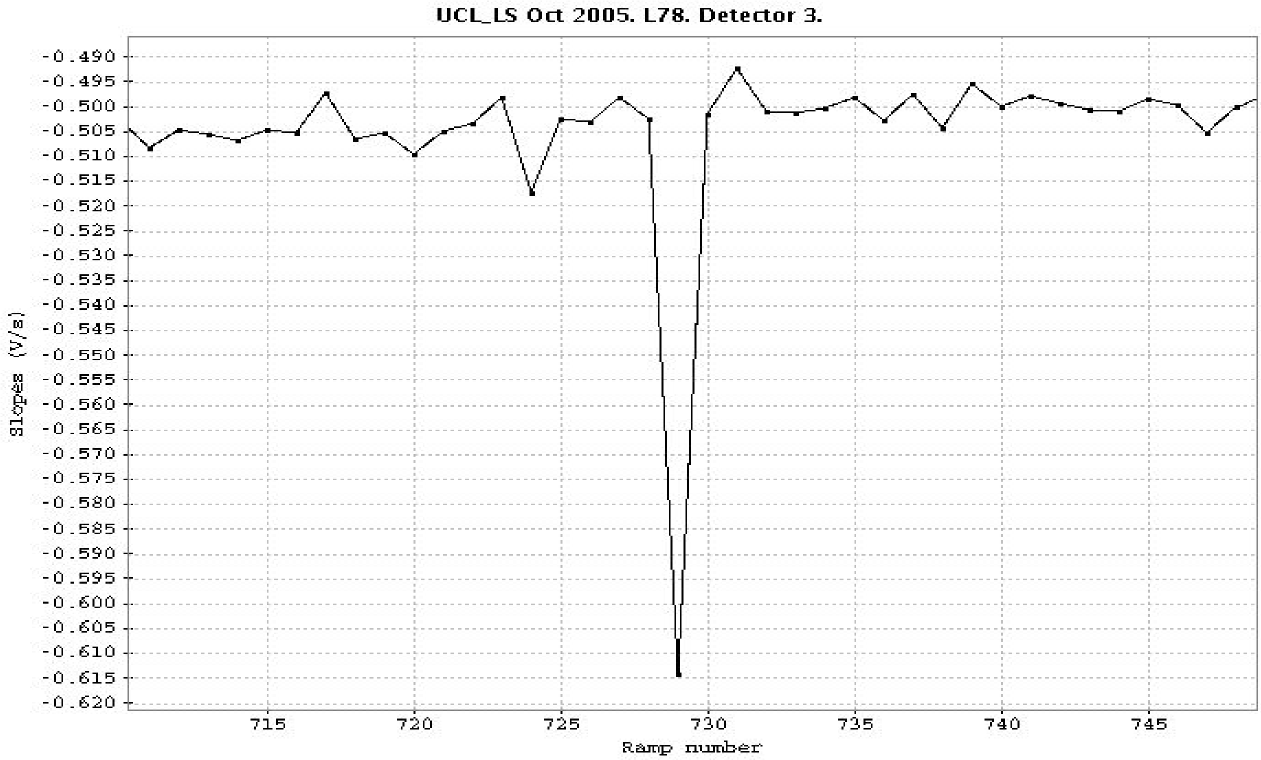

Figure 10. LS_L78. Detector 3. Slopes for ramps around number 730. Ramp 729 is affected by a glitch, which doesn't seem to have much influence on the detector.

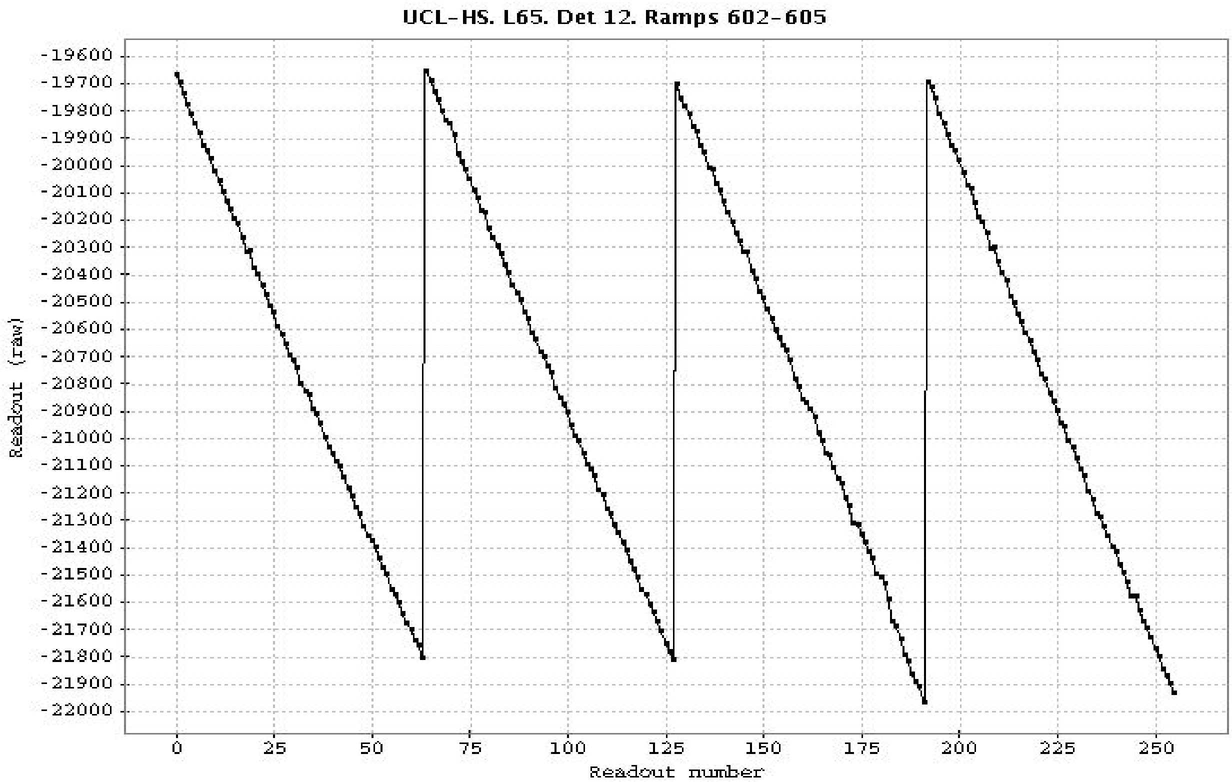

Figure 11. HS_L65. Detector 12. No obvious glitch is detected, whereas the detector responsivity is obviously and suddenly increased.

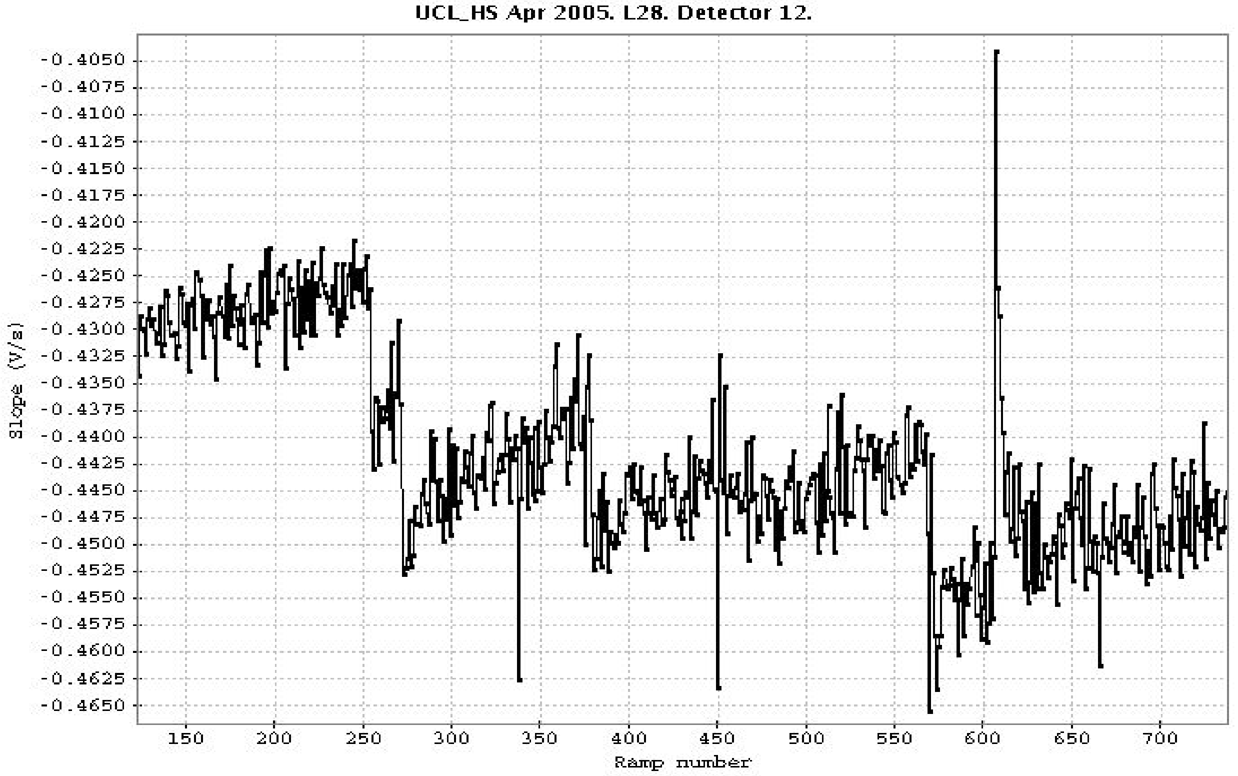

Figure 12. LS_L28. Detector 12. A general trend of increasing responsivity is visible. It is made of discrete events corresponding to glitched ramps. Between these events, a slight self-curing occurs, due to the FIR background applied. The peak at ramp 605 is zoomed on in the figure below.

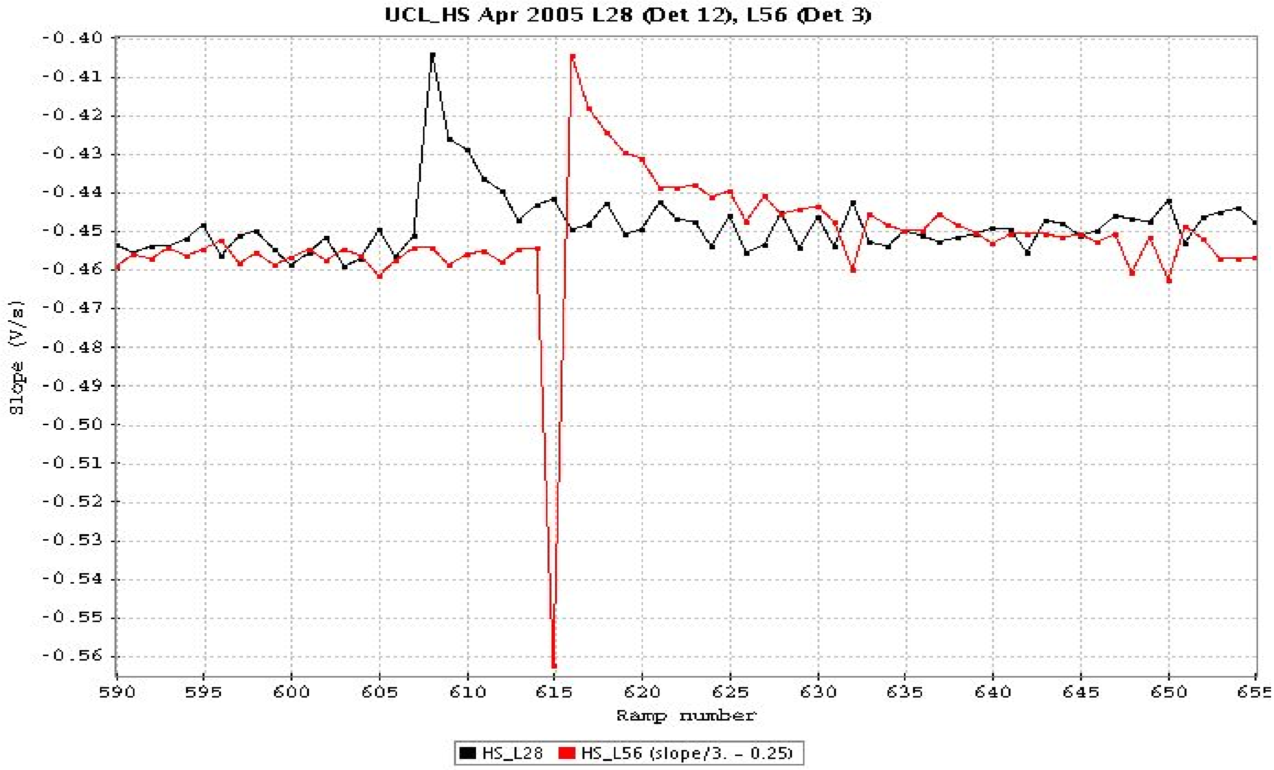

Figure 13. HS_L28 (detector 12) & HS_L56 (detector 3). Ramp 607 of the black curve and ramp 615 of the red one suffer from a glitch. Note the scaling of the red curve, hence the much higher strengh of this event.

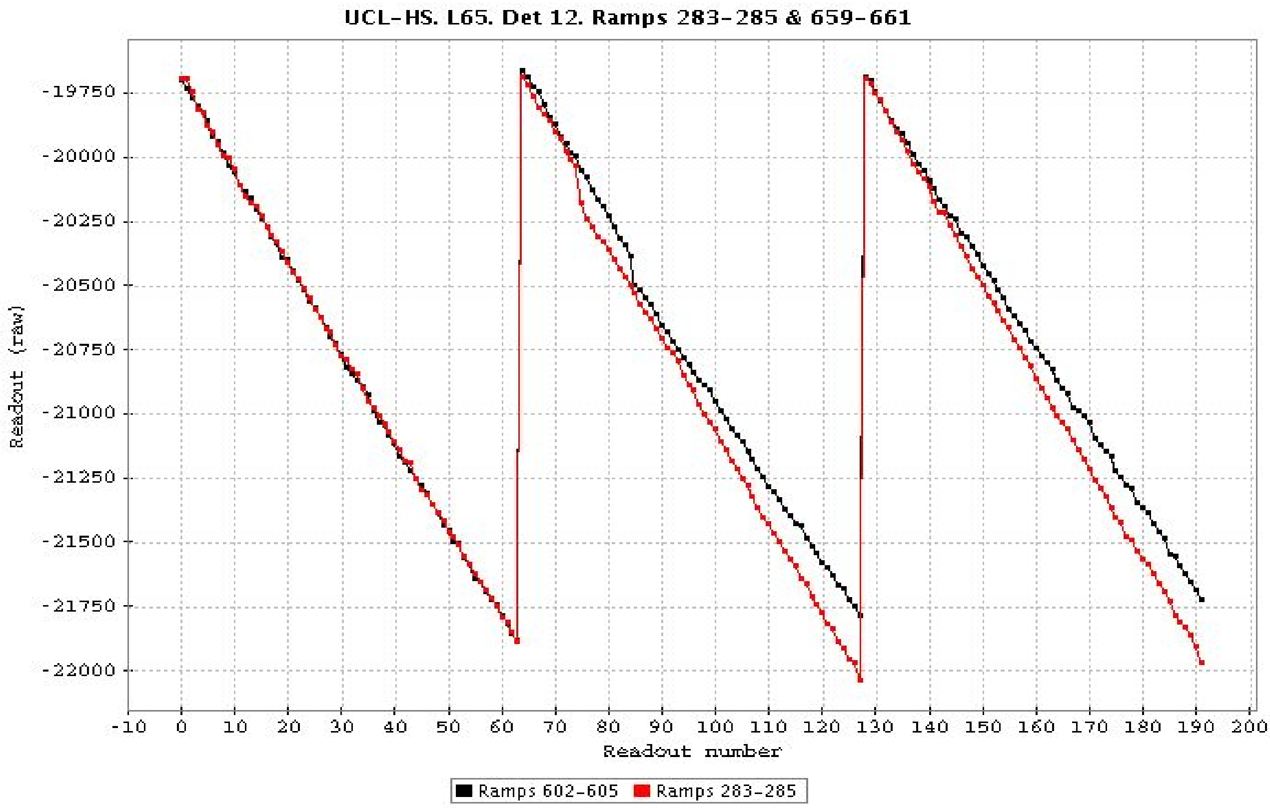

Figure 14. HS_L65 Detector 12. The two sequences of 3 ramps exhibit a glitch on the second ramp. Both ramps are very similar before the glitch and the glitches have similar amplitude. Nevertheless, one event leads to an increase, and the other to a decrease of responsivity!

6.4Anti-glitches

Figure 15 shows two cases of the same unexpected behaviour : some of the ramps exhibit “anti-glitches”. As this does not seem to impact the neighbouring ramps whathowever, we suspect the origin of these to lie purely in the electronics. It is noteworthy that this does not happen simulaneously on all pixels, but apparently just one at a time. It has been seen on both modules : HS and LS.

6.5Low Stress vs High Stress

Most of the figures 10-15 refer to HS modules. The same effects were found on the LS modules, with the following slight differences :

- the kind of events shown in figure 12 (sudden increase of responsivity), which are very common with the HS module, are rather seldom with the LS module.
- instead, for the LS module, most of the events are of the type shown in figure 13 (lower responsivity transient), with the particularity that the transient time is most often shorter (not more than 1 or 2 ramps affected).
- nevertheless, the long term increase in responsivity takes place for the LS module as well as for the HS module. Only does it happen in a more “hidden”, more continuous way.

Figures 16 & 17 show the behaviour of the LS and HS modules on a longer time span. The data shown in there were in both cases obtained on a “high responsivity plateau” reached by self curing (under low proton flux though) some time after a 'solar flare simulation'. The figures show the difference in behaviour described here above : the responsivity of the HS detector evolves in a much more discountinous way than that of the LS detector.

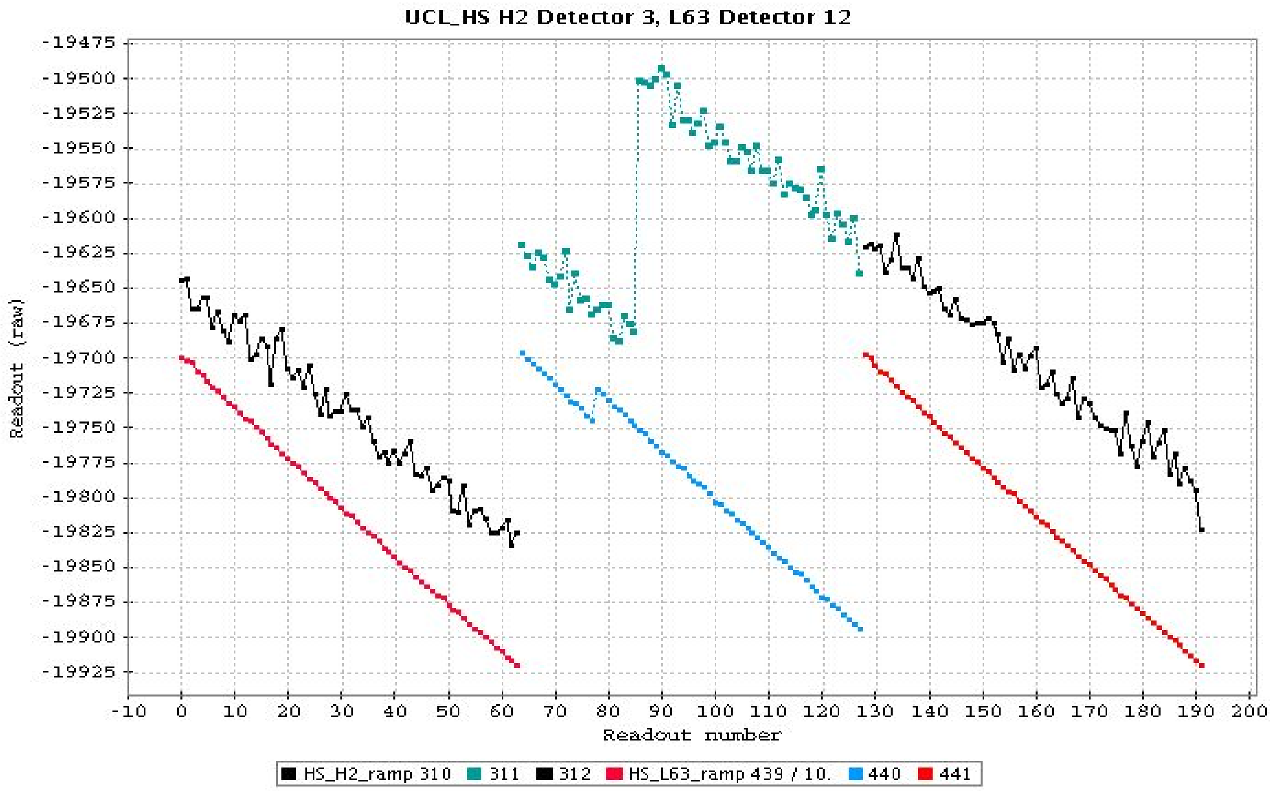

Figure 15. HS_H2 (detector 3) & L63 (detector 12). In each sequence of three consecutive ramps (black/green and red/blue), the central ramp exhibits a rather strong, totally unexpected 'anti-glitch'. The neighbouring ramps are unaffected.

7 Notes

1. Under high proton flux, when each ramp experiences several glitches, some ramps get an extremely varying behaviour. So, for instance, one might encounter ramps beginning with a steep slope, then showing a shallower slope after the first glitch, a strongly curved part after the second glitch, and again very different slopes after each of the next glitches (figure 18). Obviously, we will never be able to calibrate such data.

2. On the first test day of the LS campain (Oct 2005), a miscalibration of the proton flux lead to a too high proton flux. Whereas the goal was 10 p/cm^2/s, backwards investigation lead to think that the actual flux was more around 42 p/cm^2/s. In this note, we want to emphasize the doubt we have that the flux was actually as low as 42 p/cm^2/s.

Indeed, comparison of ramps obtained on that day with those obtained on the next day, with a, then, well-calibrated flux of 400 p/cm^2/s show even more glitches with the low flux on day 1 (~25/s/detector) than with the high flux on day 2 (~15/s/detector). See figure 19.

In addition, the number of particules inferred from that glitch frequency and the surface of the detector leads to a flux ~1000, i.e. >> 42 p/cm^2/s. If we accept that the difference is due to secondary events, then we should accept that these secondary events should also be seen on the second test day, and the very roughly comparable glitch frequency between low flux on day 1 and high flux on day 2 remains a puzzle... Consequently, we would think that the extra-events seen under 400 p/cm^2/s are due to secondary particles, while the extra events seen on day 1 are simply due to the very wrong flux calibration on that day.

Unfortunately, this still doesn't solve the puzzle completely, since comparison of the “detector degradation speed” under low flux on day 1 (figure 8) and under high flux on day 2 (figure 7) reveals a stricking difference, indicating a flux indeed much larger on day 2 than on day 1...

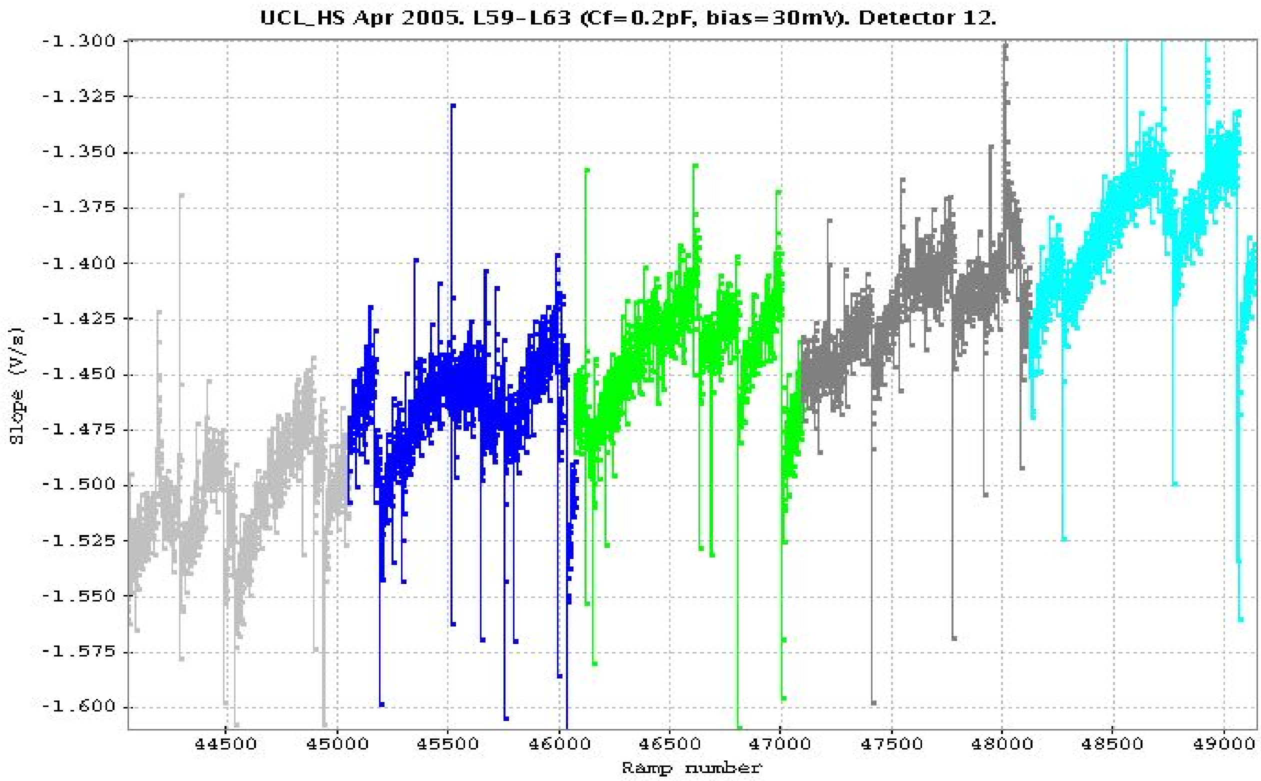

Figure 16. HS_L59-63. Detector 12. With the HS module, most of the events lead to sudden increase of responsivity. On the long term, the evolution of the responsivity is rather "chaotic".

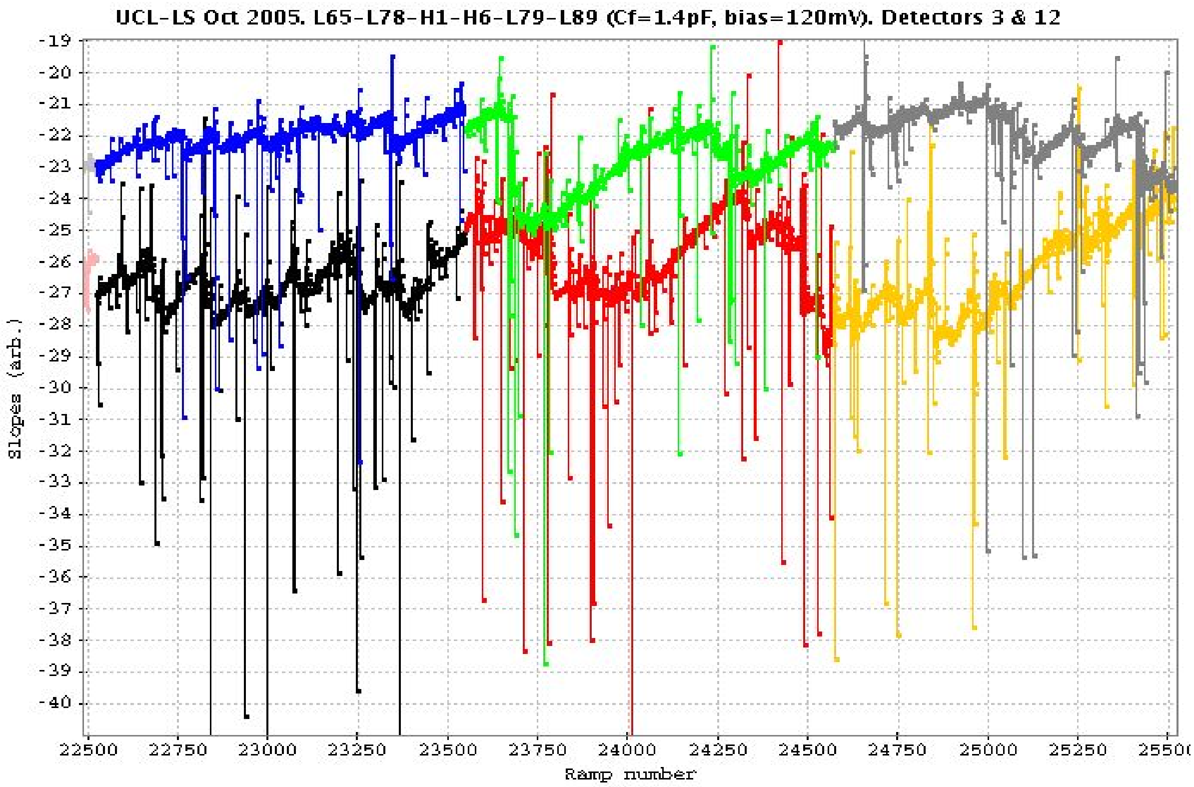

Figure 17. LS_81-83. Detectors 3 (top) and 12. With the LS module, most of the events have a short lower responsivity transient, while the responsivity evolves more "smoothly".

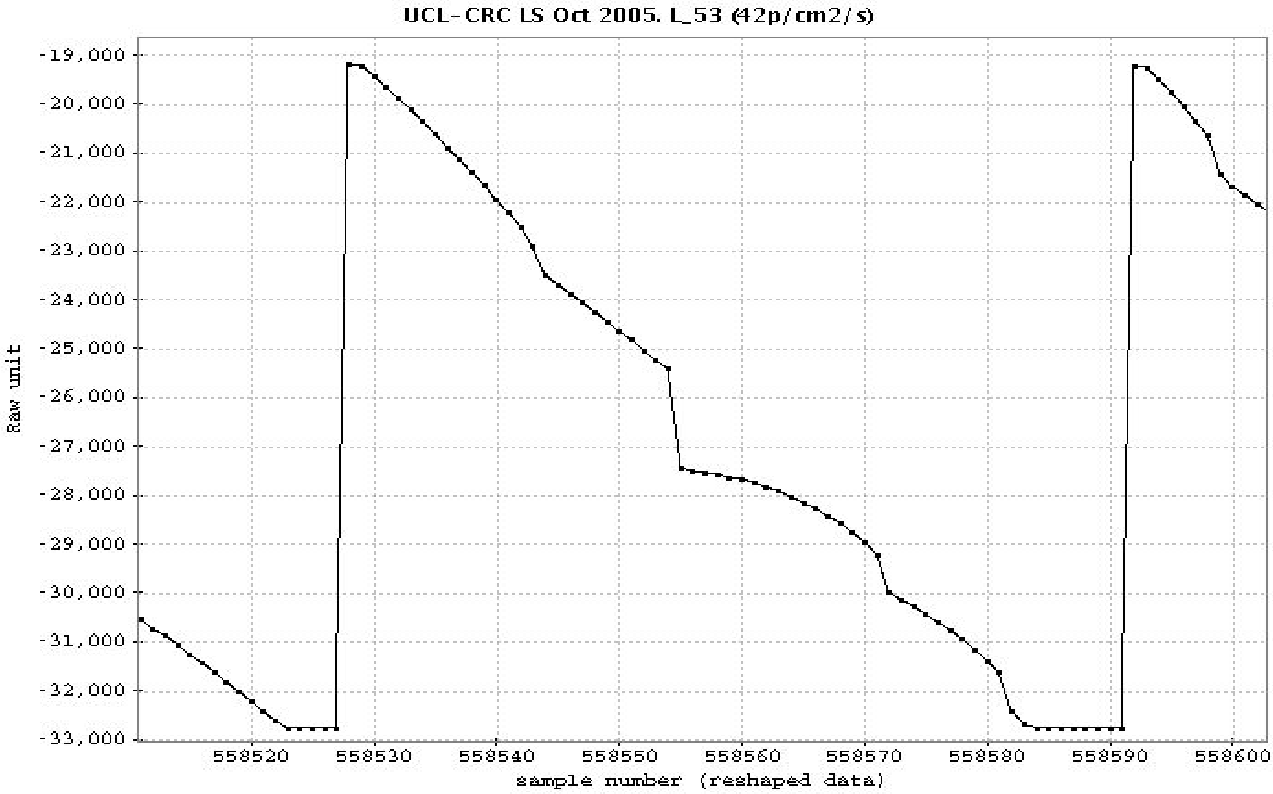

Figure 18. LS L53. This ramp exhibits 4 very clear glitches, and as many behaviours...

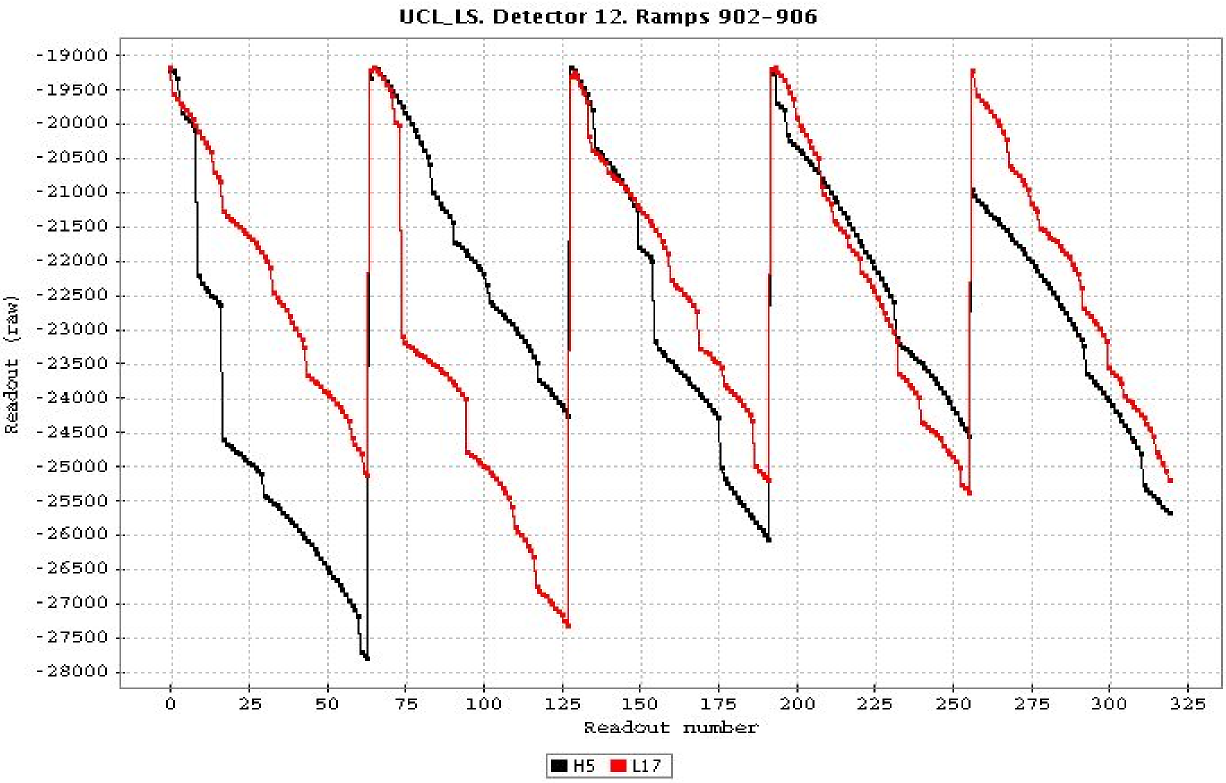

Figure 19. LS H5 (high proton flux, second test day) and L17 (low proton flux, first day). Detector 12 and ramps 902-906 in both cases. The low flux data exhibits more glitches than the high flux data...

8 Conclusions

- Curing : FIR flash & detector heating bring efficient curing of the irradiated detectors. Bias boost, though not providing as good results, works better for the LS detectors than for the HS. Taking into account both the power consumption and the time constants for cooling the detectors after having heated them, **we recommand to cure the detectors via the flasher** as far as possible.
- Glitch effects : **a continuum of glitch effects** on the detectors has been reported, going **from increasing to decreasing the responsivity** (often **on top of a transient** stronger effect), i.e. from deteriorating to curing the detectors response. Efficient methods to detect these events need to be developped before they can be characterised quantitatively.
- HS vs LS : the detector's responsivity of the HS detectors is often changed (increased) abruptly after a glitch, whereas that of the LS detectors evolves more smoothly, the (obvious) glitches having often more restricted impact (in time and amplitude) on the responsivity.
- Other effects : some electronic effects as well as a puzzle concerning the actual proton flux on the first test day of the LS test campain have been reported, and need further investigation (MPE).