Test Plan and Procedure for Investigation of Glitch Event Rate and Collected Charge Variation in the Ge:Ga Detectors during Proton Irradiation at UCL-CRC (3rd test phase)

TEST REPORT

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DOCUMENT CHANGE RECORD

Issue / Rev.	Date	Change Notice Number	Modified Pages or Paragraphs	Remarks / Nature of Change
Draft	05-09-03		all	new document
Issue 1/ 0	14-11-03		§ 4.1, 4.2, 5.7, 6	Update of several figures and text
Issue 1/ 1	18-02-04		§ 1, 4, 5, 6, 7, 8, 9	Final test procedure
Issue 1/ 2	10-03-04		§ 7, 8, 9	Test report, minor upgrades and clarifications in all paragraphs, filled-in detailed test procedure, preliminary results, observations + conclusions
Issue 2/ 1	30-03-05		all	Procedure update for 2nd test run
Issue 2/2	05-04-05		§ 1, 4, 5, 6, 7	Update of text
Issue 2/2_TR	05-05-05		§ 1, 8, 9	Logbook and conclusions
Issue 3/0	26-09-05		all	Procedure update for 3rd test run
Issue 3/1	02-10-05		§ 1, 4, 6, 7, 8, 9	Test report, filled-in test procedure

TABLE OF CONTENT

1. SCOPE

The document describes the activities necessary to perform the proposed investigation of glitch event rate and performance variation in the Ge:Ga photoconductors of the PACS detector modules over a limited range of detector operating parameters and proton fluxes at a fixed proton energy. After a first irradiation experiment in March 2004 and subsequent data analysis, conclusions and suggestions (see [RD9] to [RD12]), a second test phase at UCL-CRC was planned. It provided more information about the observed degrading of the high-stressed detector behaviour under ionizing radiation and on the best operation parameters and recovery methods that can be applied.

The proposed test is intended to determine the glitch event rate of low-stressed Ge:Ga detector pixels in a completely assembled QM detector module, serial #25, including fore-optics with cut-on filter (52µm) and FM type cryogenic read-out electronics (CRE), under realistic far infrared (FIR) background loads as they are present in the PACS instrument blue spectrometer section, i.e., about 1.5×10^{-14} W per pixel. Glitch "height" distribution and transients are also a point of investigation. Furthermore, the test should provide information, how the detector responsivity and noise depends on the history and intensity of proton irradiation, and whether or which combination of operating bias, bias boost, IR flashing and raise of detector temperature is a valuable tool for maintaining calibration and performing detector curing.

During nominal operation, the detector current produced in each pixel by incoming far infrared light is integrated on a selectable capacity in the CRE chip and the time dependent voltage signal (the "ramp") is read-out during a predefined integration interval before a reset is done. Ionizing radiation in orbit generates additional charge carriers in the detector crystal, which are collected and added to the nominal signal current. This effect shows up as a "glitch" (a vertical step) of the signal ramp. The aim of the proposed investigation is to create on ground under proton irradiation a data set of signal ramps disturbed by glitches and thus affected in their calibration quality. The proton irradiation should simulate at least partly the in-orbit conditions. Distorted signals must be expected during the whole mission.

Based on the data gained during 1st and 2nd irradiation runs at UCL-CRC with the high stressed detector module, the test program for the 3rd run (on a low stressed module) has been modified as suggested in [RD14]. With the proposed investigations and with the collected data set, most suitable data reduction algorithms for detector signal ramp restoration can be developed before PACS aboard the Herschel satellite is launched.

The detailed test procedure is included in this document. The filled-in test procedure is considered as test report, see chapter 8. All test data are collected and stored electronically in binary format during the test runs, for more information see chapter 7.

2. DOCUMENTS

[AD1] PACS-ME-PL-012 PACS Test Plan

[AD2] SCI-PT-IIDB/PACS-02126_3.4 Instrument Interface Document Part B PACS

[RD1] ESA ISO/FIRST Glitches Working Group Final Report, issue1.1, ed. Ana M. Heras, 21 August 2001

[RD2] Proton energy loss in Germanium, P. Nieminen, ESA TOS EMA, 29-01-1999

[RD3] The ISO SWS Detectors: Performance Trends and Space Radiation Effects, A. M. Heras et al, Experimental Astronomy 10, 177-197, 2000, Kluwer Academic Publ.

[RD4] L2 Radiation Environment, J. Sorensen TOS EMA, ESTEC Memo ref 00-010/JS, 14 May 2001

[RD5] FIRST L2 Radiation Environment, H. Evans, ESA/ESTEC/wma/he/FIRST/3 04 March 1997

[RD6] private communication, Ana Heras, email of 14 August 2003, see document annex 1 below

[RD7] private communication, Petteri Nieminen, email of 14 August 2003, see document annex 2 below

[RD8] PACS-MA-TR-005 Results of tests on QM FEE A02_038_15

[RD9] Herschel HSC-MOM-0453_20-September-2004 Herschel/PACS radiation environment meeting

[RD10] G. Santin: Herschel PACS photoconductor – simulation of the proton ground tests, Technical Note issue 1 rev 0

[RD11] PACS-MA-TR-016 Warm functional test on low stressed Ge:Ga Sevenpack 1

[RD12] PICC-KL-TN-011_d1_23-December-2004 CQM Proton Irradiation Test Analysis

[RD13] J. Cabrera, UCL: GEANT4 simulation for energy distribution in PACS experiment and measured beam homogeneity, Technical Note of 07-04-2005, see document annex 3 below

[RD14] P. Royer: Planning ideas for the 3rd proton irradiation test at UCL, see document annex 4 below

Document Annex 1

Subject: Re: Radiation Tests of PACS Detectors
Date: Thu, 14 Aug 2003 17:33:57 +0200
From: Ana Heras <aheras@rssd.esa.int>
To: Albrecht Poglitsch <alpog@mpe.mpg.de>
References: <000501c36195$1d3f3990$6582b782@alpog300>

Dear Albrecht,

The effect of low energy protons on the detectors depends on the shielding. With the ISO shielding, low energy protons (< 10 MeV) where mostly stopped. For example, during the big flare event on November 1997, we observed a correlation of the glitch rates with the E > 30 MeV proton flux but not with the E > 10 MeV one. Unfortunately, an important consequence of the ISO shield was the production of secondary particles and delta-rays, to the extent that they were responsible for around 50% of the glitches routinely observed in the detectors. This must be taken into account when designing the PACS shielding. P. Nieminen and his group at ESTEC (Space Environments and Effects Analysis section) can run simulations to help analyzing this problem. In addition, we also observed a very strong correlation between electron flux levels and glitch rates. The ISOPHOT instrument specialists found that the detector responsivity showed a 27-day periodicity that they associated with electron fluxes and geomagnetic activity.

Testing with 100 MeV protons is realistic for most effects. However, if no shielding is assumed, low energy protons must be considered. I forwarded your question to P. Nieminen and I have attached his reply. He thinks that adding tests with lower energies, at least with ~10 MeV protons, would give more confidence regarding possible displacement damage effects. You can also contact him directly (Petteri.Nieminen@esa.int) if you want further clarification. (Just as a comment, and although different technologies are involved, the main radiation problem with XMM was caused unexpectedly by the low-energy ~ 1 MeV protons).

Although it is better to test with the highest possible energy, I do not think it will make much difference to use 80 MeV or 100 MeV protons, considering the large range of proton energies that the detectors will actually "suffer" in orbit. Regarding fluxes, it was calculated for ISO that the E> 30 MeV cosmic ray flux during quiet periods was 4 particles/cm2/s at apogee (which is similar to L2). This number can also be derived from the ESA 1997 radiation paper. Herschel will be launched during solar minimum, but at the end of the mission solar flare protons will become important. During a big solar flare the given cosmic ray flux may be multiplied by a factor 10 to 100. For your info I attach two plots in which the proton fluences and number of solar proton events are shown as a function of solar cycle.

In case you want more information about the ISO experience, I also attach the ISO Glitches Working Group Final Report (Helmut Feuchtgruber was a member of this group).

I hope this helps.

Best regards, Ana

Document Annex 2

Email of 14 August 2003

From: Petteri Nieminen

Hi Ana,

I believe it would be prudent to carry out the tests at more than one energy, especially if this is a novel technology and not flown in space so far. The actual fluxes seen at the target level depend on the surrounding shielding, but if there is at least one measurement point at a low energy (say ~10 MeV at the photoconductor) in addition to the high-energy one, this would give more confidence regarding possible displacement damage effects.

Please find attached a paper by Ronald Bieber to be presented at the RADECS conference in September on the proton irradiations done for HIFI. Perhaps this is of some interest also in the context of PACS.
Ali Mohammadzadeh and Hugh Evans, who are in copy of this mail, may have additional comments.

Best regards,
Petteri

(See attached file: ref_6573.pdf)

Document Annex 3

GEANT4 simulation for energy distribution in PACS experiment

Juan Cabrera (Center for Space Radiations)
Université Catholique de Louvain
07-04-2005

A GEANT4 simulation has been performed to estimate the proton energy distribution inside the PACS vessel. The GEANT4 input experimental setup is a simplified version of the actual one. Figure 1 shows the experimental hall filled with air and with:

- One lead diffuser foil of 0.12 mm of thickness.
- Two stainless steel collimators of 100 mm diameter. Their thickness is 20 mm.
- One 2 mm BC400 scintillator ($H_{11}C_{10}$) for flux monitoring
- One aluminum cylinder of 100 mm diameter and 13.6 mm of thickness as approximation of the aluminum Dewar cover and shield.
- One copper cylinder of 100 mm diameter and 0.51 mm of thickness as approximation of the copper shield.

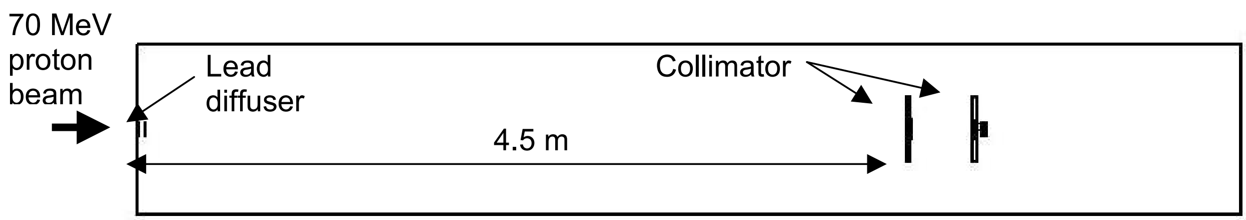


Figure 1: Experimental Setup

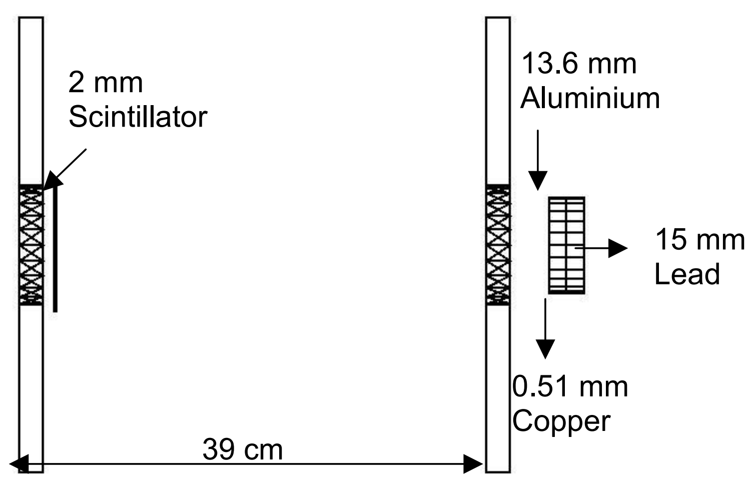


Figure 2: Experimental Setup

The monitor scintillator set between the collimators can be seen in the detailed view of Figure 2. The performed simulation aims at determining the spectrum of the proton energy behind the aluminium and copper material.

10^6 protons of 70 MeV have been simulated. About 10% of them hit the lead target set behind the copper. Figure 3 shows their energy distribution function in arbitrary units. The mean value of this distribution is **7.44 MeV** and the "variance" 3.07 MeV. The red curve represents the integral energy spectrum of protons. At each energy value corresponds the fraction of protons with an energy higher than this value. Almost no protons have an energy > 15 MeV and 50% have an energy > 7.8 MeV.

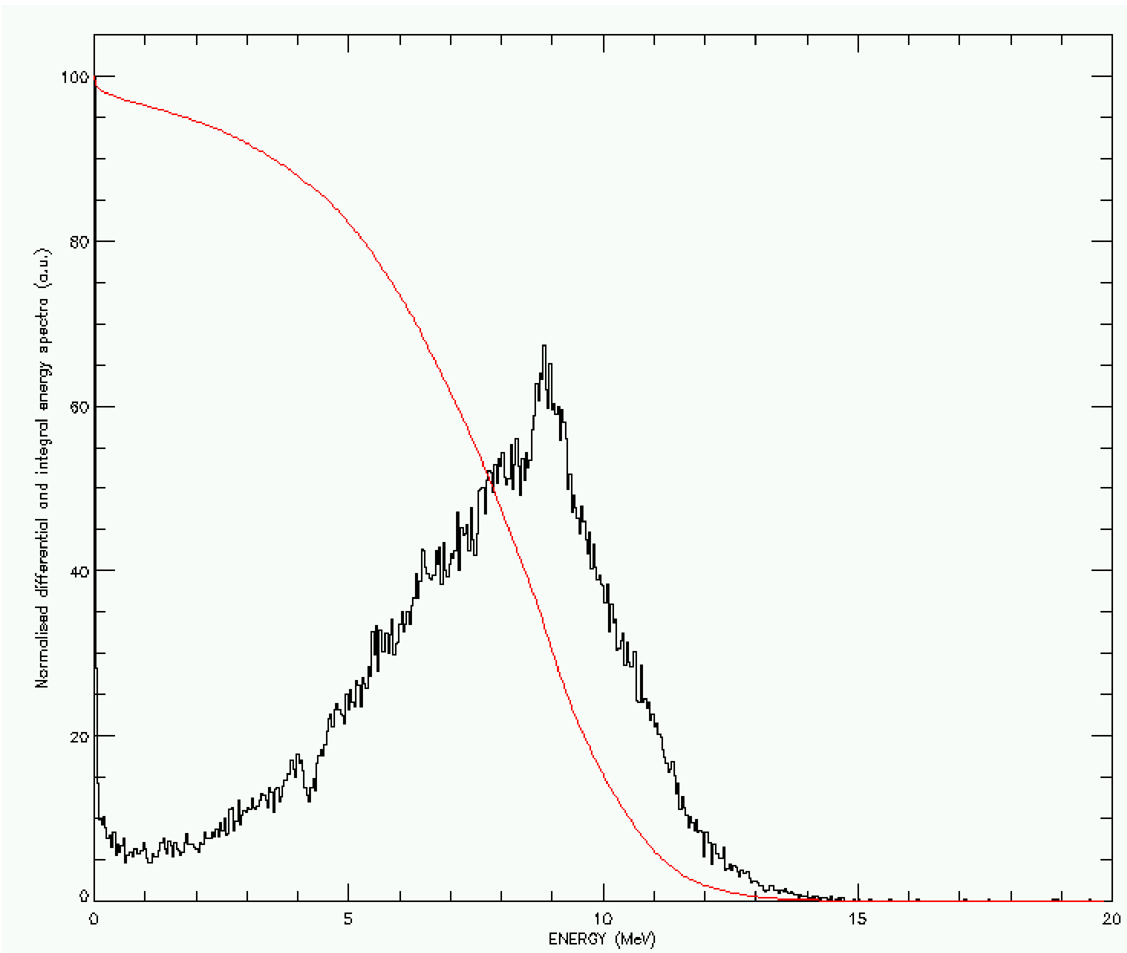


Figure 3: Energy distribution

A calculation has also been done using the range tables generated with SRIM2000. The residual energy after each crossed material is presented in Table 1. Both methods give the same order of magnitude in energy.

Material	Pb	Air	Poly	Air	Al	Cu
Thickness	0.12 mm	4.52 m	2 mm	0.42 m	13.6 mm	0.51 mm
Remaining energy	69.34 MeV	64.24 MeV	62.04 MeV	61.54 MeV	19.29 MeV	**9.88 MeV**

Table 1: Energy calculation using range tables from SRIM2000 program.

A second simulation has been done without the 2 mm plastic scintillator.
Figure 4 shows new energy distribution function. The mean value is **17.16 MeV** and the variance 1.5 MeV. This mean value can be compared with SRIM2000 calculations which are in table 2. In this configuration, Almost no protons have an energy > 23 MeV and 50% have an energy > 17.15 MeV.

Material	Pb	Air	Poly	Air	Al	Cu
Thickness	0.12 mm	4.52 m	0 mm	0.42 m	13.6 mm	0.51 mm
Remaining energy	69.34 MeV	64.24 MeV	64.24 MeV	63.74 MeV	24.33 MeV	**17.10 MeV**

Table 2: Energy calculation using SRIM2000 program without the plastic scintillator.

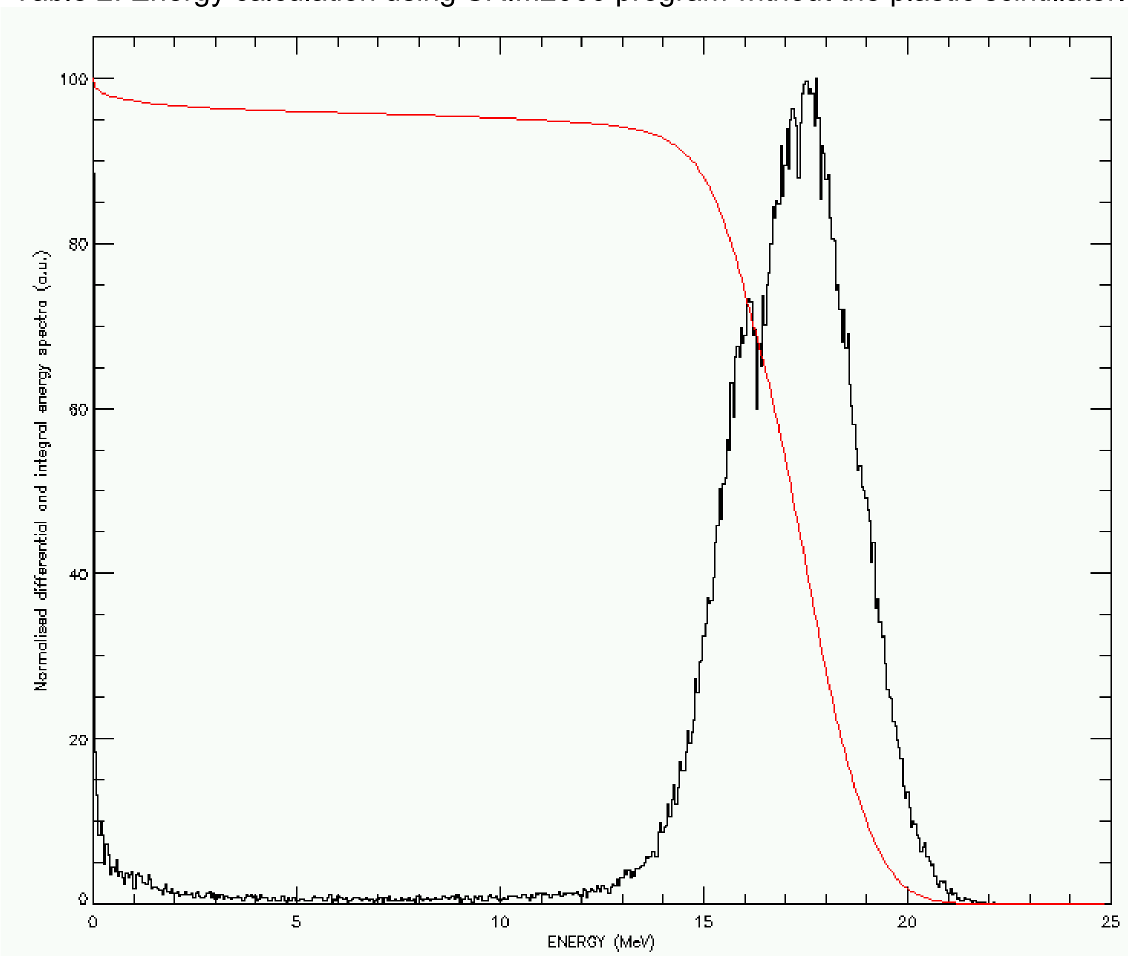
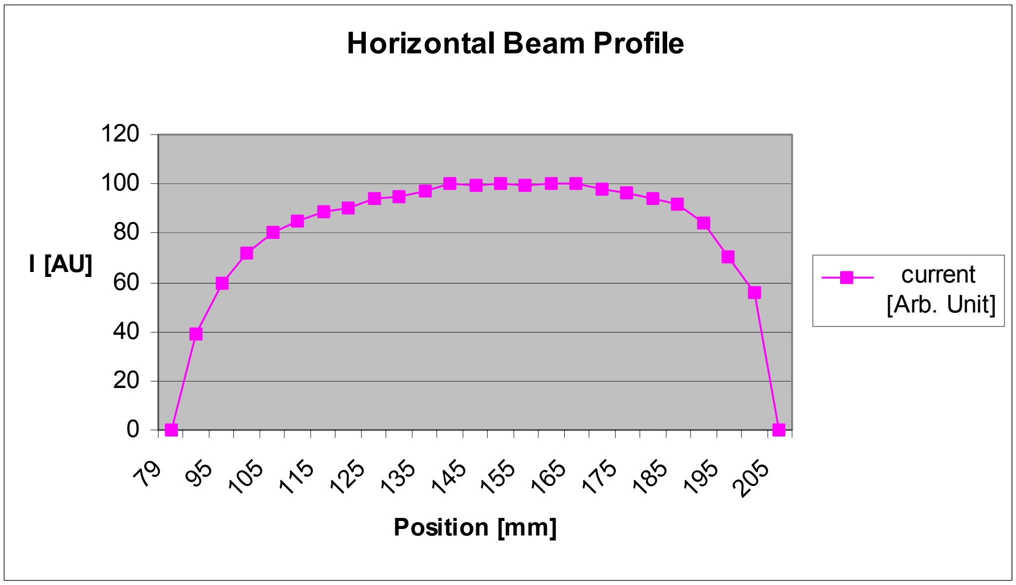


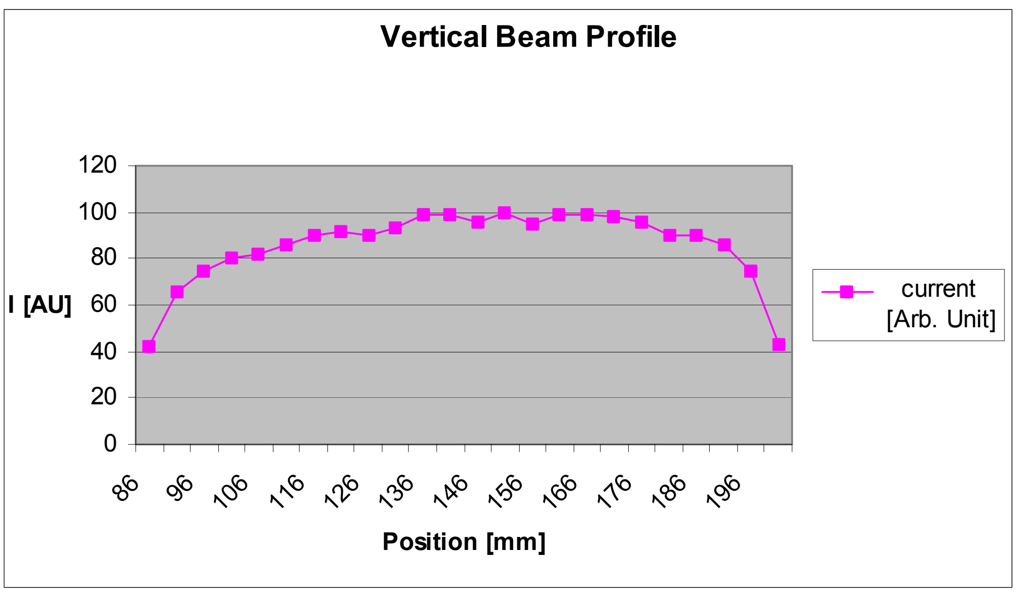
Figure 4: Energy distribution without the plastic scintillator.

Remark by R. Katterloher:
The energy distribution as given in Figure 4 was the actually used spectrum during PACS HS detector module proton irradiation runs on 07 and 08 April 2005.

Measured Proton Beam Homogeneity

(Figures provided by G. Berger)





Document Annex 4

Email of 21 September 2005

From: Pierre Royer

Datum: Wed, 21 Sep 2005 19:19:58 +0200
Von: Pierre Royer <pierre@ster.kuleuven.be>
An: Reinhard Katterloher <rkatterloher@yahoo.de>
CC: Albrecht Poglitsch <alpog@mpe.mpg.de>,
Josef Schubert <schubert@mpe.mpg.de>, Lothar Barl
<barl@mpe.mpg.de>, gerdjakob@yahoo.de, Martin Groenewegen
<groen@ster.kuleuven.be>, Helmut Feuchtgruber <fgb@mpe.mpg.de>
Betreff: Proton irradiation tests FM LS Oct 2005

Dear all,

A discussion took place at the last CM meeting (splinter) about the next proton test period. The outcomes on the planning for the next period are:
- that it would be nice to be able to synchronize the flasher with the ramp acquisition to simulate a chopped measurement. This has impact on Lothar on extremely short notice, so everybody is conscient this might be very difficult to achieve.
- some ideas for the planning, namely :

0. Chose one setting that will most probably survive the 'post-solar-flare-self-cured-plateau'
(with HS modules, this was Cf=0.2pF and bias=30mV)
1. Start with high proton flux to simulate solar flare
2. Let self curing do its job in order to get the level of the 'worst case plateau' (in responsivity)
3. Investigate the curing methods
4. Finish with efficient curing ;-)
5. Do a veeeeery long test under low proton flux, in order to see whether or not we reach the same plateau as after solar flare event, and after how long
6. At the end of the very long test
- if a plateau is reached, go to step 7.
- if the responsivity is still slowly but steadily increasing, re-simulate solar flare + self curing
7. Vary the ramp length and bias parameters in order to search for the 'optimal setting'.

If all that, as I guess, doesn't fit in one test day, step 7 could happen the second day after a solar flare simulation.

Another option is to chose 3 or 4 best guess settings, and rotate over them during the long test in order to already be able to analyse them at every stage of the process.

All comments welcome, and of course, you are those you finally decide.

Pierre
(but Lothar, who finally sends the commands, stays in full power whatever you decide of course ;-)

3. VERIFICATION MANAGEMENT

As stated in the PACS Test Plan [AD1], all test activities are performed under responsibility of the institute / organization, represented by the local coordinator. The HERSCHEL PACS test coordinator is responsible for execution of the detector proton irradiation test plan and application of procedure PACS-ME-TP-009_3.1.

The HERSCHEL PACS PA/QA organization will monitor the test activities.

Facility and test surveillance will be covered by the PA organization of the institute responsible for the execution of the test (UCL-CRC).

Anomalies or difficulties identified during the test run will be treated as follows:

A) Stop test

B) Identify whether the anomaly is in the unit or in the test set-up

C1) No failure: Continue testing, report in logbook (filled-in test procedure)

C2) Failure in the test set-up: Repair the failure and continue the test. If test results have been invalidated, the test team will redo the test, if it does not overstress the unit(s)

Activities are recorded in the logbook.

C3) Failure in the unit: Raise a NCR and process it in accordance with the PA-Plan.

4. TEST PLAN

4.1 Test Definition

The test requires a set-up consisting of two test equipments,

the MPE part, i.e., the PACS detector module QM#25, a LHe dewar with integrated and upgraded optics OGSE2 (heater, flasher etc.), a pumping unit, a detector read-out and supply electronics and a data recording system

and the UCL-CRC part, i.e., the LIF cyclotron and specific beam conditioning components and calibration devices.

The proposed test is carried out at UCL-CRC site. The test sequence is given in Fig. 1. The duration of the individual test activities is given in Fig. 2. The planned sequence of test steps is given in chapter 6 “test procedure”:

The **planned** measurements are cross-combinations of following operating parameters, see Table 1. The rationale behind the proposed sequence is to do long term “L2” irradiations at different bias voltages. Detector curing activities are specified as single events or combinations of bias boost, IR-flashing and temperature increase, executed at specific points in the overall sequence. The final decision to perform a specific curing is made “ad hoc” depending on the observed effectiveness during long term irradiation. The curing efficiency after “simulated flares” and the best operational settings are to be investigated as well.

Parameter	Setting#1	Setting#2	Setting#3	Setting#4
Proton flux p cm^{-2} s^{-1}	0	10 (42)	400	-
Mean proton energy at detector crystal MeV	≅ 17	-	-	-
LS Detector temperature Kelvin	2.5	up to 10 K for curing LS		
LS Detector bias voltage mV	0	80	120	200
Ramp integration time (reset interval) ms	67	125	250	500 or 1000
# number of ramps (total measurement time)	256 nominal	512 for specific measurements	1024 for specific measurements	others for specific measurements

Table 1

4.2 Test Sequence

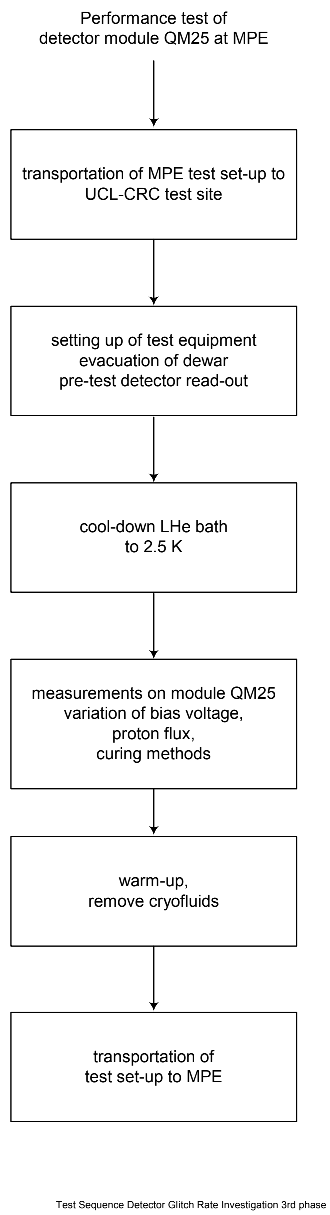


Figure 1: Test Sequence for Detector Glitch Rate Investigation (3rd test phase)

ID	Task Name	Duration	Start	Finish
1	**Detector Module QM#25 proton irradiation**	**9 days**	**29-09-05**	**07-10-05**
2	Performance check on QM#25 finished at MPE	0 days	29-09-05	29-09-05
3	packing of equipment finished	0 days	30-09-05	30-09-05
4	Transportation of MPE test set-up to CRC	1 day	30-09-05	30-09-05
5	Set up of MPE test equipment, evacuate dewar, LN2	2 days	01-10-05	02-10-05
6	Cool-down to LHe	1 day	03-10-05	03-10-05
7	Measurements / proton Irradiation QM#25	1 day	04-10-05	04-10-05
8	Measurements / proton irradiation QM#25	1 day	05-10-05	05-10-05
9	Remove MPE equipm. from test site, warm-up, packing	1 day	05-10-05	05-10-05
10	Transportation of test set-up to MPE	1 day	07-10-05	07-10-05

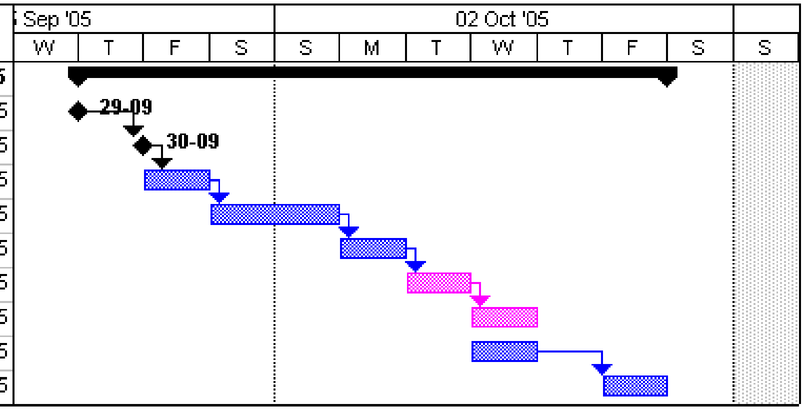


Figure 2: Schedule of 3rd Detector Glitch Rate Investigation at UCL-CRC

5. TEST SPECIMEN, TEST FACILITIES AND REQUIREMENTS

5.1 Detector module QM#25

The test specimen foreseen for the proposed investigations under proton irradiation is detector module QM#25 with a cryogenic read-out electronics (CRE) of the FM type, mounted in the center of the module. The detector part consists of a low-stressed linear array of 16 Ge:Ga detector pixels with fore-optics (linear array of 16 light cones). A complete module of this type is shown in Fig. 3 (right). A full detector array of PACS consists of 25 modules in a stacked configuration. QM#25 has been manufactured for specific test purposes and will not be integrated later with the PACS FPU FM.

Detector module QM#25 is mounted inside a LHe dewar with test optics (OGSE2) and specific detector curing devices, for details see chapter 5.3.

The detector current produced in each pixel by incoming far infrared light is integrated on a selectable capacity in the CRE chip and the time dependent voltage signal (the “ramp”) is read-out during an integration interval before a reset is done [RD8], [RD11]. An example of a disturbed sequence of signal ramps is shown in Fig. 4. The negative slope of the ramps corresponds to the detector current and is further called “signal”. Ionizing radiation generates additional charge carriers in the detector crystal, which are partly trapped or collected and added to the nominal signal current. This effect shows up as a “glitch” (step) of the ramp and a change in slope. The aim of the proposed investigation is to create on ground under proton irradiation a data set of signal ramps disturbed by glitches and affected by ionization effects. Such signal ramps are expected when the PACS instrument is in orbit. A most suitable algorithm for ramp restoration to retrieve a calibrated signal must be developed before the Herschel satellite is launched.

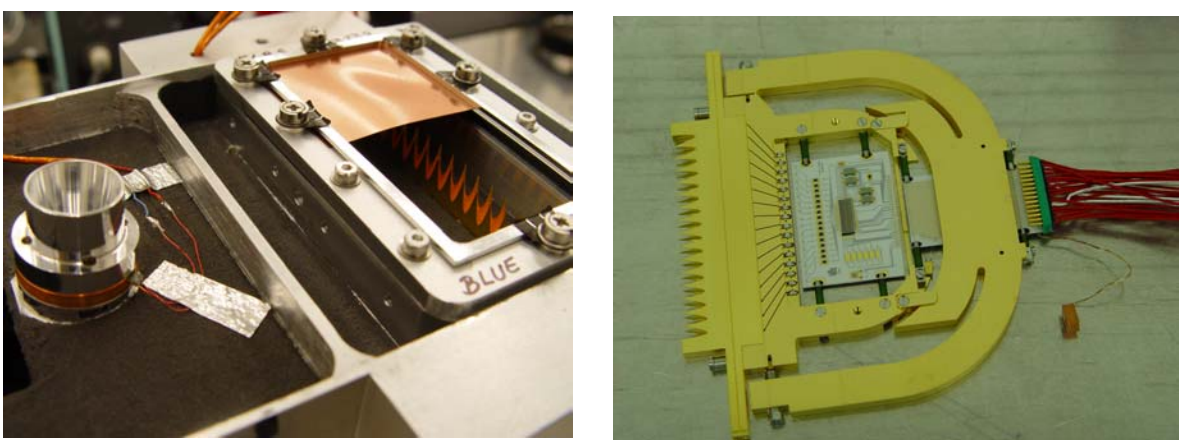


Fig. 3: PACS low stressed Detector Module (right) and details of OGSE2 test optics (left): flasher and FIR cut-on filter that covers half of the detector row (pixels 1 – 8)

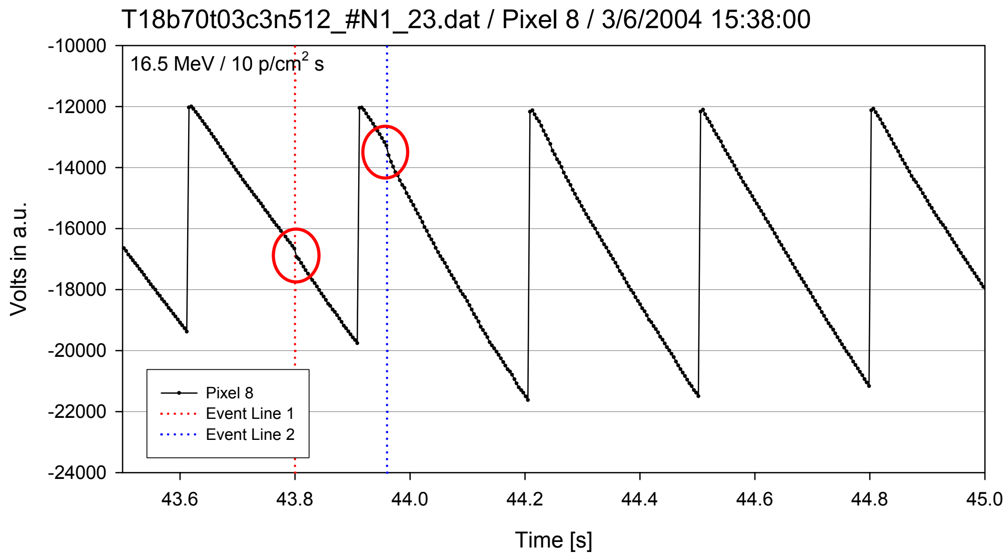


Fig. 4: Example of observed QM type FEE Detector Signal Ramps with glitches, slope increase and resets during the 1st test phase at CRC

5.2 MPE Detector Read-out Electronics and Test Set-up

A block diagram of the detector supply and read-out electronics and of the cryogenic test set-up is shown in Fig. 6. Fig. 7 shows the location of units in the CRC lab.

5.3 OGSE 2 Detector Module Test Optics

OGSE 2 consists of the LHe-dewar with a cryogenically cooled optics and an entrance window, which in combination with a 2 mm aperture generates the nominal IR-background of about $3x10^{-14}$ W to the photoconductive detector elements behind the FIR cut-on filter. The pumped LHe bath provides a LS detector module operating temperature of 2.5 K . OGSE2 has been upgraded for the 3rd test phase at CRC: Half of the detector row (pixel 1 to 8) is covered by a FIR cut-on filter (52 µm), same as is used in the PACS FPU where it covers the full array. A flasher (cryogenic BB source) is mounted near the optical beam at a position where its emitted IR radiation can enter the light cones of the detector module. The flasher will be used for detector curing, the cut-on filter allows to demonstrate whether the spectral composition of the IR light affects the curing efficiency. A second device for detector curing is an electrical heater element on the module allowing a short term temperature rise up to 11K. The flasher can also produce a small increase (few per cent) of the nominal IR background flux, this way a check of responsivity changes after irradiation is possible (sorting out dark current effects). The small flux increase produced by the flasher is shown in chapter 9.3. OGSE2 will be placed in the high energy proton beam, which is produced in the Light Ion Facility of the Centre de Recherches du Cyclotron, UCL. The OGSE 2 design principle is shown in Figures 8, 9 and 10.

5.4 Requirements for operation of OGSE 2 and detector electronics

The electrical power supply has to provide 240 V 1 phase and 3 phase, 16 A.

For cool-down and operation of the detector dewar during the 3rd test phase, 50 liters of LN_2 and 50 liters of LHe are needed. Transfer tubes are provided by MPE.

5.5 Light Ion Facility at CRC

The Light Ion Facility (LIF) of CRC is proposed for the investigation of detector glitch rates at different detector operating conditions.

Adaptation of the proton beam to the specific needs of PACS detector module testing was necessary (very low flux, large beam spot).

The proton beam irradiates the full row of detector elements as well as the CRE device, see Fig. 9.

5.6 Shielding of the Ge:Ga detectors

The germanium crystal elements (1x1x1.5 mm^3) are sitting inside the stress module that is made of aluminum. From the outside of the OGSE2 dewar up to the surface of the crystals the protons need to penetrate an average material thickness of

- 13.6 mm aluminum and
- 0.51 mm copper

To achieve this condition, the dewar has to be tilted by 10 degrees around a horizontal axis perpendicular to the line of sight. Otherwise, the bulky lower flange of the dewar would create an additional shading of the detector row.

On board of the satellite, the walls of the Herschel CVV and the PACS instrument and detector housing add up roughly to a similar thickness as for the current test set-up: A minimum total thickness of approximately 11 mm aluminum shielding exists onboard the satellite before the protons reach the detector crystal surface.

5.7 Requirements on the proton beam

The impact of ionizing particle radiation on Germanium infrared photoconductors is discussed in [RD1], [RD2], [RD3]. The results are based on experience gained during the ISO mission. The expected radiation environment for the Herschel satellite and the PACS instrument in the L2 orbit is discussed in [RD4], [RD5].

Proton fluxes and energies proposed for the measurements at UCL-CRC are suggested in [RD6], [RD7], [RD9], [RD10]. Following values are derived for the 2nd and 3rd test phase and the actual set-up using GEANT4 simulation and SRIM2000 tables [RD13]:

Proton energy at the detector pixel: 17.1 MeV (SRIM2000)

Proton energy at the detector pixel: 17.16 MeV + variance of 1.5MeV (GEANT4)

Beam diameter at the detector plane: 100 mm

Flux at the detector plane: 10 p cm^{-2} s^{-1} or 400 p cm^{-2} s^{-1}

Flux homogeneity: +/- 20 %

5.8 Calibration of the CRC beam set-up and monitoring

Further developments were needed on the actual Light Ion Facility (LIF) beam line in order to be usable for PACS spectrometer calibration. A schematic of the actual beam line is shown in Fig. 5. The necessary modifications as proposed by UCL-CRC are presented hereafter.

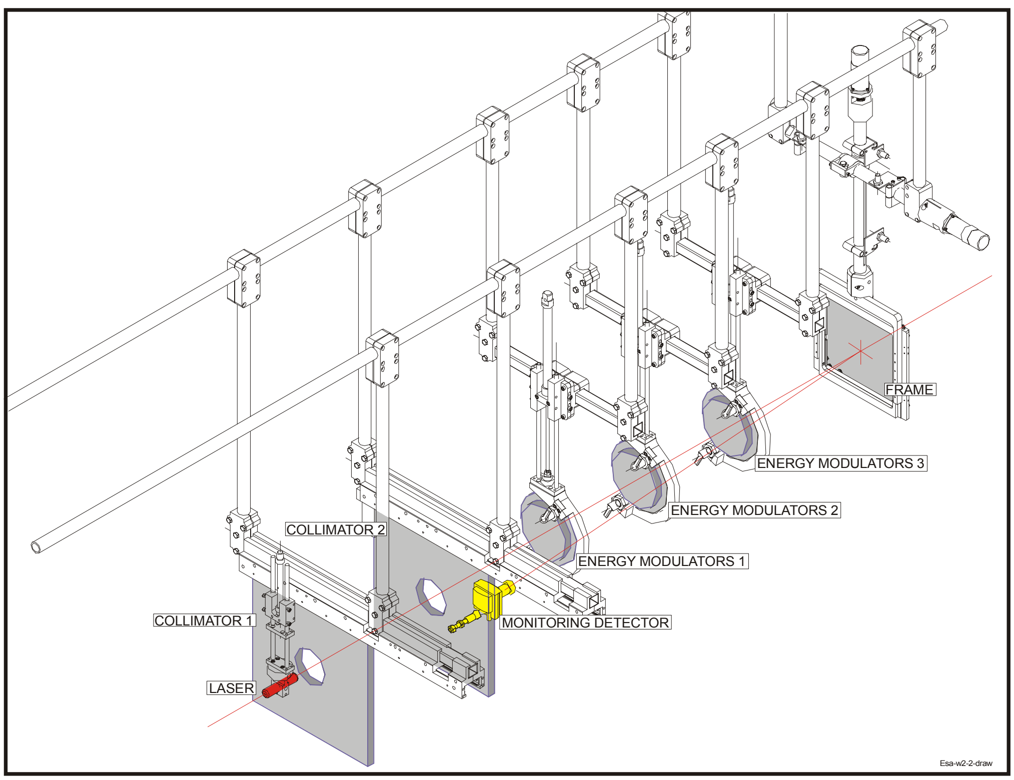


Fig. 5: LIF Beam Line (picture provided by UCL-CRC)
Energy modulator RS1 is not used during test phase 2

Beam characteristics (energy and flux)

Using a primary proton beam of 70 MeV, with the actual beam line consisting of a flight path of 5 m between the diffusion foil and the Device Under Test (DUT), a final energy of 64.2 MeV can be reached outside the detector test dewar.

Under these conditions, using SRIM2000 range tables to calculate the proton energy after a 13.6 mm Al + 0.51 mm Cu (dewar wall, shields and detector housing), 17.1 MeV protons on the crystal surface can be obtained. The GEANT4 simulation gives a mean proton energy of 17.16 MeV with 1.5 MeV variance.

It is proposed to use the standard 70 MeV proton beam.

In order to fulfill the flux requirements, i.e. about 10p/s cm² and 400 p/s cm², beam developments were needed. Indeed, these fluxes are several orders of magnitude lower than the usual LIF beams. A specific cyclotron tuning procedure is needed to obtain such a low flux while keeping a stable beam.

Beam Calibration

Before the experiment starts, a complete beam control and calibration will be carried out. For this, the actual detection system will be used.

- Beam uniformity: controlled with a diode on a X-Y arm in a water phantom (a 10 cm diameter spot with an uniformity of ± 10% is aimed for).
- Beam energy: controlled with the Bragg peak position in the same water phantom.

Monitoring detector

As the usual LIF setup is not configured to measure low proton fluxes, a newly developed beam monitoring system is used.

A 5mm thick scintillator will be placed in front of the Collimator 1 block (cf. Fig 5). This localization allows keeping the same calibration factor through whole energy range as the energy degraders are placed behind the monitoring detector. The scintillator shape will be annular to avoid additional beam energy losses.

The complete setup will be calibrated using a large surface scintillator (2 or 5 mm thickness) placed on the beam axis at the frame location.

5.9 Requirements on manpower

MPE

In order to operate the detector test equipment properly and to run the test efficiently, MPE will send the following personnel to UCL-CRC during the 3rd test phase:

- R. Katterloher (test conductor)
- L. Barl (operator, electronics responsible and quick look analysis)
- G. Jakob (cryogenics responsible)

KUL

In order to monitor and optimise the detector test phase for maximum information, KUL will send the following personnel to UCL-CRC during the 3rd test phase:

- P. Royer (program concept and data analysis)

MPIA

In order to monitor and optimise the LS detector test phase for maximum information, MPIA will send the following personnel to UCL-CRC during the 3rd test phase:

- N.N.

UCL-CRC

Operation and surveillance of the CRC LIF facility during the PACS detector test requires trained personnel of UCL-CRC. Required personnel will be made available by UCL-CRC.

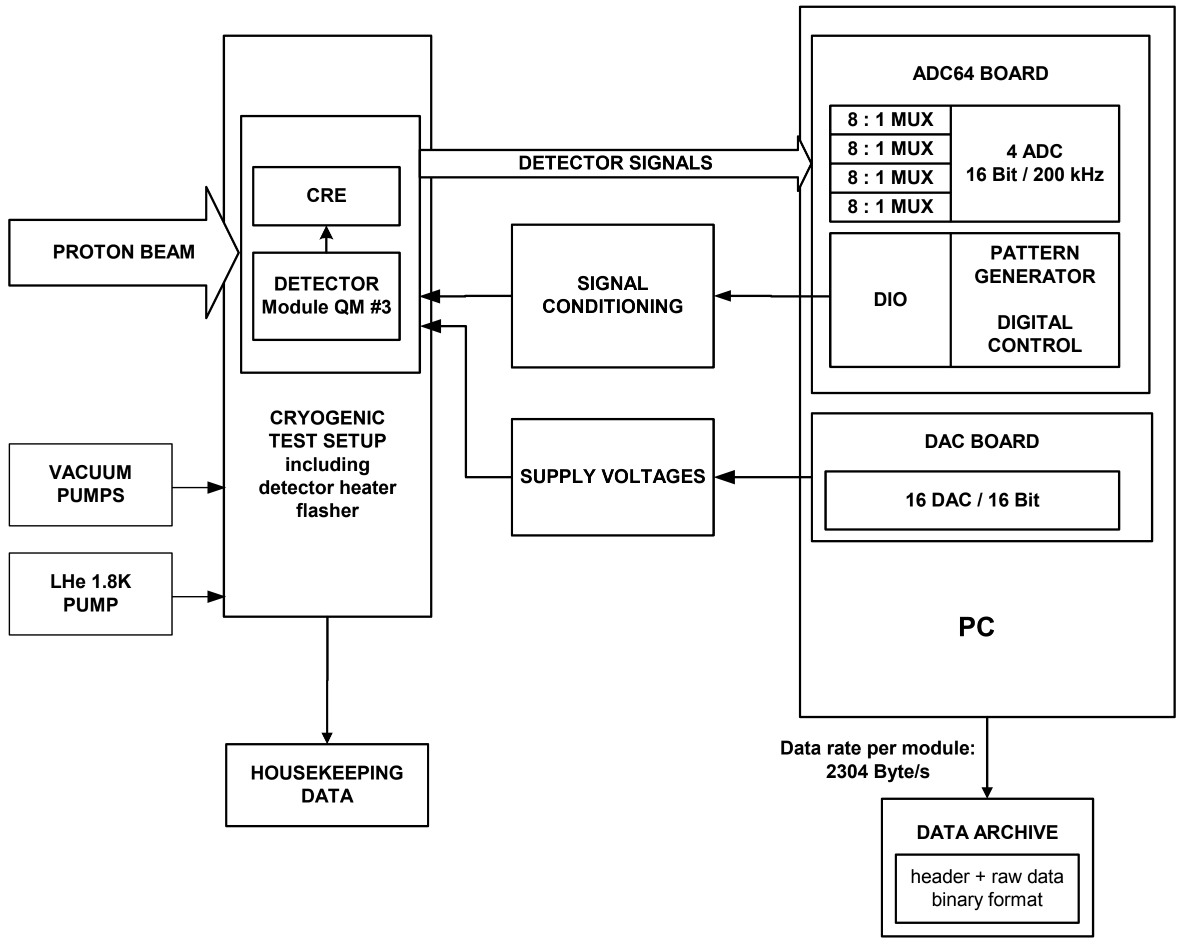


Figure 6: Block Diagram of Detector Read-out Electronics and Test Set-up

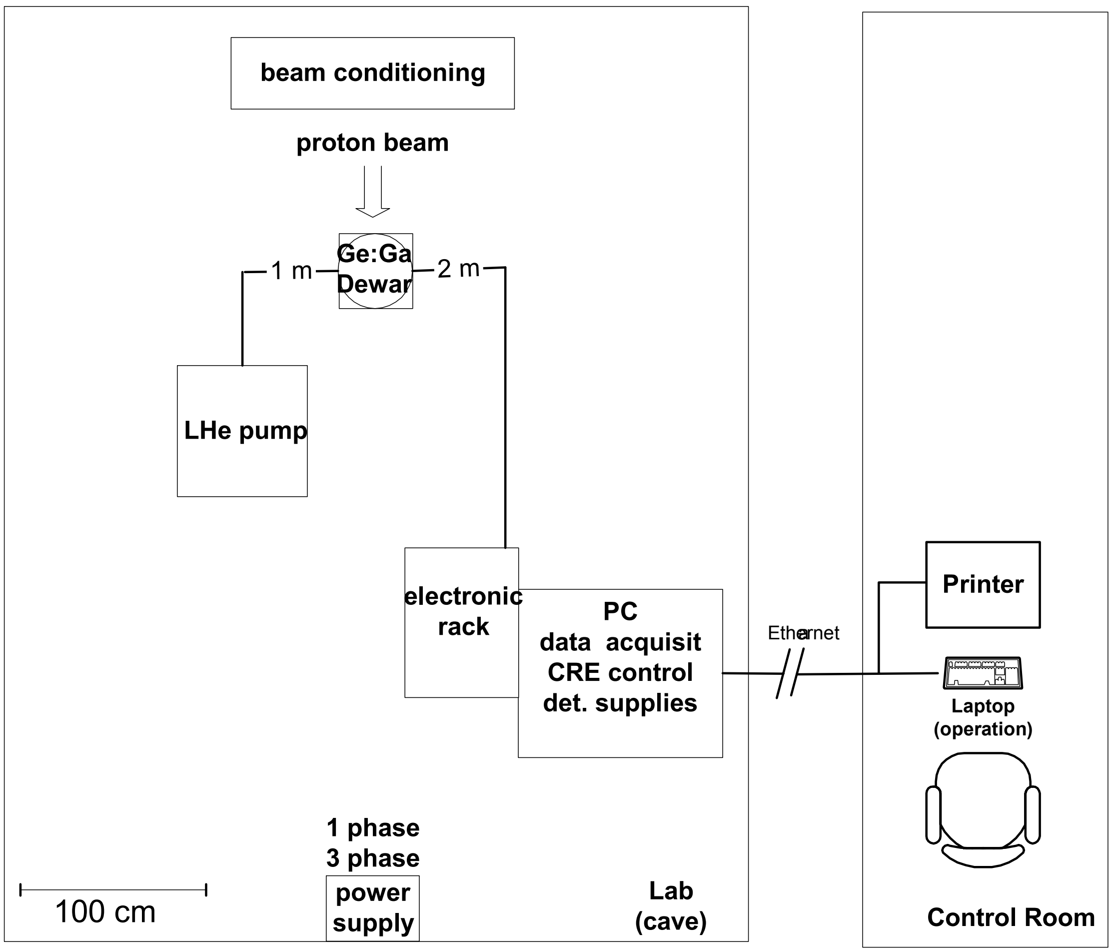


Figure 7: Proposed location of test equipment components in the CRC laboratory (further in the test procedure called "cave") and in the control room

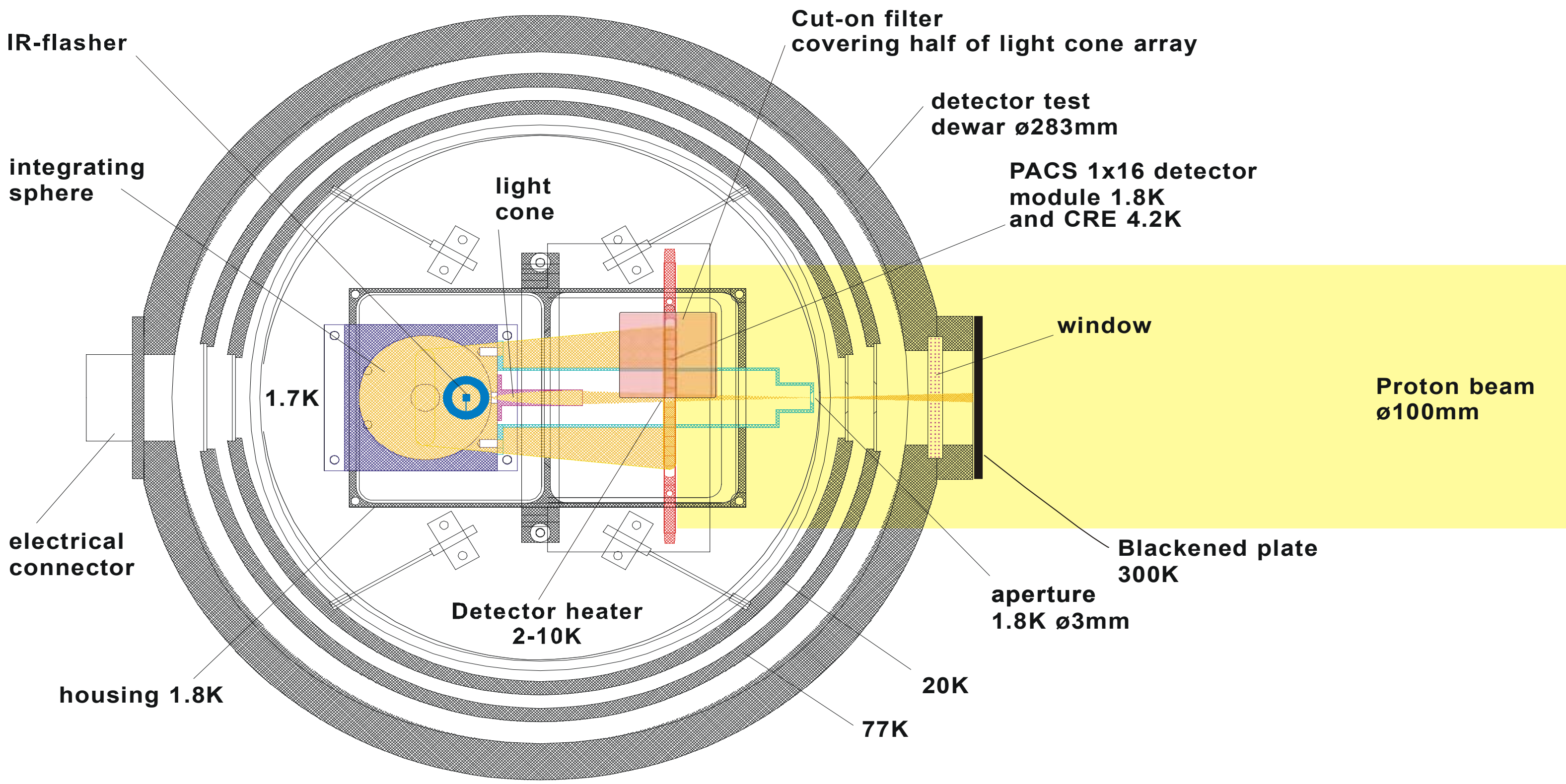
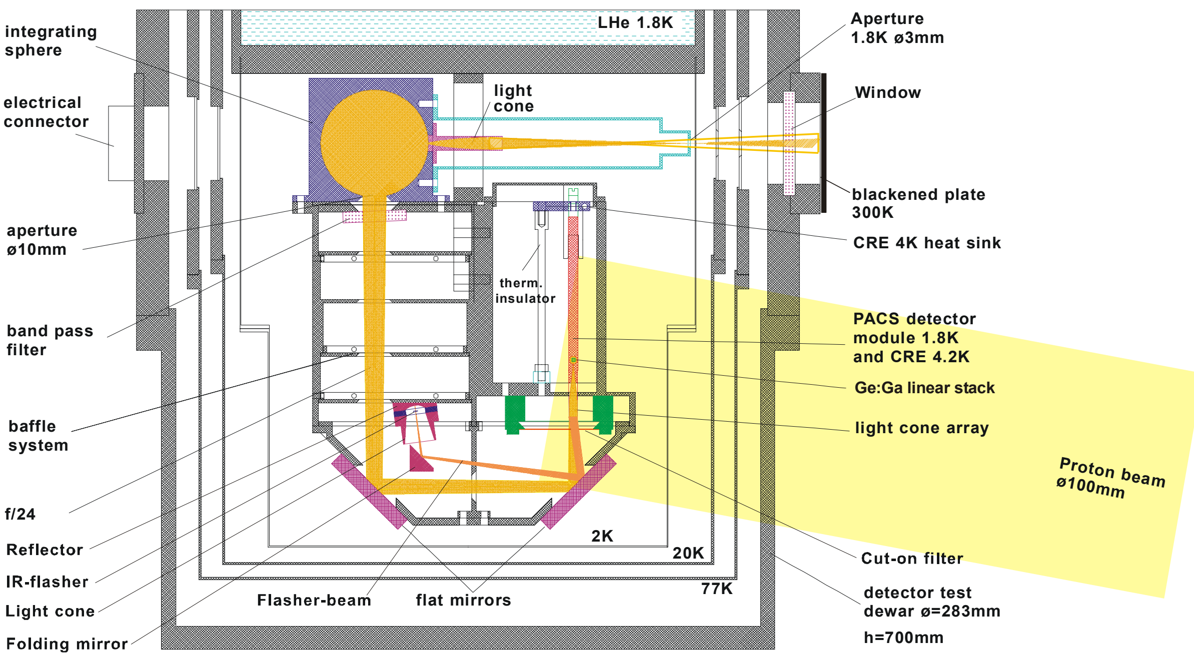


Figure 8: Upgraded OGSE 2 Cross Section horizontal



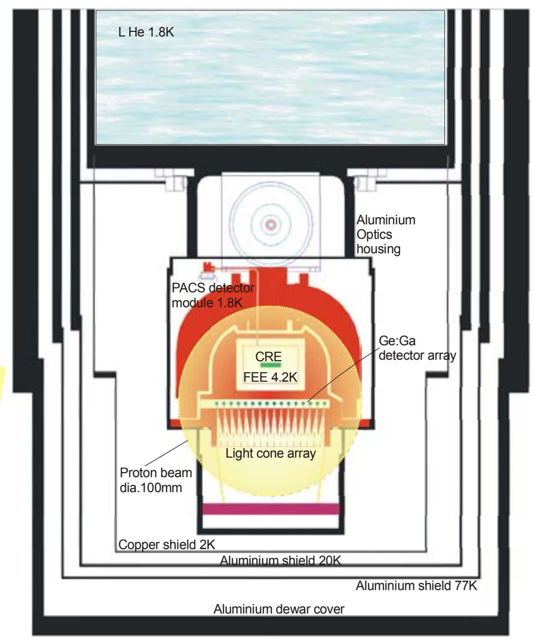


Fig. 9: Upgraded OGSE 2 Cross Section vertical (side view)

Fig. 10: OGSE 2 Cross Section vertical (front view)

6. TEST PROCEDURE

Remark: Program and sequence are tentative and may be modified during test run !

Set-up of equipment:

Prepare MPE detector equipment for test runs after transportation to UCL-CRC

Evacuate detector dewar

Connect detector dewar to read-out electronics and supply units

Perform health check of low-stressed detector module QM#25 at room temperature

Verify data recording

Cool-down detector dewar

Move test set-up to test site (beam laboratory “cave”)

Pump down LHe to 2.5 K

Verify data recording

Request readiness of CRC facility and beam conditioning equipment

Set operating parameters

Start measurement and continue according defined sequence

Test definitions and parameter settings:

(dewar configuration: proton beam enters the detector dewar underneath the dewar window as during test phase 1)

Set proton flux OFF

Measurement #N_1

CRC proton flux	0 cm^{-2} s^{-1}
CRC proton energy	NA
detector operating temperature:	2.5 K

detector bias voltage: 200 mV, 120 mV, 80 mV

CRE ramp integration time: 1 s, followed by 0.5, 0.25, 0.125, 0.067 s

number of ramps: 256 nominal (or adapted to specific needs)

Measurement numbering convention: #N_1, #N_2, #N_3, ….. (running numbers)

Record signal, determine responsivity and performance

Set next lower bias voltage and continue above sequence

Apply 3 **small** IR flux steps of 40 sec with flasher and 40 sec pause for each bias setting at a selected best integration time (to identify true responsivity increase).

Set low proton flux and continue measurements

Measurement #**L**_1

CRC proton flux: 10 cm^{-2} s^{-1} (was 42 cm^{-2} s^{-1} during first test day)

CRC proton energy: 17 MeV

detector operating temperature: 2.5 K

detector bias voltage: **200** mV

CRE ramp integration time: 0.125 s (or adapted to needs)

number of ramps : 2048 (may be continued in series)

Record signal, determine responsivity and performance changes

Apply 3 **small** IR flux steps with flasher for 40 sec and 40 sec pause at the selected bias voltage during signal increase and at the end of signal stabilization.

number of ramps : 256 TBC

Record signal, determine responsivity and performance changes

Perform curing methods:

Continue with measurement # L_x with parameter settings of #L_1.

After 1 min apply curing method
(a) bias boost 2.5V for 1 min (set CRE in appropriate mode), 1 min pause, and repeat

it few times until effect is seen or can be definitely denied
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

Continue with measurement # L

After 1 min apply curing method
(b) operate flasher at max. power (4 mA) for 1 min, 1 min pause, and repeat it few times TBC until effect is seen or can be definitely denied
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

Continue with measurement # L

After 1 min apply curing method
(c) heat-up detector heater to 10K TBC for 1 min TBC and repeat it for longer until effect is seen or can be definitely denied
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

Continue with measurement # L

After 1 min apply curing method
(d) combination of method (a) + (b) + (c) simultaneously TBC
and repeat combinations until curing effect is enhanced.
This test to be performed only in case (a), (b) or (c) alone is not sufficient.
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

Continue with measurement # L with new parameter setting:

Measurement #L

CRC proton flux	10 cm^{-2} s^{-1} (was 42 cm^{-2} s^{-1} during first test day)
CRC proton energy	17 MeV
detector operating temperature:	2.5 K
detector bias voltage:	**120** mV
CRE ramp integration time:	0.25 s (or adapted to needs)

number of ramps : 2048 (may be continued in sequence)

Record signal, determine responsivity and performance changes

Apply 3 small IR flux steps with flasher for 40 sec and 40 sec pause at the selected bias voltage during signal increase and at the end of signal stabilization.

number of ramps : 256 TBC

Record signal, determine responsivity and performance changes

Perform curing methods

Continue with measurement # L

After 1 min apply curing method
(a) bias boost 2.5V TBC for 1 min, 1 min pause, (set CRE in appropriate mode) and repeat it few times until effect is seen or can be definitely denied
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

Continue with measurement # L

After 1 min apply curing method
(b) operate flasher at max. power (4 mA) for 1 min, 1 min pause and repeat it few times until effect is seen or can be definitely denied
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

The following two curing methods (c) or (d) need very likely not to be applied if (a) or (b) are found appropriate methods in the test runs before

Continue with measurement # L

After 1 min apply curing method
(c) heat-up detector heater to 10K for 1 min and repeat it for longer or higher temperature until effect is seen or can be definitely denied
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

Continue with measurement # L

After 1 min apply curing method
(d) combination of method (a) + (b) + (c) simultaneously TBC and repeat combinations until curing effect is enhanced.

This test to be performed only in case (a), (b) or (c) alone is not sufficient.
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

Continue with measurement # L with new parameter setting:

Measurement #L

CRC proton flux	10 cm^{-2} s^{-1} (was 42 cm^{-2} s^{-1} during first test day)
CRC proton energy	17 MeV
detector operating temperature:	2.5 K
detector bias voltage:	**80** mV
CRE ramp integration time:	0.25 s (or adapted to needs)
number of ramps :	2048 (may be continued in sequence)

Record signal, determine responsivity and performance changes

Apply 3 small IR flux steps with flasher for 40 sec and 40 sec pause at the selected bias voltage during signal increase and at the end of signal stabilization.

number of ramps : 256 TBC

Record signal, determine responsivity and performance changes

Perform curing methods

Continue with measurement # L

After 1 min apply curing method
(a) bias boost 2.5V for 1 min (set CRE in appropriate mode), 1 min pause, and repeat it few times until effect is seen or can be definitely denied
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

Continue with measurement # L

After 1 min apply curing method
(b) operate flasher at max. power (4 mA) for 1 min, 1 min pause, and repeat it few times until effect is seen or can be definitely denied
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

The following two curing methods (c) or (d) need very likely not to be applied if (a) or (b) are found appropriate methods in the test runs before

Continue with measurement # L

After 1 min apply curing method
(c) heat-up detector heater to 10K for 1 min and repeat it for longer or higher temperature until effect is seen or can be definitely denied
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization

Continue with measurement # L

After 1 min apply curing method
(d) combination of method (a) + (b) + (c) simultaneously TBC
and repeat combinations until curing effect is enhanced.
This test to be performed only in case (a), (b) or (c) alone is not sufficient.
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches stabilization at an increased responsivity, then do the following check:

Continue with measurement # L with **modified ramp parameter** settings:

Measurement #L

CRC proton flux	10 cm^{-2} s^{-1} (was 42 cm^{-2} s^{-1} during first test day)
CRC proton energy	17 MeV
detector operating temperature:	2.5 K
detector bias voltage:	**80** mV
CRE ramp integration time:	0.25 s (or adapted to needs)
number of ramps :	2048 (may be continued in sequence)

Record signal, determine responsivity and performance changes

Change CRE ramp integration time:	1, 0.5, 0.25, 0.125, 0.067 s TBC
number of ramps:	256 nominal (or adapted to specific needs)

(Apply 3 small IR flux steps with flasher for 40 sec and 40 sec pause at the selected bias voltage during signal increase and at the end of signal stabilization after longest and shortest integration time TBC

number of ramps: 256 TBC)

Record signal, determine responsivity and performance

Set proton flux OFF

Measurement #N

CRC proton flux	0 cm^{-2} s^{-1}
CRC proton energy	NA
detector operating temperature:	2.5 K
detector bias voltage:	60 mV
CRE ramp integration time:	1, 0.5, 0.25, 0.125, 0.067 s
number of ramps:	256 nominal (or adapted to specific needs)

Apply a small IR flux step of 10 sec with flasher for each integr. time and bias voltage

Record signal, determine responsivity and performance

End of "low proton flux only" measurement series !

The next series of measurements should investigate the situation AFTER a simulated solar flare, e.g., a high proton flux of 400 p/cm^{2}s for 15 min TBC and then return to low proton flux.

Set low proton flux and start measurements

If the test is started the next day, do first a NO flux signal check at 120 mV (similar as done the day before), then switch to LOW flux and wait 15 min.

Measurement #L

CRC proton flux	10 cm^{-2} s^{-1}
CRC proton energy	17 MeV
detector operating temperature:	2.5 K
detector bias voltage:	**120** mV TBC
CRE ramp integration time:	0.25 s (or adapted to needs)
number of ramps :	2048 (may be continued in sequence)

Record signal, determine responsivity and performance changes

Apply 3 small IR flux steps with flasher for 40 sec and 40 sec pause at the selected bias voltage during signal increase and at the end of signal stabilization.

number of ramps :	2048

Record signal

After signal settling apply **high** proton flux as described below:

Set high proton flux and continue measurements

Measurement #H_1:

CRC proton flux	400 cm^{-2} s^{-1}
CRC proton energy	17 MeV
detector operating temperature:	2.5 K
detector bias voltage:	**120** mV TBC

CRE ramp integration time: 0.25 s (or adapted to needs)

number of ramps : 2048 (may be continued in sequence)

Record signal, determine responsivity and performance changes

After stabilization of signal (15 min TBC) **switch from high to low proton flux** and apply **self-curing** for 30 min TBC

Continue with measurement with parameter settings of #L

After 1 min apply best curing method
(e) combination of method (a) + (b) + (c) TBC and repeat TBC most effective method
Check recovery results (monitor signal and determine responsivity)

Wait until signal reaches "stabilization" (continue with measurement with parameter settings of #L)

Apply 3 small IR flux steps with flasher for 40 sec and 40 sec pause at the selected bias voltage during signal increase.

Continue with uninterrupted low flux proton irradiation for several hours TBC.

Check whether a plateau will be reached

Vary the integration ramp length TBC and record signal

Vary the bias settings TBC and record signal

If a steady increase of responsivity remains, re-simulate solar flares and self-curing to identify long term effects TBC

Evaluate all results

End of nominal test program

If time allows and baseline program was not fully completed, decide on additional test steps and program modifications, e.g. different bias voltages after solar flare simulation.

Stop measurement and operation of test equipment:

Check completeness of data recording of QM#25 tests

Stop detector measurement activities

Stop CRC beam operation

Switch off all detector test equipment electronics

Check radioactivity of devices under proton irradiation

Disconnect detector dewar from read-out electronics

Remove equipment from test site

Vent LHe tank to ambient pressure resp. 4 K

Connect temperature sensors to read-out electronics

Refill LHe and LN2 or finally remove cryo-fluids

Continue measurement sequence or finally stop operation as defined above

Reconfigure equipment for transportation to MPE

7. TEST RESULTS RECORDING

Each test step will be checked for successful completion. Each test step will be given a remark or explaining comment in the test procedure.

Each combination of parameter settings is identified in header and file name.

The file name is composed of the following elements:

Example: T25b80d10t1c04n128_#N_1.dat

T25	temperature of detector in K (here T25=2.5K)
b80	bias voltage on detector in mV (here b80=80 mV)
d10	bias voltage on dummy resistor (here b10=10mV)
t1	duration of integration ramp in s (here t1=1s, available numbers see table 1, Note: the very first sample point of each file has to be discarded)
c04	selected nominal FEE integration capacity in pF (here c04=0.41pF) available are c03=0.28/ c04=0.41/ c07=0.68/ c14=1.42 for QM25
n128	number of integration ramps recorded in this file (here n128=128)
bo25	indicates the use of bias boost at 2.5V
fl4	indicates the use of IR flasher at 4mA
he7	indicates the use of detector heater at 7V
_#N	measurement type (i.e.,proton flux, N=no flux, L=low flux, H=high flux) according to test procedure, see chapter 6.
_1	running number of repeated runs with same settings

All measured data are recorded on-line on hard disk and stored on CD.

1 original CD **"UCL-CRC-10-2005"** will be issued at MPE. A copy of the CD will be made available to Pierre Royer / Martin Groenewegen, KUL. KUL will take care of the appropriate distribution of further copies of this data set to people involved in data analysis. On all CDs are all recorded data of all files taken during the test campaign. The date and start time of each individual measurement is listed in the detailed step by step test procedure (chapter 8, logbook).

Bare measurement time (recording of data without any overhead) is about 2 x 8 hours maximum.

8. DETAILED STEP BY STEP TEST PROCEDURE (LOGBOOK)

(filled-in during assembly of test facilities and during test runs)

Test step Date	File name / parameters	Time	Remark
01-10-05	Transportation of equipment	17:00	Arrival of MPE test equipment at UCL-CRC
01-10-05	Assembly of MPE equipment	17:15	Start unpacking, setting up equipment
		18:00	Connect to pumping unit, evacuation of detector dewar
02-10-05	Pre-test preparations	10:30	electrical check-out of electronics
		12:33	QM#25 switched on at RT, OK, p=1.5*10-5mbar, start cool-down with LN2
03-10-05	Pre-test preparations	09:50	Remove LN2 from inner tank, start cool-down to LHe 10:40, finished 11:10
		13:00	Detector read-out at 4K checked, OK, re-fill LHe at 13:50
03-10-05	Pre-testing	21:00	Re-fill LHe, start LHe pump-down at 21:25
		22:15 23:30	CRC starts setting up facility for PACS, MPE hand-out flux program day1, flux re-calibrated: 10 p/cm2s equals 950 p/cm2s on the 95 cm2 in-beam detector, monitored flux varies between 800 and 1100 p/cm2s , (corresponds to 50 to 75 on the off-axis detector)
	Note on beam calibration		**Remark:** During the test runs on 04-10-2005 a too high glitch rate was observed in the detector signal indicating a too high proton flux. Re-checking the beam geometry the next day identified a mistake in the above given calculation: The “low flux” was not 10 but 42 p/cm2s during

Test step Date	File name / parameters	Time	Remark
	Start measurements		above given calculation: The “low flux” was not 10 but 42 p/cm2s during day 1. Proton energy is unchanged 17 MeV.
		23:29	2.5K, measurements outside the cave in the control room started

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
Pre-test measurements outside the cave					
03-10-2005	T25b200d10t05c14n50_1	23 :29	-	-	IR Background derived from responsivity : 1.8*10-14W/pix without FIR cut-on filter 1.3*10-14W/pix with FIR cut-on filter
	T25b200d10t025c03n256fl06_1	23 :53	-	-	Flasher 0.6 mA generates twice background signal
	T25b200d10t025c03n256fl05_1	23 :56	-	-	Flasher 0.5 mA generates 1.2 bg signal increase
04-10-2005	T25b200d10t025c03n256fl045_1	00 :02	-	-	Flasher 0.45 mA generates 1.1 bg signal increase
	-	00 :09	-	-	Heater 4V gives 6.8K
	-	00 :13	-	-	Heater 5V gives 8.0K
	-	00 :15	-	-	Heater 6V gives 9.1K

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
04-10-2005	-	00 :17	-	-	Heater 7V gives 10.2K after 2 min

Test step Date	File name / parameters	Time	Remark
04-10-05	Pre-test phase finished	00:25	Shut down electronics
		01:00	PACS equipment moved to cave
	Test set-up ready	01:20	Check out of set-up finished

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
NO proton flux measurements, bias 200/120/80 mV					
04-10-05	T25b200d10t025c14n256_#N_1.dat	01:28	-	-	Reference measurement
	T25b200d10t025c07n256_#N_2.dat	01:30	-	-	Reference measurement
	T25b200d10t025c04n256_#N_3.dat	01:31	-	-	Reference measurement
	T25b200d10t025c03n256_#N_4.dat	01:32	-	-	Reference measurement
	T25b120d10t025c14n256_#N_5.dat	01:36	-	-	Reference measurement
	T25b120d10t025c07n256_#N_6.dat	01:37	-	-	Reference measurement
	T25b120d10t025c04n256_#N_7.dat	01:39	-	-	Reference measurement
	T25b120d10t025c03n256_#N_8.dat	01:40	-	-	Reference measurement
	T25b080d10t025c14n256_#N_9.dat	01:47	-	-	Reference measurement
	T25b080d10t025c07n256_#N_10.dat	01:49	-	-	Reference measurement
	T25b080d10t025c04n256_#N_11.dat	01:51	-	-	Reference measurement

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
04-10-05	T25b080d10t025c03n256_#N_12.dat	01:53	-	-	Reference measurement
	T25b120d10t1c14n64_#N_13.dat	02:03	-	-	Modify integration time
	T25b120d10t05c14n128_#N_14.dat	02:05	-	-	Modify integration time
	T25b120d10t025c14n256_#N_15.dat	02:07	-	-	Modify integration time
	T25b120d10t0125c14n512_#N_16.dat	02:09	-	-	Modify integration time
	T25b120d10t00625c14n1024_#N_17.dat	02:12	-	-	Modify integration time
	T25b200d10t025c14n1120fl045_#N_18	02:28	-	-	Small IR flux flasher sequence check
	T25b200d10t025c07n1120fl045_#N_19	02:36	-	-	Small IR flux flasher sequence check
Low proton flux measurement, bias 200/120/80 mV					
04-10-05	T25b200d10t025c14n1024_#L_1.dat	02:45	42	17	Start proton irradiation
	T25b200d10t025c14n1024_#L_2.dat	02:49	42	17	continued
	T25b200d10t025c14n1024_#L_3.dat	02:54	42	17	continued
	T25b200d10t025c14n1024_#L_4.dat	02:58	42	17	continued

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
04-10-05	T25b200d10t025c14n1024_#L_5.dat	03:05	42	17	continued
	T25b200d10t025c14n1024_#L_6.dat	03:07	42	17	continued
	T25b200d10t025c14n1024_#L_7.dat	03:12	42	17	continued
	T25b200d10t025c14n1024_#L_8.dat	03:16	42	17	continued
	T25b200d10t025c14n1024_#L_9.dat	03:21	42	17	continued
	T25b200d10t025c14n1024_#L_10.dat	03:27	42	17	continued
	T25b200d10t025c14n1024_#L_11.dat	03:32	42	17	continued
	T25b200d10t025c14n1024_#L_12.dat	03:37	42	17	continued
	T25b200d10t025c14n1024_#L_13.dat	03:42	42	17	continued
	T25b200d10t025c14n1024_#L_14.dat	03:46	42	17	continued
	T25b200d10t025c14n1024_#L_15.dat	03:51	42	17	continued
	T25b200d10t025c14n1024_#L_16.dat	03:56	42	17	continued
	T25b200d10t025c14n1024_#L_17.dat	04:12	42	17	continued

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
04-10-05	T25b200d10t025c14n1024bo25_#L_18.dat	04:18	42	17	**Curing with bias boost 2.5V** for 1 min
	T25b200d10t025c14n1024_#L_19.dat	04:22	42	17	continued
	T25b200d10t025c14n1024_#L_20.dat	04:27	42	17	continued
	T25b200d10t025c14n1024bo25_#L_21.dat	04:33	42	17	**Curing with bias boost 2.5V** for 1 min
	T25b200d10t025c14n1024_#L_22.dat	04:38	42	17	continued
	T25b200d10t025c14n1024_#L_23.dat	04:42	42	17	continued
	T25b200d10t025c14n1024_#L_24.dat	04:47	42	17	continued
	T25b200d10t025c14n1024_#L_25.dat	04:51	42	17	continued
	T25b200d10t025c14n1024_#L_26.dat	04:57	42	17	continued
	T25b200d10t025c14n1024fl4_#L_27.dat	05:01	42	17	**Curing with 2 x flasher** 4 mA for 1 min
	T25b200d10t025c14n1024_#L_28.dat	05:06	42	17	continued
	T26b200d10t025c14n1024_#L_29.dat	05:10	42	17	Continued, check temperature 2.6K
	T26b200d10t025c14n1024_#L_30.dat	05:15	42	17	continued

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
04-10-05	T26b200d10t025c14n1024_#L_31.dat	05:20	42	17	continued
	T26b200d10t025c14n1024_#L_32.dat	05:25	42	17	continued
	T26b200d10t025c14n1024he7_#L_33.dat	05:30	42	17	**Curing with 1 x heater 7 V** for 1 min after heat-up from 2.6K -> 10.2K within 1.5 min
	T26b200d10t025c14n1024_#L_34.dat	05:34	42	17	Continued during cool down
	T26b200d10t025c14n1024_#L_35.dat	05:38	42	17	Continued, off-axis sensor monitors 90 counts
	T26b200d10t025c14n1024_#L_36.dat	05:43	42	17	continued
	T26b200d10t025c14n1024_#L_37.dat	05:47	42	17	continued
	T26b120d10t025c07n1024fl4_#L_38.dat	05:54	42	17	**120mV bias, Cint changed to c07, 1 x flasher** 4 mA for 1 min
	T26b120d10t025c07n1024_#L_39.dat	05:59	42	17	continued
	T26b120d10t025c07n1024_#L_40.dat	06:03	42	17	continued
	T26b120d10t025c07n1024_#L_41.dat	06:08	42	17	continued
	T26b120d10t025c07n1024_#L_42.dat	06:14	42	17	continued
	T26b120d10t1c07n64_#L_43.dat	06:16	42	17	Modify integration time; ramps are saturated

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
04-10-05	T26b120d10t05c07n128_#L_44.dat	06:18	42	17	Modify integration time
	T26b120d10t025c07n256_#L_45.dat	06:20	42	17	Modify integration time
	T26b120d10t0125c07n512_#L_46.dat	06:21	42	17	Modify integration time
	T26b120d10t00625c07n1024_#L_47.dat	06:24	42	17	Modify integration time
	T26b120d10t1c14n64_#L_48.dat	06:26	42	17	Cint changed to c14; modify integration time
	T26b120d10t05c14n128_#L_49.dat	06:28	42	17	Modify integration time
	T26b120d10t025c14n256_#L_50.dat	06:30	42	17	Modify integration time
	T26b120d10t0125c14n512_#L_51.dat	06:31	42	17	Modify integration time
	T26b120d10t00625c14n1024_#L_52.dat	06:34	42	17	Modify integration time
	T26b120d10t025c07n1120fl045_#L_53.dat	06:42	42	17	Small IR flux flasher 0.45 mA
	T26b120d10t025c07n1024_#L_54.dat	06:47	42	17	continued
	T26b120-80d10t025c07n1024_#L_55.dat	06:55	42	17	Change bias 120 mV to **80 mV** during file record
	T26b80d10t025c07n1024fl4_#L_56.dat	07:04	42	17	**Curing 1 x flasher 4 mA for 0.5 min**

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
04-10-05	T26b80d10t025c07n1024_#L_57.dat	07:08	42	17	continued
	T26b80d10t025c07n1024_#L_58.dat	07:13	42	17	Continued; off-axis sensor monitors 100 counts
	T26b80d10t025c07n1024_#L_59.dat	07:18	42	17	Continued
	T26b80d10t025c07n1024_#L_60.dat	07:22	42	17	Continued
	T26b80d10t025c07n1024_#L_61.dat	07:27	42	17	Continued
	T26b80d10t025c07n1120fl045_#L_62.dat	07:32	42	17	**Small IR flux flasher 0.45 mA**
	T27b80d10t025c07n1024_#L_63.dat	07:37	42	17	Continued, detector temperature 2.7K
	T27b80d10t025c07n1024_#L_64.dat	07:42	42	17	Continued; **switch off beam** at ~40000 samples
	T27b80d10t025c07n1024_#N_20.dat	07:46	-	-	No flux continued; self curing
	T27b80d10t025c07n1024_#N_21.dat	07:51	-	-	No flux continued; self curing
	T27b80d10t025c07n1120fl4_#N_22.dat	07:56	-	-	**Curing 1x flasher for 0.5 min**
	T27b80d10t025c07n256_#N23.dat	08:00	-	-	Reference measurement
	T27b200d10t025c07n256_#N24.dat	08:02	-	-	Reference measurement

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
04-10-05	T27b120d10t025c07n256_#N25.dat	08:04	-	-	Reference measurement
	T27b80d10t025c07n256_#N26.dat	08:05	-	-	Reference measurement

Test step Date	File name / parameters	Time	Remark
04-10-05	Test run finished	08:05	Measurements of first day completed, switch off electronics at 08:06
		08:15	Dewar removed from cave, refill LN2 and LHe
04-10-05	Preparation for test day 2	21:15	Refill LN2 and LHe
		21:40	Start LHe pump-down
	Beam calibration	22:00	**Remark:** re-calibration of proton flux performed: At a low flux of 10 p/cm2s the in-beam sensor should monitor 237 counts, off-axis sensor 197 counts. High flux of 400 p/cm2s corresponds to 9500 counts in the in-beam sensor, and to 7600 counts in the off-axis sensor.
05-10-05	Measurement sequence started	23:50	dewar moved over to cave
		00:21	measurements started with 120mV bias at 00:21, see next table, detector temperature 2.5K

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
NO proton flux measurements, bias 120/80 mV					
05-10-05	T25b120d10t025c14n256_#N_27.dat	00:21	-	-	Reference measurement
	T25b120d10t025c07n256_#N_28.dat	00:24	-	-	Reference measurement
	T25b120d10t025c04n256_#N_29.dat	00:26	-	-	Reference measurement
	T25b120d10t025c03n256_#N_30.dat	00:27	-	-	Reference measurement
	T25b80d10t025c14n256_#N_31.dat	00:31	-	-	Reference measurement
	T25b80d10t025c07n256_#N_32.dat	00:32	-	-	Reference measurement
	T25b80d10t025c04n256_#N_33.dat	00:34	-	-	Reference measurement
	T25b80d10t025c03n256_#N_34.dat	00:35	-	-	Reference measurement
	T25b120d10t025c14n1120fl05_#N_35.dat	00:44	-	-	**3 x small IR flasher for 40 sec 0.5 mA**

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
LOW proton flux measurement , bias 120 mV					
05-10-05	T25b120d10t025c14n1024_#L_65.dat	00:51	10	17	**Bias 120 mV**, Waiting for beam on
	T25b120d10t025c14n1024_#L_66.dat	00:55	10	17	Waiting for beam on
	T25b120d10t025c14n1024_#L_67.dat	01:00	10	17	**Beam switched to low flux** at sample 50000
	T25b120d10t025c14n1024_#L_68.dat	01:04	10	17	Continued, off-axis sensor monitors 220 counts
	T25b120d10t025c14n1024_#L_69.dat	01:09	10	17	continued
	T25b120d10t025c14n1024_#L_70.dat	01:13	10	17	continued
	T25b120d10t025c14n1024_#L_71.dat	01:17	10	17	continued
	T25b120d10t025c14n1024_#L_72.dat	01:22	10	17	continued
	T25b120d10t025c14n1024_#L_73.dat	01:26	10	17	continued
	T25b120d10t025c14n1024_#L_74.dat	01:31	10	17	continued
	T25b120d10t025c14n1024_#L_75.dat	01:35	10	17	continued
	T25b120d10t025c14n1024_#L_76.dat	01:40	10	17	continued

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
05-10-05	T25b120d10t025c14n1024_#L_77.dat	01:45	10	17	continued
	T25b120d10t025c14n1024_#L_78.dat	01:49	10	17	continued, **beam off** at sample 54000
High proton flux measurement , bias 120 mV					
	T25b120d10t025c14n1024_#H_1.dat	01:54	400	17	beam on at sample 55000, off-axis sensor 7900 ct
	T25b120d10t025c14n1024_#H_2.dat	01:58	400	17	continued
	T25b120d10t025c14n1024_#H_3.dat	02:03	400	17	continued
	T25b120d10t025c14n1024_#H_4.dat	02:07	400	17	continued
	T25b120d10t025c14n1024_#H_5.dat	02:12	400	17	continued
	T25b120d10t025c14n1024_#H_6.dat	02:16	400	17	continued, **beam switched to low flux**
Low proton flux measurement , bias 120 mV					
	T25b120d10t025c14n1024_#L_79.dat	02:21	10	17	Continued, off-axis sensor monitors 170 counts
	T25b120d10t025c14n1024_#L_80.dat	02:25	10	17	continued
	T25b120d10t025c14n1024_#L_81.dat	02:30	10	17	continued

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
05-10-05	T25b120d10t025c14n1024_#L_82.dat	02:34	10	17	continued
	T25b120d10t025c14n1024_#L_83.dat	02:39	10	17	continued
	T25b120d10t025c14n1024fl4_#L_84.dat	02:43	10	17	continued, **Curing** with 2 x flasher 4mA for 0.5 min
	T25b120d10t025c14n1024_#L_85.dat	02:48	10	17	continued
	T25b120d10t025c14n1024_#L_86.dat	02:53	10	17	continued
	T25b120d10t025c14n1120fl05_#L_87.dat	02:59	10	17	**3x small IR flux flasher 0.5 mA, t025**
	T25b120d10t025c14n1024_#L_88.dat	03:04	10	17	continued
	T25b120d10t025c14n1024_#L_89.dat	03:09	10	17	continued
	T25b120d10t0125c14n2240fl05_#L_90.dat	03:15	10	17	**3x small IR flux flasher 0.5 mA, t0125**
	T25b120d10t0125c14n4480fl05_#L_91.dat	03:24	10	17	**3x small IR flux flasher 0.5 mA, t00625**
	T25b120d10t05c14n560fl05_#L_92.dat	03:30	10	17	**3x small IR flux flasher 0.5 mA, t05**
	T25b120d10t1c14n280fl05_#L_93.dat	03:36	10	17	**3x small IR flux flasher 0.5 mA, t1**
	T25b120d10t025c14n1024_#L_94.dat	03:41	10	17	Continued, temperature check 2.5K

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
05-10-05	T25b120d10t1c14n64_#L_95.dat	03:44	10	17	Continued, tint 1
	T25b120d10t05c14n128_#L_96.dat	03:45	10	17	Continued, tint05
	T25b120d10t025c14n256_#L_97.dat	03:47	10	17	Continued, tint 025
	T25b120d10t0125c14n512_#L_98.dat	03:49	10	17	Continued, tint 0125
	T25b120d10t00625c14n1024_#L_99.dat	03:51	10	17	Continued, tint 00625
	T25b120d10t025c14n1024_#L_100.dat	03:57	10	17	Continued, off-axis sensor monitors 190 counts
	T25b120d10t025c14n1024_#L_101.dat	04:02	10	17	Continued, tint 025
	T25b120d10t025c14n1024_#L_102.dat	04:08	10	17	continued
	T25b120d10t025c14n1024_#L_103.dat	04:12	10	17	continued
	T25b120d10t025c14n1024_#L_104.dat	04:16	10	17	continued
	T25b120d10t025c14n1024_#L_105.dat	04:21	10	17	continued
	T25b120d10t025c14n1024_#L_106.dat	04:26	10	17	continued
	T25b120d10t025c14n1024_#L_107.dat	04:30	10	17	continued

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
05-10-05	T25b120d10t025c14n1024_#L_108.dat	04:35	10	17	continued
	T25b120d10t025c14n1024_#L_109.dat	04:39	10	17	continued
	T25b120d10t025c14n1024_#L_110.dat	04:44	10	17	continued
	T25b120d10t025c14n1024_#L_111.dat	04:48	10	17	continued
	T25b120d10t025c14n1024_#L_112.dat	04:56	10	17	plateau reached, responsivity increase factor 7
	T25b120d10t1c14n64_#L_113.dat	04:58	10	17	Continued, tint 1
	T25b120d10t05c14n128_#L_114.dat	05:00	10	17	Continued, tint05
	T25b120d10t025c14n256_#L_115.dat	05:02	10	17	Continued, tint 025
	T25b120d10t0125c14n512_#L_116.dat	05:03	10	17	Continued, tint 0125
	T25b120d10t00625c14n1024_#L_117.dat	05:06	10	17	Continued, tint 00625
Modify bias to 100 mV					
	T25b100d10t1c14n64_#L_118.dat	05:12	10	17	Continued, tint 1
	T25b100d10t05c14n128_#L_119.dat	05:13	10	17	Continued, tint05

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
05-10-05	T25b100d10t025c14n256_#L_120.dat	05:15	10	17	Continued, tint 025
	T25b100d10t0125c14n512_#L_121.dat	05:17	10	17	Continued, tint 0125
	T25b100d10t00625c14n1024_#L_122.dat	05:19	10	17	Continued, tint 00625
Modify bias to 80 mV					
	T25b80d10t1c14n64_#L_123.dat	05:24	10	17	Continued, tint 1
	T25b80d10t05c14n128_#L_124.dat	05:26	10	17	Continued, tint05
	T25b80d10t025c14n256_#L_125.dat	05:28	10	17	Continued, tint 025
	T25b80d10t0125c14n512_#L_126.dat	05:29	10	17	Continued, tint 0125
	T25b80d10t00625c14n1024_#L_127.dat	05:32	10	17	Continued, tint 00625
Modify bias to 140 mV					
	T25b140d10t1c14n64_#L_128.dat	05:35	10	17	Continued, tint 1
	T25b140d10t05c14n128_#L_129.dat	05:37	10	17	Continued, tint05
	T25b140d10t025c14n256_#L_130.dat	05:38	10	17	Continued, tint 025

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
05-10-05	T25b140d10t0125c14n512_#L_131.dat	05:40	10	17	Continued, tint 0125
	T25b140d10t00625c14n1024_#L_132.dat	05:43	10	17	Continued, tint 00625
Modify bias to 160 mV					
	T25b160d10t1c14n64_#L_133.dat	05:47	10	17	Continued, tint 1
	T25b160d10t05c14n128_#L_134.dat	05:49	10	17	Continued, tint05
	T25b160d10t025c14n256_#L_135.dat	05:50	10	17	Continued, tint 025
	T25b160d10t0125c14n512_#L_136.dat	05:52	10	17	Continued, tint 0125
	T25b160d10t00625c14n1024_#L_137.dat	05:55	10	17	Continued, tint 00625
Modify bias to 180 mV					
	T25b180d10t1c14n64_#L_138.dat	06:01	10	17	Continued, tint 1
	T25b180d10t05c14n128_#L_139.dat	06:04	10	17	Continued, tint05
	T25b180d10t025c14n256_#L_140.dat	06:05	10	17	Continued, tint 025
	T25b180d10t0125c14n512_#L_141.dat	06:07	10	17	Continued, tint 0125

Test step Date	File name / parameters	Time	Flux [p/s [cm^2]	Energy [MeV]	Remark
05-10-05	T25b180d10t00625c14n1024_#L_142.dat	06:09	10	17	Continued, tint 00625
Modify bias to 60 mV					
	T25b60d10t1c14n64_#L_143.dat	06:16	10	17	Continued, tint 1
	T25b60d10t05c14n128_#L_144.dat	06:18	10	17	Continued, tint05
	T25b60d10t025c14n256_#L_145.dat	06:19	10	17	Continued, tint 025
	T25b60d10t0125c14n512_#L_146.dat	06:21	10	17	Continued, tint 0125
	T25b60d10t00625c14n1024_#L_147.dat	06:24	10	17	Continued, tint 00625
Modify bias to 200 mV					
	T25b200d10t1c14n64_#L_148.dat	06:29	10	17	Continued, tint 1, off-axis sensor 190 counts
	T25b200d10t05c14n128_#L_148.dat	06:31	10	17	Continued, tint05
	T25b200d10t025c14n256_#L_150.dat	06:33	10	17	Continued, tint 025
	T25b200d10t0125c14n512_#L_151.dat	06:34	10	17	Continued, tint 0125
	T25b200d10t00625c14n1024_#L_152.dat	06:37	10	17	Continued, tint 00625, temperature check 2.6K

Test step Date	File name / parameters	Time	Flux [p/s cm^2]	Energy [MeV]	Remark
Modify bias to 120 mV					
05-10-05	T25b120d10t025c14n1024_#L_153.dat	06:44	10	17	Continued, tint 025
	T25b120d10t025c14n1024fl4_#L_154.dat	06:50	10	17	**Curing 1x IR flasher 4 mA for 0.5 min**
	T25b120d10t025c14n1024_#L_155.dat	06:55	10	17	Continued, tint 025

Test step Date	File name / parameters	Time	Remark
05-10-05	Measurements finished	07:15	dewar removed from cave, electronics switched off and removed from cave, LN2 and LHe removed from dewar,
05-10-05	Post Test Review		Not held; full test program was performed
05-10-05	Packing	14:00	Preparation of equipment for transportation
			Packing finished, Access card to CRC building and dosimeters returned to CRC staff.
			End of test campaign
06-10-05	Transportation of test equipment to MPE by car		Departure from Wavre back to Garching, stop-over at CSL Liège

9. POST TEST REVIEW AND RESULTS

9.1 Summary

The main goals of the proton irradiation test phase #3 on the low stressed detector module QM#25 have been achieved: A complete set of data is available for further analysis and evaluation of the observed impact of ionizing radiation and curing methods.

In case of the low proton flux of 10 $cm^{-2}s^{-1}$, each detector pixel should see a proton hit every 1/(10x0.1x0.15) = 7 seconds on average. Protons with an energy of 17 MeV should be able to completely penetrate the 1mm thick Ge:Ga detector crystal elements.

Major deviations from the test procedure baseline were not necessary.

All important parts of the requested measurements could be completed during the available limited beam time.

9.2 Actual Beam Settings

Three combinations of flux and energy were chosen for the 3rd irradiation run. The 70 MeV proton energy losses along the beam line in the actual set-up are shown in Table 2, the actual set-up is identical to the one used during the 2nd test phase.

- low flux of **10 p/cm2s** + high proton energy of **17.1 MeV** at detector surface
- low flux of **42 p/cm2s** + high proton energy of **17.1 MeV** at detector surface
- high flux of **400 p/cm2s** + high proton energy of **17.1 MeV** at detector surface

Material	Pb	Air	Poly	Air	Al	Cu
Thickness	0.12 mm	4.52 m	0 mm	0.42 m	13.6 mm	0.51 mm
Remaining energy	69.34 MeV	64.24 MeV	64.24 MeV	63.74 MeV	24.33 MeV	**17.10 MeV**

Table 2: proton energy loss along beam line

The table is taken from [RD13].

The **spectrum** of the actual proton beam hitting the Ge:Ga crystal elements during the 3rd test phase is shown in Fig. 11. The Figure is taken from [RD13].

Figure 11 shows the energy distribution function. The mean value is 17.16 MeV and the variance 1.5 MeV. The mean value can be compared with SRIM2000 calculations.

In the actual used configuration, almost no protons have an energy > 23 MeV and 50% have an energy > 17.15 MeV.

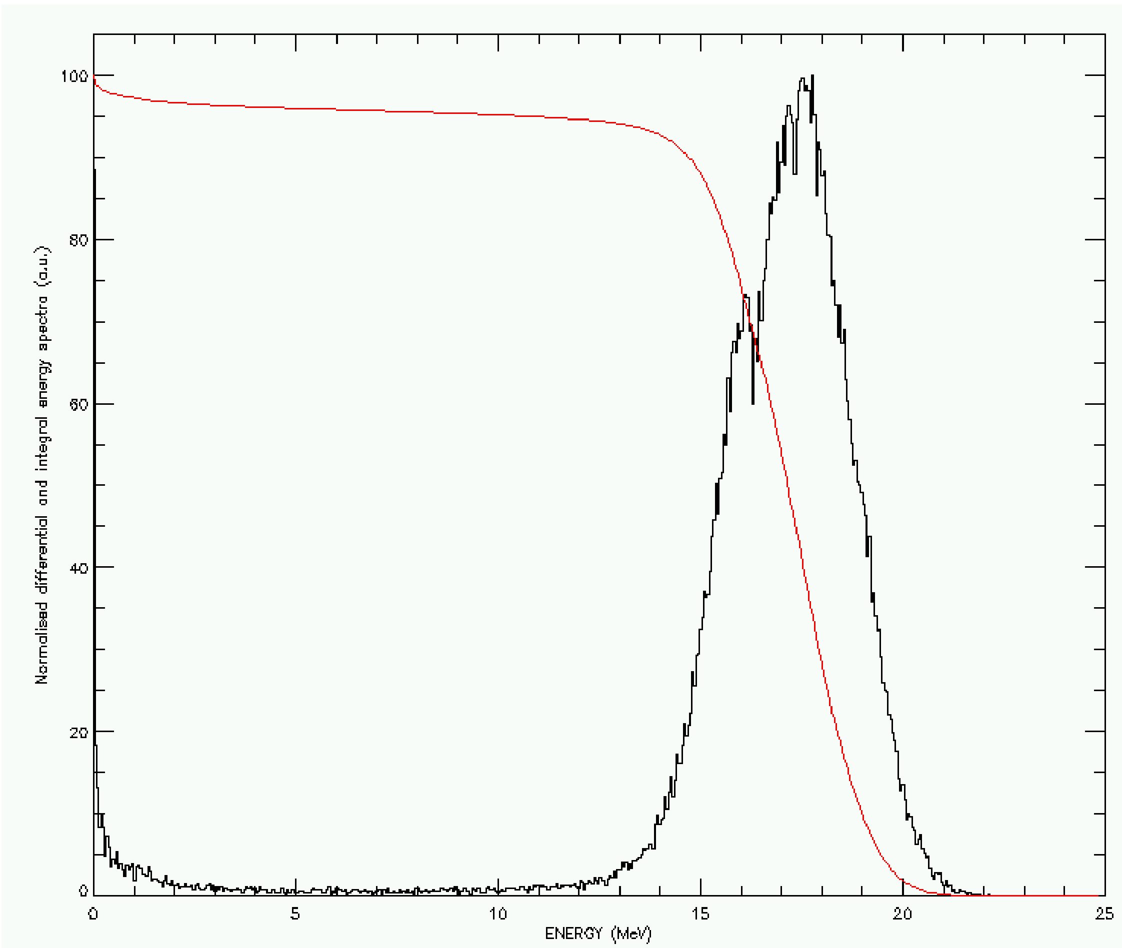


Fig. 11: Proton beam energy distribution

The **beam homogeneity** along the pixel row of the detector module and the position of the individual pixels are shown in Fig. 12. The beam profile is taken from [RD13] and the position of the detector pixels was added. Homogeneity is quite satisfying.

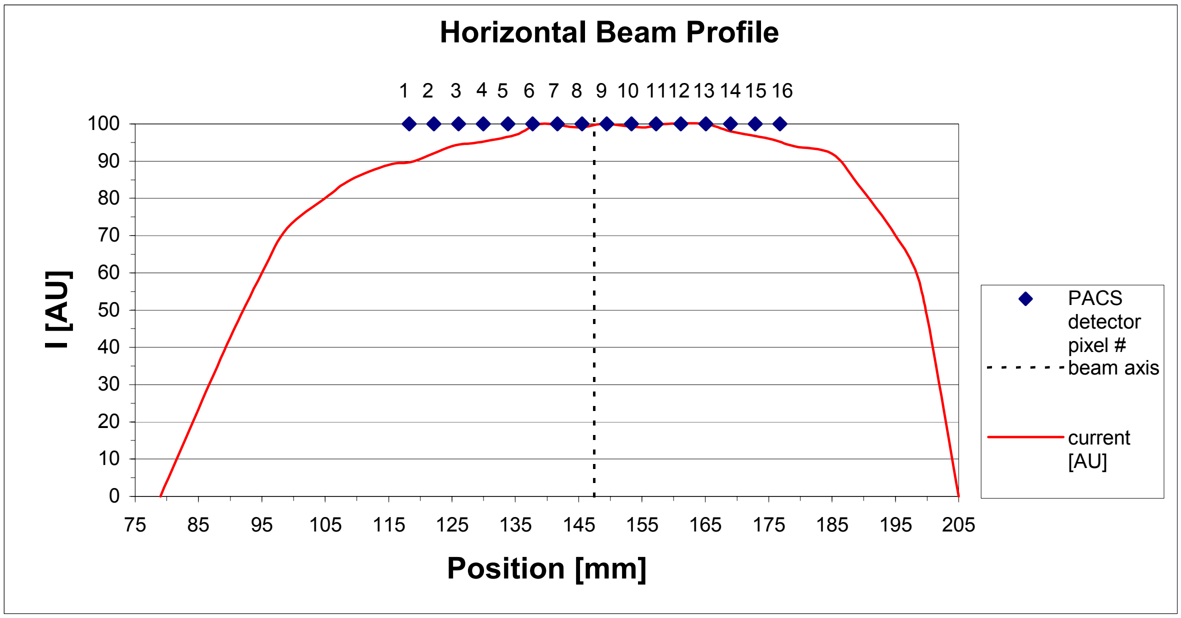


Fig. 12: Position of detector pixels in the proton beam

9.3 Preliminary results

9.3.1 General observations

Proton irradiation generates slightly more intense glitches in the signal of the low stressed detector pixels than was observed in the high stressed module.

All three executed curing methods (bias boost, IR flashing, detector heating) work nearly perfect, they can restore under permanent low proton flux the changed and increased responsivity to the value corresponding to “no radiation”. One 30 sec long IR flash seems to be sufficient to do the main annealing. Only this method was applied for curing purposes during day 2 of the 3rd test phase.

Detector pixels with an originally lower responsivity value change their behavior less pronounced than those with a higher response, but the factor of responsivity-increase might end up to the same number. This is to be verified by a more detailed analysis.

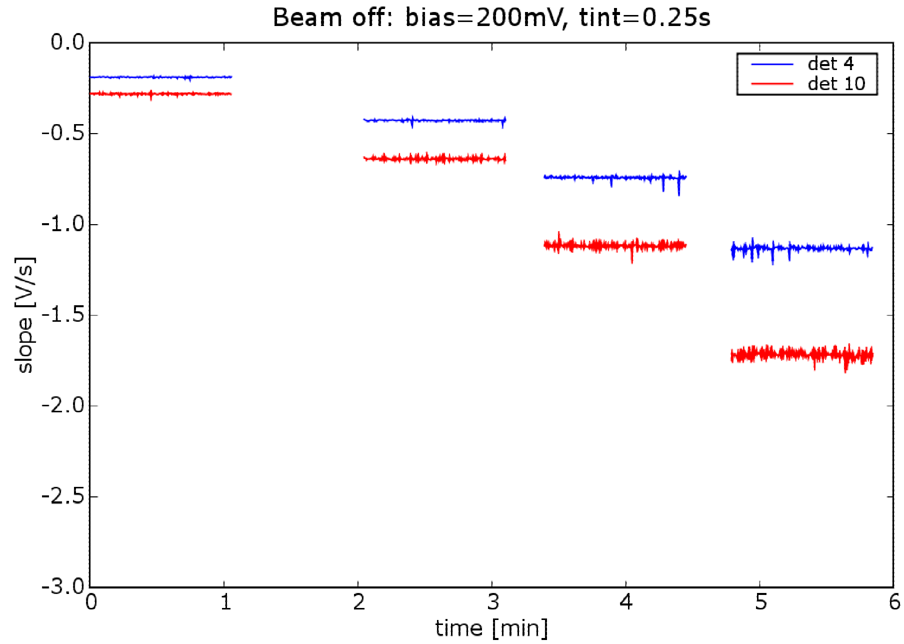
Under low proton flux, about two hours are needed before the responsivity reaches a (new) plateau. The level depends clearly on the flux intensity.

9.3.2 Selected diagrams produced from recorded data files

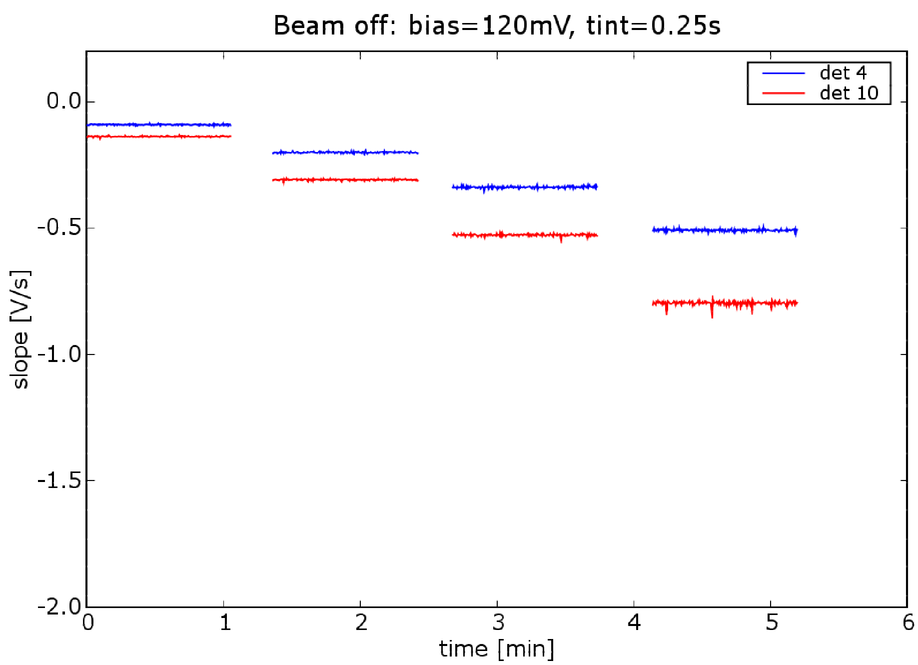
All figures shown in chapter 9.3.2 are produced with the standard MPE software used for regular PACS detector module performance characterization in the MPE laboratory. The values in the diagrams have to be considered as quick look analysis results. The following figures were produced by L. Barl, MPE.

A series of subsequent data files is used to generate a specific diagram and to illustrate a certain type of measurement.

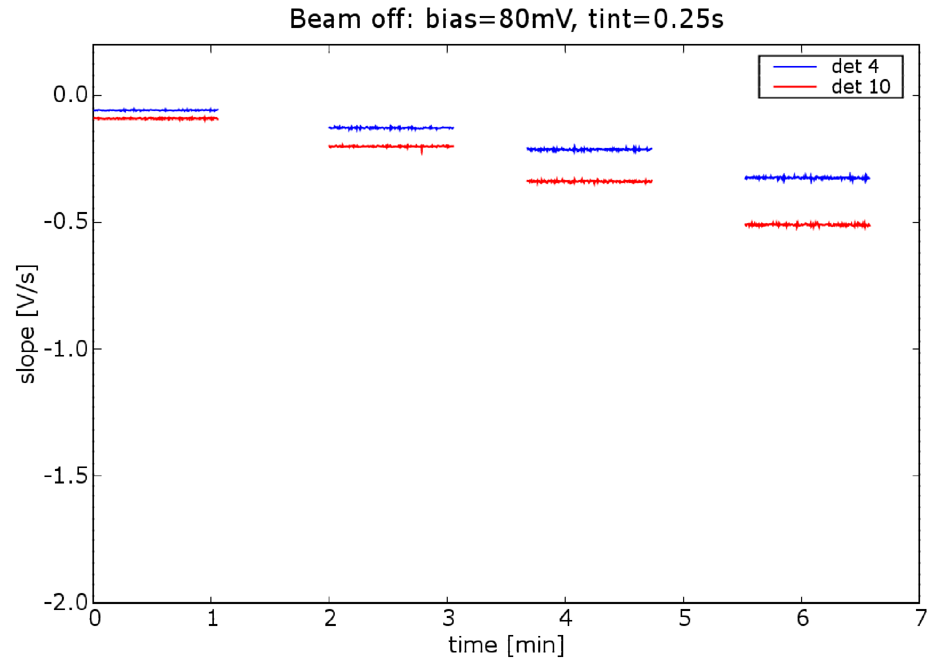
Below each diagram the running numbers of the data files are indicated, from which the total curve is composed. Not all figures have an explaining figure caption text: For all details of operating parameters of certain portions of the curves see the corresponding file name and remark as listed in chapter 8.



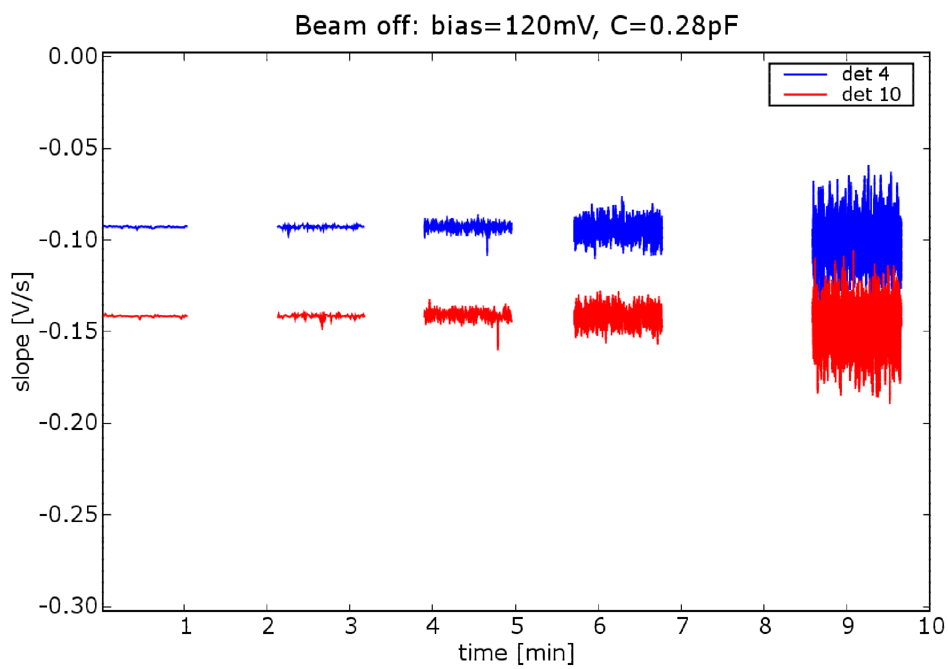
N1-N4: no proton flux reference measurement for all integration capacitors



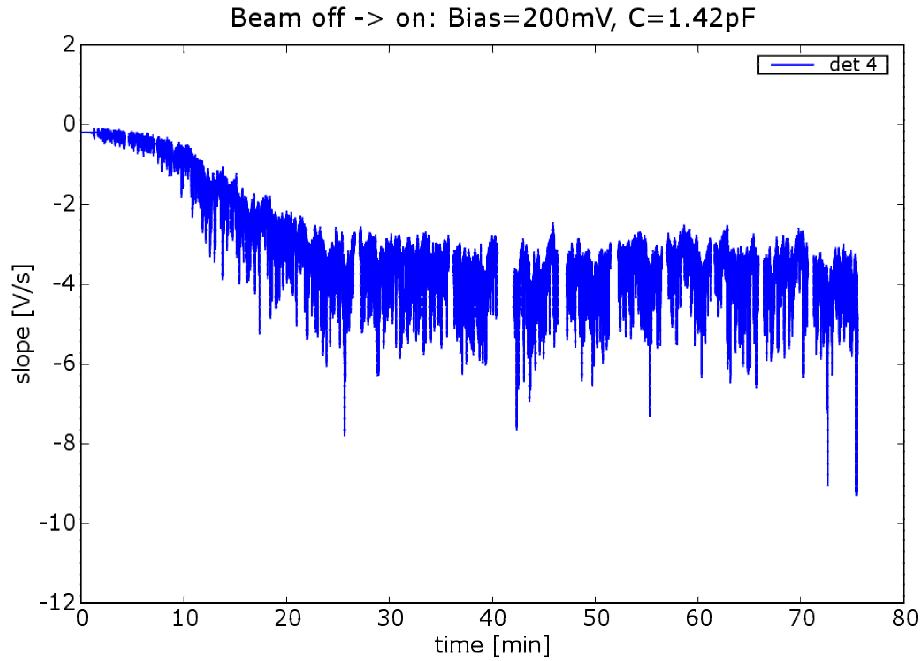
N5-N8: proton flux reference measurement for all integration capacitors



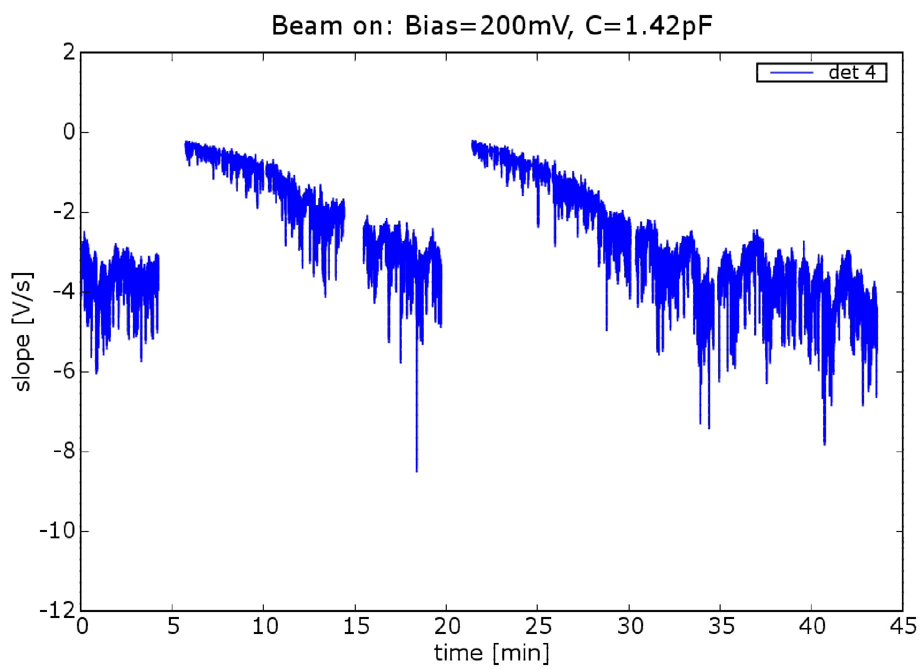
N9-N12: proton flux reference measurement for all integration capacitors



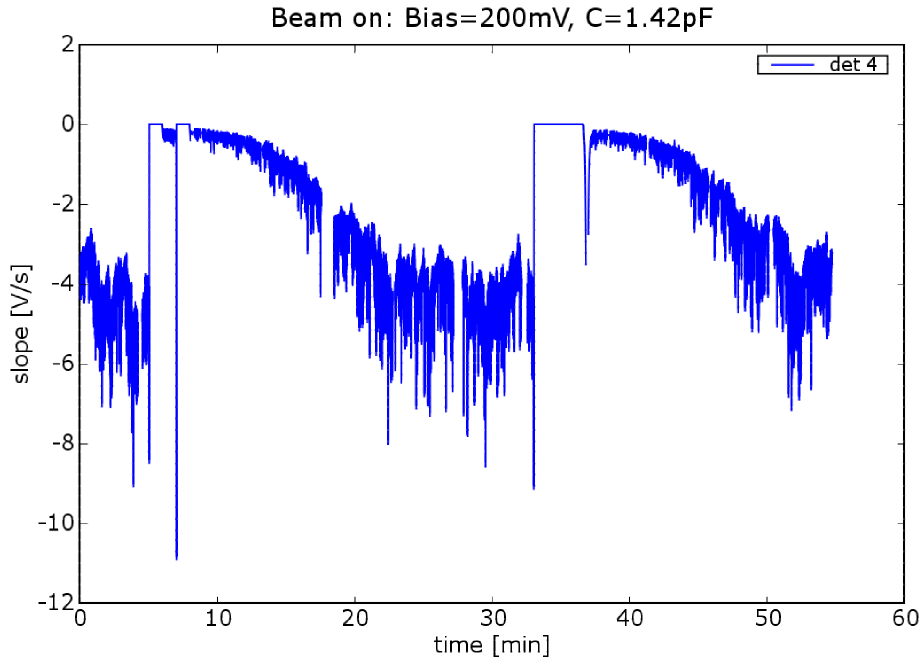
N13-N17: proton flux reference measurement for different integration times



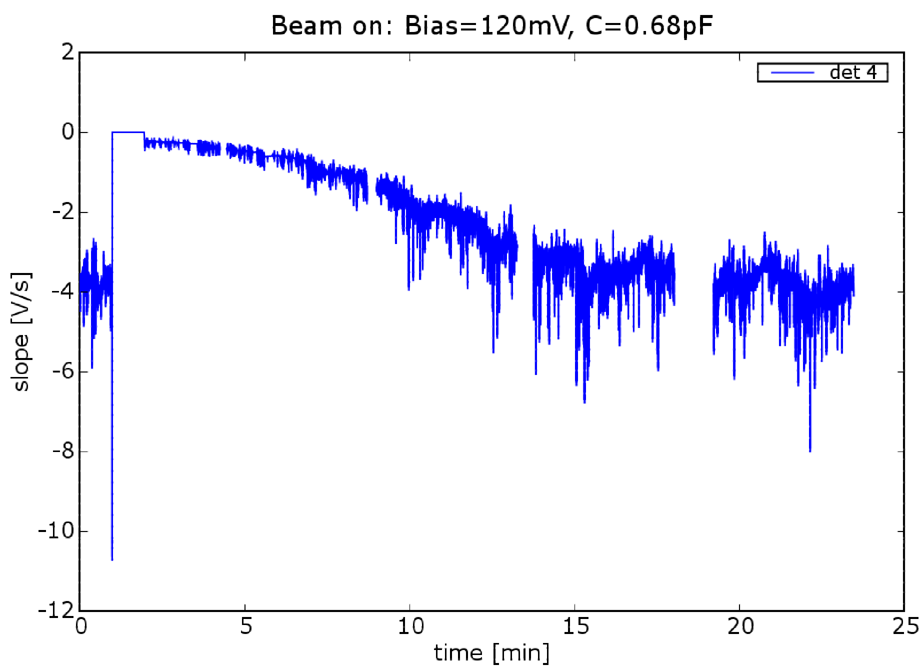
L1-L16: from beam off to low proton flux



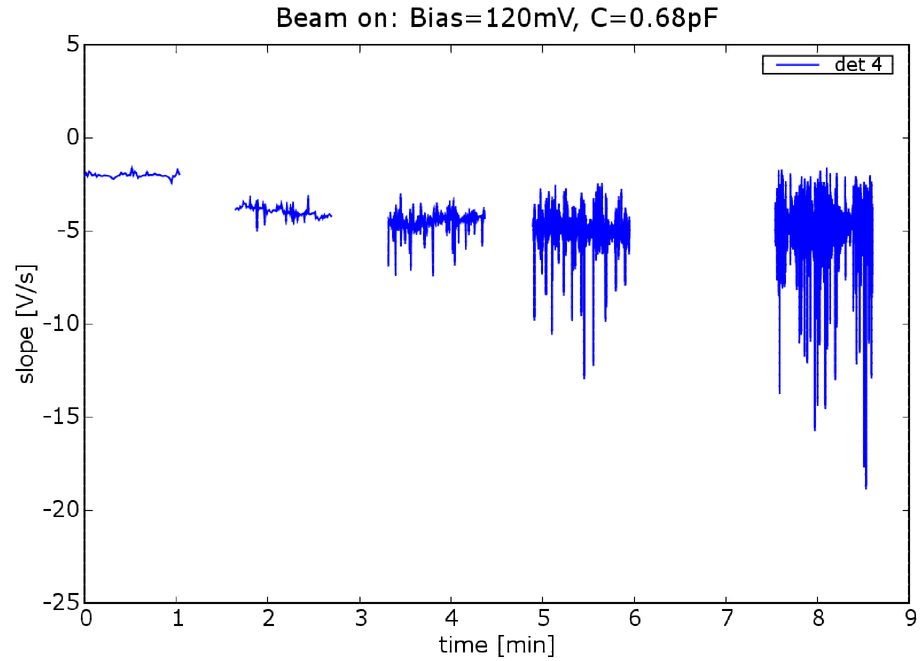
L17-L25: curing with bias boost 2.5V for 1 min two times



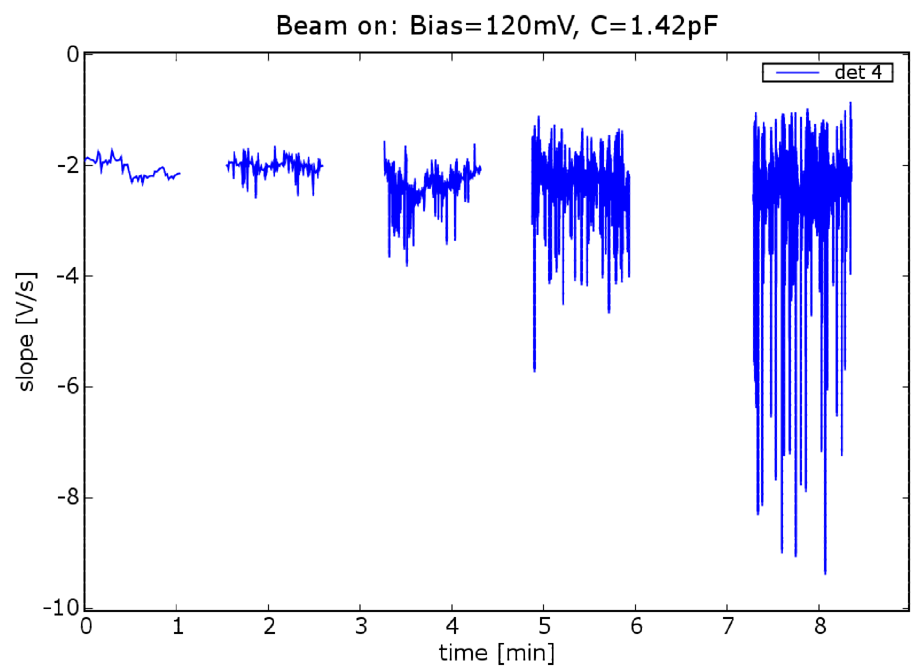
L26-L37: curing with flasher 2 x 1min and 1 x heater



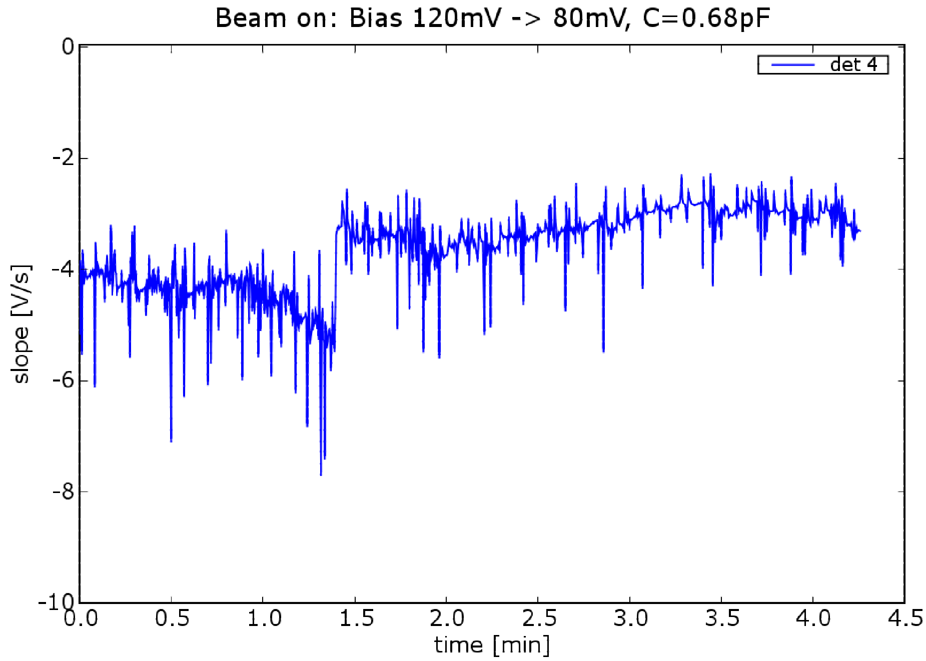
L38-L42: curing 1 x flasher



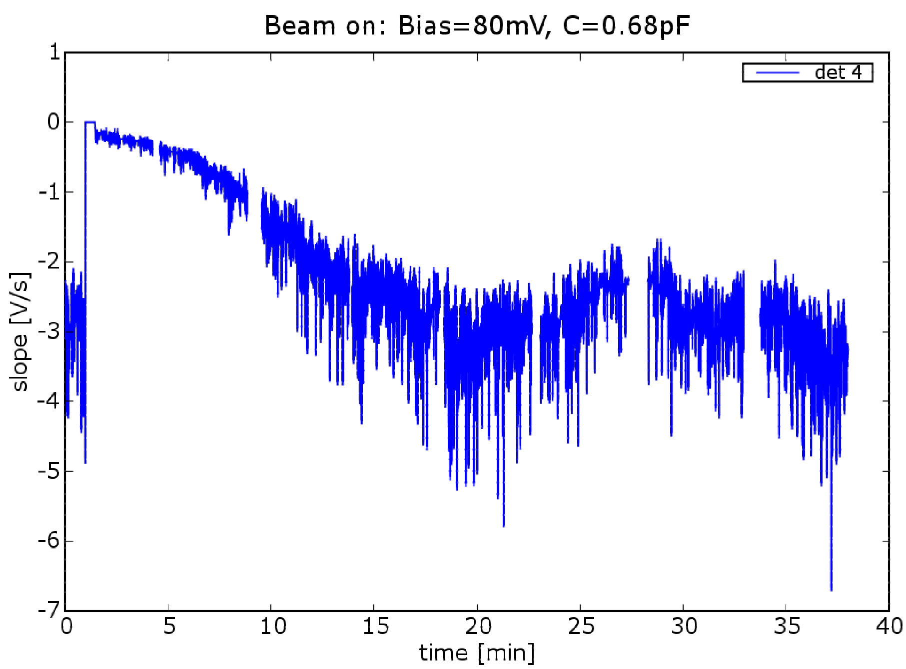
L43-L47: signal for different integration times



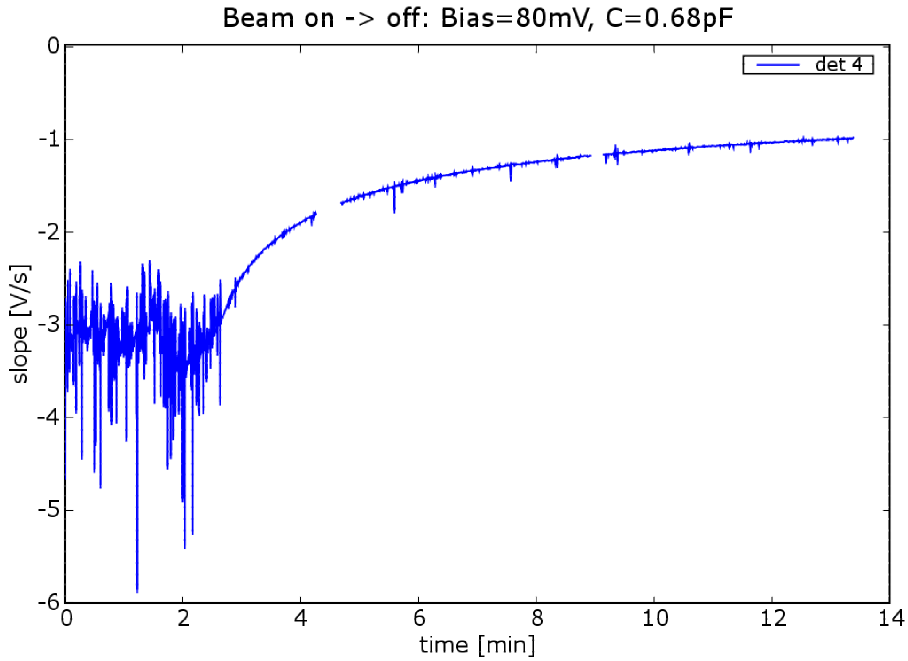
L48-L52: signal for different integration times



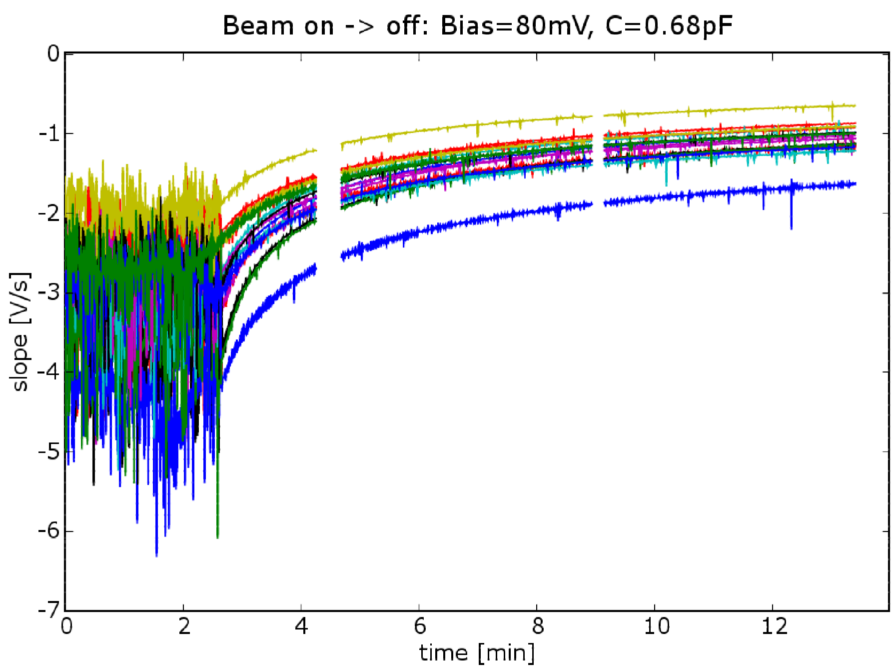
L55: bias change during irradiation



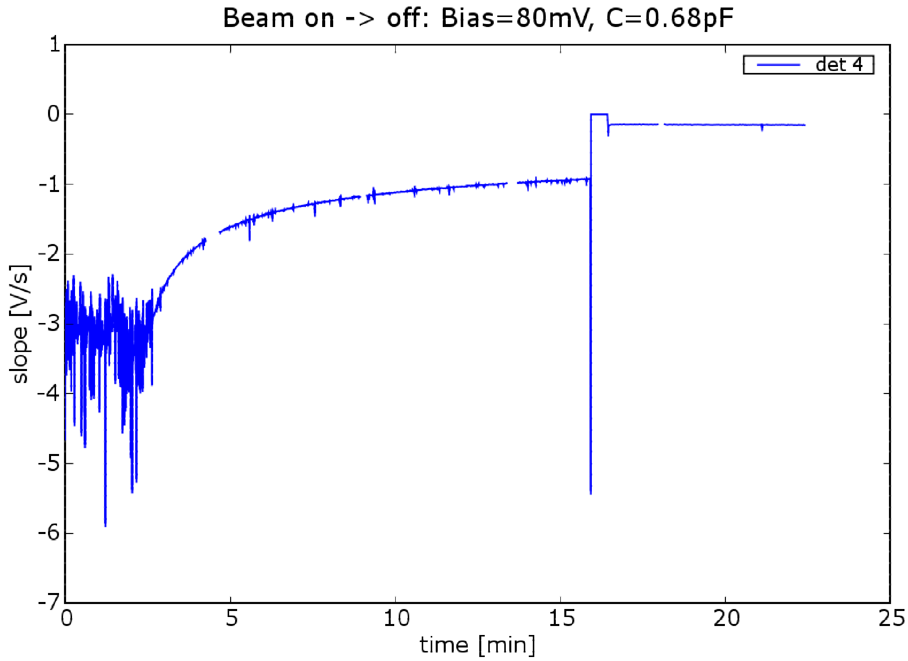
L56-L63: curing 1 x flasher and small IR flux changes starting at t =28min



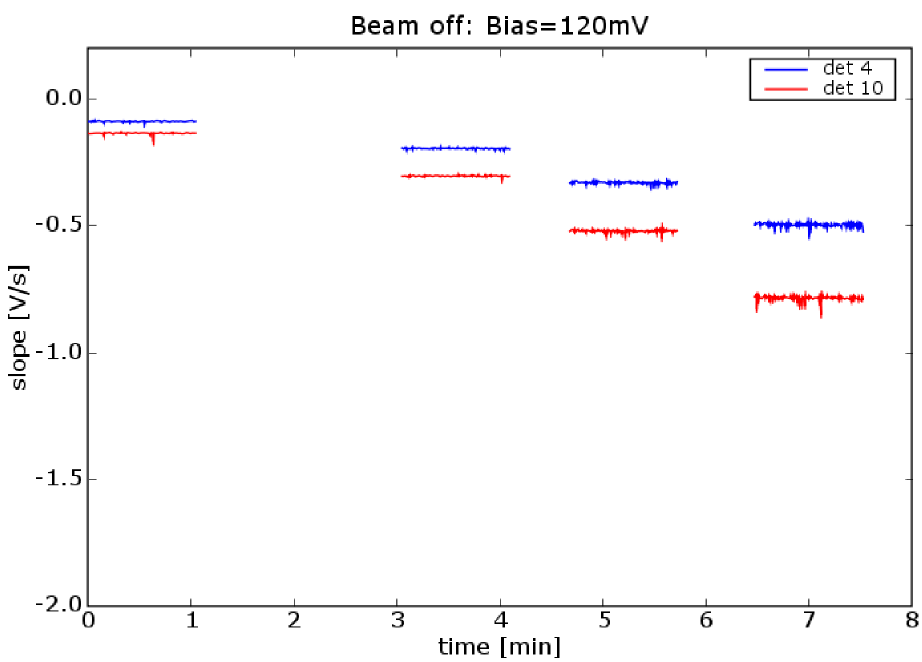
L64-N21: switch–off beam



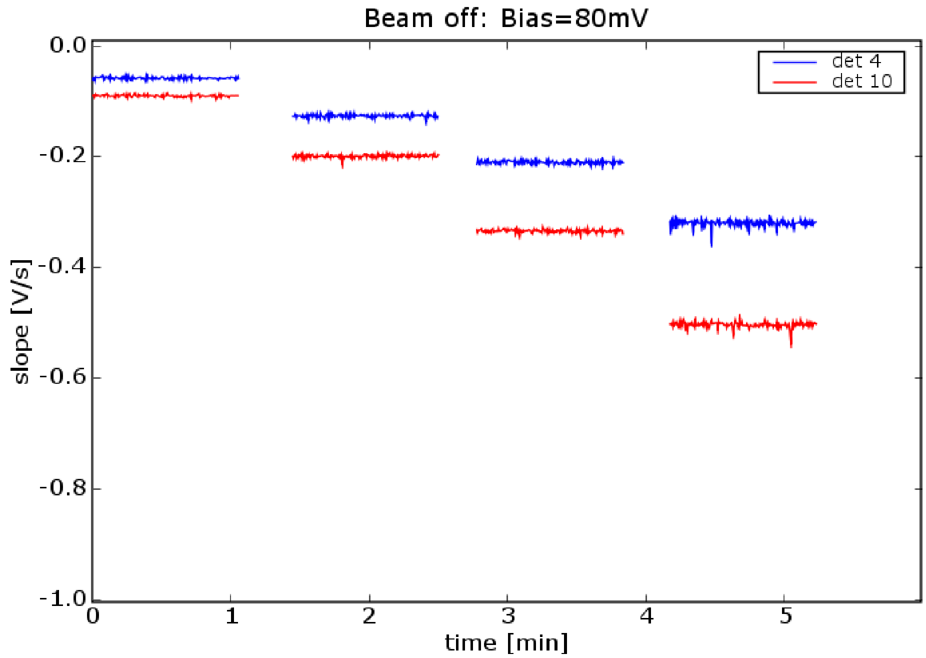
L64-N21: switch-off beam (all detector pixels)



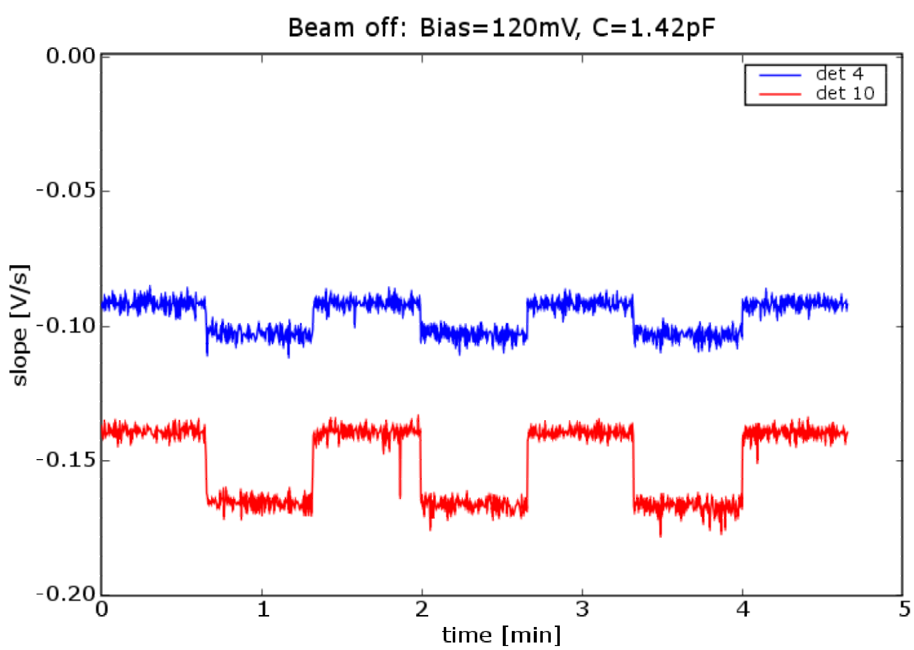
L64-N23: curing 1 x flasher for 0.5 min



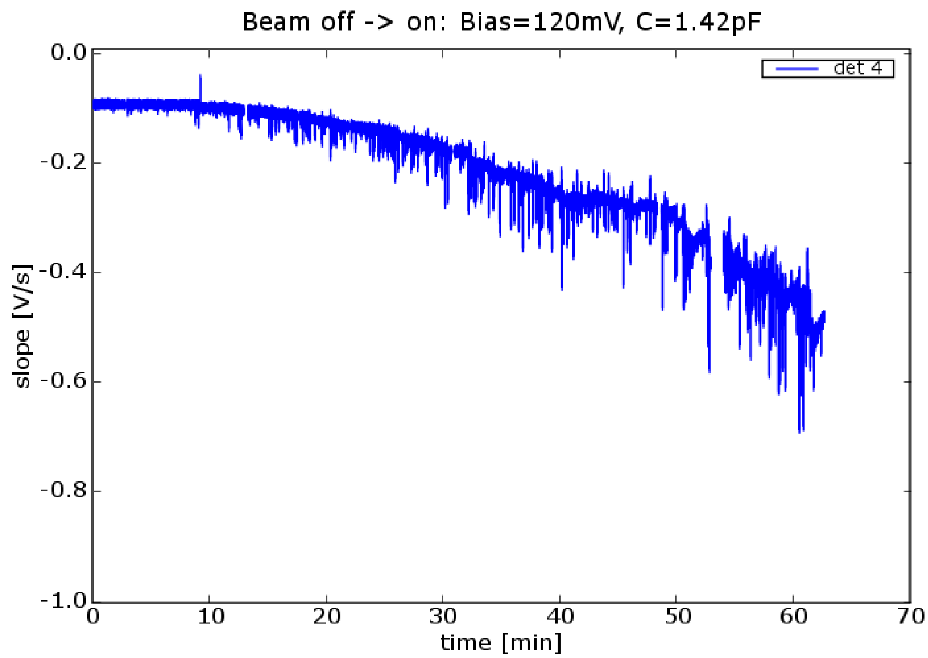
N27-N30: signal for all 4 integration capacitors



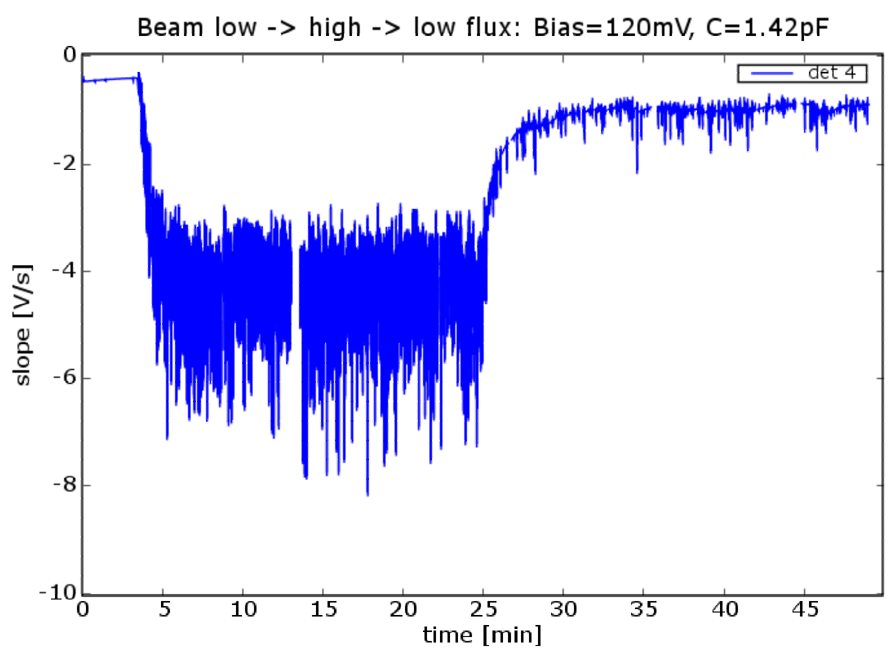
N31-N34: signal for all 4 integration capacitors



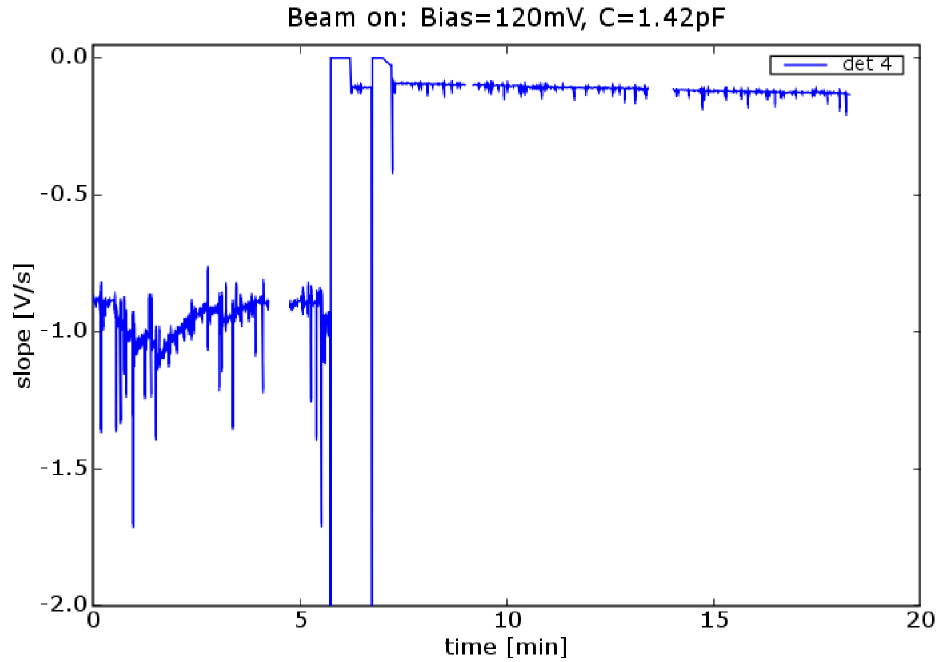
N35: 3 x small IR flux changes for 40 sec



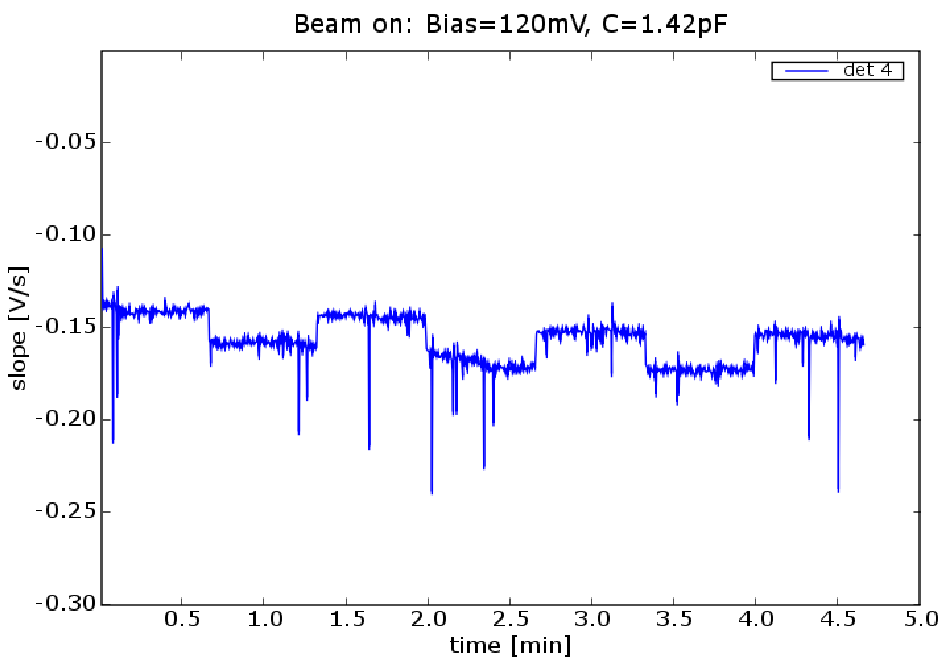
L65-L78: from beam off to low proton flux



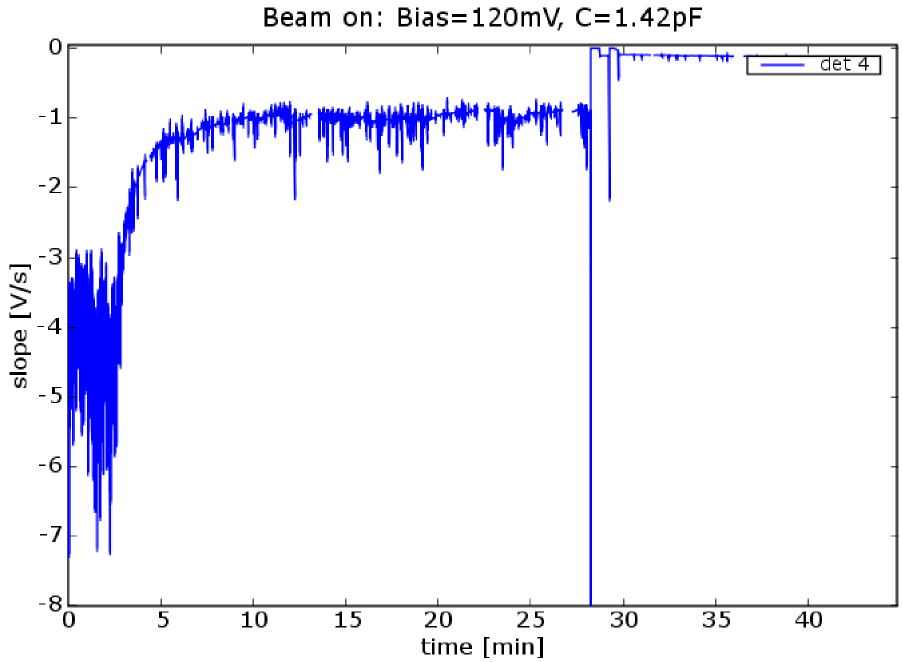
H1-L83:



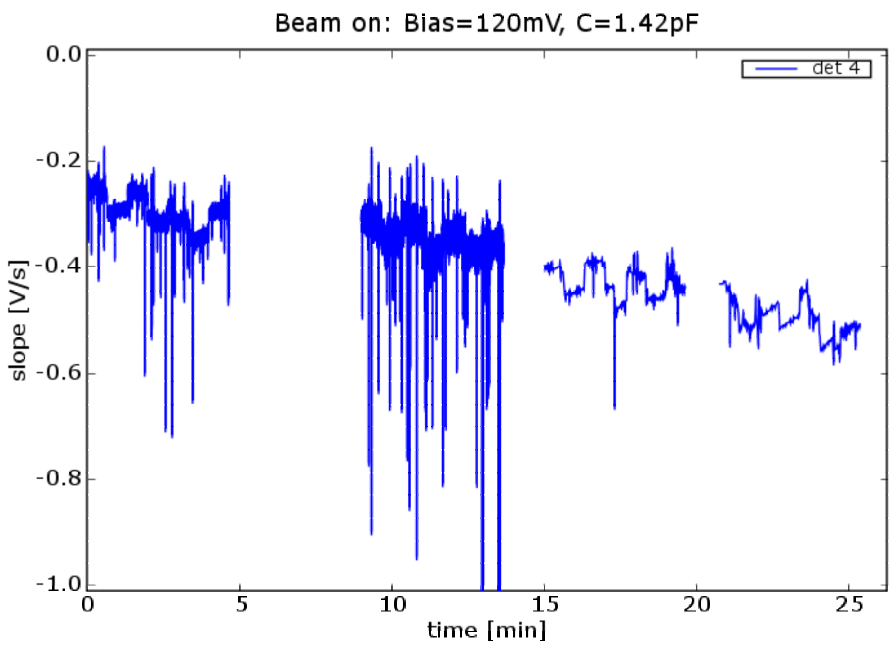
L83-L86: curing with 2 x flasher



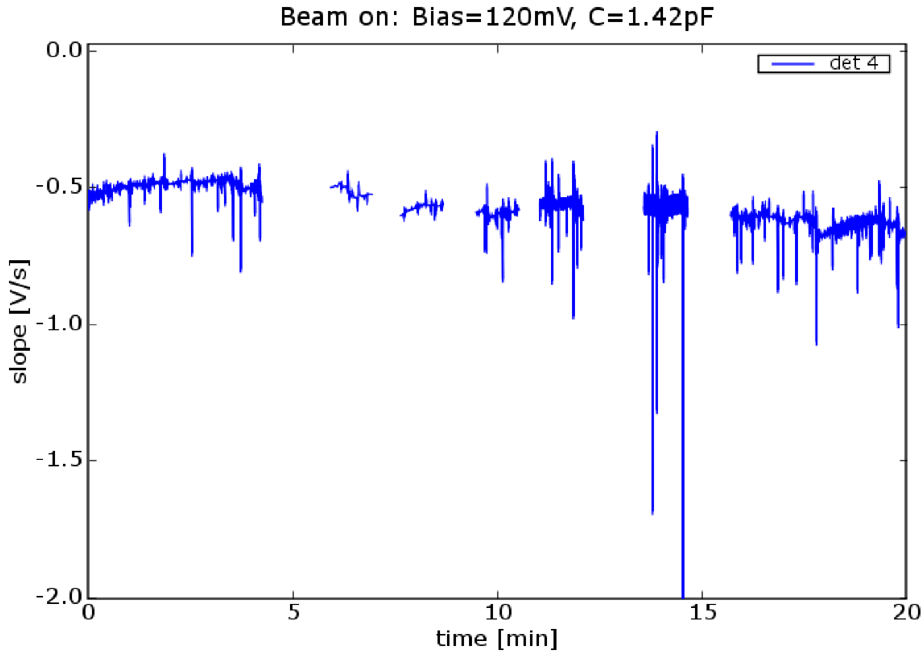
L87: 3 small IR flux changes



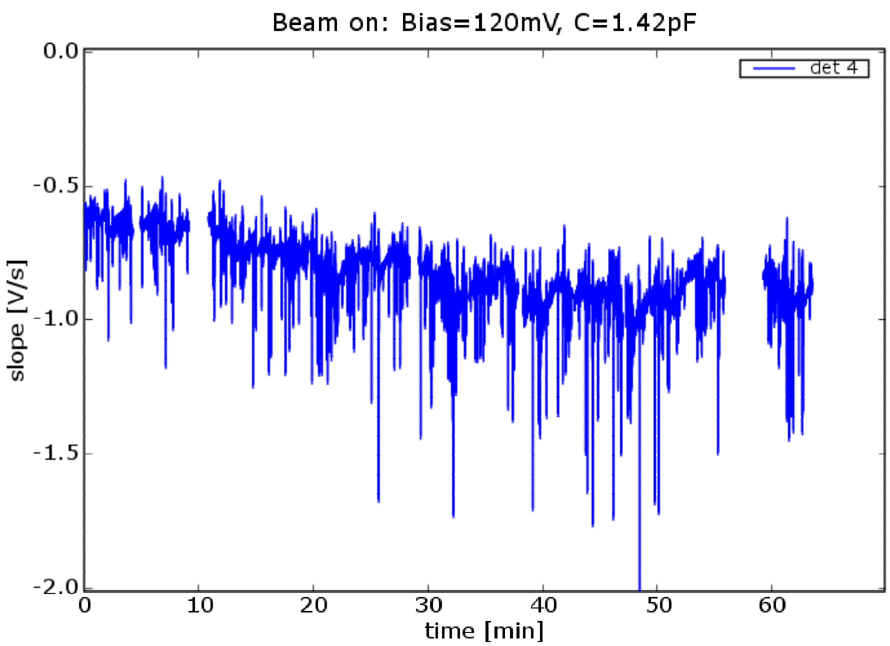
H6-L86: high proton flux / low proton flux / curing



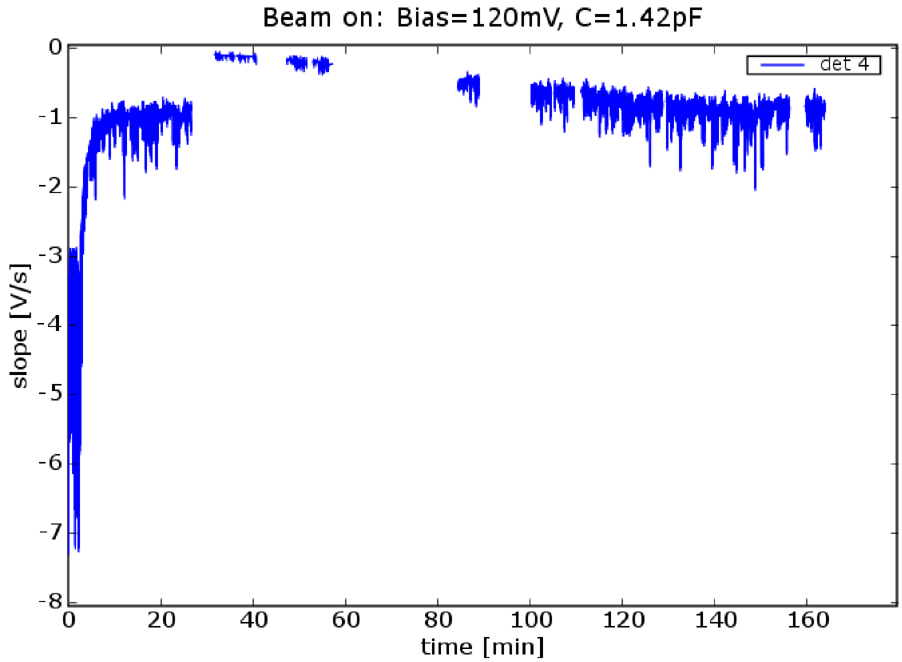
L90-L93: series of small IR flux changes for different integration times



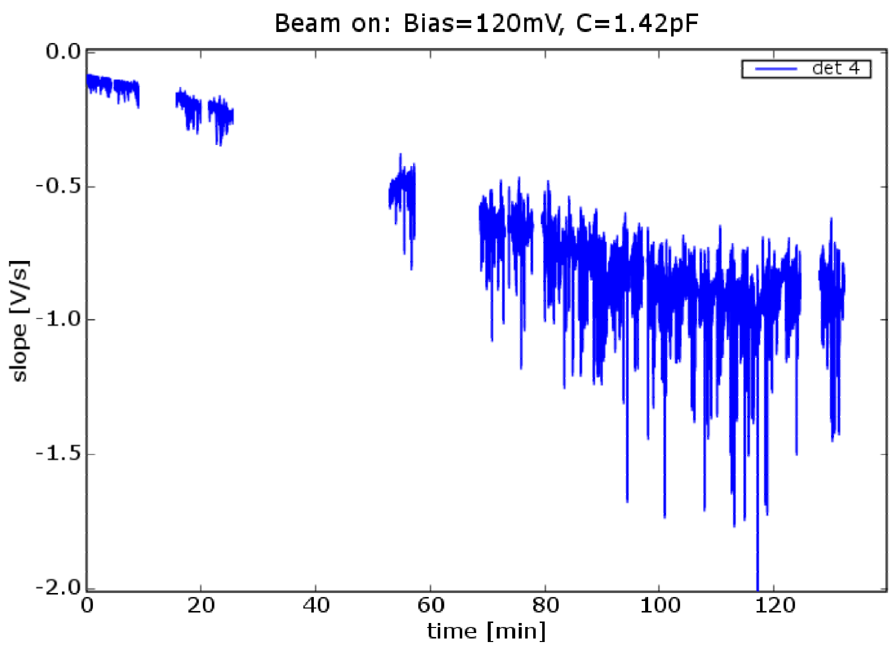
L94-L100:



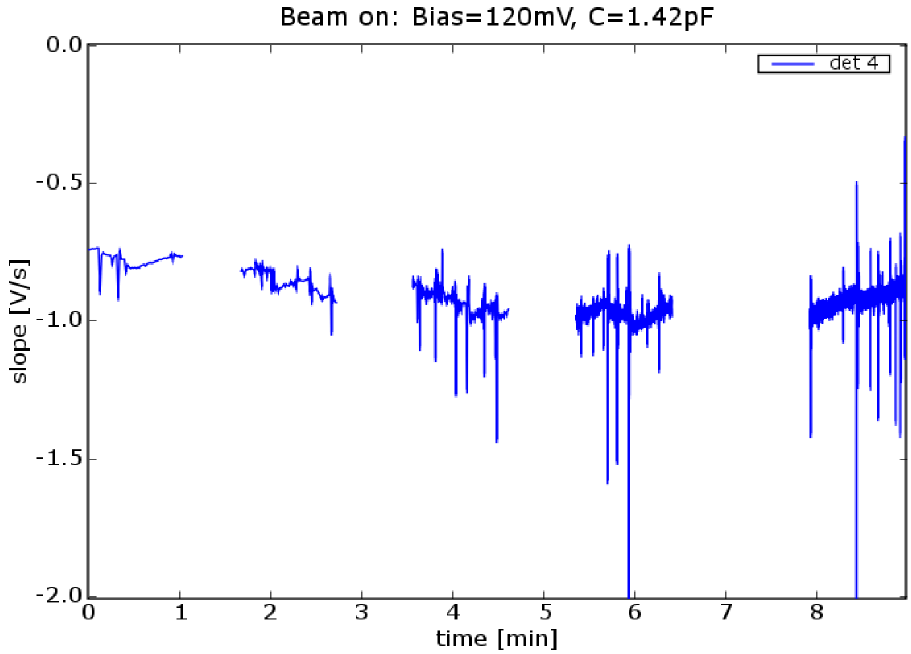
L100-L112:



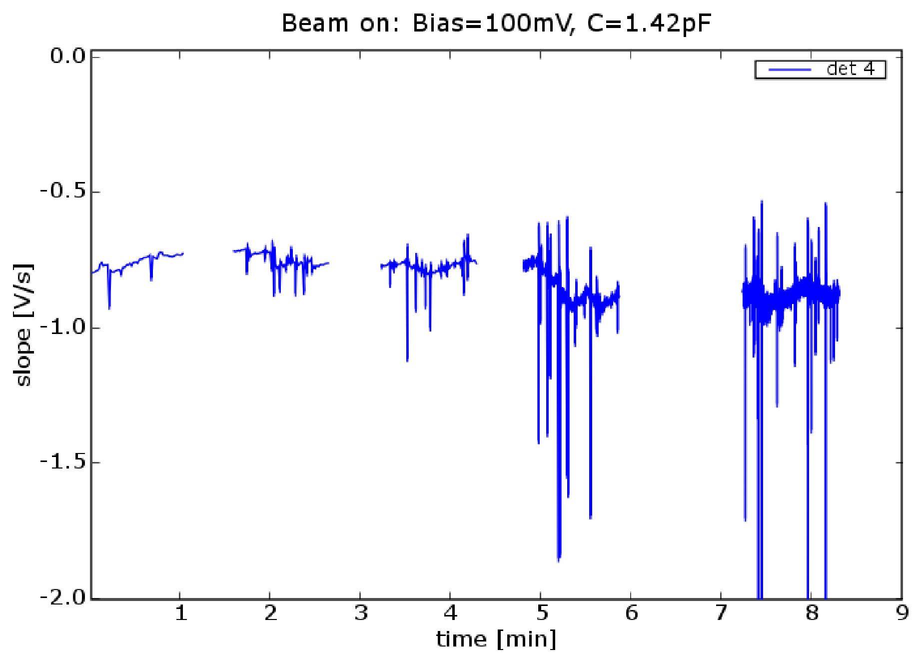
H6-L112: high proton flux / low proton flux / curing / low proton flux (plateau)



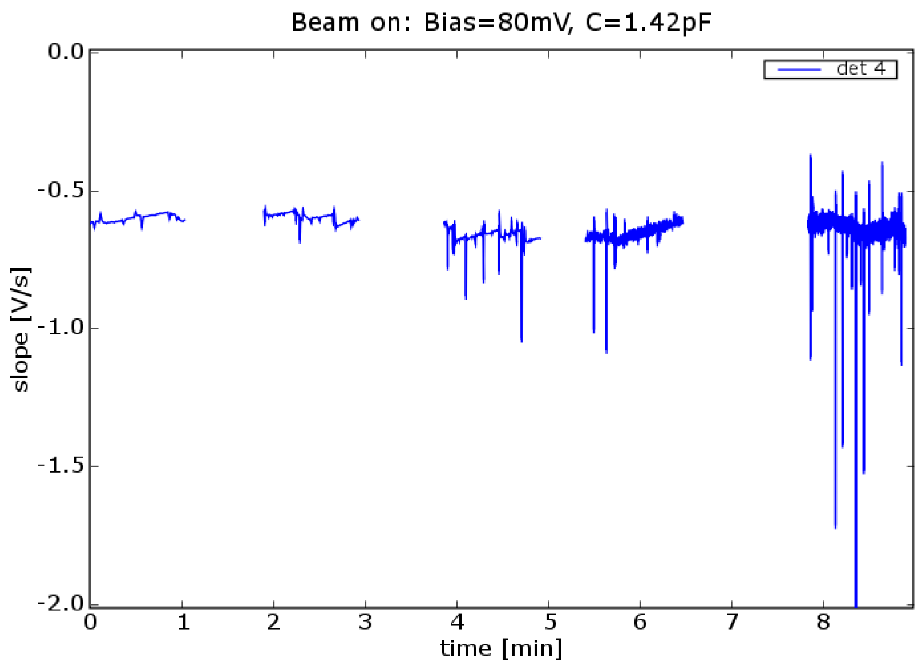
L85-L112: low proton flux (plateau)



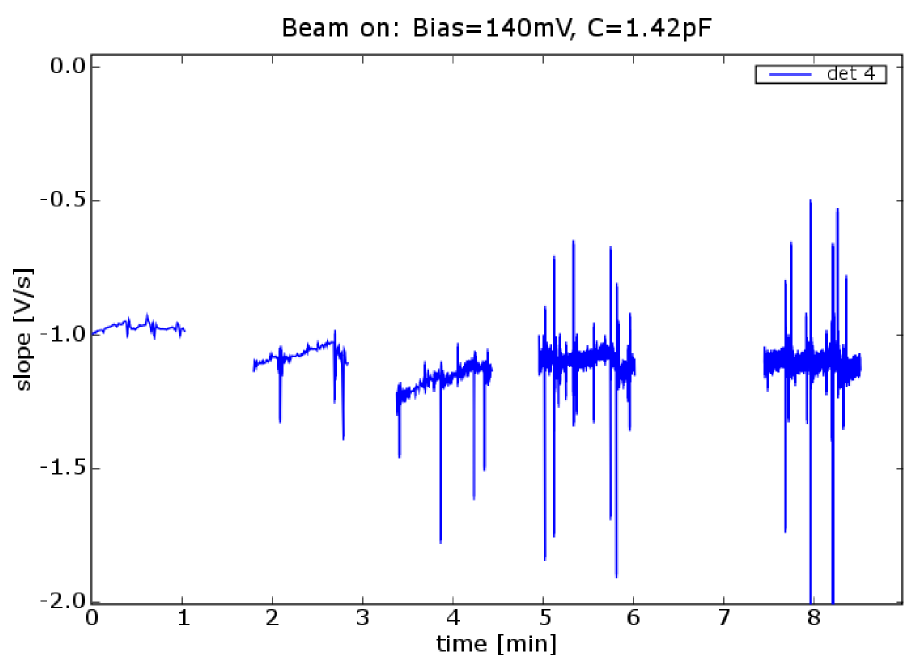
L113-L117:



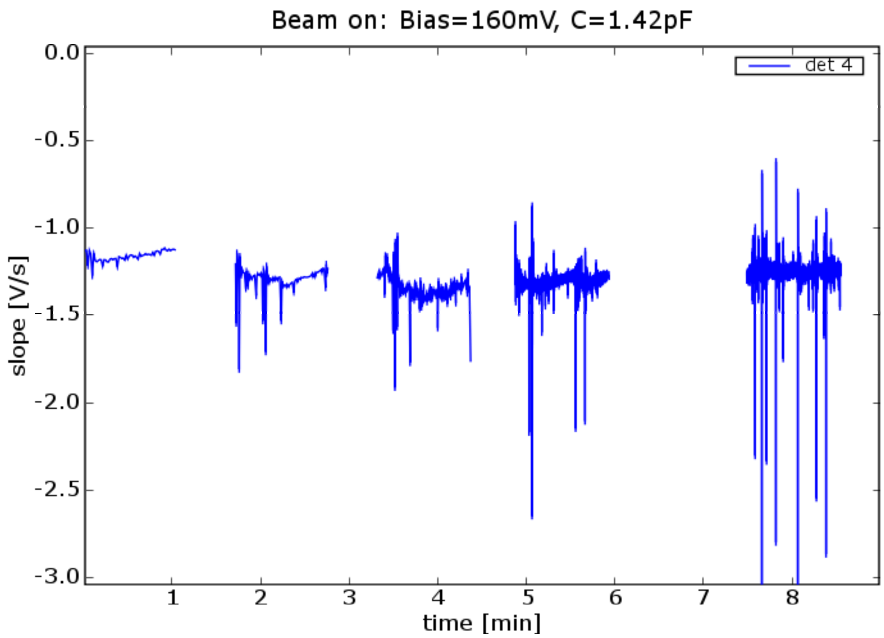
L118-L122:



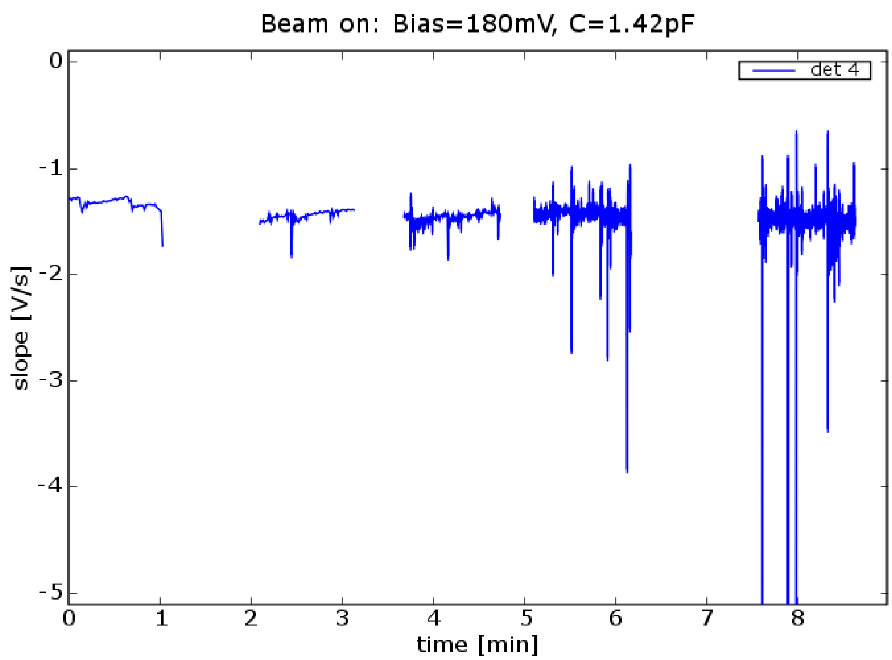
L123-L127:



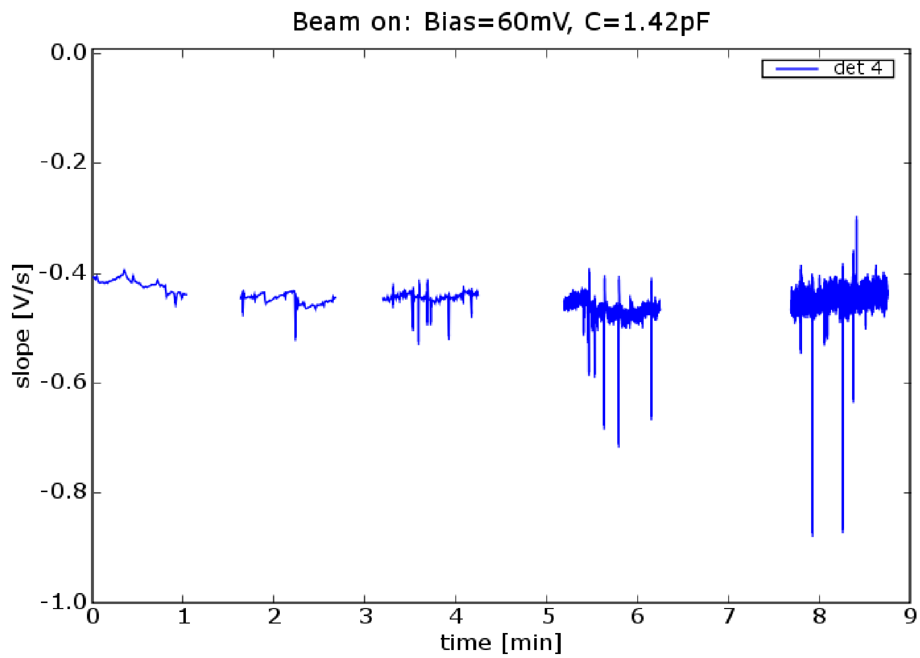
L128-L132:



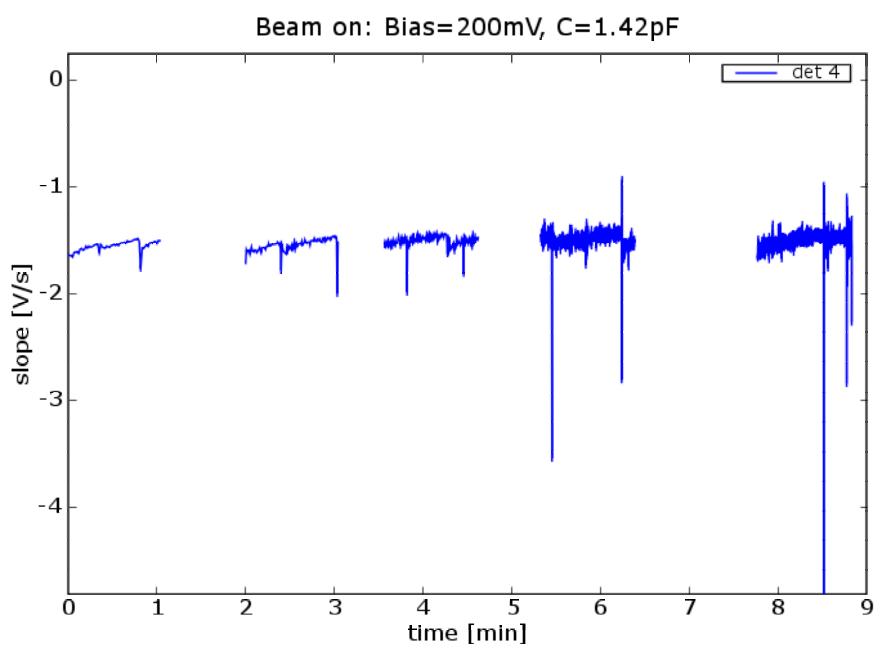
L133-L137:



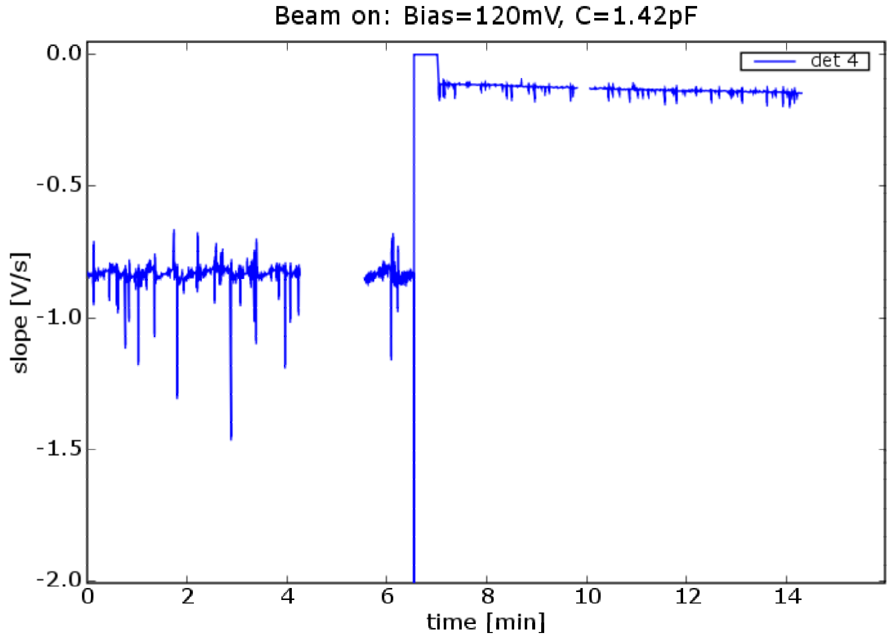
L138-L142:



L143-L147:



148-L152:



L153-L155: curing 1 x IR flasher for 0.5 min

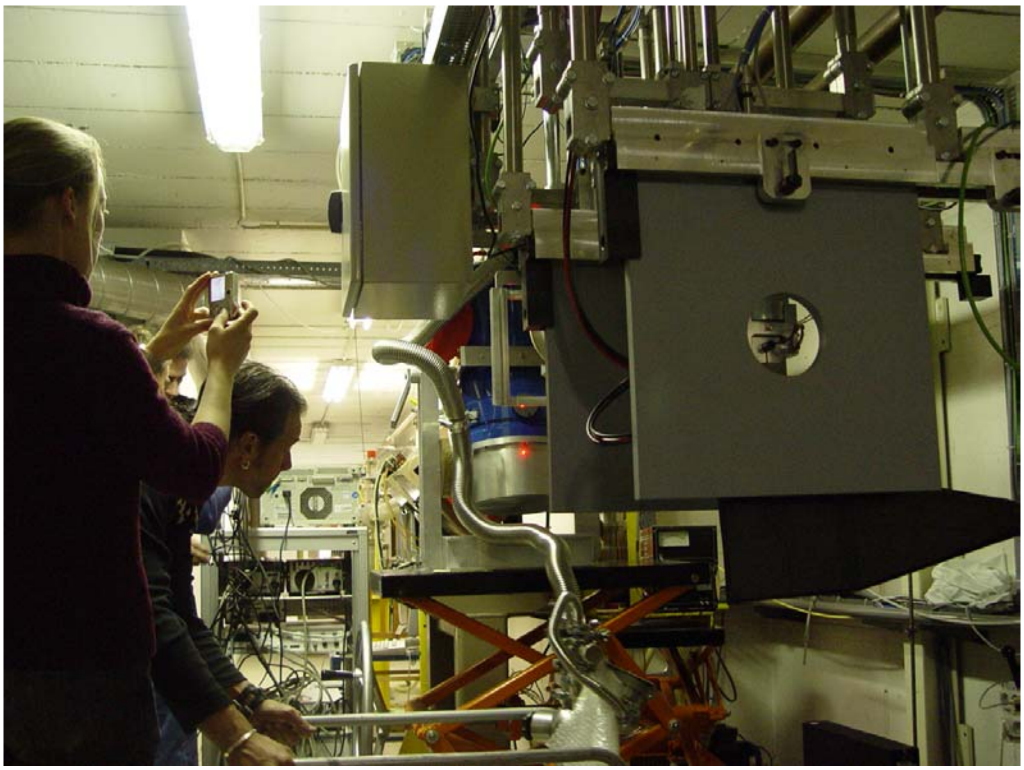
9.4 Data analysis

It will be the task of a dedicated group led by KUL to further analyze the data with different and optimized software tools and to produce more detailed results that can then be evaluated by detector experts and observers.

Based on a successful analysis of the data set and on the evaluation of the findings and the understanding of the detector behaviour, conclusions should be drawn how to best operate the photoconductor arrays in orbit under cosmic irradiation, how and how often to do an effective curing and how to retrieve the faint signals of the sky sources from the disturbed raw data maintaining a reliable photometric calibration.

It is expected that final reports with conclusions and recommendations from the dedicated working group will become available within a few months.

Test site: The “cave” of UCL’s Cyclotron Research Center Light Ion Facility



Alignment of proton beam axis with detector dewar during test phase 2