Calorimeter and SPECS Component Irradiation at PSI in June 2005

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Abstract

Several components used in the Calorimeter electronics and the SPECS Slaves have been irradiated in a 60MeV proton beam at PSI in June 2005. The conditions of the test are described and the results in term of radiation tolerance for the parts concerned are given. Half of the components in beam showed a sensitivity which makes them inadequate for the level of radiation expected in the LHCb cavern. The others have been qualified in term of dose. Moreover, no Single Event Latchup was observed during the irradiation period.

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I Irradiation conditions

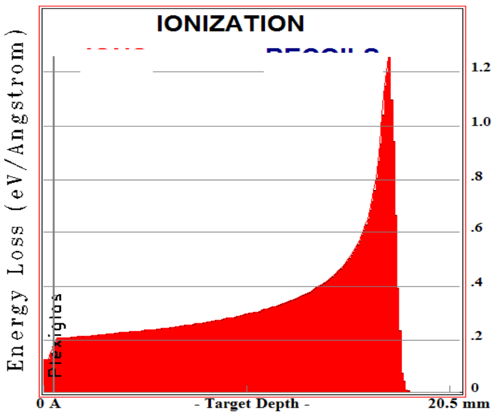
The Calorimeter electronics and SPECS group performed several irradiation tests in the past years[1]. Those irradiations usually took place at the *Centre de Proton Thérapie* (Orsay, France) or at *GANIL* (Caen, France). In june 2005, the low energy proton beam of the *Paul Scherrer Institut* (Villigen, Switzerland) was used to irradiate a few critical components of our electronics.

The list of components irradiated is

1. Oscillator 40MHz (JAUCH 0-40.0-VX3MH)
2. PROM PCF 8582
3. SN65LVDS32 (differential line receiver)
4. DS92LV090 (nine channel LVDS transceiver)
5. SN65LVDS104 (differential line receiver)
6. DS90LV001 (LVDS-LVDS buffer)

They are used on the SPECS mezzanine or on the Calorimeter Front-End and CROC boards. In the two cases the requirements are different. The SPECS mezzanine are supposed to equip sub-detectors where the dose expected may reach more than 50krad. The Calorimeter electronics should experience a maximum of 2krad over 10 years. Thus, the requirements are respectively of roughly 100krad and 10krad.

The beam was the low energy proton beam of the PIF facility at PSI. The energy was 60MeV with an average flux of 9.8×10^8 protons $cm^{-2}.s^{-1}$. Such particles deposit a dose of $127.8 krad.s^{-1}$ in silicon. Figure 1 shows the Bragg curve for the incident protons in 1mm of plexiglas[2] followed by 2 cm of silicon.



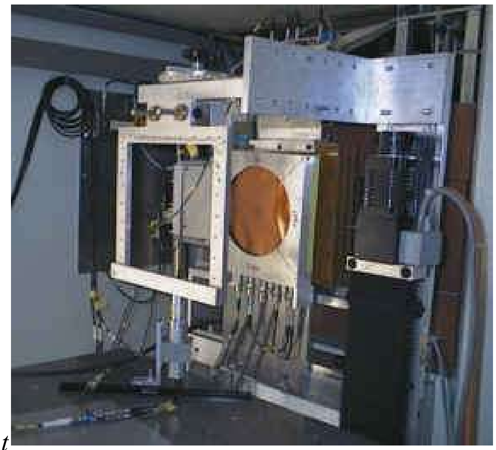


Figure 1: Left, the Bragg curve of the incident protons in the medium of the parts (SRIM calculation[0]). Right, the PSI set-up after the beam pipe window. The components were tied to a support screwed on the PSI rectangular frame. A laser beam at the rear allowed a precise positioning of the tested parts.

1 See the Annexe, page 9 or http://www.lal.in2p3.fr/~machefer/irradiation_table.htm for a list of the components irradiated and the measured tolerances.

2 In this calculation, the part cover is supposed to be made of a material whose effect on the incident particles is close to what would be observed with plexiglas. The thickness is evaluated to roughly 1mm. The impact of the cover is anyway negligible.

Two types of boards, later on referenced as *type I* and *type II* have be made for the test. The first was a SPECS Master PCB on which the parts numbered 1 to 4 of the list above had been soldered. The second one was a small board supporting two SN65LVDS104 and two DS90LV001. We had two copies of the second type at our disposal, so that three boards have been irradiated. Each board had four components and the acquisition was designed to measure four channels simultaneously.

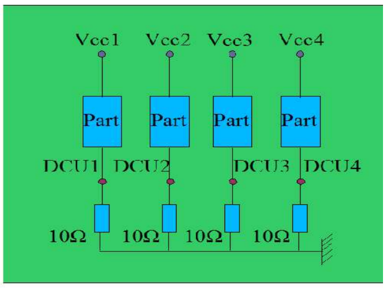


Figure 2: The schematics of the four channel power supply lines and acquisition channels of the boards (types I and II). The current was measured by the voltage drop on the power lines.

The measurement performed on each component in beam was its power consumption. Hence, each acquisition channel was measuring the voltage drop on a low value resistance along the power line of each part, as shown on figure 2 (V_{cci} and DCU$_i$ are respectively the V_{cc} line and the DCU measurement point for each one of the four channels). The voltage drop in the resistance was compensated in order for the chip to be properly powered.

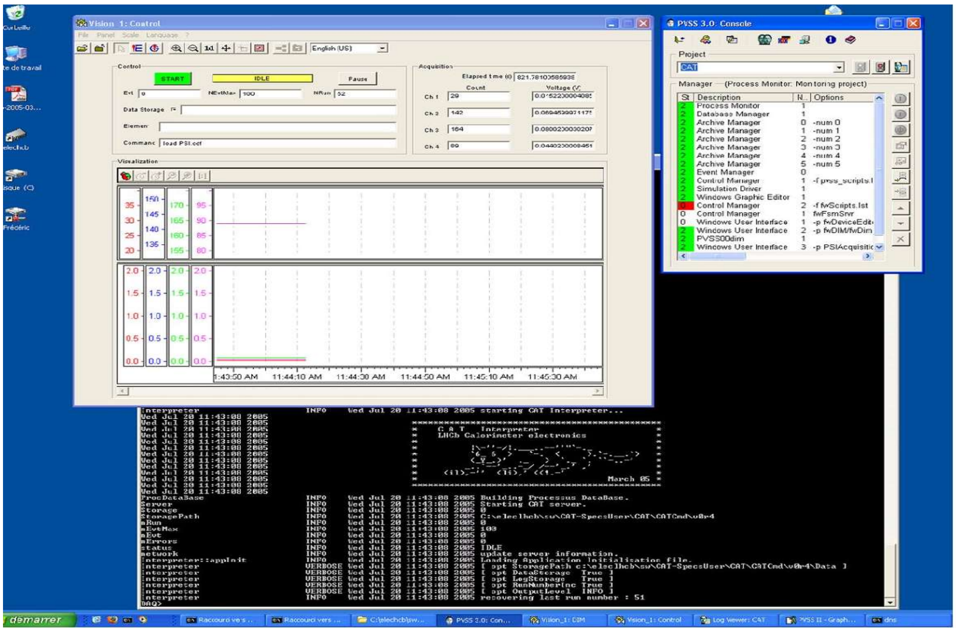


Figure 3: The acquisition was done by the CAT application running on the computer as a server. A PVSS client could command the server and received from it the acquired measurements for the four channels.

The boards were simply tied with adhesive tape on a support screwed on the PSI frame (see figure 2). The positioning was controlled with a laser aligned with the proton beam whose diameter was 9cm. The homogeneity was garantied to be 90% in 6cm. We took care of having all the tested parts in the 6cm diameter disc centred on the laser spot. In the pipe vicinity and apart from the components, the power supplies and a SPECS slave (mezzanine) used for the acquisition have been installed. A DCU ADC is mounted on the mezzanine and measures the four channels. A 30m cable linked the SPECS slave to its master plugged in the acquisition computer located in the counting room.

The program CAT [1], *Control and Acquisition Tasks*, has been used to perform the acquisition of the DCU at a tunable frequency of one hertz. The program was running in the server and command line mode, and a PVSS[2] client controlled it remotely through a DIM[3][4] service/command mechanism. Figure 3 shows the computer screen with, in the foreground, the PVSS client showing the current curves of the four channels and in the background the CAT command line controlling the electronics and sending back the measurements to the client.

II Irradiation results

1 Introduction

The three figures showed in the present section concern the three boards in beam. Each figure has two plots : at the top the voltage drop measured (in volt) and at the bottom the cumulated dose (rad) with respect to the exposition time (in second).

The three boards have been irradiated on several consecutive runs. Each figure shows the concatenation of the runs for a board, the transition being marked on the top plot by 4 superimposed dots at 1 volt (those dots are not measurements and are meant to guide the reader eyes). It is easy to see that some runs have been performed without beam (the interest was to evaluate the TID recovery of a faulty part) as the dose increase is null for some time intervals.

Finally, we mention two observations made during the irradiation period :

- The measurements exhibit larger fluctuations than observed during the preparation of the setup at LAL. The curve widths is a consequence of those fluctuations which have not been understood.
- The SPECS mezzanine used for the acquisition is not Single Event Upset[3] (SEU) protected and some bit flips were expected. In order to prevent those effects, the slave was located in the safest zone at a distance of the parts compatible with the length of the DCU acquisition cables (roughly 1.5m, below the setup, under a table). Nevertheless, a few SEU have been seen (e.g. figure 5 at 1700s) although there were not troublesome. A simple mezzanine reset sent by CAT to the slave was restoring the acquisition.

2 Type I board

On the type I board, four parts are soldered : an oscillator, a PROM, a differential line receiver (SN65LVDS32) and a nine channel LVDS transceiver (DS92LV090). Those components are supposed to be used by the SPECS slaves. The CROC clock (which is dispatched to the full crate through its backplane) is generated either by the TTCrq (normal conditions) or by an external clock. It was also considered to implant a 40MHz oscillator on the final CROC (as on the actual prototypes) for debugging purpose.

The constrains on the parts of this test board are stringent.

Oscillator

The oscillator current abruptly dropped to zero after 16.1krad (red curve on figure 4). A shut down of the beam didn't help in restoring the functionalities of the part. A current measurement performed after the irradiation confirmed the destruction of the component.

3 A single event upset is caused by a ionising particle which changes the status of a bit in a digital component.

PROM

The PROM is the first component which showed some dose effect. The current rapidly increased from 14krad (green curve on figure 4). A beam shut down exhibited a slow and partial recovery of the chip. The particle flux was very high (10^9 protons $cm^{-2}.s^{-1}$) and we had hardly any *inline* recovery of the chip. The flux in the LHCb cavern will be far smaller[4] and the recovery will be far more efficient making this test a very nasty one.

Transceiver DS92LV090

The same effect as the one seen on the PROM was observed on the transceiver (magenta curve on figure 4), but after a cumulated dose of 30krad.

Receiver SN65LVDS32

No effect was seen on this component in spite of a long irradiation that allowed to reach a maximum of 147krad (blue curve on figure 4). Two SPECS mezzanine SEU affected the acquisition, at 420 and 800s. The component is not responsible for this, as the recovery was obtained by a SPECS reset and not by switching off and on the V_{cc} of the component.

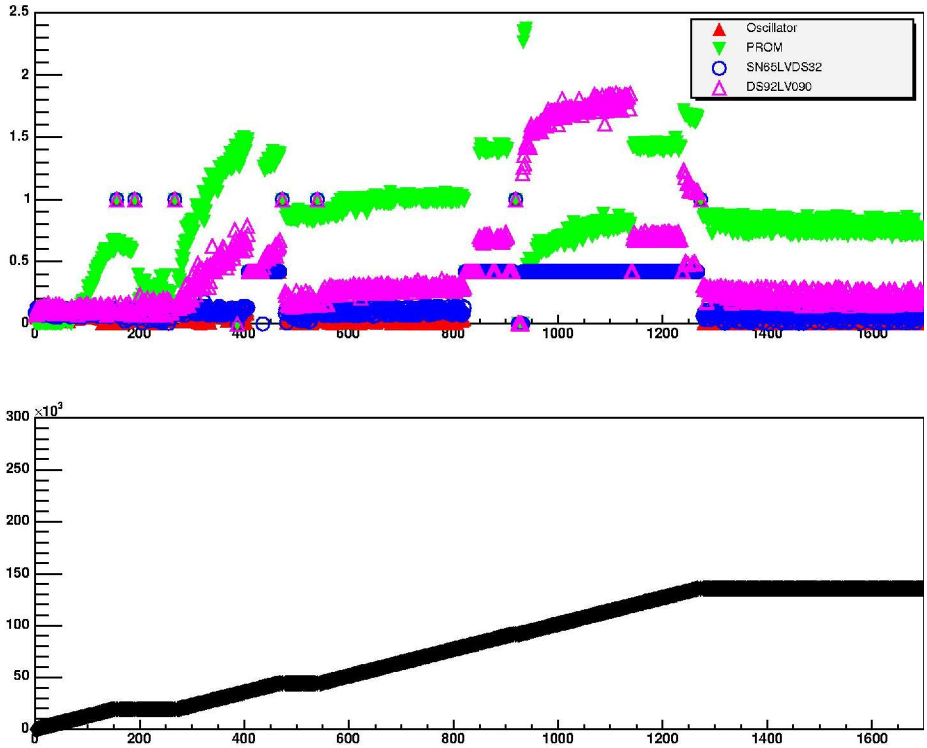


Figure 4: Measurements on the type I board. On the top the voltage drop is drawn (volt) and on the bottom the corresponding cumulated dose (rad) is represented with respect to the irradiation duration (second).

3 Type II boards

The components that equipped the type II boards are supposed to be soldered only on the Calorimeter Front-End and CROC boards. The constrains are not very stringent (10krad).

4 We estimated that $4.2x10^9$ neutrons of more than 30MeV should reach the Calorimeter electronics hotter area in a year and per cm^2 (see [5]).

Two boards have been irradiated each having two receivers (SN65LVDS104) and two LVDS-LVDS buffers (DS90LV001)

As already mentioned a SEU was observed in the acquisition after 1700s of the irradiation period of the second board. Another one occured at 2100s.

The total dose of the second board irradiation is probably not well estimated. Indeed, the instantaneous dose of the second run for this period is supposed to be null (see figure 5 bottom curve, run of 50krad, from 800 up to 1200s). This is due to the fact that the board was found untied and away from the beam at the end of this run. We thus considered the corresponding irradiation to be lost, but the final total dose for this board is most certainly between 400 and 450krad. We assume 400krad in the following.

Receiver SN65LVDS104

No effect was seen before 30krad. After 30 krad, one of the four tested components exhibited unexpected current fluctuations which reached a factor 2 with respect to the nominal value. Those fluctuations were fugitive and could be due to a problem in the acquisition system (no SPECS slave reset was triggered during the first board test period). None of the other 3 components had such a behaviour in spite of the huge cumulative dose reached. The doses obtained are respectively of 100 and 400krad (see previous comment on the second board total dose).

LVDS-LVDS buffer DS90LV001

No effect was seen for these components.

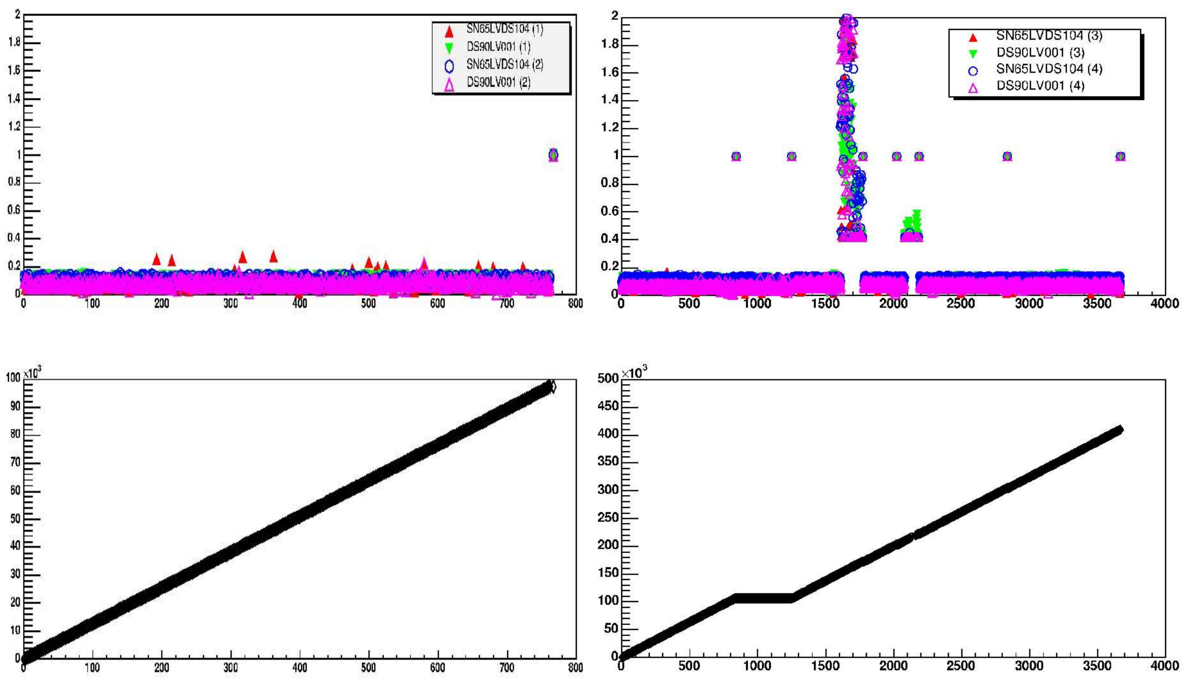


Figure 5: Left and right, measurements performed on the 2 type II boards. On the top the voltage drop is drawn (volt) and on the bottom the corresponding cumulated dose (rad) is represented with respect to the irradiation duration (second). Two SEU affected the acquisition at 1700 and 2100s during the second board irradiation. A remote acquisition reset cleared the problems.

III Conclusions

Among the components tested and taking into account the constrains imposed by their use, only the two differential line receivers (SN65LVDS32 and SN65LVDS104) and the LVDS-LVDS buffer (DS90LV001) fulfil the requirements. This will have an impact on the design of the radiation tolerant version of the SPECS slaves. No 40MHz oscillator will be mounted on the definitive version of the CROC. This is not inconvenient as it was planned exclusively for debugging purpose. We will simply operate the CROC with a TTCrq board (which is absolutely necessary during normal conditions) or with an external generator (a LEMO input exists already on the CROC prototype).

No Single Event Latchup[5] (SEL) was seen during the irradiations. We may try to evaluate the SEL tolerance of the parts in the Calorimeter electronics region by considering a flux of 4.2×10^{9} neutrons of more than 30MeV $year^{-1}.cm^{-2}$ [5]. Supposing that those neutrons above 30MeV have the same SEL cross-section as the PSI protons of 60MeV[6], five seconds at PSI correspond to a LHCb year (10^{7}s). This would lead to 206 years for the SN65LVDS32 and 1500 years for the SN65LVDS104 and the DS90LV001 without SEL and per component.

IV Acknowledgements

We would like to thank the LHCb Clermont-Ferrand group for providing the two boards of type II, the Mechanics group (SDTM) at LAL for the design of the support and Clara Gaspar for her help on the PVSS/DIM client mechanism for the use of CAT in server mode. Special thanks also to Achim Vollhardt who gave us the opportunity to perform the irradiation test and to Roger Brun from PSI for his hospitality.

5 Like the SEU, the single event latchup is produced by a ionising particle. The SEL triggers a sort of short circuit causing an increase of the current and may lead to the destruction of the component.

6 The SEL cross-section usually exhibits a quick increase with respect to the ionising particle deposited energy (LET, Linear Energy Transfer) to get to a maximum. Then, the cross-section is essentially flat. Notice that the cross-section is determined with respect to the ionising particle LET. In our case, the protons are not the ionising particles as their LET is too small. They will break a silicon nucleus and produce heavy ion fragments that will have a sufficient LET to trigger a SEL. The probability to produce such a fragment is typically of 10^{-6} for a few tens of MeV protons or neutrons.

V Annexe : Radiation Tolerance of Components

This list shows the radiation tolerance of some components irradiated by the LAL group.

Part	Date	Irradiation Conditions	Dose (krad)	Observations
Calo FE Shaper Tested at CPO and GANIL	July 2, 2001	CPO (Orsay) Proton : 200 MeV, 10^8 $s^{-1}.cm^{-2}$	22.6	No effect
			10.7	No effect
			12.3	No effect
			11.7	No effect
	December 9, 2001	GANIL (Caen) Krypton : 58MeV/A	22.9	No effect
			23.9	Small current increase (from 43mA to 52mA) observed at the end of the run (~22krad). After shutdown, current returned to nominal value.
Transmitter DS90CR215	December 14, 2001	GANIL (Caen) Krypton : 58MeV/A	6.5	No effect
Receiver DS90CR216		GANIL (Caen) Krypton : 58MeV/A	6.5	No effect
Transmitter DS90CR483		GANIL (Caen) Krypton : 58MeV/A	6.5	No effect
Receiver DS90CR484		GANIL (Caen) Krypton : 58MeV/A	6.5	No effect
FPGA Actel A54SX32A		GANIL (Caen) Krypton : 58MeV/A	6.5	No effect
FPGA Xilinx XCV50 PQ240AF		GANIL (Caen) Krypton : 58MeV/A	6.5	No effect
Test RAM IDT71V016SA		GANIL (Caen) Krypton : 58MeV/A	6.5	No effect
Calo Delay Chip	April 22-23, 2003	GANIL (Caen) Krypton 78 : 73MeV/A	28.8	2 parts irradiated simultaneously. No effect
DS92LV010A			24.2	2 parts irradiated simultaneously. No effect
SN65MLVD200		GANIL (Caen) Krypton 78 : 73MeV/A	28.8	2 parts irradiated simultaneously. No effect
Transistor NPN NE856			24.2	2 parts irradiated simultaneously. No effect
QuadBuffer 74F125		GANIL (Caen) Krypton 78 : 73MeV/A	28.8	2 parts irradiated simultaneously. No effect
			24.2	2 parts irradiated simultaneously. No effect
PROM AT17LV65		GANIL (Caen) Krypton 78 : 73MeV/A	24.2 + 28.8 = 53.0	4 parts irradiated simultaneously. No effect
		Russia (Moscow)	125	Small current increase at high dose level (?)
		GANIL (Caen) Krypton 78 : 73MeV/A	24.2	2 parts irradiated simultaneously. No effect
		GANIL (Caen) Krypton 78 : 73MeV/A	28.8	2 parts irradiated simultaneously. No effect
Current Amplifier AD 8011	June 30 - July 1, 2003	GANIL (Caen) Krypton 86 : 43.5MeV/A	91.0	2 parts irradiated simultaneously. No effect
Power Switch MAX 869L		GANIL (Caen) Krypton 86 : 43.5MeV/A	91.0	2 parts irradiated simultaneously. No effect
Oscillator 40MHz JAUCH 0-40.0-VX3MH	June 23, 2005	PSI (Zurich) Proton 60 MeV, $10^9 s^{-1}.cm^{-2}$	147	Component failure at 16krad. Consumption drops to very small value. No recovery after beam shutdown.
PROM PCF 8582			147	Continuous current increase at 14krad. Slow recovery observed if the beam is switched off.
SN65LVDS32			147	Continuous current increase at 30krad. Slow recovery observed if the beam is switched off.
DS92LV090				
SN65LVDS104			147	No effect.
DS90LVDS001			100 400	2 parts irradiated simultaneously. No effect. 2 parts irradiated simultaneously. No effect.
			100 400	2 parts irradiated simultaneously. No effect. 2 parts irradiated simultaneously. No effect.

References

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