# CHARACTERISATION OF SI DETECTORS FOR THE USE AT 2 K*

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*Abstract*

It is expected that the luminosity of the Large Hadron Collider (LHC) will be bounded in the future by the beam loss limits of the superconducting magnets. To protect the superconducting magnets of the high luminosity insertions an optimal detection of the energy deposition by the shower of beam particles is necessary. Therefore beam Loss Monitors (BLM) need to be placed close to the particle impact location in the cold mass of the magnets where they should operate in superfluid helium at 1.9 Kelvin. To choose optimal detectors n-type silicon wafers have been examined at superfluid helium temperature whilst under irradiation from a high intensity proton beam. The radiation hardness and leakage current of these detectors were found to be significantly improved at 1.9 Kelvin when compared to their operation at room temperature.

## INTRODUCTION

The magnets close to the Interaction Points (IP) are exposed to high irradiation from the collision debris.

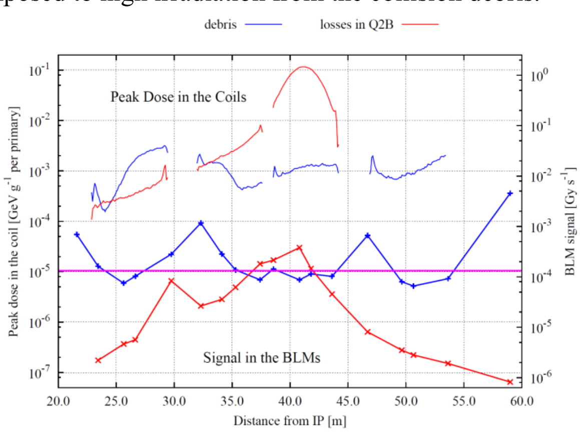


Figure 1: Simulated dose in the coil and signal in the BLM shown for two different situations: one for the debris from the interaction region (blue) and one for a simulated dangerous loss (red). It can be seen that the signal due to the debris can mask the signal from a dangerous loss [1].

It has been shown that with the present configuration of the installed BLM in this region, the ability to measure the energy deposition in the coil is limited because of the debris, masking the beam loss signal [1] (see Fig. 1). To overcome this limitation a solution, based on placing radiation detectors inside the cold mass close to the coils, is investigated [2] (see Fig. 2).

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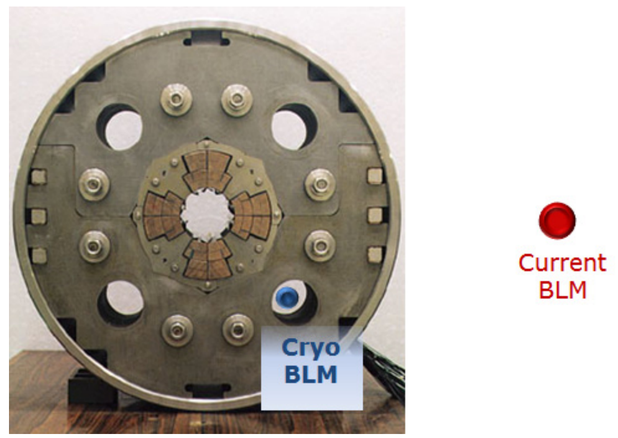


Figure 2: Cross section of the Q1 triplet magnet with the current BLM placement in red and the free region for a possible cryogenic BLM in blue.

## EXPERIMENTAL SETUP

The principle of the experiment is to irradiate the detectors being immersed inside superfluid helium during the measurements to observe the detector's degradation.

### *Detector Modules*

Three different detector modules were used in the experiment: holders for direct current (DC) measurements (see Fig. 3), holders for current pulse response measurements using Transient Current Technique (TCT) with a pulsed laser measurements [3] (see Fig. 4), and modules with 4 silicon detectors each, as beam position monitors (see Fig. 5).

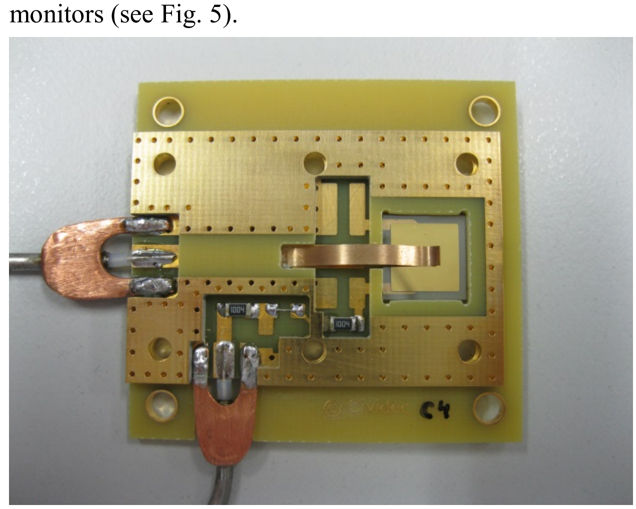

Figure 3: Holder for DC readout from Cividec.




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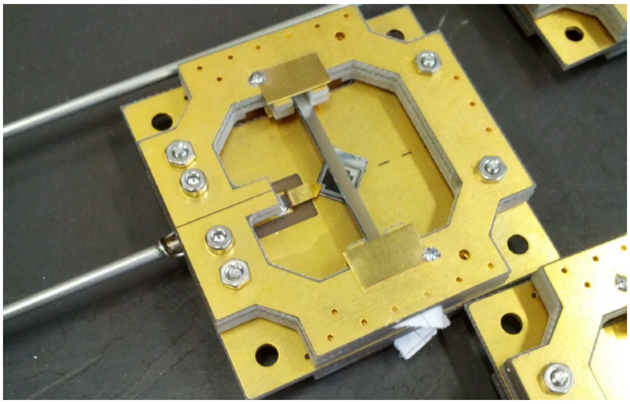

Figure 4: Holder for TCT measurements.

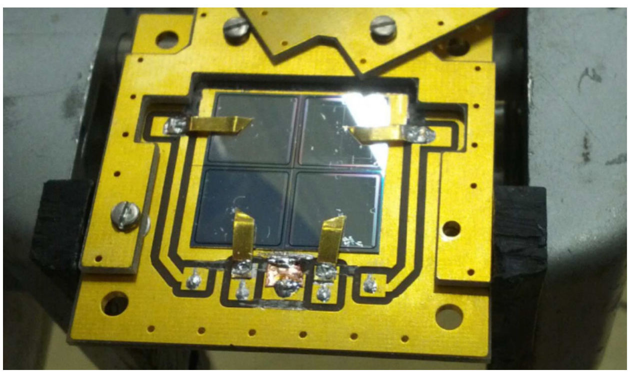

Figure 5: BPM module.

### *Signal Readout and Beam Properties*

Figure 6 depicts the shape of a signal from a spill for different stages of irradiation, the signal is recorded by the LeCroy Oscilloscope (WaveRunner 204MX-A).

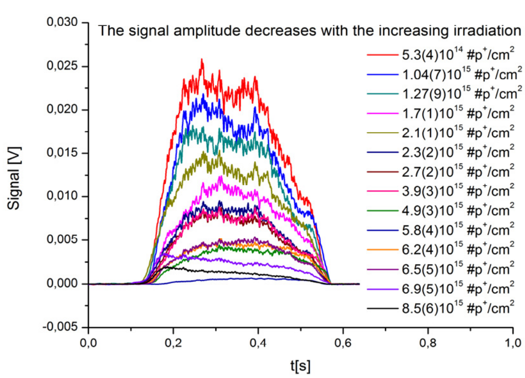


Figure 6: The shape of a signal from a spill for different stages of irradiation of a silicon detector.

The irradiation conditions are:

- Particle momentum of 24 GeV/c.
- Beam profile of FWHM 1.2 cm at the cryostat.
- Beam intensity per spill of $1.3 \cdot 10^{11}$ protons/cm$^2$, corresponding to an average of about $1 \cdot 10^{10}$ protons/s on detectors.

The irradiation lasted 4 weeks and temperature of the detectors was, most of the time, 1.9 Kelvin. At the end of the test the temperature was increased up to 80 Kelvin to simulate the temperature of the detectors during a long stop of the LHC, like e. g. the Christmas break.

## RESULTS

At the end of the irradiation a total integrated fluence of $1.22 \cdot 10^{16}$ protons/cm$^2$ was reached, corresponding to an integrated dose of about 3.26 MGy for silicon. Detectors are $p^+$-n-$n^+$ silicon structure with a thickness of 300 µm, an active squared area of 23 mm$^2$, aluminium as metallisation material and of different intrinsic resistivity. The voltage was switched from -400 V to +400 V for all detectors. This means that along with a standard reverse bias forward bias was applied that corresponds to Current Injected Detectors (CID) [4].

### *DC Measurement Results*

The figures 7 and 8 show the decrease of collected charge for the silicon devices. The curve for 10 kΩcm silicon with 100 V reverse bias has been plotted in all graphics as reference curve [5].

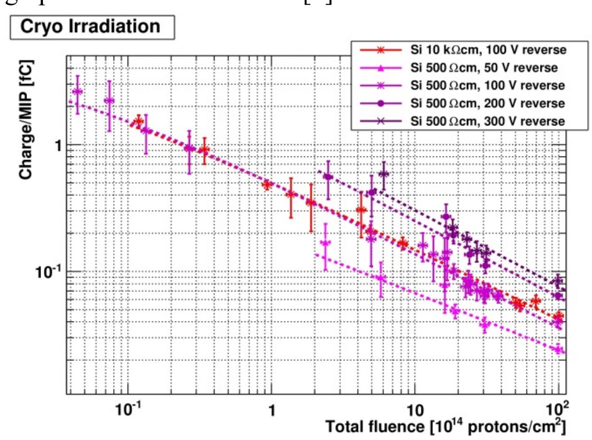


Figure 7: Dependence of the charge collected in Si detectors with a resistivity 500 Ωcm on fluence.

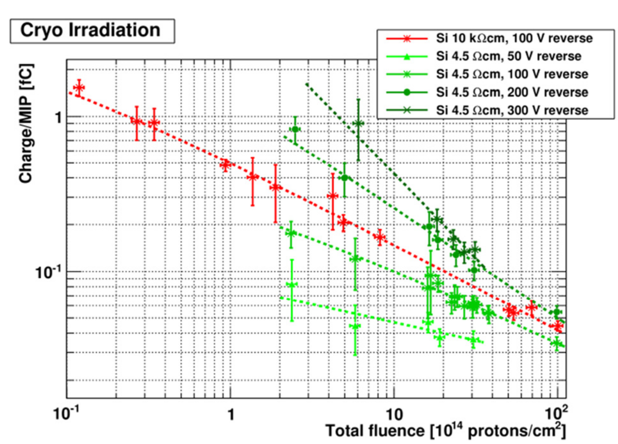


Figure 8: Dependence of the charge collected in Si detectors with a resistivity 4.5 Ωcm on fluence.

At the beginning of the irradiation and for non-irradiated or low-irradiated silicon detectors in superfluid helium bath, the forward current is about 100 µA at 100 V. With increased radiation damage, the forward current goes down. Further observations are that the forward bias for low resistivity silicon is less stable than for high resistivity silicon. This can especially be seen for the 4.5 Ωcm sample, which had a very stable but low charge collection at the beginning and increased leakage current instabilities towards the end of the irradiation.

### *Voltage Scan*

The voltage scans of the collected charge for the different detectors at different fluencies are depicted in the figures 9 and 10. In the voltage scans positive voltage denotes a forward bias.

There is no full charge collection for silicon detectors above full depletion voltage, as it would be expected for non-irradiated silicon detectors at room temperature.

Going to voltages beyond 400 V, a saturation of the charge collection is expected (as seen for room temperature irradiation), but for the considered voltage range until 400 V in cryogenic conditions, a linear fit is adequate and has been used to fit the measurements.

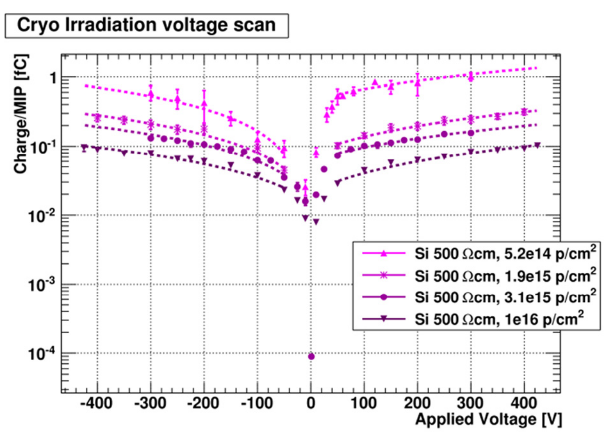


Figure 9: Voltage scan for 500 Ωcm silicon.

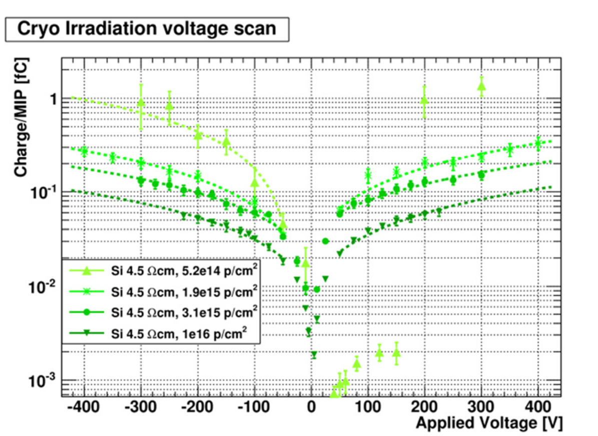


Figure 10: Voltage scan for 4.5 Ωcm silicon.

## SUMMARY

Different Si detectors at cryogenic temperatures were tested for their radiation hardness. A total integrated fluence of $1.22 \cdot 10^{16}$ protons/cm$^2$ was reached, corresponding to an integrated dose of about 3.26 MGy for silicon.

An irradiation effect on the silicon detectors sensitivity could be observed. The forward bias modus leads to high signals at the beginning of the irradiation, but unfortunately the decrease in signal at higher fluence is faster compared to reverse bias modus. Further observations are that the forward bias for low resistivity silicon is less stable than for high resistivity silicon.

The data require more treatment to allow further relevant conclusions and physical results.

More experiments with current pulse response measurements using TCT with a pulse laser at cryogenic temperatures during irradiation are foreseen.

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