CHARACTERISATION OF Si DETECTORS FOR USE AT 2 K

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MOTIVATION

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 triplet magnets (see Fig. 1).

Figure 1: LHC left of IP triplet 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 (see Fig. 2) in the cold mass of the magnets where they should operate in superfluid helium at 1.9 Kelvin.

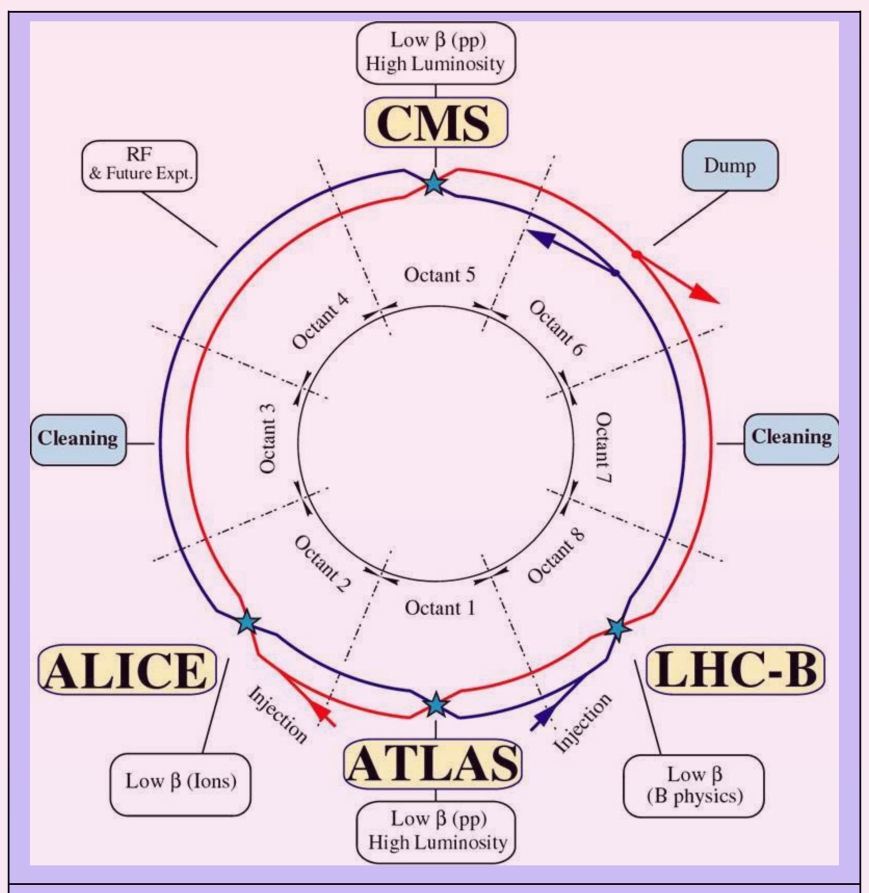

Figure 2: Overview schematic shows the four main experiments and the two ring structure of the LHC [http://lhc-machine-outreach.web.cern.ch].

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.

SIGNAL READOUT & BEAM PROPERTIES

Figure 7 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). 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 $1.3\cdot10^{11}$ protons/cm^2, corresponding to an average of about $1\cdot10^{10}$ protons/s on detectors.

The irradiation lasted 4 weeks and temperature of the detectors was, most of the time, 1.9 Kelvin.

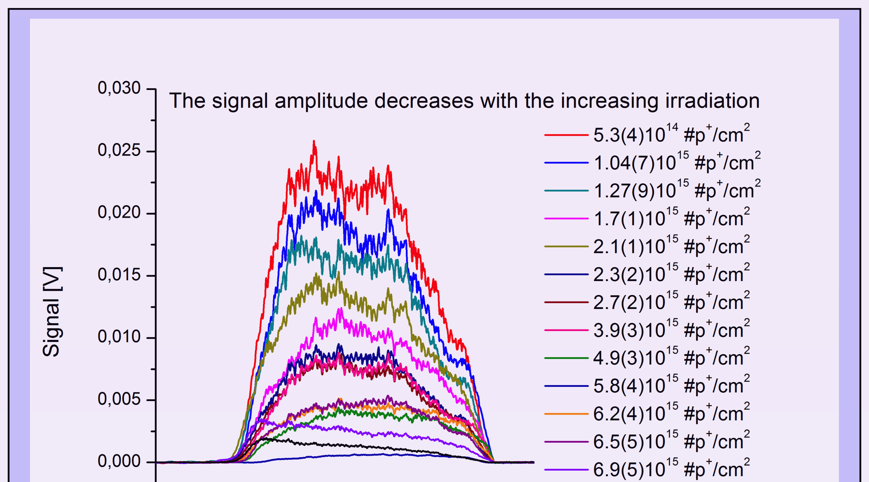

Figure 7: The shape of a signal from a spill for different stages of irradiation of a silicon detector.

INTRODUCTION

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

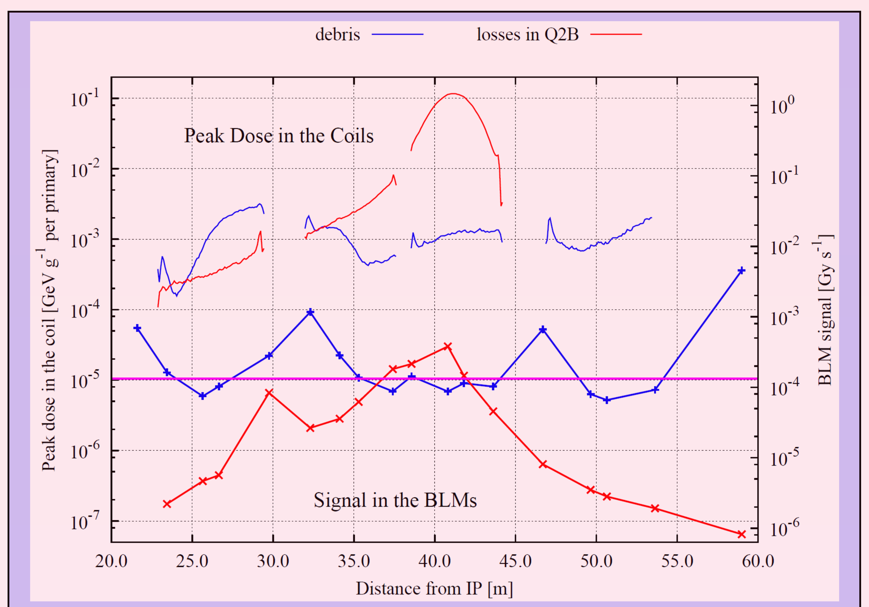

Figure 3: Simulated dose in the coil and signal in the BLM shown for two different situations: one for the debris from the interaction region (blue) and one for a simulated dangerous loss (red). It can be seen that the signal due to the debris can mask the signal from a dangerous loss [1].

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. 3). To overcome this limitation a solution, based on placing radiation detectors inside the cold mass close to the coils, is investigated [2] (see Fig. 4).

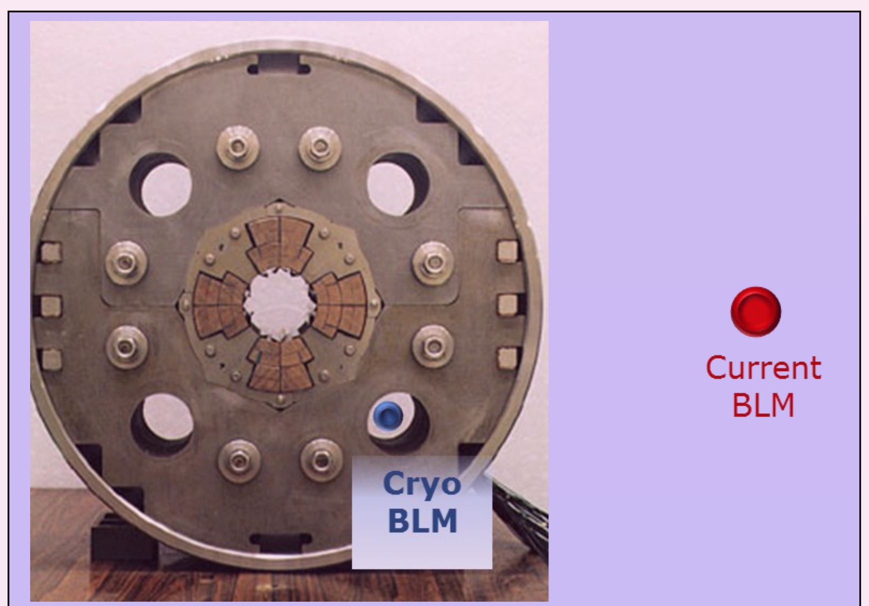

Figure 4: Cross section of the Q1 triplet magnet with the current BLM placement in red and the free region for a possible cryogenic BLM in blue.

CRYOGENIC SETUP

The cryogenic system is specially adapted to match the requirements of the radiation test facility. The main elements of the cryogenic system are the cryostat, the helium storage Dewar, the transfer line that connects the two of them and the vacuum pump as can be depicted in figure 5. Main part of the cryogenic setup installation in the T7 irradiation zone at CERN is shown in figure 6.

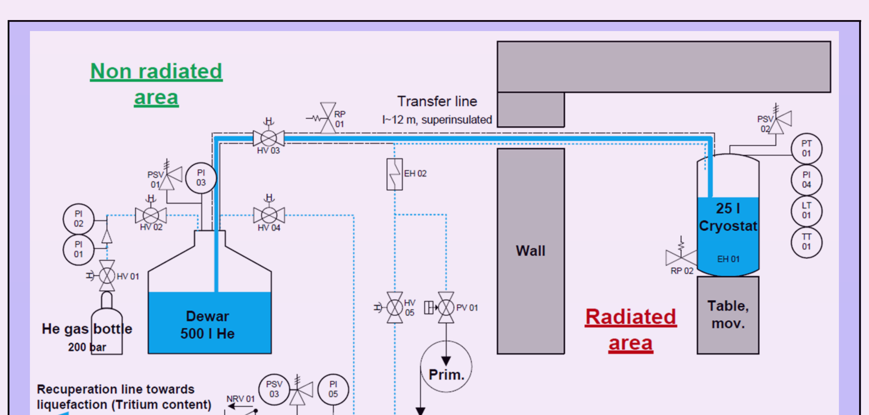

Figure 5: Cryogenic process and instrumentation diagram [Courtesy of T. Eisel].

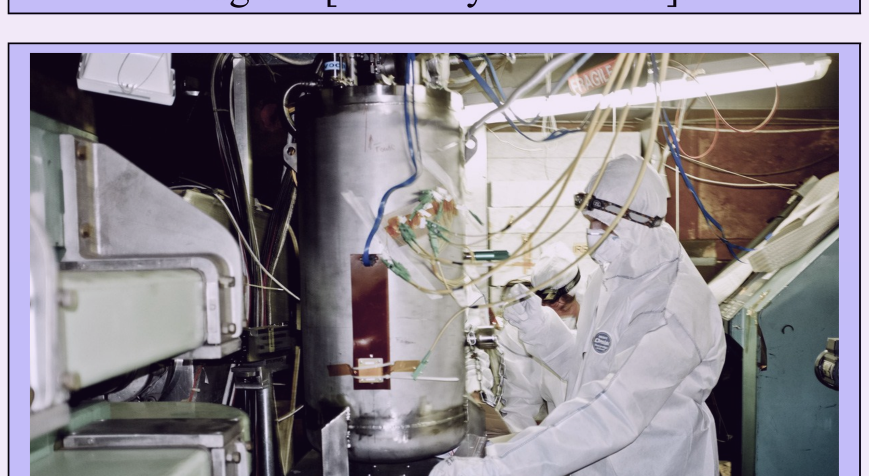

Figure 6: Preparation of the cryogenic irradiation test in T7 irradiation zone at CERN.

DETECTOR MODULES

Three different detector modules were used in the experiment (see Fig. 8): holders for direct current (DC) measurements (see Fig. 9), holders for current pulse response measurements using Transient Current Technique (TCT) with a pulsed laser measurements [3] (see Fig. 10), and modules with 4 silicon detectors each, as beam position monitors (see Fig. 11).

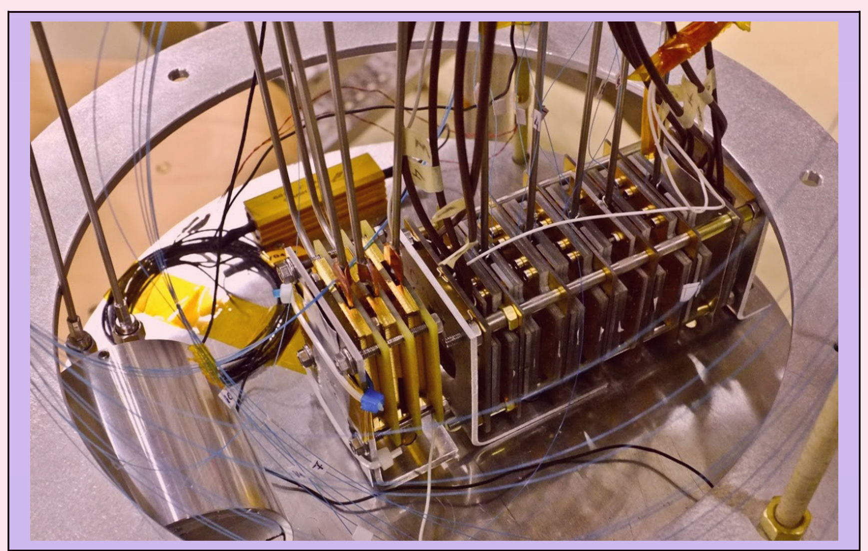

Figure 8: Detector modules mounted on plate and ready for cooling down and irradiating.

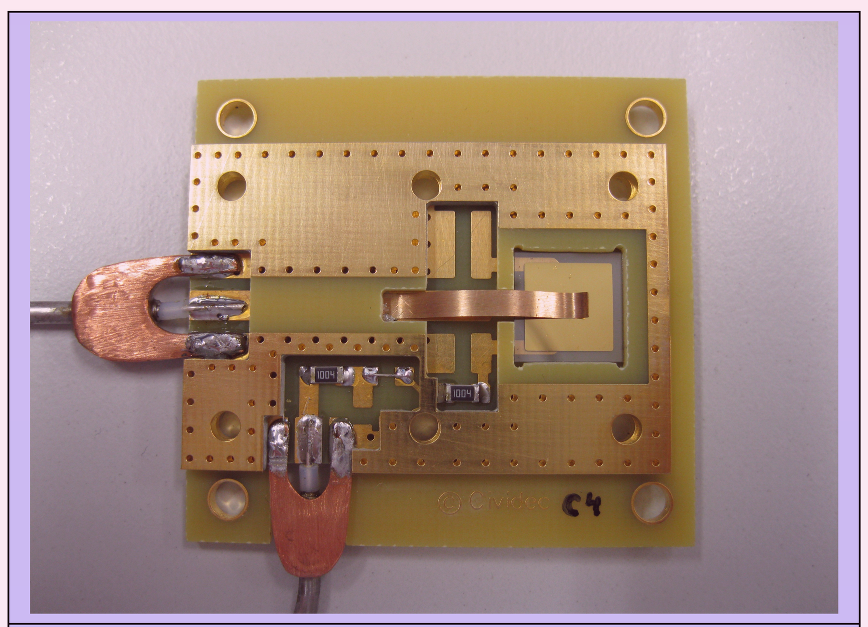

Figure 9: Holder for DC readout from Cividec.

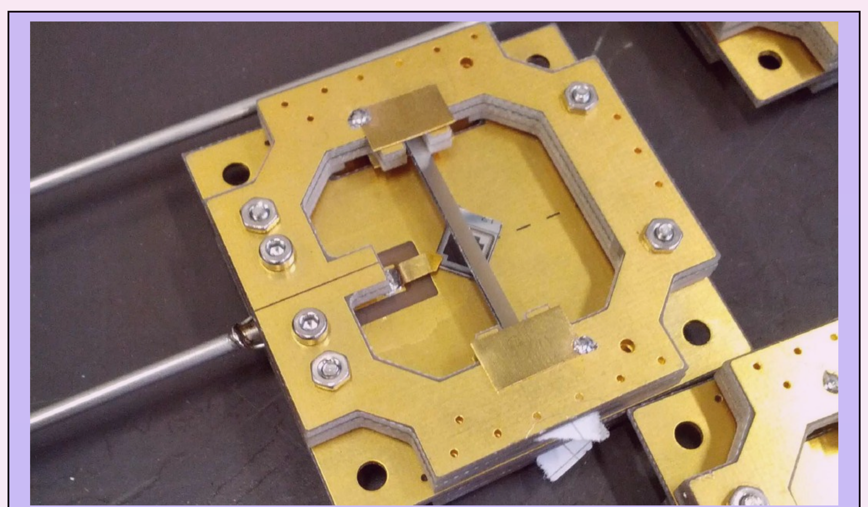

Figure 10: Holder for TCT measurements.

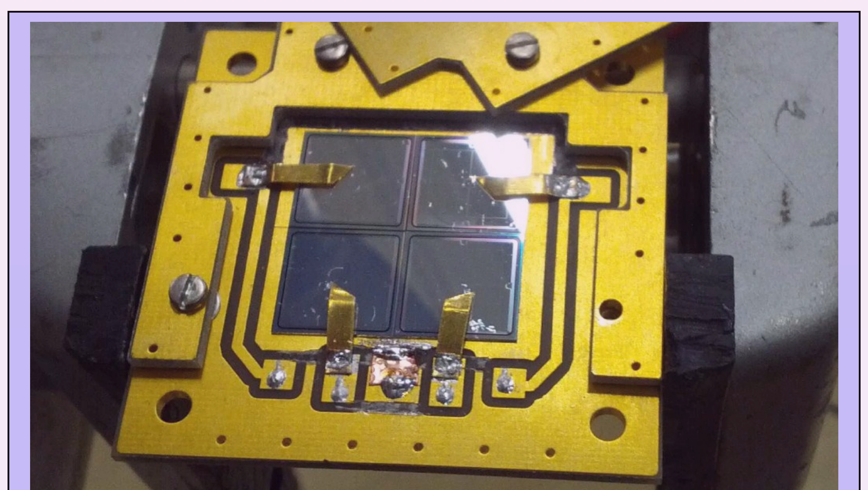

Figure 11: BPM module.

OUTLOOK

Installation of cryogenic radiation detectors on the cold mass of a LHC quadruple magnet is depicted in the figure 16.

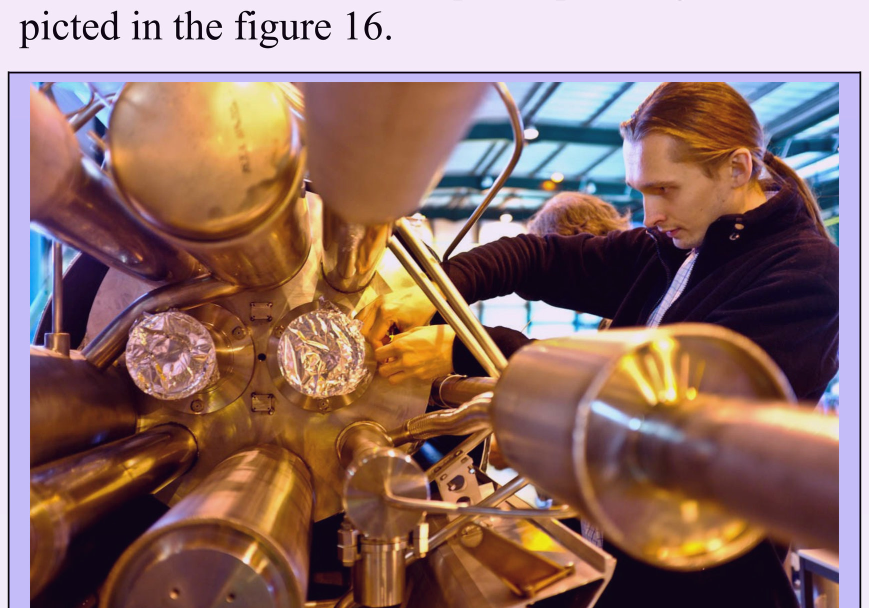

Figure 16: Installation of cryogenic particle detector on the cold mass of LHC magnet.

RESULTS

At the end of the irradiation a total integrated fluence of $1.22\cdot10^{16}$ 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.

The figures 12 and 13 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 [4].

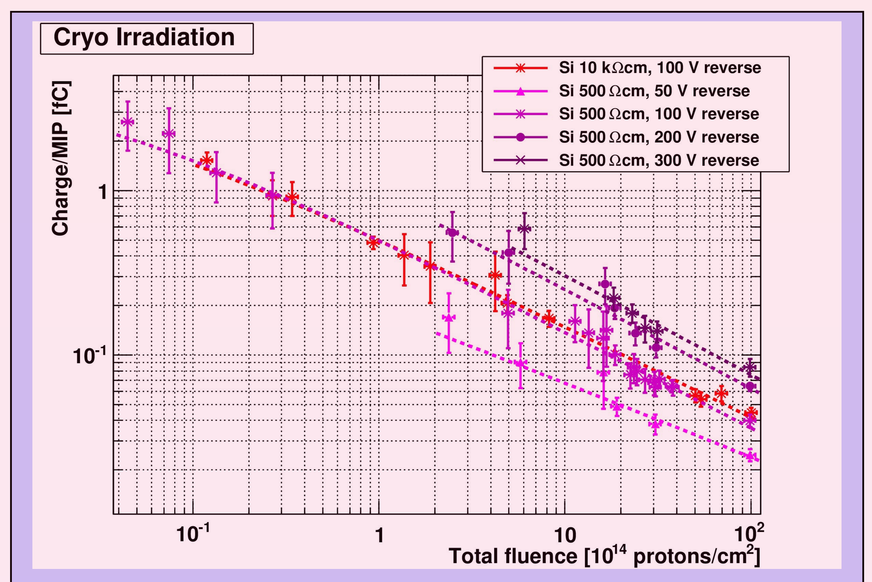

Figure 12: Dependence of the charge collected in Si detectors with a resistivity 500Ωcm vs. fluence.

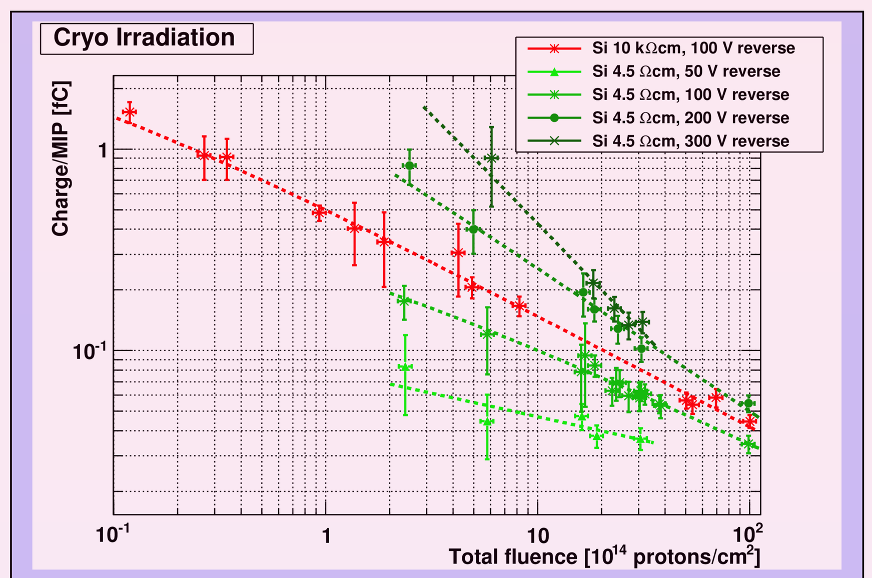

Figure 13: Dependence of the charge collected in Si detectors with a resistivity 4.5 Ωcm vs. fluence.

RESULTS—VOLTAGE SCAN

The voltage scans of the collected charge for the different detectors at different fluencies are depicted in the figures 14 and 15. In the voltage scans positive voltage denotes a forward bias.

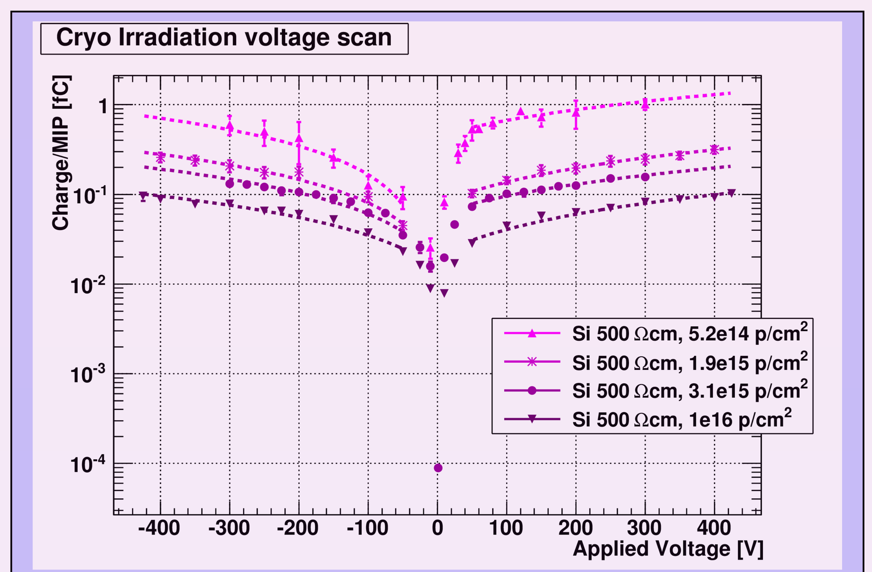

Figure 14: Voltage scan for 500 Ωcm silicon.

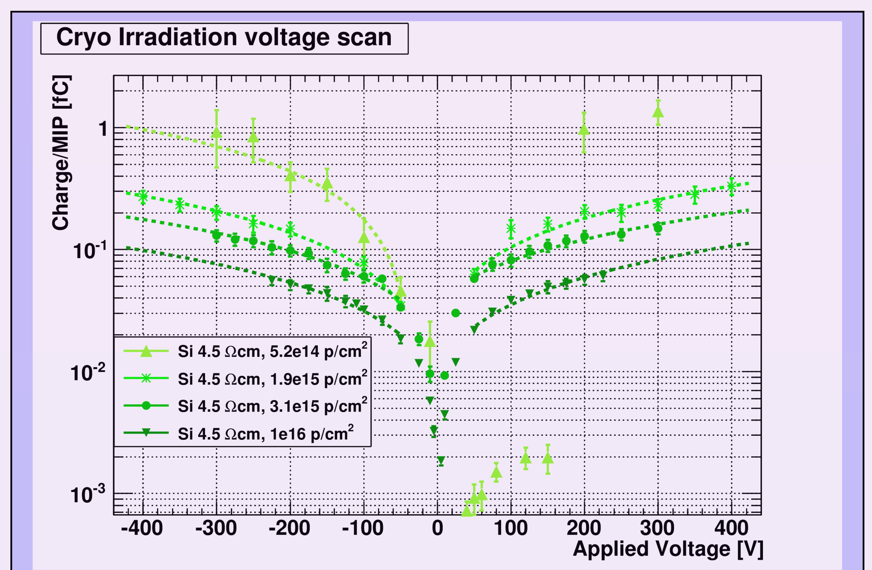

Figure 15: Voltage scan for 4.5 Ωcm silicon.

SUMMARY

Different Si detectors at cryogenic temperatures were tested for their radiation-hardness. A total integrated fluence of $1.22\cdot10^{16}$ 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 was observed. More experiments with current pulse response measurements using TCT with a pulsed laser at cryogenic temperatures during irradiation are foreseen.

REFERENCES

1] A. Mereghetti et al., “Fluka Simulations for Assessing Thresholds of BLMs around the LHC Triplet Magnets”, Geneva, October 18th, 2011.

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MARIE CURIE ACTIONS
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