CRYOGENIC BEAM LOSS MONITORS FOR THE SUPERCONDUCTING MAGNETS OF THE LHC

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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).To protect the magnets 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 K.

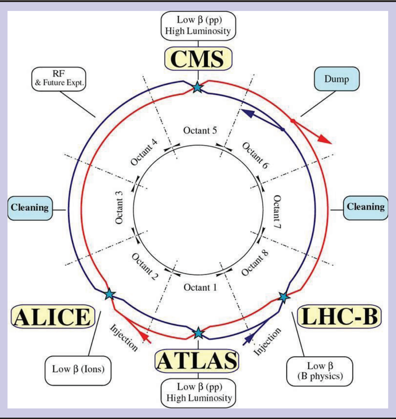

Figure 2: Overview schematic shows the four main experiments and the structure of the LHC.

Figure 1: LHC left of IP triplet magnets.

All the selected detector technologies are based on ionisation and subsequent charge carrier transport within the detector bulk. The candidates under investigation are p^+-n-n^+ silicon [4] and single crystal Chemical Vapour Deposition (scCVD) diamond [3] detectors.

Unknown is the combination of the cold with the high radiation. To answer this question a first radiation-hardness test of the diamond and the detectors performed in liquid helium environment and the first installations of cryogenic radiation detectors on the cold mass of the LHC magnets were performed.

INTRODUCTION

The magnets close to the Interaction Points (IP) (see fig. 2) are exposed to high irradiation from the collision debris. 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).

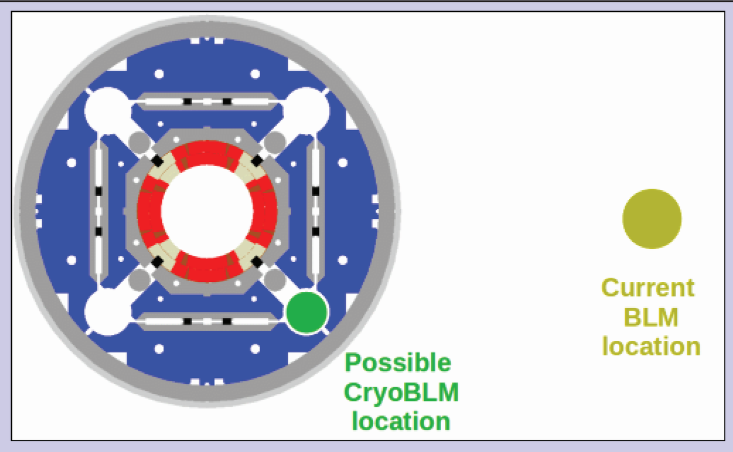

Figure 4: Cross section of the Q1 superconducting triplet magnet with the current BLM placement in red and the free region for a possible cryogenic BLM in blue.

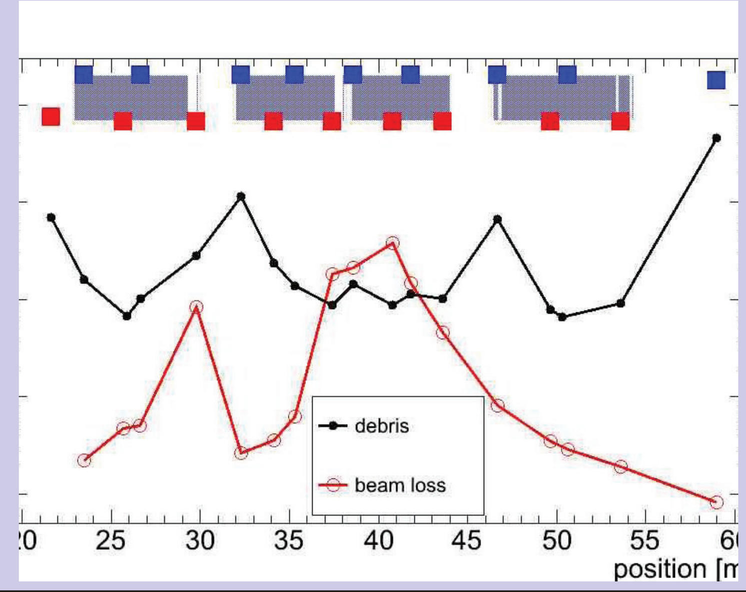

Figure 3: Doses in the coil and signal in the existing BLMs (Fluka simulation [1]); BLM signal from debris (one point for each BLM, line), in black; BLM signal from quench-provoking losses inside Q2B superconducting triplet magnet, in red.

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).

CRYOGENIC IRRADIATION RESULTS—DEGRADATION

The cryogenic BLMs specification represents a completely new and demanding set of criteria that has never been required or investigated in such a form before. That is why the first radiation hardness test of the diamond and the silicon detectors in liquid helium environment was performed at CERN. The figures 5 - 8 show the decrease of collected charge for the diamond and the silicon detectors. The curve for 10 kΩcm silicon with 100 V reverse bias has been plotted for reference.

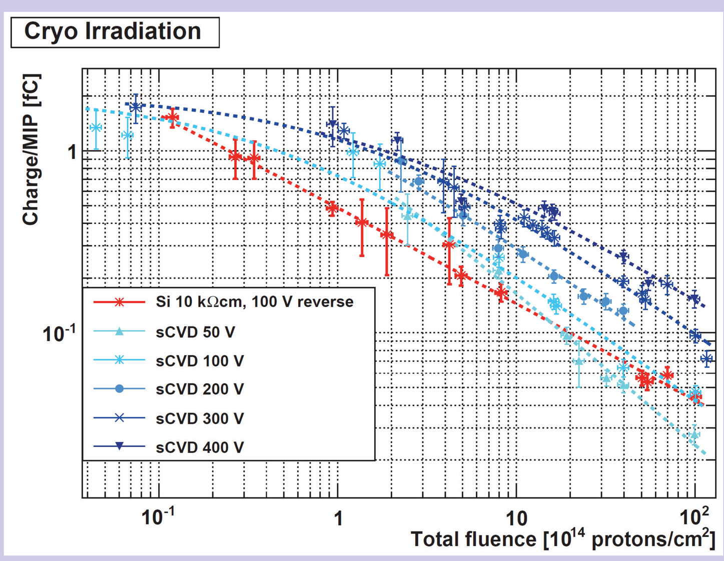

Figure 5: Dependence of the charge collected in silicon detectors with a resistivity 10 kΩcm vs. fluence.

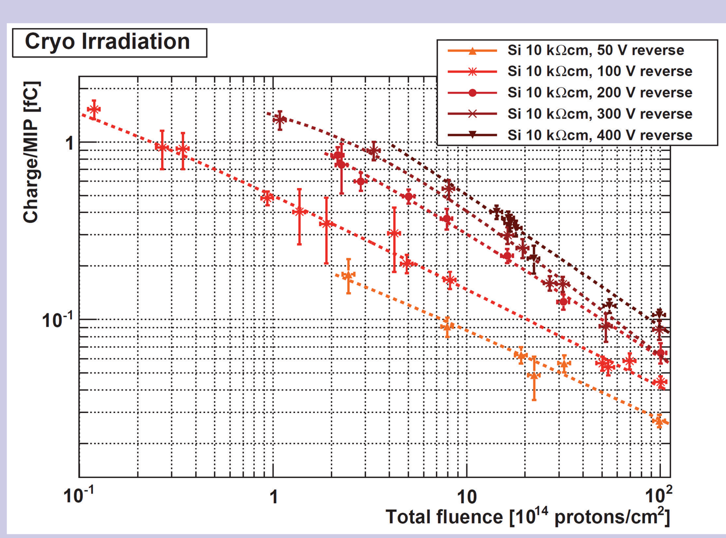

Figure 6: Dependence of the charge collected in the diamond detector vs. fluence.

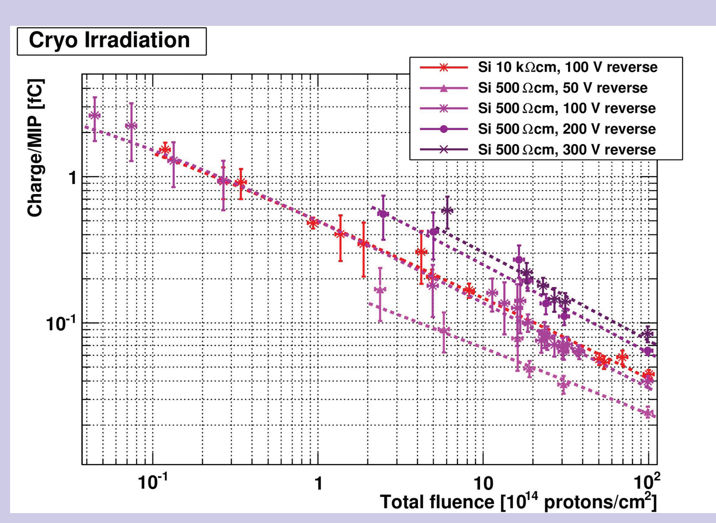

Figure 7: Dependence of the charge collected in silicon detectors with a resistivity 500 Ωcm vs. fluence.

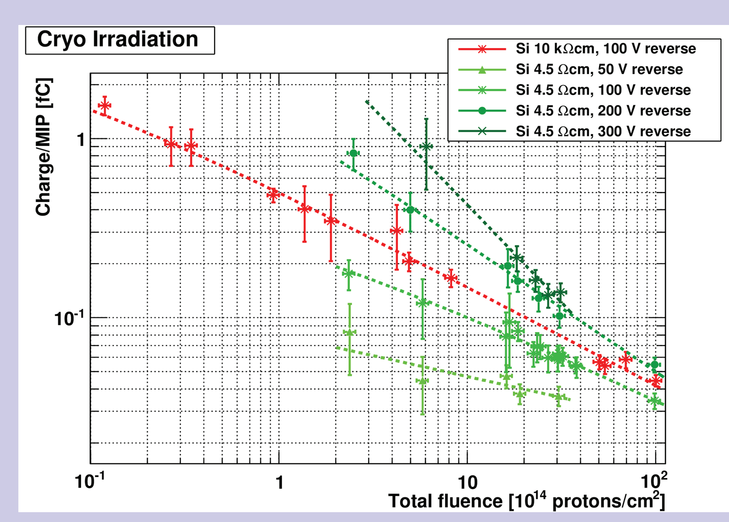

Figure 8: Dependence of the charge collected in silicon detectors with a resistivity 4.5 Ωcm vs. fluence.

CRYOGENIC IRRADIATION RESULTS—VOLTAGE SCAN

The voltage scans of the collected charge for the different silicon detectors at different fluencies are depicted in the figures 9 - 11. In the voltage scans positive voltage denotes a forward bias.

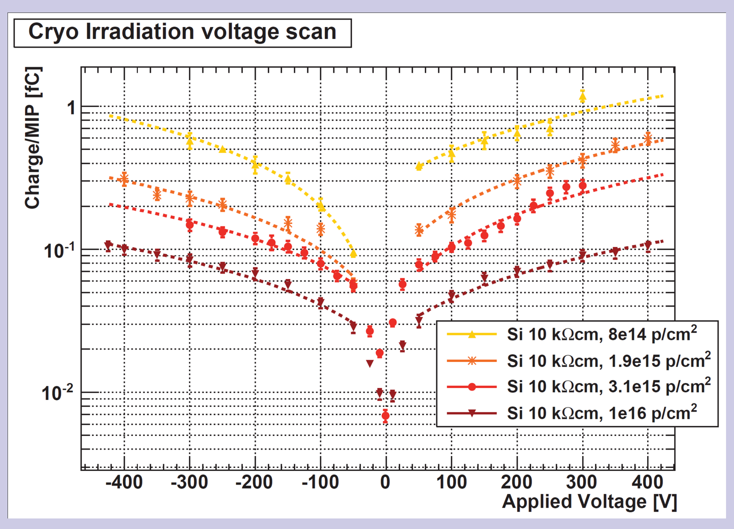

Figure 9: Voltage scan for 10 kΩcm silicon.

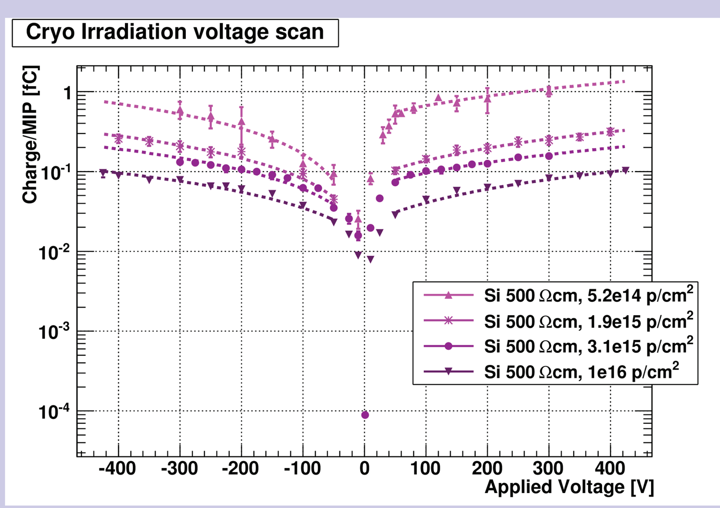

Figure 10: Voltage scan for 500 Ωcm silicon.

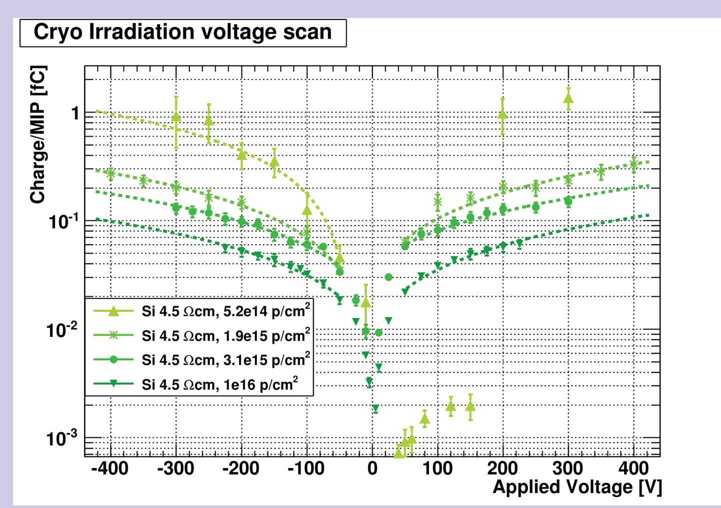

Figure 11: Voltage scan for 4.5 Ωcm silicon.

SUMMARY

Different silicon and diamond 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 the silicon** and **3.42 MGy for the diamond** detectors. The expected reduction in signal over 20 years (2 MGy) of LHC operation is a factor of **25 ± 5 for the silicon** device and a factor of **14 ± 3 for the diamond** detector.

The first cryogenic radiation detectors in superconducting LHC magnets will allow the testing of the detectors' validity of integration in setup at 1.9 K temperature, magnetic field and vacuum resistance, their long term stability and their radiation hardness for actual LHC particle showers and particle rates.

CRYOGENIC RADIATION DETECTORS IN THE LHC

During the LHC Long Shut-down 1 (LS1) the first two installations of the silicon and the diamond detectors on the cold mass of LHC magnets were performed (see fig. 12).

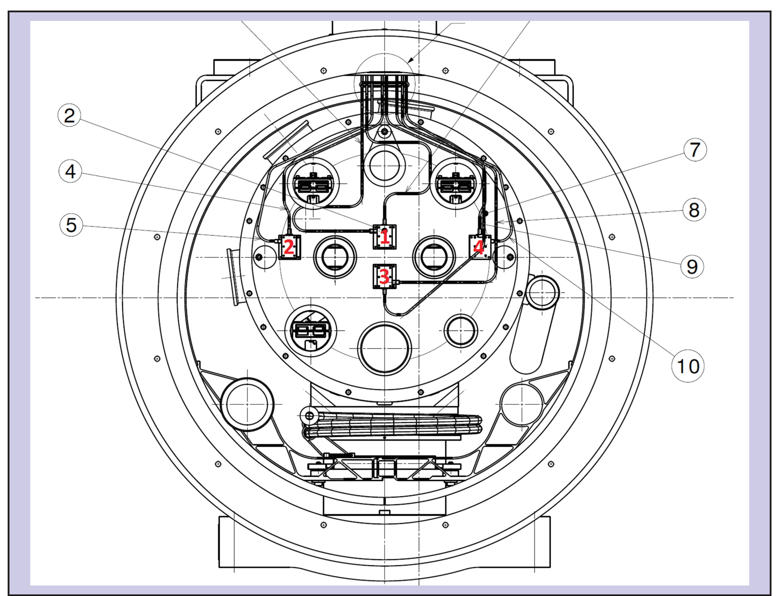

Figure 12: Cross section of LHC ring showing cryostat of superconductive dipole magnet and the position of cryogenic radiation detectors.

Frome the mechanical point of view the main challenges of the setup were the low temperature of 1.9 K and the integrated dose of about 2 MGy in 20 years [3]. Furthermore the cryogenic BLM should work in a magnetic field of 2 T and at a pressure of 1.1 bar, withstanding a fast pressure rise up to 20 bar in case of a magnet quench.

Electrical design requires that the detector response should be linear between 0.1 mGy/s and 10 mGy/s and faster than 1 ms. The detectors have to be available, reliable and stable, and operate on the cold mass of the LHC magnets for 20 years. A Multistep testing procedure including ionizing radiation response (see fig.13), laser light sensitivity, low temperature resistance, Room temperature (RT) Current-Voltage (IV) curve measurement in the LHC magnets (see fig. 14, 15) were performed.

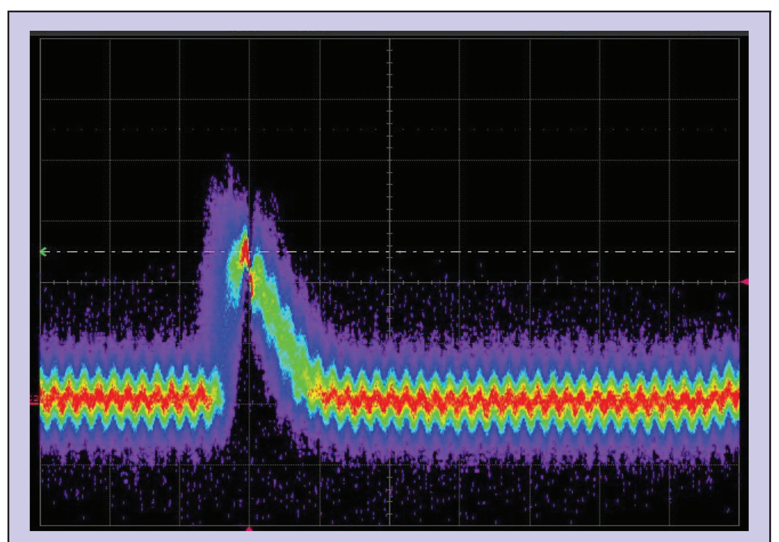

Figure 13: β-radiation induced signal from the diamond based cryogenic radiation detector in the LHC magnet (80 mV on vertical and 50 ns on horizontal scale).

These LHC cryogenic radiation detectors will allow the testing of the detectors' validity of integration in setup at 1.9 K temperature, magnetic field and vacuum resistance, their long term stability and their radiation hardness for actual LHC particle showers and particle rates.

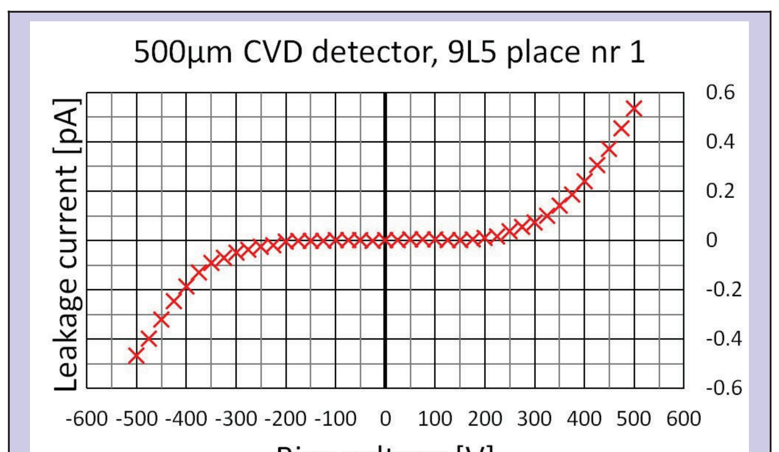

Figure 14: leakage current of the diamond cryogenic radiation detectors in the LHC.

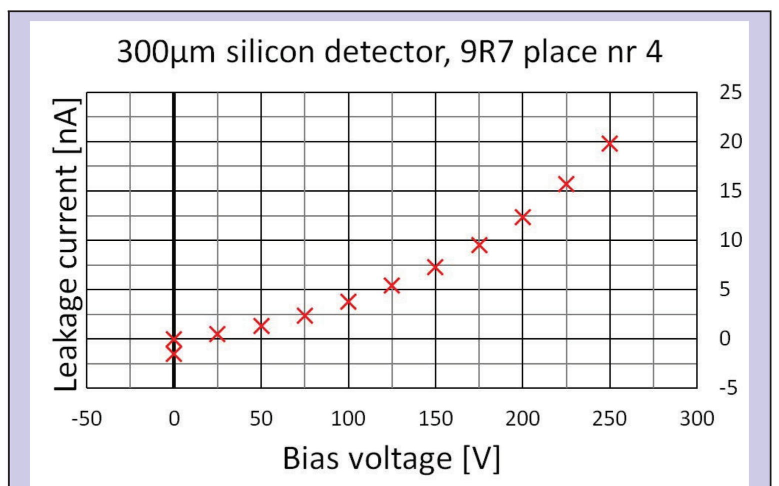

Figure 15: leakage current of the silicon cryogenic radiation detectors in the LHC.

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