BEAM LOSS MONITORS FOR THE CRYOGENIC LHC MAGNETS*

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Abstract

The Beam Loss Monitoring system of the Large Hadron Collider close to the interaction points contains mostly gas ionization chambers working at room temperature, located far from the superconducting coils of the magnets. The system records particles lost from circulating proton beams, but is also sensitive to particles coming from the experimental collisions, which do not contribute significantly to the heat deposition in the superconducting coils. In the future, with beams of higher brightness resulting in higher luminosity, distinguishing between these interaction products and dangerous quench-provoking beam losses from the circulating beams will be difficult. It is proposed to optimise by locating beam loss monitors inside the cold mass of the magnets, housing the superconducting coils, in a superfluid helium environment, at 1.9 K. The dose then measured by such cryogenic beam loss monitors would more precisely correspond to the real dose deposited in the coil. This contribution will present results of radiation hardness test of $p^+\_n{-}n^+$ silicon detectors which, together with single crystal Chemical Vapour Deposition diamond, are the main candidates for these future cryogenic beam loss monitors.

INTRODUCTION

Motivation

It has been shown with particle shower simulations [1] that with the present configuration of Beam Loss Monitors (BLMs) close to the LHC interaction points (IPs), the ability to measure the energy deposition in the coil is limited because of collision debris masking the real beam loss signal (see Fig. 1).

In the current BLM system layout the particle showers from beam loss are partly shielded by the cryostat and the iron yoke of the magnets. The system can be optimised by locating beam loss monitors as close as possible to the sensitive superconductive coils. For the high luminosity LHC upgrade (HL-LHC) BLMs are therefore foreseen to be located near the superconducting coils inside the cold mass of the magnets in the superfluid helium at a temperature of 1.9 K [2] (see Fig. 2, courtesy of P. Ferracin).

The advantage of this new location is that the dose measured by the Cryogenic BLM will correspond much better

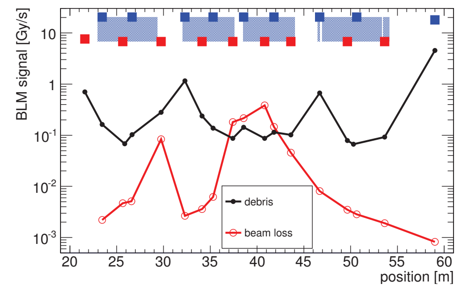

Figure 1: Signal in the coil and in the existing BLMs; Black trace: BLM signal from collision debris (one marker at each BLM location); Red trace: BLM signal from a quench-provoking loss inside the central superconducting quadrupole magnet of the focusing triplet (Q2B).

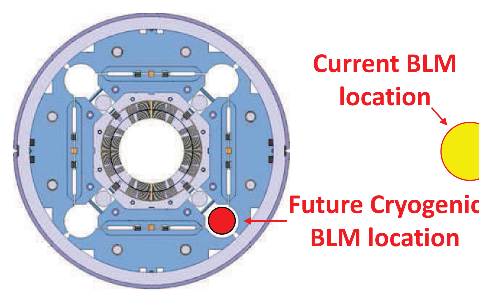

Figure 2: Cross section of a large aperture superconducting insertion magnet (MQXF) foreseen for HL-LHC with the current BLM and the future Cryogenic BLM locations shown.

to the dose deposited in the superconducting coil [6].

Cryogenic BLM Requirements

From the electronic point of view the main requirements of the detector are a linear signal relationship with the received dose in the range between 0.1 and 10 mGy/s and a response time faster than 1 ms. The main mechanical challenge of a Cryogenic BLM system is to provide 20 years of maintenance free operation at temperature of 1.9 K [6]. Furthermore the Cryogenic BLM needs to work in a magnetic field of 2 T and be capable of withstanding a fast pressure rise up to 20 bar in case of a magnet quench. The selected detector technologies are based on semiconductor radiation detectors and current readout. The candidates under investigation are single crystal Chemical Vapour Deposition (scCVD) diamond [3] and $p^+{-}n{-}n^+$ silicon [4] detectors.

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CRYOGENIC RADIATION TEST

The specifications for cryogenic BLMs represents a completely new and demanding set of criteria that have never been investigated together before. The main unknown is the combination of the superfluid helium environment with a total ionizing radiation dose of 2 MGy. This motivated the first radiation-hardness tests of the diamond and the silicon detectors in a liquid helium environment, performed at CERN in December 2012 [5]. Degradation curves of scCVD were compared with silicon detectors in forward and reverse mode for a total integrated fluence of 1.22×10^{16} protons/cm^2 (corresponding to an integrated dose of about 3.26 MGy for the silicon and 3.42 MGy for the diamond detectors). Measurements at low doses were, however, missing due to the alignment procedure at the beginning of the irradiation test [6]. In November 2014 a complementary set of cryogenic irradiation measurements were therefore performed.

Setup

The main aim of the cryogenic irradiation test in November 2014 was to investigate the radiation hardness of the new 100 μm thick Si detectors in a liquid helium environment at 4.2 K and evaluate their advantages compared with more common 300 μm thick diodes.

The irradiation experiment was performed in the IRRAD facility in the East Experimental Area at CERN. This irradiation facility is frequently used for sample irradiation and detector performance tests [7].

The IRRAD beam line provides protons with a particle momentum of 24 GeV/c. The beam intensity is 5×10^{11}protons/cm^2 per spill with an rms beam size at the sample location of about 0.25 cm^2. The spill duration is between 400 - 450 ms.

For the final implementation in the LHC, direct current (DC) measurements are required. It was therefore decided to characterise the radiation hardness of the detectors by DC measurements. These measurements were performed using a stand-alone acquisition system developed for the LHC injectors [8] for which data acquisition client and data analysis software has been developed in the Python programming language [9].

The detectors under investigation were p$^+$−n−n$^+$ silicon wafers with a thickness of 300 μm and 100 μm, 10 kΩcm resistivity, an active area of 36 mm^2 and aluminium as the metallisation material.

Results

At the end of the irradiation a total integrated fluence of 2.8×10^{15} protons/cm^2 was reached, corresponding to an integrated dose of about 0.75 MGy for the 300 μm Si.

The dependence of the collected charge on voltage (voltage scans) for the 100 μm Si and 300 μm Si detectors at different fluences are depicted in figures 3 and 4 respectively. A positive voltage corresponds to the forward bias operation mode.

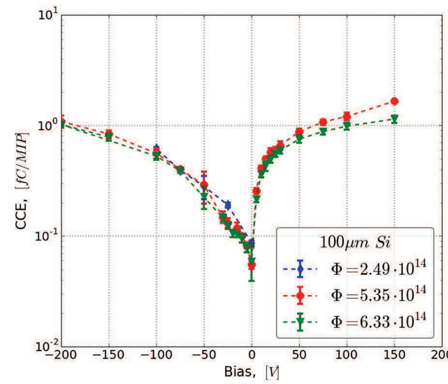

Figure 3: Voltage scan of a 100 μm Si detector for different integrated proton fluences.

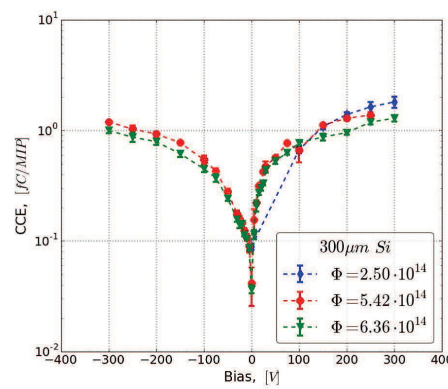

Figure 4: Voltage scan of a 300 μm Si detector for different integrated proton fluences.

The shape of the voltage scans were similar to those observed during the first cryogenic irradiation. The collected charge increases with increasing voltage and shows a slight tendency to saturate. In detectors operated as Current Injection Detector (CID), i.e. at forward bias, the increase was more apparent and the collected charge was larger than that at reverse bias.

This is caused by the reduction of the effective trap concentration due to filling via carrier injection. This implies an effective operation at low voltages which is the main advantage of a CID.

INSTALLATION OF CRYOGENIC BLMS ON THE OUTSIDE OF THE COLD MASS OF THE LHC MAGNETS

As a safety critical system, the long term reliability of the BLM detectors is very important. It was therefore decided

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to install several Cryogenic BLMs on the outside of the cold mass of existing LHC magnets (see Fig. 5).

During the LHC Long Shut-down 1 (LS1) two 500 μm scCVD diamond detectors two 100 μm Si detectors and four 300 μm Si detectors were therefore mounted on the outside of the cold mass containing the superconducting coils in the cryostat of two LHC dipole magnets. Two types of detector holders were used, an Al_2O_3 based ceramic holder for one of the scCVD diamond detectors and seven FR-4 glass-reinforced epoxy laminate based holders for the other locations (see Fig. 6). Taking into consideration that the final Cryogenic BLMs have to be reliable and operate for 20 years radiation hard connectors, feedthroughs and semi-rigid coaxial cables were also installed. A multistep testing procedure with the use of light and ionizing radiation was performed to create signals on all detectors before and after installation [10].

These first cryogenic BLMs installed in operational, superconducting magnets will not only allow the behaviour of the detectors to be tested in realistic conditions, but also determine the validity of the integration in a setup at 1.9 K and in a high magnetic field.

First results of observing LHC beam losses with these detectors are expected in September 2015.

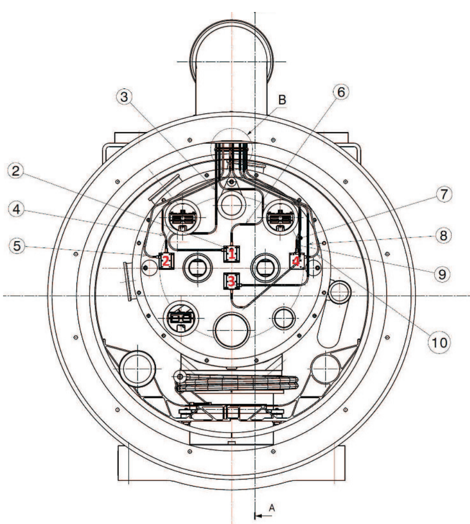

Figure 5: Cross section of an LHC dipole magnet showing the outer cryostat, the inner cold mass housing the superconducting coils and the position of cryogenic beam loss detectors on the end of the cold mass.

CONCLUSIONS

The main results are that the tested Si detectors survive under irradiation to 2.8×10^{15} protons/cm^2 in liquid helium environment, and charge carrier transport properties are strongly influenced by the electric field in irradiated detectors.

In order to minimize trapping, current injection into the detector sensitive region CID was tested. It has been shown that current injection developed as a tool for increasing the tolerance of silicon detectors to irradiation at moderate cooling, is still effective in liquid helium environment.

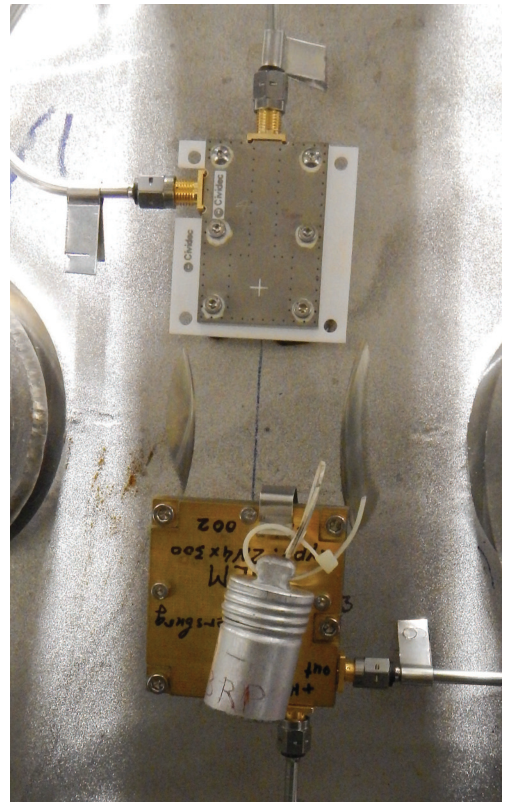

Figure 6: Top: scCVD diamond detector mounted using a ceramic based holder. Bottom: p^+-n-n^+ silicon detector mounted using an FR-4 glass-reinforced epoxy laminate based holder during testing with a gamma-radiation source (capsule).

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REFERENCES

[1] A. Mereghetti, M. Sapinski et al: Estimation of thresholds for the signals of the BLMs around the LHC final focusing triplet magnets, Proceedings of IPAC 2012, New Orleans, USA.

[2] C. Kurfuerst et al.: Investigation of the use of Silicon, Diamond and liquid Helium detectors for Beam Loss Measurements at 2K, Proceedings of IPAC 2012, New Orleans, USA.

[3] C. Kurfuerst, et al., Radiation tolerance of cryogenic beam loss monitor detectors, proc. of IPAC 2013, Shanghai, China.

ISBN 978-3-95450-176-2

[4] M. R. Bartosik, et al.: Characterisation of SI detectors for the use at 2 K, proc. of IPAC 2013, Shanghai, China.

[5] C. Kurfuerst, et al., In situ radiation test of silicon and diamond detectors operating in superfluid helium and developed for beam loss monitoring, Nuclear Instruments and Methods in Physics Research A 782 (2015) 149158.

[6] C. Kurfuerst, Cryogenic Beam Loss Monitoring for the LHC, PhD thesis.

[7] F. Ravotti, et al., Upgrade scenarios for irradiation lines: Deliverable Report, Advanced European Infrastructures for Detectors at Accelerators AIDA-D8.4.

[8] C. Zamantzas et al., System Architecture for measuring and monitoring Beam Losses in the Injector Complex at CERN, Proceeding of IBIC 12, Tsukuba, Japan.

[9] A. Alexopoulos, Cryogenic Semiconductor Detectors: Simulation of Signal Formation & Irradiation Beam Test, MSc thesis.

[10] M. Bartoisk, et al., Cryogenic beam loss monitoring for the superconducting magnets of the LHC, Proceedings of IBIC2014, Monterey, CA, USA.

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