INVESTIGATION OF THE USE OF SILICON, DIAMOND AND LIQUID HELIUM DETECTORS FOR BEAM LOSS MEASUREMENTS AT 2 KELVIN

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Abstract

At the triplet magnets, close to the interaction regions of the LHC, the current Beam Loss Monitoring (BLM) system is very sensitive to the debris from the collisions. For future beams with higher energy and higher luminosity this will lead to a situation in which the BLM system can no longer distinguish between these interaction products and quench-provoking beam losses from the primary proton beams. The solution investigated is to locate the detectors as close as possible to the superconducting coil, i.e. the element to be protected. This means putting detectors inside the cold mass of the superconducting magnets at 1.9 K. As possible candidates for such loss monitors, diamond, silicon and a liquid helium chamber have been tested in a proton beam at liquid helium temperatures. The initial promising results from these tests will be presented and discussed in this contribution.

INTRODUCTION

The magnets close to the Interaction Points are exposed to high radiation fields due to collision debris. It has been shown that with the present configuration of the installed Beam Loss Monitors (BLM) in this region, the ability to measure energy deposition in the coil is limited because of the debris, masking the beam loss signal. The situation is depicted in Fig. 1, where the signal in the BLMs are shown for the debris and a dangerous loss. Due to the proximity of the interaction point, a differentiation between signals from dangerous accidental losses and from the continuous collision debris is difficult.

A solution to this problem, based on placing radiation detectors (CryoBLMs) inside the cold mass close to the coils, is investigated. The advantage would be that the dose measured by the detector would more precisely correspond to the dose deposited in the superconducting coil. The detectors currently under investigation are:

- single crystal chemical vapor deposition (CVD) Diamond (thickness 500 μm),
- p^+-n-n^+ Silicon wafer (thickness 300 μm) and
- a liquid helium chamber, made of parallel plates using liquid helium as detection medium (3 mm distance between plates and 10 cm total length).

Beam tests in cold have been performed at CERN in the Proton Synchrotron (PS) beam line T9.

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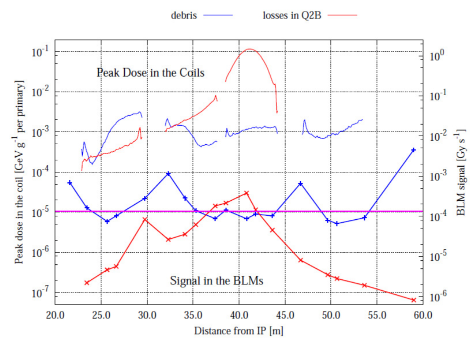

Figure 1: Doses in the magnet coil and signal in the BLM shown for two different situations: once for the debris from the interaction region and once simulated for a loss at one location. One can see that debris can mask the signal from a dangerous loss [1].

SPECIFICATIONS FOR CRYOBLM

The two main challenges for this cryogenic detector inside the cold mass are the low temperature of 1.9 K (superfluid helium) and the radiation dose of about 1 MGy in 10 years.

The detector response should be linear between 0.1 and 10 mGy/s and faster than 1 ms.

Furthermore the CryoBLM should work in a magnetic field of 2 T and at a pressure of 1.1 bar, withstanding a fast pressure rise of up to about 20 bar in case of a quench of a superconducting magnet.

Once the detectors have been installed, no further access will be possible. The detectors therefore need to be highly reliable and maintain their stability with time.

BEAM TEST

In order to measure the characteristics of the detectors at low temperatures, beam tests have been performed. A cryostat, containing the semiconductors and the chamber, was placed into a beam. Together with further cryogenic installations, like Dewar and vacuum pump, temperatures down to 1.6 K could be reached.

The detector setup is shown in Fig. 2.

Beam Characteristics

The PS beam consist of protons (dominating), positive pions and kaons with about 9 GeV/c. The beam intensity is of 350 000 particles per spill with an RMS size at focus

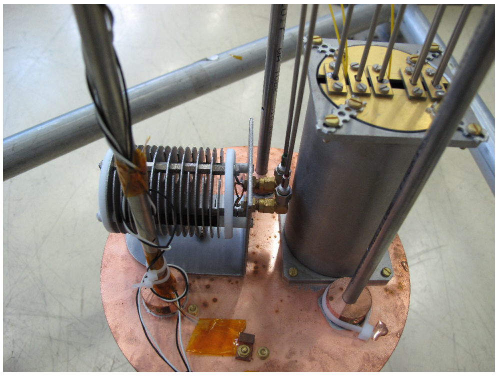

Figure 2: The detectors are mounted on a copper plate, which is lowered into the cryostat. On the left side of the picture is the 10 cm long chamber and on the right is the cylinder containing the semiconductors. Cables with low heat conduction bring out the signal from the detectors to the top of the cryostat.

of about 1 cm^2. A spill comes every 45 s and its duration is of 400 ms.

Estimated Signals

In order to decide which electronics should be used, the generated charge Q_{spill} in the detector material by the beam have been estimated. For calculation using equation 1, the following parameters have been used:

- Stopping power of the material P_{stop}
- Density of the material ρ
- Electron-hole Pair creation energy E_{pair}
- Dimensions of detector (active area A_{active} and thickness l)
- Beam characteristics (beam size A_{beam}, number of particles n_p and spill duration)

$$Q_{spill} = \frac{P_{stop} \cdot \rho \cdot l}{E_{pair}} \cdot n_p \cdot \frac{A_{active}}{A_{beam}} \tag{1}$$

The resulting estimates shown in Fig. 3 confirmed the feasibility of the planned measurements.

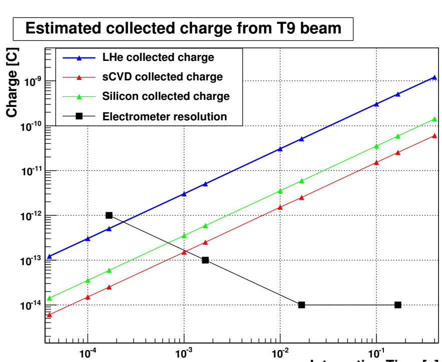

Figure 3: Estimated signals in the detectors.

Measurement Procedure

For the final application as BLM in the LHC, direct current (DC) measurements are prefered. For those measurements a Keithley electrometer 6514 has been used. It allows the application of a bias voltage on one side and a signal read out on the other side of the detector.

In addition single minimum ionising particle (MIP) measurements have been performed with the semiconducting detectors, using 40 dB current amplifiers from CIVIDEC. The pulses were recorded on a 3 GHz LeCroy oscilloscope with 200 MHz bandwidth limitation. Due to the cryogenic setup a 2 m long cable was needed between detectors and amplifiers.

In parallel all relevant cryogenic information, such as temperature, pressure and liquid helium level, was recorded.

Results

The pulses from Silicon with a reverse bias voltage of 100 V at room temperature and at liquid helium temperature is depicted in Fig. 4. From the width of the pulses, one can conclude that at liquid helium temperatures the charges drift faster.

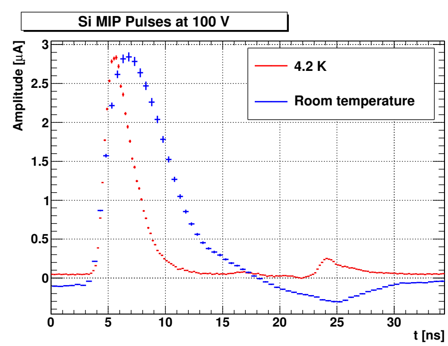

Figure 4: Average MIP pulses over 5000 measurements of Silicon at a bias voltage of 100 V. The error corresponds to the standard deviation of the mean. The curve shape at 25 ns corresponds to reflections between detector and amplifier. Those are caused by imperfections in the input impedance matching.

The pulses from Diamond with a bias voltage of 400 V at room temperature and at liquid helium temperatures is depicted in Fig. 5. The width of the pulse is again reduced, showing that at liquid helium temperatures the charges also drift faster in diamond.

Inside the liquid helium detector the liberated electrons build an “e-bubble” [2], where the electron is surrounded by bound helium atoms. This reduces the drift velocity of the charges. The detection of single particles by the chamber is not possible in this configuration. Only DC measurements have been performed with the liquid helium chamber. Fig. 6 shows the collected charge variation as a function of the beam intensity. The average number of particles

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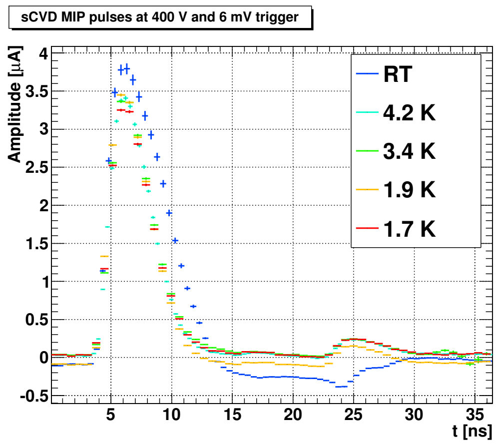

Figure 5: Average MIP pulses over 5000 measurements of Diamond at a bias voltage of 400 V. The reflections at 25 ns can be observed again.

in one spill was known with an error below 5 %. This error is reflected in the charge measurement.

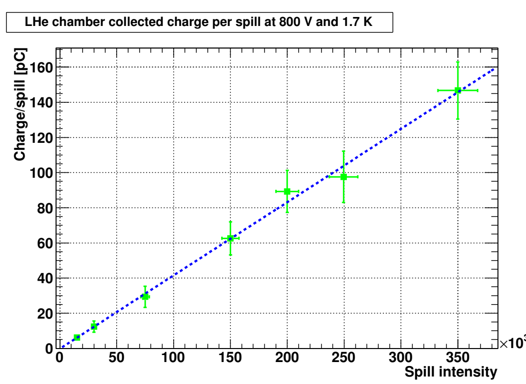

Figure 6: Liquid helium chamber charge from spill depending on beam intensity. Linearity can be observed in the analysed region.

The results of a voltage scan with the liquid helium chamber at 1.76 K can be seen in Fig. 7. A 2 x 2 cm^2 scintillator was placed outside the cryostat, about 35 cm upstream of the chamber. This way the signal in the chamber could be normalized to the number of particles on the surface of the scintillator, reducing the error on the signal measurement due to variation in beam intensity. In the analysed region, good linearity between chamber signal and applied voltage is visible.

Above 1 kV (corresponding to an electrical field of 3.3 kV/cm) in superfluid helium, a continuous discharge exceeding the instrument safety limitation was observed. This does not correspond to the breakdown region, but is rather expected to be a corona discharge [3].

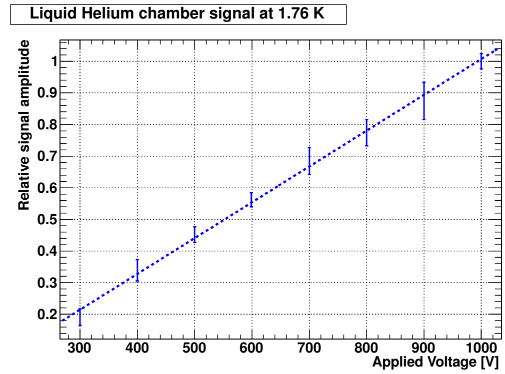

Figure 7: Liquid helium chamber signal depending on applied voltage.

CONCLUSIONS

All detectors have proven to work at liquid helium temperatures. In parallel, laboratory measurements using an alpha source and a laser have been carried out to understand the properties of the semiconducting detector material at low temperatures.

With Silicon and Diamond a fast detection system can be designed allowing both bunch by bunch resolution in the LHC and DC measurements for steady state losses. A fast system might be of interest for the LHC upgrade not only for the triplet magnets, but also for other critical locations.

The liquid helium chamber on the other hand would be an elegant solution as CryoBLM in the triplet magnets, because there are no issues with radiation hardness.

Two critical points still need to be investigated. One issue to be addressed is the radiation hardness of the semiconductors at those low temperatures, where no thermal movements take place and no annealing effect is possible. The second issue is the charge collection time of the liquid helium chamber. Due to the slow drift of the charges, a detector response below 1 ms is difficult to achieve. These issues will be addressed during challenging irradiation beam tests in 2012.

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