CHARACTERISATION OF SILICON AND DIAMOND FOR USE AT 1.9 KELVIN AS DIRECT CURRENT PARTICLE DETECTORS

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INTRODUCTION

The magnets close to the Interaction Points (IP) 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).

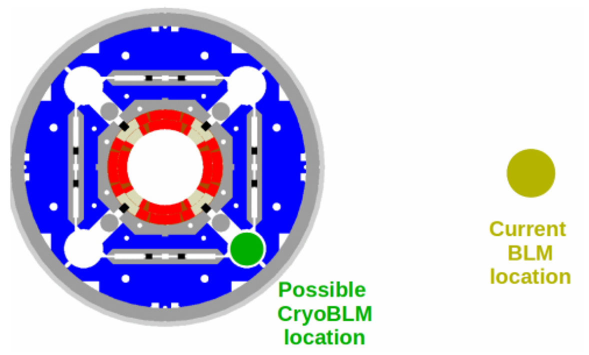

Figure 4: Cross section of the Q1 triplet magnet with the current BLM placement in red and the free region for a possible cryogenic BLM in blue.

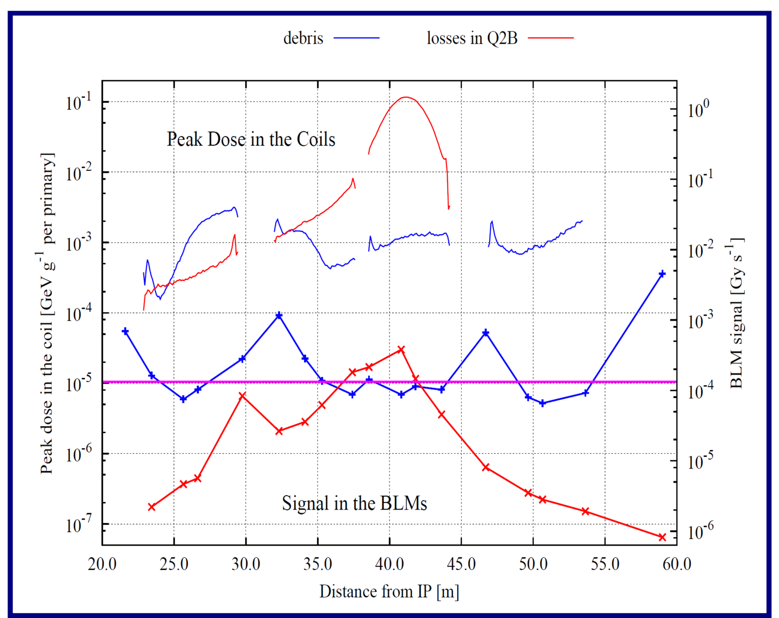

Figure 3: Simulated dose in the coil and signal in the BLM shown for two different situations: one for the debris from the interaction region (blue) and one for a simulated dangerous loss (red). It can be seen that the signal due to the debris can be mask by the signal from a dangerous loss [1].

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

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 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.

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.

Figure 1: LHC left of IP triplet magnets.

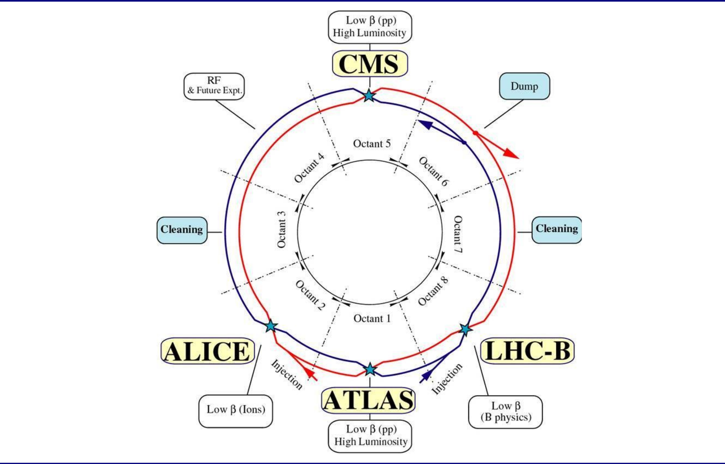

Figure 2: Overview schematic shows the four main experiments and the structure of the LHC.

RESULTS—DEGRADATION

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 have p^+-n-n^+ silicon doping structure with a thickness of 300 µm. The figures 9—12 show the decrease of collected charge for the diamond and the silicon devices. The curve for 10 kΩcm silicon with 100 V reverse bias has been plotted reference curve [4].

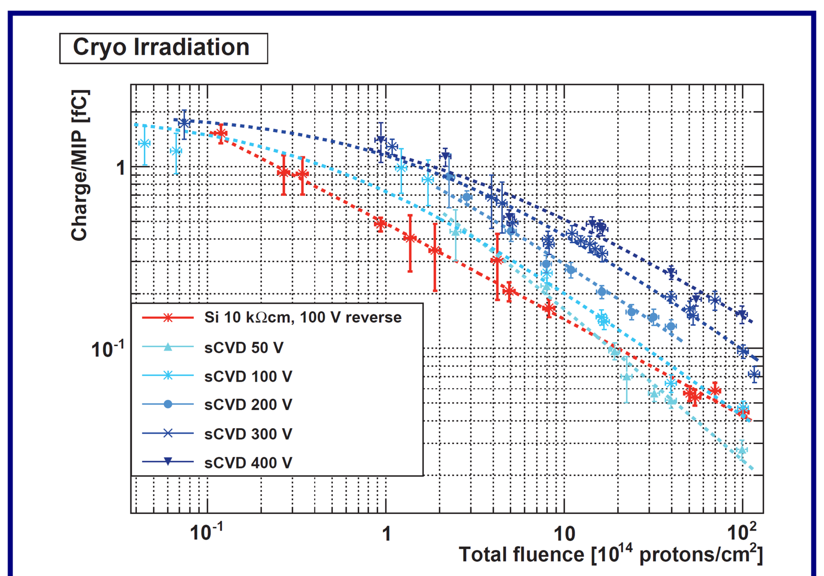

Figure 9: Dependence of the charge collected in Si detectors with a resistivity 10 kΩcm vs. fluence.

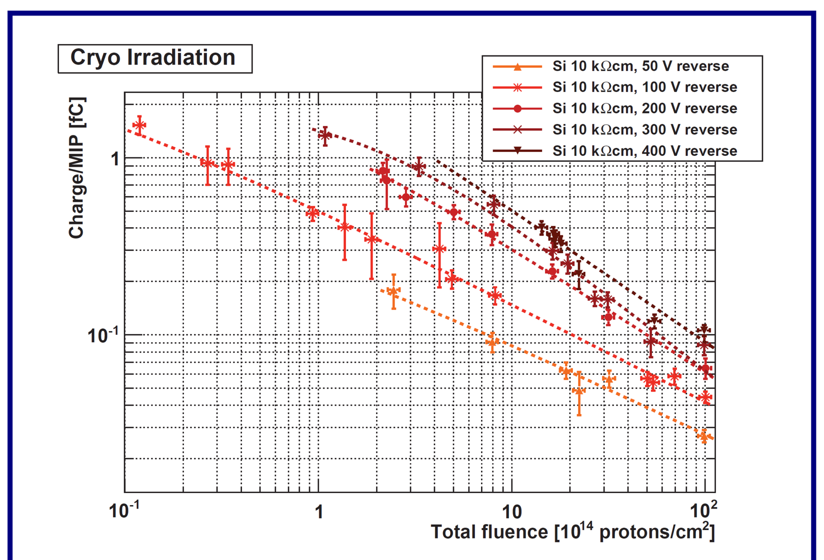

Figure 10: Dependence of the charge collected in scCVD diamond detector vs. fluence.

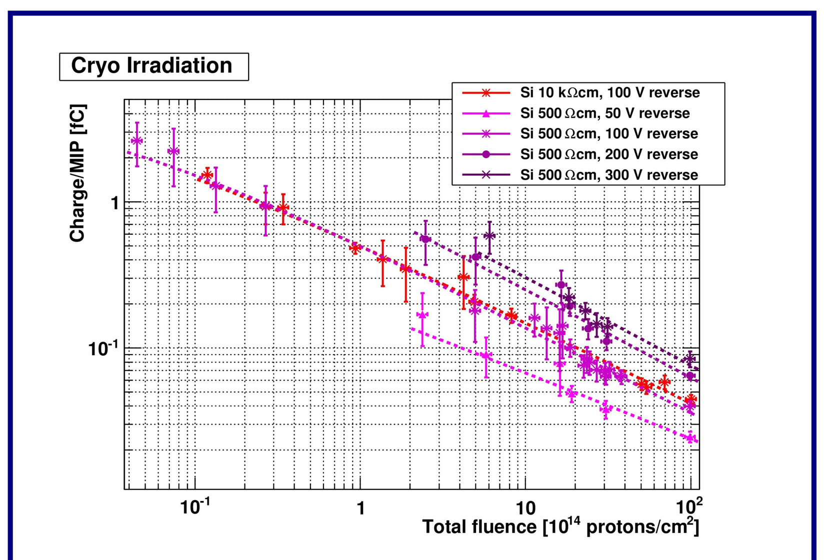

Figure 11: Dependence of the charge collected in Si detectors with a resistivity 500 Ωcm vs. fluence.

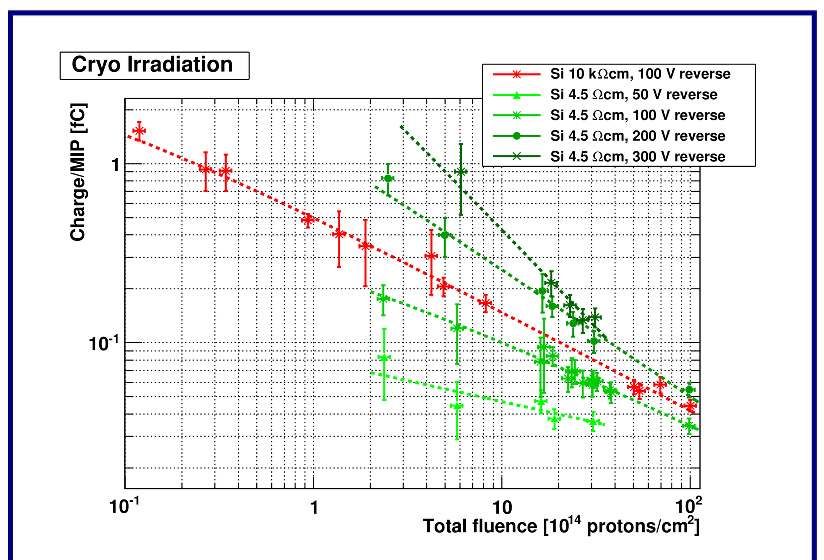

Figure 12: Dependence of the charge collected in Si detectors with a resistivity 4.5 Ωcm vs. fluence.

RESULTS—VOLTAGE SCAN

The voltage scans of the collected charge for the different silicon detectors at different fluencies are depicted in the figures 13—15. In the voltage scans positive voltage denotes a forward bias. There is no full charge collection for single crystal diamond above a voltage of 100 V and the saturation for Si detector is similar.

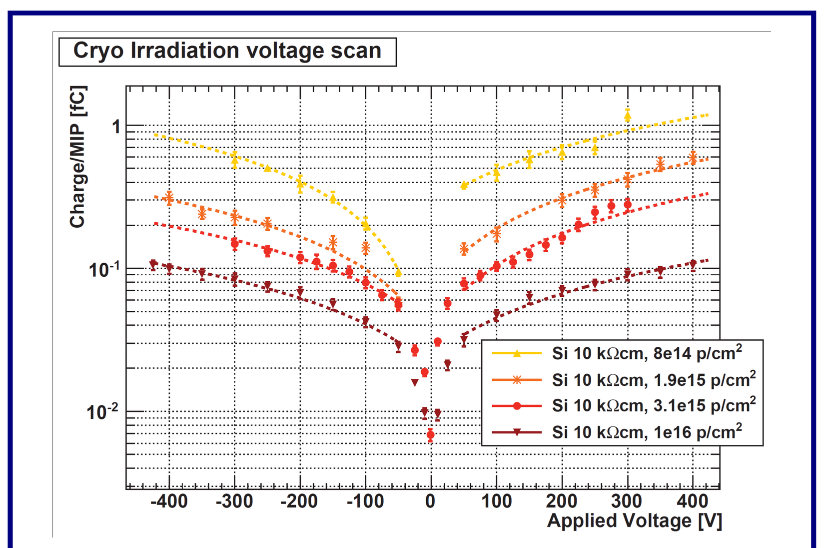

Figure 13: Voltage scan for 10 kΩcm silicon.

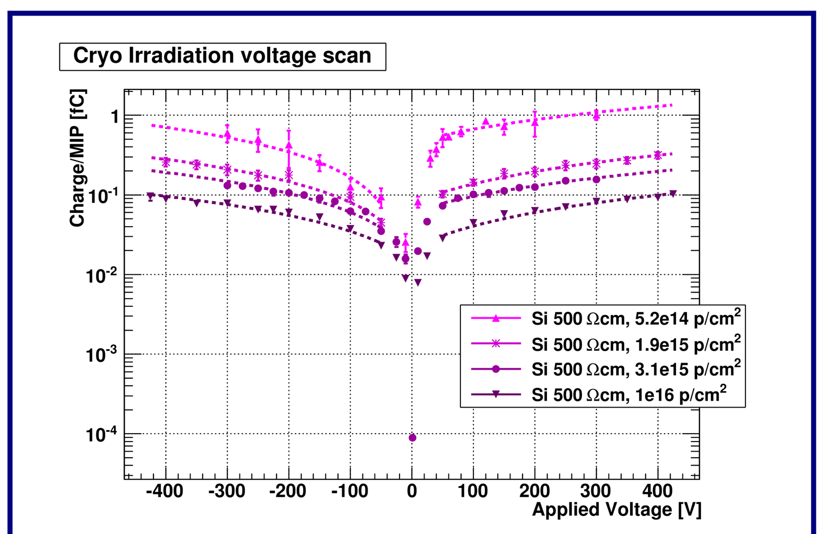

Figure 14: Voltage scan for 500 Ωcm silicon.

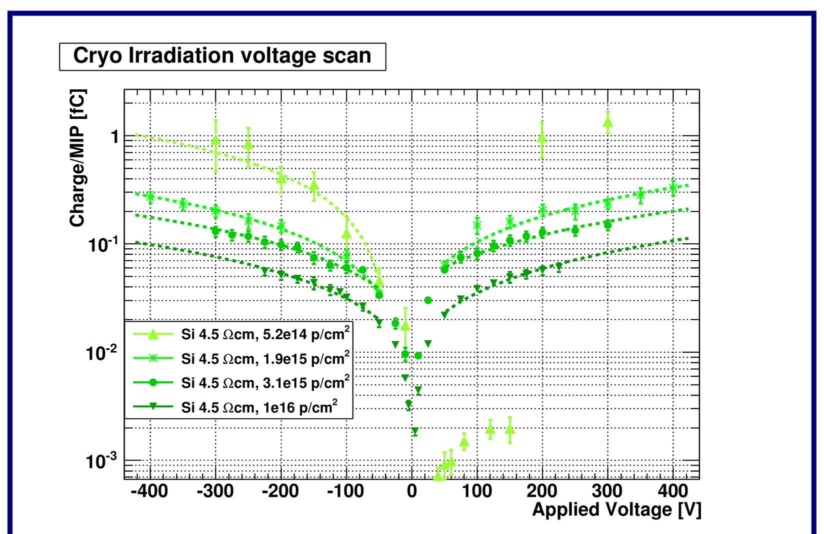

Figure 15: Voltage scan for 4.5 Ωcm silicon.

SUMMARY

Different Si and diamond 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. 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. More experiments with current pulse response measurements using TCT with a pulsed laser at cryogenic temperatures during irradiation are foreseen.

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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.

DETECTOR MODULES

Three different detector modules were used in the experiment (see Fig. 8): holders for direct current (DC) measurements, holders for current pulse response measurements using Transient Current Technique (TCT) with a pulsed laser measurements [3] and Liquid helium chamber.

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

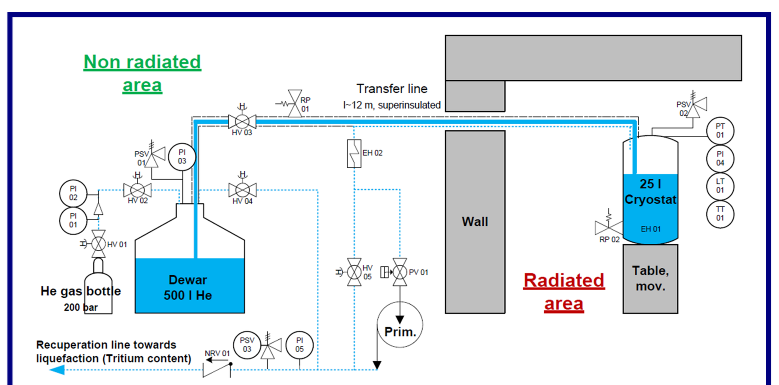

Figure 5: Cryogenic process and instrumentation diagram [Courtesy of T. Eisel].

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 1.3·1011 protons/cm2, corresponding to an average of about 1·1010 protons/s on detectors.

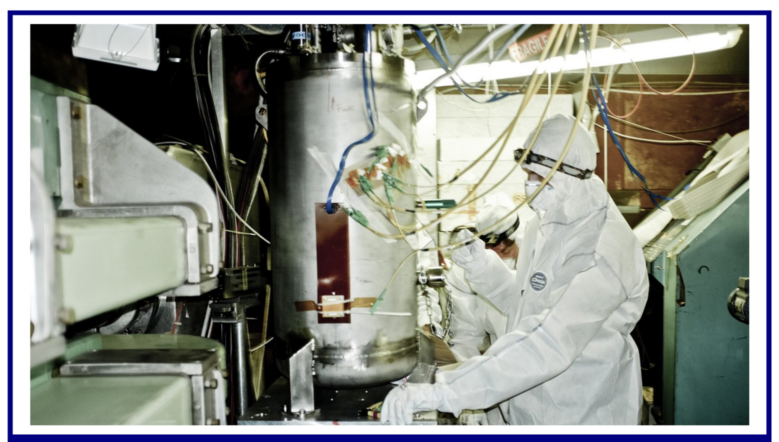

Figure 6: Preparation of the cryogenic irradiation test in T7 irradiation zone at CERN.

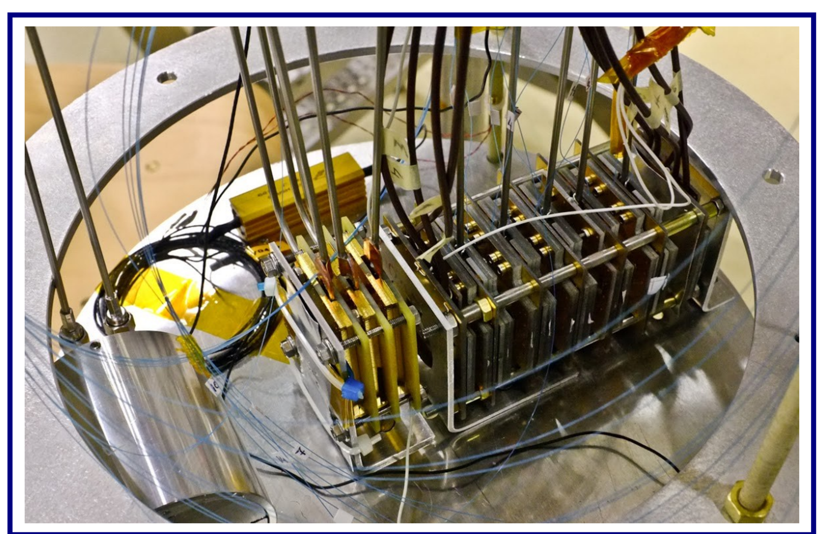

Figure 8: Detector modules mounted on a plate and ready for cooling down and irradiating.

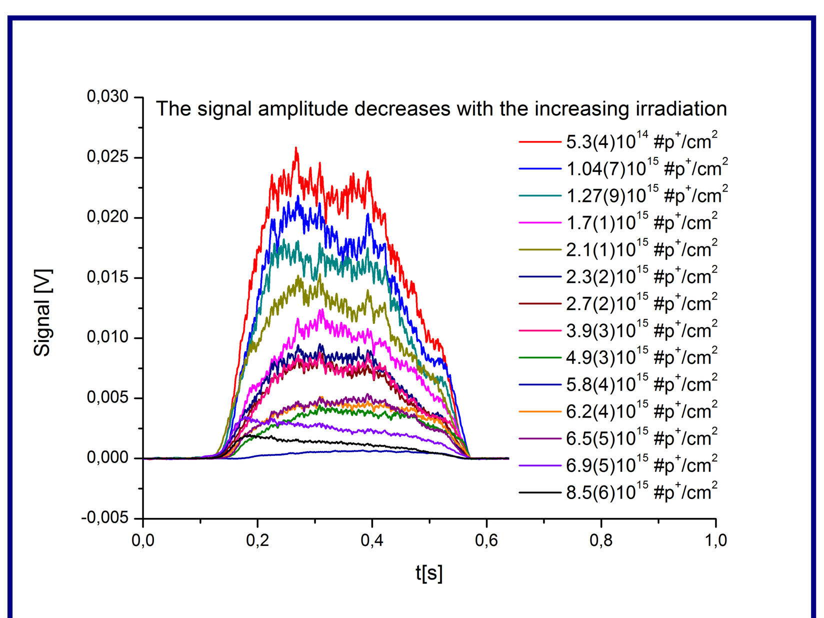

Figure 7: The shape of a signal from a spill for different stages of irradiation of a silicon detector.

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

2) C. Kurfuerst et al., "Investigation of the Use of Silicon, Diamond and Liquid Helium Detectors for Beam Loss Measurements at 2 Kelvin", IPAC, New Orleans, Louisiana, USA, May 2012, TUOAB02.

3) V. Eremin et al.,"Development of transient current and charge techniques for the measurement of effective net concentration of ionized charges […]", Nucl. Instr. and Methods A, p. 388 (1996) 372.

4) C. Kurfuerst et al., "Radiation Tolerance of Cryogenic Beam Loss Monitor Detectors", IPAC, Shanghai, China, May 2013.

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