STUDY OF THE RESPONSE OF LOW PRESSURE IONIZATION CHAMBERS

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Abstract

The Beam Loss Monitoring System (BLM) of the Large Hadron Collider (LHC) is based on parallel plate Ionization Chambers (IC) with active volume 1.5l and a nitrogen filling gas at 0.1 bar overpressure. At the largest loss locations, the ICs generate signals large enough to saturate the read-out electronics. A reduction of the active volume and filling pressure in the ICs would decrease the amount of charge collected in the electrodes, and so provide a higher saturation limit using the same electronics. This makes Little Ionization Chambers (LIC) with both reduced pressure and small active volume a good candidate for these high radiation areas. In this contribution we present measurements performed with several LIC monitors with reduced active volume and various filling pressures. These detectors were tested under various conditions with different beam setups, with standard LHC ICs used for calibration purposes.

INTRODUCTION

The BLM system [1] is responsible for protecting the superconducting LHC magnets from quench and damage due to beam losses. A large fraction of the BLM monitors are ICs with circular parallel plate electrodes of 8.9 cm diameter separated by 0.5 cm gaps. The chambers, filled with N_2 at 1.1 bar as the ionization medium, are 50 cm long and they have an active volume of 1.5l. At the largest expected LHC loss locations, where the ICs collect enough current to saturate the read out electronics, the ICs are replaced by Secondary Emission Monitors (SEM) which give much lower signals and can therefore be used to increase the dynamic range. The SEM consist of only three electrodes, the central one being of titanium due to its secondary emission properties while the volume of the detector is kept at vacuum (10^{-7} mbar). However, the sensitivity of the SEM detectors, measured to be $\sim 7 \cdot 10^4$ times lower than for ICs, was so low that they very rarely measured signals. The active volume of several SEMs were filled with N_2 at various pressures (0.1 bar to 1.1 bar) to study their response as ionization chambers. In the text we will refer to these detectors as LIC prototypes. Finally, several ionization chambers with three aluminum electrodes and a filling pressure 0.4 bar were built and tested. In the text we will refer to these detectors as LICs. In this document we describe the response of several LIC, LIC prototypes and IC under different irradiation conditions. An experimental setup on the dump line of the Proton Synchrotron Booster (PSB) allowed the response of the detectors to be verified against fast pulses ($\sim$ 50ns) of protons. The CNRad facility (connection tunnel to the neutrino beam target area, CNGS) [2] was used to irradiate the detectors with a mixed field of medium duration ($\sim 10\mu$s). The chambers were also tested with continuous losses in the LHC betatron cleaning areas.

PSB MEASUREMENTS

The response of one LIC at a pressure of 0.4 bar was tested on the dump line of the Proton Synchrotron Booster (PSB). An LHC IC was located in a neighbouring location for comparison. The set up is shown in Figure 1. The two detectors were situated on a movable device that allowed them to be moved in to intercept the beam. A ceramic plate placed upstream of the LIC detector allowed a radiation-hard videocamera to verify that the beam was hitting the chambers. The irradiation was produced by proton bunches of 50 ns length and intensities ranging from $3.0 \cdot 10^9 - 2.2 \cdot 10^{10}$ protons with kinetic energy $E_{kin} = 1.4$ GeV.

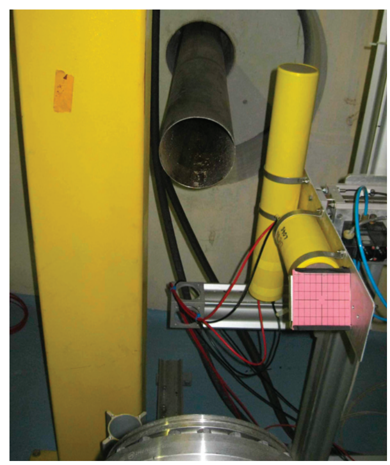

Figure 1: Detector setup in the PSB dump line. The beam direction is from bottom to top intercepting first the ceramic plate, then the LIC and finally the IC.

Figure 2 shows the response of both detectors in a time window of 1 μs were the charge collection due to electrons dominates. Figure 3 shows the response in a time window of 100 μs where the ion collection is observed. Note that in both cases the LIC detectors collect the charges faster than the IC. This is consistent with the fact that the mobility of both ions and electrons in a gas is inversely proportional to its pressure [3]. The time response of the detectors was determined as the Full Width at Half Maximum (FWHM) of the electron induced peak and was measured to be 75 ns (120 ns) for the LIC (IC) detector.

Figure 4 shows the total number of charges collected in a window of 700 ns. The response of the IC is linear with intensity collecting from 0.1 up to 0.6 μC at a rate of $2.93 \cdot 10^{-17} \mu C/proton$. For intensities lower than

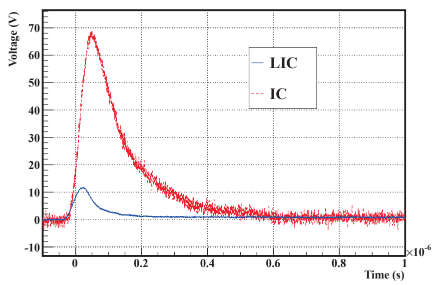

Figure 2: Electron induced signal in the ionization chambers for a beam of $8.2 \cdot 10^9$ protons.

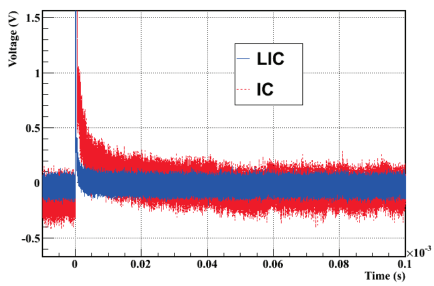

Figure 3: Ion induced tail in the ionization chambers for a beam of $7.5 \cdot 10^9$ protons.

$1 \cdot 10^{10}$ protons, the LIC detector also collects charges that increase linearly from 0.008 to 0.02 μC at a rate of $2.86 \cdot 10^{-18} \mu C/proton$. In this region, the LIC detectors collect approximately a factor 10 less charges than the IC. Due to the geometry of the setup both detectors do not receive the same dose and monte carlo simulations are required for an absolute calibration factor. With higher intensities a different linear behaviour of the LICs is observed, where extra charges are collected (larger slope). Previous measurements with a LIC prototype with filling pressure 0.1 bar showed pulses (in the absence of irradiation) with duration of a few milliseconds that were attributed to the formation of sparks. It is suspected that the read out of large currents favors the formation of such sparks.

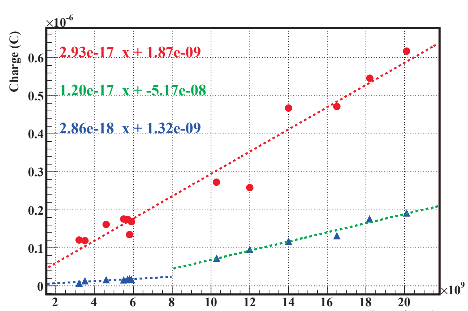

Figure 4: Charge collected in 700 ns vs intensity for IC (red circles) and LIC (blue triangles) detectors.

CNRAD MEASUREMENTS

The CNRad facility is located downstream of the CNGS target area, where a neutrino beam is produced by hitting a graphite target with a beam of $400 GeV/c$ protons. The protons are provided by the Super Proton Synchrotron (SPS) in two spills of $10.5 \mu s$ separated by 50 ms. The average proton intensity per spill was $1.818 \cdot 10^{13}$ protons. Eight different ionization chambers were located in a metallic cross as shown in figure 5, in a tunnel 50 m downstream of the target chamber and perpendicular to the beam direction. Three LIC detectors at a filling pressure of 0.4 bar and two CERN LIC prototypes at filling pressures of 0.1 and 1.1 bar were installed for verification while three standard LHC ICs were installed for calibration purposes. The signals were integrated over $40 \mu s$ via a Current to Frequency Converter (CFC) [4] and sent to the surface electronics using optical fibers for further processing. The surface electronics consists of a laptop and a test system for the BLM acquisition cards [5]. The device kept a history of the signals received and computed twelve running sums which correspond to the integrated signal in twelve different integration windows spanning 40 μs to 83.4 s.

Figure 5: View of the detectors on the metallic cross in TSG45.

The signals integrated over 40 μs during CNGS extractions in all 8 detectors are presented in figure 6 for a period of about a month. We observe channels 2, 4 and 6 (ICs) recording signals in the order of 100k-120k ADC counts. The recorded signals were found to be higher for detectors near the tunnel walls and they decrease by 0.5 %/cm when moving further away from it. This is attributed to the variation of the neutron flux. The 1.1 bar LIC prototype (connected to channel 8) showed signals in the order 10k ADC counts. One LIC prototype at pressure 0.1 bar recored signals in the order of 700 ADC counts but gave erratic behaviour with continuous spikes (presumably due to sparking). Note that the situation became worse at the end of data taking. Channels 3, 5 and 7 correspond to three LIC detectors filled at 0.4 bar showing signals in the order of 2k ADC counts. The sensitivity of the LIC detectors was studied by comparing the recorded signals with the LHC IC readings. Table 1 summarizes the charges collected by the five LIC detectors normalized to the charges collected by their closest IC neighbour for three integration windows.

ISBN 978-3-95450-115-1

The prototype LIC at 1.1 bar shows a roughly constant ratio. Note that from geometrical considerations and assuming a perfectly homogeneous radiation field a factor 30 reduction in the sensitivity was expected. However, as mentioned before this is not a realistic approximation since large variations were observed depending on the detector position. The three LICs at 0.4 bar present a lower ratio in the 40 μs integration window due to the higher mobility of the charges at lower gas pressure. This effect is also present in the response of the LIC prototype at 0.1 bar. However, for long integration times the result is dominated by a large leakage current in this particular detector. A factor $3-3.4$ reduction in sensitivity is achieved by decreasing the filling pressure from 1.1 to 0.4 bar.

Table 1: Ratio of IC to LIC integrated signals in RS01 (40 μs), RS04 (640 μs) and RS08 (655.3 ms)

P (bar)	RS01	RS04	RS08
0.1	152.0	193.0	10.5
1.1	14.0	16.5	16.3
0.4	45.9	58.9	51.2
0.4	44.6	56.8	49.4
0.4	43.9	56.6	50.1

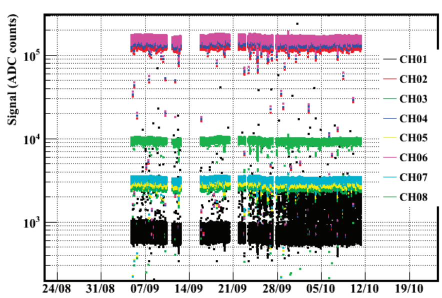

Figure 6: Signals in $40 \mu s$ vs time.

LHC BETATRON CLEANING AREAS

The response of two CERN LIC prototypes and one LIC detector were tested against steady-state losses in the betatron cleaning insertion region of the LHC. The three detectors, with filling pressures 0.1 bar, 0.4 bar and 1.1 bar, were located downstream of a graphite secondary collimator and below the beam line. In this area, protons from the tails of the LHC beams or protons scattered by primary collimators intercept the collimator jaw producing continuous particle showers throughout an LHC fill. Figure 7 presents the signals observed during 5 hours in which an $1.8 \cdot 10^{14}$ proton beam was injected into the LHC and put into collision. The signals collected in 1.3 s for the three LIC detectors are plotted versus the signals observed by the IC during the same time. Due to the complicated geometry of the setup some of the detectors are partially shielded from the showers and an absolute calibration would require monte carlo simulations. However, a very good linearity is observed between LIC and IC for relativelly high losses. A turn-on effect is observed for signals lower than $1.0^{-4} Gy/s$ in the IC were the LIC detectors are not sensitive enough to fully detect the losses produced.

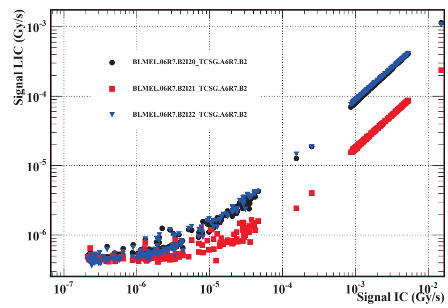

Figure 7: Signal in LIC detectors in 1.3 s vs signal observed in IC detector during the same time.

CONCLUSIONS

Several LIC prototypes, LICs and IC detectors have been tested under various irradiation conditions. As expected, the LIC detectors systematically showed lower charge collection efficiency but monte carlo simulations are required to establish an absolute calibration factor. When irradiating with proton beams a non linear effect was observed in the LIC for very large intensities, attributed to the formations of sparks. The reduction of the signal for lower gas filling pressure was verified, however, the formation of sparks in the chamber appears to occur at a higher rate for low pressures. Investigations on gas purity and the introduction of a mixture of gases to avoid this effect is ongoing.

ACKNOWLEDGMENT

The authors of this document would like to thank Anatoli Larinov and Vladimir Seleznezthe from IHEP for their careful and diligent work in the production of the LICs.

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