The Compact Muon Solenoid Experiment

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Longevity studies for the CMS-RPC system

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Abstract

In the next decades, the Large Hadron Collider (LHC) will run at very high luminosity (HL-LHC) $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, factor five more than the nominal LHC luminosity. During this period the CMS RPC system will be subjected to high background rates which could affect the performance by inducing aging effects. A dedicated longevity program to qualify the present RPC system for the HL-LHC running period is ongoing. At the CERN Gamma Irradiation Facility (GIF++) four spare RPC detectors are exposed to an intense gamma radiation for a period corresponding to the expected integrated charge at HL-LHC. The main detector parameters are under monitoring as a function of the integrated charge and the performance studied with a muon beam. Preliminary results of the study after having collected $\approx 34\%$ of the expected integrated charge will be presented.

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Longevity studies on the CMS-RPC system

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ABSTRACT: In the next decades, the Large Hadron Collider (LHC) will run at very high luminosity (HL-LHC) $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, factor five more than the nominal LHC luminosity. During this period the CMS RPC system will be subjected to high background rates which could affect the performance by inducing aging effects. A dedicated longevity program to qualify the present RPC system for the HL-LHC running period is ongoing. At the CERN Gamma Irradiation Facility (GIF++) four spare RPC detectors are exposed to an intense gamma radiation for a period corresponding to the expected integrated charge at HL-LHC. The main detector parameters are under monitoring as a function of the integrated charge and the performance studied with a muon beam. Preliminary results of the study after having collected $\approx 34\%$ of the expected integrated charge will be presented.

KEYWORDS: Resistive Plate Chambers; Gaseous detectors; Particle tracking detectors; Trigger detectors

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1 Resistive Plate Chambers at CMS and future plans

The muon detector system of the Compact Muon Solenoid (CMS) experiment [1] at the CERN Large Hadron Collider (LHC) consists of three types of detectors: Drift Tubes (DT) in the barrel region, Cathode Strip Chambers (CSC) in the endcap, and Resistive Plate Chambers (RPC) in both regions covering a pseudo rapidity region up to $|\eta| = 1.9$ with 1056 chambers.

A CMS RPC chamber [2] consists of a double gas gap operated in avalanche mode to ensure reliable operation at high rates. Each gap consists of two 2 mm wide gas gap between two high resistive High-Pressure-Laminate (HPL) electrodes with 2 mm thickness. A non-flammable three-component gas mixture of 95.2% freon ($C_2H_2F_4$), 4.5% isobutane ($i - C_4H_{10}$), and 0.3% sulphur hexafluoride (SF_6) is used with a relative humidity of $\approx 40\%$. The readout plane is located between the two gaps and consists of copper strips aligned in the η direction with a pitch between 2.28 and 4.10 cm in the barrel and between 1.74 and 3.63 cm in the endcaps. The strip signals are asynchronously sent to the Front End Boards (FEBs) [3] which shape the signal before sending it to the RPC linkboard system and the CMS data acquisition system (DAQ).

The system was designed to provide muon identification, excellent triggering, timing and momentum measurements at the LHC at the nominal luminosity of $1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$. During the LHC Run1 and Run2 data taking the performance of the muon systems was outstanding [4]. In the second phase of the LHC physics program, called High Luminosity LHC (HL-LHC), the instantaneous luminosity will reach $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$, providing to CMS an additional integrated luminosity of about 3000 fb^{-1} over 10 years of operation, starting in 2026.

2 RPC longevity studies

When exposed to a prolonged radiation, gaseous detectors can suffer aging effects that typically results in: loss of efficiency, rise in spurious signal rates, increase in dark currents, etc. The main causes behind the detector performance deterioration are chemical processes largely occurring in the hot plasma inside electron multiplication region. Gaseous molecular fragments produced inside avalanches may form polymers growing on the electrodes [5]. The severity of aging increases with

the radiation exposure and depends on many factors, such as the materials used for the electrodes, operational gas gain, gas mixture, impurities in the gas itself, gas flow rate, radiation rate, etc.

The present RPC system has been certified for 10 LHC years operation, at a maximum background rate of 300 Hz/cm^2 and a total integrated charge of 50 mC/cm^2 [1]. Based on Run2 data and assuming a linear dependence of the background rates as a function of the instantaneous luminosity, the expected background rates and integrated charge will be about 600 Hz/cm^2 and 840 mC/cm^2 , respectively (including a safety factor of three) [6]. HL-LHC will therefore be a challenge for the RPC system since the new operating conditions are much higher with respect to those for which the detectors had been designed, and could induce non-recoverable aging effects that can alter the detector properties and performance.

A new longevity test is then needed to estimate the impact of the HL-LHC conditions up to an integrated charge equivalent to the integrated luminosity of 3000 fb^{-1} , to confirm that the RPC system will survive to the expected HL-LHC conditions. Longevity studies will identify possible aging effects by monitoring the main detector parameters and performance as a function of the integrated charge.

2.1 Set-up and test procedure

A dedicated longevity study was set up at the CERN Gamma Irradiation Facility (GIF++) where it is possible to test full size detectors. The facility is equipped with a 13 TBq Cs-137 gamma source and a system of movable filters allows to varying the gamma flux, providing a fairly realistic simulation of the HL-LHC background conditions. A 100 GeV muon beam, providing an excellent probes for detector performance studies, complements the source [7].

Since the maximum background rate is expected in the endcap region, in July 2016 the irradiation test was started at GIF++ using four spare endcap chambers: two RE2/2 and two RE4/2. Two different types of chambers have been used for this test because the endcap RPC production has been performed in two periods: in 2005 for all RPCs in the endcap system, except the RE4/2 and RE4/3 chambers, which were made in 2012-2013.

In order to study the longevity of the detectors, two of the four chambers (one RE2/2 and one RE4/2), are continuously operated under gamma irradiation, while the remaining two chambers are turned on only from time to time and are used as reference.

The main detector parameters are monitored and periodically compared with those of the reference chambers (currents and counting rates at several background conditions, noise and dark current, etc). Moreover, when the muon beam at GIF++ is available, the detector performance is studied at different irradiation fluxes. The method for the data analysis is described in Ref. [8].

All measurements are performed under controlled environmental and gas conditions. The detectors are operating with two gas volume changes per hour for the irradiated chambers and one for the reference chambers, and with a relative gas humidity of $\approx 30\text{-}40\%$.

The integrated charge versus time is shown in Fig. 1. At present, about 292 mC/cm^2 and 119 mC/cm^2 have been integrated in the RE2/2 and RE4/2 irradiated detectors, which corresponds respectively to approximately 34% and 14% of the expected HL-LHC integrated charge.

Figure 1. Integrated charge versus time, accumulated during the longevity test at GIF++ for RE2/2 (red) and RE4/2 (blue) chambers. The RE4/2 chamber has been turned on a few months later because of total gas flow limitations. Different slopes account for different irradiation conditions during data taking.

2.2 Detector parameters monitoring

The rate and current are measured all the time for both irradiated and non-irradiated reference chambers. In order to spot possible variations of the electrodes' surface due to the irradiation, the detector dark currents and noise rate are periodically measured. The current and rate versus the integrated charge for the irradiated RE2/2 chamber are shown in Fig. 2; on the left the values at 6.5 kV which represent the ohmic contribution, and on the right at 9.6 kV which includes also the gas amplification. No significant variations of current and rate indicate the absence of Hydrogen Fluoride (HF) effects so far at both high voltage values.

Figure 2. Dark current (red circles) and noise rate (blue squares) versus the integrated charge, for RE2/2 irradiated chamber, at 6.5 kV (left) and at 9.6 kV (right).

The current and the rate in the presence of background radiation are periodically measured as well. To exclude the dependence on the external parameters, the ratios of the irradiated and the reference chambers is measured as a function of the integrated charge. Fig. 3 left shows the current ratio, and Fig. 3 right shows the rate ratio, for both RE2/2 and RE4/2. The difference in the ratio

between the two chambers is due to the different relative position of the RE2/2 and RE4/2 chambers with respect to the reference chambers inside the GIF++ zone. The measurements show an almost stable trend with a small decrease at the beginning of the irradiation period. This behaviour can be explained by an increase of the electrodes' resistivity caused by too low gas humidity and low gas flow rate with respect to the background rate conditions (kHz/cm²).

Figure 3. Current ratio between irradiated and non-irradiated reference chambers as a function of the integrated charge (left). Rate ratio between irradiated and non-irradiated reference chambers as a function of the integrated charge (right). Red circles correspond to RE2/2 chambers, blue squares to RE4/2. The difference in the ratio between RE2/2 and RE4/2 chambers is due to the different relative position of the chambers with respect to the reference chambers.

2.3 Detector performance monitoring

The detector performance has been tested before starting the longevity test and repeated after different irradiation periods corresponding to 18% (153 mC/cm²) and 31% (257 mC/cm²) of the total integrated charge expected by the end of HL-LHC. Figure 4 shows the detector efficiency of the RE2/2 chamber as a function of the effective HV (voltage normalized at the standard temperature and pressure) without irradiation (left), and in presence of a gamma background hit rate of about 600 Hz/cm² (right). No variations of the efficiency and working point (defined as the voltage value at which 95% of the maximum efficiency is reached) have been observed after different irradiation periods, both under 600 Hz/cm² and without gamma background rate.

A similar study has been done monitoring the muon cluster size, defined as the number of fired strips per muon. Figure 5 shows the average muon cluster size versus the effective HV, without irradiation (left), and under a gamma background hit rate of about 600 Hz/cm² (right). No significant variations have been observed so far.

The detectors performance has been measured at different background radiation conditions thanks to the GIF++ irradiator equipped with a filter system. The efficiency and the muon cluster size, at the working point, are shown in Fig. 6 as a function of the background rate, for both RE2/2 irradiated and reference chambers. For all detectors the efficiency is stable in time with a 2% decrease at the highest expected background rate, 600 Hz/cm².

Figure 4. RE2/2 irradiated chamber efficiency as a function of the effective HV, taken with no irradiation (left) and under a gamma background rate of about 600 Hz/cm² (right). The efficiency of the RE2/2 chamber is measured during different Test Beams (TB) corresponding to different fractions of the target charge to integrate: 0, 153 mC/cm² (18%) and 257 mC/cm² (31%).

Figure 5. RE2/2 irradiated chamber muon cluster size as a function of the effective HV, taken with no irradiation (left) and under a gamma background rate of about 600 Hz/cm² (right). The muon cluster size of the RE2/2 chamber is measured during different Test Beams (TB) corresponding to different fractions of the target charge to integrate: 153 mC/cm² (18%) and 257 mC/cm² (31%).

3 Conclusions

In view of HL-LHC the CMS RPCs must prove that they are able to work efficiently at the expected operating conditions for the entire period. Longevity studies on spare RPCs are ongoing at GIF++ under controlled conditions. From preliminary results, the main detectors performance and parameters are stable up to 34% of the expected integrated charge. Further investigations are needed to get closer to the final integrated charge of 840 mC/cm².

Figure 6. Evolution of the efficiency (left) and cluster size (right) at the working point, for RE2/2 chambers, as a function of the γ rate per unit area. Both irradiated and non-irradiated reference chambers are shown. The measurements have been performed before the irradiation (0%) and have been repeated after different periods of irradiation (corresponding to 18% and 31% of the total integrated charge expected by the end of HL-LHC).

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