The Compact Muon Solenoid Experiment

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Aging study for Resistive Plate Chambers (RPC) of the CMS muon detector for HL-LHC

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Abstract

During the phase II of the LHC physics program, called High Luminosity LHC (HL-LHC), the accelerator will increase the instantaneous luminosity up to $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$. At HL-LHC, the CMS Resistive Plate Chambers (RPC) system will be subjected to high background radiations which could induce non-recoverable aging effects and can alter the detector properties. A new longevity test is then needed to estimate the impact of 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 the harsher background conditions. A dedicated consolidation program is ongoing at the CERN Gamma Irradiation Facility (GIF++), where few RPC detectors are exposed to intense gamma radiation. The main detector parameters (currents, rate, resistivity) are under monitoring as a function of the integrated charge and the performance studied with muon beam. After having collected a significant amount of the total irradiation preliminary results will be presented.

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Aging study for Resistive Plate Chambers (RPC) of the CMS muon detector for HL-LHC

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Abstract. During phase II of the LHC physics program, called High Luminosity LHC (HL-LHC), the accelerator will increase the instantaneous luminosity up to $5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$. At HL-LHC, CMS Resistive Plate Chambers (RPC) system will be subjected to high background radiations which could induce non-recoverable aging effects and can alter the detector properties. A new longevity test is then needed to estimate the impact of HL-LHC conditions up to an integrated charge equivalent to the integrated luminosity of 3000fb^{-1} , to confirm that the RPC system will survive to the harsher background conditions. A dedicated consolidation program is ongoing at the CERN Gamma Irradiation Facility (GIF++), where few RPC detectors are exposed to intense gamma radiation. The main detector parameters (currents, rate, resistivity) are under monitoring as a function of the integrated charge and the performance studied with muon beam. After having collected a significant amount of the total irradiation preliminary results will be presented.

1 Introduction

At present, the Compact Muon Solenoid (CMS) muon system consists of three types of gas-ionization detectors: Drift Tube chambers (DT), Cathode Strip Chambers (CSC), and Resistive Plate Chambers (RPC). The RPC system [1] covers both Barrel and Endcap regions of CMS contributing to the trigger, reconstruction and identification of muons. It consists of 1056 RPCs, organized in 4 stations called RB1 to RB4 in the Barrel region, and RE1 to RE4 in the Endcap region.

The RPC system was designed to provide muon identification, excellent triggering, timing and momentum measurements at the Large Hadron Collider (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 [2].

In the second phase of the LHC physics program, HL-LHC, the instantaneous luminosity will reach $5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$ (factor five more than the nominal LHC luminosity), providing to CMS an additional integrated luminosity of about 3000fb^{-1} over 10 years of operation, starting in 2026. The expected conditions in terms of background, pile-up and the probable aging of the present detectors, will make the muon identification and correct p_T assignment a challenge for the

muon system. To ensure redundancy also under the HL-LHC conditions, two upgrades [3] are planned on the RPC system: the consolidation of the present system and the extension of the muon coverage at the $|\eta| < 2.4$.

2 RPC Aging studies for the present system

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 . 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 at HL-LHC will be respectively $\approx 600 \text{ Hz/cm}^2$ and $\approx 840 \text{ mC/cm}^2$, (including a safety factor of three) [3]. 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} , in order 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 Setup and test procedure

A dedicated longevity study was set up at the CERN Gamma Irradiation Facility (GIF++) where it is possible to test real size detectors. The facility is equipped with a $13 \text{ TBq } ^{137}\text{Cs}$ gamma source and a system of movable filters allow to variate the gamma irradiation conditions, providing a fairly realistic simulation of the HL-LHC background conditions. A 100 GeV muon beam, providing excellent probes for detector performance studies, complements the source [4]. 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 types. 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 2013.

In order to study the detector's longevity, two chambers out of the four (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 used as a 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 conditions. The method for the data analysis is described

Fig. 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 few months later because of total gas flow limitations. Different slopes account for different irradiation conditions during data taking.

in Ref. [5]. All measurements are performed under controlled environmental and gas conditions. The detectors are operating with two gas volumes change per hour for the irradiated chambers and one for the reference chambers and with a relative gas humidity of $\sim 30\text{-}40\%$. The integrated charge versus time is shown in Figure 1. At present, about 592 mC/cm^2 and 322 mC/cm^2 have been integrated with the RE2/2 and RE4/2 irradiated detectors, which correspond respectively at around 70% and 38% of the expected integrated charge.

2.2 Detector parameters monitoring

In order to spot possible degradations on the surface of the electrodes due to the irradiation, the detector noise rate and dark current are periodically measured. Figure 2 shows the currents (left) and noise rate (right) at the working point as a function of the integrated charge for the RE2/2 irradiated and reference chambers. No significant variations have been observed so far.

The variations of current and rate with 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. Figure 3 left shows the RE2/2 current and rate ratio. The measurements show a decreasing trend at the beginning of the irradiation period, up to $\approx 300 \text{ mC/cm}^2$, when the operating conditions, in terms of gas flow rate and relative gas humidity were too low with respect to the high gamma background rate. These operating conditions leads to the electrodes resistivity increase, which caused the observed rate and current decrease. The electrodes resistivity increase is confirmed by the measurements performed running the RPCs filled with pure Argon gas. Figure 3 right shows the coherent correlation between the RE2/2 currents ratio (red) and the resistivity variation (blue). The resistivity variation allows us to cancel out the dependence on the environmental

Fig. 2: Dark current (left) and noise rate (right) versus the integrated charge, for RE2/2 irradiated (blue) and reference (red) chamber, at the working point voltage.

conditions and is defined as:

$$\rho_{var} = \frac{\rho_{irr} - \rho_{ref}}{\rho_{irr}} \quad (1)$$

These plots show also that the resistivity increase is a recoverable effect, in fact, the resistivity starts to decrease, and the current and rate to increase when the gas flow and the gas relative humidity have been increased.

Fig. 3: Left: RE2/2 current (red) and rate (blue) ratio between irradiated and reference chamber as a function of the integrated charge. Right: RE2/2 current ratio (red) and resistivity variation (blue).

2.3 Detector performance monitoring

The detector performance has been tested using the muon beam, before starting the longevity test and repeated after different irradiation periods at GIF++, up to 51% of the expected integrated charge. Figure 4 shows the RE2/2 irradiated chamber efficiency as a function of the effective High Voltage (voltage normalized at the standard temperature and pressure), without irradiation (left), and with a gamma background rate of $\approx 600 \text{ Hz/cm}^2$ (right).

Fig. 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/cm^2 (right). The efficiency is measured during different Test Beams (TB) corresponding to different fractions of the target charge to integrate.

The performance without background rate is stable in time and we do not observe any efficiency degradation or working point shift. With a background rate of $\approx 600 \text{ Hz/cm}^2$ the efficiency remains stable at the working point, but we observe a 100 V shift, starting from 45% of the expected integrated charge. The working point shift is related to the electrodes resistivity increase since the effective voltage applied to the electrodes (HV) is reduced by the voltage drop across the electrodes, which is proportional to the current (I) produced by the ionizing particles and to the bakelite resistance (R) [6]. The effective voltage applied to the gas (HV_{gas}) is therefore defined as:

$$HV_{gas} = HV - RI \quad (2)$$

The detector operation regime is invariant with respect to HV_{gas} , therefore the efficiency as a function of HV_{gas} does not depend any longer on the background radiation and on the bakelite resistance. Figure 5 left represent the RE2/2 irradiated chamber efficiency curves at a different background radiation (up to $\approx 600 \text{ Hz/cm}^2$) and at different integrated charge. All the efficiency curves overlap and we do not observe anymore the working point shift since the electrodes resistivity increase effect has been removed. The RE2/2 irradiated chamber efficiency at the working point as a function of the background rate is shown in

Fig. 5 right. The efficiency is stable in time with a 2% decrease at the highest expected background rate, 600 Hz/cm².

Fig. 5: Left: RE2/2 irradiated chamber efficiency as a function of the HV gas, at different background irradiances and at different integrated charge values. Right: RE2/2 irradiated chamber efficiency at the working point as a function of the background rate at different integrated charge values.

3 Results and Conclusion

From preliminary results, no evidence of any aging effect has been observed so far in the RPC detectors. The main detector parameters are stable, other than minor variations like the resistivity of the electrode, which did not affect the performance and remains stable up to 51% of the expected integrated charge. Further investigations are needed to get closer to the final integrated charge of 840 mC/cm².

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