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Improving of RPC for Muon System of CMS experiment

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Abstract. In the Endcap regions, CMS Muon spectrometer is using Cathode Strip Chambers (CSCs) as muon tracking and trigger detectors, also Resistive Plate Chambers (RPCs) serve as dedicated trigger detectors and improve the muon reconstruction by providing the excellent timing resolution for identification of muon particles. At the present, the four Endcap discs are not fully equipped: RPCs are covering only Endcap disks up to $|\eta| = 1.8$. During the Long Shutdown 3 (from 2023 to 2026) of the Large Hadron Collider, Endcap stations 3 and 4 will be further instrumented with new improved RPCs (iRPCs) that will be covering the pseudorapidly region $1.8 < |\eta| < 2.4$, increasing the redundancy in this region. Nowadays, the final design of RPC chambers has been developed and the RPC double gap prototypes with a gas thickness 1.4mm are being tested. The performance and stability of iRPCs at the future HL-LHC upgrades have been studied (detection efficiency, cluster size, rate capability) at the Gamma-Irradiation Facility (GIF++) at CERN, where high energy charged particle beams (mainly muons) are combined with gammas from a 14 TBq 137Cesium source which simulates the background expected at the CMS experiments. In this paper, the main results obtained during the test at GIF ++ are presented.

1. Introduction
In 2013, the program upgrade of the LHC, which was called High Luminosity of Large Hadron Collider (HL-LHC), was approved [1]. In HL-LHC era, the luminosity will raise from 1.5 - 2 up to $5 \times 10^{34}$ cm\textsuperscript{-2} s\textsuperscript{-1}, i.e. the integrated luminosity will increase around threefold with respect to the original design values. For LHC upgrade, two long shutdown periods are scheduled to give the machine and the experiments the necessary time to anticipate these luminosity increases: Long Shutdown 2 (LS2) in 2019/2020 and Long Shutdown 3 (LS3) in 2023/2026 [1]. During these long shutdown periods the CMS Collaboration intends to hold up huge work to update and improve all systems in order to keep the high particle detection efficiency in view of the HL-LHC era.

The Muon System of CMS experiment will undergo a heavy upgrade. In particular, Endcaps region will be extended in both sides, where new muon detectors will be installed: Gas Electron Multiplier and improved Resistive Plate Chambers (iRPCs) covering the pseudorapidity from 1.8 to 2.4 as shown in figure 1 [2]. At present, pseudorapidity region of present Muon System of CMS is covered by Cathode Strip Chambers only and lacks of redundant coverage despite the fact that it is a challenging region for muons in terms of backgrounds and momentum resolution. In order to maintain good efficiency for the muon trigger in this region additional new iRPCs...
Figure 1. A quadrant of the CMS experiment, where improved RPCs are labeled with RE3/1 and RE4/1.

Figure 2. Simulated efficiency of the trigger primitive stubs at the level of 3-/4-station with and without the addition of the RPCs.

are planned to be installed. These iRPCs will have a good timing resolution and a special resolution with few centimeters to mitigate background effects and to increase the redundancy of the system as shown in figure 2.

The first large size iRPC prototype for high eta region was built at the Korea Detector Laboratory (KODEL) and was tested at the Gamma Irradiation Facility (GIF++) at CERN. The gap size as well as the electrode thickness is equal to 1.4mm, allowing to decrease the operating high voltage. The loss in gas gain will then be compensated by the higher signal amplification of improved front-end electronics. The lower deposited charge per crossing particle will also reduce the integrated charge and slow down the aging.

2. Testing of the large size iRPC’s prototype at GIF++ CERN
iRPCs will be installed in the most forward region of the Muon system, they will be located very close to the LHC beam pipe, thus, both the chambers and readout electronics will be subjected to high radiation. It is estimated that in these regions the total expected background rate will be the order of 0.6 kHz/cm². In this harsh radiation environment, new RPC stations must have a stable and high performance. Such a value of rate is equivalent to an integrated charge of approximately 1 C/cm² during the lifetime of the detectors assuming a mean charge deposition $<q>$ per avalanche of 20 pC and a safety factor 2 [3]. In order to study their performance and stability, improved RPCs have been tested at GIF++.

The GIF++ was specially designed in collaboration of the CERN’s Engineering and Physics Department to test the future detectors for HL-LHC program. GIF ++ consists of a 14 TBq 137 Cs gamma source (gamma with an energy of 662 keV corresponding to the typical energy of the neutron âŠ“ induced background radiation in the CMS experiment ) with two sets of adjustable filters to change the intensity and a high-energy muon beam with momentum up to 100 GeV/c from the secondary SPS beam line H4 in EHN1 [4]. RPC Collaboration of the CMS experiment is actively using the GIF++ to investigate efficiency, cluster size, multiplicity and so on of improved detectors under different background conditions.

In May 2017 during the test beam at SPS, a large size prototype of iRPC from KODEL, having a trapezoidal shape (larger base 92 cm, lower base 63 cm and height 166.3 cm) was tested at GIF++ CERN. The prototype was equipped with a strip panel with 2 cm wide strips, 96 in total. To read the charge deposited on the strips, the prototype has been equipped with
front-end electronics, using commercial amplifier chips and a threshold ranging in between 1 mV $\sim$ 160$\sim$180 fC and 0.3 mV $\sim$ 50 fC which was tested in KODEL. The front-end electronics threshold has been fixed of 300 $\mu$V. The prototype iRPC chamber was placed at a distance about 2m from $^{137}$Cs source. Several High Voltage (HV) scans have been performed using different radiation conditions (with and without radiation source), to define the optimal operating voltage, which is referred to as the working point (WP).

3. Determination of efficiency and cluster size for iRPC’s prototype
During the test beam that took place in May 2017 at GIF++, a beam trigger was used to determine of muon detection efficiency. The beam trigger consists of three scintillators, the first with a size of 45 cm by 45 cm and located upstream outside of the bunker, the second of the same size located downstream, outside of the bunker, and the last one a small scintillator of size 15 cm by 15 cm located in front of chamber (see the figure 3).

In this case, efficiency (E) for different background radiation levels is calculated using the appropriate formula:

\[ E = \frac{N_{\text{quadruple}}}{N_{\text{trigger}}}, \]

where $N_{\text{quadruple}}$ corresponds to the number of muons, which were detected by the chamber and scintillators and $N_{\text{trigger}}$ is the number of events, which were detected by scintillators only. The efficiency of the RPC detectors strongly depends not only on the applied high voltage, but on the environment. Using the environmental control station inside GIF ++ bunker, the temperature and pressure were determined. Thus, due to temperature and pressure variations, the applied high voltage ($HV_{\text{app}}$) needs to be corrected to obtain the effective voltage ($HV_{\text{eff}}$). The correction is performed according to the formula below [5]:

\[ HV_{\text{app}} = \beta HV_{\text{eff}} = HV_{\text{eff}}[(1 - \alpha) + \alpha \frac{P}{P_0} \frac{T_0}{T}], \]

where $\alpha = 0.8$ and $T_0 = 293K$, $P_0 = 990mbar$ are the reference temperature and pressure. $T$ and $P$ are measured during the test using the environmental control station. Usually for each RPC chamber a HV scan is performed in order to determine the optimal working point. The HV scan allows to measure the efficiency as a function of the effective voltage. This dependency can be fitted using the sigmoidal curve described by the subsequent formula[6]:

\[ <E> = \frac{E_{\text{max}}}{1 + e^{-\lambda(HV_{\text{eff}} - HV_{50})}}, \]
where $E_{\text{max}}$ is the maximum efficiency reached by chambers at $HV \rightarrow \infty$ and $\lambda$ is proportional to the slope of sigmoid at inflection. The $HV_{50}$ used in the fitting sigmoid function is defined as the high voltage at which every roll reaches 50% of the efficiency plateau. The WP is defined as $WP = \text{Knee} + 120V$ for every RPC chamber[6]. The Knee is the high voltage point on the sigmoid where the efficiency is 95% of the efficiency plateau, shown in figure 4. After the determination of the optimal WP at which the iRPC is stable and efficient, the cluster size is calculated. A consecutive set of strips, each collecting an induced charge defines a cluster. The number of the strips in the cluster gives the Cluster size, it was indicated blue dots in figure 4.

![Figure 4](image)

**Figure 4.** Efficiency and average cluster size of large size double gas gap iRPC prototype with thickness of 1.4mm as a function of the effective voltage, tested without gamma background (a) and with gamma background rate of 1.91 kHz/cm$^2$ (b). The data were measured at the fixed threshold of 300 $\mu$V.

**Conclusions**

During the third long shutdown of LHC 2023/2026, the RPC collaboration will build and install 36 improved RPC chambers with thinner gas gaps and new electronics which will cover the region of $1.8 < |\eta| < 2.4$ in Endcap. Nowadays RPC collaboration is actively working on developing RPC chambers for this highly irradiated region. Using the unique capabilities of the Gamma Irradiation Facility at CERN, the performance of our detectors can be studied with a muon beam under different background conditions. In this paper, the first results of the testing of the large size iRPCs prototype were presented. This detector was successfully tested in a high radiation environment at GIF++. The chamber has stable working efficiency of 93.4% (at gamma rate= 1.91kHz/cm$^2$) and the average cluster size is persistently below 2, which is in good agreement with the expectations [7] and the performance of all the present RPCs from the CMS Muon System. Work is ongoing and a second prototype iRPC has already been constructed to investigate of new low-noise front-end electronics.

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**References**