Posters@LHCC: Students' Poster Session at the 2018 Winter LHCC meeting, 28 Feb 2018, CERN (Switzerland)

Current State of the R&D on new iRPC for the CMS Muon System Upgrade

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1. Motivation

The high pseudorapidity region of the CMS muon system is covered by Cathode Strip Chambers (CSC) only and lacks redundant coverage despite the fact that it is a challenging region for muons in terms of backgrounds and momentum resolution. During the second long shutdown of LHC 2019/2020, two new RPC layers will be added, RE3/1 and RE4/1, which will completely cover the region of 1.8<|η|<2.4 in the Endcap (as shown in Fig.1). Thus, the additional new chambers will lead to an increased efficiency for both trigger and offline reconstruction in a region where the background is the highest and the magnetic field is the lowest within the muon system. The extended RPC system will improve the performance and the robustness of the muon trigger.

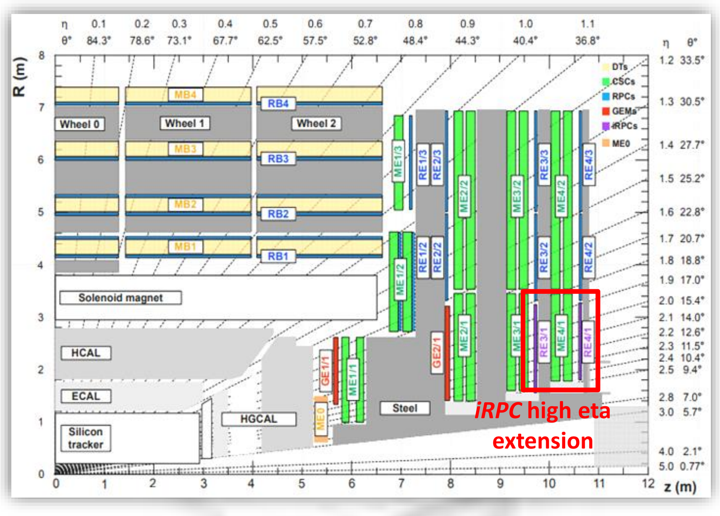


Figure 1. A quadrant of the CMS experiment. The red box indicates the region where additional RPCs will be placed to extend the muon coverage.

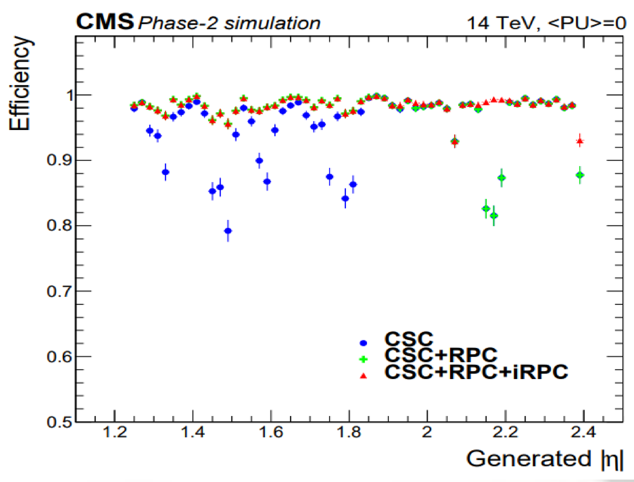


Figure 2. Simulated comparison between the L1 single muon trigger efficiencies with and without the RPC information, as a function of |η|. The contribution of iRPC starts above |η|=1.8.

Including iRPC hits into the trigger primitive stub finding algorithm helps eliminate dips caused by the presence of high-voltage spacers inside the CSC chambers . The overall impact of the inclusion of RPC hits into the single muon trigger can be seen in Fig. 2 showing the single muon trigger efficiencies with and without the use of the RPC information. A clear improvement at the level of 15% can be seen between |η|= 2.1 and 2.2. In case of any CSC trigger problems in ME3/1 and ME4/1, additional improvement would be expected [1].

2. iRPC RE3/1 and RE4/1 requirements:

In order to contribute to the precision of muon momentum measurements, muon chambers should have a spatial resolution less or comparable to the contribution of multiple scattering. In order to match CMS requirements, a spatial resolution of the proposed new RPC stations will be few cm, as shown by the simulation in Fig. 3. According to preliminary designs, RE3/1 and RE4/1 readout pitch will be comprised between 0.5 and 2 mm and 5 eta-partitions should be considered..

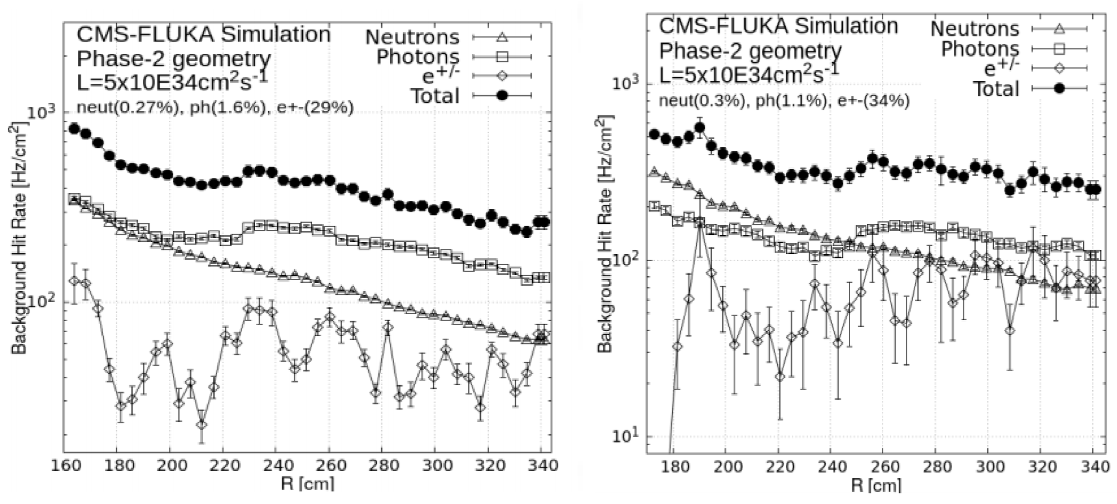


Figure 3. Estimated Background Hit Rate for the RE3/1 (left) and RE4/1 (right) [1]

A very good bunch crossing identification can be obtained with the CMS RPC system, given their fast response of the order of 1 ns.

Taking to account FLUKA simulations [2], the maximum hit rate of about 700 Hz/cm^2 is expected in the hottest points of the new RPC stations (see in Fig. 3). By including a safety factor of three, the requirement for the new chambers is to withstand 2 kHz/cm^2 [3].

3. The technology choice for iRPC RE3/1 and RE4/1 chambers

- Design of the new chambers will be quite similar to the one of existing trapezoidal RPC detectors, each spanning 20^0 in ϕ with radially oriented readout strips (see in Fig.4).
- 18 new chambers per muon disk will be instal, 72 chambers in total for the RE3/1 and RE4/1 stations in both endcaps. Each station will provide one single hit for muon reconstruction with precise time information (~1.5ns) and spatial resolution at the level of ~1cm (perpendicular to strips) and~2 cm (along strips) [5].

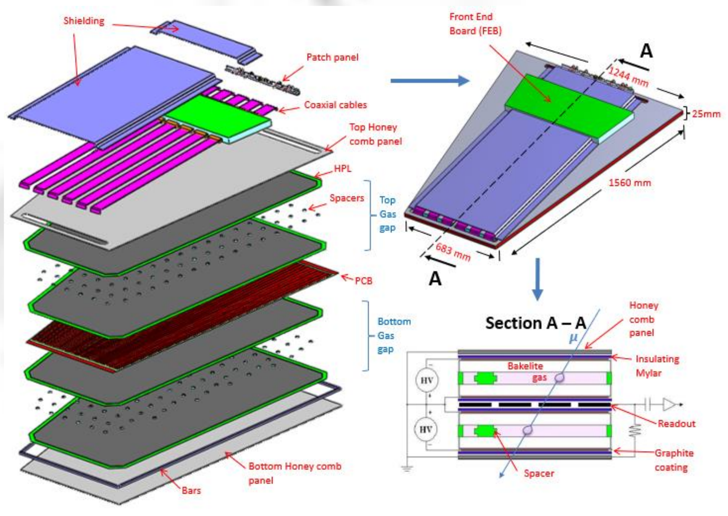


Figure 4. Schematic of the double-layer iRPC chamber with new readout electronics.

Table 1. Comparison between existing RPC and new iRPC chambers

	RPC	iRPC
Gas Gap & Electrode width	2 mm	1.4 mm
High Pressure Laminate (HPL)	2 mm	1.4 mm
Resistivity (Ωcm)	(1.0 – 6.0) x 10^{10}	(0.9 – 3.0) x 10^{10}
Strip pitch	2 – 4 cm	0.6– 1.2 cm
Electronics Threshold	150 fC	10 fC
Chamber dimension	10^0	20^0

Pick-up Strip Panel:

- 96 trapezoidal strips with a high |η| pitch of 6 mm and a low |η| pitch of 12 mm.
- Readout both ends of each strip through coaxial cables of the same impedance.

Front-end electronics:

- 32-channel ASIC with fast pre-amplifier and a fast discriminator in SiGe technology [6];
- Overall bandwidth is 1 GHz with a gain of 25;
- Charge and signal arrival time measurements;
- FPGA (Field-Programmable Gate Array) device running a TDC for the time measurement;
- The TDC time precision of the order of 50–100 ps, the information of signal arrival time from the strip's two ends will provide the hit coordinate along the strip length with a resolution of the order of a few centimetres.

Main advantages of the 1.4-mm double-gap RPC chambers:

- more effectively retard the fast growth of the pickup charges of the ionization avalanches;
- improve the rate capability;
- reduction of the operational high voltage from 9.5 kV to 7.1 kV;
- provide a wider operational plateau;
- improve the robustness of the system, reducing the failure probability of the HV system.

4. Gamma Irradiation Facility (GIF++) at CERN

The Gamma Irradiation Facility (GIF++) was designed in collaboration of the CERN Engineering- and Physics- Department to test the future detectors for HL-LHC program. RPC group of the CMS experiment is actively using the GIF++ to investigate parameters of improved detectors [7].

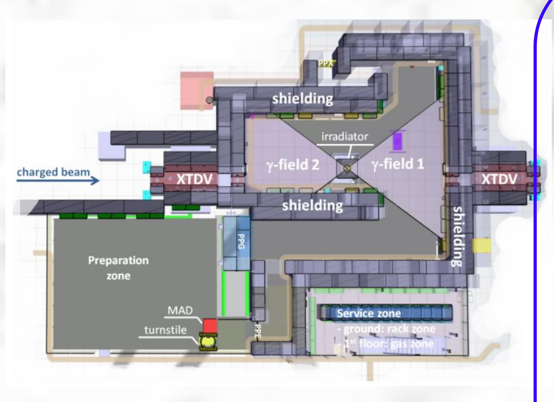


Figure 5. GIF++ layout

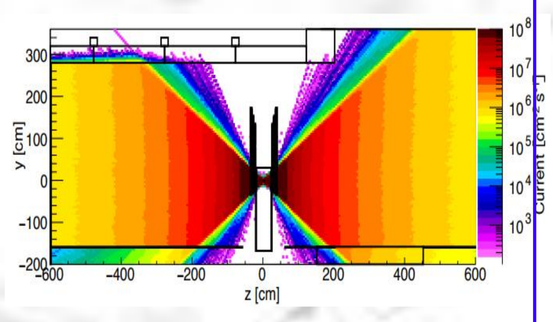


Figure 6. Photon current in the vertical plane through the source (yz plane) at x = 0.65 m; attenuation filters at factor 1.

GIF ++ main characteristics:

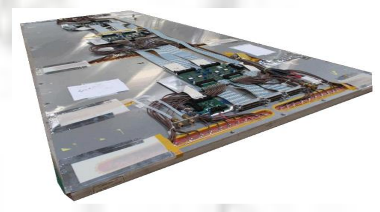
- Located at the SPS H4 beam line in North Experimental Area (EHN1);
- 100 GeV muon beam;
- 13 TBq Cs-137 intense gamma source with controllable attenuation;
- Common Detector Control System (DCS) with controlled environment with T 21° C, humidity 45 % and gas monitoring system;
- Radiation monitoring (RADMONs);
- The higher source activity produces a background gamma field that allows to accumulate equivalent doses to HL-LHC experimental conditions in a reasonable time.

5. iRPC performance tests:

5.1. Experimental set-up

One large size trapezoidal iRPC prototype with thickness of 1.4 mm double-gap and with 2 mm wide strips has been installed and tested at GIF++ with a muon beam to validate the performance under different background conditions. The KODEL front-end electronics threshold has been fixed of 300 µV.

***Dimensions of chamber**: Length = 1663 mm; Larger base = 920 mm; Lower base = 630 mm.*



Gas Gap & Electrode width (HPL)	1.4 mm
Resistivity (Ωcm)	(0.9 – 3.0) x 10^{10}
Electronics Threshold	50 fC
Strips	96
Strip pitch	1.5- 2.8 cm
Gas	C2F4:iC4H10:SF6 , 95.2%:4.5%:0.3%

iRPC : RE4 – KODEL-1.4 –TOT
Present RPC: RE2-2mm

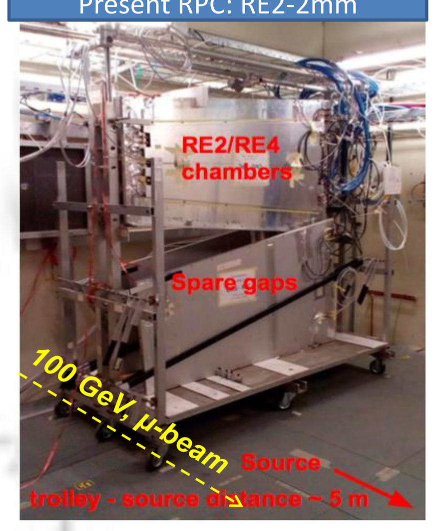


Figure 7. Large size iRPC and present RPC under test at GIF++

5. iRPC performance tests:

5.2. Efficiency and Cluster size

The efficiency and the average cluster size are plotted as a function of the applied effective voltage, in absence of background (Fig.8-left) and with a gamma background rate of 1.91 kHz/cm^2 (Fig.8 - right). The shift in the working voltage is confirmed to be less than 300 V while the efficiency remains slightly above 95% also under the maximum background rate [1].

PT – correction:

$$HVapp = HVeff\left((1-\alpha) + \alpha\frac{P}{P_0}\frac{T_0}{T}\right)$$

P_0 = 990 mbar, T_0 = 293.15 K, α = 0.8

Sigmoid function fit:

$$\varepsilon = \frac{\varepsilon_{max}}{1+e^{-\lambda(HVeff-HV50)}}$$

HVapp – applied high voltage;
Hveff - effective high voltage;
$\boldsymbol{\varepsilon_{max}}$ - maximum efficiency of detection;
HV50 - *HVeff* where the ε is 50% of ε_{max} ;
λ - slope parameter at *HV50*.

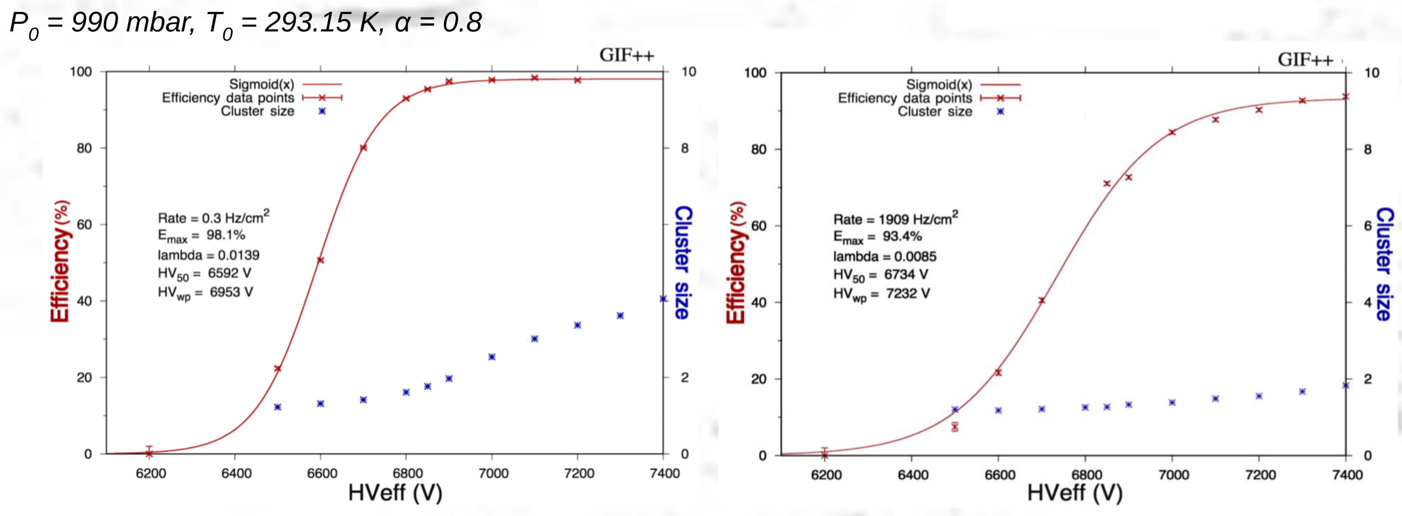


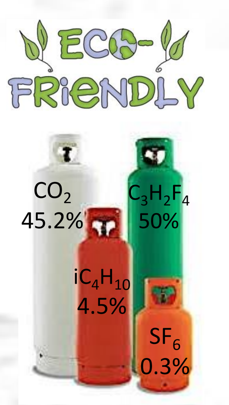
Figure 8. Efficiency and average cluster size of a 1.4 mm double-gap iRPC large size chamber as a function of the effective voltage.

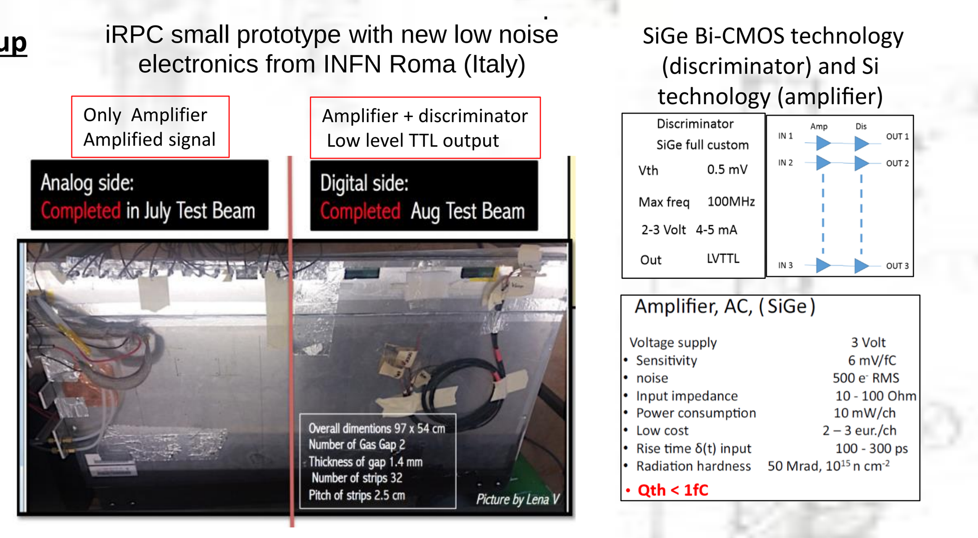
5.3. Eco-friendly gas mixtures for iRPC

The European Community has prohibited the production and use of gas mixtures with Global Warmth Potential (GWP) > 150. The $C_2H_2F_4$ and SF_6 gases used in the RPCs for example present a GWP = 1430 and 23900 respectively and need to be replaced with components with lower GWP. The R&D program of measurements has been started inside the CMS Collaboration in order to find the right eco-friendly candidate.

Tests comparing the performance of the iRPC with the standard CMS gas mixture and ecological gas mixture have been performed with cosmic rays and muon beam at the GIF++.

Experimental set-up





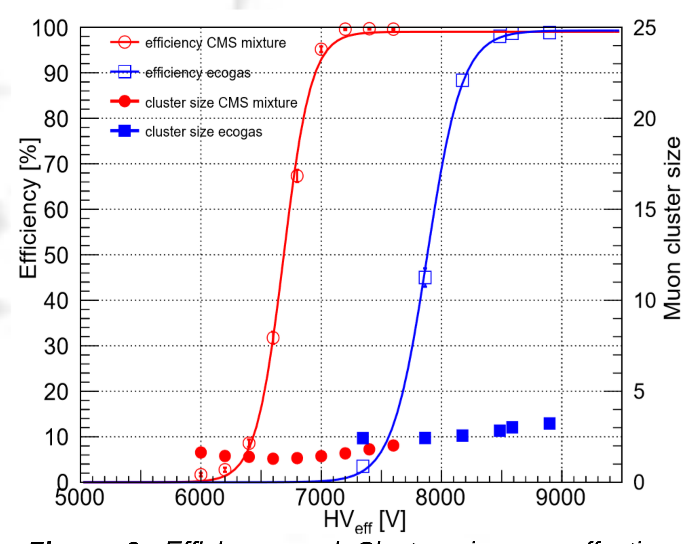


Figure 9. Efficiency and Cluster size vs. effective voltage for the CMS gas mixture and an ecological gas mixture.

In Fig. 9, the efficiency and the cluster size vs the effective High Voltage has been shown for both standard and ecological gas mixture. The efficiency at working point is consistent for both gas mixtures, with a shift of 1.3 kV. Although we measured an increase of the cluster size in the order of one strip [1].

6. iRPC aging studies at GIF++

The increase of the luminosity during the LH-LHC phase up to 5×10^{34} cm^{-2} s $^{-1}$ at a center-of-mass energy of √ s = 14 TeV will be a challenge for the RPC system which can affect the muon identification and reconstruction in the following ways:

1. **Performance:** increase of background rate which can lead to (partial) detector saturation and degradation of the performance;
2. **Aging:** continuous irradiation can induce non-recoverable aging effects inside the RPC gap materials which can alter the material properties (e.g. bakelite resistivity).

Both effects can lead to a degradation of the performance with a lower muon detection efficiency. Therefore it is necessary to estimate the impact of these effects under the HL-LHC conditions up to an integrated luminosity of 3000 fb^{-1}.
The 3rd and 4th endcap disks chambers will be subjected to a total expected background rate of the order of 700 Hz/cm^2 according Fig. 3. Such rate is equivalent to an integrated charge of approximately 1 C/cm^2 during the lifetime of the detectors assuming a mean charge deposition <q> per avalanche of 8-9 pC (Fig. 10) and a safety factor of 3.

Thus, the iRPC longevity test are to certify this new technology detectors to sustain much higher with respect the present RPC that cannot work with 2kHz, to monitor the detectors parameters and performance up to 1 C/cm^2 [8].

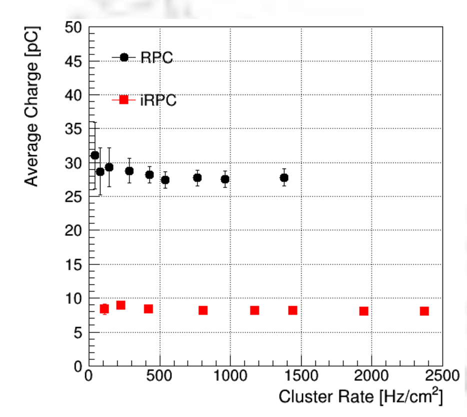


Figure 10. Average integrated charge versus cluster rate collected during the GIF++ studies for the iRPC chamber

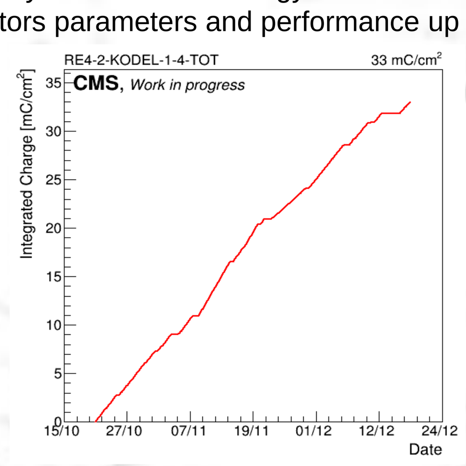


Figure 11. Integrated charge versus time collected during the GIF++ studies for the iRPC chamber.

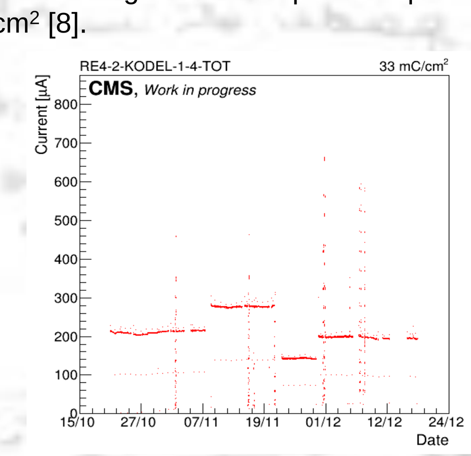


Figure 12. iRPC anode current versus time measured with different absorbtion factors at GIF++

The longevity test has been started in October 2017 for the iRPC chamber, the set-up was shown in Fig.11. The evolution of the charge collection up to now is shown in Fig.12 . At the moment iRPC prototype chamber has accumulated 3%.

7. Conclusion

Current State of the R&D on new iRPC for the CMS Muon System Upgrade is as follows:

1. The radiation environment in the CMS for the Phase-2 upgrade (L= 5x10^{34}cm^{-2}s^{-1}) was studied using FLUKA simulations. The maximum hit rate of background particles on the improved RPC chambers is expected about 700 Hz/cm2. Thus, the requirement for the new chambers is to withstand 2 kHz/cm^2 with accounting a safety factor of three.
2. The better performing RPC design with optimized electrodes (1.4 mm) and gas gap thickness (1.4 mm) were chosen. Work continues on the developing of new fast and low noise electronics for the RPC chambers.
3. The first large size iRPCs prototype was successfully tested in an environments and high radiation at the GIF++. The chamber has stable working efficiency of 93.4% (at range rate = 1.91 kHz/cm^2) and average cluster size below 2.
4. Tests comparing small size rpc prototype performance with the standard CMS gas mixture and ecological gas mixture was tested with cosmic rays and muon beam at the GIF++. In both cases the working point was shifted of 1.3 kV. Further tests are ongoing with a fine-tuning of the gas composition.
5. The iRPC longevity studies are started at the GIF++ in October 2017. At the moment the iRPC prototype chamber has accumulated 3% of the total charge expected to be collected in the new chamber in the 10 years of the HL-LHC in high eta Endcap region. Tests are ongoing.

References

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