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Fluoride production in CMS Resistive Plate Chambers and aging study

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The CMS resistive plate chambers (RPC) detectors operate with a gas mixture based on HydroFluoroCarbon components. The pollutants produced in the gas under high electrical discharge and radiation may accelerate the detectors aging, in particular the fluorine ions (F^-) produced as part of the compound hydrogen fluoride (HF) may damage the inner detector surface due to its high chemical reactivity. The HF production rate has been studied at CERN Gamma Irradiation Facility (GIF++) as a function of the background rate and the gas flow. Finally, the possible aging effects induced by the radiation in the CMS RPC system, including the HF effects, have been studied after almost seven years of operation.

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1. Current study of the CMS RPC system during Run-II

After almost seven years of operation, the CMS resistive palte chambers (RPC) system shows stable performance and high efficiency [1]. The average efficiency is greater than 95% and it is stable in time. Nevertheless, a general ohmic current increase was observed during 2018, as the LHC instantaneous luminosity increased, reaching almost $\approx 2\times10^{34}$ cm^{-2} s^{-1}. Figure 1 shows the average ohmic current measured in four representative RPC stations: W0 in the barrel and RE+1, RE+4, RE-4 in the endcap. The ohmic current measurements were taken with 6.5 kV applied to the chambers.

The ohmic current increase appears correlated with the background rate distribution [1]. Specifically, the increase is more evident in the external stations such as RE+4 and RE-4, where the background rate is $\approx 40\ Hz/cm^2$; whereas the ohmic current are almost stable with a minimal increase in the inner stations such as W0 and RE+1, where the background rate is less than 10 Hz/cm^2.

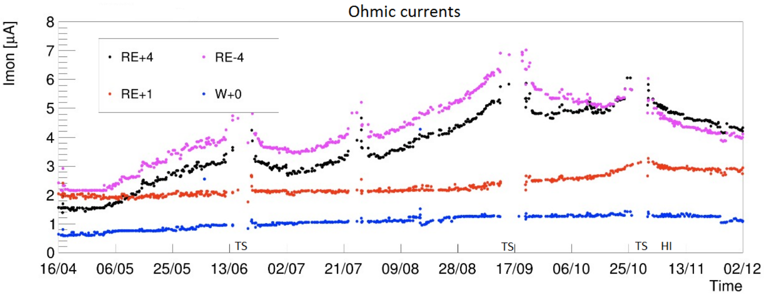

Figure 1: Ohmic current measured at 6.5 kV as a function of time. The currents were measured during 2018 in four RPC stations: W0 in the barrel and RE+1, RE+4, RE-4 in the endcap.

As shown in Fig. 2, the ohmic currents were observed to decrease during the periods with no collisions, such as the Technical Stops (TS), or during the periods with very low instantaneous luminosity, such as the Heavy Ions (HI) collision periods. The current decrease is very evident in the high background stations, whereas it is less evident in the low background regions. Thus, the observed ohmic current increase may not be permanent, but rather a partially recoverable effect.

A parameter which plays an important role for the ohmic current stability is the gas flow. The gas volume exchanges remove the pollutants created by the radiation in the detector gas gap and prevent the deposition on the inner gap surface. The demonstration of the gas-flow influence is shown in the Fig. 1. The W0 and RE+1 stations operate in similar background conditions with 0.6 gas volume exchange per hour, and follow a similar trend. The same is true for the RE-4 and RE+4, which operate with 1 gas volume exchange per hour. After the TS2, around the middle of September, the gas flow was doubled in RE-4 station, from one to two gas volume exchanges per hour, and a significant decrease in its ohmic current behaviour is observed. The increase of the gas flow mitigates the ohmic current increase in the RE-4 station compared to the RE+4 station. The higher gas flow in RE-4 during the HI collision running in November and December results in a faster decrease in the ohmic current recovery than for RE+4.

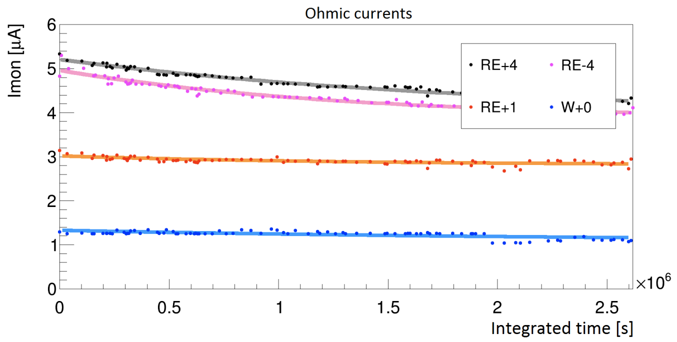

Figure 2: Ohmic currents as a function of the time, measured at 6.5 kV in four RPC stations: W0 in the barrel and RE+1, RE+4, RE-4 in the endcap. The ohmic currents were measured during the Heavy Ion period at the end of 2018.

In conclusion, the background rate and the gas flow are the two main parameters that influence the ohmic current. Figure 3 shows a roughly linear dependence of the ohmic current as a function of the integrated luminosity. The current slopes of W0 and RE+1 stations are similar since the operating conditions, in terms of background rate and gas flow, are similar. The same is true for RE+4 and RE-4 stations. The change in slope of the ohmic current in RE-4 at an integrated luminosity of $\approx 55\ fb^{-1}$ is a result of the gas flow increase. The linear dependence can be parameterized as:

$$i_{ohmic} = i_0 + k_i \times \mathscr{L}_{int} \qquad with \qquad k_i = \frac{\partial i_{ohmic}}{\partial \mathscr{L}_{int}} \tag{1.1}$$

Where i_{ohmic} is the ohmic current, i_0 is the offset which represents the intrinsic ohmic current of the detector, $\mathscr{L}_{int}$ is the integrated luminosity, and k_i is the slope representing the ohmic current variation with respect to the $\mathscr{L}_{int}$ variation.

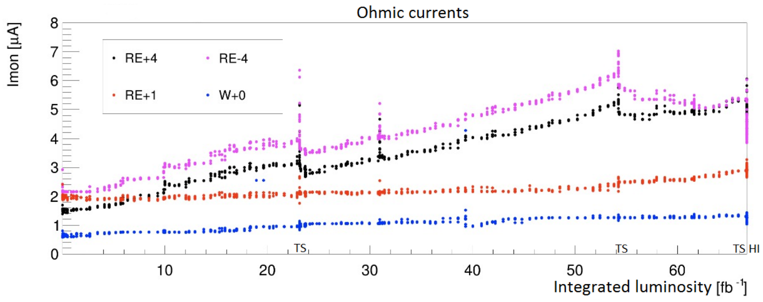

Figure 3: Ohmic current measured as a function of the $\mathscr{L}_{int}$. The currents were measured at 6.5 kV during 2018 in four RPC stations: W0 in the barrel and RE+1, RE+4, RE-4 in the endcap.

2. Hydrogen fluoride (HF) study

The presence of pollutants in gas gap may accelerate the detector aging by damaging the inner gap surface, and therefore affecting the performance. Many experiments that have used RPC detectors report a contamination of hydrogen fluoride (HF) acid in the exhaust gas [2, 3, 4, 5, 6, 7]. However, the actual HF production mechanism is still not completely clear.

The RPC gas mixture is based on hydrofluorocarbon components, in particular for the CMS RPC it is composed of: 95.2% $C_2H_2F_4$, 4.5% iC_4H_{10} and 0.3% SF_6. The decomposition of the $C_2H_2F_4$ molecules, induced by the relatively high-energy photons (i.e. UV) generated during the charge multiplication, produces a significant concentration of a fluorine ions F^- [8]. Once fluorine radical is formed, it can react with H^+ ions, which come from any hydrogen sources present inside the gas mixture, such as water vapour (RPC gas mixture is humidified) or isobutane. If this HF compound is not efficiently removed by the gas flow but remains inside the chambers, it may cause damage to the inner surface of the detector because of its high chemical reactivity [5]. The HF can harm the inner gap surface by damaging the polymerized linseed oil layer, and the effect tends to increase with time since local damage produces a local higher F^- production. Furthermore, HF may form a thin conductive layer on the inner gap surface, decreasing the surface resistivity. This effects induced by the HF may lead to an increase of the dark current and the noise counting rate.

For these reasons, the HF production rate has been studied at the CERN Gamma Irradiation Facility (GIF++) as a function of the background rate and the gas flow [9]. This HF study was also performed with the CMS RPC system to investigate the correlation with the observed ohmic current increase.

2.1 HF study at GIF++

The HF production mechanism was studied in detail at GIF++ to understand and better estimate the influence of the background rate and the gas flow. The measurement technique is based on a specific ion-selective electrode (ISE), which is a transducer (or sensor) that converts the activity of a specific ion dissolved in a solution into an electrical potential [2, 3, 6].

To measure the HF concentration, the RPC exhaust gas is bubbled inside a Total Ionic Strength Adjustment Buffer and distilled water solution, where the fluorine is detectable by the ISE as F^- free ion. This is possible because the hydrolysis reaction occurs when HF is in touch with distilled water.

When the ISE sensing element is in contact with a solution containing F^-, an electrode potential develops. The potential is measured with respect to a constant reference potential provided by the reference electrode. The measured potential, which is described by the Nernst equation, corresponds to the concentration of the F^- in solution [10]. The conversion from the measured potential to the concentration is done using the electrodes calibration curve.

The setup used at GIF++ for the HF measurements is shown in Fig. 4. The exhaust gas from an irradiated spare CMS RPC endcap chamber flows into the solution, where the ISE [1] allows the F^- measurements. Throughout the entire measurements, the ISE was immersed in the solution and the electrical potential measured was read and recorded. The gas flow fraction analysed was 0.5 l/h. The measurements were taken with the detector at working voltage ($\approx 9.8\ kV$).

The measurements were taken at various background rate conditions, and the detector was operated with three different gas flows: 0.2, 1 and 3 gas volume exchanges per hour. The results

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[1] For the measurements, HANNA Instruments electrodes have been used.

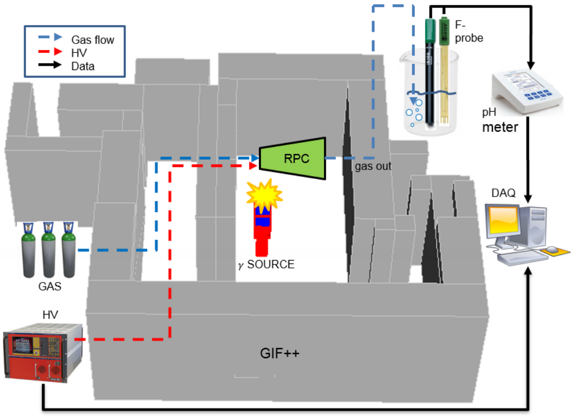

Figure 4: GIF++ experimental setup for the HF measurements.

are reported in Fig. 5 (left). The plot shows a linear dependence of the HF production rate on the background rate (and relative background current). The HF concentration linearly increases with the background rate. The HF slope depends instead on the gas flow, the higher the flow rate the lower the slope. To quantify the gas flow effect, the ratio of the slope for each gas flow to the slope at a gas flow of 1 volume exchange per hour is shown in Fig. 2 (right).

These results demonstrate the HF dependence on the background rate and on the gas flow.

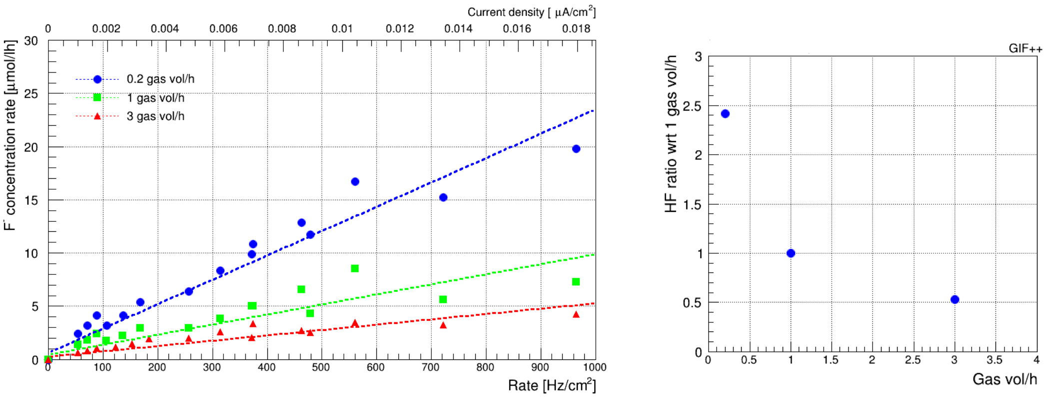

Figure 5: Left: F$^-$ concentration rate as a function of the background rate (and its corresponding current on the top X-axis), measured with three different gas flow: 0.2, 1 and 3 gas volume exchanges per hour. Right: ratio of the F$^-$ concentration measured at different gas volume exchanges with respect to 1 gas volume exchange per hour.

Finally, Fig. 6 shows the concentration of HF not efficiently removed by the gas flow as a function the background rate for various gas flows. The estimation was done considering the HF accumulated during the 8 hours just after switching off the detector. The results show that the concentration of the HF trapped inside the gas gap increases at high background rate, when the HF production is high. Above all, the concentration of the HF trapped depends on the gas flow, higher gas flow results in a lower HF concentration.

The probability that HF deposits on top of the inner gap surface, with consequent damage, obviously increase with the HF concentration and with the increase of time that the HF remains inside the gas gap.

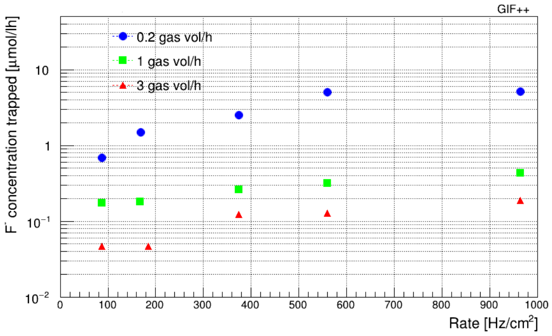

Figure 6: F^- concentration trapped inside the gas gap and not efficiently removed. The concentration was measured at different background rate, and with three different gas flows. The estimation was done considering the F^- accumulated during 8 hours of measurements, just after the detector switch off.

The HF measured at the exhaust gas represents the quantity extracted, more or less efficiently, from the gas gap by the gas flow. If the HF is a cause of detector aging, then a fraction of the HF produced must be absorbed by the inner gap surfaces.

To evaluate the HF absorption hypothesis, the detector was turned off after the last measurement, when it was not possible to extract more HF, and it was simply flushed for 20 days with the standard gas mixture. After 20 days, the chamber was flushed with pure argon gas, and a voltage of 2.4 kV producing a total current of about 200 μA, was applied. A residual HF signal was still measured, and the HF accumulated reached the plateau at $\approx$ 14 μmol after $\approx$ 30 hours. Since only argon was used, the HF could not be produced but could only be extracted from the inner gap surface, proving the hypothesis. The current circulating in the argon forced the further extraction of the HF, which was bound to the inner detector surface [6].

2.2 HF study in CMS

The HF measurements have been performed in CMS during Run-II, to study the possible detector aging and to investigate the observed ohmic current increase. The HF measurement method was the same used at GIF++, and performed at the exhaust gas of three stations:

- Endcap RE+4, which operate with 1 gas volume exchange per hour, and where the background rate is $\approx$ 40 Hz/cm^2;
- Endcap RE+1, which operate with 0.6 gas volume exchanges per hour, and where the background rate is less than 10 Hz/cm^2;
- Barrel W0, which operate with 0.6 gas volume exchanges per hour, and where the background rate is less than 10 Hz/cm^2.

The fraction of exhaust gas flowing in the solution was kept constant at 0.5 l/h. The accumulated HF concentrations were periodically measured and are reported in Fig. 7 (left) as a function of time. All the three curves follow the same trend in time, driven by the LHC operation. The periods when the HF concentrations are constant and do not increase correspond to the TS periods, during which the detectors were off and therefore there was no HF production.

Stations RE+1 and W0 accumulated a similar amount of HF, indeed the operating conditions in terms of gas flow and background are similar. In RE+4 station, the amount of HF accumulated is around 2.5 times higher than W0 and RE+1 stations, but in this case the background rate is around 4 times higher, and the gas flow around two times greater.

The HF concentration follows a linear trend with respect to the $\mathscr{L}_{int}$, shown in Fig. 7 (right), and similar to that observed for the ohmic current in Fig. 3. The linear dependence can be parametrized as:

$$HF = HF_0 + k_{HF} \times \mathscr{L}_{int} \qquad with \qquad k_{HF} = \frac{\partial HF}{\partial \mathscr{L}_{int}} \tag{2.1}$$

Where k_{HF} is the slope representing the HF variation with respect to the $\mathscr{L}_{int}$ variation. In agreement with the ohmic current analysis, the HF slope of RE+4 station is greater than the slopes of W0 and RE+1 stations, which are similar since they have similar operating conditions. The results are in agreement with the GIF++ measurements, proving the HF dependence on the background rate and the gas flow.

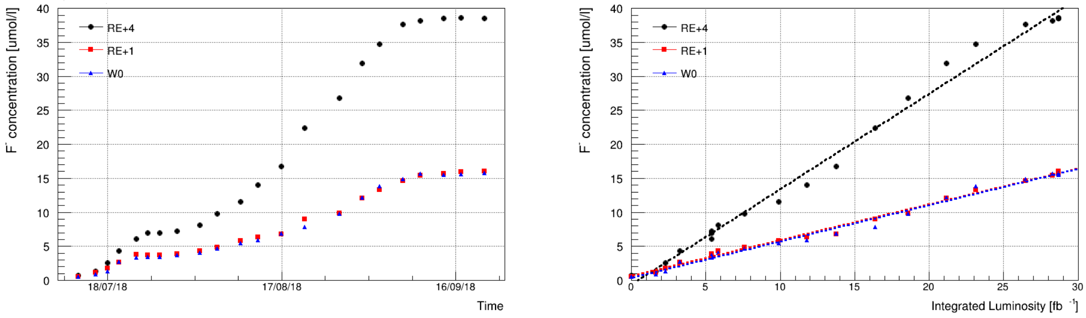

Figure 7: F^- concentration as a function of the time (left) and as a function of the $\mathscr{L}_{int}$ (right). The measurements have been performed during Run II (July - October 2018) at the gas exhaust of 3 regions: W0 in the barrel and RE+1, RE+4 in the endcap.

Finally, Fig. 8 shows the linear dependence between ohmic current and HF concentration. The slope (k) represents the ohmic current variation with respect to the HF concentration rate.

$$k = \frac{\partial i_{ohmic}}{\partial HF} = \frac{k_i}{k_{HF}} \tag{2.2}$$

The RE+1 and W0 slopes are similar and small, with a low background rate. Consequently, the HF production is low, and the current stability shows that the gas flow is enough to efficiently remove the HF produced. On the other hand, the RE+4 slope is larger, the background rate is higher, the HF production is consequently higher, and the results show that the gas flow is not sufficient to efficiently remove the HF produced. Hence the HF likely to be trapped inside the gas gap damaging the inner surface and creating a thin conductive layer causing the observed ohmic current increase.

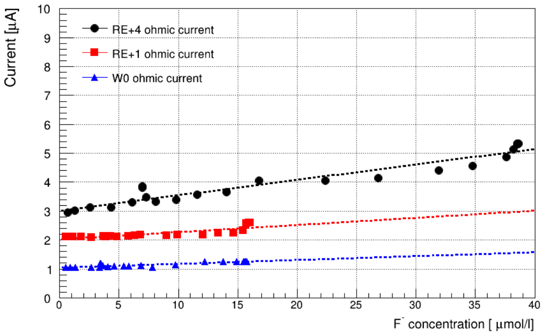

Figure 8: Ohmic current as a function of the F^- concentration.

From these results it is clear that the gas flow must be adjusted as a function of the background rate.

3. Conclusion

The CMS RPC performance is stable after almost seven years of operation. Nevertheless, an ohmic current increase was observed in the most exposed regions. As a possible cause, the HF production rate was studied at GIF++, and found to be dependent on the background rate and on the gas flow. It has also been demonstrated that the HF can be trapped inside the gas gap if the gas flow is not sufficient with respect to the HF production rate, and it is possible to remove it (or partially remove it) operating the detector with argon. The HF measurements have been performed on the CMS RPC system, confirming the GIF++ results and the hypothesis that the observed ohmic current increase was due to the HF deposits. In conclusion, for good detector operation it is necessary to fine tune the gas flow as a function of the background rate so that the HF can be efficiently removed.

References

[1] M. Shah [CMS Muon Collaboration], “CMS RPC system performance during RUN-2 and summary of LS2 Activities”, submitted to Proceedings of Science (PoS) EPS HEP2019, 2019.

[2] M. Abbrescia et al., “HF production in CMS-Resistive Plate Chambers”, Nucl. Phys. B, 2006.

[3] R. Guida et al, “HF production in CMS-Resistive Plate Chambers”, Nuclear Instruments and Methods in Physics Research 158 (2006) 30-34, 2006.

[4] R. Guida et al., “Results about HF production and bakelite analysis for the CMS Resistive Plate Chambers”, Nucl. Instr. and Meth. 594 (2008) 140âĂŞ147, 2008.

[5] C. Lu et al., “RPC electrode material study”, Nuclear Instruments and Methods in Physics Research, 2009.

[6] G. Aielli et al., “Fluoride production in RPCs operated with F- compound gases”, Nuclear Physics B, 2006.

[7] H. R. Band et al., “Study of HF Production in BaBar Resistive Plate Chambers”, Nucl. Instr. and Meth. 594 (2008) 33-38, 2008.

[8] CMS Collaboration, “The CMS muon project: technical design report”,Technical Design Report CMS, CERN-LHCC-97-032. CERN, Geneva, 1997.

[9] R. Guida [EN and EP and AIDA GIF++ Collaborations], “GIF++: A new CERN Irradiation Facility to test large-area detectors for the HL-LHC program”, PoS ICHEP2016, vol.260, 2016.

[10] D.A. Skoog, “Analytical Chemistry”, Saunders College Publishing, 2000.