Grant Agreement No: 101004761

AIDAinnova

Advancement and Innovation for Detectors at Accelerators

Horizon 2020 Research Infrastructures project AIDAINNOVA

DELIVERABLE REPORT

VALIDATION OF THE ECO-FRIENDLY GAS MIXTURES FOR RPCs AT GIF++

DELIVERABLE: D7.2

Document identifier:	AIDAinnova-Del-Dx-xTemplate-v1.0(1)
Due date of deliverable:	December 2024
Justification for delay:	[if delays occurred]
Report release date:	dd/mm/yyyy
Work package:	WP7: Gaseous Detectors
Lead beneficiary:	INFN, CERN
Document status:	Draft [Final when fully approved]

Abstract:

A complete summary of the tests performed on eco-friendly gas mixtures for RPC operation under irradiation at GIF++ facility is reported. The report covers the preliminary tests performed before the start of AIDAinnova program and the results of four years of irradiation of several RPC detectors.

AIDAinnova Consortium, yyyy

For more information on AIDAinnova, its partners and contributors please see http://aidainnova.web.cern.ch/

The Advancement and Innovation for Detectors at Accelerators (AIDAinnova) project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 101004761. AIDAinnova began in April 2021 and will run for 4 years.

Delivery Slip

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Executive summary

This report will discuss results obtained by the RPC ECOgas@GIF++ Collaboration, using Resistive Plate Chambers operated with new eco-friendly gas mixtures, based on Tetrafluoropropene and carbon dioxide. Tests aimed to assess the performance of this kind of detectors in high-irradiation conditions, analogous to the ones foreseen for the coming years at the Large Hadron Collider experiments, were performed, and performance results are presented. Long term ageing tests have also been carried out, with the goal to study the possibility of using these eco-friendly gas mixtures during the whole High Luminosity phase of the Large Hadron Collider and showing possible limits.

1. INTRODUCTION

Resistive Plate Chambers (RPCs) are a widespread detector, used in several domains as astro-particle and accelerator physics experiments, and environmental monitoring and medical applications. In particular, at the Large Hadron Collider (LHC) at CERN, three experiments, namely ALICE, ATLAS, CMS use them in slightly different configurations and for multiple purposes [1] [2] [3], while LHCb is considering to use RPCs, although not as baseline for the upgrade [4].

Presently, the RPCs used at the LHC experiments are operated with gas mixtures containing Tetrafluoroethane (TFE) as the main component. TFE, whose empirical formula is $C_2H_2F_4$ and is also commercially known as R-134a, is usually mixed with iso-butane (i-C_4H_{10}) and Sulphur hexafluoride (SF_6) in various percentages, to exploit the well-known discharge quenching properties of these gases. However, TFE is characterised by a Global Warming Potential (GWP[1]) around 1430, and regulations by the European Community, derived from the adoption of the Kyoto protocol, established a complete phase-out by 2050 [5]. Given the uncertainty in availability and price of F-gases as well as their impact on the environment, the LHC experiments decided to investigate for possible replacements of TFE with other, more eco-friendly, gases.

The goal of the AIDAinnova task 7.2.2 is to study possible eco-friendly alternatives to the so-called "standard" gas mixture used in ATLAS and CMS experiments and to verify RPC long-term performance under background conditions similar to those foreseen at the LHC experiments.

[1] The GWP of a certain gas depends on the time frame considered. Here and in the following we will refer to the GWP over 100 years. For all tables and calculations, moreover, we will use the GWP reported in [5].

2. DIFFERENT APPROACHES TO THE ECOGAS PROBLEM

In research facilities, greenhouse gas (GHG) emissions could arise from the operation of the facility itself but also of the detectors. In the case of CERN, the majority of the GHG emissions comes from CERN's core experiments of which around 80% are fluorinated gases used for particle detection and detector cooling. In particular, for particle detection, the F-gases employed are $C_2H_2F_4$, SF_6, CF_4 and C_4F_{10}. In Run 2, the $C_2H_2F_4$ and SF_6 contributed for more than 80% of particle detection emissions due to their usage in the ATLAS and CMS RPC systems where several leaks are present at the detector level. The CERN's objective is to reduce its scope emissions by 28% by the end of Run 3 (with respect to 2018 data). To fulfil this objective and to further pursuit the GHG reduction, the CERN EP-DT Gas Team, the CERN Environmental Protection Steering board (CEPS) and the LHC experiments elaborated a strategy based on three action lines [6]:

- **Gas recirculation.** The gas mixture is taken at the output of the detectors, purified and sent back to the detectors. It is technically possible to recycle 100 % of the gas mixture
- **Gas Recuperation.** The gas mixture is sent to a recuperation plant where the GHG is extracted, stored and reused.
- **Alternative gases**. Search for alternative gas mixtures suitable for particle detectors that do not contain or limit the use of GHGs.

The first two research lines have been already implemented while the use of new eco-friendly gas mixtures has to be validated for the detector long-term operation.

The reduction of the use of F-gases is fundamental for next LHC Runs and future particle detector applications also because of the implementation in Europe of the F-gas regulation [7]. This regulation, recently updated, establishes the total elimination of hydrofluorocarbons by 2050. This regulation has already, and it will have in the future, an important impact on prices and availability of these gases. The search for eco-friendly gas mixtures for particle detectors is therefore important for the future operation of research facilities.

3. SEARCH FOR NEW ECOLOGICAL GASES

The goal of the Aida Innova task 7.2.2 is related to the search for new eco-friendly gas mixtures with low environmental impact fulfilling the performance expected for the LHC operations and for future applications as well as the validation of the RPCs performance after long periods of irradiation.

Studies on the search of new eco-friendly gaseous components suitable to replace TFE in RPCs started several years ago. In this search, it is important to consider that the new gas has to be available on the market and at a reasonable price as it could be used in large quantities in the experiments. Summarising the work of many years, the main idea was to replace TFE with tetrafluoropropene, whose empirical formula is $C_3H_2F_4$, which is an hydrofluoroolefin (HFO) characterised by a quite low GWP. In particular, its allotropic form, commercially known as HFO-1234ze, proved to be the most suitable for applications in detectors for particle physics, and is characterised by a GWP around 7 [5]. HFO is widely used in refrigeration industry, making it easy to procure and it is relatively not expensive.

HFO-1234ze has a molecule quite similar to TFE, nevertheless its first effective Townsend coefficient, at a given electric field strength, is lower with respect to the one of TFE (for a recent measurement of gas parameters of HFO-1234ze and a comparison with TFE, see [8]). In the presentday RPCs, replacing TFE with HFO would result in too large operating voltages to be compatible with the high voltage systems and readout electronics used at the LHC experiments. Therefore, in order to keep the operating voltage within an acceptable range, it was proposed to replace TFE with a binary mixture, made either of HFO-1234ze and CO_2, or HFO-1234ze and He, He being discarded as it can affect the operation of photomultipliers in the experimental caverns. (see, for instance, [9] and [10]).

Note that it has been pointed out that HFO, in the high atmosphere, can dissociate giving eventually origin to trifluoroacetic acid (TFA), which is potentially harmful for the environment and the human health, if removed from the atmosphere by rainfalls [11], [12]. A long debate has been going on the subject, whose outcome seems to demonstrate that the actual impact should be irrelevant (see [13] and references therein). Nevertheless, this is one of the potential issues to be considered and will probably require deeper insights in the future.

Some studies about the performance of RPCs filled with HFO-1234ze/CO_2 mixtures have already been reported, showing encouraging results, in terms of performance obtained as in [14] [15] [16] [17] and [18]. Nevertheless, at the moment of the AIDAinnova startup, a long-term ageing test of RPCs filled with eco-friendly gas mixtures based on HFO-1234ze and CO_2, operated under a high particle radiation background, was still missing, and this is a crucial point if such gas mixtures are to be considered for use in the High-Luminosity phase of the LHC (HL-LHC).

Joined by the common interest for this topic, a collaboration across multiple groups working on RPCs at the LHC experiments was established, with the specific goal to carry on these long term, high irradiation conditions, tests. Groups from the ALICE, ATLAS, CMS, LHCb/SHiP experiments, together with the EP-DT gas group from CERN, are components of this collaboration, usually called the "RPC ECOGas@GIF++ Collaboration". Testing the same HFO-1234ze/CO_2 gas mixtures, with the different detector layouts and front-end electronics brought by the various groups, provides deep insights both on the gas and the detector behaviours, and, in principle, may allow to disentangle the various effects that could be related either to the specific designs and/or to the production techniques, and/or the electronics use.

4. EXPERIMENTAL SET-UP

The performance studies and the ageing program have been carried on at the CERN Gamma Irradiation Facility (GIF++) [19]. Several RPC chambers with different size, number of gaps, gas gap thickness and front-end electronics have been mounted on two trolleys positioned at around 3 and 6 m from the ^{137}Cs source and along the direction of a muon beam used for dedicated tests. Most of the chambers are based on the characteristics of a specific LHC experiment and are defined by the name of the experimental collaboration that is taking care of it. Table 1 shows the main parameters of the chambers under test.

Group	Distance from source (m)	Dimensions (cm x cm)	gap thickness (mm)	electrode thickness (mm)	# of strips	strip pitch (mm)

ALICE	6.0	50 x 50	2	2	16 + 16	30
ATLAS	3.2	55 x 10	2	1.8	1	N/A
CMS	3.5	(41.5 - 23.9) x 100.5	2 + 2	2	128	5.5 - 11
EP-DT	3.0	70 x 100	2	2	7	21
LHCb/SHiP	6.2 -> 3.0	70 x 100	1.6	1.6	32 + 32	10.6

Table 1: Characteristics of the chambers under test. All chambers were rectangular, except the one from CMS, which was trapezoidal in shape, so dimensions of the smaller and larger bases are shown, as well as the minimum and maximum strip pitch. The ALICE and LHCb/SHiP detectors were equipped with two sets of strips, perpendicular to each other, while the ATLAS chamber with one single central strip, 3 cm wide. In the ALICE case the readout strips covered basically the entire detector surface, while for EP-DT and LHCb/SHiP they were positioned just onto their central part. The distance from the source of the LHCb/SHiP chamber was changed from 6.2 to 3 m after the first test beam.

In the ALICE, CMS and LHCb/SHiP chambers, signals induced on the readout strips were amplified, discriminated and formed by means of suitable front-end electronics which was connected to Time to Digital Converters (TDCs), downstream in the Data Acquisition (DAQ) chain. ATLAS and the CERN EP-DT groups used CAEN digitizers V1730 or V1742, from which they directly acquired the wave-forms from the readout strips and stored them for subsequent analysis. Each experiment group analysed the data with its own custom analysis algorithms. More details on the detector setup and the front-end electronics can be found in [20].

Due to the fact that the detectors under test were placed at different distances from the ^{137}Cs source, different rates of photons were impinging on them, even when the same filter was placed in front of the source. On the other hand, meaningful comparisons across the various detectors have to be done at the same flux of impinging photons, therefore, using different filter configurations. This strategy could be actuated by using a dosimeter, mod. MIRION RDS-31iTx S/R [23], with which the actual gamma ray dose at various positions inside the GIF++ irradiated area was measured.

The tests were performed when flushing the RPCs with the so-called "standard" gas mixture (STD mixture in the following), used in the RPCs of the CMS experiment. Subsequently, the RPCs were filled with gas mixtures where TFE was replaced by HFO-1234ze and CO_2, in different percentages. We tested, in particular, two gas mixtures, hereafter conventionally called ECO2 and ECO3[2]. The percentage compositions, in volume, of the gas mixtures used, and their GWP, are listed in Table 2.

[2] The ECO1 gas mixture was studied in an earlier phase of the tests on eco-friendly gas mixtures performed by the RPC ECOGas@GIF++ collaboration and featured a larger content of HFO. It was soon discarded because first tests indicated a too large operating voltage and an increase, with time, of the current absorbed by the detectors, maybe associated to an augmented production of impurities in the gas volume, with respect to the STD gas mixture [21].

	R134a (%)	HFO1234ze (%)	CO2 (%)	i_C4H10 (%)	SF6 (%)	GWP	CO2e (g/l)
STD	95.2			4.5	0.3	1485	6824
ECO2		35	60	4	1	476	1522
ECO3		25	69	5	1	257	1519
Density (g/l)	4.68	5.26	1.98	2.69	6,61		
GWP	1430	7	1	3	22800		

Table 2: Percentage composition, in volume, of the gas mixtures used for these tests, their GWP with respect to CO2, and their CO2e, in grams, for one litre of mixture. For the calculations of the GWP and CO2e, the gas densities at STP (p = 1013 hPa, T = 273.15K) of the component gases, reported in the penultimate line of the Table and taken from [22], were used.

The ECO2 and ECO3 gas mixtures were proposed to reduce the greenhouse gases emissions with respect to the STD gas mixture, and in fact they feature, respectively, a GWP of around 476 and 527, namely, roughly a factor three less than the STD mixture.

Note that the GWP of the gas mixtures, listed in Table 2, are computed, as prescribed in [5], as the weighted average of the GWPs of the respective gaseous components, where the weights used for the average are their fractions in mass. This implies that the GWPs reported are meaningful only if one wants to compare the potential contribution to the greenhouse effect of equal masses of different gas mixtures.

However, as a matter of fact, the RPC detectors at the LHC are usually operated at constant fractions of gas volume exchanges. Therefore, it is also useful to compute the carbon dioxide equivalent (CO_2e) of one litre of the various gas mixtures considered, namely the amount (in grams) of CO_2 that, if injected into the atmosphere, would contribute to the greenhouse effect for the same amount of the one litre of gas mixture considered. This CO_2e is computed by calculating the amount (in grams) of the various gaseous components in one litre of the gas mixture, multiplying them for their respective GWP, and summing up. The CO_2e values computed in this way are also reported in Table 2, and indeed show that the CO_2e for one litre of ECO2 and ECO3 is around 4.5 times lower than the CO_2e of one litre of STD mixture. Moreover, ECO2 and ECO3 mixtures feature similar values of CO_2e because most of it is due to the emission of SF_6, which is quite similar in the two cases.

5. AIDAINNOVA TASK 7.2.3 TIMELINE

The AIDAinnova project officially started in March 2021 and supported the activities of the EcoGas@GIF++ Collaboration during the startup of the systematic efforts to study ageing effects on RPC operated with eco-friendly gas mixtures.

During the preparation phase of the set-up for the ageing studies, in 2021 and 2022 two test-beams were performed to define the baseline performance before the irradiation process. Results of these tests will be reported in section 9. From spring 2022 a systematic process of irradiation and monitoring of the performance was started and will be discussed in sections 11. Test beams have been repeated once or twice per year in 2023 and 2024 in order to compare the performance as a function of the integrated charge of the detectors. Comparison results will be reported in section 13.

6. BASELINE TEST-BEAM

Before starting any ageing campaign, it is necessary to assess the detector performance. This was done at the GIF++ facility in presence of a 100 GeV muon beam in 2021 and 2022. The performance of all RPCs were evaluated using the muon beam without radiation firstly, and afterwards with different gamma rates in order to simulate the irradiation conditions foreseen during the HL-LHC Phase. The different scans were done using three different gas mixtures: STD, ECO2 and ECO3.

The detector parameters analysed to assess if the chambers performed in a similar way are: efficiency, current density, and cluster size. Fig. 1 shows the efficiency and current density for the CMS and EP-DT chamber at source off for the three gas mixtures. The CMS RPC reaches higher efficiencies at lower voltage with respect to the EP-DT chamber, due to the fact that it is a double-gap chamber, and signals from the two gaps add up on the same readout strips. All efficiency curves reach a plateau efficiency above 95% and for the ECO2 mixture is the rightmost one, featuring full efficiency above 11.5 kV for 2 mm gap RPCs.

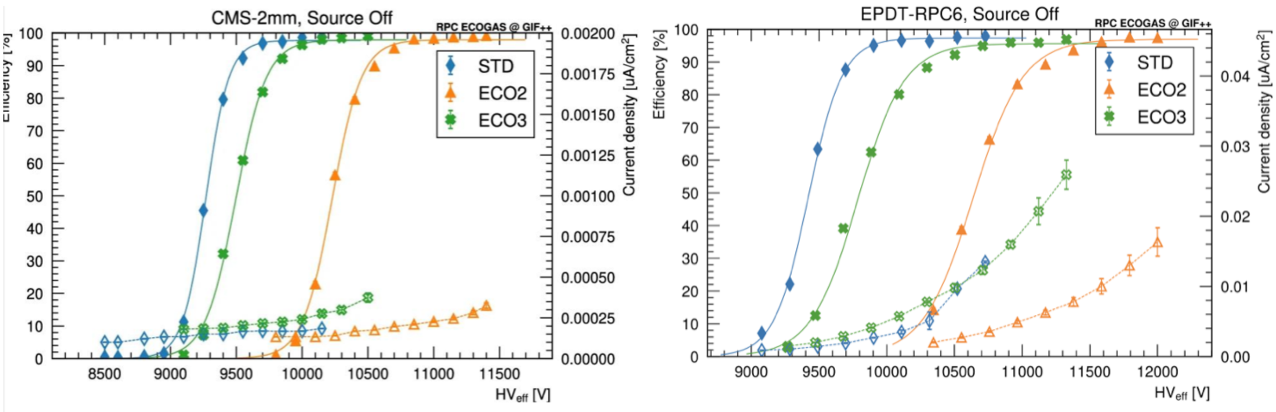

Fig. 1 Efficiency and current density, as a function of HVeff, measured for the CMS chamber (left) and EP-DT chamber (right) without irradiation, filled, in sequence, with the STD, ECO2 and ECO3 gas mixtures.

As a general trend, the plateau efficiency decreases when passing from STD, to ECO2, and to ECO3 mixtures, namely when the fraction of CO_2 in the gas mixture considered increases. In the last two cases, this effect might be related to the reduced number of primary ion-electron pairs produced by the impinging particles, as well as the increased distance among them. The charge distributions of the induced signals were measured using a digitizer for the EP-DT and ATLAS chambers. As an example, Fig. 2 shows the charge distribution for the three gas mixtures: it is visible how the increased percentage of CO_2 in the eco-friendly mixtures broadens the charge distributions and increases the fraction of signals at a larger charge.

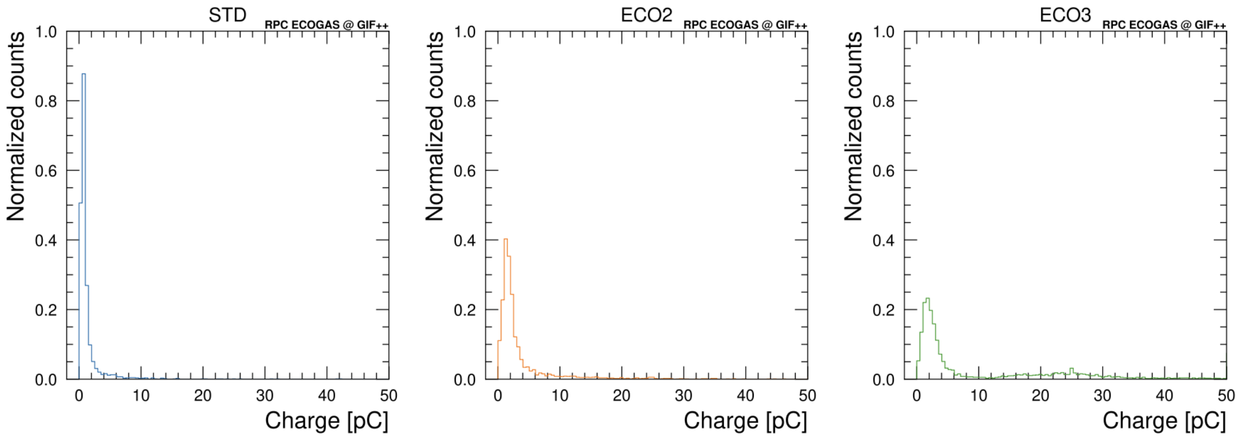

Fig. 2 Charge distributions of the signals induced on the 3 cm wide strip of the ATLAS RPC, measured at HVknee, for the STD, ECO2 and ECO3 gas mixtures, from left to right, respectively.

As a second step, detector performances were evaluated with a muon beam under irradiation. Multiple ABS factors were used reaching rates of hundreds of Hz/cm^2 but for the sake of brevity, only results obtained with few ABS will be shown (the most relevant ones). Fig. 3 shows the efficiency and current density as a function of HVeff for source off and two ABSs for the three different gas mixtures for the ALICE chamber ABS = 10 and ABS = 2.2 correspond to an absorbed dose on the chamber of 510 and 2070 µGy/h respectively. A decrease of the plateau efficiency is present by increasing the absorbed dose and it is larger when using ECO2 and ECO3 gas mixtures. Concerning current density, an increase is already visible when using ECO2 and ECO3 gas mixtures with respect to STD. This behaviour can be related to the wider charge distributions that were reported in Fig. 2. Similar behaviour has been seen also with other chambers.

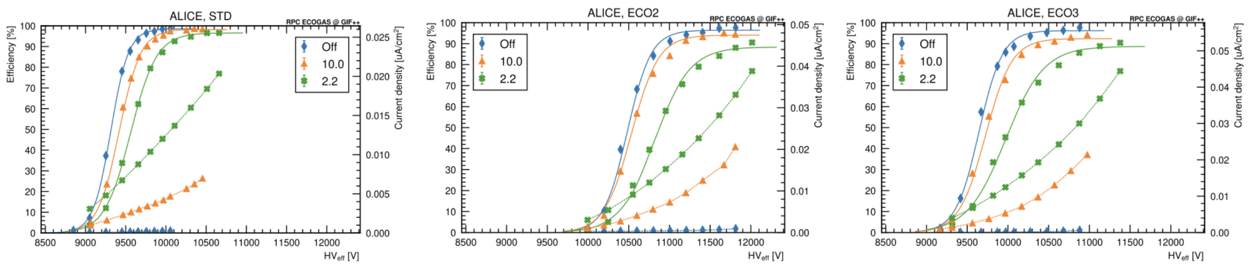

Fig. 3 Efficiency and current density as a function of HVeff, for the ALICE chamber filled with the STD (left), ECO2 (middle) and ECO3 (right) gas mixtures obtained with no irradiation, and with ABS= 10 and 2.2.

From the results obtained, we can state that RPCs operated with ECO2 and ECO3 gas mixtures exhibit comparable detection efficiency, spatial and timing resolution to those using conventional gas mixtures. However, in presence of irradiation, the usage of ECO2 and ECO3 implies larger current densities with respect to the STD mixture as well as a higher drop in efficiency by increasing the radiation dose. This is not an issue for detection and trigger capabilities for the existing RPC systems of the LHC experiments but, in general, it is known that large currents could cause ageing effects in RPCs. It is therefore fundamental to carry on an ageing campaign where the detector performance can be afterwards compared to the one shown here, obtained before any irradiation. A complete description of the performance of the RPC chambers before the ageing campaign can be found in [20].

7. AGEING GOALS AND METHODOLOGY

The selected gas mixture for the ageing test is the ECO2 gas mixture as it permits to operate the detectors at reasonable working voltage limiting at the same time the dark currents of the RPCs.

All the detectors under test are flushed with the ECO2 gas mixture, while kept at fixed HV (irradiation voltage) suitably chosen by each group to run the chamber at a working current reasonable for safe operations.

The chambers are irradiated so that, depending on the trolley position with respect to the GIF++ source, they absorb a dose typically between 1 and 5 mGy/hour and are subjected to a background rate between 400 and 1000 Hz/cm^2.

The HV and the absorbed current are continuously monitored, and data stored every 30 s thanks to a dedicated Grafana page.

Every week, usually on Wednesday, when the GIF++ source is off, an HV scan is performed to monitor the absorbed (dark and ohmic) currents without irradiation.

The typical Current vs HV trend is reported in Fig. 4 for one of the chambers under test. The typical behaviour of the chamber is that after a linear trend until 4000-5000 Volts, the current starts to increase exponentially due to the trigger of the multiplication processes inside the gas gap.

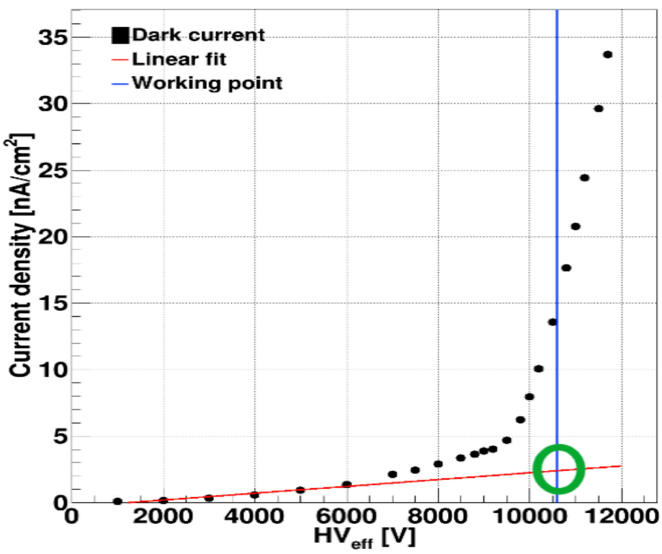

Fig. 4 Typical current density vs effective Voltage curve taken during source off operations. The first HV pints are fitted with a linear function (in red) to evaluate the ohmic contribution at working voltage (blue line).

For each chamber, the total current at a suitable working voltage and the ohmic part of the current at the same HV values were monitored, taken from the extrapolation of the linear trend up to the operation voltage. The section 7.1 will report the results of these measurements.

In general, two or three times per year a dedicated test to measure the resistivity of the chamber is performed and results will be reported in section 7.2 together with the test procedure.

All these results have been reported as a function of the time and of the integrated charge. The integrated charge along a certain elapsed time is usually the main ageing factor for the RPCs and each LHC experiment has defined a target value according to the irradiation conditions at which the detectors are subjected. For instance, for ALICE the target value is 100 mC/cm^2, while for CMS is 1 C/cm^2 (adding a safety factor 3). The integrated charge for each RPC is evaluated integrating in time all the currents driven by the detector during the time. Fig. 5 shows the integrated charge for each chamber in July 2024.

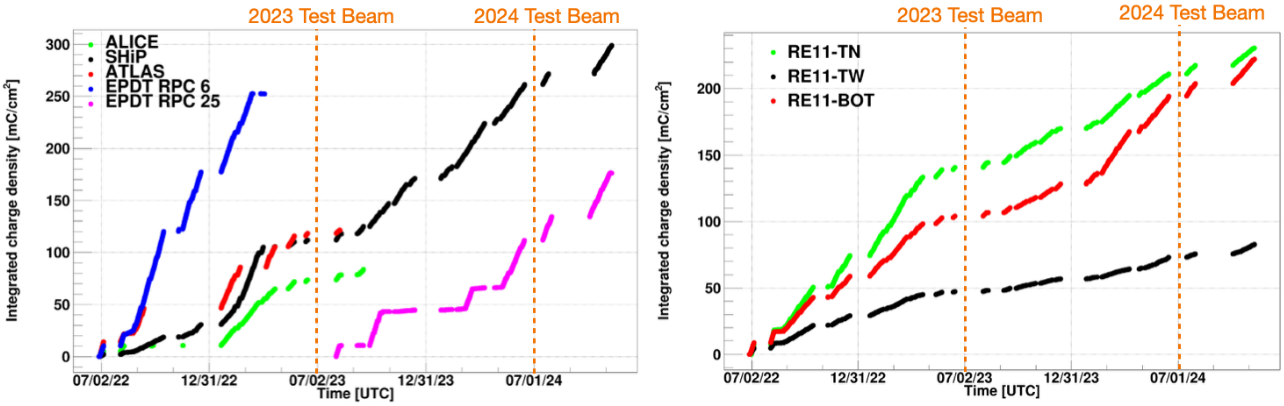

Fig. 5 Integrated charge vs time for the chambers under test since 2022. The CERN-EPDT chamber was removed at the beginning of 2023 for a mechanical problem and replaced with a new one. Dashed lines show the test beam period.

7.1. DARK CURRENT RESULTS

Fig. 6 left and right show the current density at working point as a function of the integrated charge for the LHCb/Ship (1.6 mm wide gap) and for the bottom gap (2 mm wide) of the CMS RE11 chamber. Similar behaviour is seen also in the other chambers under test. Up to about 100 mC/cm^2 of integrated charge, the current is almost stable or showing only a minor increase with time.

After 100 mC/cm2 all chambers show fluctuations and slow rise in time mainly in the total density current. The increase of the ohmic part of the current is evident in all chambers but less clear for the CMS bottom gap.

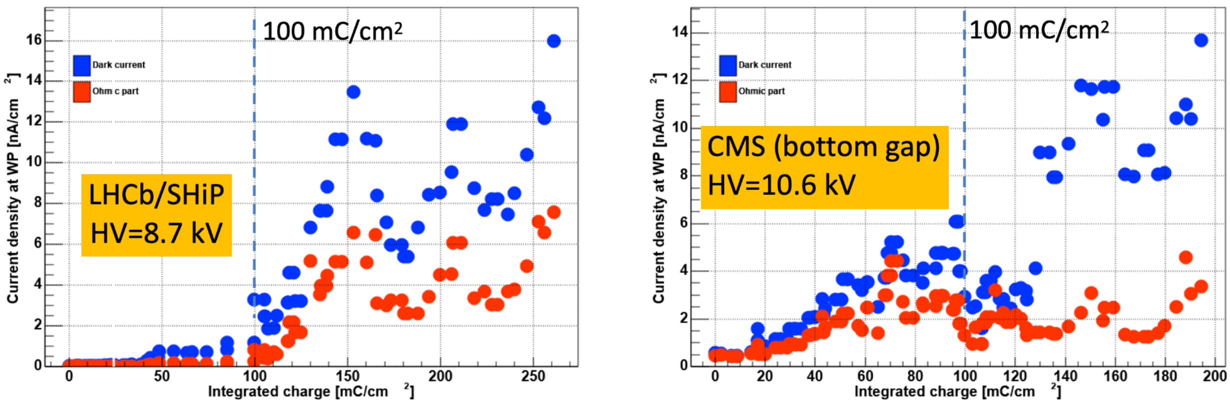

Fig. 6 Current density vs integrated charge with source off for the 1.6 mm wide gap of LHCb/SHiP chamber (left) and for one of the 2 mm wide gap of the CMS RE11 chamber (right). In Blue is plotted the total density current at working voltage, in red the ohmic part extrapolated to the working point.

The increase of the ohmic part of the current could be a hint of deterioration of the internal surface of the detectors. The Collaboration is planning to open a chamber at the end of the tests to examine the surface quality. Chemical analysis of possible deposits on the electrode could also be very useful to understand this issue.

7.2. RESISTIVITY MEASUREMENT RESULTS

A crucial parameter to monitor during ageing processes is the electrode resistivity which can deteriorate under irradiation or in presence of impurities on the electrode surface.

During the ageing campaign about two, three times per year a dedicated resistivity test is performed with Argon method. Chambers are flushed in pure Argon and the current is measured as a function of the HV. When the working voltage reaches the breakdown voltage for the Argon, the gas gap behaves as a short circuit and the current follows the Ohm law with the two bakelite electrodes as resistors. In these conditions it is possible to extract electrode resistivity by a linear fit on the Current vs HV on the higher voltage points.

Fig. 7 left and right show the measured resistivity as a function of the time for the LHCb/SHiP chamber and for the bottom gap of the CMS RE11 chamber. All the chambers show an increase, of different amounts. The origin of this increase should be investigated more and could be due to a not sufficient humidification of the gas mixture.

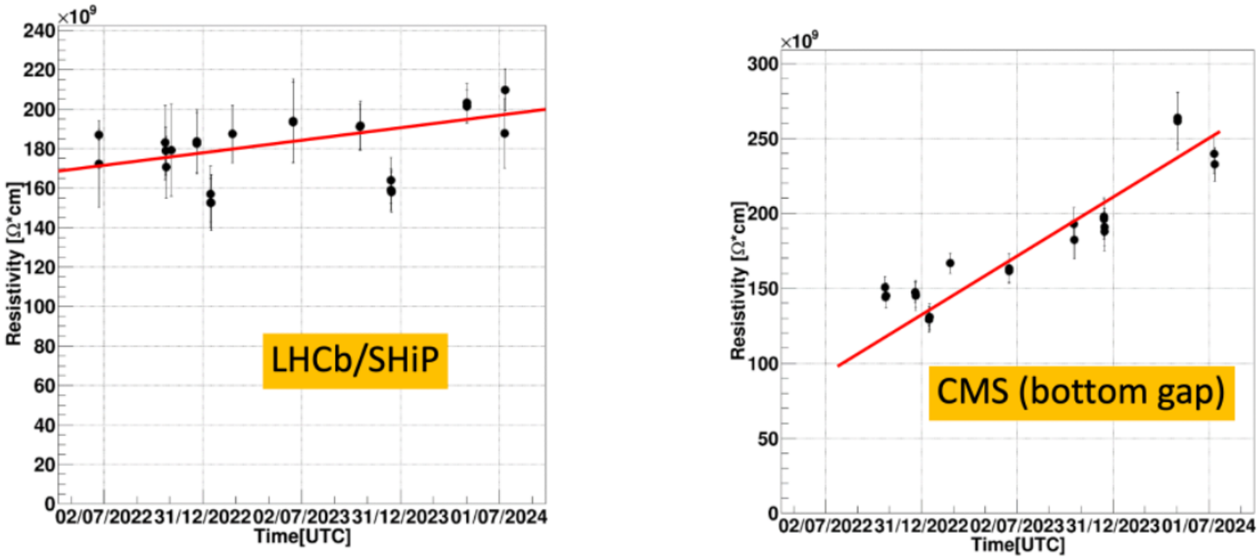

Fig. 7 Electrode resistivity vs time for the 1.6 mm wide gap of LHCb/SHiP chamber (left) and for one of the 2 mm wide gap of the CMS RE11 chamber (right).

8. TEST BEAM PERFORMANCE COMPARISON AFTER AGEING TESTS

Beyond the monitoring of the physics and ohmic currents as a function of integrated charge during the irradiation campaign, it is fundamental to check the detector performance to spot any ageing effect. This was done in dedicated test-beam campaigns performed every year since 2021. A comparison of all different detector parameters for the different years was performed for the three gas mixtures at source off and with different ABS factors. For simplicity, comparison of different test-beam and different chambers will be shown in the following.

The first parameter to check is the detector efficiency. Fig. 8 shows the efficiency curves for the three gas mixtures in 2022, 2023 and 2024 for the LHCb/SHiP chamber. Between 2022 and 2024 test-beams, the detector accumulated ~250 mC/cm^2. A shift of efficiency curves towards larger HV is observed for all gas mixtures tested, both at source off and at ABS 2.2 even if the plateau efficiency remains approximately stable after the irradiation. As the shift is present in all gas mixtures, this means that it is not directly caused by the gas itself. Nevertheless, it can be noted that the HV shift is smaller for the STD gas mixture with respect to ECO2 and ECO3.

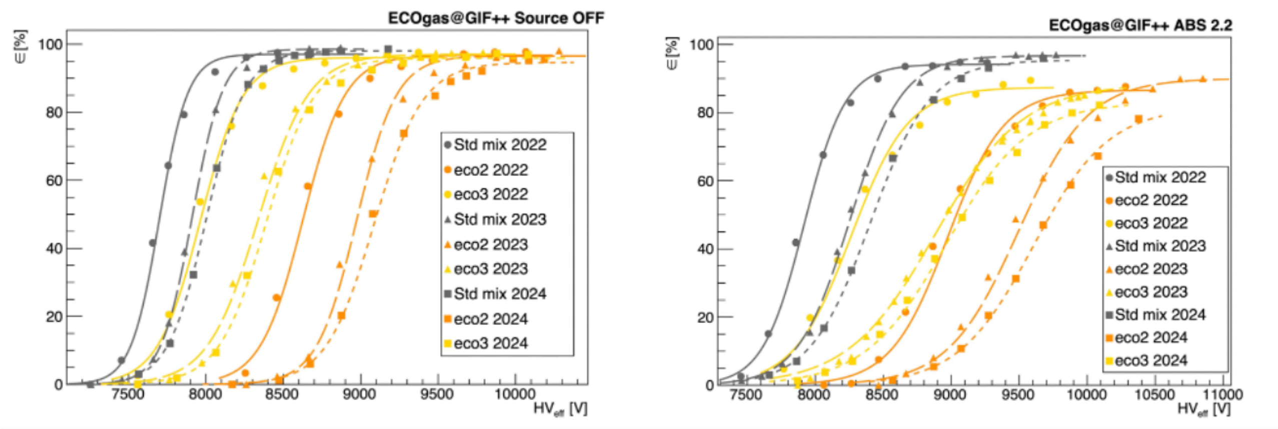

Fig. 8 Efficiency curves as a function of HVeff, for the LHCb/SHIP chamber filled with the STD, ECO2 and ECO3 gas mixtures obtained with no irradiation (left) and with ABS 2.2 (right) in the 2022 and 2023 test-beam.

Fig. 9 reports the currents at different rates for the standard and ECO2 gas mixtures in 2023 and 2024 for the EP-DT chamber after accumulating 165 mC/cm^2 (106 mC/cm^2 from June 2023 to June 2024). Also here it is visible the increase of currents for both standard and ECO2 mixtures for basically all rates tested.

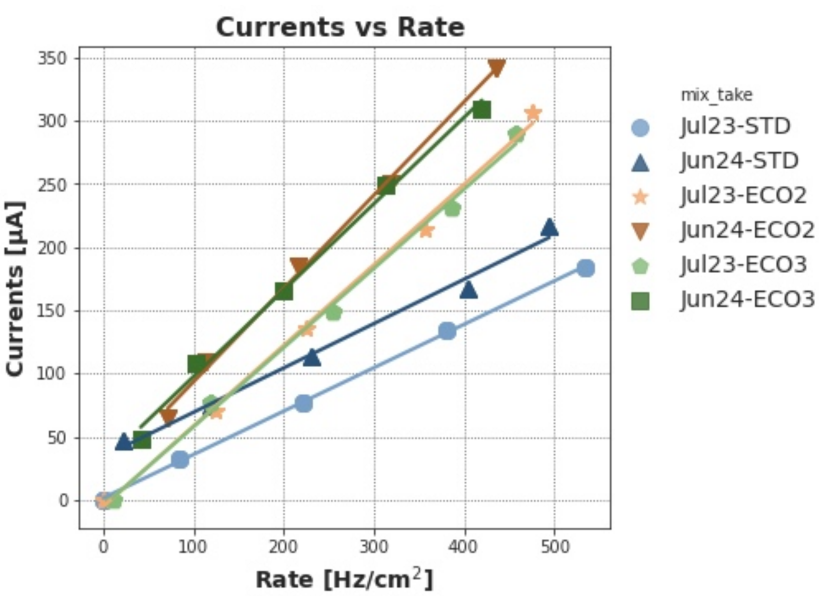

Fig. 9 Detector current as a function of gamma rate for the EP-DT chamber filled with the STD, ECO2 and ECO3 gas mixtures in the 2023 and 2024 test-beam.

The increase of the working point and current is very similar for all chambers along the different years of irradiation. As shown in the previous session, the HPL resistivity of most of the chambers increased along the years: the shift of the operating voltage and the increase of currents could be caused by this phenomenon. Studies are on-going to quantify these effects on WP and currents or to further understand if other factors could play a role. To better understand the detector status, in the future one RPC chamber will be opened to check the status of the internal surface: the increase of ohmic current might be a hint of degradation of the surface.

9. CONCLUSION

During the 4 years of the AIDAinnova project, the EcoGas@GIF++ Collaboration performed several test-beams using different eco-friendly gas mixtures and carried out a long-term ageing campaign on RPC irradiated at GIF++ and operated with an eco-friendly gas mixture. Several useful and interesting results have been obtained and have been described in this report.

The tests with the so-called "ECO2" gas mixture have shown that high efficiencies are preserved also after a few hundreds mC/cm^2 of integrated charge on the chambers. The main effect of the ageing of the detector working with ECO2 mixture is the increase of dark current and a slight increase of resistivity of the HPL electrodes that could be due to some deterioration of the inner surface of the electrodes. The effect of these increases partially explains the shift of the working voltage after several mC of integrated charge, but in any case, has no effect on the maximum efficiency.

Some of the effects found will require additional investigations but in general the gas mixtures based on HFO and CO_2 would permit the RPCs to operate with reasonable performance for the LHC needs. It is up to the single experiment to evaluate if the higher currents drawn by the detectors and the slightly higher working voltage needed, would be affordable in the experiment.

The AIDAinnova Project has supported in a crucial way the activities of the EcoGas@GIF++ Collaboration. A hardware setup is in operation with a new gas mixer and humidifier, a group of motivated people coming from different collaboration and experimental groups is efficiently working and the plan would be to continue the activities to integrate more charge under irradiation and to try to clarify the open issues. The idea is also to open the facility to different groups to test with eco-friendly mixtures different layouts of RPCs.

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ANNEX: GLOSSARY

Acronym	Definition
xxx	Definition of xxx