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Eco-friendly gas mixtures for future RPC detectors

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Since a few years a joint collaboration between ALICE, ATLAS, CMS, LHCb/SHiP and CERN EP-DT groups is in place with the goal to study the performance of RPCs operated with eco-friendly gas mixtures under different irradiation conditions at GIF++.

The performance of several chambers with different layout and electronics has been studied during dedicated beam tests, with and without gamma irradiation at GIF++. The RPCs have been operated with different gas mixtures based on CO_2 and HFO1234ze gases. Results of these tests together with the future plans for aging studies of the chambers will be presented.

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1. Search of an environment-friendly gas mixture for Resistive Plate Chambers

The Resistive Plate Chambers [1] are gaseous detectors composed of two parallel planar resistive electrodes generating a uniform electric field inside the gas gap which is filled with a proper gas mixture. In High Energy Physics RPCs are widely used for triggering thanks to their excellent time resolution (<1 ns) and fast response. The low cost per unit area make them suitable to be used in large area experiments, like those operating at the CERN Large Hadron Collider (LHC). At LHC they operate in avalanche mode thanks to the standard gas mixture composed of $C_2H_2F_4$/i-C_4H_{10}/SF_6, which guarantees low working current, good rate capability and slow detector aging for long term operation. The F-gases, like $C_2H_2F_4$(TFE) and SF_6, are now considered to be non-eco-friendly due to their high Global Warming Potential (GWP), which represents the measurement of the greenhouse impact of a gas normalized to the CO_2 (GWP =1). The impact of the standard gas mixture is dominated by the GWP of $C_2H_2F_4$ around ~1430. CERN is pursuing a campaign toward the reduction of its greenhouse gas emission with the aim of substituting the TFE in RPC detectors, thus the search of an environment-friendly gas mixture is currently one of the main topics within the RPC community. In this framework several laboratories are performing measurements in order to find an alternative gas mixture, which can maintain the performance of the standard one but with low GWP. The most promising substitute of $C_2H_2F_4$, is a proper mixture of CO_2/$C_3H_2F_4$ (HFO1234ze), where the HFO is used as quencher, while the CO_2 is used to decrease the operating voltage.

2. The RPC ECOGAS@Gif++ collaboration

During the past few years the RPC ECOGAS@Gif++ collaboration was born, where people from different institutes share person-power, instrumentation, ideas in order to find an alternative gas mixture for RPC. The collaboration is composed of people from ATLAS, CMS, LHCb/SHiP, ALICE and CERN EP-DT. Each experiment contributes with detectors with different sizes, electrodes, gas gap widths and electronics.

Performance and aging tests are continuously performed on several gas mixtures at the CERN Gamma Irradiation Facility (GIF++) [2] under strong photon irradiation and in presence of a muon beam (100 GeV/c). Currently, the collaboration is testing the performance of RPCs operating with the following three gas mixtures: ECO1: CO_2/$C_3H_2F_4$/i-C_4H_{10}/SF_6=(50/45/4/1)%, ECO2: CO_2/$C_3H_2F_4$/i-C_4H_{10}/SF_6=(60/35/4/1)% and ECO3: CO_2/$C_3H_2F_4$/i-C_4H_{10}/SF_6=(69/25/5/1)%.

The first mixture under study was ECO1, which showed a significant increase of the detector currents after few months of operation under irradiation [3]. Therefore, the collaboration adopted a new strategy testing gas mixtures with lower HFO content [4]. In this way the operating voltage moves towards lower values and the concentration of fluorine molecules which affects the aging, is reduced.

3. Results

In this section the results of the tests performed at the GIF++ with a muon beam and in presence of a strong photon background are summarized.
Figures 1(a), (b) and (c) show the efficiency and the current density as a function of the high voltage for the SHiP detector (gas gap and electrodes 1.6 mm-thick) operating with the (a) standard gas, (b) ECO3 and (c) ECO2 gas mixtures. The amplified signals are read with 32+32 strips using a Time to Digital Converter (TDC) and are studied in different irradiation environments, corresponding to the situation with no photon irradiation (OFF), ~ 250 Hz/cm^2(ABS 2.2) and ~ 100 Hz/cm^2 (ABS 10) of converted photons.

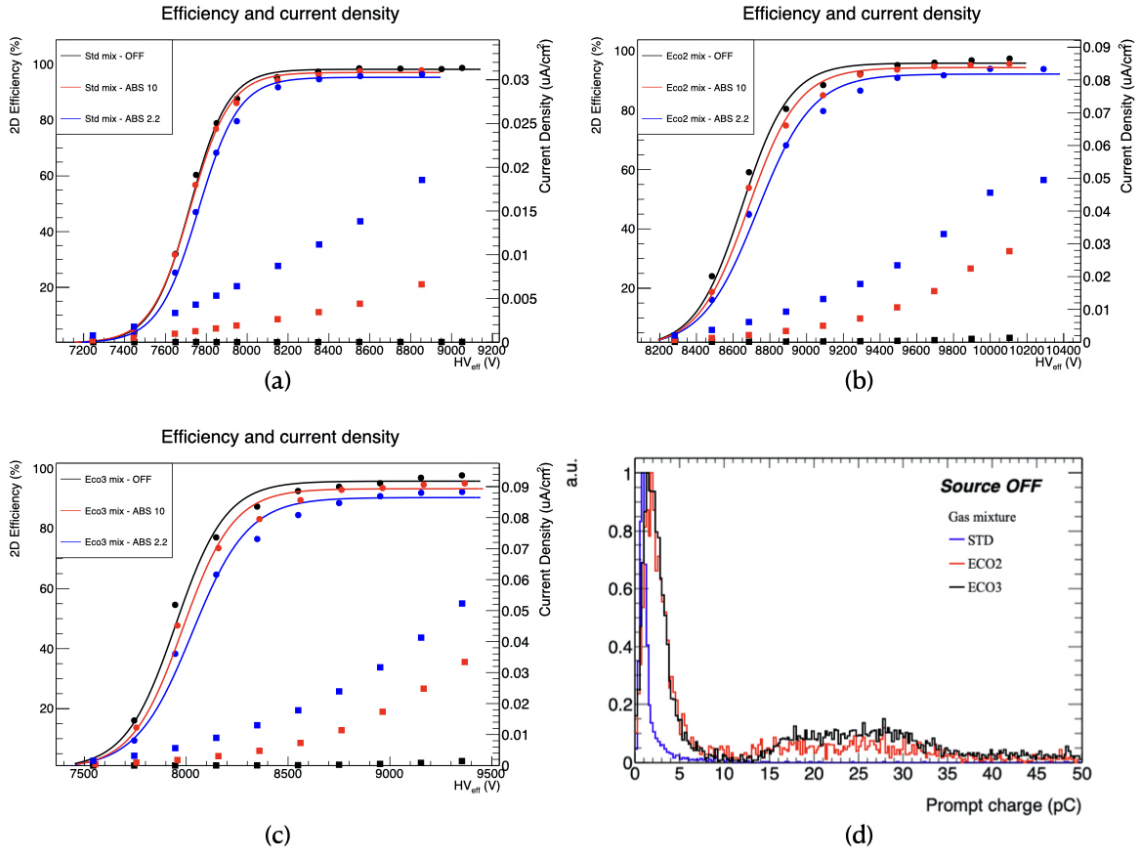

Figure 1: Efficiency and current density as a function of the high voltage for (a) the standard, (b) ECO3 and (c) ECO2 gas mixtures in case of no photon irradiation (OFF), ~ 250 Hz/cm^2(ABS 2.2) and ~ 100 Hz/cm^2 (ABS 10) of converted photons.(d) Prompt charge distribution at the working point with standard, ECO2 and ECO3 gases

At source off the detection efficiency is above 95% for all the gas mixtures and the corresponding current densities are comparable and well below 10 μA. At ~ 250 Hz/cm^2 the efficiency drop is around 3%, 4% and 6% respectively for the standard, ECO2 and ECO3 gas mixtures and the eco-gases show a higher current density with respect to the standard gas, being $I_{STD} \sim 70\mu A$ at the working point, $I_{ECO2} \sim 2I_{STD}$ and $I_{ECO3} \sim 3I_{STD}$.

The higher currents of the eco gas mixtures are due to the premature occurrence of high charge events, transition events and/or streamers, as shown in Figure 1(d) which represents the electronic charge distributions at full efficiency measured with the ATLAS detector (2 mm gas gap and 1.8 mm electrode thickness, with the not-amplified signal acquired with a Digitizer).
The results show that both eco-gas mixtures guarantee good performance without being irradiated as well as under photon irradiation. The production of Fluorine molecules, strictly correlated to the detector ageing, has to be evaluated. Preliminary studies have been performed using the Ion Selective Electrode Analysis (ISE) by letting the return line of the gas bubble into a TISAB II solution and using the electrodes to read the F^- concentration. The F^- concentration at the working point as a function of the current for several irradiations showed a linear trend, with an absolute value higher in the eco-gases with respect to the standard one. The measurement are on going to establish their impact on the detector longevity.

4. Conclusions

The RPC ECOGAS@Gif++ collaboration is actively engaging in the research of an eco-friendly gas mixture for Resistive Plate Chamber detectors, performing systematic studies of performance, ageing and fluorine production with several gas mixtures at the CERN Gamma Irradiation Facility++ using detectors with different sizes, gas gaps, electrode thickness and materials. Three test beams have been performed during July, September and October 2021 and the results are very encouraging. The ECO2 gas mixture, $CO_2/C_3H_2F_4$/i-C_4H_{10}/SF_6=(60/35/4/1)%, has been chosen for the ageing campaign to ensure long term operation in the HL-LHC environment.

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