Study of environment-friendly gas mixtures for the Resistive Plate Chambers

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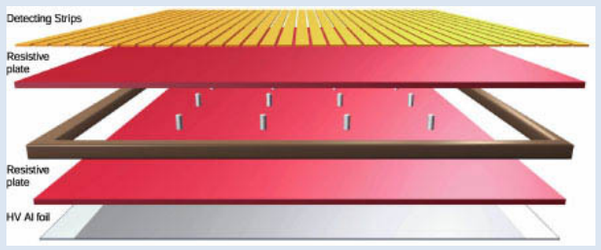
The Resistive Plate Chamber

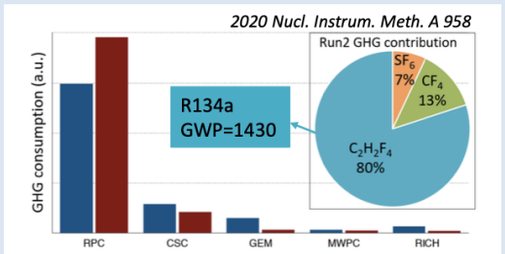
The Resistive Plate Chambers are gaseous detectors composed of two parallel planar resistive electrodes generating a uniform electric field inside the gas gap which is filled with a proper gas mixture.



In High Energy Physics the RPC are widely used for triggering thanks to their excellent time resolution (<1 ns) and velocity. The low cost per unit area make them suitable to be used in large area experiments, like those operating at the Large Hadron Collider. At LHC they operate in avalanche mode by means of the standard gas mixture

The Standard gas mixture

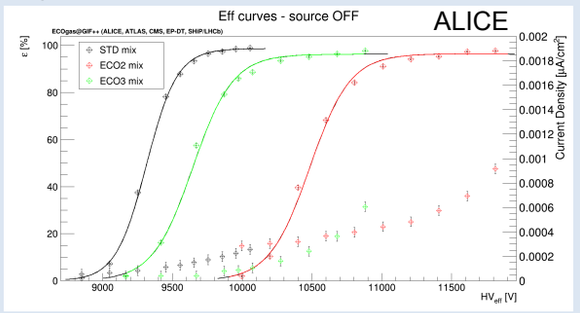
The standard gas mixture is composed of $C_2H_2F_4$/i-C_4H_{10}/SF_6 . It guarantees a large pure avalanche working mode and low working current, ensuring good rate capability and slow detector aging for long term operation. Moreover, its high density ensures high detection efficiency even in the millimeter range size



The F-gases, like $C_2H_2F_4$ and SF_6, are now considered to be non-eco-friendly for 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 standard gas mixture has a GWP ~ 1430.
CERN is doing a campaign toward the reduction of its greenhouse gas emission with the aim of substitute the TFE in RPC detectors

Environment-friendly gas mixtures

The search of an environment-friendly gas mixture is one of the main topic within the RPC community. Several laboratories are performing measurement in order to find an alternative gas mixture, which can maintain the performance of the standard one but with low GWP.



The main standard gas mixture component, the $C_2H_2F_4$, is now substituted by a proper mixture of CO_2/$C_3H_2F_4$ (HFO1234ze). The HFO is used as quencher, while the CO_2 is used to decrease the operating voltage in order to work with lower current.

- 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)%
- ECO3 =CO_2/$C_3H_2F_4$/i-C_4H_{10}/SF_6=(69/25/5/1)%

→ GWP ~ 230

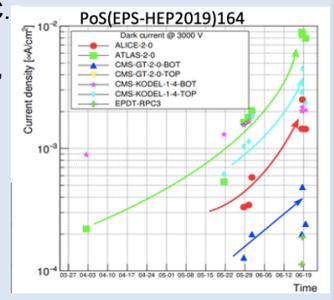
The RPC ECOGAS@Gif++ collaboration

In these few past years 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 gas group.

Each experiment contributes with detectors with different sizes, electrodes, gas gap size and electronics

Performance and aging test are continuously performed on several gas mixtures at the Gamma Irradiation Facility (GIF++) at CERN.



The first mixture under study was ECO1, which showed a significant increase of the detector currents after few months of operation under irradiation.

New strategy : test of gas mixtures with low-HFO content. In this way the operating voltage moves towards lower values, thus current, and the concentration of fluorine molecules which affects the aging, is reduced.

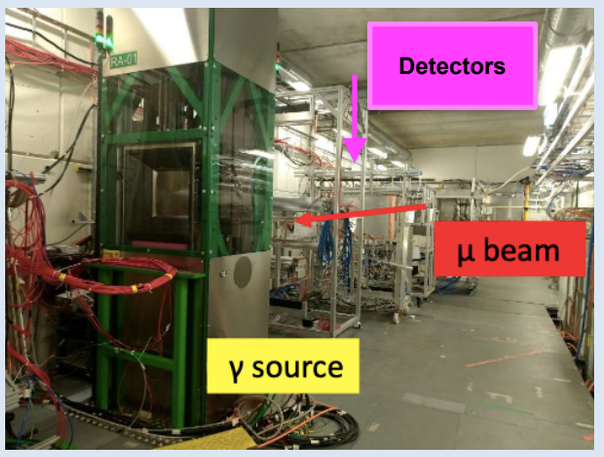
Test Beam @GIF++ (CERN)

The detectors performance have been tested under strong photon irradiation and in presence of a muon beam (100 GeV/c)

Mixtures under study : standard, ECO2, ECO3

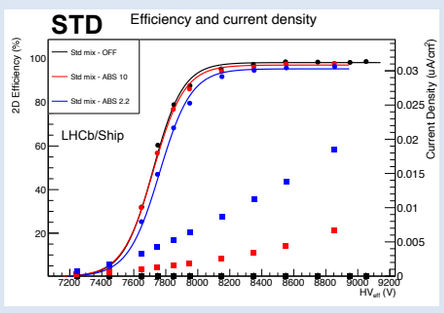
Detectors tested:

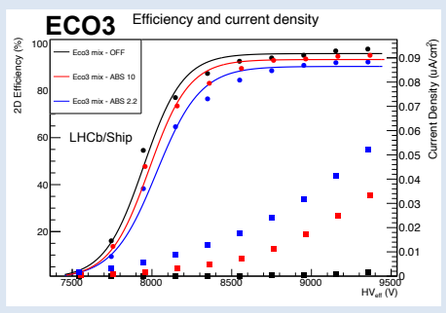
Experiment	Detector dimension	Gas gap size and electrode thickness	Readout	Distance from the source
ATLAS	(55 x 10) cm^2	2 mm / 1.8 mm	single strip , digitizer. The signal is not amplified	3 m
CMS	Trapezoidal, height 10 cm, bases 51 cm and 33 cm	2 mm / 2 mm	128 strips, 1 cm pitch, TDC. The signal is amplified	3 m
ALICE	(50 x 50) cm^2	2 mm / 2 mm	16+16 strips, 3 cm pitch, TDC. The signal is amplified	6 m
LHCb/Ship	(70 x 100) cm^2	1.6 mm / 1.6 mm	32+32 strips, 1 cm pitch, TDC. The signal is amplified	6 m
EPDT	(70 x 100) cm^2	2 mm / 2 mm	7 strips, 2.1 cm pitch, digitizer. The signal is not amplified	3 m

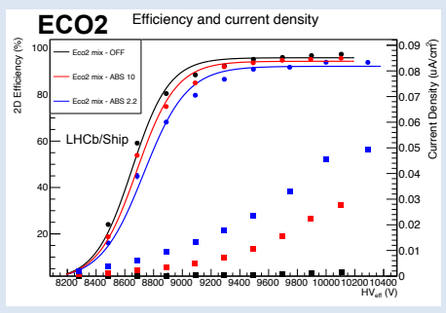


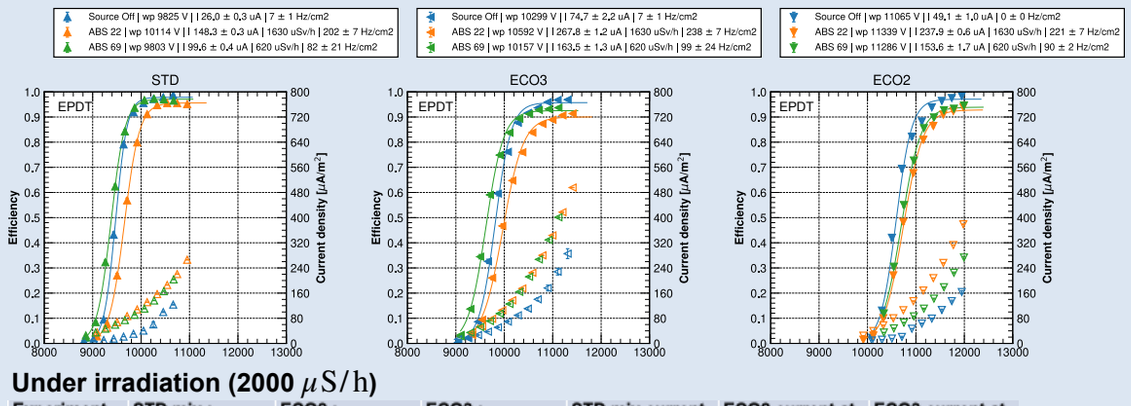
Test beam results on STD mixture, ECO2 and ECO3

Efficiency and current density









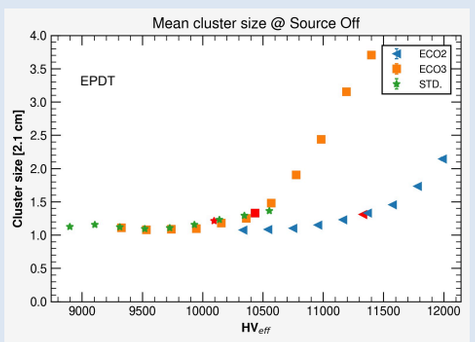
Source OFF

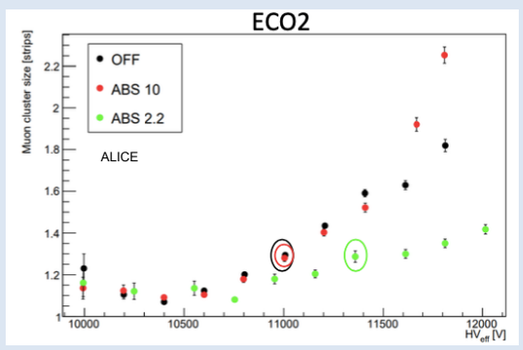
Experiment	Efficiency plateau	ECO2 :Operating voltage shift wrt STD	ECO3 :Operating voltage shift wrt STD	STD mix current at WP	ECO2 current at WP	ECO3 current at WP
LHCb/Ship	Comparable for the 3 mixtures and >95%	1000 V	300 V	<< 10 uA/m2	~ I_{std}	~ I_{std}
EPDT	Comparable for the 3 mixtures and >95%	1200 V	450 V	25 uA/m2	$2I_{std}$	$3I_{std}$

Under irradiation (2000 $\mu S/h$)

Experiment	STD mix : efficiency plateau drop	ECO2 : efficiency plateau drop	ECO3 : efficiency plateau drop	STD mix current at WP	ECO2 current at WP	ECO3 current at WP
LHCb/Ship	3%	4%	6%	70 uA/m2	2 I_{std}	3 I_{std}
EPDT	2%	4%	6%	140 uA/m2	1.5 I_{std}	1.8 I_{std}

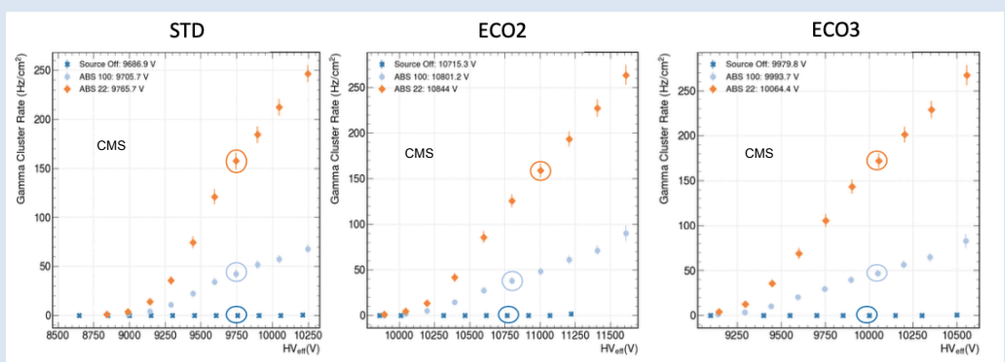
Cluster size





The average cluster size is comparable at the working point for the three gas mixtures, both with source off and under irradiation

Gamma cluster rate

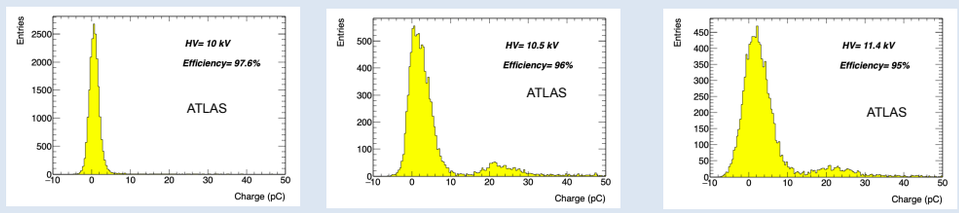


The measured gamma rates are comparable at the working point at the same irradiation condition:

ABS100 ~ 40 Hz/cm^2

ABS 22 ~ 160 Hz/cm^2

Charge distribution at source OFF

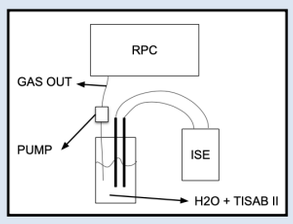


The electronic charge distribution of the standard gas mixture is well-peaked and within 10 pC. The eco gas mixtures show a second peak in the charge range between 15 pC and 30 pC, due to the contamination of transition events. A small tail is present at charge above 30 pC due to streamer contamination.
The tail toward negative values is due to the contribution of a negative baseline in the waveform acquisition.

Fluorine measurement : preliminary

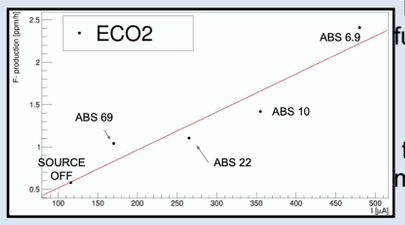
The production of the fluorine molecules is one of the parameter involved in the aging estimation

Setup



The returned gas bubbled in a 330 ml solution of distill water and TISAB II (50/50) for ~ 2 hours with the HV switched on at the detector working point
The measurements have been performed at different irradiation condition

Results



Several preliminary tests have been performed

The fluorine production as a function of the current shows a linear trend

Some issues during data taking due to stability of the mass flow meter and source.

Additional measurement needed and in program

Conclusions

The RPC ECOGAS@Gif++ collaboration is actively engaging in the research of environment-friendly gas mixture for Resistive Plate Chambers detector. Three test beams have been performed during July, September and October 2022 and the results are very encouraging. The eco-gas under study are composed of $C_3H_2F_4$/CO_2/i-C_4H_{10}/SF_6 (GWP ~ 230) in the proportion (60/35/4/1)% (**ECO2**) and (69/25/5/1)% (**ECO3**) and the results have been compared with those obtained with the standard gas mixture. The aging campaign will continue after July with ECO2.