Reduction of Greenhouse Gases impact in the EEE Project

C Ripoli[16,17], M Abbrescia[1,2], C Avanzini[3], L Baldini[3,6], R Baldini Ferroli[7], G Batignani[3,6], M Battaglieri[8,9], S Boi[10,11], E Bossini[3,6], F Carnesecchi[5,13], C Cicalò[11], L Cifarelli[5,13], F Coccetti[4], E Coccia[14], A Corvaglia[15], D De Gruttola[16,17], S De Pasquale[16,17], F Fabbri[7], A Fulci[18], L Galante[19,20], M Garbini[4,5], G Gemme[8], I Gnesi[4,21], S Grazzi[8,18], D Hatzifotiadou[5,12], P La Rocca[22,23], Z Liu[24], G Mandaglio[18,23], G Maron[25], M N Mazziotta[2], A Mulliri[10,11], R Nania[5], F Noferini[5], F Nozzoli[26], F Palmonari[5,13], M Panareo[15,27], M P Panetta[4,15], R Paoletti[3,28], C Pellegrino[25], O Pinazza[5], C Pinto[22,23], S Pisano[4,7], F Riggi[22,23], G Righini[29], M Rizzi[2], G Sartorelli[5,13], E Scapparone[5], M Schioppa[21,30], A Scribano[28], M Selvi[5], G Serri[10,11], S Squarcia[8,31], M Taiuti[8,31], G Terreni[3], A Trifirò[18,23], M Trimarchi[18,23], A S Triolo[18], C Vistoli[25], L Votano[32], M Ungaro[9], M C S Williams[5,24], A Zichichi[5,12,13], R Zuyeuski[24]

[1] Dipartimento Interateneo di Fisica, Università di Bari, Bari, Italy
[2] INFN Sezione di Bari, Bari, Italy
[3] INFN Sezione di Pisa, Pisa, Italy
[4] Museo Storico della Fisica e Centro Studi e Ricerche “Enrico Fermi”, Rome, Italy
[5] INFN Sezione di Bologna, Bologna, Italy
[6] Dipartimento di Fisica, Università di Pisa, Pisa, Italy
[7] INFN Laboratori Nazionali di Frascati, Frascati (Rome), Italy
[8] INFN Sezione di Genova, Genoa, Italy
[9] Thomas Jefferson National Accelerator Facility, Newport News, VA, USA
[10] Dipartimento di Fisica, Università di Cagliari, Cagliari, Italy
[11] INFN Sezione di Cagliari, Cagliari, Italy
[12] CERN, Geneva, Switzerland
[13] Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy
[14] Gran Sasso Science Institute, L’Aquila, Italy
[15] INFN Sezione di Lecce, Lecce, Italy
[16] Dipartimento di Fisica, Università di Salerno, Salerno, Italy
[17] INFN Gruppo Collegato di Salerno, Salerno, Italy
[18] Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università di Messina, Messina, Italy
[19] Dipartimento di Scienze Applicate e Tecnologia, Politecnico di Torino, Turin, Italy
[20] INFN Sezione di Torino, Turin, Italy
[21] INFN Gruppo Collegato di Cosenza, Cosenza, Italy
[22] Dipartimento di Fisica e Astronomia, Università di Catania, Catania, Italy
[23] INFN Sezione di Catania, Catania, Italy
[24] ICSC World laboratory, Geneva, Switzerland
[25] INFN-CNAF, Bologna, Italy
[26] INFN Trento Institute for Fundamental Physics and Applications, Trento, Italy
[27] Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy

[28] Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, Università di Siena, Siena, Italy
[29] CNR Istituto di Fisica Applicata "Nello Carrara", Sesto Fiorentino (Florence), Italy
[30] Dipartimento di Fisica, Università della Calabria, Rende (Cosenza), Italy
[31] Dipartimento di Fisica, Università di Genova, Genoa, Italy
[32] INFN Laboratori Nazionali del Gran Sasso, Assergi (L'Aquila), Italy

cripoli@unisa.it corresponding author

Abstract The whole Extreme Energy Events (EEE) array is composed of 61 telescopes installed in Italian High Schools, built and operated by students and teachers, constantly supervised by researchers. The muon telescope of the EEE Project is made by 3 Multigap Resistive Plate Chambers (MRPC). The unconventional working sites are a unique test field for checking the robustness and the low-ageing features of the MRPC technology for particle tracking and timing purposes. The MRPCs are fluxed with a standard mixture (98% $C_2H_2F_4$ - 2% SF_6) of greenhouse gases (GHG) phasing out of production. The EEE Collaboration is currently studying alternative mixtures environmentally and economically sustainable. The EEE Collaboration actions to reduce the Global Warming Potential (GWP) in the MRPC array of the EEE experiment are progressing.

1. Introduction

European Union (EU) regulations set an upper limit for the GWP allowed in gas-operated devices (GWP < 150) [1]. Important efforts need to be made in order to reduce the volumes of GHG currently released into the atmosphere, but together with quantity, the GWP plays a crucial role as well. Despite the EU limit is referred to industrial and commercial uses and not to research purpose, reduced demand for such gases will have an impact on their price, pushing them out of production. For the EEE experiment, this item needs to be considered from two different perspectives simultaneously: on one hand the gas volumes need to be reduced through flow volumes optimization and leakage reductions, on the other hand new mixtures need to be investigated in order to achieve lower GWPs without affecting the system performance.

2. Steps to reduce GWP

The GWP is an index used to quantify the impact of GHG: each gas has a specific GWP, normalized to CO_2 that by definition has a GWP equal to 1. The EEE detectors are composed of 3 large area (1.58 × 0.82 m^2) MRPCs and each chamber has six 300 μm gas gaps. As a part of the EEE upgrade after 2017, the gap width has been reduced from 300 μm to 250 μm in order to reach a full efficiency at a lower HV value (namely around 16 kV). The chambers, operating in avalanche mode at atmospheric pressure, are filled with a mixture 98% tetrafluoroethane ($C_2H_2F_4$) and 2% sulfur hexafluoride (SF_6). The GWP of $C_2H_2F_4$ and SF_6 are respectively 1430 and 23900, consequently the GWP of the EEE mixture is about 1880. The EEE experiment has planned three steps to reduce gas emission and mixture GWP.

2.1. Gas Recirculation System

Gas recirculation system is part of the strategy adopted by the EEE Collaboration to reduce gas emission. A prototype has been developed on one of the EEE telescope at CERN. This system, compact, cheap, easy-to-use, allows the output gases flow to be recirculated back into the telescope, thus reduce emissions by reusing a fraction (~ 60%) of the mixture [2]. The obtained results are promising and the system is going to be optimized and validated.

2.2. *Gas flow reduction*

Another efficient way to strongly reduce the gas emissions, preserving the telescopes performance, is the adjustment of the gas flow inside the telescopes. The gas mixture used in EEE experiment is injected with a flow of about 2-3 l/h but the MRPCs can operate at a lower flow, 1l/h [3].
The flow reduction campaign started in September 2019 and it paused in March 2020 due to Covid-19 also because the telescopes are mainly installed in Italian High Schools. A percentage of 65% of EEE detectors can work at the moment with a flow about 1 l/h.

2.2.1. Performance at low flow The excellent performance in terms of time and space resolution (σ_t=238ps, σ_x=1.47cm, σ_y=0.92cm), efficiency (93%) and stability are not affected by the flow reduction. The stability of the rate of muon tracks in four EEE telescopes monitored before and after the flow reduction is shown in Figure 1.

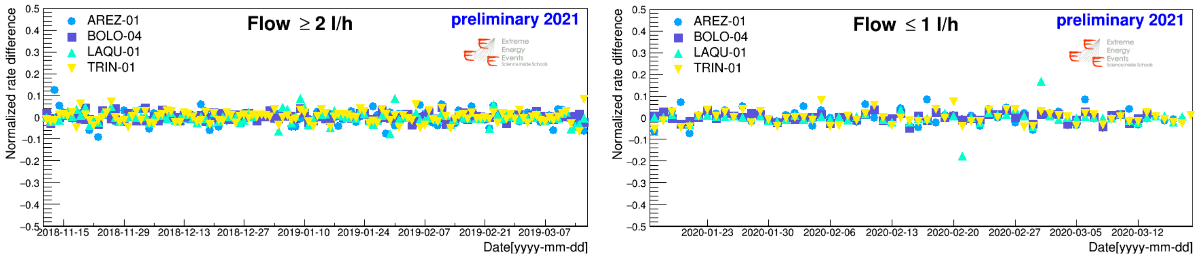


Figure 1. Track rate before (left) and after (right) the flow reduction. The *y* axis shows the rate variation day by day.

2.3. *Eco - friendly gas mixtures*

The choice of a new gas mixture with a GWP within the EU restrictions is a crucial point. Tetrafluoropropene $C_3H_2F_4$ (commercial name is R1234ze) characterized by a GWP equal to 6, is a very promising candidate to substitute the dominant component of the EEE nominal mixture thanks to its lower GWP value compared with $C_2H_2F_4$ (commercial name is R134a) that shows a GWP equal to 1430. Different percentages of $C_3H_2F_4$, CO_2 and SF_6 have been explored (Table 1).

Table 1. Tested gas mixtures

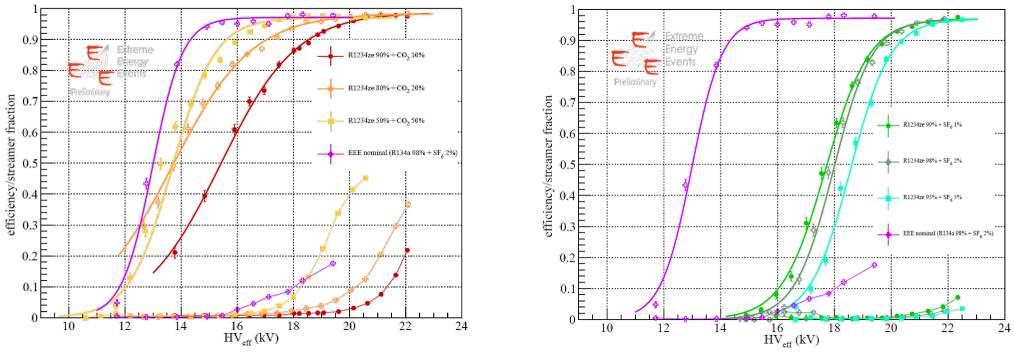
Percentage of gas mixtures
Pure $C_3H_2F_4$ (100 %)
$C_3H_2F_4$ (90 - 80 - 50) % + CO_2 (10 - 20 - 50) %
$C_3H_2F_4$ (95 - 98 - 99) % + SF_6 (5 - 2 - 1) %
Pure CO_2 (100 %)
CO_2 (98 %) + SF_6 (2 %)

Tests with the new mixtures have been performed at CERN on the telescope CERN-01 built with 250 µm gas gaps [4]. The streamer fraction has been evaluated as the ratio between the number of hits with a cluster size ≥ 5 and the total number of hits. Efficiency, current and cluster size have been analysed as a function of applied HV. The last two mixtures in the table have been discarded due to low efficiency and high noise; the results obtained with the other mixtures are briefly discussed below.

2.3.1. Pure $C_3H_2F_4$ In the case of pure $C_3H_2F_4$, the streamer component is kept below 5% in the entire interval. A stable efficiency plateau is reached when the HV approaches 21kV. Nevertheless, this condition is too close to the upper limit of operability regime of the EEE MRPCs.

2.3.2. $C_3H_2F_4$ and CO_2 For this mixture the efficiency plateau decreases as the CO_2 fraction increases. For the mixture $C_3H_2F_4$ (50 %) + CO_2 (50%) it is possible to determine a potential working point at 17 - 18 kV but this mixture shows a too high streamer percentage (Figure 2a).

2.3.3. $C_3H_2F_4$ and SF_6 In order to reduce the avalanche size, SF_6 has been added to $C_3H_2F_4$ as quencher (Figure 2b). Due to its high GWP (23900), SF_6 percentage should not exceed 0.5% (SF_6 is a very effective quencher also in a small percentage). Indeed, such a mixture would have a GWP of 125 respecting the EU limits. In addition, a mixture with SF_6 at 0.5% should decrease the working point wrt to the curves corresponding to higher SF_6 percentages.



(a) (b)

Figure 2. Efficiencies and streamer percentage for different mixtures of $C_3H_2F_4$ with CO_2 (a) and SF_6 (b).

3. Conclusions

On the basis of the results hereby presented additional and promising tests are ongoing. As a first step new tests are in progress on both MRPC types (300/250µm gaps) by investigating different percentages of $C_3H_2F_4$+CO_2 and $C_3H_2F_4$+He in order to assess the best compromise in terms of efficiency and sustainability. On this purpose a few stations are being equipped with all proposed eco-friendly mixtures for tests in full operational mode on a longer time scale. In addition, flow reduction is well advanced: the final goal to run 100% of the array at 1 l/h will be achieved soon. Finally, different methods to optimize the recirculation system are currently under investigation.

References

[1] Regulation (EU) No 517/2014 of the European Parliament and of the Council on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006.
[2] M.P. Panetta et al. (EEE Collaboration) Strategies to reduce the enviromental impact in the MRPC array of the EEE experiment - JINST 15 (2020) C11011. doi:10.1088/1748-0221/15/11/C11011.
[3] M.Abbrescia et al. (EEE Collaboration), First results from the upgrade of the Extreme Energy Events experiment, JINST. 14 (2019) C08005, doi:10.1088/1748-0221/14/08/C08005.
[4] S. Pisano et. al. (EEE Collaboration), New eco-gas mixtures for the Extreme Energy Events MRPCs: results and plans, JINST. 14 (2019) C08008, doi:10.1088/1748-0221/14/08/C08008