Studies on environment-friendly gas mixtures for the Resistive Plate Chambers of the ALICE Muon Identifier

Livia Terlizzi*, on behalf of the ALICE collaboration and ECORPC collaboration

*University and INFN Torino

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Outline

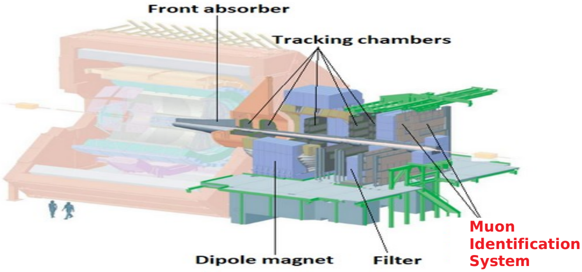
- ALICE Muon Identification System (MID)
- ALICE MID Resistive Plate Chambers
- Search of environment-friendly gas mixture

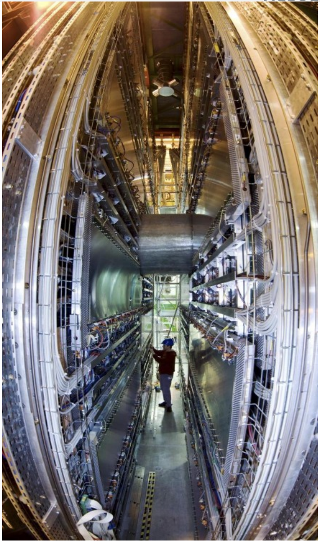
  → from Tetrafluoroethane to Tetrafluoropropene
  → Carbone dioxide and Isobutane percentage variation
  → Sulfur hexafluoride percentage variation

- R&D at Gamma Irradiation Facility (GIF) at CERN

The ALICE Muon Identification System

- It consist of 72 Resistive Plate Chambers arranged in 2 stations of 2 planes each
- Each planes is ~ 5.5 x 6.5 m^2, with ~ 1.2 x 1.2 m^2 central hole (beam pipe and shielding)
- Each RPC is ~270 x 70 cm^2, and is equipped with X-Y strips (21k strips with ~1, 2 and 4 cm pitch)



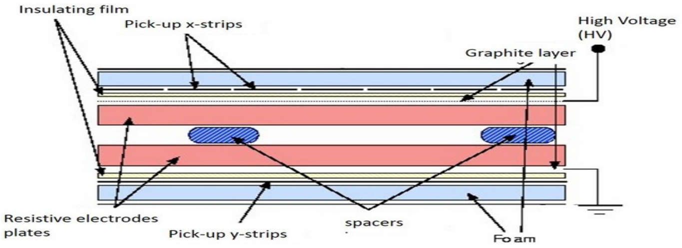


Resistive Plate Chambers (RPCs)

- ALICE MID RPCs are single gas gap (2 mm thick) detectors with resistive bakelite electrodes (2 mm thick, $\rho \simeq 3 \times 10^{9} - 1 \times 10^{10}\ \Omega$ cm)

- The signal is picked-up inductively by means of copper strips

- During Run 1 and Run 2 ALICE RPCs worked with:
  → effective applied HV of about 10200 - 10500 V at 970 mbar of pressure and 20°C
  → maxi-avalanche mode (average charge per hit of 100 pC)
  → **gas mixture**: 89.7% $C_2H_2F_4$, 10% i-C_4H_{10}, 0.3% SF_6



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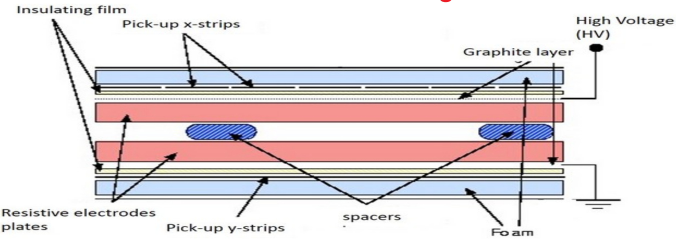
Greenhouse and flammable gas mixture



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Search of environment-friendly gas mixture (1)

- **Global Warming Potential (GWP)**: relative measure of how much heat a gas traps in the atmosphere ($GWP_{CO_2} = 1$ by definition)

ALICE mixture	$C_2H_2F_4$	*i*-C_4H_{10}	SF_6
GWP	1300	3.0	23500

- European regulations have imposed the reduction of the emission of fluorinated greenhouse gases (e.g. tetrafluoroethane) in atmosphere, and CERN is pushing for the search of more environmentally friendly gas mixtures for particle detectors

→ **goal: new ALICE mixture with more eco-friendly gases**

Search of environment-friendly gas mixture (2)

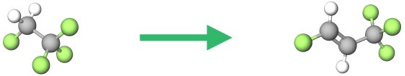
- **Reasons for R&D studies for the ALICE MID**:

  - the present ALICE gas mixture has a GWP of 1350 → **reduction of greenhouse gas**

  - EU restrictions:
    → tetrafluoroethane is being phased out and prices are going up
    → sulfur hexafluoride banned except for research
    } **cost saving**

  - ALICE gas mixture is flammable → **security reasons**

- R&D studies are **still ongoing**. Up to now work is being carried out on the substitution of tetrafluoroethane (95% of the total GWP of the mixture) with **tetrafluoropropene** $C_3H_2F_4$



$C_2H_2F_4$ → $C_3H_2F_4$

Tetrafluoropropene properties:

- not flammable at room temperature
- GWP = 7
- the strong electron attachment make it a promising choice for electric insulation

- Tetrafluoropropene is more electronegative than tetrafluoroethane → a direct replacement would lead to a higher Working Point (WP) → need to add also a gas that lowers the WP

Experimental set-up

- The tests on eco-friendly gas mixtures are performed in the INFN Torino laboratory, using cosmic rays
- Experimental set-up composed of:

  - one MID RPC with reduced dimensions (50×50 cm^2)

  - 16 readout strips per side, with 2 and 3 cm pitch

  - three scintillators for the trigger (total trigger area equals to 6×6 cm^2)

  - FEERIC front-end electronics which amplifies and discriminates signals ($Q_{induced} \sim 130$ fC)

  - HV applied with temperature and pressure correction

  - possibility to mix 4 different gases

Standard ALICE gas mixture

- Standard ALICE gas mixture is used as reference → RPC characterized with the standard gas mixture
- The new eco-friendly gas mixture should provide similar detector performance with respect to the standard ALICE gas mixture
- Mixture:

  - $C_2H_2F_4$ = 89.7 %
  - i-C_4H_{10} = 10.0 %
  - SF_6 = 0.3 %

- The plot shows the efficiency (black curve) and the streamer probability (white dots)

  → **Working Point (WP) ~ 9800 V**

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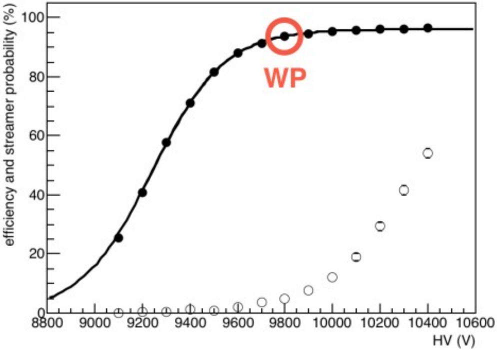


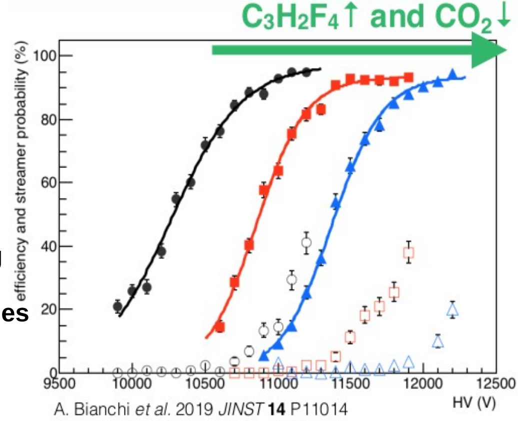
$C_3H_2F_4$ – based gas mixture: ratio with CO_2

- Efficiency has been measured for tetrafluoropropene-based gas mixtures, with the addition of different concentrations of other gases, in order to find the most promising environment-friendly gas mixture

1) Mixture with different $C_3H_2F_4$ and CO_2 ratio; constant *i*-C_4H_{10} (10.0%) and SF_6 (1.0%):

- $C_3H_2F_4$ = 33.5%; CO_2 = 55.5%
- $C_3H_2F_4$ = 39.0%; CO_2 = 50.0%
- $C_3H_2F_4$ = 44.5%; CO_2 = 44.5%

- By increasing $C_3H_2F_4$ and decreasing CO_2 :
  - **WP shifted towards higher voltages**
  - no significant variation on the streamer probability



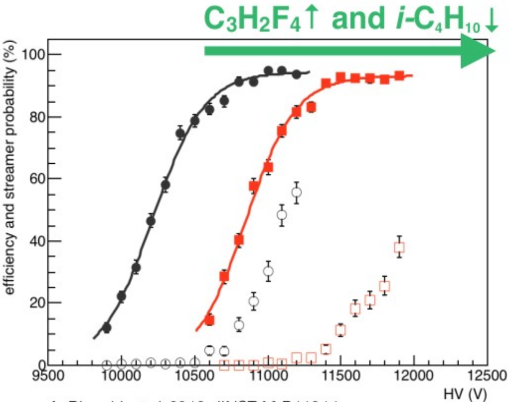
$C_3H_2F_4$ – based gas mixture: ratio with *i*-C_4H_{10}

- Efficiency has been measured for tetrafluoropropene-based gas mixtures, with the addition of different concentrations of other gases, in order to find the most promising environment-friendly gas mixture

2) Mixture with different $C_3H_2F_4$ and i-C_4H_{10} ratio; constant CO_2 (50.0%) and SF_6 (1.0%):

- $C_3H_2F_4$ = 29%; *i*-C_4H_{10} = 20%
- $C_3H_2F_4$ = 39%; *i*-C_4H_{10} = 10%

- Same consideration as before with CO_2
- Conclusion: **strong dependence between the concentration of $C_3H_2F_4$ and the WP**



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Ratio between CO_2 and *i*-C_4H_{10} (1)

- Mixtures with different CO_2 and *i*-C_4H_{10} ratio; constant $C_3H_2F_4$ (~34%) and SF_6 (1.0%) :

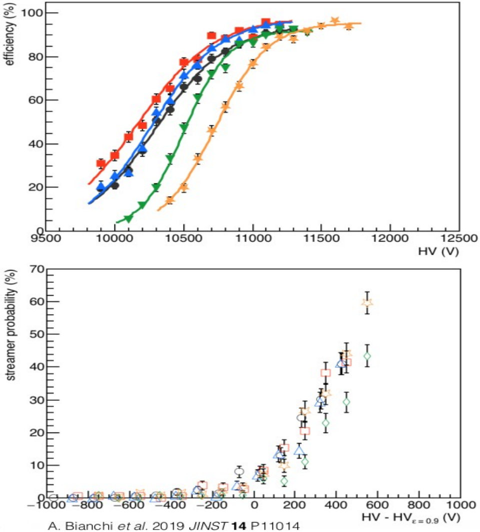
  - CO_2 = 65.5%; *i*-C_4H_{10} = 0.0%

  - CO_2 = 60.5%; *i*-C_4H_{10} = 5.0%

  - CO_2 = 55.5%; *i*-C_4H_{10} = 10.0%

  - CO_2 = 50.0%; *i*-C_4H_{10} = 15.0%

  - CO_2 = 44.5%; *i*-C_4H_{10} = 20.0%



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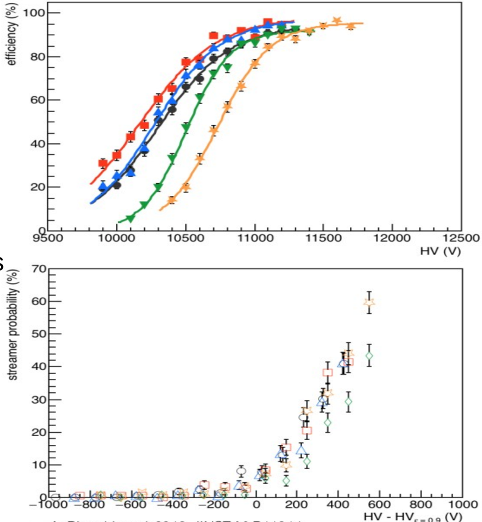
Ratio between CO_2 and *i*-C_4H_{10} (2)

- Mixtures with different CO_2 and *i*-C_4H_{10} ratio; constant $C_3H_2F_4$ (~34%) and SF_6 (1.0%) :

  - the **WP** does not vary monotonically

  - very similar **streamer probability** in all cases (note that the plot below refers to the shift between the applied HV and the HV at the WP)

  - the reduction of *i*-C_4H_{10} is desirable because it is **flammable**, but its reduction results in less steep turn-on of efficiency, which is not desirable



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ALICE

Variation of SF_6 (1)

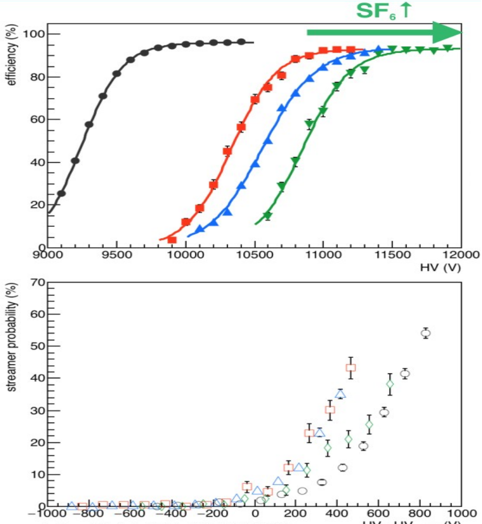
- Mixtures with different percentage of SF_6 compared with ALICE standard gas mixture (black curve):

  - SF_6 = 0.3%; $C_2H_2F_4$ = 89.7%; *i*-C_4H_{10} = 10.0%

  - SF_6 = 0.3%; $C_3H_2F_4$ = 39.7%; CO_2 = 50.0%; *i*-C_4H_{10} = 10.0%

  - SF_6 = 0.6%; $C_3H_2F_4$ = 39.4%; CO_2 = 50.0%; *i*-C_4H_{10} = 10.0%

  - SF_6 = 1.0%; $C_3H_2F_4$ = 39.3%; CO_2 = 50.0%; *i*-C_4H_{10} = 10.0%



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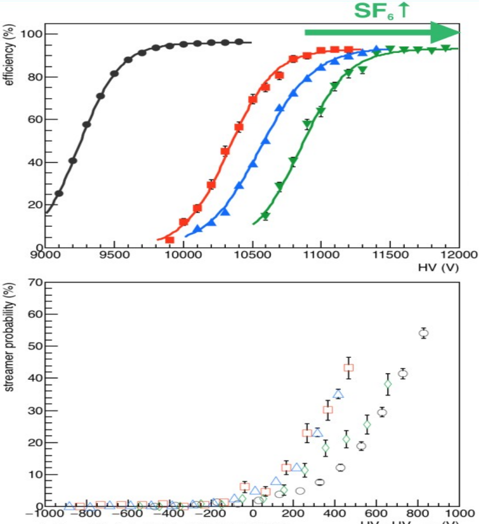
Variation of SF_6 (2)

- Mixtures with different percentage of SF_6 compared with ALICE standard gas mixture (black curve):

  - a small variation of SF_6, from 0.3% to 1.0%, leads to a **variation of the WP of ~ 500 V**

  - there is no significant variation in the **streamer probability** when increasing SF_6 from 0.3% to 0.6%

  - the suppression of the streamers is slightly higher with 1.0% of SF_6



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Most promising gas mixtures (up to now) (1)

- The most promising gas mixtures with low GWP are shown in the plots

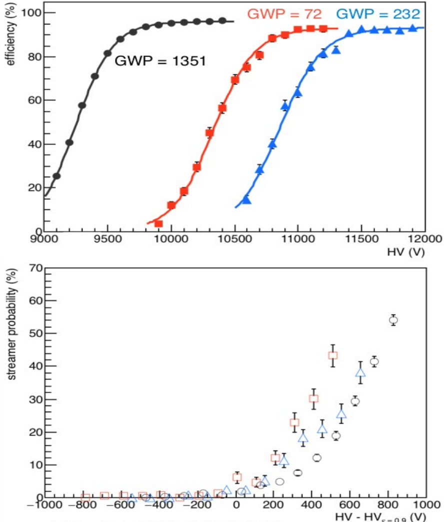
- The black curve represent the ALICE standard gas mixture, with GWP = 1351

1) CO_2 = 50.0%; $C_3H_2F_4$ = 39.7%; *i*-C_4H_{10} = 10.0%; SF_6 = 0.3%

- **GWP = 72** (~ 20 times lower than the ALICE mixture)

- **WP** close to the one of the ALICE RPCs during Run-I and Run-II of LHC **(~ 1 kV higher)**

- **Streamer probability** higher than the ALICE one



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Most promising gas mixtures (up to now) (2)

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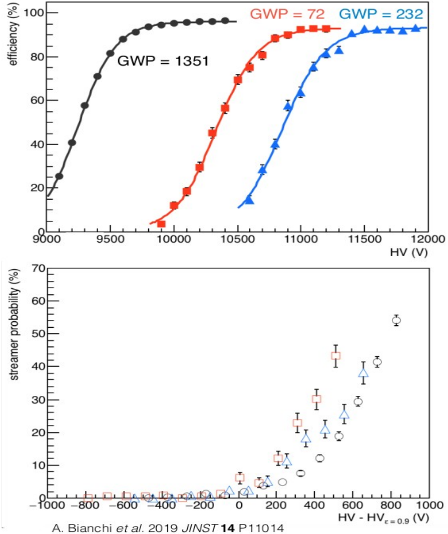
- The black curve represent the ALICE standard gas mixture, with GWP = 1351

2) **CO_2 = 50.0%; $C_3H_2F_4$ = 39.0%; *i*-C_4H_{10} = 10.0%; SF_6 = 1.0%**

- **GWP = 232** (~ 5 times lower than the ALICE mixture)

- Higher **WP (~ 1.5 kV)**

- **Streamer probability** similar to the ALICE one



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Most promising gas mixtures (up to now) (3)

- In the plots are shown the most promising gas mixtures with low GWP
- The black curve represent the ALICE standard gas mixture, with GWP = 1351

1) **CO_2 = 50.0%; $C_3H_2F_4$ = 39.7%; *i*-C_4H_{10} = 10.0%; SF_6 = 0.3%**

2) **CO_2 = 50.0%; $C_3H_2F_4$ = 39.0%; *i*-C_4H_{10} = 10.0%; SF_6 = 1.0%**

- *More details in:*
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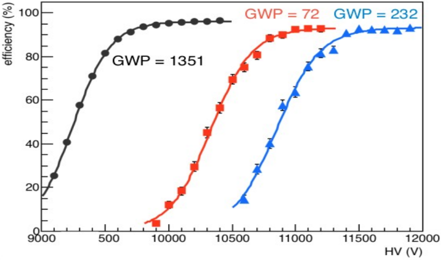

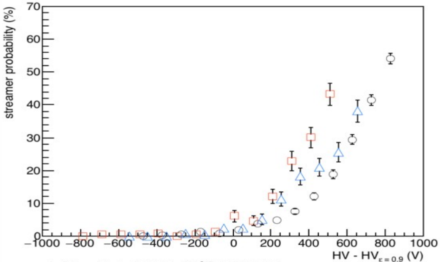

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Gamma Irradiation Facility (GIF++)

- **Aging test**: it is important to test the new gas mixtures to see if they are stable during long term operations → RPC are exposed to a high radiation dose in order to simulate many years of operations while keeping track of performances over time

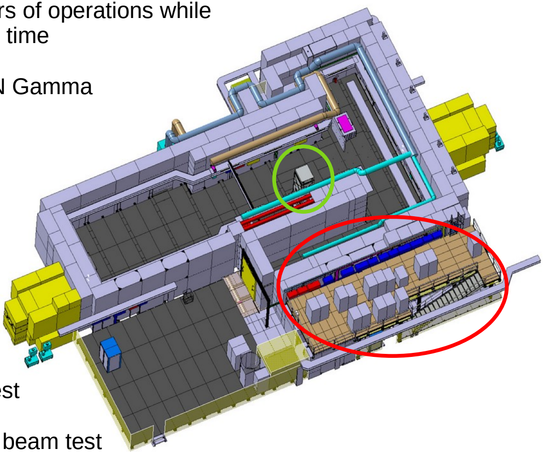
- These tests are performed at CERN Gamma Irradiation Facility (GIF++):

  - **Cs137** radioactive source which provides gamma rays in order to accelerate the aging process

  - the electronic modules and the gas supply are placed in the **service zone**

  - **filters** are used to modulate the radiation on the detectors under test

  - possibility to have muon beam for beam test



Aging test at GIF++

- Aging test have been performed with two mixtures called ECO1 and ECO2, and more *work is still in progress*:

  - **ECO1**: CO_2, HFO, *i*-C_4H_{10}, SF_6 in the proportion 50/45/4/1

  - **ECO2**: CO_2, HFO, *i*-C_4H_{10}, SF_6 in the proportion 60/35/4/1

- Chambers are kept at a certain HV value close to the WP of the RPC and are irradiated for a certain amount of time **(stability test)**

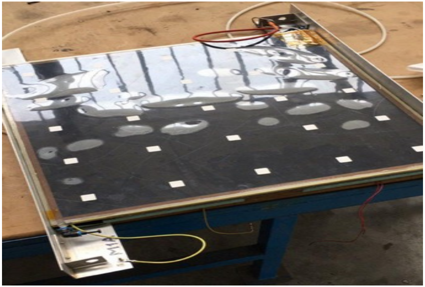
- Every week an **high voltage scan** to measure the current is performed without source in order to measure the dark current (i.e. current with no source) and observe its behavior over time

- If the current is stable
  → efficiency is measured (both with cosmics and with test beams)

Experimental set-up at GIF++

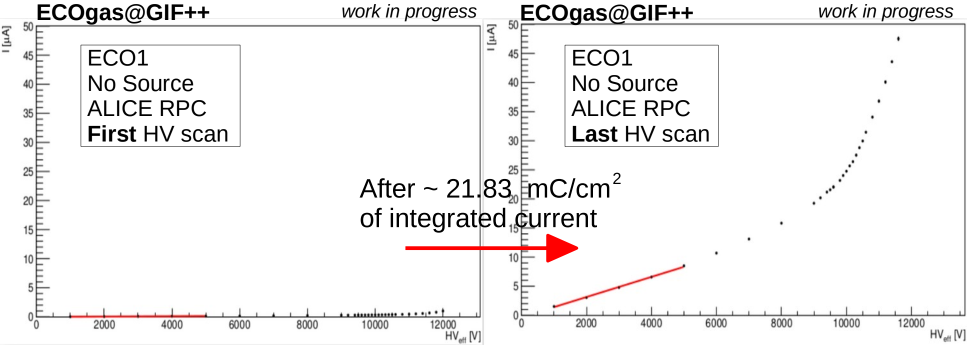
- The location of the **Cs137** gamma rays source with the attenuation filters is shown in the blue circle

- **ECOgas@GIF++** collaboration (ALICE, ATLAS, CMS, EP-DT, ShiP) has been created to perform these aging tests. RPCs have been provided by the different groups and have been installed onto a **common trolley** placed inside the bunker.
  In the picture below the ALICE RPC is shown.



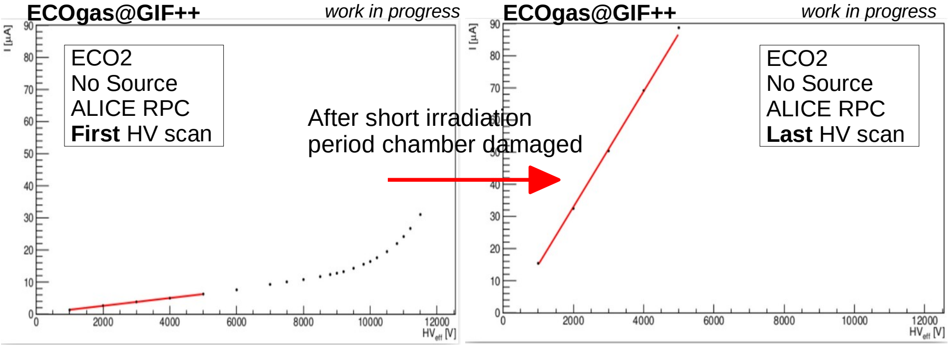
Aging test at GIF++ (1)

- The I-V curves for the ECO1 gas mixture for the ALICE RPC are shown in the following plots, **before and after** the stability test (**5 months** between the two tests)
- The scans have been performed with no source, in order to measure the dark current, i.e. the current absorbed with no irradiation → we can observe an **increase of the dark current**
- The fit used to estimate the Ohmic component of the dark current at 11.4 kV is shown in red



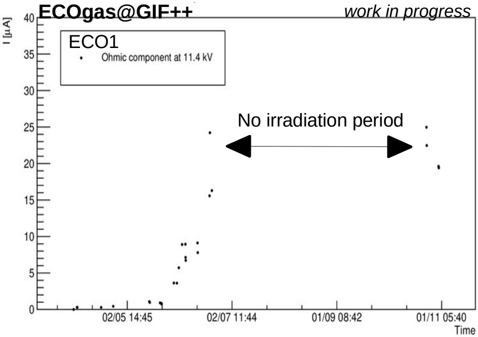
Aging test at GIF++ (2)

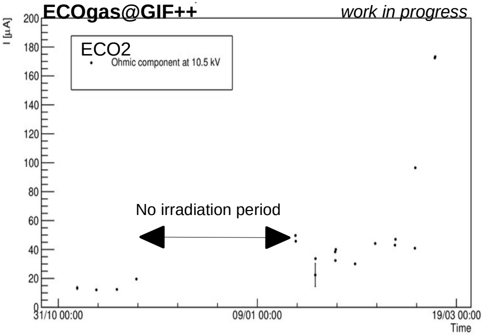
- Same as before, the I-V curves for the ECO2 gas mixture for the ALICE RPC, are shown in the following plots, **before and after** the stability test
- We have observed a large increase of the current as soon as we started the tests with ECO2 → for this reason the last HV scan for the ALICE RPC is not reliable
- Tests have continued with other RPCs from the collaboration → ***results under investigation***



Aging test at GIF++ (3)

- The Ohmic component (extrapolated with linear fit from I-V curve) of the current for both the ECO1 and ECO2 gas mixture, at the RPC working point, is shown in the following plots
- Each point in the plots corresponds to an HV scan executed every week, without source
- It is possible to observe an increase of the current over time → ***causes under investigation***





Conclusions

- **R&D on the low GWP gas mixtures:**

  - $C_3H_2F_4$ seems a possible candidate to replace $C_2H_2F_4$

  - direct replacement of $C_2H_2F_4$ with $C_3H_2F_4$ is not suitable because of the high WP (> 14 kV) → addition of CO_2 to operate at lower voltages

  - a promising gas mixtures is composed of $C_3H_2F_4$, CO_2, *i*-C_4H_{10} and SF_6 → GWP reduced by a factor 5-20 depending on the percentage variation of the gases

- **GIF++:**

  - observed increase of current with the gas mixtures under test → this is under investigation and more work will be done

  - a test beam has been performed in July at GIF++ with others RPC groups, in order to do more tests on ECO2 gas mixture

  - two others test beams will take place in September and October 2021

Thank you for your attention!