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

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Outline

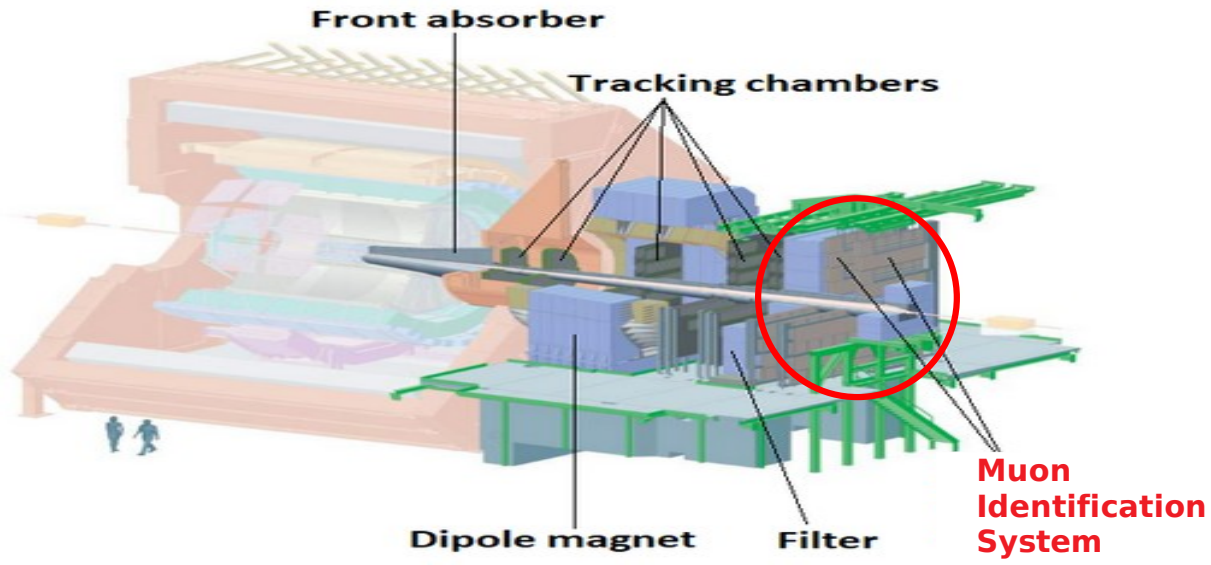
- ALICE Muon Identification System (MID)
- ALICE MID Resistive Plate Chambers
- Search for environment-friendly gas mixture

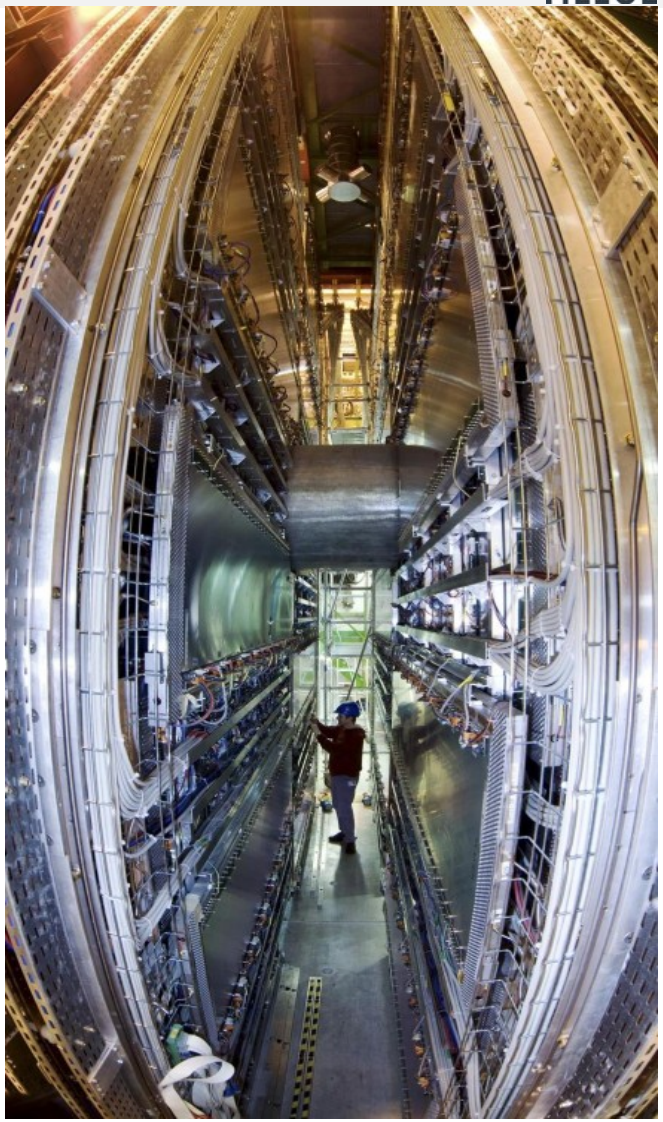
  → from Tetrafluoroethane to Tetrafluoropropene
  → Carbone dioxide and Isobutane percentage variation
  → Sulfur hexafluoride percentage variation

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

The ALICE Muon Identification System

- It consists of 72 Resistive Plate Chambers arranged in 2 stations of 2 planes each
- Each plane 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)



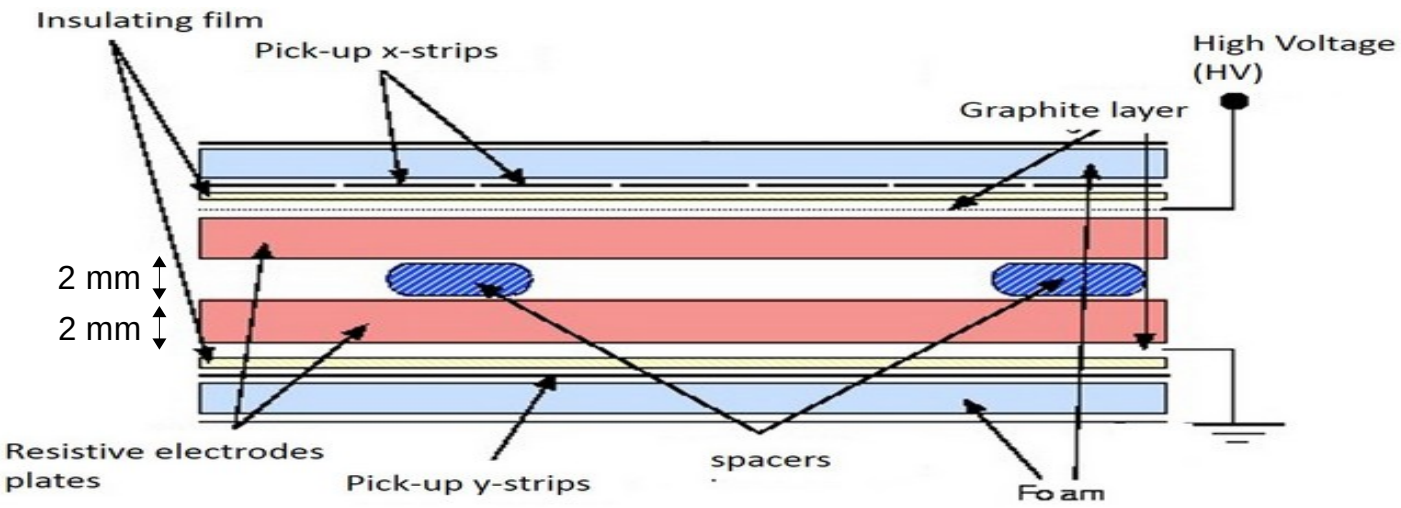


Resistive Plate Chambers (RPCs)

- 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 with 50 Ω impedance

- During Run 1 and Run 2 ALICE RPCs worked with:
  → effective applied HV of about 10.2 – 10.5 kV at 970 mbar of pressure and 20°C
  → maxi-avalanche mode (average charge per hit of 100 pC)
  → **gas mixture**: 89.7% $C_2H_2F_4$, 0.3% SF_6, 10% *i*-C_4H_{10}, humidified at 35-40%



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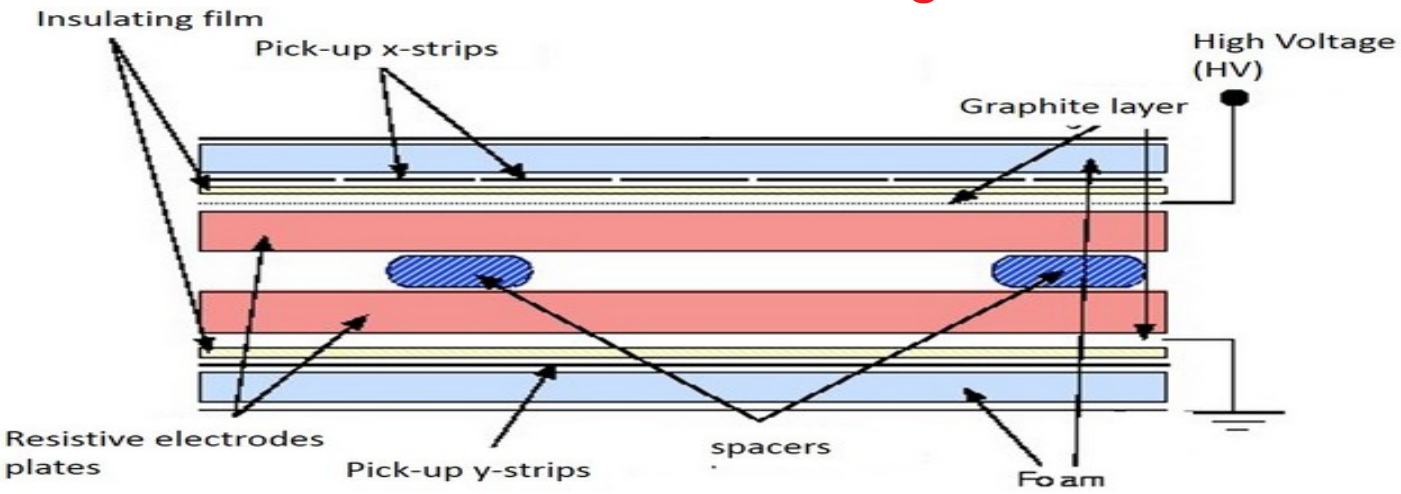
Greenhouse and flammable gas mixture



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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_{100yr}	1300	3.0	23500

GWP values calculated by IPCC Fifth Assessment Report

- 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 an higher percentage of eco-friendly gases**

Search of environment-friendly gas mixture (2)

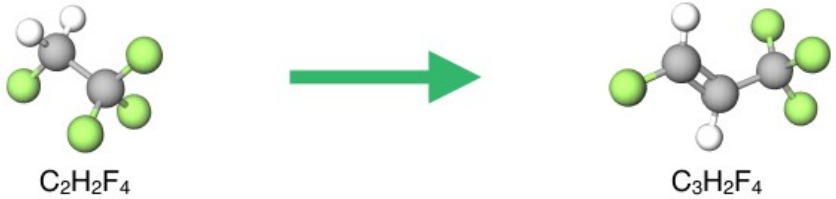
- **Reasons for R&D studies for the ALICE MID**:

  - the present ALICE gas mixture has a GWP of 1351 → **reduction of greenhouse gas**

  - tetrafluoroethane is being phased out (EU restrictions) and **prices are going up**

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

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



Tetrafluoropropene properties:

- not flammable at room temperature
- GWP ~ 1

- Electron capture is more dominant for tetrafluoropropene than tetrafluoroethane → a direct replacement would lead to a higher HV Working Point (WP) → need to add CO_2 in order to lower 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 ALICE MID RPC with reduced dimensions (50 x 50 cm^2)

  - 16 readout strips per side, with 2 cm pitch

  - three scintillators for the trigger (total trigger area equals to about 6 x 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 up to 4 different gases

Standard ALICE gas mixture

- Standard ALICE gas mixture is used as reference:

  - Tetrafluoroethane $C_2H_2F_4$ = 89.7 %
  - Isobutane *i*-C_4H_{10} = 10.0 %
  - Sulfur hexafluoride SF_6 = 0.3 %

- The new eco-friendly gas mixture should provide similar detector performance with respect to the standard ALICE gas mixture

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

  → **Working Point (WP) ~ 9.8 kV**

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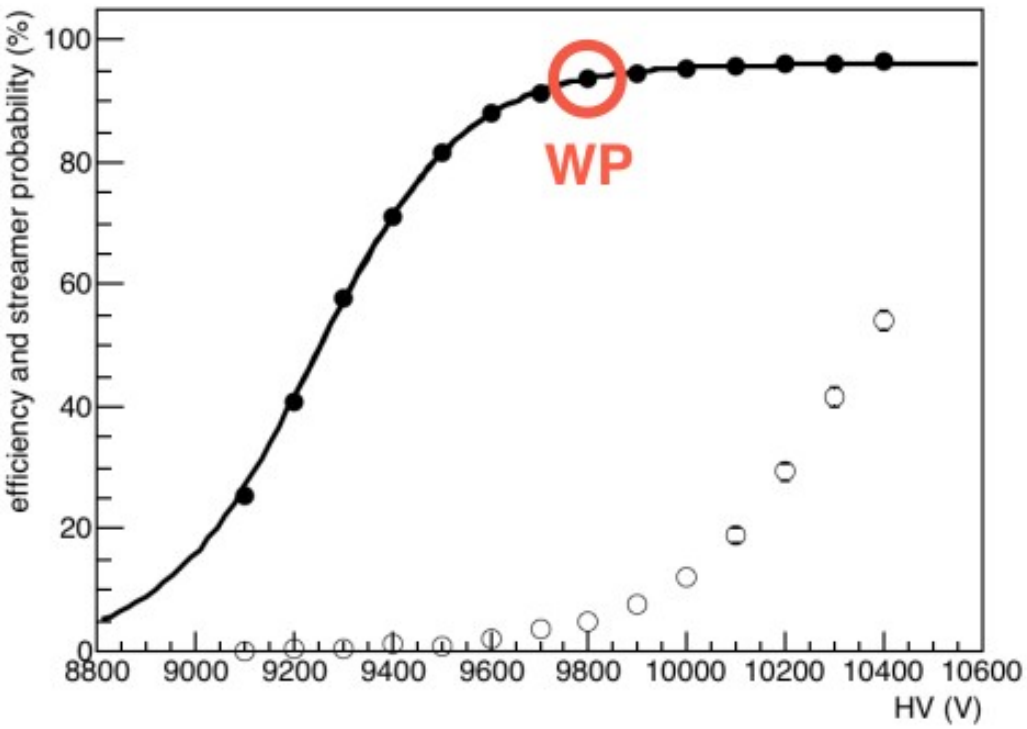


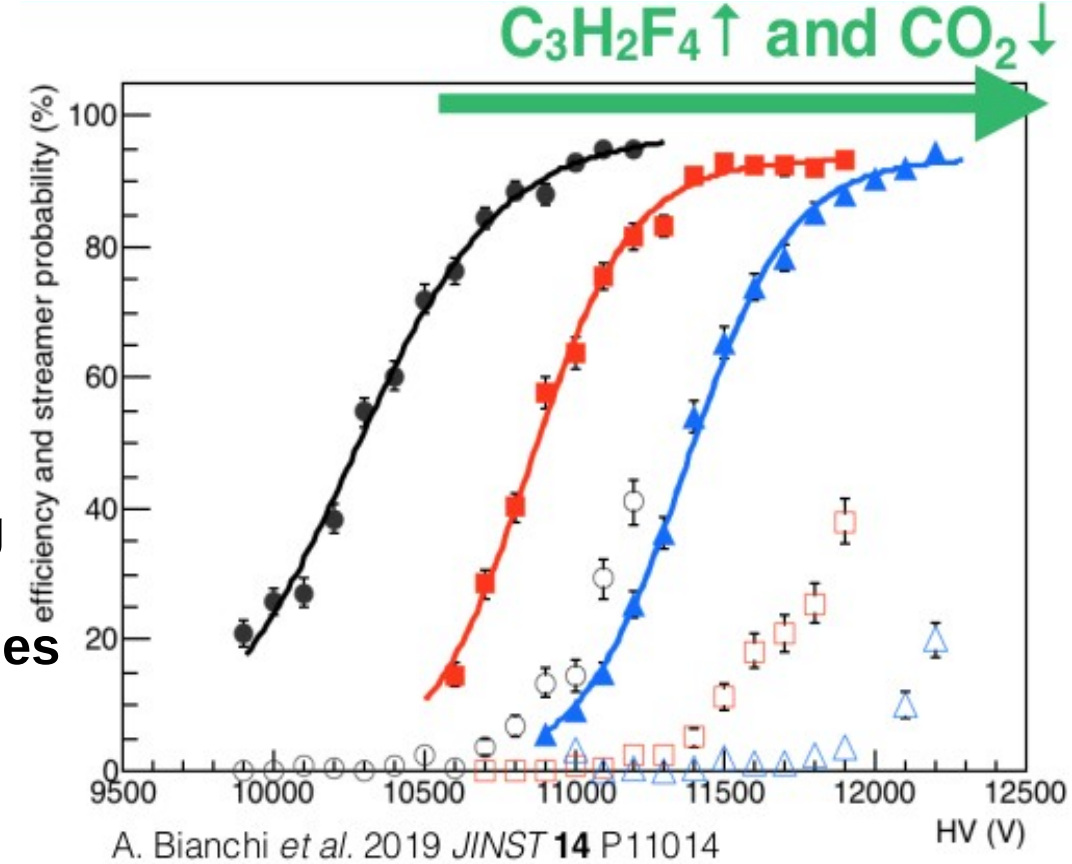
Tetrafluoropropene – based gas mixture: ratio with CO_2

- Efficiency has been measured for **tetrafluoropropene-based** gas mixtures, with the addition of **different concentrations of CO_2**, in order to find the most promising environment-friendly gas mixture

1) Mixtures 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 of the streamer probability



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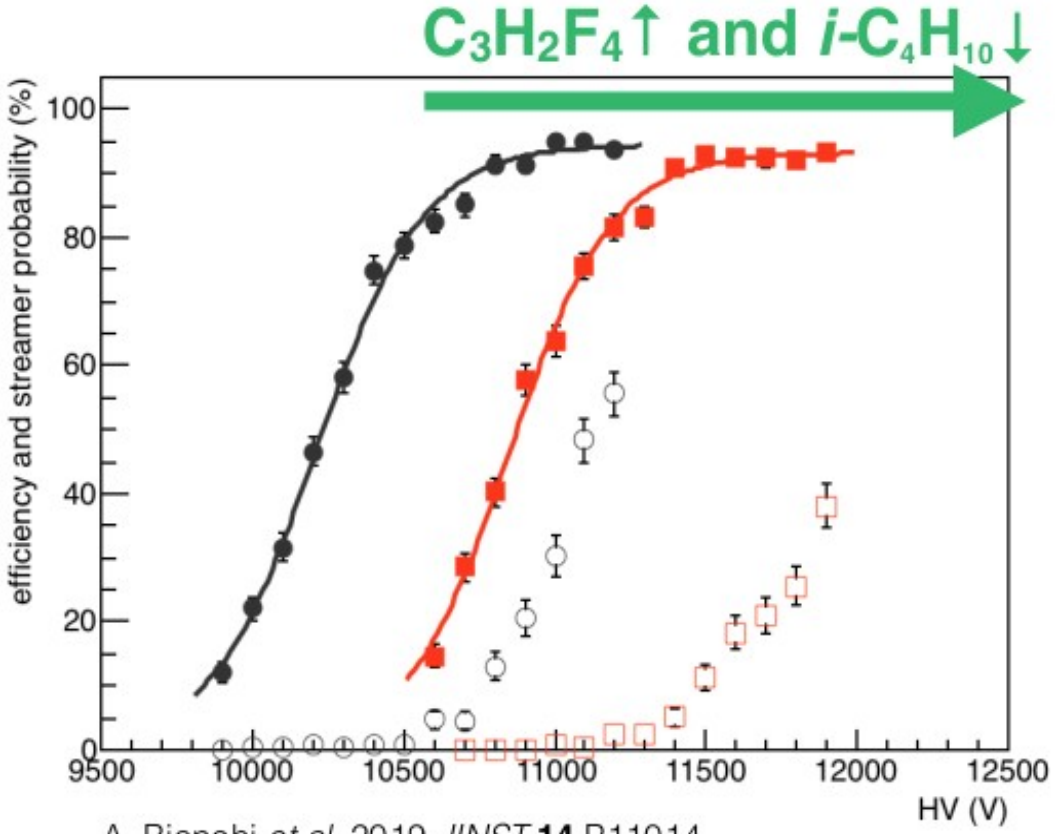
Tetrafluoropropene – based gas mixture: ratio with *i*-C_4H_{10}

- Efficiency has been measured for **tetrafluoropropene-based** gas mixtures, with the addition of different concentrations of **isobutane**, 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%) :

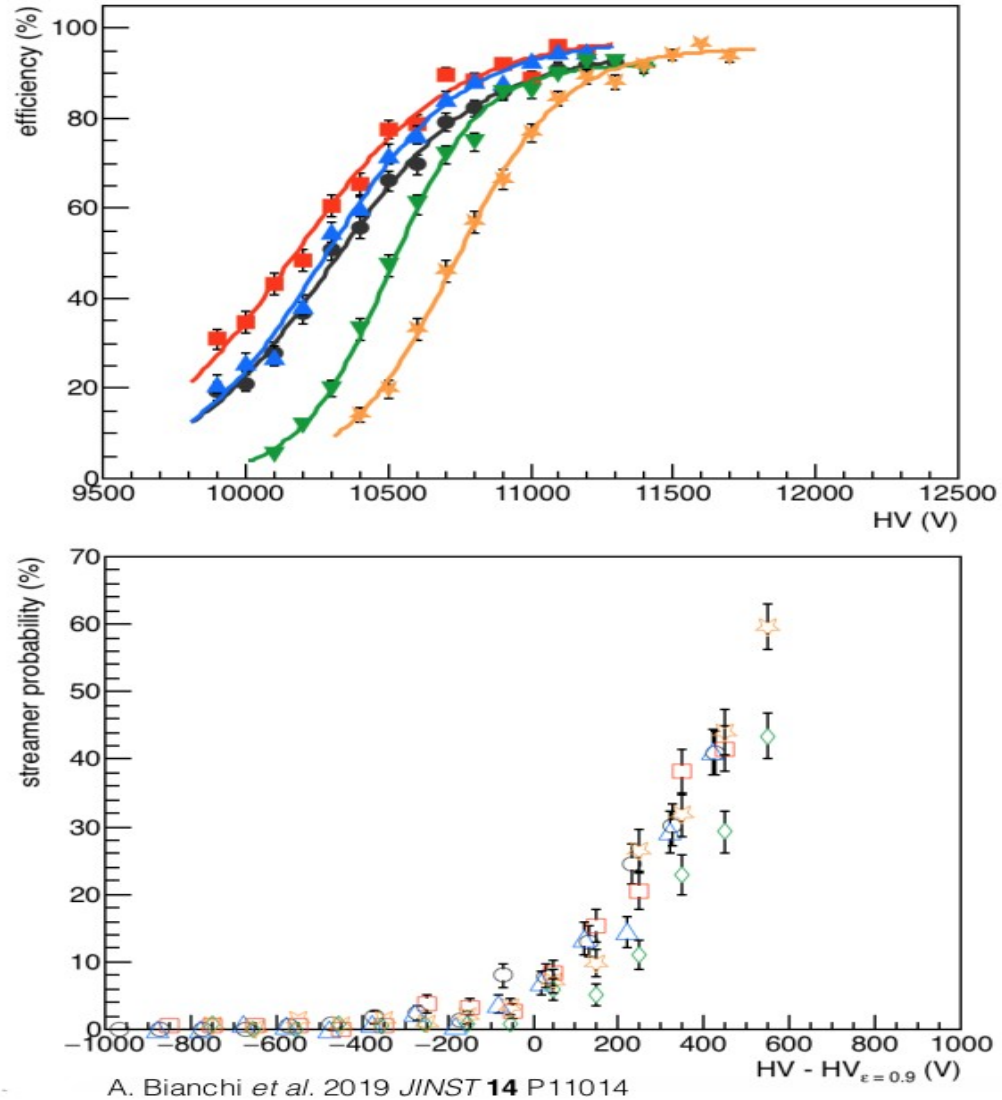
  - CO_2 = 65.5%; *i*-C_4H_{10} = 0.0%

  - 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%



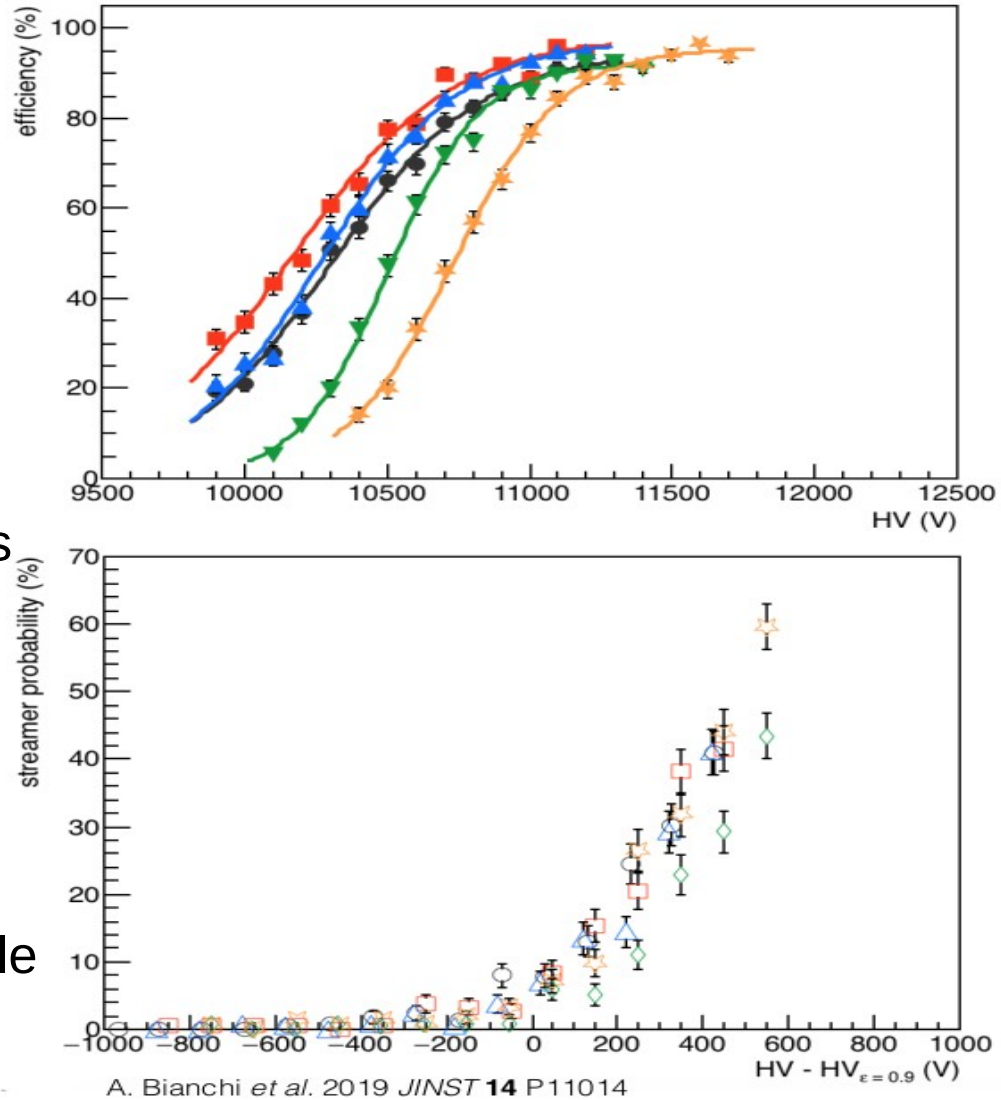
Ratio between CO_2 and *i*-C_4H_{10} (2)

- 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 90% of efficiency)

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



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Variation of SF_6 (1)

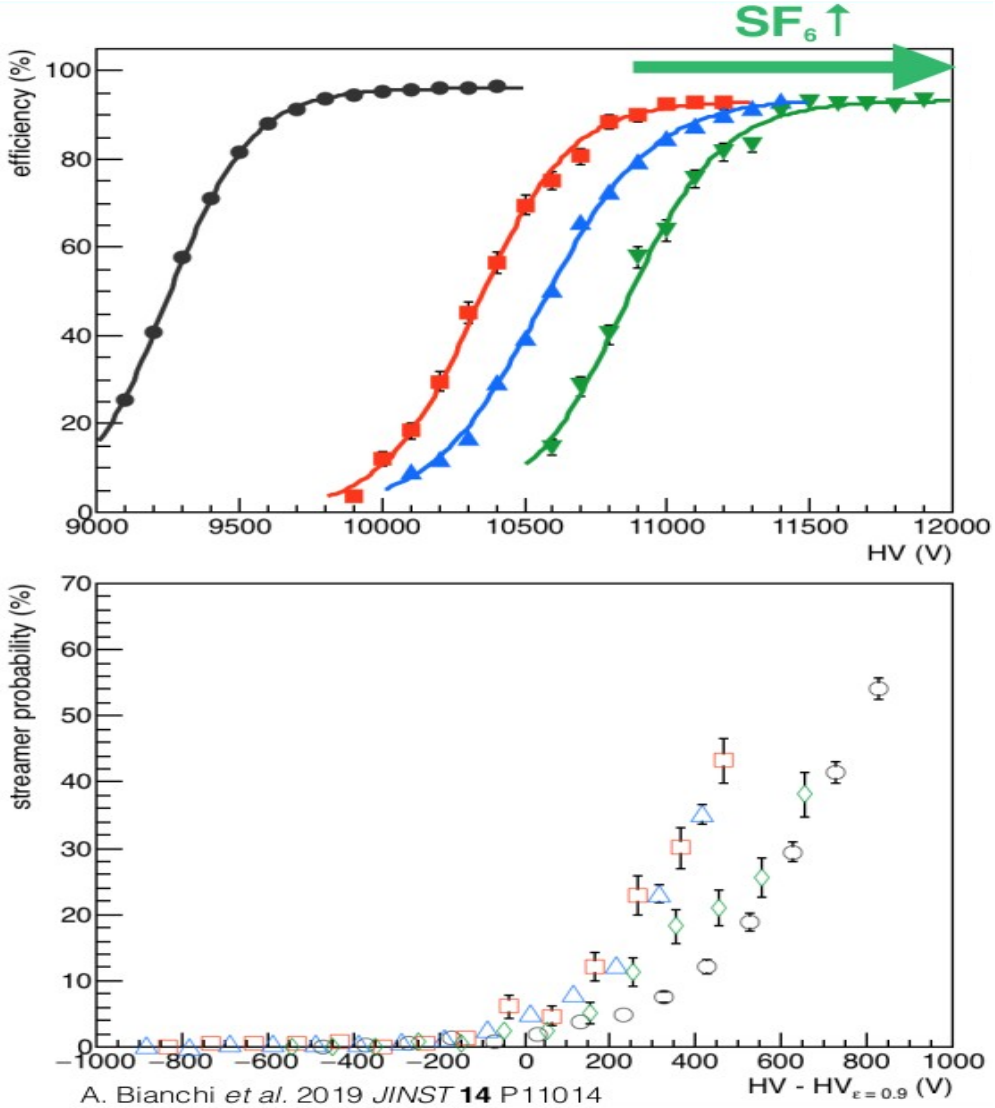
- Mixtures with different percentage of SF_6 compared with ALICE standard gas mixture (black curve):

  - **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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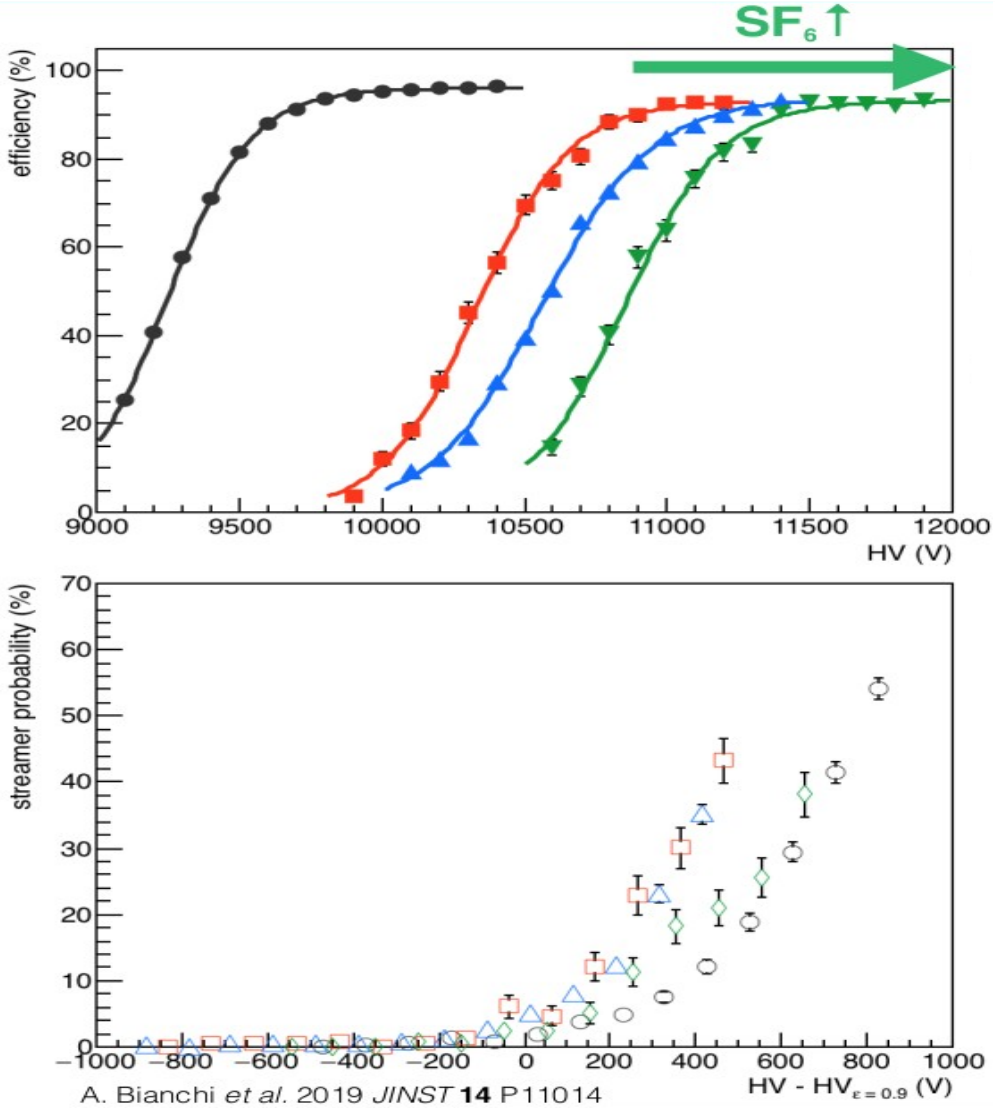
Variation of SF_6 (2)

- 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



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

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

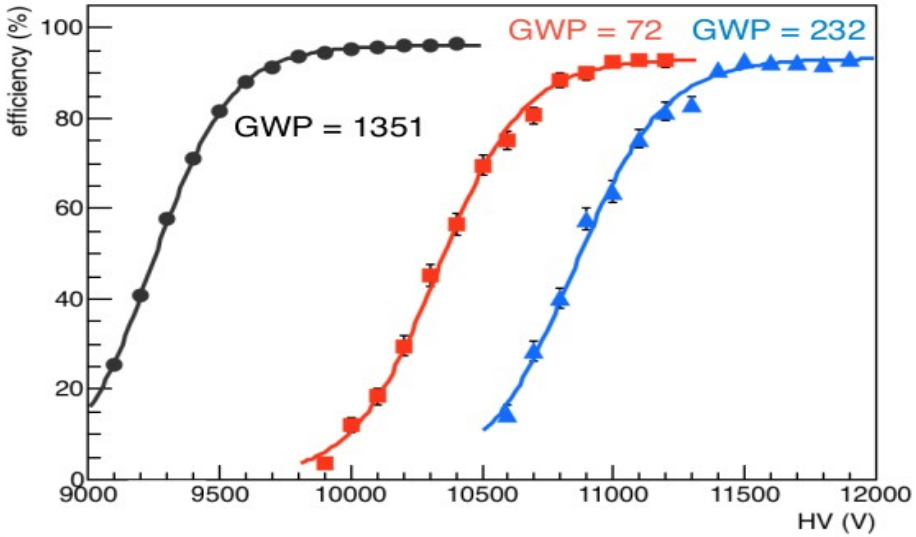
- The black curve shows the performances of RPCs with the ALICE standard gas mixture, with GWP = 1351

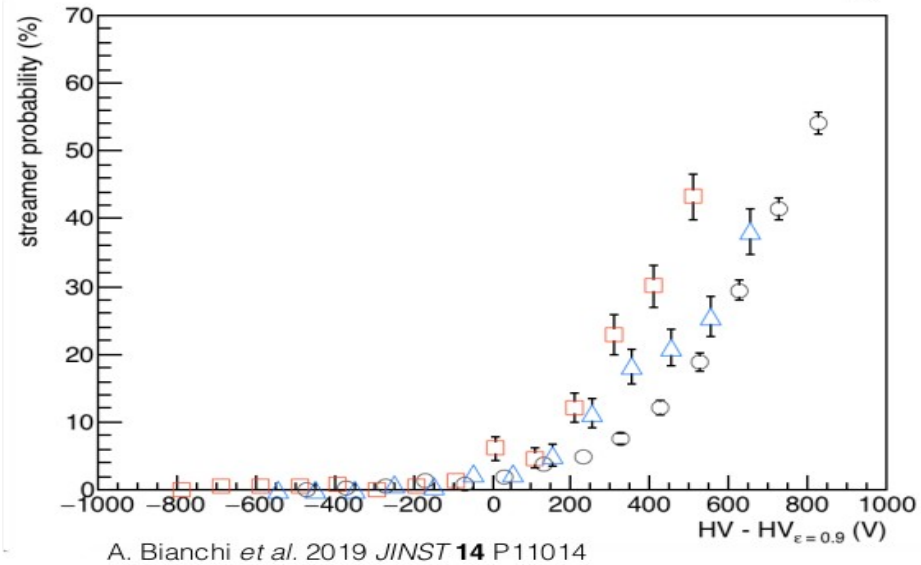
1) **CO_2 = 50.0%; $C_3H_2F_4$ = 39.7%; *i*-C_4H_{10} = 10.0%; SF_6 = 0.3%**

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

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

- **Streamer probability** is higher than that with the ALICE mixture





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

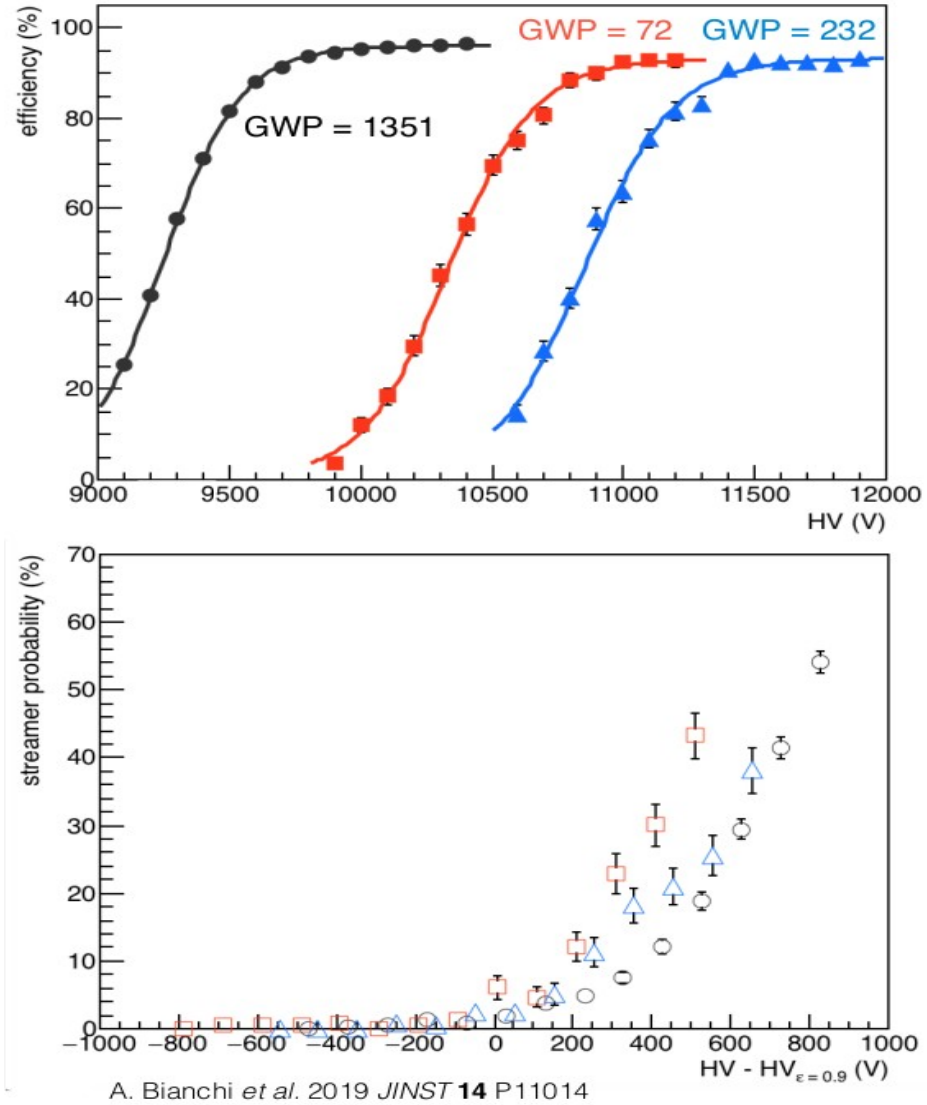
- The most promising gas mixtures with low GWP are shown in the plots
- The black curve shows the performances of RPCs with the ALICE standard gas mixture, with GWP = 1351

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** is similar to that with the ALICE mixture



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

- In the plots the most promising gas mixtures with low GWP are shown
- The black curve shows the performances of RPCs with 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 = 0.1%**

- *More details in:*
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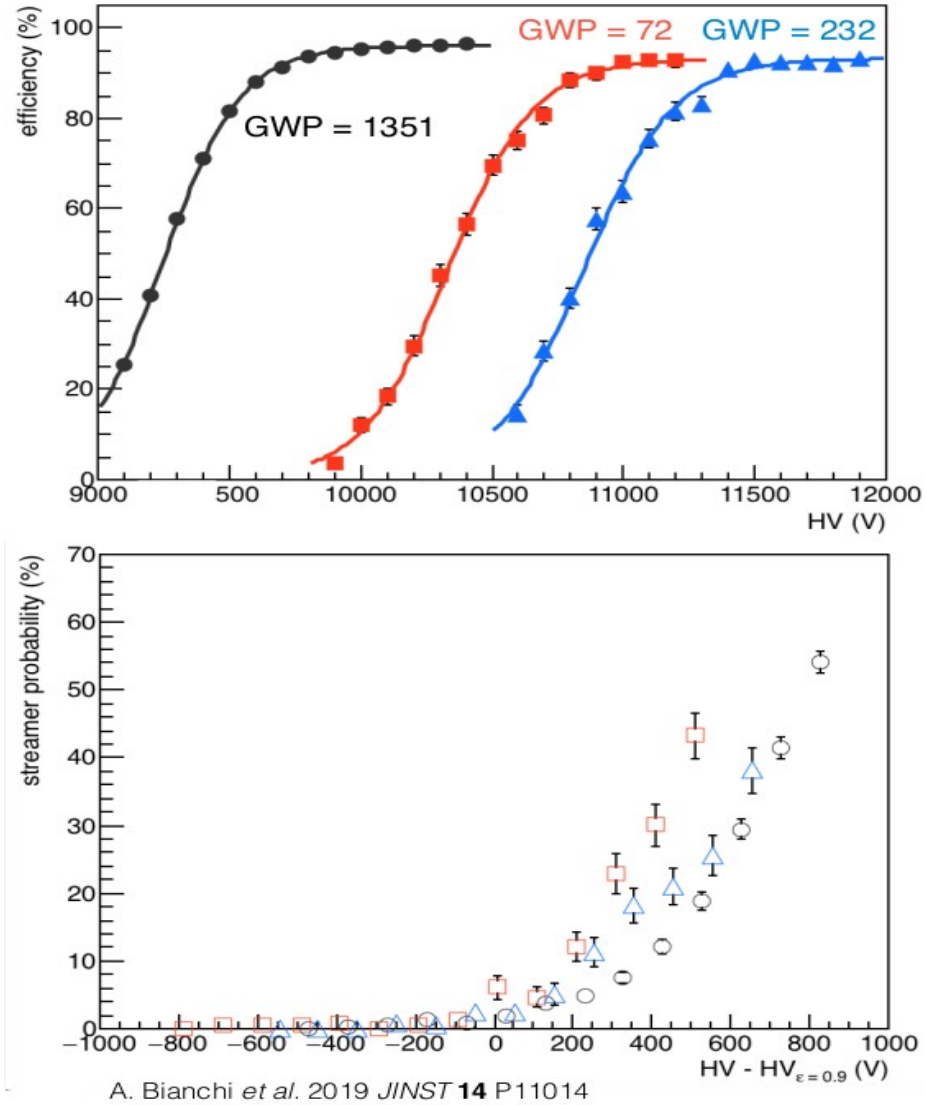

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Gamma Irradiation Facility (GIF++)

- **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

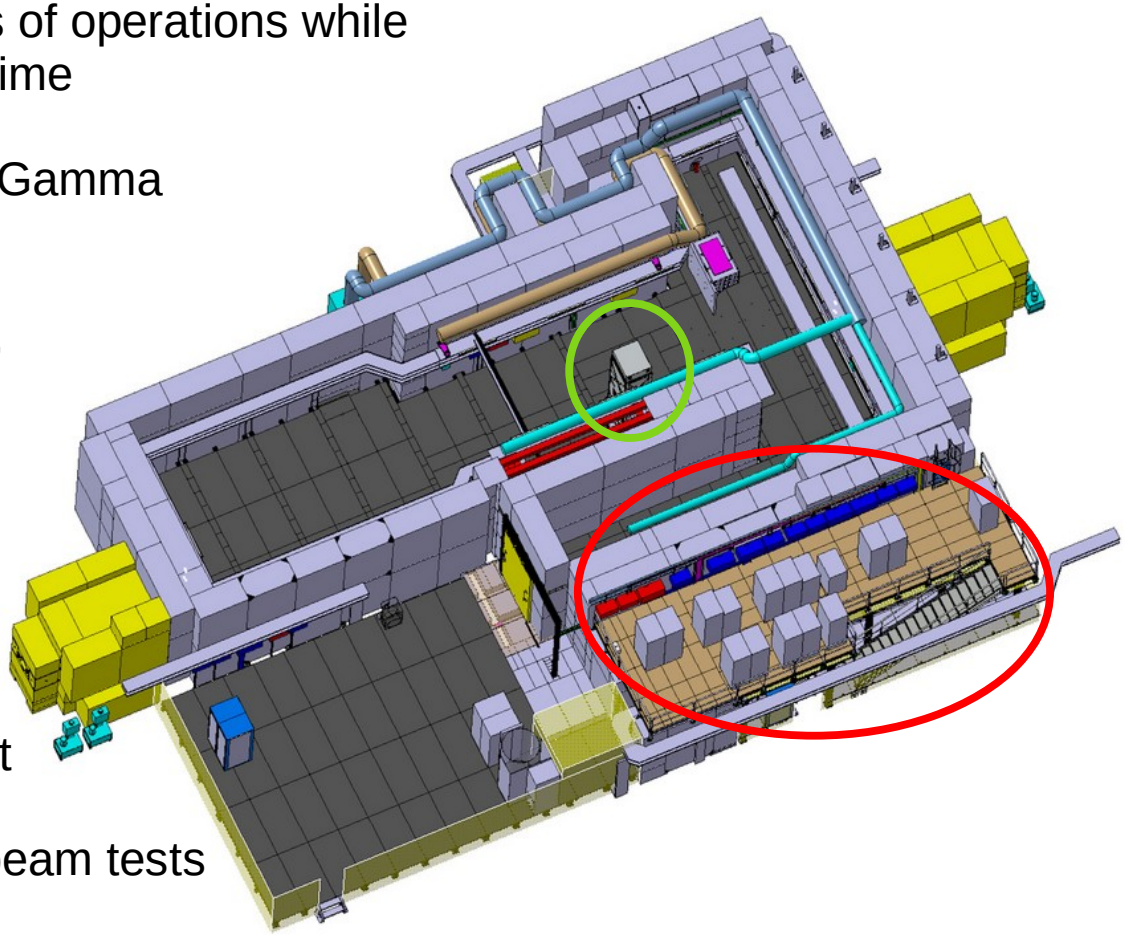
- These tests are performed at CERN Gamma Irradiation Facility (GIF++):

  - **Cs137** radioactive source (14 TBq), emitting 662 keV gamma rays

  - 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 tests



Aging test at GIF++

- Aging test have been performed since 2019, 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

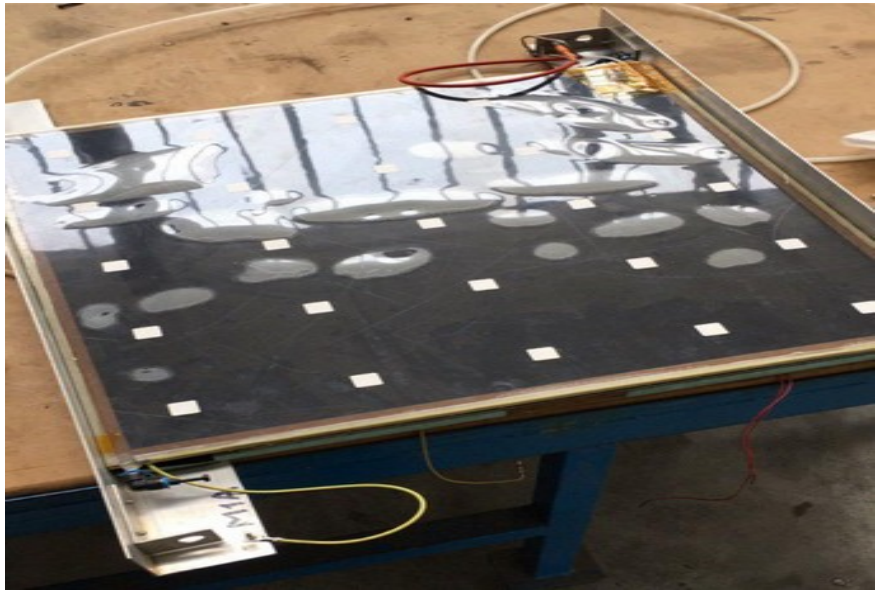
- Chambers are kept at a certain HV value close to the WP of the RPC and are irradiated for a certain amount of time **(stability test)**

- 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

Experimental set-up at GIF++

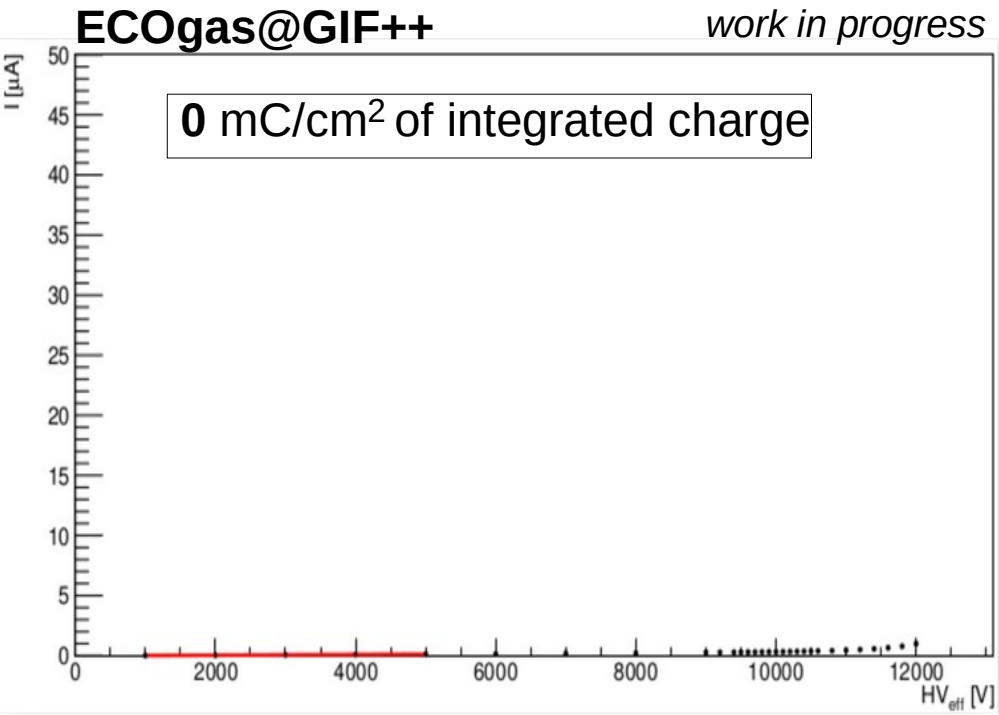
- The location of the **Cs137** gamma rays source with the attenuation filters is shown in the blue circle

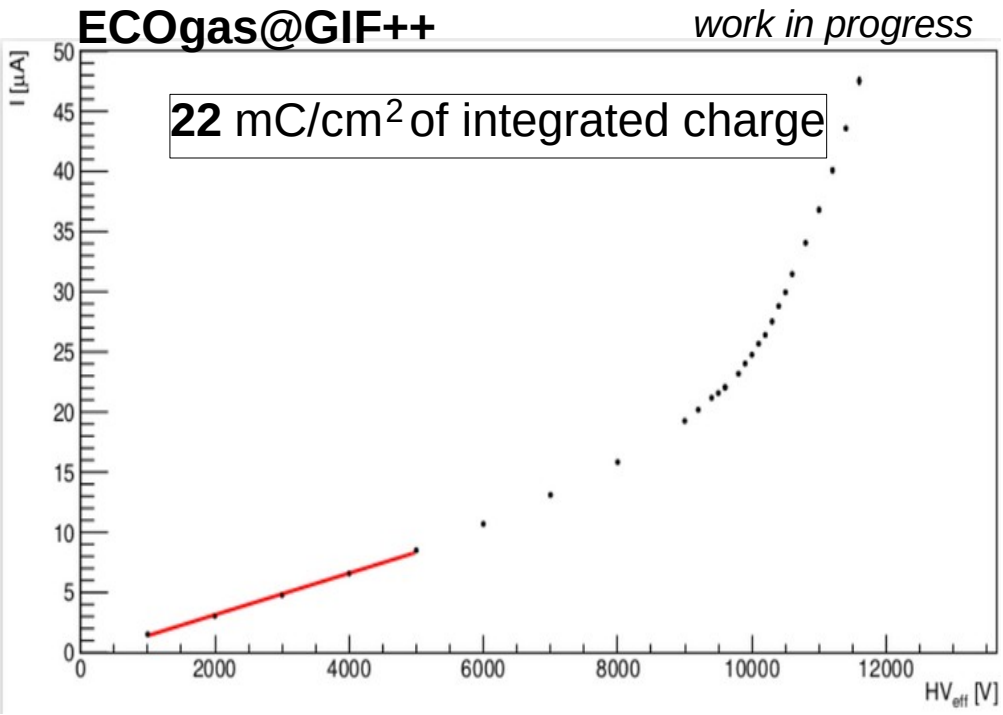
- **ECOgas@GIF++** collaboration (ALICE, ATLAS, CMS, EP-DT, ShiP) has been created to perform these aging tests. RPCs have been provided by the different groups and have been installed onto a **common trolley** placed inside the bunker.
  In the picture below the ALICE RPC is shown.



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

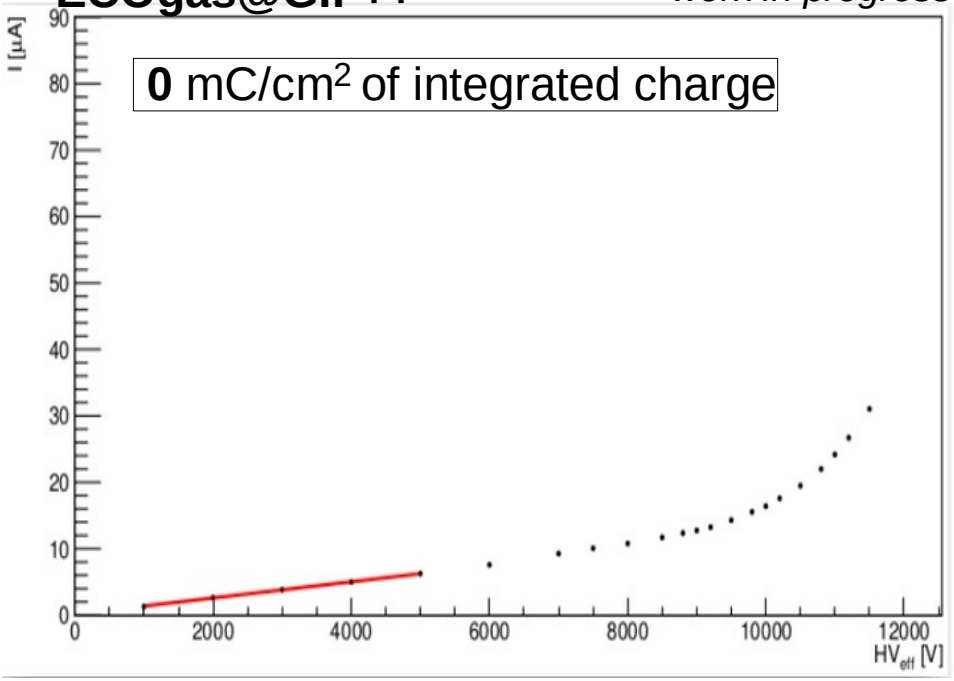




Aging test at GIF++ (2)

- 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
- By **increasing the percentage of CO_2** we have observed a large increase of the current as soon as we started the tests with ECO2 → the last HV scan for the ALICE RPC is not reliable
- Tests have continued with other RPCs from the collaboration → ***results under investigation***

ECOgas@GIF++ *work in progress*



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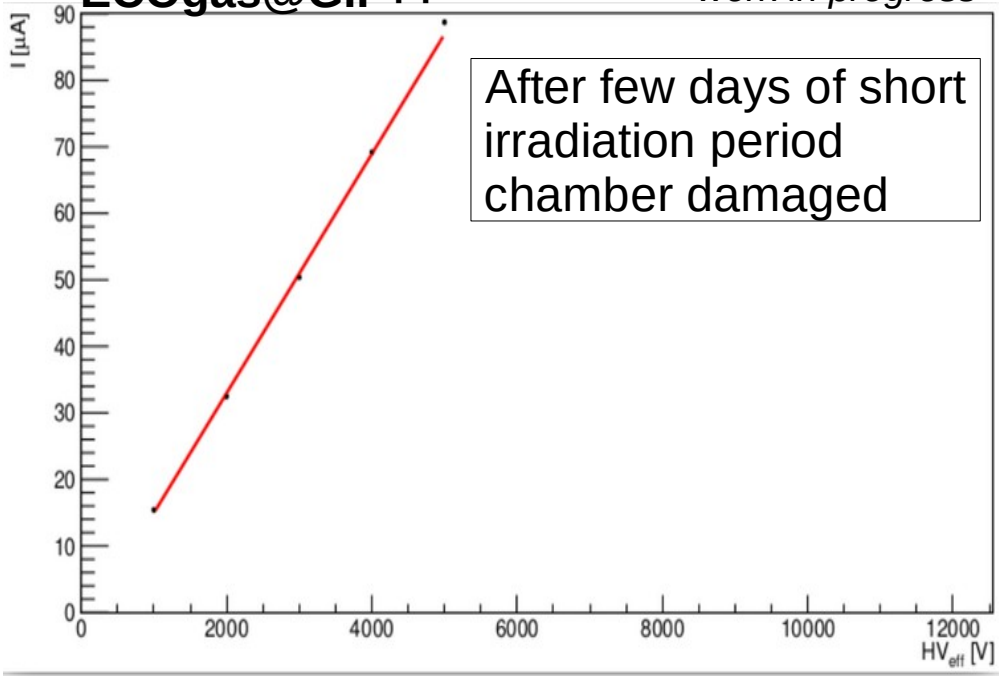
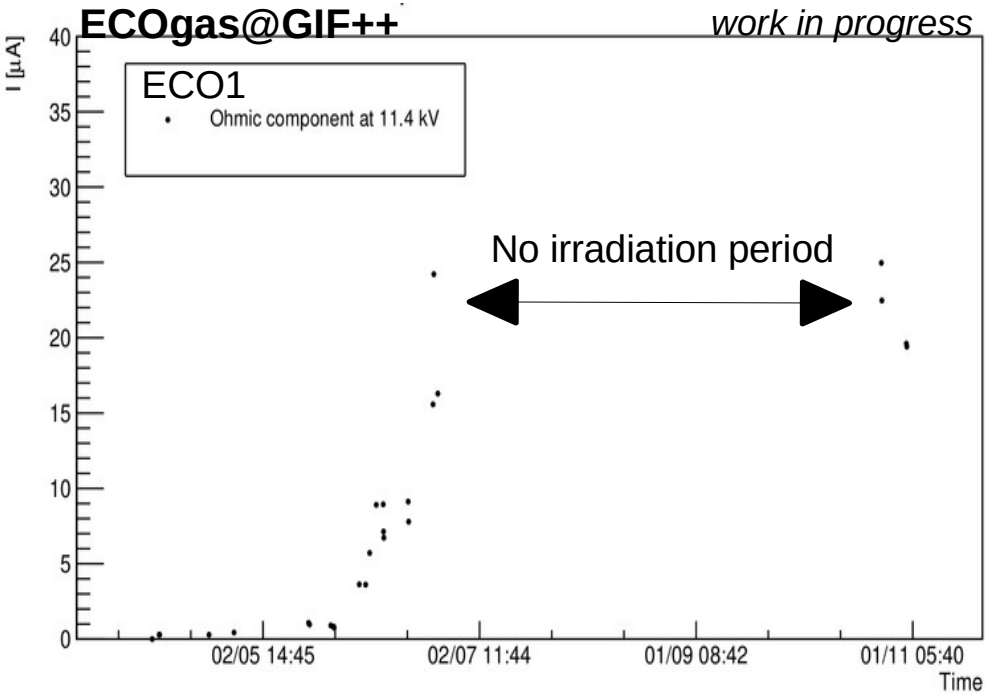
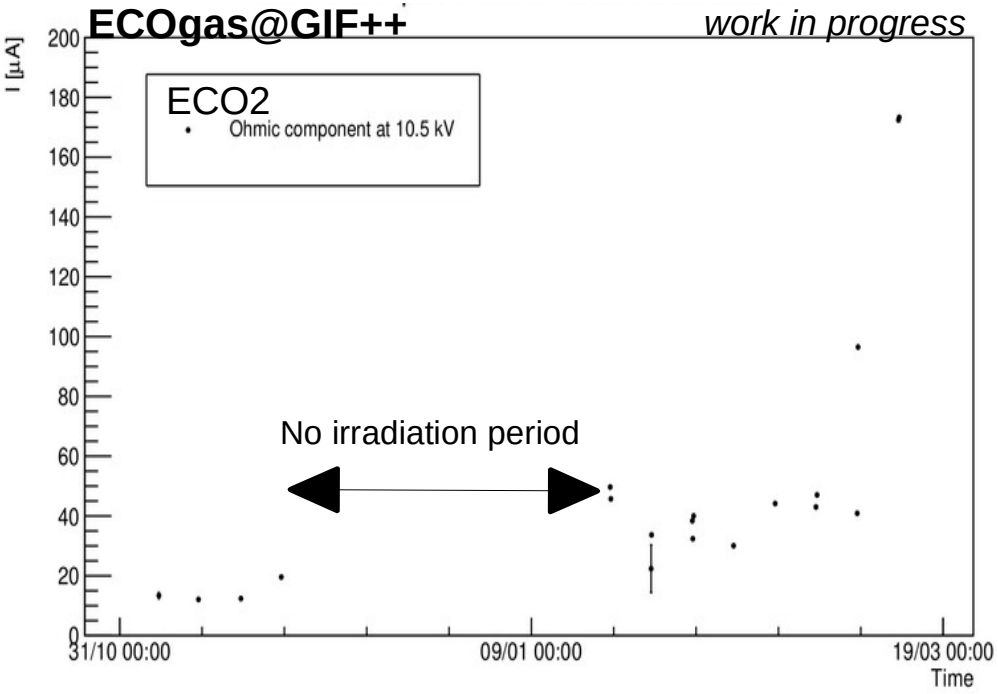


Aging test at GIF++ (3)

- 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 once a 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 mixture consists 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 both ohmic and working current with the gas mixtures under test → link with CO_2 percentage in the gas mixture is *under investigation*

  - 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!