Studies on tetrafluoropropene-CO2 based gas mixtures for the Resistive Plate Chambers of the ALICE Muon IDentifier

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on behalf of the **ALICE collaboration** and **ECOgas@GIF++** collaboration

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Outline

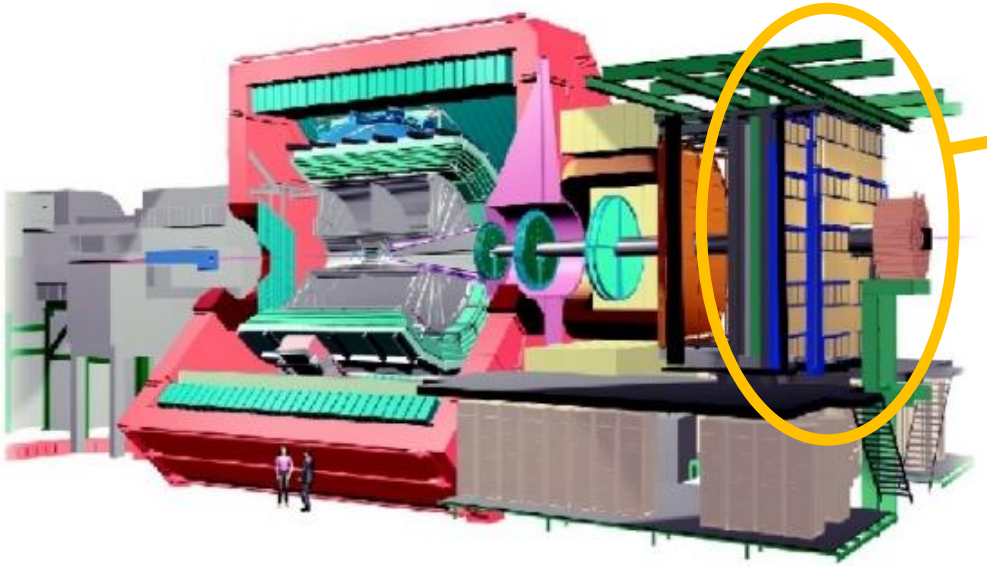
- ALICE Muon Identification System (MID)
- ALICE MID Resistive Plate Chambers
- Search for environment-friendly gas mixture

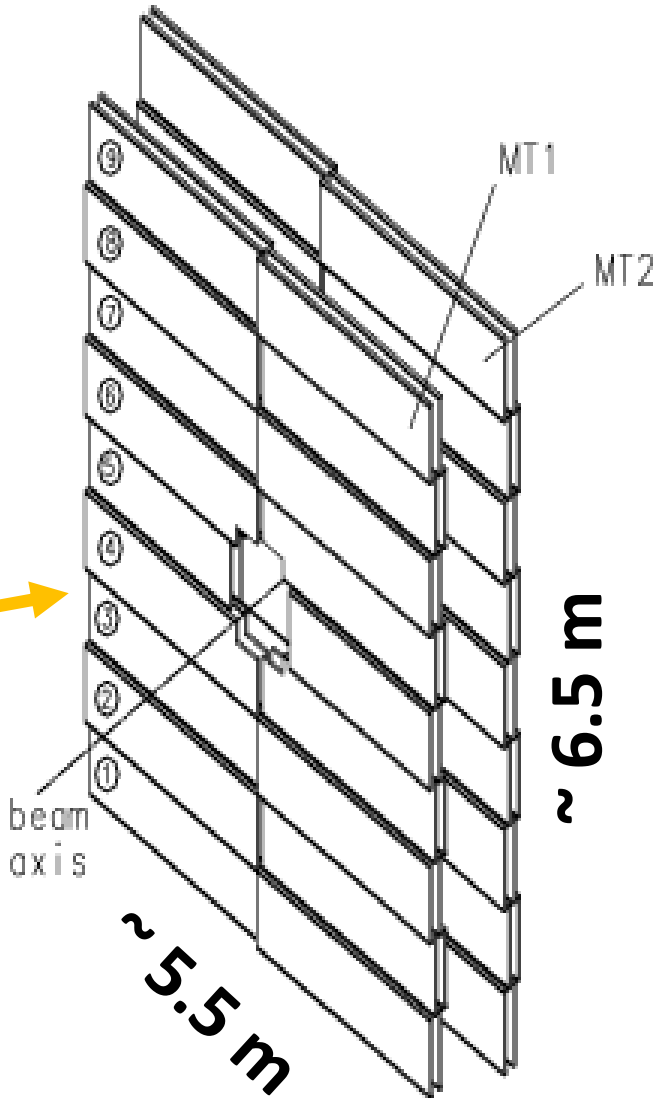
  → from Tetrafluoroethane to Tetrafluoropropene
  → Carbon dioxide and Isobutane percentage variation
  → Sulfur hexafluoride percentage variation

- RPC ageing studies with Tetrafluoropropene-based mixtures at Gamma Irradiation Facility (GIF) at CERN

The ALICE Muon IDentification System (MID)

- Identifies muons in the ALICE Muon Spectrometer accepance
- 72 Resistive Plate Chambers arranged in 2 stations of 2 planes each
- Individual RPCs are ~270 x 70 cm^2, equipped with 21k x-y readout strips (1, 2 and 4 cm pitch)
- Maximum hit rate: < 100 Hz/cm^2





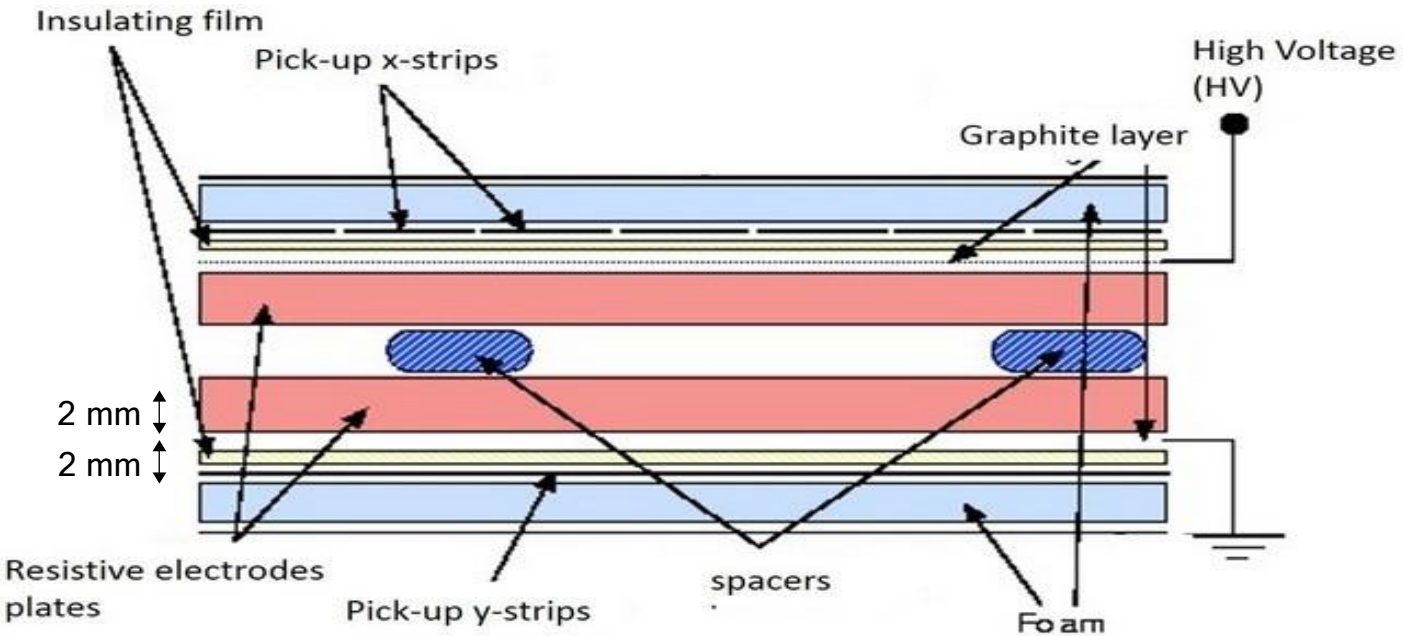
Single gap Resistive Plate Chamber (RPC)

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

- The signal is picked-up inductively by means of copper strips with 50 Ω impedance

During Run 1 and Run 2, MID RPCs worked in maxi-avalanche mode: no signal pre-amplification, 7 mV discrimination threshold (inducted charge ≃100pC)

- gas mixture: 89.7% $C_2H_2F_4$(tetrafluoroethane),10% i-C_4H_{10}, 0.3% SF_6 (35-40% RH)
- effective applied HV of 10.2 -10.5 kV at 970 mbar of pressure and 20°C



Search of environment-friendly gas mixture (1)

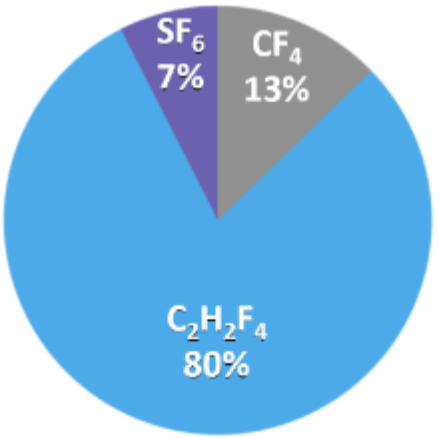
- **Global Warming Potential (GWP)**: relative measure of how much heat a gas traps in the atmosphere (CO_2 GWP = 1 by definition)

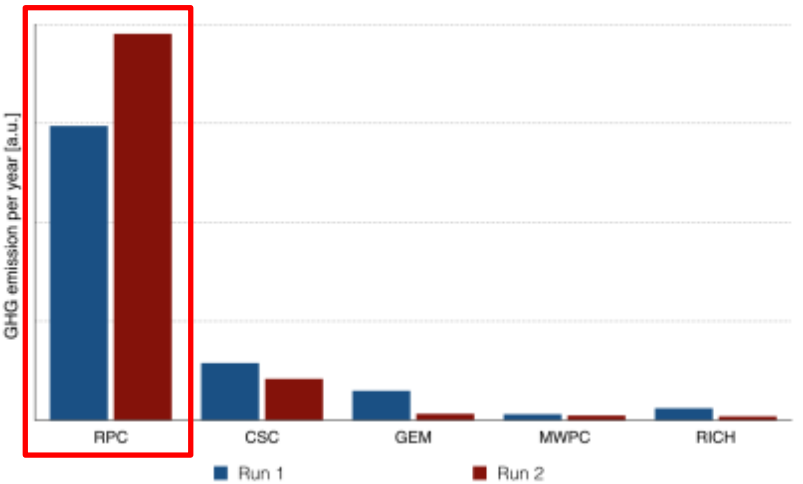
	$C_2H_2F_4$	*i*-C_4H_{10}	SF_6
GWP_{100yr}	1300	3.0	23500

GWP values calculated by IPCC Fifth Assessment Report

- CERN is pushing for more environment-friendly gas mixtures for particle detectors

Relative contribution of GHGs and detectors used at CERN LHC experiments



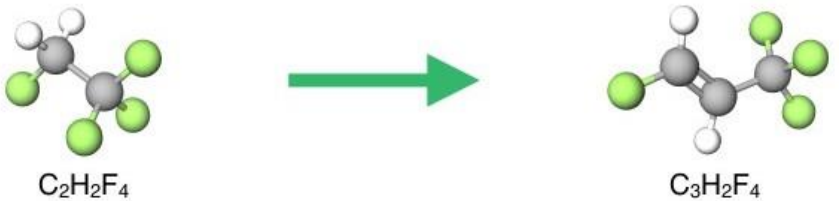


→ **goal: new RPC mixture with a lower GWP**

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

- R&D studies are **still ongoing**. Up to now work is being carried out on the replacement of tetrafluoroethane (R134a, 95% of the total GWP of the mixture) with **1,3,3,3-Tetrafluoropropene** ($C_3H_2F_4$, HFO-1234ze(E))



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 much higher HV Working Point (WP)

→ need to lower the HV by adding less electronegative component (CO_2)

Experimental setup for gas studies

- The tests on eco-friendly gas mixtures were performed in the INFN Torino laboratory, using cosmic rays

Setup 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 cosmic ray triggering (total trigger area ~6 x 6 cm^2)
- ALICE FEERIC pre-amplified front-end discriminators ($Q_{induced}$threshold ~130 fC)

HV applied with temperature and pressure correction

Possibility to mix up to 4 different gases

Performance with 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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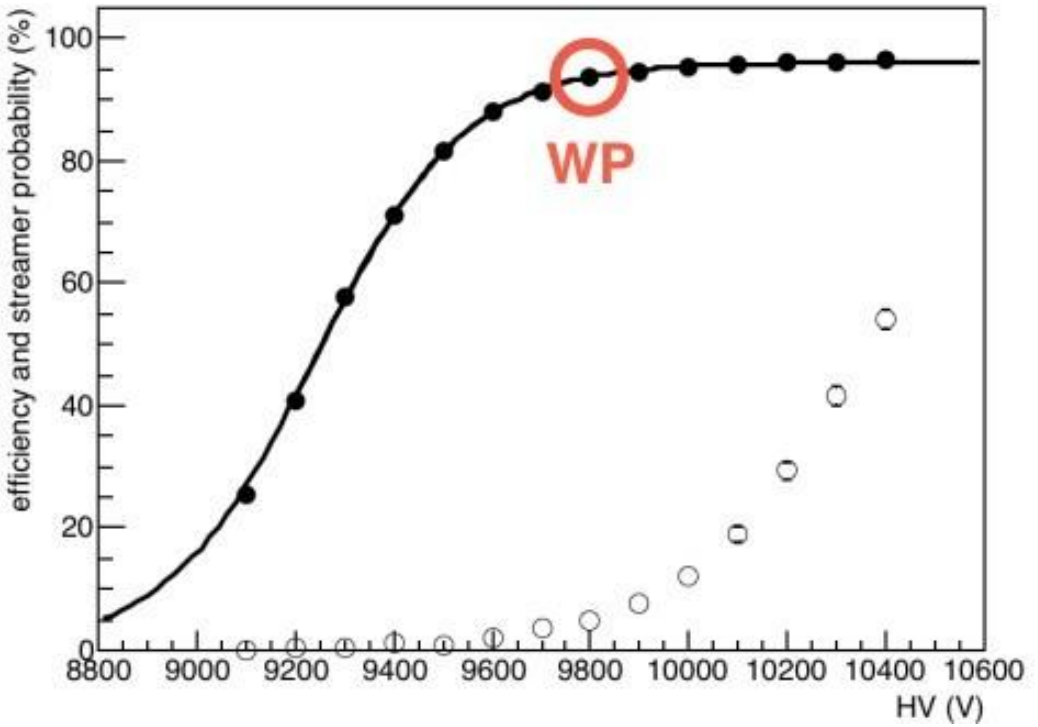
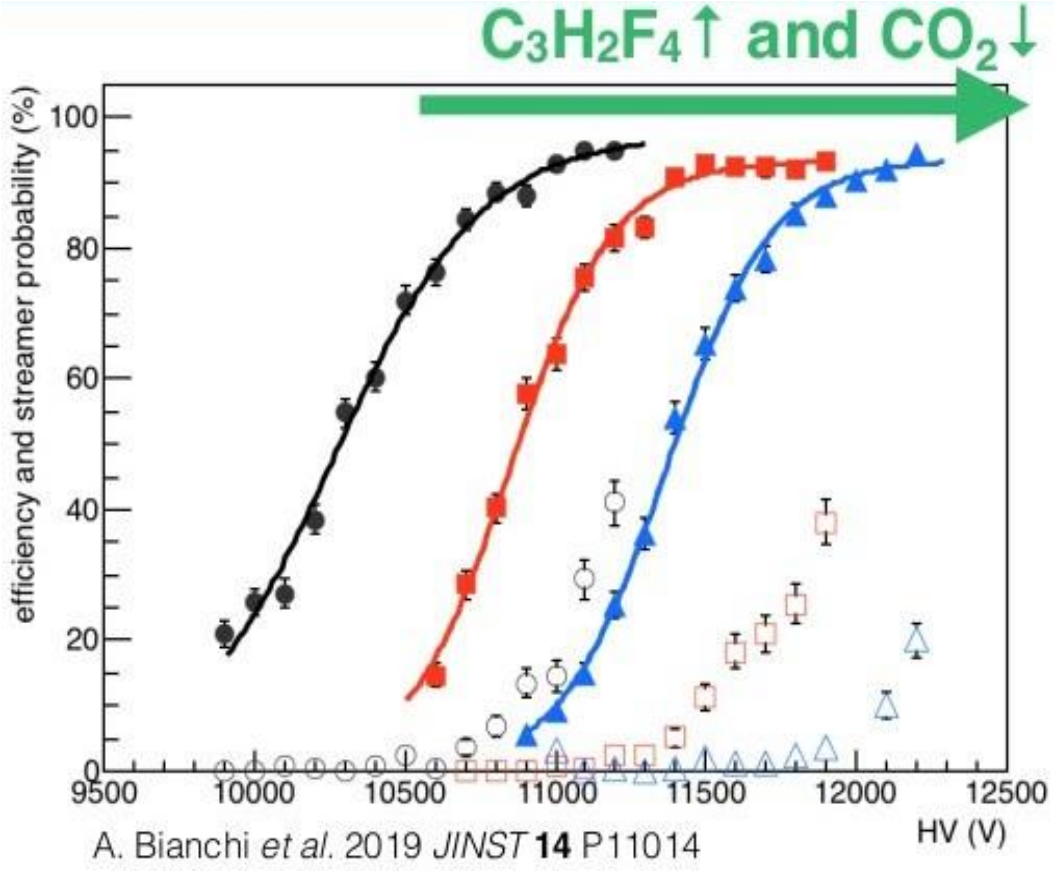


Tetrafluoropropene – CO_2 ratio studies

- 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
- Mixtures with <u>different</u> $C_3H_2F_4$ and CO_2 ratio; <u>constant</u> *i*-C_4H_{10} (10.0%) and SF_6 (1.0%) ratio.

  - $C_3H_2F_4$ = 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 :
  - **HV shifted towards higher Voltages**
  - no significant variation of the streamer probability



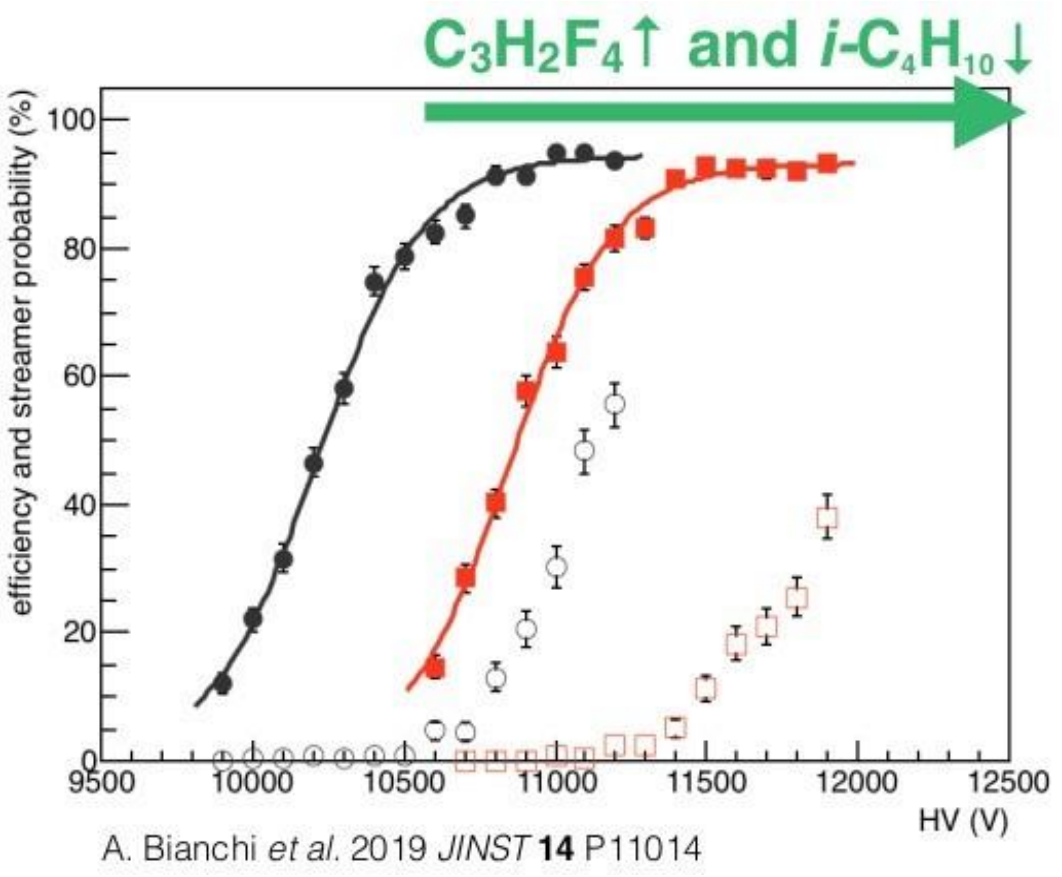
Tetrafluoropropene – *i*-C_4H_{10} ratio studies

- The same study has been performed in order to evaluate the RPC behaviour when changing the **tetrafluoropropene-isobutane** ratio

2) Mixture with <u>different</u> $C_3H_2F_4$ and i-C_4H_{10} ratio; <u>constant</u> 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%

- The higher the tetrafluoropropene fraction, the higher the HV
- Conclusion: **strong dependence between the concentration of $C_3H_2F_4$ and the HV**



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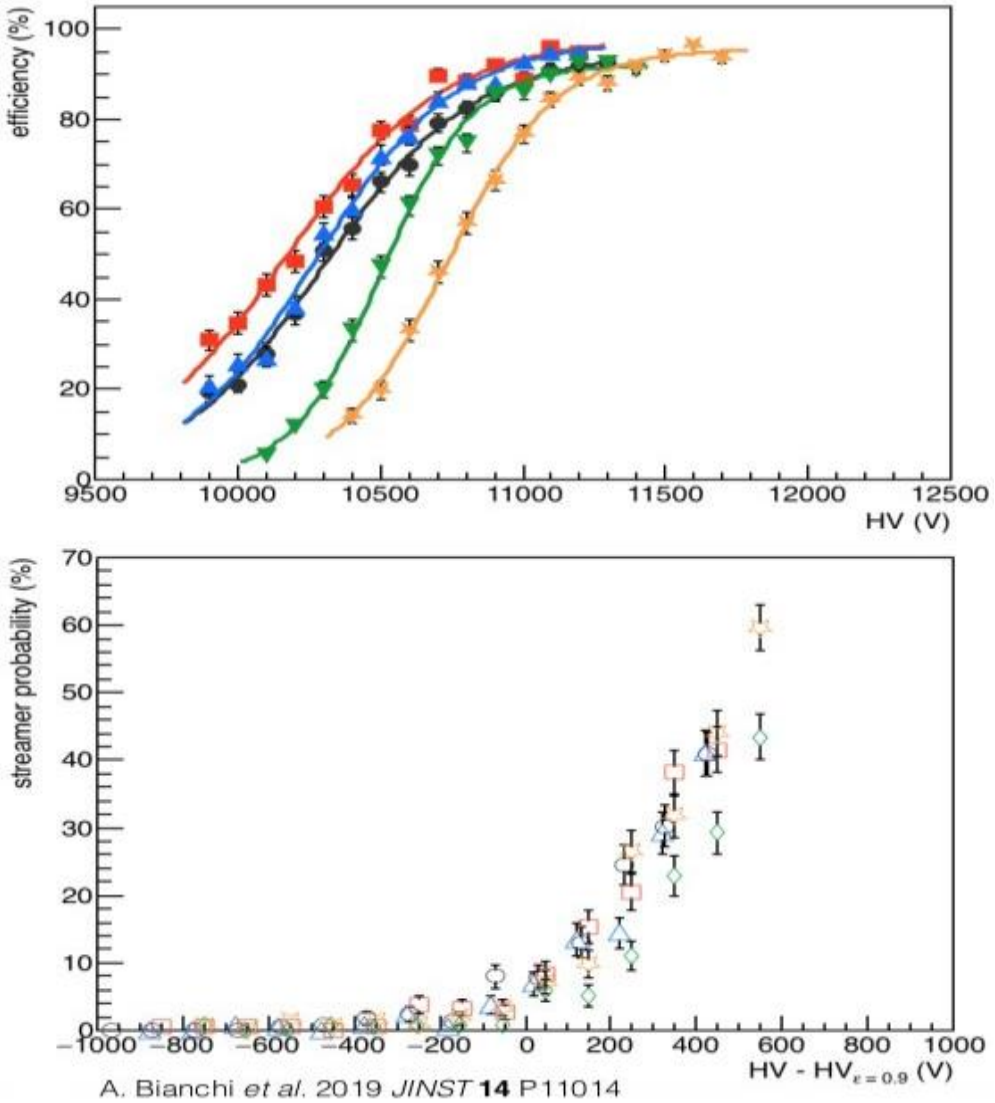
Studies on ratio between CO_2 and i-C_4H_{10}

- Mixtures with <u>different</u> CO_2 and i-C_4H_{10} ratio; <u>constant</u> $C_3H_2F_4$ (~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%

  the working **HV** 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)



Variation of SF_6 fraction

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

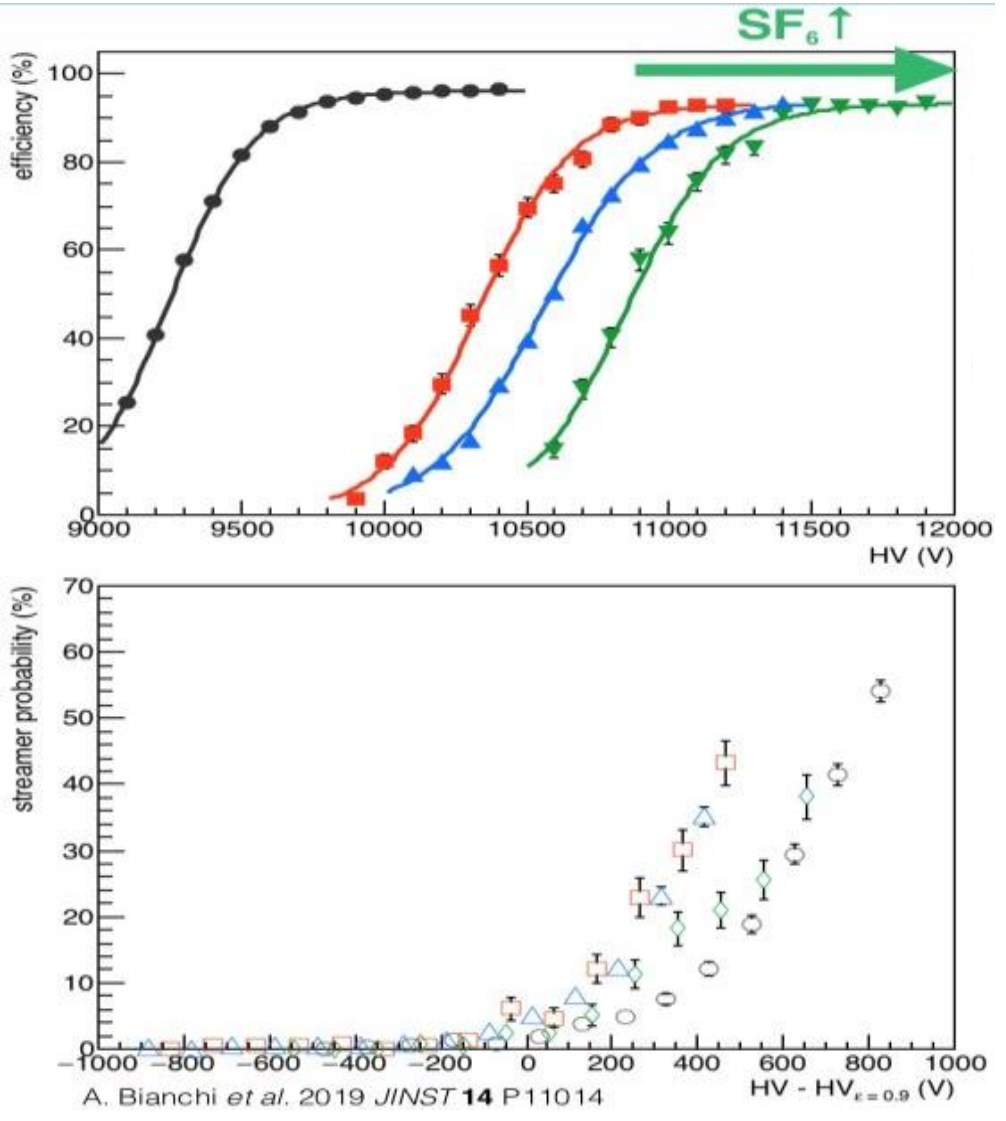
  - **SF_6 = 0.3%**; $C_2H_2F_4$ = 89.7%; *i*-C_4H_{10} = 10.0% (standard)

  Tetrafluoropropene mixtures:

  - **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%

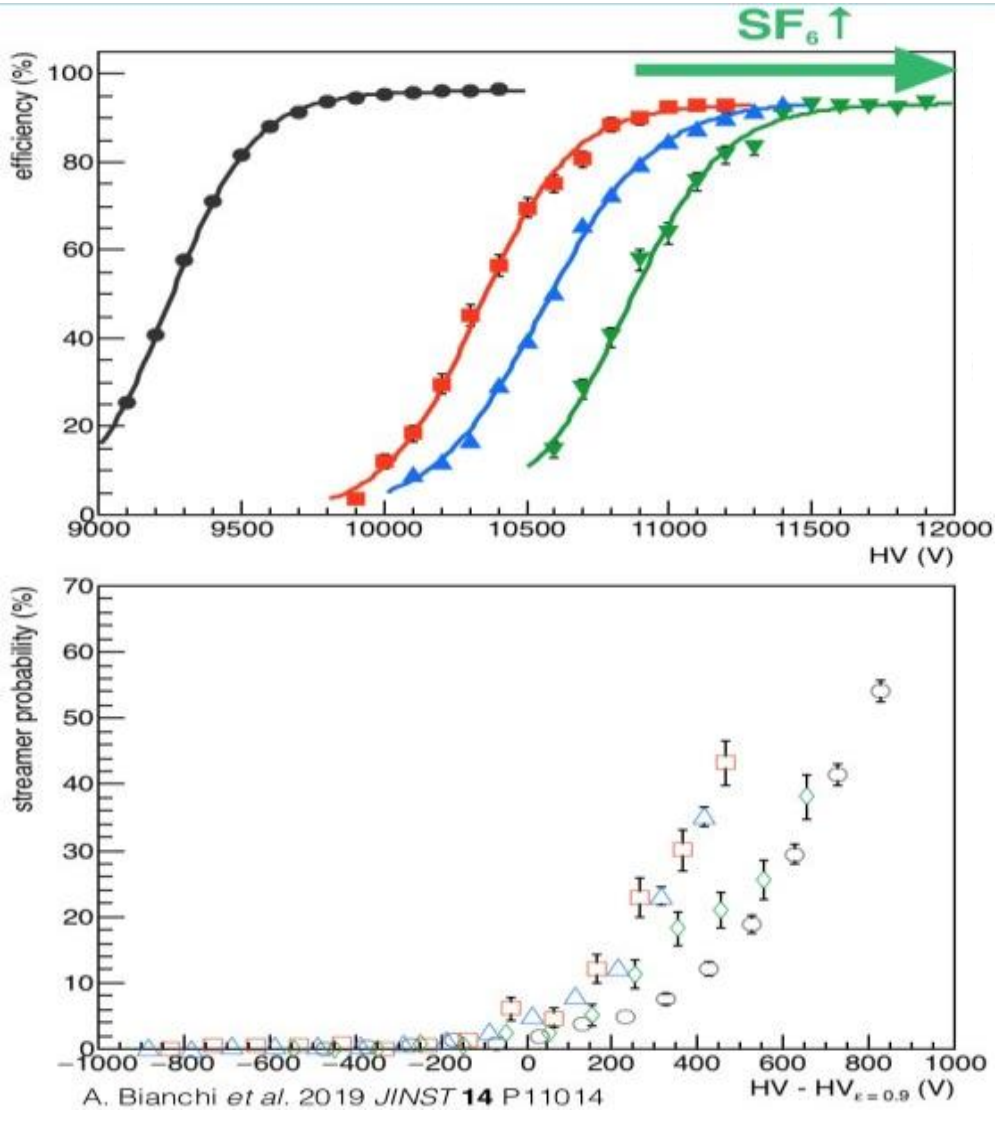


Variation of SF_6 (2)

- 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)

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

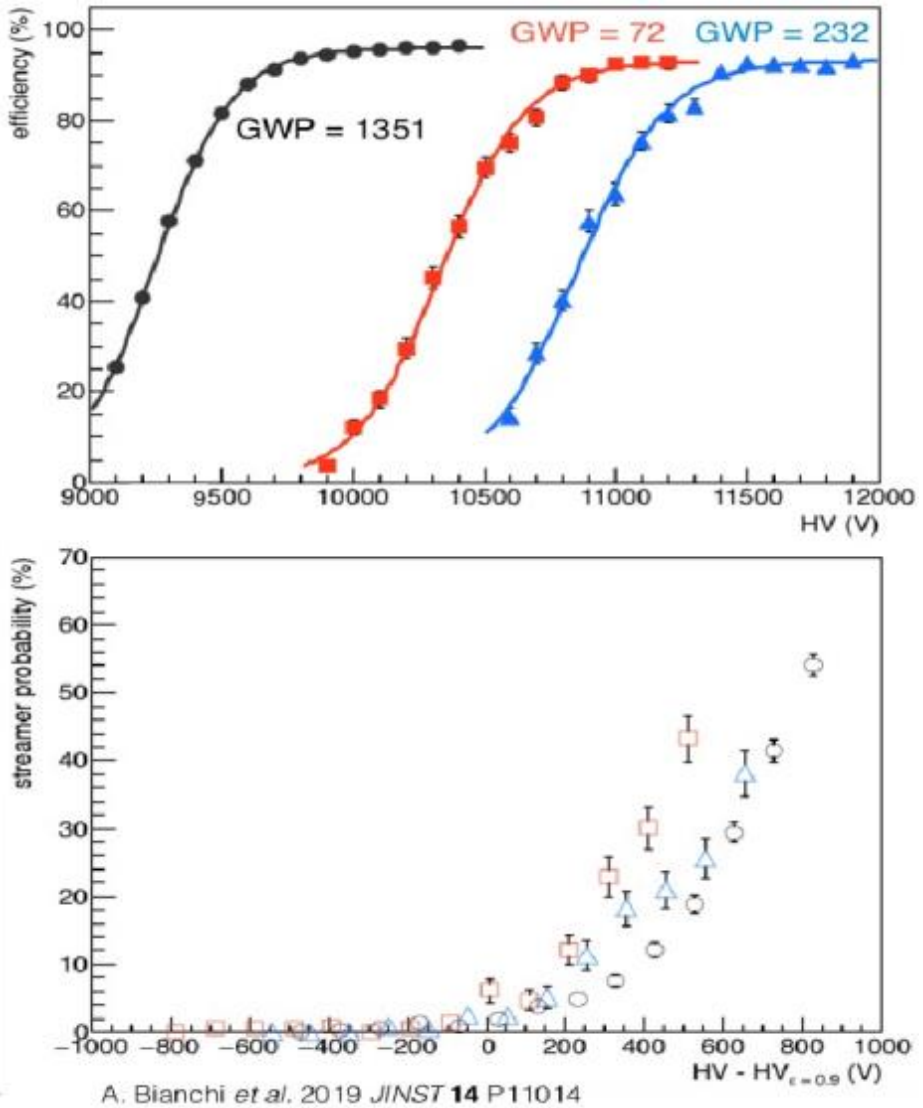
- The black curve shows the performances of RPCs with the ALICE standard gas mixture, with GWP = 1351

  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)

  - **HV 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



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

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

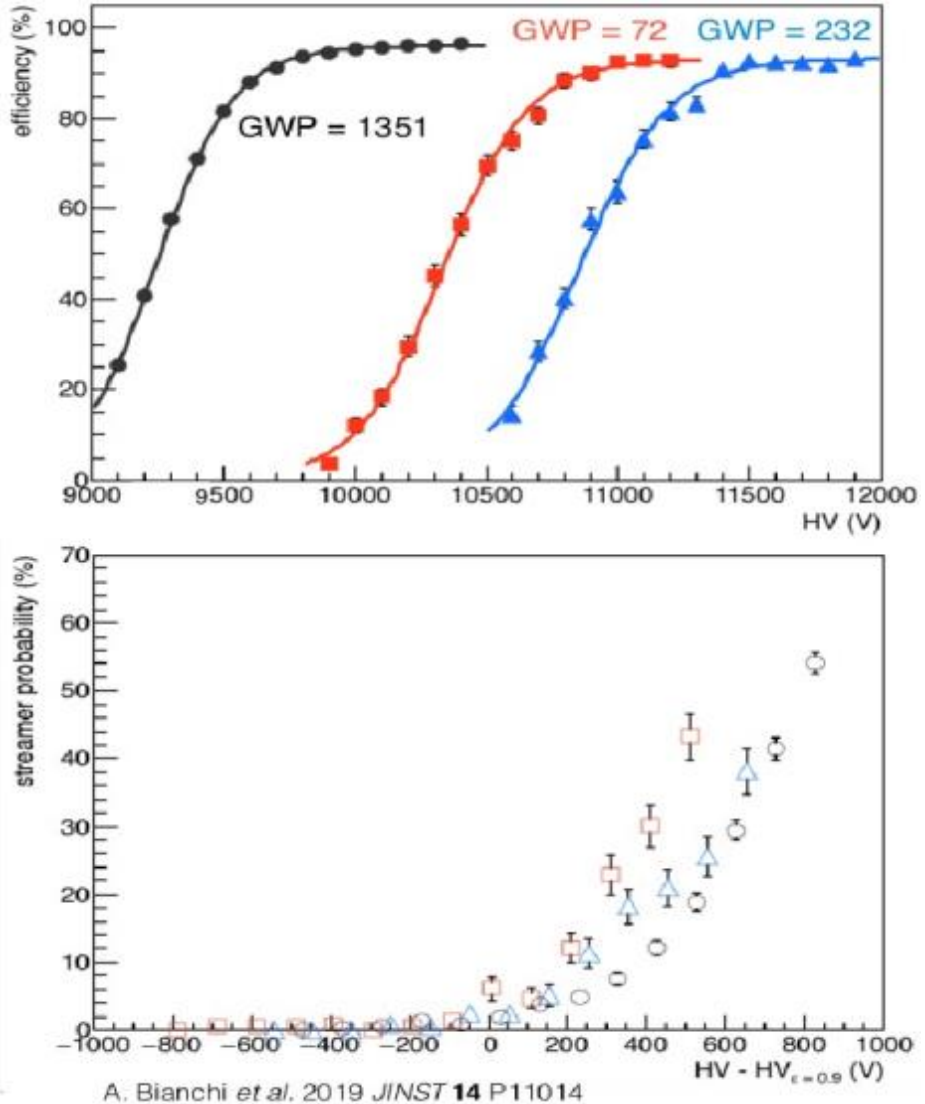
- The black curve shows the performances of RPCs with the ALICE standard gas mixture, with GWP = 1351

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



Tests at Gamma Irradiation Facility (GIF++)

- **Aging test**→ RPC ageing is mostly due to deterioration of the inner electrodes surface smoothness, which depends on UV and chemical action
- Ageing strongly influenced by the gas mixture
- To check the ageing performance before installation, active detectors are exposed to a high radiation dose in order to simulate many years of operations, keeping track of performances over time

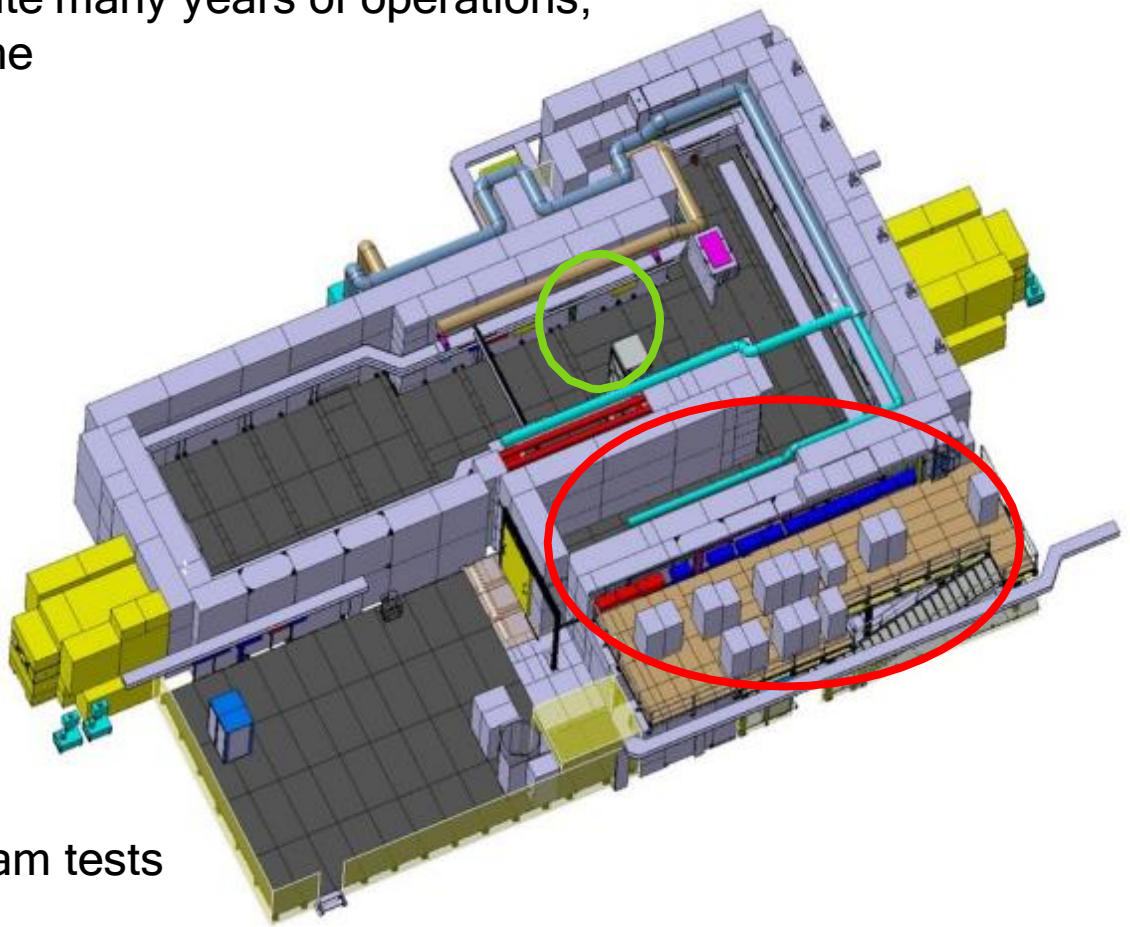
- Tests performed at CERN Gamma Irradiation Facility (GIF++):

  - **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++

- **ECOgas@GIF++** collaboration has been created among RPC groups in different experiments (ALICE, ATLAS, CMS, EP-DT, ShiP) to perform these aging tests in a shared way

- 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

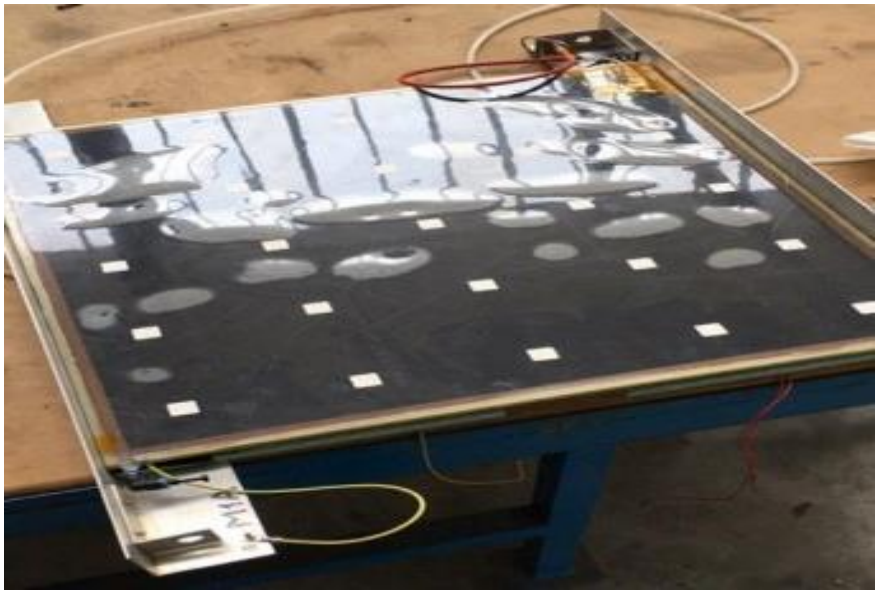
- Chambers are kept at a HV value close to the WP of the RPC and are irradiated for a long amount of time **(stability test)**

- Every week an **high voltage scan** to measure the **current** is performed without irradiation in order to measure the dark current (ageing indicator) 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

- RPCs have been provided by the different groups and have been installed on a **common trolley** placed inside the bunker.



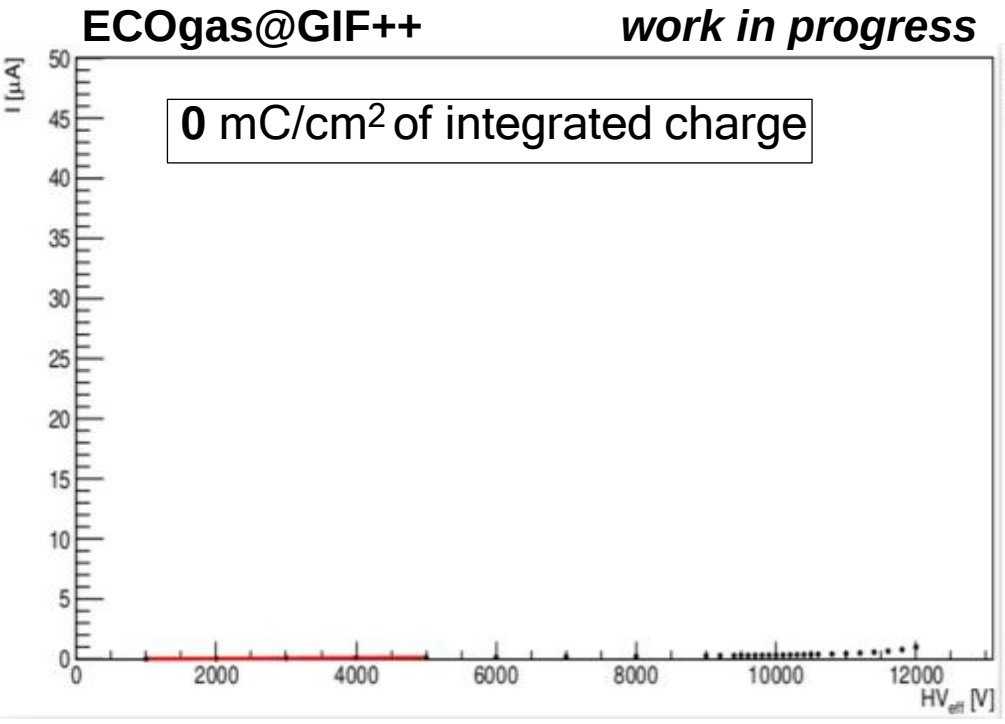
ALICE RPC gas gap

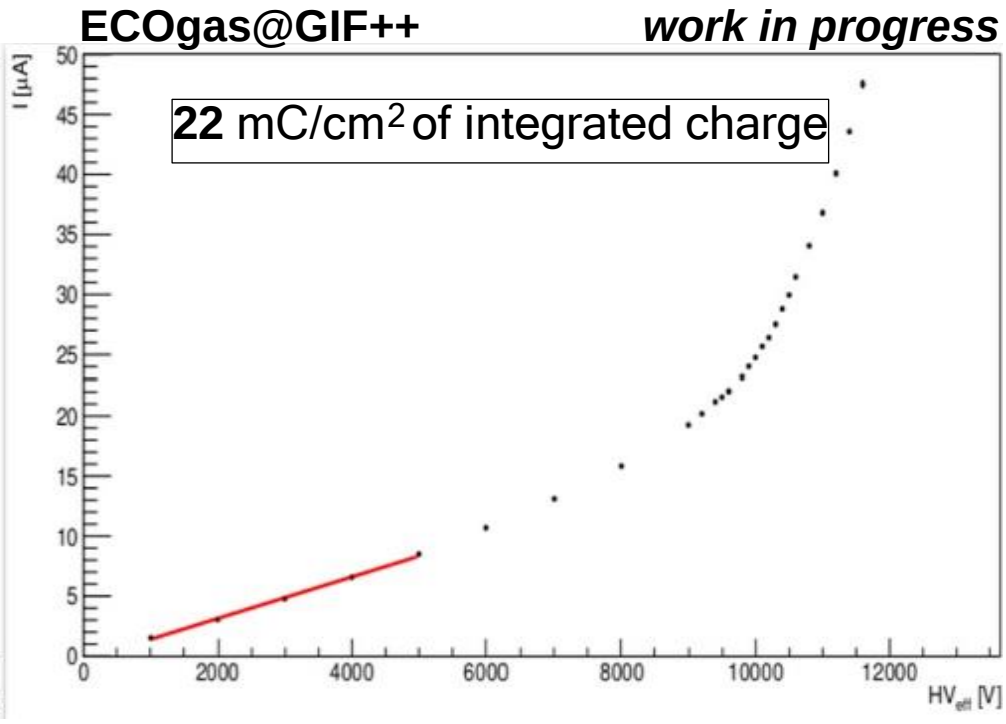
Aging test at GIF++ (1)

- The I-V curves for the ECO1 gas mixture with source OFF 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





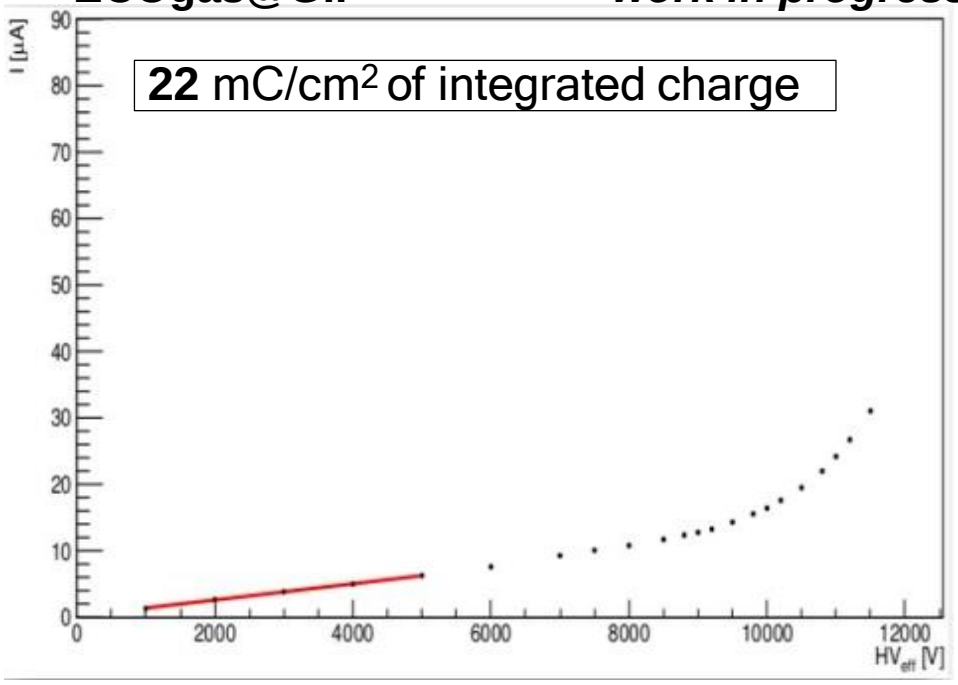
Aging test at GIF++ (2)

- 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 irradiation

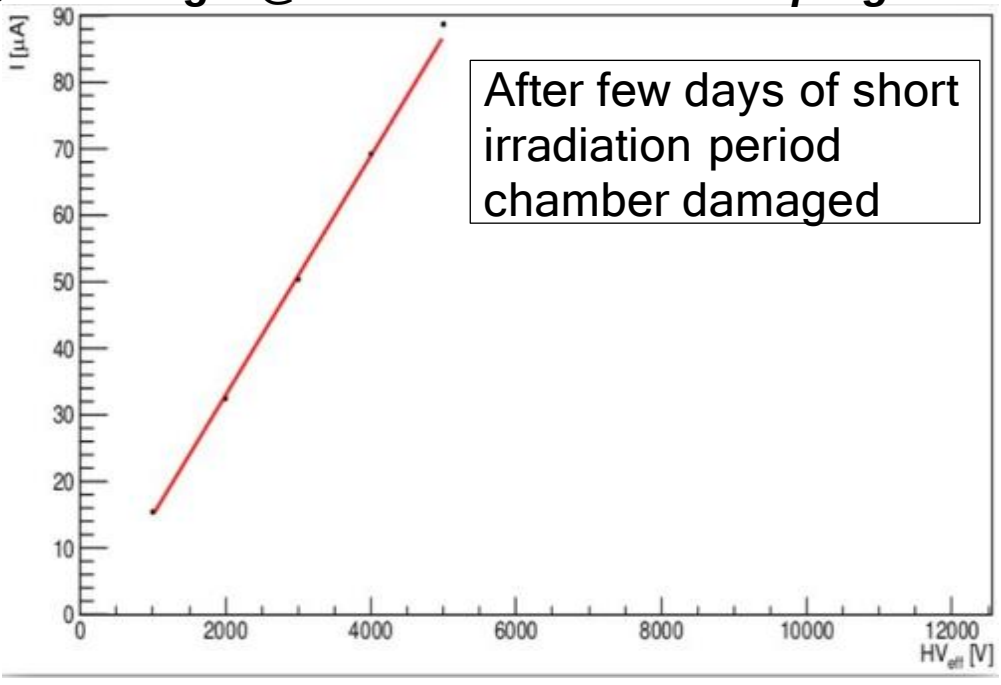
- By **increasing the percentage of CO_2** we have observed a large increase of the current as soon as we started the tests with ECO2 → the last HV scan for the ALICE RPC is not reliable

- Tests have continued with other RPCs from the collaboration→ ***results under investigation***

ECOgas@GIF++ ***work in progress***

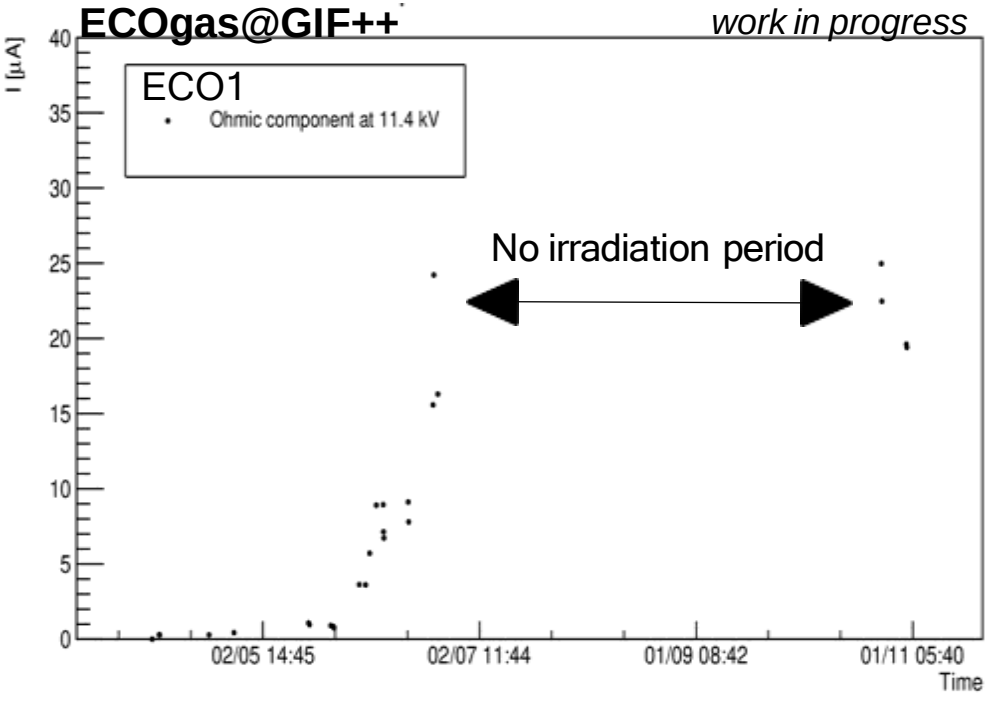


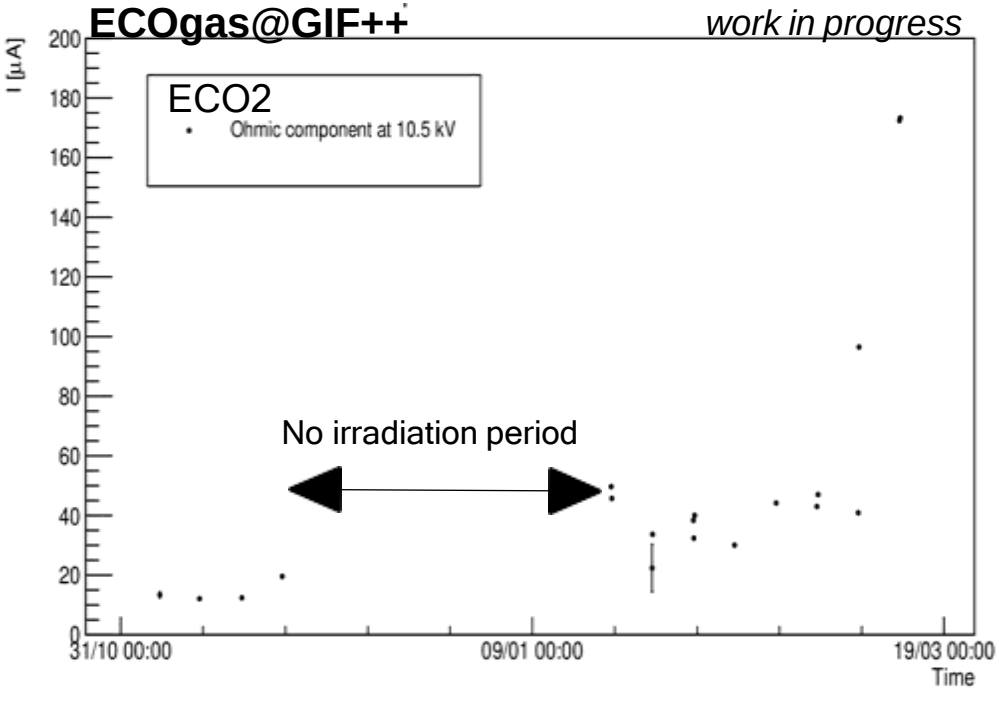
ECOgas@GIF++ ***work in progress***



Aging test at GIF++ (3)

- The Ohmic component of the current (extrapolated with linear fit from I-V curve up to the HV working voltage) after ECO1 and ECO2 irradiation 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 and outlook

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

  - Tetrafluoropropene seems a possible candidate to replace Tetrafluoroethane

  - Direct replacement is not suitable because of the high WP (> 14 kV) → addition of CO_2 to lower operating voltage

  - 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 other beam tests will take place in September and October 2021