INFN BARI
Istituto Nazionale di Fisica Nucleare
Sezione di Bari

XIII International Conference on New Frontiers in Physics
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Long-term ageing studies on Eco-Friendly Resistive Plate Chamber detectors

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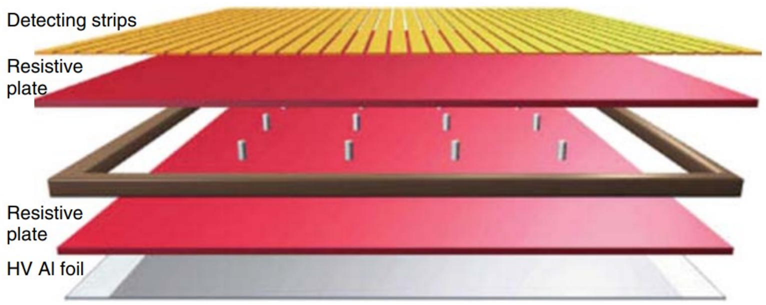
Resistive Plate Chambers

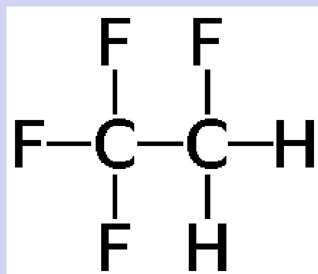


Gaseous detectors widely employed in HEP experiments for triggering and particle identification purposes:

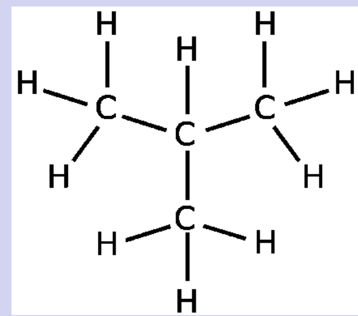
- low cost per unit area;
- high efficiency and time resolution;
- ease of construction and robustness.

«Standard» gas mixture for RPCs

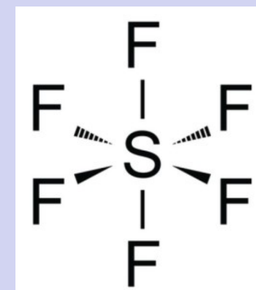
- High density of primary ion-electron pairs:
  high RPC efficiency
- Good quenching properties and electronegativity
  good rate capability and "slow" detector aging



R134a (>90%)



iC_4H_{10}



SF_6 (<1%)

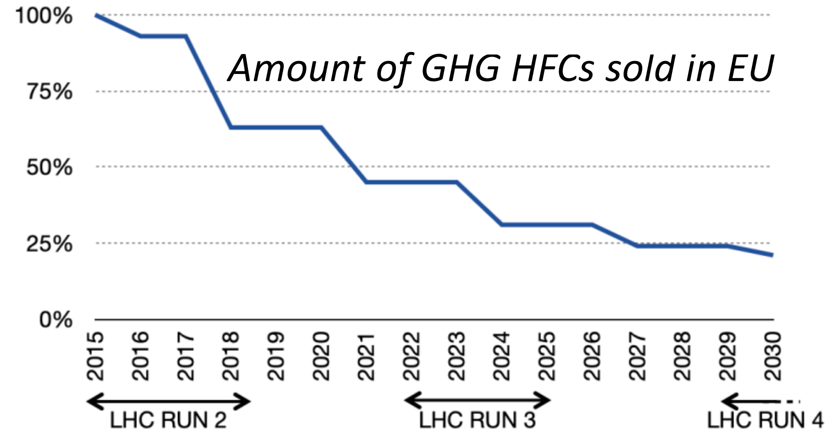
However, R134a and SF_6 are Fluorinated Greenhouse gases (F-gases) having high **Global Warming Potential (GWP)***
[e.g. the main component for standard gas mixture (R134a) has GWP as high as 1430]

**measure of the heat trapped in the atmosphere by a ton of a given gas, if compared to a ton of CO_2*

The limitation of greenhouse gases

- The sale and the use of F-gases have been limited in EU [EU regulation 517/2014].

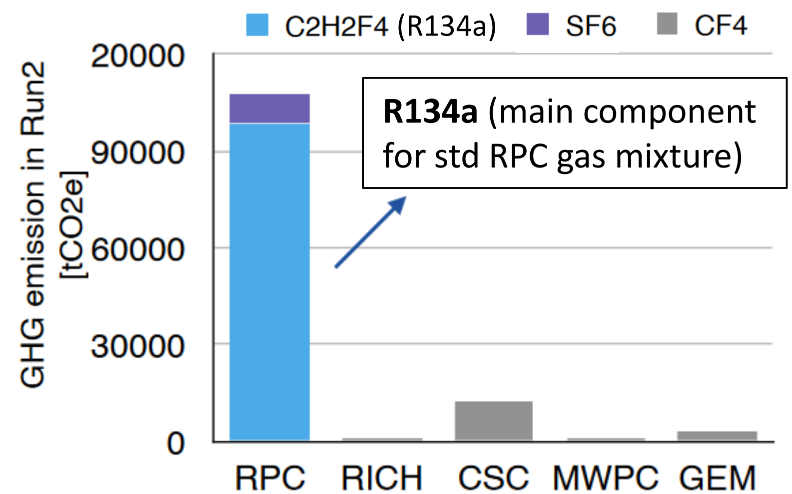
Prices of F-gases are increasing in the EU and their availability in the future is not known.



- CERN is committed to reducing its direct greenhouse gas emissions [CERN Env. Report].

Largest contribution: R134a operated in the RPCs

Intense research activity on **alternative gas mixtures ongoing**.
[Requirements: low GWP, low toxicity, not flammable and performance comparable with std mix.]

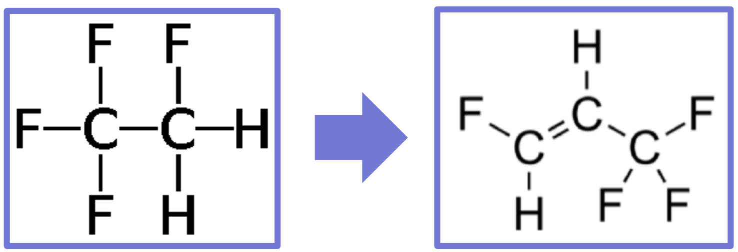


The **RPC ECOGAS@GIF++ Collaboration** is a joint effort between RPC communities from different experiments [ALICE, ATLAS, CERN Gas team, CMS, LHCb/SHiP]
goal: study of new eco-friendly gas mixtures for RPCs

New eco-gas mixtures for RPCs

- R134a is being replaced in industrial applications with HydroFluoro-Olefins (HFOs)
  ➡ similar chemical structure but lower GWP.

R134a, GWP=1430 **HFO-1234ze, GWP=6**

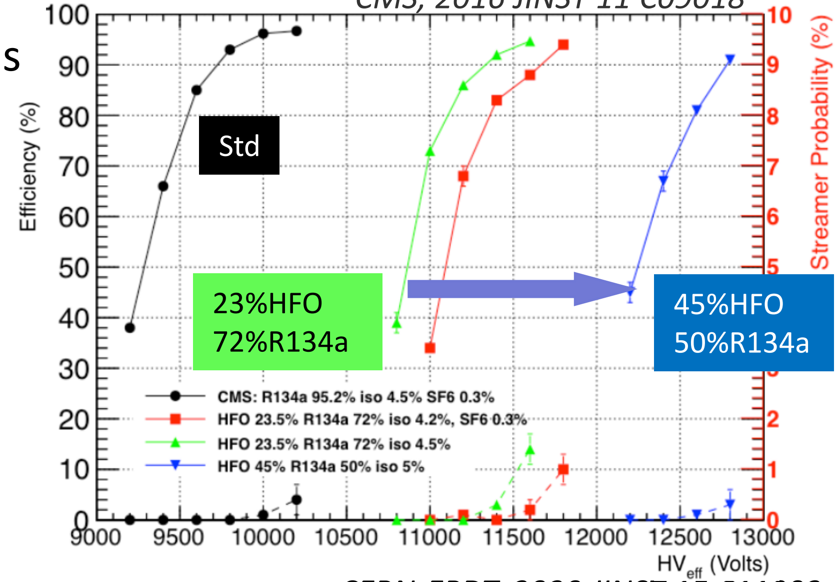


- Several tests performed in laboratories from different institutes of the Collaboration:

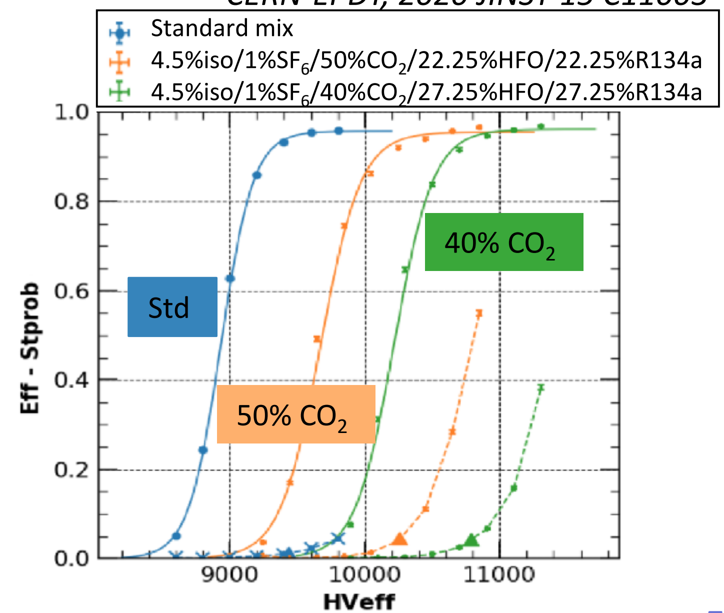
  - The replacement of R134a with HFO moves the operating voltage to very high values (>13kV for 2mm gaps).

  - The addition of CO_2 helps in decreasing the WP.

CMS, 2016 JINST 11 C09018

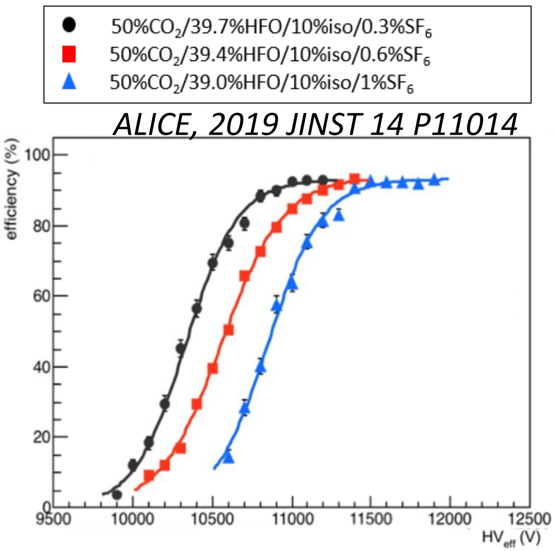


CERN-EPDT, 2020 JINST 15 C11003

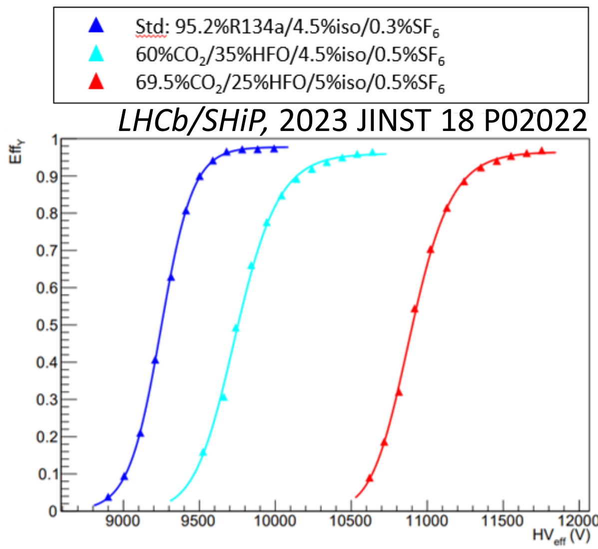


New eco-gas mixtures for RPCs

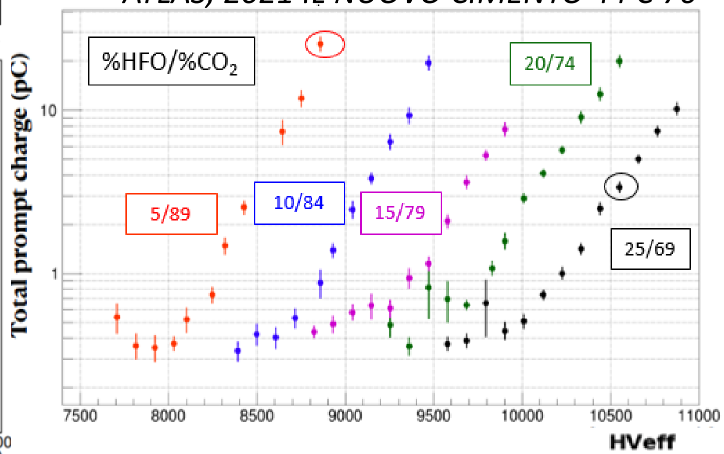
Several R134a-free mixtures with CO_2/HFO/iC_4H_{10}/SF_6 tested in the various laboratories



ALICE, 2019 JINST 14 P11014



LHCb/SHiP, 2023 JINST 18 P02022



ATLAS, 2021 IL NUOVO CIMENTO 44 C 70

Promising results have been obtained with the gas mixtures:

ECO1: 45% HFO / 50% CO_2 / 4% iC_4H_{10} / 1% SF_6
ECO2: 35% HFO / 60% CO_2 / 4% iC_4H_{10} / 1% SF_6
ECO3: 25% HFO / 69% CO_2 / 5% iC_4H_{10} / 1% SF_6

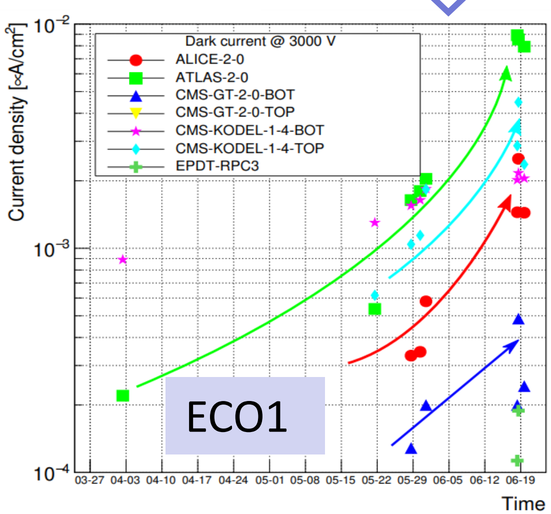
GWP reduced by 1/3 w.r.t. the std mixture!

These mixtures have been tested with different RPC detectors at various background conditions at the CERN Gamma Irradiation Facility (GIF++).

RPC EcoGas@GIF++ Collaboration timeline

2018 — RPC EcoGas@GIF++ Collaboration

Studies in different laboratories
Setup of the system at GIF++ and first HFO/CO_2 based gas mix. under irradiation



ECO1 discarded due to high current increase after ~20 mC/cm^2 integrated charge

AidaInnova Startup

2021

2021 testbeam — 2022 testbeam — 2023 testbeam — 2024 testbeam

Irradiation campaign for ageing studies

Performance baseline

Performance comparison

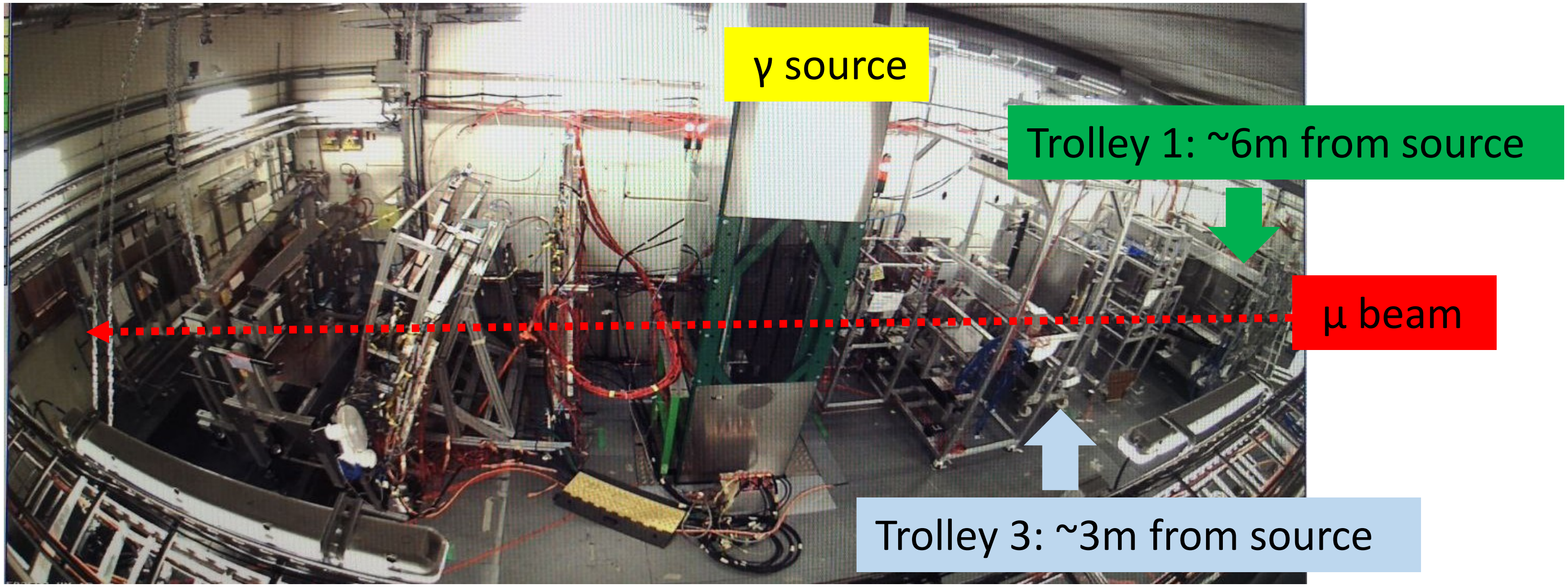
Std, ECO2 and **ECO3** mixtures tested under irradiation. First results in papers *[1][2][3]*.

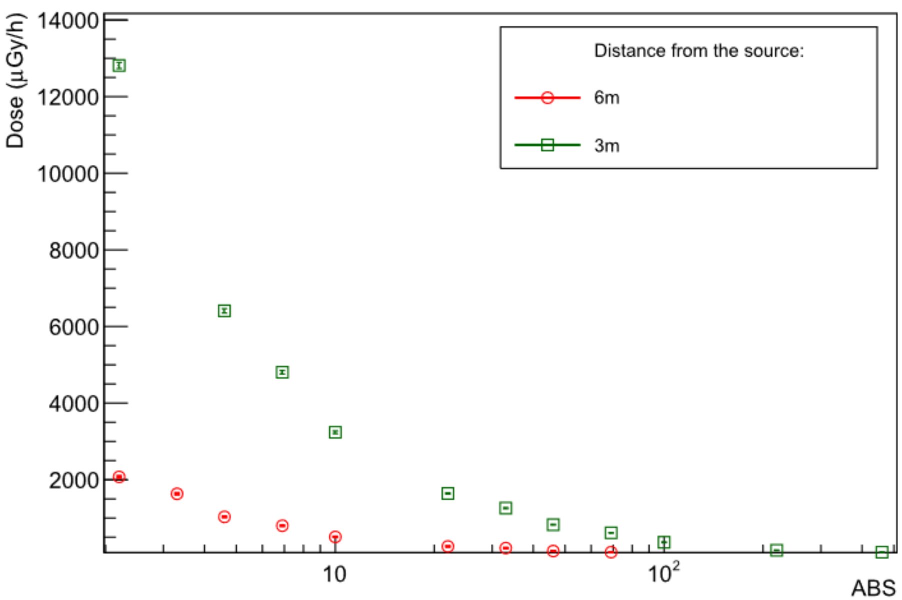
[1] "High-rate tests on resistive plate chambers operated with eco-friendly gas mixtures", 2024 Eur. Phys. J. C.

[2] "Performance of thin-RPC detectors for high rate applications with eco-friendly gas mixtures", 2024 Eur. Phys. J. C.

[3] "Preliminary results on the long term operation of RPCs with eco-friendly gas mixtures under irradiation at the CERN Gamma Irradiation Facility" – submitted to EPJplus.

Setup at GIF++



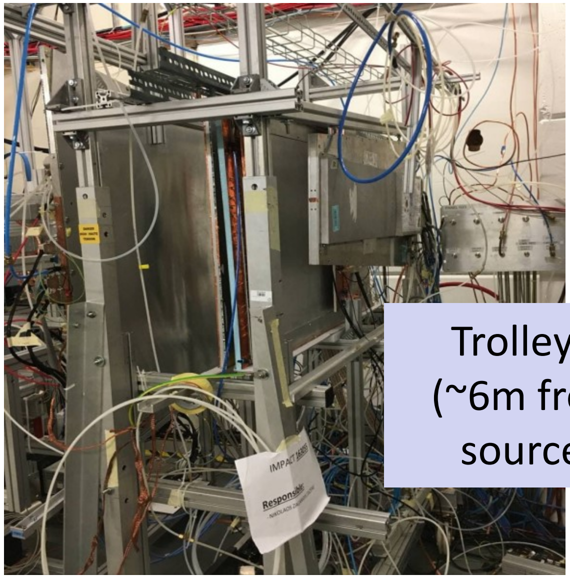


- 12.5 TBq ^{137}Cs source producing γ (at ~660keV) + adjustable filters (24 possible attenuation factors, ABS);
- Two mechanical frames (Trolleys 1 and 3) installed inside the GIF++ bunker hosting RPCs.
- Periodical beam tests of the detectors: muon beam (~100 GeV/c) from the secondary CERN SPS H4 beam line;
  beam trigger provided by the coincidence of two scintillators positioned on Trolley 1 and 3 with the GIF++ external scintillators.

Setup at GIF++

RPC	Gap thickness	Electronics
ALICE	2mm	FEERIC + TDC
ATLAS	2mm	Digitizer
CMS	2mm – double gap	CMS FEB + TDC
CMS upgrade	1.4mm – double gap	CMS FEB + TDC
EP-DT	2mm	Digitizer
LHCb/SHiP	1.6mm	FEERIC + TDC

- RPCs with different dimension, gap thickness and features installed on Trolley 1 and 3.
- Dedicated HV modules and readout electronics for each RPC
- Gas mixer unit to provide up to 4 component gas mixture (humidified) to all the RPCs.
  [gas mix currently under test: Std, ECO2, ECO3]
- Flowmeter to monitor gas flow for each RPC
  → keep a stable flow in the detectors.

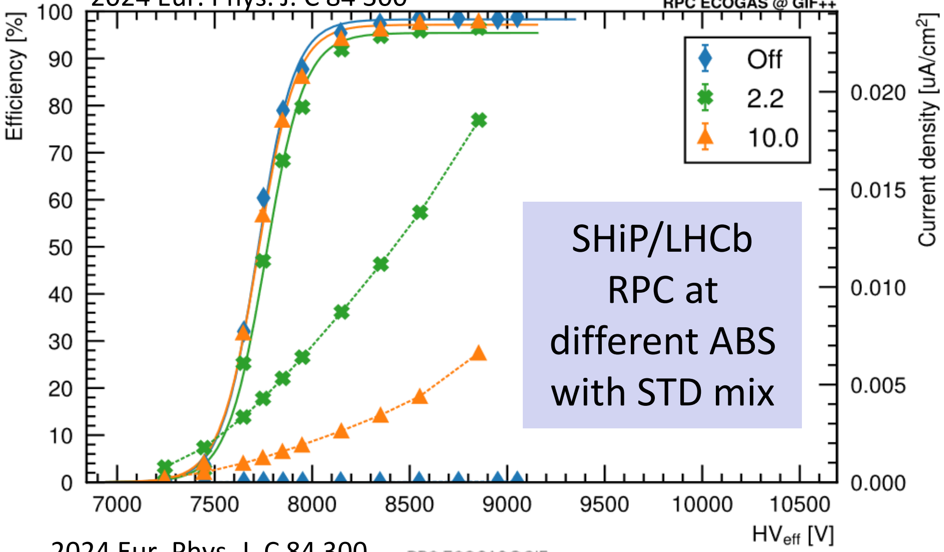


Trolley 1 (~6m from source)

Trolley 3 (~3m from source)

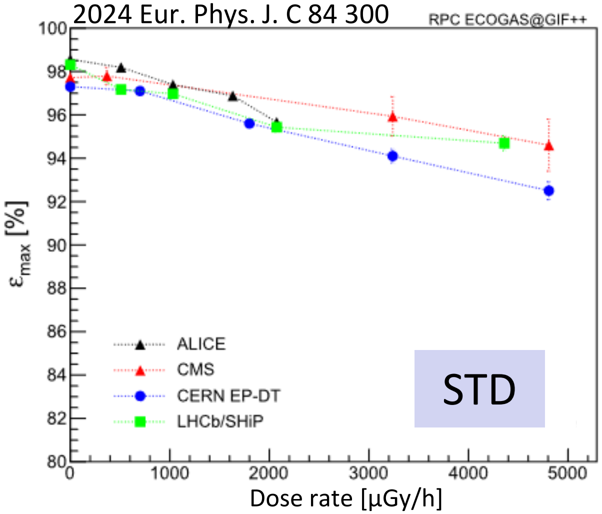
RPC performance under irradiation: baseline

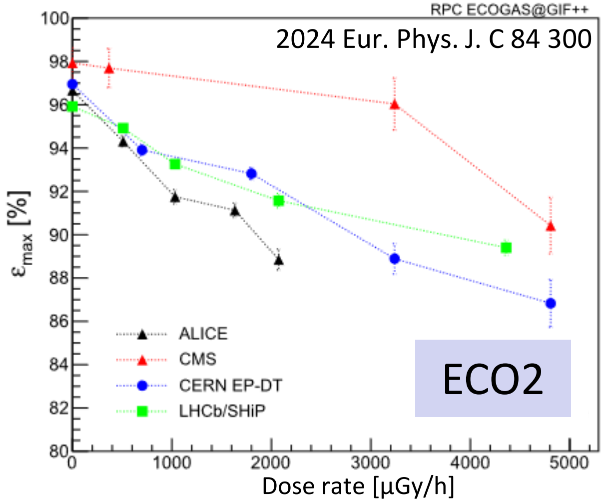
2024 Eur. Phys. J. C 84 300



- HV is corrected for temperature and pressure variations*
  *[1995 Nucl. Instrum. Meth. A 359 603-609]
- Fit of efficiency curves with logistic function: $$\varepsilon(HV_{eff}) = \frac{\varepsilon_{max}}{1 + e^{-\gamma\cdot(HV_{eff}-HV_0)}}$$
- The working point is defined as: *$WP = HV_{eff}(@eff=95\%) + 150\ V$*

2024 Eur. Phys. J. C 84 300





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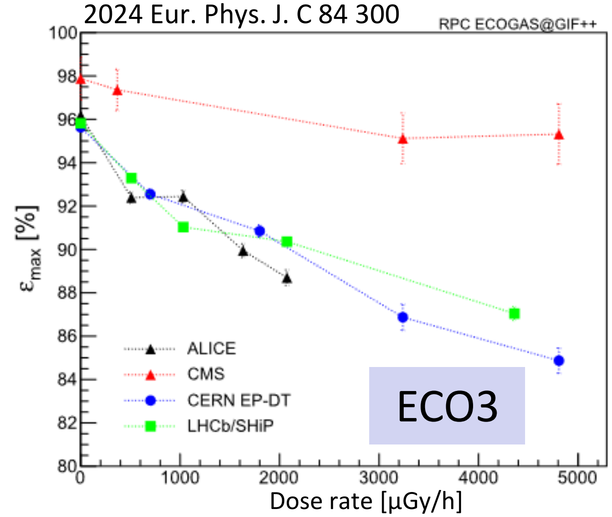
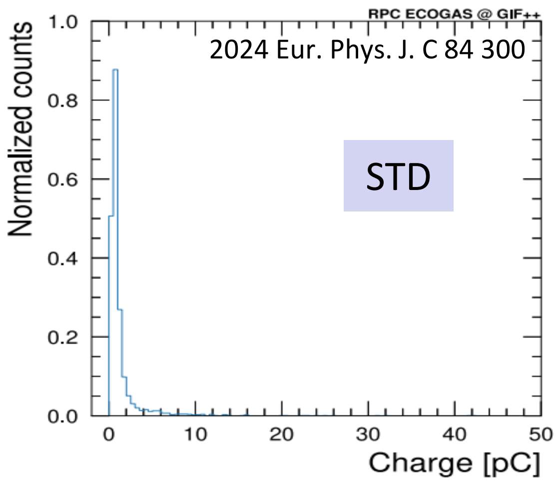


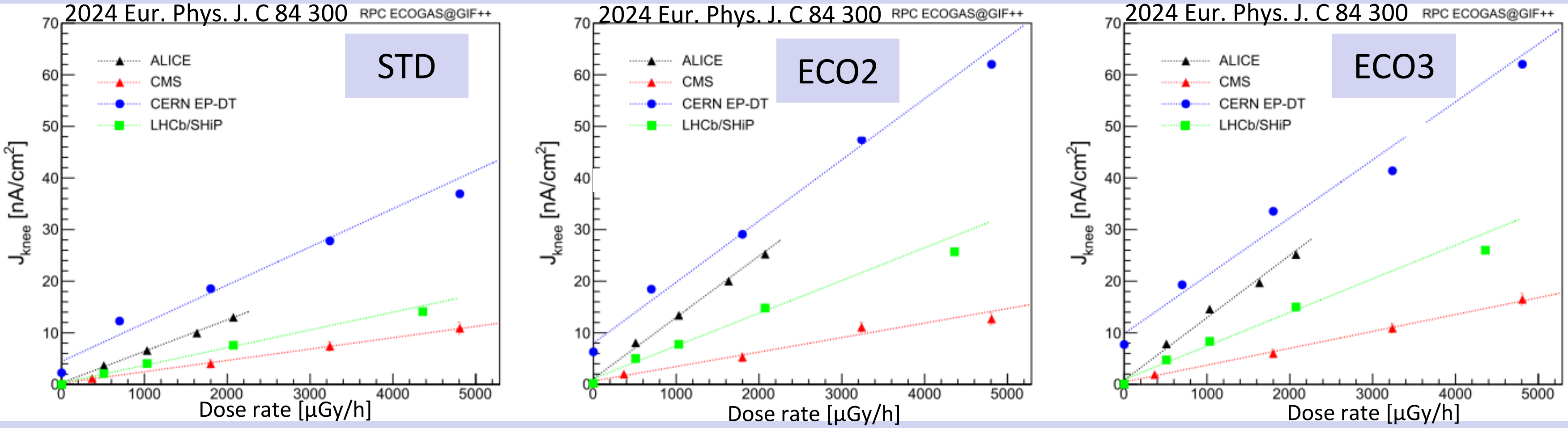
From 0 to the maximum irradiation (5000 µGy/h, i.e. several hundreds of Hz/cm^2):
eff decrease with std ~5% further decreased by a few % with eco-gas

RPC performance under irradiation: baseline

Charge distributions of the signals induced on ATLAS RPC at HV_{knee} without source.
Increase of events with large charge for eco-gas w.r.t. std.



At the same irradiation, the current density J_{knee} at HV_{knee} is a factor of ~2 higher for eco-gas w.r.t. std.

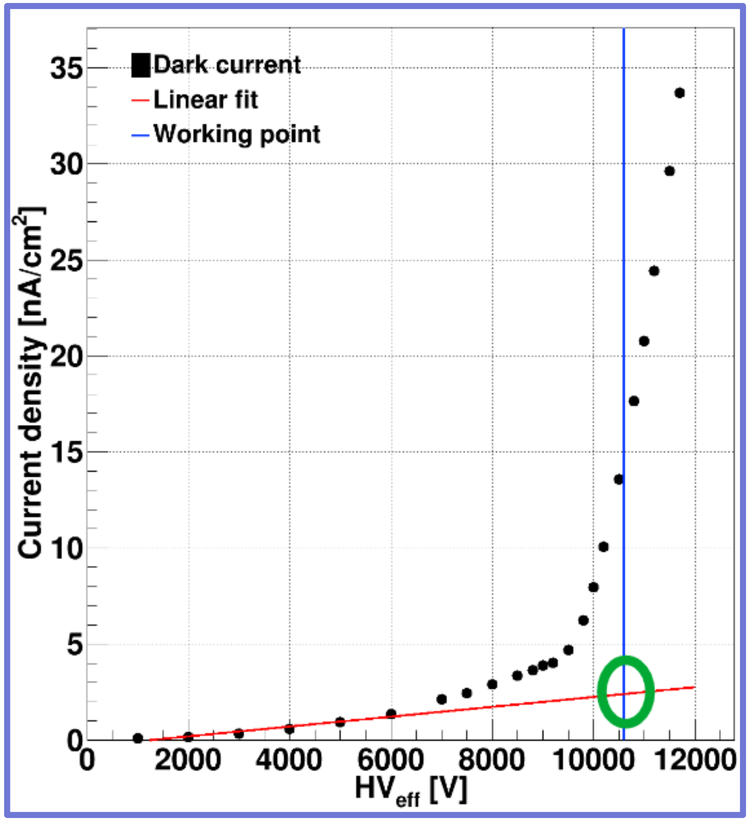


Higher currents and charge with eco-gas → higher pollutant production and faster RPC aging?

Ageing study: methodology

- RPCs flushed with ECO2, switched on at fixed HV (irradiation voltage) value and continuously irradiated at ~500 Hz/cm^2 background rate
- Monitoring of HV and absorbed current ➡ data stored every 30 s
- Weekly current vs HV scan to monitor the absorbed current without irradiation (**dark current**)
- Calculation of the charge integrated by each RPC under irradiation from the current flowing through the gas **I_{tot} - I_{Ohmic}**

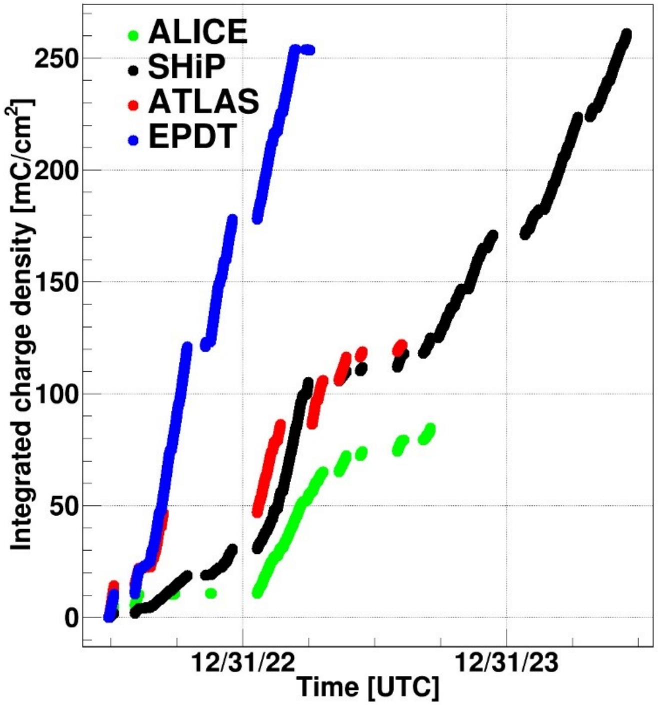
  Ohmic current *(could flow through other conductive paths in the detector)*
- Periodical check of detector performance during beam tests



Ageing study: integrated charge

Gap	Q_{int} (mC/cm^2)	Period
ALICE	85	2022-2023
ATLAS	125	2022-2023
EPDT	110	2023-2024
CMS	200	2022-2024
CMS upgrade	45	2023-2024
LHCb/SHiP	260	2022-2024

Charge integrated by all the RPCs in their irradiation period



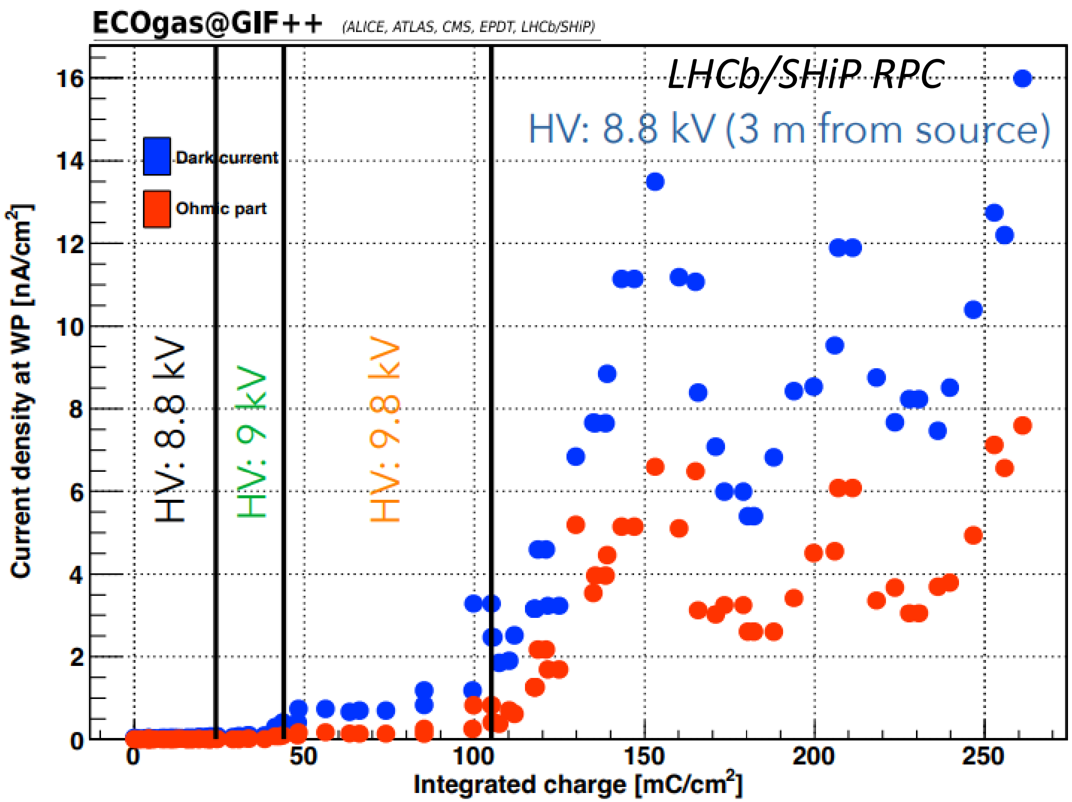
Different integrated charge values for the detectors in a given irradiation period:

- efficiency corresponding to irradiation voltage is not the same for all RPCs
- different distances from source

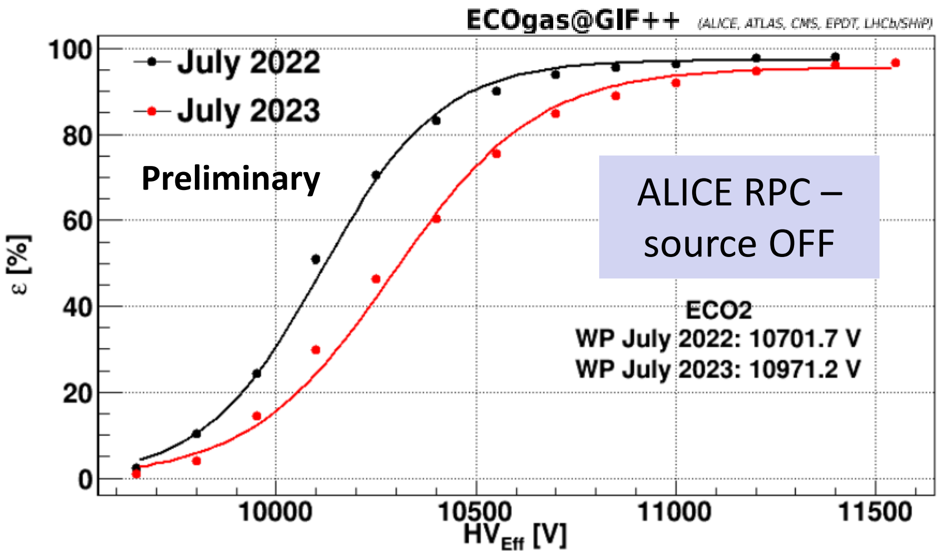
In ~1 year of irradiation (2022-2023): about 100 mC/cm^2 on average

Ageing study: results

- Up to ~100 mC/cm^2 current trend stable over time (I increases with the HV_{eff})
- Appearance of instabilities after ~100 mC/cm^2 → under investigation
- Similar trend for the other chambers in the Collaboration

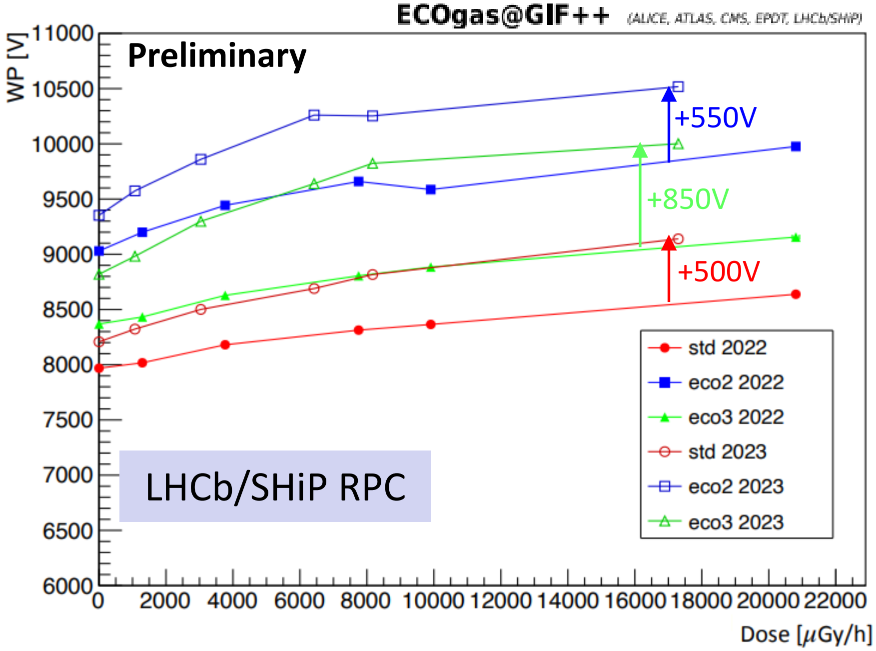


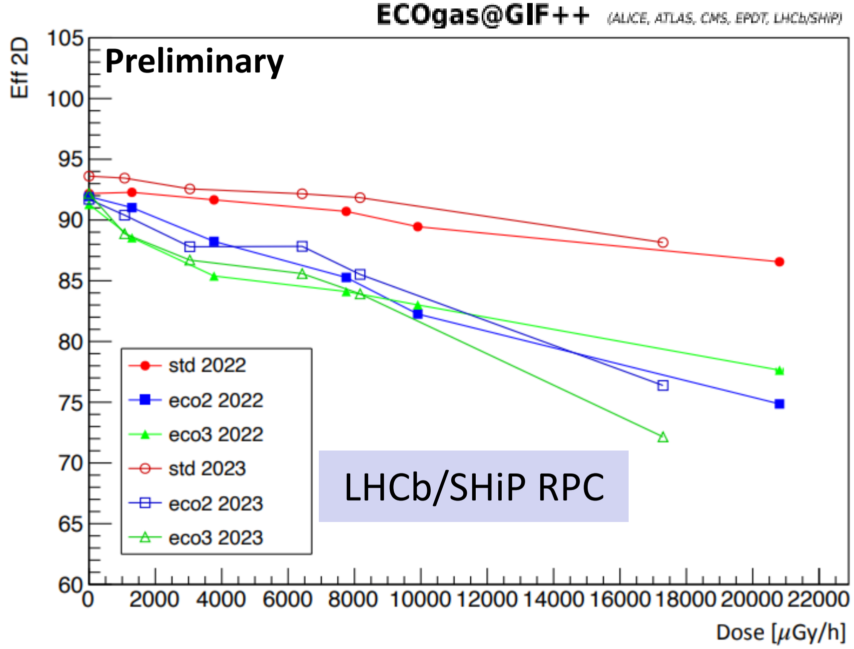
RPC performance after irradiation campaign



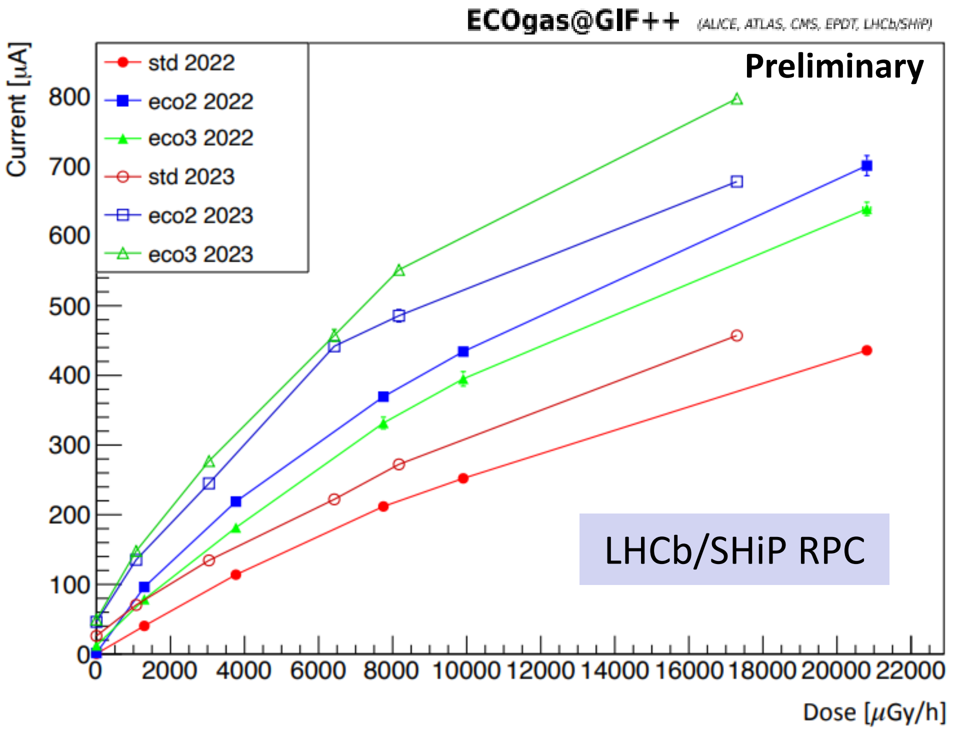
Efficiency:

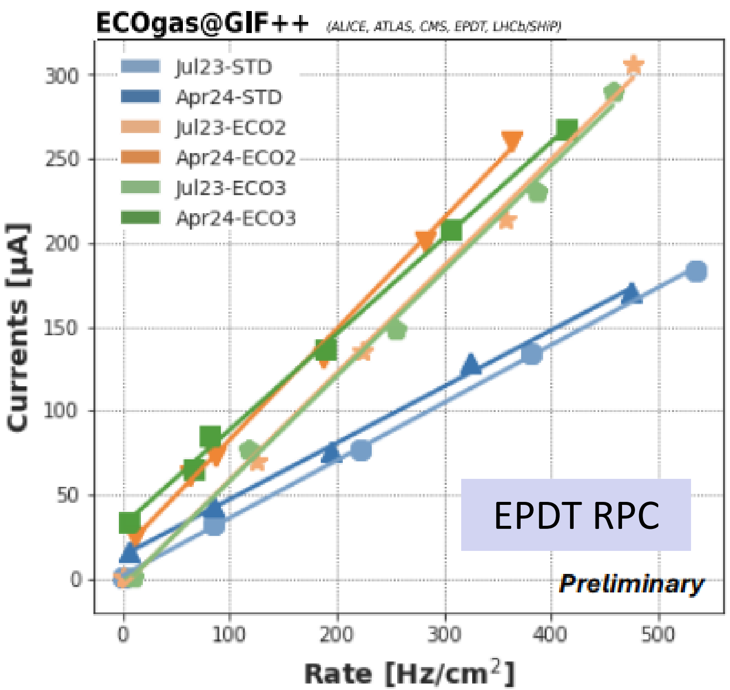
- After 1 year of irradiation, efficiency curve shift ➡ hint of current increase?
- **The efficiency at WP is comparable between 2022 and 2023.**





RPC performance after irradiation campaign

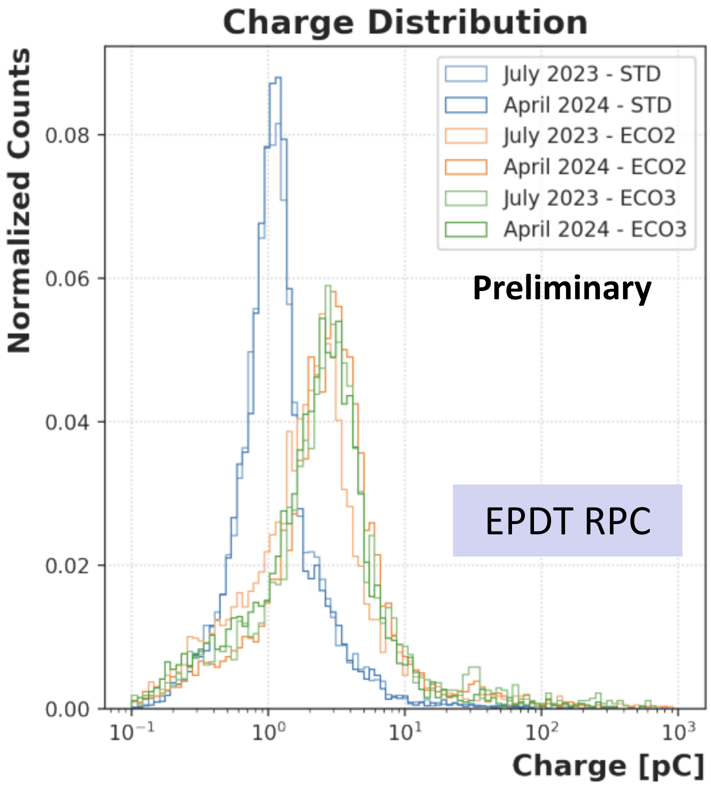


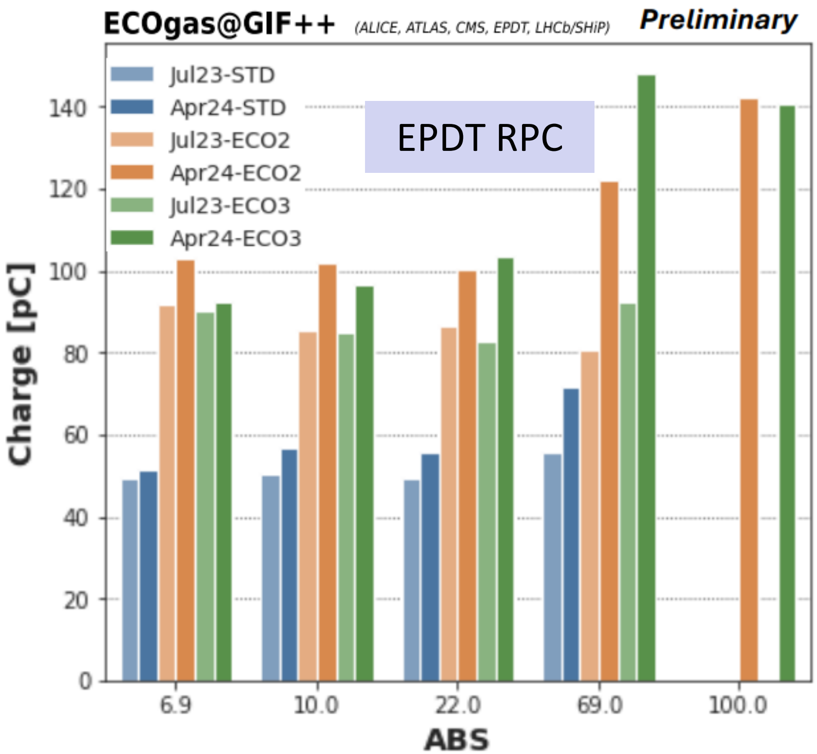


Currents: increase in 1 year of irradiation.

- For EPDT RPC: around 10% more for all the gas mixtures
- For LHCb/SHiP RPC: around 10% more for std and ECO2 – further increase for ECO3

RPC performance after irradiation campaign





Charge:

- In terms of charge distribution calculated around the working point at source OFF, no visible differences after 1 year of irradiation.
- In terms of charge per ABS filter, small increases have been observed, consistent with the current increase.

Conclusion

- The RPC ECOGAS@GIF++ Collaboration is a joint effort between RPC communities from ATLAS, ALICE, CERN Gas team, CMS, LHCb/SHiP with the aim of searching for new eco-friendly gas mixtures for RPCs.

- Several tests of different alternative eco-gas mixtures have been performed both with cosmic rays and in different irradiation conditions at the GIF++. Promising results have been obtained with gas mixtures based on HFO-1234ze/CO_2 in relative fractions 60%/35% and 69%/25%.

- An ageing test campaign of RPCs operated with the new eco-gas mixtures was launched at GIF++ in 2022 and a systematic long-term performance study is being carried out by means of periodical beam tests.

- No reduction of RPC efficiency has been observed up to now. A shift of the WP and an increase trend of the currents have been measured and will be further investigated. The aeging campaign is going on with the aim of testing long-term RPC operation at the High-Luminosity LHC conditions.

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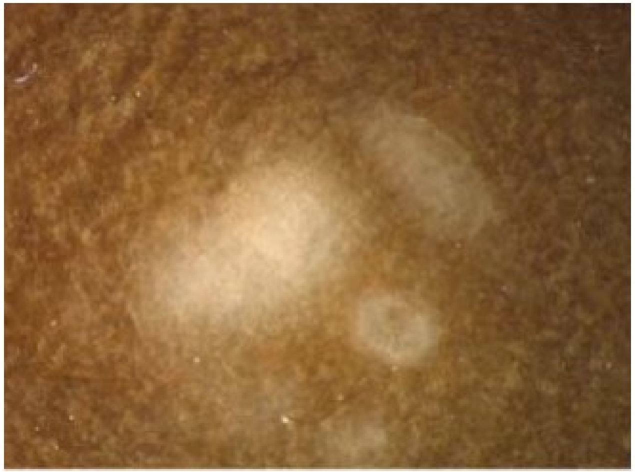
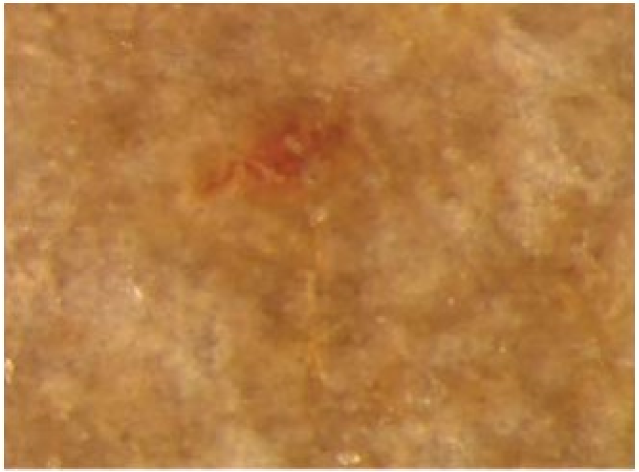
Thank you for your attention!

RPC ageing

The decomposition of F-rich gas molecules (such as R134a and HFO) could led to the production of fluoride (F^-). It combines with H_2O, producing HF acid that could damage the inner surface of RPC electrodes.

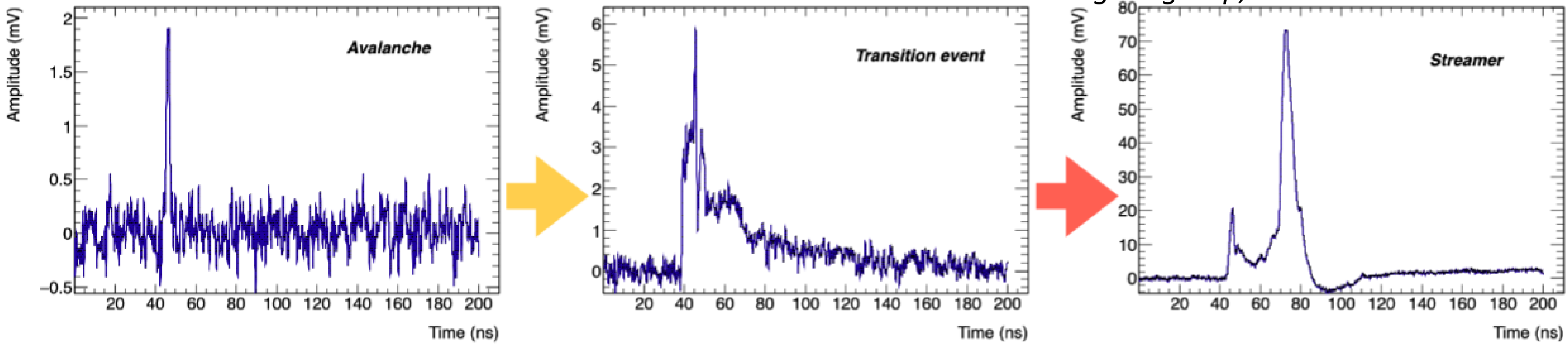



Pictures of spots, appearing on the inner surfaces of Bakelite electrodes that could be due to the chemical interaction with HF

M. Abbrescia et al., Resistive Gaseous Detectors, 2018 WileyVCH.

Event classification

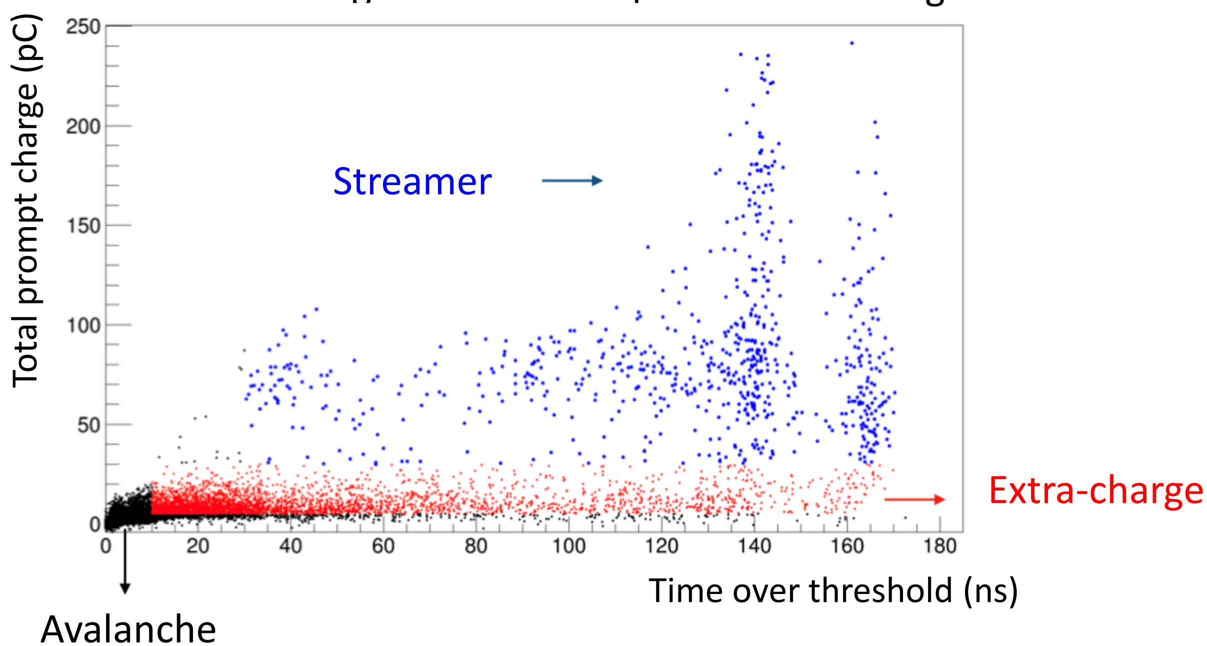
Roma Tor Vergata group, contribution to VCI2022



Avalanche: very short signal

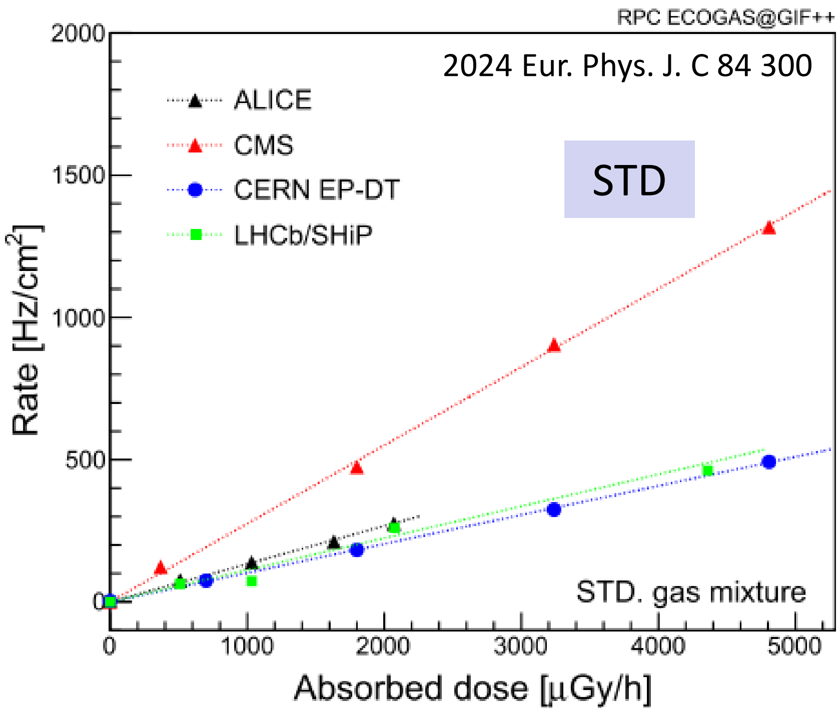
Extra-charge events: multiple avalanche signal and/or large tail following the avalanche precursor

Streamer events: avalanche signal precursor followed by a signal lasting tens of ns



Gamma rate

- Gamma cluster rate -> number of clusters related to γ photons from the Cs source per unit of area and unit of time
- It is measured with random triggers during beam interspill



up to several hundreds of Hz/cm^2