Eco-friendly gas mixtures for RPCs: results from a long-term ageing study at CERN GIF++

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on behalf of the RPC EcoGas @ GIF++ collaboration

RPC2026 - XVIII Conference on Resistive Plate Chambers and related detectors
Rio de Janeiro (Brasil)
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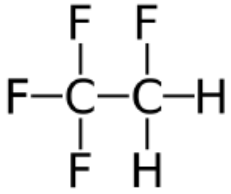
Use of Greenhouse gases in HEP

GHGs are used in several gaseous particle detectors due to their characteristics suitable for optimal detector performance AND long term operation

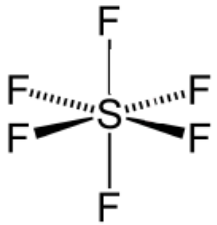


$C_2H_2F_4$

GWP 1430

Containment of charge
Rate capability

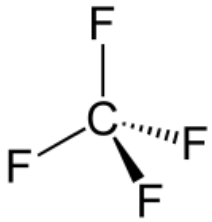
Resistive Plate Chamber (RPC)



SF_6

GWP 22800

- Electronegative: limiting charge development



CF_4

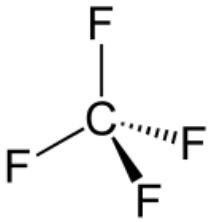
GWP 7390

- time resolution

Micro Pattern Gaseous Detectors (MPGD)

- Mitigation of aging phenomena

Cathode Strip Chamber (CSC)
Multi Wire Proportional Chamber (MWPC)



C_4F_{10}

GWP 8860

- Cherenkov radiator

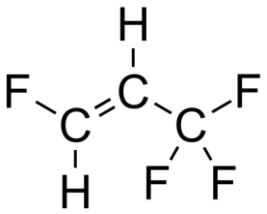
Ring-imaging Cherenkov detector (RICH)

- 30 years ago we had to get rid of Ozone Depletion gases
- At the time there was not the same feeling about GHGs → many detectors were designed from the beginning to be used with GHGs

The importance of collaborative effort

- All high energy experiments (ALICE, ATLAS, CMS, LHCb, etc.) and the CERN gas group (CERN EP-DT) started, already several years ago, an intense R&D program to find suitable gas mixtures.

- Practically all research trendlines concentrate around the idea of replacing:
  $C_2H_2F_4$ (GWP=1430) → $C_3H_2F_4ze$ (GWP=4)
  + CO_2 (GWP=1) or He



EEE
10.1088/1748-0221/19/11/P11003

- ✓ $C_3H_2F_4$ (here indicated as HFO for short) is the molecule most similar to TFE but with low GWP
- ✓ CO_2 (or He) are essentially added to reduce the operating voltage.

The RPC EcoGas@GIF++ is a Collaboration **transversal to ALICE, ATLAS, CERN EP-DT, CMS, and LHCb** willing to put together expertise and resources in order to test potential candidates of eco-friendly gas mixtures with different detectors and electronics.

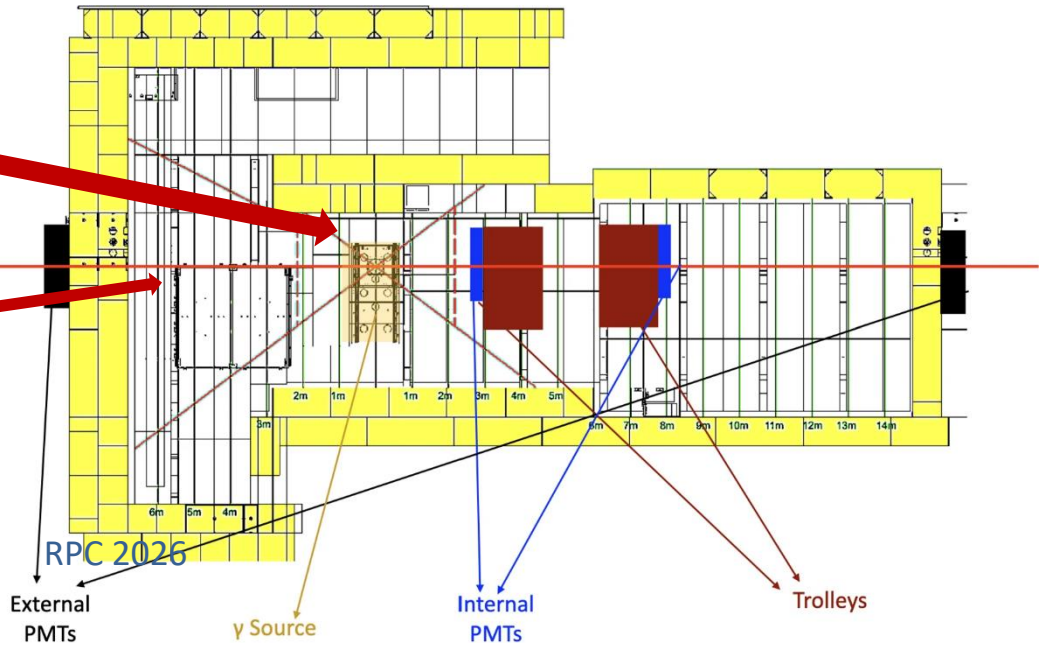
Experimental set-up @GIF++

- Two eco-friendly gas mixtures identified in home laboratories tests, with various concentrations of HFO and CO_2.

Name	TFE (%)	HFO-1234ze (%)	CO_2 (%)	iC_4H_{10} (%)	SF_6 (%)	GWP	CO_2e
STD	95.2	0	0	4.5	0.3	1488	6824
ECO2	0	35	60	4.0	1.0	482	1522
ECO3	0	25	69	5.0	1.0	529	1599

Irradiation campaign started in 2022 by the EcoGas@GIF++ collaboration at the GIF++:

- 12.5 TBq 137Cs source
  - ✓ to generate background (high rate)
  - ✓ to accelerate aging processes
- 100 GeV muon beam
  - ✓ to measure detector performance



Detectors @ GIF++

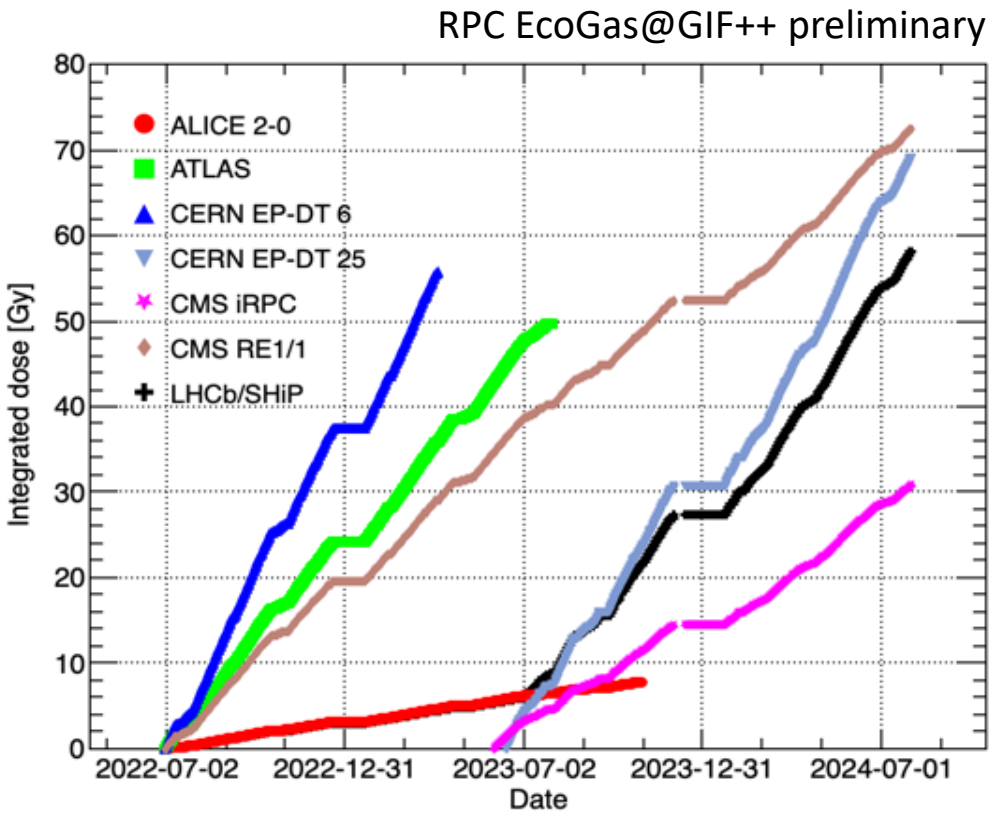
Chamber	Distance (m)	Dimensions (cm)	Gap thickness (mm)	Electrode thickness (mm)
ALICE 2-0	6.0	50×50	2	2
ALICE 2-1	6.0	50×50	2	2
ATLAS	3.2	55×10	2	1.8
CERN EP-DT 6	3.0	70×100	2	2
CERN EP-DT 25	3.0	70×100	2	2
CMS RE1/1	3.5	$(41.5-23.9) \times 100.5$	$2+2$	2
CMS iRPC	3.5	45×45	$1.4+1.4$	1.4
LHCb/SHiP	6.2	70×100	1.6	1.6

- Various detectors, mounted on two trolleys, equipped with various electronics.

→ Help in disentagling common observed effect from effects specific of ONE detector

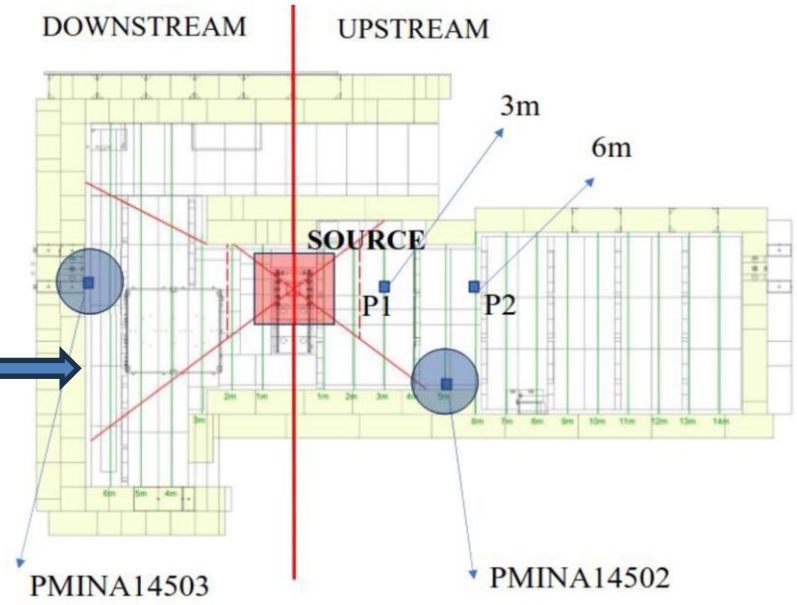
- **Irradiation was performed using ECO2, tests with ALL gas mixtures mentioned.**

Integrated dose



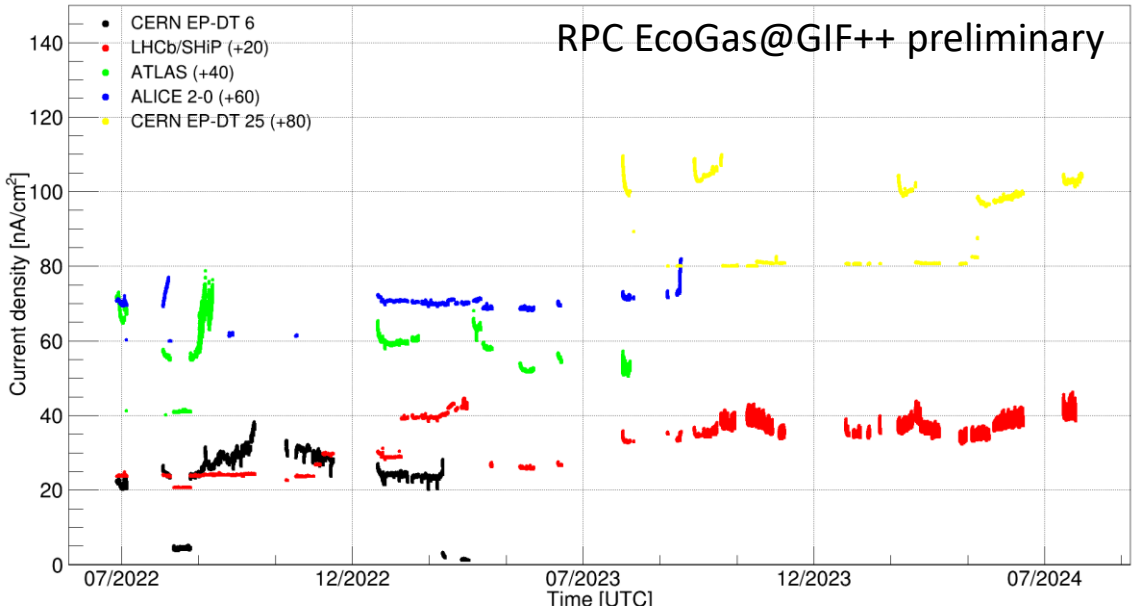
Doses integrated by the chambers under test during the irradiation campaign, and until the end of July 2024. The overall systematic uncertainty of the estimation procedure is around 20%.

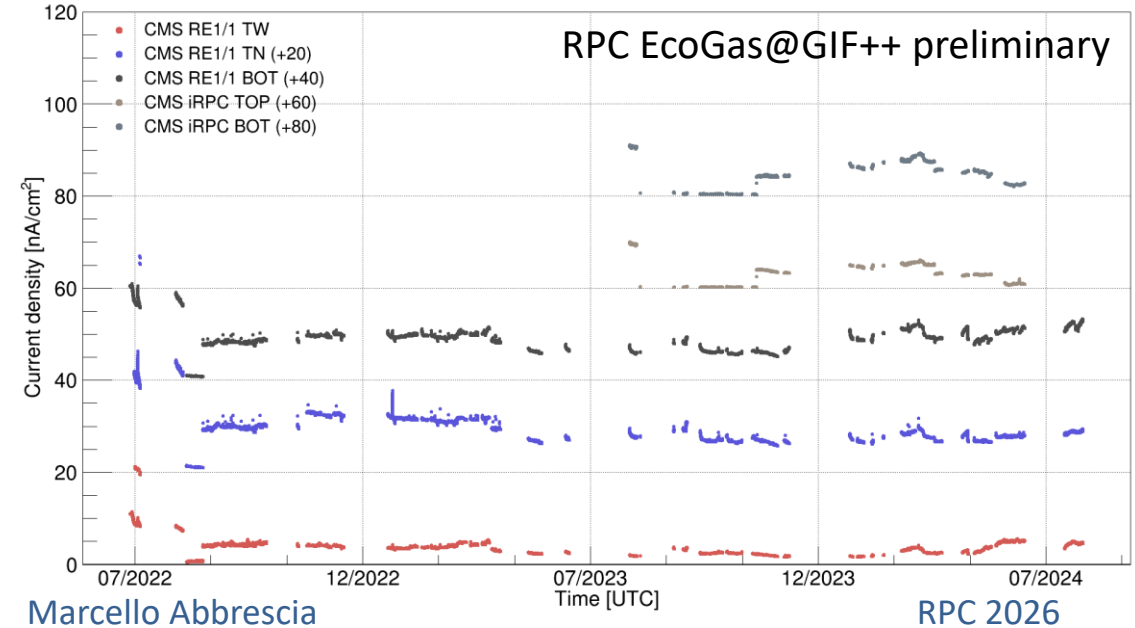
The integrated dose was measured by the PMINA dosimeters (fixed and movable) and rescaled for the distance and material shielding.



Results presented here are up to the end of July 2024. Tests performed after this date are being analyzed.

Current densities during irradiation



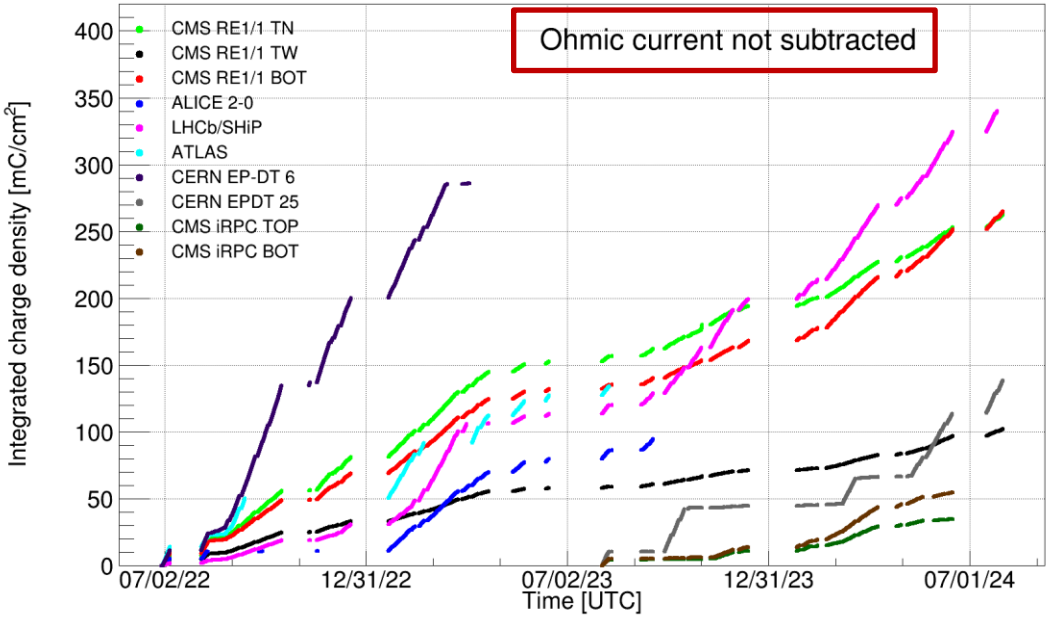


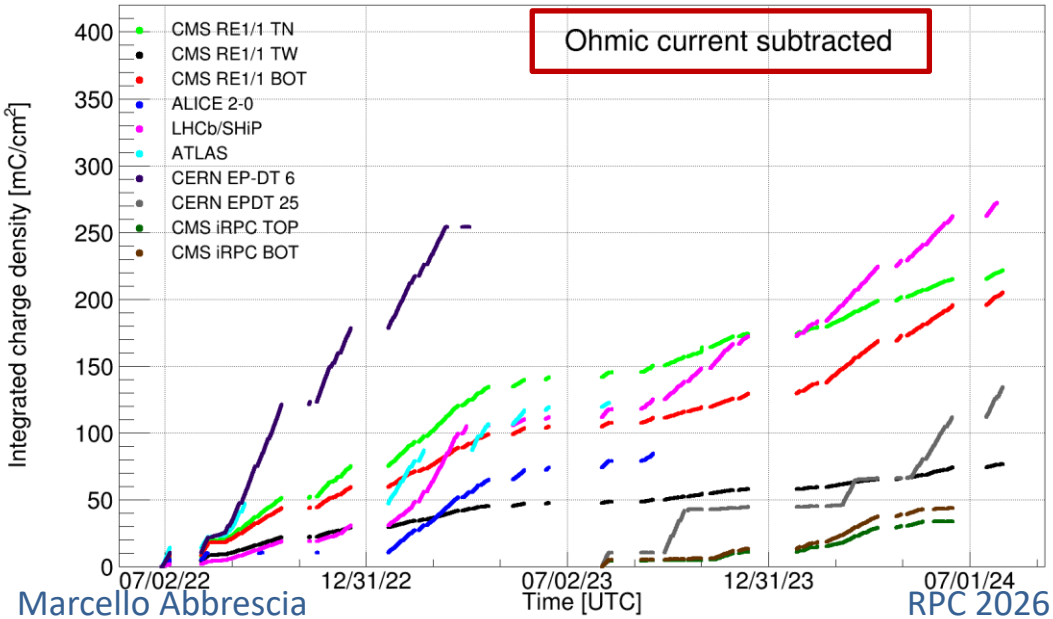
Current densities measured during irradiation at ABS = 2.2 for the chambers under test.

- ✓ The data points are vertically shifted with gap-dependent factors (indicated in the legend as +20, +40, …) to improve readability.

Currents remain basically stable during the irradidation period.

Charge integrated during irradiation





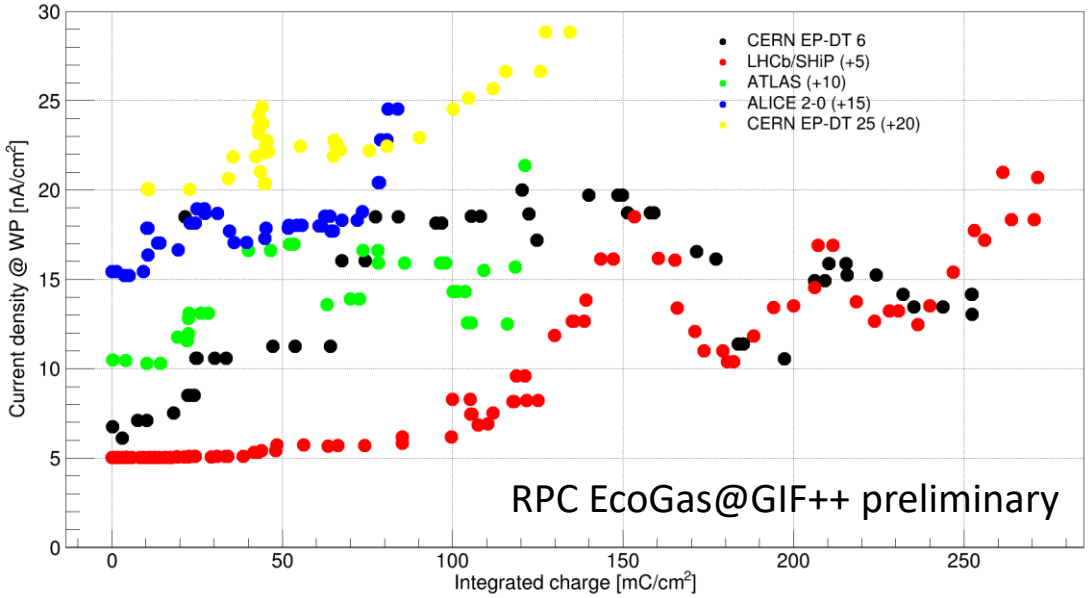
Integrated charge per unit area accumulated by the RPC chambers during the tests.

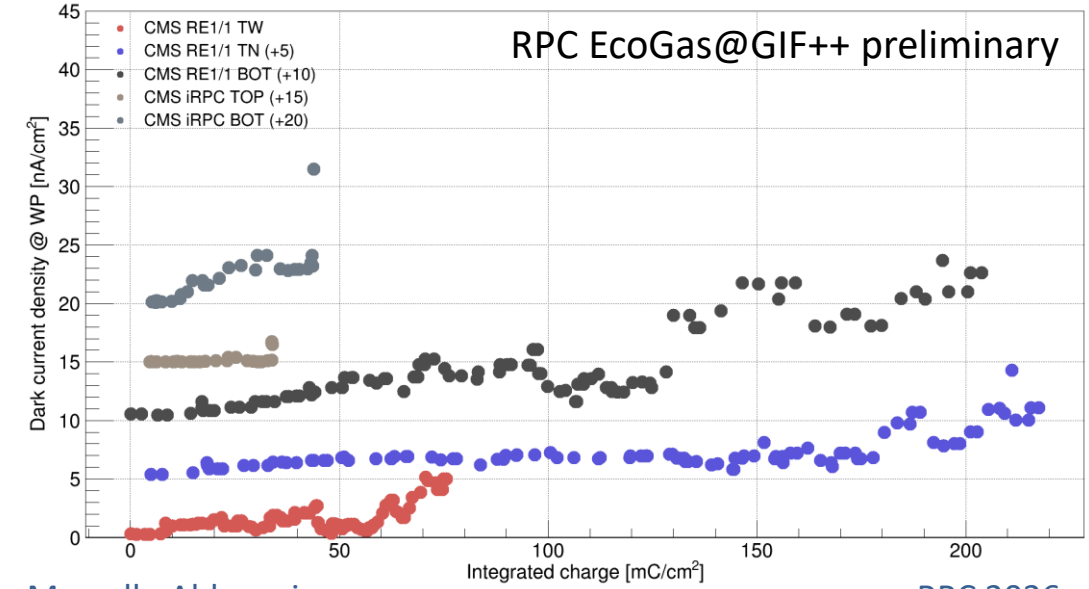
- ✓ The interruptions visible at the end of each year correspond to the GIF++ technical stops, when the detectors were powered off.

Integrated charge is another important evaluator for aging processes in gaseous detectors.

- ✓ **Both integrated dose and integrated charge are a significant fraction of the total during HL-LHC,exact fraction depending on the experiment.**

Dark (without irradiation) current



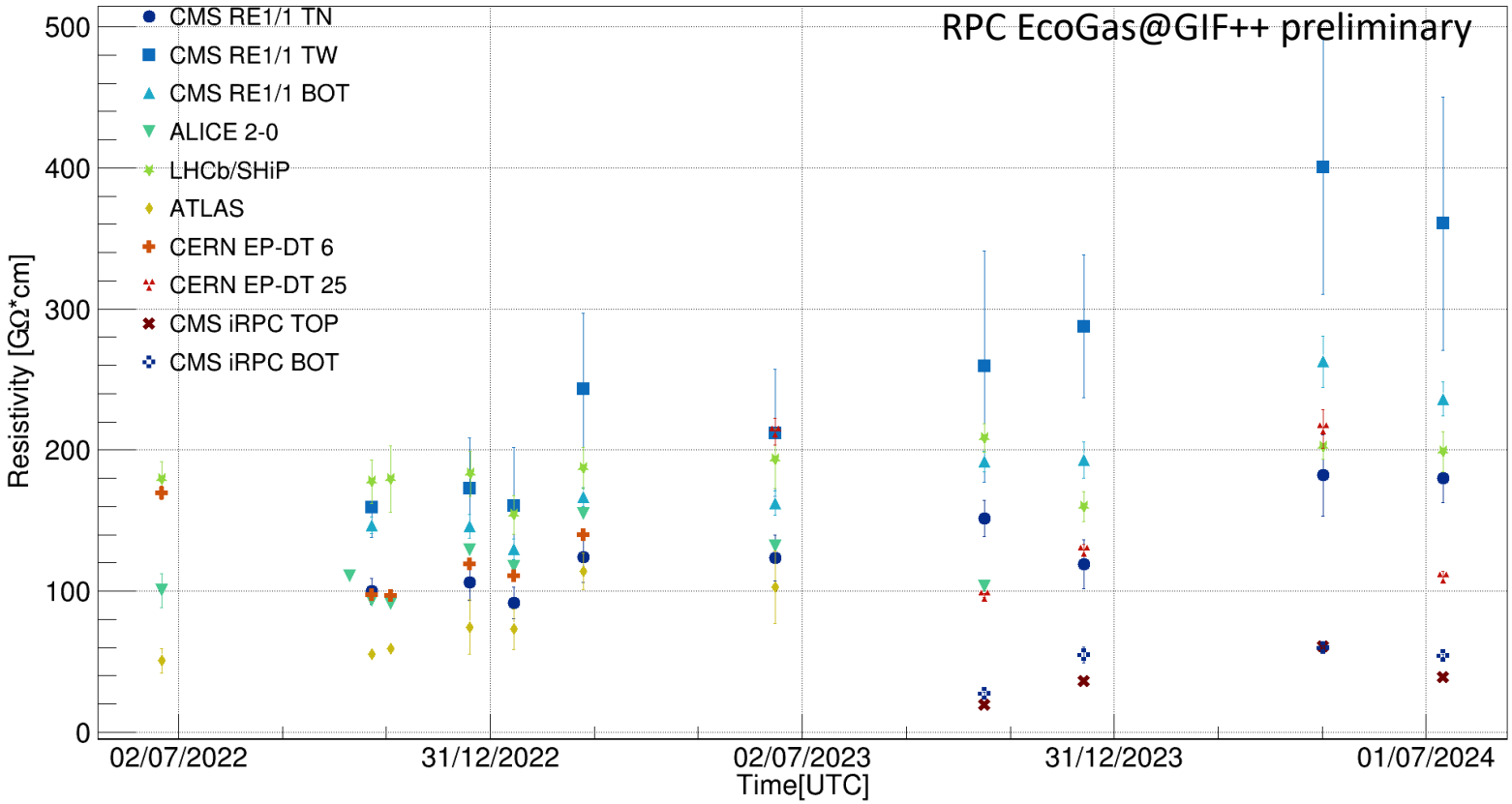


Total dark current density at Working Point (WP) as a function of the total integrated charge.

- ✓ Obtained from HV scans performed without irradiation.
- ✓ The data points are vertically shifted with gap-dependent factors (indicated in the legend as +20, +40, …) to improve readability.

Currents slowly increase and, in some cases, show oscillations.

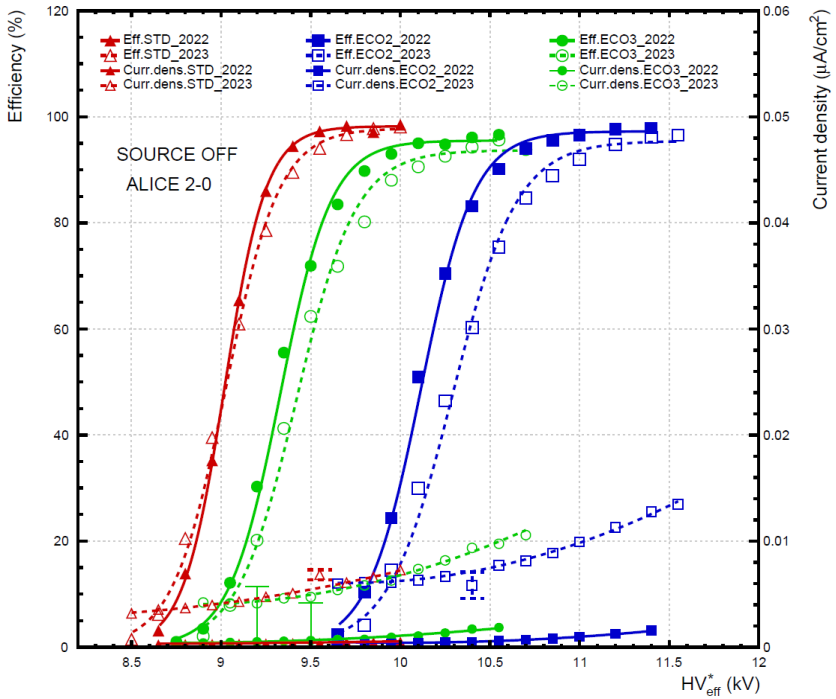
Resistivity vs. time



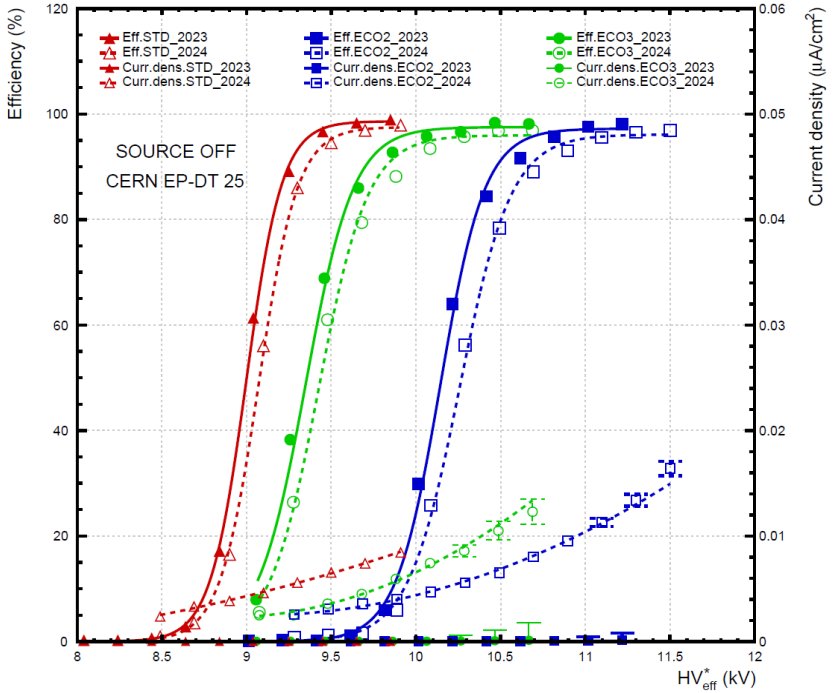
Time evolution of the electrode plates resistivity for the RPC chambers under test vs. time. It was determined by filling the chambers with Argon and extracting the slope of the current–voltage curves in the linear region.

Most chambers show stable or slowly increasing values, with the TW gap of the CMS RE1/1 chamber exhibiting the most significant variation.

Efficiency at low rate



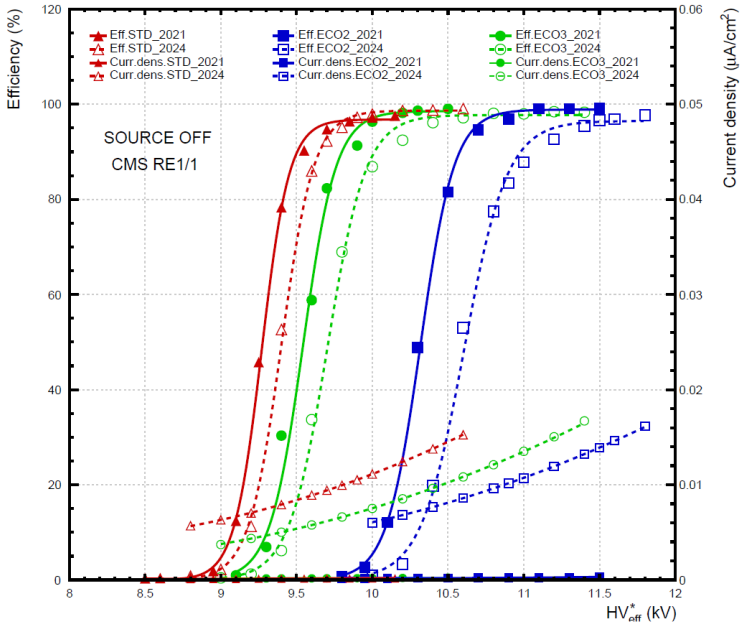
RPC EcoGas@GIF++ preliminary

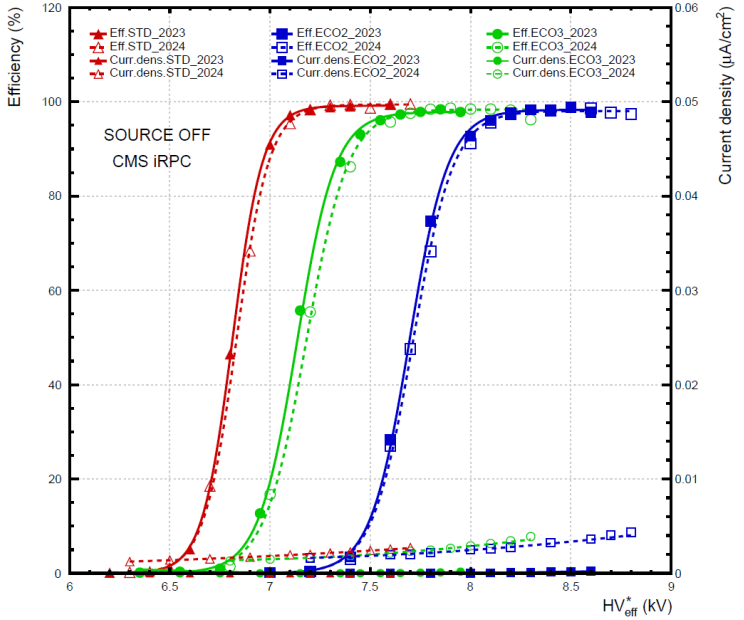


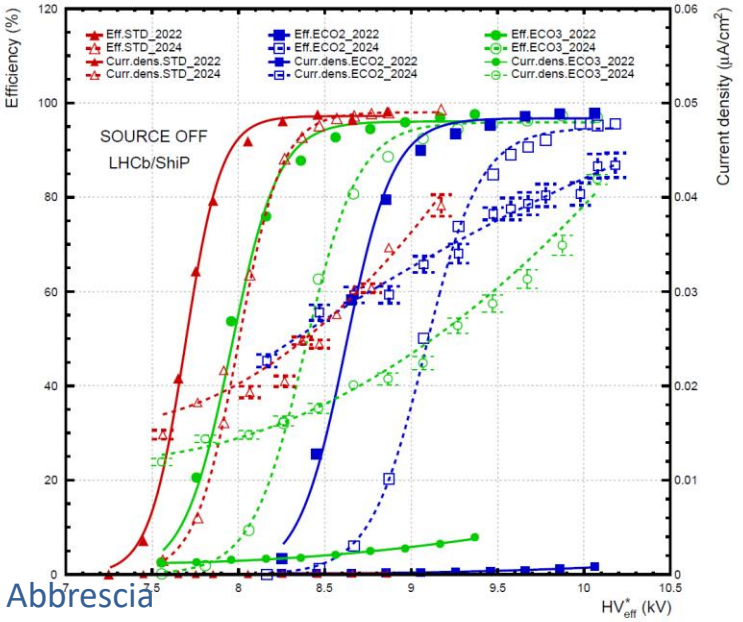
Efficiency and dark current density for the ALICE 2-0 and CERN EP-DT 5 chambers with STD, ECO2 and ECO3 mixtures, comparing data taken before and after (2024) the aging campaign, with the source off. Pressure and temperature effects were corrected.

- ✓ **Plateau efficiency basically stable**
- ✓ **Shift of the efficiency curves toward higher voltages**
- ✓ **Increased current density**

Efficiency at low rate







Basically the same behaviour for all chambers:

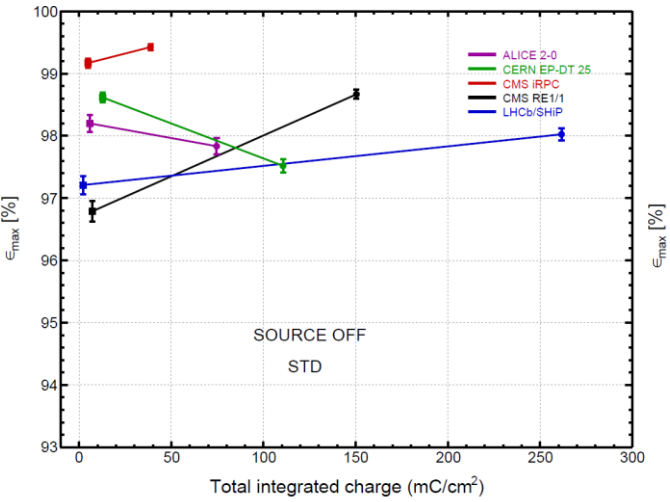
- ✓ CMS iRPC the chamber been exposed for the shorter time to irradiation
- ✓ CMS RE 1/1 and more than 10 years old chamber, with a gap only partially operating since the beginning.

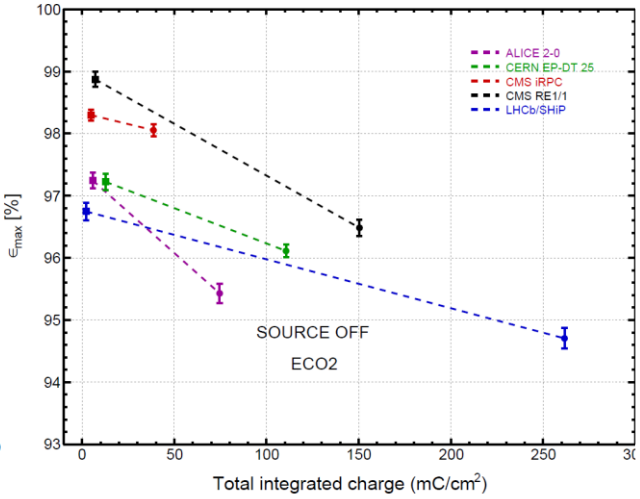
RPC EcoGas@GIF++ preliminary

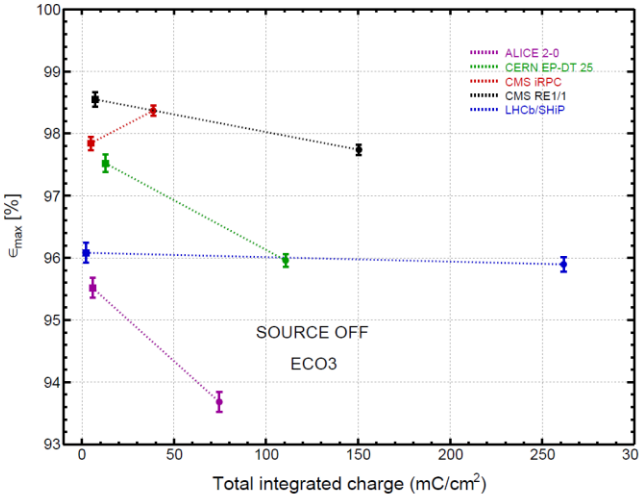
Plateau efficiency at low rate

vs. integrated charge

RPC EcoGas@GIF++ preliminary

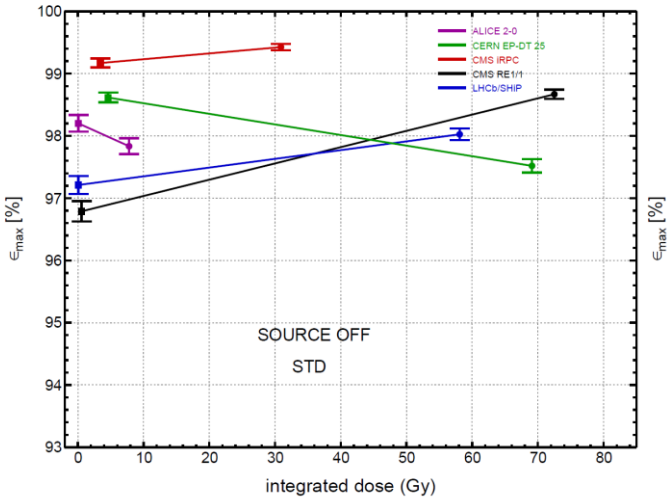


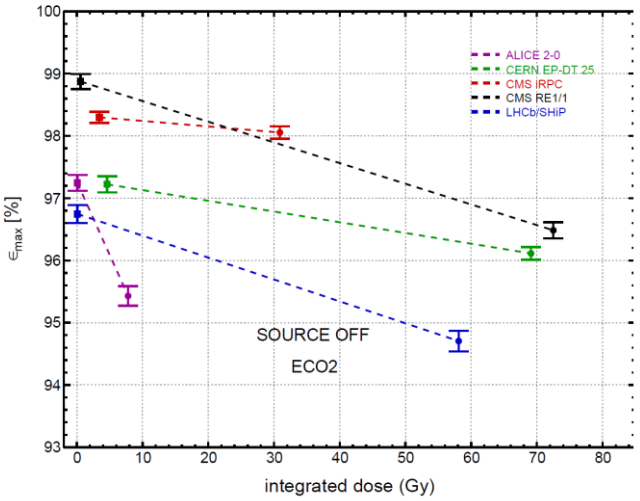


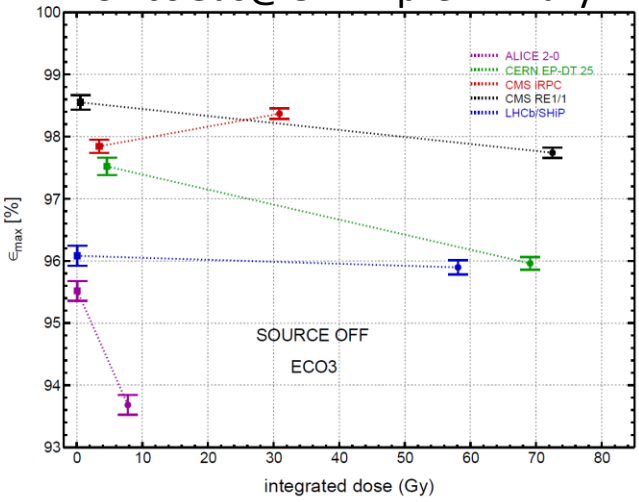


vs. integrated dose

RPC EcoGas@GIF++ preliminary





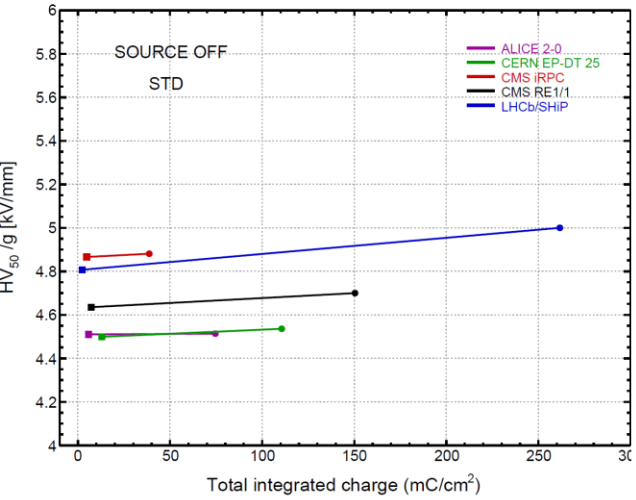


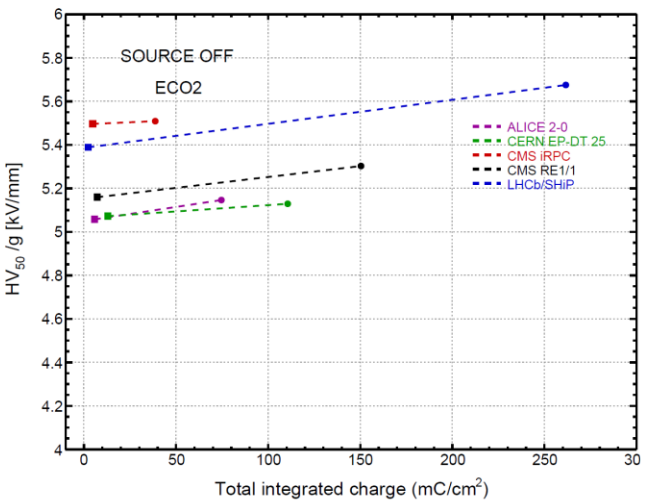
Most chambers show stable or slightly decreasing plateau efficiency, more evident with ECO2 and ECO3 gas mixtures.

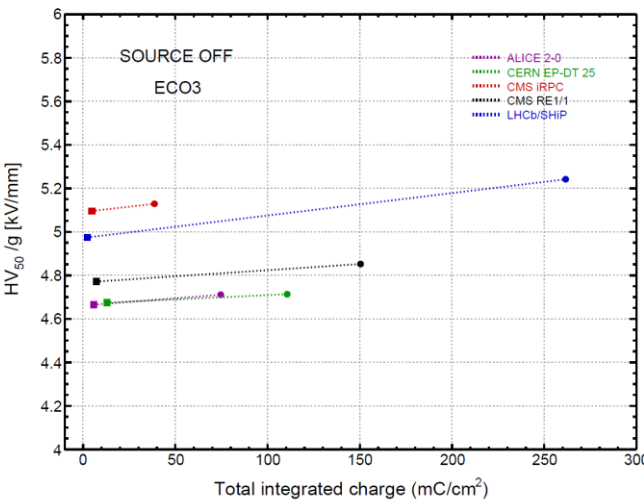
Electric field at HV_{50}

vs. integrated charge

RPC EcoGas@GIF++ preliminary

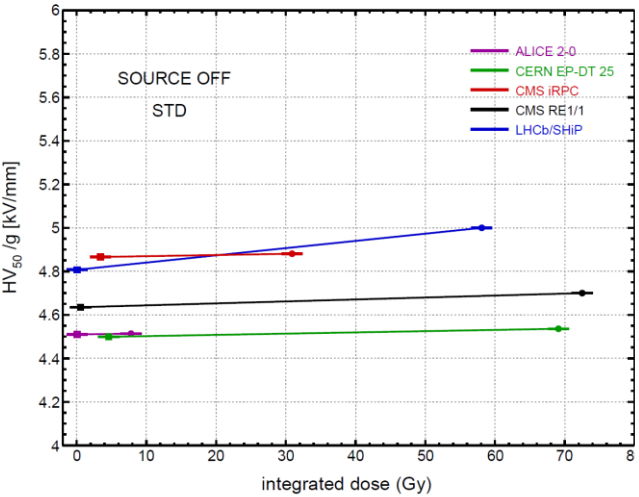


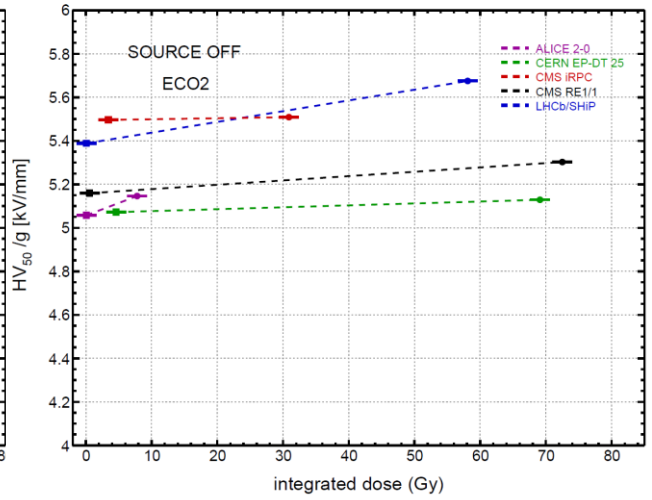


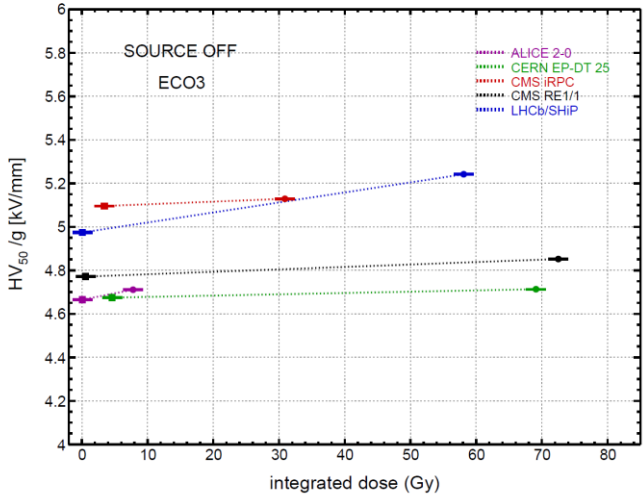


vs. integrated dose

RPC EcoGas@GIF++ preliminary



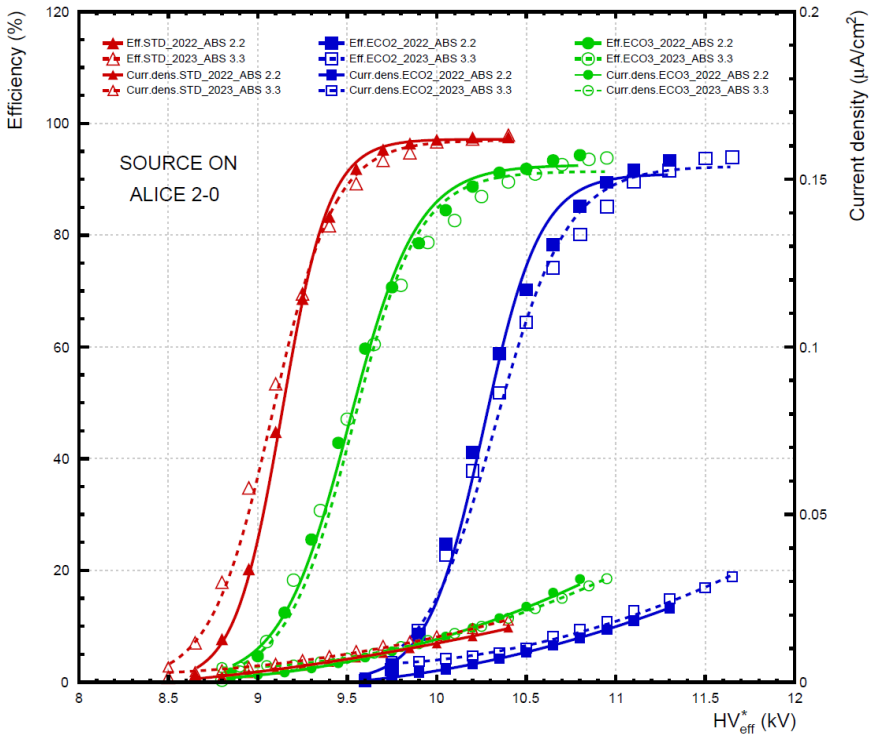


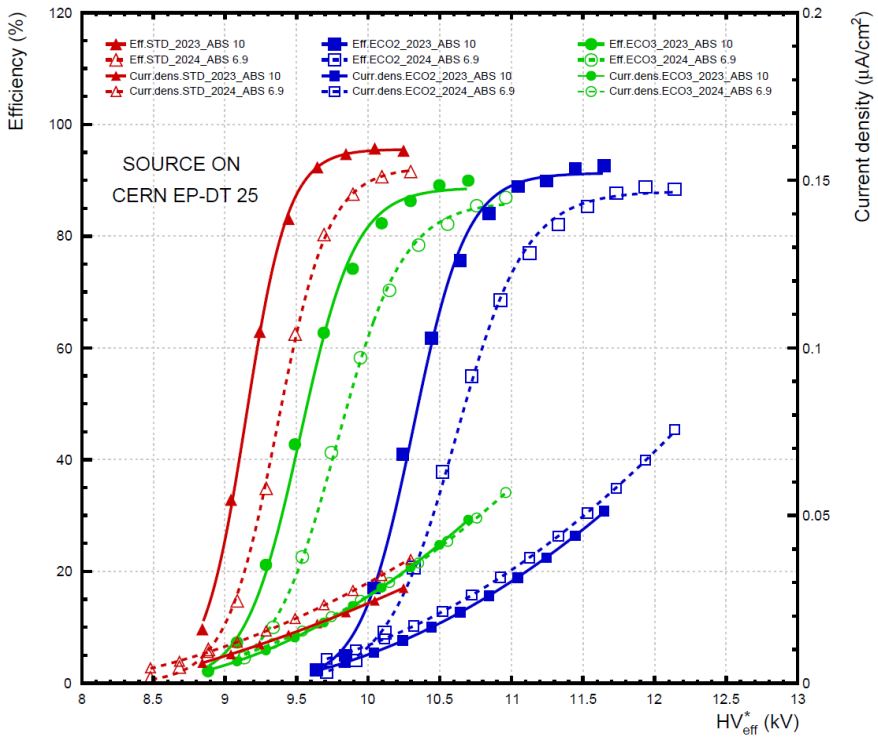


All chambers feature a shift toward the right of the efficiency curves, whose amount looks quite comparable to each other.

Efficiency at high rate

RPC EcoGas@GIF++ preliminary



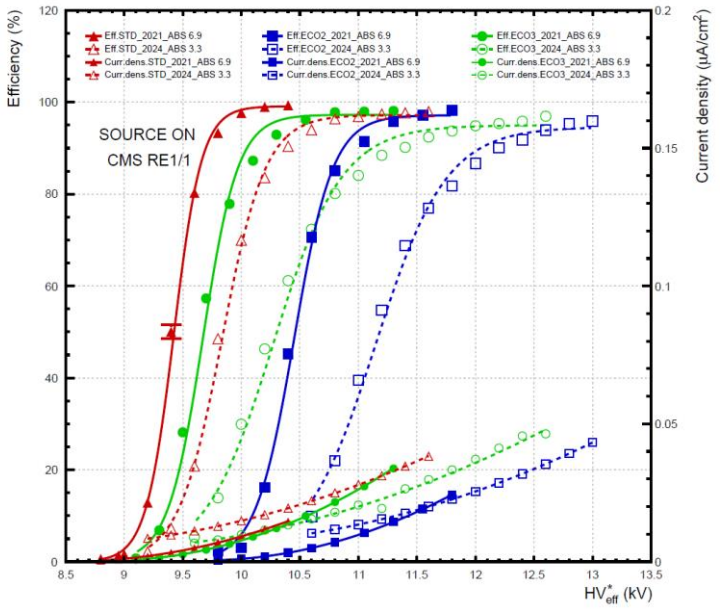


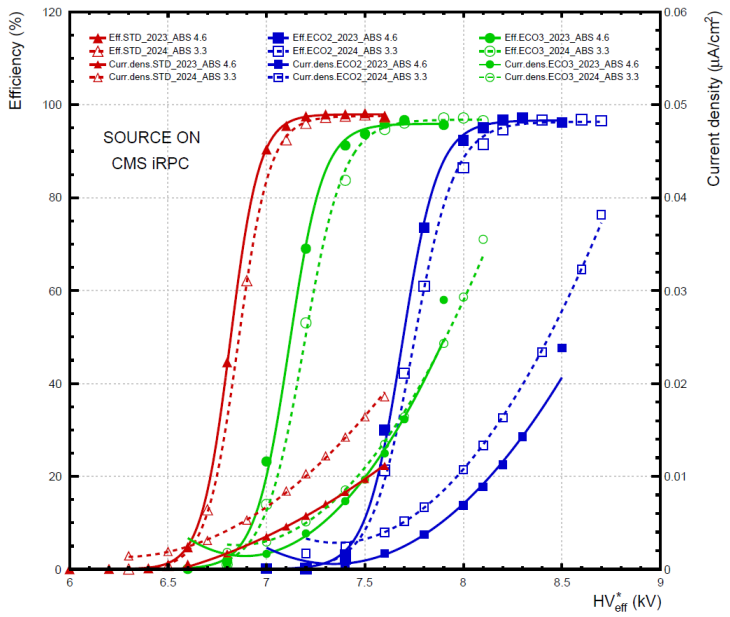
Efficiency and current density versus for ALICE 2-0 and CERN ET-DT 5 chambers with STD, ECO2 and ECO3 mixtures, comparing data taken before and after the irradiation campaign.

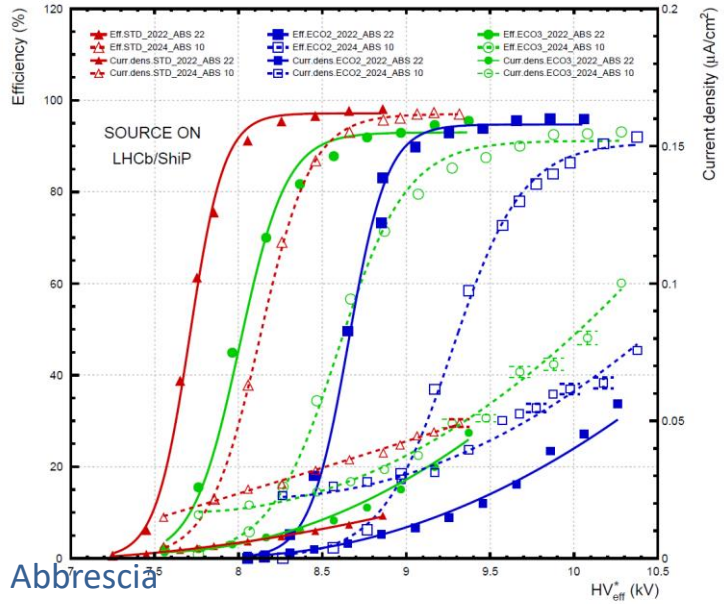
- ✓ Source was ON.
- ✓ **The ABS were chosen so that the instantaneous dose before and after irradiation was as similar as possible (taking into account the decay of the source activity).**

Efficiency at high rate

RPC EcoGas@GIF++ preliminary







Basically the same behaviour observed at low rate:

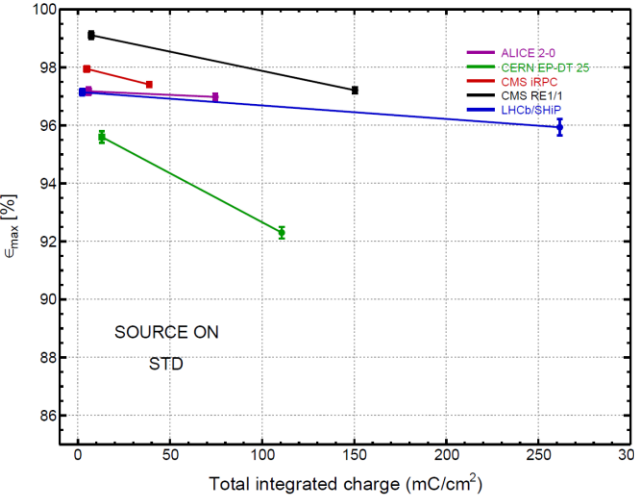
- ✓ Efficiency stable or slightly decreasing.
- ✓ Shift of the efficiency curves.
- ✓ Increase of the current density.

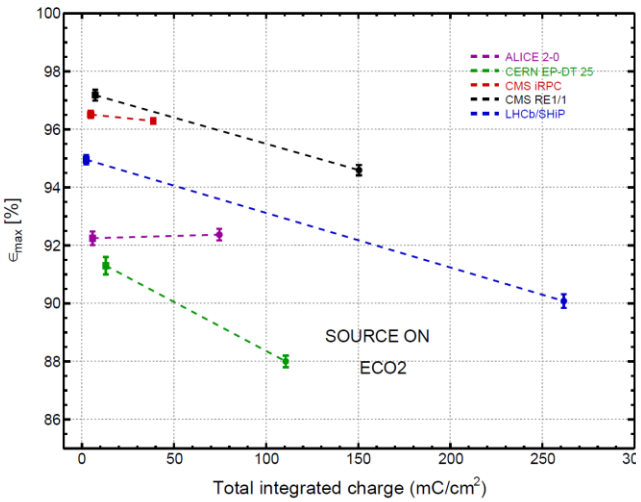
Effects slightly more evident at high rate wrt. low rate.

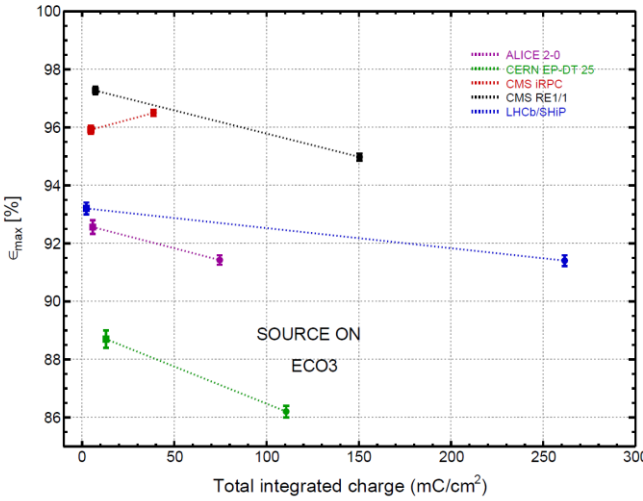
Plateau efficiency at high rate

vs. integrated charge

RPC EcoGas@GIF++ preliminary

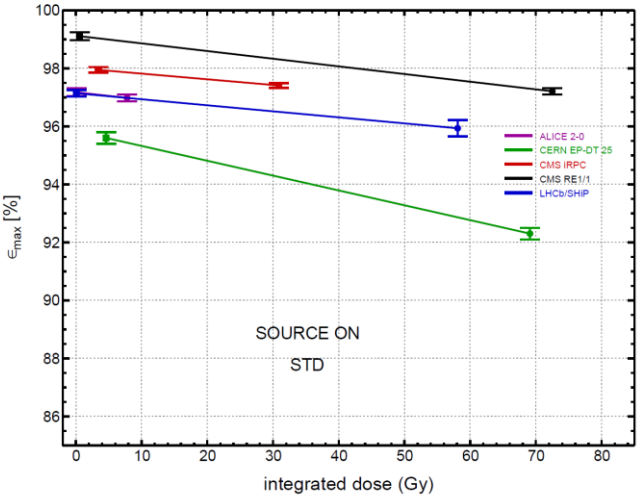


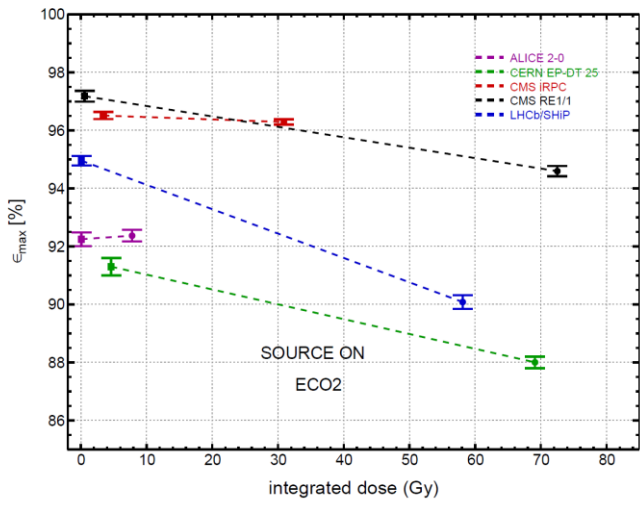


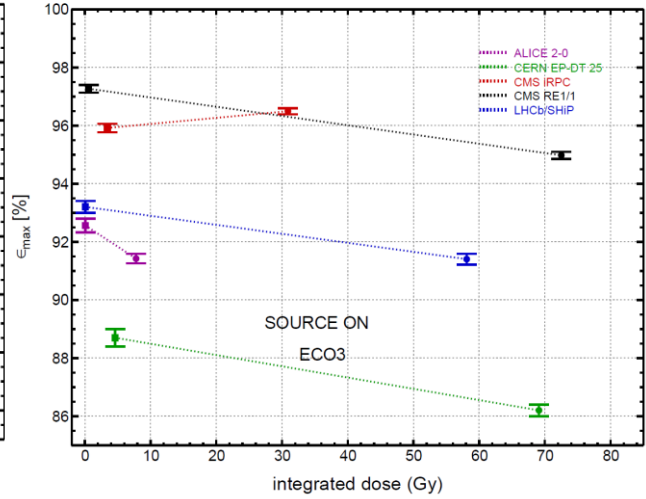


vs. integrated dose

RPC EcoGas@GIF++ preliminary



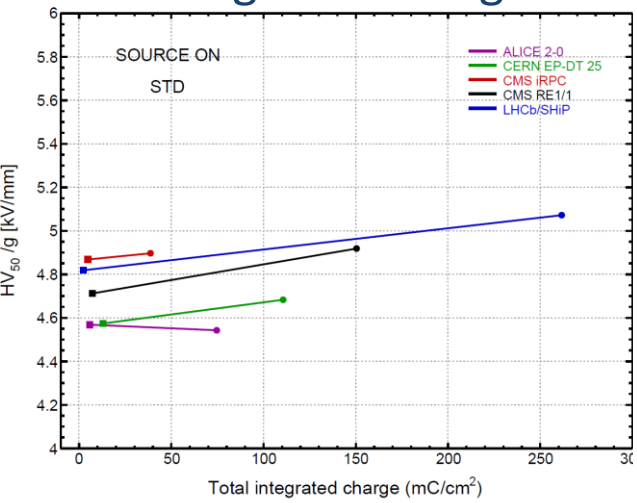


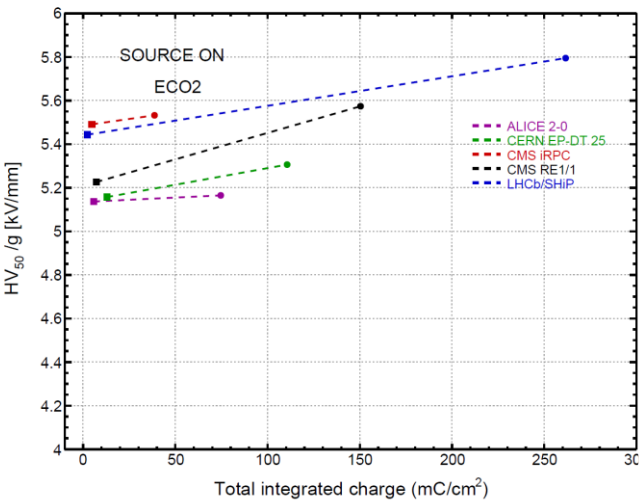


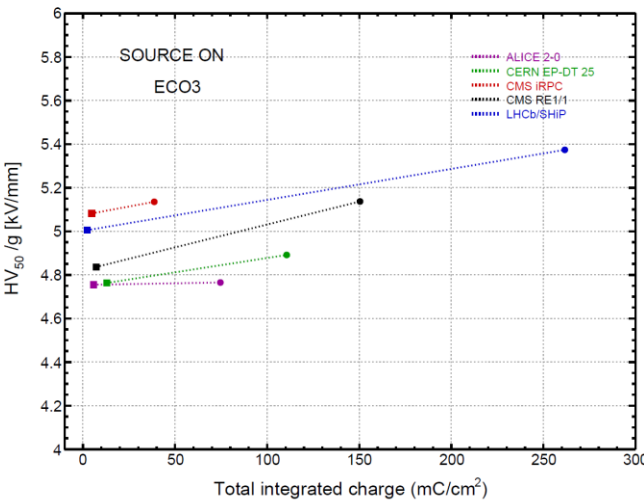
Electric field at HV_{50} at high rate

vs. integrated charge

RPC EcoGas@GIF++ preliminary

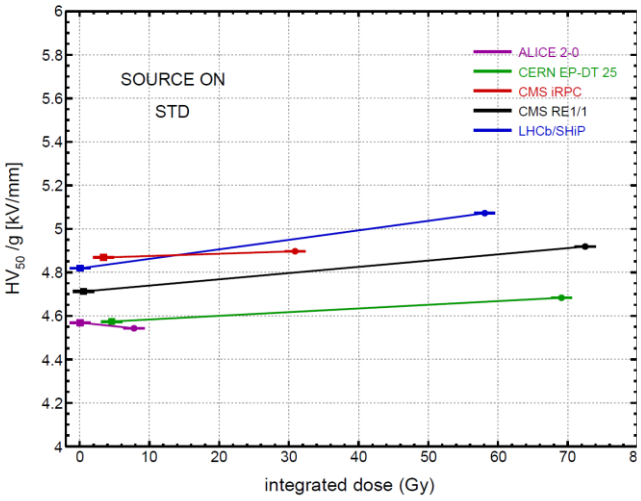


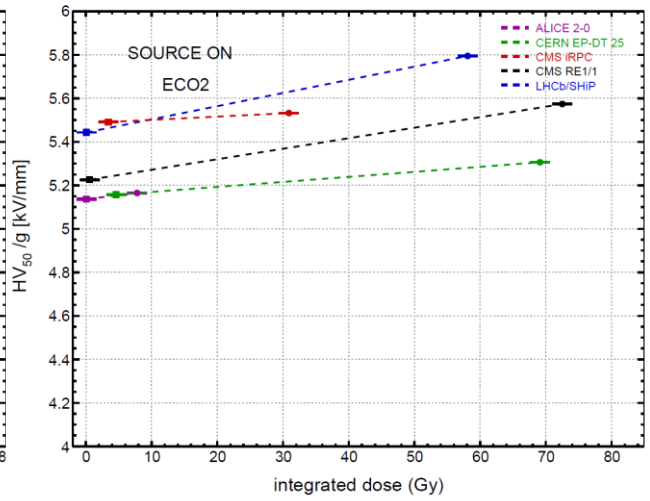


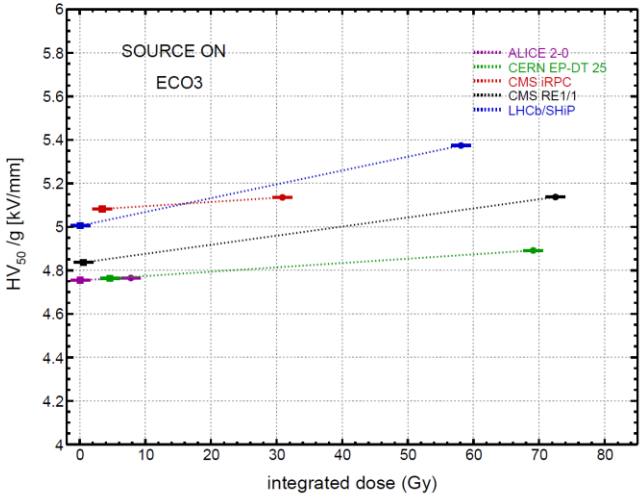


vs. integrated dose

RPC EcoGas@GIF++ preliminary







Current density at WP at high rate

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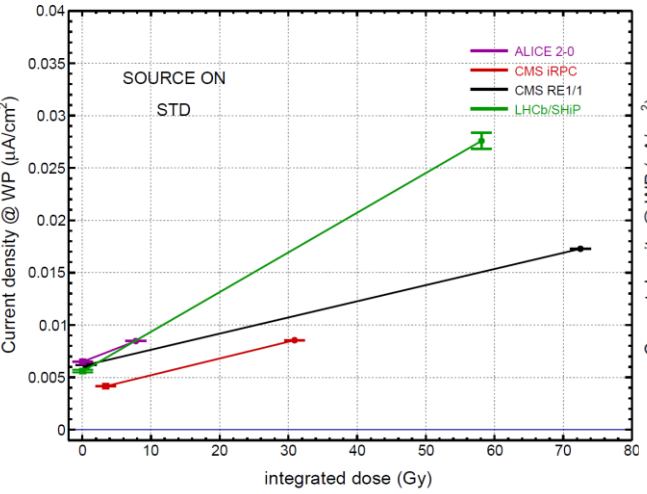

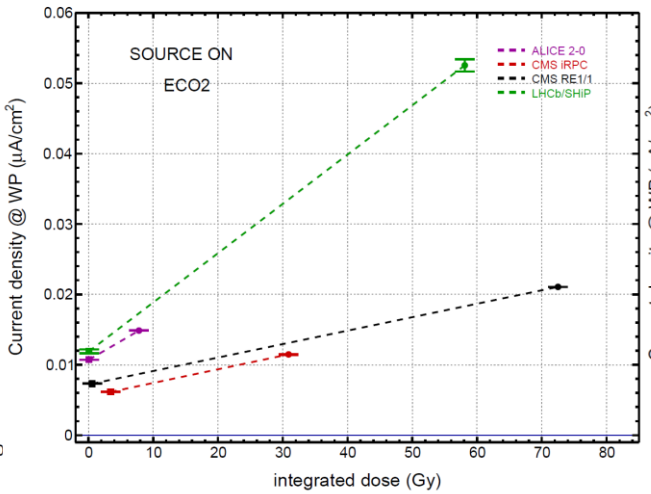

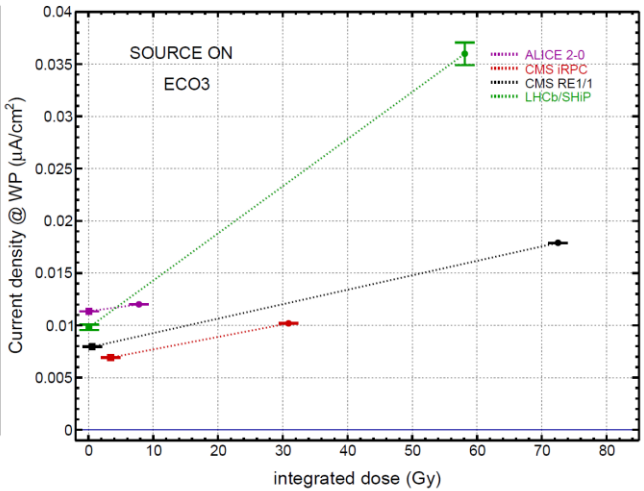

Current density measured at the Working Point (WP) as a function of the integrated dose for the chambers considered in this study.

- ✓ Increase of the current density observed.
- ✓ Might be correlated to the shift of the efficiency curves.
- ✓ Tried to make a prediction of the shift of the efficiency curves, but with not quantitative agreement.

Conclusions and outlook

➢No evident showstopper in using HFO in place of TFE found: at the macroscopic level the performance before and after the irradiation campaign is basically similar.

➢After the end of July 2024 some chambers were brought off the GIF++ and opened for material studies: (see L. Quaglia later today on and https://indico.global/event/16058/contributions/154198/)

➢ General comment: disentangle effects due to HFO wrt. the ones due TFE not trivial: more studies needed on this topic.