Long-term performance of eco-friendly Resistive Plate Chamber detectors

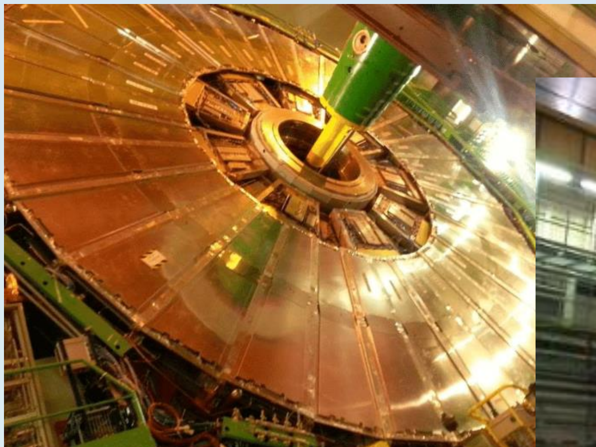
M. De Serio (University of Bari and INFN Bari)
on behalf of the RPC EcoGas@GIF++ Collaboration

Outline

- RPCs in HEP: status of the art
- Greenhouse gases: regulation and possible strategies
- Towards new generation RPCs
- RPC performance with eco-friendly HFO-CO_2 based mixtures
- Conclusions and outlooks

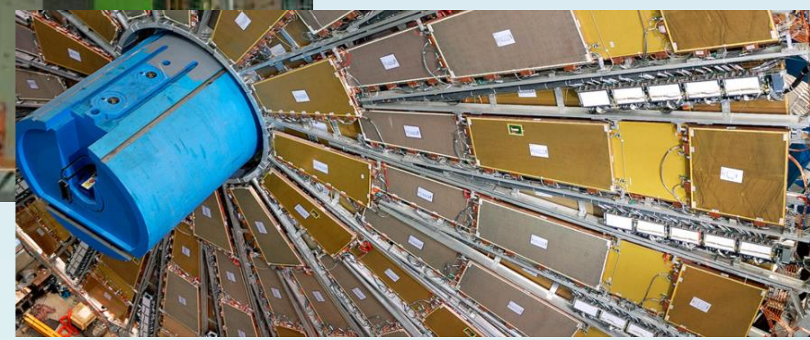
RPCs in HEP: status of the art

- Detector technology widely adopted in HEP experiments (streamer or avalanche mode):



CMS endcap

OPERA muon spectrometer



ATLAS muon spectrometer

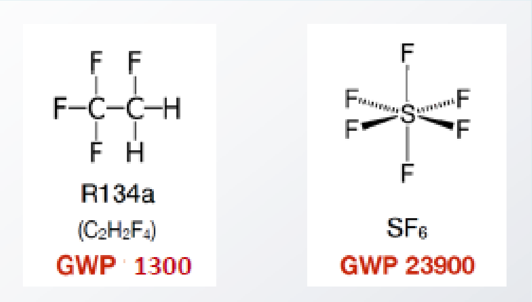
ARGO detector

- Main features:
  - high efficiency and good time resolution
  - ease of construction and robustness
  - low cost per unit area

RPCs in HEP: status of the art

- *Standard* gas mixture (STD) in avalanche mode :
  - $C_2H_2F_4$ (R134a) major component (~ 95%) → ionization and multiplication processes
  - i-C_4H_{10} (< 5%) → photon quenching properties
  - SF_6 (< 1%) → electron quenching properties

- R134a and SF_6 are fluorinated greenhouse gases (F-gases) with *high* Global Warming Potential (GWP*)



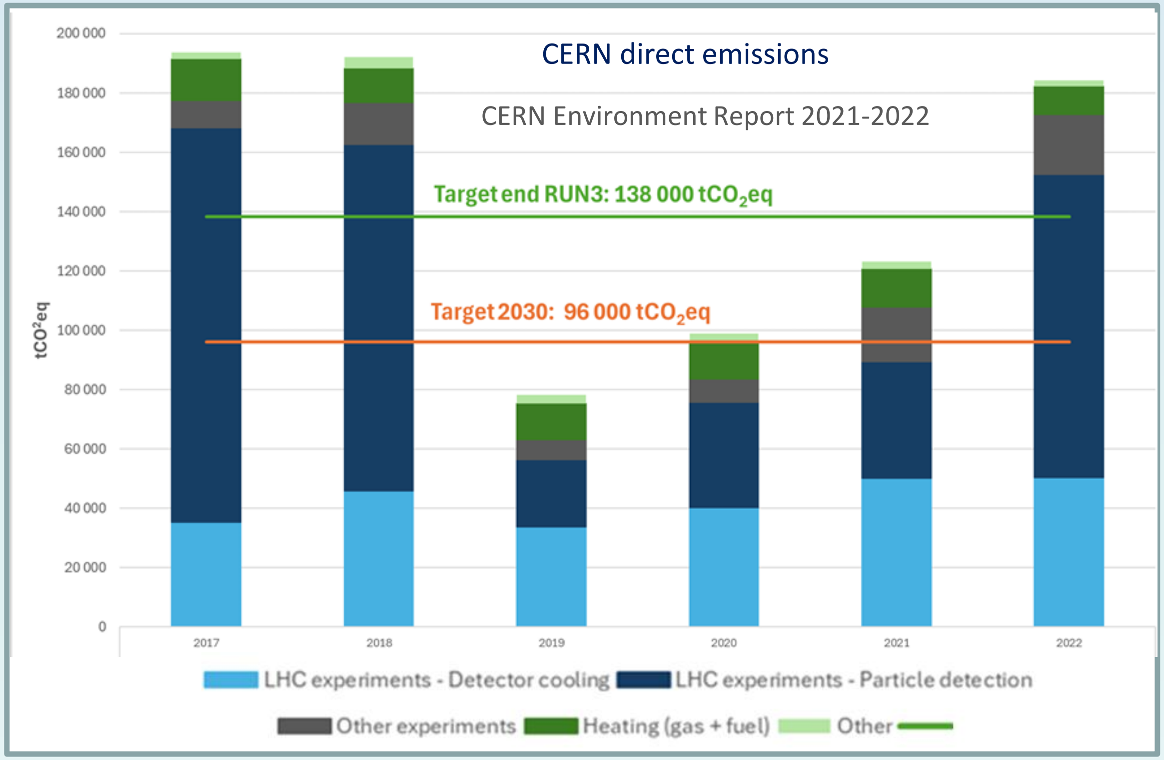
*GWP = heat trapped in the atmosphere by a ton of a given gas compared to a ton of CO_2 in 100 years

Greenhouse gas regulation

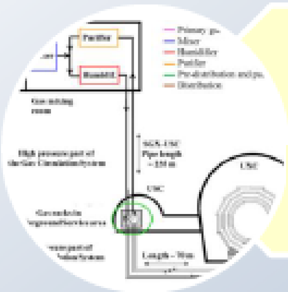
Since the Kyoto Protocol, production, usage and emission of F-gases subject to increasingly strict regulations

Impact on scientific activities

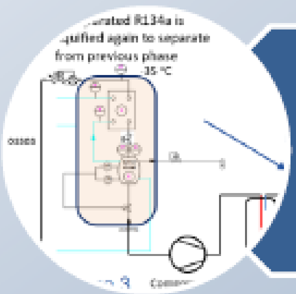
- Dedicated efforts toward greenhouse gas reduction



Greenhouse gases: possible strategies



Gas Recirculation

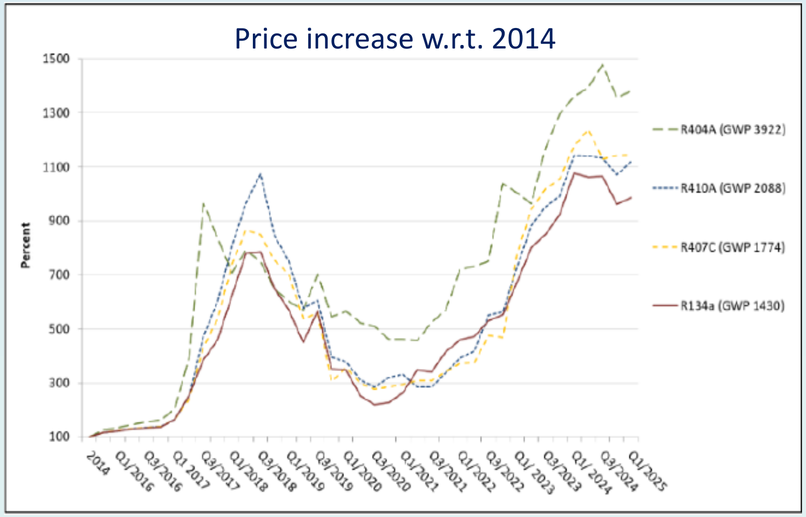


Gas Recuperation

Gas Disposal

BUT..

- Legislative landscape is rapidly evolving
- F-gas availability not granted
- Prices are increasing



DRD1 Workshop “Towards Sustainable Gas Mixtures for Future Detectors”

Towards new generation RPCs

Promotion of R&D on possible alternatives to current gas mixtures for the future operation of gaseous detectors

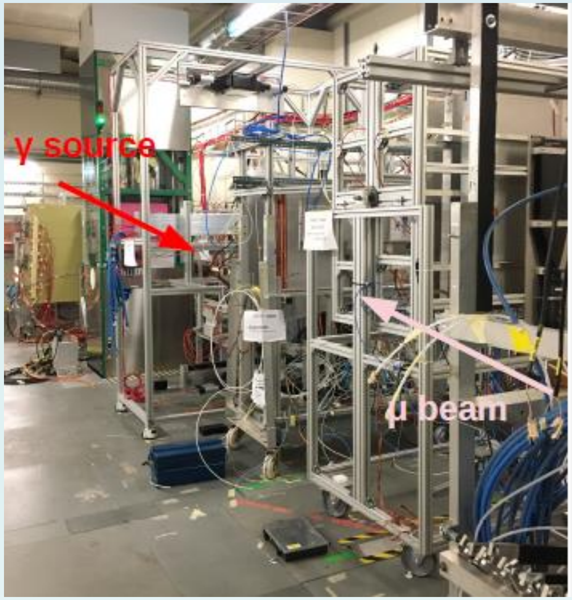
The RPC EcoGas@GIF++ Collaboration

- Cross-experiment Collaboration (ALICE, ATLAS, CMS, LHCb/SHiP, CERN EP-DT group) active since 2019
- Studies on possible environmental-friendly alternatives to the *STD mixture* using RPCS operated in avalanche mode with diverse electronics and detector geometries

CERN Gamma Irradiation Facility (GIF++)

- **12.5 TBq ^{137}Cs source** producing (660keV) γ's
- Attenuation filters
- **Muon beam** (100 GeV/c) in dedicated beam test periods

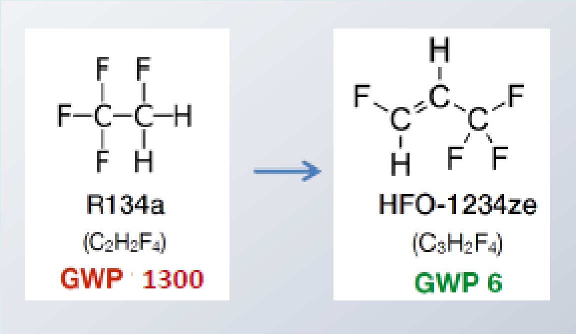
> **Combination of γ source with high-energy beam: Detector performance in different background conditions**
>
> **High-activity γ source: Aging studies**



Towards new generation RPCs

Promotion of R&D on possible alternatives to current gas mixtures for the future operation of gaseous detectors

RPCs: focus on Hydrofluoroolefins (HFOs)



First goal: validation of HFO-1234ze as a replacement of R134a (main component of the STD mixture)

- Commercially available (refrigerator)
- *Similar* chemical formula as R134a
- Lower first Townsend coefficient w.r.t. R134a

Towards new generation RPCs

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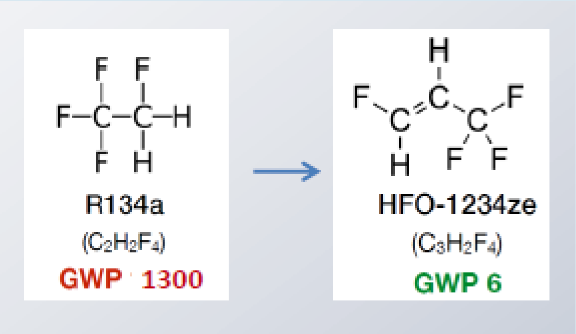

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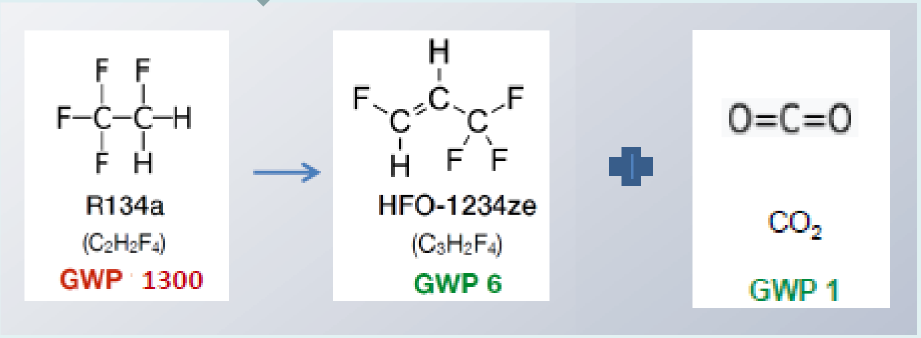


Need to dilute HFO with another component to keep the detector operating voltage to *reasonable* values

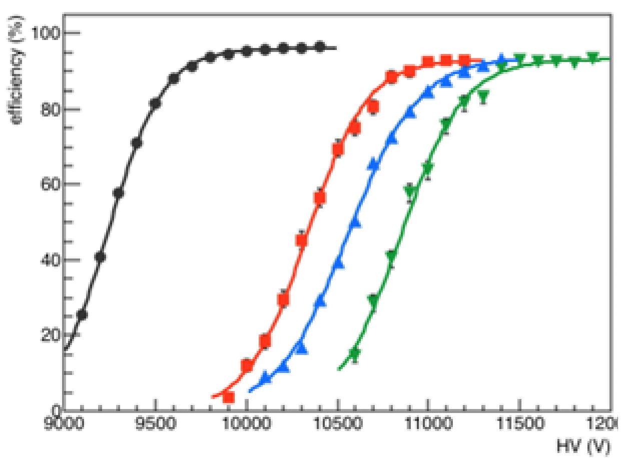
Towards new generation RPCs

- Several mixtures with different fractions of $HFO/CO_2/i\text{-}C_4H_{10}/SF_6$ extensively tested in various laboratories of the Collaboration

- Two mixtures selected:
  - **ECO2**: 35% HFO / 60% CO_2 / 4% $i\text{-}C_4H_{10}$ / 1% SF_6
  - **ECO3**: 25% HFO / 69% CO_2 / 5% $i\text{-}C_4H_{10}$ / 1% SF_6

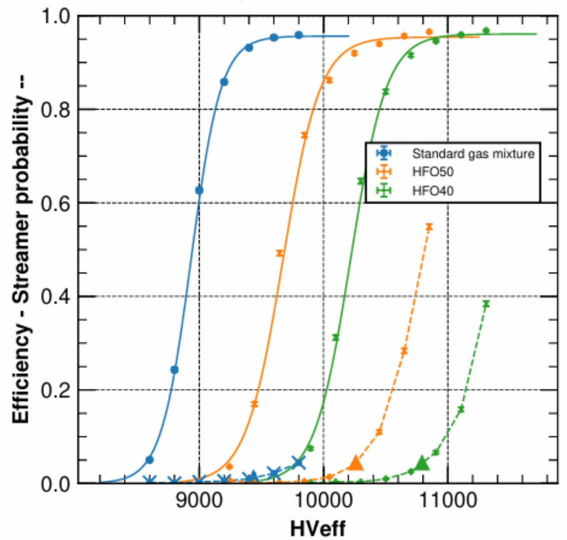
A few examples

ALICE, 2019 JINST 14 P11014



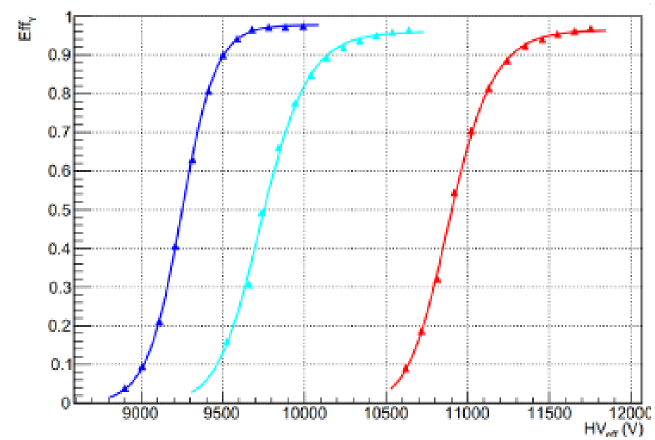
$C_2H_2F_4/i\text{-}C_4H_{10}/SF_6$ 89.7/10.0/0.3
$CO_2/HFO/i\text{-}C_4H_{10}/SF_6$ 50/39.7/10.0/0.3
$CO_2/HFO/i\text{-}C_4H_{10}/SF_6$ 50/39.4/10.0/0.6
$CO_2/HFO/i\text{-}C_4H_{10}/SF_6$ 50/39.0/10.0/1.0

CERN EP-DT, 2020 JINST 15 C11003



95.2% R-134a + 4.5% $i\text{-}C_4H_{10}$ + 0.3% SF_6	Standard
22.25% HFO, R-134a + 4.5% $i\text{-}C_4H_{10}$ + 1% SF_6 + 50% CO_2	HFO50
27.25% HFO, R-134a + 4.5% $i\text{-}C_4H_{10}$ + 1% SF_6 + 40% CO_2	HFO40

SHiP, 2023 JINST 18 C02022

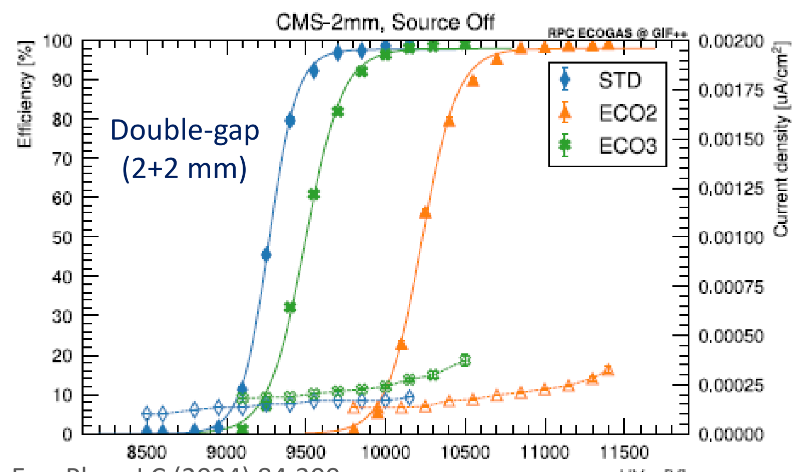


95.2% R134a/ 4.5% iC_4H_{10}/ 0.3% SF_6 (standard)
60% CO_2/ 35% HFO/ 4.5% iC_4H_{10}/ 0.5% SF_6
69.5% CO_2/ 25% HFO/ 5% iC_4H_{10}/ 0.5 % SF_6

Tests@GIF++: Performance with HFO-CO_2 mixtures

RPC	Gap/electrodes thickness (mm)	Electronics
ALICE	2 / 2	FEERIC + TDC
ATLAS	2 / 1.8	DIGITIZER
CMS	2+2 / 2	CMS FEB + TDC
CERN EP-DT	2 / 2	DIGITIZER
LHCb/SHiP	1.6 / 1.6	FEERIC + TDC

All chambers: HPL (bakelite) electrodes



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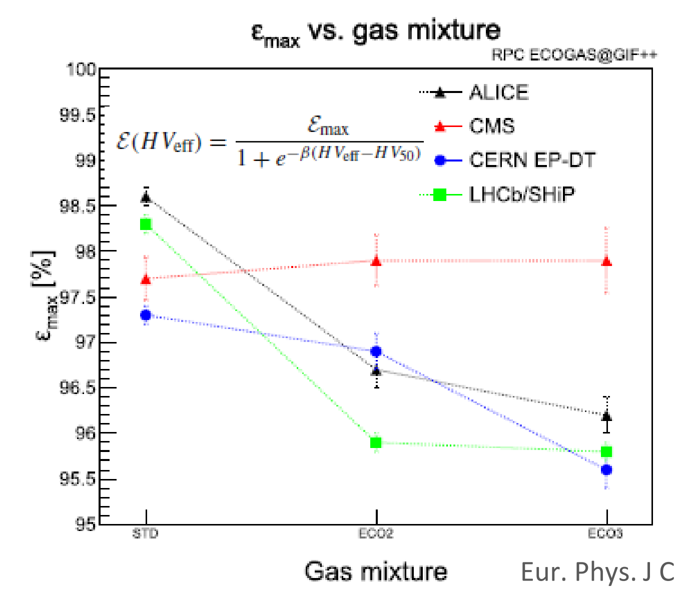

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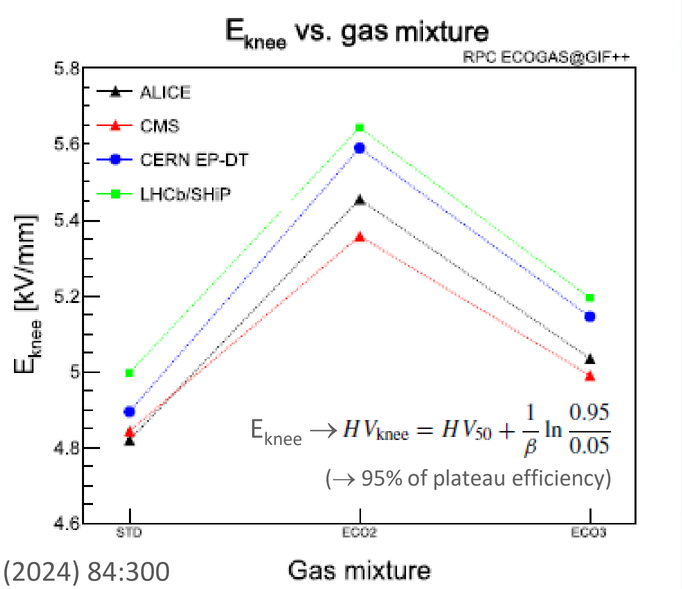

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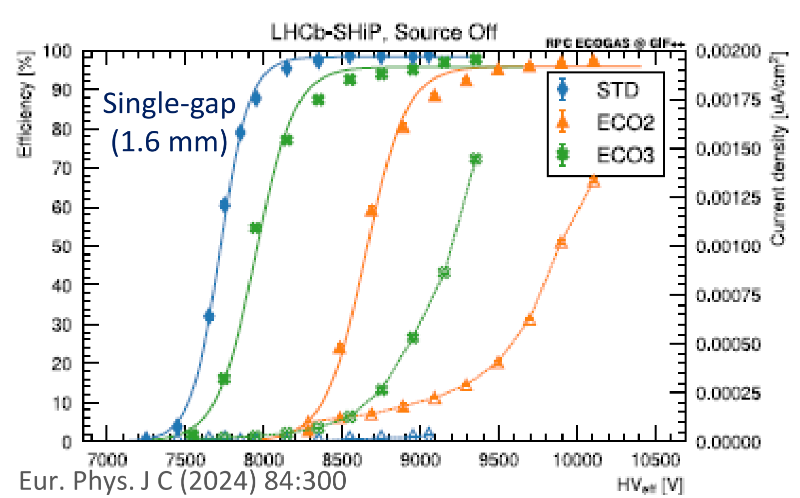

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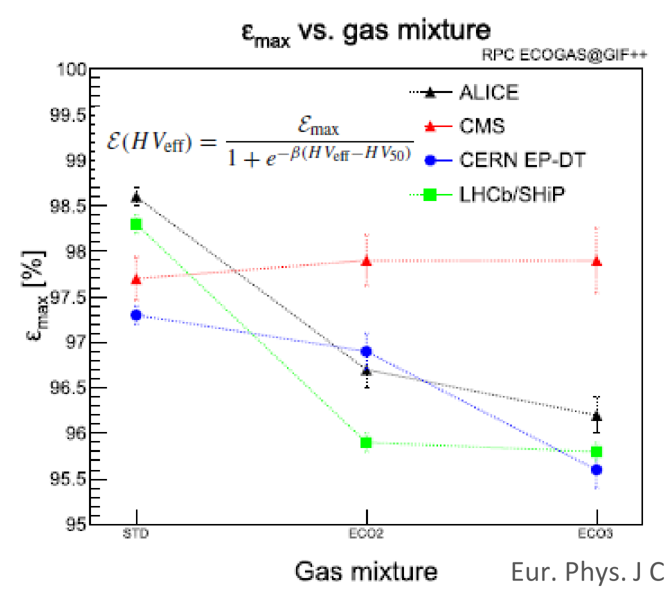

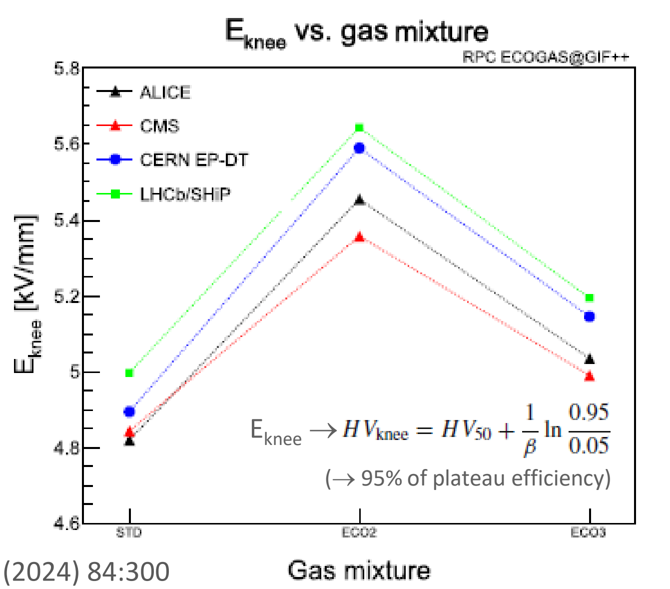

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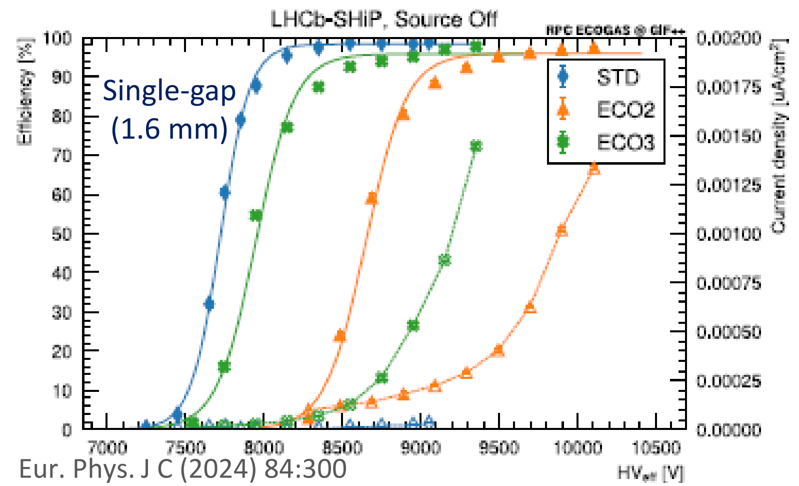

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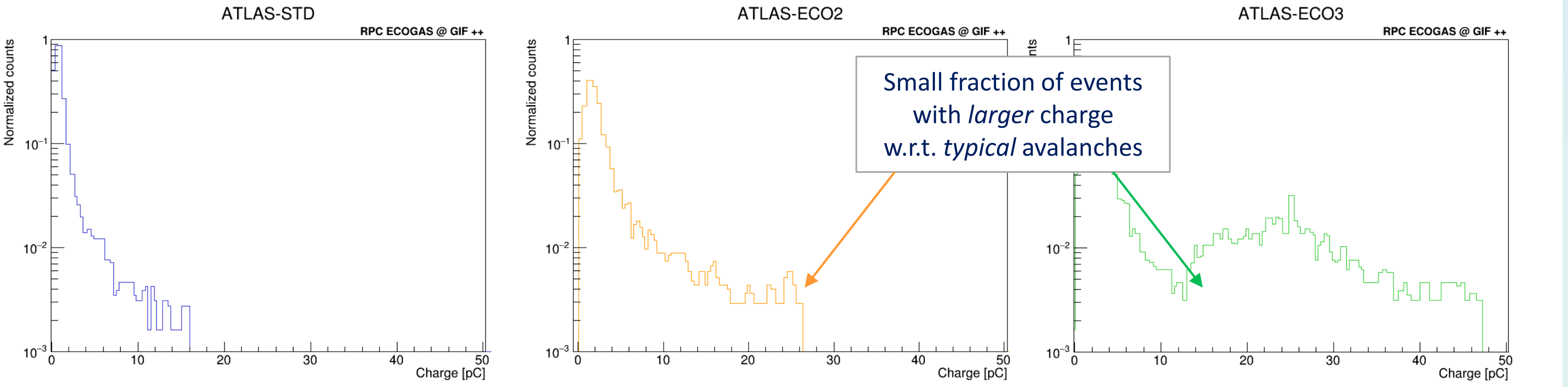
Charge distributions



ATLAS chamber
(1 single strip, 3 cm wide)

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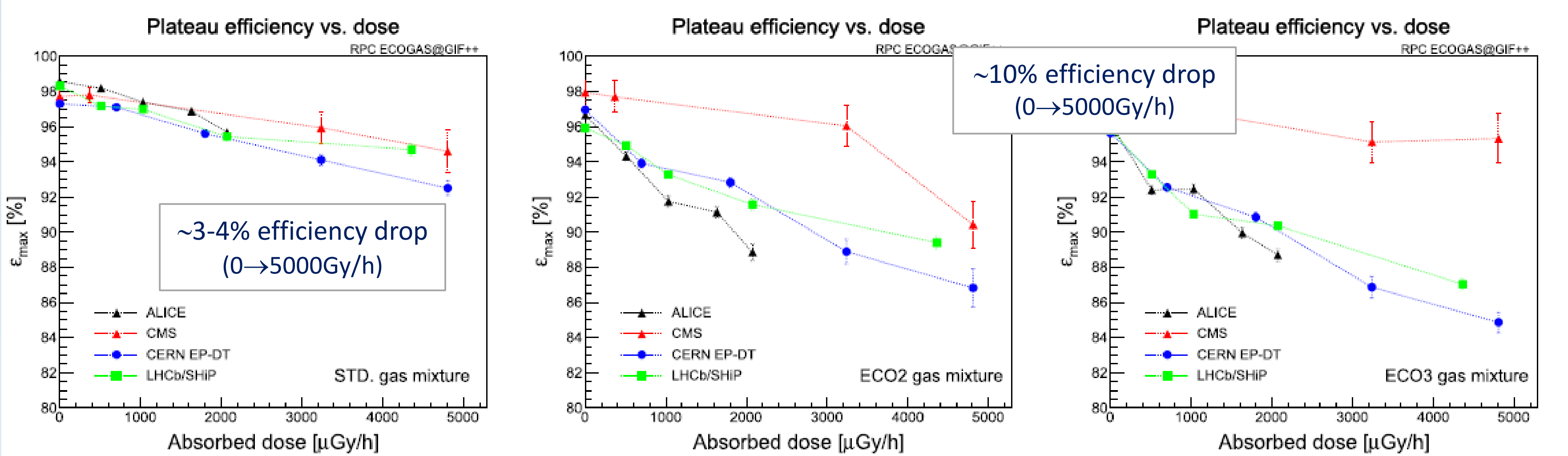
Tests@GIF++: Performance with HFO-CO_2 mixtures under irradiation



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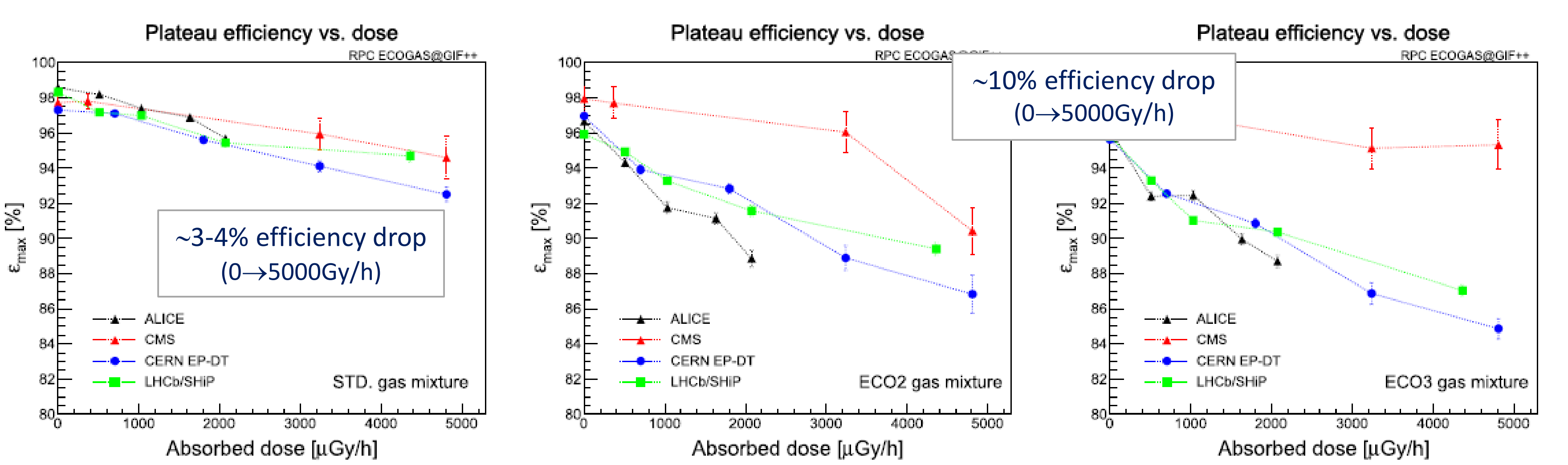

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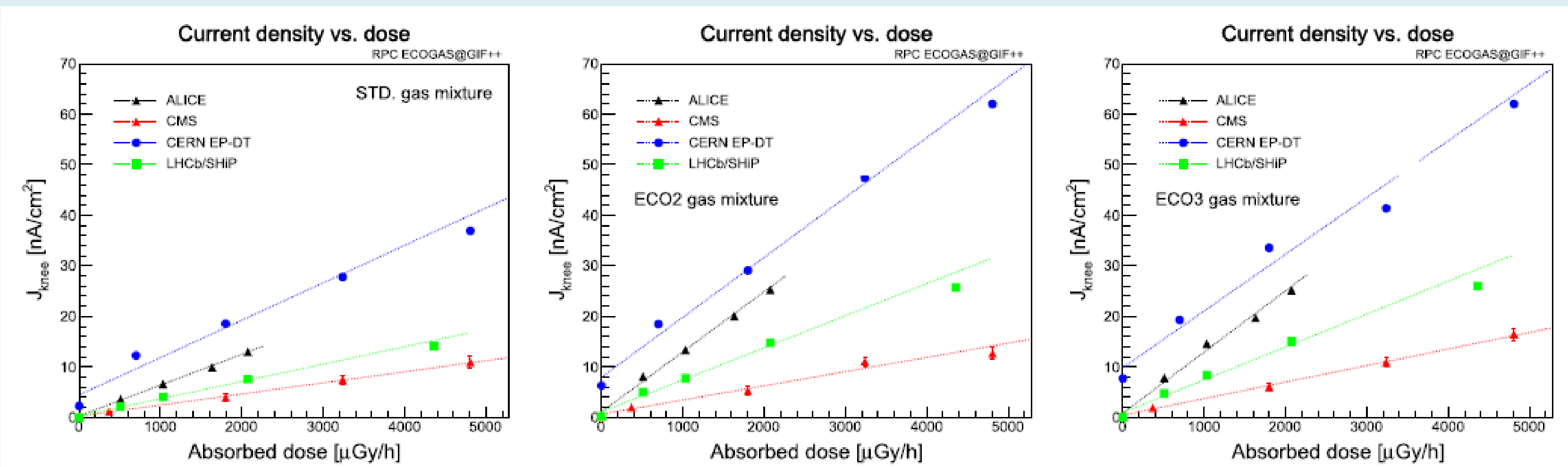

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5000 Gy/h ↔ ~ 1 kHz/cm²

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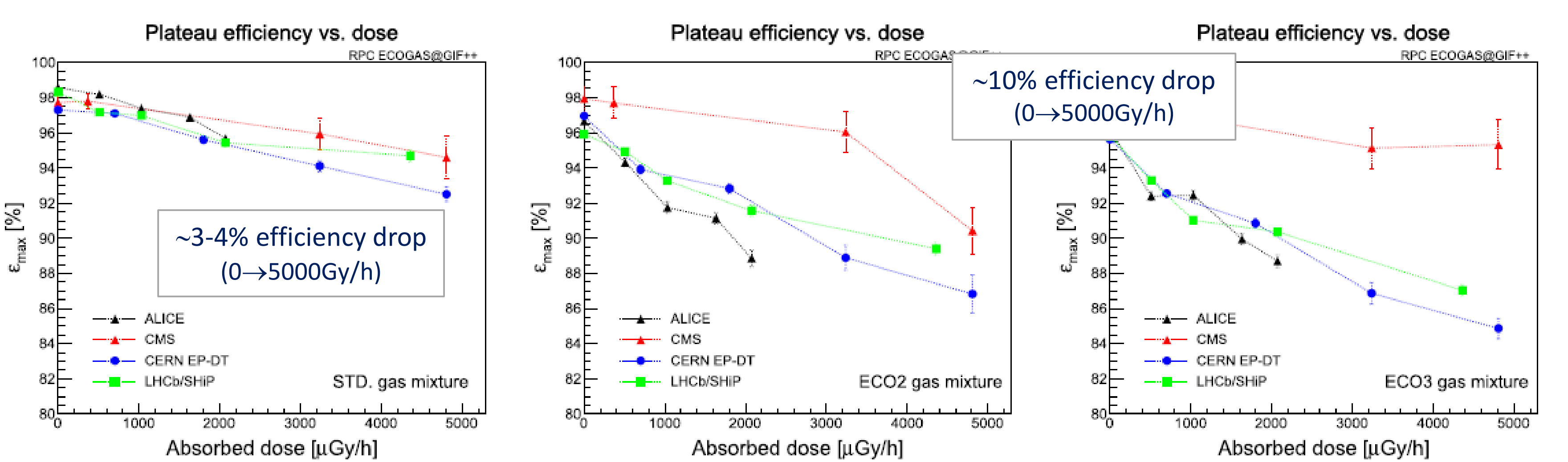

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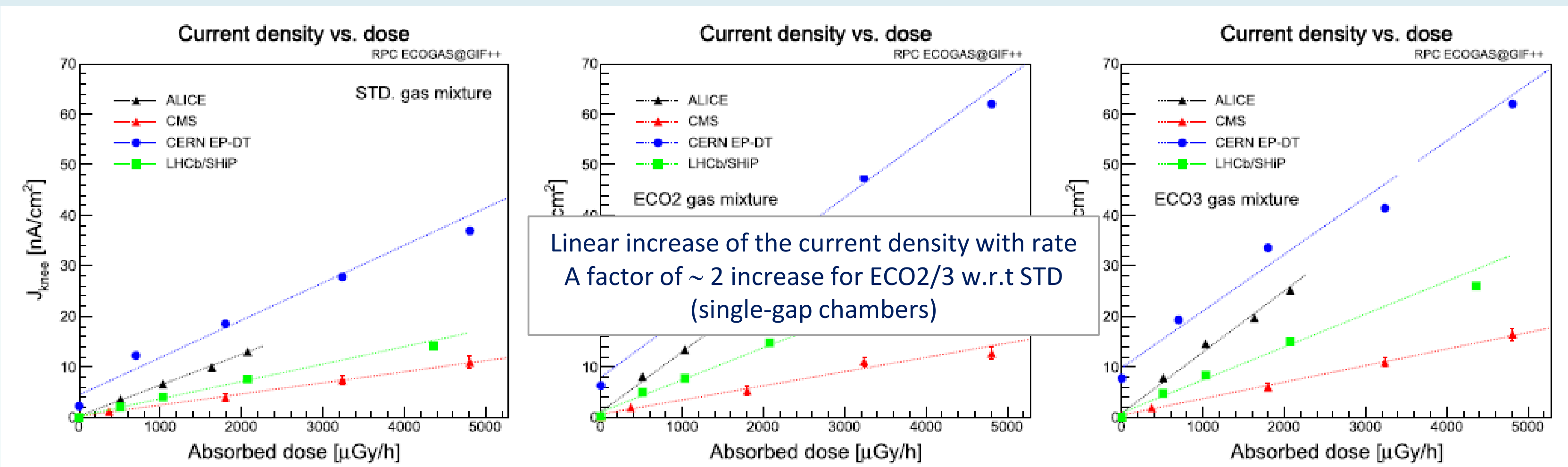

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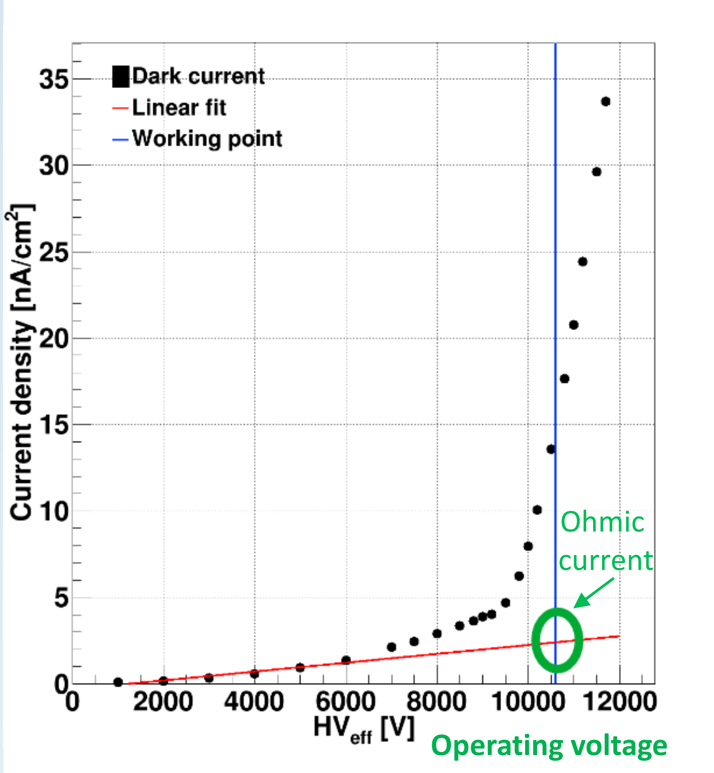
Tests@GIF++: Assessing long-term performance with HFO-CO_2 mixtures

The method

- Chamber kept at fixed HV while flushed with the gas mixture under test
- Continuous γ irradiation
- HV and current values monitored and stored every 30s
- Weekly measurement of the detector *dark current* (no γ background)
- Beam test (2-3/year) to measure the detector performance with increasing **integrated charge density**
- Measurement of the detector resistivity (2-3 times/year)



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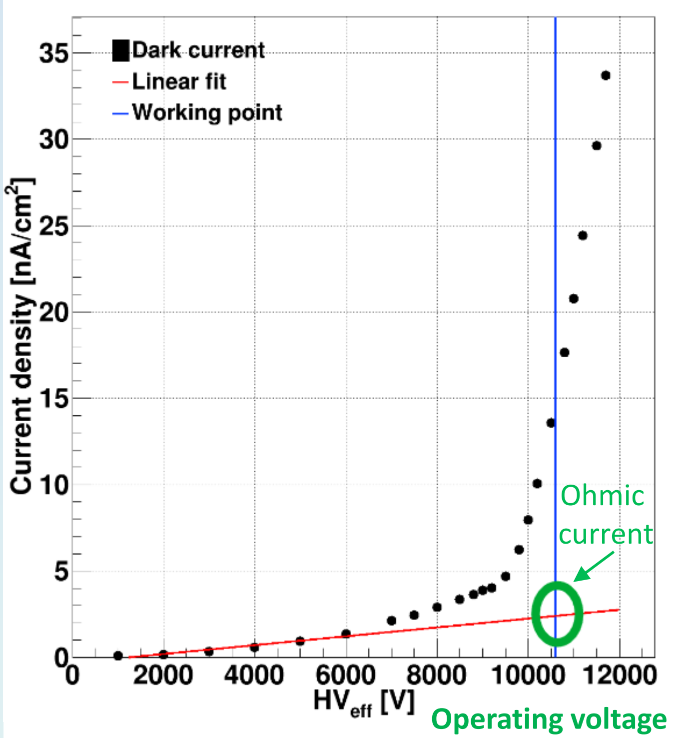
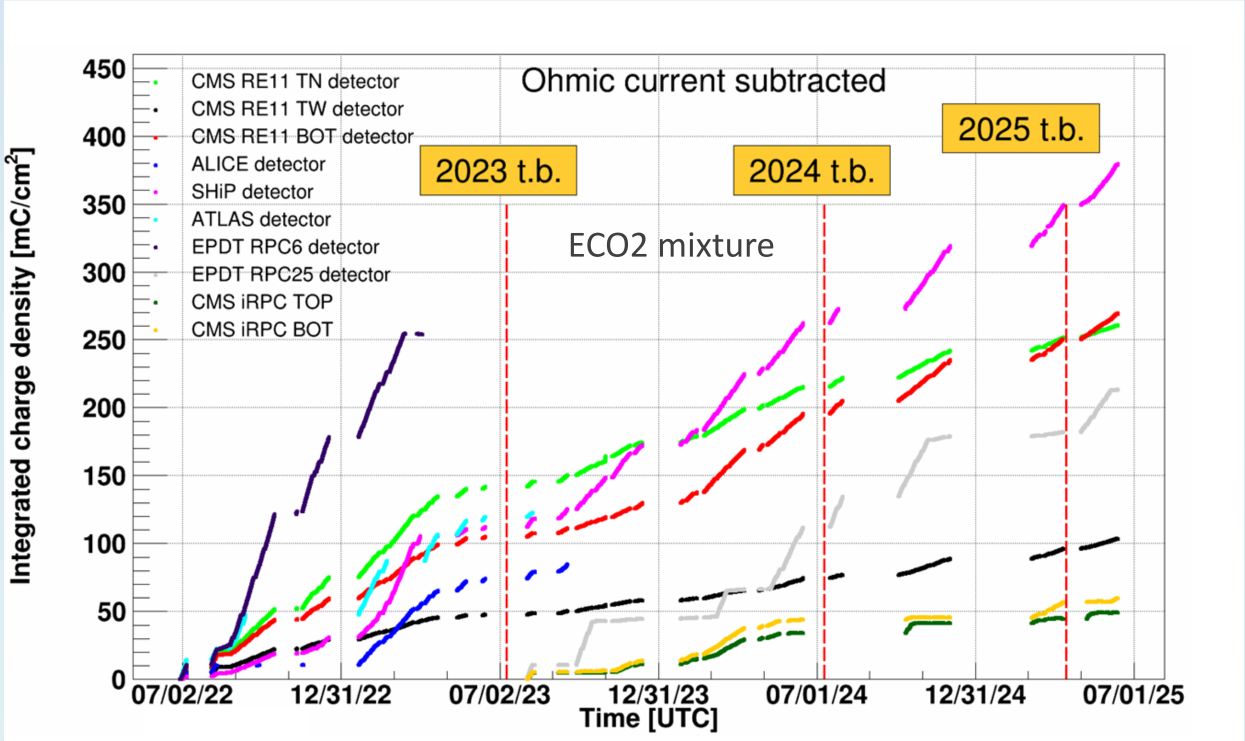


Aging in RPC

- Increase of integrated charge $\Rightarrow$ production of HF (and TFA for HFO) $\Rightarrow$ degradation of the electrodes' inner surfaces
- Changes in the HPL resistivity due to its drying up

Tests@GIF++: Long-term performance of HFO-CO_2 mixtures

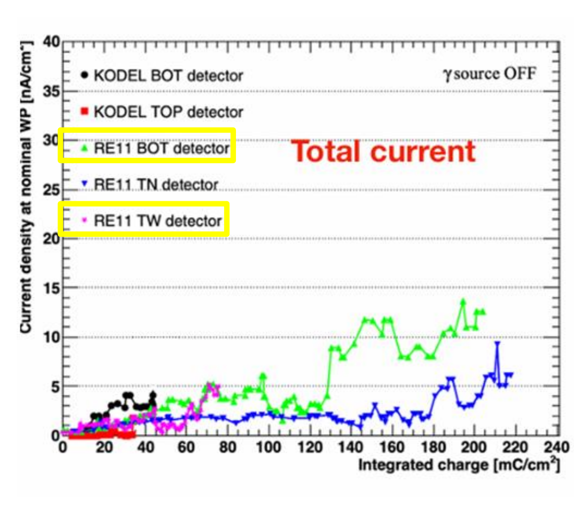


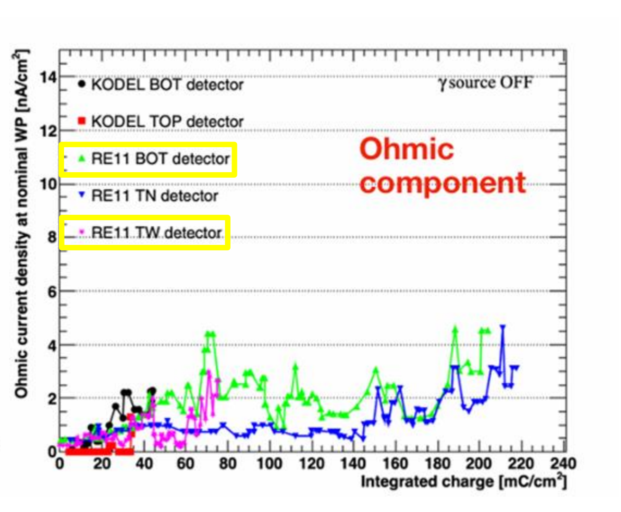
Different irradiation periods, distances from source and operating voltages

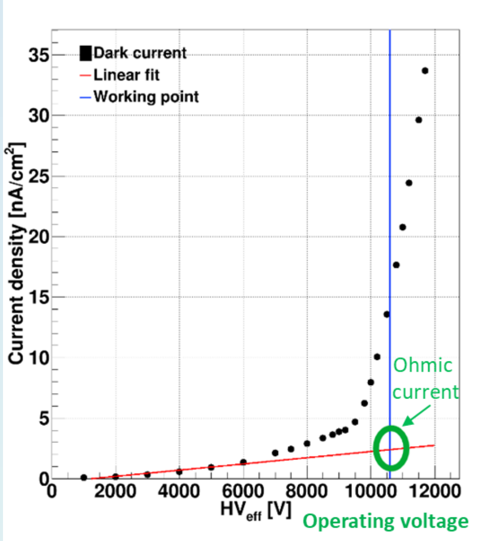
⇒ integrated charge density ~50÷400 mC/cm²

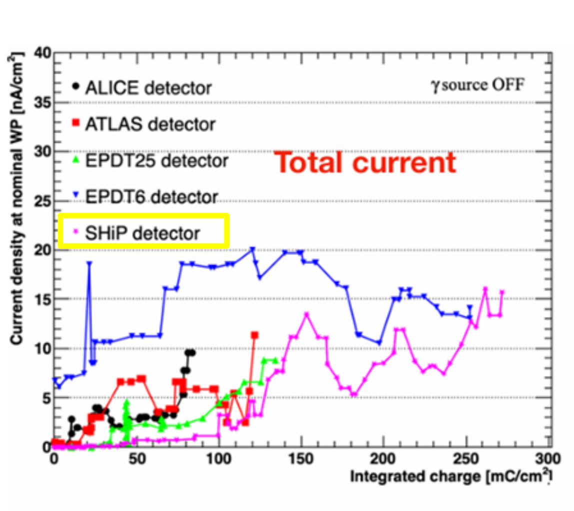
Tests@GIF++: Long-term performance of HFO-CO_2 mixtures

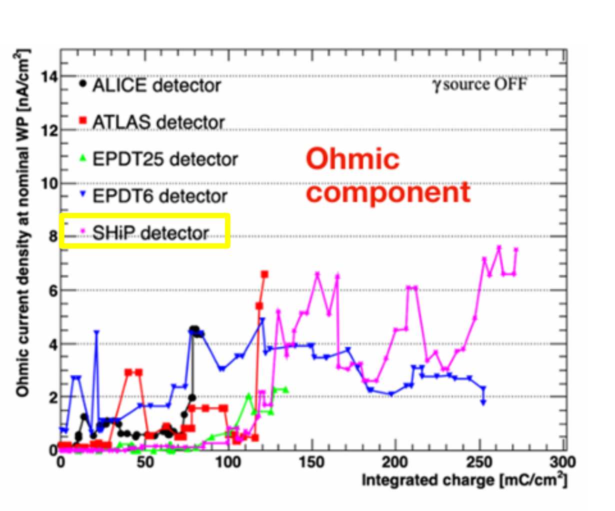
ECO2 mixture











Tests@GIF++: Long-term performance of HFO-CO_2 mixtures

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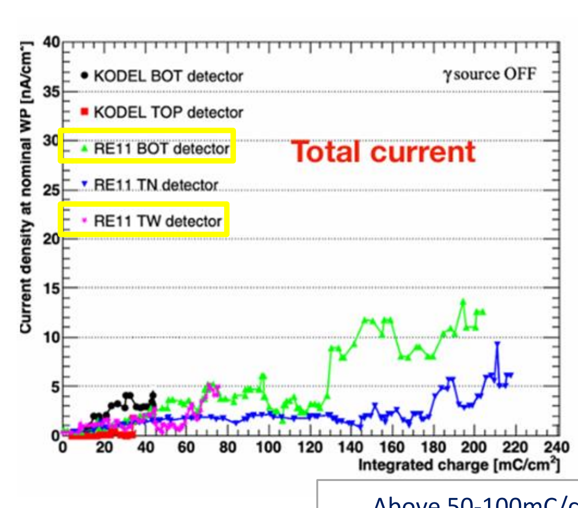

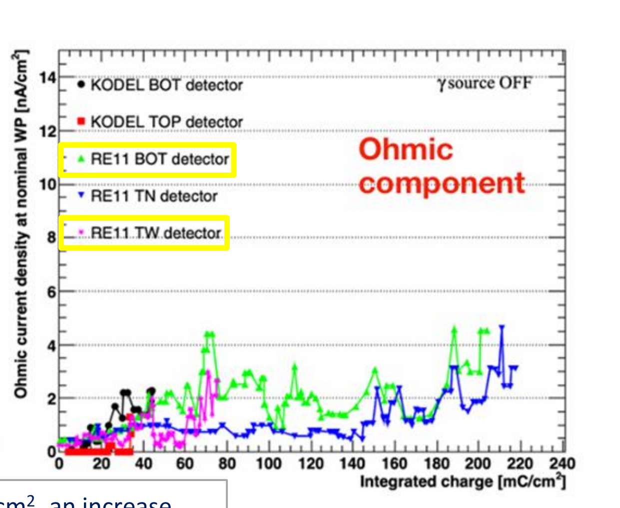

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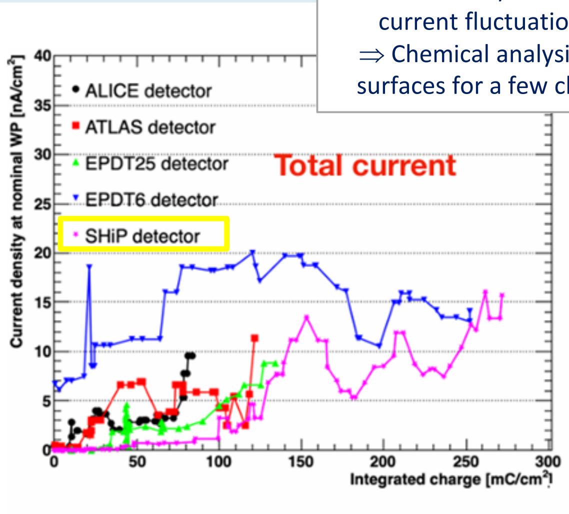
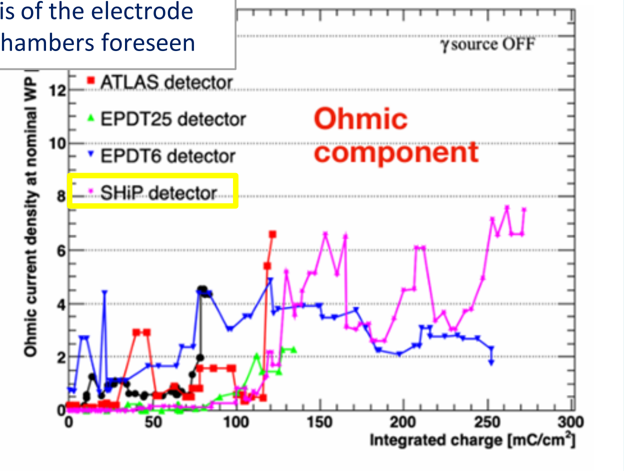
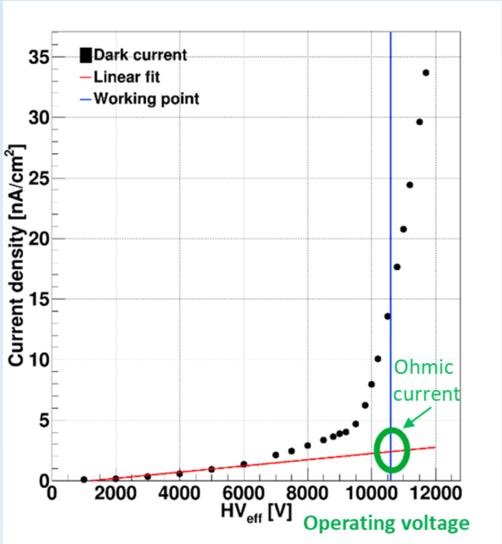
⇒ Chemical analysis of the electrode surfaces for a few chambers foreseen







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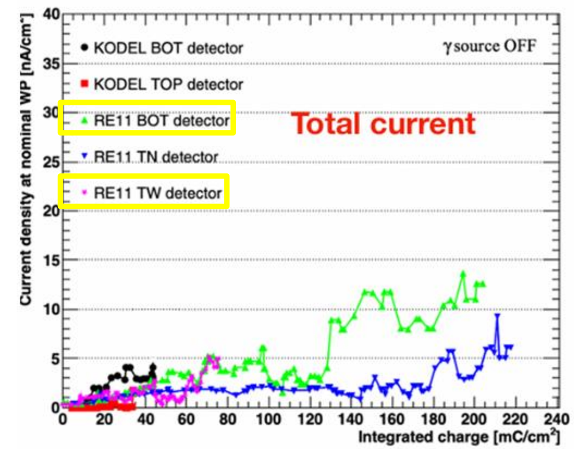

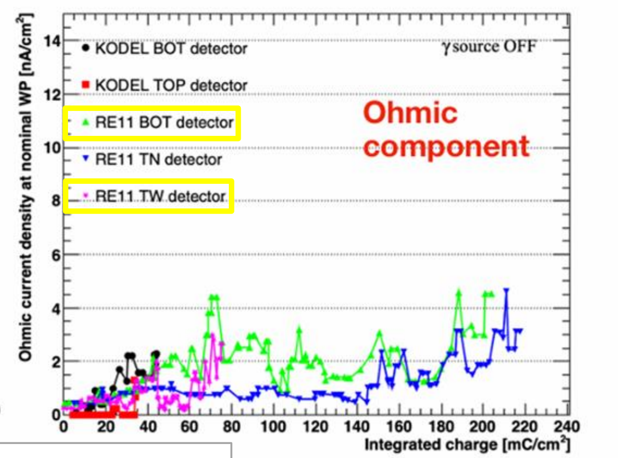

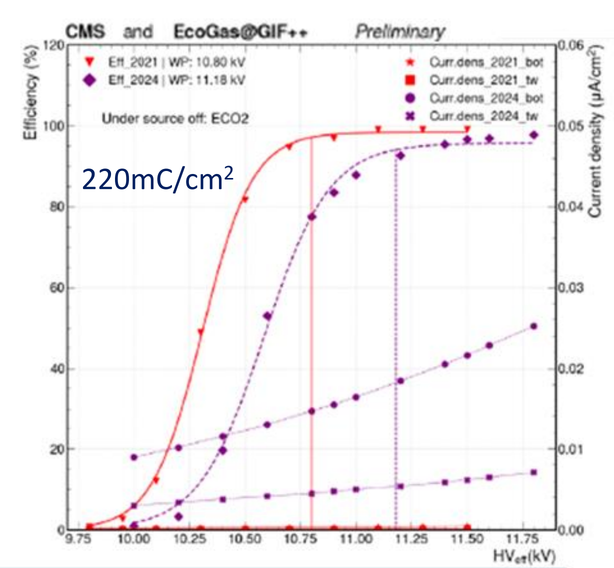

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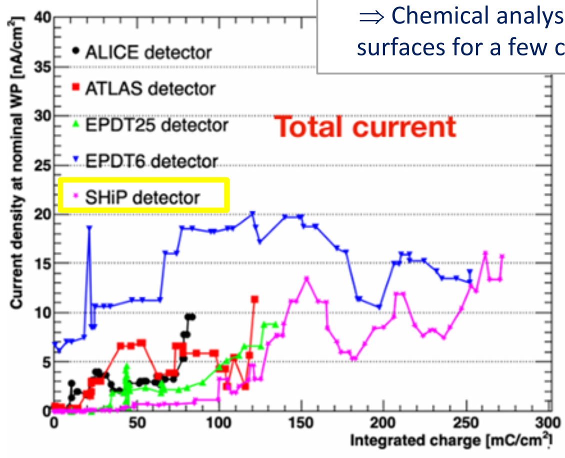
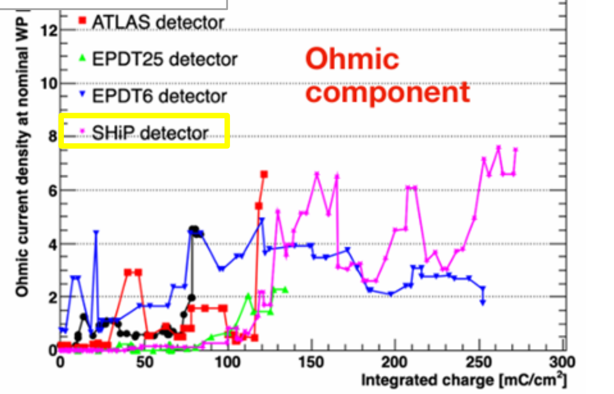
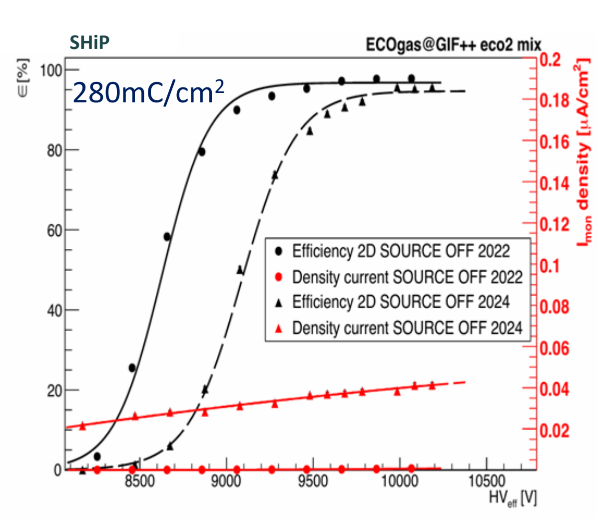


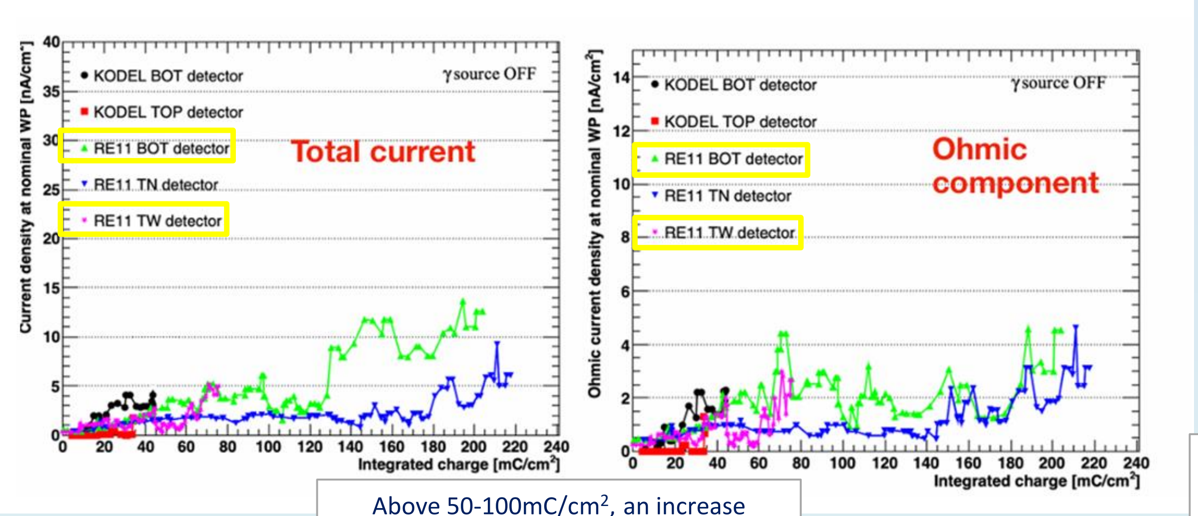




Tests@GIF++: Long-term performance of HFO-CO_2 mixtures

EcoGas GIF++ RPC

ECO2 mixture



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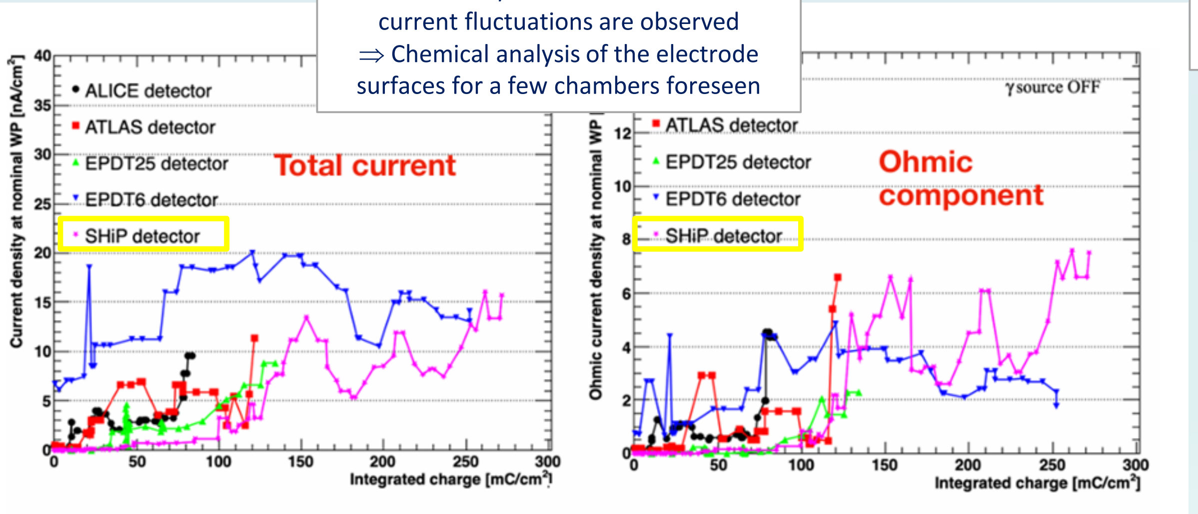
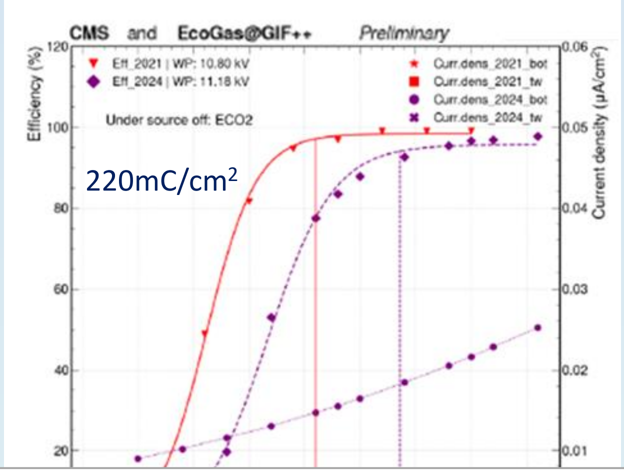
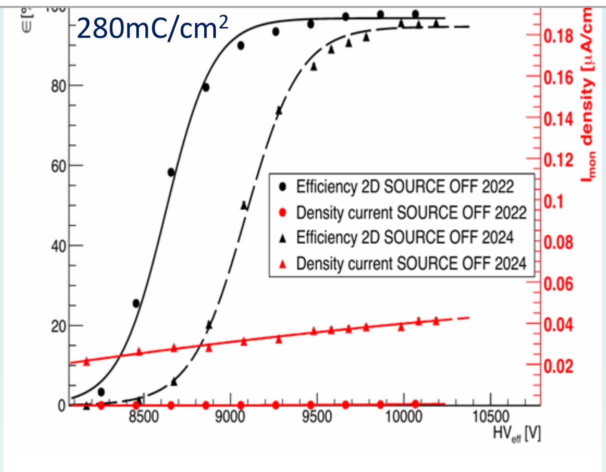




Performance comparison before/after aging campaign:
Stable plateau efficiency, eff. reduction of few %
WP shift observed, increase of current
No clear trend observed in the electrode resistivity
(not shown)

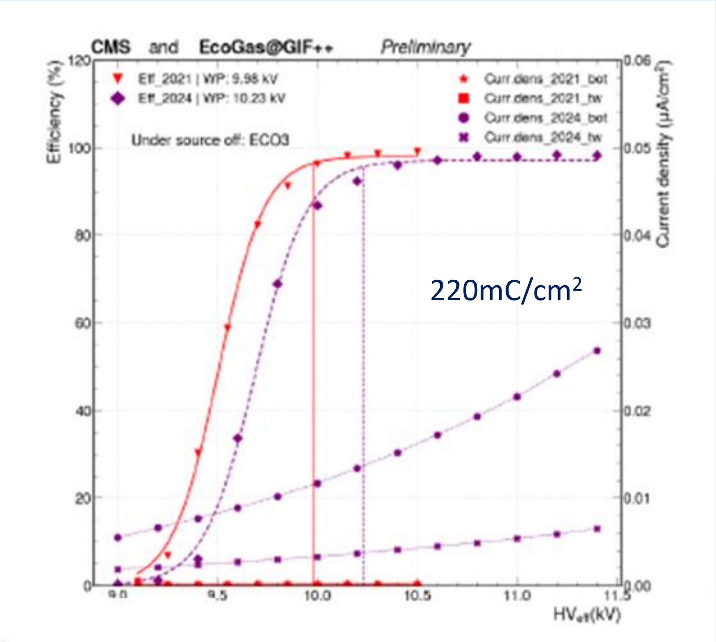


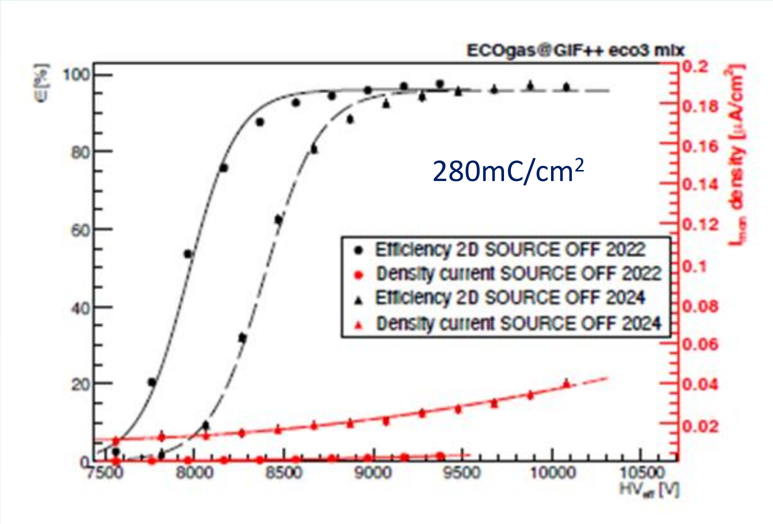
NOTE: 2025 beam test data analysis in progress

Tests@GIF++: Long-term performance of HFO-CO_2 mixtures

EcoGas@GIF++ RPC

ECO3 mixture





similar considerations apply to ECO3 mixture

Conclusions and outlooks

- Scientific community committed to environmentally responsible research

  ⇒ dedicated efforts toward greenhouse gas reduction

  ⇒ promotion of R&D on possible eco-friendly gas alternatives for future operation of gaseous detectors

- Since 2019, the RPC EcoGas@GIF++ Collaboration engaged in studying detector performance with R134a-free mixtures in different background conditions, as well as aging effects

- Focus on two mixtures based on HFO-CO_2 (ECO2 69%/25%, ECO3 60%/35%):
  - Extensive tests with/out irradiation show adequate performance up to a few hundred Hz/cm^2
  - Aging test campaign started in 2022 for long-term performance studies
  - Preliminary results show an increase in dark current for integrated charge densities > 50-100mC/cm^2, shift of the detector working point, no clear trend in electrode resistivity observed up to now
    ⇒ analysis of 2025 beam test data ongoing

- Next future: address SF_6 replacement, some interesting candidates already in play

Thank you for your attention