EP-DT
Detector Technologies

Task 7.2.3: Eco-friendly gas mixtures for RPCs

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on behalf of EcoGas@GIF++ Collaboration

AIDAinnova 3rd Annual Meeting
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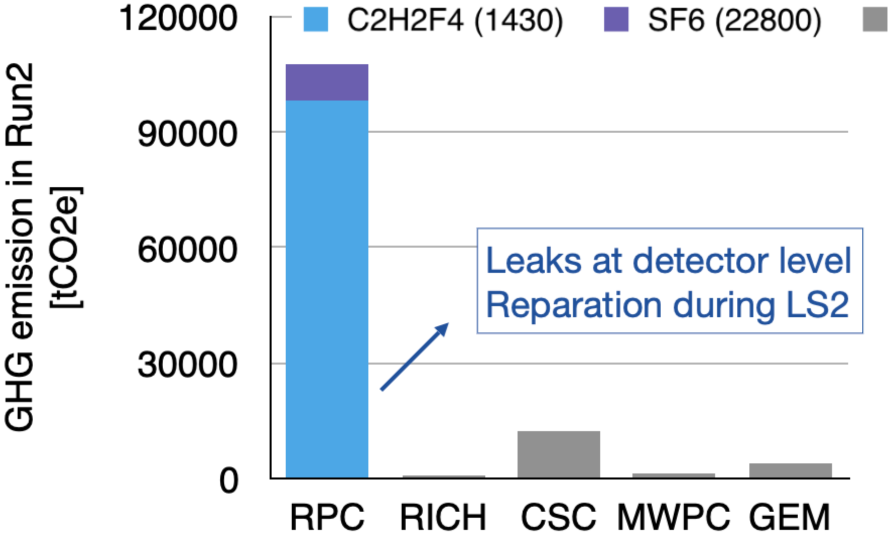
GHG for particle detectors



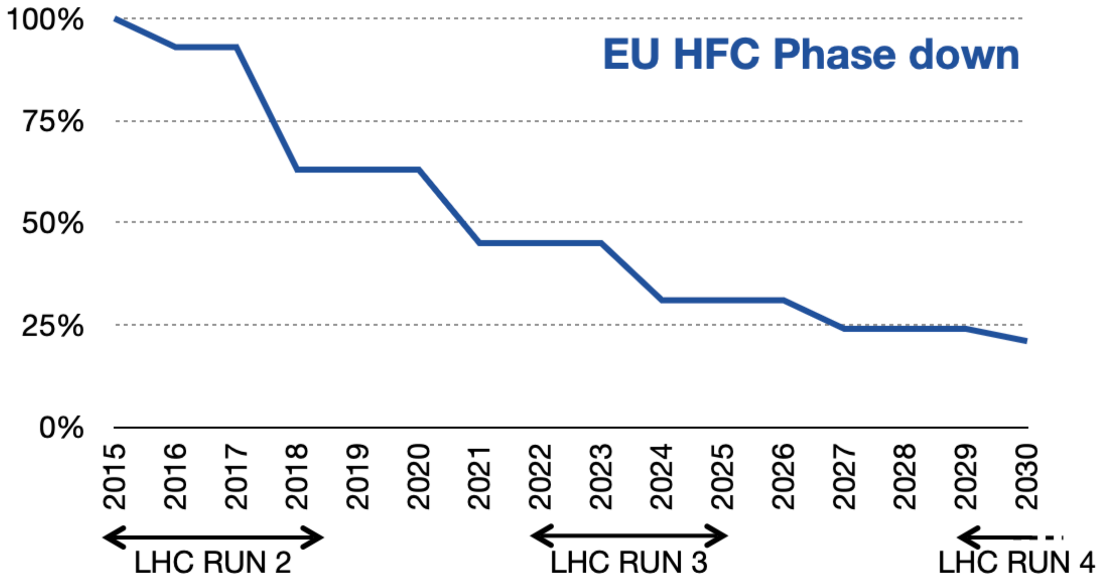
CERN GHG emissions from particle detectors

- **Main contributor is $C_2H_2F_4$** used for ALICE, ATLAS and CMS RPC systems
- **Emissions mainly due to leaks** at detector level (fragile connectors) in ATLAS and CMS.
- **Campaign** for leaks reparation in LS2

RPC gas mixture
~95%$C_2H_2F_4$ - ~5%iC_4H_{10} - 0.3%SF_6

European Union "F-gas regulation":

- **Limiting the total amount** of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030.
- **Banning the use** of F-gases where less harmful alternatives are widely available.
- **Preventing emissions** of F-gases from existing equipment by requiring checks, proper servicing and recovery



Prices are increasing in EU and availability in the future is not known.
Reduction of use of $C_2H_2F_4$ is fundamental for next LHC Runs and future applications

AIDA WP 7.2.3: Eco-gas studies

Deliverable:
Report on performance studies of several eco-friendly gas mixtures for RPCs operated at different background conditions

Motivation

- Different RPC communities testing eco-friendly gases
- Up to now no eco gas mixture was found to fulfil requirements for already installed RPCs at LHC
  - Layout is fixed, not possible to change FEB and HV cables
- It is fundamental to search for new eco-gases for RPC detectors for LHC and not-LHC experiments as well as for future applications

Studies in the AIDainnova Task WP 7.2

- Identification if suitable eco-friendly gas mixture for RPC operation under gamma irradiation
- Long term performance studies on RPC detectors operated under gamma irradiation
- Detector performance with muon beam and gamma background
- F-based impurities production measurements

The ECOGAS@GIF++ collaboration is a joint effort between CERN Gas Team, ALICE-RPC, ATLAS-RPC, CMS-RPC, LHCb-SHIP communities

Institues involved

Institute	Main contact person
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Detectors and gas mixtures

HPL RPC from different experiments

- Different electrode thickness
  - HPL produced in different companies
- Different gap thickness
  - Performance can vary depending on gap thickness

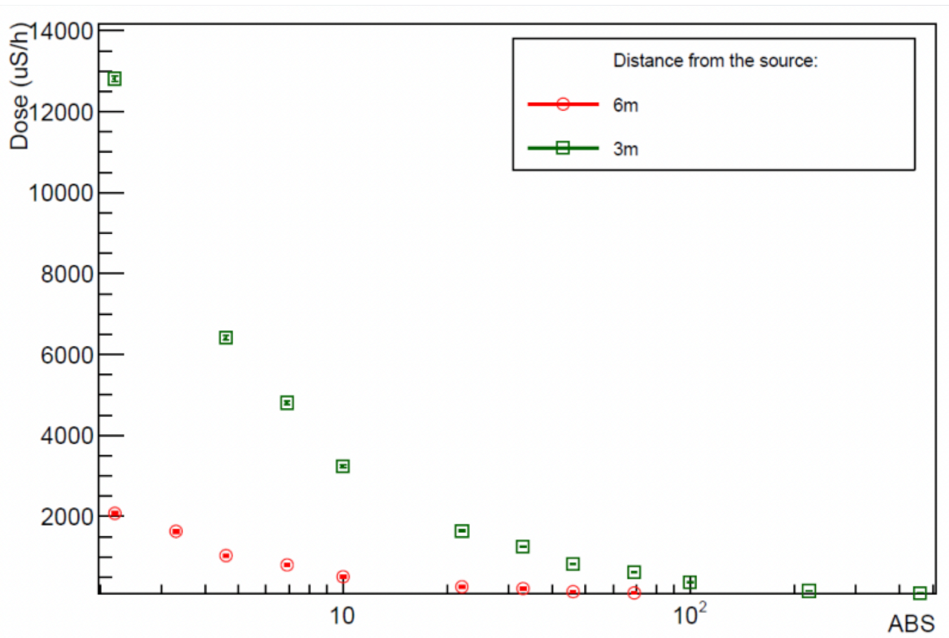
Detector	# of gaps	Gap thickness (mm)	Electrode thickness (mm)	Gap area (cm^2)
ALICE	1	2	2	2500
ATLAS	1	2	1.8	550
EP-DT	1	2	2	7000
CMS	2 (TW/TN + BOT)	2	2	3637 + 4215
LHCb/SHiP	1	1.6	1.6	7000

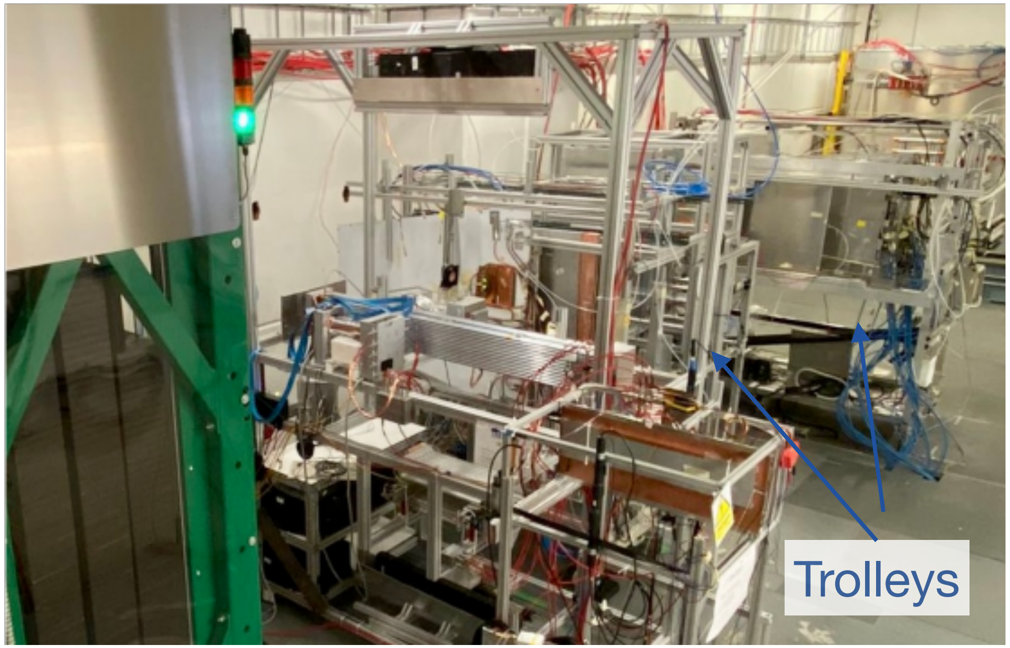
Three gas mixtures tested

Name	R134a (%)	HFO (%)	CO_2 (%)	I-C_4H_{10} (%)	SF_6 (%)
STD (reference)	95.2	0	0	4.5	0.3
ECO1	0	45	50	4	1
ECO2	0	35	60	4	1

Set-up at GIF++

- GIF++
  - 12.2 TBq ^{137}Cs + H4 SPS beam line: muon beam 100 GeV/c
- Gas mixer unit to provide up to 4 component gas mixture
  - $C_2H_2F_4$, iC_4H_{10}, SF_6, CO_2, Ar, HFO
  - Monitoring of gas flow
  - Dedicated humidifier module
- HV and electronics: dedicated power supply and readout electronics for each detector
- 2 trolleys at different distances from the gamma source
  - Different irradiation rates





Improvement of the set-up in 2023

New mixer and humidifier module

- New gas mixing unit ATEX
  - ATEX, possible to easily use flammable gases
  - Up to 4 gas components
  - Easily to move from gas mixture to Ar for resistivity measurements
- New humidifier module
  - On-going automatic regulation of humidity
  - Different humidity sensors under test

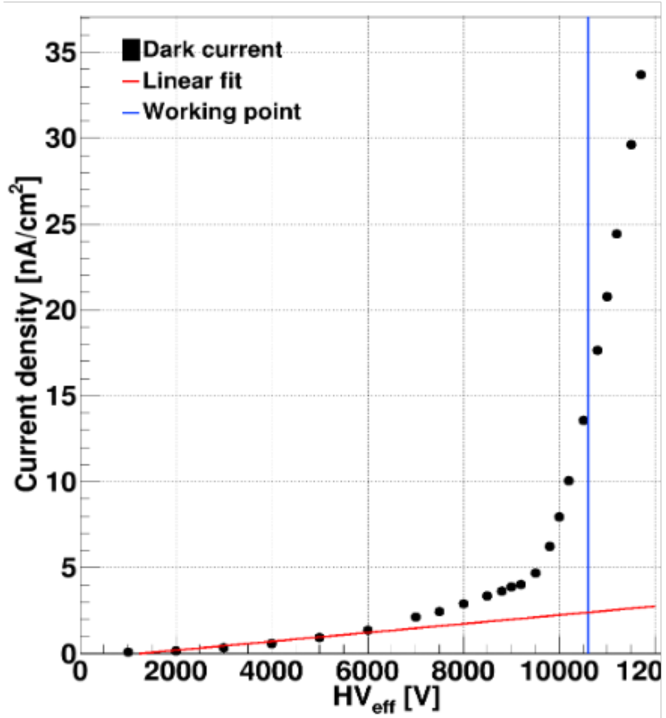
Flowmeter to monitor gas flow for each RPC

- Fundamental to keep a stable flow in the detectors
- OMRON sensors
  - Cheap and easy to read

Ageing studies methodology

Dark current scan vs effective high voltage

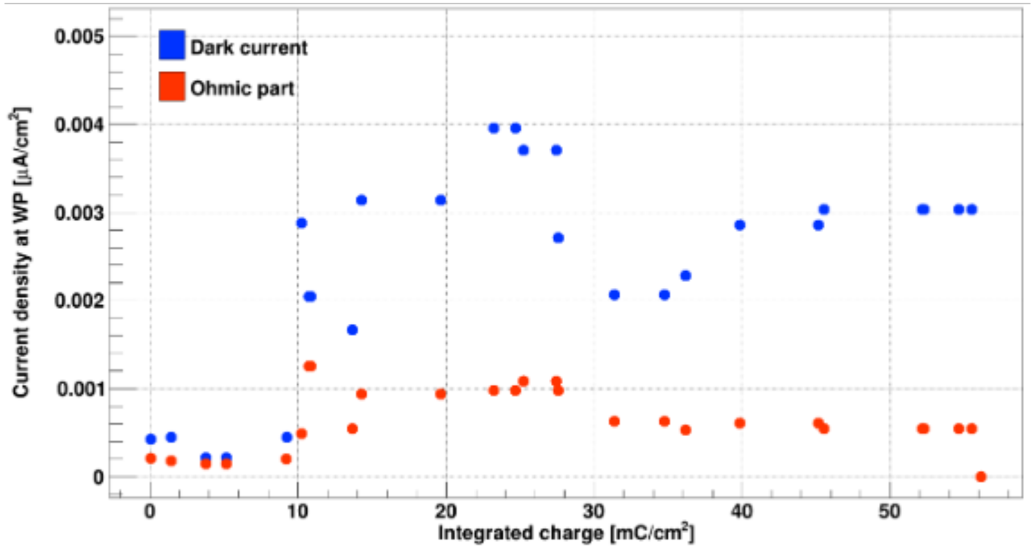
- One scan per week during the aging studies
- Linear fit between 0 and 5 kV to extrapolate Ohmic component of the dark current at the irradiation voltage
  - This current does not necessarily flow through the gas
  - Subtracted from the current absorbed under irradiation to calculate the integrated charge density



ALICE - 2 mm single gap

Long-term irradiation

- Detector continuously flushed at ~ 1 vol/h and humidity monitored
- Constantly irradiated at ~500 Hz/cm^2
- Weekly voltage/current scans at source off to assess detector performance
  - HV scan to measure absorbed current without irradiation (dark current)
- Monitor of detector performant with muon beam
  - 2-3 times per year



Ageing studies methodology

Monitoring of gas parameters and source status

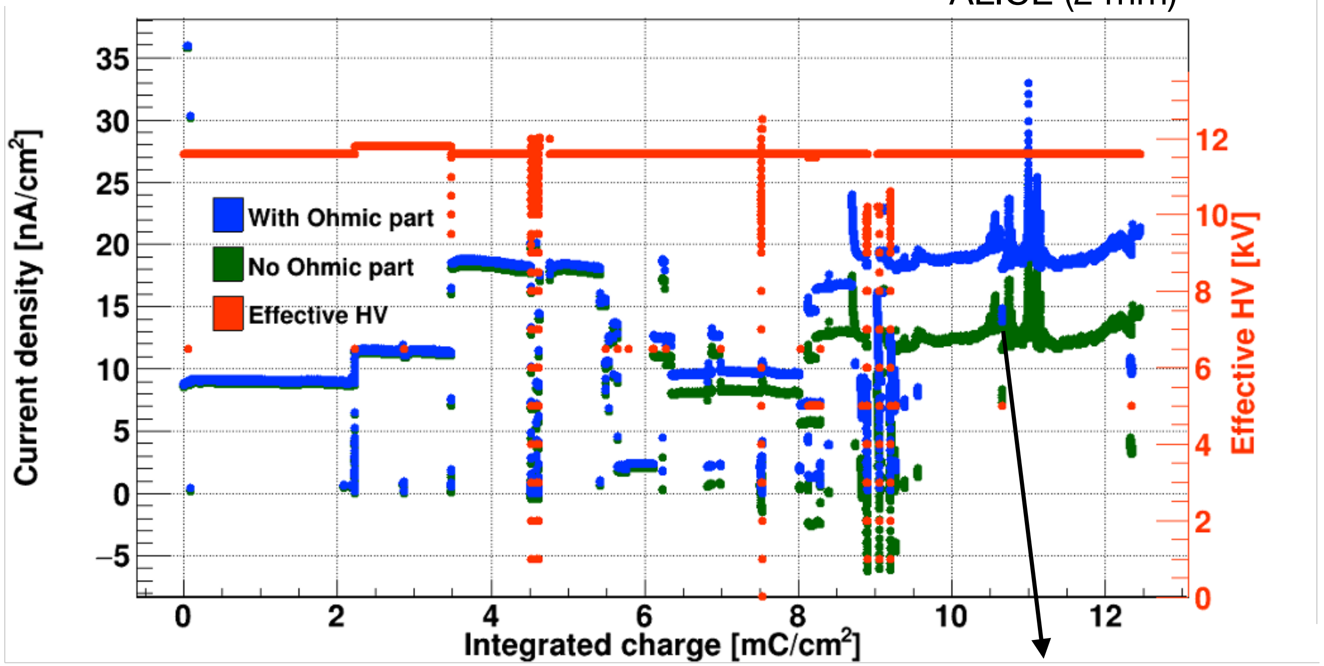
Ageing studies methodology

Monitoring of HV applied and detector currents

Ageing studies results with ECO1

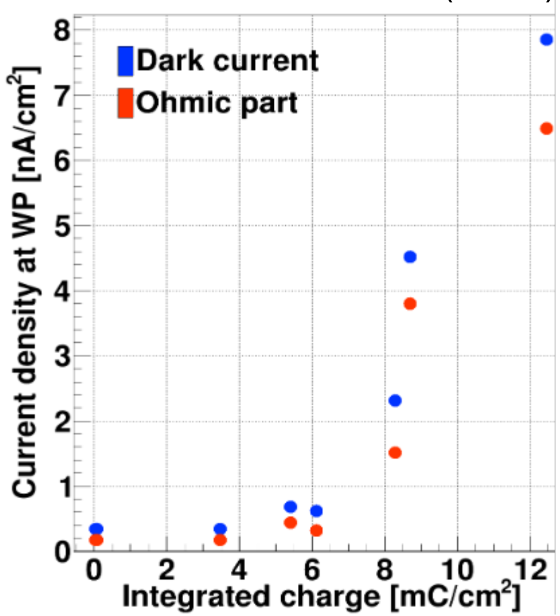
- Preliminary aging campaign with standard gas mixture to test stability of the system
- First eco-friendly candidate tested: ECO1 (50% CO_2 and 45% HFO)
  - Higher current (~1.5 x) and higher working point with respect to standard gas mixture
  - Higher production of F- impurities
- Current instabilities observed after few mC/cm2
- Increase of total dark current (Ohmic and total) for most of the detectors

ALICE (2 mm)



Current instabilities

ALICE (2 mm)

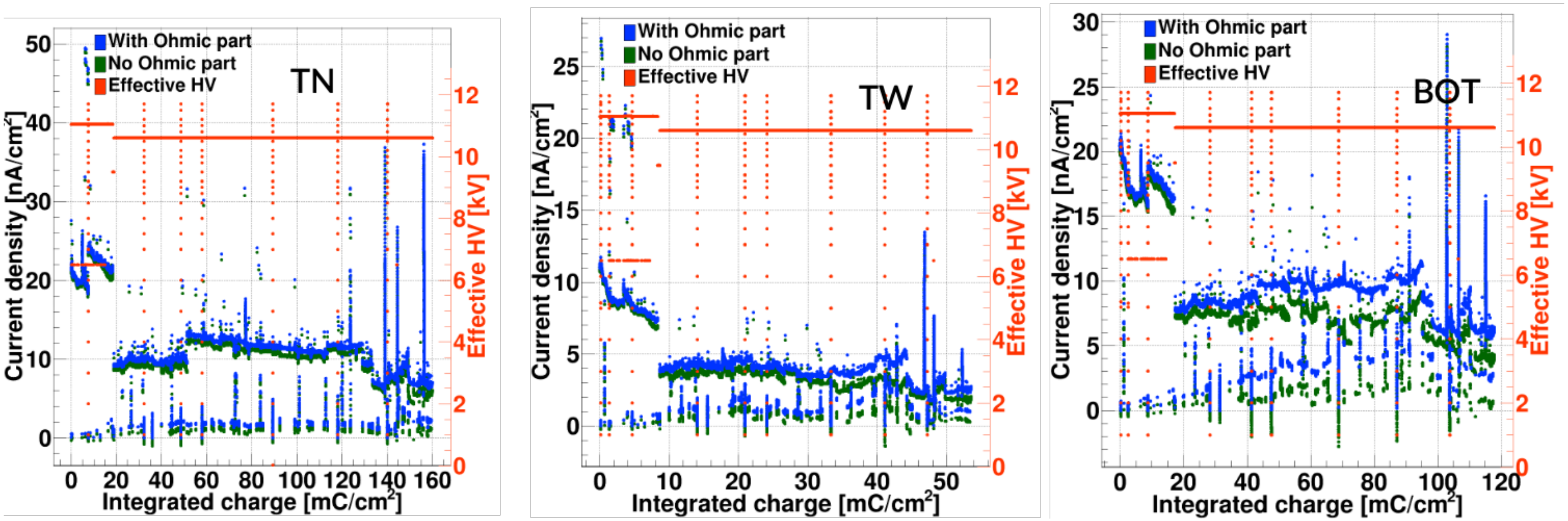


→ ECO1 gas mixture discarded

Ageing studies results with ECO2

- Second eco-friendly candidate tested: ECO2 (60% CO_2 and 35% HFO) at 1 vol/h
  - Idea is to lower HFO to check for effects
- Irradiation voltage set at 10.6 kV
  - Source OFF knee to limit the absorbed current for long periods of time
- Stability of absorbed current over time but quite different for the three gaps
  - TW current lower for the same HV

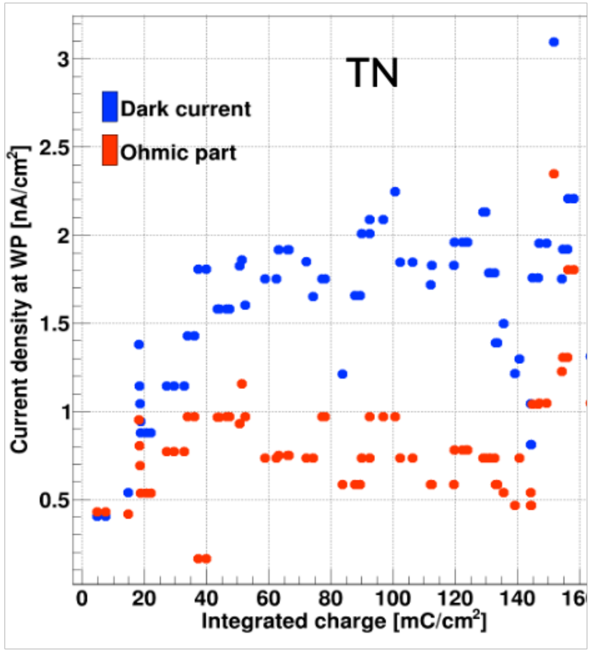
CMS

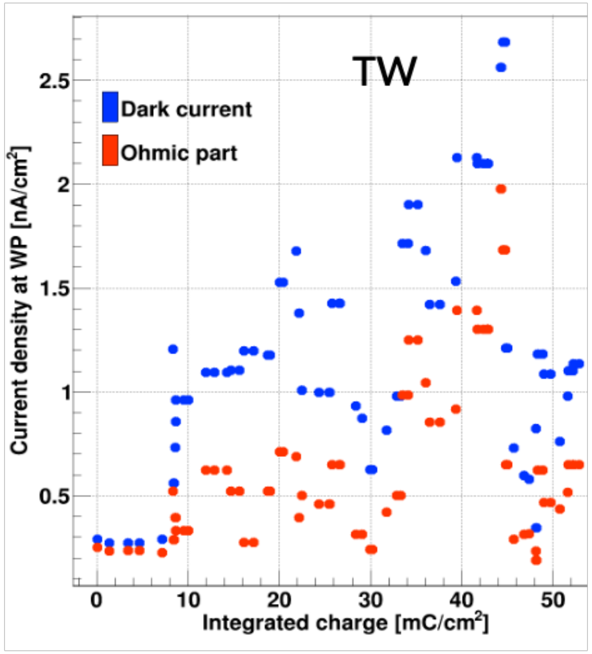


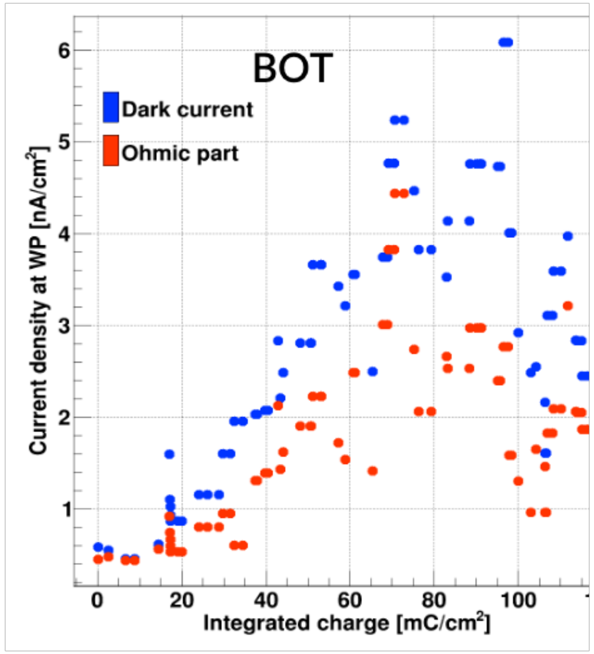
Ageing studies results with ECO2

- Total and Ohmic dark currents at working point vs integrated charge
- Stable for TN gap (after a small increase at the beginning)
- Similar behaviour for TW and BOT

CMS







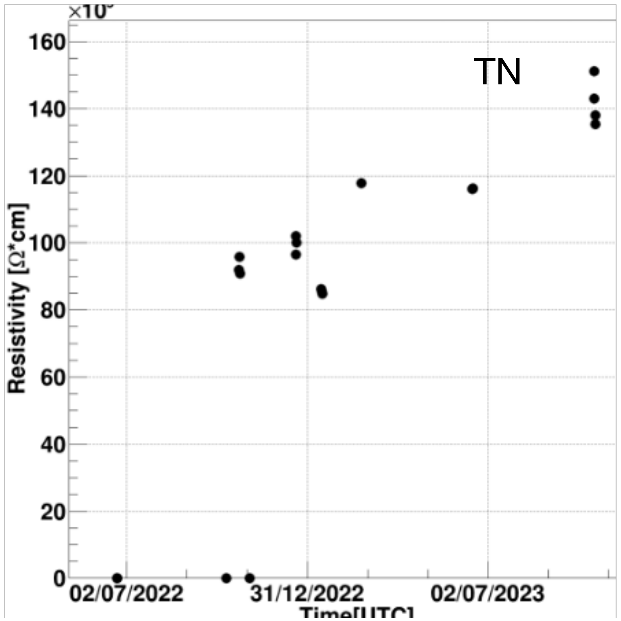
No clear behaviour, investigation on-going

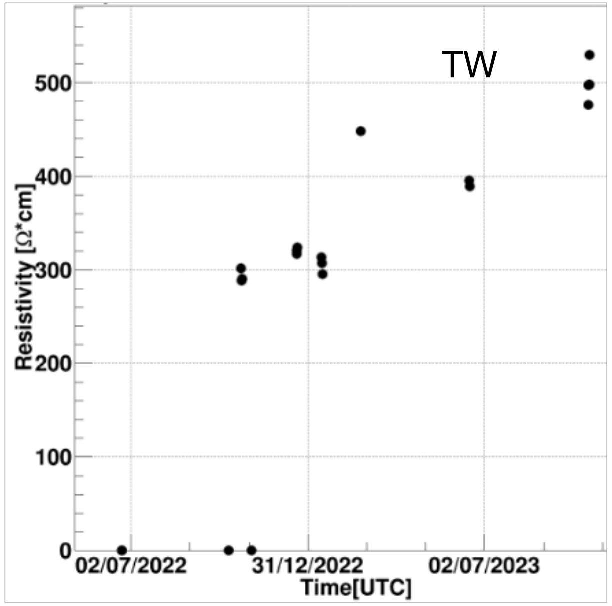
Ageing studies results with ECO2: resistivity

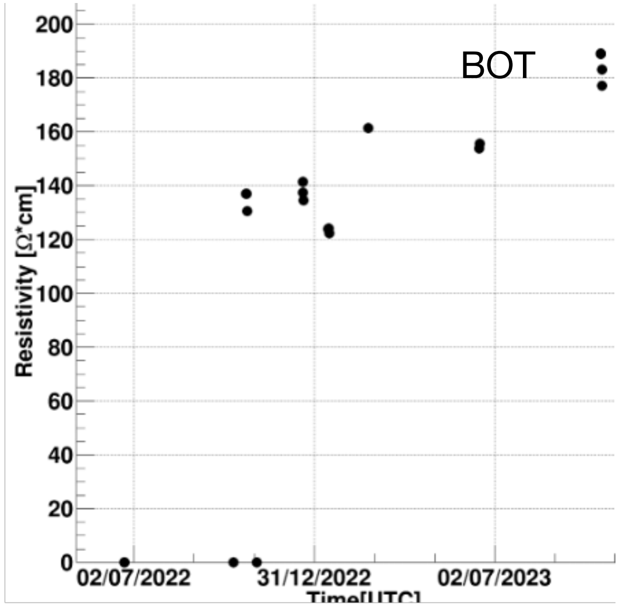
Resistivity measurements

- Different current density: to check resistivity of the electrodes
- Resistivity measurements done with Ar
- Resistivity values normalised at 20 C
- TW shows lowest absorbed current and highest resistivity

CMS





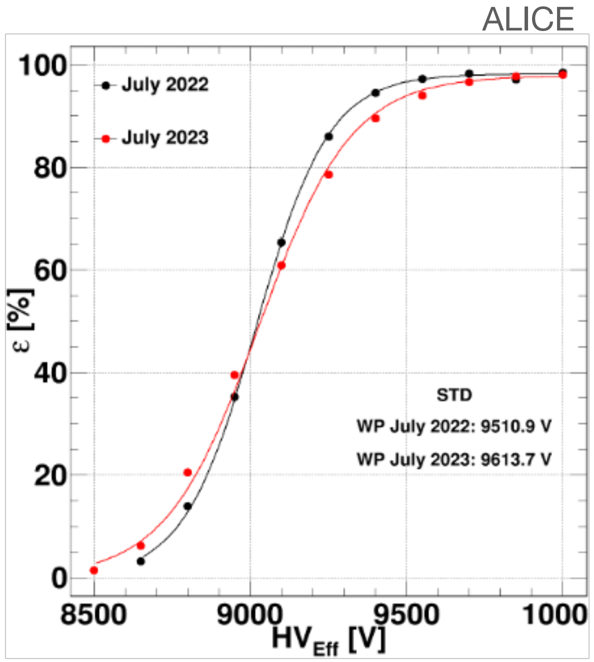


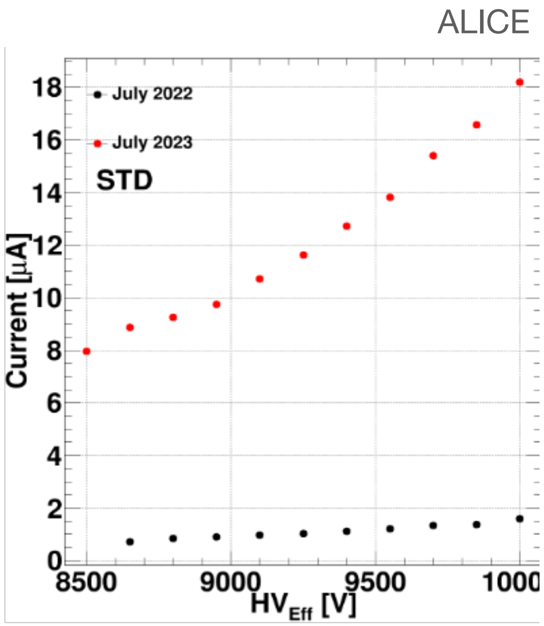
Increasing resistivity over time under investigation, similar also for other detectors

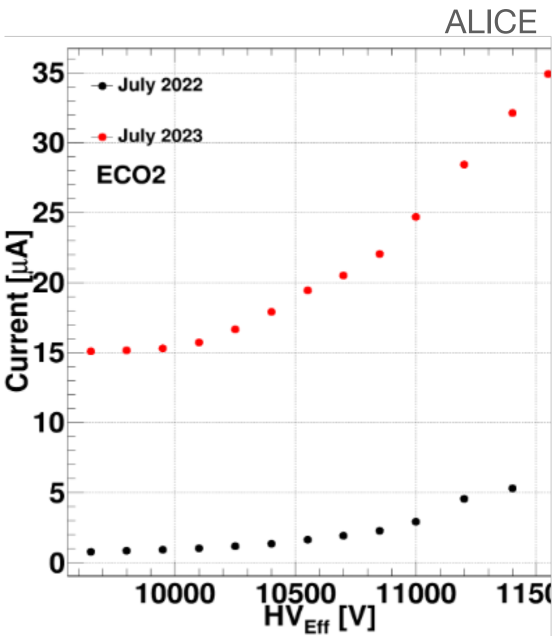
Ageing studies results with ECO2: test-beam

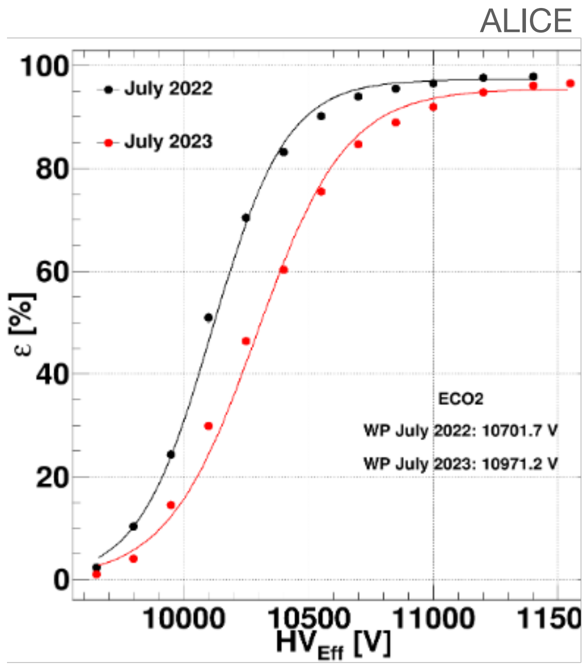
RPC performance comparison during test-beam

- Comparison for standard gas mixture and ECO2 after 1 year of irradiation
  - 75 mC/cm2
- Increase of working point for both gas mixtures
- No decrease in plateau efficiency
  - But decrease of slope with ECO2
- Increase of current for both gas mixtures but higher increase for ECO2









List of conferences/papers

Paper accepted for publication on European Physical Journal C

- “High-rate tests on Resistive Plate Chambers filled with eco-friendly gas mixtures”

EPJplus focus point on the green transition of particle detectors

- ”Preliminary results on the long term operation of RPCs with eco-friendly gas mixtures under irradiation at the CERN Gamma Irradiation Facility”

Conferences

- PSD13: The 13th international conference on position sensitive detectors
- 11th Beam Telescopes and Test Beams Workshop
- Workshop on Search for the ECO-friendly gas-mixtures for the muon detectors at LHC and beyond
- Third International Conference on Detector Stability and Aging Phenomena in Gaseous Detectors
- XII International Conference on New Frontiers in Physics

AIDA budget

CERN funds

- All funds used for material
- New gas mixing unit ATEX
  - ATEX, possible to easily use flammable gases
  - Up to 4 gas components
  - Easily to move from gas mixture to Ar for resistivity measurements
- New humidifier module
  - On-going automatic regulation of humidity
  - Different humidity sensors under test
- Material for F^- measurements and improvement of the set-up
  - Electrodes, solutions
  - Ready of gas flow

INFN funds

- Post-doc position for two years
  - 50% funded by AIDAinnova: fully dedicated to activities related of ECOGAS@GIF++ collaboration

Conclusions

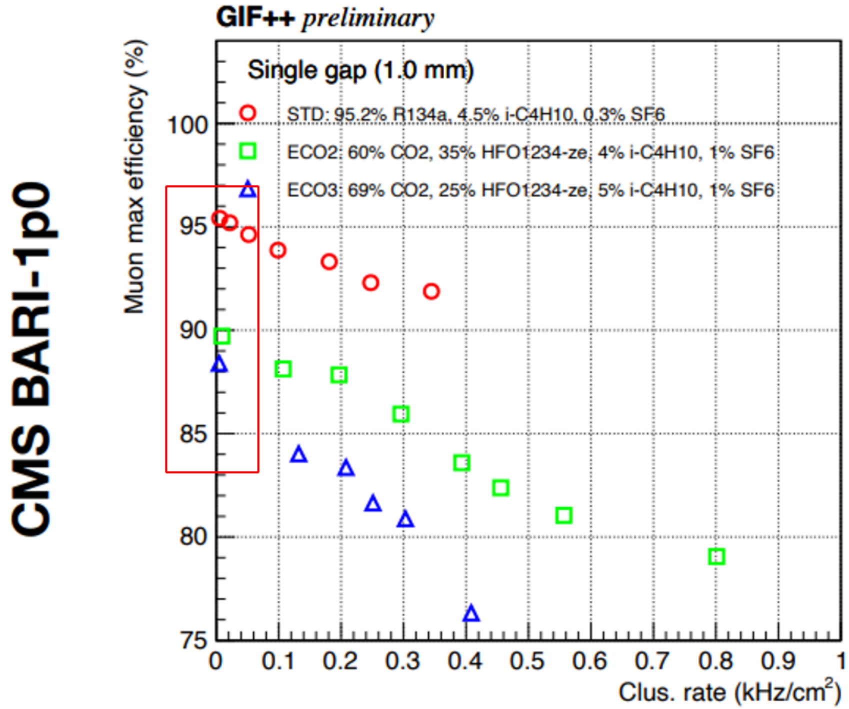
- Two eco-gas mixtures selected by the community for test at GIF++
  - ECO1 discarded as ageing effects visible
  - ECO2 under test since 2022
- 2023 fully dedicated to ageing campaign
  - Included a test-beam to verify detector performance
- Different behaviour of irradiated detectors under investigation
  - No clear pattern visible
  - Several factors have to be taken into account
  - Not always stable environment conditions (humidity, temperature, etc)
  - To improve parameters under control
- EP-DT chamber investigated in laboratory and it will be opened to check internal surface
  - Visual inspection and SEM analysis
- Planned test-beam in 2024

Tests with thinner gaps

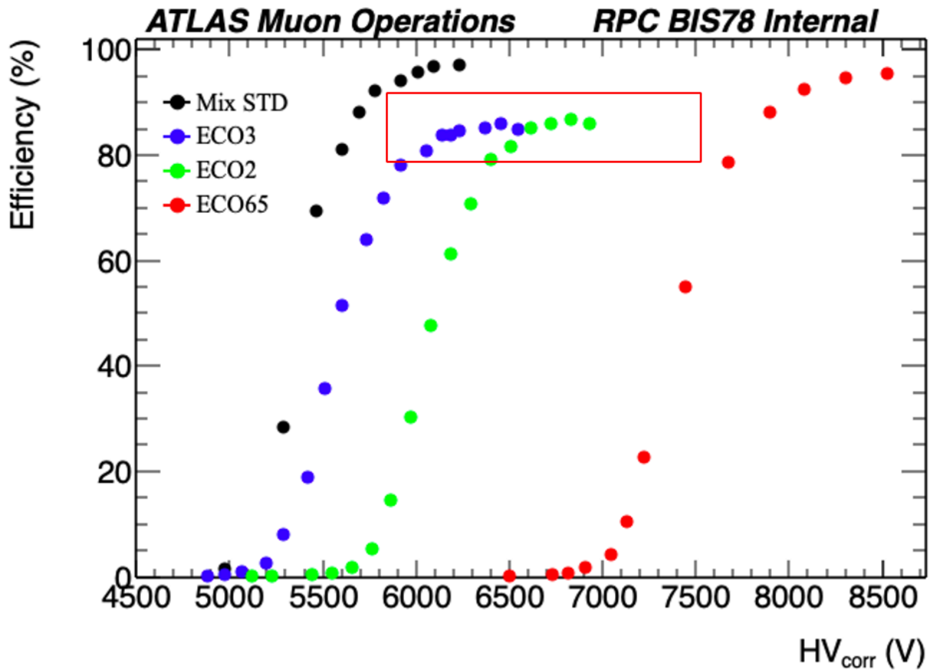
Set-up used also for specific tests on different chambers

- Tests performed on gas gaps of 1 mm
  - ATLAS BIS upgrades
  - CMS

D: Ramos ICNFP 2023

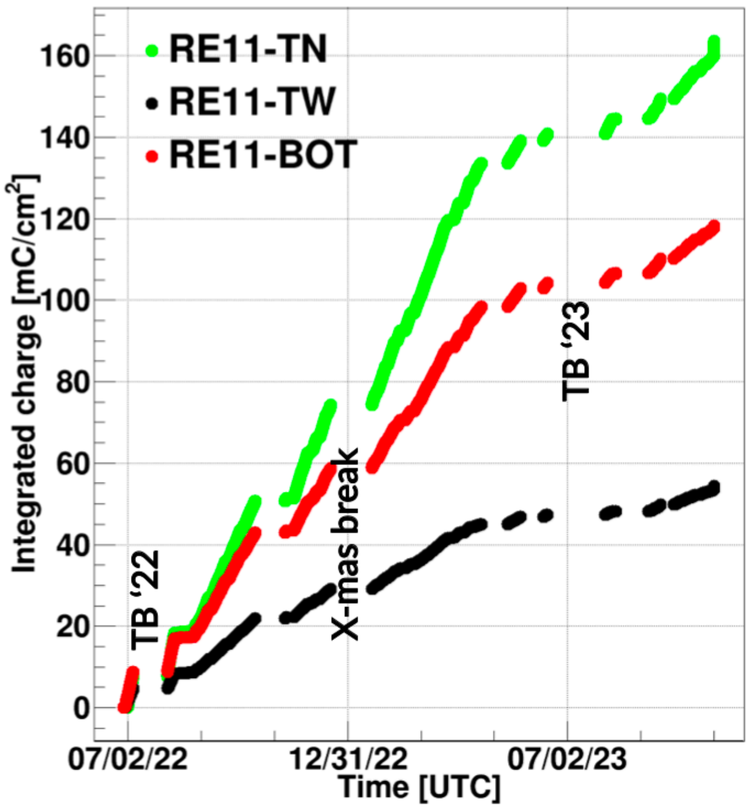


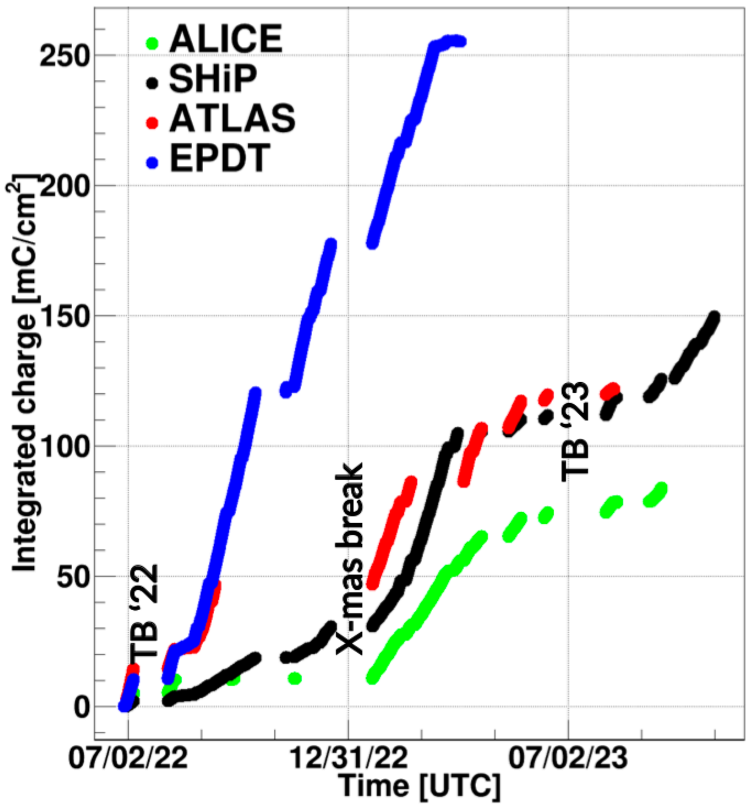
G. Aielli, RPC 2022



Higher content of CO2 decreases the maximum efficiency plateau

Accumulated charge up to now





- Different maximum values of integrated charge reached by the different RPC
  - Different distance from sources, period of stops, different currents
- Target of dose: 300 mC/cm2