Istituto Nazionale di Fisica Nucleare
Sezione di Bari

Politecnico di Bari

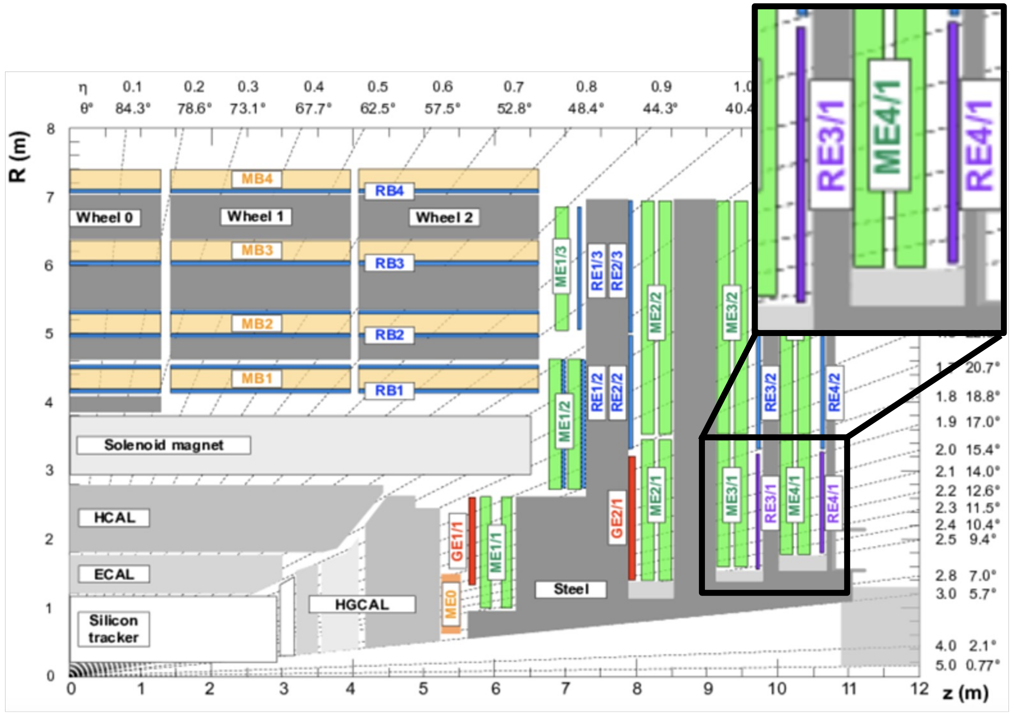
RPC 2024 Santiago de Compostela (Spain)

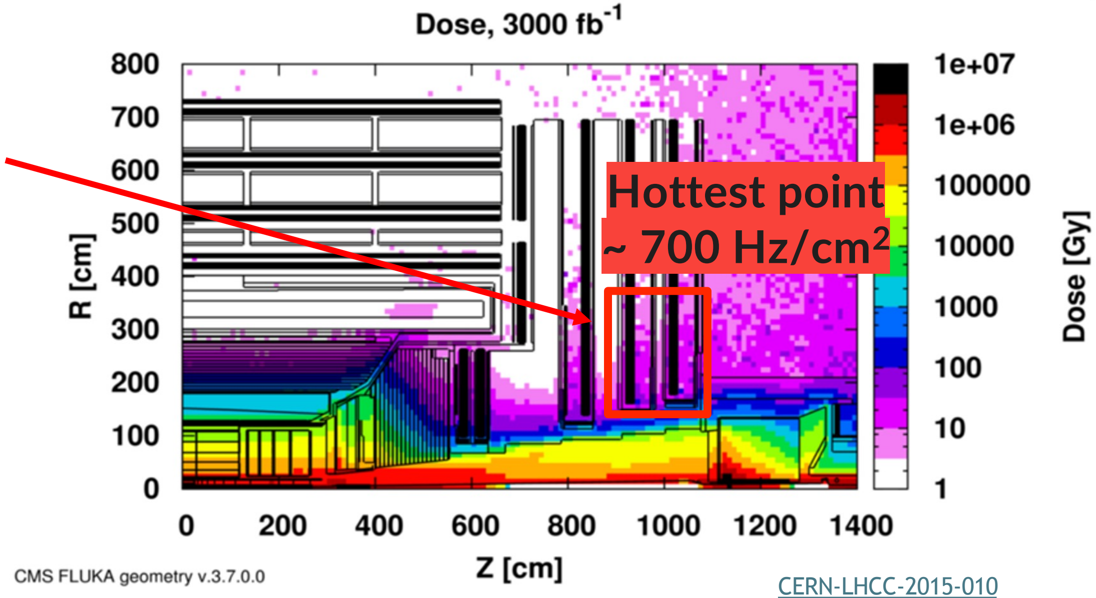
New RPC Gas Mixtures for Sustainable Operation in the CMS Experiment

Dayron Ramos Lopez
on behalf of CMS and RPC EcoGas@GIF++ Collaboration
dayron.ramos.lopez@cern.ch

CMS RPC Upgrade Project

- To cope with the high particle rate and high pileup environment due to increased luminosity in HL-LHC, the CMS forward region demands → **improved trigger and reconstruction performance!**
- Installation of new RPC stations in the forward region → **Improved Resistive Plate-Chambers (iRPC)**

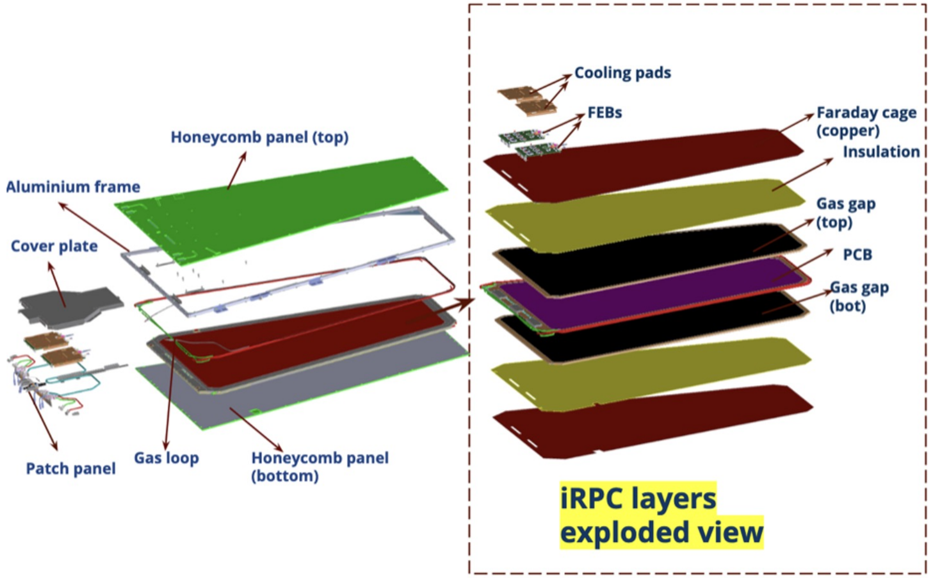




CERN-LHCC-2015-010

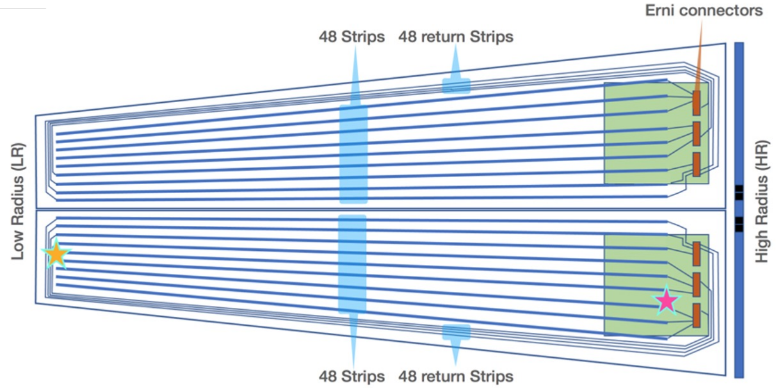
CMS RPC Upgrade Project

iRPC: improved Resistive Plate Chambers



	RPC	iRPC
HPL thickness (mm)	2	1.4
Number of gas gaps	2	2
Gas gap thickness (mm)	2	1.4
Resistivity (Ωcm)	1 - 6 x 10^{10}	0.9 - 3 x 10^{10}
Charge threshold (fC)	150	30 - 40
Space resolution in η (cm)	20 - 28	1.5
Space resolution in ϕ (cm)	0.8 - 1.9	0.3 - 0.6
Intrinsic timing resolution (ns)	1.5	0.5

- Double readout in the strips high and low radius
- Charge threshold between 30 and 40 fC



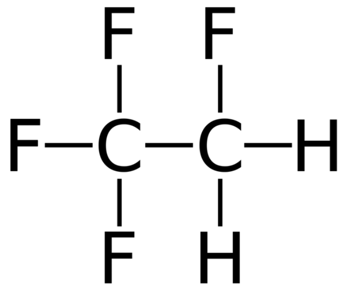
Strip PCB allow Return line concept

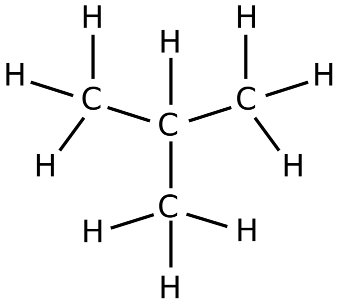
FEB positioned external and @ HR (lowest dose region)

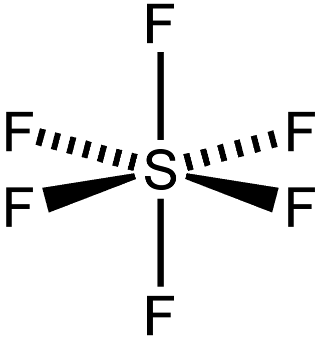
More details in talks: Innovative Resistive Plate Chambers for the CMS Phase 2 Upgrade: Project Summary, Construction, and Quality Assurance by Jules Vandenbroeck and iRPC front-end board readout electronics by Maxime Gouzevitch

Gaseous mixture for RPC operation at CMS

STD: TFE ($C_2H_2F_4$) 95.2% + iC_4H_{10} 4.5% + SF_6 0.3%





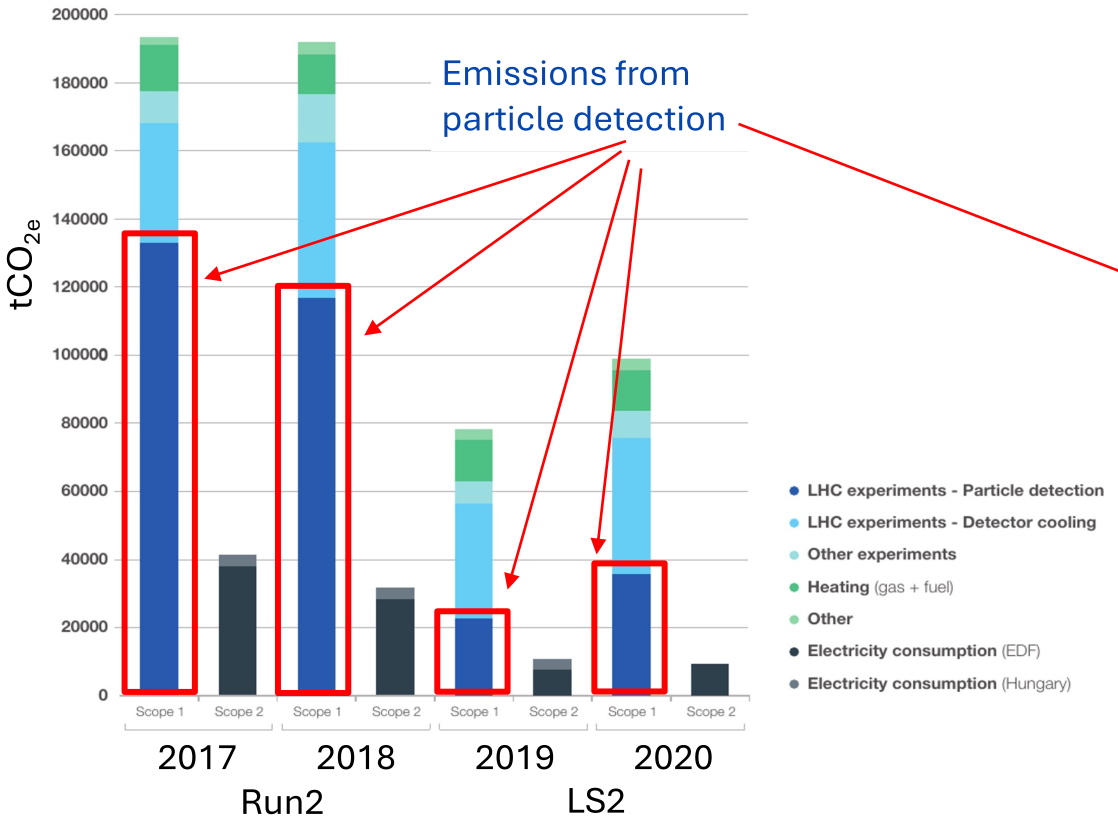


- High density of primary ion-electrons pairs → high RPC efficiency
- Good quenching properties and electronegativity → very low streamer probability
- High rate capability

Nowadays increased attention on GHGs emissions: F-gas regulation aims in limiting emissions, GHGs availability, price

Greenhouse gas usage at CERN (1)

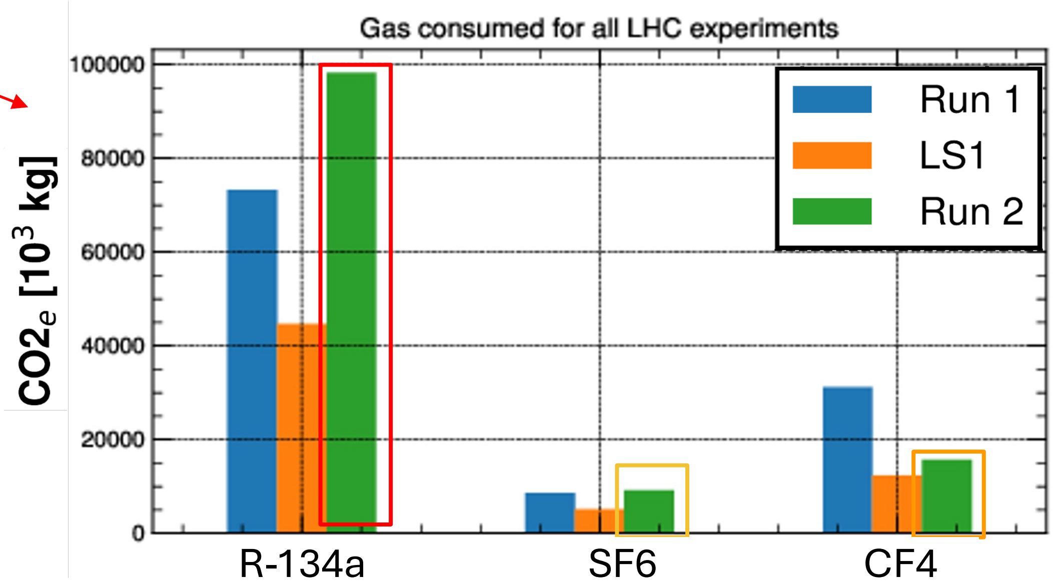
- [CERN Environment Report 2019-2020]
- [2021: CERN's Year of Environmental Awareness.]
- [CERN Environment workshop: 12 and 13 October 2022]
- [CERN Environment Report 2021-2022]



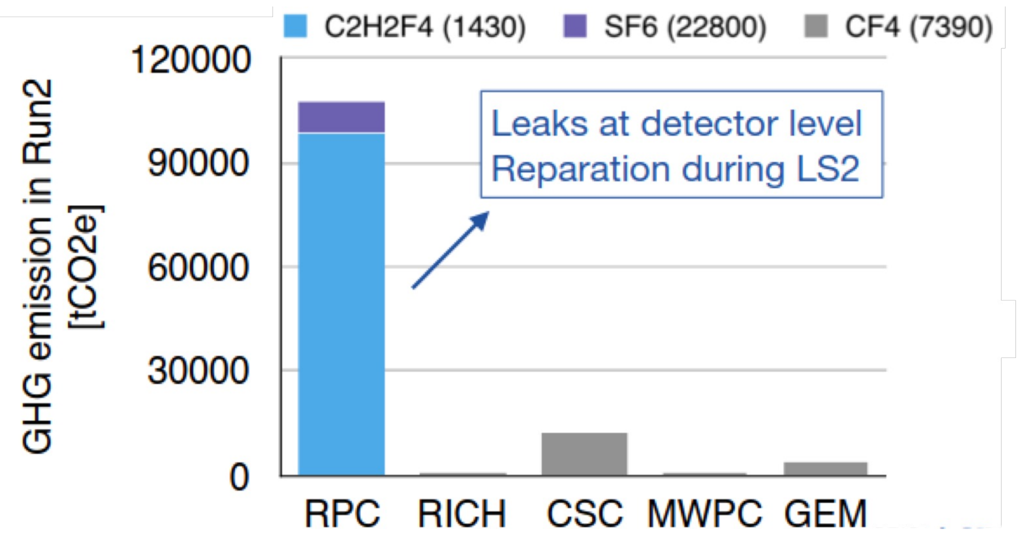
Total CERN emissions during 1 year of Run 2 ~ **200 000 tCO2e**

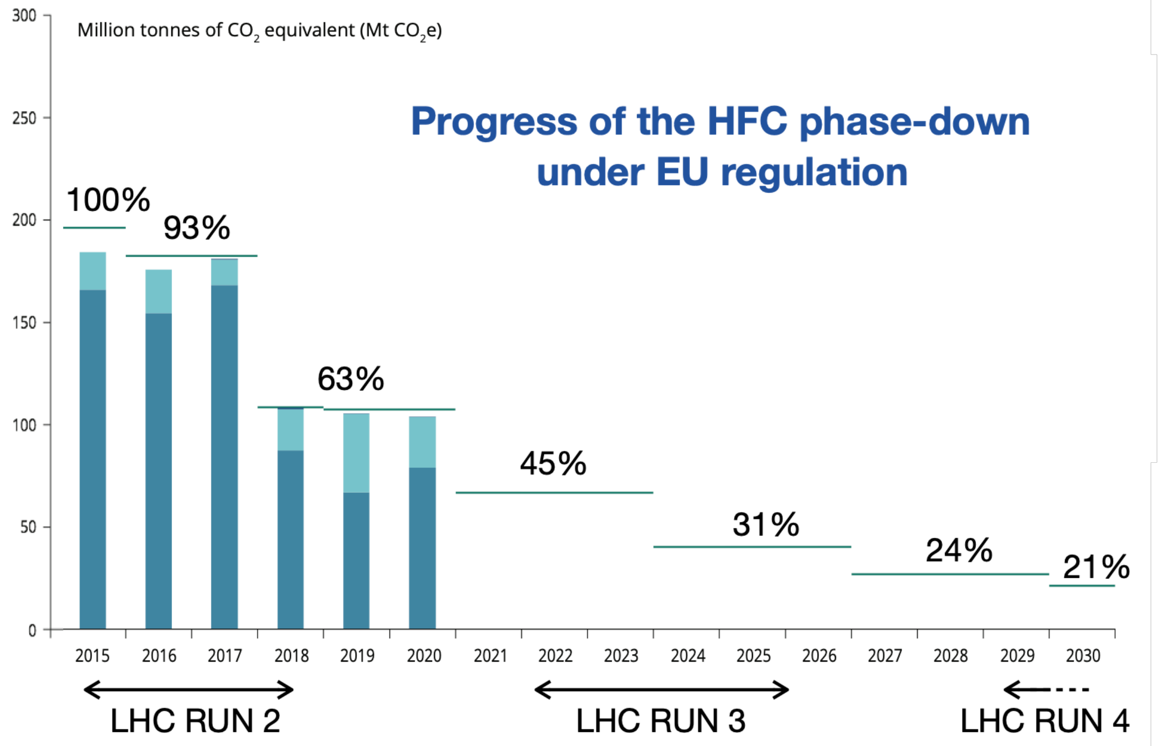
~ 50% from particle detectors

- **$C_2H_2F_4$/R-134a** biggest contributor → leaks from RPC detector, used for ALICE, ATLAS and CMS systems
- **CF_4** → due to operation of CSC and RICH systems
- **SF_6** → Related to RPCs as R-134a



Greenhouse gas usage at CERN (2)





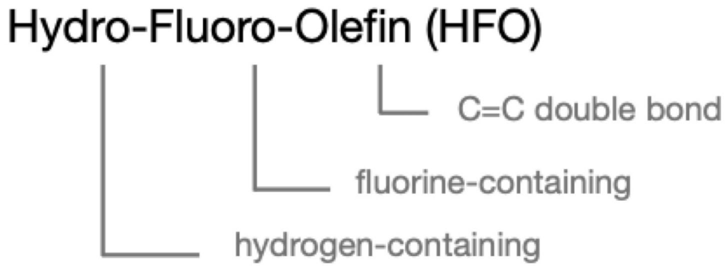
Limiting the total amount of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030.
Banning the use of F-gases where less harmful alternatives are widely available.
Preventing emissions of F-gases from existing equipment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

Eco-friendly mixtures candidates

- Requirements: low GWP, low toxicity, not flammable and detector performance comparable with standard one

In industrial applications $C_2H_2F_4$ is being replaced with HydroFluoro-Olefins (HFOs)

- the replacement of $C_2H_2F_4$ with HFO moves the operating voltage at much higher values (es. >13kV for 2 mm gap)
- the addition of CO_2 helps in decreasing the WP



	TFE (%)	HFO-1234ze (%)	CO_2 (%)	iC_4H_{10} (%)	SF6 (%)	GWP	CO_2e (g/l)
STD	95.2	-	-	4.5	0.3	1485	6824
ECO2	**-**	**35**	**60**	**4**	**1**	**476**	**1522**
ECO3	**-**	**25**	**69**	**5**	**1**	**527**	**1519**
Density (g/l)	4.68	5.26	1.98	2.69	6.61	-	-
GWP	1430	7	1	3	22800	-	-

GWP with respect to CO_2, and their CO_2e, in grams, for one litre of mixture

In mixtures containing HFO, values mainly driven by SF_6

Alternatives mixtures candidates

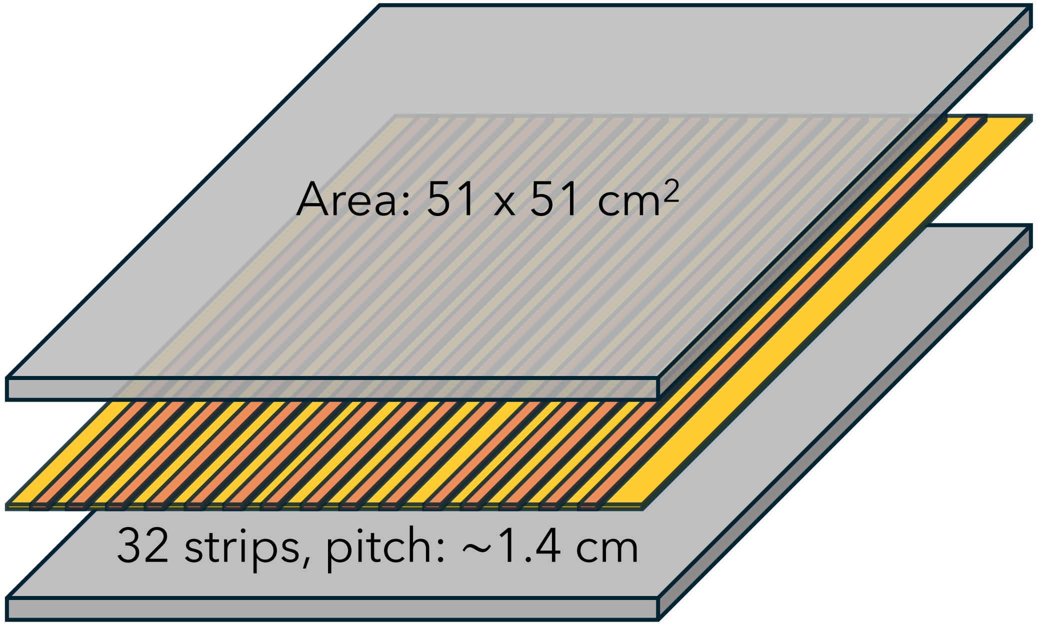
- Alternatives mixtures based on **TFE/CO_2** have been also explored at GIF++ as mitigation solution to the continue increases of the TFE's price in the market due to the EU banning

	TFE (%)	HFO-1234ze (%)	CO_2 (%)	iC_4H_{10} (%)	SF6 (%)	GWP
STD	95.2	-	-	4.5	0.3	1485
ECO2	**-**	**35**	**60**	**4**	**1**	**476**
ECO3	**-**	**25**	**69**	**5**	**1**	**527**
MIX1	**64**	**0**	**30**	**5**	**1**	**1529**
MIX2	**54**	**0**	**40**	**5**	**1**	**1353**
MIX3	**64.5**	**0**	**30**	**5**	**0.5**	**1337**
Density (g/l)	4.68	5.26	1.98	2.69	6.61	-
GWP	1430	7	1	3	22800	-

Aging and **performance** results operating iRPC gaps with this mixtures can be found in the talk: Performance and longevity of CO2 based mixtures in CMS Improved Resistive Plate Chambers in the HL-LHC environment by Joao Pinheiro

iRPC gaps prototype

Double gap layout of iRPC gaps prototype

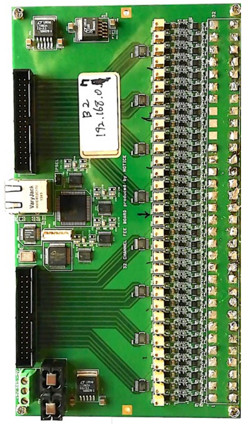


Electrode bulk resistivity: 1.17-1.39 x 10^{10} Ωcm

R&D readout system

- Single side strip readout (strips terminated with 50 Ω)
- KODEL Front-end electronic
  + CAEN multi-hit TDC model V1190

KODEL FEB



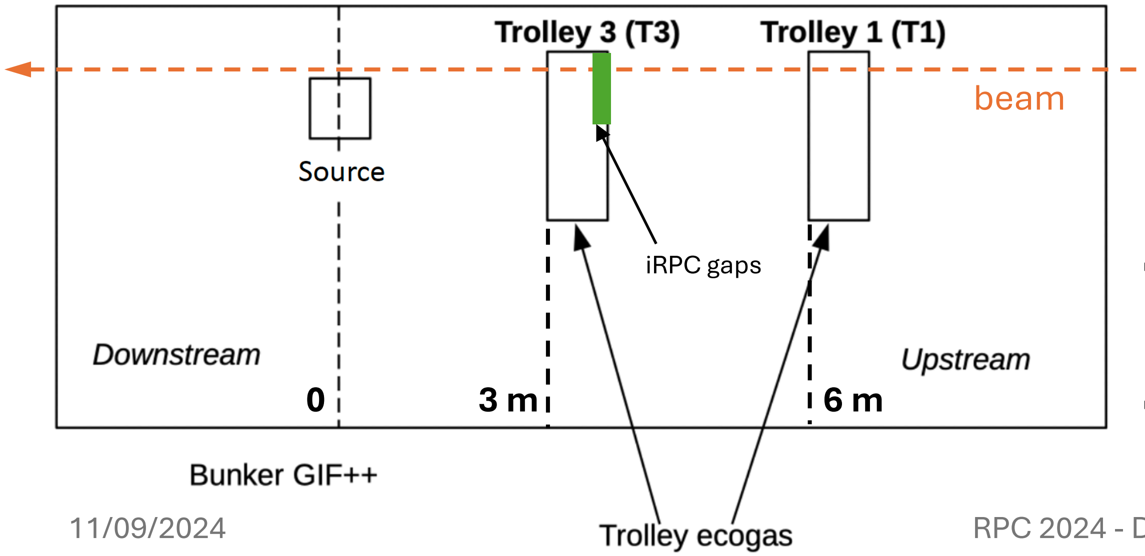
PETIROC ASICs
32 channels
Independent linear amplification (gain 200)
THR range 20-100 fC (ethernet controller) → set at 60 fC

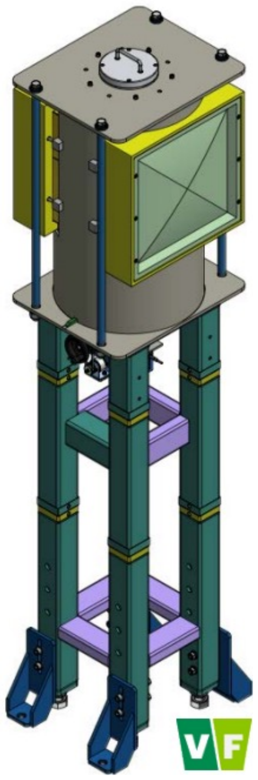
Setup at GIF++

- 12.2 TBq ^{137}Cs + H4 SPS beam line
- Radiation intensity attenuated by combination of filters

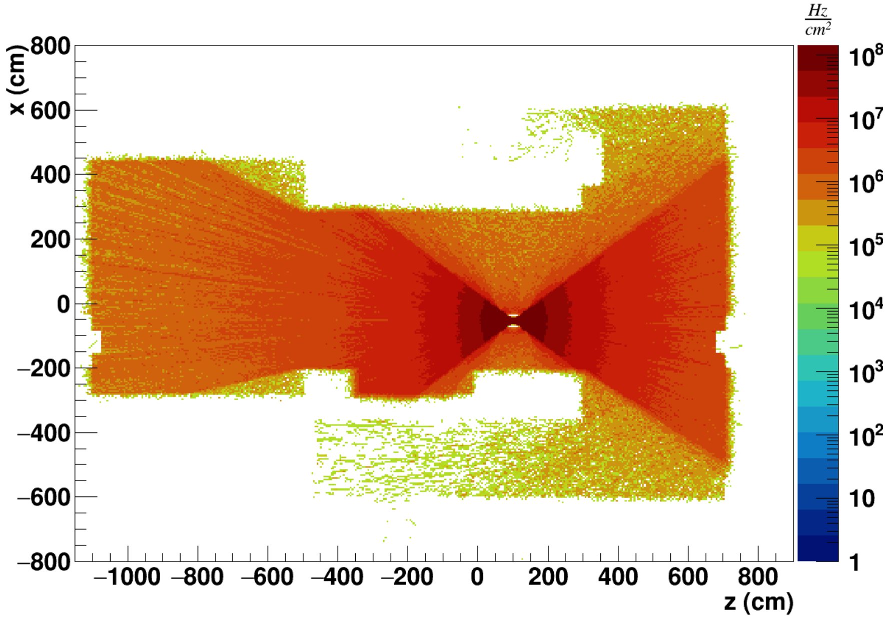
Gas mixer unit to provide up to 4 component gas mixture (humidified)

- $C_2H_2F_4$, iC_4H_{10}, SF_6, CO_2, Ar, HFO





Simulated gamma flux @ GIF++ (A = 11,5 TBq)



Gamma flux study at GIF++ in talk: Upgraded simulation of the CERN Gamma Irradiation Facility by Nicola Ferrara

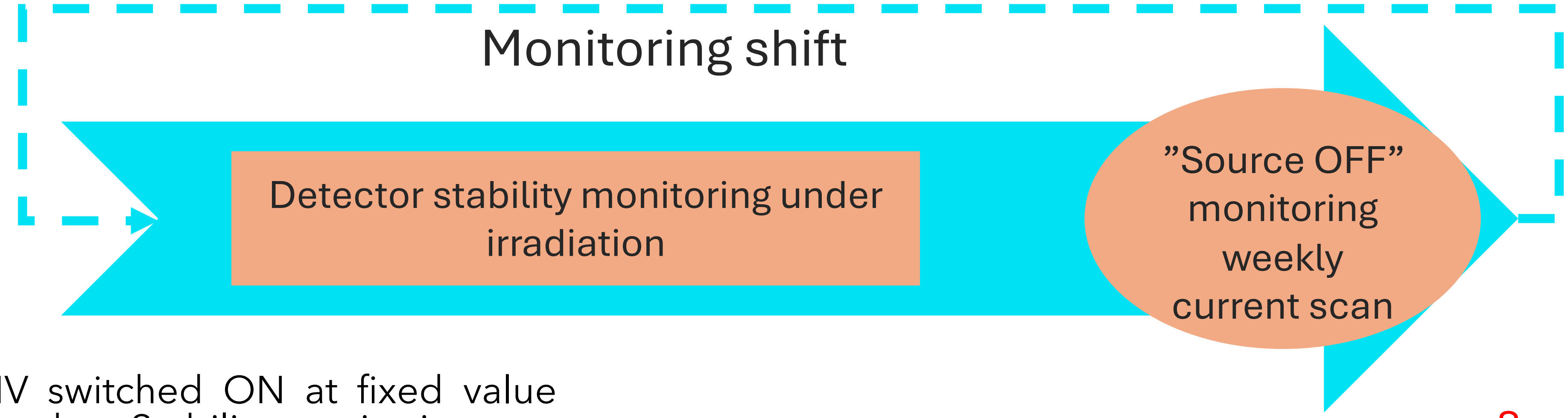
- **Aging studies**

Monitoring of currents

- **Detector performance studies (beam tests)**

Aging studies

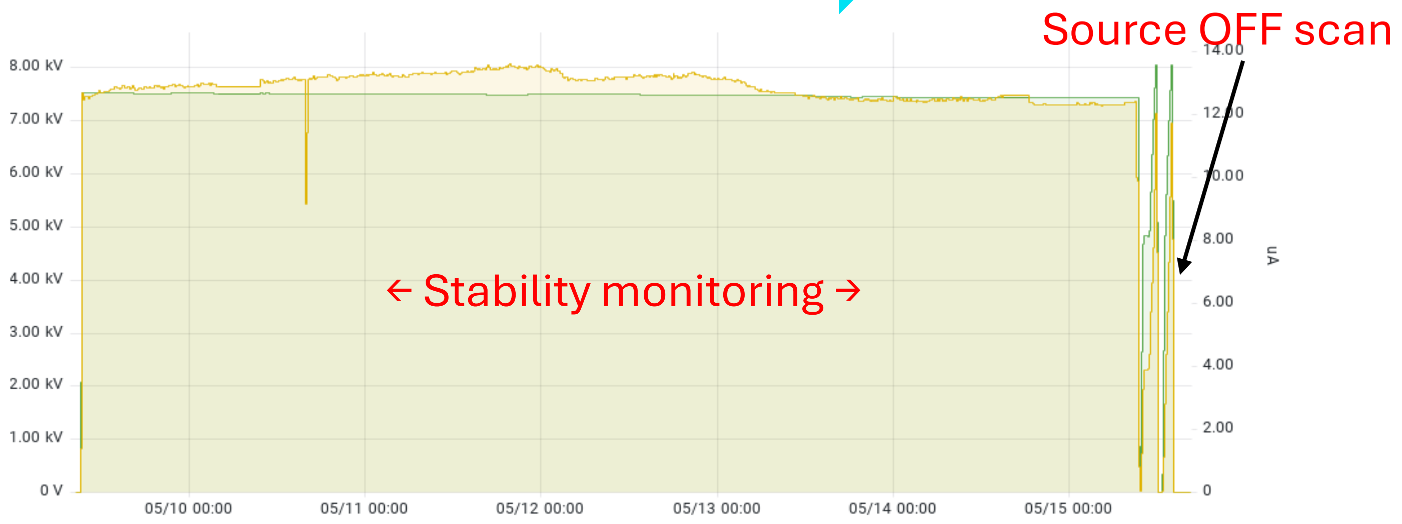
Aging program in EcoGas@GIF++



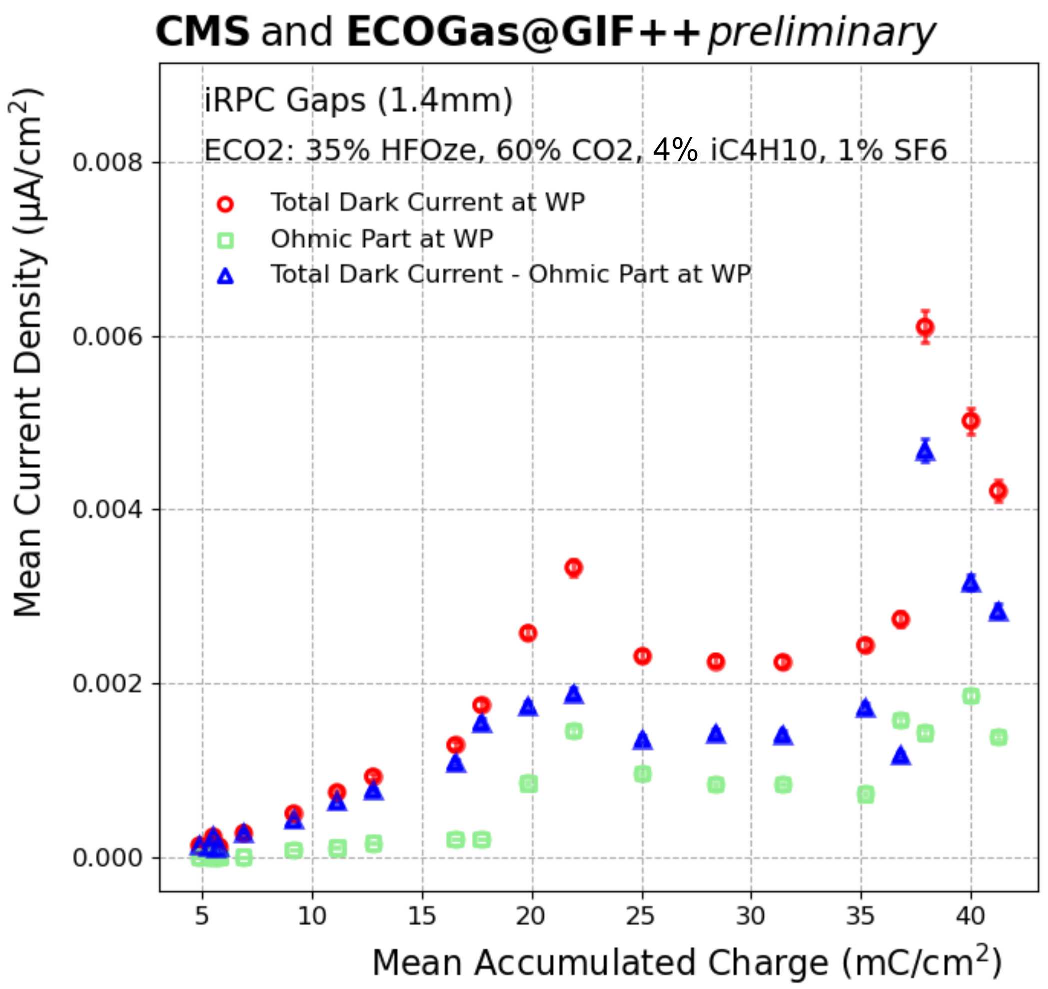
- Detector HV switched ON at fixed value during all week → Stability monitoring
- HV is corrected every minute

$$HV_{app} = HV_{eff}\left[(1-\alpha) + \alpha\frac{P}{P_0}\frac{T_0}{T}\right]$$

- Detectors are exposed to the γ flux from the ^{137}Cs source → current and voltages are monitored by shifts
- Source OFF scans are performed at the end of each monitoring shift for dark current monitoring

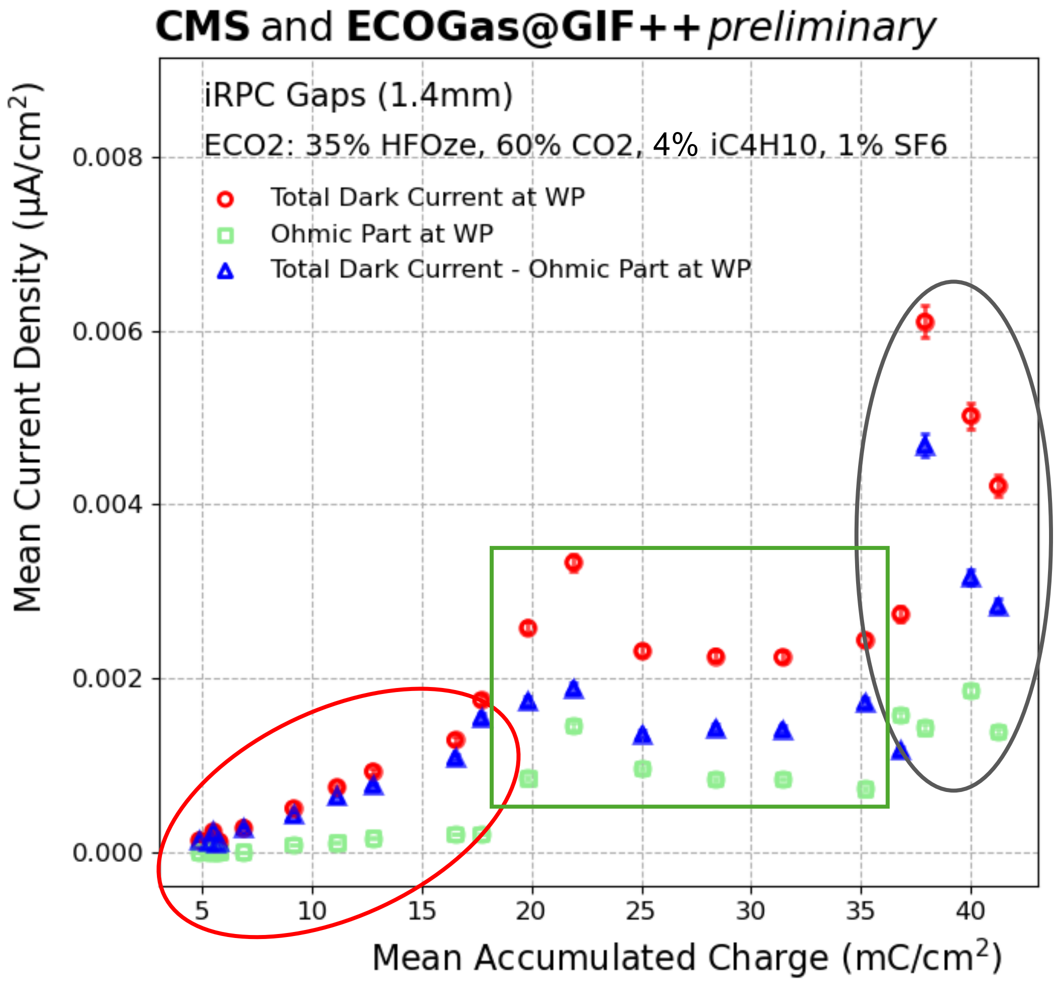


Aging monitoring



- ~ 45 mC/cm^2 have been slowly integrated and current values are monitored at the estimated operational value for ECO2 mixture (WP ~ 8.1 kV)

Aging monitoring

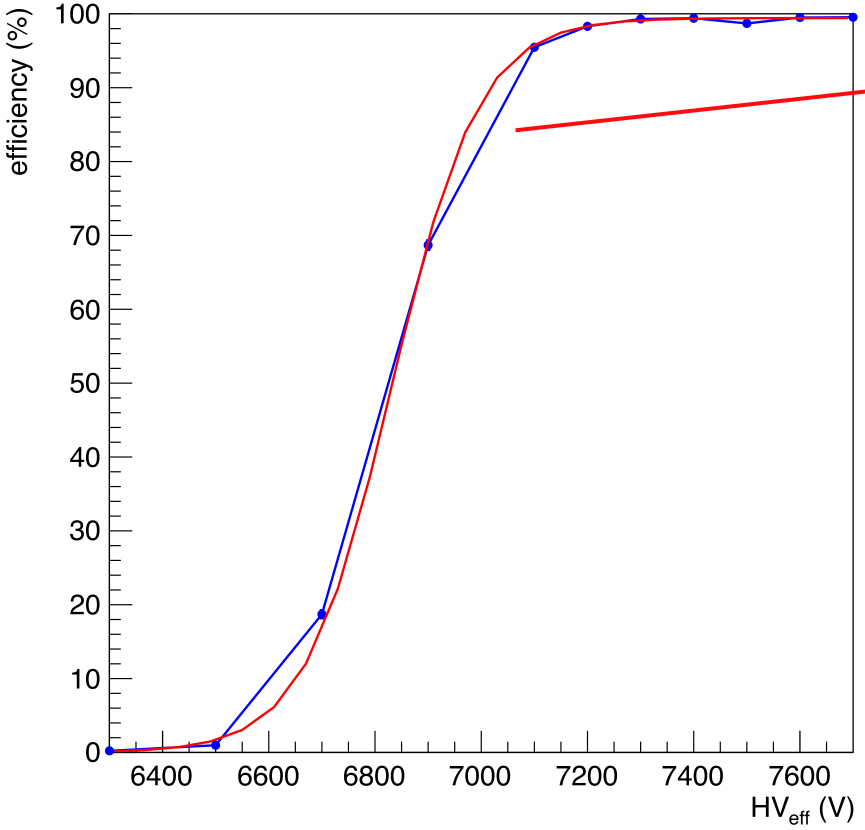


- ~ 45 mC/cm^2 have been slowly integrated and current values are monitored at the estimated operational value for ECO2 mixture (WP ~ 8.1 kV)
- Initial current increase up to ~ 17 mC/cm^2 followed by stable values
- Some instabilities at around ~ 40 mC/cm^2 which will be verified after more charge accumulation

Performance verification

Some definitions

Example of high voltage scan of a chamber in absence of gamma background



Logistic function for efficiency fit

$$\varepsilon(HV) = \frac{\varepsilon_{max}}{1 + e^{-\beta(HV - HV_{50})}}$$

Working point

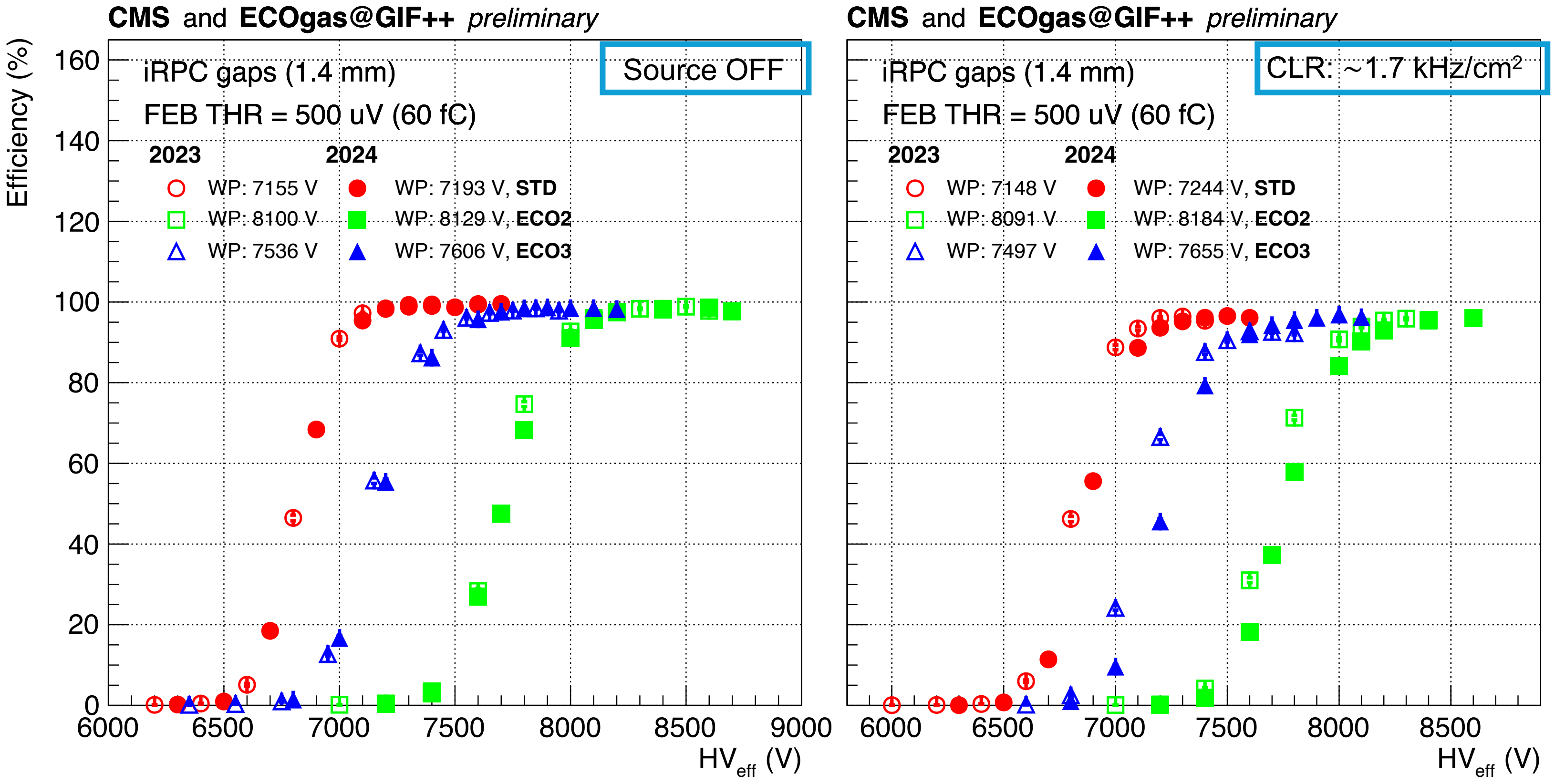
$$\mathrm{WP} = \frac{\log 19}{\beta} + HV_{50} + 150\ \mathrm{V}$$

Effective high voltage corrected to be applied

Environmental correction to the high voltage also applied during irradiation (see slide 12)

Performance verification (1)

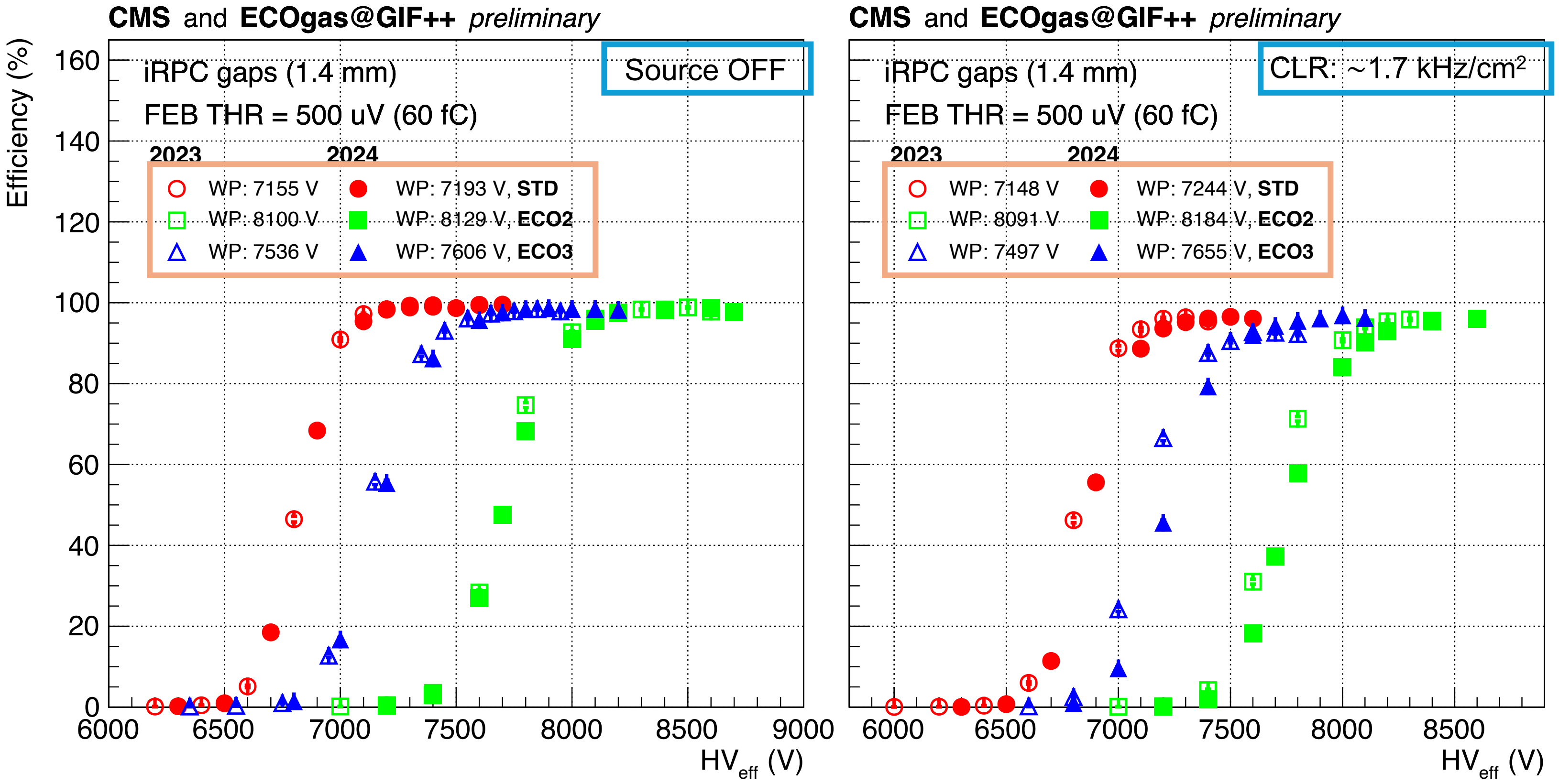
Efficiency and Working Point



- Efficiency measured up to the higher background conditions achievable at GIF++ shows no drops after irradiation

Performance verification (1)

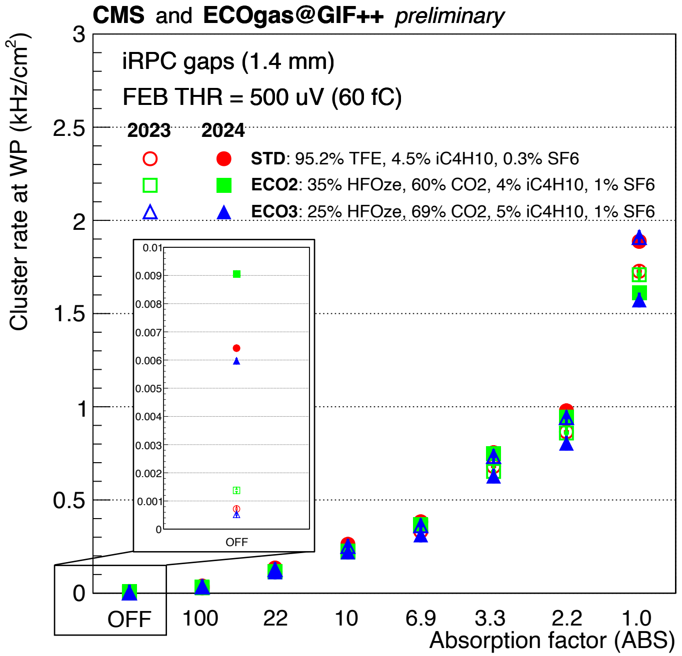
Efficiency and Working Point



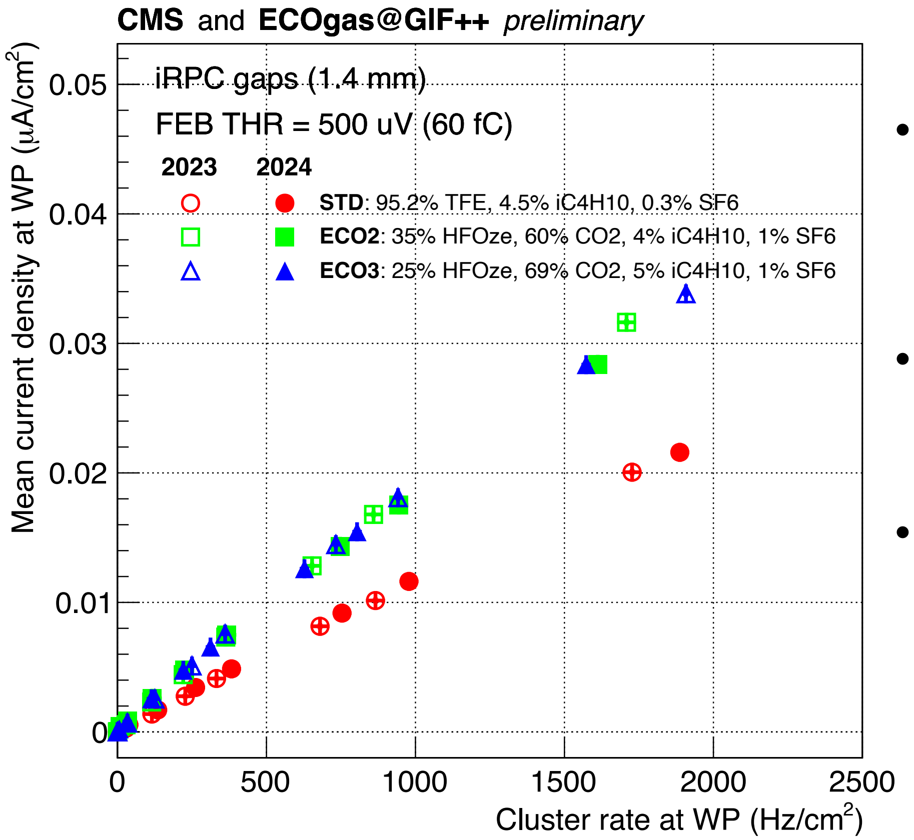
- Efficiency measured up to the higher background conditions achievable at GIF++ shows no drops after irradiation
- Slightly shift of WP to higher higher values have been observed (effect observed in all chamber of EcoGas@GIF++ Collaboration, see talk Performance and long-term ageing studies on Eco-Friendly Resistive Plate Chamber detectors by Marcello Abbrescia)

Performance verification (2)

Rates and current density



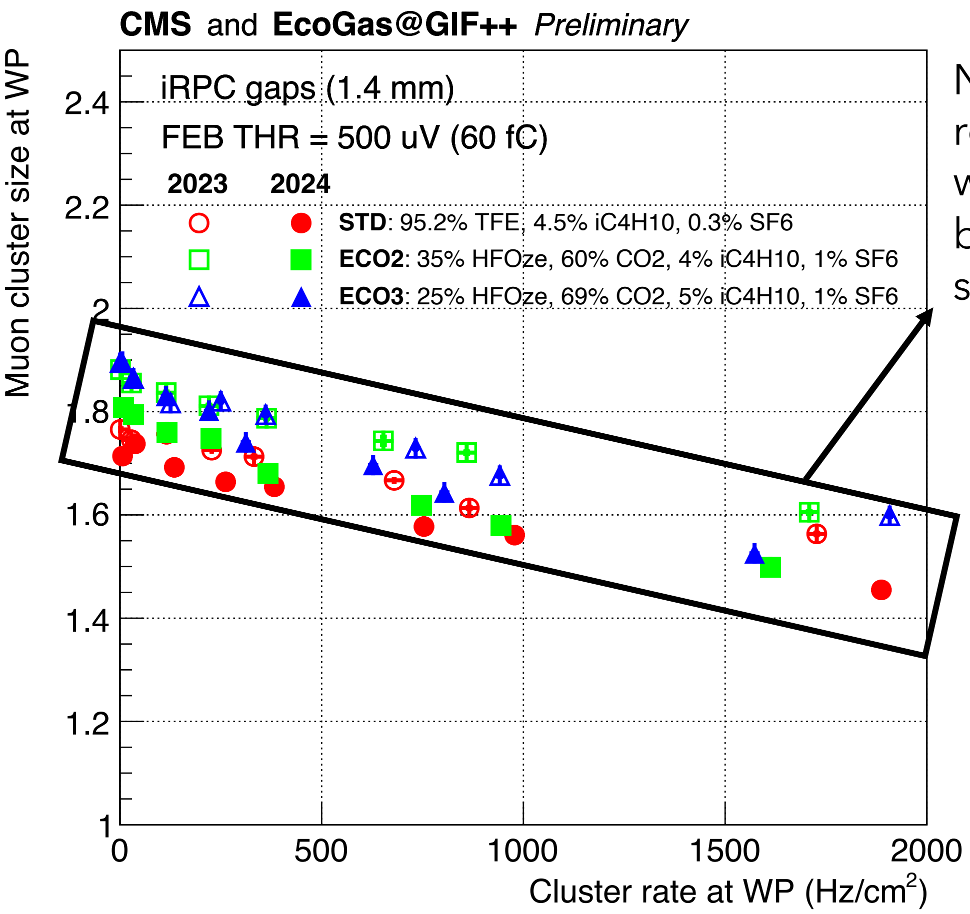
Cluster rates were measured for each ABS as external reference → noise increased after irradiation



- **Lower current values** monitored operating the prototype with **STD mixture**
- **Similar values and slope** using **eco-friendly candidates**
- **Stable chamber:** current values in agreement after irradiation according the cluster rates measured

Performance verification (3)

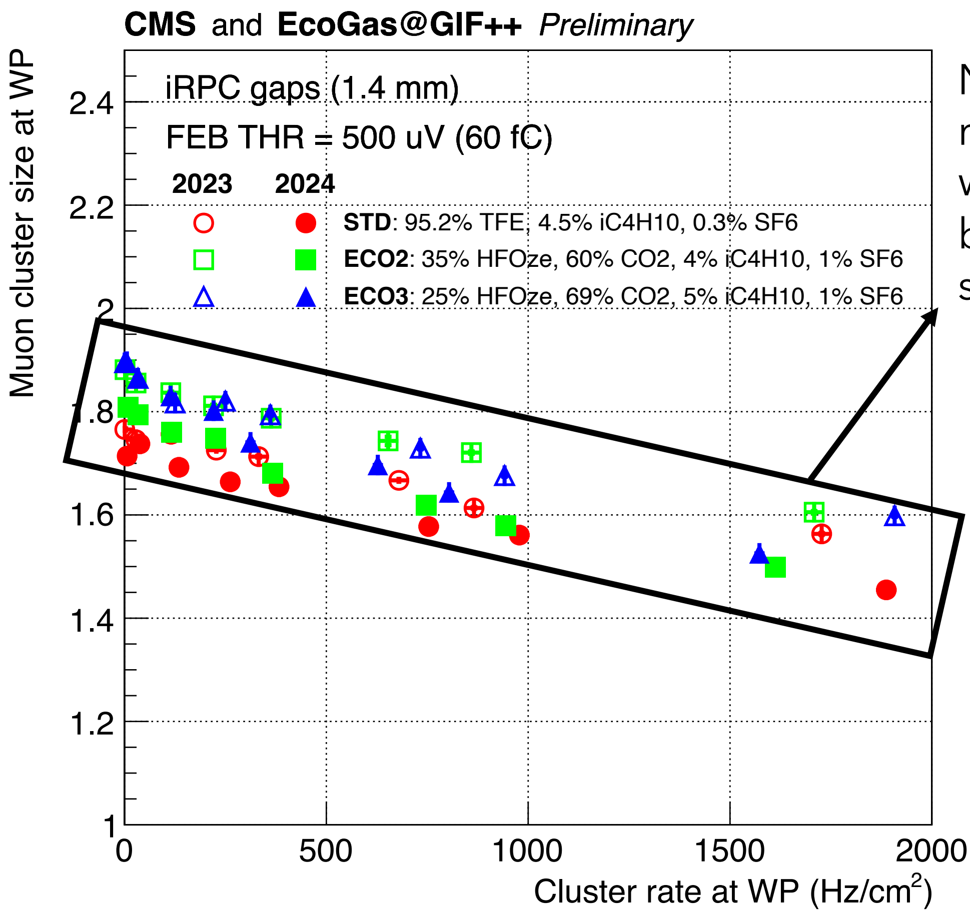
Muon cluster size and gamma cluster charge



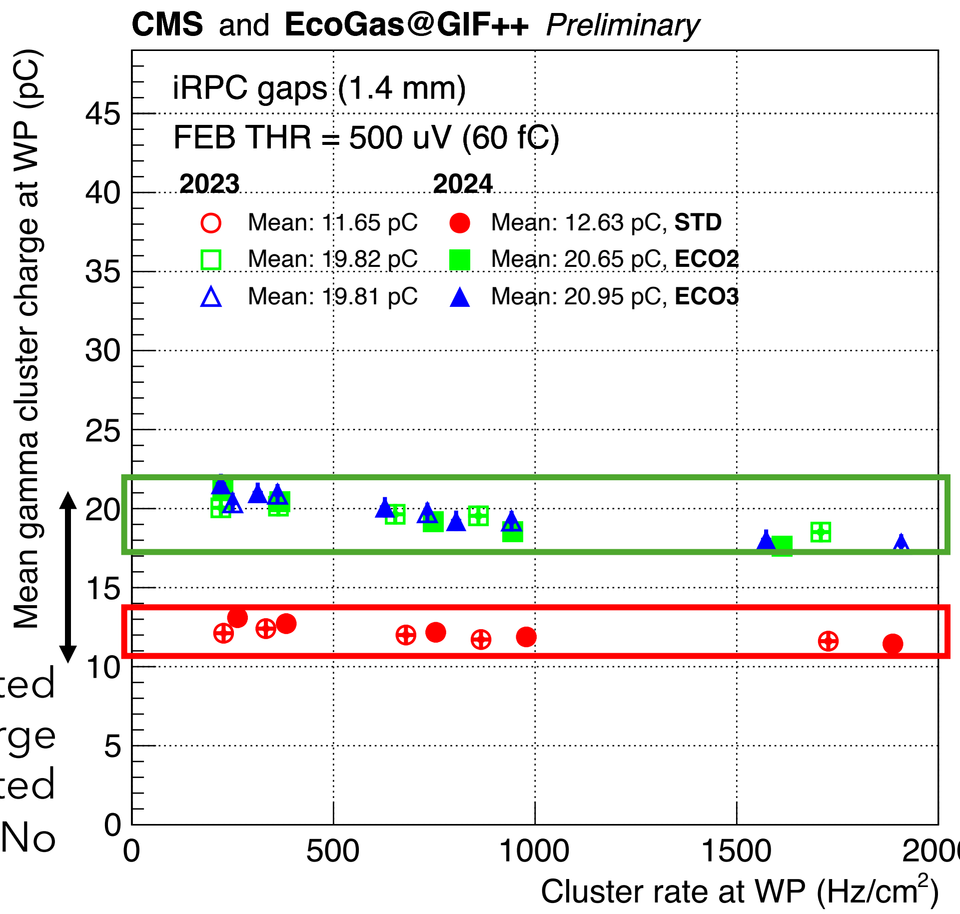
Negligible differences values reported after irradiation without large differences between mixtures and similar slopes.

Performance verification (3)

Muon cluster size and gamma cluster charge



Negligible differences values reported after irradiation without large differences between mixtures and similar slopes.



Mean charge values reported ~40% higher cluster charge when the chamber is operated with ecological candidates. No changes after irradiation

Summary

- Involved in the CERN phase-down of fluorinated GHG emissions, the **CMS** within RPC **EcoGas@GIF++** collaboration have joined efforts to find a solution for the **environmentally friendly operation of RPCs** on view of the HL-LHC phase
- After a few months of aging campaign (charge integration: ~45 mC/cm^2), **the performance of a prototype equipped with iRPC gaps has been verified** through beam test at GIF++
- The chamber has reported a **increased noise level after irradiation without** suffering **efficiency losses** even under higher gamma backgrounds
- **Slightly higher WP were estimated after irradiation** for all the mixtures.
- **Mean gamma cluster charge values** have been verified to be **40% higher when the chamber is operated with the ecological candidates** what might foresee the appearance of faster aging effects in case of their existence
- The aging campaign will continue for a better understanding of longevity effects operating iRPC gaps with HFO/CO_2 and TFE/CO_2 based mixtures

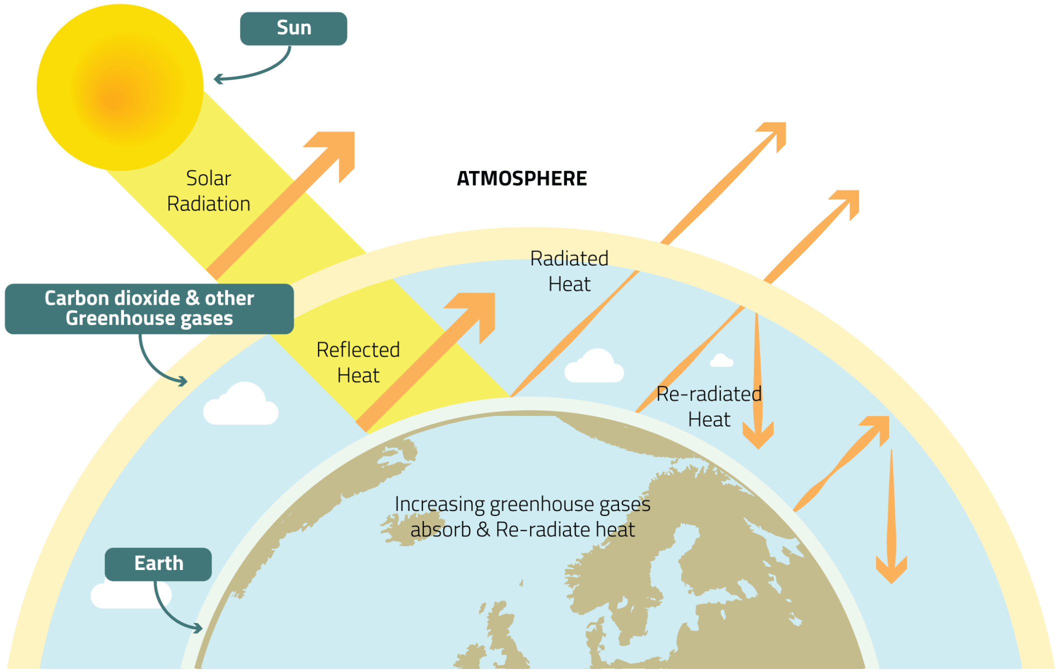
THANKS!

dayron.ramos.lopez@cern.ch

Backup slides

Global Warming Potential (GWP) and GHG emissions at LHC

Greenhouse Gases (GHGs) are gases in the earth's atmosphere that trap heat.



Global warming potential (GWP) is an index to measure of how much infrared thermal radiation a GHG would absorb over a given time. It is expressed as a multiple of the radiation that would be absorbed by the same mass of carbon dioxide, which is taken as a reference gas.

Gas	Atmospheric lifetime	$GWP_{100\ years}$
CO_2	50-200 years	1
R-134a	14 years	1430
CF_4	50,000 years	7390
C_4F_{10}	2600 years	9200
SF_6	3200 years	22800

Gases used at CERN with high GWP

EcoGas at GIF++ collaboration timeline

EcoGas@GIF++
Collaboration

AidaInnova
startup

Irradiation at GIF++ for aging studies

2018

2021

Test Beam
2021

Test Beam
2022

Test Beam
2023

Test Beam
2024

Setup of the system and first HFO-CO2 mixtures tested under irradiation at GIF++

ECO1: CO_2 50%, HFO 45%, iC_4H_{10} 4%, SF_6 1%
High current increase of dark current After ~ 20 mC/cm2 integrated charge

ECO2: CO_2 35%, HFO 60%, iC_4H_{10} 4%, SF_6 1%

ECO3: CO_2 25%, HFO 69%, iC_4H_{10} 5%, SF_6 1%

STD, ECO2 and ECO3 mixtures under performance test and irradiation