CMS RPC
GIF++ Annual Meeting

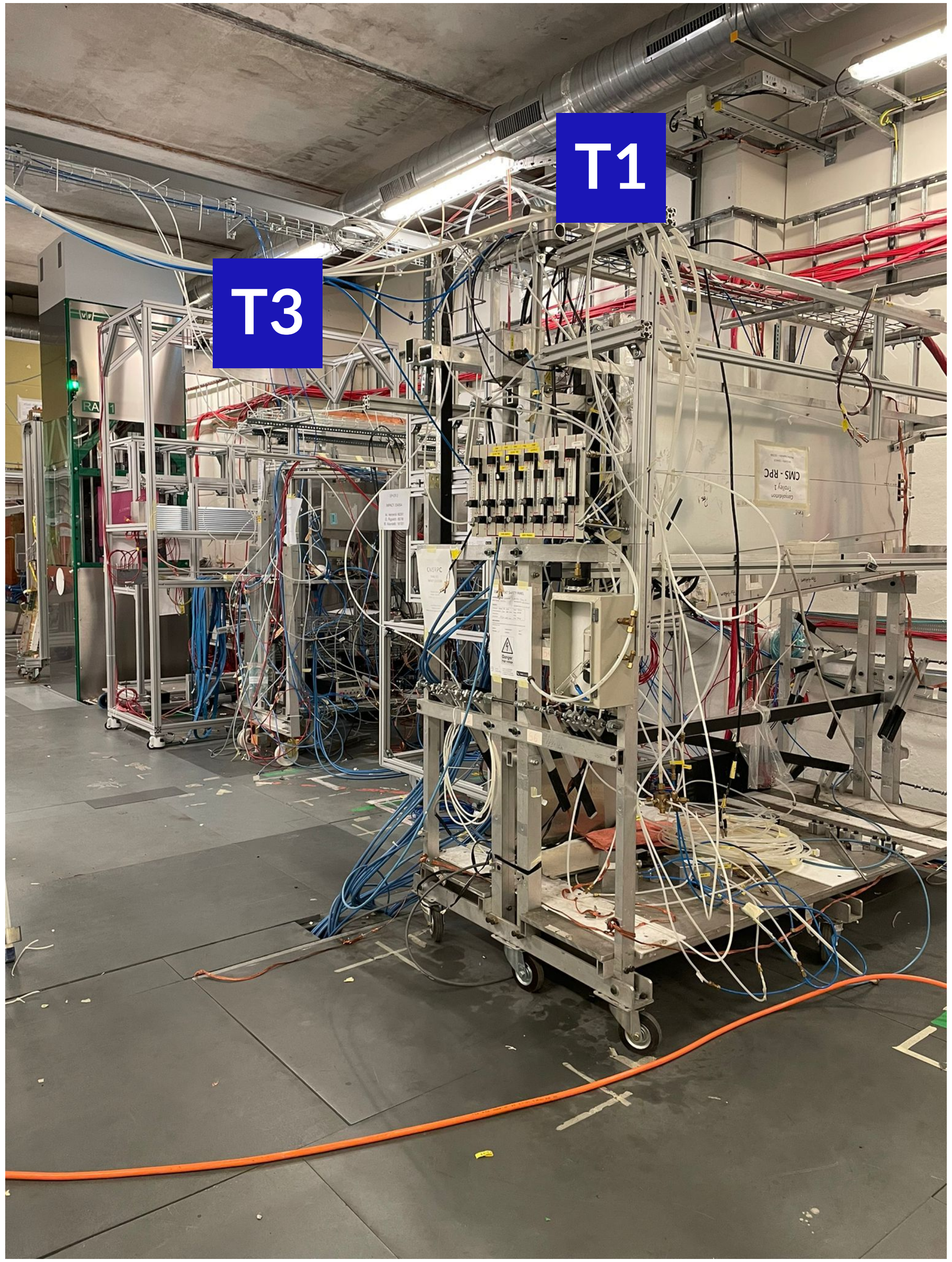
João Pedro Gomes Pinheiro (UERJ - Brazil)
on behalf of CMS RPC Group

December 3rd 2024

Outline

- Longevity for existing RPC chambers (T1)
    - Longevity status and results
- Alternative mixtures for RPC detector (T3)
    - R&D with lower GWP gas mixtures
    - Alternative ECOGas mixtures (HFO + CO_2)
    - Alternative CO_2 based mixture (TFE + CO_2)
- iRPC FEB and BEB validation (T3)
    - iRPC Longevity!
- Future Plans

Upstream region @ GIF++ bunker



Longevity studies for current RE2 and RE4 chambers

Longevity Status

Expected conditions @ HL-LHC

Expected Integrated charge :

Max. IC: ~ 280 mC/cm^2

~ **840** mC/cm^2 (**safety factor 3**)

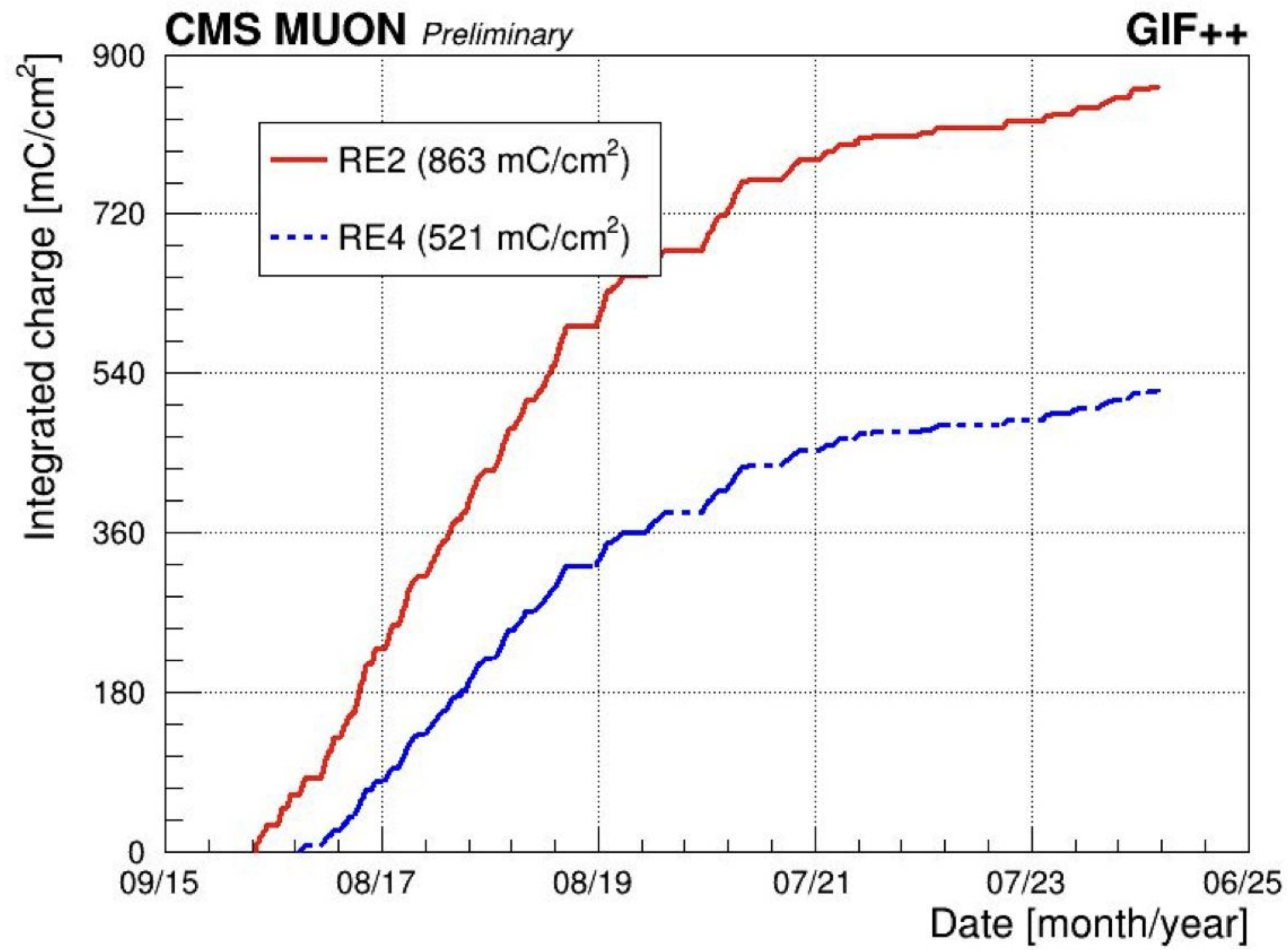
Barrel chambers factor 2 less

Expected Rate:

Max. Rate: ~ 200 Hz/cm^2

~ **600** Hz/cm^2 (safety factor 3)

Barrel chambers factor 2 less

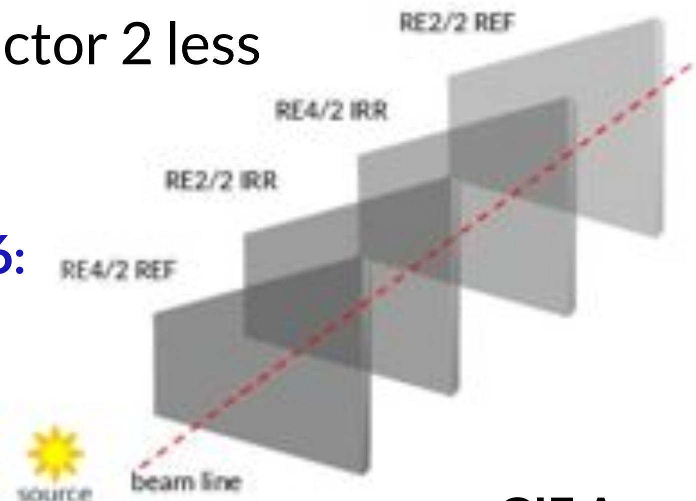


RE2	RE4
✓ IRR. In 3 July 2016	✓ IRR. In 25 Nov. 2016
✓ Q_{int} : 863 mC/cm^2	✓ Q_{int} : 521 mC/cm^2
> 100%	62%

Setup @ GIF++ since July 2016:

RE2 chambers (Irrad. & Ref.)

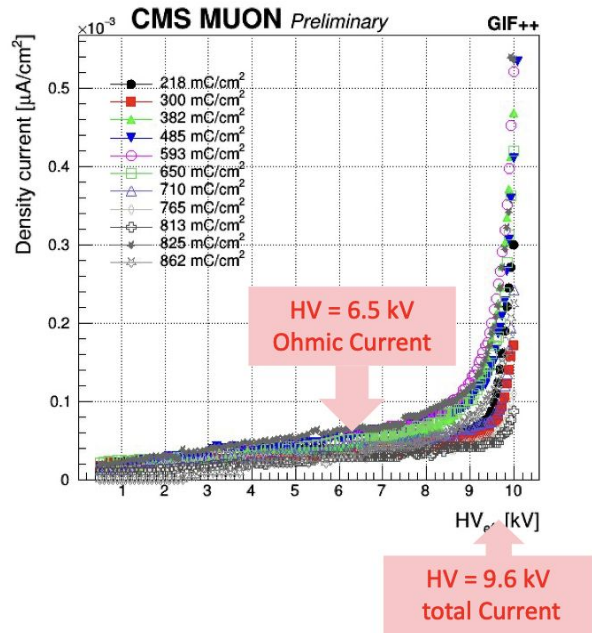
RE4 chambers (Irrad. & Ref.)



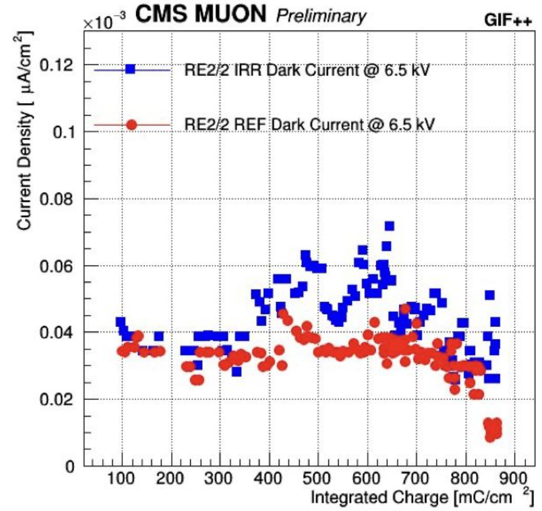
Current 2 mm double gap (CMS endcap RPC) chambers with standard gas mixture under test @ GIF++

Dark current for RE2 and RE4 chambers

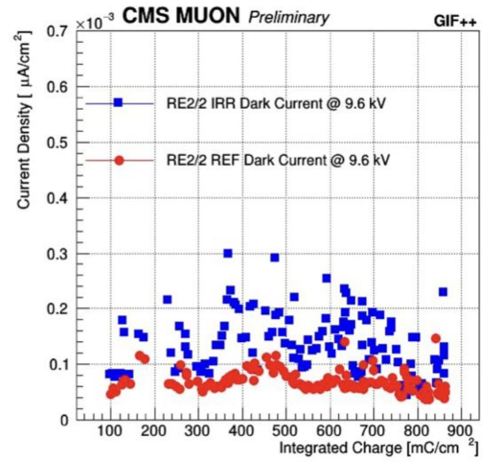
RE2/2 Irradiated dark current



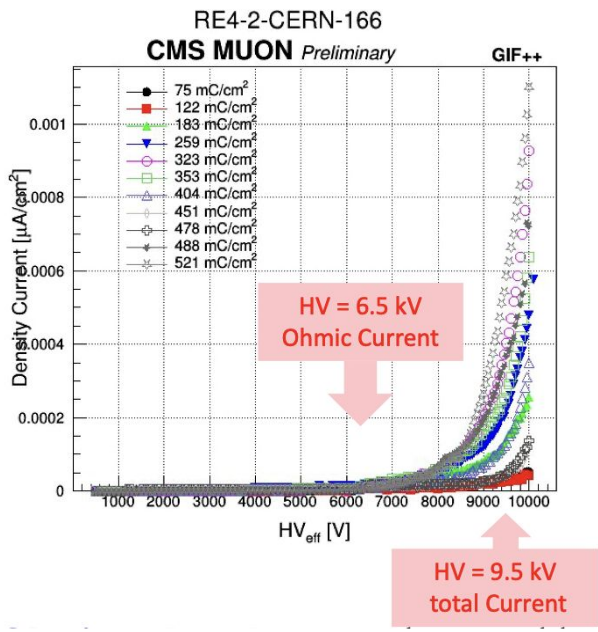
RE2/2 IRR. & REF **ohmic** current



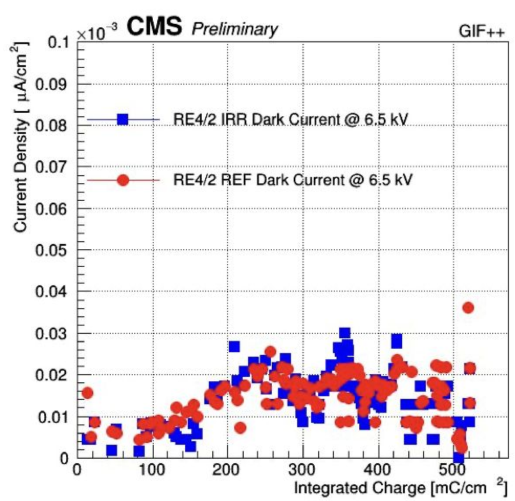
RE2/2 IRR. & REF **total** current



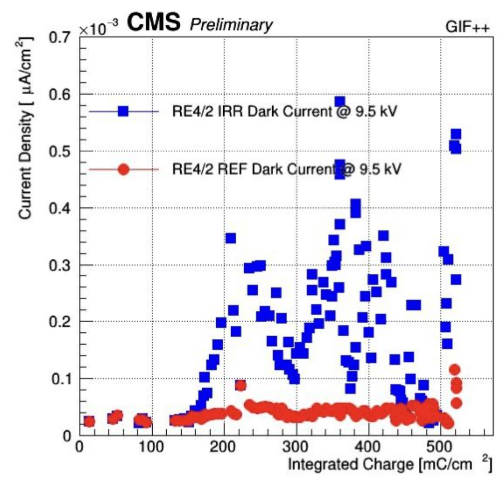
RE4/2 Irradiated dark current



RE4/2 IRR. & REF **ohmic** current

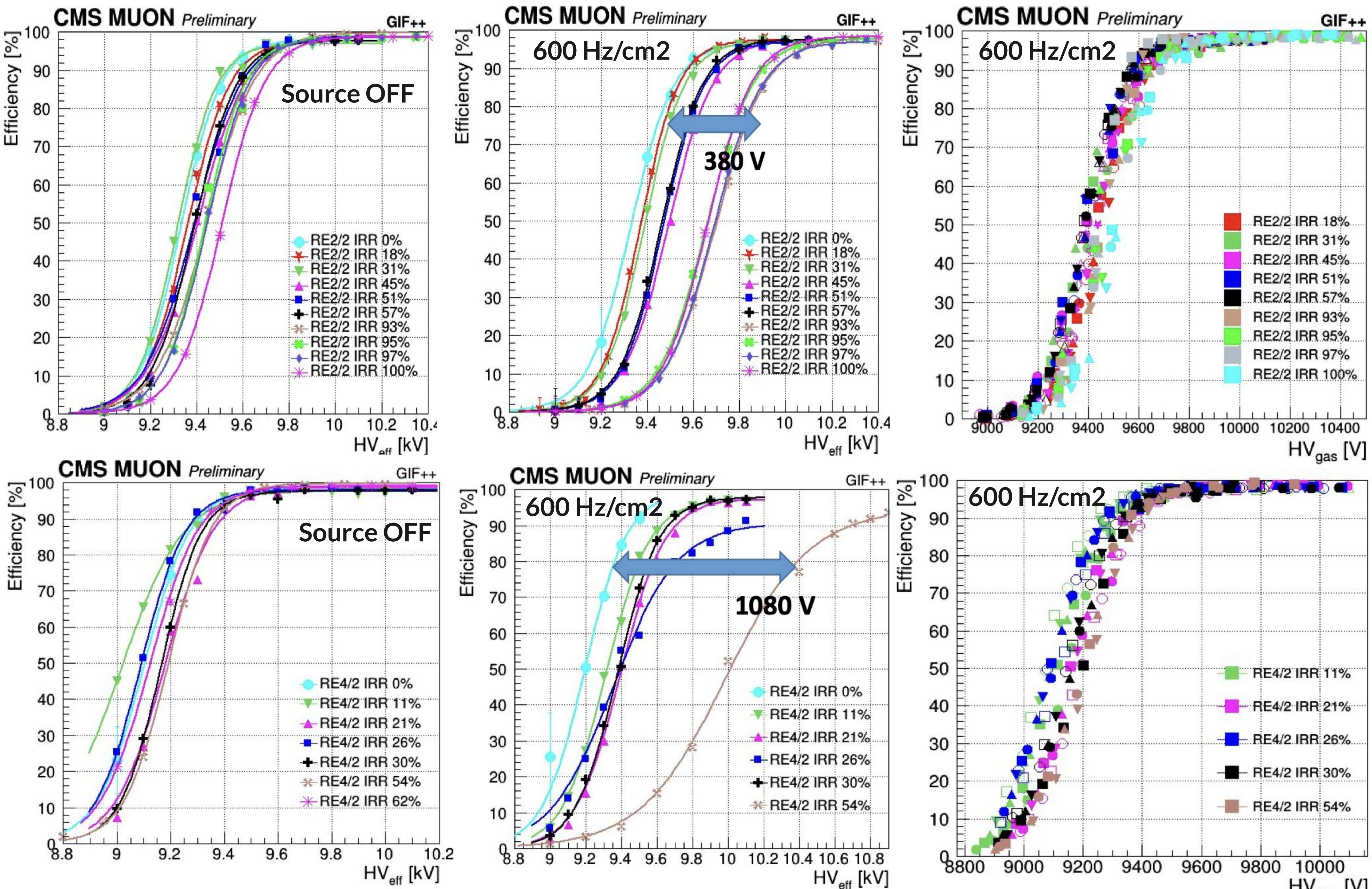


RE4/2 IRR. & REF **total** current



Ohmic and total current almost stable with time and after collecting charge for RE2 and RE4 and in agreement with values before the irradiation for IRR & REF chambers

Performance of RE2 and RE4 chambers

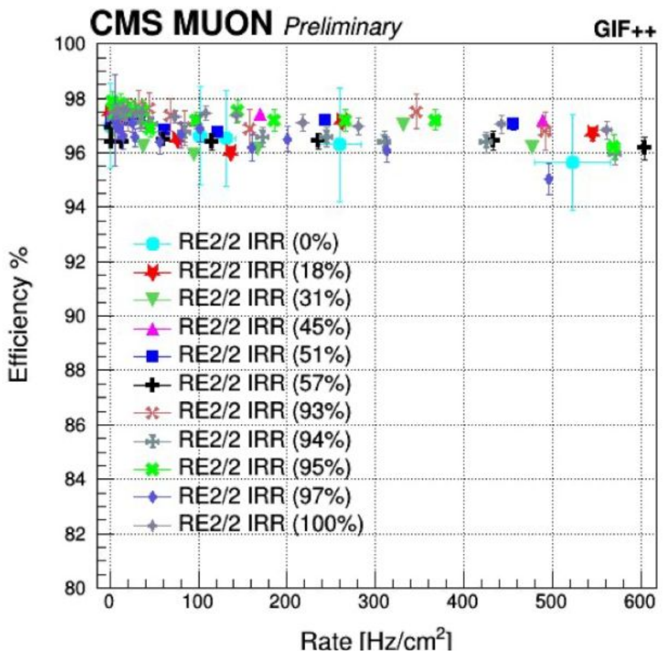


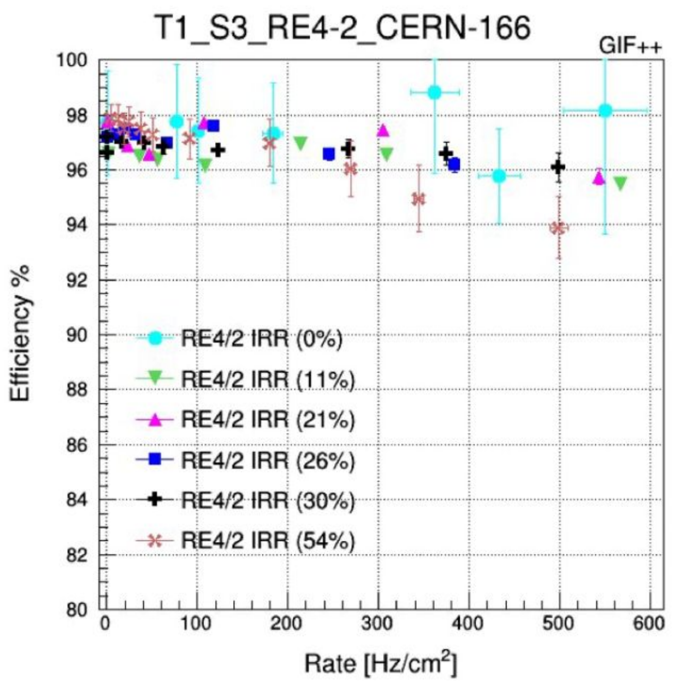
Stable efficiency!

Increase in the WP with radiation only due to ohmic component, RE4 still under studies

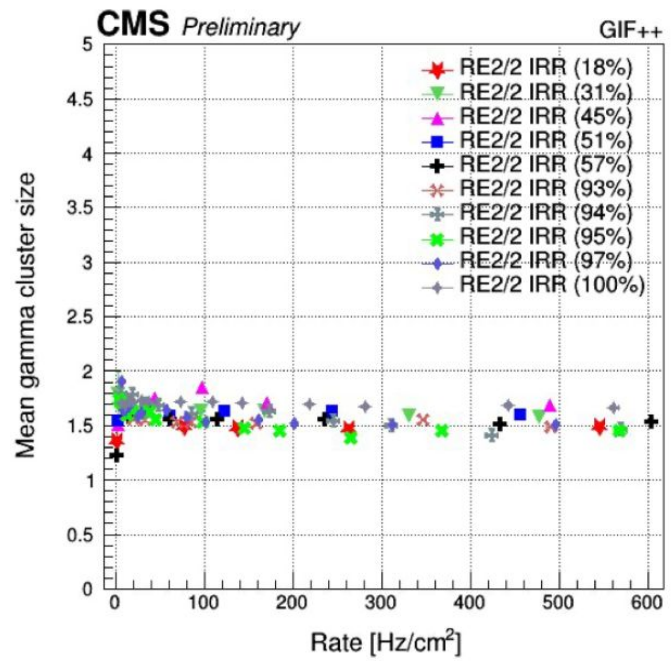
Performance of RE2 and RE4 chambers

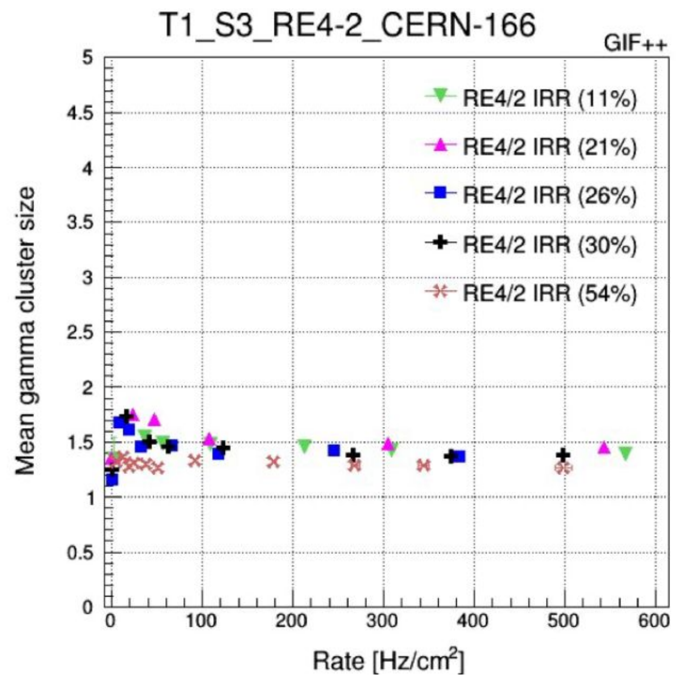
Efficiency vs. Rate @ different Test Beam



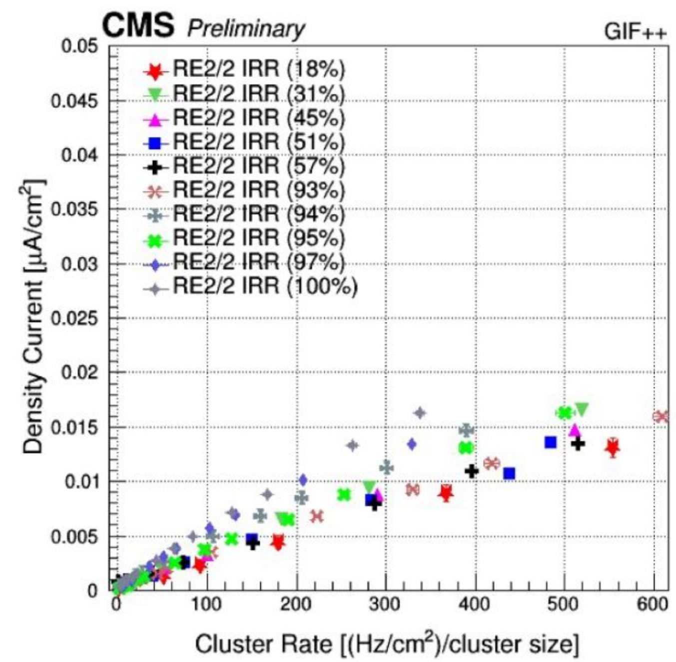


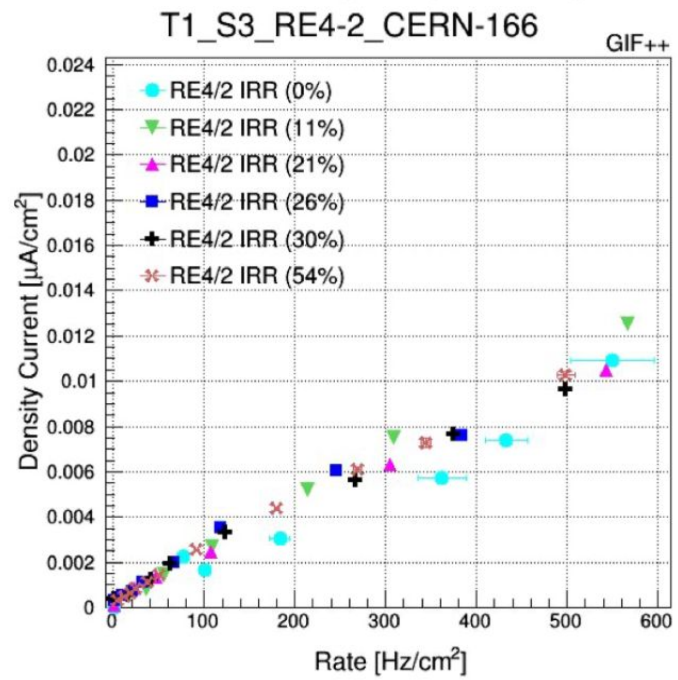
Gamma cluster size vs. Rate @ different Test Beam





Current Density vs. Rate @ different Test Beam





Stable efficiency, cluster size and current density after irradiation

Longevity studies for current RE2 and RE4 chambers

Longevity Summary

- **No effects of ageing have been observed so far!**

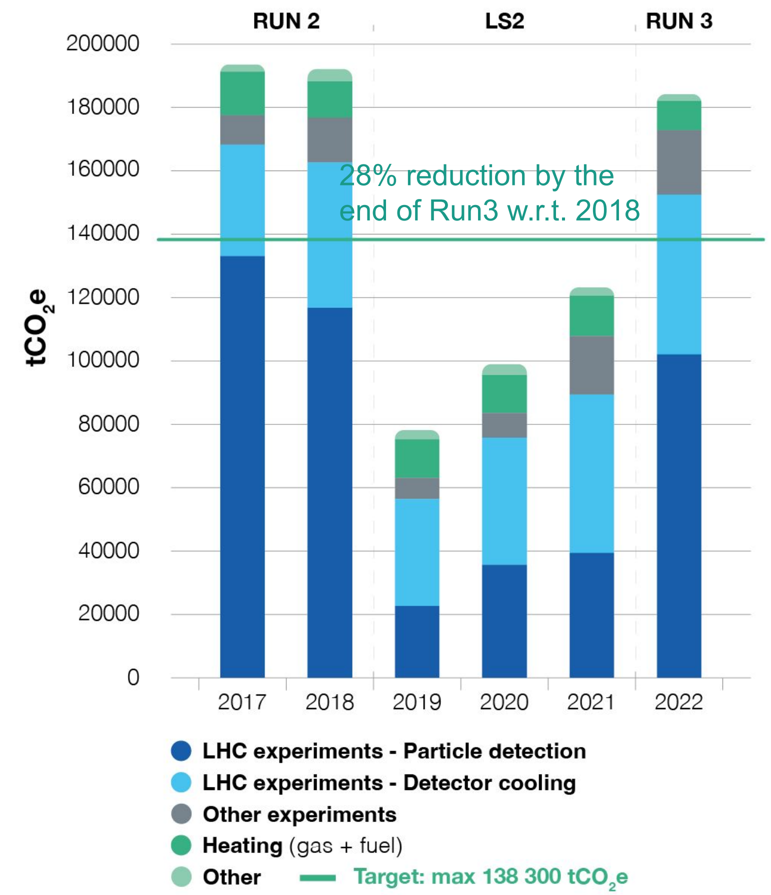
- The current accumulated IC for RE2 chamber (863 mC/cm^2) is:
  - corresponding to > 100 % of expected IC @ HL-LHC for **RE2** Chambers (including safety factor 3)
  - corresponding to 100 % of expected IC @ HL-LHC for **RE1** Chambers (including safety factor 2)
    → **Continue the irradiation campaign** to cover safety factor 3 for RE1 chambers!
  - stable noise rate and dark current & detector performance is stable with time and up to the maximum expected rate (600 Hz/cm^2).

- The current accumulated IC for RE4 chamber (521 mC/cm^2) is:
  - corresponding to 62 % of expected IC @ HL-LHC for **RE4** Chambers (including safety factor 3)
    → **Continue the irradiation campaign** to cover safety factor 3 for RE4 chambers!

- Irradiation of RE2 paused due to the lack of gas:
  → (50 L/h available: 20 L/h for RE4 + 20 L/h new iRPCs longevity
  - 10L/h spare used for other colleagues)

The Greenhouse gases emission at CERN

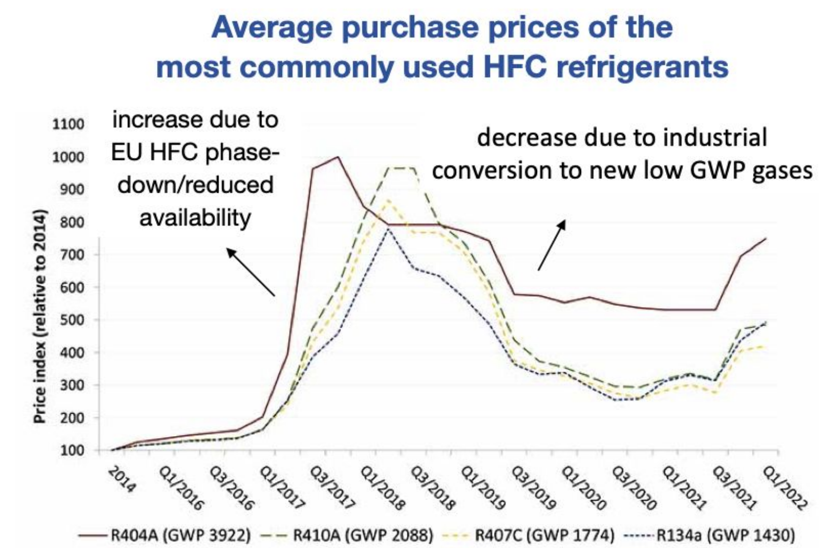
- European Union has set targets to **reduce greenhouse gas (GHG) emissions by 55% by 2030** and achieving **net-zero emissions by 2050**. The European Green Deal.
- The use of fluorinated gases (F-gases) like $C_2H_2F_4$ is tightly regulated due to their **high global warming potential (GWP)**.
- Around 90% of direct emissions come from experiments, where more than 78% of GHG emission is a direct result of the use of F-gases. CERN Environment Report 2021-2022.



CERN SCOPE 1 EMISSIONS FOR 2017–2022 BY CATEGORY.
"Other" includes air conditioning, electrical insulation, emergency generators and the fuel consumption of the CERN vehicle fleet.

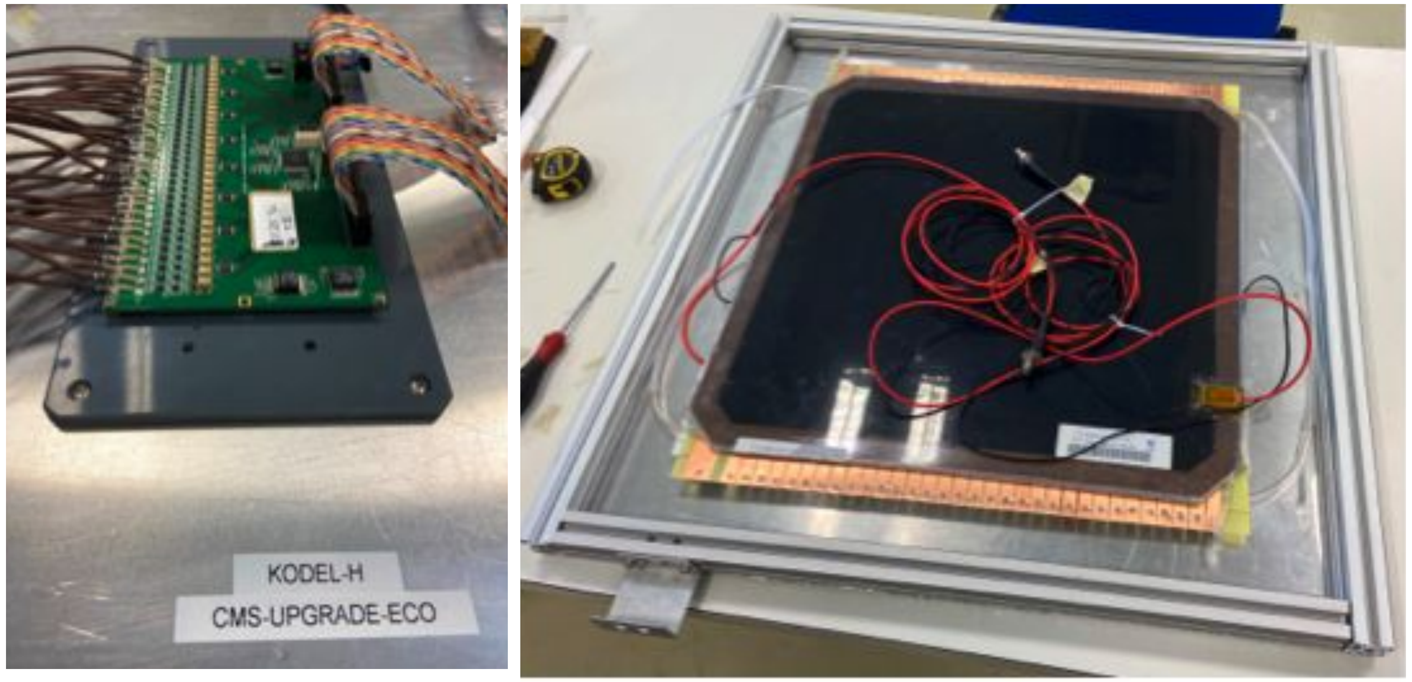
CERN Fluorinated Gases (F-Gas) Policy (July 24th, 2024):

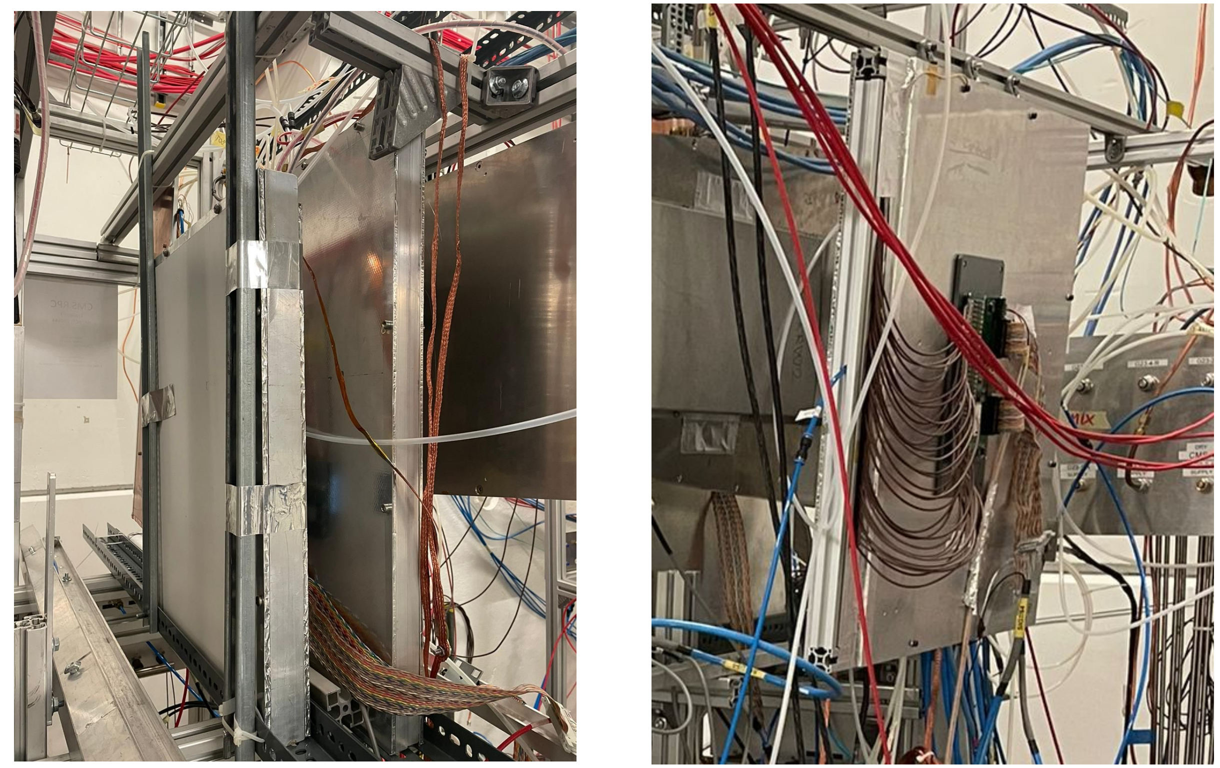
- minimize the use of F-Gases at CERN, particularly by:
  - **the promotion of research and development into F-Gas alternatives,**
  - **the replacement, to the extent possible, of F-Gases already used in its installations and activities with gases with no - or less - impact on the environment,** and
  - the minimization, to the extent possible, the use of F-Gases in new installations and activities.
- limit its emissions of F-Gases, particularly by:
  - the prohibition of intentional releases,
  - **the detection and reduction of leaks,**
  - appropriate training of personnel concerned.
- monitor and manage the use and emissions of F-Gases within the Organization,
- establish and update appropriate internal procedures and regulations and monitor compliance with them,
- communicate proactively,
- collaborate with the Host States.



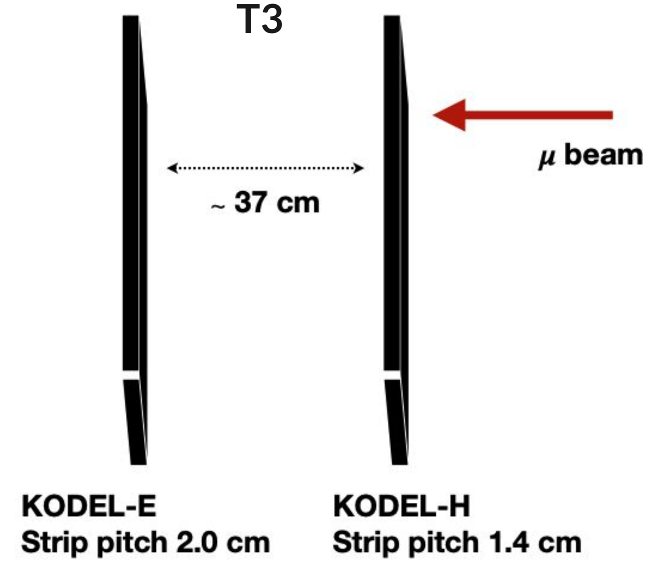
Setup at T3 Upstream

KODEL-E (since April/23)





KODEL-H assembled in June/23



- RPC prototype (KODEL E and H):
  - 1.4mm double gap
  - $\varrho \sim 1.3 \times 10^{10}$ Ω.cm
  - 45.5×45.5 cm^2 active area
- Readout electronics:
  - Current sensitive mode for input signals
  - Input impedance 20 Ω
  - Threshold 0.5 mV ~60fC

Alternative gas mixtures for RPC detectors

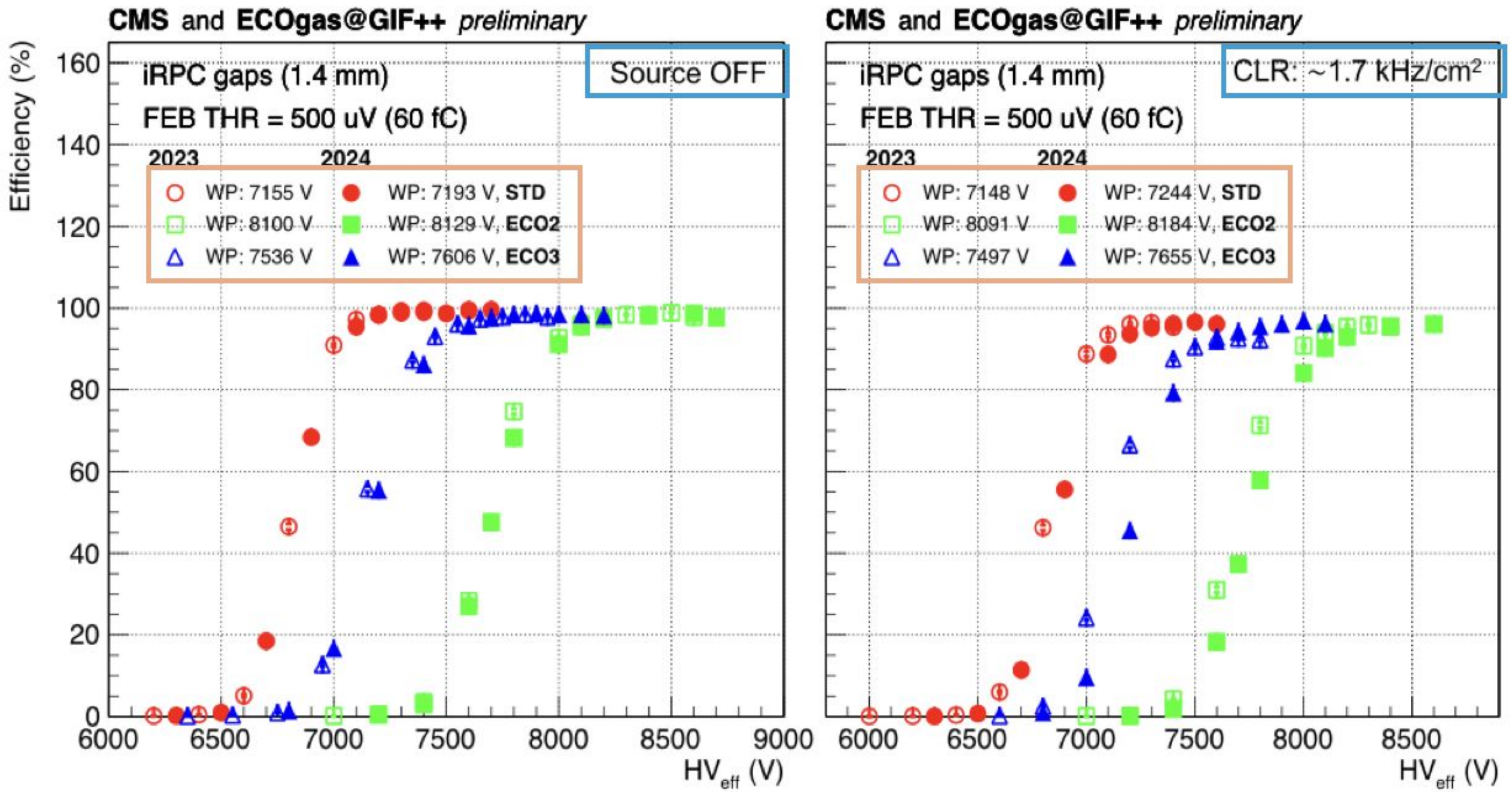
	TFE (%)	HFO-1234ze (%)	CO_2 (%)	i-C_4H_{10} (%)	SF_6 (%)	CO2e(g/l)
GWP	1430	7	1	3	22800	
Density (g/L)	4.68	5.26	1.98	2.69	6.61	
STD	95.2			4.5	0.3	6824
ECO2		35	60	4	1	1522
ECO3		25	69	5	1	1519
30%CO_2 + 1%SF_6	64		30	5	1	5650
30%CO_2 + 0.5%SF_6	64.5		30	5	0.5	4940
40%CO_2 + 1%SF_6	54.5		40	5	1	5000

RPC ECOGAS@GIF Collaboration (ECO2, ECO3)

Collaboration with ATLAS-RPC and EP-DT Group (30%CO_2 + 1%SF_6, 30%CO_2 + 0.5%SF_6, 40%CO_2 + 1%SF_6)

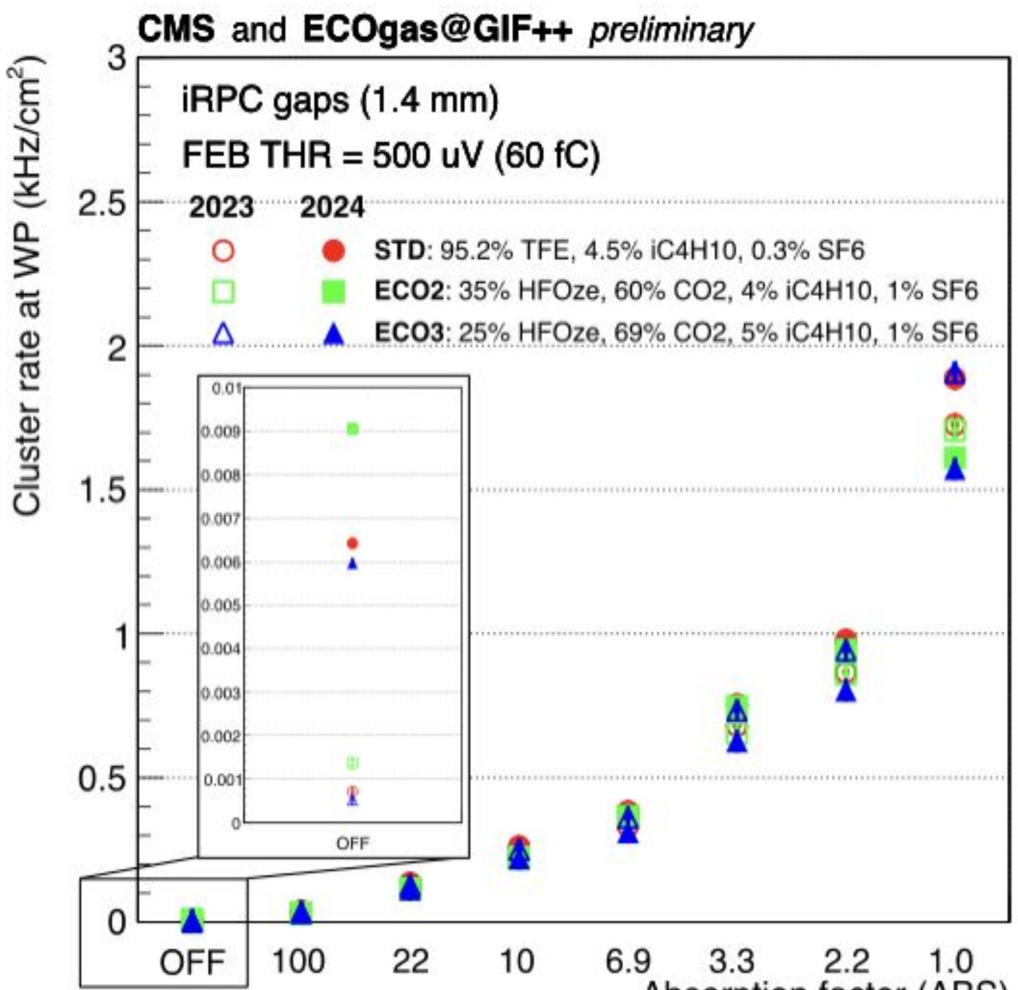
- Requirements: low GWP, low toxicity, not flammable and detector performance comparable with standard one
- ECOGAS collaboration R&D with the full replacement of TFE by HFO-1234ze adding CO_2 to decrease the WP
- Efforts with ATLAS-RPC and EP-DT to study the effects of replacing a small amount of TFE for CO_2, decreasing the GWP and the WP.
- The GWP values are mainly driven by SF_6 which is increased up to 1% to decrease cluster size and streamer probability (as shown in previous EP-DT studies)

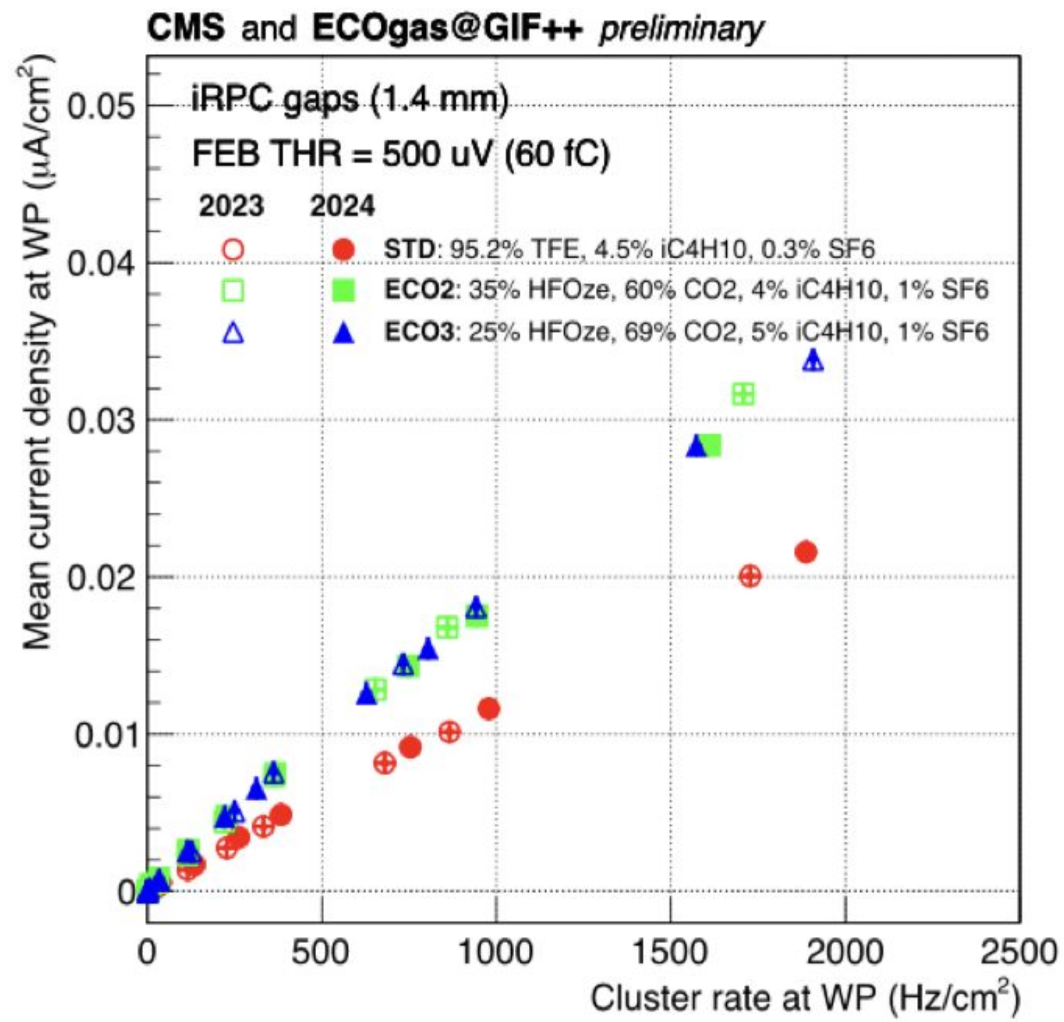
HFO+CO2 based mixtures for RPC detectors



- Around **40 mC/cm^2** was integrated between 2023 and 2024
- Efficiency measured up to the higher background conditions achievable at GIF++ shows **no drops after irradiation**
- Slightly shift of WP to higher values have been observed

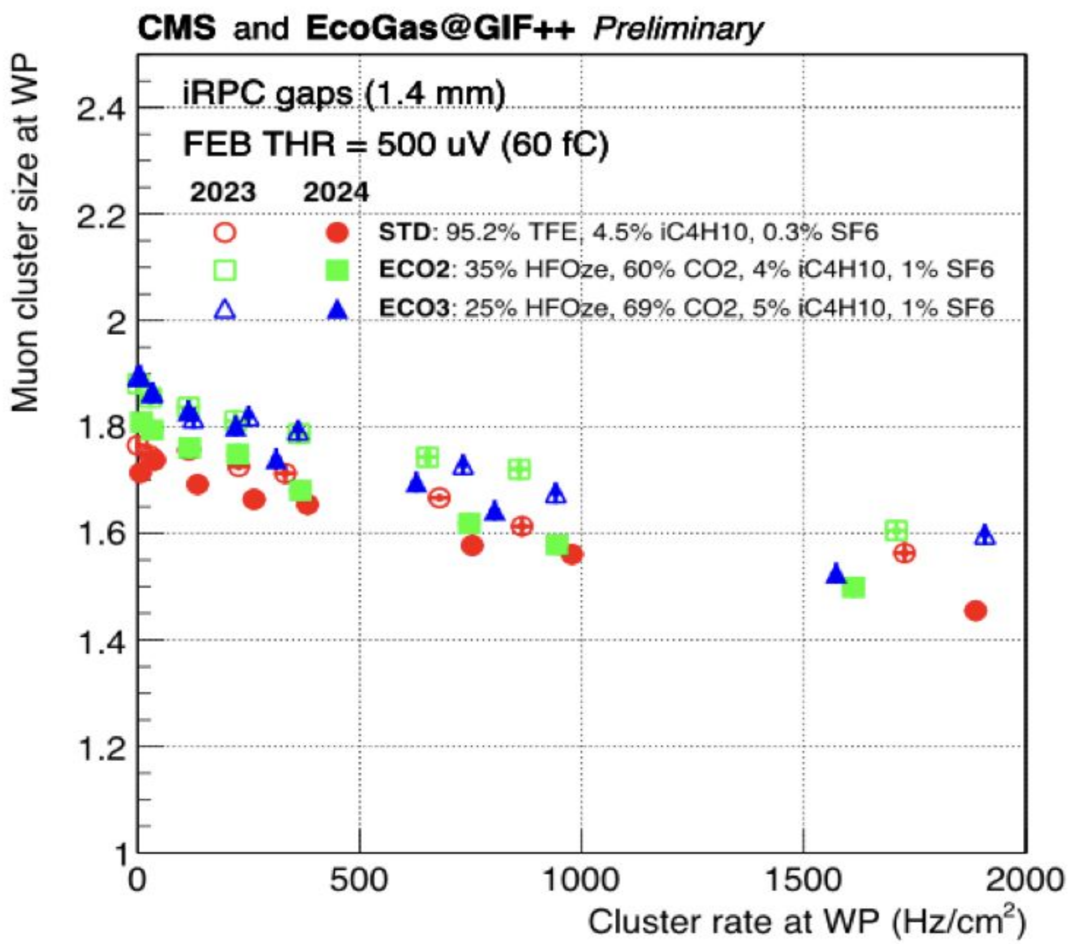
HFO+CO2 based mixtures for RPC detectors

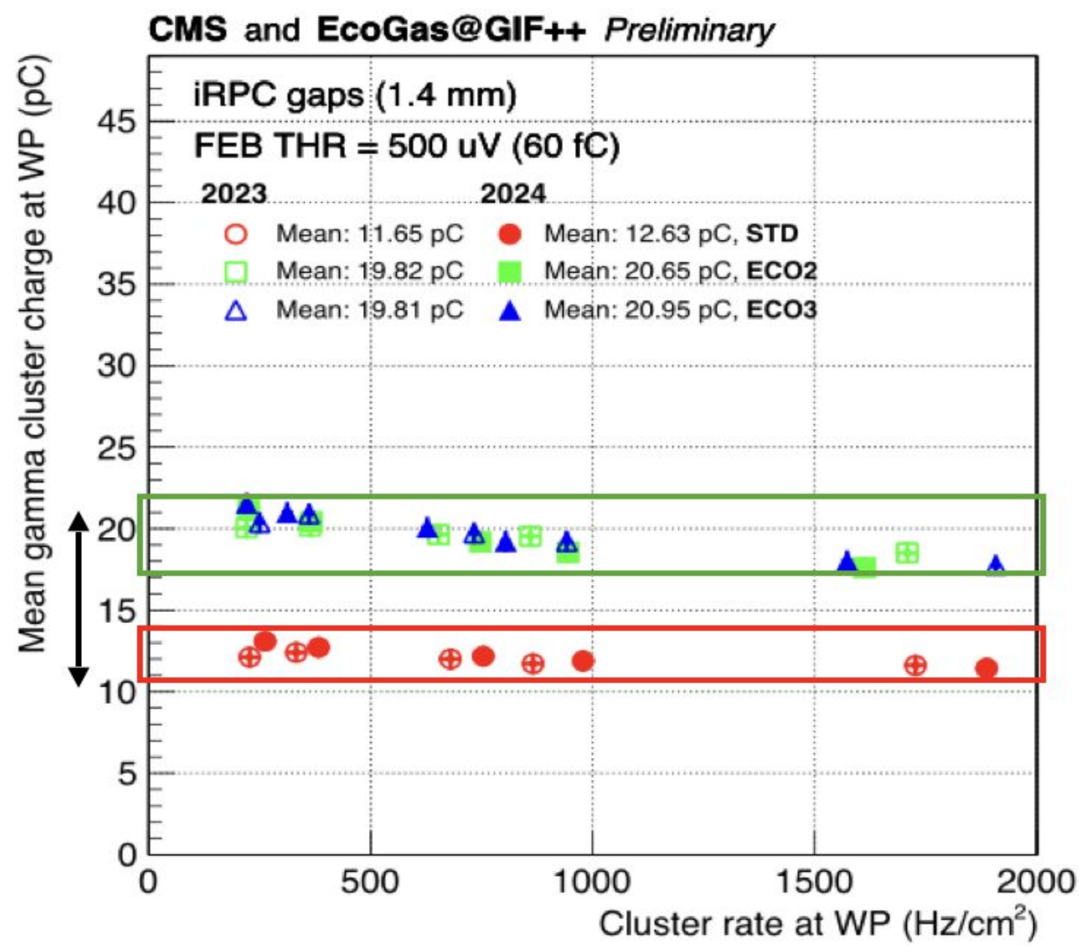




- **Lower current values** monitored operating the prototype with STD mixture
- **Similar values and slope** using eco-friendly candidates
- **Stable chamber:** current values in agreement after irradiation according the cluster rates measured

HFO+CO2 based mixtures for RPC detectors





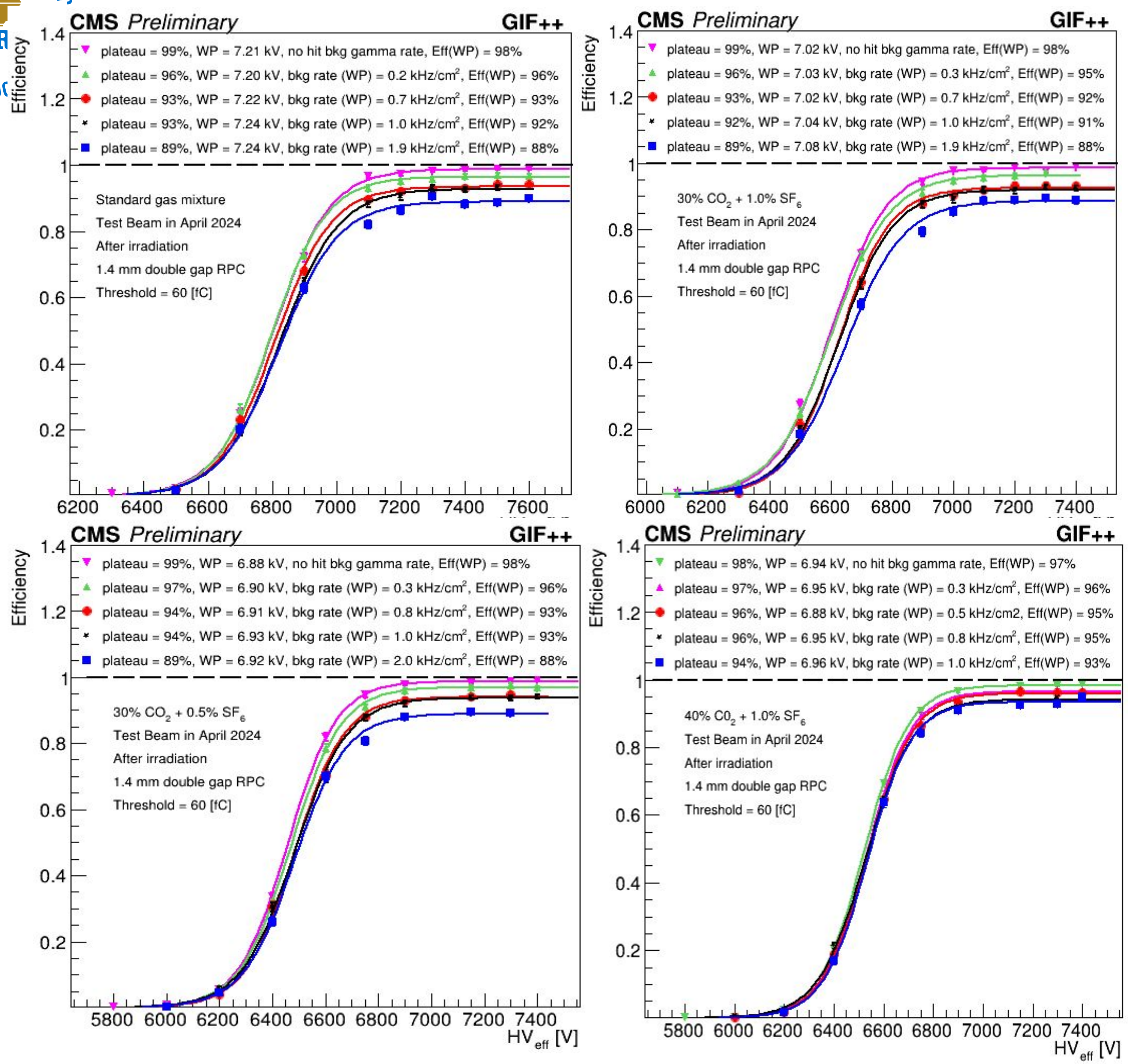
- **Negligible differences values** reported after irradiation without large differences between mixtures and similar slopes.
- Mean charge values reported **~40% higher cluster charge** when the chamber is operated with ecological candidates. **No changes after irradiation**

Alternative gas mixtures: HFO/CO2 mixtures
Summary

- **Comparable performance of ECO mixtures w.r.t the standard one for both tested chambers**
- **4%** charge integrated for CMS-iRPC prototype and **20%** for RPC (RE1/1)
- Shift in efficiency curve of few V, still under investigation
- WP(ECO2) > WP(ECO3) > WP(STD)
- Muon and gamma cluster size **are comparable and don't change** after radiation campaign for all the tested mixtures
- Noise is shown to be **higher** after irradiation
- Mean gamma cluster charge values **40% higher** for ECO mixtures
  → can speed up aging effects

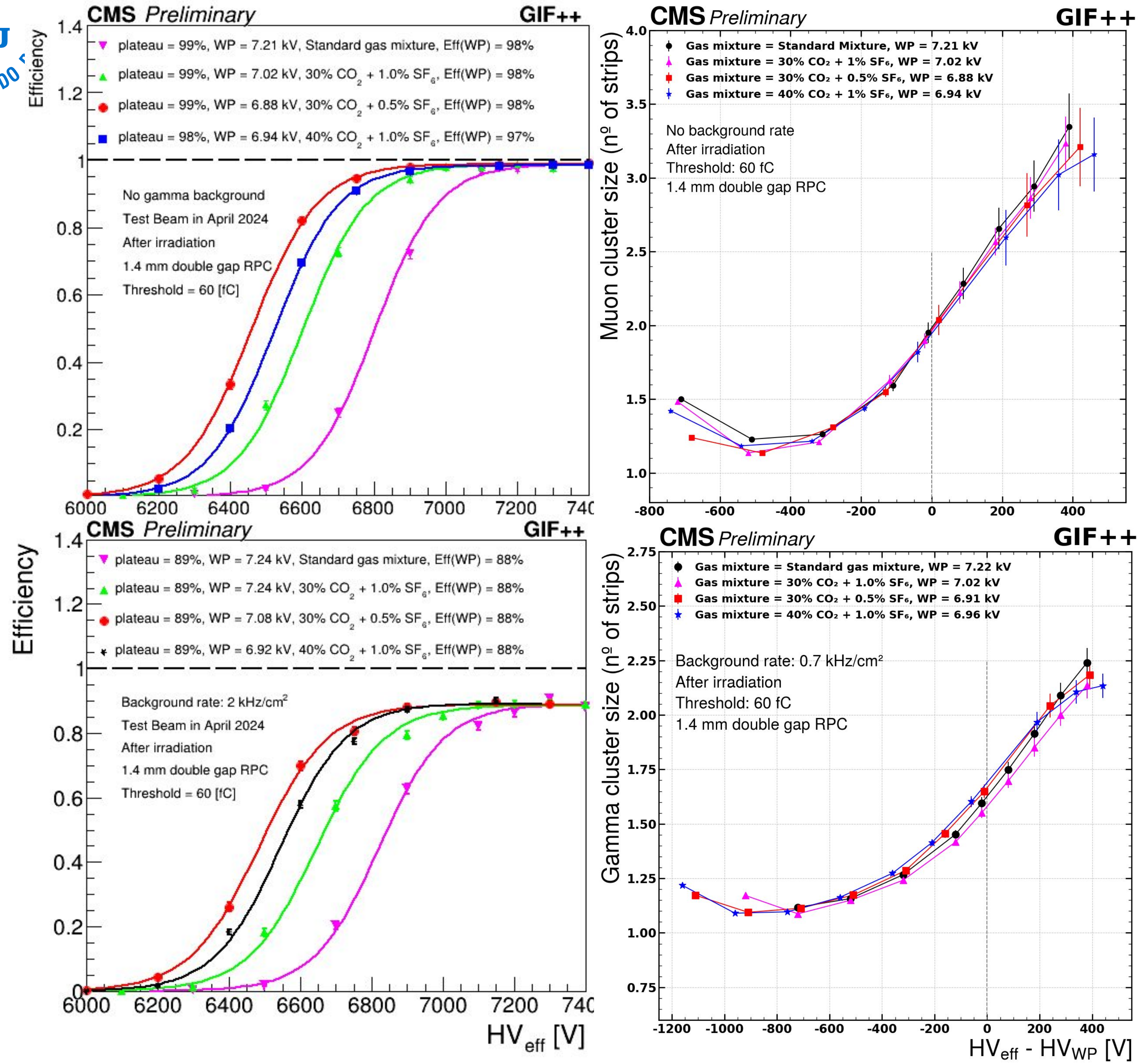
The aging campaign will continue for a better understanding of longevity effects with HFO/CO2 mixtures

TFE+CO2 based mixtures for RPC detectors



- During no beam period, a dedicated irradiation campaign took place at GIF++
- It was collected around **40 mC/cm²**, corresponding to **~ 4 %** of what is expected during HL-LHC within **a safety factor 3**
- Revalidation with standard gas mixture:
  - **Consistent and stable efficiency** and Working Point (~ 30 V higher) for moderate background rate
  - Drop in efficiency for high background rate, **mostly driven due to the FEB aspects**, which is not designed for that high radiation environment

TFE+CO2 based mixtures for RPC detectors

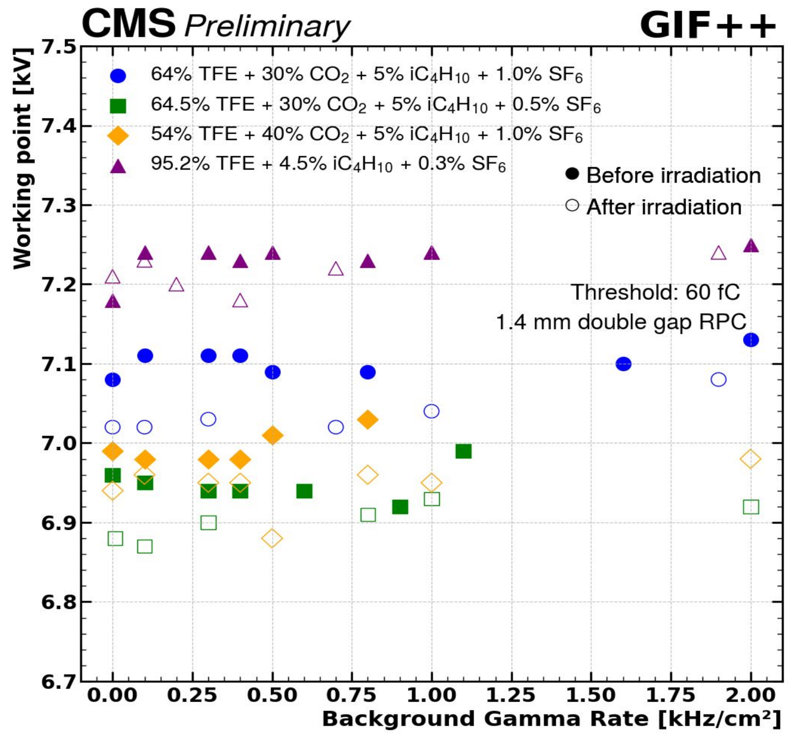


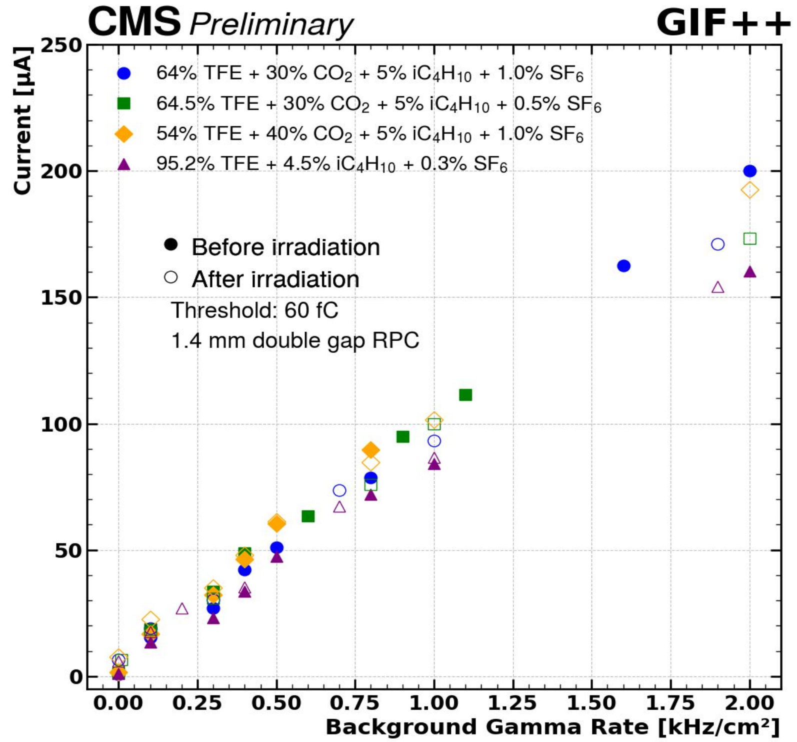
No change in the efficiency without radiation

but < 90% for 2 kHz/cm^2 (mostly FEB drive, no gas mixture related)

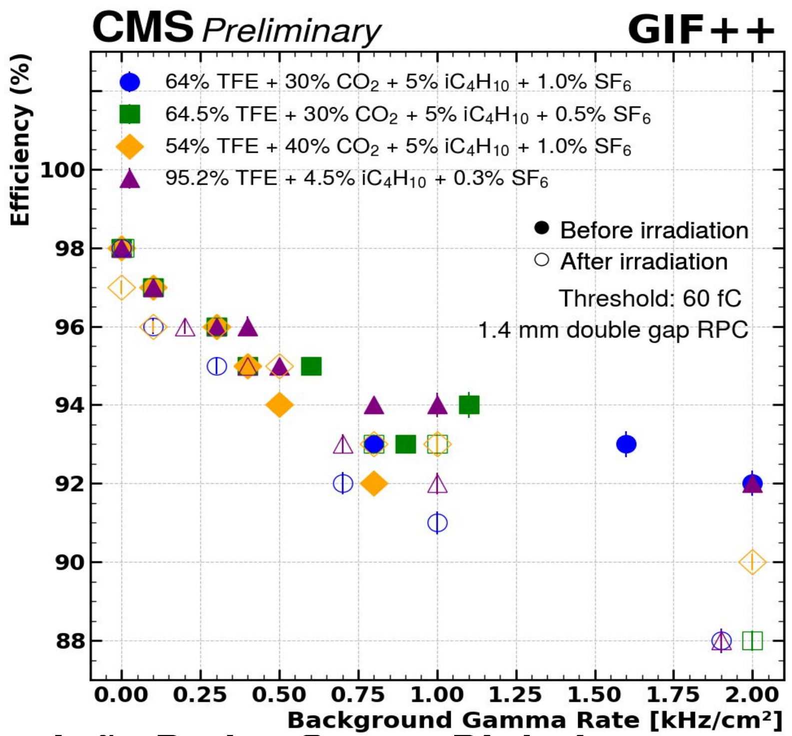
No difference between CO_2 based mixtures and also no changes w.r.t the results before irradiation!

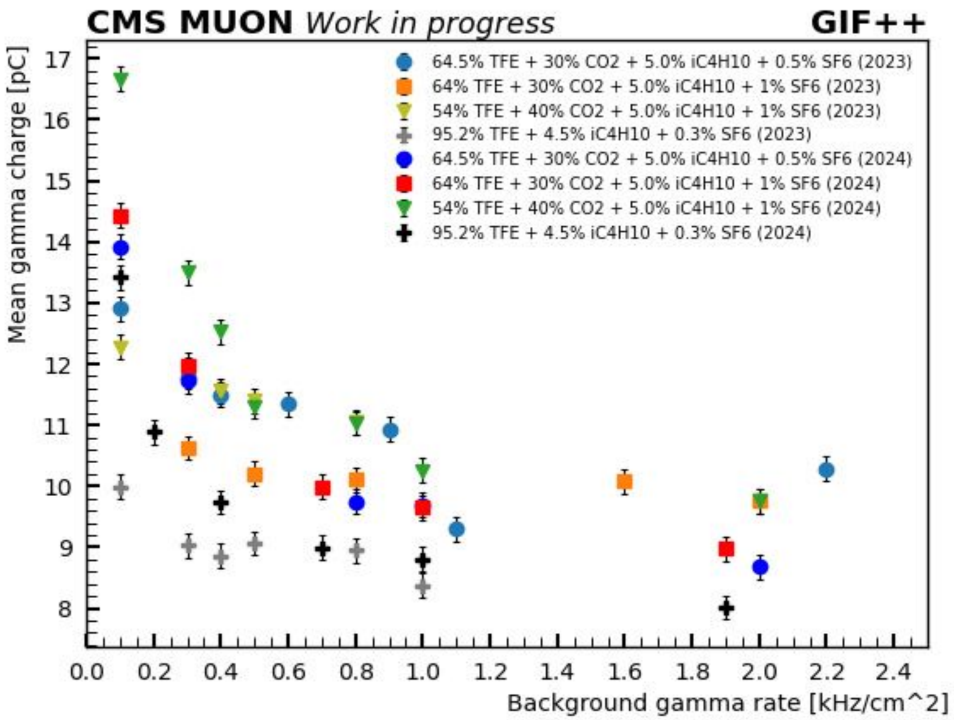
TFE+CO2 based mixtures for RPC detectors





- **No change** in the working point after irradiation campaign
- Drop in efficiency with background **similar** before/after irradiation for moderate rates
- Current and mean gamma charge is shown to be **~20% higher** for CO_2 based mixtures, with similar results after and before irradiation





Irradiation campaign will continue in order to integrate more charge

Alternative gas mixtures: TFE/CO2 mixtures

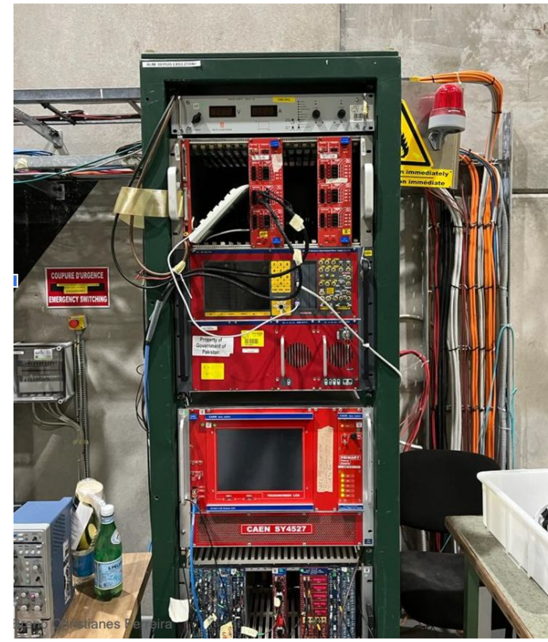
Summary

- **First results of an iRPC prototype with double 1.4 mm gap with CO_2 based gas mixtures**
- Similar efficiency and lower working point for all CO_2 based gas mixtures tested w.r.t the standard one
- **Integrated charge around 4% of what is expected at HL-LHC x 3**
- No efficiency degradation related to the gas mixture was observed
  - Efficiency drop is electronics related, similar for all tested mixtures
- No change in the working point was observed
- No change in the muon and gamma cluster size was observed
- **20 % higher currents** for CO_2 based mixtures **- no change after irradiation**

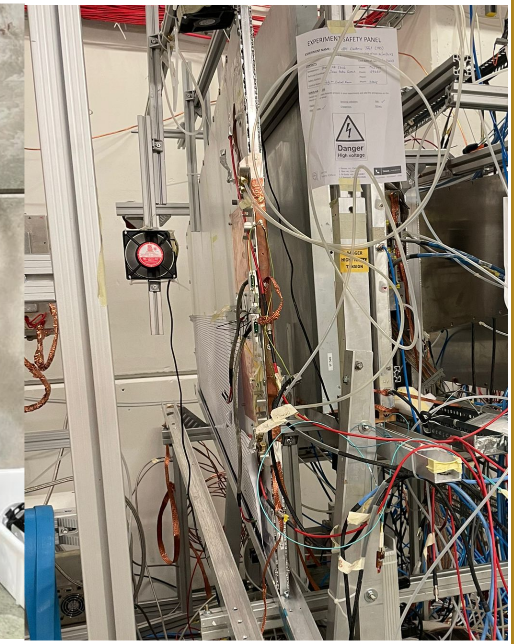
Studies will continue at GIF++ with the aim to integrate more charge during irradiation campaign, perform further studies, as timing resolution, and investigate better the efficiency drop observed.

iRPC Front-end and Back-end validation

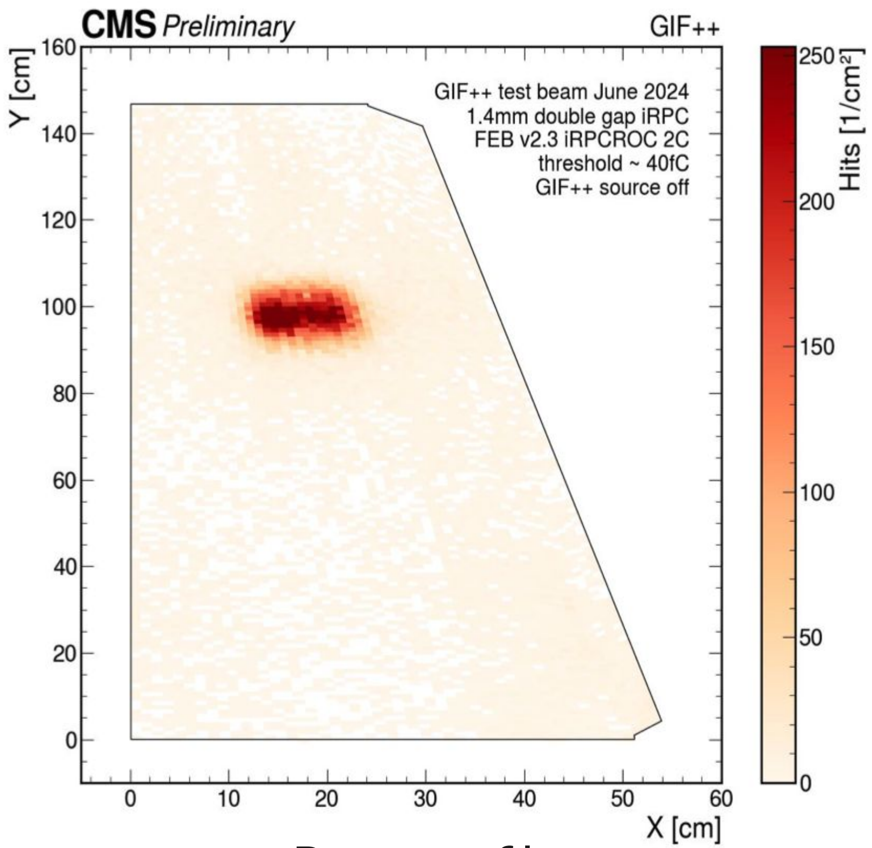
- Fine tuning of FEB-BEB integration during 2024 for iRPC
- Cluster reconstruction studies by BEB team
- Tests performed with final mass production iRPC
- Efficiency > 95 % @ 2.3 kHz/cm^2 and working point ~ 7 kV



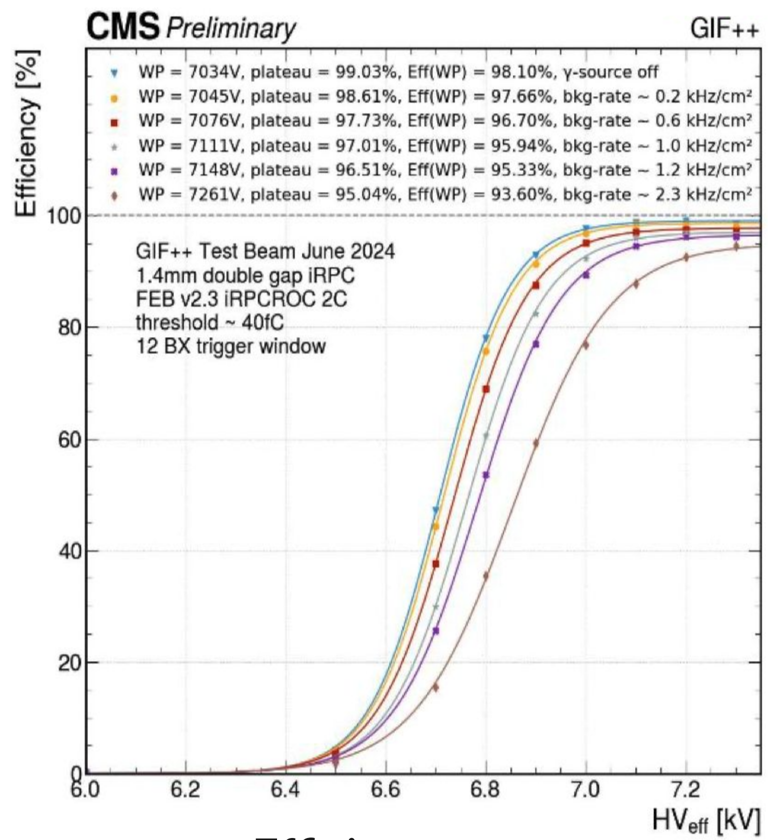
HV and LV power supply in preparation area



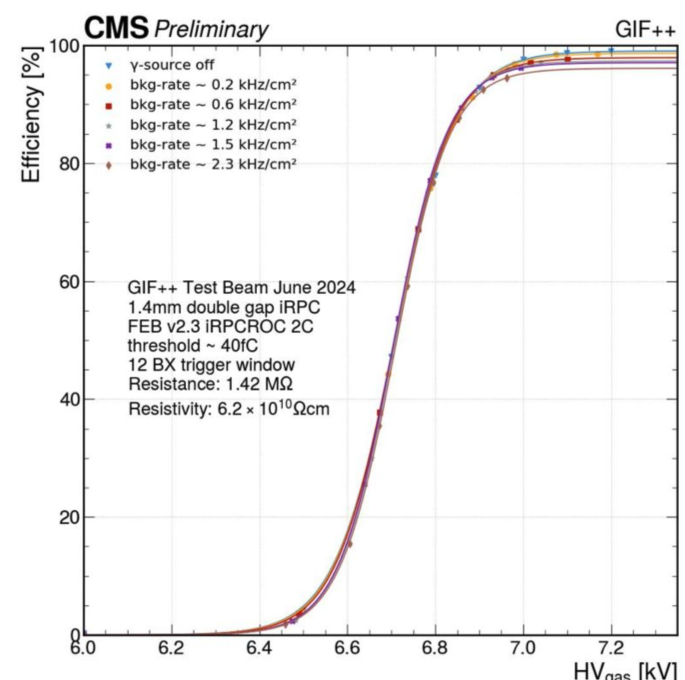
Real iRPC chamber in T3



Beam profile



Efficiency curve



Efficiency curve after ohmic correction

Future Plans

- CMS-RPC team had a nice data taking period at GIF++ during 2024 with different setups

- Continue the Longevity program for existing CMS-RPC chambers in T1
  - 2 RE2 (?) and 2 RE4 chambers

- Continue the Longevity program for ECOGAS and TFE/CO_2 mixtures in T3.

- Install one 2 mm double gap RPC chamber prototype with existing electronics for TFE/CO_2 mixture validation and longevity (T3).

- Continue the recently started iRPC longevity plan (T3)

- Continue iRPC tests with final FEB and BEB uTCA
  - mass production in the end, final validation for installation ongoing

Thank you!
Questions?

12th April 2024

Special thanks to Guiseppe and Paolo for all the support - and donuts!

Backup

Justification for data taking during 2025:

CMS-RPC setup at GIF++ consists in three chamber prototypes for alternative gas mixtures, two of them in collaboration with ECOGAS group (KODEL-H and RE11), 4 existing CMS-endcap chambers for Longevity analysis and 2 real size iRPC for FEB and BEB integration studies. Also brand new iRPC chambers were installed to start longevity studies. All setups need to be able to reconstruct the muons in a high radiation environment (as foreseen for HL-LHC) and show no ageing after the integration charge expected in the Phase-II of LHC. For next year, we would like to keep all the existing setups, since there's still a lot of work to do, as integrate more charge for longevity studies (with standard and alternative gas mixtures) and perform data taking with last FEB version integrated with BEB for new iRPCs. Additionally, we would like to add one small 2mm gap RPC chamber in Trolley 3 to perform tests with TFE/CO_2 alternative gas mixtures using existing CMS-RPC electronics.

Justification for data taking during LS3:

Nowadays, CMS-RPC setup at GIF++ consists of three iRPC chamber prototypes for alternative gas mixtures, two of them in collaboration with ECOGAS group (KODEL-H and RE11), 4 existing CMS-RPC endcap chambers for Longevity studies and 2 real size iRPC for FEB and BEB integration studies. Longevity program for existing CMS-RPC achieved 60% of integrated charge w.r.t what is expected at HL-LHC within safety factor of 3, so we would like to finish this study in the coming years. Regarding the iRPC studies with alternative gas mixtures, we also would like to profit of next years and LS3 period to integrate charge, since it just started this year. In addition, we started the longevity program for the new generation of improved RPC chambers that are going to be installed in large eta region of CMS in the following years. Furthermore, we want to continue with the studies of iRPC electronics, since final ATCA crates and serenity boards will be available by that time and we have a dedicated cosmic trolley to take data with muons profiting of the radiation source outside beam time periods.

Conference presentations with GIF++ data - 2024

16th Pisa Meeting 2024: 16th Pisa Meeting on Advanced Detectors

Improved Resistive Plate Chambers for Phase-II upgrade of the CMS detector at LHC
Joao Pinheiro (Univ. Estado Rio de Janeiro)

Longevity study of CMS Muon Detector facing the High Luminosity LHC phase
Raphael Gomes De Souza (Univ. Estado Rio de Janeiro)

New RPC Gas Mixtures for Sustainable Operation in the CMS Experiment
Dayron Ramos Lopez (Univ. di Bari e Sez. dell'INFN)

iWoRiD 2024: International Workshops on Radiation Imaging Detectors

Longevity study of CMS Muon Detector facing the High Luminosity LHC phase
Dayron Ramos Lopez (Univ. di Bari e Sez. dell'INFN)

ICHEP2024: 42nd International Conference on High Energy Physics

Improved RPC (iRPC) detector for CMS data taking in HL-LHC
Salvatore Buontempo (INFN di Napoli)

Latest results of longevity studies on the present CMS Resistive Plate Chamber (RPC) system for the HL-LHC phase
Mapse Barroso Ferreira Filho (Univ. Estado Rio de Janeiro)

Performance of eco-friendly alternative gas mixtures in CMS iRPC detector in the HL-LHC environment
Joao Pinheiro (Univ. Estado Rio de Janeiro)

Conference presentations with GIF++ data - 2024

RPC2024: XVII International Conference on Resistive Plate Chambers and Related Detectors (RPC2024)

New RPC Gas Mixtures for Sustainable Operation in the CMS Experiment
Dayron Ramos Lopez (Univ. di Bari e Sez. dell'INFN)

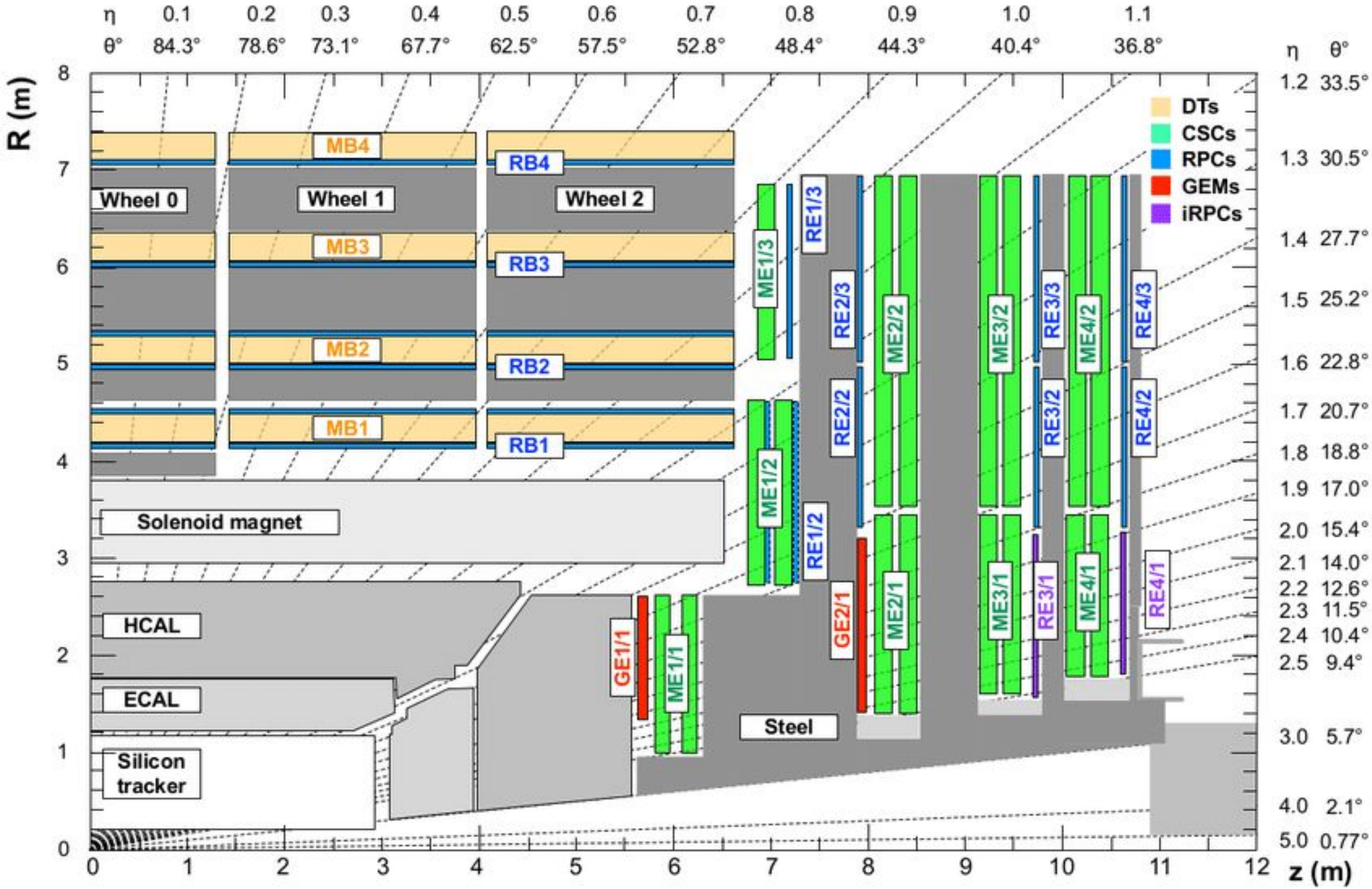
iRPC front-end board readout electronics
Maxime Gouzevitch (IPN, IN2P3-CNRS, UCB Lyon 1)

Innovative Resistive Plate Chambers for the CMS Phase 2 Upgrade: Project Summary, Construction, and Quality Assurance
Jules Vandenbroeck (Ghent Univ.)

Performance and longevity of CO2 based mixtures in CMS Improved Resistive Plate Chambers in the HL-LHC environment
Joao Pinheiro (Univ. Estado Rio de Janeiro)

iRPC clustering algorithm and hit reconstruction
Mauricio Thiel (Univ. Estado Rio de Janeiro)

Preliminary aging studies of improved RPC gaps operated with HFO based mixtures
Zubayda Eve Kofi (University of Dundee)



η 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1
θ° 84.3° 78.6° 73.1° 67.7° 62.5° 57.5° 52.8° 48.4° 44.3° 40.4° 36.8°
R (m)
z (m)
η θ°
1.2 33.5°
1.3 30.5°
1.4 27.7°
1.5 25.2°
1.6 22.8°
1.7 20.7°
1.8 18.8°
1.9 17.0°
2.0 15.4°
2.1 14.0°
2.2 12.6°
2.3 11.5°
2.4 10.4°
2.5 9.4°
3.0 5.7°
4.0 2.1°
5.0 0.77°
DTs
CSCs
RPCs
GEMs
iRPCs
MB4
MB3
MB2
MB1
RB4
RB3
RB2
RB1
Wheel 0
Wheel 1
Wheel 2
Solenoid magnet
HCAL
ECAL
Silicon tracker
Steel
ME1/3
RE1/3
ME1/2
RE1/2
GE1/1
ME1/1
RE2/3
RE2/2
GE2/1
ME2/2
ME2/1
ME3/2
ME3/1
RE3/3
RE3/2
RE3/1
ME4/2
ME4/1
RE4/3
RE4/2
RE4/1

Offline Analysis

from J. Eysermans

Clusterization (algo)

Algorithm for clusterization (both muon/gamma), per event level:

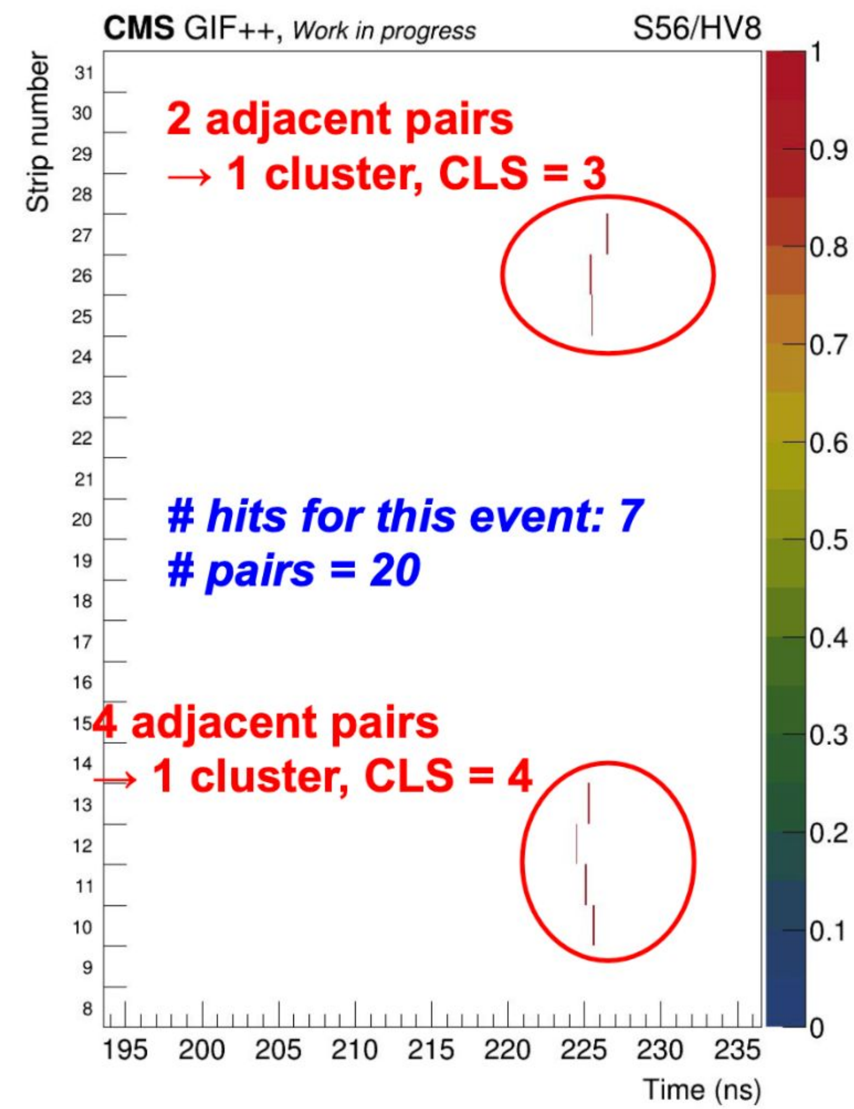
- for each event, loop over the hits which are in the appropriate time window
- make pairs of hits if the following conditions are satisfied:
  1) the corresponding strips must be adjacent
  2) the time between two hits cannot exceed ΔT ns (next slide)
- group the pairs into clusters which are spatially adjacent; the non-paired hits are added as single clusters (singlets)
  - No correction for dead strips → cluster "breaks"

→ the **cluster multiplicity** is the amount clusters (as groups of pairs or singlets)

→ the (mean) **cluster size** is the average size of all formed clusters (including singlets)

→ more precise timing, better clusterization!

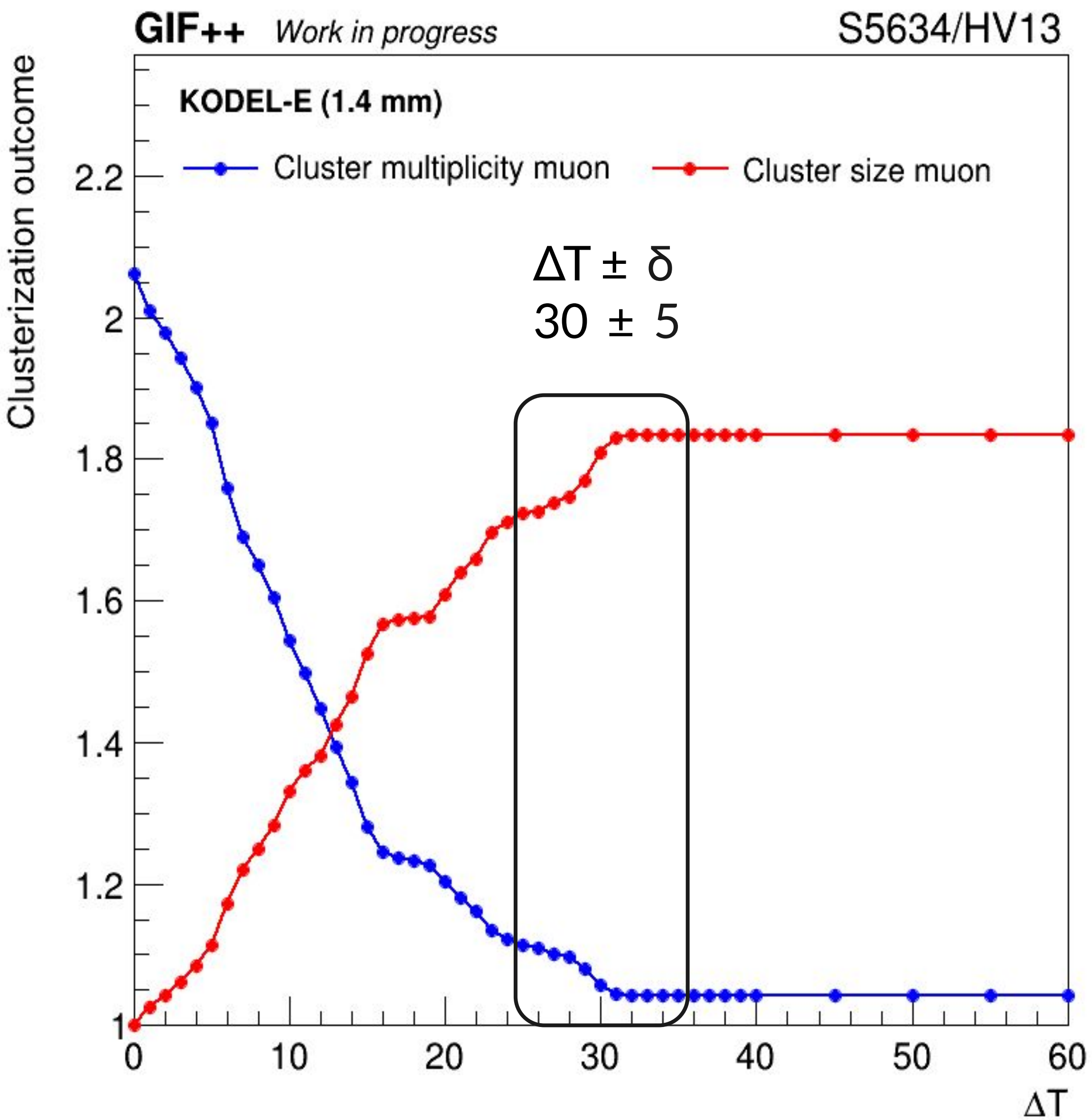
→ for muon clusterization: fine-tune algorithm with source OFF or even cosmics, target a multiplicity of 1!



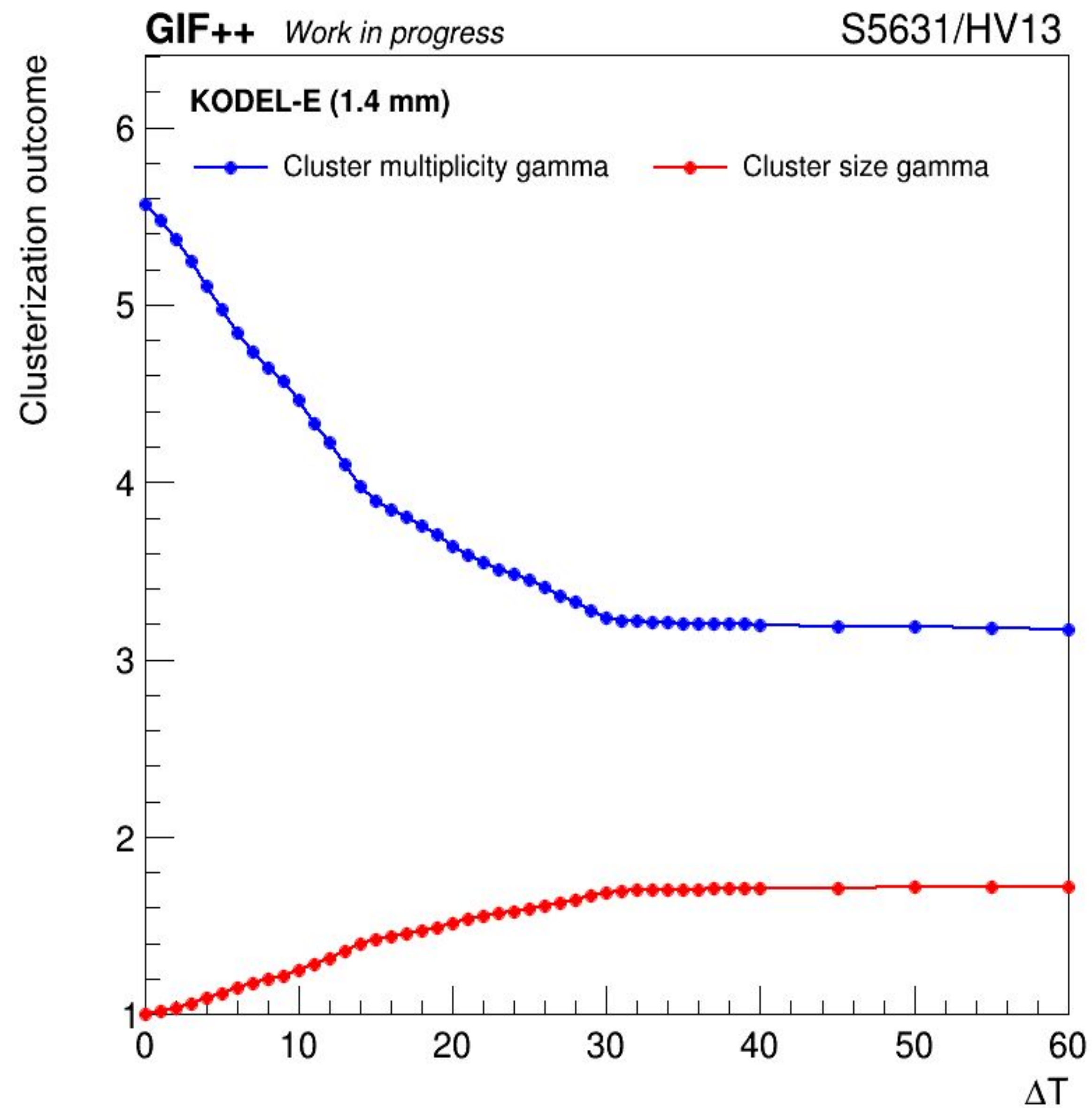
muon time window

Offline Analysis

Source OFF



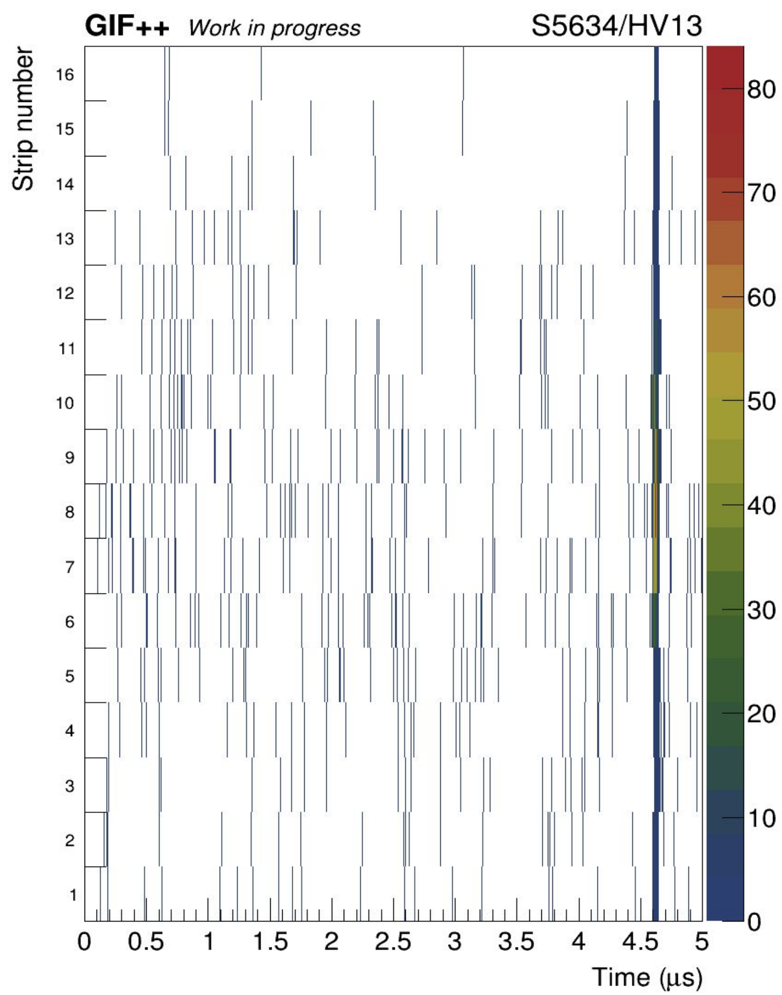
Source 10

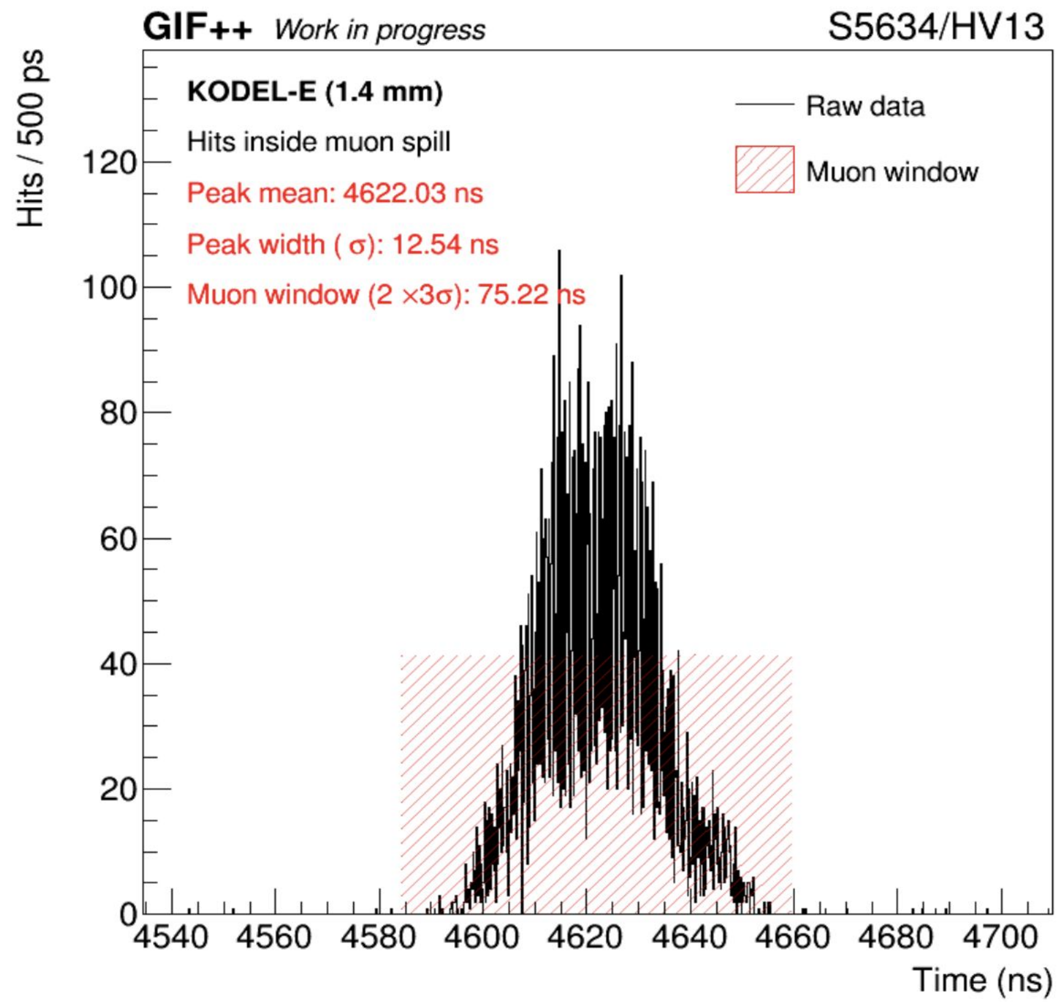


Offline Analysis

Standard mixture @ WP: no background

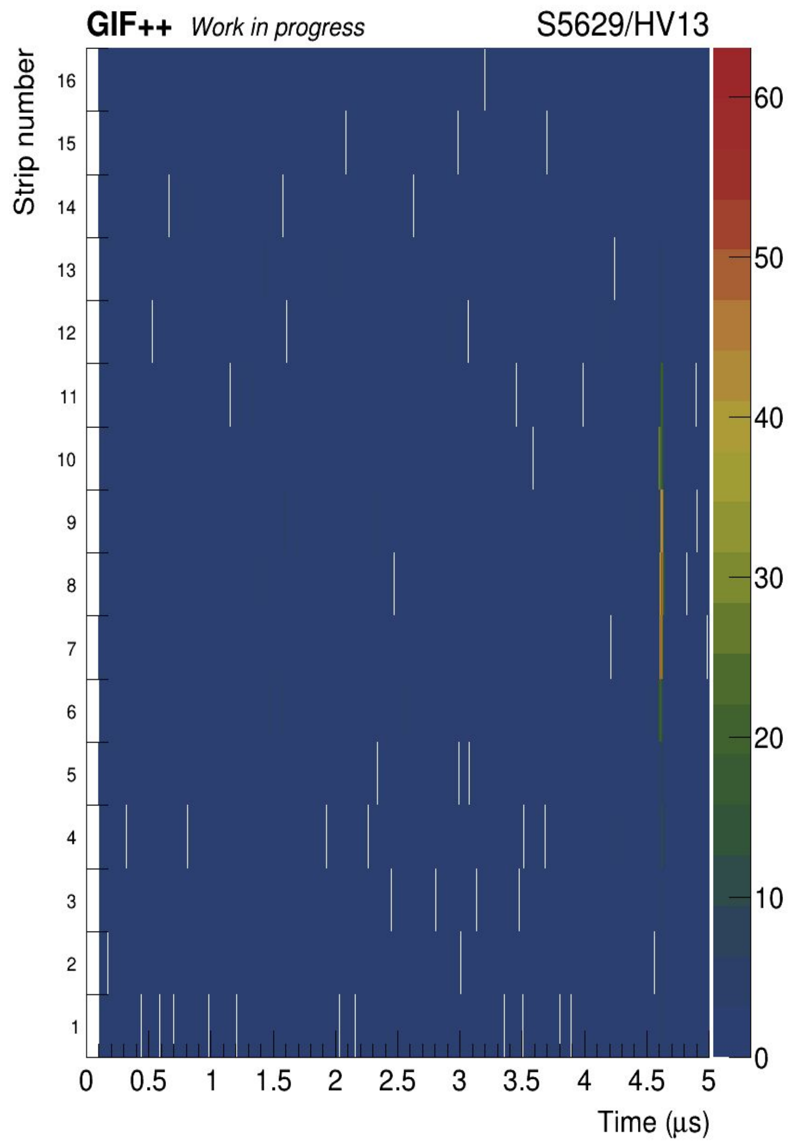
$$Eff(\mu) = \frac{\text{N clusters inside muon window}}{\text{N triggers}}$$

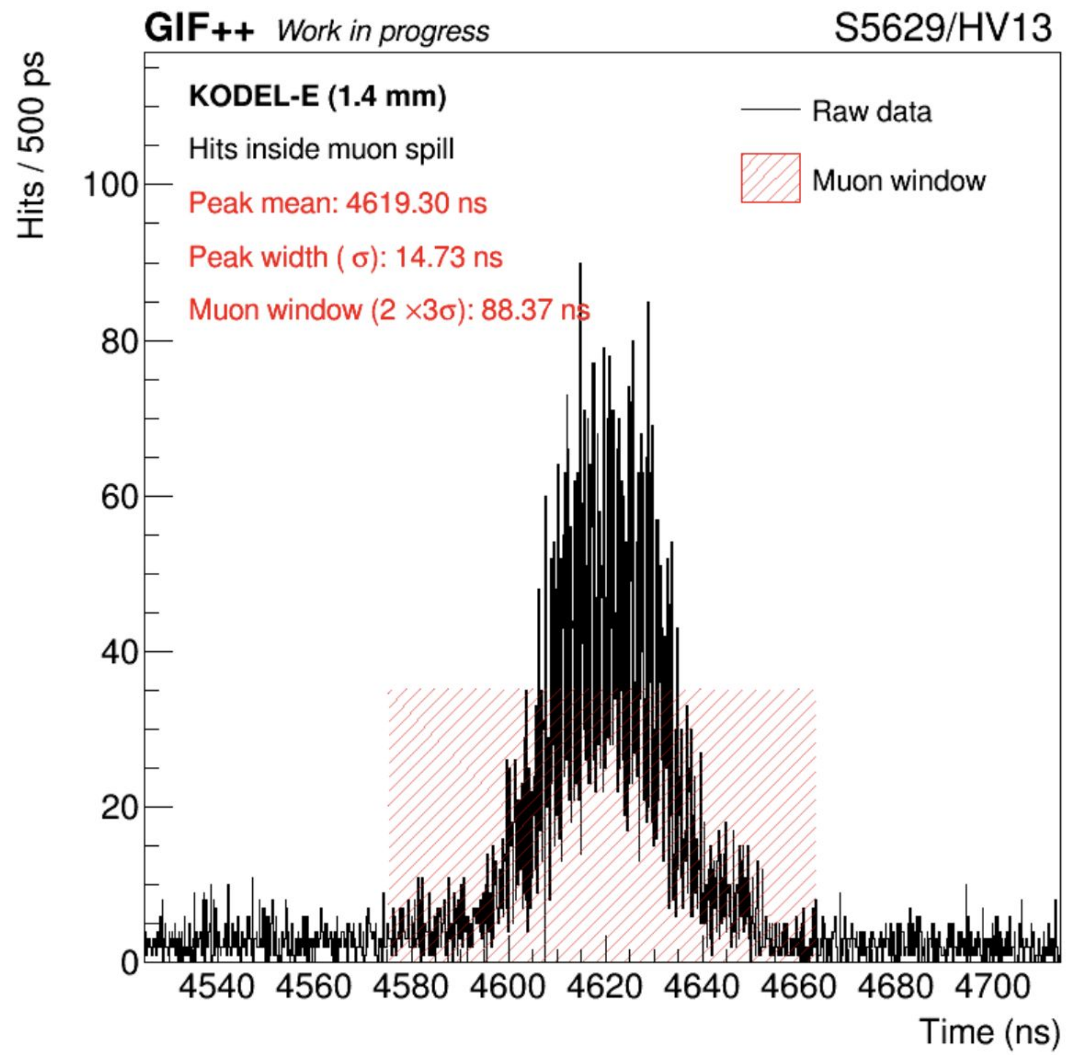




Offline Analysis

Standard mixture @ WP: ~0.9kHz/cm2





$$P_{tot} = P_\mu + P_\gamma - P_\mu \times P_\gamma$$

$$P_\mu = \frac{P_{tot} - P_\gamma}{1 - P_\gamma}$$

Offline Analysis

$$\epsilon = \frac{\epsilon_{max}}{1 + e^{-\lambda(HV_{eff} - HV_{50\%})}}$$