

# Results of long-term ageing tests on Eco-Friendly Resistive Plate Chamber detectors

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EP-DT  
Detector Technologies



13th Beam Telescopes and Test Beams Workshop



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# Outline



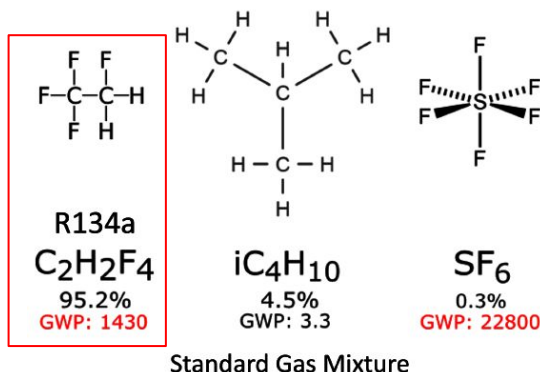
- Greenhouse gases emission at CERN
- Resistive Plate Chambers: introduction and operating principles;
- ECOGAS@GIF++ collaboration: Goal and Study methodology;
- Gas mixture selection;
- Ageing campaign;
- Test beam performance evaluation;
- Conclusion.



# Greenhouse gas emissions at CERN

## RPCs dominate CERN GHG emissions:

- Large area (5000 m<sup>2</sup>/experiment);
- Large volume (15 m<sup>3</sup>/experiment);
- Gas leaks at detector levels;
- High GWP mixture:

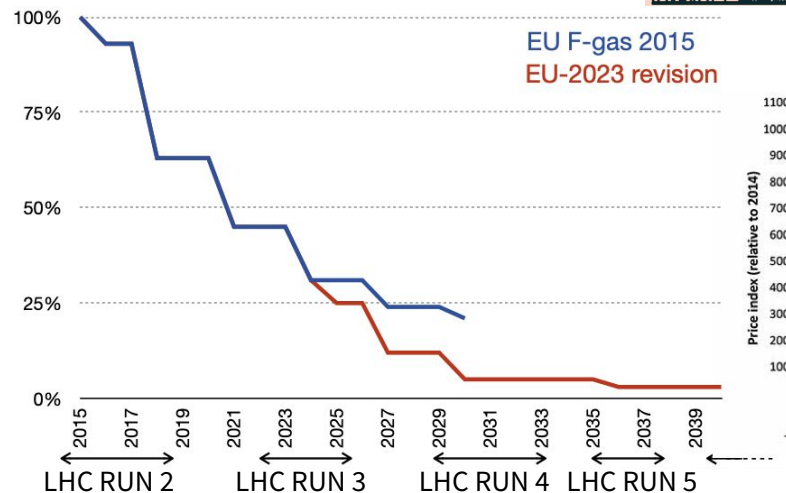


## EU fluorinated gases regulation (2024) [1]

- reducing products availability of fluorinated GHGs;
- this regulation already affected the fluorinated gases prices.

## CERN environmental report [2]

Reduce GHG emission by 28% by the end of LHC RUN3.



Among the GHG reduction strategies is the search for eco-friendly gas alternatives:

- Partial substitution to R134a:
  - > CO<sub>2</sub>-based gas mixture;
- Complete substitution of R134a:
  - > **RPC ECOgas@GIF++ Collaboration.**

The **goal** of this work is to find a non-toxic, non-flammable, eco-friendly gas mixture compatible with the current LHC RPC systems (HV supply, FEB electronics, gas systems...) and ensure good detectors performance.



# HPL Resistive Plate Chamber detectors

## Structure:

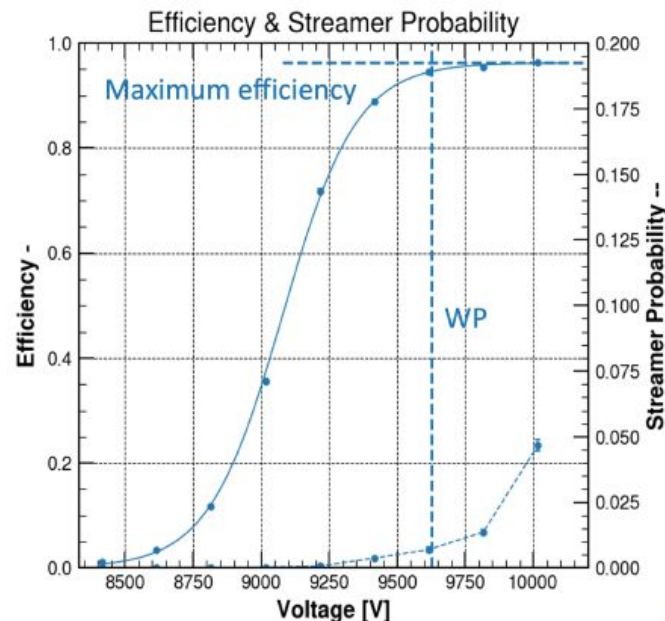
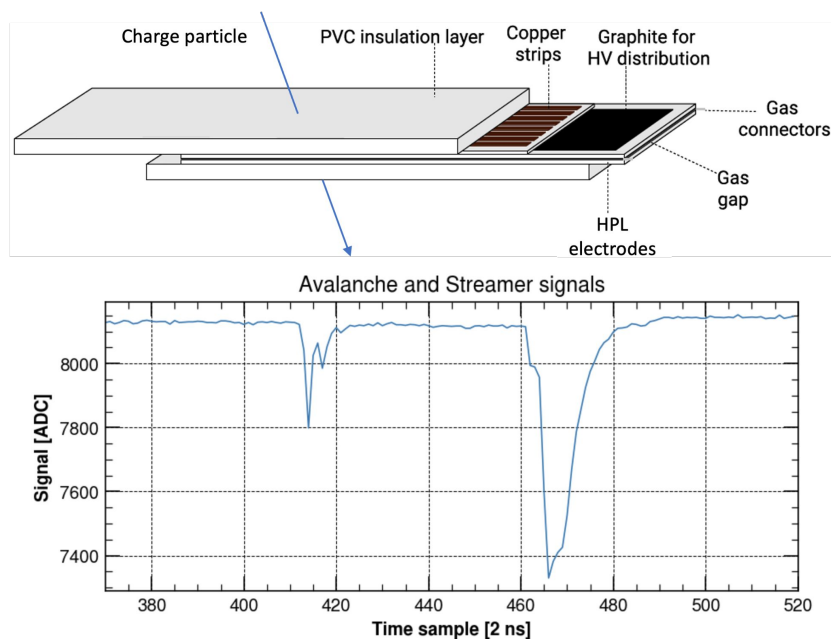
- Planar resistive electrodes made of HPL;
- Electrodes separated by spacers;
- Gas gap between the electrodes filled with gas mixture;
- Copper strips for signal readout.

## Operating principle:

- High voltage applied to the electrodes;
- Gas ionization inside the gap;
- Charge multiplication;
- Charge induction on readout strips.

## Foremost parameters:

- Detector currents;
- Prompt charge;
- Efficiency;
- Working point: voltage where the efficiency reach 95% of its maximal values, plus 150 V.

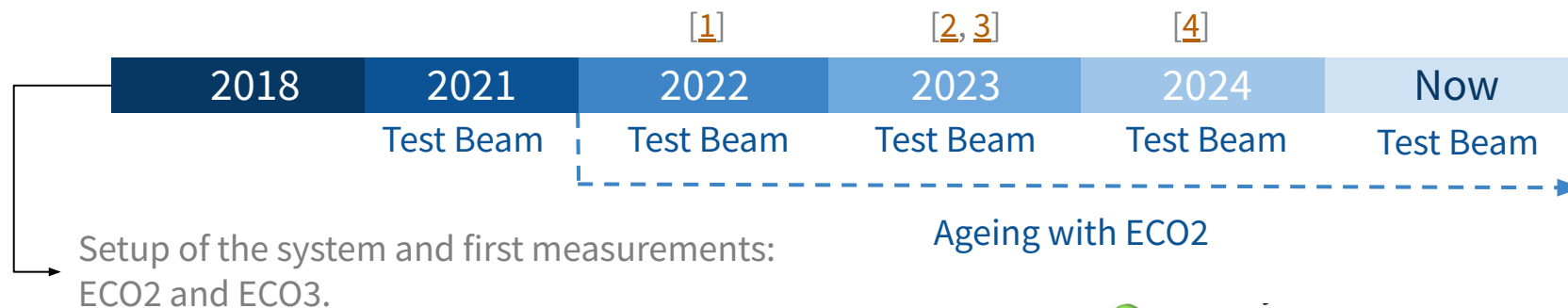




# RPC ECOgas@GIF++ Collaboration

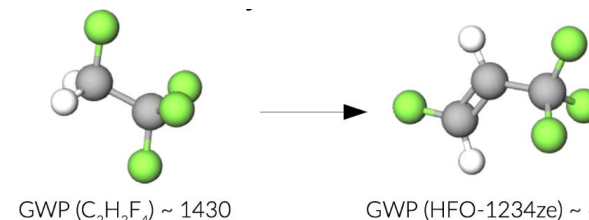
The collaboration focus on find a **complete alternative to R134a**

**Cross-experiment collaboration:** CMS, ALICE, ATLAS, SHiP/LHCb and EP-DT group of CERN.



from R134a to **Hydro-Fluoro-Olefin** (HFO) family of gases:

- Similar chemical structure as R134a but lower GWP;
- Among all HFOs, HFO-1234ze selected (not toxic, not flammable).



1:1 replacement of R134a with HFO not possible:

- WP moved over 15 kV due to the lower Townsend coefficient;
- HFO +  $CO_2$  found to be the most promising candidate.

Mixture	R134a [%]	HFO [%]	$CO_2$ [%]	$iC_4H_{10}$ [%]	$SF_6$ [%]	GWP
STD	95.2	-	-	4.5	0.3	1485
ECO2	-	35	60	4	1	482
ECO3	-	25	69	5	1	529



# RPC ECOgas@GIF++ Collaboration

Each group provided an RPC prototype to be tested with eco-friendly gas mixtures:  
 -> installed on two setups, one at 3, from the source and one at 6m.

Different detector layouts and front end electronics:

-> Disentangle the effect of specific design, production technique or electronic used.

Group	Area [cm <sup>2</sup> ]	# of gaps	Gap/electrodes Thickness [mm]	Readout	# of strips
ATLAS	500	1	2/1.8	Digitizer	1
CMS	4350	2	2/2	TDC	128
CMS Upgrade	7000	2	1.4/1.4	TDC	32
EP-DT	7000	1	2/2	Digitizer**	7
ALICE	2500	1	2/2	TDC/Digitizer*	16 + 16 (x,y)
SHiP/LHCb	7000	1	1.6/1.6	TDC	32 + 32 (x,y)

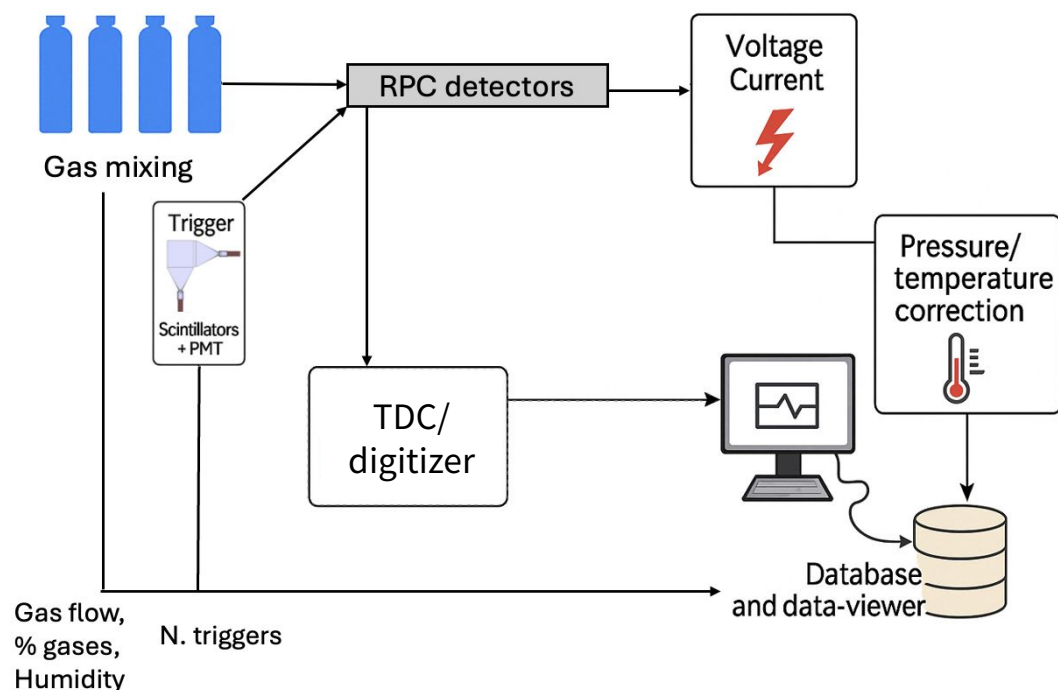
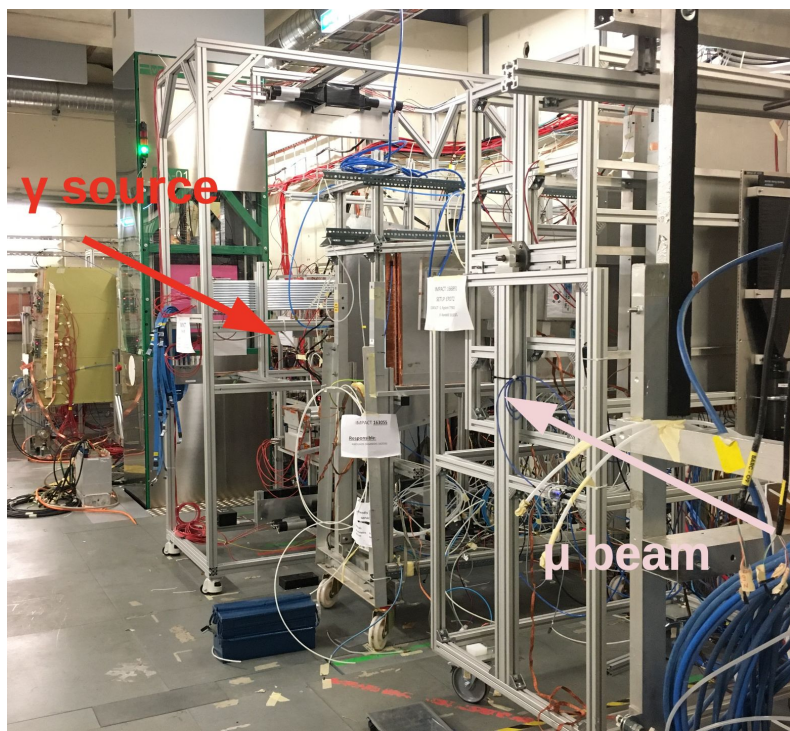
\*7 y strips read with CAEN Digitizer DT5742, 12-bit at 1-5 Gs/S,  $V_{pp} = 1$  V

\*\*CAEN Digitizer v1730, 14-bit at 500 Ms/s,  $V_{pp} = 1$  V



# RPC ECOgas@GIF++ Collaboration

- Studies carried out at the **CERN Gamma Irradiation Facility (GIF++)**:
  - 12 TBq  $^{137}\text{Cs}$  source to emulate the background irradiation of the LHC experiments. Irradiation can be modulated by means of attenuation filters;
  - High energy (100 GeV/c) muon beam in dedicated beam time period.

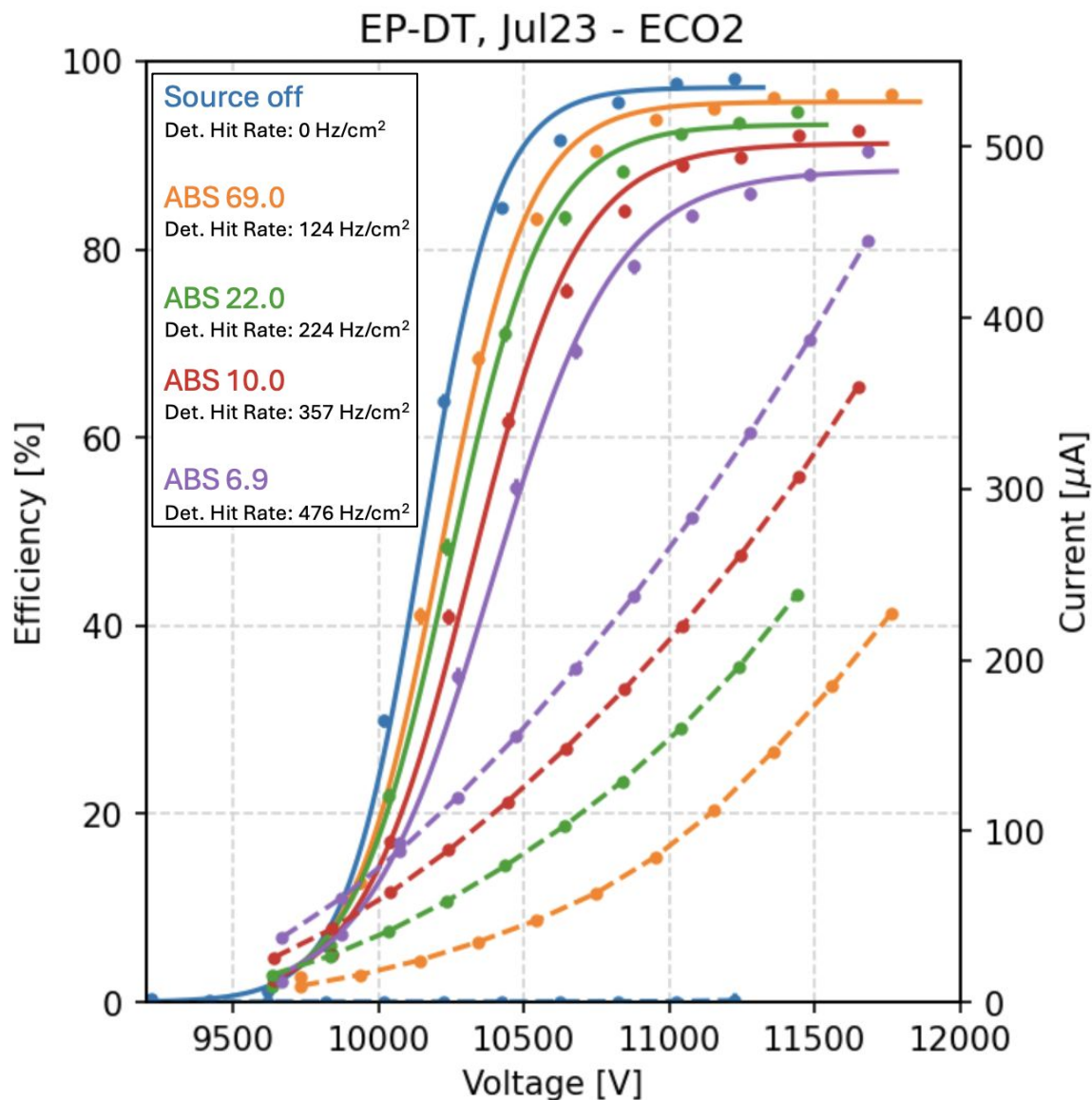




# Gas mixture selection

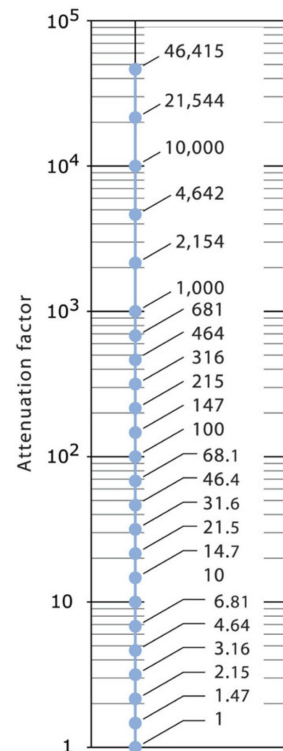


# Gas mixture selection: data taking



Example of TB data acquisition:

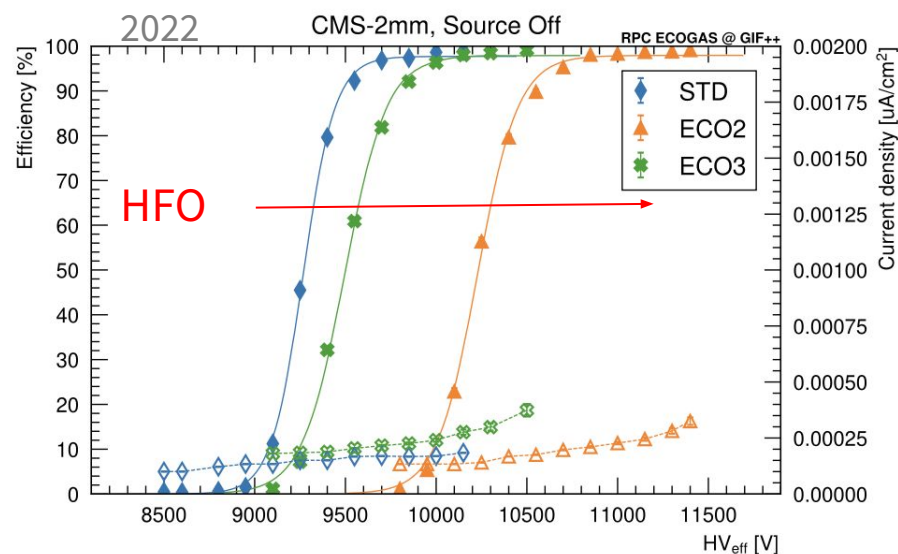
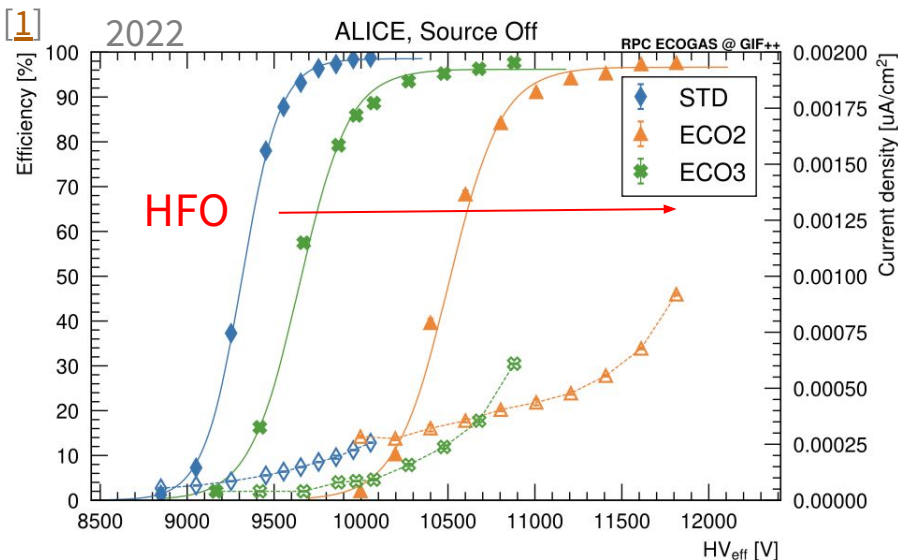
- Several source filter tested: **detector hit rate**, for the EP-DT RPC, from 0 up to ~500 Hz/cm<sup>2</sup>.



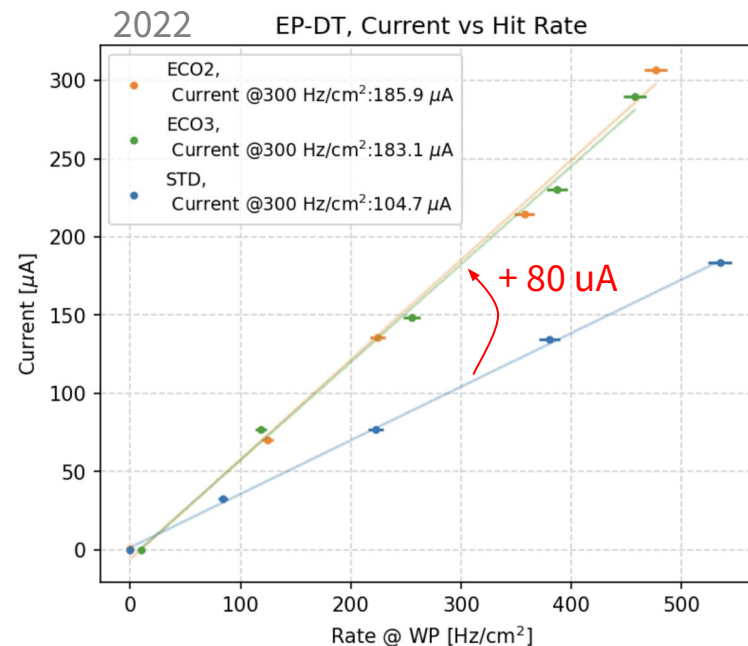
Possible source  
attenuation factor  
(ABS)



# Gas mixture selection



- Reached efficiency  $> 95\%$ , all detectors;
- HFO increase  $\rightarrow$  WP increase, wrt STD:
  - ECO2:  $+ 650\text{-}700$  V/mm;
  - ECO3:  $+ 200\text{-}280$  V/mm;
- Similar currents between ECO2 and ECO3:  
 $\rightarrow$  **Selected ECO2 for long-term study.**

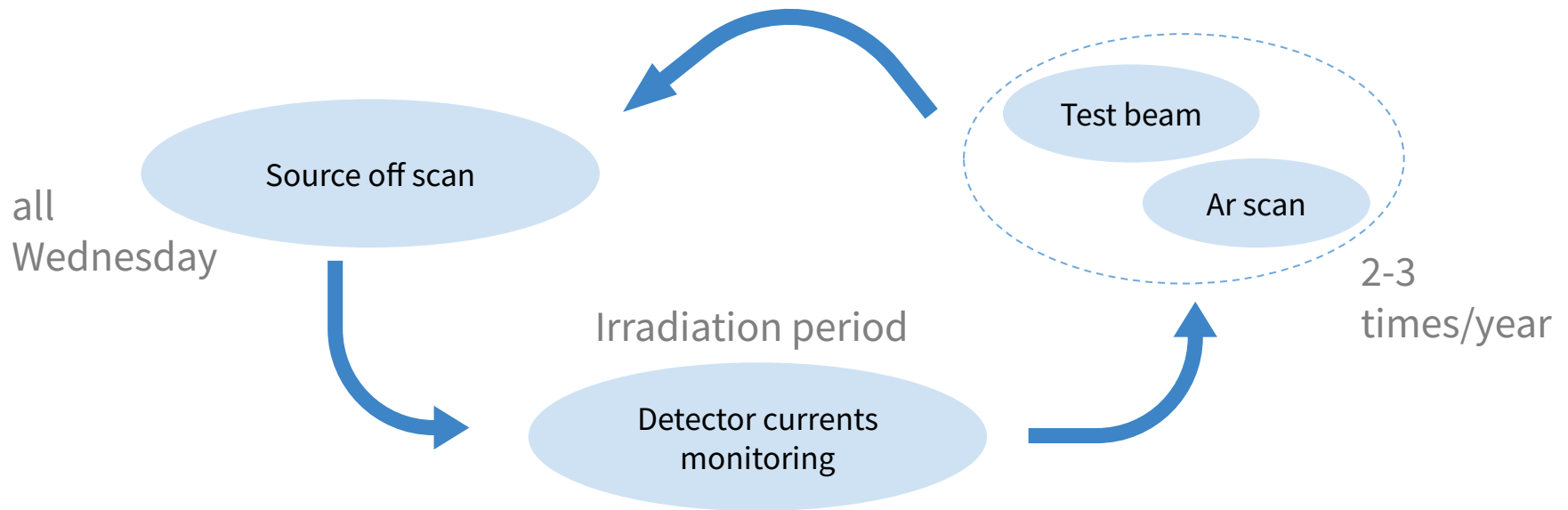




# Ageing campaign: weekly scan



# ECOGAS@GIF++ Collaboration



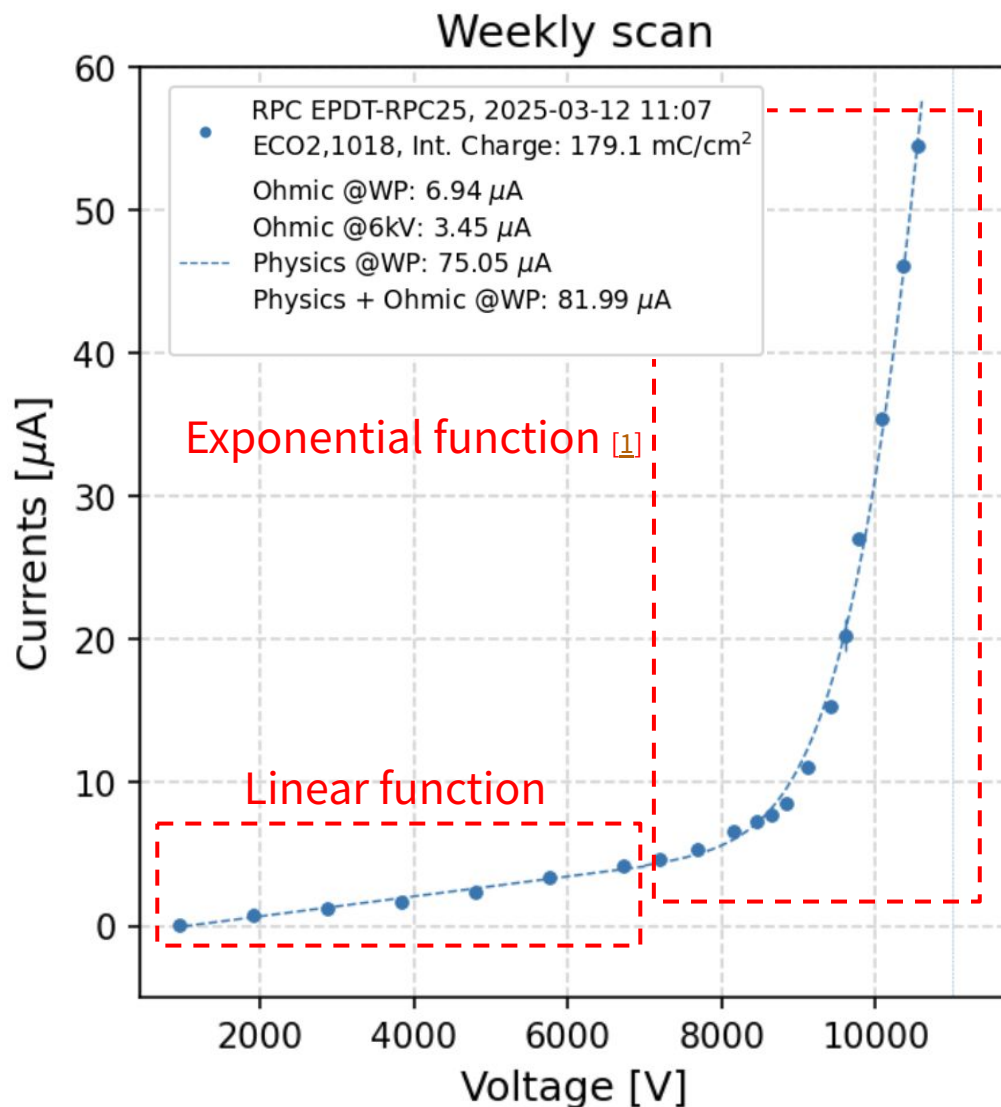
- **Stability Monitoring**: Detector HV on at fixed values during the week
- **T/P correction** every minute:

$$HV_{app} = HV_{eff} \left[ (1 - \alpha) + \frac{PT_0}{P_0T} \right]$$

- **Source off scans** are performed every Wednesday for dark current monitoring.



# Ageing campaign: weekly scan



Weekly scan to evaluate:

- Ohmic dark current @ 6 kV and @ WP;
- Physic current @ WP;

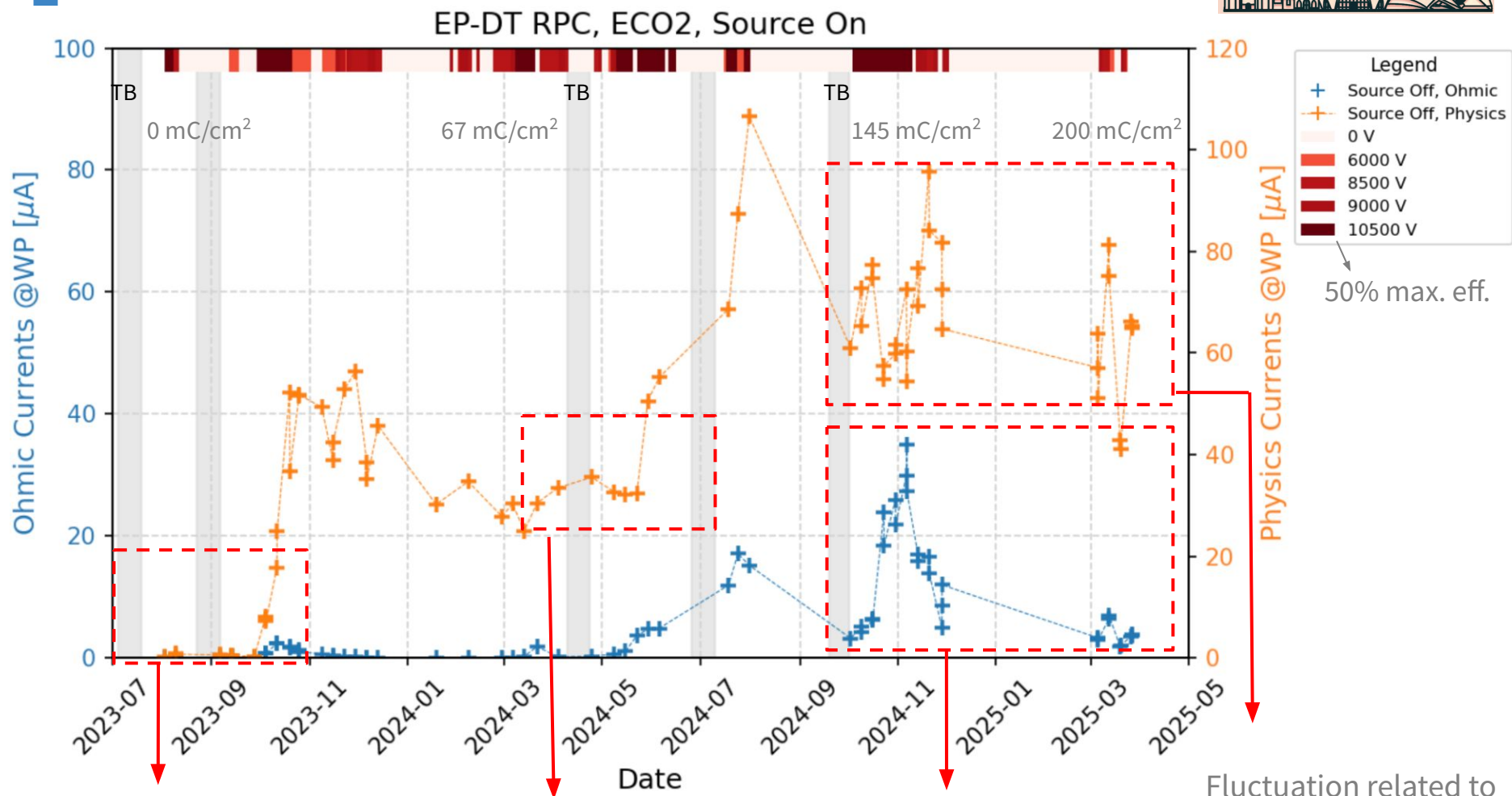
the values obtained are then considered as a function of the integrated charge.

During operation, the detector is not kept at working point, since the nominal attenuation filter of the source is too low:

-> we want to maintain the operation around 200-300 Hz/cm<sup>2</sup>.



# Ageing campaign: irradiation overview



Initial increase mainly due to detector's conditioning

Increase after 1 month of continuous irradiation

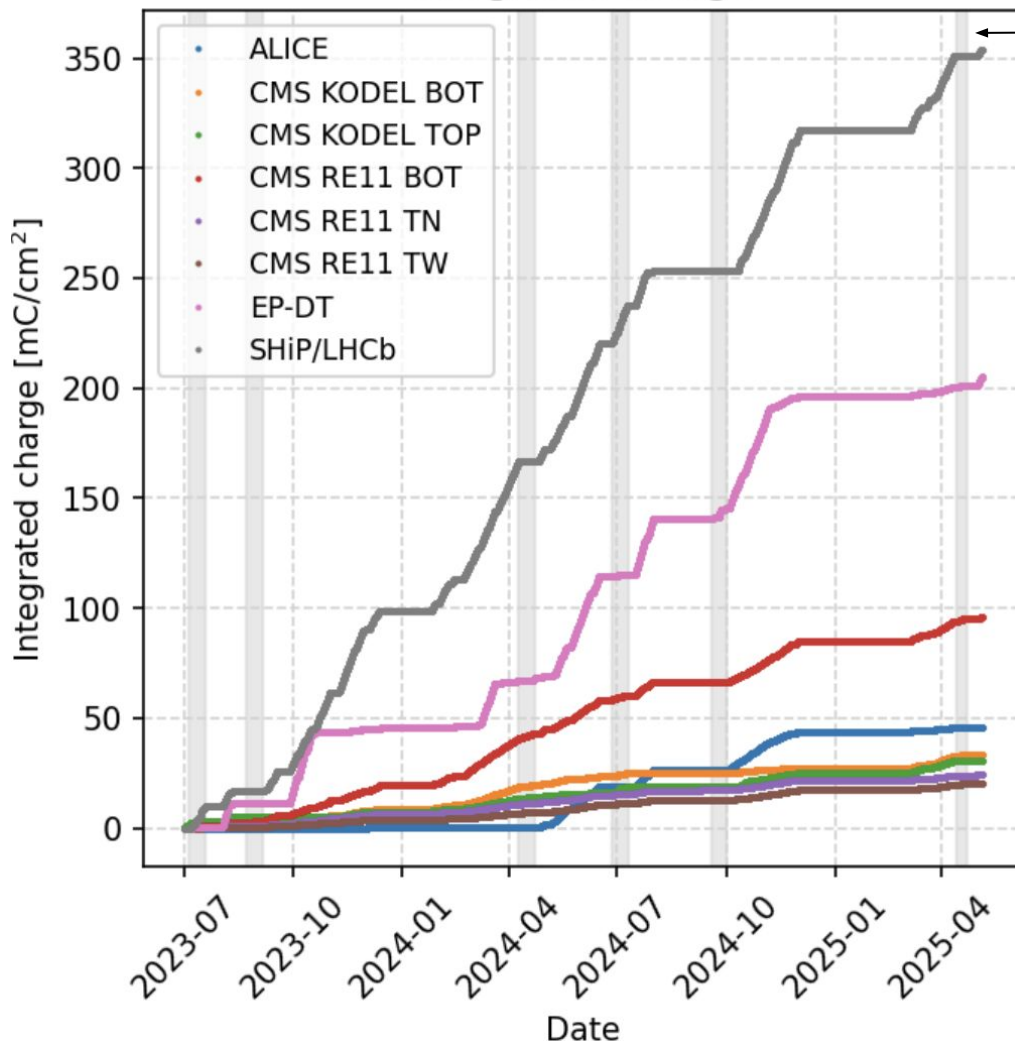
Recover of dark current after lowering HV

Fluctuation related to the HV status before the scan  
-> under investigation



# Ageing campaign: irradiation overview

Integrated charge



Test beam periods

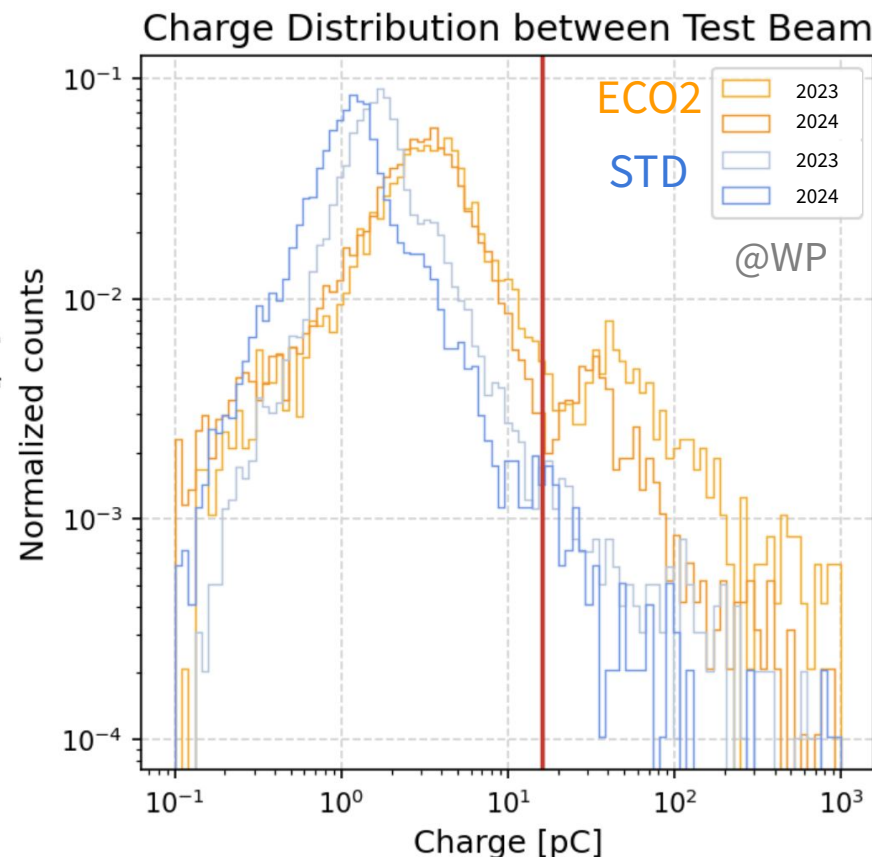
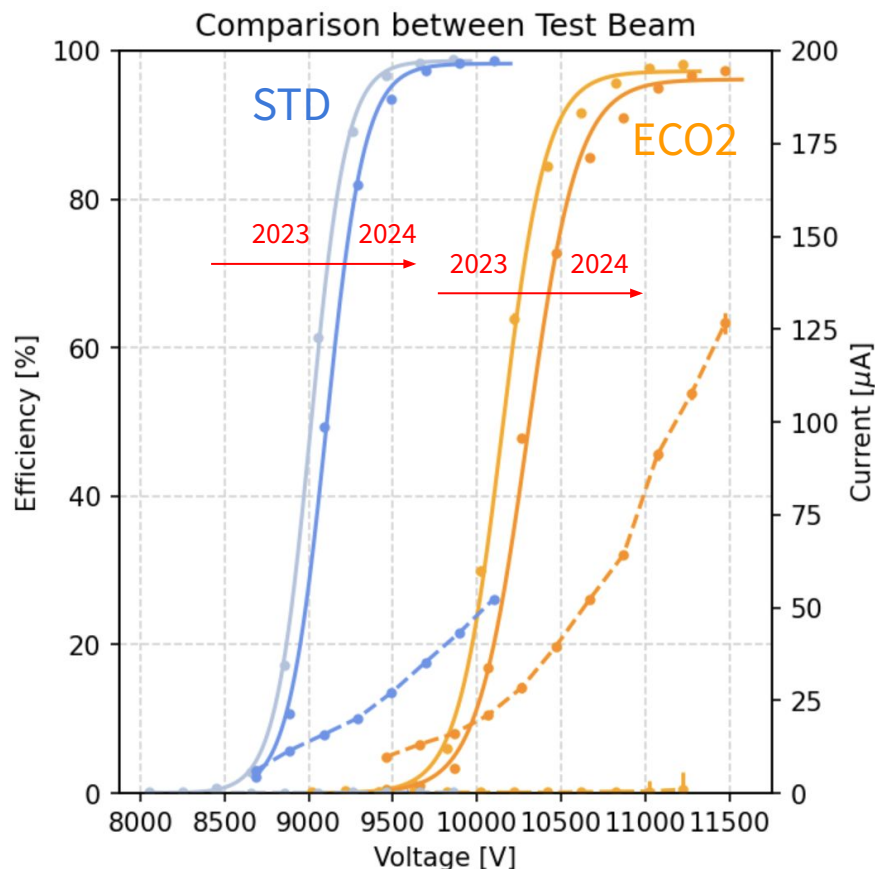
- Integrated charge different between the detector;
- Reached values between 25 and 350 mC/cm<sup>2</sup> in April 2025;



# Performance evaluation: Test Beam



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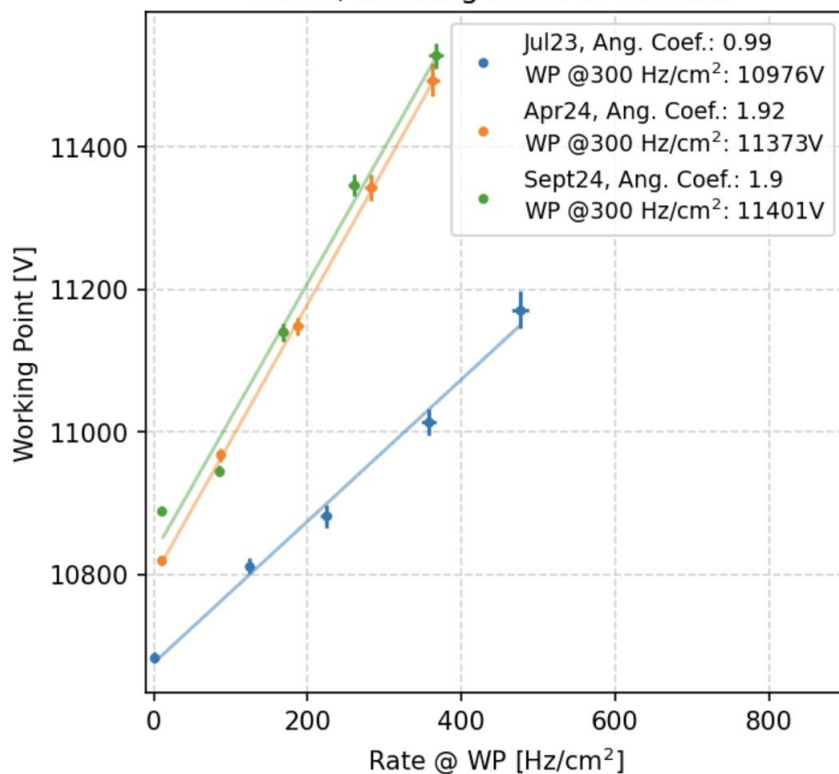


- Similar maximum efficiency reached after an integrated charge of  $145 \text{ mc/cm}^2$  ;
- Higher current values for both the gas mixture -> mainly related to detectors imperfection.

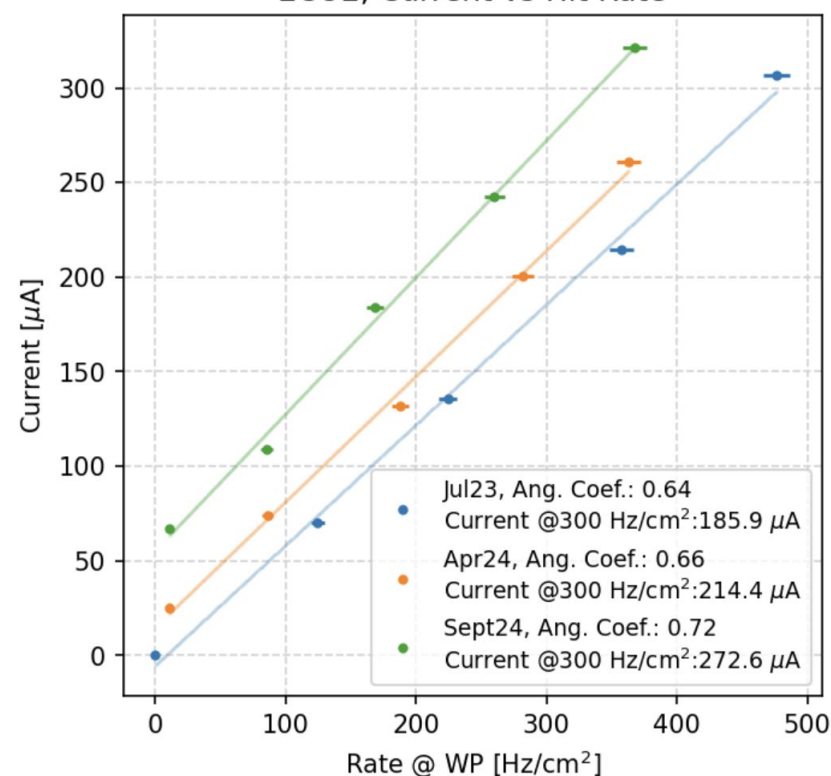


# Performance evaluation: Test Beam

ECO2, Working Point vs Hit Rate



ECO2, Current vs Hit Rate



- Increase in WP angular coefficient vs detector hit rate July 2023-April 2024:
  - > Stabilize after April 2023, likely linked to detector resistivity, under investigation;
- Current increases with time, visible also in the weekly scans:
  - > Current increases even at 0 Hz/cm<sup>2</sup>;
  - > Since the linear fit slope remains unchanged, this suggests a step increase due to detectors imperfections.



# Conclusion

- RPC ECOgas@GIF++ is performing ageing studies and periodic test beam on RPCs with **R134a fully replaced by CO<sub>2</sub> and HFO-1234ze**;
- The integrated charge reached is different between the collaboration detectors ranging from 25 to 350 mC/cm<sup>2</sup>;
- As a case study, after almost 2 year of irradiation, the EP-DT detector reached ~200 mC/cm<sup>2</sup> of integrated charge;
- **No significant performance degradation** observed within the test beams;
- Initial increase in the **working point**, likely due to detector resistivity followed by stable behavior across the test beam periods
- **Current** increases appear as step-like changes but follow a similar linear trend with the detector hit rate over the irradiation period. These steps are likely related to detector imperfection, more than issue with the gas mixture. This is also suggest by the similar charge distribution of the different Test Beams.
- The irradiation campaign is still ongoing and the data for the April 2025 Test Beam are under analysis.

# Backup



# Backup

Voltage Interval (V)

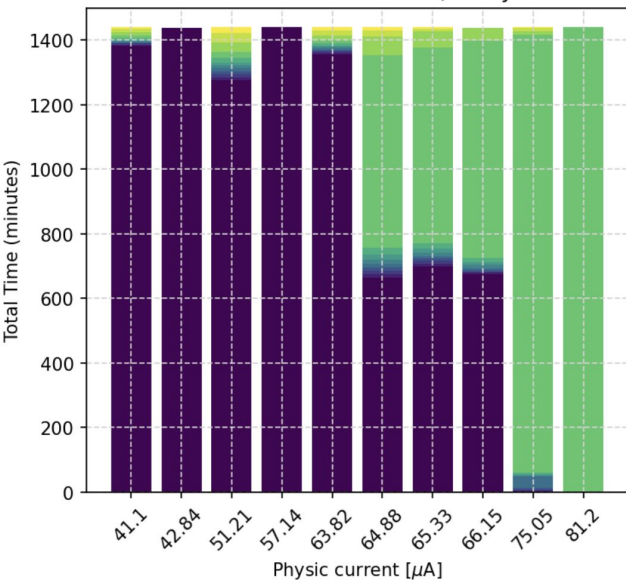
- 1000
- 2000
- 3000

- 4000
- 5000
- 6000
- 7000

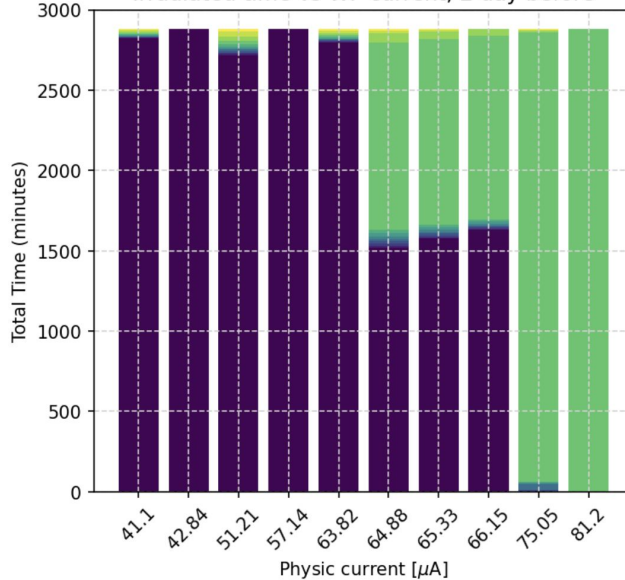
- 8000
- 9000
- 10000
- 11000
- 12000



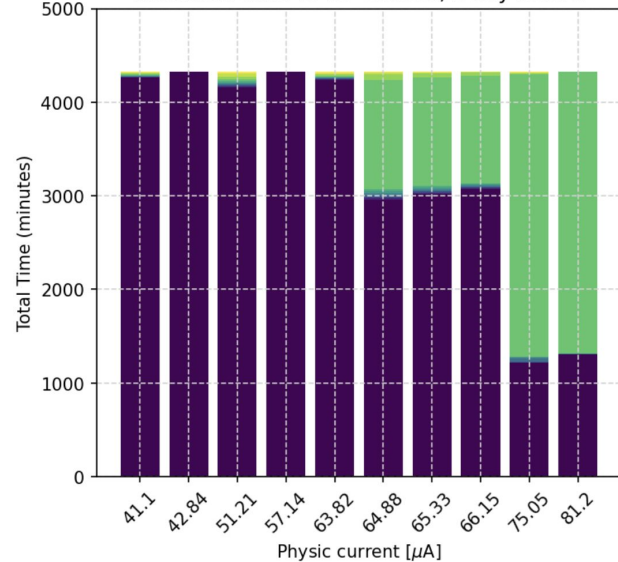
Irradiated time vs WP current, 1 day before



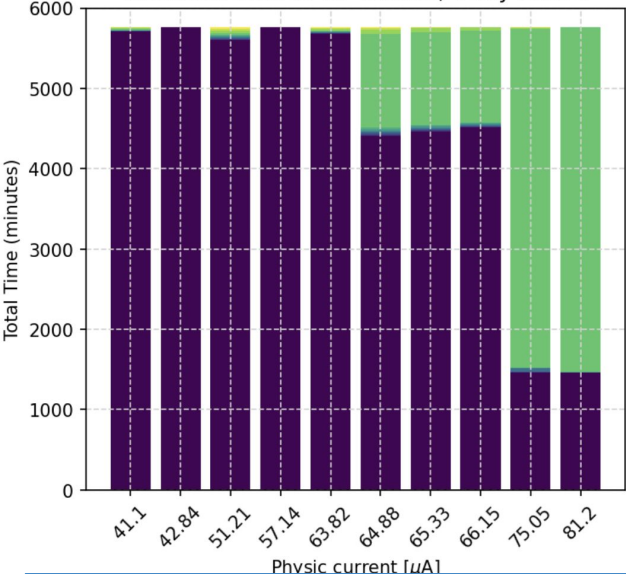
Irradiated time vs WP current, 2 day before



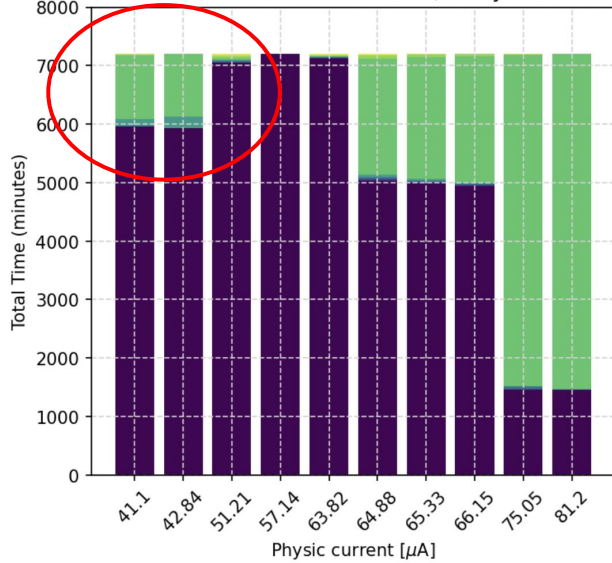
Irradiated time vs WP current, 3 day before



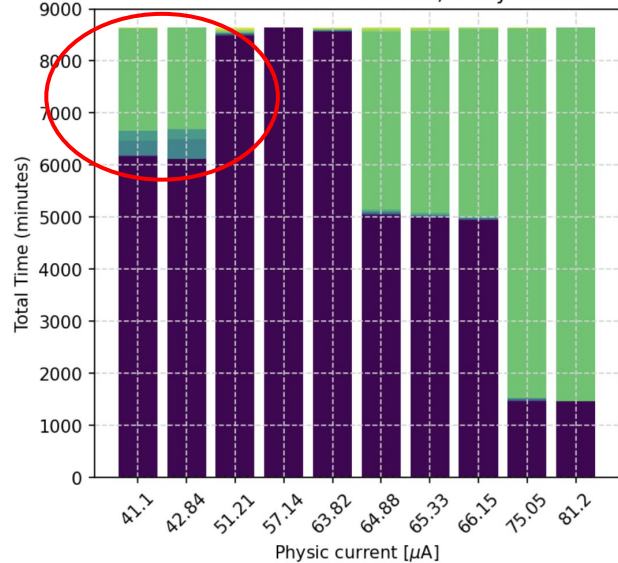
Irradiated time vs WP current, 4 day before



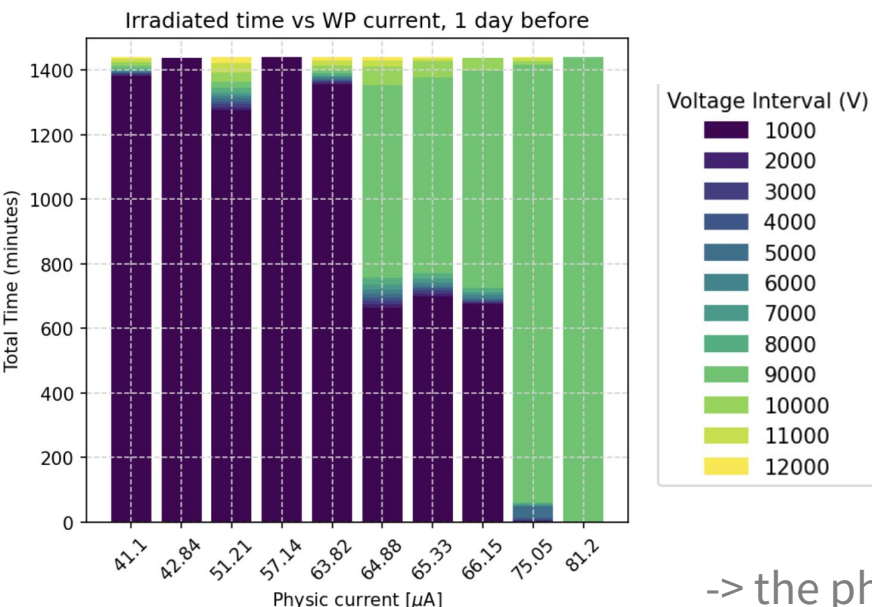
Irradiated time vs WP current, 5 day before



Irradiated time vs WP current, 6 day before

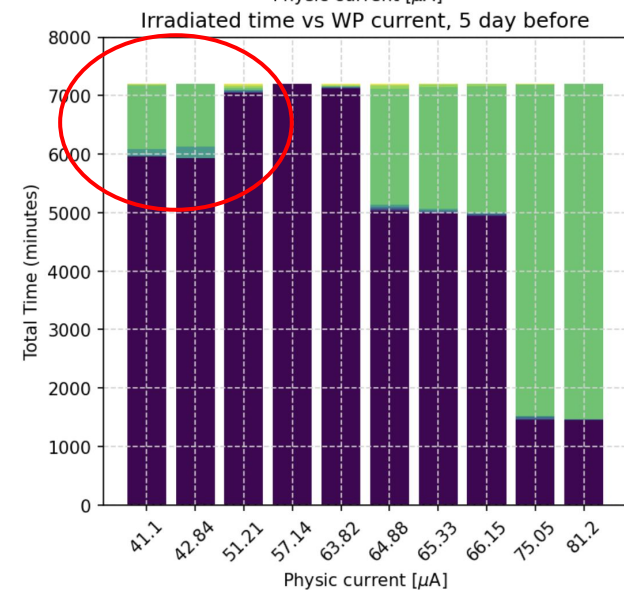


# Backup

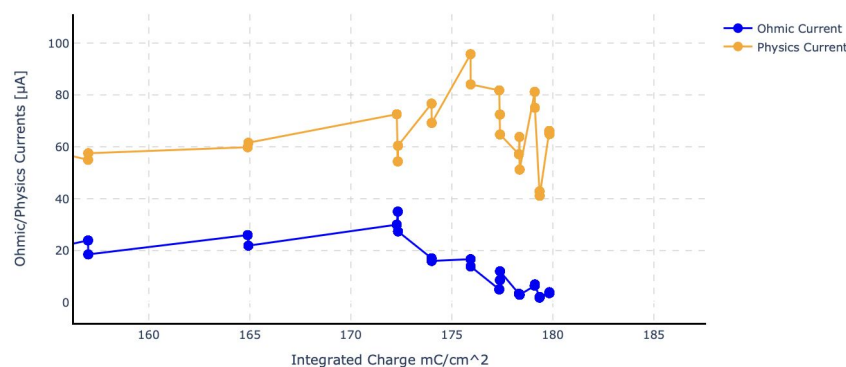


1. More the detector was kept on the day before, higher the current
2. This effect is stable if we consider the detector status up to 4 days before the scan
3. Before day 4, if the detector was kept on and then switched off for the day later, it manage to reduce the current before the scan.

-> the physical current is strongly influenced by the detector status at least the 4 days before the scan. To be confirmed by the other detectors



EPDT-RPC25, ECO2, Source Off



# Backup

