Politecnico di Bari

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Performance studies of green Resistive Plate Chamber detectors at the CERN Gamma Irradiation Facility

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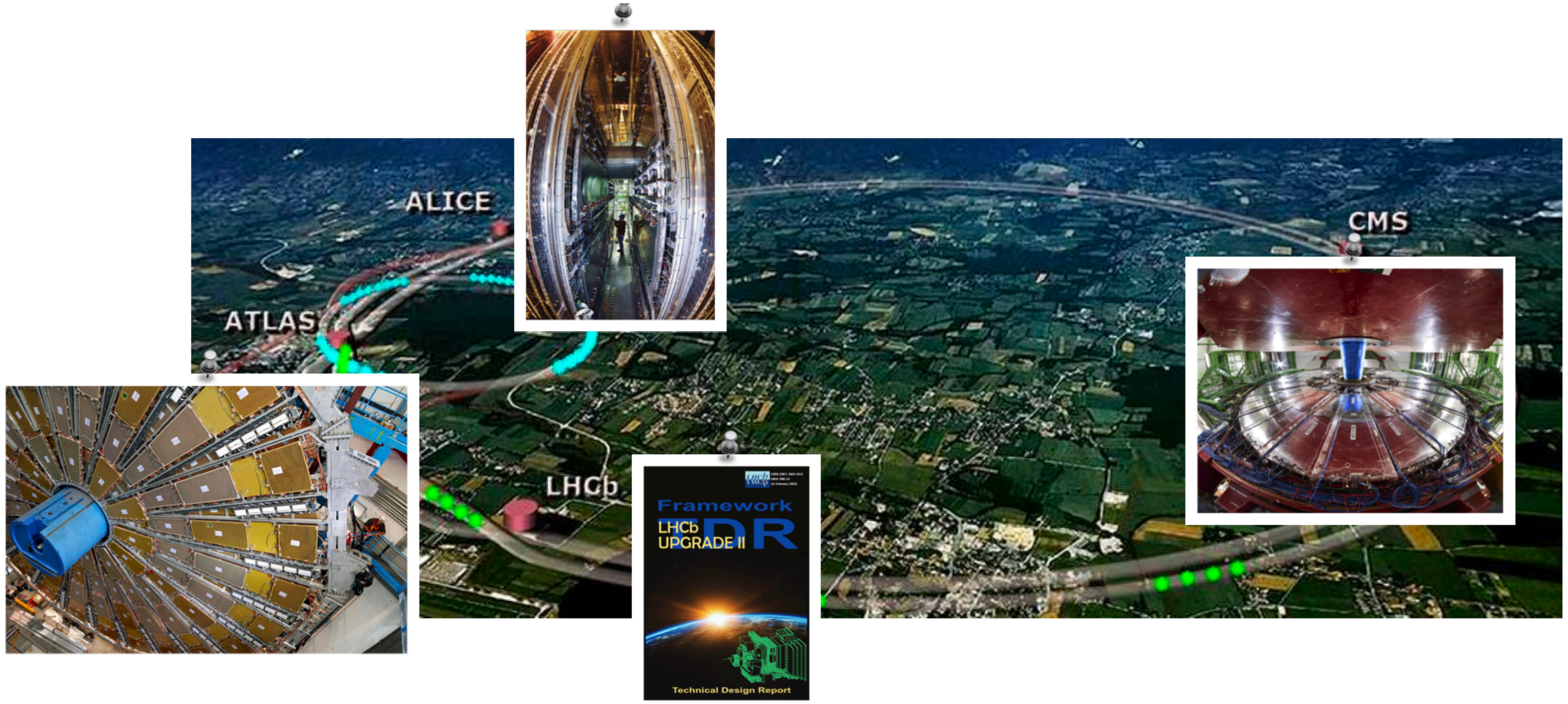
on behalf of the **RPC ECOgas@GIF++ collaboration**

RPCs in High Energy Physics experiments

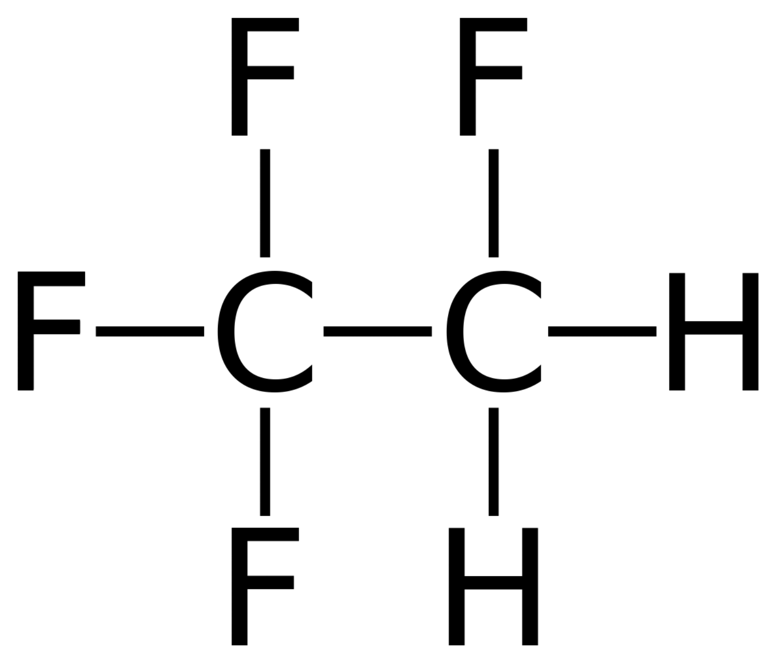
Resistive Plate Chambers:

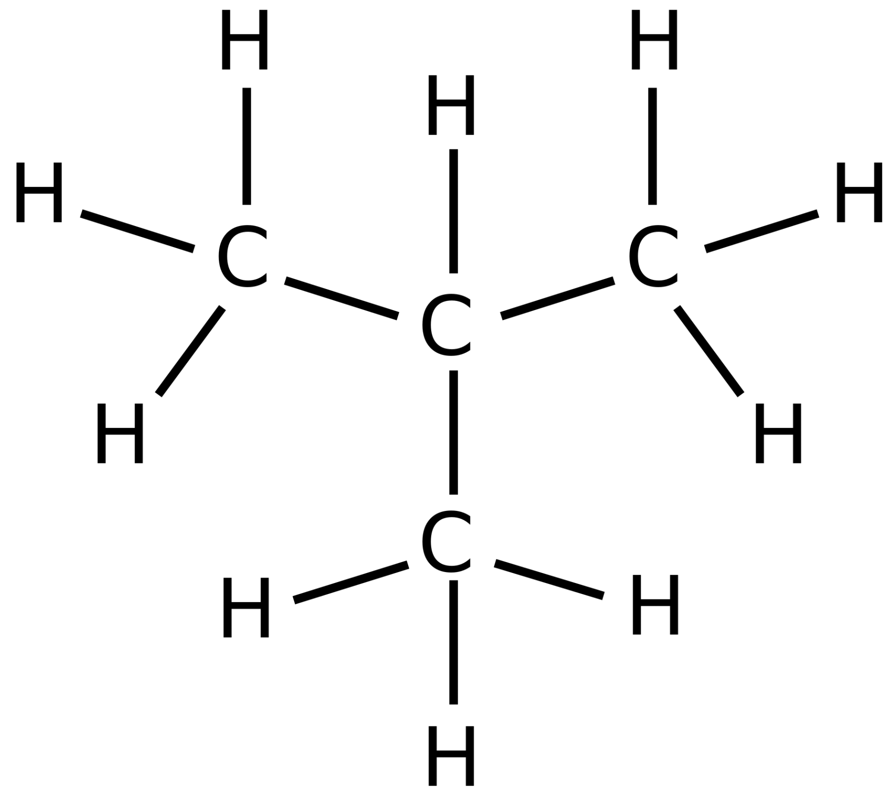
- **Gaseous detectors**
- **High efficiency** and **time resolution**
- **Relatively cheap**: allow to cover large areas
- Largely used for muon detection
- **Fast response**: used for triggering and identification purposes
- Widely employed in **High Energy Physics** experiments, operated with **tetrafluorethane (TFE) based mixtures**

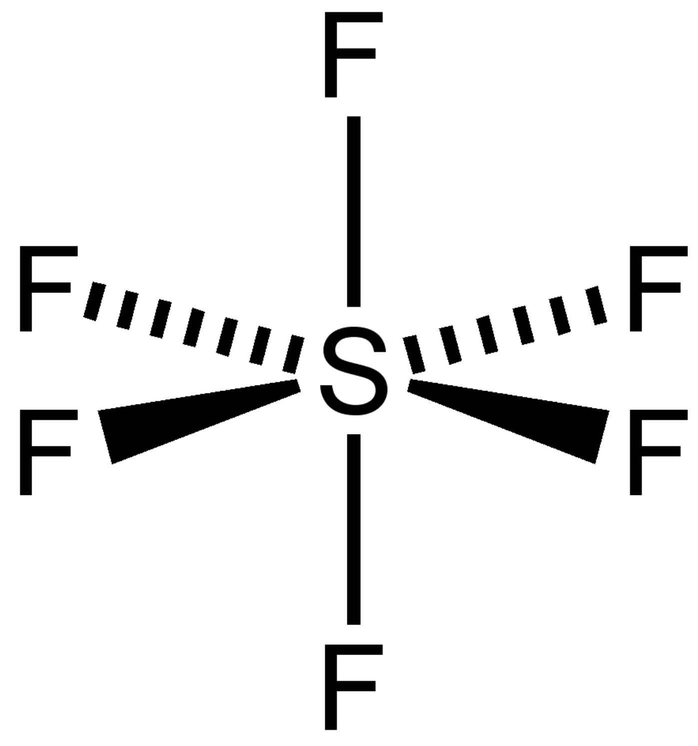


Standard gas mixture

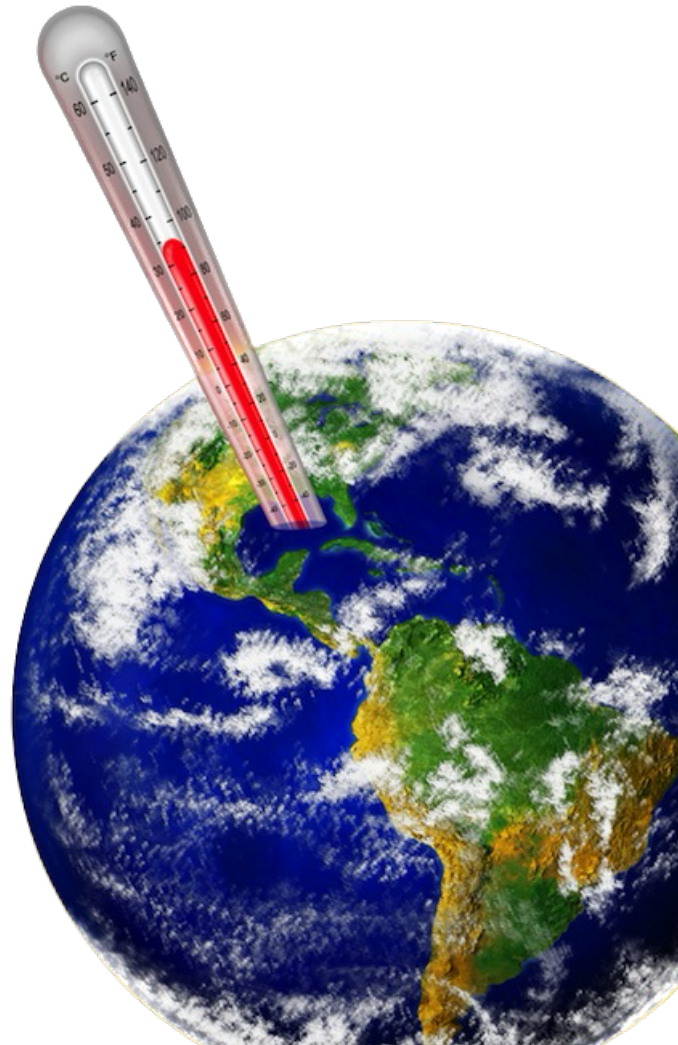
TFE ($C_2H_2F_4$) ~ 95% + iC_4H_{10} ~ 4-5% + SF_6 < 1%





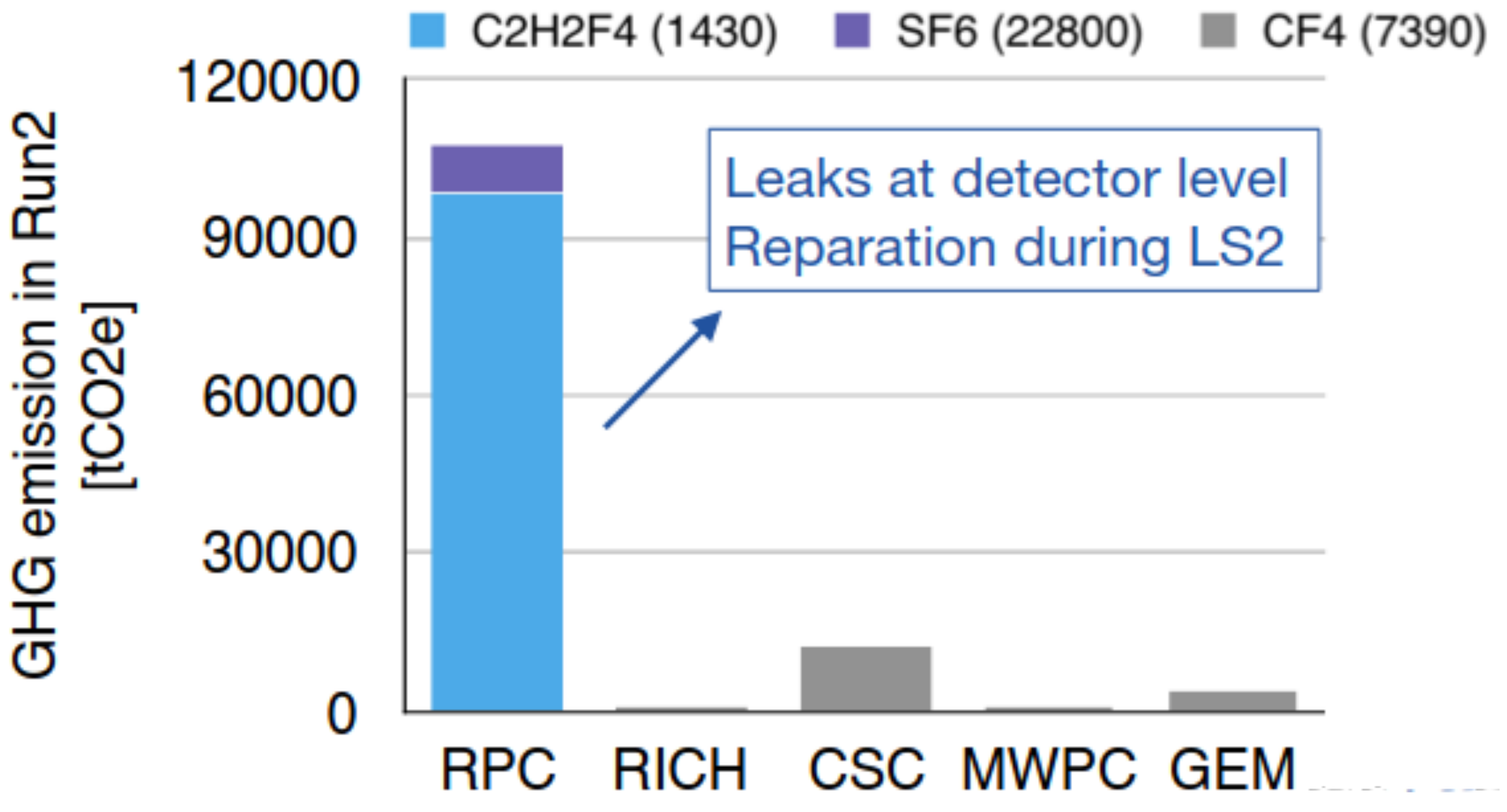


- **High density of primary ion-electrons pairs → high RPC efficiency**
- **Good quenching** properties and **electronegativity** → very **low streamer probability**
- $C_2H_2F_4$ and SF_6 are **fluorinated greenhouse gases** (F-gases) with high Global Warming Potential*:
  - GWP($C_2H_2F_4$) = 1430
  - GWP(SF_6) = 22800
  - GWP_{total} = 1485



* Global Warming Potential (GWP) measure greenhouse effect of gases if compared to CO_2: GWP(CO_2) = 1

GHG emissions @CERN and EU regulation



CERN GHG emissions from particle detectors

Main contributor is C2H2F4 used for ALICE, ATLAS and CMS RPC systems

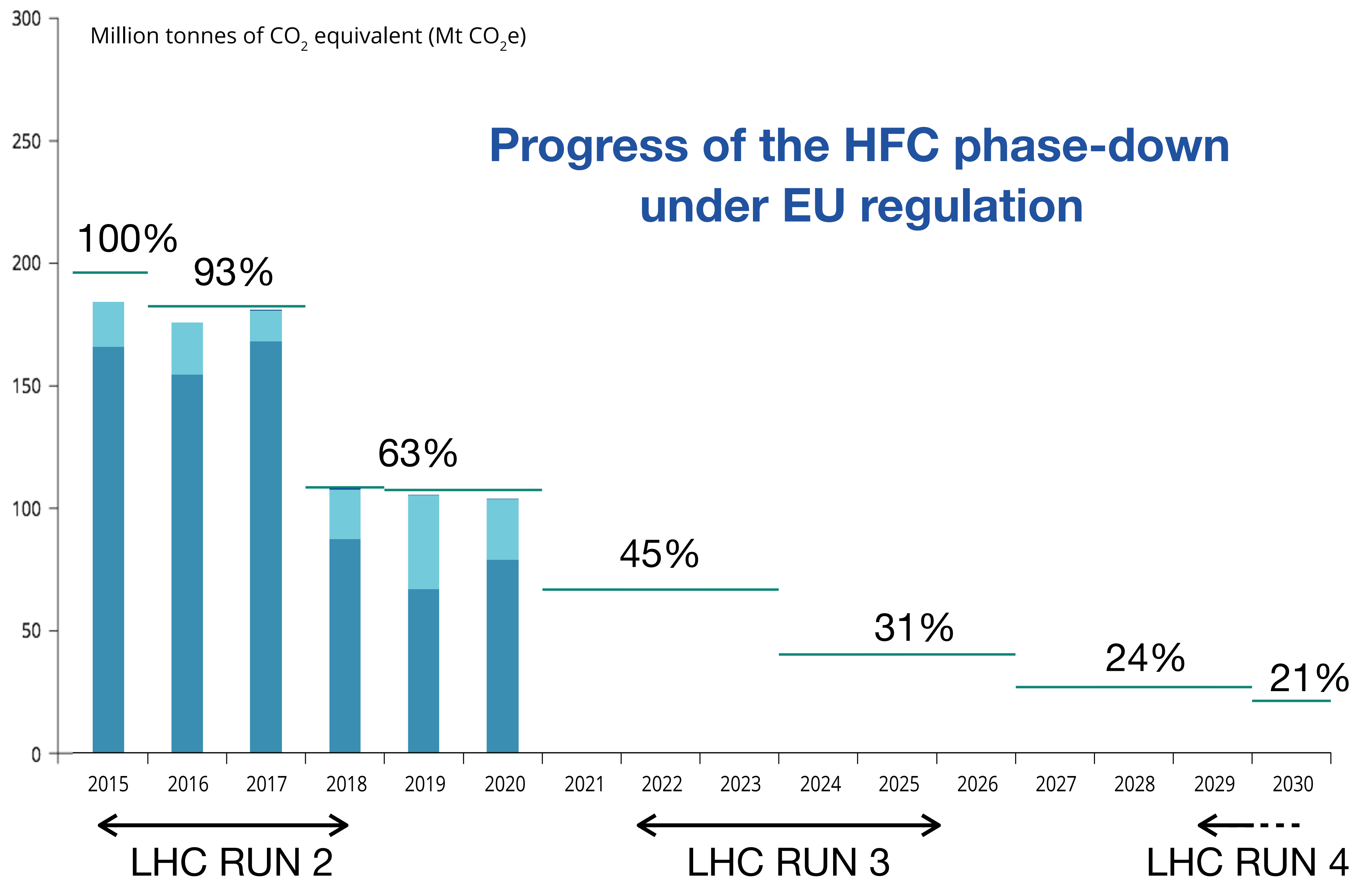
Emissions mainly due to leaks at detector level (fragile connectors) in ATLAS and CMS

Campaign for leaks reparation in LS2

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.

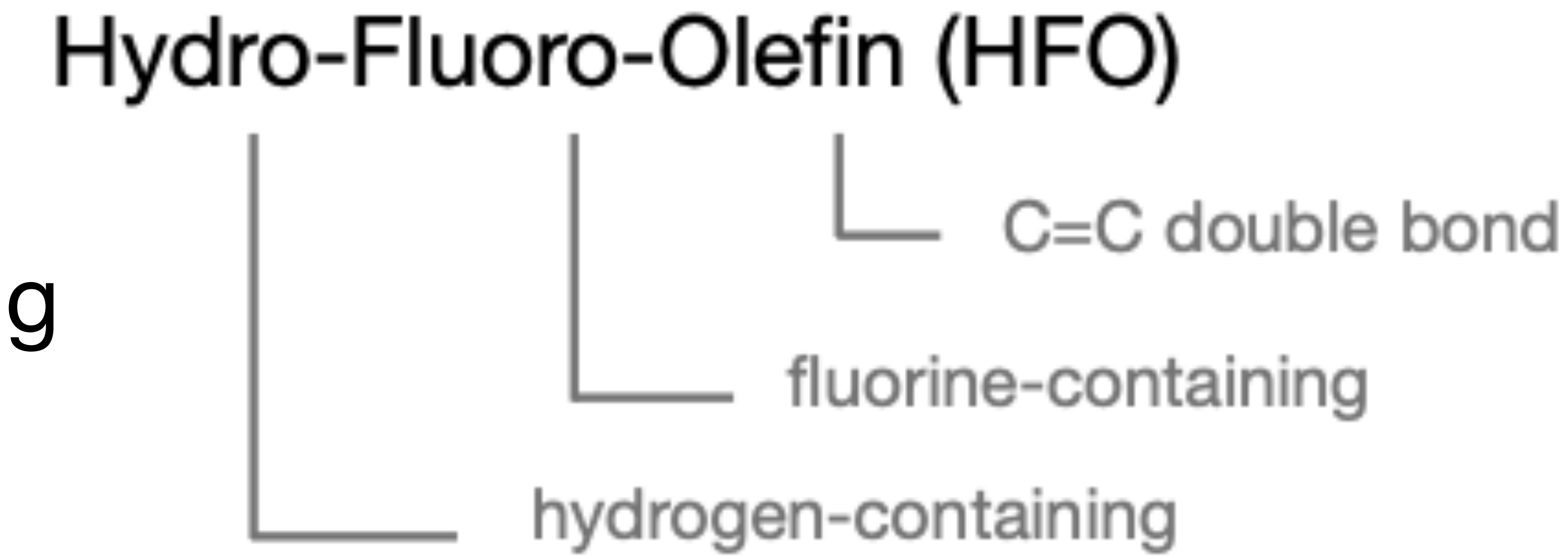
Banning the use of F-gases where less harmful alternatives are widely available.

Preventing emissions of F-gases from existing equipment by requiring checks, proper servicing and recovery



New gas mixtures

- Requirements: low GWP, low toxicity, not flammable and detector performance comparable with standard one
- In industrial applications C2H2F4 is being replaced with HydroFluoro-Olefins (HFOs)
  - the replacement of C2H2F4 with HFO moves the operating voltage at much higher values (es. >13kV for 2mm gap)
  - the addition of CO2 helps in decreasing the WP

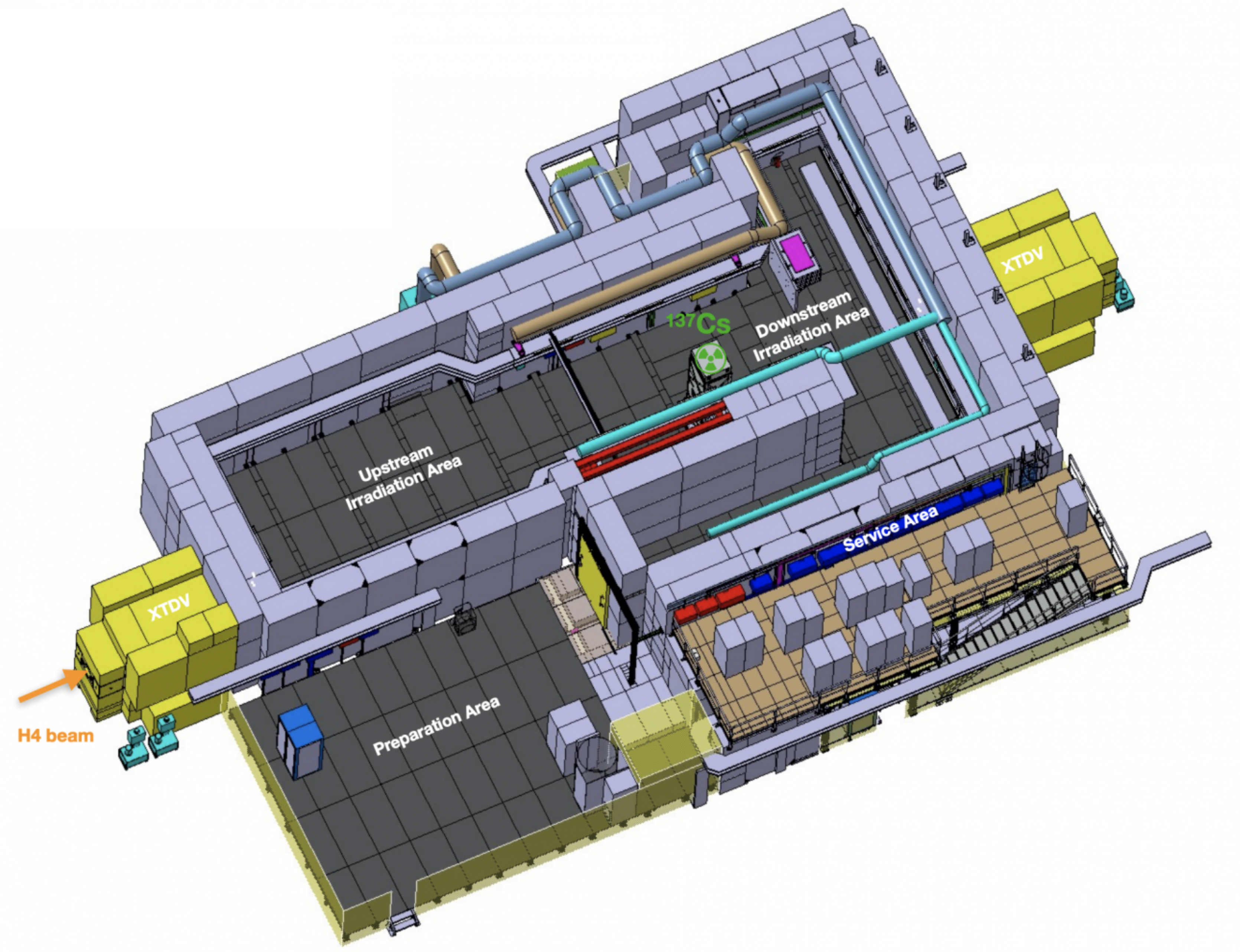


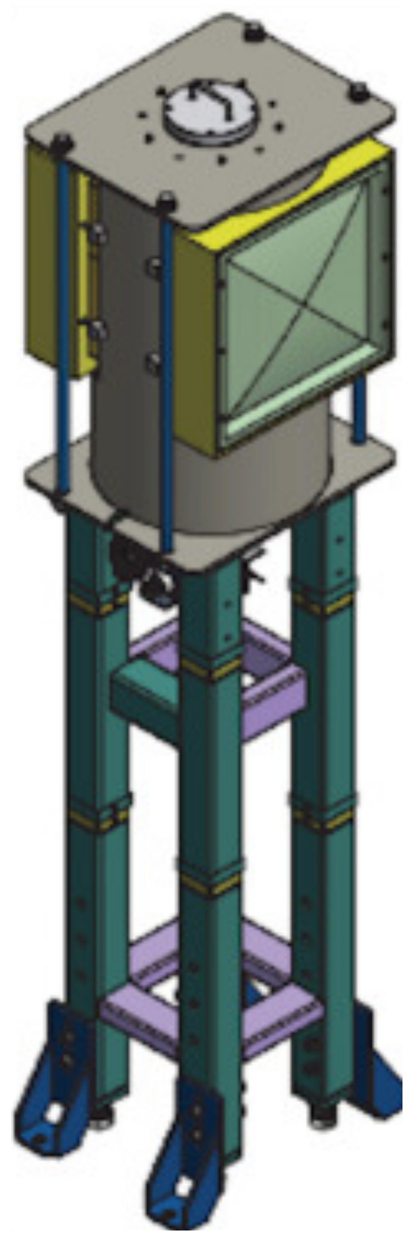
	R134a (%)	HFO-1234ze (%)	CO_2 (%)	i-C_4H_{10} (%)	SF_6 (%)	GWP	CO_2e (g/l)
STD	95.2			4.5	0.3	1485	6824
ECO2		35	60	4	1	476	1522
ECO3		25	69	5	1	527	1519
Density (g/l)	4.68	5.26	1.98	2.69	6.61		
GWP	1430	7	1	3	22800		

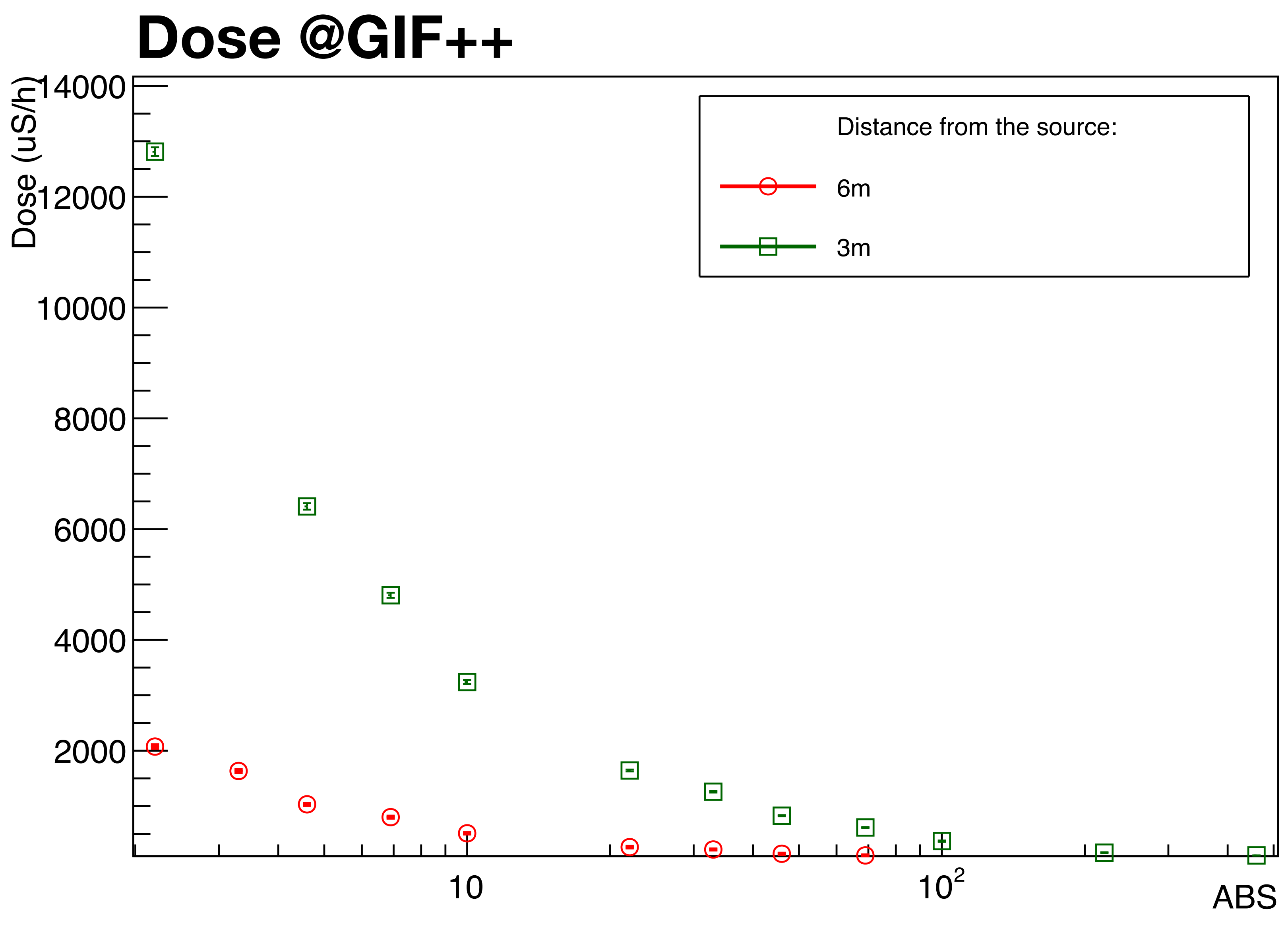
GWP with respect to CO2, and their CO2e, in grams, for one litre of mixture
Values mainly driven by SF6

NIST Chemistry WebBook, the NIST Standard Reference Database Number 69, https://webbook.nist.gov/chemistry/, retrieved on April 2, 2023

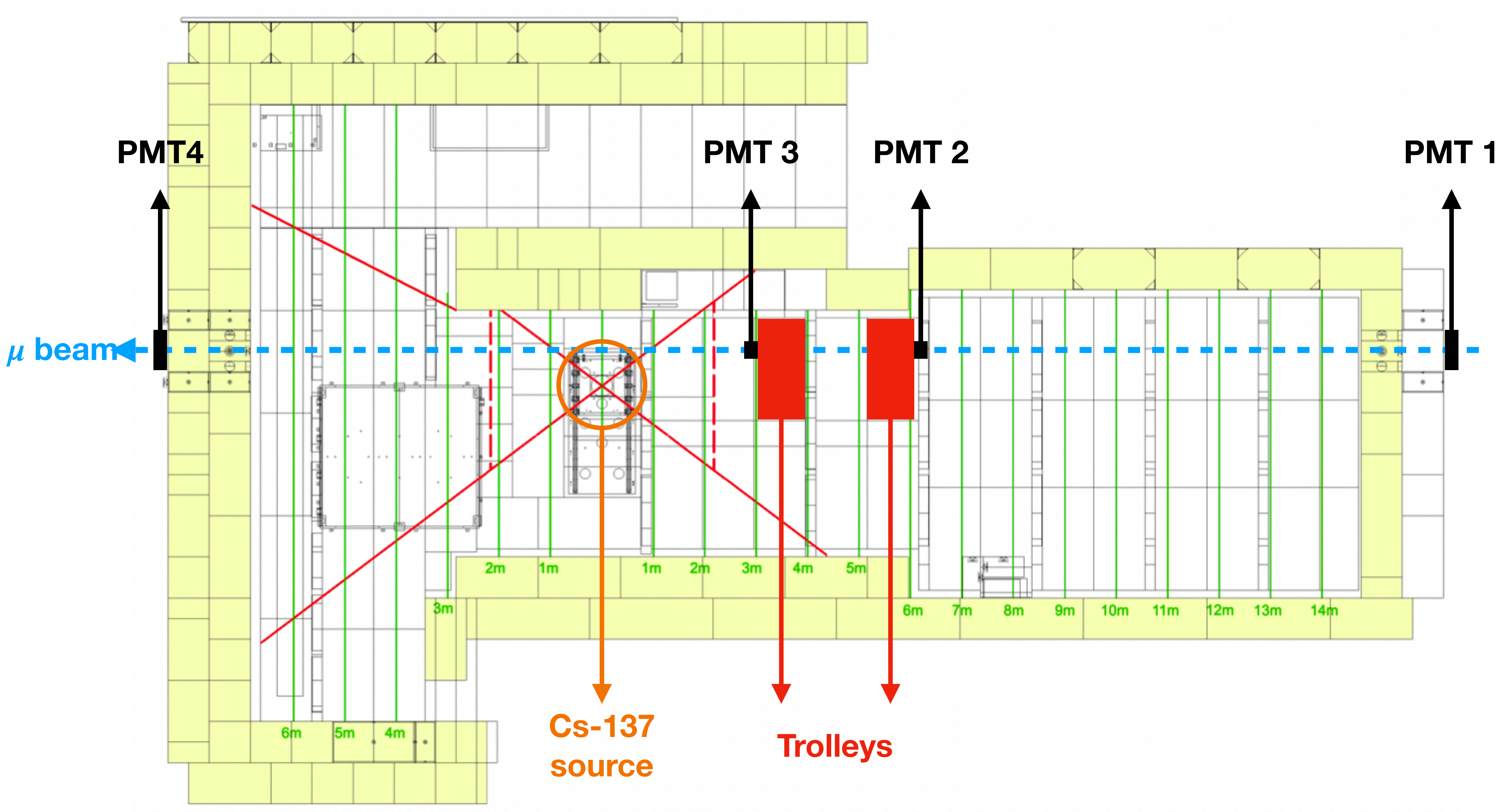
Gamma Irradiation Facility







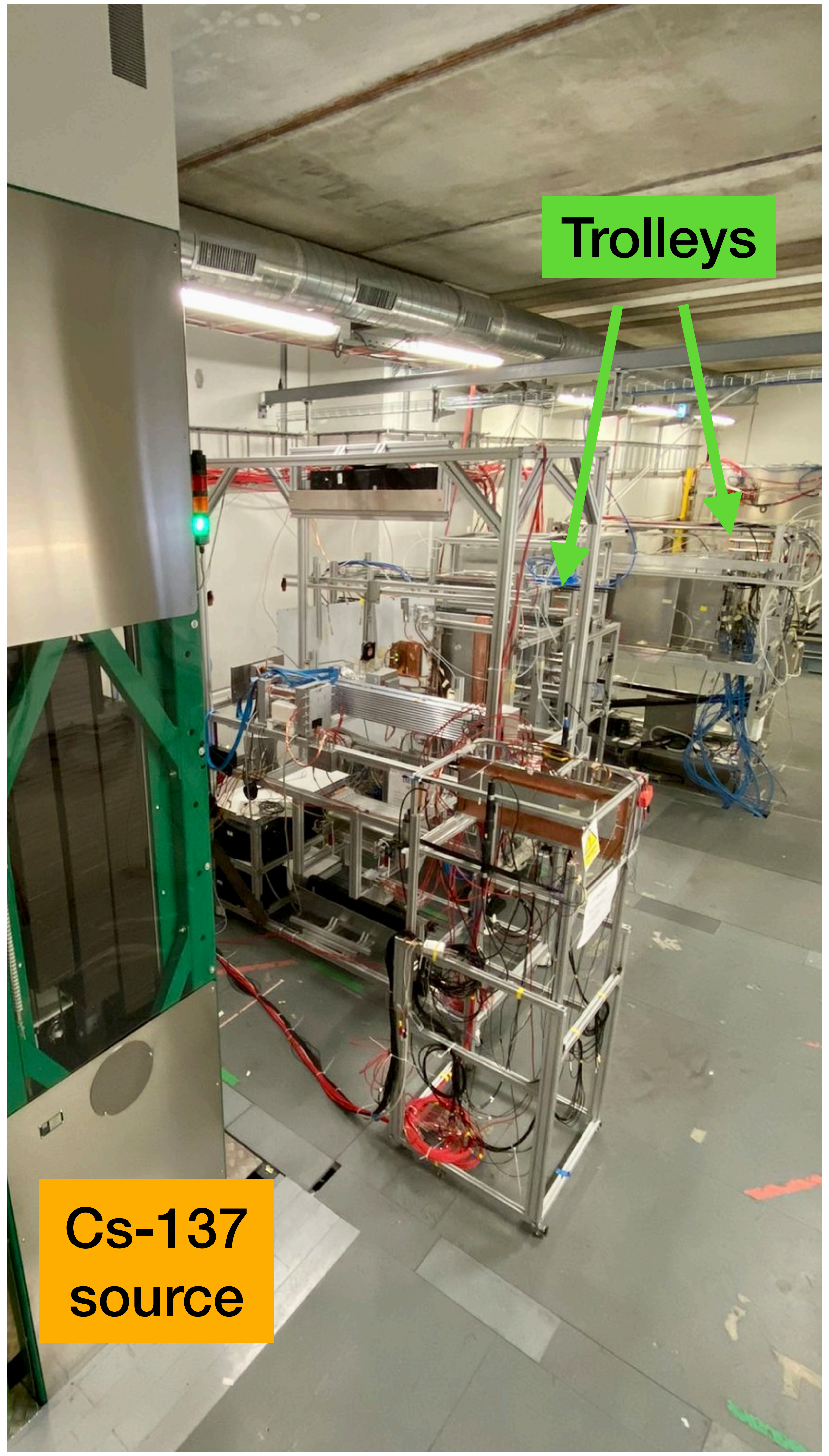
- H4 beam line in EHN1, CERN NA
- **Cs-137 gamma source** up to 12 TBq
- **Muon beam** 10-450 GeV/c
- Gamma flux modulated independently using a system of six attenuation filters (ABS)



Gamma Irradiation Facility

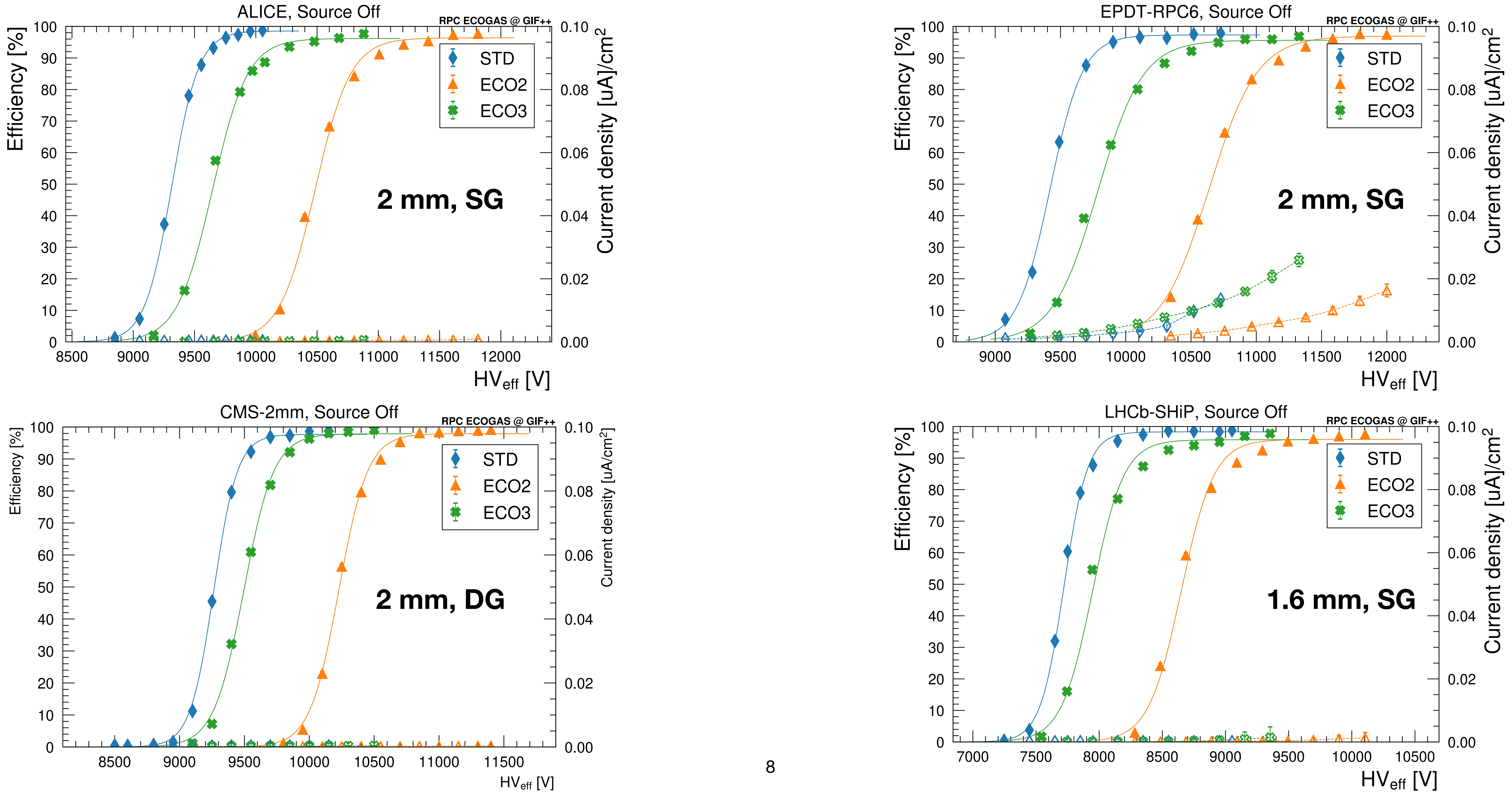
Detector setup

	RPC characteristics	Readout
ALICE	50x50 cm^2 2 mm single gap 2 mm bakelite electrodes	2D readout (16+16 strips) 3 cm pitch TDC
ATLAS	10x55 cm^2 2 mm single gap 1.8 mm bakelite electrodes	1D readout (1 strip) 3 cm pitch Digitizer
CMS BARI-1p0	70x100 cm^2 1.0 mm single gap 1.43 mm bakelite electrodes	1D readout (32 strip) 0.5 cm pitch TDC
CMS	Trapezoidal (height 10 cm, bases 51cm and 33 cm) 2 mm double gap 2 mm bakelite electrodes	1D readout (128 strip) 1 cm pitch TDC
CERN EP-DT	50x50 cm^2 2 mm single gap 2 mm bakelite electrodes	1D readout (7 strips) 2.1 cm pitch Digitizer
LHCb-SHiP	70x100 cm^2 1.6 mm single gap 1.6 mm bakelite electrodes	2D readout (32+32 strips) 1 cm pitch TDC



Performance results from TB @GIF++

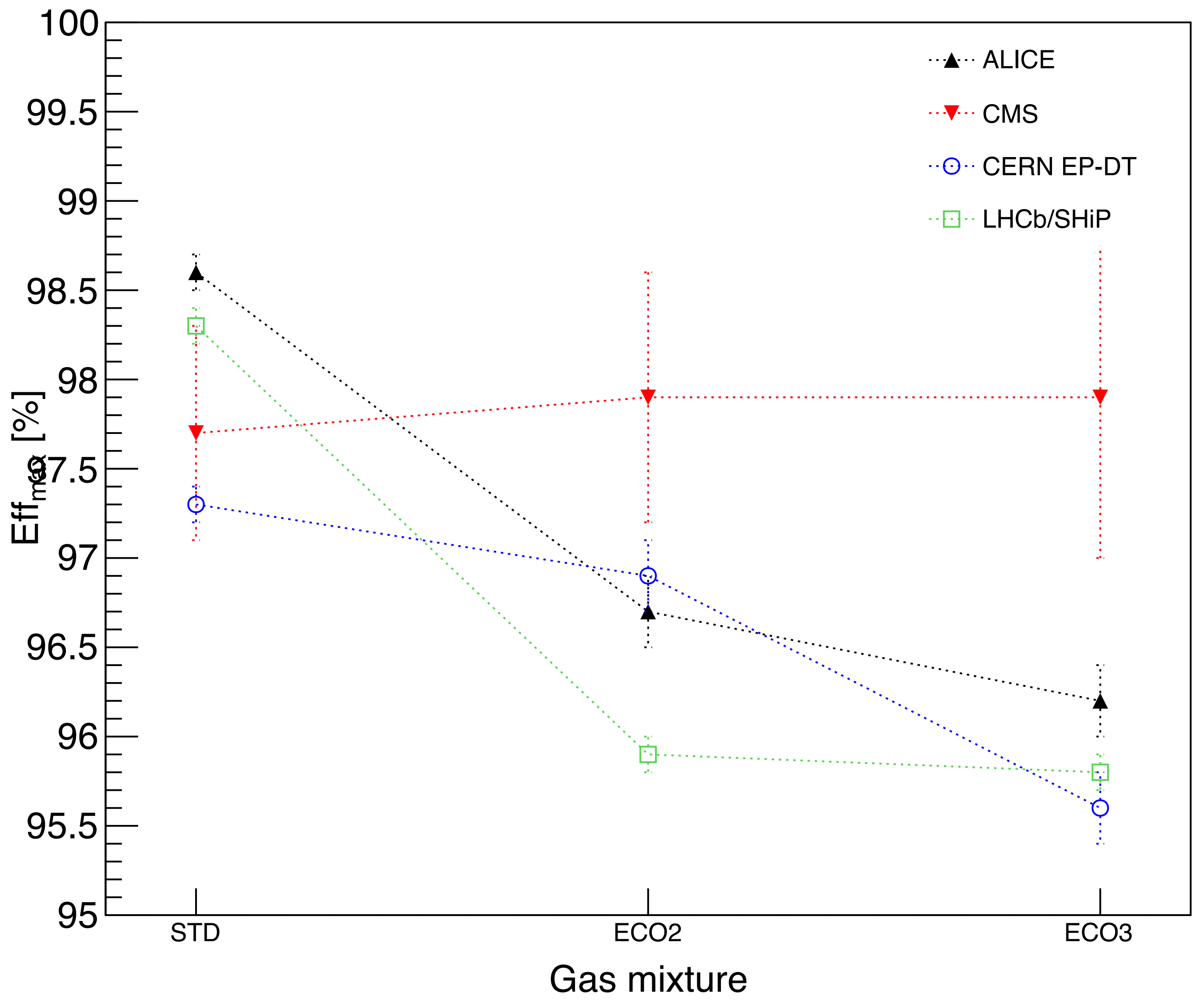
In absence of background radiation (source OFF)

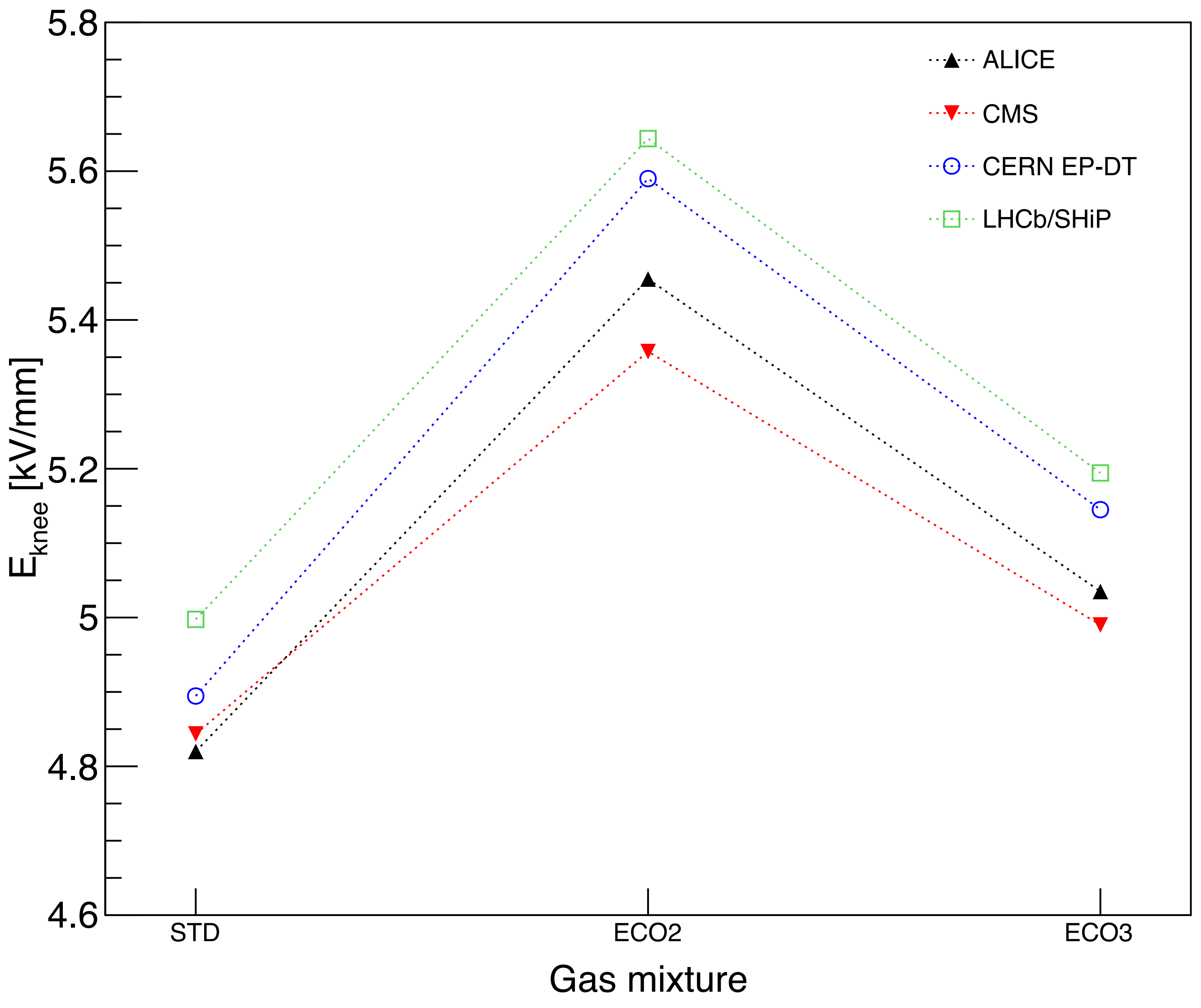


Performance results from TB @GIF++

In absence of background radiation (source OFF)

Fitted sigmoidal function $Eff(H_{Veff}) = \dfrac{Eff_{max}}{1 + e^{-\lambda^*(H_{Veff} - HV50)}}$

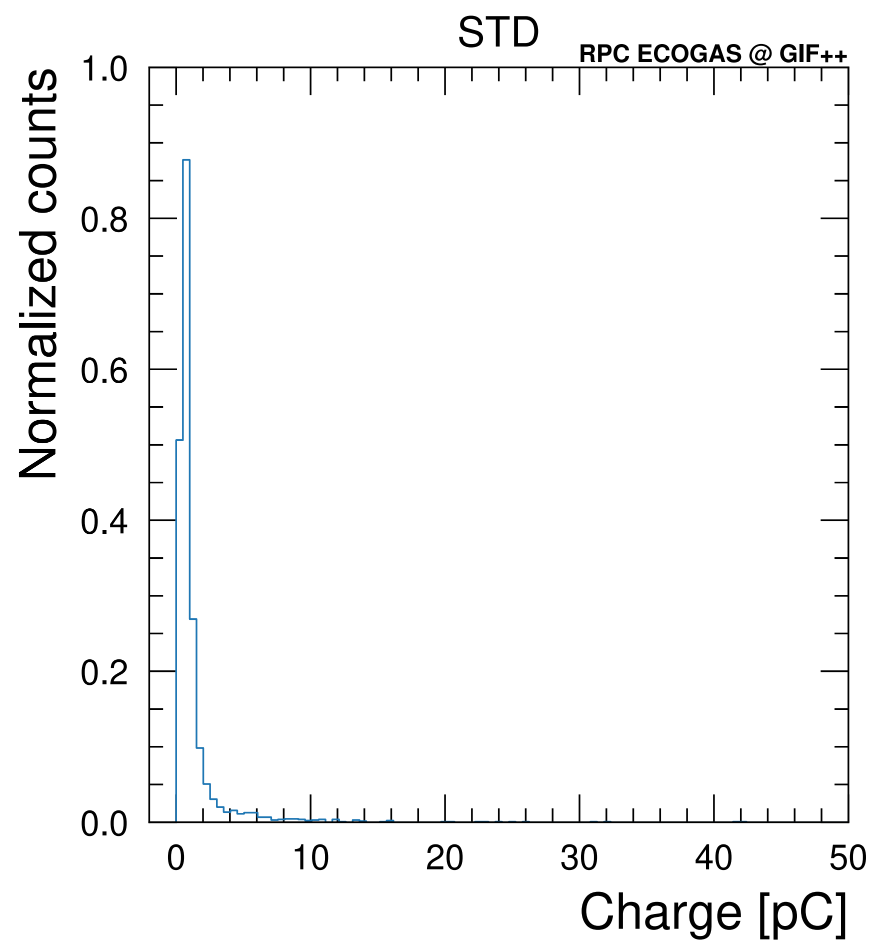


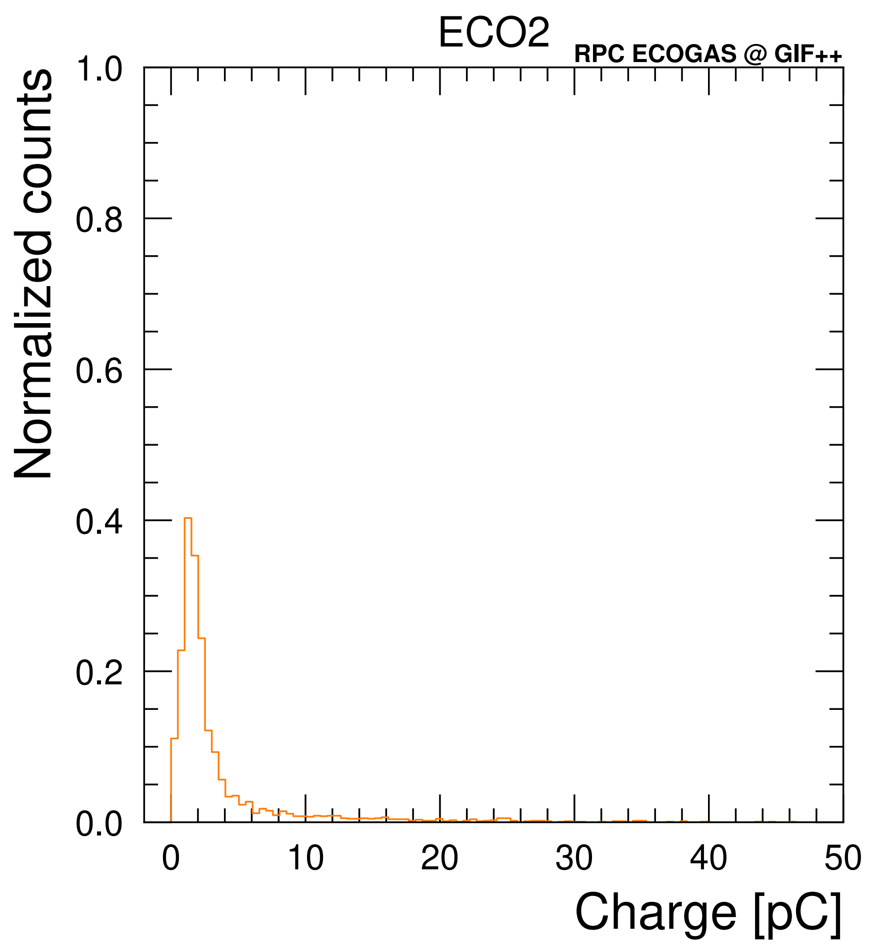


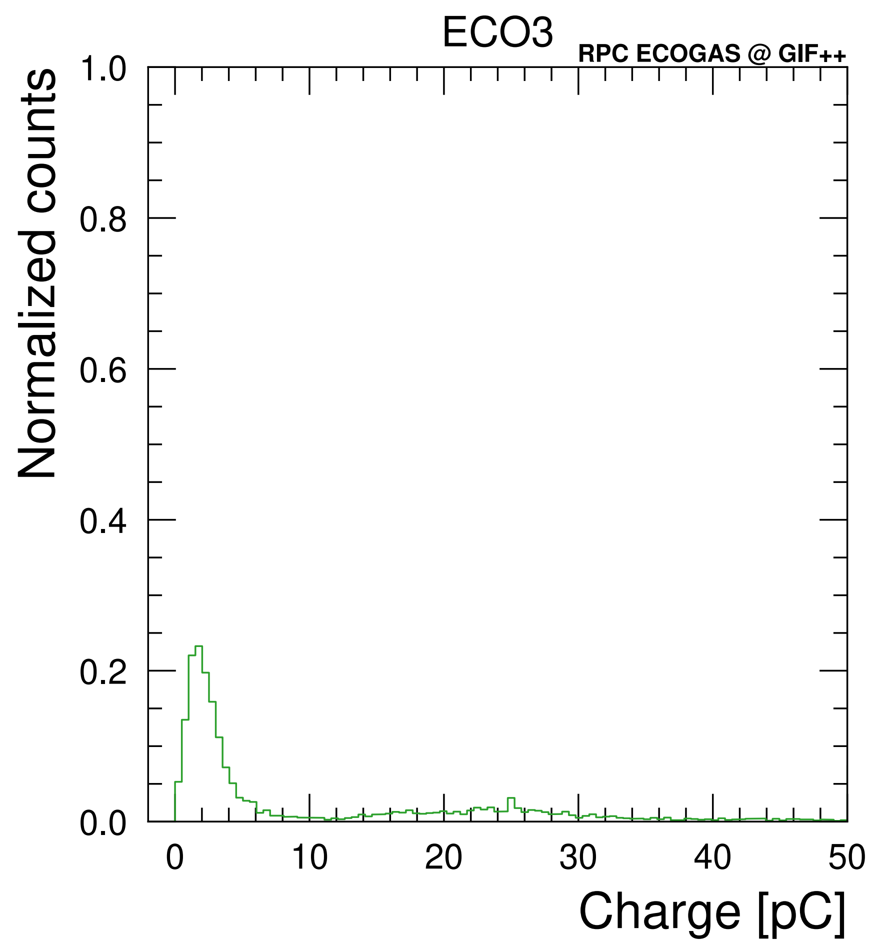
Effmax well above 95% decreases for ECO2 and ECO3 (lighter target due to CO2)
Double gap CMS is less sensitive

Electric field @ knee higher for ECO2 and ECO3

ATLAS RPC charge distribution







Higher streamer contribution for ECO2 and ECO3

Performance results from TB @GIF++

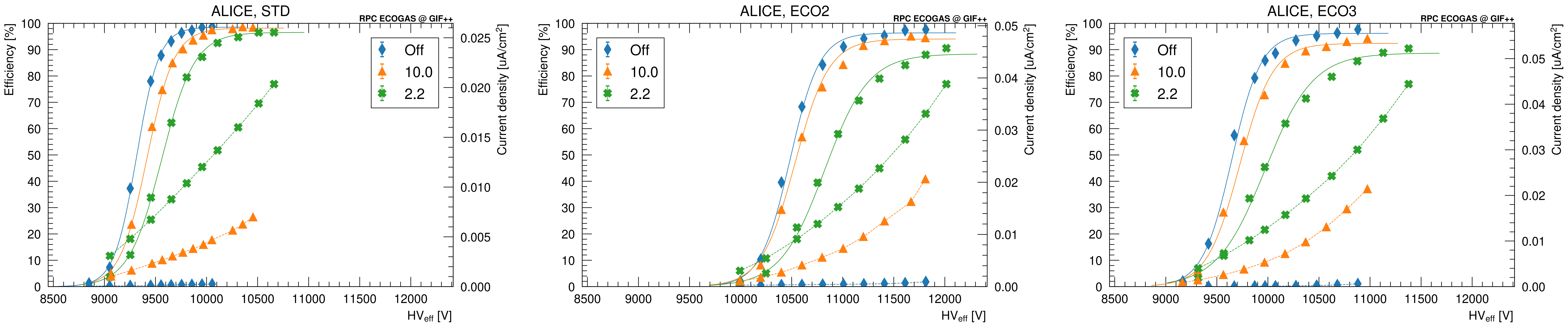
With background radiation (source ON)

Efficiency and current density

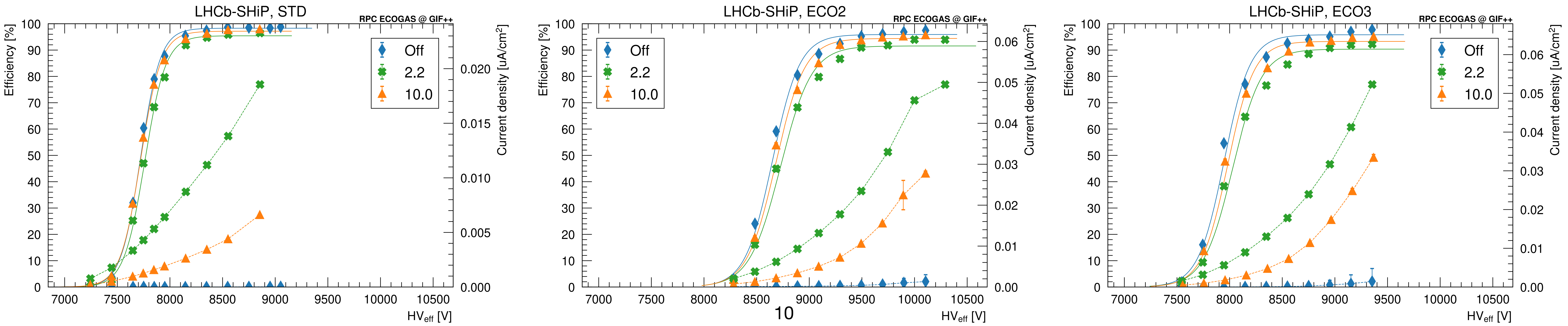
Data taken at different ABS:
- ALICE-LHCb/Ship (6 m far from source)
  - OFF
  - ABS 10 (510 uSievert/hour; 70* Hz/cm² @knee)
  - ABS 2.2 (2070 uSievert/hour; 280* Hz/cm² @knee)

Data taken at different ABS:
- CMS-EPDT (3m far from source)
  - OFF
  - ABS 69 (700 uSievert/hour; 80* Hz/cm² @knee)
  - ABS 22 (1800 uSievert/hour; 200* Hz/cm² @knee)

ALICE

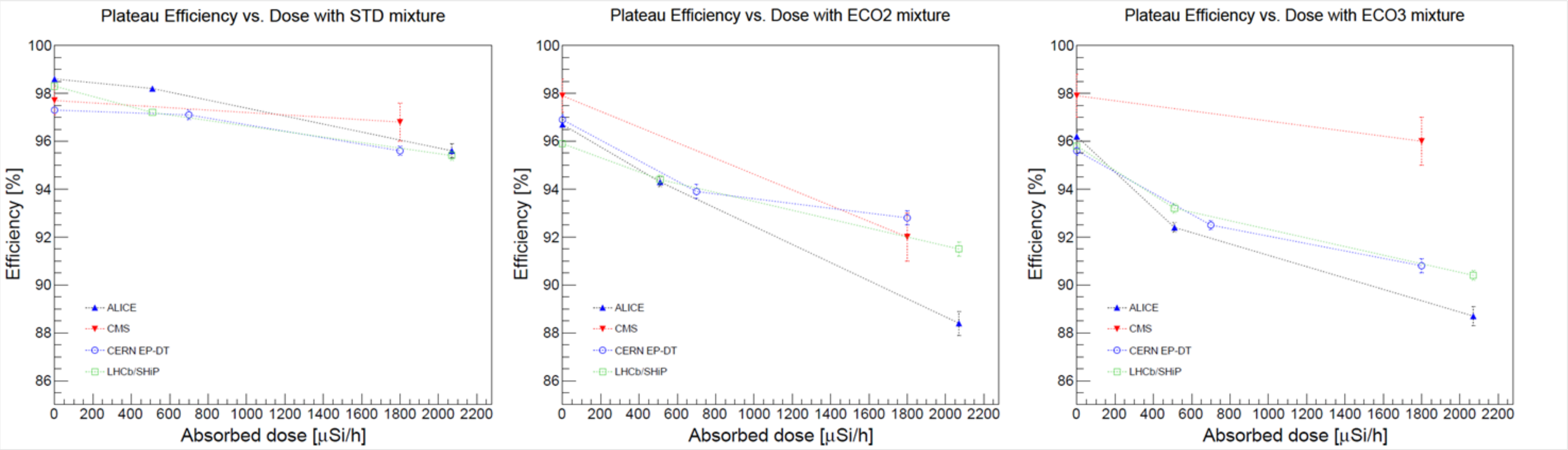


LHCb-SHiP



Performance results from TB @GIF++

With background radiation (source ON)



Larger efficiency drop when using ECO2 and ECO3 mixtures

Performance results from TB @GIF++

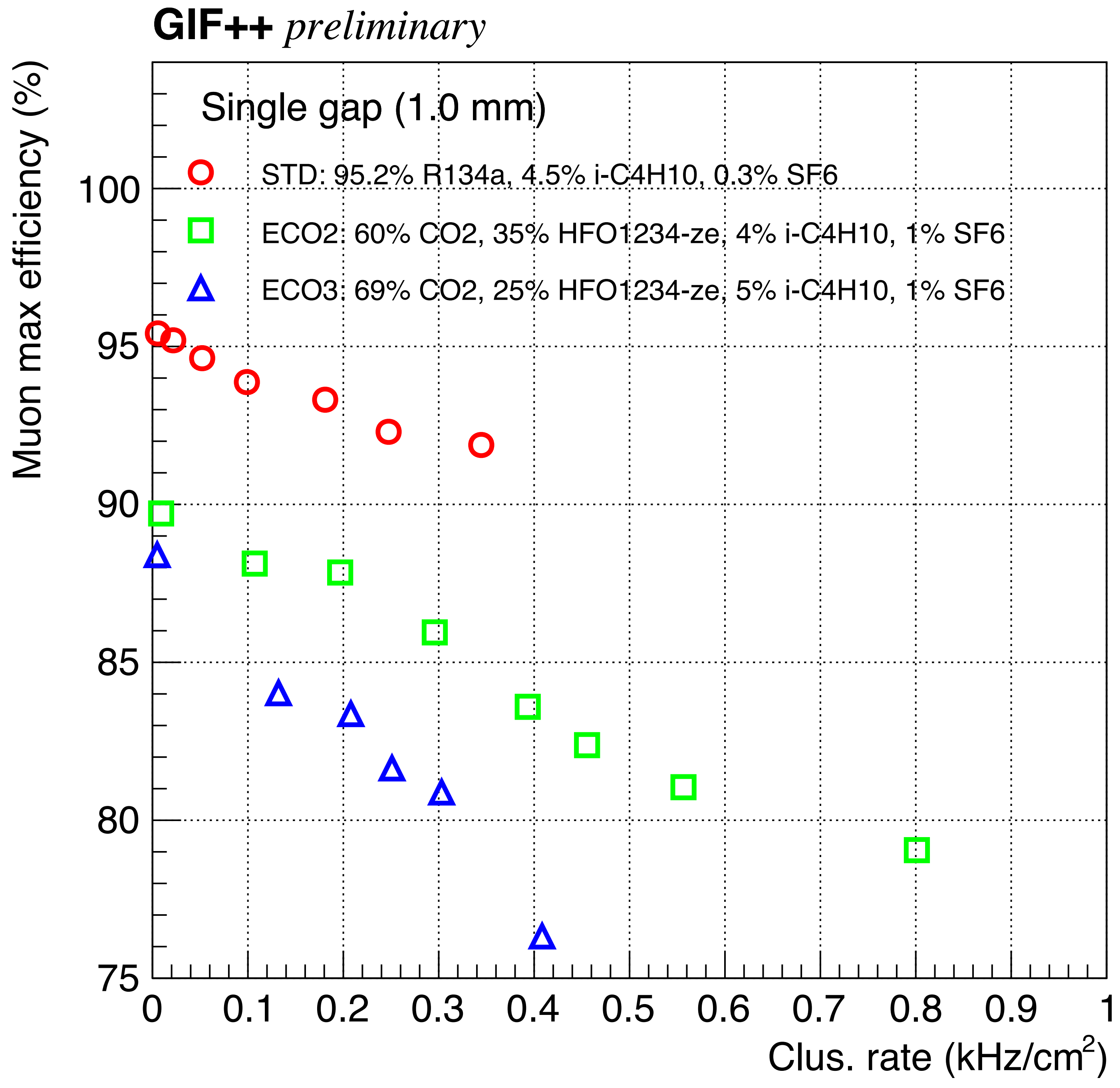
With background radiation (source ON)

Efficiency, Working Point and cluster size

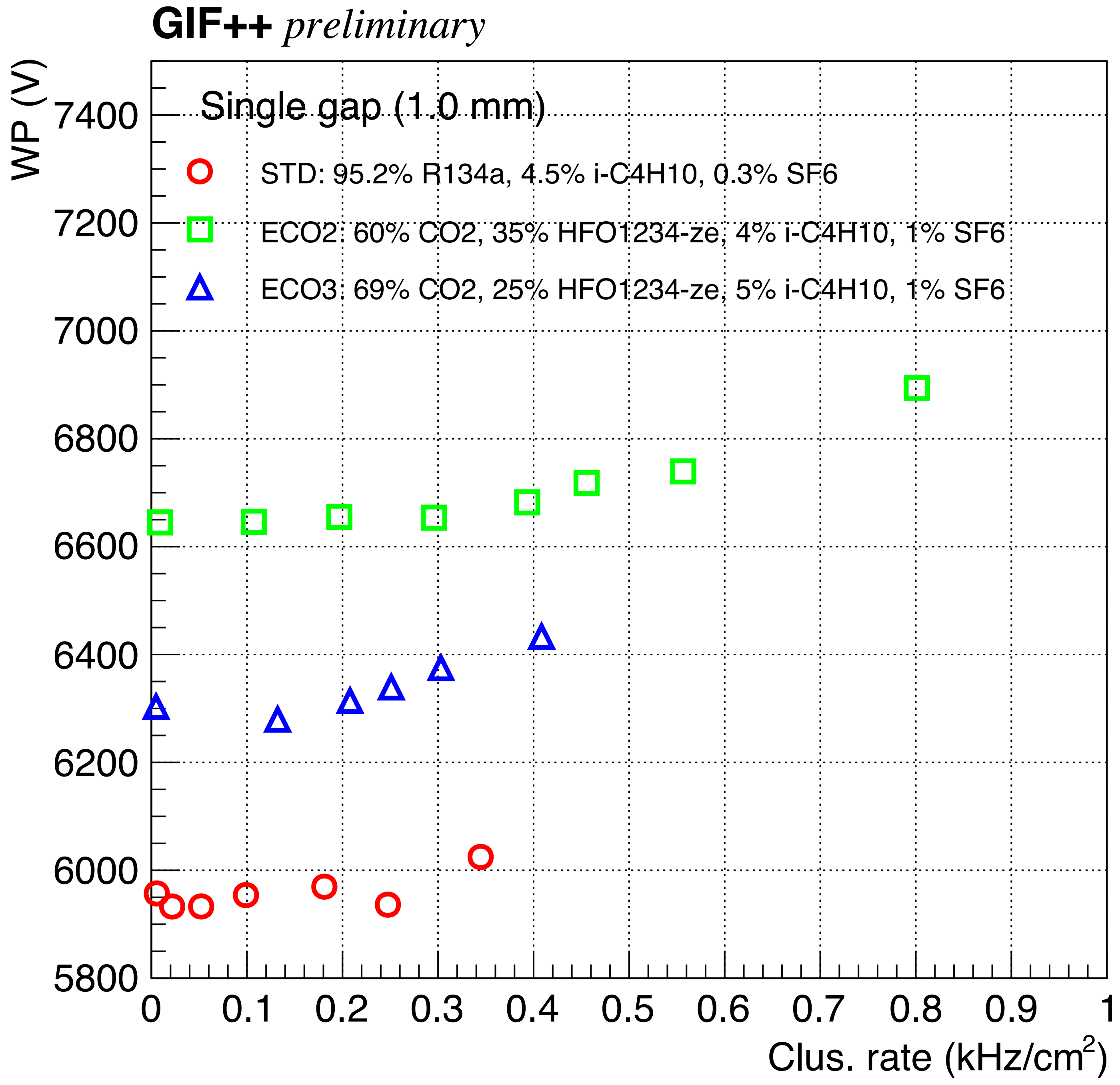
knee

$$WP = -\frac{log(1/(0.95-1))}{\lambda} + HV50 + 120V$$

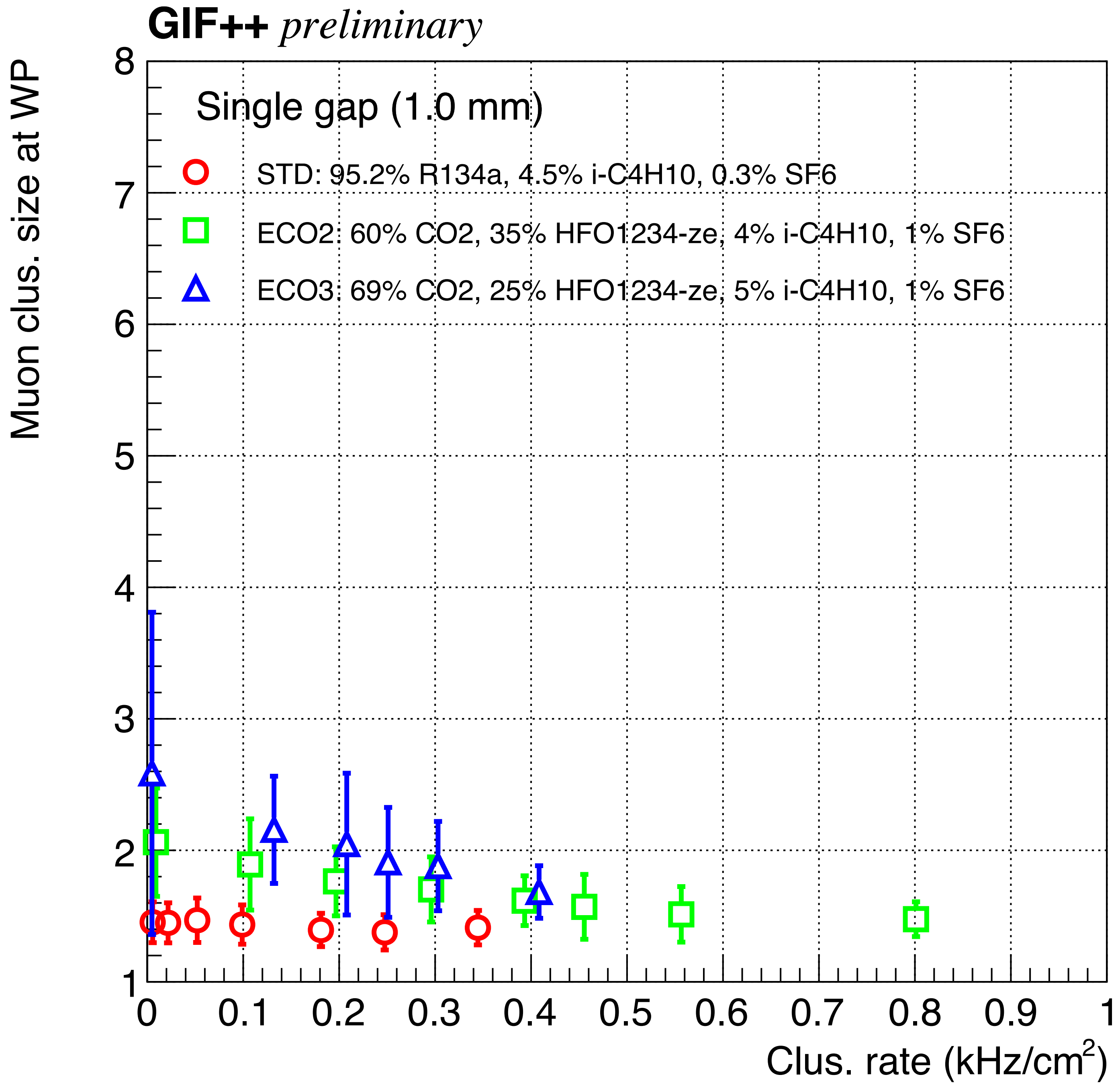
CMS BARI-1p0



Adding CO2 to 1 mm single gap RPCs, limits the maximum achievable efficiency



Higher WP for ECO2 and ECO3

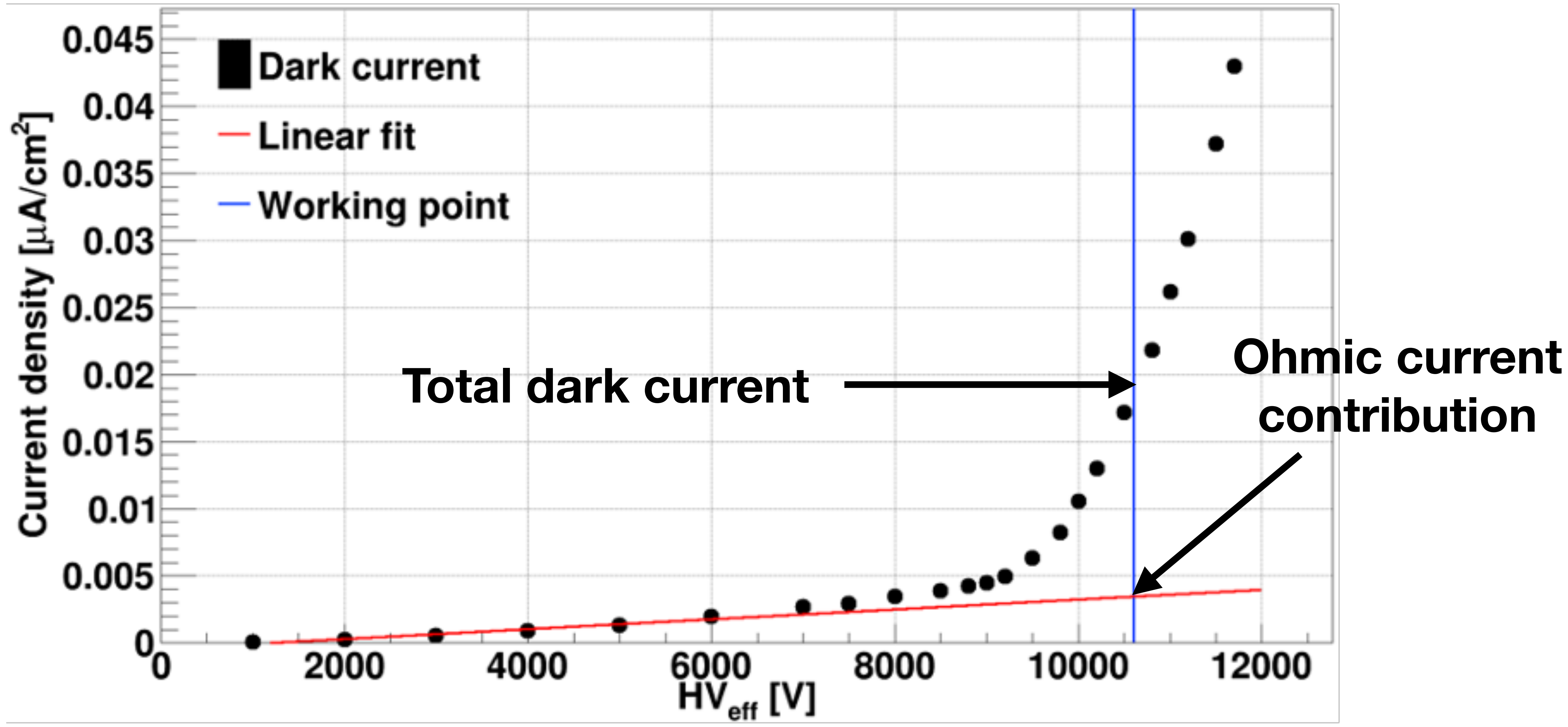


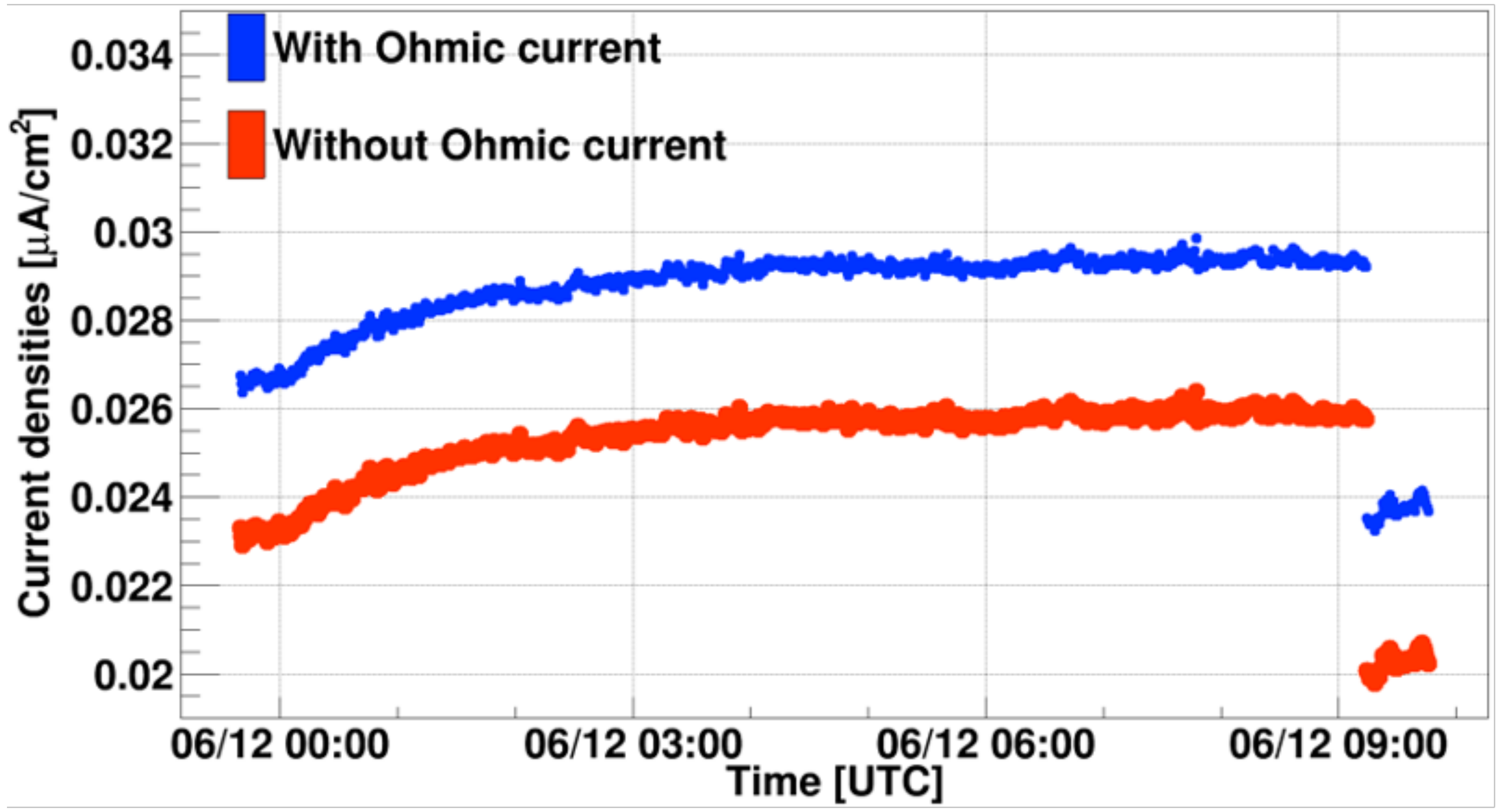
Higher CLS and larger error bars for ECO2 and ECO3

Ageing studies @GIF++

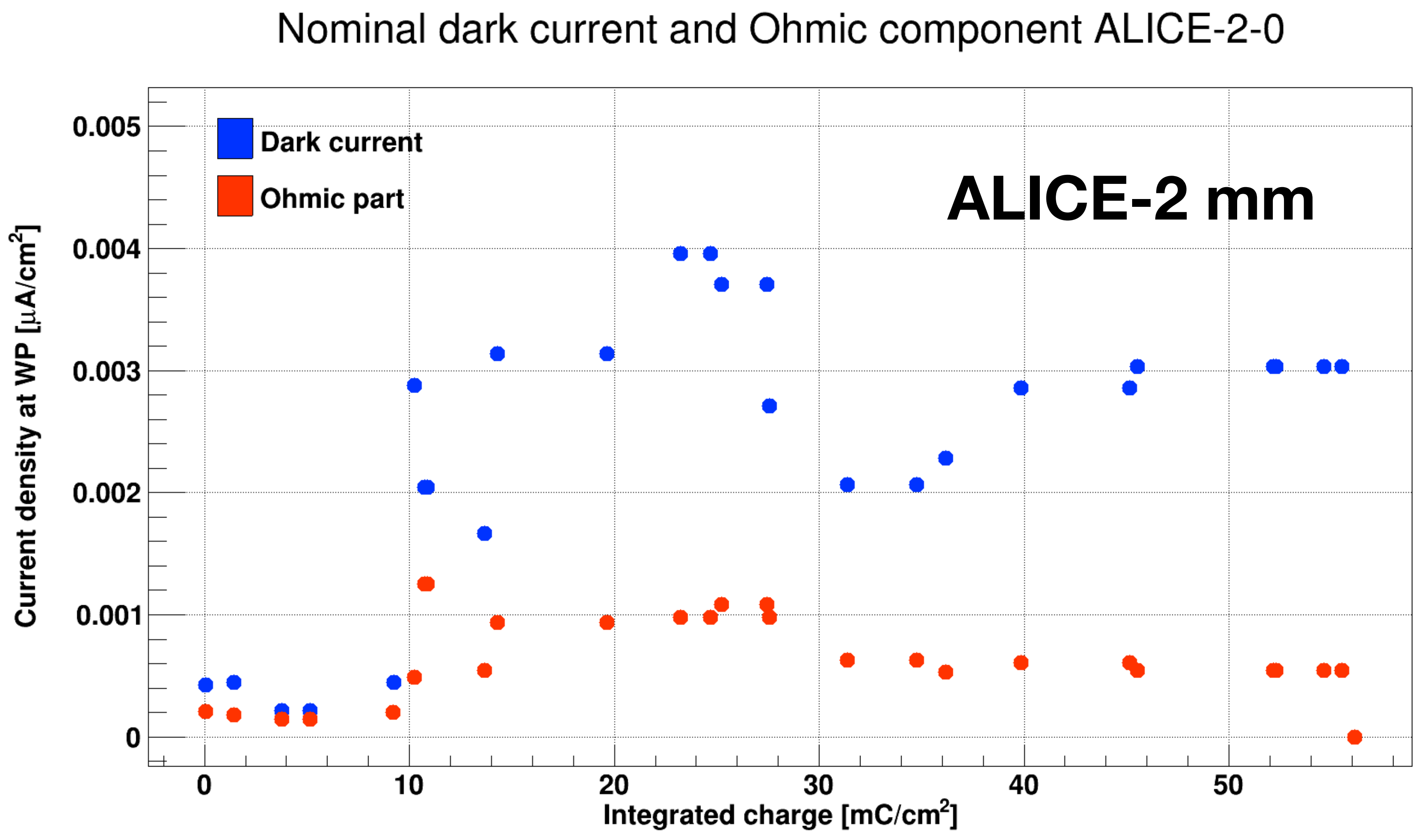
Irradiation campaign with ECO2

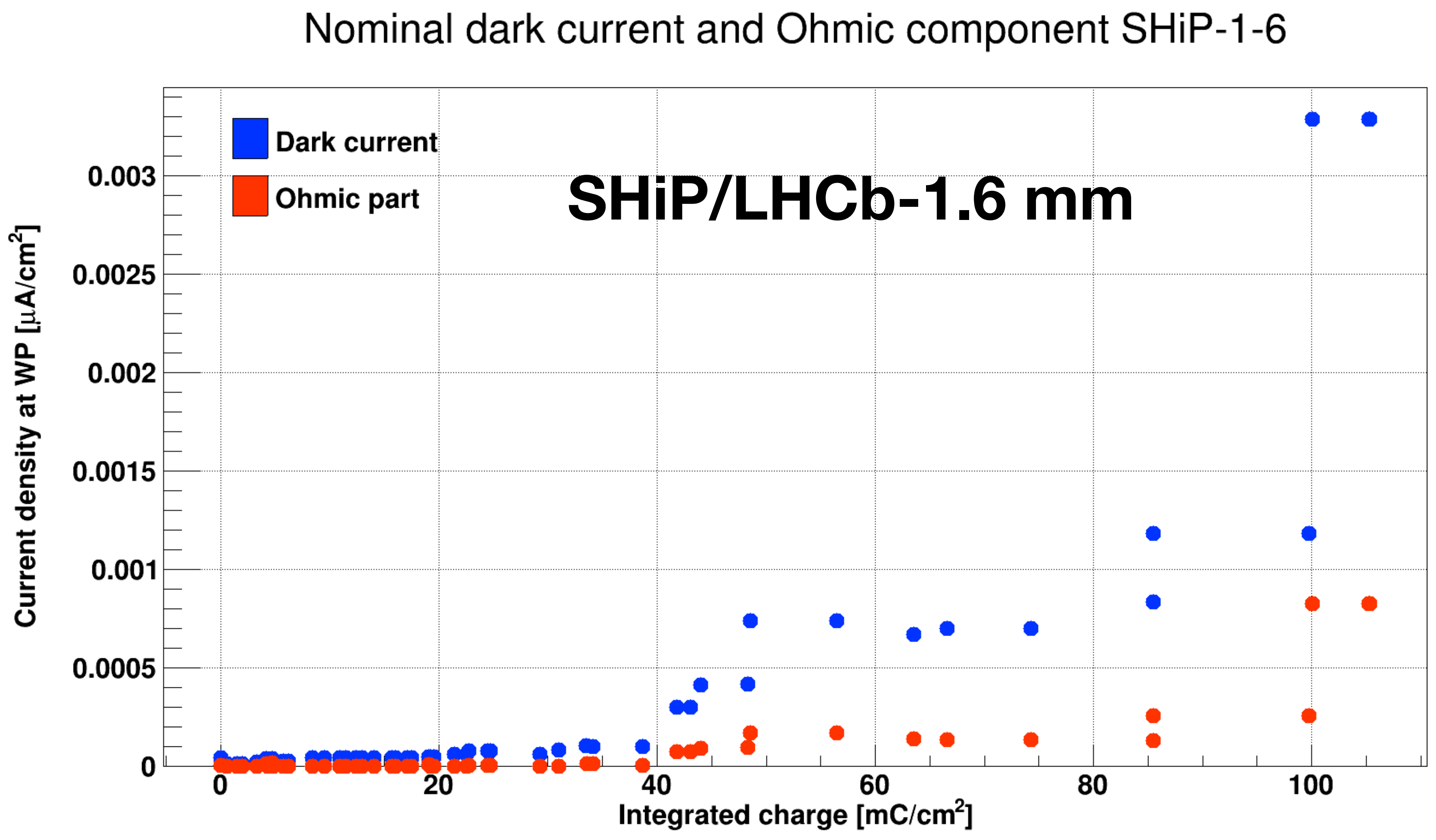
- **Irradiation for all the week**
    - ABS 2.2 (ALICE and LHCb: 2000 uSievert/h 280 Hz/cm2 @knee)
    - ABS 2.2 (CMS and EPDT: 13000 uSievert/h 1600 Hz/cm2 @knee)
- **Control weekly HVscan** in absence of background radiation (source OFF)
- 50 - 250 mC/cm2 **integrated charge** according to the RPC

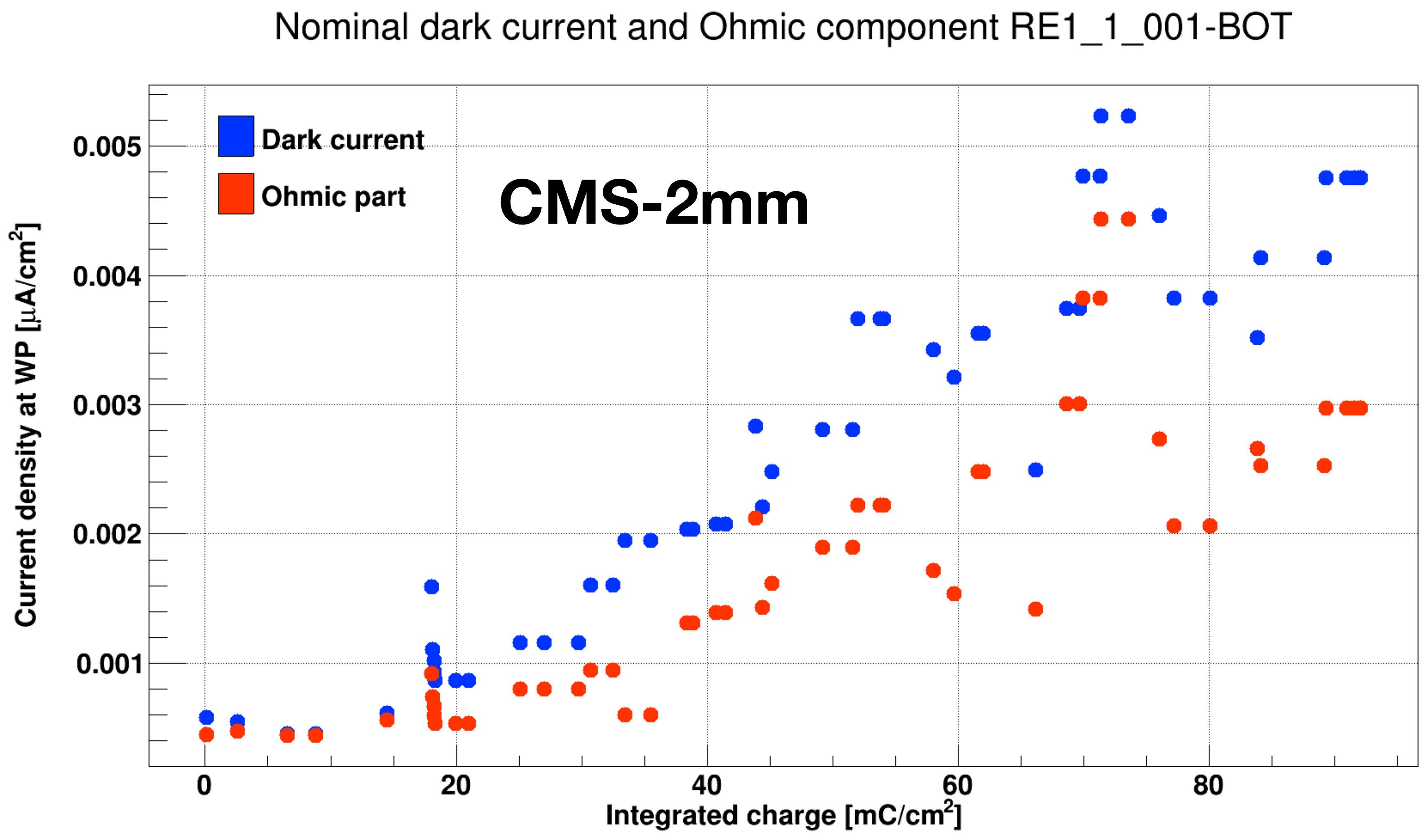


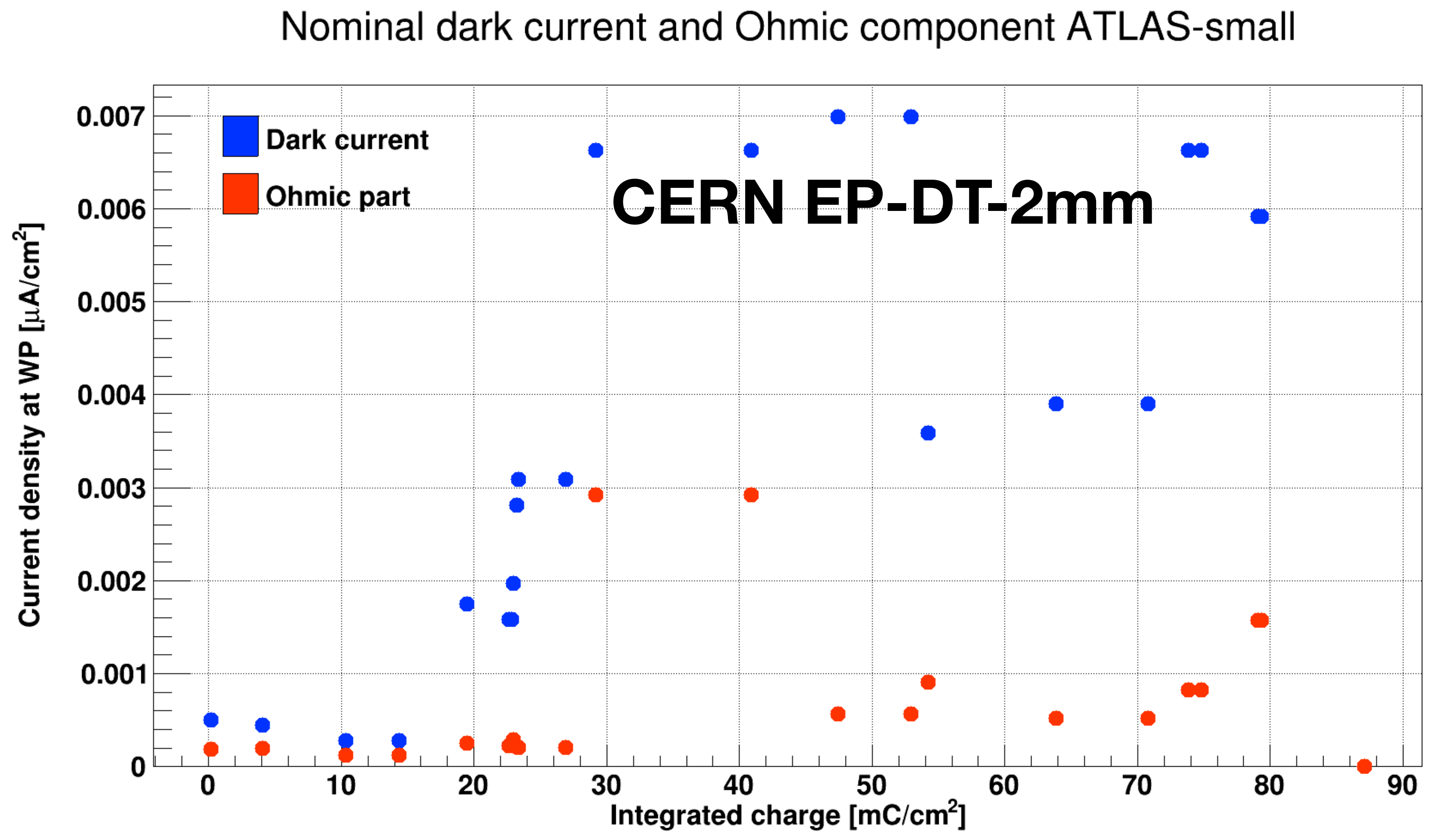


Ageing studies @GIF++ Current monitoring









- **Ohmic component** quite constante (not for CMS-2mm)
- Total **dark current** increasing with the integrated charge for all chambers

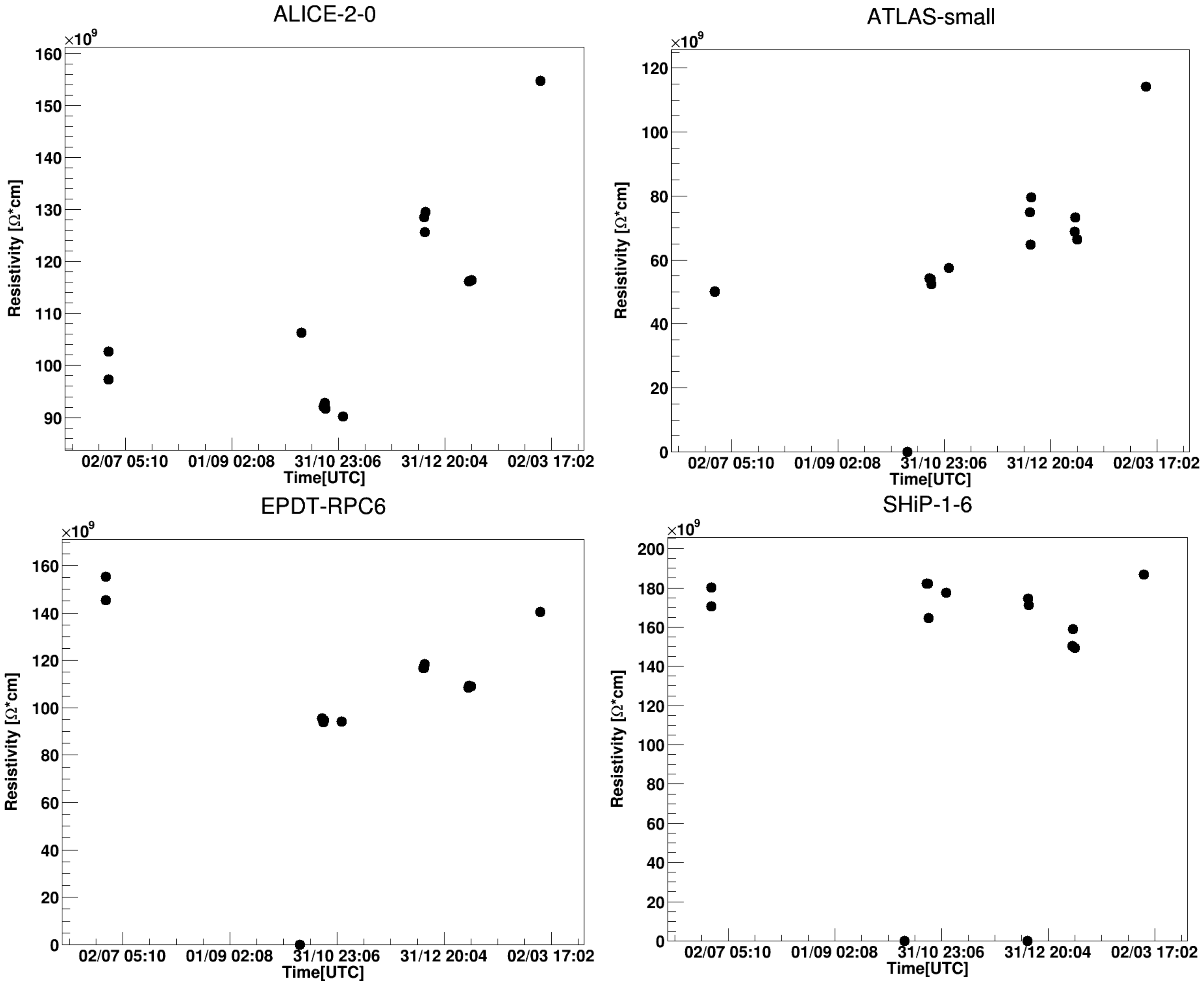
Ageing studies @GIF++

Resistivity

- **Resistivity** normalised to **T = 20 °C**

$$\rho(T)=\rho(T_0)*4.4^{\frac{T_0-T}{12°C}}$$

- Increasing trend for 2mm chambers (ALICE, ATLAS, CERN EP-DT) while quite constant for 1.6mm (LHCb/ SHiP)



Conclusions and beyond

- **Resistive Plate Chamber** detectors in HEP are operated **F-gases based mixture** with **very high GWP** → huge commitment to find a performant **eco-friendly replacement by RPC ECOgas@GIF++ collaboration.**

- The Test Beam periods show **ECO2 (HFO 35% + CO_2 60% + iC_4H_{10} 4% + SF_6 1%)** as **promising mixture** for RPCs with gap thickness in the range 1.6 - 2.0 mm, not like that for 1.0 mm.
- The ageing studies show a **slight increase of dark current and resistivity** (only 2mm gaps) → ongoing investigation
- A **new Test Beam** period is scheduled to crosscheck the performances before and after irradiation (Ongoing in GIF++ @ CERN)
- Studies for a **future replacement of the SF_6** (GWP = 22800) is foreseen