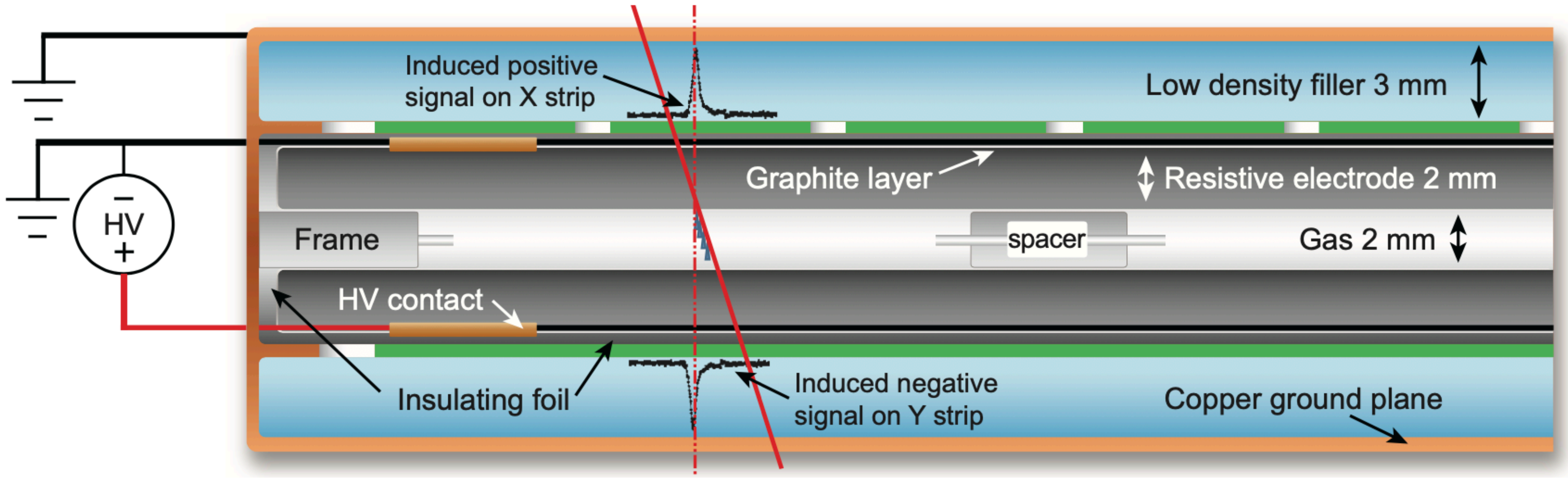
Tests of Resistive Plate Chambers with ecological gas mixture at GIF++ facility

Giuliana Galati

on behalf of the RPC EcoGas@GIF++ collaboration

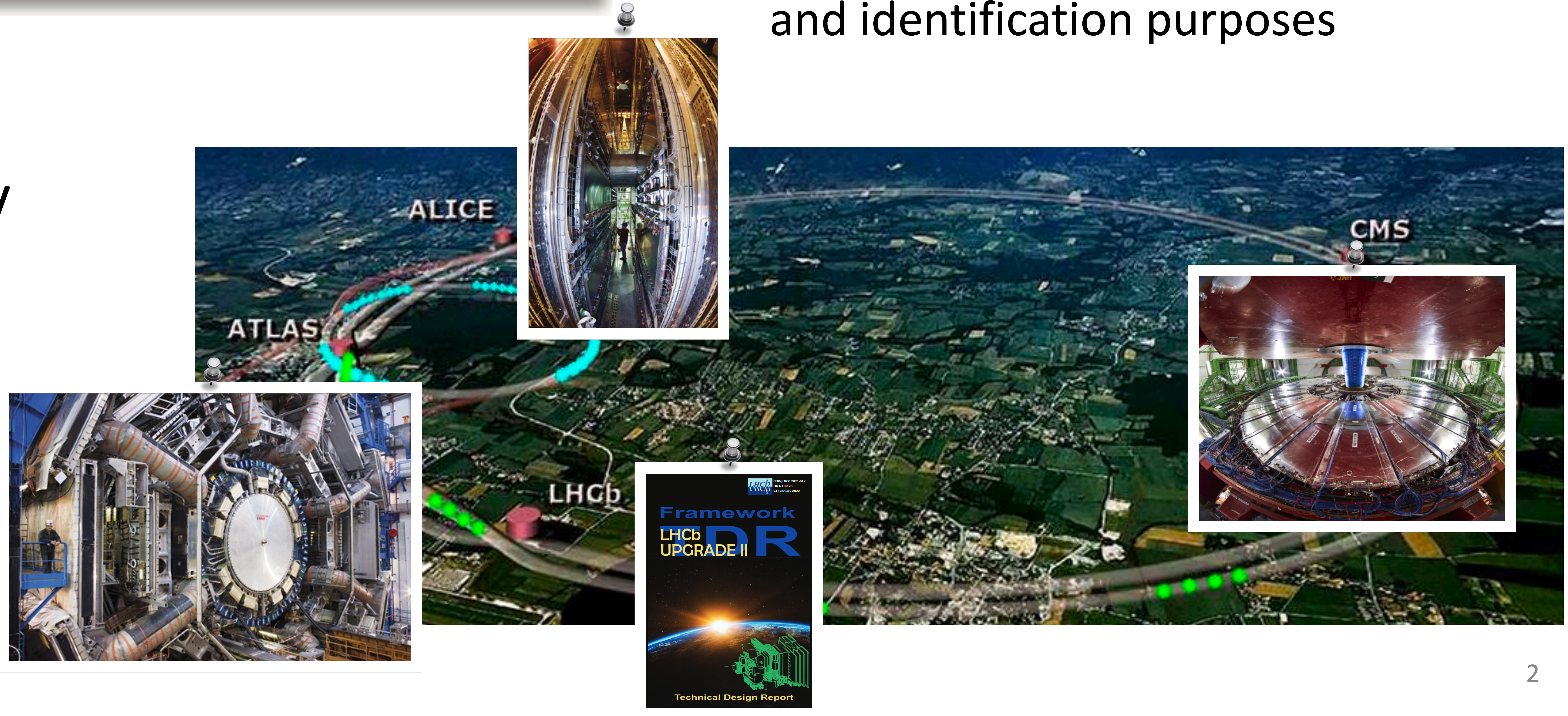
Università di Bari Aldo Moro & INFN Bari

RPCs in High Energy Physics



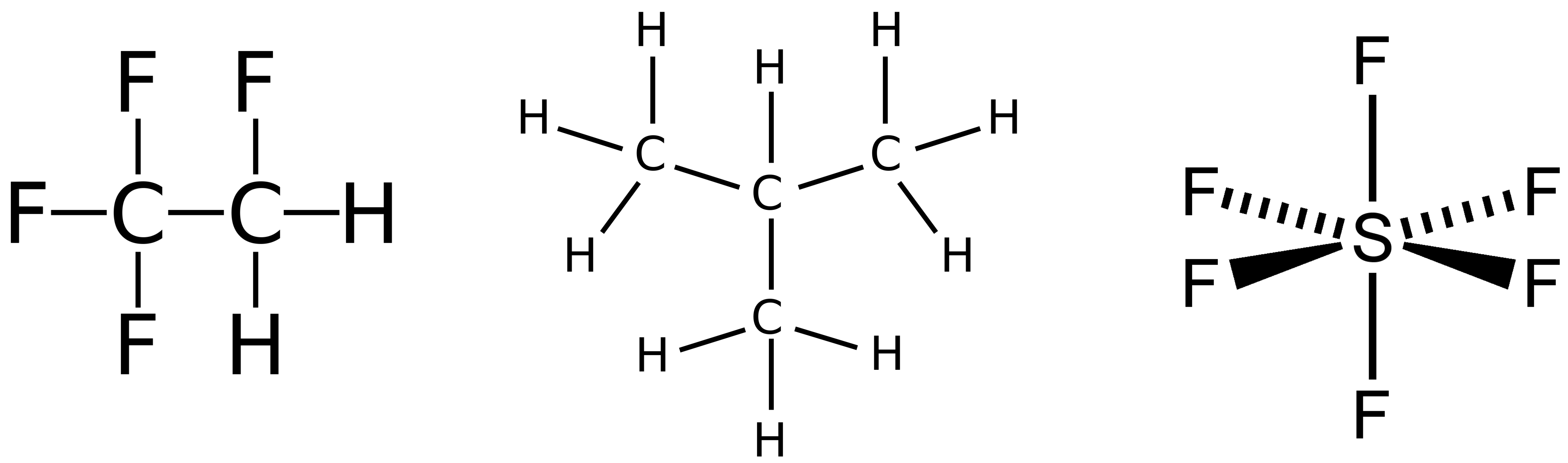
- High efficiency and time resolution
- Relatively cheap: allow to cover large areas
- Largely used for muon detection
- Fast response: used for triggering and identification purposes

RPC detectors widely employed in HEP:



The “standard” gas mixture

- The “standard” gas mixture used up to now in avalanche mode is made by $C_2H_2F_4$ (>90%), iC_4H_{10} and SF_6



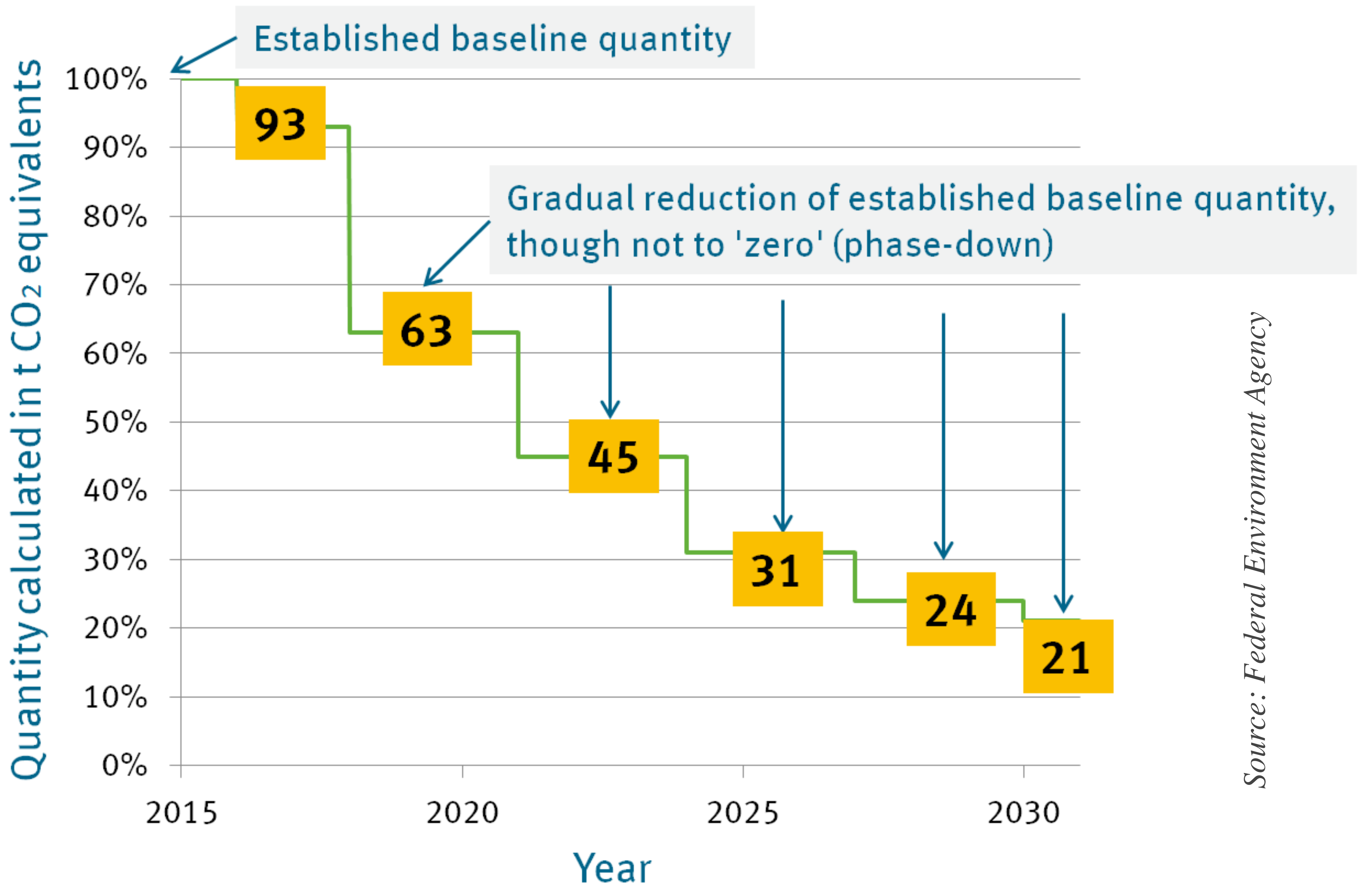
- High density of primary ion-electron pairs: high RPC efficiency
- Good quenching properties: reduced streamer probability

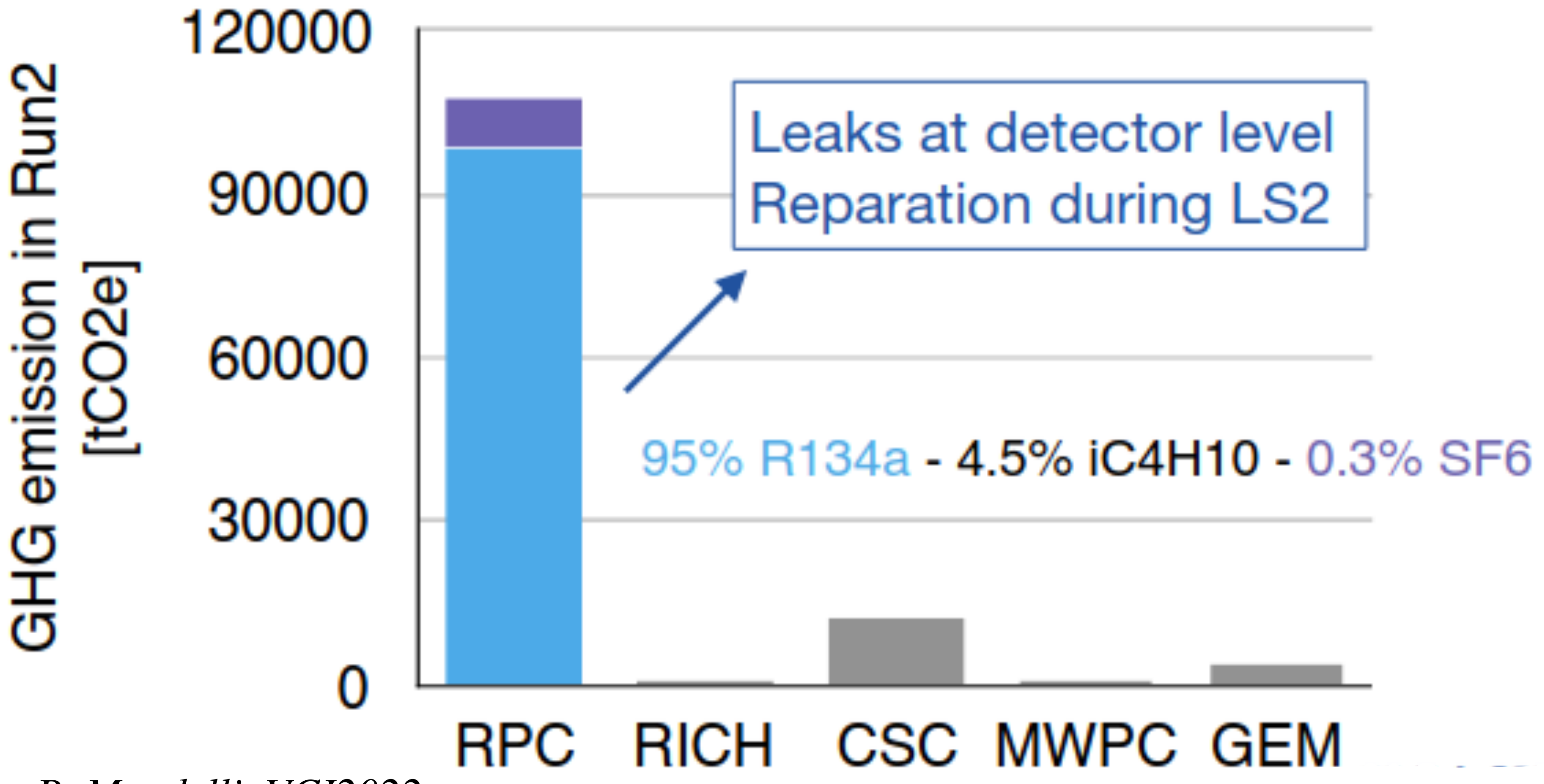
- $C_2H_2F_4$ and SF_6 are fluorinated greenhouse gases (F-gases), having high Global Warming Potential*:
  - ➡ GWP($C_2H_2F_4$) = 1430
  - ➡ GWP(SF_6) = 22800
  - ➡ Total GWP of the gas mixture: 1485

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

The "standard" gas mixture

- F-gases with high Global Warming Potential have been limited by the EU regulation 517/2014
- CERN is committed to reducing its direct greenhouse gas emissions
- Intense research activity on alternative eco-friendly gas mixtures for RPCs





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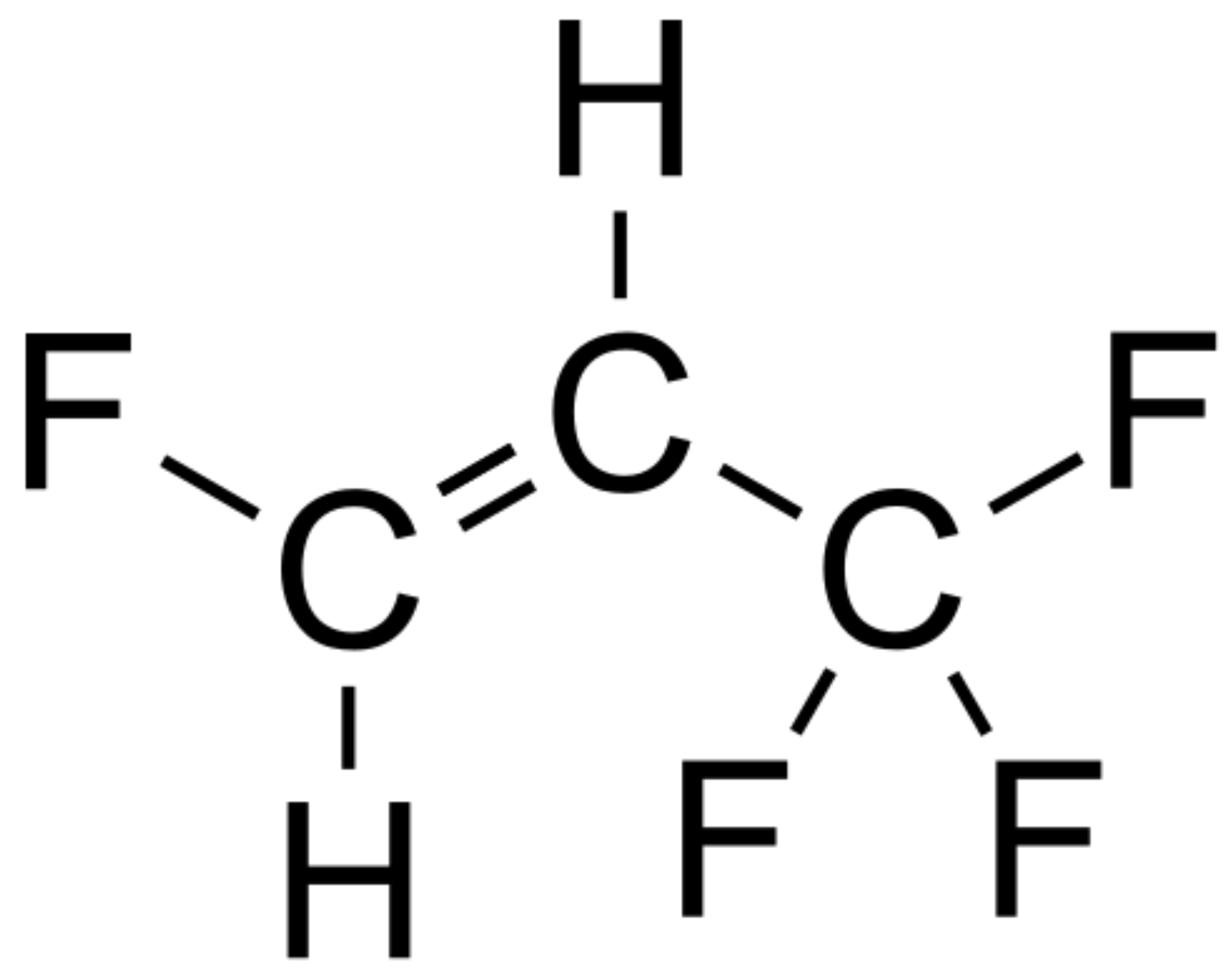
➡ Phase down of the production and consumption of such gases

➡ Ban of the gases if a more eco-friendly alternative is available

➡ Reduction of emissions from existing equipment

The search for a new gas-mixture

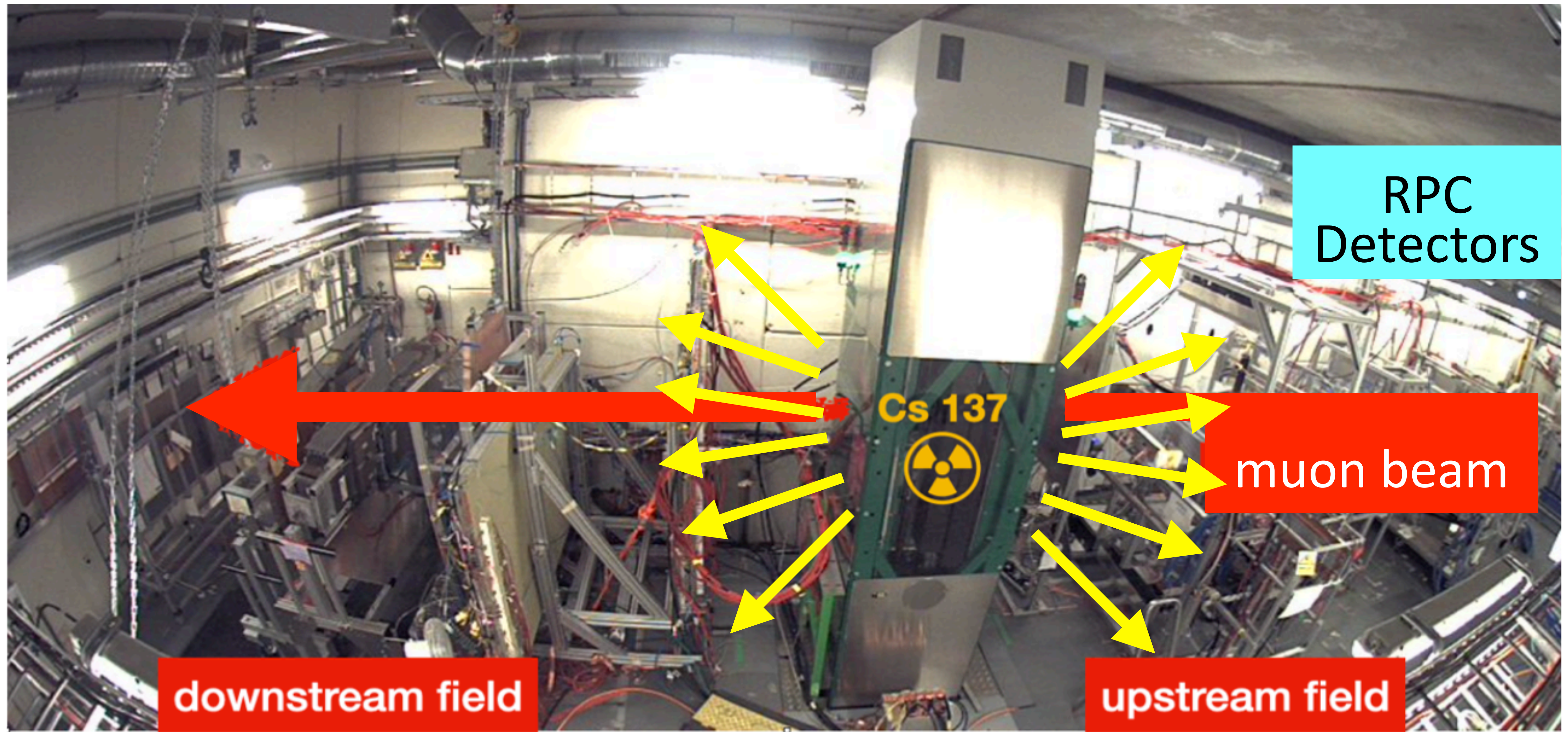
- Requirements: low GWP, low toxicity, not flammable and detector performance comparable with standard one
- In industrial applications $C_2H_2F_4$ is being replaced with HydroFluoro-Olefins (HFOs)
  - the replacement of $C_2H_2F_4$ with HFO moves the operating voltage (working point WP) at much higher values (es. >13kV for 2mm gap)
  - the addition of CO_2 helps in decreasing the WP



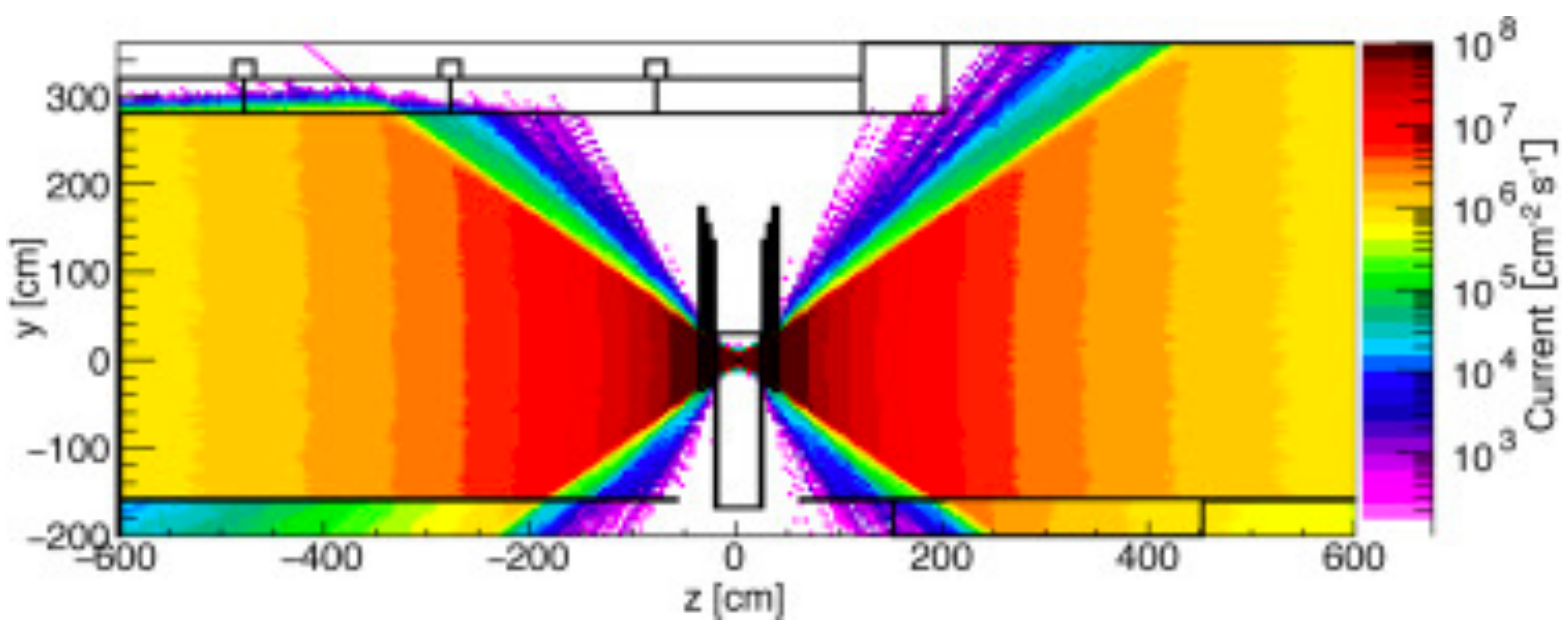
The RPC ECOGAS@GIF++ Collaboration

- The RPC ECOGAS@GIF++ Collaboration is a joint effort between RPC communities from different experiments with the goal to study of new eco-friendly gas mixtures
  - New gas mixtures studied independently in laboratories from different institutes
  - Common tests of eco-gas mixtures at different LHC-like background conditions at CERN GIF++
  - Testing the very same gas mixtures with different detector layouts and front-end electronics allow to disentangle the effects related either to specific RPC designs and/or production techniques
- People involved from: ALICE, ATLAS, CERN EP-DT, CMS, LHCb/SHiP

The GIF++ Facility



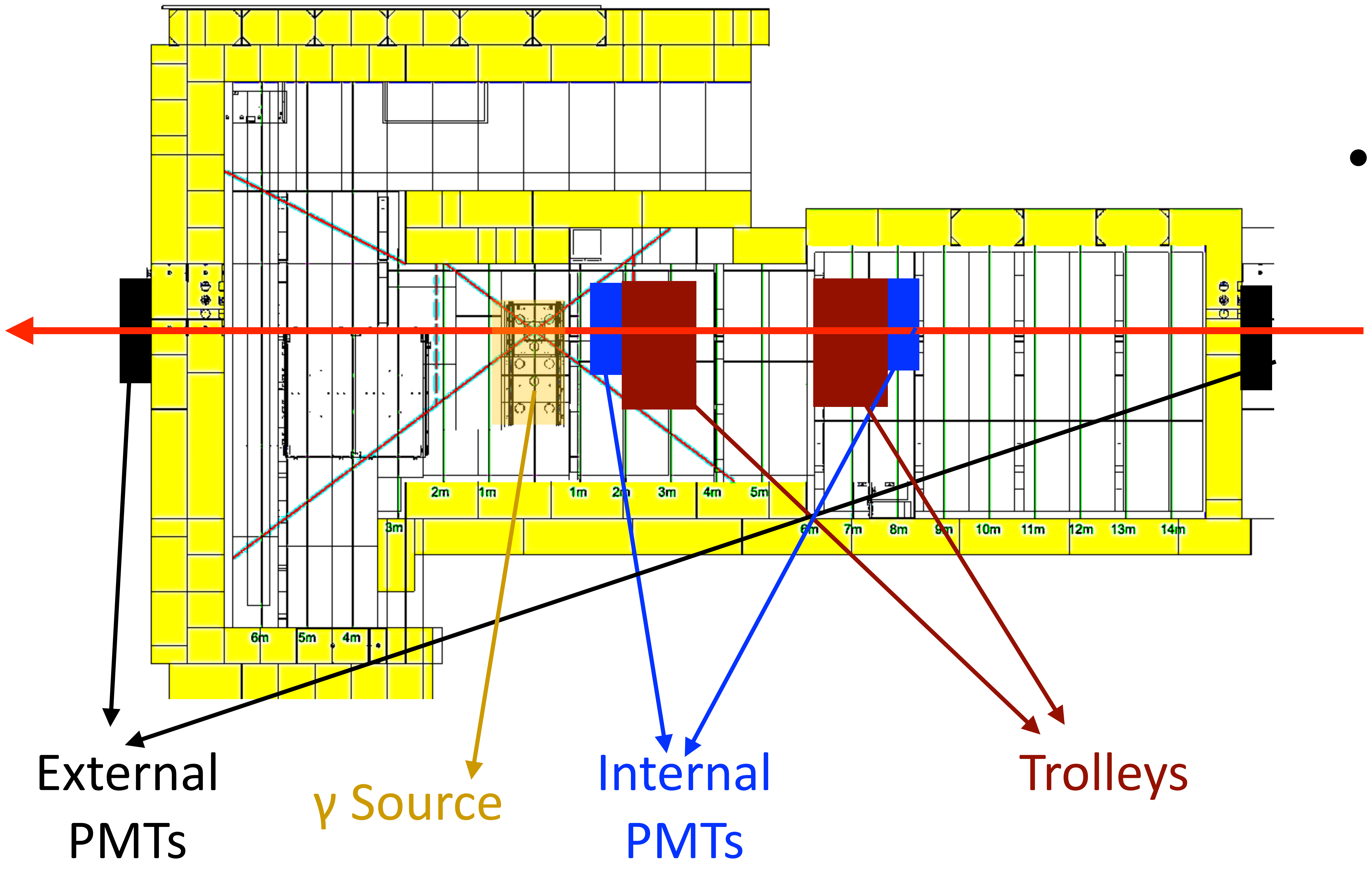
- 137Cs source producing γ (primary photons at ~660 keV) with activity ~13 TBq + adjustable filters (24 possible attenuation factors, ABS)



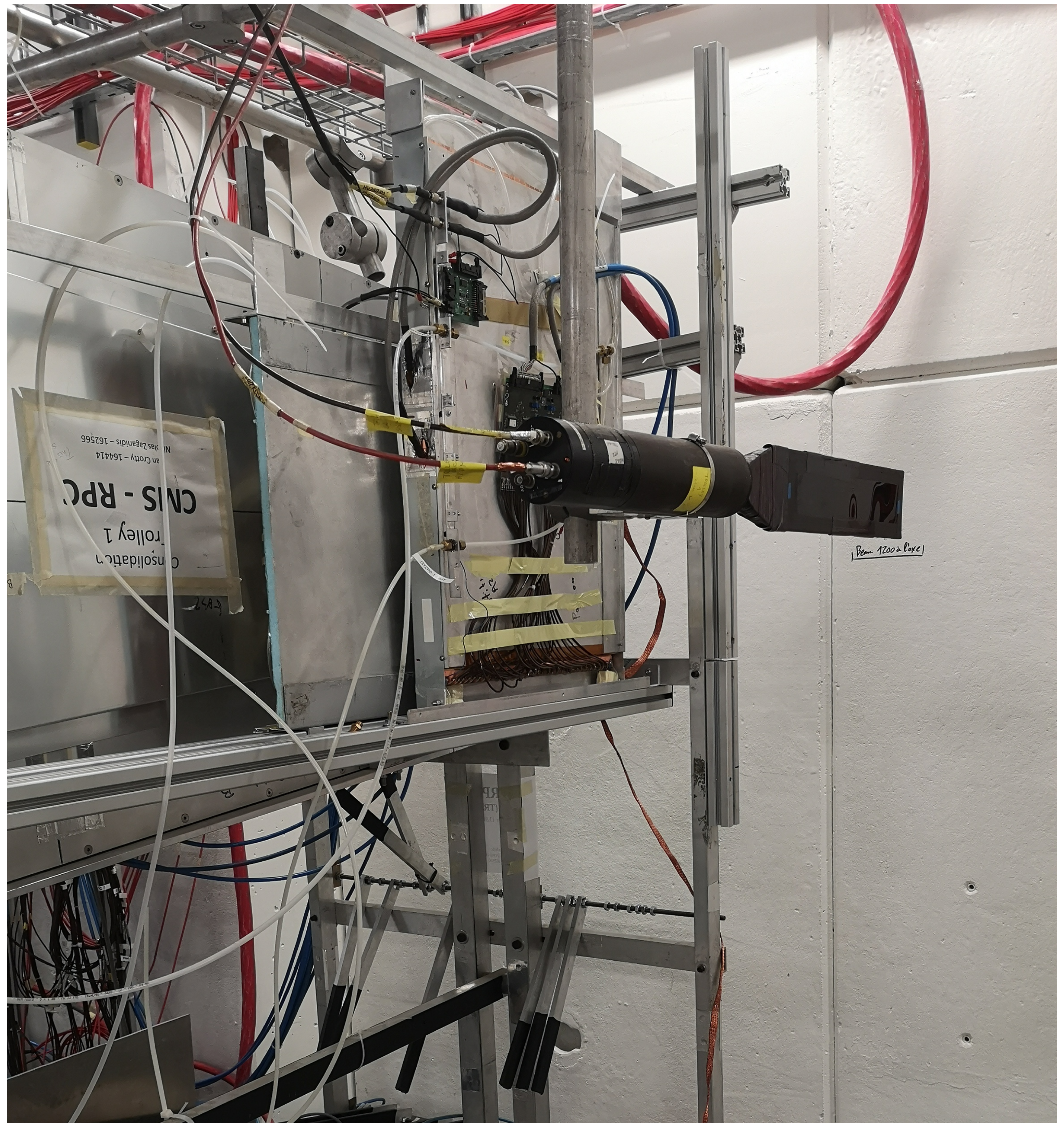
https://doi.org/10.1016/j.nima.2017.05.045

- High-energy muon beam (100 GeV/c) from the secondary CERN SPS H4 beam line.

The GIF++ Facility



- RPC trolleys placed in the upstream field



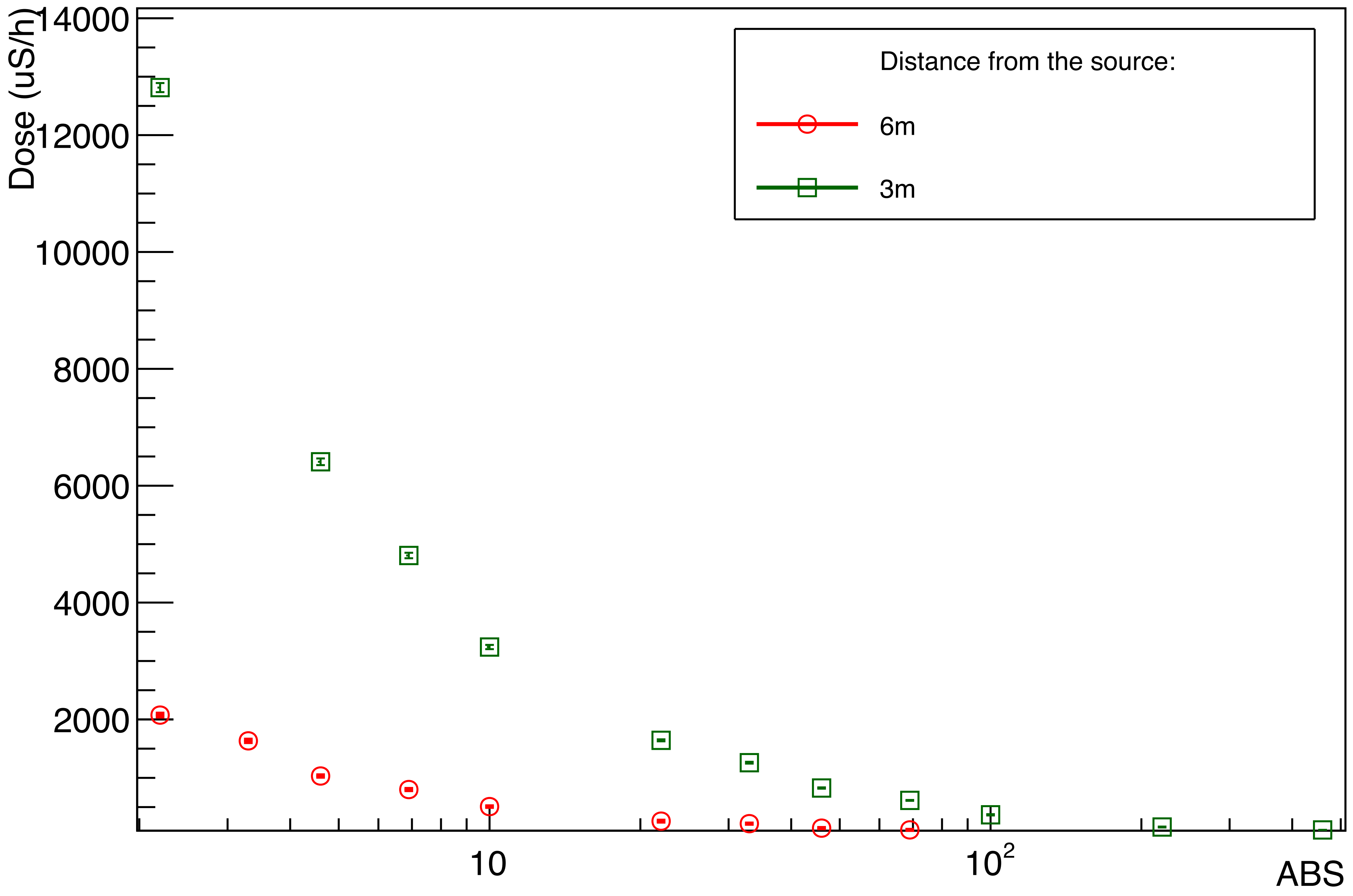
One of the scintillators inside the bunker

- Beam trigger during μ spill provided by coincidence of 4 scintillators (2 inside the bunker and 2 outside) → Effective area 10x10 cm^2
- Gamma rate evaluation (autotrigger mode) during interspill

Beam tests at GIF++

- Three mixture tested with several ABS with 6 chambers:
  - Std: 95.2% $C_2H_2F_4$ / 4.5% iC_4H_{10} / 0.3% SF_6
  - Eco2: 60% CO_2 / 35% HFO / 4% iC_4H_{10} / 1% SF_6
  - Eco3: 69% CO_2 / 25% HFO / 5% iC_4H_{10} / 1% SF_6

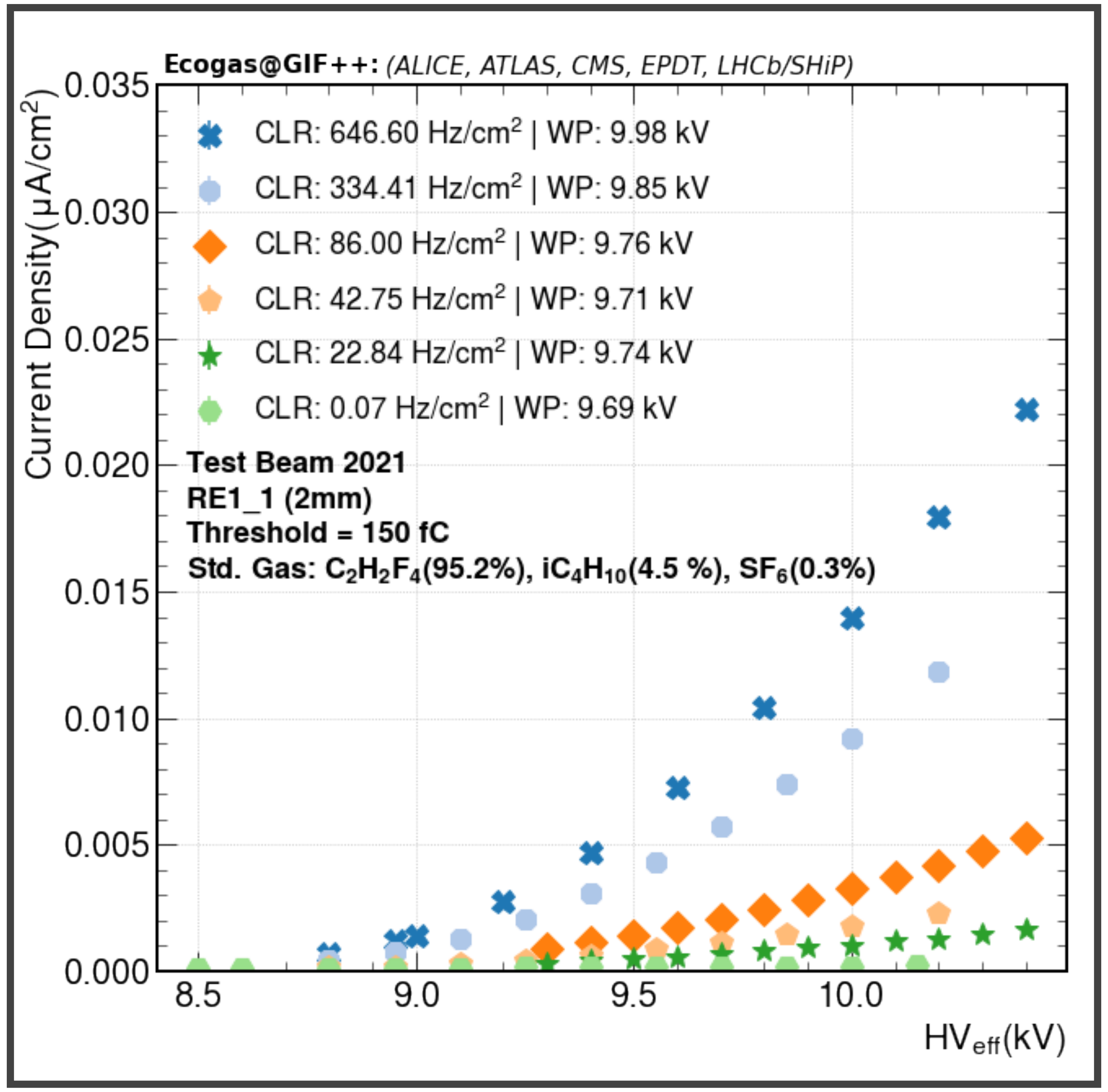
- Data comparison among chambers located at different distances from source is performed at the same dose measurement

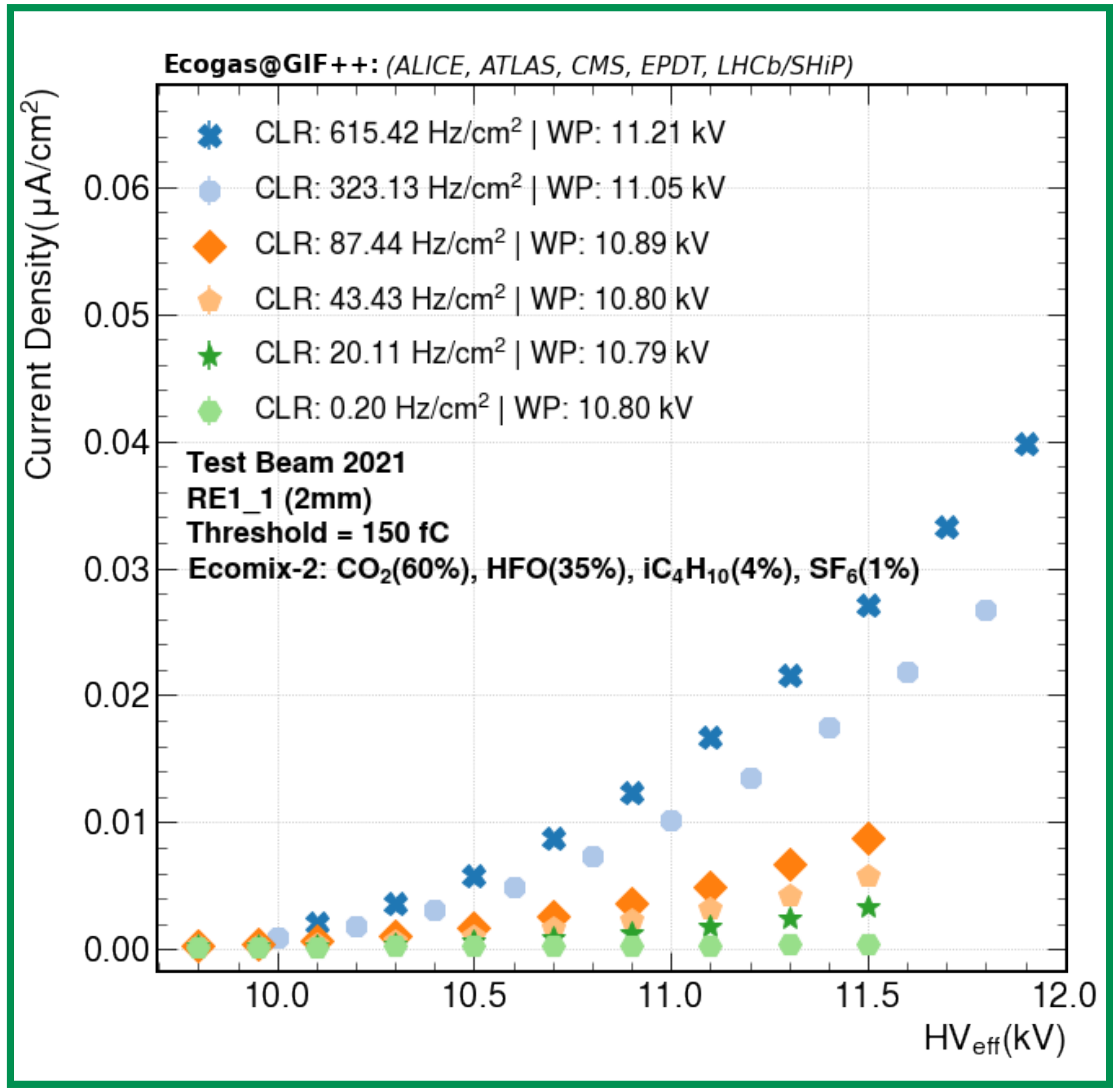


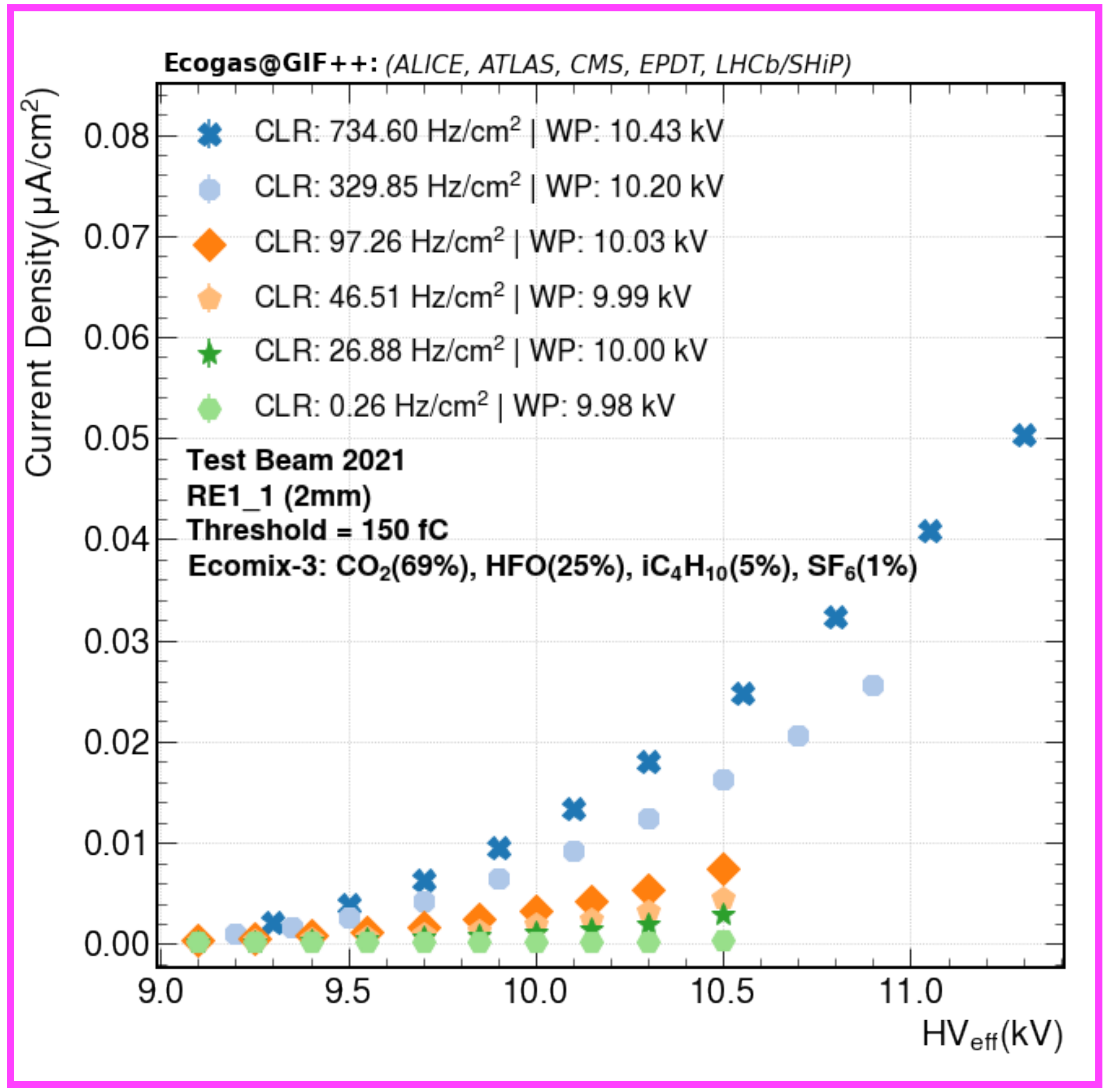
Beam tests at GIF++

	Chamber 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
BARI_1mm	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 100 cm, bases 51 cm and 33 cm) 2 mm double gap 2 mm bakelite electrodes	1D readout (128 strip) 1 cm pitch TDC
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

Current





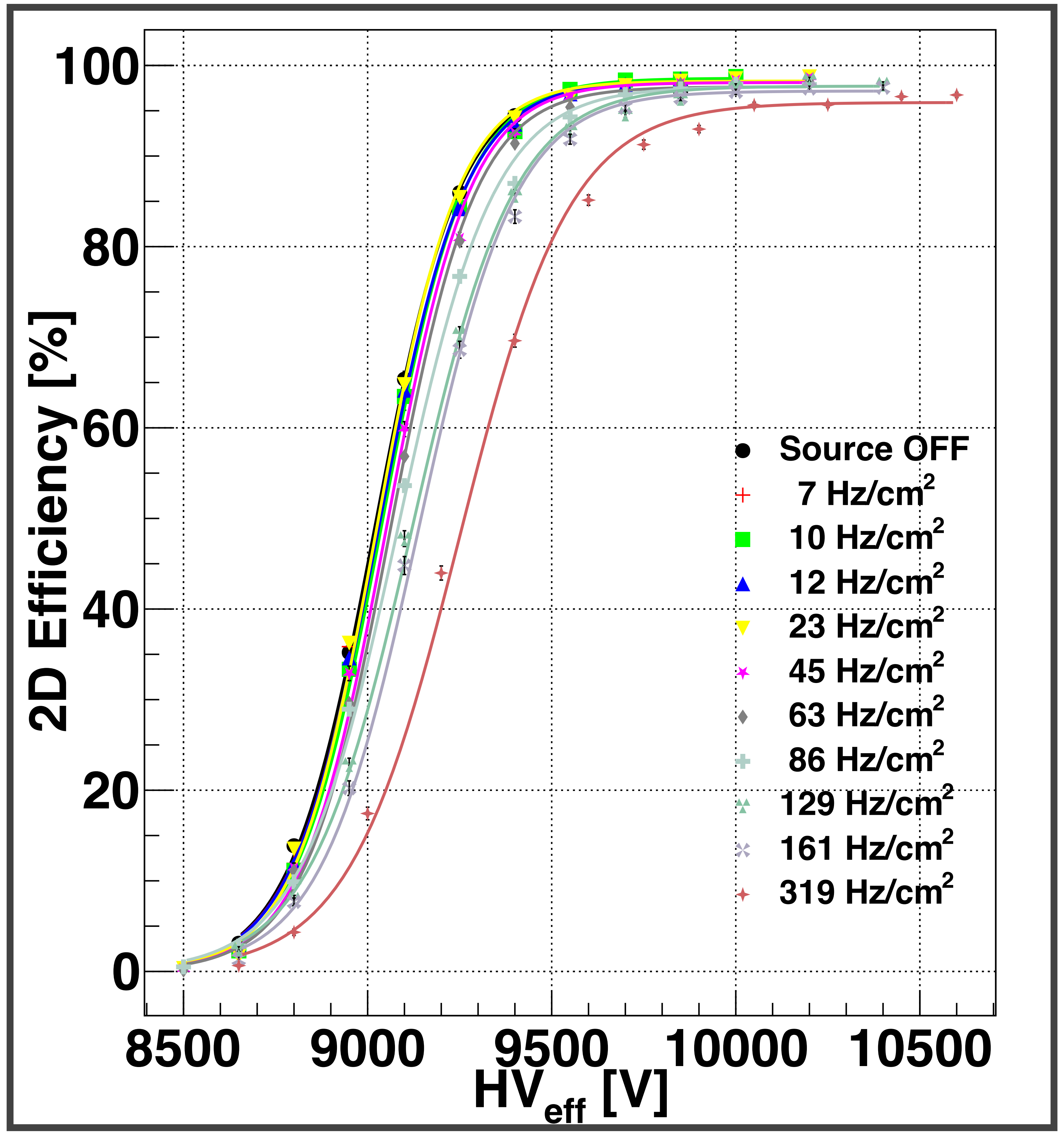


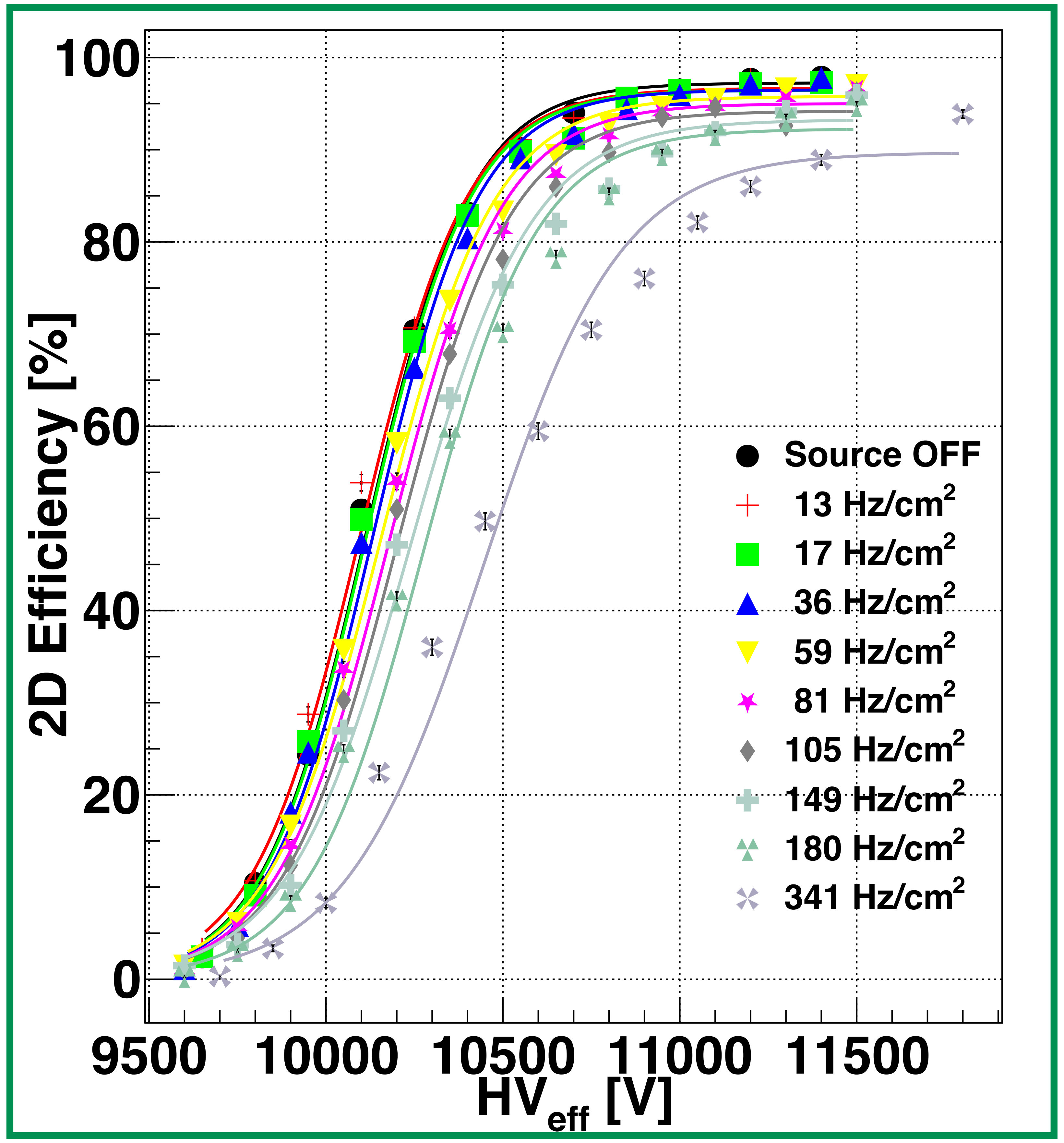
e.g. CMS RPC 2 mm double gap, 128 readout strip

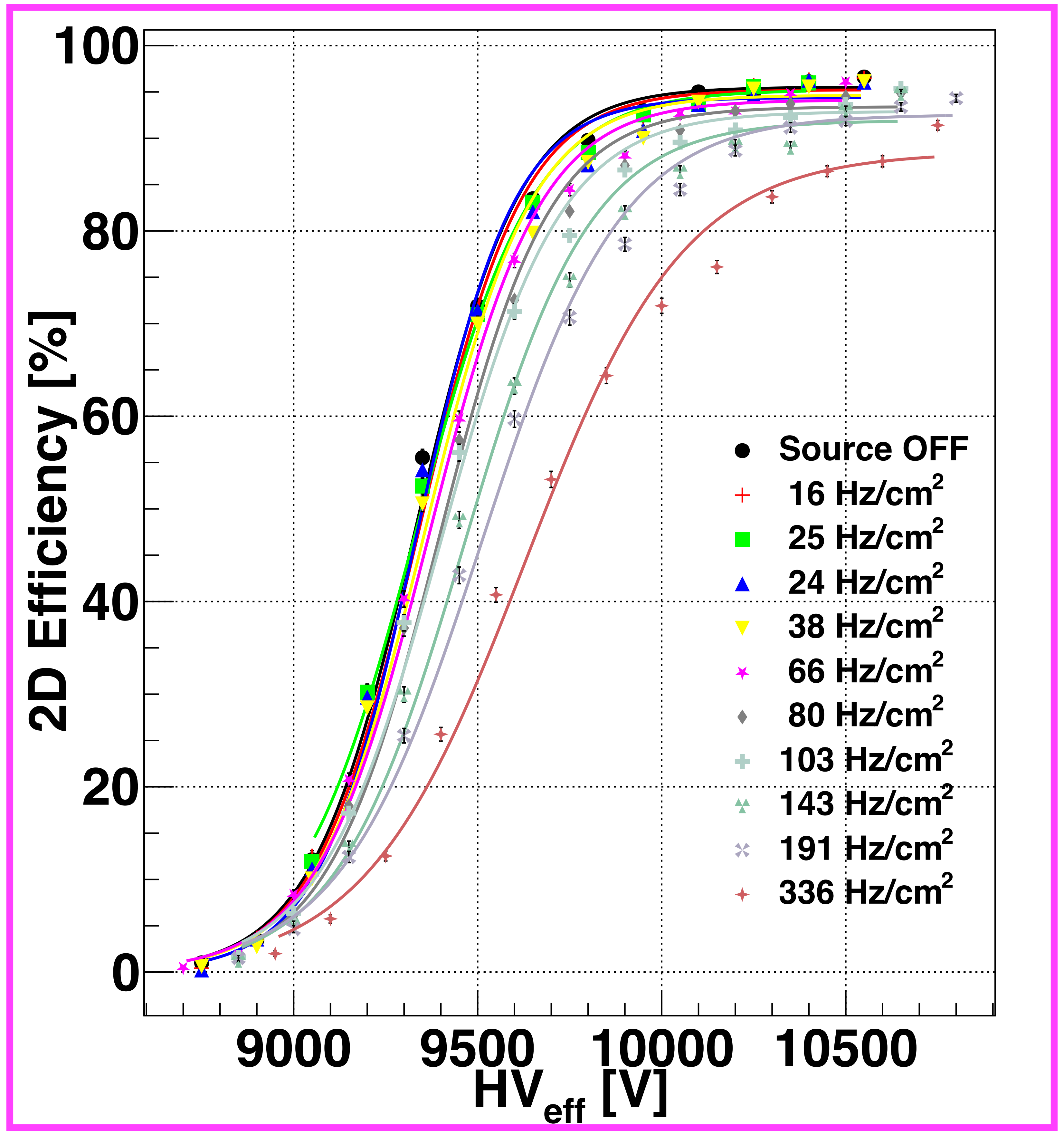
Current increases with eco gas mixtures

Efficiency

- Comparable efficiency plateau without irradiation. Visible drop with irradiation
- Eco2: better performance in terms of current at Working Point and efficiency



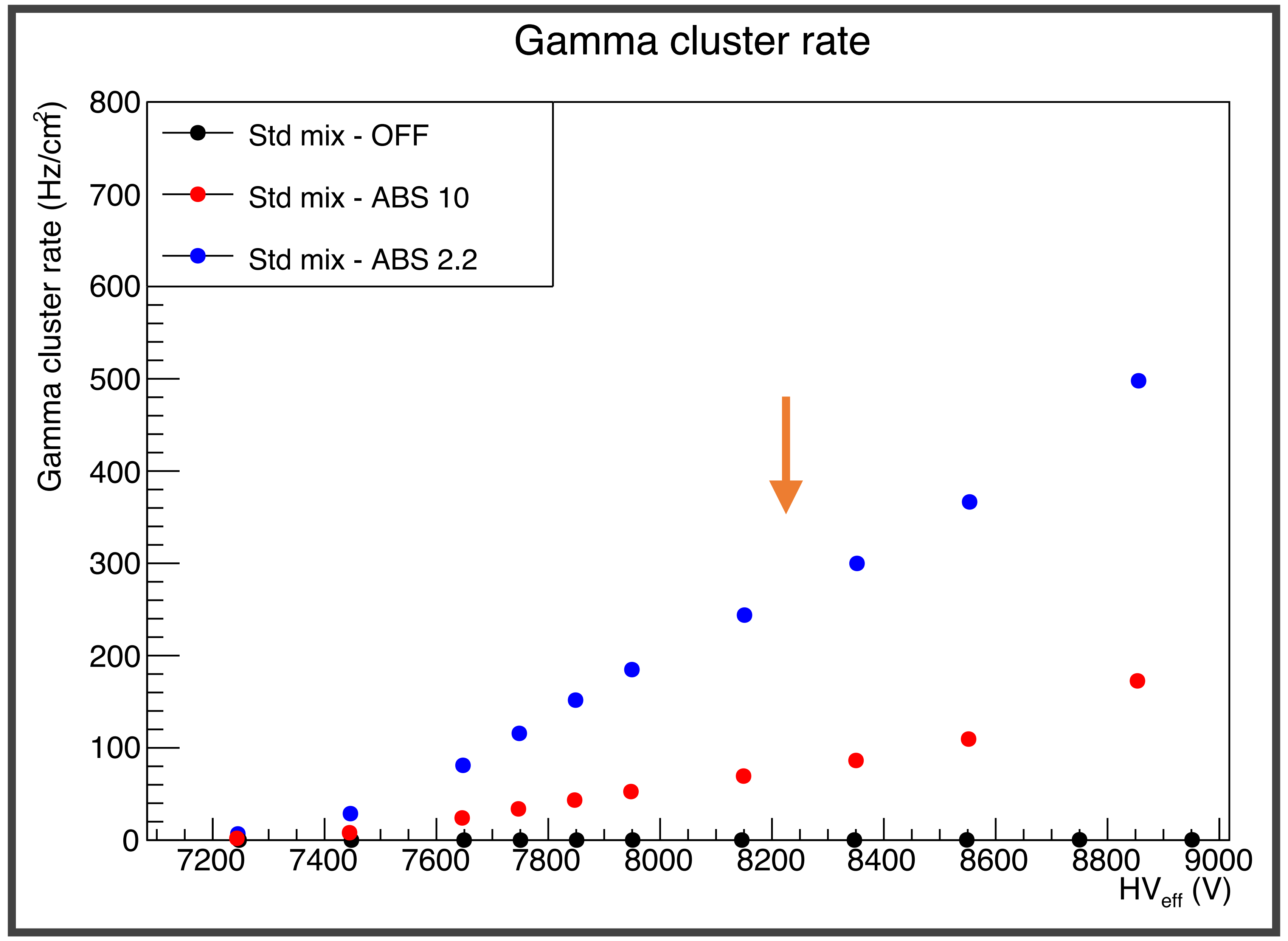


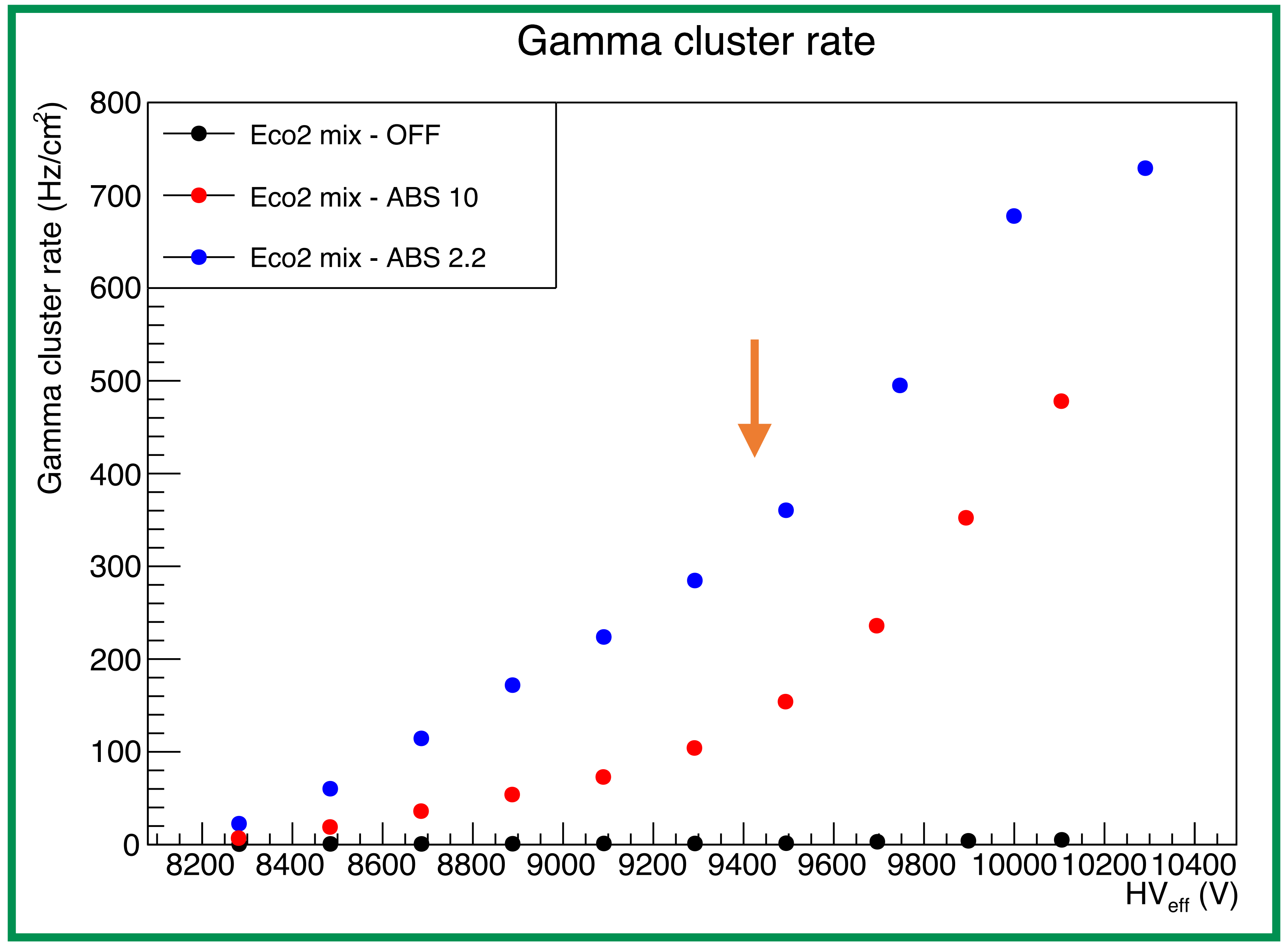


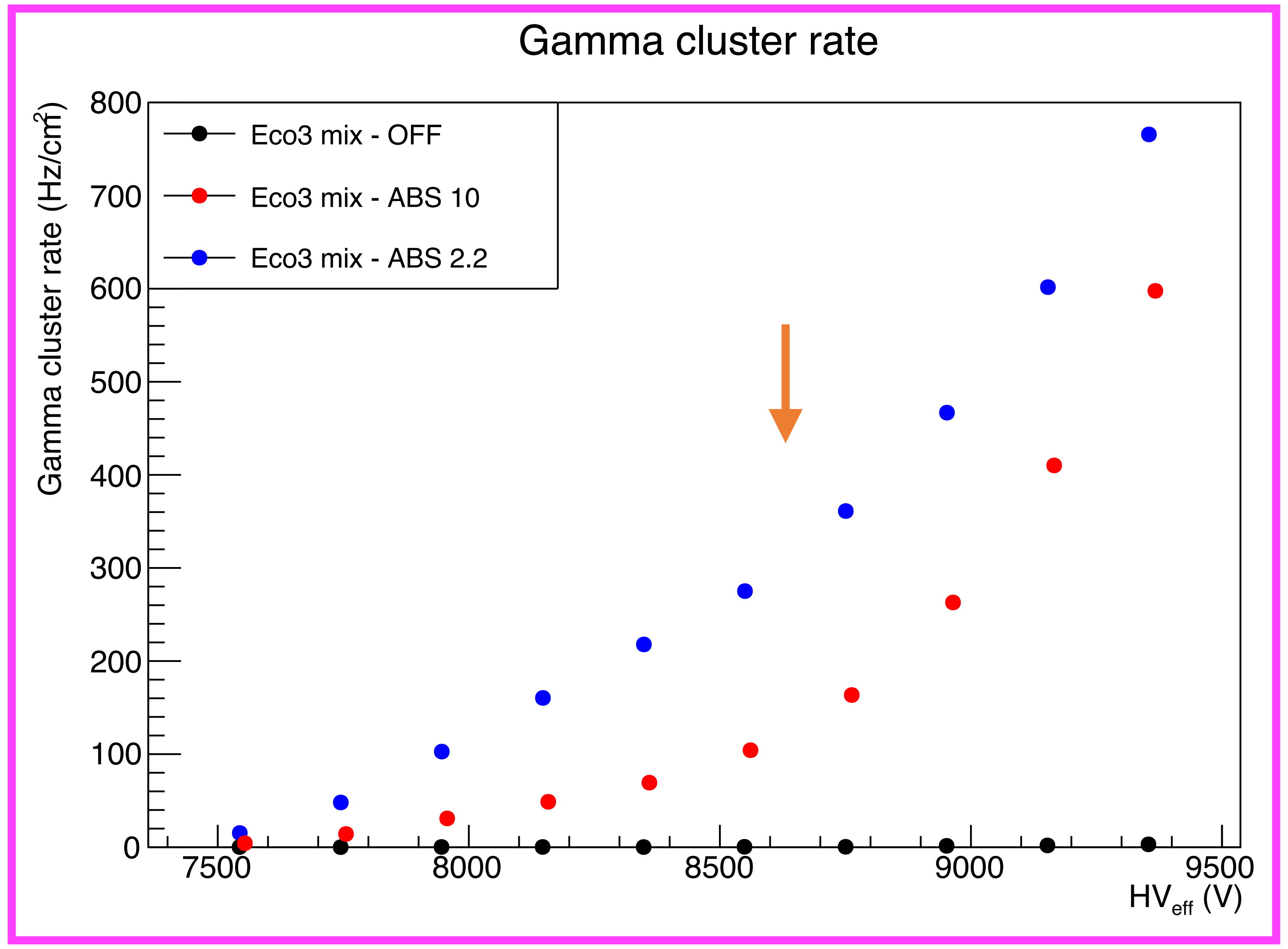
e.g. ALICE RPC 2 mm gap, 16+16 readout strip

Gamma cluster Rate

- Gamma rates measured with the three mixtures are comparable at the WP for the same ABS
- The increase with HV is more pronounced at higher irradiation conditions



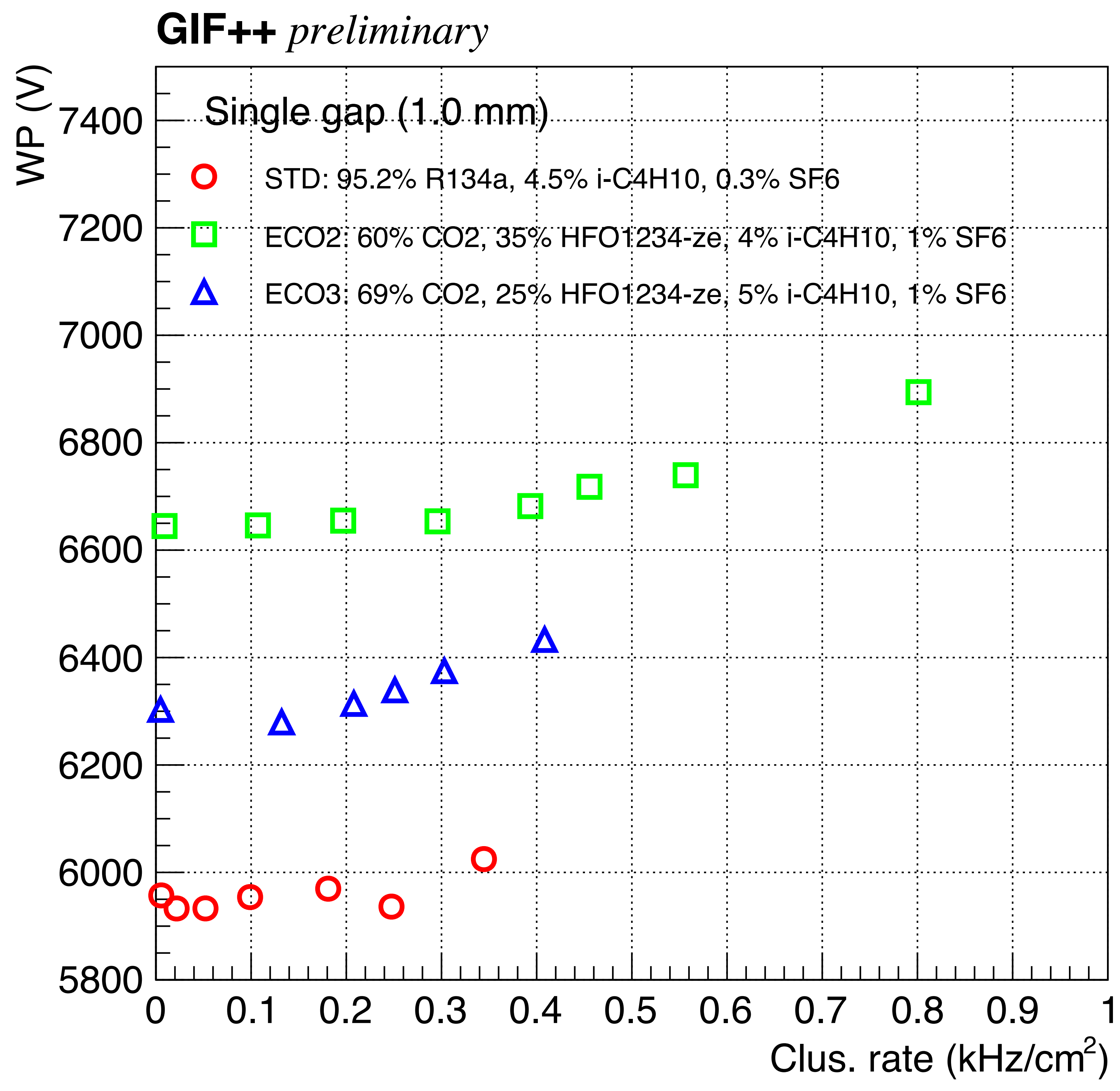


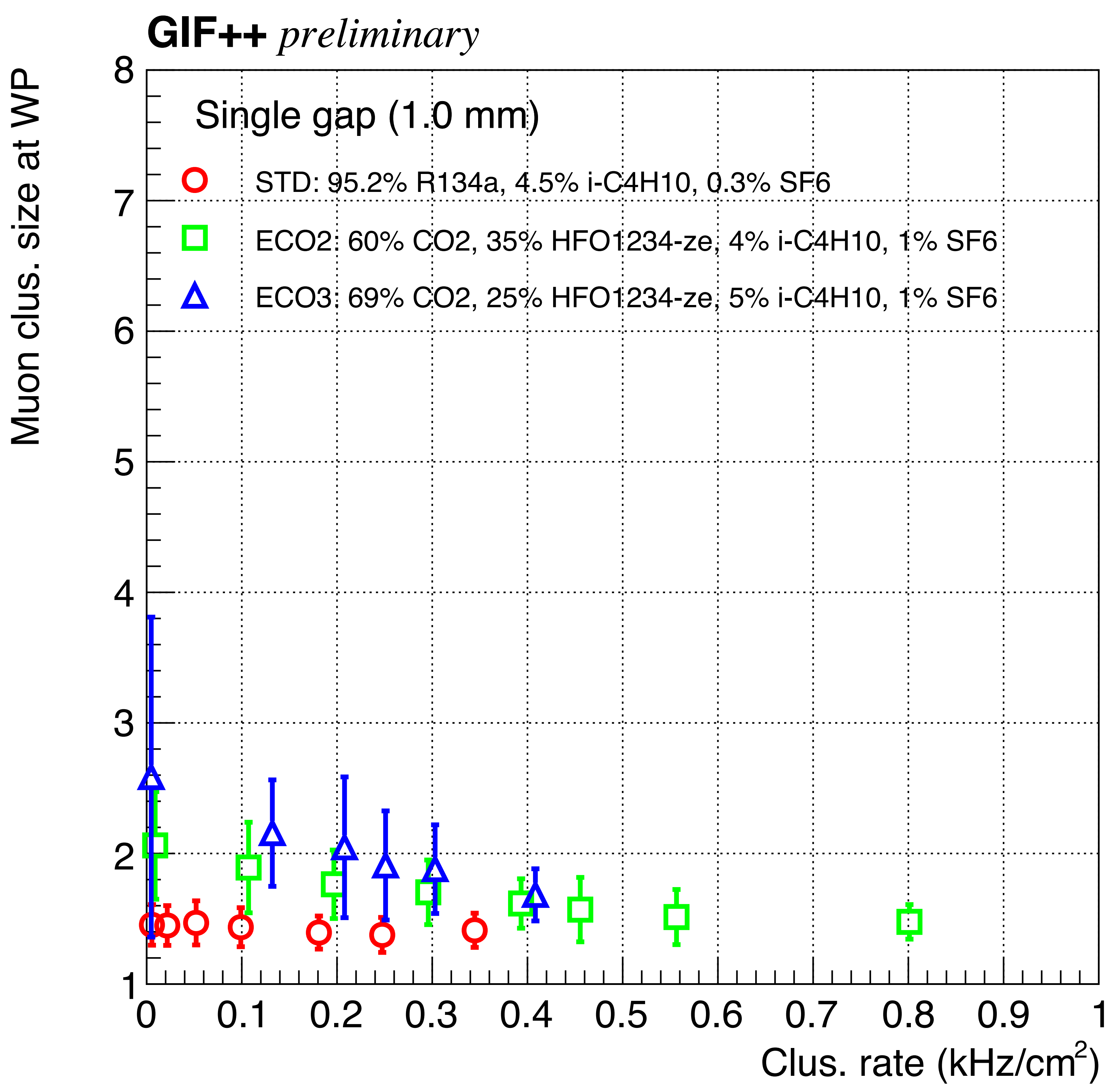


e.g. LHCb/SHiP RPC 1.6 mm gap, 32x32 readout strip

Cluster rate and size

- Cluster rate almost constant for the different gas mixtures at Working point
- Cluster size constant for std mix, decreasing for eco2 and eco3

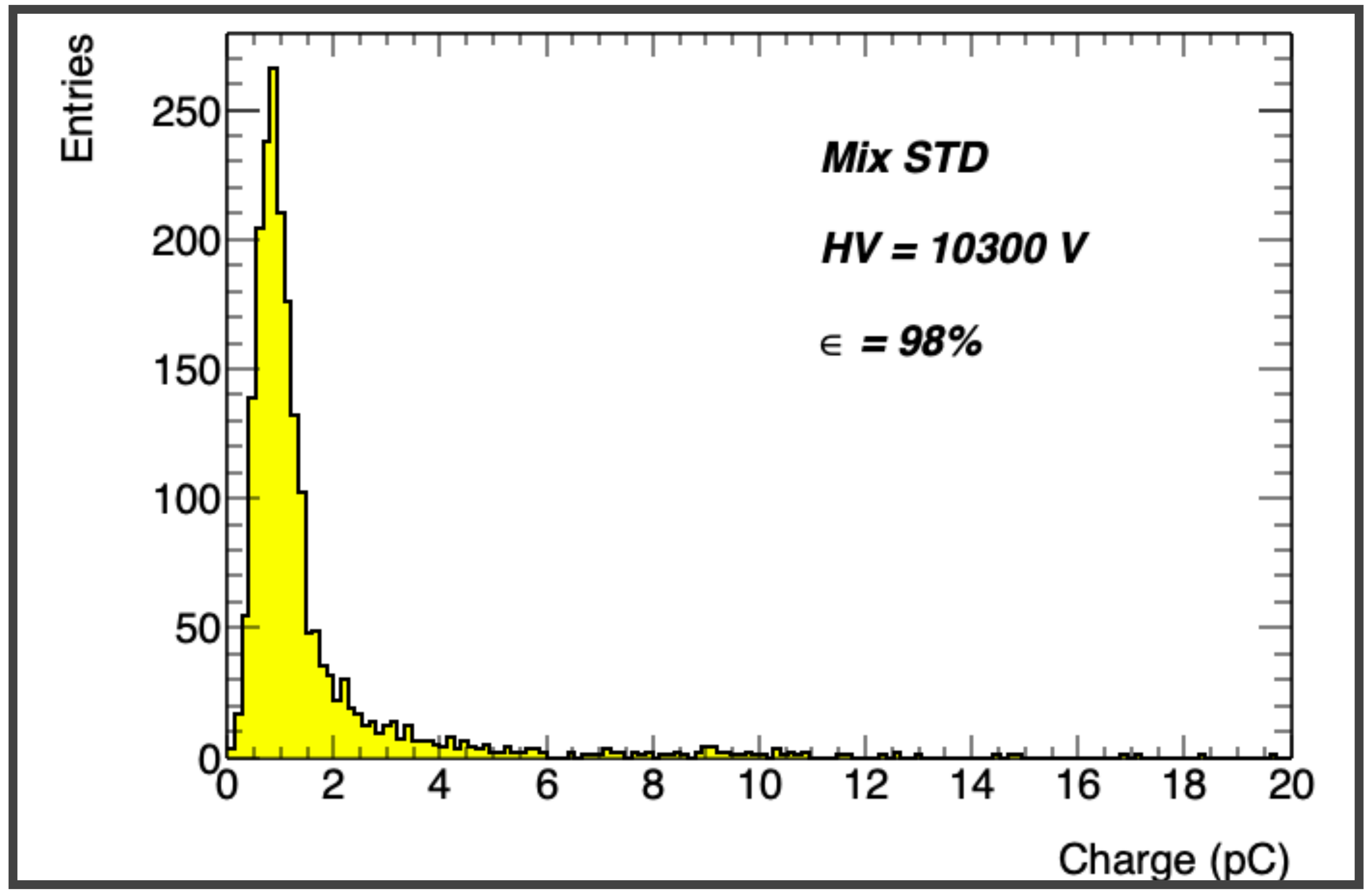


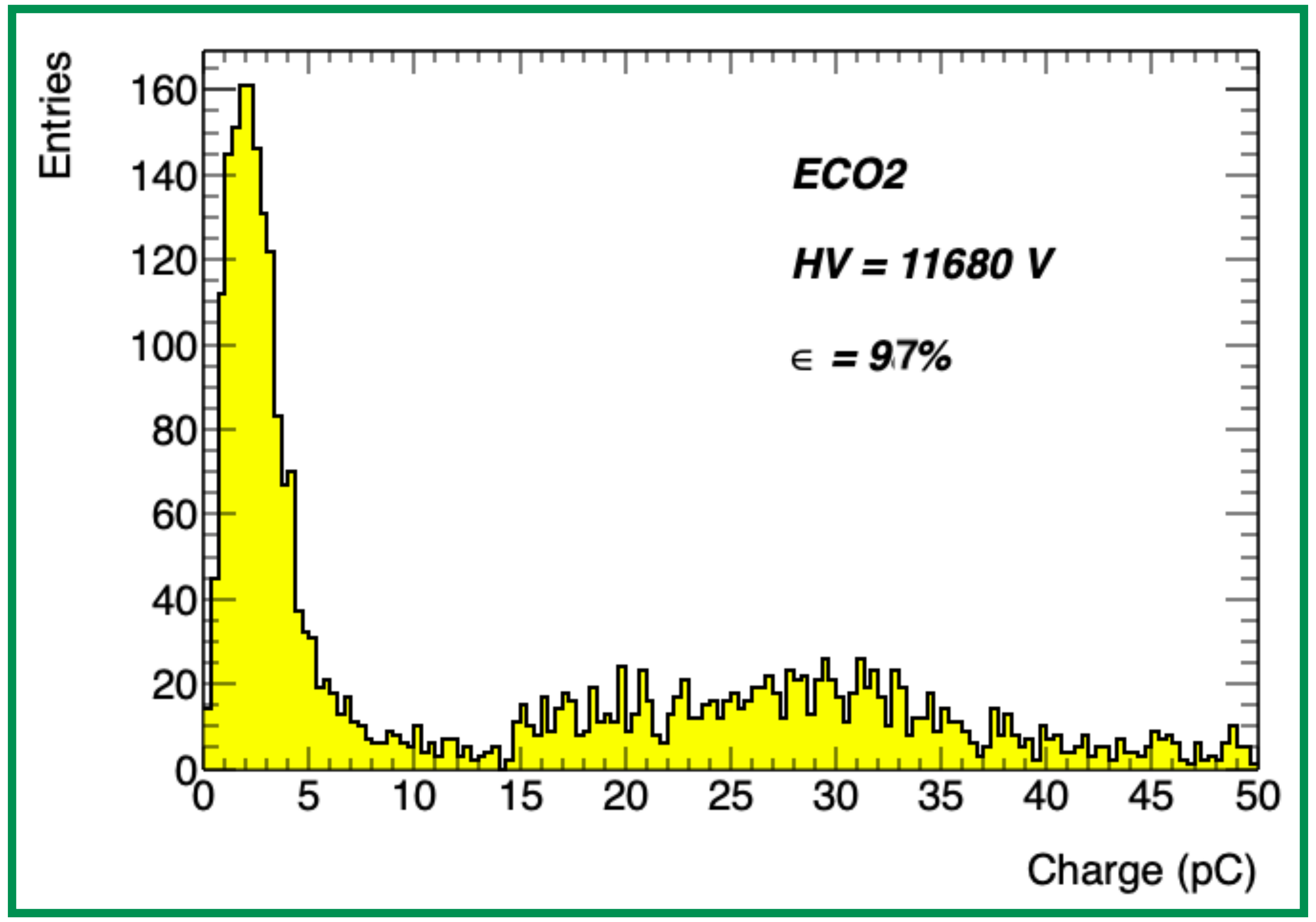


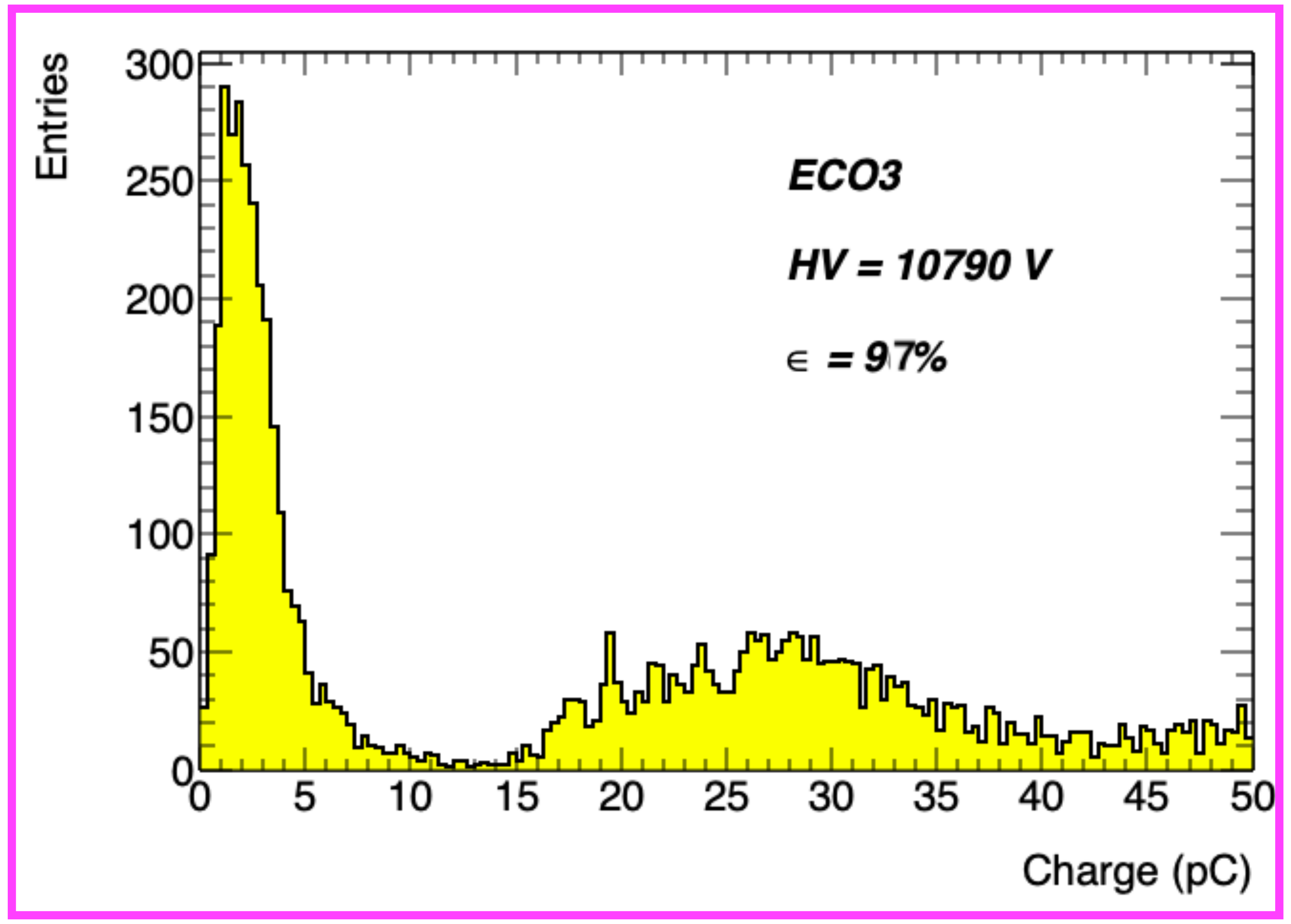
e.g. BARI_1mm RPC 1 mm gap, 1 readout strip

Charge

Second peak for eco gas mixtures due to multiple avalanche signals



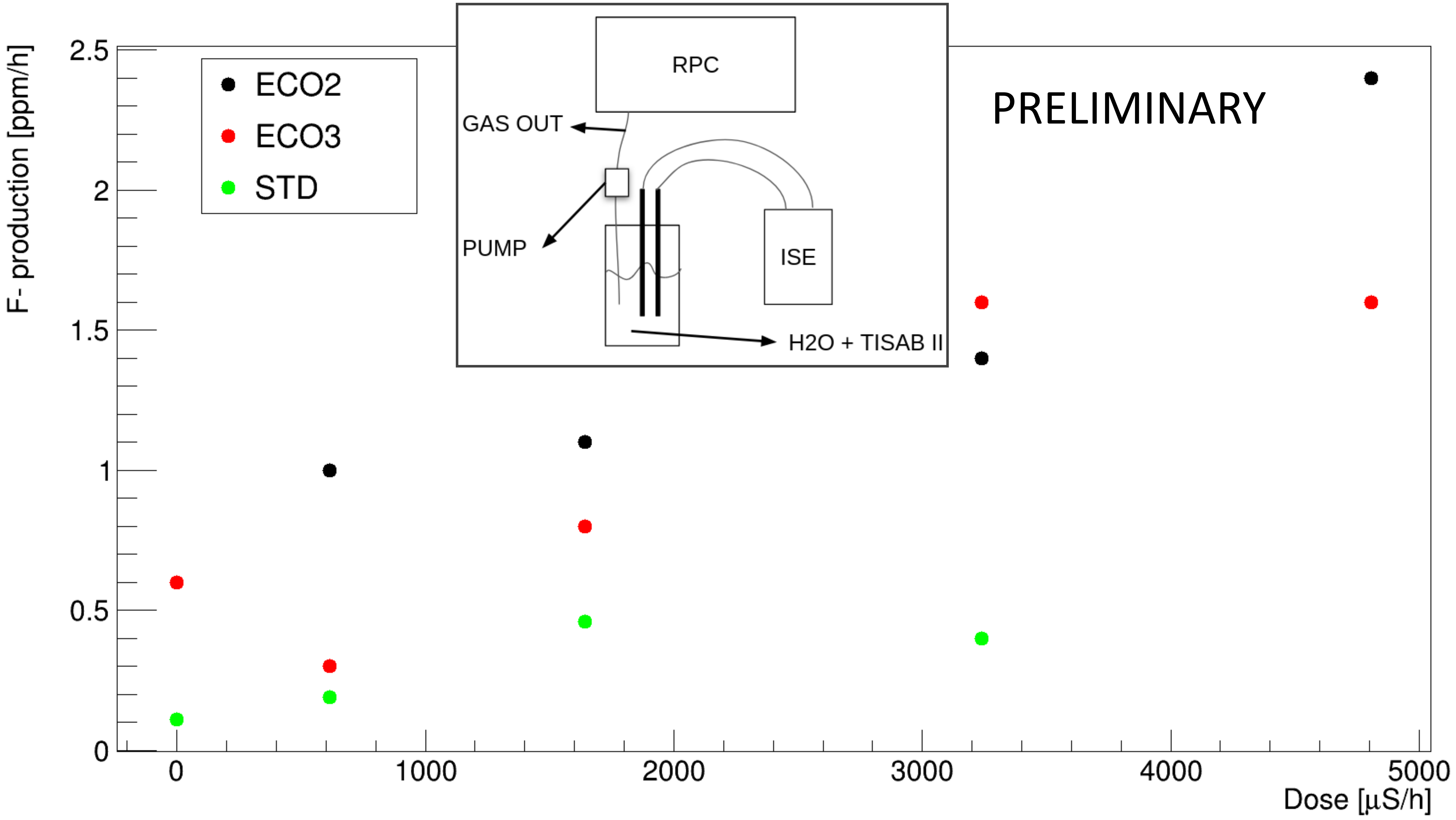




e.g. ATLAS RPC 2 mm gap,
1 readout strip
No irradiation

Long term performance studies

- F^- produced from the $C_2H_2F_4$ and $C_3H_2F_4$ molecules, especially in high irradiation conditions and high electric fields, combines with H_2O, producing HF acid: aging effects to be carefully evaluated

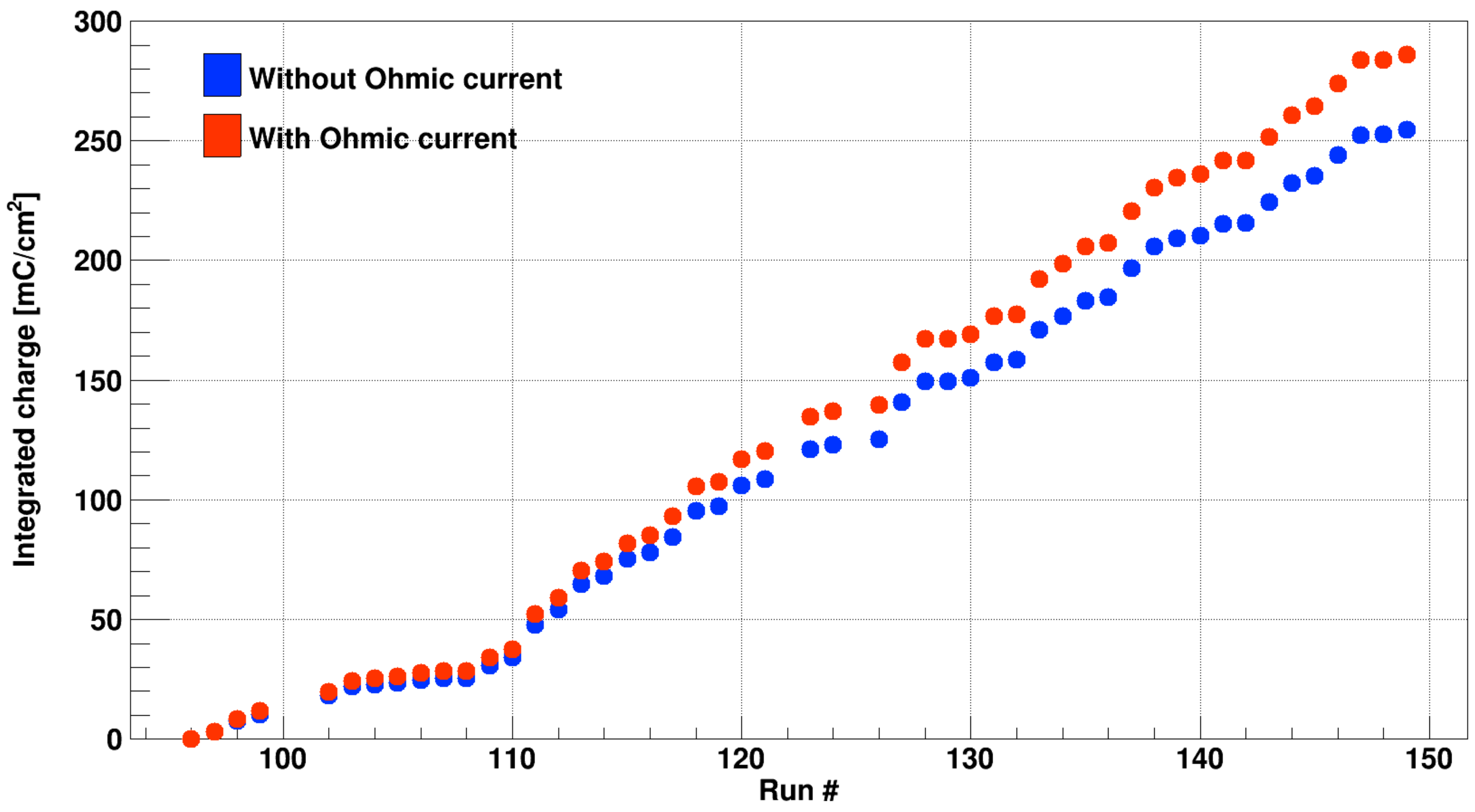


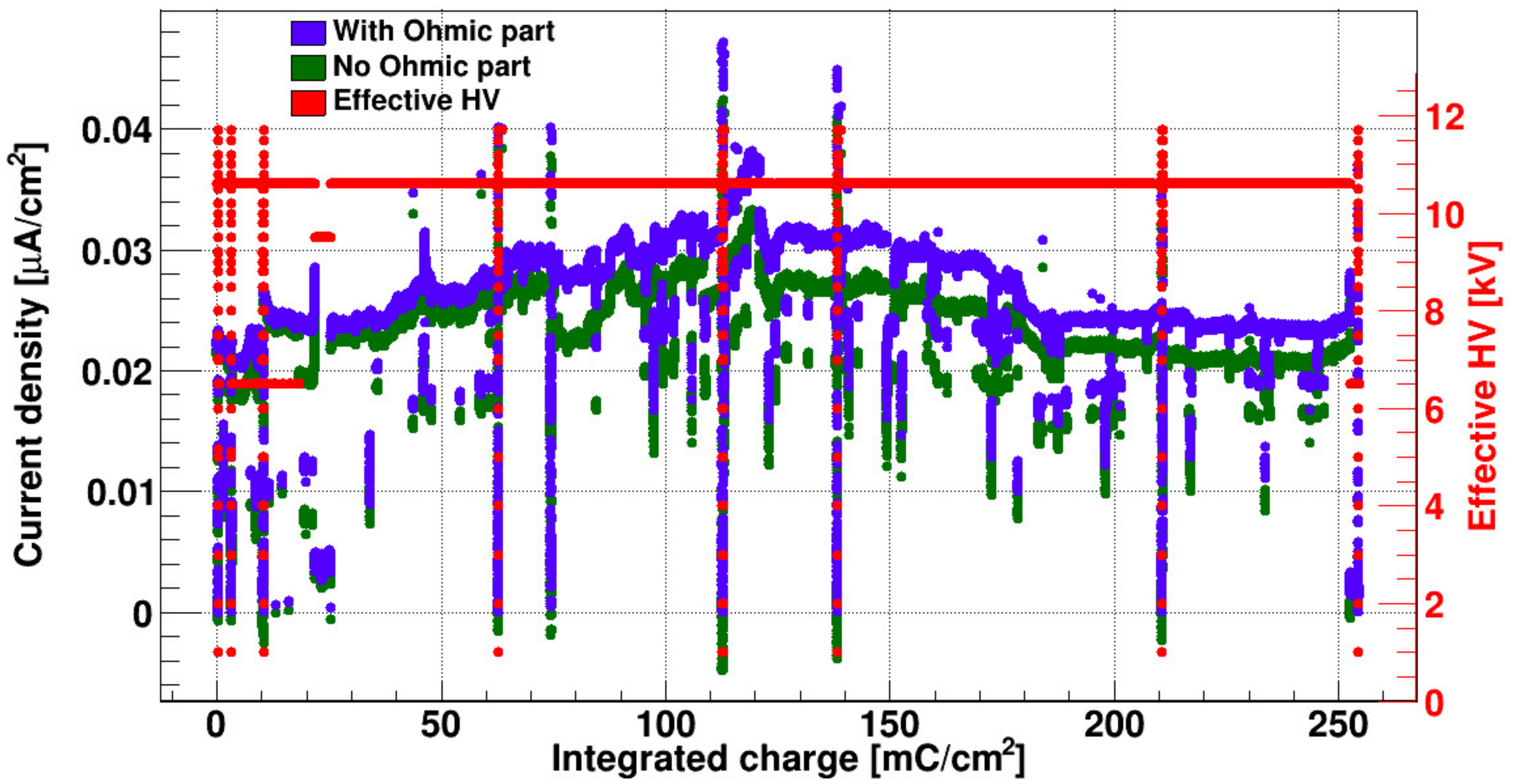
- RPC is exposed to different gamma rates and F^- concentration of output gas is measured (in ppm) and production (in ppm/h) is estimated
- Production at fixed ABS for the gas mixtures tested
- Hints to a higher production for eco-friendly gases

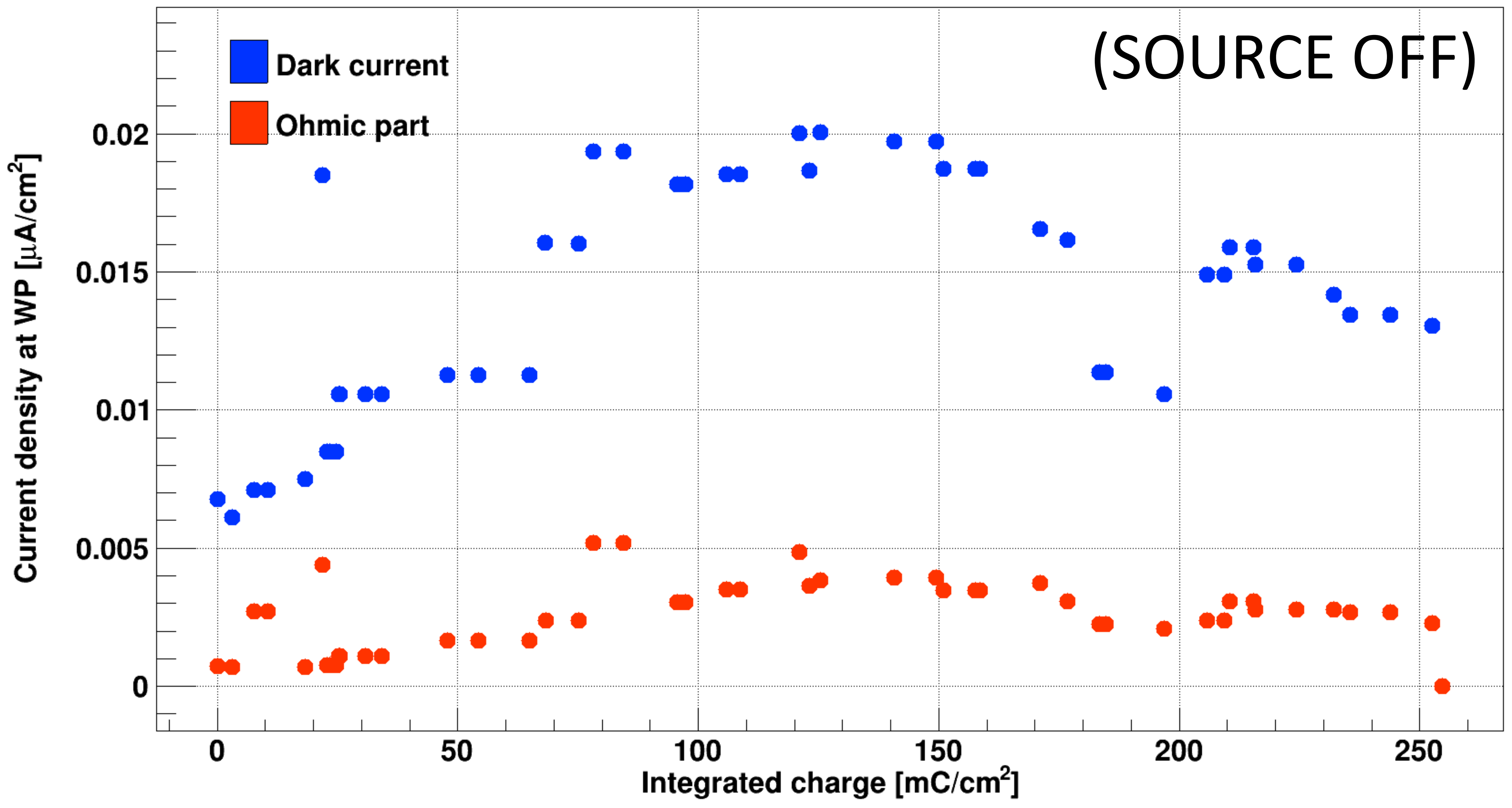
Long term performance studies

- Ageing campaign started with ECO2 (60% CO_2/35% HFO/4% iC_4H_{10}/1% SF_6) gas mixture, better performance shown in beam test
  - Detectors are exposed to gamma irradiation with high voltage applied at fixed value (~ 50% of Maximum Efficiency)
  - Measure of current stability in time under irradiation (ABS 2.2, ~2000µS/h for ALICE and SHiP/LHCb, ~13000µS/h for other chambers)
  - Weekly voltage scans to monitor the stability of the current without irradiation (dark current)

Long term performance studies







e.g. EP-DT RPC 2 mm gap, 7 readout strip

Conclusions

- Resistive Plate Chambers are among the most widely used gaseous detectors for HEP applications, especially in trigger and muon identification systems
- RPC standard gas mixture contains F-gases, with very high GWP
  - New EU regulations are imposing a phase out in the use and marketing of such gases
  - RPCs are the main contributor to CERN F-gases emission
  - Need to find more eco-friendly gas mixtures for current and future experiments: an intense R&D activity is currently ongoing
- Since a few years, a joint effort between RPC communities from ATLAS, ALICE, CERN EPDT, CMS and LHCb/SHiP is in place with the aim of searching for new eco-friendly gas mixtures for RPCs and assessing their performance in different irradiation condition
- Several gas mixtures have been tested. Two of them have shown to be very promising and their ageing effects are now under investigation