UNIVERSITÀ DEGLI STUDI DI TORINO

ALICE

INFN

R&D studies on eco-friendly gas mixtures for the ALICE Muon Identifier

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on behalf of the ALICE Collaboration

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Outline

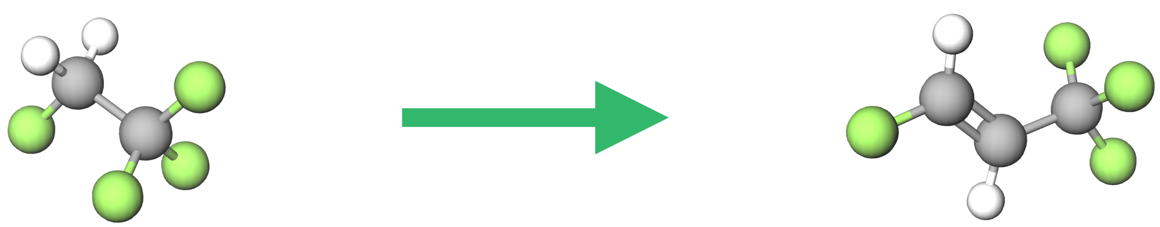
- **R&D on eco-friendly gas mixtures for Resistive Plate Chambers (RPCs):**

  → goal: a non-flammable mixture without greenhouse gases

- **Characterization of mixtures with HFOze:**

  → replacement of tetrafluoroethane with more eco-friendly gases

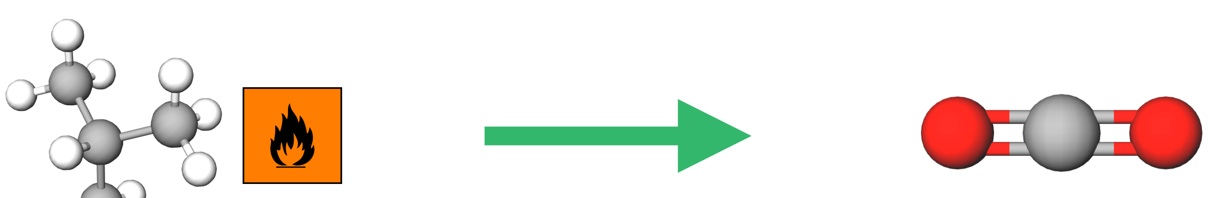
  → HFOze and CO_2 could act for a good solution instead of $C_2H_2F_4$



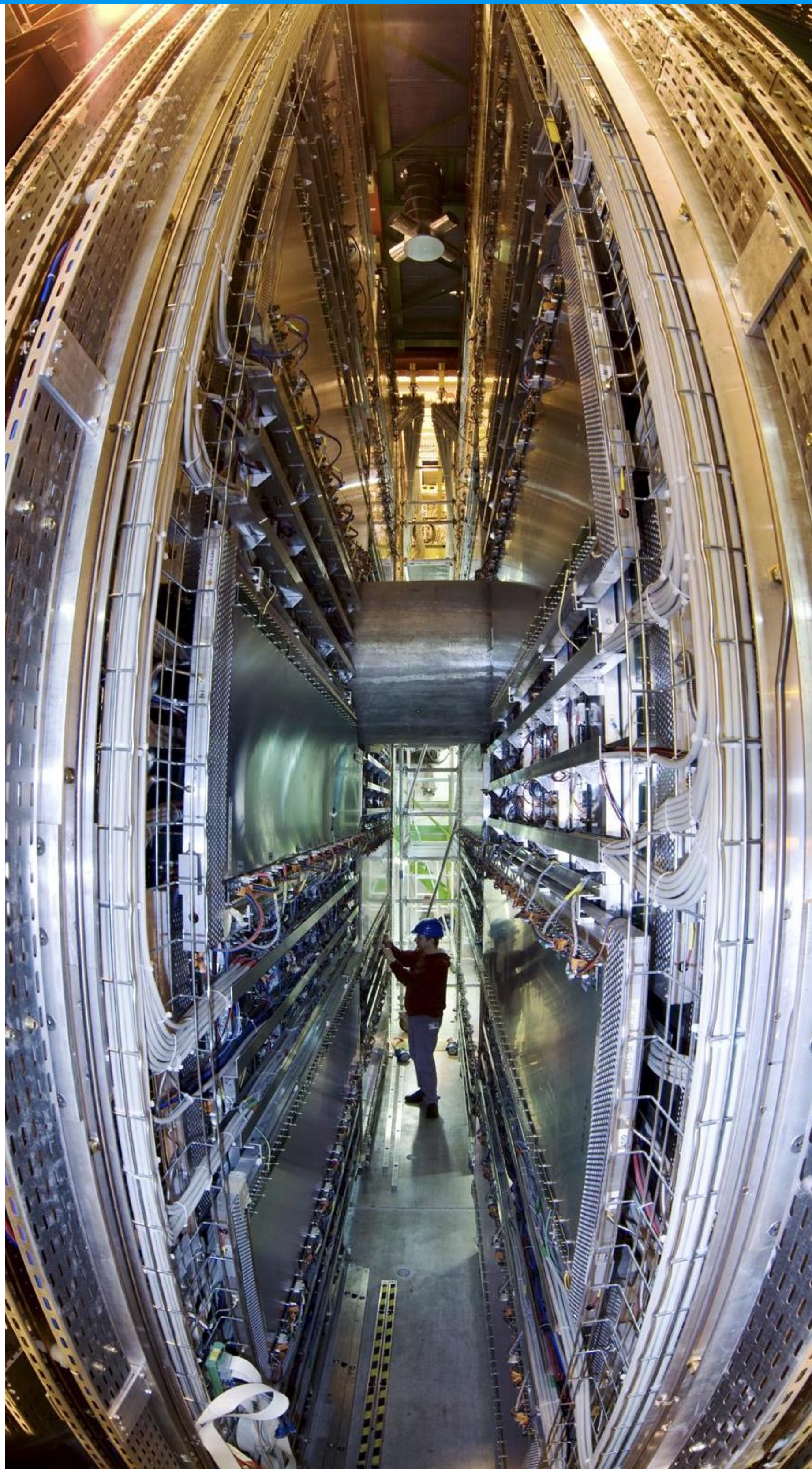
$C_2H_2F_4$ $C_3H_2F_4$

- **Operation stability of RPCs with CO_2-based mixtures:**

  → replacement of isobutane with non-flammable gases in $C_2H_2F_4$-based mixtures



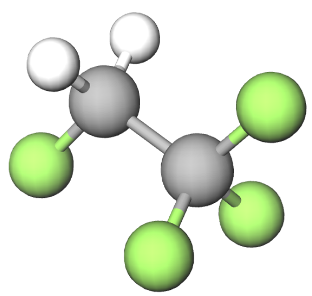
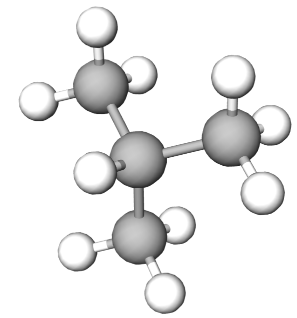
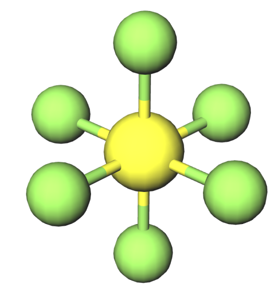
iC_4H_{10} CO_2



ALICE Muon Spectrometer Trigger Chambers

Motivation

RPCs in the ALICE Muon Trigger are currently operating in maxi-avalanche mode at ~10300 V with:

$C_2H_2F_4$	iC_4H_{10}	SF_6
		
tetrafluoroethane	i-butane	sulfur hexafluoride
89.7 %	**10.0 %**	**0.3 %**
GWP = 1430	**GWP = 3.3**	**GWP = 22200**

Global Warming Potential (GWP): is the relative measure of how much heat a greenhouse gas traps in the atmosphere.

GWP_{CO2} = 1 by definition

Motivation for R&D studies on new gas mixtures for the forthcoming Muon Identifier at ALICE:

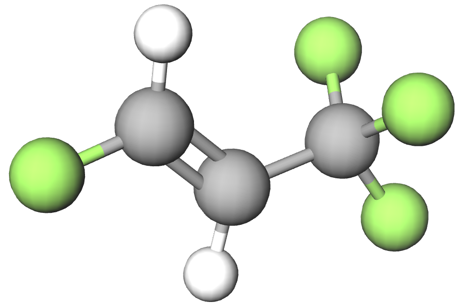
- **security reasons**: the current gas mixture is flammable
- reduction of greenhouse gas emissions into the atmosphere: the present gas mixture has a **GWP = 1350**
- **cost saving**: $C_2H_2F_4$ is being phased out by EU restrictions; SF_6 is banned except for research → **possible rise of prices and limited future availability** → the gas volume at ALICE is quite small (about 0.3 m^3), nevertheless an **alternative gas mixture is welcome**
- the upgrade of front-end electronics is planned in view of Run 3 and enables to operate the RPCs in avalanche mode *(talk: A. Ferretti, "The upgrade of the RPC-based ALICE Muon Trigger", RPC workshop 2018).*

We have just started R&D studies on gas mixtures for possible upgrades in the future.

Experimental approaches

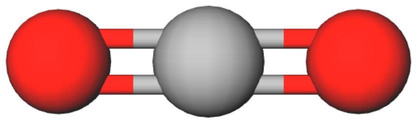
95% of the total GWP for the current ALICE mixture is due to the presence of $C_2H_2F_4$:

- hydrofluoroolefins (HFOs) may be appropriate candidates to replace $C_2H_2F_4$, thanks to their very low GWPs:
  - HFOze and CO_2 could act for a good solution instead of $C_2H_2F_4$
  - chemical structure of HFOze (*C=C-C*) suggests a good capability to absorb photons
- experimental tests are ongoing in Torino to:
  - check the RPC performance with new eco-friendly mixtures
  - identify **some promising gas mixtures for the requirements of the ALICE Muon Identifier**
- as next step, long-time stability tests of new gas mixtures to check rate capability and performance (aging issue)



HFOze

The high concentration of iC_4H_{10} makes the ALICE mixture flammable:



CO_2

- ongoing tests with CO_2 instead of iC_4H_{10} to avoid the use of flammable gases:

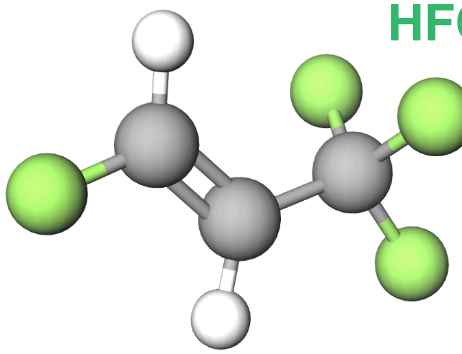
  → non-flammable components would be advisable to make the operation of detectors simpler and safer
- medium-term stability of detectors has been tested with cosmic-ray flux

Guideline for HFOze and CO_2

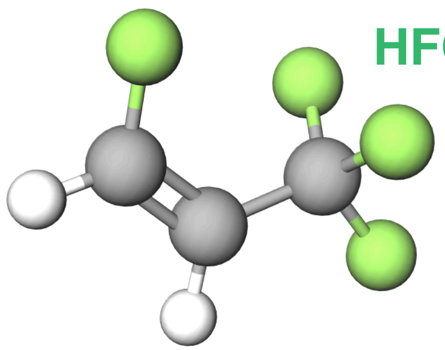
HFOze:

- tetrafluoropropene (*$C_3H_2F_4$*):
  - → it is an **olefin** (double bond in the chain of carbon atoms)
  - → **two isomers** (*z* = hydrogen atoms on the same side, whereas *e* = hydrogen atoms on opposite side)
  - → isomers **z** and **e** have slightly different physical proprieties (i.e. boiling points) but similar electrical properties; different batches can contain different concentration of HFOz (10-30%)
- **GWP < 1** (revision at 5th IPCC)
- it is **not flammable** at room temperature
- the **strong electron attachment makes HFOze a promising gas for electric insulation**:
  - → in particular for high voltage gaseous insulation equipments (doi:10.1088/0963-0252/25/4/045005)

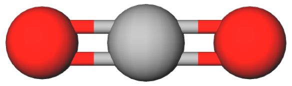
HFOe



HFOz

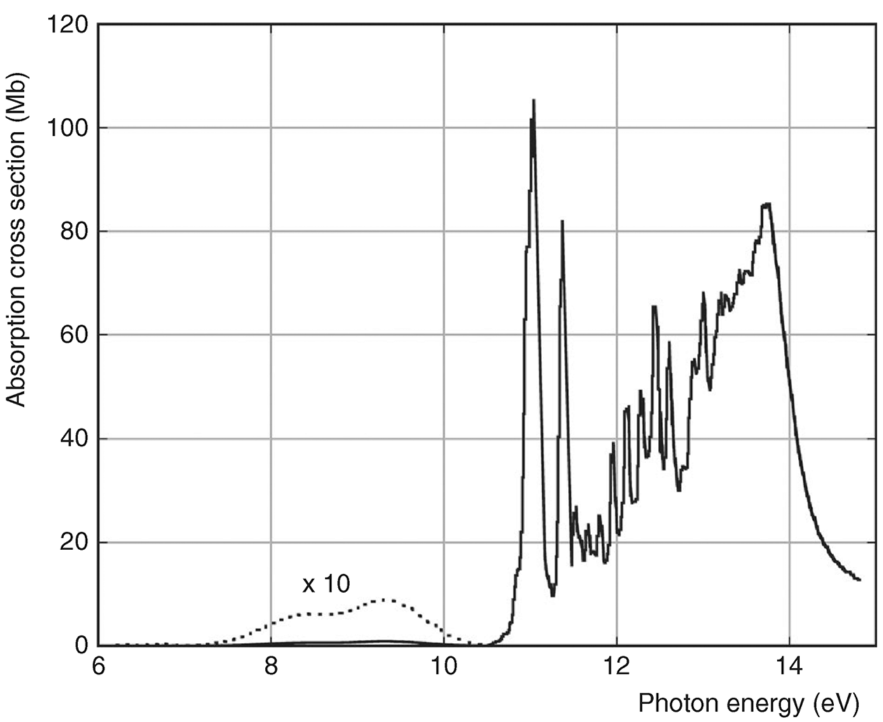


Carbon dioxide:

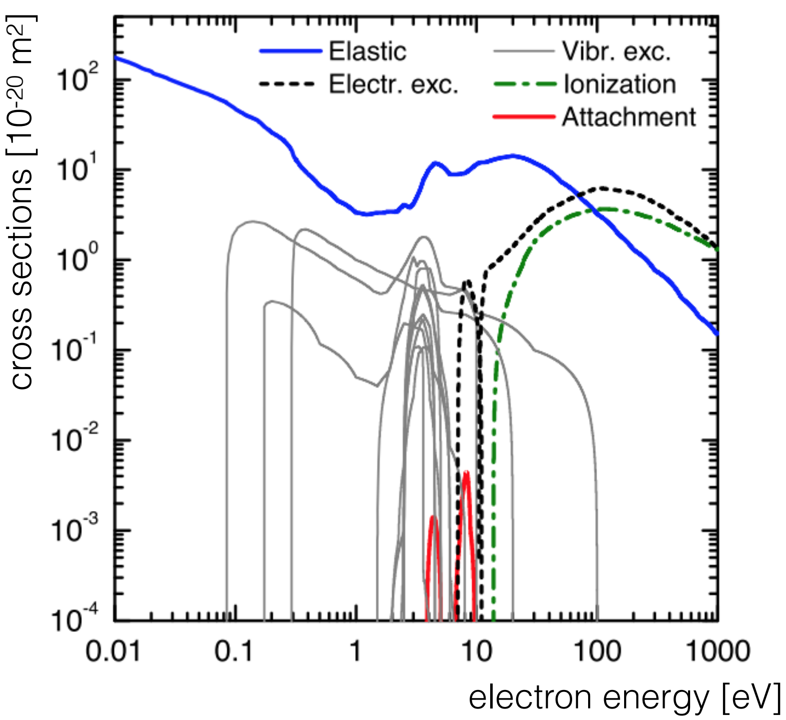


- *CO_2*
- **GWP = 1** by definition
- it is **not flammable**
- cluster density = 34/cm
- ionization potential = **13.8 eV**
- **photon absorption > 11 eV**
- **weak attachment coefficient**

photoabsorption cross section for CO_2



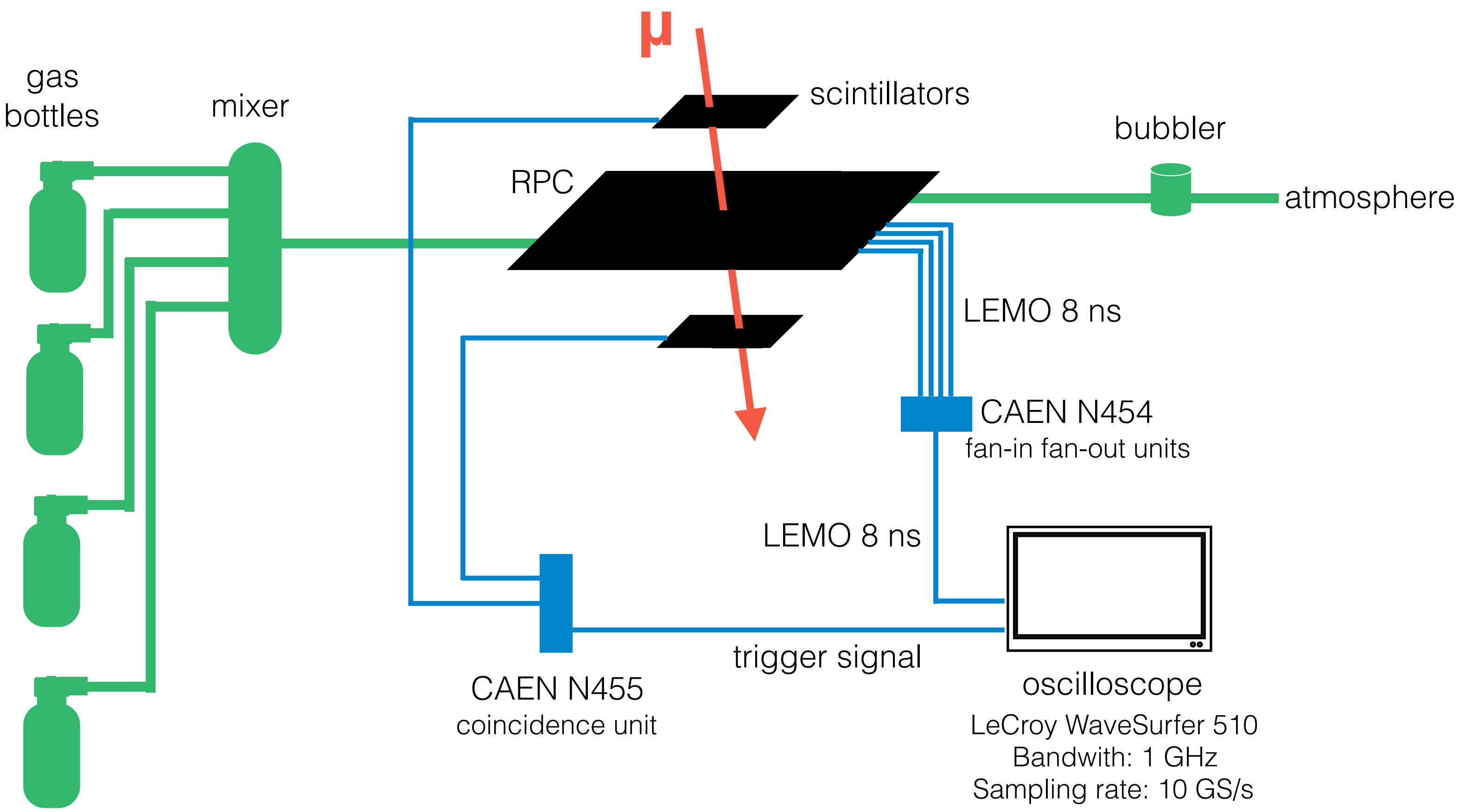
cross sections between electrons and CO_2

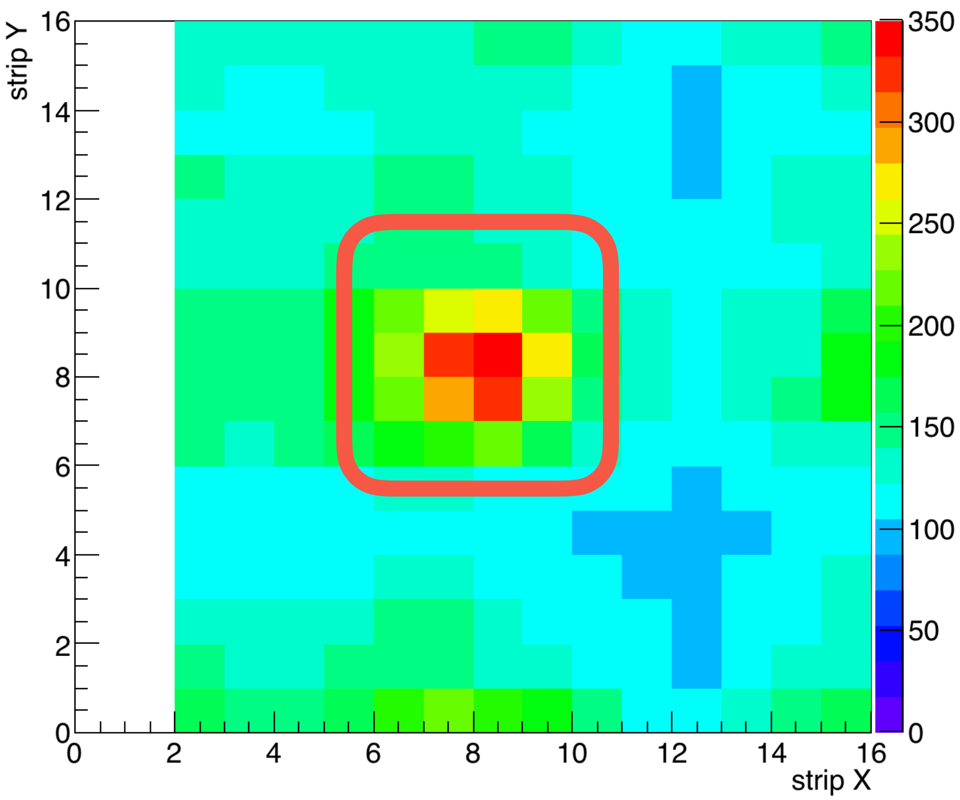


Experimental set-up

R&D studies on eco-friendly gas mixtures:

- two small-size (50 x 50 x 0.2 cm^3) RPCs inside a Faraday cage
- read-out strips (2 x 50 cm^2) which are terminated with 50 Ω resistors
- trigger: four scintillators coupled with photomultipliers
- the HV is applied with temperature and pressure correction
- gas mixture:
  → possibility to mix at maximum 4 different gases
  → it is dry: the resistance of bakelite is kept optimal, flowing the RPCs with wet mixture every 10/15 days



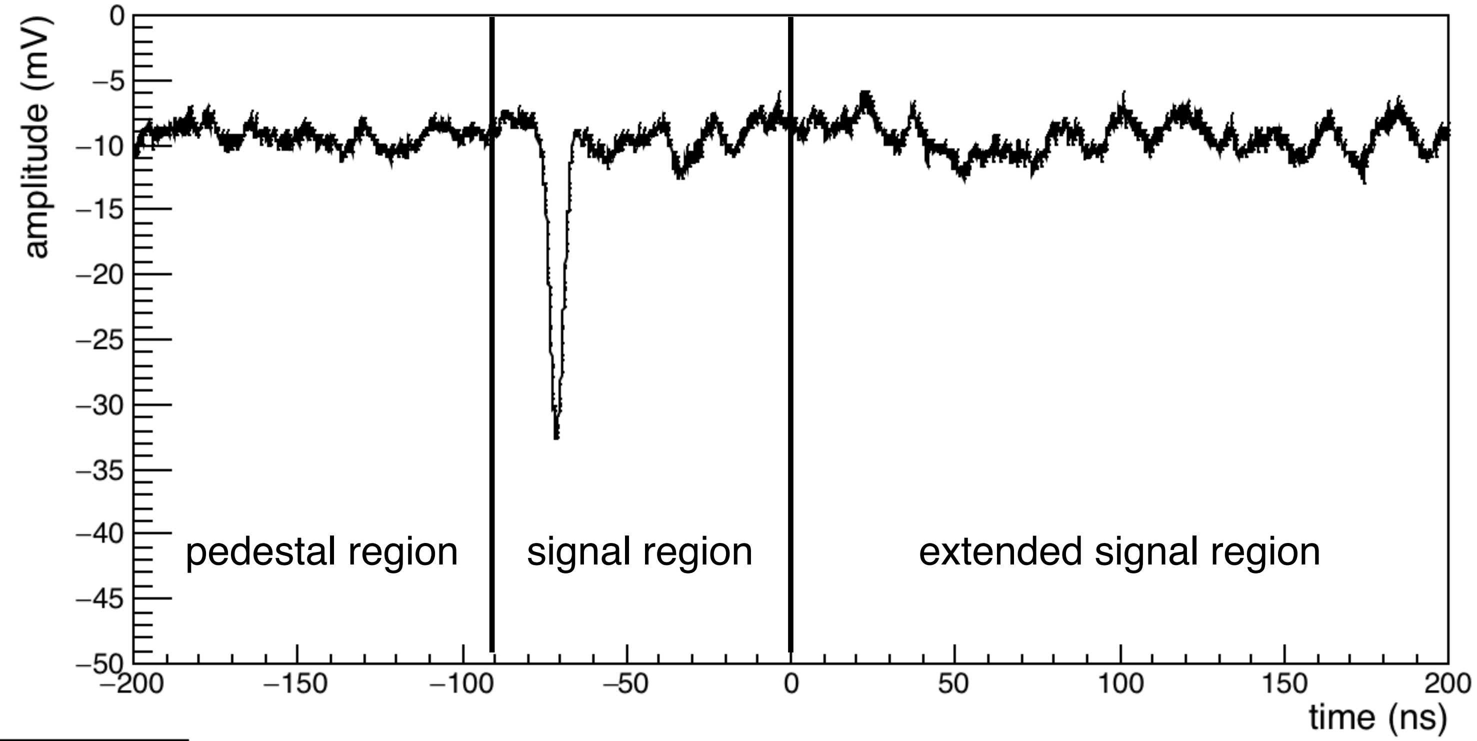


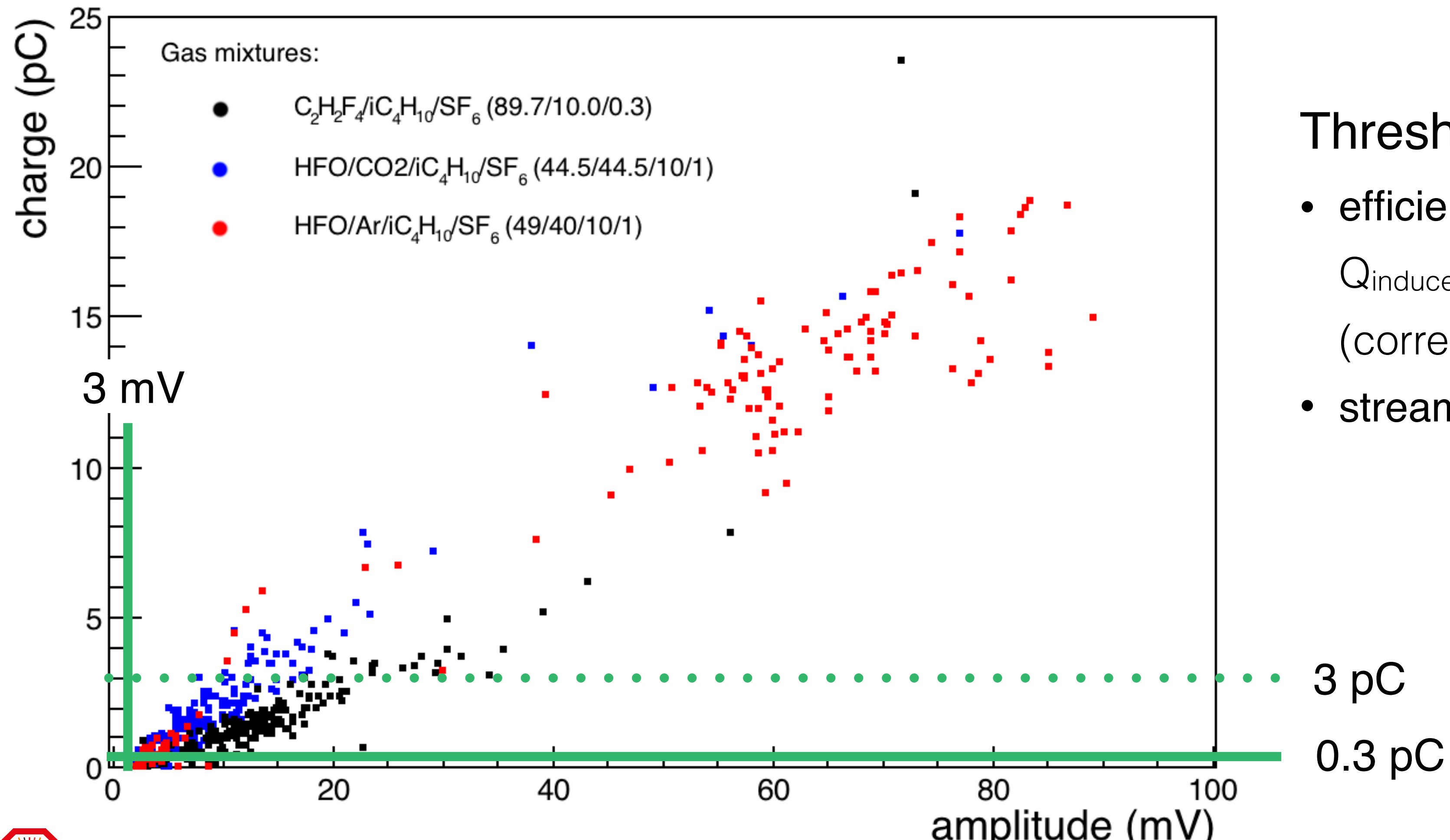
total trigger area: ~ 6 x 6 cm^2

Signal analysis

Three regions for the signal analysis:

- the pedestal region to define the voltage baseline
- the signal region to calculate the charge and the amplitude
- extended signal region to check possible after pulses

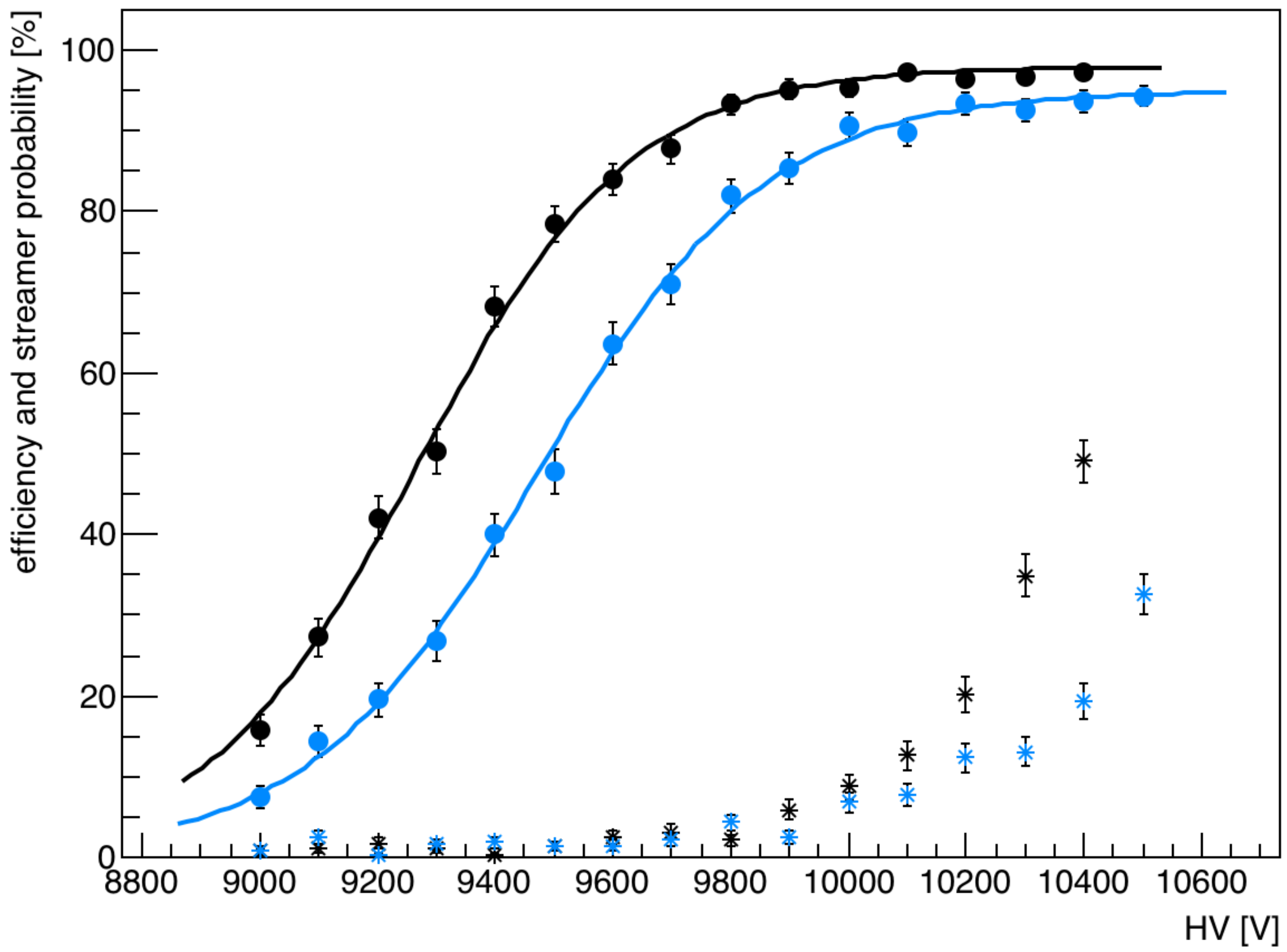




Thresholds used for the analysis:

- efficiency: $Q_{induced}$ > 0.3 pC and amplitude > 3 mV (corrected by baseline)
- streamer: $Q_{induced}$ > 3 pC

Characterization with standard mixtures



ALICE mixture ($C_2H_2F_4$/iC_4H_{10}/SF_6 89.7/10.0/0.3):
- ● efficiency
- ✱ streamer probability

ATLAS-CMS mixture ($C_2H_2F_4$/iC_4H_{10}/SF_6 95.2/4.5/0.3):
- ● efficiency
- ✱ streamer probability

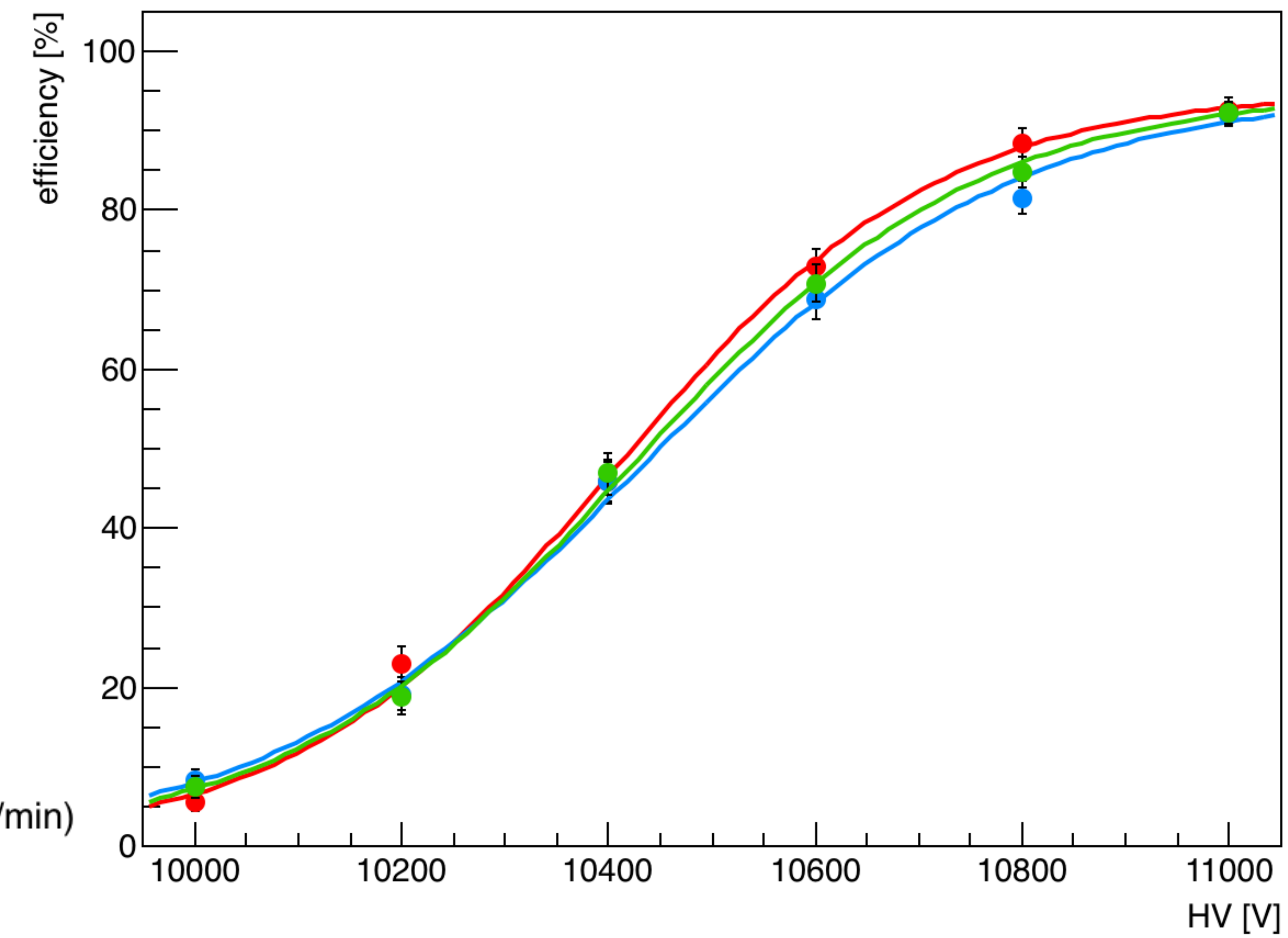
The RPC has been characterized with the most common gas mixtures used at LHC

An 18 day long test has been carried out to check whether the HFOze changes the RPC performance:

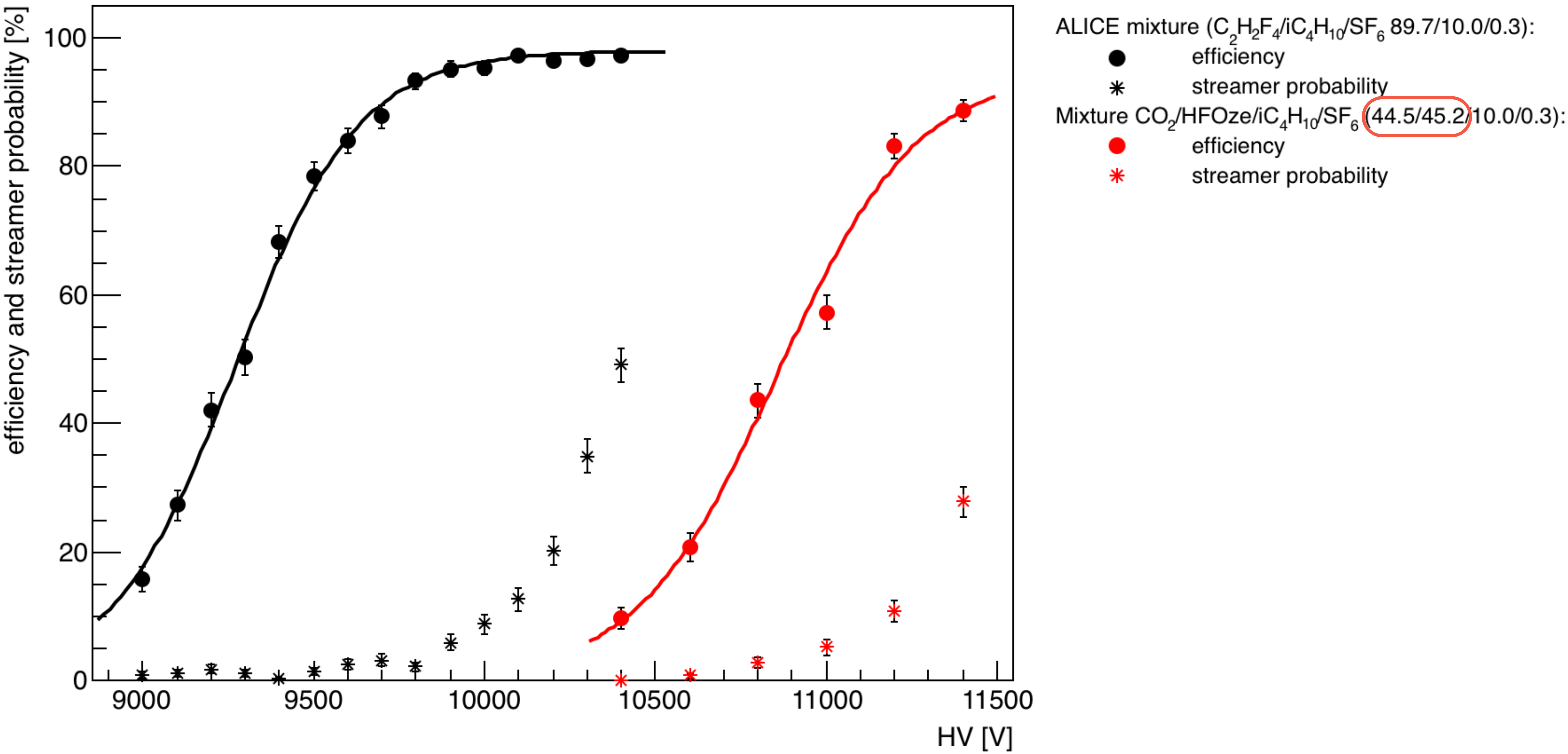
→ no hints of negative effects observed (same efficiency curves and no increase of current during the test)

Mixture Ar/HFOze/iC_4H_{10}/SF_6 (40/49/10/1):

● (red)	efficiency on 06/11/2017
for 9 days	RPC off (gas flow = 50 cc/min)
● (blue)	efficiency on 15/11/2017
for 9 days	RPC at 10500 V (gas flow = 50 cc/min)
● (green)	efficiency on 24/11/2017



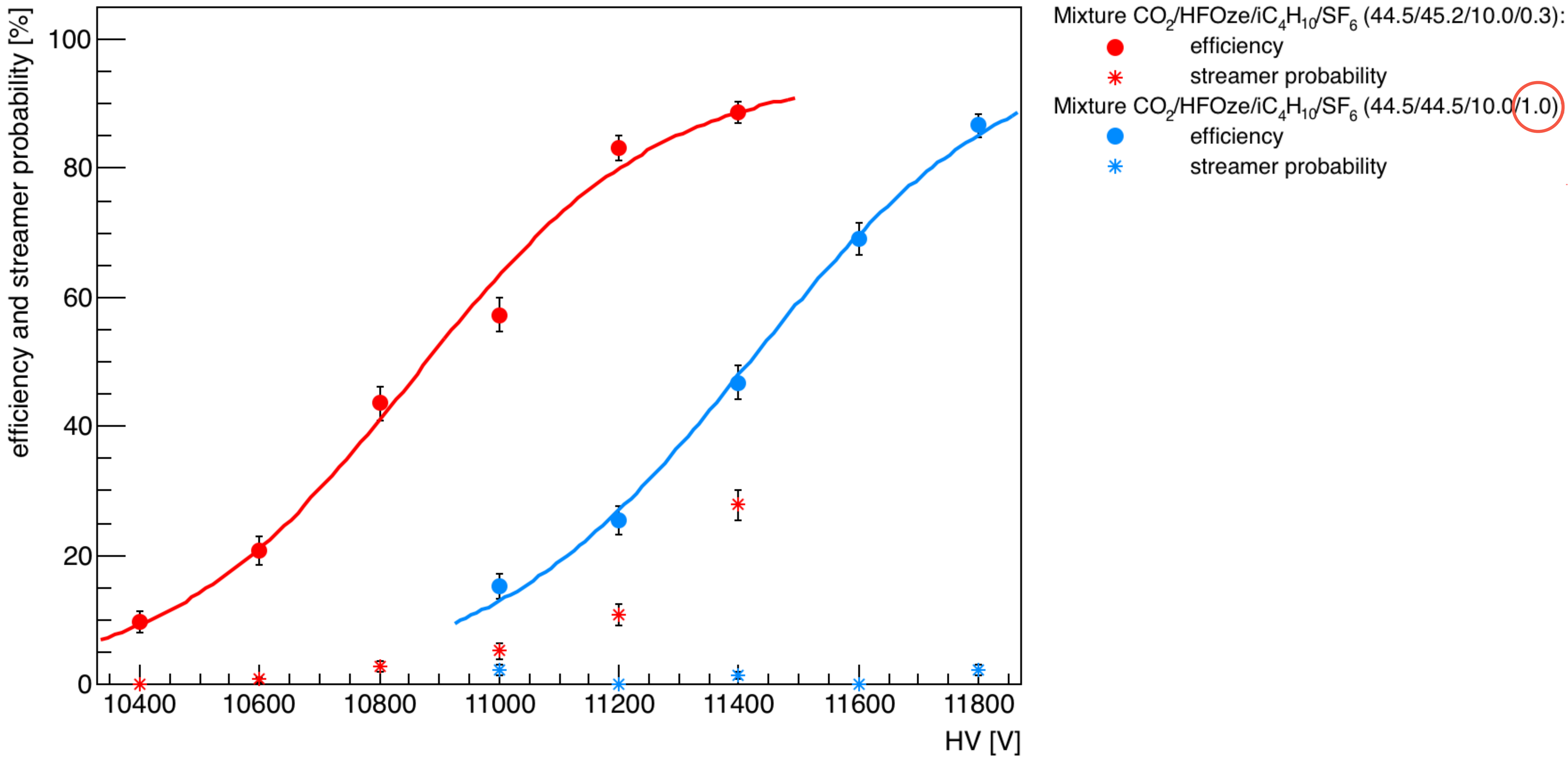
HFO/CO_2 based mixtures



Mixture CO_2/HFOze/iC_4H_{10}/SF_6 (44.5/45.2/10.0/0.3):

- the concentrations of iC_4H_{10} and SF_6 are equal to the ones in the ALICE mixture
- 89.7% $C_2H_2F_4$ has been replaced by 44.5% CO_2 and 45.2% HFOze
- **the working point is shifted by about 1500 V and the streamer probability is increased**

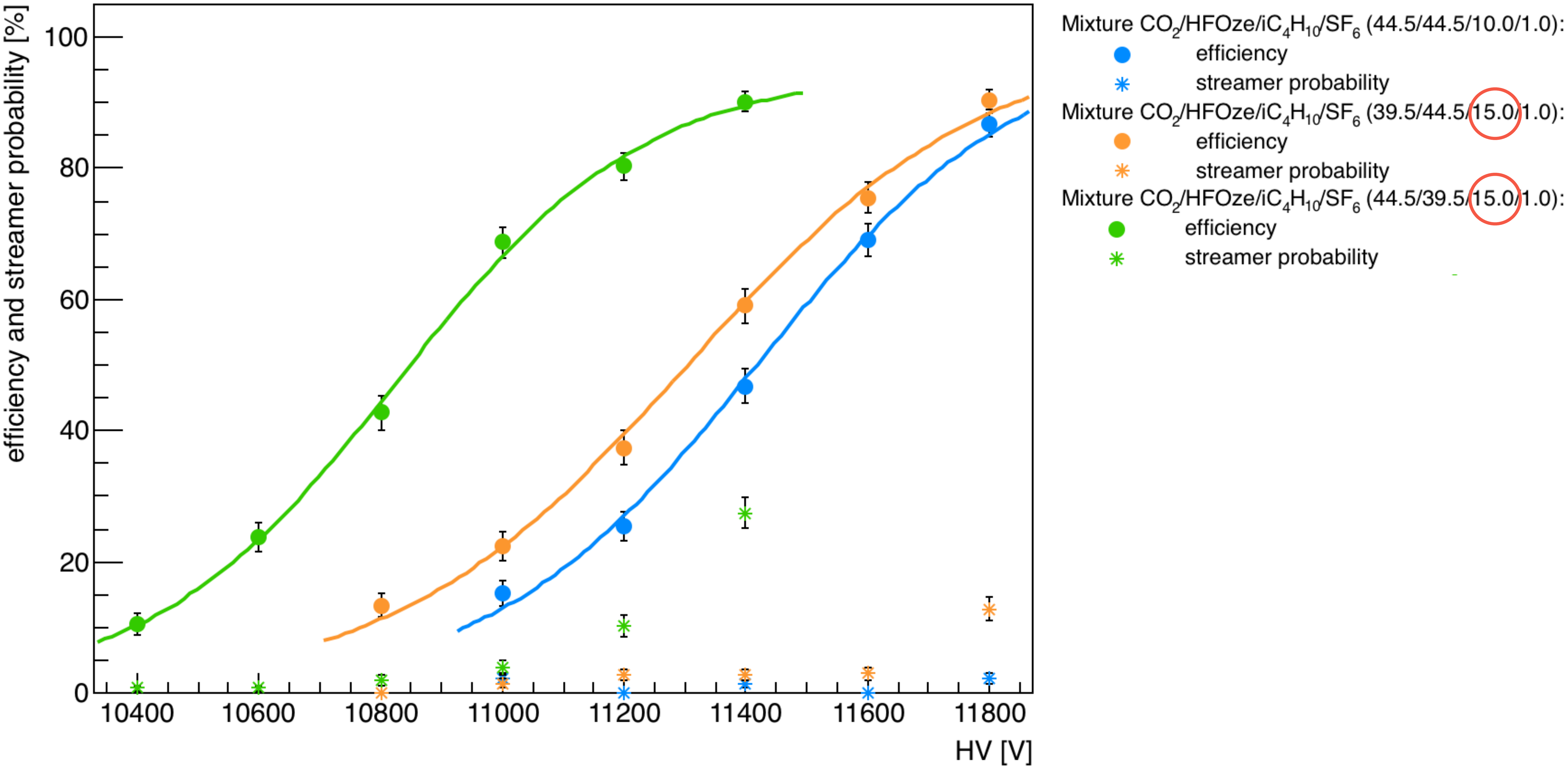
HFO/CO_2 based mixtures



Mixture CO_2/HFOze/iC_4H_{10}/SF_6 (44.5/44.5/10.0/1.0):

- **0.7% increase of SF6** → working point: + 500 V and streamer probability (@ eff. = 90%) < 5%
- **GWP = 223:** six times lower than the current ALICE mixture (1350)

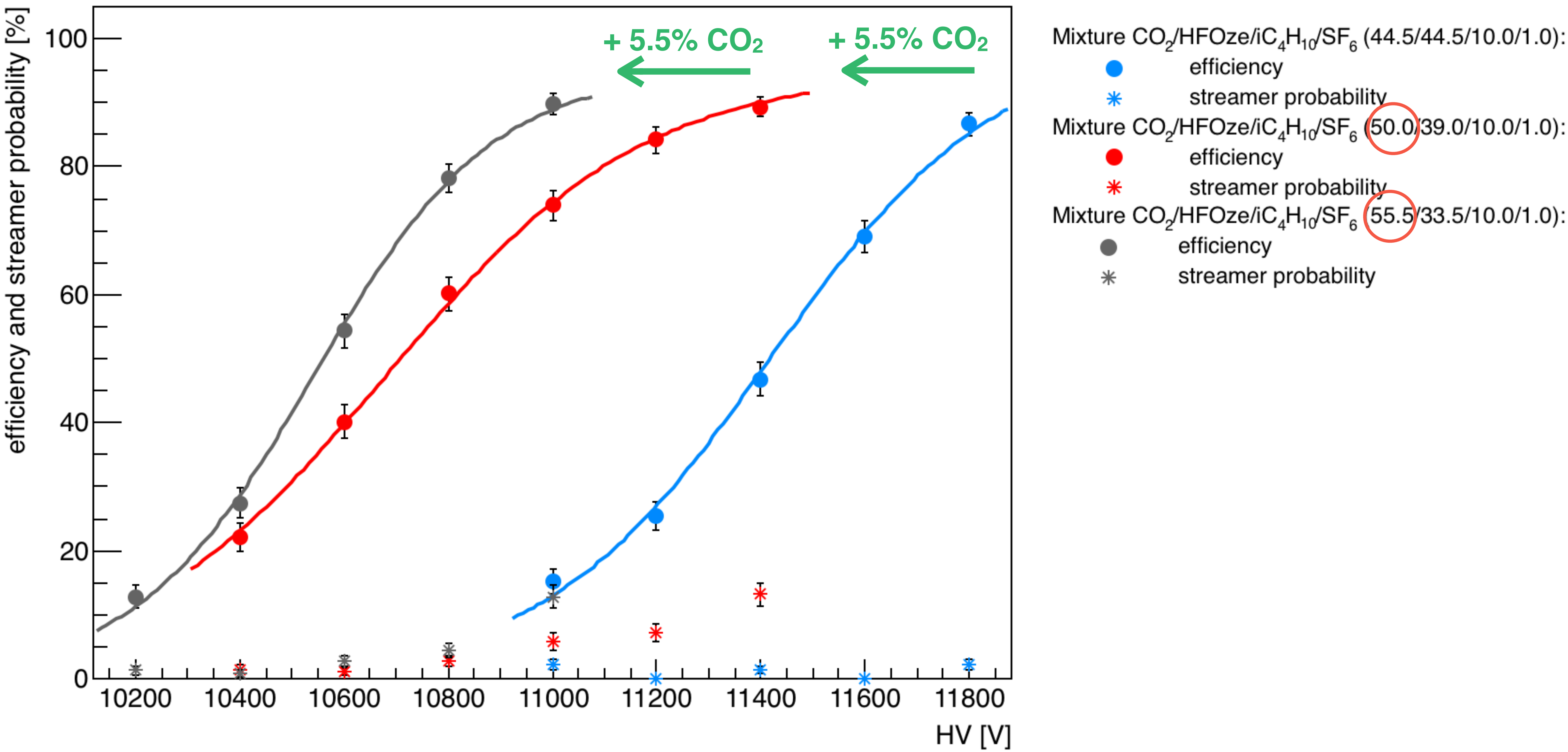
HFO/CO_2 based mixtures



Increasing the concentration of iC_4H_{10}:

- **same concentration of HFOze** as the previous mixture → small change in working point; slightly increase of streamers
- **5% decrease of HFOze** → working point: + 500 V and streamer probability (@ eff. = 90%): 25%

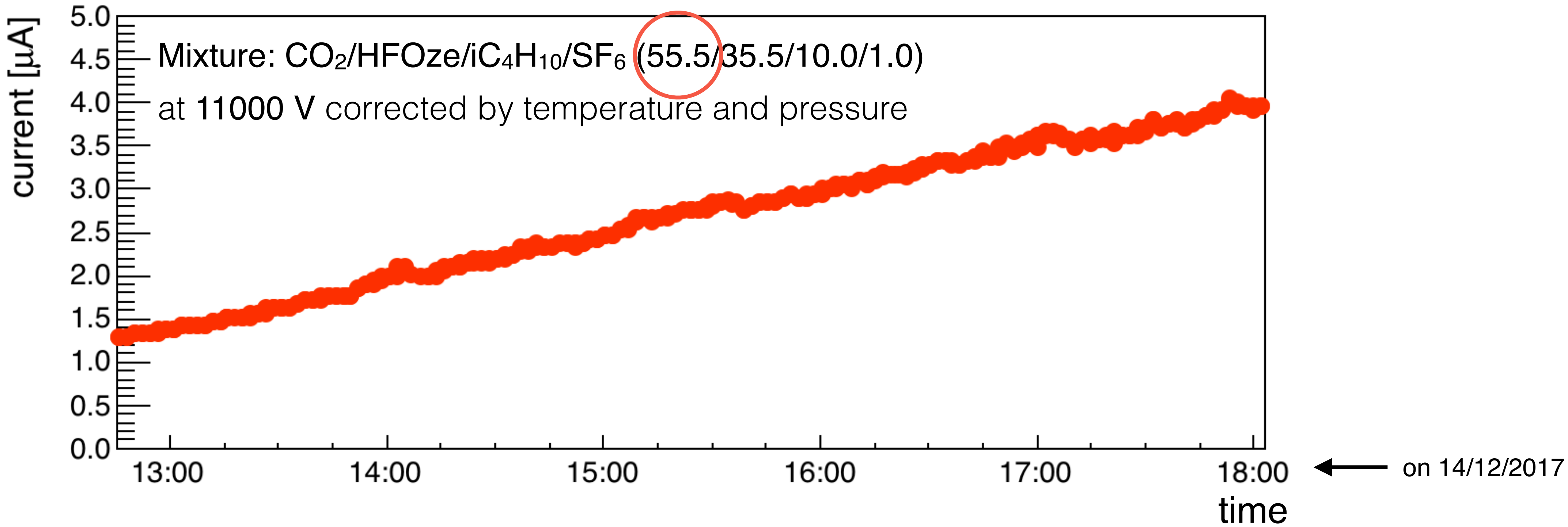
HFO/CO_2 based mixtures



Ratio between CO_2 and HFOze changes:

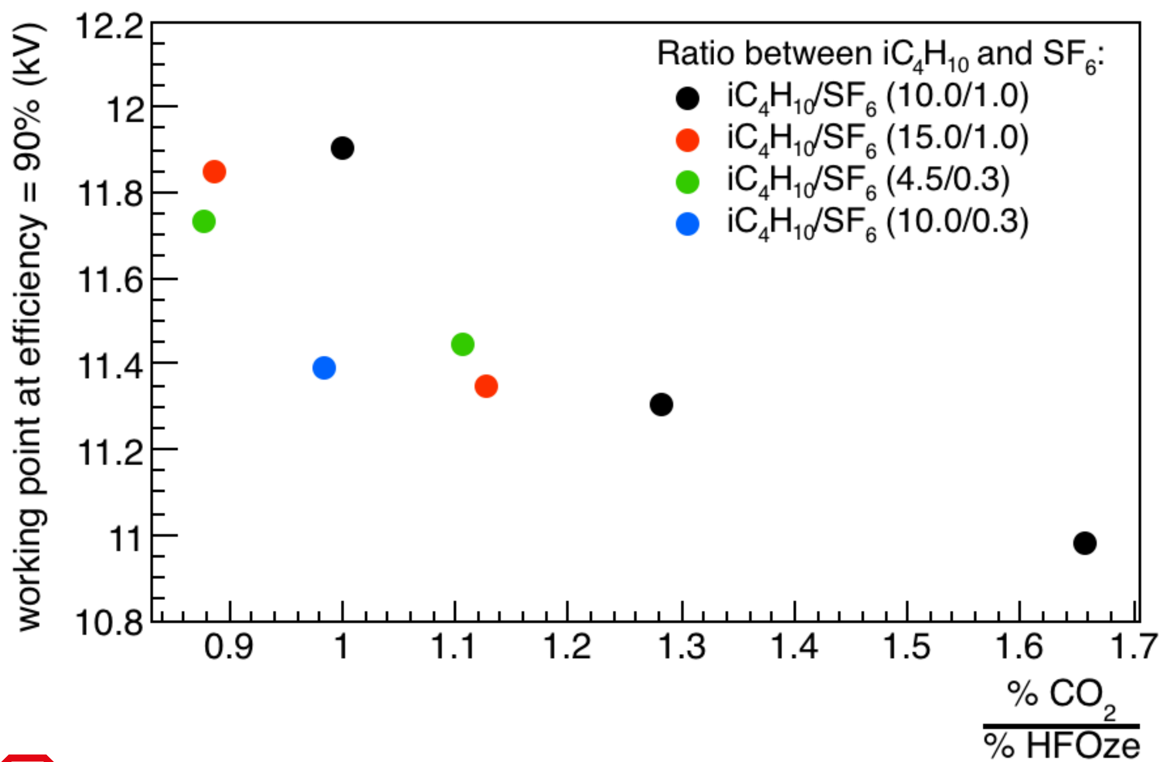
- if the concentration of **CO_2 increases**, the working point decreases, whereas the streamer probability increases up to 10% (with efficiency equal to 90%)
- if the concentration of **CO_2 is equal to 55.5%**, the current is not stable at constant voltage

HFO/CO_2 based mixtures



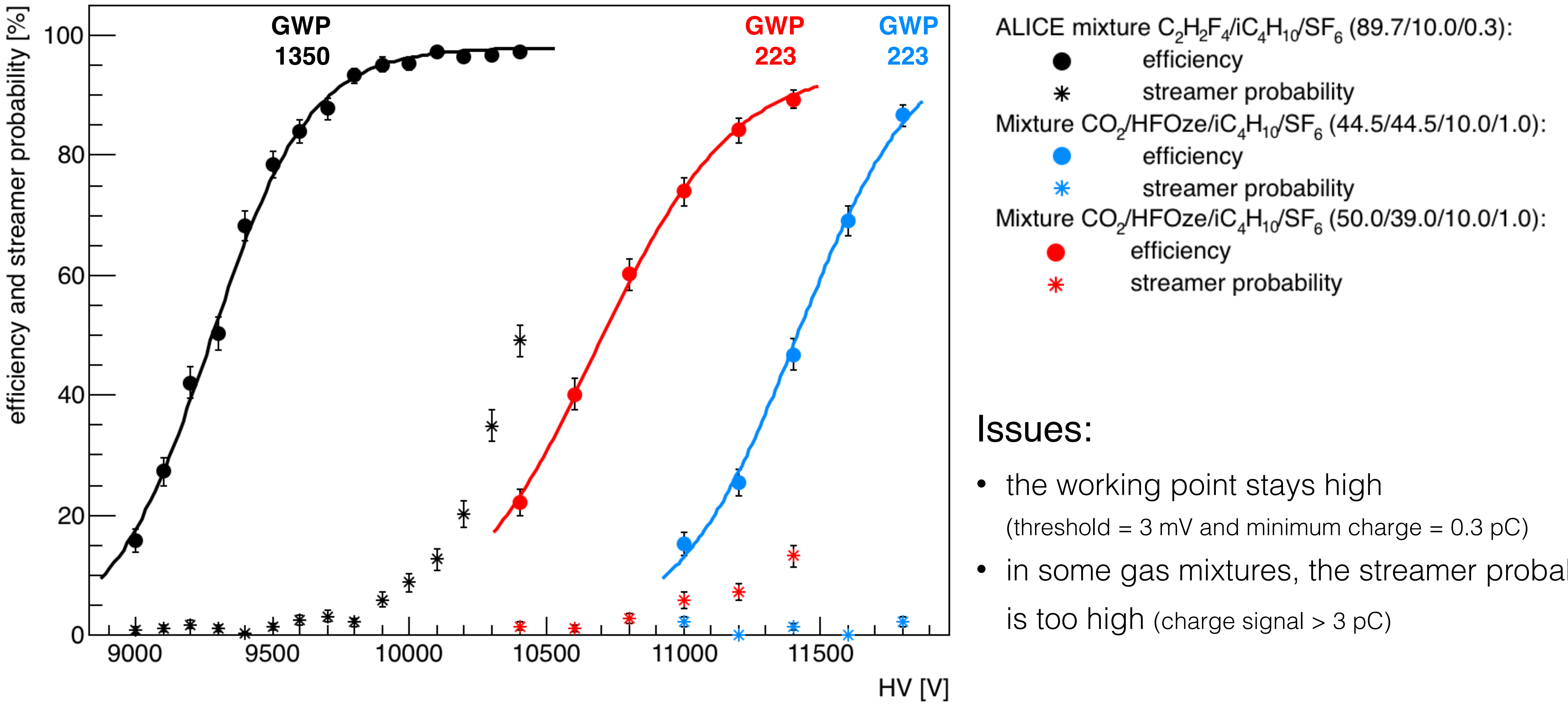
The addition of CO_2 into HFO-based mixtures reduces the working point:

- +10% of CO_2 → -1000 V in working point but unstable current if CO_2 = 55.5%



CO_2 (%)	HFOze (%)	iC_4H_{10} (%)	SF_6 (%)	CO_2/HFOze	working point	stable current
44,5	44,5	10	1	1,00	11902 V	yes
50	39	10	1	1,28	11306 V	yes
55,5	33,5	10	1	1,66	10981 V	no
39,5	44,5	15	1	0,89	11851 V	yes
44,5	39,5	15	1	1,13	11349 V	yes
44,5	50,7	4,5	0,3	0,88	11734 V	yes
50	45,2	4,5	0,3	1,11	11448 V	yes
44,5	45,2	10	0,3	0,98	11391 V	yes

Promising mixtures



Issues:

- the working point stays high
  (threshold = 3 mV and minimum charge = 0.3 pC)
- in some gas mixtures, the streamer probability is too high (charge signal > 3 pC)

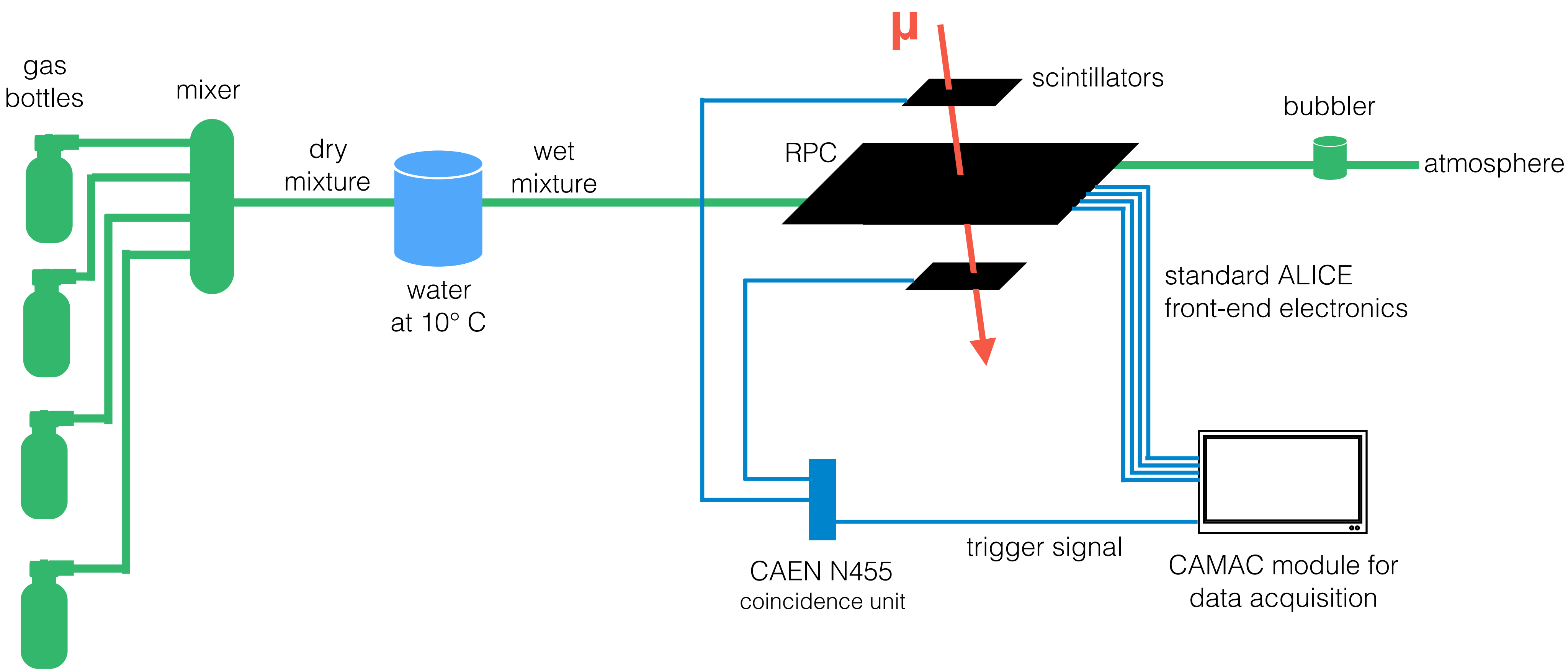
However:

- the new front-end electronics (with amplification) allows to achieve the maximum detector efficiency at lower values of electric field, in which streamers have smaller chance to develop

→ **hints of stability problems have been observed with large amount of CO_2 (to be investigated further)**

Stability of RPCs without flammable gases

Motivation: necessity to remove flammable gas in the current ALICE mixture, in particular we evaluated whether the CO_2 might have been a suitable substitute of iC_4H_{10}

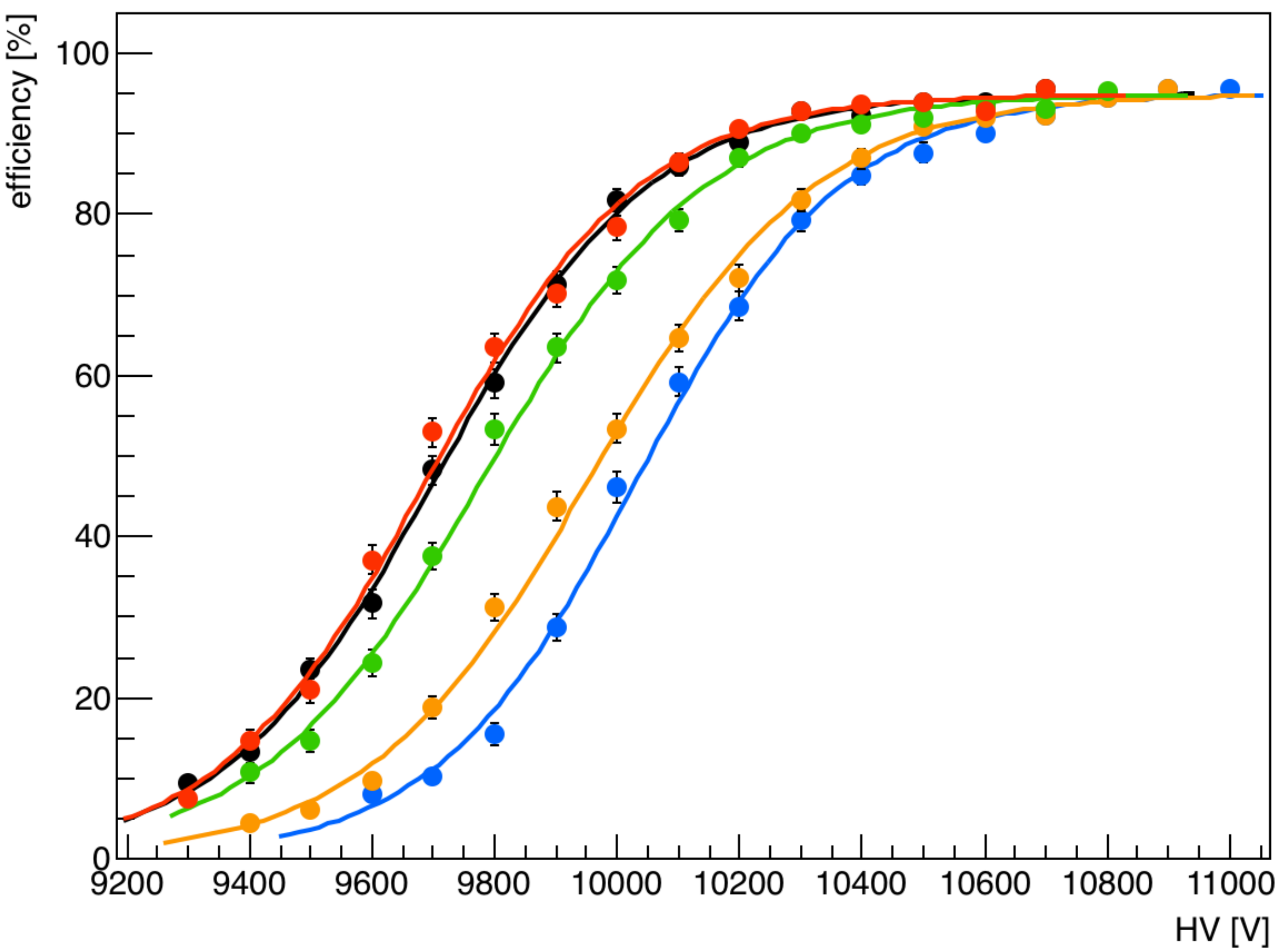


Experimental set-up:

- for the data acquisition, the standard ALICE front-end electronics has been used (threshold = 7 mV, no amplification)
- trigger on cosmic-ray flux (4 scintillators in coincidence)
- in the gas mixture, the **only replacement is the use of CO_2 instead of iC_4H_{10} in different concentrations**
- the gas mixture is wet (the mixture bubbles in water at 10° C)

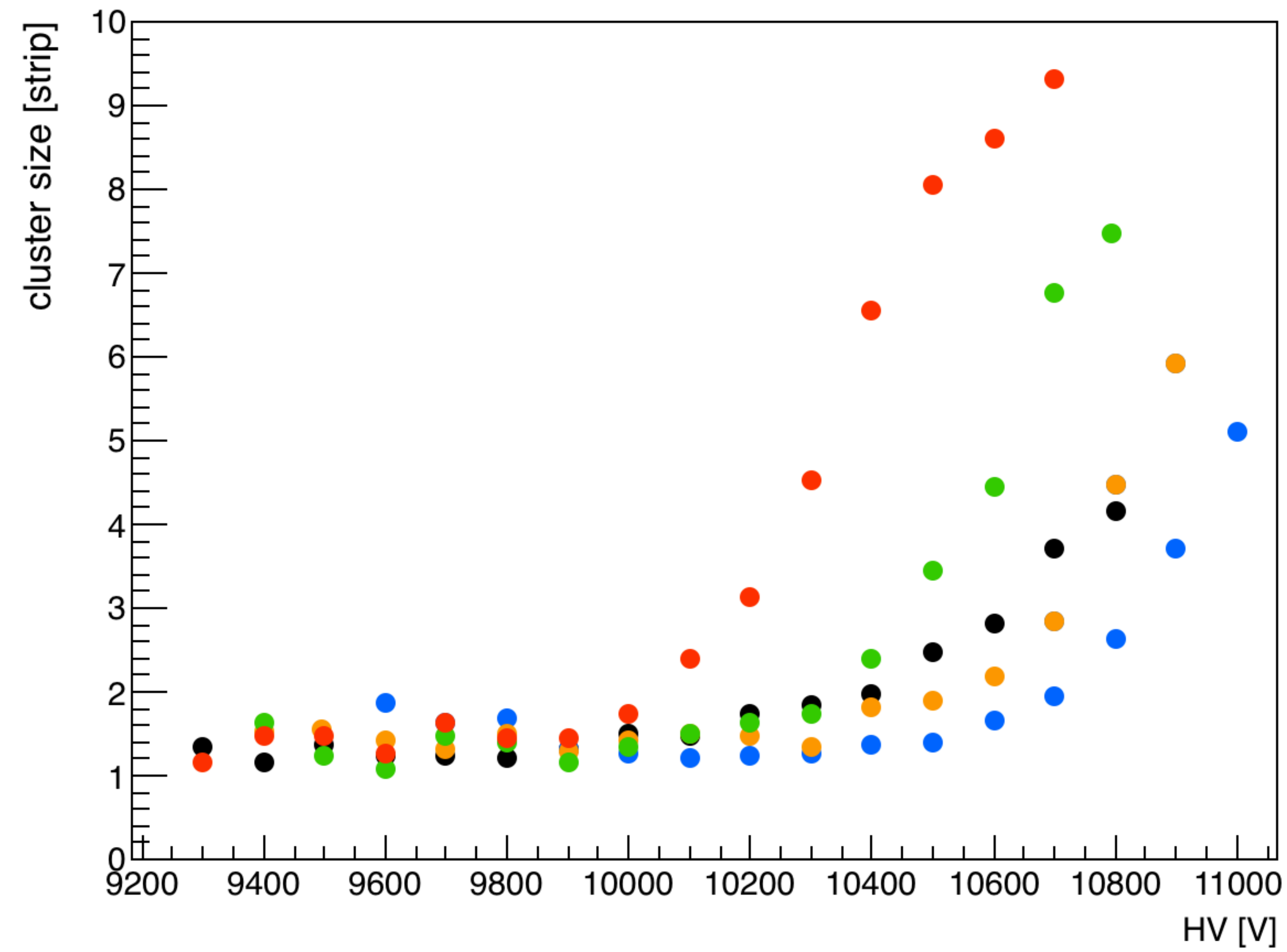
Operation of RPCs with CO_2-based mixtures

After the characterization of RPCs with ALICE mixture, we changed the iC_4H_{10} with different concentrations of CO_2:



Mixtures:

- ALICE mixture $C_2H_2F_4/iC_4H_{10}/SF_6$ (89.7/10.0/0.3)
- $C_2H_2F_4/CO_2/SF_6$ (96.7/3.0/0.3)
- $C_2H_2F_4/CO_2/SF_6$ (94.7/5.0/0.3)
- $C_2H_2F_4/CO_2/SF_6$ (89.7/10.0/0.3)
- $C_2H_2F_4/CO_2/SF_6$ (75.7/24.0/0.3)



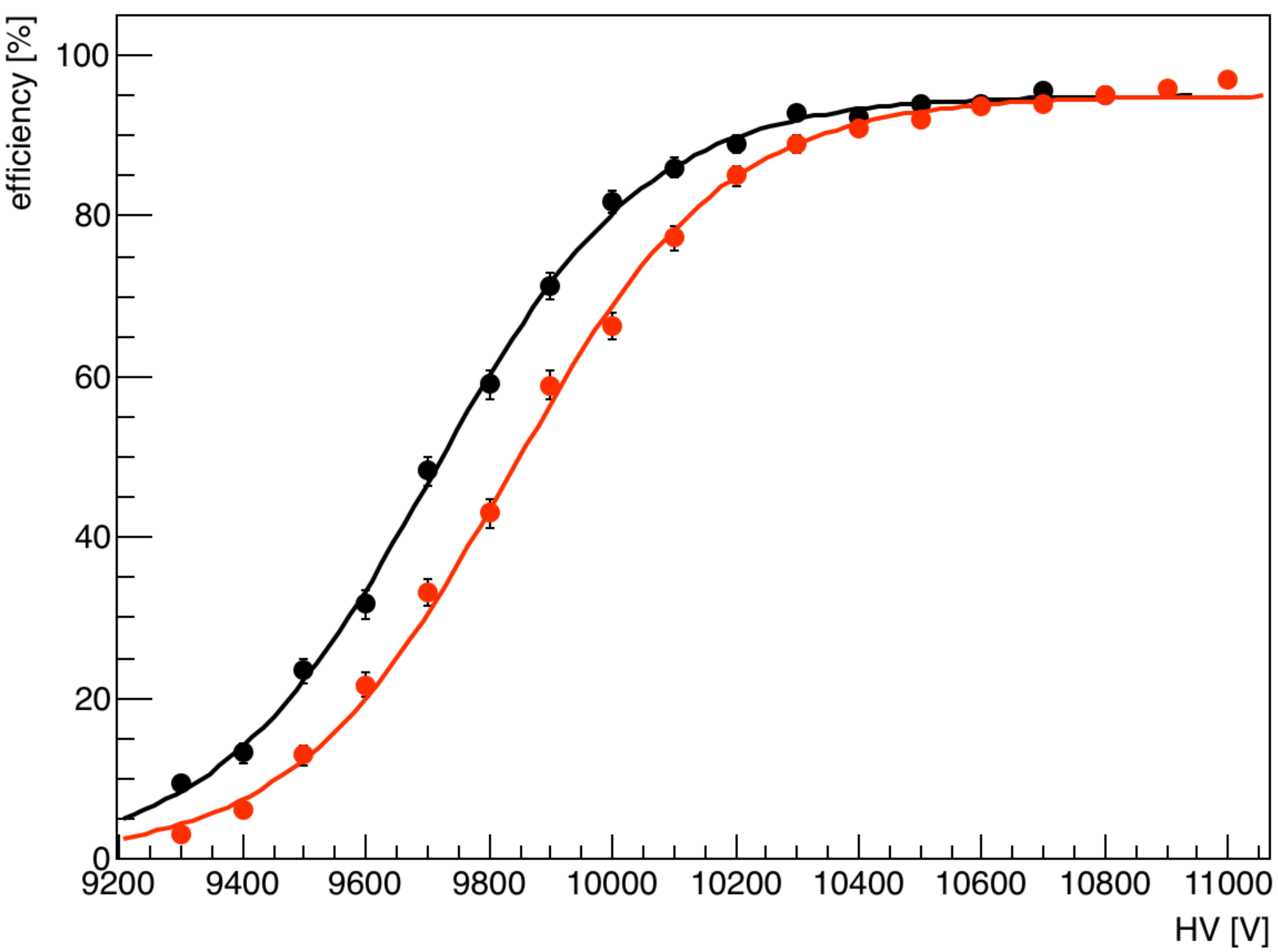
Issues:

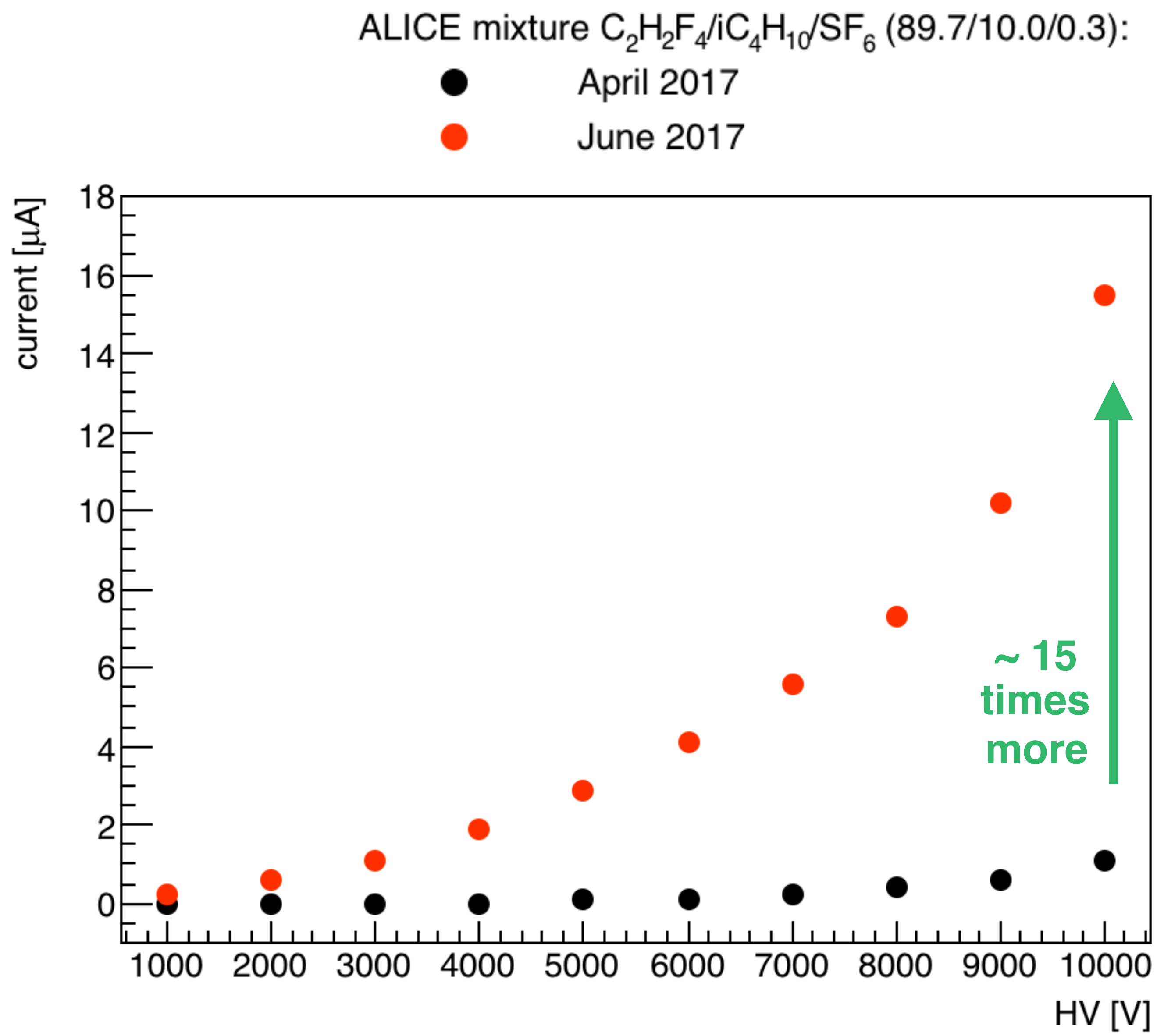
- the cluster size with CO_2-based mixtures results in being higher than with the current ALICE mixture
- CO_2 does not appear to be a suitable photon quencher to replace iC_4H_{10} in $C_2H_2F_4$-based mixtures

Operation stability of RPCs with ALICE mixture

After about two months of operation with CO_2 in $C_2H_2F_4$-based mixtures:

- the efficiency curve is shifted by about 100 V
- a huge increase in current has been observed





The issue on the operation stability is under investigation:

gas quality, environmental conditions, humidity, chemical reactions between bakelite/linseed oil with CO_2, chemical reactions between CO_2 and the other components of mixture, damages due to the high photons flux and etc.

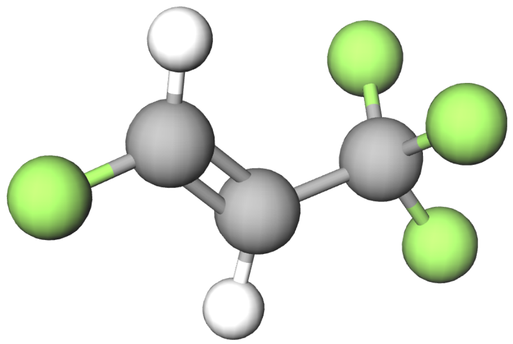
Conclusions and outlooks

- **R&D on eco-friendly gas mixtures:**

  → goal: to have a non-flammable mixture without greenhouse gases (at least with a low GWP)

  → HFOze is a possible candidate to substitute $C_2H_2F_4$, thanks to its low GWP

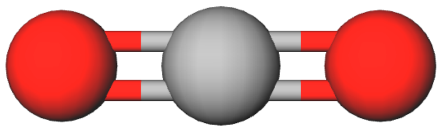
  → interest to substitute totally or partially iC_4H_{10}, because it is a flammable gas



- **Characterization of mixtures with HFOze:**

  several tests on HFO-based mixtures with addition of various gases are ongoing and encouraging results have already been obtained (i.e. addition of CO_2):

  - the addition of CO_2 to HFOze is required to operate at lower values of electric field
  - some of HFOze/CO_2-based mixtures are promising but cluster size and time resolution are not already measured and long-time stability tests are required to check:
    - rate capability
    - effect of background radiation
    - long term performance (aging issue)



- **Operation stability of RPCs with CO_2-based mixtures:**

  → CO_2 does not appear to be a suitable photon quencher to replace iC_4H_{10} in $C_2H_2F_4$-based mixtures

  → an increase in current has been observed after two months of operation with cosmic-ray flux

  → further tests are fundamental to check the compatibility of CO_2 in gas mixtures for RPCs