Tetrafluoropropene-based gas mixtures for Resistive Plate Chambers:

an experimental and simulation study

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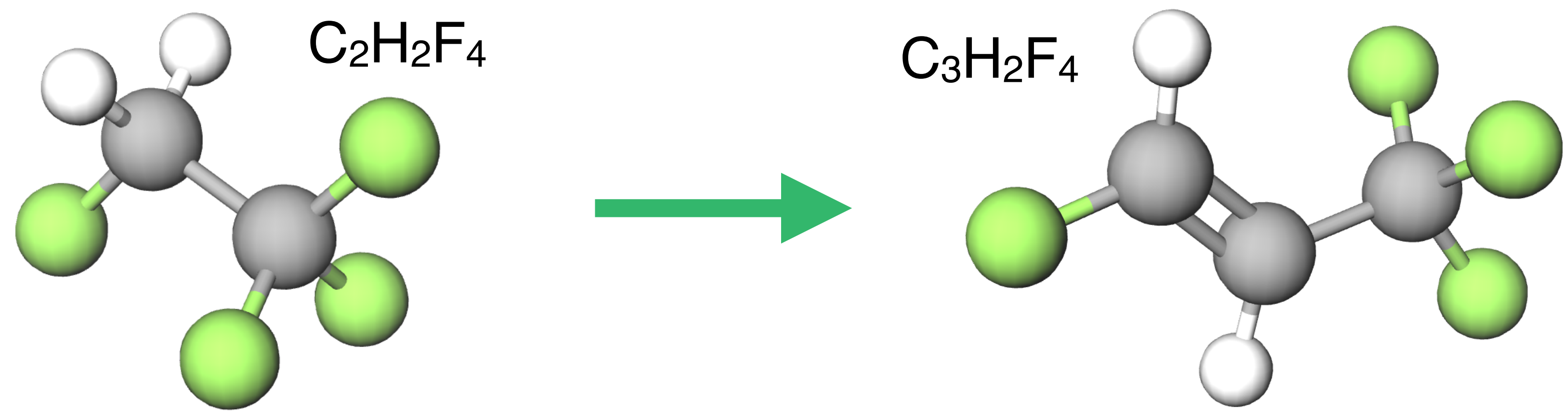
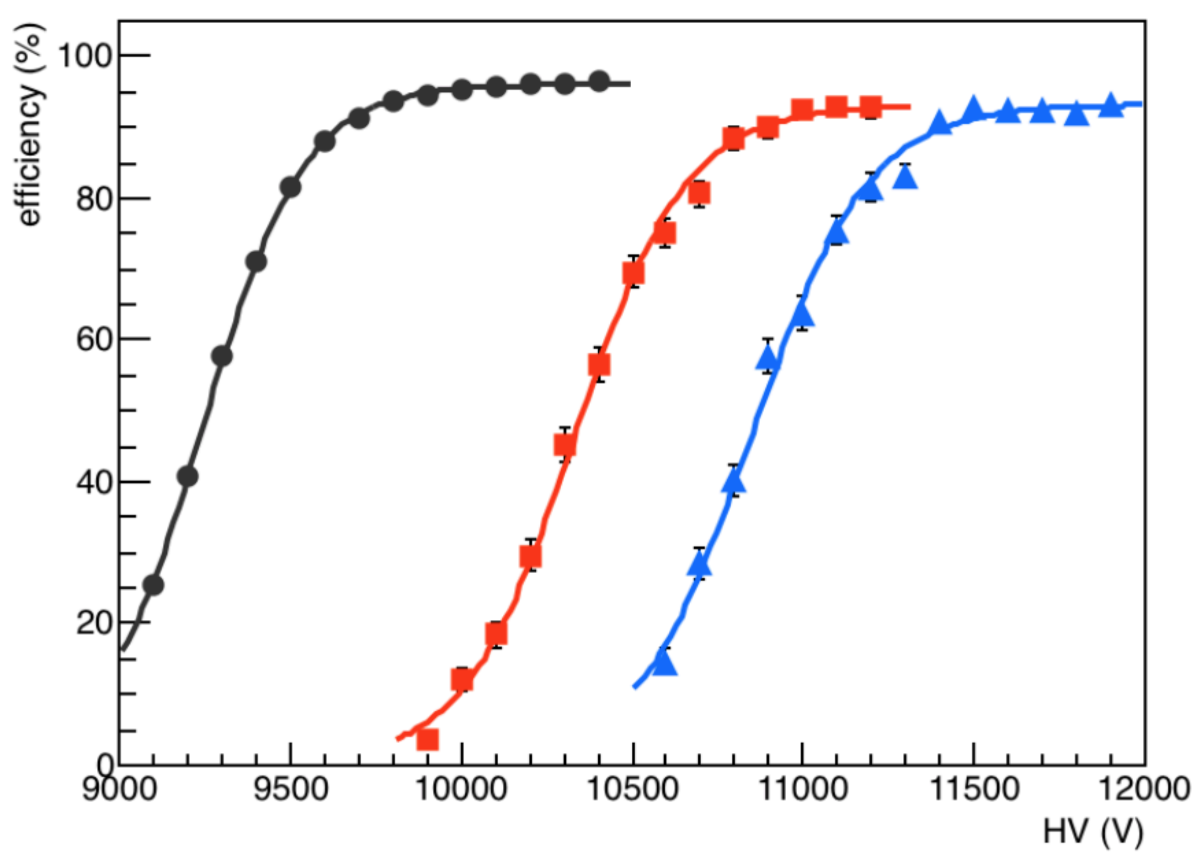
Outline

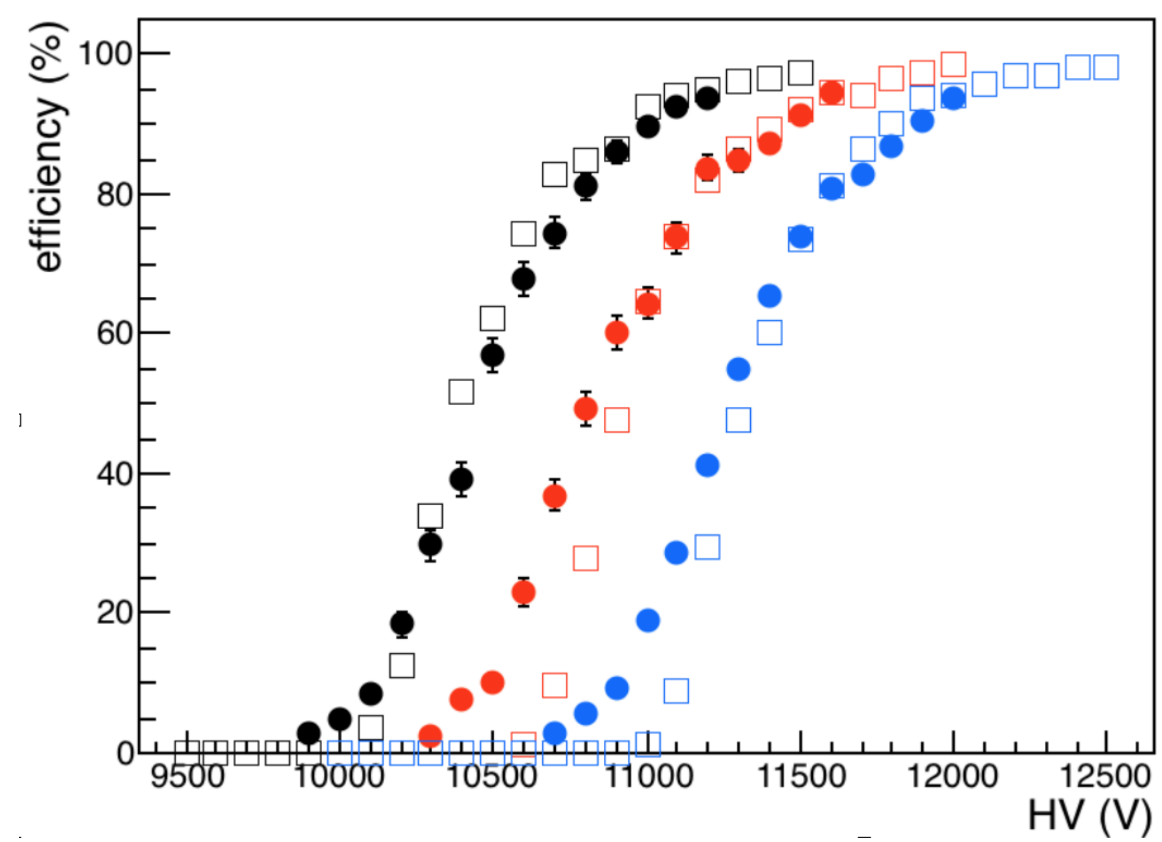
- **Search of environment-friendly gas mixture for RPCs**
  - experimental approach
  - simulation approach



measurements

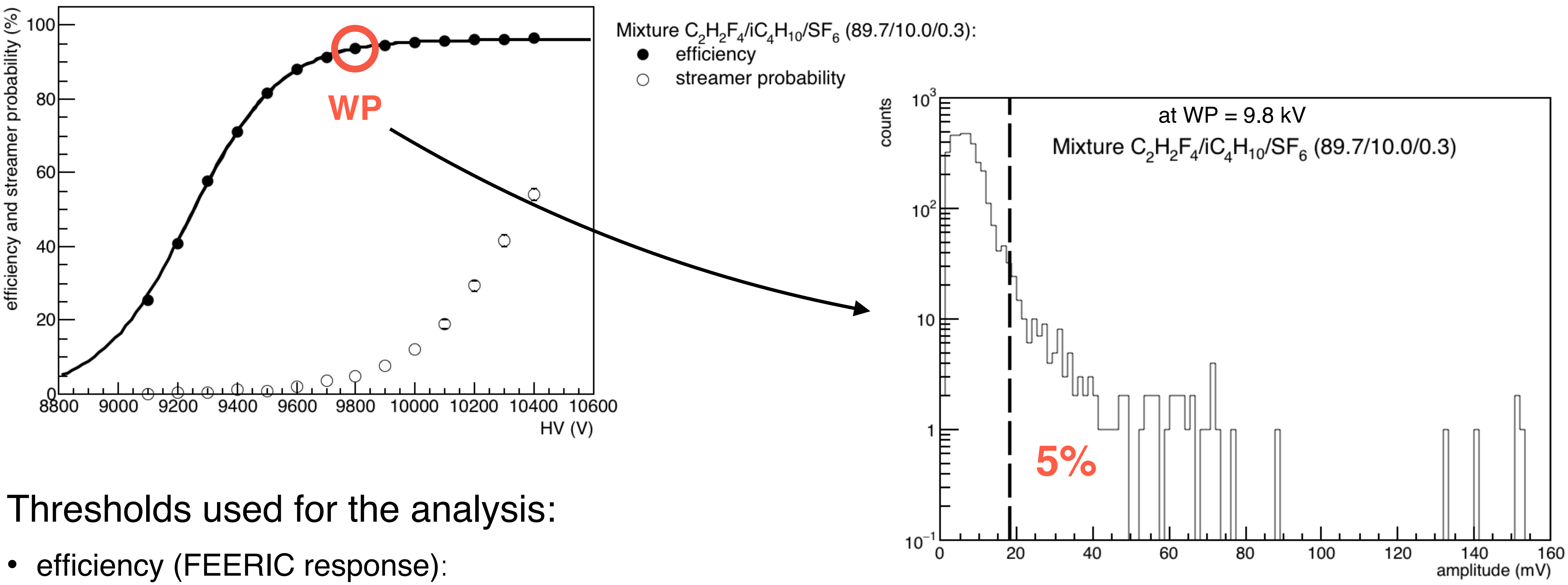


simulations



Characterization with ALICE mixture

Efficiency and streamer probability with ALICE mixture, which is used as reference:



The 2-mm gap RPC is horizontally placed and exposed to the cosmic-ray flux

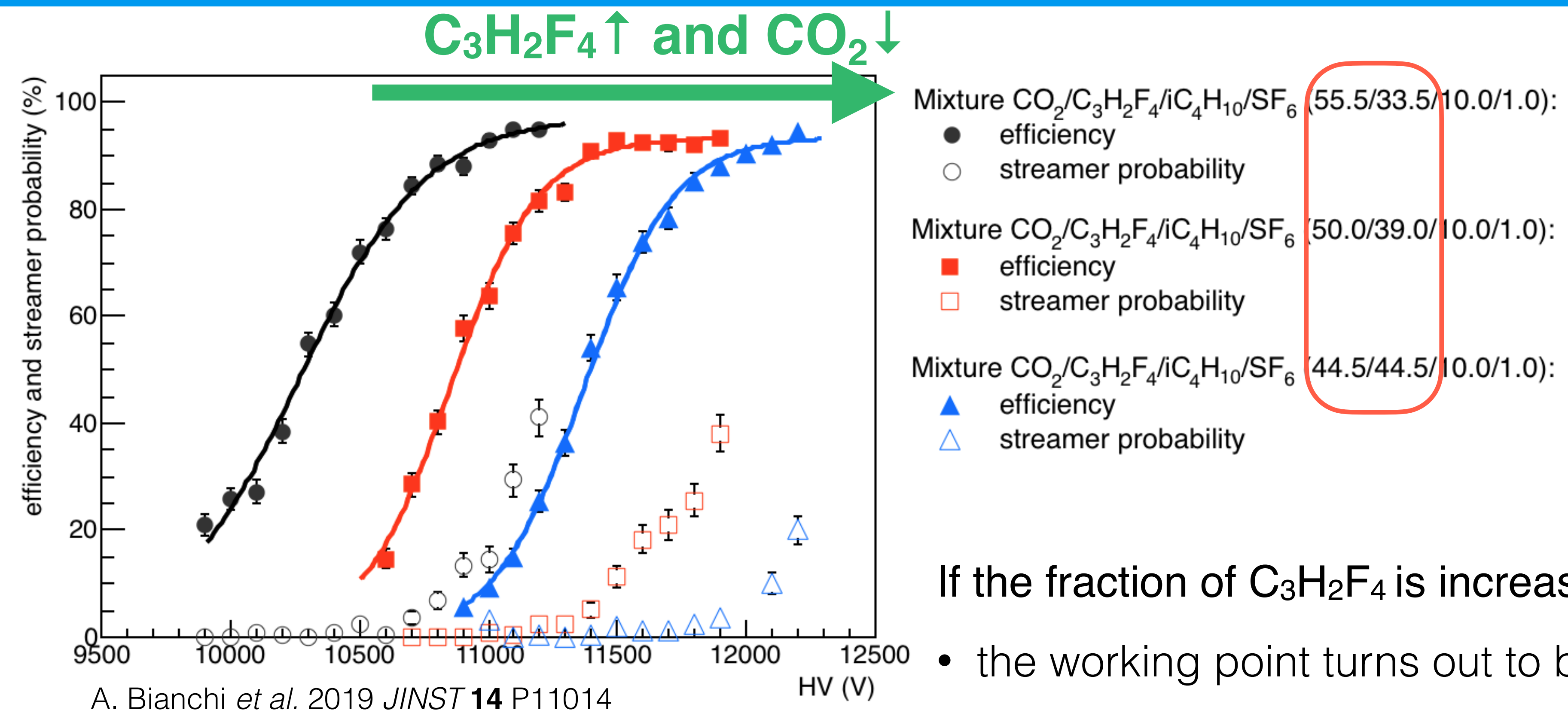
Thresholds used for the analysis:

- efficiency (FEERIC response):
  $Q_{induced}$ = ~130 fC (70 mV after amplification)
- streamer probability:
  amplitude (by the oscilloscope) > 18 mV
  (threshold used to tag 5% largest signals)

Systematic study: gas mixtures with $C_3H_2F_4$ and CO_2 has been carried out with the addition of *i*-C_4H_{10} and SF_6

Methodology: changing the fractions of two gas components out of four at a time, evaluating how their ratio affects the performance of the RPC → more details: A. Bianchi *et al.* 2019 *JINST* **14** P11014

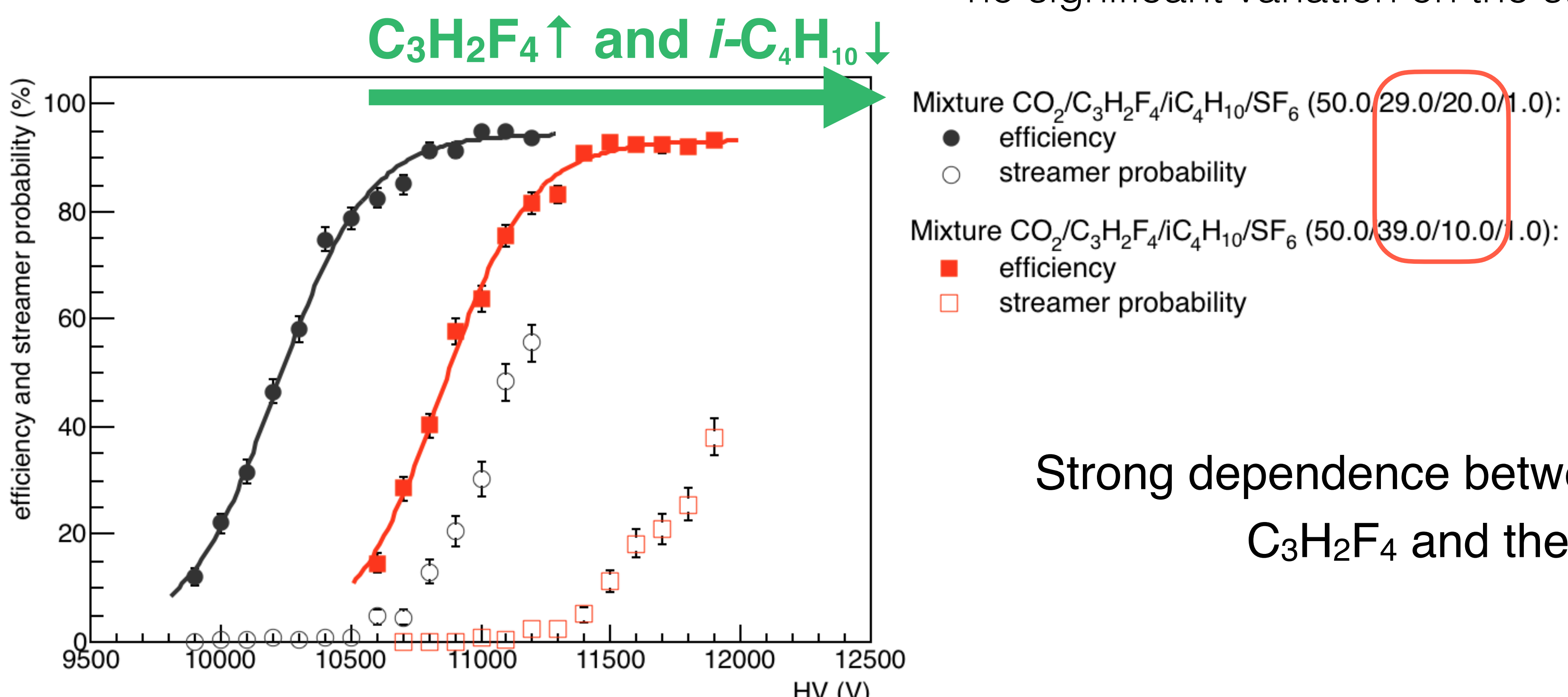
Ratio between $C_3H_2F_4$ and CO_2/i-C_4H_{10}



A. Bianchi *et al.* 2019 *JINST* **14** P11014

If the fraction of $C_3H_2F_4$ is increased and CO_2 or i-C_4H_{10} is decreased:

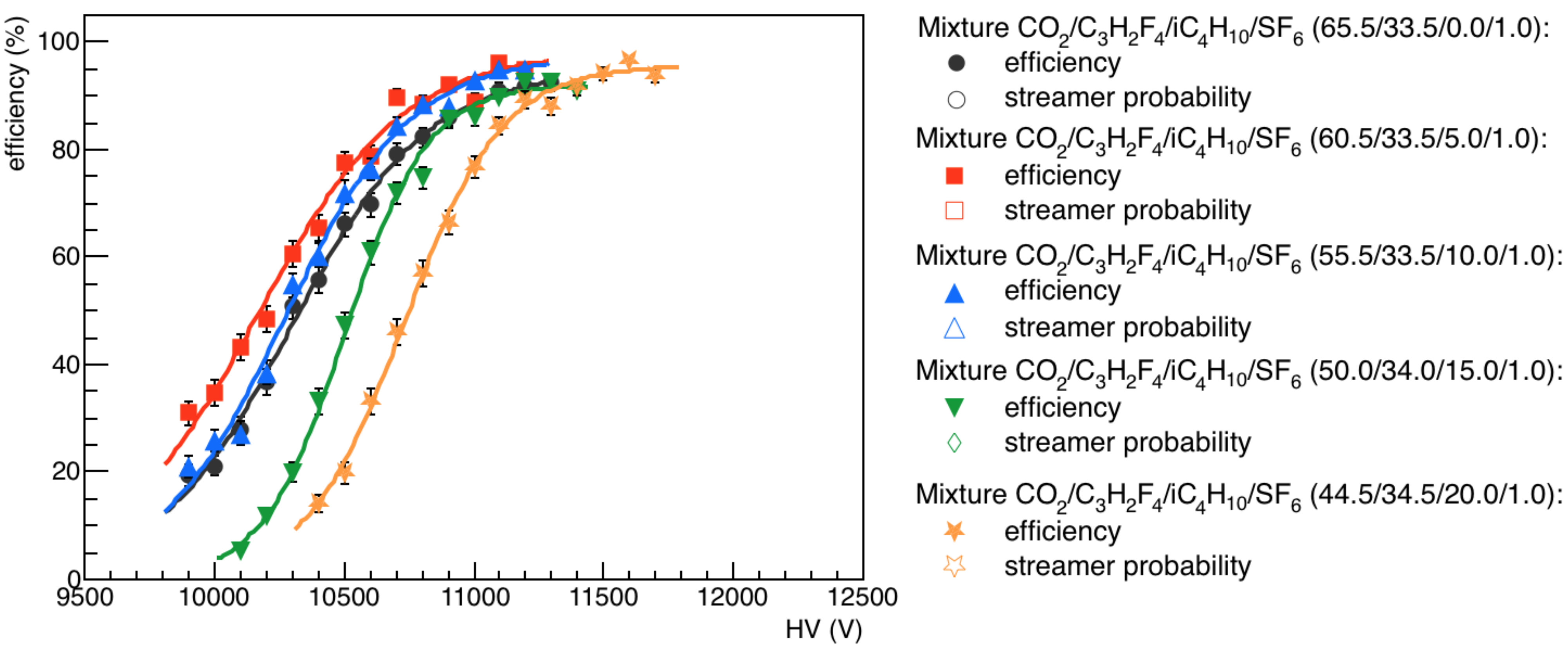
- the working point turns out to be shifted towards higher voltages
- no significant variation on the streamer probability



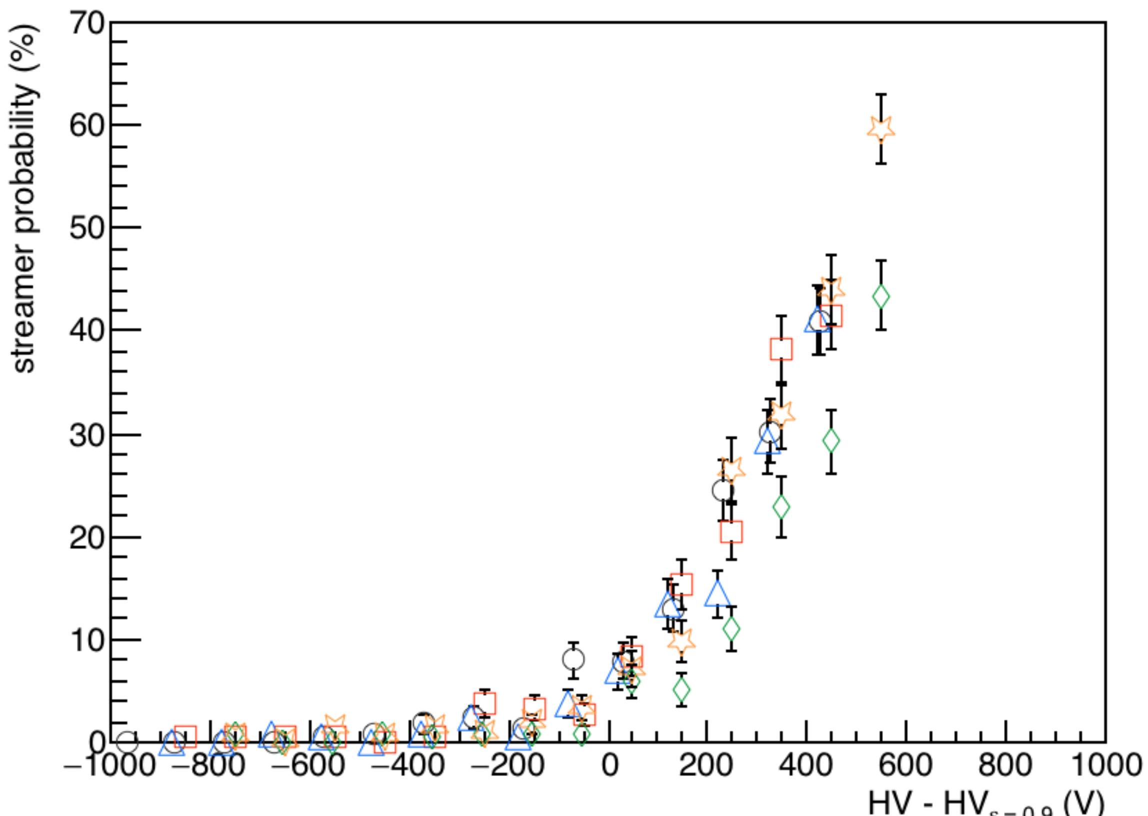
A. Bianchi *et al.* 2019 *JINST* **14** P11014

Strong dependence between the concentration of $C_3H_2F_4$ and the working point

Ratio between CO_2 and *i*-C_4H_{10}



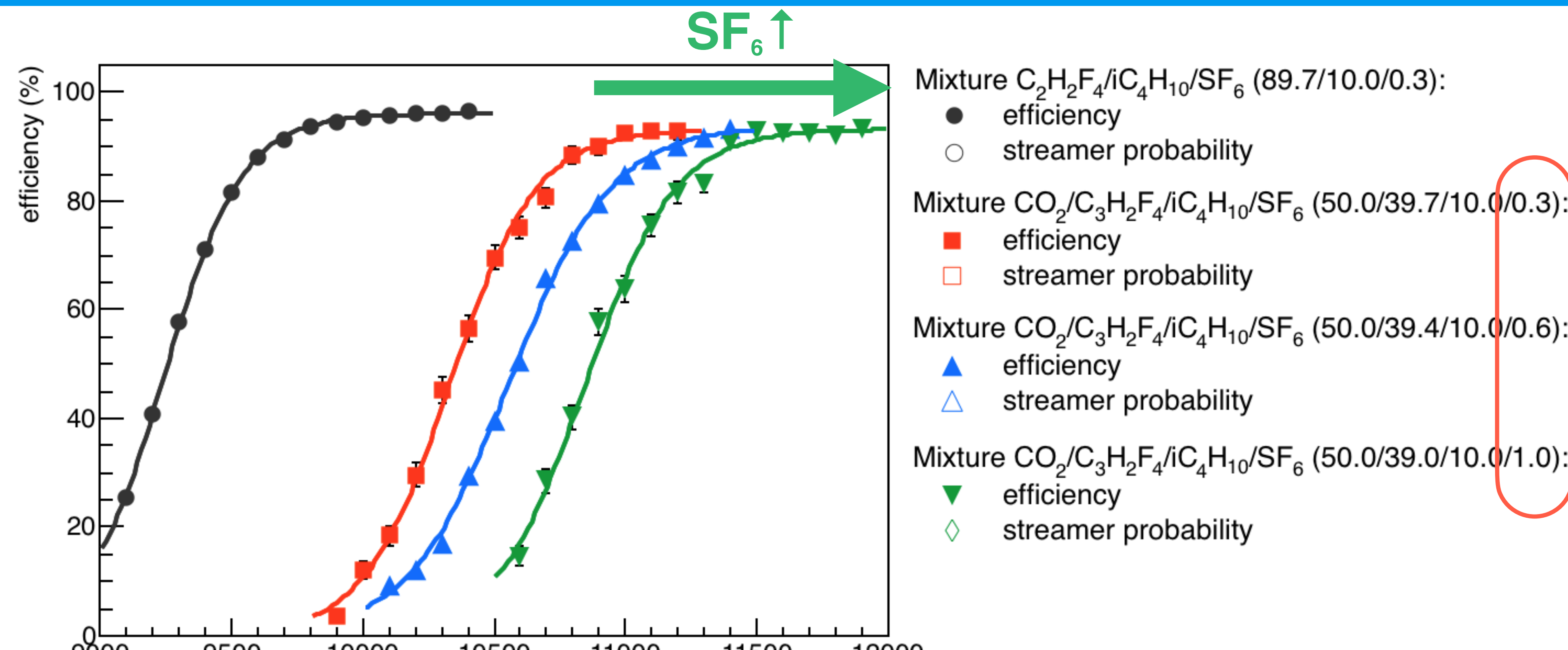
i-C_4H_{10} ↑
and
CO_2 ↓



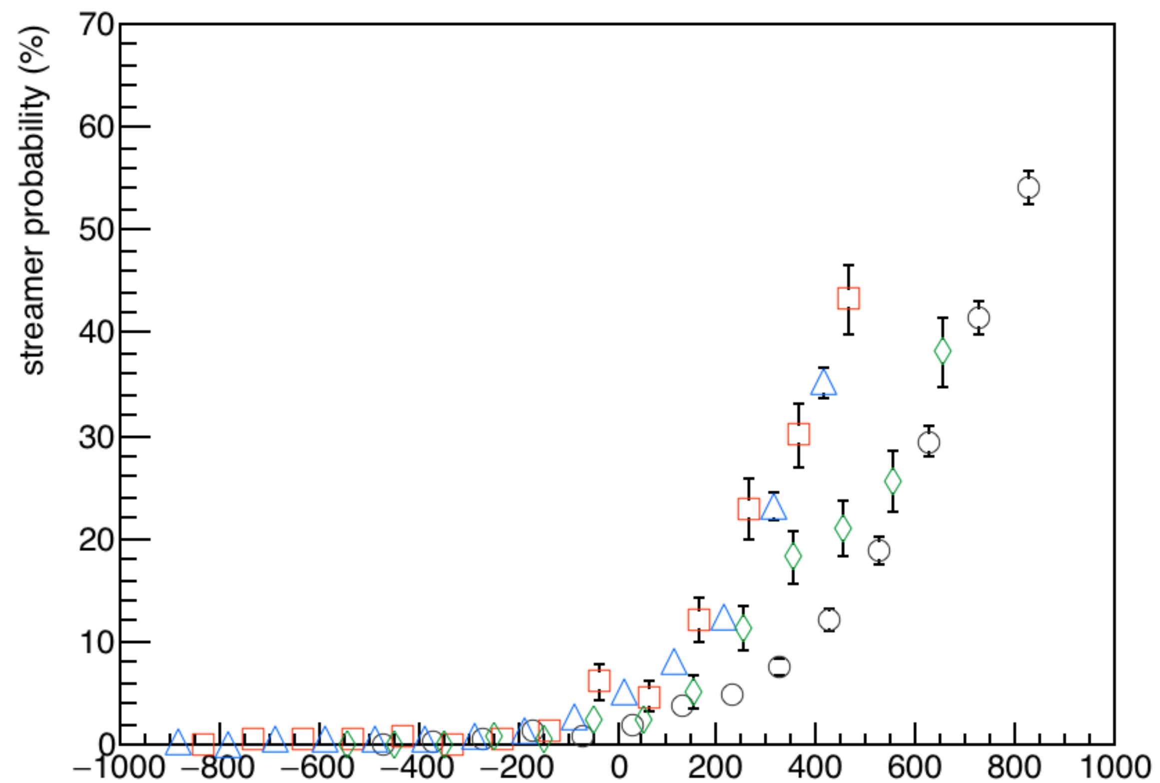
A. Bianchi *et al.* 2019 *JINST* **14** P11014

- The **working point does not vary monotonically**
- **Streamer probability is very similar in all cases**, with the possible exception of 15% *i*-C_4H_{10}
- The **reduction of *i*-C_4H_{10} (flammable) is desirable** for safety and practical reasons, but it seems that reducing *i*-C_4H_{10} would result in less steep turn-on of the efficiency, which is a drawback

Variation of SF_6



A small variation on the concentration of SF_6 leads to an important effect on the working point: the shift of the working point is ~500 V from 0.3% to 1.0% SF_6



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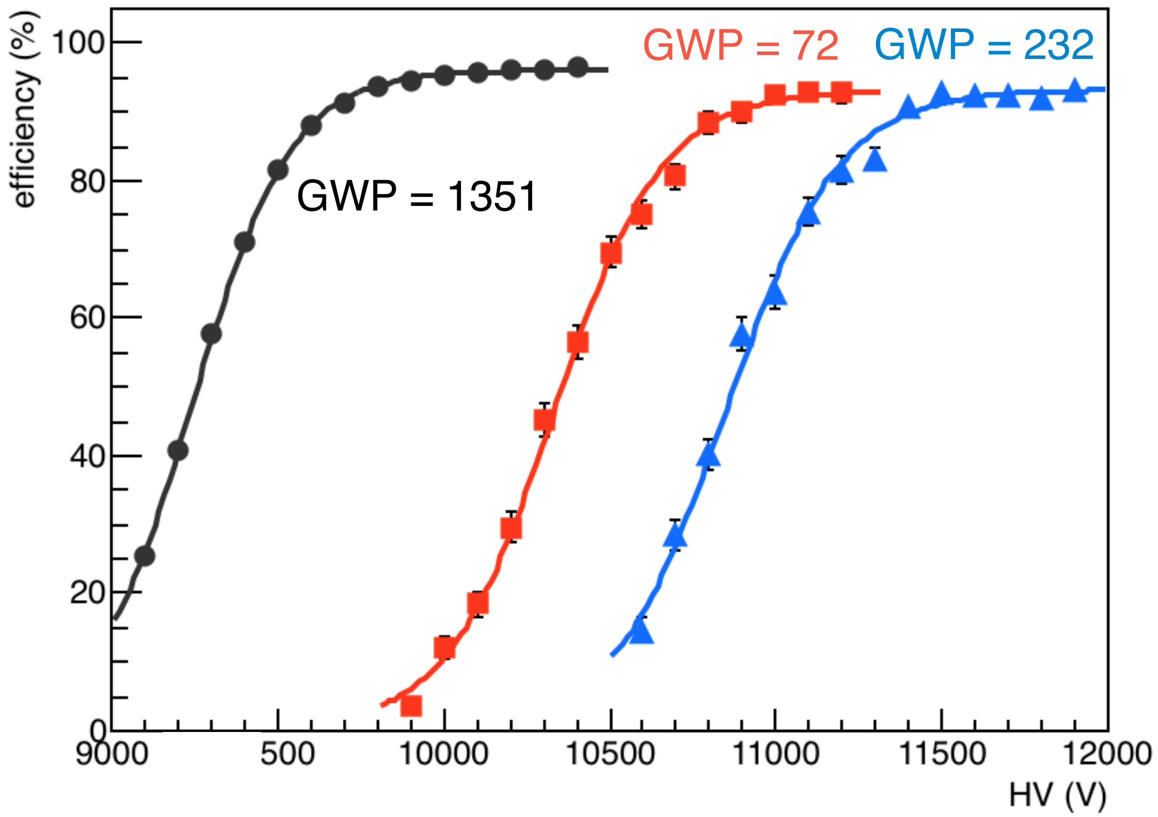
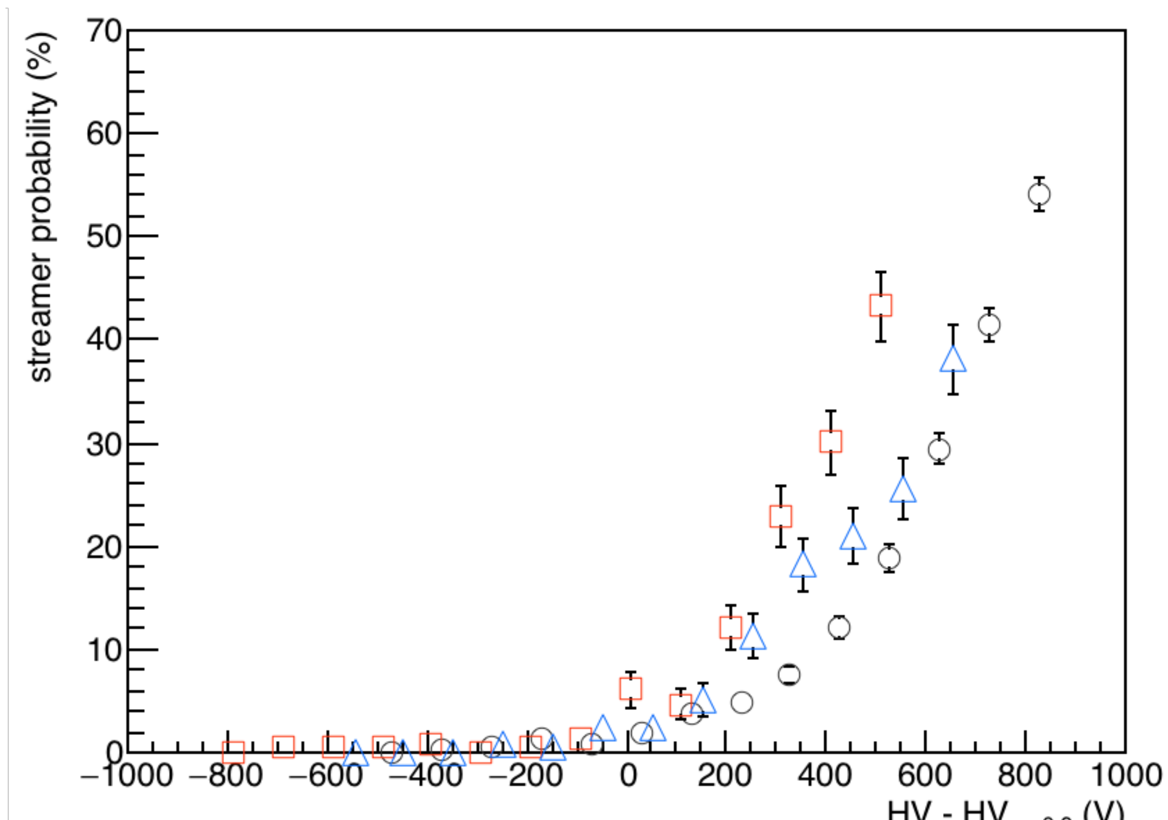
No significant variations in the streamer probability are observed if SF_6 is increased from 0.3% to 0.6%, while **the suppression of streamers is slightly higher with 1.0% SF_6**

Promising gas mixtures with low GWP





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Mixture $C_2H_2F_4$/iC_4H_{10}/SF_6 (89.7/10.0/0.3):
- ● efficiency
- ○ streamer probability

Mixture CO_2/$C_3H_2F_4$/iC_4H_{10}/SF_6 (50.0/39.7/10.0/0.3):
- ■ efficiency
- □ streamer probability

Mixture CO_2/$C_3H_2F_4$/iC_4H_{10}/SF_6 (50.0/39.0/10.0/1.0):
- ▲ efficiency
- △ streamer probability

50% CO_2, 39.7% $C_3H_2F_4$, 10% *i*-C_4H_{10}, 0.3% SF_6:

- GWP: 72 (~20 times lower than the GWP of ALICE mixture)
- the working point is quite close to the working point of the ALICE RPCs during LHC Run 1 and Run 2 (~1.0 kV)
- the streamer probability is not as low as in the current ALICE mixture

50% CO_2, 39% $C_3H_2F_4$, 10% *i*-C_4H_{10}, 1% SF_6:

- GWP: 232 (~5 times lower than the GWP of ALICE mixture)
- the working point is higher (~1.5 kV)
- the streamer probability is similar to the ALICE mixture, although slightly higher

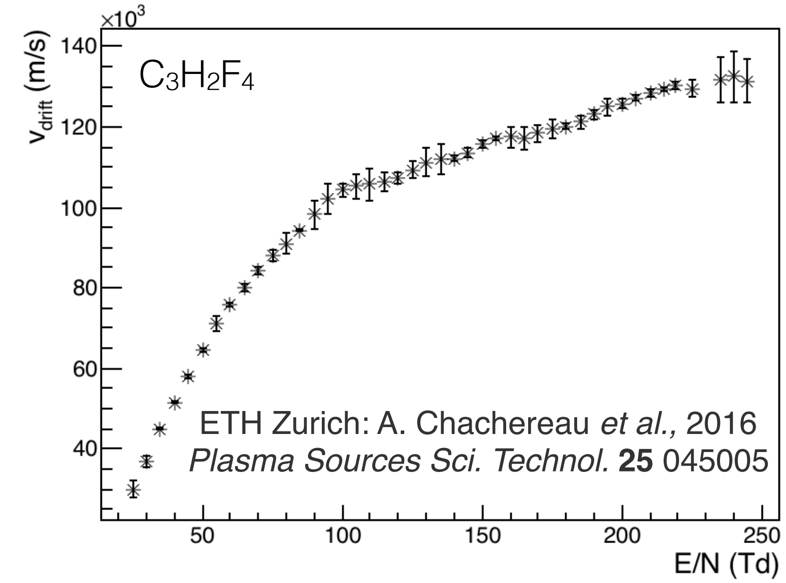
→ in both cases, values of cluster size are similar to those obtained with the ALICE mixture

→ more details in: A. Bianchi *et al.* 2019 *JINST* **14** P11014

Simulations of RPC performance

Reliable simulations of electron transport parameters in $C_3H_2F_4$-based gas mixtures turn out to be extremely useful to **optimize** the RPC performance, but also for:

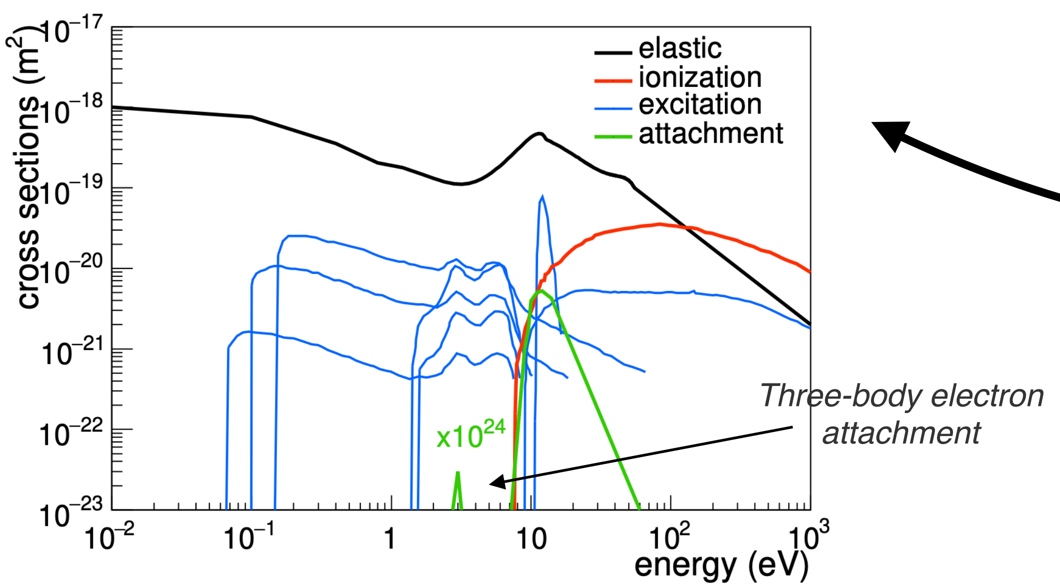
- different experiments with different operational conditions (ATLAS/CMS or ALICE)
- different types of RPCs and other gaseous detectors (i.e. GEM)



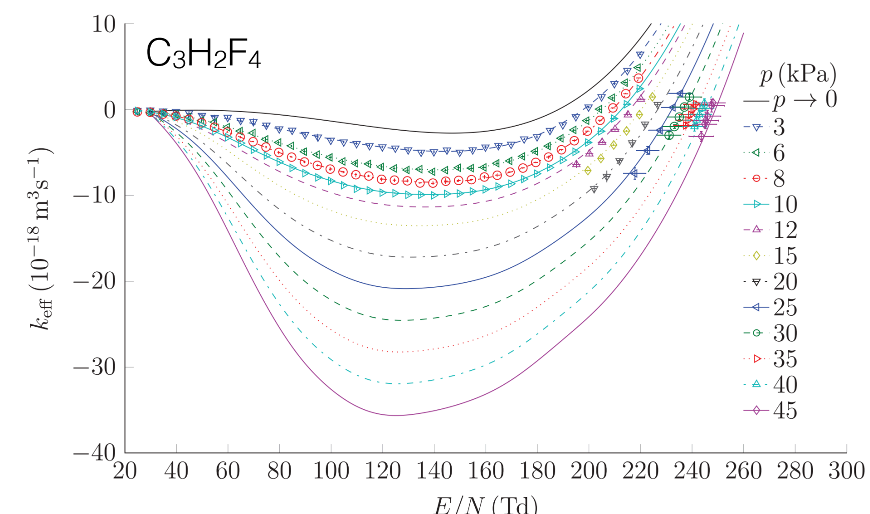
Numeric solvers or Monte Carlo simulations

electron collision cross sections — **Boltzmann transport equation** → transport coefficients and reaction rates

Inverse problem



A. Bianchi *et al.*, 2021, arXiv: 2103.08643

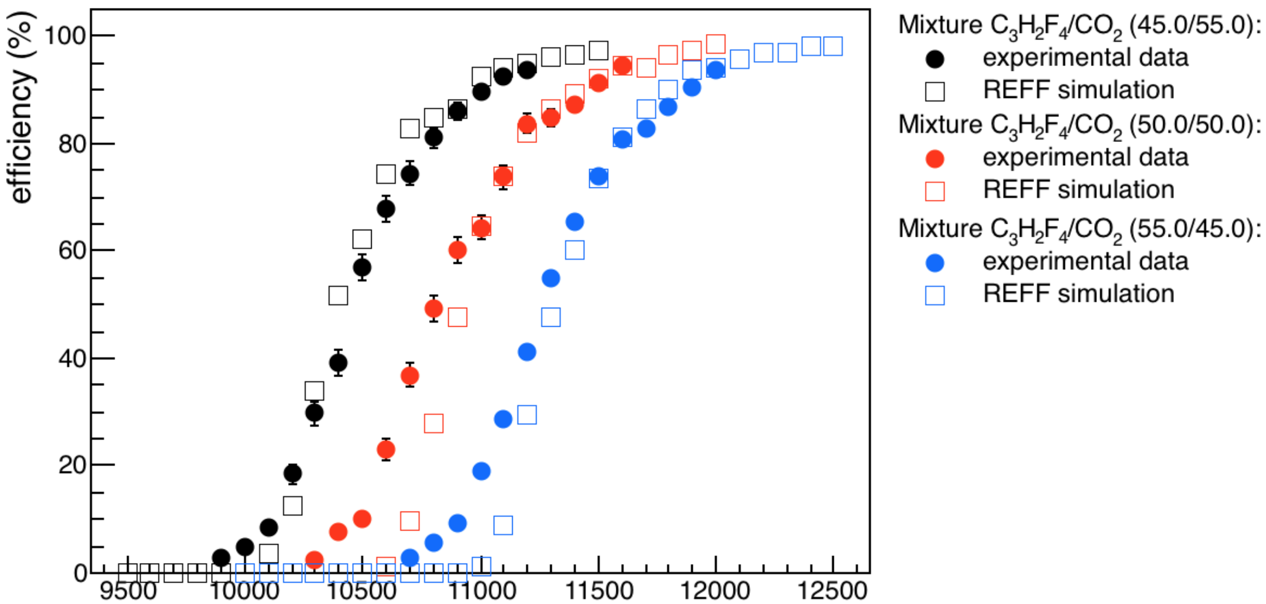


ETH Zurich: A. Chachereau *et al.*, 2016 *Plasma Sources Sci. Technol.* **25** 045005

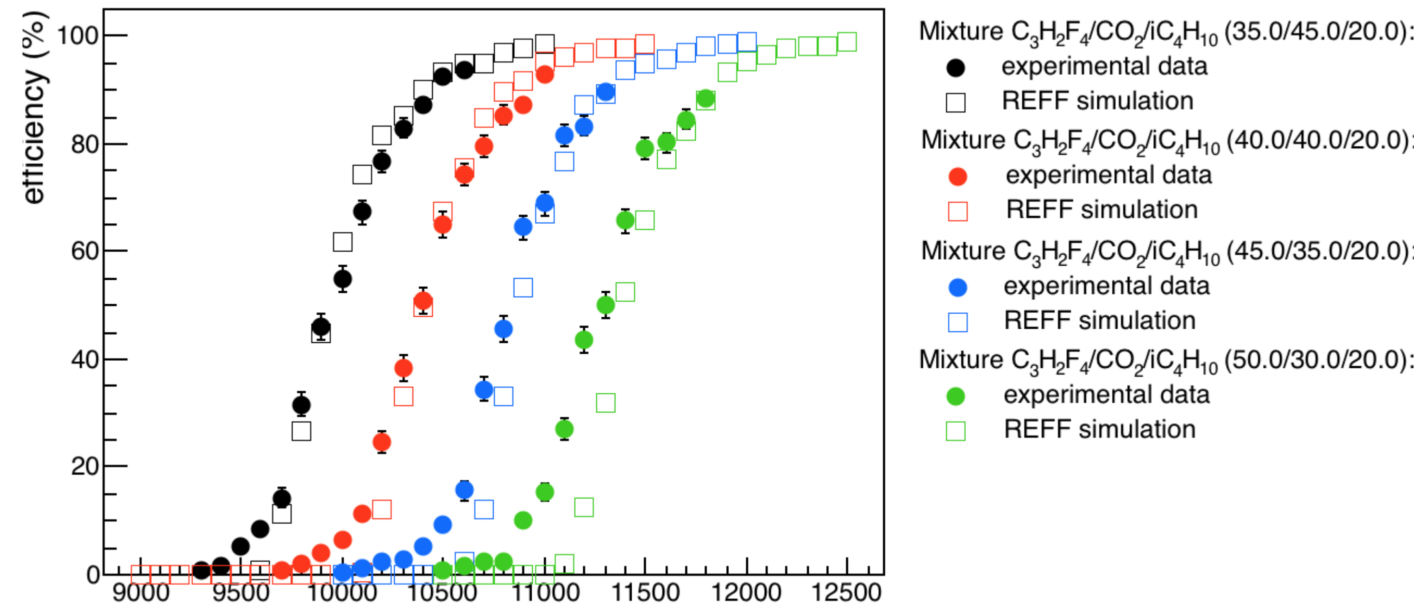
Electron collision cross sections of $C_3H_2F_4$ are obtained by unfolding its electron swarm parameters

Results of simulation

Variation of the ratio between $C_3H_2F_4$ and CO_2 without *i*-C_4H_{10} and with 20% *i*-C_4H_{10}:

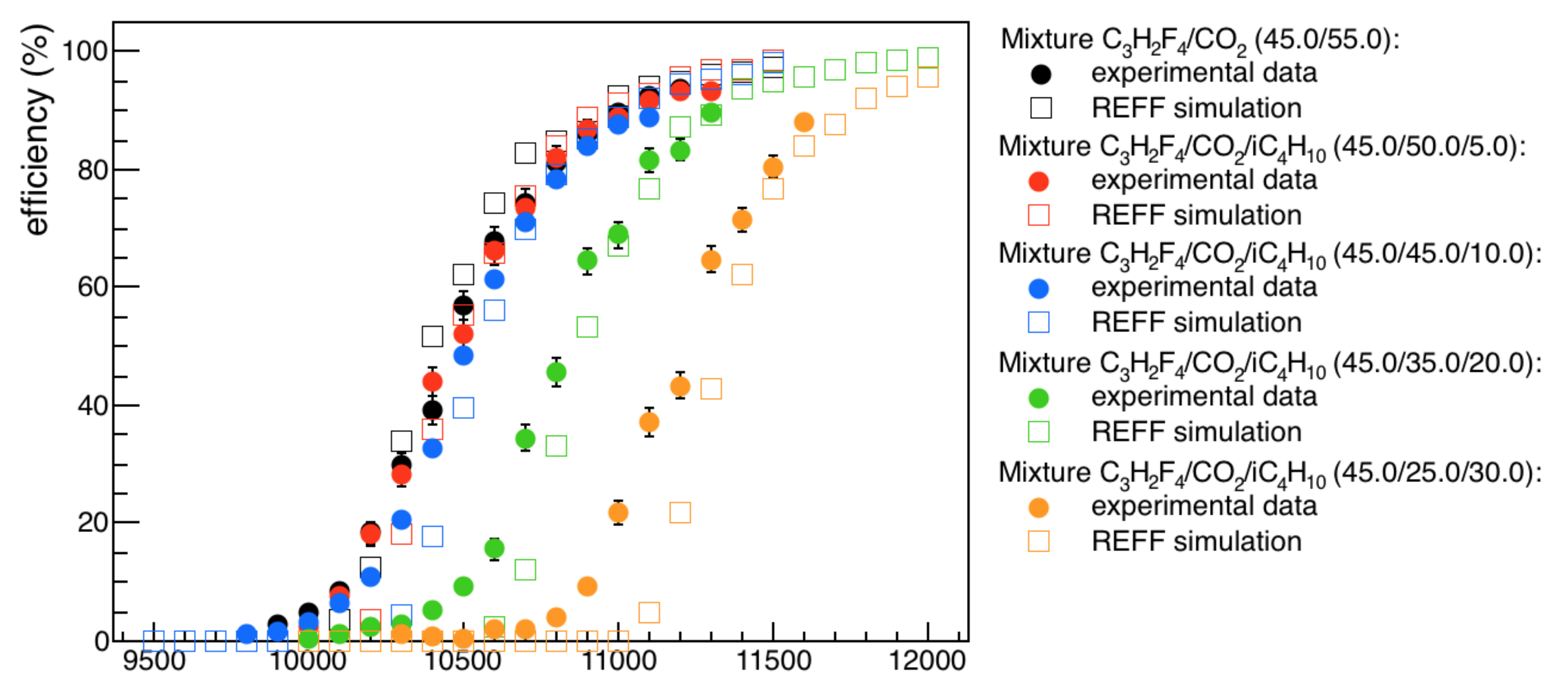


A. Bianchi *et al* 2020 *JINST* **15** C09006



A. Bianchi *et al* 2020 *JINST* **15** C09006

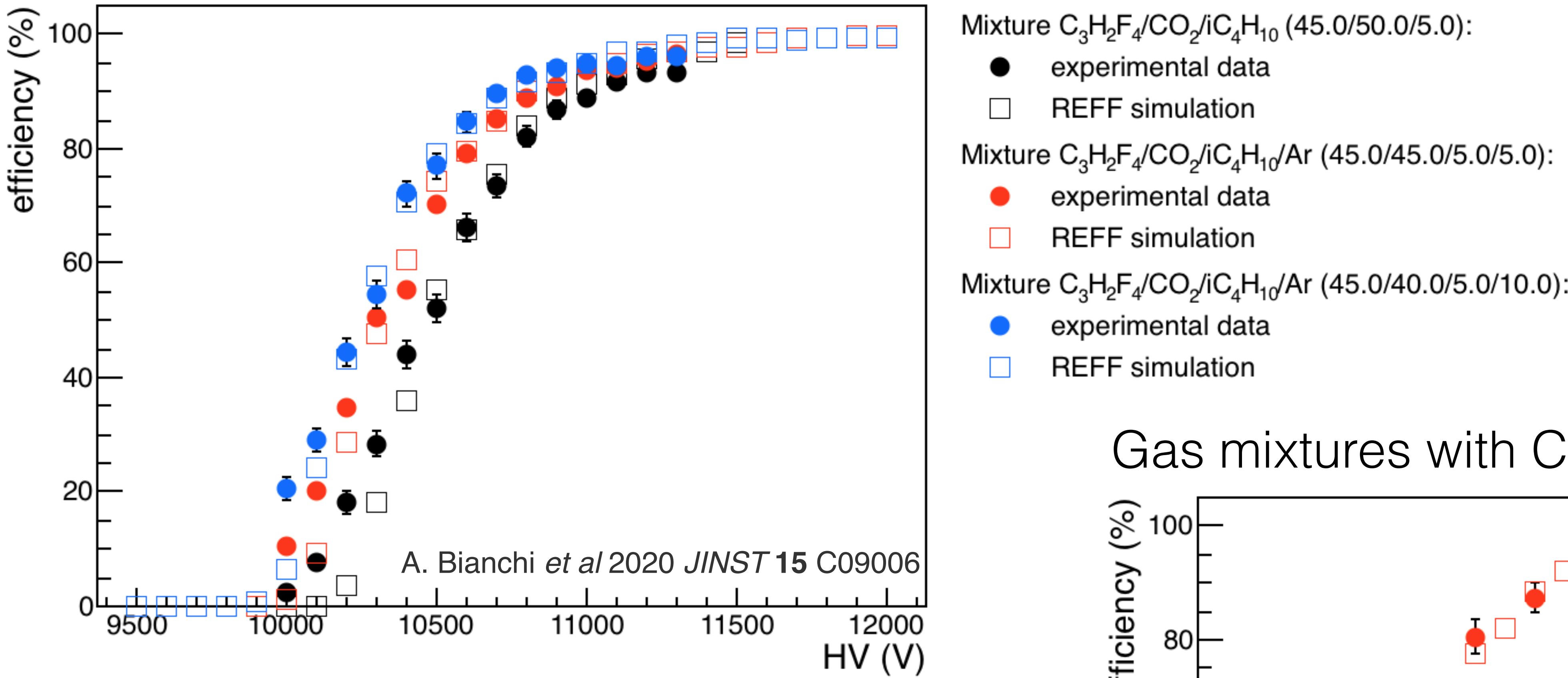
Variation of the ratio between CO_2 and *i*-C_4H_{10} while $C_3H_2F_4$ fraction is kept constant at 45%:



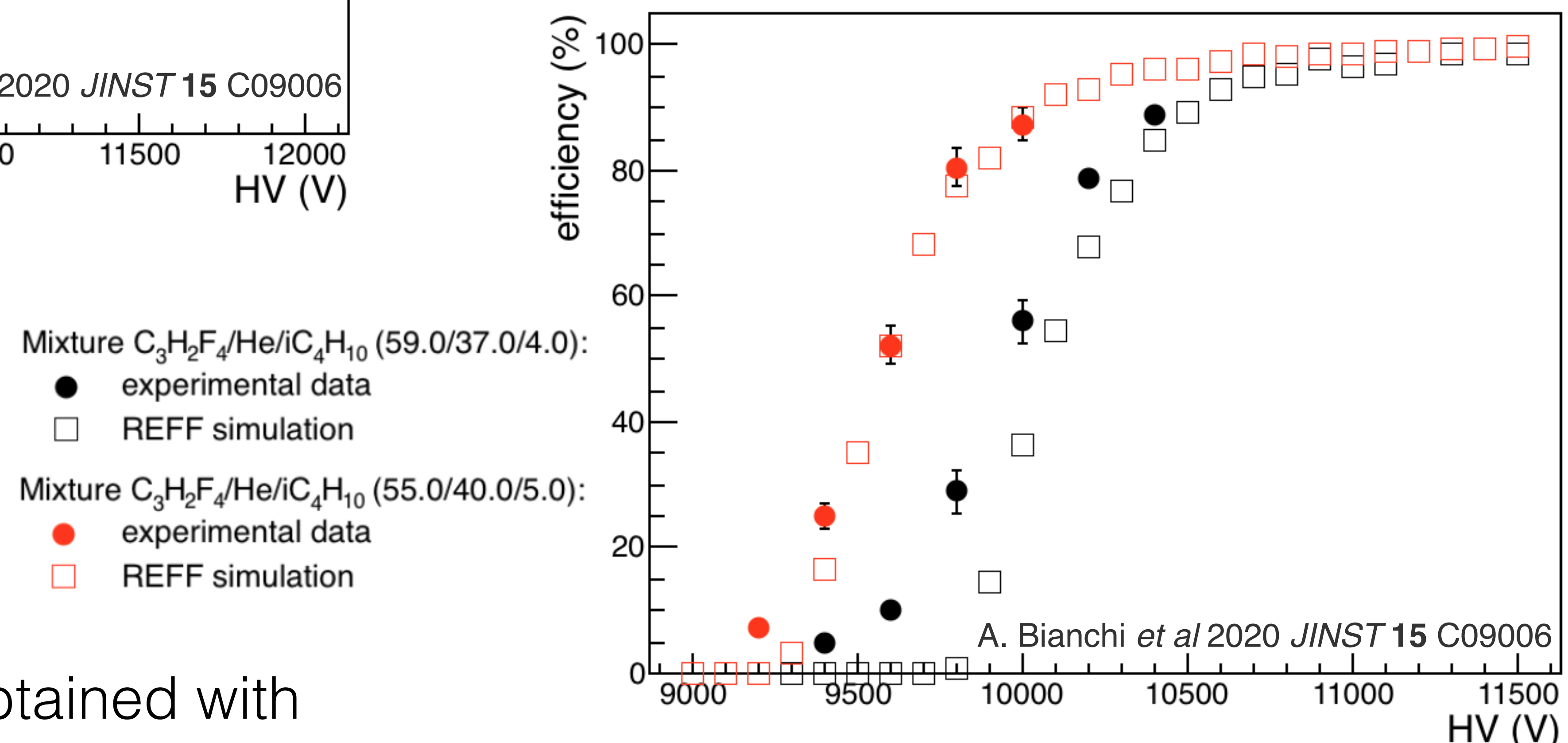
A. Bianchi *et al* 2020 *JINST* **15** C09006

Results of simulation

Variation of the ratio between CO_2 and **Ar** with 45% $C_3H_2F_4$ and 5% *i*-C_4H_{10}:



Gas mixtures with $C_3H_2F_4$, *i*-C_4H_{10} and **He**:



Experimental data by M. Abbrescia *et al.*, 2016, *JINST* P08019:
Discrimination threshold of ~300 fC while it was ~130 fC in the previous cases

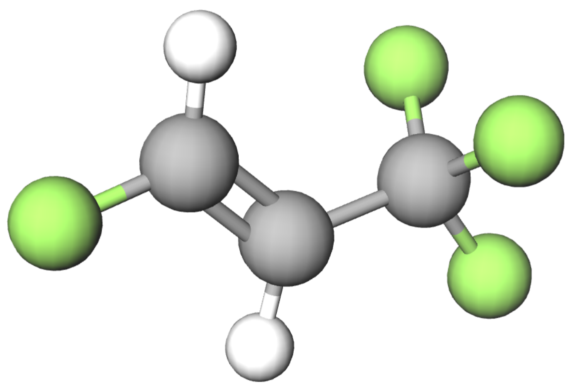
Good results are also obtained with gas mixtures of $C_3H_2F_4$, CO_2 and O_2

Conclusions and outlook

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

  → goal: to have a eco-friendly gas mixture (at least with a low GWP)

  → **$C_3H_2F_4$ is a possible candidate** to substitute $C_2H_2F_4$, thanks to its low GWP



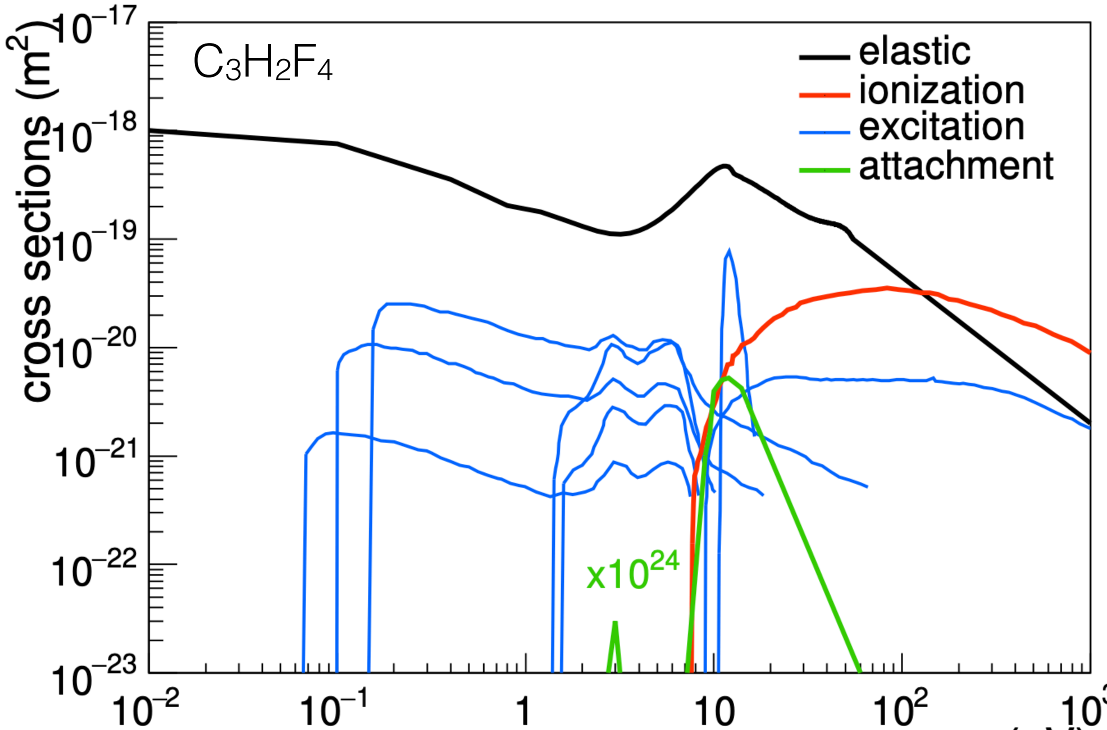
- **Characterization of mixtures with $C_3H_2F_4$:**
  - strong dependence between the working point of the detector and the concentration of $C_3H_2F_4$
  - direct replacement of $C_2H_2F_4$ with $C_3H_2F_4$ is not suitable (working point > 14 kV) → the **addition of CO_2** to $C_3H_2F_4$-based gas mixtures is required to operate at lower voltages
  - **promising $C_3H_2F_4/CO_2$-based mixtures with *i*-C_4H_{10} and SF_6:**

    GWP reduced by a factor 5-20 (A. Bianchi *et al.* 2019 *JINST* 14 P11014 and A. Bianchi *et al.*, 2020 *JINST* 15 C04039)

- **Simulation of RPC efficiency:**
  - set of electron collision cross sections of $C_3H_2F_4$

    (A. Bianchi et al., 2021, arXiv: 2103.08643)
  - **reliable predictions** of the RPC efficiency in **$C_3H_2F_4$-based gas mixtures with** the addition of ***i*-C_4H_{10}, CO_2, O_2, Ar, He**

    (A. Bianchi *et al* 2020 *JINST* 15 C09006)
  - **future developments** of our simulation, including **space charge effects**, with the aim to evaluate the streamer probability, cluster size, etc.



A. Bianchi *et al.*, 2021, arXiv: 2103.08643