Studies on RPC operation with low GWP gases

G. Rigoletti, B. Mandelli, R. Guida

on behalf of the CERN Gas Team

PHAST
PHYSIQUE
ET ASTROPHYSIQUE
UNIVERSITÉ DE LYON

ÉCOLE
DOCTORALE
52

CERN | EP-DT
Detector Technologies

UNIVERSITÉ
DE LYON

Outline

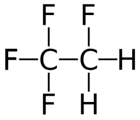
- Overview on RPC gas mixtures and possible alternatives
- Performance studies of RPC operated with low-GWP gases
  - Laboratory conditions
  - LHC-like conditions
- Conclusions and future ideas

RPC gas mixtures and possible alternatives

RPC gas mixtures at LHC

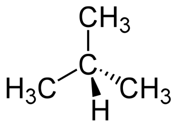
- Bakelite RPCs: ATLAS, CMS, ALICE (MTR/MID)
- Mixture made of 3 components: R-134a, i-C4H10, SF6.
- 95% of the GWP due to R-134a
- ~5% due to SF6

~95 %



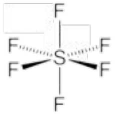
GWP 1430

~5 %

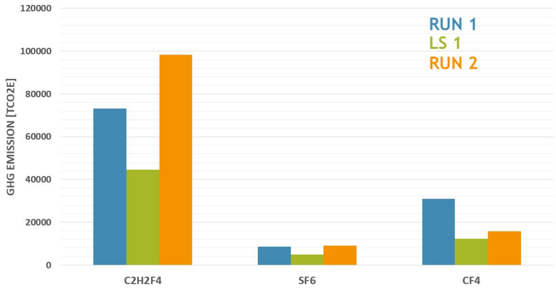


GWP 3.3

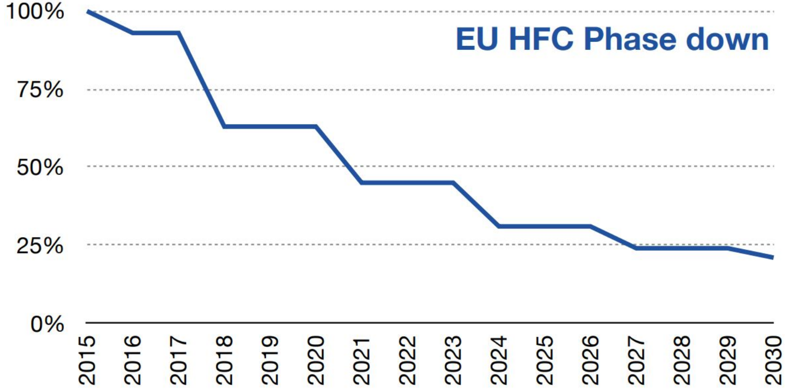
~0.3 %



GWP 22800



RPCs accounts for ~ 85% of GHG emissions from particles detectors at CERN



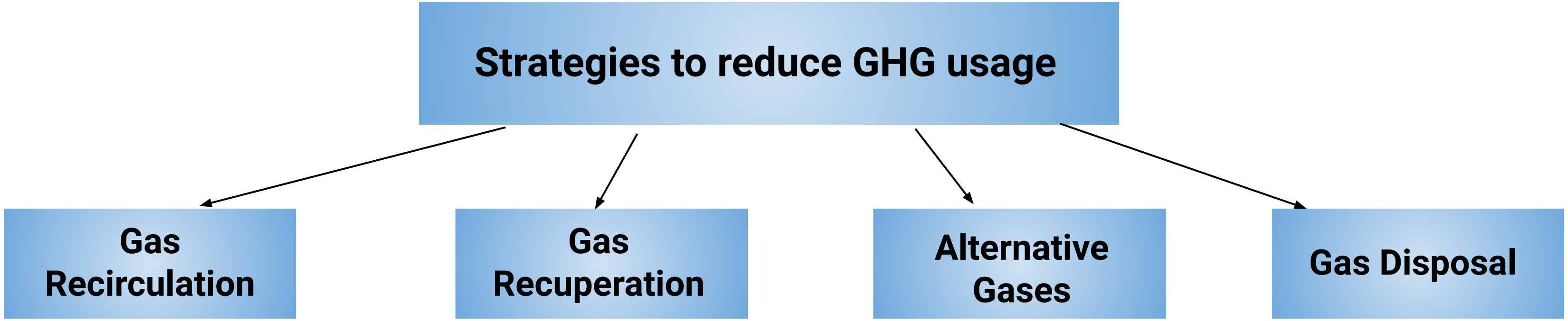
European F- regulation

- **Limit** the total amount of high-GWP F- gases on the market
- **Ban** use where alternatives are present
- **Prevent** emission by proper equipment checks

Prices could increase in EU and availability in the future is not known.

Reduction of use of C2H2F4 is fundamental for next LHC Runs

Strategies to reduce GHG emissions



RPC R&D:

- Alternatives to R-134a
- Alternatives to SF6

<u>RPC R&D Goal:</u>

Find a low-GWP gas mixture suitable for LHC-operation that requires no change in the current RPC systems (i.e. no change in electronics, HV, gas systems, etc.)

R-134a alternatives: HFCs, HFOs, HCFOs

Lower GWP HFCs

Example: R-32, R-152a, R-245fa

Pros:

- good availability on the market
- vapour pressure comparable with R-134a one

Cons:

- Some might be flammable
- effective GWP gains on the mixture

HFOs

Examples: R-1234yf, ***R-1234ze***, R-1225ye

Pros:

- low GWP (<10)
- good availability on the market

Cons:

- flammability concerns
- price still higher than R-134a

HFCOs

Have a Chlorine atom in the molecule

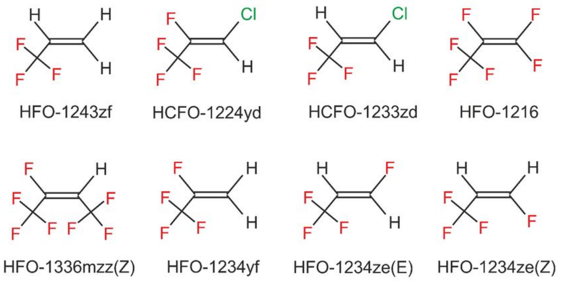
HCFO-1233zd, HCFO-1336mz, HCFO-1224yd

Pros:

- low GWP
- possible quenching properties

Cons:

- low vapour pressure -> difficult to operate in high concentrations or high flow
- low availability on the market
- Effects of Chlorine on the detector not known



SF6 alternatives

SF6 alternatives studies ongoing in the electrical industry:

Novec™

Examples: 5110, 4710, 7000

Pros:

- Good availability on the market
- SF6-like performance, depending on the gas
- low GWP compared to SF6

Cons:

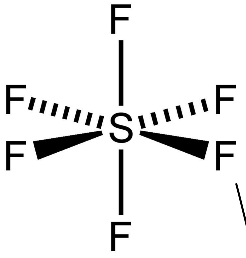
- Low vapour pressure
- Poor performance, depending on the gas

C4F8O

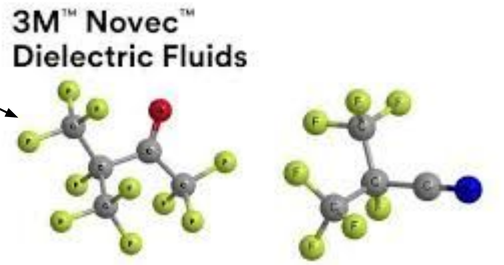
- GWP higher than alternatives

CF3I

- Mutagenic toxicity

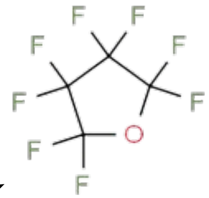


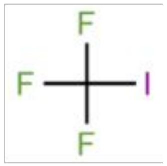
SF6
GWP 22800



Novec 5110
GWP < 1

Novec 4710
GWP 2100





C4F8O
GWP 8700

CF3I
GWP < 1

HFO flammability tests

R-1234yf and R-1234ze main HFO candidates

- R-1234yf classified as mildly flammable -> Focus on R-1234ze

R-1234ze + i-C4H10 + 40% RH flammability test conducted:

ISO 1056 standard flammability test (detachement + flame propagation criteria)

Results

- *Mixture with 1% i-C4H10 + R-1234ze is flammable*
- Water vapour plays an important role

HFOs alone + i-C4H10 is flammable -> Effects of the CO2 on the mixtures to be understood

illustration of a flame detachment with flame propagation over a distance of at least 100 mm as criterion for flammability

test no.	Iso-butane fraction in test gas mixture in mol%	fraction of test gas mixture of iso-butane and HFO1234ze in mol%	fraction of air including 2.25 mol% water in mol%	reaction
9	**6.2**	**15.0**	**85.0**	**+**
10	6.0	20.0	80.0	-
11	**4.2**	**13.0**	**87.0**	**+**
12	**3.1**	**10.0**	**90.0**	**+**
13	**2.2**	**13.0**	**87.0**	**+**
14	1.1	13.0	87.0	-
15	**1.0**	**10.0**	**90.0**	**+**
16	0.0	12.0	88.0	-
17	0.0	11.0	89.0	-
18	0.0	10.0	90.0	-
19	0.0	9.0	91.0	-

https://edms.cern.ch/document/2463340/1

Why it is difficult to find eco gas mixtures

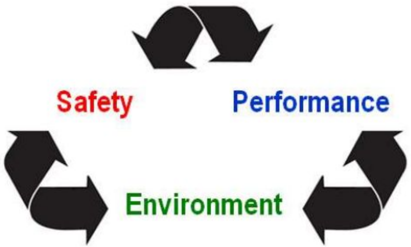
Several key factors to take into account:

Environment -> GWP

- Related to IR absorbance *over time*

Performance -> atmospheric lifetime

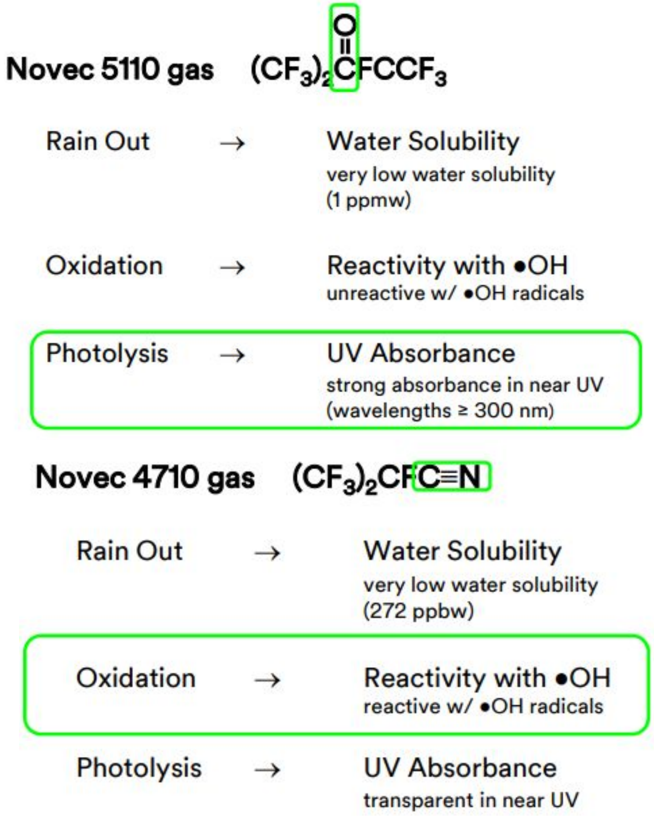
- Water solubility -> Rain out
- OH^- reactivity -> Oxidation
- UV absorbance -> Photolysis



Performance -> LHC operation:

- Non toxic -> CF3I main concern
- Non flammable -> R-1234ze/yf under evaluation

SF6 and R-134a performance are difficulty matched also because of their stability in atmosphere



John G. Owens, 3M, Greenhouse Gas Emission Reductions from Electric Power Equipment through Use of Sustainable Alternatives to SF6

Performance studies of RPCs operated with low-GWP gases

RPC performance evaluation

RPC performance evaluated by different means:

Cosmic muons detection performance

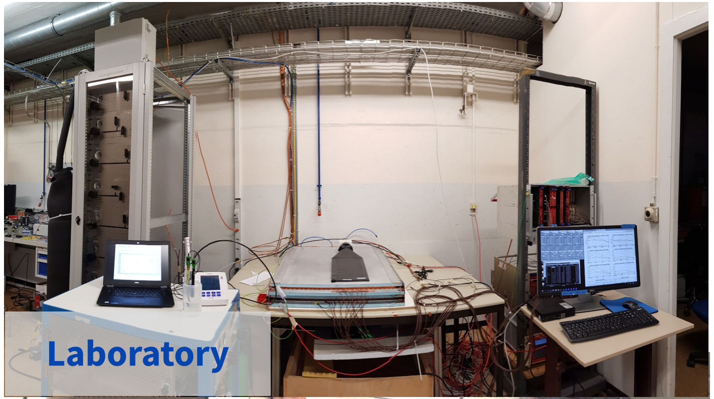
- Raw signals studies: efficiency, streamer probability, avalanche/streamer prompt charge, cluster size, time resolution
- Gas mixture characterization: mass spectroscopy and gas chromatography

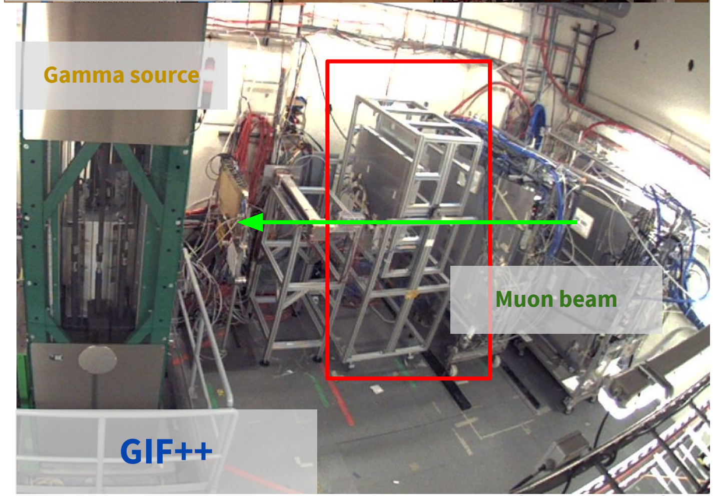
Longevity studies under gas recirculation and gamma irradiation

- Current stability under irradiation
- Ohmic and dark currents monitoring
- Rate of F- impurities production

LHC-like performance (gas recirculation + gamma background + muon beam)

- Similar to cosmic muons studies





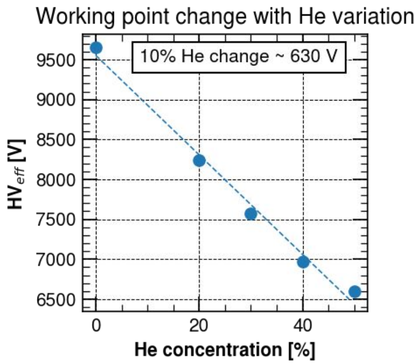
Characterization of the standard gas mixture

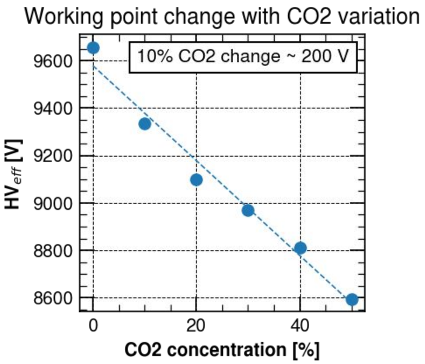
Better understanding of the effects of the single component of the gas mixture

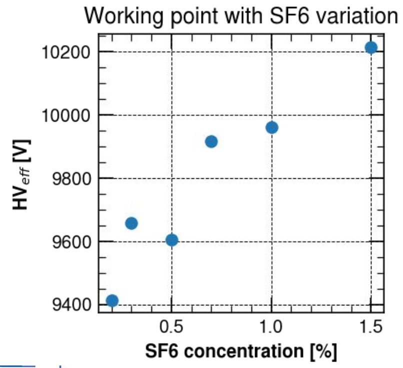
- Working point shift -> necessary when HFO is used
- Prompt, avalanche, streamer charge variation

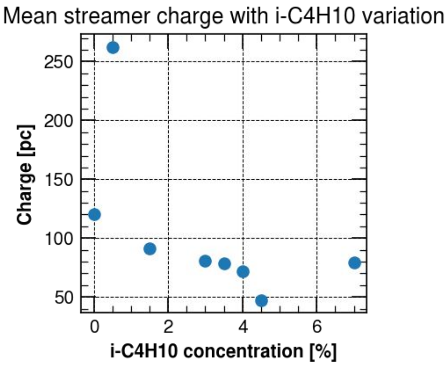
Standard CMS-RPC gas mixture studied by varying SF6/R-134a and i-C4H10/R-134a

- SF6 range from 0.2 to 1.5 %
- i-C4H10 from 0% to 7%









He and CO2 added in the standard gas mixture:

- Addition 10% of He ~ - 600 V shift working point
- Addition 10 % of CO2 ~ -200 V shit working point

HFO-based gas mixtures

More than 100 different gas mixtures tested:

- With HFCs alternatives (R-32, R-245a, etc.)
- With HFOs alternatives (R-1234ze, R-1234yf)

Few 5-components gas mixtures selected:

- R-1234ze + R-134a kept in same amount to control streamer contamination performance
- i-C4H10 same as std. gas mixture
- SF6 slightly increased
- Addition of He or CO2 to lower the working point

gas_mixture	GWP[100]	Working Point	avalanche	σt	Cluster Size [2cm strips]	Streamer probability
R134A/SF6/IC4H10 95.2/0.3/4.5	1430	9657	1.6	1.42	1.5	0.5%
R134A/SF6/IC4H10/CO2/HFO 22.25/1.0/4.5/50.0/22.25	548	10239	2.1	1.47	1.8	1.8%
R134A/SF6/IC4H10/CO2/HFO 22.4/1.0/4.5/49.7/22.4	551	10084	**1.5**	1.42	**1.5**	**0.7%**
R134A/SF6/IC4H10/CO2/HFO 27.25/1.0/4.5/40.0/27.25	620	10686	2.2	1.46	1.7	1.8%
R134A/SF6/IC4H10/HFO/HE 21.63/0.6/4.5/43.27/30.0	**449**	10403	2.5	1.44	1.8	3.2%
R134A/SF6/IC4H10/HFO/HE 32.45/0.6/4.5/32.45/30.0	603	**9863**	2.5	1.42	1.7	1.9%
R134A/SF6/IC4H10/HFO/HE 37.45/0.6/4.5/37.45/20.0	675	10845	2.3	1.41	1.7	1.5%

SF6 alternatives studies

4 gases identified as SF6 alternatives

Performance studied in laboratory by replacing SF6 in the standard gas mixture:

C4F8O

- GWP ~ 12000
- Good performance at 1.5 % -> not low-GWP

CF3I

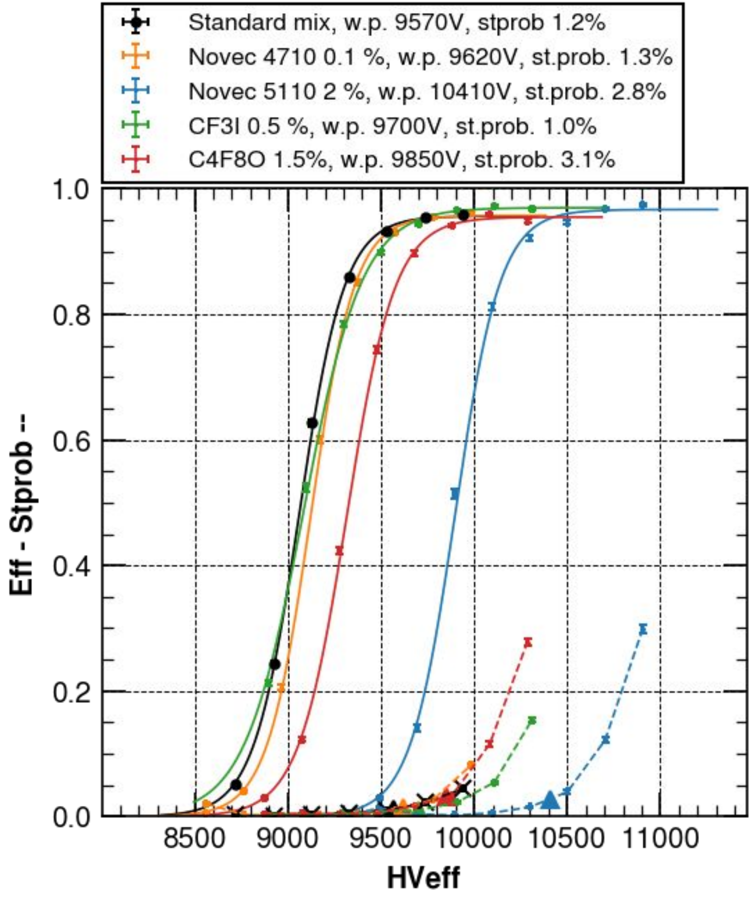
- GWP < 1
- Good performance at 0.5 %
- Mutagenic toxicity -> not suitable for LHC operation

Novec™5110

- GWP < 1
- Discrete performance at 2 %
- Liquid at room temperature -> difficult to operate

Novec™4710

- GWP = 2100
- Excellent performance at 0.1%
- May react with water -> Under investigation



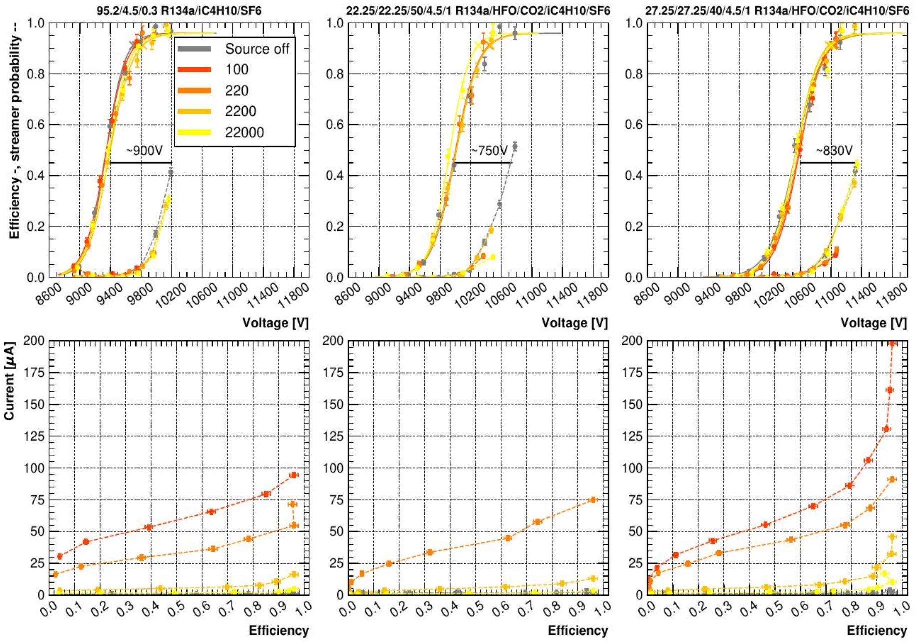
RPCs with LHC-like conditions: muon beam

After selecting HFO-based gas mixtures RPCs were studied under LHC-like conditions at GIF++:

- Background radiation
- Muon beam

ABS	100	55.3	2200	22000
Gamma Rate [KHz/cm^2]	220	41.2	3.75	0.774

Performance of RPCs with LHC-like conditions and HFO-based gas mixtures studied at GIF++ in 2018



Muon beam + gamma irradiation of HFO+CO2 gas mixtures:

- Rate capability matching std. gas mixture
- Higher currents than std. gas mixture at fixed efficiency
- Relatively high working point

RPCs with LHC-like conditions: long term studies

Final goal: validate RPC operation under LHC-like conditions with eco-friendly gas mixtures

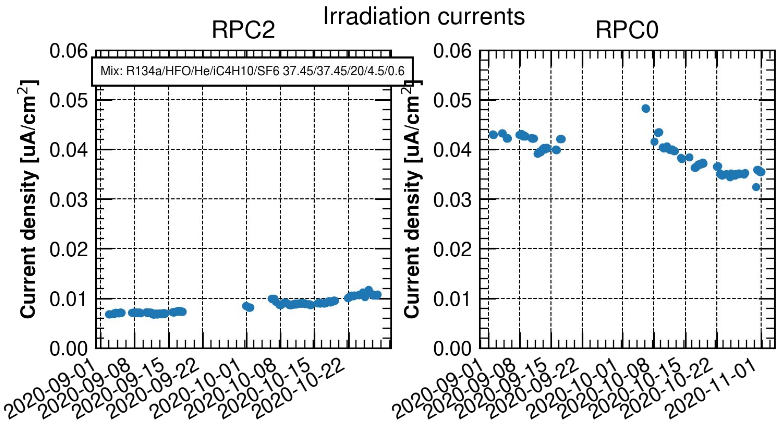
- Gas recirculation up to 90%
- Gas humidification
- Gas purification
- Detectors at working point

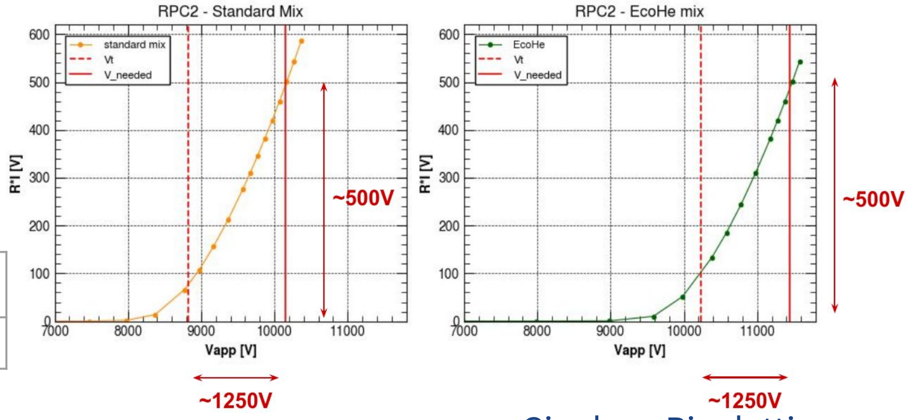
Target:

- Integrated charge up to expected HL-LHC one ~ 840 mC/cm^2(CMS-RPC Endcap case)
- Ohmic and dark currents stability

Campaign:

- Monitor irradiation currents
- Check dark and ohmic currents stability with no irradiation
- Resistivity measurements (Ar and high flux rate models)
- F- based impurities production studies





~ 2 years of continuous irradiation needed to reach the target

HL-LHC target	Currently Integrated charge	Integrated charge rate	Campaign progress
840 mC/cm^2	182 mC/cm^2	1.07 mC/cm^2 / day	21 %

Impurities studies

Electric field + Gamma background break gas molecules -> impurities production

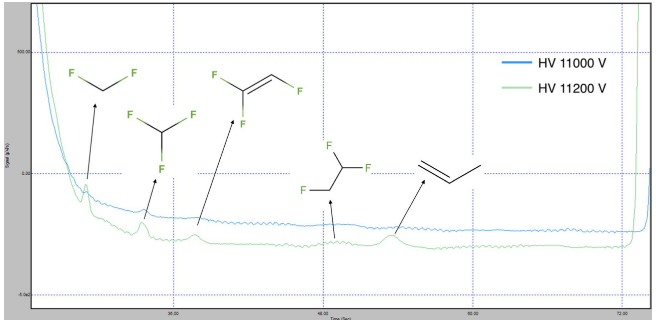
- Gas Chromatograph (GC)
  - Impurities quantification
- Mass Spectrometer (MS)
  - Impurities identification
- Ion Selective Electrodes (ISE)
  - F- quantification

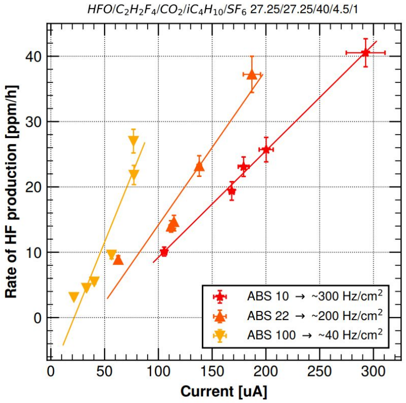
F- production of RPCs under irradiation at working point measured on std. mixture and HFO+CO2 based gas mixture

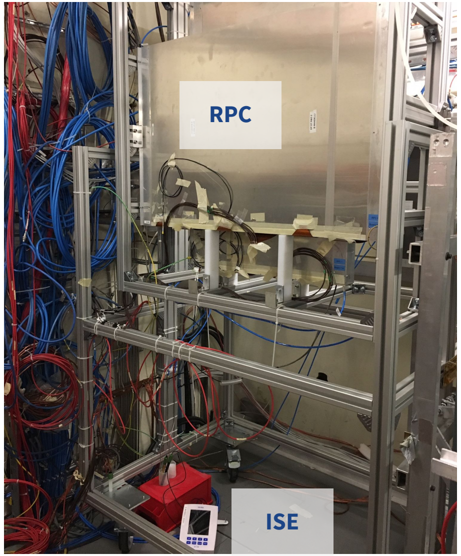
- HFO+CO2 based gas mixture breaking ~ 4 times more than std. gas mixture
- R-1234ze seems to break ~ 10 times more easily than R-134a

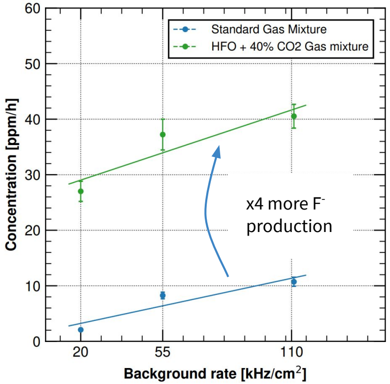
Purifiers in gas systems may be able to absorb F- impurities

- Study ongoing -> Measurements of purifiers efficiency in trapping F-
- Preliminary results shows efficiency > 95%









Conclusions

EP-DT-FS Gas Systems strategies to reduce GHG:

- Alternative gases → search of new low GWP gases for RPCs

Low GWP gas mixtures pose several challenges:

- Safety, Environment, Performance

Search for new low GWP gas mixtures:

- In laboratory conditions
- Few HFO+CO_2 and HFO+He gas mixtures selected
    - 5 components → R-134a kept in some amount

Few HFO-based gas mixtures selected as valid candidates for RPC operation

- Muon beam + irradiation tests performed on HFO+CO_2 gas mixtures
- Irradiation campaign started with HFO+He
- Studies on impurities production and possible solutions with HFO+CO_2 and HFO+He

Thank you!