EP-DT
Detector Technologies

Performance studies of RPC detectors with new environmentally friendly gas mixtures in presence of LHC-like radiation background

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CERN

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Foremost parameters for selected mixtures

More than 50 gas mixtures tested

	Chem struc	GWPmix	HV (V)	Streamer (%)	Pulse charge (pC)	ΔV Eff-Stream (V)	Clu Size (strip)
R32-iC_4H_{10} -SF_6 0.6	c	1030	7500	14	0.5 / 6.5	600	1.5
R134a-iC_4H_{10}-SF_6 0.3	**c-c**	**1490**	**9600**	**1.5**	**0.5 / 6**	**1000**	**1.5**
R152a-iC_4H_{10}-SF_6 0.6	c-c	430	10000	10	1 / 8.5	760	1.6
R245fa-iC_4H_{10}-SF_6 0.6-He 50	c-c-c	1260	6600	20	1 / 7	610	2
HFO-iC_4H_{10}-SF_6 0.3-Ar 42.5	c=c-c	130	8900	70	2 / 15	160	4
HFO-iC_4H_{10}-SF_6 0.6-He 50	c=c-c	370	9000	20	1.5 / 8	700	4
HFO-R134 37.45-iC_4H_{10}-SF_6 0.6-He 20	**c=c-c**	**890**	**10500**	**1.8**	**0.5 / 6**	**970**	**1.6**
HFO-R134a 50-iC_4H_{10}-He 20	c=c-c	430	10800	50	1.5 / 8	400	2.5
HFO-R134a 22.5 -iC_4H_{10}-CO_2 50- SF_6 1	**c=c-c**	**560**	**10500**	**5**	**1.5 / 7.5**	**950**	**1.5**

*Parameters given at the efficiency knee

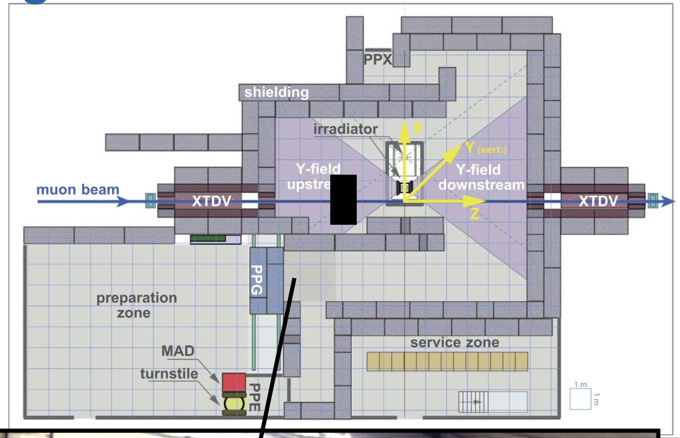
- C and C2 structures —> direct operation
- C3 structure (HFO) —> addition of Ar, He or CO_2
  - Ar brings to high streamer probability
  - He and CO_2 based gas mixtures look promising but need to add more SF_6
- Still necessary to have R134a in the mixture to be competitive to standard gas mixture

RPC 2016: https://indico.ugent.be/event/0/session/18/contribution/40/material/slides/0.pdf
TIPP 2017: https://indico.ihep.ac.cn/event/6387/session/55/contribution/49/material/slides/0.pdf

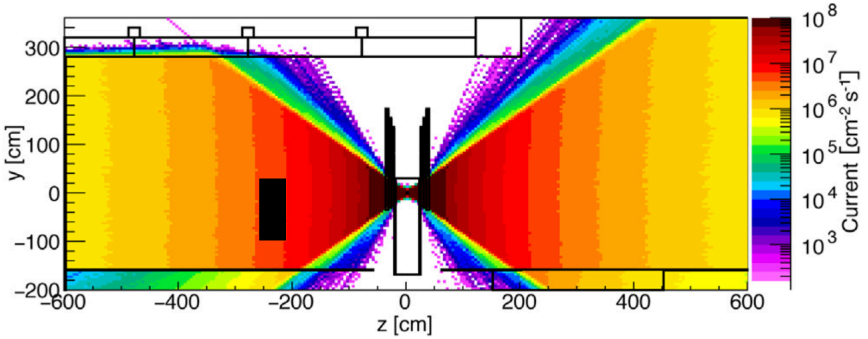
CERN Gamma Irradiation Facility (GIF++)

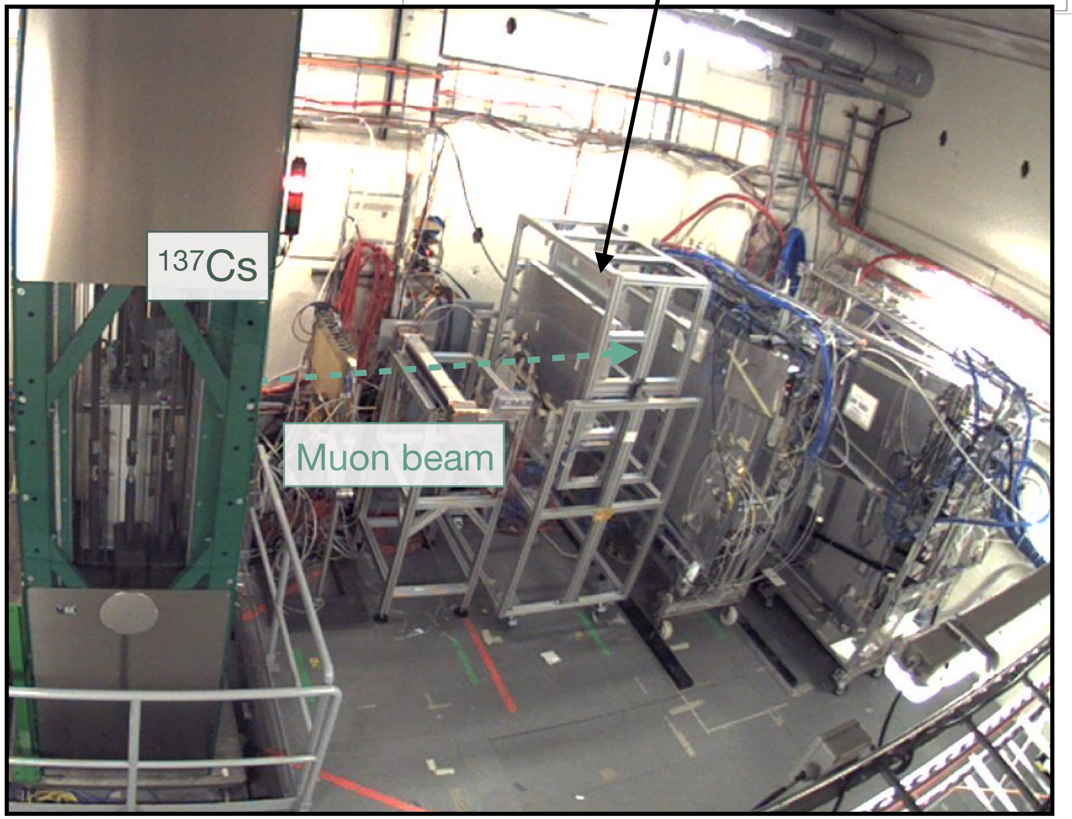
RPC performance studied at different gamma rates for 3 gas mixtures: standard gas mixture and two eco-friendly gas mixtures

- 95.2/4.5/0.3 R134a/iC4H10/SF6
- 22.25/22.25/50/4.5/1 R134a/HFO/CO2/iC4H10/SF6
- 27.25/27.25/40/4.5/1 R134a/HFO/CO2/iC4H10/SF6



- Gamma source
  - ^{137}Cs of 14 Tb —> 662 keV gamma
  - Lead filters to allow attenuation factors (ABS) between 1 and 46000
- Muon Beam
  - 100 GeV and 10^4 muons/spill (core beam size 10 cm x 10 cm)

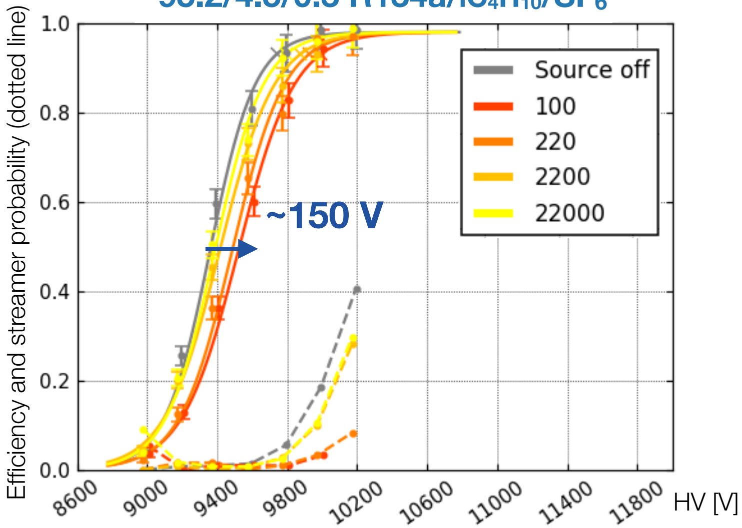




ABS	Gamma Rate (kHz/cm^2)
100	55.3
220	41.2
2200	3.75
22000	0.774

Muon efficiency and detector currents

95.2/4.5/0.3 R134a/iC_4H_{10}/SF_6



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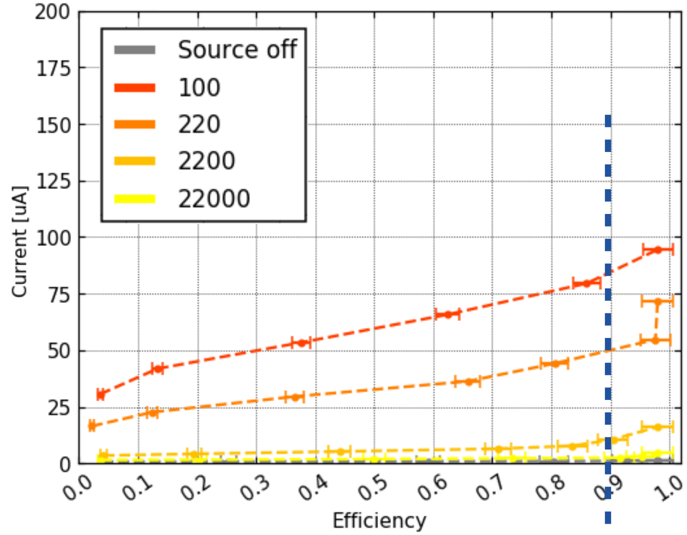
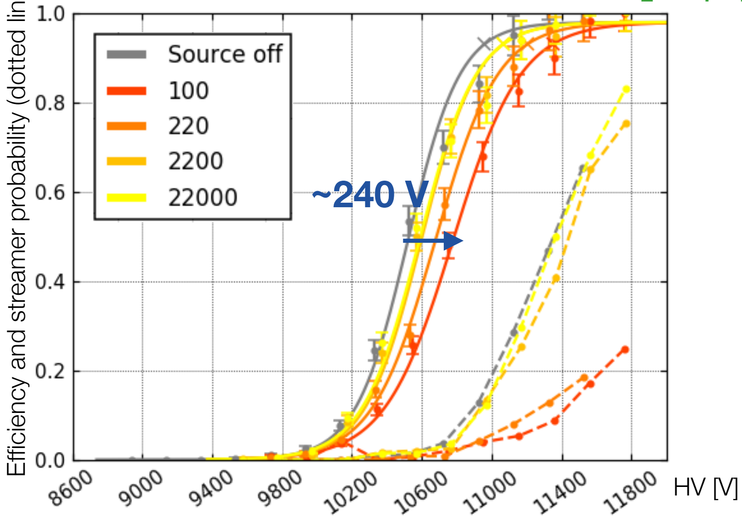
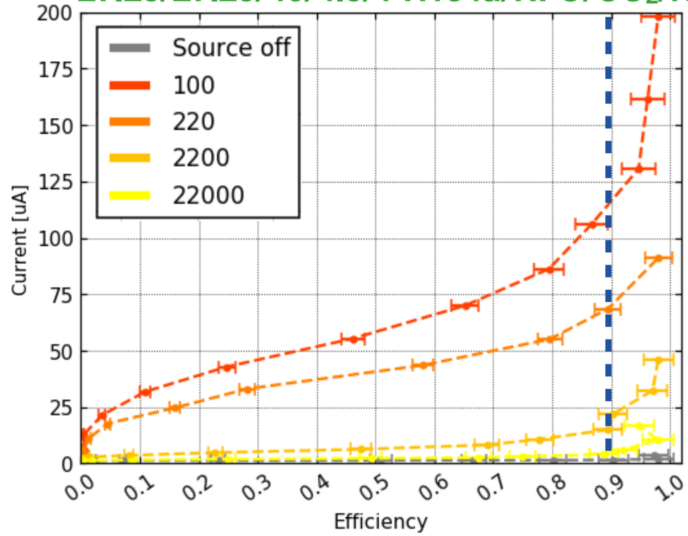


27.25/27.25/40/4.5/1 R134a/HFO/CO_2/iC_4H_{10}/SF_6



27.25/27.25/40/4.5/1 R134a/HFO/CO_2/iC_4H_{10}/SF_6

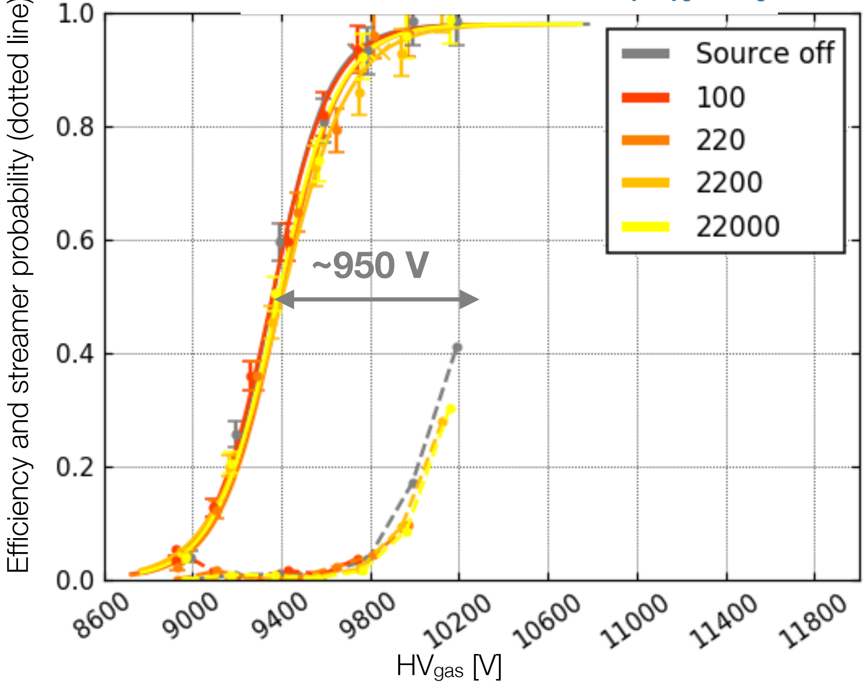


- The voltage drop is higher with the HFO-based gas mixture at different radiation rates
- At same efficiency, the currents of RPC operated with HFO-based gas mixture are higher with respect to the standard gas mixture

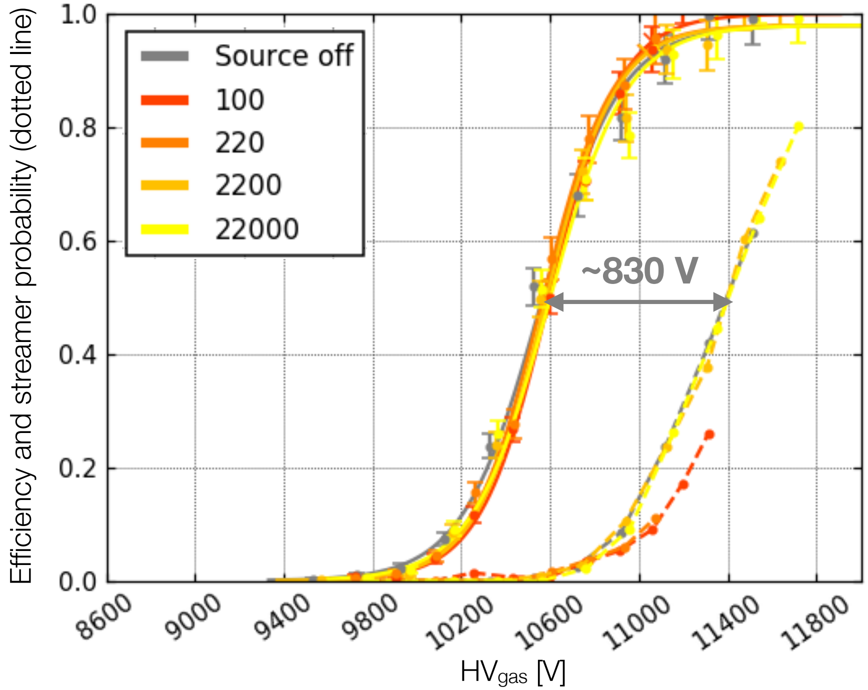
Muon efficiency and streamer probability

- The effective voltage applied to the gas is: $HV_{gas} = HV - RI$
- The efficiency plotted as a function of HV_{gas} does not depends on the background radiation for both gas mixtures

95.2/4.5/0.3 $R134a/iC_4H_{10}/SF_6$



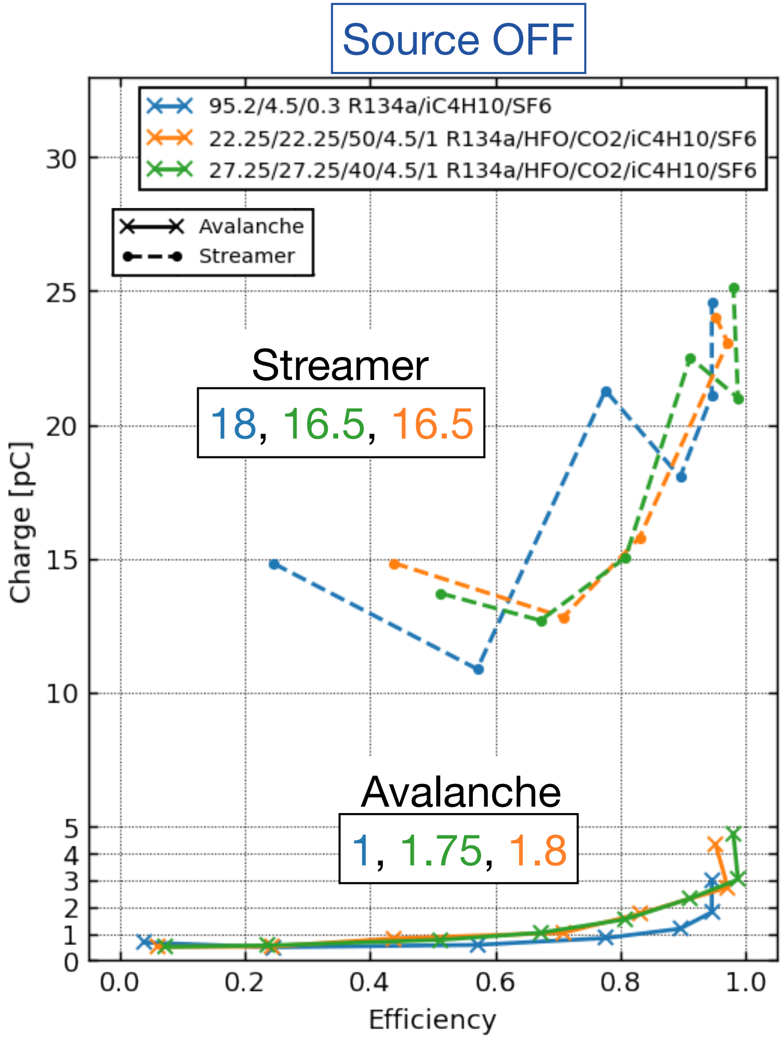
27.25/27.25/40/4.5/1 $R134a/HFO/CO_2/iC_4H_{10}/SF_6$

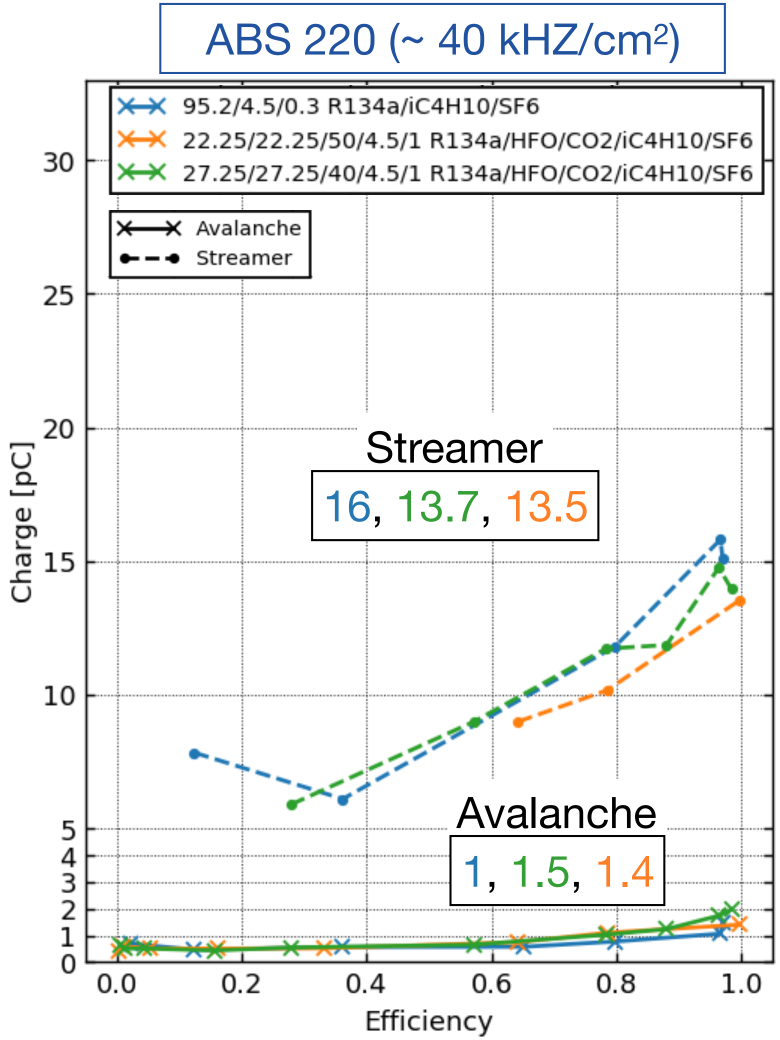


Streamer probability at ABS 220 (counting rate ~ 250 Hz/cm²)

Gas mixture	At HV knee	At efficiency (+150 V)
Standard gas mixture	3%	13%
HFO + 40% CO_2	8%	25%
HFO + 50% CO_2	15%	23%

Pulse charge



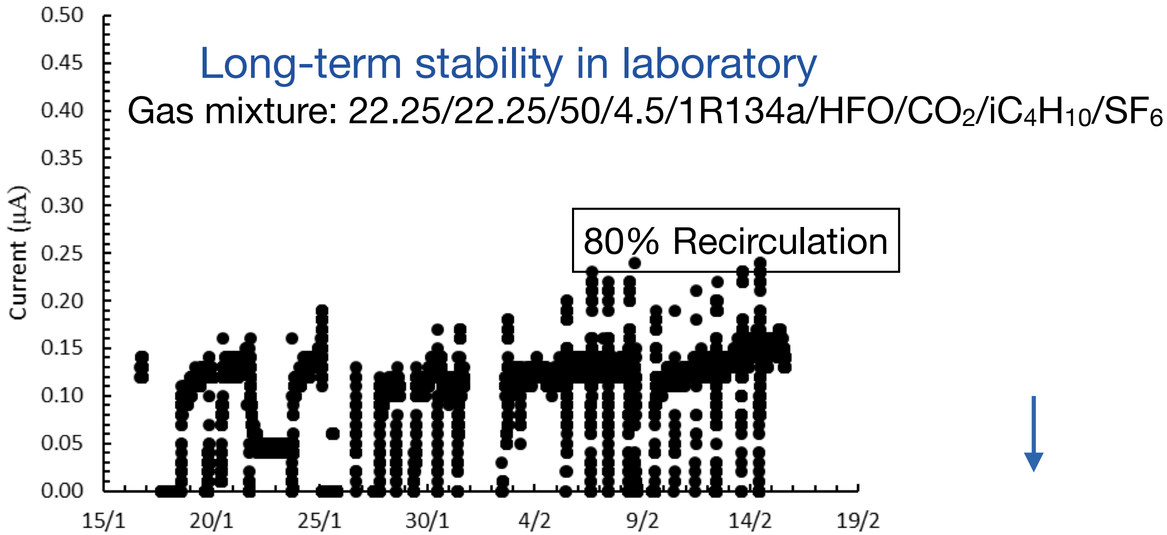


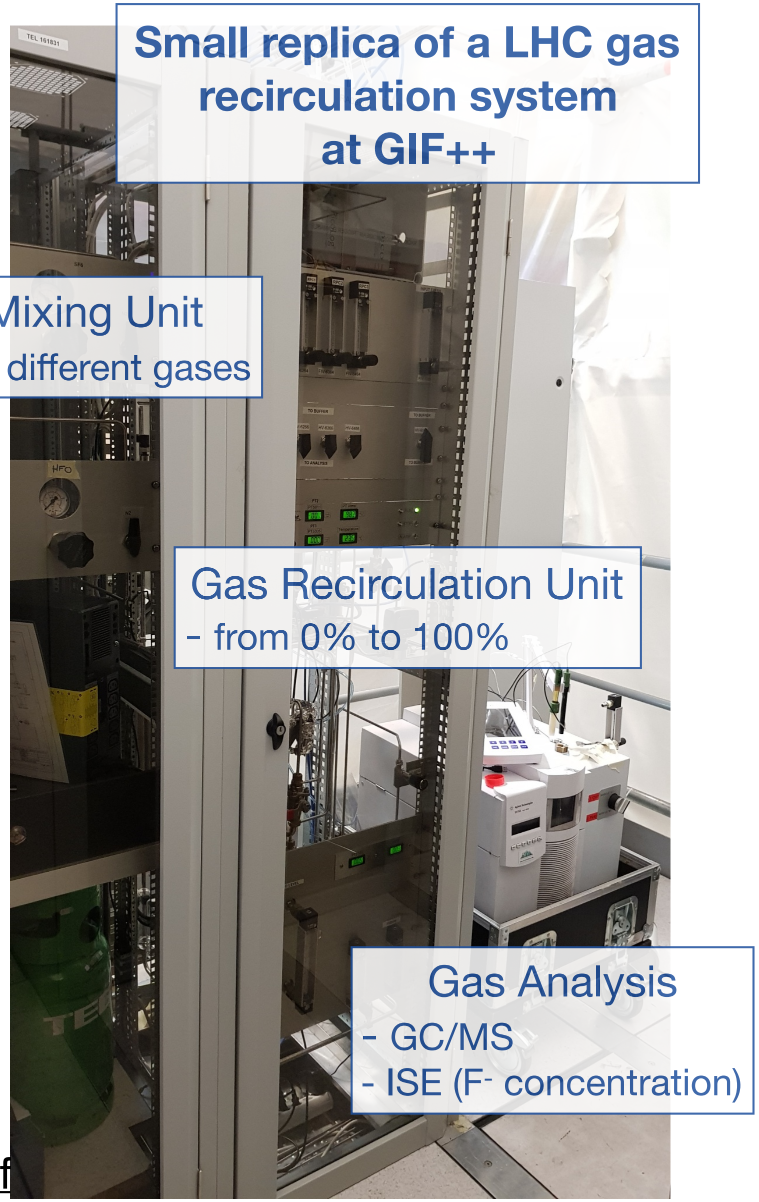
- The avalanche charge is higher for these eco-friendly gas mixtures
- The streamer charge is lower for these eco-friendly gas mixtures
  - They decrease with the increase of radiation probably due to charge development effects

Gas recirculation with new eco-friendly gases

RPC detectors at LHC are working under gas recirculation:
important to validate RPC operation under gas recirculation and high background rate

- RPCs operated under gas recirculation with eco-friendly gas mixture in laboratory
  - Cosmics (low currents)
  - Performance were stable
- Now RPCs under gas recirculation at GIF++
  - Very high gamma rate
  - Up to 100% recirculation
  - Creation of impurities with radiation
- Monitoring of currents and performance





RPC2018: https://indico.cern.ch/event/644205/contributions/2866962/attachments/1604692/2545485/RPC2018_Roberto_v3.pdf

Creation of impurities under irradiation: R134a

Impurities created from $C_2H_2F_4$ breaking

- Under the effects of high background radiation and electric field, $C_2H_2F_4$ molecule breaks into fluorine radicals
  - Creation of F^- radical free: very chemical reactive
  - Sub-products in the order of hundreds ppm
  - Accumulation in case of closed loop system
- Creation of these impurities also present in the RPCs at LHC experiments in Run 2
  - Not well know the maximum limit for safety of the detector

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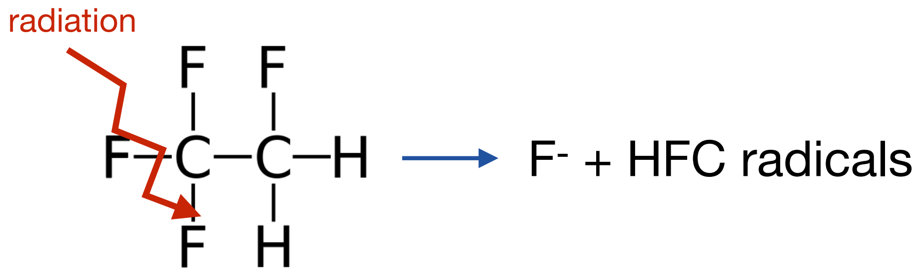
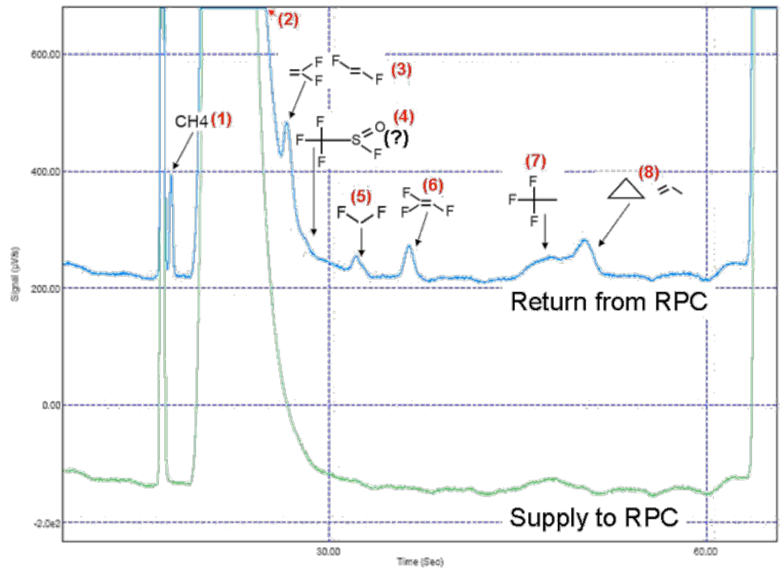
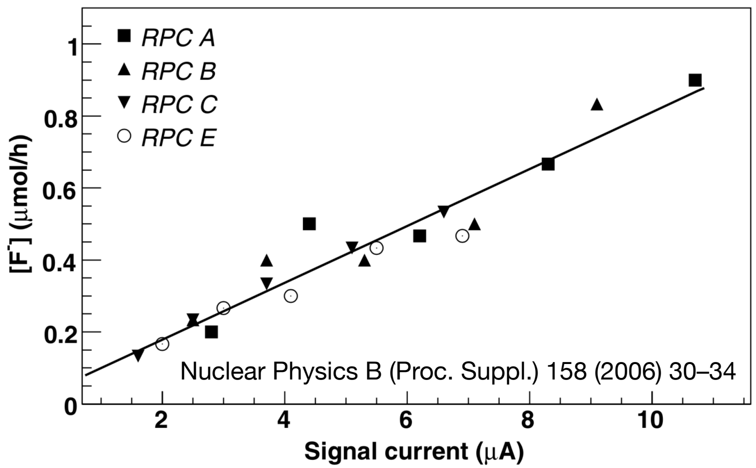
RPC2018: https://indico.cern.ch/event/644205/contributions/2862258/attachments/1604693/2545475/BMandelli_RPC2018.pdf







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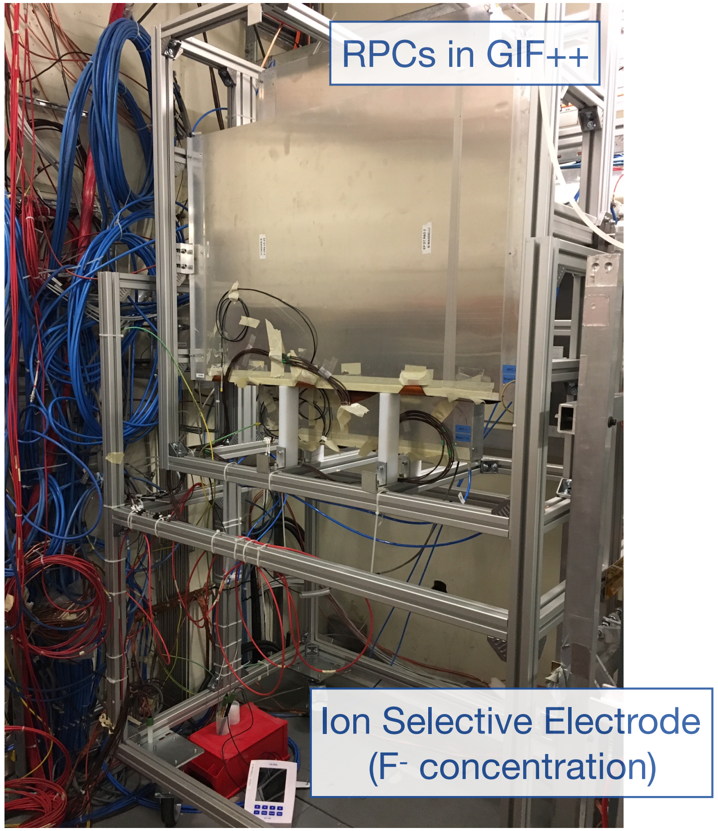
What about HFOs?

- HFOs have a very short atmospheric lifetime
  - They are destroyed easier than $C_2H_2F_4$
- RPC operated with HFO-based gas mixture have higher currents with respect to std gas mixture

Creation of impurities under irradiation: HFO

Radiation measurements with HFO-based gas mixture

- Test performed at GIF++ by irradiating 2 RPCs detectors with 662 keV gamma
  - Scan in HV and at different ABS
- Gas mixtures tested: RPC standard and selected eco-friendly
  - Comparison between the production of impurities
- Impurities measured with different analysers
  - GC/MS
  - Ion Selective Electrode station for free F^-



At detector efficiency

95.2% $C_2H_2F_4$
+ 4.5% iC_4H_{10} + 0.3 % SF_6
(40% relative humidity)

F^- production → **3 ppm/h**

27.25% $C_2H_2F_4$ + 27.25% HFO
+ 40% CO_2 + 4.5% iC_4H_{10} + 1 % SF_6
(40% relative humidity)

F^- production → **5 ppm/h**

By assuming other components inert in the process

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→ **HFO breaks 5 times more easily than $C_2H_2F_4$**

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Preliminary

Is there any risk for long-term detector operation?

Conclusions

R&D goal: to find a eco-friendly gas mixture that is compatible with the current ATLAS and CMS RPC systems

Eco-friendly gas mixtures for RPCs

- Direct substitution of $C_2H_2F_4$ (R134a) with HFOs not possible
- No many alternatives available on the market
- Need to work with 4-6 components gas mixtures

Characterisation of RPCs with different eco-friendly gas mixtures

- More than 50 gas mixtures tested
- Necessary to add an inert gas to lower the HV working point of HFO-based gas mixtures
- Few eco-eco-friendly gas mixtures show similar properties with respect to standard gas mixture

RPC operation with eco-friendly gas mixtures under high background radiation

- RPC tested up to ~ 300 Hz/cm^2
- Slightly higher currents and streamer probability with HFO-based gas mixtures
- HFO seems to break more easily than R134a: studies on-going to understand possible effects