EP-DT
Detector Technologies

RPC 2016

Characterization of RPC operation with new environmental friendly mixtures for LHC applications and beyond

M. Capeans, R. Guida, B. Mandelli
CERN, EP-DT

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Outline

- Why new gases for RPC?
- First experience and criticalities with new gases for RPC
- Experimental results
- Summary of the results
- Conclusions

Why looking for a new mixture?

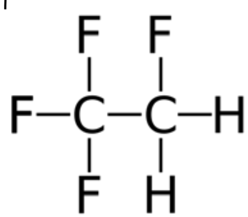
1) RPC detectors dominate the Greenhouse gas emission from particle detection at CERN

A greenhouse gas (GHG) absorbs and emits radiation within the thermal infrared range (greenhouse effect).

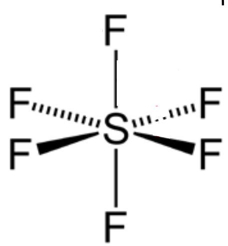
The primary greenhouse gases in Earth's atmosphere are: H_2O, CO_2, CH_4, N_2O, O_3.

For particle detection:

RPC

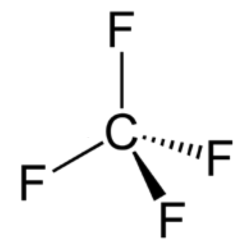


GWP 1430



GWP 23900

CSC, GEM, MWPC



GWP 5700

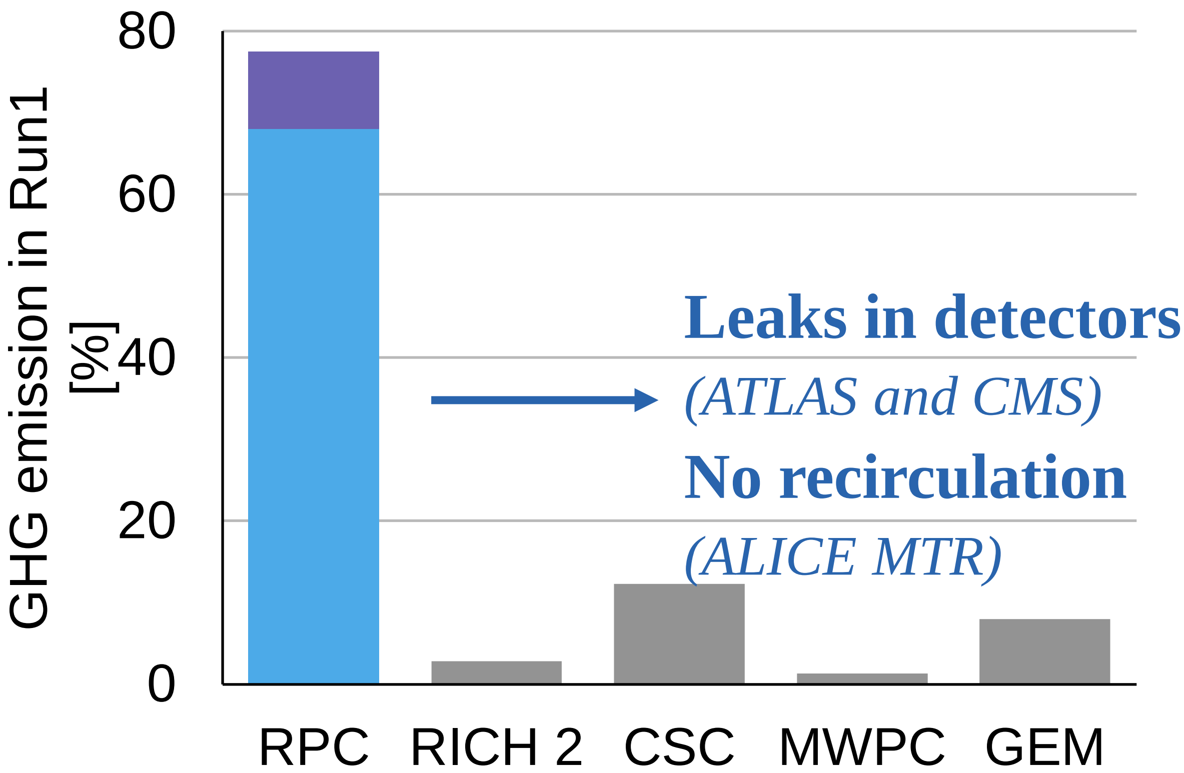
Global warming potential (GWP): relative measure of how much heat a greenhouse gas traps in the atmosphere.

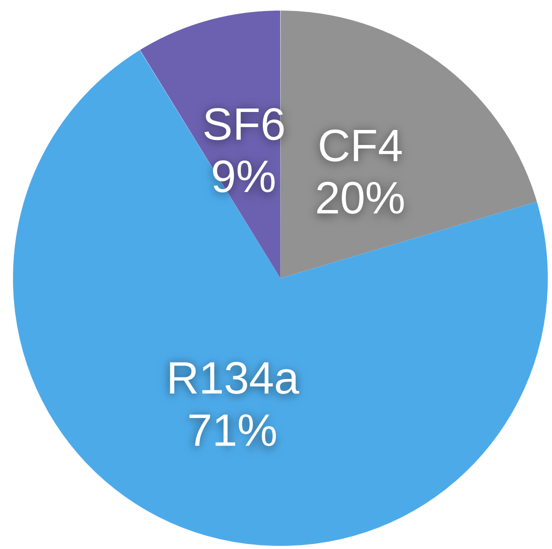
GWP = heat trapped by a certain mass of the gas in question / heat trapped by a similar mass CO_2

Why looking for a new mixture?

<u>Current «LHC» RPC situation:</u>

Large systems already recirculate gas!





Why looking for a new mixture?

Leaks are difficult to access and to repair but if repaired:

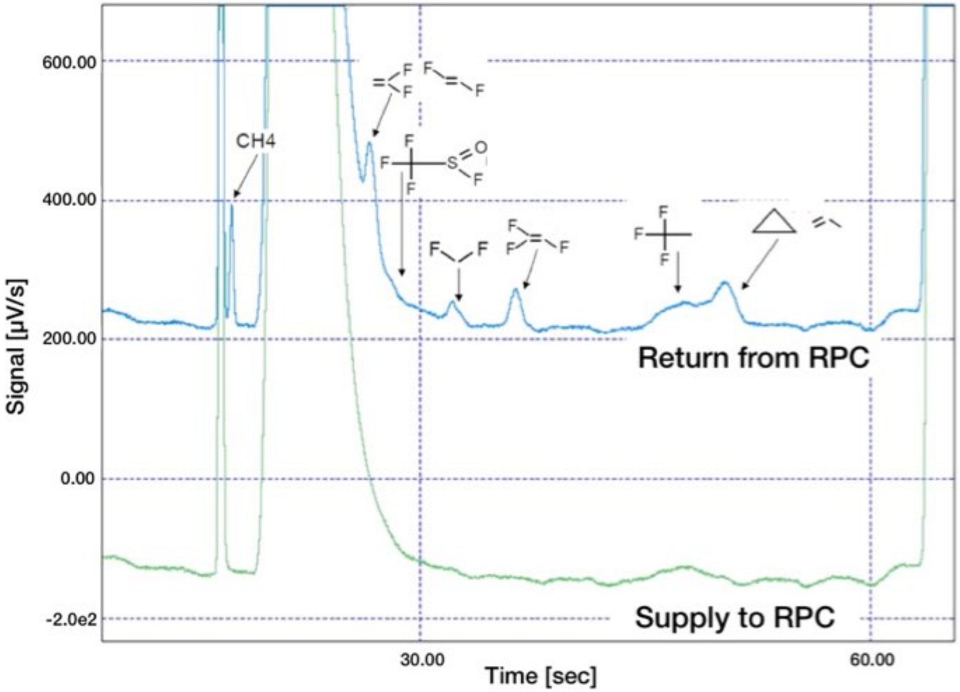
- *What is the maximum recirculation rate for safe RPC operation?*

. Today systems are operated at about 87% recirculation. Limiting factor are only the leaks.

. Max recirculation tested at GIF for a short period was 95%

. Potential problem due to the accumulation of R134a radicals.

Accumulation of impurities
during mixture recirculation at GIF (2007)



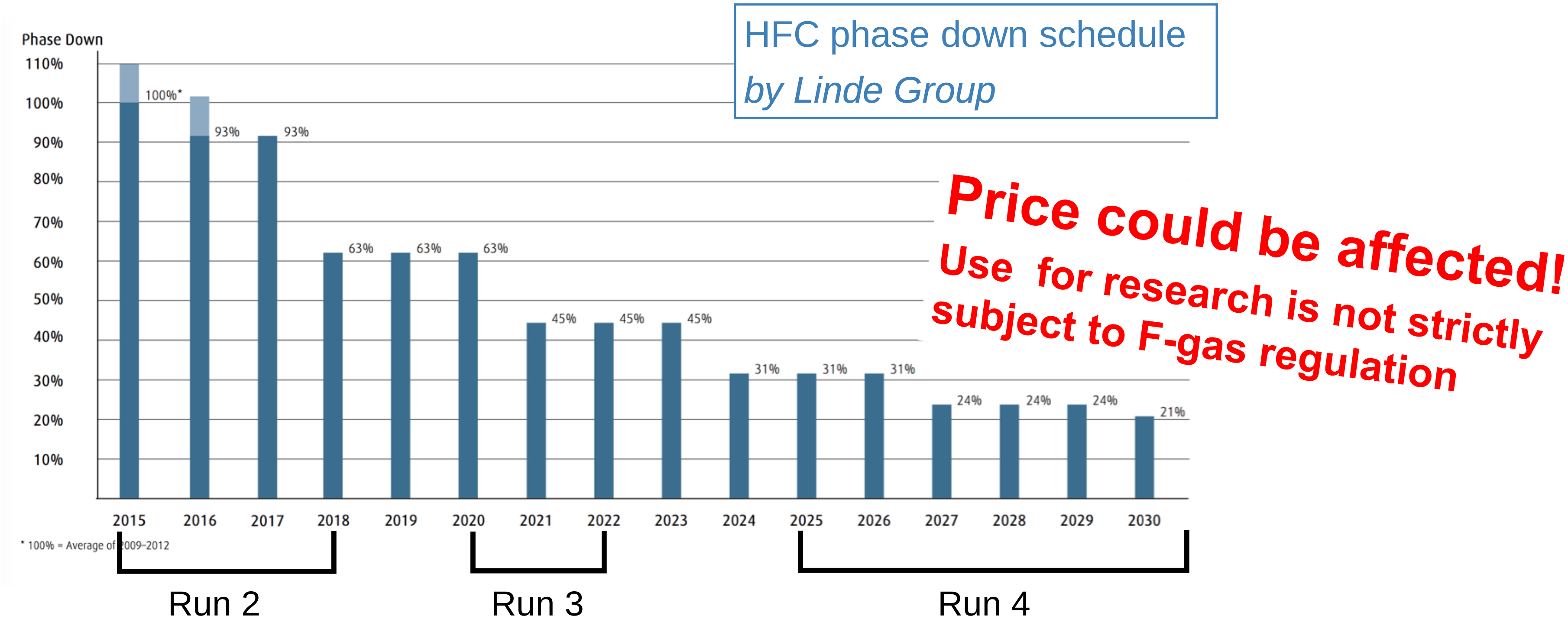
- *What will be the flow needed in the future at LHC experiments (HL-LHC)?*

. Flow increase?

Why looking for a new mixture?

2) European Union "F-gas regulation" – i.e. Phase out

Limiting the total amount that can be sold in the EU from 2015 phase down (2014 to 2030).



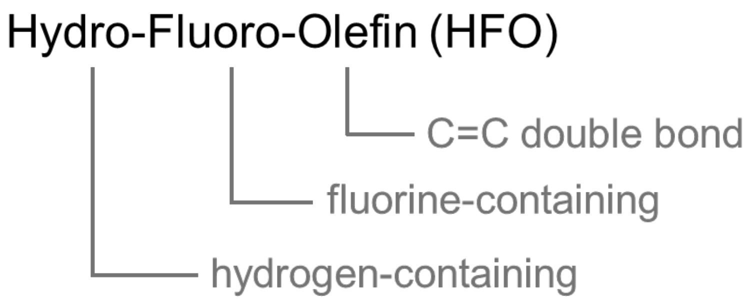
Banning the use where less harmful alternatives are widely available.

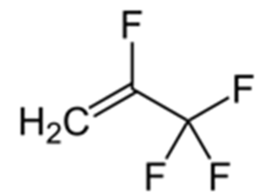
Preventing emissions of F-gases from existing equipment by requiring checks, proper servicing and recovery of the gases.

Why looking for a new mixture?

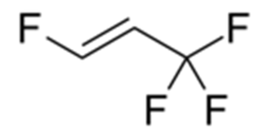
3) <u>New alternatives to R134a for cooling</u>

New low GWP gases alternative to R134a are already available on the market and used by industry





HFO-1234yf (flam)
($C_3H_2F_4$)
GWP 4



HFO-1234ze
($C_3H_2F_4$)
GWP 6

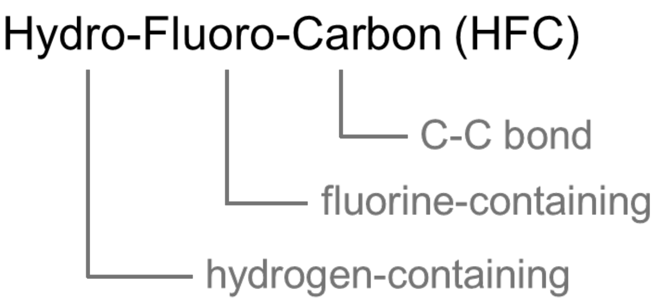
Refrigerant properties of both HFOs are well known while studies of ionisation processes in particle detectors just started…

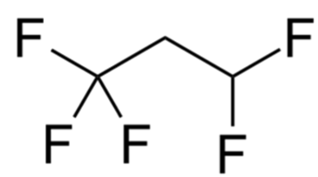
Test ongoing in many labs

Why looking for a new mixture?

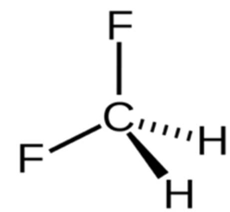
4) *Low GWP "old" alternatives to R134a*

Other HFCs available with lower GWP wrt R134a

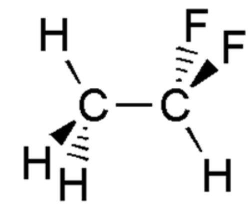




HFC-245fa
($C_3H_3F_5$)
GWP 1030



HFC-32 (flam)
(CH_2F_2)
GWP 675



HFC-152a (flam)
($C_2H_4F_2$)
GWP 120

No info concerning ionisation processes in particle detectors. Studies just started…

Test ongoing

5) *SF_6 is still accepted (because. no alternatives available)*

Use of environmentally friendly gases

<u>Some issues to be addressed for new and old low GWP gases:</u>

1) *Flammability*

Some of them are slightly flammable. Tests might be useful to understand underlying mechanisms but they cannot be used for current «LHC» RPC systems (presence of leaks).

2) *Low vapour pressure at ambient temperature*

Not enough pressure for operation (especially if high flow is needed). Very easily they become liquid in the gas system. Mixer MFCs are affected.

3) *MFC suffered pollution*

Regulation disks and measurement capillary have been affected by oily-like pollution during operation. Probably following liquefaction of the gas after expansion in the MFC.

Use of environmentally friendly gases

<u>*Some issues to be addressed for new and old low GWP gases:*</u>

4) Availability of MFC calibration data

No data for MFC calibration were available. In some occasions Bronkhorst was redirecting the requests to us.

Calibration data are available and have been already shared with some collaborators.

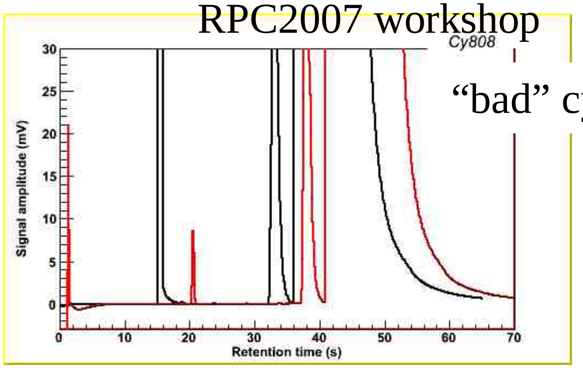
https://edms.cern.ch/document/1497359/1

5) Quality (GC analysis needed. Remember the work done at beginning for R134a)

Large contamination from air and other HFC was measured at the beginning (validation phase for «LHC» RPC operation).

Similar problem recently during validation of new CERN supplier for R134a

RPC2007 workshop

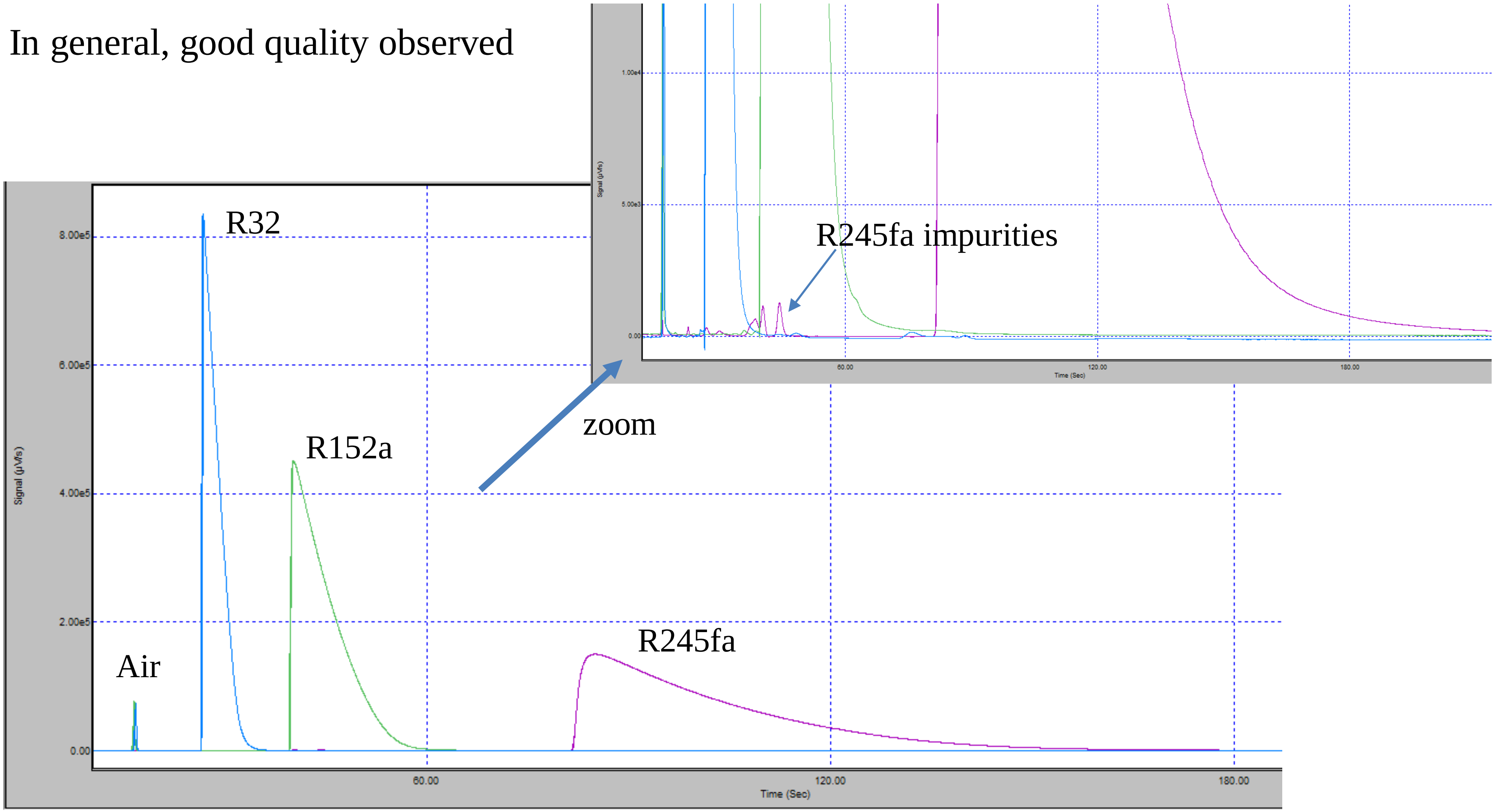


“bad” cylinder

Use of environmentally friendly gases

6) Quality: GC analysis before use of new gases

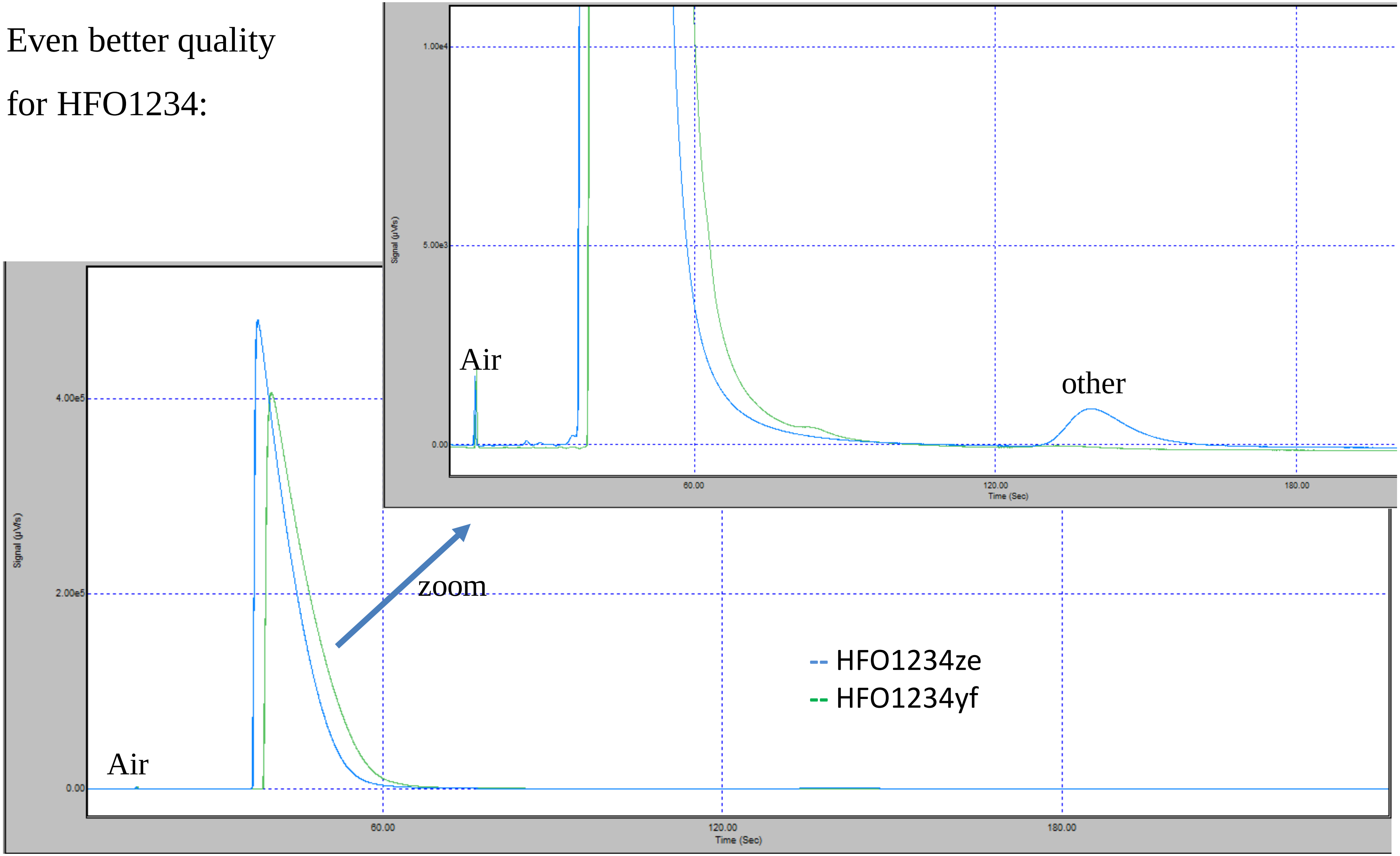
In general, good quality observed



Use of environmentally friendly gases

Even better quality

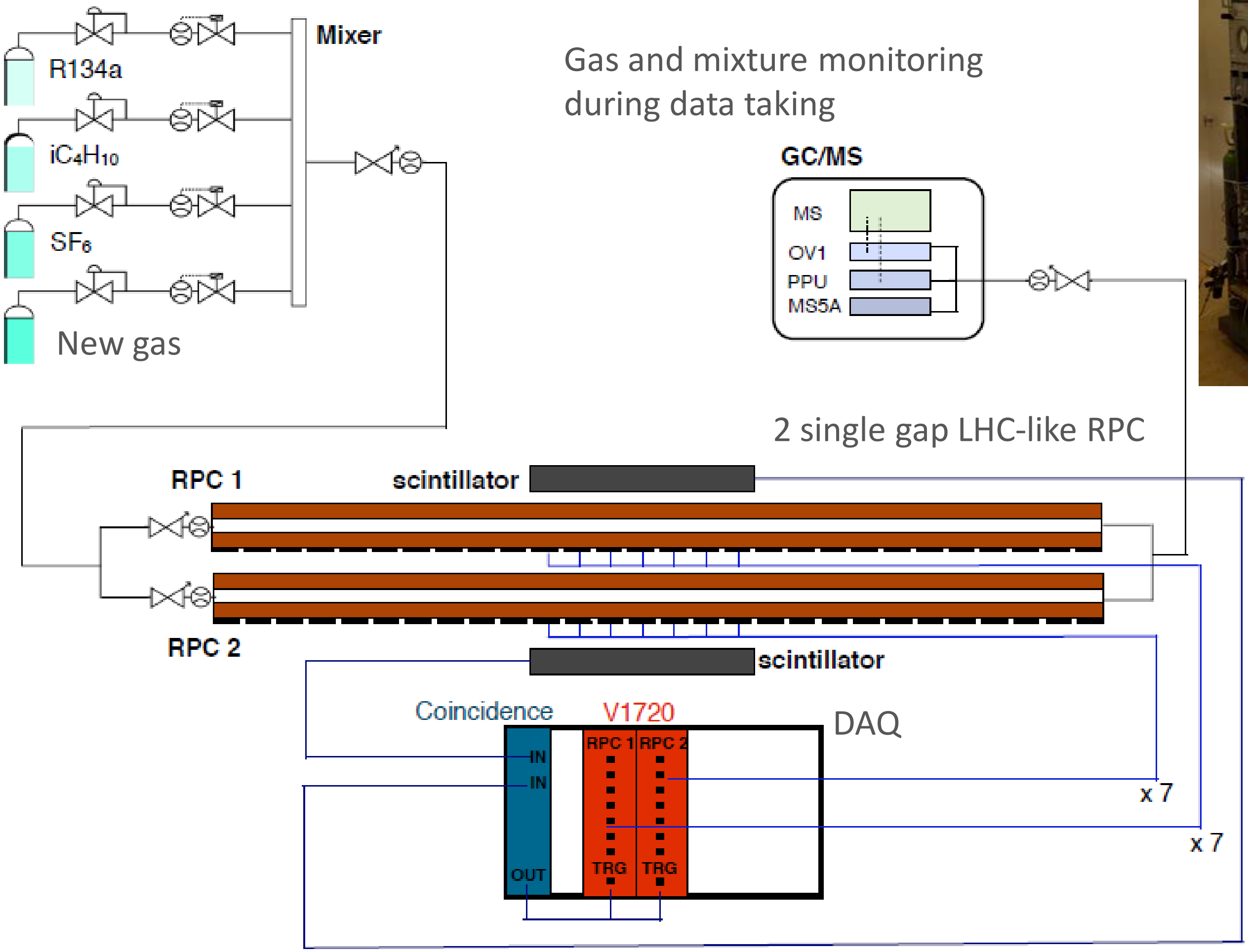
for HFO1234:



Setup for new gas studies

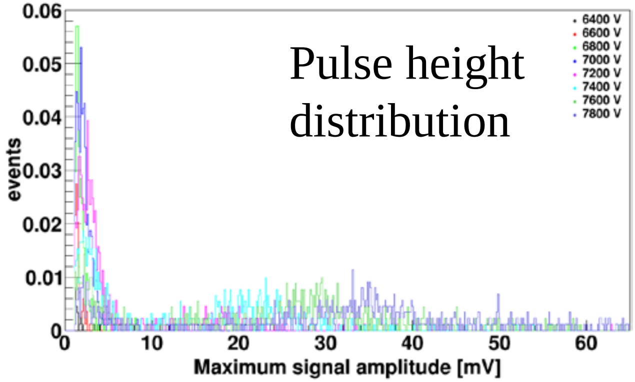
Gas system components (P regulators, MFCs, Gas analysers GC/MS)

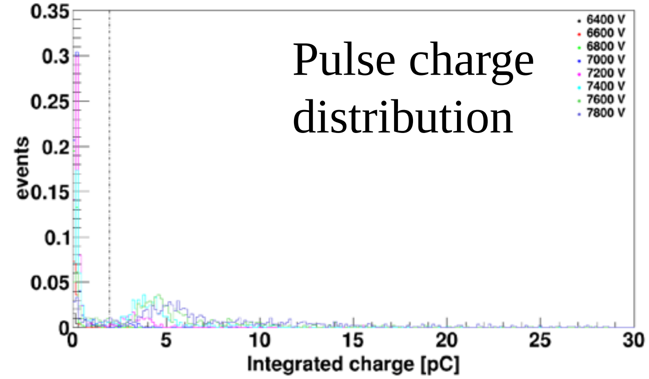
and RPC detectors tests with new gases



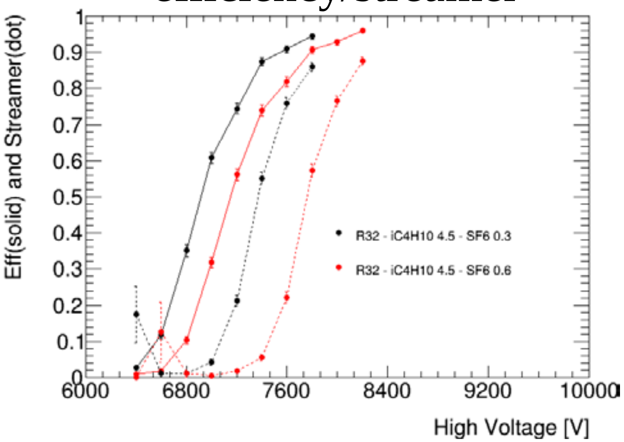
Analysis steps

Examples of plots:

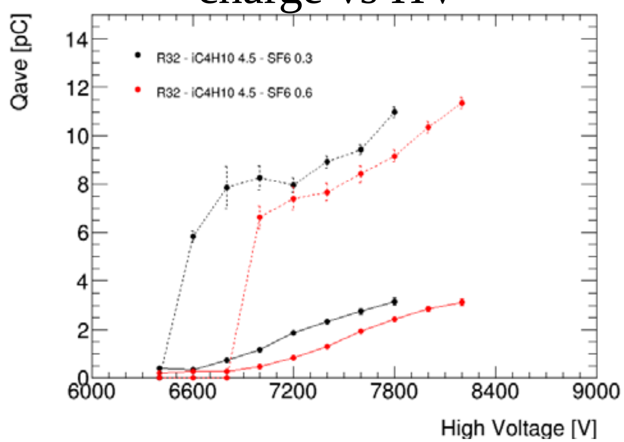




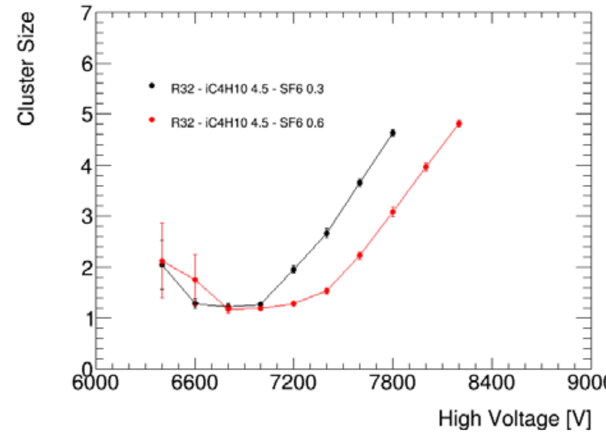
efficiency/streamer



charge vs HV

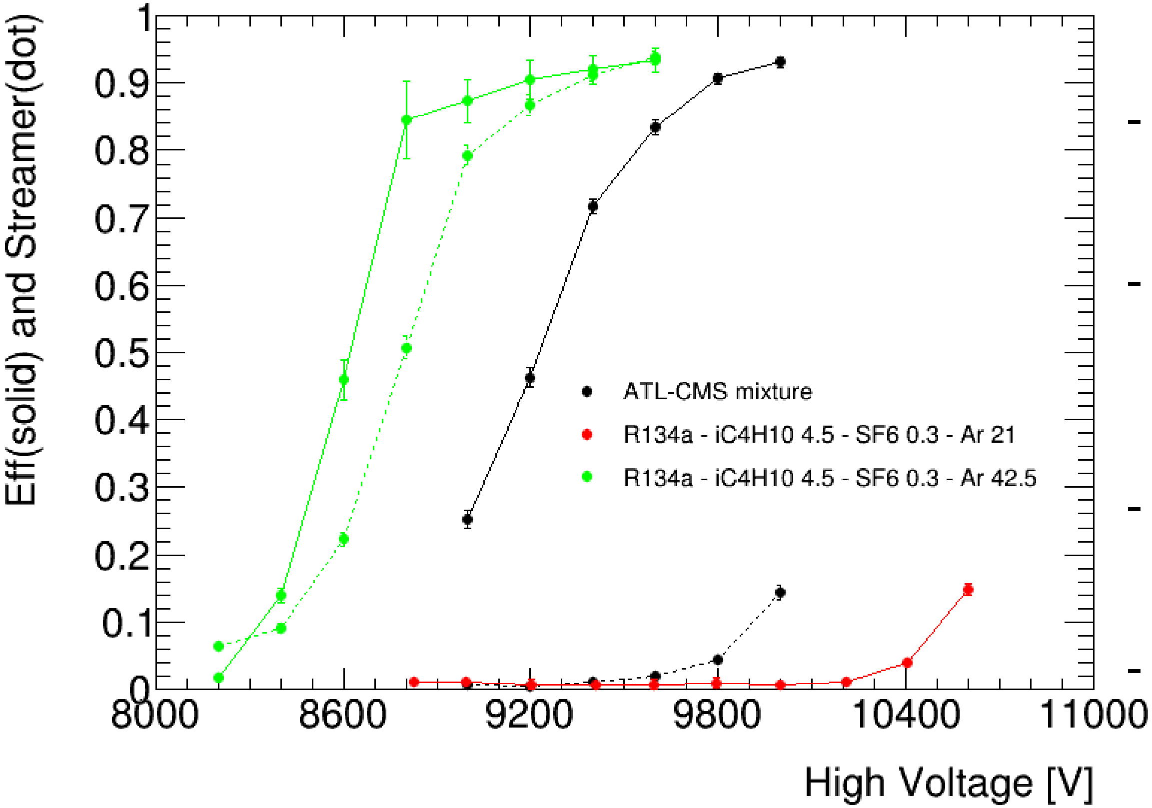


cluster size



HFO – 1234 & Ar

GWPmix ≈ 150

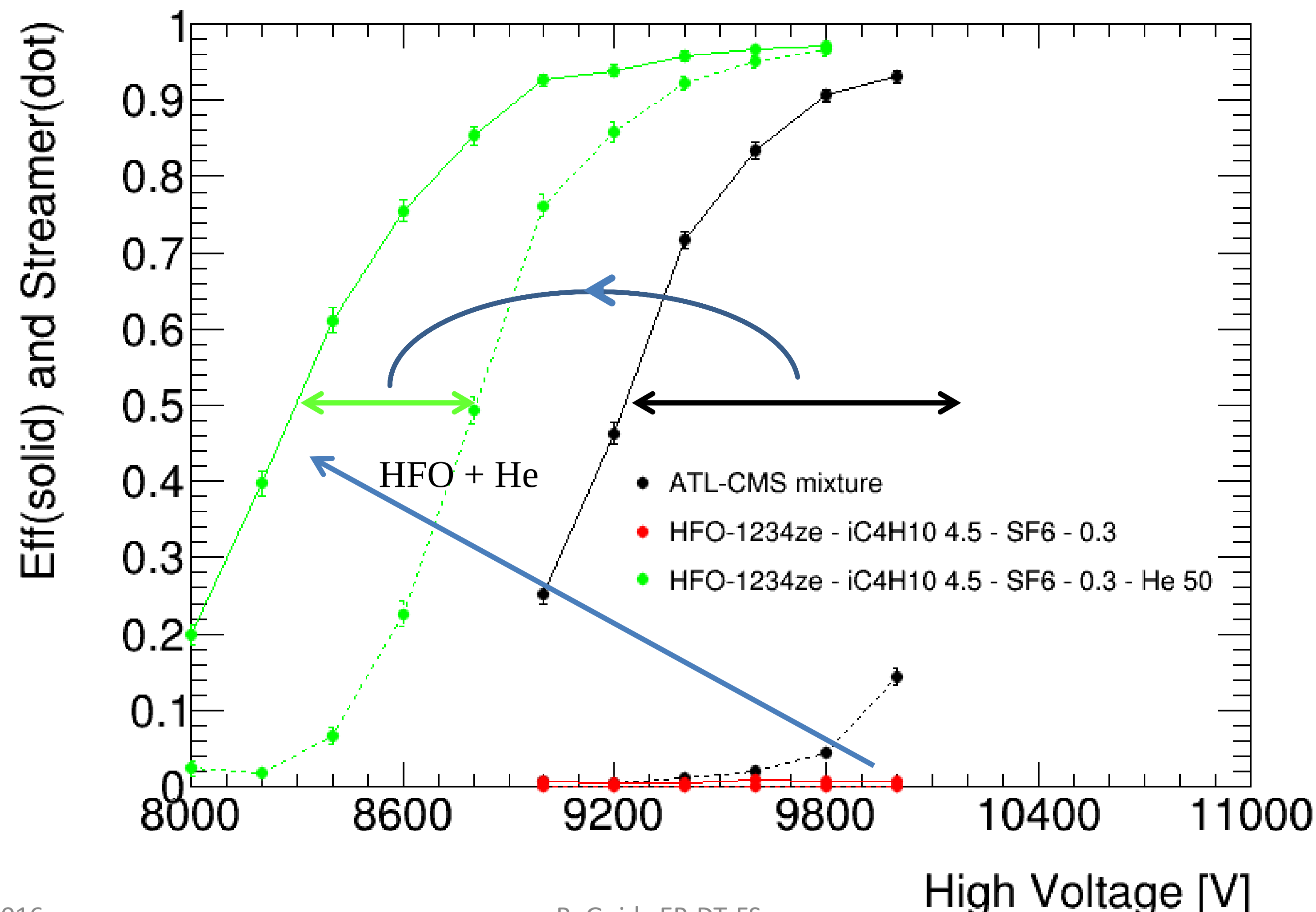


- **similar behaviour of the two HFOs**
- HFOs are much less electronegative than SF_6
- HFOs has different quenching properties than iC_4H_{10}
- Conclusion: **HFOs cannot directly replace $C_2H_2F_4$ using current electronic/sensitivity**
- **With Ar, RPCs work in streamer but not suitable for LHC**
- RPC operation needs to consider ATLAS-CMS requirements and conditions (i.e. existing HV cables, FEB electronics)

HFO – 1234 & He

He has a better effect than Ar but still the **operation region without streamer is reduced**

GWPmix ≈ 400

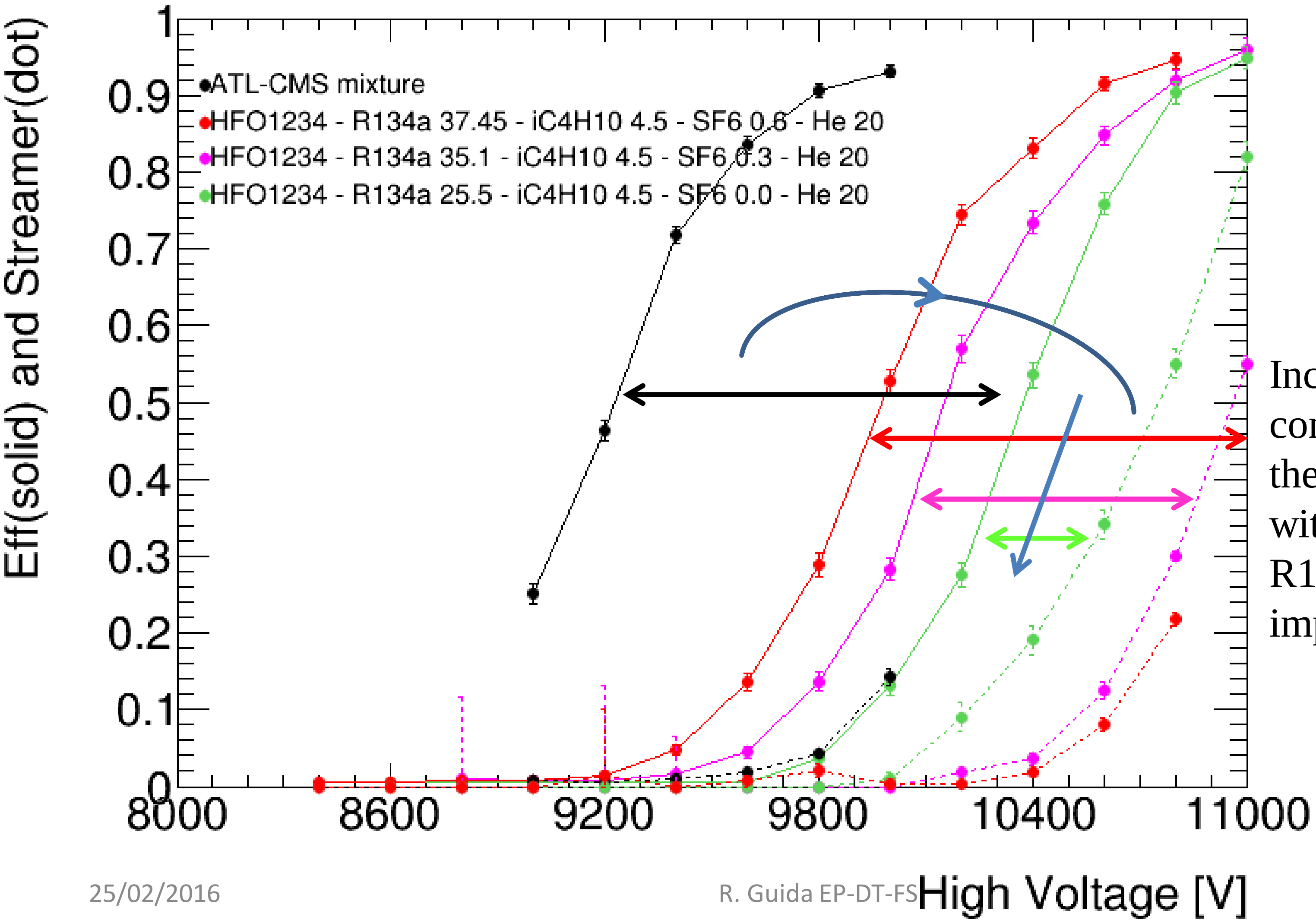


HFO – 1234 & R134a & He

Good results obtained with HFO1234, R134a and He mixtures

(iC_4H_{10} and SF_6 kept constant)

GWPmix ≈ 800



Increasing HFO concentrations reduce the operation region without streamers R134a still plays important role

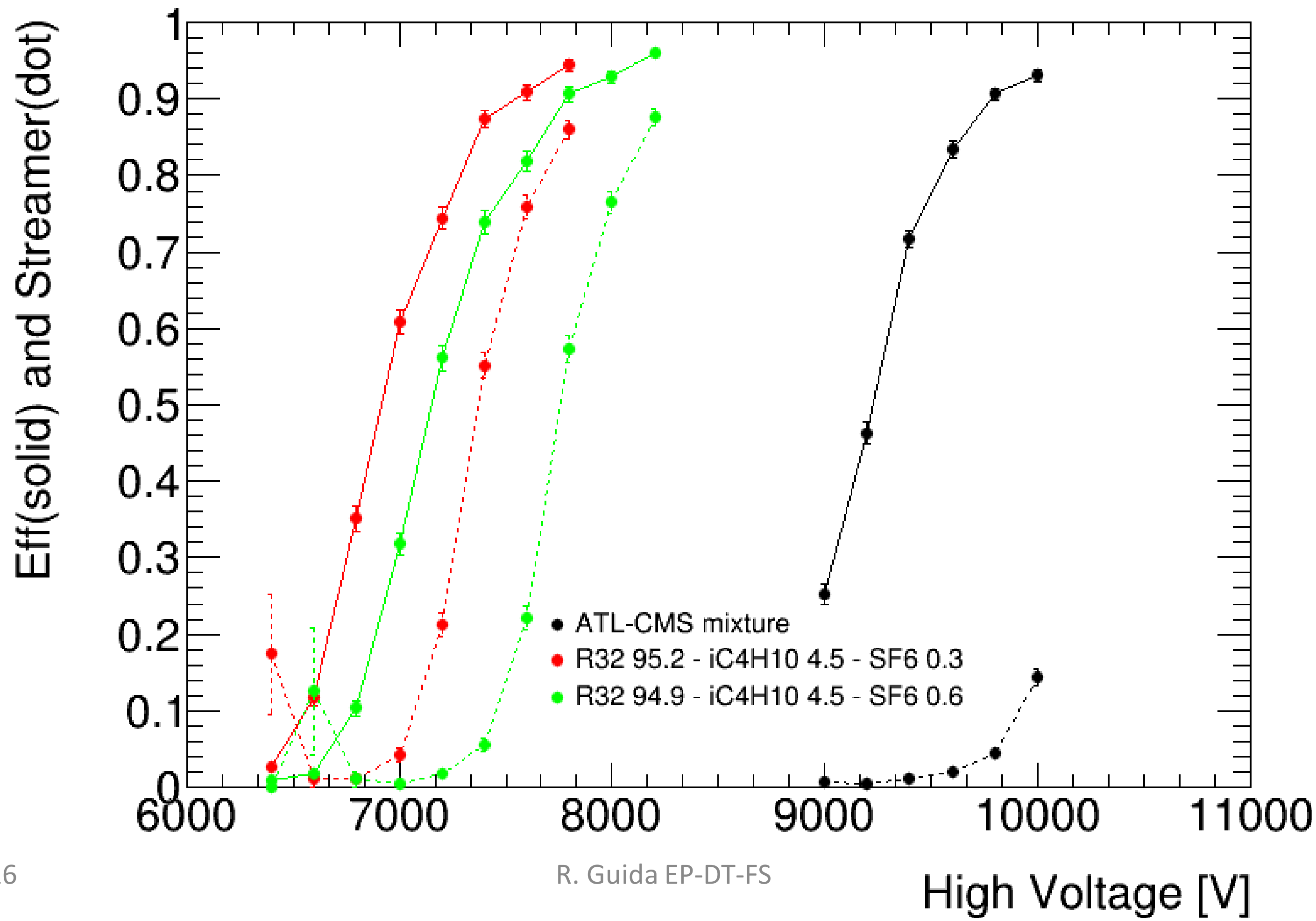
HFC – 32

Very simple molecular structure

Low working point

Poor quenching capacity (large cluster size) and it “moves” to streamer very easily

GWPmix ≈ 1000

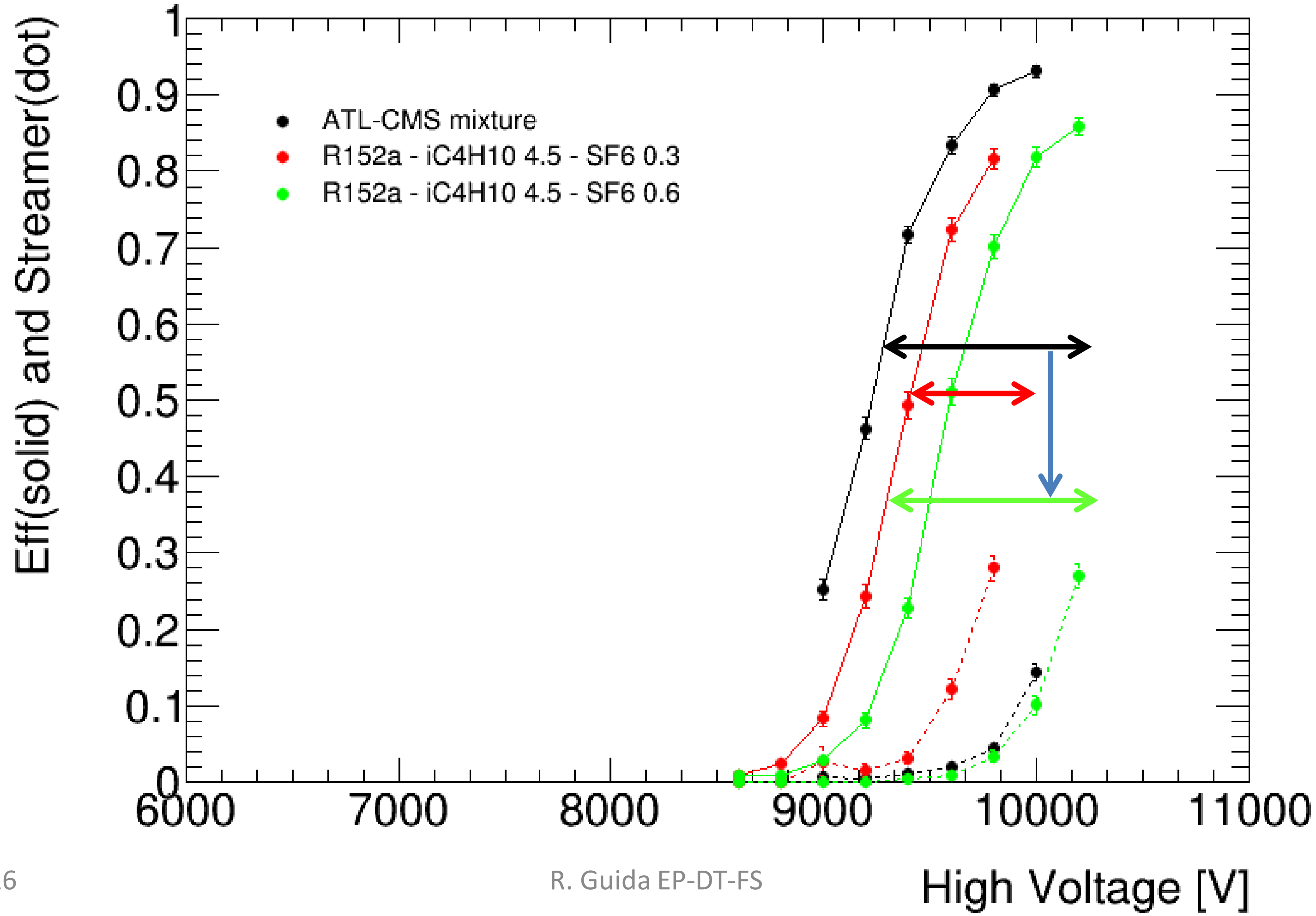


HFC – 152a

RPC efficient when R152 replaced with of R134a but limited region without streamer

Missing Fluorine? R134a = 4/8 = 50% → R152a = 2/10 = 20%

GWPmix ≈ 500

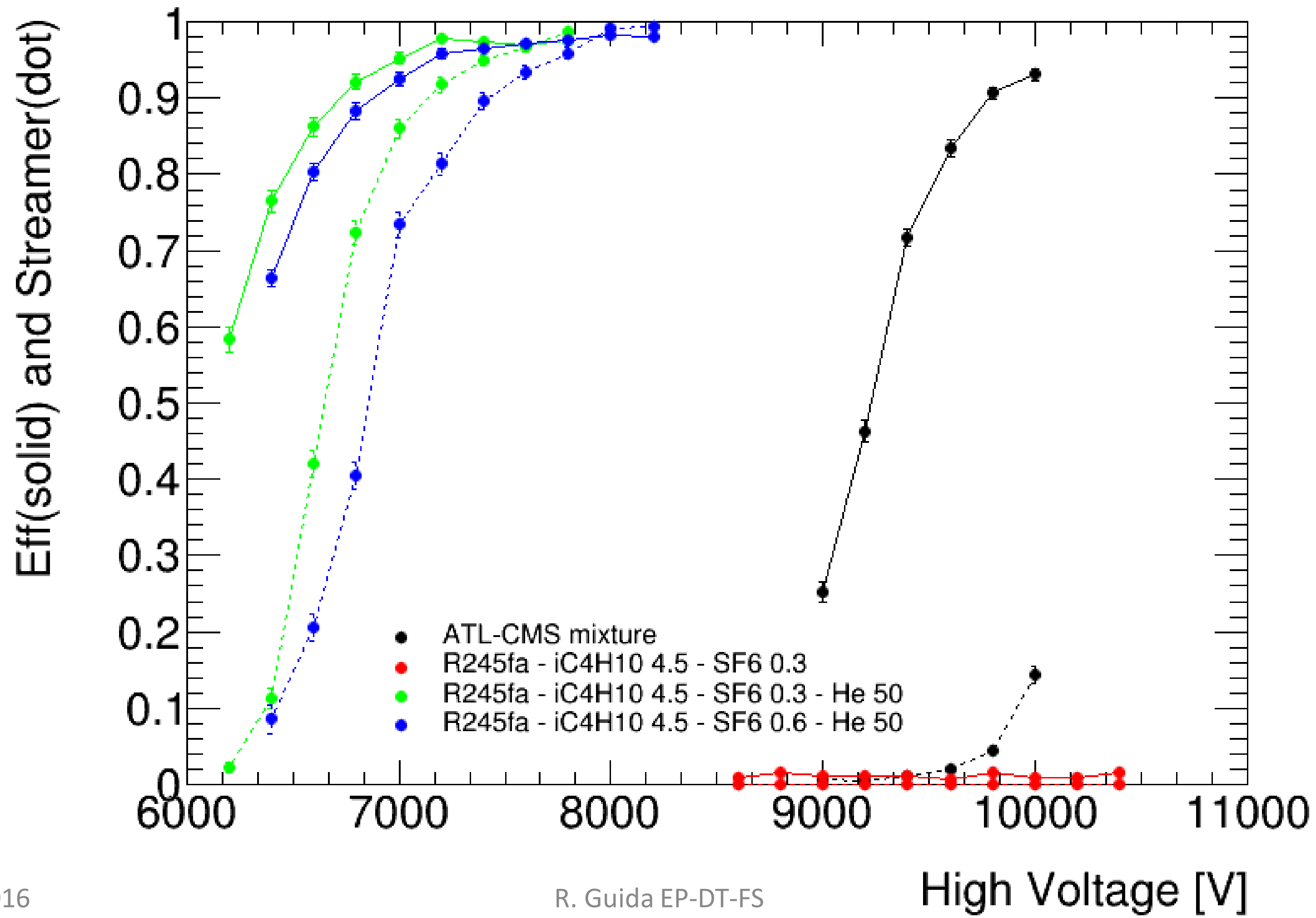


HFC – 245fa

Molecular structures above C_2 need He addition to be efficient below 10 kV

Further studies ongoing

GWPmix ≈ 1300



Summary

More than 50 different mixtures testes. Most relevant results summarized below.

HV, Streamer probability, pulse charge (avalanche and streamer), cluster size are given at the efficiency knee.

ΔV Efficiency to streamer at 50% efficiency

Mixture	Chem. Struct.	GWPmix	HV (V)	Strem (%)	Pulse charge (pC)	ΔV Eff-Stream (V)	Clu size (strip)
R32 -iC4H10 4.5 - SF6 0.6	C	1027	7500	14.0	0.5 / 6.5	600	1.5
R134a -iC4H10 4.5 - SF6 0.3	**C-C**	**1491**	**9581**	**1.5**	**0.5 / 6.0**	**1000**	**1.5**
R152a -iC4H10 4.5 - SF6 0.6	C-C	430	10000	10.0	1.0 / 8.5	764	1.6
R245fa -iC4H10 4.5 - SF6 0.6 - He 50	C-C-C	1263	6666	20.0	1.0 /7.0	610	2
HFO1234 -iC4H10 5 - SF6 0.3 - Ar 42.5	C=C-C	134	8900	70.0	2.0 / 15.0	160	4
HFO1234 -iC4H10 4.5 - SF6 0.6 - He 50	C=C-C	373	9020	22.0	1.5 / 8.0	700	4
HFO1234 - R134a 37.45 - iC4H10 4.5 - SF6 0.6 - He 20	**C=C-C**	**889**	**10450**	**1.8**	**0.5 / 5.8**	**970**	**1.6**
HFO1234 - R134a 40.1 - iC4H10 4.5 - SF6 0.6 - He 20	C=C-C	726	10500	8.0	0.5 / 6.5	700	1.6
HFO1234 - R134a 50 - iC4H10 4.5 - He 20	C=C-C	434	10800	50.0	1.5 / 8.0	415	2.5

- C, C_2 direct operation
- C_3 needs addition of He or Ar
- Ar brings immediately to operation in streamer mode
- HFO1234 and He mixture are not as good as R134a
- Addition of R134a to HFO&He mixture gives good results but it dominates the GWPmix
- Further tests needed
- Is HFO1234 good at higher HV? Can CO_2 help in HFO mixtures?

Conclusions

Several reasons to look for a new mixture:

- R134a has a high GWP:
- it will be subject to phase out and price instability
- RPC systems at LHC dominate the GHG emission due to particle detection at CERN
- Leaks at detector level do not allow to increase recirculation.

Alternatives to R134a already available

- but they behave very differently from R134a.
- New gases showed some critical behaviour (flammability, low vapour pressure, impurities affecting gas system components).

More than 50 mixtures tested

- Similar performance can be achieved with complex mixtures including R134a and He
- Similar performance are needed because it is difficult to replace RPC-FEB on ATLAS and CMS)