EP-DT
Detector Technologies

Performance of Resistive Plate Chamber operated with new environmental friendly gas mixtures

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Outline

Green House Gas (GHG) Emission from particle detection at LHC

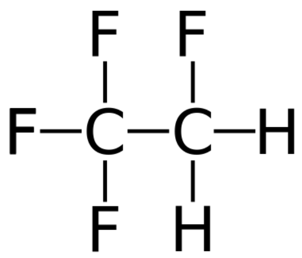
Resistive Plate Chamber gas mixture and possible replacements

Experimental results with eco-friendly gas mixtures

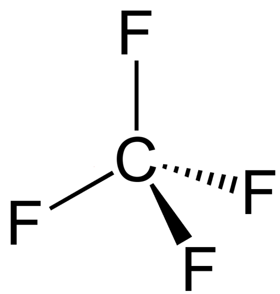
Conclusions

GHG for particle detection at LHC

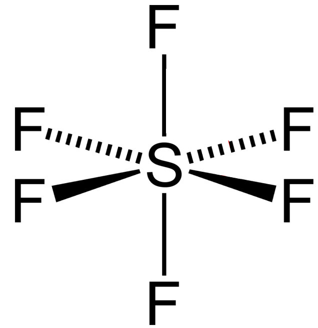
A greenhouse gas is any gaseous compound that is capable of absorbing infrared radiation, thereby trapping and holding heat in the atmosphere



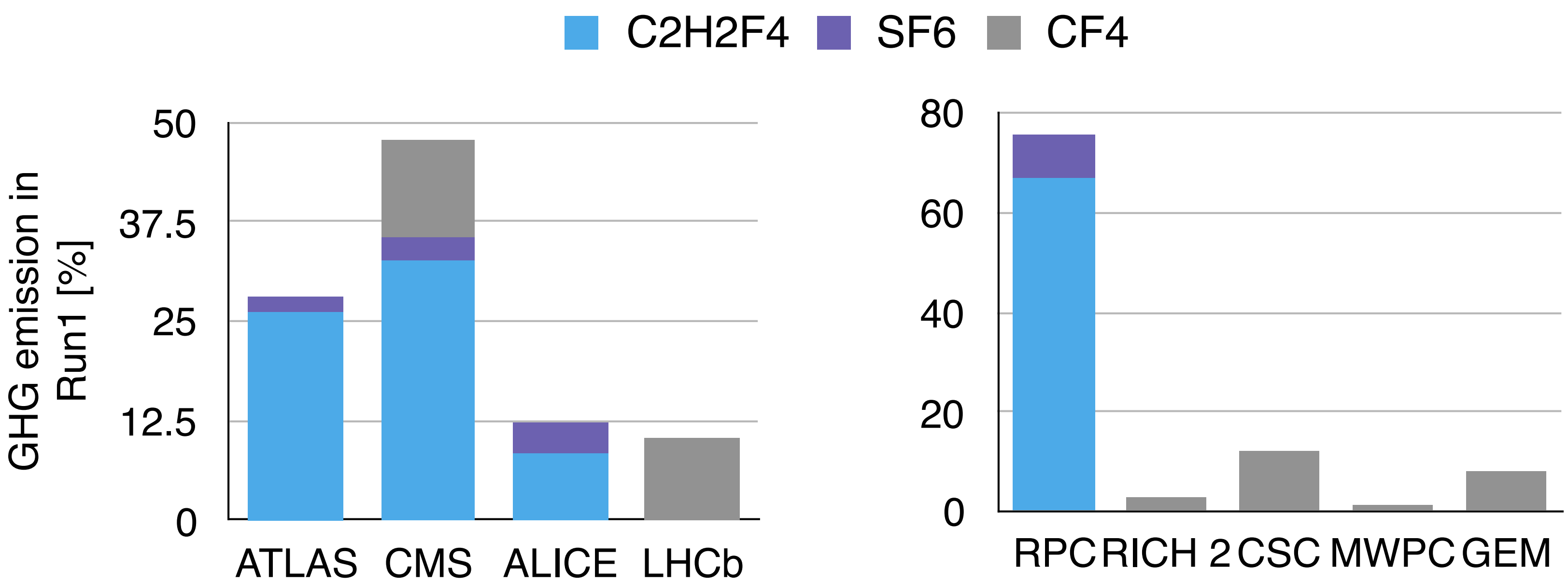
GWP 1430



GWP 5700



GWP 22200



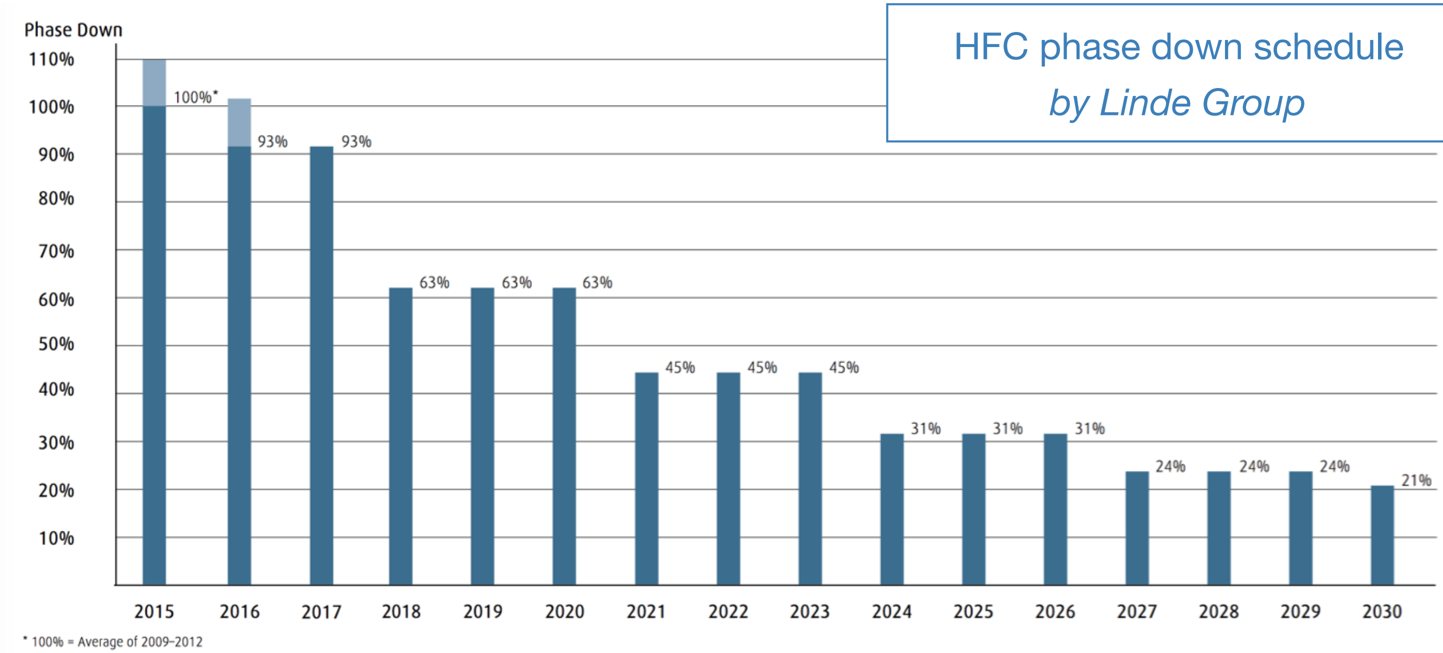
F-gas regulation in Europe

European Union “F-gas regulation”:

- **Limiting the total amount** of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030.
- **Banning the use** of F-gases in many new types of equipment 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 at the end of the equipment's life.

HFC phase down

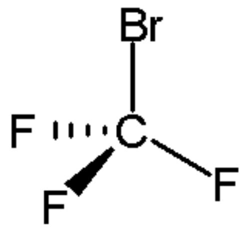
- $C_2H_2F_4$ is being phased out by EU
  - $C_2H_2F_4$ and SF_6 will remain available for research applications
  - But price could raise…



HFC phase down schedule
by Linde Group

The RPC gas mixture

At the very beginning
RPC worked with Ar and/or R13B1

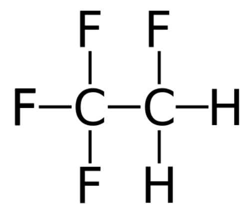


R13B1

(CBrF3)

GWP 6900 - ODP 10

Replacement of
R13B1 with R134a



+ (iC_4H_{10} ~5% + SF_6 0.3%)

R134a

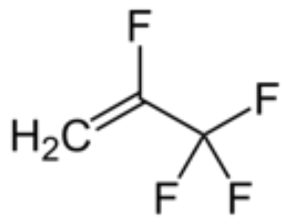
($C_2H_2F_4$)

GWP 1430 - ODP 0

Nowadays we look for a replacement for R134a

Hydro-Fluoro-Olefin (HFO)

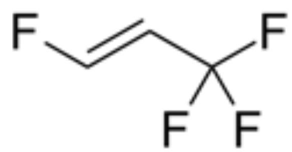
- C=C double bond
- fluorine-containing
- hydrogen-containing



HFO-1234yf (flam)

($C_3H_2F_4$)

GWP 4



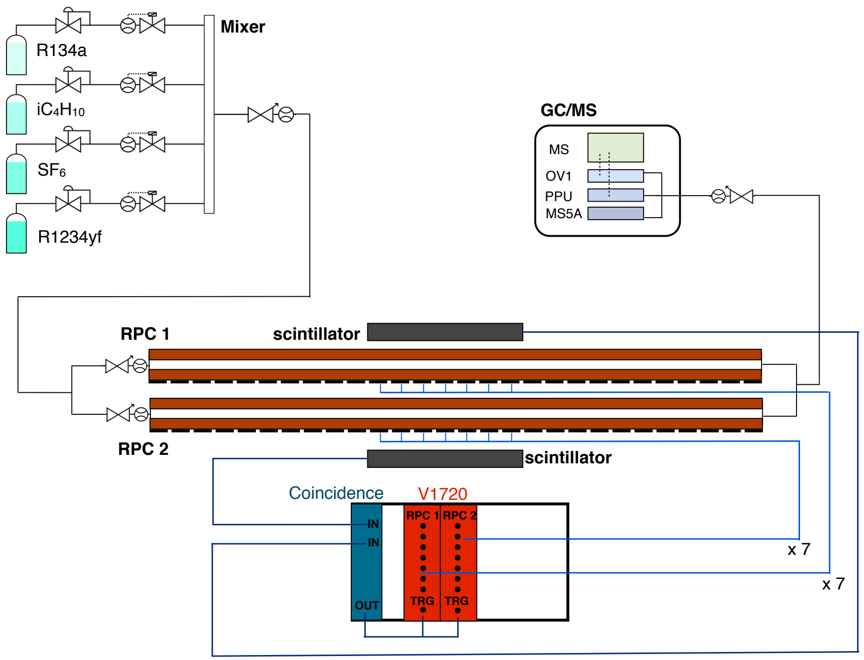
HFO-1234ze

($C_3H_2F_4$)

GWP 6

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

Experimental set-up



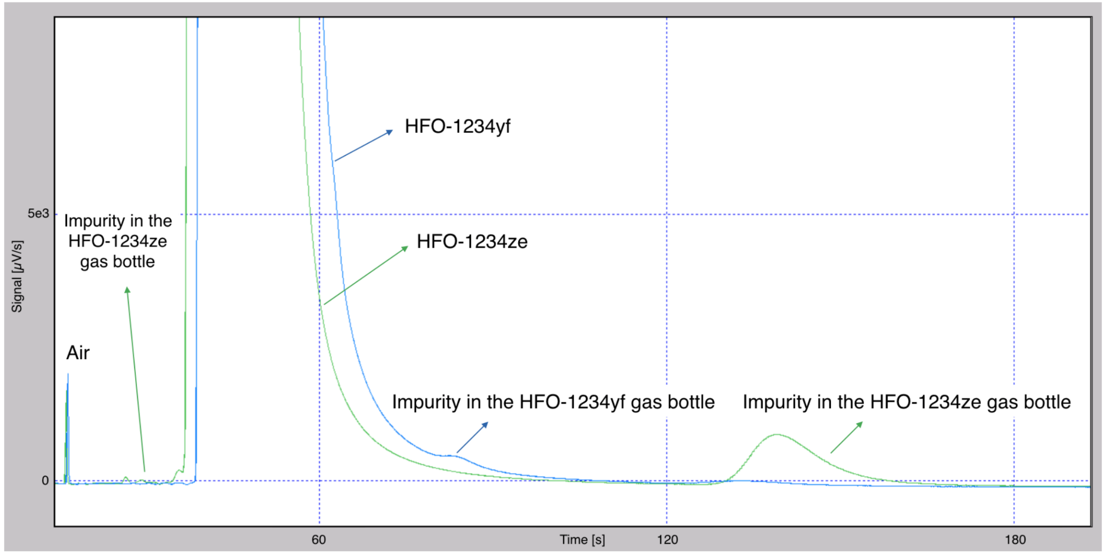
- Two Resistive Plate Chambers:
  - high pressure laminate
  - 2 mm gas gap
  - read-out strips of 2.1 cm
- Electronics
  - CAEN Digitizer V1730: 16 Channel 14-bit 500 MS/s
  - digitalization of analog signal
- Gas system components validation
  - GC/MS gas analysis
  - Interaction between new gases and gas system components

RPC operation needs to consider ATLAS-CMS requirements and conditions (i.e. existing HV cables, FEB electronics)

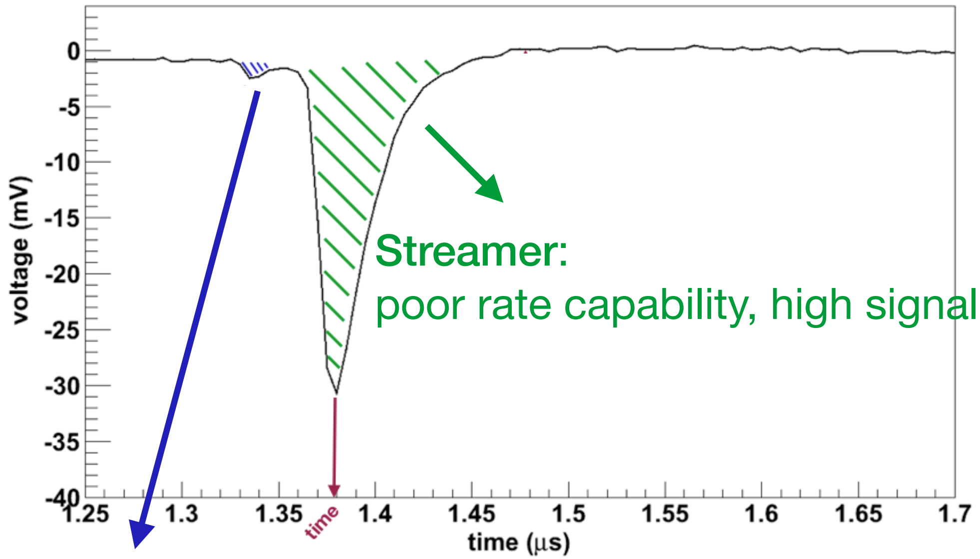
Validation of gas and detector components

Requirements for the use in LHC experiments

- Not-flammable gas mixture
  - Some of the gas tested are slightly flammable
  - Not possible to use a flammable gas mixture if leaks are present
- Low vapour pressure at ambient temperature
  - Not enough pressure for operation: it represents a limitation to the maximum delivered flow
  - It might lead to vapour condensation in the gas system
- Mass Flow Controllers
  - Found oily-like pollution in HFO sample bottles
  - MFC suffer pollution: protection of input necessary
  - Calibration with new gases not always available
- Quality of new freons is fundamental for detector operation
  - the selected gases have been developed to be used as refrigerants in industries
  - they could not fully satisfy the detector or experiments requirements
- Gas Chromatograph and mass spectrometer analysis
  - detection of impurities in some samples



Analysis steps

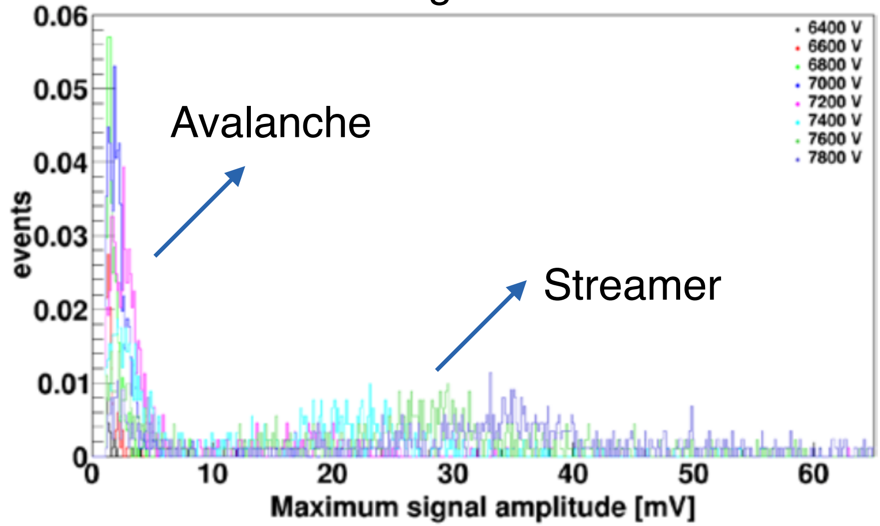


Avalanche:
good rate capability, low signal

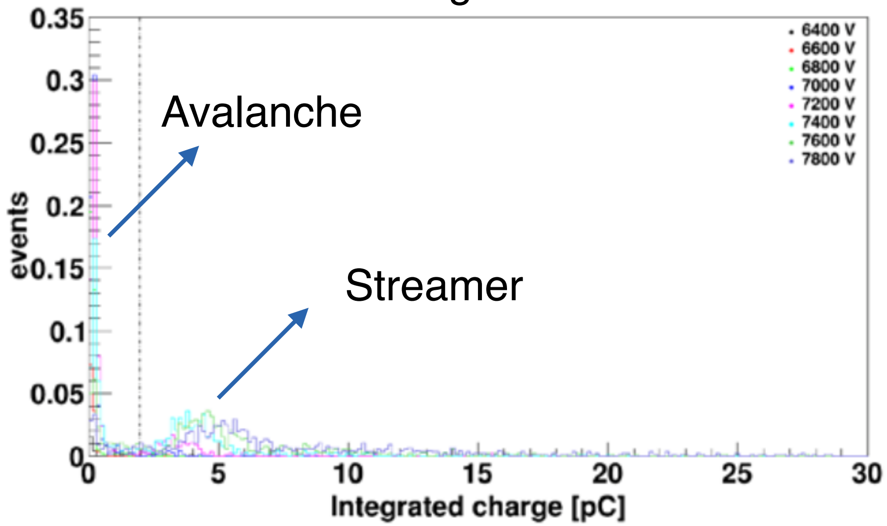
Recording of analog signals

- Parameters extracted from the signal:
  - pulse height
  - integrated charge
  - time
- Detector performance analysis:
  - efficiency
  - pulse height for avalanche and streamer
  - charge for avalanche and streamer
  - avalanche vs streamer probability
  - cluster size
  - time resolution

Pulse height distribution



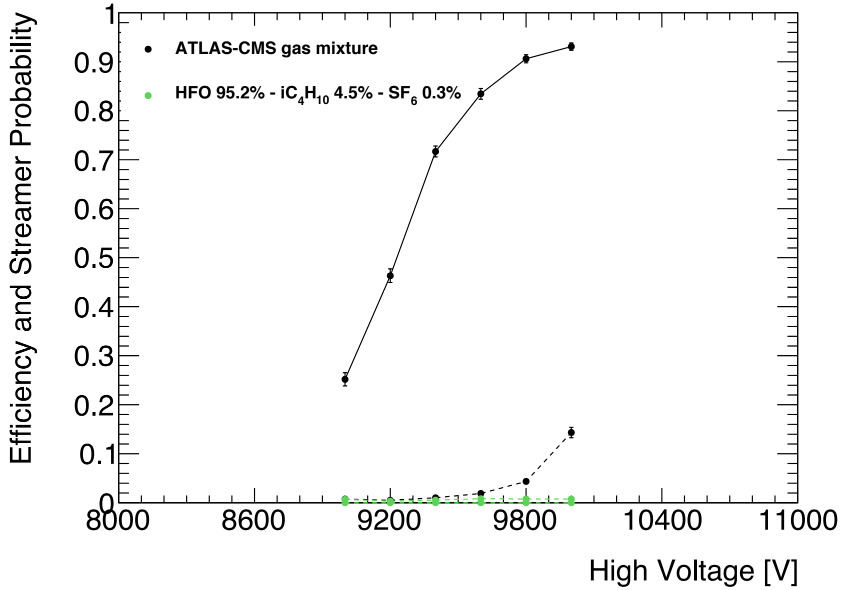
Pulse charge distribution



HFO vs R134a

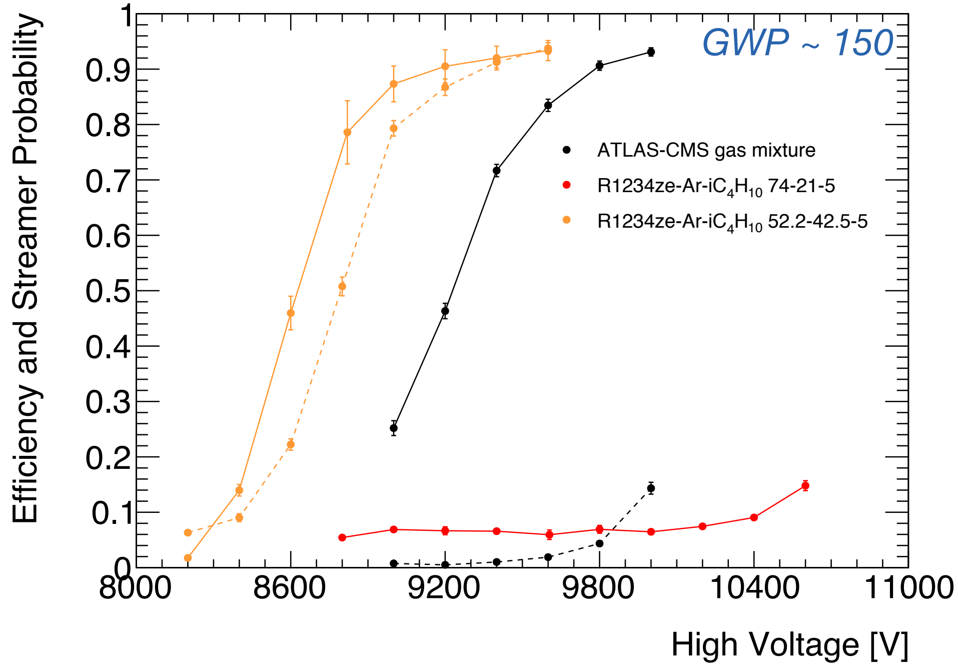
HFO in RPC standard gas mixture

- Both HFOs substituted to $C_2H_2F_4$, iC_4H_{10} or SF_6 to study the properties of the new gas
  - similar behaviour of the two HFOs
  - HFOs are much less electronegative than SF_6
  - HFOs has different quencing effects than iC_4H_{10}
- HFOs cannot directly replace $C_2H_2F_4$
  - higher applied voltage necessary (>14kV)
  - very small avalanche signal



Addition of Argon

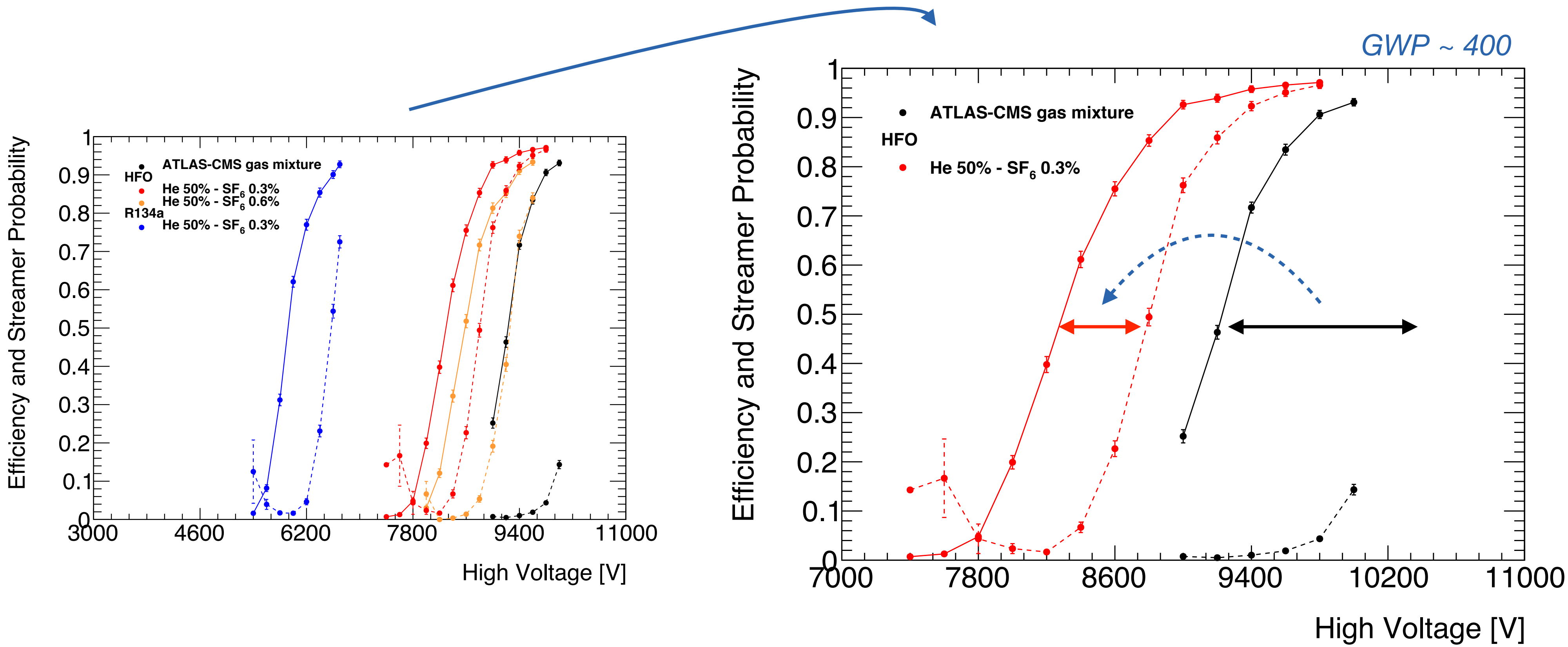
- Argon helps in charge developing
  - Ar becomes the first player
- RPCs work in streamer mode
  - not suitable for LHC operation
  - ok for rate < 10Hz/cm²



Addition of He

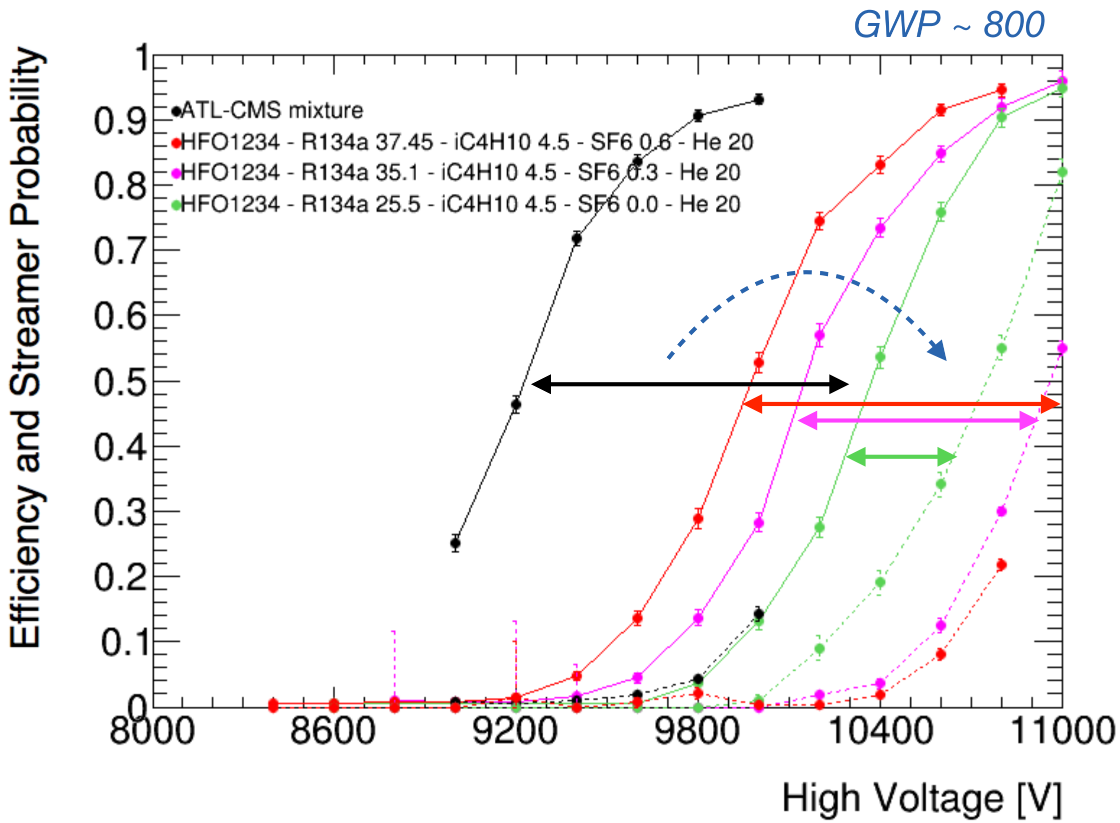
- Helium helps in reducing the HV working point
  - in first approximation it doesn't take part in the avalanche processes
  - it helps to reduce the gas partial pressure
- Addition of He in different percentages
  - 30% - 50%
- Increase of streamer probability
  - due to drastically reduction of the $C_2H_2F_4$
  - slight increase of SF_6 does not help

$$HV_{eff} = HV_{appl}\frac{p_{STD}}{p}\frac{T}{T_{STD}}$$



Addition of He and $C_2H_2F_4$

- Addition of He does not work for LHC conditions
  - $C_2H_2F_4$ is still the main contributor for charge reduction
- Try with gas mixtures containing both HFO and $C_2H_2F_4$
  - HFO reduces the GWP
  - $C_2H_2F_4$ reduce the signal charge
  - gas mixture GWP is lower than standard RPC gas mixture

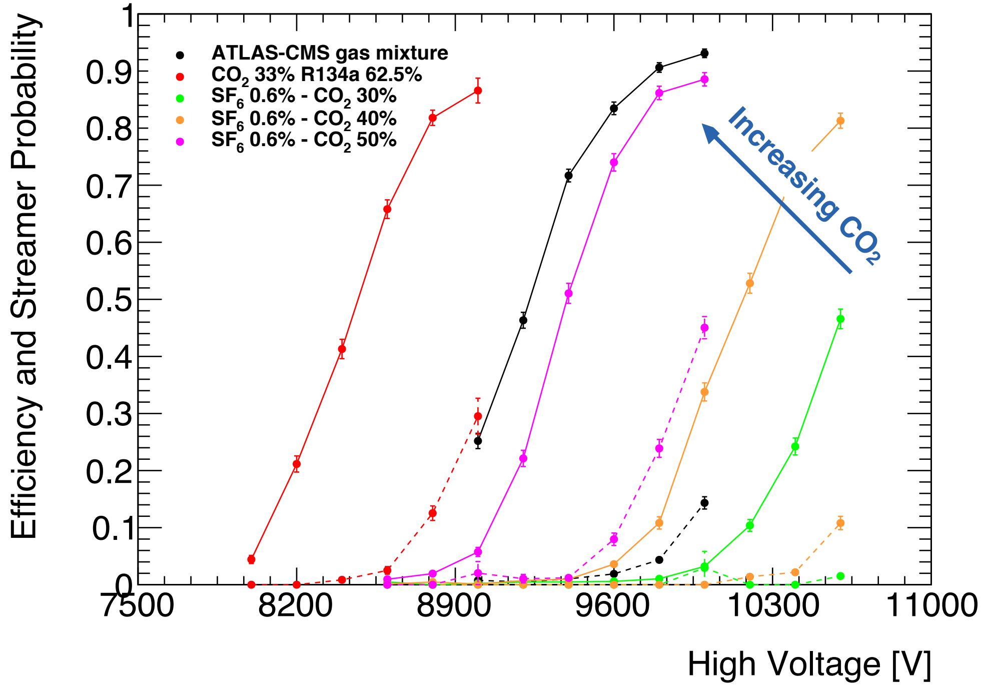


Addition of CO_2

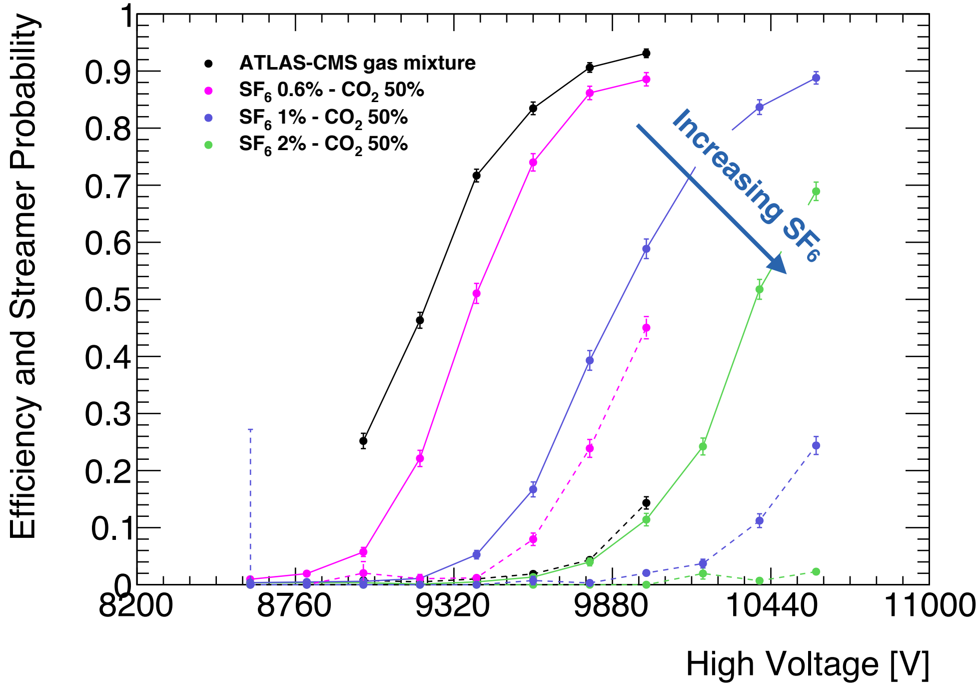
- CO_2 is used as quencher gas in gaseous detectors
  - typical gas mixtures are Ar/CO_2 (70/30 or 85/15) and Ar/CO_2/CF_4 (in different proportions)
- CO_2 is less quencher than iC_4H_{10}
  - RPC uses about 5% of iC_4H_{10}
- Addition of HFO and CO_2 to standard gas mixture

All gas mixtures have same quantity of R134a and HFO

Different % of CO_2 *GWP ~400-500*

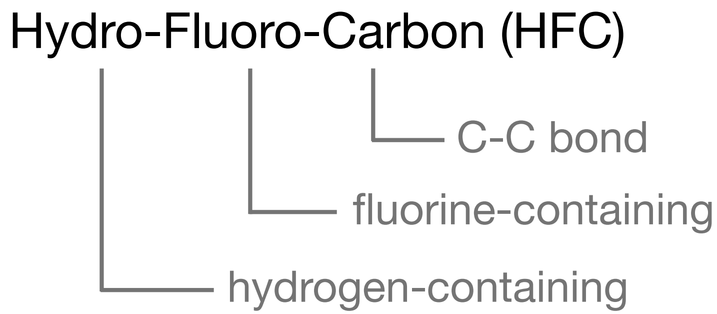


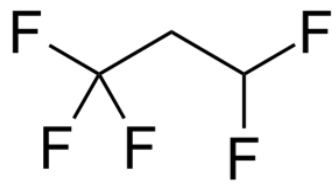
CO_2 50% + different % SF_6 *GWP ~ 500-600*



Other possible environmental friendly gases

Alternatives to $C_2H_2F_4$ (GWP 1430):

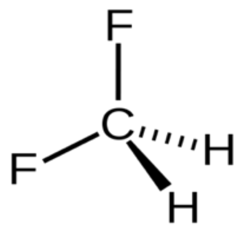




HFC-245fa

($C_3H_3F_5$)

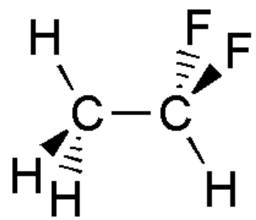
GWP 1030



HFC-32 (flam)

(CH_2F_2)

GWP 675

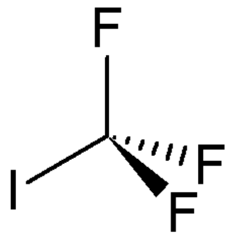


HFC-152a (flam)

($C_2H_4F_2$)

GWP 120

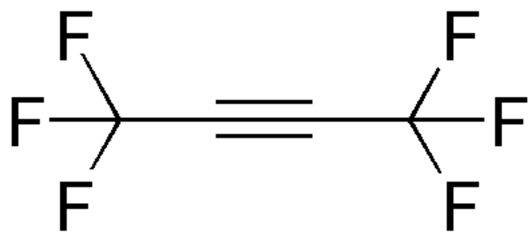
Alternatives to SF_6 (GWP 22200)*:



Trifluoroiodomethane

(CF_3I)

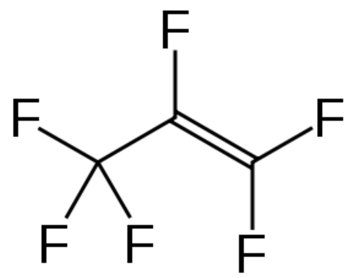
GWP <5



HFB

(C_4F_6)

GWP 260



(toxyc!)

(C_3F_6)

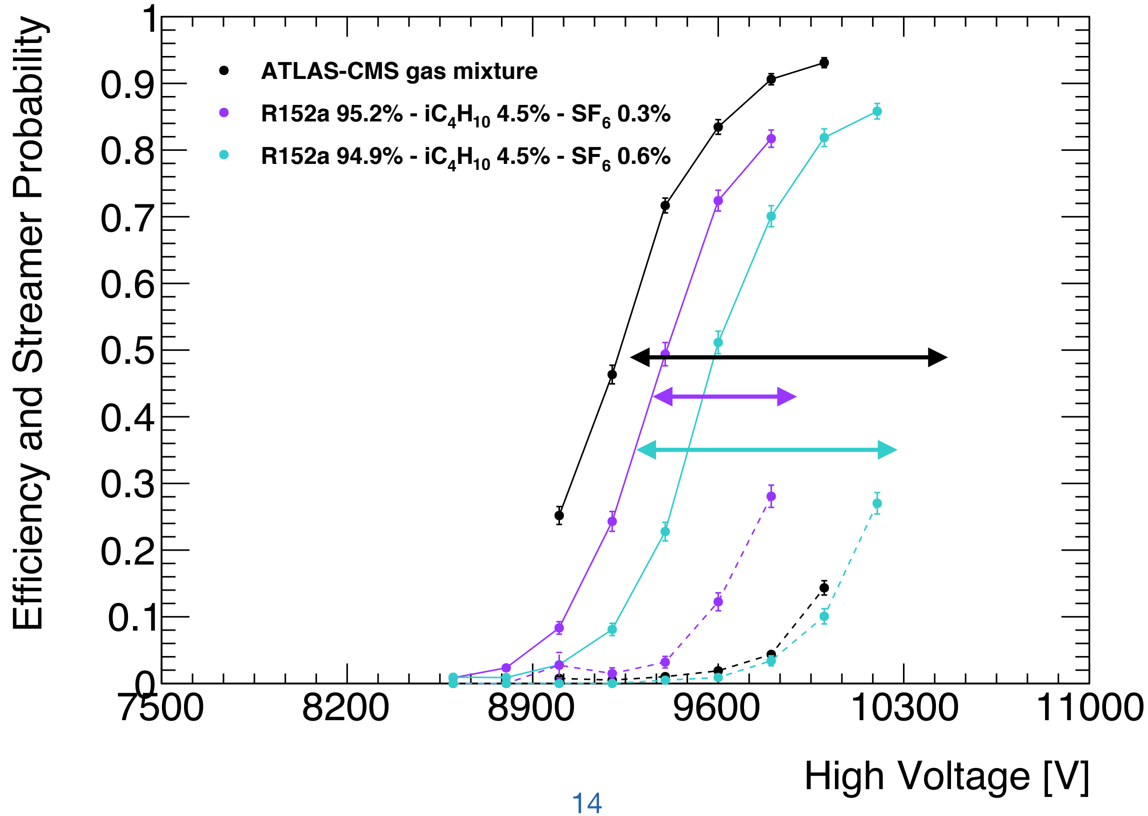
GWP <5

** … and to CF_4 (GWP 5700)*

Example with other HFC (R152a)

- R152a ($C_2H_4F_2$) vs R134a (C_2H_2F4): missing two fluorines!
  - equal chemical structure (ethane)
  - R152a GWP: 120
  - R152a: 2/8 —> 20%
  - R134a: 4/8 —> 50%
- RPC efficient and low streamer probability
  - Region without streamer limited
  - Need to add SF_6
- R152 is flammable

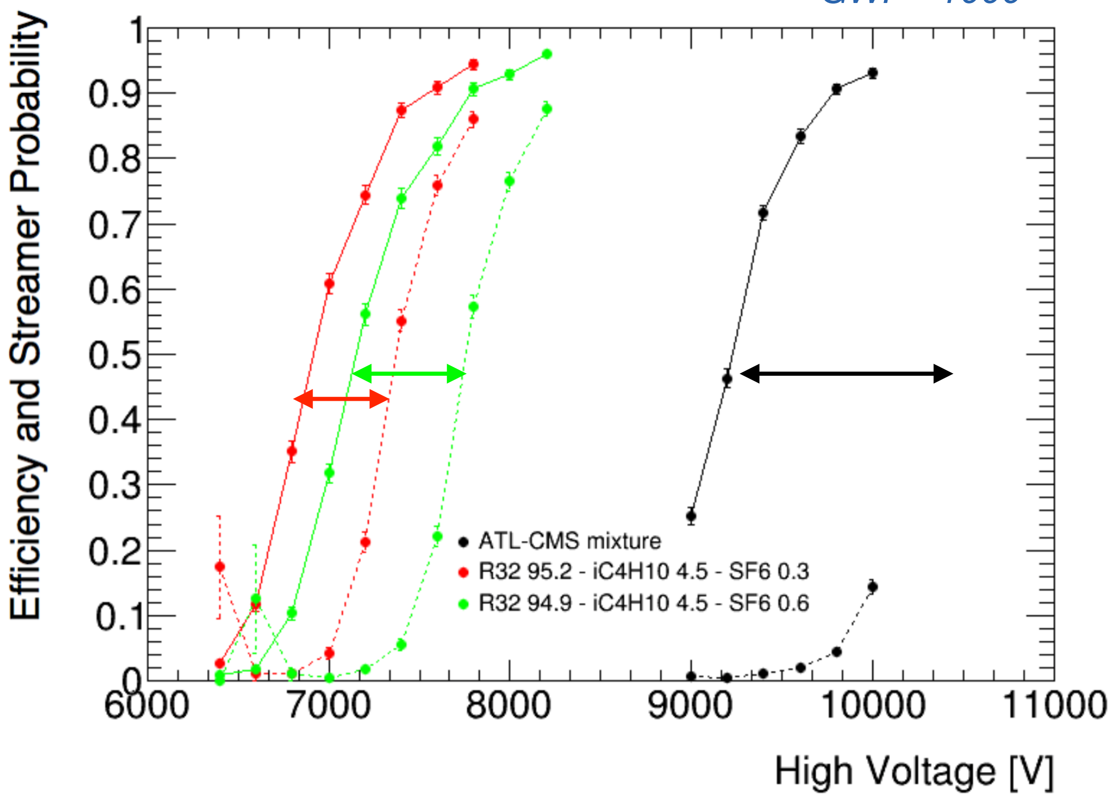
GWP ~400



Example with other HFC (R32)

- R32 (CH_2F_2) vs R134a ($C_2H_2F_4$): missing one carbon and two fluorines!
  - R32 has a very simple chemical structure based on methane
  - R32 has one carbon and two fluorine atoms less than R134a making suppose that the electron attachment is lower
- RPC efficient at lower working point
- Streamer probability is almost 100%
  - Poor quenching capacity

GWP ~1000



Summary of results

More than 50 gas mixtures tested

	Chem struc	GWPmix	HV (V)	Streamer (%)	Pulse charge (pC)	ΔV Eff-Stream (V)	Clu Size (strip)
$R32\text{-}iC_4H_{10}\text{-}SF_6$ 0.6	c	1030	7500	14	0.5 / 6.5	600	1.5
$R134a\text{-}iC_4H_{10}\text{-}SF_6$ 0.3	**c-c**	**1490**	**9600**	**1.5**	**0.5 / 6**	**1000**	**1.5**
$R152a\text{-}iC_4H_{10}\text{-}SF_6$ 0.6	c-c	430	10000	10	1 / 8.5	760	1.6
$R245fa\text{-}iC_4H_{10}\text{-}SF_6$ 0.6-He 50	c-c-c	1260	6600	20	1 / 7	610	2
$HFO\text{-}iC_4H_{10}\text{-}SF_6$ 0.3-Ar 42.5	c=c-c	130	8900	70	2 / 15	160	4
$HFO\text{-}iC_4H_{10}\text{-}SF_6$ 0.6-He 50	c=c-c	370	9000	20	1.5 / 8	700	4
HFO-R134 37.45-$iC_4H_{10}\text{-}SF_6$ 0.6-He 20	**c=c-c**	**890**	**10500**	**1.8**	**0.5 / 6**	**970**	**1.6**
HFO-R134a 40-$iC_4H_{10}\text{-}SF_6$ 0.6-He 20	c=c-c	730	10500	8	0.5 / 6.5	700	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 -$iC_4H_{10}\text{-}CO_2$ 50- SF_6 1	**c=c-c**	**560**	**10500**	**5**	**0.5 / 6.5**	**950**	**1.5**

- C and C2 structures —> direct operation
- C3 structure —> addition of Ar, He or CO_2
  - Ar brings to high streamer probability
  - He reduces the HV working point
  - CO_2 based gas mixtures look promising
- Still necessary to have R134a in the mixture to be competitive to standard gas mixture

Conclusions

Several reasons to look for a new RPC gas mixture

- $C_2H_2F_4$ will be subject to phase out and price instability in Europe
- RPC systems at LHC dominate the GHG emission due to particle detection at CERN

Alternatives to $C_2H_2F_4$ already available on the market

- HFO as replacement of $C_2H_2F_4$ as refrigerant
- To be tested for aging, radiation hardness, reactivity to detector and gas components

Not an easy task to find a gas mixture to replace the current one for LHC experiments

- Complex gas mixtures (4-6 components) necessary but still not good as standard one
- Keep going on to search the good gas mixture composition

In case of streamer mode, operation with new environmental friendly gas mixture possible

- Addition of Ar or He reduce the HV working point

For new experiments possible to work with the new environmental friendly gases

- Impact on gas system under control
- Dedicated electronics
- Detector HV working point higher