EP-DT
Detector Technologies

Strategies for reducing the environmental impact of gaseous detector operation at the CERN LHC experiments

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CERN

The 14th Vienna Conference on Instrumentations
16 February 2016

Outline

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

Reduction of GHG emission at LHC

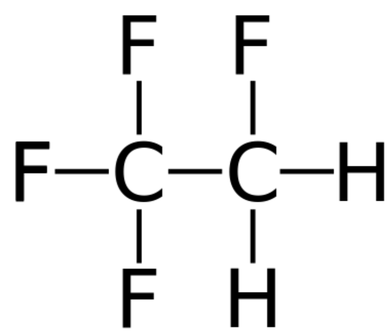
- Gas Recirculation system
- Gas Recuperation system
- Achievements during LS1 and future expectations

Search for new environmentally friendly gases for particle detectors

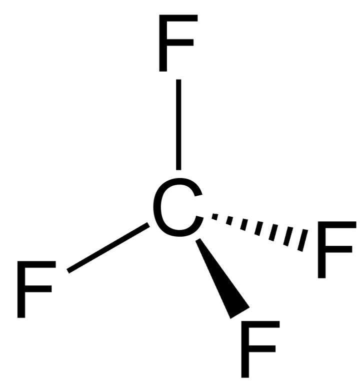
- RPC operation with eco-friendly gases

GHG for particle detection at LHC

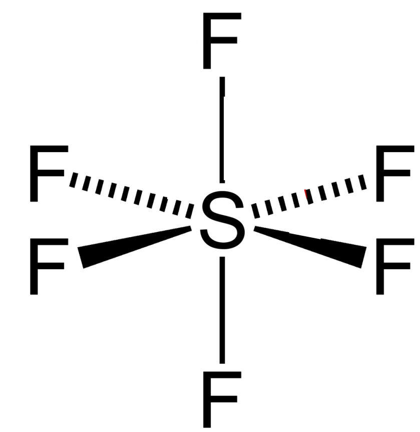
A greenhouse gas is any gaseous compound that is capable of absorbing infrared radiation, thereby trapping and holding heat in the atmosphere



GWP 1430

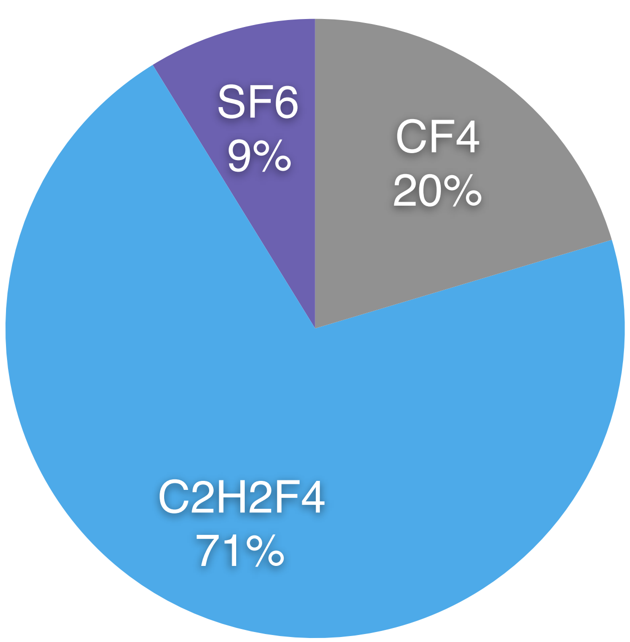


GWP 5700



GWP 22200

GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere



Total GHG contribution

GHG for particle detection at LHC

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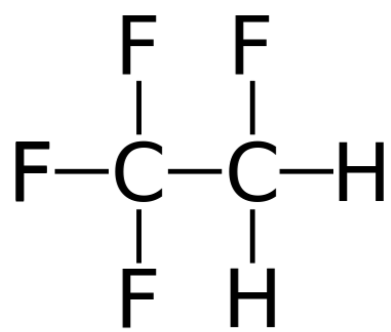

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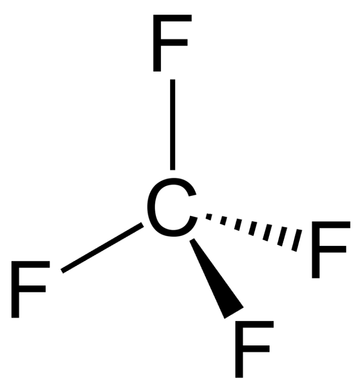

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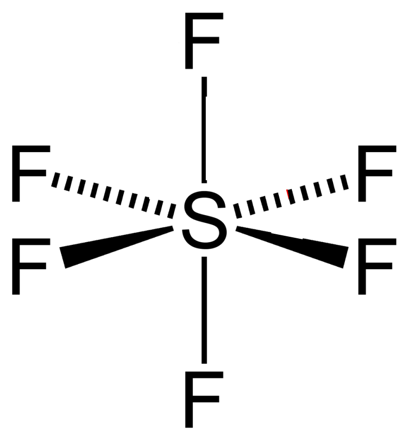

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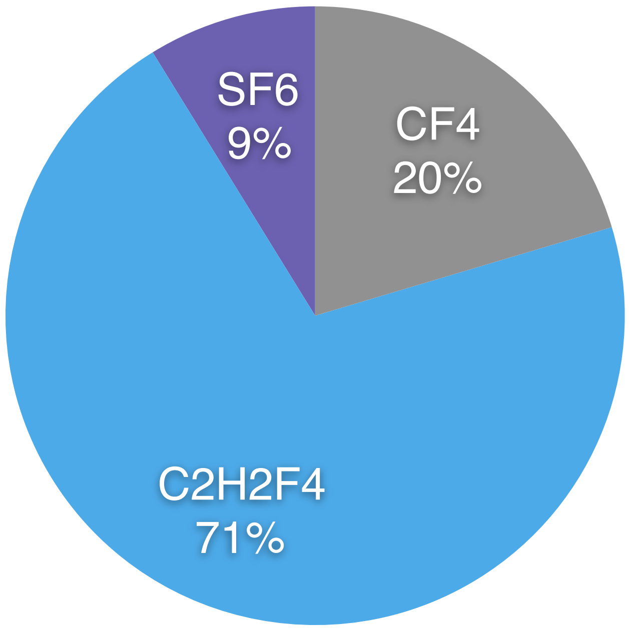
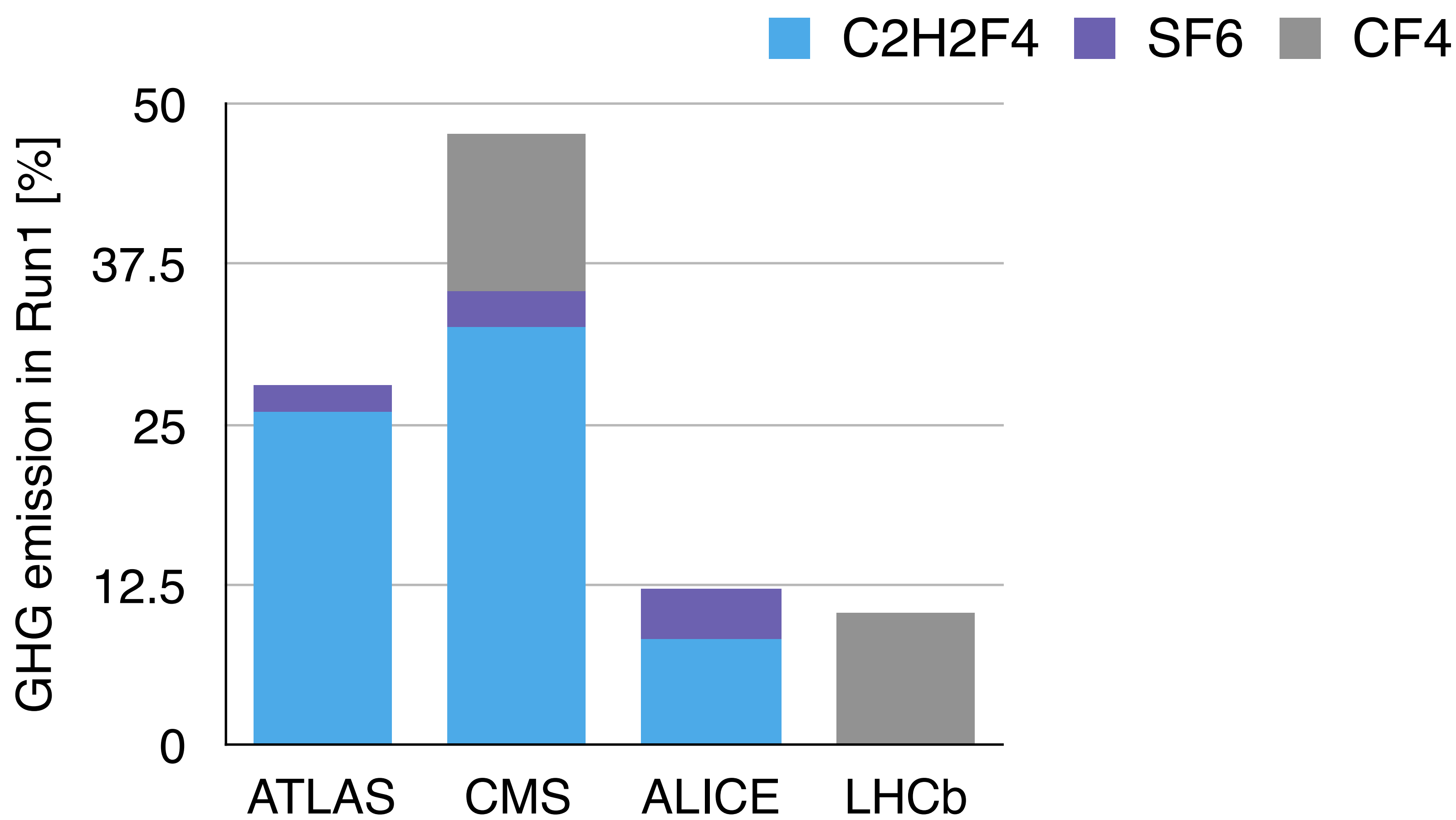


Total GHG contribution

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.

Where does the GHG emission come from?



Very large Detector volumes!

10-100 m^3

Small Detector volumes!

0.01 - 0.3 m^3

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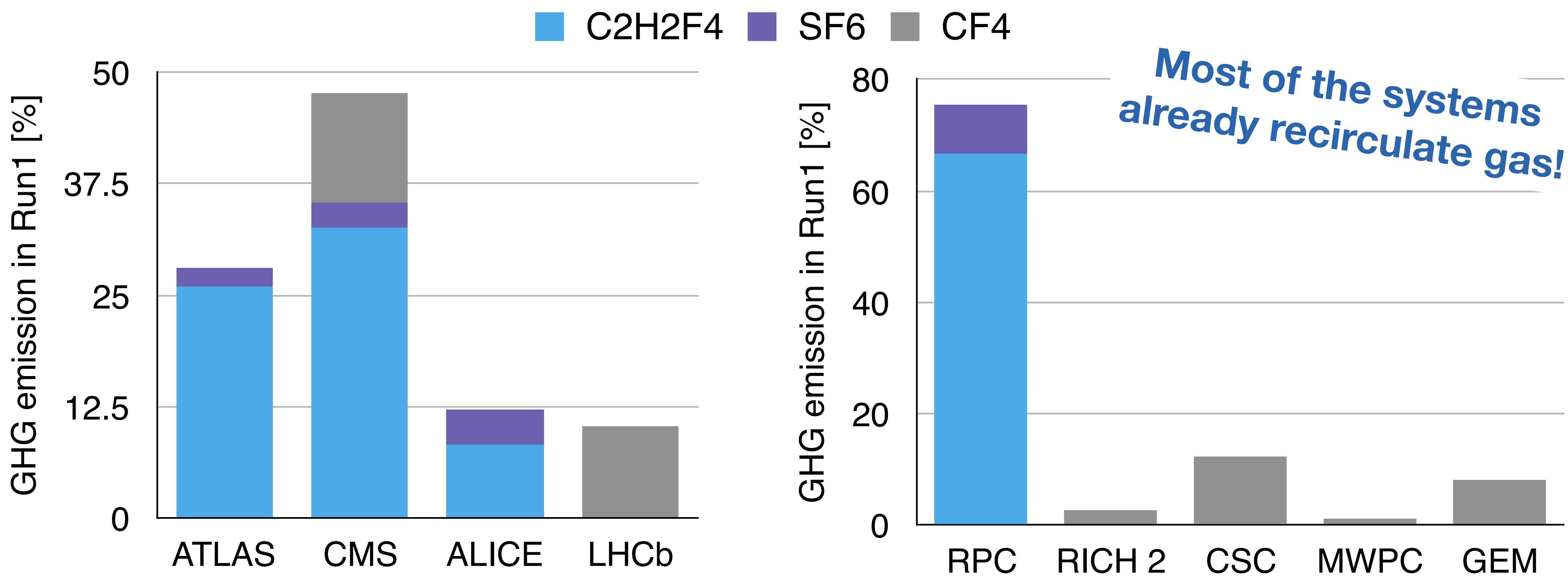


Most of the systems already recirculate gas!

Very large Detector volumes!
10-100 m³

Small Detector volumes!
0.01 - 0.3 m³

Leaks in detectors
(ATLAS and CMS)
No recirculation
(ALICE MTR)

Permeation to Air
(CMS)

No recirculation
(LHCb)

Gas Systems at the LHC experiments

Open mode operation

12 LHC gas systems in open mode

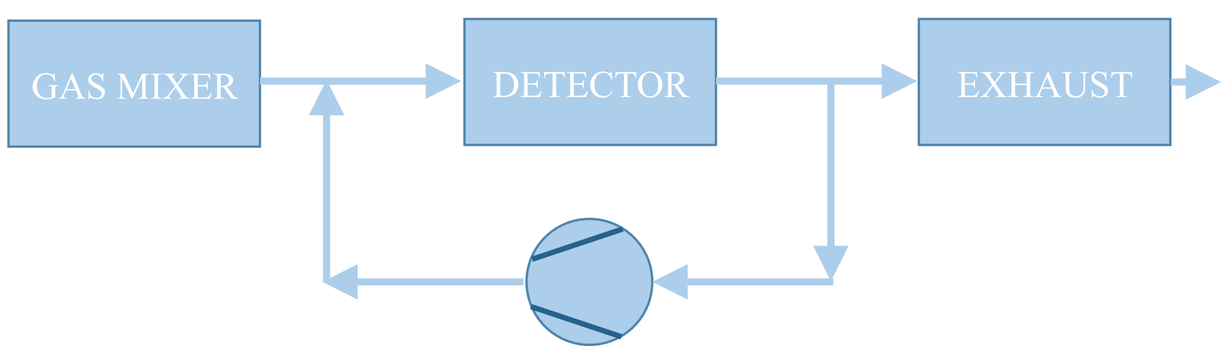
Advantages:

- simple operation, flexibility

Disadvantages:

- potential source of high gas consumption

Gas recirculation system



13 LHC gas systems in closed mode

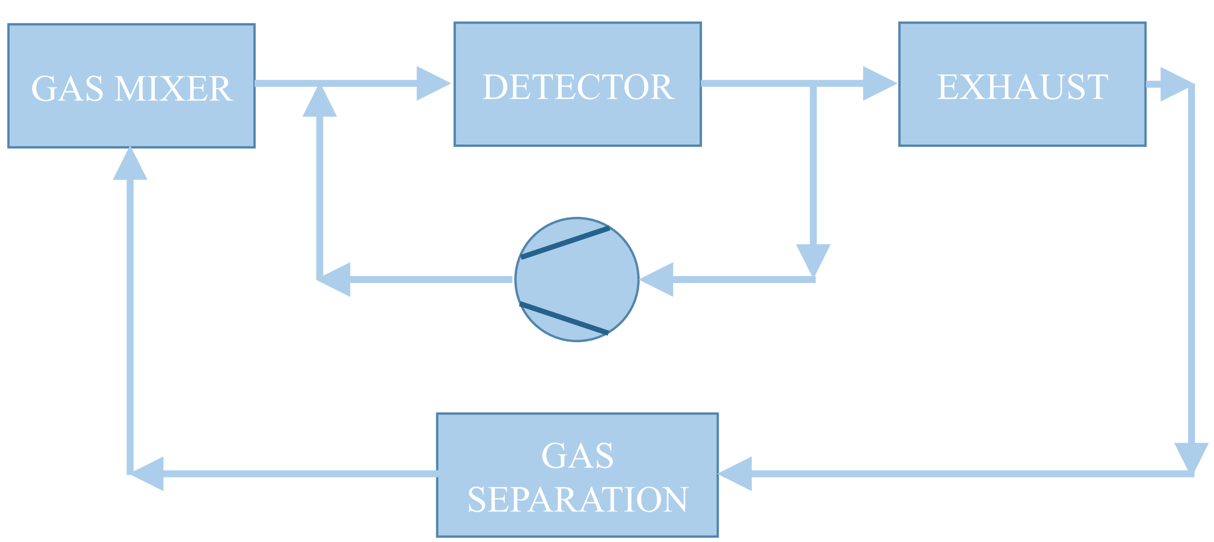
Advantages:

- reduction of gas consumption

Disadvantages:

- complex systems
- constant monitoring (hardware and gas)
- sophisticated gas purifying techniques

Gas recuperation plant



5 LHC gas systems with gas recuperation

Advantages:

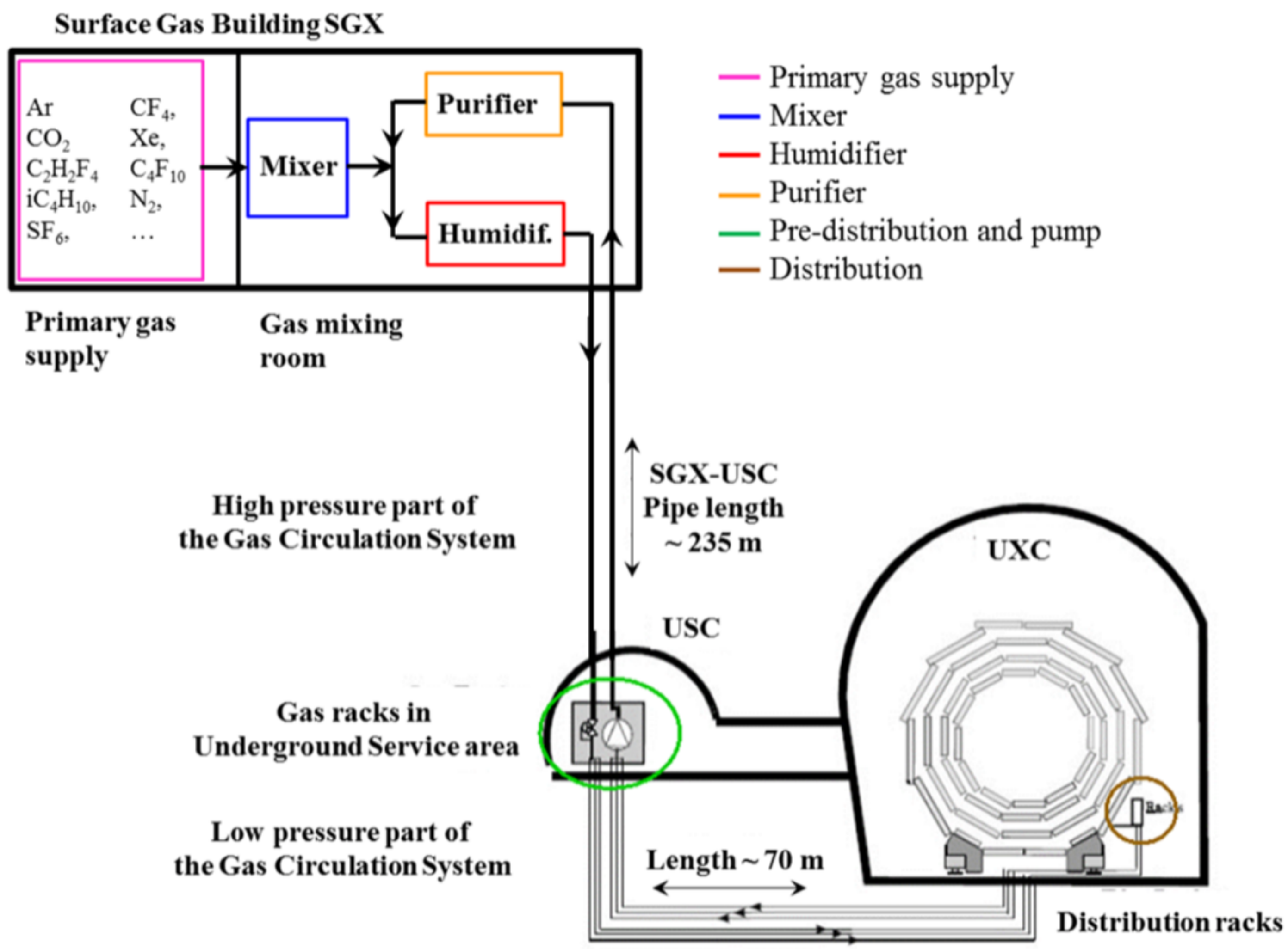
- further reduction of gas consumption

Disadvantages:

- higher level of complexity
- dedicated R&D

Gas recirculation systems

Thanks to gas recirculation GHG emission already reduced by > 90%!!!



Nevertheless…

- 85% of remaining emission still from gas recirculation systems… why?
  - Large detector volumes and presence of detector leaks
- 15% of remaining emission from open mode gas systems
  - Upgrade to gas recirculation!

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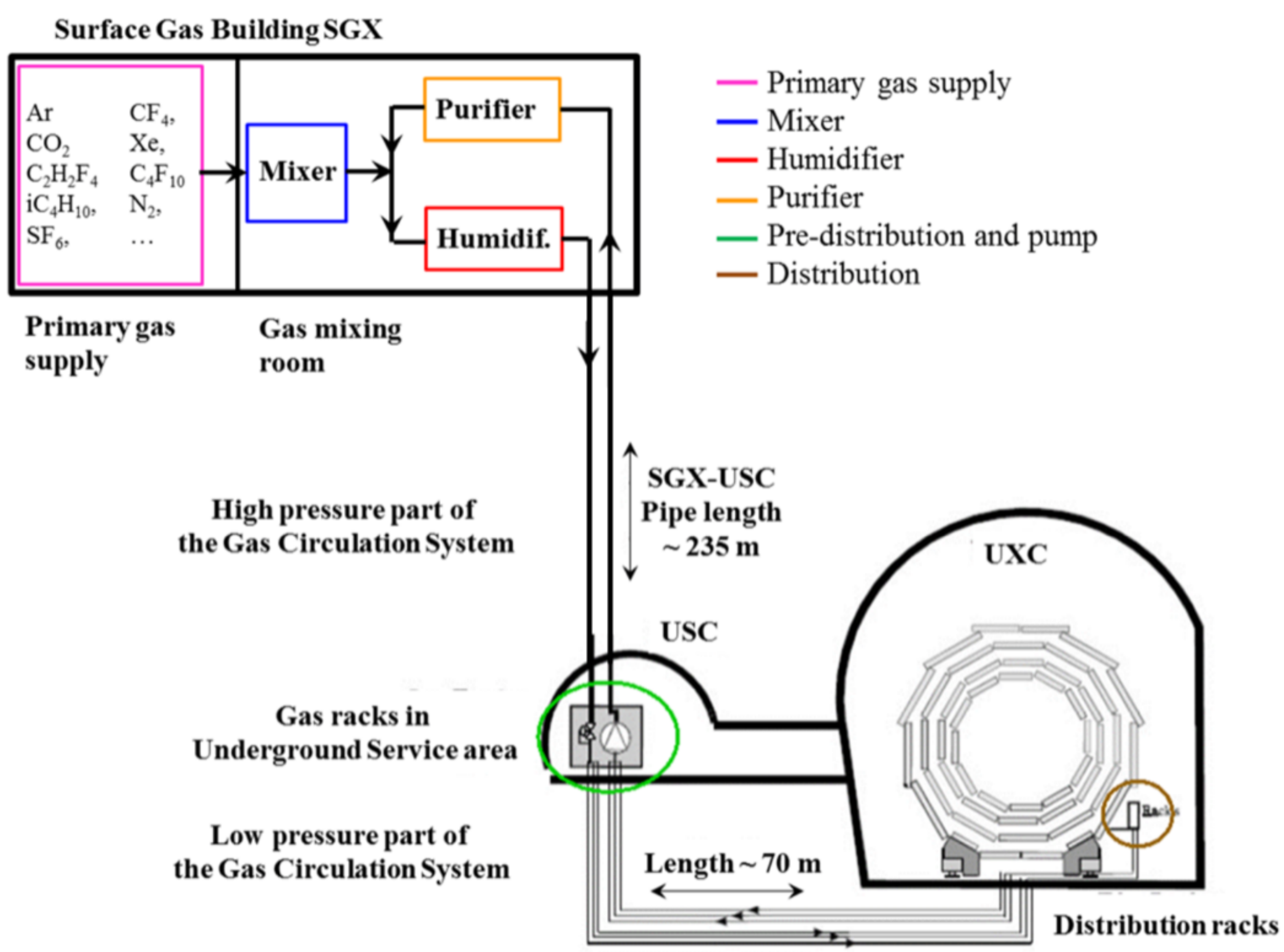

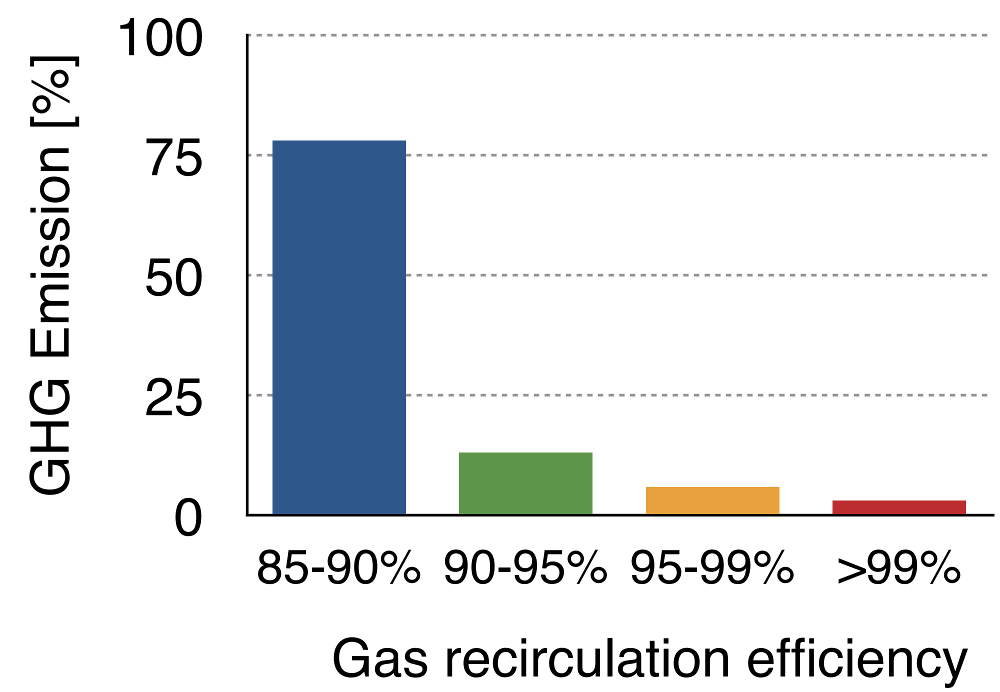

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Gas recirculation systems: improvements

Improvements during LS1:

- ALICE MTR in gas recirculation
  - $C_2H_2F_4$-iC_4H_{10}-SF_6 (89.7-10-0.3)
  - **30% GHG reduction** (4% wrt total emission)
  - At maximum exploitation: **90% GHG reduction**
- Tuning of gas recirculation systems
  - LHCb RICH1, RICH2, ALICE TOF, …
  - **40% GHG reduction per system** (2% wrt total emission)
- Leak searches
- Implementation of flexible gas recirculation unit
  - Suitable for lab, test-beam, upgrades and R&D applications
  - 10% of GHG emission during LS1 came from detector R&D and upgrades

Upgrades during YETS:

- LHCb GEM in gas recirculation
  - Intense R&D needed
  - It will pave the way for CMS GEM
  - When fully operational: **90% GHG reduction** (6% wrt total emission)

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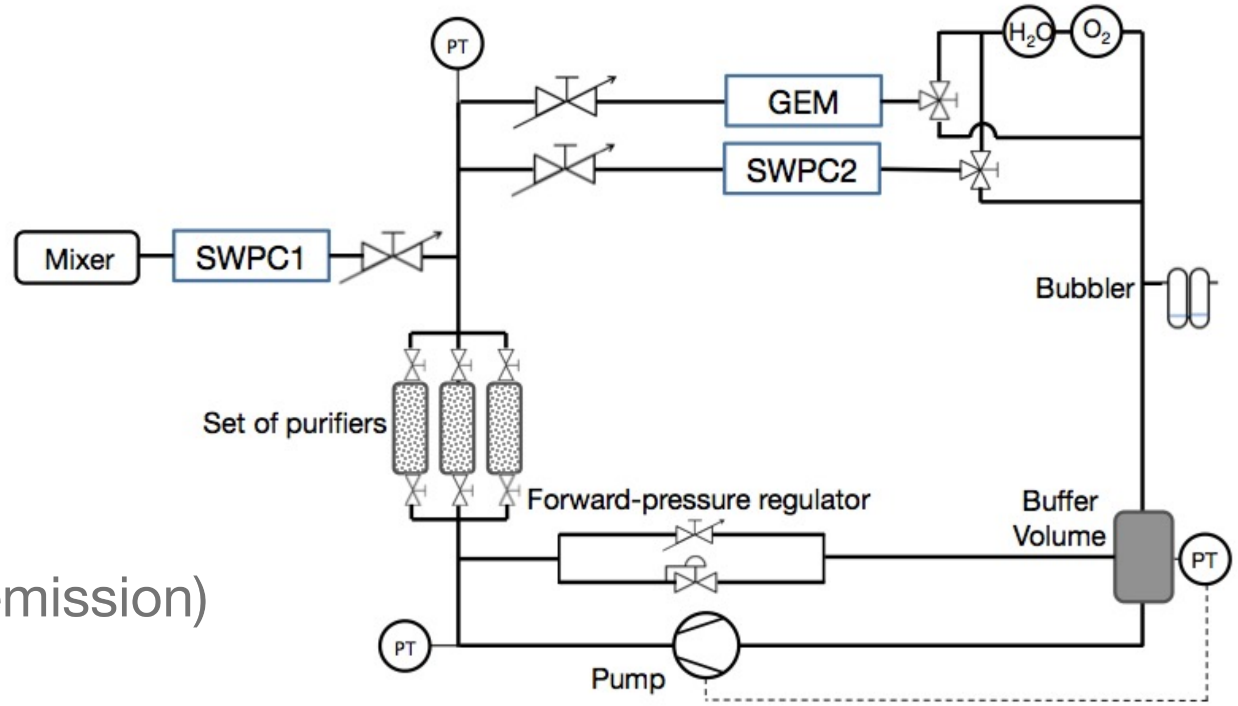

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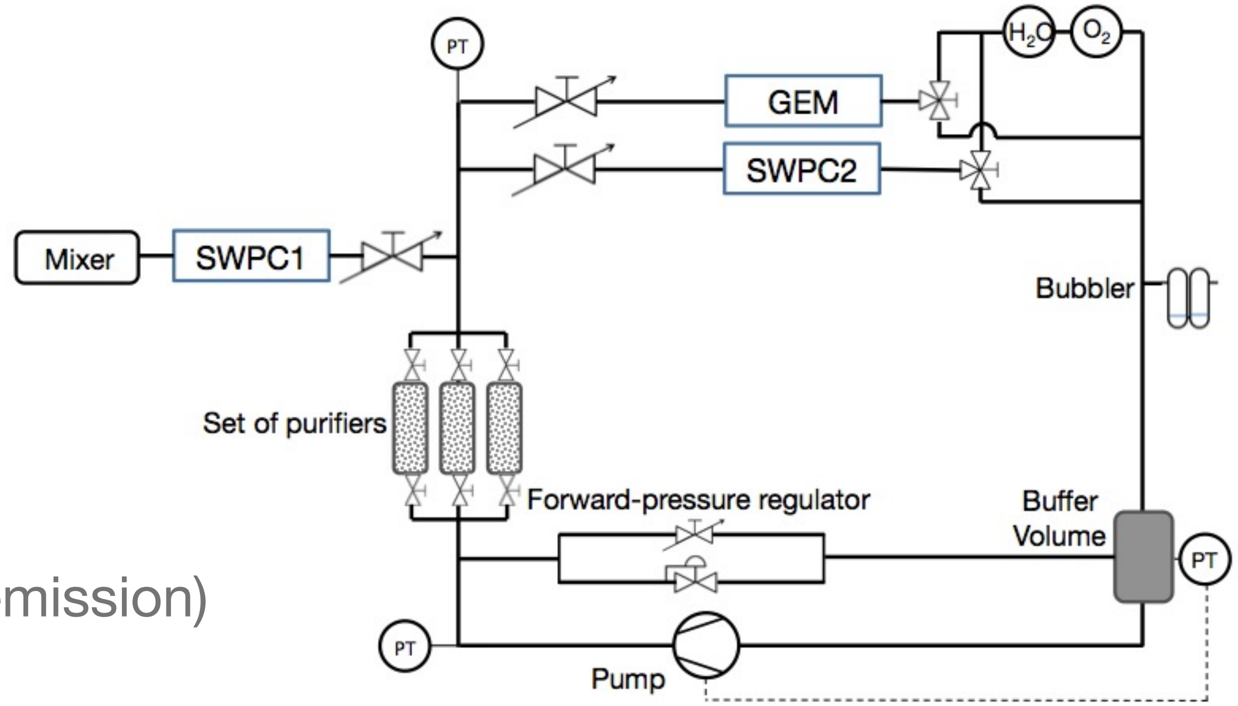

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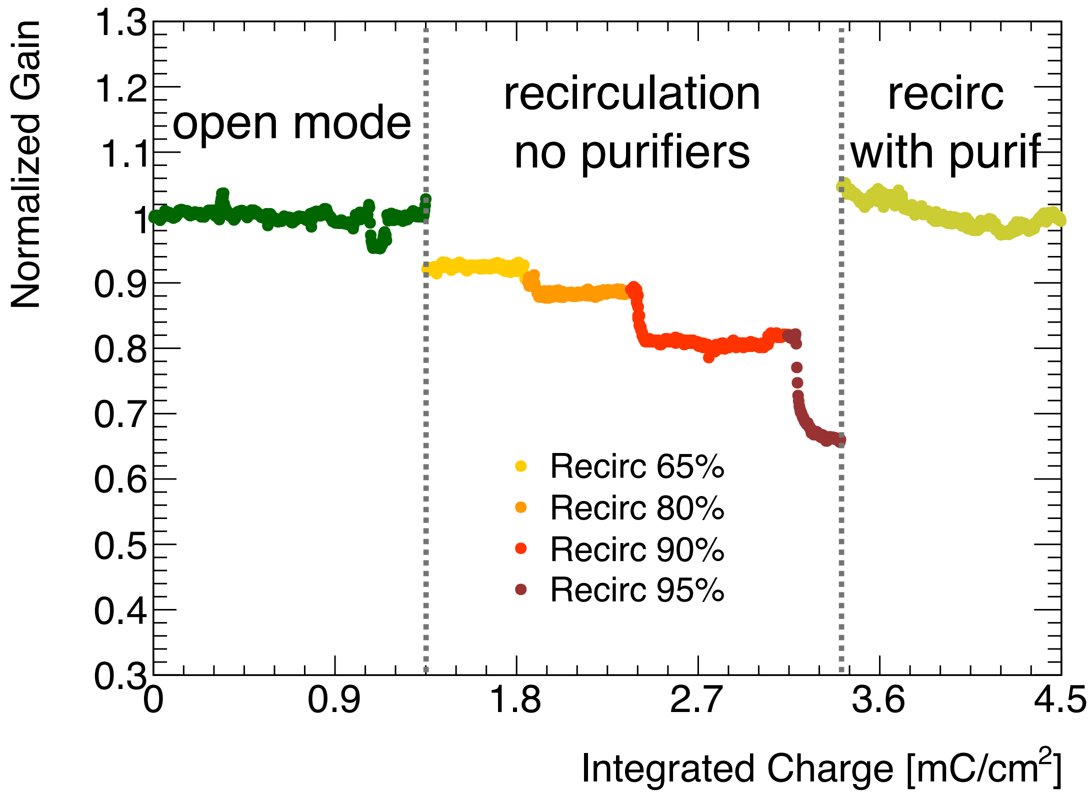
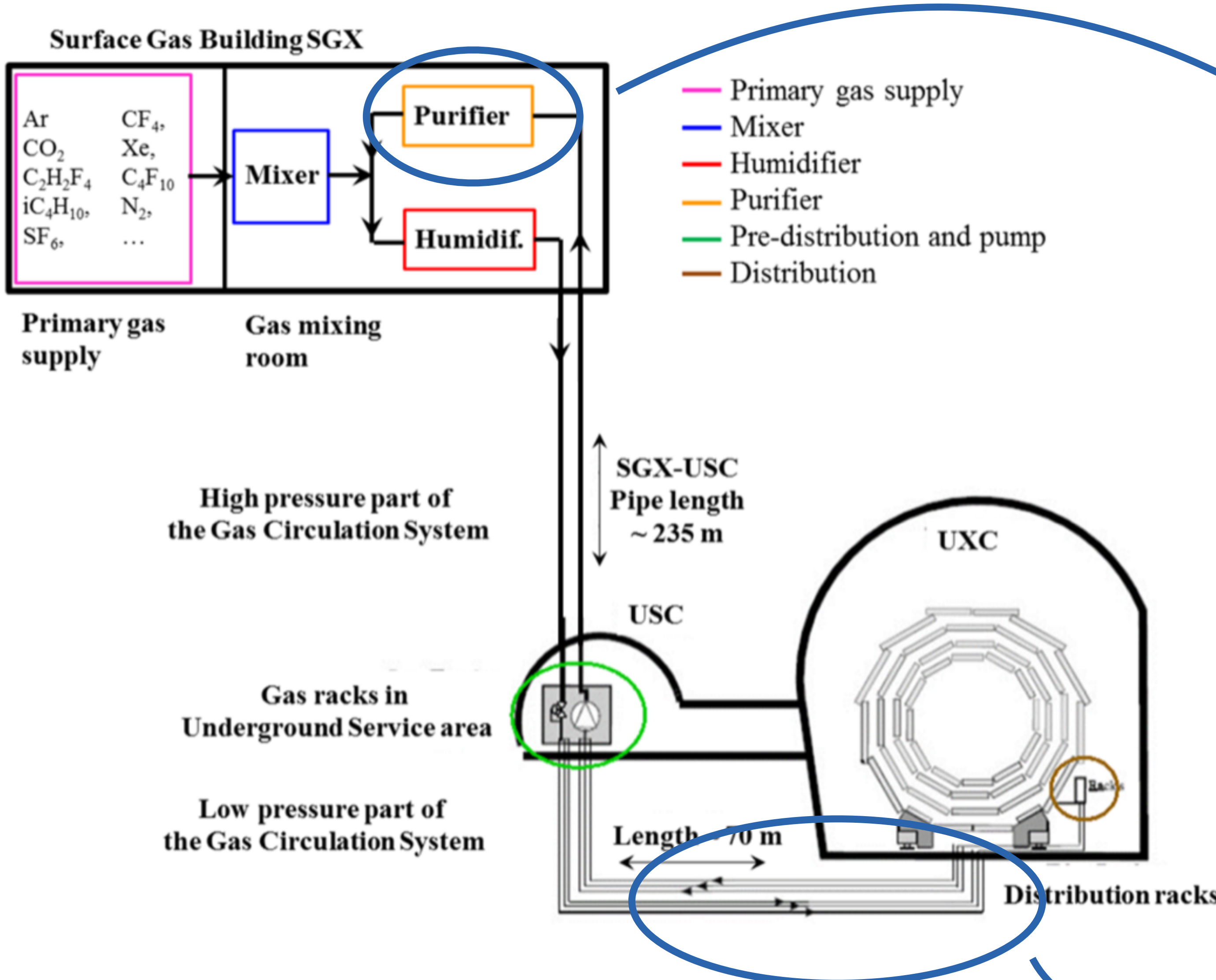
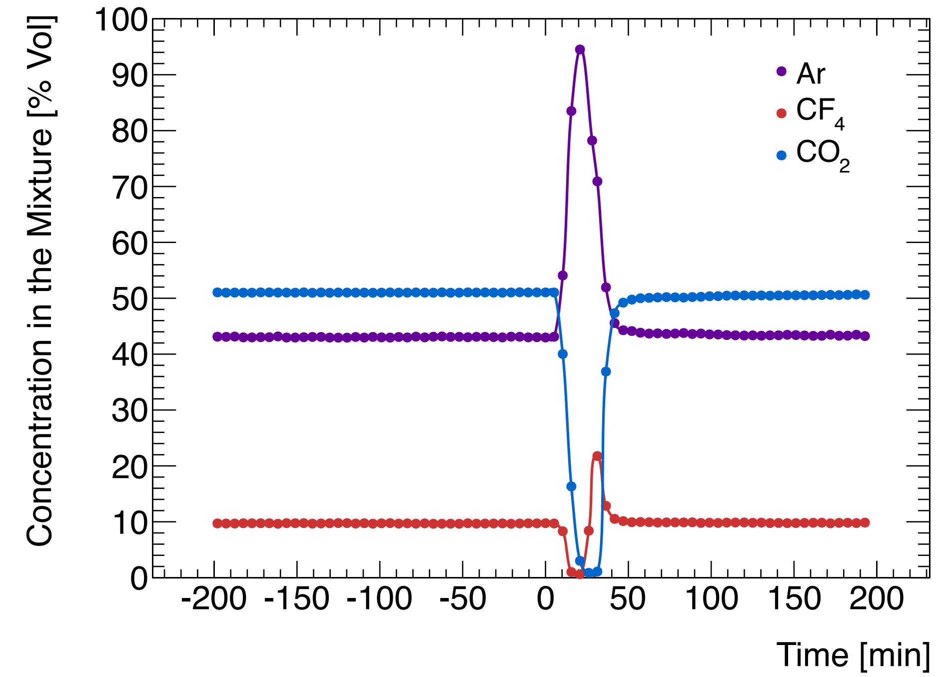


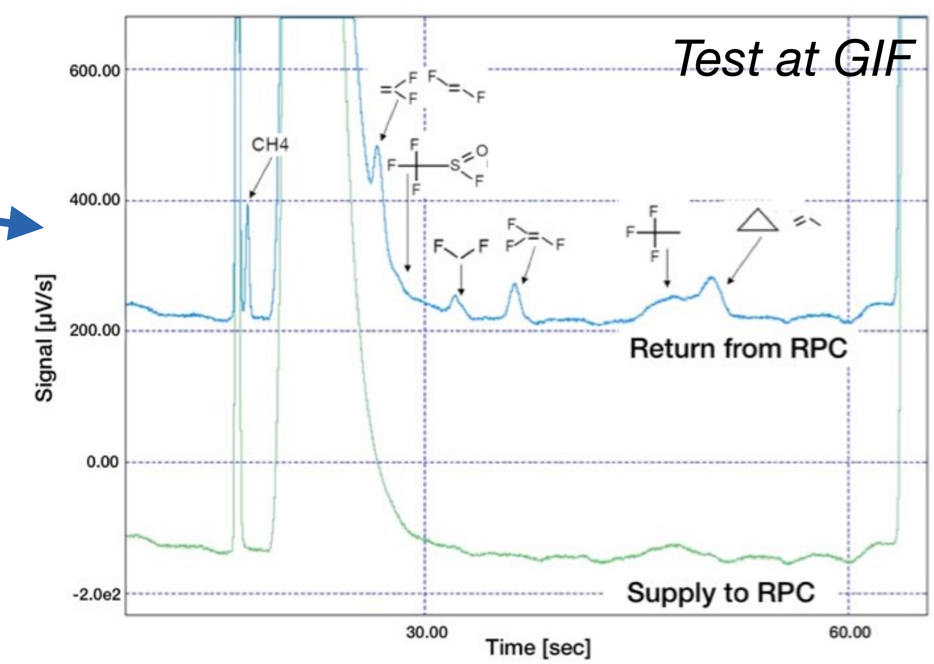
Gas recirculation systems: complexity



Destabilisation of the gas mixture



Creation and accumulation of impurities



Gas recirculation systems are complex and they need particular attention

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Gas detector performance and operation can be affected!

Gas Recuperation system: CMS CSC example

If detectors permeable to Air
not possible to go high in recirculation!

Detector volume Nominal Flow	90 m^3 6 m^3/h
Operating gas mixture	CO_2-Ar-CF_4 50-40-10
Gas mixture impurity limits	O_2: 100 ppm N_2: 3000 ppm
Average O_2 intake in one gas replacement	300 ppm
Average N_2 intake in one gas replacement	**1200 ppm**
Fresh gas replenishing rate	**630 l/h**

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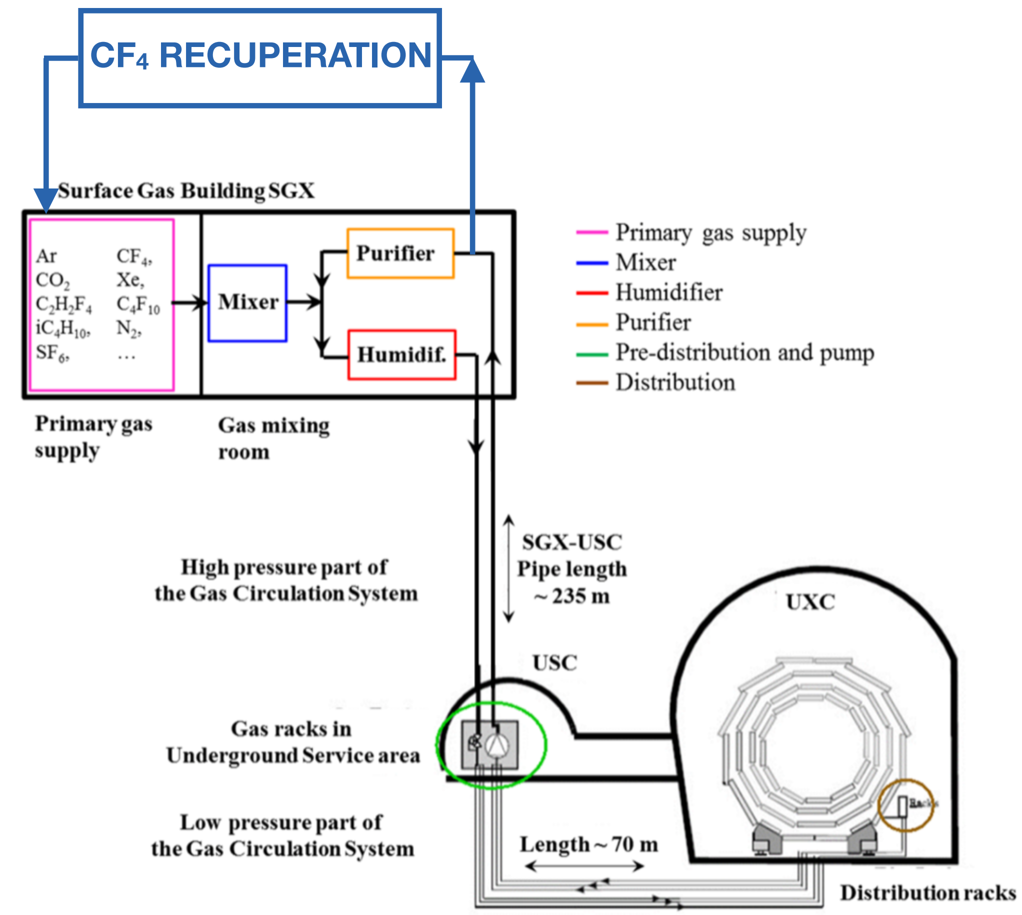


Recuperation of CF_4 with warm separation!

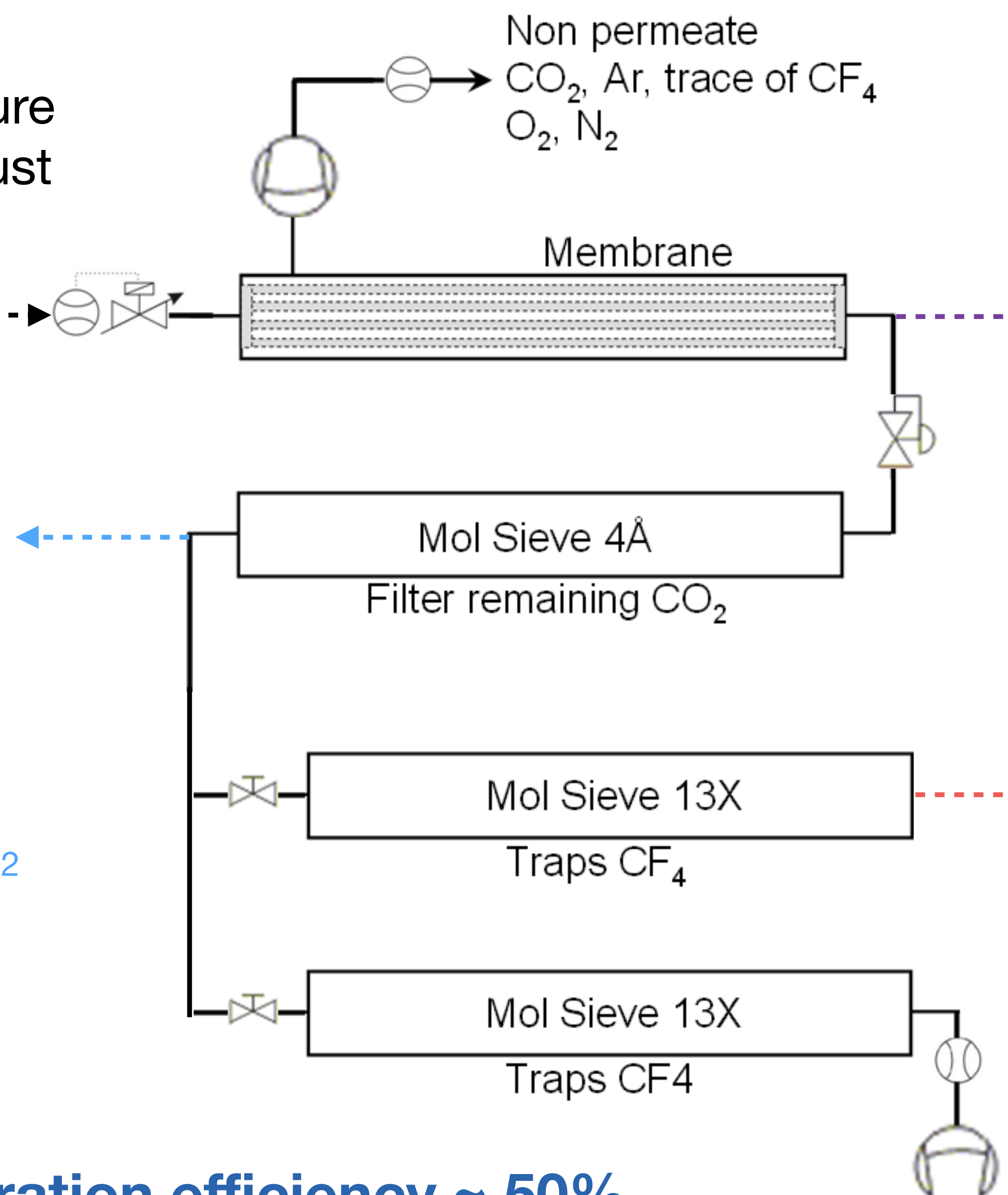
- Innovative CF_4 recuperation plant
  - Complex, long R&D development (first attempt of warm separation)
  - Impact today: **37% GHG reduction** (4.6% wrt total emission)
- Still needs optimisation of the CF_4 separation process
  - Future expectation: **50-60% GHG reduction** (12% wrt total emission)

Gas Recuperation system: CMS CSC example

Phase 0:

CSC gas mixture from the exhaust

Ar	40%
CO_2	50%
CF_4	10%



Phase 1:

Absorption of CO_2

CF_4 bulk separation

Ar	63%
CO_2	<1%
CF_4	37%

Phase 2:

Absorption of remaining CO_2

Ar	65%
CO_2	~ppm
CF_4	35%

Phase 3a:

CF_4 absorption

Phase 3b:

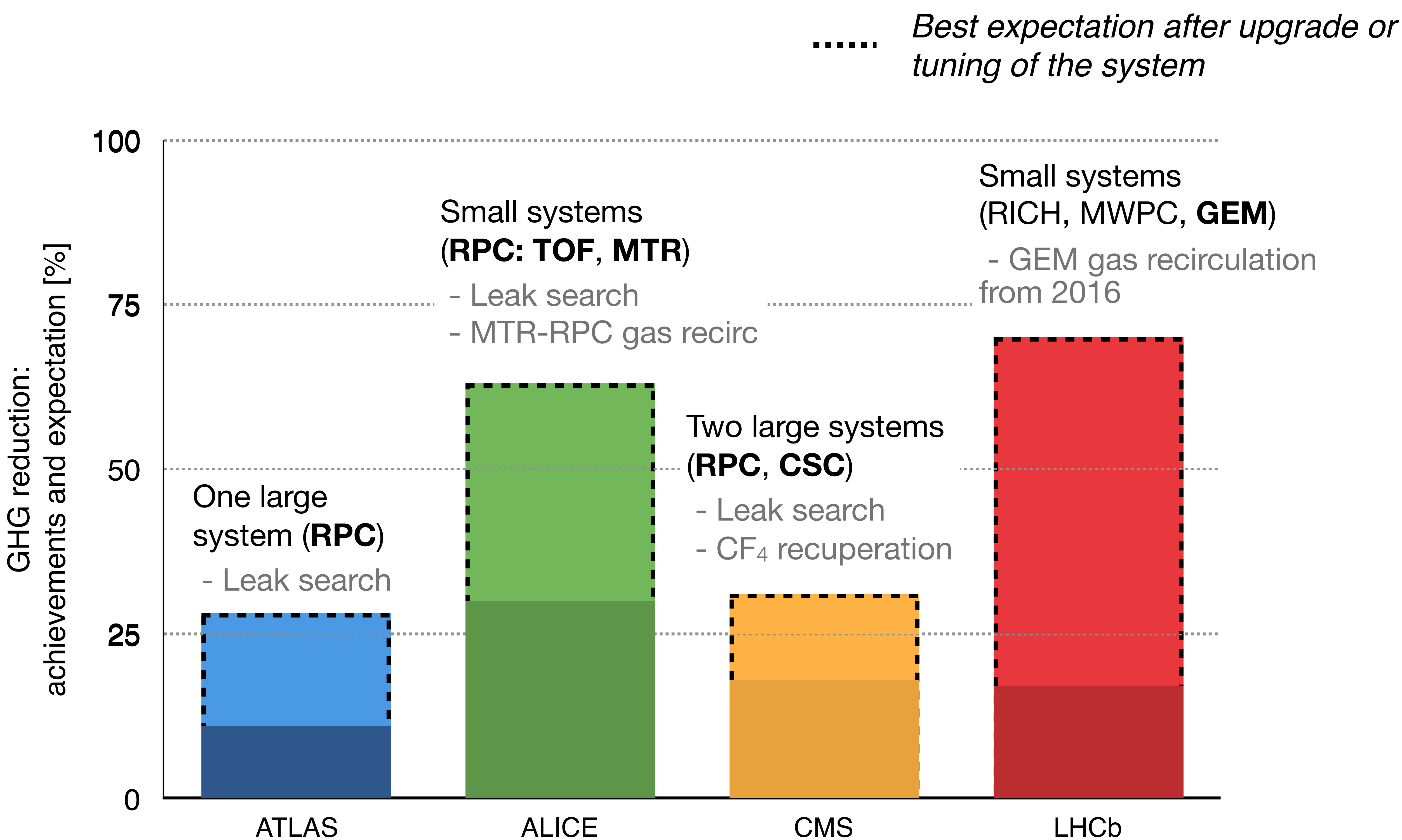
CF_4 extraction

Ar	10%
CO_2	~ppm
CF_4	90%

Currently recuperation efficiency ~ 50%

- About 100 m^3 of CF_4 recuperated during Run 1
- CF_4 quality satisfactory
- CSC detector operated with recuperated CF_4 during LS1
  - No change in the CSC performance observed

GHG emission: achievements from Run1 to Run2



Status of RPC systems for Run 2 and beyond

ATLAS and CMS RPC systems are the main contributors to GHG emission

- Gas systems already in recirculation mode at the maximum possible rate allowed by the present detector leaks
  - Under study the possibility to tune the gas flow according to run periods
- Detector leaks localised in few chambers but difficult to repair
- After leak search campaign during LS1: **11% (ATLAS) and 6% (CMS) GHG reduction** (3% and 2.3% wrt total emission)

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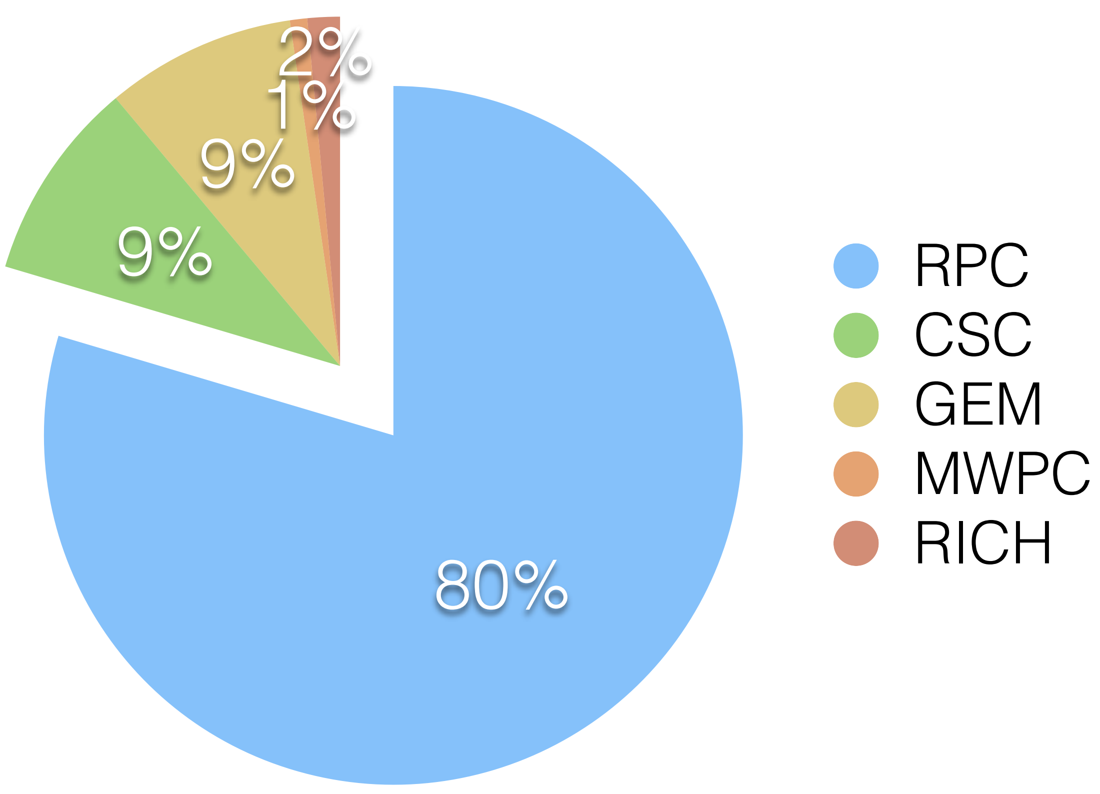
Even if leaks will be fixed,
what is the maximum recirculation rate
for safe RPC operation?

↓

Is it possible to change
the gas mixture?

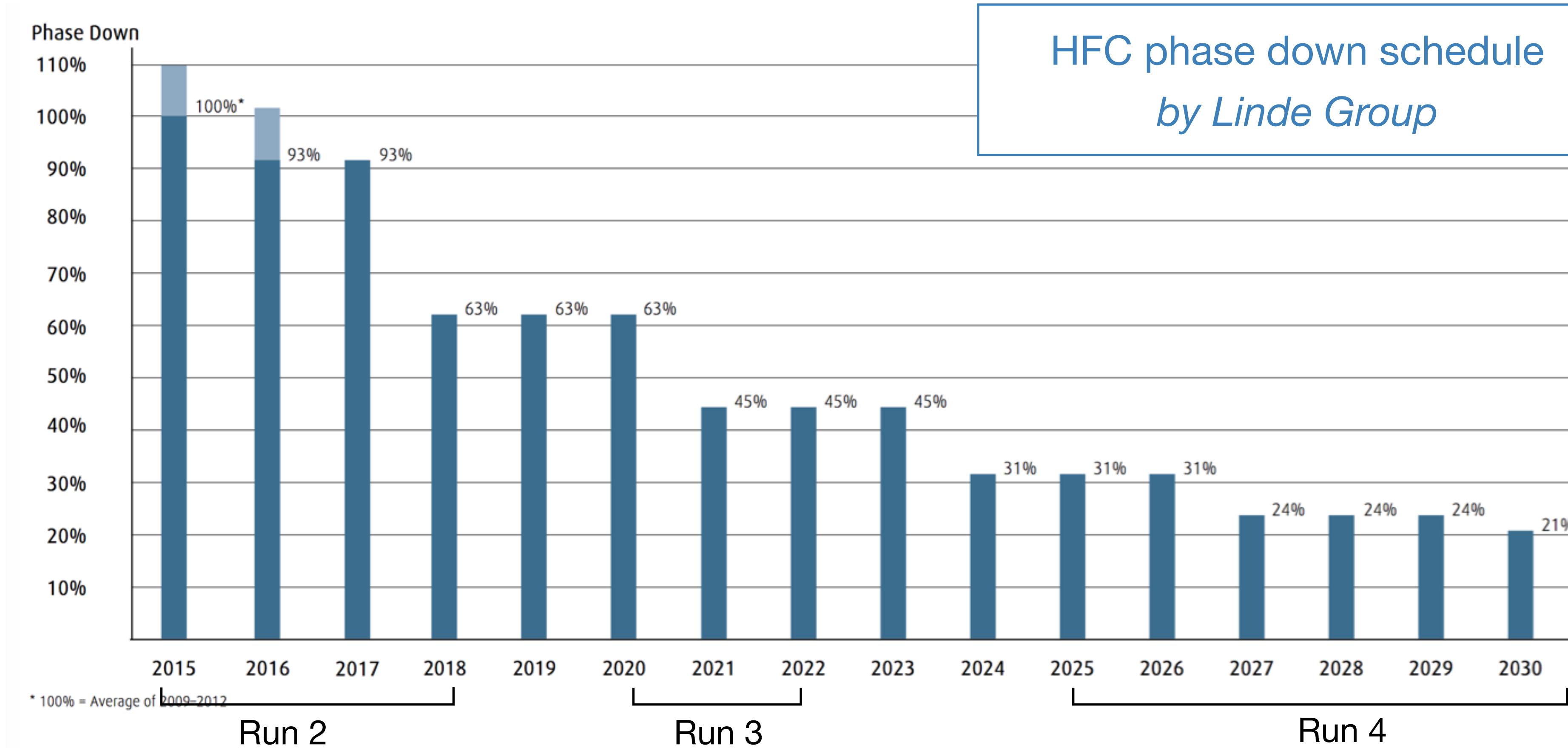


New environmentally friendly gases

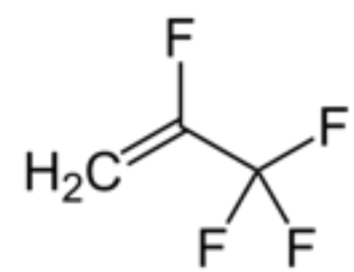
HFC phase down

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

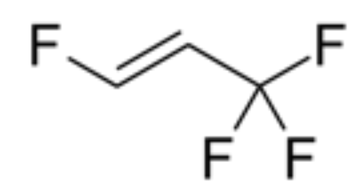
HFC phase down schedule
by Linde Group



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

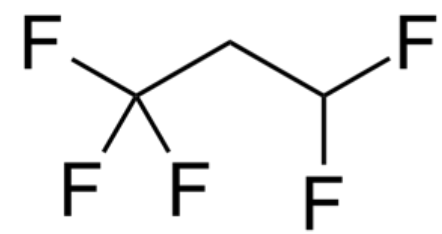
Refrigerant properties of both HFOs are well known while studies of ionisation processes in particle detectors just started…

Other possible environmentally friendly gases

Alternatives to $C_2H_2F_4$ (GWP 1430):

Hydro-Fluoro-Carbon (HFC)

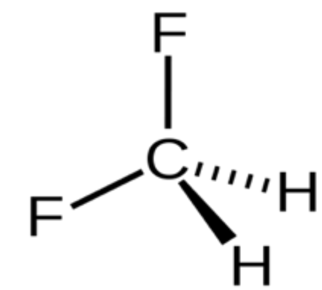
- C-C bond
- fluorine-containing
- hydrogen-containing



HFC-245fa

($C_3H_3F_5$)

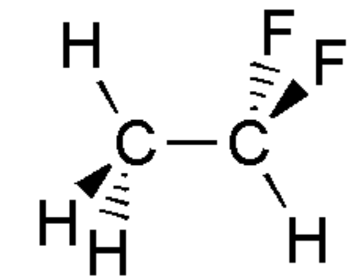
GWP 1030



HFC-32 (flam)

(CH_2F_2)

GWP 675

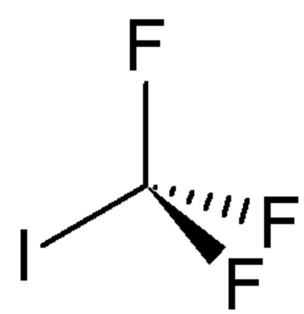


HFC-152a (flam)

($C_2H_4F_2$)

GWP 120

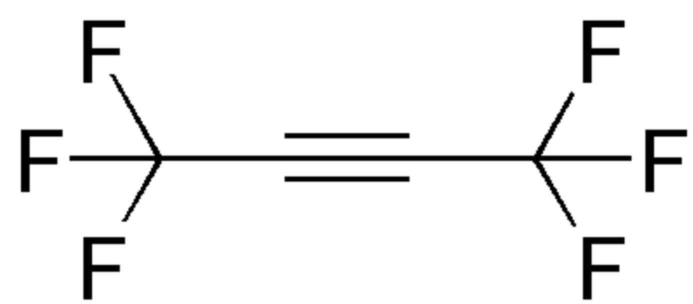
Alternatives to CF_4 (GWP 5700) and SF_6 (GWP 22200):



Trifluoroiodomethane

(CF_3I)

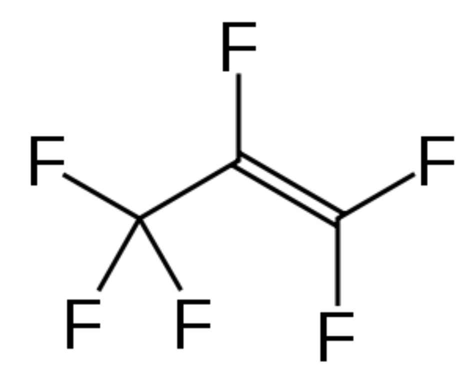
GWP <5



HFB

(C_4F_6)

GWP 260



(toxyc!)

(C_3F_6)

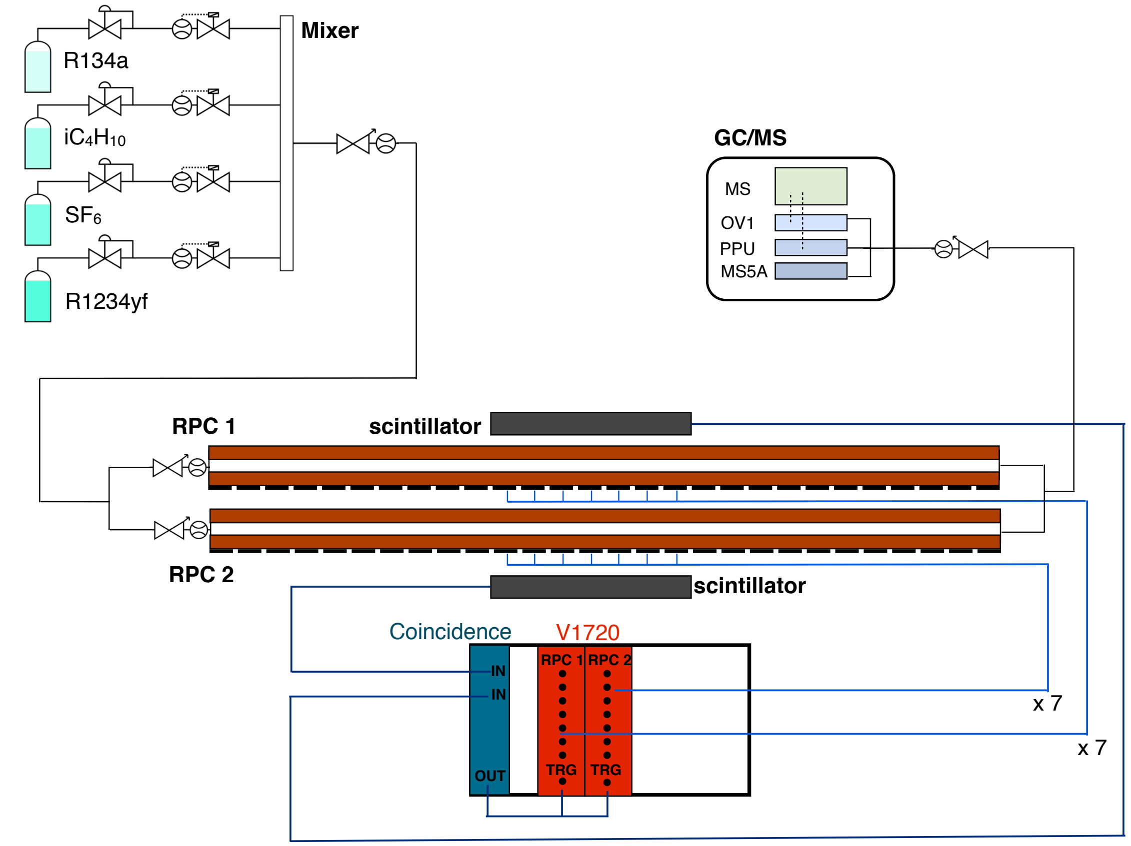
GWP <5

RPC performance with new freons

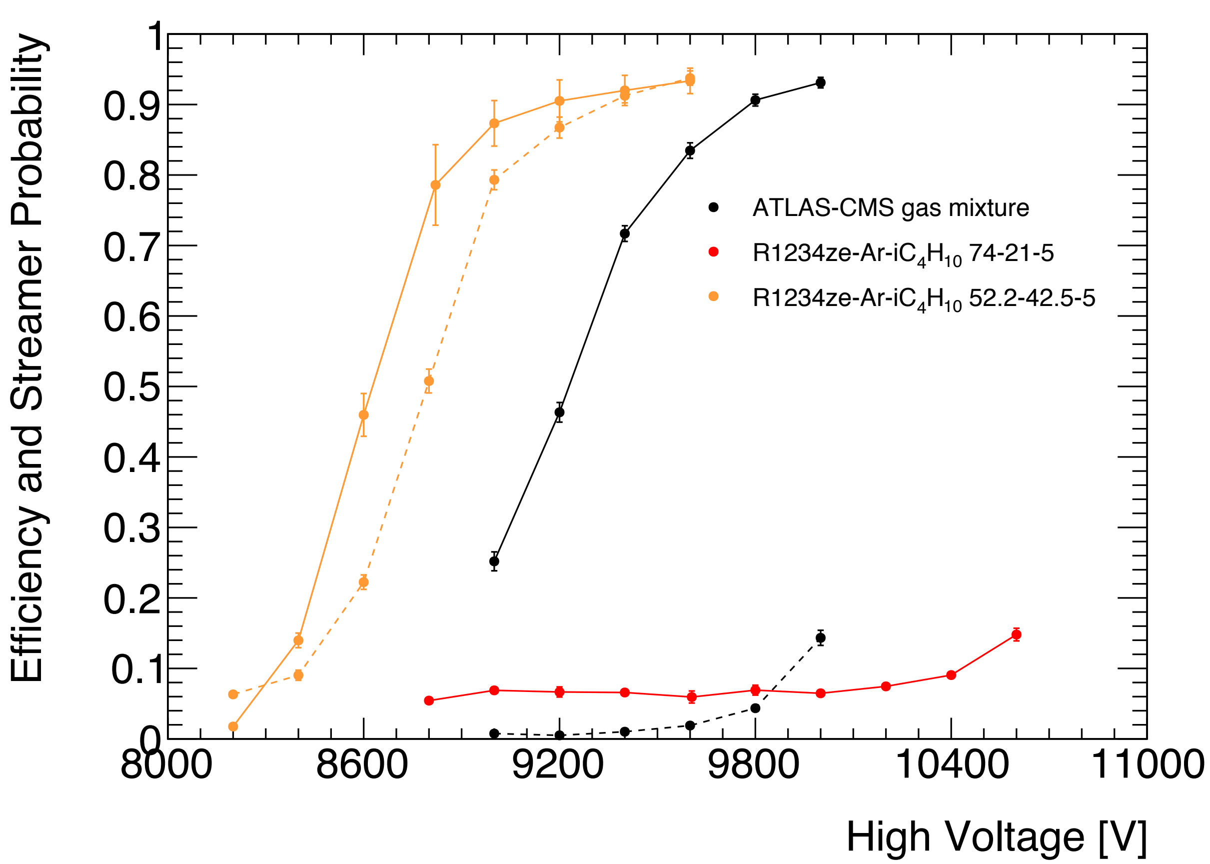
Direct replacement of $C_2H_2F_4$ (or SF_6) with HFOs:

Both HFOs substituted to $C_2H_2F_4$, iC_4H_{10} or SF_6 to study the properties of the new gas mixture:

- similar behaviour of the two HFOs
- HFOs are much less electronegative than SF_6
- HFOs has less quencing effects than iC_4H_{10}
- HFOs cannot directly replace $C_2H_2F_4$



HFOs and Argon mixtures:



RPC operation in avalanche mode for ATLAS and CMS

- With Ar RPCs work in streamer
  - Not suitable for LHC
- RPC operation needs to consider ATLAS-CMS requirements and conditions

RPC performance with new freons

More complex gas mixtures:

Addition of He:

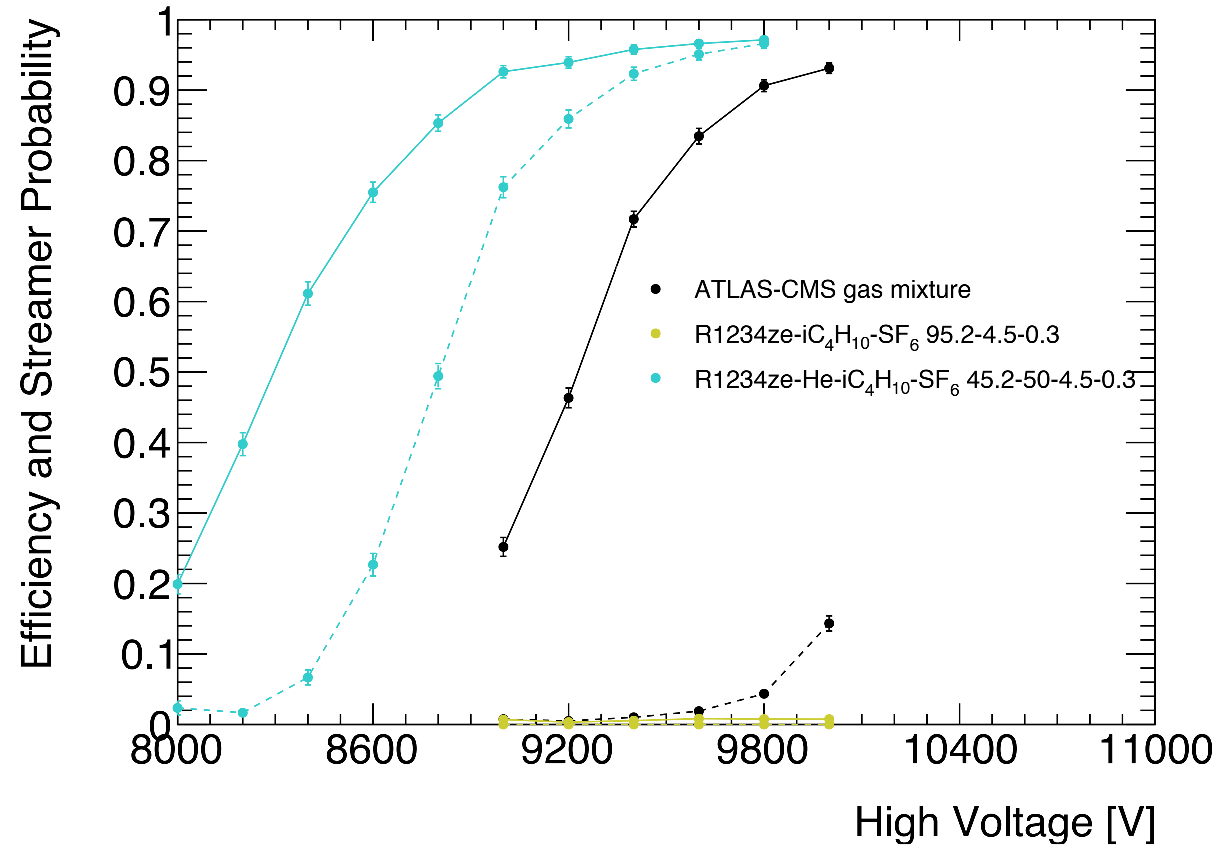
- help in reduced the HV working point
- Not enough for streamer suppression

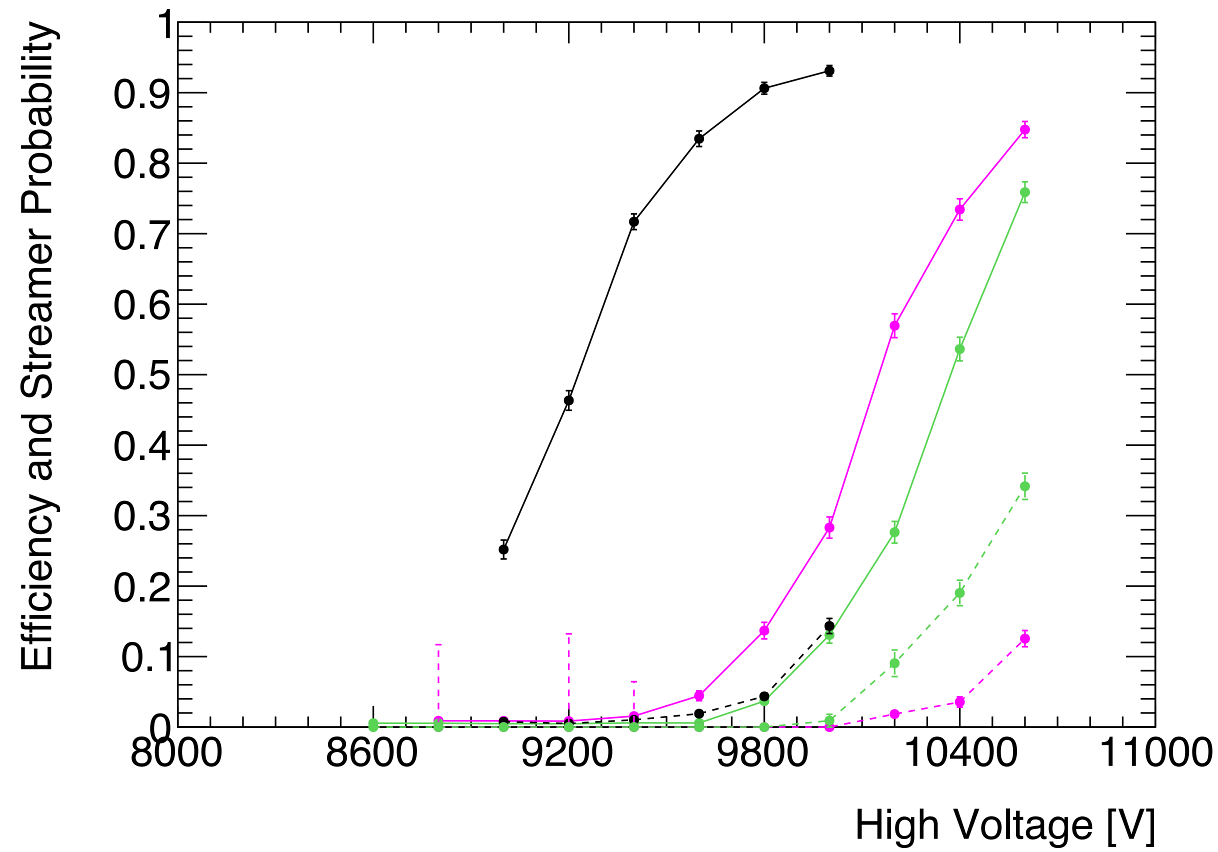
Addition of He and $C_2H_2F_4$:

- 70% GWP reduced with respect to standard gas mixture
- Good operation in avalanche mode (suitable for LHC operation)
- Still a long R&D in front of us

Further tests needed for

- radiation hardness
- reactivity to detector and gas components
- aging effects





- ATLAS-CMS gas mixture
- R1234ze-$C_2H_2F_4$-He-iC_4H_{10}-SF_6 40-35.2-20-4.5-0.3
- R1234ze-$C_2H_2F_4$-He-iC_4H_{10} 50-25.5-20-4.5

Conclusions

- The current GHG emission is produced by few detector systems
  - Constrains on operation conditions
  - Leaks on detectors
- Gas systems well mastered
  - All detectors using GHG are operated with gas recirculation systems
  - Technologies to recuperate gas well established
- R&D on gas and detector starting
  - Intense R&D activities in the communities
  - Summarise requirements for future detectors
- New environmentally friendly gases
  - Different alternative for $C_2H_2F_4$ have been identified and under test
  - Investigate SF_6 and CF_4 replacements
  - Preliminary results are encouraging for RPC but still a long way in front of us