EP-DT
Detector Technologies

R&D for the optimization of the use of greenhouse gases in the LHC particle detection systems

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Outline

- Greenhouse gases (GHG) for particle detection
- LHC Gas Systems
- Strategies for optimizing use of GHG
- Results, new projects and plans
- Conclusions

Greenhouse gases used for particle detection

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

The **Global Warming Potential** (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere with respect to CO_2

Gas	GWP - 100 years
$C_2H_2F_4$	1430
CF_4	7390
SF_6	22800

GHGs like R134a ($C_2H_2F_4$), CF_4, SF6, C_4F_{10}, … are used by several particle detector systems at the LHC experiments

Due to the environmental risk, "**F-gas regulations**" started to appear in many countries.
For example, the EU517/2014 is:

- **Limiting** the total amount of the most important F-gases that can be sold from 2015 onwards. By 2030, it limits the use to one-fifth of 2014 sales.
- **Banning** the use of F-gases in new equipment where less harmful alternatives are available.
- **Preventing** emissions of F-gases from existing equipment by requiring checks, proper servicing and recovery of gases.

F-gas regulations have already affect **gas price** (especially for R134a in EU)
Future **availability** can also be affected (especially where replacements are available)

Gaseous detector systems at LHC

Very Large detector volume
- *From 10 m^3 up to several 100 m^3*

Use of many gas components
- *R134a, SF_6, CF_4, C_4F_{10}, … (GHG)*
- *many others neutral but some expensive (Xe, …)*

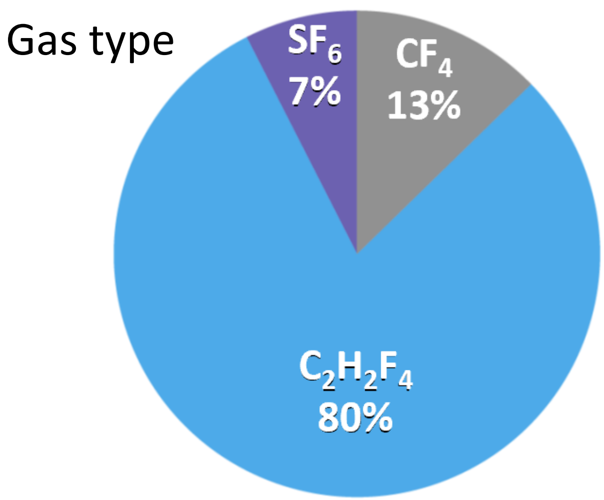
+ High mixture flow
+ Operational costs issue

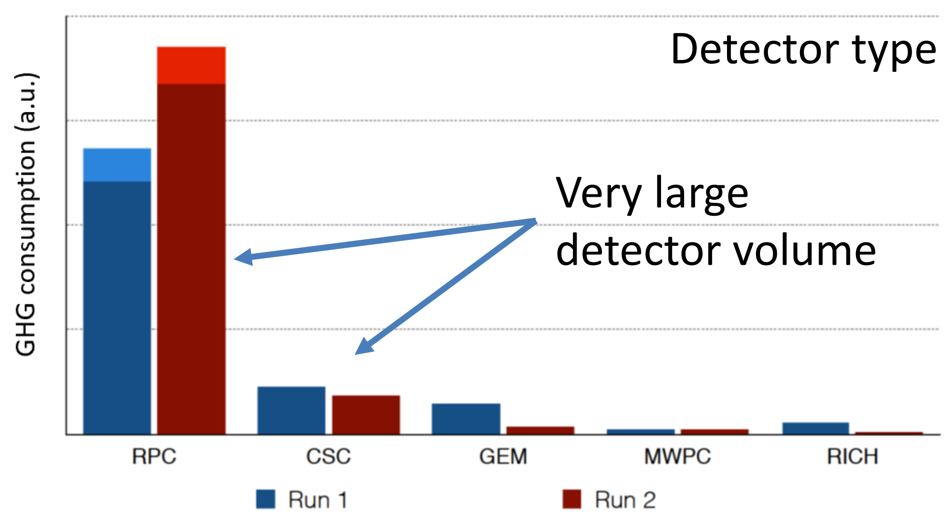
→ **Need of optimizing gas usage**

A lot of work already from the design phase

→ otherwise operational costs due to gas consumption would have been huge

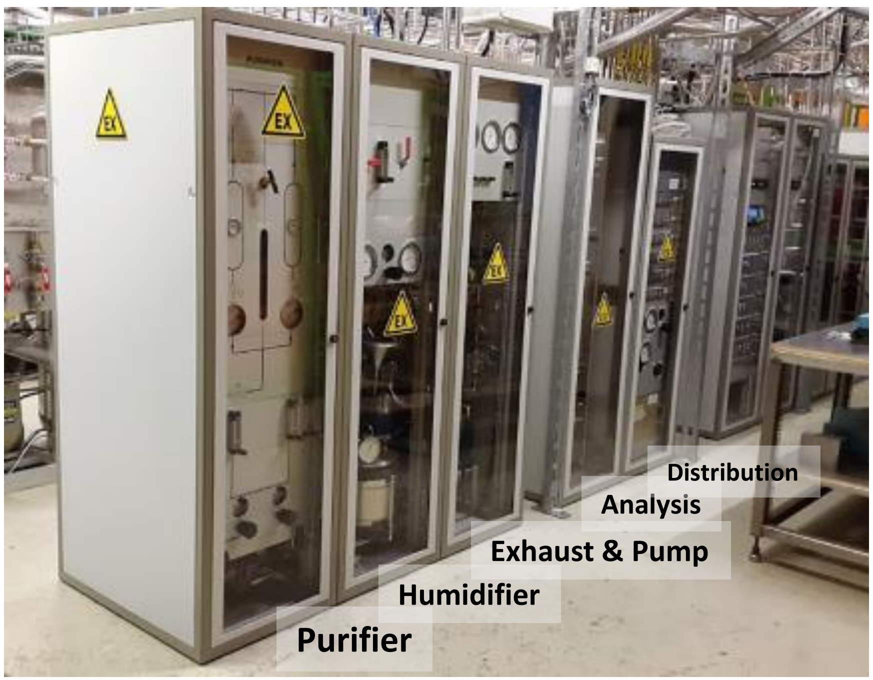
Relative contribution of GHGs used at LHC experiments





Gas systems for LHC experiments

- <u>Gas system for detector at LHC experiments:</u>
  - Very large apparatus
  - Mixing the different gas components in the appropriate proportion
  - Distributing the mixture to the individual chambers
- <u>Gas systems are made of several configurable functional modules</u> (*building blocks*):
  - Simplifies maintenance, operation, training of personnel, …



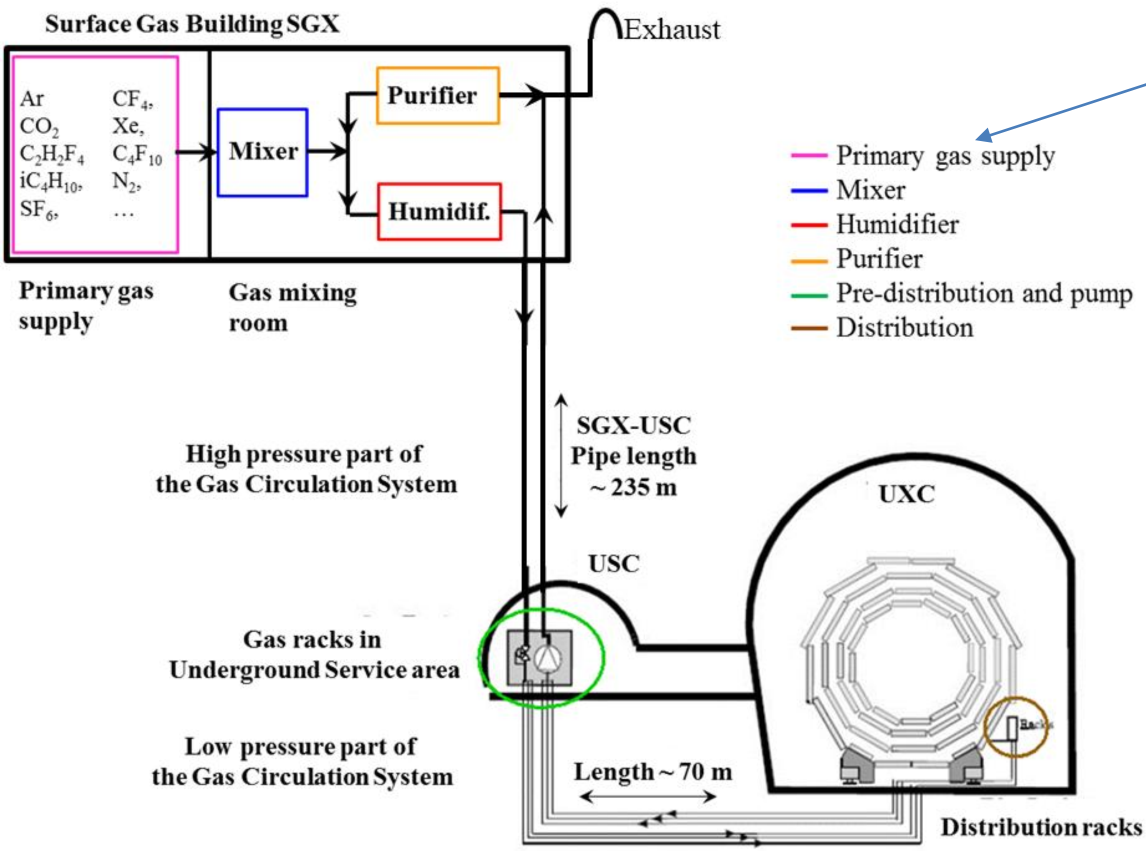
Three keywords for such a large infrastructure:

- **Reliability**
  - LHC experiments are operational 24/24 7/7
  - Gas systems must be available all time
- **Automation**
  - Large and complex infrastructure
  - Resources for operation
  - Repeatability of conditions.
- **Stability**
  - Detector performance are strictly related with stable conditions (mixture composition, pressures, flows, …)

Gas systems for LHC experiments

Gas systems extend from the surface building to the service balcony on the experiment following: a route few hundred meters long.

1 gas system = ~ 10 active modules



LHC gas systems = 30 systems =
= 300 modules

LHC gas systems modules > 500 m

GHG Optimization Strategies

Four R&D lines for optimizing the use of gases
Different strategies can be combined together

Optimization of current technologies

- Gas recirculation
- Particular attention to operation
- Improved controls and monitoring of current gas recirculation plants
- Important to secure detectors (but very heavy work)

Gas Recuperation

Recuperation of used gas:
-Membrane separation
-Cryogenic separation
-Pressure swing

Abatement

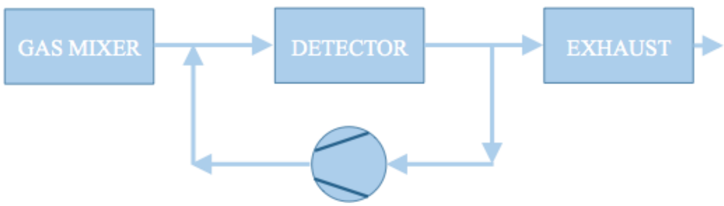
Destruction of GHGs
- Catalytic decomposition
- Plasma decomposition
- Burn-wet

Alternative Gases

New eco-friendly gases
HFOs, …

Optimization of current technologies

- First step done at the early design phase:
  - Most of the systems were designed to recirculate the gas mixture:
    average 90% gas recirculation → 90% reduction of consumption



Advantages:

- Reduction of gas consumption

Disadvantages:

- Complex systems
- Constant monitoring (hardware and gas)
- Sophisticated gas purifying techniques

  - The remaining 10% is what we started to address from LS1. It is needed to compensate for:
    - Leaks at detector: 85 % (mainly ATLAS and CMS RPC systems)
    - 15% N_2 intake (CMS-CSC, LHCb-RICH1, LHCb-RICH2)

- Two remaining open mode systems upgraded to gas re-circulations from Run1 to Run2:
  - ALICE-MTR and LHCb-GEM

ALICE-RPC upgrade

Much smaller wrt ATLAS and CMS-RPC systems

Therefore originally designed in open mode → upgraded to gas recirculation in 2015

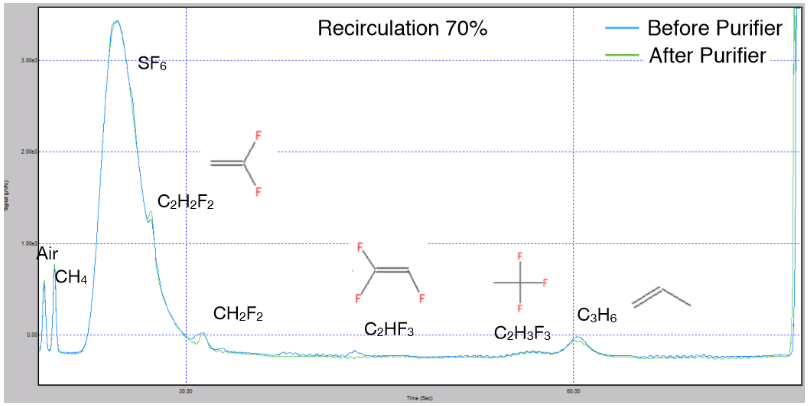
From Run1 to Run2: 75% GHG reduction

RPC operated in slightly different conditions (higher pulse charge):

→ Impurities due to fragmentation of main gas components are visible

→ Closely monitored

→ Detector performance are not affected by gas recirculation



More details in
[Gas mixture monitoring for the RPC at LHC (RPC2018)]

LHCb-GEM upgrade

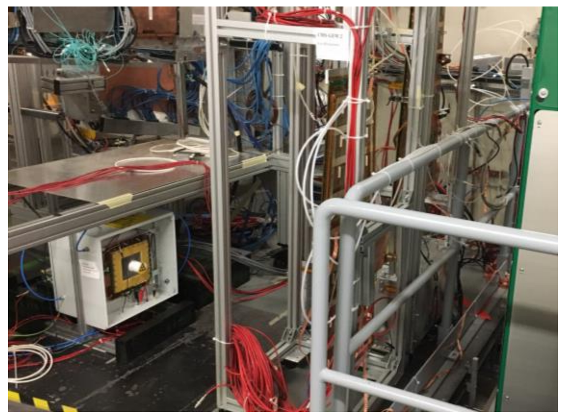
From Run1 to Run2: 90% GHG reduction

R&D for operation of large GEM detector systems with gas recirculation plant

2013: Development of small gas recirculation systems for R&D
Started test in lab with radioactive source

2016-…:
Validation continued at CERN Gamma Irradiation Facility

2016-…:
LHCb-GEM upgraded to gas recirculation



Gas mixture purification studies

LHCb-GEM detector operation became more stable thanks to less frequent replacement of CF_4 cylinders

ATLAS and CMS RPC systems

GHG usage is dominated by the large RPC systems of ATLAS and CMS

– mixture recirculation almost at design level (85-90%)

Further optimization requires:

- Fixing leaks at detector level
  - Huge effort from detector communities
  - but critical/fragile gas connectors are extremely difficult to access
  - Good technical progress
- Gas system upgrade to minimize any pressure/flow fluctuation
- Minimize impact of cavern ventilation
- Detector R&D to validate higher recirculation fraction
- Gas recuperation plant
- Tools to check gas system tightness

Positive effects already visible:
→ Reduced leak developments at start-up
→ Pressure regulation improved by 70%

All these activities are already ongoing

- Some started as soon as the leaks appeared and now improved
- Others designed recently

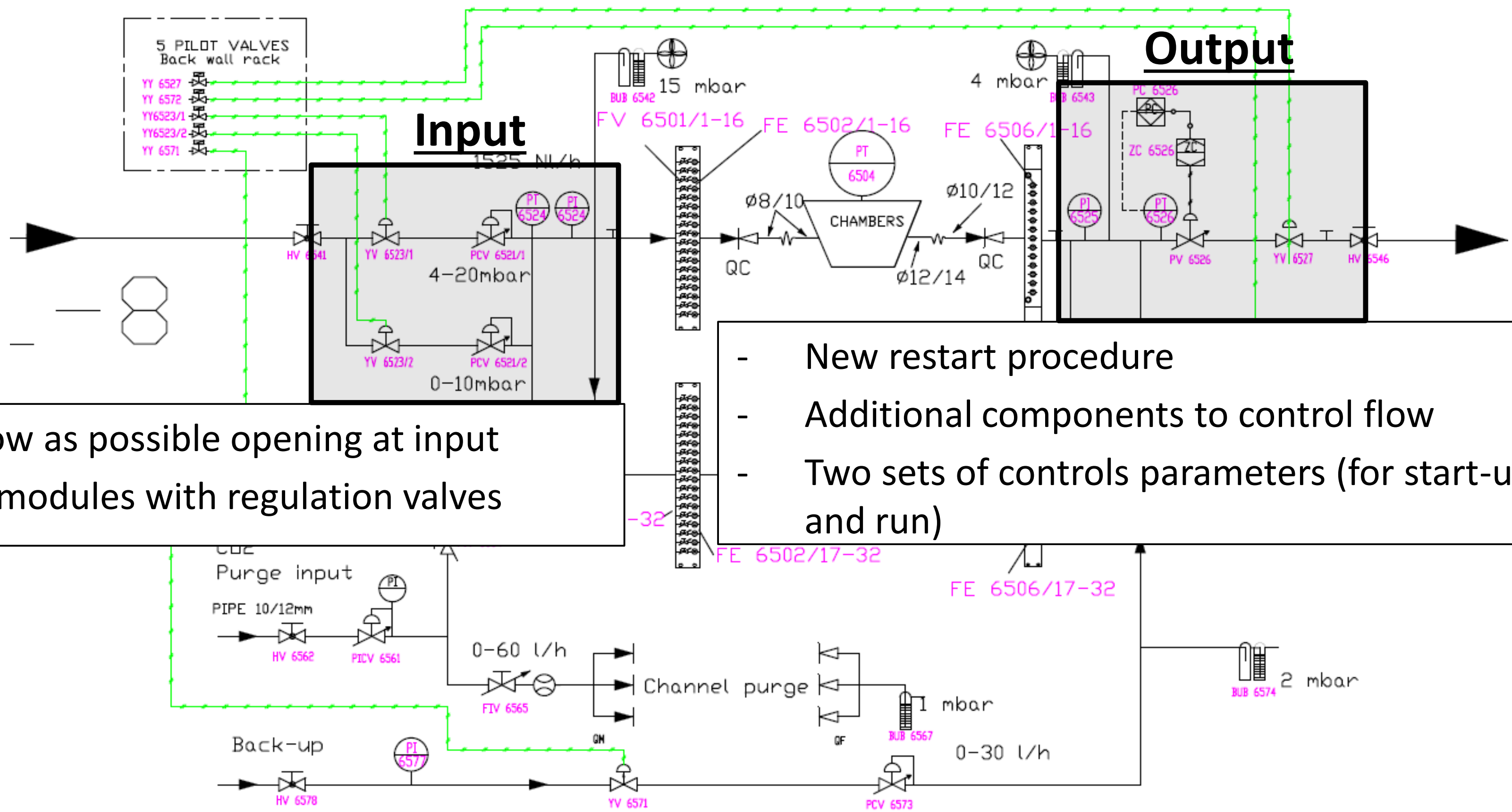
RPC Gas system upgrade

Goal: minimize any chamber pressure/flow fluctuation

from some 0.1 mbar to << 0.1 mbar

Work on **mixture distribution modules**

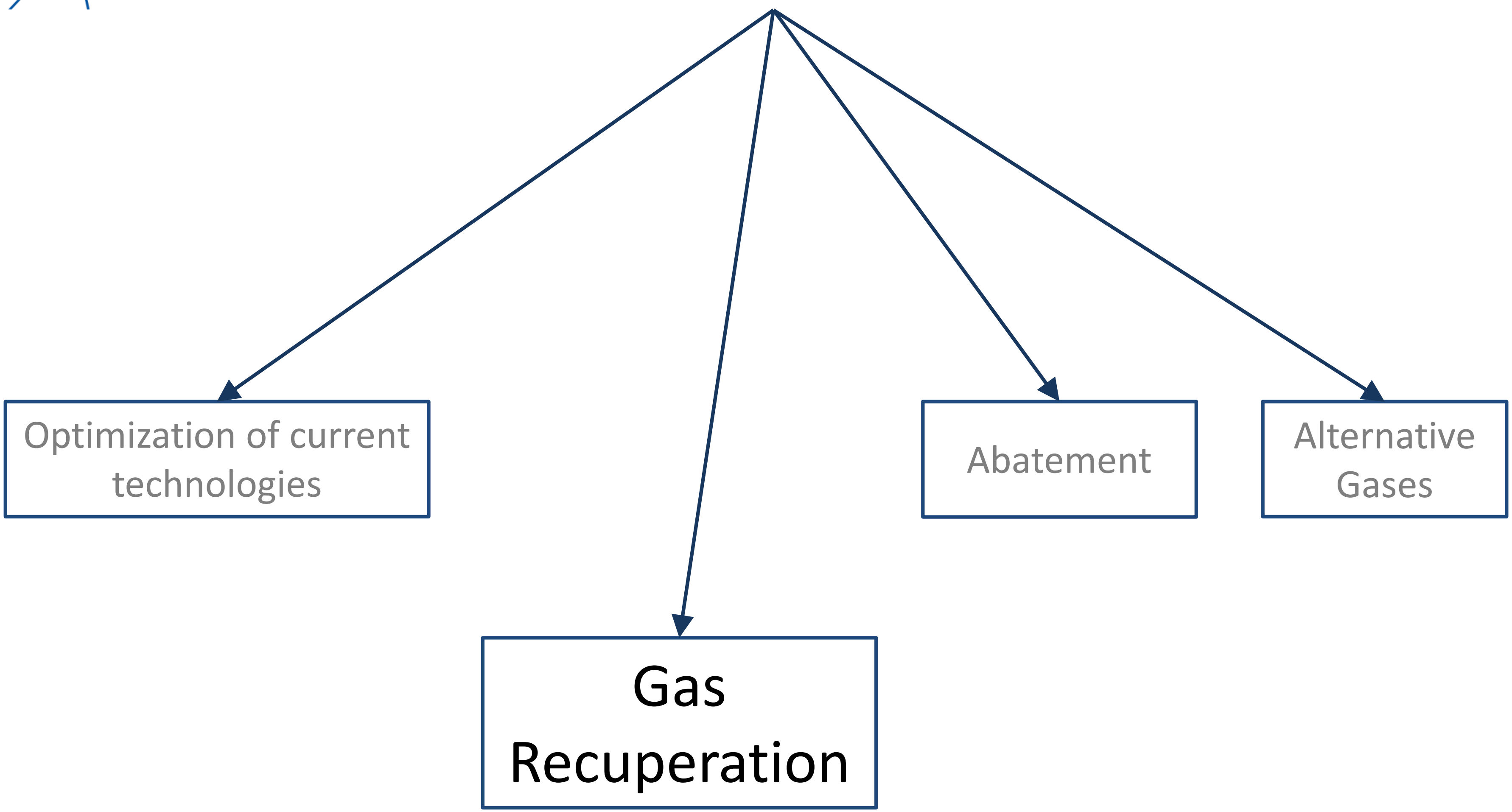
one example



- As slow as possible opening at input
- New modules with regulation valves

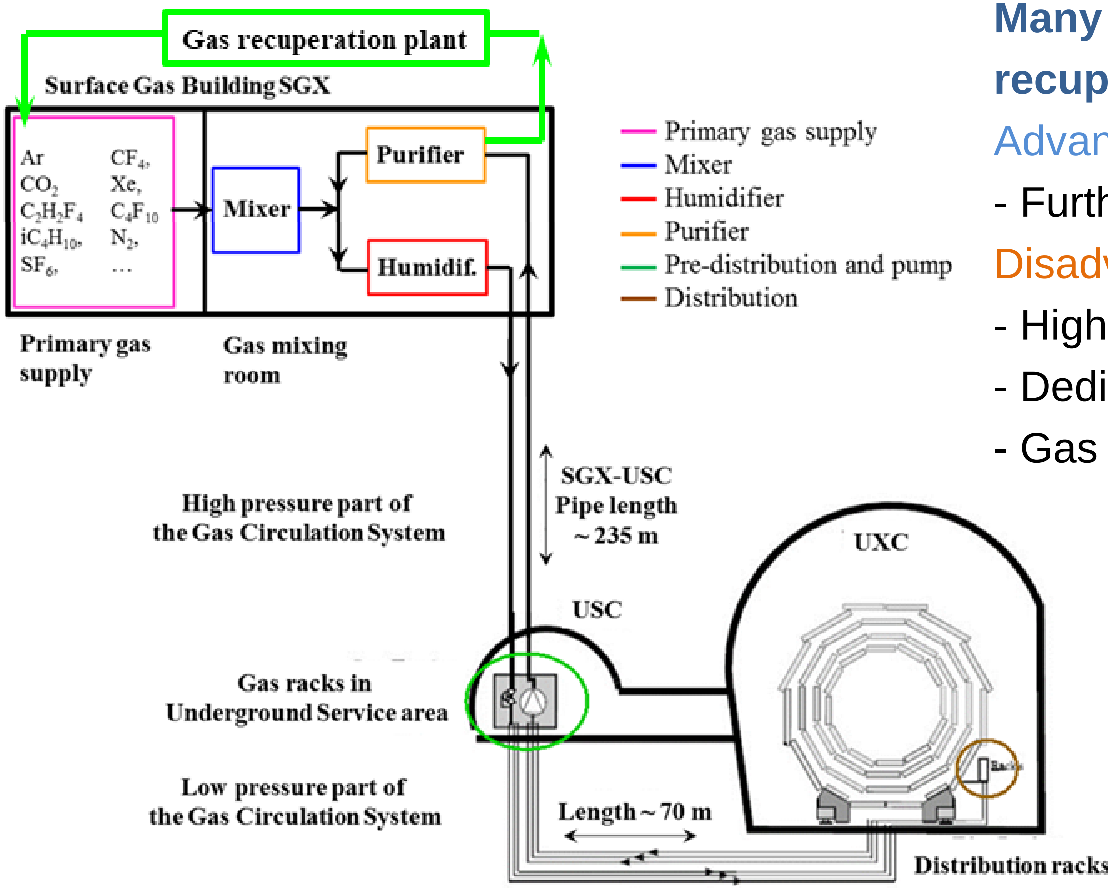
- New restart procedure
- Additional components to control flow
- Two sets of controls parameters (for start-up and run)

GHG Optimization Strategies



Gas systems and recuperation

Possibility to recuperate a single gas component from exhausted mixture



Many LHC gas systems already with gas recuperation

Advantages:

- Further reduction of gas consumption

Disadvantages:

- Higher level of complexity
- Dedicated R&D
- Gas mixture monitoring fundamental

Gas Recuperation systems

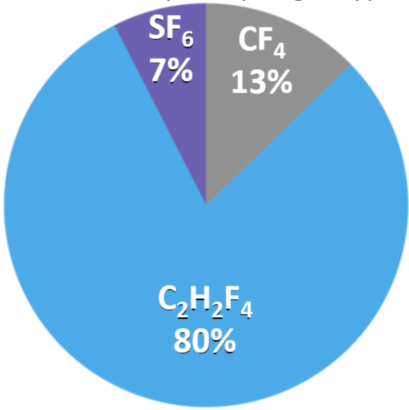
The mixture recirculation ratio is sometime limited by accumulation of impurities, i.e. balance of detector intake and filtering capacity (as it is the case in presence of N_2).

Gas recuperation can be seen also as a way of "cleaning". It is already used for many detectors

- ALICE-TRD (Xe), ATLAS-TGC (nC_5H_{12}), ATLAS-TRT (Xe), CMS-CSC (CF_4), LHCb-RICH1 (C_4F_{10}), LHCb-RICH2 (CF_4)

- *The ongoing R&D aims in testing the feasibility for new recuperation systems*:
  - R134a for ALICE-RPC, ATLAS-RPC, CMS-RPC, ALICE-TOF
- *and substantial improvements of existing systems:*
  - CF_4 for CMS-CSC, LHCb-RICH2
  - C_4F_{10} for LHCb-RICH1

Relative consumption per gas type



- Recuperation systems will be effective only if leaks at detector level will be reduced
- R134a recuperation can drastically decrease GHG consumption
- R&D costs for first R134a recuperation system can be potentially paid back with one year of operation already at 50% efficiency

Gas recuperation: the CF_4 case

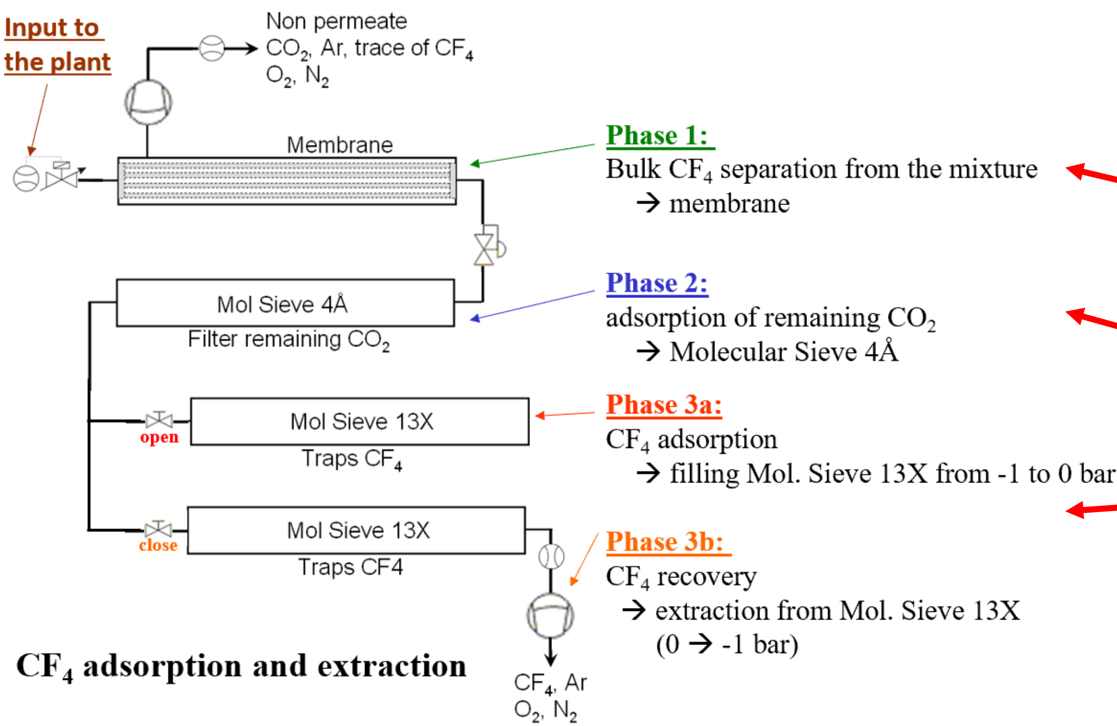
From Run1 to Run2
30% GHG reduction

CMS-CSC CF_4 recuperation plant

Problem:
Too high N_2 concentration for gas recirculation due to diffusion leak from detector components

Technical challenge:
First plant built for CF_4 warm adsorption
A completely non-standard system

Operation started in 2012. Several technical problems → Average efficiency 50%
R&D will either solve current limitations or convert the last module for cryogenic separation



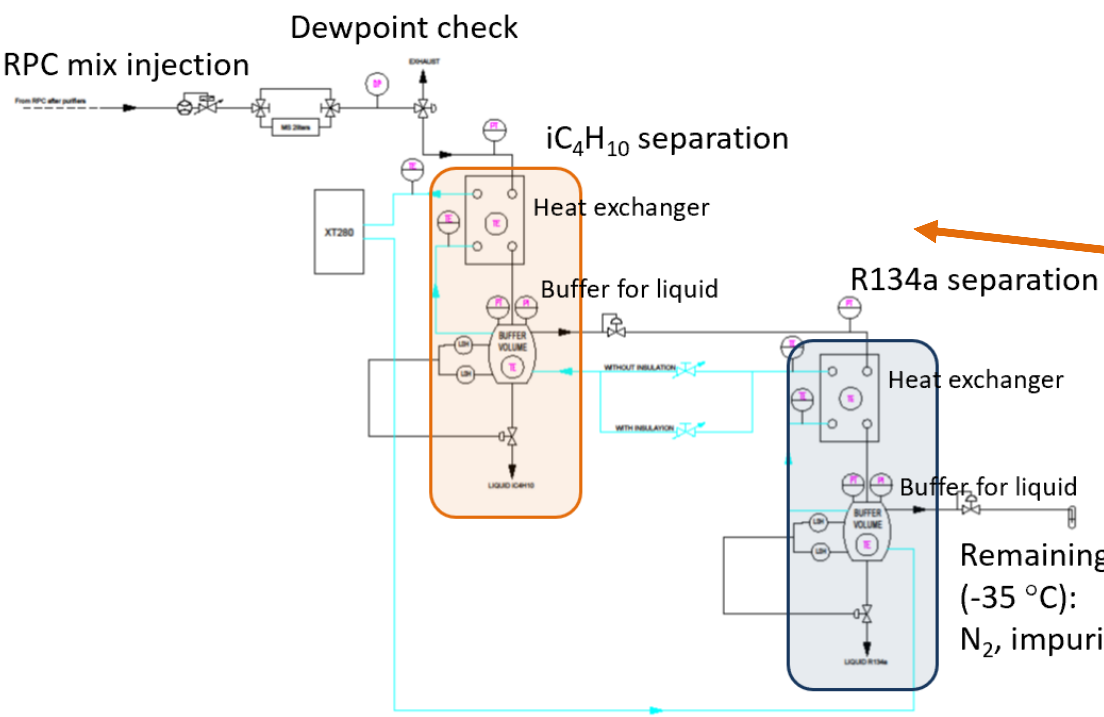
CF_4 adsorption and extraction

Gas recuperation: R134a prototype0

Prototype0 was tested connected to ATLAS-RPC

Objectives:

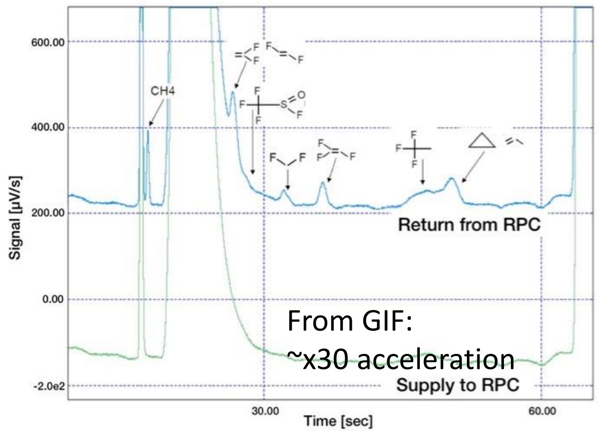
- Prove principle of operation
- measurement of recuperation efficiency
- effectiveness of air/N_2 removal
- separation of iC_4H_{10} and SF_6 from recuperated R134a



Gas recuperation: R134a prototype 0

From Run2 to Run3
Potential 90% GHG reduction

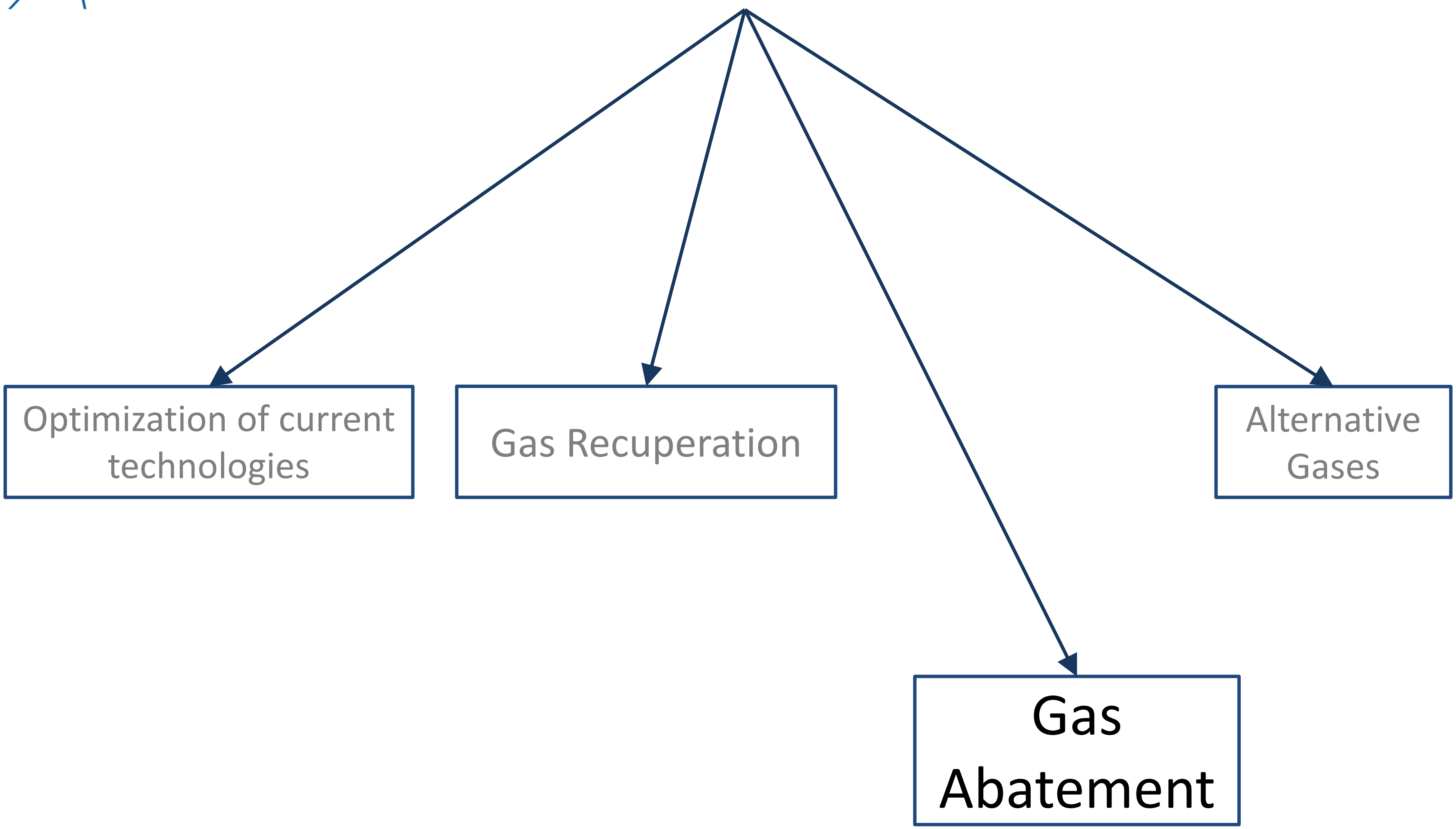
- Results from prototype0 are very encouraging:
  - about 100 % efficiency
  - air/N_2 removed to same level of new R134a
  - the recuperated R134a does not contain iC_4H_{10} or SF_6
- Coming steps:
  - Separation study of specific RPC impurities: to be evaluated before Run 3



Molecule	Boiling point (°C)	Molecule	Boiling point (°C)
C2H2F4	-26	C2H2F2(e)	-42
iC4H10	-12	CH2F2	-51
SF6	-64	CHF3	-84
		C2HF3	-51
CH4	-161	C2H3F3	-47
C2H4F2	-117	C3H6 (propene)	-33
CF4SO	110	C3H6 (cyclopropane)	-47
C2H2F2(z)	-20		

  - Build and test compressor module for storage/reuse
  - Test possibility of SF_6 recuperation

GHG Optimization Strategies



GHG abatement system

In case all studies on recuperation will not bring to efficient recuperation plants, industrial system able to destroy GHGs avoiding their emission into the atmosphere have been considered

Abatement plants are employed when GHG are polluted and therefore not reusable.

Quite heavy infrastructure required:

- CH_4/city gas + O_2 supply + N_2 supply
- Waste water treatment
  - PFC/HFC are converted in CO_2 + HF acid dissolved in water
  - disposal of remaining waste/mud

Joint CMS and EP-DT gas team is studying the feasibility

Found also one company available to take PFC/HFC based mixture for disposal:

but extremely expensive

GHG Optimization Strategies

Optimization of current technologies

Gas Recuperation

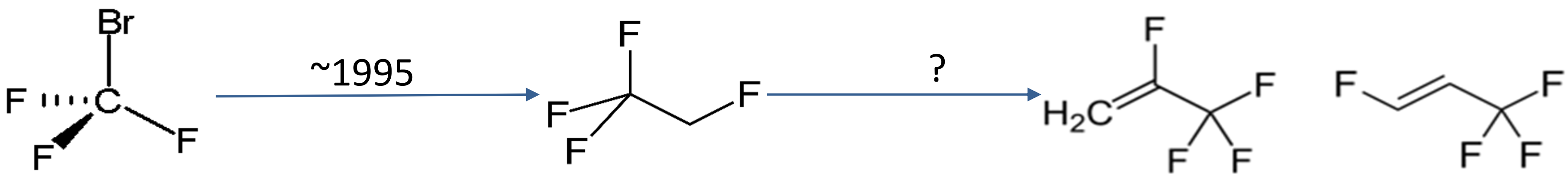
Gas Abatement

Alternative Gases

Alternative Gases

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

It is not the first time this happens in particle detection:



R13B1	R134a	HFO1234yf	HFO1234ze
($CBrF_3$)	($C_2H_2F_4$)	($C_3H_2F_4$)	($C_3H_2F_4$)
ODP* 10	ODP 0	ODP 0	ODP 0
GWP 6900	GWP 1430	GWP 4	GWP 6

HFOs refrigerant properties are well known while studies of ionisation processes just started…

R&D studies are ongoing. *Main constrain is coming from need of maintaining current infrastructures (HV cables, Front End electronics) very difficult to access for replacement.*

More details on Thursday, Gaseous Detector session:
"Performance studies of RPC detectors with new environmentally friendly gas mixtures in presence of LHC-like radiation background"

*The Ozone Depletion Potential (ODP)

Conclusions

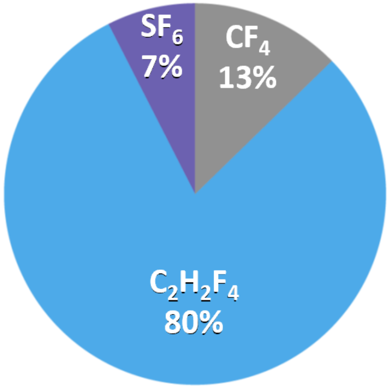
Program described aims in developing systems allowing for optimization of GHG usage:

- For many gases used today there is no equivalent replacement available
- Availability and price of used GHGs can be affected (one more good reason for optimizing consumption)

Four strategies identified:

- **Optimization of current technologies**
  - Particular attention to gas system and detector operation
  - Gas systems upgrade beyond original design
  - Improved/higher gas recirculation
- **Gas recuperation plant**
  - Recuperation system for R134a, SF_6 will be effective only if leaks at detector level will be reduced
  - R&D costs for R134a recuperation system is well justified by running costs
  - R134a recuperation prototype0 showed very good performance (excellent quality and >90% efficiency)
  - Consolidation of existing plants (CF_4, C_4F_{10}) needed

Recuperation of R134a can drastically decrease GHG consumption



Conclusions

- **GHGs abatement/disposal**
  - Commercial systems exist. Adopted when gases cannot be reused.
  - Heavy infrastructures required (CH_4+O_2 supply, Waste water treatment)
  - Since availability can become a real problem in the future it is always better to minimize consumption
  - Only one company found for destruction. Even more expensive than Gas abatement system.
- **New eco-gases**
  - HFO1234ze promising but difficult for already installed detectors (many constrains)
  - First test of gas recirculation with HFO started (in lab and with high radiation background)
  - However, it is not for tomorrow
  - More details on Thursday https://indico.cern.ch/event/716539/contributions/3245961/

Optimized gas systems, new recirculation plants, … are

- Nevertheless increasing complexity for operation
- Requiring qualified personnel
- Development and application of strict maintenance and operation procedures

Optimization of gas consumption