R&D on gas recirculation and recuperation systems for RPC detectors

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Outline

- Greenhouse gases (GHG) for particle detection
- LHC Gas Systems
- Strategies for optimizing use of GHG
- RPC case
- Conclusions
Greenhouse gases used for particle detection

GHGs like R134a (C₂H₂F₄), CF₄, SF₆, C₄F₁₀, ... are used by several particle detector systems at the LHC experiments.

Due to the environmental risk, “F-gas regulations” started to appear. For example, the EU 517/2014 is:

- **Limiting** the total amount to one-fifth of 2014 sales by 2030
- **Banning** the use of F-gases where less harmful alternatives are available.
- **Preventing** emissions of F-gases by requiring checks, proper servicing and recovery of gases.

F-gas regulations already affected gas price (especially for R134a in EU)
Future availability can also be affected (especially where replacements are available)
For the moment CERN/Switzerland seems to be not affected.

<table>
<thead>
<tr>
<th>Gas</th>
<th>GWP - 100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₂H₂F₄</td>
<td>1430</td>
</tr>
<tr>
<td>CF₄</td>
<td>7390</td>
</tr>
<tr>
<td>SF₆</td>
<td>22800</td>
</tr>
</tbody>
</table>

HFC phase down schedule by Linde Group
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$_4$F$_{10}$, ... (GHG)
- and many others, some expensive (Xe, ...)

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

- C$_2$H$_2$F$_4$ 80%  
- CF$_4$ 13%  
- SF$_6$ 7%

Detector type
- Very large detector volume

Gas type
- Run 1
- Run 2
Gas systems for LHC experiments

Gas system for detector at LHC experiments:
- Very large apparatus
- Mixing the different gas components in the appropriate proportion
- Distributing the mixture to the individual chambers

Keywords:
- **Modularity**
  - Gas systems are made of functional modules
  - Simplifies maintenance, operation, training of personnel, ...
- **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, ...)

13/02/2020
R. Guida CERN EP-DT Gas Team
GHG Optimization Strategies

How to reduce greenhouse gas usage

- Optimization of current technologies
  - Optimization of present gas recirculation systems
- Gas Recuperation
  - R134a (ATLAS, CMS and ALICE-RPC)
- Alternative Gases
  - Ecogas for RPC (LHC experiments and GasTeam working group)
- Gas disposal
  - Destruction of GHGs

- R134a: ATLAS, CMS, ALICE-RPC
- CF4: CMS-CSC, LHCb-RICH2
- C4F10: LHCb-RICH1

Program supported/funded by CERN Environmental Protection Steering board
Gas recirculation system: Terminology and Flow balance

Flow Injected from mixer: 850 l/h
Circulation flow at detector: 9000 l/h
Output flow at exhaust: 45 l/h
Re-circulation ratio: \( \frac{9000 - 850}{9000} = 91\% \)
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 $\rightarrow$ 90% reduction of consumption

  ![Diagram of gas flow](image)

  **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
Much smaller wrt ATLAS and CMS-RPC systems
Therefore originally designed in open mode → upgraded to gas recirculation in 2015

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

From Run1 to Run2: 75% GHG reduction

More details in
Gas mixture monitoring for the RPC at LHC (RPC2018)
GHG usage is dominated by the large RPC systems of ATLAS and CMS
  – mixture recirculation almost at design level (85-90% as validated during ageing test)

Optimization of gas system beyond original design to cope with observed detector fragility:
  - Start-up procedure (after “long” stop)
  - Gas system upgrade to minimize any pressure/flow fluctuation
  - Different regulation parameters for start-up and run phases
  - Tight warning limits
  - Monitoring tools to quickly spot correlation between development of leaks and any operation
  - Gas recuperation plant
  - Tools for periodic check of gas system tightness
  - Minimize impact of cavern ventilation

More critical situation for ATLAS-RPC due to:
  - Appearing of new leaks at start-up after shutdown (Xmas or LS)
  - Significant increase of leaks during run (from 2012 and in particular from 2015)

Positive effects already visible:
  ➔ Reduced leak developments at start-up
  ➔ Pressure regulation improved by 70% where modification implemented
Goal: minimize any chamber pressure/flow fluctuation from some 0.1 mbar to < 0.1 mbar

Work on mixture distribution modules

- 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)
- Test of additional regulation valves
High granularity at distribution (Gas mixture quality for CMS RPC RPC2020 talk)

Manual valves present to equalize pressure between different detector zones → make difficult pressure regulation
- About 10 different models tested in lab
- 4 installed at CMS for test (other under evaluation in lab)
Detector pressure regulation is done sensors at rack level

→ Weight of hydrostatic column is not taken into account
→ Particularly critical during fill and emptying phases
→ Pressure sensors already present at detector level cannot be used due to risk of detector leak presence/development

- Installation of volumes that simulates detectors ("dummy RPC") is on-going
“Lab size” gas systems

Sometimes lab tests are using relatively high gas quantity if compared with large LHC systems: example from GIF++ tests, EEE telescope, ...

Development of Recirculation system for laboratory applications

Fresh input from mixer

Distribution to detectors

Monitoring of pressure, $O_2/H_2O$, temperature, atmospheric pressure

Humidifier

"A portable gas recirculation unit"

JINST 12 T10002
GHG Optimization Strategies

How to reduce greenhouse gas usage (not only for RPC)

- Optimization of current technologies
- Alternative Gases
- Gas disposal

Gas Recuperation
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
- Keep impurities like N2 under control
- Operation at lower detector pressure

Disadvantages:
- Higher level of complexity
- Dedicated R&D
- Gas mixture monitoring fundamental
Gas recuperation: R134a

Dec2018: Prototype0 was tested connected to ATLAS-RPC with low (100 nl/h) input flow

- Results very encouraging:
  - Very high efficiency (close to 100%)
  - air/N$_2$ removed to same level of new R134a
  - recuperated R134a was very clean
Gas recuperation: R134a

Dec 2019: Prototype 0 is now connected to CMS-RPC. Test just started.
Goals:

- Run at higher flow (500-1000 nl/h)
- Test R134a compression and storage
- Re-use recuperated R134a for RPC gas system operation
Gas recuperation: R134a

Dec2019: Prototype0 is now connected to CMS-RPC. Test ongoing. Not straightforward to re-find setting with new components (compressor, storage, ...)

![System Controls panel diagram with R134a Recuperation system controls](image-url)
Gas recuperation: R134a

Next steps:

- Separation study of specific RPC impurities (i.e. not only N2): to be evaluated before Run 3

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Boiling point (°C)</th>
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<th>Boiling point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2H2F4</td>
<td>-26</td>
<td>C2H2F2(e)</td>
<td>-42</td>
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<tr>
<td>iC4H10</td>
<td>-12</td>
<td>CH2F2</td>
<td>-51</td>
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<td>SF6</td>
<td>-64</td>
<td>CHF3</td>
<td>-84</td>
</tr>
<tr>
<td>SF6(z)</td>
<td>-20</td>
<td>C2H4F2</td>
<td>-117</td>
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<tr>
<td>C2H4F2</td>
<td>-161</td>
<td>C2H3F3</td>
<td>-47</td>
</tr>
<tr>
<td>C2H3F3</td>
<td>-51</td>
<td>C3H6 (propene)</td>
<td>-33</td>
</tr>
<tr>
<td>CHF3</td>
<td>-84</td>
<td>C3H6 (cyclopropane)</td>
<td>-47</td>
</tr>
<tr>
<td>C2H2F2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From GIF: ~x30 acceleration

- Test possibility of SF6 recuperation
GHG Optimization Strategies

How to reduce greenhouse gas usage (not only for RPC)

- Optimization of current technologies
- Gas Recuperation
- Gas disposal
- Alternative Gases
Alternative gases

A lot of R&D ongoing
Common working group for the RPC community of ALICE, ATLAS and CMS experiments
One common setup at CERN-GIF++
Results presented at EPS2019 conference
https://indico.cern.ch/event/577856/contributions/3420164/

Studies of RPC operations with ecological gas mixture under irradiation at GIF++

Gianluca Rigoletti
on behalf of ECOGAS collaboration
Université Claude Bernard Lyon I (FR)

RPC and eco-friendly gas mixtures

Resistive Plate Chambers at the LHC:
- Used in ATLAS, CMS and ALICE experiments
- Gas mixture based on ~95% of C2H2F4
  - C2H2F4/R134a
    - C2H2F4 has a high Global Warming Potential (GWP10 years = 1430)
    - European regulation aims at reducing the use of C2H2F4
  - HFO-1234ze is a suitable alternative of C2H2F4 in refrigerants industry
  - Tests were started on using HFO based gas mixture for RPC detectors

C3H2F4/HFO1234-ze
  - Goal: to characterize the HFO-based gas mixtures for RPC under LHC like background conditions

Experimental setup

- 5 HPL chambers under test: ATLAS, ALICE, CMS-GT, CMS-KODEL, CERN-EPDT
- 4 component gas mixer + humidifier module
- CAEN SY1527 HV mainframe with two A1526 boards
- WEB-DCS software designed by CMS group
- Grafoana web-app for monitoring

CERN Gamma Irradiation Facility (GIF++)

- Situated on H4 SPS beam line
- A 74 TBq source of 137Cs simulates the background radiation expected at High Luminosity LHC
- System of filters (ABS) allows to regulate the gamma background rate
GHG Optimization Strategies

How to reduce greenhouse gas usage (not only for RPC)

- Optimization of current technologies
- Gas Recuperation
- Alternative Gases
- Gas disposal
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:
- CH₄/city gas + O₂ supply + N₂ supply
- Waste water treatment
  . PFC/HFC are converted in CO₂ + 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
Conclusions

R&D program aims in developing systems allowing to optimize GHG usage:

- For many gases used today there is no “easy” 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 development beyond original design
  - The specific case of ATLAS and CMS RPC detector systems
  - Improved/higher gas recirculation
  - Controls, Purifier and other module upgrades (here only example of distribution was presented)
  - Development of small gas recirculation system for laboratory application

- **Gas recuperation plant**
  - Recuperation system for R134a, SF₆ will be effective if leaks at detector will be reduced
  - R&D costs for R134a recuperation system is well justified by running costs
  - R134a recuperation prototype showed good performance (both quality and efficiency)
Conclusions

- **New eco-gases**
  - HFO1234ze promising but difficult for already installed detectors (many constrains)
  - Many tests ongoing everywhere
  - New common effort: joint EcoGas collaboration for RPC at GIF++
  - However, it does not look for tomorrow

- **GHGs abatement/disposal**
  - Commercial systems exist. Adopted when gases cannot be reused.
  - Quite heavy infrastructures required
  - Gas availability can become a real problem in the future it is always better to minimize consumption

*Optimized gas systems, new recirculation plants, ... are*
- Nevertheless increasing complexity for operation
- Development and application of strict maintenance and operation procedures
Optimization of gas consumption

**gas recirculation** for most detectors:
90% optimization at design

**gas recuperation** improvement:
- CF$_4$: CMS-CSC

**gas recirculation** increasing:
- ALICE-RPC
- LHCb-GEM

**run optimization**:
- LHCb-RICH1
- LHCb-RICH2

**gas recuperation**:
- CF$_4$: CMS-CSC

Zoom in