PH-DT
Detector Technologies

The gas systems for the LHC experiments

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Instrumentation Days on gaseous detectors June 25-26, 2014 IPNO, Orsay

Outlook

Outlook

- Introduction
- Gas systems:
  - Construction
  - Building blocks. Examples: mixer, purifiers, analysis, recuperation, …
- Gas systems performances:
  - reliability over the past years
- Long Shutdown 1:
  - maintenance, consolidation and upgrades
- Gas emissions from particle detectors
- Small gas recirculation systems for lab applications
- Conclusions

Gas systems for the LHC experiments

Introduction

- The basic function of the gas system is to mix the different gas components in the appropriate proportion and to distribute the mixture to the individual chambers.
- 28 gas systems (about 300 racks) delivering the required mixture to the particle detectors of all LHC experiments.
- Gas mixture is the sensitive medium where the charge multiplication is producing the signal.
- Correct and stable mixture composition are basic requirements for good and stable long term operation of all detectors.

Summary of the sub-detector gas systems at the LHC experiments.

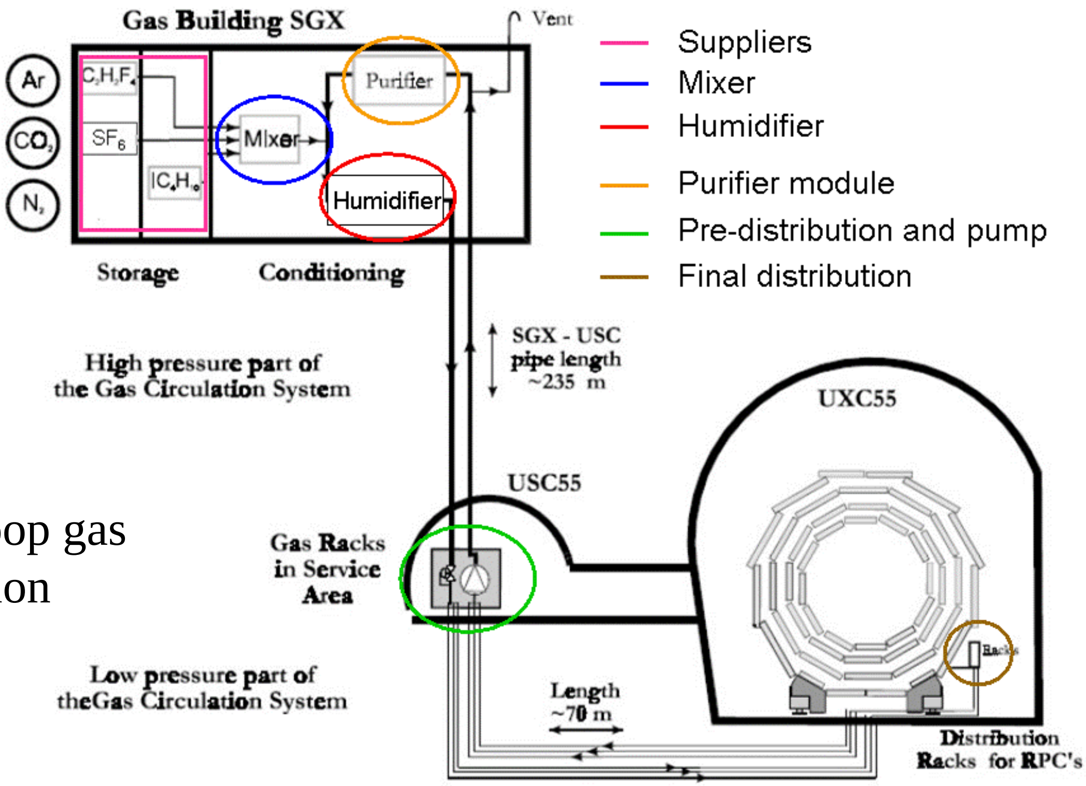
14 Closed loop detector gas system; 11 Single pass detector gas systems
3 Flushing systems for N_2, CO_2, and compressed air

LHC Point 1 ATLAS	LHC Point 2 ALICE	LHC Point 5 CMS and TOTEM	LHC Point 8 LHCb
MDT	TPC	DT	OT
CSC	TRD	CSC + CF_4 recovery	Muon MWPC
TGC	TOF	RPC	Muon GEM
RPC	HMPID	T1-CSC (Totem)	RICH1
TRT	CPV	T2-GEM (Totem)	RICH2
LUCID(*)	PMD	SX5 + 904(*) Mixers	
ID flushing	Muon Track.	ID Flushing	
TRT CO_2 Cooling	Muon Trig.		

Gas systems for the LHC experiments

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

- Primary gas supply point is located in surface building
- Gas system distributed in three levels:
  - Surface (SG)
  - Gas Service room (USC)
  - experimental cavern (UXC)



Large detector volume (from m^3 to several 100 m^3) and use of expensive gas components:

→

The majority is operated in closed loop gas circulation with a recirculation fraction higher than 90-95 %.

The “CERN *Gas Service Team*”

Gas systems construction

- The gas systems were built according to a common standard allowing minimization of manpower and costs for maintenance and operation.
  - Construction started early 2000
  - Operational since 2005-2006
- Result of the CERN gas service team (now part of PH-DT-DI)

PH-DT
Detector Technologies

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Benjamin Philippe Marichy
Herve Martinati
+ support from CERN users (technicians)

- Software controls developed in collaboration with CERN/EN-ICE

Gas system: design

Gas systems construction

Gas systems (as detectors) are subject to severe requirements on material & gas for safe detector operation:

- Mainly (if needed only) stainless steel pipe and components
- Need to validate most of the gas system components
- Documentation for QA and easy operation/maintenance follow up
- Monitoring of gas system operation
- Monitor of supply gases and mixture composition
- Evaluation of operational cost
- Flexible design to accommodate detector requirements/upgrades
- Careful evaluation of
  - resources for operation
  - resources for maintenance activity
  - Stability required
  - Balance requirements vs safety (as much as possible)

Gas system construction

- Gas systems are made of several modules (*building blocks*): mixer, pre-distribution, distribution, circulation pump, purifier, humidifier, membrane, liquefier, gas analysis, etc.

- Functional modules are equal between different gas systems, but they can be configured to satisfy the specific needs of all particle detector.
  - Implementation: control rack and crates (flexible during installation phase and max modularity for large systems)

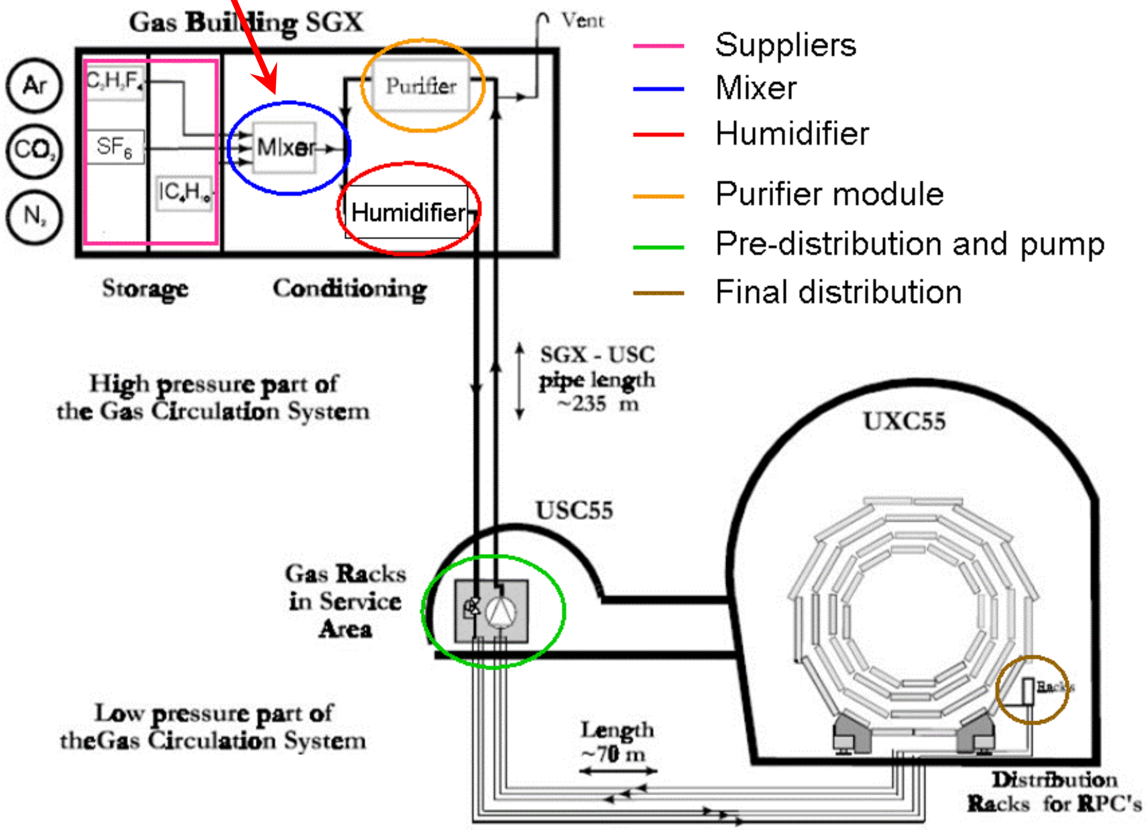
Control rack

Control crate (PLC)

Modules crates
Profibus connection to control crate

Example: Mixer module

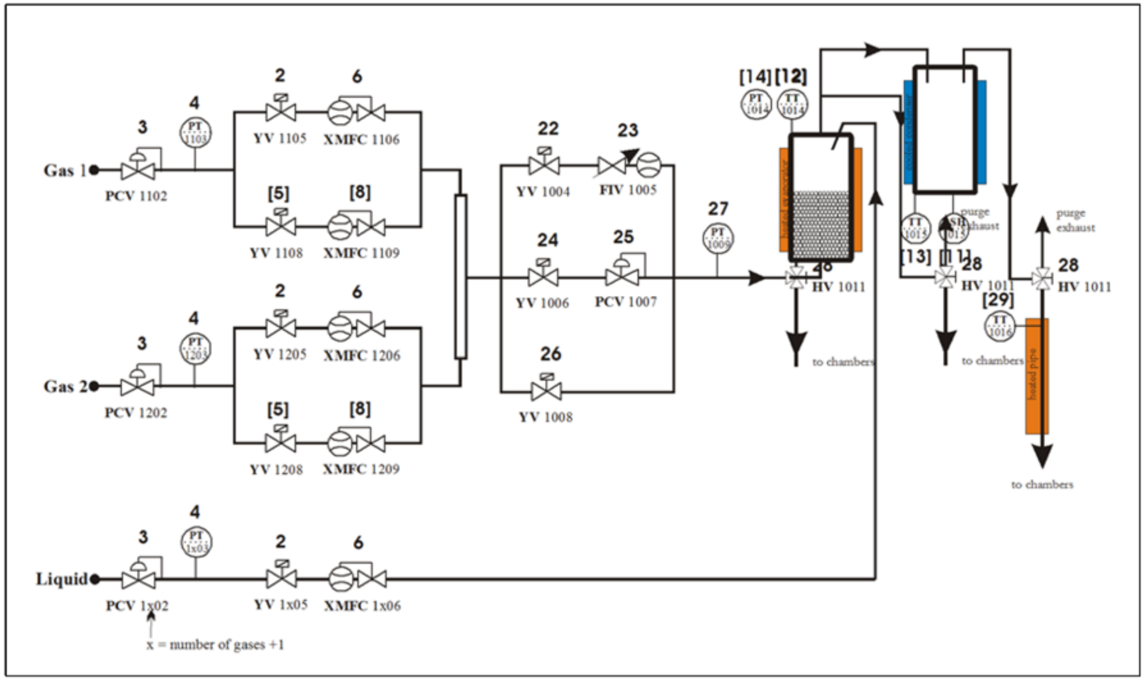
Where is it?



Mixer module

Gas systems building blocks

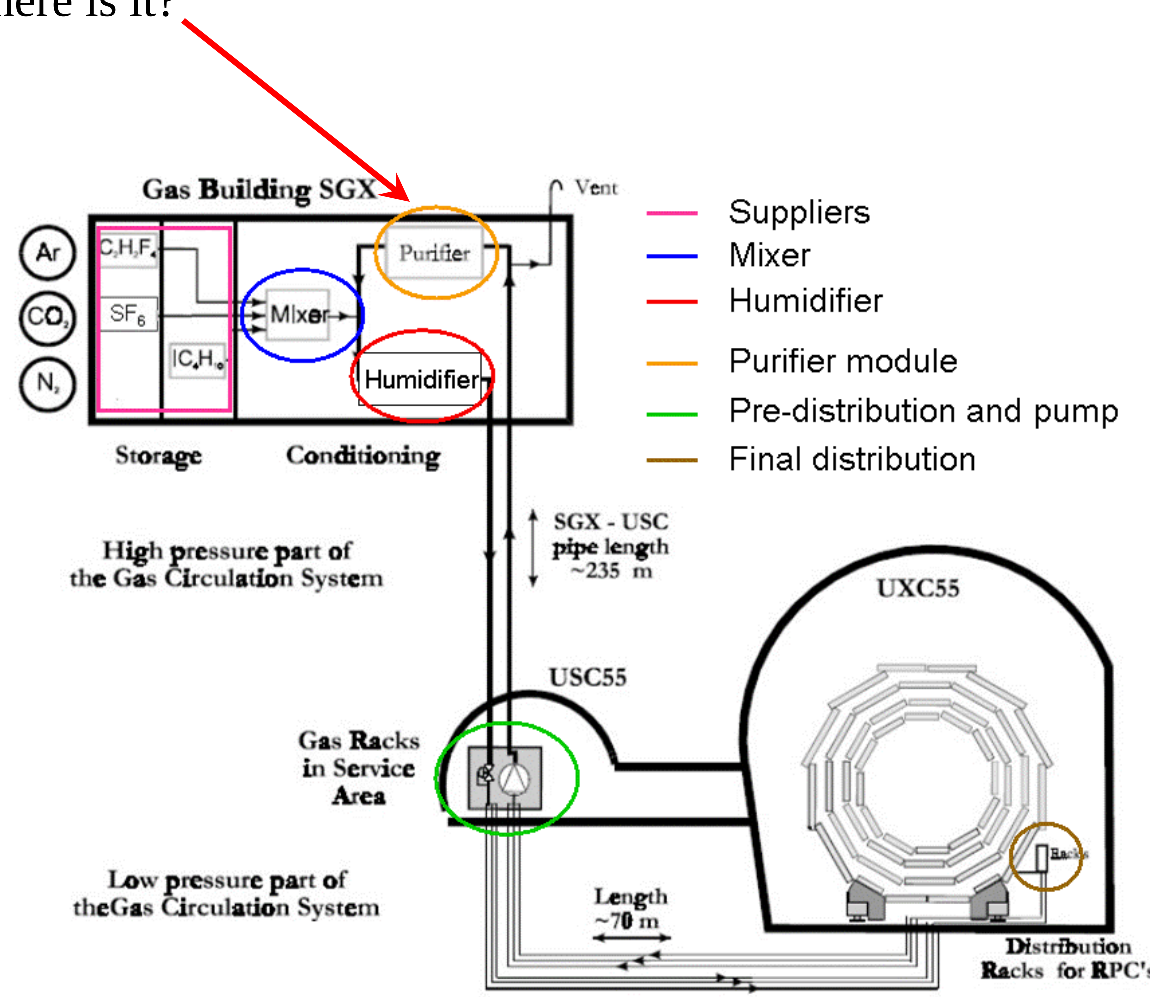
- Standard Mixer module can have <u>up to 4 input lines</u> (gas and liquid).
- Primary task: provide the sub-detector with a suitable gas mixture during run.
- Different needs for filling or purging (i.e. high flow or different mixture)
- <u>Mixture injection regulated according to detector need</u>:
  - Correction for atmospheric pressure change (majority of detector are operated at constant relative pressure, i.e. the quantity of gas in the detector follow the atmospheric pressure changes → mixture need to be stored)
  - Mixture replacement in the detector
  - Recuperation efficiency or leak rate
- Warning/Alarms available:
  - Gas supply pressures
  - Flow not stable/reliable
  - Flow regulation (Mixing ratio)



Example: Purifier module

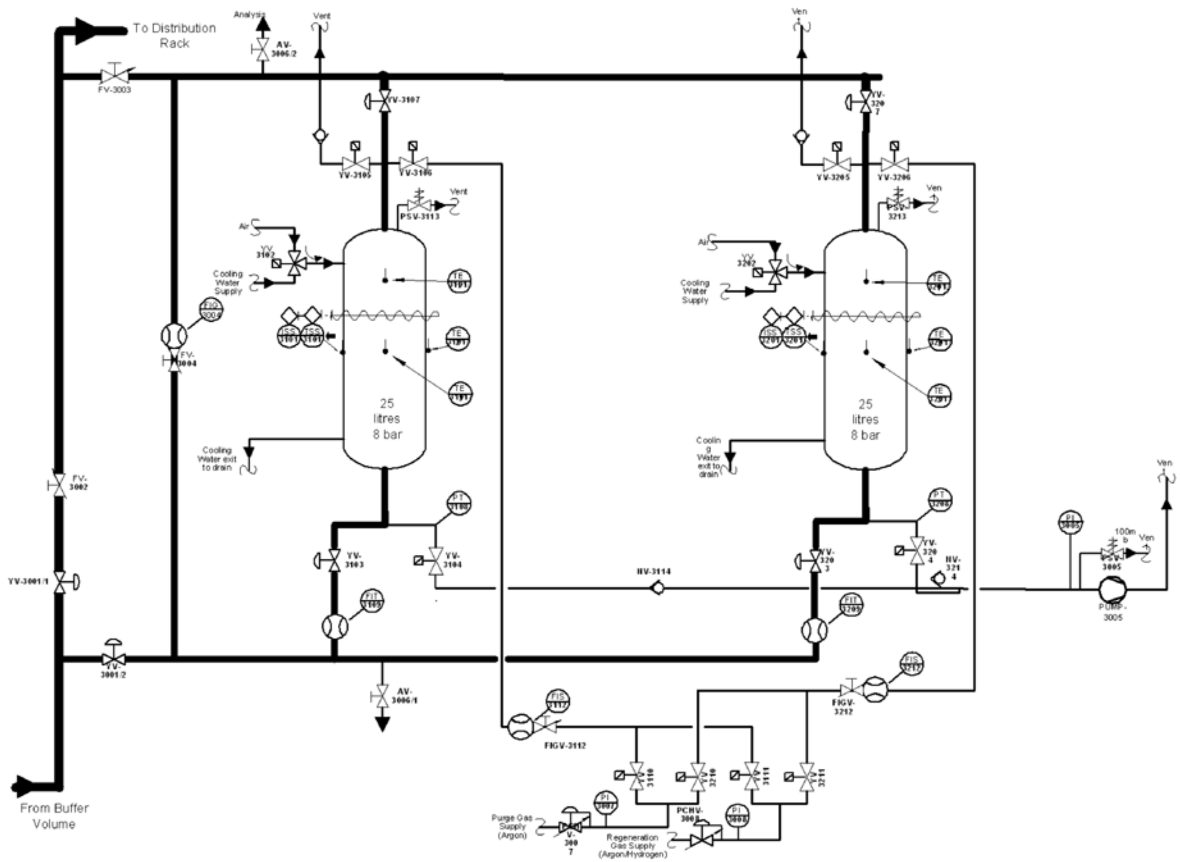
Gas systems building blocks

Where is it?



Purifier module

- One of the most complex modules
- Used to remove O_2, H_2O and more from mixture
- Fully automated cycle
- 2 x 24 l columns filled with suited absorber:
  - Molecular sieves
  - Metallic catalysts
  - others



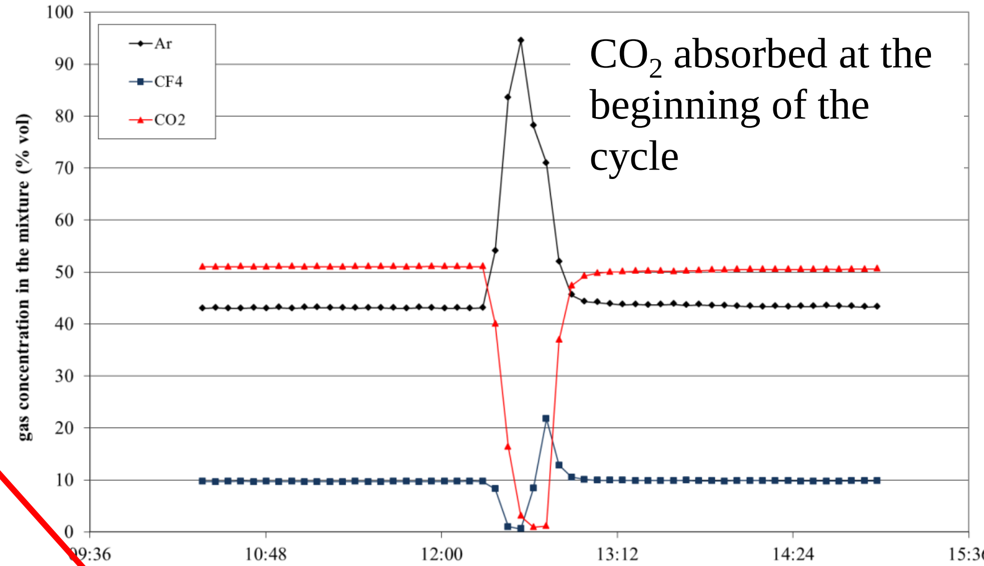
Purifier module

- Many modules operational with many different gas mixtures and cleaning agents

Purifier module

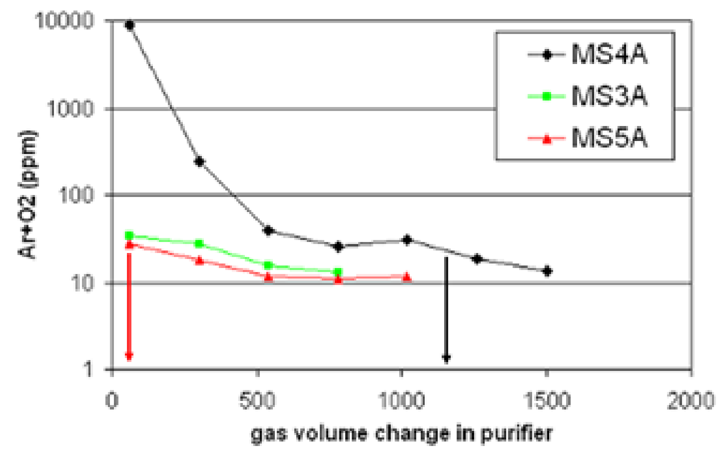
Gas systems building blocks

- Many development tricks:
  - Cleaning agents absorb not only impurities → mixture was destabilized at the beginning of each cycle
  - Gas used during regeneration remains trapped in the cleaning agents
  - Too much gas was absorbed right at the beginning of the cycle → pressure destabilized



CO_2 absorbed at the beginning of the cycle

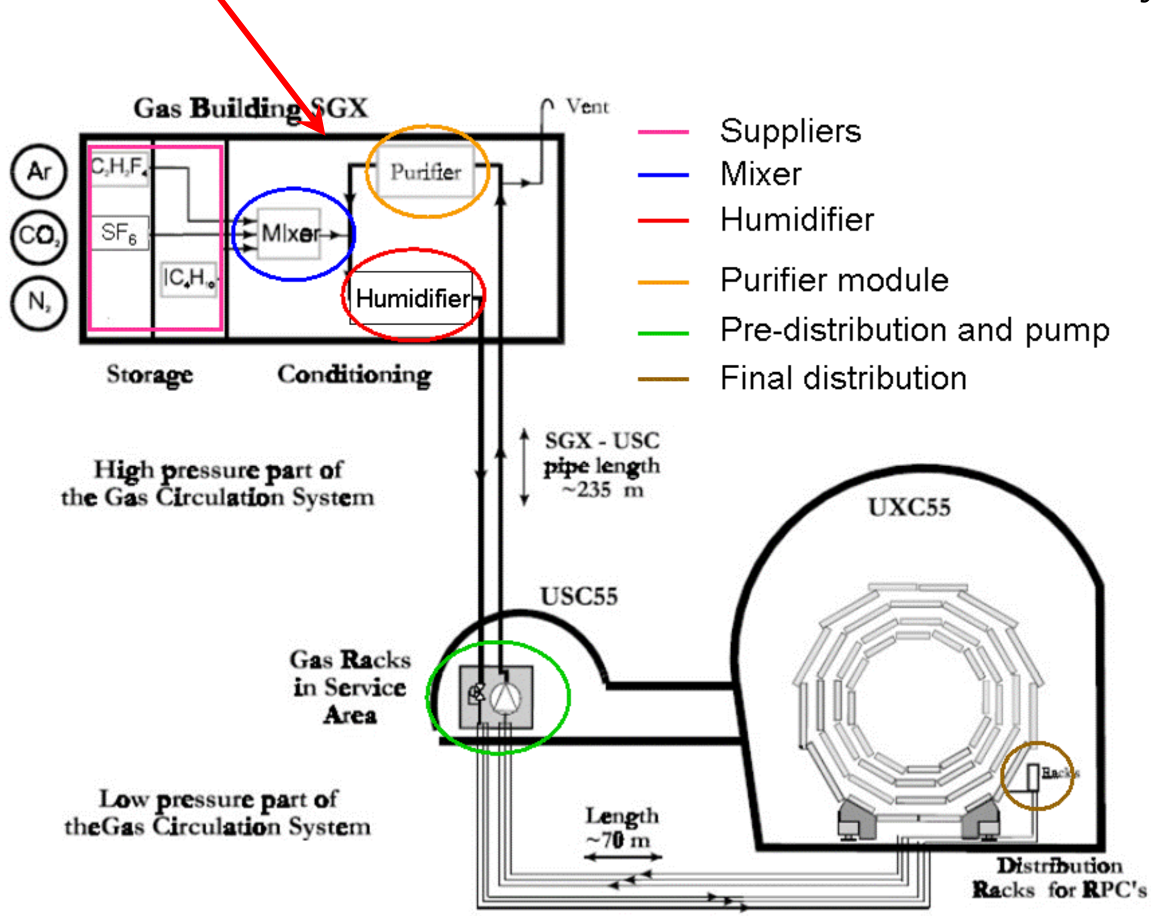
Ar is released by molecular sieves:



- Operation sequence was completely reviewed and still under discussion:
  - Preparation for Run phases introduced
  - Optimization of regeneration sequence

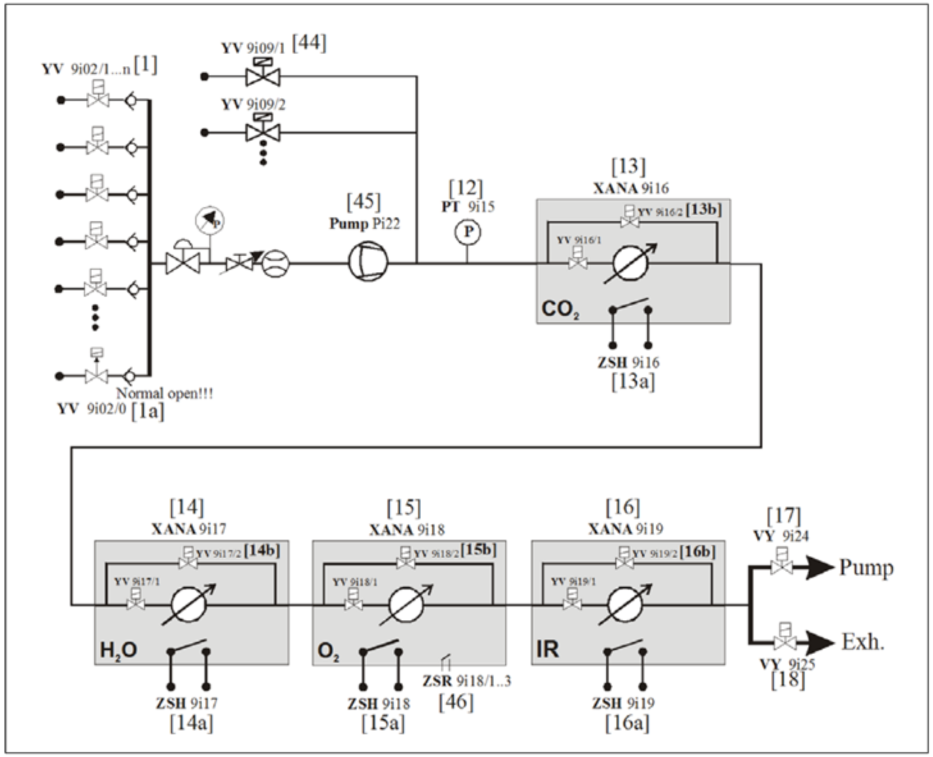
Example: Gas analysis module

Where is it? Many connections in SGX, but also in US or UX… basically everywhere



Gas analysis module

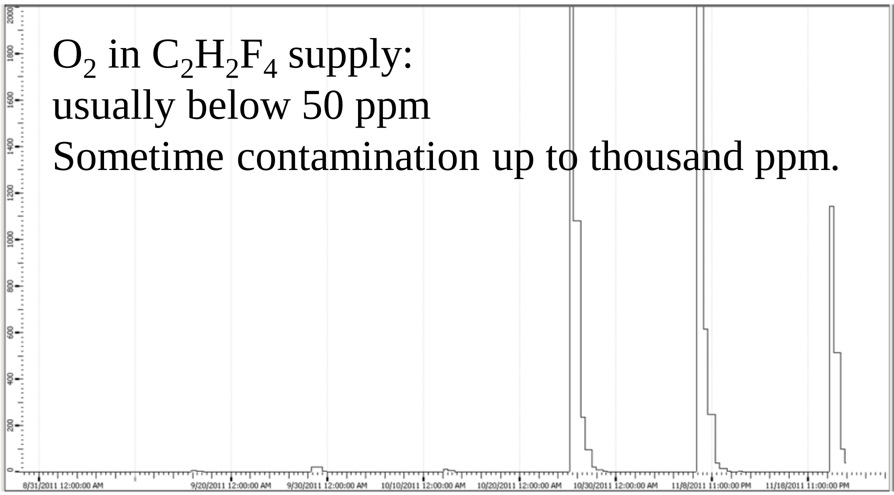
- Used to analyze the gas mixture
- Two types: gas source selected by means of standard valves or special n-way valves.
  - Several sample chains may be organized in several physical location.
  - Each sample chain completely independent
- The module operated in automatic mode:
  - sample the gas streams or the reference gases selected by experts.
  - experts are able to trigger sampling of selected sources.
  - length of the sampling lines taken in considerations to define flushing delays.
- Alarm and data exchange with detector DCS
- Used for safety (flammability level)
- Gas chromatographs connected for more specific analysis

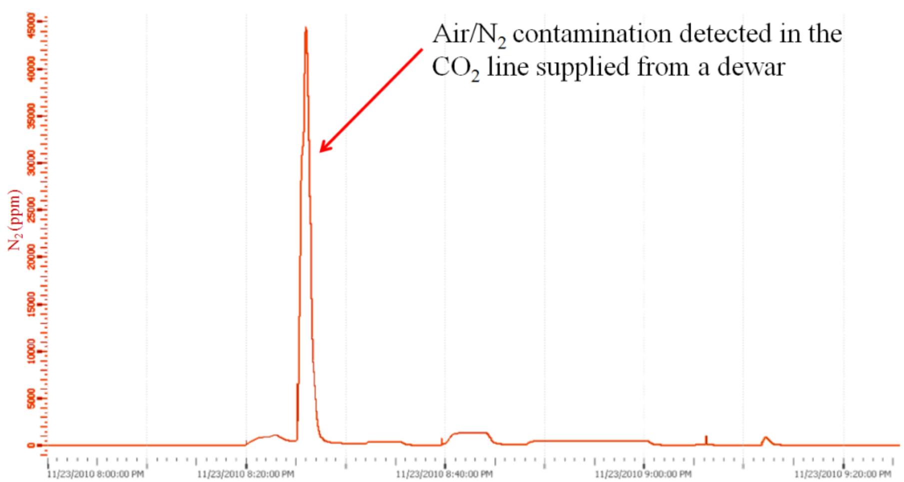


Gas analysis module

Gas systems building blocks

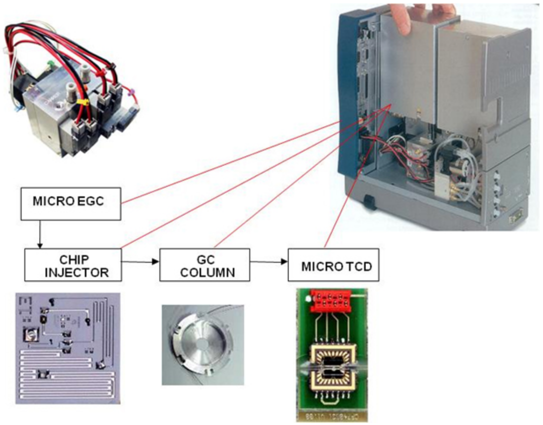
- Fully automated O2 + H2O analysis module

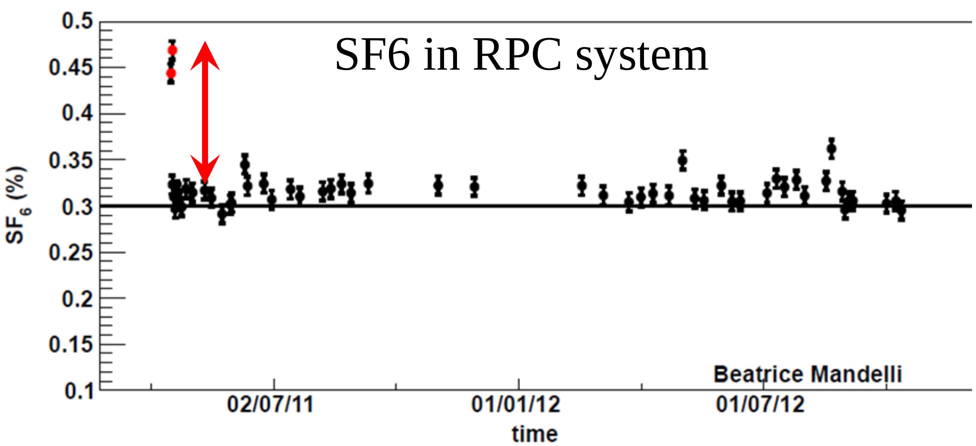


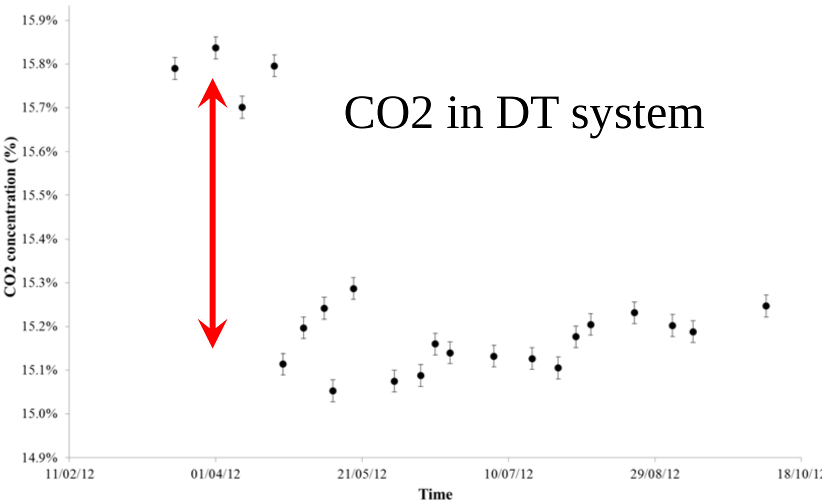


Gas analysis module

- Gas chromatographs are used to monitor:
  - Stability of mixture composition
  - Presence of more complex impurities
- CMS and LHCb equipped with GC connected to the selection manifold of the standard analysis rack.
- Others GC are directly operated by users





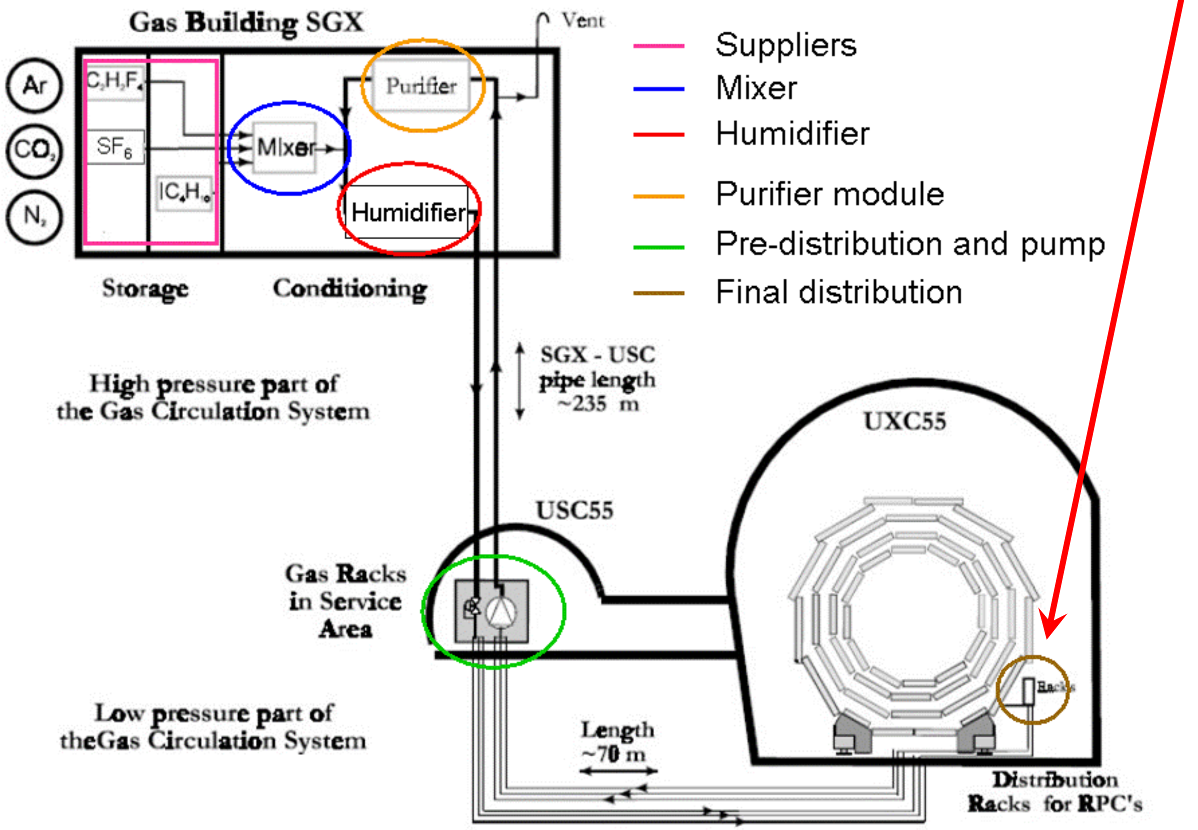


- Other monitoring system based on detector are under development

Example: distribution system

Gas systems building blocks

Where is it?



Example: distribution system

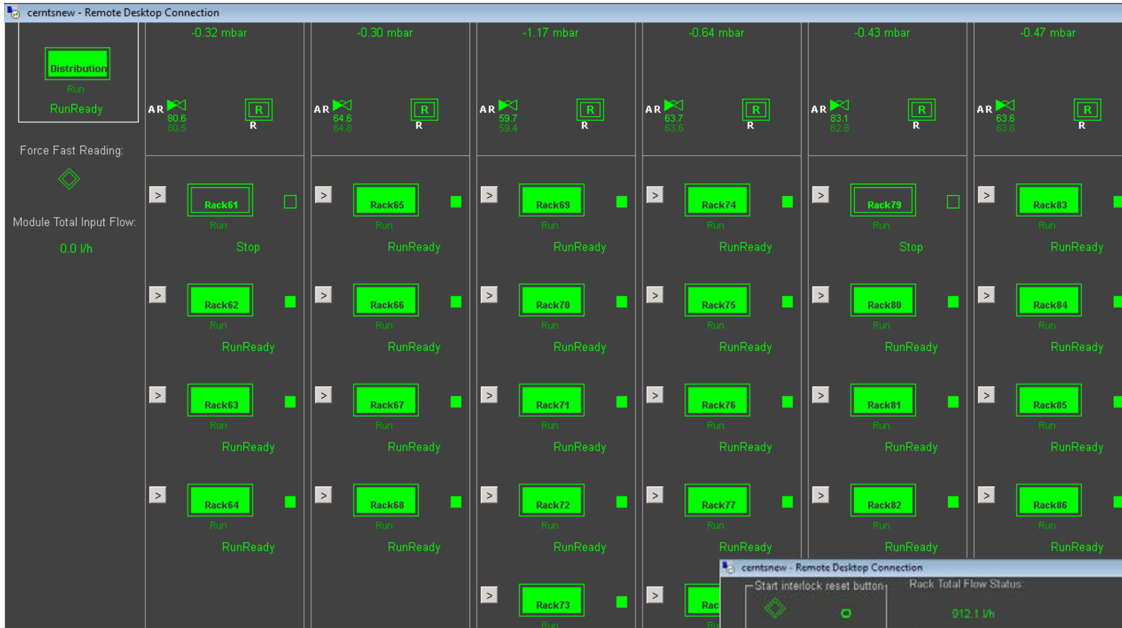
Mixture distribution modules equipped with:

- Supply and return flow read-out system
- Flow regulation system

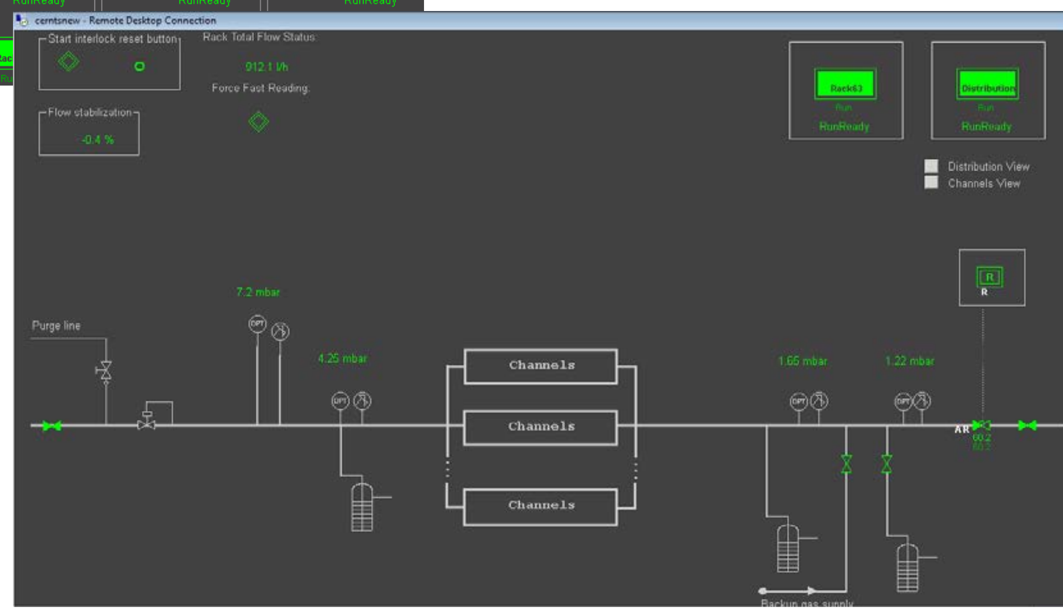
At channel/chamber level

Example: distribution system

Gas systems building blocks



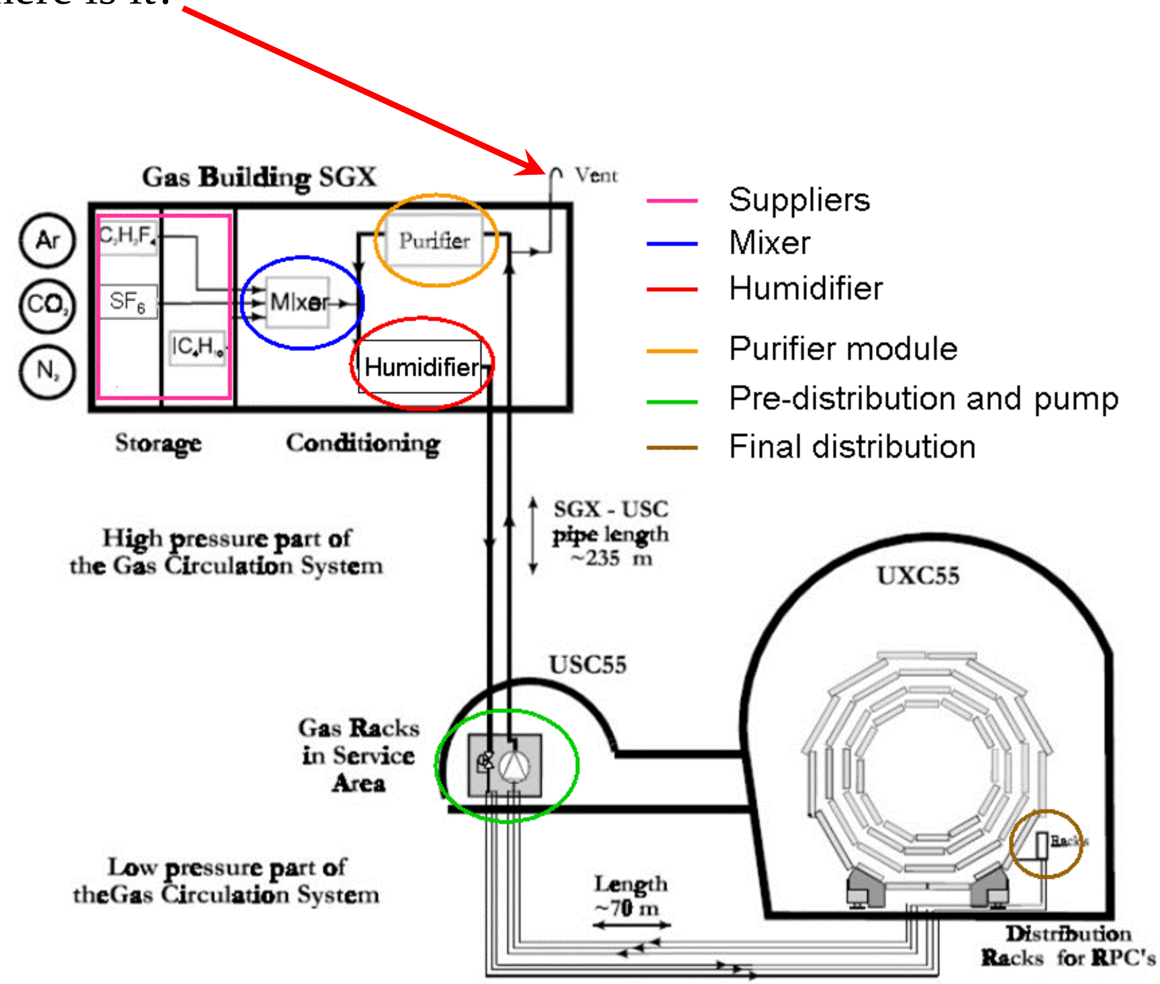
View of control system for mixture distribution of one gas system



Some of the parameters monitored for each unit

Example: Recuperation plants

Where is it?



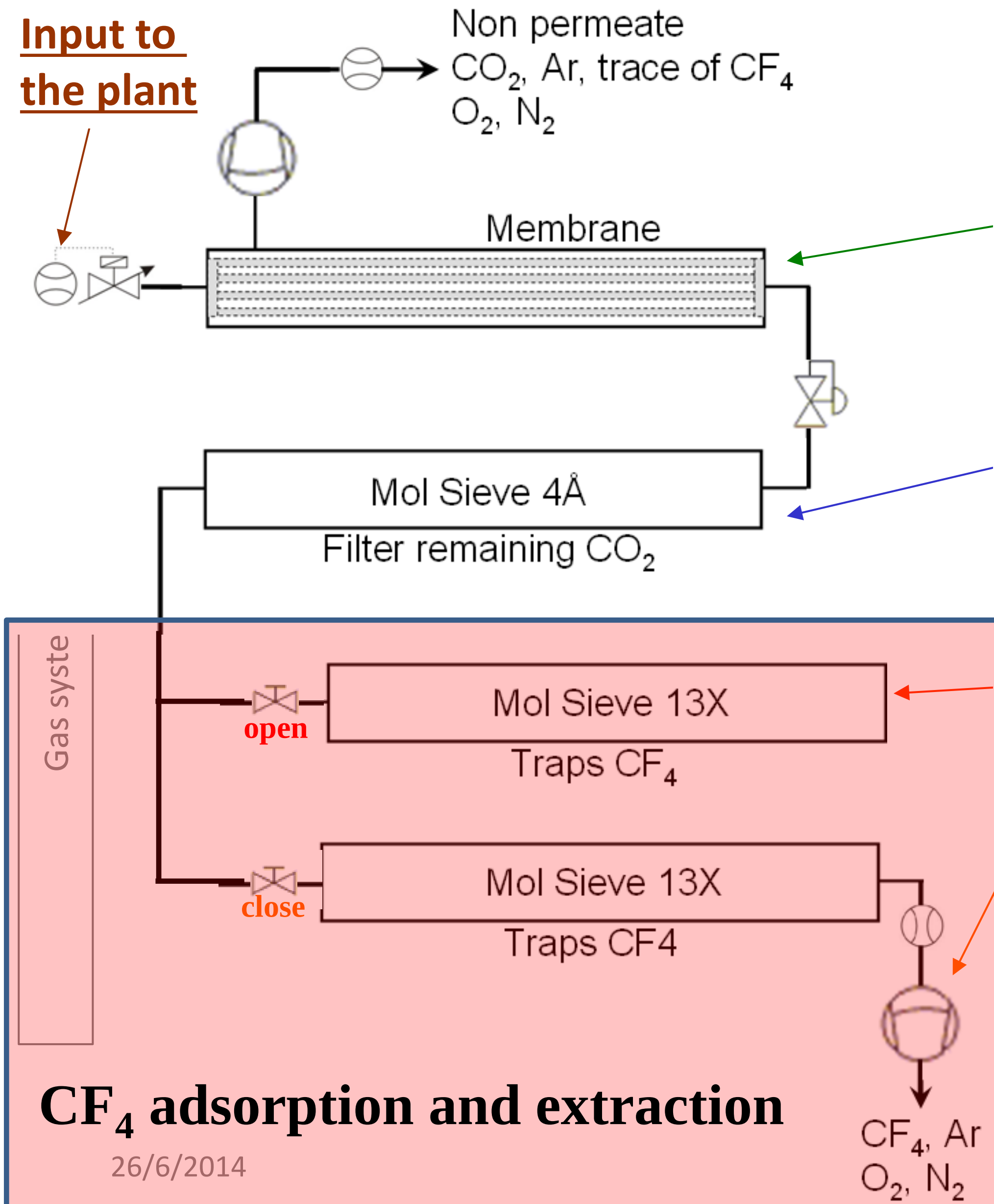
Recuperation systems: CF_4

Gas systems building blocks

- Recuperation systems: needed for empting and regulating impurity levels reducing as much as possible gas consumption
- Example:
- CMS-CSC CF_4 warm adsorption:
  - built and fully commissioned during 2011-2012.
  - fully automated system running on a dedicated PLC. All the parameters can be monitored and controlled through a PVSS remotely accessible software interface.
  - the system consists of 5 physical racks
  - it was built following the standard used for the construction of the gas systems for the LHC experiments.
  - plant is paid back in about two years of operation.
  - operational since June 2011

Details presents at IEEE2012, N14-127

Recuperation systems: CF_4



Technical challenge:

first plant built for CF_4 warm adsorption

It is a completely non-standard system

Phase 1:

Bulk CF_4 separation from the mixture

→ membrane

Phase 2:

adsorption of remaining CO_2

→ Molecular Sieve 4Å

Phase 3a:

CF_4 adsorption

→ filling Mol. Sieve 13X from -1 to 0 bar

Phase 3b:

CF_4 recovery

→ extraction from Mol. Sieve 13X

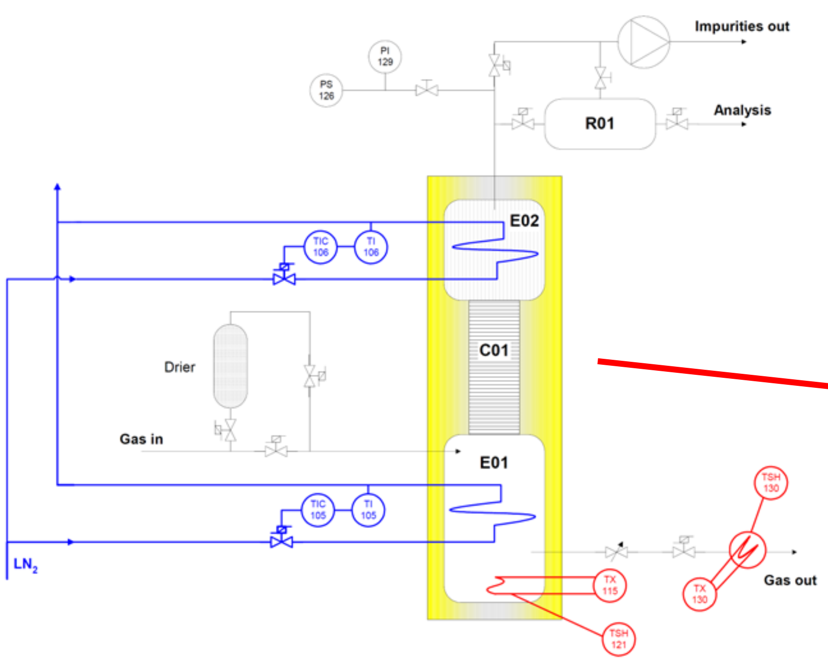
(0 → -1 bar)

CF_4 adsorption and extraction

Recuperation systems: Xe

- Xe cold trapping (ALICE-TRD, ATLAS-TRT)

Gas	Freezing point (°C)	Boiling point (°C)
N_2	-209.86	-195.8
Xe	-111.9	-108.1
CO_2	-78.4 (sublim.)	

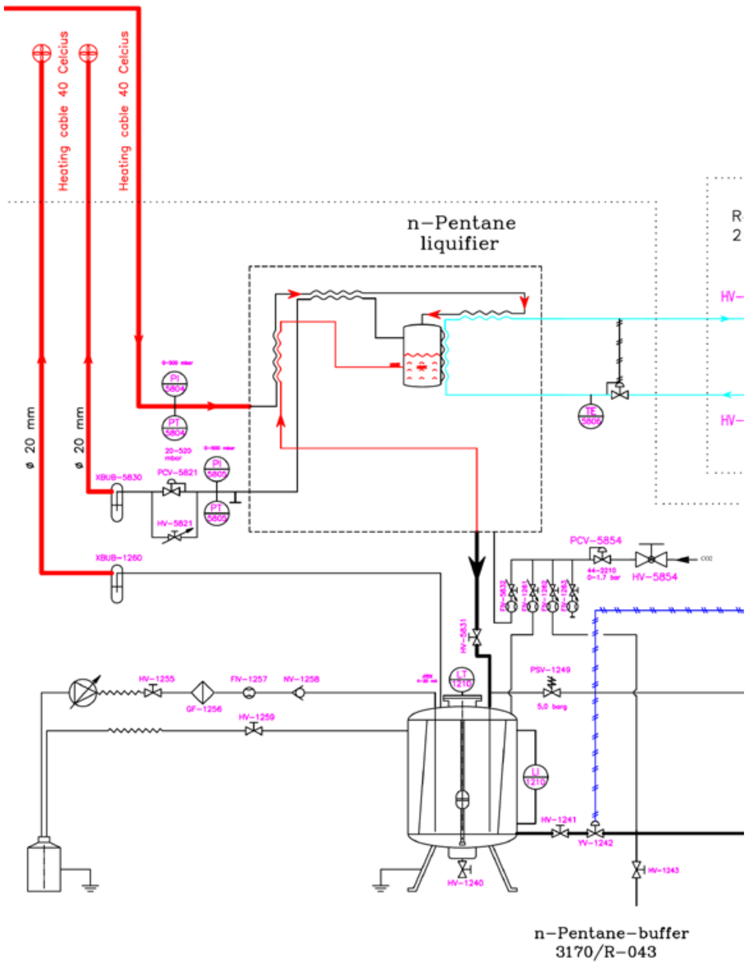


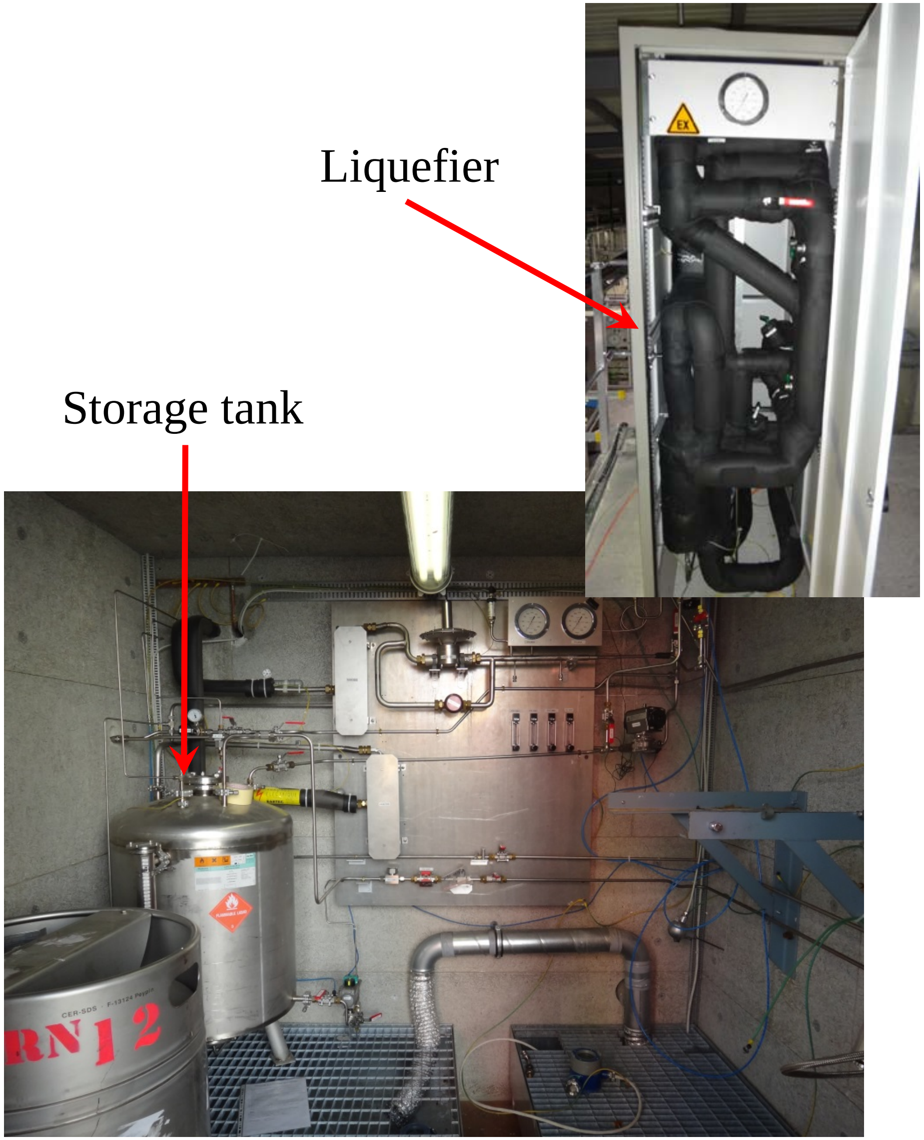
Old distillation column

New control rack and interface for automated operation

Recuperation systems: nC_5H_{12}

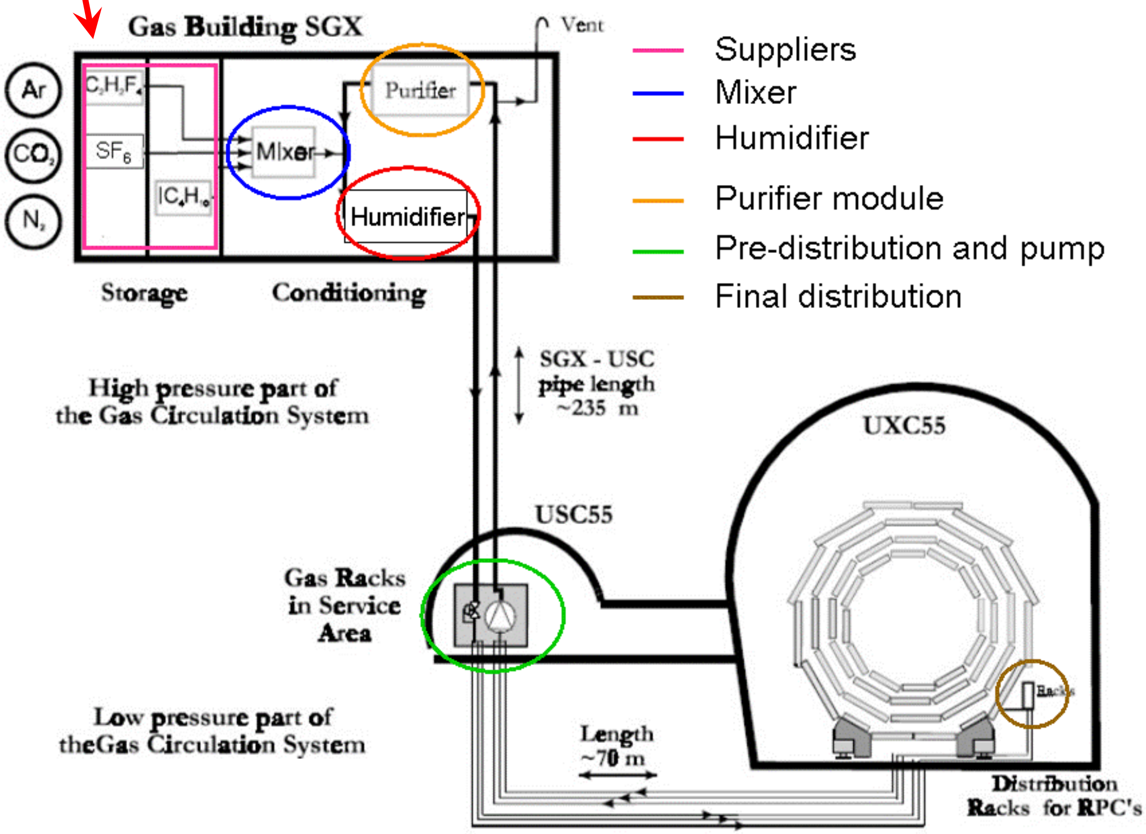
- nC_5H_{12} cold trapping (ATLAS-TGC)





Example: Gas supply monitoring system

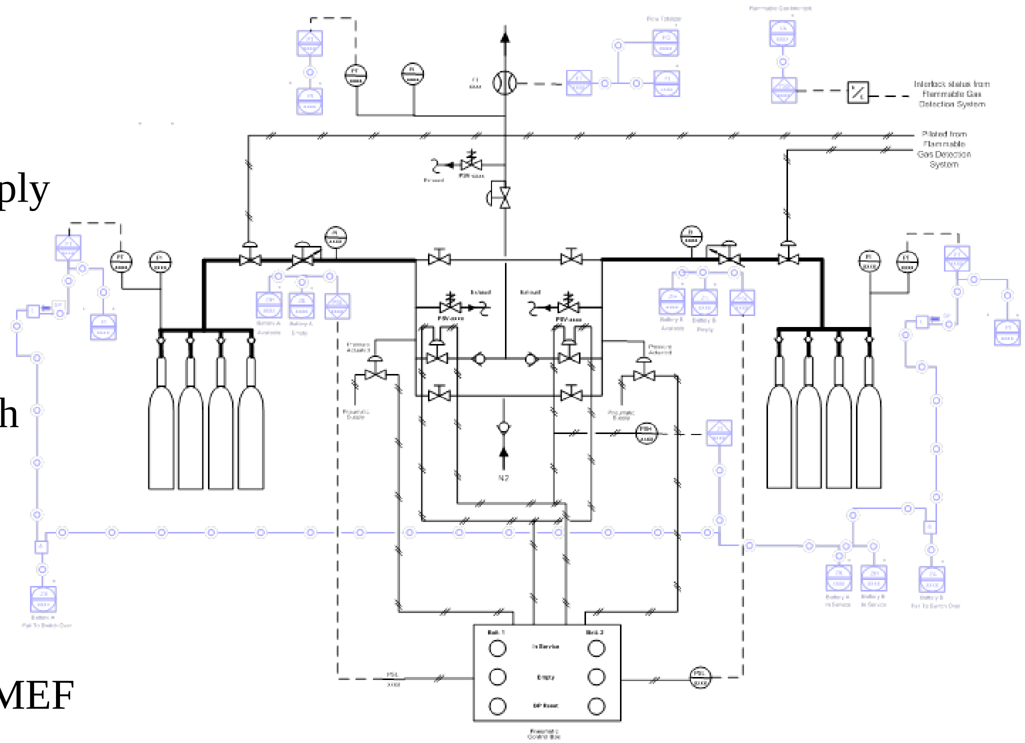
Where is it?



Gas supply monitoring system

Gas systems building blocks

- Monitoring for :
  - <u>Gas quality (via analysis devices) before in service operation</u>
  - Replaced battery availability
  - Gas flow for each gas supply
- Operational Warnings and Alarms:
  - Battery failed to change over
  - Low pressure/weight in active supply
  - High flow demand
  - Flammable gas interlock active
  - I/O faults
  - H_2O levels in analysed gas too high
  - O_2 levels in analysed gas too high
  - Backup gas supply not enabled
  - Dewar full but not in service

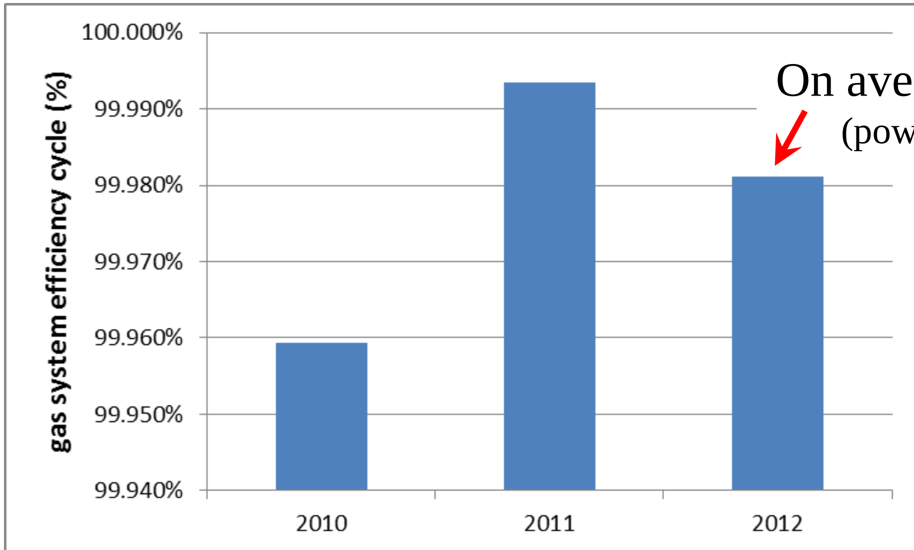


- Implemented in collaboration with EN-MEF

Reliability over the past years

Gas systems performances

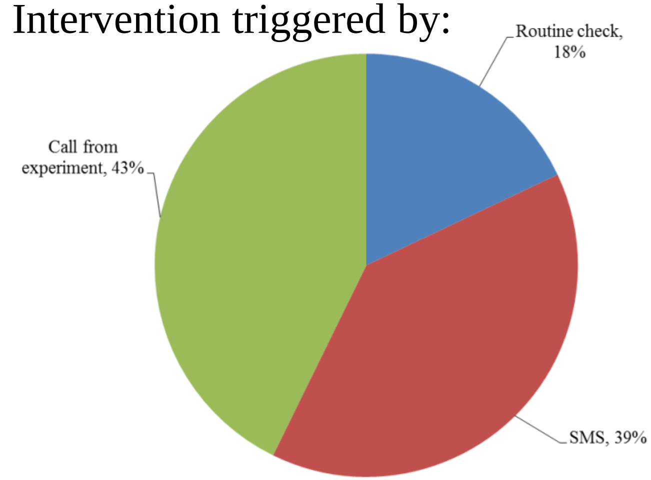
- Results from analysis of the interventions performed during 2010-2012

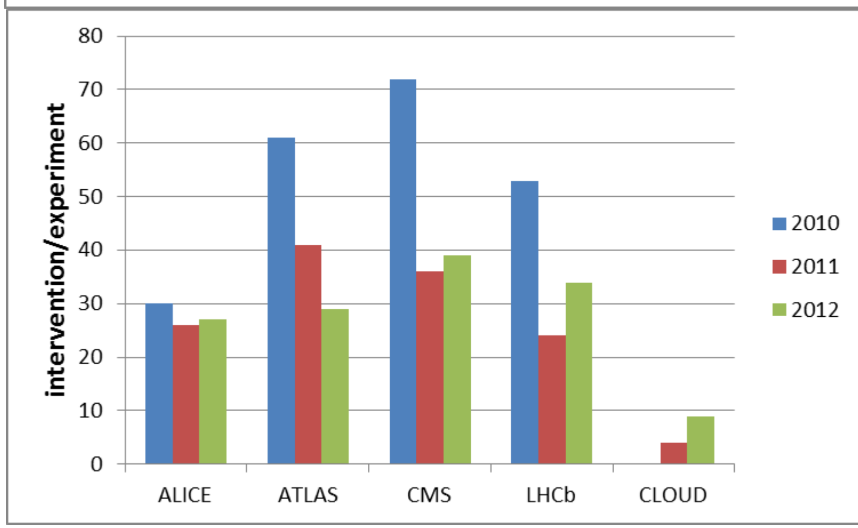


On average only 1.5 h/year/system of downtime
(power-cuts and outside events excluded)

24/24h on-call service provided

Intervention triggered by:



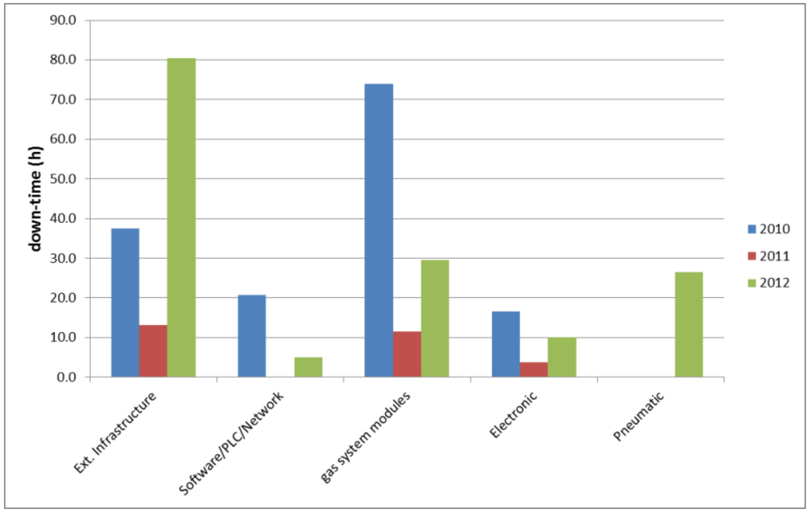


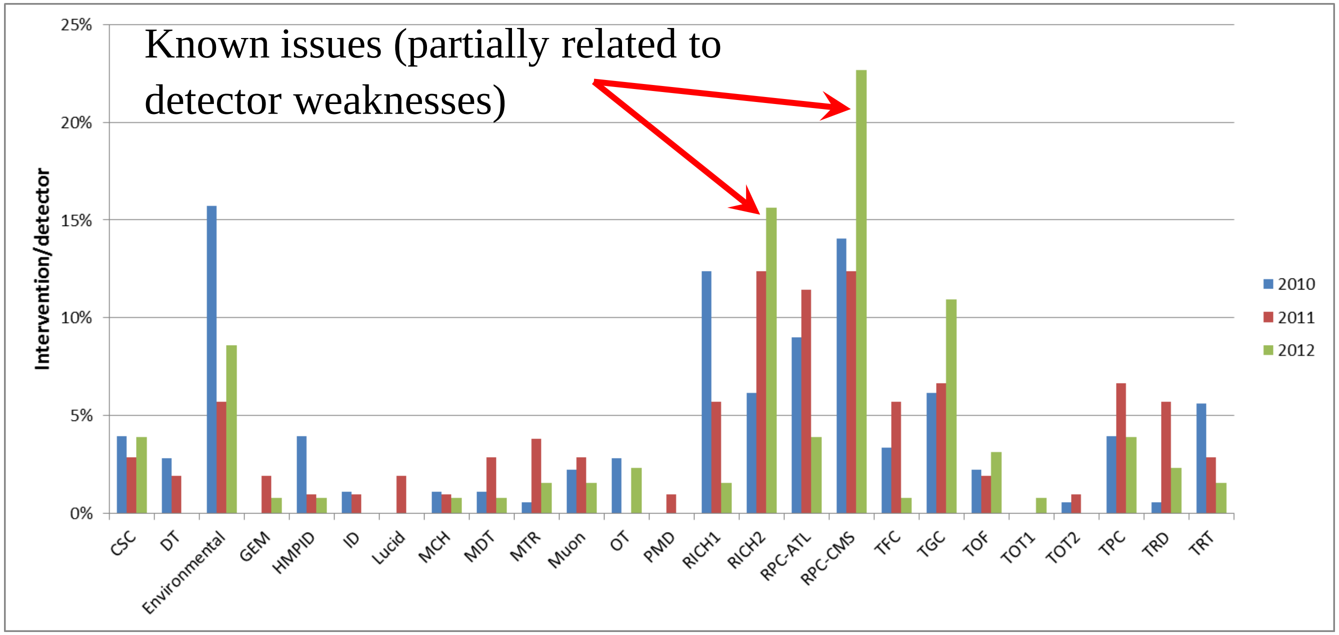
Intervention are
- Equally distributed between experiments
- Decreasing with time ☺

Reliability over the past years

Sources of down-time, analysis:

Issues with gas system modules account only for about 30 h / 150 h



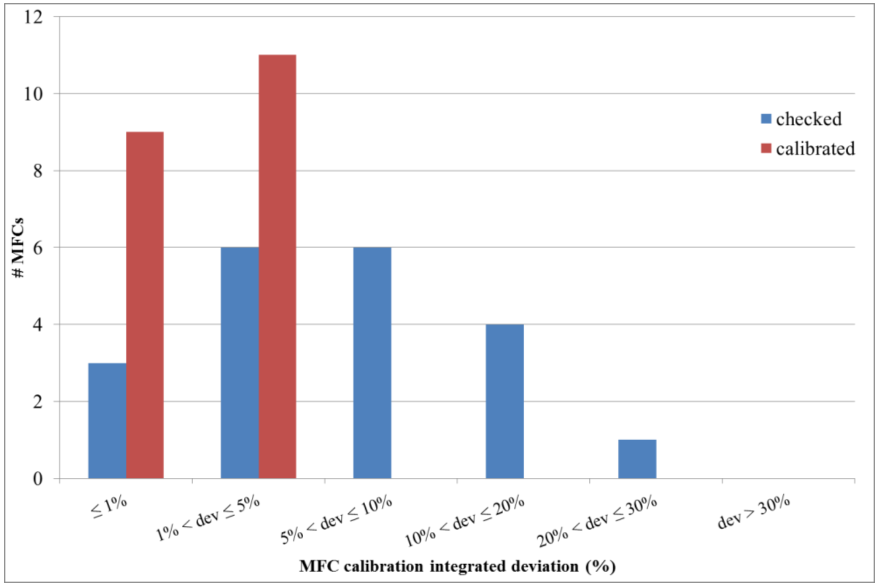


LS1 maintenance activities

- Extensive maintenance program on going during LS1 including:
  - Standard maintenance (yearly maintenance), i.e. circulation pumps, safety valves, power supply, …
  - LS1 extraordinary maintenance, i.e. analysis devices, flow-cells calibration, MFCs calibration, …

- Consolidation/upgrade program during LS1:
  - upgrade circulation pump modules (one pump redundancy)
  - Replace H_2O analysers
  - Complete analysis modules for gas supply monitoring system
  - Modify system from open mode to recirculation

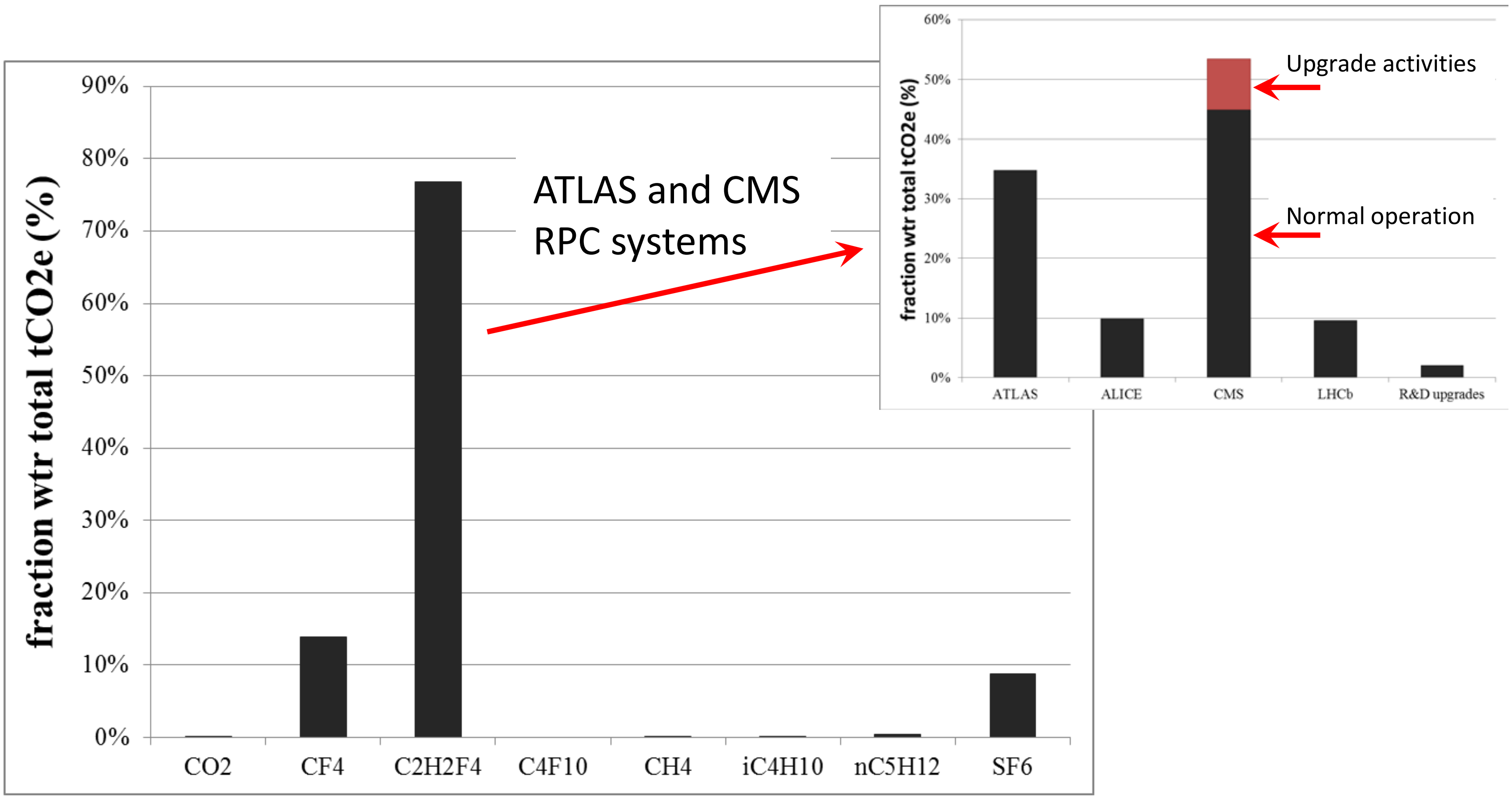
Example:
- About 150 MFCs need to be checked/calibrated
- Maintenance started
- Found important discrepancy especially in high flow MFCs (used during detector fill)



Gas systems performances

Gas emissions from particle detectors

- Operational costs and Green House Gas (GHG) emission
- Total emission: ~127100 tCO_2e
- Main contribution $C_2H_2F_4$(R134a), CF_4, SF_6

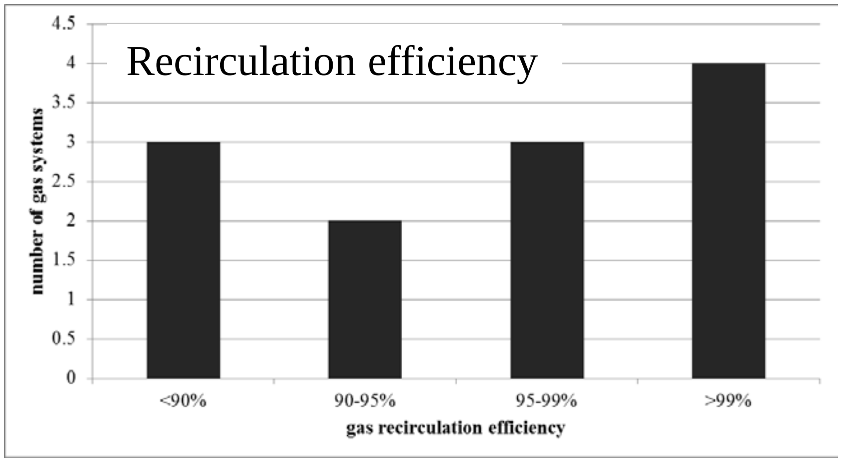


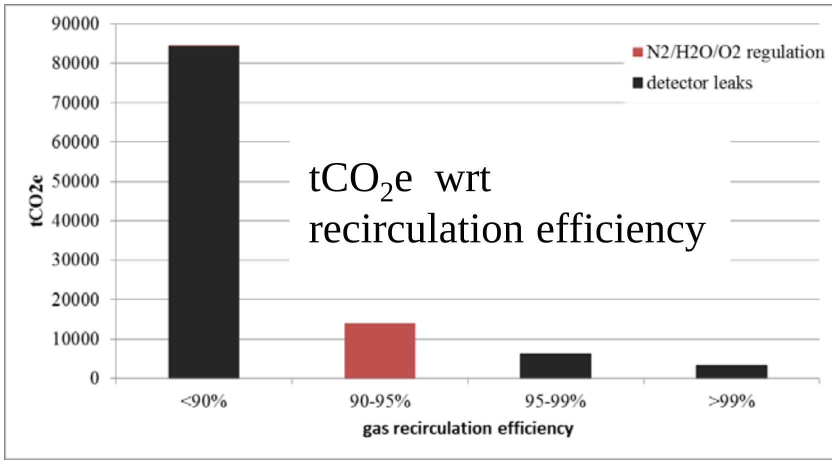
Gas consumption: cost and GHG emission

Gas emissions from particle detectors

13 gas systems already equipped with gas recirculation:

- nevertheless they represent *85% of total tCO_2e emission*
- but emissions already reduced by more than 90%.
  - Remaining 10% due to:
    - Leaks in detector: 74 % (mainly ATLAS and CMS RPC systems)
    - Need of controlling N_2, H_2O, O_2 levels and purifiers: 11% (mainly CMS-CSC)





12 gas systems without gas recirculation

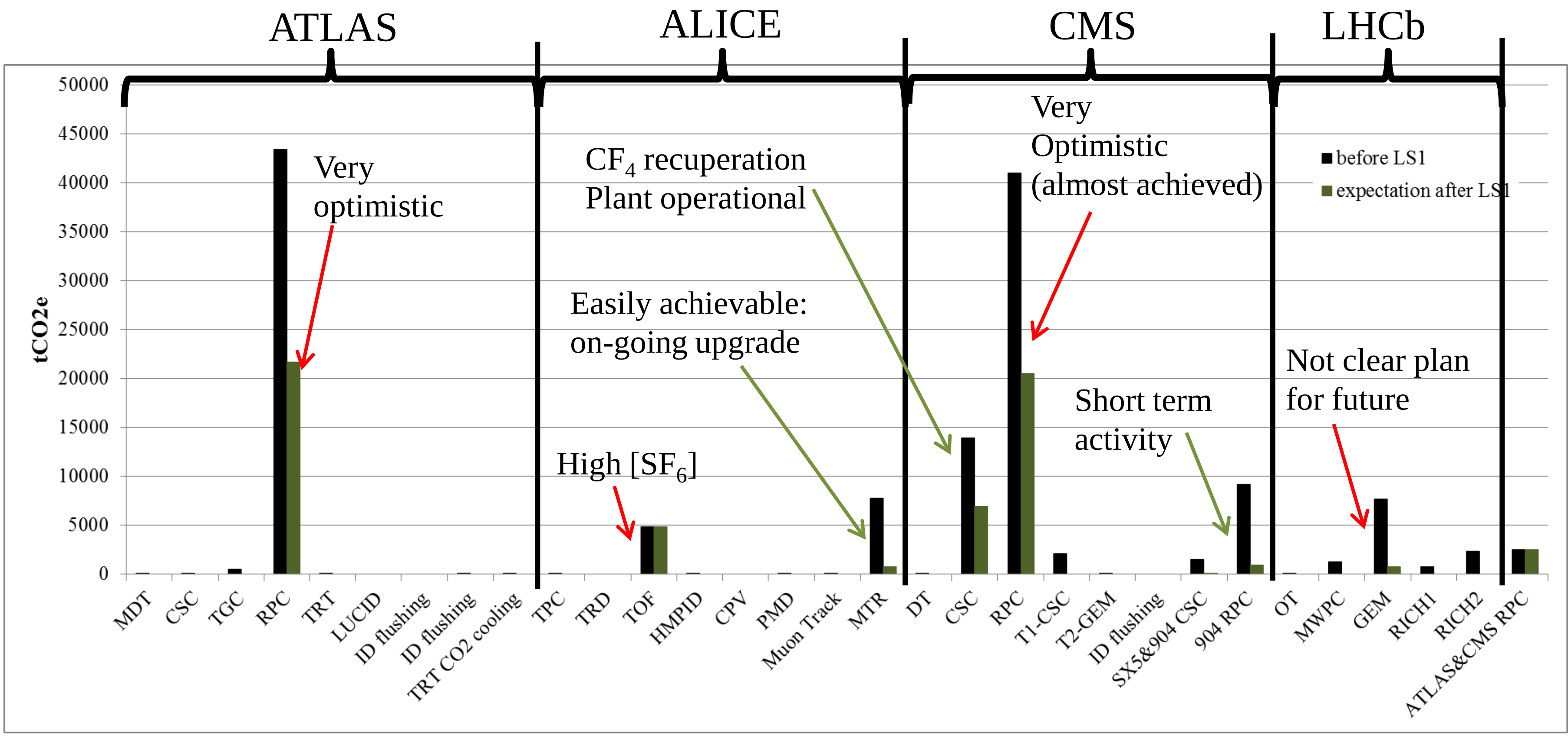
- *15% of total tCO_2e emission*
- some room for improvement (details in the following)

3 ID flushing systems

- negligible contribution (< 1%)

Gas consumption: cost and GHG emission

GHG emission by detector: expectation after LS1



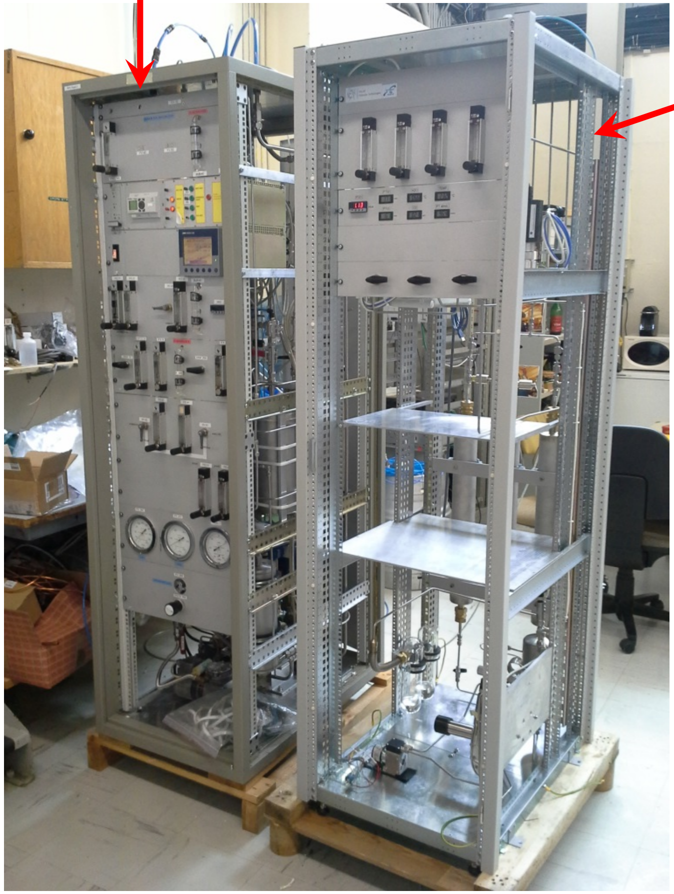
Gas emissions from particle detectors

Possible overall reduction by 40%... However, strongly dependent on results from leak search campaign on RPC systems

Small recirculation system for R&D

Two small systems developed:

- Prototype used at GIF (2003)
- New simplified version for lab R&D (2012-2014)



Conclusions

Conclusions

- 28 gas systems (about 300 racks) delivering the required mixture to the particle detectors of all LHC experiments.
- Designed and built according to functional modules:
  - Simplified maintenance and operation activities for the team
  - Fully automated systems with remote control/monitoring
  - few examples (mixer, purifier, analysis, recuperation, …) were briefly discussed
- Gas systems have demonstrated an impressive availability level:
  - On average 1.5 h downtime/year (excluded external causes, i.e. power-cuts, …)
- LS1 maintenance and consolidation plan (trying to improve, prepare for new detector requirements, anticipate ageing of components)
- Strategy for reducing gas emissions due to particle physics activities at CERN (reduce costs and green house gases)
- Small prototype systems developed for R&D applications in any lab

Thanks for your attention