EP-DT
Detector Technologies

Gas Systems
for
Particle Detectors at the LHC experiments: overview and perspectives

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Outlook

- Introduction
- Gas systems for LHC experiments:
  - Infrastructure for LHC experiments: few numbers
- Gas systems description:
  - Construction
  - Building blocks
  - Controls software
  - Web monitoring
- Gas systems performances:
  - Operation, maintenance, consolidations, upgrade, …
- Conclusions

Gas systems for the LHC experiments

- 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.

- 30 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

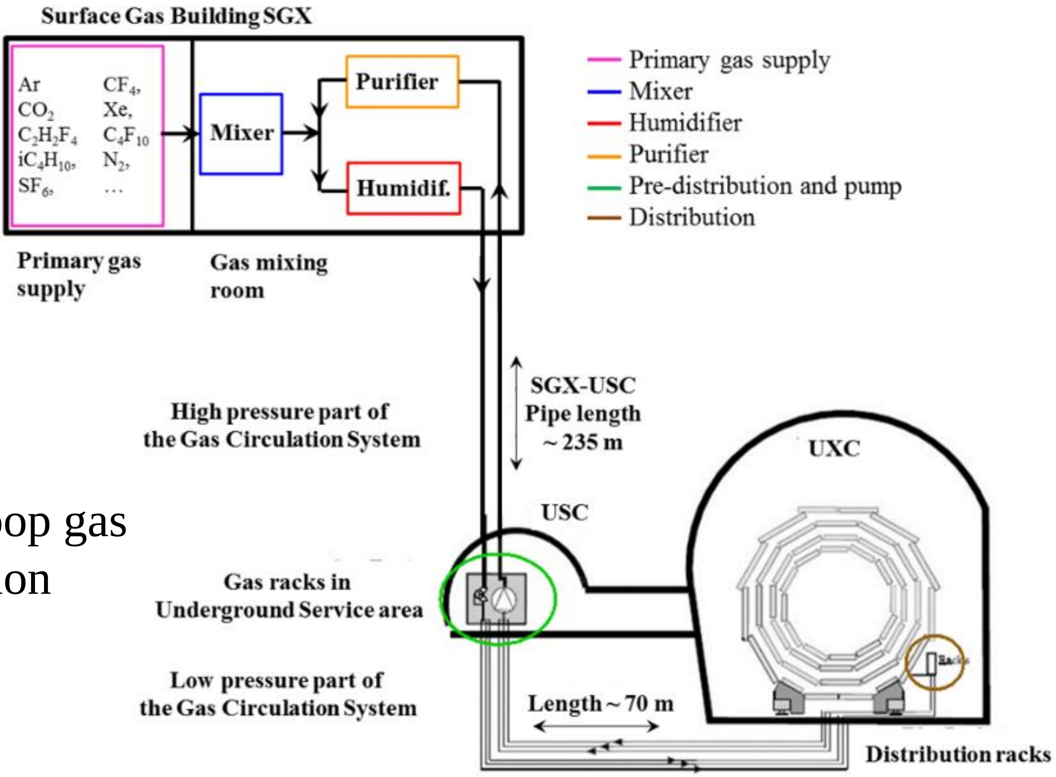
LHC Point 1 ATLAS	LHC Point 2 ALICE	LHC Point 5 CMS and TOTEM	LHC Point 8 LHCb
MDT	TPC	DT	OT
CSC	TRD	CSC + CF_4 recovery	Muon MWPC
TGC	TOF	RPC	Muon GEM
RPC	HMPID	T1-CSC (Totem)	RICH1
TRT	CPV	T2-GEM (Totem)	RICH2
LUCID(*)	PMD	SX5 + 904(*) Mixers	
ID flushing	Muon Track.	ID Flushing	
TRT CO_2 Cooling	Muon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



Gas systems for the LHC experiments

Few numbers:

- Construction started in 2000
- Operational since 2005-2006
- 30 gas systems detectors at the LHC experiments
- 300 Universal Euroracks → x2 height of Eiffel Tower
- 60 PLCs
- 150 MFCs
- 4000 flow meters in distribution racks
- ~ 70 gas analyzers and 6 gas chromatographers
- Per gas system:
  - ~ 2-3 km pipes
  - > 1000 connectors and 500 welds
  - ~ 40 Pressure sensors
  - ~ 10 Regulation valves
  - < 0.1 l/h leak rate

Organization:

EP-DT:

- Hardware and software design
- Operation, maintenance, upgrade

BE-ICS:

- Software implementation

Tour Eiffel: 324 m

LHC gas system racks: > 500 m

Gas systems for the LHC experiments

Three fundamental words:

- **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 system: design requirements

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

- Mainly (or exclusively) stainless steel pipe and components
- Need to validate most of the gas system components
- Documentation for QA and 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

Gas system construction: modularity

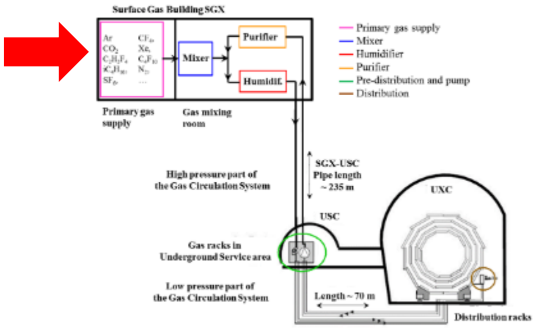
- Gas systems are made of several modules (*building blocks*): mixer, pre-distribution, distribution, circulation pump, purifier, humidifier, membrane, liquefier, gas analysis, etc.
- Functional modules are equal between different gas systems, but they can be configured to satisfy the specific needs of all particle detector.
  - Implementation: control rack and crates (flexible during installation phase and max modularity for large systems)

Control rack

Control crate
(PLCs)

Modules crates
Profibus connection to
control crate

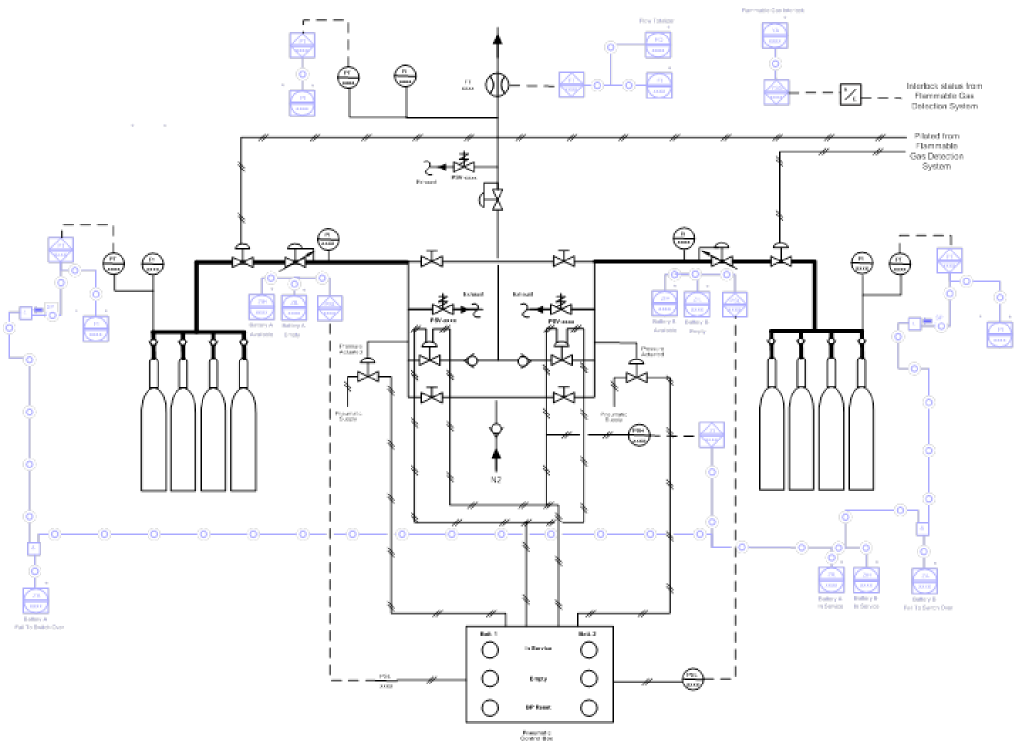
Gas supply monitoring system



- Monitoring for :
  - Ensuring reliability: make sure standby battery is availability
  - Gas flow for each gas supply
  - Gas quality (via analysis devices) before in service operation

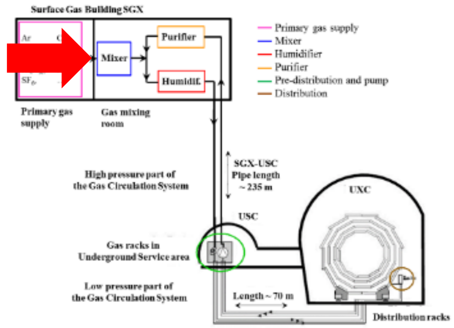
- Operational Warnings and Alarms:
  - Battery failed to change over
  - Low pressure/weight in active supply
  - High flow demand
  - Flammable gas interlock active
  - I/O faults
  - H_2O levels in analysed gas too high
  - O_2 levels in analysed gas too high
  - Backup gas supply not enabled
  - Dewar full but not in service

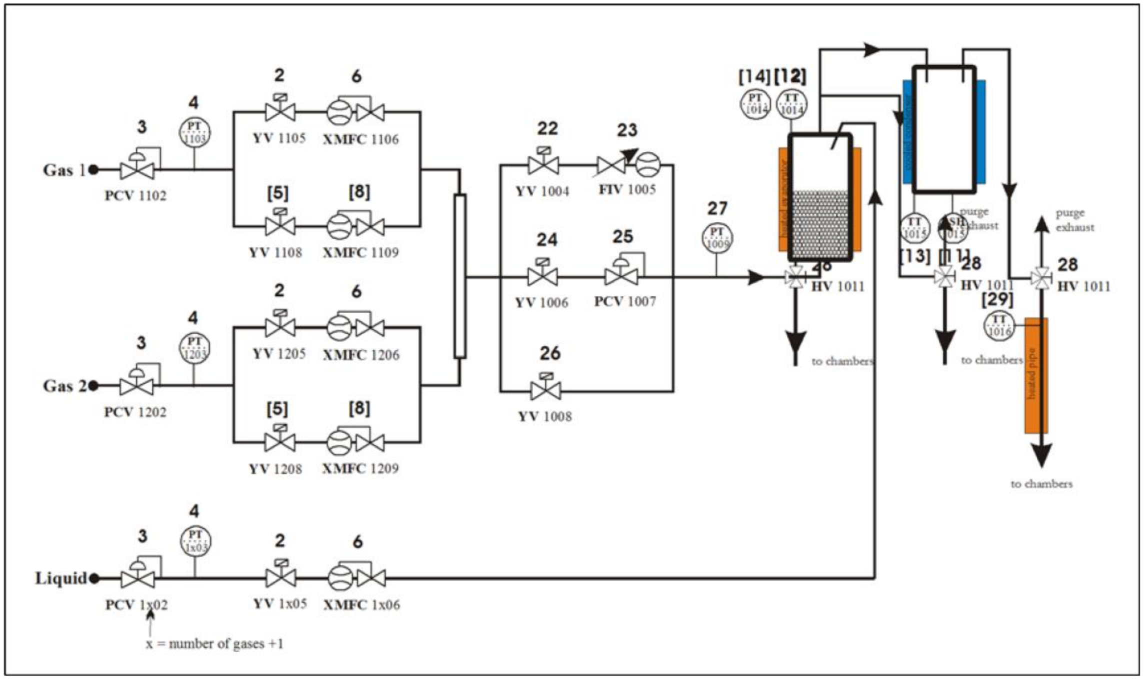
- Implemented in collaboration with EN-EA



Mixer module

- Standard Mixer module can have <u>up to 4 input lines</u> (gas and/or 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
  - Mixture replacement in the detector
  - Recuperation efficiency or leak rate
- Warning/Alarms available:
  - Gas supply pressures
  - Flow not stable/reliable
  - Flow regulation (Mixing ratio)



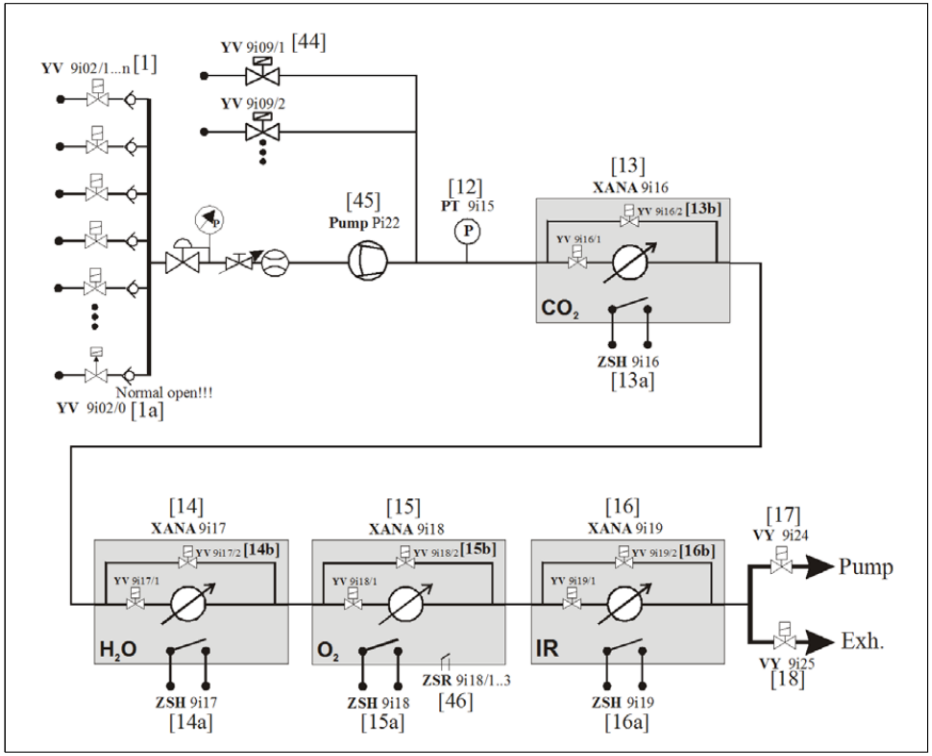


Gas analysis module

basically everywhere

- 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
- Alarm and data exchange with detector DCS
- Used for safety (flammability level)
- Gas chromatographs connected for more specific analysis
- Monitoring systems based on detector performances (for example, Single Wire chambers application for the CMS-CSC)

More details in B. Mandelli poster ID-47



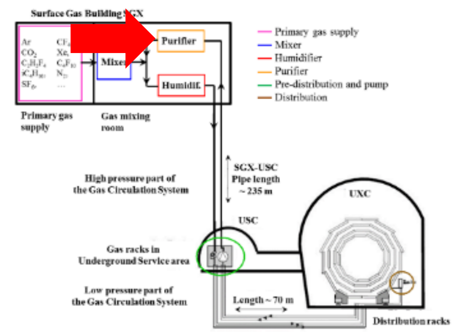
Purifier module

Most of detectors use gas recirculation systems

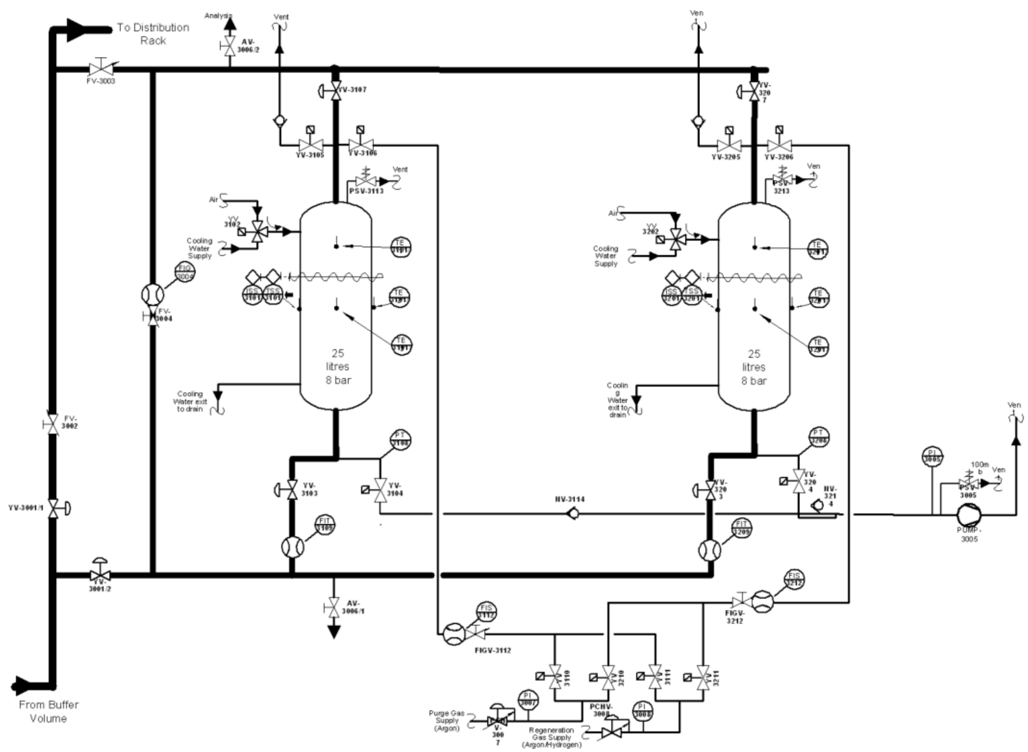
- Reduced operational cost and greenhouse gas emissions

  (*More details in B. Mandelli talk on Thursday*)

But bring to accumulation of impurities and therefore require gas purification modules



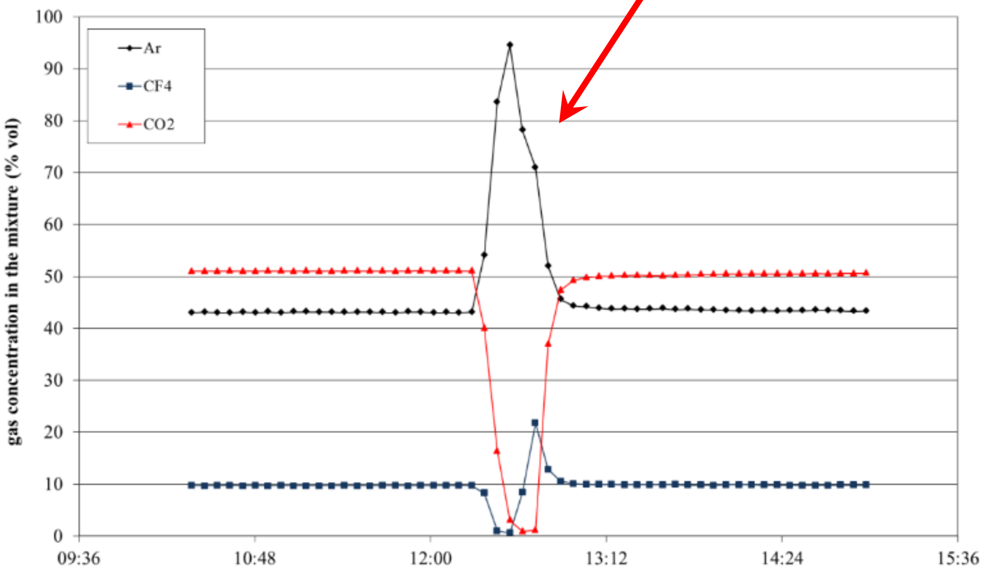
- It is one of the most complex modules
- Used to remove O_2, H_2O and more from mixture
- Fully automated cycle
- 2 x 24 l columns filled with suited absorber:
  - Molecular sieves
  - Metallic catalysts
  - others



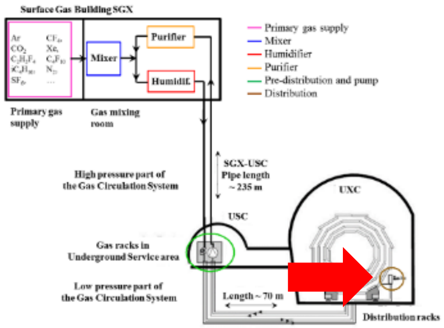
Purifier module

~ 20 modules operational with many different gas mixtures and cleaning agents

- A lot of experience and developments:
  - Example: cleaning agents absorb not only impurities → mixture was destabilized at the beginning of each cycle



Distribution module

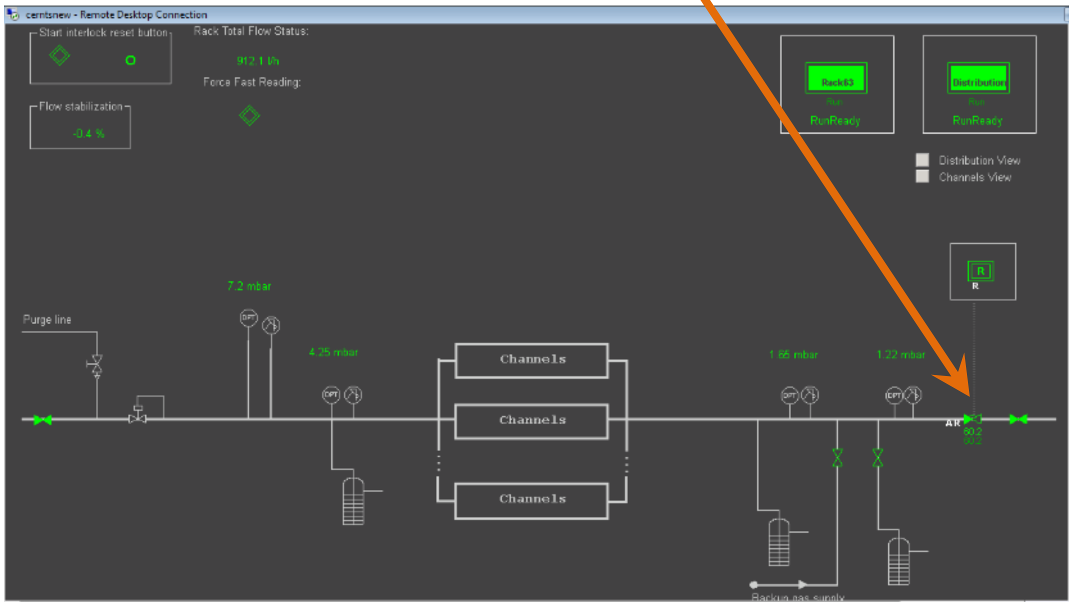


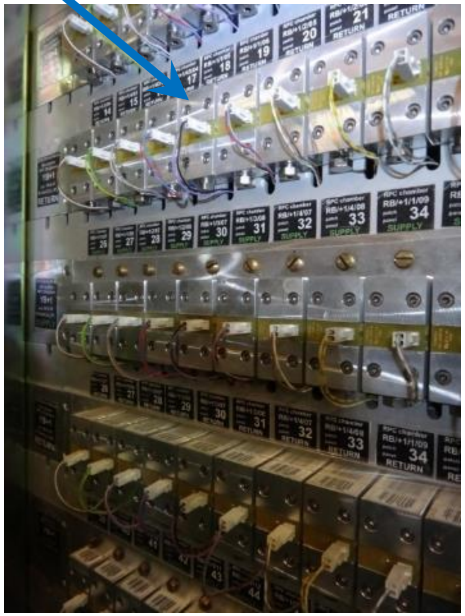
Mixture distribution modules are equipped with:

- Supply and return flow read-out system developed in the team
- Pressure/Flow regulation system

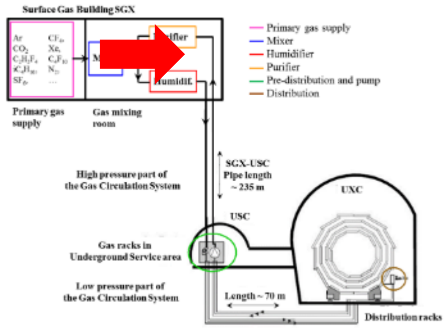
At channel/chamber level

Distribution unit: controls view





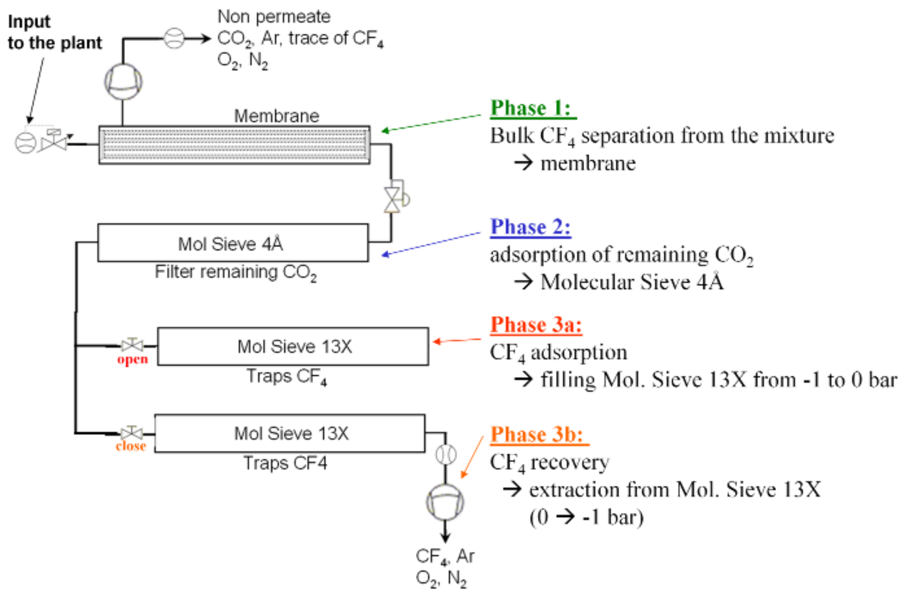
Gas recuperation systems



Recuperation systems: needed for emptying and/or regulating impurity levels reducing as much as possible gas consumption

Example:

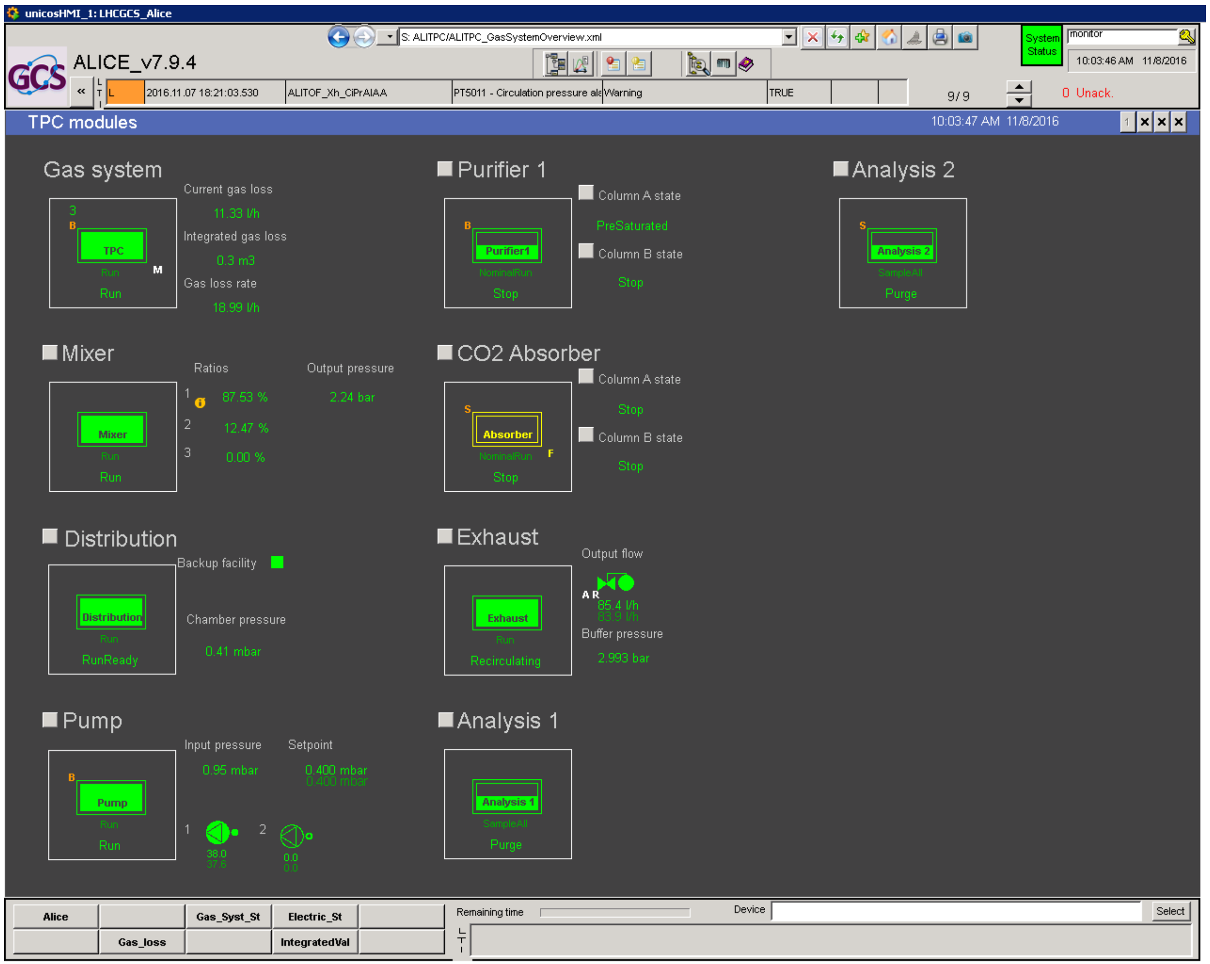
- CMS-CSC CF_4 warm adsorption:
  - built and fully commissioned during 2011-2012.
  - fully automated system running on a dedicated PLC. All the parameters can be monitored and controlled through a PVSS remotely accessible software interface.
  - the system consists of 5 physical racks and it was built 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



Gas Controls System: overview

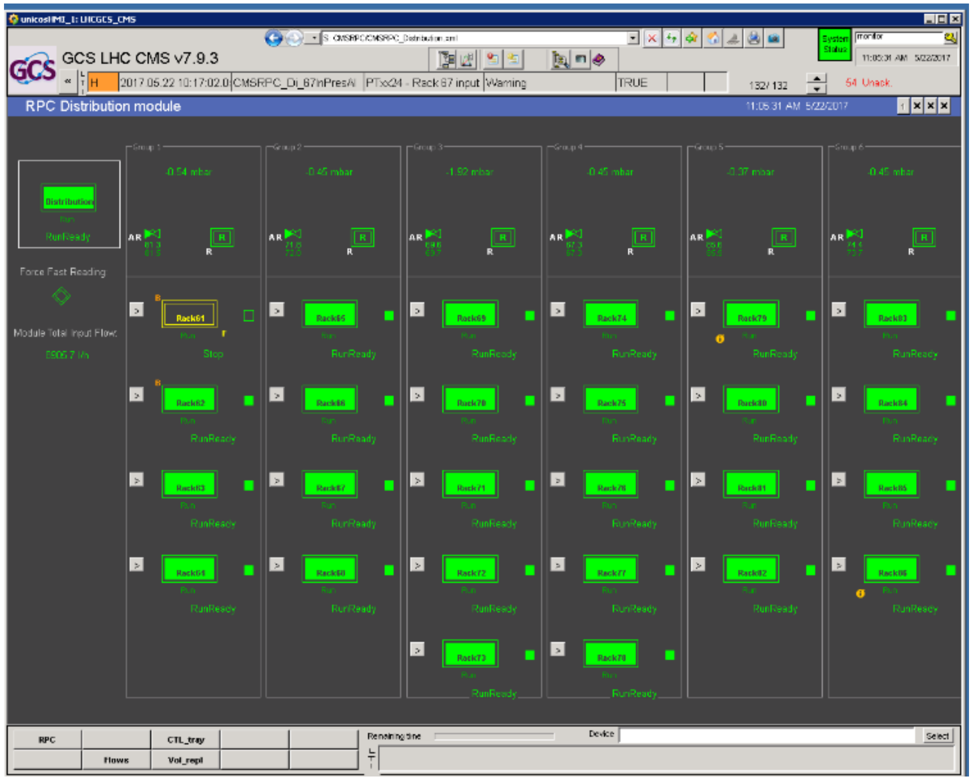
Overview of the modules from the Gas Controls Software interface:

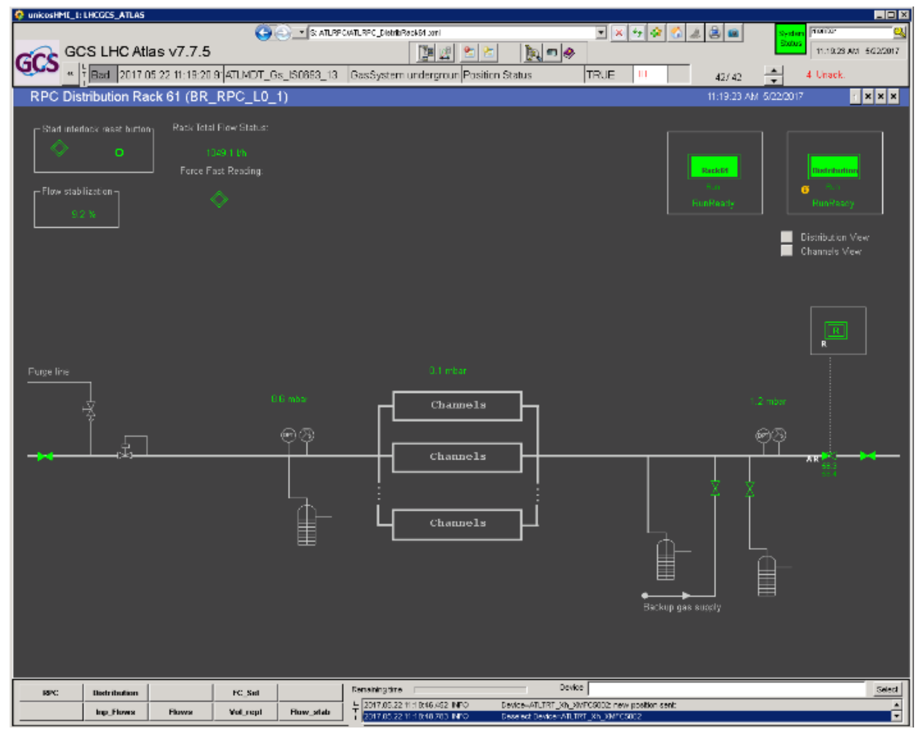
Functional modules



Gas Controls System: Distribution

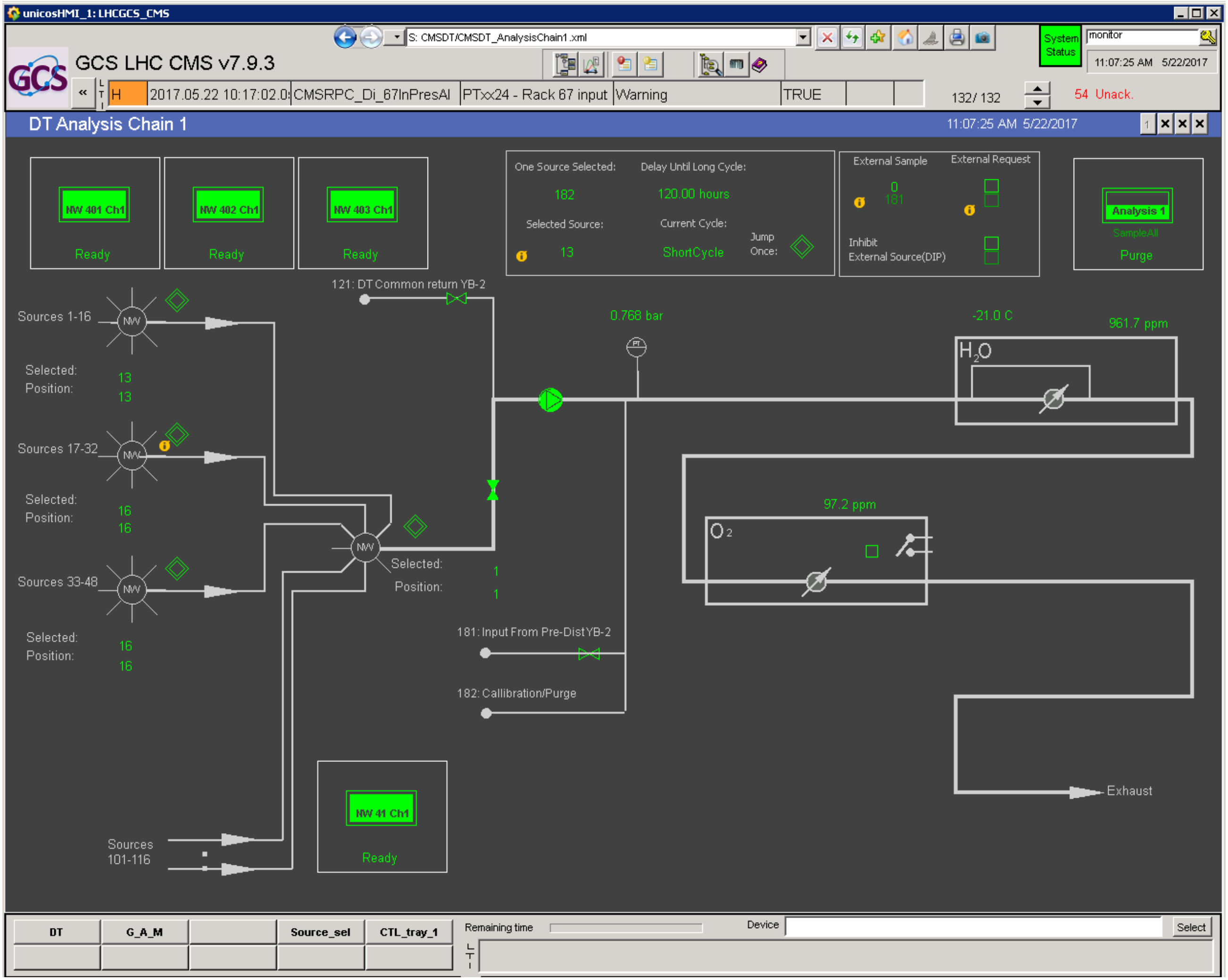
Gas distribution schema:





Gas Controls System: Analysis

Dedicated gas analysis:



GASePlus: a web application quick overview

Under development for a fast overview

LHC GCS SYSTEM STATUS

PUMPS - ANALYSIS DEVICES - CALIBRATION LEVELS - HOME PAGE

ALICE

	Distribution	Gas System	Mixer	PlcCounter	Pump	Exhaust	Purifier1	Humidifier	CO_2Absorber	Membrane	Envelope	Analysis1	Analysis2	
CPV	ON	WIP	ON											CPV
HMP	ON	WIP	ON											HMP
MCH	ON	WIP	ON											MCH
MTR	ON	WIP	ON		ON	ON		ON						MTR
PMD	ON	WIP	ON											PMD
TOF	ON	WIP	ON		ON	ON	ON							TOF
TPC	ON	WIP	ON		ON	ON	OFF		WIP					TPC
TRD	ON	WIP	ON		ON	ON	ON			WIP				TRD

ATLAS

	Distribution	Gas System	Mixer	PlcCounter	Pump	Exhaust	Purifier1	Purifier2	Purifier3	Humidifier	Membrane	Envelope	Liquifier	Circulation	Injection	Analysis1	
CSC	ON	WIP	ON														CSC
MDT	ON	WIP	ON		ON	ON											MDT
RPC	ON	WIP	ON		ON	ON	ON	ON	OFF	ON							RPC
TFC		WIP			Undefined									WIP	WIP		TFC
TGC	ON	WIP	ON		ON		ON						WIP				TGC
TRT	ON	WIP	ON		ON	ON	OFF				WIP						TRT

CMS

	Distribution	Gas System	Mixer	PlcCounter	Pump	Exhaust	Purifier1	Purifier2	Purifier3	Humidifier	Analysis1	Analysis2	Analysis3	Analysis4	
RPC	ON	WIP	ON		ON	ON	ON	ON	OFF	ON					RPC
CSC	ON	WIP	ON		ON	ON	ON								CSC
DT	ON	WIP	ON		ON	ON	OFF								DT
T1	OFF	WIP	ON												T1
T2	ON	WIP	ON												T2
GEM	ON	WIP	ON												T2
CF_4 Recovery															CF_4 Recovery

LHCb

	Distribution	Gas System	Mixer	PlcCounter	Pump	Exhaust	Purifier1	Membrane	Liquifier	Analysis1	Analysis2	
GEM	ON	WIP	ON		ON	ON	ON					GEM
MWP	ON	WIP	ON		ON	ON	ON					MWP
RI1	ON	WIP	ON		ON	ON	ON	WIP	WIP			RI1
RI2	ON	WIP	ON		ON	ON	ON	WIP				RI2
OT	ON	WIP	ON		ON	ON	OFF					OT

Elog: keep track of intervention

> 1000 interventions

recorded in the last year

EP-DT
Detector Technologies

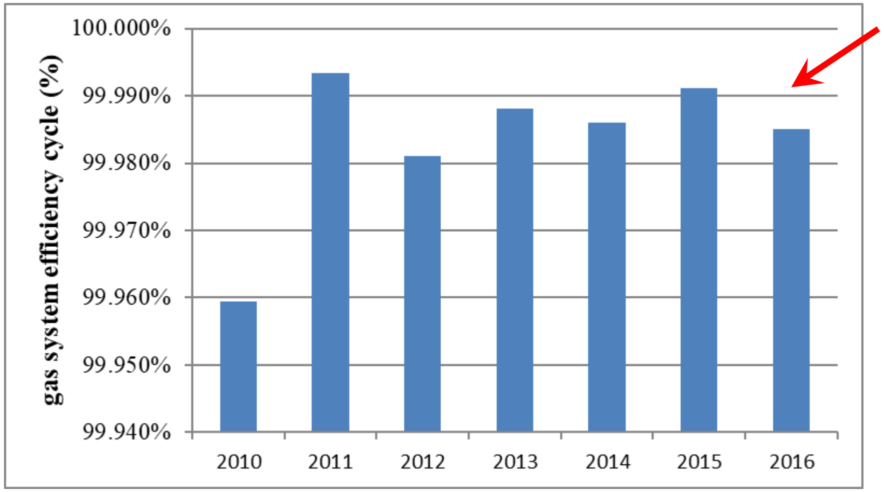
CERN GAS Team eLog

In case of question please contact eLog responsibles: B.Mandelli , A.Diez or G.Candreva

Logbook	Entries	Last submission
Maintenance and Operation		
GASSYSOperation&Maintenance Gas System ELOG Operation (v1.0)	638	19/05/2017, 16:09 by albin wasem
GAS_PIQUET Gas System ELOG Operation (v1.0)	227	20/05/2017, 01:51 by Patrick CARRIÉ
Non-LHC Experiments Gas System ELOG Operation (v1.0)	90	18/05/2017, 19:15 by Patrick CARRIÉ
Material_Borrowed Gas System ELOG Operation (v1.0)	8	18/05/2017, 16:41 by Roberto Guida
New Projects		
CLOUD Gas System ELOG Operation (v1.0)	20	08/11/2016, 15:14 by albin wasem
CLOUD Water Gas System ELOG Operation (v1.0)	3	17/01/2017, 14:23 by Louis-Philippe De Menezes
sClosedLoop Gas System ELOG Operation (v1.0)	12	12/10/2016, 13:43 by Roberto Guida
ATL-sTGC Gas System ELOG Operation (v1.0)	4	12/08/2016, 15:44 by Frederic Merlet
Mixer-IR Gas System ELOG Operation (v1.0)	2	16/09/2016, 22:02 by ALVARO DIEZ GONZALEZ PARDO
Analysis Boxes Gas System ELOG Operation (v1.0)	1	01/08/2016, 13:38 by Louis-Philippe De Menezes
Portable GC Gas System ELOG Operation (v1.0)	3	07/12/2016, 16:12 by ANDREA D'AURIA
CMS_GEM Gas System ELOG Operation (v1.0)	12	26/10/2016, 10:24 by Roberto Guida
MFC Gas System ELOG Operation (v1.0)	62	24/02/2017, 10:35 by vdarras
CF4 Recovery CMS CSC CF4 Recovery eLog	23	05/04/2017, 15:41 by Giulio Candreva
FlowCell Gas System ELOG Operation (v1.0)	3	10/05/2017, 17:07 by Roberto Guida
Gas System Status		
ATLAS ATLAS Gas System Status	1	06/01/2017, 14:52 by Frederic Merlet
CMS CMS Gas System Status	1	16/01/2017, 08:41 by ANDREA D'AURIA
ALICE ALICE Gas System Status	1	06/01/2017, 15:23 by Louis-Philippe De Menezes
LHCb LHCb Gas System Status	1	15/02/2017, 12:21 by Patrick CARRI�D: 15
TOTEM TOTEM Gas System Status	1	06/01/2017, 16:41 by Giulio Candreva

Reliability over the past years

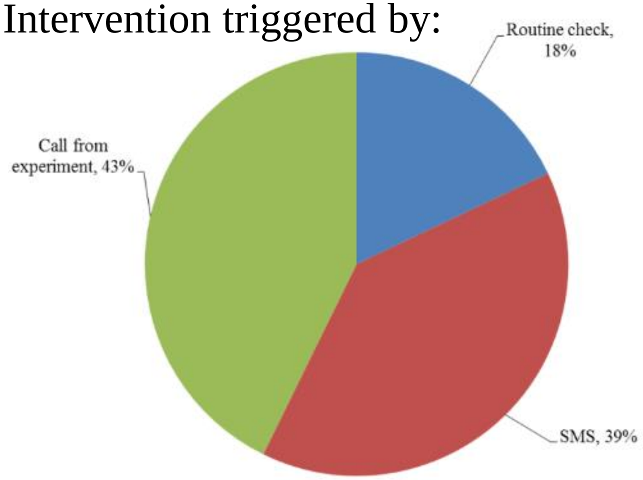
- Results from analysis of the interventions performed during 2010-2016

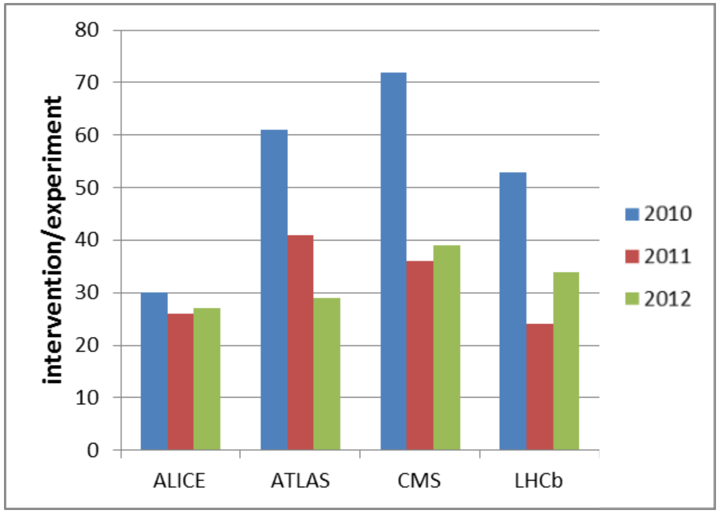


On average less than 1h/year/system of downtime
(power-cuts and outside events excluded)

24/24h on-call service provided

Intervention triggered by:



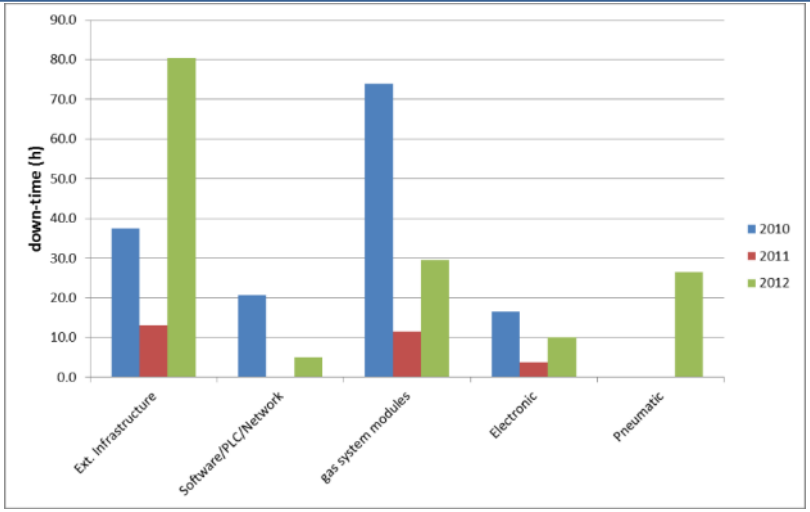


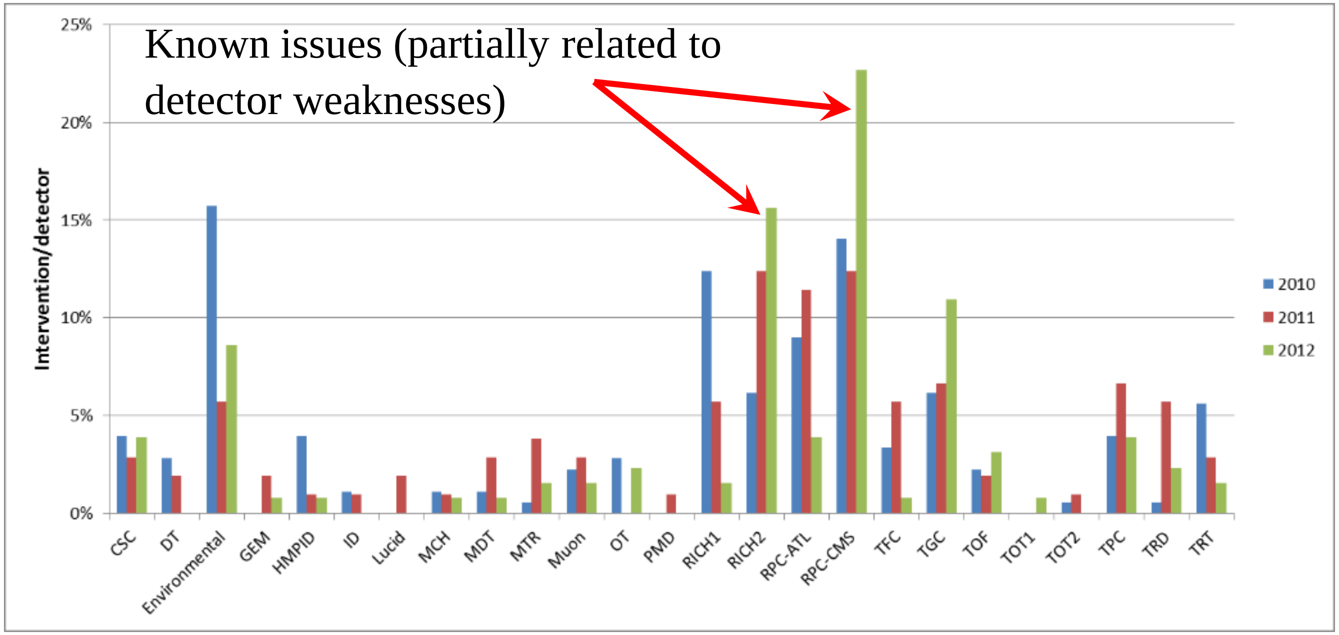
Intervention are
- Equally distributed between experiments
- Decreasing with time ☺

Reliability over the past years

Sources of down-time, analysis:

Issues with gas system modules account only for a small fraction of the total



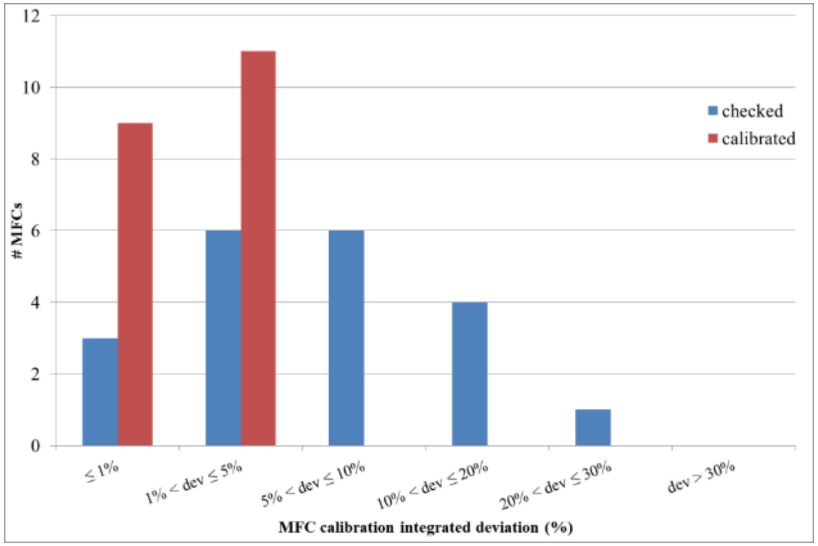


Maintenance challenges

- Extensive maintenance program for each TS or LS:
    - Standard maintenance (yearly maintenance), i.e. circulation pumps, safety valves, power supply, …
    - LS extraordinary maintenance, i.e. analysis devices, flow-cells calibration, MFCs calibration, …

- Consolidation/upgrade program during LS:
    - upgrade circulation pump modules (need to cope with higher circulation flow)
    - Replace H_2O analysers
    - Complete analysis modules for gas supply monitoring system
    - Improve recuperation systems

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



Conclusions

- 30 gas systems (about 300 racks) delivering the required mixture to the particle detectors of all LHC experiments:
  - ~ 2 times the height of the Eiffel tower
  - ~ 1000 intervention of maintenance (preventive and corrective) and consolidation per year

- Designed and built according to **functional modules**:
  - Simplified maintenance and operation activities for the team
  - **Fully automated** systems with remote control/monitoring
  - few examples have been briefly presented
  - **Stable operation** since LHC start-up (> 10 years)

- Gas systems have demonstrated an **impressive reliability level**:
  - On average about 1 h downtime/year (excluded external causes, i.e. power-cuts, …)

- **Maintenance** is fundamental to ensure reliability at long term
- **Consolidation and upgrades** are fundamental to cope with new requirements