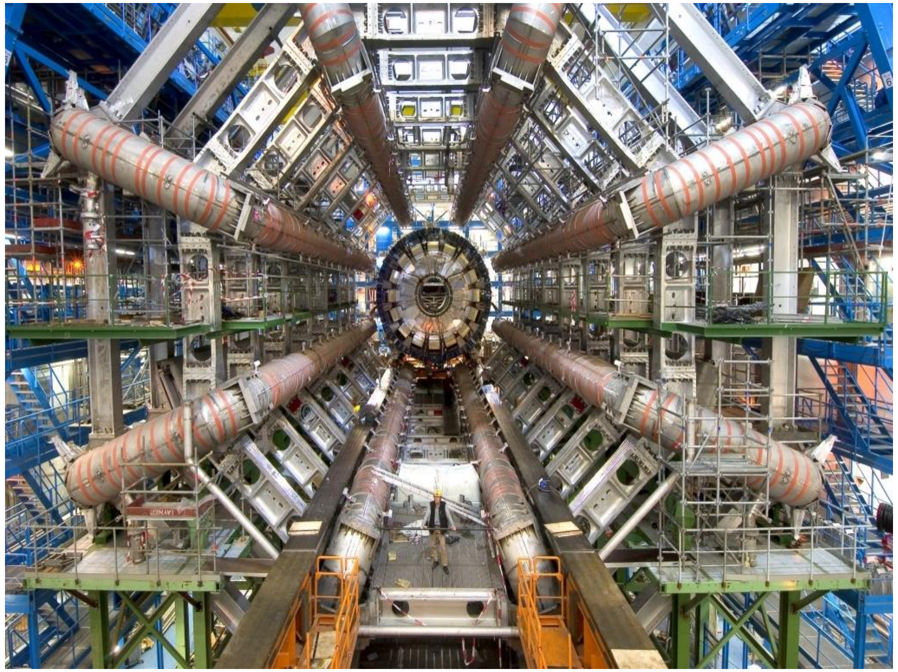
F-gases usage and reduction strategy plan in the ATLAS and CMS experiments

G. Aielli, G. Pugliese and K. Kuznetsova

On Behalf of ATLAS and CMS collaboration

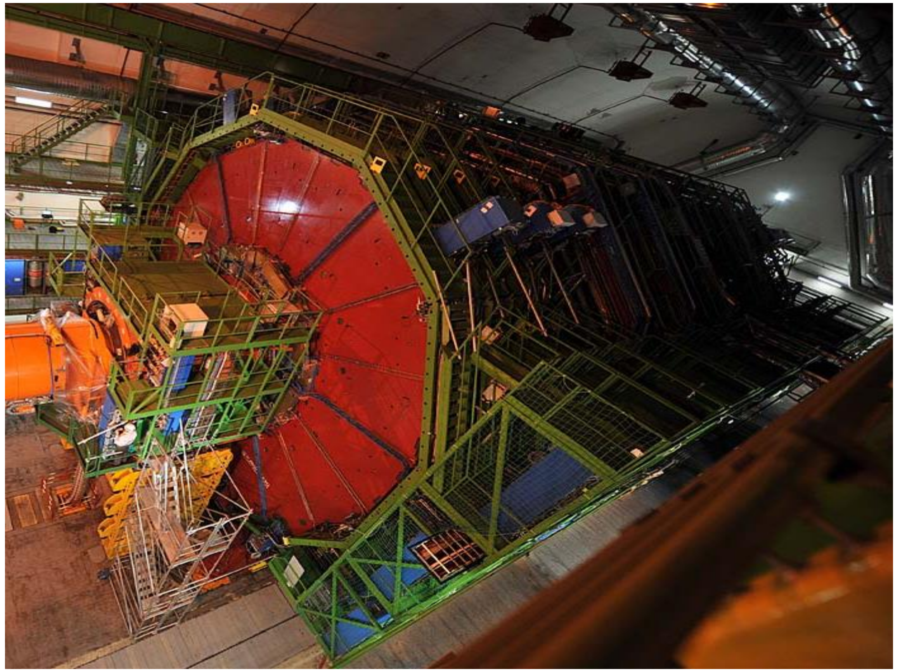
F-gases in ATLAS and CMS experiments



In ATLAS F-gases are used in the RPC system (Barrel only)

- RPC gas mixture: $C_2H_2F_4$+iC_4H_{10}+SF_6 (94.7+5+0.3)%

RPC are crucial for the muon trigger and measurement of the azimuthal coordinate



In CMS F-gases are used in two muon detector systems: CSC (Endcap) and RPC (Barrel + Endcap)

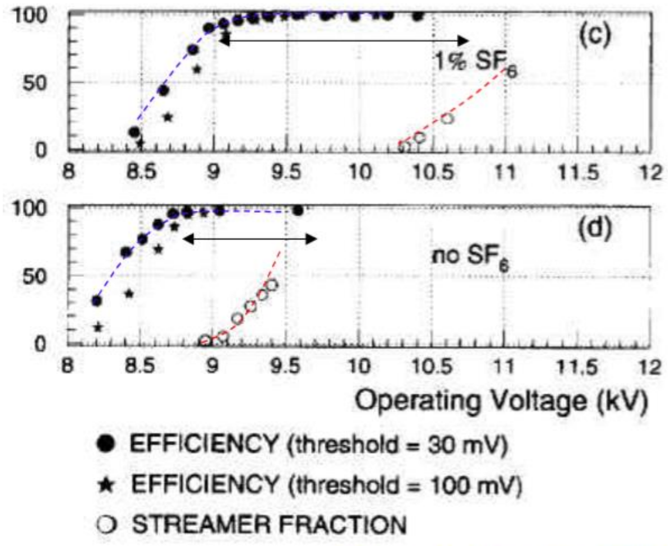
- CSC gas mixture: Ar+CO_2+CF_4 (40+50+10)%
- RPC gas mixture: $C_2H_2F_4$+iC_4H_{10}+SF_6 (95.2+4.5+0.3)%

CSC & RPC are crucial for the muon trigger and reconstrucion

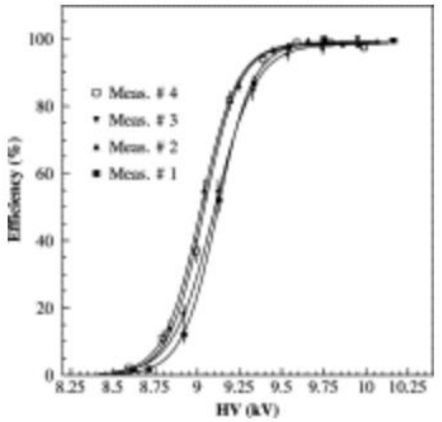
Why $C_2H_2F_4$ and SF_6 in RPC gas mixture?

In 2000s, ATLAS and CMS RPCs mixture was selected to guarantee:

- **Stable detector performance** (high efficiency, large avalanche stability plateau, prevention against ageing effects) **for 10 years of LHC operation.**



R. Santonico, Scient. Acta XII N2(1997)1
P. Camarri et al, Nucl. Instr. and Meth. A414(1998)317

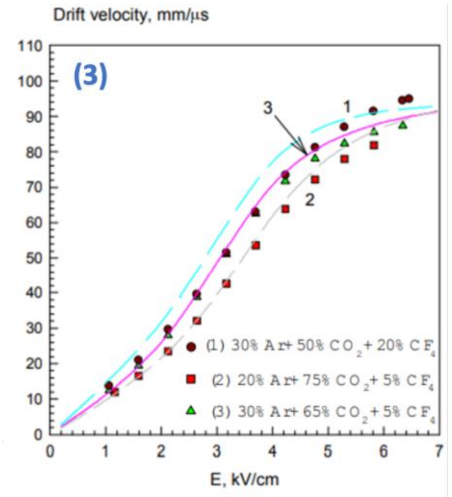


Aging study for resistive plate chambers of the CMS muon trigger detector, M. Abbrescia et al. https://doi.org/10.1016/j.nima.2003.09.021

- Easy procurement and stable price ($C_2H_2F_4$ was the gas used for refrigeration)
- Non Ozone-depleting (replacing the CF_3Br, used in the RPC, that was banned in 1990s)

Why CF_4 in CSC gas mixture?

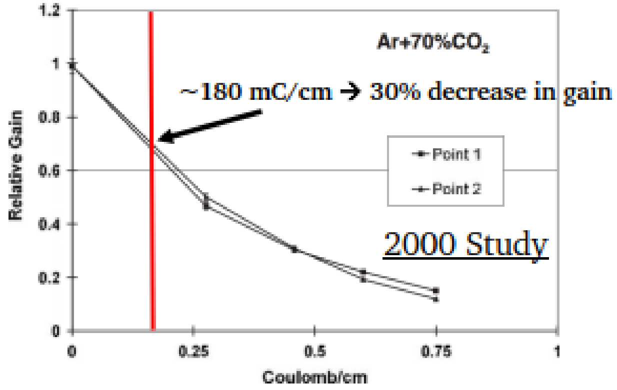
- CSC Drift time varies very slightly for gas mixtures with different low contents of the CF_4

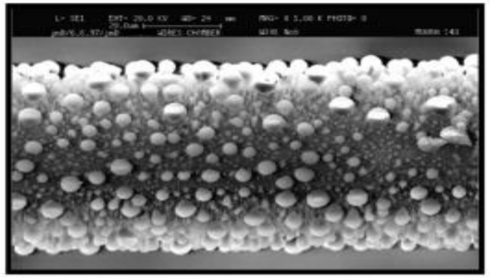


O. Kisselev, V. Soulimov/ CMS NOTE 1997/047

- CF_4 has well known aging prevention properties: it protects from Si deposits and prevents formation of carbon polymerization on anode wires.

- Past irradiation tests (~2000th) with increasingly reduced concentration of CF_4 (**20, 10, and 0%**) on early chamber prototype showed that **with 0%:**
    - Large relative gas gain drop observed from the beginning
    - Anode wire polymerization from Si deposits

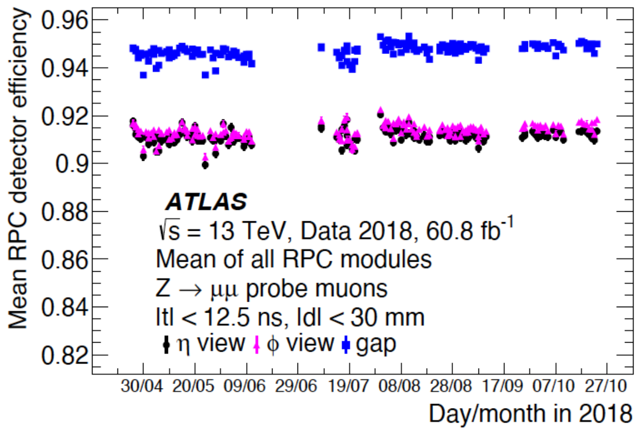


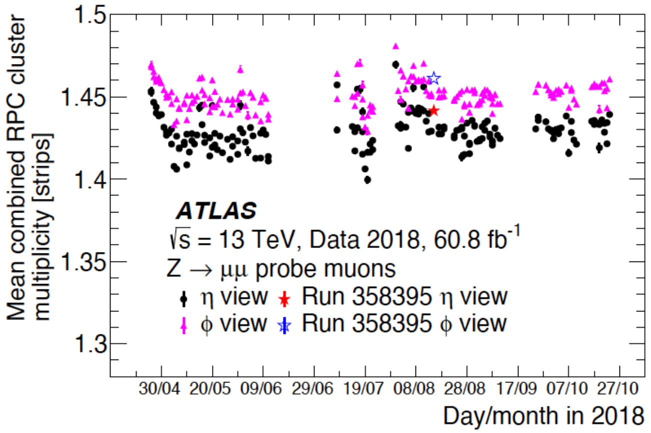


T. Ferguson Nim. A 488 (2002) 240 -257 Aging studies of CMS muon chamber prototype

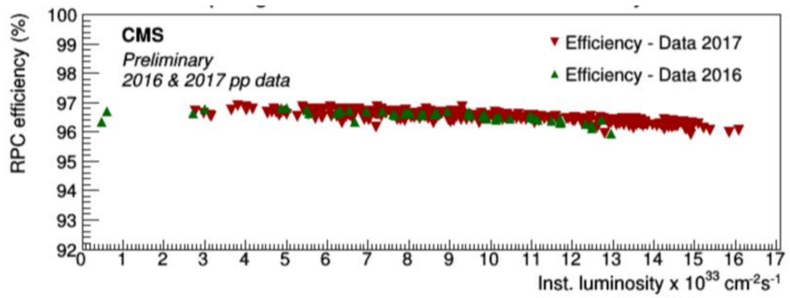
RPC and CSC Systems in operation at LHC

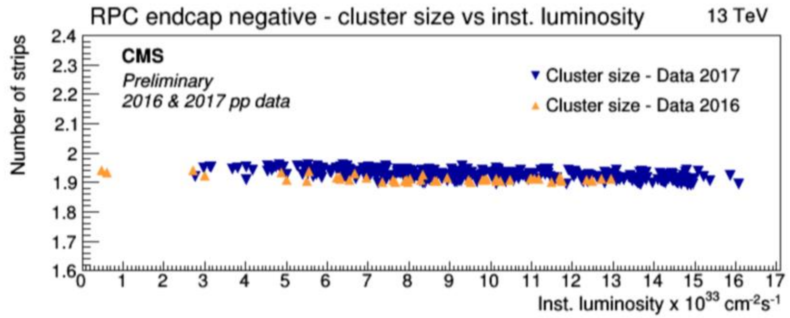
- ATLAS and CMS experiments are in operation since 2010 with an increase of instantaneous luminosity up to 2 10^{34} $cm^{-2}s^{-1}$ delivered by the LHC.
- **Stable performance of both RPC and CSC systems.**

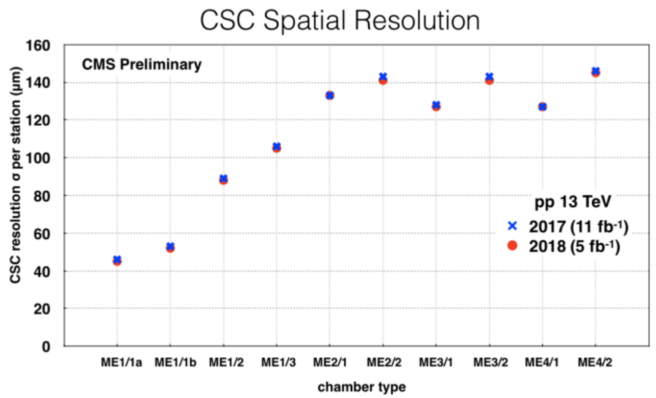




ATLAS RPC efficiency and Cluster size vs. time







Spatial resolutions of CSCs in 2017 and 2018

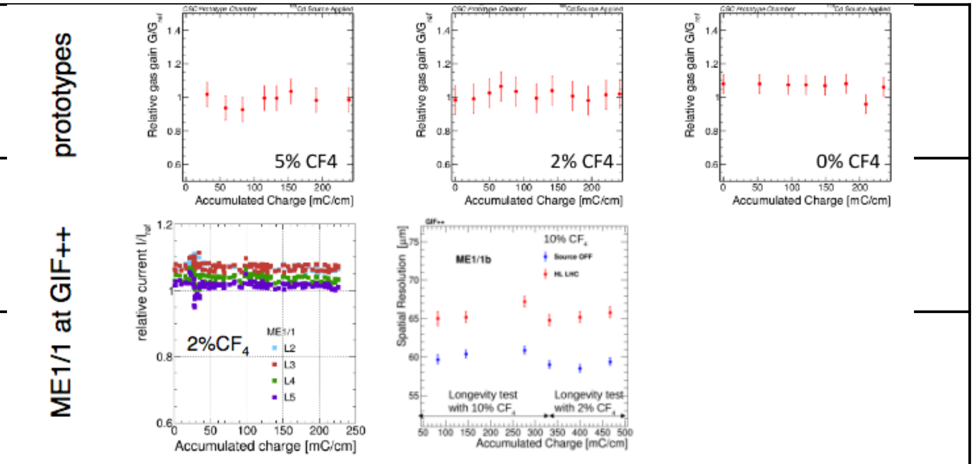
CMS RPC efficiency and Cluster size vs. instantaneous LHC Luminosity

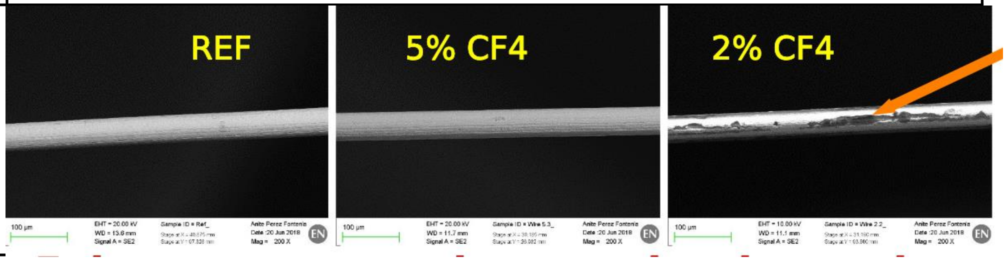
- **F-gases are crucial to guarantee stable detector performance in ATLAS and CMS experiments**

New Irradiation test with reduced CF_4%

- New irradiation test campaigns with **reduced concentrations of CF_4** between 10% and 0% is ongoing on real CMS chamber ME1/1 and on small CSC prototypes:

Irradiation test	Chamber type	Integrated Charge (C/m)	%CF4	Results
GIF++	M1/1 & M2/1	0.33	**10**	**no significant performance degradation**
	M1/1	0.27	**2**	**no significant performance degradation**
904, GIF++ and PNPI	Mini CSCs (ME2/1 type)	0.24	**10** **5** **2** **0**	- **no significant performance degradation** - Anode depositions are seen with 2 and 0 %CF4

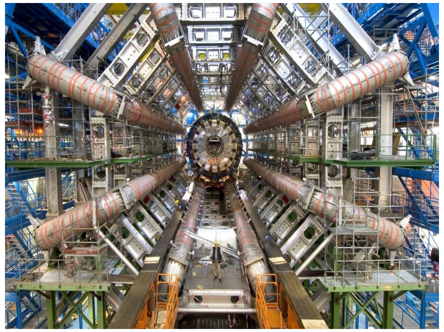


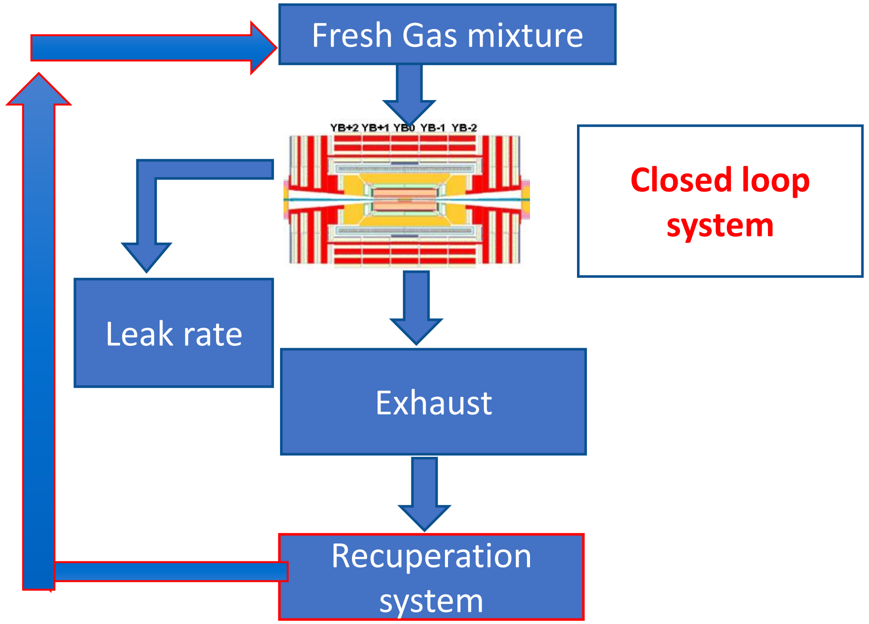


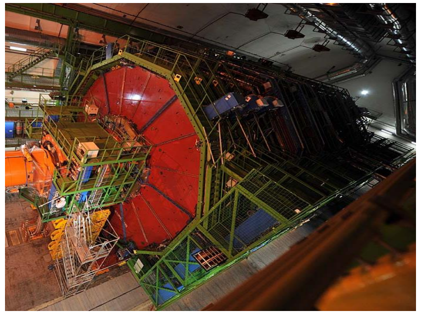
Note: ***0.72 C/m*** *is the expected integrated charge in 3 x HL-LHC period (from recent simulation studies)*

- **Longevity studies for mixtures with reduced CF_4% (2 and 5%) are continuing.**
- **Preliminary, it seems possible to operate the CSC with 5% of CF4 (with 50% of reduction on the emission with respect to RUN2).**

ATLAS and CMS Gas Systems







CMS and ATLAS are very large experiments:

- CMS RPC system has detector volume ~13 m^3
- ATLAS RPC system has detector volume ~15 m^3
- CMS CSC system has detector volume ~70 m^3

→All systems were certified to work in closed-loop gas circulation mode with **10% of fresh gas replenishing** rate

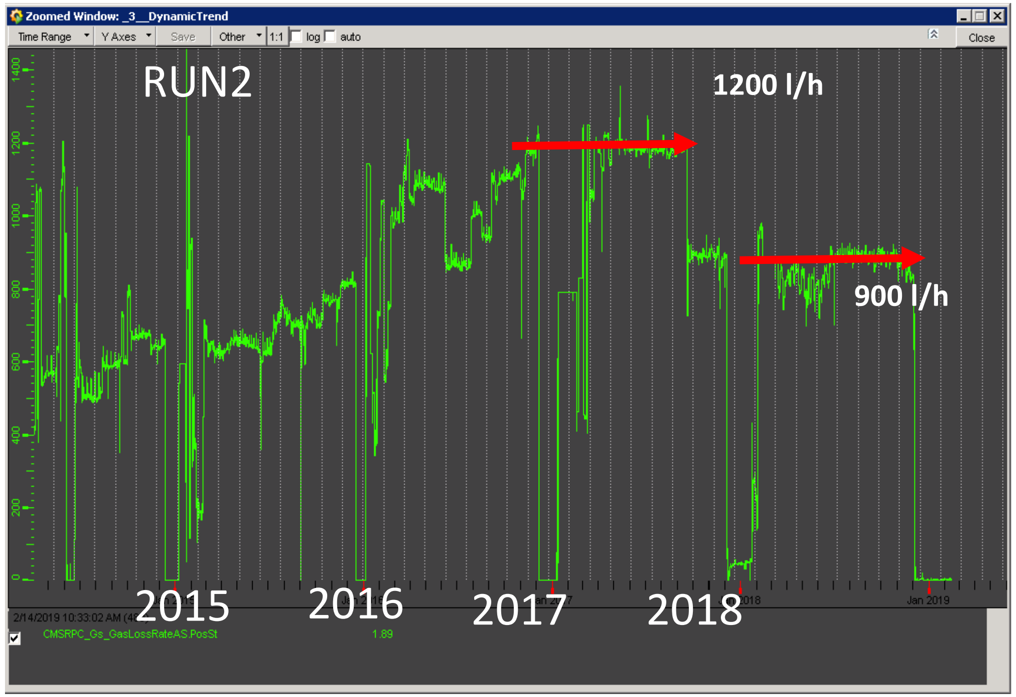
New R&D is going to start in GIF++ to improve the gas purification to reduce the fraction of fresh gas in the closed loop system (reducing the F-gases emission (see Beatrice's talk)

→Since beginning of **RUN2,** CMS CSC gas system is equipped with **a CF4 recuperation system** with **40% of efficiency)**

R&D ongoing to improve the recuperation efficiency reducing the F-gases emission (see Beatrice's talk)

Detector gas tightness: CMS case

CSC system is reasonably gas tight: leak rate is ~1% of total flow (constant in time).

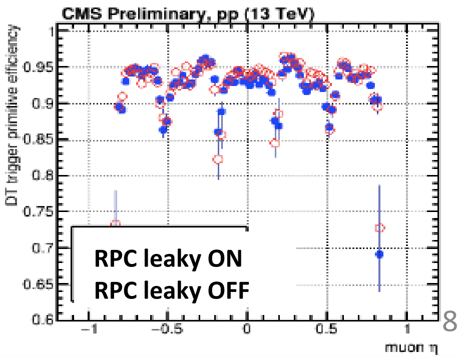


RPC system:

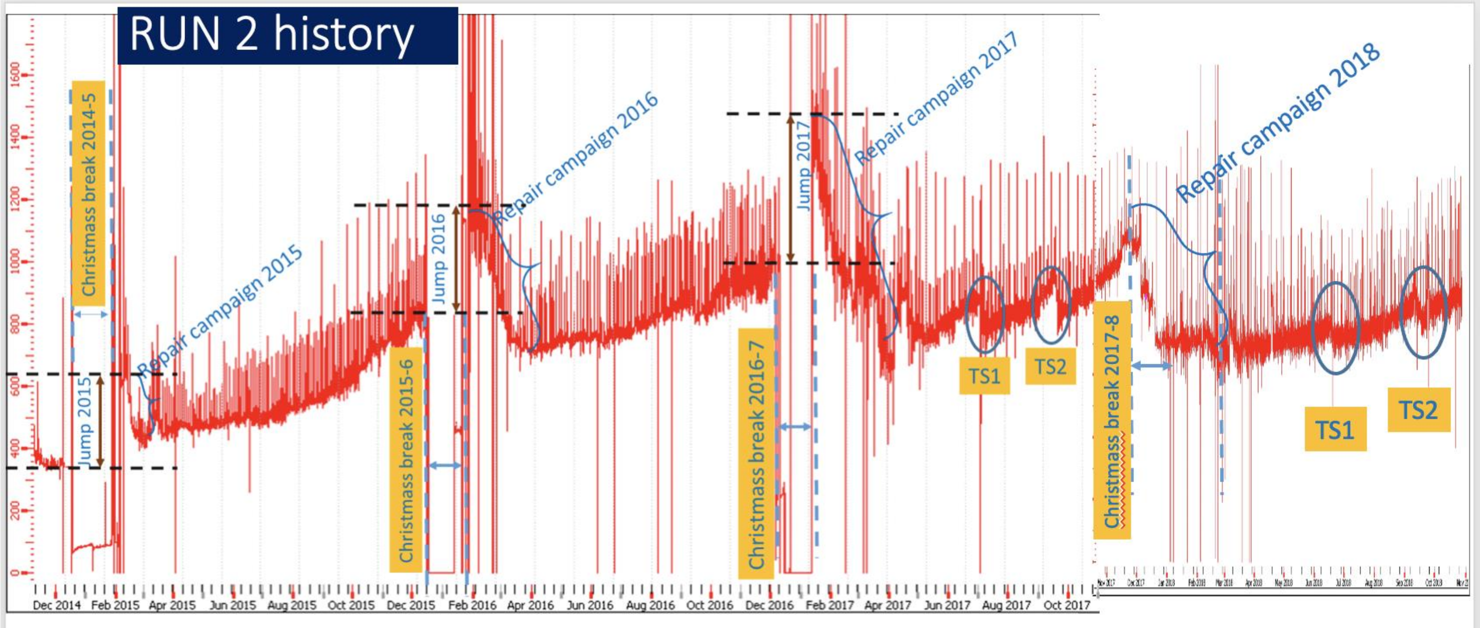
- A significant increase of leak rate detected in 2015 and 2016, bringing the leak rate from 600 l/h to 1200 l/h (Run 1 leak rate in backup)
- Since 2017 up to end of RUN2 stability has significantly improved, due to of improved operation mode and controls system of the Cavern ventilation system which was causing abrupt changes pressure.
- **Leaky chambers are located mostly in the Barrel region**

Note

- In Sept. 2017, 26/480 Barrel RPC, not repairable because no access to the detector, have been disabled.
  - Degradation of L1 Trigger performance at a few percent level (thanks to the CMS Muon "redundant" system)
- This has reduced the leak rate from 1200 l/h to 900 l/h and brought the replenishing gas rate from 12% to 10%



Detector gas tightness: ATLAS case

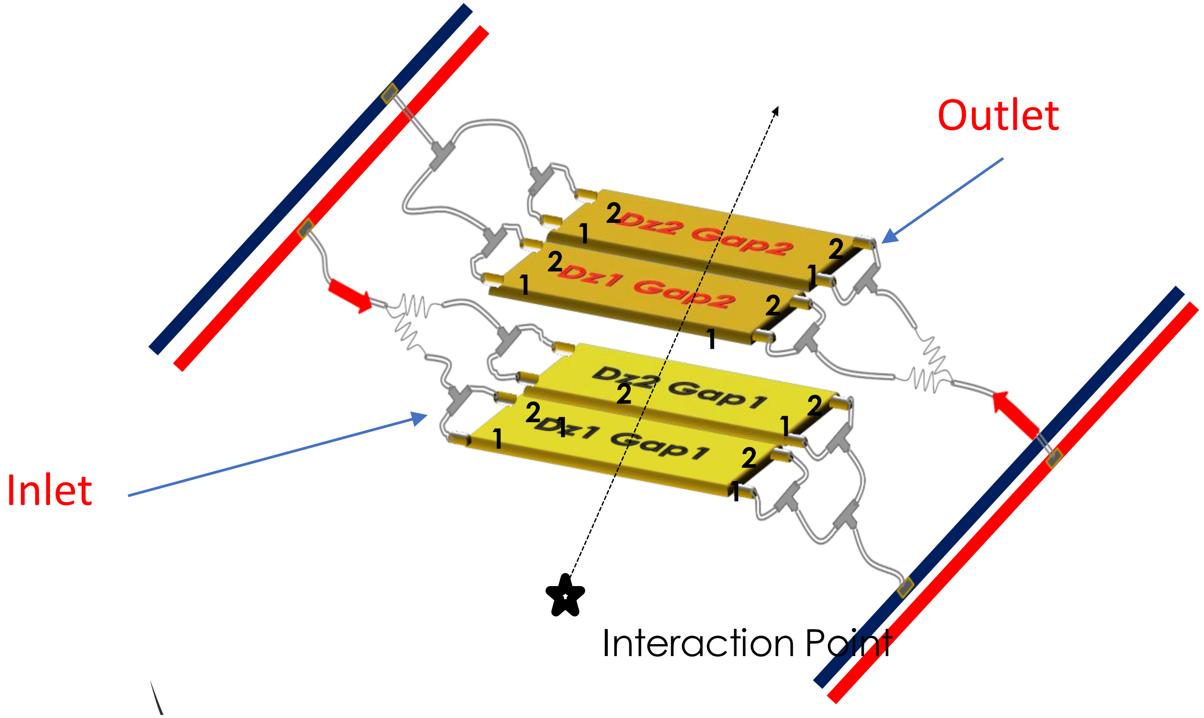


- Leak rate increases at increasing speed during the run.
- Year after year the leak rate increase vs time lowered.
- Repair campaign performed during each Technical Stop with an increased capacity during each campaign (more detail later).
- Disruptive events in 2015-16-17 YETS: This was caused by the start-up procedure of the gas system, in particular concerning the initial purge operation.
- The long term consolidation of the system started

Causes of the leak: ATLAS case

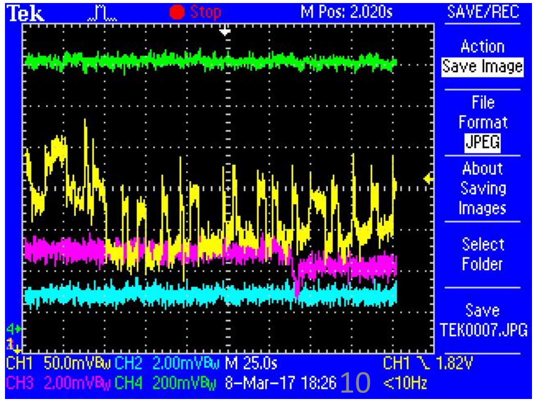
The ATLAS RPC leaks are **concentrated in the gas inlets and outlets.**

Typical new cracked inlet



The following main causes were individuated:

- A lower than expected quality in the original polycarbonate moulded inlet and outlet production
- A stress applied to the gas inlets through the gas pipes
- The gas system is generating a constant stress in form of fast propagating flow changes (order of 1-2 %)
- The former purge procedure (happening at each YETS) was producing a very large shock with a consequent large system damage.

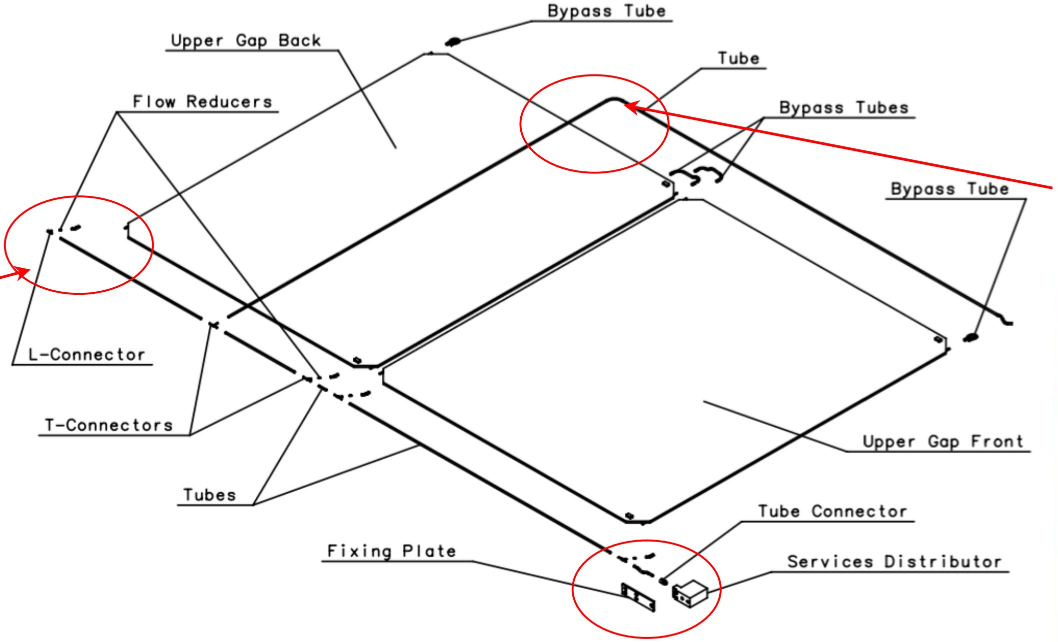


Causes of the leak: CMS case

The CMS RPC leaks are mainly caused by:

1. T or L polycarbonate gas connectors break due to too much stress applied through the gas pipes.
2. Polyethylene LD pipes brittle/deteriorated or cut. This problem is mainly present in the last two station where two chambers are internally connected in parallel.
   - One “bad” batch of pipes was identified. Cracked pipes are all coming from the same batch.
   - Environmental cavern Humidity can accelerate this process.

Broken L



Cut bypass pipe RB3/RB4

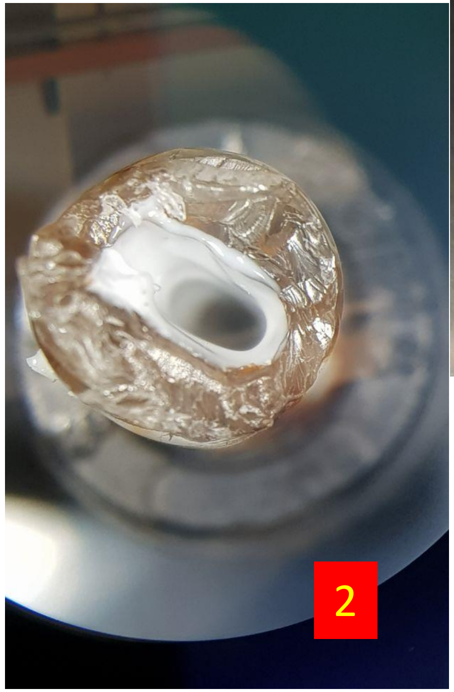
Leak repair technique: ATLAS case

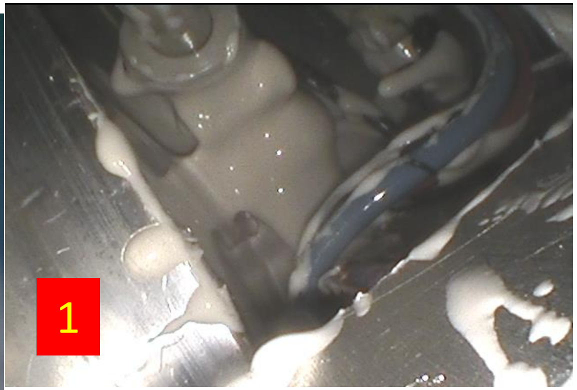
Repair interventions are strongly affected by limited access (space and time) and by the availability of specialized person power.

An extensive R&D was done to develop the most efficient and fast repair technique to reach cracks that must be repaired remotely.

1. With the present method, a glue can be precisely sprayed with a special tool driven with Ultra-Thin wireless endoscope to completely cover the surface of the leaking inlet.
2. A thin sealant layer in the internal inlet surface (trough pipes) can be deposited (if the crack is not complete), to stop or prevent further degeneration.
3. We are studying to completely fill the service boxes using an expanded polyurethane.

1



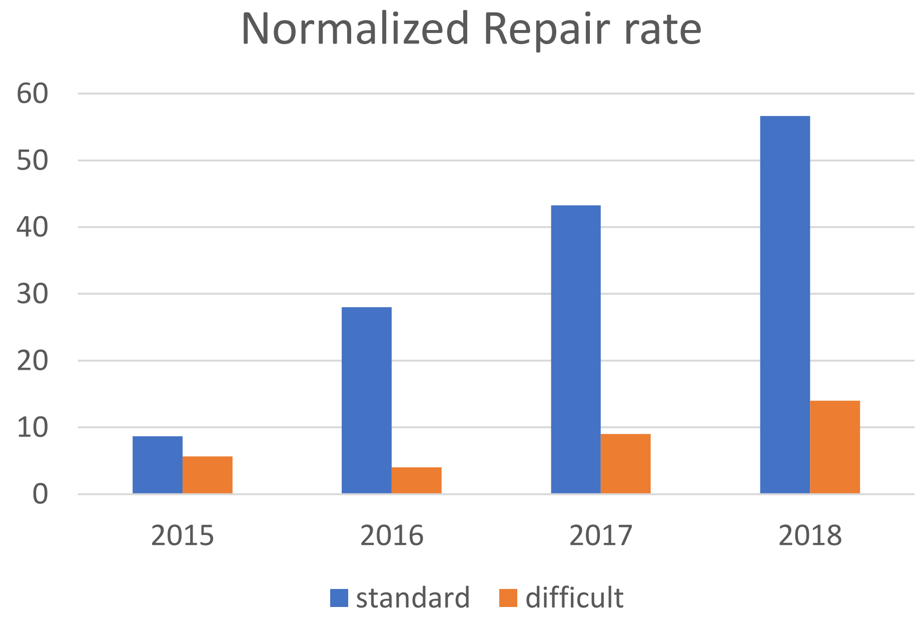


The resistance of the reparations depend on glue characteristics a lot of test were done to identify a better candidate, Dow corning 3140 used from this year seems considerably stronger than the old 734

ATLAS RPC Leak repair campaign

Chambers FIXED *		2018	2017	2016	2015	2008-2015
not BOL	***# Gas Layer Fixed***	***82***	***105***	***49***	***13***	***194***
	# Inlets Fixed	*170*	*173*	*84*	*26*	*340*
BOL chambers	***# Gas Layer Fixed***	***20***	***22***	***6***	***5***	***57***
	# Inlet Fixed	*42*	*36*	*12*	*17*	*115*

Chambers leaking now		very difficult-postponed
not BOL	***101***	***15***
BOL	***85***	***16***



340*

	RUN1 LS1	RUN2				LS2		
	0	2015	2016	2017	2018	2019	2020	2021
# Gas Layer Fixed* (tot=2136)	***251***	***18***	***55***	***127***	***102***	***270***	***94***	***33***

**Gas layer is one or two RPC gas Gap in series*

in each chamber there are 2 to 8 Gas Layers

*known number gas layers to be repaired at begin of 2020

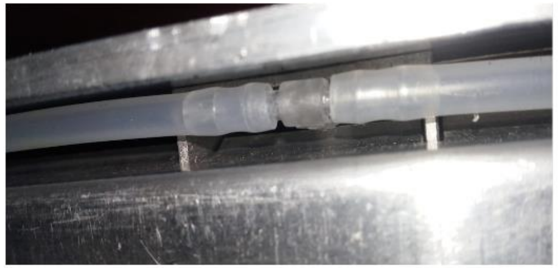
Huge person power effort is put in place to fix the leaks

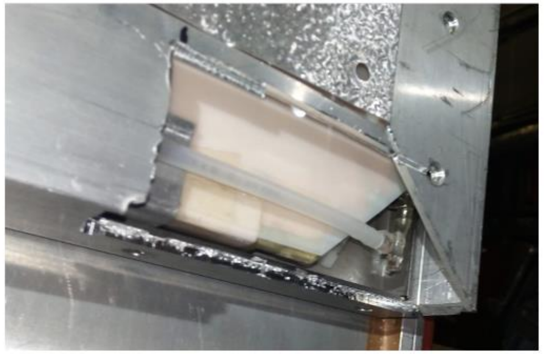
Leak repair technique: CMS case

CMS RPC Barrel chambers are coupled with the DT chambers and inserted in the iron. Very difficult to have access to the broken component. New repair procedure in-situ was developed consisting of partial extraction of the muon station (RPC and DT) of 80 cm from **back** or front side; “chirurgical” cut the C illumining profile to have access to the broken component (gas pipes or T/L connectors); repair/replace of the component.

Back extraction example:

Access to broken component





Repairs

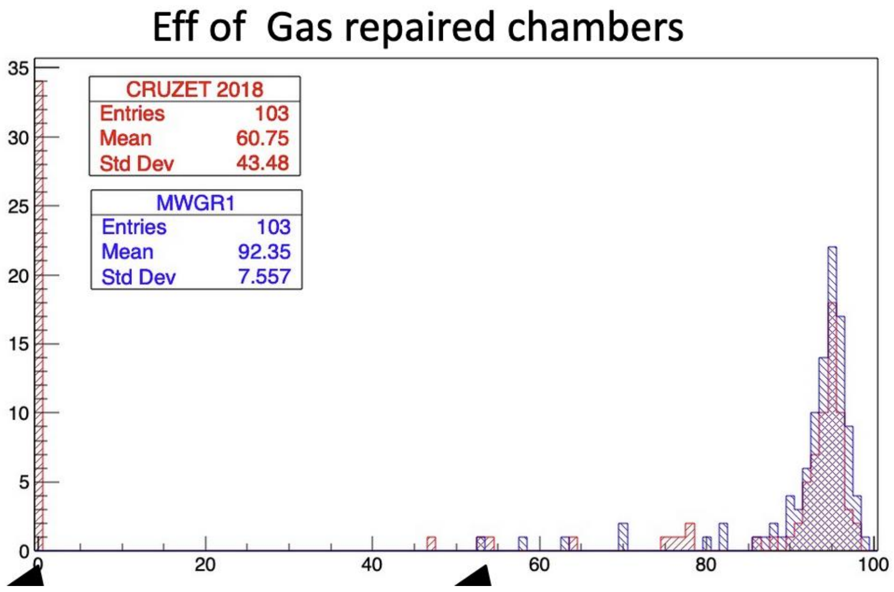
1. Repair done by removing the broken pipe and by-passing the internal circuit and moving externally the parallel connection of two chambers
2. Repair done by gluing the L connector

Closing and validation

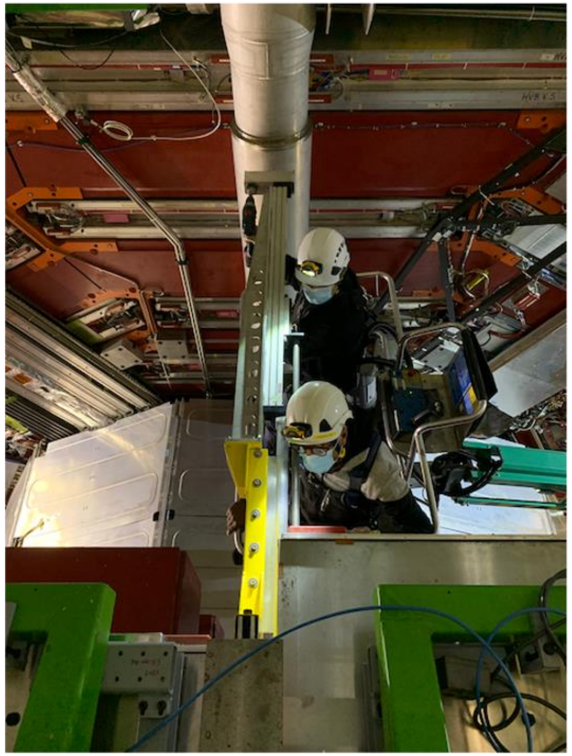
CMS RPC Leak repair campaign

Extensive RPC leak repair and commissioning campaign is carrying out in LS2.

REPAIRED and Commissioned	Leak not identified	NO reparation possible with partially extraction
51%	30%	19%



Efficiency with cosmic muons after Gas leak repair intervention

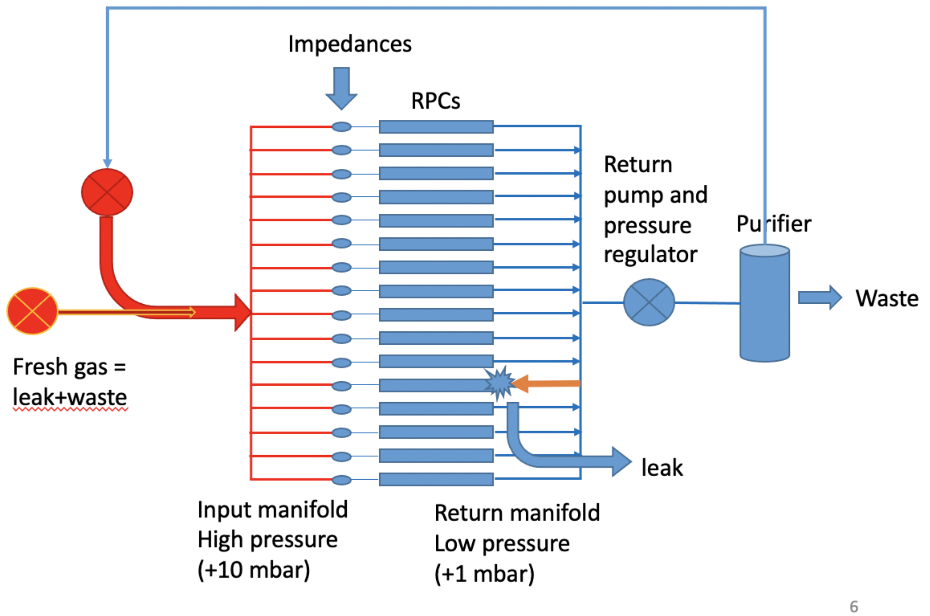


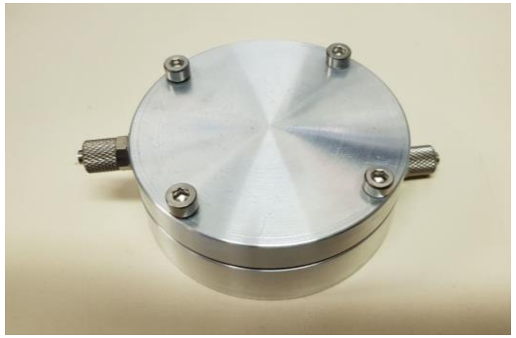
- 50 RPCs successfully repaired and commissioned.
- 49 RPCs are still leaking. For these chambers, the gas distribution has been modified by moving the services box in an accessible place to connect and disconnect the chambers at any moment.

Mitigation of the effect of the leaks (ATLAS case)

A large fraction of gas is lost during the LHC runs due to new leaks appearing:

- It can last months until the next TS (when access to the detector is possible)
- Each of these leaks lose 10 of l/h
- In Atlas up to 24 RPC gaps are connected in parallel to the same manifold line.





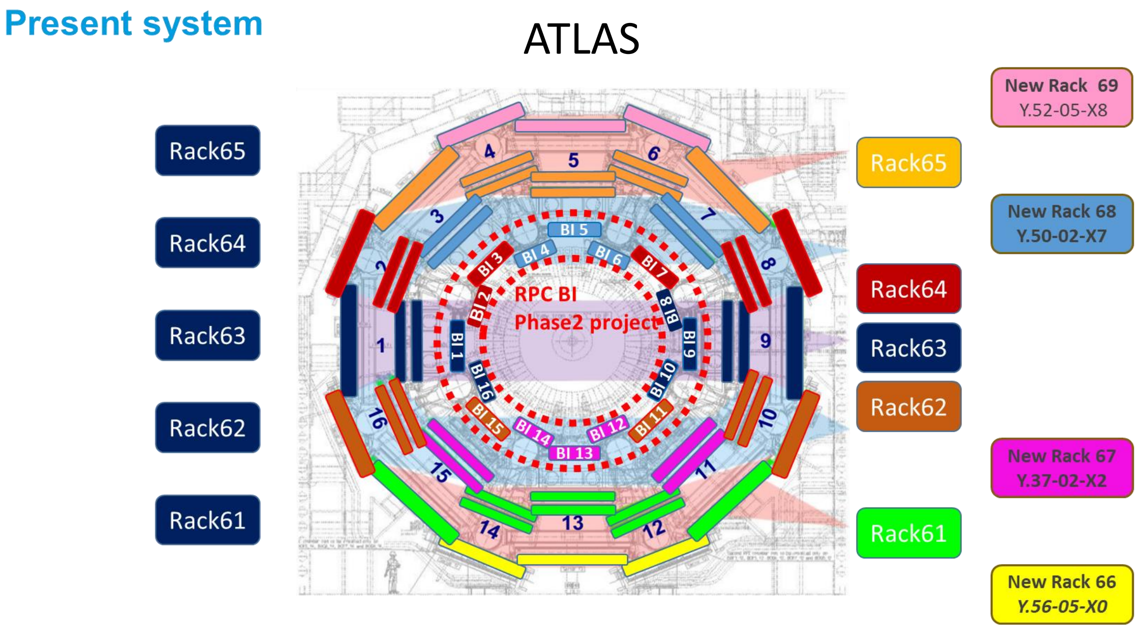
Non-return valve

- This leak can be stopped by installing a non-return valve at the RPC output to close up with an overpressure of a fraction of a mbar.
- R&D done in Roma Tor Vergata to design, build and validate such new device which does not exist on the market.
- The installation of 1200 valves is planned for LS2.

Consolidation of the Distribution Gas system

see Beatrice's talk

Atlas Consolidation
Fast Flow Pulses amplitude reduction:
The fast pulses amplitude is reduced introducing a little gas impedance in the output manifold of each Rack. A better setting in the PID parameters of the control valves will be implemented for RUN3.
Pressure Chambers Reduction: new 4 Rack to increase the vertical partition of the distribution.

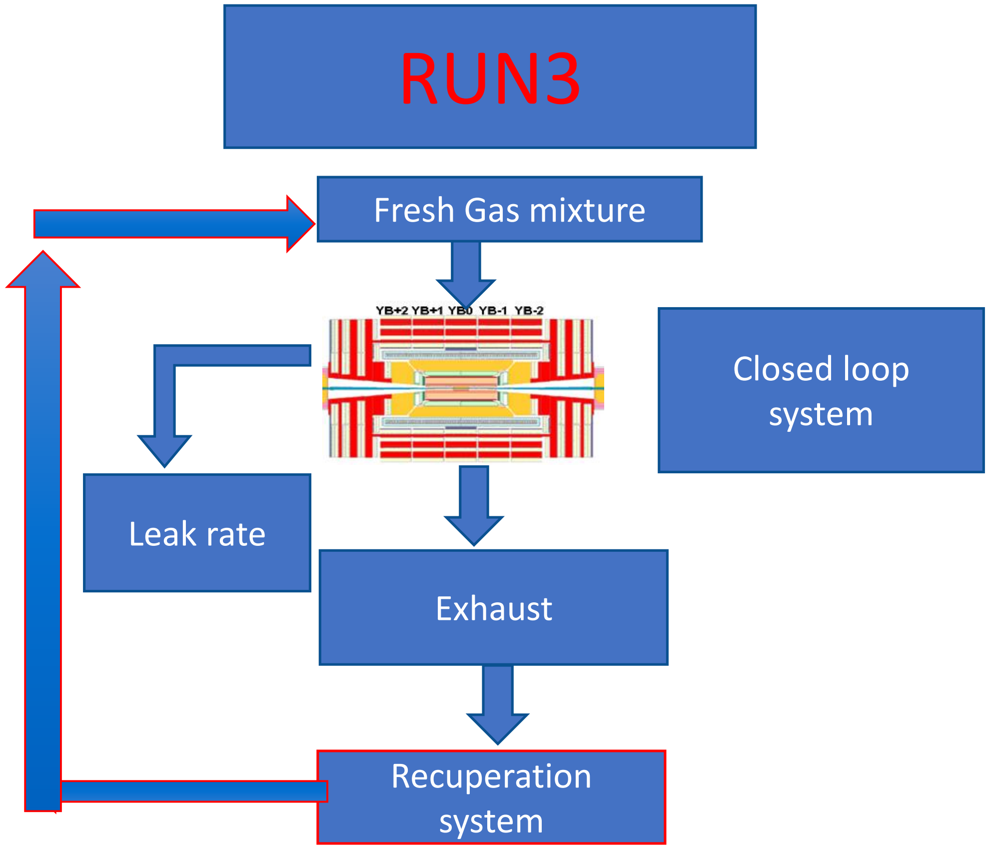


CMS Consolidation

LS2 Upgrade

Automatic regulation valves: in each gas rack, a pressure regulation valve will be added to minimize pressure variations in the chambers: Nowadays pressure regulation is done automatically for group of racks and manually for each distribution rack. We want to install new automated regulation valves on the return of each distribution rack to minimize any pressure changes decrease and decrease the risk of developing new leaks at the detector level.
Reference chambers: the pressure used to control the new automatic valve will be measured by using new "dummy" chambers (cylindrical volume) instead of, as it is now, the rack pressure which is a measurement taken at a different height with respect to the chambers.

RUN3 and beyond expected operation and reduction emission



CMS

RPC:

- Reduce the leak rate from **900 l/h to 120 l/h**
- Restore the exhaust
- Install $C_2H_2F_4$ recuperation system with **an efficiency of 80%**
- **Reduce the fraction of fresh gas**

CSC:

- **Improve CF4 recuperation** system efficiency from **40 to 70%**
- Reduce of CF4 fraction in the gas mixture from 10 to 5%

→ **Expected reduction of F-gases usage is 80%**

ATLAS

- Reduce the leak rate from an average of 800 l/h to 600 l/h (pessimistic estimation)

→ **Reduction could be bigger if all actions in place will give positive results**

Conclusions

F- gases are crucial to guarantee stable performance of the RPC and CSC systems in the ATLAS and CMS experiments.

Since 2013 the ATLAS and CMS groups are working in synergy with EP-DT groups in order to **drastically reduce the F-gas emissions exploring several R&Ds:**

- On CSCs:
  - Reduce the CF_4 fraction from 10% to 5%
  - Increase the CF_4 efficiency recuperation system from 40% to 70%
- On RPCs:
  - Repair the leaks, mitigate the effect of the leaks, consolidate the gas distribution system
  - Reduce the fraction of fresh gas in closed loop circulation
  - Develop and install a $C_2H_2F_4$ recuperation system with an efficiency of 80%

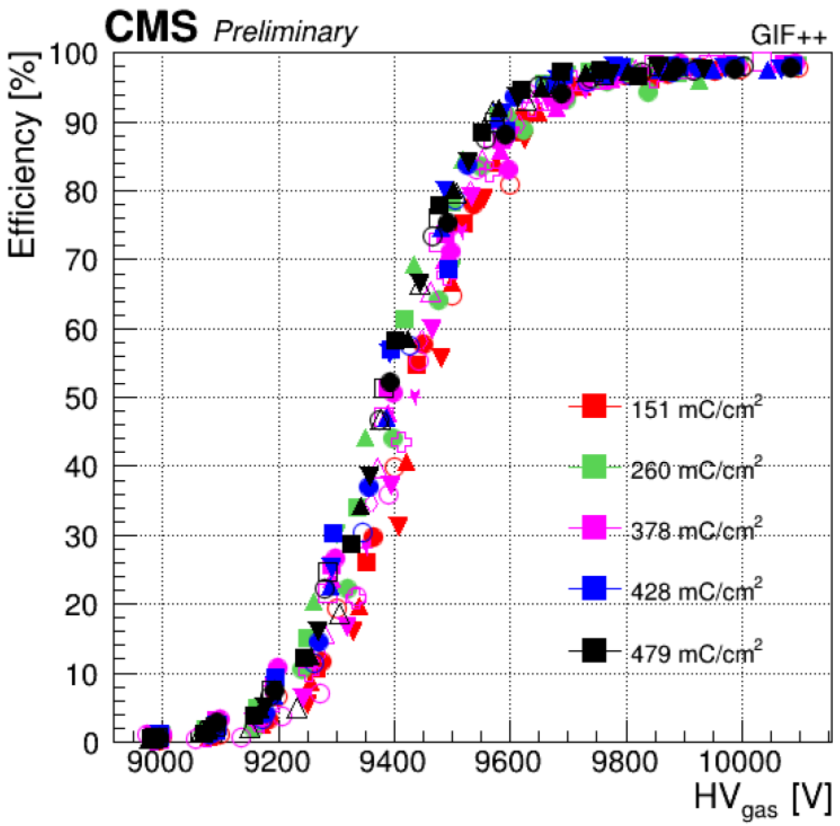
SPARES

New RPC Irradiation test for HL-LHC

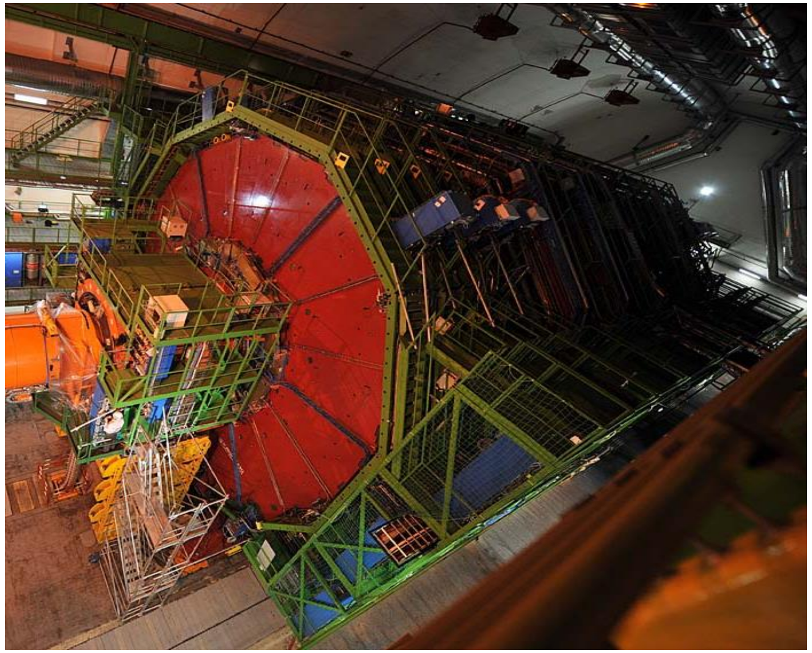
- Since 2016, a new RPC longevity test started in GIF++ to validate the RPCS for 3x HL-LHC operations.

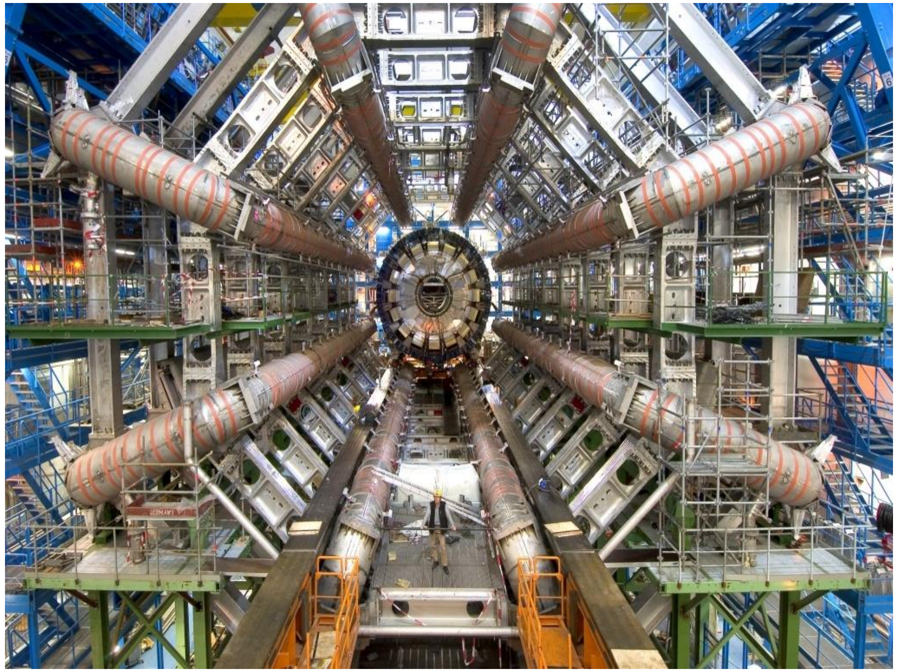
- 1 m/C2 is the expected 3 HL_LHC integrated charge

- Stable performance so far.
- Next beam test in July 2021 (after having irradiated 90% of the total charge)



ATLAS and CMS experiments in numbers





Compact Muon Solenoid

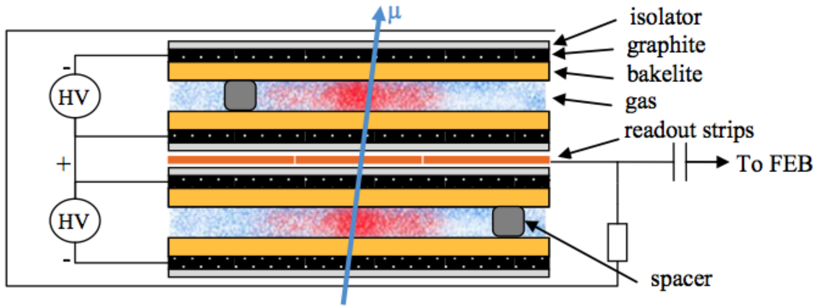
- **15 m wide** and **28.7 meters long**
- **Weighs:14000 t** (twice as much as the Eiffel Tower)
- **Solenoid magnet field: 3.8 T**
- Scientists and engineers: ~2000

A Toroidal LHC ApparatuS

- **25 wide** and **46 meters long**
- Weighs: 7000 t
- Toroidal Magnet: 1 T (in the muon chambers)
- Scientists and engineers: ~3000

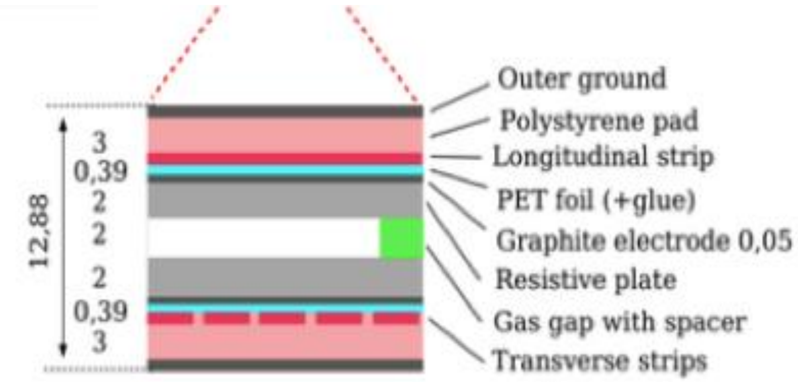
ATLAS and CMS RPCs

CMS



- **Double gaps: 2mm gas gap width**
- **Working in avalanche mode**
- **Bakelite** bulk resistivity: $\rho = 2 - 5 \times 10^{10}\,\Omega cm$
- **Gas Mixture** 95.2% $C_2H_2F_4$+4.5% i-C_4H_{10}+ 0.3%SF_6
- **Strip read-out:** 2 ÷ 4 cm
- **Charge per hit ≈ 25 pC**

ATLAS



- **Single gap: 2mm gas gap**
- **Working in avalanche mode**
- **Bakelite bulk resistivity:** $\rho = 2 - 5 \times 10^{10}\,\Omega cm$
- **Gas Mixture** 94.7% $C_2H_2F_4$+5.0% i-C_4H_{10}+ 0.3%SF_6
- **Strip read-out in η and φ:** 2.3-3.5 cm
- **Charge per hit ≈ 20- 30 pC**

CMC RPC leak in RUN1