The CMS RPC system readiness for LHC Run-3 data taking

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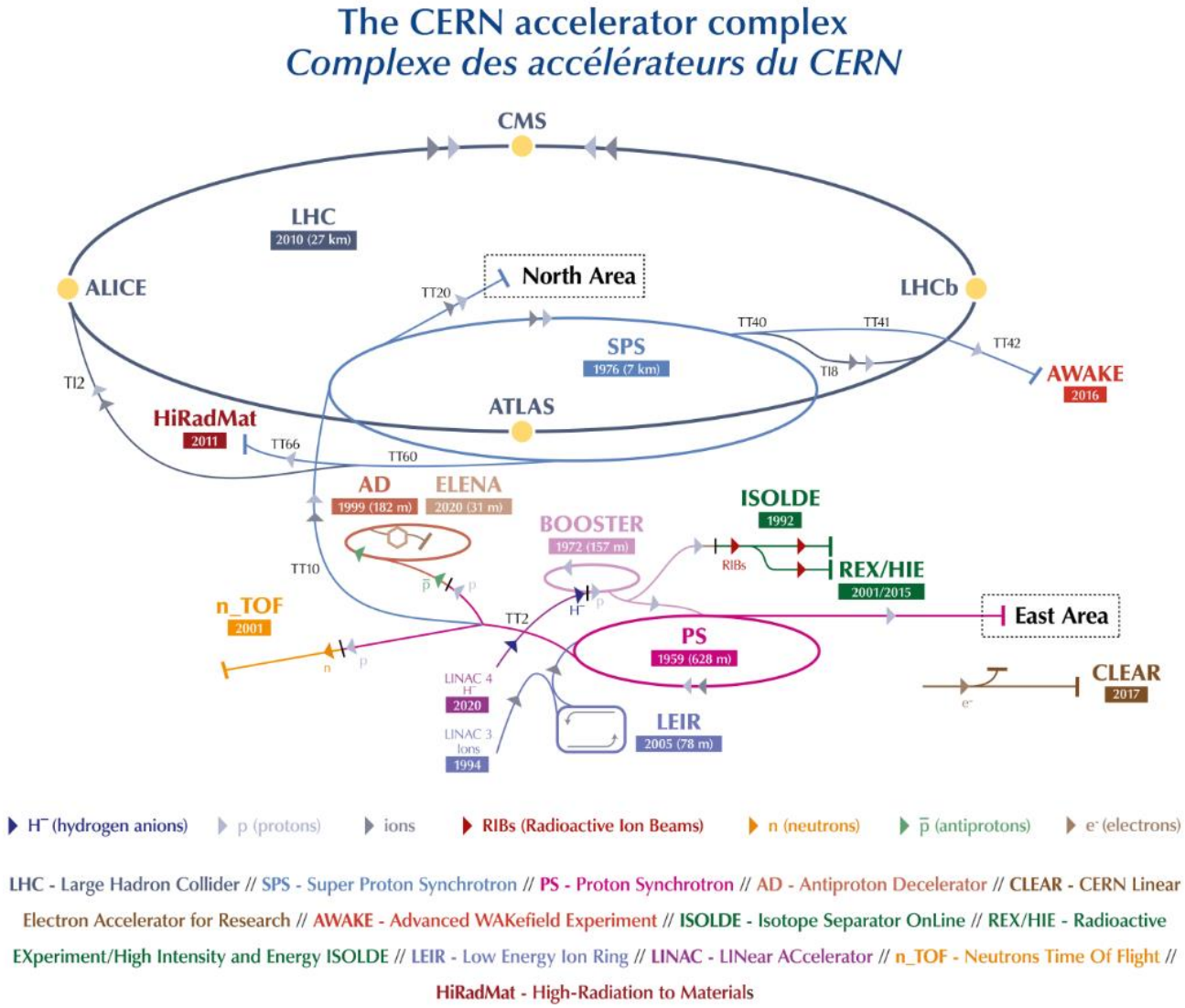
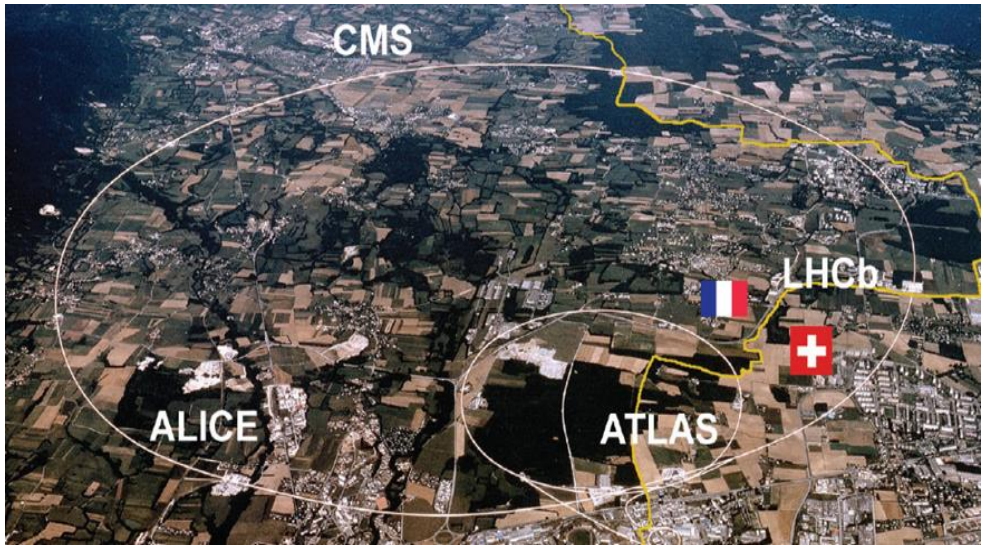
on behalf of the CMS Collaboration

CERN Accelerator Complex and the Large Hadron Collider LHC

http://home.cern/topics/large-hadron-collider

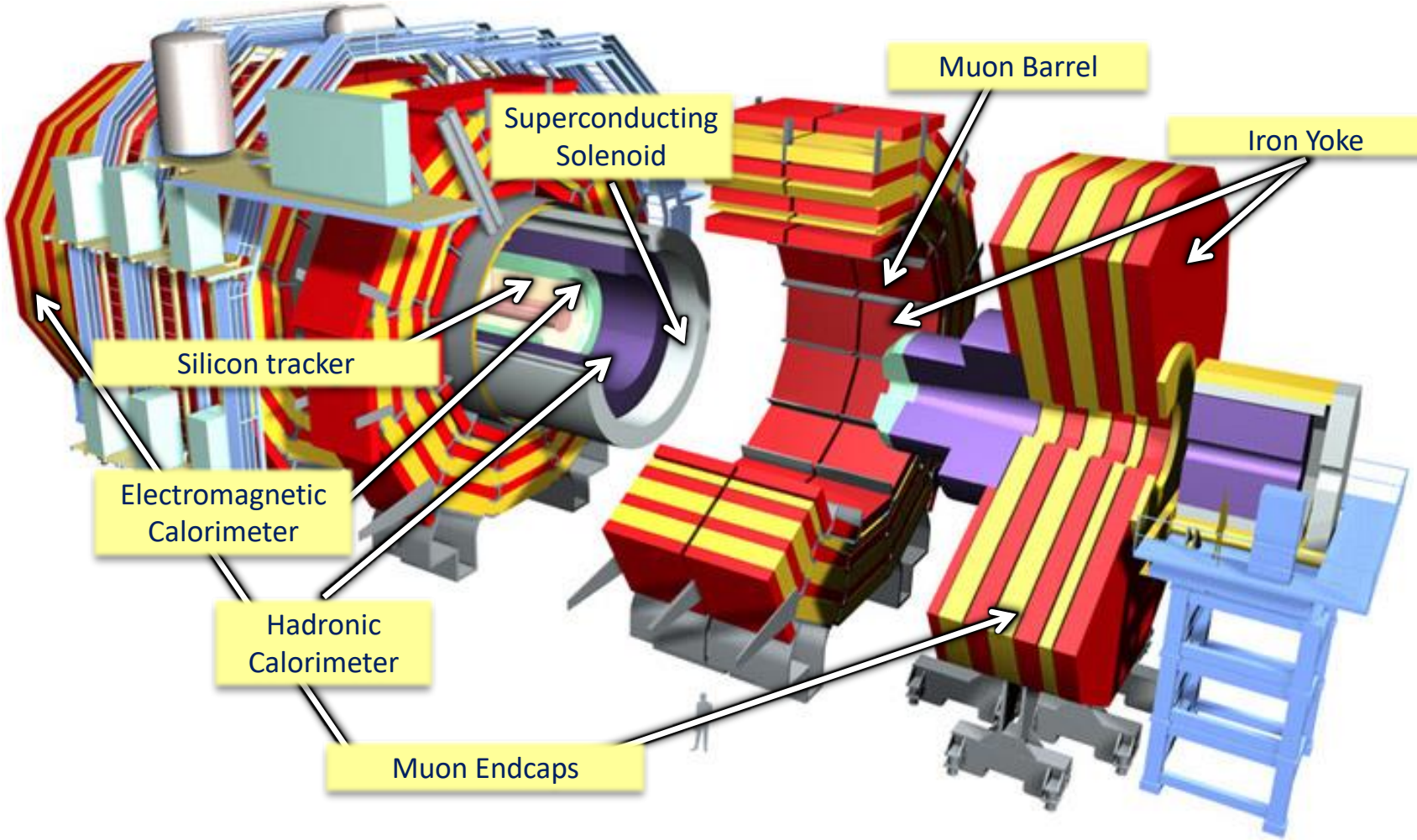


The Large Hadron Collider is installed in ~27 km circular tunnel (former tunnel of LEP) at ~100 m beneath the surface near the French-Swiss border.



Accelerated particle beams are colliding at four points around its length, where the main detector experiments are placed – ATLAS, CMS, LHCb and ALICE.

Compact Muon Solenoid (CMS) Experiment



Overall length 28.7 m
Overall diameter 15 m
Overall weight of 14 500 t

CMS Muon system:

- **Cylindrical Barrel region** – **Drift Tubes (DTs) & Resistive Plate Chambers (RPCs)**
  - **4 coaxial stations interleaved with the iron return yoke plates, grouped into 5 wheels around the beam line.**
- **Planar Endcap region** – **Cathode Strip Chambers (CSCs), Gas Electron Multipliers (GEMs) & RPCs**
  - **4 planar stations (disks) interleaved with the iron return yoke plates.**

General purpose detector searching for new physics phenomena in all the available energy ranges.

CMS Muon System

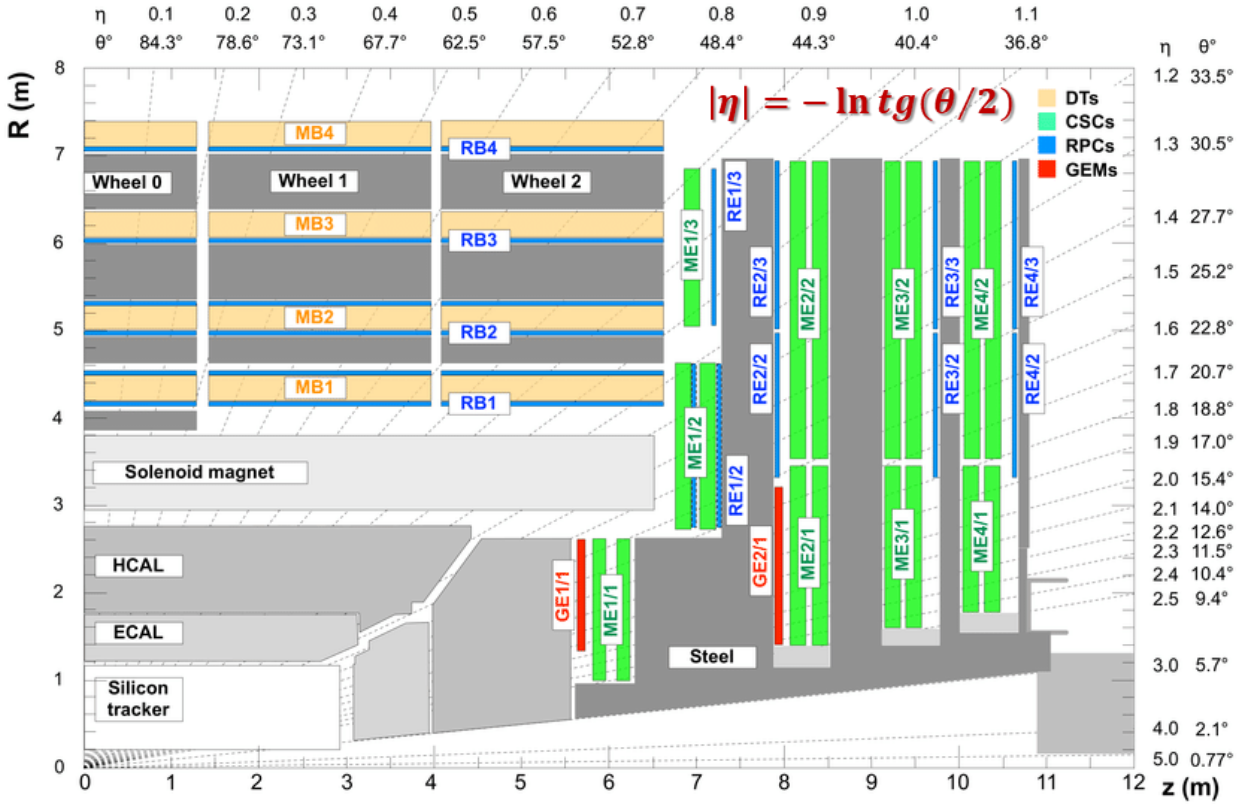
Robust, efficient and redundant muon system

Muon system requirements:

- **muon identification**
- **muon p_T and charge measurement**
- **triggering and bunch crossing (BX) association**

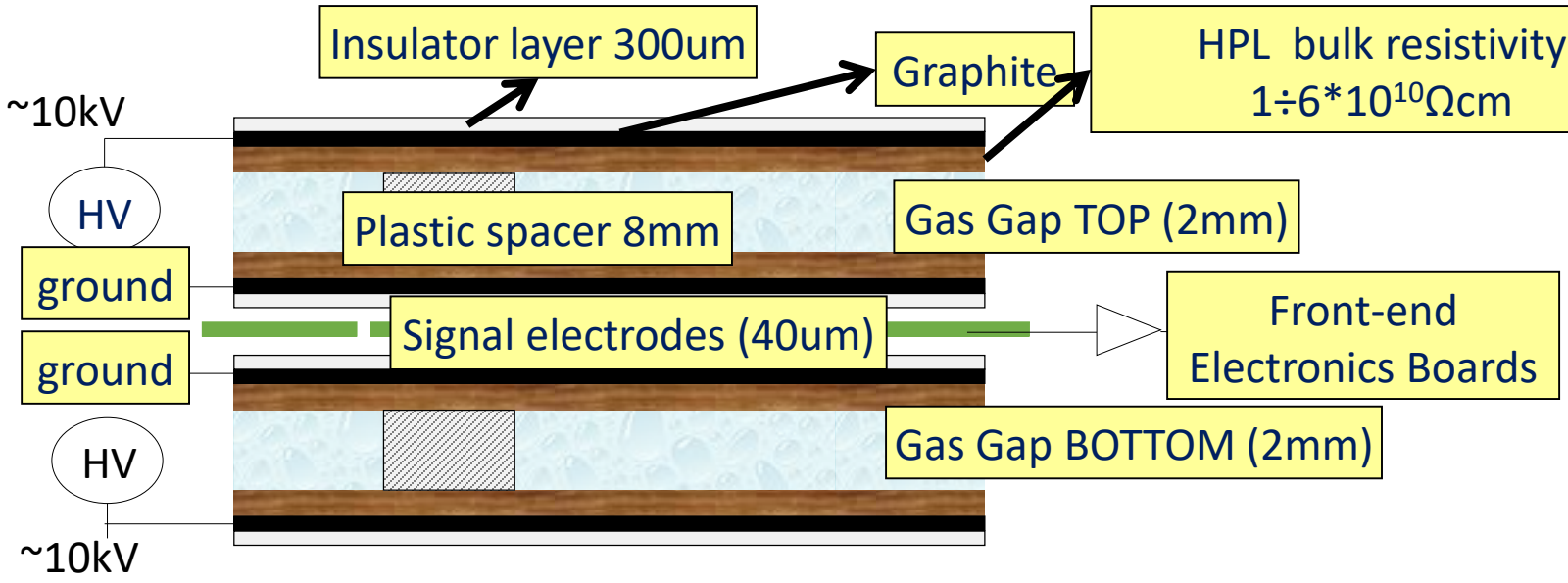
Four different gaseous detector technologies are used to trigger and reconstruct muons:

- Barrel: **DT** & **RPC** $|\eta| < 0.8$
- Overlap: **DT** & **CSC** & **RPC** $0.8 < |\eta| < 1.2$
- Endcap: **CSC** $(1.2 < |\eta| < 2.4)$,
  RPC $(1.2 < |\eta| < 1.9)$ & **GEM** $(1.5 < |\eta| < 2.2)$



Drift Tubes (DTs) (Barrel), **Cathode Strip Chambers (CSCs)**(Endcaps) , ***Resistive Plate Chambers*** *(Barrel and Endcaps)* , ***Gas Electron Multipliers (GEMs)*** *(Endcaps)*

CMS Resistive Plate Chambers



RPC present system

- Covers **|η| < 1.9**
- Total number of **1056 chambers** (480 in barrel and 576 in endcap)
- More than **110000 electronic channels**
- Strip width: **1 – 4 cm.**
- Operated in **avalanche mode**

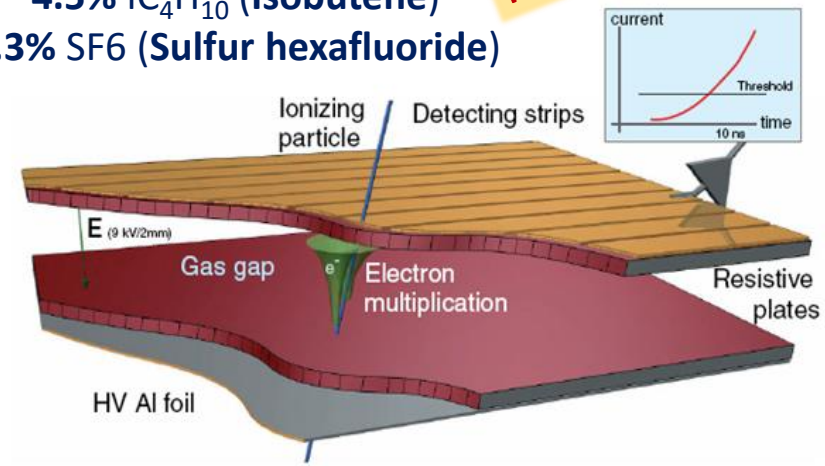
CMS Standard Gas Mixture:

95.2% $C_2H_2F_4$ **(Freon)**

4.5% iC_4H_{10} **(Isobutene)**

0.3% SF6 **(Sulfur hexafluoride)**

Relative Humidity 40%



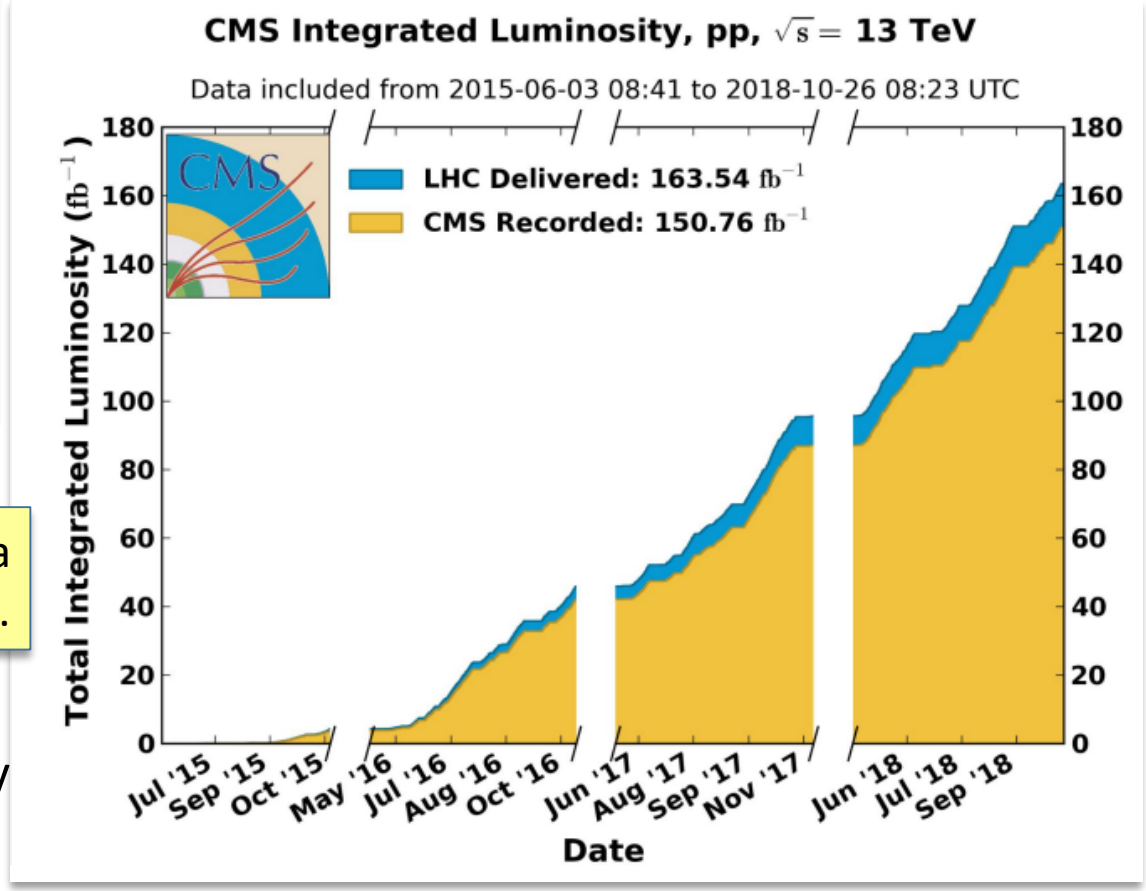
Requirement of RPC system:

- **High rate capability (~300 Hz/cm²)**
- **High detection efficiency > 95%**
- **Intrinsic time resolution < 1.6 ns (BX identification)**
- **Intrinsic Noise < 5 Hz/cm²**
- **Average cluster size ~2 strips**
- **Spatial resolution ≈ 10 mm**
- **Ability to withstand in long term operation and high background radiation**

CMS & RPC in Run-2 data taking

- **RPC Run effectiveness of 99.97%.**
  - The RPC contribution to the **CMS downtime** was ~ 0.03%.
- The amount of **data lost** due to RPC during Run-2 was ~ 0.15% (fraction of luminosity of ~ 231 pb^{-1}), concentrated mainly in 6 events, caused by electronic failures and software configuration errors.

CMS recorded L_{int} ~ 150 fb^{-1} in Run-2

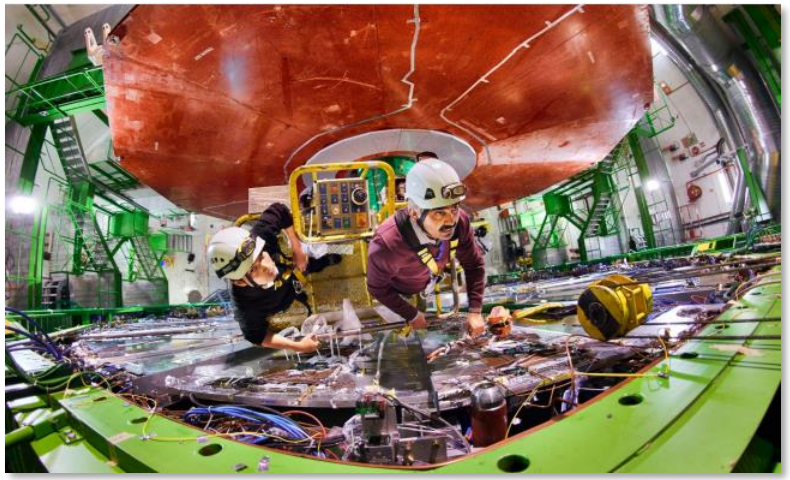


Key of success: Robust hardware and clear procedures for a prompt intervention during all beam-off and technical access time.

Run-2 Experience : Crucial to study the system's longevity in view of Run-3 and High Luminosity LHC.

-> Full details on longevity shown in Reham's talk "Latest results of Longevity studies on the present CMS RPC system for HL-LHC phase"

RPC Activities in Long Shutdown 2 (LS2)

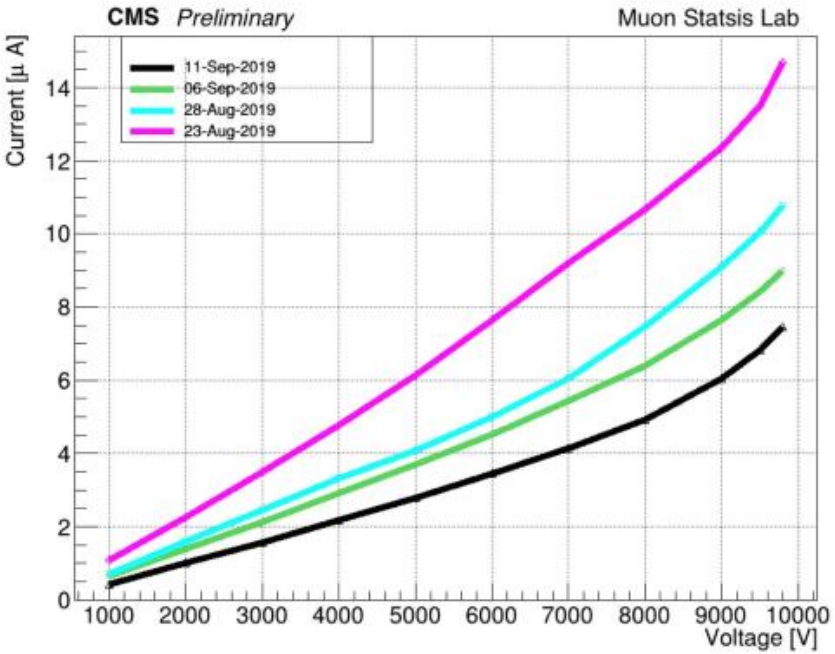


RE4 Extraction/Installation

One of the main activities of LS2 was the **extraction of the 72 super modules (SM) of the RE4 station**.

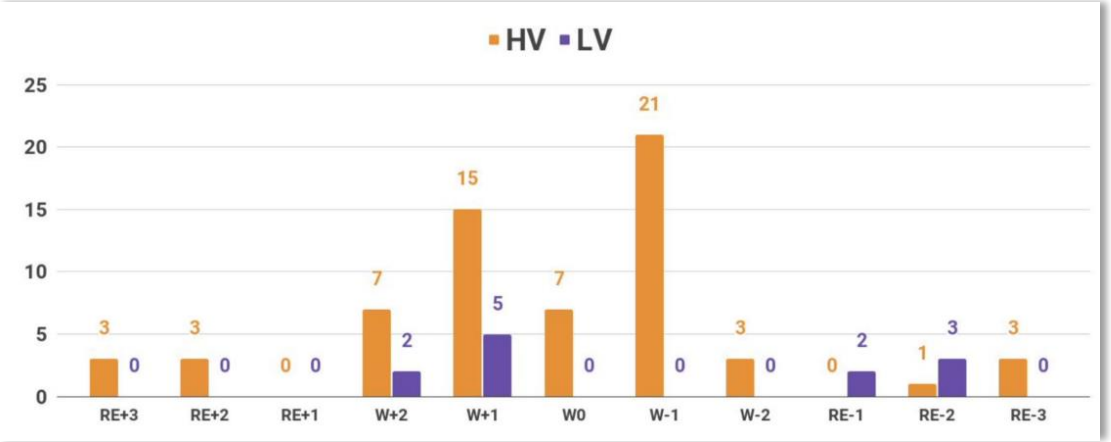
- Each SM is about 4 meters long and weighs 230 kg, which poses a great challenge to the extraction/installation.

A new lab with controlled environmental conditions, including temperature and relative humidity (T, RH), was built in an existing Point 5 building to house dismounted RE4 SM.



- **Increase of currents observed on the surface. The gaps were under stable high voltage (HV) for 4 weeks and the currents went lower.**
- **FEBs were tested to spot silent/noisy strips.**
- **After revalidation (HV, low voltage (LV), gas, cooling) the chambers were reinstalled. 6 problematic chambers replaced with spares.**

RPC Activities in Long Shutdown 2 (LS2)

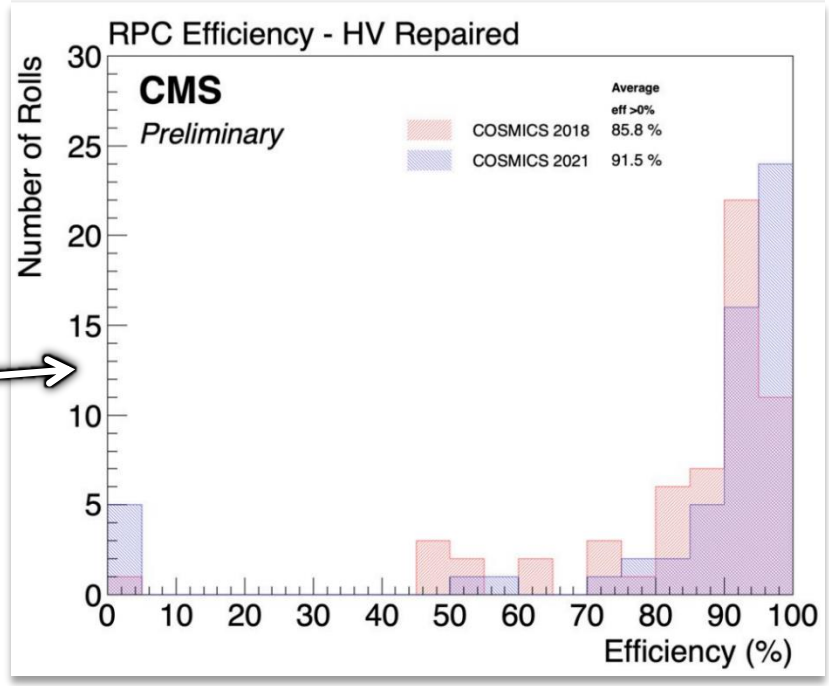


Extensive HV and LV repair campaign:

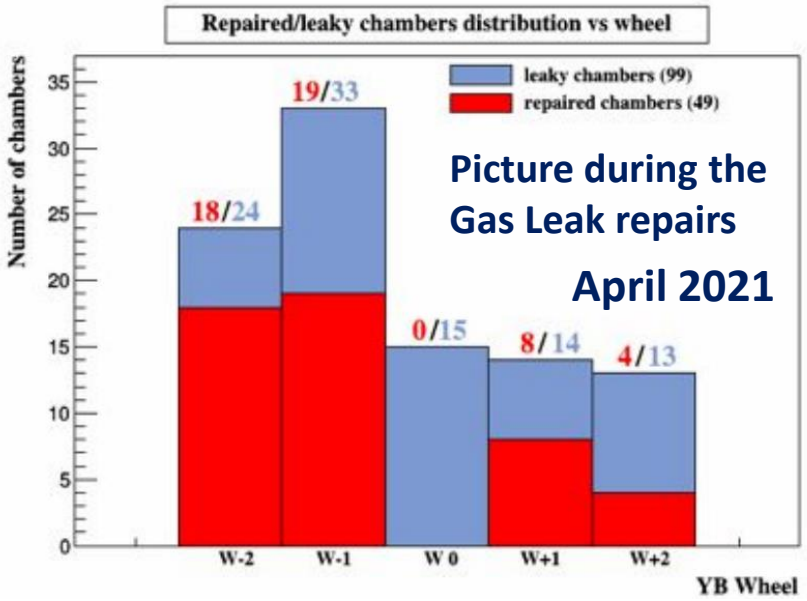
- **65 HV** repairs performed.
  - Out of those, **45 HV new trips** developed in LS2 due to **multiple power cycling operation mode** (due to COVID issues).
- **12 LV (threshold (TH))** repairs successfully done.

Comparison between cosmics runs in 2018 (end of Run-2) and in 2021 show **increase of ~ 6% in average efficiency**.

- Due to recovery of gaps and the change of operation mode from single gap to double gap.



RPC Activities in Long Shutdown 2 (LS2)



The Gas Repairs had the highest priority during LS2.

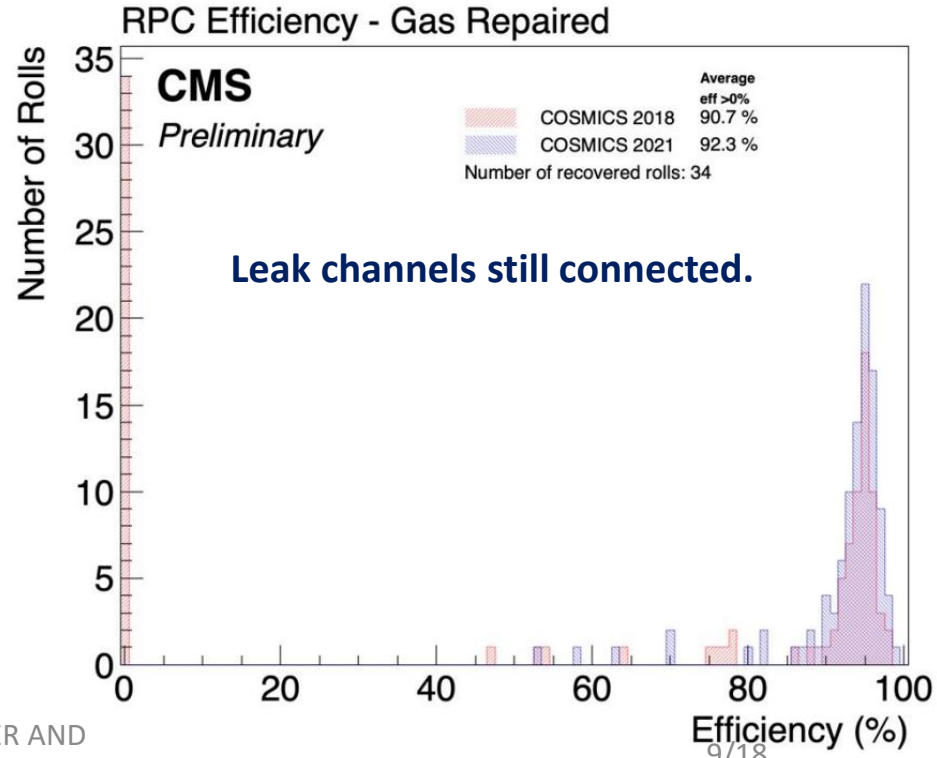
- The leaks were identified due to cracks or broken pipes.

49 out of 99 gas leaky RPCs were repaired:

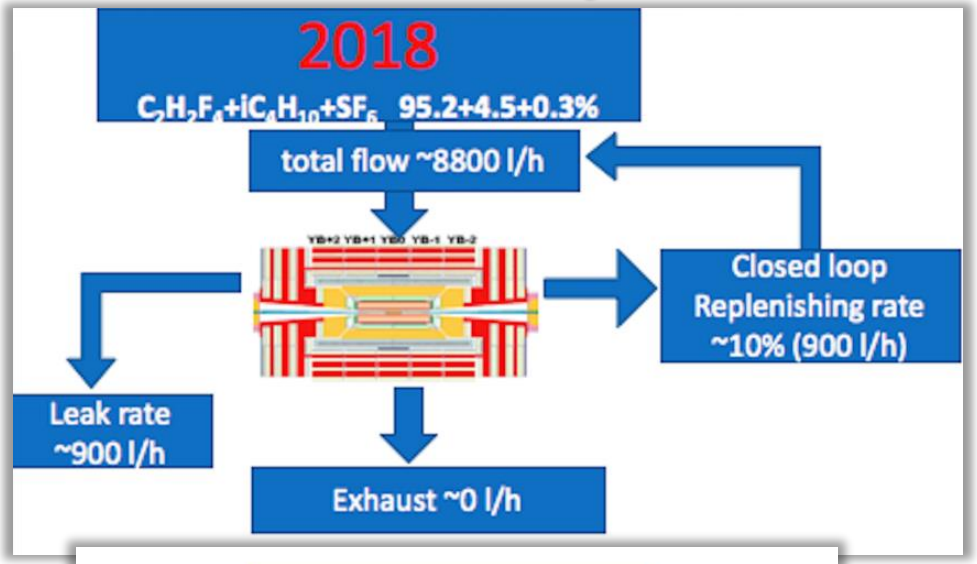
- All located in the barrel region.
- Out of which 17 chambers were off in Run-2.

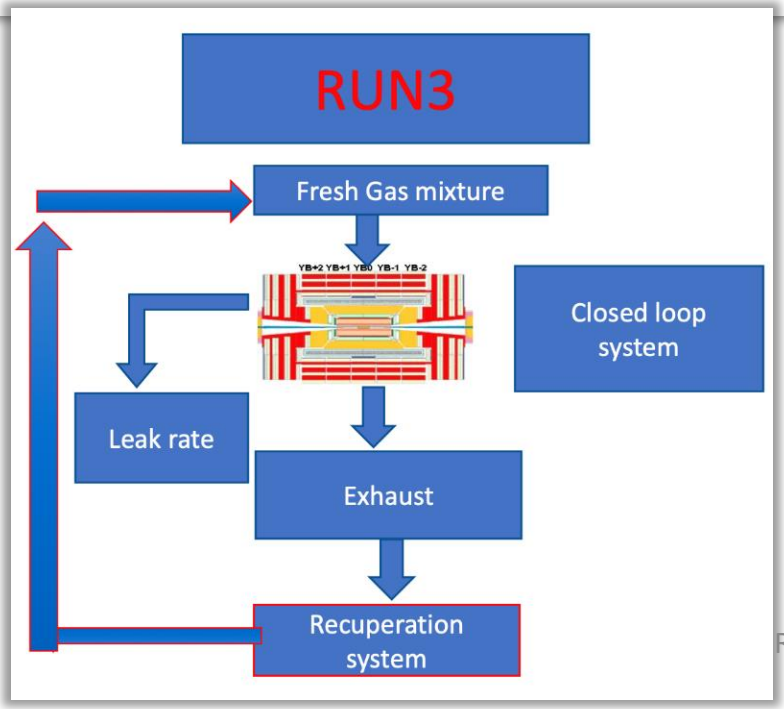
The comparison between the repaired chambers show an **increase in the average efficiency**.

- It was considered only the chambers that were ON for the average.
- Considering the OFF chambers the average of 2018 goes down to ~ 60%.
- Some of the leak chambers were put in single gap operation mode because of the high currents. After the repair, they were put back to double gap. This explains the gain of 1.4% on the average efficiency.



RPC Gas system for Run-3





- **Aiming to minimize the environmental impact of the RPC system ($C_2H_2F_4$ and SF_6 have very high GWP).**
- **Recuperation of the Exhaust (not working during Run-2)**
- **CERN EP-DT Gas team R&D to develop the first $C_2H_2F_4$ recuperation system.**
- **Current policy: disconnect leak channels in order to restore the Exhaust.**

Automatic regulation valves were installed in Nov 2021. They are properly operating since Nov 2021 (barrel) and middle Jan 2022 (endcap).

The recuperation system is expected to be ready/operational by the end of 2022.

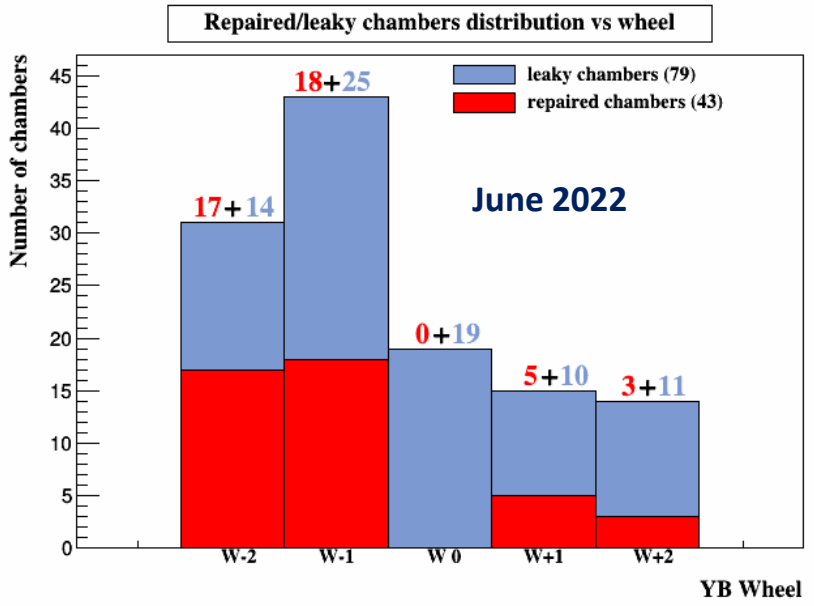
RPC Gas system for Run-3

	Leak/Dead	OFF Connected to leaking	OFF [Leaky/Dead + Connected to leaking]
W+2	9/2	1	12
W+1	7/3	0	9
W0	14/5	8	27
W-1	21/4	15	39
W-2	14/0	7	21
Total Barrel	**65/14**	**31**	**108**

- **88% (active channels)**

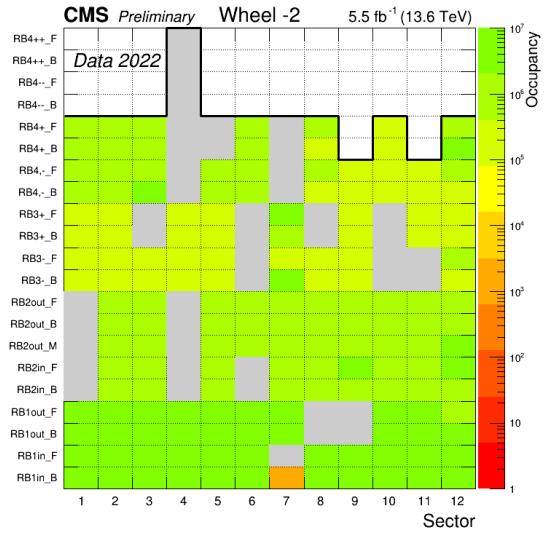
Disconnected chambers in the barrel

- Operational leaking chambers: 63
- Dead leaking chambers: 14
- Operational not leaking chambers connected to leaking one: 31
- Total # Chambers: 108 (63+14+31)

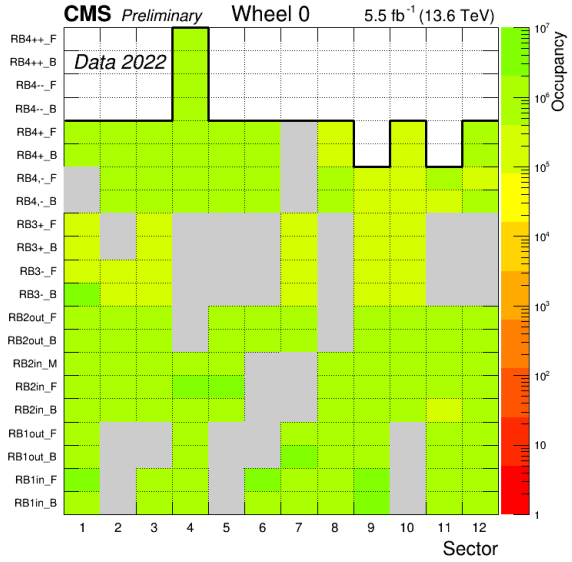


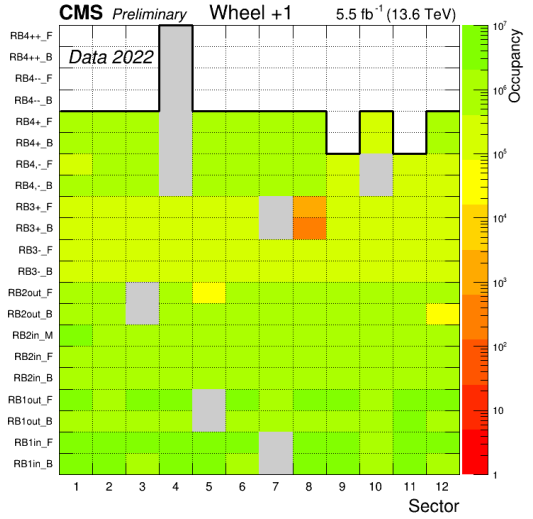
RPC Strategy: *Disconnect every new leaking chamber to have gas in the exhaust and to be possible to operate the recuperation system.*

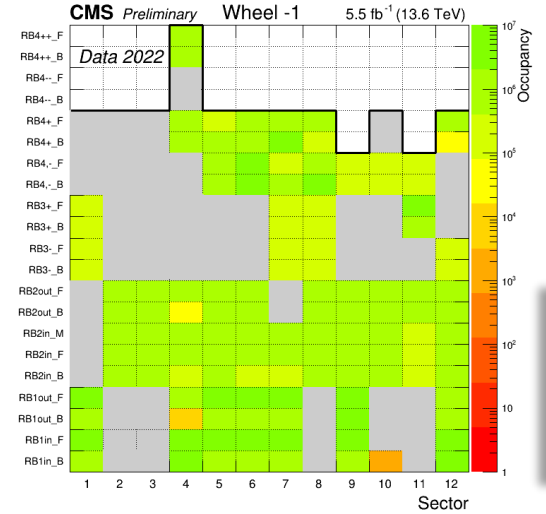
RPC Barrel Occupancy in Early Run-3 collisions

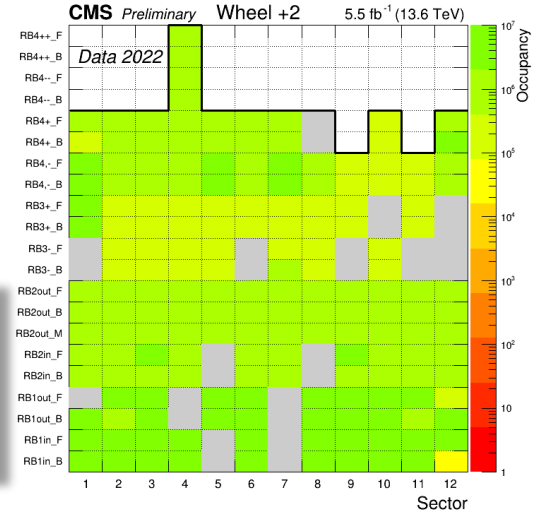


RPC Occupancy (all detected RPC hits), obtained during early 2022 proton-proton collisions, is one of the main parameters to monitor the system performance.





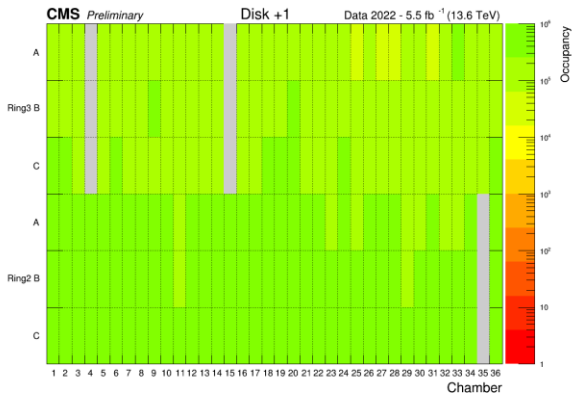


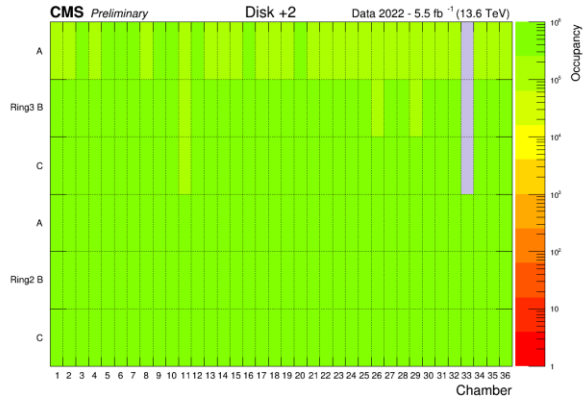


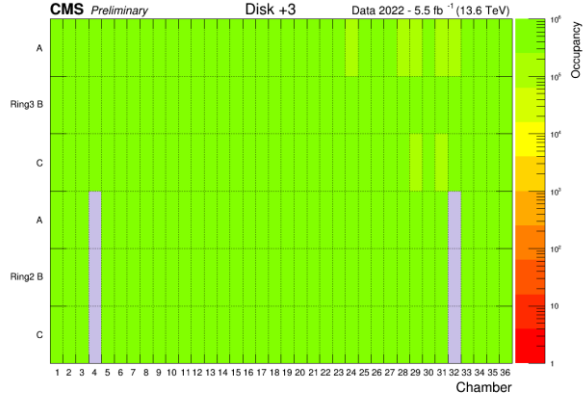
The **grey entries** correspond to the detector units which are switched off due to known hardware problems or to comply with CMS gas leak reduction policy.

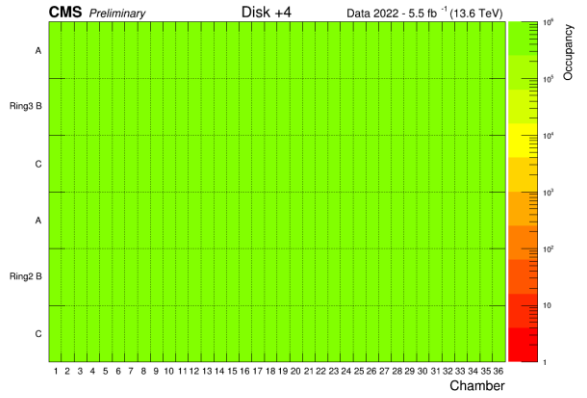
RPC Endcap Occupancy in Early Run-3 collisions

Positive Endcap









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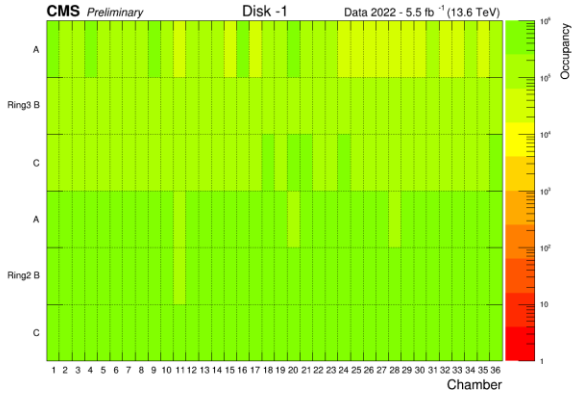
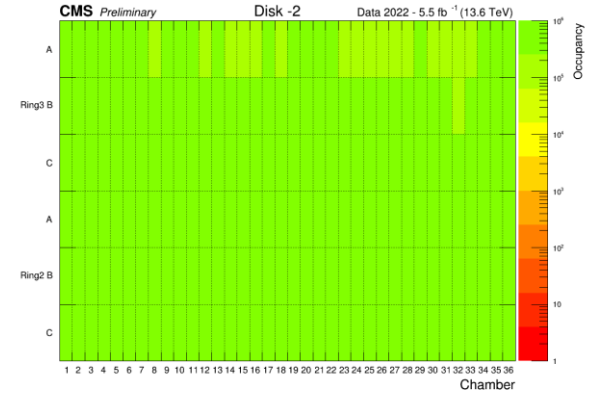
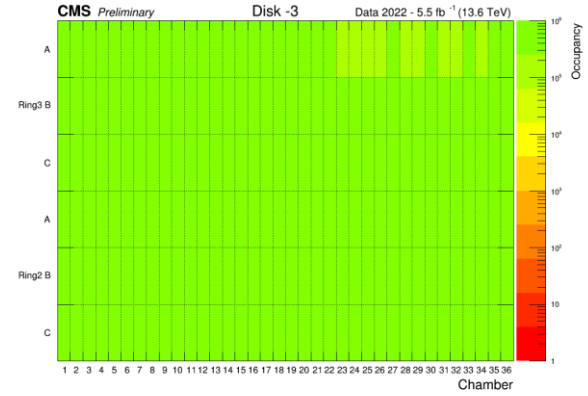
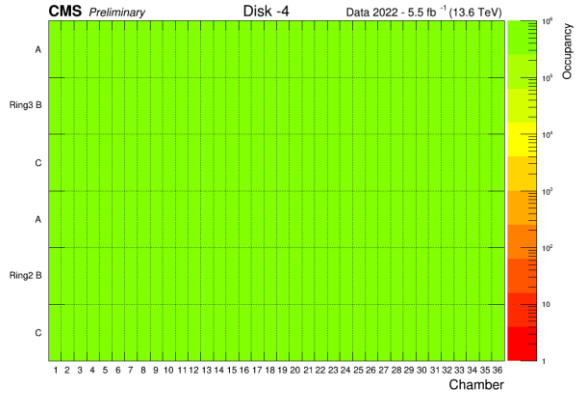
Negative Endcap



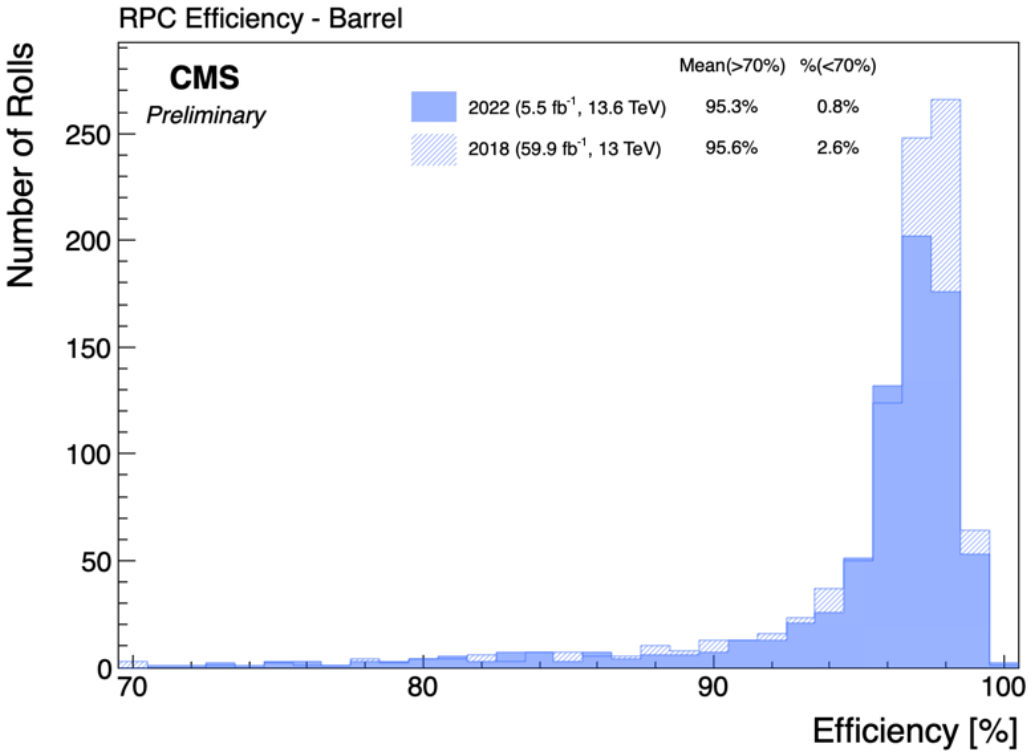


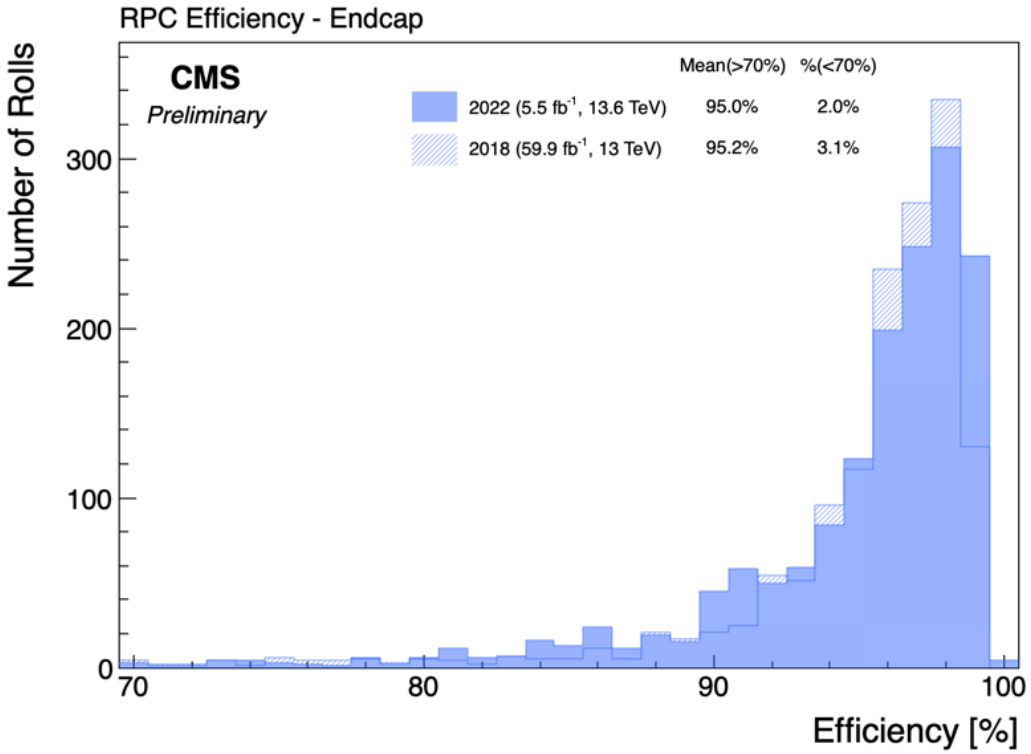




RPC performance in Early Run-3 collisions

Overall Efficiency distributions are obtained using the **Segment Extrapolation Method.**

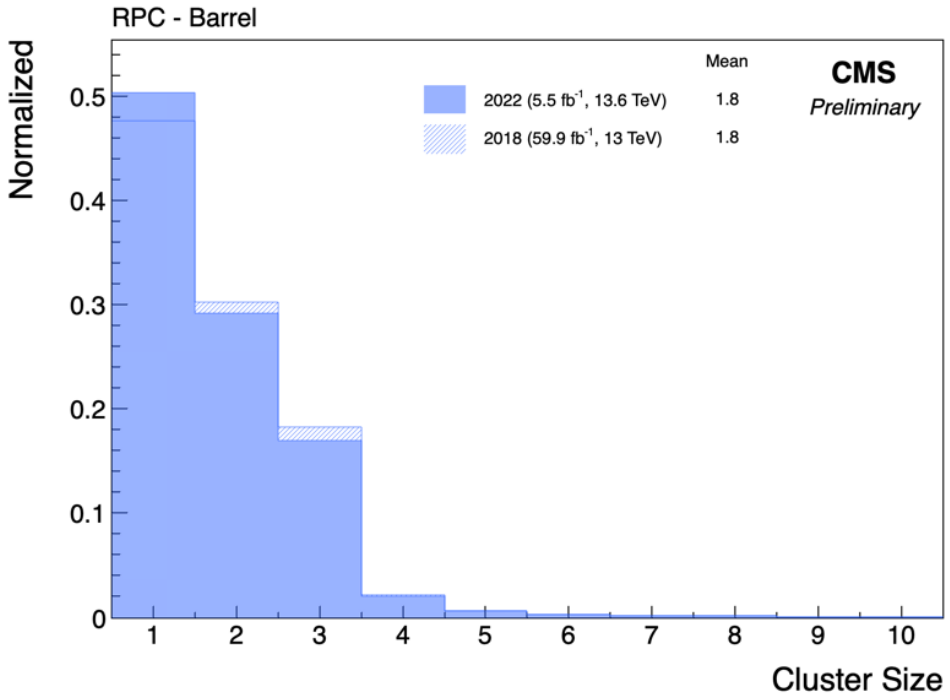


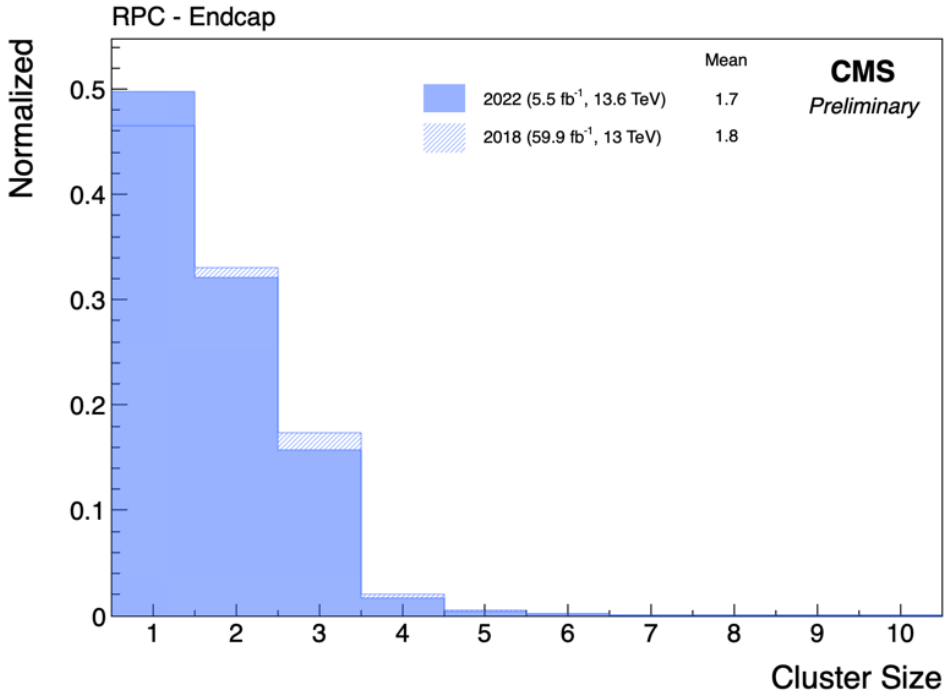


After all the LS2 interventions, the performance of the detector in 2022 early data taking is comparable and in agreement with expectations.

RPC performance in Early Run-3 collisions

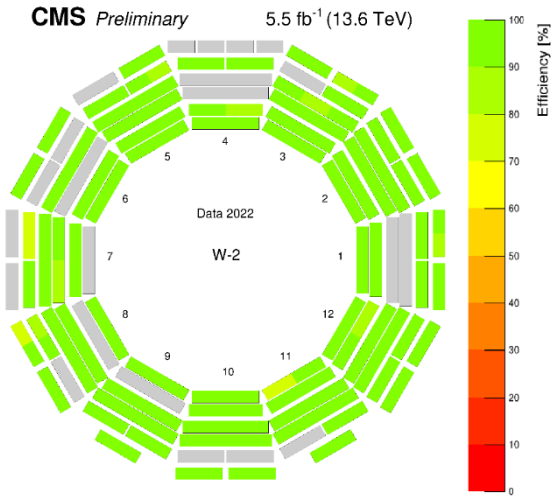
Cluster size distribution of RPC hits associated with muons

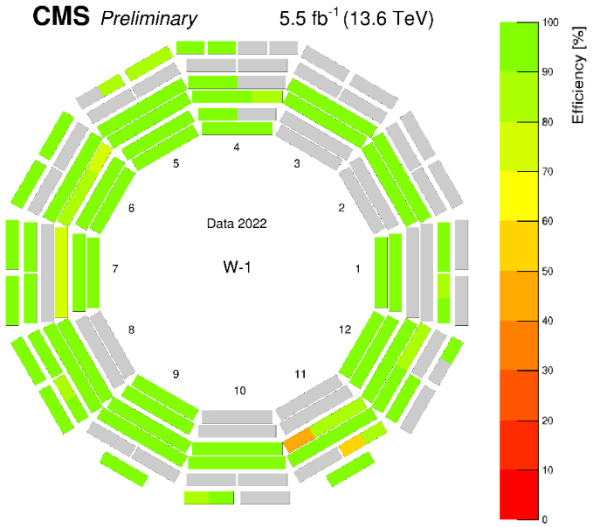




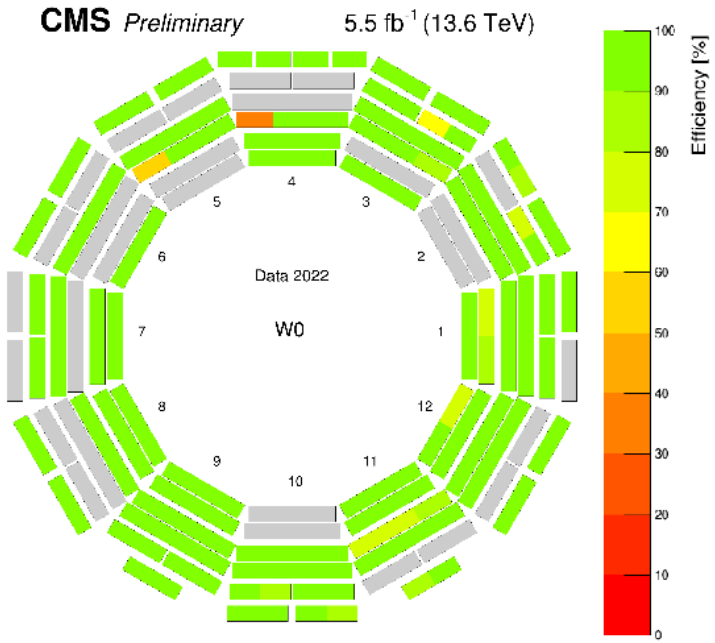
RPC mean cluster size measured in early 2022 data taking is below 2, which is comparable and in agreement with the expectations

RPC Barrel Efficiency





RPC Efficiency is calculated using the Segment Extrapolation Method.



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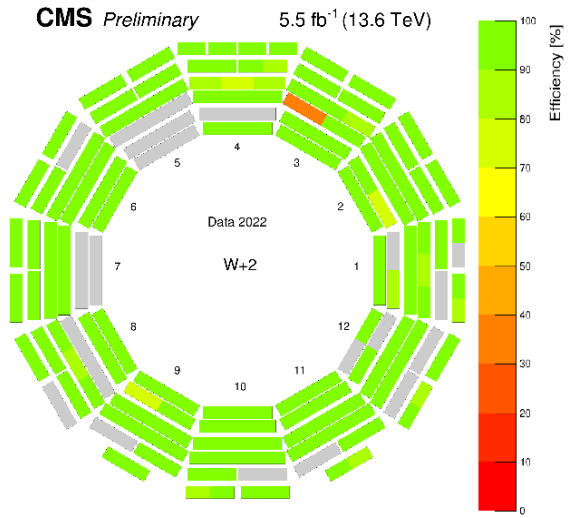
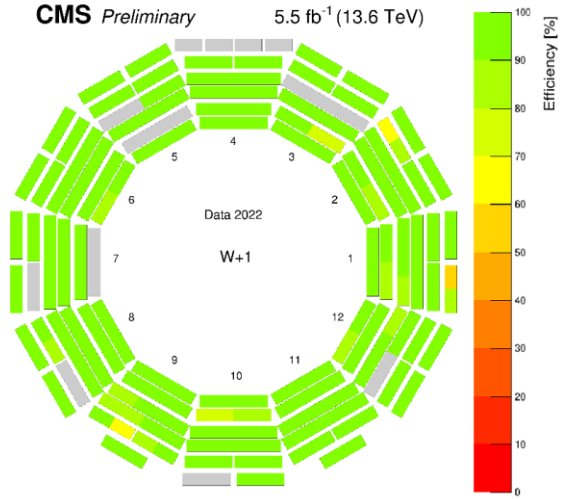
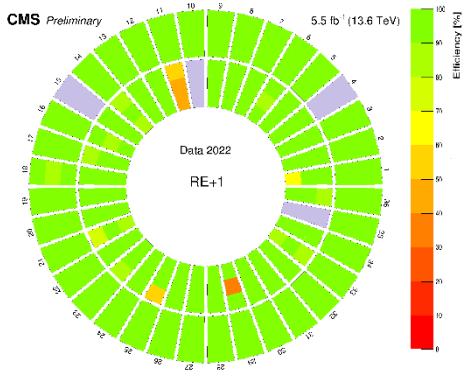
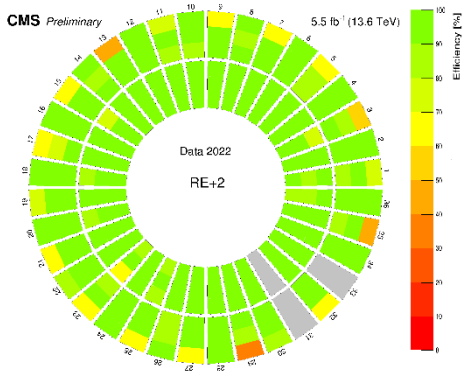




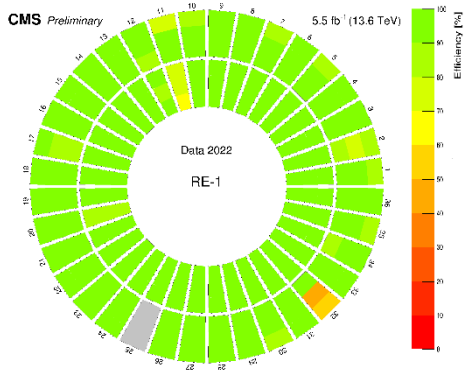
RPC Endcap Efficiency

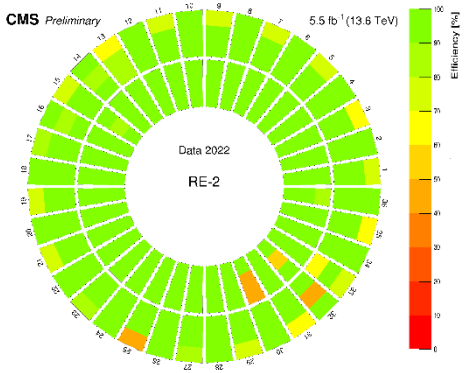
Positive Endcap



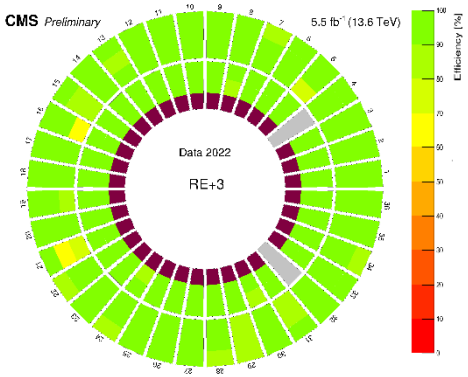


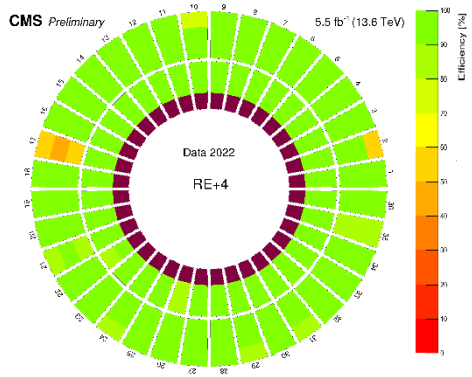
Negative Endcap

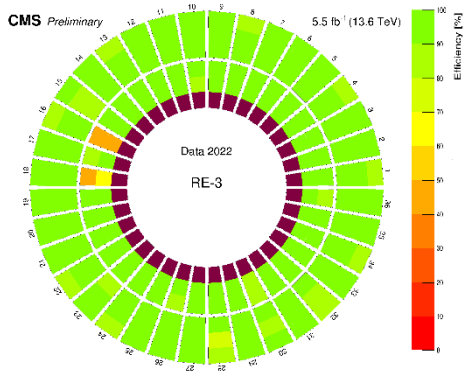


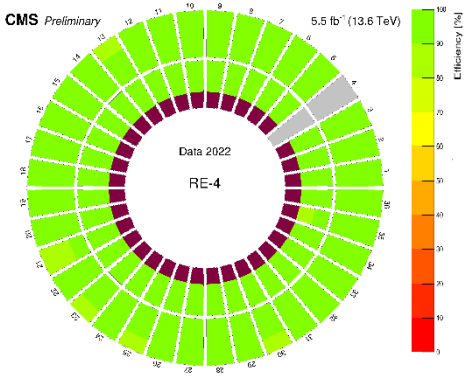


The **grey entries** correspond to the detector units which are switched off due to known hardware problems. The **purple ones** correspond to the detector units, which are excluded from efficiency calculation because the used software algorithm is not effective for them.









RPC Efficiency is calculated using the Segment Extrapolation Method.

Conclusion

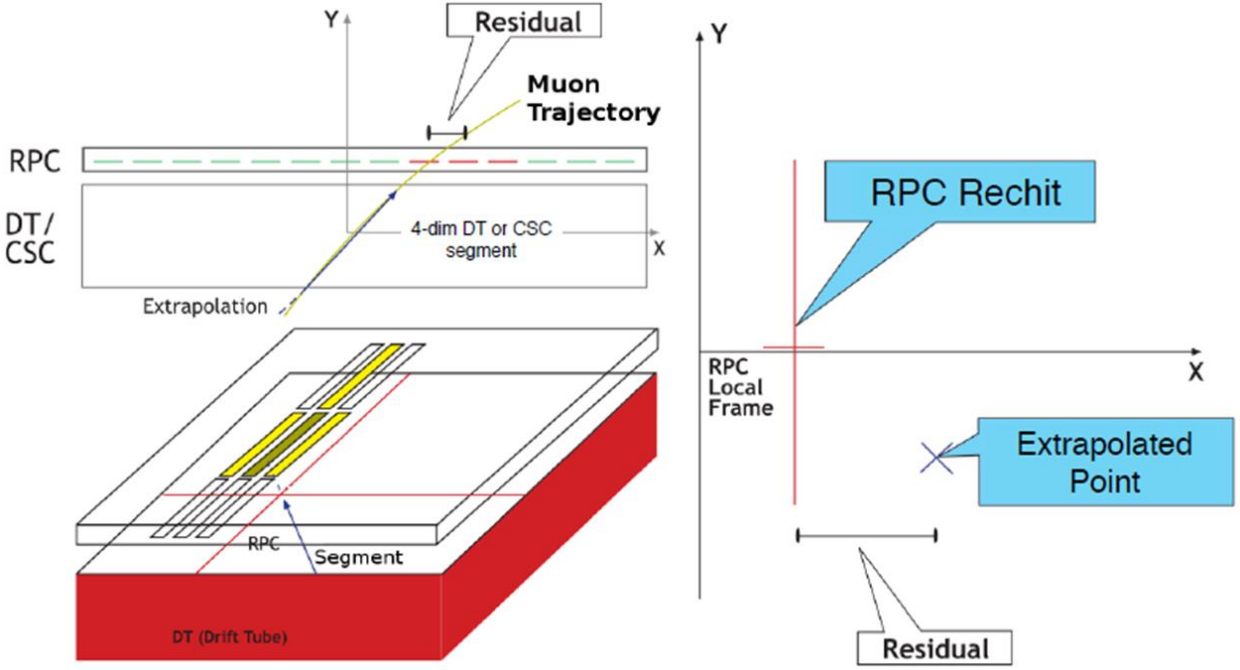
- **Massive maintenance campaign to repair gas leaks, HV and LV issues during LS2.**

- **Plan to minimize the environmental impact of the RPC system**
  - **Gas Leak repairs and R&D of a $C_2H_2F_4$ recuperation system.**
  - **Turn OFF all leaky chambers to keep the leaks at minimum.**

- **Stable performance in early Run-3 data taking:**
  - **Average Efficiency: ~ 95%**
  - **Average CLS: ~ 2 strips**

Backup Slides

Segment Extrapolation Method

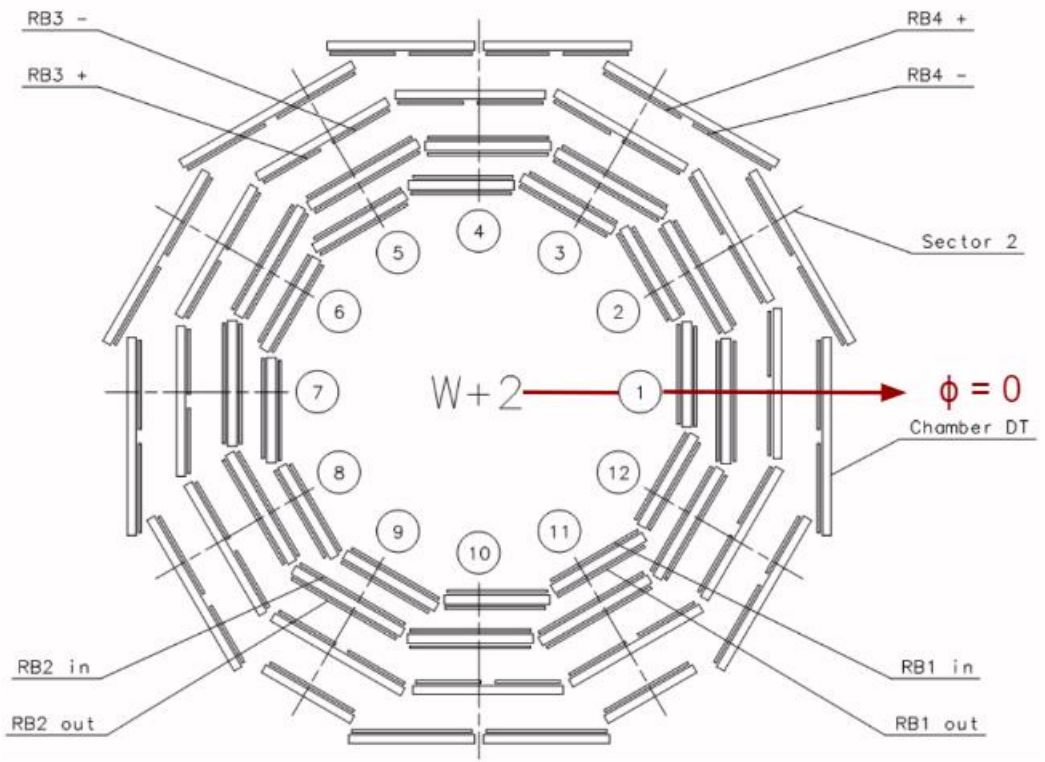


RPC hit efficiency is obtained using the Segment Extrapolation Method (JINST 5 (2010) T03017, DOI: 10.1088/1748-0221/5/03/T03017), where the RPC efficiency is calculated as the ratio between the number of detected and the number of expected hits. Segments (DT in the Barrel and CSC in the Endcap) that belong to a standalone muon track with timing corresponding to RPC readout BX windows are selected and extrapolated to the plane of a given RPC. The detector unit is considered efficient if an RPC reconstructed hit is found within ± 2 strips from the position extrapolated from the DT/CSC segment.

RPC Distribution in the Barrel

In the barrel the RPC are distributed in 5 wheels (-2, -1, 0, 1, 2). In each wheel the RPC are distributed in 4 stations or rings called RB1, RB2, RB3 and RB4 and 12 sectors that are distributed in an anti-clockwise direction starting with sector 1 in φ=0. Stations RB1 and RB2 have two chambers per sector called IN and OUT, the IN chamber is closer to the center and the OUT chamber is farther away. Stations RB3 and RB4 also have two chambers at the same distance from the center but with different phi values, the chamber with the higher phi value is called "+" and the one with the lower phi value "-". There are two exceptions:

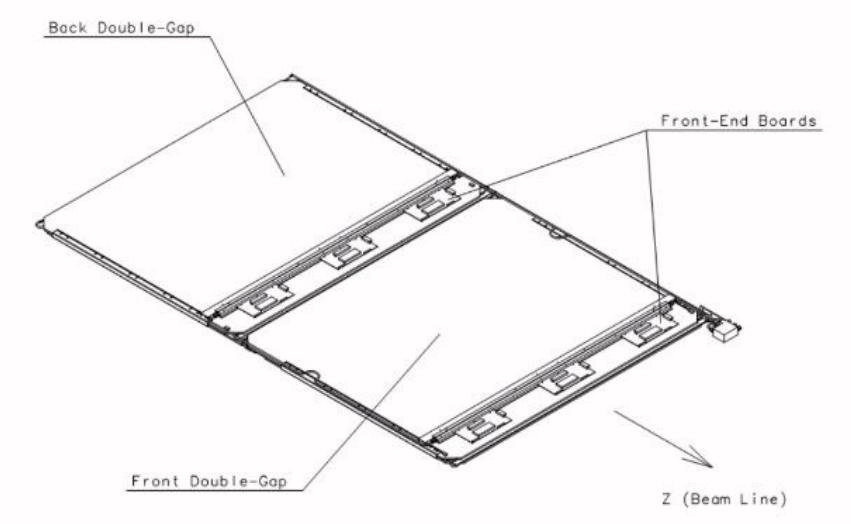
- Sector 4 has 4 chambers at station RB4 (++,+,-,--)
- Sectors 9 and 11 have only one chamber each at station RB4 (-).



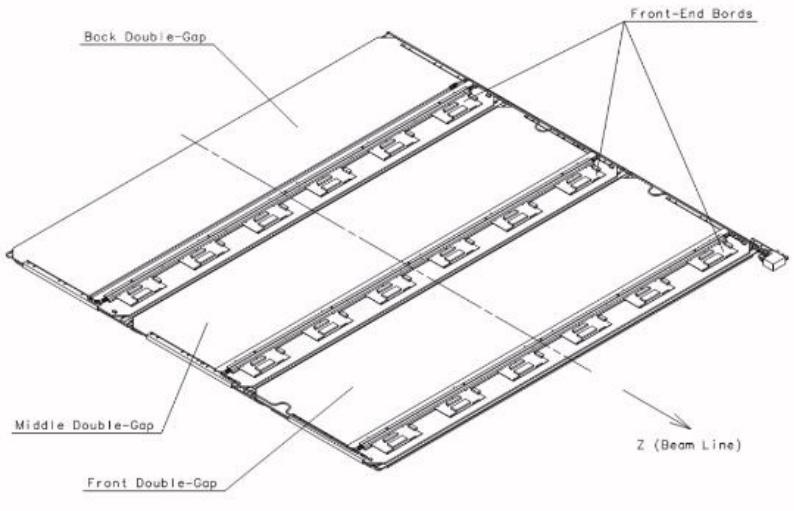
Source:
https://twiki.cern.ch/twiki/pub/CMSPublic/RPCPlots/RPC_Geometry.png

RPC Distribution in the Barrel

Eta partitions -> Rolls



With two eta partitions

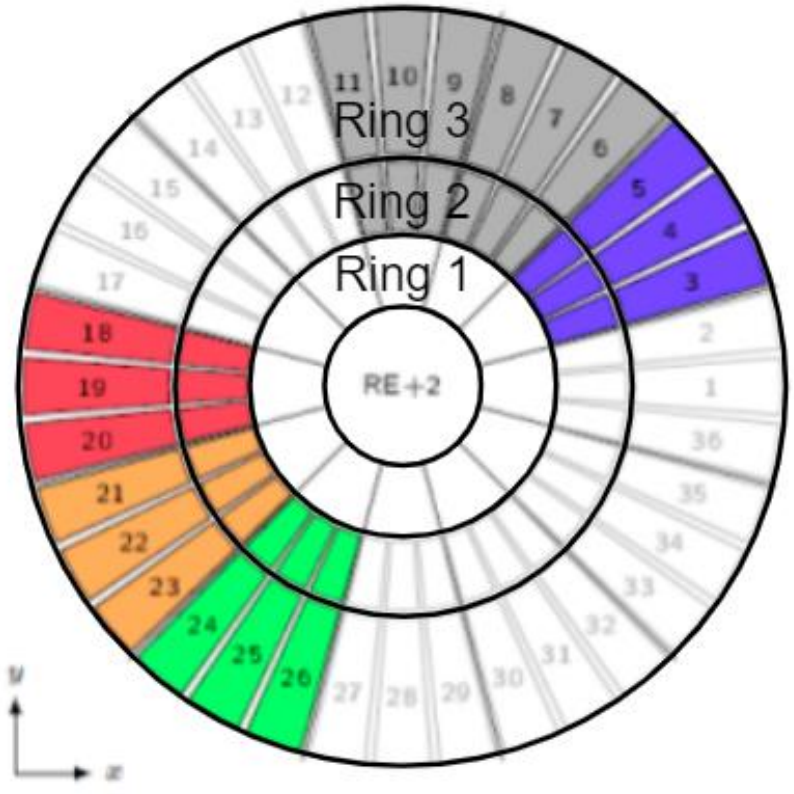


With three eta partitions:
RB2in Wheels +1, 0 , -1
RB2out Wheels +2, -2

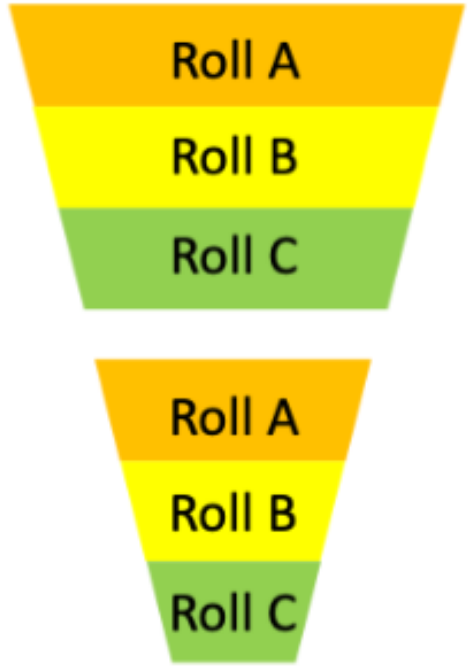
Chambers in the barrel are divided in 2 eta partitions (also called rolls): Forward and Backward. With the exception of RB2in in Wheels +1, 0 , -1 and RB2out in Wheels +2, -2 that have 3 eta partitions: Forward, Middle and Backward.

Source: https://twiki.cern.ch/twiki/pub/CMSPublic/RPCPlots/RPC_Geometry.png

RPC Distribution in the Endcap



In the endcap region, the RPC are distributed in 8 disks (4 in the positive endcap and 4 in the negative endcap). In each disk the RPC are distributed in 3 rings. Ring 1, the inner one, is not installed. Each ring has 36 chambers, and every chamber is divided in three eta partitions (also called rolls): Roll A, roll B and roll C. Roll C is the one located more towards the center.



Source:
https://twiki.cern.ch/twiki/pub/CMSPublic/RPCPlots/RPC_Geometry.png