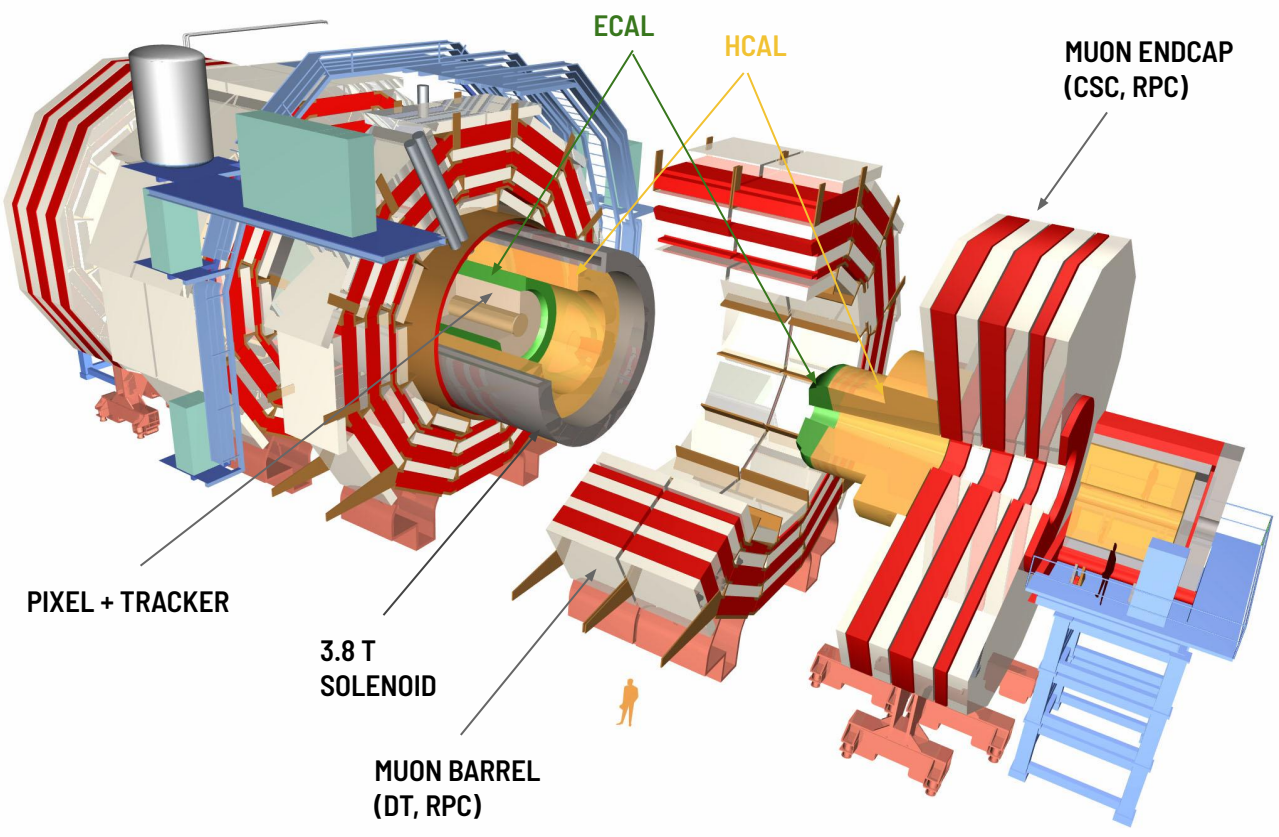
CMS RPC data taking during the CMS Run-2 and activities during Long Shutdown 2

Kevin Mota Amarilo (kevin.amarilo@cern.ch),
on behalf of the CMS Collaboration
TIPP2021, 24-29 May 2021

Rio de Janeiro State University, Brazil

The CMS Experiment



CMS (Compact Muon Solenoid)

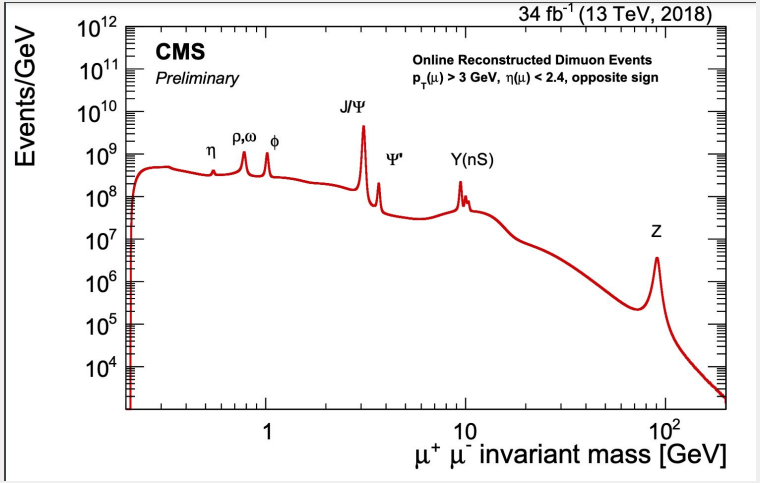
- General Purpose Detector
- Total weight: ~14000 t
- Overall diameter: 15 m
- Overall length: 28.7 m

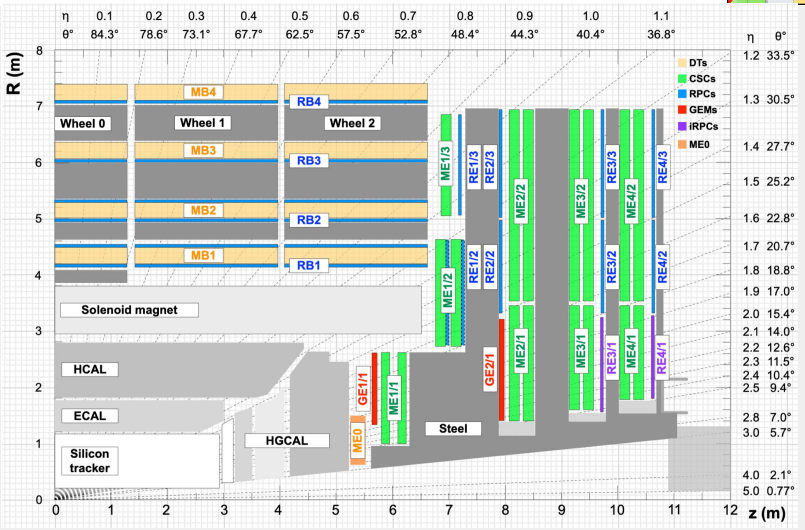
Designed to measure with high precision the particles produced in *pp* and heavy-ions collisions.

CMS Muon System

- Muons are present as final state in many standard model and Beyond Standard Model (BSM) processes.
- They are long-lived particles and have very small interaction with matter. Therefore, they are not stopped at the ECAL as electrons.

The CMS Muon system uses gaseous detector technologies to make precise identification and measurement of muons properties in addition to triggering and charge identification.





Up to Run 2 there were three different technologies in the CMS Muon System:

- **DT:** Drift Tubes; $|\eta| < 0.8$
- **CSC:** Cathode Strip Chambers; $0.8 < |\eta| < 2.4$
- **RPC:** Resistive Plate Chambers; $|\eta| < 1.9$

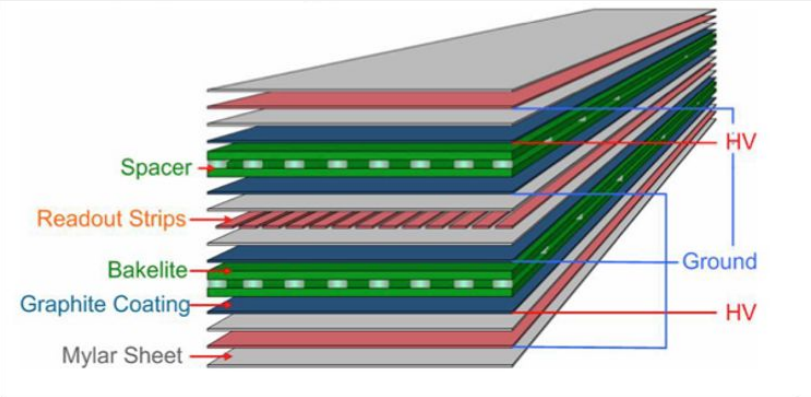
The upgrade in the muon system will add new GEMs (Gas Electron Multiplier) and iRPCs in the higher η region.

- More info: [CMS Muon System Posters]

CMS Resistive Plate Chambers

CMS RPC present system

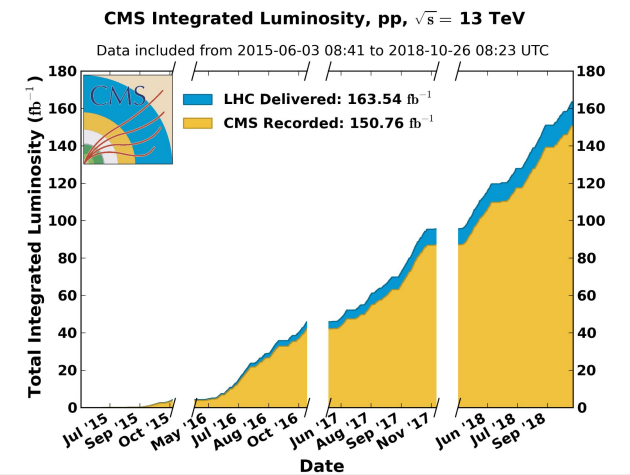
- Double gap Bakelite RPC Chamber
  - ρ: 1-6 x 10^{10} Ω·cm
  - 2 mm gas width
- Coverage: $|\eta| < 1.9$
- 1056 chambers
  - 480 in Barrel (5 Wheels)
  - 576 in Endcap. (8 Disks)
- More than 110000 electronic channels
- Rate capability: ~300 Hz/cm^2
- Intrinsic time resolution ~1.5 ns
  - Link boards only read during the LHC BX (25 ns)
  - Link System upgrade will enable CMS to use full RPC timing capability. (details on Behzad's Poster CMS RPC Link System upgrade)

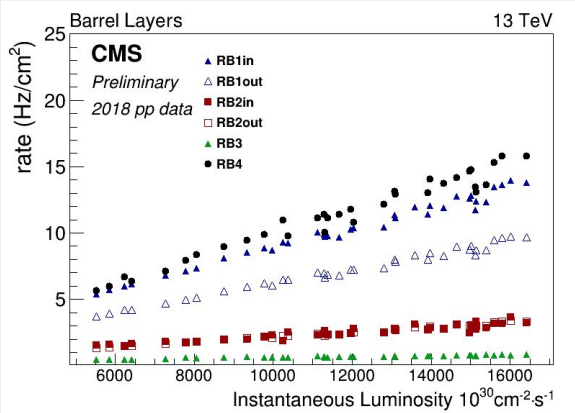


- Closed loop gas system:
  - Mixture: 95.2% $C_2H_2F_4$, 4.5% iC_4H_{10}, 0.3% SF_6
  - Humidity: 40%
  - Replenishing rate: 10%

Due to its very good time resolution, the RPC is very important for CMS Trigger.

Run-2 Data Taking summary





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

- RPC run effectiveness was 99.97 %
- The amount of data classified as bad due to RPC was ~0.15 % (concentrated mainly in 6 events, because of electronic failures and software configuration errors).

Background at $L=1.5 \times 10^{34} cm^{-2} s^{-1}$:

- In Barrel RB1 and RB4 were the most exposed layers. Rate ~20 Hz/cm^2
- In Endcap RE4 station was the most exposed. Rate ~40 Hz/cm^2

After ~ 9 years operation (~185 fb^{-1} integrated luminosity), the integrated charge is:

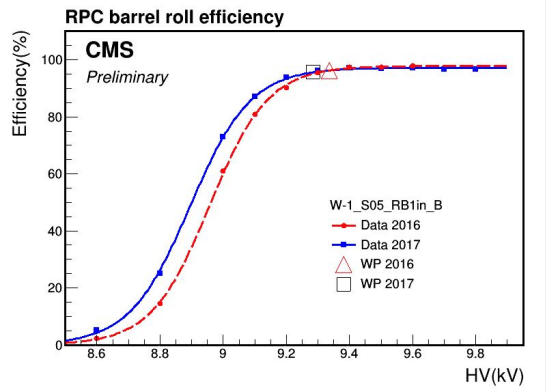
- ~2.3 mC/cm^2 for Barrel
- ~7.5 mC/cm^2 for Endcap

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

RPC Working Point Calibration

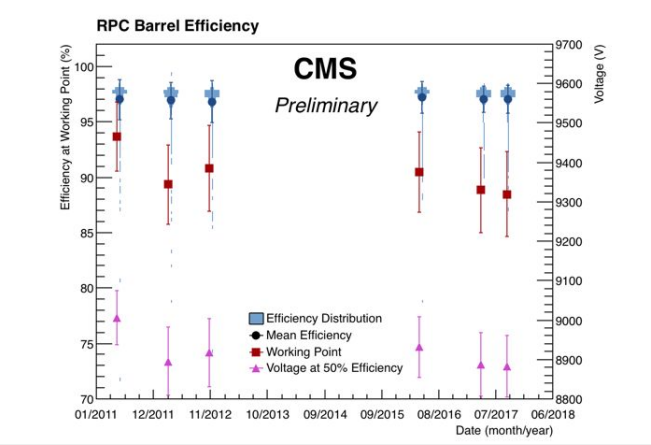
- Three HV scans have been performed every year with a dedicated collision runs.
- Main goals: optimize chamber Working Point (WP) and monitor in time the performance.

$$HV_{WP} = HV_{knee} + \begin{cases} 100V\ (Barrel) \\ 120V\ (Endcap) \end{cases}$$



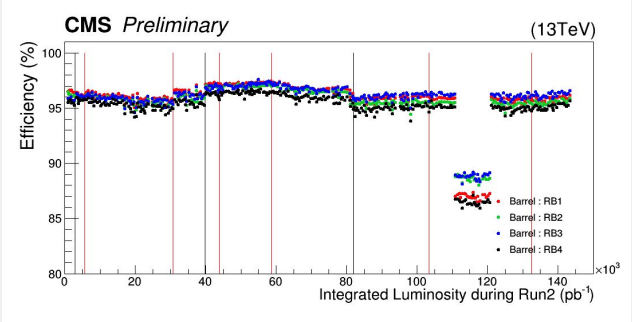
Efficiency vs HV with different isobutane concentration in 2016 and 2017.

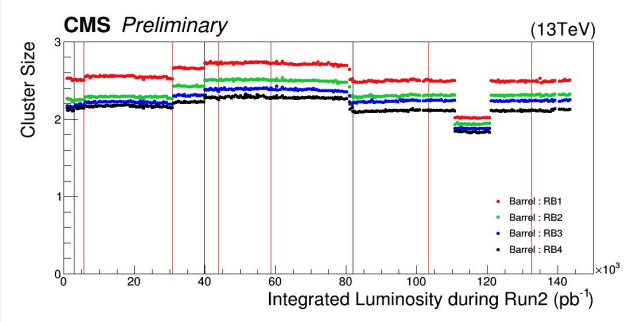
Isobutane concentration history. In 2016 concentration was higher because of mass flow controller problem.

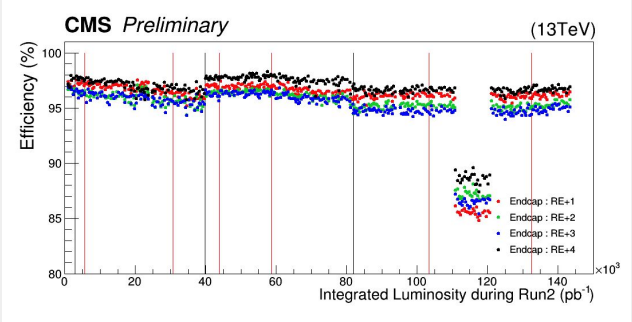


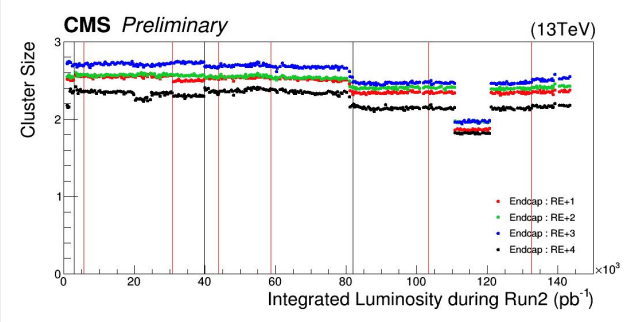
RPC WP, Efficiency history Run 1 and Run 2 (2016 and 2017).

Efficiency and Cluster Size









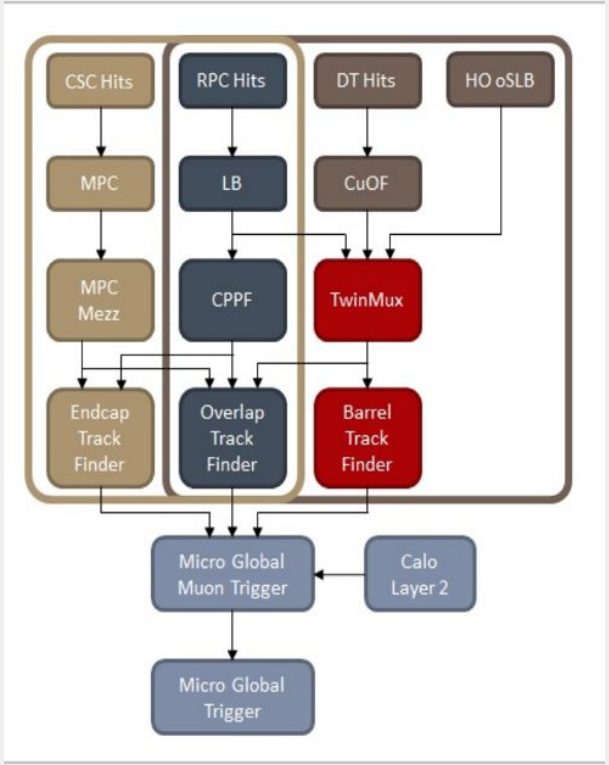
The RPC Efficiency and Cluster Size (CLS) is calculated using Tag-and-Probe Method.

The efficiencies during Run 2 above 95%. Showing high and stable performance.

The cluster size is also stable around 2 strips, within the CMS trigger requirements.

- In 2016 because of higher isobutene concentration (5.3%), efficiency was lower as the WPs were not changed to compensate the wrong gas mixture. After the deployment of the new HV working points in September 2016, the efficiency increased by ~1% and cluster size increased sharply.
- Gas concentration was back at 4.5 % in 2017 but the WP were not changed. New WP deployed by end of 2017.
- In 2018, because of a operational problem the WP were not set properly, and we see lower efficiency (less than 90%) and CLS.

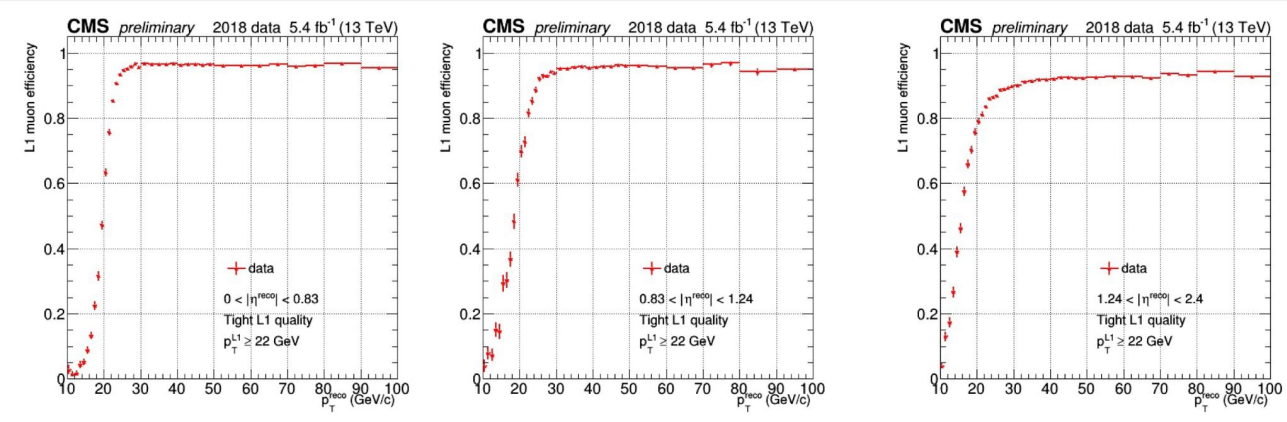
CMS Muon Trigger



CMS Muon Trigger is divided in 3 regions.

- Barrel Muon Track Finder (BMTF) ($|\eta| < 0.83$)
- Overlap Muon Track Finder (OMTF) ($0.83 < |\eta| < 1.24$)
- Endcap Muon Track Finder (EMTF) ($1.24 < |\eta| < 2.4$)

The three Track Finders are independent algorithms. They build tracks and assign p_T for different η region using the Trigger Primitives from the different muon detectors.
RPC provides information for the all Track Finders.

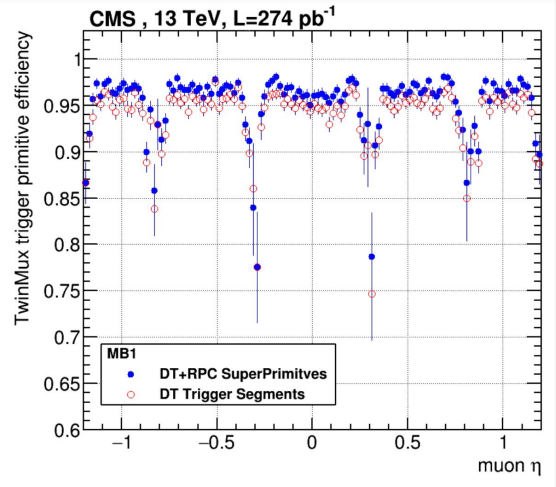


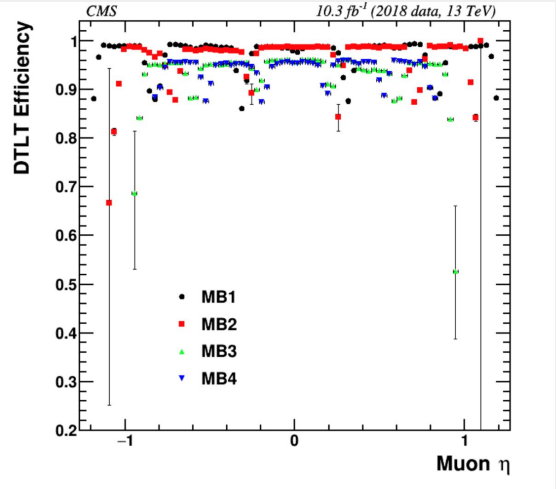
(BMTF) (OMTF) (EMTF)

RPC Contribution to Muon Trigger

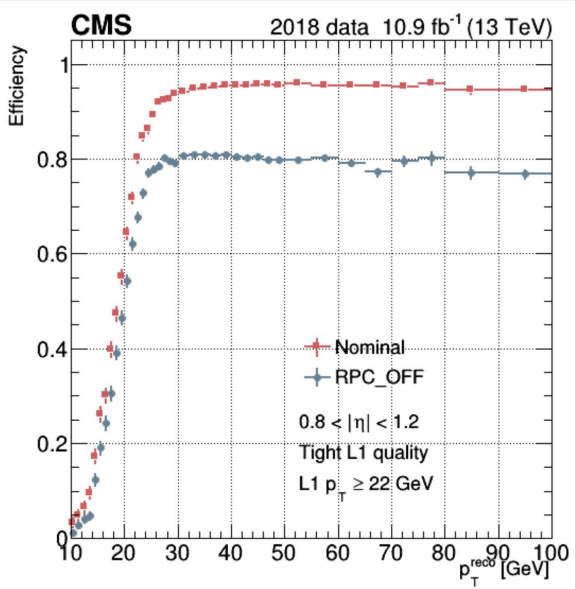
The addition of RPC information to the DT segments increases the efficiency of the trigger primitives that will serve as input to the BMTF and OMTF.

Also, RPC-only segments are built for stations MB1 and MB2 in case of DT segment absence. The efficiency for these stations are around 4% greater than stations MB3 and MB4.





In the Overlap region, The RPC system plays a key role there as it provides 8 measurements for muon trajectory reconstruction. The muon trigger efficiency is increased in about 15%



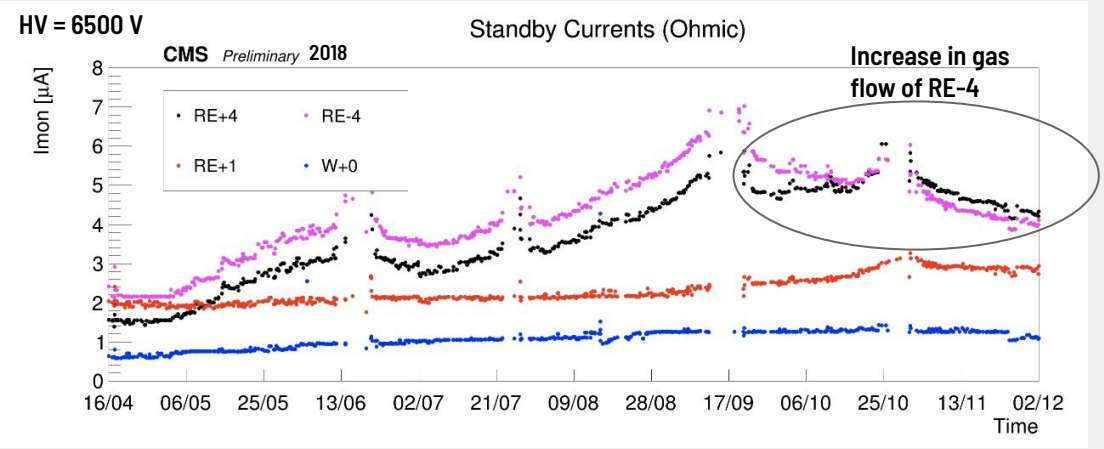
Ohmic Currents

Ohmic Current is the current with no beam up to around 7000 V, where the gas amplification has no contribution to the current.

Reversible ohmic current increase observed in high background regions, at $L=1.5x10^{34}cm^{-2}s^{-1}$

- RE4 background ~40 Hz/cm^2.
- RE1 and W0 < 10 Hz/cm^2.

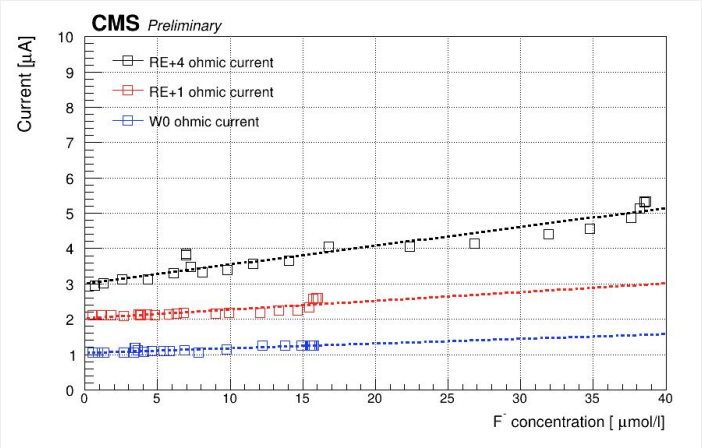
Faster recovery observed with higher gas flux.



The Concentration of Fluorine ions (F-) showed a linear dependency with the increase of Ohmic current and the background.

F- can produce HF which can increase the ohmic current.

More info: [Gas mixture quality studies for the CMS RPC detectors during LHC Run 2]



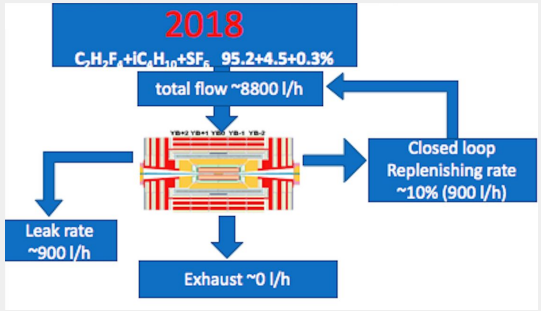
LS2 Activities

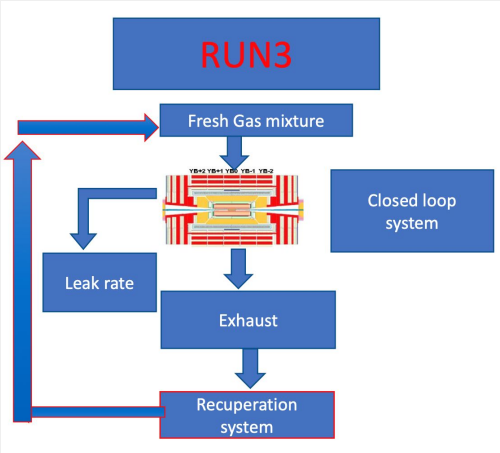
- Installation of thousands of kilometers of HV, LV cables, support equipment, gas pipes from gas distributor racks to the chambers and optical fibers for servicing and reading the signals of new detectors (iRPC)

- HV/LV Maintenance
  - **65 HV** repairs performed
  - **12 LV (TH)** repairs

- Extraction of the chambers of the two RE4 stations.
  - The chambers were brought to the surface, revalidated and reinstalled.

- Gas System Interventions
  - Main activities of LS2, aiming to minimize the environmental impact of the RPC system ($C_2H_2F_4$ and SF_6 have very high GWP).
  - **49 out of 99 gas leaky** RPCs were repaired.
  - 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 with efficiency of 80%.

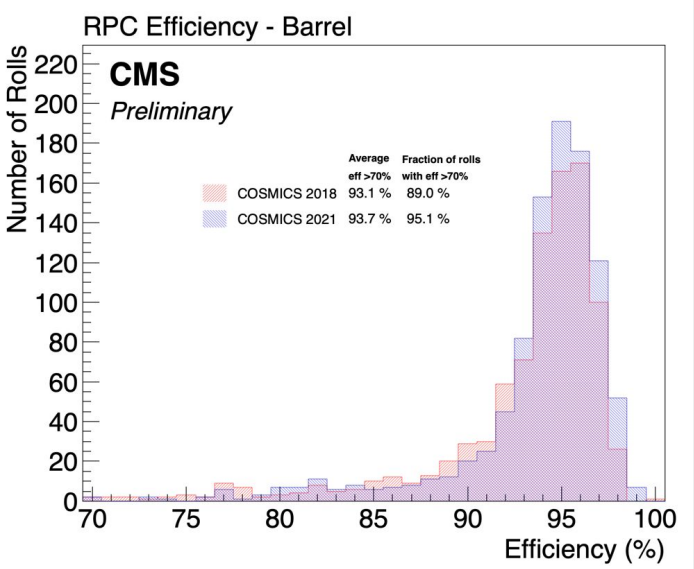


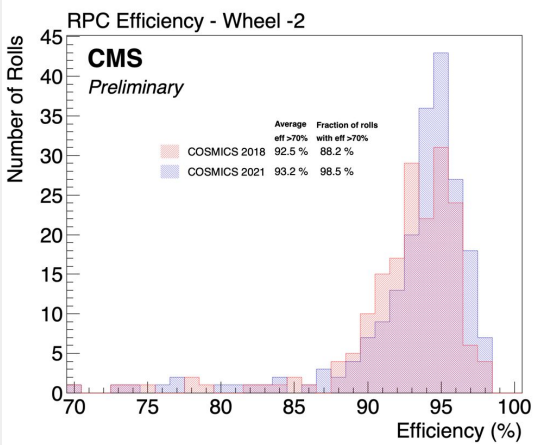


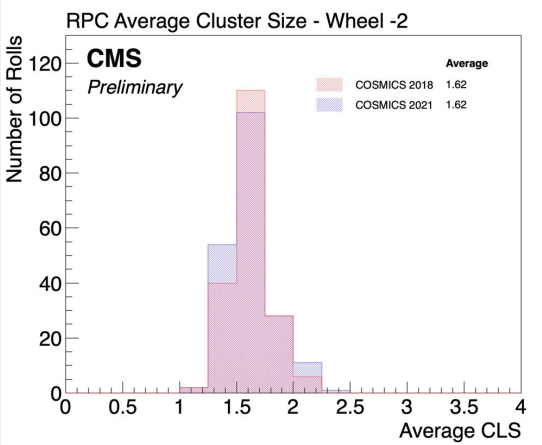
Performance Comparison (Cosmics)

After all the LS2 interventions, we can see that the performance of the detector in 2021 is much better than in the end of Run 2 (2018).

The number of chambers in good condition is increased (more than 6% for the full Barrel). The overall efficiency and cluster size is in accordance with the expected.







- RUN3: RPC plan to turn off all the leaky chambers (3.5% of total system) to reduce it from 900 to ~200 l/h by:
  - Restoring the exhaust
  - Reduce the fraction of fresh gas

Conclusion

- Stable performance after operation in extreme conditions during Run 1 and Run 2 (~185 fb^{-1})
  - Average Efficiency: ~95%
  - Average CLS: ~ 2 strips
- Reversible ohmic current increase observed in high background regions.
- 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 (~200 l/h with gas going to exhaust).
- System is ready to participate in Run 3 data taking.

Backup Slides

CMS Muon System Posters

GEM detectors for the upgrade of the CMS Muon Spectrometer

- Speaker: Shivali Malhotra (Texas A&M Univ.)

High rate capability studies of triple-GEM detectors for the ME0 upgrade of the CMS Muon spectrometer

- Speaker: Francesco Fallavollita (CERN)

Radiation Background estimation for the GE1/1 Triple-GEM detector in the CMS endcap

- Speaker: Sunil Kumar (Panjab Univ.)

CMS RPC upgrade program

- Speaker: Felipe Silva (Univ. Estado Rio de Janeiro)

Improved Resistive Plate Chambers for the upgrade of the CMS muon detector

- Speaker: Amrutha Samalan (Ghent Univ.)

CMS RPC Link System upgrade

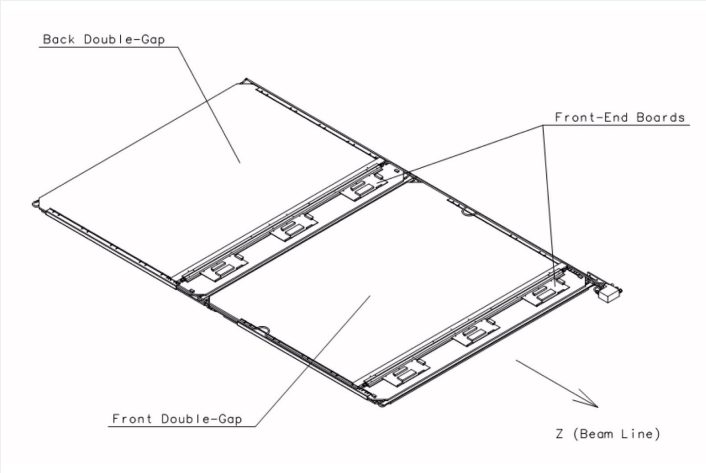
- Speaker: Behzad Boghrati (Inst. for Studies in Theoretical Physics & Math. (IPM))

Barrel RPC Geometry

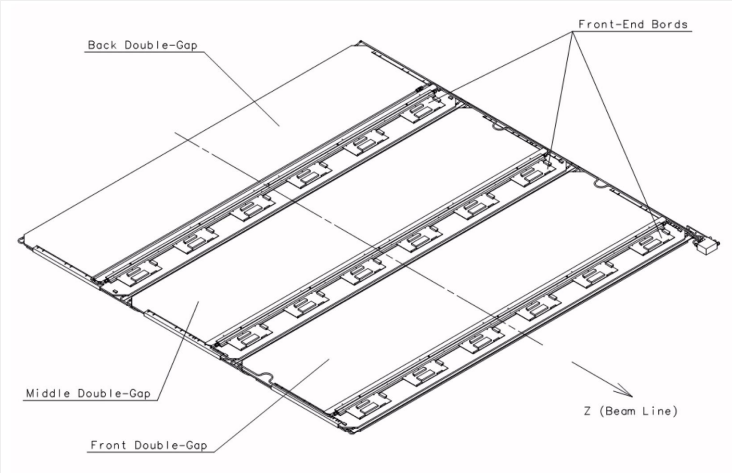
RPC barrel chambers are divided into 2 or 3 eta partitions along the z axis. In barrel there are 480 chambers installed resulting in 1020 eta partitions called as “rolls”.

Results shown in the coming slides are measured for every roll.

RPC	W+2	W+1	W0	W-1	W-2	Total
RB1in	12	12	12	12	12	60
RB1out	12	12	12	12	12	60
RB2in	12	12	12	12	12	60
RB2out	12	12	12	12	12	60
RB3	24	24	24	24	24	120
RB4	24	24	24	24	24	120
Total	96	96	96	96	96	480



2 partition chamber



3 partition chamber

RE4 Extraction/Installation

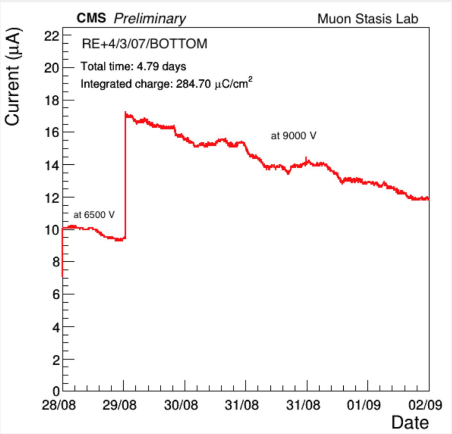
One of the main activities of LS2 was the extraction of the 72 super modules (SM) of the RE+4 station.

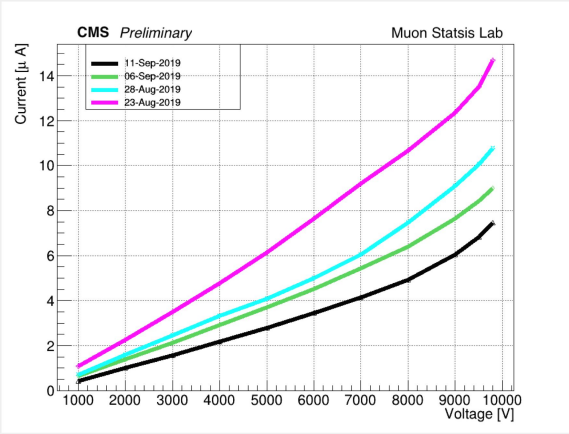
- Each SM is about 4 meters long and weighs 230 kg, which poses a great challenge to the extraction/installation.

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.

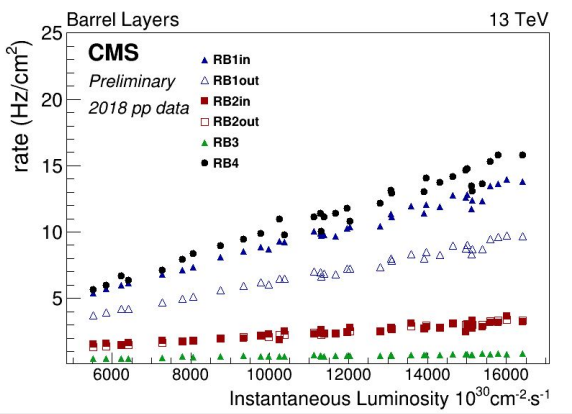
Increase of currents observed on the surface.
The gaps were under stable HV for 4 weeks and the currents went lower.

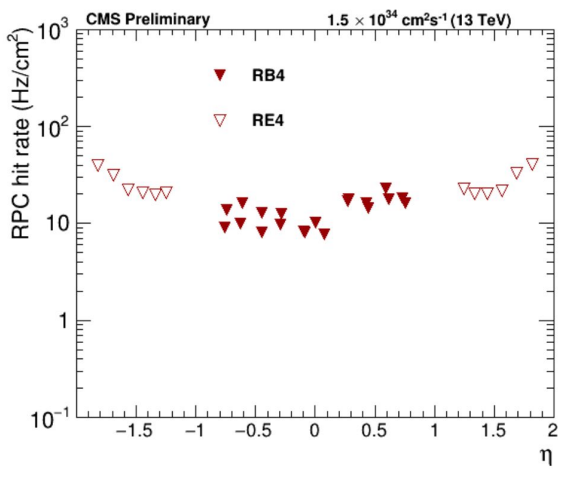
- FEBs were tested to spot silent/noisy strips.
- After revalidation (HV, LV, gas, Cooling) the chambers were reinstalled. 6 problematic chambers replaced with spares.





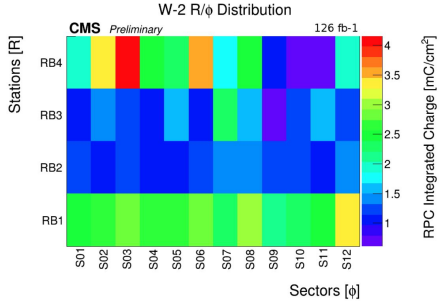
Background/Integrated Charge





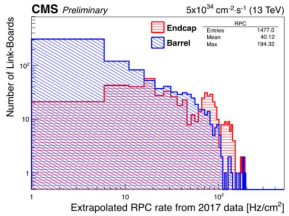
After ~ 9 years operation → ~ 185 fb^{-1} integrated luminosity

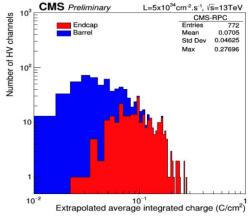
- ~2.3 mC/cm^2 for Barrel
- ~7.5 mC/cm^2 for Endcap



RPC expected rate & charge at HL-LHC conditions

The charge integrated at LHC collisions and linear trend of rate vs luminosity is used to estimate the expected integrated charge and rate at HL-LHC assuming a total integrated luminosity of 3000 fb^{-1} and instantaneous luminosity of 5×10^{34} $cm^{-2}\cdot s^{-1}$





→ Maximum expected integrated charge **≈ 272 mC/cm^2**
→ The expected mean and maximum rate for barrel and endcap are **40 Hz/cm^2** and **194 Hz/cm^2**.

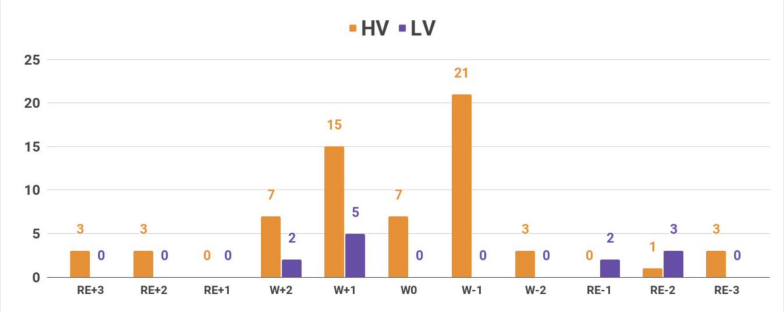
HV and LV Repairs

Extensive HV and LV repair campaign:

65 HV repairs performed.

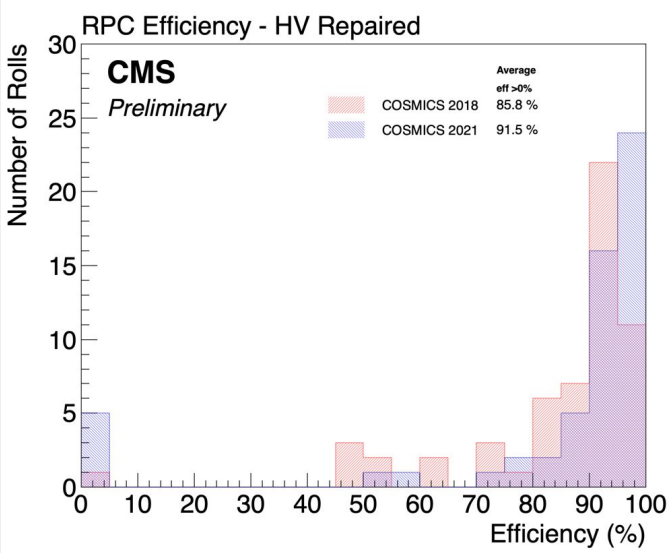
- Out of those, **45 HV new trips** developed in LS2 due to **multiple power cycling operation mode** (due to COVID issues).

12 LV (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.



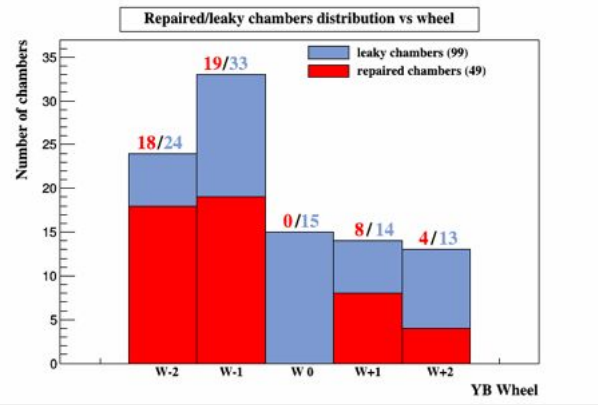
Gas Leak Repairs

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.