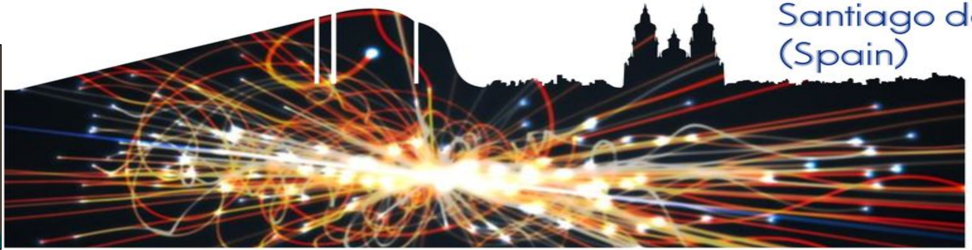


Santiago de Compostela (Spain)

RPC 2024

XVII Workshop on Resistive Plate Chambers and Related Detectors

CMS RPC performance and operation in LHC Run 3

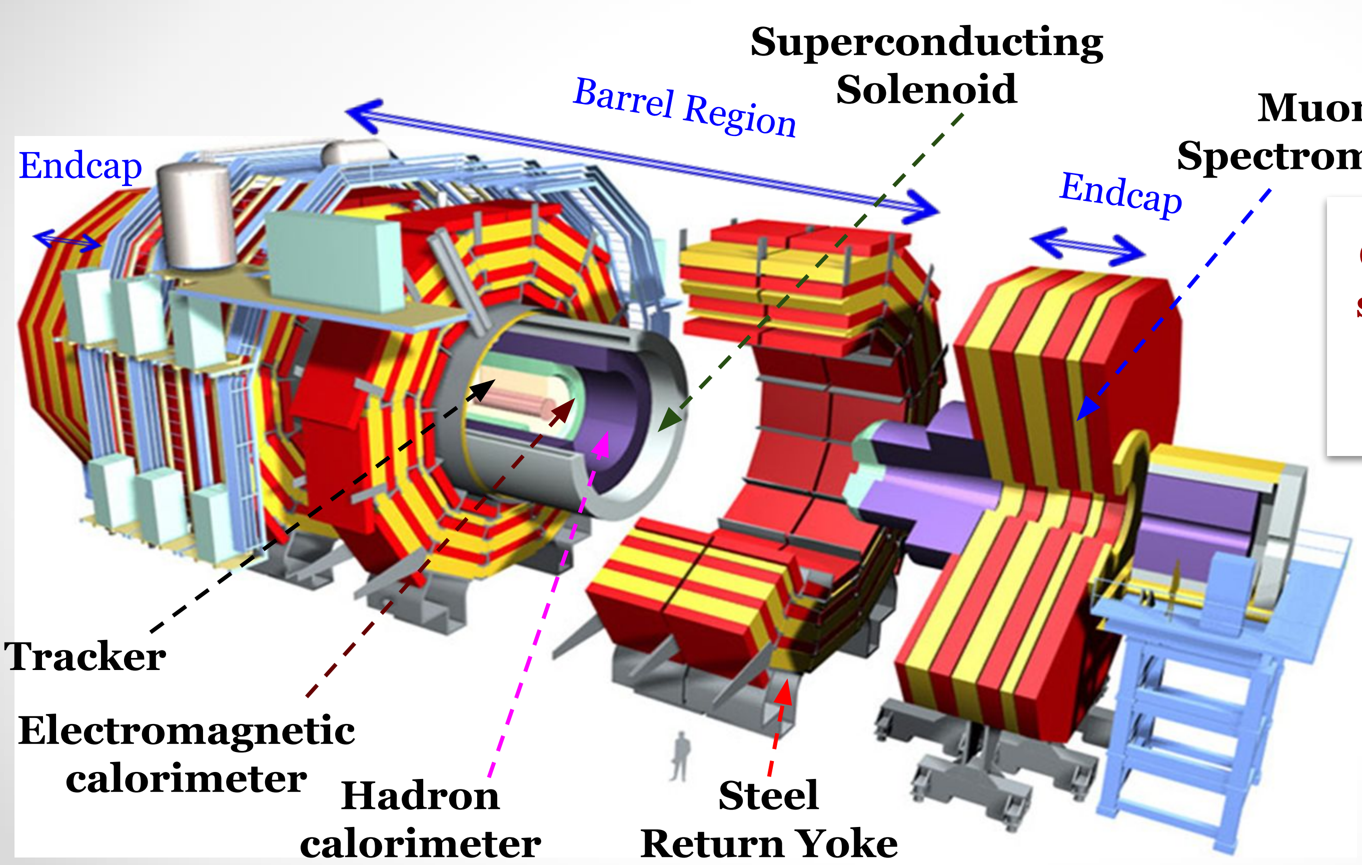
Mariana Shopova

Bulgarian Academy of Sciences, Bulgaria

on behalf of the CMS Collaboration

September 9th 2024

CMS Detector

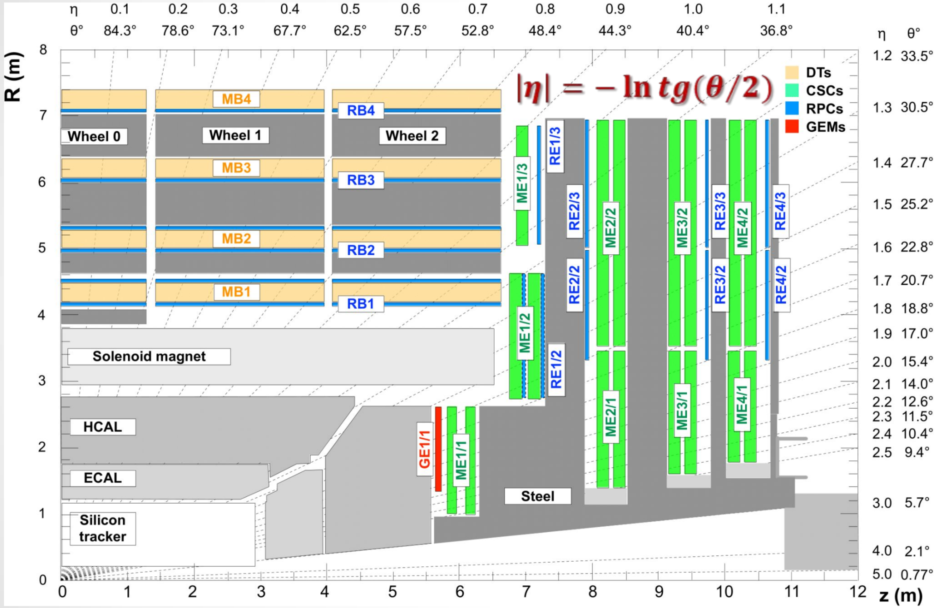


General purpose detector searching for new physics phenomena in all the available energy ranges.

Overall length 28.7 m
Overall diameter 15 m
Overall weight of 14 000 t

CMS Muon System

Robust, efficient and redundant muon system



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

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 $(1.5 < |\eta| < 2.2)$

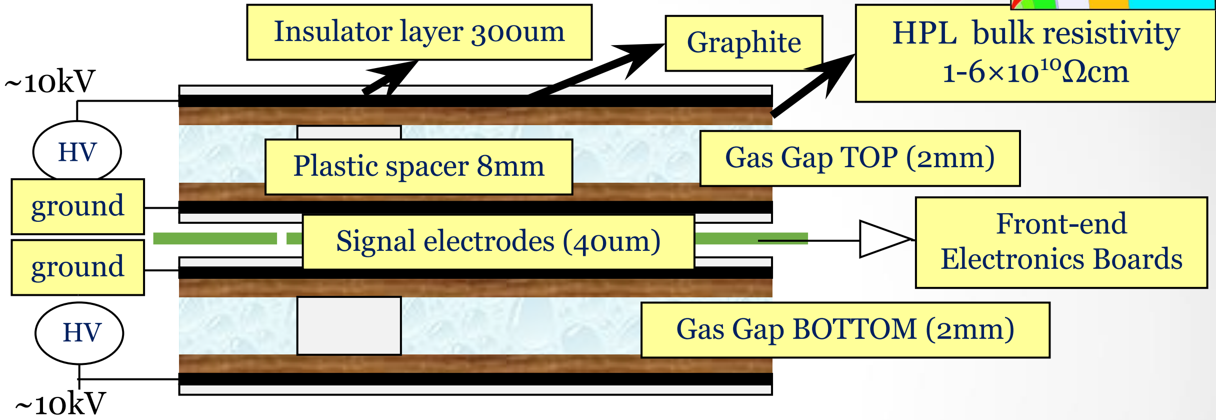
Muon system requirements:

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

CMS Resistive Plate Chambers

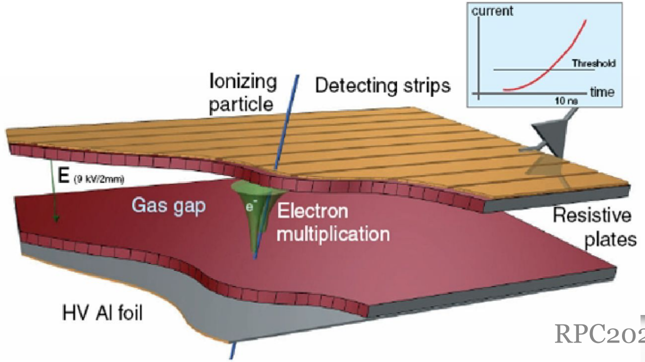
RPC present system

- Covers |η| < 1.9
- Total number of **1056 chambers** (480 in barrel and 576 in endcap)
- ≈ **120 k 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% SH_6 (Sulfur hexafluoride)

Relative Humidity 40%



Requirement of RPC system:

- **High rate capability (~300 Hz/cm²)**
- **Intrinsic Noise < 5 Hz/cm²**
- **High detection efficiency > 95%**
- **Average cluster size ~2 strips**
- **Intrinsic time resolution < 1.6* ns**

*(*not fully exploit due to 25 ns limit of DAQ system)*

- **Spatial resolution** 0.8 - 1.3 cm**

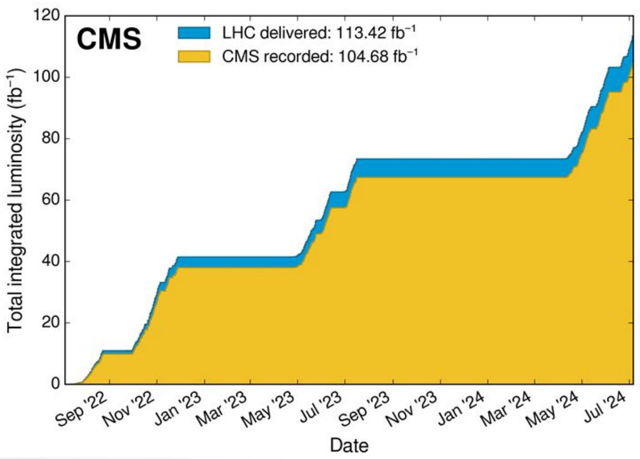
*(**precision of coordinate measurement in bending plane)*

- **Ability to withstand in long term operation and high background radiation**

CMS and RPC operation in Run 3

Excellent CMS data taking efficiency > 92% in Run 3

No Luminosity loss due to RPC



Stable fraction of RPC active channels -
following the CMS gas leak reduction policy

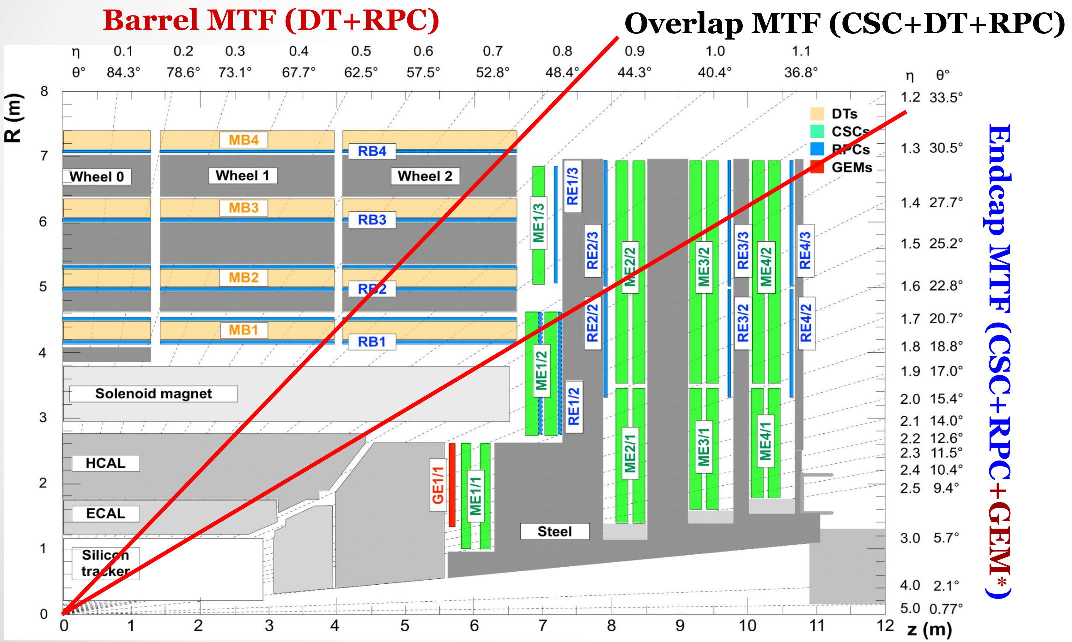
Year	2018	2022	2023	2024
% of RPC active channels	96.5	89.6	87.7	82.6

Key to success: Clear procedures for a prompt intervention during all beam-off and technical access time.

Since 2022, all channels with leaky chambers (located only in the Barrel region) have been disconnected to reduce GHG emissions and to ensure the use of the new RPC recuperation system efficiently.

RPC contribution to CMS Muon Trigger

CMS Muon Trigger uses Trigger Primitives (TP) from different sub-detectors to identify tracks associated to muons and evaluate their transverse momentum.



*A. Hayrapetyan et al 2024 JINST 19 P05064 - DOI: 10.1088/1748-0221/19/05/P05064

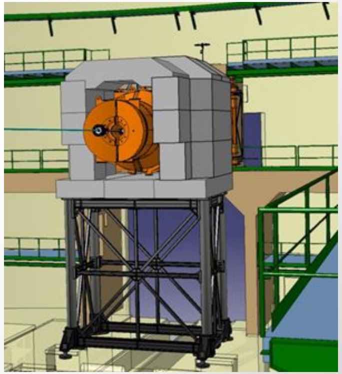
RPC system contributes to all 3 Muon Track Finders:

- **Barrel** Muon Track Finder (BMTF) - DT+RPC
- **Overlap** Muon Track Finder (OMTF) - CSC+DT+RPC
- **Endcap** Muon Track Finder (EMTF) - CSC+RPC+GEM*
  (*GEM - to be included in the trigger)

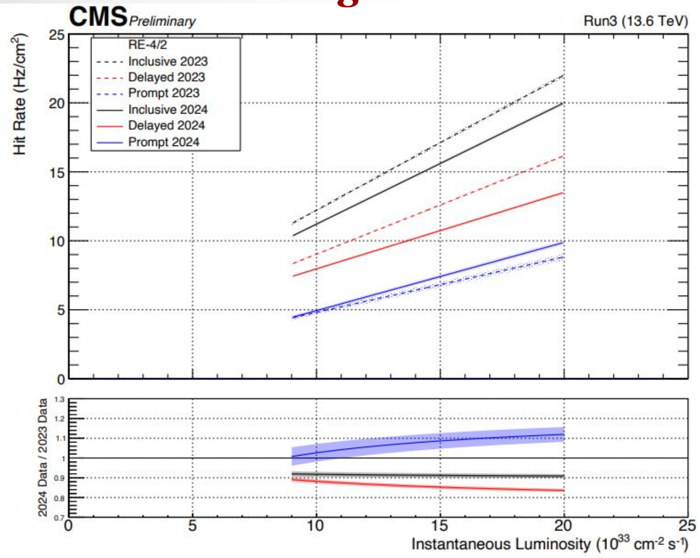
More details on the CMS L1 Trigger in Andres Cabrera's talk later today

RPC Background

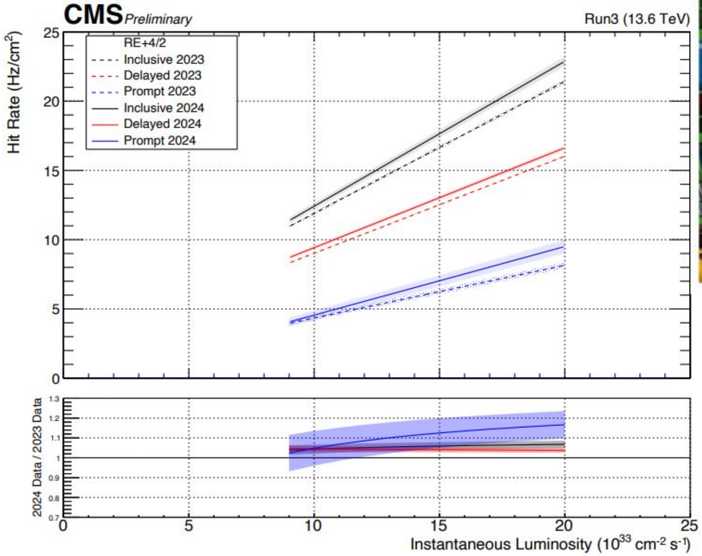
New Forward Shielding was designed to reduce background in the CMS cavern.
It was installed during Year "End" Technical Stop (YETS) 23/24 only on the **negative side**.



Negative side



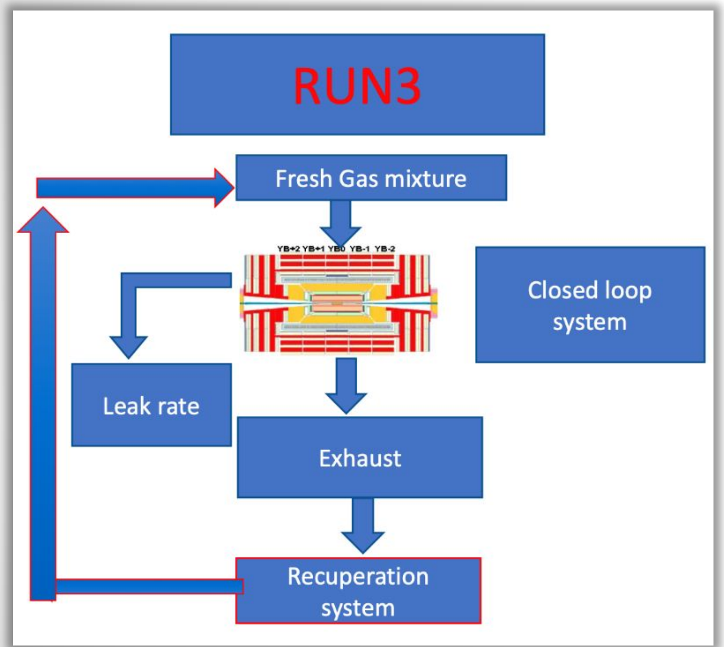
Positive side



RPC offline hit rate vs Instantaneous Luminosity per background for RE4 stations

More details on the CMS RPC Background studies shown in Leonardo Favilla's poster

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 developed the first $C_2H_2F_4$ recuperation system (also called R134a) - operational since July 2023**
- **Current policy: disconnect leak channels in order to restore the Exhaust.**

Recuperation system working conditions:

- **Feed flow - between 100 and 500 l/h**
- **Recuperation efficiency: 80%**

More details on the R134a recuperation system in Roberto Guida's talk on Wednesday

RPC Gas system - Leak repairs

Cern 904 Laboratory - repair trial

A **new gas leak reparation procedure** was tested in CERN 904 Laboratory and then successfully validated during YETS 23/24.

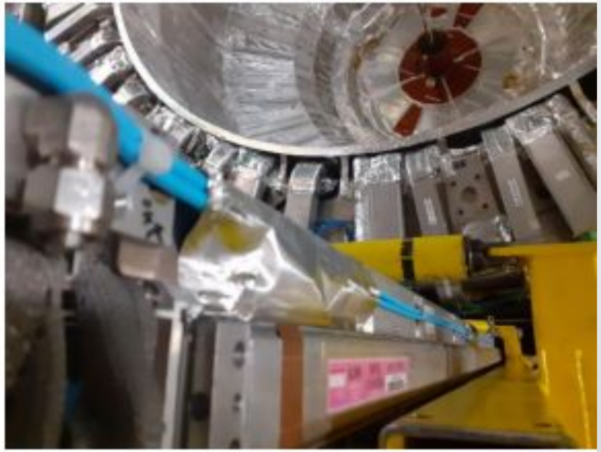
Only in first and second Barrel stations

**DT/RPC station configuration - RPC+DT+RPC*

A full extraction of a DT/RPC station* allows access for improvement of all weak points, relevant for leak development - replacement of all polyethylene pipes and T and L connectors inside the RPC detectors.

Two DT/RPC stations fully extracted during YETS 23/24 and all **four RPC detectors** (2 complete gas loss (full leaks) + 2 connected to them) got new pipes and new robust connectors.

After a series of tests done - all repaired chambers are fully operational with no side effects from the reparation and no gas leak!



CMS cavern - full extraction

RPC Gas system - status

Period	Leak assigned	New full	Old increasing	New small (<50%)	Disconnected chambers	Disc/ Rec	Leaking connected	Possible chambers to recover
Nov 23 - Mar 24	**8**	**4**	**4**	**0**	**145**	**18/2**	**27**	**35**
Apr 23 - Oct 23	3	2	1	7	129	0/0	38	30
Apr 23 - Mar 24	11	6	5	7	145	18/2	27	35
Apr 22 - Mar 23	24	13	11	5	129	26/5	29	30

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

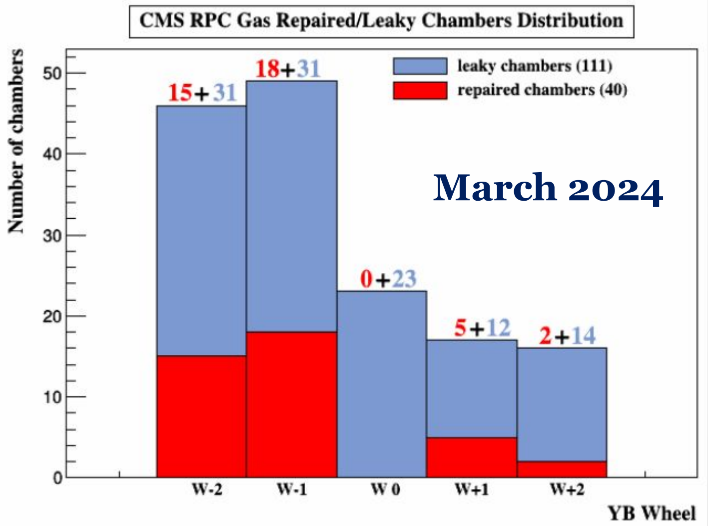
RPC system active channels - 83% (2024)

Leaking chambers - 111

Only in Barrel!

Disconnected chambers - 145

- ***110*** *leaking* + ***35*** *can be recovered in case of access*



For the first time reduced number of full leaks with respect to last three YETS!

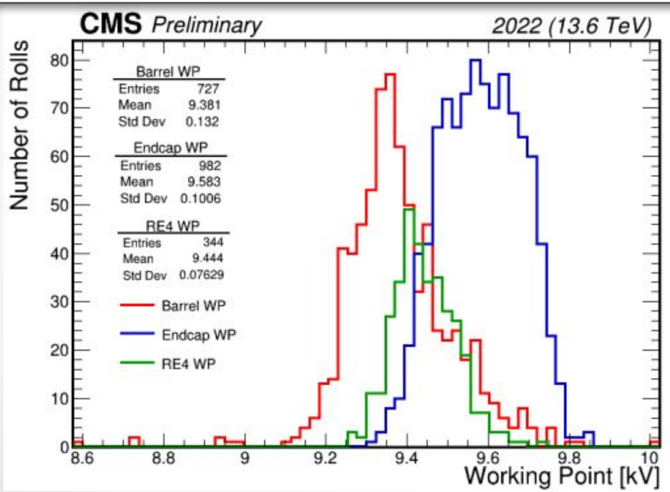
RPC Working Point calibration

HV scans are done periodically (2022 & 2024 - *under analysis*) with dedicated collision runs.

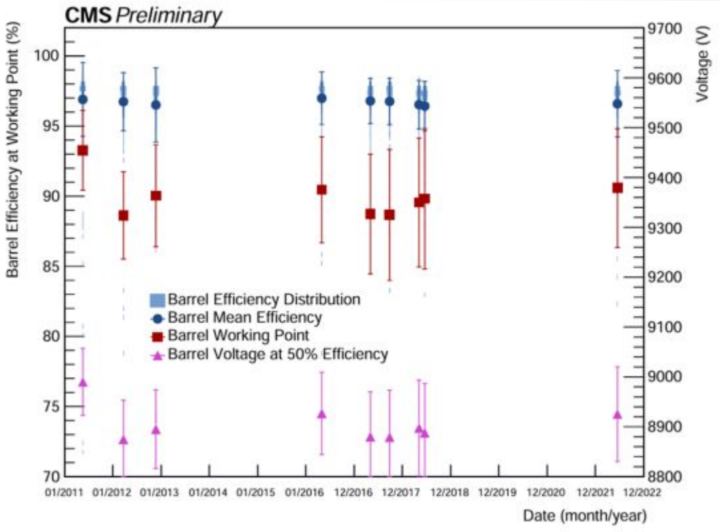
Main goals:

- **optimize each RPC detector Working Point (WP)**
- **monitor the performance in time.**

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



RPC Working Point distribution for different detector regions



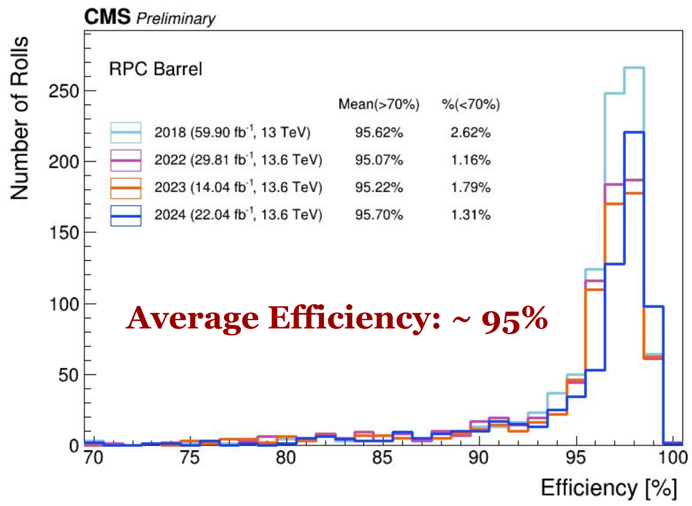
RPC WP, Efficiency and HV50 history over the years.

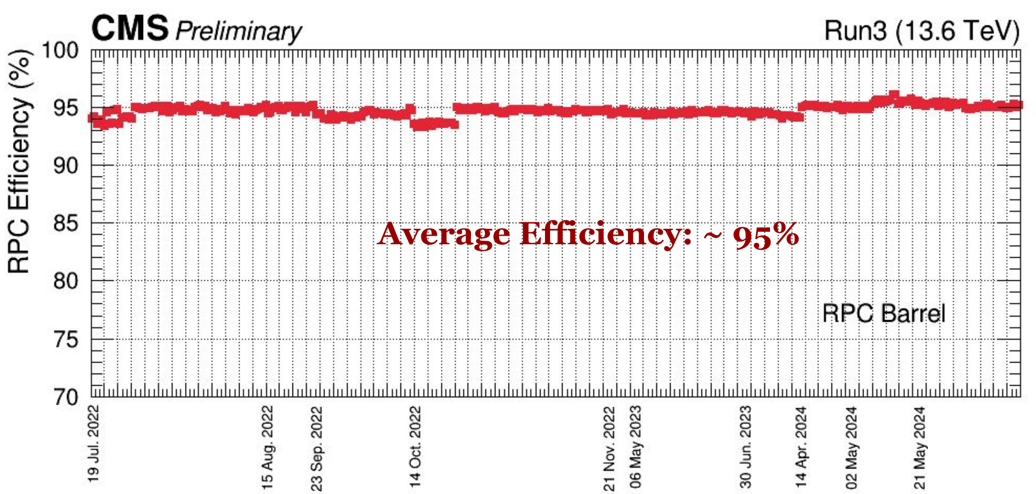
Special Machine Learning approach developed for HV scan data analysis - details in Mihaela Pehlivanova's poster

RPC performance in Run 3

RPC performance is measured using the **Segment Extrapolation Method** where DT/CSC Segments (in the Barrel/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.

Stable RPC Barrel performance in RUN 3 and in agreement with previous LHC Runs

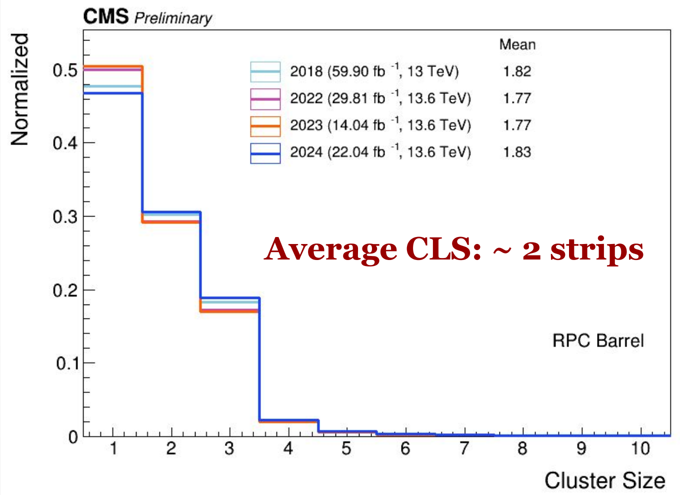


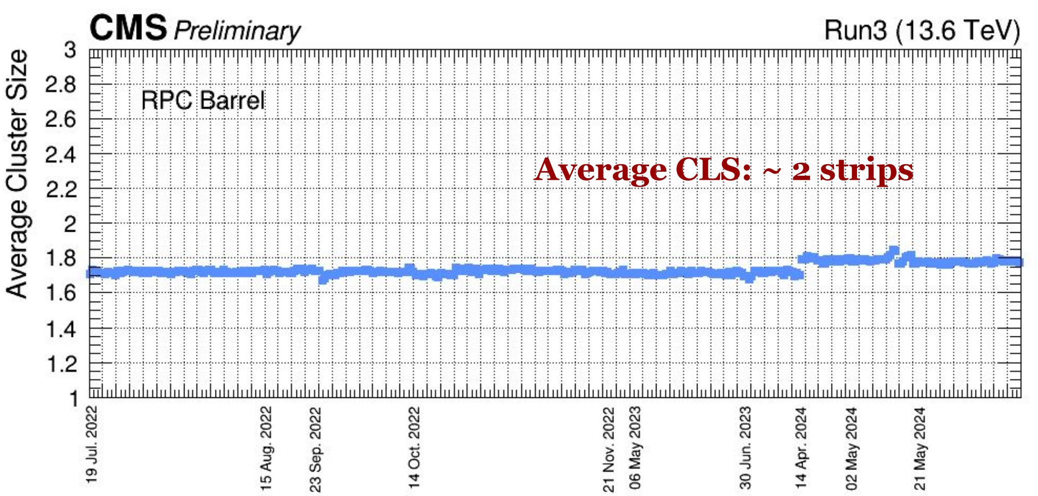


More details on RPC efficiency studies using Tag-and-Probe method shown in Jongwon Shin's poster

RPC performance in Run 3

RPC performance is measured using the **Segment Extrapolation Method**

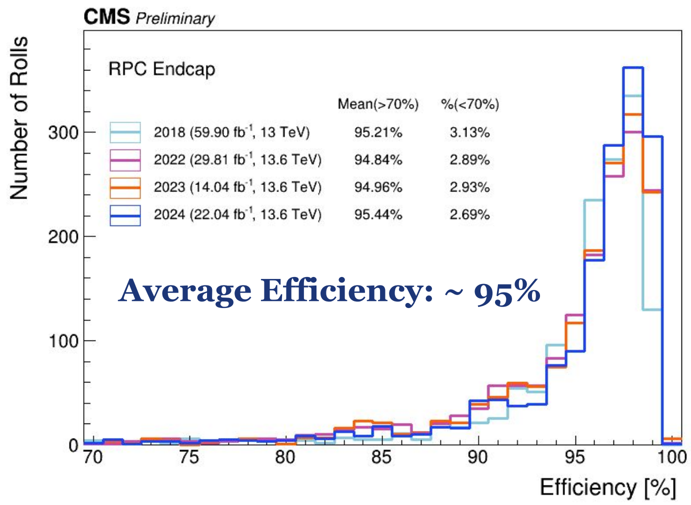


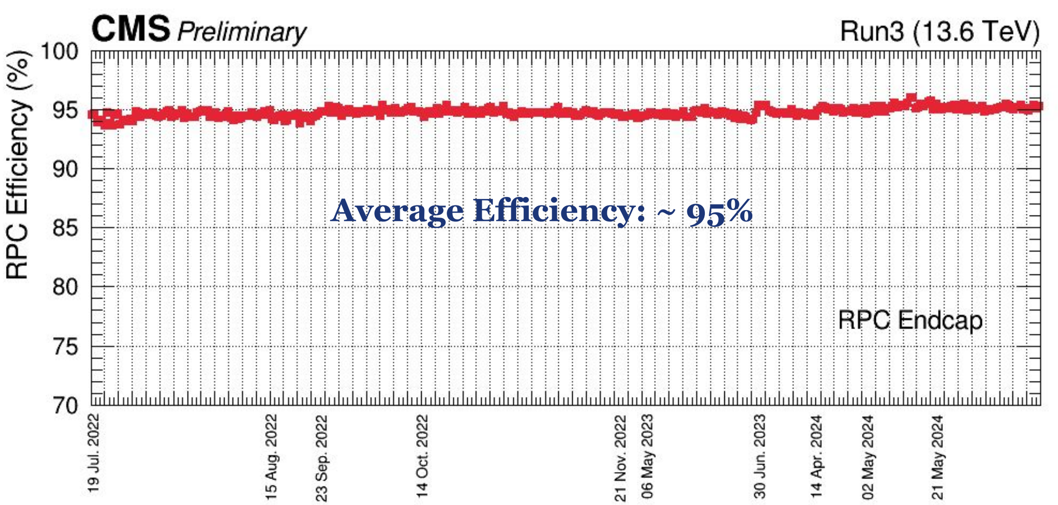


Stable RPC Barrel performance in RUN 3 and in agreement with previous LHC Runs

RPC performance in Run 3

RPC performance is measured using the **Segment Extrapolation Method**



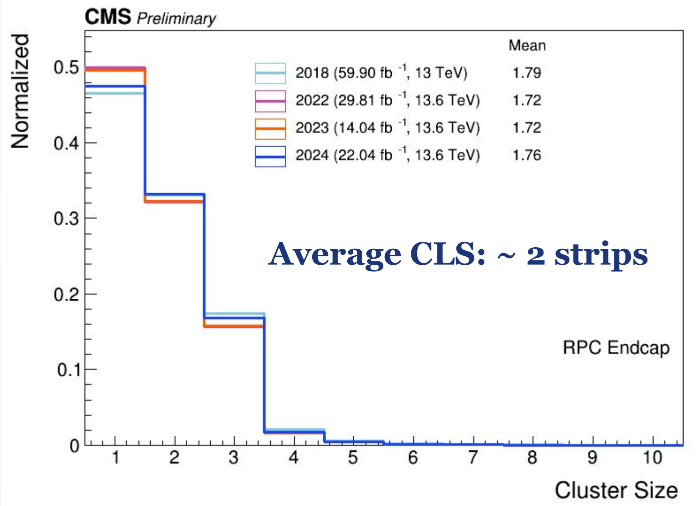


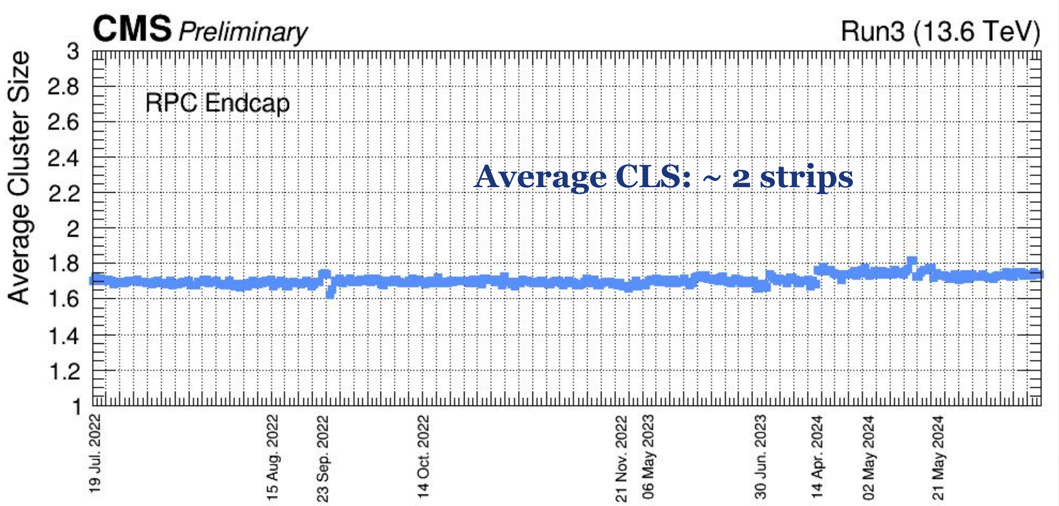
Stable RPC Endcap performance in RUN 3 and in agreement with previous LHC Runs

More details on RPC efficiency studies using Tag-and-Probe method shown in Jongwon Shin's poster

RPC performance in Run 3

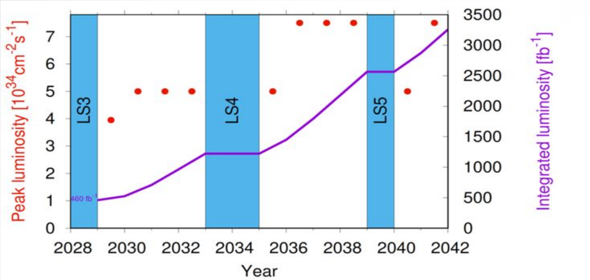
RPC performance is measured using the **Segment Extrapolation Method**

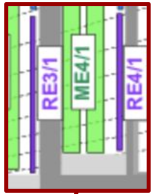


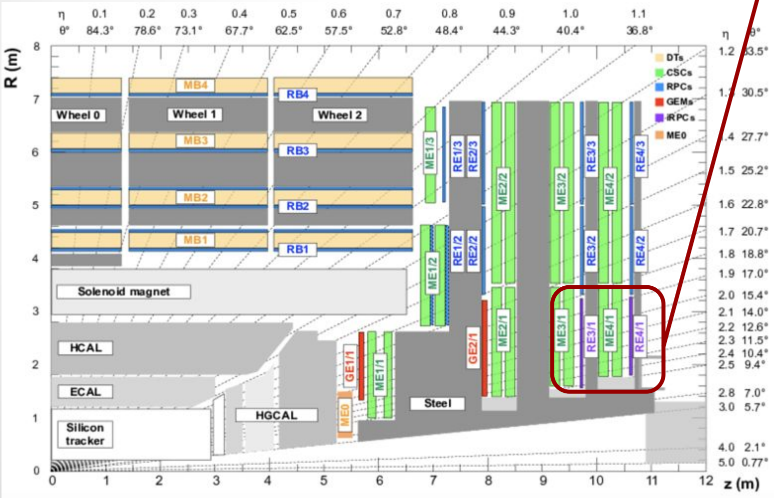


Stable RPC Endcap performance in RUN 3 and in agreement with previous LHC Runs

RPC system upgrade for HL-LHC







RPC system upgrade for HL-LHC

- **Upgrade Link System of existing RPC system***
- **Installation of new detectors in the CMS forward region**
  - **Improved Resistive Plate Chambers (iRPC)** in station RE3/1 and RE4/1**

More details on RPC Link System are shown in Fateme Esfandi's poster

*****More details on the iRPC for CMS Phase-2 Upgrade in Jules Vandenbroeck's talk this afternoon***

Images: CERN Document Server courtesy

Conclusion

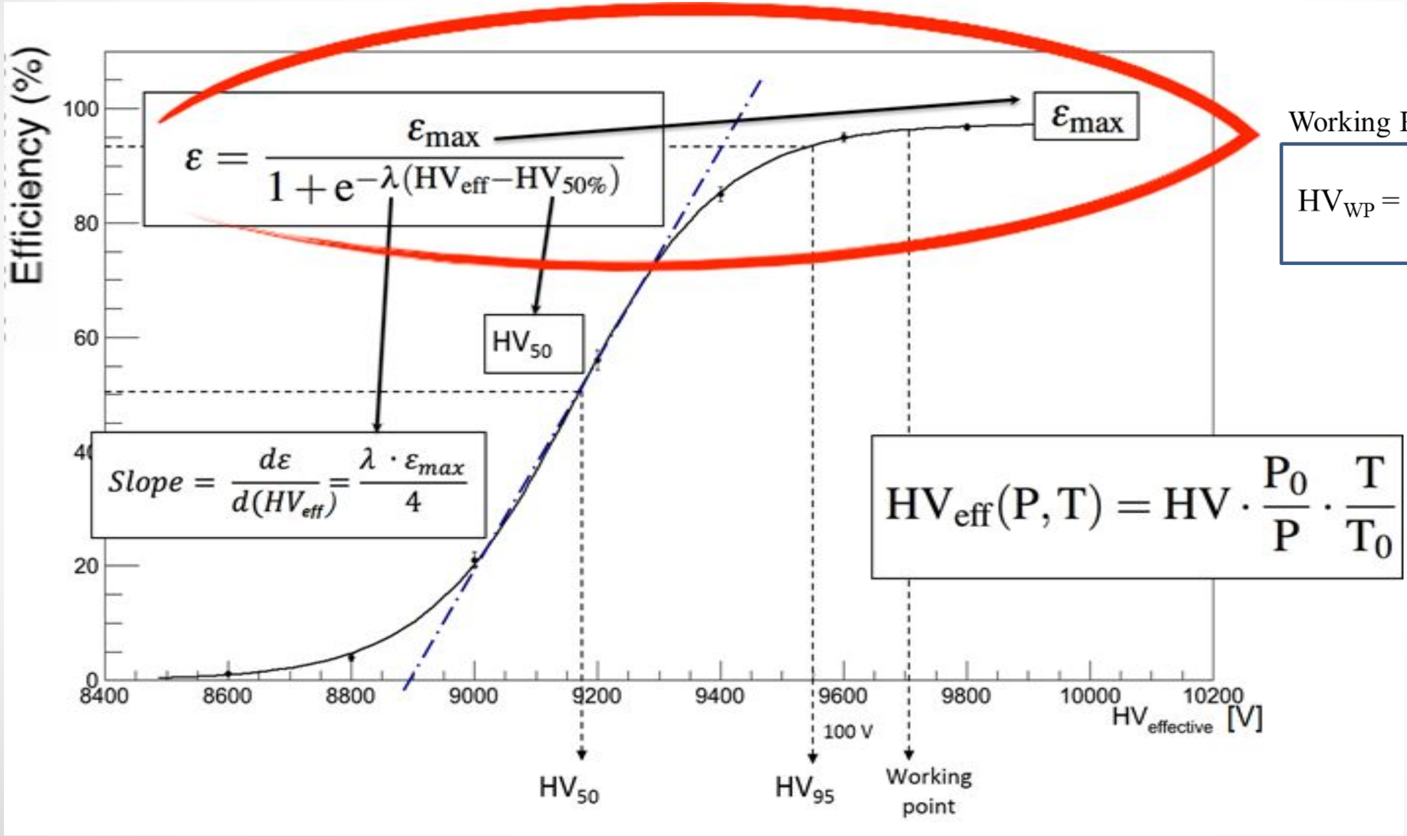
- **CMS RPC system is operating with stable performance in Run 3 data taking:**
  - **Average Efficiency: ~ 95%**
  - **Average CLS: ~ 2 strips**
  - **Important contribution in all sections of the CMS Muon Trigger (BMTF, OMTF and EMTF)**

- **Plan to continue minimizing the environmental impact of the RPC system**
  - **Gas Leak repairs following the newly developed reparation procedure**
  - **Maintenance and further R&D of the $C_2H_2F_4$ recuperation system.**
  - **Turn OFF all leaky channels to keep the leaks at minimum.**

- **Keep the ability to withstand long term operation and high background radiation in the view of the HL-LHC**
  - **Upgrade Link System of the existing RPC system**
  - **Extend the RPC system coverage up to $|\eta| < 2.4$ by installing new iRPC detectors in the CMS forward region**

Backup Slides

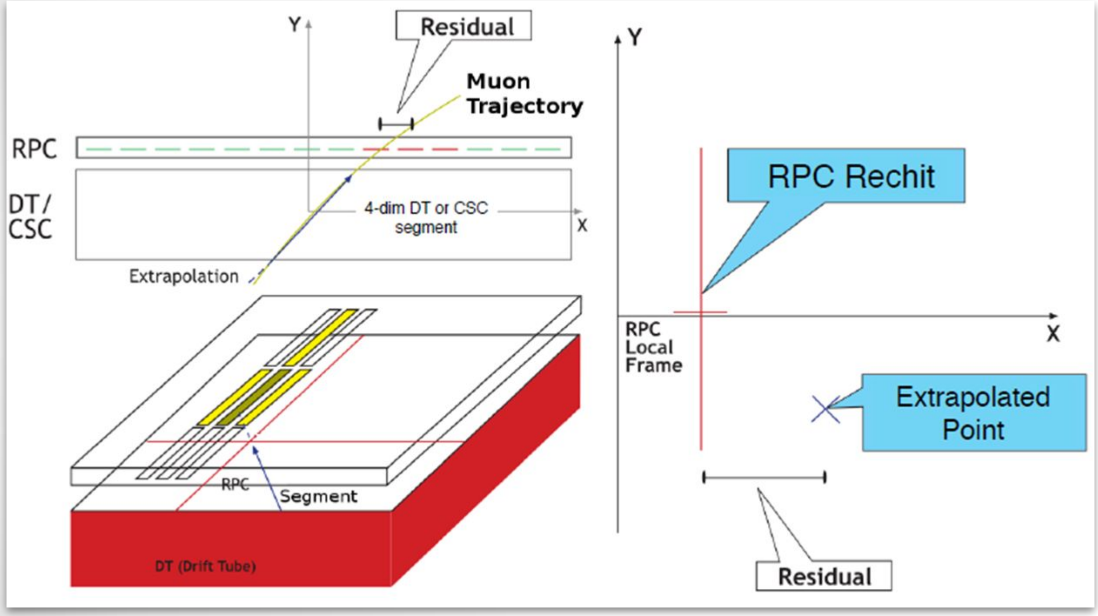
HV scan parameters



Working Point Definition

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

Segment Extrapolation Method



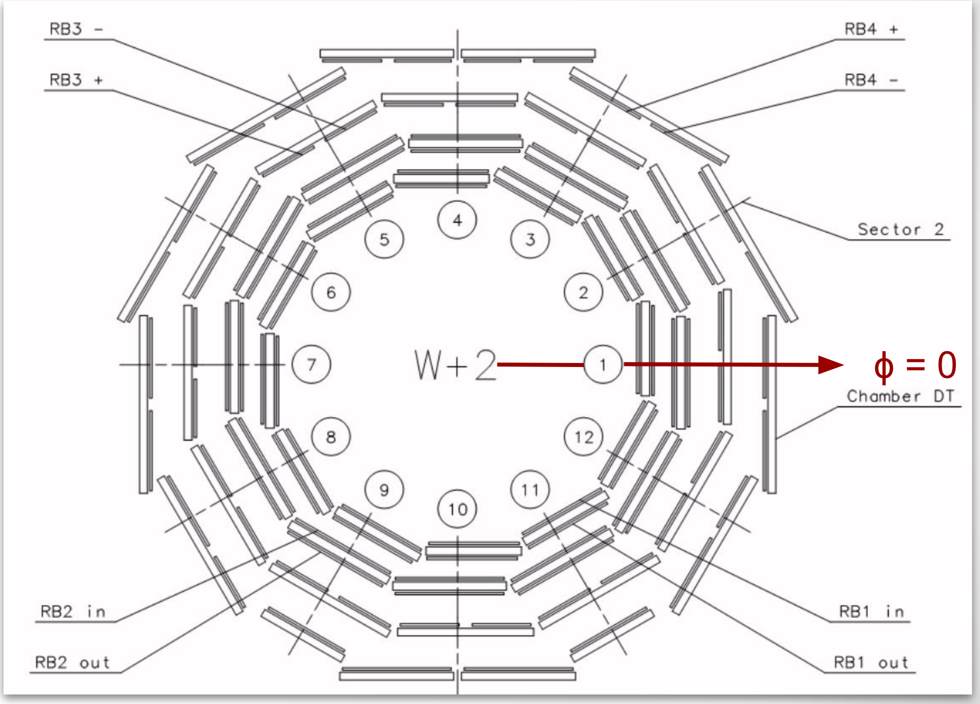
RPC hit efficiency is obtained using the Segment Extrapolation Method (JINST 5 (2010) T03017, DOI: 10.1088/1748-0221/5/03/T03017), where the RPC efficiency is calculated as the ratio between the number of detected and the number of expected hits. Segments (DT in the Barrel and CSC in the Endcap) that belong to a standalone muon track with timing corresponding to RPC readout bunch crossing (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 RPCs are distributed in 5 wheels (-2, -1, 0, 1, 2). In each wheel the RPCs 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(-).

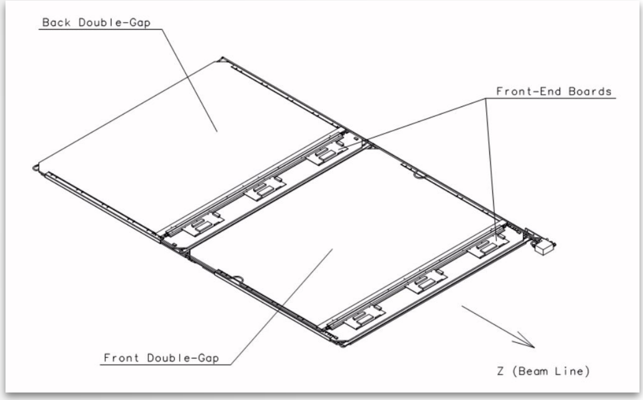
Source: CMS-DP-2017-053



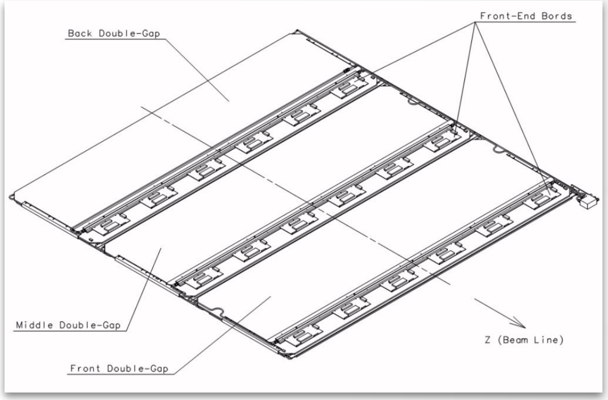
RPC Distribution in the Barrel

Source: CMS-DP-2017-053

Eta partitions -> Rolls



With two eta partitions



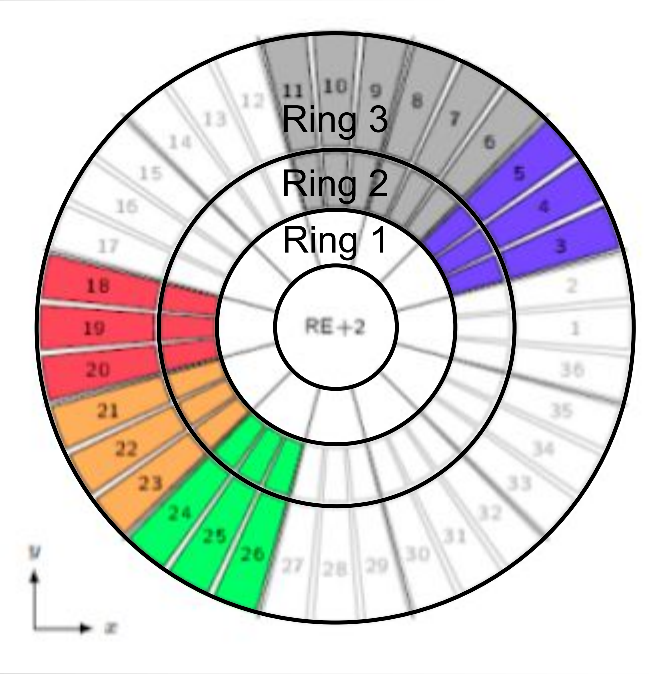
With three eta partitions:
RB2in Wheels +1, 0 , -1
RB2out Wheels +2, -2

Chambers in the barrel are divided in 2 eta partitions (also called rolls): Forward and Backward.

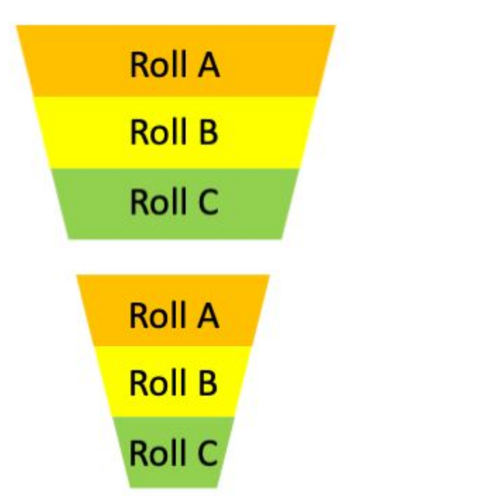
With the exception of RB2in in Wheels +1, 0 , -1 and RB2out in Wheels +2, -2 that have 3 eta partitions: Forward, Middle and Backward.

RPC Distribution in the Endcap

Source: CMS-DP-2017-053



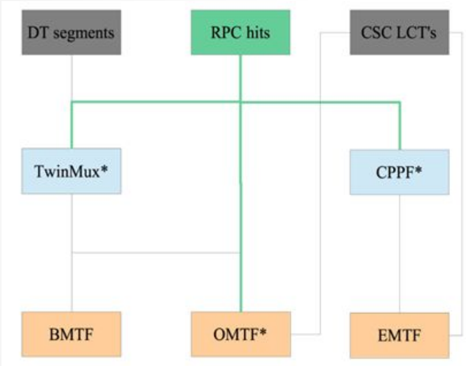
In the endcap region, the RPCs are distributed in 8 disks (4 in the positive endcap and 4 in the negative endcap). In each disk the RPCs are distributed in 3 rings. Ring 1, the inner one, is not installed. Each ring has 36 chambers, and every chamber is divided in three eta partitions (also called rolls):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



RPC contribution to Muon trigger

In the Barrel region, to provide optimal online reconstruction inputs to Level-1 Muon Trigger Track Finders, **DT and RPC information is processed in two stages**.

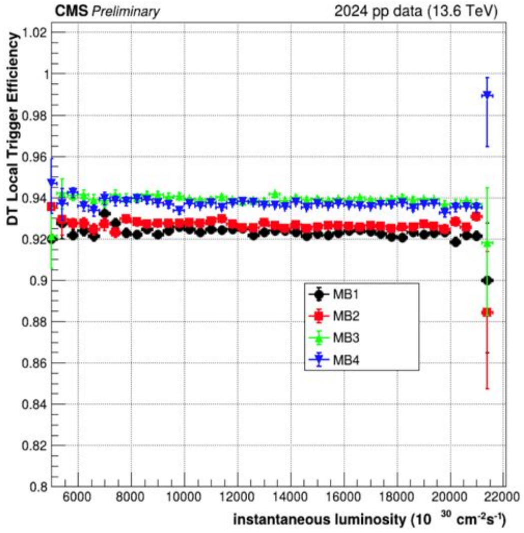
*Module with RPC hit clustering and cluster selection



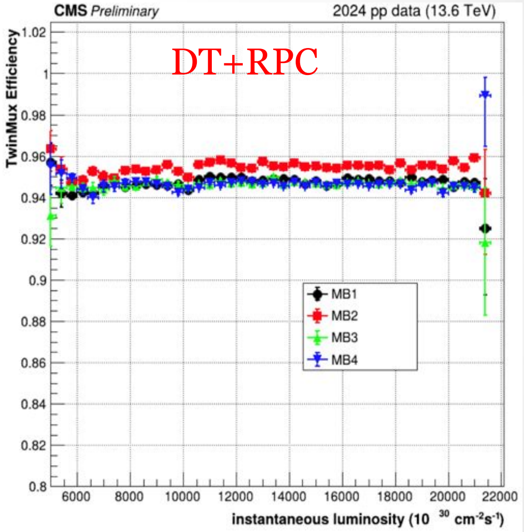
In the first layer, TwinMux boards match RPC hit clusters with DT Local Trigger segments to:

- **recover** DT inefficiencies in MB1 and MB2 stations using RPC-only primitives
- **improve** BX identification efficiency by exploiting the RPC's excellent time resolution

DT Local Trigger efficiency as a function of LHC Instantaneous Luminosity



TwinMux efficiency as a function of LHC Instantaneous Luminosity



Increase in the efficiency of the TwinMux segment, compared to the DT Local Trigger efficiency:

- ~3% in the MB1 and MB2
- ~1.5% in MB3 and MB4