CMS RPC System status and performance in Run 3

Mauricio Thiel on behalf of CMS Collaboration

mauricio.thiel@cern.ch

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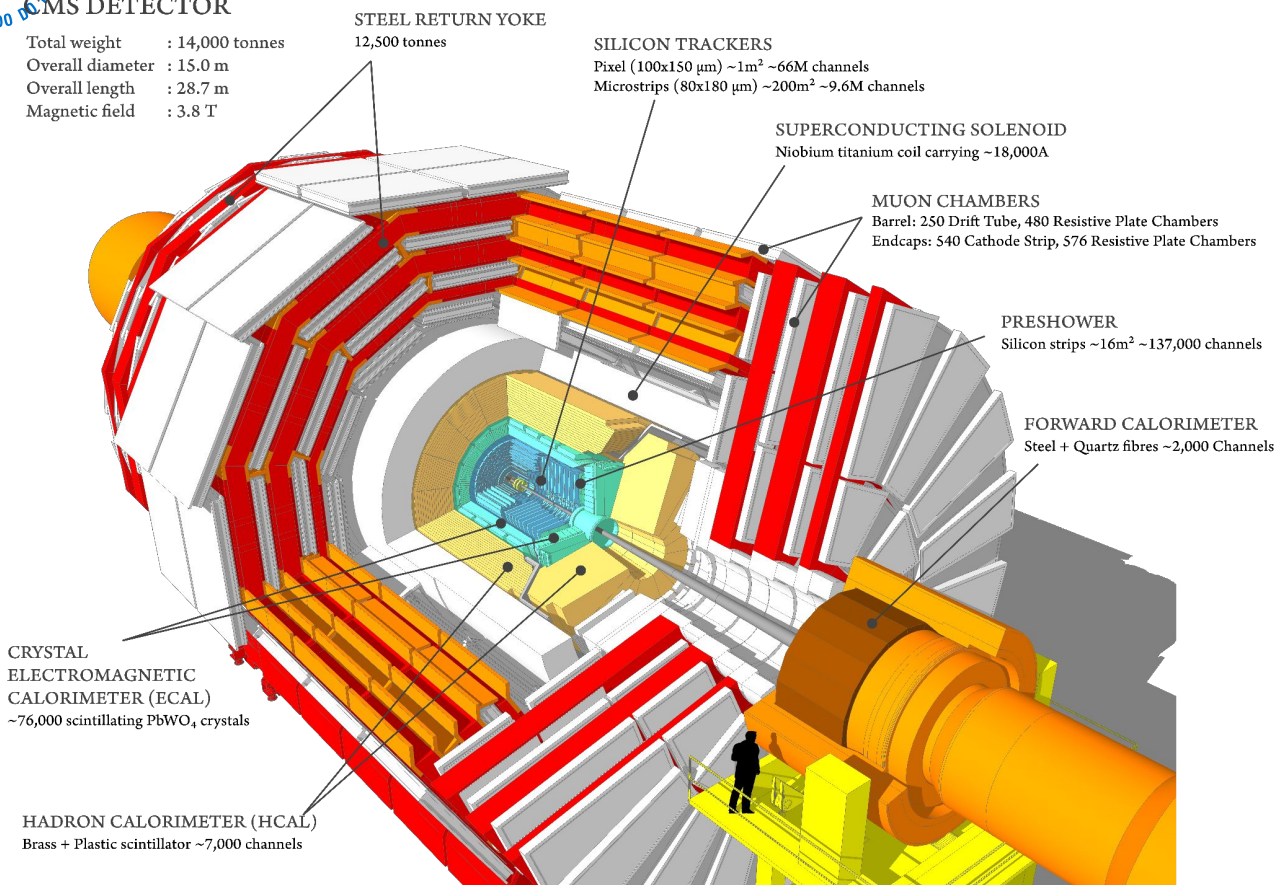
Outline

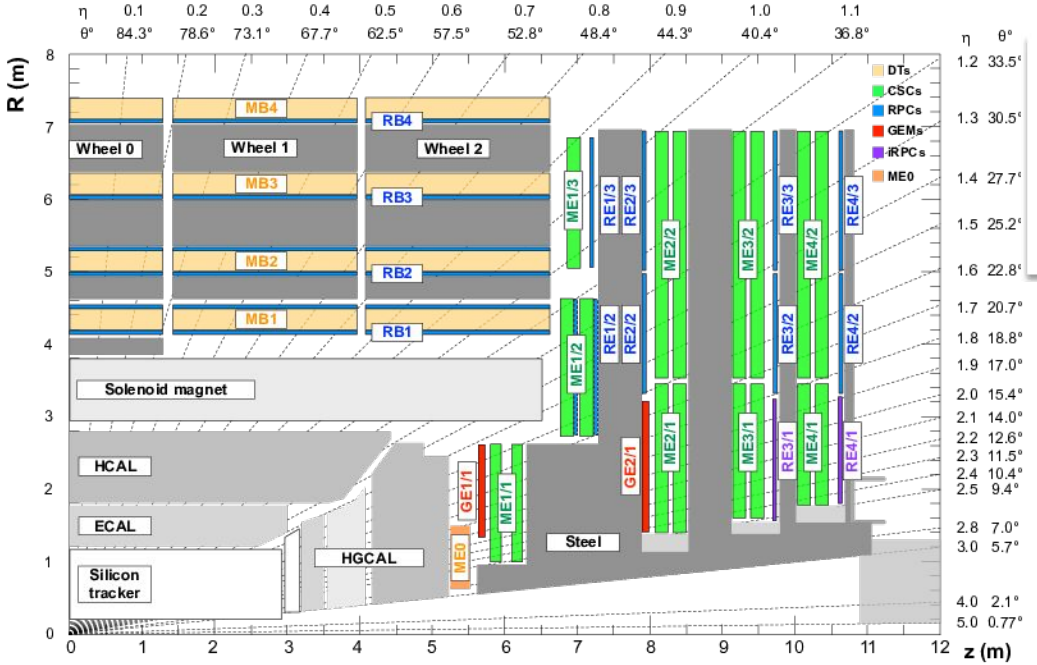
- The CMS Experiment and Muon System
- Resistive Plate Chambers at CMS
- Performance at Run 3
- Gas system - Leak repairs
- Working point calibration
- The Phase-2 Upgrade

The CMS Experiment and Muon System



The CMS experiment is a general-purpose detector designed to explore a wide range of physics phenomena at the highest energies provided by the LHC.

The CMS Experiment and Muon System



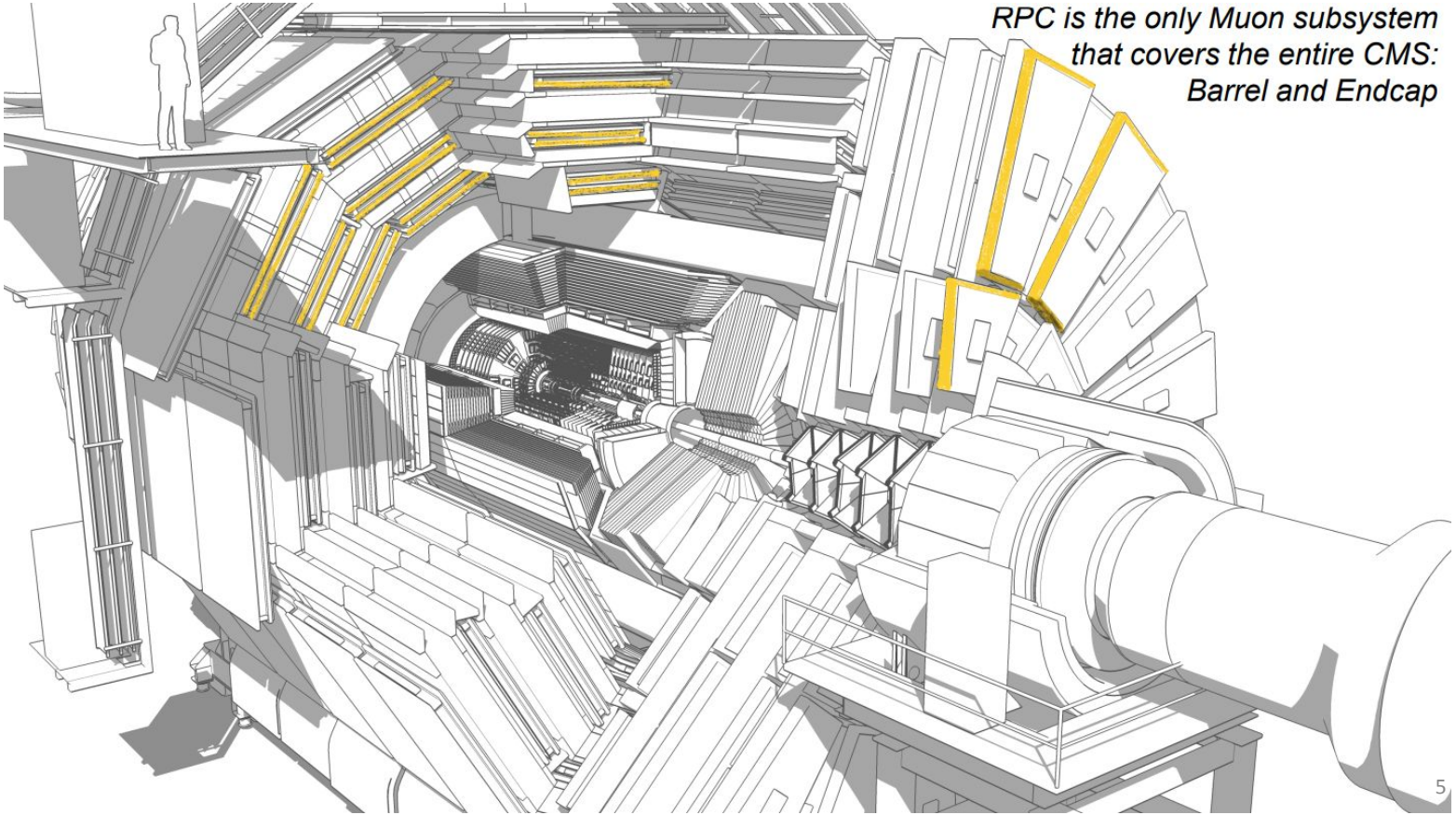
A quadrant of the CMS detector

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

The CMS Muon System was designed to be robust, efficient, and redundant, enabling precise muon identification, pT measurement, triggering, and bunch crossing assignment.

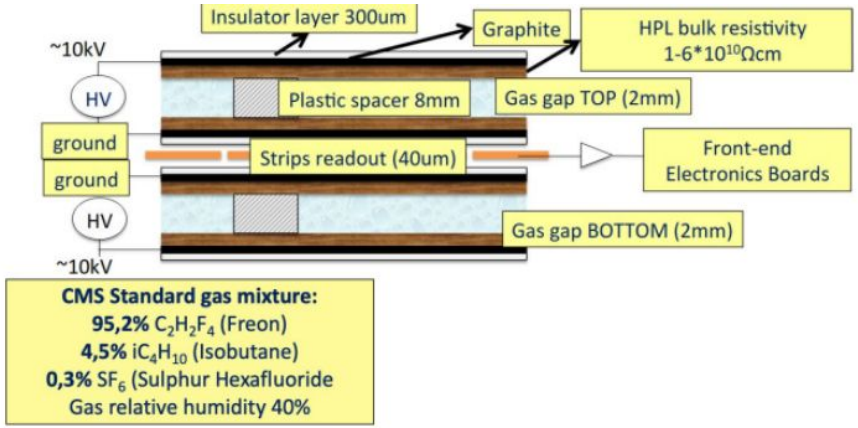
Resistive Plate Chambers at CMS



Resistive Plate Chambers at CMS

RPC System:

- Covers |η | < 1.9
- 1056 chambers (480 in barrel and 576 in endcap)
- More than 110000 electronic channels
- Bakelite bulk resistivity: ρ = 1 - 6 x 10^{10} Ωcm
- Double gaps gas chamber: 2 mm gas width
- Strip width: 1 − 4 cm.
- Operated in avalanche mode

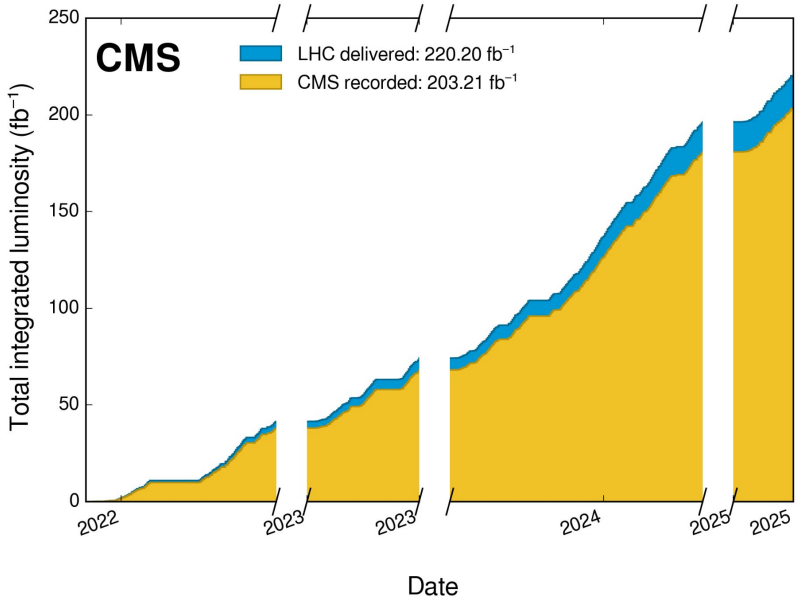


RPC requirements :

- High rate capability
- 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
- Long term operation and high background radiation

Performance at Run 3

More than 200 fb^{-1} recorded by CMS in Run 3



Cumulative delivered and recorded luminosity versus time for 2022-2025 (pp data only)

% of RPC active channels per year

2018	2022	2023	2024	2025
96.5	89.6	87.7	82.6	79.6

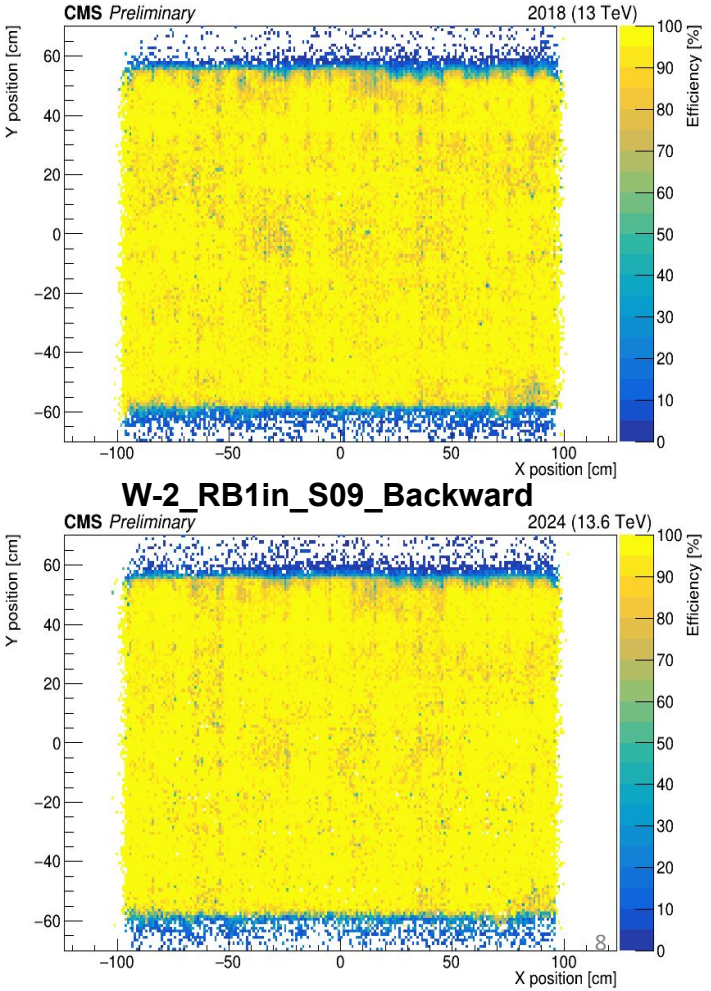
Since 2017, all channels with leaky chambers (located only in the Barrel region) have been disconnected to reduce Greenhouse Gas (GHG) emissions and to ensure the use of the new RPC recuperation system efficiently.

Gas system - Leak repairs

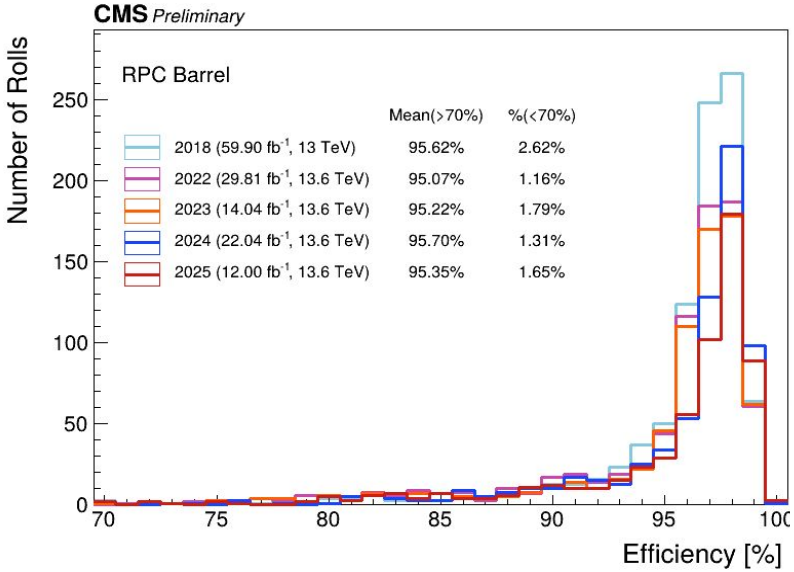
A new gas leak reparation procedure, tested at the CERN 904 Laboratory, was successfully validated during YETS 2023/2024. As part of this effort, two DT/RPC stations were fully extracted, and all four associated RPC detectors were equipped with new gas pipes and robust connectors.

On the right, an example of a chamber's performance before and after gas line reconnection is shown

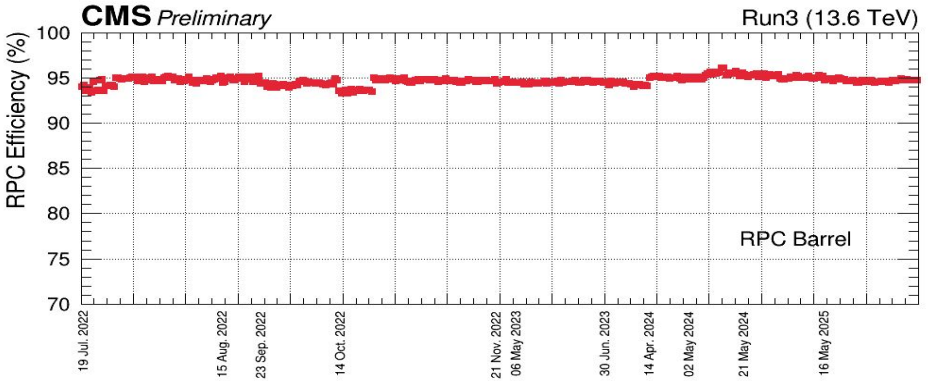
- Operated continuously throughout Run 2
- Disconnected from the gas supply due to a gas leak
- Reconnected to the gas supply to gas in 2023
- **This plot shows that the chamber has stable performance once it receives an appropriate gas flow**



Performance at Run 3 - Barrel

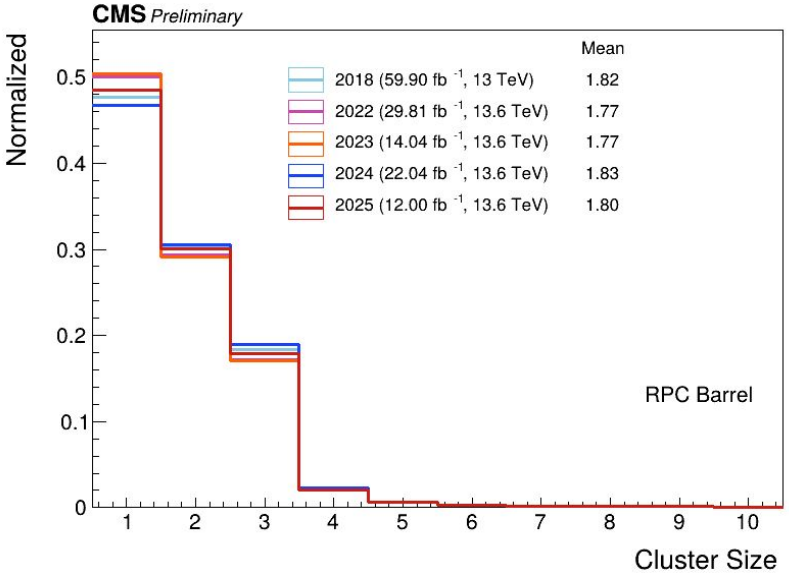


The RPC hit efficiency is determined using the **Segment Extrapolation Method**, in which the efficiency is calculated as the ratio of detected to expected hits. The expected hits are obtained by extrapolating DT and CSC segments to the plane of a given RPC.



The RPC performance is stable and high efficient!

Performance at Run 3 - Barrel



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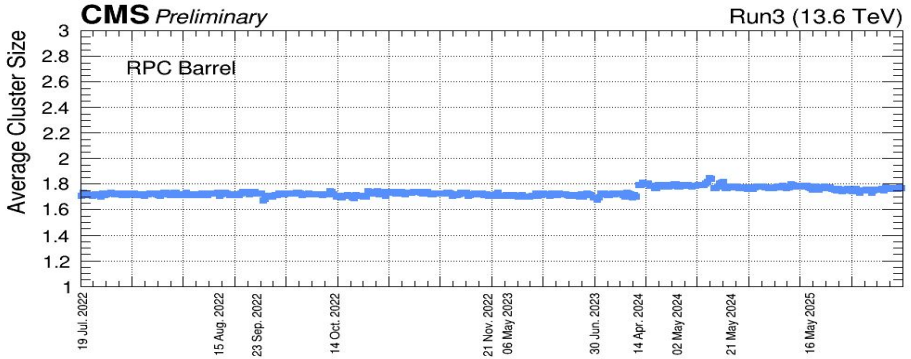
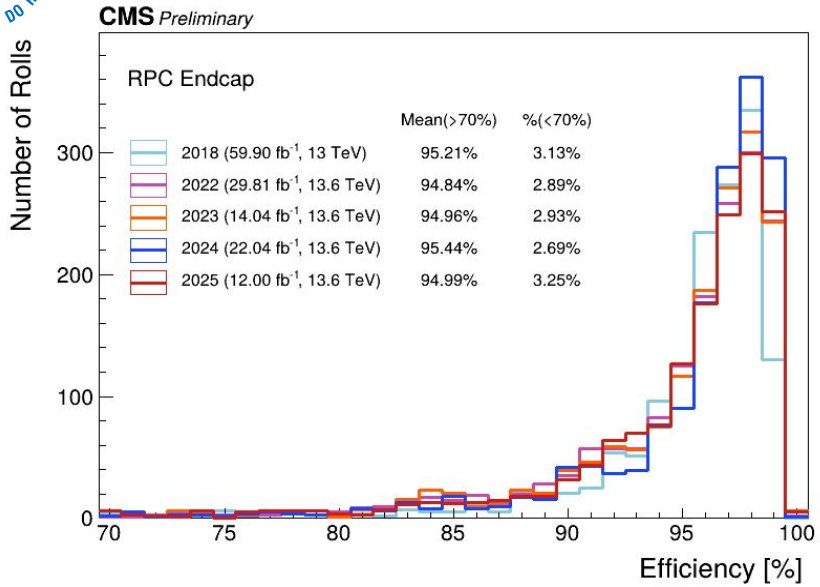


Stable Cluster size about 2 strips, within CMS requirements!

Performance at Run 3 - Endcap



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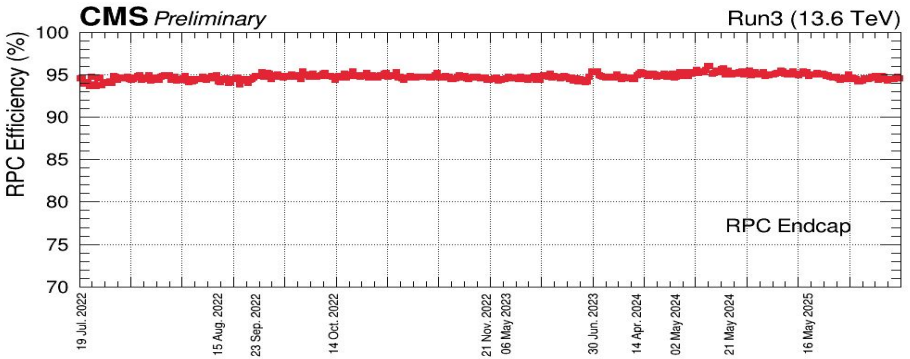

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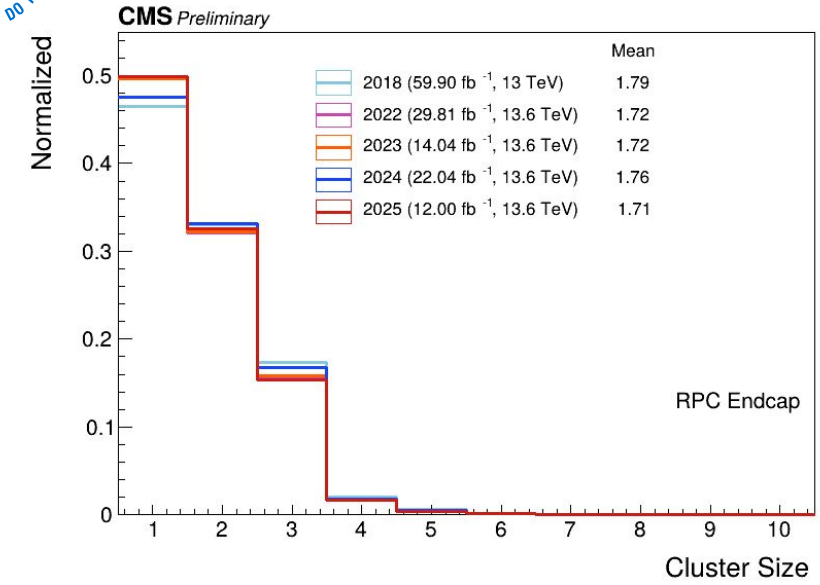

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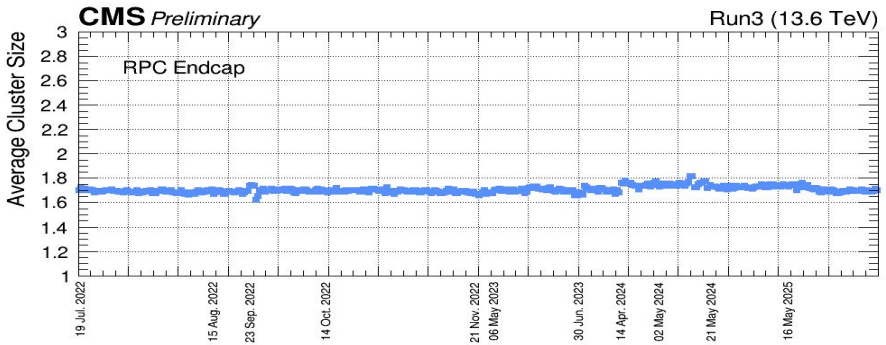
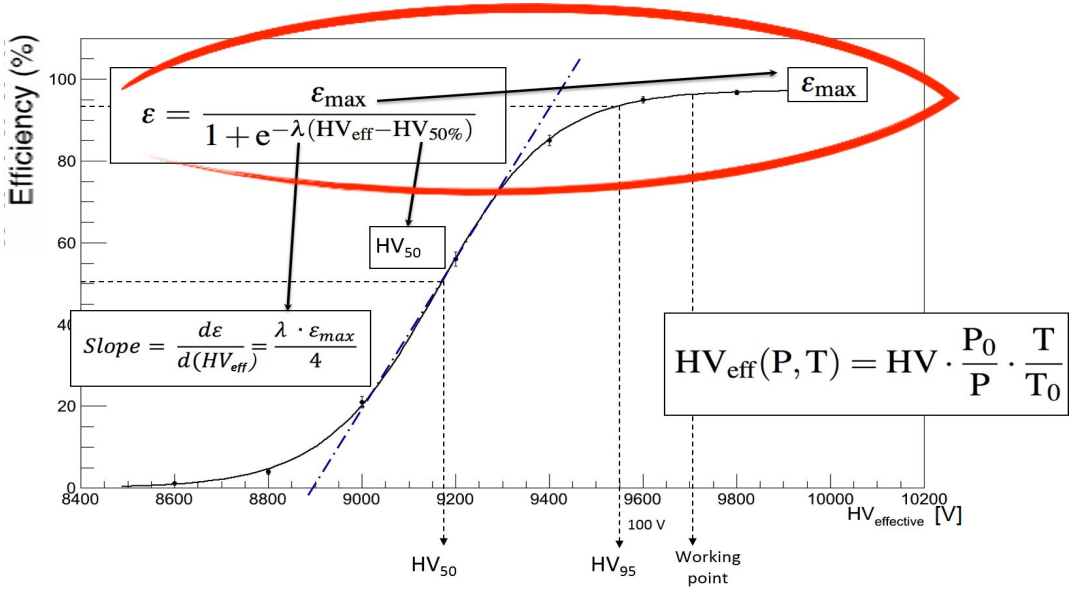


Stable Cluster size about 2 strips, within CMS requirements!

Working point calibration

High Voltage (HV) scans are periodically performed using dedicated collision runs, with the main goals of optimizing the Working Point (WP) of each RPC detector and monitoring their performance over time.

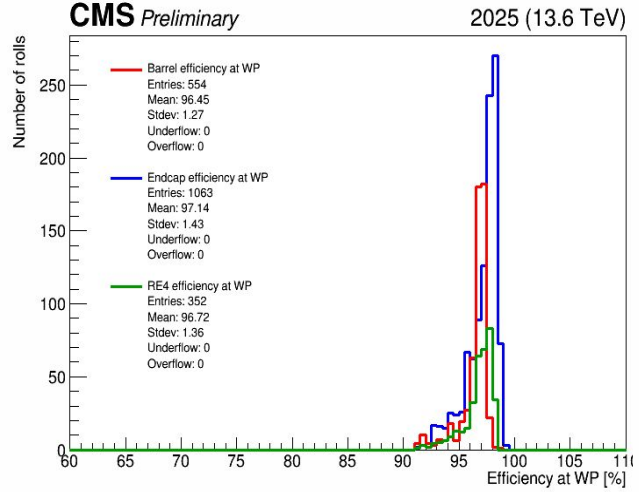


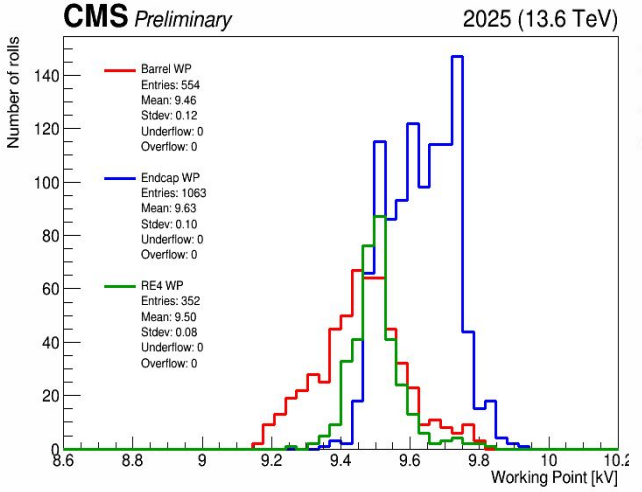
Working Point Definition

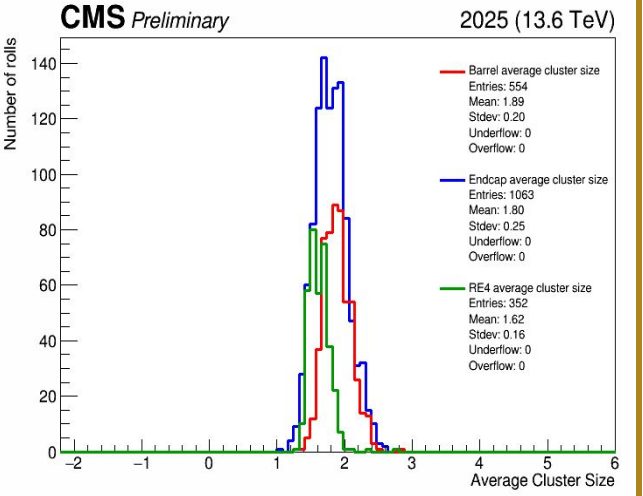
$$HV_{WP} = HV_{knee} + \begin{cases} 100\ V\ (Barrel) \\ 120\ V\ (Endcap) \end{cases}$$

Working point calibration

- In June a new HV scan was performed
- Special Machine Learning approach was developed for HV scan data analysis -> **ML paper**
- **Working point, efficiency and cluster size in agreement with expected**







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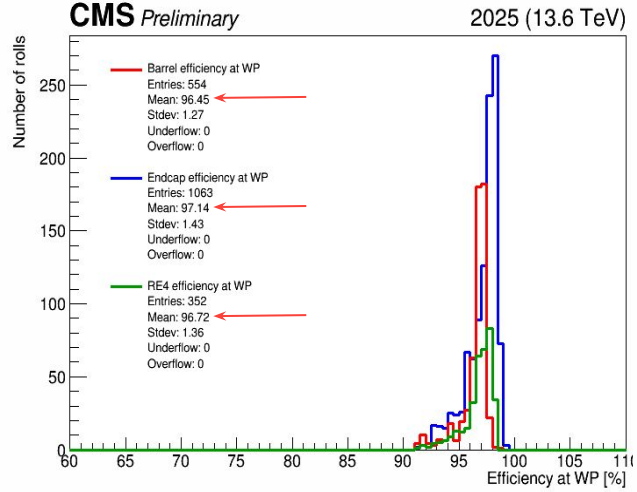
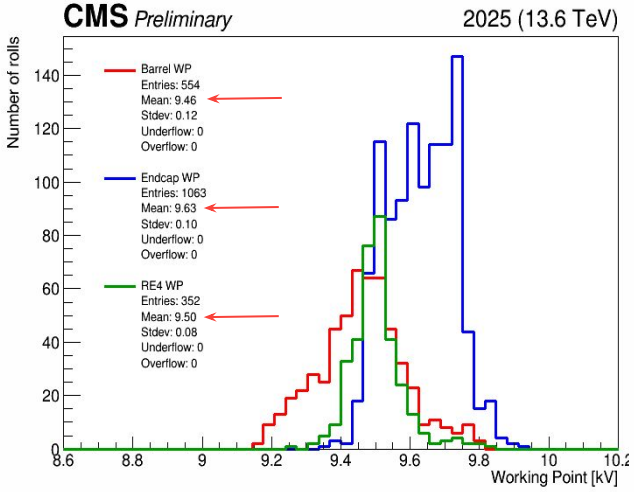
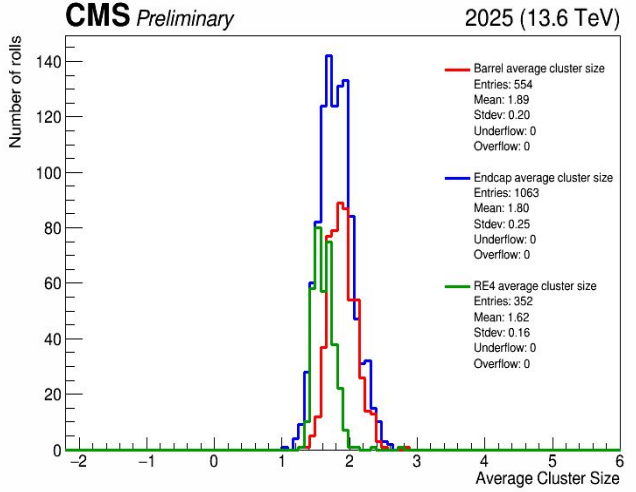




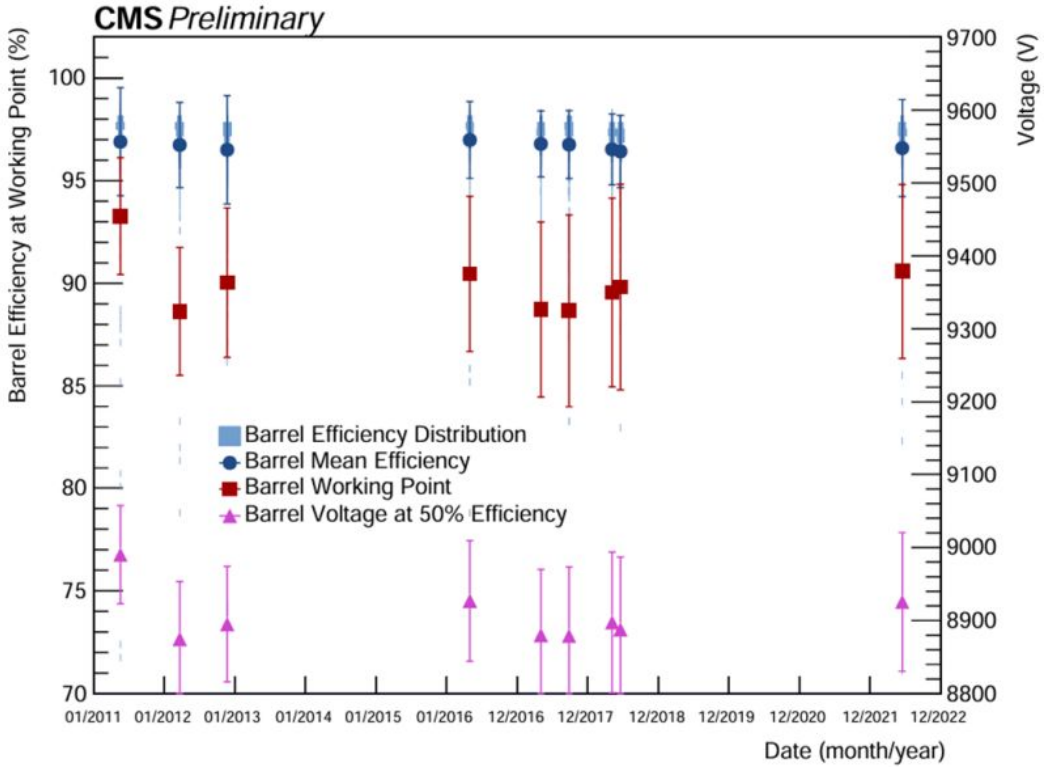


Working point calibration - Barrel

- RPC Barrel Working Point and Efficiency at Working Point

  In 2025
  Efficiency: **96.45%**
  Working point: **9.46 kV**

- **Efficiency and Working Point very stable!**

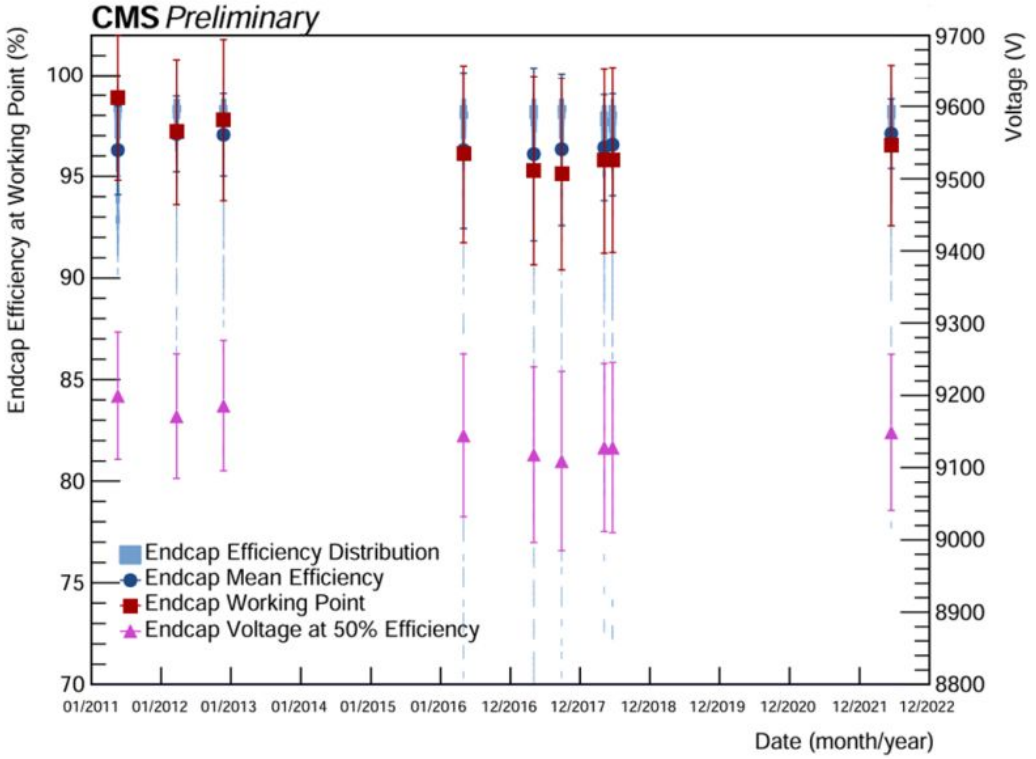


Working point calibration - Endcap

- RPC Endcap Working Point and Efficiency at Working Point

  In 2025
  Efficiency: **97.14%**
  Working point: **9.63 kV**

- **Efficiency and Working Point very stable!**

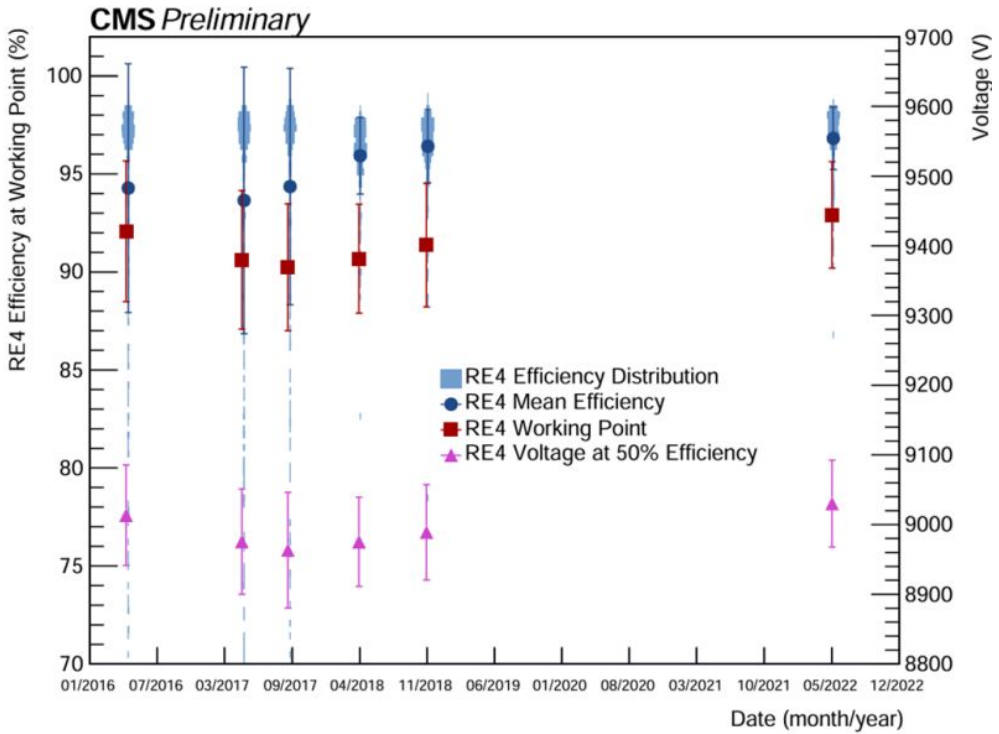


Working point calibration - Endcap RE4

- RPC RE4 Working Point and Efficiency at Working Point

  In 2025
  Efficiency: **96.72%**
  Working point: **9.50 kV**

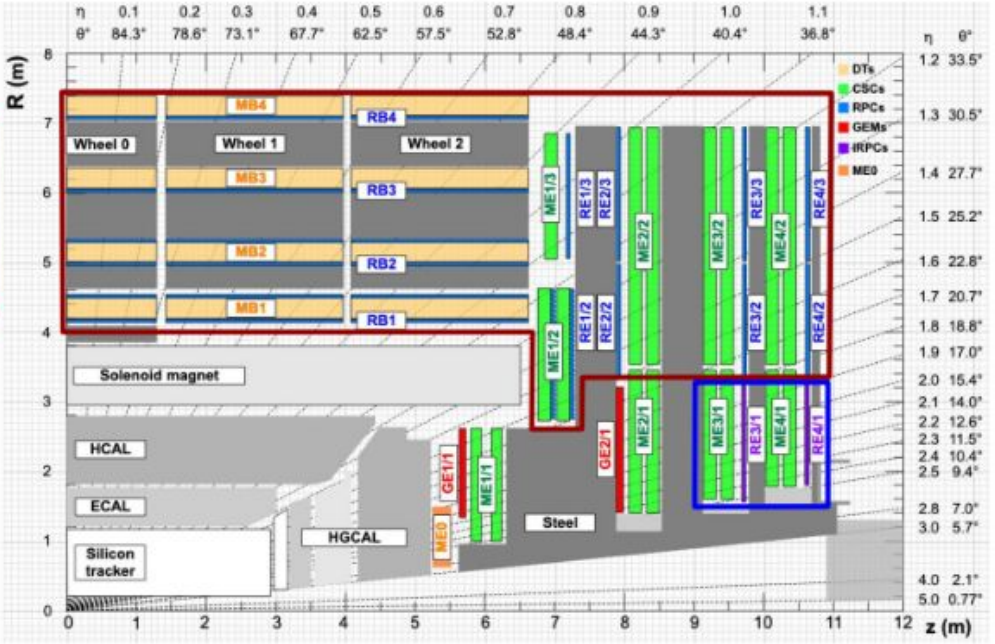
- **Efficiency and Working Point very stable!**



The Phase-2 Upgrade

RPC system upgrade for HL-LHC

Link system upgrade for the existing RPC system |η|<1.9



iRPC: extend the RPC coverage to |η|<2.4

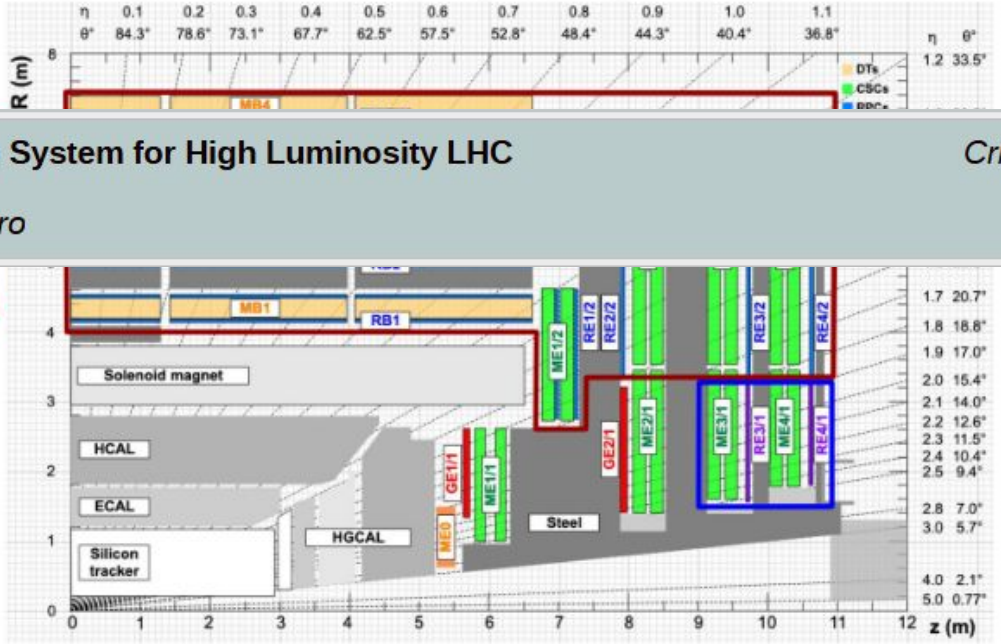
The Phase-2 Upgrade

RPC system upgrade for HL-LHC

Upgrade plans of the CMS Muon System for High Luminosity LHC *Cristina Fernandez Bedoya*

Auditorium Gastaut, Palais du Pharo 09:42 - 10:00

RPC system
|η|<1.9



iRPC: extend the RPC coverage to |η|<2.4

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Conclusion

- After 13 year of operation the RPC is showing:
  - Very high and stable efficiency (>95%)
  - Stable cluster size (~2 strips)
  - Working points with stable evolution
- Preparation for Phase-2 upgrade ongoing