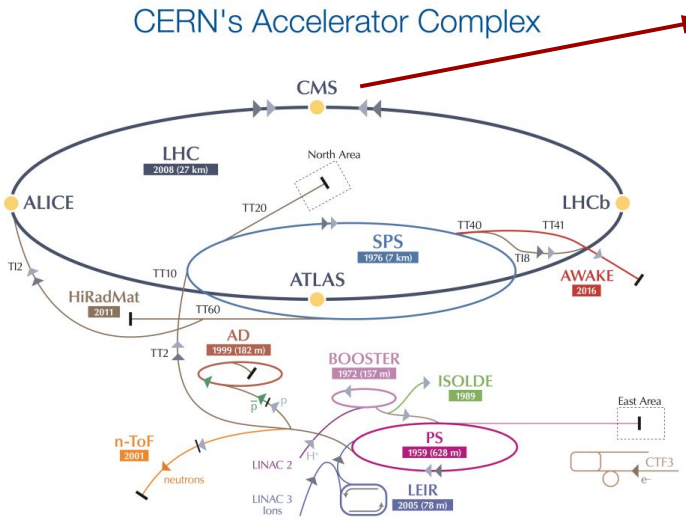


Andrés Cabrera on behalf of the CMS Collaboration
Universidad de los Andes
Colombia

September 14, 2026
https://indico.global/event/15349
XVIII Conference on Resistive Plate Chambers and Related Detectors

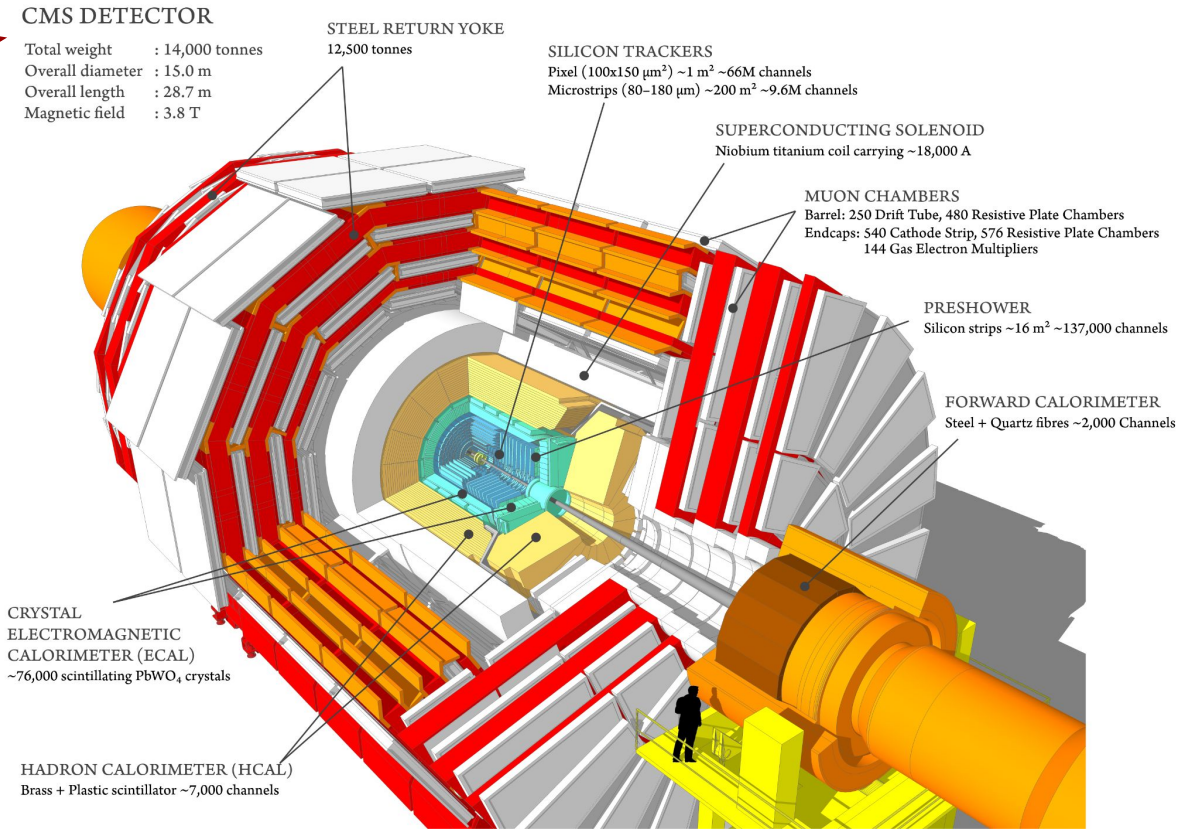
Operation and performance of the CMS RPC system during LHC Run 3 data taking

The Compact Muon Solenoid



[OPEN-PHO-ACCEL-2013-056]

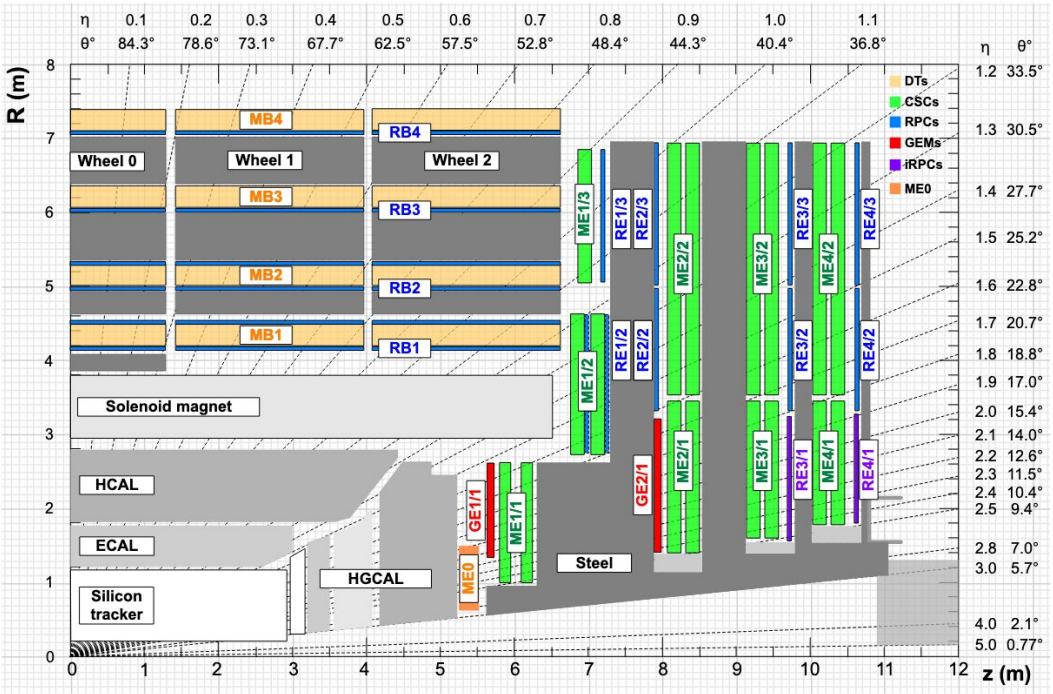
The CMS experiment is a general-purpose detector that is designed to explore a wide range of physical phenomena at the highest energies available at the LHC.



[CMS-OUTREACH-2019-001]

The CMS Muon System

[CMS-TDR-016, Fig 1.4]



An *R-z* cross section of a quadrant of the CMS detector, including the Phase-2 upgrades that increase the η range to 2.4 for RPCs and 2.8 for GEMs.

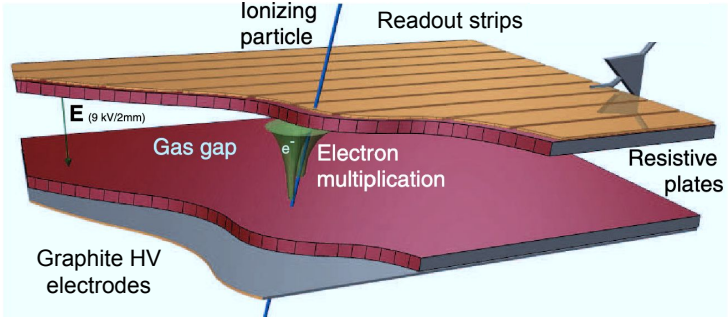
The CMS Muon System was designed to be robust, efficient and redundant. This facilitates precise muon identification, p_T measurement, and time reconstruction.

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

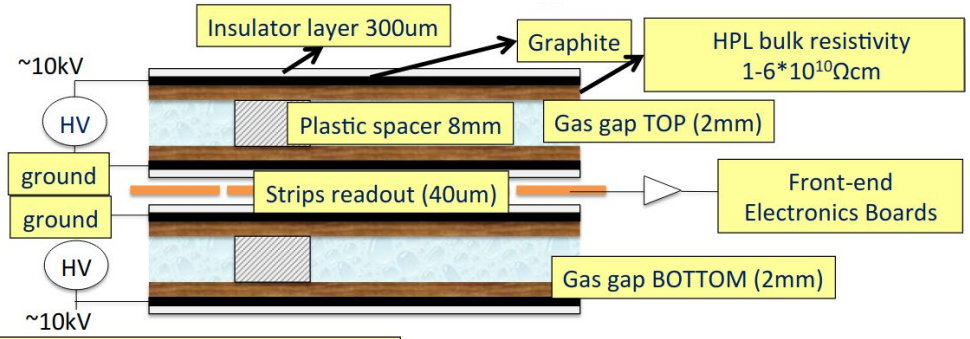
- **Barrel:** DT & RPC $|\eta| < 0.8$
- **Overlap:** DT & CSC & RPC $0.8 < |\eta| < 1.2$
- **Endcap:** CSC $(1.2 < |\eta| < 2.4)$, RPC $(1.2 < |\eta| < 1.9)$ & GEM $(1.5 < |\eta| < 2.2)$

The Resistive Plate Chambers in CMS

Operated in avalanche mode

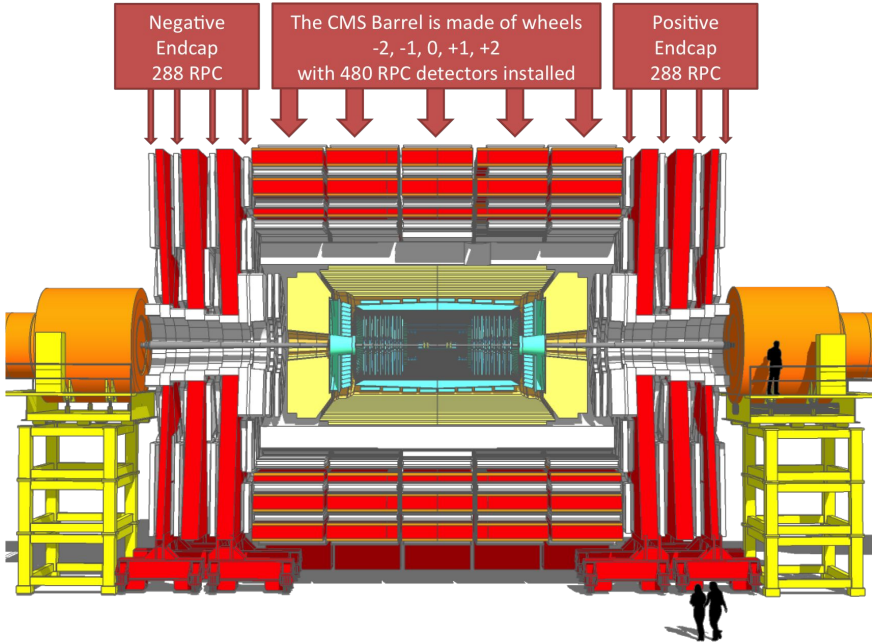


[CMS-OUTREACH-2018-05]



[CMS-CR-2016-435, Fig 2]

CMS Standard gas mixture:
95,2% $C_2H_2F_4$ (Freon)
4,5% iC_4H_{10} (Isobutane)
0,3% SF_6 (Sulphur Hexafluoride
Gas relative humidity 40%



1056 RPCs in total (present system)

[CMS-CR-2016-435, Fig 4]

It is the only Muon subsystem that covers the entire CMS: Barrel and Endcap

The

Operated

The CMS RPC Construction Database: Lifecycle Traceability and Quality Assurance Across Multiple Detector Generations
Talk by Anton Dimitrov

Latest results from Longevity Studies of CMS RPC Chambers towards HL-LHC Operation
Talk by Reham Aly

Study of CMS RPC signal shape parameters by using HFO1233ZD gas mixture
Poster by Dalmo Da Silva Dalto

CMS RPC system consolidation and upgrade for the LHC Phase-II programme
Poster by Katherine Maslova

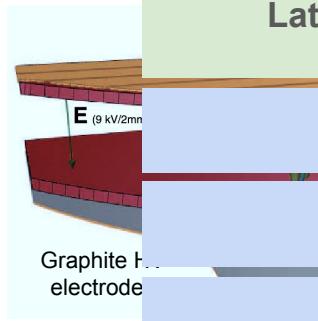
The impact of the RPC system on the trigger primitives in CMS barrel region
Poster by Raphael Gomes De Souza

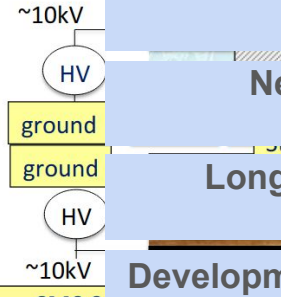
CMS-RPC Timing Resolution Evolution Under the Longevity Campaign
Poster by Mauricio Thiel

Neural Network-Based Prediction of CMS RPC Efficiency with Alternative Gas Mixtures
Poster by Giulia Giannandrea

Long-Term Evolution of the CMS RPC Integrated Charge and Projections for the HL-LHC Era
Poster by Jose Antonio Reyes Vega

Development and Validation of a Low-Cost Volume-Based Gas Mixing System for CMS Resistive plate chambers
Poster by Mahdi Majeed S. Almubarak

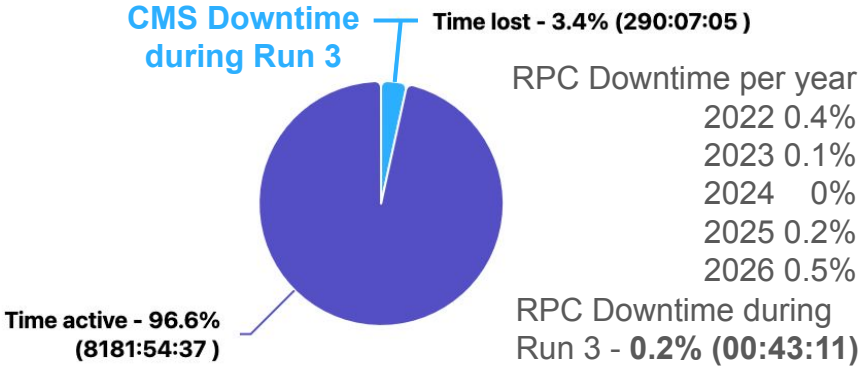




CMS S
95,
4,5%
0,3% SF_6 (Sulphur Hexafluoride
Gas relative humidity 40%

the entire CMS: Barrel and Endcap

Performance during Run 3



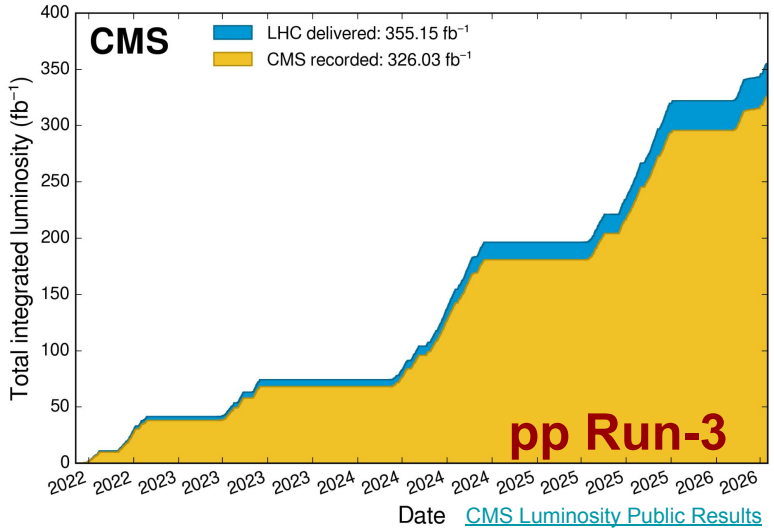
RPC Downtime per year
2022 0.4%
2023 0.1%
2024 0%
2025 0.2%
2026 0.5%

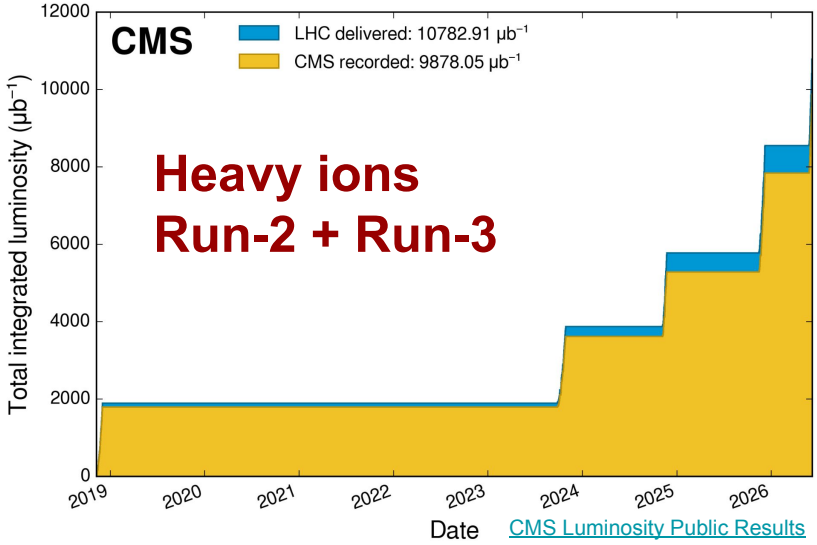
RPC Downtime during Run 3 - **0.2% (00:43:11)**

% of RPC active channels per year

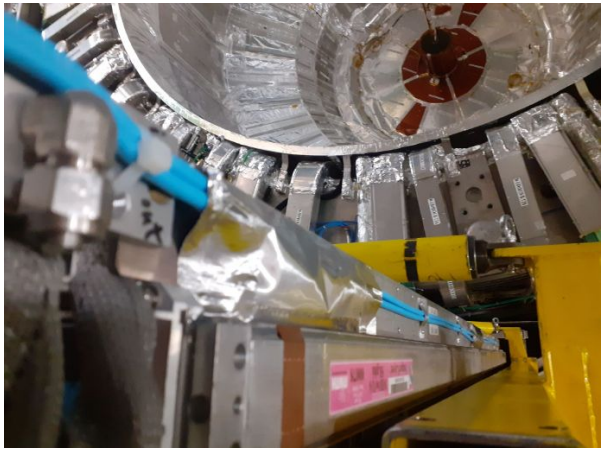
Year	2018	2022	2023	2024	2025	2026
Percentage [%]	96.5	89.6	87.7	82.6	79.6	76.9

Since 2018, all gas channels with leaky chambers have been disconnected. These channels are located exclusively in the Barrel region. This measure has been implemented with the objective of reducing Greenhouse Gas (GHG) emissions.





Gas leak repair

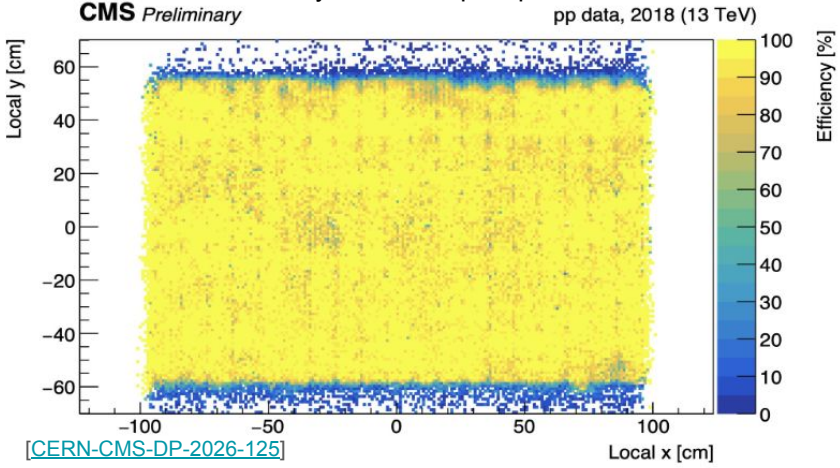


- The gas pipes break because the polyethylene becomes brittle over time due to radiation (a bad batch of pipes).
- Since 2018, leaking chambers (>10 L/h) have been disconnected.
- During LS2 (2019–2021), the leaks were repaired promptly at the source, but new leaks often appeared in other parts of the pipe.
- A more robust procedure was introduced in 2023: replacing all pipes and connectors with full chamber extraction.

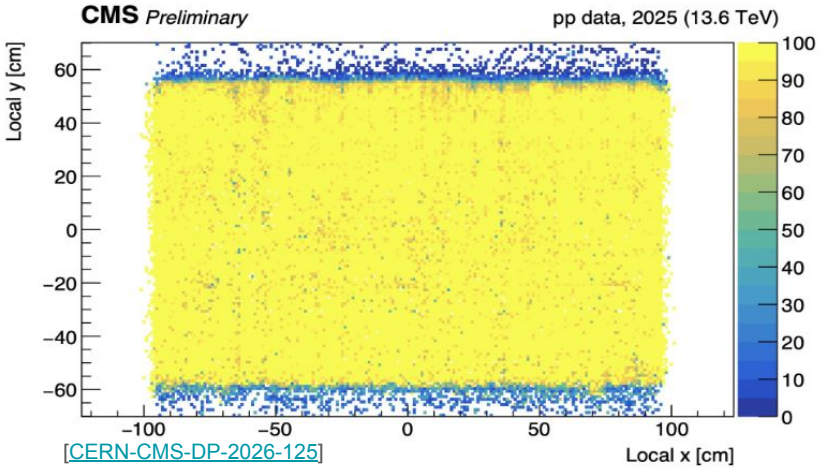
Below is an example of a chamber's performance before and after gas line reconnection:

- Operated continuously throughout Run 2.
- Disconnected from the gas supply due to a gas leak in 2018.
- Reconnected to the gas supply in 2023.
- No gas flow for 5 years
- **This results demonstrate that, once an adequate gas flow has been established, the chamber exhibits consistent performance.**

RPC efficiency vs local impact point

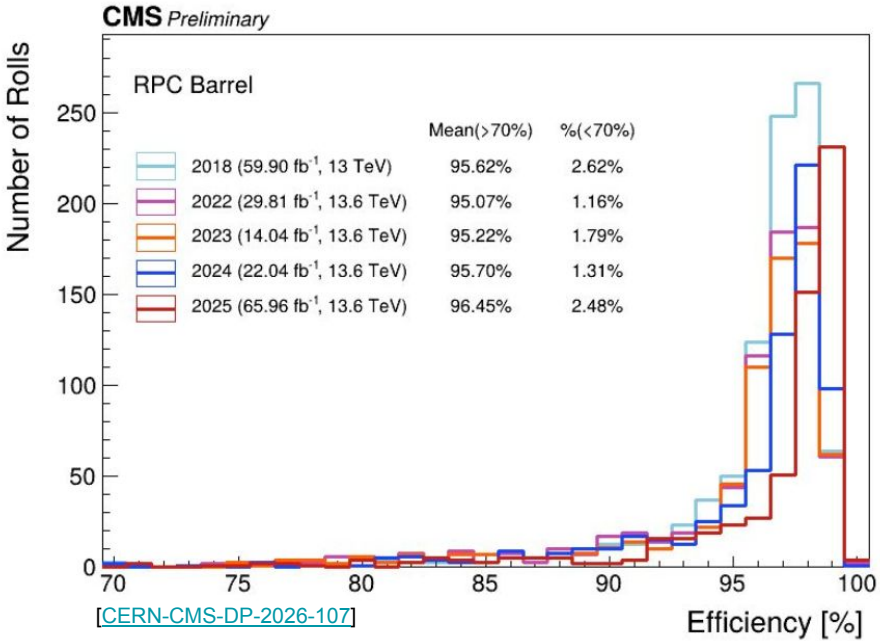


[CERN-CMS-DP-2026-125]



[CERN-CMS-DP-2026-125]

Performance at Run 3 - Barrel

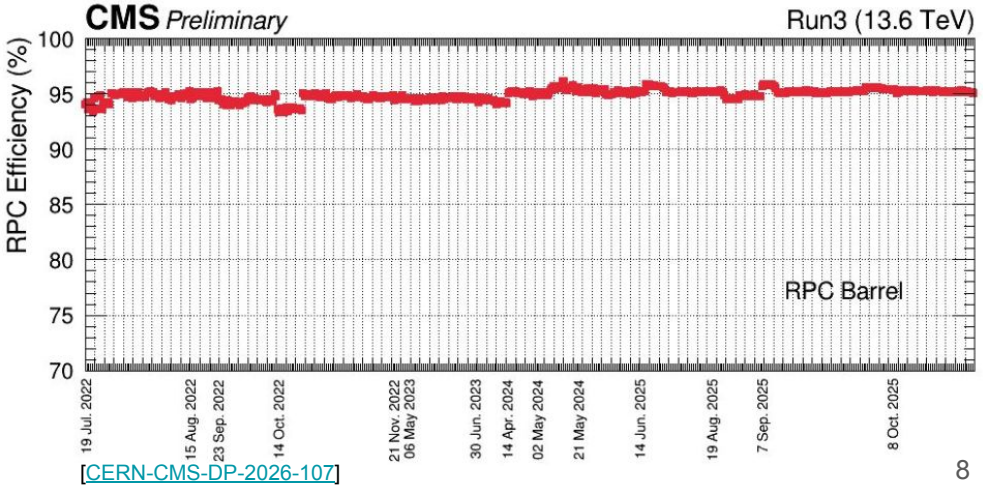


[CERN-CMS-DP-2026-107]

The RPC hit efficiency is determined using the **Segment Extrapolation Method** (JINST 8 (2013) P11002), 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.

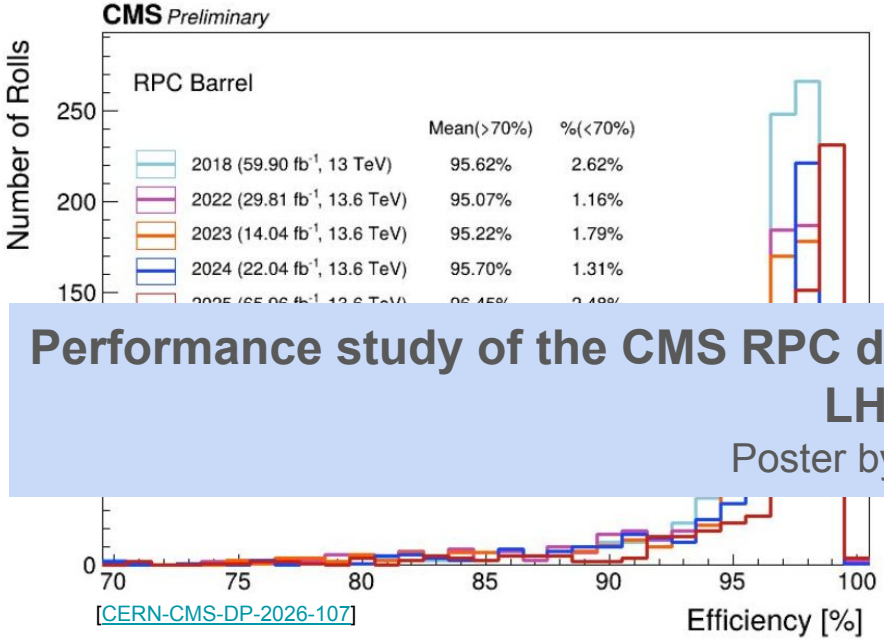
An alternative method that can be used to determine efficiency is the Tag-and-Probe method (CERN-CMS-DP-2024-109).





[CERN-CMS-DP-2026-107]

Performance at Run 3 - Barrel



[CERN-CMS-DP-2026-107]

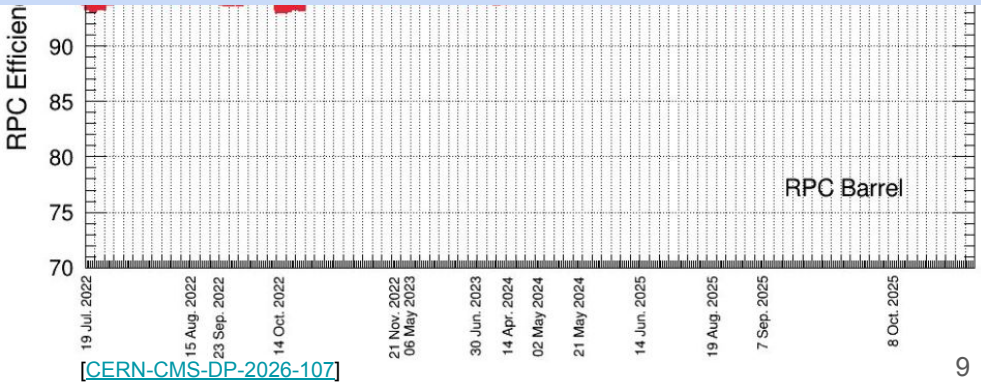
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An alternative method that can be used to determine efficiency is the Tag-and-Probe method (CERN-CMS-DP-2024-109).

Performance study of the CMS RPC detector using the Tag-and-Probe method in LHC Run 3

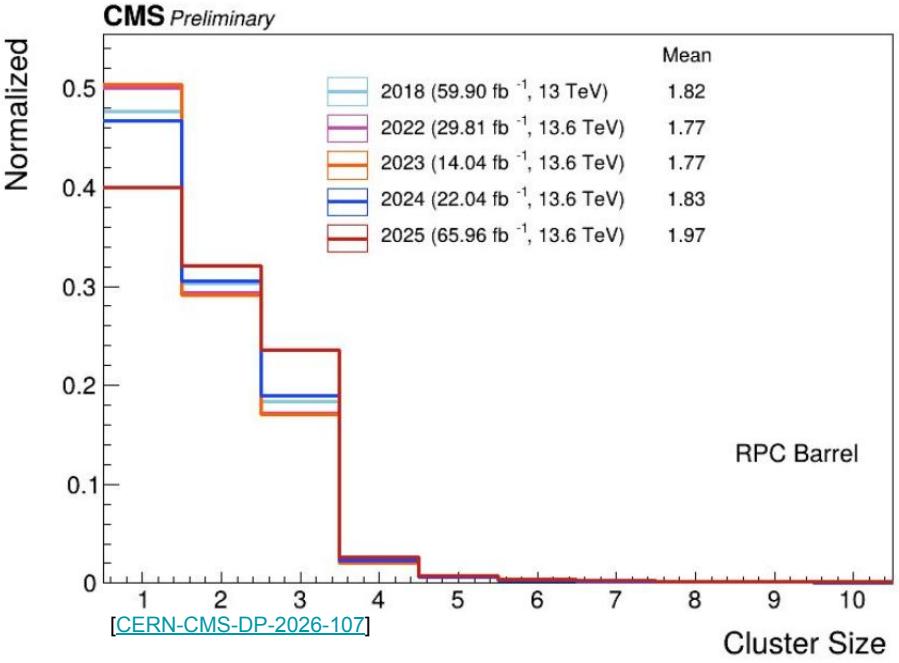
Poster by Jongwon Shin





[CERN-CMS-DP-2026-107]

Performance at Run 3 - Barrel

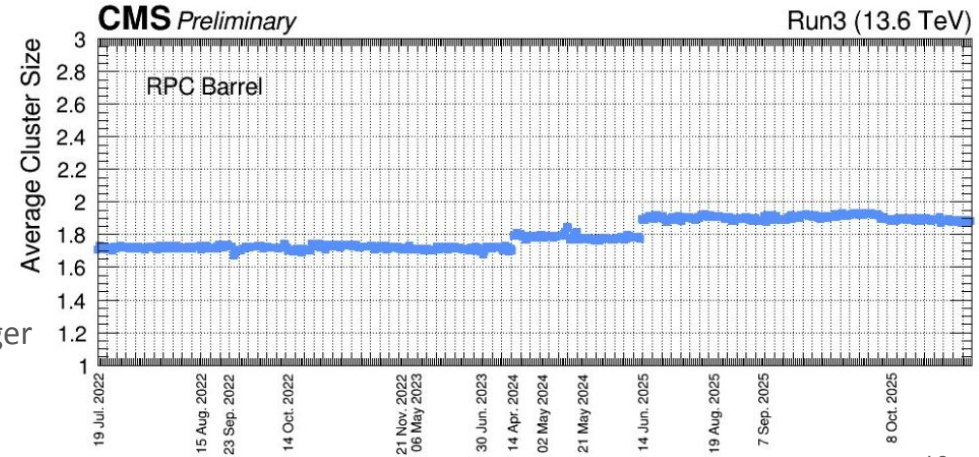


[CERN-CMS-DP-2026-107]

The RPC cluster size remains stable and well within the CMS trigger requirements of less than three strips (CMS-TDR-6-1), with an average value of less than two strips.

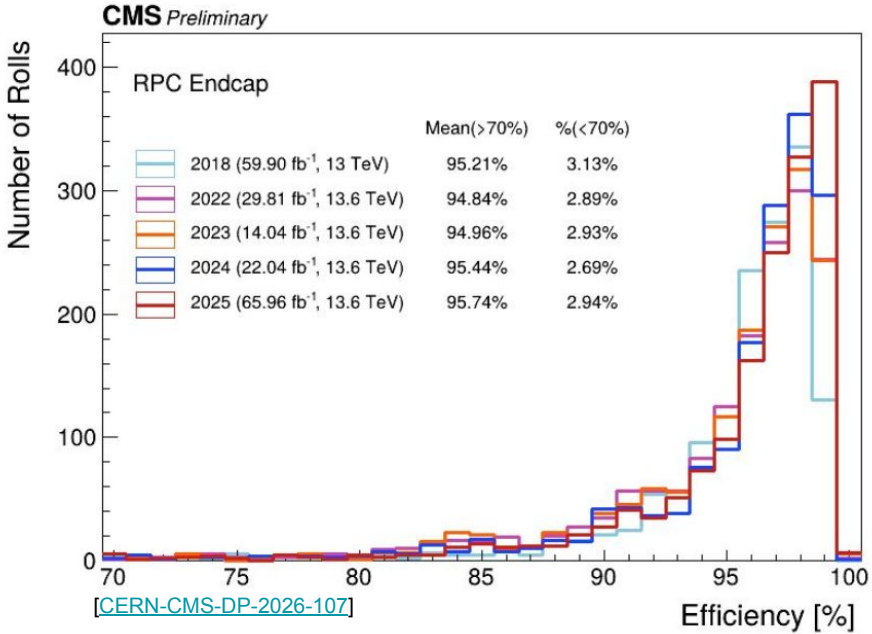
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[CERN-CMS-DP-2026-107]

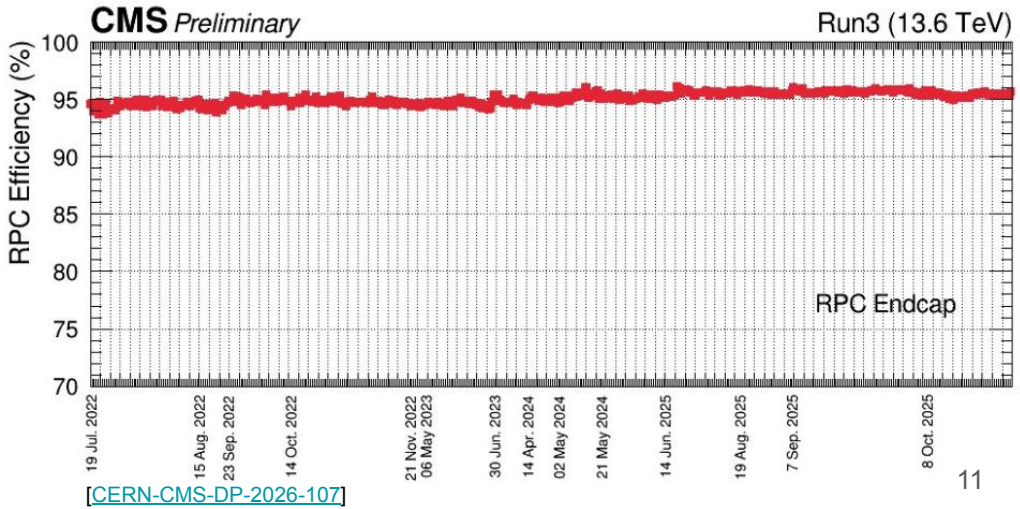
Performance at Run 3 - Endcap



[CERN-CMS-DP-2026-107]

The RPC hit efficiency is determined using the **Segment Extrapolation Method** (JINST 8 (2013) P11002), 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.

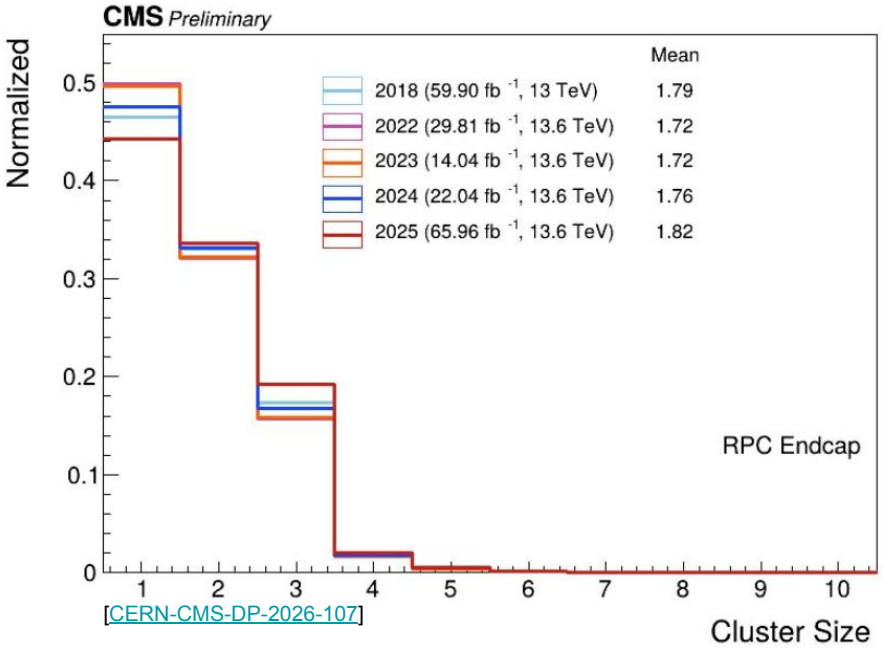
An alternative method that can be used to determine efficiency is the Tag-and-Probe method (CERN-CMS-DP-2024-109).



[CERN-CMS-DP-2026-107]

The RPC performance is stable and efficient!

Performance at Run 3 - Endcap

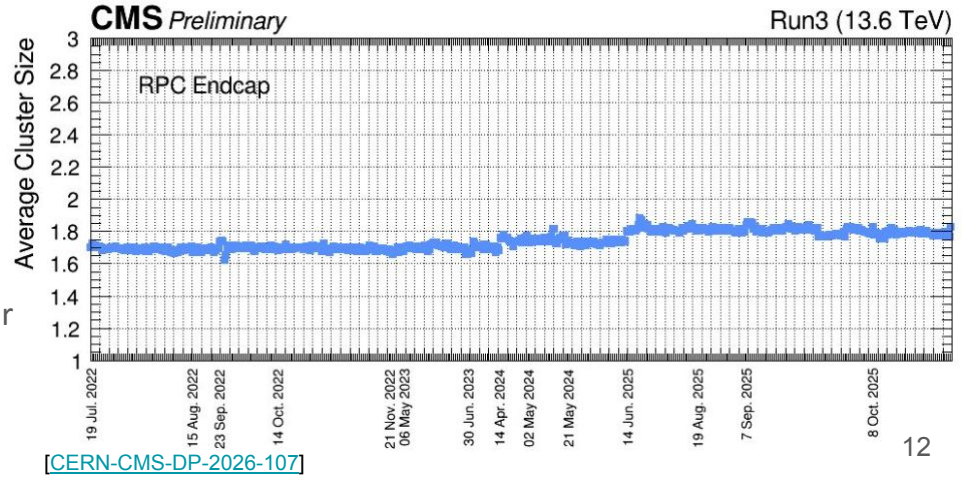


[CERN-CMS-DP-2026-107]

The RPC cluster size remains stable and well within the CMS trigger requirements of less than three strips (CMS-TDR-6-1), with an average value of less than two strips.

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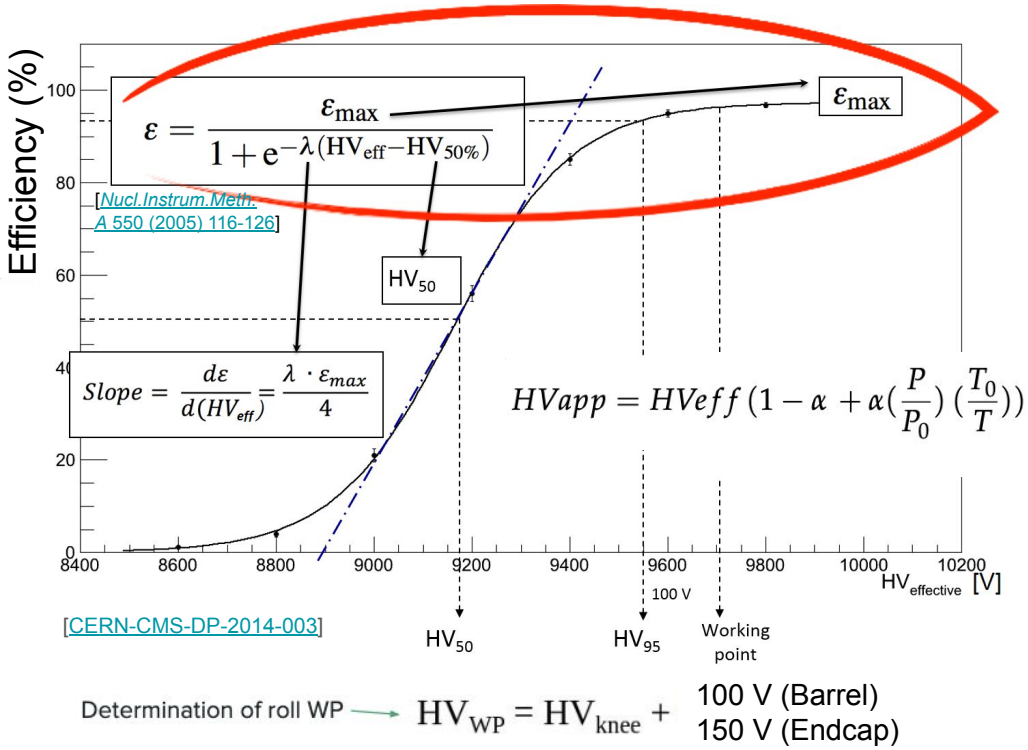
An alternative method that can be used to determine efficiency is the Tag-and-Probe method (CERN-CMS-DP-2024-109).



[CERN-CMS-DP-2026-107]

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.

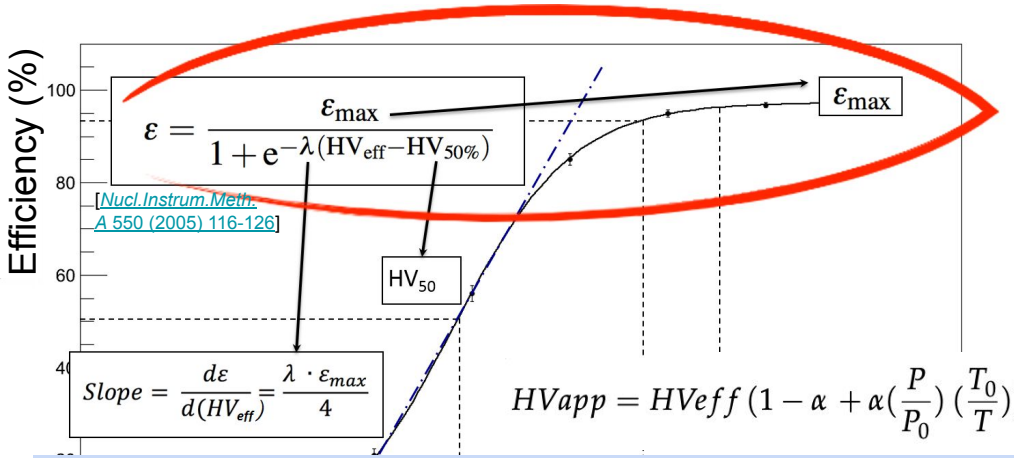


A new algorithm has been developed to determine the working point for each channel!

[CERN-CMS-DP-2026-124]

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.



A new algorithm has been developed to determine the working point for each channel!

[CERN-CMS-DP-2026-124]

An Optimized Algorithm for Determining CMS RPC HV Channel Working Points

Poster by Mihaela Pencheva Pehlivanova

[CERN-CMS-DP-2014-003]

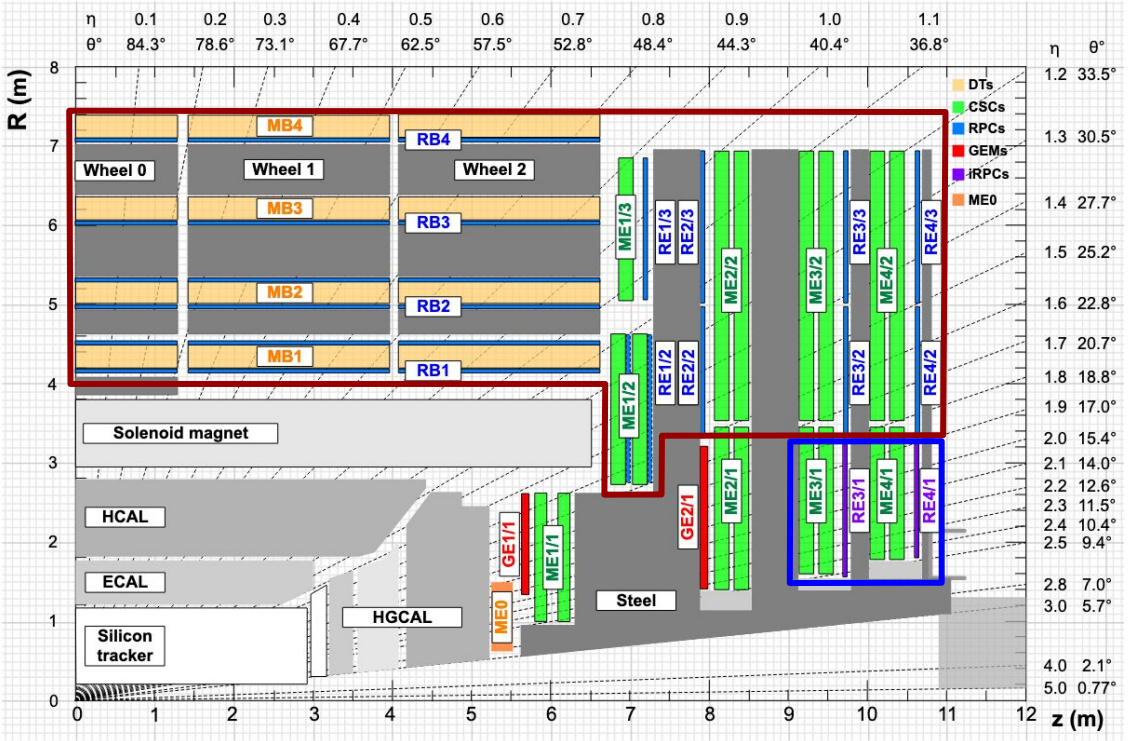
HV_{50} HV_{95} Working point

Determination of roll WP → $HV_{WP} = HV_{knee} +$ 100 V (Barrel) 150 V (Endcap)

CMS RPC Upgrade Project

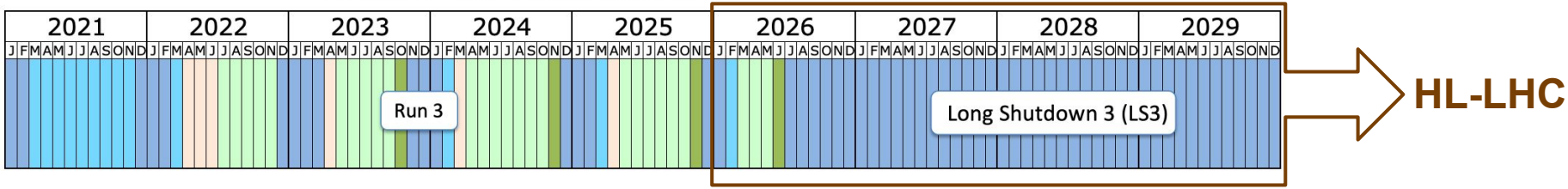
[CMS-TDR-016, Fig 1.4]

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

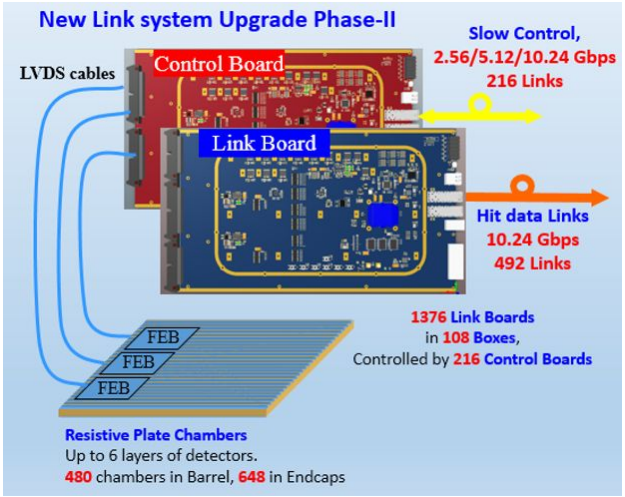


iRPC: extend the RPC coverage to |η|<2.4

[Longer term LHC schedule]

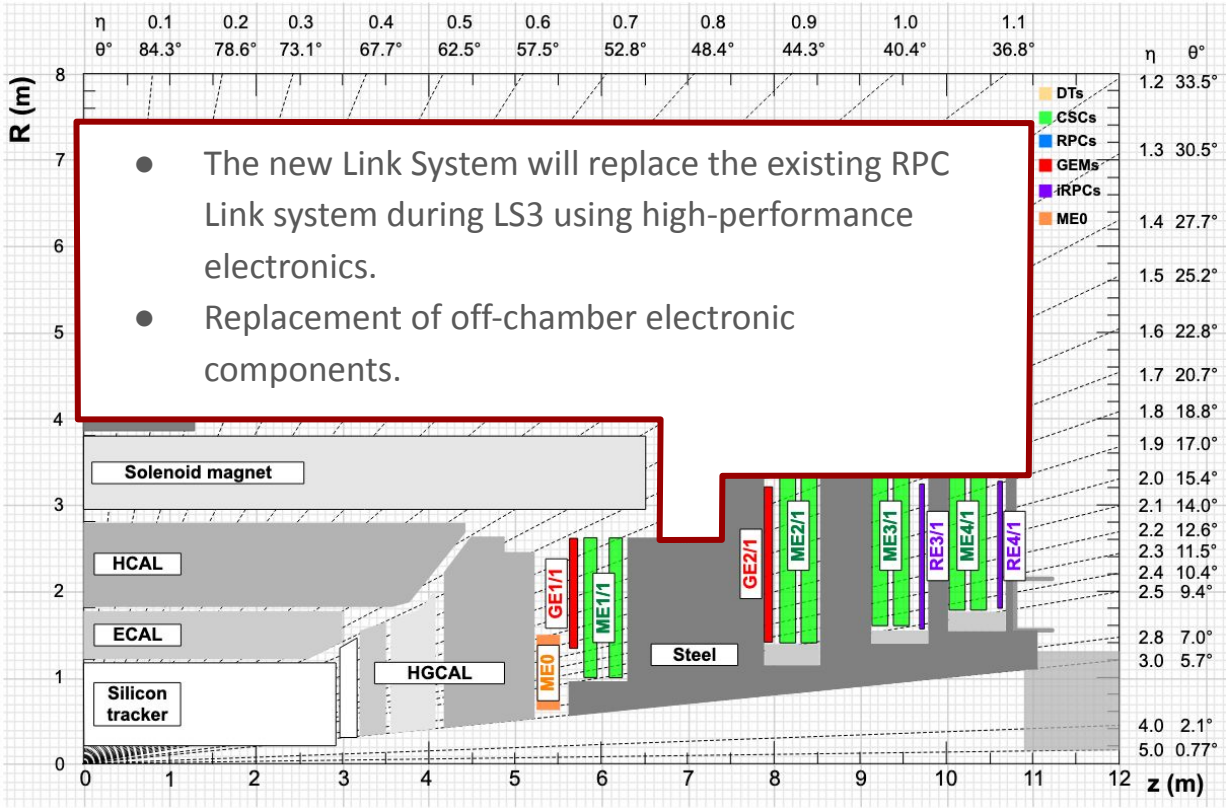


CMS RPC Upgrade Project -> Link System



Key parameters:

- This will improve the time resolution from **25 ns to 1.56 ns.**
- Data transmission will be increased from **1.6 Gbps** to **10.24 Gbps.**
- Control Board communication with RPC Backend electronics: **4.8 Gbps**



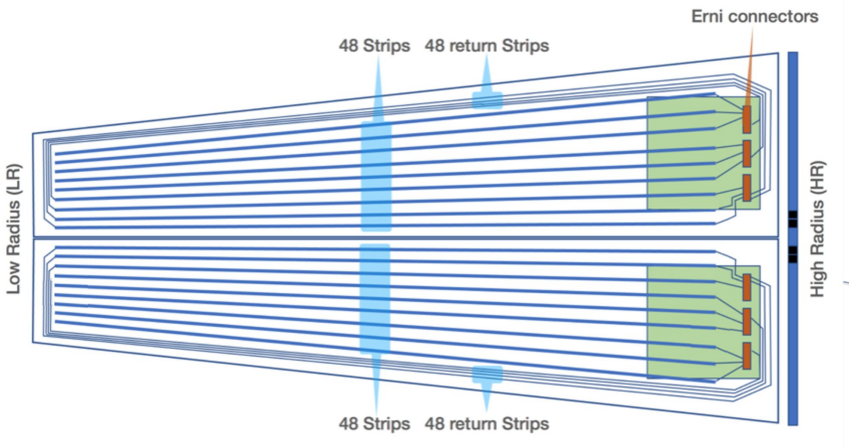
- The new Link System will replace the existing RPC Link system during LS3 using high-performance electronics.
- Replacement of off-chamber electronic components.

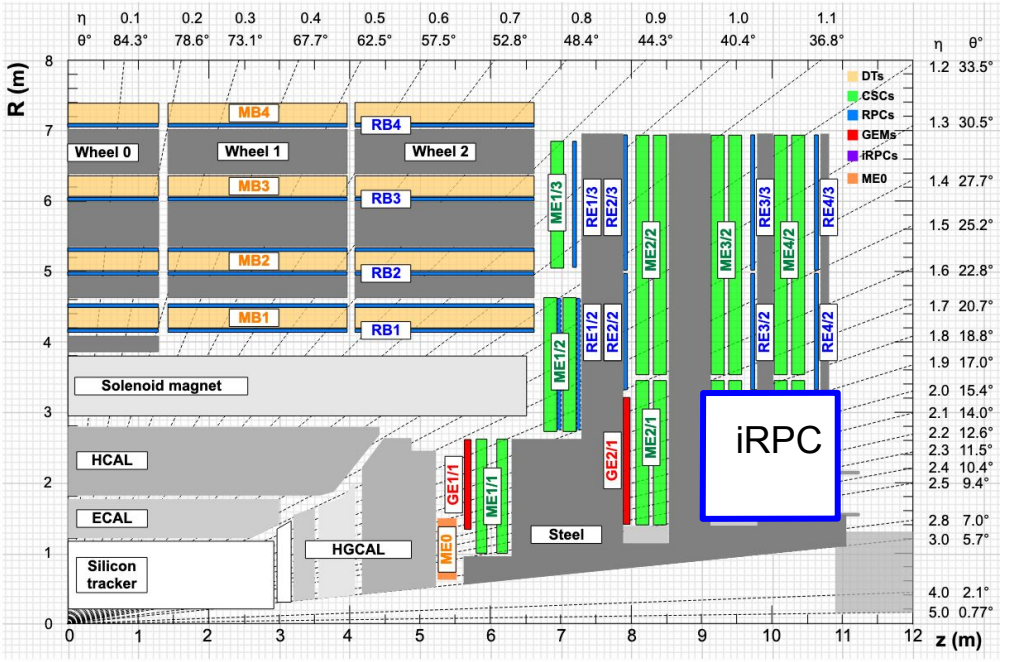
[CMS-TDR-016, Fig 1.4]

CMS RPC Upgrade Project -> iRPC

[CMS-TDR-016, Fig 1.4]

	RPC	iRPC
HPL thickness (mm)	2	**1.4**
Number of gas gaps	2	**2**
Gas gap thickness (mm)	2	**1.4**
Space resolution in η (cm)	20 - 28	**1.5**
Space resolution in φ (cm)	0.8 - 1.9	**0.3 - 0.6**
Intrinsic timing resolution (ns)	1.5	**0.5**





- Double readout in the strips high and low radius.
- Total 72 iRPC (20°) chambers
- $1.8 < |\eta| < 2.4$
- iRPC are able to sustain high expected rates of up to 2 kHz/cm2, with hit efficiency > 95%

Development and Validation of the iRPC Back-End Electronics Prototype for CMS Phase-II Upgrade
Talk by Canming Li

Study of CMS iRPC waveforms parameters and classification of signals using Machine Learning
Talk by Dalmo Da Silva Dalto

Improved Resistive Plate Chambers (iRPC) Mass Production and Performance for the CMS Phase-II Upgrade
Talk by Eduardo Alves Coelho

Long-term operation of CMS improved Resistive Plate Chambers with alternative CO2-based mixture under high irradiation environment
Talk by Joao Pinheiro

Cosmic-Ray Study of HSCP Search Capability Based on the CMS iRPC Prototype Readout System
Talk by Zhen-An Liu

Quality Control Protocols of CMS iRPC Chambers for Phase-II CMS Muon System Upgrade
Poster by Anas Idriss Laayouni El Oudghiri

First Simulation Studies of iRPC Reconstruction in CMS
Poster by Juhee Song

Performance Characterization of CMS iRPC Detectors at GIF++
Poster by Silas Santos De Jesus

Aging studies of CMS Improved Resistive Plate Chambers through spectroscopic and microscopic characterization of irradiated HPL
Poster by Mapse Barroso Ferreira Filho

Development and Validation of a Thermal Protection Circuit Breaker for the CMS iRPC Front-End Electronics
Poster by Mehar Ali Shah

Conclusions

Following a 15-year period of operation, the RPC is showing:

- High and stable efficiency (>95%)
- The cluster size is stable with an average value of less than two strips.
- Repaired chambers show stable performance once gas flow is restored independently of the time duration they were without gas and HV off.

Preparations for Phase 2 are currently underway. This will enable **an enhancement in time resolution**, reducing it from 25 ns to 1.56 ns.