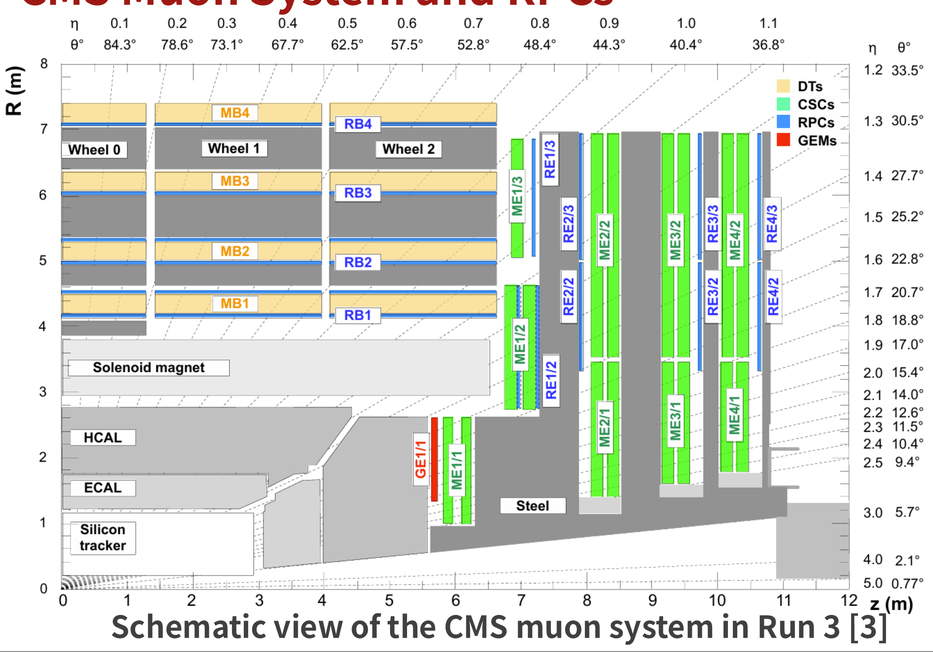
Performance study of the CMS RPC detector using the Tag-and-Probe method in LHC Run 3

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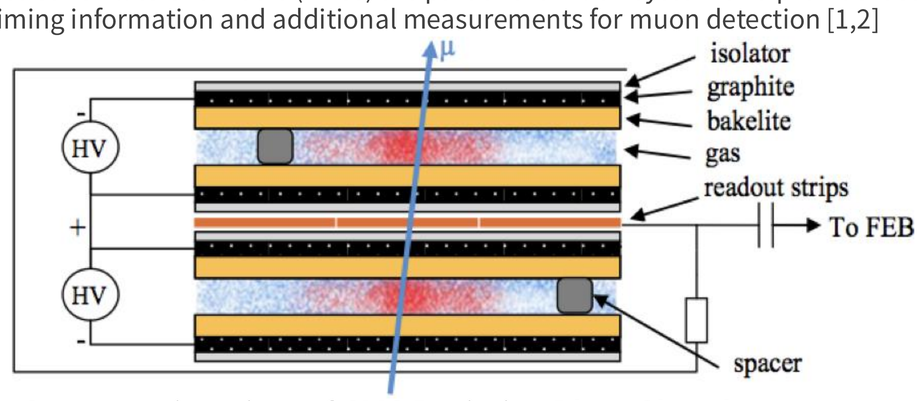
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CMS Muon System and RPCs



Schematic view of the CMS muon system in Run 3 [3]

- During the third data–taking period of the Large Hadron Collider (LHC), known as Run 3, proton-proton collisions are recorded by the Compact Muon Solenoid (CMS) experiment [3]
- Muons produced in these collisions are identified and measured using the CMS muon system, which surrounds the central tracking detector [1,2]
- Resistive Plate Chambers (RPCs) are part of the muon system and provide fast timing information and additional measurements for muon detection [1,2]



Cross-section view of CMS Resistive Plate Chamber

CMS RPCs in Run 3 [1-3]	
Detector Configuration	Double-gap
Gas gap thickness	2 mm
Operating mode	Avalanche
Electrode material	High-resistivity bakelite
Gas mixture	$C_2H_2F_4$ / i–C_4H_{10} / SF_6
Active area	3200 m^2
Detector coverage	$\lvert\eta\rvert < 1.9$ (η: pseudorapidity)
Number of chambers	1056

Tag-and-Probe Method

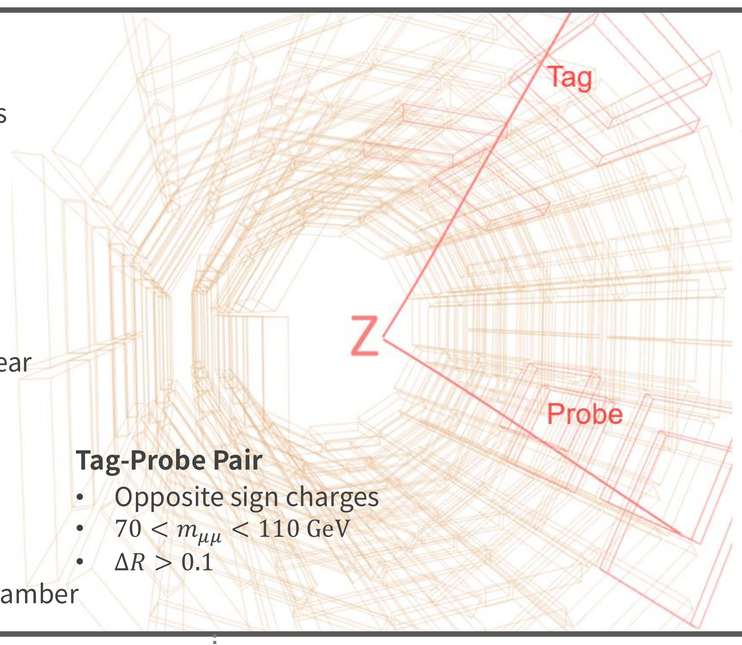
- The Tag-and-Probe method uses $Z \to \mu^+\mu^-$ events to obtain a clean sample of muons for evaluating the RPC detector response [4,5]
- The Tag is a well-identified and isolated muon used to select the event
- The Probe is reconstructed independently of the RPC system, providing an unbiased test of the RPC response
- The Probe trajectory is extrapolated to the RPC system and matched to an RPC hit near the expected crossing position

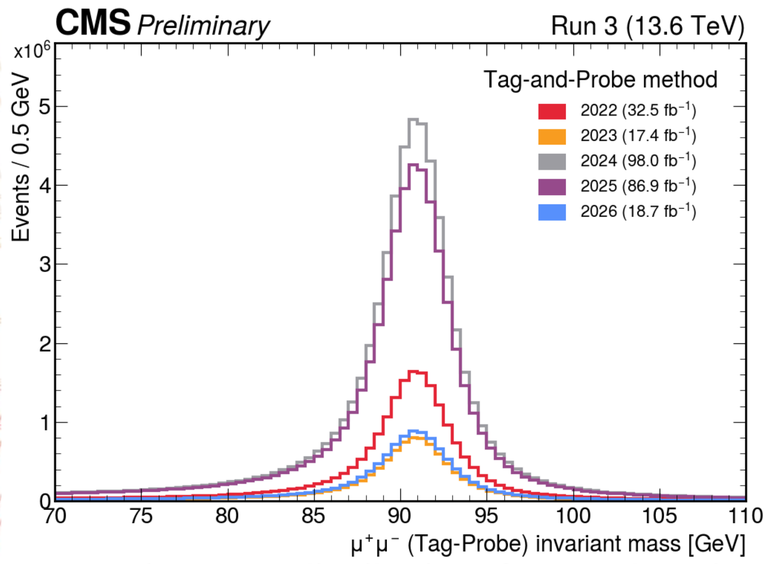
Tag Muon
- Well identified
- Isolated and trigger matched
- $p_T > 30$ GeV
- $|\eta| < 2.4$

Probe Muon
- Reconstructed without RPC information
- Tracker track matched to a DT/CSC segment
- $p_T > 15$ GeV
- $|\eta| < 2.1$

❖DT: Drift Tube
❖CSC: Cathode Strip Chamber

Tag-Probe Pair
- Opposite sign charges
- $70 < m_{\mu\mu} < 110$ GeV
- $\Delta R > 0.1$

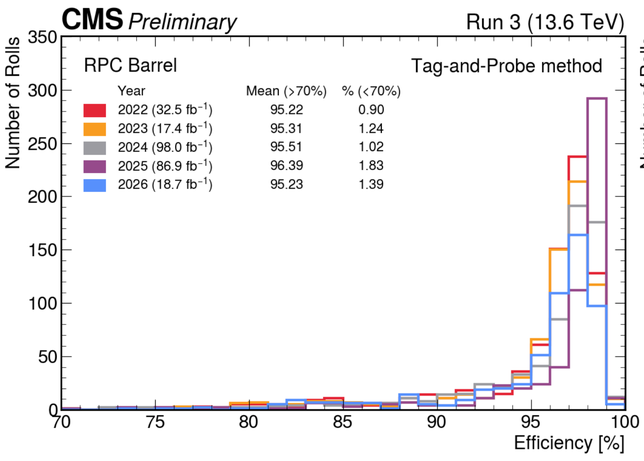


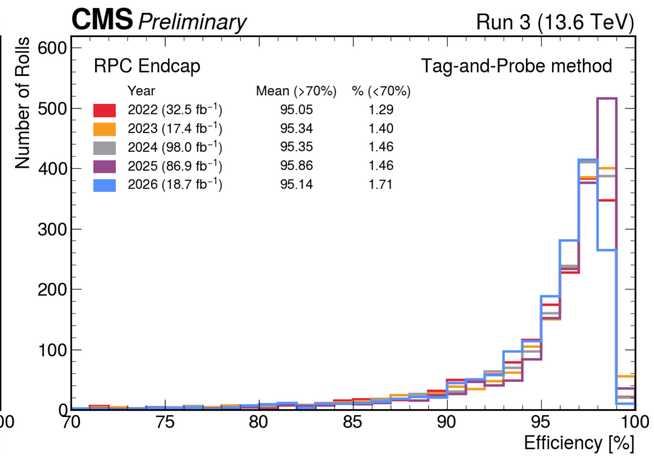


Invariant mass distribution of Tag-Probe pairs

RPC Performance in Run 3

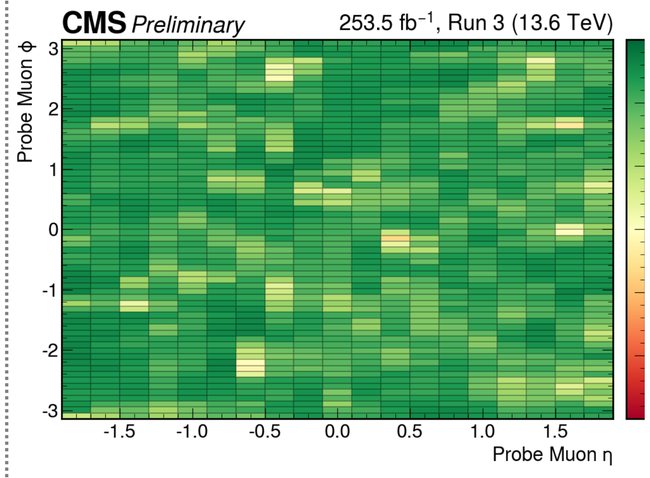
❖ Runs and chambers affected by known issues are excluded
❖ Barrel chambers operated under the gas-leak reduction policy are also excluded

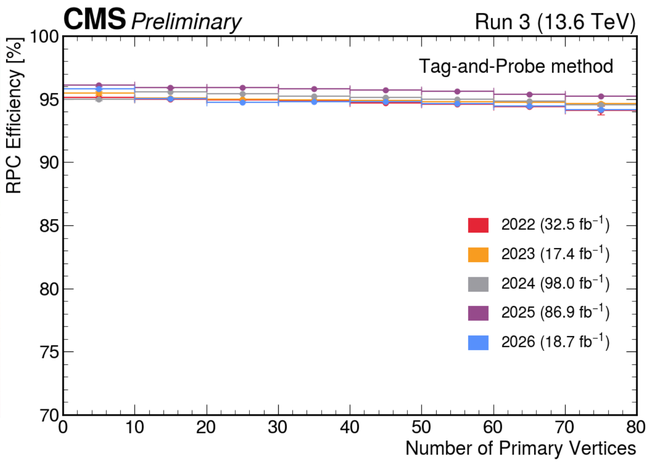




RPC roll efficiency distribution

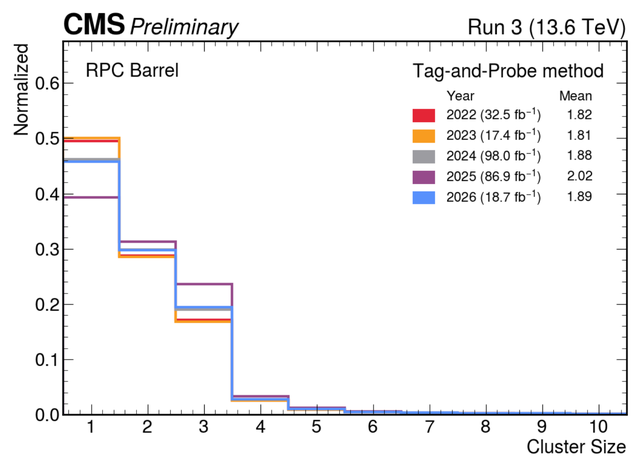
- RPC roll efficiency is defined as:
  - $\epsilon_{\mathrm{RPC}} = \frac{N_{\mathrm{matched}}}{N_{\mathrm{fiducial}}}$, where
    - N_{fiducial}: Probe crossings within the fiducial region
    - N_{matched}: Fiducial Probe crossings matched to an RPC hit
- The average efficiency remains around 95% in both the Barrel and Endcap throughout Run 3

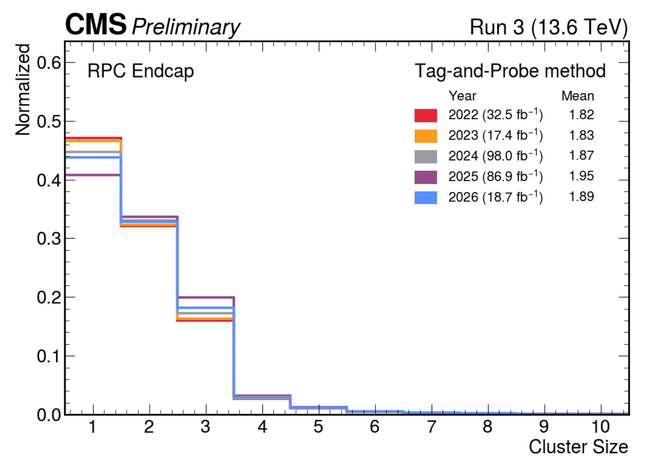




RPC efficiency in the Probe-muon η–ϕ plane and vs number of primary vertices

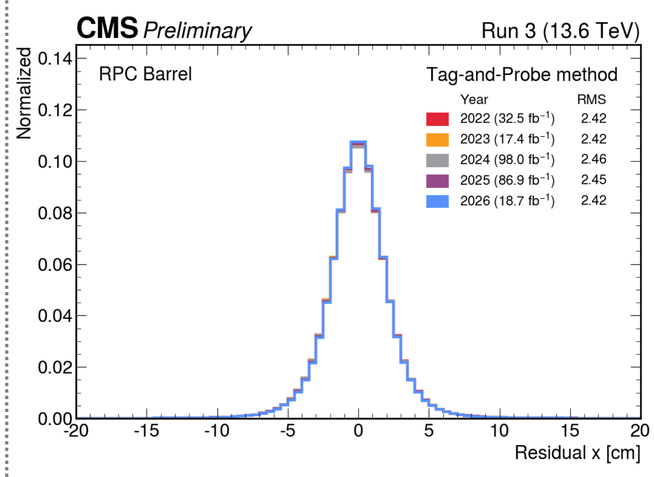
- The RPC efficiency in each bin is defined as the fraction of fiducial Probe crossings matched to an RPC hit
- The RPC efficiency is broadly uniform across the Probe-muon η–ϕ plane
- The RPC efficiency remains stable over the range of the number of primary vertices observed in Run 3

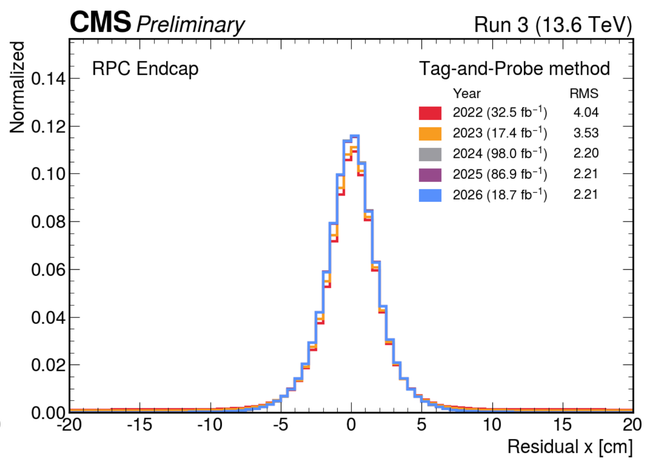




RPC cluster size distribution

- Cluster size is defined as the number of adjacent readout strips in the RPC hit associated with the Probe
- The mean cluster size remains close to two strips in both the Barrel and Endcap throughout Run 3





RPC local-x residual distribution

- The local-x residual is defined as the difference between the RPC hit position and the extrapolated Probe position, $\Delta x = x_{\mathrm{hit}} - x_{\mathrm{probe}}$
- The local-x residual remains stable throughout Run 3; the larger Endcap values observed in 2022–2023 result from a known software geometry issue

Summary

- For the first time, the CMS RPC performance is studied over the full LHC Run 3 data-taking period (2022–2026)
- The study uses the Tag-and-Probe method with $Z \to \mu^+\mu^-$ events enabling an unbiased evaluation of the RPC response
- The RPC system maintains average roll efficiencies of about 95% in both the Barrel and Endcap throughout Run 3
  - Barrel ~ 95.6% / Endcap ~ 95.4%
- The cluster size and local-x residual also remain stable throughout Run 3

References

[1] CMS Collaboration, The CMS Experiment at the CERN LHC, JINST 3 (2008) S08004.
[2] CMS Collaboration, The CMS Muon Project: Technical Design Report, CERN-LHCC-97-032, CMS-TDR-3 (1997).
[3] CMS Collaboration, Development of the CMS detector for the CERN LHC Run 3, JINST 19 (2024) P05064.
[4] J. Goh et al., CMS RPC efficiency measurement using the tag-and-probe method, JINST 14 (2019) C10020.
[5] J. Shin, CMS RPC efficiency using tag-and-probe method in LHC Run 3, Nucl. Instrum. Meth. A 1077 (2025) 170492.