CMS RPC efficiency studies using Tag-and-Probe method in LHC Run 3

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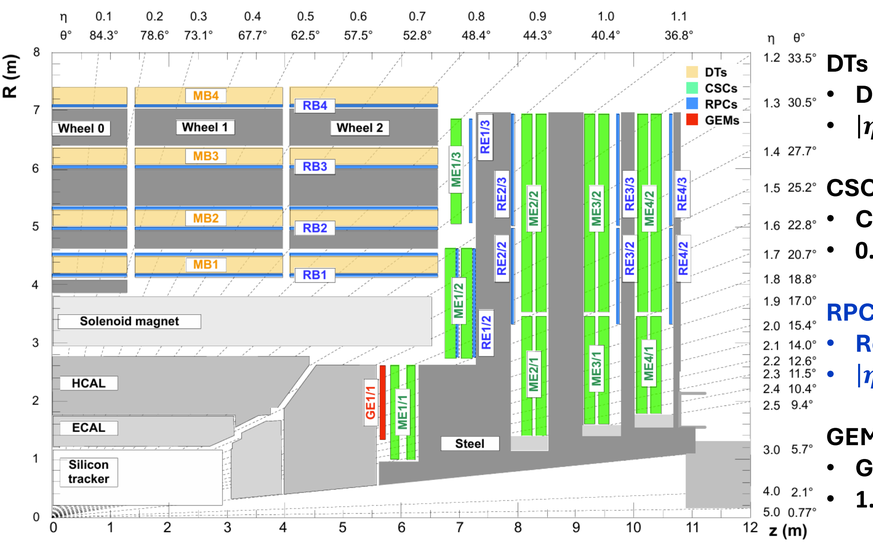
CMS Muon System

- The CMS (Compact Muon Solenoid) muon system has played a key role in many physics results obtained from previous runs of the LHC (Large Hadron Collider) including the discovery of the Higgs boson
- The main goals of the CMS Muon system are identification, momenta measurement and triggering on muons
- The Muon System consists of four gaseous detectors (|η|: pseudorapidity)



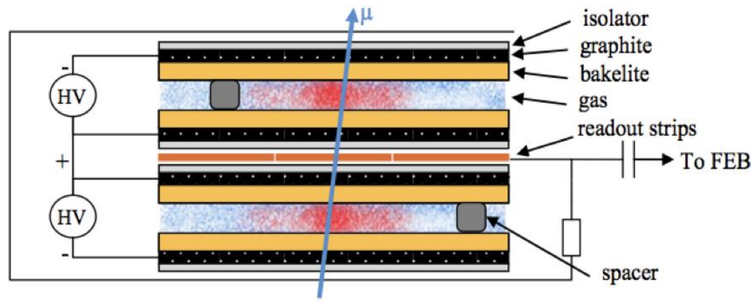
DTs
- **Drift Tubes**
- **$|\eta| < 1.2$**

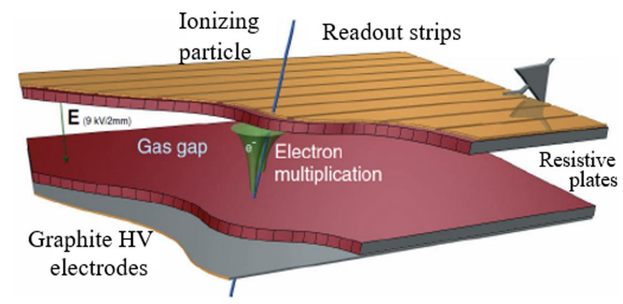
CSCs
- **Cathode Strip Chambers**
- **$0.9 < |\eta| < 2.4$**

RPCs
- **Resistive Plate Chambers**
- **$|\eta| < 1.9$**

GEMs
- **Gas Electron Multipliers**
- **$1.5 < |\eta| < 2.4$**

CMS RPC System





CMS RPC:

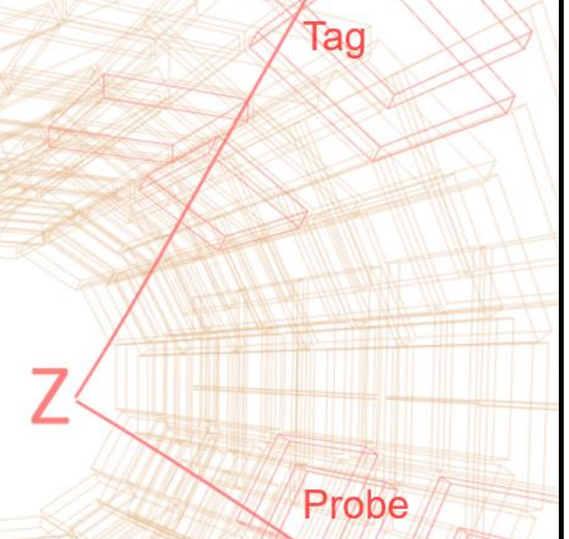
- Equipped with two gas gaps, each having $2\ \mathrm{mm}$ width and a copper readout plane between them
- Operated in avalanche mode
  - Applied with high voltage to the graphite electrodes, which are coated on the surface of high-pressure laminate plates with bulk resistivity in the range of $1\text{-}6 \times 10^{10}\ \Omega\mathrm{cm}$
  - With a gas mixture $C_2H_2F_4$ / iC_4H_{10} / SF_6 (95.2 % / 4.5 % / 0.3 %) and with 40 % relative humidity

CMS RPCs in Run 3:

- Cover both the Barrel and Endcap regions
  - (the Barrel: W0, W±1, W±2)
  - (the Endcap: RE±1~4)
- Total 1056 chambers
  - (480 in the Barrel, 576 in the Endcap)
  - ≈ 120 k electronic channels
- $3200\ \mathrm{m}^2$ of active area
  - ($2300\ \mathrm{m}^2$ in the Barrel, $900\ \mathrm{m}^2$ in the Endcap)
- 0.8-1.3 cm of spatial resolution along ϕ direction
  - (1-4 cm strip width)
- 1.5 ns of intrinsic time resolution
  - (not fully exploited since limit of DAQ system)

Method Description

- The Tag-and-Probe method was used to select high-purity & unbiased (by the RPC system) muon samples to be used as Probes
- Tag-and-Probe method
  - One muon (Tag) is required to pass tight muon identification and isolation criteria and must match a trigger object used to accept the event
  - We then select a Probe muon, which is a tracker track matched with at least one track segment in the DT or CSC
  - The Tag-Probe pair have opposite charges and an invariant mass within the range $70 \leq m_{\mu\mu} \leq 110$ GeV, corresponding to the $Z \rightarrow \mu^+\mu^-$ resonance
- RPC efficiency with Probe muons
  - $\epsilon_{roll} = \frac{N_{roll}^{pass}}{N_{roll}^{pass}+N_{roll}^{fail}} = \frac{N_{roll}^{pass}}{N_{roll}^{all}}$
  - N_{roll}^{pass}: Number of Probe muons with matched RPC hit on the roll
  - N_{roll}^{fail}: Number of Probe muons without matched RPC hit on the roll

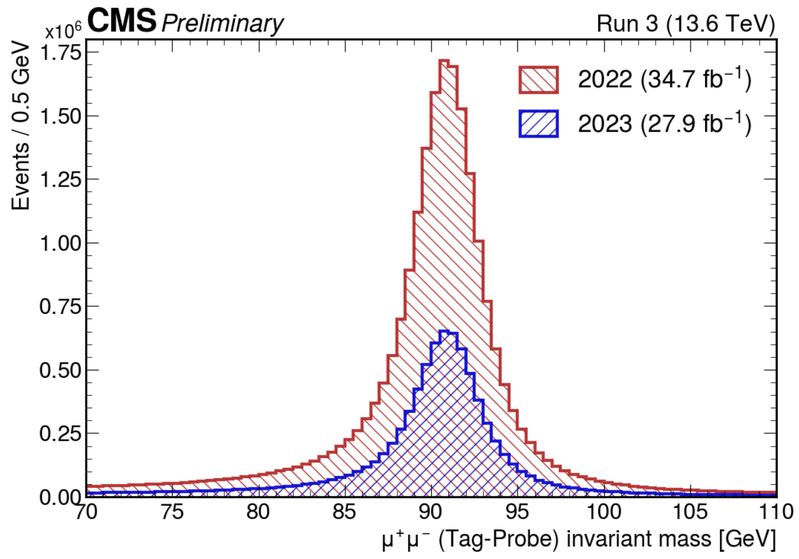


Selection Criteria

Tag Muon
- Trigger matched
- Tight muon ID
- Tight isolation cut
  - ($I_{rel} \leq 0.25$)
- $p_T > 30$ GeV
- $|\eta| < 2.4$

Probe Muon
- Tracker muon ID
- $p_T > 10$ GeV
- $|\eta| < 2.1$

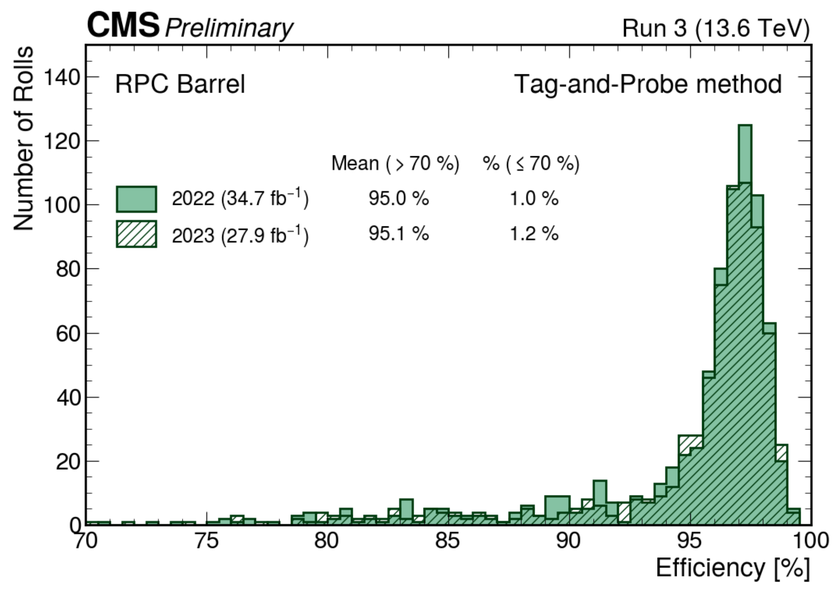
Tag-and-Probe Muon Pair
- Opposite sign charges
- $70 \leq m_{\mu\mu} \leq 110$ GeV
- $\Delta R > 0.1$

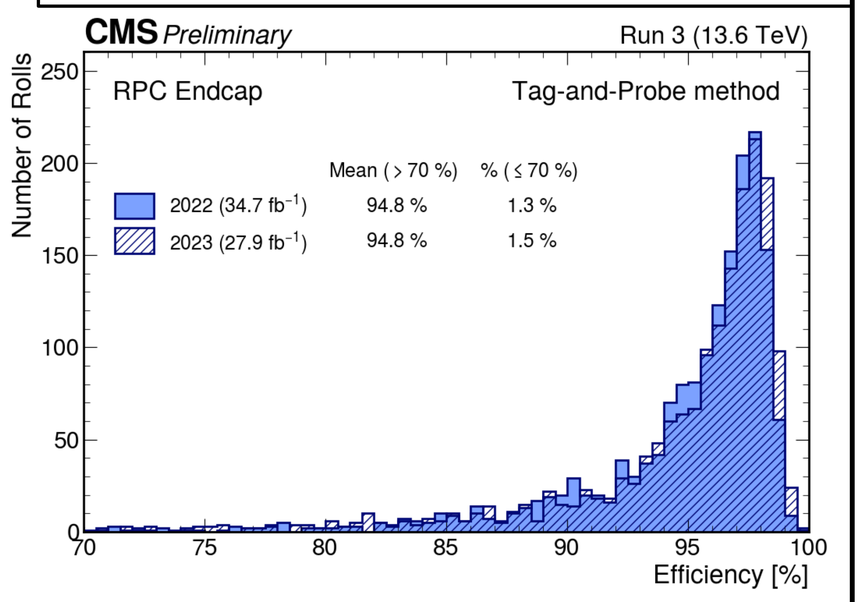


(Invariant mass distribution of Tag-Probe pairs from Run 3 data)

Overall Efficiency Distribution

$Mean$ (> 70 %): The average efficiency without underflow
% (≤ 70 %): The percentage of underflow





- The plots represent the overall efficiency of RPC rolls in the **Barrel** (left) and **Endcap** (right)
- The underflow entries are from rolls with efficiency ≤ 70 % caused by known temporary hardware problem
- Entries from known hardware problems (long-term ones) or that fall under the CMS gas leak reduction policy (Barrel only) are excluded
  - 2022: 110 chambers, 108 of which are due to gas leak reduction policy
  - 2023: 130 chambers, 129 of which are due to gas leak reduction policy
- **Overall efficiencies of RPC rolls (with above 70 % efficiency):**
  - **2022**: **95.0 %** for the **Barrel** and **94.8 %** for the **Endcap**
  - **2023**: **95.1 %** for the **Barrel** and **94.8 %** for the **Endcap**

Summary & Plan

- For the first time, we measured the CMS RPC system efficiency in Run 3 using the Tag-and-Probe method
- Tag-and-Probe method provides a high purity muon samples (Probes) that are unbiased by RPC system
- We measured RPC efficiency with Probe muons:
  $$\epsilon_{roll} = \frac{N_{roll}^{pass}}{N_{roll}^{pass}+N_{roll}^{fail}} = \frac{N_{roll}^{pass}}{N_{roll}^{all}}$$
- For this analysis, overall efficiencies of RPC rolls (with efficiency above 70 %) are:
  - **2022**: **95.0 %** (the Barrel) and **94.8 %** (the Endcap)
  - **2023**: **95.1 %** (the Barrel) and **94.8 %** (the Endcap)
- We plan to implement RPC efficiency measurement using Tag-and-Probe method to the CMS central software
- We plan to do same analysis for 2024 data, which is ongoing at the moment

Reference

1) CMS Collaboration, The CMS Experiment at the CERN LHC, JINST 3 (2008) S08004.
2) CMS Collaboration, The CMS muon project, CERN-LHCC-97-032 (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