Gas gaps and chambers quality control of improved resistive plate chambers (iRPC)

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Introduction

In preparation for the Phase-II upgrade for the high-luminosity LHC program, 72 improved Resistive Plate Chambers (iRPCs) will be installed in the third and fourth endcap disks of the Compact Muon Solenoid (CMS) during the next year-end technical stop.

These new generation of RPC detectors will operate in a low transverse momentum (extending RPC coverage from pseudorapidity |η| = 1.9 to 2.4), in a high radiation environment, and will bring a better space and time resolution for this challenging region. Assembly of the new detectors is taking place at CERN 904 laboratory and Ghent University. To ensure proper performance, iRPC chambers undergo a series of quality control (QC) tests at each stage of the assembly chain. These tests include QC1 for the basic components, QC2 for chamber elements such as gaps and cooling, QC3 for evaluating the full chamber performance after production, which includes noise, efficiency, current, and lastly QC4 for the final validation test. In this poster, we present the results of the QC tests for the newly built iRPCs at the assembly sites.

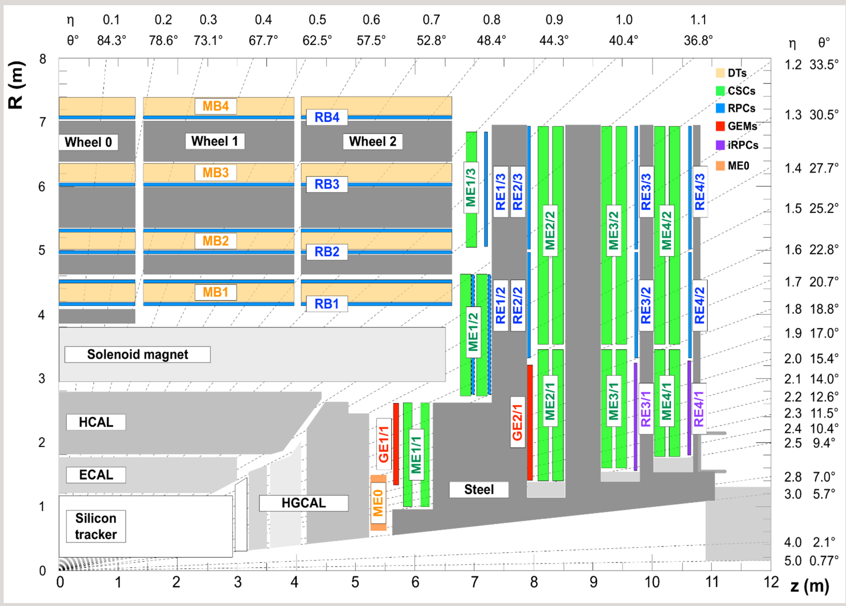

Figure 1 - A quadrant of the CMS experiment. In purple, the locations of the two endcap iRPC stations - RE3/1 and RE4/1 .

iRPC

An iRPC chamber consists of a double-gap detector, each made of two 1.4 mm High Pressure Laminate (HPL) electrodes coated with a thin graphite resistive layer separated by a gas gap of the same thickness.

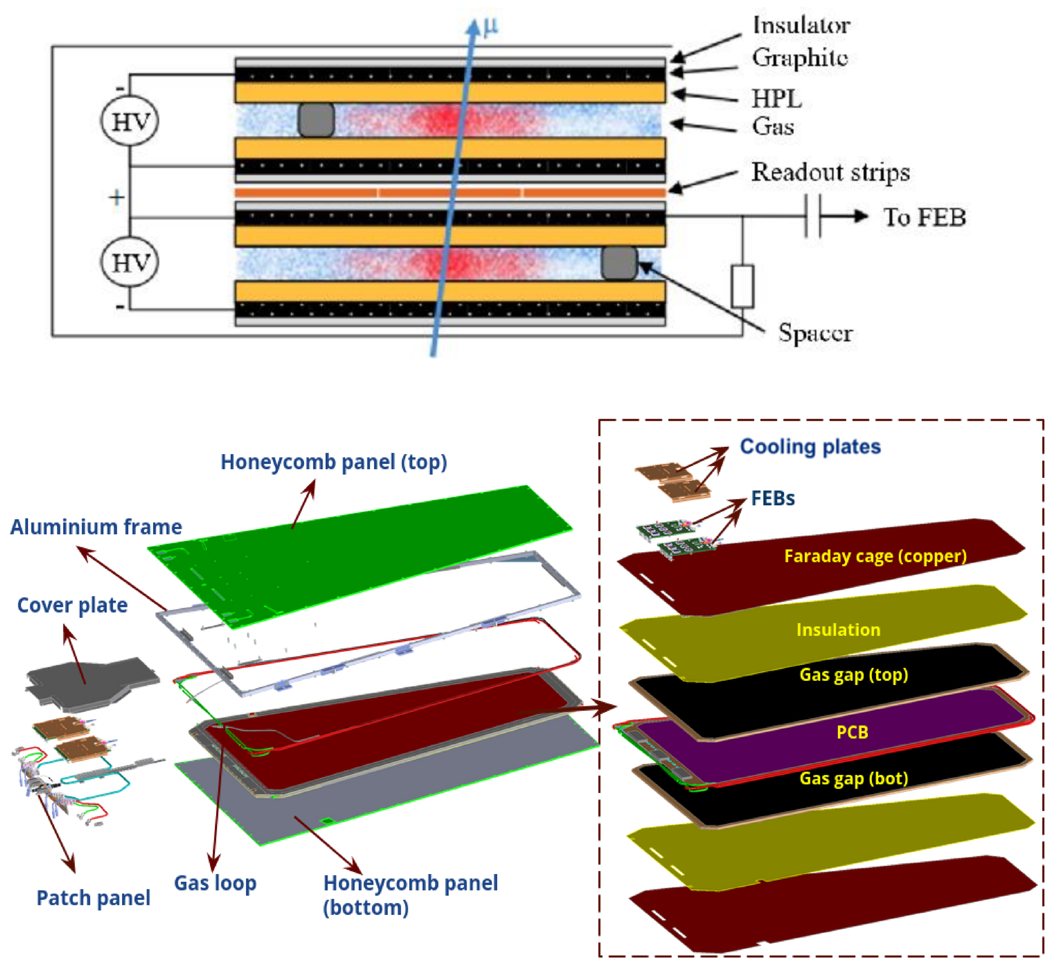

Figure 2 - Illustrations of the internal structure of an iRPC detector. The detector consists of multiple layers, including two mylar sheets on top and bottom for insulation, two gaps and two printed circuit boards (PCB), all enclosed within a Faraday cage. The HV is high voltage, and FEB is Front-End-Board.

IRPC are using the standard gas mixture for CMS with 95.2% $C_2H_2F_4$ which accounts for the number of primary ion-electron pairs, 4.5% iC_4H_{10} that allows to avoid photon feedback effects and 0.3% SF_6 which is an electron quencher.

The two PCBs are positioned on the left and right, each containing 96 readout strips.

QC 1 – chamber components

They are tested at the following sites:

HPL (INFN), Strip PCB (Lyon), Front-End-Board (FEB) (Lyon), Cooling system (Georgia)

QC 2 - gaps

- Gaps produced in the Korea Detector Laboratory (gas leak, spacer bonding, dark current scans)
- At assembly sites: (the same tests as above)

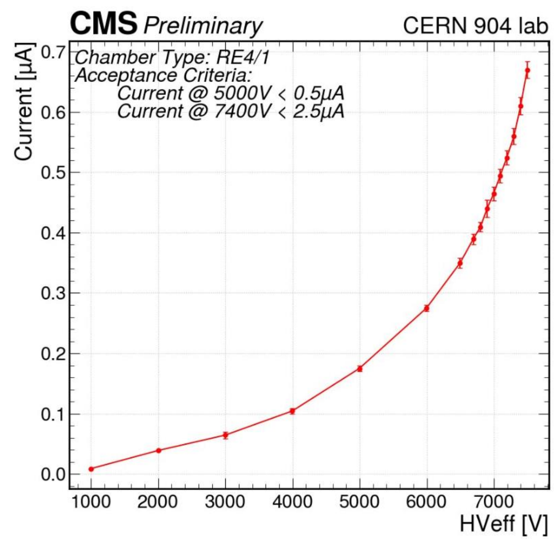

Figure 3 - This plot shows the dark current as a function of the effective high voltage (HVeff) for an iRPC gap. In the linear ohmic region, the current increases proportionally with voltage, indicating that the electric field is not strong enough to cause significant electron avalanches. The exponential region starts around 6250 V, where the dark current rises rapidly with voltage due to the onset of electron avalanches. The maximum acceptable current is 0.5 μA at 5000 V and 2.5 μA at 7400 V.

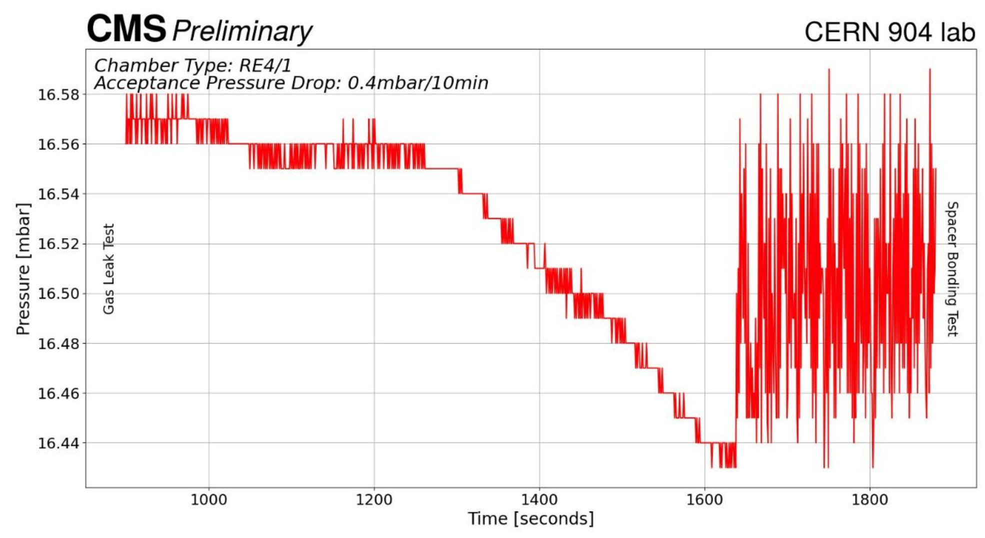

Figure 4 - This plot shows the gas leak tightness and spacer bonding test for an iRPC gap at CERN. The gas leak test indicated a decrease of 0.15 mbar/10 min, well below the 0.4 mbar/10 min limit. The spacer bonding test showed smooth transitions, confirming good bonding quality. Overall, the detector met the required standards, allowing progression to the next quality control stage.

QC 3 – Chamber @ assembly sites

- QC3.1 – Chamber assembly tests
- QC3.2 – Chamber cosmic test with 1 portable FEB (noise, efficiency, cluster size)

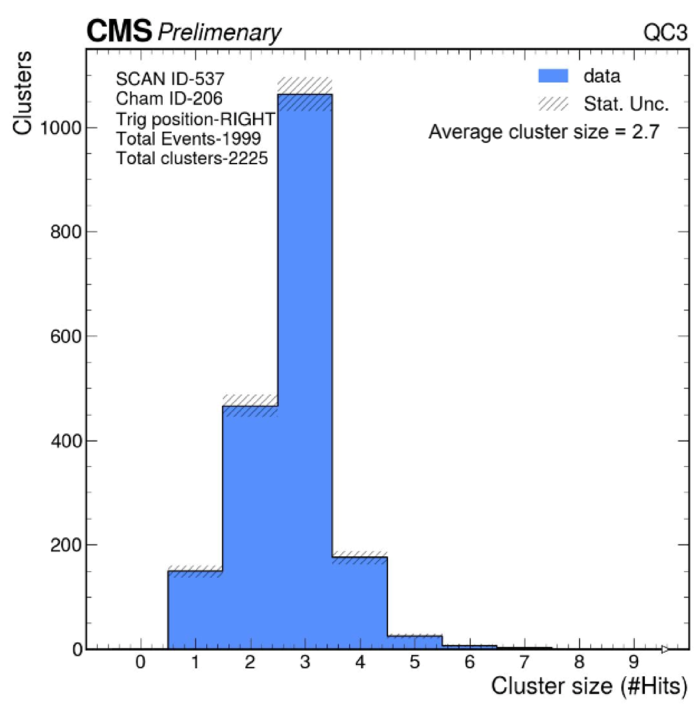

Figure 5 - The plot shows the cluster size distribution at a working voltage of 7.05 kV for an iRPC detector. Cluster size, which represents the number of consecutive strips activated by a muon, varies due to strip widths ranging 0.60 - 1.23 cm, with strips around the scintillators measuring about 1 cm. This variation impacts spatial resolution. The data was collected with cosmic muons .

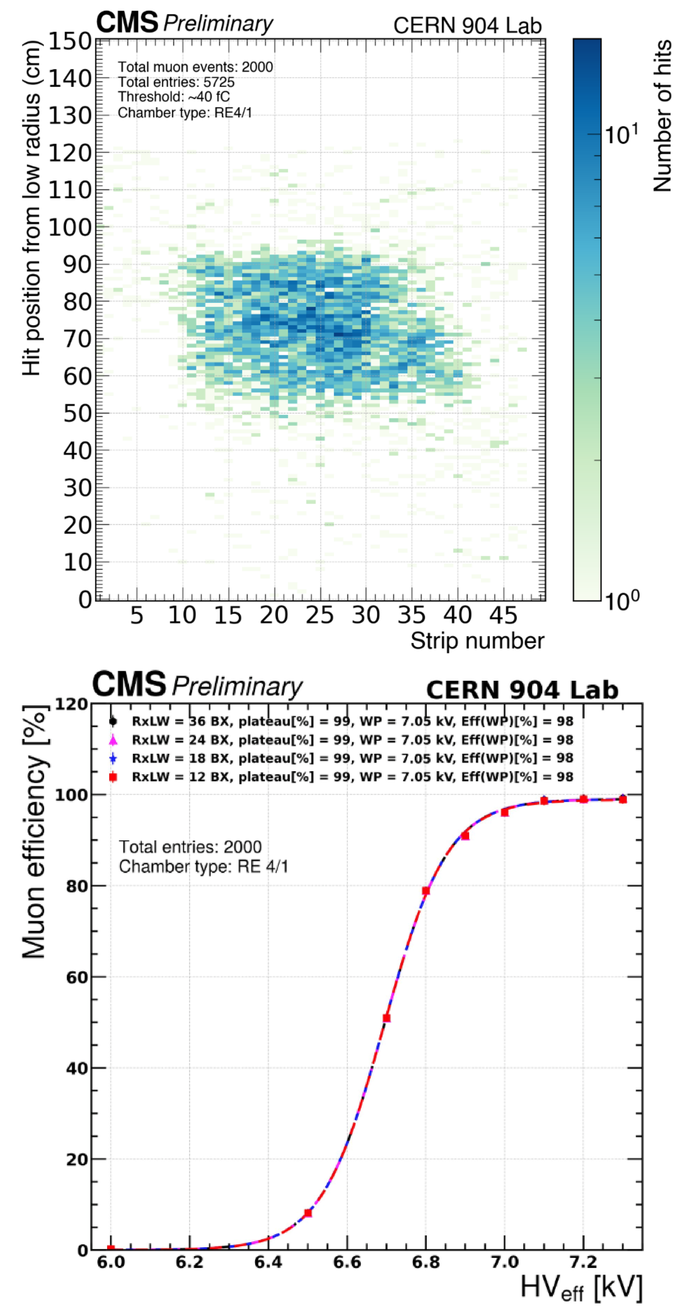

Figure 6 – Upper: The plot shows a 3D reconstruction of muon hit positions for an iRPC chamber at a working point with a charge threshold of 40 fC. The data was collected using a triple scintillator coincidence trigger with area of 30x40 cm^2.
Lower: The plot displays cosmic muon detection efficiency versus effective high voltage (HVeff). Efficiency peaks at 99%, with the working point defined as the voltage at which efficiency is 95% (HVknee) plus 150V.

QC 4 – chambers @ CERN

- QC4.1 – Final chamber tests: Cooling leak test, Gas leak test, Dark current scan
- QC4.2 – Long term HV stability
- QC4.3 – Chamber cosmic test (with final FEBs)

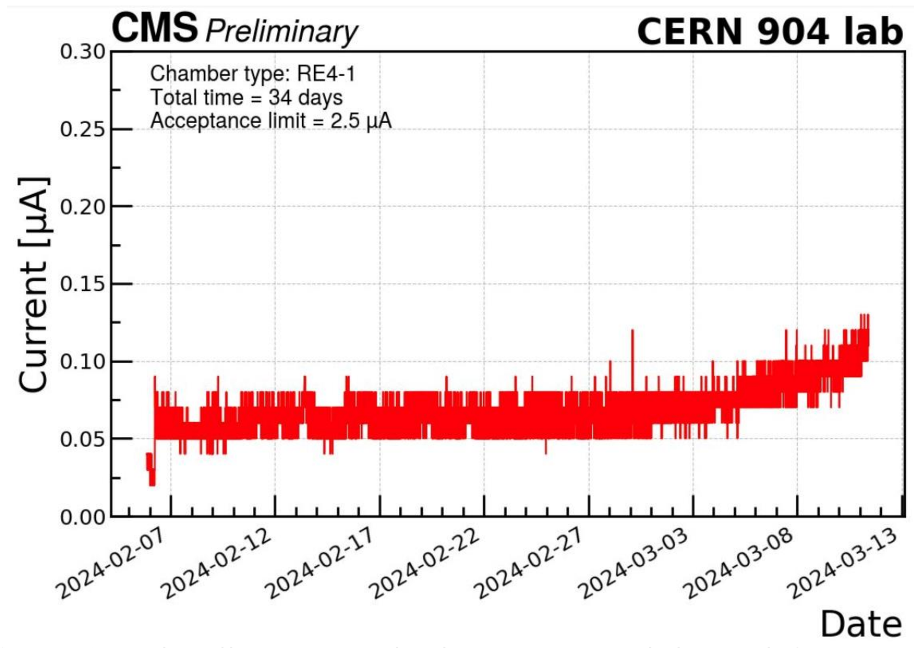

Figure 7 - Plot illustrating the long-term stability validation test for the chamber. The graph shows the current of one of the two high-voltage layers of an iRPC production chamber maintained at 7kV over a period of more than a month.
The current acceptance limit for a chamber to pass this test is 2.5 μA.

Conclusion

iRPC production is in final phase. Quality control tests are ongoing smoothly. A total of 62 chambers were assembled so far, 27 chambers of the endcap station RE3/1 and 35 of RE4/1. The first two mass production chambers were installed on the CMS detector in the winter of 2023, the 70 remaining chambers will be installed in the year-end technical stop YETS24.

References

[1] CMS Collaboration, "The phase-2 upgrade of the CMS muon detectors", CERN LHCC-2017-012, CMS-TDR-016 (2017).

[2] S. K. Park et al. "CMS endcap RPC gas gap production for upgrade", JINST 7 (2012) P11013.

[3] A. Samalan et. al. "Upgrade of the CMS Resistive Plate Chambers for the High Luminosity LHC", JINST 17 (2022) C01011.