Quality Control Protocols of CMS iRPC Chambers for Phase-II CMS Muon System Upgrade

B. El-Mahdy, Center for Theoretical Physics, The British University in Egypt, Egypt
A. El Oudghiri, University of Dundee, United Kingdom
M. Almubarak, American University of Bahrain, Bahrain
A. Alamoudi, Effat University, Jeddah, Saudi Arabia
On behalf of CMS Collaboration

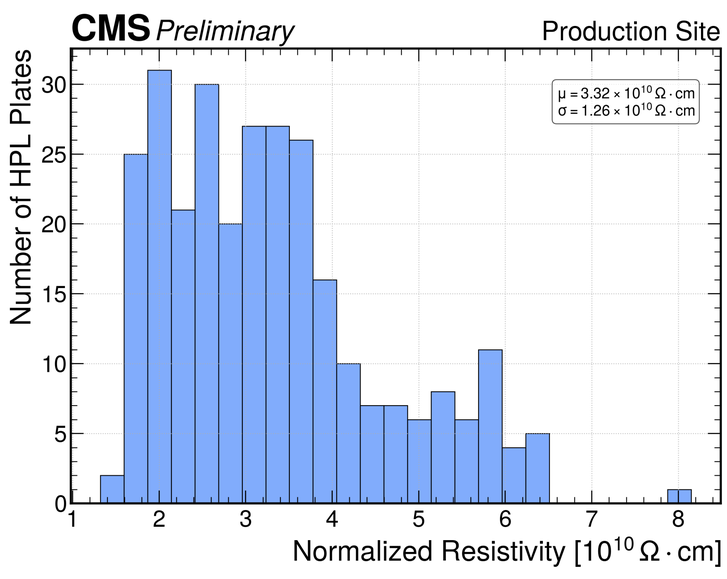
Abstract

In preparation for the Phase-II upgrade for the High-Luminosity LHC program, out of 72 improved Resistive Plate Chambers (iRPC) 36 are already installed and remaining 36 are to be installed in the third and fourth endcap disks of the Compact Muon Solenoid (CMS) during LS3.

This new generation of RPC detectors will operate in a low-angle momentum (extending RPC coverage from pseudorapidity $|\eta| = 1.9$ to 2.4), in a high radiation environment, and will bring a better space and time resolution for this challenging region. To ensure proper performance, iRPC chambers undergo a series of quality control (QC) tests at each stage of the assembly chain. In this poster we present the different QC stages and discuss test results for the full production of CMS iRPCs.

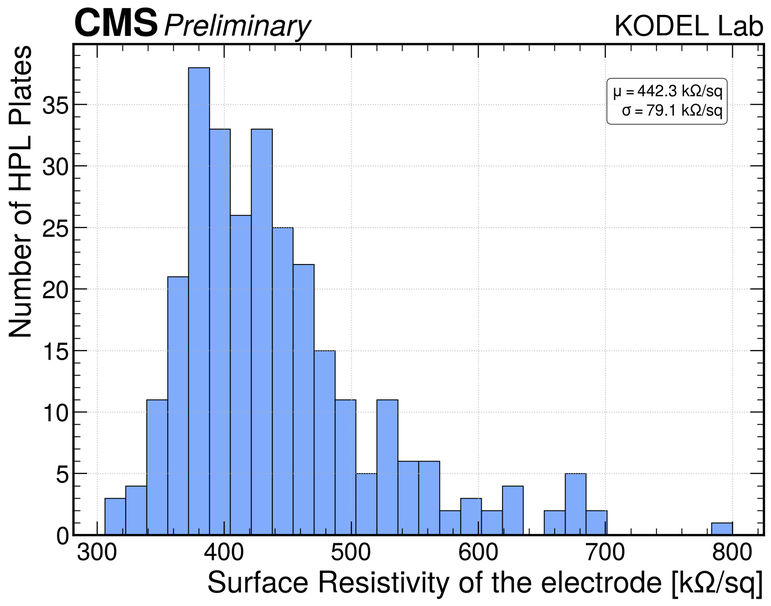
HPL criteria

1 . Bulk Resistivity Measurement



This histogram presents the HPL resistivity measurements for 290 plates tested as part of the CMS Preliminary Quality Assurance campaign for the Phase-II upgrade. The tests were performed at the production sites. The distribution demonstrates robust quality control of the plate resistivity achieved during large-scale fabrication, which is critical for ensuring the stability of the iRPC gas gaps. The measurements are normalized to $T = 20\,^{\circ}\mathrm{C}$ and 50%relative humidity. With a mean resistivity of $\mu = 3.3 \times 10^{10}\ \Omega \cdot$ cm, the majority of the plates are tightly clustered within the optimal range of $\mu = 1 - 3 \times 10^{10}\ \Omega \cdot$ cm as stated in CMS-TDR-016.

2 . Surface Resistivity Measurement



This histogram shows the distribution of the average surface resistivity of the graphite coating the HPL electrodes. Compiled from 291 plates tested at the KODEL Lab, the distribution demonstrates the consistency and reliability of the industrial-scale fabrication process. The vast majority of the plates exhibit a surface resistivity centered around $440k\Omega/sq$. The optimal range is considered to be within $300 - 700k\Omega/sq$. Maintaining the surface resistivity within this range is important for detector performance. Too low resistivity can lead to excessively large cluster sizes and, consequently, reduced spatial resolution. Conversely, too high a surface resistivity can degrade the detectors rate capability.

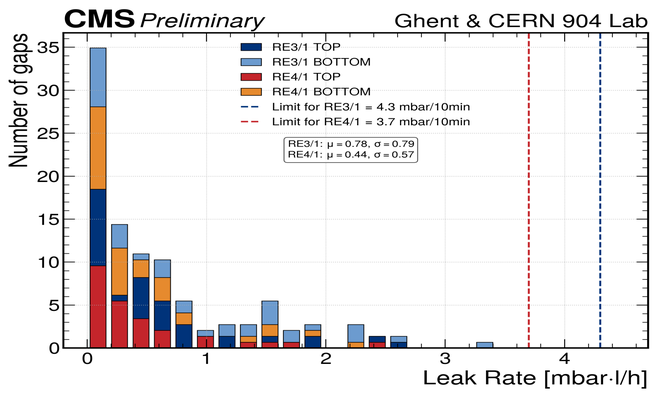
Leak Test

The leak rate is defined as the pressure drop over time, multiplied by the internal volume of the gap:

$$\textbf{Leak Rate} = \left(\frac{\text{Pressure Drop}}{\text{Time}}\right) \times \text{Volume}$$

Since the test duration is 10 minutes ($1/6$ hour) and the max pressure drop is 0.4 mbar:

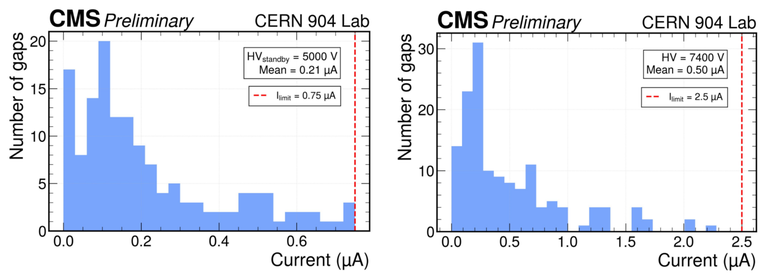
- **Simplified Logic:** $(0.4 \times 6) \times$ Volume
- **RE3/1:** $2.4 \times 1.776 = \mathbf{4.26}$ mbar · l/h
- **RE4/1:** $2.4 \times 1.556 = \mathbf{3.73}$ mbar · l/h



This plots show the leak test results for gaps after enclosed in iRPC chambers eligible for CMS (72 + 1 RE3/1 spare) performed to ensure tightness of gas in gaps after installed inside the chambers. The test is done overpressuring the gap to $5mbar$ for $10mins$. The average leak showing smaller value than for bare gaps due to a better gas connectorization. For the combined internal volume of the 144 iRPC gaps in CMS the total gas loss is estimated to be negligible ($0.1L/h$ for standard $T = 20\,^{\circ}\mathrm{C}$ and $P = 1atm$ conditions.

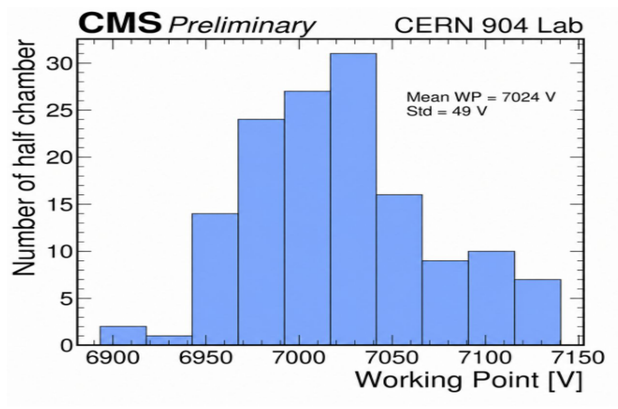
Dark Current

Investigation of these current values sheds light on the Ohmic and exponential behavior regions of a gap. This test, conducted at an ambient temperature of $20.5\,^{\circ}\mathrm{C}$, relative lab humidity (RH) of 55% and 40% gas humidity at CERN 904 assembly site.

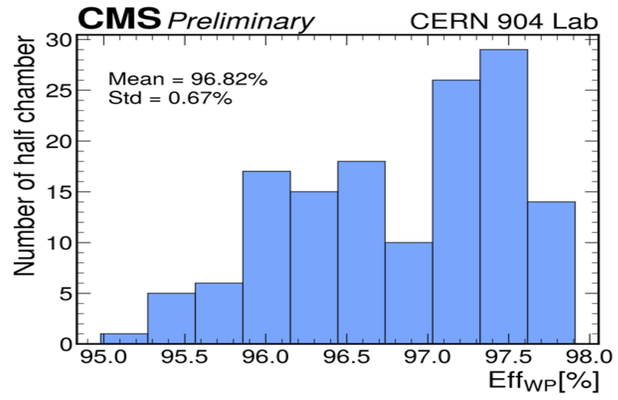


These plots represent the currents at 5000 V (left) and 7400 V (right) of iRPC production gaps tested at assembly sites (CERN 904 lab and Ghent). Analysis of these current values elucidates the characteristics of the ohmic and exponential regions resulting from the avalanche process within the detector. This test, conducted under controlled environmental conditions, exhibits an observed current reached $0.750\mu A$ for 5000 V, and maximum current value of $2.28\mu A$ for 7400 V. Remarkably, these measurements demonstrate conformity with the acceptance criteria of current less than $0.750\mu A$ (for 5000 V) and $2.5\mu A$ (for 7400 V), validating consistency in the assessment of the system's performance.

Working points and Effeciency



The histogram depicts the statistical distribution of the Working Point values obtained from tests conducted using a Front-End Board (FEBv23) with charge threshold of $\simeq 40fC$ for both the left and right strip printed circuit boards. Each chamber has two FEBs and each FEB reads half of the chamber: one reads the left side and the another reads the right side. Efficiency based on triple fold coincidence. The measurements were performed one readout at a time. It provides a visual representation of the distribution with a mean of $7024V$.



The histogram depicts the statistical distribution of Efficiency at Working Point values obtained from tests conducted using a portable Front-End Board with charge threshold of $\simeq 40fC$ for both the left and right strip printed circuit boards. Each chamber has two FEBs and each FEB reads half of the chamber: one reads the left side and the another reads the right side. Efficiency based on triple fold coincidence. The measurements were performed one readout at a time. It provides a visual representation of the distribution with a mean of 96.82%.

Conclusion

Rigorous QC across all production sites validates the robustness and reliability of the iRPC construction for the Phase-II upgrade.

- **Material and Assembly Quality:** HPL within TDR-016 ranges; leaks negligible (0.1 L/h); dark currents (0.21 μA @ 5000 V, 0.5 μA @ 7400 V) far below limits.
- **Working Point:** The operating voltage is consistently centered at $\mathbf{7024\,V}$.
- **Detector Efficiency:** The full production batch achieves a high mean efficiency of 96.82% at this Working Point.

With 36 installed and 36 ready for LS3, the iRPC system is fully on track for HL-LHC.

KEY REFERENCES

CMS Collaboration, "The Phase-2 Upgrade of the CMS Muon Detectors," CERN-LHCC-2017-012, 2017. https://cds.cern.ch/record/2283189.

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