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RE3/1 & RE4/1 chambers integration in the inner region of the Forward Muon Spectrometer of the CMS experiment

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Abstract: The high pseudorapidity region of the CMS muon system is covered by cathode strip chambers only and lacks redundant coverage despite the fact that it is a challenging region for muons in terms of backgrounds and momentum resolution. During the third long shutdown of LHC 2024/2026, two new improved RPC layers will be added, RE3/1 & RE4/1, which will completely cover the region of $1.8 < \eta < 2.4$ in the Endcap. Thus, the additional new chambers will lead to an increased efficiency for both trigger and offline reconstruction in a region where the background is the highest and the magnetic field is the lowest within the muon system. The extended RPC system will improve the performance and the robustness of the muon trigger. The final design of iRPC chambers and the concept to integrate and install these new detectors in the CMS Muon System is being finalised. In this report, the main results demonstrating the implementation and installation of the new iRPC detectors in the CMS Muon System at high pseudorapidity η region will be presented.

Keywords: Large Hadron Collider, Compact Muon Solenoid experiment; Muon spectrometers; Gaseous detectors; Resistive-plate chambers.

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Contents

1 Introduction

The increase of the energy and luminosity during the future upgrades of the LHC machine will adversely affect the performance of the CMS Muon System due to the harsh background environment and the high pile-up. The CMS collaboration is currently improving the Muon System to maintain the high level of performance achieved during the first period of operation (Run 1) also in the challenging environment of the high-luminosity LHC (HL-LHC). The operating in the the high background particle rates imposes severe restriction on the gaseous detection technology that can be used: new detector requirements include a high rate capability $O(MHz/cm^2)$, a good spatial resolution $O(100\ \mu m)$ for tracking, a good time resolution for triggering, and in addition, radiation hardness.

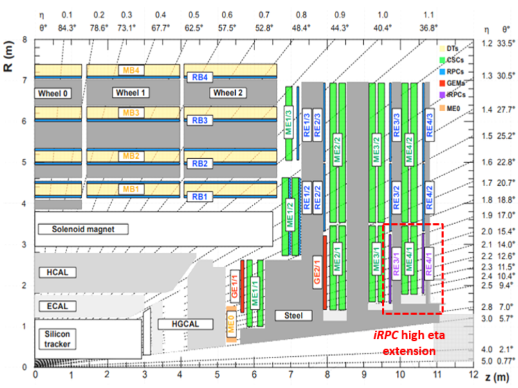

Figure 1. A quadrant of the CMS experiment.

To fulfil these requirements new and improved technology of the gaseous detectors were choose such as the Gas Electron Multiplier (GEM) and improved Resistive Plate chambers (iRPC). Exactly, these additional sets of muon detectors has been planned to install. Before this upgrade eight RPC layers in total were installed in the relative four existing Endcap disks covering up to $\eta = 1.6$ (the total number of layers should be 12 per 4 disks). At the moment the very forward region is still remain empty after Long Shutdown 1 (LS1) and could be instrumented up to $\eta = 2.4$ during LS2 (for GEM project) and LS3 (for RPC project) (Figure 1) [1]. The presence of a inner layer in the Endcap rigion equipped with an new improved RPC stations, called RE3/1 and RE4/1 will increase the overall robustness of the CMS muon spectrometer. The new iRPC RE3/1 and RE4/1 chambers will complement the Cathode Strip Chambers (CSC) stations ME3/1 and ME4/1 and enhance the local muon measurement by adding track hits. The additional hits provided by these new detectors will recover the efficiency losses due to acceptance gaps in this region. The effect will be especially pronounced for high quality muons with hits identified in all four muon stations.

2 Design of the new improved RPC chambers

The 3D-drawing of the new iRPC chambers for inner layers of the Endcap stations is shown in Figure. 3 and main geometrical parameters of the RE3/1 and RE4/1 chambers are given in Table 2. To uniformly fill in along the radius and to reduce number of dead areas in the inner layers Endcap stations, design of the new iRPC chambers was chosen identical to the existing wedge-shaped RPC detectors. The new iRPCs will be contain a double 1.4 mm high-pressure laminates (HPL) plate, forming of 1.4 mm thick of the gas gap [2], which is coated with a conductive graphite paint to form electrodes and insulated from the electrodes by plastic material. In fact, the design will use two identical large gas gaps at the bottom and on top of the chamber with a radially oriented readout panels placed in between. The entire sandwich will be gas tight. The chamber will be embedded in a honeycomb box with the chamber services (readout electronics, gas in and outlets and water cooling circuit) will be mounted on the outside.

***Table 1**. Comparison between existing RPC and new iRPC chambers*

	RPC	**iRPC**
Gas Gap & Electrode width	2 mm	1.4 mm
High Pressure Laminate (HPL)	2 mm	1.4 mm
Resistivity (Ωcm)	(1.0 – 6.0) x 10^{10}	(0.9 – 3.0) x 10^{10}
Strip pitch	2 – 4 cm	0.6– 1.2 cm
Electronics Threshold	150 fC	10 fC
Chamber dimension	10^0	20^0
Total thickness	32	25

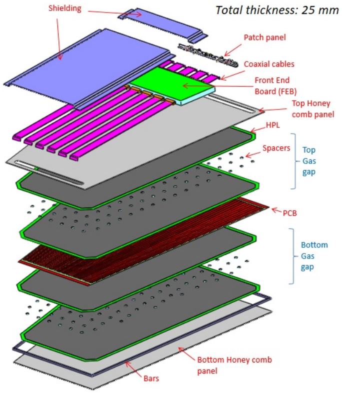

Figure 2. Schematic layout of an iRPC chamber.

***Table 2**. The geometrical parameters of the RE3/1 and RE4/1 chambers*

	RE3/1	**RE4/1**
R_{in} [mm]	1527	1770
R_{out} [mm]	3192	3140
Area [m^2]	1.39	1.19
Number of strips	96	96
Average strip pitch [mm]	9.15	8.4

The readout panel will consist the signal pick up strips are embedded in a readout board made of two parts, i.e. a two large trapezoidal Printed Circuit Boards (PCB). Both ends of each strip will connected through coaxial cables (the same impedance as strips) to two different channels of the front-end chip located on the front-end board. The iRPC's front-end electronics (FEB) is an 32-channel PETIROC ASIC developed by OMEGA based on the SiGe technology [3], includes broad band fast pre-amplifier and a fast discriminator. Each channel provides a charge measurement and a trigger output that can be used to measure the signal arrival time. The FEB will be include the field-programmable gate array (FPGA) device running a TDC for the time measurement. The each chamber will divided in 4 η-partitions, with 24 strips each, yielding a total of 96 strips per chambers.

The iRPC project will be add of 18 new chambers per muon disk, or 72 chambers in total for the RE3/1 and RE4/1 stations in both endcaps. Each station will provide one single hit for muon reconstruction with precise time information (~ 2 ns) and spatial resolution at the level of (~ 0.3 cm) (perpendicular to strips) and (~ 2 cm) (along strips). In addition to the above, the differences between existing RPC and new iRPC chambers are presented in Table 1.

3 Installation & Integration of iRPC chamber in the Endcap region

The RE3/1 chambers will be mounted directly on the endcap yoke 3 (YE3) iron disk, using the foreseen mounting points threaded into the yoke steel. In this case, they will be cover the circular neutron shielding attached to the inner part of YE3 and reach the cylindrical neutron shielding surrounding the collar that separates the yokes YE2 and YE3. During the installation of the chamber, the "L" - shape mounting brackets will used. Due to the lack space between iRPC and CSC chambers (only 20 mm is the available space) and to decrease the thermal load, which is coming from CSC electronics, iRPC Frond End electronics (FEB) will be installed underneath chambers (in the space between iRPC chambers and YE3).

The installation of the RE4/1 chambers will be difficult due to the fact that they will be mounted on the same side of YE3 where the RPC Super Modules and CSC (ME4s) chambers are located. In this case, a thin light weight frame made from aluminum alloy 8 mm thick will be used which will be mounted into the extended CSC mounting posts. The chamber will directly screwed to this frame. Aluminum frames and chambers are mounted separately.

All iRPC's high and low power system will use the existing infrastructure of the RPC CMS power system. The new HV supply boards will be add and be occupy of 4 existing racks, using CAEN A3512N 6-channel HV boards with 12 kV negative polarity as like the present RPC detectors, in total 72 HV channels will be distributed into 12 HV boards. Each chamber will have two HV lines supplying power to the top and bottom gaps, respectively. The LV power supply to the FEBs will be powered on the CAEN A3016 6-channel $8V/90W$ instead of the CAEN A3009 12-channel $8V/45W$ board. Each new LV board will supply of 9 chambers and in total two LV boards will be needed per disk [4]. All FEBs will be cooled by circulating water from the Endcap cooling circuit. The new iRPC chamber will use the same gas mixture ($C_2H_2F_6/iso-\ C_4H_{10}/SF_6$ (96.2/3.5/0.3); gas flow is of 5.0 L/hr for each chamber). The present gas system will be extend, the new piping and bulkheads will be installed around the yoke. All services (pipe and cable routings) have been planned to instal next year during the LS2.

4 Conclusions

The R&D activity was performed RPC CMS group, that was allowed to improve the resistive plate chamber technology and to fulfill the CMS requirements for HL-LHC. The baseline of the new 1.4 mm thick iRPC chamber design was chose the similar to the present trapezoidal RPC detectors, which were successfully used in the Endcap region. During the Yearly Technical Stops at the end of 2022 and 2023 RE3/1 and RE4/1 chambers will be planned to install. RE3/1 chambers will be directly mount on the YE3 using the simplified kinematic mounts. The RE4/1 chambers installation will be quite different as they will be mounted of the CSC. In this case, the CSC mounting posts will be extended to install the mounting plate for RE4/1 and special mountig frame will be used. The RE3/1 and RE4/1 HV power system will be accommodated in the actual RPC HV rack locating in the underground service cavern, therefore no new main frames will be required. The RE3/1 and RE4/1 LV power system will be an extension of the present RPC LV system, located mainly in the underground experiment cavern. The new chamber will use the same gas mixture, thus existing gas system will be extend and cooling system as well. All services will be install and mount during LS2 2019/2020.

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