CMS Improved Resistive Plate Chamber Studies in Preparation for the High Luminosity Phase of the LHC

Cecilia Uribe Estrada[1] on behalf of the CMS Collaboration

[1] *Instituto de Ciencias de la Benemérita Universidad Autónoma de Puebla. Apartado Postal 1350, Puebla, Pue., México*

cecilia.uribe.estrada@cern.ch

Introduction

The high luminosity expected from the HL-LHC will provide a unique opportunity for precise physics measurements and searches for new physics. Nevertheless, the increased rate of particles coming from the collisions will pose a challenge for the CMS detectors. To prepare the muon system for the challenging conditions during the high luminosity phase, several upgrades have been planned and are being developed. Thanks to their fast time and space resolution, the Resistive Plate Chambers form part of the trigger system and are installed both in the barrel and endcap regions as a subsystem of the muon detector. As part of the upgrades, the muon forward region will be enhanced with two stations, called RE3/1 and RE4/1, equipped with improved Resistive Plate Chambers (iRPCs). These detectors use thinner electrodes, a narrower gas gap (1.4 mm compared to 2 mm in the current design) and improved front-end electronics. These features allow them to withstand particle rates up to a few kHz/cm^2. Furthermore, they will extend the geometrical acceptance of the RPCs from a pseudorapidity of 1.9 to 2.4. In this work we present different studies related to the iRPC prototypes in preparation for the high luminosity phase of the LHC.

The RPCs in the CMS Muon System

To deal with the harsh conditions encountered during the HL-LHC the CMS RPC system is preparing for a planned upgrade (by 2023) with the installation of 72 iRPCs (with improved back-end electronics) at the endcap stations known as RE3/1 and RE4/1. In CMS muons can be identified and measured individually and accurately, with the help of 1056 RPCs: 480(barrel) and 576(endcap). These operate in avalanche mode with the gas mixture: 95.2% $C_2H_2F_4$, 4.5% iC_4H_{10}, 0.3% SF_6. Fig. 1: (a) The RPCs are mainly used as trigger devices, but also contribute to the reconstruction of particles in both barrel and endcap regions up to $|\eta| = 1.9$, (b) The implementation of new RPCs with improved technology (iRPC) at the endcap region will increase the eta coverage up to $|\eta| = 2.4$ [1], (c) The RE3/1 chambers will be mounted directly on the endcap yoke 3 (YE3) iron disk, (d) RE4/1 chambers will be installed in a high η region, close to the RPC's super modules [2].

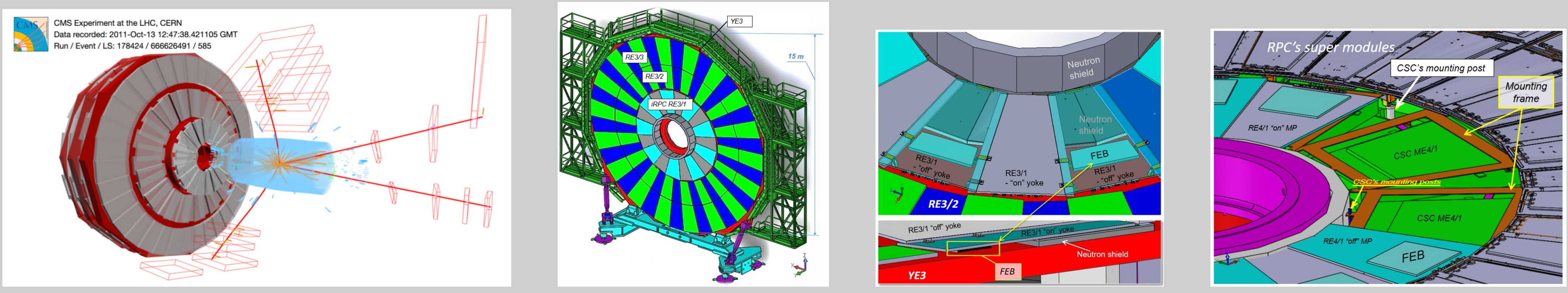

Figure 1: (a) CMS event display with four muons, likely stemming from a Higgs boson decay with activated RPCs shown as red boxes. (b) 3D drawing of the RE3/1 chambers fixed on the YE3. (c) Top: Detailed scheme of installation of the RE3/1 chambers on YE3. Bottom: The FEBs mounted behind RE3/1 chambers. (d) RE4/1 chambers mounted on the mounting plate.

The improved RPCs (iRPCs)

The muon system includes RPCs (blue) in both barrel and endcaps, Drift Tubes (DT, yellow) and Cathode Strip Chambers (CSC, green). The upgrades for the HL-LHC include Gas Electron Multipliers (GEM, red) and iRPCs (purple).

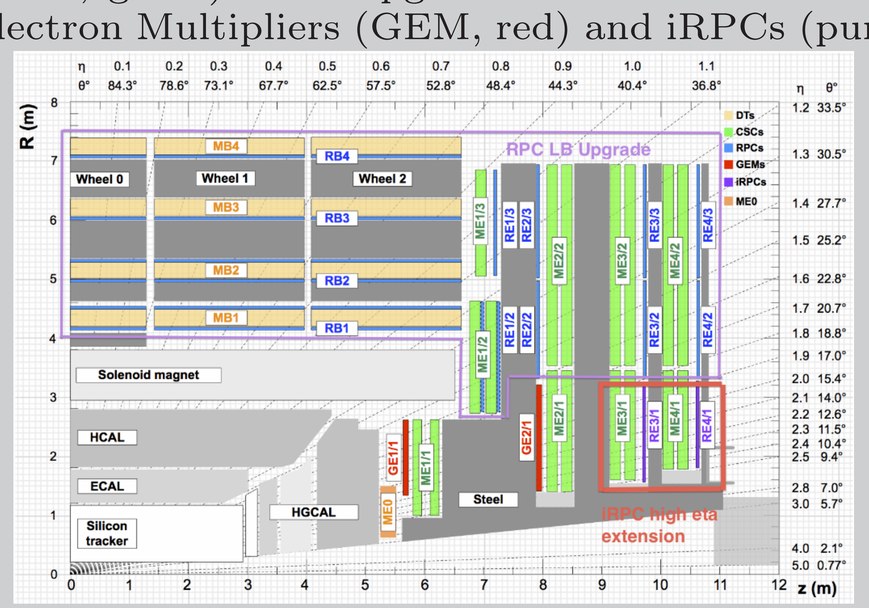

Figure 2: The red square indicates where the iRPCs will be placed to extend the muon system coverage [1].

The high η region, with low magnetic field and highest background, is the most challenging region for muon triggering and identification in CMS. The iRPCs will increase the number of hits per muon track up to $|\eta| = 2.4$.

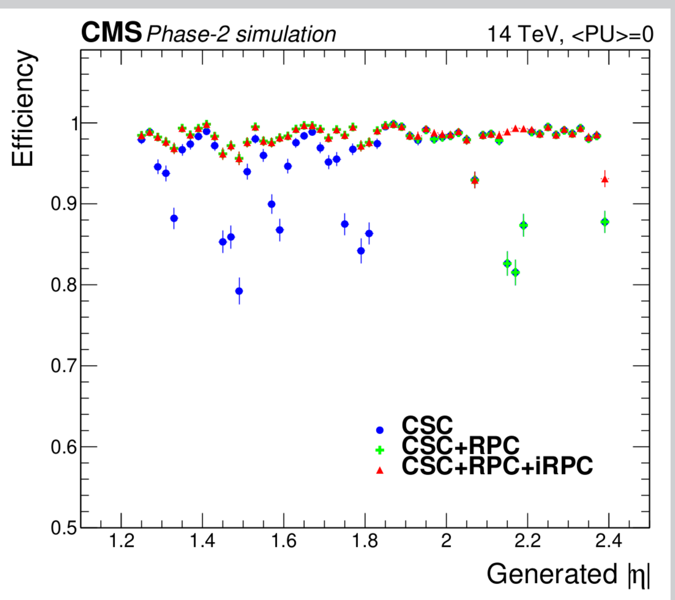

Figure 3: An improvement of the trigger efficiency is expected when the RPC hits are added to the L1 single muon trigger [3].

iRPC Design and Specifications

Specifications to increase the RPC rate capability [1-6]:

- Electrode thickness (1.4mm): Reduces the recovery time of the electrodes & increases efficiency of extracting the pickup charge from the avalanche charge.
- Gas Gap thickness (1.4mm): Reduces fast growth of pickup charge of the ionisation avalanches & lowers the operational high voltage, making system robust, including less chance of ageing.
- Electronic Threshold (50fC): Lower electronic threshold helps to provide better sensitivity to reduce charge.

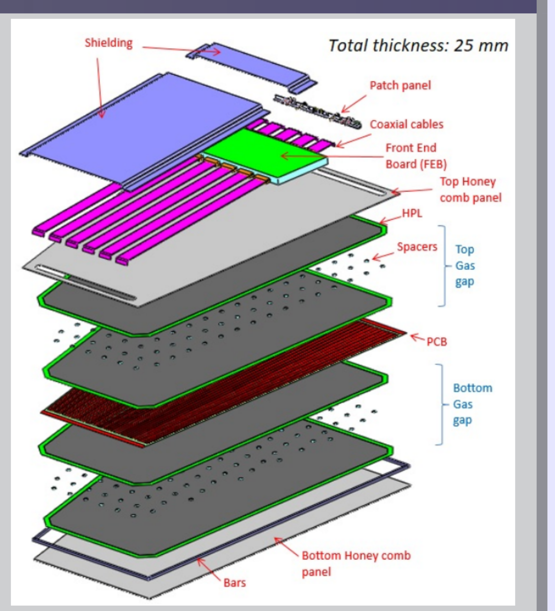

Figure 5: Schematic layout of the iRPC chamber.

Figure 6: Assembly of first 2 prototypes (Ghent, Jan 2020)

iRPC requirements for HL-LHC		
Specification	**RPC**	**iRPC**
$\|\eta\|$ coverage	0-1.8	1.9-2.4
Max. expected rate (safety factor 3 included)	600 Hz/cm^2	2 kHz/cm^2
Max. Integrated charge (safety factor 3 included)	~ 0.8 C/cm^2	~ 1 C/cm^2
High Pressure Laminate thickness	2 mm	1.4 mm
Number and thickness of gas gap	2 and 2 mm	2 and 1.4 mm
Resistivity (Ωcm)	1 - 6 x 10^{10}	0.9 - 3 x 10^{10}
Charge threshold	150 fC	50 fC

Background at RE3/1 & RE4/1

Sensitivity is defined as the probability for a background particle to create a signal in at least one of the RPC gas gaps. Sensitivity of the iRPC simulation as a function of the energy of the incident particles for n, γ, $e^{\pm}$ using GEANT4 are shown in the figure at the right.

The hit rate is defined as the number of particles reaching the RPC station (particle flux) convoluted with a detector response (sensitivity) [7-9].

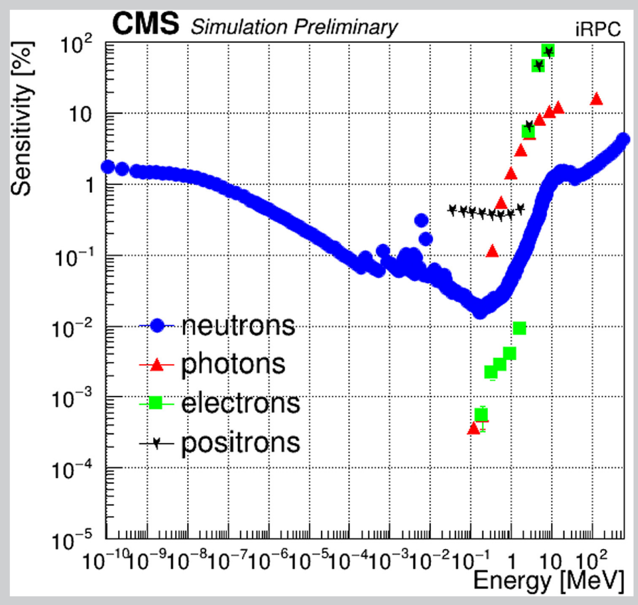

Figure 7: Estimation of the iRPC sensitivity with respect to the different background particles at the expected HL-LHC spectra.

MC iRPC hit rates, expected at base HL-LHC scenario, with instantaneous luminosity of $1.5 \times 10^{34} cm^{-2}s^{-1}$ (integrated luminosity of $3000 fb^{-1}$) as a function of the radial distance from the interaction point are shown below. All values are averaged over the azimuthal angle φ [10].

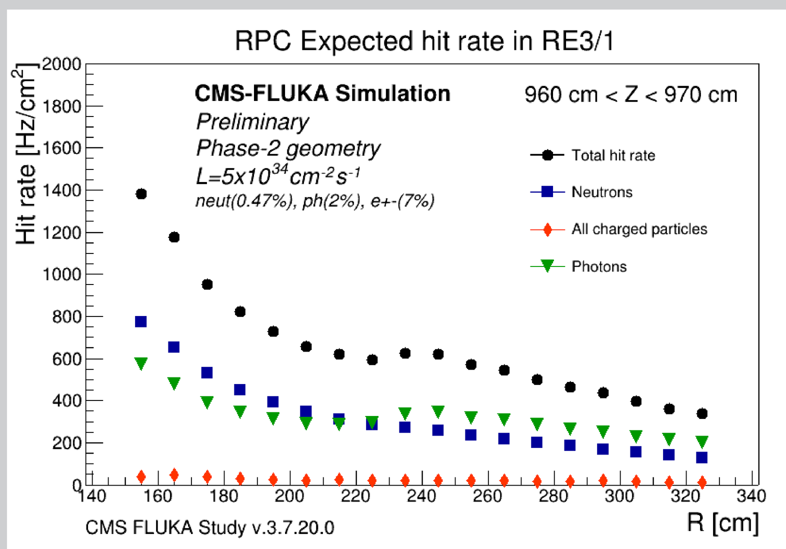

Figure 8: At $1.5 \times 10^{34} cm^{-2}s^{-1}$ the average expected RE3/1 hit rate is $\sim 660 Hz/cm^2$ (including SF of 3 $\sim 2000 Hz/cm^2$). At $7.5 \times 10^{34} cm^{-2}s^{-1}$ it is $\sim 1000 Hz/cm^2$ (including SF of 3 $\sim 3000 Hz/cm^2$).

For the ultimate HL-LHC scenario an instantaneous luminosity of $7.5 - 10 \times 10^{34} cm^{-2}s^{-1}$ (integrated luminosity of $4000 fb^{-1}$) could be attained.

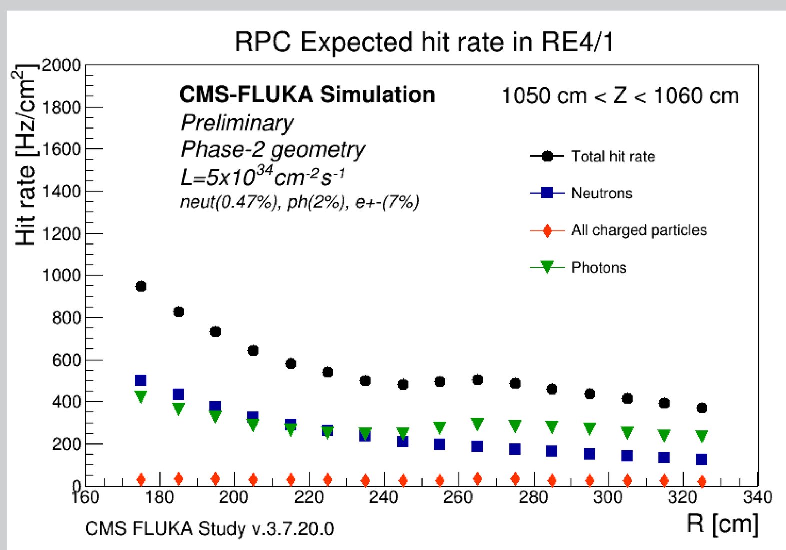

Figure 9: At instantaneous luminosity of $1.5 \times 10^{34} cm^{-2}s^{-1}$ the averaged expected RE4/1 hit rate is $\sim 500 Hz/cm^2$ (including SF of 3 $\sim 1600 Hz/cm^2$). At $7.5 \times 10^{34} cm^{-2}s^{-1}$ it is $\sim 800 Hz/cm^2$ (including SF of 3 $\sim 2400 Hz/cm^2$).

Front-End Board (FEB)

The iRPCs' new FEB readout should be able to withstand high rates ($\sim 2kHz/cm^2$). An iRPC efficiency drop (2.8% at $1.8kHz/cm^2$) due to the FEB's dead time (10 ns) in presence of high γ irradiation fluxes prompted developing **a new PETIROC ASIC with individual channel reset** and building the dielectrics of the strip panels with a **new material (EM888)** to improve the signal attenuation along the strip [4]. The thin PCB ($0.6mm$) where each strip is read out on both ends allows good resolution ($\sim 200ps$ or 1.7cm) along the strip.

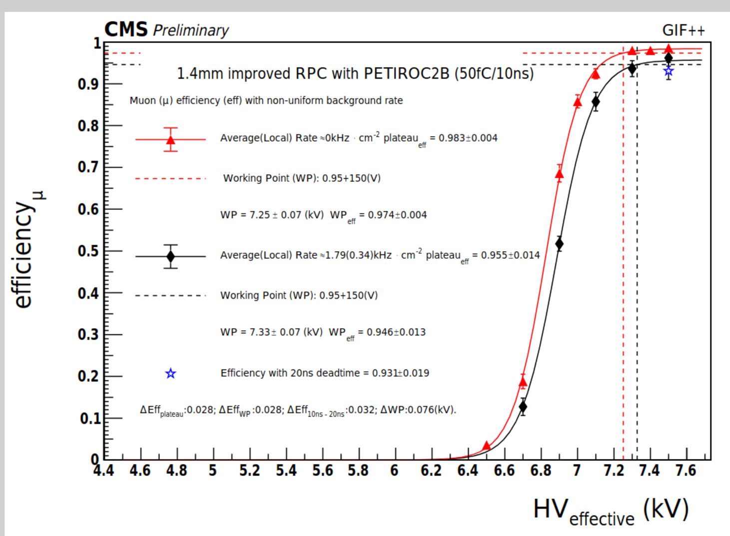

Figure 4: iRPC efficiency loss due to the FEB's dead time in presence of different γ irradiation fluxes.

Conclusions

To ensure that the muon system performs highly during what are expected to be harsh HL-LHC conditions, the installation of 72 improved RPCs in the endcap, which will extend the $|\eta|$ coverage from 1.9 to 2.4, will play an important role. The level-1 muon trigger is crucial for the CMS physics program and significantly relies on the RPC system; including the iRPC hits in the trigger will increase the efficiency. Simulation background studies indicate that, during the high luminosity phase, the average background rate expected in the RE3 and RE4 stations is $\sim 600 Hz/cm^2$ (or $\sim 2kHz/cm^2$ with a safety factor of 3). To cope with this we have pursued a higher detector sensitivity compared to the RPCs presently installed in CMS. Studies performed with the iRPC prototypes indicate that the rate capability of the RPCs can be improved by reducing the recovery time of the electrodes and the total charge produced in a discharge. The new iRPCs, Front-End Boards (FEBs) and new link system (to improve timing of muon hit information and speed of data transmission) will satisfy the required conditions. Taking into account the results of the present studies, six iRPC demonstrators are under development.

References

Acknowledgements: Work supported by project No.A1-S-39980, CB-2017-2018 CONACyT, Mexico.

[1] CMS Collaboration, "The Phase-2 Upgrade of the CMS Muon Detectors," CERN-LHCC-2017-012, CMS-TDR-016, Sep. 2017.
[2] E. Voevodina et al., 2019 JINST 14 C10027.
[3] A. Samalan et al., 2020 JINST 15 C10007, "RPC system in the CMS Level-1 Muon Trigger".
[4] K. Shchablo et al., 2021 JINST 16 C05002 "Front-end electronics for CMS iRPC detectors".
[5] P. Kumari et al., 2020 JINST 15 C11012.& B. Boghrati et al 2021 JINST 16 C05003.
[6] B. Boghrati et al., 2021 JINST 16 C05003.
[7] A. Gelmi et al., Nuclear Inst. and Methods in Physics Research, A 936 (2019).
[8-9] C. Uribe Estrada et al., Proceedings of Science (LHCP 2019), 049. & C. Uribe Estrada et al., 2019 JINST 14 C09045.
[10] R. Hadjiiska et al., 2021 JINST 16 C04005.