# improved-RPC for the CMS muon spectrometer upgrade for HL-LHC

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## 1. CMS-RPC Upgrade project

The **Resistive Plate Chambers (RPC)** system of the Compact Muon Solenoid (CMS) [1] experiment at the CERN Large Hadron Collider (LHC) covers both Barrel and Endcap regions up to $|\eta| < 1.9$, contributing to the trigger, reconstruction and identification of muons.

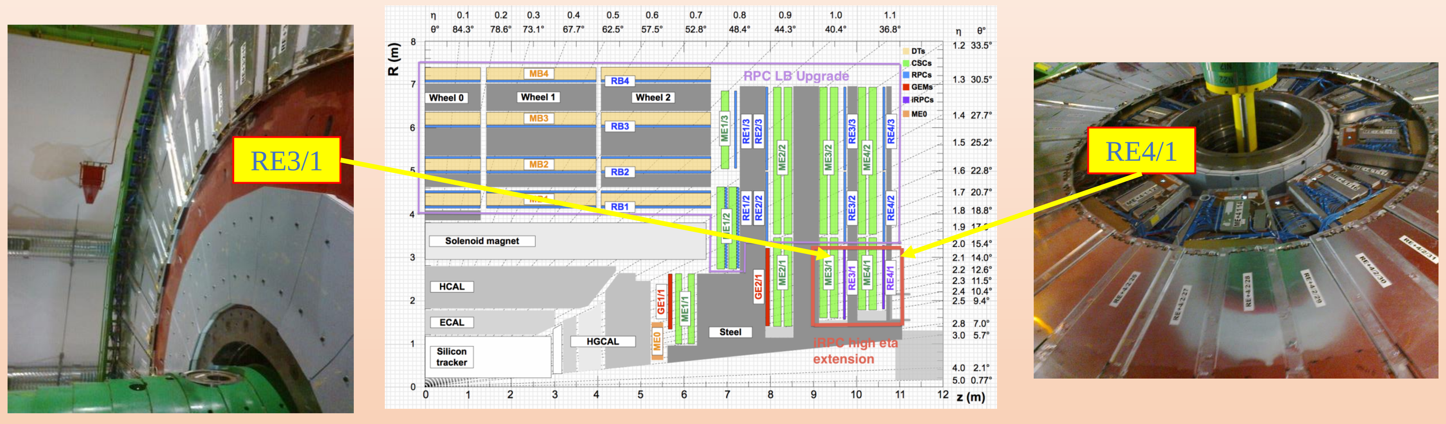


Figure 1: R-z cross section of a quadrant of the CMS detector, including the Phase-2 upgrades. The red box indicates the region where additional RPCs will be placed to extend the muon coverage.

In the next decades, at **High Luminosity LHC** (HL-LHC), the instantaneous luminosity will increase up to $5 \cdot 10^{34}$ cm$^{-2}$ s$^{-1}$ (factor five more then the nominal LHC luminosity), and the expected integrated luminosity, over 10 years of running, will be 3000 fb$^{-1}$ [1]. The expected conditions in terms of background rate, pile-up and the probable aging of the present detectors will make the muon identification and correct $p_T$ assignment a challenge for the muon system. In order to maintain the excellent performance and to ensure redundancy of the muon system also under the HL-LHC conditions, two project are planned for the RPC system upgrade:

- **extension of the muon coverage up to | η | < 2.4** [1]
- **longevity study of the present system** [2]

## 2. RPC system extension: motivations and background

**MOTIVATIONS:** CMS lacks redundancy in the high eta region, where the background is the highest and the magnetic field is low. In order to maintain the high performance, to maintain the muon reconstruction efficiency in case of muon detector degradation, and to ensure redundancy, the RPC system will extend the eta acceptance up to | η |= 2.4.

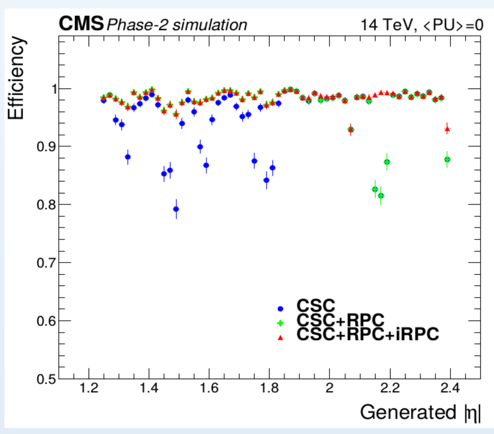


Figure 2: L1 single muon trigger efficiencies with and without the RPC information, as a function of | η |.

Figure 2 shows the overall impact of the inclusion of RPC hits into the single muon trigger with and without the use of the RPC information. **A clear improvement of the additional stations at the level of 15% can be seen in | η | = 2.1 and 2.2.**

Two Endcap stations RE3/1 and RE4/1 will be equipped with a new generation of improved Resistive Plate Chamber (iRPC), based on RPC technology but with some improvements that allows to work efficiently in presence of the high background rate expected at HL-LHC.

The expected **incident particles flux** has been estimated with a **FLUKA simulation** taking into account the CMS geometry upgrade [2] (CMS Fluka study v.3.7.7.0), including the HGCal option, the high eta region rebuild and the latest beam pipe version. The accelerator upgrade has been also considered, assuming the proton-proton collisions at 14 TeV at the nominal instantaneous luminosity of $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$.

The expected background hit rate has been estimated evaluating the **iRPC sensitivity** in a **GEANT** Monte Carlo simulation [3].
The detector sensitivity is defined as the probability for a background particle $N_{bkg}$ at a given energy, reaching the detector surface, to produce a signal $N_{HIT}$:

$$S(E) = \frac{N_{HIT}}{N_{bkg}}(E)$$

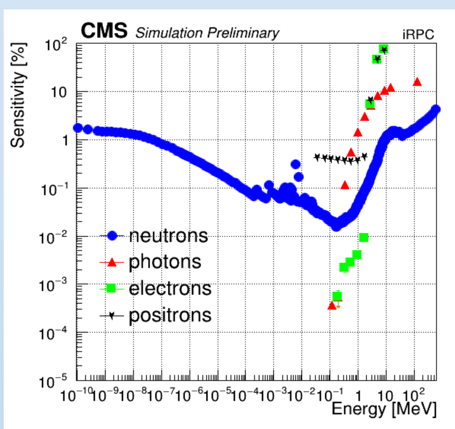


Figure 3: iRPC sensitivity vs incident particles energy spectra.

The iRPC sensitivity has been estimate with respect to the different particles that compose the CMS background at the expected HL-LHC spectra.

From the convolution of the sensitivity and the incident particles flux, obtained by FLUKA, the expected **hit background rate** as a function of the incident particles energy has been estimated.

FLUKA simulation
Incident fluxes $\phi^{CMS}_{bkg}(E)$

GEANT simulation
Detector sensitivity $S(E)$

Hit rate
$$R_{CMS}(E) = \phi^{CMS}_{bkg}(E) \times S(E)$$

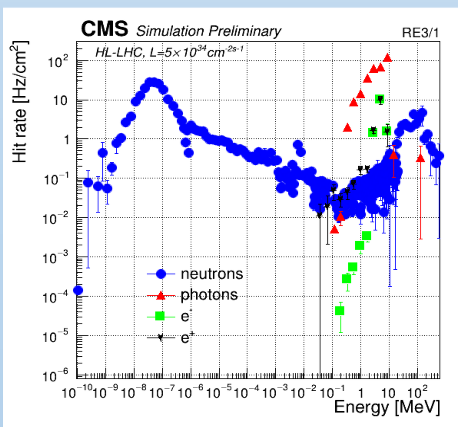


Figure 4: RE3/1 expected hit rate vs incoming particles energy.

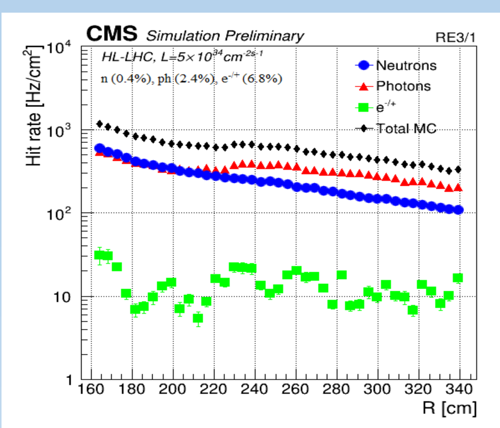


Figure 5: RE3/1 expected hit rate vs R for the different background particles.

The iRPC average sensitivity values for the different background particles:
**n (0.4%), ph (2.4%), e-/+ (6.8%),**
have been used to scale the incident particles fluxes in order to estimate the background hit rate along the detector surface.
The average expected background hit rate has been estimated:

**BACKGROUND: ≈ 2 kHz/cm²** including a safety factor three

## 3. iRPC design & new electronics

In order to increase the RPC rate capability all relevant detector improvement factors have been investigated and several RPC prototypes have been built using similar technology of the present RPC but having different geometry configurations:

- electrodes resistivity,
- electrodes thickness,
- gas gap thickness.

Extensive tests [4,5] performed at GIF++ allowed to define the baseline for the iRPC [1], resumed in the Table 1.

Table 1: iRPC baseline

| | RPC | iRPC |
|---|---|---|
| N gas gap | 2 | 2 |
| Gas Gap | 2 mm | 1.4 mm |
| High Pressure Laminate | 2 mm | 1.4 mm |
| Resistivity (Ωcm) | $1 - 6 \times 10^{10}$ | $0.9 - 3 \times 10^{10}$ |
| Strip pitch | 2-4 cm | 0.7-1.2 cm |
| Electronics Threshold | 150 fC | 10 fC |
| Chamber dimension | 10 degrees | 20 degrees |

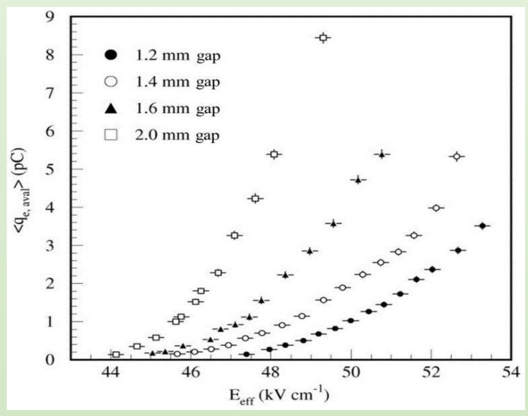


Figure 6: Average charges per avalanche measured in double-gap RPCs with different gas gap thicknesses as a function of the electric field strength.

The thinner gap thicknesses:
- more effectively retard the fast growth of the pickup charges of the ionization avalanches
- reduce aging effect
- reduce of the operational high voltage from 9.5 kV to 7.1 kV improving the robustness of the system and reducing the failure probability of the HV system

New electronic more sensitive is needed in order to detect the lower charges (<10 fC) without affecting the detector performance.
BASELINE: **PETIROC ASIC + TDC**
- 32 channels
- low noise
- gain 25
- fast pre-amplifier and fast discriminator in SiGe technology
- Readout double coordinate: **XY position (2D)**

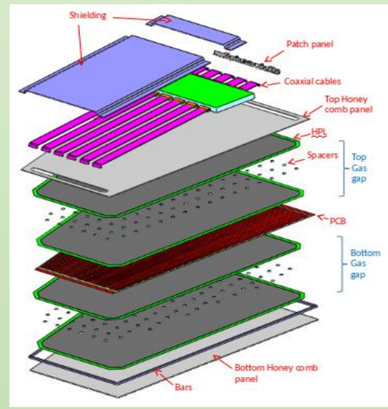

Figure 7: iRCP design including the new read out electronics

## 4. iRPC performance

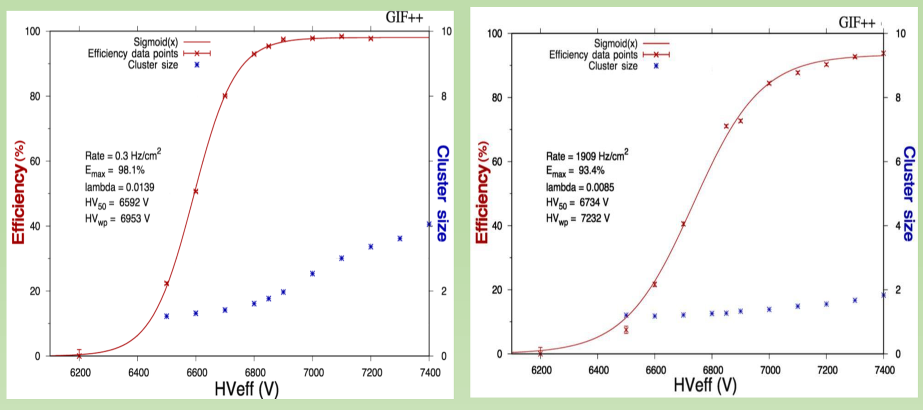

Figure 8: iRPC efficiency and average cluster size as a function of the effective voltage, tested without gamma background (left) and in presence of a gamma background rate of ≈ 2 kHz/cm² (right).

The performance of a large size trapezoidal iRPC prototype has been validated at GIF++ with a muon beam, up to a background gamma rate of ≈2 kHz/cm² (Figure 8 (right)) [1].

- ✓ **Achieved rate capability with more than 95% of efficiency at 2 kHz/cm²**
- ✓ **Working Point shift 300 V**

## 5. iRPC longevity study

Longevity test is started at GIF++ on a large size prototype of improved RPC.
**iRPC must maintain the performance for entire HL-LHC period.**

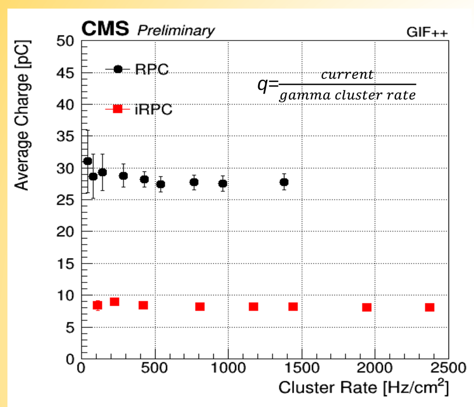


Figure 9: RPC (black) and iRPC (red) avalanche charge

iRPC expected Rate R ≅ 2 kHz/cm²
iRPC avalanche charge q ≅ 8 pC
Effective time @ nominal luminosity T = $6 \cdot 10^{10}$ s

Integrated charge: $Q = R \cdot q \cdot T$

Expected integrated charge:
**≅ 1 C/cm²** (safety factor 3 included)

**Main parameters are stable so far**

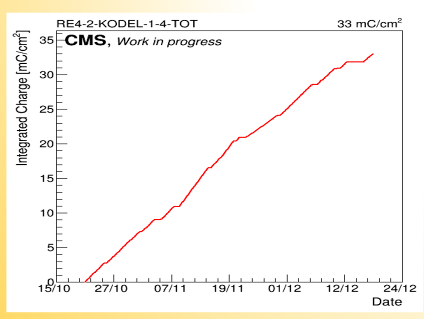

Figure 10: iRPC integrated charge at GIF++ versus time

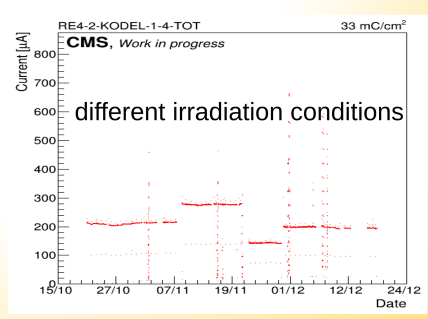


Figure 11: iRPC current stability during the longevity study at GIF++

## 6. Conclusions

In view of the HL-LHC, the RPC system will be extended in the high et region, up to | η | < 2.4.
The estimation of the background hit rate expected during HL-LHC in the RE3/1 and RE4/1 stations has been done studying the iRPC sensitivity using a GEANT4 Monte Carlo simulation. The sensitivity value has been then used to scale the incident particles flux, simulated by FLUKA. The results show that the expected average hit rate will be ≈ 2 kHz/cm² including a safety factor three.
The R&D activity allowed to define the baseline for the new iRPC detectors, which have a thinner gas gaps and electrode thickness (1.4 mm) with respect to the RPCs (2 mm) with the main aim to improve the rate capability. The performance have been validate with muon beam at different radiation condition at GIF++. The longevity study for the certification of the iRPC for the entire HL-LHC period is recently started and the main parameters are stable so far.

## References

[1] CMS Collaboration, The Phase-2 Upgrade of the CMS Muon Detectors, CERN-LHCC-2017-012, CERN, Geneva Switzerland, LHC Experiments Committee (2017) [CMS-TDR-016]
[2] A. Gelmi [CMS Muon Collaboration], Longevity studies on the CMS-RPC system, Submitted to JINST
[3] J. T. Rhee et al., Study of the neutron sensitivity for the double gap RPC of the CMS/LHC by using GEANT4, J. Korean Phys. Soc. 48 (2006) 33
[4] G. Pugliese [CMS Muon Collaboration], R&D towards future upgrade of the CMS RPC system, PoS ICHEP 2016 (2016)
[5] K.S. Lee et al., Radiation tests of real-size prototypes RPCs for the phase2 Upgrade of the CMS Muon system, JINST 11 (2016), C08008

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