CMS RPC Background Studies and Measurements

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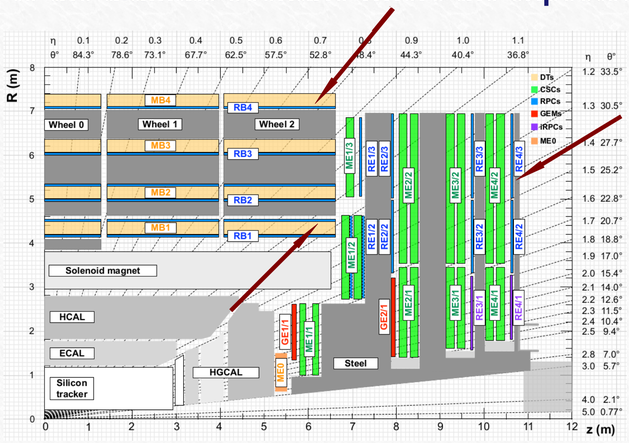
RPC expected background has been studied using MC prediction with CMS FLUKA simulation of the detector cavern. Latest Phase-2 geometry v.3.7.20.0 has been used. The present FLUKA geometry describes third and forth RPC stations (RE3 and RE4) up to |η|<1.9 and does not include the RPC upgrade between 1.9 < |η|< 2.4. The presented results will be updated accordingly after an update of the FLUKA geometry description.

The background has been studied in terms of expected particle rates, integrated dose and fluence. Two sets of detector sensitivities [1, 2] have been applied – for upgrade and for the present RPC system. The particle fluxes, predicted by FLUKA, have been convoluted with the RPC sensitivities for a given particle type to obtain the hit rate. Estimations included SF (Safety factor) of 3 have been considered.

The base HL-LHC (High Luminosity LHC) scenario – expected instantaneous luminosity of $5x10^{34}$ $cm^{-2}s^{-1}$ and integrated luminosity of $3000fb^{-1}$, has been compared to the ultimate scenario where the expected instantaneous and integrated luminosity are respectively $7.5x10^{34}$ $cm^{-2}s^{-1}$ and $4000fb^{-1}$.



CMS Detector

A quadrant plot of the CMS detector is shown. The RPC stations are labeled with RB (in the barrel) and RE (in the endcap). The present RPC stations are given in blue, while the planned upgrade (for 2023) stations RE3/1 and RE4/1 – in violet [3].

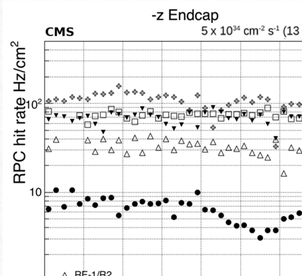
Presently there are two main source of radiation background identified in the muon system:

- From collision and radiation leak from the HCAL gap – it affects mainly the first station of external barrel wheels;
- Neutron induced background from the cavern - Affects mainly the outermost endcap stations and the chambers from the 4th barrel station.

The main focus of the present investigations is on the third and fourth endcap stations:

- RE3/1 and RE4/1 – first rings of the RE3 and RE4 (Upgrade Project) – where the highest rate for all the RPC system is expected (MC predictions);
- Present chambers on RE3/23 and RE4/23- second and third ring of the RE3 and RE4, where the highest expected rate has been predicted, based on the experimental data from the present RPC stations.

The balcony region for the entire system (all Z range), where the RPC racks with electronics (Link System) are installed, is also considered. The typical place of the RPC racks is in the range of 750 cm < R < 800 cm.

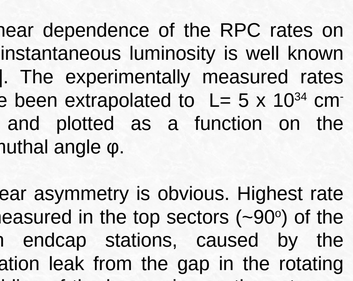


Schematic view of installation of the RE3/1 chambers

The RE3/1 chambers (plot on the left) will be mounted directly on the endcap yoke 3 (YE3) iron disk using the foreseen mounting points threaded into the yoke steel. They will cover the circular neutron shielding attached to the inner part of YE3 and reach the cylindrical neutron shielding surrounding the flange that separates the yokes YE2 and YE3. The FEBs (Frond-End Boards) will be mounted behind RE3/1 chambers.

RE4/1 chambers (plot on the right) will be installed in a high |η| region over theME4/1 chambers.

More details about the RE3/1 and RE4/1 integration and installation might be found in [4].



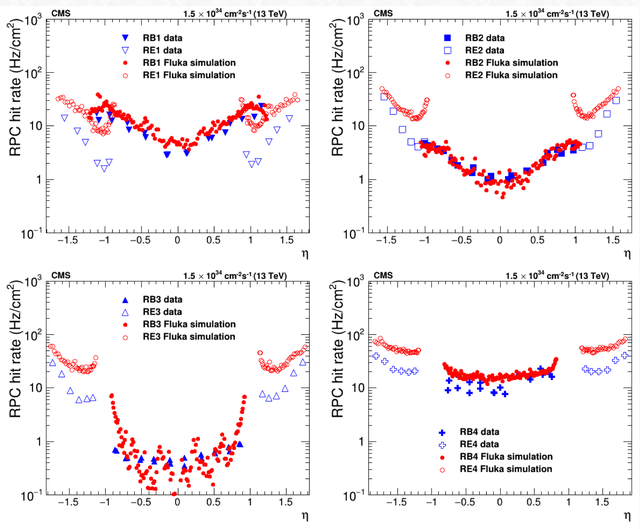
Schematic view of of installation of the RE4/1 chambers

RPC Hit Rates vs FLUKA Simulation

MC data from FLUKA have been validated with RPC experimental measurements during 2018 pp collisions.

RPC rates at instantaneous luminosity $1.5x10^{34}cm^{-2}s^{-1}$ as a function of pseudorapidity η are given on the plots. They represent a comparison between the experimentally measured RPC hit rates (in blue) and the rates predicted by FLUKA (in red). The full markers correspond to the barrel part, while the empty ones - to the endcap. RPC barrel layers are labeled as RB (RPC Barrel), while the endcap – as RE (RPC endcap) followed by the station number. The presented values are averaged over azimuthal angle φ.

The plots show a good agreement between the experimentally obtained results and MC predicted ones in the barrel region (|η|<1). Some discrepancy is observed in the endcap, which is larger at lower pseudorapidity (larger radii). Averaged discrepancy is ~ 2 and it is caused mainly by the geometry description in the simulation.



RPC Hit Rates vs φ

A linear dependence of the RPC rates on the instantaneous luminosity is well known [5,6]. The experimentally measured rates have been extrapolated to L= 5 x 10^{34} $cm^{-2}s^{-1}$ and plotted as a function on the azimuthal angle φ.

A clear asymmetry is obvious. Highest rate is measured in the top sectors (~90°) of the forth endcap stations, caused by the radiation leak from the gap in the rotating shielding of the beam pipe on the entrance of it in the cavern.

Maximum expected rates are ~ 200 Hz/cm². With a SF (safety factor) of 3 it is about 600 Hz/cm².

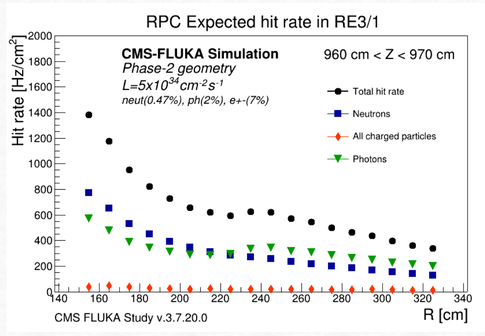
Expected rates in RE3/1 and RE4/1

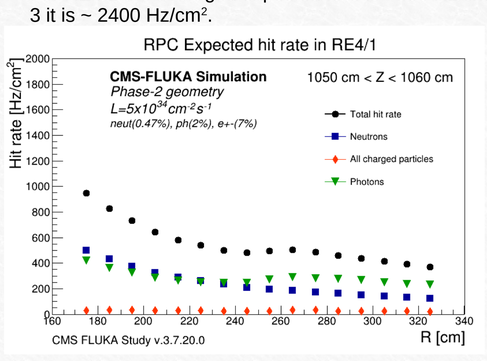
RPC hit rates, expected at instantaneous luminosity of $5x10^{34}cm^{-2}s^{-1}$ in the upgrade RE3/1 (on the right) and RE4/1 (on the bottom left) regions are shown. All values are averaged over φ.

- Averaged expected RE3/1 hit rate is ~660 Hz/cm², including SF of 3 it is ~ 2000 Hz/cm².
- For RE4/1 the averaged expected rate is ~500 Hz/cm². Including SF of 3 it is ~ 1600 Hz/cm².

Considering a scenario of instantaneous luminosity of $7.5x10^{34}cm^{-2}s^{-1}$:

- Averaged expected RE3/1 hit rate is ~1000 Hz/cm², including SF of 3 it is ~ 3000 Hz/cm².
- For RE4/1 the averaged expected rate is ~800 Hz/cm². Including SF of 3 it is ~ 2400 Hz/cm².





Expected RE3/1 and RE4/1 rates per strip:

Considering a scenario of instantaneous luminosity of $5x10^{34}cm^{-2}s^{-1}$:

- The expected rate per RE3/1 strip in the range (150 cm ≤ R ≤ 320 cm) is ~93 kHz. Including SF of 3 it is about 280 kHz or 0.007 [hits/bx].
- The expected rate per RE4/1 strip in the range (180 cm ≤ R ≤ 320 cm) is ~68 kHz. Including SF of 3 it is about 204 kHz or 0.005 [hits/bx].

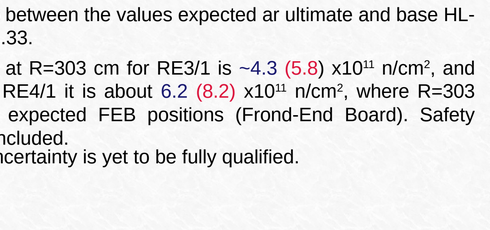
- Considering a scenario of instantaneous luminosity of $7.5x10^{34}cm^{-2}s^{-1}$:
- The expected rate per RE3/1 strip in the range (150 cm ≤ R ≤ 320 cm) is ~140 kHz. Including SF of 3 it is about 420 kHz or 0.011 [hits/bx].
- The expected rate per RE4/1 strip in the range (180 cm ≤ R ≤ 320 cm) is ~102 kHz. Including SF of 3 it is about 306 kHz or 0.008 [hits/bx].

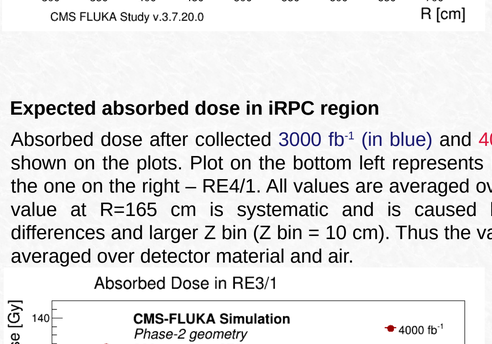
The systematic uncertainty is yet to be fully qualified.

Expected rates in RE3/2&3 and RE4/2&3

RPC hit rates, expected at instantaneous luminosity of $5x10^{34}cm^{-2}s^{-1}$ in the present RE3/2&3 (on the right) and RE4/2&3 (on the bottom left) regions are shown. All values are averaged over φ.

- Averaged expected RE3/2 and RE3/3 hit rates are ~135 Hz/cm² and 70 Hz/cm² respectively. Including SF of 3 they are ~ 410 Hz/cm² and 210 Hz/cm².
- Averaged expected RE4/2 and RE4/3 hit rates are ~180 Hz/cm² and 120 Hz/cm² respectively. Including SF of 3 they are ~ 540 Hz/cm² and 360 Hz/cm².





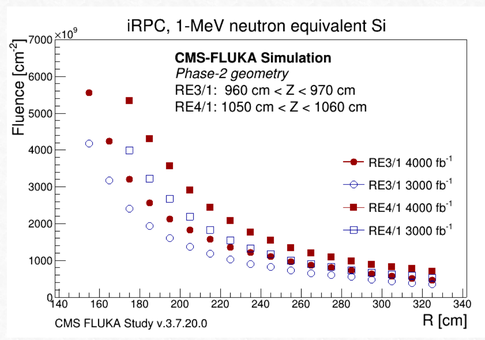
Considering a scenario of instantaneous luminosity of $7.5x10^{34}cm^{-2}s^{-1}$:

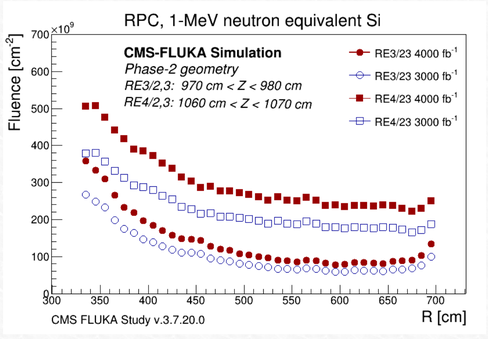
- Averaged expected RE3/2 and RE3/3 hit rates are ~200 Hz/cm² and 100 Hz/cm² respectively. Including SF of 3 they are ~ 600 Hz/cm² and 300 Hz/cm²;
- Averaged expected RE4/2 and RE4/3 hit rates are ~260 Hz/cm² and 180 Hz/cm² respectively. Including SF of 3 they are ~ 780 Hz/cm² and 540 Hz/cm².

The systematic uncertainty is yet to be fully qualified.

Expected fluence in RPC system (3000 fb^{-1}) vs Ultimate (4000 fb^{-1}) HL-LHC scenario

Expected fluence in terms of 1-MeV neutron equivalent in Si, after collected 3000 fb^{-1} (in blue) and 4000 fb^{-1} (in red) is shown on the plots. Plot on the right represents the upgrade iRPC region – RE3/1 and RE4/1 and on the bottom left – the present RE3/2&3 and RE4/2&3. All values are averaged over φ.



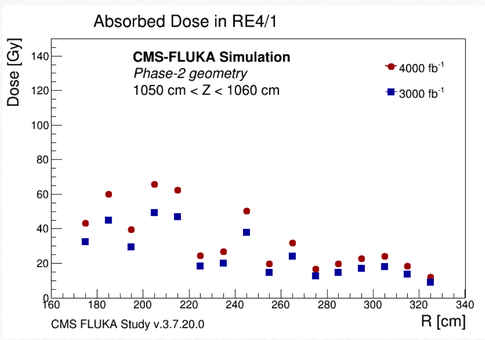


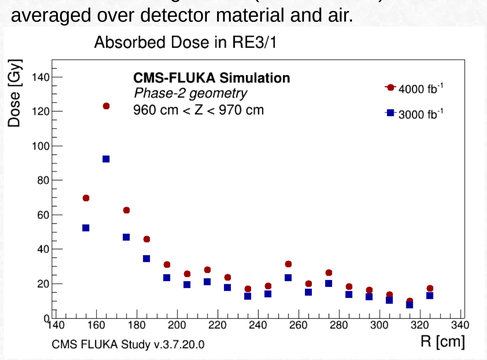
The average ratio between the values expected ar ultimate and base HL-LHC scenario is 1.33.

Expected fluence at R=303 cm for RE3/1 is ~4.3 (5.8) x10^{11} n/cm², and at R=304 cm for RE4/1 it is about 6.2 (8.2) x10^{11} n/cm², where R=303 (304)cm are the expected FEB positions (Frond-End Board). Safety factor of 3 is not included.
The systematic uncertainty is yet to be fully qualified.

Expected absorbed dose in iRPC region

Absorbed dose after collected 3000 fb^{-1} (in blue) and 4000 fb^{-1} (in red) is shown on the plots. Plot on the bottom left represents RE3/1 region and the one on the right – RE4/1. All values are averaged over φ. The highest value at R=165 cm is systematic and is caused by the geometry differences and larger Z bin (Z bin = 10 cm). Thus the value in the Z bin is averaged over detector material and air.



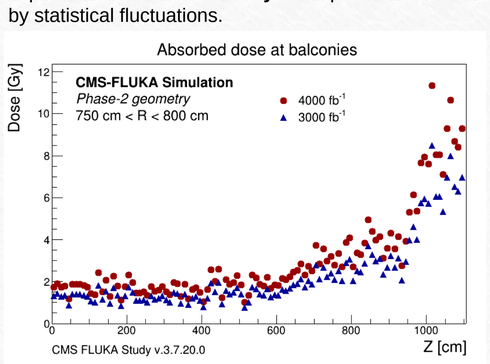


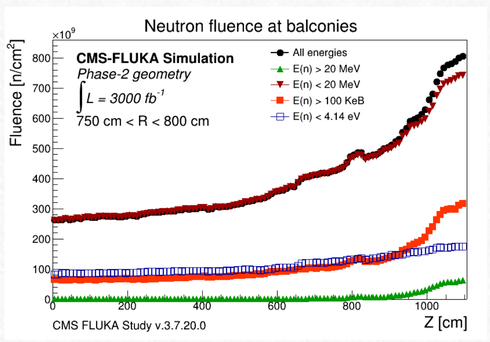
The average ratio between the values from the ultimate and base HL-LHC scenario is 1.33.
Expected dose at R=303 cm for RE3/1 is ~10 (13.6) Gy, and at R=304 cm for RE4/1 it is about 18 (24) Gy, where R=303 (304)cm are the expected FEB (Front-End Board) positions. Safety factor of 3 is not included.

The systematic uncertainty is yet to be fully qualified.

Expected absorbed dose at HL-LHC in the Balcony region

The expected absorbed dose in the balcony region after collected 3000 (4000) fb^{-1} is shown on the bottom left plot. All values are averaged over φ. The average ratio between the ultimate and base HL-LHC scenario is 1.33. Maximum expected integrated dose for the barrel (Z < 600 cm) is about 1.5 (2) Gy, while for the endcap (Z > 600 cm) the highest expectations are below **10 Gy**. Two points above this value are caused by statistical fluctuations.





Expected neutron fluence at HL-LHC in the Balcony region

Plot on the right shows the expected neutron fluence after collected **3000** fb^{-1}. The highest contribution is from the neutrons with E < 20 MeV. Maximum expected fluence for the barrel (Z<600 cm) is below 350x10^9 n/cm², while for the endcap (Z>600 cm) the highest expectations are about 800x10^9 n/cm². The values in the Z bin are averaged over detector material and air. The systematic uncertainty is yet to be fully qualified.

[1] C. Uribe Estrada et al. "RPC radiation background simulations for the high luminosity phase in the CMS experiment" JINST 14 (2019) no.09, C09045;
[2] A. Gelmi, E.Voevodina on behalf of the CMS Collaboration, "Background rate study for the CMS improved-RPC at HL-LHC using GEANT4" NIMA Volume 936, 21 August 2019, Pages 430-432;
[3] CMS Collaboration,The Phase-2 Upgrade of the CMS Muon Detectors. Technical Design Report,CERN-LHCC-2017-012;
[4] E. Voevodina et al., RE3/1 & RE4/1 RPC chambers integration in the inner region of the forward muon spectrometer in the CMS experiment, JINST 14 (2019) no.10, C10027
[5] S. Costantini et al.,Radiation background with the CMS RPCs at the LHC, 2015 JINST 10 C05031, [arXiv:1406.2859];
[6] R.I. Rabadan-Trejo et al., Long-term performance and longevity studies of the CMS Resistive Plate Chambers, 2018 JINST 13 P08024