RESULTS OF THE RADIATION DOSE STUDY AROUND THE TESTED GEM MUON DETECTOR AT CMS

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The higher luminosity delivered by the future HL-LHC imposed the development and testing of a new type high-rate detector known as GEM (Gas Electron Multiplier). A monitoring system, designed to measure the radiation dose and particle fluence around the GEM detectors, has been developed and installed at the CMS detector. It consists of a main controller, to which up to 12 radiation monitors (RADMON) can be connected. There are two types of sensors in each unit: RadFETs, measuring the total radiations dose and p-i-n diodes for 1 MeV neq fluence. A few GEM chambers were installed in the inner CMS endcap in early 2017 for a slice test. One RADMON is installed in one of the chambers to measure the surrounding radiation. After about two years of operation, the obtained results are analyzed. They show that for an integrated luminosity of about 118 fm^{-1} the dose and the 1 MeV fluence are relatively low. Therefore, only two more sensitive sensors are giving data. The experimental results confirm the dose and fluence values simulated by FLUKA v.3.0.0.0.

Keywords: gas electron multiplier (GEM) detector, radiation dose, particle fluence, monitoring

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1. Introduction

The increase of the luminosity after the current upgrades of the CERN LHC toward the HL-LHC era will result in a corresponding increasing of the events rate and the radiation background throughout the CMS detector. To meet the higher requirements it was decided to upgrade the CMS forward muon system [1]: for the next LHC run a new type gas filled detector – the so-called GEM (Gas Electron Multiplier) [2] will be developed and installed in the free Gem Endcap Ring 1 Station 1 (**GE1-1**) (fig. 1) to cover the pseudorapidity region 1,6 < η < 2,5. A dosimeter system [3] was developed to control the radiation level in GE1-1 station.

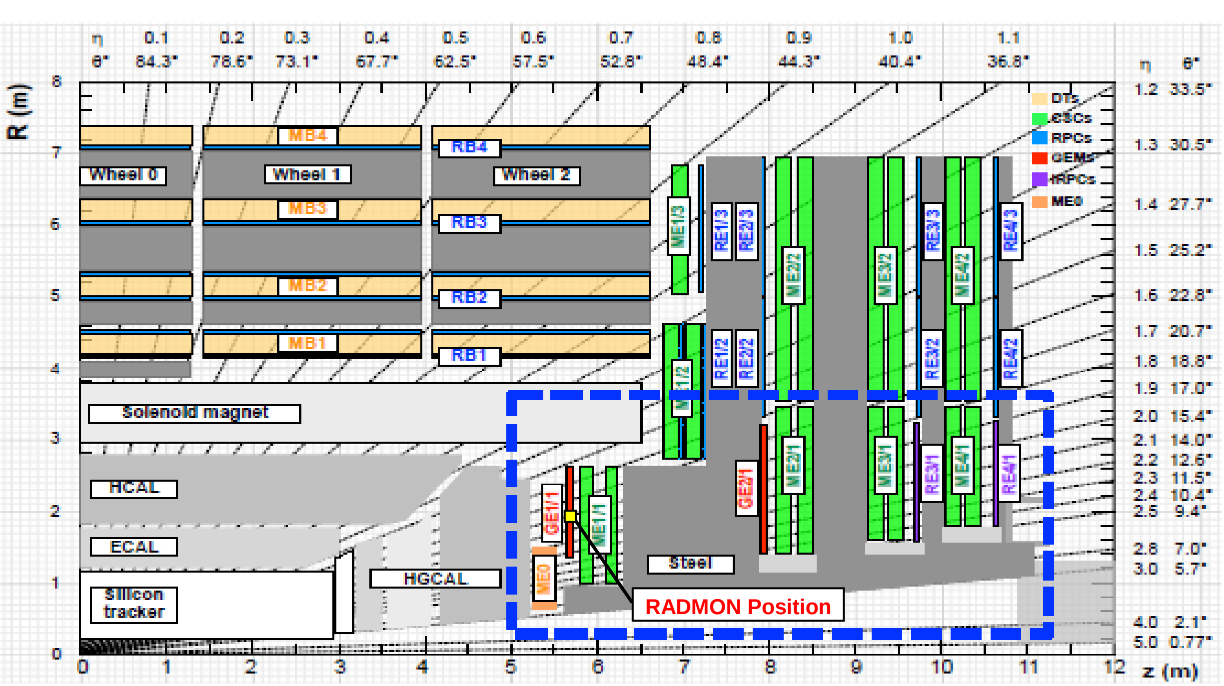

Figure 1. Transverse section of the CMS detector showing the present muon system. The RADMON was installed with a test GEM chamber in the free inner endcap station GE1/1

For a slice test, several GEM chamber prototypes were produced and installed in two GE1/1 slots during March 2017 [4]. In such a manner, they were tested under an integrated luminosity of about 118 inverse femtobarns (fm^{-1}), delivered to CMS and ATLAS experiments during the 2017 and 2018 LHC run.

During this time, the radiation background at Slot 1 of GE1/1 is measured by one radiation monitor (RADMON) of the system, which was installed at the center of the GEM chamber (see fig. 1).

RADMONs and Readout system.

The schematics of the RADMON is shown in fig. 2a and its photo – in fig. 2b. It contains four radiation sensors: two RadFETs – REM 250 and REM 130, measuring the total radiation dose and two

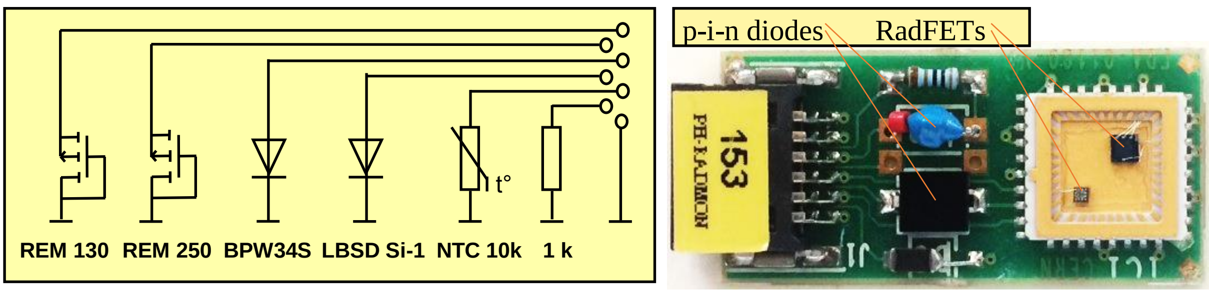

Figure 2. RADMON PCB: Schematics (left) and Photo (right)

p-i-n diodes – to measure the 1 MeV neutron equivalent (n. eq.) fluence [5]. In addition, a 10 kΩ thermistor is installed to control the sensors temperature as well as an 1 kΩ resistor to check the connection quality.

Table 1. RADMON sensor parameters

Function	Type	Device	Operating range	Sensitivity / Resolution
Total Dose Sensor (high doses)	RadFET	REM 250	A few 10^{-1} Gy to > $2x10^4$ Gy	~ 20 mV/Gy (initial)
Total Dose Sensor (very high doses)	RadFET	REM 130	A few Gy to > $2x10^5$ Gy	~ 3 mV/Gy (initial)
1 MeV n. eq. Fluence Sensor (high sensitivity)	p-i-n diode	LBSD Si-1	10^{10} cm^{-2} to $2x10^{12}$ cm^{-2} (almost linear)	~ $2.1x10^8$ cm^{-2}/mV
1 MeV n. eq. Fluence Sensor (low sensitivity)	p-i-n diode	BPW34S	2.10^{12} cm^{-2} to $4x10^{14}$ cm^{-2} (linear)	~ $1x10^{10}$ cm^{-2}/mV
Temperature sensor	Thermistor	NTC 10 k	-55 ^{0}C to 125 ^{0}C	0.1 ^{0}C
Line checking	Resistor	1 k		1%

The basic parameters of all components are shown in Table 1 [6]. As can be seen, both sensors of each type are of different sensitivity to cover a wider range of the measured values.

The voltage drop across all radiation sensors is proportional to the measured radiation magnitude. In RadFETs the relation between the gate threshold voltage shift ΔV_{th} and the radiation dose D is nonlinear and can be best approximated by $\Delta V_{th} = a \times D^b$, (resp. $D = (\Delta V_{th}/a)^{1/b}$) [6]. The coefficients a and b depend on the RadFET type as well as on the measured dose range. Therefore, for each RadFET the entire operating dose range is divided into zones, for each of which a and b have different values.

The shift of the p-i-n diodes forward voltage ΔV_F is proportional to the 1 MeV neutron equivalent fluence Φ [cm^{-2}]. The relation is generally linear – $\Phi = c\Delta V_F$, where c depend of the diode type.

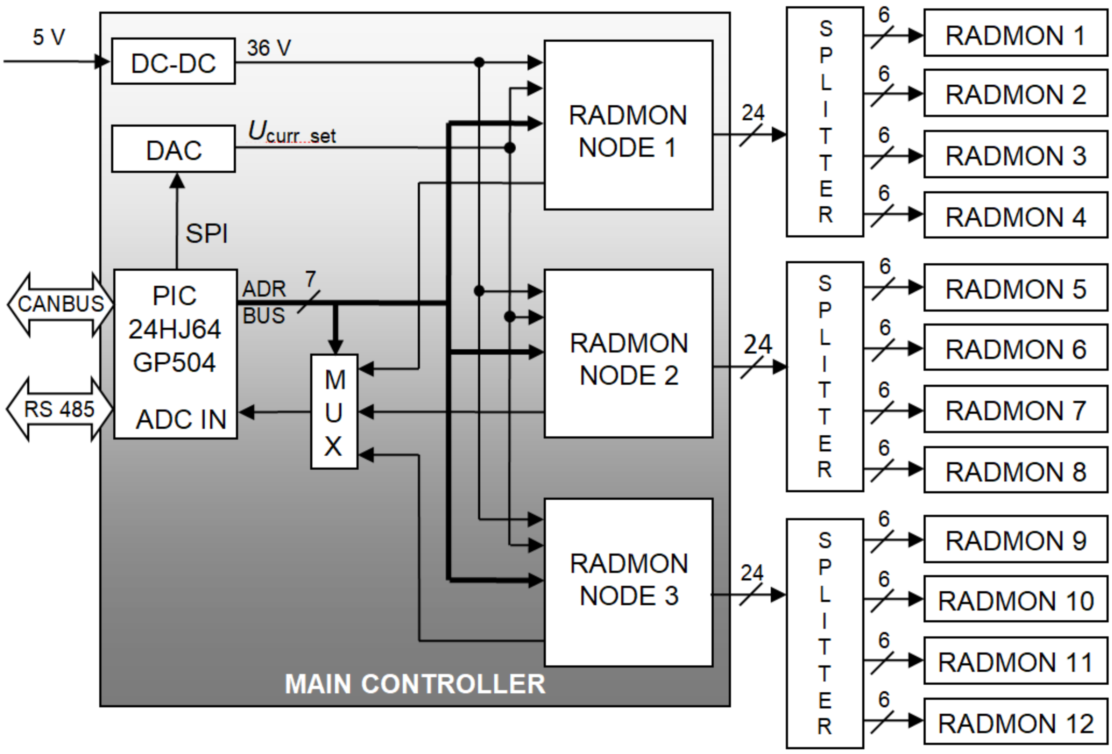

Figure 3. Block diagram of the RADMON Control and Read-out System

The radiation control and readout system [3] has a modular structure. Each module (fig. 3) is designed to operate with up to 12 RADMONs. For the next LHC run, they will be installed in the GEM chambers at every 30^0 of the endcap GE1-1 station.

The main controller reads consistently the voltages across all sensors in each RADMON. For the purpose, current pulses with fixed amplitude and duration are passed through every censors and the corresponding voltage is measured (by a common 12-bit ADC) and memorized. The current pulse parameters are specific for each censor and are prescribed by the producer. Periodically the accumulated data are transferred to the GEM Detector Control System (DCS) system, using the suitable standard interface: CANBUS or RS-485.

The final processing of the data takes place in DCS and the real values of the measured quantities are obtained and memorized there.

4. Experimental results

A preliminary analysis of the first data received in 2017 was done in [7]. Now we analyze here all results, received during the 2017 and 2018 LHC run.

The annual integrated luminosity delivered to CMS is shown in fig. 4 [8]. The total cumulated luminosity for 2017 and 2018 is 117,7 fm^{-1}.

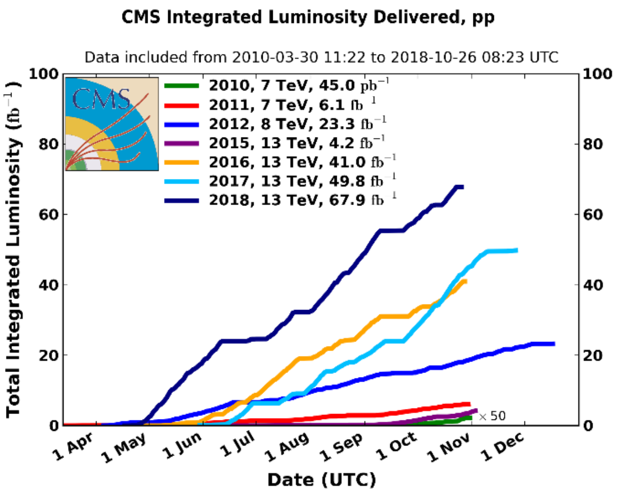

Figure 4. Annual integrated luminosities delivered to CMS

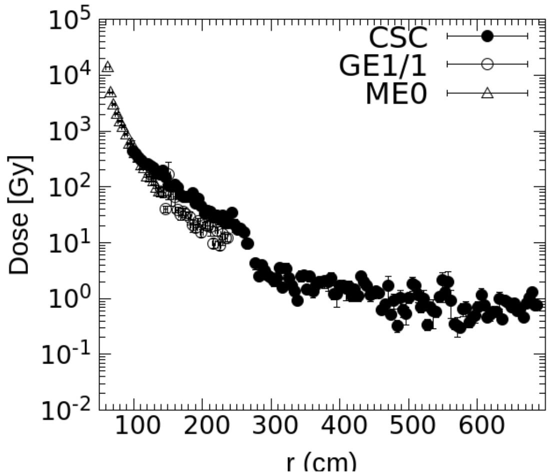

Figure 5. CMS Phase 2 simulation – combined dose at 3000 fb^{-1}

We have not received data from the GEM DCS and DAQ systems for the whole 2018. Nevertheless, we were able to measure all the sensors in 2019, after the completion of LHC operation. The new results had to show the radiation dose and 1 MeV neq fluence accumulated during the complete testing period of 2017 and 2018.

First of all, these results confirms that both sensors REM 130 and BPW34S cannot give useful data, due to their lower sensitivity in comparison with the other two sensors REM 250 and LBSD Si-1. Considering that, according to the FLUKA simulation v. 3.7.7.0 [9], the expected combined dose in the GE1-1 zone during CMS phase 2 will average 20 Gy (at a delivered integrated luminosity of 3000 fm^{-1} – fig. 5) probably the replacement of REM 130 by a more sensitive sensor will be actual.

The results of the two more sensitive sensors – REM 250 and LBSD Si-1 – received during the test period are shown in Table 2. They are compared with the results of the BRILL simulation of the dose and fluence distribution in CMS and cavern received by FLUKA v. 3.0.0.0, which is actual for the Run 2 of LHC.

Table 2. Experimental and simulated radiation data

Date of measurement	Integrated luminosity	Dose		Fluence	
		REM 250	FLUKA v.3.0.0.0	LBSD Si-1	FLUKA v.3.0.0.0
	fb^{-1}	Gy	Gy	cm^{-2}	cm^{-2}
07.08.2017 г.	14,5	0,132	0,15	4,42E+09	3,10E+09
15.08.2017 г.	17,3	0,134	0,15	4,63E+09	4,00E+09
05.09.2017 г.	21,7	0,218	0,20	6,50E+09	5,00E+09
18.10.2017 г.	39,3	0,361	0,35	1,13E+10	1,00E+10
01.11.2017 г.	46,0	0,448	0,45	1,43E+10	1,20E+10
31.10.2018 г.	117,6	1,073	1,1	3,52E+10	3,40E+10

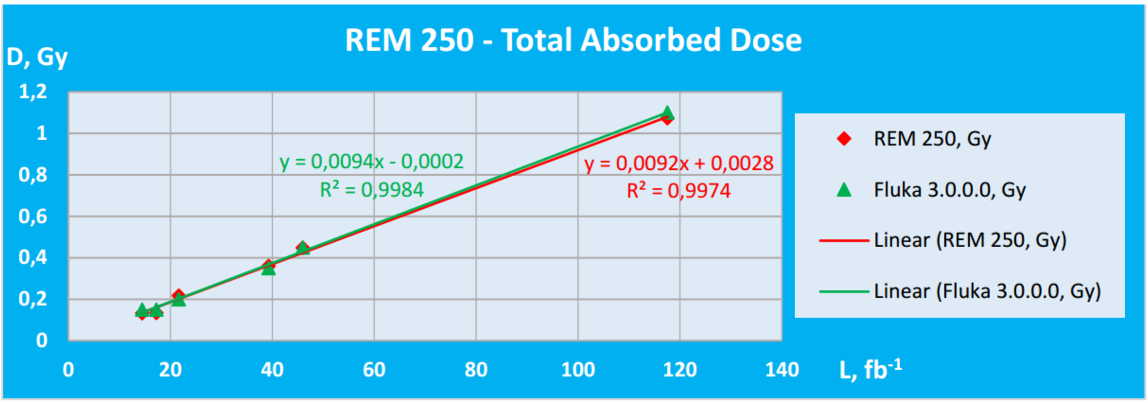

Figure 6. Experimental and simulated data for the total absorbed dose around Slot 1 of GE 1/1

The analysis of the combined absorbed dose, measured by REM 250, can be done from the graphics in fig. 6. They show that the new measured value, corresponding to the full delivered integrated luminosity of 117,7 fm-1, aligns very well with the 2017 data [7] – R2 = 0,9974. The experimental data are also practically identical with these, simulated by FLUKA v.3.0.0.0.

Similar results are received for the 1 MeV neutron equivalent fluence (fig. 7). But in this case, the simulated data are a little lower (by about 1.5x108 cm-2) than those from the RADMON measurements.

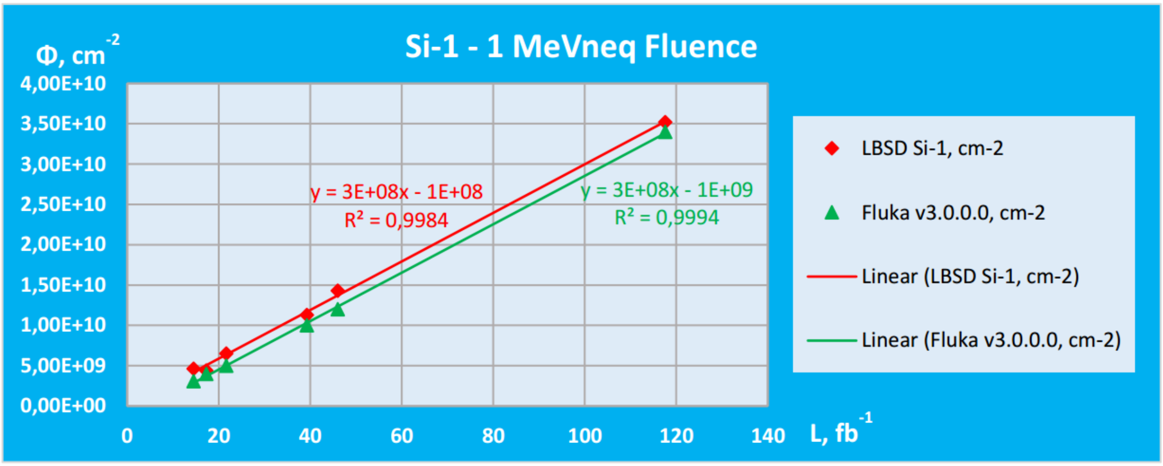

Figure 7. Experimental and simulated data for the total absorbed dose around Slot 1 of GE 1/1

All results confirms the linear relation between the integrated luminosity delivered by LHC and the radiation dose (resp. the fluence).

5. Conclusions

- The experimental results obtained confirm the good qualities of the selected radiation sensors for the control of the combined absorbed dose and the 1 MeV neutron equivalent fluence. However, a more accurate estimation of the expected dose and fluence during the Run 3 of LHC will be useful to select the sensors with most appropriate sensitivity.
- Our results show also that for this region of CMS (around the slot GE1/1) the BRILL simulations by FLUKA v. 3.0.0.0 estimates well the dose and fluence distribution.
- We rely on the GEM DAQ and DCS for all data in Run3.

6. Acknowledgements

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