FIRST RESULTS OF THE RADIATION MONITORING OF THE GEM MUON DETECTORS AT CMS

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The higher energy and luminosity of 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 absorbed by the GEM detectors has been produced and installed at the CMS detector of LHC. It consists of a readout-control module, to which there can be connected up to 12 radiation monitors (RADMON). There are in each unit two types of sensors: RadFETs, measuring the total radiations dose and p-i-n diodes – for particle fluence.

For the first test, a group of 6 GEM chambers was placed at the inner CMS endcap in March this year with one RADMON controlling the dose. After about 4 months of operation, the first results are analyzed. They show that for the integral luminosity 46 fm^{-1} the dose and the particle fluence are low (about 0,5 Gy and 3.10^{10} cm^{-2} 1 MeVneq fluence) and only two more sensitive sensors are giving measurements and providing data that can be analyzed. Nevertheless, the experimental results confirm the dose and fluence values simulated by FLUKA. This is an important result for the radiation hardness test plans of the GEM part of the CMS muon detector.

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

1. Introduction

The increase of the energy and luminosity during the coming upgrades of the CERN LHC creates a more hostile environment for the detector used. In the muon system of the CMS the heaviest conditions will be created in the region with pseudorapidity 1,6 < η < 2,2, (fig. 1), where for the high- luminosity phase of the LHC, Monte Carlo simulation gives particle rates of several kHz/cm^2. This imposes severe restriction on the technology that can be used.

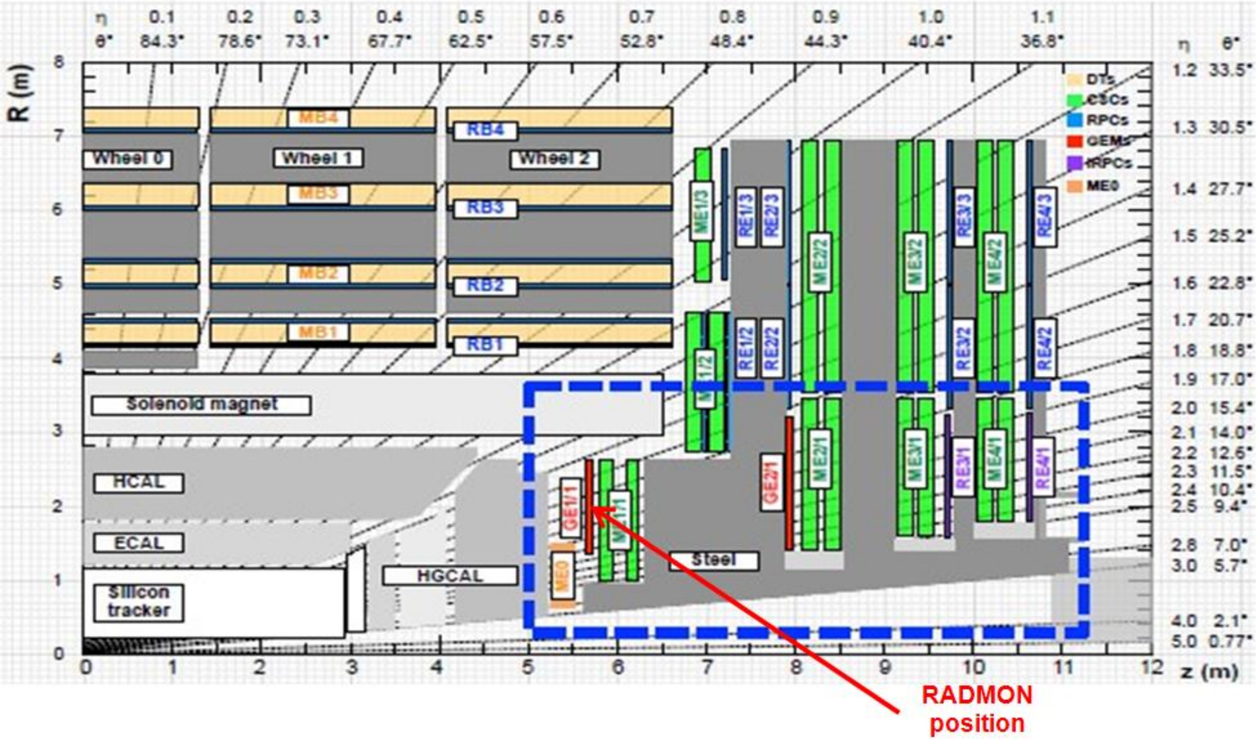

Figure 1. Transverse section of the CMS detector showing the present muon system including RPCs, DTs and CSCs. The test GEM chambers are installed at the free place in inner endcap marked as GE 1/1

To solve the problem it was decided [1] to investigate the possibilities of the so-called GEM detectors. They are [2] Micro-Pattern Gaseous Detectors that feature 50-100 microns spatial resolution, 4-5 ns time resolution, high detection efficiency, as well as proven high-rate capability and resilience against aging effects. The very high time and spatial resolution enables their simultaneously application for triggering and tracking information.

After numerous tests [3,4] three GEM detector prototypes were produced and tested at the end of 2016. Each prototype is composed by two chambers, which are mounted face-to-face and called GEM super-chamber. In correspondence with the CMS plans [5], in December 2016 they were installed in the first vacant insertion slots at inner endcap stations (labeled GE1/1, fig. 1). For the first test, only one radiation monitor (RADMON) of the created GEM dosimetric system [6] was installed at the center of one of the GEMs super-chambers.

2. Sensors and Readout system.

The installed RADMON (fig. 2) is a little different from the described in [6]. The RadFET LAAS 16, which has a relatively small working dose range ($10^{-3} \div 10$ Gy [7]), was replaced by another type – REM 130, with a dose range up to 200 kGy. The reason is that the same RADMON will be used at the GEM chambers, which will be installed nearer to the beam – in the insertion slot ME0 (2,1 < η < 2,5, see fig. 1). There a much higher dose value is expected.

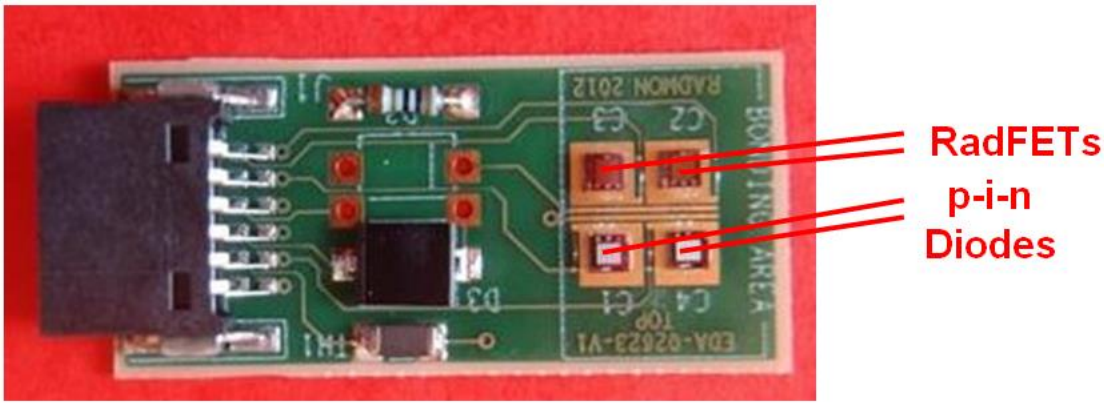

Figure 2. RADMON PCB. The four radiation sensors are installed at its right side

Table 1. Information of the used radiation sensors

Function	Type	Device	Operating Range	Sensitivity / Resolution
Total Dose sensor (high-dose)	RadFET	REM 250nm	a few 10^{-1} Gy to > than 2×10^4 Gy	~20 mV/Gy (initial)
Total Dose sensor (ultra-high dose)	RadFET	REM 130nm	a few Gy to > than 2×10^5 Gy	~3 mV/Gy (initial)
1MeV n eq. Fluence sensor (broad dynamic range)	p-i-n diode	BPW34S	~2×10^{12}cm^{-2} to ~4×10^{14} cm^{-2} (linear)	~1×10^{10} cm^{-2}/mV
1MeV n eq. Fluence sensor (high-sensitivity)	p-i-n diode	LBSD Si-1	10^{10}cm^{-2} to ~2×10^{12} cm^{-2} (non-linear)	~2×10^{8} cm^{-2}/mV
Temperature sensor	Thermistor	NTC 10kW	-55 ºC to 125 ºC	0.1 ºC
Line check	Resistor	1kW resistor	---	---

The basic data of the radiation sensors used are shown in Table 1. The relation between the RadFET's gate threshold voltage shift ΔV_{th} and the radiation dose D is strongly dependent on the electric field in the oxide during irradiation and on the process parameters, especially the thickness of the gate oxide. It is nonlinear and best approximated by $\Delta V_{th} = a\times D^b$, (resp. $D = (\Delta V_{th})^{1/b}/a$), where the coefficients a and b depend on the RadFET type as well as on the measured dose range. For this purpose, the entire operating dose range is divided into zones for each of which a and b have different values [8,9]. As can be seen from the table 1 the new RadFET REM 130 has about six times lower sensitivity than the REM 250 for the initial dose range.

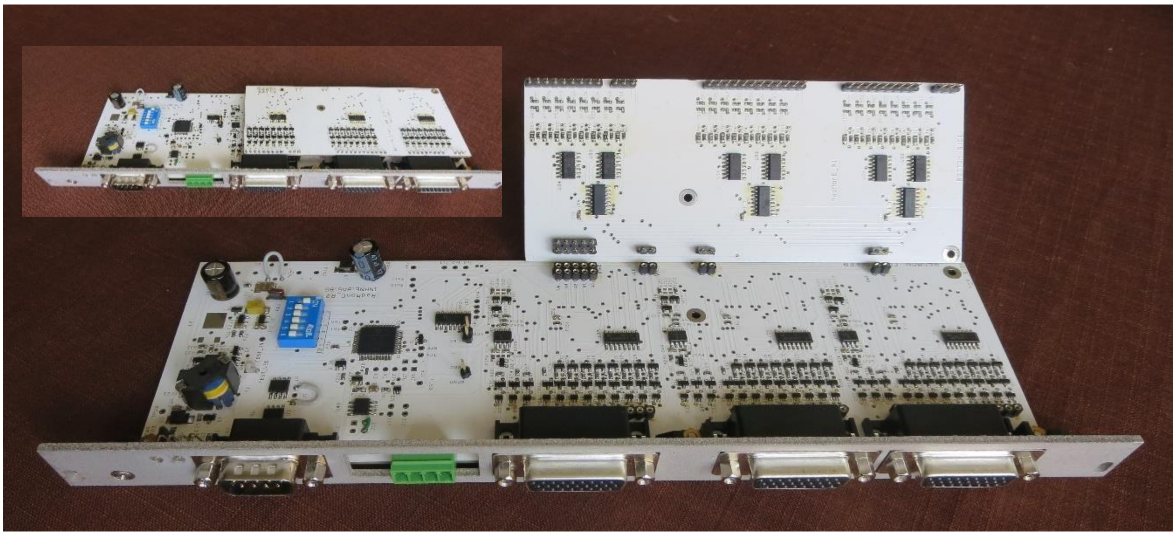

Figure 3. RADMON control and read-out

The shift of the p-i-n diodes forward voltage ΔV_F is proportional to the 1-MeV neutron equivalent particle fluence Φ [cm^{-2}]. The relation is generally linear – $\Phi = c\Delta V_F$, where c depend of the diode type. Table 1 shows that LBSD Si-1 is about 50 times more sensitive than BPW34S.

The readout system measures the voltages on the sensors using current pulses of different amplitudes and durations prescribed by the producer [6]. Each read analog voltage is fed to a common 12-bit ADC whose least output voltage step is 8 mV and defines the resolution of the dose/fluence measurements. The system has a modular structure and one module (fig. 3) can read and control up to 12 RADMONS.

4. Experimental results

Here we shall try to analyze the first data, read during the period of 15.05 to 1.11.2017 (the last data are received after the NEC-2017 symposium, during the preparation of this talk for publication and were very important to precise the analyses). First of all it has to be mentioned, that the CMS integrated luminosity delivered by LHC during this period (about 46 fb^{-1}, fig. 4 [10]) is relatively low,

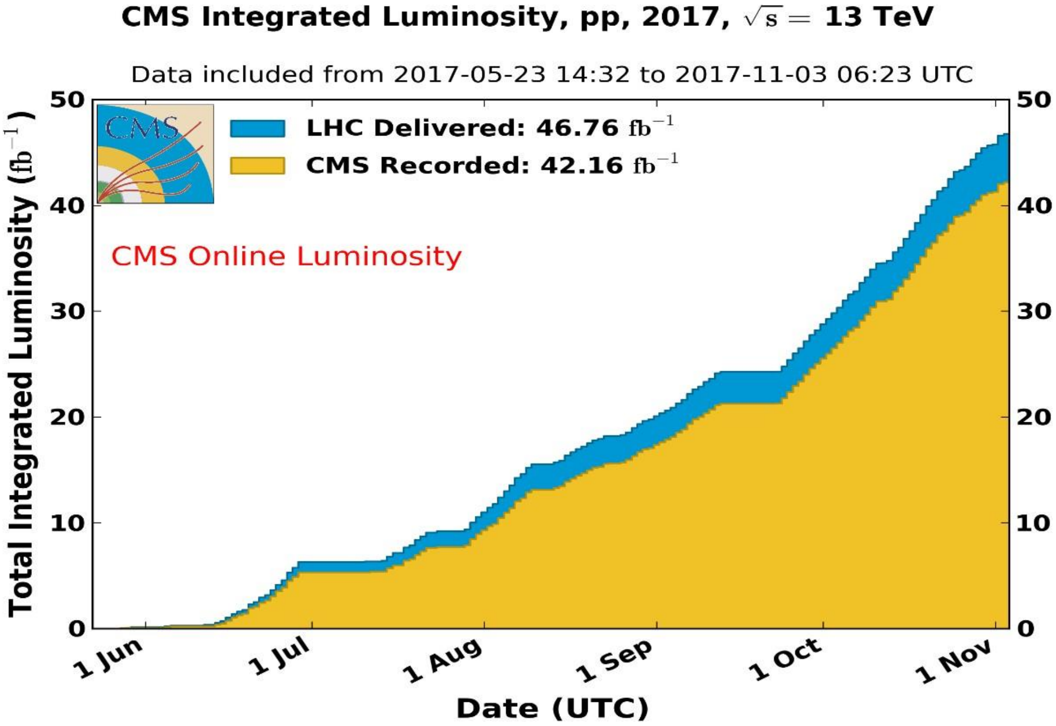

Figure 4. CMS integrated luminosity 2017

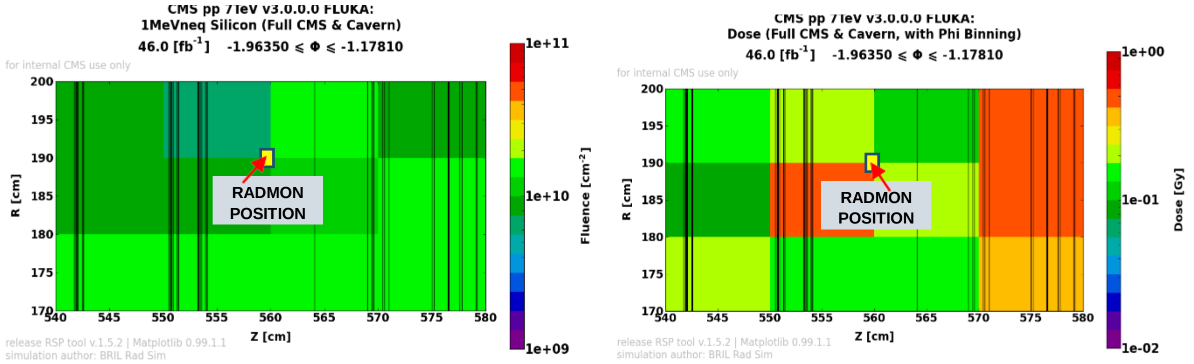

Figure 5. FLUKA simulation of the dose and 1-MeVneq fluence around the RADMON position in CMS

for the operating ranges of the sensor used. This can be seen from the FLUKA simulations of the dose and fluence distribution in CMS and cavern (fig. 5, [11]): around the RADMON position a dose of about 0,5 Gy and a 1MeVneq fluence of about 10^{10} cm^{-2} can be estimated.

These results immediately show that there will be no useful data from the sensors REM 130 and BPW34S, whose operating ranges begin from a few Gy and 2.10^{12} cm^{-2} respectively. Nevertheless, we found, that the voltage values received from them are not zero, which means that these sensors are operating and the control system read their data normally.

For our investigation, we took the experimental data from 5 different days during the period of LHC operation. In Table 2 for each of these days there are shown: the LHC integral luminosity until this moment; the total radiation dose – simulated by FLUKA and measured by the RadFET REM250; the 1MeVneq-fluence – simulated and measured by the p-i-n diode LBSD Si-1. These results are illustrated and linearly approximated in fig. 6. The errors are relatively high because of the low values of the dose and fluence – the maximal measured voltage shifts are only about several tens of millivolts.

Table 2. Dose and fluence results

Date of measurements	Integral luminosity	DOSE		FLUENCE	
		FLUKA	REM250	FLUKA	LBSD Si-1
	fb^{-1}	Gy	Gy	cm^{-2}	cm^{-2}
7.8.2017	15	0,15	0,13	4,50E+09	4,63E+09
15.8.2017	17	0,15	0,13	4,50E+09	4,42E+09
5.9.2017	22	0,20	0,22	6,50E+09	6,95E+09
18.10.2017	38	0,35	0,36	1,05E+10	1,13E+10
1.11.2017	46	0,5	0,45	1,35E+10	1,43E+10

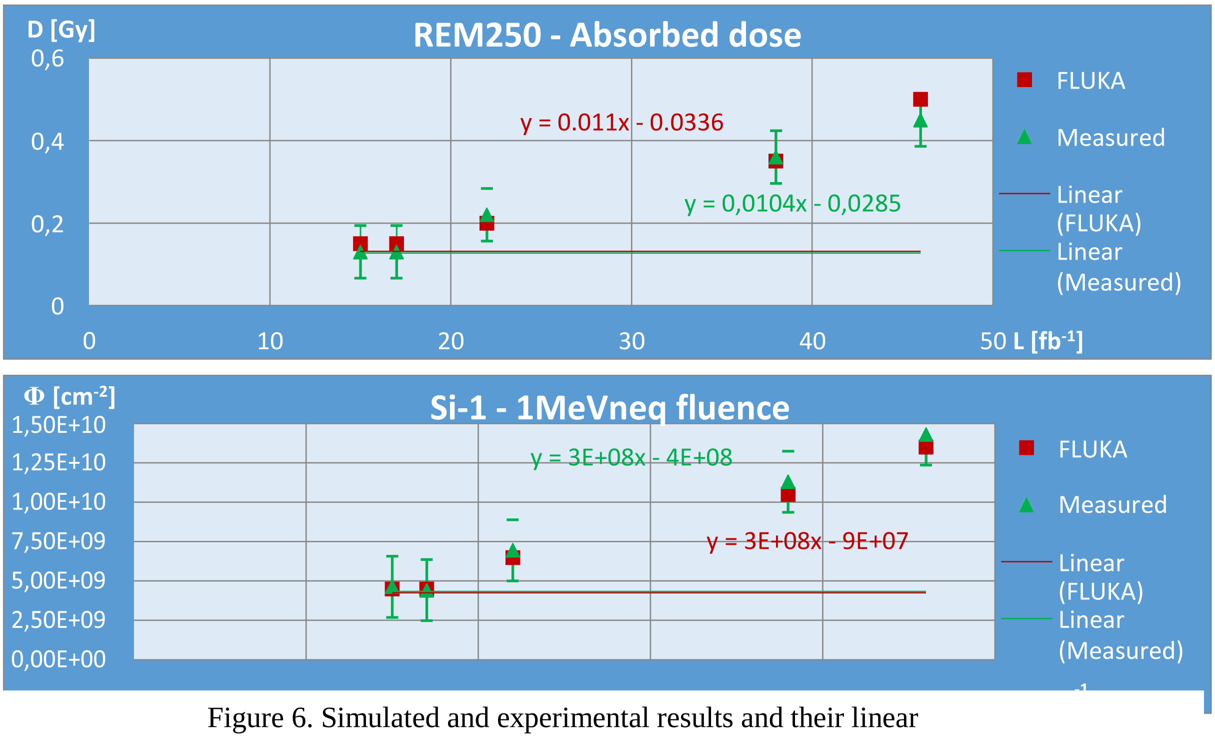

Figure 6. Simulated and experimental results and their linear

The results show a very small difference between the simulated and measured value especially taking into account the lower precision of the sensors in their initial operating range. They indicates also, that the relation between the integrated luminosity delivered by LHC and the absorbed dose (resp. the fluence) can be consider linear.

5. Conclusions

- Due to the relatively low integral luminosity delivered by LHC until now, the measured dose and fluence values are in the initial operating range of the sensors. For this reason, only the more sensitive sensors give useful data until now though with lower accuracy.
- There is good agreement between the data from FLUKA and the experiment, which is a confirmation of the reliability of the CMS BRILL dose simulation at the position of the GE1/1.
- All radiation sensors are active and with the increasing of the LHC integral luminosity the data from all the RADMON sensors can be analyzed and compared with the FLUKA.

6. Acknowledgements

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