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The Compact Muon Solenoid Experiment

Conference Report

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04 December 2017 (v2, 22 January 2018)

Upgrades of the CMS muon system in preparation of HL-LHC

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Abstract

The present CMS muon system operates three different detector types in the barrel drift tubes (DT) and resistive plate chambers (RPC), along with cathode strip chambers (CSC) and another set of RPCs in the forward regions. In order to cope with increasingly challenging conditions various upgrades are planned to the trigger and muon systems. New detectors will be added to improve the performance in the critical forward region large-area triple-foil gas electron multiplier (GEM) detectors will already be installed in LS2 in the pseudo-rapidity region $1.6 < \eta < 2.4$, aiming at suppressing the rate of background triggers while maintaining high trigger efficiency for low transverse momentum muons. For the High Luminosity (HL)-LHC operations, the muon forward region should be enhanced with another large area GEM based station, called GE2/1, and with two new generation RPC stations, called RE3/1 and RE4/1, having low resistivity electrodes. These detectors will combine tracking and triggering capabilities and can stand particle rates up to few kHz/cm^2. In addition to take advantage of the pixel tracking coverage extension, a new detector, ME0 station, will be installed behind the new forward calorimeter, covering up to η = 2.8.

Presented at *IEEE-NSS-MIC-2017 2017 IEEE Nuclear Science Symposium and Medical Imaging Conference*

1 Introduction

The CMS detector [1] has a large coverage for muon detection, using three different technologies, combining both barrel muon chambers and endcap muon chambers. The goal of the muon system is to trigger, identify muons and measure the muon momentum. The High Luminosity (HL)-LHC program conditions will compel an upgrade of all systems, as well as an extension in the forward region. The physics potential will be improved with respect to the current muon system.

2 CMS muon chambers

The barrel muon Drift Tubes (DT) system [2] consists of 250 DT chambers, located in five wheels. A total of 172000 channels allows a coverage up to η = 1.2 with an overlap with the endcap chambers starting η = 0.9. The typical hit resolution in the phi coordinate is in the range 200 to 250 μm. The muon track spatial resolution is about 100 μm while the time resolution reaches 2 ns. Figure 1 shows an example of an individual DT cell.

The Cathode Strip Chambers (CSC) system [2] covers the following η range : $0.9 < \eta < 2.4$. There are 540 chambers for a total of 477000 channels, including strips and wires, as shown in Fig.1. The spatial resolution is between 50 to 140 μm, depending on the location, and the time resolution is about 3 ns.

The Resistive Plate Chambers (RPC) equip both the barrel (480 chambers) and the endcaps (576 chambers). The coverage is currently limited up to $\eta < 1.9$. The total number of channels is 123000, reaching a spatial resolution between 0.8 to 1.3 cm and a time resolution of 1.5 ns. An RPC cell is shown in Fig.1.

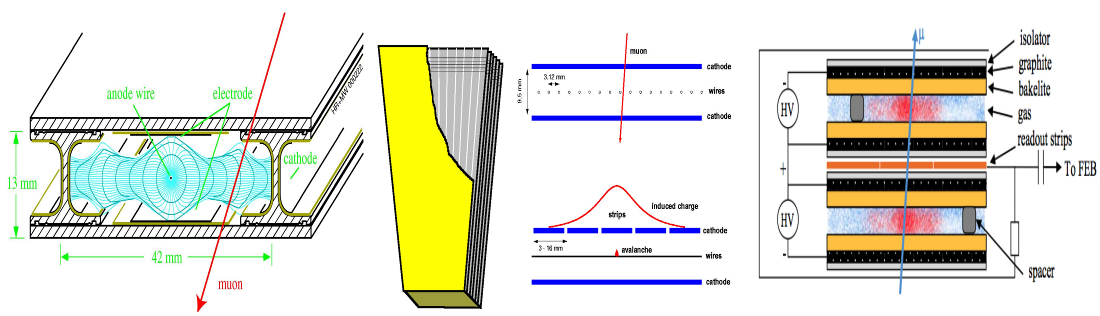

Figure 1: From left to right : the DT cell, the CSC cell and the RPC cell.

3 Detector upgrades for HL-LHC

Table 1 summarizes the HL-LHC conditions, as the peak luminosity and the average number of pileup events. Those conditions imply some requirements for the muon system, in particular about the trigger acceptance rates, the trigger latency and the data transfer rate, as shown in Tab.2.

	LHC design	HL-LHC design	HL-LHC ultimate
peak luminosity (10^{34} cm^{-2}s^{-1})	1.0	5.0	7.5
integrated luminosity (fb^{-1})	300	3000	4000
number of pileup events	30	140	200

Table 1: HL-LHC conditions parameters.

	HL-LHC needs	CMS 2017	CMS upgraded
Level-1 trigger accept rate (kHz)	750	DT: $<$ 300 CSC: $<$ 250	DT: $>$ 750 CSC: 4000
Level-1 latency (μs)	12.5	DT: 20 CSC: 3.6	DT: $>$ 12.5 CSC: 28.8
Total DAQ data transfer rate (Gbit/s)	DT: 1082 CSC: 1026	DT: 42 CSC: 230	DT: 3600 CSC: 2764

Table 2: HL-LHC requirements for muon system.

The electronics of the different muon systems will compel an upgrade to the latest technology with high bandwidth of data transfer. The trigger latency will be enlarged and some faster processing units used. In addition, the electronic high-tech components will need to be replaced because of the aging. The radiation damages were evaluated using a gamma irradiation facility. Finally, the background coming from neutrons and low energy gammas demands a better redundancy in the forward region. For all these reasons the electronics of the several muon systems needs an upgrade to maintain the performance of the muon system in phase 2. Furthermore an extension from $|\eta|$ = 2.4 up to $|\eta|$ = 2.8 increases the acceptance for muons, which is important for example for the golden Higgs decay channel into 4 muons.

Figure 2 shows the projection of the fraction of living channels for the DT system in absence of any upgrade, following different hypotheses. The total loss of channels could be in the range 19 to 46%. In addition the current level-1 trigger acceptance is limited at 300 kHz. To avoid this limitation a new on-board electronics has been developed, with the aim to be more robust and allow a higher living channels fraction at the end of HL-LHC program.

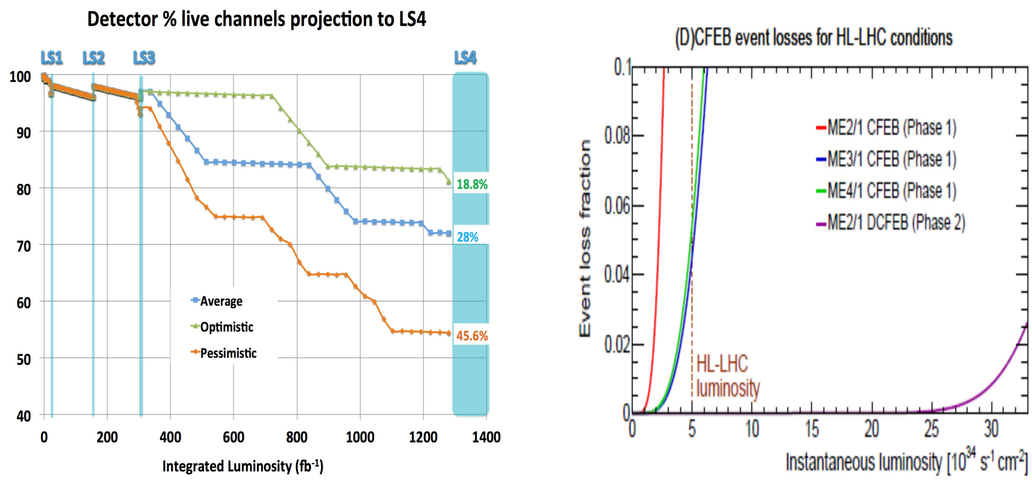

Figure 2: Left: Detector percentage of living channels for DT in absence of any upgrade. Right: Expected event loss fraction for CSC system.

The expected level-1 trigger rate at HL-LHC is actually too high for the current CSC system, as shown in Fig.2. The increase of trigger latency would also overflow the front-end pipelines, so that it requires a new electronics for CSC. Some new 3.2 Gb/s optical links will be installed and the pipelines will be improved with a negligible dead time.

The RPC electronics needs also an upgrade, as the link system, used to send data, is not certified for HL-LHC conditions. The 1376 link boards will be replaced by some faster FPGA units. The upgraded system will exploit the best possible intrinsic time resolution of about 1.5 ns. It will allow the removal of out of time background hits and a better synchronization.

4 Muon system extension in forward region

The main issues in the forward region are the weaker B-field and the higher background at HL-LHC. To compensate for these difficulties, several new muon chambers will be installed before phase 2. Some Gas Electron Multiplier (GEM) detectors will reinforce the forward region for $1.6 < \eta < 2.4$. A demonstrator was already installed during last winter shutdown in CMS. Figure 3 shows the locations where those new chambers, labelled GE1/1 and GE2/1, will be installed. Another type of six layers GEM detector will be placed for triggering in the very forward region to cover up to $|\eta|$ = 2.8. It's labelled ME0 in Fig.3. Those ME0 chambers will be installed up to the maximum possible coverage due to mechanical constraints. Finally some new RPC chambers using an improved technology will complete the coverage of the existing RPC chambers in the endcaps, covering the region $1.8 < |\eta| < 2.4$, as described in Fig.3 as RE3/1 and RE4/1.

The GE1/1 and GE2/1 chambers are two layers triple-GEM detectors and will provide up to two additional hits, improving the overall redundancy of the muon system. In addition, the space between these GEM detectors and the CSC chambers will improve the local lever arm, improving the CSC endcaps level-1 trigger efficiency. Finally, the GEM detectors can handle rates up to few MHz/cm^2, which is even higher than the required value in this region.

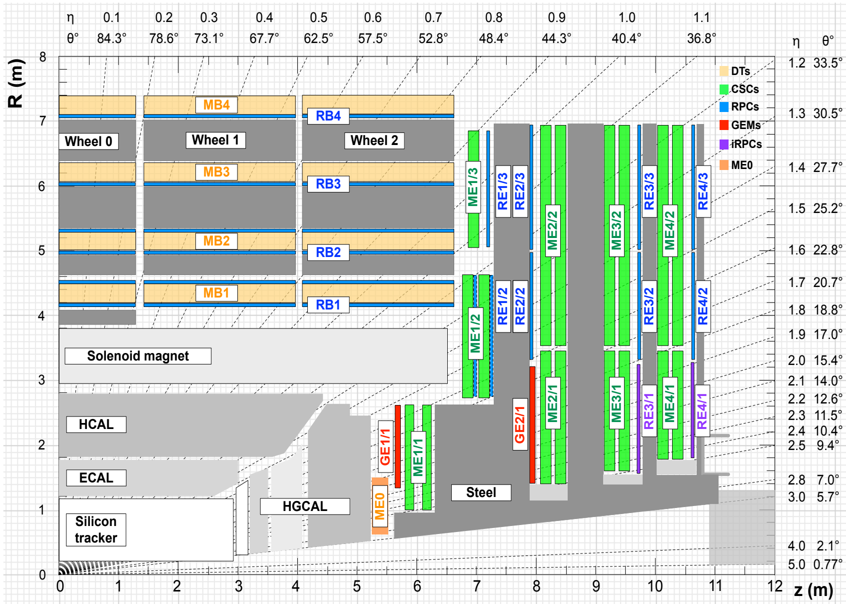

Figure 3: Extension of the muon system in the forward region, using new GE1/1, GE2/1, ME0 GEM detectors, and improved RPC RE3/1 and RE4/1.

The new RE3/1 and RE4/1 stations are called improved RPC as they are using a higher signal amplification, as well as better front-end electronics. They can handle rates up to 2 KHz/cm^2, while reaching a hit efficiency above 95%. The spatial resolution will be better than 5 mm and the time resolution 1.5 ns.

5 Performance of the upgraded system

The additional detectors are expected to improve both the single muon trigger efficiency and reduce the trigger rates. Figure 4 (left) shows the capacity to improve the level-1 trigger [4] efficiency using new detectors in forward region. The muon identification will benefit from all these improvements, as shown in Fig.4 (right). Combining all GEM and RPC detectors will allow a muon efficiency close to 1 for tight muon selection criteria in the forward and very forward region.

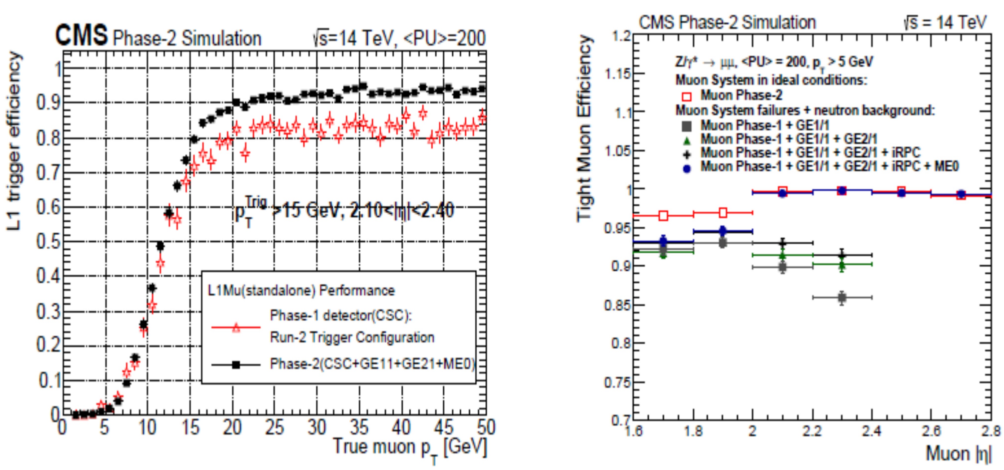

Figure 4: Performance of the upgrade of the muon system in the forward region.

All the combined ingredients (better acceptance, improved trigger efficiency and better muon reconstruction efficiency) will lead to some improvements for the physics potential of the phase 2 at HL-LHC. Figure 5 (left) presents the potential of analyses looking at the Higgs boson signature in the $H \rightarrow ZZ \rightarrow 4$ muons channel. The Higgs boson signal efficiency will increase by 17% due to the upgraded muon system. Figure 5 (right) shows another example with the beyond Standard Model analysis searching for displaced muons in supersymmetric scenarios. In this case the signal cross-section production could be improved by a factor three.

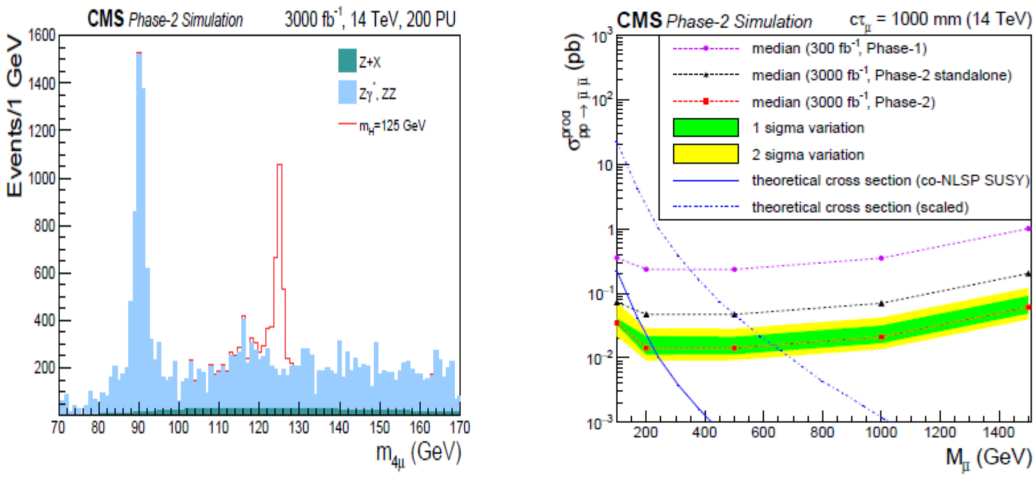

Figure 5: Improvements for Higgs decaying to four muons analysis (left) and BSM displaced muons searches (right).

6 Conclusion

The muon system should perform up to the end of the HL-HLC program, with the same level of performance, or even better, than during phase 1. Several muon systems will have an upgrade of their electronics. Indeed the redundancy and the extension of the muon system is required to cope with higher background conditions. The expected improvements include a better level-1 trigger efficiency and a higher muon identification, that will benefit to the physics potential for all analyses.

Acknowledgments

This work was supported by the BMBF (Bundesministerium für Bildung und Forschung).

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