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Status of the commissioning of the CMS GE1/1 station

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Summary. — This article describes the results obtained from a test on GE1/1 GEM detectors in magnetic field. The motivation of the test was driven by the need of defining a safe operation procedure for GE1/1 detectors installed in CMS, after many instabilities were observed on the High Voltage (HV) system during the first ramp of the CMS magnet in October 2021.

1. – Introduction

After the end of the second data taking phase, Run-2, of the experiments installed on the Large Hadron Collider (LHC) ring, the Compact Muon Solenoid (CMS) collaboration started an upgrade campaign of the detector, to cope with the future High Luminosity LHC working conditions.

In particular, the upgrade activities involve the CMS muon system. In this context, the installation of a new technology of muon detectors in the CMS endcaps has been programmed. These new detector stations are based on the Gas Electron Multiplier technology (GEM) [1, 2]. The first of these stations, GE1/1, has been installed in CMS during the Long Shutdown 2 (LS2) period of the LHC and covers the pseudorapidity range $1.55 < \eta < 2.18$.

The main purpose of the installation of the GE1/1 station is to increase the redundancy of the muon system in the η region covered by the station, to improve the L1 muon trigger rate.

2. – The test of GE1/1 detectors in the Goliath magnet

During the final commissioning phases at the end of 2021, the GE1/1 detectors were operated for the first time in the presence of the magnetic field generated by the CMS magnet. During the first magnet ramp, many protection turn-offs (also called *trip* events) of the High Voltage (HV) system powering the chambers were observed. This was due to the occurrence of discharges inside the detectors.

To investigate these phenomena, an R&D test was prepared in the CERN North Area. Here, 4 GE1/1 chambers were positioned inside of the Goliath Magnet, where they were operated in a maximum magnetic field $B = 1.48\,\mathrm{T}$ [3]. The HV was provided to the chambers with individual powering channels with 2 A1515 CAEN boards [4], using 4 independent cables. The advantage of powering each chamber with its own group of HV channels offers the possibility of studying the phenomena of each chamber in an independent way. This powering configuration is different from the one adopted for the chambers installed in CMS, powered in pairs by the same group of channels, were the data read by the power supply contain the superimposed effect of phenomena occurring in the pair of chambers.

The main purpose of the test was to define a safe procedure for the operation of the GE1/1 detectors installed in CMS, to adopt during the magnetic field ramps.

3. – HV power system data

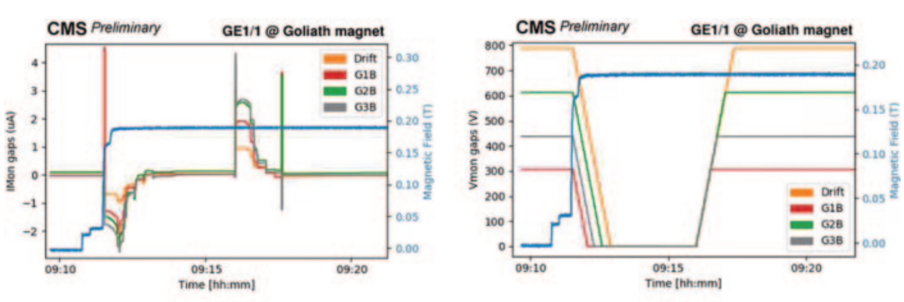
The test consisted in performing several magnetic field ramps, varying the operation parameters of the detectors, such as the HV working point and the gas flux. For each magnet ramp, the current and voltage data observed by the A1515 power supply channels were collected and analyzed. The powering scheme is illustrated in [5]. An example of the data observed on the 7 power supply channels needed to power the detector is illustrated in fig. 1.

The plot in fig. 1(a) illustrates the currents observed on the HV channels powering the detector gas gaps. The current spike in the left part of this plot identifies the occurrence of a discharge in the detector. In particular, this discharge triggered a HV trip, recovered after few minutes, as can be seen from the plot showing the voltages applied on the gaps (fig. 1(b)). The data concerning the electrodes powering the foils are illustrated in [5].

A complete statistics of the discharges observed during the test is illustrated in fig. 2(a), while fig. 2(b) shows the fraction of discharges where the maximum current, observed among the 7 electrodes during a discharge event, overcomes a given threshold. This distribution is indeed important to set the maximum current the power supply can drain during the detector operation. If this threshold value, called I_0, is overcome, a protection turn off of the HV of this channel is triggered (trip event). In the trip event illustrated in fig. 1, all the electrodes turn off, since the detector was operated in such a way that all the channels turned off, if the I_0 limit is overcome on at least one channel (GEM mode).

4. – Evolution of the discharge rate

Figure 3 shows the evolution in the number of discharges observed per magnet ramp. To have an easier understanding of the trend, a moving average over 5 consecutive magnet ramps was adopted. In the bottom part of the figure, the configuration of the detector in



(a) (b)

Fig. 1. – Current and voltage data read from A1515 board channels.

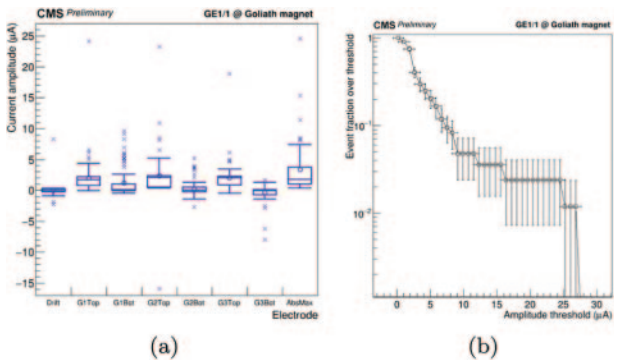


Fig. 2. – (a) Maximum current value observed per each discharge. The bins illustrate this value for each electrode and the maximum value observed among the 7 electrodes during each discharge event (AbsMax); (b) Fraction of discharges where the maximum current observed during the discharge event overcomes a given threshold value.

terms of HV working point and gas flux are illustrated. Vertical dashed red lines show the moments when a series of magnet ramps were performed keeping off the detectors' HV.

The orientation of the chambers during the first part of the test was with the chamber plane orthogonal to the magnetic field, the same configuration of the chambers installed in CMS. During the last magnet ramps, identified with the yellow box in the plot, the chambers' plane was parallel to the magnetic field orientation.

In addition, two vertical black lines show the moment when a mechanical stress was applied to the chambers, to simulate the CMS endcap disk movements. Finally, a solid red line shows when the magnetic field sign was changed for the first time.

Figure 3 shows how the discharge rate decreases in time, performing a series of consecutive magnet ramps. On the other hand, an increase can be observed in correspondence of the application of the mechanical stress and of the first inversion of the magnetic field. These phenomena are compatible with the hypothesis that some dust trapped inside of the detector moves during the magnet ramps, triggering a discharge when falls inside

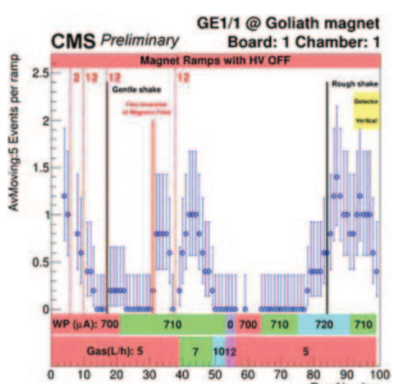


Fig. 3. – Evolution of the number discharges observed per magnet ramp. The discharge rate is computed using a moving average over 5 consecutive magnet ramps.

a GEM hole, where it gets burned. Furthermore, the plots does not show any evident variation of the discharge rate due to a change in the gas flux and HV working point parameters. Finally, one short circuit was created during a magnet ramp performed with the HV off. The occurrence of such an event allowed for the estimation of the probability of short circuit generation per magnet ramp: $p_{short} = 0.42^{+0.94}_{-0.35}\%$ ($CL = 68\%$). The probability was obtained with the Clopper-Pearson method, using the total number of ramps performed on the 4 detectors $n = 240$ as the number of trials. The short circuit was then burned applying 500 V to the two faces of the affected GEM foil for less than one second, using a Multi Mega-ohmmeter.

5. – Conclusions

The observed phenomena suggest that the HV should be maintained ON during the magnet ramps, allowing the burning of dust residuals to prevent the creation of short circuits. These have been indeed observed only when a magnet ramp was performed with the HV off, preventing the prompt burning of dust residuals. This is confirmed by what was observed in CMS, with the generation of 6 short circuits during the CMS magnet ramp down performed on 1st November 2021, with HV off on all the 144 GE1/1 detectors.

For this reason, the configuration adopted in CMS during the magnet ramp is:

- HV on the foils ON, while OFF on the gas gaps. This allows burning residuals inside the foils and reduces the effects of discharges which could propagate between the foils.

- I_0 set at 20 μA over the baseline current value, to prevent the turn off of the HV during the ramp, creating the conditions of absence of HV, where the detector is more prone to the generation of short circuits. To be even more conservative, also a parameter called *trip time* was raised to $t = 3$ s. This parameter is linked to the maximum time interval during which the current flowing in a channel of the power supply can overcome the I_0 threshold.

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