CMS

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1 Introduction

The Compact Muon Solenoid (CMS) [1) 2)] is one of the four experiments around the interactions points of Large Hadron Collider at CERN. The experimental program of CMS is wide and general purpose, namely it is build to study all possible phenomena that could happen at the huge Energy produced in LHC. CMS is composed by several layers of detectors surrounding the LHC collision point and that works as a big and complex 3-dimensional camera with 140 Millions channels and able to shot 40 Million "pictures" per second (as many as the protons collisions in LHC). The scientific program of the CMS experiment is vast and cover the study of the characteristics of the Higgs Boson [3)], the search for dark matter particles and any possible sign of anomalies with respect to the present theoretical picture, the Standard Model. To face up this ambitious research program, the experimental apparatus is composed by several devices around the interaction point and immersed in a magnetic field of about 4 Tesla.

At moment the LHC and the CMS experiment are facing an extensive upgrade in preparation of the High-Luminosity operations of the phase-2. The LHC will restart in May 2021 and the experiments are working on the consolidation of the present system and the installation of new devices that will improve the detector performances.

Many activities that are going on during this shutdown period concern the upgrade of the muon system [4) 5)]. One of the key element of the CMS detector is the highly performing and redundant muon system. Drift tubes and Resistive Plate Chambers (RPC) in the Barrel and Cathode Strip Chambers and RPCs in the endcap are used for both triggering and tracking of muon particles. New Gas Electron Mutlipliers [5)] (GEM) detectors are going to be installed during this period with the goal to improve the muon trigger performance in the high pseudorapidity region.

The activity of the CMS Frascati group is focused on various responsibilities in the operation and monitoring of the RPC detector. In view of the high luminosity LHC upgrades of phase-2, the group is also highly involved in studies of longevity of the present system and in the construction of GEM detectors, for the completion of the muon system at high η, that are in phase of installation now and will be commissioned during the next months.

2 Main responsibilities of the CMS Frascati group

The Frascati group is deeply involved in the muon project of the CMS experiment since 2005 and has been holding responsibilities since then. The group has been responsible of both construction and maintenance of the Gas Gain Monitor system of the RPC muon detector and is involved in all the activities related to the running of the detector and the reparations during shutdown periods. Moreover the Frascati group has the responsibility of the construction of part of the GEM chambers for the CMS upgrade program. Several official roles have been covered by members of the group during the last years.

- Detector Performance Group coordination (2010-11)
- RPC Run coordination (2011-12)
- GEM hardware coordination (2013-now)
- RPC National Representative (2013-14 and 2015-16)
- GEM Resource Manager (2015-17)
- GEM National Representative (2018-now)

In parallel the group is at moment responsible for the construction of the GEM chambers for the CMS muon upgrade, and for the R&D efforts to find an ecological gas mixture for the RPC operations. and to study its interactions with GEM and RPC materials.

2.1 GEM chamber assembling at Frascati

As part of the muon upgrade program for the CMS phase-2 [6], GEM detectors have been installed in the pseudo rapidity range of $1.6 < |\eta| < 2.2$ during the Second Long Shutdown (LS2) of the LHC (2019). The existing CMS muon system has been built with complementary trigger capability by using three detection technologies: Drift Tubes (DTs), Cathode Strip Chambers (CSCs) and Resistive Plate Chambers (RPCs). The detectors coverage at CMS of DTs, CSCs and RPCs in pseudo rapidity range is < 1.2, $1.0 < |\eta| < 2.4$ and $\eta > 1.6$ respectively. The RPCs are not implemented beyond pseudo rapidity 1.6 and to maintain existing performance of the CMS detector during High Luminosity LHC (HL-LHC), the empty region has to be instrumented. The GEM is the most suitable detector technology for this region thanks to good time resolution (4 to 6 ns) and high rate capability (100 MHz/cm^2). The addition of GEM to the CMS muon system will improve the muon momentum resolution, reduce the global muon trigger rate, assure a high muon reconstruction efficiency, and increase offline muon identification coverage.

The first stations installed are those in the innermost station of the muon system at the higher η position, the so called GE1/1. They have been built between the end of 2017 and May 2018. After construction each chamber has been tested and installed in CMS during the 2019. The Frascati group had the responsibility to assemble and test 14 chambers. Each chamber after

assembly has been tested for gas tightness (up to 25 mbar) and HV stability. The dark current, the average chamber gain and the detailed gain map as a function of the postiion, is performed illuminating the chamber with a x-ray source. After passing these tests, the chambers have been packed into a dedicated transportation box and shipped to CERN for the final validation and then prepared for the installation in the CMS experiment. The Frascati group is also involved in the chambers preparation at CERN during which the Front End Electronic is installed as well as the on chamber gas distribution system and the Fiber Bragg Grating (FBG) optoelectronic system [9] [10] [11] [12] used to monitor the temperature of the chamber once installed in the experiment. This monitoring system is under the total responsibility of Frascati group.

The second set of GEM chambers that will be installed for the Phase-2 of CMS are those in the second station of the muon system, called GE2/1. Starting from fall 2019 the CMS Frascati group started the preparation of the assembly and test facility for the new GE2/1 detector. The construction of a larger number of chambers (about 53) will start in spring 2020. These chambers are larger than the GE1/1 and during the 2019 the local Frascati infrastructures have been improved to handle this new type of GEM detectors.

2.2 GGM maintenance and data analysis

The Gas Gain Monitoring (GGM) [7] [8] is part of the CMS RPC detector with the task of monitoring the stability of gain for changes due to differences in the gas mixture compositions. The GGM has been designed, built and operated under responsibility of the Frascati group since its proposal, in 2005. In year 2019 a radical rewriting of software was begun. All data acquisition system was ported to C++, the data analysis ported to ROOT and all operative systems aligned with the latest versions used by CMS. Two servers have been updated and tested. During 2020 the hardware system will be maintained. Two gaps need to be replaced, the full system will be interfaced with the online control systems of CMS and updated.

2.3 GEM and RPC gas mixture R&D

During 2019 the Frascati group has continued to develop the R&D program to find an ecological replacement for the tetrafluorethane $C_2H_2F_4$ (commonly called r134a) used for the Resistive Plate Chambers. Two candidates have shown interesting properties [14] [15] [16]: Tetrafluoropropane ($C_3H_2F_4$) and Trifluoroiodometano (CF_3I). Both of them are very electronegative and cannot be used alone to replace the r134a because the working voltage is moved at very high values not compatible with the present CMS RPC HV system. Several combinations of these components with CO_2, Argon, Helium have been tested. The most interesting gas composition found so far involves a mixture of $C_3H_2F_4$, CO_2, isobuthane and SF_6. This gas mixture has been tested in the second part of 2019 at the GIF++ irradiation facility. A new collaboration involving groups working on RPCs at the LHC experiments and at not LHC experiments has been formed and several chambers have been installed at the GIF++ by monitoring their performances with $C_3H_2F_4$ based gas mixtures and under irradiation. Up to now no clear conclusions can be extracted although it

has been shown that the detectors reach the full efficiency at higher working voltage as expected and that the Tetrafluoropropane based mixture produce about three times more HF than the standard RPC gas mixture. Dark currents are carefully monitored and the impact of the total gas flow, the amount of Tetrafluoropropane and of other parameters are under study.

2.4 New materials for HL-LHC gas detectors

Identifying, testing and characterising new ecofriendly gas mixtures requires the study of the behavior of RPC and GEM materials in presence of the new gas components. The original concept of the RPC detector is based on bakelite plates coated with linseed oil. Such a design dates back to last century and is not immune of problems, with the dependance to temperature, not to exceed 24C for safe operation, being the most critical. An investigation of new resistive materials to be used for RPC and GEM [13)] detector has been initiated by the Frascati group since a few years, centered on competences and instrumentation available to the CMS Frascati associates from Sapienza Ingegneria dei Materiali. A branch of study focussed on the development of conductive polymer was finalized at the end of 2019 under the form of a declaration of invention. The invention, currently under scrutiny of the INFN and Sapienza Technology Transfer Offices, regards the fabrication of a novel polymer whose resistivity can be tuned in the range requested by the safe operation of RPC and GEM detectors. The polymer is suitable for both coating and bulk operation and provides surface rugosity comparable to the linseed oil.

2.5 AIDA2020

The CMS Frascati group is responsible for WP 13.8 "Control of MPGD foils mechanical tensioning via optical methods" with the goal to apply FBG sensor to monitor the stretching of foils over time, and to use interferometric techniques during chamber construction. All the milestones have been fulfilled at beginning of 2019.

3 Activity planned for 2020

IN 2020 the Frascati group will participate in the upgrade and installation activities for both the GEM and the RPC detectors. The Gas Gain Monitoring system will be commissioned in view of the start-up pf the experiment expected in May 2021. The production of the GE2 GEM chambers will start in the Frascati laboratories and is expected to involve the group for the full year. Frascati indeed is one of the GEM production sites together with INFN Bari, Florida Institute of Technology and CERN. Studies of ecogas mixtures for RPC detectors will continue at irradiation facilities GIF++ at CERN, inside the new created collaboration that involves groups working on RPCs in all the LHC experiments and in activities beyond collider physics. A proposal has also been submitted in the AIDAnova framework with the goal to improve the infrastructures used to study on long time base the new ecofriendly gas mixtures under irradiation.

4 Conference talks and papers by Frascati Authors

For the complete listing of CMS papers in 2018 see /www.slac.stanford.edu/spires/

1. G. Ramirez-Sanchez *et al.*, "Search for Heavy Stable Charged Particles in the CMS Experiment using the RPC Phase II upgraded detectors," JINST **14**, no. 11, C11011 (2019). doi:10.1088/1748-0221/14/11/C11011

2. J. Goh *et al.*, "CMS RPC efficiency measurement using the tag-and-probe method," JINST **14**, no. 10, C10020 (2019). doi:10.1088/1748-0221/14/10/C10020

3. R. Reyes-Almanza *et al.*, "High voltage calibration method for the CMS RPC detector," JINST **14**, no. 09, C09046 (2019). doi:10.1088/1748-0221/14/09/C09046

4. E. Voevodina *et al.* [CMS Collaboration], "RE3/1 and RE4/1 RPC chambers integration in the inner region of the forward muon spectrometer in the CMS experiment," JINST **14**, no. 10, C10027 (2019) doi:10.1088/1748-0221/14/10/C10027 [arXiv:1905.07814 [physics.ins-det]].

5. A. Gelmi *et al.*, "Longevity studies on the CMS-RPC system," JINST **14**, no. 05, C05012 (2019). doi:10.1088/1748-0221/14/05/C05012

6. D. Abbaneo *et al.* [CMS Muon Collaboration], "Performance of GE1/1 Chambers for the CMS Muon Endcap Upgrade," arXiv:1903.02186 [physics.ins-det].

7. D. Abbaneo *et al.* [CMS Muon Collaboration], "Layout and Assembly Technique of the GEM Chambers for the Upgrade of the CMS First Muon Endcap Station," Nucl. Instrum. Meth. A **918**, 67 (2019) doi:10.1016/j.nima.2018.11.061 [arXiv:1812.00411 [physics.ins-det]].

8. M. A. Shah *et al.* [CMS Collaboration], "The CMS RPC Detector Performance and Stability during LHC RUN-2," JINST **14**, no. 11, C11012 (2019) doi:10.1088/1748-0221/14/11/C11012 [arXiv:1808.10488 [physics.ins-det]].

9. F. Lagarde *et al.*, JINST **14**, no. 10, C10037 (2019) doi:10.1088/1748-0221/14/10/C10037

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1. CMS Collaboration home page is /cms.cern.ch/.

2. R. Adolphi *et al.*, "The CMS experiment at the CERN LHC," JINST **3** (2008) S08004

3. S. Chatrchyan et al., "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC", Phys. Lett. B 716 (2012) 30

4. M. Tytgat, *et al.*, "The Upgrade of the CMS RPC System during the First LHC Long Shutdown," PoS RPC **2012** (2012) 063 [JINST **8** (2013) T02002] [arXiv:1209.1979 [physics.ins-det]].

5. D. Abbaneo, *et al.*, "A GEM Detector System for an Upgrade of the High-eta Muon Endcap Stations GE1/1 + ME1/1 in CMS," arXiv:1211.1494

6. A. Colaleo, *et al.*, "CMS TECHNICAL DESIGN REPORT FOR THE MUON ENDCAP GEM UPGRADE," CERN-LHCC-2015-012 ; CMS-TDR-013. - 2015. (Technical Design Report CMS ; 13)

7. S. Colafranceschi *et al.*, "Operational experience of the gas gain monitoring system of the CMS RPC muon detectors," Nucl. Instrum. Meth. A **617** (2010) 146. doi:10.1016/j.nima.2009.06.095

8. L. Benussi *et al.*, "The CMS RPC gas gain monitoring system: An Overview and preliminary results," Nucl. Instrum. Meth. A **602** (2009) 805 doi:10.1016/j.nima.2008.12.175 [arXiv:0812.1108 [physics.ins-det]].

9. L. Benussi *et al.*, "Fiber Bragg Grating sensors for deformation monitoring of GEM foils in HEP detectors," arXiv:1512.08629 [physics.ins-det].

10. D. Abbaneo *et al.*, "A novel application of Fiber Bragg Grating (FBG) sensors in MPGD," arXiv:1512.08529 [physics.ins-det].

11. D. Abbaneo *et al.*, "Fiber Bragg Grating (FBG) sensors as flatness and mechanical stretching sensors," arXiv:1512.08481 [physics.ins-det].

12. L. Benussi *et al.*, "Fiber Bragg grating sensors for deformation monitoring of GEM foils in HEP detectors," doi:10.1109/IWASI.2015.7184954

13. L. Benussi *et al.*, "Characterization of the GEM foil materials," arXiv:1512.08621 [physics.ins-det].

14. L. Benussi *et al.*, "Candidate eco-friendly gas mixtures for MPGDs," arXiv:1512.08542 [physics.ins-det].

15. L. Benussi, S. Bianco, M. Ferrini, L. Passamonti, D. Pierluigi, D. Piccolo, A. Russo and G. Saviano, "A study of HFO-1234ze (1,3,3,3-Tetrafluoropropene) as an eco-friendly replacement in RPC detectors," arXiv:1505.01648 [physics.ins-det].

16. L. Benussi *et al.*, "Properties of potential eco-friendly gas replacements for particle detectors in high-energy physics," arXiv:1505.00701 [physics.ins-det].