

## CMS

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# 1 Introduction

The Compact Muon Solenoid (CMS) <sup>1) 2)</sup> is one of the four experiments around the interaction 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 <sup>3)</sup>, 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 and the experiments are working on the consolidation of the present system and the installation of new devices that will improve the detector performances.

The 2021 as 2022 has been a hard year due to the covid restrictions and many activities have proceeded slowly.

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 <sup>5)</sup> (GEM) detectors will improve the muon trigger performance in the high pseudorapidity region. In 2020 the installation and commissioning of the innermost layer of GEMs (GE1/1) have been completed.

The next step is the production of the second layer (GE2/1) of GEM chambers that will complete the upgrade of the endcap muon system. The GE2/1 chamber production as started at CERN despite the heavy difficulties due to the pandemic restrictions, which slowed down the raw material procurement (GEM foils, PCB readout boards and drift PCB boards, inner and outer chamber frames, etc.)

The activity of the CMS Frascati group is focused on various activities involved in the Muon project. Many responsibilities are covered by Frascati members, and in view of the high luminosity LHC upgrades of phase-2, the group is also highly involved in the construction of GEM detectors. Maintenance of the Gas Gain Monitoring of the CMS and studies of eco-friendly alternative gas mixture for the RPC operations are the other two core activities of the group.

## 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 for 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 (2018-2020)

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 <sup>6)</sup>, 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<sup>2</sup>). 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  $\eta$  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 production of the second set of GEM chambers (called GE2/1), that will be installed for the Phase-2 of CMS, was expected to start from the beginning of 2020. the CMS Frascati group started the preparation of the assembly and test facility for the new GE2/1 detector in fall 2019 but due to the COVID pandemic, the construction of a larger number of chambers (about 53) will start in spring 2021. 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.

In 2020 the GEM Frascati group, with the limit of the lockdown restriction, was able to provide a significative support to the GEM detector activity at CERN. In summer 2020 we gave support to the activity of the commissioning of the latest GE1/1 super-chambers before their installation on the detector and we participated to the test of the first GE2/1 GEM foils delivered and to their validation in term of production quality.

After the summer 2021 the Frascati group participated and CERN to the assembly of some modules of the GE2/1 chambers, providing a significant help to the GEM CMS group in the organization of the new QC stations for the GE2/1 forthcoming production.

The GE2/1 chamber production is expected to start at the end of April and the Frascati group has the commitment to assemble and qualify 43 Chambers modules.

## 2.2 GGM maintenance and data analysis

The Gas Gain Monitoring (GGM) [7] [8] [9] is part of the CMS RPC detector. Purpose of the GGM is to monitor the stability of gain for changes due to differences in 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. The whole data acquisition system was ported to C++, the data analysis software was ported to ROOT and all operative systems aligned with the latest versions used by CMS. Two servers have been updated and tested. The system uses pressure, temperature, relative humidity sensors originally read out by a PICO system and LabView software. As a part of the upgrade, the readout of PICO system was moved to Linux OS. The upgraded system was scheduled to be implemented and tested over 2020. Because of the COVID-19 outbreak, the plan was swiftly changed. A clone of the GGM DAQ system was realised in Frascati and has been currently operating since then. The Frascati group implemented the upgrade with collaborators from Eastern Mennonite University, Harrisonburg, VA (USA) (S. Colafranceschi and collaborators) who remotely operated the system. The upgrade operations on the GGM was declared high priority task by the CMS management (CMS RPC GGM Maintenance IMPACT 157814). The GGM system went into major upgrade both for what concern the environmental sensor system hardware (gas pressure, temperature and humidity and

atmospheric parameters) and both the software needed to control the new sensor hardware based on Arduino system<sup>?)</sup>. The whole system is at the moment under final debug and will be ready for the next LHC run at the end of April 2022. Since 2019, the GGM system is a Frascati institutional responsibility.

## 2.3 RPC gas mixture R&D

After a long R&D program developed in laboratory, starting from the end of 2019 the main activity in the ecogas studies has been to test the RPC performance with eco-friendly gas mixtures under irradiation at GIF++. R&D program has found two interesting candidates<sup>12) 13) 14)</sup> to replace the tetrafluoroethane  $C_2H_2F_4$  (commonly called r134a) used for the Resistive Plate Chambers: 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. One of them ( $C_3H_2F_4$ ) is at moment used to operate RPCs at GIF++ under irradiation. A Collaboration of people coming from CMS, ATLAS, ALICE and LHCb/Ship experiments has been set up with the goal to study the operation stability of the RPCs with Tetrafluoropropane or any other interesting gas that will be found in laboratory tests. Starting from March 2021 this activity has been covered also under the AidaInnova European program. The plan is to characterize the RPC performances with a gas mixture based on  $C_3H_2F_4$ ,  $CO_2$ , isobutane and  $SF_6$  in different percentage of  $CO_2$ . Several test beams have been performed at GIF++ and efficiency, rate and dark currents have been studied under different background conditions. A campaign to analyze the HF production of this new mixture under background is also started. Plans for 2022 are to continue the HF measurements and to evaluate again the RPC performances in dedicated test beams after a period of gamma irradiation.

## 2.4 AIDAInnova

The call for AidaInnova has been launched during 2020. The CMS frascati group in collaboration with groups of ATLAS, ALICE, LHCb/Ship, and CERN has proposed a project to upgrade the RPC setup at GIF++ in order to continue in a more effective way the studies of ecological gas mixtures for RPC operations. Although the tetrafluoropropane ( $C_3H_2F_4$ ) has been identified as the most interesting candidate to replace r134a gas in RPC operations, there are no results on the long term performance of the RPCs operated with such gas under irradiation. In the AidaInnova project a task to upgrade the system at GIF++ and to continue the measurements under irradiation has been proposed. The project has been approved and will be part of the task 7.2 of AidaInnova that is going to officially start at the beginning of 2021 under the responsibility of one member of the Frascati group.

### 3 Activity planned for 2022

The year 2021 will be crucial for the production of GE2/1 chambers. Although the production and installation plans will be affected by the pandemic situation, at moment the production of the GEM chambers should start at the middle of the year and all the laboratories involved are starting to prepare the setup for production an quality monitor. Frascati is one of the production sites with the goal to produce 48 chambers .....

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 of the experiment expected in May 2022.

The production of the GE2 GEM chambers will start in the Frascati laboratories starting at the end of April 2022 and is expected to involve the group for the full year.

Frascati indeed is one of the GEM production sites together with INFN Bari and others institute from India and China.

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 2021 see [/www.slac.stanford.edu/spires/](http://www.slac.stanford.edu/spires/)

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