CMS

L. Benussi, S. Bianco
M. A. Caponero (Ass.)
M. Parvis (Ass.)
L. Passamonti (Tecn.), D. Piccolo (resp. locale)
D. Pierluigi (Tecn.)
A. Russo (Tecn.), M. Santinicola (Ass.), G. Saviano (Ass.)

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 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 2020 has been a hard year due to the covid restrictions and many activities have proceeded slowly. Nevertheless the Muon community has been able to complete the installation of the GE1/1 chambers as planned for the upgrade of the system [4) 5)] at high eta. 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 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 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 GainMonitoring 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 [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 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.

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) and extended visits to CERN were performed by members of the Frascati group in August, September and November 2020. Before the end of 2020, the DAQ was successfully upgraded in both the Frascati clone and the GGM system at CERN.

2.3 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 [10] detector has been initiated by the Frascati group since a few years, thanks to competences and instrumentation available to the CMS Frascati associates from Sapienza Ingegneria dei Materiali. The study of development of a novel conductive polymer finalized at the end of 2019 under the form of a declaration of invention continued in 2020, *albeit* at a delayed rate due to substantial inaccessibility of chemical laboratories. The invention, that has been under scrutiny of the INFN and Sapienza Technology Transfer Offices over 2020, 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 roughness comparable to linseed oil. At the end of 2020 a pre-existing competing patent was found and studies are underway to ascertain the feasibility of an approach which overcomes the preexisting claims.

2.4 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-frindly gas mixtures under irradiation at GIF++. R&D program has found two interesting candidates [15] [16] [17] to replace the tetrafluorethane $C_2H_2F_4$ (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. Due to the pandemic restrictions, the test program has been slowly than expected, anyway several measurements with a gas mixture based on $C_3H_2F_4$, CO_2, isobuthane and SF_6 in different percentage of CO_2 have been performed. In view of the next year activities, this item is also covered in the AIDAInnova European program.

2.5 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 prosed. The project has been approved and will be part of the 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 2021

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 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 2020 see /www.slac.stanford.edu/spires/

1. G. Rigoletti *et al.*, "Studies of RPC detector operation with eco-friendly gas mixtures under irradiation at the CERN Gamma Irradiation Facility" Volume 364 - European Physical Society Conference on High Energy Physics (EPS-HEP2019)

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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]].

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

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

12. 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].

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