CMS

L. Benussi, S. Bianco (Resp.)
M. A. Caponero (Ass.), M. Ferrini (Ass.)
S. Muhammad (Dottor.) M. Parvis (Ass.)
L. Passamonti (Tecn.), D. Piccolo
D. Pierluigi (Tecn.), F. Primavera (Ass.Ric)
G. Raffone, A. Russo (Tecn.), G. Saviano (Ass.)

1 Introduction

The Compact Muon Solenoid (CMS) [1] [2] is a general-purpose experiment designed to study the structure of the Universe and to search for the elusive new elementary particles that are believed to account for the large missing mass (the so called dark matter). The former goal was reached in 2013 with the observation of the predicted but never discovered Higgs boson. The latter goal is currently pursued with a significantly improved spectrometer. To do so, CMS detects, reconstructs and analyzes the proton-proton interactions provided by the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN). The detection of muons is of paramount importance, since these are copiously produced by the decay of both the Higgs boson and of the expected new particles. The CMS muon system is being upgraded with the Gas Electron Multiplier (GEM) detectors technology to improve performances in operation at high collision rates.

The CMS experiment restored data taking in early 2018, and started to explore the new energy regime of 13 TeV collisions to improve the precision on the Higgs boson [3] parameters and to search for new physics beyond the standard model. 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.

The activity of the CMS Frascati group is focused on various responsibilities in the operation and monitoring of the RPC detector, as well as in the quality control of data and physical data analysis. In view of the high luminosity LHC upgrades of phase II, 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 will be installed in 2019.

2 Activity 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 has been heavily involved in all the activities both during the running periods and during the last years shutdown efforts. Several responsibilities have been covered by members of the group during these years. In 2010 and 2011 the RPC DPG (Detector Performance Group) coordinator was a Frascati charge. In 2011 and 2012 the RPC Run coordination. From 2013 the CMS GEM hardware coordination is covered by Frascati with the charge to coordinate the R&D and the construction of the CMS GEM detector. For the period 2013-14 a member of the group was the RPC national responsible. In 2015 the main efforts of the group were devoted to the support to the commissioning activities of CMS RPC and on studies and R&Ds for the future muon upgrades at high eta. Since 2015 the Frascati group has the responsibility to coordinate the general CMS GEM production. A member of the group was CMS GEM Resource Manager (2015 -2017) while another member was in 2018 in charge of GEM Italian National responsible.

2.1 GEM chamber assembling at Frascati

The GEM detectors will be installed in CMS in a 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. At the proposed GEM installation region, a very high flux of particles (neutrons, photons, charged particles) is expected, the neutron flux is $1.5\ 10^5$ Hz/cm^2 when LHC runs at luminosity $5\ 10^{34}$cm^{-2} s^{-1}. For neutrons, the GEM detectors discharge probability is negligible therefore the GEM can work safely in such environment. The GEM detectors have proven their capability to run under LHC requirements (rate capability 10 kHz/cm2, efficiency $> 97\%$, time resolution 10 ns, gain uniformity 15%) of the CMS experiment in high particle background.The GEM detectors planned to be installed in CMS during LS2 is known as GE1/1 (standing for GEM Endcap station n.1, ring n.1). A total of 144 GE1/1 chambers will be installed at two forward muon stations, i.e. positive and negative sides of the CMS symmetrically. The GE1/1 production has started in 2017 and continued in 2018. Each chamber is approximately 110 cm long and 60 cm wide and are based on the triple-GEM geometry (3-1-2-1).

The CMS Frascati group plays a central role having a member of the group in charge as general production supervisor, with the responsibility to supervise the production in the other assembly sites (INFN Bari, Florida Institute of Technology and CERN). Frascati itself is a production site of GE1/1 chambers. In the Frascati CMS laboratory, the chambers will be assembled and tested under several quality controls setups, requested to accept a chamber for the final installation in the experiment. Quality control tests performed in Frascati include gas leak, HV vs I characteristic curve, gain curve, gain mapping for uniformity.

The CMS Frascati Group has also the responsibility of the installation and operation of a network of Fiber Bragg Grating optoelectronics temperature sensors mounted in each GE1/1 chamber. The FBG sensors will provide a detailed map of the temperature gradient in the GE1/1 region, and online monitoring.

2.2 GGM maintenance and data analysis

The Gas Gain Monitoring (GGM) construction has been the first contribution of the Frascati group to the RPC collaboration. The system monitors the changes in working point due to gas variations, by means of monitoring of anodic charge in small RPC gaps in a cosmic ray telescope. During 2018 a full software upgrade was planned, to be deployed in 2019.

2.3 AIDA2020

The CMS Frascati group is responsible for WP 13.8 "Control of MPGD foils mechanical tensioning via optical methods". The goal is to apply FBG sensor to monitor the stretching of foils over time, and to use interferometric techniques during chamber construction. For the latter, it was proposed to use moiré techniques for the first time in HEP detectors. By using moiré interferometry a 30μm precision on the transverse plane was reached on small field of view. The programme was concluded in 2017 by realising the engineering prototype apt to large scale MPGD production, and to verify that the design resolution is reached on large field of views (approximately half a GE1/1 chamber). In 2018 the AIDA activity was focussed on the preparation of papers on the tasks completed.

2.4 New materials for HL-LHC gas detectors

The use of gas detectors for muon at HL-LHC poses challenges due to high-rate, and detector lifetime due to ageing caused to increase radiation levels. The search for new, eco-friendly gases is also dictated by the changing conditions of the market in terms of industry-produced fluorocarbons. Both conditions ask for detailed investigations on the interaction of materials used in gas detectors with the new gases, and the tolerance of materials to increase radiation levels.

The Frascati group was funded by INFN Phase2 R&D programme to carry on a set of investigations on both ecogases and materials. The material characterisation is carried on by means of the component of associates from Sapienza University of Rome, Materials Engineering. Collaboration with associates of Turin Polytechnic allowed to address issues on polymer deposition and 3D-printing of coatings. The FBG programme is carried out with the CMS Frascati associates from ENEA.

During 2018, in order to perform material characterization of the GEM detector, mechanical tests were performed to examine the mechanical performance of Polyimide (Kapton) and GEM foil. Bearing in mind the mechanical stresses imposed during the assembly and subsequently during operation of the detector for many years in the harsh radiation and environmental conditions at the CMS, a series of the tensile tests were performed by using different samples which were prepared accordingly, i.e. a set of the samples was exposed to neutrons and another exposed to gamma radiation, and then these were made extra dry and wet to assess the effects of radiation and humidity on their tensile properties. Lastly, a set of the samples was thermally treated between 300^{o}C and 360^{o}C to check the temperature response of the foils in terms of surface morphology and tensile behaviour. It was found how the radiation and environment variation conditions the degradation of the GEM material is not so significant with respect to its toughness, but the Young modulus was effected. The heat treatment significantly affected the tensile properties of the material but no chemical and composition changes were detected.

CERN has recognised the importance of such studies and actively collaborates with the Sapienza associates of the Frascati group. A summer student fellowship was granted for the third year in a row (with a member of Frascati group as co-supervisor along with A.Sharma - GEM Project Manager), by the title "Analysis of Mechanical Properties for the GEM Foil". Tensile tests are performed both at CERN and at Sapienza, by using high resolution microscope and tensile test setup. The samples are cut in the transverse directions (no HV sector grooves) and were made dry and wet.

To study long-term stability of GEMs under constant stress, the creep tests were performed on the GE1/1 samples which were prepared in the transverse and longitudinal directions. Two creep tests were performed for 29 days and 40 days continuously respectively. The HV grooves effects are significant such as the elongation rate was faster for the grooves samples than the samples without grooves, in both cases it is seen that after 20-25 days the elongation was negligible small. New materials and coatings for Resistive Plate Chambers (RPCs) are being also investigated, by modifying the existing materials and by proposing new materials. Several coating techniques are tested, with equipments available both at Sapienza and Turin Polytechnic. Surface morphology and roughness are studied using Scanning Electron and Atomic Force Microscopes. For chemical structure of the surface the Fourier Transform - IR analysis was performed. In the second approach, we are trying to develop a new material for the RPCs electrodes. The work on the second approach is ongoing in close collaboration with the Synchrotron Radiation Lab in Frascati.

2.5 GEM and RPC gas mixture R&D

During 2018 the Frascati group has continued to develop an intensive 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: Tetrafluoropropane ($C_2H_2F_4$) 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. Several combinations of these components with CO_2, Argon, Helium have been tested.

For each gas mixture the efficiency, the induced charge and the time resolution have been measured. More studies are needed to find the correct balance between different components in order to be used for the CMS experiment and to verify the aging properties of such gases in high background environments. Tests started at the GIF++.

2.6 Physics analysis: high mass resonances

The Frascati group is involved in the physics analysis activity of Run 2 data. During year 2018 the analysis efforts focussed on the search for the MSSM Higgs decaying into 2 muons, namely in the optimization for the 13 TeV data.

3 Activity planned for 2019

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 completely renewed for software, and maintained for hardware. In Frascati prodution of GE2 GEM chambers will commence. Frascati is one of the GEM production site and has also the responsibility to follow the production in the other four assembly sites, INFN Bari, Florida Institute of Technology and CERN. Studies of ecogas mixtures for RPC detectors will take place at irradiation facilities.

4 Conference talks and papers by Frascati Authors

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

1. K. S. Lee *et al.*, "Study of Thin Double-Gap RPCs for the CMS Muon System," J. Korean Phys. Soc. **73** (2018) no.8, 1080. doi:10.3938/jkps.73.1080

2. 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** (2019) 67 doi:10.1016/j.nima.2018.11.061 [arXiv:1812.00411 [physics.ins-det]].

3. D. Abbaneo *et al.*, "Operational Experience With the GEM Detector Assembly Lines for the CMS Forward Muon Upgrade," IEEE Trans. Nucl. Sci. **65** (2018) no.11, 2808. doi:10.1109/TNS.2018.2871428

4. A. M. Sirunyan *et al.* [CMS Collaboration], "Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s} = 13$ TeV," JINST **13** (2018) no.06, P06015 doi:10.1088/1748-0221/13/06/P06015 [arXiv:1804.04528 [physics.ins-det]].

5. M. Tytgat *et al.* [CMS Collaboration], "Quality control for the first large areas of triple-GEM chambers for the CMS endcaps," EPJ Web Conf. **174** (2018) 03003. doi:10.1051/epjconf/201817403003

6. S. Muhammad *et al.*, "CMS GEM detector material study for the HL-LHC," PoS EPS **-HEP2017** (2017) 799. doi:10.22323/1.314.0799

7. L. Benussi *et al.*, “Characterization of the water diffusion in GEM foil material,” EPJ Web Conf. **174** (2018) 03005 doi:10.1051/epjconf/201817403005 [arXiv:1512.08621 [physics.ins-det]].

8. L. Benussi *et al.*, “Candidate eco-friendly gas mixtures for MPGDs,” EPJ Web Conf. **174** (2018) 05004 doi:10.1051/epjconf/201817405004 [arXiv:1512.08542 [physics.ins-det]].

9. D. Abbaneo *et al.*, “A novel application of Fiber Bragg Grating (FBG) sensors in MPGD,” EPJ Web Conf. **174** (2018) 03002 doi:10.1051/epjconf/201817403002 [arXiv:1512.08529 [physics.ins-det]].

10. G. Saviano *et al.*, “Properties of potential eco-friendly gas replacements for particle detectors in high-energy physics,” JINST **13** (2018) no.03, P03012 doi:10.1088/1748-0221/13/03/P03012 [arXiv:1505.00701 [physics.ins-det]].

11. G. Saviano et al., ’A study of mechanical properties of foil materials for the GEM detector proposed for the CMS muon system upgrade at LHC”, Polymer engineering and science, **58** (2018) 1539-1547 https:doi.org10.1002pen.24739

Theses

1. S.Muhammad, PhD Thesis Sapienza Universita’ di Roma, Faculty of Materials Engineering (G. Saviano supervisor).

References

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

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

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

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

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

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

13. 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].

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].

15. V. Khachatryan *et al.* [CMS Collaboration], Phys. Lett. B **768** (2017) 57 doi:10.1016/j.physletb.2017.02.010 [arXiv:1609.05391 [hep-ex]].