Upgradation of muon system of CMS Detector with triple-GEM Detector

Harjot Kaur[1],* Vipin Bhatnagar[1], Nitish Dhingra[2,1], and J.B. Singh[1]
[1]*Department of Physics, Panjab University, Chandigarh - 160014, INDIA and*
[2]*Department of Soil Science, Punjab Agricultural University, Ludhiana - 141004, INDIA*

At the LHC, muons play a crucial part in the study of several physics sectors, from the decay of Standard Model (SM) Higgs boson to the "new physics" aspects. As a result, the CMS muon system is designed and constructed to provide excellent muon triggering, identification, and reconstruction over a wide range of energies up to several TeV momenta. The muon system of CMS detector consists of DTs in barrel, CSCs in the endcaps and RPCs in both barrel and endcap regions. In order to improve and maintain the forward muon triggering and muon reconstruction at high luminosity, CMS detector is planned to be equipped with an additional layer of new technology based set of muon detectors, called Gas Electron Multiplier (GEM). In this paper, the upgradation of CMS muon system related to GEM detector is discussed.

1. Introduction

The Compact Muon Solenoid (CMS) [1] detector is a multipurpose detector installed at the Large Hadron Collider (LHC) [2] at CERN. The central feature of the CMS detector is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. A tracker detector detects the tracks of charged particles, and two calorimeters (an electromagnetic and a hadron calorimeter) measure the energy of particles. The entire setup is placed inside the solenoidal magnetic field. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. The muon system plays a crucial role in CMS as the production of new particles generally involves one or more muons. The muon system of CMS detector consists of Drift Tubes (DT) in barrel region up to pseudorapidity ($|\eta|$) < 1.2, Cathode Strip Chambers (CSC) in the endcaps (0.9< $|\eta|$ <2.4) and Resistive Plate Chambers (RPC) provide redundant trigger and fine position measurement in both barrel and endcap regions. The forward region of the endcap is only instrumented with CSCs and the possible degradation of CSC performance due to the sustained operation in a high rate environment could drastically affect the entire muon system. Therefore, major improvements are planned by installing an additional set of muon detectors, called Gas Electron Multiplier (GEM) [3] in the first endcap muon station to improve and maintain the forward muon triggering and reconstruction in the region 1.6 < $|\eta|$ <2.2 at high luminosity.

2. GEM detector

In 1997, F. Sauli introduced the GEM technique to preamplify signals in Micro-Strip Gas Chambers (MSGCs) [4]. It is composed of a thin insulating polymer (polyimide) layer, typically 50 μm in thickness, coated with a 5 μm copper layer on both sides and chemically perforated with numerous microscopic holes. The average hole diameter is 70 μm, with a pitch of 140 μm. By applying a potential difference between the two copper layers, an intense electric field of several 10 kV/cm is established within the holes. When the primary electrons, generated by the passage of a charged particle such as muon, reach these GEM holes, they undergo acceleration in the strong electric field and acquire enough energy to cause an avalanche, as depicted in Fig 1. Subsequently, the charge is amplified and drifts towards a readout board, where it generates an electrical signal.

*Electronic address: `harjot.kaur@cern.ch`

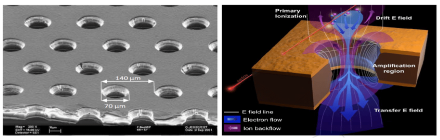

FIG. 1: Scanning Electron Microscope picture of a GEM foil (left) and schematic view of the electric field lines (white), electron flow (blue), and ion flow (purple) through a GEM hole (right).

3. GE1/1 muon chamber upgrade

The CMS triple-GEM detector (GE1/1) comprises a drift cathode, three GEM foils, and a Printed Circuit Board (PCB) anode (or readout board) as depicted in Figure 2. GE1/1 production chamber has a 3/1/2/1 mm (drift/transfer1/transfer2/induction) gas gap configuration, providing a good compromise between the mechanical constraints and the required magnitude of electric fields for charge transfer between electrodes. The drift gap, where the charge conversion occurs, is generally larger to maximize the sensitivity for the incoming particles and to ensure that the number of primary electrons is sufficient to compensate for any potential losses before amplification.

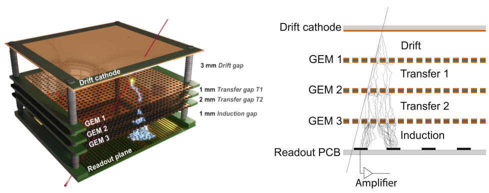

FIG. 2: Schematic view of a triple-GEM detector.

GE1/1 is segmented into three ϕ and eight η sections, resulting in 24 individual detector segments, each with 128 strips. These strips are read by 128 channel application-specific integrated circuits known as VFAT3. The VFAT3 digitizes and amplifies small charge signals from the GEM detector's electrodes using a 40 MHz internal clock. The data from VFAT3 is transmitted to the GEM Electronics Board (GEB) and from there, data is sent to FPGA boards known as GEM OptoHybrids (OH). The data is transmitted between the GEM electronics and the off-detector DAQ system using optical fibers. The GE1/1 upgrade involved fabricating and testing 144 GEM detectors at various sites. Panjab University assembled 8 GE1/1 detectors, which passed quality control tests (QC2-QC5) and were later sent to CERN for installation.

4. Phase-II upgradation of muon chamber

A major upgrade, known as High Luminosity LHC (HL-LHC) has been planned which will increase the integrated luminosity tenfold compared to the designed value, and raise the center of mass energy of proton-proton collisions to 14 TeV. The high luminosity data-taking period with the upgraded LHC, called Phase-II [5], is expected to end in 2038. To cope with the increase in background rates and trigger requirements, two major upgrades, GE2/1 and ME0, will take place in CMS muon station. The GE2/1 upgrade will involve upgrading the second ring of GEM detectors in the endcap region next to ME2/1 chambers. These new GE2/1 chambers will partially overlap with the existing GE1/1 chambers and will cover the range of $1.62 < |\eta| < 2.43$. The introduction of new ME0 detectors will increase the geometrical acceptance for muons and will cover the range $2.03 < |\eta| < 2.8$ using six layers of triple-GEM detectors. The ME0 system will provide unique coverage in the range $2.4 < |\eta| < 2.8$, and will strengthen the coverage provided by the CSCs, RPCs, and GE2/1 in the range $2.03 < |\eta| < 2.4$.

References

[1] CMS Collaboration, CMS Physics Technical Design Report **5**, (2006).
[2] Evans *et al.*, JINST **3**, S08001 (2008).
[3] CMS Collaboration, CMS Technical Design Report for the Muon Endcap GEM Upgrade, (2015).
[4] F. Sauli, Nucl. Instrum. Meth. A **805**, 2-24 (2016).
[5] Mohit Gola, Journal of Physics: Conference Series **1498**, 012054 (2020).