Fiber Bragg Grating (FBG) sensors as flatness and mechanical stretching sensors

Saleh Muhammad[1),2),3)]

On behalf of the CMS GEM Collaboration

1) INFN-Laboratori Nazionali di Frascati, Italy

2) University of Rome "La Sapienza", Italy

3) National Centre for Physics, Quaid-i-Azam University Campus, Islamabad, Pakistan

Introduction:

The large active area of each GE1/1 chamber consists of a triple-GEM foil stack to be mechanically stretched in order to secure its planarity and consequent uniform performance of the GE1/1 chamber across its whole active area. Fiber Bragg Grating (FBG) sensors act as low cost precision spatial and temperature sensing tools. These sensors, that are easy to mount, have a proven track record in high energy physics experiments. FBGs are also commonly used for very precise strain measurements (ref[1-3]). In this work we present a novel use of FBG sensors to measure the planarity and mechanical tension of the GEM foils used in the construction of GE1/1 chambers, shown in Figure 1, of the CMS experiment at the CERN LHC. The GE1/1 CMS muon system upgrade consists of 144 GEM chambers of approximately 0.5 m^2 active area each and based on the triple-GEM technology. This system will be installed in the pseudorapidity region 1.6 < |eta| < 2.2 of the CMS endcap. For further information on GE1/1 chambers please refer to the following work presented to in this conference:

- **Status Report of the Upgrade of the CMS muon system with triple-GEM detectors** (Talk G. De Lentdecker)
- **Test beam and irradiation test results of Triple-GEM detector prototypes for the Upgrade of the Muon System of the CMS experiment** (Poster I. Vai)
- **Impact of the GE1/1 station on the performance of the muon system in CMS** (Poster A. Magnani)

The scientific case:

The GE1/1 assembly procedure employs a mechanical stretching procedure to apply tension to the GEM foils by means of a series of lateral screws inserted into the internal frame as shown in Figure 2. This novel technology allows mechanical assembly of the GEM chamber without the use of internal spacers or glue. This procedure reduces the assembly time, with respect to construction techniques that employ glue and spacers, and allows the user to replace one or more GEM foils after the chamber has been assembled. However this mechanical stretching technique needs to be validated. One issue raised during the project's peer-review process was to prove that the mechanical stretching technique applies a uniform tensile load on the triple-GEM stack to the design specifications.

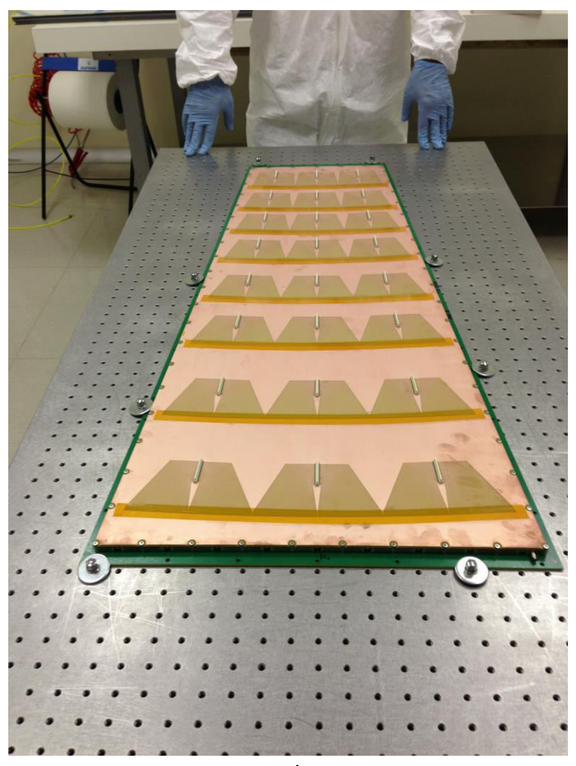

Figure 1: Full scale GE1/1 chamber prototype

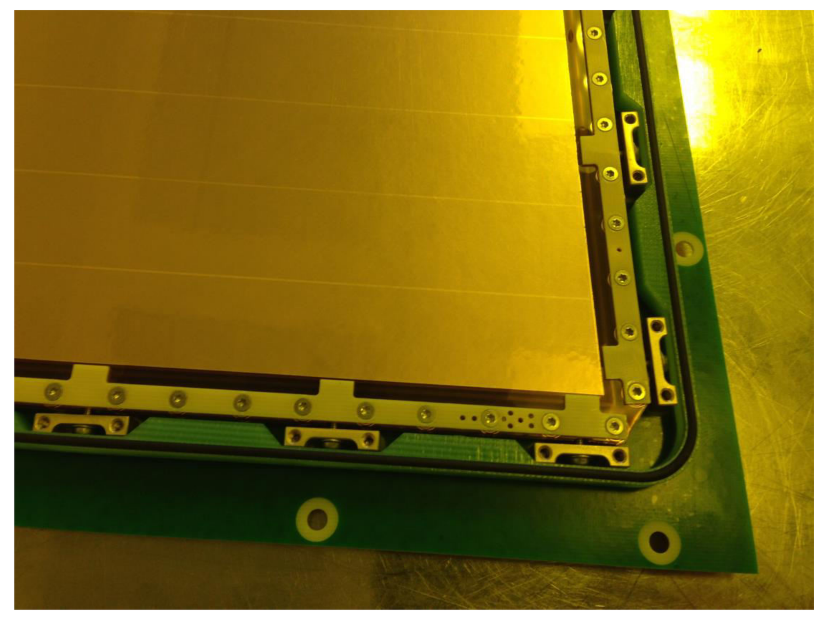

Figure 2: Internal view of a GE1/1 chamber prototype in which the lateral screws used in the mechanical stretching procedure are visible. Once the foils are stretched the GE1/1 chamber is closed with the readout board. No glue is used during the assembly process.

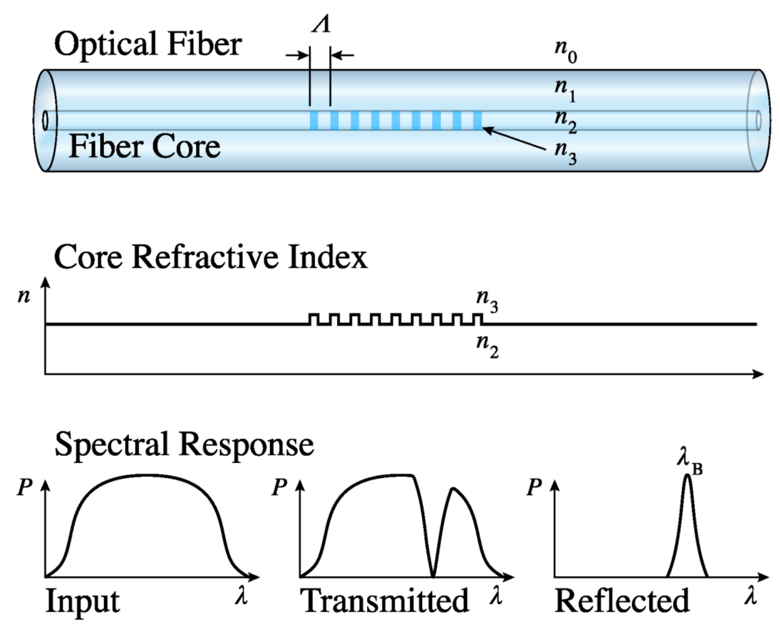

Figure 3: A Fiber Bragg Grating structure, with refractive index profile and spectral response

The idea:

A Fiber Bragg Grating (FBG) is a type of distributed Bragg reflector, shown in Figure 3 constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. The sensitivity of FBG in terms of strain, relative elongation w.r.t the initial position is of the order of 0.1 micron. This is achieved by creating a periodic variation in the refractive index of the fiber core, which generates a wavelength-specific dielectric mirror. A FBG can therefore be used as a strain measurement tool since variation of the FBG translates into different light frequency response. In order to validate the mechanical stretching technique used in GE1/1 assembly we affixed a network of FBG sensors, as shown in Figure 4 on the triple-GEM stack of a GE1/1 chamber prototype. The sensors active region is 1 cm long and the six sensors on the same foil are connected serially and read the the DAQ system (fig. 5 left). The sensors on the three foils are glued (as shown in Figure 5 right) with the same pattern in the three layer. This allow to immediately compare the response of sensors located in the same corresponding point in the three different GEMs. Due to the extremely high sensitivity of FBG the thermal dilatation of the materials used needs to be corrected. This is done by means of a FBG glued on the surface of a 10-by-10cm^2 GEM stretched into a small RF4 frame firmly fixed on the working bench. The response of the FBG on this small GEM allow us to cope the thermal effect since it is in the same temperature environment.

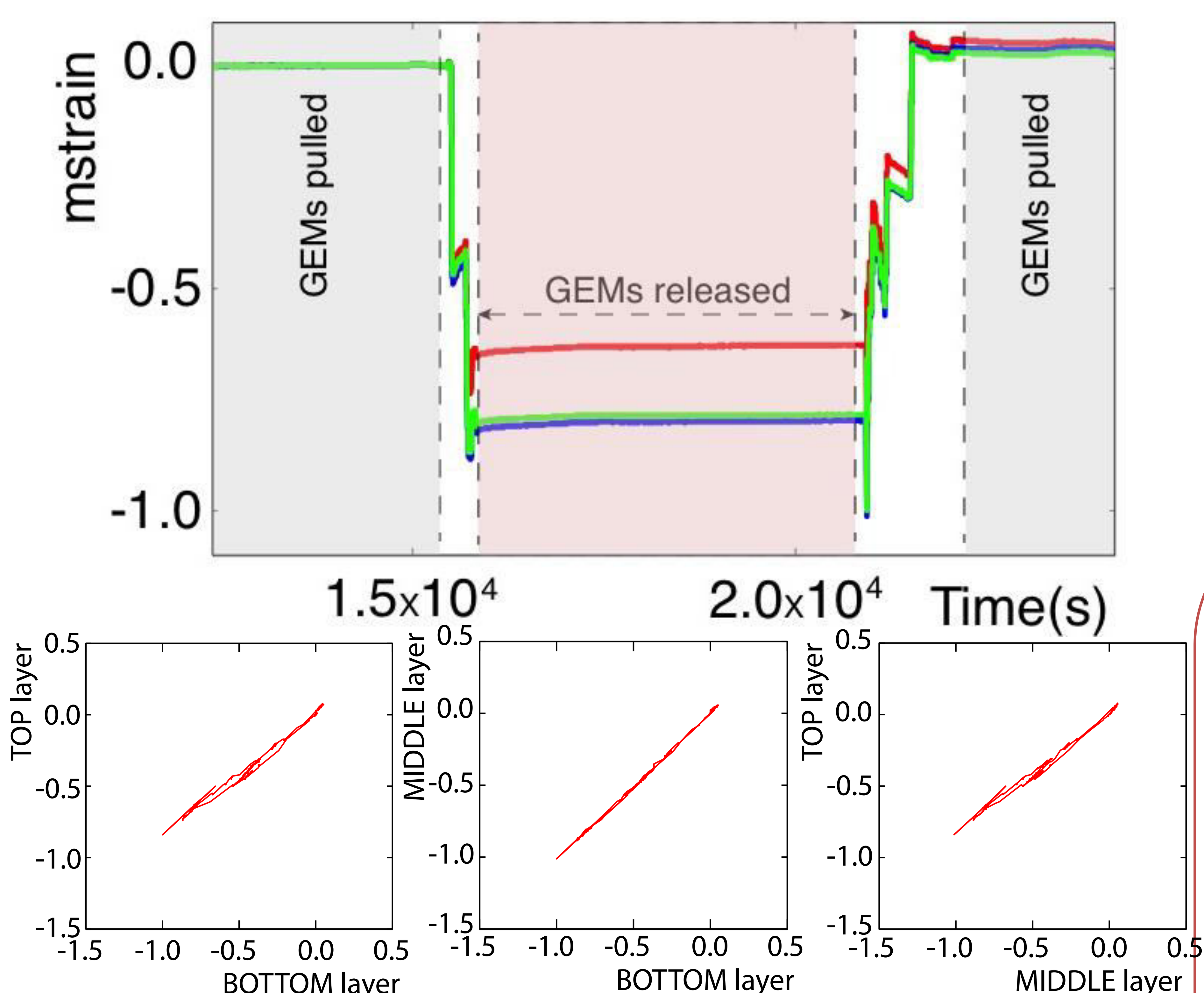

Fig 6: Typical response of the FBG sensors glued on the GEM surfaces of the GE1/1 chamber under test. The upper plot clearly shows three regions corresponding to the mechanical stretched GEMs and the central one corresponding to the non stretched GEMs. The steps behavior separating the three regions correspond to the un-screwing and screwing actions during the test. The three lower plots shown the correlations between the same sensors of the upper plot. TOP MIDDLE and BOTTOM refer to the GEM foil position in the stack

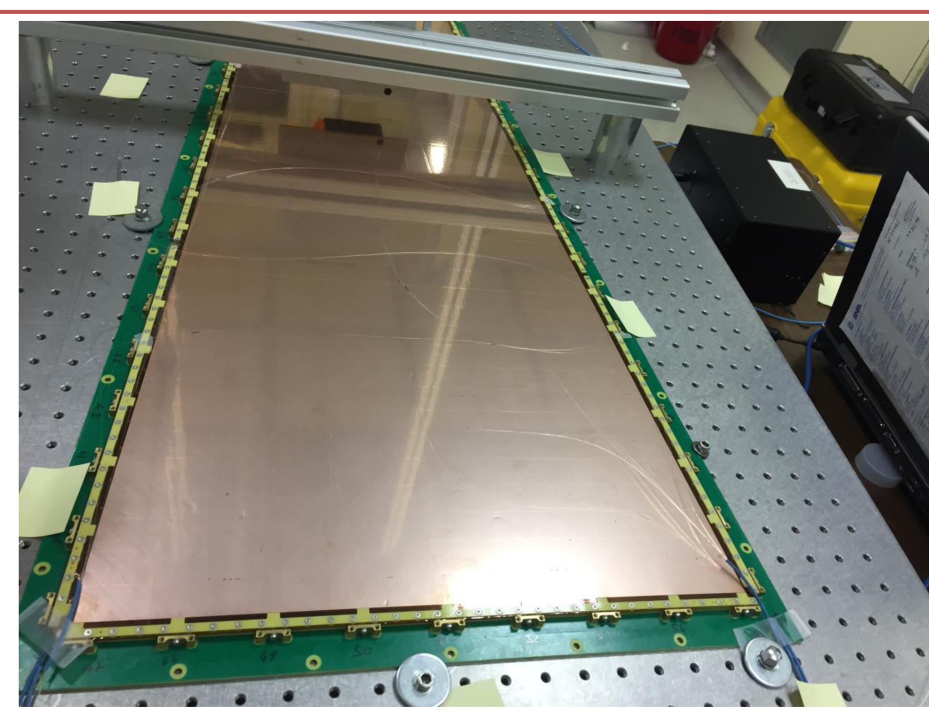

Fig 4: The top GEM foil of a GE1/1 chambers with FBG sensors glued on the surface. All the three foils have sensors glued on the surface. A total of 12 sensors were glued onto the foils

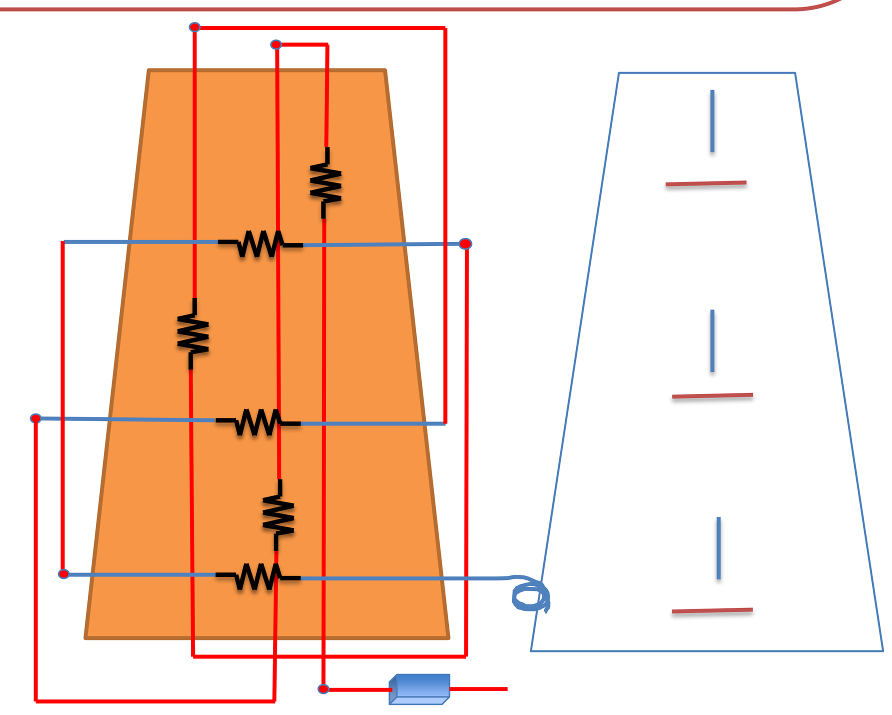

Figure 5:At left: conceptual schema of the FBG connection on one GEM foil. At right: the pattern of the glued FBG on the GEM foils

The measurements:

The test were in the following steps. During each step the FBG sensors were continuously monitored and data are recorded:

1) The chamber normally assembled with the GEM stack mechanically stretched to the nominal tensile load.
2) The mechanical stretching of the GEMs is released and remains as such for several hours.
3) The GEMs are stretched again up to the nominal tensile load.

The responses of three FBG sensors during these actions are shown in the upper Figure 6. The steps visible correspond to the actions during the un-screwing and screwing of the stack during the test. The red curve correspond to the TOP (TOP, MIDDLE, and BOTTOM mean the GEM foil position in the stack) of the stack; and have a sensible offset once the foil is loose due to the random position in that point the GEM assumed with respect to the other two. As to the underlined that once the stack has been pulled to the nominal load again the sensors have almost recovered their initial length. It can be seen from Fig. 6 that the reaction time of FBG sensors to changing tensile load is instantaneous. The three lower plots of Fig. 6 show the correlations of the three sensors responses. Similar behaviour for the other FBG sensors is obtained as to what is presented in Fig. 6. These results allow us to fully validate the mechanical stretching assembly technique for GE1/1 chambers. Further test are ongoing to confirm other important parameters such as the 1) optimal tensile load to be applied to the GEMs, 2) the maximum planarity obtainable for the GEMs without applying a load beyond the "Young's region" for GEM foils.

Conclusions:

With the use of FBG sensors we successfully demonstrated that, the novel glue-less technique adopted to assemble the GE1/1 chambers for the LS2 update of CMS is reliable and secure the correct tensioning of the three GEM foils. Several tests are ongoing using the same FBG sensors to optimize the tensile load and the GEM foils planarity.

References:

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Contacts:

saleh.muhammad@cern.ch and luigi.benussi@lnf.infn.it