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Investigation of a two-stage amplifying detector module with a fourfold sensor plane

T. Barvich, P. Blüm[a], Th. Erbacher, K.Kärcher, D. Knoblauch[b], D. Mörmann, Th. Müller, D. Neuberger, A. Pallarès[c], M. Schilling, H.J. Simonis, W.H. Thümmel.

Institut für Experimentelle Kernphysik ,Universität Karlsruhe (TH)

Abstract

We report on the construction and first test beam results of a prototype of two-stage amplifying detector module with four trapezoidal elements arranged in a geometry as planned for the CMS forward tracker. The performance of the detector is studied for different operational parameters in a high energy pion beam at CERN.

[a] *corresponding author; email: peter.blum@cern.ch*

[b] *now at Becker Automotive Systeme*

[c] *now at Groupe de Recherche en Physique des Hautes Energies, Universite de Haute Alsace*

1 Introduction

A mandatory request for modern tracking detectors is the capability to cope with high particle fluxes. In case of the CMS tracker system fluxes in the order of several 10^4 Hz/mm^2 are expected. The CMS tracker group has developed a suitable detector scenario which is described in full detail in the technical design report [1]. A large fraction of the sensors in this scenario will be MicroStrip Gas Chambers (MSGC). Detector modules have been designed both for the barrel and for the forward/backward region [2]. Particular efforts had been devoted to the problem of discharges induced by heavy ionizing particles. Those particles can be easily produced by nuclear reactions in the MSGC substrate. In the baseline design of the CMS tracker one uses therefore substrates coated with a layer of semiconductive glass of adequate resistivity ($\geq 10^{16}\Omega/\Box$), narrow anode width (7 μm), and passivation along the cathode edges.

In this paper we report on a detector where in addition to a MSGC an internal preamplification stage (gas electron multiplier - GEM, developed by F. Sauli [3]) is used. Such detectors are expected to provide enough safety margin to be operated in the hostile radiation enviroment of LHC. A comparison of the performance of a standard MSGC alone and with the addition of a gas electron multiplier (GEM) as a preamplifying stage showed a considerable increase of operational safety during irradiation with a high x-ray flux of $\approx 10^4$ Hz/mm^2 [4]. Those results were obtained using small scale modules. Our goal was to validate these findings in case of the CMS detector design.

The module which is described here is a closed system of four trapezoidal detector units mounted together in a segment of a ring (called *detector module*) with the read-out electronics and high voltage connections outside of the gas volume of the detector. In between the substrate and the drift plane a gas electron amplifier is inserted. The detector components and construction details are described and first beam test results are given. In a forthcoming note the experience of the forward community with the GEM technology under LHC-like conditions will be presented [5].

2 Concept of the detector module : *The GEM-banana*

The module is designed for 4 wedge-shaped MSGC substrates with 512 read-out channels each. In order to save expenses, only the 2 innermost sections are equipped with real detectors, the remaining ones are covered by glass plates homogeneously coated with a 20 nm thick layer of gold. The geometrical dimensions have been chosen to be those of the outer ring module for the MF1 milestone [2] in order to make as much as possible use of existing tools and equipment. Figure 1 shows an exploded view of the detector module consisting of 4 frames supporting substrates, GEM-foil, and drift cathodes.

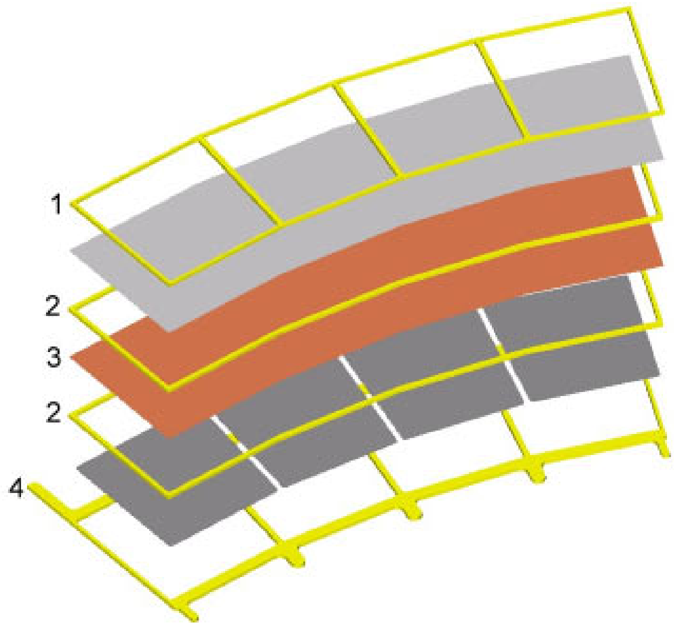


Figure 1: A schematic view of a detector module; (1) top frame carrying the drift-cathodes, (2) spacer frame , (3) GEM-foil, (4) bottom frame carrying the substrates.

2.1 Substrates

The artwork of the substrates has been produced in gold on bare 300 μm DESAG D263 glass by IMT[1]. The thickness of the gold strips is 500 nm. On each substrate, 512 anodes, each 10 μm wide and 170 mm long, are interleaved with cathode strips with a width varying from 110 to 139 μm. The resulting pitch varies from 250 to 212 μm to guarantee uniform gain along the strips [6].

Anodes are read out individually while cathodes are grouped together in 31 blocks of 16 and one block of 17 cathodes strips.

2.2 Drift cathodes

The drift cathodes are made of 360 μm thick Ferrozell, a glass fiber enforced epoxy[2], on which a 20 nm thick layer of gold has been evaporated. One drift cathode plate covers two substrates. Due to the low density of 1.75 g/cm^3 the thickness correspond to 250 μm glass, however, with a much higher mechanical stability. As the thermal expansion coefficient of Ferrozell ($1.6 \cdot 10^{-5} K^{-1}$) is comparable to that of Stesalit[3], the material of the support frames, no thermal stress is expected.

2.3 Frames

The module frames as shown in figure 1 are manufactured of Stesalit in the mechanical workshop of the institute. Because of the small cross section of only $2 \times 3\ mm^2$ both bottom and top frame have to be enforced with spokes to support drift and substrate plates and to provide additional mechanical stability to hold the tensile strength of the GEM foil. The spacer frames between drift and upper side of the GEM and between the lower side of the GEM and the substrates are both 3 mm high and without internal bars.

2.4 Gas electron multiplier (GEM)

The GEM has been produced at the workshop at CERN[4]. It consists of a 50 μm thick Kapton foil, copper cladded on both sides. By lithographical methods and chemical etching a regular matrix of holes has been produced. The pitch of the holes is 120 μm and the diameter is 70 μm in the copper and about 30 μm in the Kapton. Applying a voltage difference between both copper sides produces a dipol field high enough to provide charge amplification by ionization (see figure 2).

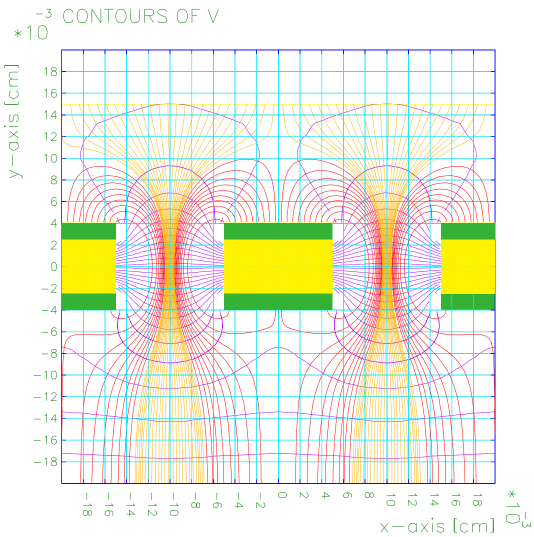


Figure 2: Electric field lines and equipotentials in a GEM.

[1] IMT AG, Im Langacher, Greifensee, Switzerland.

[2] Ferrozell GmbH, Augsburg, Germany.

[3] Stesalit AG, Zullwill, Switzerland.

[4] A. Gandi, R. De Oliveira, CERN-EST-SM, Geneva, Switzerland.

Figure 3 shows details of the GEM foil used for the detector module described in this note. Figure 5 shows the four individual segments each corresponding in size to that of a substrate. The segmentation is a preventive measure to reduce the capacity in case of a discharge.

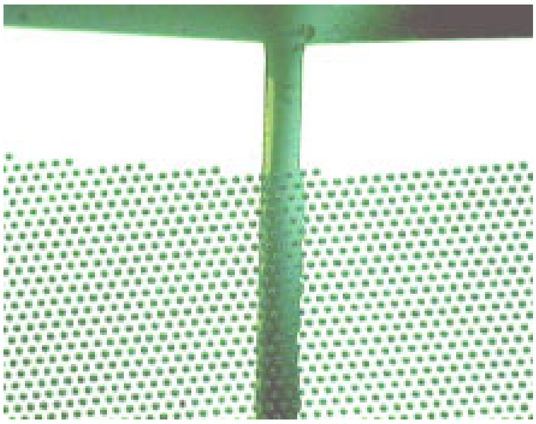


Figure 3: Corner of two subfields of the GEM used in this detector module.

3 Assembly

The mechanical assembly has to be done thoroughly to ensure a reliable performance of the detector. This requires careful quality control of all components, strict observance of high grade cleanness during assembly, elaborate production procedures, and dedicated tools to minimize failures and damages.

3.1 Quality control

3.1.1 Substrates

As part of substrate quality control the capacity and the resistance of each individual anode/cathode pair is measured. A computer controlled probestation connects the individual pairs to a Keithley 590 CV analyzer. The acceptance criteria for substrates at the production phase (no shorts between an anode and the neighbouring cathodes and less than 2 % broken anode strips) are loosened for the present prototype study. One substrate has two shorts and two broken anodes, the other one only two broken anodes.

3.1.2 GEM-foil

The quality control of the GEM consists of an optical inspection and an electrical test for shorts between both copper sides. Moreover, the electrical insulation is tested in dry nitrogen up to 400 V. To reach this voltage difference a careful “training” procedure is followed; in particular the GEM is operated for 12 hours at 300 V. A leakage current of less than 20 nA at 400 V is required for acceptance.

3.2 Cleaning

Before mounting, all mechanical parts are cleaned in an ultrasonic bath with deionized water, followed by a bath in isopropanol and a subsequent drying procedure.

A more complicated bath sequence is used to clean the substrates and the drift cathodes: 10 min aceton bath, flush under deionized water, 10 min isopropanol bath, flush under deionized water, 20 min ultrasonic deionized water bath at 60 °C, and drying with nitrogen (procedure suggested by IMT).

The GEM is thoroughly flushed with dry nitrogen before glueing.

3.3 Alignment and glueing of the substrates

The substrates are carefully aligned with respect to a defined fiducial point on the support frame by means of a 3D coordinate measuring table and a dedicated glueing jig. Figure 4 shows the situation just after the alignment process. The alignment precision is of the order of 5 to 10 μm. The substrates are glued with room curing epoxy, Stycast 2057 [5)].

Figure 4: Aligned substrates on the glueing jig.

3.4 Glueing of GEM-foil and drift cathod-plane

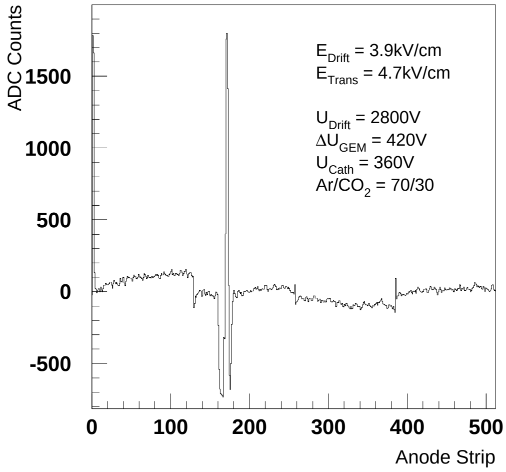
Since the GEM foil is supported only by the thin spacer frame particular care is given to the assembly procedure of the drift cathode and the GEM in order to provide enough stability to keep the GEM stretched: In a first step the drift cathodes are glued in one assembly routine between top and spacer frame. After curing this part is glued to the GEM stretched by means of a spring-loaded dedicated tool (see figure 5).

Figure 5: GEM stretched by means of a dedicated tool.

Finally, the substrate part and the drift-GEM part are joined closing the active volume of the detector module. An aluminized Kapton foil, 25 μm thick, is glued to the backside of the bottom frame to seal the gas return line. The gas flows parallel into the active detector volume, above and below the GEM, and the exhaust is redirected into the return line to remove any stress due to gas pressure from this delicate part of the detector. All glueing is done using Stycast 2057.

Since the available GEM foils are slightly too large for MF1 detector frames the active GEM area extends underneath the frames. Thus glue penetrates the holes along the frames. Therefore, after curing for 24 hours at room temperature an additional curing step in an oven at 60 °C was applied to ensure proper electrical conditions for the glue.

[5)] Emerson & Cuming, Maintal, Germany.



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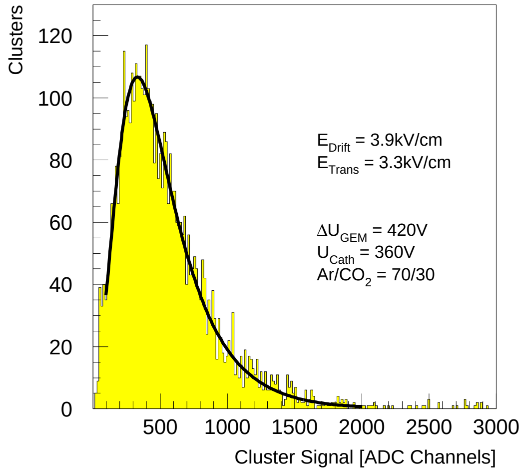

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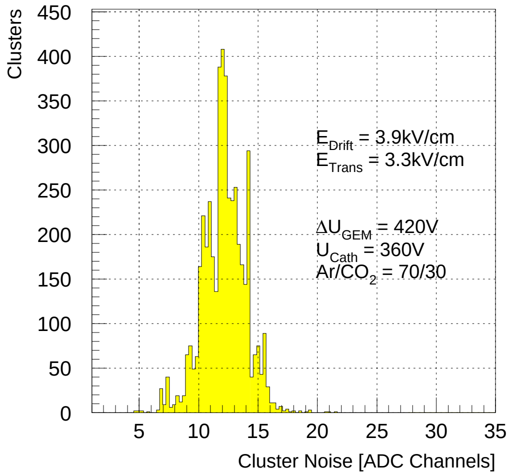

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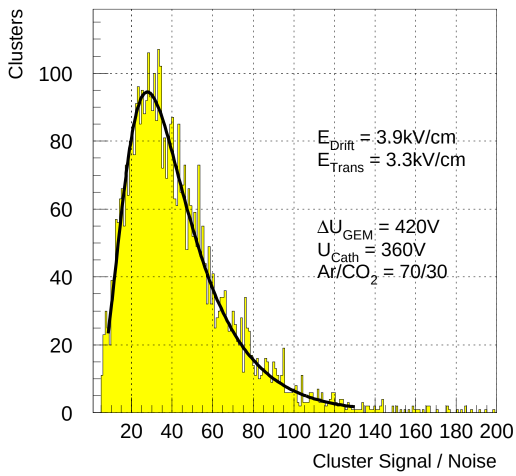

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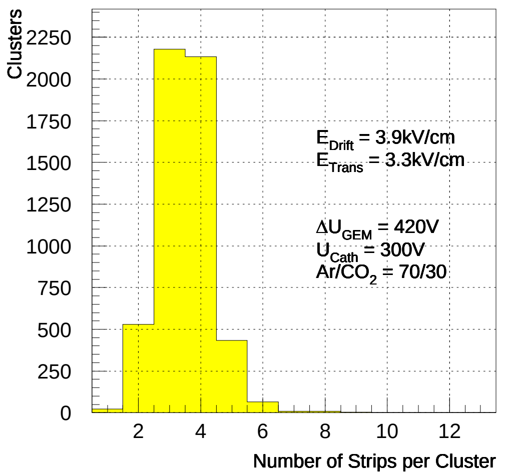

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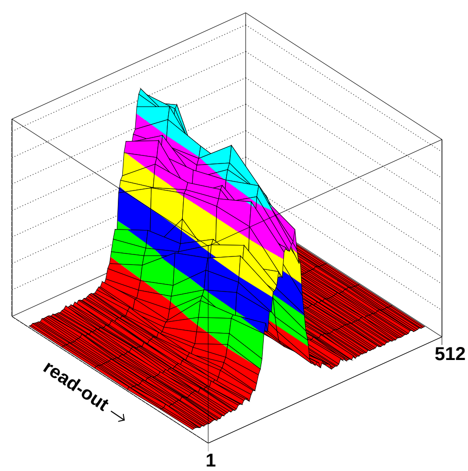

(f)

Figure 6: (*a*) detector response, (*b*) charge distribution, (*c*)signal to noise ratio, (*d*) cluster noise, (*e*) number of strips per cluster, (*e*) beam profil scan along an anode .

3.5 Connections

3.5.1 High voltage connections

All the connection pads are outside of the gas volume of the detector. Connections to the drift cathodes are made by soldering thin high voltage cables to the pads. Araldit passivation is applied on the remaining metallized structure to avoid discharges. Cathode groups are wire-bonded to a high voltage hybrid with 5 MΩ resistors for each group of 16 cathode strips preceeded by a common 10 MΩ protection resistor and a filtering capacitor of 1 nF.

3.5.2 Read-out electronics

The anodes are wire-bonded to a pitch adaptor reducing the 250 μm pitch to the 45 μm pitch of the Premux readout chip [7].

A set of 4 Premux chips, each containing 128 channels of charge preamplifiers and shaper-amplifiers plus 128 channels of double-correlated sampling circuitry and an analogue multiplexer, are mounted to form the read-out hybrid. With additional electronics, which handles token-passing and output buffering, a single Flash-ADC board channel is sufficient to read-out an entire detector module.

4 First test beam results

In order to study the operational parameters a beam test has been performed in October '98 in the T9 beam line of the CERN East Area.

A trigger on the 8 GeV pion beam was obtained by the coincidence of 2 plastic scintillators of dimensions 10×10 and 2×2 cm^2, respectively.

The detector module was sitting on an optical bench and was flushed with Ar:CO_2 in the ratio 70:30 which we consider as a cheap gas mixture with no particular safety risk.

4.1 Charge response and signal to noise ratio

A typical detector response is given by the set of plots of figure 6. These plots refer to perpendicular tracks with cathode voltage $V_{cath} = V_{GEM} = -420$ V, and drift voltage $V_{drift} = -2700$ V with an Ar/CO_2 (70:30) gas mixture.

Figure 6 a) shows a typical raw data event. The distribution of the total charge (figure 6 b)) collected in a cluster can be fitted by a Landau function as shown in the plot. The cluster noise and signal to noise ratio, S/N, defined as cluster charge over cluster noise, are shown figure 6 c) and d). The cluster noise distrubtion clearly displays the contribution of clusters with three and four strips. The number of strips per cluster is given by plot 6 e). One can see that the charge of the cluster is mainly, about 75%, shared by 3 or 4 strips. Figure 6 f)) shows a beam profile scan along an anode. It nicely demonstrates the homogeneous response of the detector.

4.2 Drift field scan

The electric field extending in the region between the drift plane and the upper side of the GEM (drift field) is particularly responsible for potential losses of primary charge [8]. Therefore, S/N has been studied as function of the drift field. From figure 7 and the fact that the drift velocity saturates around 4 kV/cm for this gas mixture [9] we conclude that a field of about 3.8 kV/cm is a reasonable choice.

4.3 Transfer field scan

Also the dependance of the detector performance on the field between the lower side of GEM and the substrate (transfer field) has been investigated. Figure 8 shows that a field higher than 3.5 kV/cm is desirable. Unfortunately, the assembly deficiency in the present prototype, glue penetrating partly into the GEM holes, prevents an operation of the detector at higher field.

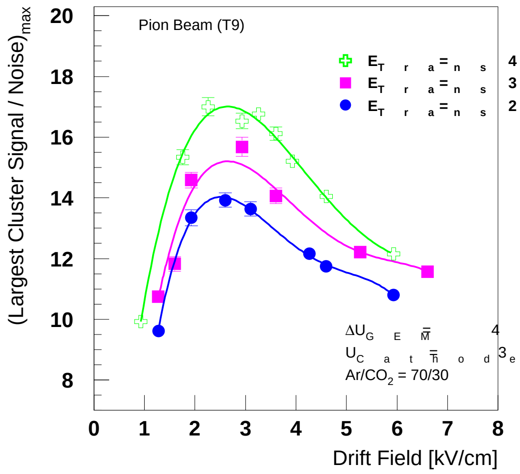

Figure 7: S/N as function of the drift field.

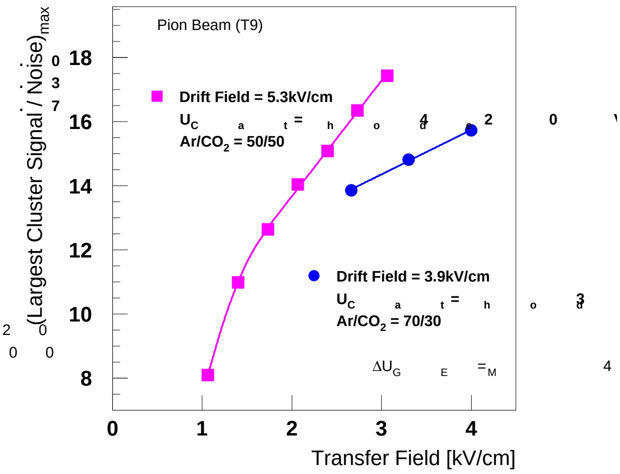

Figure 8: S/N as function of the transfer field.

5 Conclusions

This paper describes the construction of a detector module geometrically identical to MF1 with a two-stage amplification. All assembly details are given. The assembly procedure as described here allows for the construction of a large number of modules.

In a first beam test we have investigated the optimal operational parameters of this detectors. A detailed analysis of the beam studies, including the findings from a high intensity exposure at a pion beam at PSI will be described in a forthcoming paper.

References

[1] *Technical Design Report, CERN, LHCC98-6* (1998).

[2] *CMS-NOTE 1998/095*

[3] F. Sauli et al., NIM **A386** (1997) 531.

[4] R. Bouclier et al., NIM **A396** (1997) 50.

[5] *CMS forward/backward MSGC Tracker group in preparation CMS-NOTE 1999/xxx*.

[6] ATLAS Internal note INDET-NO-076.

[7] L.L. Jones, **Premux specification**, Version 2.3, 1995.

[8] J. A. Benlloch et al., NIM **A419** (1998) 410.

[9] W. Beaumont et al., NIM **A413** (1998) 105.