Gas Electron Multiplier Beam Profile Monitor

Kondo Gnanvo, Leszek Ropelewski, Fabio Sauli, Jens Spanggaard, Gerard Tranquille

Abstract—**Multi Wire Proportional Chambers (MWPC's) are used in many transfer lines and experimental areas at CERN. These chambers are mostly used for beam steering but can also provide reliable profiles measurements. MWPCs, however, also present intrinsic limitations such as limited spatial resolution and gain drop at high rate. Experience shows that MWPCs are fragile and expensive both to produce and repair. Profile measurements from MWPCs can not always be trusted. This is the case with the chambers installed in CERN's low energy Antiproton Decelerator (AD) which are not only destructive for the beam, but, also strongly perturb the profile measurement due to the low energy of the AD beam. For these reasons, we have developed a new, robust, low cost and high precision profile monitor based on Gas Electron Multiplication (GEM). Our GEM detector is designed to be backward compatible as a direct replacement for our old MWPCs. The GEM detector perform simultaneous profile measurements in the both X and Y plane. This paper presents the two first prototypes of the GEM profile monitor and report on measurements from both low energy and high energy beams. Finally highlights and drawbacks of both detectors are discussed with a view to replace MWPCs with GEMs for many applications at CERN.**

Index Terms—**Gaseous detector, GEM, Profile monitor.**

I. Introduction

BEAM profile measurement are made using MWPC's on the extraction lines of the CERN's antiproton decelerator (AD) as well as on the SPS north area experimental lines.

For the AD, the energy of interest is very low (5.3 MeV) which implies that the MWPC is installed in a vacuum tank. Moreover the antiprotons are annihilated by the first H-plane of the chamber so that measurement on the downstream V-plane are drastically perturbated. The use of the GEM based detector is aimed to avoid this drawback and to enable a more precise profile measurement of the beam in both planes.

The simple construction and the performances of the GEM chambers also make them suitable to replace the MWPC's on higher energy beam lines such as for the PS and SPS north areas experimental lines.

After a brief description of the GEM technology and the GEM profile monitor arrangement, we present the results of the tests meeasurements on the AD, PS and SPS extraction and transfer lines and the discussion for the future.

II. Gas Electron Multiplier based profile monitor

A. The GEM detector

A micro pattern gaseous detector operating as with gas electron multiplier (GEM) has been introduced in 1996 by the detector group headed by Fabio Sauli at CERN. [1]. The main feature of this chamber is the GEM that consists of a double sided thin metal-clad polymer foil, perforated with a high density of chemically etched holes (typically ten thousand per square centimeter). On application of a potential difference between the two sides, the foil acts as a charge multiplier for electrons produced by ionization in the gas. A patterned charge-collection anode permits the detection and localisation of the primary ionization [2], [3].

The GEM chamber is an assembly of a window foil, a drift cathode, 1,2 or 3 GEM foils and a readout plane on a substrate, defining the separated stages of the ionisation zone, the amplification zone and the charge transfer zone to the readout. This separation in different stages ensures a flexibility on the readout pattern and a better control of discharge in the chamber. A resistance network is needed to apply the specific high voltages to the differents stages.

B. Principle of GEM profile monitor

GEM detectors have been developped for HEP experiments like for COMPASS at CERN [4]. Nevertheless, we propose to use them for beam profile measurements as previously done for MWPC's. Some modifications of a standard GEM detector has been done to

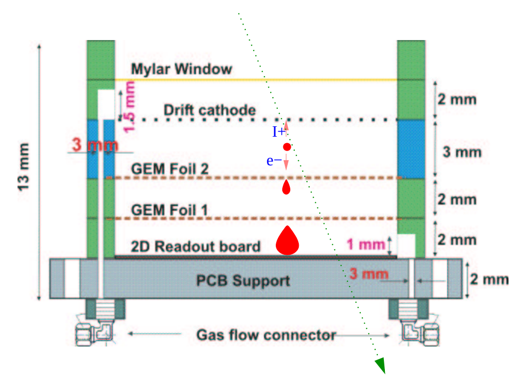

Fig. 1. Double GEM Profile monitor drawing.

- ◇ reduce the matter seen by the beam using a 50 μm micro-mesh nickel foil with more than 80% transparency for the particle as drift cathode.
- ◇ render the GEM chamber compatible with the existing electronics for the old MWPCs. Therefore different adapters have been developped to ensure a flexible use of the chamber for the CERN AD, PS and SPS beam lines.
- ◇ fit into the specific mechanical installations (support and dimensions etc...) available for the MWPC's on the AD, PS and SPS beam lines.

Fig. 1 shows a drawing of a double GEM detector. The GEM foils as well as the nickel micro-mesh drift cathode and the

20 μm Mylar window are glued on respectively 2 mm, 3mm and 2mm thick $124\text{mm} \times 124\text{mm}$ frames and then glued to the readout board (see Fig. 1). The readout consists of 2D cartesian pick-up strips ([3]) with a pitch of 400 μm, this gives 256 strips per plane on a 2 mm thick semi-circular subtrate. The width of the upper electrode strips is 80 μm and 340 μm on the lower plane. The 256 strips on each plane, are later regrouped four by four into 64 channels by the means of an adapter board. The chamber has an active area of $100\text{mm} \times 100\text{mm}$. All the elements except the micromesh cathode foil, used to build have been made at CERN and the GEM foils are standard in the CERN store.

C. Construction of three prototypes

Three prototypes of the GEM profile monitor have been built. The first, a single GEM chamber tested in open air on the AD/DEM low energy antiproton beam line. The second chamber is a double GEM installed in a vacuum tank integrated on the AD/DEM beam line to perform profile monitoring of the low energy antiproton beam. The third chamber, a triple GEM, has been installed on the SPS M2 and X7 beamlines for the high energy particles measurement. Fig. 2 is a photo of the triple GEM chamber. The circular shape is aimed to fit with AD vacuum tank mechanical conditions.

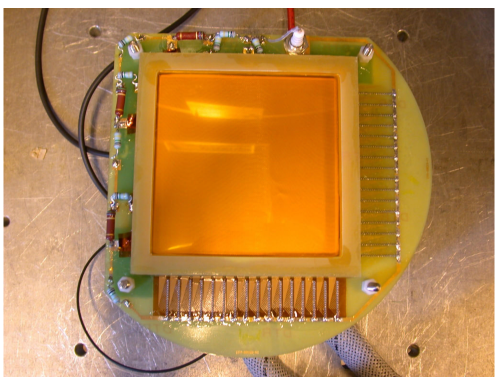

Fig. 2. triple GEM Profile monitor photo.

III. Laboratory Tests & Measurement on beam

A. The laboratory test of the GEM profile monitor

Different preliminary tests have been done for the validation of the chamber before installation on the beam. The validation procedure described in [5] has been done with the collaboration of Fabio Sauli and Leszek Ropelewski at CERN/PH/TA1/GDD section.

The validation of the chamber is followed by the measurement of the gain uniformity for each GEM chamber. For this purpose, we have set up a test bench with a ^{90}Sr source to uniformly irradiate the chamber under a 70/30 Argon-CO2 mixture gas flow. The avalanche charges produced by GEM are received by the 64 channels on each plane and collected by 64 integrators of the existing test bench for the MWPCs. Fig. 3 shows a very good gain uniformity for both horizontal and vertical planes for the triple GEM chamber with a high voltage of 386 V on each GEM foil, a drift field of 2280 V/cm and a transfer and induction field of about 3420 V/cm. An equal sharing of the charges between the superimposed readout planes can be deduced from the two figures. The test bench for the gain uniformity is suitable for the double and the triple GEM chamber. The single GEM could not be tested this way because the integrators we used are not sensitive to the very low signal of a single GEM chamber. The three GEM chambers have

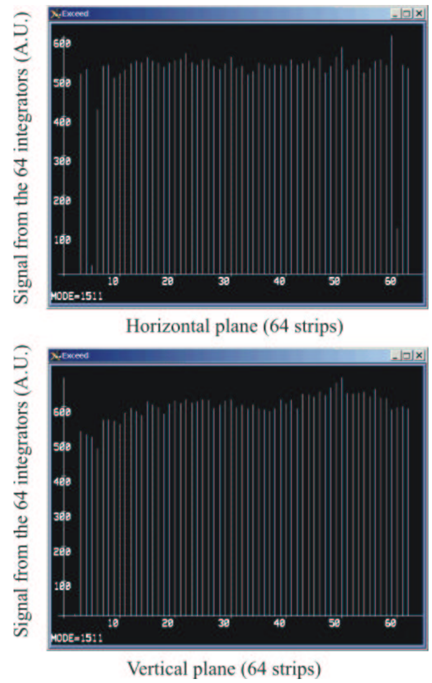

Fig. 3. Gain uniformity of the triple GEM monitor with a 70/30 $\mathrm{ArCO_2}$ gas mixture irradiated by ^{90}Sr.

been developped to be tested on different beam conditions in order to study the replacement of the MWPCs used on different extraction and experimental lines at CERN.

B. Beam profile measurement on AD/DEM

The AD machine at CERN is for the production of low energy (5.3 MeV) antiproton beam for four antimatter experiments ATRAP, ATHENA, ASACUSA and ACE. The antiproton beam of an intensity of a few 10^7 particles is extracted within about 200 ns after a 2 min cycle. The short extraction time leads to a high instantaneous beam current such that the gaseous detectors used for profile measurement are used in a low gain mode to avoid discharge, or space charge effects in the chamber.

First a double GEM chamber was tested the AD/DEM beam line. The chamber in a vacuum tank is integrated on the beamline and can be inserted or removed from the beam via to an in & out system. Each plane is connected to 16 integrators used for the AD MWPCs to collect the signal data. Figure 4 shows the profiles in both planes of the double GEM. A displacement of the profile in the horizontal plane is observed

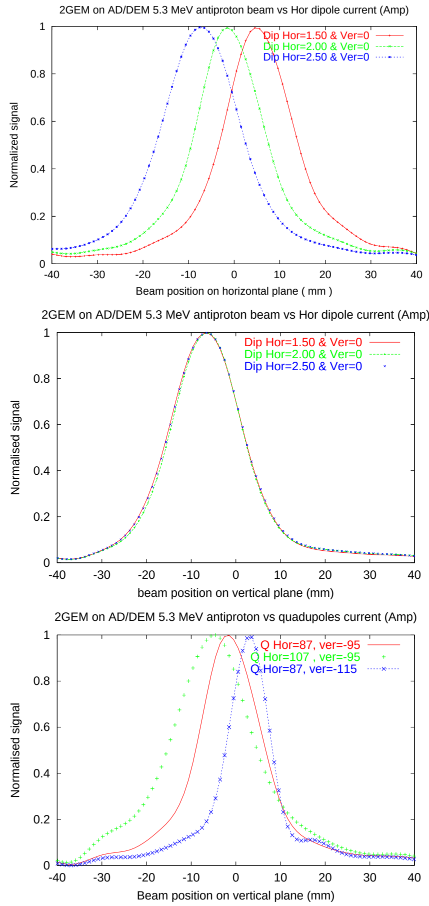

Fig. 4. Profile Measurement of the double GEM on the AD/DEM 100 MeV/c antiproton beam.

when we change the horizontal dipole current used for steering the machine, at the same time we can see there is no shift for the vertical position. The third graph shows the profiles when the beam is focused (linespoint) or defocused (cross) in the vertical plane. The shift between the three profiles shows that beam is not centered in the quadrupoles.

In the AD, a single GEM chamber with a lower gain is more appropriate. Measurement have been done with a single GEM chamber prototype in open air and direct comparisons with MWPCs was possible. We see on the figure 5, the profile measured in the same 300 MeV/c antiproton beam condition for the single GEM and a standard MWPC. Good profiles in both horizontal and vertical planes are obtained with the single GEM chamber whereas the MWPC provides more distorted profiles specially in the vertical plane.

The results obtained are completed by the profile measurement at different applied high voltages (see Fig. 6) on the chambers in order to increase the gain and thus the charges received by the integrators. We observe for all chambers some profile shape distortion for high values of the applied voltage for the 300 MeV/c antiproton beam. The distortion is more pronounced for the MWPCs and the double GEM than for the single GEM chamber. We suspect these distorted distribution

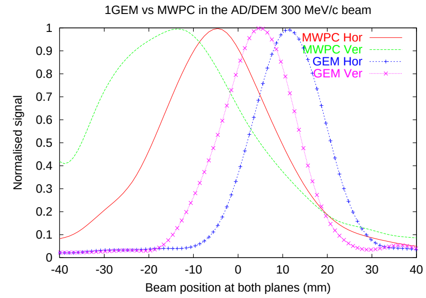

Fig. 5. Profile Measurement comparaison between a single GEM and a standard MWPC on the AD/DEM 300 MeV/c antiproton beam.

could be explained by a non linearity of the charge integrator response at high rate. This phenomenon is under investigation. We can nevertheless conclude that for the AD machine, a single GEM chamber appears to be the more interesting for us as a beam profile monitor.

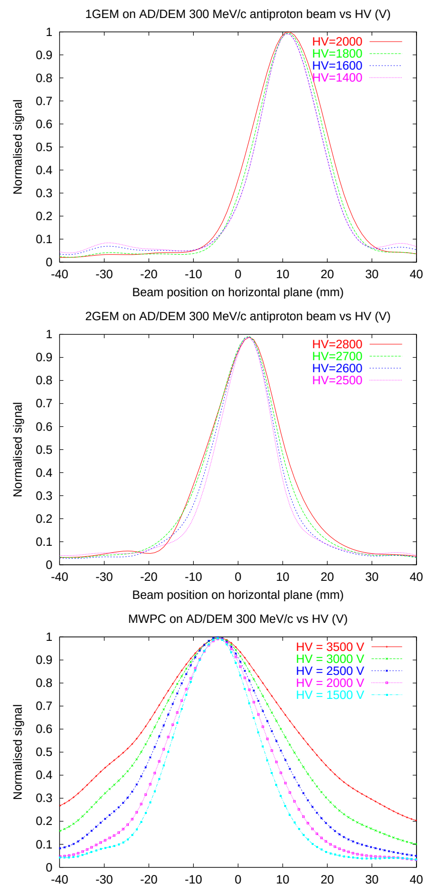

Fig. 6. Profile from the single GEM, double GEM and a MWPC on the AD/DEM 300 MeV/c antiproton versus the high voltage.

C. Beam profile measurement on SPS/NA/M2

A second set of tests have been performed on the CERN Super Proton Synchrotron (SPS) experimental beam lines. A triple GEM chamber prototype has been installed on the SPS

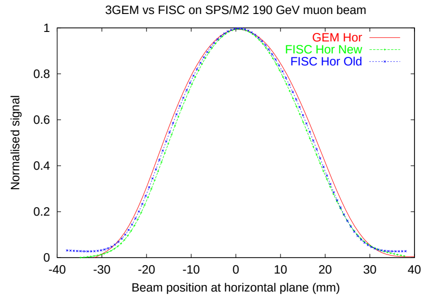

Fig. 7. Profile comparison between a triple GEM and a FISC on the SPS/NA/M2 190 GeV/c hadron beam.

north area Muons beam line (SPS/NA/M2). The M2 beam line is a hadron beam (65% of protons, 32% of pions and 3 % of kaons) of a nominal energy of 190 GeV and with an intensity of around 5 10^5 particles per 2.5s spill.
The triple GEM chamber uses the existing analog electronics for the conventional MWPCs made of 32 integrators for each plane.

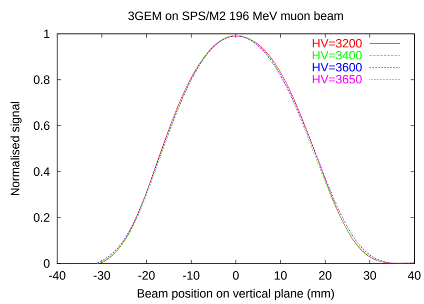

Fig. 8. Profile from a triple GEM versus the high voltage

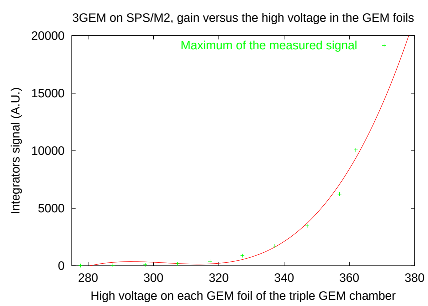

Fig. 9. Gain of the chamber (A.U.) versus the applied High voltage

On figure 7, we have profile from the triple GEM chamber compared to the results obtained from a FISC (Filament Scintillator see [6]) also used in different SPS experimental lines as a beam profile monitor. The FISC can be used in two modes. The fast mode which gives the profile by scanning the beam during the the spill and the slow mode where the filament is positioned in the beam at each spill and moved to another position between the spills. We have a very good agrement between the the two profile monitors.

Figures 9 show some results from a high voltage tests of the triple GEM on M2 beam. On the first graph , the measured profile is the same over a wide interval of the high voltage of the chamber. This is an interesting result as we would like to use the chamber for different intensity beam available on the SPS experimental lines. We can see on the second graph a plot of the maximum relative gain of the chamber with respect to the high voltage on the chamber. We can predict then the lower limit of the beam intensity needed to have a good profile with the GEM chamber.

Fig. 10 and 11 show measurement at different intensities (from 5×10^4 to 4×10^5) of a 120 GeV electron beam at the SPS west area X7 beam line with the triple GEM. The measurement were done for a high voltage varying from 3900 to 4000 V. Fig. 10 show the profiles obtained at 4000 V at different intensity. Our prototype can be used for intensity beam as low as as 4×10^4 pps. But we can expect to measure profile from lower beam intensity if we have a cleaner chamber than the prototype we built which have a limitation of the applied voltage to 4000 V to avoid discharge. On Fig 11 we have a linear response of the chamber with the beam intensity at different. Once again from these graphes we can expect to have a profile measurement for a beam at intensity under 1×10^4.

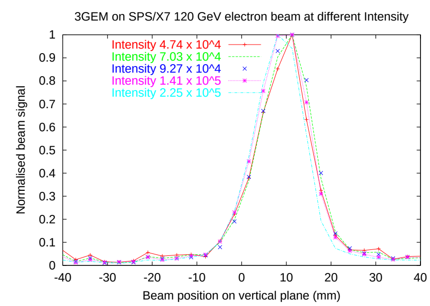

Fig. 10. Profile from a triple GEM at SPS/X7 at low intensity beam

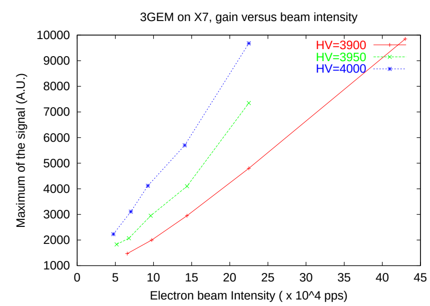

Fig. 11. Gain of the chamber (A.U.) versus the beam intensity

IV. Discussion & Perspectives

The tests results from three prototypes of GEM chambers that we have built allow some comments for the future.

1) The first concerns the tests with the single and double GEM chamber on the low energy at the AD/DEM experimental line. As we were expecting and forecasting in a previous paper [7], the single GEM chamber gives excellent results in comparison with the ones obtained from a conventional MWPC and even a double GEM chamber. Problems of gain saturation due to the high

pulse intensity antiproton beam at the AD, or electron diffusion due to the low electric field when using a MWPC or a double GEM are optimised for the single GEM chamber and thus, profile measurement in both planes with this chamber gives very good results.

We have also tested an ionisation chamber using the same readout as for a GEM chamber but without GEM foil amplification stage. The first results obtained with this new concept were not conclusive.

2) Concerning the low extraction beam conditions with a lower beam intensity such as for the PS and SPS experimental lines, a triple GEM prototype appears to be a good candidate for the replacement of the MWPCs. Results from our tests at high energy hadrons beam at SPS/M2 and low energy muon beam at SPS/X7 shows that the triple GEM could operate with a beam intensity under than 10^4 pps. In order to improve the capacity of the triple GEM chamber, and make it operational at lower intensity, care should be taken during the fabrication of the chamber to eliminate any source of impurities in the chamber that lead to discharges in the chamber at high voltage. The chamber should be as clean as possible to be used at higher gain.

   We could also increased the ionisation stage width (fom 3mm to 10 mm) to enable a higher the number of primary ionisation charges. This would give a better signal at a lower voltage applied on the chamber. If these conditions are fulfilled, we can reasonably expected to use a triple GEM chamber as a profile monitor for a beam with an intensity of about 10^4 pps as we can have for some PS experimental lines.

3) The last point is the fabrication of such chamber entirely done at CERN at low cost compared to the fabrication cost of a MWPC. We can say that a fabrication of a triple GEM chamber is about 5 times cheaper than the MWPC used for the CERN experimental lines and the performances are as we have shown better for the low energy beam and equivalent for the high energy particle beams.

V. Conclusion

We have designed and constructed a new beam profile monitor based on GEM detector technology as an alternative to MWPCs used on the CERN AD, PS and SPS experimental and transfer beam lines. Successful tests have been done on different beam conditions.

At low energy as such as the AD, this new chamber allows a more precise beam profile measurement than a conventional MWPC. Results obtained from tests on the AD low energy and high intensity antiproton beam, have been presented in this paper. We have tested two prototypes (double and single GEM foils chambers) on the antiproton beam of momentum equal to 100 MeV/c and 300 Mev/c . The single GEM chamber appears to be the ideal solution as it enables a good profile in both planes. The higher gain of the double GEM chamber is not required for the high pulse intensity beam at the AD. Moreover high gain chamber leads to a saturation effect that can degrades the measured profile. Nevertheless both GEM chambers give better results than conventional MWPCs.

For the higher energy beam in the SPS M2 and X7 beam lines, the we have a very good agreement on the profiles provided by the triple GEM prototype and existing beam profile monitor such as the FISCs or MWPCs. We also made some intensuity measurement to evalute the lower beam intensity required for a triple GEM to give a good profile measurement.

Small technical improvements are required for a future production of the GEM chamber in order to replace the MWPCs used as beam profile monitor in the SPS, AD, PS beam lines.

Acknowledgment

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