GEM DETECTORS FOR THE TRANSVERSE PROFILE MEASUREMENT OF LOW ENERGY ANTIPROTONS AND HIGH ENERGY HADRONS

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Abstract

Gas Electron Multipliers (GEM) are finding more and more applications in beam instrumentation. Gas Electron Multiplication is a very similar physical phenomenon to that which occurs in Multi Wire Proportional Chambers (MWPC), but for small profile monitors GEMs are much more cost effective to produce and maintain.

In 2012, all Multi-Wire Proportional Chambers in the experimental areas of the Antiproton Decelerator at CERN were successfully replaced by Gas Electron Multipliers. This paper describes the choice of detector and reports on the commissioning of 20 GEM detectors for transverse profile measurement on low energy antiproton beams (5.3 MeV, equal to 100 MeV/c). It will also cover the development of, and first results from, a new 200x200 mm GEM detector for profiling the high energy muon beam (172 GeV/c) delivered to the COMPASS experiment and discuss the outlook for replacing all Multi-Wire Proportional Chambers in the CERN experimental areas by GEM based monitors.

INTRODUCTION

Over the past two years, we have had the opportunity to develop and test GEM detectors for transverse profile measurements on both low energy antiproton beams and standard high energy hadron beams.

On the extraction lines of CERN's Antiproton Decelerator, beam profile measurements were made using MWPC. The technology of these chambers is such that, at the energy of concern (5.3 MeV), the antiprotons are annihilated in the first H-plane so that measurements made in the downstream V-plane are drastically perturbed. Moreover these rather fragile detectors were installed some 20 years ago and their acquisition system had become completely obsolete.

In order to overcome the MWPC profile distortion, the GEM technology, where the profiles of both planes are produced simultaneously, was chosen and a new equipment-oriented acquisition system was developed [1].

For profile measurement and energy spectroscopy on secondary beam lines in the experimental areas of the SPS, four different types of MWPC have been used over the last 38 years: Standard 100x100 mm MWPC, 200x200 mm muon MWPC, Digital MWPC and Delay Wire Chambers, DWC [2].

Also here these chambers require important resources and infrastructure to maintain and so far we have investigated the possibility to replace the first two types with GEM based detectors. A GEM based replacement of the popular DWC will be dealt with in a separate paper.

GEM BASED PROFILE MONITORS

Historical Background

The micro pattern gaseous detector operating as a gas electron multiplier (GEM) was introduced at CERN in 1996 by Fabio Sauli [3].

Detector Arrangement for Antiprotons

Our GEM chamber for low energy antiprotons is an assembly of a thin combined drift-cathode/gas-window, 1, 2 or 3 GEM foils and a readout plane on a substrate together with a set of resistor network to apply high voltages to the various electrodes in the chamber.

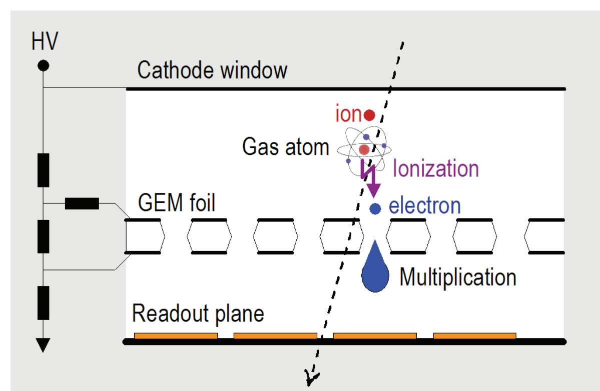

Figure 1: GEM detector principle.

Fig. 1 shows a schematic drawing of our GEM chamber containing a single GEM foil. The combined gas-window/cathode is a crucial element to minimize absorption and multiple scattering of the beam. It is made of the same base material as GEM foils: copper-clad polyimide. The copper is etched away in the active area of the detector, leaving just a thin 100 nm layer of chromium which is there to act as a tie coat for a better adhesion of the copper layer to the polyimide substrate.

The GEM-foil itself consists of a double sided 50 µm copper-clad polymer foil (like a PCB), perforated with a high density of chemically etched holes. On application of a voltage difference between the two sides, the foil acts as a charge multiplier for electrons produced by ionization in the gas. A patterned charge-collection read-out plane [4 and 5] permits the detection and localization of the primary ionization. All elements of the chamber have been manufactured at CERN and the GEM foils are standard items from the CERN store.

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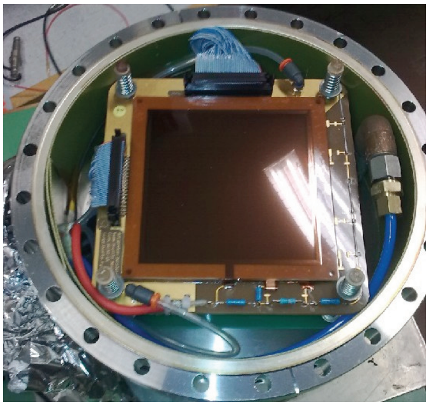

Figure 2: Single-GEM device installed inside the pendulum.

In 2011 the first such prototypes were installed in the experimental areas of the AD and first measurements were very encouraging. It was therefore decided to replace all MWPC and produce and install 20 new GEM based profile monitors in all transfer lines.

CERN's Antiproton Decelerator delivers antiproton beam at two different energies. The antihydrogen experiments ALPHA, ASACUSA, ATRAP and AEGIS receive 5.3 MeV kinetic energy beams (100MeV/c) while the ACE experiment for cancer therapy uses higher energy beams of 126 MeV (502 MeV/c).

The 20 new detectors were installed inside in-out pendulums (fig. 2) for the 2012 startup where intensive validation tests were carried out at both energies. It was even shown that, at nominal intensity of 35 million particles per 150 ns spill, a detector was able to operate as an ionisation chamber without a GEM foil, but only at the lower energy where ionization is more than an order of magnitude stronger and where also annihilation sets in.

Figure 3 shows the new graphical user interface, GUI, developed for operation and the operator can now for the first time rely on these profile measurements for beam steering. The transverse profiles have proven much more precise and the blow-up effect observed on the second plane using MWPC [6] has now completely vanished.

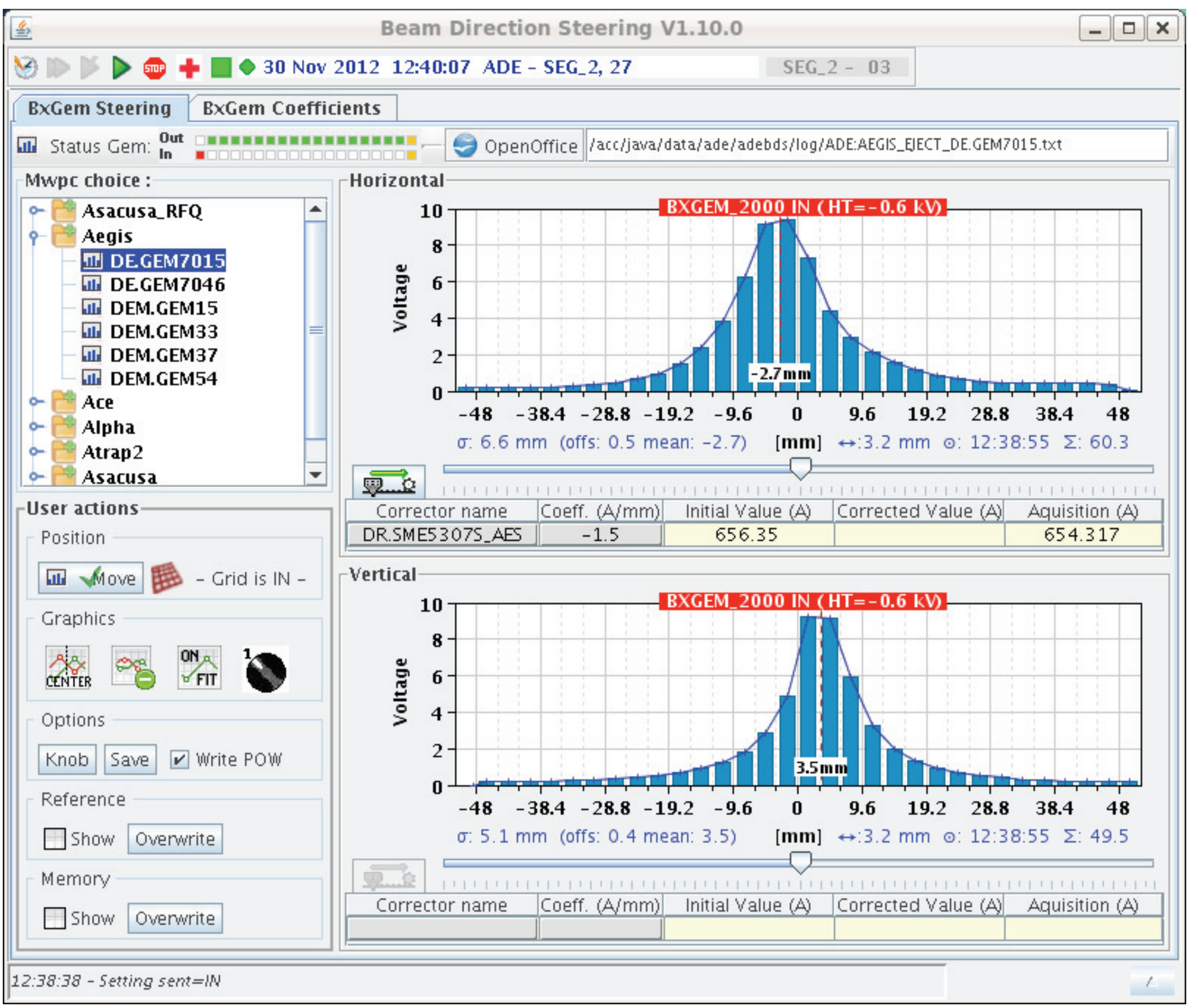

Figure 3: Simultaneous horizontal and vertical readout from a single-GEM detector using the new acquisition system. The 32 channel profiles are here acquired with 3.2 mm resolution. 1.6 mm pitch is also an option.

Detector Arrangement for high energy Hadrons

Historically some 80 MWPC of different types have been used for both transverse profile measurement and energy spectroscopy in the experimental areas of the SPS. On the M2 beam line used for COMPASS, 'big' 200x200 MWPC are installed whereas standard 100x100 mm MWPC are used in most other areas. On all these high energy beam lines, typically with energies above 10 GeV, intensities are often much lower and 2-3 order higher gain is therefore required. On the other hand there are not the same issues with multiple scattering and annihilation as at the Antiproton Decelerator described above.

Looking for candidates to replace the MWPC, it was therefore possible to give more priority to the robustness of the new detector and prioritising an industrial design enabling low cost and low maintenance need.

To this end a standard triple-GEM chambers as well as a 'big' triple-GEM chamber were developed and tested towards the end of the 2012 run.

Especially for the 'big' GEM (200x200 mm), bulging of the combined cathode/gas-window is an issue and this window is also (as on the MWPC) very fragile. We have therefore chosen to cover the complete entrance window, as well as the back of the readout plane, with a very light but stiff 4 mm ROHACELL cover. This does add to the material budget (Xo) but is negligible at these energies.

First measurements from a 'big' GEM prototype on the M2/COMPASS beam line can be seen in figure 4. During the test this new detector, called XGEM.065.057, replaced a large MWPC (XWCM.065.057) installed 1057 metres downstream to the target. The only difference that could be observed on the profiles given by the two detectors was a more smooth shape on the GEM profiles.

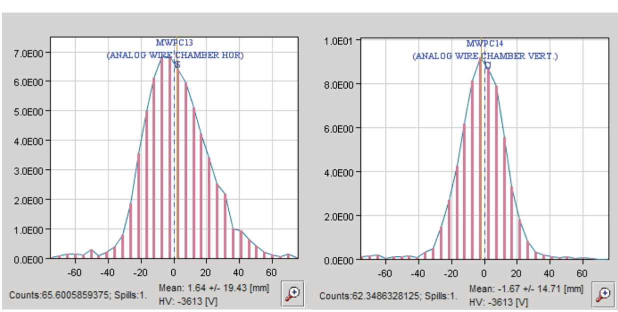

Figure 4: First profile readouts from the 'big' prototype GEM (200x200mm) on December 2nd 2012.

Also the standard 100x100 mm triple-GEM tested on the H4 and H6 beam lines gave satisfactory results as a promising candidate to replace old MWPC at the SPS.

OUTLOOK

CERN is planning to produce antiprotons at even lower energy. A future additional decelerator, ELENA, will provide ultra-low energy phase-space compressed beam, enhancing the number of usable pbars by up to 2 orders of magnitude with respect to that of a simple degrader foil. Even though GEM chambers are now deployed with success everywhere at the Antiproton Decelerator, we do not believe that GEM technology is suitable for profile measurements at ELENA which will bring the antiprotons down to only 100keV. Antiprotons will be stopped by any material at these energies and we now plan to simply place a wire plane directly inside the vacuum tube and read it out as a secondary emission monitor, SEM, grid.

For high energy applications at CERN, on the other hand, we hope soon to be able to replace the vast majority of MWPC in the experimental areas of the SPS.

CONCLUSION

We have demonstrated that Gas Electron Multiplier technology can be used to replace Multi Wire Proportional Chambers in most applications for transversal profile measurement.

20 new single-GEM detectors have been validated with success as low energy profile monitors in the transfer lines of CERN's Antiproton Decelerator. Our new GEM devices allow more precise beam profile measurement than a conventional MWPC and recent results obtained from tests on the AD low energy, high intensity antiproton beam, have been presented in this paper.

Furthermore two triple-GEM prototypes (100x100 mm and 200x200 mm) have been tested on different hadron beams in the experimental areas of the SPS. The results are also here very promising even though the material budget in terms of Xo could be an issue in a few special cases. However, all these devices are motorized and can easily be moved out of the beam.

Finally these GEM chambers are more cost-efficient to produce and much more robust to handle than the multi wire proportional chambers used so far.

ACKNOWLEDGEMENT

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