GAS ELECTRON MULTIPLIERS FOR LOW ENERGY BEAMS

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Abstract

Gas Electron Multipliers (GEM) find their way to more and more applications in beam instrumentation. Gas Electron Multiplication uses a very similar physical phenomenon to that of Multi Wire Proportional Chambers (MWPC) but for small profile monitors they are much more cost efficient both to produce and to maintain. This paper presents the new GEM profile monitors intended to replace the MWPCs currently used at CERN's low energy Antiproton Decelerator (AD). It will be shown how GEMs overcome the documented problems of profile measurements with MWPCs for low energy beams, where the interaction of the beam with the detector has a large influence on the measured profile. Results will be shown of profile measurements performed at 5 MeV using four different GEM prototypes, with discussion on the possible use of GEMs at even lower energies needed at the AD in 2013.

INTRODUCTION

On the extraction lines of CERN's antiproton decelerator, beam profile measurements are made using MWPC chambers. 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 is now 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.

We describe four detector prototypes for profile measurement as well as the newly developed VME-board for the acquisition of profiles. Recent results from beam tests on the AD extraction and transfer lines are presented and needs for even lower energy profile measurement are discussed with an outlook to the future low energy facility, ELENA, at the antiproton decelerator.

GEM BASED PROFILE MONITOR

Electron Multiplication

The micro pattern gaseous detector operating as a gas electron multiplier (GEM) was introduced at CERN in 1996 by Fabio Sauli [1]. A GEM foil 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].

Detector Arrangement

Our GEM chamber is an assembly of a window foil, a drift cathode, 0, 1, 2 or 3 GEM foils and a readout plane on a substrate with a set of resistor network to apply the specific high voltages to the different stages of the chamber.

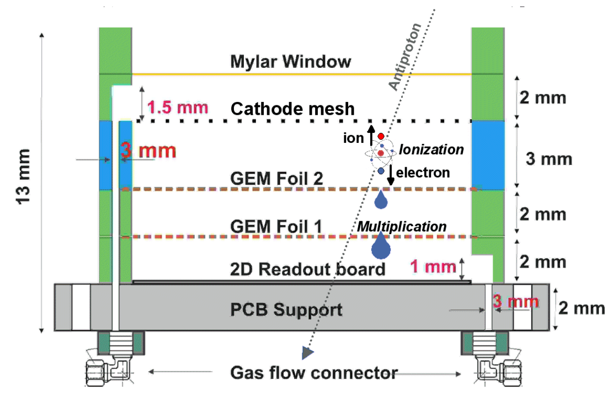

Figure 1: GEM detector principle.

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 have an active area of 100×100 mm. They are glued on respectively 2 mm, 3mm and 2mm thick 124×124 mm frames and then glued to a readout board that consists of 2D cartesian pick-up strips [3] with a pitch of 400 µm. In order to have an equal charge distribution between the two planes, the width of the upper electrode strips is only 80 µm where as the lower plane has 340 µm strips. All elements of the chamber, except the cathode mesh, have been manufactured at CERN and the GEM foils are standard items from the CERN store.

Four Detector Protypes

The mechanics of our GEM profile monitor was first described in 2004 [4]. The project was then abandoned due to an uncertain future of the AD machine at CERN.

AD is now scheduled to run for many years to come and a consolidation project has been started. In the light of this recent decision we have again started to build and test new GEM profile monitors.

Four different detector prototypes have been build and tested at 5.3 MeV at the CERN Antiproton Decelerator: Triple- double- single- and "zero-GEM". The latter is in fact just an ionization chamber without any GEM-foils but with the same 2D charge-collecting readout anode.

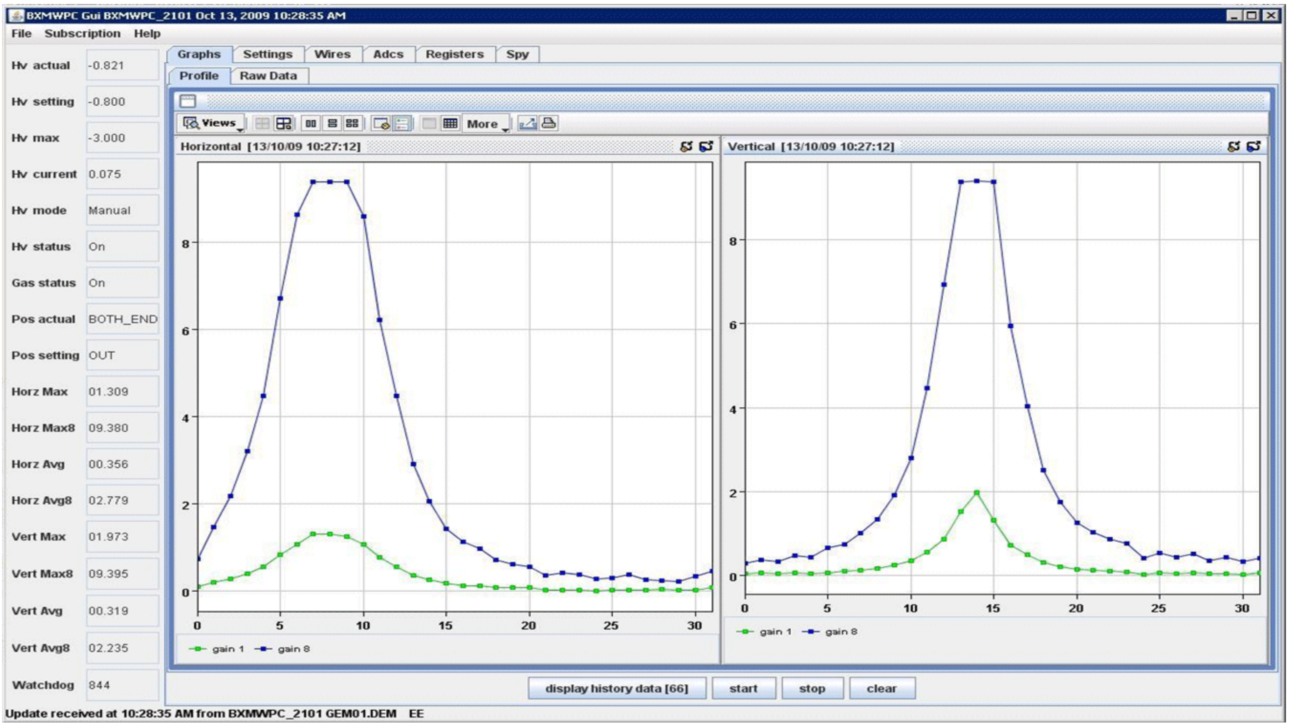

Figure 2: Profile readout from a single-GEM with the new acquisition system. As extractions only occur every 2 minutes, two different gain outputs help the user to get a decent profile reading in one go. Post processing allows you to use data from the gain-8 output if the unity gain output was too noisy. On the other hand the unity gain output can be used if the gain 8 output was saturated. Each of the 32 channels in the figure represents 3.2 mm.

Different preliminary tests have been carried out in order to validate the chambers before installation on the beam line. The validation procedure described in [5] has been done in collaboration with the CERN/PH/DT/TP section.

NEW ACQUISITION SYSTEM

The old obsolete electronics for the MWPC featured only 16 by 16 channels and a non linear resolution with 4 mm at the center and 8-16 mm close to the extremities of the chamber.

Our new GEM detectors are born with 256 by 256 channels and a high resolution of 400 um. Such a resolution is not required in the AD transfer lines. Therefore the charge-collecting strips are here grouped together by four inside the tank to provide a maximum of 64 by 64 channels outside. Our new acquisition system has been designed with 32 by 32 channels. A summary of possible resolutions (default in bold) is given in Table 1.

The electronics to acquire the profiles from the GEM is divided in local integrators close to the detector and a new equipment-oriented VME board [6] in the control room. The two units are linked via a serial connection providing both a unity gain and a gain 8 output for simultaneous acquisition.

Expert Application

The VME front-end computers with the LynxOS real time operating systems use FESA, the CERN Front-end Software Architecture. This is a framework that facilitates the creation of low-level software. It relies on a formal description of the device, which is used to generate device drivers, data structures and Graphical User Interfaces for experts. Such an expert application, providing 32 channel profile readouts, is shown in Fig. 2 above.

Table 1: Summary of possible readout resolutions.

Resolution [um]	Active area [mm]	Number of channels	Regrouping
400*	100 x 100	256 by 256	(*not used)
1600	100 x 100	64 by 64	4 strips
1600	50 x 50	32 by 32	4 strips
3200	**100 x 100**	**32 by 32**	**8 strips**

BEAM MEASUREMENTS

All profile measurements were made on the AD/DEM line at 100 MeV/c (5.3 MeV kinetic). The AD typically deliver 120 ns spills of 3.5x10^7 particles every 2 minutes.

At this nominal AD intensity even the "zero-GEM" ionization chamber gave excellent profiles (Fig. 3). However, this detector had to be operated at 2-3 kV (corresponding to 7-10 kV/cm) with little room to raise the gain. Detectors equipped with GEM foils have much more margin to cope with lower intensity beams.

However, the relative high gain of the double- and triple-GEM might lead to saturation effects that can degrade the measured profile. The fast extraction from the AD machine results in a very high instantaneous beam current. Under certain circumstances discharge or space charge effects inside the chamber have been observed. This is particularly true with the MWPC.

The best choice for the AD seems to be the single-GEM where the profile reproduction is good and there still is a good margin for extra amplification. Playing with the high voltage divider, these detectors do even open the flexibility to work either as an ionization chamber or as a GEM with a higher gain.

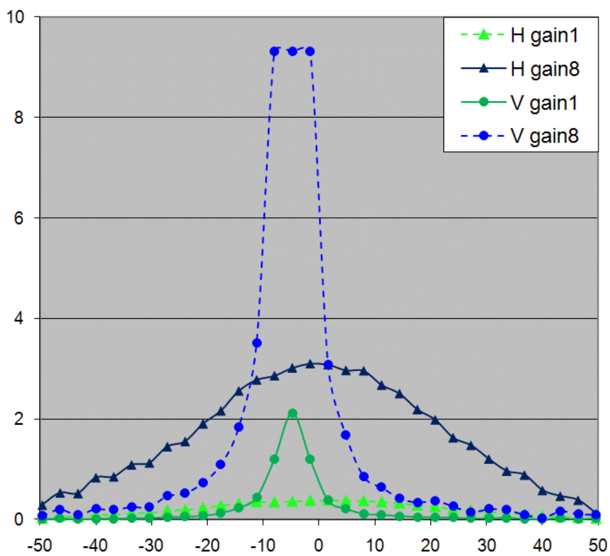

Figure 3: Ionization chamber / "zero-GEM" profile at a position where the horizontal profile is very broad. The gain 8 output from the vertical profile is saturated.

Single-GEM Voltage Divider

Figure 2 show the horizontal and vertical profiles of a single-GEM operated at 800 volts. The detector receives its different high voltages from a simple voltage divider fitted with resistor protection against discharge. Applying 800 volts to the cathode mesh result in the following internal electrical fields: A drift field of 1000 V/cm, a GEM foil voltage of 200 volts and an induction field of about 1500 V/cm.

OUTLOOK

The observed blow-up [7], especially on the second plane of the old MWPCs, has not been seen with any of the new GEM prototypes but more beam measurements at different energies are need in order to quantify this parameter. It is also planned to run simulations on the interaction between antiprotons and material from windows and cathode mesh at low energy.

Furthermore, 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. This 26 m circumference machine is planned for 2013. The instrumentation needs of this facility are not yet specified but we intend to look into the possibility of using GEMs at even lower energies than presently at the AD.

CONCLUSION

Gas Electron Multiplier technology seems to be a good choice to replace Multi Wire Proportional Chambers as low energy profile monitors in the transfer lines of CERN's antiproton decelerator. Our new GEM allows more precise beam profile measurement than a conventional MWPC. Results obtained from tests on the AD low energy, high intensity antiproton beam, have been presented in this paper. We have tested four prototypes on the antiproton beam with momentum equal to 100 MeV/c and 300 Mev/c. The "zero-GEM" ionization chamber provides an excellent true profile but it has no gain reserve for lower intensities. The high gain of the double- and triple-GEM might leads to saturation effects that can degrade the measured profile.

Finally the single-GEM chamber appears to be the ideal solution as it combines a good profile readout with a reasonably margin for measuring on low intensity beams. After final tests planned for this coming run, a series production of 25 profile monitors will be launched with the aim to replace all old MWPC for the 2011 start-up.

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