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A beam monitor based on MPGD detectors for hadron therapy

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Abstract. Remarkable scientific and technological progress during the last years has led to the construction of accelerator based facilities dedicated to hadron therapy. This kind of technology requires precise and continuous control of position, intensity and shape of the ions or protons used to irradiate cancers. Patient safety, accelerator operation and dose delivery should be optimized by a real time monitoring of beam intensity and profile during the treatment, by using non-destructive, high spatial resolution detectors. In the framework of AMIDERHA (AMIDERHA - *Enhanced Radiotherapy with HAdron*) project funded by the Ministero dell'Istruzione, dell'Università e della Ricerca (Italian Ministry of Education and Research) the authors are studying and developing an innovative beam monitor based on Micro Pattern Gaseous Detectors (MPDGs) characterized by a high spatial resolution and rate capability. The Monte Carlo simulation of the beam monitor prototype was carried out to optimize the geometrical set up and to predict the behavior of the detector. A first prototype has been constructed and successfully tested using ^{55}Fe, ^{90}Sr and also an X-ray tube. Preliminary results on both simulations and tests will be presented.

1 Introduction

Hadron therapy is nowadays the most precise technique of external radiation therapy [1]. Unlike particles used in conventional radiation therapy (photons or electrons), hadrons (mainly protons and light ions) can penetrate through the body and deposit most of their kinetic energy at the end of their path, giving rise to the Bragg Peak. Since hadron therapy is very sensitive to uncertainties during treatment planning and dose delivery, it is imperative to know the exact location of the dose deposition to ensure the tumor target is being irradiated, and not the surrounding healthy tissues. The hadron beams used in particle therapy are characterized by high currents (the beam flux is of the order of 10^9 particles $\mathrm{cm}^{-2}\mathrm{s}^{-1}$), the increasing use of dose delivery technique based on the Active Scanning System [2] and, as a consequence, the need to synchronize the therapeutic beam with the movements of organs such as lungs, require precise monitoring of the beam parameters such as beam intensity, beam profile, beam position and transverse beam direction, in order to ensure that the prescribed dose is correctly delivered [3].

Since GEM (GEM - *Gas Electrons Multiplier*) [4] detectors provide excellent spatial (less than 1 mm) and time resolution (1 ns) and linearity of response over a wide dynamic range, in the framework of AMIDERHA project [5] the authors are studying and developing an innovative beam monitor based on GEM detectors. Two main devices for beam monitors are under study: a Triple-GEM based detector and a Time Projection Chamber (TPC) prototype. In the present work we report on some preliminary results on both Monte Carlo simulations and first laboratory tests of GEM based beam monitors for hadron therapy application.

2 Triple GEM detector prototype

The triple GEM beam monitor consists of three GEM foils, the drift volumes is $3 \times 100 \times 100\ mm^3$, the two transfer gap are 1 mm and 2 mm wide, while the induction gap is 1 mm wide. The read-out electrode is segmented in strips (strips are 300 μm wide and spaced 400 μm apart), the device is filled with a gas mixture of Ar and CO_2. Fig. 1 shows a scheme of such a triple GEM beam monitor. Fig. 2 shows the unit cell of the GEM stack simulated with the ANSYS software [7]. The geometrical parameters of the GEM foils, also used for the Monte Carlo simulation, are the following: hole outer radius = 35μm, hole middle radius = 25 μm, kapton thickness = 50 μm, hole pitch = 140 μm, copper thickness = 5.0 μm.

2.1 Monte Carlo simulation

The detector simulation study was based on the Monte Carlo simulation code Garfield++ [6] which as been developed by the RD51 collaboration for the detailed simulations of drift chambers with gaseous media. Garfield++

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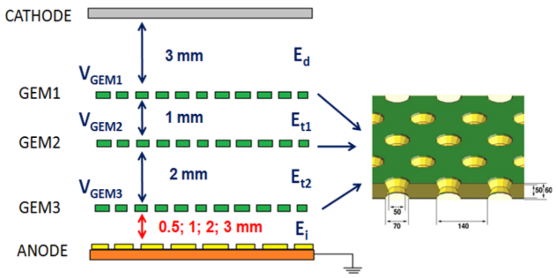

Figure 1. Triple GEM beam monitor set up.

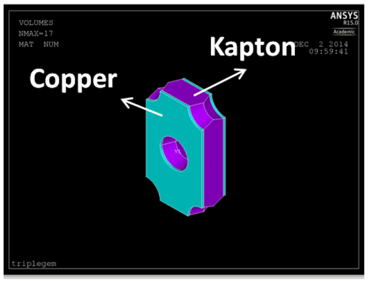

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Figure 2. Unit cell of GEM foil simulated with ANSYS showing copper part (light blue) and kapton part (violet).

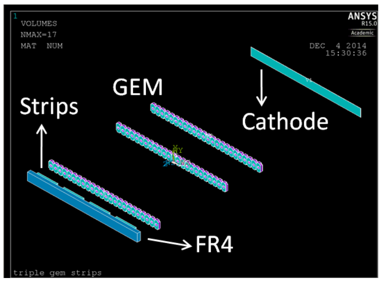

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Figure 3. Triple GEM beam monitor ANSYS CAD model showing the cathode at the top, the three GEM foils and the readout strips at the bottom.

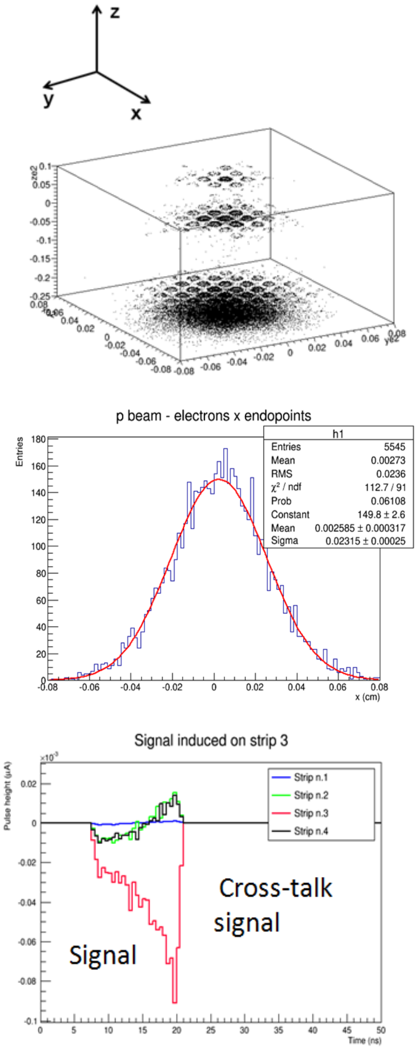

Figure 4. Avalanche production (top), spatial resolution (center) and the raw signal (bottom) produced on the anode strips simulated with Garfield++ code.

code can provide the simulation of primary and secondary tracks inside the gas and it allows the simulation of simple electric fields, for example produced by electrodes with thin-wire or plate geometry. MPGDs, like GEMs, require the simulation of electric field in complex geometries, for this reason it is necessary to calculate the electric field using finite element methods (FEM) software. The triple GEM chamber CAD model implemented in ANSYS software is shown in Fig. 3.

With the electric field map produced with ANSYS the planar triple GEM detector response to a 60 MeV proton projectile was simulated by using the Garfield++ toolkit. Results on avalanche production and spatial resolution are shown in Fig. 4 at the top and at the center respectively. Also the raw current signal induced by electrons on the anode strips was simulated thanks to the weighting fields produced by ANSYS software and the application of the Shockley–Ramo theorem. Fig. 4 (bottom) shows the raw signal induced by the avalanche electrons on a readout strip and the cross-talk signal produced on the adjacent strips.

2.2 Experimental set up

Laboratory tests were made to test the planar triple GEM detector, Fig. 5 shows the chamber during a measurement, while the charge signal produced by ionizing radiation is shown in Fig. 6. Here we report on the charge spectrum obtained with a ^{55}Fe (Fig. 7) source, while in Fig. 8 the gain obtained by irradiation with a ^{90}Sr source for different threshold values and different gas mixtures is shown.

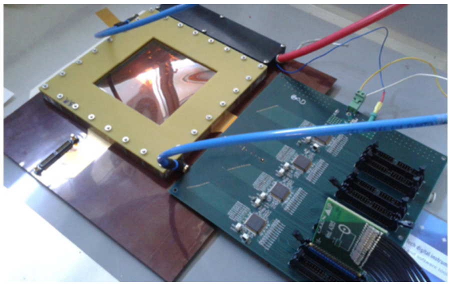

Figure 5. Planar triple GEM detector during the tests.

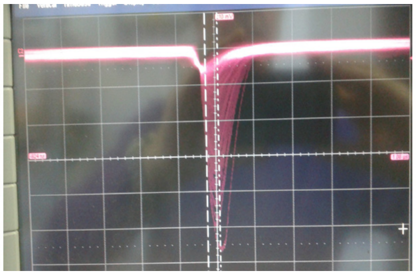

Figure 6. Triple GEM detector charge signal.

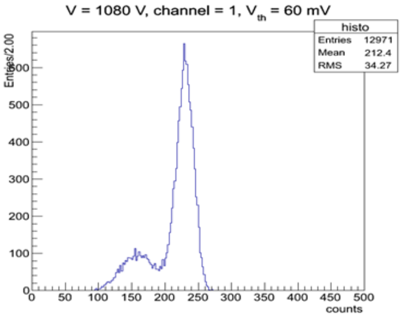

Figure 7. ^{55}Fe charge spectrum.

3 TPG detector prototype

A GEM based beam monitor has very good spatial and time resolution but a suitable beam monitor should also perturb as little as possible the beam characteristics. A TPC-GEM (TPG) detector, due to the low amount of material in the active volume, is “not invasive”, therefore the beam characteristics are preserved, so minimizing the uncertainties on beam position, intensity and stability. For these reasons a TPG detector prototype has been designed. The TPG consists of the drift volumes of $40 \times 100 \times 100$ mm^3 with a uniform electric field produced by a field cage (100 μm diameter wires with a pitch of 2 mm).

The field cage has the shape of a cuboid, and is the first prototype which has the two transparent sides orthogonal with respect to the beam direction (to reduce the beam degradation as much as possible). The two others sides, parallel with respect to the beam direction, are printed circuits boards on which the wires are soldered. The detectors is made of three GEM foils, such that the two transfer gaps are 1.6 mm wide and the induction gap is 2.1 mm wide. The read-out electrode is divided into pads, there are two available geometries: 60×2 pads of 6×2 mm^2 and 30×4 pads of 3×3 mm^2. The detector is filled with a gas mixture of Ar and CO_2. In the future we will report also on tests with Ar and CF_4 gas mixtures.

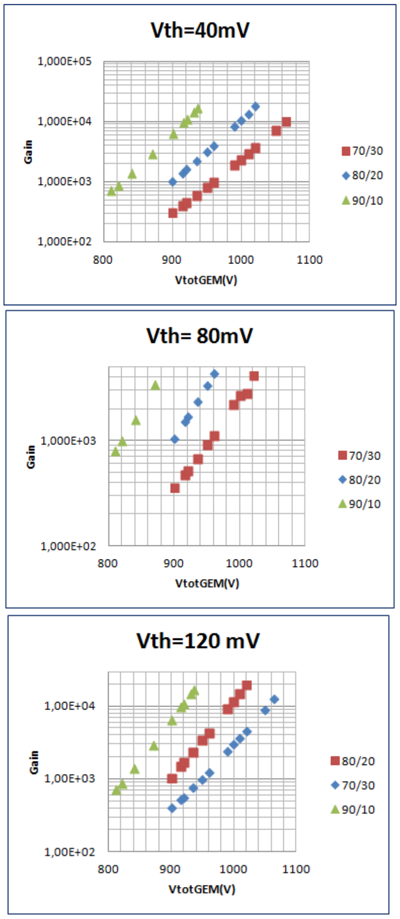

Figure 8. Gain as a function of the gas mixture (Ar and CO_2) and the threshold with a ^{90}Sr radioactive source.

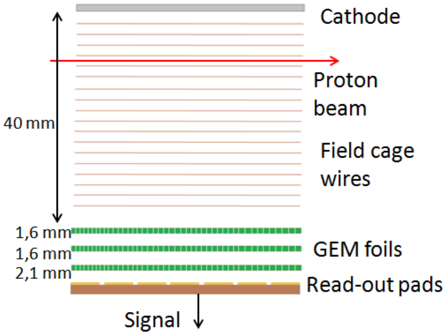

Figure 9. 13 TPG prototype schema. The beam cross the detector through two mylar windows.

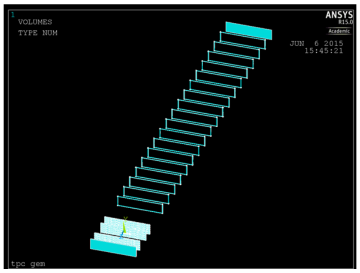

Figure 10. TPG ANSYS CAD model showing the cathode at the top, the field cage wires, the three GEM foils and the read-out plane at the bottom.

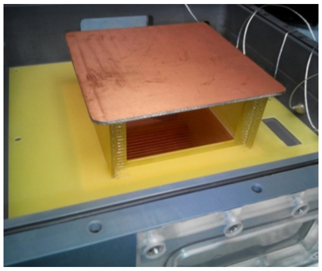

Figure 11. TPG prototype.

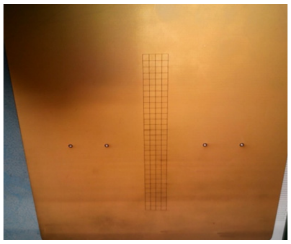

Figure 12. $3 \times 3\ mm^2$ pad readout layout.

3.1 Monte Carlo simulation

The Monte Carlo simulation of the TPG prototype, as the simulation of the planar triple GEM detector, is based on the Garfield++ code and the engineering software ANSYS. The CAD model of the TPG implemented with ANSYS is shown in Fig. 10. The simulation of the electric field and detector performance are under development, and will be used in future studies to optimize the gas mixture and electric field.

3.2 Experimental set up

The TPG detector has been recently assembled and the experimental tests will start soon. Fig. 11 shows the TPG prototype, while in Fig. 12 the $3 \times 3\ mm^2$ pad readout is shown. The very preliminary gain results with the use of an X-ray tube (30 kV, 130 μA, 2 mm collimator) are shown in Fig. 13. The distance between the TPG and the source is 30 cm, the drift region surface irradiated by the X-ray beam has a radius of 3 cm, the electric fields used are the following: 200 V/cm for the drift gap, 2 kV/cm for the two transfer gaps and 2.1 kV/cm for the induction gap.

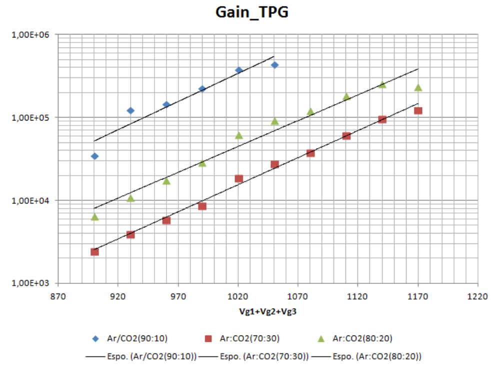

Figure 13. Preliminary TPG gain as a function of the gas mixture (Ar and CO_2) measured with an X-ray tube.

4 Conclusions

In the framework of AMIDERHA project the authors are studying and developing an innovative beam monitor based on MPGDs. Two main devices are under study: a Triple GEM based detector and a TPC-GEM prototype. Preliminary results from simulations and tests are encouraging and show that GEM based detectors are suitable for medical application. Next, we plan to test our prototypes, in particular the TPG detector, with a therapeutic proton beam.

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