Large Bulk Micromegas detectors for TPC applications

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Abstract

A large volume TPC will be used in the near future in a variety of experiments including T2K. The bulk Micromegas detector for this TPC is built using a novel production technique particularly suited for compact, thin and robust low mass detectors. The capability to pave a large surface with a simple mounting solution and small dead space is of particular interest for these applications. We have built several large bulk Micromegas detectors (36x34 cm^2) and we have tested one in the former HARP field cage with a magnetic field. Prototypes cards of the T2K Front End Electronics, based on the AFTER ASIC chip, have been used in this TPC test for the first time. Cosmic ray data have been acquired in a variety of experimental conditions. Good detector performances, space point resolution and energy loss measurement have been achieved.

Key words: Micromegas, TPC, T2K

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1 Introduction

A large volume TPC will be used in the near future for a variety of experiments, including T2K, and it is envisaged for a Linear Collider detector. In the case of the T2K experiment [1], a neutrino beam with peak energy around 600 MeV, produced in the JPARC accelerator complex in Tokai (Japan), will be directed towards the SuperKamiokande detector 295 km away. A near detector will be installed at 280 m from the proton target. It will measure the neutrino flux and spectrum and the ν_e contamination of the beam. Measurements of various neutrino-nucleus cross-sections are also foreseen.

This magnetized near detector (B=0.2 T) comprises three large TPC's which will measure the tracks produced by the interactions of the neutrino beam in two plastic scintillator active targets. The requirements on the performances of these TPC's, dictated by the physics program of T2K, are: momentum resolution better than 10% at a momentum of 1 GeV/c, and good energy deposit measurement, better than 10 %, to distinguish the electrons produced by ν_e interactions, from the muons produced by ν_μ interactions. The area to be instrumented corresponds to almost 9 m^2 and a pad size of $9.65 \times 6.85\ \mathrm{mm}^2$ has been chosen. The pad size depends on the specific application. In our case it has been chosen taking into account several factors, from physics requirements to readout complexity and cost.

In the following section we describe the detectors that we have designed, built and tested. It is the first prototype of the T2K TPC Micromegas Module, to be tested on a TPC field cage with its Front End electronics. Previous tests of Micromegas prototypes were reported in Ref. [2]. The tests described in this article were performed on substantially larger Micromegas prototypes, corresponding to the geometrical specifications of the T2K TPC. Moreover, the detector design and fabrication technique has been improved. The T2K TPC Front End electronics has been used for the read out, with a great improvement in the performances, especially in terms of signal to noise ratio.

After a description of the Micromegas detectors in section 2, section 3 documents the experimental setup for the TPC tests at CERN. The results of these tests are reported in section 4.

2 The bulk Micromegas detector

For the TPC readout plane, the ”bulk” Micromegas technology [3] is an excellent technical solution to minimize the dead zones on the edges of the modules and to improve the gas gain uniformity. Moreover, this technique is suited to industrialization and mass production, thereby offering the perspective of a cheap alternative to wire chambers.

This technique for manufacturing Micromegas detectors in a single process has been developed in 2004 by a CERN-Saclay collaboration and is described in detail in Ref. [3]. A woven mesh is laminated on a Printed Circuit Board (PCB) covered by a photo-imageable film. At the end of the process, the micromesh is sandwiched between 2 layers of insulating material. The detector undergoes then UV exposure with an appropriate mask, followed by chemical development. A few millimeter wide border at the edge can thus be produced and avoids the need of an external additional frame to support the stretched micromesh. Such a detector 'all-in one', called 'bulk' Micromegas, is robust and allows large areas, up to 100x100 cm^2 or more, to be made in one piece.

One end plate for the T2K TPC has dimensions of approximately 0.7x2 m^2. In our design, this large surface, which is also typical for other applications, is segmented with detector units that can easily be replaced. In particular, no service or connection is needed from the inner volume of the TPC.

Following these design considerations, several bulk Micromegas detectors have been built in the CERN/TS-DEM PCB production facility. The PCB, segmented into 1726 pads, 9.65x6.85 mm^2, with a 150 μm insulation between them (Fig. 1) is 2.3 mm thick. It comprises three layers of FR4 with blind vias in the inner layer (Fig. 2). This solution avoids the gas tightness problems arising from the conventional two layers structure with vias sealed with epoxide resins. The top conductive layer is realized with $25\ \mu m$ thick copper deposited on FR4. The other three conductive layers are used for the routing network, the grounding and the connectors.

The pads are arranged in 48 rows of 36 pads for an active surface of 36x34 cm^2. In one corner a 2 pads equivalent surface is reserved for the micromesh high voltage supply connection from the backside of the PCB.

A sandwich of two layers of 64 μm Pyralux PC1025 Photoimageable coverlay by DuPont [5], a woven micromesh and finally a layer of Pyralux is laminated on the PCB. The woven micromesh [4], is built out of 19 μm thick 304L stainless steel wires. After weaving its thickness is reduced by 20-30% by a lamination process. The wires are spaced with a pitch of 59 μm. After photo-imaging, the mesh is held in place by the coverlay frame and 20736 regularly distributed pillars, maintaining the amplification gap of 128 μm. The pillars, 12 per pad, are cylindrical with a diameter of 0.5 mm.

After protecting the sensitive detector surface with a melamine plate, the outer coverlay and PCB frame is cut to 3.2 mm in order to reduce the inactive area. Finally, the detector is glued onto a support structure to reinforce the PCB mechanical rigidity and to assure a 0.1 mm planarity tolerance. This structure hosts the seal for gas tightness.

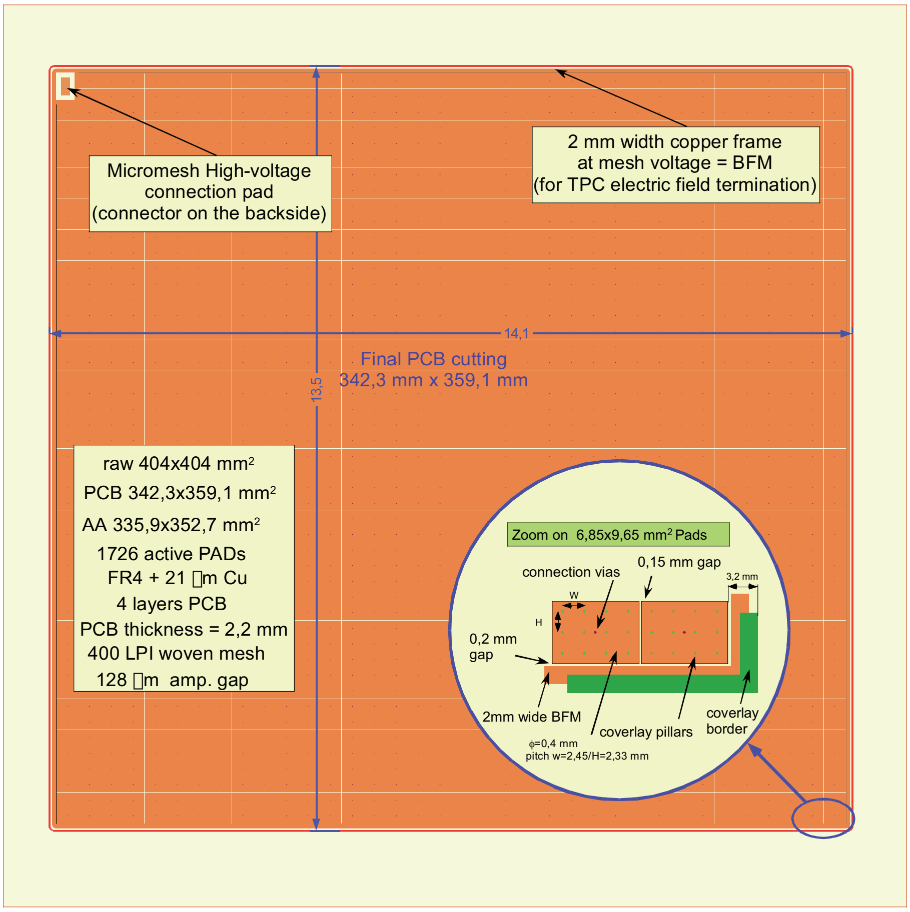

Fig. 1. View of the PCB from the anode pads side.

After the production, the detectors have been tested, first in air and then in a gas box. A good quality detector must stand in air a high voltage of around 900 V with less than a few sparks per hour. During the production of 12 prototypes, less than two defective pads were identified. This proves the very high quality reached in the detector production procedure.

A gas box provided an easy way to test the detector in a specific gas mixture with a ^{55}Fe source. The box was provided with a mylar window and an electrode to create a drift electric field pushing electrons toward the Micromegas mesh. The gaussian width of the energy resolution was measured to be 9 % for a 5.9 KeV X-ray from the width of the Fe line (Fig. 3) in Ar-CF_4(3%)-iC_4H_{10}(2%). The spark rate was measured to be less than 0.1/hour at a gain of 1000 (HV=-350 V).

3 The TPC experimental setup

The TPC experimental setup at CERN consists of the former HARP TPC field cage inside a solenoidal magnet and its gas system. The TPC field cage is described in

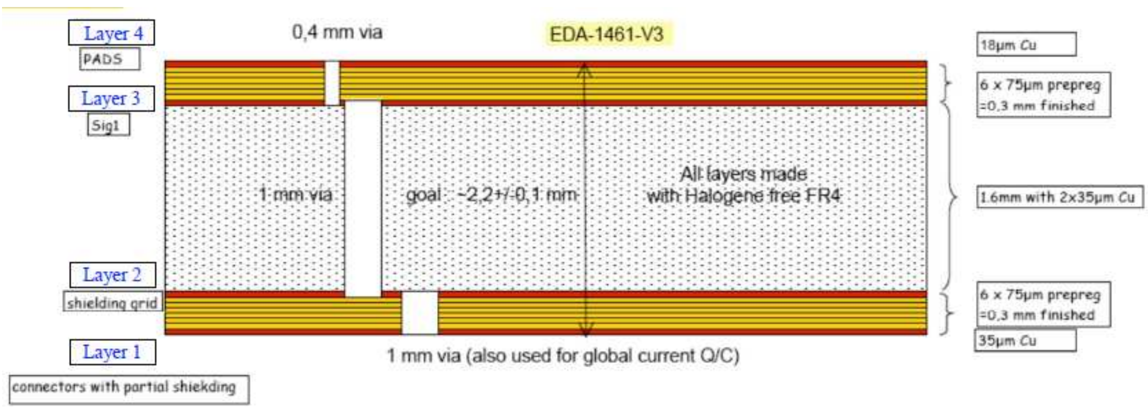

Fig. 2. The PCB cross-section.

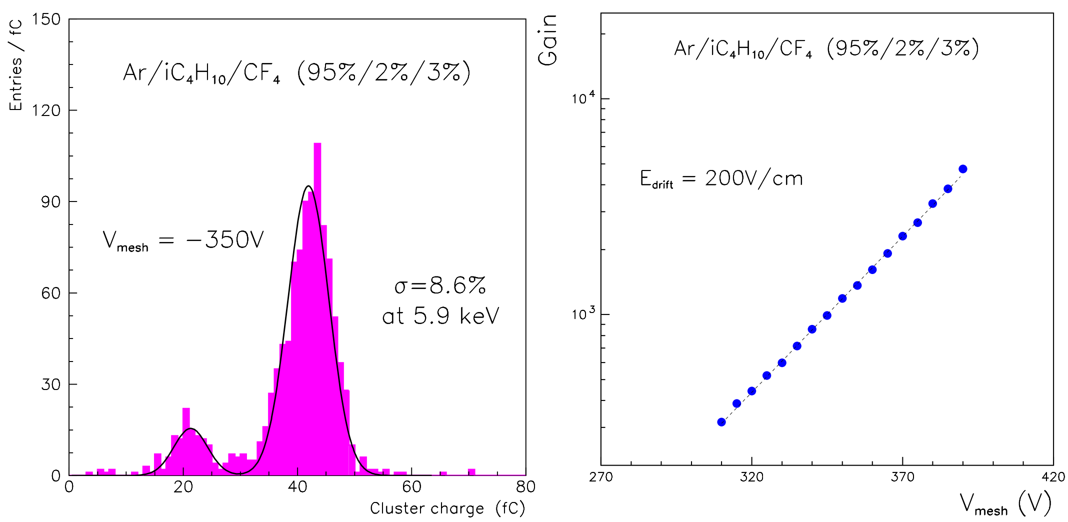

Fig. 3. Left: charge spectrum obtained with a ^{55}Fe X ray source showing a resolution of 8.6 %. Right: gain versus micromesh high voltage in Ar-CF_4(3%)-iC_4H_{10}(2%).

more details in [6]. It consists of a large cylindrical vessel, 80 cm inner diameter and 154.1 cm in drift length, where a series of strips connected by a resistor chain creates an axial electric field. The cathode was set at a potential corresponding to an electric field of 160 V/cm. The TPC field cage is mounted inside a solenoidal magnet of 90 cm inner diameter and 225 cm length. A system of seven scintillators, above and below the magnet, equipped with PMT, provided the trigger signal on cosmic rays.

The end-plate hosting one Micromegas module (Fig. 4) consists of an aluminum support structure covered on its inner surface by a large PCB with copper coating for an uniform termination of the drift electric field. The end-plate was mounted in

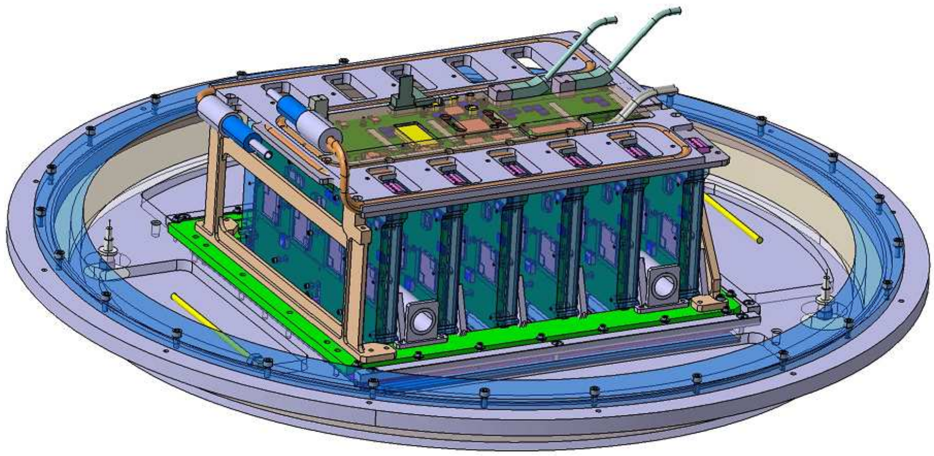

Fig. 4. The Micromegas Module, complete of six FEC cards, one FEM cards and the cooling system, mounted on the TPC endplate.

a such a way that the longer side of the detector pads was tilted by 8° with respect to the vertical direction. In this way the track projections on the detector plane were crossing several times the boundary between pads.

The tests have been performed with the gas mixture Ar-CF_4 (3%)-iC_4H_{10} (2%). According to the Magboltz simulation [7], it offers a fairly large drift velocity (6.5 cm/μs) close to its maximum at the electric field of 160 V/cm, low diffusion coefficient at small magnetic field (237 $\mu\mathrm{m}/\sqrt{\mathrm{cm}}$ for B=0.2 T) and allows operation of Micromegas with a gain of several 10^3. Small contaminations of oxygen and water were present in the TPC gas volume at a level of 20 ppm.

The bulk-Micromegas prototypes were read out using the T2K/TPC Front-End Electronics (FEE) based on the AFTER ASIC chip [8]. The AFTER chip, built in a 0.35 μm CMOS AMS process, houses 72 detector channels. Each channel contains a front-end part followed by a Switched Capacitor Array with 511 analog memory cells which can be sampled at a frequency up to 100 MHz. The front-end part performs charge collection, amplification and shaping of the detector signals. It provides 4 full charge ranges (120 fC to 600 fC) on 12 bits and 16 peaking time values (100 ns to 2 μs). The equivalent noise charge (ENC) is 700 e rms for 400 ns peaking time. In our tests, the sampling frequency was set to 16.6 MHz, with a charge range of 120 fC and peaking times of 200 and 400 ns.

Four AFTER chips are mounted on a Front End Card (FEC). The FEC is mainly an analog electronic card but it also performs digitization. A detector module is read out by 6 FEC plugged directly on the Micromegas PCB backpane and one Front End Mezzanine (FEM). The FEM is a pure digital electronics card that controls several FECs and gathers event data digitized by the FECs. Each FEM has a 2 Gbps optical link to communicate with off-detector electronics.

A cooling system, comprising a cold plate in thermal contact with a serpentine water pipe, and aluminum plates mounted on the FEC and FEM cards, has been designed, built and deployed for this prototype. It assured that the FEC cards operated at a constant temperature of $23\,^{\circ}\mathrm{C}$ for an input water temperature of $18\,^{\circ}\mathrm{C}$.

The Data Acquisition Software had been designed using a DAQ Configuration framework developed at CEA Irfu for test benches and medium size experiments [9]. It is written in C++ and runs both on Linux and Windows. The use of the Configuration framework GUI and API allows both users and developers of the DAQ to define and setup their run parameters with great ease, using a natural tree-like structure and a powerful default value mechanism. The setups can be saved either in XML files or in a database.

4 Results

We have taken cosmic ray data with this setup with the Ar-CF_4(3%)-i$C_4H_{10}(2\%)$ gas mixture for almost one month. Typical Micromegas voltages were in the range 340-370 V corresponding to gains between 800 and 2500. The magnetic field was varied from 0 to 0.4 T. The detector operated smoothly, the typical current drawn from the power supply being 1 nA. We observed sporadic sparks, triggering the current limit of the detector high voltage power supply (500 nA), without consequence neither for the detector nor for the electronics.

Data taken with cosmic rays have been analyzed using a complete analysis chain including an event display, a reconstruction program and a full simulation based on the GEANT4 package [10]. A threshold equal to 3.5 times the RMS of the pedestal (typically 5 ADC counts) is applied to the raw data. The reconstruction has been performed with two algorithms. In the first, described in Ref. [2], space points are formed and a least squares fit is performed to extract the track parameters. In the second, a likelihood fit is applied directly on the signal of each pad. The two methods gave similar results.

Cosmic ray tracks are reconstructed and fitted separately in the two projections (one in the readout plane, the other in the plane containing the vertical axis and the drift direction). The space point resolution in the direction of the longer pad size for each cluster has been studied considering the residual between its position and the extrapolated track position without using this clusters.

Figures 5, 6, and 7 shows the gaussian widths of the residuals for various values of the magnetic field, in fair agreement with the result of the GEANT4 simulation. At B=0.2 T and for clusters with two or three pads in the row, the typical resolution is 600 μm at a drift distance of 1 m. The momentum resolution of a TPC equipped with these detectors and measuring a track length of 70 cm in a 0.2 T magnetic field is expected to be 7% at 1 GeV/c, better than the required performance of 10% for the T2K tracker.

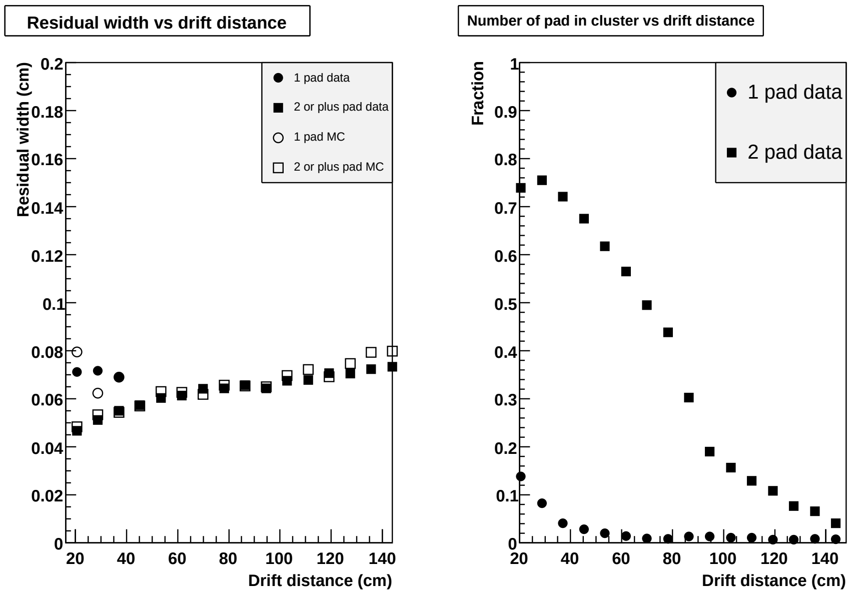

Fig. 5. Left plot: the gaussian width of the residuals for the clusters with one pad and two or more as a function of the drift distance for B=0. The open symbols show the width estimated using the Geant4 MC simulation. Right plot: the fraction of clusters with one pad (circles) and two pads (squares).

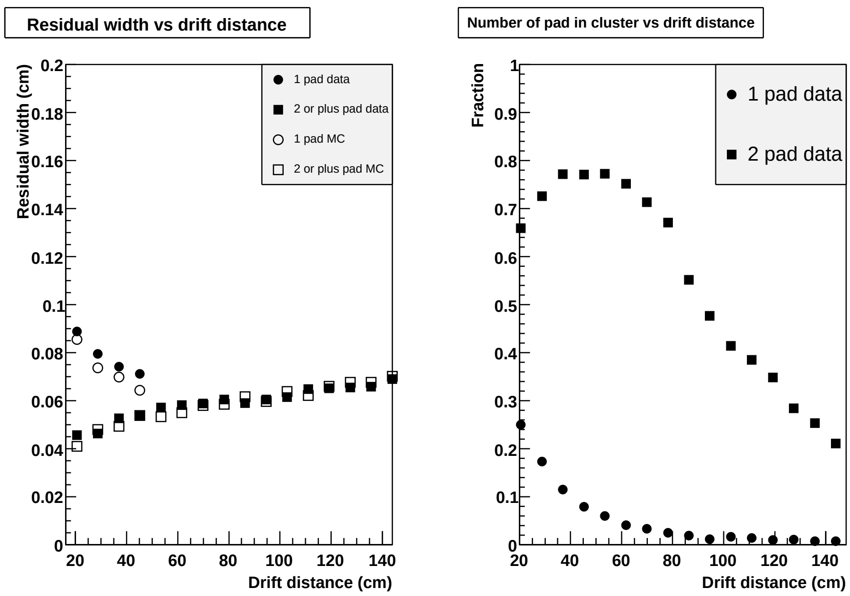

Fig. 6. Left plot: the gaussian width of the residuals for the clusters with one pad and two or more as a function of the drift distance for B=0.2 T. The open symbols show the width estimated using the Geant4 MC simulation. Right plot: the fraction of clusters with one pad (circles) and two pads (squares).

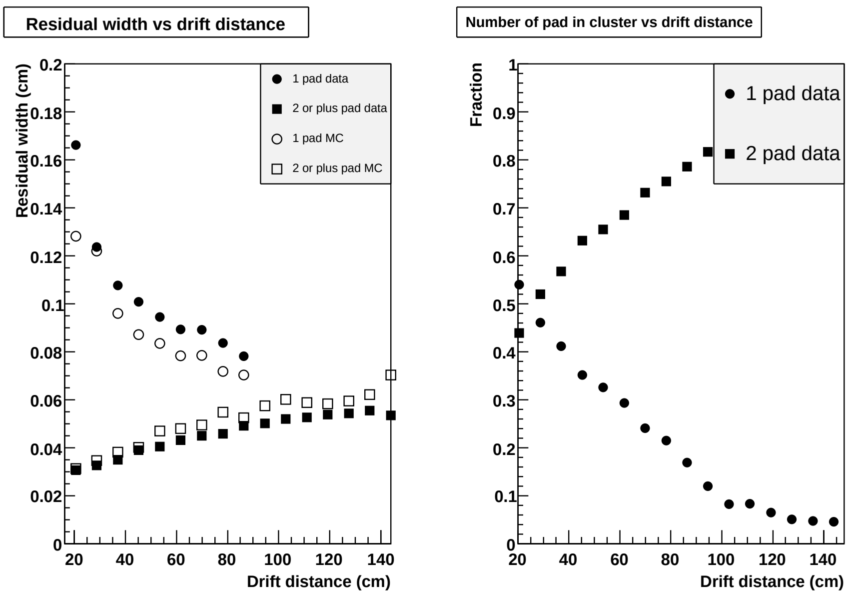

Fig. 7. Left plot: the gaussian width of the residuals for the clusters with one pad and two or more as a function of the drift distance for B=0.4 T. The open symbols show the width estimated using the Geant4 MC simulation. Right plot: the fraction of clusters with one pad (circles) and two pads (squares).

A study of the gas properties has been done by studying tracks that cross the field cage cathode. These tracks give a very precise measurement of the drift velocity: $v_d = 6.26 \pm 0.13\ \mathrm{cm}/\mu\mathrm{s}$ and $v_d = 4.21 \pm 0.13\ \mathrm{cm}/\mu\mathrm{s}$ for an electric drift field E_d of 160 V/cm and 100 V/cm respectively. These values are in fair agreement with the Magboltz [7] predictions of $v_d = 6.50\ \mathrm{cm}/\mu\mathrm{s}$ and $v_d = 4.46\ \mathrm{cm}/\mu\mathrm{s}$. The likelihood fit allows to fit track by track for the width of the electron cloud and therefore to estimate the transverse diffusion coefficient (Table 1). These values are in fair agreement with the Magboltz prediction: the systematic uncertainty attached to these values will be evaluated in a further study. The attenuation length has been measured to be 14 m.

Table 1
Expected (Magboltz predictions) and measured (last column) transverse diffusion coefficient C_T ($\mu\mathrm{m}/\sqrt{\mathrm{cm}}$) for different experimental conditions.

Mag. Field (T)	El. Field (V/cm)	C_T (exp)	C_T (meas)
0	160	309	288
0.2	160	237	209
0.4	160	157	155

A first study of the energy deposit per unit length, has been performed considering for each track the total charge detected in each pad row. A truncated mean retaining only 80% samples with lower measured charge has been used. This mean has been corrected for the track length in the active volume of the TPC. The results are shown in figure 8. A resolution on the energy deposit of $12.2 \pm 1.0\%$ for momenta between 700 MeV/c and 1 GeV/c has been obtained for a nominal track length of 36 cm and 36 samples. Using the PDG parametrization [11], a resolution around 10 % is expected for this track length. Finally, using the energy deposit on each pad, we have measured the gain uniformity across the Micromegas plane. We have found an excellent uniformity, the gaussian width of the pad gain being 3.6 %. This result has been confirmed by further studies on a dedicated test bench that will be used to qualify all the Micromegas detectors produced for the T2K TPC.

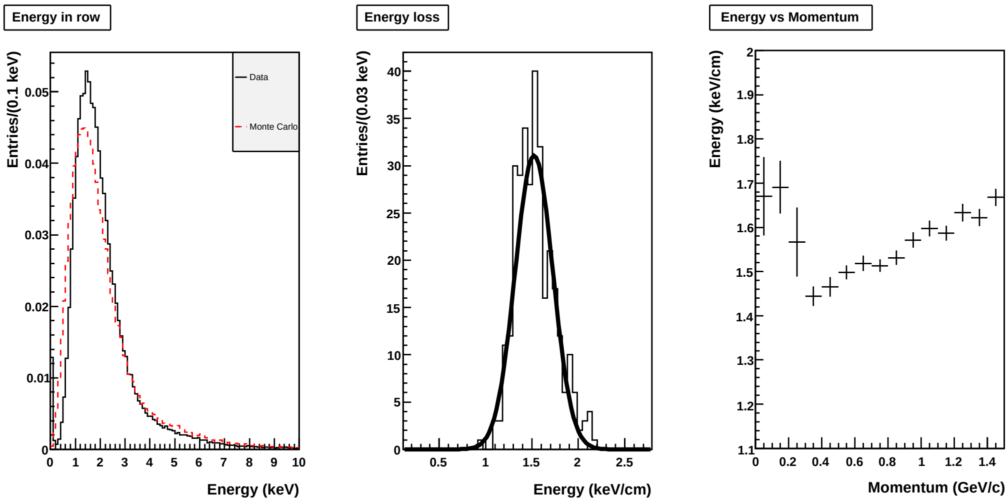

Fig. 8. Left: the deposited energy per pad row for the data (continuous line) and the Monte Carlo simulation (dashed line). Middle: the 80% truncated mean for the tracks in the 0.7 to 1 GeV/c momentum interval. A resolution of 12.2% has been obtained. Right: the measured energy deposit versus the track momentum.

5 Conclusion

We have built several large bulk Micromegas detectors as prototypes for the T2K TPC. We have tested a detector in the former HARP field cage setup with a magnetic field. Cosmic ray data have been acquired in a variety of experimental conditions. The detector has shown good performances in terms of reliability of operation, gain and space point resolution.

Acknowledgements

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