MICROMEGAS DETECTOR DEVELOPMENTS FOR MIMAC

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Abstract. The aim of the MIMAC project is to detect non-baryonic Dark Matter with a directional TPC. The recent Micromegas efforts towards building a large size detector will be described, in particular the characterization measurements of a prototype detector of $10 \times 10$ cm$^2$ with a 2 dimensional readout plane. Track reconstruction with alpha particles will be shown.

1 Introduction

The MIMAC (MIcro TPC MAtrix of Chambers) collaboration (Santos et al. 2010) aims at building a directional Dark Matter detector composed of a matrix of Micromegas (Giomataris et al. 1996) detectors. The MIMAC project is designed to measure both 3D track and ionization energy of recoiling nuclei, thus leading to the possibility to achieve directional dark Matter detection (Spergel et al. 1988). It is indeed a promising search strategy of galactic Weakly Interacting Massive Particles (WIMPs) and several projects of detector are being developed for this goal (Ahlen et al. 2010). Recent studies have shown that a low exposure CF$_4$ directional detector could lead either to a competitive exclusion (Billard et al. 2010), a high significance discovery (Billard et al. 2010), or even an identification of Dark Matter (Billard et al. 2011), depending on the value of the WIMP-nucleon axial cross section.

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Gaseous detectors are attractive as they can reconstruct the track of the nuclear recoil providing both the energy and the track properties. Micropattern gaseous detectors are particularly suited to reconstruct low energy (few keV) recoil tracks of a few mm length due to their very good granularity, good spatial and energy resolution and low threshold. Micromegas detectors have shown these qualities in different environments (Aune et al. 2009; Dafni et al. 2009; Dafni et al. 2011; Delbart et al. 2010). In particular thanks to the new manufacturing techniques, namely bulk (Giomataris et al. 2006) and microbulk (Andriamonje et al. 2010), where the amplification region is produced as a single entity.

The concept of the MIMAC experiment is described in detail in the contribution (Santos et al. 2011) of these proceedings. This paper is devoted to the recent Micromegas developments done with bulk detectors in order to show the feasibility of a large TPC (Time Projection Chamber) for directional detection.

2 The 10 × 10 cm² MIMAC prototype

In order to have a detector that can stand operation at low and high pressure the design relies on the idea of assembling a leak-tight read-out plane on a 2 cm aluminium cap. A general sketch of the mechanical assembly is given in figure 1.

The bulk Micromegas is on a Printed Circuit Board (PCB), called Readout PCB, of 1.6 mm thickness (a in figure 1). The active surface is of 10.8×10.8 cm² with 256 strips per direction. The charge collection strips make-up an X–Y structure out of electrically connected pads in the diagonal direction through metallized holes as can be seen in figure 2 (left). This readout strategy reduces the number of channels with a fine granularity covering a large anode surface. The pads are 200 µm large with an isolation of 100 µm resulting into a strip pitch of 424 µm. The quality of the surface of the readout plane can be observed in figure 2 (right). The 100 µm diameter metallized holes have been fully filled yielding a completely uniform surface. This fact is a prerequisite to obtain a uniform performance of a bulk Micromegas detector.

The strips signals are rooted into 4 connectors prints at the sides of the Readout PCB. The Readout PCB is screwed on a thick 0.5 cm PCB, called Leak Tight PCB (d in figure 1), that will ensure the leak tightness of the system. The Leak Tight PCB is constituted of various layers of FR4 with blind metallized vias in the inner layer. This piece is then screwed on a 2 cm thick aluminium cap that constitutes the bottom of the TPC (c in figure 1). The signal connections from one board to another are done by means of SAMTEC connectors (GFZ 200 points) that are placed and screwed between the two boards (b in figure 1 (left)). On the outside of the vessel an Interface card distributes the signals to the desired electronics (e in figure 1). Two versions of this card exists: one dedicated to the laboratory set-up and a second one for the final MIMAC electronics.

This design offers several advantages: a simple, compact and leak-tight way for the signal connections and a versatility for two different types of electronics. Bulk Micromegas with two different amplification gaps were produced in order to choose the best gap for different running pressure conditions. Characterisations
tests described in the next section concern three readout planes with a gap of 128 µm and two with a gap of 256 µm.

Fig. 1. Left: Sketch of the general assembly constituting the readout plane and the interface to electronics. Left: Zoom of the Readout PCB (a in the image), Leak tight PCB (d) and the Interface PCB (e).

Fig. 2. Left: Sketch of the 2D readout used. Right: Microscope photograph of the 2D readout.

3 Characterization measurements

A dedicated vessel was built as shown in figure 3. The set-up is described in detail in [F.J Iguaz et al. 2011]. The characterization measurements were realized in an Argon(95%)-Isobutane(5%) mixture at atmospheric pressure. The strips were connected to ground and the readout was illuminated by an iron $^{55}$Fe source (X-rays of 5.9 keV) located on the TPC window. The mesh signal was read out by an ORTEC 142C preamplifier, whose output was fed into an ORTEC 472A Spectroscopy amplifier and subsequently into a multi-channel analyzer AMPTEK MCA-8000A for spectra building. In order to measure the gain of the detectors the
ratio of drift and amplification fields was fixed in the region where the mesh showed the maximum electron transmission. The tested readouts reach gains greater than $2 \times 10^4$ before the spark limit for both amplification gaps as can be seen in figure 4 (left). The energy resolution stays constant for a wide range of amplification fields as shown in figure 4 (right). At low fields, the resolution worsens due to the noise level that is comparable to the signal height. At high fields, it deteriorates due to the gain fluctuations.

4 Track measurements

The T2K electronics Baron et al. (2009 2010) has been used to read the signals induced in the strips to fully validate the concept of MIMAC readouts for the reconstruction of tracks. An example of the strips pulses and the XZ reconstruction of one event is shown in figure 5.

In the two spatial projections (x and y) of the event, different parameters characterising the charge were calculated like mean position, width and number of activated strips. The analysis was then extended to the perpendicular direction using the amplitudes of strips pulse in each temporal bin. Finally, the total charge of each event was obtained summing the charge of both projections. After having tested the readout with low energy events, we evaluated its performance at low gain with high energy events. For this purpose, an $^{241}$Am alpha source was installed in the source keeper screwed at the center of the drift plate. The source consists of a metallic circular substrate of 25 mm diameter where the radioactive material
Fig. 4. Left: The absolute gain as a function of the amplification field is shown for the readouts with a 128 $\mu$m (red squared line) and 256 $\mu$m-thick amplification gap (blue circled line) obtained with an iron $^{55}$Fe source using an Argon(95%)-Isobutane(5%) mixture at 1 bar. The extension at low gain (green star line) for the 256 $\mu$m readout was obtained with an alpha source. The maximum gain was reached just before the spark limit. Right: Dependence of the energy resolution at 5.9 keV with the amplification field for the readouts of 128$\mu$m (red squared line) and 256 $\mu$m-thick amplification gaps (blue circle line).

Fig. 5. Left: Example of pulses induced in the strips acquired with the T2K electronics. Right: The reconstruction of the XZ projection of the same event. The physical event is an electron candidate of 44.4 keV with a final charge accumulation (or blob). has been deposited on its center in a circular region of about 8 mm of diameter. The alpha particles are emitted isotropically. The 5.5 MeV alphas were used to characterize the readout as it was done with the iron source in section 3 generating the gain curves shown in figure 4 (left).

The spectra generated by the $^{241}$Am source showed an energy resolution of 5.5% FWHM, as the one shown in figure 6. This value was independent of the drift voltage and the readout gain. To check the possible presence of attachment effects in the gas, mesh pulses were acquired by a LeCroy WR6050 oscilloscope. In an offline analysis, the amplitude and risetime of the pulses were calculated and the 2D distribution of these parameters was generated to look for correlations.
Alpha events showed the same amplitude, independently of their risetime, i.e., their spatial direction. Therefore attachment effects are not observed. An example of these 2D distribution is shown in figure 6 (right).

Several alpha tracks were also acquired with the T2K electronics, as shown in figure 7 (left). The mesh and drift voltages were respectively set to 400 and 820 V, which correspond to a gain of 85 and a drift field of 70 V/cm. For each event, the length of the track projection on the XY plane was calculated and the distribution of this variable was generated. The maximum value obtained (54 mm) matches the theoretical length expected for a 5.5 MeV alpha particles in an argon-based mixture (Iguaz 2010).

The discrimination capabilities of this detector for low energy photons has also been studied. Detailed results can be found in (Iguaz et al. 2011).
5 Conclusions and Outlook

A bulk Micromegas detector has been designed and built for the MIMAC project. Characterisation measurements in the laboratory have shown good performance in terms of gain, uniformity, energy resolution and track measurements with an Argon(95%)-Isobutane(5%) mixture at atmospheric pressure. The detector will be now tested with CF$_4$ in a neutron beam facility with neutrons of few keV using the specifically designed MIMAC electronics to reach the ultimate performance of the detector for the detection of Dark Matter. It is foreseen in the next coming months to test a module containing two $10 \times 10$ cm$^2$ detectors in the Frejus underground laboratory. This measurement, in a realistic environment for a Dark Matter experiment, will give crucial information (background rejection as well as intrinsic contamination of the used materials) before the construction of a 1 m$^3$ experiment.

In any case the results obtained up to now validate the MIMAC concept for the construction of a large TPC for directional detection of Dark Matter.

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