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# Metal-core pad-plane development for ACTAR TPC

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ABSTRACT

With the recent development of active targets and time projection chambers (ACTAR TPC) as detectors for fundamental nuclear physics experiments, the need arose for charge collection planes with a high density of readout channels. In order to fulfill the mechanical constraints for the ACTAR TPC device, we designed a pad-plane based on a metal-core circuit with an conceptually simple design and routing for signal readout, named *FAKIR* (in reference to a fakir bed of nails). A test circuit has been equipped with a micro mesh gaseous structure (*micromegas*) for signal amplification and a dedicated readout electronics. Test measurements have been performed with an $^{55}$Fe X-ray source giving an intrinsic energy resolution (FWHM) of $22 \pm 1\%$ at 5.9 keV, and with a 3-alpha source for which a resolution of about $130 \pm 20$ keV at 4.8 MeV has been estimated. The pad-plane has been mounted into a reduced size demonstrator version of the ACTAR TPC detector, in order to illustrate charged particle track reconstruction. The tests preformed with the X-ray and the 3-alpha sources shows that results obtained from pads signals are comparable to the intrinsic result from the micro-mesh signal. In addition, a simple alpha particle tracks analysis is performed to demonstrate that the pad plane allows a precise reconstruction of the direction and length of the trajectories.

## 1. Introduction

The need for time projection chambers (TPC) in low energy nuclear physics experiments has considerably increased in the last decade. Such instruments may be used as active targets, like the MAYA detector [1], where the gas volume plays the role of the nuclear reaction target and of the detector for reaction products. They may also be used as thick stopper for radioactive ions produced at fragmentation facilities and as detector for the decay products of the implanted ions, as in the case of the TPC [2] used for the studies of 2-proton radioactivity and possibly other exotic decay modes.

Since the requirements are very similar for the various nuclear physics cases, the ACTAR TPC collaboration started the development of a second generation TPC aiming to fulfill the requirements for a broad physics program including reactions, structure and decay studies. The principle of operation of the ACTAR TPC detector is to collect the ionization signal from the charged particles traveling through the active volume on a collection plane made of pads, so that the signal on all pads gives directly a 2D projection $(X, Y)$ of the particles tracks. In addition, the readout of the pads signal is performed by the GET electronics [3,4]: the signal on each pad is sampled in time, which allows a digitization of the signal along the 3rd dimension $Z$ [5].

The pad size is a compromise between the granularity for tracks reconstruction and the number of electronics channels. The ACTAR TPC project aims to construct two TPC chambers sharing the same electronics: a "cubic" version for nuclear reactions (where the reaction products may have long transverse tracks) with a pad-plane of $256 \times 256$ mm$^2$, and a "cuboid" version with a $128 \times 512$ mm$^2$, better adapted for decay studies at fragmentation facilities where the ions implantation depths

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have a large dispersion and the decay products may have short track lengths (as for 2-proton radioactivity studies [6,7]). For the pads, the pitch has been chosen to be $2 \times 2$ mm$^2$, which corresponds to 16 384 pads for both geometries [8]. For signal amplification, the pad-plane is equipped with a *bulk micromegas* [9].

For the readout of the signal collected on the pads, there are 2 options: either the pad-plane is totally in the gas volume, which requires an interface that transports the pads signals outside the chamber, or the plane is used as the interface between the inner and outer sides of the gas volume. Due to the number of channels and in order to limit the number of connexion elements and the linear capacitance per channel, the latter option was chosen.

Nevertheless, this imposes some constraints on the printed circuit board (PCB) on which the pads are designed. The PCB must then be part of a flange of the gas chamber, and fulfill the sealing conditions. In addition, since the chamber may be used with a wide range of gas pressure, the PCB must be able to resist the deformation caused by the pressure difference between the inside and the outside of the chamber, that may deform or even damage the *micromegas* or destroy a standard epoxy pad-plane. A possible solution is to glue the PCB on a metallic flange with only a few holes for small connectors that concentrate the signals of pads for a large surface. This requires a sophisticated routing for signals from pads on the inner side of the PCB to the connectors on the outer side. While it has been tested successfully for a small size demonstrator of ACTAR TPC [10], it requires a specific study for the full size detector.

We studied another solution to this problem by considering a PCB built on a metal core in order to stand the mechanical constraint, with a direct connection through the circuit from the pads to a connector with a 2 mm pitch (the size of 1 pad).

Despite being conceptually simple and elegant, the manufacturing of the PCB is not straightforward, and Section 2 explains the process that we developed in order to realize the metal-core pad-plane. Measurements have been preformed with an $^{55}$Fe X-ray source and a 3-alpha source with a test set-up. The measurements of the global signal collected on the *micromegas* mesh (or *micromesh*) are used to extract the intrinsic resolution of the plane and these are described in Section 3. In Section 4, we present the measurements performed with the electronics connected to the pads, and illustrate the track reconstruction with the ACTAR TPC demonstrator.

## 2. The FAKIR (bed of nails) metal-core PCB for the pads plane

Since the pad-plane PCB represents the interface between the interior of the gas chamber and the exterior at atmospheric pressure, any pressure difference will result in a deformation of the plane, depending on the surface of the PCB. For the full size detector with the $128{\times}512$ mm$^2$ pad-plane ("cuboid" geometry), the expected deformation is in the order of 0.1 mm with a 4 mm thick high resistance aluminum core. In order to get the same order of deformation for the $256 \times 256$ mm$^2$ pad-plane ("cubic" geometry), a 7 mm thick core of stainless steel is required. The calculations have been performed with the ANSYS® software [11]. Since the development has been carried out on the small size ACTAR TPC demonstrator ($64 \times 128$ mm$^2$), the prototype presented here has been built with a 4 mm thick high resistance aluminum core.

The principle of the direct connection between the pads and the connectors to the readout electronics is illustrated in Fig. 1.

Most of the manufacturing process has been carried out at the CERN PCB workshop. The main steps of this process are as follows:

- the metal plate is drilled to obtain 1.5 mm diameter holes every 2 mm on the whole surface that will contain pads;
- the holes are filled with an epoxy resin, that is used to insulate the pads connection from the metal core;
- the PCB layers (25 μm Krempel adhesive, 75 μm polyimide and 18 μm copper) are added on both sides of the plate;

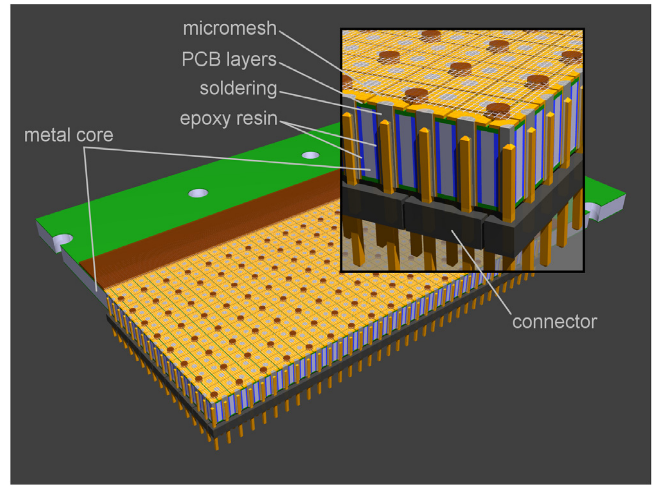


**Fig. 1.** Schematic view of the metal-core PCB, with a direct connection from the pad to the signal readout connector, with the same pitch as the pads spacing. Each pad is connected to a pin of the connectors. The pins at the end of pads rows are used to ground the structure and the ring around the pads. A 128 μm bulk micromegas, with pillars every 4 mm is added on top of the pads.

- the resulting stack is drilled again, at a diameter of 1 mm, inside the holes previously filled with resin;
- the pads (and ground ring around the active area) are etched on both sides of the plane;
- the copper surfaces (pads, ring) and the holes are metallized (20 to 30 μm);
- a protection solder mask is applied around the pads;
- the connectors with pins every 2 mm (commercially available) are inserted and wave soldered (this part of the process has been realized by an external company, FEDD company [12]);
- final grinding and polishing are applied;

The thickness of metal core (4 mm) covered with a PCB is 4.29 mm. Once the PCB is complete, a 128 μm *bulk micromegas* [9] is added to the pads side for signal amplification. This final step is also done at CERN PCB workshop. The resulting pad-plane is shown in Fig. 2.

## 3. Intrinsic resolution

In order to check the performances of the pad-plane, we first measured the signal collected on the *micromesh*, regardless of the pads individual signals, using a very simple test set-up. The tests presented in this paper have been performed with P10 gas (90% argon and 10% methane), at various pressures.

### 3.1. Test set-up

For these measurements, the pads were grounded and a high voltage $HV_{mesh}$ was applied on the *micromesh*. This voltage depends on the signal to measure: it was typically on the order of −500 to −600 V for the 5.9 keV X-ray of an $^{55}$Fe source (limited by sparks that appear around −650 to −700 $V$) and on the order of −350 V for the 3-alpha source, with alpha particles energies around 5 MeV (the HV is reduced here to avoid saturating the micro-mesh preamplifier and the pads signal). An electrode located a few cm above the active area defines the active volume by applying a high voltage around −1000 V. The P10 gas pressure was 1 bar and 400 mbar for the $^{55}$Fe X-ray source and the 3-alpha source, respectively. The test set-up is shown in Fig. 3.

The ionization electrons produced by charged particles in the active volume drift towards the *micromesh*, where the signal is amplified by an avalanche process. The *micromesh* is connected via a decoupling