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# Tests of Micro-Pattern Gaseous Detectors for active target time projection chambers in nuclear physics

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ABSTRACT

Active target detection systems, where the gas used as the detection medium is also a target for nuclear reactions, have been used for a wide variety of nuclear physics applications since the eighties. Improvements in Micro-Pattern Gaseous Detectors (MPGDs) and in micro-electronics achieved in the last decade permit the development of a new generation of active targets with higher granularity pad planes that allow spatial and time information to be determined with unprecedented accuracy. A novel active target and time projection chamber (ACTAR TPC), that will be used to study reactions and decays of exotic nuclei at facilities such as SPIRAL2, is presently under development and will be based on MPGD technology. Several MPGDs (Micromegas and Thick GEM) coupled to a $2\times2$ mm$^2$ pixelated pad plane have been tested and their performances have been determined with different gases over a wide range of pressures. Of particular interest for nuclear physics experiments are the angular and energy resolutions. The angular resolution has been determined to be better than 1° FWHM for short traces of about 4 cm in length and the energy resolution deduced from the particle range was found to be better than 5% for 5.5 MeV $\alpha$ particles. These performances have been compared to Geant4 simulations. These experimental results validate the use of these detectors for several applications in nuclear physics.


## 1. Introduction

With the ongoing improvements in radioactive ion beam production at several facilities worldwide, new possibilities will soon be available for studying the structure and decays of the most "exotic" nuclei, which are those furthest from the line of beta stability [1]. The intensity of the most exotic beams available remains however usually low. In this regard, the use of active targets has become an attractive alternative to study the most exotic nuclei. This type of detection setup, where the detection medium is also used as a target, presents several advantages. It allows the simultaneous detection and identification of low-energy recoils that would stop in a classical solid target. The effective target thickness can thus be increased (by adjusting the pressure) to study nuclei produced at the lowest intensities, or to study reactions with very negative Q-values where the recoils are emitted with low energies. Active targets designed to study specific types of reactions are already in existence. The IKAR active target [2] has been used to study the matter distribution of very exotic light ions through proton inelastic scattering. The CENBG TPC [3] is used to provide the 3-dimensional reconstruction of two-proton radioactivity events and was used to prove the existence of this type of decay in $^{45}$Fe. Other active targets like MAYA at GANIL [4] have been built for more general use. With a solid angle coverage of about $2\pi$, MAYA has been used for the study of transfer reactions with very exotic beams [5–7] or giant resonances [8] in radioactive Ni isotopes.

With the upcoming availability of fission fragment beams at SPIRAL2, there is an obvious need for active targets with higher dynamic range in order to study, for example, the evolution of shell structure around the neutron number $N=50$ and $N=82$ magic numbers via single neutron transfer reactions. Higher granularity and higher counting-rate capabilities will permit the study of giant resonances and key reactions for those nuclei situated in, or near, the astrophysical rapid neutron and rapid-proton capture processes [9]. In this framework, based on the concept of the active target MAYA, the more efficient and versatile ACTAR TPC (ACtive TARget and Time Projection Chamber) is being developed. This detector will consist of a gas-filled volume of approximately $25\times25\times20$ cm$^3$. As in the MAYA active target, the ionization electrons produced along the charged particle tracks, i.e. the beam or the charged recoils produced in the reactions of

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interest between projectiles with the gas atoms, drift under the influence of an electric field to an amplification gap. The latter will consist of either Micromegas [10] (as used in the AT-TPC at MSU [11]) or ThGEM (Thick GEM) [12,13] chosen for their robustness and high-rate counting purposes. The amplification system will be coupled to a high granularity pad plane with $2 \times 2\ mm^2$ pixels, which will allow events to be reconstructed with good angular resolution even for short track lengths and with an excellent spatial resolution on the stopping points and hence a good energy resolution.

Regarding the foreseen geometry, several validation tests have been performed using 1 ThGEM of 600 microns (with 0.4 mm diameter holes and 0.7 mm pitch) and 2 Micromegas detectors of 128 and 256 microns amplification gaps, respectively. These tests consisted of several angular resolution and stopping-point measurements using a pixelated pad plane with $2 \times 2\ mm^2$ pads. The setup consisted of an $\alpha$ source and a silicon strip detector to select $\alpha$ trajectories above the pad plane. The entire ensemble was installed in the existing drift-field cage of MAYA. Gases at different pressures ($He+CF_4$ (2%) from 400 to 800 mbar and $iC_4H_{10}$ from 25 to 75 mbar) were used. Another gas, $Ar+CF_4$ (2%), was used to stop the alpha-particles over the pad plane and determine the energy and range resolutions.

In Sections 2 and 3, the experimental setup and the data analysis are presented in detail. Section 4 is devoted to the results of angular resolution with the different conditions of gas and pressure. The stopping point measurements are described in Section 5. Experimental results are then compared to simulations in Section 6.

## 2. Experimental setup

The prototype MPGDs were mounted on a circular PCB pad plane of 5.6 cm diameter with square pads of 2 mm side length that totaled 576 channels. As only 288 channels could be read using a single AFTER card (electronics previously developed for the T2K experiment [14]), only a fraction of the total pads could be connected while all others were grounded. The AFTER card was placed either below the pad plane in the gas or outside the chamber depending on the thermal conductivity of the gas. Two bulk Micromegas [15] were tested on this pad plane, one with an amplification gap of 128 μm and the other with 256 μm. A ThGEM foil of 600 μm thick was also tested and was positioned at a height of 2 mm above of the pad plane. The detection system was inserted at the bottom of the MAYA drift field cage and was surrounded by a copper plate that was biased at the micromesh or the ThGEM voltage to maintain the homogeneity of the electric drift field. The field cage is composed of printed circuit board with copper strips (with 3 mm pitch) on the front and side panels and a wire plane on the back panel to allow particles to escape [4]. As shown in Fig. 1, a DSSSD (Double Sided Silicon Strip Detector) with 16 channels on each side and a strip pitch of 3.12 mm was placed at the end of the chamber. A mask with 16 slits of $10 \times 0.6\ mm^2$ was positioned in front of the DSSSD. A mixed alpha source (3 alpha-particles with energies of 5.1 MeV, 5.5 MeV and 5.8 MeV from $^{239}Pu$, $^{241}Am$ and $^{244}Cm$, respectively) was inserted at a distance of 184 mm from the Si detector and at a height of 10 cm above the MPGD pad plane. In the horizontal direction, the source was 13 mm from the start of the active area of the detector. The source has a diameter of 5 mm and can be collimated. The data acquisition system was triggered by the detection of an alpha-particle in the Si detector and the charge signals on the pad plane were used to reconstruct the alpha trajectory. The slits of the Si mask were positioned either vertically or horizontally depending on the desired angular resolution measurement.

The filling gas used in the chamber was supplied through a gas regulation system that ensured a constant flow and pressure. The 128 μm Micromegas prototype was tested in $He+CF_4$ (2%) at 500, 600 and 800 mbar whereas the 256 μm detector was tested at 400, 500 and 600 mbar and in pure $iC_4H_{10}$ at 25, 50 and 70 mbar. The ThGEM was only tested in pure $iC_4H_{10}$ at 25, 50 and 75 mbar. The maximum pressures (800 mbar in the He mixture and 75 mbar in isobutane) were chosen so that the alpha particles could reach the silicon detector. The lower pressures were adapted to the different amplification systems and their own sparking limits and gain properties. For this reason, the 256 μm Micromegas was preferred to the 128 μm in isobutane [16]. The values of voltages are specified for each result given later in this paper. For Micromegas, they are given as follows: $V_{mesh}/V_{drift}$ with $V_{mesh}$ the micromesh voltage and $V_{drift}$ the voltage applied to the drift cathode. For the ThGEM, they are given as follows: $V_{down}/V_{up}/V_{drift}$ with $V_{down}$ being the voltage applied to the bottom electrode in front of the pad plane (generally called extraction voltage) and $V_{up}$ the voltage applied to the top electrode.

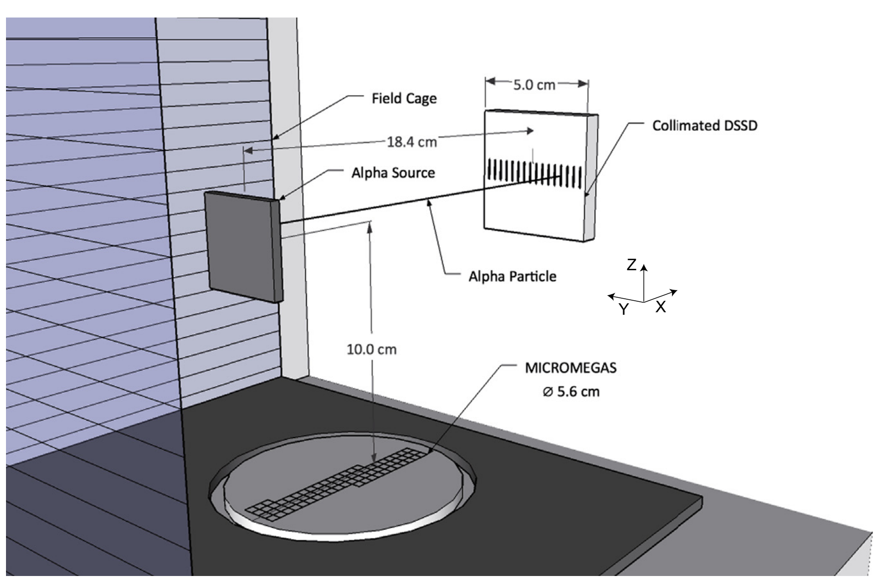


**Fig. 1.** Schematic view of the complete setup for horizontal measurements. For vertical measurements the DSSSD and the mask were rotated by 90°.