Nuclear Instruments and Methods in Physics Research A 772 (2015) 76–82

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Understanding avalanches in a Micromegas from single-electron response measurement

T. Zerguerras [a,*], B. Genolini [a], F. Kuger [b,c], M. Josselin [a], A. Maroni [a], T. Nguyen-Trung [a], J. Pouthas [a,1], P. Rosier [a], Ö. Şahin [d], D. Suzuki [a], R. Veenhof [d,e]

[a] Institut de Physique Nucléaire (UMR 8608), CNRS/IN2P3-Université Paris-Sud, F-91406 Orsay Cedex, France
[b] University of Würzburg, 97070 Würzburg, Germany
[c] CERN, Geneva, Switzerland
[d] Department of Physics, Uludağ University, 16059 Bursa, Turkey
[e] RD51 Collaboration, CERN, Geneva, Switzerland

ARTICLE INFO

Article history:
Received 4 July 2014
Received in revised form
19 September 2014
Accepted 5 November 2014
Available online 13 November 2014

Keywords:
Gaseous detectors
Micromegas
Single-electron response
Avalanche charge fluctuations
Magboltz Monte-Carlo model

ABSTRACT

Avalanche fluctuations set a limit to the energy and position resolutions that can be reached by gaseous detectors. This paper presents a method based on a laser test-bench to measure the absolute gain and the relative gain variance of a Micro-Pattern Gaseous Detector from its single-electron response. A Micromegas detector was operated with three binary gas mixtures, composed of 5% isobutane as a quencher, with argon, neon or helium, at atmospheric pressure. The anode signals were read out by low-noise, high-gain Cremat CR-110 charge preamplifiers to enable single-electron detection down to gain of 5×10^3 for the first time. The argon mixture shows the lowest gain at a given amplification field together with the lowest breakdown limit, which is at a gain of 2×10^4 an order of magnitude lower than that of neon or helium. For each gas, the relative gain variance f is almost unchanged in the range of amplification field studied. It was found that f is twice higher ($f \sim 0.6$) in argon than in the two other mixtures. This hierarchy of gain and relative gain variance agrees with predictions of analytic models, based on gas ionisation yields, and a Monte-Carlo model included in the simulation software Magboltz version 10.1.

1. Introduction

For more than a decade, micro-pattern gaseous detectors (MPGDs), such as the GEM [1] and the Micromegas [2], have proven to be valuable tools for high-energy physics thanks to their good energy, time and position resolutions, their high rate capability, their low spark rate and their ability to limit ion backflow. MPGDs are found in virtually all high energy physics experiments [3–6]. They also appear as most promising technologies for the LHC instrumentation upgrade [7–9] and are considered as part of the detection system associated to the future International Linear Collider (ILC) facility [10].

MPGD devices are also growing in importance in modern nuclear physics, where new generations of radioactive-isotope beam facilities [11–14] will soon be extending horizons of spectroscopic studies on short-lived nuclei. A new generation of MPGD enables a unique access to nuclear reactions at low energies or rare decay processes. A time-projection chamber (TPC) using a stack of four GEM foils realised direct measurements of two-proton decay of ^{45}Fe, a very rare mode of radioactivity [15]. Active reaction targets for radioactive-beam reactions are another example of applications that are attracting much of attention [16–18]. These devices are based on TPC technology, where the tracking gas is used simultaneously as the target of nuclear reactions. The reaction vertex and energy deposition of particles, of which the uncertainty usually leads to critical deterioration of resolutions, can be directly and precisely measured. In pursuit of better resolution and higher luminosity, active targets using MPGD devices such as ACTAR TPC [19], AT-TPC [20], or CNS-TPC [21] are currently under development.

This paper looks into the multiplication process in a Micromegas detector, with particular focus on the avalanche charge fluctuations which limit the energy [22] and position [23] resolutions. Although experimental data quantifying these fluctuations are critical for gaseous detectors simulation programmes, they are rather scarce in tables and literature. This paper proposes a method ideally suited to get such data. It is based on measurements of the single-electron response (SER) of a Micromegas detector, operated with helium, neon and argon gas mixtures with

* Corresponding author. Tel.: +33 1 69 15 64 42; fax: +33 1 69 15 50 01.
E-mail address: zerguer@ipno.in2p3.fr (T. Zerguerras).
[1] Present address: Laboratoire de Physique Corpusculaire, ENSICAEN, Bvd Maréchal Juin, 14050 Caen, France.

http://dx.doi.org/10.1016/j.nima.2014.11.014
0168-9002/

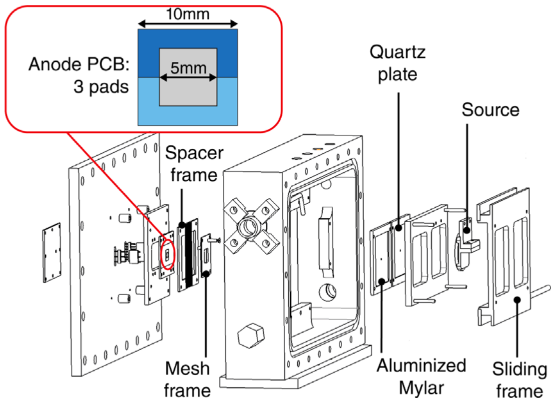

Fig. 1. Exploded view of the detector.

isobutane. Compared to the traditional use of a radioactive source or a charged particles beam, this method provides a direct measurement of the absolute gain and the relative gain variance but requires an optimised test-bench, in terms of detector mechanics and electronics signal-to-noise ratio, to enable single electron detection in a wide range of electric field, down to gains as low as a few 10^3.

Section 2 describes the experimental method and the setup. Section 3 reports on the peculiarities of the avalanche process in the used gas mixtures. Results and interpretations of SER measurements, including gain curves and relative gain variance, are given in Section 4.

2. Experimental method

The set-up relies on a previously used optical test-bench [24], that consists of a 337-nm pulsed laser, model VSL-337 from Spectra-Physics [25], a telescope collimating the laser beam, a periscope adjusting its height and a 60-mm focal length triplet, giving a spot size smaller than 100 μm. The purposes of the present measurements call for a new detector, shown in Fig. 1, with an improved design compared to that used in Ref. [24], including a simplified anode pad plane and readout electronics with an improved signal-to-noise ratio to lower the single-electron detection threshold.

The Micromegas drift electrode is divided into a stretched aluminized Mylar® foil for measurements with an ^{55}Fe source and a thin quartz plate with a 0.5-nm thick nickel–chromium layer for operation with the laser. The drift electrode is mounted on a sliding frame which allows us to place either part of the electrode in front of the Micromegas mesh. The ^{55}Fe source is mounted on the sliding frame and faces the Mylar® foil. The mesh foil of the Micromegas is a 333 lines-per-inch electroformed nickel micro-mesh, manufactured by Buckbee-Mears and supplied by Industrial Netting [26], with an optical transparency of 70%. The Micromegas has an active area of 10×10 mm^2 and was installed 3.2 mm from the drift electrode. The gap between the mesh and the anode is defined by 160-μm diameter stretched nylon fishing lines at 2 mm intervals. The anode printed-circuit board (PCB) is divided in a 5×5 mm^2 square pad and two adjacent bracket-shape pads. The Micromegas structure with the ^{55}Fe source is enclosed in a vessel equipped with a quartz entrance window (not shown in Fig. 1) which transmits the laser-light unattenuated. The vessel is mounted on three 1-μm precision motors to move the detector relative to the laser beam.

In order to lower the charge threshold for SER measurements, the signal-to-noise ratio of the pads readout electronics was enhanced by replacing the Gassiplex chips [27] used in Ref. [24] by CR-110 charge preamplifiers manufactured by Cremat [28]. This chip achieves high gain (1.4 V/pC) with a much lower noise level (200 e^- RMS) than the Gassiplex. The CR-110 chips were mounted on a board enclosed in a metallic box connected to the anode pads on the rear side of the vessel. The box was also equipped with three test-inputs to inject a generator pulse signal through a 1 pF high-precision capacitance for charge calibration and electronics noise measurement of each channel. When connected to the detector, the electronics noise was increased to 380 e^- RMS due to the detector capacitance. However, this is still a factor of 5 lower than in the previous set-up using Gassiplex chips.

Each preamplifier output feeds a 16-channel CAEN N568B spectroscopy amplifier [29] with a shaping time set at 3 μs. The N568B module outputs both slow and fast signals. The slow signals were digitised by an 11-bit CAMAC-standard peak-sensing ADC module AD811F. The data acquisition was triggered by the fast signal of the central pad when using the ^{55}Fe source and the events with full energy deposition in the central pad were selected in the analysis of the ^{55}Fe data.

The single-electron regime is achieved following the method described in Ref. [24]: the pulsed laser is focused on the metallic layer of the quartz plate to generate a signal on the central pad only. Then, the laser light intensity is attenuated with calibrated neutral density filters to a regime where the probability of producing one electron is much greater than the probability of giving more than one. In this new set-up, the laser light was attenuated by a factor of 200 and fewer than 5% of the triggered events have a non-zero signal (charge greater than 2×10^3 electrons, which is 5 times the RMS noise). Among these non-zero signals, the probability of producing more than one electron is lower than 0.25%. In single-electron mode, the trigger was generated using a split laser light that was routed by an optical fiber to a Photonis XP2282B photomultiplier [30]. The charge of the anode signal from the photomultiplier was recorded in a standard CAMAC QDC module (model Lecroy AD2249A) to monitor the laser light fluctuations. The Micromegas drift field is kept at 900 V/cm.

The three gas mixtures were of 95% of argon, neon or helium, and 5% isobutane (iC_4H_{10}). The Air Liquide company [31] supplied the gases, with a purity better than 99.999% for the rare gases and 99.5% for isobutane, which were then mixed according to the aforementioned proportions by adjusting the gas flows using Brooks [32] digital flowmeters. A gas regulation system is connected at the gas input and output to empty the vessel, and maintain a stable flow and a constant pressure of 748 Torrs. All measurements were conducted in a controlled-temperature room at 293 ± 0.5 K.

Isobutane is an efficient quenching gas due to its high photo-absorption cross-section [33]. The argon-based mixture is widely used for characterising Micromegas detectors and a typical ^{55}Fe spectrum measured with the present set-up is shown in Fig. 2, where the main 5.9 keV and the 2.9 keV escape peaks are both visible. The energy resolution obtained for the 5.9 keV peak is 20% FWHM. Neon mixtures are light and feature high gains with low spark rates [34]. Performances of Micromegas in helium-based mixture are important for the active target application as helium nuclei are widely used targets of nuclear reactions.

To avoid any damage on the Cremat chips, the mesh voltage where Micromegas was safely operated without discharge was determined before starting any measurements. During this preparation, the preamplifiers were dismounted and the anode pads were directly grounded. The mesh voltage was increased up to observe a first spark and the maximum operation voltage was set 10 V below the measured discharge threshold. The corresponding electric field of amplification ranged from 24 to 35 kV/cm.