Nuclear Instruments and Methods in Physics Research A ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Low material budget floating strip Micromegas for ion transmission radiography

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ARTICLE INFO

Article history:
Received 25 March 2016
Accepted 1 May 2016

Keywords:
Tracking detectors
Micro-pattern gaseous detectors
Scintillator range telescope
µTPC reconstruction
Timing

ABSTRACT

Floating strip Micromegas are high-accuracy and discharge insensitive gaseous detectors, able to track single particles at fluxes of 7 MHz/cm^2 with 100 µm resolution. We developed low-material-budget detectors with one-dimensional strip readout, suitable for tracking at highest particle rates as encountered in medical ion transmission radiography or inner tracker applications. Recently we additionally developed Kapton-based floating strip Micromegas with two-dimensional strip readout, featuring an overall thickness of 0.011 X_0.

These detectors were tested in high-rate proton and carbon-ion beams at the tandem accelerator in Garching and the Heidelberg Ion-Beam Therapy Center, operated with an optimized Ne:CF$_4$ gas mixture. By coupling the Micromegas detectors to a new scintillator based range detector, ion transmission radiographies of PMMA and tissue-equivalent phantoms were acquired. The range detector with 18 layers is read out via wavelength shifting fibers, coupled to a multi-anode photomultiplier.

We present the performance of the Micromegas detectors with respect to timing and single plane track reconstruction using the µTPC method. We discuss the range resolution of the scintillator range telescope and present the image reconstruction capabilities of the combined system.

1. Introduction

Floating strip Micromegas detectors are discharge insensitive micro-pattern gaseous detectors with excellent spatial and good temporal resolution. They are an advancement of standard Micromegas detectors [1]. Micromegas are parallel plate avalanche chambers with strongly asymmetric drift and amplification region, separated by a thin metallic micro-mesh. Charged particles ionize the detector gas in the several millimeters wide drift region, ionization electrons are guided by a 0.2 kV/cm drift field into the high-field amplification region between micro-mesh and copper anode structure, where they are amplified in Townsend avalanches. The anode structure is segmented in strips or pads that are individually read out, providing an excellent spatial resolution and a good multi-hit resolution. Short ion drift paths in the 0.15 mm wide amplification region enable a fast drain of positive ions and thus avoid the creation of space charge, rendering Micromegas extremely high-rate capable [2].

Thus, they are well suited for accurately measuring particle tracks in medical ion transmission radiography. In this paper we present for the first time measurements with novel floating strip Micromegas with two-dimensional strip readout structure.

2. Floating strip Micromegas

During the last years we have developed and characterized high-rate capable floating strip Micromegas detectors [3]. Apart from being generic detector R&D for charged particle tracking detectors at highest rate, this research aims at developing a detector system for medical ion transmission radiography and tomography. For this purpose we developed detectors with an active area of 64 × 64 mm^2 and a low material budget of 0.0088 X_0.

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http://dx.doi.org/10.1016/j.nima.2016.05.003
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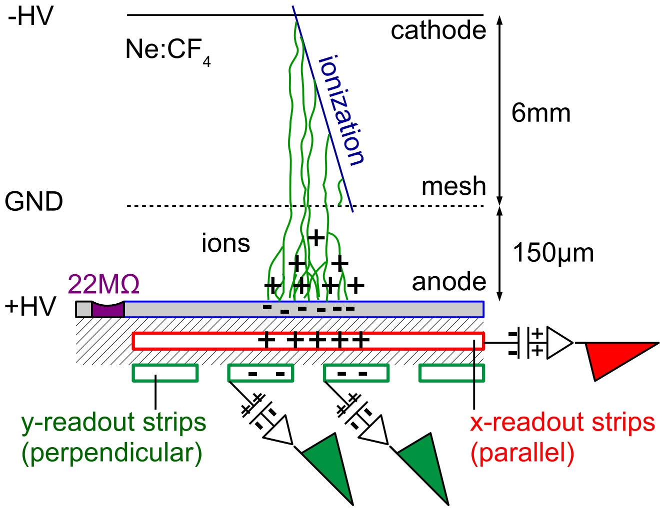

Fig. 1. Schematic of a floating strip Micromegas with two-dimensional strip readout structure. Not to scale.

The internal structure of a novel floating strip Micromegas with two-dimensional strip readout structure is shown schematically in Fig. 1. Charged particles ionize the Ne:CF_4 based detector gas in the drift region between cathode and mesh. Charge signals are detected on the 64 mm × 64 mm copper anode structure, after amplification in Townsend avalanches. The anode consists of 300 μm wide copper strips with 500 μm pitch, individually connected to high-voltage via screen-printed resistors.

During the drift of positive ions from gas amplification towards the mesh, the charge on the copper anode strips is picked up by the parallel layer of readout strips. They are 80 μm wide and feature the same pitch as the anode strips. A negative charge signal is detected by the connected readout electronics. The perpendicular layer of readout strips, consisting of 400 μm wide strips with 500 μm pitch, detects a localized positive charge signal.

Charge densities exceeding $2\times10^6\ e/0.01\ \mathrm{mm}^2$ in the amplification region can lead to streamer development between anode structure and mesh, followed by a non-destructive discharge. The major advantage of floating strip Micromegas with respect to standard Micromegas comes from the individual high-voltage connection and the very small capacitance of the anode strips, while completely avoiding the use of resistive material in the active region: The few strips affected by the discharge adapt to the mesh potential quickly, as they are quasi-floating, and interrupt the discharge. All other strips remain unaffected and thus efficient. Due to the small overall strip capacitance of the order 40 pF, the recharge of the affected strips is fast, despite the large quenching resistor.

3. Ion transmission radiography

Tumor irradiation with particle beams exploits the specific depth-dose profile and the excellent steerability of particle beams to accurately deliver dose to the desired region. Imaging techniques before and during treatment are essential for a precise diagnostics and an accurate modeling and planning of the irradiation as already minor anatomical changes or a mis-modeling of the target volume lead to particle range uncertainties on the order of millimeters or more [4].

In ion transmission imaging an image information is deduced from the energy loss of ions in the patient [5]. Spatial resolution is provided by tracking detectors in front of and behind the patient. Contrast information is acquired by measuring the residual particle energy or the Bragg peak position in a suitable detector, such as a multi-layer scintillator based range telescope.

Using the same particle type for imaging and treatment avoids calibration uncertainties between X-ray absorption coefficient and particle energy loss during treatment planning. This ultimately leads to a more accurate irradiation while being able to spare sensitive tissue around the target volume. Additionally, the dose deposition in the patient can be reduced with respect to X-ray imaging by a factor of 10–100 [6].

4. Three-dimensional μTPC reconstruction

The finite drift time of electrons in the drift region can be exploited to reconstruct full three-dimensional track information for inclined particle tracks in a Time Projection Chamber-like mode, Fig. 2.

4.1. Reconstruction method

Ionization electrons created close to the mesh reach the amplification region almost instantaneously while those produced close to the cathode drift for about 60 ns before they can be detected on readout strips. Measuring the signal timing on individual strips yields the ionization electron arrival time. Using calculated drift velocities from MAGBOLTZ [7], this can be translated into a drift distance.

A line fit to the (drift distance, strip)-data points yields the track inclination angle and also the particle hit position. This μTPC hit position is more accurate than the usual centroid hit position for track inclinations above 15° with respect to the direction of drift field lines.

4.2. Results in 20 MeV proton beams

The μTPC reconstruction capabilities of floating strip Micromegas with two-dimensional strip readout structures have been studied with 20 MeV protons at the tandem accelerator in Garching. The detectors have been inclined with respect to the beam. In Fig. 3 the reconstructed track inclinations are shown, measured simultaneously on both readout strip layers of the same detector. The average reconstructed track inclinations agree very well with the expectation, the angular resolution is for both layers $+3°$, $-2°$.

Optimum angular resolutions of $+1.9°$, $-1.6°$ are observed at

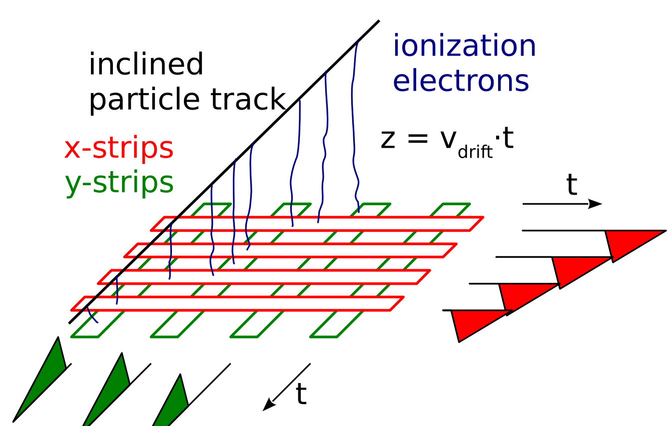

Fig. 2. Measuring the arrival time of ionization electrons on readout strips allows for a direct determination of the track inclination and a full three-dimensional track reconstruction in a single detector.

Please cite this article as: J. Bortfeldt, et al., Nuclear Instruments & Methods in Physics Research A (2016), http://dx.doi.org/10.1016/j.nima.2016.05.003