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The μ-RWELL: A compact, spark protected, single amplification-stage MPGD

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ABSTRACT

In this work we present two innovative architectures of resistive MPGDs based on the WELL-amplification concept:

– the micro-Resistive WELL (μ-RWELL) is a compact spark-protected single amplification-stage Micro-Pattern Gas Detector (MPGD). The amplification stage, realized with a structure very similar to a GEM foil (called WELL), is embedded through a resistive layer in the readout board. A cathode electrode, defining the gas conversion/drift gap, completes the detector mechanics. The new architecture, showing an excellent space resolution, ~50 μm, is a very compact device, robust against discharges and exhibiting a large gain (>10^4), simple to construct and easy for engineering and then suitable for large area tracking devices as well as digital calorimeters.

– the Fast Timing Micro-pattern (FTM): a new device with an architecture based on a stack of several coupled full-resistive layers where drift and multiplication stages (WELL type) alternate in the structure. The signals from each multiplication stage can be read out from any external readout boards through the capacitive couplings, providing a signal with a gain of 10^4–10^5. The main advantage of this new device is the improvement of the timing provided by the competition of the ionization processes in the different drift regions, which can be exploited for fast timing at the high luminosity accelerators (e.g. HL-LHC upgrade) as well as for applications like medical imaging.

1. Introduction

The modern photolithographic technology on flexible and standard PCB supports has allowed the invention of novel and robust MPGDs, such as GEM [1], THGEM [2,3] and Micromegas [4]. These detectors exhibit good spatial [5] and time resolution [6], high rate capability [7], large sensitive area [8], flexible geometry [9], good operational stability [10] and radiation hardness [11].

However, due to the fine structure and the typical micrometric distance of their electrodes, MPGDs generally suffer from spark occurrence that can eventually damage the detector.

A further limitation of such MPGDs is correlated with the complexity of their assembly procedure. In particular, a GEM chamber requires some time-consuming assembly steps such as the stretching and the gluing of the GEM foils [12–14]. Similar considerations can also be done for Micromegas, where the metallic mesh, defining the detector amplification region, requires a precise stretching.

2. μ-RWELL detector

The μ-RWELL [15] has been designed at the Laboratori Nazionali di Frascati and realized for the first time in the 2009 by TE-MPE-EM Workshop at CERN in parallel with the CERN-GDD group [16,17]. A similar device based on THGEM technology has been recently proposed by other groups [18].

The μ-RWELL, as shown in Fig. 1, is realized by merging a suitable etched GEM foil with the readout PCB plane coated with a resistive deposition. The copper on the bottom side of the foil has been patterned in order to create small metallic dots in correspondence with each WELL structure. The resistive coating has been performed by screen printing technique. The WELL matrix geometry is realized on a 50 μm thick polyimide foil, with conical channels 70 μm (50 μm) top (bottom) diameter and 140 μm pitch. A cathode electrode,

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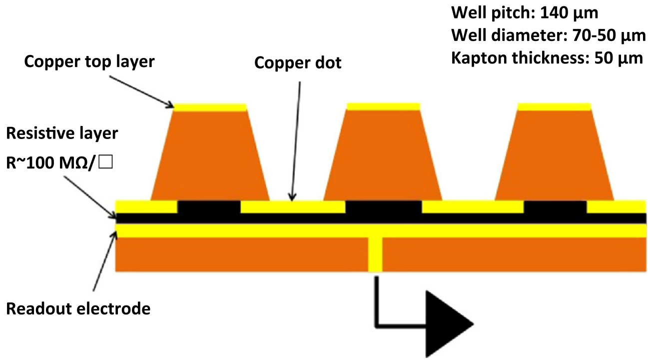

Fig. 1. Schematic drawing of the μ-RWELL PCB.

defining the gas conversion/drift gap, completes the detector mechanics.

The μ-RWELL has features in common either with GEMs or Micromegas :

- From GEM it takes the amplifying scheme with the peculiarity of a "*well defined amplifying gap*", thus ensuring very high gain uniformity.
- From Micromegas it takes the resistive readout scheme that allows a strong suppression of the amplitude of the discharges.

The assembly aspect of the resistive-WELL technology is obviously a strong point in favour of this architecture. The μ-RWELL is composed of only two components: the readout-PCB, with the amplifying part embedded in it, and the cathode. Its assembly does not require gluing or stretching of foils or meshes: a very critical and time-consuming construction step of both GEM and MM technologies. The stretching of a GEM foil as well as a metallic mesh requires mechanical tension, of the order of 1 kg/cm, that clearly must be supported by suitable rigid mechanical structures.

The μ-RWELL with respect to the GEM and MM is extremely compact, does not require very stiff (and large) support structures, allowing large area covering based on a *PCB-splicing* technique (with a dead space within 0.2–0.3 mm) while keeping a "*well defined amplifying gap*".

2.1. Detector performance

In the following we report the results about the tests performed on the μ-RWELL prototypes. The detector gain has been measured with X-rays, in current mode, as a function of the potential applied across the amplification stage and the resistive layer. As shown in Fig. 2, the operation with an iso-buthane based gas mixture allows to achieve a gas gain larger than 10^4, comparable with the gain at which standard triple-GEM and MM are normally operated.

The introduction of a high resistivity layer between the amplification stage and the readout reduces the capability to stand very high particle fluxes. In Fig. 3 the normalized gain of the single-GEM is compared with that obtained for the μ-RWELL with three different collimator diameters: 10 mm, 5 mm and 2.5 mm. The gain of the GEM is substantially constant over the explored range of radiation flux (up to 3 MHz/cm^2), while the maximum particle flux that the μ-RWELL is able to stand, in agreement with an Ohmic behaviour of the detector, decreases with the increase of the effective diameter of the X-ray spot on the detector. A function that, taking into account only the effect of the resistive layer for the gain drop [15], has been used to fit the points in Fig. 3 and to evaluate the radiation flux when the detector is expected to have a gain drop of 3%, 5% and 10% for all the collimators. These results, as

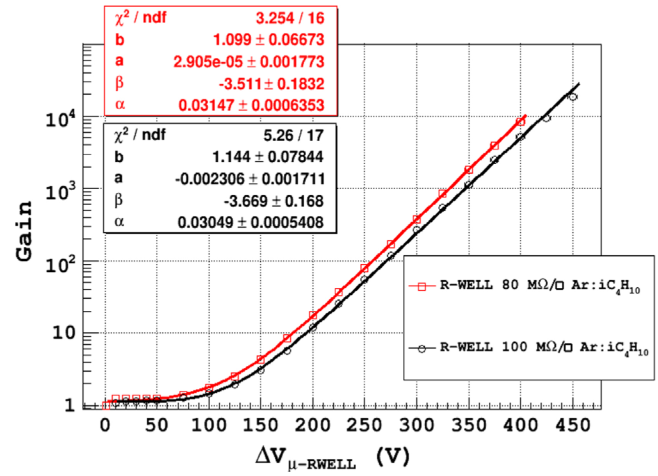

Fig. 2. Gas gain in Ar:iso-buthane (90:10), for two different μ-RWELL geometry: 80 MΩ/□ (red points) and 100 MΩ/□ (black points).

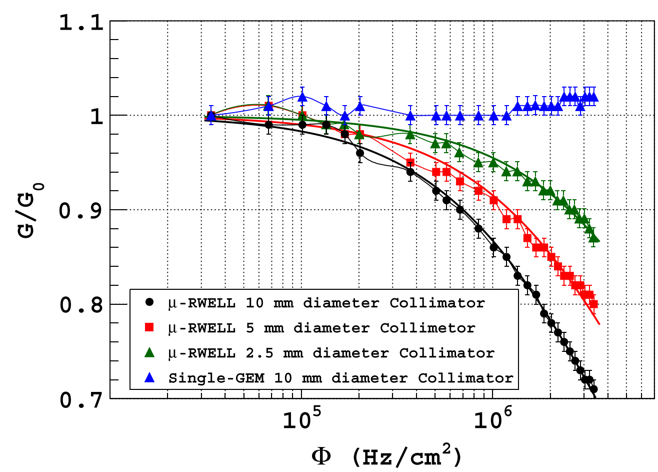

Fig. 3. Comparison of the normalized gain (a.u.) for the GEM (blue) and the μ-RWELL for different collimator diameters (G_0=3000 with Ar:CO_2 70:30). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

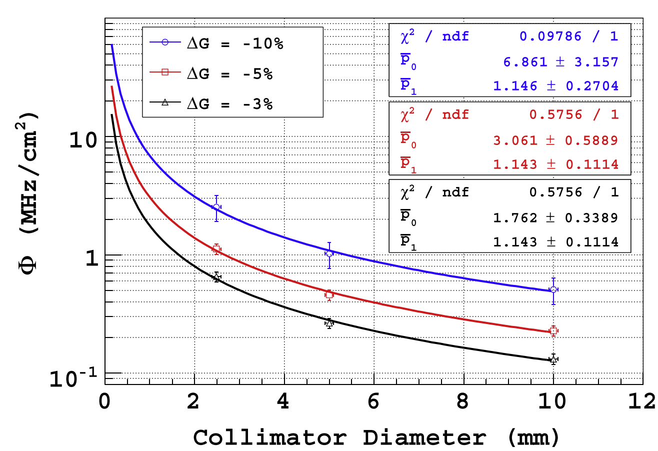

Fig. 4. Rate capability (with X-rays) for the μ-RWELL as a function of the diameter of the collimator, for different value of the accepted gain drop (−3% black line; −5% red; −10% blue). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

shown in Fig. 4, seem to indicate that the rate capability of the detector can be tuned (typically from 100 kHz/cm^2 to 600 kHz/cm^2, for a surface resistivity of about 100 MΩ/□) with a suitable segmentation of the resistive layer [18].

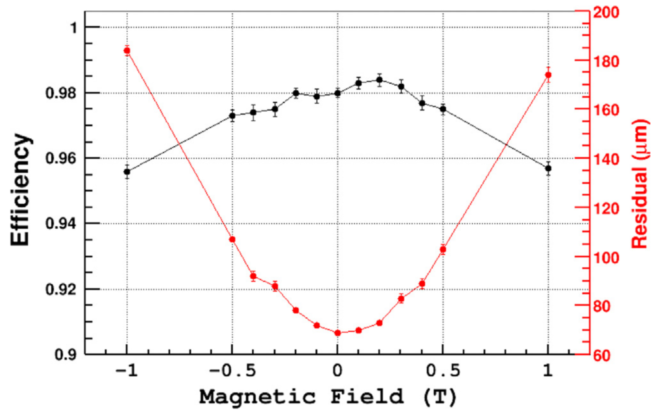

Fig. 5. Track reconstruction efficiency and track fit residual for μ-RWELL, with 1D strip readout, for orthogonal incidence as a function of the magnetic field. The detector gain was ~ 4000.

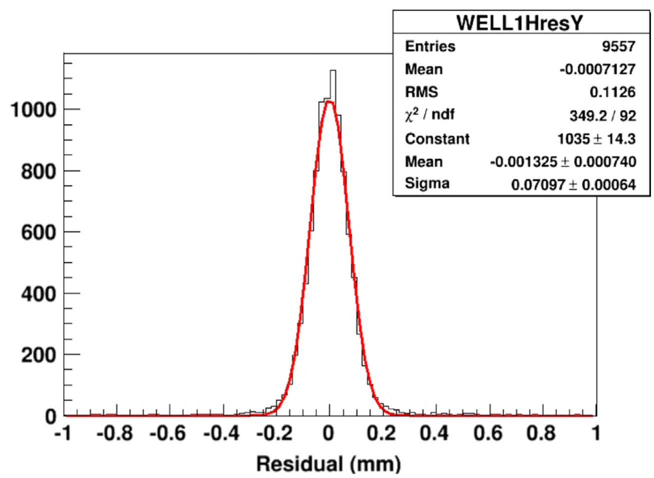

Fig. 6. Track fit residual for the μ-RWELL with a gas gain of ~ 4000 and $B = 0$ T. The estimated space resolution of the μ-RWELL is 52 ± 6 μm.

The performance of a 5×5 cm^2 μ-RWELL with 4 mm gas gap has been tested at the H4-SPS beam line for orthogonal incidence tracks and in magnetic field. The prototype has a surface resistivity of 80 MΩ/□ and it was equipped with a 1D strip readout of 400 μm pitch strip. Each strip was readout by the APV25 chip and the center of gravity method (COG) has been used in the reconstruction of tracks. An external tracker, immersed in the magnetic field and composed of three triple-GEM detectors, has been used in the test. Results from such a beam test show:

- a detection efficiency of the order of ~98% for an absolute value of the magnetic field below 0.5 T; while few percent of efficiency is lost at higher magnetic fields due to the higher diffusion of the primary electrons in the drift gap, that should induce signal below the front-end electronics threshold (Fig. 5);
- a detector residual below 70 μm at $B = 0$ T, which corresponds to a space resolution of 52 ± 6 μm after the subtraction of the contribution due to the track fit, 42 ± 2 μm, performed with external trackers (Fig. 6);
- a high efficiency and good detector residual at relative low gas gain (~ 2000) due to the high sensitivity of the APV25 chip and the use of 1D strip readout (Fig 7);
- a limited cluster size due to the use of high surface resistivity, which allows to shrink the induced signal on the readout strips (Fig. 8).

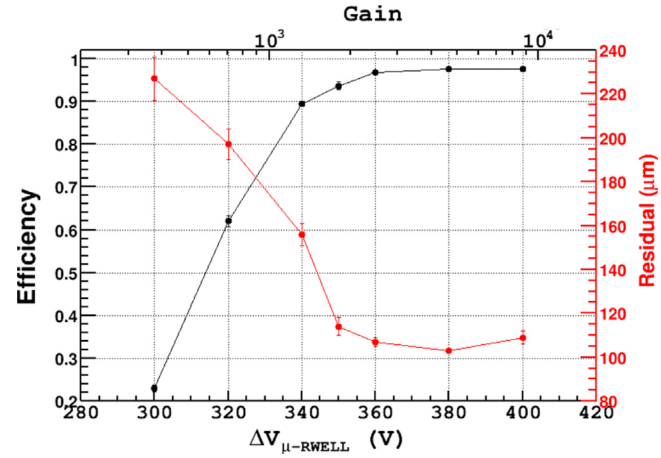

Fig. 7. Track reconstruction efficiency and track fit residual for μ-RWELL, with 1D strip readout, for orthogonal incidence and $B = 0.5$ T as a function of the gas gain.

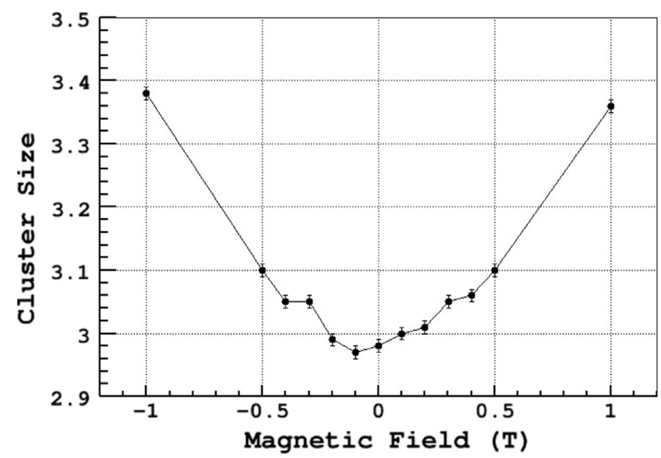

Fig. 8. Cluster size for μ-RWELL, with 1D strip readout, for orthogonal incidence as a function of the magnetic field. The detector gain was ~ 4000.

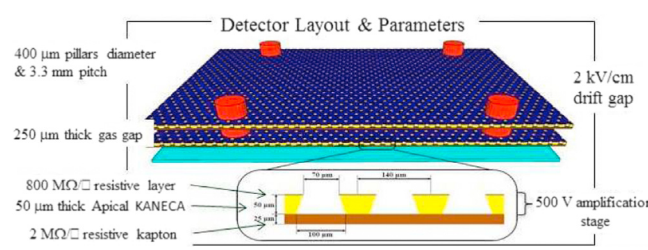

Fig. 9. Schematic drawing of the Fast Timing Micro-pattern Gas Detector.

3. FTM: Fast Timing Micro-pattern Gas Detector

The FTM detector [19] layout is based on the concept of the μ-RWELL detector: two or more layers are used as sketched in Fig. 9. The foils are a 50 μm thick Apical KANECA with hole diameters of 100 μm and 70 μm and pitch is 140 μm. The kapton foil is coated on the top with diamond-like carbon (DLC) techniques (~800 MΩ/□), while a 25 μm thick XC Dupont Kapton (~2 MΩ/□) is used on the bottom. A drift volume of 250 μm thick is ensured by a set of pillars obtained by the PCB technique with photo-imageable coverlay. The pillar diameter is 400 μm with a pitch of ~ 3.3 mm. The use of resistive layers in the architecture allows signals coming from the layers to be externally extracted thanks to the resulting transparency of polarising electrodes. The prototype has been operated with a $Ar/CO_2/CF_4$=45/15/40 gas mixture. The different regions have been polarised with the CAEN N1470 power

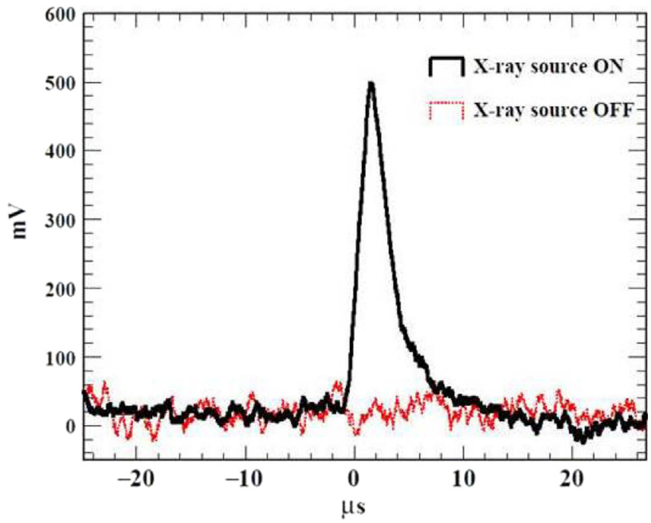

Fig. 10. Average FTM signal with X-ray source on (full line) and off (dotted) line.

supply in order to give an electric field of 2 kV/cm for the drift regions and ~ 100 kV/cm for the amplification regions. The signals from the readout electrode have been sent to the low-noise charge-sensitive ORTEC PC142 preamplifier. The resulting inverted signal outputs have been amplified by the ORTEC 474 NIM module and acquired with a Tektronix TDS 2024C oscilloscope. An X-ray source has been used in order to demonstrate the capability of signal extraction, and the results are shown in Fig. 10, where an average signal is shown in the presence and in the absence of the source.

4. Conclusions

The µ-RWELL is a very promising technology showing important advantages with respect to classical GEMs and MMs: the detector is "*thin-large-simple*" and exhibits effective spark quenching. Besides high gas gain ($>10^4$) and good rate capability (~ 600 kHz/cm^2 at G~5000 with X-rays and a resistivity of about 100 MΩ/□-without resistive layer segmentation), a space resolution better than 60 µm has been measured. The R&D on the FTM detector has begun and it is expected that this technology can be used for applications in high energy physics experiments, particularly for upgrades at LHC where subnanosecond time resolutions with a high particle rate is a challenging issue for particle identification and vertex separation.

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