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The micro-RWELL for future HEP challenges and beyond

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Abstract: The forthcoming High-Energy Physics (HEP) experiments necessitate particle detection technologies that are efficient, scalable, and compatible with industrial production. The μ-RWELL, a single-stage resistive MPGD based on sequential build-up technology, meets these demands. This contribution outlines the detector's characteristics, detailing design and testing at INFN-LNF, as well as the construction processes conducted at the ELTOS Company and CERN MPT Workshop. Our findings demonstrate that much of the detector construction can be industrialized, significantly reducing production time and costs. Notably, the development of large DLC foils for the amplification stage represents a key advancement, enabled by the acquisition of a DC-magnetron sputtering machine through a joint CERN-INFN initiative. We present test results from X-ray gun studies at LNF and particle beams at CERN's North Area, alongside preliminary outcomes from a 2023 co-production pilot test, which achieved a 90 % production yield. This marks an important step towards the industrial-scale production of larger detectors for HEP applications. In addition to technology transfer and process refinement, we pursued R&D to optimize the μ-RWELL for diverse applications, including trigger for the LHCb Phase II Muon System, fine tracking in the IDEA Muon system, and sensors for neutron detection in Homeland Security.

Keywords: Particle tracking detectors (Gaseous detectors); Large detector systems for particle and astroparticle physics; Muon spectrometers; Timing detectors

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1 Introduction

The μ-RWELL [1] is a resistive MPGD. A 50 μm thick polyimide (Apical®) foil, copper-clad on the top side and sputtered with DLC (typically in the range 50 ÷ 100 MΩ/□) [2] on the bottom side, is coupled to a standard PCB readout board, through a 50 μm thick pre-preg foil. The DLC resistivity is adjusted to provide discharge suppression as well as current evacuation. A chemical etching is performed to create a GEM-like matrix of truncated cones with 70(50) μm top(bottom) diameter and 140 μm pitch. This pattern constitutes the amplification stage. The signal is capacitively induced on the strips/pads on the readout board [3]. The introduction of the resistive layer allows achieving large gas gains up to 10^4 with a single amplification stage, while partially reducing the capability to stand high particle fluxes [4].

2 High rate μ-RWELL for the LHCb experiment

The μ-RWELL technology has been proposed for the Phase-II Upgrade of the innermost regions of the muon detection system of the LHCb experiment at High Luminosity LHC (HL-LHC) [5]. The main requirements for the detectors are the capability to withstand high particle fluxes, up to 1 MHz/cm^2, and achieving a high efficiency within a 25 ns time window. This endeavour will involve the production of approximately 600 detectors with an active area ranging from 25×30 cm^2 up to 30×65 cm^2, see section 4.

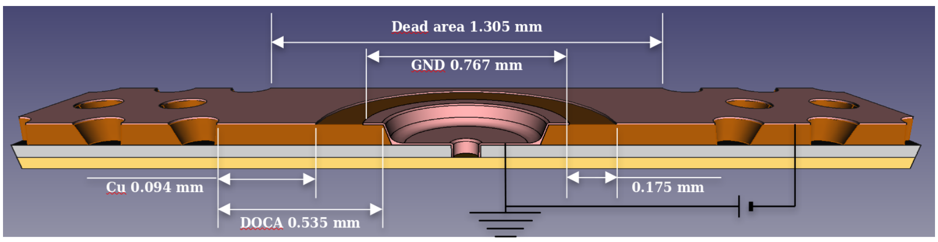


Figure 1. Sketch of the PEP-DOT μ-RWELL.

It is possible to overcome the intrinsic rate limitations of the baseline µ-RWELL layout implementing a high-density grounding network for the resistive stage (DLC) [4]. The current high rate scheme is the PEP (Patterning-Etching-Plating): this layout is based on a single DLC layer, in which the grounding network of the resistive stage is patterned by etching from the top copper layer through the Kapton foil down to the DLC, figure 1. The DLC grounding is realized with a matrix of conductive dots connecting the DLC with the underlying readout pads (similar to plated blind vias) and has a pitch of 9 mm. The layout is easily scalable to large sizes and is easily engineered, as it is based on Sequential Build Up (SBU) technology. The detector show an efficiency larger than 95 %, figure 2 and a rate capability larger than 10 MHz/cm^2, figure 3.

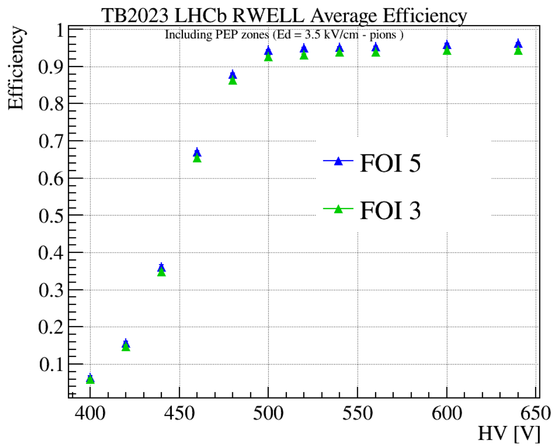


Figure 2. Efficiency measurement for a µ-RWELL with a 9 mm PEP-DOT pitch, done with 150 GeV muon beam at CERN SPS-H8 beam area, with $Ar:CO_2:CF_4$ 45:15:40 gas mixture.

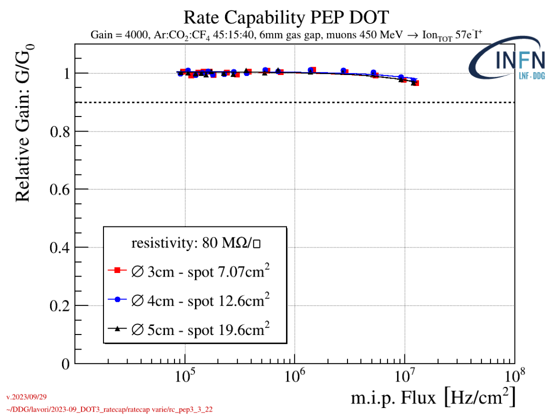
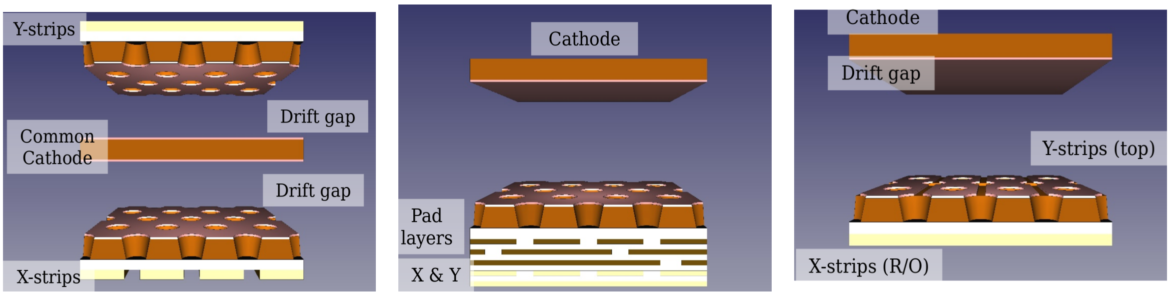


Figure 3. Rate capability for a µ-RWELL with a 9 mm PEP-DOT pitch, measured with 5.9 keV X-rays.

3 Tracking µ-RWELL for FCC-ee

The µ-RWELL tracking capabilities have been studied in different frameworks. Regarding 1D reconstruction, using the Charge Centroid and the µTPC algorithm, a resolution below 100 µm has been achieved over an angular range of 0° ÷ 45°, with detectors with 400 µm strip readout [6].

The Innovative Detector for Electron-positron Accelerators (IDEA) is a general purpose apparatus considered for the installation at the interaction point of future e^+e^- colliders [7]. The µ-RWELL is proposed for the preshower (130 m^2) and muon system (1530 m^2) and one of the main challenges is to provide a suitable space resolution, below 400 µm, reducing as possible the number of FEE channels in order to contain the total cost. Different two-dimensional layout have been tested, figure 4: two 1D µ-RWELL (strip pitch 800 µm) back to back, one µ-RWELL with the top electrode segmented for obtaining the second coordinated (strip pitch 800 µm), one µ-RWELL with Capacitive Sharing [8] readout (strip pitch 1.2 mm). The R&D is still ongoing because, while the overall tracking performance are quite good (figure 5), the layout has either a low plateau efficiency or a working point that is too high for the desired stability of the detector.



(a) Two 1D detector back to back. (b) Segmented top layout. (c) Capacitive sharing.

Figure 4. Different options for 2D trackin μ-RWELL.

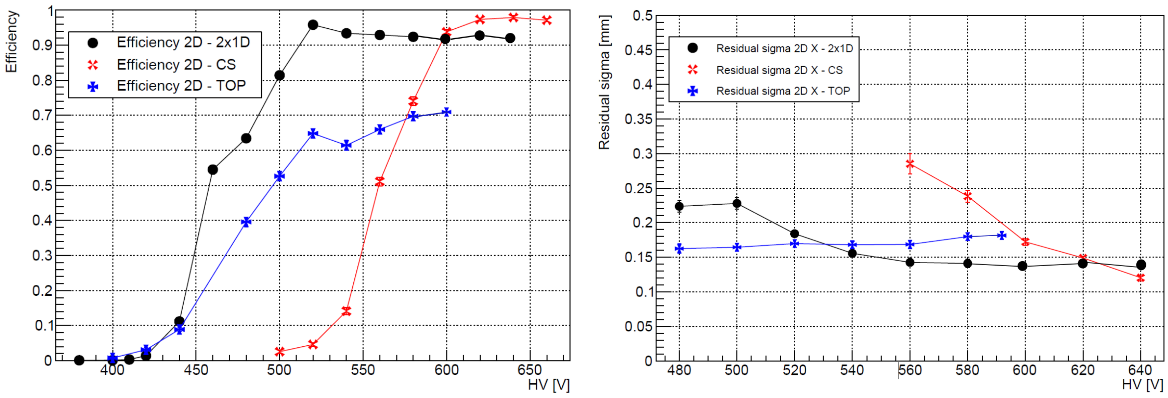


Figure 5. Efficiency (left) and space resolution (right) for the layouts in figure 4. Measurement done with 150 GeV muon beam at CERN SPS-H8 beam area, with Ar:CO_2:CF_4 45:15:40 gas mixture, more details in [9, 10].

A new detector concept, the G-RWELL has been designed as a solution for this problem, figure 6. The main idea is to use a single GEM foil as preamp-stage for a μ-RWELL, thus creating a final detector with two amplification stages [11]. Preliminary results show how a stable gas gain larger than 50000 is achievable, figure 7, thus allow to use a 2D readout similar to the one used in the COMPASS experiment [12], with a detector operating at a large gain in order to compensate the charge sharing between the two coordinate.

4 Technology transfer to industry

The manufacturing process of the μ-RWELL can be divided in the following tasks: detector design, DLC sputtering on Apical®, production of PCB readout, DLC patterning, DLC foil gluing on PCB, creation of the PEP structure, amplification stage patterning, and electrical cleaning in dry atmosphere. Supervised by our group and following this workflow, ELTOS and CERN have jointly produced several $10 \times 10\,\text{cm}^2$ μ-RWELL prototypes with $9 \times 9\,\text{mm}^2$ pad readout based on the PEP-DOT layout, whose performance are reported in [13, 14]. The manufacturing process of the detector begins with producing the core component of the amplification stage, the DLC-Apical®-Cu foil, using the CERN-INFN DLC (C.I.D.) sputtering machine, operational since early 2023. DLC patterning is required before coupling the DLC foil to the PCB: the DLC material must be removed from all areas except the detector's active

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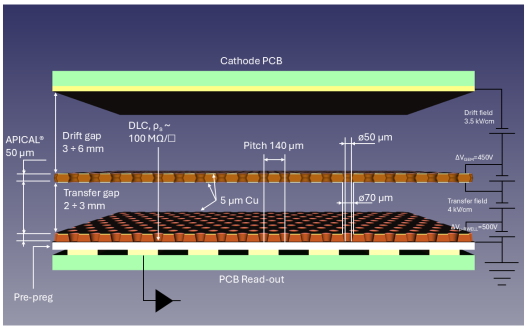

Figure 6. Sketch of the G-RWELL.

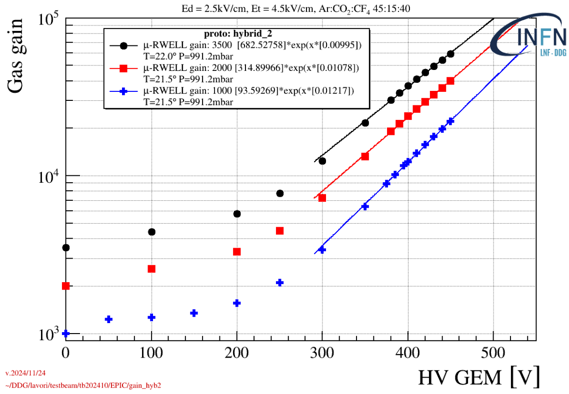

Figure 7. G-RWELL gas gain as a function of the GEM voltage, for different µ-RWELL voltages.

area. The final operation at ELTOS involves the gluing of the DLC to the readout PCB using a thin sheet of prepreg (typically in the range 28 ÷ 50 µm), with a press at 210°C and a pressure of 180 N/cm^2. Once the manufacturing at ELTOS is complete, the µ-RWELL PCB is shipped to CERN for the photolithographic processes with Apical®, creating the PEP structure and the aplification blind holes.

5 Thermal neutron detection

The uRANIA-V project focuses on developing innovative neutron detectors using a $^{10}B_4C$ conversion stage: boron can be deposited on detector surfaces via magnetron sputtering, embedding the converter in the active detector volume. Prototypes with $10 \times 10\,\mathrm{cm}^2$ active areas and various $^{10}B_4C$-coated cathode structures have been tested, showing that different $^{10}B_4C$ configurations achieved thermal neutron detection efficiencies of 4% to 8% with a single detection layer [15].

The µ-RWELL is suitable for large-scale production and a possible implementation is the construction of high-efficiency multilayer structures, ideal for monitoring large areas, such as in Radiation Portal Monitors at ports and airports: by stacking detectors, an efficiency of tens of percent can be achieved.

Conclusions. The µ-RWELL technology has proven to be mature and reliable, with R&D efforts focusing on enhancing stability and simplifying production. For high-rate applications, the µ-RWELL prototypes for the LHCb PEP-DOT project satisfy requirements with a gas gain of $\sim 10^4$, a rate capability of $O(1\,\mathrm{MHz/cm^2})$, and a time resolution below 7 ns (currently limited by the FEE). In the IDEA detector, µ-RWELL with a GEM-based preamp stage achieve a gas gain of $6 \cdot 10^4$, with expected good performance using a COMPASS-like readout. Technology transfer for PEP-DOT has progressed, with DLC and DLC+Cu foils produced in collaboration with ELTOS and CERN, in order to supply the large demand for the LHCb Phase II Upgrade. Outside high energy physics, thermal neutron detectors based on resistive gaseous detectors and $^{10}B_4C$ converters have been successfully tested, showing good stability and promising results.

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