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AIDAinnova

Advancement and Innovation for Detectors at Accelerators

Horizon 2020 Research Infrastructures project AIDAINNOVA

MILESTONE REPORT

BUILD A 0.3X0.3 M2 PROTOTYPE AND THE READ-OUT PLANE WITH THE NEW STRUCTURE

MILESTONE: MS27

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Abstract:

This milestone report provides an overview of the co-production and testing of large-size μ-RWELL detectors in collaboration with industry and CERN. The project focuses on the development of four μ-RWELL detectors with a 30x25 cm² active area, designed for the LHCb Phase 2 Upgrade. The detectors utilize the PEP-DOT grounding layout, optimized for high-rate capability. Detailed tests, including gas gain and rate capability measurements, were performed using X-ray guns, demonstrating the detector's performance and scalability. The results validate the feasibility of industrial-scale production of μ-RWELL detectors for high-energy physics applications.

For more information on AIDAinnova, its partners and contributors please see http://aidainnova.web.cern.ch/

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Executive summary

This report summarizes the co-production and evaluation of large-size μ-RWELL detectors, developed for the LHCb Upgrade Phase 2, as part of milestone MS27 under the AIDAinnova project. The milestone aimed to scale up μ-RWELL technology to larger detectors, co-produced by INFN, ELTOS, and CERN. Four detectors, each with a 30x25 cm² active area, were produced using the PEP-DOT grounding scheme to optimize rate capability. Following production, the detectors underwent detailed performance testing. A 20 keV X-ray gun was used to validate the readout, confirming uniform signal distribution, while a 5.9 keV X-ray gun demonstrated the detectors' ability to handle fluxes above 1 MHz/cm². Comparative gain measurements with smaller detectors revealed some performance differences, which, although not compromising the detector's operation, are currently under investigation. The successful completion of this milestone confirms the scalability and industrial viability of μ-RWELL technology, marking a critical step toward its full implementation in high-rate physics experiments such as the LHCb muon system upgrade.

1. INTRODUCTION

This report provides a comprehensive overview of the construction of a large-size μ-RWELL, manufactured within an industrial framework, and serves as an addendum to the Deliverable 7.3 report (D7.3) [1]. The project involved the development and testing of four μ-RWELL detectors [2,3], each with dimensions of 30x25 cm². The increase in detector size is a natural step in the finalization of the manufacturing process carried out within the framework of WP7.3.2.

Future High-Energy Physics (HEP) experiments face significant challenges in developing muon detection systems, which must be both robust and cost-effective to cover large areas. These systems, typically positioned far from the primary interaction point, require detectors that offer good spatial and time resolution, high efficiency, and high-rate capability. Gaseous detectors, particularly Micro-Pattern Gaseous Detectors (MPGDs), have proven to be ideal for these applications [4].

Recent advancements in MPGD technologies, such as Gas Electron Multipliers (GEM) [5] and MicroMegas [6], have been crucial for upgrades in major experiments like CMS [7] and ATLAS [8]. Among the most promising developments is the micro-Resistive WELL (μ-RWELL), which was designed to combine simplicity, high performance, and industrial scalability. The μ-RWELL detector is now a leading candidate for large-scale projects, including the upgrade of the LHCb muon system [9] and future detectors for the proposed Future Circular Collider (FCC-ee) [10].

In the D7.3 report, considerable progress made in the industrialization of μ-RWELL technology has been described in detail. The focus was on the successful production and characterization of small-size μ-RWELL detectors (10x10 cm²). The manufacturing process was developed in collaboration with the industrial partner ELTOS, a company specialized in Printed Circuit Board (PCB) production [11]. A key part of the work involved transferring complex technological steps from the laboratory to industry, including the deposition of Diamond-Like Carbon (DLC) layers, crucial for the resistive structure of the μ-RWELL [12]. This was achieved using a DC magnetron sputtering machine, co-funded by INFN and CERN, which allowed for precise control of the DLC's thickness and resistivity.

The production process included multiple stages: from the initial detector design at INFN-LNF to the production of the DLC-coated μ-RWELL_PCB at ELTOS and the finalization of the detector at CERN's EP-DT Micro-Pattern-Technology (MPT) Workshop. The small-size prototypes featured high-rate layouts, including innovative grounding schemes such as the PEP-DOT layout, which minimized the dead zone and optimized rate capability. These high-rate versions, produced and tested under the supervision of INFN-LNF, demonstrated excellent performance in both X-ray characterization and beam tests at CERN.

A pilot co-production test, conducted in collaboration between CERN and ELTOS has been carried out: sixteen small μ-RWELL detectors were manufactured, achieving a production yield larger than 90%. These detectors were characterized by their excellent gas gain stability and rate capability, indicating that the industrialization process could scale effectively for larger detectors required for future experiments.

The D7.3 work laid a solid foundation for scaling up the μ-RWELL technology for larger detectors, ensuring that both the manufacturing process and performance metrics could be replicated and improved upon. This industrialization phase demonstrated that μ-RWELL detectors can be reliably produced with the necessary quality control and consistency for high-energy physics applications.

Building on this, the MS27 milestone aims to further advance this co-production process by focusing on the development of large-size μ-RWELL prototypes, specifically 30x25 cm² detectors. The goal of MS27 is to establish a successful co-production effort between industry and CERN, refining the manufacturing process for larger detectors while maintaining the same high performance and scalability demonstrated in the earlier small-size prototypes.

2. THE μ-RWELL

The μ-RWELL is a resistive MPGD composed of two PCBs: a PCB acting as the cathode, defining the gas detector gap, and the μ-RWELL_PCB that couples in a unique structure the electron amplification and the readout stages, as shown in Fig. 2.1. A 50 μm thick polyimide (APICAL) foil, copper clad on the top side and sputtered with DLC on the bottom side, is coupled to a standard PCB readout board, through a 50 μm thick pre-preg foil. The thickness of the DLC layer (typically in the range 10÷100 nm) is adjusted according to the desired surface resistivity value (50÷100 MΩ/square) to provide discharge suppression as well as current evacuation. A chemical etching process of the polyimide foil is performed on the top surface of the overall structure to create a GEM-like matrix of truncated cones with 70 μm (50 μm) top (bottom) diameter and 140 μm pitch. This pattern constitutes the amplification stage. The high voltage applied between the copper and the resistive DLC layers produces the required electric field within the WELLs that is necessary to develop charge amplification, Fig. 2.2. The signal is capacitively induced on the strips/pads on the readout board [13]. The introduction of the resistive layer allows to achieve large gas gains up to 10^4 with a single amplification stage, while partially reducing the capability to stand high particle fluxes [14].

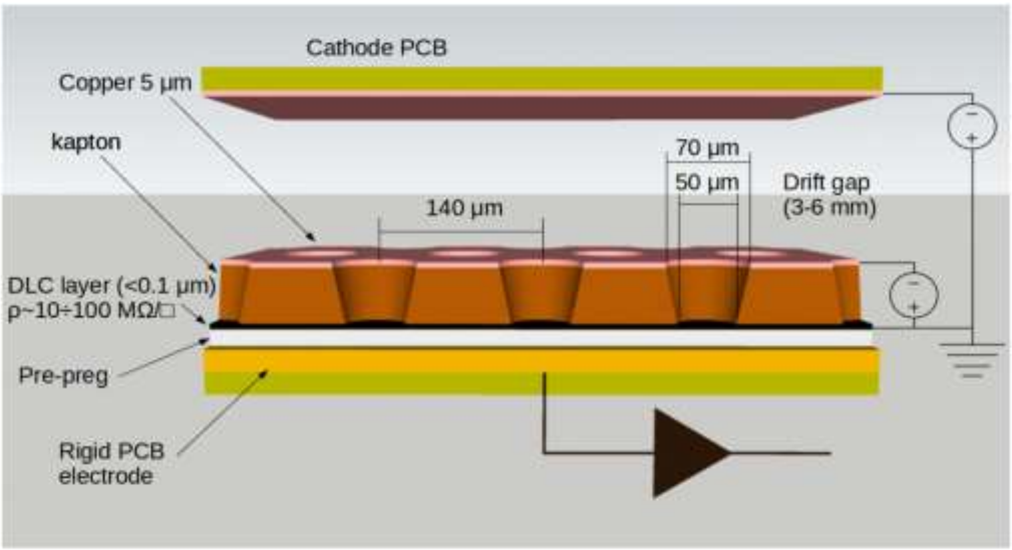

Fig.2.1 *Basic layout of a μ-RWELL*

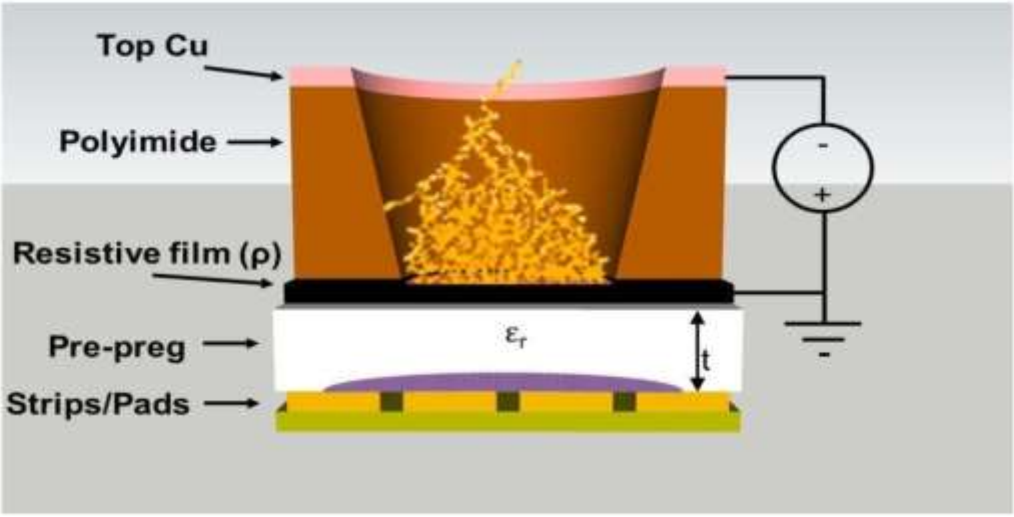

Fig.2.1 *Principle of operation of a μ-RWELL*

3. DETECTOR LAYOUT AND CONSTRUCTION

The four 30x25 cm² detectors feature a 952 9x9 mm² pad readout layout, incorporating eight Hirose connectors and six HV sectors. These parameters were specifically chosen for the LHCb Phase 2 upgrade, as the μ-RWELL is proposed for the instrumentation of the innermost part of the muon system [2].

These detectors utilize the PEP-DOT high-rate grounding scheme [15]: the PEP-DOT ground connections are one for each pad, creating a 9 mm pitch matrix. This design was chosen to optimize the detector's rate capability and overall performance. The layout was designed at INFN LNF, and the production process was divided between two locations: ELTOS, an industry partner specialized in PCB manufacturing, and CERN, where the detectors were finalized, as described in the deliverable report. This dual-site production approach ensures both precision and quality in the final product. The manufacturing details are analogous to those reported in the Deliverable 7.3 report, section 4, which focused on the 10x10 cm² μ-RWELL.

To visually complement the description, Figure 3.1 shows a side view of the detector: the larger PCB on top is the RWELL_PCB, with the FEE connectors (4 visible in the picture) and the HV connector (attached on the brass support on the right), then the light brown 6 mm PEEK frame (with the 4mm gas tube connected) and the last PCB on the bottom (same size as the frame) is the 1.6 mm FR4 cathode. Figure 3.2 (left) presents a photograph showcasing all four detectors together. The external side of the cathode PCB is coated with copper to act as a Faraday cage. A counterbore has been milled in the centre of the PCB, leaving only a few hundred microns of FR4. This modification allows for the measurement of rate capability using a 5.9 keV X-ray gun, as described in Section 4.3. Additionally, Figure 3.2 (right) shows the back of one detector, where the pad routing is visible, along with the integration of eight APV25 chips used as the Front-End Electronics (FEE) [16]. An intermediate board (not visible) is necessary to couple the APV25 Panasonic connector to the detector's Hirose connector.

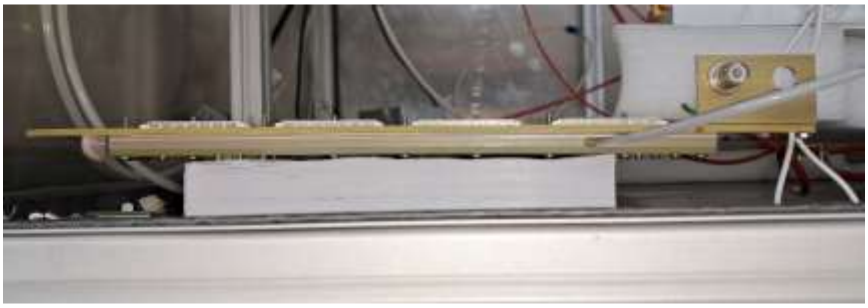

Fig.3.1 *Side view of an assembled detector.*
From top: detector PCB with FEE connectors, 6mm FR4 frame, 1.6 mm FR4 cathode

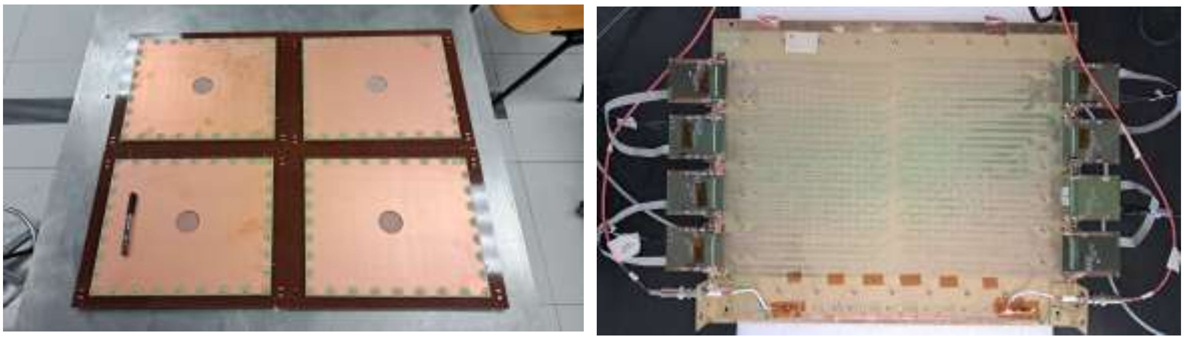

Fig.3.2 *(left) the four 30x25 cm^2 detector produced, picture from the cathode view (right) picture of a single detector from the backplane view: the R/O routing and the FEE instrumentation are visible.*

4. DETECTOR PERFORMANCE

4.1. READOUT VALIDATION

The performance of the detectors was evaluated using a 20 keV X-ray gun for gas gain and readout (R/O) quality control, and a 5.9 keV X-ray gun for rate capability measurements. The resulting HitMap, captured by the APV25, demonstrates the detector’s ability to accurately record the distribution of signals across its surface, Figure 4.1. The acquisition for the HitMap was performed using the APV internal trigger. Event selection was executed by retaining waveforms whose maximum value lies within a designated fiducial time window, ensuring that the selected value is indeed the maximum of the signal. The charge associated to the event was determined by the maximum ADC counts within this window and was used as a weight in creating the HitMap. A further acquisition has been done with a set of 2 mm thick lead shielding, creating geometrical shadows in the HitMap, effectively validating the R/O map used for the pads, Figure 4.2.

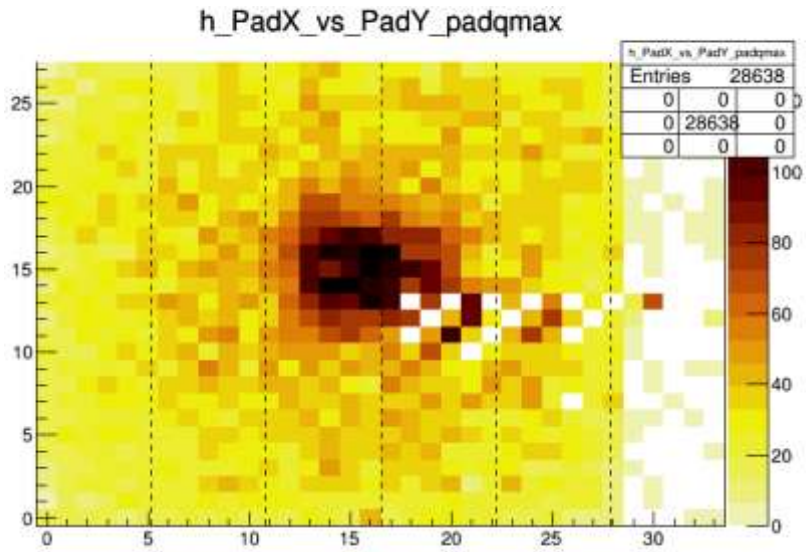

Fig.4.1 *HitMap acquired with APV25*

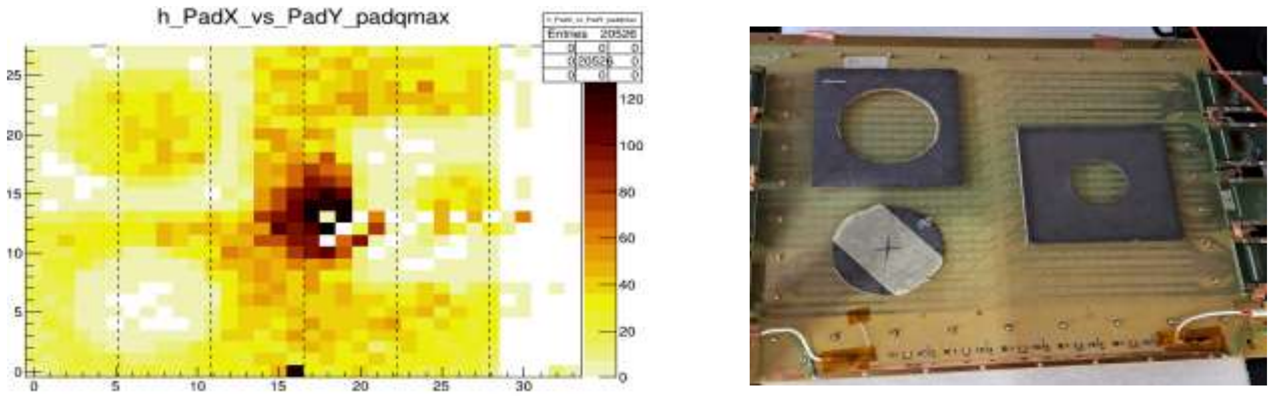

Fig.4.2 *(left) HitMap acquired with APV25 and random trigger (right) picture of the lead shields between the detector and the X-Ray gun.*

4.2. GAIN MEASUREMENT

A comparative analysis of the gain performance between the 30x25 cm² detectors and the previously tested 10x10 cm² detectors has been conducted. This comparison is essential for understanding how detector size influences performance and could lead to further optimizations in detector design for future applications (Figure 4.3). During gas gain calibration, the correlation between the maximum achievable gas gain and DLC resistivity can be studied. The maximum gas gain is defined as the gain at which the current measurement remains stable, without exhibiting instabilities such as current spikes larger than 10%. Figure 4.4 shows the maximum gas gain for the 10x10 cm² and the four M2R1 detectors. By increasing DLC resistivity, it is possible to achieve a higher gain and improve detector stability. A preliminary observation is that small and large detectors appear to follow two distinct curves. The hypothesis is that larger detectors have a higher likelihood of small defects, which may trigger instabilities at lower voltages.

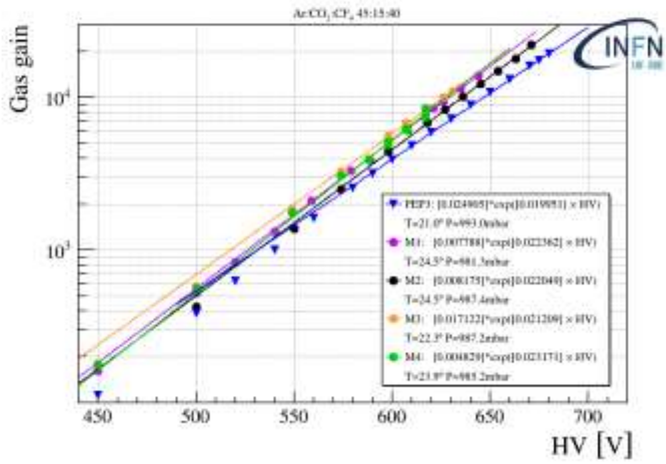

Fig.4.3 *Gas gain calibration for different μ-RWELL prototypes: (blue) 10x10 cm² from D7.3 report (black) 30x25cm² from this report.*

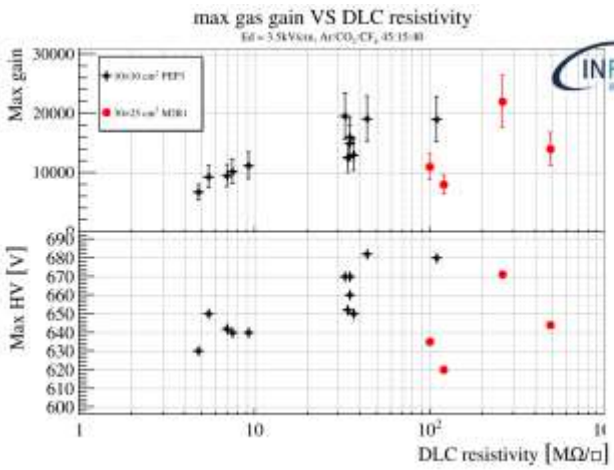

Fig.4.4 *Maximum HV value and corresponding gas gain for small and large μ-RWELLs.*

4.3. RATE CAPABILITY MEASUREMENT

The rate capability of one of the detectors was specifically tested using a 5.9 keV X-ray gun, to assess the detector's performance under different rates of incident radiation. The different spots have been defined using 2 mm thick lead shields, covering all the active area with the exception of a circular zone in the middle, aligned with the cathode blind hole. The results, shown in Figure 4.4, demonstrate the detector's ability to handle fluxes exceeding 1 MHz/cm², a value sufficient to make this technology suitable for the aforementioned LHCb upgrade. The rate capability is almost the same for the different spots and these measurerements validate the PEP-DOT high-rate scheme for the large size µ-RWELL: if the irradiated area is larger than the grounding cell the performance should not change (different from the low-rate scheme behaviour) [3].

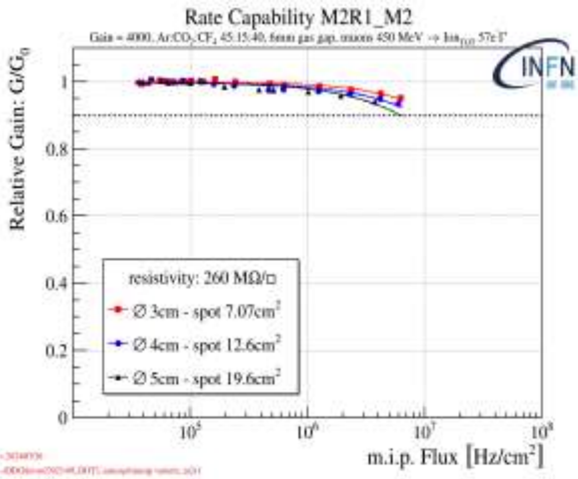

Fig.4.4 Rate capabity of one of the detectors, for various spot size.

5. CONCLUSION

The development of large-size µ-RWELL detectors, featuring a 30x25 cm² active area and a PEP-DOT grounding layout, marks a significant step forward in the advancement of this technology. The detectors, designed at INFN-LNF and produced in collaboration with ELTOS and CERN, have been evaluated for their performance under varying experimental conditions.

The tests conducted with both the 20 keV and 5.9 keV X-ray guns have demonstrated the effectiveness of the detectors in handling high radiation fluxes, exceeding 1 MHz/cm², which is critical for the LHCb Upgrade Phase 2. The ability to maintain stable gain and performance under these conditions makes the µ-RWELL a strong candidate for instrumentation in high-energy physics experiments.

The comparative gain analysis between the larger 30x25 cm² detectors and the previously tested 10x10 cm² detectors highlighted some differences in behavior that are currently under investigation. These findings will inform future optimizations in the design and scaling of the detectors, ensuring further refinement of the technology.

The experience gained during this project confirms that the µ-RWELL technology is not only scalable but also industrially viable, with the dual-site production approach ensuring both high-quality control and efficiency. The successful validation of these detectors brings us closer to the full-scale implementation of µ-RWELLs in high-rate environments such as the upgraded LHCb muon system.

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ANNEX: GLOSSARY

Acronym	**Definition**
MPGD	Micro-Pattern-Gaseous-Detector
GEM	Gas-Electron-Multiplier
µ-RWELL	micro-Resistive WELL
DLC	Diamond-Like-Carbon