RD_FCC (R&D per Futuri Acceleratori)

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RD_FA stands for R&D for Future Accelerators, it was initiated in 2017 by the CSN1. The activity is organized in Working Packages as follows:

- WP1: Fisica e simulazione
- WP2: Machine Detector Interface (M. Boscolo, convener)
- WP3: Pixel detectors
- WP4: RICH e TPC con MPGD
- WP5: Ultralight drift chamber
- WP6: Silicon microstrip tracking
- WP7: micro-RWELL gaseous detector R&D

For the year 2021 the LNF group was involved in WP2 and WP7. In the following we summarize the activity.

1 WP7: Micro-RWELL R&D

The µ-RWELL, a recently introduced resistive-MPGD [1], inherits the best characteristics of the GEM and MM detectors, while further simplifying the manufacturing process, thus enabling the technology transfer to standard PCB industry. This detector is among the candidates for building future large muon detection systems at the FCC-ee [2] and CEPC [3] future large circular leptonic colliders. A µ-RWELL detector is composed of two PCBs: a mono-layer PCB acting as the cathode, defining the gas detector gap, and a µ-RWELL-PCB that couples in a unique structure the electron amplification (a well-patterned GEM-like matrix) and the readout stages, as shown in Fig.1. A 50 μm thick polyimide foil (similar to the one used for GEM detector), copper clad on the top side and sputtered with Diamond Like Carbon (DLC [4]) on the opposite (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 (10-100 MΩ/square) in order 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 in order to create the WELL pattern: truncated cone wells of 70 μm (50 μm) top (bottom) in diameter and 140 μm pitch) that 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. The signal is capacitively collected at the strips/pads on the readout board.

The µ-RWELL technology is envisaged to realise the muon detection system and the preshower of the IDEA detector concept [5] that is proposed for the FCC-ee and CEPC future large circular

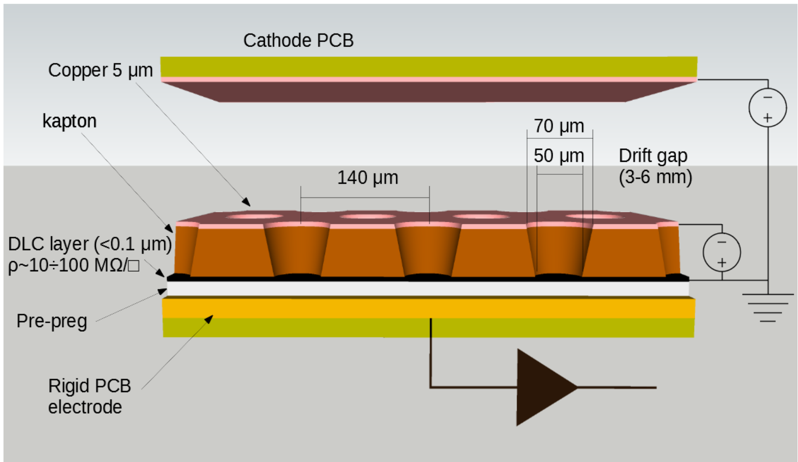

Figure 1: Basic layout of a µ-RWELL.

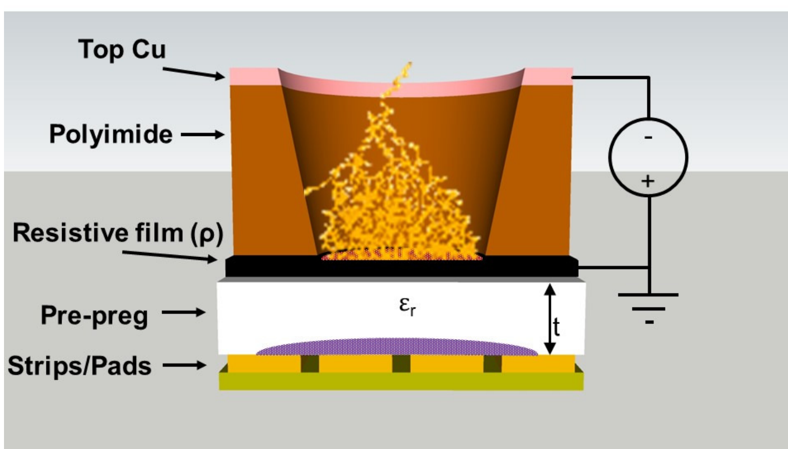

Figure 2: Principle of operation of the µ-RWELL.

Station	Radius (m)	Length (m)	Strip pitch (mm)	Strip length (mm)	Area (m^2)	N. of modules	Channels
1	4.52	9.0	1	500	260	1040	1040000
2	4.88	9.0	1	500	280	1120	1120000
3	5.24	10.52	1	500	350	1400	1400000

Table 1: Dimensions of the 3 IDEA barrel muon stations, together with the number of individual detector modules and the number of readout front -end channels.

leptonic colliders. Both the preshower and the muon detector would follow the IDEA geometry with a central cylindrical barrel region closed at the two extremities by two endcaps to ensure hermeticity. The preshower detector would consist of a single layer of µ-RWELL detectors in both the barrel and the endcap regions. The preshower will have a modular design (50x50 cm^2) µ-RWELL detectors with two layers of strip readout placed perpendicularly to each other. In order to achieve a good position resolution, of the order of 100 μm, a fine strip pitch of 400 μm is envisaged. The muon detection system will consist of three muon stations in the barrel and endcaps regions, at increasing radial distance from the interaction point, housed within the iron yoke that closes the solenoidal magnetic field. Each station will consist of a 50x50 cm^2 µ-RWELL detector modules. In order to profit of the industrial production capabilities of this technology a modular design has been adopted for both the preshower and the muon detection system and the main difference being the pitch between the readout strips: 400 μm and 1 mm for the preshower and the muon system, respectively.

In table 1 are listed the dimensions, number of basic µ-RWELL modules and readout channels of the 3 muon stations. In total, between the barrel and endcap muon stations, there would be about 5800 µ-RWELL modules with a total of roughly 6 million readout channels. Each µ-RWELL would be able to identify muon hits with 98% efficiency and measure the coordinate perpendicular to the strip direction with a precision of about 400 μm. Such a detector would be able to provide 3 three-dimensional space points (the third coordinate coming from the known radial position of the µ-RWELL module) and from these reconstruct the tracks crossing the muon stations. These muon tracks could then be used to complement the tracks reconstructed in the central tracker providing the best momentum measurement of muons. The muon detector could also reconstruct charged particle tracks coming from the decays of hypothesized long-lived particles (LLP) that would produce a secondary vertex outside ($\geq$ 2.5 m from the primary interaction point) of the central tracker. This could significantly enhance the detector capabilities to study these interesting signatures of possible new physics beyond the Standard Model.

In the 2021, the R&D program on the µ-RWELL detectors has been focused to optimize the best values of the DLC resistivity and the strip pitch to achieve the required spatial resolution. For this reason, we have built 2 sets of -RWELL prototypes with one dimensional readout coordinate. Each set is made of 5 detectors for the preshower and 3 detectors for the muon with an active area of 16x40 cm^2 and 40 cm long strips. For the preshower prototypes the strip pitch is fixed to 400 μm and DLC resistivity is ranging from 10 to 200 MΩ/square, while for the muon ones the DLC resistivity is about 20 MΩ/square and the strip picth is varying from 0.8 to 1.6 mm. All these detectors have been exposed in October 2021 to a muon/pion beam at the CERN SPS. The setup has been composed of two trigger scintillators and two tracking stations each consisting of µ-RWELL with one-dimensional strip readout in X and Y coordinate. All gaseous detectors have been operated in $Ar:CO_2:CF_4$ (45:15:40) at atmospheric pressure and were read-out with APV [6] front-end cards, interfaced by the Scalable Readout System. The APV chip, supplying analog output signals, allows the study of the detector tracking performance based on the charge centroid method.

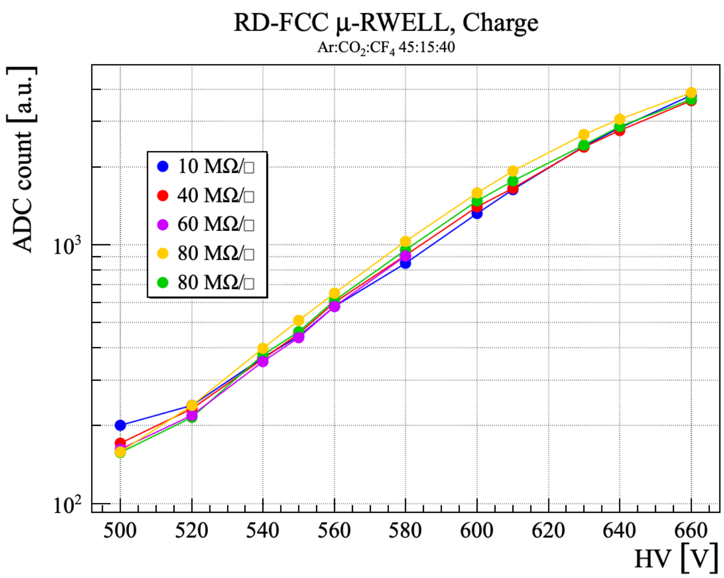

Figure 3: Cluster charge as a function of the HV for different DLC resistivity and for the pre-shower prototypes.

All the prototypes seem to be equalised to the voltage difference applied to the amplification WELLs (fig. 3) since the detector gas gain is not affect by the DLC resistivity. In fig. 4 the tracking efficiency of the detectors is reported as a function of HV: all prototypes achieve a tracking efficiency above 95% with a long plateau of about 100 V. The shift of the efficiency curve of the 10 MΩ/square prototype with respect to the others is correlated with the large charge spread occurring at low DLC resistivity (fig.5): the charge dispersion on the readout strips increases, the signal collected by each pre-amplifier channel decreases thus requiring a higher gain to reach the full detector efficiency. A tracking residual better 50 μm with orthogonal tracks has been measured (fig.6) for all the prototypes without subtracting the contribution of the external trackers. A minimum has been measured for the 10 MΩ/square detector with a residual of $\sim$ 30 μm.

The very positive and promising results obtained during the test beam compaign open the way for a completely new and competitive MPDG tracking device for high energy physics experiments.

2 List of Conference Talks in Year 2021

1. M. Poli Lener, The preshower and the muon detection system of the IDEA detector for FCC-ee, EPS-HEP Conference 2021, Virtual Edition, July 26-30, 2021.

References

1. G. Bencivenni at al., *The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD*, JINST 10 (2015) P02008.

2. Abada, A. et al., *FCC Physics Opportunities: Future Circular Collider Conceptual Design Report Volume 1*, Eur. Phys. J. C79 (2019) 474.

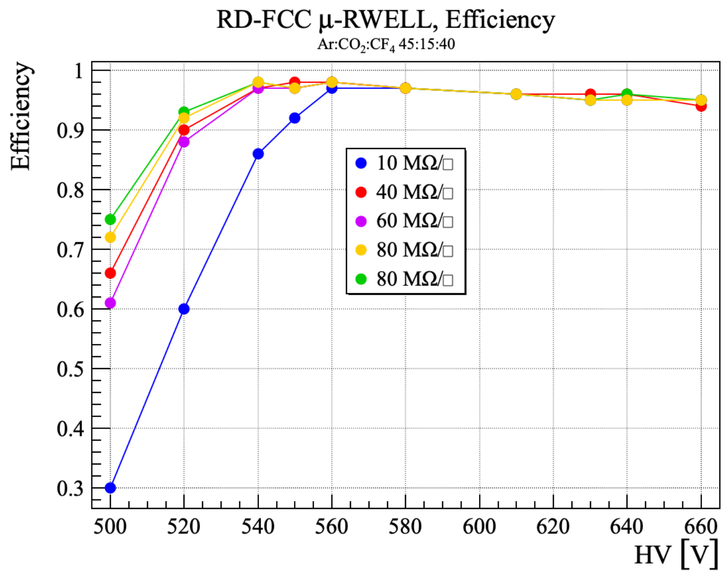

Figure 4: Tracking efficiency as a function of the HV for different DLC resistivity and for the pre-shower prototypes.

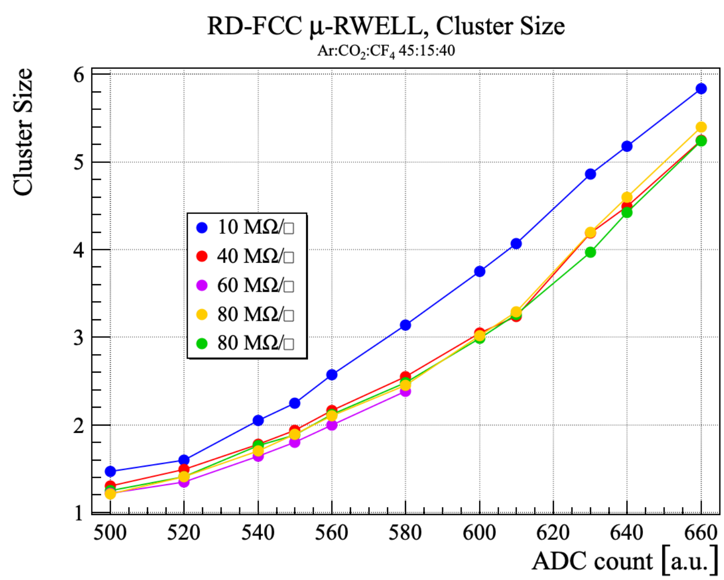

Figure 5: Strip cluster size as a function of the HV for different DLC resistivity and for the pre-shower prototypes.

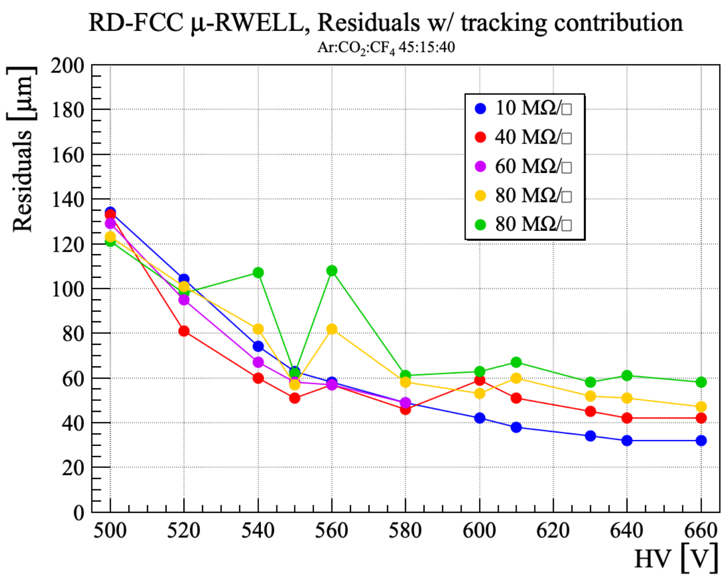

Figure 6: Residuals as a function of the HV for different DLC resistivity and for the pre-shower prototypes.

3. The CEPC Study Group, *CEPC Conceptual Design Report: Volume 2 - Physics Detector*, arXiv:1811.10545 (2018).

4. A. Ochi et al., *Carbon sputtering Technology for MPDG detectors*, Proceeding of Science (TIPP2014) 351.

5. R. Aly et al., *First test-beam results obtained with IDEA, a detector concept designed for future lepton colliders*", Nucl. Instrum. Meth. A958 (2020) 162088.

6. M. Raymond et al., *The APV25 0.25 m CMOS readout chip for the CMS tracker*, IEEE Nucl. Sci. Symp. Conf. Rec. **2** (2000) 9/113.