A microRWELL-based preshower and muon system for the IDEA detector

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1 System requirements

The IDEA detector concept has been designed to operate at a future large circular e^+e^- collider, like FCC-ee or CEPC. The IDEA detector has an innovative design with a central tracker enclosed in a superconducting solenoidal magnet. Going outwards, a pre-shower system followed by a dual readout calorimeter is foreseen. In the iron yoke, that closes the magnetic field, are then located three stations of muon detectors. The pre-shower and muon detectors are based on the μ-RWELL technology that inherits the best characteristics of the GEM, in particular the layout of the amplification stage, and Micromegas detectors, that inspired the presence of a resistive stage. To profit of the industrial production capabilities of this technology, a modular design has been adopted for both systems: the μ-RWELL tile will have an active area of 50x50 cm^2, but with a readout strip pitch between of 400 μm for the pre-shower and about 1 mm for the muon system. Other requirements are: a spatial resolution of the order of $<$100 μm for the pre-shower and a reasonable total number of front-end channels for the muon system. A vigorous program of R&D is being carried out for quite a few years on the μ-RWELL technology. The goal is to optimize the DLC resistivity and the strip pitch, we have built several sets of prototypes, to define the basic characteristics, like surface resistivity and strip pitch of the μ-RWELL tiles for both the pre-shower and the muon detector. For the pre-shower and the muon detector prototypes the DLC resistivity ρ_s is ranging from 40 to 100 MOhm/square. All these prototypes have been exposed to muon/pion beams at the CERN SPS.

1.1 Pre-shower requirements

The pre-shower detector is located immediately after the superconducting solenoid and just before the dual readout calorimeter. In fact, even though the solenoid adopted is very thin, it still corresponds to about half a radiation length of material and therefore electromagnetic showers might develop before reaching the calorimeter. For this purpose, the pre-shower has to measure with accurate precision the position of charged pions produced in the showers and of the e^+e^- pairs due to the decays of neutral pions. Accurate measurement of their position is vital to improve the energy measurement provided by the dual readout calorimeter, therefore, optimizing its energy resolution. For this reason, the basic μ-RWELL tile foreseen has a narrower strip pitch of 400μm than that of the muon detector. This should guarantee a position resolution of about 60-80μm.

1.2 Muon system requirements

Muon detection systems have to identify muons with very high efficiency. Muon systems are typically composed of several stations of tracking detectors located several meters of distance from the primary interaction point. For a muon detector at a leptonic collider like FCC-ee [1] it is possible to envisage two possible working scenarios: a) a simple muon tagger, that would measure with a precision of $>$ 2-3 mm the position of the hits left in the muon detector and confirm that a charged particle track reconstructed in the central tracker of the experiment is indeed a muon, or b) a more sophisticated muon detector that measures the position of the hits in the detector with high precision, O(100 μm), and provides an accurate standalone momentum measurement that can be used to match the track reconstructed by the central tracker and complement its measurement.

In some cases, one may also require the muon detector to provide a standalone muon trigger and bunch-crossing identification, even though this feature is less relevant for a lepton collider than it is for a hadron collider where the background and particle rates are much higher.

Given their very large dimensions, exceeding in complex modern detectors thousands of square meters of surface, for obvious reasons of price, the detector technology of choice has to be very cost-effective.

Detector	Strip pitch [mm]	Area [m^2]	Number of tiles	Strips per tile	Channels [k]
Preshower	0.4	130	520	2500	1300
Muon detector	1.2	1525	6100	830	5060

Table 1: Dimensions of the IDEA preshower and muon detection system, together with the number of individual detector tiles and the number of readout channels.

2 Technology choice and detector design

The µ-RWELL, fig.1, is a single-amplification stage resistive Micro-Pattern-Gaseous-Detector (MPGD) [2–5] that combines in a unique approach the solutions and improvements achieved in the last years in the MPGD field. The R&D on µ-RWELL aims to improve the stability under heavy irradiation while simplifying the construction procedures in view of an easy technology transfer to industry: a milestone for large-scale applications in fundamental research at the future colliders.
The detector is composed of two elements: the cathode, a simple FR4 PCB with a thin copper layer on one side, and the µ-RWELL _PCB, the core of the detector. The µ-RWELL _PCB, a multi-layer circuit realized by means of standard photo-lithography technology, is composed of a well patterned single copper-clad polyimide (Apical®) foil[1] acting as an amplification element of the detector; a resistive layer, realized with a Diamond-Like-Carbon (DLC) film sputtered on the bottom side of the polyimide foil, as discharge limitation stage; a standard PCB for readout purposes, segmented as strip, pixel or pad electrodes.
Applying a suitable voltage between the copper layer and the DLC, the well acts as a multiplication channel for the ionization produced in the drift gas gap, fig.2. The charge induced on the resistive film is spread with a time constant [3, 6], which depends on the surface resistivity and the distance between the resistive layer and the readout plane.
The spark suppression mechanism is similar to the one of the Resistive Plate Counters - RPCs, [7–10]: the streamer created inside the amplification volume, inducing a large current flowing through the resistive layer, generates a localized drop of the amplifying voltage with an effective quenching of the multiplication process in the gas. This

[1] 50 µm thick polyimide covered on one side with 5 µm thick copper, similar to the GEM base material.

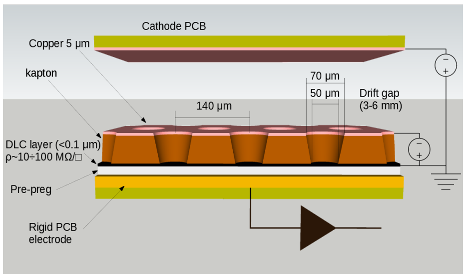


Fig. 1: Layout of the µ-RWELL.

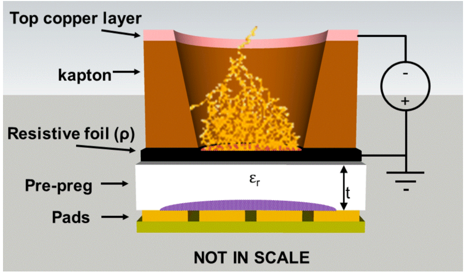


Fig. 2: Principle of operation of the µ-RWELL.

mechanism strongly suppressing the discharge amplitude allows an operation of the detector at large gains ($\geq 10^4$) with a single amplification stage.
A drawback, correlated with the Ohmic behavior of the detector, is the reduced capability to stand high particle fluxes. This effect is correlated to the average resistance faced by the charge produced in the avalanche which depends on the distance between the particle incidence position and the detector grounding line.

The simplest scheme for the evacuation of the current in a µ-RWELL is based on a single resistive layer with a grounding line all around the active area, fig.3, (Single-Resisitive layout - SRL). For large-area devices, the path of the current to the ground could therefore be large and strongly dependent on the incidence point of the particle. In order to cope with this effect the solution is to reduce the average path towards the ground connection, introducing a higher density grounding network with respect to perimeter grounding one of the SRL. The PEP layout (fig. 4)[2] is the new single DLC layer high-rate scheme recently introduced for the Phase II Upgrade of the Muon apparatus of the LHCb experiment [11]. The idea is to realize in the active area ground connection as a conductive grooves by etching from the top Cu layer of the base material (where also the amplification stage is realized) through the Kapton foil down to the DLC. The conductive grooves grid acts as a high-density 2-D current evacuation system. For the pre-shower and the muon system of the IDEA experiment, where a maximum rate of less than 1 kHz/cm^2 is expected, a PEP groove line every 10 cm is foreseen.

The R&D program of the last years has been focused on the optimization of the DLC resistivity and the strip pitch in order to achieve the required spatial resolution for both pre-shower and muon apparatus. A first set of detectors has been realized for resistivity-dependent studies with a DLC resistivity values ranging between 10÷80 MΩ/□. The main results are reported in Fig. 5, showing that all the prototypes exhibit the same performance except the 10 MΩ/□ one. The shift of the efficiency curve of the 10 MΩ/□ prototype with respect to the other detectors is correlated with a slightly larger charge spread occurring at low DLC resistivity: the charge dispersion on the readout strips increases and the signal collected by each pre-amplifier channel decreases consequently requiring a higher gain to reach the full detection efficiency.

[2]The name PEP is the acronym of the three main processes involved in the production of this layout: Patterning-Etching-Plating.

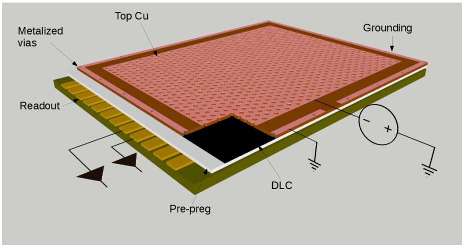


Fig. 3: Sketch of the Single-Resistive layout.

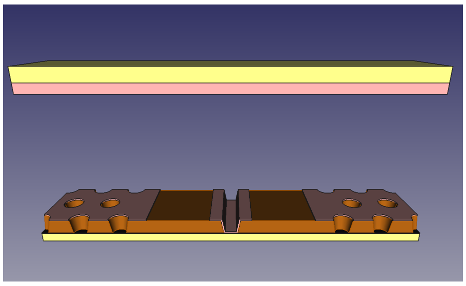
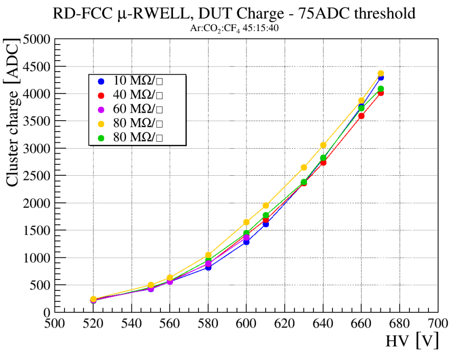
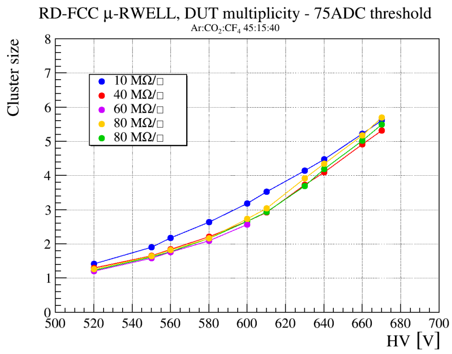


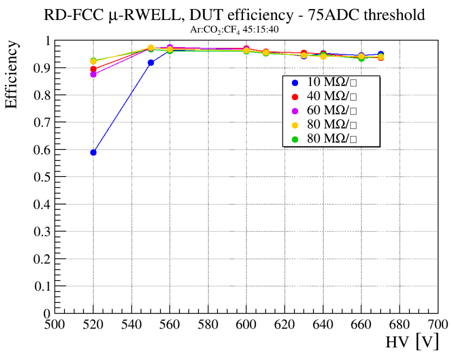
Fig. 4: Sketch of the PEP layout.



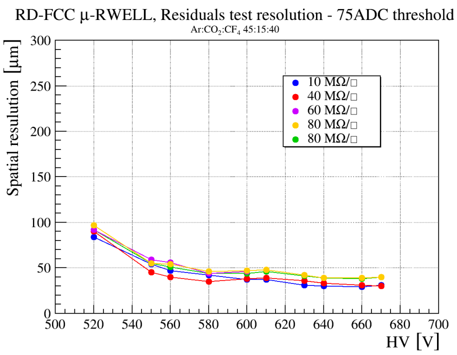
(a) Cluster charge for different HV.



(b) Strip cluster size for different HV.



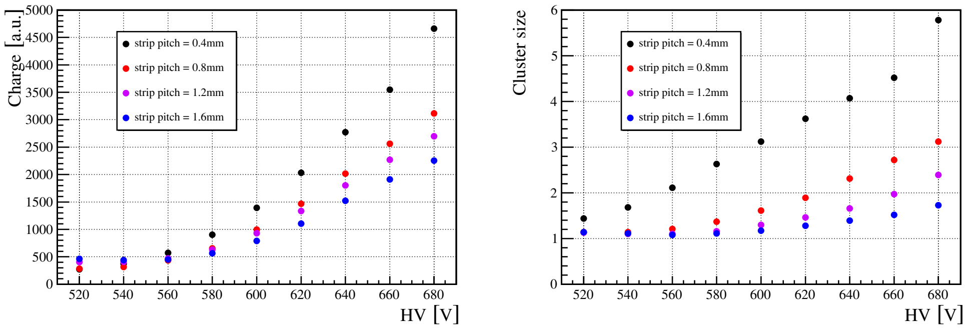
(c) Tracking efficiency for different HV.



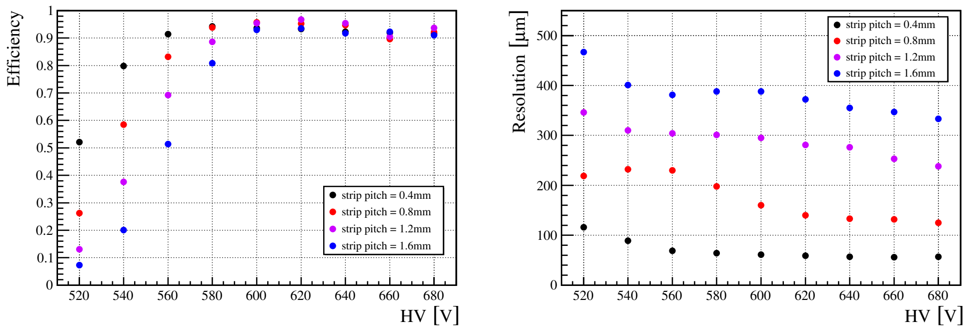
(d) Residuals width for different HV.

Fig. 5: Results of the DLC resistivity scan test campaign for the pre-shower prototypes.

The second set of detectors was composed of four µ-RWELL chambers, with a strip pitch of $[0.4, 0.8, 1.2, 1.6]$ mm. The DLC surface resistivity of all detectors was around $40\,\mathrm{M}\Omega/\square$. The results are shown in fig. 6 and they point out that the larger the strip pitch lower is the signal charge on the strip readout requiring a higher gain to reach the full detection efficiency. Concurrently increasing the strip pitch the number of fired strips sensibly decreases, tending to a cluster size very close to 1, affecting spatial resolution which tends to the limit pitch/$\sqrt{12}$. Only with the high granularity readout (0.4 mm strip pitch) a spatial resolution better than 100 µm is achieved Besides the



(a) Cluster charge for different HV. (b) Strip cluster size for different HV.



(c) Tracking efficiency for different HV. (d) Residuals width for different HV.

Fig. 6: Results of the pitch scan test campaign.

tuning of the parameters (resistivity, strip pitch, and width) still in progress, the first ideas for the two-dimensional readout of a µ-RWELL have been designed and are under construction. One of the most common 2-D layout techniques is to embed in the readout plane two parallel layers of strips, with a defined angle between them (XY, XV), as done for example for COMPASS triple GEM detectors [12]. In this layout (*à la Compass*) the charge is equally shared between the two readout views, thus requiring a high detector gain. Of course, for a single amplification stage detector, such as the μ-RWELL, this may not be the optimal choice. Other alternative approaches could be investigated:

- a couple of one-dimensional detectors, coupled through a common cathode. This is the simplest solution as it consists of using two standard detectors. They can operate at the usual gas gain being the readout strip completely separated. This layout is a feasible option thanks to the μ-RWELL overall small thickness, due to the compactness of the μ-RWELL_PCB.
- a single two-dimensional μ-RWELL, with the standard 1-D readout on the PCB plus a strip patterned top electrode for the second coordinate. The main advantage of this layout with respect to the previous readout scheme is that it does not require the increase of the detector gas gain. In this option the top electrode and the PCB readout strips are grounded while the DLC layer is kept at positive voltage.
- a single two-dimensional μ-RWELL based on the capacitive-sharing anode readout[13]. The concept of capacitive-sharing is based on a spatial arrangement of metallic pads between dielectric layers in a vertical stack of these layers that allows the transfer of the induced charge signal from the μ-RWELL amplification through capacitive coupling between the pad layers to the coarsely segmented strip electrodes of the anode readout PCB of the detector. This layout offers a high spatial performance with a significant reduction of electronic channels required to read out very large area apparatus.

The above-mentioned 2-D μ-RWELL has been already designed and the first prototypes should be ready for a test beam planned for the middle of June 2023 at SPS-H8 beam line at CERN.

3 Electronics

The μ-RWELL detectors will be readout by the TIGER/GEMROC system which is a compact, modular, scalable, and highly customizable electronics [14].

The chip TIGER (Torino Integrated GEM Electronics for Readout) was developed in recent years for the readout of the Cylindrical Gas Electron Multiplier (CGEM) of the BESIII experiment. It is a mixed-signal chip with 64 channels on an area of 5 x 5 mm2. Each channel has a full readout chain with amplification, signal conditioning, and discrimination, as well as a data payload containing the timing and charge information for each event. TIGER is versatile for the readout of radiation sensors up to 50 fC and for high rates up to 60 kHz. Its output is passed to two shapers optimized for time and charge measurement. The peak time of the shaper for the time branch was set to the expected charge collection time (60 ns) to enable measurements with low jitter. The shaper for the energy branch has a slower peak time (170 ns) for better charge resolution and ENC optimization.

Special off-detector electronics was developed at INFN-Ferrara using FPGA-based modules. These readout cards (GEMROC) provide interfaces to up to eight TIGERs in terms of power supply and data processing. At the heart of each GEMROC is a development kit based on an Intel/ ALTERA ARRIA V GX family FPGA connected to an interface card designed for the CGEM detector. The GEMROC modules can process the received data in two different ways. In triggerless mode, the data received from the activated TIGERs is merged and transmitted via the Ethernet output port using the UDP protocol. In trigger-matched mode, a finite state machine selects the hits to be transmitted as follows. The incoming data from each TIGER pair is stored in a latency buffer circular memory, which is divided into pages of 32 memory locations each. This memory is intended to buffer the incoming TIGER data until a selection trigger occurs.

A first test of the TIGER/GEMROC readout connected to a μ-RWELL has been performed with a planar 10x10 cm^2 prototype. A threshold scan on one TIGER chip connected to a μ-RWELL is shown in Fig. 7. The average noise level i about 1 fC. Further characterization of the TIGER/GEMROC performance as μ-RWELL readout will be done by means of cosmic ray and Test Beam with a more complex setup.

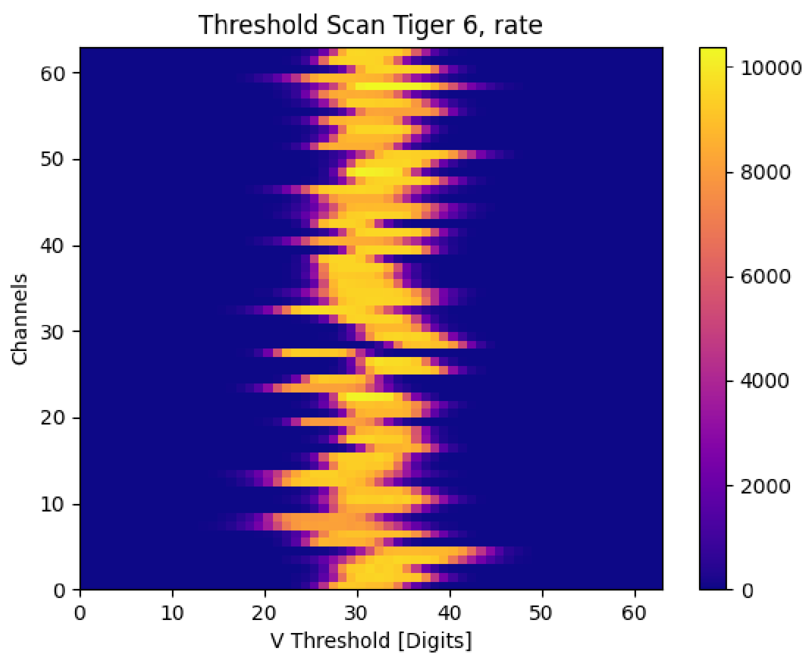


Fig. 7: Threshold scan of the 64 channels of a TIGER chip connected to a μ-RWELL

4 Cost

Item	Detector cost [k€]	HV boards [k€]	HV crates [k€]	ASICs [k€]	Frontend boards [k€]	Readout cards [k€]	LV system [k€]	Total [k€]
Preshower	1040.0	108.3	6.8	38.6	967	806	1000	3967.1
Muon detector	12200.0	1270.8	79.4	150.5	3767	3139	2500	23107.1

Table 2: Dimensions of the IDEA preshower and muon detection system, together with the number of individual detector tiles and the number of readout channels.

Acknowledgments. Acknowledgments are not compulsory. Where included they should be brief. Grant or contribution numbers may be acknowledged.

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