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# $\mu$ -RWELL muon system and pre-shower for FCC- ee

To cite this article: R. Farinelli *et al* 2025 *JINST* **20** C06064

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## $\mu$ -RWELL muon system and pre-shower for FCC-ee

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**ABSTRACT:** This proceeding provides a full review of the R&D for the  $\mu$ -RWELL technology for the FCC-ee application, with the report on an update on the detector optimization, on the studies to improve the ASIC, and on the evaluation of the proposed performance within the IDEA framework. In the IDEA experiment,  $\mu$ -RWELL technology is proposed for the muon systems and the pre-shower. This MPGD exploits a compact manufacturing technique and provides competitive performance. This design keeps the cost of the entire system affordable and, benefiting from the ongoing technological transfer within the MPGD community, will maintain a strong connection with industries. Optimizing the readout electronics channels is needed to advance this technology's state of the art and meet the IDEA requirements. Ongoing activities focus on readout segmentation with various schemes, such as strips, capacitive sharing, and top-readout. Performance comparisons between new TIGER electronics and the APV-25 will be reported. These inputs will be used to define the final configuration for the detector proposal. Moreover, the activities include simulations for both the detector and the experiment: a simulation of the  $\mu$ -RWELL with TIGER or APV electronics is performed, and tuning with experimental data will improve their reliability and provide a useful tool to define the characteristics of a new ASIC. A simulation of the  $\mu$ -RWELL muon system in the IDEA simulation framework is also implemented in DD4HEP. This powerful tool connects the gas detector community to the needs of the FCC experiment.

**KEYWORDS:** Charge transport and multiplication in gas; Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc); Muon spectrometers

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<sup>1</sup>Research grant funded by E.U. Project AIDAInnova GA no 101004761.

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### 1 FCC-ee collider and IDEA detector

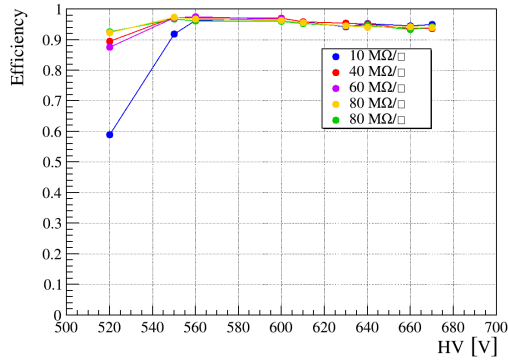
A Future Circular Collider (FCC-ee) with high luminosity and high energy lepton collider installed on a 100 km tunnel is proposed [1]. The physics program will extend the knowledge of known particles (Z, W, and H bosons and the top quark) and improve the precision measurements in literature to increase the sensitivity for new physics. The “International Detector for Electron-positron Accelerators” (IDEA) is a detector proposal [2] composed of a silicon pixel vertex detector, a large volume wire chamber, and a silicon micro-strip detector for the tracking volume, a low mass superconducting solenoid coil, a pre-shower detector, a dual-readout calorimeter and muon chambers within the magnet return yoke. The IDEA layout may change in the future but the actual R&D is focused on this proposal. A Micro Pattern Gaseous Detector based on  $\mu$ -RWELL technology is under study as an option for the pre-shower system and the muon chamber.

The  $\mu$ -RWELL is a single-amplification stage resistive MPGD [3]. The detector amplification component is implemented using a single copper-clad polyimide foil, micro-patterned with a matrix of blind holes (wells) and integrated into the readout Printed Circuit Board (PCB) via a thin resistive film sputtered with Diamond-Like Carbon (DLC). The DLC layer mitigates the transition from streamer to spark, enables high gains ( $10^3$ – $10^4$ ) with a single amplification stage, and enhances detector performance through the charge dispersion effect [4]. The spatial resolution goals are 100  $\mu\text{m}$  for the pre-shower and 400  $\mu\text{m}$  for the muon system; an efficiency above 95% and an optimization of the readout segmentation to reduce the cost of the subsystems since the area to be instrumented is 130  $\text{m}^2$  in the pre-shower and 1525  $\text{m}^2$  in the muon system. A simulation based on DD4HEP [5] describes the two systems (pre-shower and muon detector) using 50 $\times$ 50  $\text{cm}^2$  tiles of  $\mu$ -RWELL technology together with the other IDEA sub-detectors for physics studies and simulations.

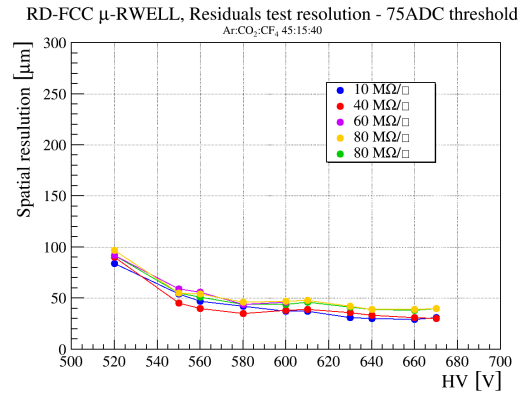
### 2 Optimization 1D

A first test beam campaign conducted in 2020 and 2021 at the H8 test line of CERN’s North Area, using a 140 GeV/c muon beam, investigated two sets of detectors. These detectors featured a layout segmented into strips of 40 cm length, an Ar/CO<sub>2</sub>/CF<sub>4</sub> (45/15/40) gas mixture, and were readout using the APV-25/SRS system [6]. The study included a scan of DLC resistivity values ranging from 10 to 80 M $\Omega/\square$  to evaluate the performance of the  $\mu$ -RWELL detector with a 400  $\mu\text{m}$  strip pitch and a 6 mm

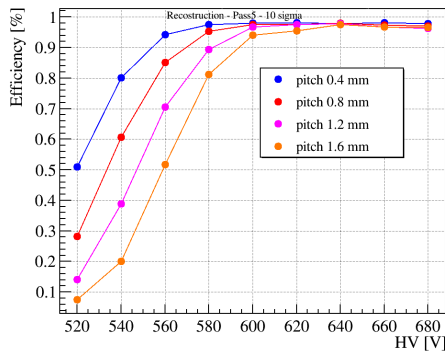
gas gap with 3.5 kV/cm drift field. It is observed that lower resistivity values increase charge dispersion, as expected. Within the tested resistivity range, the detector with a resistivity of 10 MΩ/□ exhibited an increase in multiplicity due to charge dispersion up to 25%, and the other detectors showed a more homogeneous behavior as reported in figure 2 and figure 9. Combining the charge dispersion with the threshold effects, the detector with 10 MΩ/□ resistivity shifted the efficiency plateau to higher HV settings as shown in figure 1. Consequently, the operational range of DLC resistivity was determined to be between 40 and 200 MΩ/□. The second set of detectors examined the performance for a fixed resistivity value of 80 MΩ/□ and strip pitches of 0.4, 0.8, 1.2, and 1.6 mm. As expected, the higher the segmentation, the better the spatial resolution. A pitch of 0.4 mm achieved a spatial resolution below 100 μm, while a pitch of 1.6 mm achieved a resolution below 400 μm. For larger pitches, the efficiency plateau was reached at higher HV settings (approximately 40 V) due to threshold effects as shown in figure 3. Both the 1.2 and 1.6 mm pitches are suitable for the muon system, with the 1.2 mm pitch being preferred due to its longer plateau. Conversely, only the 0.4 mm pitch can meet the spatial resolution requirements for pre-shower applications, see figure 4 and figure 10. If a layout different from those described in [3] is used, good performance can still be achieved with a larger strip pitch, as discussed in the next paragraph, in figure 6 and in [7].



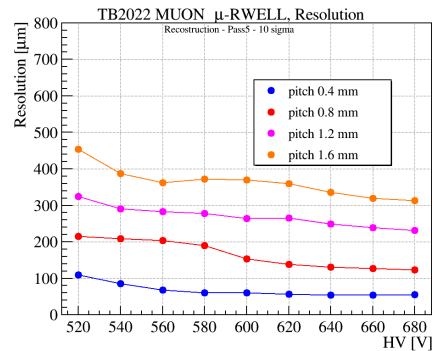
**Figure 1.** Efficiency curves for different DLC resistivity on μ-RWELL testbeam campaign in section 2.



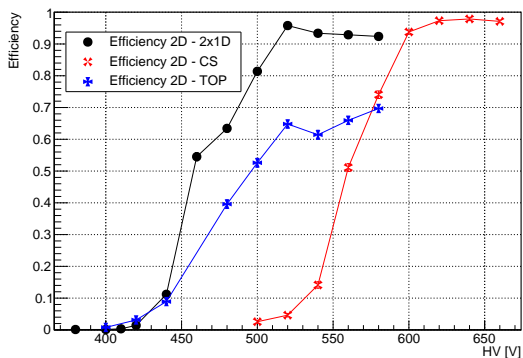
**Figure 2.** Spatial resolution curves for different DLC resistivity on μ-RWELL testbeam campaign in section 2.



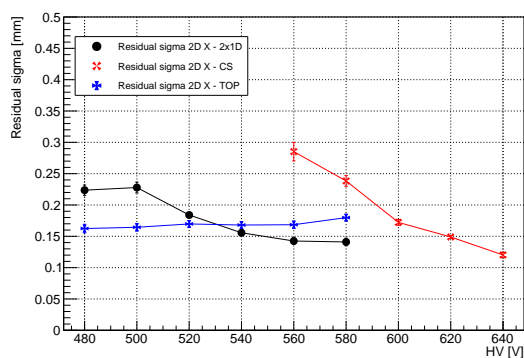
**Figure 3.** Efficiency curves for different strip pitch on μ-RWELL testbeam campaign in section 2.



**Figure 4.** Spatial resolution curves for different strip pitch on μ-RWELL testbeam campaign in section 2.



**Figure 5.** Efficiency curves for different bi-dimension readout segmentation on  $\mu$ -RWELL testbeam campaign in section 3.



**Figure 6.** Spatial resolution curves for different bi-dimension readout segmentation on  $\mu$ -RWELL testbeam campaign in section 3.

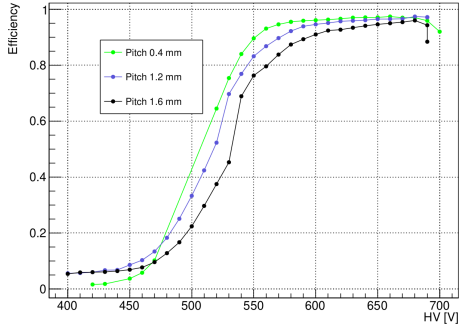
### 3 Optimization 2D

A second test beam campaign conducted in 2021 and 2022 at the H8 test line of CERN’s North Area, utilizing a 140 GeV/c muon beam, investigated three different layouts for a two-dimensional readout. To optimize the number of readout channels, only strip segmentation was considered, no pixels nor pads. All three configurations use a DLC resistivity of  $50 \text{ M}\Omega/\square$ , and different strip pitches, a 6 mm gas gap with 3.5 kV/cm drift field. The first layout consists of two 1D detectors rotated by  $90^\circ$  relative to each other, with a pitch of 0.76 mm. The second layout employs a pitch of 1.2 mm and a “charge sharing” (CS) configuration [7]: four layers with chromium pads and increasing segmentation (0.3, 0.6, 1.2, and 1.2 mm) between the amplification stage and the readout spread the induced signal over a larger area. The third layout, labeled as “top readout” (TOP), utilizes a pitch of 0.8 mm and the segmentation of the amplification layer to divide the readout strips into two stages: above and below the amplification stage of the well. The results demonstrated good spatial resolution performance of approximately 150–200  $\mu\text{m}$  for all configurations as reported in figure 6. Regarding efficiency in figure 5, the third layout achieved a plateau of 70%, limited by the segmentation above the amplification stage, which introduced dead areas. The second layout exhibited a plateau shift of approximately 100 V compared to the first configuration. The first layout shows a slightly lower plateau than the others because the efficiency measurement combines two separate and independent measurements. As a result, the inefficiency of each 1D detector is propagated. In contrast, the other two layouts measure the efficiency along the X and Y axes from the same signal, leading to a strong correlation between the measurements.

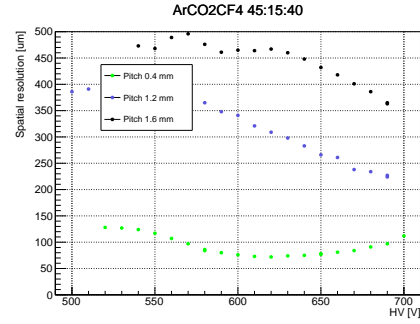
### 4 A new electronics and a $\text{CF}_4$ -less gas mixture

A third testbeam campaign is completed in 2024. A new readout chain is used to extend the optimization of the  $\mu$ -RWELL to the electronics integration. A first evaluation of the detector performance, together with the TIGER/GEMROC readout system [8], defined the state of the art for that innovative technology. The TIGER chip handles 64 channels, performing time and charge measurements. Signals are amplified, split into time (60 ns peaking time) and charge (170 ns peaking time) branches. The dynamic range varies from 2 to 50 fC, and the noise on the expected electronic noise is less than 0.5 fC. The detectors tested are the same as the pitch scan of the first testbeam campaign (section 2) and two different gas mixtures: the  $\text{Ar}/\text{CO}_2/\text{CF}_4$  (45/15/40) as in the previous campaign, and the  $\text{Ar}/\text{CO}_2$  (70/30) to define

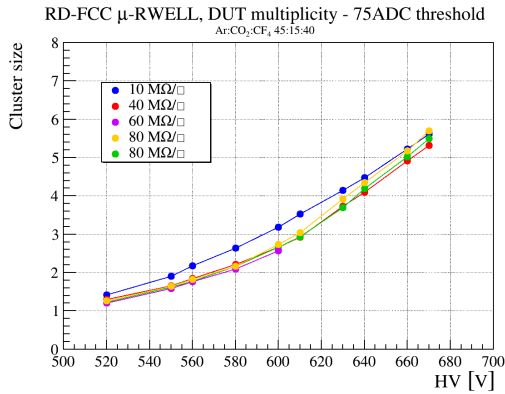
a performance benchmark without  $\text{CF}_4$ . This greenhouse gas contributes to the greenhouse effect with a greenhouse warming potential 6500 times that of  $\text{CO}_2$ . The results (spatial resolution and efficiency) with  $\text{CF}_4$  confirmed those obtained with APV-25, as shown in figures 7 and 8. The results obtained with the other gas mixture showed a shift in the working point of about 50–100 V due to different ratios of Argon but similar performance in the spatial resolution.



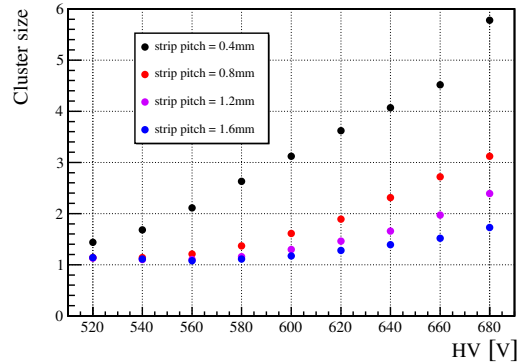
**Figure 7.** Efficiency curves for different strip pitch with TIGER chip on  $\mu$ -RWELL testbeam campaign in section 4.



**Figure 8.** Spatial resolution curves for different strip pitch with TIGER chip on  $\mu$ -RWELL testbeam campaign in section 4.



**Figure 9.** Cluster multiplicity for DLC resistivity on  $\mu$ -RWELL testbeam campaign in section 2.



**Figure 10.** Cluster multiplicity for different strip pitch on  $\mu$ -RWELL testbeam campaign in section 2.

## 5 Simulation

A PARAMetrized SIMulation (PARSIFAL) library is developed for extending the optimization of the  $\mu$ -RWELL detector and the TIGER electronics. A parametrization of key physics processes, such as primary and secondary ionization, electron drift, and diffusion up to the readout plane, is extracted from GARFIELD++ [9]. More details can be found in the literature [10, 11]. The behavior of the resistive layer is modeled according to charge dispersion studies from the literature [12]. PARSIFAL allows the reproduction of the main features under study: strip multiplicity with different DLC parameters, the charge collected and number of strips above threshold with different detector gain settings, and spatial performances of charge centroid or  $\mu$ TPC algorithms as a function of the angle.

A tuning procedure with the experimental data from the three testbeam campaigns is ongoing to foster the integration of the detector and the electronics.

## 6 Conclusion

Ongoing R&D on  $\mu$ -RWELL technologies is focused on developing large-area detectors (50×50 cm tiles) for the pre-shower and muon systems in the IDEA detector. These efforts aim to optimize performance together with the segmentation of the readout. Key studies on DLC resistivity, strip pitch, and various 2D readout configurations have provided valuable information. A test beam using TIGER electronics has been performed, and simulations will be used to optimize the integration between the detector and electronics.

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