PROCEEDINGS OF SCIENCE

# The μ-RWELL technology for the pre-shower and muon detectors of the IDEA detector

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In view of the construction of a circular $e^+e^-$ collider, like FCC-ee, the scientific community of RD-FCC is conceiving the IDEA apparatus: the Innovative Detector for Electron-positron Accelerator. The detector is composed, from the innermost region going outward, of a central tracker, the magnet, the pre-shower, the calorimeter and the muon system. The micro-Resistive WELL technology has been proposed for the realization of the pre-shower and the muon counters with proper tuning of the detector parameters due to the different requirements of the two systems. In particular, the readout strip pitch will be 400 μm for the pre-shower and 1 mm for the muon stations. This is possible thanks to the industrialization of the production process, which started to make the technology cost-effective. A key role in this task is represented by the choice to make the apparatus systems modular. Other requirements for the detectors 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. The optimization of the surface resistivity with a fixed strip pitch was achieved by the construction of a set of prototypes with an active area of 5×40 cm$^2$ and 40 cm long strips. For the pre-shower prototypes, the resistive stage has been chosen with a surface resistivity $\rho_S$ ranging from 10 to 80 MΩ/□, while for the muon ones $\rho_S$ is about 20 MΩ/□. All these detectors have been exposed in October 2021 to a muon/pion beam at the CERN SPS. The very positive results obtained open the way for a completely new and competitive MPDG tracking device for high-energy physics experiments.

*41st International Conference of High Energy Physics - ICHEP2022*
*6-13 July 2022*
*Bologna, Italy*





PoS(ICHEP2022)333

## 1. A future electron-positron collider and its detectors

A new high-energy electron-positron collider, Future Circular Collider (FCC-ee), has been proposed to continue the research on particle physics with greater precision than the state of the art. Thanks to a 100 km tunnel and proper detectors to measure the interaction products, it will serve the worldwide community [1]. Combining novel elements with past and present lepton colliders, the FCC-ee design achieves outstandingly high luminosity and high beam precision. The FCC-ee physics program will be focused on the heaviest known particles, such as the Z, W, and H bosons, together with the top quark. The low background of lepton colliders, together with accurate beam-energy measurements and the presence of two detectors designed for precision measurements will improve the sensitivity to the new physics. The detector proposals define two complementary designs named "CLIC-Like Detector" (CLD) and the "International Detector for Electron-positron Accelerators" (IDEA). This paper focuses on the IDEA detector.

To achieve the precision measurements needed to overstep the state of the art, the IDEA detector will be defined by the following components, as shown in Fig. 1:

- a silicon pixel vertex detector with a spatial resolution of a few µm to provide a precise primary and secondary vertex resolution and deal with the large luminosity expected in FCC-ee, based on the ALICE inner tracker system [2];
- a detector for momentum measurements and particle identification (PID) built up by a large volume wire chamber with a spatial resolution of 100 µm and a low material budget of $10^{-2}\ X_0$. The PID will be performed by the known dE/dx mechanism together with the new approach of cluster counting [3];
- a silicon micro-strip detector with a 15 µm spatial resolution to complete the tracking volume, together with the drift chamber and the tracking system;
- a low-mass superconducting solenoid coil

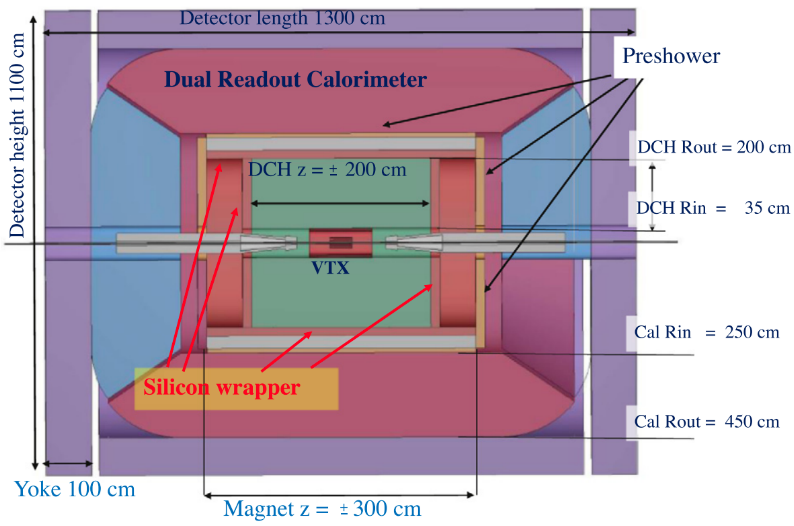


**Figure 1:** A schematic layout of the IDEA detector.

- a μRWELL-based pre-shower to help match points in the tracking volume and the calorimeter in presence of interactions with the coil, and to tag charged particles or photons before the calorimeter;
- a dual-readout calorimeter that can measure both the scintillation and the Cerenkov signals using optical fiber and SiPM [4];
- a muon chamber within the magnet return yoke to identify the clear signal of muons with the μRWELL technology.

The layout of the tracking volume is optimized through a reduced material budget. A fast simulation reports a transverse momentum resolution of $\sigma(1/p_t) \approx a \oplus b/p_t$, with a $\approx 3\times10^{-5}$GeV$^{-1}$ and b$\approx 0.6\times10^{-3}$ [1]. Outside the magnet coil, the pre-shower is used to tag the particles and it provides position measurements matched with the calorimeter, resulting in an improvement in the reconstruction performance. The interplay between the pre-shower and the calorimeter has been evaluated in a combined testbeam and the preliminary results are shown in [5].

## 2. Resistive MPGD technology

A Micro Pattern Gaseous Detector (MPGD) measures the ionization signal released by charged particles interacting with its gas volume. Thanks to photo-lithographic processes and etching techniques, an MPGD can generate a high electric field in a reduced space region (few μm) to amplify hundred primary electrons with gain factors of $10^3$-$10^4$, depending on the MPGD type. The most common ones are triple-GEM [6] and MicroMegas (MM) [7]. A novel MPGD, that overcomes the mechanical limitation of the large area GEM detector and the production complication of the MM, is the μ-RWELL: a single-stage amplification detector with a spark protection resistive layer [8]. The detector is composed of a cathode and a unique multi-layer with a well-patterned single copper-clad polyimide foil acting as the amplification element of the detector; a resistive layer, realized with a DLC film sputtered on the bottom side of the polyimide foil; a standard PCB for readout purposes. See Fig. 2. The charge induced on the resistive film is spread with a time

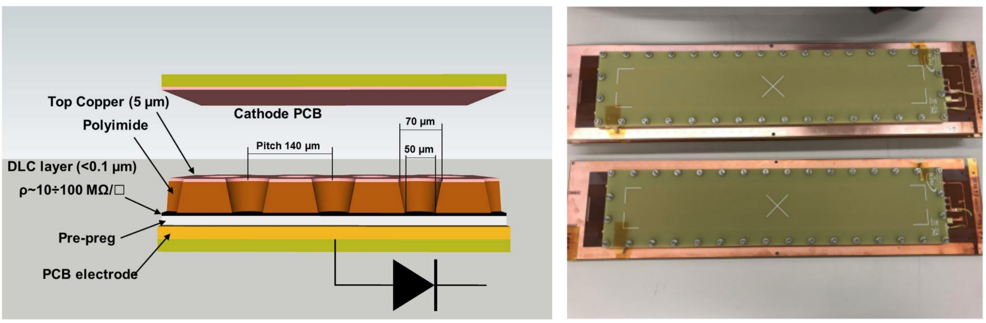


**Figure 2:** A schematic layout of the μ-RWELL detector (left) and a picture of the detector under test in the testbeam (right) are shown.

constant depending on the layout [9]. This charge dispersion effect impacts the behavior of the detector as shown in the following paragraph. The performance achieved by this technology is in

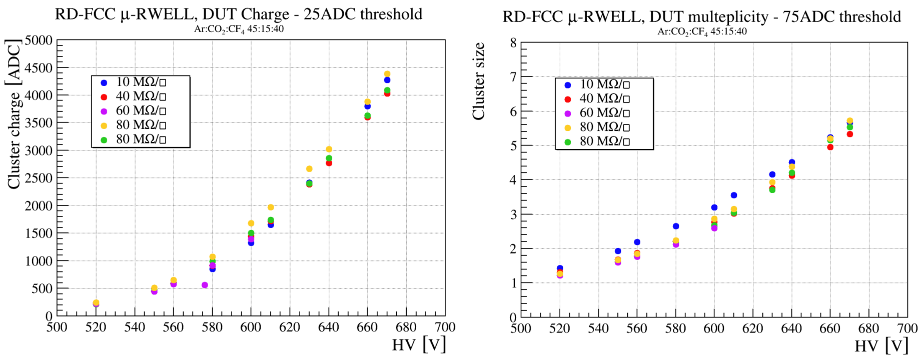


**Figure 3:** Average amount of the charge collected (left) and average number of strips fired (right) as a function of the HV on the amplification stage for different resistivity values in µ-RWELL detectors.

line with the other MPGD: a spatial resolution of 50 µm and an efficiency above 97-98% have been measured with muons in a testbeam in the North Area SPS at CERN while a rate capability of up to 10 MHz/cm$^2$ in another testbeam with pions at PSI [10, 11].

## 3. µ-RWELL optimization for IDEA

The state of the art for µ-RWELL technology already fulfils most of the IDEA requirement both for the pre-shower and the muon chamber: good spatial resolution, high efficiency, and large area production routine developed. In detail, the pre-shower has to tag the incoming particles, while the muon detector has to cover more than 4000 m$^2$ of the surface with a spatial resolution of a few mm. Room for the detector optimization layout and a reduction of the number of electronic channels $O(10^7)$ is given by the tuning of the DLC resistivity ($\rho_S$) together with the pitch size of the detector. As expected from the literature, a reduced $\rho_S$ spreads the charge distribution on a larger area while a high $\rho_S$ *freezes* the induction area on the amplification point. Two testbeams were planned (one in 2021 and 2022) to optimize the DLC and the pitch. A set of µ-RWELL detectors with an active area of 5×40 cm$^2$ active area, 400 µm pitch, and 40 cm long strip segmentation have been manufactured are CERN. The strip length of these detectors is close to the one expected in the IDEA layout (50 cm) and so is the noise level. The resistivity of the detectors has been varied between 10 and 80 MΩ/□ to measure the impact on the performances, while keeping constant the other layout parameters. The detectors under test (DUT) have been installed together with a tracking system (XY) on the H8 beam line at CERN North-Area and the setup has been tested with a muon beam of 140 GeV/$c$ momentum. The chosen gas mixture was Ar/$CO_2$/$CF_4$ (45/15/40), following results already in the literature [11]. The first detector characterization is focused on the signal shape induced on the readout, which can be achieved with a study of the total charge collected and the number of strips fired as shown in Fig. 3. As observed from the data, no large effects of the charge spread are shown in the resistivity range studied; only a slightly larger multiplicity is observed at low HV for the 10 MΩ/□ value. A larger effect is expected with a lower resistivity value but this would limit the DLC spark protection effects. A more detailed study of performance is done using the tracking system. A comparison between the position measured by the tracking ($x_{trk}$) system and the DUTs ($x_{DUT}$) have been performed. This allows for alignment of the setup both for a shift

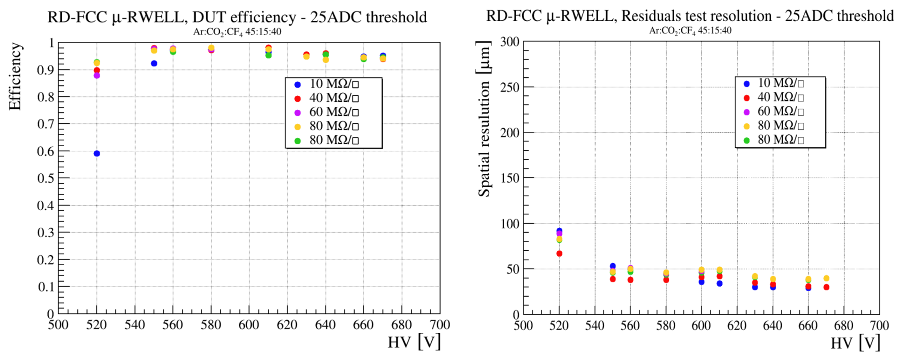


**Figure 4:** Efficiency (left) and spatial resolution (right) as a function of the HV on the amplification stage for different resistivity values in μ-RWELL detectors.

and an XY tilt of the detector. A Gaussian function fit of the residual distribution ($x_{trk}$ - $x_{DUT}$) is used to evaluate the spatial resolution of the DUTs, including the contribution of the tracking system. The sigma of the fit as a function of the HV together with the efficiency are reported in Fig. 4. The efficiency is evaluated by the ratio of the number of entries with $|x_{trk} - x_{DUT}| < 1$ mm over the number of events with a good track.

## 4. Conclusion

The μ-RWELL technology has been chosen to develop the pre-shower and the muon system of the IDEA experiment. Due to the large area to cover and the performance needed and optimization of the DLC resistivity and the pitch size is ongoing. A testbeam with μ-RWELL of 40 cm strip length performed at H8 CERN North-Area has been completed. The charge dispersion effect, measured with a strip pitch of 400 μm, does not show critical behavior in the safety of the detector, nor the performance degradation. A spatial resolution below 50 μm was achieved for each resistivity value of the DUTs.

## Acknowledgment

This project has received funding from the Eu commission under the G.A. 101004761 (H2020-INFRAINNOV-2019-2020 Aidainnova) and G.A. 872901 (H2020-MSCA-RISE-2019 FEST). The group thanks the RD51 collaboration for their support on the MPGD technologies.

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