PROCEEDINGS OF SCIENCE

The µ-Rwell technology for the IDEA detector

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The IDEA detector, designed for future e+e- colliders like FCC-ee or CEPC, features an innovative design with a central tracker enclosed in a superconducting solenoidal magnet, a pre-shower system, and a dual readout calorimeter. Positioned within the iron yoke are three muon detector stations. The pre-shower and muon detector employ µ-RWELL technology, inheriting the best characteristics of GEM and Micromegas, being spark-robust and simple to assemble. Both preshower and muon detectors follow a modular design, with 50x50 cm^2 µ-RWELL tiles. The preshower targets a 100 µm spatial resolution, while the muon detector prioritizes channel count. Vigorous R&D on µ-RWELL technology has yielded various prototypes characterized in lab and test beams, and technology transfer to industries for mass production.

42nd International Conference on High Energy Physics (ICHEP2024)
18-24 July 2024
Prague, Czech Republic

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PoS(ICHEP2024)1103

1. Intruduction

The Future Circular Collider (FCC) is the proposed project to replace the Large Hadron Collider (LHC) at CERN. Thanks to LHC, the physics of the Standard Model (SM) has been deeply studied, particularly with the discovery of the Higgs Boson in 2012. FCC design will allow the investigation of possible scenarios beyond the SM reaching an outstanding luminosity and center mass energy [1]. The new facilities will be hosted in a tunnel of 90.7 km circumference, to host up to 4 experiments. The infrastructure will initially host an electron-positron collider (FCC-ee), working in the energy range from 88 to 365 GeV. In a second phase, the same structure will host FCC-hh, reaching the energy of 100 TeV. In particular, FCC-ee spanning from the energy of the Z pole over the WW threshold and HZ production peak to the $t\bar{t}$ threshold and above, will allow to investigating the heaviest particles, improving the precision of measurements in literature and the sensitivity to new physics [2]. Two general-purpose detectors are understudying: the "CLIC-Like Detector" (CLD) and the "International Detector for Electron-positron Accelerators" (IDEA).

The IDEA detector, outlined in Figure 1, foresees a series of concentrical detectors: a silicon pixel vertex detector, for the precise determination of the impact parameter of charged particles. An ultra-light drift chamber surrounded by a layer of silicon micro-strip detectors, ideal for particle identification. A compact and light superconducting solenoid coil, able to generate a 2 T magnetic field. A pre-shower, just outside the solenoid, allows to tag charged particles and photons. It provides a precise position measurement ($\sigma_{r\phi}$ <100 µm) just before the dual readout calorimeter. The last element is the muon system, which consists of layers of chambers embedded in the magnet return yoke, and it will provide a spatial resolution <400 µm.

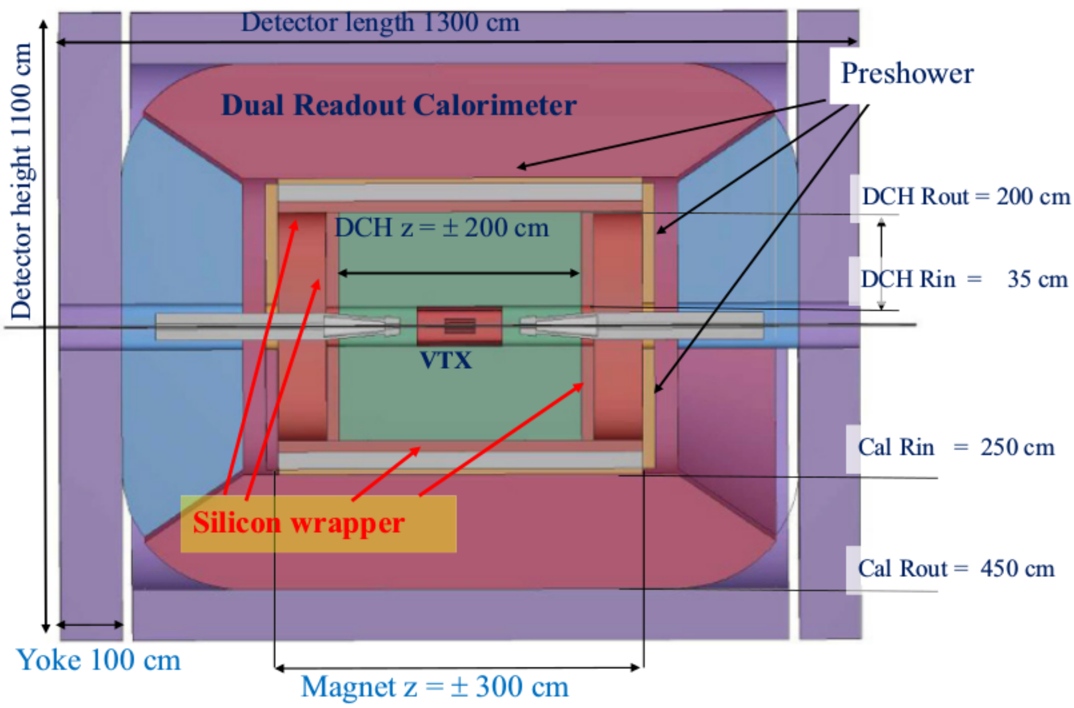

Figure 1: A schematic layout of the IDEA detector

2. The micro-RWELL technology

The pre-shower and the muon detector must cover an area of 130 m^2 and 1525 m^2 respectively. Micro Pattern Gas Detectors are an efficient choice to cover these large areas, particularly micro-Resistive WELL (μ-RWELL). The μ-RWELL is a single amplification stage detector composed mainly of the cathode and the readout Printed Circuit Board (PCB), which host the amplification stage. Figure 2 shows a cross-section of a standard μ-RWELL. The PCB is realized by employing standard photo-lithography technology. It is composed of a well-patterned single copper-clad polyimide foil acting as an amplification element of the detector, a resistive layer, realized with a thin film of Diamond-Like-Carbon (DLC), and a standard PCB for readout purposes, (segmented as strip, pixel, or pad electrodes). The main mechanisms that rule the μ-RWELLs behavior are described in detail in [3]. The high resistivity of the DLC decreases the discharge amplitude allowing reach gains of the order of 10^4 and it improves the detector performances, thanks to the charge dispersion effect [4]. With this technology, an efficiency of ~98 % is achievable, with a rate capability up to 10 MHz/cm^2 and a spatial resolution of the order of 50 μm, with a strip pitch of 400μm [5].

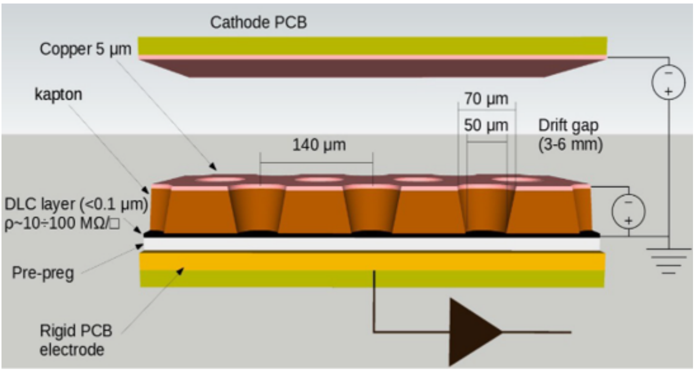

Figure 2: Scheme of a μ-RWELL, showing the layout of the PCB, the WELL pattern, and where the potential differences are applied.

3. The μ-RWELL R&D program

The pre-shower and the muon system are based on the same technology but they have to fulfill different requirements. The pre-shower should provide a high spatial resolution, while the muon system has to cover a large area with a spatial resolution of a few mm, with a reasonable number of readout channels. The R&D program initially has been focused on the optimization of the DLC resistivity and strip pitch. A first set of 1-D detectors has been realized, with DLC resistivity ranging from 10 MΩ/□ to 80 MΩ/□ and with a strip pitch of 400 μm. All these detectors show a nice efficiency plateau region, around 98 %, 100 V wide, and with a correlated spatial resolution below 50 μm. The only relevant difference regards the 10M Ω/□ detector, which reaches the efficiency plateau after the other chambers, due to the larger charge spread [6].
A second set of 1-D detectors has been produced with a strip pitch of [0.4,0.8,1.2,1.6] mm and the same DLC resistivity (40 MΩ/□). These chambers reach the efficiency plateau at different HV

values, since the larger the strip pitch, the lower the charge signal induced in the strip readout requiring a higher gain to get the plateau. The detectors with strip pitch of 0.4 mm and 0.8 mm reach the plateau at 600 V, with a spatial resolution below 600 μm. At the moment of writing of this proceeding the resolution was found below 200 μm for both pitches.
Both the pre-shower and the muon system should provide 2-D position measurement, hence another phase of the R&D program regards the technology for the bidimensional readout. Three approaches have been explored:

- a pair of 1-D detectors, (X and Y), coupled through a common cathode;
- a single μ-RWELL with the usual readout PCB, plus a pattern of strip on the TOP of the amplification stage for the second coordinate, called μ-RWELL TOP readout;
- a single 2-D μ-RWELL based on the Capacitive-Sharing (CS) readout. This technology exploits the capacitive coupling between different layers of pads or strips, sandwiched between polyimide foils, to simultaneously transfer and spread the signal produced in the amplification stage [7].

A test beam was performed in the H8 test line of the CERN North Area using a muon beam of 140 GeV/c momentum and a set of detectors based on both TOP readout and capacitive sharing. Figure 3 shows the results of the HV scan. The TOP readout detectors present a low-efficiency (~70 %) plateau due to the dead zone that the pattern of strips (X-strips) on the TOP of the amplification stage induces on the active area. The resolution in the X-coordinate is almost digital, compatible with no charge spread and it is given by: pitch/$\sqrt{12}$. In this case, the strip pitch was 0.8 mm. The Y-coordinate resolution changes as a function of the voltage applied due to the DLC spread, and above 550 V is below 200 μm. While the detectors based on the capacitive-sharing reach an efficiency of about 95 % and a resolution of ~150 μm at 600 V, with a strip pitch of 1.2 mm. The CS detectors reach the plateau at a higher HV, 100 V after the TOP readout because the charge is shared on both views in the PCB below the amplification stage.

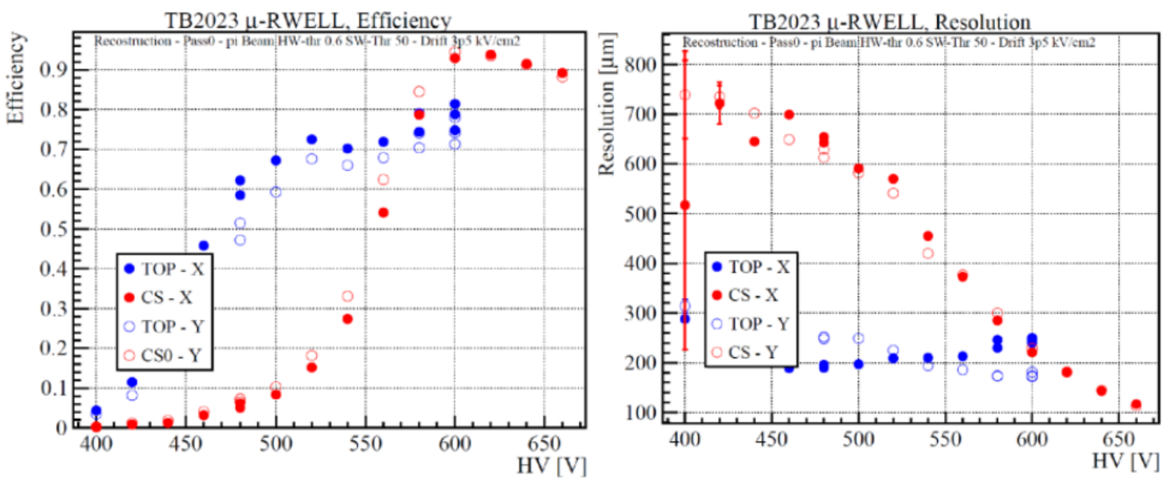

Figure 3: Efficiency and resolution comparison between the CS and the top-segmented readout

4. TIGER-GEMROC test beam

One proposal for the data acquisition chain for μ-RWELLs is the TIGER/GEMROC readout chain, which has been developed for the CGEM-IT detector [8]. This electronics was originally developed for reading triple-GEM detectors, but because of its versatility, it can also be used with other MPGDs, such as the μ-RWELLs.

It can be considered as composed of *the ON-detector* and *the OFF-detector* electronics. The on-detector electronics consists of a series of Front-End Boards (FEBs), each of which provides a digitized output with the time and energy measurement related of each strip. FEBs host two TIGER chips (Torino Integrated GEM Electronics for Read-out), which is a 64 mixed signal ASIC capable of performing charge and time measurement simultaneously. TIGER represents a versatile chip for the readout of detectors up to 50 fC and for high rates, even beyond 60 kHz per channel. A full description of the TIGER chip is given in [9]. The GEM ReadOut Cards (GEMROCs) are the main component of the OFF-detector electronic. Each GEMROC handles up to 4 FEBs. In particular, the GEMROC distributes the analog and digital voltage to the FEBs, the configuration of the FEBs, monitors the FEBs parameters (temperature, currents, and voltages), and manages the data coming from the TIGERs [10].
To evaluate the performance of the μ-RWELLs chamber with TIGER/GEMROC, a test beam at SPS-H8 beam line at CERN was organized in July 2024. On this occasion, the already mentioned 1-D detectors with [0.4,0.8,1.2,1.6] mm pitch have been tested, to compare the results with those obtained using the APV-SRS readout system. Figure 4 shows a preliminary plot of the collected charge as a function of the trigger time, of a 0.8 mm pitch μ-RWELL at the test beam.

The μ-RWELL R&D program will focus on the study and design of the 2-D readout to reach the desired stability and performance, the study for the electronics integration, and the research for the industrialization of the production process.

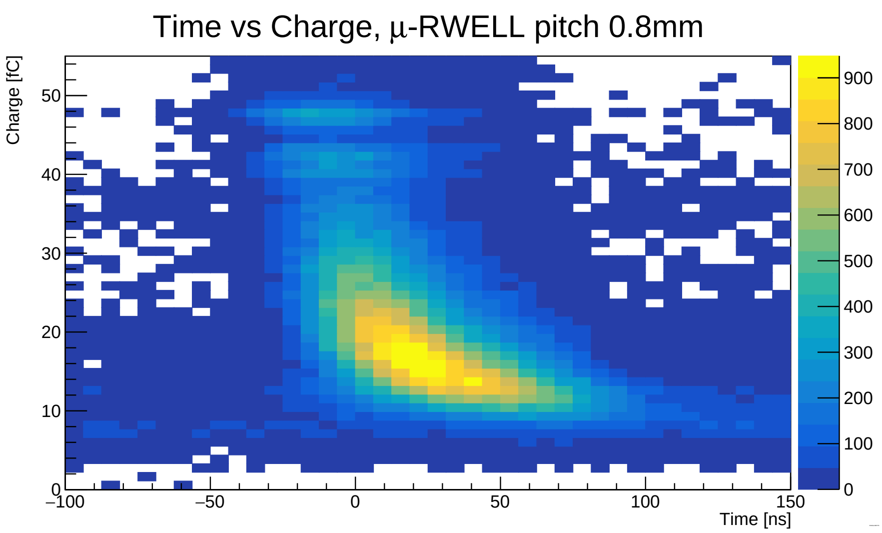

Figure 4: Plot of the charge signal vs trigger time

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