PROCEEDINGS OF SCIENCE

# Validation of a μRtube: a new geometry concept for MPGD technologies.

**R. Farinelli,**[a] **A. Bortone,**[b] **G. Cibinetto,**[c] **F. Chiapponi,**[a] **F. Cossio,**[b] **I. Garzia,**[c,d] **M. Greco,**[b,e] **S. Gramigna,**[c,d] **L. Lavezzi,**[b] **F. M. Melendi,**[c,d] **G. Mezzadri**[c,f] **and M. Scodeggio**[c]

[a] *INFN, Sezione di Bologna, Viale Berti Pichat, 6/2, 40127 Bologna, Italy*
[b] *INFN, Sezione di Torino, via P. Giuria 1, 10125 Torino, Italy*
[c] *INFN, Sezione di Ferrara, via G. Saragat 1, 44122 Ferrara, Italy*
[d] *Department of Physics, University of Ferrara, via G. Saragat 1, 44122 Ferrara, Italy*
[e] *Department of Physics, University of Turin, via P. Giuria 1, 10125 Turin, Italy*
[f] *Institute of High Energy Physics, Chinese Academy of Sciences, 19B YuquanLu, Beijing, 100049, People's Republic of China*

*E-mail:* rfarinelli@bo.infn.it

A new detector concept optimizes MPGD geometry for low-cost and large-area applications while keeping the same performance. The base element, a μRtube, is a cylindrically shaped μRWELL of 0.9 cm radius, which works as an amplification stage and readout. The external sleeve is 18 cm in diameter and accommodates the cathode, completing a radial tubular TPC having a small internal surface used for the readout. This geometry significantly reduces the number of electronic channels per unit area and brings a new technological achievement with an unprecedented curvature radius of MPDG for imaging and particle identification applications. The detection technique of the μRtube is based on the TPC approach where time information is used to reconstruct the ionizing particle path inside the drift volume. A report on the detector concept and its validation through a full simulation, relative gain measurements using a radioactive source, and test beam is presented. A preliminary spatial resolution of approximately 700 μm was achieved.

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



https://pos.sissa.it/

PoS(ICHEP2024)1059

## 1. Introduction

The µRWELL is a type of resistive Micro-Pattern Gaseous Detector (MPGD) with a single amplification stage [1]. It is composed of two main parts: the cathode and the µRWELL printed circuit board (PCB). The PCB is made using standard photolithographic techniques and consists of three layers. The first layer is a copper-clad polyimide foil with a well-patterned structure that acts as the amplification element. The second layer is a resistive Diamond-Like Carbon (DLC) film, sputtered onto the bottom of the polyimide foil, which serves to limit electrical discharges. The third layer is a copper-clad polyimide foil that collects the signals. Generally, this layer is segmented by strips, pixels, or pads.

When a voltage is applied between the copper layer on the first layer and the DLC, the well structure amplifies the ionization electrons generated in the drift region. The DLC layer prevents discharges, protecting the electronics and allowing the detector to achieve a gain of $10^4$ in a single amplification stage. Additionally, the DLC influences the detector's rate capability and spatial resolution [2]. The design used here is a "low-rate" version, capable of handling particle rates of a few MHz/cm$^2$ with only a 10% drop in gain.

In the CGEM-IT projects, such as KLOE-2 and BESIII, cylindrical layers of MPGDs, specifically triple-GEMs, were deployed around the beam pipe, with radii ranging from 77 mm to 205 mm and a length of approximately 700 mm [3, 4]. Building on this concept, a new cylindrical inner tracker based on µRWELL technology is being developed for the EURIZON project and the Super Tau-Charm Factory proposal [5, 6], with radii between 50 mm and 160 mm. The key innovation in these projects is the ability to shape the detector into a cylindrical form by exploiting the flexibility of the polyimide foil and PCB, whereas previous experiments typically used MPGDs with planar geometries. The use of µRWELL technology for cylindrical detectors simplifies construction and reduces costs by utilizing a single amplification stage, in contrast to the three stages required for GEMs.

The idea of shaping MPGDs with curved geometries led to the concept of the µRtube. The technological challenge to bend a single µ-RWELL PCB to unprecedented curvature radius can open new applications of this technology. In this paper, a cylindrical µRWELL with a reduced radius is described, referred to as the µRtube. The inner surface has a radius of 0.9 cm and contains a µRWELL, which functions as both the amplification stage and the readout. The outer sleeve has a diameter of 18 cm and hosts the cathode, forming a radial tubular TPC with a small internal surface used for readout. Figure 1 left shows a sketch of the detector operation.

## 2. Motivation

The detection technique of the µRtube is based on the TPC approach, where time information is used to reconstruct the ionizing particle path inside the drift volume. A radial electric field between the cathode and the anode is created, similar to a wire detector: the field lines converge on the anode with its proper segmentation. This convergence significantly reduces electron diffusion compared to a planar µRWELL, allowing the readout of a large volume with fewer electronic channels. The µRtube will perform imaging in a cylindrical volume with an 18 cm diameter and 10 cm length using a 1D readout segmented into 128 axial strips and readout by TIGER electronics

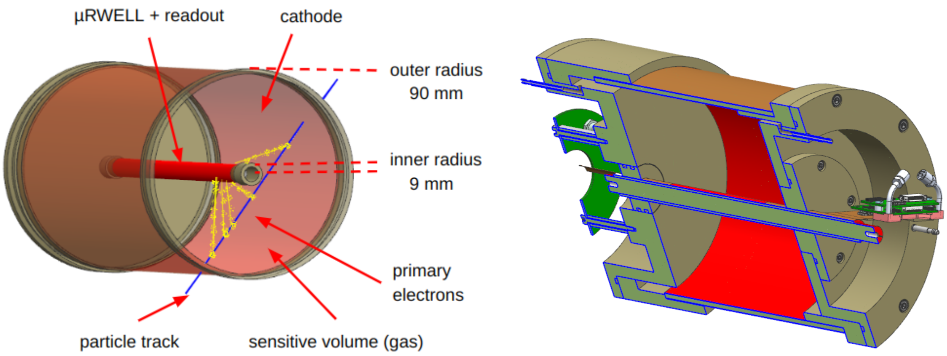


**Figure 1:** (Left) Sketch of the μRtube working principle. A large gas volume interacts with an incoming charged particle. The primary electrons are collected to the central region with a radial electric field. There, the μ-RWELL amplifies the signal and it collects it on the 1D segmented readout. (Right) Section of the mechanical drawing of the μRtube detector. The inner cylinder defined by the μ-RWELL is instrumented by the TIGER electronics from one side and the HV connectors on the other side. The gas volume is enclosed by PEEK-based end-caps and the outer cylinder which serves as the cathode.

and GEMROC FPGA [7]. This layout allows the reconstruction of the particle position only in the radial plane. The strips have a pitch of 400 μm and a width of 150 μm.

This prototype aims to demonstrate the mechanical bending limits of a μRWELL PCB and its technological consequence in the detector field. For example, in the proposed design here, using 128 electronic channels is possible to reconstruct in one dimension a particle track in a volume of 2520 cm$^3$. This characteristic makes the prototype well-suited for large-volume tracking systems, with potential applications as an external layer in a muon system, a large tracking volume for long-lived particles, and in muonography systems.

This new geometry concept provides an innovative collection of the charge that reduces significantly the transversal diffusion of the electron diffusion and it provides an optimized number of readout channels for the sensitive gas volume. A comparison of the electron diffusion between a planar geometry and the one proposed here is performed using GARFIELD++, a toolkit for the detailed simulation of particle detectors based on ionization measurement in gases [8]. Two different simulations are performed, the first with two planar electrodes with a 9 cm distance; and the second with two cylindrical electrodes with a 9 cm radial distance. The gas volume is filled with Ar:$CO_2$ gas mixture and the electrodes are set to 5000 V and 0V respectively. A thousand electron diffusion is simulated for both setups. A reduction by 3 orders of magnitude is measured in the transversal diffusion, while the temporal diffusion has a compatible value. An example is reported in Fig. 2 left.

A second comparison is performed by measuring the number of electronic channels of detectors from different technologies and geometries. It is important to mention that the chosen detectors do not have the same application but they share similar detection technique. In Fig. 2 right, the sketch of four detectors is reported. The μ-RWELL share the same pitch of 0.4 mm while the drift chamber has a cell size of 12×12 mm$^2$. The reduction of the number of readout channels improves from a factor of 3.5 up to 10 with respect to the μRtube.

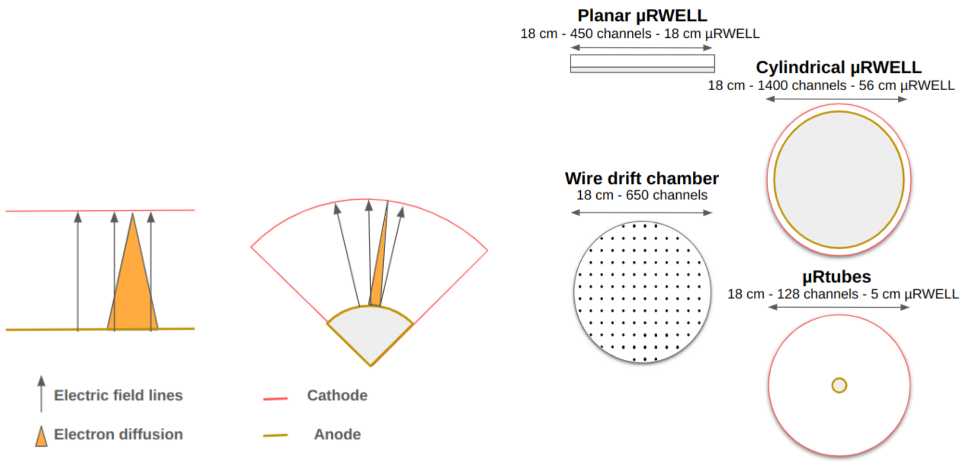


**Figure 2:** (Left) Example of the different electron diffusion processes in two configurations: planar and cylindrical geometry. (Right) A comparison between different technologies and geometries reporting the number of electronic channels.

## 3. Detector validation

The detector validation is studied with three approaches: a full simulation of the detector, a test using a Sr-90 radioactive source to verify the amplification of the µ-RWELL after the PCB shaping, and a performance evaluation using a tracking system and a muon beam with a momentum of 140 GeV/c.

### 3.1 Full detector simulation

A parametrized MPGD simulation has been developed to evaluate the detector's performance across various configurations, including different electric fields, gas mixtures, radial drift gaps, and strip pitches. Additionally, this simulation facilitates the development of a reconstruction algorithm suitable for a radial TPC design and helps define the electronics requirements. The PARametric SImulation tool (PARSIFAL) describes the detector [9]. 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++ [8]. The behavior of the resistive layer is modeled according to charge dispersion studies from the literature [10], as described in Eq. 1.

$$Q(t) = \frac{q}{2}\left[erf\left(\frac{x_2 - x_0}{\sqrt{2\pi}[\sigma_0(1+\frac{t-t_0}{\tau})}\right) - \left(\frac{x_1 - x_0}{\sqrt{2\pi}[\sigma_0(1+\frac{t-t_0}{\tau})}\right)\right] \tag{1}$$

where $q$ is the charge collected on the strip, $x2$ and $x1$ are the position edges of the strip, $\tau$ is the RC value of the resistive layer and the strip, and $\sigma_0$ is the dimension of the well. A Landau function describes the µRWELL amplification. The readout system is simulated using an RC-CR circuit or the electronics transfer functions. The reconstruction algorithms are based on this simulation, accounting for the non-linear space-time correlations the radial electric field gives. The results from the simulation defined the need for using the TIGER and GEMROC readout chain [7]. TIGER is a mixed-signal ASIC with 64 parallel channels, each dedicated to amplifying and processing signals.

It provides a fully digital output, with charge and time information delivered through two separate branches. In Fig. 3 left is reported the signal collected on a μRtube strip, the TIGER transfer function in the center, and the charge dispersion on the neighbor strips due to the resistive layer on the right.

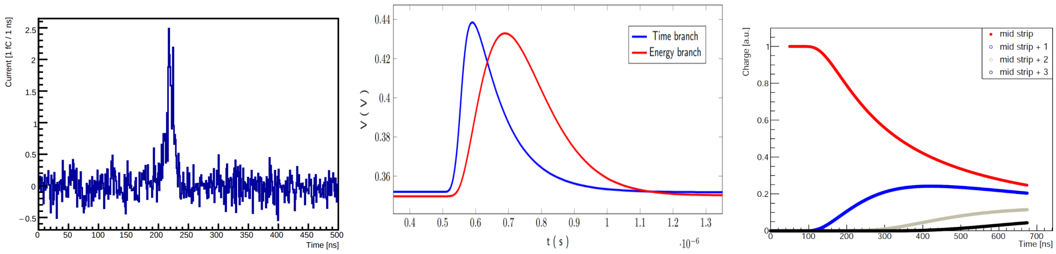


**Figure 3:** (Left) Signal inducted on a single strip by a muon, including white noise background. (Center) E-branch and T-branch TIGER transfer function. (Right) The charge evolution as a function of time in neighbor strips due to the charge dispersion in the resistive DLC layer.

### 3.2 Sr-90 radioactive source

After the detector design, as reported in Fig. 1 right, and its manufacturing, the first test to assess any potential damage caused by shaping the μRWELL to this unprecedentedly small curvature radius involved operating the detector under a high electric field within the wells. The test was conducted using a CAEN A1461 board with a current resolution of 50 pA. A high-voltage scan from 400 V to 500 V was performed with an Ar:$CO_2$ gas mixture, and no leakage current above 2 nA was detected. A second scan was carried out by irradiating the detector with a Sr-90 radioactive source. This method enabled the evaluation of the detector's relative gain curve by measuring the current flowing through the amplification electrodes, as the current is proportional to the detector's gain. A variation from 0 nA to 450 nA was observed, following an expected exponential trend, as reported in Fig. 4 left. This result confirmed the successful fabrication of the detector.

### 3.3 Testbeam with high energy muons

A setup consisting of two XY triple-GEM trackers and a μRtube was installed in the H4 North Area at CERN. The μRtube was tested using a muon beam with a momentum of 140 GeV/c. The tracking system provided the expected position of the particle track to be compared with the position measured by each strip of the μRtube. All detectors were equipped with TIGER electronics and GEMROC FPGA. The trigger window for data collection was set to 5 μs for the detector under test and 200 ns for the tracking system. The reconstruction algorithms developed in the simulation were applied to the experimental data. The measured time information was used to reconstruct the particle tracklet within the gas volume and hits with a residual distribution within 5 mm was used to evaluate the cluster charge. The collected charge as a function of the high-voltage bias on the amplification stage exhibited behavior similar to that observed in earlier tests. A preliminary spatial resolution of 720,μm was measured, validating both the fabrication of the μRtube and its imaging performance. These results are presented in Fig. 4 center and right. Further improvements in resolution are expected with the inclusion of time calibration, which currently introduces bias in the measurements.

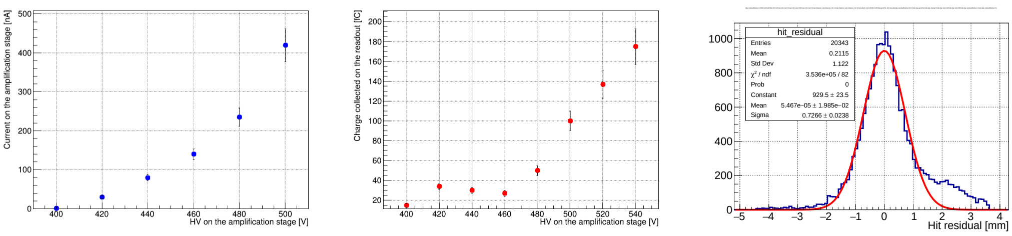


**Figure 4:** (Left) Current measured on the amplification stage with a Sr-90 radioactive source. (Center) Charge collected on the readout plane during the testbeam. (Right) Spatial residual distribution with a Gaussian fit.

## References


[1] G. Bencivenni et al., On the space resolution of the μ-rwell, JINST 16 (2021) P08036. doi:10.1088/1748-0221/16/08/P08036

[2] G. Bencivenni et al., Performance of μ-RWELL detector vs resistivity of the resistive stage, NIMA 886 (2018) 36-39 doi:10.1016/j.nima.2017.12.037

[3] I. Balossino et al., The cgem-it: An upgrade for the besiii experiment, Symmetry 14 (2022) doi:10.3390/sym14050905

[4] A. Balla et al., The cylindrical gem detector for the kloe-2 inner tracker, JINST 9 (2014) C01014 doi:10.1088/1748-0221/9/01/C01014

[5] G. Bencivenni et al., Status report on r&d work on inner tracker for the sct detector, 2022. https://www.cremlinplus.eu/sites/sites_custom/site_cremlinplus/content/e102473/e110259/e148088/infoboxContent162027/D5.2_Status_report_RD_inner_tracker_SCT.pdf

[6] H. Zhou, Design and simulation of a cylindrical μRWELL inner tracker for the experiment at the Super Tau-Charm Facility, JINST 18 (2023) P06015 doi:10.1088/1748-0221/18/06/P06015

[7] A. Amoroso et al., The CGEM-IT readout chain, JINST 16 P08065 (2021) doi:10.1088/1748-0221/16/08/P08065

[8] R. Veenhof, Garfield, recent developments, NIMA (1998) doi:10.1016/S0168-9002(98)00851-1.

[9] A. Amoroso et al., Parsifal: A toolkit for triple-gem parametrized simulation, Computer Physics Communications 295 (2024) 109000 doi:10.1051/epjconf/202429503028

[10] M.S. Dixit, Simulating the charge dispersion phenomena in micro pattern gas detectors with a resistive anode, NIMA 566 (2006) 281-285. doi:10.1016/j.nima.2006.06.050.162