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Muon detectors and Micro-Pattern Gas Detectors

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Almost all experimental apparatuses at existing colliders employ large muon systems located after all other subdetectors. Given the large size of most of the experimental detectors, the existing muon system has to cover areas of a few thousand square meters. It can be anticipated that future detectors at future colliders will be even larger in size. Therefore, for a practical reason of cost, the most suited detectors to realize these large muon systems are gas detectors. In particular, in recent years, Micro-Pattern Gas Detectors (MPGDs) have enjoyed very interesting developments, providing several new types of detectors with very good spacial and time resolution, high-rate capability and high radiation tolerance. MPGDs also have the distinct advantage of being, at least for some detectors and some parts of them, mass produceable by industry, since they employ materials and manufacturing procedures that are extensively used for Printed Circuit Boards (PCBs) production. A particularly innovative MPGD, the μRWell, is described as a possible candidate to build large muon systems for future colliders. The results obtained so far with this new technology are reported.

Keywords: Muon; detectors; micro-pattern; gas.

1. Introduction

Most current large experimental apparatuses at high-energy colliders have a cylindrical structure closed at the two ends by two endcaps. It is foreseeable that future detectors at future accelerators will adopt a similar design. All these detectors will have a length exceeding 20 m and a radius of at least 7–8 m. Muon detection systems being the outermost detectors will, therefore, need to cover an overall surface of several thousands of square meters.

Muon detection systems have to identify muons with very high efficiency and measure their momentum with accurate precision. In the case of hadronic collisions, they also have to provide a standalone muon trigger and bunch-crossing identification. Muon systems are typically composed of several stations of detectors, often

interleaved in the iron return yoke used to close the magnetic field, at several meters of distance from the primary interaction point. For obvious reasons of price, the most suitable detectors to build these large muon systems are gas detectors. In the past decade, a new generation of gas detectors, the Micro-Pattern Gas Detectors (MPGD), has been able to meet the increasingly challenging requirements of fast time response and radiation hardness. Different from the classical gas counters, where the distances between anodic and cathodic electrodes are of the order of several mm, in MPGDs, the ionization charge produced by the charged particle in the gas is multiplied by microstructures with distances between electrodes of order 10–100 μm, resulting in a much faster time response. These architectures are implemented, for example, by microholes in GEM[1] and μRWell[2–4] and by micromesh in MicroMegas.[5] The last generation of MPGDs exploits modern photolithography technology on flexible and rigid supports. As an example, GEM and MMs are successfully operated in COMPASS, LHCb and TOTEM experiments at CERN, in KLOE at Frascati-INFN, and are being built for the upgrades of ATLAS[6] and CMS[7] experiments at LHC.

A new type of MPGD, the μRWell, has taken the best characteristics of the GEM and MicroMegas detectors, while further simplifying the manufacturing process. A technology transfer with a few industries is already in place and this should allow to be able to mass manufacture this detector in the near future at a very competitive cost. This detector is therefore an excellent candidate to be the technology of choice for building the future large muon detection systems.

2. The μRWell Technology

The μRWell is a compact, spark-protected and single amplification stage MPGD. In the μRWell technology, an additional discharge resilience with respect to the triple-GEM detectors is foreseen as well as a simplified assembly geometry. A μRWell detector[2–4] is composed of two PCBs: a standard GEM Drift PCB acting as the cathode and a μRWell PCB that couples in a unique structure the electron amplification (a WELL patterned matrix) and the readout stages (Fig. 1(a)). A standard GEM 50 μm polyimide foil is copper clad on one side and Diamond Like Carbon (DLC) sputtered on the opposite side. The thickness of the DLC layer is adjusted according to the desired surface resistivity value (50–200 M$\Omega/\square$) and represents the bottom of the WELL matrix providing discharge suppression as well as current evacuation. The foil is then coupled to a readout board (Fig. 1(b)). A chemical etching process is then performed on the top surface of the overall structure in order to create the WELL pattern (conical channels 70 μm (50 μm) top (bottom) in diameter and 140 μm pitch) that constitutes the amplification stage (Fig. 1(c)). The high voltage applied between the copper and the resistive DLC layers produces the required electric field within the WELLs that is necessary to develop charge amplification. The signal is capacitively collected at the readout strips/pads.

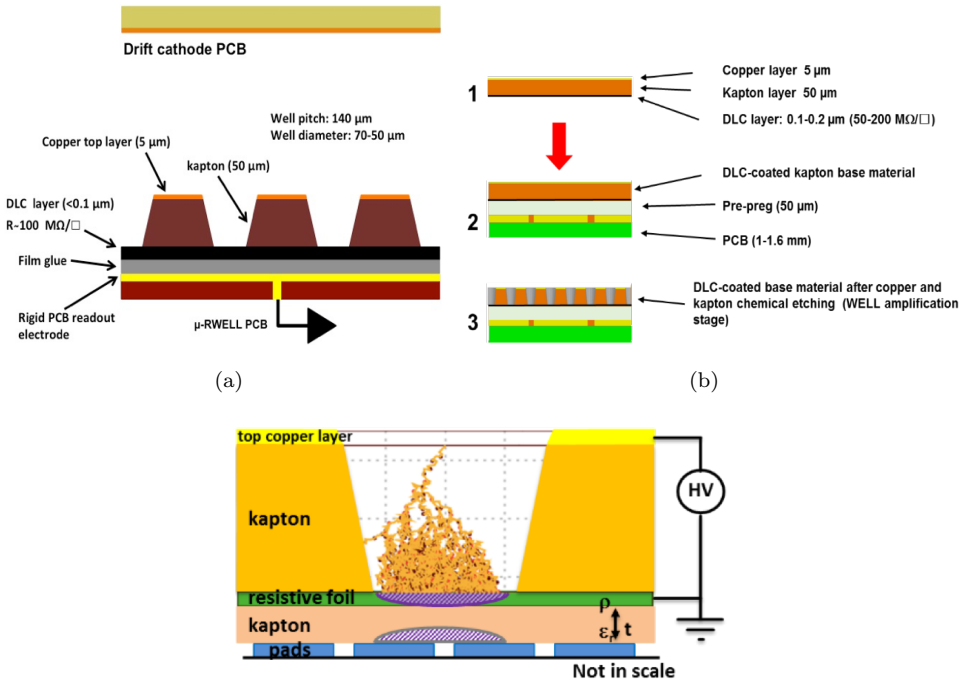


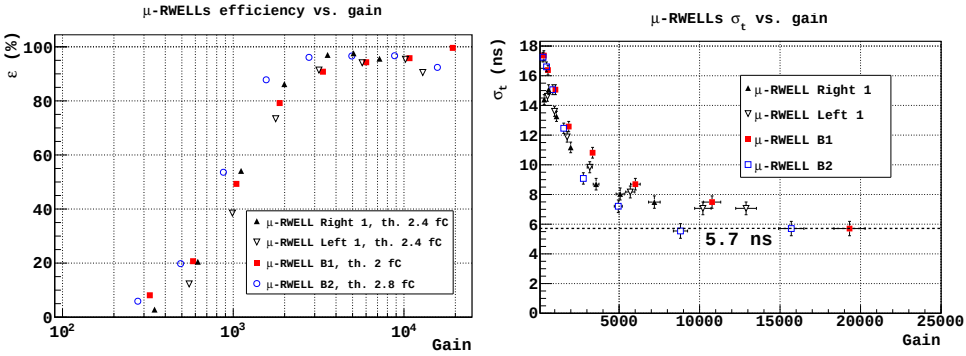
Fig. 1. (a) Layout of a μRWell detector module; (b) coupling steps of the μRWell PCB and (c) amplification stage directly coupled with the readout.

Two main schemes for the resistive layer can be envisaged: a *low-rate* scheme (for particles fluxes lower than 100 kHz/cm^2) based on a simple resistive layer of suitable resistivity; and a *high-rate* scheme (for a particle flux up to 1 MHz/cm^2) based on two resistive layers intra-connected by vias and connected to ground through the readout electrodes. Finally, a drift thickness of 3–4 mm allows for reaching a full efficiency while maintaining a versatile detector compactness.

A distinctive advantage of the proposed μRWell technology is that the detector does not require complex and time-consuming assembly procedures (neither stretching nor gluing), and is definitely much simpler than many other existing MPGDs, such as GEMs or MicroMegas. Being composed of only two main components, the cathode and anode PCBs are extremely simple to be assembled.

The single-resistive layer μRWell is a mature technology that has been proposed as tracking device for the CMS Phase2 upgrade of the muon detector. In this framework, an R&D for the engineering, construction and test of large size single-resistive layer μRWells has been pursued. The task has been accomplished in strict collaboration with an Italian PCB Company (ELTOS SpA, http://www.eltos.com/).

As a first step, a $\sim 1.2 \times 0.5$ m^2 μRWell (GE1/1-μRWell prototype) was designed, built and characterized in a beam test at the H8-SPS area at CERN,



(a) (b)

Fig. 2. (a) Efficiency versus gain and (b) time resolution versus gain.

smaller than the final GE2/1,[a] but $\sim$40 times larger than any μRWell prototype previously built. The GE1/1 prototype had a resistive DLC surface resistivity of about 70 M$\Omega/\square$ (in the *low-rate* configuration). The strips pitch was 800 μm and the chamber was equipped with VFAT2 front-end electronics. The gas mixture used was $Ar/CO_2/CF_4$ (45/15/40), with a drift gap of 7 mm. Due to the different geometries used for the amplification stage, the prototype was divided into two sectors (left and right) of slightly different gain. Both sectors were tested for efficiency and time resolution and the results compared with the performance of small μRWell prototypes (10 cm $\times$ 10 cm, built in the *high-rate* configuration) used into the same experimental setup and equipped with the same electronics. Figure 2(a) shows the efficiency as a function of gain for the GE1/1 size prototype and two small (10×10 cm^2) μRWell prototypes: one can observe that the three detectors have an identical behavior. Figure 2(b) shows the time resolution as a function of gain: a resolution better than 6 ns is obtained for all three μRWell prototypes for a gain of about 10,000.

In July 2017, the first GE2/1 20 degree sector equipped with two large area M4 μRWell detectors (each of dimensions $\sim 50 \times 60$ cm^2) was assembled. It was subsequently exposed to a muon beam at the H4 test beam at CERN. The detector was placed on a remotely controllable moving platform in order to allow to scan the surface of the detector across the muon beam, as can be seen in Fig. 3. Only one-half of one M4 was equipped with readout electronics and horizontal scans across one-half of the M4 at the time were performed. The GE2/1 sector was flushed with an AR/CO_2 70/30 gas mixture. The beam line was equipped with a tracker composed of two GEM detectors and two small size μRWell prototypes. The efficiency of the GE2/1 sector was defined as the number of triple coincidences GE21 $\times$ GEM1 $\times$ GEM2 divided by the double coincidence GEM1 $\times$ GEM2.

[a]GE1/1 and GE2/2 refer to two new CMS muon station disks located in the endcaps.

Fig. 3. Picture of the CMS GE2/1 sector with two M4 μRWell prototypes.

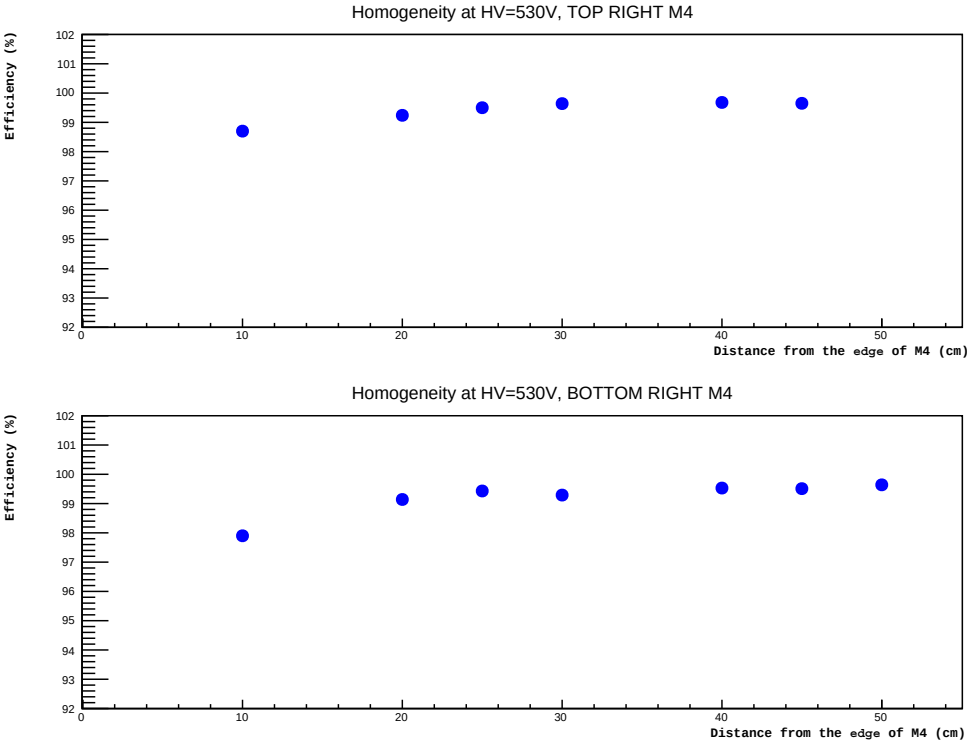


Fig. 4. GE2/1 efficiency across the whole surface of one M4 detector. Two horizontal scans were performed in two vertical positions separated by 20 cm in height. All points are within 98–99% efficiency providing an excellent uniformity.

An operating voltage of 530 V was chosen, that is, in the middle of the HV plateau. The nominal gain at this operating voltage is about 10,000. Two horizontal scans were then performed at this voltage across the whole surface of one M4 detector: the two scans were performed at two vertical positions separated by 20 cm in height, in order to illuminate the whole surface of the detector. Figure 4 shows the efficiency obtained in the various points of the two horizontal scans. All points are within 98–99% efficiency, therefore showing the excellent uniformity achieved by the detector over all its surface.

3. Conclusions

The next generation of experiments at future accelerators will need very large active area muon detection systems. A muon detection system has to efficiently identify muons, accurately measure their momentum and eventually provide a standalone muon trigger and bunch crossing identification, all this while operating in a rather hostile environment in terms of integrated radiation. The most suitable detectors to meet these stringent requirements and also keep a reasonable price tag are MPGDs. In particular, we have described an innovative type of MPGD, the μRWell detector, which possesses all the best characteristics and performances of these gas detectors, while simplifying further the manufacturing process. This simplified process is well suited to be transferred to industrial partners. This technology transfer will help to significantly reduce the cost of this device, making it extremely appealing also for other industrial applications beyond high-energy physics, like medical and homeland security applications, X-ray and neutron imaging.

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