# The micro-Resistive WELL detector for the phase 2 upgrade of the LHCb muon detector

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The LHCb experiment is a single-arm spectrometer dedicated to the study of the CP violation and other rare phenomena in the decay of Beauty particles. One of its feature is a fast and versatile trigger system to select the interesting events. The apparatus is designed like a fixed-target experiment due to the very forward peaked b-quark distribution at LHC.

It is composed of five systems: vertexing, tracking, ring cherenkov detectors, the calorimeters and the muon system.

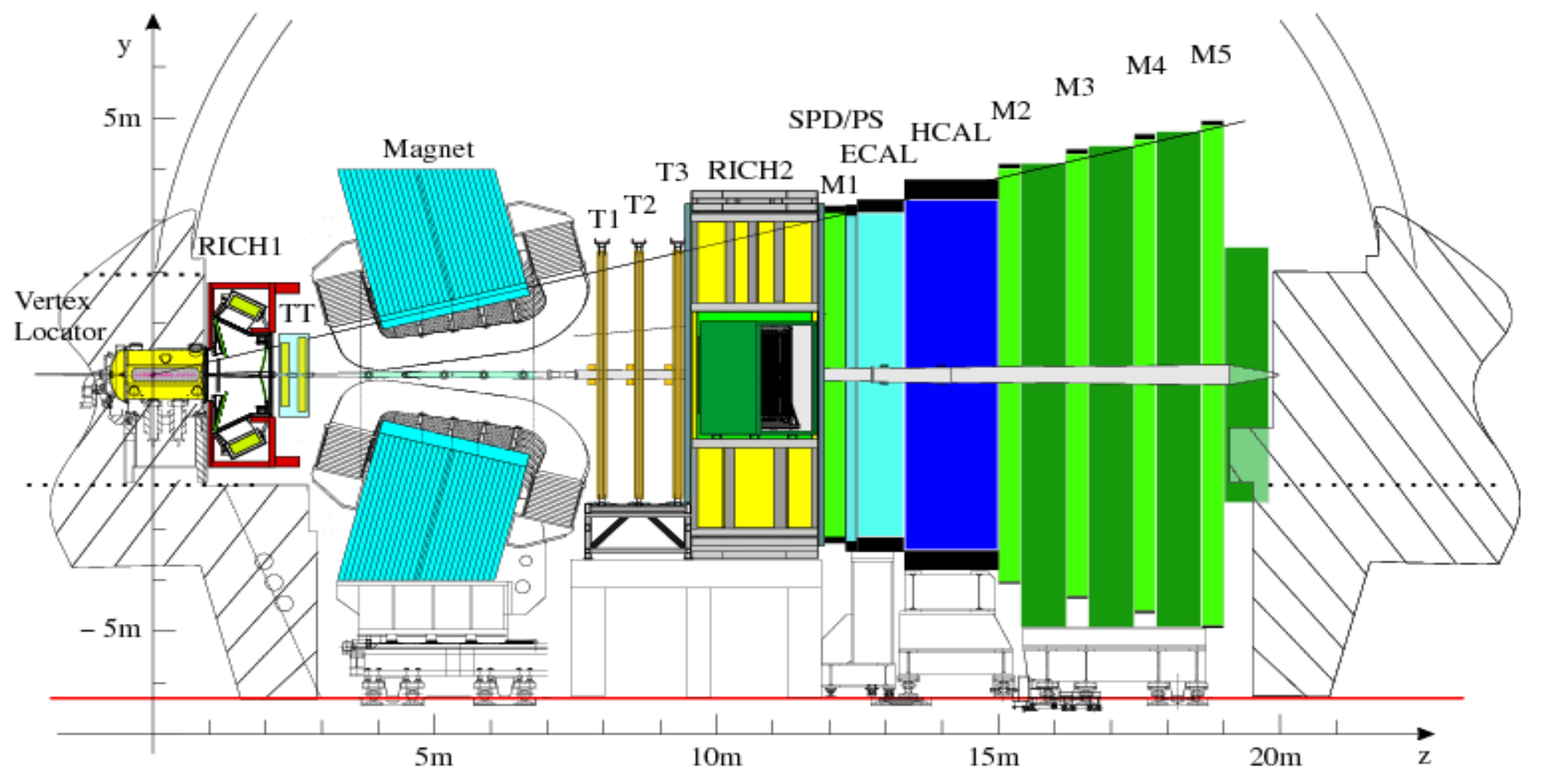
Up to the end of 2017 LHCb has recorded a total luminosity of 7 fb$^{-1}$ and in the next year, since LHC is going to increase its luminosity, the apparatus needs to upgrade its system.

For the first phase only the replacement of the FEE will be done.

For the phase 2, the detectors should show a rate capability up to 3 MHz/cm$^2$, an efficiency for single gap > 95% within 25 ns (BX), stability up to 6 C/cm$^2$ integrated charge in 10 y at G=4000.

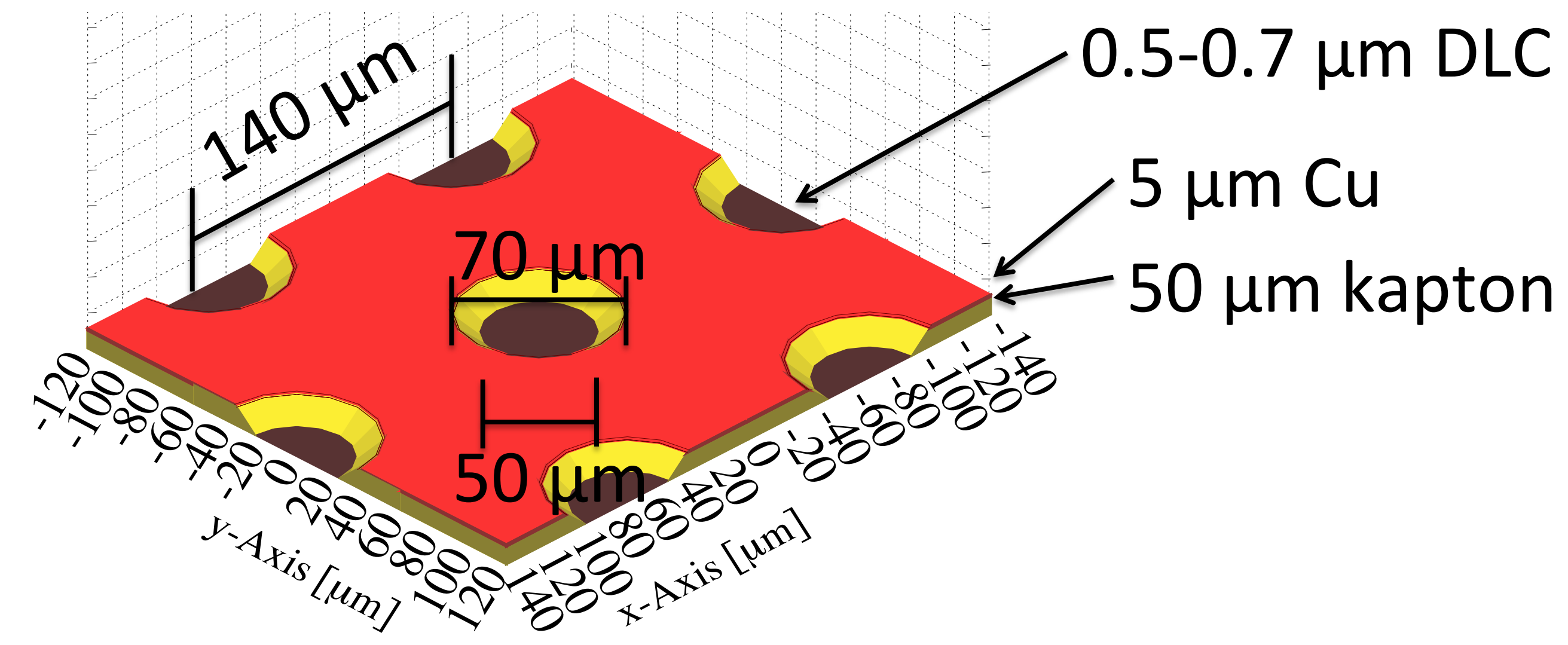
So we propose for this upgrade the micro-Resistive WELL.

| | Expected max rate MHz/cm2 | Active area cm2 | Pad Size cm2 | Rate/Pad MHz | # pad/gaps | # gaps | #chamber (2 gaps) |
|---|---|---|---|---|---|---|---|
| M2R1 | 3 | 30x25 | 0.63x0.77 | 1.5 | **1536** | **24** | 12 |
| M2R2 | 0.5 | 60x25 | 1.25x1.58 | 1 | **768** | **48** | 24 |
| M3R1 | 1 | 32.4x27 | 0.67x1.7 | 1 | **768** | **24** | 12 |
| M3R2 | 0.15 | 64.8x27 | 1.35x3.4 | 0.7 | **384** | **48** | 24 |

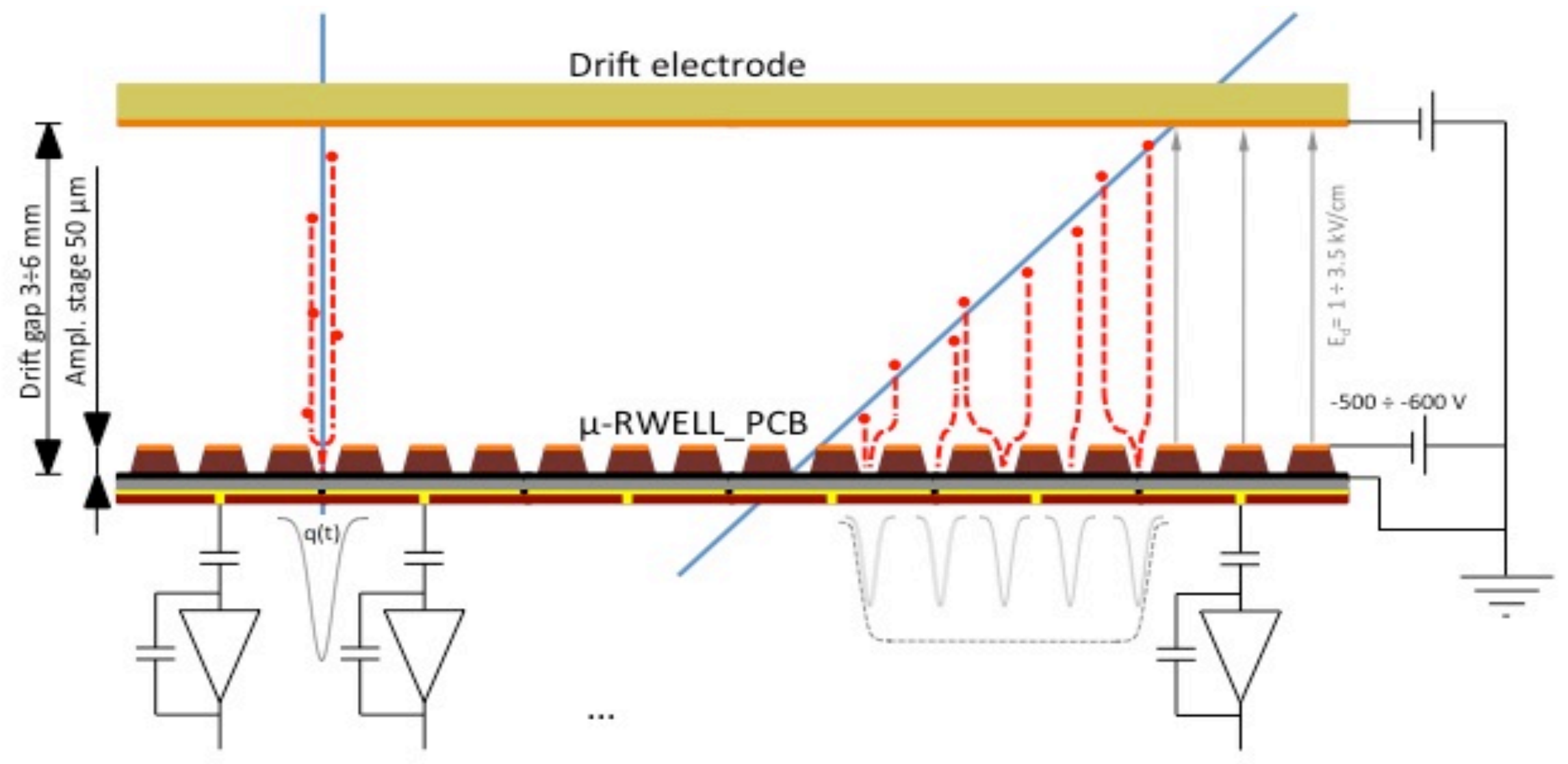


## The micro-Resistive WELL

**The µ-RWELL has been invented at LNF** with the aim to simplify the detector assembly, avoiding time consuming operations (i.e. epoxy curing cycle) and to improve the operation stability under heavy irradiation. The detector looks very compact and merges the features of two well-known MPGDs: it inherits from the GEM the amplification stage (50 µm Kapton® claded on one side with 5 µm Cu layer patterned with high density of holes) and from the MM the presence of a high resistive (10-200 MΩ/☐) layer (DLC- diamond like carbon) above the readout plane. This layer mitigates the passage to the streamer region due to the drop of the amplification field strongly quenching the amplitude of the sparks. The surface resistivity must be optimized since features like the rate capability, the response speed and the spatial resolution are strongly dependent on the chosen application (HEP, neutron or gamma detection).

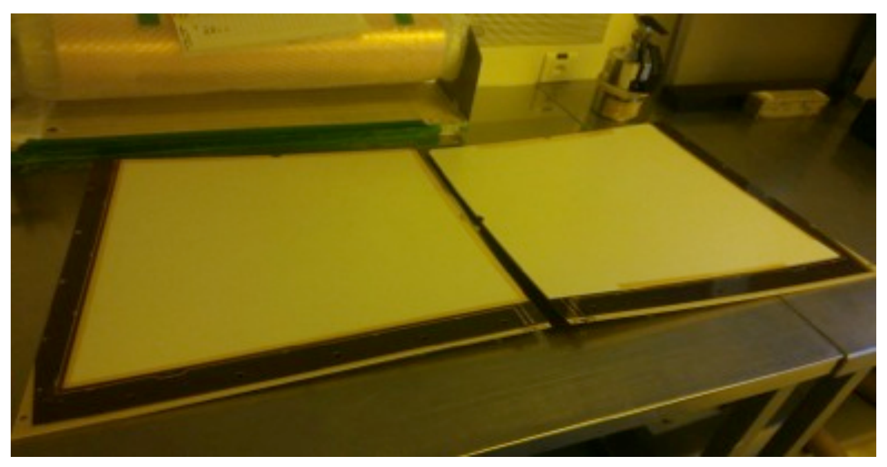


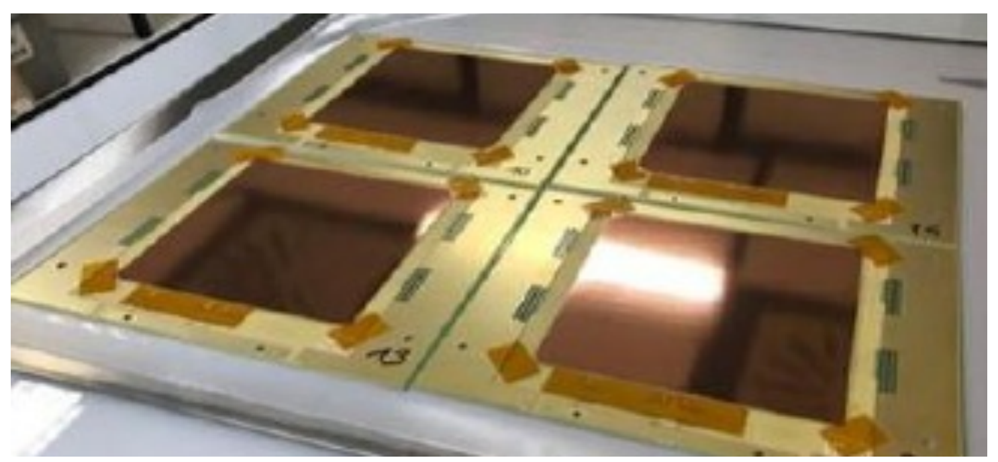
The detector is then completed with a cathode to define the gas conversion volume. The stack of the amplification stage with the resistive layer and the readout plane is called µ-RWELL_PCB



## The µ-RWELL and the TT

The realization of the µ-RWELL_PCB has been assigned to industry, with the aim to reduce the cost of the device. So far the very fruitful collaboration with the **ELTOS S.p.A** in San Zeno (AR, Italy) allowed the production of several µ-RWELL_PCB with 10x10 cm$^2$ active area as well as the production of large prototypes (about ¼ m$^2$) for a proposal for CMS. The DLC sputtering has been instead done at **Be-Sputter ltd** sited in Japan, while the chemical opening of the amplification channels (blind holes) is done at the **PCB-Workshop of CERN** (by one of the authors). A collaboration is ongoing also with **TECHTRA z.o.o.** (POLAND).

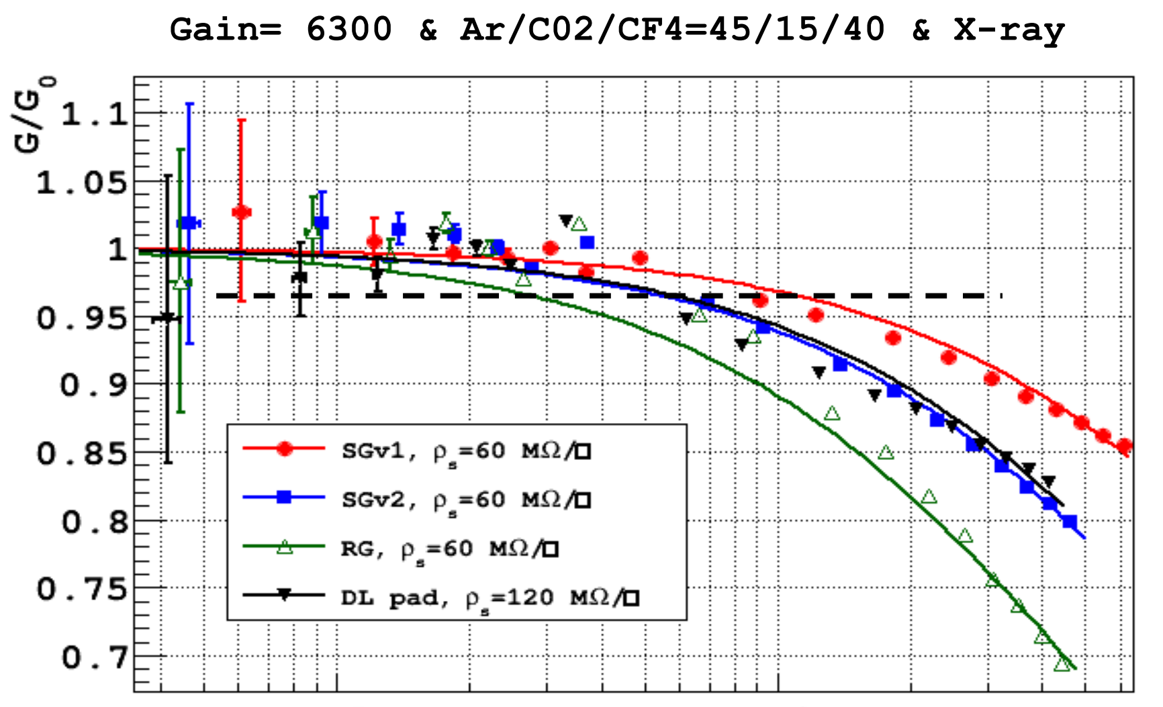

prototypes for CMS


prototypes for LHCb

## Different layouts, different applications

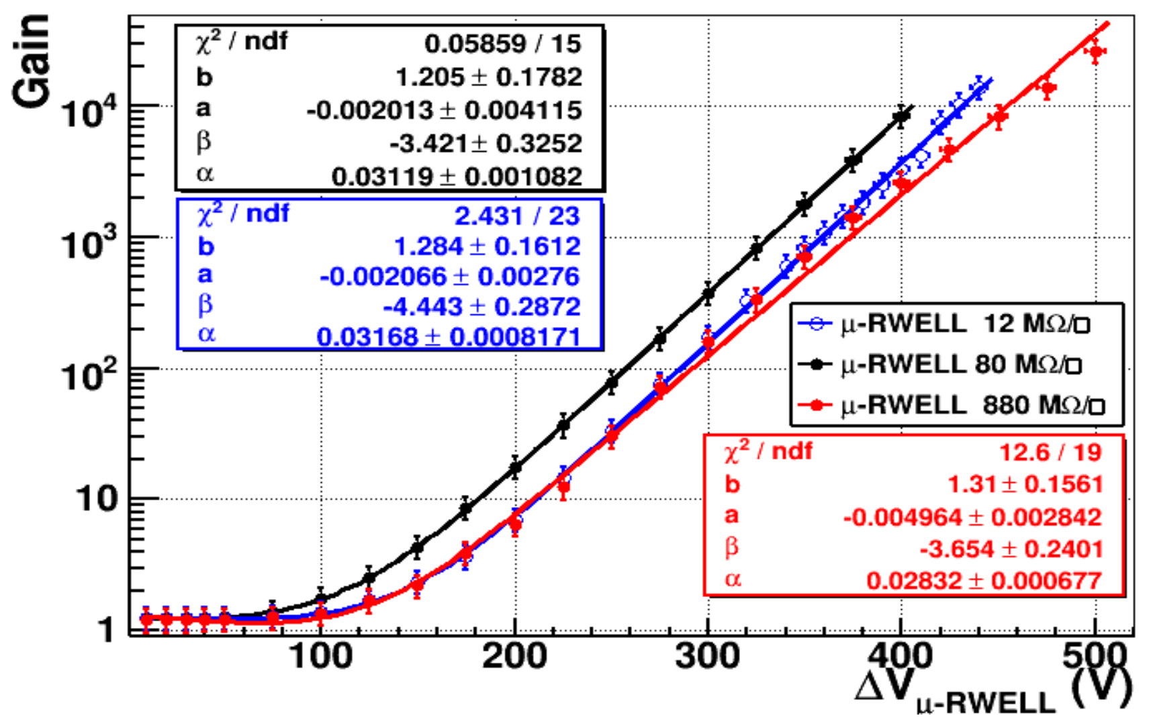
The presence of the resistive stage affects the detector rate capability since the resistive layer can be locally charged-up. For this reason different charge evacuation schemes on the resistive layer have been drawn, realized and tested in order to face up to 3 MHz/cm$^2$ rate without loosing efficiency.

| High rate scheme | Resistive layer | Pitch grid/ vias | Type | Dead/ Active area |
|---|---|---|---|---|
| Silver Grid 1 (SGv1) | single | 6 mm | Conductive grid | ~33% |
| Silver Grid 2 (SGv2) | single | 12 mm | Conductive grid | ~10% |
| Resistive Grid (RG) | single | 6 mm | Resistive grid | - |
| Double layer (DL) | double | 6 + 6 mm | Conductive vias | - |

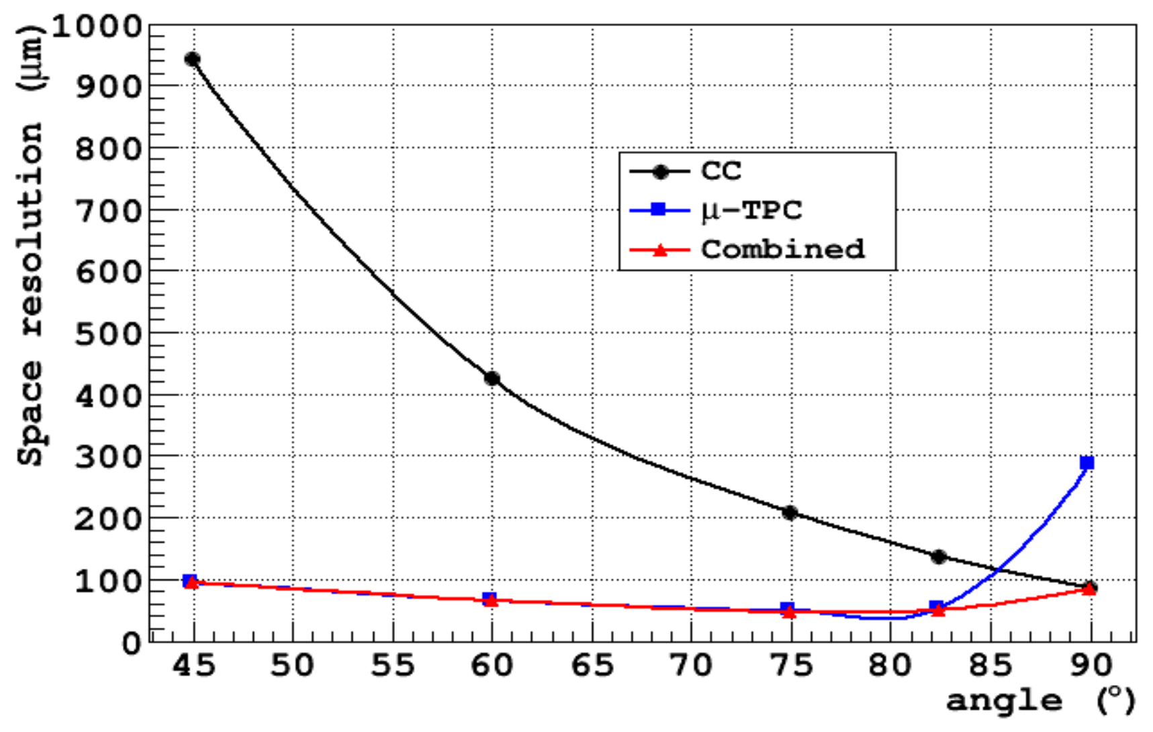


5.9 keV X-ray produces 7 times the primary ionization of a m.i.p.

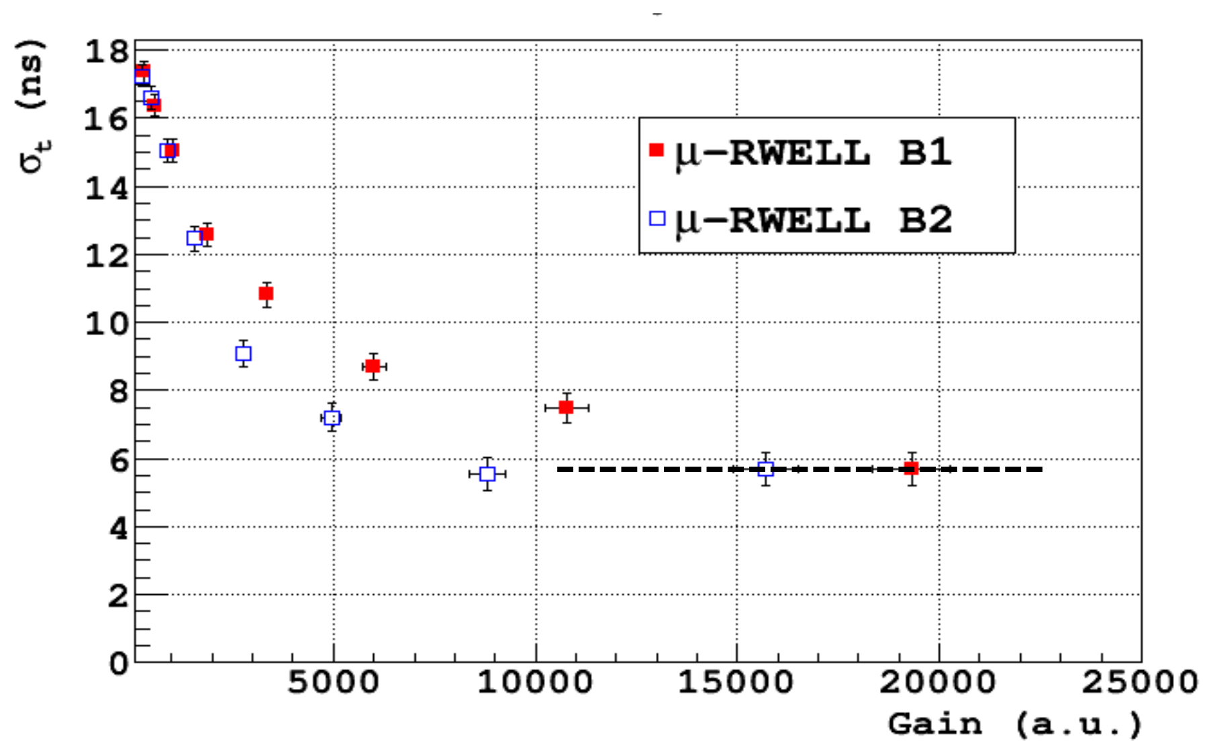
## Detector Performances



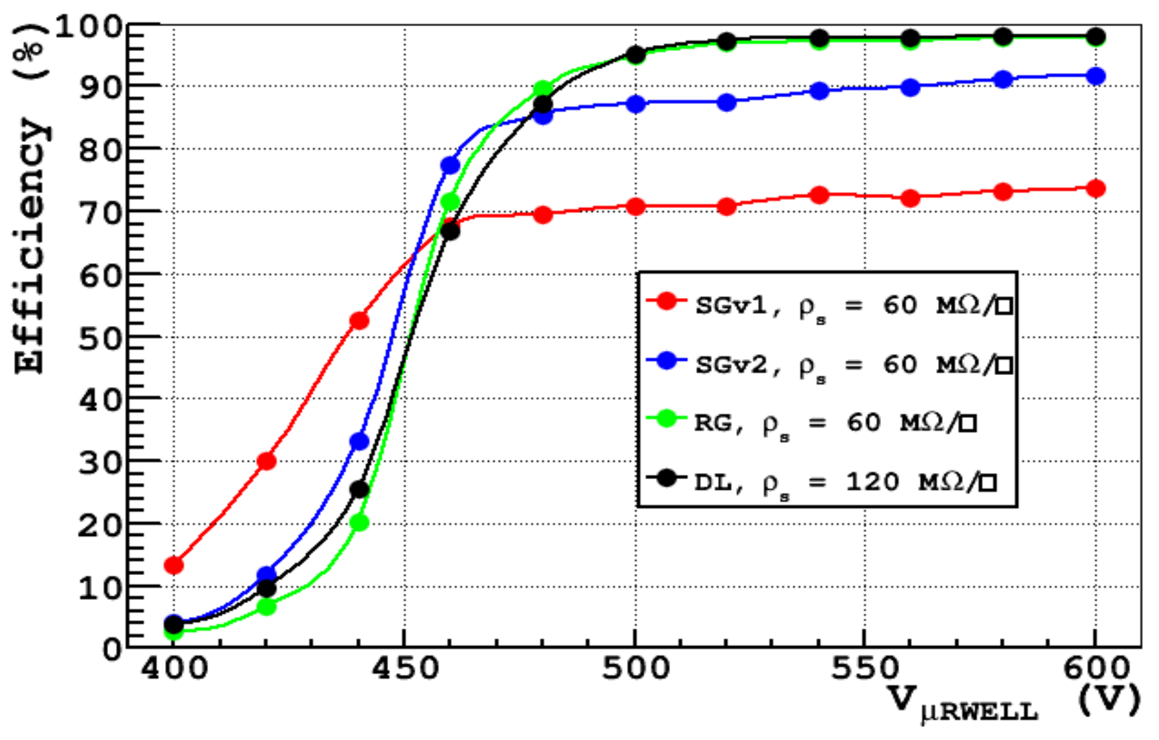
The gain is measured in current mode with a X-ray tube at LNF (Frascati). This measurement has been done for all the delivered prototypes and for different gas mixtures. The one reported here is with **Ar:iC$_4$H$_{10}$ 90:10**
**[G. Bencivenni et al., NIM A 886 (2018) 36]**



For non-orthogonal tracks the charge centroid (CC) algorithm provides a bad spatial resolution. This can be improved implementing the µ-TPC mode (NIM A 617) only possible with an analog FEE (in this case APV25, **Ar:CO$_2$:CF$_4$(45:15:40)**). **Thanks to G. Cibinetto, L. Lavezzi and R. Farinelli**



A time resolution of 5.7 ns has been measured with VFAT2 with **Ar:CO$_2$:CF$_4$(45:15:40)** dominated by the saturation of FEE. To be compared with the one measured with GEM by the LNF-LHCb-GEM group: 4.5 ns with VTX chip
**[G. Bencivenni et al., NIM A 494 (2002) 156]**



Efficiency with muon beam as a function of the voltage applied on the amplification stage. The SGv1 has a geometrical efficiency of 66%, the SGv2 of 90%. The larger exhibited efficiency is supposed to be due to a better (than expected) charge collection on the dead area as the gain increases.

## Conclusions and outlook

The µ-RWELL technology is very promising and its R&D is converging to a final resistive layout allowing to face up to **3 MHz/cm$^2$** (for LHCb purposes) limiting the efficiency losses. Its tracking performances, measured with the LHCb-GEM gas mixture, are very interesting: **98% efficiency fulfilled**, a **spatial resolution well below 100 µm** obtained merging the CC and µ-TPC algorithm, a **time resolution of 5.7 ns** with a FEE saturation effect. The cooperation with the companies (ELTOS, Be-Sputtering) is helping for a complete Technological Transfer of the different resistive layouts. Further optimizations must be done, addressed by the measurements with X-rays and with high intensity hadron beam.