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Towards a two-dimensional readout of the improved CMS Resistive Plate Chamber with a new front-end electronics

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Abstract: As part of the Compact Muon Solenoid experiment Phase-II upgrade program, new resistive plate chambers will be installed in the region at low angle with respect to the beam collision axis, in order to improve the detection of muons with a low transverse momentum. High background conditions are expected in this region during the high-luminosity phase of the Large Hadron Collider, therefore an improved-RPC design has been proposed with a new front-end electronics to sustain a higher particle rate capability and better time resolution. A new technology is used in the front-end electronics resulting in low achievable signal detection of 1–20 fC. Crucial in the design of the improved-RPC is the capability of a two-dimensional readout in order to improve the spatial resolution, mainly motivated by trigger requirements. In this work, the first performance results towards this two-dimensional readout are presented, based on data taken on a real-size prototype chamber with two embedded readout planes with orthogonal strips.

Keywords: Front-end electronics for detector readout; Gaseous detectors; Resistive-plate chambers; Radiation-hard detectors

Contents

1 Introduction

The first Resistive Plate Chambers (RPC) detectors [1] were developed for cosmic ray experiments, where low count rate capability, good time resolution and low cost per unit of area were needed. In order to serve as muon trigger at collider experiments like the Compact Muon Solenoid (CMS) [2], these same features are required, with the addition of high rate capability and good spatial resolution. The RPC system of the CMS experiment [3] at the CERN Large Hadron Collider (LHC), in figure 1 the CMS detector cross-section, has been designed to efficiently contribute to the muon trigger providing precise measurement of muon momentum and charge, track reconstruction up to a pseudo-rapidity $|\eta|$ of 1.9. The CMS muon system worked very well at the nominal luminosity of $2 \cdot 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ reached during the LHC Run I and Run II data taking [4, 5]. Due to the large background expected in the High Luminosity LHC (HL-LHC), the RPC detector system needs to be upgraded in order to achieve the spatial resolution imposed by trigger requirements and to increase its rate capability, so to be able to work efficiently in high rate environment. The RPC system upgrade will take place during the CMS Phase-II upgrade program [6]. The best way to improve the spatial resolution consists in developing a two-dimensional readout, while a high rate capability implies developing front-end (FE) electronics able to detect signals of the order of few hundreds μV, allowing a drastic reduction of the average charge per count [7]. In fact, the RPC rate capability is mainly limited by the current that can be driven by the high resistivity electrodes and can be improved by modifying the parameters which define the voltage drop on the electrodes. The possible ways to increase the detectable particle flux are:

- Decrease the electrode resistivity;
- Reduce the electrode thickness;
- Reduce the average charge per count.

The average charge per count reduction is the only viable solution to increase the rate capability while operating the detector at fixed current. As a consequence, a very sensitive FE electronics is required. An improved-RPC chamber has been designed by reducing the electrode and gas gap thickness. A full-size prototype of a double-gap improved-RPC chamber was built for testing purposes under high irradiation. Overall dimensions of the trapezoidal chamber are 58 (100) cm for the small (large) base with a length of 167 cm. The chamber has both a gas gap width and an electrode width of 1.4 mm and a resistivity of $0.9\text{–}3 \cdot 10^{10}\,\Omega\cdot$cm.

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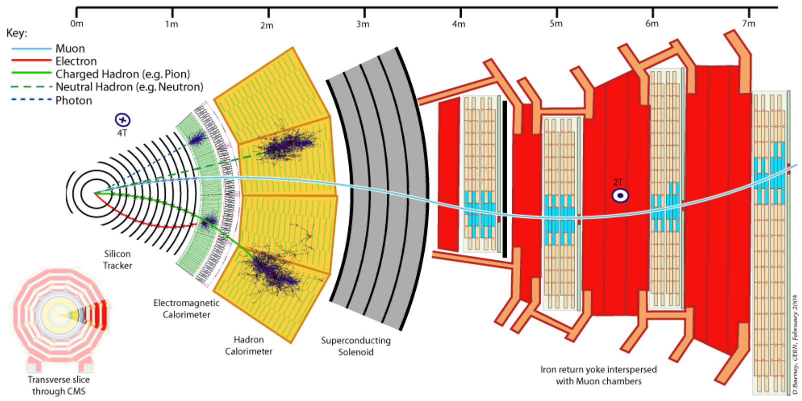

Figure 1. CMS detector cross-section.

A new front-end electronics developed by the INFN Rome Tor Vergata group has been integrated on the PCB strip plane, with the following characteristics [7]. Each FE board can read 8 channels and is equipped with 8 pre-amplifiers (amplification range 0.2–0.4 mV/fC) and 2 full-custom ASIC discriminators with 4 channels each. A pull-up system and LVDS transmitters are integrated inside the FEs. The FEs are directly soldered on the PCB strip plane to avoid any noise pick-up and the strips are properly terminated on the other end with a resistor. Typical thresholds of the order of 1–20 fC are achievable with the new electronics, resulting in a low charge avalanche operational regime of the RPC chamber, yielding a lower operational voltage, hence suppressing aging effects. The new front-end electronics is radiation-hard up to a total dose of $\sim$ 1 Mrad (equivalent to a Non Ionizing Energy Loss of 10^{13} n/cm^2) [7].

2 Experimental setup and analysis method

The improved-RPC prototype was tested at CERN with cosmic rays. The LVDS FE signals are read by a CAEN TDC module with a resolution of 100 ps. In all tests We used a threshold of 10 fC for the FE. For the longitudinal direction, the total number of strips connected was 16, of which 2 were noisy and one dead (all outside the trigger region). The noisy strips were neglected as located outside the trigger region and uncorrelated with the trigger. The strips width was not constant and varies in the range 0.5–1 cm, since the strips plane has the same chamber trapezoidal shape and the strips width scales with the trapezoid height. The longitudinal strips were positioned between the two gaps of the detector, therefore they were operating in double gap mode. For the orthogonal direction, the total number of strips connected was 10, of which 2, outside the trigger region, were noisy and have been neglected. In this case the strips were wider and its width was of 5 cm. The orthogonal strips were positioned upon the top gap, therefore they were operating in single gap mode. Data were taken in the overlap region between longitudinal and orthogonal strips, as indicated in figure 2.

Hits in the detector recorded by the TDC system are clustered under the following conditions: 1) strips should be adjacent, 2) clustering within a time interval of 10 ns. The presence of dead strips is neglected and does not disrupt the cluster formation, as all the neglected strips are outside of the trigger region, so the used strips for the tests are all adjacent. The time interval is defined

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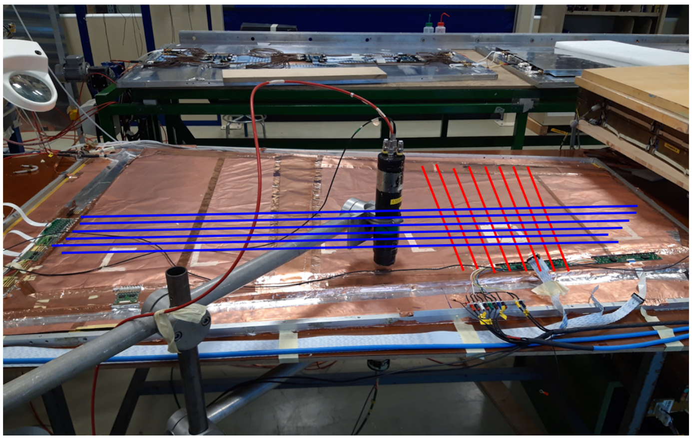

Figure 2. The real-size chamber used for the measurements. In blue (red) the orientation of the longitudinal (orthogonal) strips is shown. Measurements were taken in the strip overlap region.

considering the distribution of the cluster size at the working point as a function of the time interval to cluster hits. Such distribution reaches a plateau around 6 ns and the value of 10 ns at the center of the plateau has been defined as the time interval to cluster hits. The time interval definition is dominated by TDC trigger resolution, so it is not related to the physics of the detector (e.g. cross-talk of the strips), but to the instrumentation. The dark noise is evaluated considering a random trigger, i.e not a muon trigger but just a device random pulse, and for each random trigger a very long time window of 10 µs is considered. The dark noise appeared to be negligible. A systematic uncertainty is taken into account by varying the time interval with 10 ± 4 ns.

The detector efficiency is calculated as the ratio of the amount of hits in the detector over the amount of collected triggers, restricted to the muon time window. The efficiency is measured as a function of high voltage (HV) and in order to extract the necessary parameters, a sigmoid curve is fitted, defined as:

$$\epsilon = \frac{\epsilon_{\max}}{1 + e^{\lambda(\mathrm{HV}_{\mathrm{eff}} - \mathrm{HV}_{50\%})}}$$

where λ, $\mathrm{HV}_{\mathrm{eff}}$ and $\mathrm{HV}_{50\%}$ are respectively the slope of the curve, the effective high voltage corrected for pressure variations and the high voltage to which corresponds an efficiency of 50% of the maximum efficiency $\epsilon_{\max}$. The detector working point is defined as:

$$WP = \ln(19)/\lambda + \mathrm{HV}_{50\%} + 150\,\mathrm{V}$$

and is calculated imposing an efficiency of 95% of $\epsilon_{\max}$.

3 Results of two-dimensional measurements on real-size chamber

An extensive efficiency measurement campaign with 1-dimensional readout have been already performed [8] at the CERN gamma irradiation facility GIF++ [9]. The 1-dimensional measurement of cluster size and muon efficiency for longitudinal and orthogonal strips have been repeated for comparison and benchmark at the CERN-RPC facility with the new FE electronics, using cosmic rays.

Figure 3 shows the muon cluster size as a function of the effective high voltage $\mathrm{HV}_{\mathrm{eff}}$ for the longitudinal and the orthogonal strips, respectively. The smaller cluster size for the orthogonal

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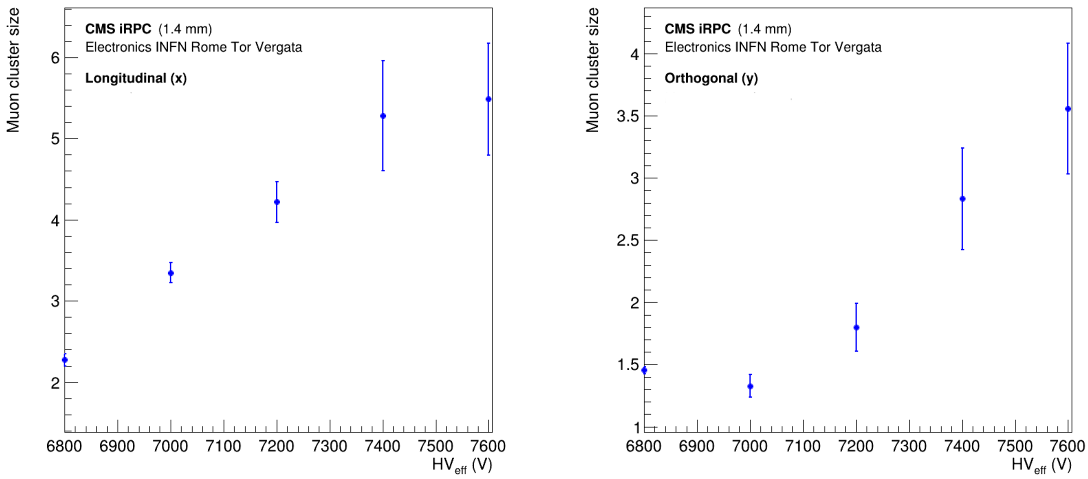

Figure 3. Muon cluster size as function of high voltage, on the left for the longitudinal direction and on the right for the othogonal one. The longitudinal (orthogonal) cluster size was measured in the region where the strip pitch is around 0.5 cm (5 cm).

strips is due to the larger width of the strips. The error becomes larger at higher voltages as more streamers are present, which cause the increase of hits close to the incident muon, resulting in the presence of separated fired strips in time, that leads to larger clusters. Figure 4 shows the muon efficiency for the orthogonal (right) and the longitudinal (left) strips. For the longitudinal strips, a working point of 7.1 kV is measured with an efficiency of 98.7%. For the orthogonal strips, a working point of 7.2 kV is measured with an efficiency of 97.1%. For the latter, a higher working point is expected as the orthogonal strips are on the outer plane of the double gap, therefore sensitive to the induction of charges in one gap. The orthogonal strips also present a lower efficiency due to the fact that the working regime is in single gap mode.

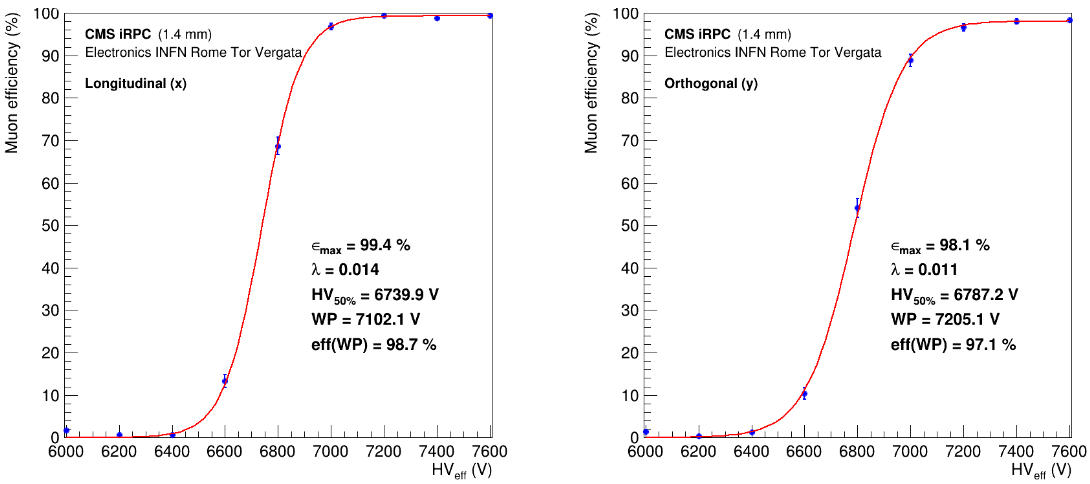

Figure 4. Muon efficiency for the orthogonal (right) and the longitudinal (left) strips, as a function of the high voltage.

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In figure 5 is shown the muon efficiency in two-dimensional mode, i.e. for the combination of the longitudinal and orthogonal strips, as function of high voltage. A hit in this configuration requires at least one strip fired simultaneously on both longitudinal and orthogonal direction. The maximum efficiency and working point are driven by the orthogonal strips parameters, working in single gap top mode. The combined efficiency at the working point does not indicate any substantial deterioration in two-dimensional configuration, as shown in figure 6.

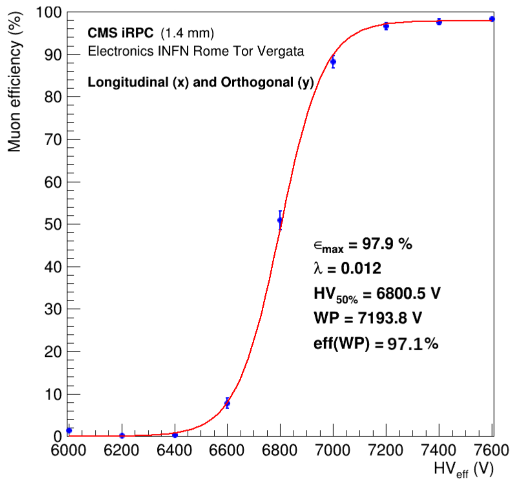

Figure 5. Muon efficiency for the combined longitudinal and orthogonal strips as a function of the high voltage.

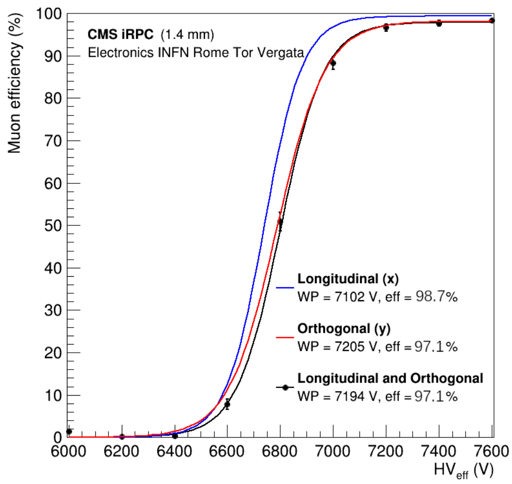

Figure 6. Muon efficiency curves comparison between the longitudinal (blue), orthogonal (red) and the combined two-dimensional efficiency (black).

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4 Conclusion

A real size improved-RPC 1.4 mm gap equipped with new front-end electronics developed at INFN Tor Vergata has been tested with cosmic rays.A combined two-dimensional configuration (Longitudinal + Orthogonal strips) have been considered and efficiency and cluster size measured as a function of the high voltage. The combined maximum efficiency at the working point does not exhibit signs of deterioration in the two-dimensional configuration. The results obtained so far show that the considered solution is a suitable upgrade for the RPC CMS detector upgrade with respect to the present RPC system, more studies at the CERN GIF++ irradiation facility are envisaged to complete the study.

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