High counting rate, two-dimensional position sensitive timing RPC

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ABSTRACT: Motivated by the requirements of the next generation experiments in terms of very good time and position resolution in high counting rate and multiplicity environment, a new architecture of differential, strip structure, symmetric, multi gap timing RPC was developed. The results on efficiency, time resolution, position resolution and performance in high counting rate environment using low resistivity glass electrodes are reported.

KEYWORDS: Gaseous detectors; Resistive-plate chambers

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1 Introduction

More than a decade ago, we proposed a novel concept of a multigap RPC (Resistive Plate Counter) which has a completely symmetric structure and is read out via multistrip anodes, similar to Pestov counters [1–4]. This new RPC configuration was adopted as a solution to upgrade the particle identification performance of the FOPI \((4\pi)\) experiment at SIS (Schwerionen Synchrotron) of GSI (Gesellschaft für Schwerionenforschung), Darmstadt. The readout electrode of the first prototype had 16 readout strips of 300 mm length with a pitch of 2.54 mm; the second one had an anode with 12 readout strips of 900 mm length with a pitch of 3.44 mm. During the preparation of the paper [3], where we reported a time resolution of 70-80 psec, \(\sim 95\%\) efficiency and a non-Gaussian tail of 1\%, we learned that Coimbra group has built and tested a detector of \(160 \times 10\) cm\(^2\) of similar structure with two anode strips of 50 mm width [5]. As a conceptual difference, our design is able to measure the position across the strips with an accuracy better than digital resolution given by the strip width. Following the first promising results, the intense R&D activities on both sides, detector [6] and front end electronics [7, 8] were finalized with the construction of the FOPI RPC TOF (Time-of-Flight) barrel [9, 10] successfully running in the last 4 years. The first large area multi gap timing RPC based on many wide strips (3.2 cm pitch) was developed for muons detection in extensive air showers, as well as for looking for unexpected cosmic events, within the EEE (Extreme Energy Events) Project [11].
Next generation experiments such as CBM (Compressed Baryonic Matter) \cite{12} at FAIR (Facility for Antiproton and Ion Research) aim to select rare probes in high multiplicity environment at collision rates up to $10^7$ events/sec. Hadron identification in such conditions is a real challenge requiring intensive R&D activities for developing very good time resolution, position resolution and high granularity detectors at reasonable cost. The low polar angles region of CBM-TOF detector will be exposed at counting rates of the order of $20$ kHz/cm$^2$. Being a fixed target experiment aiming to measure collisions up to Au+Au at 25 A·GeV the hit density varies from $6 \cdot 10^{-4}$/cm$^2$ at the outer regions to $10^{-2}$/cm$^2$ for the most inner zone of the detector. Therefore, an occupancy smaller than 5% requires very high granularity. Promising results in terms of performance of standard single ended strip structure RPC or differential architecture strip RPC based on low resistivity glass electrodes ($7 \times 10^9$ $\Omega$cm) of Pestov type were obtained already a few years ago \cite{13, 14}. The single-ended configuration showed a time resolution of $\sim 65$ ps under the conditions of a uniform exposure of the active area to a particle flux of about 1 kHz/cm$^2$. The differential readout configuration maintained a time resolution of $\sim 80$ ps up to 16 kHz/cm$^2$ counting rate.

In order to increase the granularity, the longitudinal strip architecture was replaced by a transverse strip architecture, the performance in terms of efficiency and time resolution being presented at the last RPC2010 Workshop \cite{15}. Based on these promising results new prototypes were developed; their constructive details and in-beam test results are presented in this paper.

2 Description of detector configuration

As it was mentioned in the introduction, we designed and built new RPC prototypes based on a complete symmetric architecture relative to median plane. This can be followed in the zoomed zone of figure 1. Among other advantages, such a structure allows to use lower absolute values of the applied voltages as far as this is applied on both, cathode and anode electrodes. The high
voltage and read-out electrodes have the same strip structure. The main construction details of the tested prototypes are described below.

2.1 Construction details of RPC prototypes with 2.54 mm strip pitch

The strip configuration was maintained the same as in the case of previous prototypes [15], i.e. 2.54 mm pitch, 1.1 mm strip width and 1.44 mm spacing between strips; the strip length was 46 mm. Three such prototypes were built. Each RPC prototype has 72 strips which define an active area of $46 \times 180 \text{ mm}^2$. The difference among them is the following: the RPC1 has the strip structured high voltage electrode in contact with a resistive layer deposited on the last float glass electrode while in case of RPC2 the strip structured high voltage electrode is in direct contact with the last float glass electrode. Both, RPC1 and RPC2, are based on float glass resistive electrodes of 0.55 mm thickness and have $2 \times 7$ $140 \mu$m gas gaps. RPC3 is based on low resistivity glass electrodes ($2.5 \times 10^{10} \Omega \text{cm}$) [16] of 0.7 mm thickness, $2 \times 5$ $140 \mu$m gas gaps, the high voltage electrode strips being in direct contact with the last glass electrode. Each of these RPC structures is housed in a gas-tight aluminium box as it can be followed in figure 3.

2.2 Construction details of RPCs prototypes with 7.11 mm strip pitch

As it will be seen in the next section, the results obtained with RPC1, RPC2 and RPC3 prototypes in terms of time resolution and position resolution along and across the strips are excellent. However, the number of channels required to equip the most forward polar angles of the CBM TOF Wall with RPC cells of this type is quite high ($\sim$ 140,000 electronic channels), with direct consequence on the cost. In order to reduce the cost, a new prototype (RPC4) was designed and built. The strip structure of the electrodes has 7.112 mm pitch (5.588 mm strip width and 1.524 mm space between strips) and 96 mm length. The RPC cell active area of $96 \times 280 \text{ mm}^2$ is covered by 40 strips.
Figure 3. CERN-PS in-beam position of the first three RPC prototypes.

Two such identical cells (RPC4a and RPC4b), based on low resistivity glass electrodes [16] of 0.7 mm thickness, $2 \times 5140 \mu m$ gas gaps were constructed. They were staggered having an overlap of 6 mm along the strips as is shown in figure 2 and introduced in the same tight gas box.

3 In-beam tests

Detailed tests done in laboratory in Bucharest showed a negligible noise and dark counting rate of all the prototypes described in the previous section. The dark current of the prototypes using low resistivity glass was lower than 1 nA up to the highest applied voltage ($2 \times 7.5$ kV for RPC1 and RPC2 and $2 \times 5.8$ kV for RPC3, RPC4a and RPC4b). In-beam tests of the counters described above were performed at CERN-PS and Jülich-COSY facilities.

3.1 CERN-PS beam test

The in-beam tests of the first three prototypes (RPC1, RPC2, RPC3) were performed at T10 beam line of CERN-PS, using a pion beam of 6 GeV/c. A photo of the in-beam experimental set-up is presented in figure 3. In order to estimate the position resolution along the strips, for some runs, one of the RPC was positioned orthogonal relative to the other two. With this geometry we were able to condition the position along the horizontal strips of the rotated RPC by requiring coincidence with the hits on the vertical strips of the non-rotated RPC, as it can be followed in figure 4. Signals delivered by the RPC strips at both ends were amplified and discriminated by differential front end electronics (FEE) based on NINO chips (ALICE-type) [17]. Time and Time-over-Threshold (ToT) signals from both sides of 15 strips of each counter were recorded.

Figure 4. A sketch of the intersecting fired strips in the situation when one of the RPC is rotated by 90°, horizontal strips, for position resolution measurement along the strip direction.

Two pairs of plastic scintillators, with $1 \times 1 \text{ cm}^2$ overlap, were used as active collimators and two plastic scintillators readout at both ends, ($2 \times 2 \text{ cm}^2$ overlap), were used as time reference. Two channels of each TDC were used for recording the signals of both ends of a reference plastic scintillator. Three different gas mixtures were tested, i.e. $85\% C_2F_4H_2 + 5\% SF_6 + 10\% iso-C_4H_{10}$, $90\% C_2F_4H_2 + 5\% SF_6 + 5\% iso-C_4H_{10}$ and $95\% C_2F_4H_2 + 5\% SF_6$. 
Figure 5. Efficiency for the three 2.54 mm strip pitch RPCs as a function of applied voltage

Figure 6. Cluster size for the three 2.54 mm strip pitch RPCs as a function of applied voltage

3.2 Jülich-COSY in-beam test

High counting rate tests were performed at Jülich-COSY with a proton beam of 2.5 GeV/c. The beam intensity was of $10^4 - 10^6$ protons/s. A new mother board version, with an 8 channel NINO chip bonded on it and housed by a front-end board designed in our group, was used as FEE for signal processing. This highly integrated front-end electronics was mounted on the back plane of the housing box. Signals from 64 strips readout at both ends were recorded. Beside the new RPC4 prototype (based on the two RPC cells of 7.112 mm strip pitch), in the beam line was installed also RPC3, used as time reference. The RPCs were flushed by $85\% C_2F_4H_2 + 10\% SF_6 + 5\% iso-C_4H_{10}$ gas mixture.

In both in-beam tests the LVDS-NINO outputs were sent to 32-channels V1290A CAEN TDCs. ToT information delivered by NINO chip was used for slewing correction and position information across the strips.

4 Experimental results

4.1 Detection efficiency and cluster size

The efficiency of each RPC is calculated as the number of events with hits with a valid time and ToT information at both ends of the operated strips divided by the number of triggers. The results are presented in figure 5. At lower voltages, before reaching the efficiency plateau, systematically RPC3 based on low resistivity glass ($2.5 \times 10^{10} \, \Omega \text{cm}$) has higher efficiency than RPC1 based on float glass ($4 \times 10^{12} \, \Omega \text{cm}$) with the strips of the high voltage electrode in contact with a resistive layer applied on the last glass electrode. RPC2, where the high voltage strips are in direct contact with the glass electrode, has the lowest efficiency. However, at 2.1 kV/gap all prototypes have an efficiency of $\sim 97\%$.

The cluster size as a function of applied voltage per gap is shown in figure 6 for the three RPCs. RPC2, in which the strips of the high voltage electrodes are in direct contact with the float glass electrodes, systematically shows a lower cluster size with about 0.25 strips. At $\sim 2.1 \, \text{kV/gap}$ where an efficiency large than 95% is reached, the cluster size is $\sim 3$ strips, i.e. 7.5 mm.
4.2 Time resolution

The time resolution was measured using the plastic scintillators as reference time or the time difference between two RPCs considering that they have the same time resolution. In figure 7 is presented the time resolution of RPC1 as a function of applied voltage, for three gas mixtures, using the plastic scintillator as reference time. The isobutane improves the time resolution by $\sim 15\%$, at 2.1 kV/gap the time resolution being better than 50 psec. This improvement could be explained by the higher primary ionization in isobutane. Figure 8, where the time resolution for different runs using the time difference between RPC3 and RPC2 is presented, confirms the previous result. Considering that the five runs were measured over a time period of 6 hours this result confirms the stability of the counters, gas flow and electronics.

4.3 Position resolution

As far as each strip is read-out at both ends, using the time difference one could access the position information along the strip. In order to extract the resolution, we selected the tracks collimated
within a strip pitch (2.54 mm) of the non-rotated RPC prototype, as it schematically presented in figure 4. The obtained position resolution along the strip direction is presented in figure 9 for two strips of the rotated RPC by 90° using the condition on 5 orthogonal strips of the reference counter. A position resolution of ~4.5 mm is obtained. The position information across strips was obtained using the runs where all three prototypes had the same orientation. In figure 10 is presented the result obtained for RPC3 using the residuals distribution relative to the track reconstructed using the position information of all three counters. The hit position in each counter was obtained using a Gaussian Pad Response Function. The position resolution depends on the type of glass and the way in which the high voltage is applied, i.e. directly on the glass electrodes or via a resistive layer. It ranges between 220 µm and 450 µm. The RPCs were operated at 2.1 kV/gap. As it can be seen in figure 10, RPC3 based on low resistivity glass electrodes has a position resolution across the strips of about 400 µm.

4.4 High counting rate performance

The counting rate performance of the 7.112 mm pitch prototype, based on two overlapping cells can be followed in figure 11. Figure 11 shows the time resolution obtained using the time difference between the overlapped zones of RPC4a and RPC4b - full triangles while by full dots is represented the efficiency using the RPC3 as reference counter. Even at 100,000 particles/cm²·sec, the time resolution remains better than 70 psec and the efficiency higher than 90%.

5 Conclusions

Based on the results presented in this contribution it can be concluded that differential, strip readout, multi gap timing RPC, based on low resistivity glass electrodes, is the way to go for high counting rate and high granularity TOF detector, required by the next generation experimental devices. Test for multi-hit performance and high counting rates all over the counter will be performed in the near future.
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