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In-beam test of the RPC architecture foreseen to be used for the CBM-TOF inner wall

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Abstract. The Time Of Flight (TOF) subsystem is one of the main detectors of the CBM experiment. The TOF wall in conjunction with Silicon Tracking System (STS) is foreseen to identify charged hadrons, i.e. pions, kaons and protons, with a full azimuthal coverage at 2.5^0 - 25^0 polar angles. A system time resolution of at least 80 ps, including all contributions, such as electronics jitter and the resolution of the time reference system, is required. Such a performance should be maintained up to a counting rate larger than 30 kHz/cm^2 at the most inner region of TOF wall.

Our R&D activity has been focused on the development of two-dimensional position sensitive Multi-gap Resistive Plate Counter (MRPC) prototypes for the forward region of the CBM-TOF subdetector, the most demanding zone in terms of granularity and counting rate.

The in-beam tests using secondary particles produced in 30 GeV/u Pb ion collisions on a Pb target at SPS - CERN aimed to test the performance of these prototypes in conditions similar to the ones expected at SIS100 at FAIR. The performance of the prototypes is studied in conditions of exposure of the whole active area of the chamber to high multiplicity of reaction products.

The results show that this type of MRPC fulfill the challenging requirements of the CBM-TOF wall. Therefore, such an architecture is recommended as basic solution for CBM-TOF inner zone.

1. Introduction
Compressed Baryonic Matter (CBM) experiment at Facility for Antiproton and Ion Research (FAIR) in Darmstadt is a fixed target experiment with the mission to investigate the high net-baryon density matter produced in nucleus-nucleus collision in an energy range between 2 - 11 GeV/u delivered by SIS100 accelerator. The CBM experiment is designed for precision measurements of multidimensional correlations among different observables including particles with very low production cross sections, hyperons, heavy flavor hadrons, hypernuclei and strange

objects, using the high-intensity heavy-ion beams provided by FAIR accelerators [1]. The beam extracted to the CBM cave will reach intensities up to 10^9 Au ions per second. The interaction rate will reach up to 10^7 reactions per second, with a charged particle multiplicity up to 1000 per event. In order to meet the challenging physics goal of measuring rare probes at such high interaction rate and multiplicity, the experimental set-up has to identify leptons and hadrons in a high counting rate environment. This requires fast and radiation hard detectors and front-end electronics, self triggered data acquisition and fast on-line event selection.

The Time Of Flight (TOF) subsystem is one of the core detectors of the CBM experiment. The TOF wall in conjunction with Silicon Tracking System (STS) is foreseen to identify charged hadrons, i.e. pions, kaons and protons, in the full acceptance of the system (the angular range covered by the STS detector of 2.5^0-25^0). It covers an active area of about 120 m^2 approximately rectangular in shape. A system time resolution of at least 80 ps including all possible contributions, such as electronics jitter and the resolution of the time reference system is needed [2]. Such a performance should be maintained up to a counting rate which, very close to the beam pipe, exceeds 30 kHz/cm^2 [2]. In order to fulfill these chalenging requirements at afordable costs, the CBM - TOF wall will be built based on state-of-the-art Multigap Resistive Plate Chambers (MRPC) [3].

2. A basic architecture for the inner zone of the CBM-TOF wall

Our R&D activity has been focused on the development of a Multi-Gap RPC with Multi-Strip readout (MSMGRPC) [4] for high counting rate and multiplicity environment, as it is anticipated for the inner zone of the CBM-TOF. Very good results in terms of efficiency, time and two-dimensional position resolutions were reported [5], for in-beam tests with minimum ionizing particles. Beased on these results we define a basic architecture of a module for CBM-TOF wall, assembling four MSMGRPC counters (strip pitch of 7.4 mm, 5.6 mm width and a strip length of 96 mm) in a staggered configuration on both x and y directions, in order to obtain a continuous coverage of the active area. Construction details of this basic architecture prototype (called further RPC2012) and its performance in the in-beam tests at CERN-PS accelerator using minimum ionizing particles and at CERN-SPS facility using reaction products produced by an Ar beam of 13 GeV/u on a Pb target, were reported in [6, 7]. The average cluster size was 1.6 strips per hit and the time resolution, including the electronics, was of ∼60 ps [7]. For the signal processing in the tests mentioned above, a front-end electronics (FEE) based on 8 channels NINO chip [8] was used.

In the present contribution are reported the results obtained using the RPC2012 prototype in a heavy-ion in-beam test performed at CERN-SPS accelerator, in conditions closer to those foreseen for SIS100. In this test the signals delivered by the MSMGRPC were processed by a the FEE developed for the CBM-TOF wall.

3. In-beam tests of the basic architecture prototype

The in-beam test was performed at CERN-SPS with reaction products resulted from 30 GeV/u Pb ions collided on a Pb target. The signals delivered by the four counters of RPC2012 were processed by a FEE based on a 32 channel motherboard [2] containing 4 PADI chips[10], the front-end electronics anticipated to be used for the CBM-TOF wall. The signals were digitized by 32-channel FPGA-TDCs [11] and readout via TRB3 [12] data hubs. A comprehensive description of the whole setup is given in [9]. The experimental set-up was positioned at a polar angle of about 3^0 relative to the beam axis. The RPC2012 prototype was 'sandwiched' between two MSMGRPC prototypes called RPC2015SS [15] and RPC2015DS [14] (SS- Single Sided, DS-Double-Sided), housed in RPC2015 box and the RPCref prototype [5], as is shown in Fig. 1. The time difference between one of the two diamond detectors positioned in front of the target and the RPCref positioned downstream, at 4 m distance from the target, was used for particle
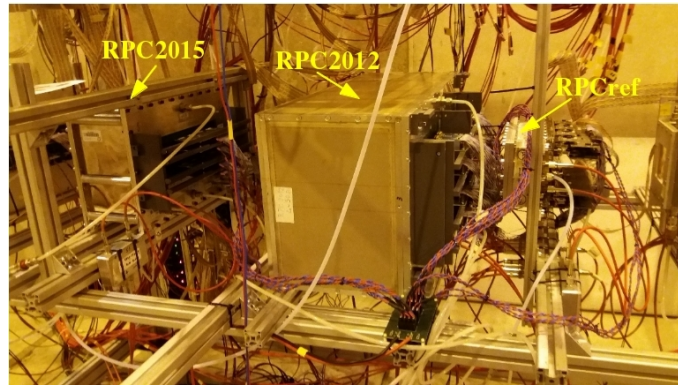
Figure 1. Photo of the experimental set-up based on MSMGRPC prototypes used in the in-beam test.

velocity correction. The relative spatial position of the seven MSMGRPCs and the operated
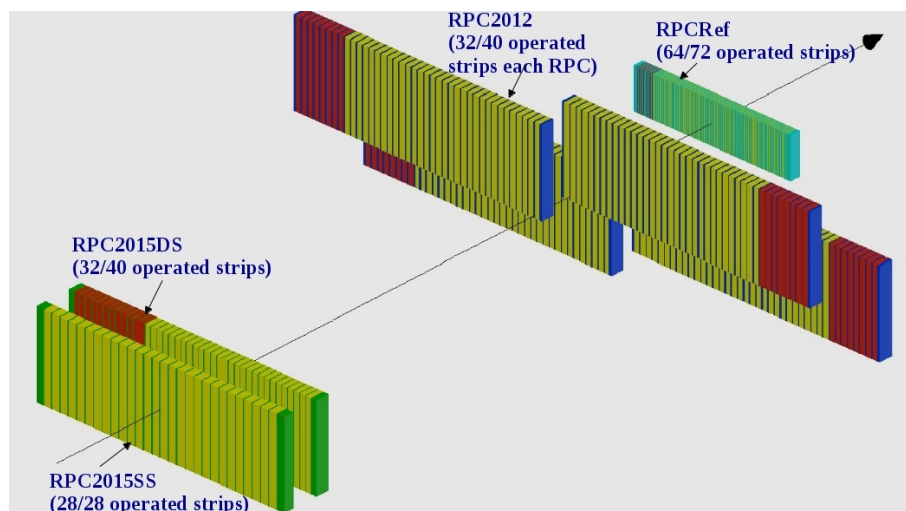
Figure 2. Sketch of the relative spatial positions of the seven MSMGRPCs in the experimental set-up at CERN-SPS.

area (green color) of each of them are presented in Fig. 2. One could observe in the figure that there is a partial overlap of the active area of each of the four RPC2012 counters, considered as detectors under study (DUT) with the the active area of DSRPC2015 positioned upstream, considered as reference (REF) counter for estimation of the time resolution and efficiency in the performed analysis.

4. Results
Details on the data analysis starting from unpacking to calibration and corrections for slewing effect, position and reaction product velocity spread, are described in [16]. In addition, due to the partial overlap of the active area between each DUT and REF, position cuts on both x and y directions were applied in the REF counter. In this way, hits which are focused on the middle of overlapped active area of both DUT and REF counters, were selected.

The efficiency is calculated as the ratio of the best matched hits between the diamond detector, RPC2015DS (REF), one of the RPC2012 (DUT) and RPCref, relative to the number

of hits when only diamond detector, RPC2015DS, and RPCref are present. The time of flight (TOF) spectrum is obtained as the difference of the times measured by the RPC2015DS and one of the RPC2012 counters. The system time resolution (the contributions of both RPC2015DS and one of the RPC2012 counter) is defined by the standard deviation σ of the Gauss function fitted to the TOF distribution.

With the aim to reach steady-state operating conditions for studying the working curve of the RPC2012 detectors, they were operated for about 8 hours with the same parameters: applied high voltage corresponding to 157 kV/cm electric field in the gas gap and 205 mV threshold set to the FEE. The detector performance was monitored over this period in terms of efficiency and time resolution and a clear conditioning effect was evidenced. Through this conditioning effect, the resistive electrodes reach a steady state potential and the microimpurities accidentally existing inside the detector are burned out. As it is shown in Fig. 3, the efficiency does not change during conditioning period while a slight improvement in the time resolution is observed.
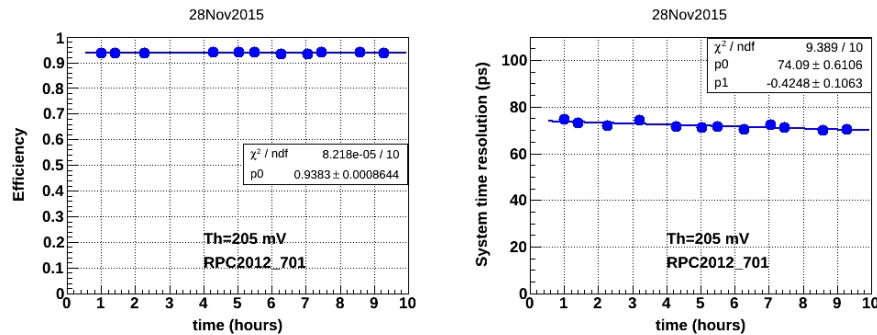
Figure 3. Efficiency - left and time resolution - right as a function of time for 157 kV/cm electric field and 205 mV FEE threshold. The statistical errors are within the marker size.

In the left side of Fig. 4 is presented the time difference spectrum between one of the four counters positioned in the upper, left side of the text box (called RPC2012_1) and RPC2015DS (see reference [14, 13]), with the same inner geometry and the same strip pitch. The 63 ps
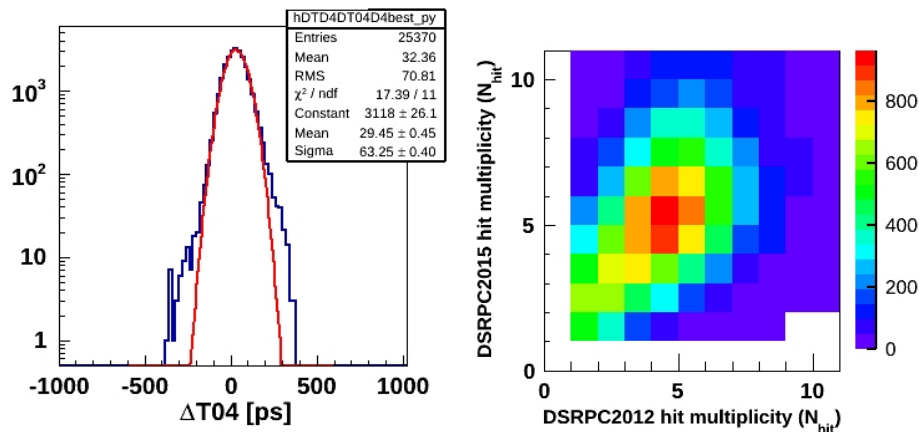
Figure 4. Time difference spectrum - left (Statistical errors are within the marker size). Hit multiplicity correlation - right.

standard deviation (σ) of the Gauss fit demonstrates the very good system time resolution. A

single counter time resolution of 44 ps, including the electronic contribution is obtained supposing equal contributions of the two detectors. The comparison of the 63 ps standard deviation with the 71 ps RMS of the spectrum shows a non-significant contribution of the non-Gaussian tails, estimated to be of 2.8% in a $\pm(3 \cdot \sigma)$. The correlation of the hit multiplicities in the two counters (Fig. 3 - right) shows that almost the same number of hits are simultaneously incident on both detectors. The detectors were operated at 2 x 5.5 kV voltage (157 kV/cm electric field).
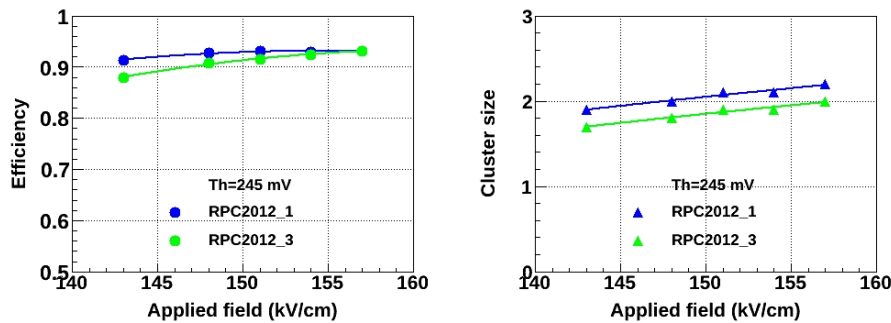
Figure 5. Efficiency - left (statistical errors are within the marker size) and cluster size - right as a function of high voltage for RPC2012_1 and RPC2012_3.

The expected behaviour of the efficiency and cluster size as a function of high voltage for RPC2012_3 and RPC2012_1 (upper - right side relative to the axis shown in Fig.2), for a PADI threshold of 245 mV can be followed in Fig.5. In the mentioned geometry of the experiment, a 93% efficiency for both counters was obtained. Due to their staggered positions, position cuts on both x and y directions were applied in the RPC2015DS, considered as reference counter, for efficiency estimation. However, due to a partial overlap of the active area of each of the four counters relative to the RPC2015DS, the obtained values are still affected by the hits lost at the edges of the overlapped area. The average cluster size was found to be 2.2 strips for RPC2012_1 and 2.0 strips for RPC2012_3 in the region of efficiency plateau. Average system time resolution of 73 ps for RPC2012_1 and of 67 ps for RPC2012_3 remains almost unchanged over the investigated high voltage range, as it is shown in Fig. 6. The detector performance stability
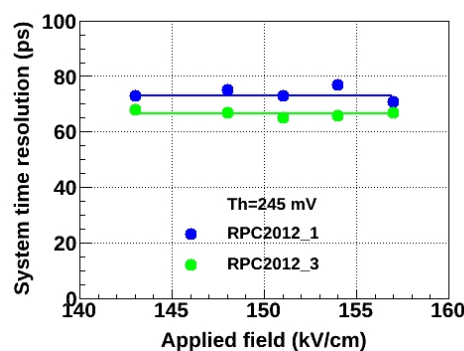
Figure 6. Time resolution as a function of high voltage for RPC2012_1 and RPC2012_3. Statistical errors are within the marker size.

was checked for a period of operation of about 15 hours with the same settings (157 kV/cm) for both DUT and REF counters.
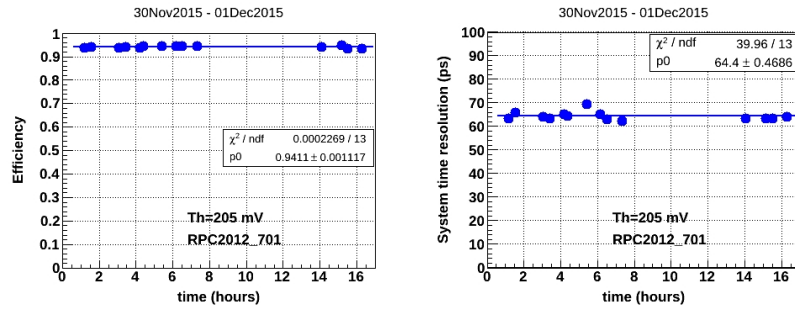
Figure 7. RPC2012_1 performance during 15 hours operation (the high voltage and threshold settings were the same for the entire period). Statistical errors are within the marker size.

The stability of the detector performance is demonstrated by the plots presented in Fig. 7 and Fig. 8. The average efficiency of 94% and a time resolution better than 70 ps remains constant over the entire measurement period of about 15 hours. This demonstrates that the performance of the detector remanains unchanged over the whole period in which the counters were exposed to the reaction products, about two weeks of in-beam test.
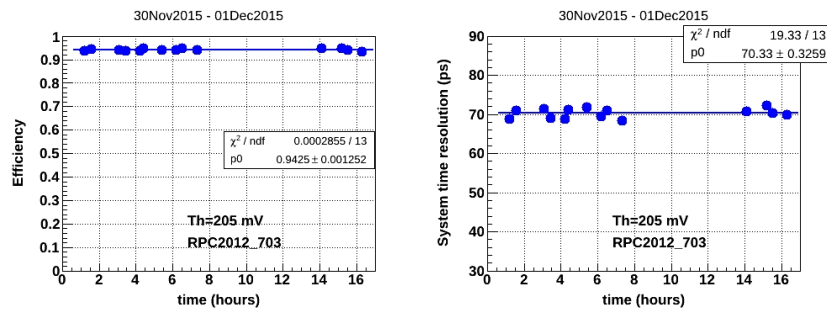
Figure 8. RPC2012_3 performance during 15 hours operation (the high voltage and threshold settings were the same for the entire period). Statistical errors are within the marker size.

5. Conclusions

The results presented in this contribution show that the MSMGRPC prototypes and the proposed basic architecture fulfill the performance requirements for the inner zone of the CBM-TOF wall. The proposed geometry will be implemented in the architecture of the modules designed for the region of low-polar angles of the CBM-TOF wall.

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