

# Towards the construction of the inner zone of the CBM-TOF wall

**M. Petriș\*, D. Bartoș, V. Duță, M. Petrovici, L. Rădulescu, V. Simion**

National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest-Magurele,  
P.O.Box MG-6, RO-077125, Romania

**J. Frühauf**

Gesellschaft für Schwerionenforschung, Darmstadt, Germany

**I. Deppner, N. Herrmann**

Physikalisches Institut, University of Heidelberg, Germany

E-mail: \* mpetris@nipne.ro

**Abstract.** The Time-of-Flight (TOF) subsystem, one of the core detectors of the CBM experiment, is dedicated to the identification of all charged hadrons produced in beam-target interaction. The targeted system time resolution of 80 ps and an efficiency above 90% should be maintained at a particle flux up to 30 kHz/cm<sup>2</sup> in the region of low polar angles. In order to cope with these challenging requirements, CBM-TOF wall will be equipped with Multi-Gap Resistive Plate Counters with Multi-Strip readout (MSMGRPC).

Our R&D activity has been focused on the development of a MSMGRPC prototype for the most demanding region of the CBM-TOF wall, the region of low polar angles (from 2.5° to ~12° around the beam pipe). The results obtained in heavy ion in-beam tests have demonstrated the performances of the developed prototypes in conditions of exposure of the whole active area to high flux and high multiplicity reaction products. The latest developed prototypes have an optimized design which fulfills simultaneously two important requirements for MSMGRPCs, the granularity for the inner zone of the CBM-TOF subdetector and the impedance matching to the front-end electronics. Based on the obtained in-beam test results and the architecture of the developed prototypes, a modular structure of 12 units called modules is proposed. A total number of 470 MSMGRPCs (~30000 readout channels) assures an uniform coverage of the active area.

## 1. Introduction

The Compressed Baryonic Matter (CBM) experiment, one of the four major scientific pillars of the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, is aiming to investigate the QCD phase diagram at large baryon densities [1], in heavy ion collisions at interaction rates up to 10 MHz, (2 - 11A GeV Au+Au collisions).

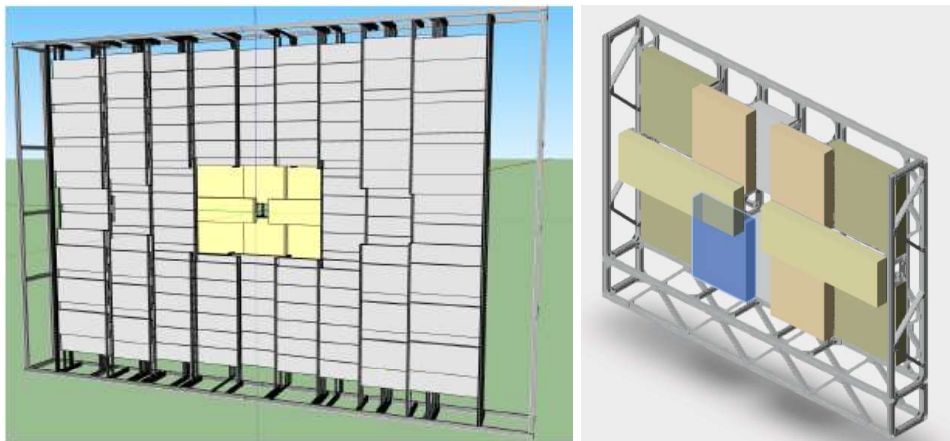
The Time-of-Flight (TOF) system, one of the core detectors of the CBM experiment is dedicated to the identification of charged hadrons produced in this fix target experiment. The targeted system time resolution of 80 ps and an efficiency above 90% should be maintained



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up to  $30 \text{ kHz/cm}^2$  particle flux anticipated in the region of low polar angles [2, 3]. In order to cope with these challenging requirements, the  $120 \text{ m}^2$  area of the CBM-TOF wall (Fig 1), covering a polar angle aperture between  $2.5^\circ$  -  $25^\circ$ , will be equipped with multi-gap resistive plate counters [4] with multi-strip readout [5], installed in basic units called modules. Taking into consideration the desired occupancy of less than 5% over the whole area of the CBM-TOF wall, the detector granularity scales with the track density which drops from low to large polar angles.

Our R&D activity has been focused on the development of a Multi-Strip Multi-Gap Resistive Plate Counter (MSMGRPC) prototype for the most demanding region of the CBM-TOF wall in terms of counting rate and hit multiplicity. This region called inner zone (shown in yellow in Fig. 1) covers polar angles between  $2.5^\circ$  and  $12^\circ$ . It is a high rate region where the particle flux varies from  $30 \text{ kHz/cm}^2$  to  $5 \text{ kHz/cm}^2$ .



**Figure 1.** Modular structure the CBM-TOF wall; inner zone - yellow collar - left. Exploded view of the modular structure of the inner zone - right.

The results obtained with the developed prototypes in the in-beam tests performed at international accelerator facilities demonstrated the detector performances in conditions of exposure to high flux and high multiplicity reaction products [6, 7].

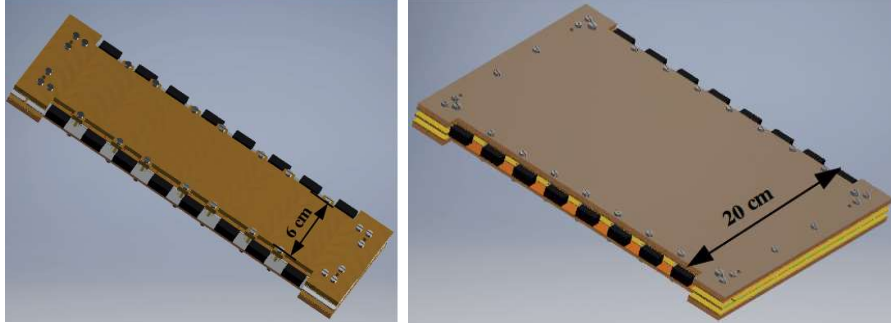
In order to cope with the very high interaction rates, CBM detectors will be operated by a free-streaming data acquisition system, i.e. the signals passing the electronic threshold will be digitized, time stamped and processed. In this continuous readout mode operation, in order to avoid a large amount of data from possible fake signals produced by reflections, an impedance matching is mandatory. Therefore, in order to fulfill simultaneously the granularity and impedance matching requirements, an innovative method [8] was applied for the optimization of the MSMGRPC design.

Based on the architecture and performance of the developed prototypes [6, 7, 9], a modular structure of the inner zone was developed (see Fig. 1 - right). In the proposed design, an uniform coverage of the  $14 \text{ m}^2$  active area of the CBM-TOF inner zone is performed with a total of 470 MSMGRPCs installed in 12 modules. Details on the type of the counters and the modules which will to be used to equip the CBM-TOF inner zone are presented.

## 2. MSMGRPCs for the inner zone

Taking into account the decrease of the granularity (see Sect. 1) with increasing polar angle, the baseline design of the inner zone is subdivided in three granularity regions foreseen to be

equipped with three types of MSMGRPCs: MRPC1a from  $2.5^0$  to  $\sim 5^0$ , MRPC1b from  $\sim 5^0$  to  $\sim 8^0$  and MRPC1c from  $\sim 8^0$  to  $\sim 12^0$

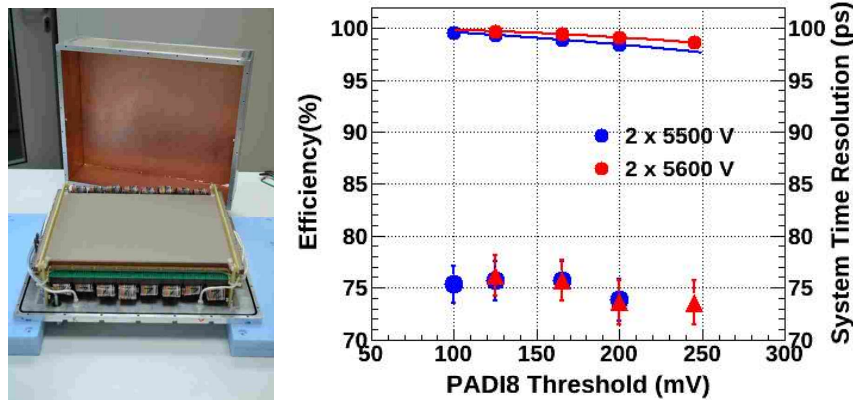


**Figure 2.** The 6 cm (MRPC1a, left) and 20 cm (MRPC1c, right) strip length MSMGRPC for the inner zone.

All three types of MSMGRPCs have the same inner geometry [9]: two symmetric stacks of resistive electrodes ( $2 \times 6$  plates) separated by  $140 \mu\text{m}$  gas gaps ( $2 \times 5$  gaps). In order to cope with the high particle flux, the resistive electrodes are made of a special low resistivity glass, with an average resistivity of  $1.5 \times 10^{10} \Omega\text{cm}$  [10]. The readout and high voltage (HV) electrodes have a strip structure, the 30 cm length of the counter (limited by the maximum available size of the low resistivity glass) being covered by 32 strips of 0.902 cm pitch. However, based on the innovative method described in [8], the width of the high voltage strip (7.36 mm) differs from the one of the readout strip (1.27 mm), the granularity of the detector being defined by the HV electrode structure while the transmission line impedance is adjusted by the width of the readout strip. Therefore, the counters differ only by their strip length: 6 cm (Fig.2-left) (MRPC1a), 10 cm (MRPC1b) and 20 cm (Fig.2-right) (MRPC1c).

### 2.1. MSMGRPC prototypes for the inner zone

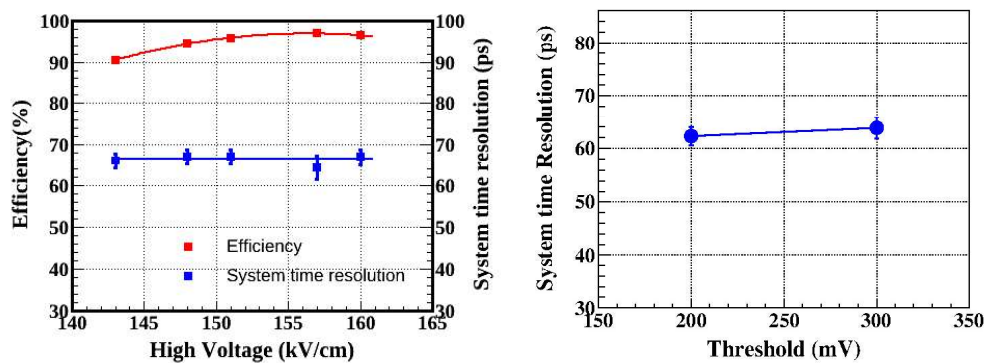
During our R&D activity we covered all three types of MSMGRPCs mentioned above. The developed prototypes were designed, assembled and tested in real operation conditions at different accelerator facilities.



**Figure 3.** The prototype with 20 cm strip length - left. The efficiency and time resolution as a function of FEE threshold, for two applied high voltages - right.

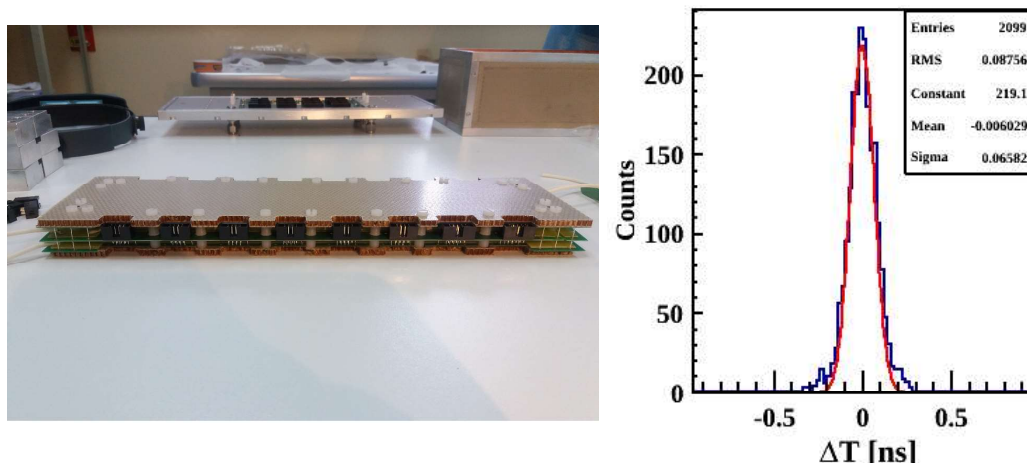
A prototype with 20 cm strip length (Fig. 3 - left) was tested at SIS18 facility of GSI

Darmstadt with reaction produced by a 1.1A GeV Sm beam on a Pb target. Its performance in terms of system time resolution (contains the contribution of both reference counter (REF) and detector under study (DUT)) and efficiency as a function of the front-end electronics (FEE) threshold [12], is shown in Fig. 3 - right [7].



**Figure 4.** Results obtained with 10 cm strip length prototype. Efficiency and time resolution as a function applied high voltages in a triggered readout - left. Time resolution as a function of FEE threshold in a free streaming readout - right.

A 10 cm strip length prototype operated in a triggered mode was tested at CERN-SPS accelerator with 30A GeV Pb beam incident on a Pb target. A very good system time resolution of  $66 \text{ ps} \pm 2 \text{ ps}$  and an efficiency of 97% at the operation plateau (Fig. 4 - left) was obtained [9]. If we suppose equal contributions of DUT and REF to the system time resolution, a single counter time resolution is  $\sim 47 \text{ ps}$ . Using a free streaming readout in the in-beam tests at CERN-SPS accelerator (30/150A GeV Pb beam incident on a Pb target) the performance was confirmed as it is shown in Fig. 4 - right [13]. A single counter time resolution of 45 ps was estimated, while the slight lower efficiency of 93% is under investigation.



**Figure 5.** The prototype with 6 cm strip length - left. Time difference spectrum measured between two identical prototypes - right.

The last developed prototype, the one of 6 cm strip length corresponding to the highest granularity of the CBM-TOF wall, is shown in Fig. 5-left. Two identical such MSMGRPCs were

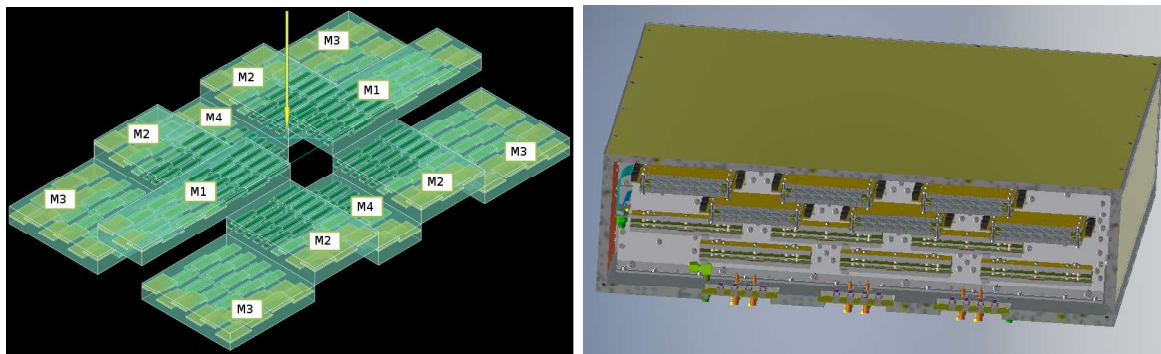
tested with a 1.6A GeV Ag beam incident on a Au target in a dedicated CBM test setup called mCBM [14], installed at SIS18 of GSI Darmstadt.

The signals delivered by the detectors were processed by a free streaming readout system, similar with the readout system which will be used in the CBM experiment. Similar very good performance of  $66 \text{ ps} \pm 3 \text{ ps}$  system time resolution ( $46 \text{ ps}$  single counter time resolution) (Fig.5-right), including electronic chain contribution was obtained.

All the above discussed prototypes have an  $100 \Omega$  characteristic impedance of the signal transmission line matched to the input of the front-end electronics.

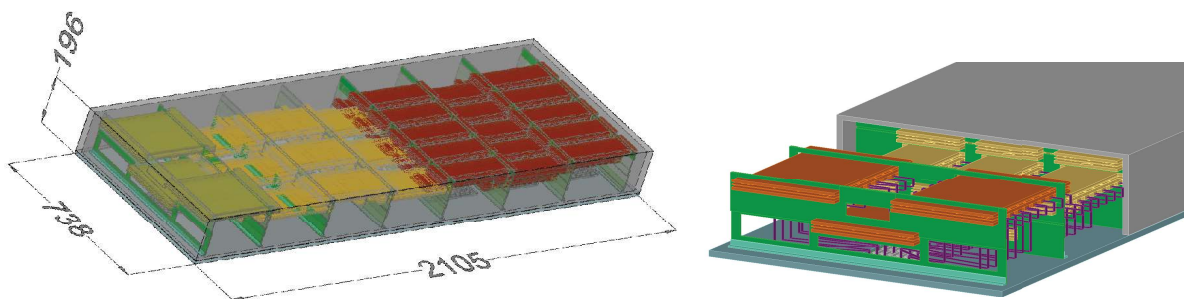
### 3. Inner zone modules

Based on the obtained results and the architecture of the MSMGRPCs discussed above, we designed a modular configuration for the inner zone of the CBM-TOF wall, organized in twelve modules of four types (M1, M2, M3, M4) as it is shown in Fig.6 - left.



**Figure 6.** Modular configuration of the CBM-TOF inner zone - left side. 3D view of a module architecture - right.

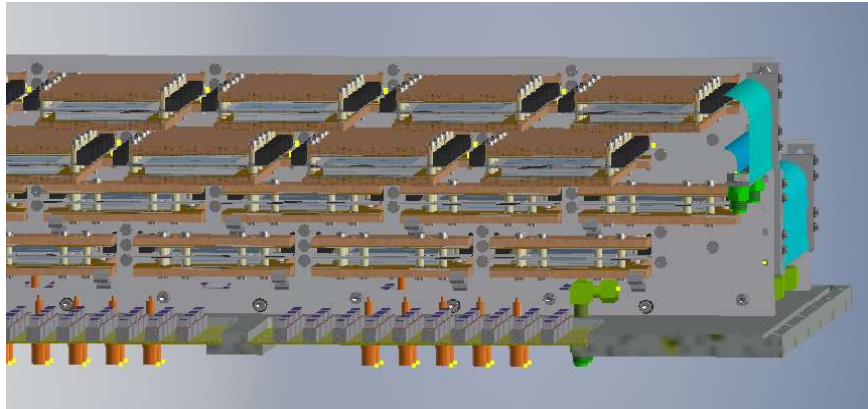
A module is an independent unit composed from a housing box which contains MSMGRPCs mounted in a staggered geometry (Fig.6 - right) using a complex system of mechanical supports. For an uniform coverage of the active area of the inner zone, the neighboring counters and modules overlap in space. The design of the inner zone was made with the lowest possible overlap between the counters, as well as between the modules, in order to minimize the number of readout channels.



**Figure 7.** Module M1: 30 MRPC1a (red), 18 MRPC2a (yellow), 3 MRPC1c (green) - left. Mechanical supports (light green) and signal cables (dark blue) in module M1.

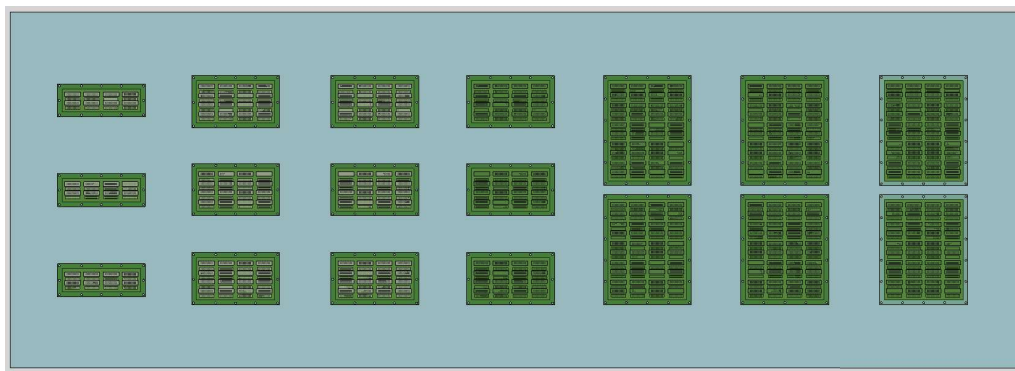
The basic geometry of a module is a rectangular box closed by a back panel. Except the back panel, the walls of the gas tight box are made of a light composite material, a Nomex honeycomb

structure sandwiched between two very thin glass fiber epoxy laminate sheets. The inner sides of the walls are covered by a thin Cu plate for electromagnetic screening. The back panel is made of an Al plate of 12 mm thickness, carrying on the front-end electronic cards mounted on external mechanical supports and all the services, i.e. high voltage and gas connectors. As an example,



**Figure 8.** Gas deflector (blue color - right side of the module) mounted in the module. The gas connectors are shown in green color and the high voltage connectors in brick-red color.

in Fig.7 the design of the module M1 with 210.5 cm length, 73.8 cm width and 19.6 cm height is presented. It contains 51 MSMGRPCs of all three types: 30 MRPC1a, 18 MRPC1b and 3 MRPC1c staggered on four layers in order to provide the necessary overlap for a continuous coverage of the active area. The counters are fixed in precise mechanical positions by a complex mechanical supports network (green in Fig. 7-right) organized in eight rows. The signal delivered by the MSMGRPCs were transported to the connectors of the back panel through twisted pair cables (dark blue in Fig. 7-right) with 100  $\Omega$  characteristic impedance.



**Figure 9.** Front view of the back pannel of the module, with the connector boards glued on the milled rectangular openings.

The gas mixture which will be used in the operation of these detectors consists of 85%  $C_2H_2F_4$ , 5%  $C_2H_{10}$  and 10%  $SF_6$  flushed at normal pressure and temperature. Due to the high particle flux on the counters of the CBM-TOF inner zone, a faster refreshing of the gas mixture in the 140  $\mu m$  gas gaps is needed. In order to assure this fast gas exchange, a gas deflector (Fig. 8 - blue color) which conduct the gas toward each of the four levels on which the counters are staggered was implemented in the module design.

The 3264 signals delivered by the 51 MSMGRPCs are transmitted to the input of the front-end electronics through printed circuit boards (PCBs) with connectors on both sides, glued on the corresponding openings milled on the back panel of the module.

There are eighteen such connector boards, as it is shown in Fig. 9. Six of them (right side of the figure), distributed on two rows, with the largest number and density of connectors, correspond to the area equipped with MRPC1a. The nine middle ones (three rows on three columns) are used for connecting the signals delivered by the MSMGRPC1b and the last three boards (one row, one column) transmit the signals delivered by the MSMGRPC1c counters.

The active area of inner zone is covered by 2 M1, 4 M2, 4 M3 and 2 M4 modules which contain 220 MRPC1a, 164 MRPC1b and 86 MRPC1c leading to a total of 470 counters and 30080 readout channels.

#### 4. Conclusions

The developed MSMGRPC prototypes showing a very good performance in the in-beam tests performed at different accelerator facilities, are recommended to equip the inner zone of the CBM-TOF subsystem. A modular design for the CBM-TOF inner zone was performed in such a way to obtain a continuous active area.

#### 5. Acknowledgements

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