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Radiation hard ceramic RPC development

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Abstract. We report recent advances in R&D on the Beam Fragmentation and T0 Counter (BFTC) for the CBM experiment, based on RPCs with floating electrodes made of resistive ceramic material. An optimal value of the ceramics bulk resistivity has been determined to be about $5{\cdot}10^9$ Ω·cm. RPCs with such electrodes show even characteristics and stable operation under particle fluxes of up to 150 kHz/cm^2, with the detection efficiency above 90%.

1. Beam Fragmentation T0 Counter

The future CBM experiment at FAIR [1] will have to tolerate the interaction rates of up to 10 MHz, produced in the fixed target by a beam of heavy ions with the intensity of 10^9 ions/sec. The Time-of-Flight (TOF) detector is the key particle identification system of the experiment. For precise operation it requires a reference time T0 referring to the moment when incident ions interact with the target. In fixed target experiments, positioning the TOF system elements at very small angles relative to the beam line, gives a way to detect particles in the forward region. Assuming that the majority of these particles travel along straight trajectories with almost the speed of light, T0 can be calculated by the TOF system on the fly [2]. In peripheral and semi-central collisions this task is suggested to be carried out by the Beam Fragmentation T0 Counter (BFTC) assembled of Resistive Plate Chambers (RPC) with ceramic electrodes. A detailed description of the detector may be found in [3]. BFTC, meant to be operated in a harsh environment, with particle fluxes of more than 150 kHz/cm^2, must be built of radiation-hard materials. Figure 1 shows simulated particle fluxes on the TOF wall in the CBM experiment, generated by SHEILD for Au–Au collisions at 10 and 25 A GeV. More details about the TOF wall occupancies in the CBM experiment can be found at [4].

2. Beam tests of ceramic RPCs

Since BFTC must provide both high counting rate and fine time resolution, the bulk resistivity of floating RPC electrodes needs to be compromised: it should be low enough to keep RPC efficient at high counting rates, and high enough to suppress the streamer formation in the gas volume under high electric field. To optimize resistivity, several RPC samples with the bulk resistivity of the floating electrodes varying between 10^8 and 10^{10} Ω·cm, were produced. The samples were then assembled into a mini-module of 8 chambers and placed into a single gas volume, as shown in figure 2.

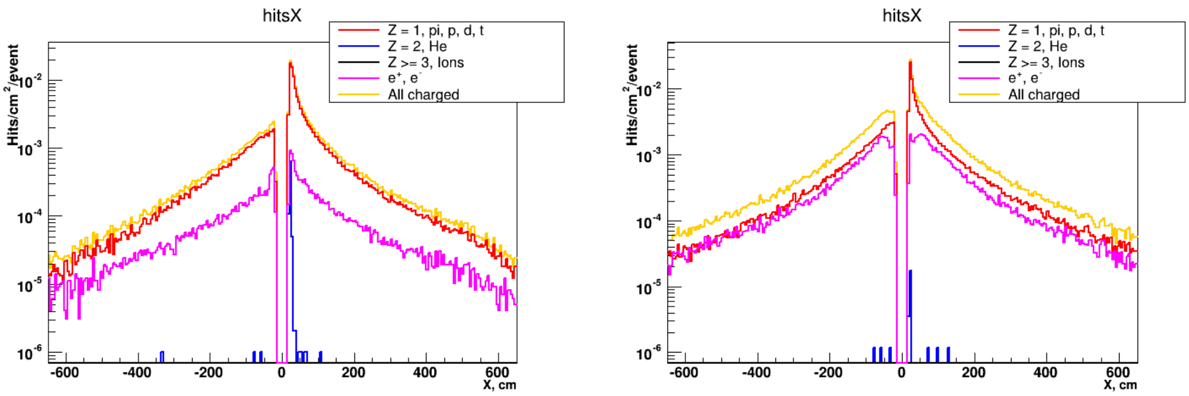

Figure 1. Flux of charged particles at the TOF plane positioned 6 m (left) and 10 m (right) away from the target in the CBM experiment. The events were generated by SHIELD generator at 10 (left) and 25 (right) AGeV. Middle region along the X axis is shown, with |y| < 10 cm and centre of coordinates in the beam-pipe centre.

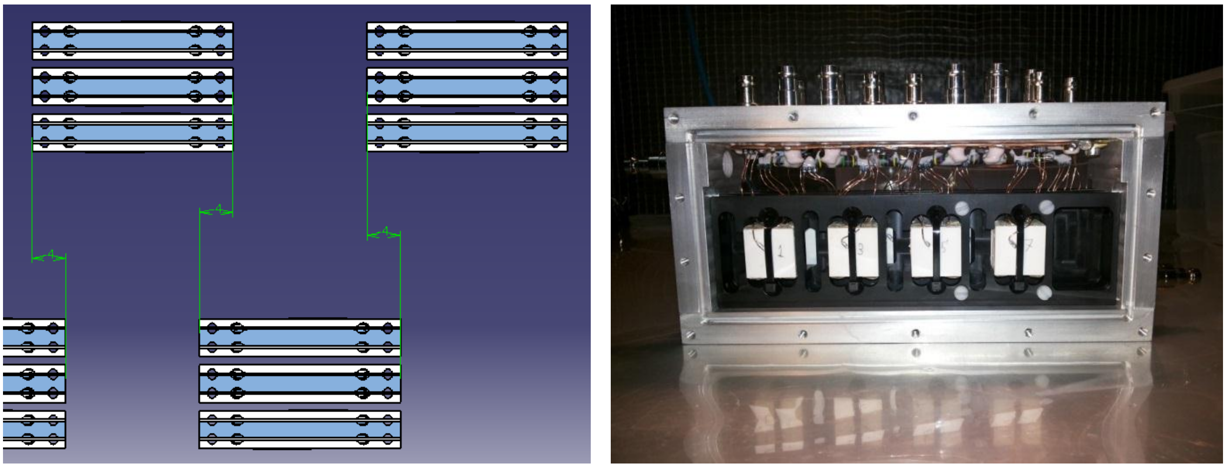

Figure 2. The mini-module (right) and the scheme of detecting cells position (left).

Ceramic RPCs were tested at two beam facilities: ELBE at Helmholtz-Zentrum Dresden-Rossendorf, Germany (HZDR), and PS at CERN. ELBE provides an electron beam of 30 MeV, with the possibility to vary particle fluxes in the range between few Hz/cm^2 and 1 MHz/cm^2. An independent time reference is provided by the accelerator RF. A downside of this facility is a high scattering of soft electrons on detector materials that increases the RPC inefficiency and makes its properties dependent on the geometrical position. To minimize these effects, two narrow triggering counters, operated in coincidence, were installed in front and behind RPCs. Alternatively, PS at CERN provides a 5 GeV hadron (π^-) beam with no possibility to increase the particle flux over 20 kHz/cm^2. All measurements involved the use of MAXIM 3760 preamplifier along with CAEN TDC and ADC to make the results comparable with those obtained during R&D for ALICE TOF [5, 6].

Working curves representing observed dependence of the RPC efficiency on the value of electric field in the gas volume are shown in figure 3. Chambers with the electrode bulk resistivity of the order of 10^9 Ω·cm proved to have a wide operational plateau spreading up to the electric field of 92 kV/cm, while keeping the streamer probability below 3%. RPCs with the bulk resistivity of the order of 10^8 Ω·cm do not show any plateau, with the currents going as high as 0.5–1 µA already at 86 kV/cm.

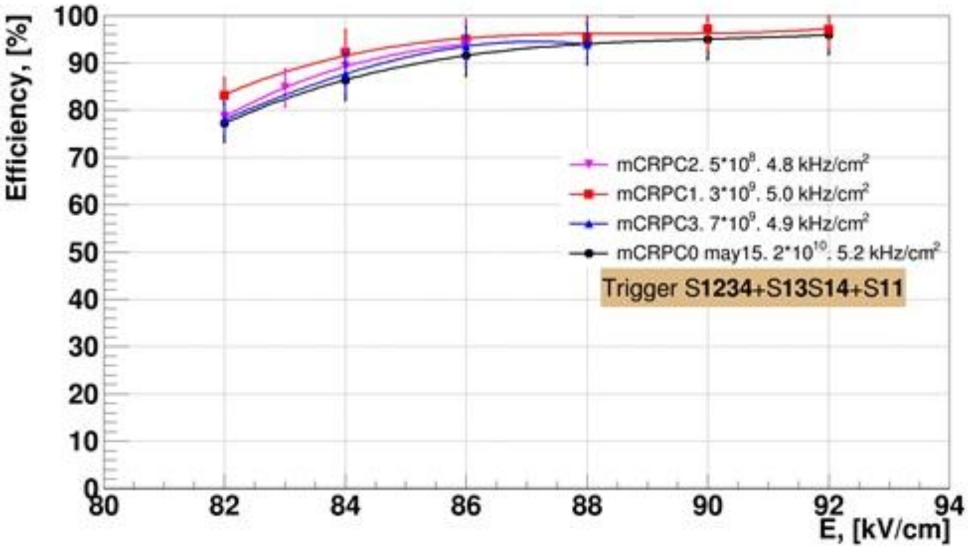

Figure 3. Working curve measured at the particle flux of about 5 kHz/cm^2. Lines connecting points are guide to the eyes only.

Rate scans represented in figure 4 show the dependence of RPC efficiency on the particle flux at a fixed value of the electric field, chosen at the very beginning of the working plateau, and same to all chamber samples. The bulk resistivity of over $6 \cdot 10^9$ Ω·cm proved to be too high for the particle fluxes of over 80 kHz/cm^2, as the corresponding efficiency drops below 90%. On the other hand, the bulk resistivity below $3 \cdot 10^9$ Ω·cm cannot provide sufficient quenching, due to a significant excess leakage current in the chambers at high rates.

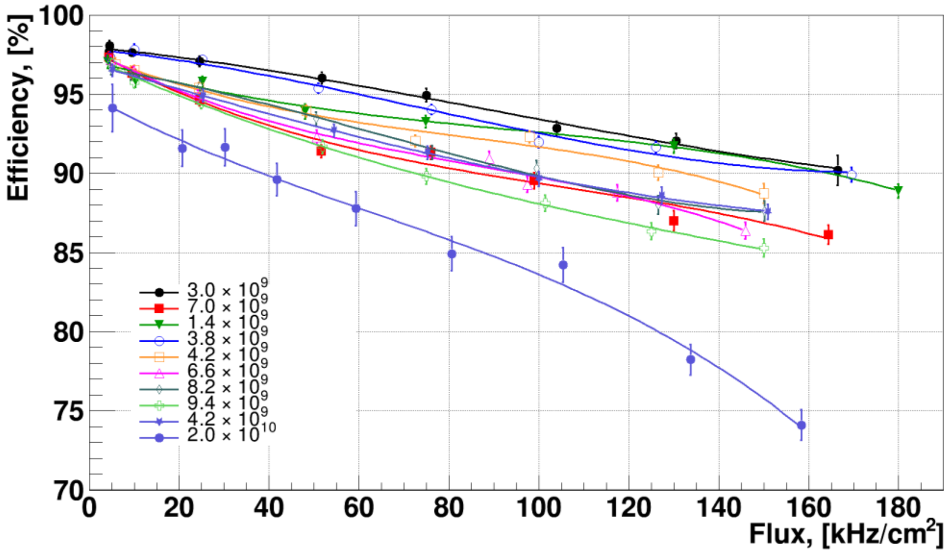

Figure 4. Rate scan of all the chambers measured with the applied electric field of 88 kV/cm. Lines connecting points are guide to the eyes only.

Timing measurements were contaminated by a high electronic jitter and various technical problems during the beam tests at ELBE. As shown in figure 5, RPCs manifested the time resolution of 80–120 ps. It can be seen that the time resolution of the chambers with the lowest and highest resistivity

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increases with the particle flux, while the chambers with intermediate values of resistivity show stable time resolution under particle fluxes of up to 150 kHz/cm^2. The final values of the time resolution have to be re-measured with ASIC PADI electronics, planned to be used in the CBM experiment.

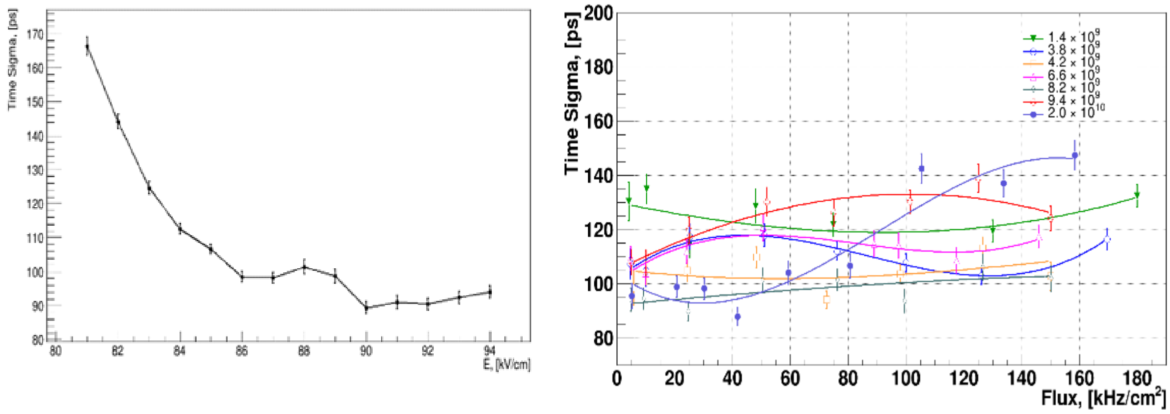

Figure 5. Time resolution as a function of the applied electric field (left, CERN test) and particle flux (right, ELBE test at E=88 kV/cm). Lines connecting points are guide to the eyes only.

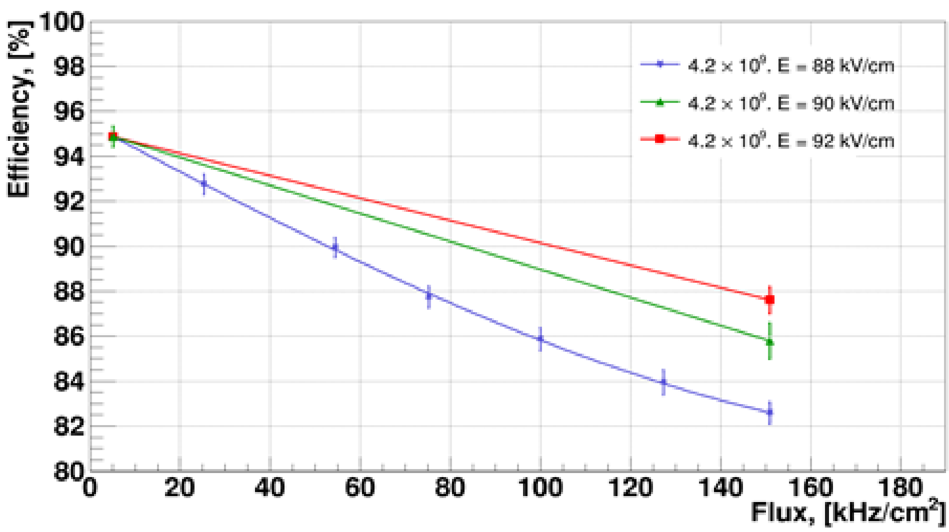

Figure 6. Detection efficiency of the chamber with the bulk resistivity of $4.2 \cdot 10^9$ Ω·cm for different values of the applied electric field as a function of the particle flux. Lines connecting points are guide to the eyes only.

Figure 6 shows the behaviour of RPC with the bulk resistivity of $4.2 \cdot 10^9$ Ω·cm at the highest available rate and increased values of the electric field. A stable operation with no leakage currents and low streamer probability has been observed. Increasing the electric field by 5 kV/cm improves the efficiency by 5% under the particle fluxes of 150 kHz/cm^2. Adding two more gaps to the stack can be an additional way to increase the RPC detecting efficiency up to (94–95)%. Amplitude spectra of all the chamber samples, measured at particle fluxes of a few kHz/cm^2, are shown in figure 7. Chambers with intermediate resistivity produce similar spectra, which proves uniformity of their assemblage and construction. This fact also provides an opportunity to apply the same voltage to all cells within the future BFTC prototype module.

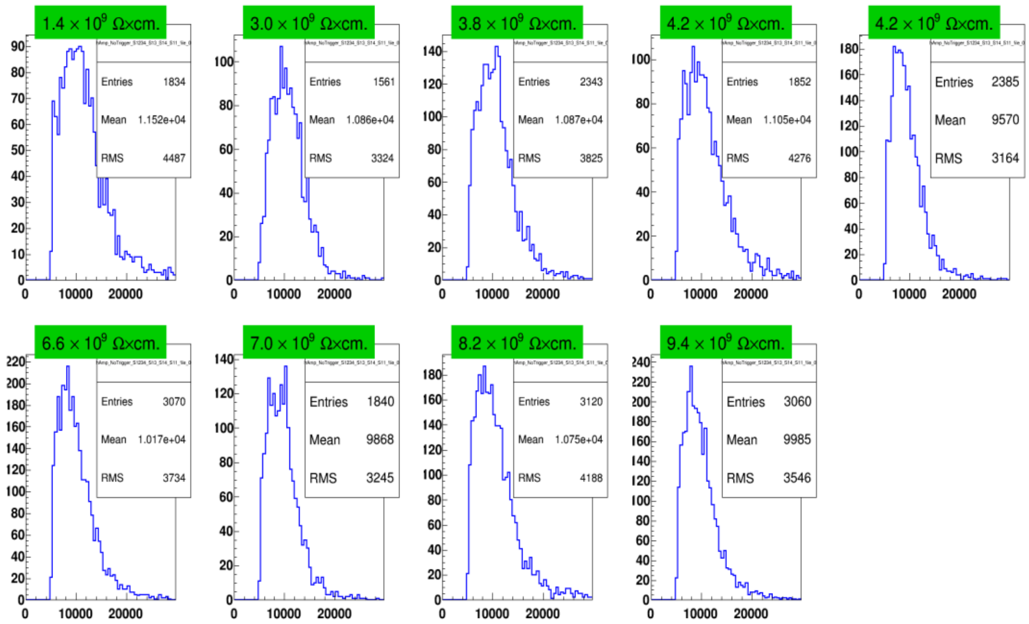

Figure 7. Amplitude spectra of the tested RPC.

3. Conclusion

The presented results of R&D look very promising. Ceramic RPCs with bulk resistivity of the floating electrode about $5 \cdot 10^9$ Ω·cm are manifesting stable performance under particle fluxes up to 150 kHz/cm^2. Efficiency of such RPCs is above 90% on all range of tested particles rates. The tolerance level for the optimal value of the bulk resistivity has been determined to be 20%.

Last tests should be done with final PADI electronics [7] and free streaming CBM readout system before the mass production of BFTC detecting cells begins in 2018. Also, system aspects (especially cross-talk minimization) will be study during 2017–2018 for a few tens cell chess-board module based on ALICE ceramic R&D prototypes [8].

References

[1] Senger P 2002 *J. Phys.* G: *Nucl. Part. Phys*. **28** 186

[2] Kiselev S 2013 *CBM Progress Report*

[3] Akindinov A *et al.* 2016 Radiation-hard ceramic Resistive Plate Chambers for forward TOF and T0 systems *NIM in Phys. Res.* A

[4] Sultanov R 2013 *CBM Progress Report*

[5] Akindinov A *et al*. 2001 *IEEE Transactions on Nuclear Science* **48**(5) 1658

[6] Scapparone E and the TOF group 2007 *J. Phys.* G: *Nucl. Part. Phys*. **34** S725

[7] Ciobanu M *et al.* 2014 PADI, an Ultrafast Preamplifier-Discriminator ASIC for Time-of-Flight Measurements *IEEE Transactions on nuclear science* **61**(2)

[8] ALICE Collaboration 2000 ALICE Time-of-flight system Technical Design Report *CERN/LHCC-2000* **8** 12