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# Radiation-Hard Ceramic Resistive Plate Chambers for Forward TOF and T0 Systems

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## Abstract

Resistive Plate Chambers with ceramic electrodes are the main candidates to be used in precise multi-channel timing systems operating in high-radiation conditions. We report the latest R&D results on these detectors aimed to meet the requirements of the forward T0 counter at the CBM experiment. RPC design, gas mixture, limits on the bulk resistivity of ceramic electrodes, efficiency, time resolution, counting rate capabilities and ageing test results are presented.

*Keywords:*

Multi-gap RPC, ceramic RPC, bulk resistivity, high rate, TOF, time resolution, efficiency, CBM, T0, BFTC

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## 1. Introduction

Precise determination of the collision time  $T_0$  and the reaction plane in high-energy experiments at accelerators of elementary particles and heavy ions are of essential importance for time-of-flight measurements and further physics data analysis. For this purpose, T0 systems are implemented, such as the one operating in the ALICE detector [1], which also provides inputs to the trigger system and luminosity measurements. A significant advance in development of Resistive Plate Chambers (RPC) as high-resolution timing detectors was achieved during the last two decades, mostly during the R&D for the ALICE TOF project [2].

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28 The resulting chambers represent multiple layers of electrically floating glass  
29 electrodes with pad readout and have been successfully implemented in the AL-  
30 ICE [3] and STAR [4] experiments. Having proved to be a reliable solution  
31 in mid-rapidity region, the RPCs of this design, however, manifest poor rate  
32 capabilities and high cross-talk rate, unacceptable in the forward region. In  
33 this case, a low-resistivity and radiation-hard material of the RPC electrodes  
34 combined with chessboard-like single pad readout is considered as a preferable  
35 solution.

## 36 **2. Beam Fragmentation T0 Counter for the CBM TOF Detector**

37 Every time-of-flight (TOF) measurement requires the reference time  $T_0$ , or  
38 start time, referring to the moment of collision. The proposed solution for the  
39 start time determination in the Compressed Baryonic Matter (CBM) experi-  
40 ment [5] at the planned Facility for Antiprotons and Ion Research (FAIR) in  
41 Darmstadt, Germany, is the Beam Fragmentation T0 Counter (BFTC) [6]. It  
42 should cover the region from about 20 to 60 cm from the beam pipe (overlapping  
43 with the acceptance of the Projectile Spectator Detector) and be positioned in  
44 the centre of the TOF wall, 6 m away from the target (Fig. 1). In addition  
45 to T0 measurements, it will provide for particle identification and the reaction  
46 plane determination during heavy-ion collisions.

47 SHIELD simulations predict that the BFTC region will be exposed to harsh  
48 conditions with the particle flux being as high as  $2 \times 10^5$  Hz/cm<sup>2</sup> [7]. In this  
49 environment, BFTC will have to provide the time resolution below 60 ps and  
50 the registration efficiency above 98%. A single cell size of  $20 \times 20$  mm<sup>2</sup> is limited  
51 by the requirement that the double-hit probability should not exceed 2%. The  
52 electrical cross-talks between neighbouring cells that may produce false signals  
53 should stay within 1-2%.

54 As discussed elsewhere [8–11], current efforts are concentrated on RPCs with  
55 electrodes made of low-resistivity Si<sub>3</sub>N<sub>4</sub>/SiC ceramics that have proven to op-  
56 erate well in the high radiation environment and provide good rate capabilities.

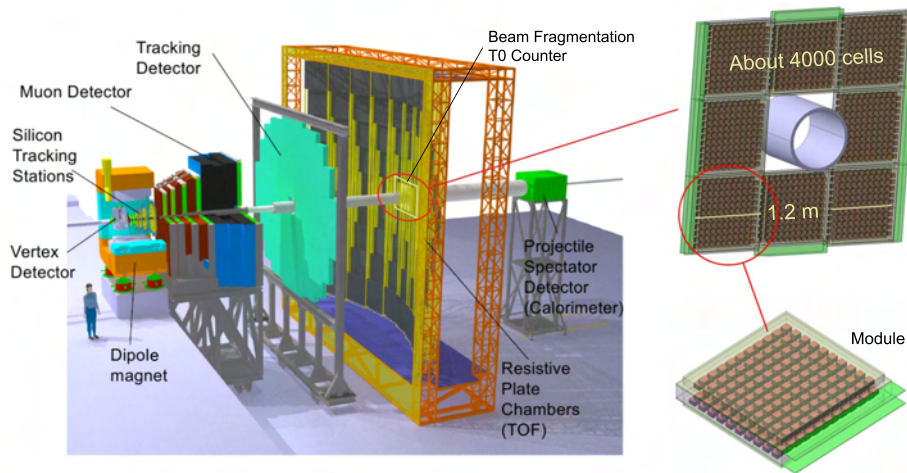


Figure 1: Positioning, size and structure of BFTC in the CBM experiment.

57 The bulk resistivity of  $\text{Si}_3\text{N}_4/\text{SiC}$  is variable within a wide range from  $10^7 \Omega \text{ cm}$   
 58 to  $10^{12} \Omega \text{ cm}$  and can thus be optimized for BFTC operating conditions. A sin-  
 59 gle RPC cell represents a 3-layer sandwich of double-gap RPCs (see Fig. 2). The  
 60 outer electrodes are made of aluminium oxide  $\text{Al}_2\text{O}_3$  covered by metal evapora-  
 61 tion with thin conductive layers of Cu/Cr that are used for high voltage distri-  
 62 bution and signal readout.  $\text{Si}_3\text{N}_4/\text{SiC}$  electrodes are used as internal electrodes  
 63 and are kept electrically floating. All electrodes have Rogowski-shaped edges  
 64 (internal  $\text{Si}_3\text{N}_4/\text{SiC}$  electrodes—on both sides) to minimize the electric break-  
 65 down probability. Gas-filled gaps are kept  $250 \mu\text{m}$  wide by means of rectangular  
 66 spacers made of  $\text{Al}_2\text{O}_3$ . Such multilayer design implements the Dielectric Re-  
 67 sistive Plate Chamber technology that has long since proved to be a promising  
 68 timing technique for high radiation conditions [12]. The working gas is mixed of  
 69  $\text{C}_2\text{H}_2\text{F}_4$  and  $\text{SF}_6$  in 90%/10% or 95%/5% proportions. As reported in [9], the  
 70 use of iso-butane has been abandoned due to its observed harmful effect on the  
 71 surface of metallized electrodes resulting in the formation of localized polymer  
 72 whiskers.

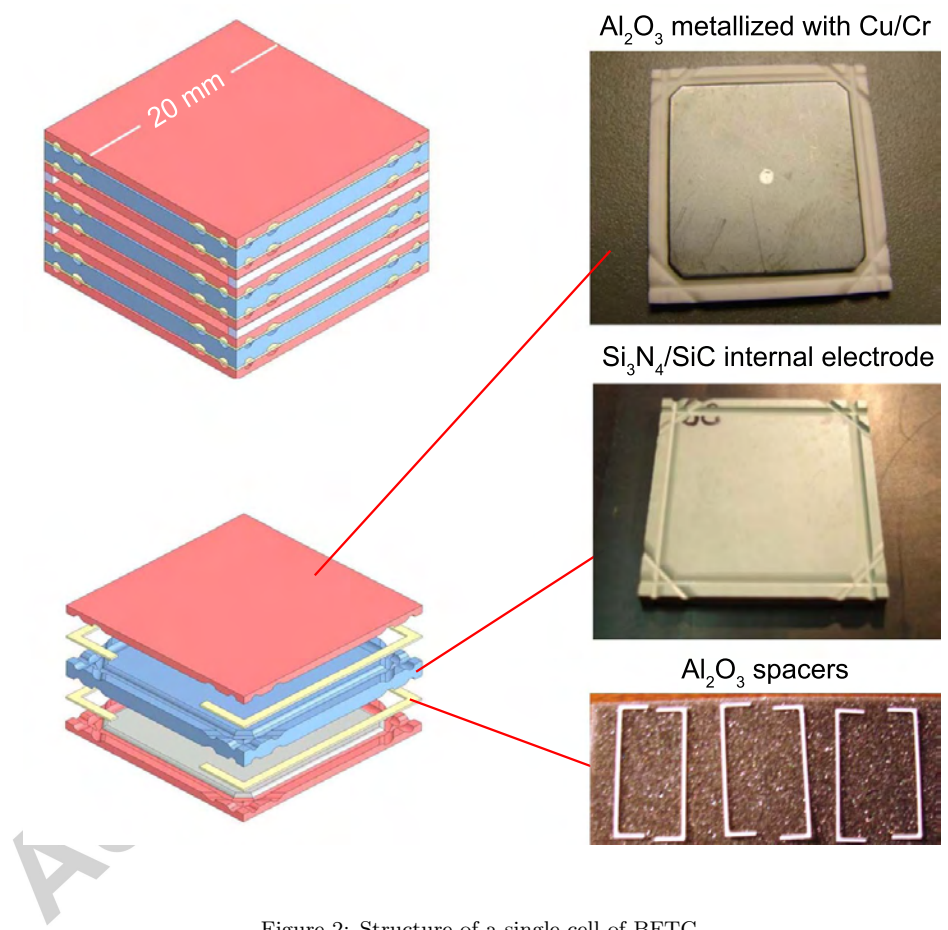


Figure 2: Structure of a single cell of BFTC.

### 73 3. Latest Progress on RPCs for BFTC

74 In 2015, the finalized design of outer RPC electrodes was implemented.  
 75 Cu/Cr layer is now coated with an improved mask on grooved  $\text{Al}_2\text{O}_3$  ceramic  
 76 electrodes sized  $2 \times 2 \text{ cm}^2$ . For best timing performance, the signal is read-out  
 77 from the centres of electrodes: the soldering spot may be seen as a white dot  
 78 on the electrode surface in top right photo in Fig. 2.

79 The optimal bulk resistivity of the floating electrodes was studied with beams  
 80 of 30 MeV electrons in November 2015 at the radiation source ELBE at HZDR  
 81 [13]. Four final size chambers ( $2 \times 2 \text{ cm}^2$ ,  $6 \times 250 \mu\text{m}$  gaps) with different  
 82 values of resistivity of the floating electrodes, were produced. Namely, mCRPC0  
 83 had floating electrodes with the bulk resistivity of  $2 \times 10^{10} \Omega \text{ cm}$ , mCRPC1—  
 84  $3 \times 10^9 \Omega \text{ cm}$ , mCRPC2— $5 \times 10^8 \Omega \text{ cm}$ , mCRPC3— $7 \times 10^9 \Omega \text{ cm}$ . Test results for  
 85 all four chambers are compared in Figs. 3 and 4. The chamber mCRPC2 became  
 86 unstable already at 87-88 kV/cm producing multiple streamers and manifesting  
 87 poor time resolution of over 140 ps. The rest of the chambers showed stable  
 88 and efficient operation. The chamber mCRPC3 could not be tested within the  
 89 whole electric field range due to the lack of the beam time. RPCs manifested  
 90 the efficiency of 95-97% under particle fluxes of a few kHz/cm<sup>2</sup>. It has been  
 91 observed that for higher fluxes, the bulk resistivity of  $10^{10} \Omega \text{ cm}$  is too high,  
 92 resulting in the drop of efficiency to 74% under 160 kHz/cm<sup>2</sup>. Due to technical  
 93 problems, the chambers mCRPC1 and mCRPC3 were measured only up to 70  
 94 kHz/cm<sup>2</sup>. The drop of efficiency was related to the resistivity of the chambers  
 95 as was expected. The bulk resistivity of the floating electrodes of the order of  
 96  $10^9 \Omega \text{ cm}$  has proved to be the most appropriate for BFTC purposes.

97 Two samples of low-resistivity ceramic plates were exposed to non-ionizing  
 98 radiation doses of the order of  $10^{13} n_{\text{eq}}/\text{cm}^2$  at the neutron beam of MEDAPP  
 99 at FRM II in Munich [14]. The bulk resistivity of both probes was measured  
 100 before and after the irradiation, and decreased by a factor of 2. This decrease  
 101 has no impact on the efficiency and time resolution. Irradiation of the  $\text{Al}_2\text{O}_3$   
 102 electrodes with fluxes of up to  $10^{15} n_{\text{eq}}/\text{cm}^2$  does not lead to any degradation

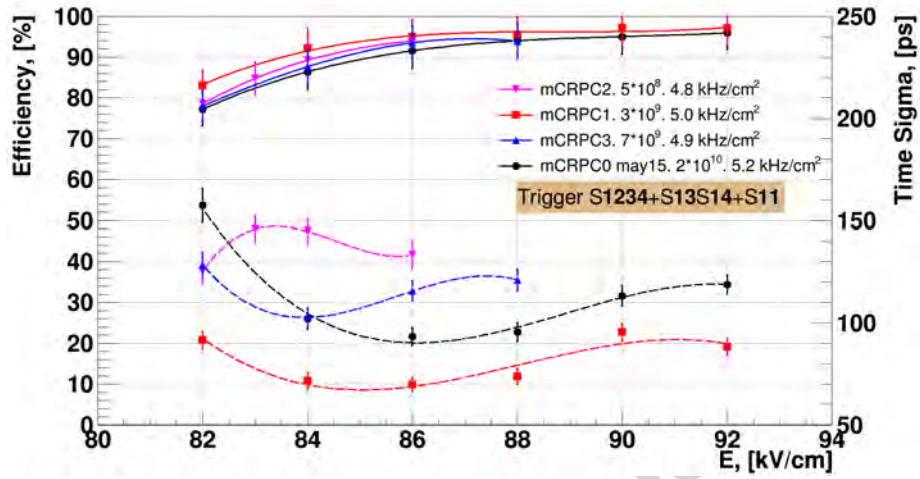


Figure 3: Efficiency and time resolution (after time-walk correction) measured with different types of  $2 \times 2$  cm<sup>2</sup> chambers as a function of applied electric field.

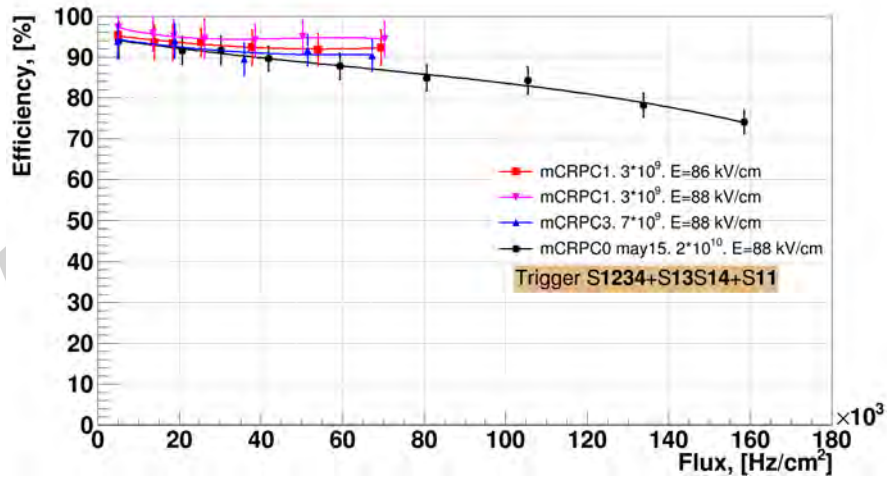


Figure 4: Efficiency of  $2 \times 2$  cm<sup>2</sup> chambers as a function of hit rate.

103 of detector performance.

#### 104 4. Conclusions and outlook

105 The presented R&D results look very promising. The radiation hardness of  
106 ceramics has been confirmed. Use of the 90% C<sub>2</sub>H<sub>2</sub>F<sub>4</sub> / 10% SF<sub>6</sub> gas mixture  
107 showed no aging effects on the RPC material after a few months of continuous  
108 operation. Rough limits for the optimal bulk resistivity of internal electrodes  
109 have been found. A more precise scan of 8 new chambers with the bulk resistivity  
110 of internal electrodes between  $1.5 \times 10^9 \Omega \text{ cm}$  and  $8 \times 10^9 \Omega \text{ cm}$  is scheduled  
111 to be performed in 2016 at the ELBE accelerator. The goal is to find the best  
112 resistivity value that could provide a stable RPC operation with the efficiency  
113 above 95% within the whole range of hit rates up to 200 kHz/cm<sup>2</sup>.

114 Also, a significant improvement of the time resolution is expected with the  
115 implementation of advanced CBM PADI front-end electronics.

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