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# CMS Conference Report

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10 January 2002

## Effect of temperature variation and gas composition on the stability of the RPC operation<sup>a)</sup>

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### Abstract

An Inverted Double Gap RPC made of bakelite of  $5 \times 10^9 \Omega\text{cm}$  volume resistivity was tested at avalanche rates up to  $1 \text{ kHz/cm}^2/\text{gap}$  in the Gamma Irradiation Facility at CERN in 2001. The inner surfaces of the chamber electrodes were cladded using linseed oil varnish. Dependence of the intrinsic RPC noise and the stability of the gas gain on the gas temperature and the gas composition are discussed.

Presented at the *VI-th Workshop on Resistive Plate Chambers and Related Detectors*,  
Coimbra, Portugal, 26-27 November, 2001

Submitted to *Nuclear Instruments and Methods, Sec. A*

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<sup>a)</sup> Work partially supported by the Polish Committee for Scientific Research under grant KBN 5 P03B 02420.

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# 1 Introduction

The medium size Resistive Plate Chambers (RPC) having electrodes made of bakelite of the volume resistivity of  $10^8 \div 10^{10} \Omega\text{cm}$  have shown the efficient detection capability in the radiation environment inducing the avalanche rate of few  $\text{kHz}/\text{cm}^2$  due to the flux of ionising particles [1, 2, 3, 4].

Laboratory measurements of the Parallel Plate Avalanche Counter with one bakelite plate as the resistive electrode have shown that medium-term operation at such high rates causes local reduction of the gas gain which might be related to the change of the bakelite conductivity due to the electric power dissipation [5].

The aim of this work is to demonstrate the significance of some factors influencing the stability of the gas gain and the detection efficiency in an environment of LHC experiments - constant flux of background radiation corresponding, for example in the CMS endcaps, to the ionisation rate up to  $1 \text{ kHz}/\text{cm}^2/\text{gap}$  in RPCs [6].

## 2 Detector construction

The medium-size RPC module consists of two rectangular submodules of 2 mm width of the gas gap assembled in an Inverted Double Gap configuration, in which high voltage planes of the two modules are facing each other [4]. The active area of the detector is  $0.34 \text{ m}^2$ .

The electrodes are made of 2 mm thick bakelite plates having the volume resistivity of  $5 \times 10^9 \Omega\text{cm}$ . The high voltage plane and the strip readout plane were formed directly on the bakelite surfaces by  $50 \mu\text{m}$  thick aluminium foil integrated during the production of the plates.<sup>3)</sup> This eliminates the need of the standard graphite coating to apply electric potentials to the chamber. An advantage of this solution is a better signal coupling to the readout electrodes as compared to standard graphite coated RPCs. The anodes were etched to form rectangular strips ( $12 \times 200 \text{ mm}^2$ ) in four sections of 32 strips. The corresponding pairs of strips of single modules were wire-OR-ed and connected to individual read-out channels, thus allowing the double gap mode operation. Two single gap modules were pressed by rigid honeycomb plates which provided electric shielding. Each submodule could be individually operated by a separate high voltage supply. The detailed description of the detector may be found in [4].

It has been observed that the smoothing of the inner surfaces of electrodes improves the RPC operation [7]. The inner surfaces of the electrodes were covered, after the module assembly, with a thin film of a special liquid mixture containing: linseed oil varnish, heptane and siccativ.

## 3 Test conditions

The 32 central strips of two neighbouring sections were equipped with front end chips<sup>4)</sup> having 2 mV/fC sensitivity amplifier, discriminator and monostable circuit of 100 ns LVDS output. The digital signals, after conversion into ECL standard, were read out by LeCroy 3377 TDC of 0.5 ns resolution with multi-hit capability.

The chamber was tested in the Gamma Irradiation Facility (GIF) at CERN, which provides intense flux of 662 keV photons from 740 GBq  $^{137}\text{Cs}$  source.<sup>5)</sup> A set of remotely controlled lead absorbers allows one to select a desired photon flux in the detection plane. The chamber was located at 154 cm distance from the source's plane and in the spot of low-intensity muon beam from the SPS accelerator. The ionisation rate at maximum source intensity of about  $1.1 \text{ kHz}/\text{cm}^2/\text{gap}$  is expected at this position according to our previous measurements [8]. Detailed information about the GIF can be found elsewhere [9]. The trigger for the detection efficiency measurement was provided by  $10 \times 10 \text{ cm}^2$  scintillation counters installed upstream the beam.

Two gas mixtures were tested:  $\text{C}_2\text{H}_2\text{F}_4$  + Isobutane (96.8/3.2) and  $\text{C}_2\text{H}_2\text{F}_4$  + Isobutane +  $\text{SF}_6$  (96.3/3.2/0.5), referred in this work as non- $\text{SF}_6$  and  $\text{SF}_6$  mixtures, respectively.

Atmospheric pressure and ambient temperature have been monitored during the experiment by the set of sensors installed in the experimental area [10]. A dedicated temperature sensor was located in contact with one of sub-modules (referred as gap no.1) on the external bakelite surface of RPC which allows the detector temperature monitoring.

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<sup>3)</sup> Produced by IZO-ERG S.A., Gliwice, Poland.

<sup>4)</sup> Courtesy of the Bari INFN group.

<sup>5)</sup> Intensity as of 5 March 1997, i.e. 667 GBq in September 2001 [9].

## 4 Method of analysis

A single avalanche can induce signals above a fixed threshold on more than one strip. In order to estimate the real rate of avalanches we attempted to group hits corresponding to single avalanche into one cluster. The following cluster finding algorithm was used: a fixed time window with respect to the trigger pulse was opened, then hits were ordered according to their arrival time for each of two 16-strip sections and, finally, for each pair of neighbouring hits we looked for the time interval of at least 200 ns, which separated our clusters. The first hit of a cluster defined the avalanche arrival time. Two methods of cluster rates calculation were used, referred as direct counting method and corrected method. The first method was a simple counting of the number of clusters in a fixed time window. The second one assumed that non-correlated clusters should follow exponential behavior. From the slope of such distribution we calculated the corrected cluster rate which is close to the real rate of avalanches. Because the cluster finding algorithm does not distinguish between clusters closer than 200 ns in time, the direct counting may result in the rate underestimation by factor up to 2 with respect to the corrected method.

For the efficiency measurement only the signals inside 50 ns time window with respect to the trigger pulse were accepted for the analysis.

## 5 Results

In Fig. 1 the detection efficiency and the average number of fired strips in a single event (cluster size) are shown for the non-SF<sub>6</sub> gas mixture as a function of high voltage for several radiation background fluxes corresponding to: full source intensity (ABS=1), half intensity (ABS=2) and the natural background with the source closed. Even for the highest background rate efficiency plateau of 95 % is reached and it remains constant in the voltage range of at least 1 kV. The cluster size decreases when the radiation is increased at each voltage.

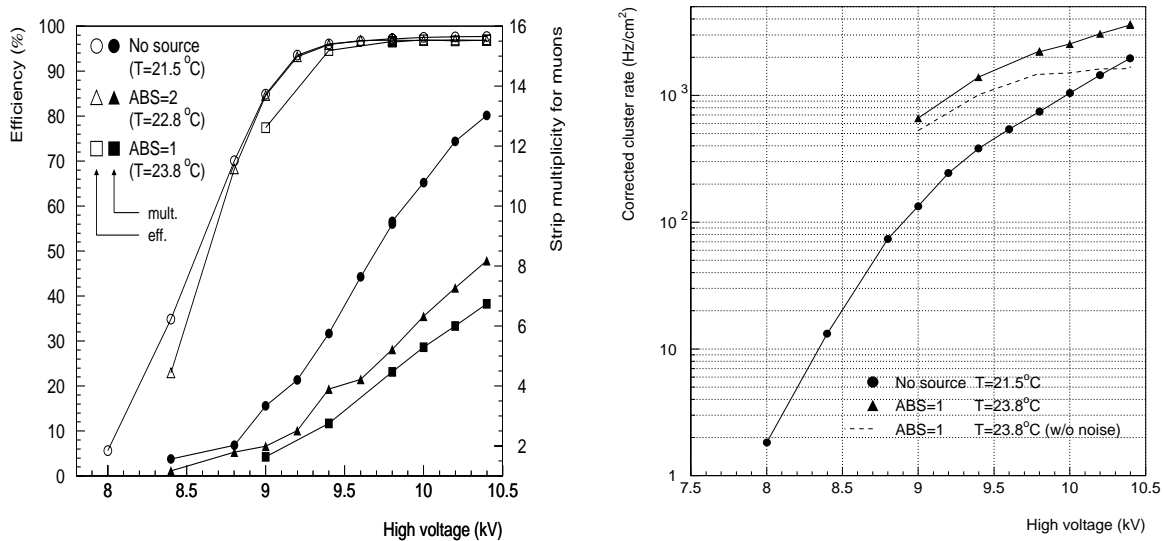


Figure 1: Detection efficiency (open markers) and avalanche cluster size (filled markers) as a function of the applied voltage in double gap mode (non-SF<sub>6</sub> gas mixture, 100 fC threshold).

Figure 2: Corrected cluster rate as a function of the applied voltage in double gap mode. Average bake-lite temperature for each curve measured is indicated (non-SF<sub>6</sub> gas mixture, 100 fC threshold).

It can be seen in Fig. 2 that the cluster rate increases monotonically with the applied voltages. The cluster rate dependence on the applied voltage is similar for the highest and the lowest radiation fluxes with the shift corresponding to the expected ionisation rate difference. The spontaneous avalanche noise rate reaches  $2 \times 10^3$  kHz/cm<sup>2</sup> at the highest voltage applied. The dashed line in Fig. 2, result of a simple subtraction of the two curves measured, approximates the primary ionisation rate due to the flux from the source. Flatness of the dependence in the voltage range of the efficiency plateau for muons indicates the efficiency of gamma rays detection. In the plateau region the rate increases by a factor of about 2.4 what indicates the significant noise component at high radiation flux.

Adding 0.5 % of SF<sub>6</sub> to the gas mixture changes the chamber characteristics regarding the avalanche counting rate (Fig. 3). Although the detection efficiency curve was not measured, one can estimate from previous measurements with similar detector that addition of small amount of SF<sub>6</sub> shifts the efficiency curve by few hundred volts to higher voltages [11].

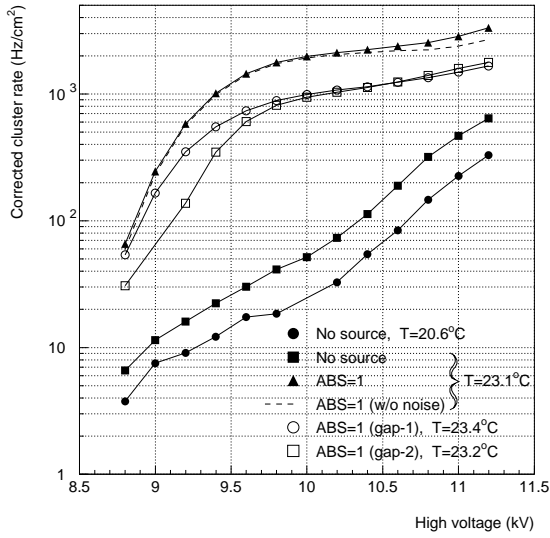


Figure 3: Corrected cluster rate as a function of the applied voltage in double gap mode (filled markers) and in single gap mode (open markers). Average bakelite temperature for each curve is indicated (SF<sub>6</sub>-gas mixture, 100 fC threshold).

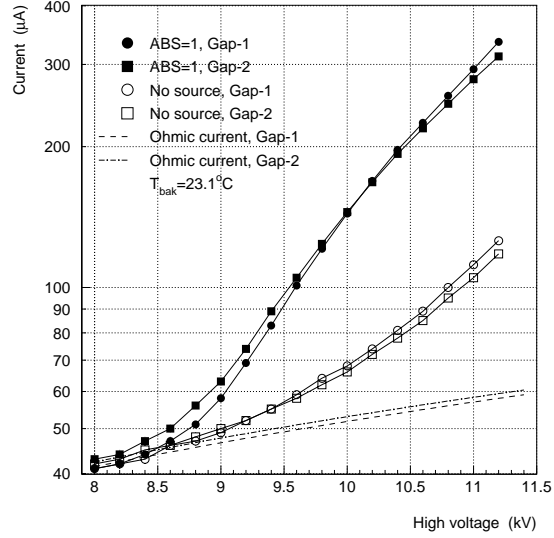


Figure 4: The charge current in single RPC gaps as a function of applied voltage. Dashed lines show an estimated ohmic component of the current for the bakelite temperature of 23.1 °C (SF<sub>6</sub>-gas mixture, 0.34 m<sup>2</sup> active area).

For full source intensity a plateau of the cluster rate of about 1 kHz/cm<sup>2</sup>/gap is clearly visible, starting from 9.8 kV. It hints that the single RPC gap of 2 mm width and filled with adequate gas mixture may allow the full detection efficiency of ionising particles with the constant flux of 1 kHz/cm<sup>2</sup>. The ionisation rate due to gamma rays measured in each single gap RPC module is half of the rate for double-gap operation. The noise rate measured for the SF<sub>6</sub> gas mixture is 5 to 10 times smaller than the one for the non-SF<sub>6</sub> gas in similar working conditions. The avalanche rate measured for the high radiation flux increases by the factor smaller than 1.5 in the voltage range of 1 kV in the full efficiency region. The sensitivity of the detector operation to the temperature variations is reflected in the noise rate difference for measurements at two values of the ambient temperature. The increase of the detector temperature by 2.5 °C only results in increasing of the noise rate by a factor of 2 or, alternatively, it shifts the operating voltage by about 300 V to the lower values.

The current drawn by each submodule is shown in Fig. 4 for fully opened source and for the source closed. The estimated level of the dark current due to the ohmic component is set by the current flow through the frame and the spacers<sup>6)</sup> at a given temperature.

From the data presented in Fig. 3 and Fig. 4 one can deduce the single avalanche charge as a function of the applied voltage in the full efficiency range. The single avalanche total charge is about 20 pC at 9.8 kV and at the highest voltage applied it reaches 50 pC due to the charge gain of about 10<sup>7</sup>. Hence, one can estimate the total power dissipated in the single gap detector operated at full efficiency to be of 2.0 W/m<sup>2</sup> and 7.4 W/m<sup>2</sup> for 9.8 kV and 11.0 kV, respectively, for the radiation flux of about 1.1 kHz/cm<sup>2</sup> and for the electronic readout threshold of 100 fC. Without an efficient heat exchange with the detector surrounding the temperature of the chamber could increase due to the avalanche current in the long-term operation.

The effect of the chamber self-heating was observed, indeed, when the high voltage was gradually increased between subsequent runs as it is shown in Fig. 5. The results confirm the expectations qualitatively. While an

<sup>6)</sup> Frame and spacers were made of high resistivity bakelite  $\sim 10^{12}$  Ωcm.

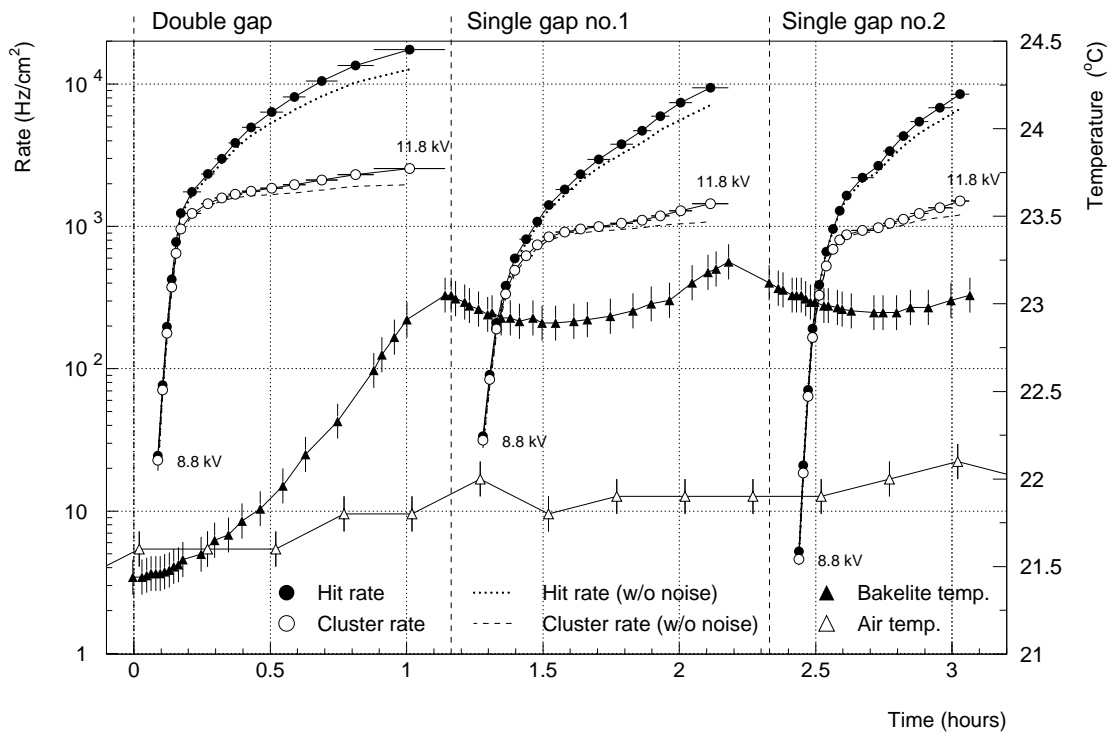


Figure 5: Rate of single hits and rate of clusters (direct counting method) for fully opened source. In each of three periods the applied voltage was increased from 8.8 to 11.8 kV in 200 V steps. Changes of bakelite and air temperatures are shown (SF<sub>6</sub>-gas mixture, 125 fC threshold).

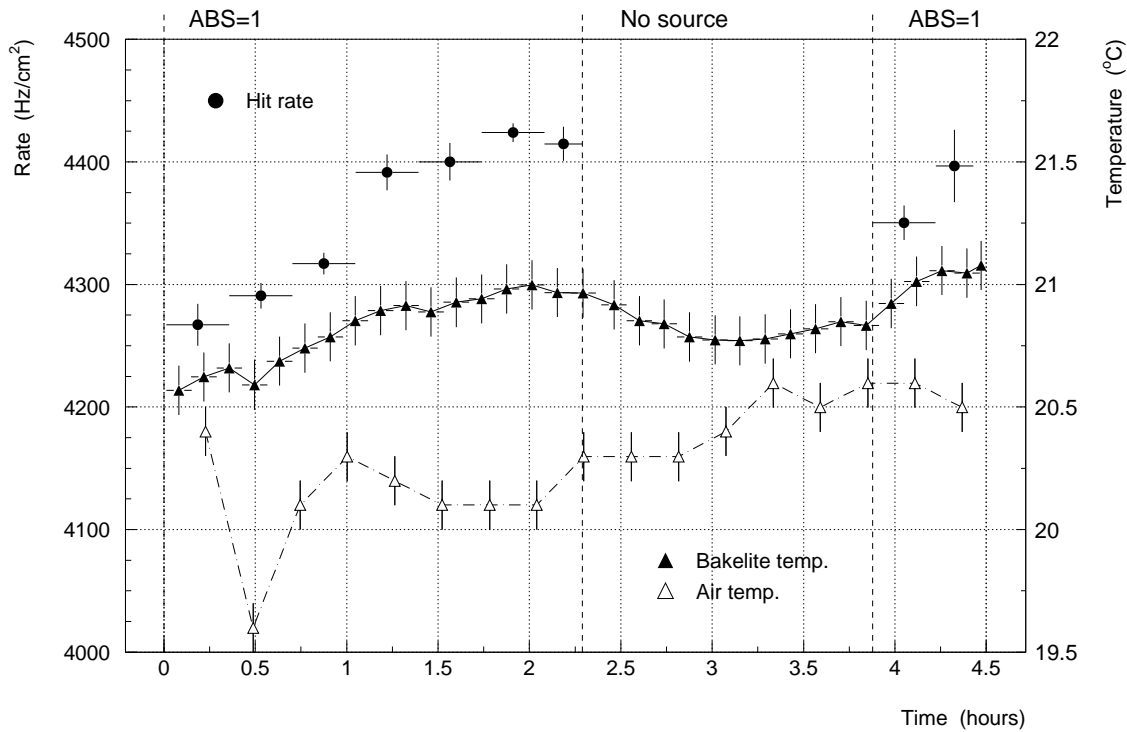


Figure 6: Rate of single hits for constant applied voltage of 10.4 kV measured during the three runs: full intensity, no source, full intensity. Changes of bakelite and air temperatures are shown (SF<sub>6</sub>-gas mixture, 125 fC threshold).

ambient air temperature remained almost unchanged the temperature of the anode of gap no.1 raised by 1.5 °C during the first period (both gaps active) and then only slightly decreased during next two periods (only one gap active at the time) when high voltage was lowered by few kV.

The cluster size of avalanches induced by gamma rays, defined as the ratio of the hit rate and the cluster rate shown in Fig. 5, remains smaller than 2 up to 10.6 kV and increases to about 6 for the highest voltage studied.

The short-term stability of operation at the constant applied voltage of 10.4 kV was measured (Fig. 6). It can be seen that during first two hours of operation at full source intensity the rate of single hits grew by 4 %, while the electrode temperature raised by 0.5 °C. During the time period without irradiation the bakelite temperature approaches the level of the ambient one. Re-opening of the source has initiated the heating again. However, the cluster rate due to gamma rays has remained almost unchanged during the experiment. More of long-term studies are needed to observe possible saturation of the gas gain with time.

## 6 Discussion and conclusions

The medium size model RPC has been tested in the radiation environment expected for the CMS detector in the large rapidity region. The quality of the detector operation depends strongly on the gas mixture used. A small addition of SF<sub>6</sub> to the C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>+Isobutane mixture stabilizes the operation by substantial reduction of the intrinsic RPC noise. The temperature of the detector influences its characteristics significantly. This effect should be carefully studied for the long-term experiments applications. A single RPC gap of 2 mm width filled with adequate gas mixture allows full detection efficiency of ionising particles flux of about 1 kHz/cm<sup>2</sup>.

## Acknowledgements

Our special thanks are addressed to H. Czyrkowski, R. Dąbrowski and Z. Sałapa for technical support. We would like to thank I. Crotty and M.J. Clayton from CERN as well as CMS group from Korea for a very pleasant cooperation during the test.

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