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The performance of RPCs with bakelite electrodes of various resistivity under high radiation fluxes

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Abstract

Three medium-size RPCs with bakelite electrodes having resistivity of $5 \cdot 10^8$, $5 \cdot 10^9$ and $3 \cdot 10^{10} \Omega\text{cm}$ were tested in the Gamma Irradiation Facility at CERN in 1997, 1998 and 1999. The 2 mm gap modules working in an Inverted Double Gap configuration filled with gas mixtures containing freon $C_2H_2F_4$ and operated in avalanche mode exhibit wide efficiency plateau, good time resolution and small time walk due to rate variation even at intensities as high as $1 \text{ kHz/cm}^2/\text{gap}$ of a continuous radiation flux.

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1 Introduction

The Warsaw group has been studying the Resistive Plate Chambers for the last few years in view of employing them in the endcap region of the CMS detector at the LHC collider as devices used for providing fast first level muon trigger [1]. The feasibility of such a triggering scheme was reported in [2].

The detailed simulation of the CMS detector [3] indicates, that the incident flux of radiation ionizing the gas volume of the detectors at the positions foreseen for the forward RPCs may reach values up to 1 kHz/cm^2 at the LHC maximum luminosity. The triggering detector must exhibit efficiency of at least 95% at such continuous radiation background. It should also provide timing information enabling us to assign the muon candidate to a given LHC bunch crossing. This translates to signal spread in time not larger than about 3 ns, including contribution from the possible time-walk due to rate variation.

The performance of a RPC depends on many parameters, one of the more important ones being resistivity of the plates constituting the electrodes of the detector. In order to study this dependence three medium-size RPCs have been constructed using bakelite plates with volume resistivity ranging from $5 \cdot 10^8 \Omega\text{cm}$ to $3 \cdot 10^{10} \Omega\text{cm}$.

2 Chamber construction

The RPC prototypes were built as the Inverted Double Gap structures using the custom made bakelite plates ¹⁾. The properties of the bakelite plates are reported in [4]. The description of the chamber construction may be found in [5, 6]. In all chambers the gas gap width was set to 2 mm. In 1997 we used bakelite of the resistivity $5 \cdot 10^8 \Omega\text{cm}$ (denoted later as low- ρ), in 1998 - $3 \cdot 10^{10} \Omega\text{cm}$ (denoted later as high- ρ) and in 1999 - $5 \cdot 10^9 \Omega\text{cm}$.

The surface resistivity of outer faces of the plates used for the 1997 chamber construction was set to $25 \text{ k}\Omega/\square$ by pressing the carbon paper sheet directly into the plate. In the case of two other prototypes the strip read-out electrodes were cut in the $50 \mu\text{m}$ thick Al-foil integrated in the plate surface during the production process. The high voltage was applied to the aluminum foils on the inner side of the stack.

3 Test conditions

All of the prototypes were tested in CERN at the Gamma Irradiation Facility (GIF), which provides intense flux of 661 keV photons from a 740 GBq cesium source. Information about the GIF may be found in [5]. The photon flux is controlled with a set of filters. A low intensity muon beam from the SPS accelerator enables us to study the timing and the efficiency of the chambers. During all testing periods our chambers were situated at about 130 cm from the source, being exposed to photon fluxes as high as about $3.5 \cdot 10^6 \text{ Hz/cm}^2$ with all filters removed. This flux may create the ionization rate in a single gas gap up to a few kHz/cm^2 .

Since the chambers were operated in the avalanche mode, the charge sensitive fast amplifiers were employed for the strip read-out. In 1997 we used hybrid amplifiers with charge sensitivity of about $1.5 \text{ mV/fC}^2)$, followed by standard discriminators and NIM-ECL converters. In 1998 and 1999 we used special front-end chips produced in Bari [7]. Those chips contain amplifiers of about 1.6 mV/fC charge sensitivity, shapers and discriminators providing LVDS signals, which have to be converted to the ECL standard. The signals were read out with multihit LeCroy 2277 TDCs. The gas mixture used in 1997 consisted of $C_2H_2F_4$ (90%) with isobutane (10%) while in 1998 and 1999 we used $C_2H_2F_4$ (95.5%), isobutane (3.5%) and SF_6 (1.5%).

4 Results

In Fig. 1 the hit rate per square cm of a single plane is shown for the low- ρ prototype. The rate grows steadily with the source intensity, in the same way as obtained with source-monitoring scintillators.

In order to accept an event we search for a hit inside a 40 ns wide time window, opened with a precisely defined delay with respect to the trigger pulse. The earliest signal found within this window is taken as the one corresponding to the chamber response to the beam particle. The chamber efficiency is then defined as the ratio of the number of events within this window to the total number of triggers. In the present work we show mainly comparison

¹⁾ Produced by IZO-ERG S.A., Gliwice, Poland.

²⁾ Courtesy of the Bari INFN group.

Figure 1: Chamber hit rate for a single plane as a function of the source intensity for the low- ρ prototype. The value of the voltage applied assures full detection efficiency at low radiation rates.

Figure 2: Chamber efficiency as a function of the source intensity for three values of HV.

Figure 3: The signal arrival time as a function of the source intensity for three HV values. The vertical scale zero is arbitrary.

Figure 4: The signal arrival spread as a function of the source intensity for three HV values.

between the results obtained in 1997 and 1998, since the 1999 data are yet being studied. They will be reported in later time. In the following set of figures we present the chamber properties as a function of the nominal source intensity. The value 1 of source intensity corresponds to the source fully opened.

Fig. 2 shows the chamber efficiency variation with the increasing source intensity for three HV values for the low- ρ

and high- ρ RPCs. Two of the HV points were chosen on the full efficiency plateau measured for the low radiation rates, while the lowest value corresponds to the knee of the voltage efficiency curve. Only at 9400 Volts the low- ρ chamber shows the efficiency drop to 91% at the highest source intensities. The expected maximum value of the hit frequency at the LHC is of the order of 1 kHz/cm² per single plane, which corresponds to the nominal source intensity of 0.3. We are therefore confident, that such chambers may perform well in the CMS environment, with the efficiency larger than 95% in the voltage range of about 400 V.

In Fig. 3 the variation of the pulse arrival time with radiation rate is shown. Its shift over the full source intensity range is equal to about 5 ns for the low- ρ data and even less for high- ρ , which may be due to using the SF_6 in our gas mixture. The shift is below 2.5 ns in the range of the source intensity up to 1 kHz/cm² for both detectors. The signal spread in time is shown in Fig. 4. In the relevant region of source intensities it stays below 2 ns for high voltage above 9600 V for the low- ρ data. The high- ρ data are all well below 2 ns, even for highest fluxes.

5 Conclusions

We have shown that RPCs with plates of specific resistivity of $5 \cdot 10^8$ and $3 \cdot 10^{10}$ Ω cm operate well in the high radiation environment similar to the one expected at the LHC. Its main characteristics such as the efficiency and timing properties are all in the ranges required for such a detector in the muon trigger system of the CMS experiment [8]. The small time walk implies that no adjustment of timing will be necessary in the trigger electronics.

Different gases and readout electronics employed during the measurement make difficult to disentangle effects due to electrode resistivity from other sources. It is possible that the addition of SF_6 in the gas mixture stabilizes the chamber operation and speeds up its response, thus allowing better timing with wider efficiency plateau of the RPC made out of the highest resistivity bakelite used to construct the detectors.

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