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Nuclear Instruments and Methods in Physics Research A 456 (2000) 82–86

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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# An RPC $\gamma$ irradiation test

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**Abstract**

LHC muon trigger detectors are supposed to work for 10 yr under an intense flux of radiation. Therefore, in the framework of ATLAS, the performance of full and reduced size RPC prototypes, heavily irradiated with $\gamma$ sources, were measured for variable incident fluxes. We introduce here a detector description in terms of the "global" parameters based on experimental data such as current, total counting rate and $\gamma$ fluxes. In this test the ATLAS final front-end electronics was used for the first time. © 2000 Elsevier Science B.V. All rights reserved.

*PACS:* 7.77. – u, 52.80.Dy

*Keywords:* Gamma irradiation test; RPC model; Front-end electronics; ATLAS; RPCs

## 1. Introduction

In order to study the performance of RPCs equipped with the final version of the ATLAS 8-channel full-custom GaAs front-end board, we irradiated a $10 \times 10$ cm$^2$ RPC using our $\gamma$ irradiation facility, located at the INFN laboratories of the University of Roma "Tor Vergata". This facility was already used to perform irradiation and ageing tests on RPCs equipped with the previous version of front-end electronics [4].

We measured the total operating current and counting rate vs. the applied voltage for different distances of the source.

Two quantities derived from the data are introduced: $Q_\gamma$, the total charge per ionizing photon, and $Q_c$, the total charge per count, that behave like "state" functions of $V_{gas}$, that is the high voltage actually applied on the gas once the ohmic drop across the resistive plates has been taken in account. This description permits the evaluation of important detector parameters like total RPC plate resistance and charge multiplication inside gas, and is the starting point for a rate-dependent simulation model which will be the subject for a forthcoming paper.

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## 2. The experimental setup

The experimental setup (Fig. 1) consists of a irradiation cubic lead cell (edge = 1 m), equipped with a nominal 4 mCi $^{60}$Co source, in which a $10 \times 10$ cm$^2$ RPC was placed. A direct calibration measurement made 2 yr before the present data gave $3.8 \pm 0.3$ mCi [1], corresponding to the present $\gamma$ rate of $2.2 \times 10^8$ $\gamma$/s over $4\pi$.


PII: S0168-9002(00)00967-0

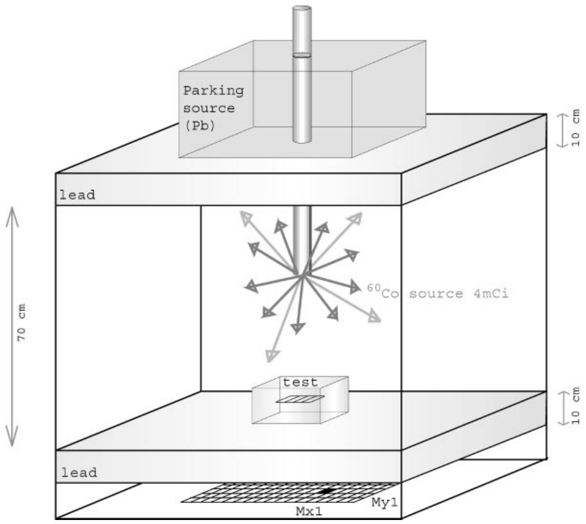


Fig. 1. Experimental setup.

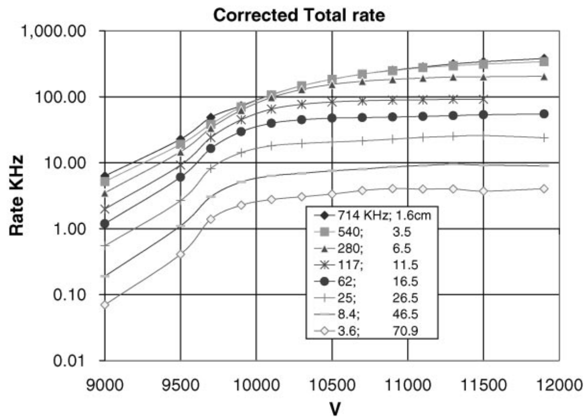


Fig. 2. Counting rates at various distances.

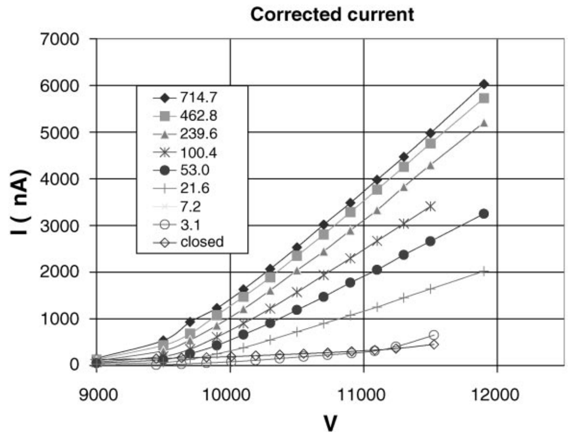


Fig. 3. Total operating current.

The RPC was filled with 97% $C_2H_2F_4$, 2.5% $C_4H_{10}$ and 0.5% $SF_6$ gas mixture. Its bakelite volume resistivity was $\sim 4.4 \times 10^{10}$ $\Omega$ cm at room temperature. It was equipped with the ATLAS 8-channel front-end board, four of which were connected to the 3 cm wide readout strips. The threshold is given by the difference between an internal reference value ($-1.5$ V) and an external input $V_{th}$. A 100 k$\Omega$ resistor placed in series with the HV return line, provided a precise $V$–$A$ current readout.

## 3. Data taking and experimental results

Fig. 2 shows the single RPC counting rates vs. high voltage for different source distances. The value of $V_{th}$ was set at $-1.45$ V. The number of photons that produce gas ionization are also reported along with the source distance. These are obtained from the total photon flux $\Phi_\gamma$ and the RPC sensitivity for the $^{60}$Co, $s_\gamma = (0.9 \pm 0.1)\%$ [1].

The total rate ranges from 3.1 to 714 kHz on $10 \times 10$ cm$^2$ for distances of the source ranging from 70.9 to 1.6 cm.

Each curve is corrected subtracting the closed source measurement. We observe that the two curves corresponding to the higher rates do not reach the plateau in the present voltage range and this can be considered as an effect due to the plates resistivity. Nevertheless, it has to be stressed that in this case the rate of converted photons is $\sim 50$ kHz cm$^{-2}$ in the central region of the detector due to loss of photons uniformity. The produced counting rates are compatible with those already obtained using the previous electronics in the same set up.

Fig. 3 shows the measured currents which are corrected with the closed source values for different distances of the source. The almost linear growth of the current is typical of operation with $SF_6$ [2].

## 4. Discussion of results

For a uniformly irradiated detector we define $V_{gas} = V - \bar{I}R$ as the average voltage across the gas gap, $V$ being the power supply voltage, $\bar{I}$ the average current and $R$ the total resistance of the detector plates. The use of $V_{gas}$ in place of $V$ allows to describe the system independent of the voltage drop due to the current flowing into the resistive plates.

Fig. 4 shows the dependence of $Q_\gamma = \bar{I}/(\Phi_\gamma s_\gamma)$ from the applied voltage $V$. The quantity $Q_\gamma$, that is the average charge per ionizing photon, should depend only on the gas multiplication phenomena, as a function of effective voltage in the gas. Indeed the set of different curves plotted in Fig. 4 "melt" into one, if the correct voltage scaling from $V$ to $V_{gas}$ is applied, as shown in Fig. 5. This was obtained introducing $R$ as a free parameter and it was fixed by minimizing the distances of the curves in Fig. 4. The obtained value ($R = 2.2 \times 10^8\ \Omega$) should be interpreted as the plates resistance and gives a resistivity of $\rho = 5.5 \times 10^{10}\ \Omega$ cm. With the purpose of testing this result we made a direct measure on the RPC after data taking: the plates were short circuited, filling the detector with pure water, to obtain the slope of its ohmic $V$–$A$ characteristic. The resulting resistivity of $\sim 4.4 \times 10^{10}\ \Omega$ cm has an acceptable agreement with the parameter value, thus confirming the interpretation of $R$ as the electrodes resistance. This give us the possibility of monitor the detector total resistance during its life.

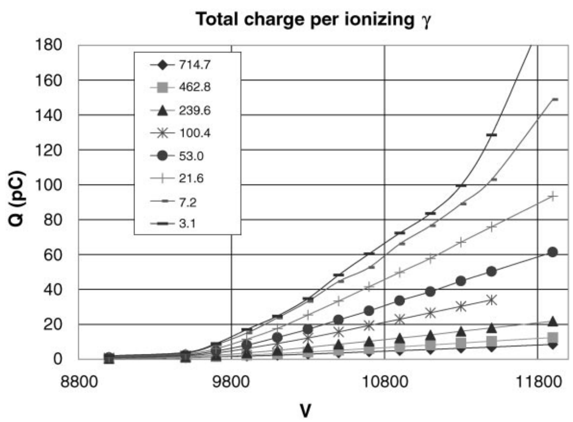


Fig. 4. Charge per ionizing photon: $Q_\gamma$.

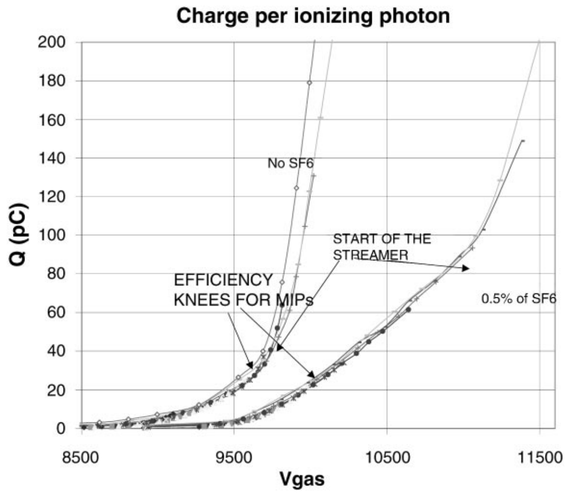


Fig. 5. $Q_\gamma$ vs. $V_{gas}$ with and without $SF_6$.

In Fig. 5 is also presented the comparison with the binary gas mixture, free from the $SF_6$ component. It is apparent that, after an exponential growth, the mixture with 0.5% of $SF_6$ presents a linear growth in a 1 kV range, that is probably due to a saturation mechanism [3]. On the other hand, the mixture without $SF_6$ abruptly enters its streamer regime after a barely visible linear range.

This highlights another feature of this technique: extracting information about the gas properties with a quick and simple procedure. In particular, this plot gives the effective multiplication law that includes all the non-linear effects due to the space charge and for that we used it as a starting point to develop a more complete detector model.

Fig. 6 shows the counting rate and the operating current vs. $V_{gas}$, with the source set at 16.5 cm. The average charge per count $Q_c = \bar{I}/(counting\ rate)$, also plotted in Fig. 6, shows a minimum $Q_{th}$ at a voltage corresponding to about half of the maximum rate. We interpret the value of this minimum as the average total charge per count, produced in the gas, corresponding to a fast signal of amplitude equivalent to the front-end threshold.

It is possible to make a threshold scanning at fixed source distance to determine the correlation between the minima positions and threshold $V_{th}$.

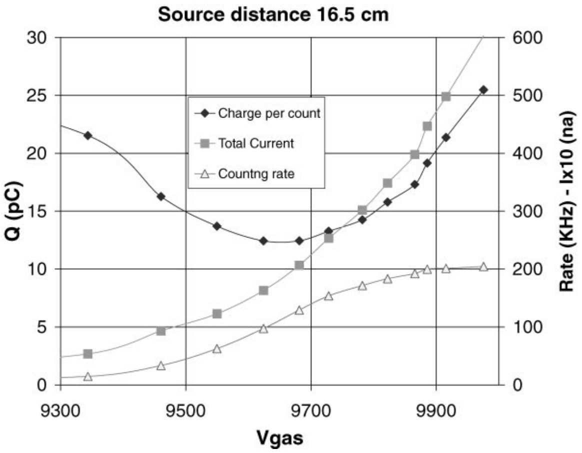


Fig. 6. The ratio $Q_c = \bar{I}/(counting\ rate)$, shows a minimum.

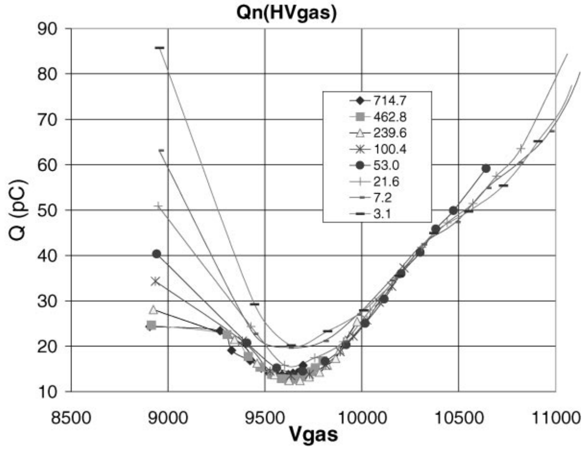


Fig. 8. The minimum position does not depend on $\gamma$ rate.

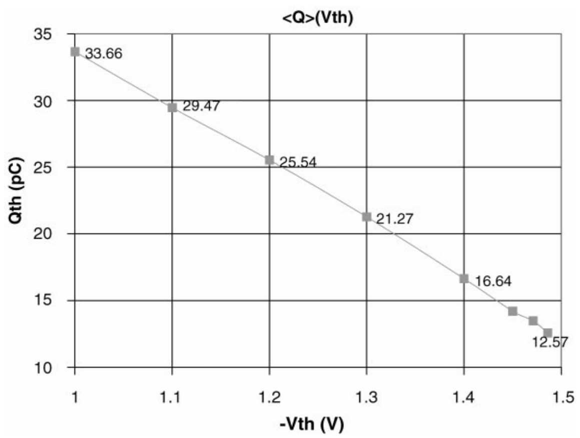


Fig. 7. Total charge $Q_{th}$ vs. the set threshold.

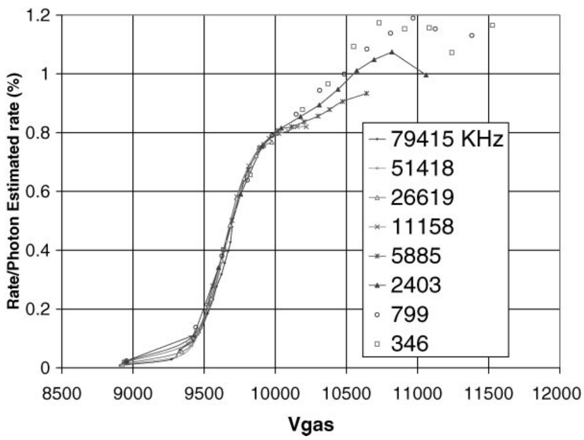


Fig. 9. Counting rate to $\gamma$ rate ratio.

This is shown in Fig. 7 where the source was at 6.5 cm and $V_{th}$ ranged between $-1$ and $-1.486$ V

If the $V_{gas}$ variable is used, the minimum position should not depend on the incident rate, as is apparent in Fig. 8. This gives another way to determine the RPC total plates resistance, imposing the alignment of the minima, and the result is the same as the previous method.

Nevertheless, we see that the minimum value depends on the source distance meaning that the calculated $V_{gas}$, is not sufficient to describe the detector in this voltage range.

In Fig. 9 the ratio of counting rate to estimate the number of photons vs. $V_{gas}$ is reported. After an initial common slope, very similar to the one typical of minimum ionizing particles efficiency curve, the slopes spread at the knee, increasing with the source distance, to reach a roughly constant value at higher $V_{gas}$. This effect, if not instrumental, could be due to the albedo $\gamma$s, whose fraction increases with source distance.

The knee around 10 kV corresponds to a sensitivity of 0.85% for the direct component of the photons emitted by the $^{60}Co$ source.

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