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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Resistive Plate Chambers in avalanche mode: a comparison between model predictions and experimental results[1]

M. Abbrescia[a,*], A. Colaleo[a], G. Iaselli[a], F. Loddo[a], M. Maggi[a], B. Marangelli[a], S. Natali[a], S. Nuzzo[a], G. Pugliese[a], A. Ranieri[a], F. Romano[a], G. Gianini[b], S.P. Ratti[b], P. Vitulo[b]

[a] *Dipartimento Interateneo di Fisica, Sezione INFN, Via G. Amendola 173, 70126 Bari, Italy*
[b] *Dipartimento di Fisica Nucleare e Teorica, Sezione INFN, Pavia, Italy*

Abstract

In this paper a model simulating the main aspects of avalanche growth and signal development in Resistive Plate Chambers (RPCs) is presented. The model has been used to compute the performances, in particular, charge distribution and efficiency of single- double- and multi-gap RPCs, and to compare them with the available experimental results.

This model could be used to optimize the characteristics of this type of detector with a view to its use in the future large experiments at LHC: ATLAS and CMS. © 1998 Published by Elsevier Science B.V. All rights reserved.

1. Introduction

Resistive Plate Chambers (RPCs) were developed at the beginning of 1980s [1], and were originally thought to be operated in streamer mode, meaning that the electric field inside the gas gap is so intense as to generate limited discharges localized near the track of an ionizing crossing particle. This operation mode allows us to obtain good detection efficiency ($> 95\%$) and time resolution (~ 1 ns), in particular, when a low flux of incident particles is involved. At higher fluxes ($\geqslant 200$ Hz/cm^2) RPCs begin to lose their efficiency, due to the fact that, after the streamer development, the area of the electrode plates involved in the discharge needs a certain time (~ 10 ms) to get charged again.

A way to overcome this problem is to operate RPCs in avalanche mode; the idea consists in using lower electric fields, to reduce, as a consequence, the size and charge of the avalanches taking place in the gas gap and the corresponding electrode discharged area. In this way a consistent improvement in the rate capability can be achieved. Satisfactory results up to a rate of about 1 kHz/cm^2 have been reported [2]; for this reason, RPCs operated in avalanche mode have been proposed as the dedicated detector for the generation of the first-level muon trigger, both in CMS and ATLAS at LHC.

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* Corresponding author. Tel.: + 39 80 5443140; fax: + 39 80 5442470; e-mail: marcello.abbrescia@ba.infn.it.

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2. The model

A detailed description of the model used in the simulation and its results will be reported in a forthcoming paper; here just the main items will be repeated. The program starts from considering an ionizing particle which crosses the gas gap and generates a certain number of clusters of ion–electron pairs. The electrons contained in the clusters drift towards the anode and, if the electric field is sufficiently high, give rise to the avalanche processes.

The primary cluster positions and the avalanche growth are assumed to follow, respectively, simple Poisson statistics and the usual exponential law. Avalanche gain fluctuations have been taken into account using a Polya distribution [3]. After the simulation of the drifting avalanches, the program computes, by means of the Ramo theorem, the charge q_{ind} induced on the external pick-up electrodes (strips or pads) by the avalanche motion. Under certain approximations, this is given by the formula [4]

$$q_{\mathrm{ind}} = \frac{k}{\eta g} \sum_{\mathrm{clusters}} q_{\mathrm{el}} n_0 M k [\mathrm{e}^{\eta(g - x_0)} - 1],$$

where q_{el} is the electron charge, η the 1st effective Townsend coefficient, g the gap width, x_0 the cluster initial distance from the anode, n_0 the number of initial electrons in the considered cluster, M the avalanche gain fluctuation factor. k takes into account the fact that not the whole charge can actually be read out on the pick-up electrodes. In addition to q_{ind}, the current $i_{\mathrm{ind}}(t)$ induced on the same electrodes (as a function of time) by the drifting charge $q_{\mathrm{d}}(t) = q_{\mathrm{d}}(x/v_{\mathrm{d}})$ may be computed as

$$i_{\mathrm{ind}}(t) = -kMq_{\mathrm{d}}(t)\boldsymbol{v}_{\mathrm{d}} \cdot \boldsymbol{E}_{\mathrm{w}},$$

where $\boldsymbol{v}_{\mathrm{d}}$ is the electron drift velocity and $\boldsymbol{E}_{\mathrm{w}}$ is the weighting field inside the gap. The computation of $i_{\mathrm{ind}}(t)$ allows to reproduce the whole information coming out from RPCs; it is possible to input the simulated signals in simulated amplifiers, discriminators, etc., reproducing, with accuracy, the data taking conditions of a real experiment.

3. Results

The comparison between the simulated charge spectra for single narrow ($g = 2\,\mathrm{mm}$) and wide ($g = 9\,\mathrm{mm}$) gap RPCs is reported in Fig. 1 (the gas mixture is 90% $C_2H_2F_4$ and 10% i-C_4H_{10}, and will remain the same in all the following plots); the value of the 1st effective Townsend coefficient η has been chosen in such a way that the averages of the two distributions are roughly the same: 0.6 pC the former, 0.75 pC the latter. A change in the gas gap width has the effect to change the shape of the charge distributions; more precisely, as it can be seen from the figure, in the case of a narrow gap the charge distribution tends to diverge near the origin, while the opposite is true for a wide gap. This has deep implications for the efficiency and the rate capability that can be obtained with the two different kinds of chamber.

It is worth noting that, under certain approximations, the shape of these distributions can be predicted by means of simple analytical calculations; for instance, if only the contribution of the first cluster (i.e. the closest to the cathode) is considered, the probability distribution function $f_1(q_{\mathrm{ind}})$ of the induced charge q_{ind} can be expressed as

$$f_1(q_{\mathrm{ind}}) = Aq^{((\lambda/\eta)-1)},$$

where A includes the normalization constant and λ is the primary cluster density. This function is reported in Fig. 1, and superimposes well to the simulated spectra, in particular, in the region near the origin, which is the region of main interest; for a better agreement in the other regions the contributions coming from the other clusters should be considered. A comparison between the predicted and the experimental charge distribution for single gap 2 mm RPCs is reported in Ref. [5].

The events characterized by an induced charge q_{ind} lower than the discrimination threshold account for the chamber inefficiency; such events, in fact, are not experimentally detected. This means that, starting from charge distributions, it is possible to compute chamber efficiency; this is shown in Fig. 2 for single 2 and 3 mm gap $10 \times 10\,\mathrm{cm}^2$ RPCs. The chamber efficiency has been measured with cosmic μ, by counting the coincidences between signals coming from the chamber (with

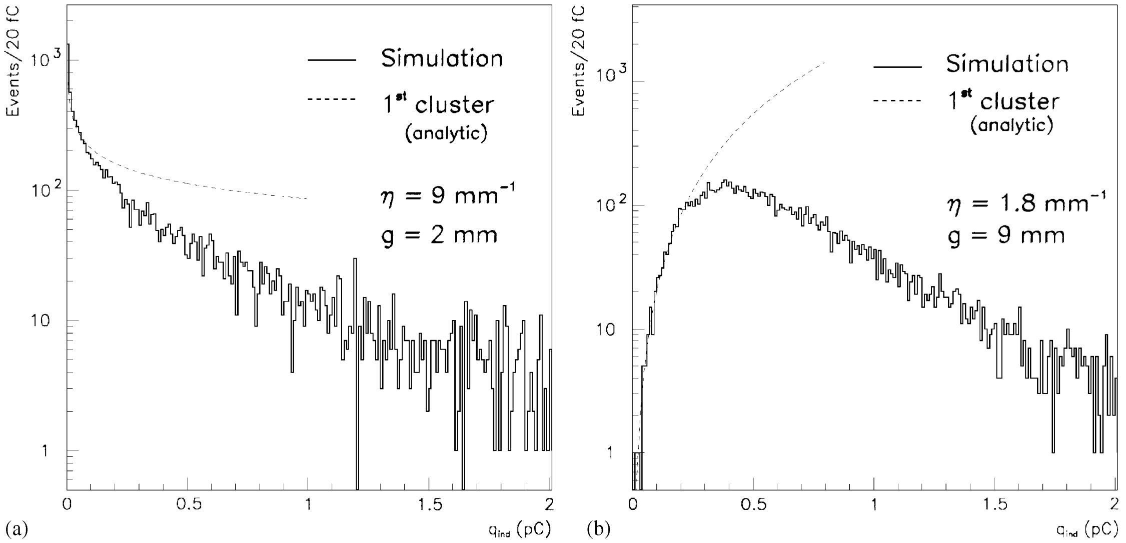

Fig. 1. Comparison between the simulated charge spectra for single (a) narrow ($g = 2\,\mathrm{mm}$) and (b) wide ($g = 9\,\mathrm{mm}$) gap RPCs.

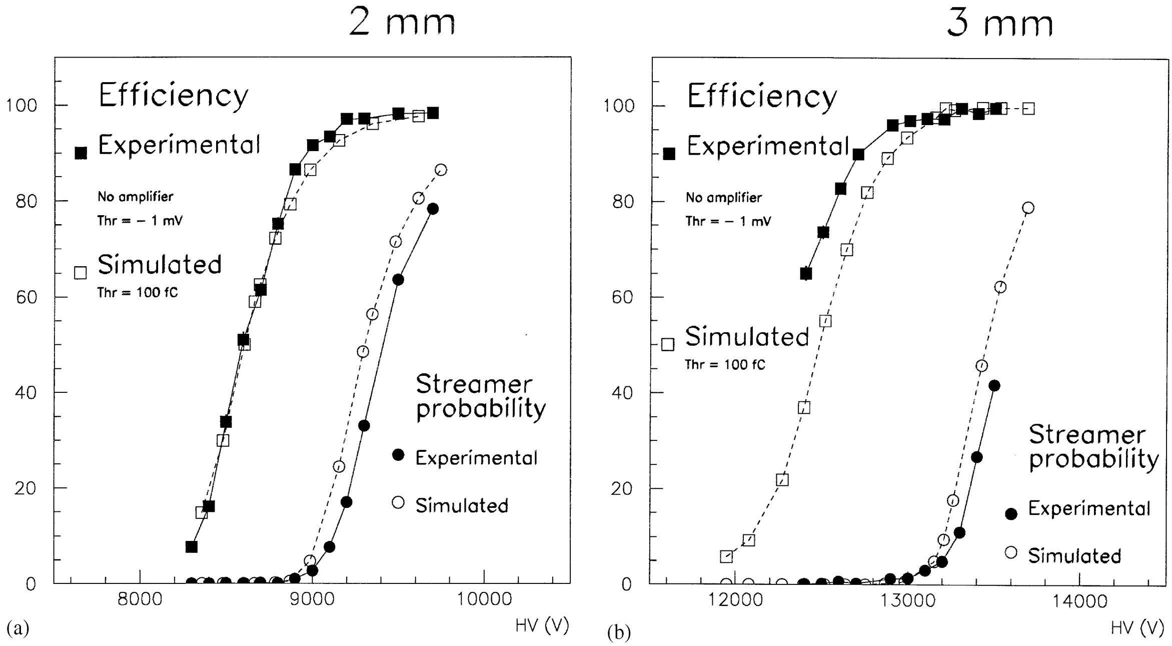

Fig. 2. Simulated and experimental efficiency and streamer probability for single 2 and 3 mm RPCs.

a 1 mV discrimination threshold, i.e. 3 times more than the noise level) and 4 trigger scintillators. The experimental 1 mV amplitude threshold has been simulated with a 100 fC charge threshold, for both chambers. The predicted and the experimental curve superimpose very well, in particular the ones concerning the 2 mm chamber. Also the predicted streamer probability is reported in Fig. 2; it has been computed by counting the number of events with at least one avalanche characterized by a gain greater than $e^{20} \simeq 4.9 \times 10^8$, which are compared with events experimentally characterized by an amplitude greater than 30 mV.

The leap from the case of single gap RPCs to double or multi-gap RPCs is, in principle, simple. It is sufficient to simulate two or more identical gaps and sum the signals (instant by instant) coming from the gaps on the common read out electrode. However, the ratio $k/\eta g$ between the charge q_{ind} which is actually read out on the strips and the electron charge which reaches the anode depends on the type of RPC considered. In particular, as shown in Ref. [4], in a single gap 2 mm RPC $k \simeq 0.71$, in a double gap $k \simeq 1.42$ and in a multi-gap $k \simeq 0.78$; this has the effect that, given a certain operating condition for a single-gap RPC, a double gap or a multi-gap made out of two or three gaps will have a different average value of the induced charge q_{ind}. This is shown in Fig. 3, where, in fact, the reported simulated charge spectra for single- double- and multi-gap 2 mm RPCs are characterized, respectively, by an average value of 0.34, 0.68 and 0.37 pC. In addition, from the figure it can be noted that the shape of the charge spectra changes, passing from the usual inverse power law of the single gap to a "Landau" shape for the double and the multi-gap.

The comparison between Monte-Carlo and experimental charge spectra for a single and a double 2 mm gap $50 \times 50\,\mathrm{cm}^2$ RPC is shown in Fig. 4; data were taken with the CMS-H2 beam line at CERN-SPS, using 300 GeV/c muons: experimental data taking conditions are reported in detail in Ref. [2]. The single-gap distribution was obtained using the

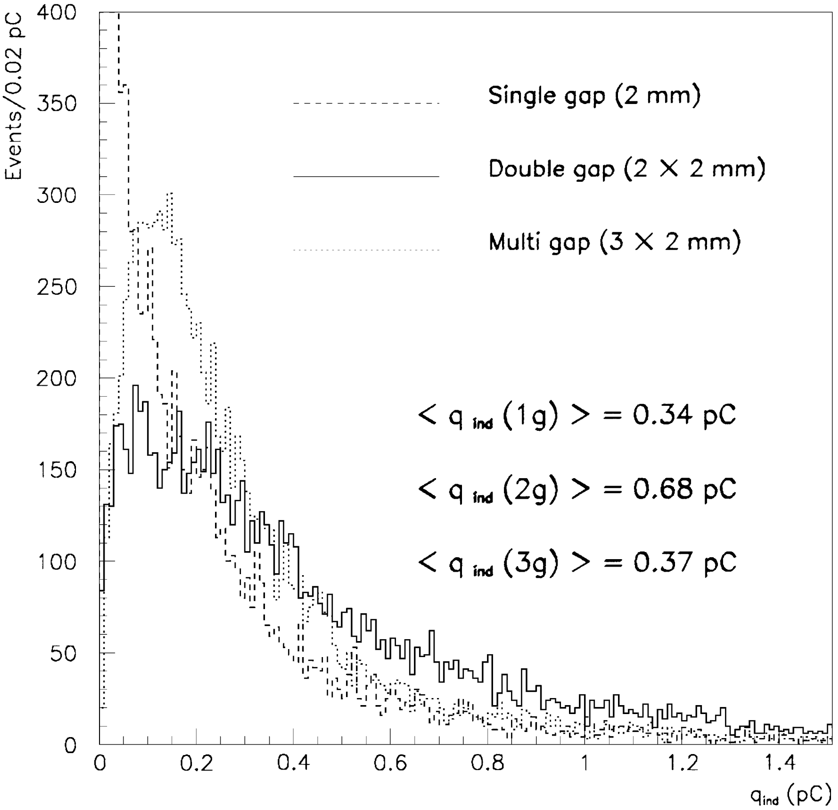

Fig. 3. Monte Carlo charge spectra for single- double- and multi-gap RPCs.

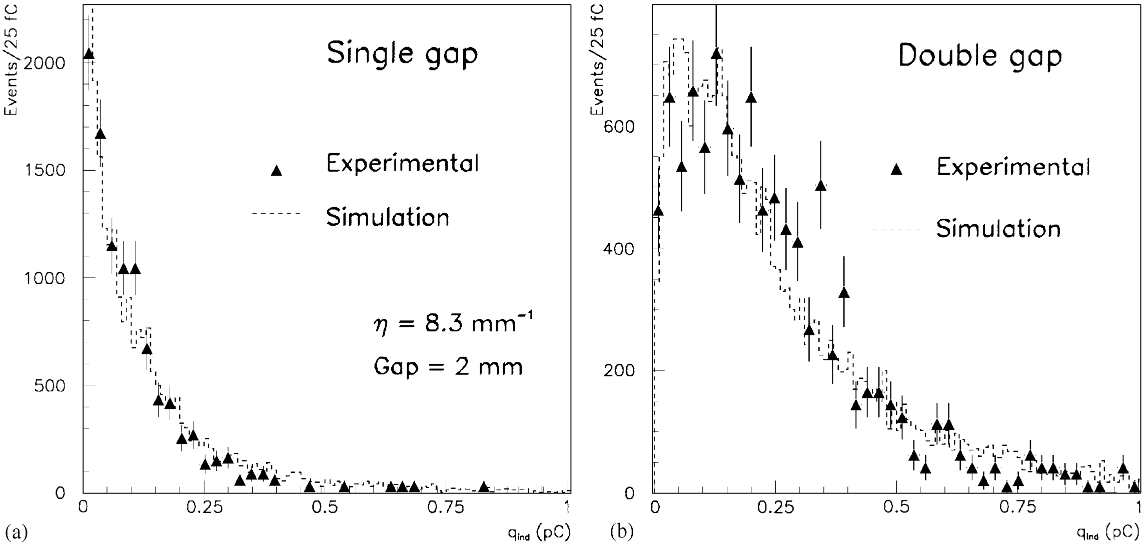

Fig. 4. Simulated and experimental charge distributions for single and double 2 mm RPCs.

double-gap chamber with a gap turned off; the agreement between the predictions and the experimental data is very good and, in particular, it has verified the change in the spectra shapes.

4. Conclusions

A model describing the basic processes taking place in RPCs in avalanche mode has been developed. This model has been used to reproduce the available experimental data, and explains most results, taken in many different conditions of operation and with different kinds of chambers (single- double- and multi-gap). The agreement between the simulation and the real data is very good where it concerns charge distribution and efficiency. The simulation will be a very useful tool to exercise a choice among different RPC types, depending on the performances required.

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