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Nuclear Instruments and Methods in Physics Research A 433 (1999) 513–517

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Single-electron pulse-height spectra in thin-gap parallel-plate chambers

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Abstract

Single-electron pulse-height spectra were measured in 0.6 and 1.2 mm parallel-plate chambers developed for the TOF system of the ALICE/LHC-HI experiment. Mixtures of Ar with ethane, isobutane, and SF_6 were studied. The observed spectrum shows a clear peak for all gases, suggesting efficient single-electron detection in thin parallel-plate structures. The pulse-height spectrum can be described by the weighted sum of an exponential and a Polya distribution, the Polya contribution becoming more important at higher gains. Additionally, it was found that the maximum gain, above 10^6, is limited by the appearance of streamers and depends weakly on the gas composition. The suitability of each mixture for single-electron detection is also quantitatively assessed.

Keywords: Single-electron pulse-height spectra; Parallel-plate chambers

1. Introduction

The advent of heavy-ion collision physics has renewed the interest in Time-of-Flight (TOF) techniques for particle identification, since the momentum spectrum of many of the large number of particles emerging from the interaction is within the range covered by TOF.

The ALICE [1] experiment at the CERN's Large Hadron Collider heavy-ion program will include a TOF barrel system covering the ± 1 rapidity range. The technology now chosen to implement this detector is based on parallel-plate chambers, similar in construction to the ones tested in this work.

We, hereby, investigate the characteristics of the Pulse Height Spectra (PHS) of avalanches initiated by single electrons extracted from the chamber cathode by UV photons. This experimental situation is relatively similar to the one found in the TOF application because when an ionizing particle crosses an amplifying parallel-plate gap only those electrons created close to the cathode by ionizing collisions will be subject to the full gap amplification. For a sub-millimeter gap only a few electrons at most will be in such conditions.

The measured PHS constitutes also a basic input information to any Monte Carlo model of such detectors.

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0168-9002/99/$ - see front matter
PII: S0168-9002(99)00309-5

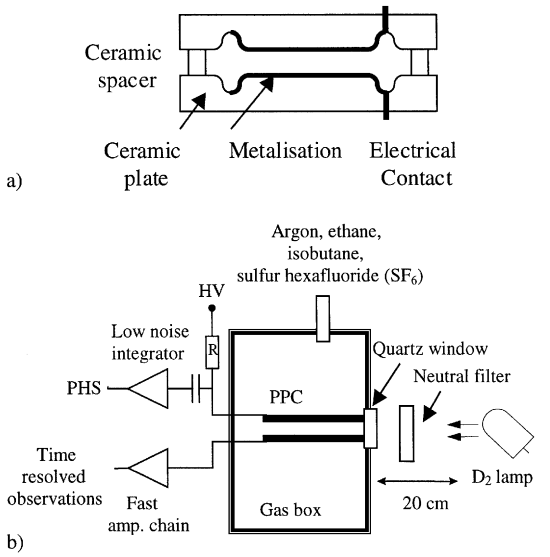

Fig. 1. (a) Structure of the detector cell and (b) experimental setup.

2. Experimental setup

The detector cell is constituted by a gas gap confined by two identical metallic electrodes. These electrodes were deposited on profiled ceramic plates [2] and the electrical contact made through a small perforation in the plate, placed outside the active gap volume. The gap width is defined by a set of four spacers placed in the corners of the square-shaped ceramic plates and also lying outside the active gap volume. A cross section of the detector cell can be seen in Fig. 1a.

The experimental setup is schematically represented in Fig. 1b. The cell is illuminated from the side by light emitted from a D_2 continuous discharge lamp, attenuated by an adjustable color-neutral filter.

The detector is read out from the cathode by a spectroscopy pre-amplifier and amplifier (CANBERRA 2001) chain and the resulting signals analyzed by a pulse height analyzer. The spectra are calibrated in charge by injection of a known voltage pulse to the pre-amplifier test input. The 50 μs integration time of the amplifying chain allows the full signal charge to be integrated. The counting rate is kept below a few hundred Hz in order to ensure that even after integration most pulses correspond to a single avalanche. Since the shape of the measured pulse height spectra was independent of the light source intensity, we conclude that most of the avalanches were initiated by single photoelectrons.

On an independent measurement made with a chamber having one glass and one metallic electrode, but otherwise similar, it was established that for a given light source intensity and gas mixture the counting rate strongly depended on whether the cathode was the metallic surface or the glass plate, being higher for the former case. This indicates that most of the electrons are released from the metallic surface and not from the gas, in which case there would be no difference between both situations.

The anode is readout by a fast current amplifier [3,4] with a rise time of 2 ns. This amplifier was used for the time-resolved measurements presented below.

The chamber was kept in a gas-tight box where an externally prepared gas mixture would continuously flow. No dependence of the measurements on the gas flow was found.

3. Results

For all mixtures studied the observed PHS can be fitted (with $\chi^2_{\mathrm{red}} < 2$) by the weighted sum of an exponential and a gamma distribution,[2] with weighting factors a and b, and parameters λ_1, λ_2, and k:

$$y = a\lambda_1 \mathrm{e}^{-\lambda_1 x} + b\,\frac{x^{k-1}\lambda_2^k \mathrm{e}^{-\lambda_2 x}}{\Gamma(k)}. \tag{1}$$

The mean value of this distribution, equal to the gas gain when x corresponds to the number of collected electrons, is given by

$$G = \frac{a}{\lambda_1} + \frac{bk}{\lambda_2}$$

being the variance given by

$$\sigma^2 = \frac{a^2}{\lambda_1^2} + \frac{kb^2}{\lambda_2^2}.$$

[2]Also known as the Polya distribution.

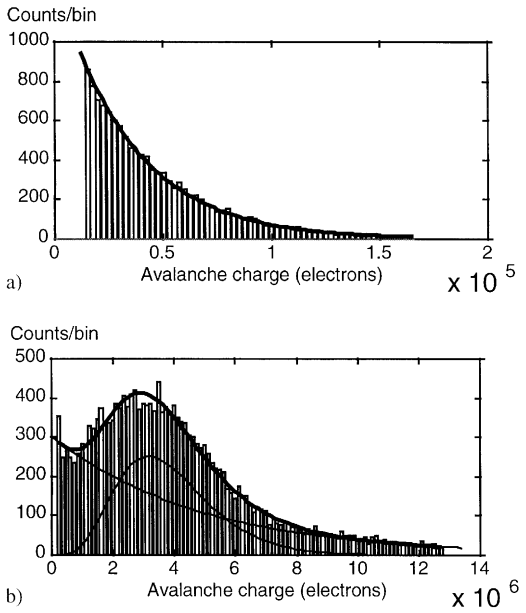

Fig. 2. Typical observed pulse height spectra for low gain (4×10^4) and high gain (3×10^6), with the adjusted analytical distributions (see text) superimposed. The gas mixture was Ar + 10% isobutane.

An example of the adjustment of the distribution (Eq. (1)) to the data is presented in Fig. 2.

A figure of merit, $0 \leq p \leq 1$, which measures the departure of the observed distribution from a pure exponential distribution corresponding to the same gas gain, is plotted in Fig. 3a as a function of the gas gain for several gas mixtures and gaps of 1.2 and 0.6 mm.

$$p = \int_0^\infty \left| y - \frac{e^{-x/G}}{G} \right| dx. \quad (2)$$

For each curve the point at larger gain corresponds to the maximum achievable gain, defined as the gain at which a breakdown rate of a fraction of Hz is observed. Such information is summarized in Fig. 4.

From Fig. 3a it can be inferred that the departure from an exponential PHS occurs mainly ($p > 0.1$) at the larger gains, above 10^5 for argon–hydrocarbon mixtures and above 10^6 for mixtures containing SF_6. The effect is larger for the 1.2 mm gap than for the 0.6 mm gap and it is much smaller for mixtures containing SF_6 (a strongly electronegative gas). At high gains, above 10^6, three families of lines with distinct magnitudes of p can be recognized.

Since the PHS shape changes with the gas composition (most notoriously with SF_6 which yields the lowest values of p) it is unlikely that the observed shape will be due to an irregular deposition of primary charge or chamber gain inhomogeneities (on the edges for instance).

Another useful figure of merit can be defined as the efficiency for single-electron detection at a given detection threshold. This detection efficiency, taken as the ratio between the number of counts above the detection threshold and the total number of counts, was calculated from the measured pulse height spectra. Notice that the pedestal was about 2000 electrons wide, corresponding to less than one bin of the multichannel analyzer. The results, for a detection threshold of 10^5 collected electrons, are presented in Fig. 3b.

The three families of lines already identified in Fig. 3a at gains above 10^6, corresponding to different magnitudes of p, can also be identified in Fig. 3b. For those mixtures where the PHS is more peaked (higher p) a given efficiency is achieved at a lower gain, but since the mixtures having a smaller value of p seem to achieve larger gains, the final efficiency is similar.

To check whether the observed PHS shape is due to some form of feedback (photon and ion feedback being the most common forms), we looked for the presence of aftercurrents following the main avalanche but no statistically significant evidence of such processes was found.

In Fig. 5, we show a typical current signal in the vicinity of a breakdown event. The characteristic precursor–streamer structure of the Raether breakdown mechanism [5–8] is clearly visible, in sharp contrast with the slow current growth typical of the feedback-mediated Townsend breakdown mechanism [5–8], thereby confirming that feedback does not play a major role in the chamber behavior.

The results shown in Fig. 4 indicate that, although some optimization is possible, the maximum achievable gain for all gases studied lies within the same order of magnitude. The maximum avalanche charge is more than one order of magnitude smaller than the well-known Raether criterion of streamer breakdown (10^8 electrons). This may be related to the fact that the streamer is triggered by

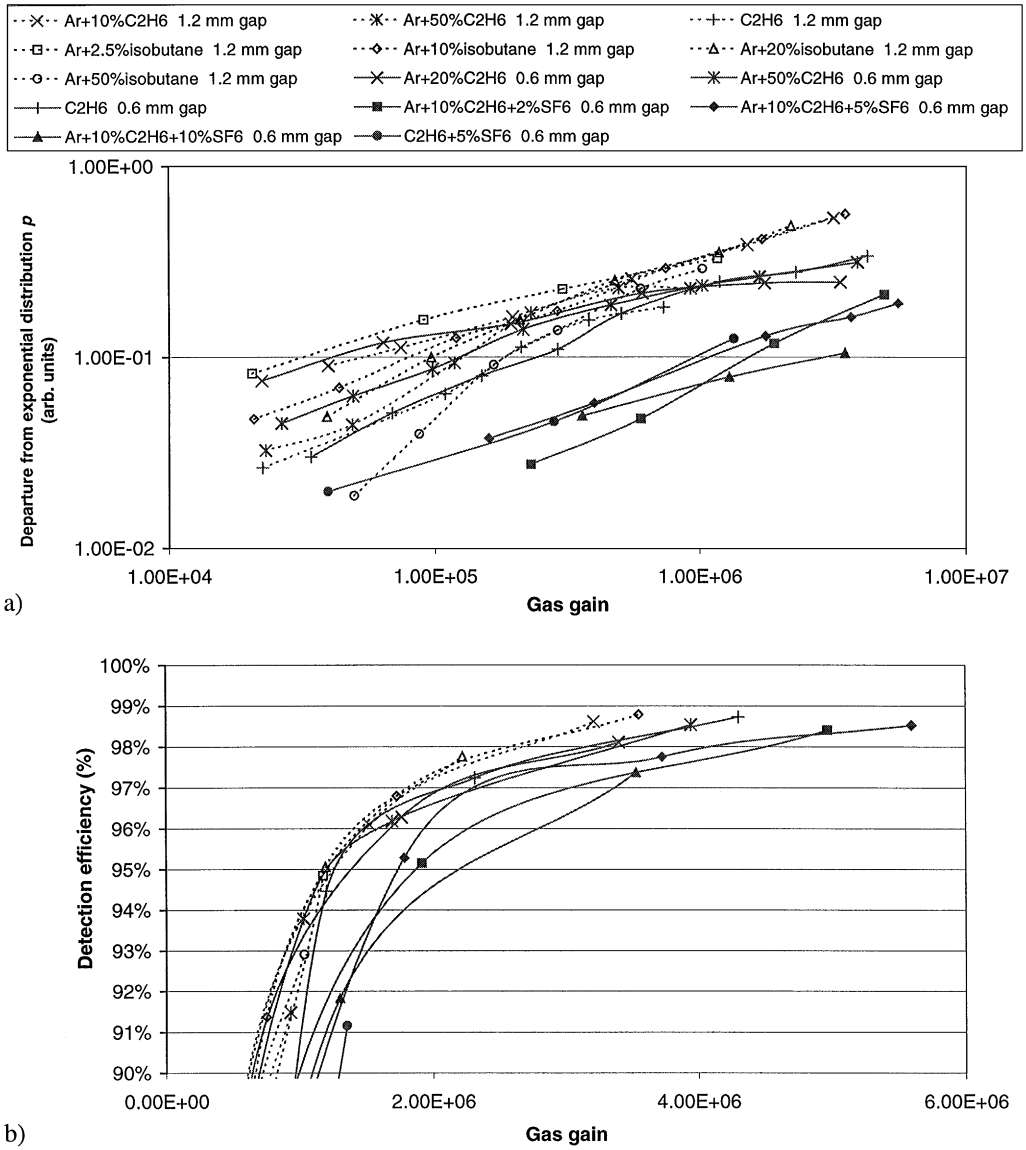

Fig. 3. (a) Departure of the observed distribution from a pure exponential distribution, as defined by Eq. (2); (b) Detection efficiency for single photoelectrons, considering a detection threshold of 10^5 collected electrons.

a space charge effect that depends on the charge density inside the avalanche, that is, on the inverse of the cube of the avalanche linear dimensions. Since the gaps are very narrow and the width of the primary charge deposition is null (1 electron) necessarily the avalanche will be smaller than in the (more common) case of a gap with a few mm width.

4. Conclusions

We studied the PHS of avalanches initiated by single electrons in thin-gap PPCs suited for TOF detectors. The measured PHS constitutes a basic input information to any Monte Carlo model of such detectors.

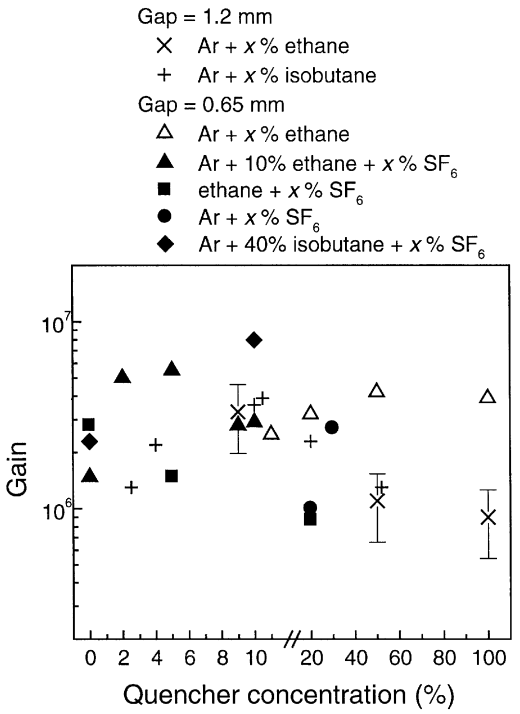

Fig. 4. Maximum achievable gain for several different gas and gap length conditions. Some estimated representative error bars are also displayed.

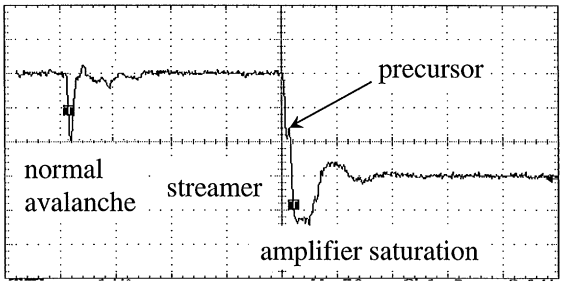

Fig. 5. Current signal for a breakdown event recorded on a digital oscilloscope via the fast amplifier chain described above. The horizontal scale corresponds to 50 ns/division and the vertical scale is in arbitrary current units. The gas was Ar + 10% ethane on a 0.6 mm gap.

At large gains the PHS shape departs from the exponential distribution observed at lower gains, forming a peak. The magnitude of such departure (p) depends upon the gas gain, the gap width and the nature of the gas mixture.

No relevant photon or ion feedback was observed, ruling out such origin for the peaked PHS shape. The dependency of the spectrum shape on the gas mixture, for a given detector, seems to exclude that the effect would be caused by gain inhomogeneities within the chamber or on its edges.

The maximum achievable gain lies between 10^6 and 8×10^6 for all mixtures studied, limited by the appearance of streamers.

For some gas mixtures single photoelectron detection efficiencies in excess of 98% were measured for a detection threshold of 10^5 collected electrons. For such mixtures an inverse relation seems to exist between the magnitude of p and the maximum achievable gain, resulting in identical maximal detection efficiencies.

Acknowledgements

Some of the necessary hardware was provided by ITEP, Moscow, but this work would never have been started without the friendly encouragement of Dr. Francois Piuz.

References

[1] ALICE - Technical Proposal for A Large Ion Collider Experiment at the CERN LHC, CERN/LHC/95-71, December 1995.
[2] V. Akimov et al., Nucl. Instr. and Meth. A 344 (1994) 120.
[3] R. D'Alessandro et al., preprint ITEP 51–95.
[4] A. Martemianov, Proceedings of the First Workshop on Electronics for LHC Experiments, Lisbon, 11–15 September, 1995.
[5] H. Raether, Electron Avalanches and Breakdown in Gases, Butterworths, London, 1964.
[6] J.M. Meek, in: J.A. Rees (Ed.), Electrical Breakdown of Gases, MacMillan, London, 1973.
[7] P. Fonte et al., Nucl. Instr. and Meth. A 310 (1991) 140.
[8] P. Fonte, IEEE Trans. Nucl. Sci. NS-43 (1996) 2135.