Manifestation of Aging Effect in Gas Proportional Counters

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Abstract

Influence of aging on energy resolution, length of energy resolution plateau, decrease of gas gain and on the so-called count rate effect has been measured. Special attention has been put to the performance of aged counters under high gas gain and high count rate.

1 Introduction

Ageing of gaseous detectors designates a permanent decrease of the observed signal amplitude as the total accumulated charge increases. This degradation of the response is most often due to solid deposits on the anode wire, which eventually leads to a break down of the operational stability of the detector. The aging of gaseous detectors is complex process, which depends upon a large number of parameters, which very often get out of hand. Most of the aging studies of gas counters are performed at much faster dose rates then standard proportional counter operation condition [1].

In our measurements, iso-pentane has been selected as the admixture to age the counters at short time at their standard operation close below 1 μA/om of anode wire. The detectors were exposed to radiation coming from the ^{109}Cd and ^{90}Sr sources. Four cylindrical, proportional counters were investigated [2]. Below are given detailed information on counters and aging conditions:

- Counter no. 1 and 2, Ar/iso-pentane 95/5 working gas; ^{90}Sr – aging source; brass cathode, 25 mm in diameter; W/Au anode, 100 μm in diameter, aging current – 1 μA.
- Counter no. 3, Ar/CO_2/N_2/iso-pentane 70/10/10/10 working gas; ^{90}Sr – aging source; brass cathode, 32,1 mm in diameter, W/Au anode, 100 μm in diameter, aging current – 85 nA.
- Counter no. 4, ^{109}Cd – aging source; aging current – 20 nA; all other parameters the same as for counter no. 3.

The impacts of aging on counter energy resolution, gas gain, and shape of the pulse height spectra and on the so-called count rate effect have been experimentally studied. Special attention has been put to the performance of aged counters under high count rate and high gas gain. The main scope of this work is to find which detector parameter is mostly sensitive on ageing.

2 Influence of aging on energy resolution

If we accept as a measure of the resolution the relative variance of the pulse height distribution determined in a given electronic circuit, then for monoenergetic radiation with energy E this variance equals the sum of three statistically independent terms:

$$\left(\frac{\sigma E_S}{E}\right)^2 = \left(\frac{\sigma E_A}{E}\right)^2 + \left(\frac{\sigma E_n}{E}\right)^2 + \left(\frac{\sigma E_o}{E}\right)^2$$

The first term accounts for the statistical fluctuations of charge produced in the active counter volume in two processes: primary ionisation and avalanche multiplication. The resolution defined by these processes will be termed the limiting resolution and depends strongly on the gas amplification factor.

The sources of current and voltage noise occurring in the amplification line give rise to additional statistical fluctuations of the signal amplitude thus resulting in a deterioration of the resolution.

There is a third, statistically independent factor, $\sigma E_0 / E$, which limits the resolution of each spectrometric system, normally the spread in the rise-time of current pulses generated in the counter. A non-zero spread in the rise-time spectrum is determined among other things by the diffusion processes which terms depends on the relative contribution of weak fields occurring in the active volume of the counter.

One can expect that any deterioration in electric field in the region of avalanche lead to the broadening of the measured pulse height distribution. Change in the relative variance of the gas amplification factor (first term in above equation) and the spread pulse rise-time are taking part. The formation of insulating layers on the anode of proportional counter is a major effect of its long-term exposition to the radiation. The presence of the insulating deposit modifies by the surface charging the space distribution of the electric field in the active volume of the counter, thus degrading the energy resolution [3].

Obtained results of measurements of energy resolution and of the length of energy resolution plateau as function of collected charge and applied high voltage are displayed on Figs. 1, 2, 3 and 4 respectively. It is seen clearly, that energy resolution linearly depredates with the increase of collected charge. Effect is much stronger for the higher applied HV.
It should be underline that for all measured counters, the obtained results are in excellent agreement.

3 Influence of aging on gas gain

The change in gas gain was determined from the measured charge in pulse height distribution of ^{55}Fe – line. Denoting by k the amplification factor of the amplifier one can write the following expression for the pulse amplitude at the output of spectroscopic circuit, U:

$$U = f(\bar{t}, t_r)k\left(\frac{E}{W}\right)A,$$

where: $f(\tau, t_r)$ is a factor depending on, among others, the pulse shaping time constant τ and on the shape of pulse; t_r – is the pulse rise-time; W – is the mean energy loss needed to produce an ion-electron pair in the given gas; A – gas gain. If the shape of all the pulses produced in the counter were identical, t_r = constant, then for a given energy E measured in a detecting system of the parameters τ, k and W one state that the amplitude is a function of the gas gain factor A only, ($U = f_1(A)$).

Most of the parameters, which describe the growth of electron avalanche in an electrical field, especially α/p (α – Townsend's first ionisation coefficient, p – gas pressure) are explicit functions of electric field strength E_r. In a cylindrical counter of diameter $2r_k$ with an anode of diameter $2r_a$ placed along the axis of the cylinder, the electric field strength E_r is given by the standard relation:

$$E_r(r) = \frac{V}{r \ln \frac{r_k}{r_a}},$$

where V is the voltage applied between the cathode and anode. Thus $U = f(A(V, r_a))$, for all other parameters kept constant. One of the indications of aging is the increase in anode diameter caused by the deposit of insulating or conducting layers. This leads to decrease in E_r, its strong non-uniformity followed by reduction in gas gain.

For instance, generation of the layer, 0.5 μm in the thickness on anode wire, 25 μm in diameter can reduce gas gain by (20 – 40)% [4]. In case of an insulator layer, the anode is shielded and the layer is negatively charged up. It conducts to further reduction in gas gain, by decreasing in V.

The results of measurements of relative decrease in gas gain as function of collected charge, for counters no. 1 and 2, for different value of applied HV are displayed on Figs. 5, 6. For both counters, relative decrease in peak position is linear function of collected charge, the effect is much stronger for higher HV. For fixed collected charge, the relative decrease in peak position is also linear function of applied HV (Figs. 7, 8).

4 Influence of aging on count rate effect

The increase of radiation intensity measured by a proportional counter leads to undesirable changes of its parameters, such as pulse height and energy resolution. It has been found that both the pulse height and the energy resolution significantly decrease with increasing radiation intensity. These changes are called "count rate effect". At present there are four different concepts explaining the count rate dependence of the pulse amplitude shift in proportional counters. Hendricks' concept considers the pulse amplitude shift as arising from the continuous decrease in the gas amplification factor, resulting from the presence of slowly moving positive ions in the avalanche multiplication region. Spielberg and Tsarnas suggested that the primary mechanism for the shift is the build up on the anode wire of a loosely bound layer of polarizable molecules, or molecular fragments of quench gas, which effectively increases the diameter of the anode wire, thereby decreasing the gas gain for a fixed applied voltage. In both above maintained concepts, the quality of anode surface is important and can strongly influence on measured change in the pulse height. Theory proposed by Mahesh and Bednarek are independent of anode surface quality [5-10].

To determine the influence of aging on count rate effect, following counter parameters were determined:

- Energy resolution as the function of count rate for different value of collected charge.
- Relative changes in peak position MnK – line as function of count rate for different value of collected charge.
- The changes in pulse spectra were also followed.

Selected, representative results are shown in Fig. 9 and 10. Energy resolution, R, for new counters is nearly independent on intensity of registered radiation, while for aged counter strongly depends on count rate. For instance, for the flux of incoming photon ~ 10 kcps, for new counter, R = 16% (for ^{55}Fe – line); for collected charge Q = 1.38 C, R = 26% but for Q = 3.54 C, R = 38%. Pulse height spectra for different flux of photon are presented in Fig. 11. It should be pointed out that for count rate I = 490 cps, quite good spectrum is obtained, but for I = 710 cps second peak starts to appear. It is clearly seen from Figs. 9, 10 and 11, that count rate below 400 cps, R is aging independent.

5 Conclusions

- Strong degradation in energy resolution and shortening of energy resolution plateau were observed. This effect is much stronger for higher gas gain.
- The decrease in gas gain for fixed HV function of collected charge.
- The decrease in gas gain, for fixed collected charge is also linear function but of applied high voltage.
- Count rate effect of aged counters strongly depends on collected charge and applied high voltage, for low gas gain and low intensity of registered good spectrum is observed, while for high gas gain and a little higher count rate the double peak is measured.

It should be underlined that all aging tests were realized for normally encountered anode current.

6 References

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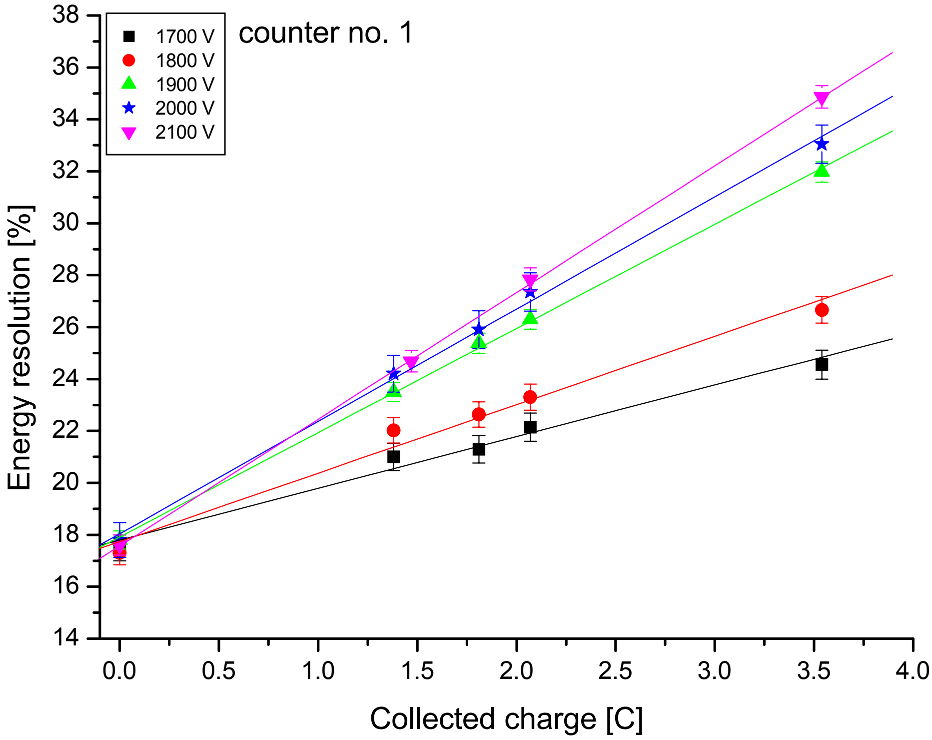

Fig. 1. Energy resolution as function of collected charge, for different applied high voltage, for aged counter no. 1.

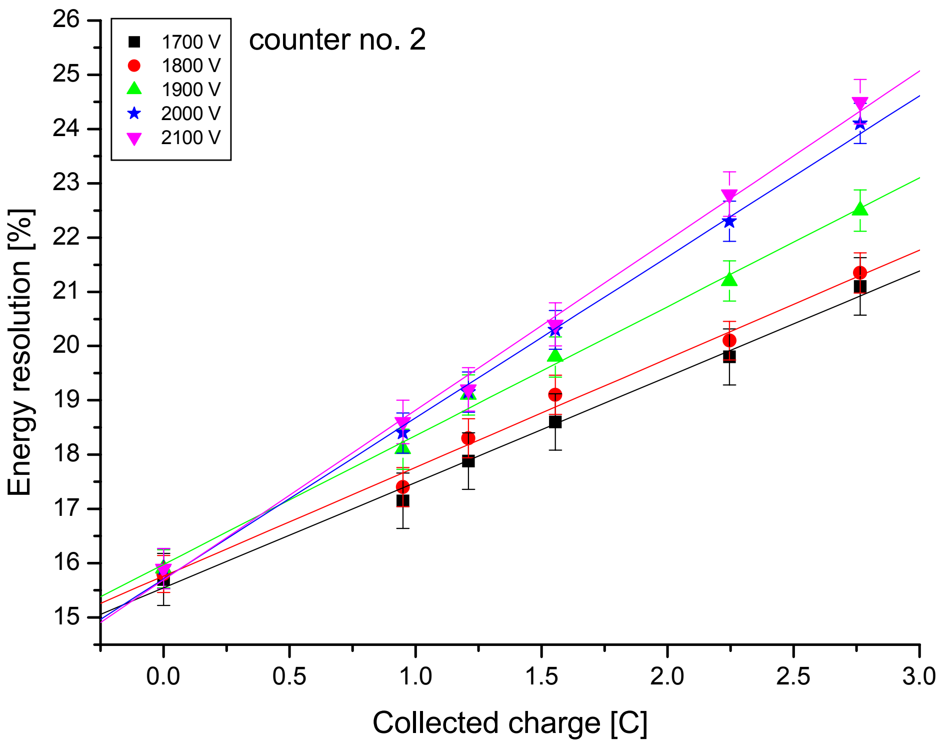

Fig. 2. Energy resolution as function of collected charge, for different applied high voltage, for aged counter no. 2.

For new counters, the energy resolution plateau length is near 500V, while for aged counters, the plateau doesn't exist.

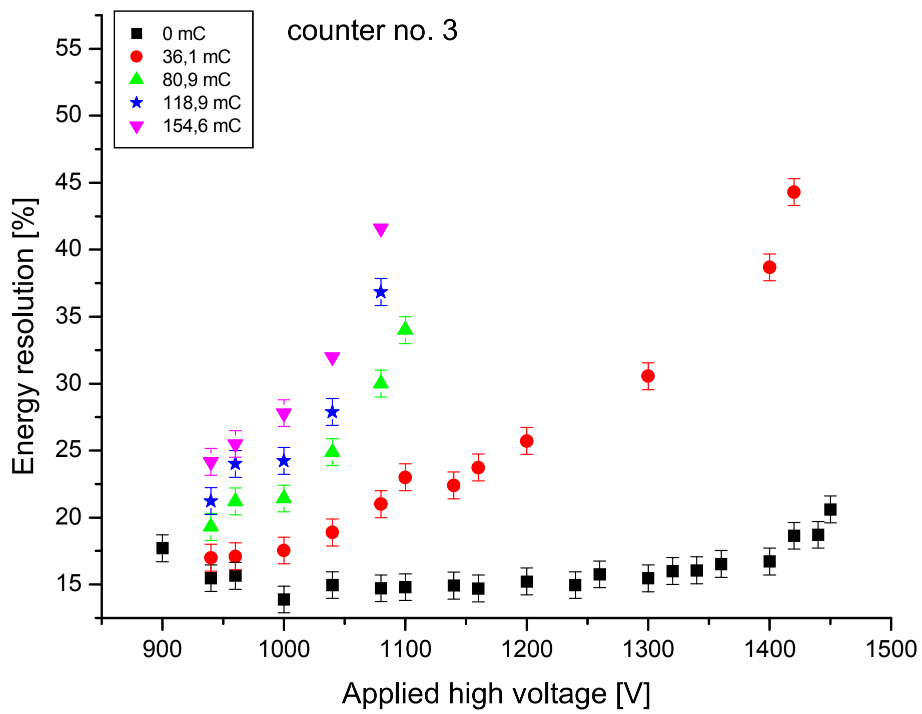

Fig. 3. Energy resolution as function of applied high voltage, for different value of collected charge, for aged counter no. 3.

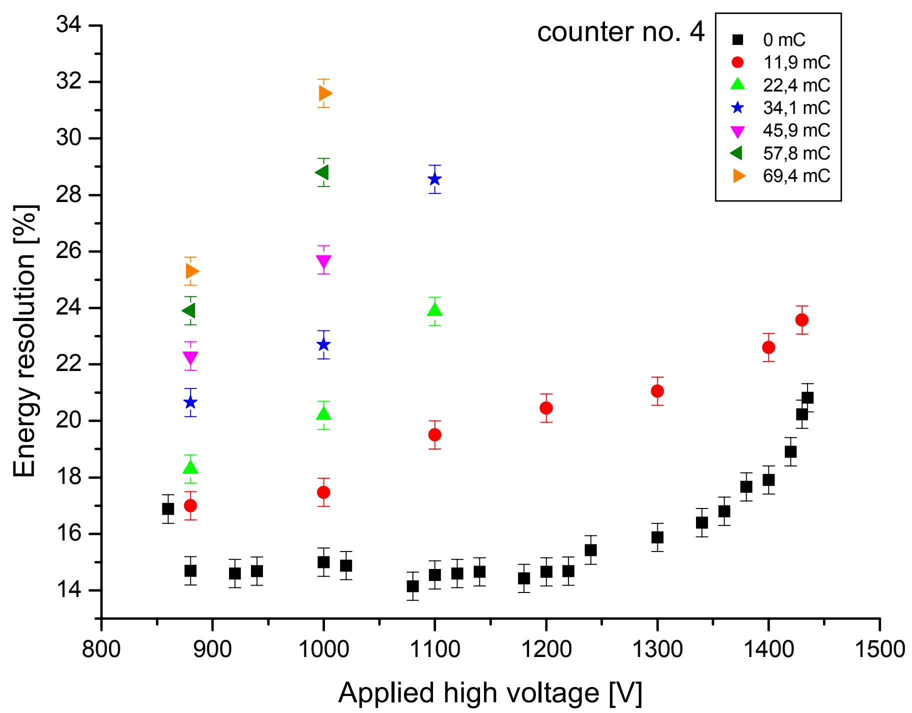

Fig. 4. Energy resolution as function of applied high voltage, for different value of collected charge, for aged counter no. 4.

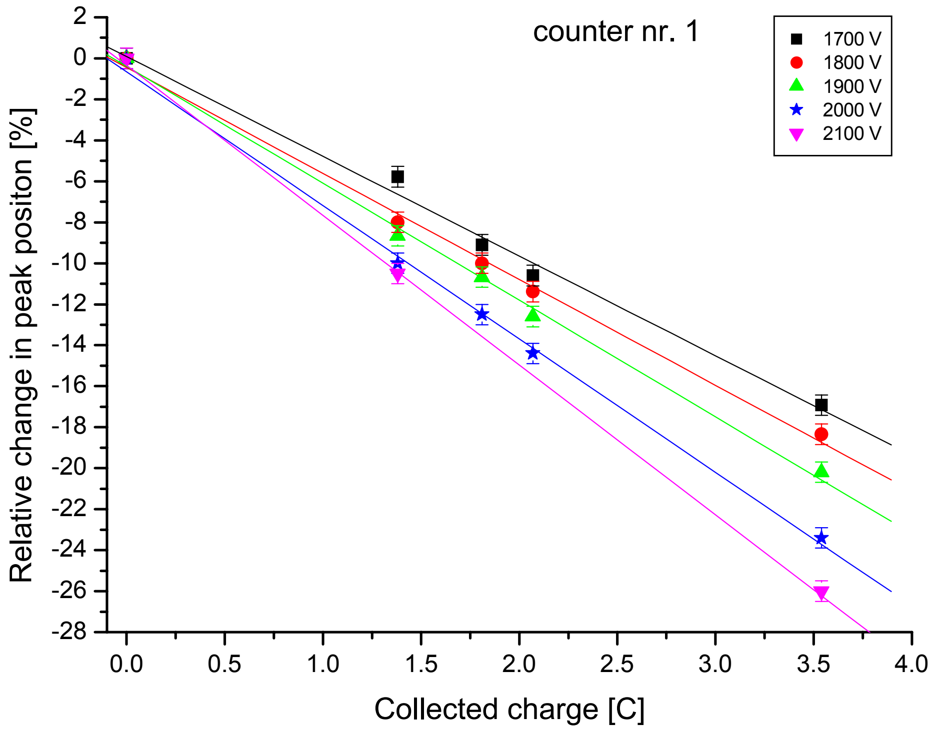

Fig. 5. Relative change in the pulse height as a function of the collected charge for proportional counters filled with a mixture of Ar/iso-pentane 95/5, for counter no. 1. The ordinate is the relative decrease in pulse height from the value corresponding to the new counter.

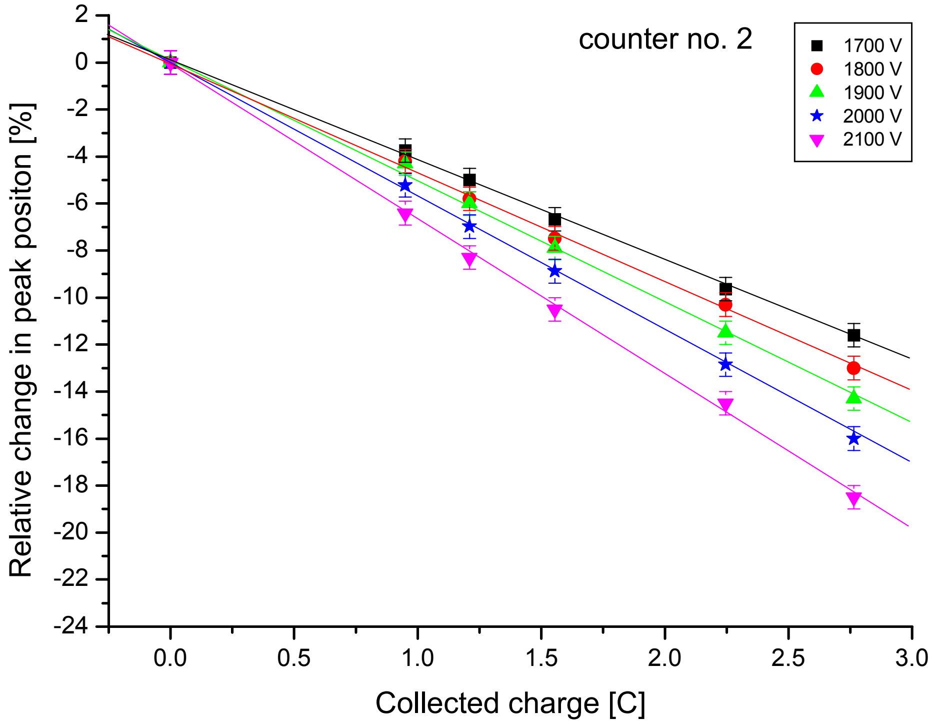

Fig. 6. Relative change in the pulse height as a function of the collected charge for proportional counters filled with a mixture of Ar/iso-pentane 95/5, for counter no. 2. The ordinate is the relative decrease in pulse height from the value corresponding to the new counter.

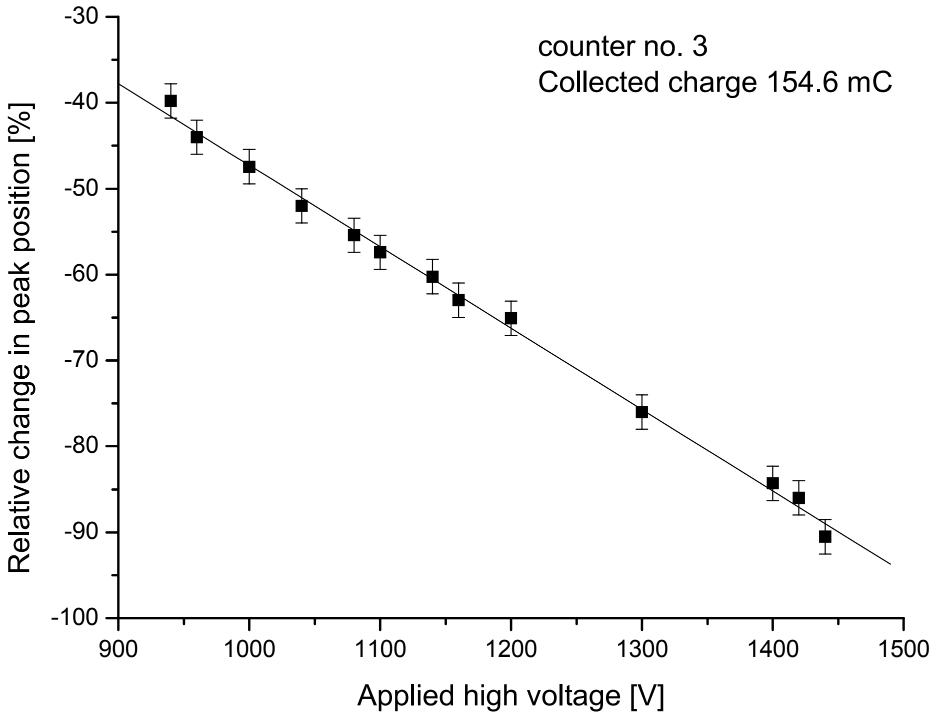

Fig. 7. Relative change in the pulse height as a function of applied HV for proportional counters filled with a mixture of Ar/CO2/N2/iso-pentane 70/10/10/10, for counter no. 3. The ordinate is the relative decrease in pulse height from the value corresponding to the new counter.

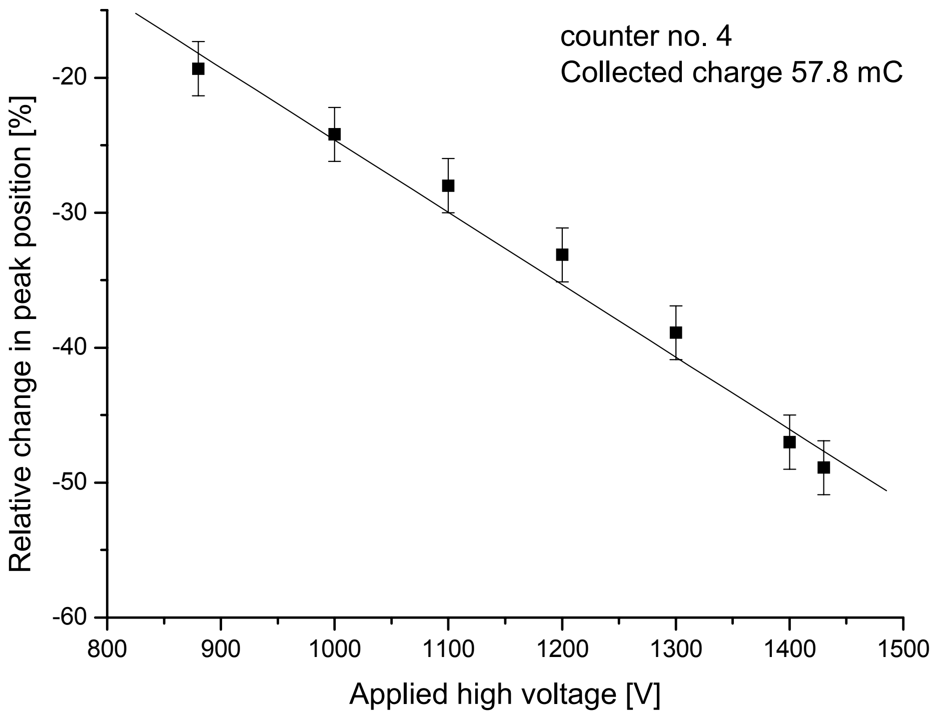

Fig. 8. Relative change in the pulse height as a function of applied HV for proportional counters filled with a mixture of Ar/CO2/N2/iso-pentane 70/10/10/10, for counter no. 4. The ordinate is the relative decrease in pulse height from the value corresponding to the new counter.

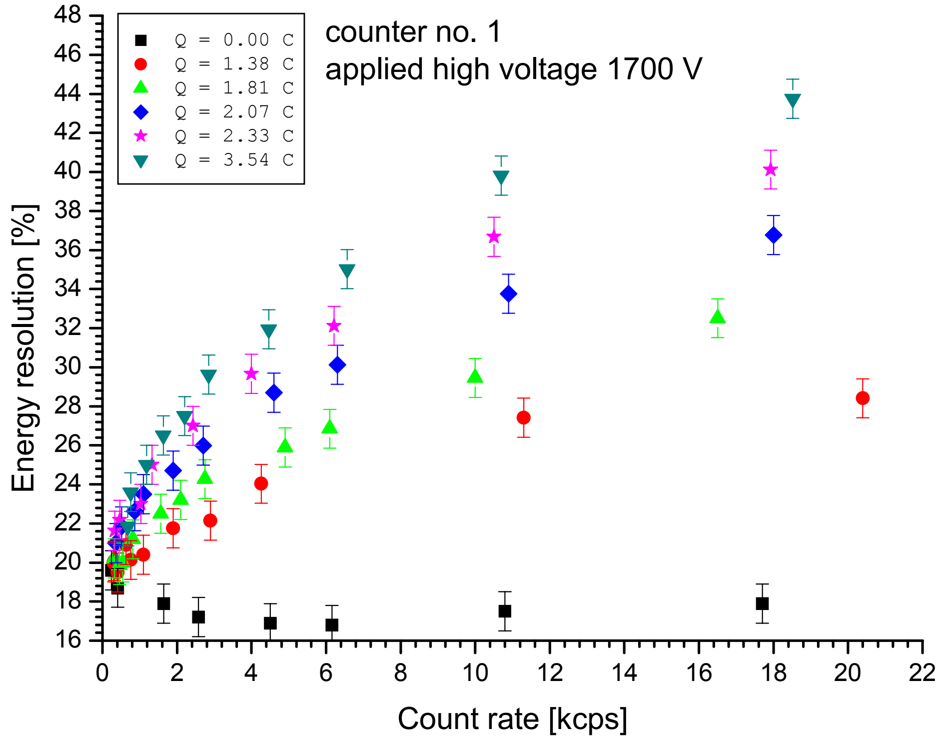

Fig. 9. Energy resolution as function of count rate, for counter no. 1, for different value of collected charge.

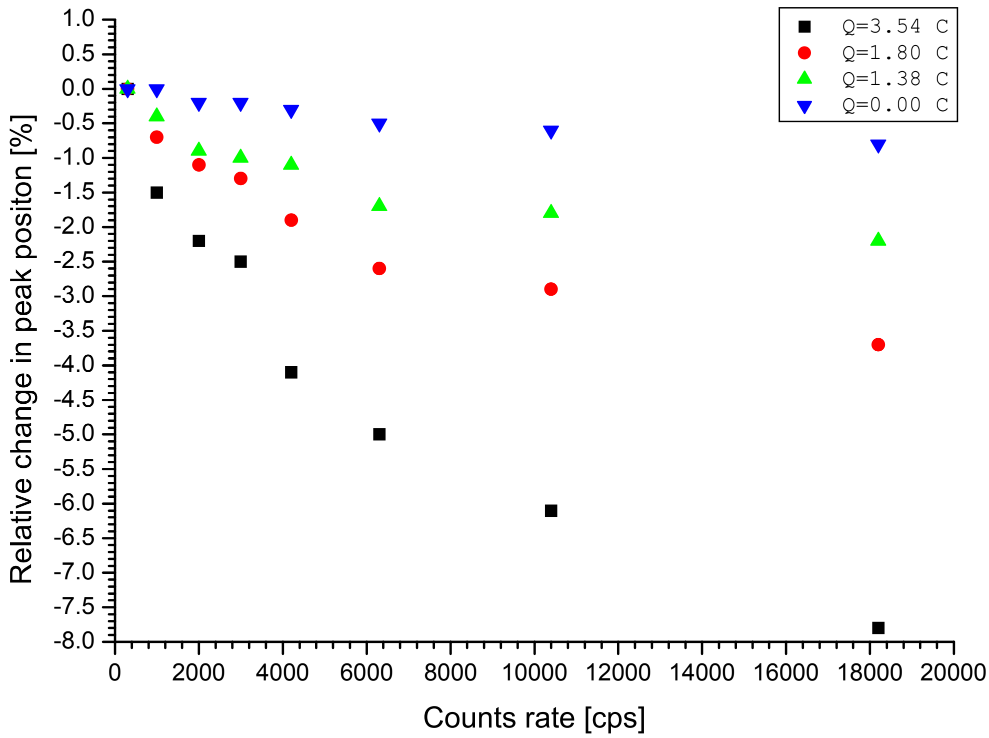

Fig. 10. Relative change in the pulse height as a function of the count rate for counter no. 1, for different value of collected charge. The ordinate is the relative decrease in pulse height from the value corresponding to the count rate below 400 cps.

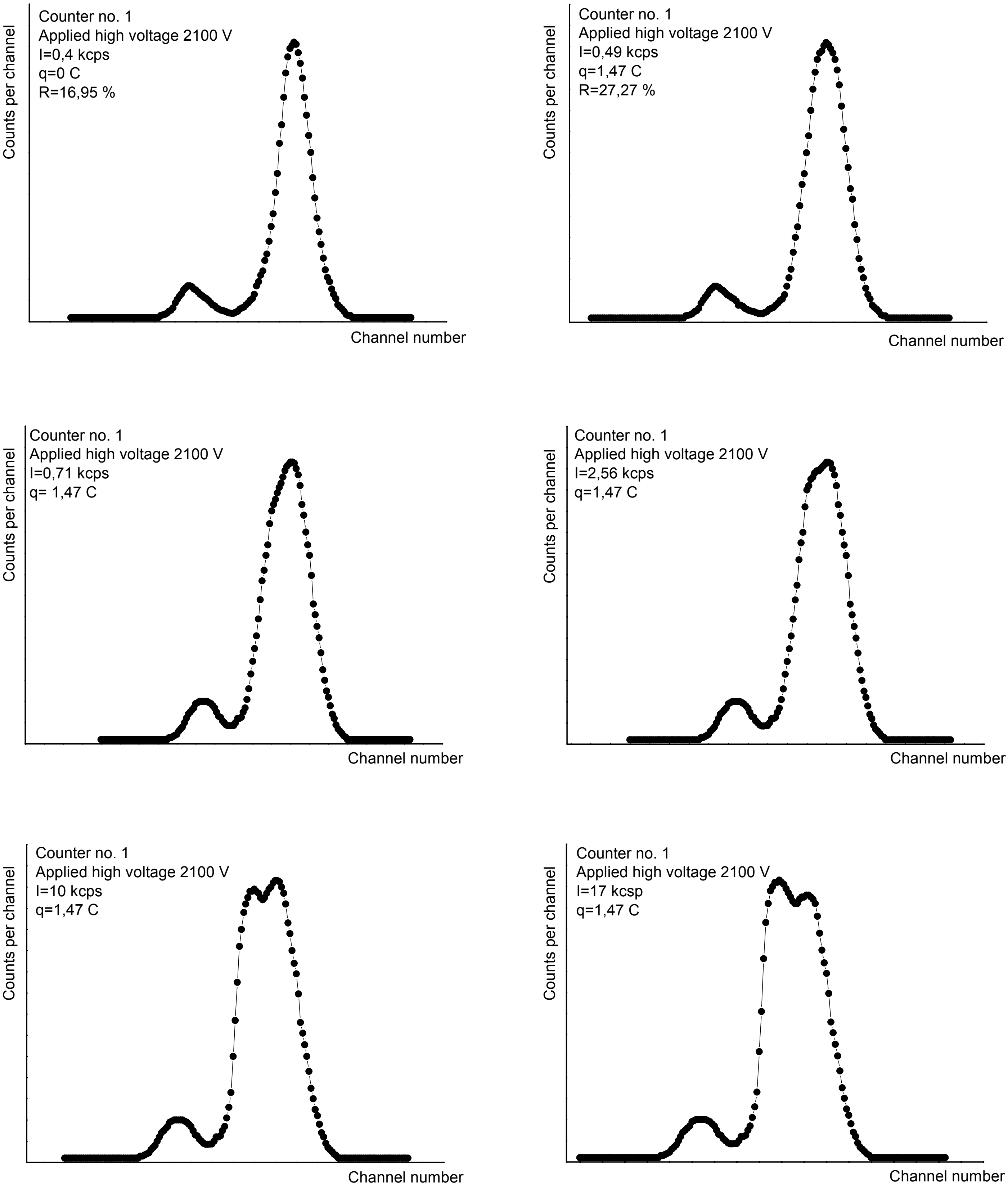

Fig. 11. Pulse height spectra, for counter no. 1, for fixed both collected charge q = 1.47 C and applied HV = 2100 V, but for different count rate, I.