Nuclear Inst. and Methods in Physics Research, A 910 (2018) 164–167

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

# A multi-cathode counter in a single-electron counting mode

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ARTICLE INFO

*Keywords:*
Proportional counter
Single-electron counting
Low threshold detector

ABSTRACT

We describe the operation of the multi-cathode counter developed by us. It has an aluminum alloy cathode and operates in single-electron counting mode. The calibration results are given. The gas gain was found from the calibration spectra. The electric fields and the operation of this detector in two configurations are described. Our original idea was to measure the effect of electrons emitted from the cathode surface according to the difference in count rates in two configurations. We found the optimal potential difference between the first and second cathodes in the two configurations using the calibration measurements of the count rates. In addition, the advantage of using a multi-cathode counter for measuring the intensity of single-electron emission from a metal is explained.

## 1. Introduction

At present, low-threshold detectors with a high efficiency for detecting low-energy ionizing radiation are used in experiments such as the search for dark matter and observations of coherent elastic neutrino-nuclear scattering. One of the background sources in these detectors is single electrons emitted from a metal surface. In a number of experiments [1–4], the rates of emission of single electrons from the photocathode of a photomultiplier were measured at different temperatures from cryogenic to room temperature. Contrary to expectations, the rate of emission does not decrease with decreasing temperature: measurements showed that it increased significantly. The effect was observed when using the Hamamatsu R7725-Mod and R5912-Mod photomultipliers with a bi-alkali photocathode (K–Cs–Sb) on a thin platinum backing to improve the characteristics at low temperatures. This unexpected result has still not been explained satisfactorily. In the measurements with the photomultiplier, a photocathode with a low work function of about 1 eV or less was used. Thermionic emission from a metal, which depends on the work function $w$ and the temperature $T$ in Kelvin, is expressed by the well-known Richardson equation:

$$R_{therm} = a \cdot T^2 \cdot e^{-\frac{w}{kT}} \quad (1)$$

where $R_{therm}$ is the thermionic dark rate and $k$ the Boltzmann constant. Consequently, because of the strong temperature dependence for a small work function, the contribution of thermionic emission can be large at room temperature. In low-threshold detectors, the electrodes are usually metals with a relatively high work function (about 4–5 eV). It is expected that the contribution of thermionic emission from these detectors will be much lower. We need to measure the emission rate for different metals with a high work function. The emission rate for these metals is expected to be lower than for a photomultiplier photocathode with a low work function. Thus, a detector with a high sensitivity to single electrons and with a very low emission rate of less than 0.001 electron Hz/cm$^2$ is required for this task. The device may be used also for searching for hidden photons from cold dark matter by counting single electrons emitted from a metallic cathode [5]. It seems to be expedient to use a gas detector with a low dark rate for these measurements. To register single electrons, the detector must have a high gas gain, but also a large surface and low dark rate and so on, which seem somewhat contradictory. To fulfill all the requirements, we developed a special multi-cathode counter. Other types of gas detectors, such as GEM or solid state electronic counters, usually have a much higher dark rate [6]. A brief description and preliminary results of measurements using a copper cathode counter have been published [7,5]. Here the operation of our counter with an aluminum alloy cathode and focusing rings is described in detail. Aluminum was chosen because its quantum efficiency in the vacuum-ultraviolet (VUV) region [8], where the counter has a high sensitivity, is about 1.5 times higher than that of copper. Focusing rings allow us to reduce the edge effect of the ends of the counter. For optimal selection of the potential on the first and second cathodes, the counting rate was measured when the detector was irradiated with a UV lamp in two different configurations (Fig. 5).

## 2. Design and method

The counter and a schematic drawing are shown in Fig. 1. The detector is encapsulated in a sealed stainless steel cylinder, and all electrical connections are made through vacuum seals at one end of the counter.

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https://doi.org/10.1016/j.nima.2018.09.075
Received 16 April 2018; Received in revised form 17 September 2018; Accepted 17 September 2018
Available online xxxx

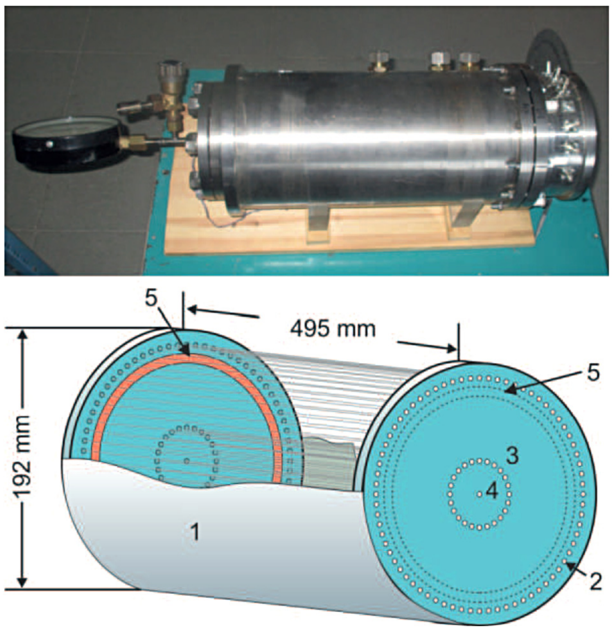


**Fig. 1.** Top — the picture of the counter. Bottom — schematic drawing of a multi-cathode counter. 1 — an aluminum cathode, 2 — second cathode, 3 — third cathode, 4 — anode, 5 — focusing rings.

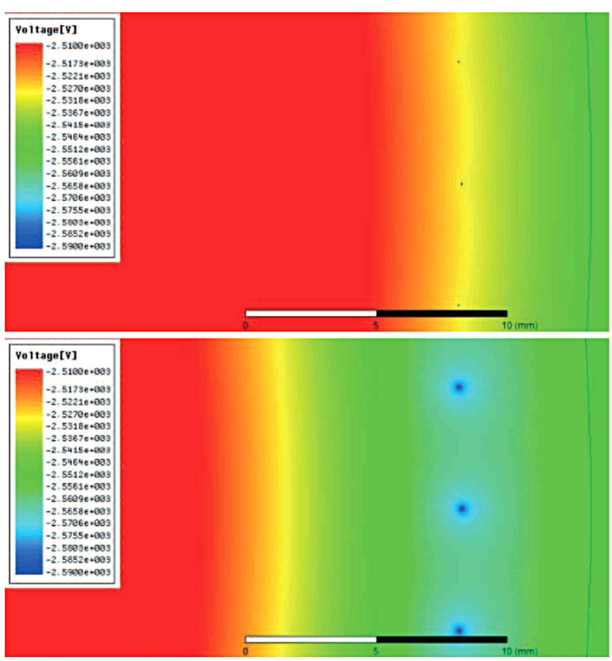


**Fig. 2.** The potentials in configurations 1 (top) and 2 (bottom).

It has a high sensitivity for detecting single electrons emitted by the cathode due to the relatively large surface (≈ 3000 $cm^2$) of the outer cathode. The second cathode is 5 mm from the outer cathode. It consists of a series of nichrome wires of diameter 50 μm with a pitch of 4.5 mm. Electrons emitted from the surface of the outer cathode drift to the central counter, which has the third cathode. This has a diameter of 40 mm and consists of nichrome wires spaced 6 mm apart. The anode of the central counter is made of gold-plated wire made of W-Re with diameter 25 μm. This geometry makes it possible to obtain a relatively high gas gain factor of about $10^5$. As a working gas, a mixture of $Ar$ and 10% $CH_4$ is used at a pressure of 0.1 MPa. The focusing rings at

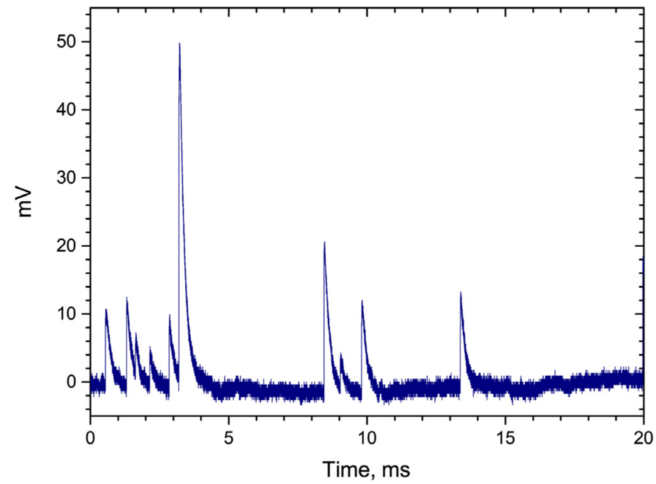


**Fig. 3.** The pulses from single electrons on the output of charge sensitive preamplifier observed during calibration by UV lamp.

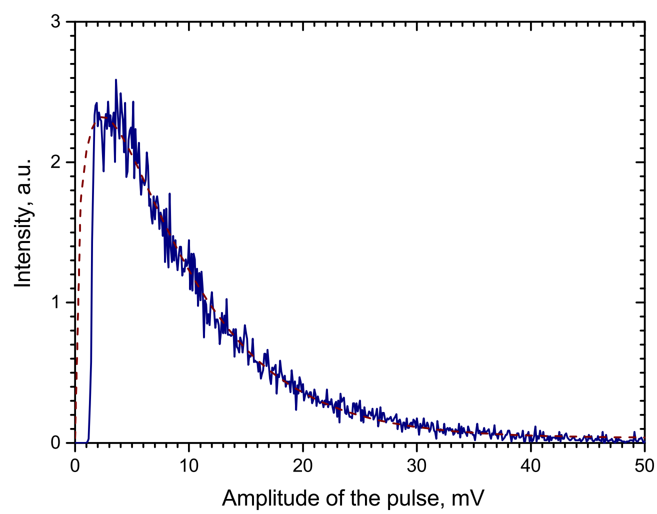


**Fig. 4.** The calibration spectrum of single-electron events obtained in a first configuration. Dashed line — Polya distribution.

the ends of the counter under the potential of the second cathode are used to shift the trajectories of the drifting electrons from the ends of the counter to its center, which prevents the electrons emitted by the cathode being absorbed by the surface at the ends of the counter. To protect the detector from external $\gamma$-radiation, the counter is placed in an iron cabinet 30 cm thick. The measurements were made on the ground floor in Troitsk, Moscow Region. A high voltage from three sources was applied to cathodes 1, 2, and 3: $U_1 = -2550$ V to cathode 1, $U_2 = -2530$ V to cathode 2 in the first configuration and $U_2 = -2590$ V to cathode 2 in the second configuration, and $U_3 = -1800$ V to cathode 3. Fig. 2 shows the potentials at the edge of the counter (calculations performed by ANSYS Maxwell), which shows the effect of the barrier from the second cathode in configuration 2.

The signal from the anode wire is fed to the charge-sensitive preamplifier (CSP) input, which has a sensitivity of about 0.4 V/pC. The CSP output is connected to the input of an 8-bit NI5152 digitizer. The pulse shapes were digitized in intervals of ± 50 mV with a frequency of 10 MHz and a sampling step of 400 μV. Each measurement lasted for 12 h, after which the data obtained were processed offline. The data were collected in two configurations: (1) the potential $U_2 = -2530$ V applied to the second cathode allows electrons emitted from the outer cathode to drift freely to the central counter and (2) a retarding potential $U_2 =$