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Timing performance of spark counters and photon feedback ¹

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Abstract

It was shown experimentally that delayed signals from the spark counters ("tail problem") could be connected with low gain avalanches. The development of these avalanches is stopped by the anode electrode but they still have a chance to produce a delayed streamer by photon feedback. Good absorption characteristics of the gas mixture at wide photon energy range (starting from a cathode work function up to the x-ray region) and a high cathode work function value reduce the tail.

1 Introduction

A TOF system provides good particle identification if the time resolution spectrum has small tails. The nature of the timing tail from the spark counters [1] proposed as detector for TOF systems [2] is under discussion in this paper.

Fig. 1 shows the principle layout of this type of the counter. The counter is read out via strip lines positioned on the outer side of the resistive plate electrode. The wave impedance of each strip line is equal to 50Ω . Signals from sparks are detected by fast discriminators at both sides of each strip. The counter characteristics were optimized for particle identification. The 2 mm thick anode was made of semi-conducting glass with a bulk resistivity value of more than $10^9 \Omega\text{cm}$. The cathode was metallic. A gap size of 100 mm and the gas pressure of 12 bar provided a time resolution up to 25 ps at about 96% efficiency [3]. The gas mixture absorbed photons from low energies

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corresponding to the cathode work function up to the X-ray range to exclude secondary sparks by the photon feedback. Fig. 2 (curve 1) shows the absorption spectrum of the standard gas mixture consisting of 0.07(bar) C_4H_6 + 0.3 C_2H_4 + 2.4 C_4H_{10} + 9.23 Ar = 12 bar. Each gas component absorbs photons at a different photon energy range.

Many previous experiments with various gas compositions (but without freons) and with various cathode materials [4] observed a strong influence of the photon feedback on the discharge localization at the wide photon energy range starting from the cathode work function up to the X-ray region. Fig. 3 shows new examples of this effect. The average signal from the counter was used to estimate the level of the discharge localization. For the standard gas mixture but without 1,3-Butadiene (C_4H_6) the localization decreased dramatically (Fig. 3, curve 2). After the replacement Ethylene (C_2H_4) by the same quantity of Propylene (C_3H_6) the localization of the gas composition without 1,3-Butadiene (C_4H_6) was almost restored (Fig. 3, curve 3) because the absorption characteristic of this new component covered partially the absorption region of 1,3-Butadiene (see Fig 2, curve 1). Please note the practical result of the last experiments: it was found another gas mixture for the spark counters without 1,3-Butadiene, which is now considered to pose a potential health hazard.

2 Timing performance of the spark counter

2.1 Experimental characteristics

The characteristics of the spark counters discussed in this paper were measured in experiments with cosmic rays, heavy ion beams at the GSI accelerator facility and γ -source.

The experimental setup for the cosmic tests consisted of two spark counters, which were placed on the top of each other at a distance of 50 mm. The timing spectra between these counters were taken using as a trigger the coincidence signal of both counters. The features of these experiments are: a) the full area of 40×300 mm² of each counter was under test; b) about 1-2 days were needed to accumulate a timing spectrum; c) stability and reproducibility of the results during more than one month of operation were demonstrated.

Fig. 4 shows the counter time resolution based on the FWHM of the experimental distributions depending on the overvoltage U/U_0 , where U_0 is the counter threshold. To estimate quantitatively the percentage of the timing tail events two characteristics were calculated for each experimental distribu-

tion: the "non-gaussian tail", i.e., the part of a distribution, which extends beyond the gaussian curve, and the "timing tail > 500 ps", i.e., the input in the tail from events with a delay time more than 500 ps. This last value corresponds roughly to the average time interval from a primary ionization to the appearance of the streamer . Fig. 5 shows dependence of these two characteristics on the overvoltage for the counters with the standard gas mixture (standard organic + Argon) and with a new gas mixture (standard organic + Neon).

The experimental setup for the spark counter tests at the GSI heavy ion beam facility is described in [5]. At these experiments a comparative test of the spark counter performance with different gas compositions based on the organic part from the standard gas mixture in combination with a noble gas (Helium, Neon, Argon, Krypton or Xenon) was done. The correlation between the timing tail and the type of noble gas in the gas mixture was obtained. The tail values were at a minimum with the Neon based gas mixture and strongly increased with heavier noble gases [5].

The direct observation of a precursor signal from the spark counter was done with γ -source. A fast 5GS/s oscillograph with two beams was used to obtain the pulse shape directly from two neighboring strips of the spark counter (Fig. 1). A spark counter with the standard gas mixture was used. The primary ionization in the counter was initiated by a ^{60}Co γ -source. Measurements were done at three different HV settings: a) near at the counter threshold at 3 kV; b) at the beginning of the plateau at 3.6 kV and c) at 4.0 kV. Typical signal pulses at HV=3.6 kV are presented here because the time resolution of the oscillograph at this case is well adapted to the counter time characteristics. The average signal amplitude from the spark counter was ≈ 100 mV on 50Ω load at HV=3.6 kV. Fig.6 shows the beginning of the signal formation in the case when a primary ionization appears just between the two strips looked at. Most signals had a sharp front (Fig.6, top). However, more than 12% of the events had a precursor signal. The average amplitude of these signals was about 2 mV. The appearance of precursor signals in many cases was very close in time to the front of the main pulse (Fig.6, middle). Fig.6, bottom shows another example of a precursor signal, which was separated from the main signal by ≈ 1 ns.

2.2 Nature of delayed signals (model)

It is important for further understanding to recall the physical principle of a standard parallel plate counter. The spark counter works in the streamer discharge mode. The spark development starts from a free electron, which produces a Townsend avalanche in the high electric field. When the number of

electrons at the head of the avalanche reaches $\approx 10^8$ (Meeks criterion), a new, very fast streamer mechanism of ionization propagation appears. The delay time of the discharge development from an electron to a spark is mainly determined by the first Townsend avalanche and equal to $20/\alpha v_- \equiv X_0/v_-$, where α and v_- are the first Townsend coefficient and the electron drift velocity, respectively. The fluctuation of the delay time is the sum of the fluctuation of the avalanche development and the occurrence of the streamer. As it was shown experimentally the counter time resolution is roughly proportional to the delay time [6].

However, the anode stops the development of some avalanches before they reach the "critical" charge. This happens in the cases, when a primary ionization appears near to the anode in a gas layer with a thickness of $X_0=20/\alpha$. The basis of the proposed model consists of the assumption that these avalanches play a major role in the delayed streamer initiation by the photon feedback mechanism. Two distinct mechanisms of delayed streamer creation could be considered:

- 1) The initial avalanche continues to grow due to secondary avalanches initiated by the feedback photons and finally reaches the "critical" charge. The additional delay time in the occurrence of the streamer depends on the additional charge ΔQ needed for streamer creation and the ionization property of the gas mixture. In the case of a small ΔQ this delay time is very short. An increase of the gas ionization cross section reduces the timing tail because secondary electrons will at this case be created by photons closer to an initial avalanche.
- 2) An avalanche (or a chain of avalanches) initiated by feedback photons grows without interference with the initial avalanche. In this case the additional delay time of the streamer is equal or exceeds the standard streamer delay time. It is important to be aware that streamers initiated by photoelectrons from the cathode belong to this group of events.

The model predicts an improvement of the timing tail with increasing HV due to changing of the gas layer thickness ($X_0=20/\alpha$), where delayed signals are initiated. The experimental data (Fig.5) confirm this model prediction.

The spark counter time resolution is proportional to X_0/v_- and the timing tail (for a small X_0) is, according to the model, also proportional to X_0 . The experimental data confirm a correlation in the behavior of the time resolution and timing tail curves with changing HV (Fig.4, 5).

For the gas mixture used the "tail > 500 ps" is a small fraction of the "non-gaussian" tail (Fig.5). In the framework of the model this experimental result means that the delayed streamers were created mainly by a continuous increase of the initial avalanche (the first way, see above) and that the ioniza-

tion property of the gas mixture is important. Only Isobutane and Argon in the standard gas mixture provide a photon absorption by the gas ionization but the argon cross section falls down at a photon energy higher than 30 eV. The model predicts a improvement of the timing tail with the replacement of Argon by Neon because Neon has the best absorption characteristics among noble gases at this photon energy range (Fig.2, curve 2). The experimental results confirmed this prediction.

The direct observation of a precursor signal has also an obvious explanation in the framework of the model: a precursor signal is a low gain avalanche, which initiates the delayed signal.

It is important to be aware that presently the model predictions are qualitative only and many additional effects were not taken into account (for example, the dependence of the emission spectrum on the HV applied as well as on the gas composition and so on).

3 Conclusions

A model for the appearance of the tail in spark counters is proposed. It is based on the assumption that low gain avalanches stopped by the anode produce delayed streamers (sparks) by the photon feedback mechanism. The presented experimental results confirmed the qualitative predictions of the model. However, for final conclusions new experimental tests as well as model developments are needed.

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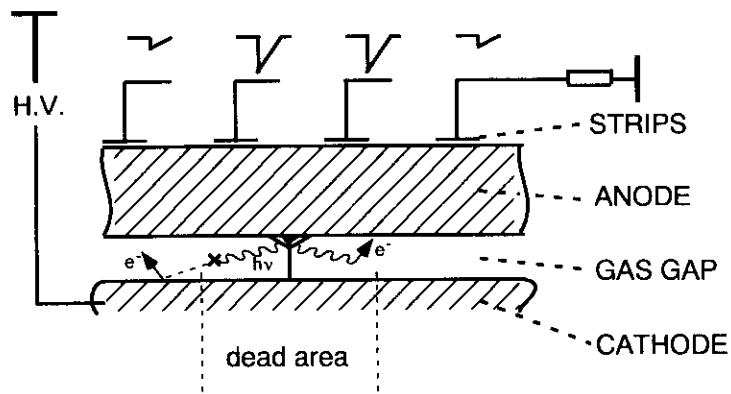


Fig. 1. Schematic layout of the spark counter.

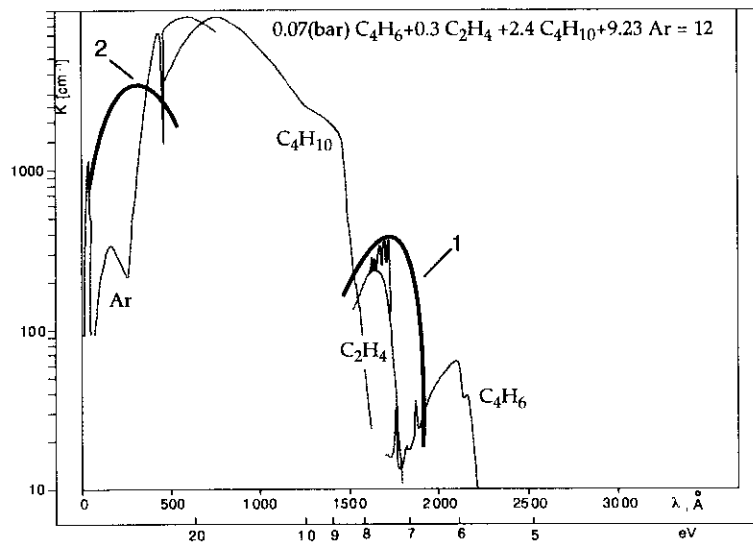


Fig. 2. Absorption spectra of the gas components corresponding to their quantity in the gas mixtures used. 1) Propylene (C_3H_6); 2) Neon.

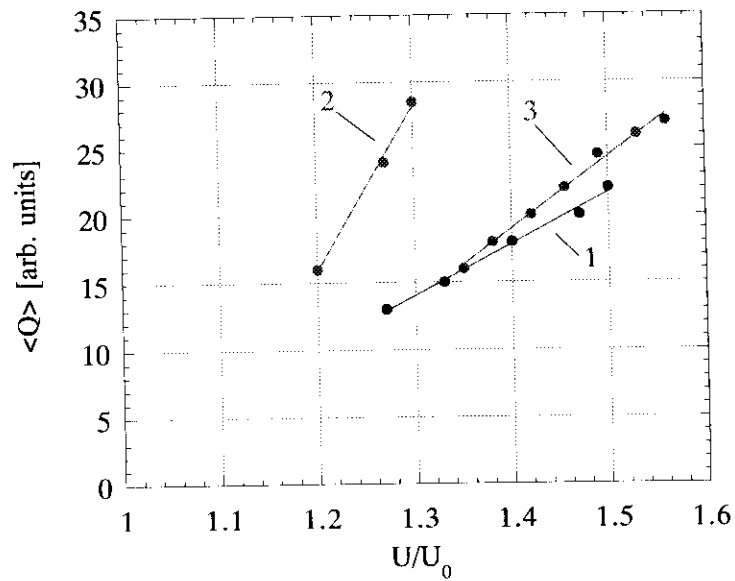


Fig. 3. Average charge from the spark counter: 1) the standard gas mixture; 2) the standard gas mixture but without 1.3-Butadiene (C_4H_6); 3) the standard gas mixture without 1.3-Butadiene (C_4H_6) and with replacement of Ethylene (C_2H_4) by Propylene (C_3H_6).

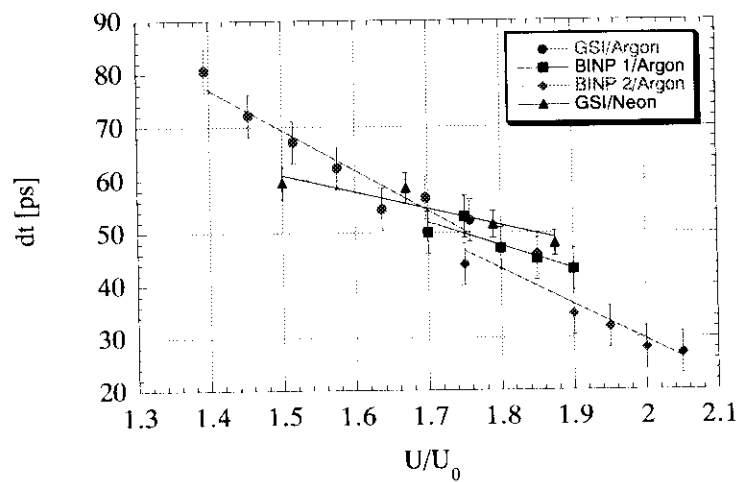


Fig. 4. Spark counter time resolution.

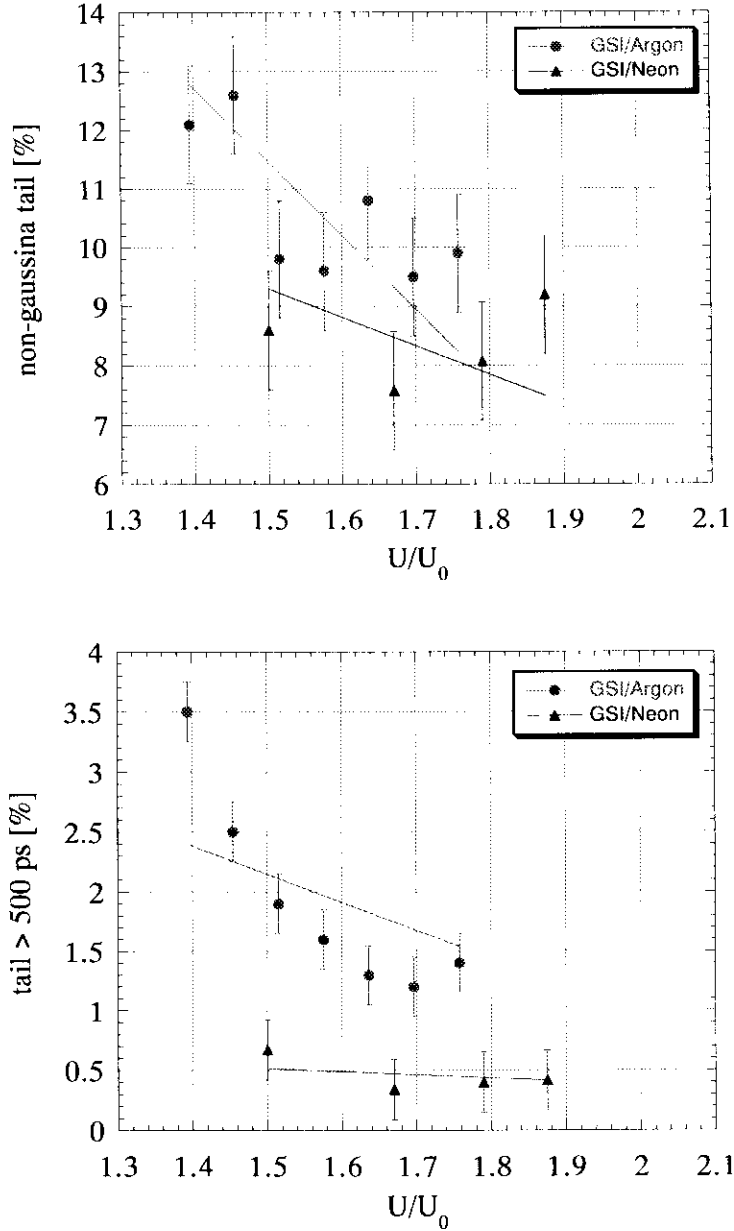


Fig. 5. "Non-gaussian tail" (top) and "timing tail >500 ps" (bottom). The lines are the model prediction based on the assumption that the timing tail is proportional to the time resolution (Fig. 4).

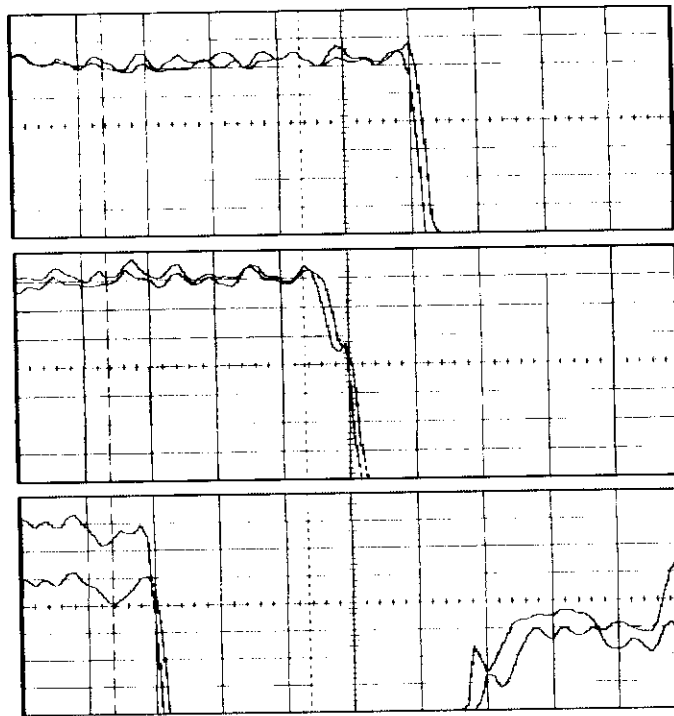


Fig. 6. Front of counter signals from two neighboring strips using the standard gas mixture, HV=3.6 kV and oscillograph amplitude and time sensitivities of 2 mV/div and 2 ns/div, respectively.