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DEVELOPMENT OF SPARK COUNTERS FOR PARTICLE IDENTIFICATION

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Development of Spark Counters
for Particle Identification*)

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ABSTRACT

The status of the R&D programme of the TOF system based on spark counters for particle identification is described. The main parameters of this system are: the spark counter time resolution $\sigma t = 25$ ps, the material thickness is 0.1 radiation length, the geometrical thickness is 100 mm. The spark counter prototype for the TOF system has been constructed. Its performance proves the feasibility of the TOF system with the designed parameters.

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1. INTRODUCTION

The idea of a spark counter with a localized discharge was proposed and realized at INP, Novosibisk in 1971 [1]. The first application of these spark counters in the physical experiment was in the pion formfactor measurement near the threshold at the VEPP-2 collider in 1978—1981 [2]. In that work the spark counters were used both for particle identification by the TOF and for determination of the geometrical characteristics of events.

During last ten years the R&D programme of spark counters at INF, Novosibisk and at some other world laboratories was aimed at better understanding of the physical processes in the spark counter with the aim of their characteristics improvement: the life time, the time and coordinate resolution, the matter thickness decrease, the technological design simplicity etc. [3].

As a result of these efforts the TOF system was proposed based on the spark counters [4]. The main parameters of this system are given in the second part of this report. In the third part the design of the spark counter prototype for this system is described. The performance of the prototype is given in the fourth part. In the last part of the report the conclusion is drawn about the feasibility of the TOF system with the project parameters.

2. PROJECT OF THE TOF SYSTEM

The TOF system consists of two layers of spark counters (Fig. 1). Each spark counter has electrodes with 40 mm width, 2 mm thick and several metres total length. The spark counter con-

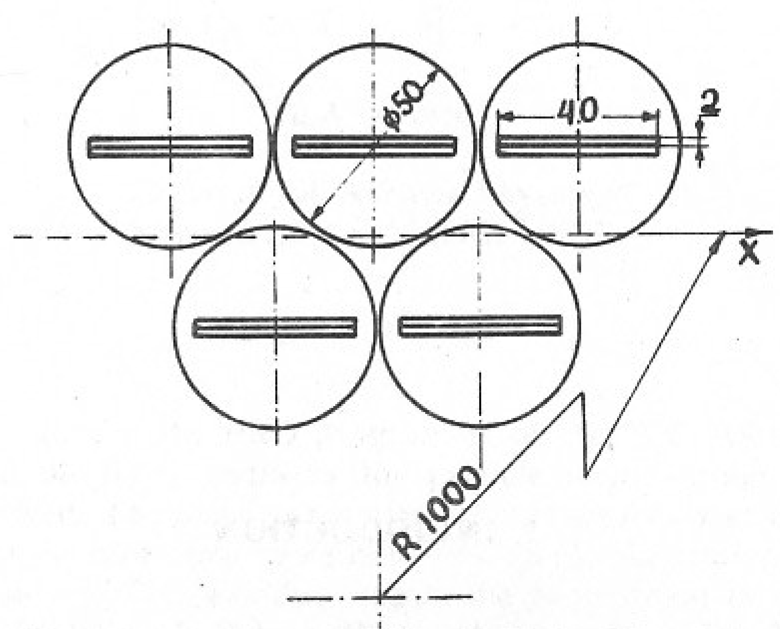

Fig. 1. A thin time-of-flight system based on spark counters.

tainer is a tube with a diameter of 50 mm, so the thickness of the geometrical layers is equal to 100 mm. The average material thickness for particles crossing the system normally to the layers is equal to 0.1 radiation length. Over a flight path of 1 m time resolution for each counter of $\sigma t = 25$ ps allows one to distinguish pions and kaons up to the momentum of 2.7 GeV/c, kaons and protons up to 4.6 GeV/c at the 2σ level.

3. DESIGN AND PRINCIPAL ELECTRIC SCHEME OF THE SPARK COUNTER PROTOTYPE FOR THE TOF SYSTEM

3.1. Prototype Construction

Fig. 2 shows the principal construction of the spark counter prototype. It consisted of two spark counter electrodes *1*, a plexiglass electrode support *2* and a container *3*.

Spark counter electrodes had the thickness of 2 mm, and the width of 40 mm. The anode electrode was made of semiconductive glass with a bulk resistivity $\rho = 6 \cdot 10^9$ Ohm·cm. On the outside to the gas gap of the anode electrode the copper layer was deposited by the magnetron cathode sputtering [5]. Sparks induced elecric signals on this conductive layer used for the readout. The cathode was made of usual glass, on which the copper layer was deposited by the magnetron cathode sputtering. Electrode surfaces were poli-

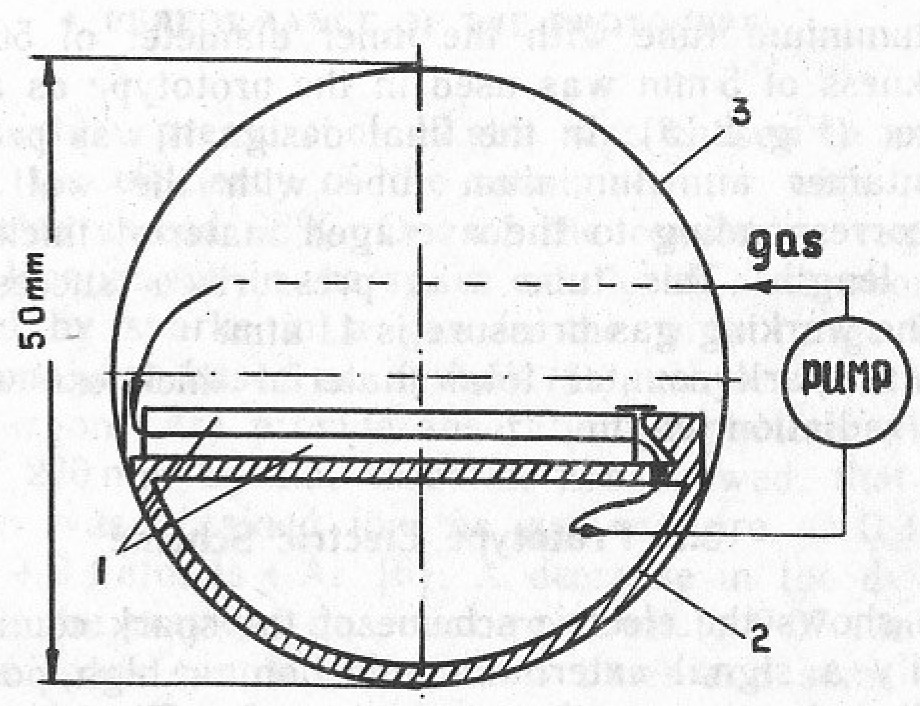

Fig. 2. Principal mechanical design of the prototype: *1*—electrodes; *2*—plexiglass support; *3*—aluminium tube.

shed with a tolerance of 1 mkm on any electrode region of the order to 40×40 mm. The electrode material thickness averaged over the container size was equal to 0.029 radiation length.

The gas gap of 0.1 mm was produced by two lines of pins glued in the semiconductive electrode. The number of pins formed 40 pieces on each 0.5 m counter length. The accuracy of their height with respect to the electrode surface was 0.5 mkm. Around each pin the electric field decrease was formed by a smooth hollow in the semiconductive electrode. The dead area due to the decreased electric field around pins was less than 1.4% of an electrode area.

It was proposed that the spark counter total length would be made from separate spark counters put in the series on one plexiglass support. To check the connection between counters the prototype of the total length of 0.5 m was made of two spark counters with the lengths of 0.2 m and 0.3 m.

The plexiglass hollow support for counter electrodes (Fig. 2, *2*) with the wall thickness of 1 mm was used also as a part of the gas flowthrough system. This system was designed to provide a circular gas velocity in the gap of 1 m/s. The gas, coming from the circulation pump to the space over electrodes was directed through a gas filter to the gap and then through special holes into the plexiglass support, which was also connected with the circulation pump. An intensive gas flow was required to provide spark counter long-term operation.

An aluminium tube with the inner diameter of 50 mm and the wall thickness of 5 mm was used in the prototype as a container of the counter (Fig. 2, *3*). In the final design it was proposed to use as a container an aluminium tube with the wall thickness of 0.5 mm, corresponding to the averaged material thickness of 0.018 radiation length. This tube was pressurized successfully up to 25 atm. The working gas pressure is 11 atm.

Thus, a spark counter total material thickness would be less than 0.05 radiation length.

3.2. Prototype Electric Scheme

Fig. 3 shows the electric scheme of the spark counter prototype. To simplify a signal external connection, a high positive voltage was applied to the spark counter anode. Electric signals from sparks travel to both ends of the counter in the strip line, formed

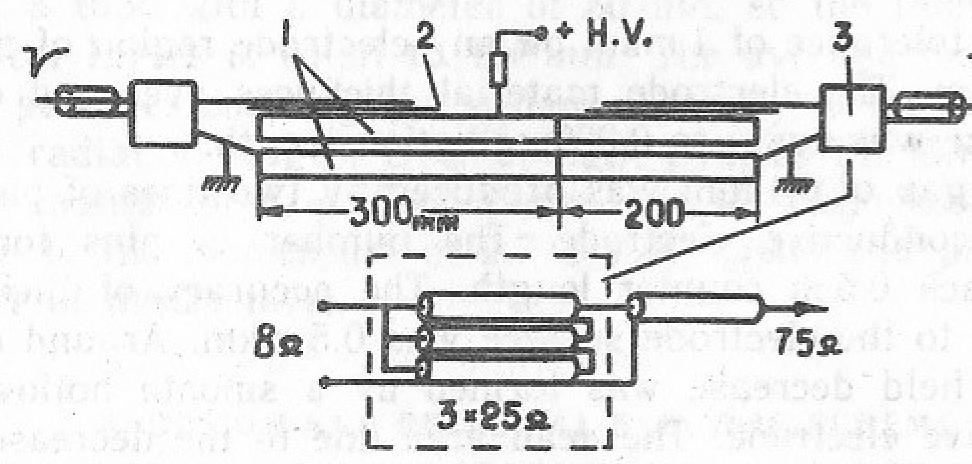

Fig. 3. Principal electrical design of the prototype:
1—electrodes; *2*—insulator; *3*—transformer.

by the conductive layers on the anode and the cathode. A measured impedance of this strip line was about 8 Ohm. As stated above, the prototype consisted of two spark counters, put close to one another on one plexiglass support. The signal strip lines of these spark counters were connected in series. The external connection to the strip was carried out through an insulation mylar film with the thickness of 0.1 mm because of a high voltage to the strip was applied (Fig. 3, *2*). A cable transformer was used to match the 8 Ohm impedance of the strip line with a 75 Ohm signal cable (Fig. 3, *3*).

4. PERFORMANCE OF THE PROTOTYPE

The gas mixture pressure of 12 atm was chosen to satisfy the condition that the efficiency of the spark counter with respect to charged particles exceed 96%. One of the conditions required for the discharge localization in the spark counter is absorption of photons, produced by sparks in a gas in the wide range of wavelengths. Gas mixtures based on dyvinil (D), ethylene (Eth), isobutan (Is) and argon (Ar) provide absorbtion of photons with wavelengths under 220 nm. Special research has showed, that the best time resolution was obtained for the gas mixture of 0.3 atm D+ +0.3 atm Eth+2.4 atm Is+Ar [6]. A decrease in the dyvinil partial pressure in the previous gas mixture down to 0.07 atm gave an increase of the spark counter life time 5 times and some degradation of the spark counter time resolution [6].

The undermentioned spark counter prototype characteristics were obtained at these two gas mixtures, № 1 and № 2 accordingly. The threshold of charged particle detection was 3.13 kV for the № 1 gas mixture and 2.9 kV for the № 2. The prototype characteristics were measured after detection of $\sim 10^6$ sparks/cm^2 to preliminary stabilize in time counter parameters.

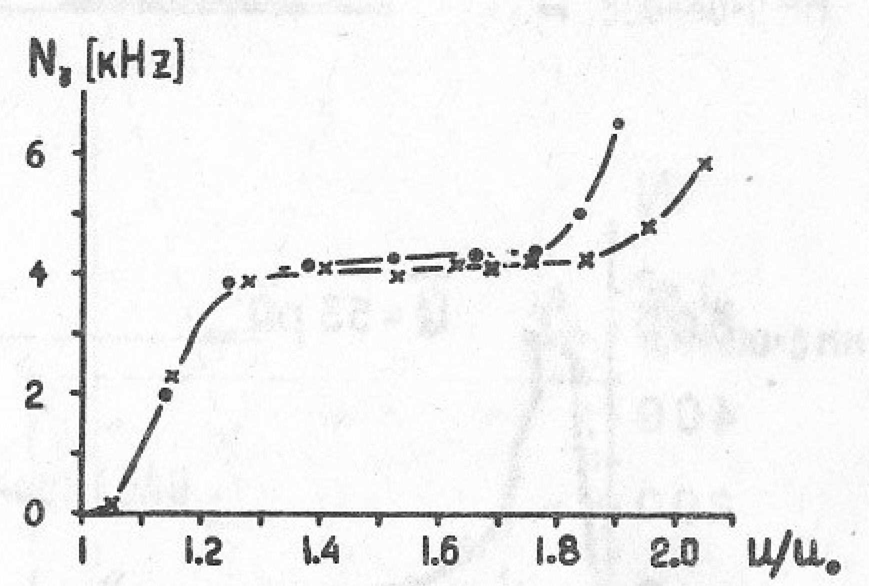

Fig. 4. Plateau curve of the prototype at two gas mixtures: × — № 1, ● — № 2.

4.1. Plateau Curve and Pulse Height Characteristics

Fig. 4 shows the plateau curves of the spark counter prototype obtained with a γ-source for two gas mixtures above. The counting rate increase at the end of the plateau curves was connected with afterpulses, delayed 0.1 — 1 mks, which increase quickly with over-

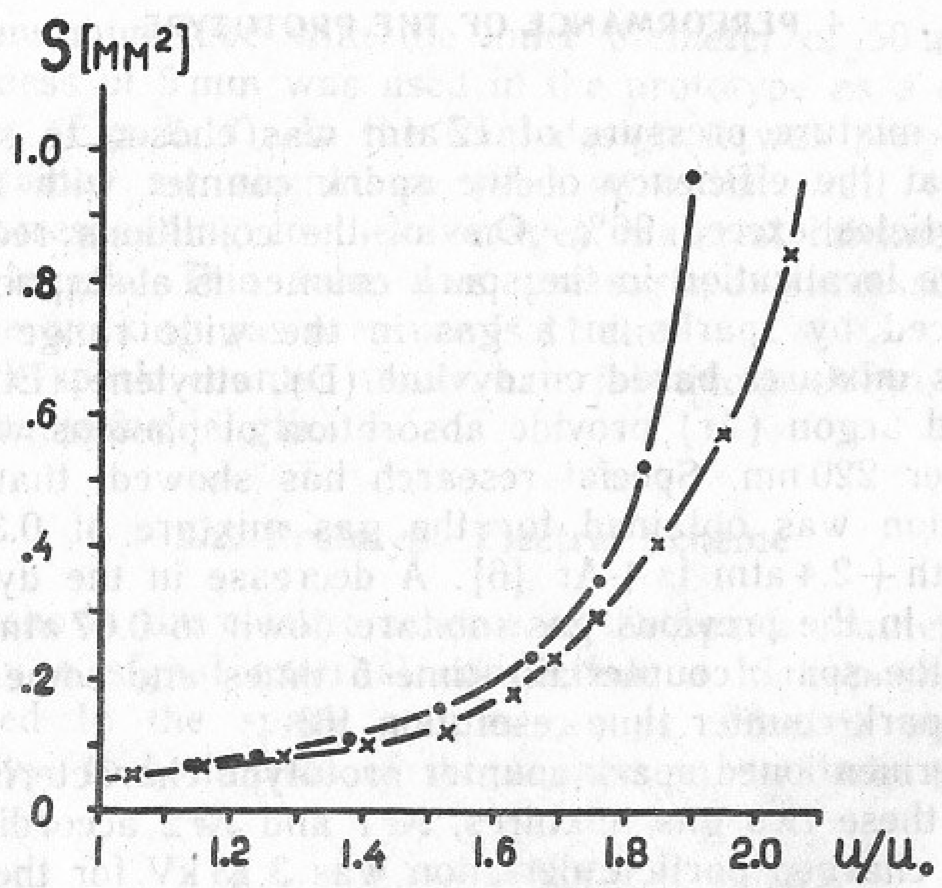

Fig. 5. Dependence of average discharge area on overvoltage at two gas mixtures: × — № 1, ● — № 2.

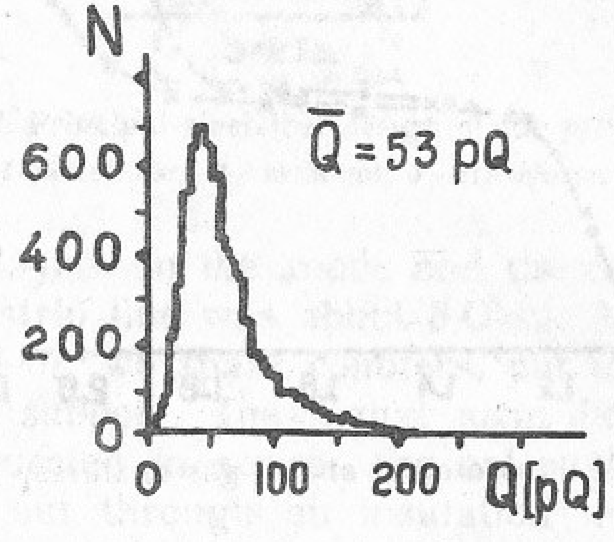

Fig. 6. Pulse height distribution from the prototype at the № 2 gas mixture, $U/U_0 = 1.83$.

voltage transforming into the Geiger discharge. For the first gas mixture the plateau is wider, than for the second one.

The dependence of the average discharge area on the overvoltage is shown in Fig. 5. For the second gas mixture discharge localization was visibly worse, than for the first one, because it was not enough of dyvinil for photon absorption in the second gas mixture.

The signal rise time from the prototype was expected to be fractions of nanosecond. As a load of 50 Ohm on the oscillograph with its own rise time of 2 ns, a pulse height ranged from 0.2—0.4 V at the plateau end. A puls had the exponential tail with the decay time about 5 ns. Fig. 6 showes the spectrum of the charge distribution from the prototype at the plateau end. The FWHM of this distribution is equal approximately to the mean pulse height.

4.2. Time Resolution

Time properties of the prototype were studied in the experiment, which principal scheme is shown in Fig. 7. The time of flight for

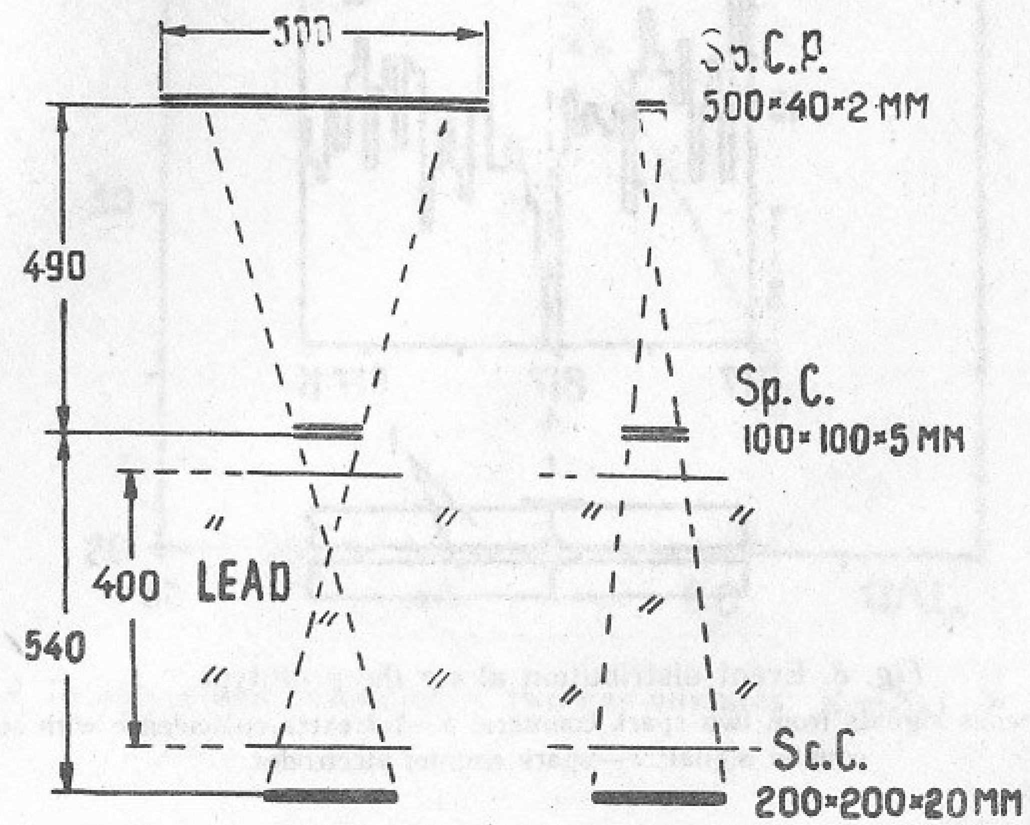

Fig. 7. Schematic droawing of the test setup.

cosmic particles was measured between the prototype and the spark counter with the electrode thickness of 5 mm and an area of 100×100 mm. Both counters were filled with the same gas mixture

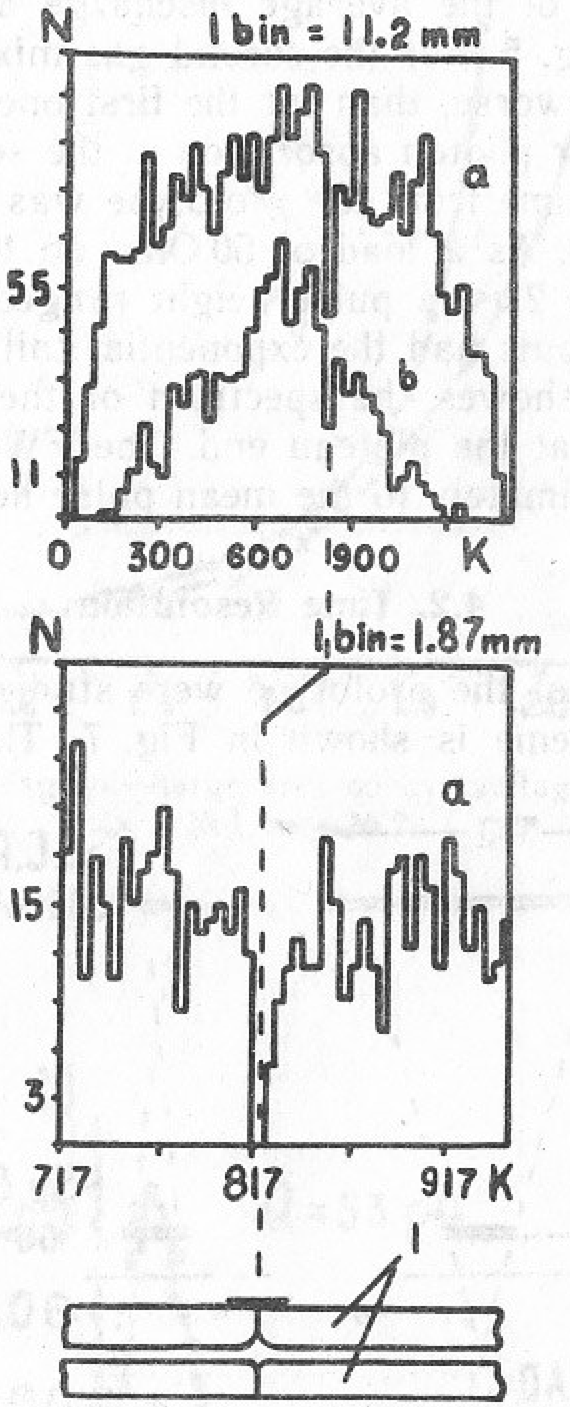

Fig. 8. Event distribution along the prototype:

a—for simultaneous signals from two spark counters; *b*—for extra coincidence with scintillation counter signal; *1*—spark counter electrodes.

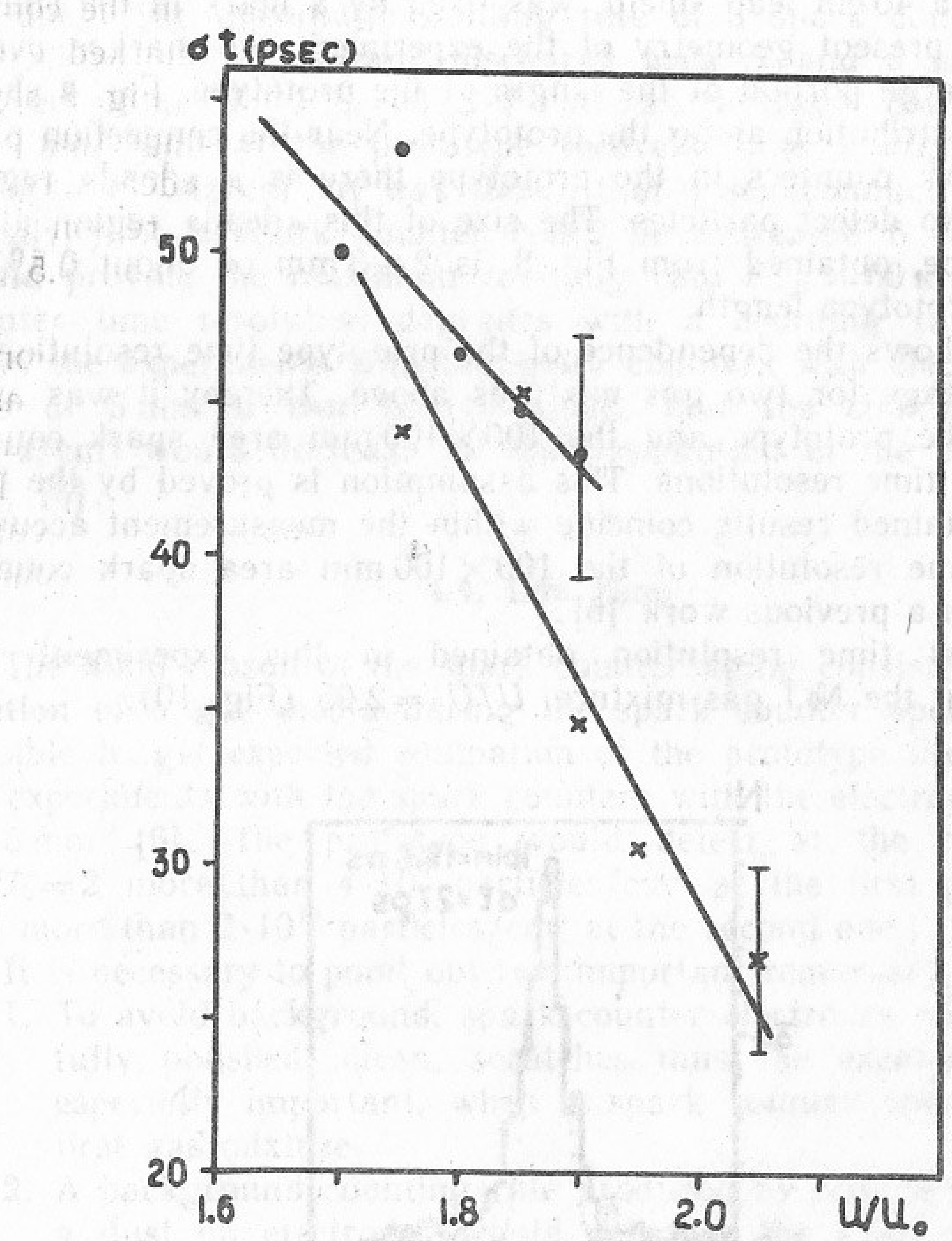

Fig. 9. Prototype time resolution at two gas mixtures: × — № 1, ● — № 2.

and the measurements were performed at the same overvoltages. Events, that had signals from both counters simultaneously, were used for the trigger. The operation of the scintillation counter, placed behind a 40 cm lead shield, was fixed by a mark in the computer. In the present geometry of the experiment the marked events covered a large portion of the length of the prototype. Fig. 8 shows the event distribution along the prototype. Near the connection place of two spark counters in the prototype there is a «dead» region, that failed to detect particles. The size of this «dead» region along the prototype, obtained from Fig. 8, is 2—3 mm or about 0.5% of the 0.5 m prototype length.

Fig. 9 shows the dependence of the prototype time resolution on the overvoltage for two gas mixtures above. Thereby it was assumed that the prototype and the 100×100 mm area spark counter had similar time resolutions. This assumption is proved by the fact, that the obtained results coincide within the measurement accuracy with the time resolution of the 100×100 mm area spark counter, measured in a previous work [6].

The best time resolution obtained in this experiment was $\sigma t = 27$ ps at the № 1 gas mixture, $U/U_0 = 2.05$ (Fig. 10).

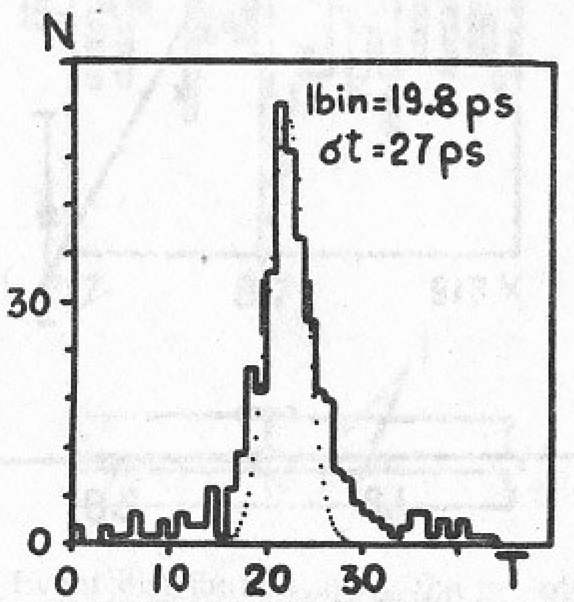

Fig. 10. Time difference of the prototype and the 100×100 mm area spark counter using cosmic rays.

4.3. Rate Capability

The detailed study of the rate capability of the prototype was not done. The maximum counting rate of a spark counter F_{max} is determined by an average discharge area S and a high voltage recovery time T: $F_{max} = 1/S \cdot T$. At an average discharge area $S = 1\ mm^2$ and at the prototype recovery time $T = 0.01$ s, F_{max} is equal to 10 kHz/cm^2. It was shown that a semiconductive electrode resistivity of a spark counter could be decreased 6 times, which would provide the maximum counting rate $F_{max} = 60$ кHz/cm^2. The counter time resolution degrades with a counting rate increase. From the experiments with the spark counters with electrode thickness of 5 mm it can be concluded, that the counting rate of 2 kHz/cm^2 would decrease the time resolution of the prototype by 15% [6].

4.4. Life Time

The main reason of the spark counter aging consists in polymerization of a gas media during the spark counter operation. It is possible to get expected estimation of the prototype life time from the experiments with the spark counters with the electrode thickness of 5 mm [6]. The prototype would detect at the overevoltage $U/U_0 = 2$ more than $4 \cdot 10^9$ particles/cm^2 at the first gas mixture and more than $2 \cdot 10^{10}$ particles/cm^2 at the second one.

It is necessary to point out two important remarks.

1. To avoid background, spark counter electrodes must be carefully polished, clean, scratches must be excluded. That is especially important, when a spark counter operates at the first gas mixture.
2. A background counting rate produced by chance scratches or a dust on electrodes would decrease the spark counter life time essentially. It is necessary to carry out measurements of this background counting rate behaviour in a long time interval.

4.5. Coordinate Resolution and Electronics

The particle coordinate along spark counter strips (Z-coordinate) is determined by the difference of the arrival times of the signals at opposite ends of the spark counter. In paper [6] the longitudinal coordinate resolution of 0.5 mm was obtained for the spark counter with the electrode thickness of 5 mm and it was determined by the electronic resolution. In paper [6] it was also shown, that the spark counter coordinate and time resolution remained constant within the measurement accuracy at an angle of cosmic-ray particles inclination to the electrode plane changing at least in range from 30 to 150 degrees.

The electronics in the present work was the same as in [6] and it consisted of discriminators with a low threshold of 6 mV and time-amplitude converters with their own resolution of 1-2 ps. Analog sygnals were digitized by a 13-bit amplitude-digital converter. The range of measurements was 20 ns at the resolution of 3 ps. To improve integral and differential nonlinearities up to 0.005 and 1.5% respectively the electronics was calibrated by a random puls generator. The sensitivity of a time scale of the electronics was estimated by the calibration using an air delay line.

Thus, the expected longitudinal coordinate resolution of the prototype would be about $\sigma z = 0.5$ mm. The transversal coordinate accuracy of the prototype determined by the electrode width $\sigma x = 40/\sqrt{12} = 12$ mm.

CONCLUSION

The considered above performance of the spark counter prototype proves the feasibility of the TOF system with given parameters.

The spark counter time resolution $\sigma t = 25$ ps at a life time over $4 \cdot 10^9$ sparks/cm^2 seems to be real at the first gas mixture. A 5 times longer life time could be obtained at the time resolution $\sigma t = 40$ ps at the second gas mixture. The rate capability of the spark counter would exceed 2 kHz/cm^2. The longitudinal coordinate resolution of the spark counter $\sigma z = 0.5$ mm may provide the useful additional information to coordinate measurements in drift chambers in real experiments. In this work there was demonstrated the feasibility of lengthening of the spark counter by connecting separate counters in series.

Two technological problems must be solved for the mass production of the spark counters for the TOF system. Firstly, the convenient technology for an electrode support production must be found. Secondly, it is necessary to find a simple technology for the precise glueing of pins, which make the gas gap, in a semiconductive electrode. The rest of spark counter components look simple enough for the counter mass production.

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