# STUDY OF THE SQS MODE BY THE INDUCED CHARGE METHOD

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*(Received 16 April 1986)*

*ABSTRACT* — Preliminary data using the cathode induced charge method to study the self-quenching streamer (SQS) mode are reported. Very strong and reliable anisotropy has been detected. Several characteristics of these streamers are considered from the point of view of the physics of long sparks.

## 1 – INTRODUCTION

Detectors based on the self-quenching streamer (SQS) mode are now used in experiments in high energy physics. They are rugged, feature good position resolution along the wire and are associated to inexpensive electronics. At the moment, roughly as much effort is being put on the understanding of the process and on the measurement of some relevant intrinsic properties, as in its applications to detectors. This research goes on since the last few years.

During the last decades the engineering research on the U.H.V. transmission line insulation was actively pursued. In recent years it developed more and more towards the physics of long sparks, trying to reach a detailed knowledge of the mechanisms involved (space charge distribution, electron energy, gas temperature and density, etc.).

No doubt, the fundamental physics processes associated to the SQS mode and to the long spark formation are the same. However, the techniques used to initiate the discharge processes are different and the physical dimensions of the streamer may

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vary by several orders of magnitude, between the conventional SQS detector and the point-to-plane arrangements, convenient to study the non uniform field geometries. In the SQS mode a steady high voltage (and this is an important feature for a detector) is applied to the anode wire and the streamer is triggered by an ionizing particle; in studies of the mechanism of long spark formation, in a non uniform long gap, a short high voltage pulse is applied to trigger the process. For a detailed review of the mechanisms of long spark formation see for example ref. [1].

The method of induced charges in a convenient set of electrodes is a powerful technique to study charge distributions. Spatial resolutions of about 5 microns have been achieved [2, 3], this accuracy being essentially limited by the number of bits of the digital charge measuring devices. The proportional counter mode has been studied using this techniques, the time evolution of the process was considered [4], and the so called left-right ambiguity in drift chambers is now currently solved by looking for induced charge asymmetries.

In this work we report preliminary results using the induced charge method applied to the study of the SQS mode. One can reasonably expect that work under these lines may be relevant to the fields of physics referred to above.

## 2 — EXPERIMENTAL SET-UP

For this study an adequate detector was built. It is a single wire chamber, the cathode of which consists of eight copper strips (copper clad epoxy board), about 8 mm wide and 144 mm long, spaced by about 1.5 mm. These strips were mounted parallel to the anode (nichrome wire, 60 micron diameter) in an octogonal arrangement with the anode located in the center. A cross section of the chamber is sketched in Fig. 1. This system of electrodes was inserted in a stainless steel cylinder and the anode wire was fixed to epoxy insulators.

The signal from each strip passes through a current sensitive output buffer ( $Z_{in} = 50\,\Omega$, gain = 10, $Z_{out} = 50\,\Omega$ ), is delayed and fed to one channel of a current integrating CAMAC ADC ( LRS 2249 W ), gated during 150 ns by a discriminator triggered on the anode signal. This gating time is sligthly larger than the current pulse duration, as observed in a fast oscilloscope.

Each channel (both the current sensitive output buffer and the following ADC) was calibrated individually by electronic means and software corrections for linearity and bias were further checked by sending a fast pulse to the chamber's anode and looking to the capacitive coupled signals on the cathode strips. This technique should also provide information on the accuracy of the mechanical arrangement of the set of electrodes. Every observed event corresponds then to a set of eight numbers that are read-out to a microcomputer interfaced to the system.

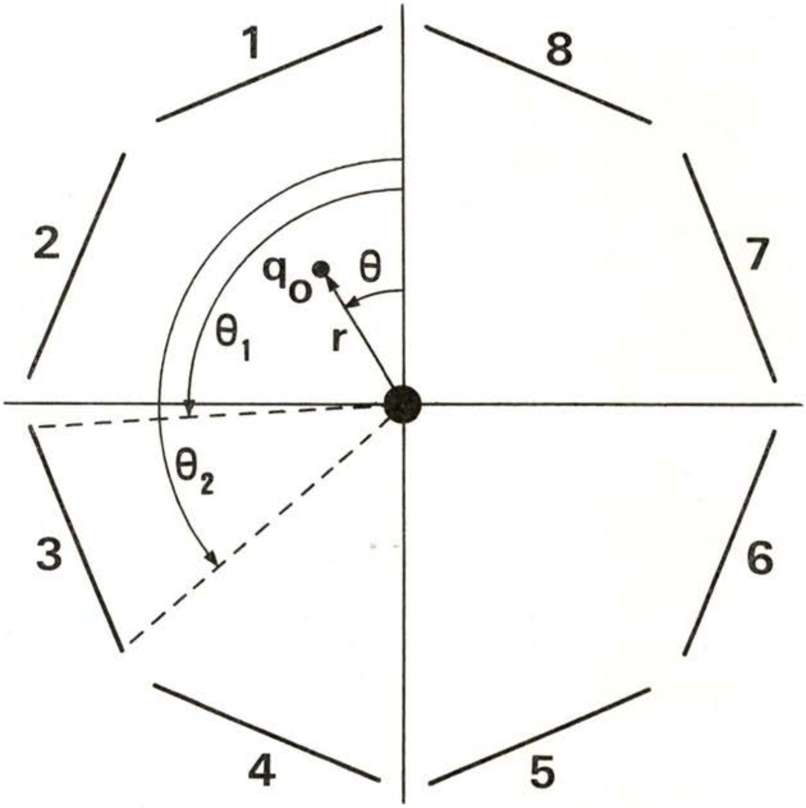

Fig. 1 — Schematic cross section of the detector, showing the coordinate system used in the theoretical calculations.

Experimental data were recorded for a typical SQS mixture, 52 % argon + 48 % isobutane, at atmospheric pressure in a constant flow regimen, at four different anode voltages (3500, 3700, 3900 and 4100 volts) using a $^{55}$Fe X-ray source.

## 3 – THEORETICAL MODEL

Through optical measurements [5, 6] it is already known that, in the SQS discharge mode, the avalanche extends up to approximately 2-3 mm from the anode surface, for geometries similar to ours. It is then a case completely different from the proportional counter mode, where the dimensions involved are of the order of tens of microns and the ion motion determines the pulse shape. In the SQS mode, and using usual fast electronics, the total induced charge is essentially due to the contribution of the electron motion that, in a short time of about 150 ns, leaves a cloud of positive ions practically at rest. In this work, as a first approximation, a point like ion space charge is assumed to be responsible for the distribution of the induced charges on the several electrodes.

In the ideal coaxial counter (the geometrical conditions of this work are shown in Fig. 1), for a point charge $q_0$, located at $(r, 0)$ between two cylinders of radii a and b $(a < b)$, the total charge induced on the outer cylinder (cathode) is

$$Q_b = -q_0 \ln(r/a) / \ln(b/a) \qquad (1)$$

The charge induced on that part of the cathode which is bounded by angles zero and $\Theta$ is given, exactly, by [7]:

$$S(\Theta) = Q_b \frac{\Theta}{2\pi} - \frac{q_0}{\pi} \sum_{n=1}^{\infty} \frac{1}{n} \left(\frac{r}{b}\right)^n \frac{1-(a/r)^{2n}}{1-(a/b)^{2n}} \sin n\Theta \qquad (2)$$

So, for a point charge at $(r, \Theta)$ the charge induced on a sector of the cathode bounded by angles $\Theta_2$ and $\Theta_1$ is $Q = S(\Theta_2 - \Theta) - S(\Theta_1 - \Theta)$.

Approximate expressions for the usual case $b >> a$, with $\Theta = 0$, are also available [8]:

$$Q = -(q_0/2\pi)\{-[1/\ln(b/a)](\Theta_2 - \Theta_1)\ln(b/r) + 2\beta\}$$

where $\tan\beta = \dfrac{[1-(r/b)^2]\,[\tan(\Theta_2/2) - \tan(\Theta_1/2)]}{(1-r/b)^2 + (1+r/b)^2\,\tan(\Theta_2/2)\,\tan(\Theta_1/2)}$

Two computed distributions for the charge induced on the eight cathode strips, using the expression (2) for $\Theta = 0$, and corresponding to two different values of r, typical of the SQS mode, are shown in Fig. 2.

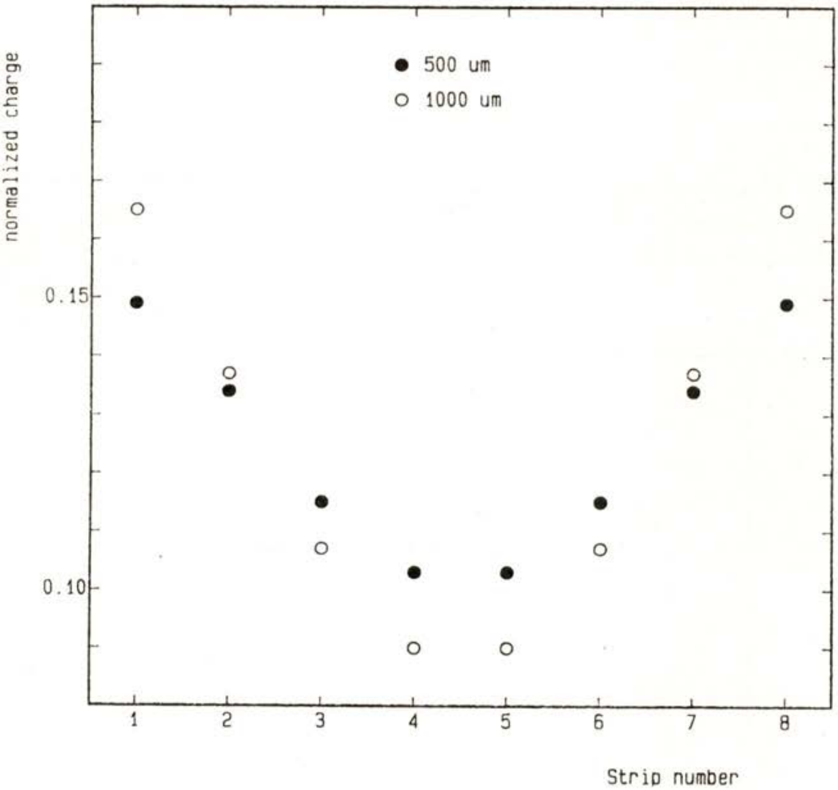

Fig. 2 — Calculated distribution of the charges induced on each cathode strip by a point charge located at $\Theta = 0$, $r = 0.5$ mm (full circles) and $\Theta = 0$, $r = 1$ mm (open circles).

To characterize the anisotropy of the distribution, two convenient parameters can be defined :

$$
\begin{aligned}
Y(r, \Theta) &= \ln [(q_1 + q_8) / (q_4 + q_5)] \\
X(r, \Theta) &= \ln [(q_7 + q_6) / (q_2 + q_3)]
\end{aligned}
\qquad (3)
$$

$q_i$ ʼ$i = 1, 2, \ldots 8$ ) being the charge induced in the ith cathode strip. Again for the ideal coaxial geometry, it can be shown that with errors less then 0.1 %

$$Y^2 (r, \Theta) + X^2 (r, \Theta) = R^2 (r) \tag{4}$$

and that the function $R(r)$ is, fortunately, an almost linear function of r.

## 4 – EXPERIMENTAL RESULTS

The pulse height spectrum obtained at 3900 V, using the total charge induced on the cathode strips ( $Q_b = \Sigma\, q_i$ ), is displayed in Fig. 3. It corresponds essentially to a typical SQS

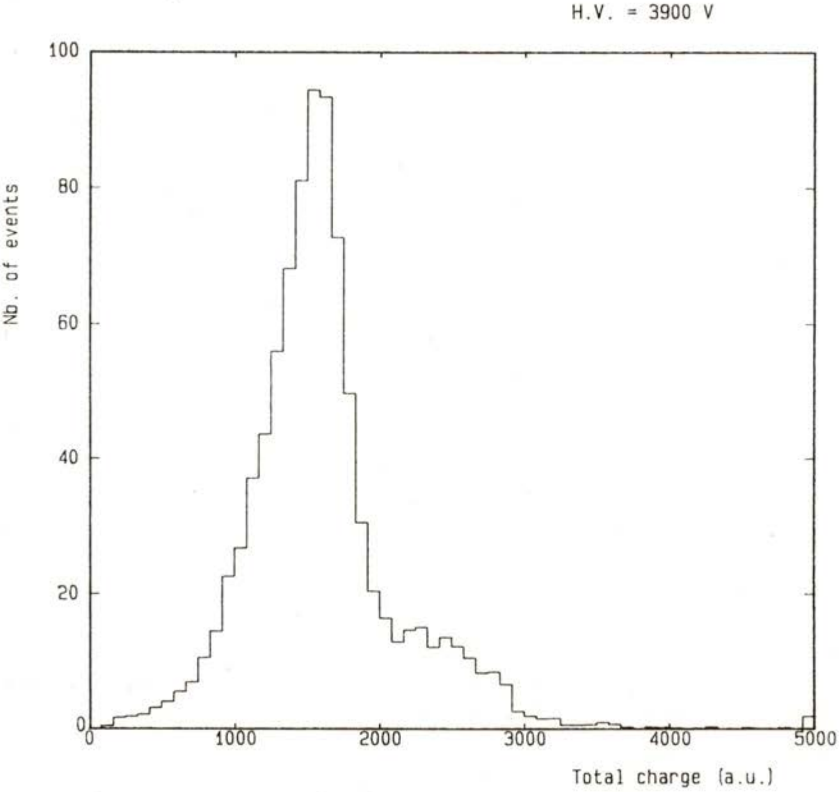

Fig. 3 — Pulse height spectrum, at 3900 V, of the total charge induced on the cathode strips.

distribution and the beginning of higher charge streamers can be observed. In these experimental conditions calculations with the observed data were accomplished, by substituting in eq. 3 the $q_i$ by the corresponding ADC values suitably software corrected for linearity and bias.

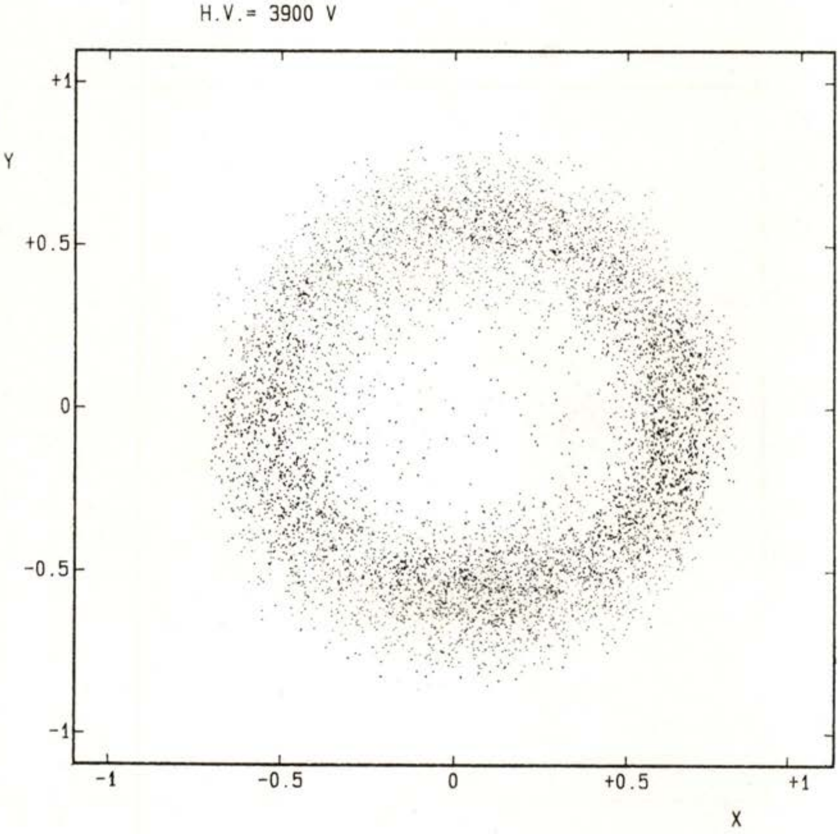

Fig. 4a) — Distribution of X, Y values defined by Eq. 3. Experimental data correspond to 10000 events taken at an anode voltage of 3900 volts.

Fig. 4a) is a typical plot of the resulting X, Y values for 10000 experimental events corresponding to all values of the charge distribution (see Fig. 3).

A more conventional way of defining a position would make use of the expressions $X' = \Sigma q_i x_i / \Sigma q_i$ and $Y' = \Sigma q_i y_i / \Sigma q_i$, where the $x_i$ and $y_i$ are the mean coordinates of the strip i.

A comparison of both techniques was made and Fig. 4b) shows the distribution obtained, for the same 10000 events, using the X′ and Y′ parameters. Since there was no obvious difference between the two distributions and in view of the properties of R ( r ), X and Y coordinates are used.

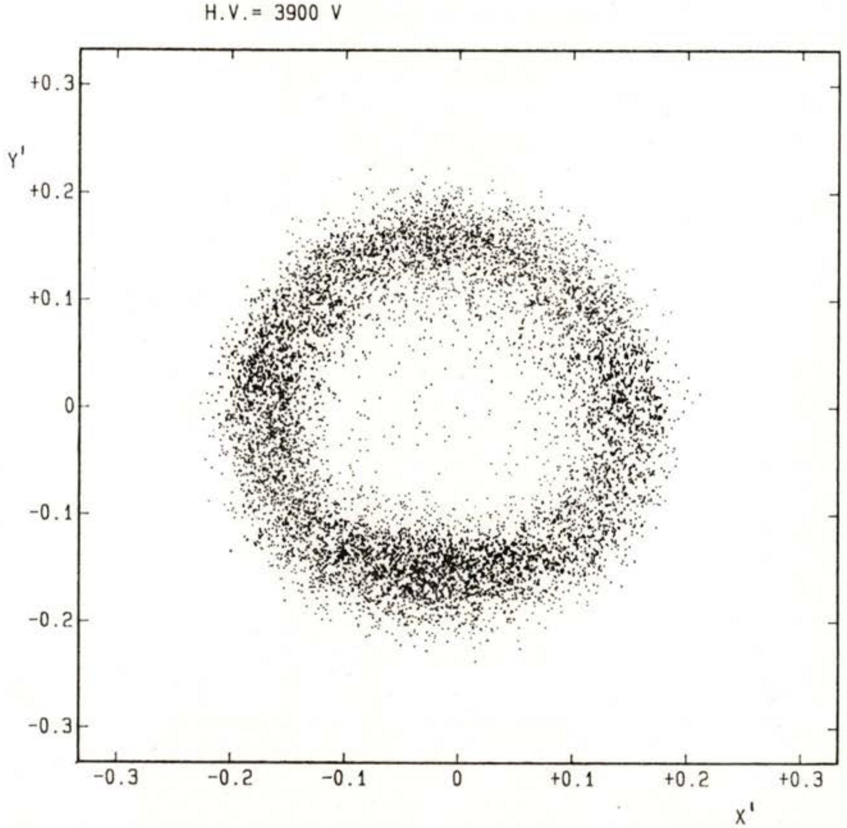

Fig. 4b) — Distribution obtained for the same events as in a), but making use of parameters X′ and Y′ (see text for their definition).

Using the relationship between r, the physical radius of the point like ion distribution, and R, referred to above, the data for all values of the total charge were analyzed in order to study the distribution of the mean radial position of the discharges. The corresponding distribution (at 3900 V) is plotted in Fig. 5, where the events with positive and negative Y are separated. The two peaks have similar widths and mean values close to 1 mm.

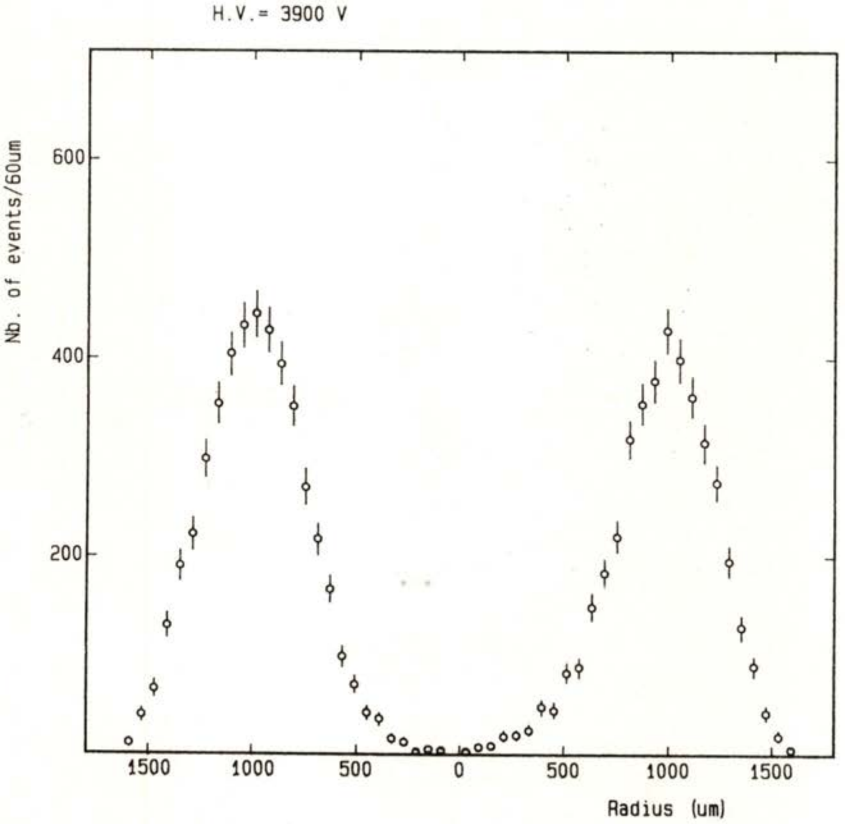

Fig. 5 — Distribution of the radial dimensions, r, of the discharge: right peak for streamers with Y > 0, left peak for the others.

Within the limitations of the model, knowledge of r and $Q_b$ ($Q_b = \Sigma q_i$), allows the determination of $q_0$, in arbitrary units. The conversion into real charges simply requires a charge calibration.

The physical process of the SQS discharge strongly suggests a correlation between its radial extension and the total charge involved. Concerning this problems, two different situations should be considered, namely when the applied field is constant and when it varies, as the quenching of the discharge is determined, among other parameters, by this one.

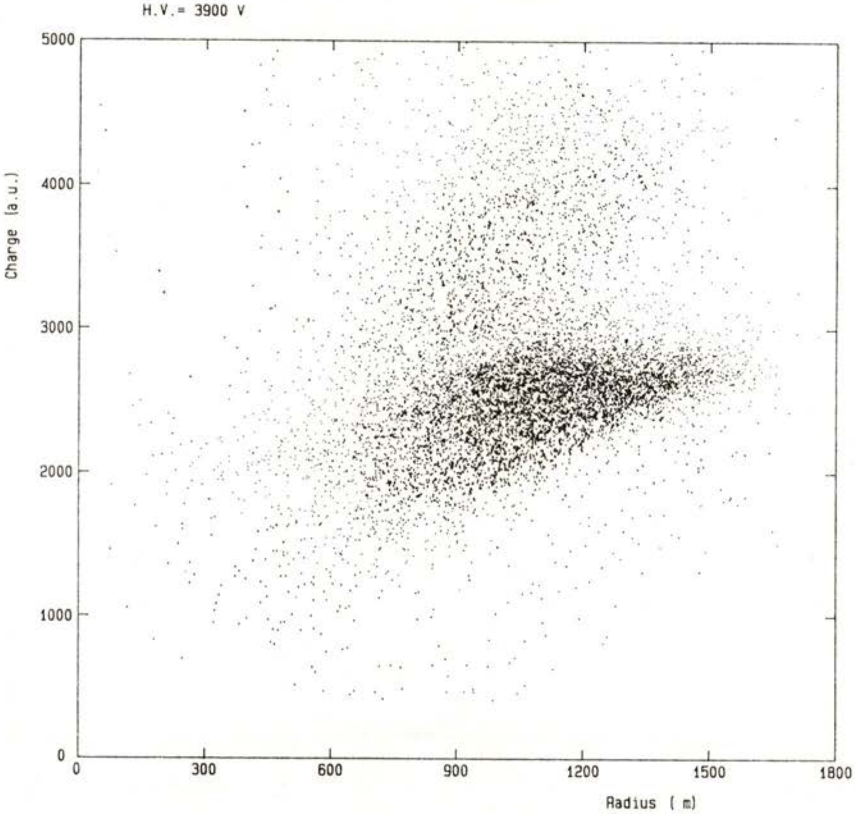

Fig. 6 — Correlation between the charge $q_0$ and its radial position r, for all values of the induced charges, for 3900 V anode voltage.

For the same high voltage used to obtain the data presented previously (3900 V), Fig. 6 displays the correlation between $q_0$ and r.

By varying the applied high voltage between 3500 and 4100 V and, for each voltage, using events corresponding to a thin slice in r around the peak (see Fig. 5), within the approach described previously the mean values of $q_0$ were determined. In Fig. 7 are shown the mean values of r and the corresponding $q_0$ ; the bars correspond to the width of the slices defined in r.

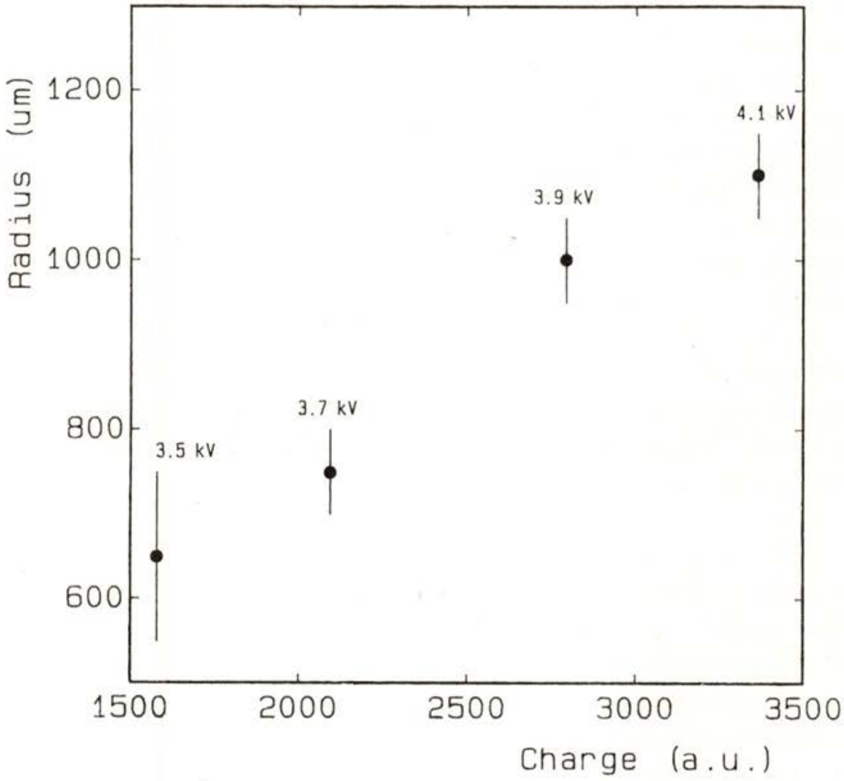

Fig. 7 — Mean value of r, black dot, as a function of the value of the mean charge $q_0$ of the streamer, for several values of the applied high voltage. Events near the peak of each radius distribution were used. The bars correspond to the width of the radial slices taken.

## 5 – CONCLUSIONS

Although the experimental data obtained reveal clearly features that are worth further investigation, only the main general characteristics will be referred to. A good example relates to Fig. 6 where most of the events reflect a strong correlation between charge $q_0$ and radial dimensions r, which, in any model for the distribution of the space charge, is naturally related to the streamer length. According to the data, r increases with $q_0$, but for some events, an important increase in charge leads to small variation of r. Are these events related to higher charge streamers (see Fig. 3) and could they correspond to streamer branching or discharges that surround the wire?

An important result that arises out of this work is that, as one should expect for streamers orthogonal to the anode wire, the anisotropy of the induced signals is very large (about a factor two), such that it can be used with cheap electronics. And it is quite clear that this anisotropy should be even much larger for shorter gate duration, as one looks essentially to the furthermost part of the streamer.

Probably even more remarkable is the great stability of the streamer dimensions for a certain voltage, and then the stability of the anisotropy; only a negligible number of events are inside the main ring in Fig. 4; there are essentially no events with $r \sim 0$ that could arise from discharges built around the wire (see Fig. 5 and 6).

An important feature that was not studied in this work, is a possible correlation between the angle of arrival of the field lines that guide the electron to the anode and the angle of emergence of the streamer, $\Theta$, which can be measured easily. In no way can one be sure that such a correlation exists, naturally disturbed by diffusion effects. Indeed, although it was quite clearly observed in the proportional counter mode, it is possible that a complete loss of memory occurs if, prior to the streamer formation, the avalanche surrounds the wire in the region of strong space charge effects [2]. The increase of the anode wire diameter or of the quencher concentration may eventually help to establish such a geometrical correlation that, in view of the strong anisotropy detected, could have important applications in instrumentation. A simple example could be in the localization of tracks in high energy physics by drift time measurements, the effort put in simple electronic hardware during data aquisition eventually paying, compared with the off-line computation time.

Assuming r as the approximate streamer length, considering that the streamer has a cross section corresponding to a radius of about 30 micron (see ref. 9 for mean free path of ionizing photons) and since the total measured streamer charge at 3900 V is 62 pC, then one is dealing with space charges of about $10^{14}$ electrons/cm$^3$, a typical value associated with space charges in streamer tips of long sparks. The strong correlation observed between charges and "length" of the streamer, and of course also with high voltage (see Fig. 7), is in qualitative agreement with data for unbranching streamers arising from work in the long spark formation [1]. The influence of the applied electric field on the streamer quenching was also considered. For the high voltages 3500, 3700, 3900 and 4100 V the electric fields at the corresponding mean value of r for the streamers are 9.3, 8.4, 6.7 and 6.4 kV/cm, respectively. These results could be explained by the guiding effect of the cloud of primary electrons, if the streamer emerges along this cloud. This difficulty can be avoided by triggering the SQS mode with single electrons.

The model assumed in this work, in which the distribution of induced charges corresponds to a point like ion, can be easily improved. It provides a very clear first approach to the problem but, of course, extended space charge distributions can be computed. One of the problems would be to what extent the distributions of the induced charges is in practice sensitive to the model distribution for the density of charges in the streamer. Previous work on the mechanism of long spark formation lends us a relatively simple formalism that evolves out of the complex interaction of electromagnetic, hydrodynamic and thermodynamic elementary processes [1] and that allows the calculation of the variation of the charge in the streamer tip for every step of its propagation. In this work no study was made of the experimental shape of the induced charge distribution, but attention should be called to this problem. An interesting approach arises, using current sensitive output buffers with larger gains and fast enough, such that several time slices can be taken during the electron motion, each one providing information on the local ion space charge density along the streamer. Notice that for each time slice the charges involved are of the order of those associated to proportional counters.

Surely one of the important limitations to this type of work is related to mechanical accuracies, in particular deviations from the ideal coaxial geometry. Although the electrostatics of the situation can be very accurately computed, simple algebraic formulae should be available if complex space charge situations are to be handled within a reasonable time and money scale.

The authors are particularly indebted to Mr. Cidálio Cruz for his careful construction of the detector used in this work and to Dr. Rob Hollander from the IRI-ISO group of the Delft University of Technology, Holland, who designed and constructed the current sensitive output buffers. We acknowledge also the valuable help in data acquisition equipment from de Swiss Institute for Nuclear Research (SIN), Switzerland. Thanks are also due to Dr. H. Van Der Graaf, NIKHEF-H, Amsterdam, for his interest in the work. Financial support from Instituto Nacional de Investigação Científica is acknowledged.

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