3-DIMENSIONAL SIMULATION OF ELECTRON AVALANCHES IN LOW PRESSURE WIRE CHAMBERS AND PROPORTIONAL COUNTERS

H. Průchová *
GSF - Forschungszentrum fur Umwelt und Gesundheit
Institut fur Strahlenschutz, Neuherberg
85758 Oberschleissheim, Germany
on leave from Czech Technical University, Prague, Czech Republic

and

B. Franěk
Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX,
United Kingdom

ABSTRACT

Monte Carlo code AVALAN was designed to simulate an electron avalanche development under any operating conditions of a proportional counter such as different gas pressures and electric fields. It alows to study any temporal and space aspects of the avalanche development. Initial simulations were performed for low pressure cylindrical counter filled with methane gas. Some results from these simulations are discussed.

1 Introduction

The design of proportional counters and wire chambers intended for various applications could be significantly facilitated by a better understanding of the electron motion in a force field (electric and/or magnetic) in various gases and their mixtures. This is especially true in the case of counters operating at low gas pressures and high electric fields such as, for example, counters used in

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microdosimetry. The region close to the anode in these counters is characterized by extremely high values of E/N (E being the electric field strength and N the number of gas molecules per unit volume). In such regions, moving electrons find themselves in the so called 'non-equilibrium state' and the traditional methods used for describing the motion of electron swarms in an electric field, and based mainly on the solution of the Boltzman equation, are not applicable.

There were attempts to improve these traditional methods and to take the non-equilibrium effects into account but only with limited success and invoking additional and rather unclear assumptions. See, for example, Segur et al [1], [2], [3]. Also, in recent years, several methods have been published based on microscopical Monte Carlo modeling of electron motion in gases [4], [5], [6], [7], [8]. However, these latter methods either address only few macroscopic aspects of the electron avalanche development such as the gas gain (e.g. [4], [5]) or make approximations which are only valid at small values of E/N ([6], [7], [8]). For example they do not take the magnitude and the gradient of the electric field into account when calculating the time step and base it only on the mean free path.

We have developed a Monte Carlo technique suitable for the simulation of electron motion and electron avalanche development in counters operating under any operating conditions. This alows the study of any aspect (temporal and spatial) of these processes in any level of detail.

2 Method

The Monte Carlo program, AVALAN, was developed to simulate the electron motion in a force field and all electron interactions with gas molecules. The program starts with a given number of initial electrons deposited at chosen space points at time t=0. These electrons are then 'simultaneously' followed in the force field of the counter in given small time steps dts. In every time interval $(t, t + dts)$, each individual electron existing at time t is followed from time t to time $t + dts$ in the following way:

The electron is followed in small and variable length time intervals t_{elm} which are fractions of dts. Before every step, the magnitude of t_{elm} is calculated from the magnitude of the velocity of the electron and from the magnitude of the force field and its gradient. The necessary requirement in this calculation is that t_{elm} must be sufficiently small in order that the relative change of the vector of the electron's velocity during this time is very small. Also, it is required that the vector of the force field at the new electron's position differs only very little from that at its original position (before t_{elm}). Satisfying these requirements means, that in the time interval t_{elm} the trajectory of the electron can be approximated by a straight line with constant velocity and the force field can be considered constant. Before every step t_{elm}, the program also decides by random number generation whether the electron will interact with a gas molecule before reaching the end of t_{elm}.

For this purpose the tables of measured total cross-sections for electron-molecule processes for a given gas (gases) are used. If it turns out that the electron will interact before reaching the end of t_{elm}, the time t_{elm} is shortened so that the electron will interact exactly at the time $t + t_{elm}$. The electron is then 'moved' in time t_{elm} and its new vector of position and velocity are calculated. If the electron interacts at the end of the time interval t_{elm}, then first the type of the interaction is randomly chosen using the relative values of measured cross-sections for various electron-molecule processes and then the interaction is simulated resulting in a change of the electron's velocity vector. The following interactions were taken into consideration: elastic, excitation (rotational excitation, vibrational excitation and neutral dissociation) and ionization. At the present time, mainly due to the lack of reliable data in the given energy range, angular distributions in all these interactions are approximated by isotropic distribution. In nonelastic collisions the electron also loses energy and this is taken into account using available data. In ionization collisions a new electron is created and it shares the energy remaining after the collision with the original electron. This secondary electron is also isotropically scattered.
When the electron finally reaches the time $t + dts$, then all the new electrons created in the time interval $(t, t+dts)$ in the ionization collisions and which are descendants of this electron, are followed in the same way until they all reach the time $t + dts$.

At the end of every time step, dts, the positions and velocities of all the electrons existing at time $t + dts$ are recorded. Simulation ends when all electrons are captured by the anode (anodes) of the detector. Fig. 1 shows the simulated trajectory of one of the electrons in an avalanche projected onto the plane perpendicular to the anode wire (the little circle at the origin). The dots show the positions at which the positive ions were created during the avalanche process. The picture demonstrates the level of detail of the simulation.

3 Preliminary results

Initial simulations have been performed for a half inch cylindrical proportional counter used in microdosimetry (so called TEPC) with a cathode diameter of 1.27 cm and an anode diameter of $7 \mu m$. The counter was assumed to be filled with pure methane. The latest available cross-section data for this gas were collected and used [9]-[19]. Simulations of the avalanche development have been performed at various gas pressures between 6.9 and 69 torr and the same anode voltage of $760V$. The coordinate system of the counter has been chosen such that the anode wire is perpendicular to the x, y plane and goes through the origin. In all simulations we started with a single electron released far from the anode wire at $(x = 4000 \mu m, y = 0, z = 0)$. Fig. 2 and 3 show a typical avalanche development in this counter. We have scanned many such pictures to determine the important features and also to find out how to quantitatively describe the avalanche so that

we could then study the avalanche development statistically (using samples of many independent avalanches). Based on this scanning, we have introduced a number of so called *avalanche parameters* which we then use for this purpose. Examples of these parameters are gain, radial or time extent of an avalanche *etc.* Due to the lack of space we cannot discuss these statistical studies here but will merely point out some of the more noteworthy results:
At these pressures, the electron avalanche completely surrounds the anode wire (see Figs. 2 and 3). This is a very different situation from the *conventional* counters (operating usually at 1atm) where the avalanche is developing and contained on the side of the anode wire from which the primary electron is approaching. This effect increases with decreasing gas pressure and is caused by the fact that, as the mean free path between the collisions with gas molecules becomes comparable to the diameter of the anode, an electron has more chance to miss the wire and cause ionizations on the other side of the wire. This effect can be quite clearly seen on Fig. 1.
Also, the avalanche is not 'homogeneous' but consists of many *partial* avalanches started by what we call *seeding* electrons in the *seeding region*. The seeding region provides an explanation for the nature of the dependence of certain avalanche parameters on gas pressure. The existence of the seeding region can be clearly seen from Fig. 4. In this figure the points are the x coordinates of all electrons existing at a given time. Fig. 5 shows a similar picture of the same avalanche zooming only on one of the partial avalanches. The squares are space-time points where the positive ions were created. Rotation of the electrons around the anode wire is quite clearly apparent. These two figures also demonstrate how various time characteristics of the avalanche development can be studied.

4 Conclusion

The Monte Carlo code has been developed to simulate the motion of electrons in a force field of a proportional counter and electron's interactions with gas molecules. The method does not make any assumptions about the operating conditions of a counter and works reliably in the most extreme situations such as at high E/N. The only uncertainties come from the measured experimental data on electron-molecule interactions. It enables to study all aspects of spacial and temporal development of the electron avalanche in proportional counters and wire chambers and should help in their design.

References

[1] Segur, P., Peres, I., Boeuf, J.P., Bordage, M.C. Microscopic Calculation of the Gas Gain in Cylindrical Proportional Counters. Rad. Prot. Dosimetry Vol. 29, No 1/2, 23 (1989)

[2] Segur, P., Colautti, P., Moutarde, C., Conte, V., Alkaa,A., Talpo, G., Tornielli, Rabehi, A. Comparison between Experimental and Theoretical Determination of the Space Variation of the Gas Gain inside Low Pressure TEPC's. Radiation Protection Dosimetry Vol. 52, Nos 1-4, pp. 65-71 (1994)

[3] P. Segur, L. Peres, J.P. Boeuf and J. Barthe, *Radiation Protection Dosimetry* **31** (1990) 107–118

[4] Cukier, M., Dhez, P., Jaegle, P. Etude Experimentale et Theorique de l'Amplification Gazeuse dans un Compteur Proportional Cylindrique a Basse Pression. Rev. Phys. Appl. 7, pp. 357 - 365 (1972)

[5] Matoba, M., Hirose, T., Sakae, T., Kametani, H., Ijiri, H., Shintake, T. Three Dimensional Monte Carlo Simulation of the Electron Avalanche around an Anode Wire of a Proportional Counter. IEEE Transaction on Nuclear Science, Vol. NS-32, No. 1, 541 (1985)

[6] Groh, J. Computersimilation der Elektronenlawine in zylindersymmetrischen elektrischen Feldern. Dissertation Universitat Hamburg (1989)

[7] Groh, J., Schenuit, E., Spitzer, H. Computer Simulation of the Electron Avalanche in Cylindrically Symmetric Fields. NIM A**283**, 730 (1989)

[8] Groh, J., Schenuit, E., Spitzer, H. Computer Simulation of the Electron Avalanches in Argon-Methane filled Wire Chambers. NIM A**293**, 537 (1990)

[9] B. Schmidt, Anisotropic low energy electron collision cross sections for methane derived from transport coefficients. *J.Phys.B: Mol. Opt. Phys.* **24** (1991) 4809–4820. and private communication.

[10] B.Lohmann and S.J.Buckman, Low-energy electron scattering from methane. *J.Phys.B: Mol. Opt. Phys.* **19** (1986) 2565–2570.

[11] H. Tanaka and L. Boesten, Elastic DCS for $e + CH_4$ collisions, $1.5 - 100eV$ *J.Phys.B: Mol. Opt. Phys.* **24** (1991) 821–832.

[12] T. Sakae, S. Sumiyoshi, E. Murakami, Y. Matsumoto, K. Ishibashi and A. Katase, Scattering of electrons by CH_4, CF_4 and SF_6 in the $75 - 700eV$ range. *J.Phys.B: Mol. Opt. Phys.* **22** (1989) 1385–1394.

[13] B. Mapstone and W.R. Newell, Vibrational excitation of methane by electron impact *J.Phys.B: Mol. Opt. Phys.* **27** (1994) 5761–5772.

[14] H. Chatham, D. Hills, R. Robertson and A. Gallagher, *J.Chem.Phys.* **81** (1984) 1770.

[15] H.F. Winters, *J.Chem.Phys.* **63** (1975) 3462.

[16] S.F. Biagi, A Multiterm Boltzmann Analysis of Drift Velocity, Diffusion, Gain and Magnetic-field Effects in Argon-Methane-Water-Vapour Mixtures. *Nucl.Instr. and Methods A* **283** (1989) 716–722; and private communication

[17] H. Nishimura and H. Tawara, Total electron impact ionisation cross sections for simple hydrocarbon molecules. *J.Phys.B: At.Mol.Phys.* **27** (1994) 2063–2074.

[18] D. Rapp and P. Englander-Golden, Total Cross Sections for Ionization and Attachment in Gases by Electron Impact. I. Positive Ionisation. *J.Chem.Phys.* **43**(5) (1965) 1464–1479.

[19] O. J. Orient, S. K. Srivastava, Electron impact ionisation of H_2O, CO, CO_2 and CH_4. *J.Phys.B: At.Mol.Phys.* **20** (1987) 3923–3936.

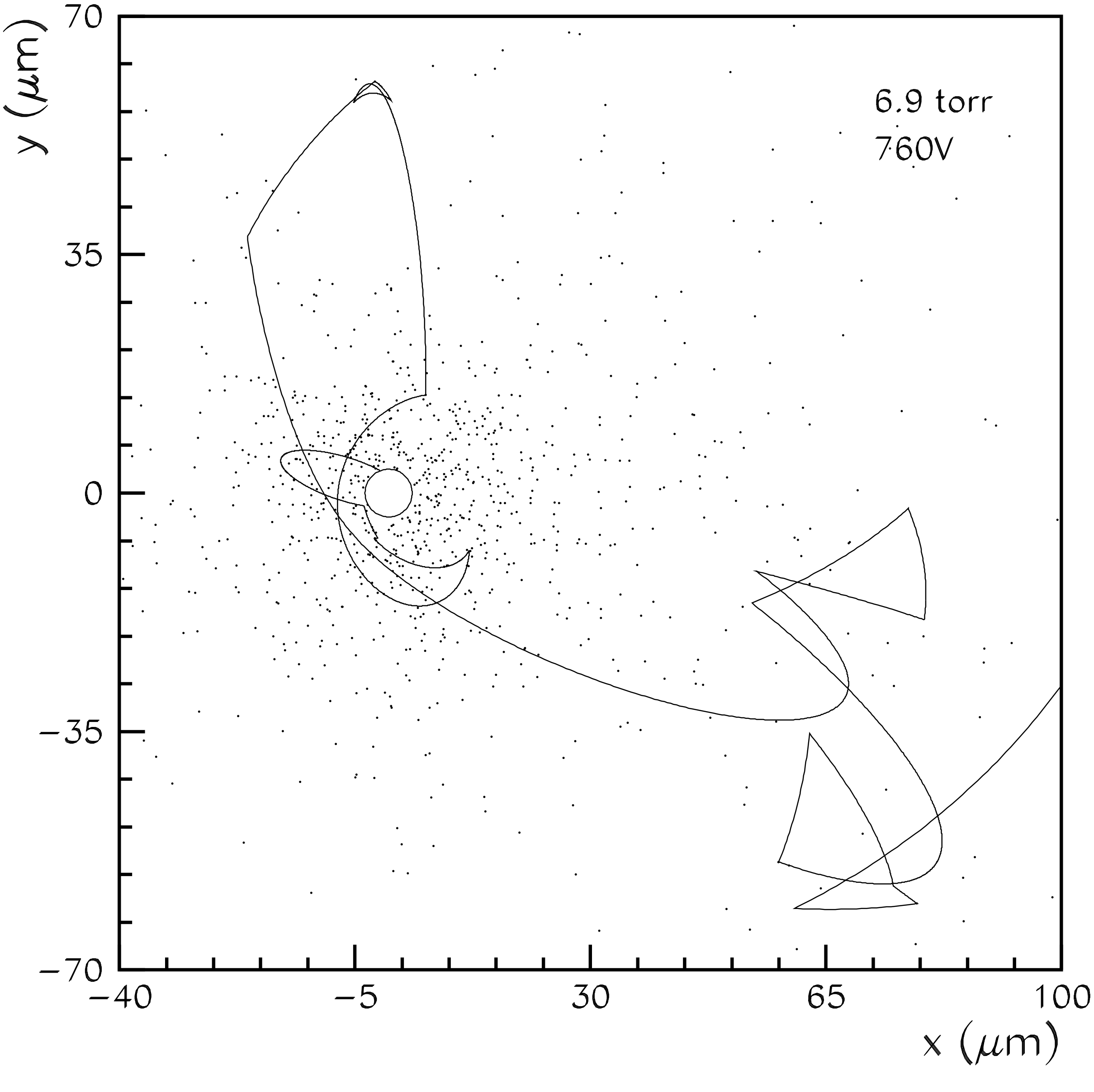

Figure 1: Simulated trajectory of one of the electrons in an avalanche projected onto the plane perpendicular to the anode wire (the little circle at the origin). The dots show the positions at which the positive ions were created during the avalanche process.

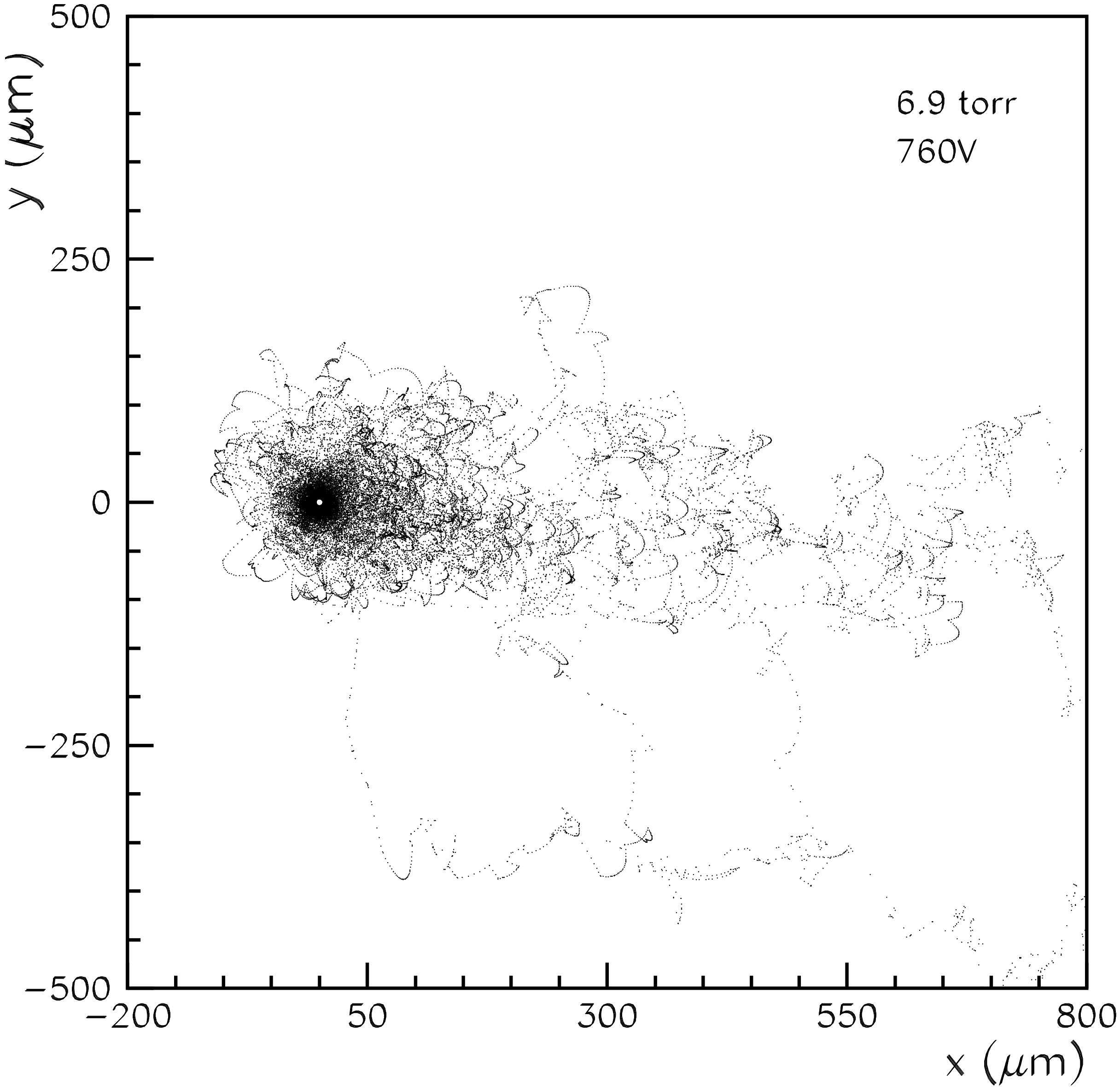

Figure 2: Trajectories of all the electrons in a typical avalanche projected into xy plane. Not all the trajectory points are shown.

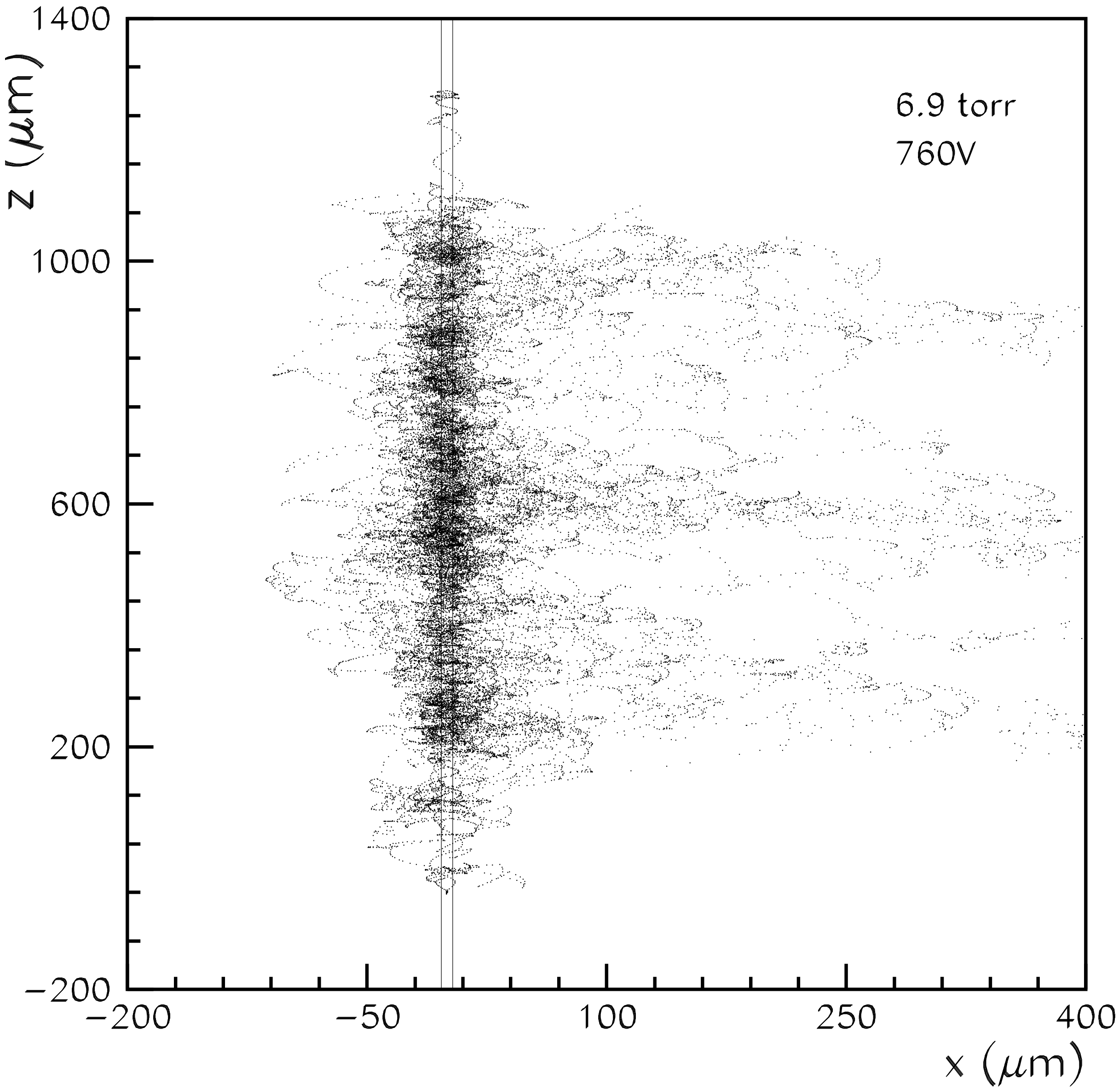

Figure 3: Trajectories of all the electrons in a typical avalanche projected into xz plane. Not all the trajectory points are shown.

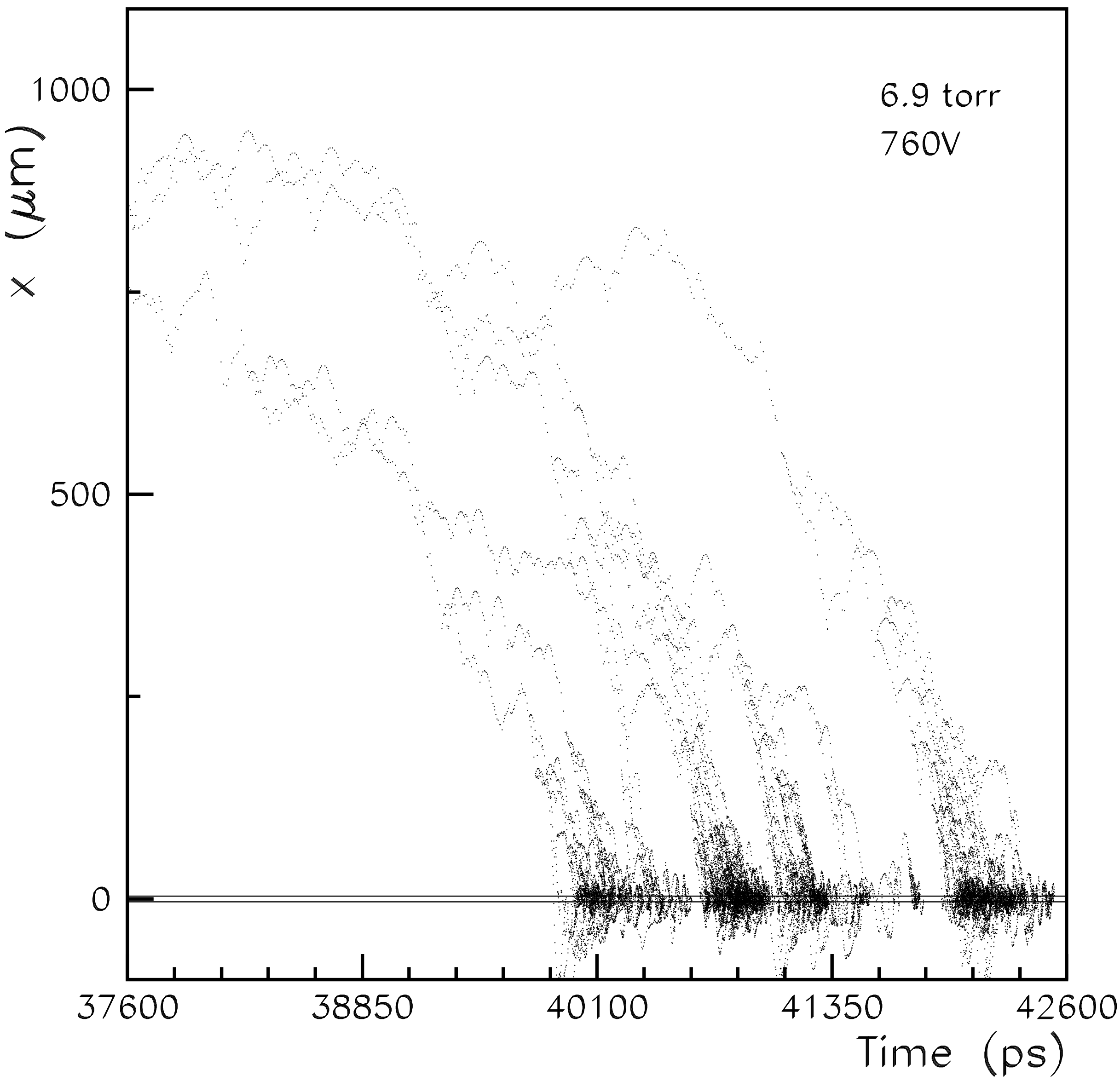

Figure 4: The space-time picture of a typical avalanche development. The points are the x coordinates (vertical axis) of all electrons existing at a given time (horizontal axis).

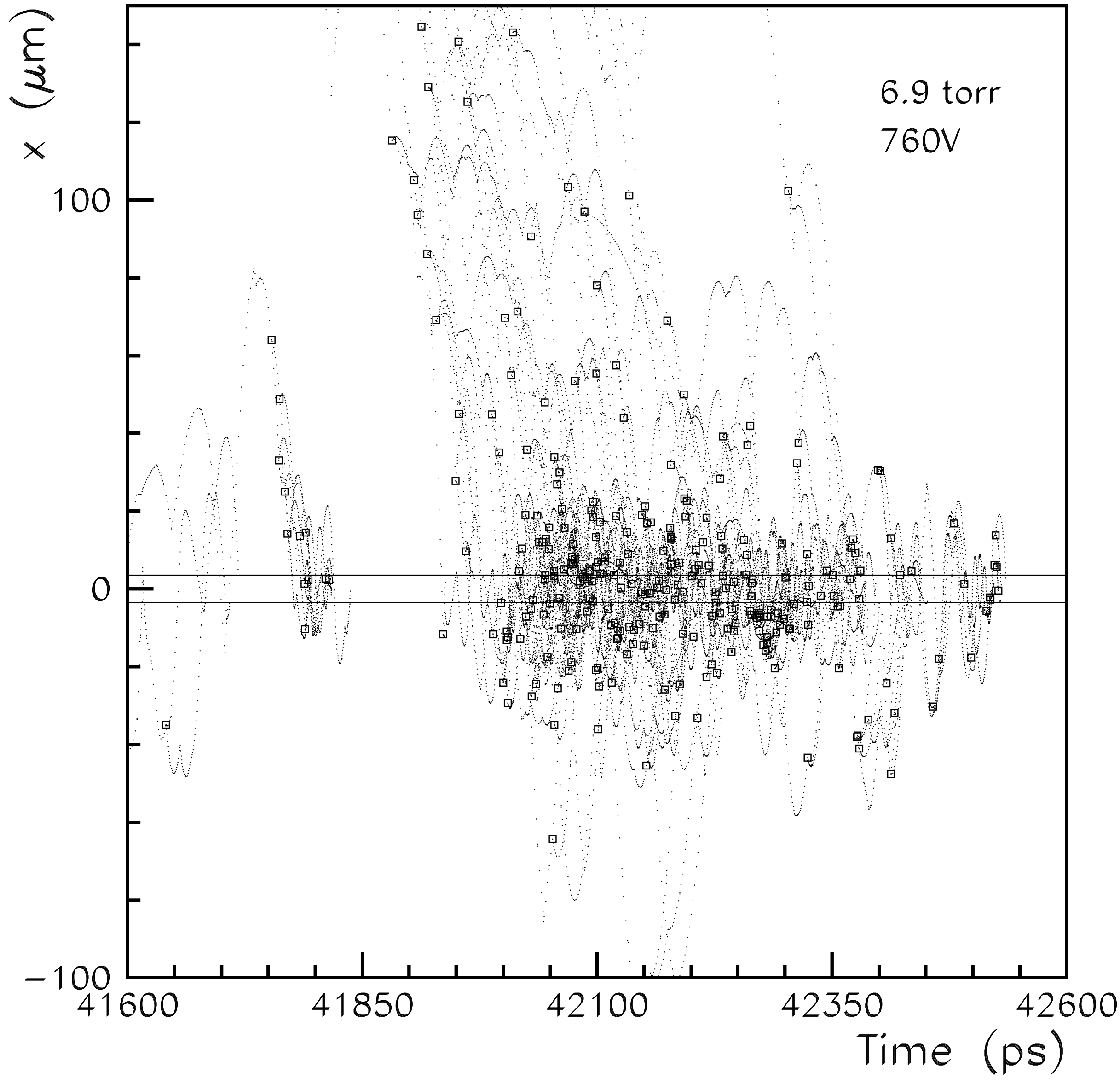

Figure 5: The space-time picture of avalanche development. Same as Fig. 4 but zooming on one of the *partial avalanches*. The little squares are the space-time points where the positive ions were created