TRIUMF Experiment E614
Technical Note 81

Accurate GARFIELD calculations of DC4 at B=0

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16 May 2003

1 Method: Description and Evaluation

A standard DC4 cell of E614 has been used for further calculations: signal wire with $15\mu m$ diameter at $HV = 1950V$, wire spacing is $4.000mm$, cathode gap is $3.994mm$, DME gas at $p = 760Torr$, $T = 300K$, and $B = 0$ or $B = 2T$. Positron with $E = 20 - 50MeV$ and π^+ with $p = 120MeV/c$ have been used as test particles. X-axis goes through wire centres, Y-axis is orthogonal to cathode planes, Z-axis is parallel to wire directions. Particle tracks lie in XY-plane. Angle $\theta = 0$ corresponds to a track going along Y-axis.

1.1 Particle track and drift electrons

Subprogram HEED of the GARFIELD has been used for simulation of drift electrons in DME gas. Short quotation from *http://consult.cern.ch/writeup/heed/main.html*: "The algorithm is based on a Monte-Carlo simulation of the energy transfers from the incident particle to the atomic electrons. After knocking out of a primary delta-electron, a vacancy remains in the atomic shell. The number of shell with vacancy and the type of atom in the gas mixture are specified for each energy transfer. It allows to calculate the delta-electron energy and generate a cascade of secondary particles emitted by the excited atom (the Auger electrons and the fluorescence photons). The calculations include the simulation of both the absorption of them in the matter and of the creation of conduction electrons." The HEED serves as the basic tool for a chamber simulation in many present experiments (ATLAS, for example).
Examples of positron track produced by the HEED shown in Figs. 1-4. The δ-electrons give a long tail on a STR as one can see further. Figs. 5-8 present distance distributions between a track and a drift electron for positron and pion at $B = 0$ and $B = 2T$ in E614 geometry with $B_y = 2T, B_x = B_z = 0$. A particle goes along Y-axis. Let me point out a dramatic decreasing of the average distances at $B = 2T$ (from $154 - 331\mu m$ to $16 - 41\mu m$) because of low energy δ-electrons have a small helix radius at $B = 2T$. Figs. 9-12 present distribution of drift electron number for positron and pion with and without δ-electrons contribution. Number of primary electrons (no δ-electrons) calculated by the HEED practically coincides with references [1,2]. Total number of electrons (with δ-electrons contribution) is less than it is in the references because of a part of δ and γ produced by a particle leaves our small size cell. Data about drift electrons are summarized in Tabl. 1.

1.2 Drift of electron and signal creation by GARFIELD

Signal section of the GARFIELD program has been used for further simulation.

- GARFIELD calculates a gas gain value G with a big error. Therefore usual way is to select the G value from experimental data. Average amplitude of signal from preamplifier+cable system is about 80mV according to beam measurements with positrons at $E = 30MeV$. This value corresponds to $G = 15000$ according to GARFIELD simulation. Gain of postamplifier selected to be 20 times. More careful measurements are needed for a more accurate simulation.

- The amplification is a statistical process which for a cylindrical geometry is well described by a Polya [3] distribution

Table 1: Drift electrons calculated by GARFIELD in DME gas. Average drift electron numbers and distances are presented.

Particle	Primary electrons		Total electrons	Distance track-electron, μm	
	1/cm	Spacing, μm	1/cm	$B=0$	$B=2T$
$e^+, 20MeV$	70	143	85.4	134.5	20.7
$e^+, 25MeV$	71	141	86.0	154.2	19.2
$e^+, 30MeV$	71.5	140	87	140	17.8
$e^+, 35MeV$	71.8	139	88	126.4	20.3
$e^+, 40MeV$	72	139	88	154.6	19.8
$e^+, 45MeV$	72	139	85	95.9	16.3
$e^+, 50MeV$	72	139	89	154.4	16.4
$\pi^+, 120MeV/c$	103.4	97	159	331.1	41.2

$$G(x) \propto x^{\Theta} e^{-(1+\Theta)x}$$

where Θ is a parameter between 0 and 1. Θ was chosen to be 0.4 [3,4]. Changing of Θ in wide limits does not shift STR and resolution.

- Ion mobility near sense wire at a high electric field $E \approx 500kV/cm$ gives most important contribution to a signal shape. Mobility of DME^+ ion in DME gas equals to $0.56 \cdot 10^{-6} cm^2/V \cdot \mu s$ at $E \approx 5kV/cm$ has been used for the simulation. Data of the ion mobility at $E \approx 500kV/cm$ are needed for more accurate simulation.

- Preamplifier defines a shape of an output signal. VTX preamplifier response on delta signal has impulse rise time of $5ns$ and fall time of $16ns$ [5]. The VTX has, after our long cable, rise time of $15ns$ and fall time of $60ns$ according to scope measurements. Therefore an amplifier response function

$$\overline{f}(t) = (t/\tau)^n e^{-t/\tau}, \overline{f}_{max} = n^n e^{-n}$$

was chosen [7] with $n = 3$ and $\tau = 17ns$ to provide the above signal shape.

- A Gaussian noise with $\sigma = 1mV$ has been added to preamplifier output signal. Changing of the σ in wide limits does not shift STR and resolution.

- Typical signal from positrons had amplitude of $\simeq 2V$ on input of a discriminator after the above parameters selection. Single electron signal had amplitude of $90mV$. Threshold of $140mV$ corresponds to $\simeq 1.6e$. Several signals are presented in Figs. 13-16.

1.3 Methods of STR and resolution calculation by GARFIELD

Three methods are in the GARFIELD for a calculation. Results of the methods are compared for drift distance of $d = 1.6mm$ at $\theta = 0$.

- Drift line calculation.

  Drift time $t(x, y)$ of an electron is calculated from any point (x, y) of a cell. The Runge Kutta Fehlberg drift line and a total drift time of an electron is calculated without taking into account diffusion, δ-electrons from a track, gain and its fluctuation, attachment, a dead zone around sense wire. A $TABLE$ of $t(x, y)$ introduced in a track reconstruction program. Calculated here electron drift time is $t_0 = 171ns$ for $d = 1.6mm$ $(x = 1.6mm, y = 0)$.

- Arrival time of any electron from a track.

  Drift time of any electron from a track is calculated by either Runge Kutta Fehlberg or Monte Carlo method. The Runge Kutta Fehlberg method only used below. The method takes into account diffusion, δ-electrons from a track, attachment. Gain calculation using Townsend coefficient gives too much value and can not be used because a drift time of electron having number n is calculated. Different track models are used including a single cluster, any electron distribution along a cluster, drift electron generation using the HEED program. A model with Poisson distributed electrons along a track introduced in GEANT. Examples of an arrival time distribution are shown in Figs. 17-20. The above method does considerate so called dead zone with $r \simeq 100\mu m$ around a sense wire [6]. Calculated here electron drift time is $t_0 = 166.77ns$ (Fig.17) for $d = 1.6mm$ ($x = 1.6mm, \theta = 0$).

- SIGNAL section of the GARFIELD.

  A signal from a particle is calculated by the program taking into account all processes in chamber and front-end electronics as that been described in Section 1.2. Examples of an arrival time distribution at different requirements are shown in Figs. 21-24. Case with no δ-electrons, no multiple scattering, or no attachment gives the same values of t_0 and σ_t. For example, even case of Fig.24 with additional requirement of no δ-electrons gives $t_0 = (181.93 \pm 0.16)ns$. One can see that t_0 has the same value practically in all figures. Changing of σ_t value describes a contribution of different processes to a time resolution. Value of $\sigma_t = 2.25ns$ from Fig.24 corresponds to an ionization statistics contribution to time resolution. Contribution of different processes to the time resolution is shown in Tabl. 2. The $\sigma_t = 4.29ns$ corresponds to space resolution of $\simeq 12\mu m$ at $d = 1.6mm$. Calculated here electron drift time is $t_0 = 181.47ns$ (Fig.21) for $d = 1.6mm$ ($x = 1.6mm, \theta = 0$).

Table 2: Contribution of different processes to time resolution. Positron with $E = 50MeV$, HEED, drift distance is $d = 1.6mm$.

	δ-electrons	Scattering	Attachment	Noise	POLIA gain distribution	Ionization	Diffusion	Total
σ_t, ns	< 0.5	< 0.5	< 0.5	0.74	1.43	2.25	3.27	4.29

1.4 The method evaluation

The proposed procedure of a chamber simulation has been tested using of published data. SIGNAL section has been used for calculations.

- Drift chamber of the ATLAS MUON detector (MDT) is most investigated device. Drift tubes with radius of $15mm$ are used in the detector. The MDT characteristics have been investigated using practically all possible methods [7-9]. GARFIELD simulation results have been compared with a direct measurement of STR, time and space resolution using a silicon telescope with a resolution of $5\mu m$ for the track position at the chamber [10]. The MDT characteristics have been simulated here using the described above procedure. Published values of gain, Polya parameter Θ, threshold, noise, and amplifier response function have been used for the calculation. Results are shown in Figs. 25, 26. One can see an almost coincidence with the original data with $Ar/CO_2(93/7)$ gas.

- Results of detailed measurement of a drift chamber characteristics with DME gas [11] have been compared with GARFIELD simulations. A drift cell had wire spacing of $11.4mm$ and cathode gap of $10.0mm$. Only gain value of $2.0 \cdot 10^4$ is named in Ref. [11]. Other parameters of used front-end have been put according to a common sense. Results are shown in Figs. 27, 28. One can see a good coincidence with STR curve. Calculated space resolution almost coincides with the curve "B" describing a space resolution because a "contribution of ionization statistics". Measured space resolution is worse at $r > 2mm$. Quotation from Ref. [11]: "The simulation of the resolution requires a sizeable constant contribution of about $20\mu m$ which has to be attributed to various imperfections". Probably the $20\mu m$ is an accuracy of the chamber manufacturing. According to published results a minimal space resolution of $\simeq 20\mu m$ with DME gas can be explained either a manufacturing accuracy [12] or a time jitter [13].

2 HEED track and track with Poisson distributed electrons

- HEED track.

  One can see from Figs.13-16, 21-24 that the fitted curve differs from a Gaussian form. Tabl. 3 presents dependence of χ^2, t_0, and σt_0 from total statistics. One can see 300-400 events is a maximal allowed statistics to do a Gaussian fit. Total statistics of 300 events is used below for time-distance calculations.

Table 3: Gaussian fit of an arrival time distribution as a function of total statistics. DC4, drift distance is $1.0mm$, $\theta = 0$, NDF=16, positron with $E = 50MeV$, HEED, SIGNAL section, all processes are ON. t_0 is a mean and σt_0 is an error of a fitting curve.

Number of events	100	200	300	400	500	600	800
χ^2	14.6	16	15.2	14.9	28.1	21.3	29.7
$t_0/\sigma t_0$, (ns)	50.81/ 0.70	50.22/ 0.29	50.68/ 0.15	50.67/ 0.14	50.63/ 0.14	50.66/ 0.12	50.68/ 0.09

  Arrival time distributions for 30000 events are shown in Figs. 29-32. δ-electrons do not change t_0 and σ_t, but they produce $> 2 \cdot 10^{-3}$ events far less from $t_0 \simeq 170ns$. Low energy δ-electrons produce the events (see Figs.2, 3). Each this event simulates a kink, but no a kink in reality because δ-electron energy is a few KeV only. δ-electrons produce about $2 \cdot 10^{-3}$ events with a wrong time in nearest cells and in a next DC4 plane according to simulation. The events have a normal signal width (see Fig.19) and their contamination is the same at $threshold = -560mV$ even (Fig.32).

- Track with Poisson distributed electrons.

  Straight tracks with Poisson distributed electrons along the tracks have been simulated using the SIGNAL section and taking into account all processes excluding δ-electron production and multiple scattering. Only 300-400 events as before can be fitted by a Gaussian curve because χ^2 worsening. The tracks been simulated for different mean number of electrons per cm. Results are shown in Figs.33, 34. One can see from Fig.33 that calculated t_0 value coincide with t_0 from HEED simulation for positron with $E = 50MeV$ at $MEAN = 71e/cm$ and for pion with $120MeV/c$ at $MEAN = 116e/cm$. One can see from Fig.34 that Poisson method gives less value of $\sigma_t = 3.2ns$ for positrons compare with $\sigma_t = 4.29ns$ calculated by the HEED (see Tabl.2). Difference between t_0 values calculated by HEED for positron and by Poisson from drift distance shown in Fig.35. The difference is close to zero.

3 STR, time and space resolution of DC4

STR and time resolution have been calculated using the HEED for positrons with $E = 50MeV$. The calculations are done for our DC4 cell with $HV = 1950V$ at $B = 0$ for tracks orthogonal to cathode plane. Results of the calculations together with fiting curves are shown in Figs.36-39.

Space resolution σ_d has been calculated as

$$\sigma_d = \sigma_t / f'(d),$$

where $f'(d)$ is derivative of fitting function $t_0 = f(d)$.
The calculated σ_d shown in Figs.40, 41. Let me point out that nobody seen so small space resolution, for example, $\sigma_d = 7 - 8\mu m$ at $d = 1.8mm$. Shifting of threshold of -140mV from -100 to -200mV changes the σ_d on $< \pm 10\%$. Minimal electric field on the track is $E = 400V/cm$. Values of a drift velocity and diffusion coefficient calculated by GARFIELD practically coincide in this area of E with experimental data [14,15]. Probably it is the real space resolution of the DC4. The coincidence of calculated results with experimental data (see Figs.25-28) confirms this point of view.

Difference Δt between t_0 calculated by HEED and extracted from $TABLE$ (see 1.3) shown in Figs.42,43 together with fitting of the difference. Most part of Δt can be explained by a rise time of preamplifier (see 1.2). Some value of Δt can be explained because the $TABLE$ procedure ignores a dead zone [6] around a sense wire.

Figs.44,45 demonstrate TDC spectra for random distribution of a positron track along a cell. Fig.46 demonstrates a gain dependence from distance between a sense wire and a drift electron. One can see a "dead zone" with radius $r \simeq 100\mu m$ around a sense wire where gain drops off a standard value. Fig.47 demonstrates a Polya function of gain distribution.

4 Conclusion

- Simple calculation of a drift line does not provide a real STR of a chamber because it ignores all interactions of a drift electron with a drift gas.
- Procedure of arrival time calculation takes into account all interactions of an electron with a drift gas. It has two disadvanteges. First of all the procedure of a gain calculation gives a wrong number (in 10 and more times) therefore we have not an accurate arrival time value t_0 and time resolution σ_t. Furthermore the arrival time of 1st electron can not be measured practically because a gain has a broad distribution (see Fig.47).
- SIGNAL section takes into account all interactions of an electron in a gas (drift velocity, diffusion, multiple scattering, attachment, gain distribution, avalanche development) and frontend characteristics (rise and fall time of a preamplifier, noise, threshold). Total electron signal is created as a sum of multiplicated single electrons. A real signal from a wire defined by electrons movement to the wire and ions movement from the wire. The SIGNAL section is used for a chamber simulation in present experiments. ATLAS team spent a lot of effort to study their chambers.
- The note results could be used for track reconstruction and alignment at B=0. It is possible to create a detailed table for STR and time resolution at B=0 and B=2T.

5 References

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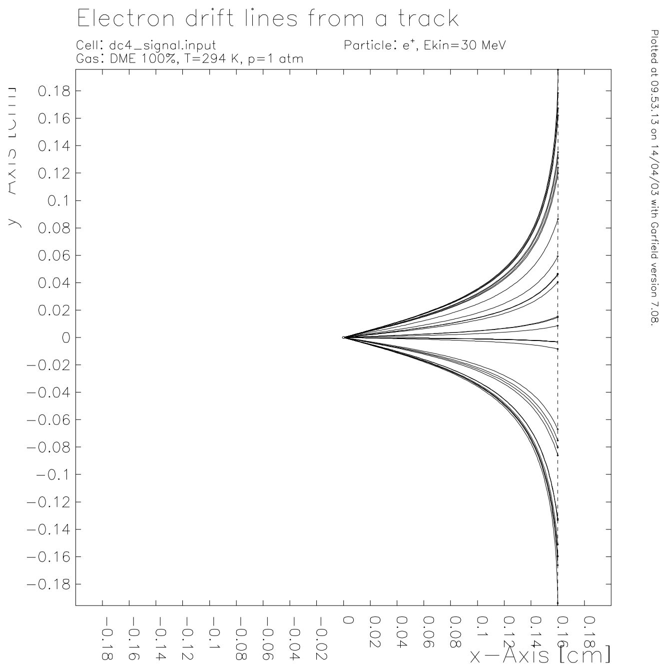

Figure 1: An usual track and drift lines from positron with $E = 30MeV$. Delta electron production, its tracing, and multiple scattering are ON. A small energy δ produces a drift electron near $y = 0$.

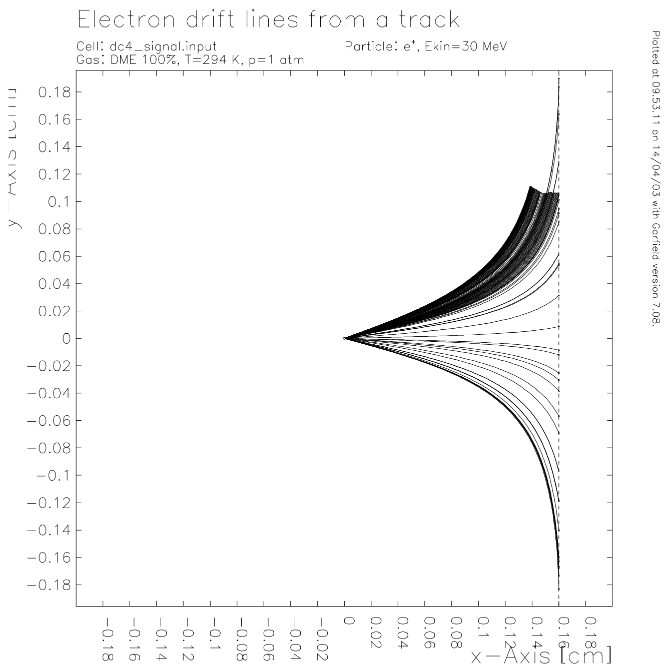

Figure 2: Positron track with short δ electron. One can see drift electrons from the δ.

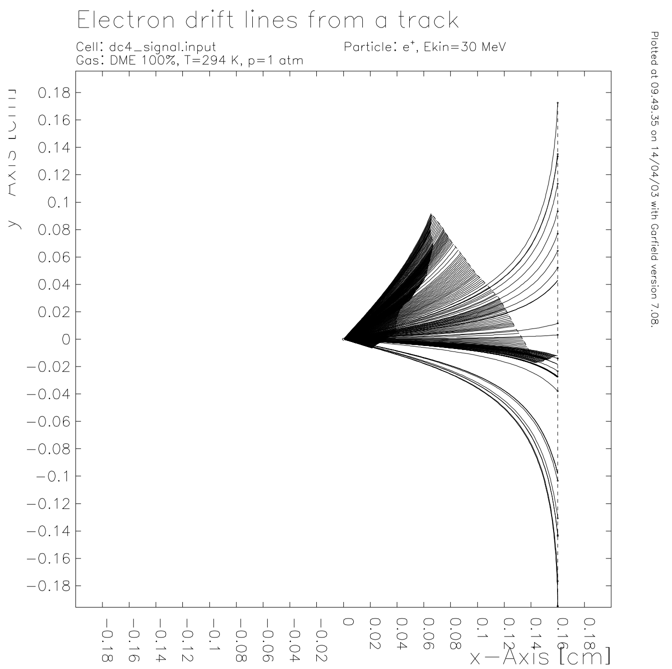

Figure 3: Positron track with a high energy δ-electron.

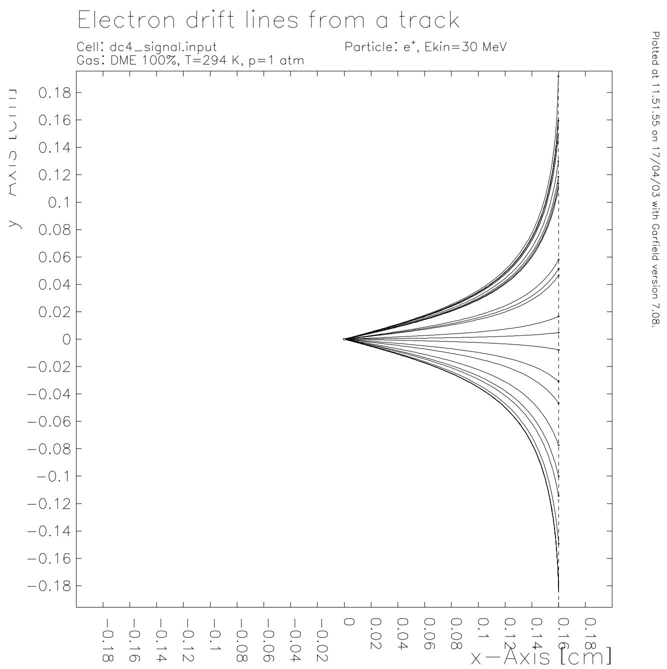

Figure 4: Positron track with no δ-electrons production.

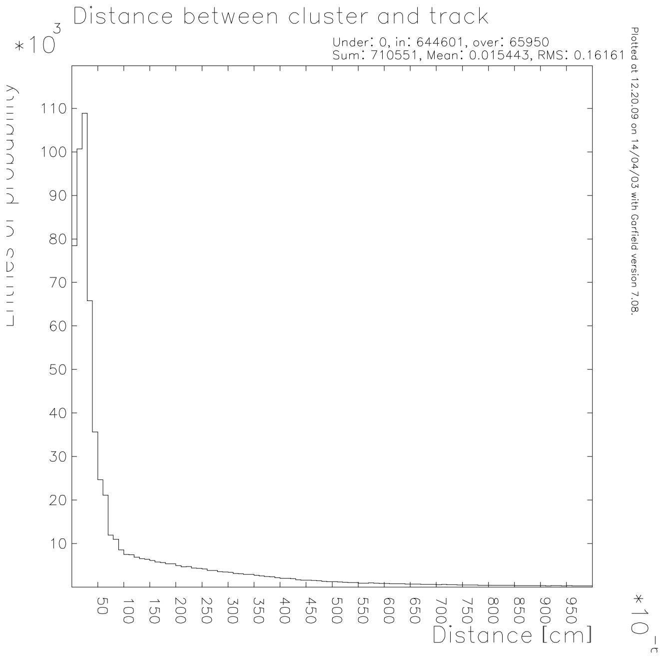

Figure 5: Distribution of distance between positron track with $E = 50MeV$ and drift electron. $B = 0$, average distance is $154\mu m$. Horizontal axis - $cm \times 10^{-6}$.

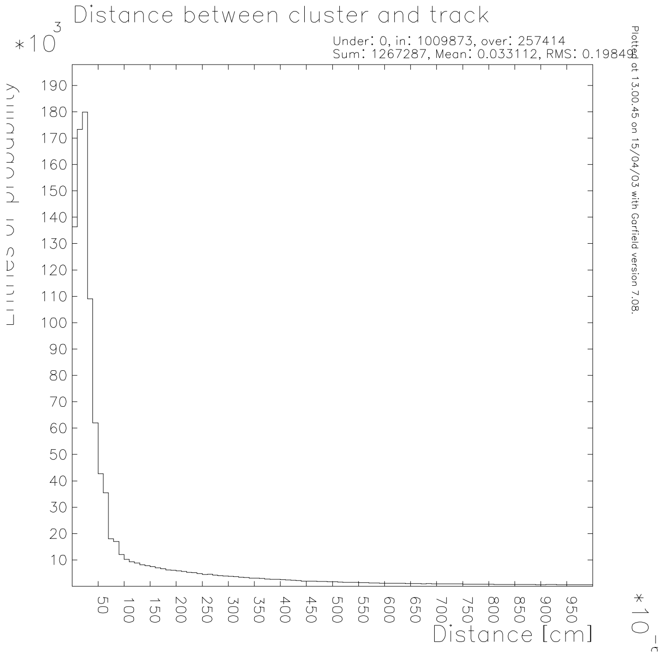

Figure 6: Distribution of distance between π^+ track with $p = 120MeV/c$ and drift electron. $B = 0$, average distance is $331\mu m$. Horizontal axis - $cm \times 10^{-6}$.

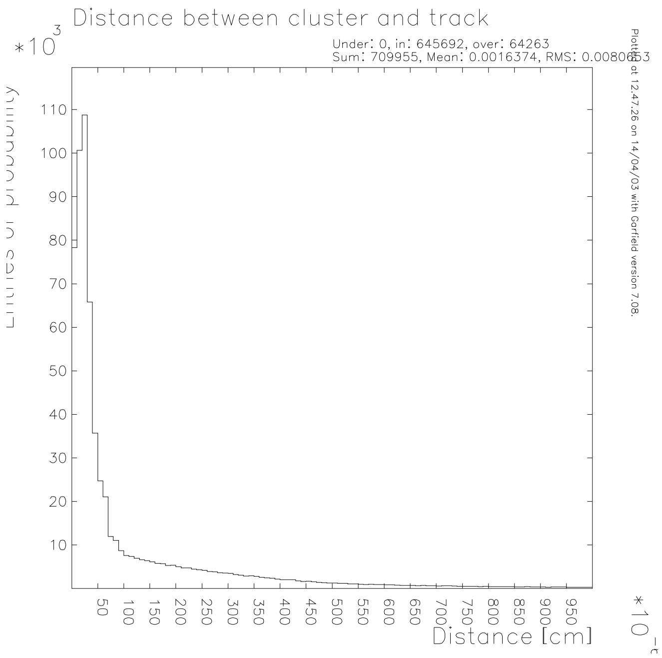

Figure 7: Distribution of distance between positron track with $E = 50MeV$ and drift electron. $B = 2T$, average distance is $16\mu m$. Horizontal axis - $cm \times 10^{-6}$.

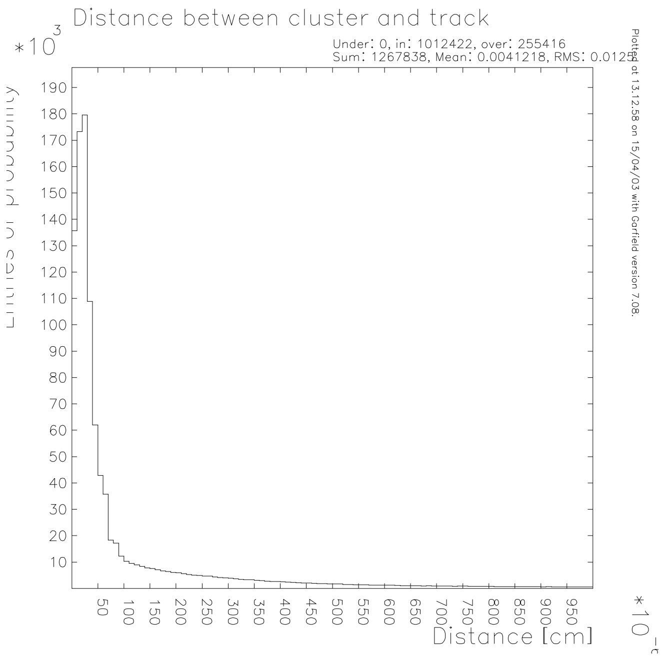

Figure 8: Distribution of distance between π^+ track with $p = 120MeV/c$ and drift electron. $B = 2T$, average distance is $41\mu m$. Horizontal axis - $cm \times 10^{-6}$.

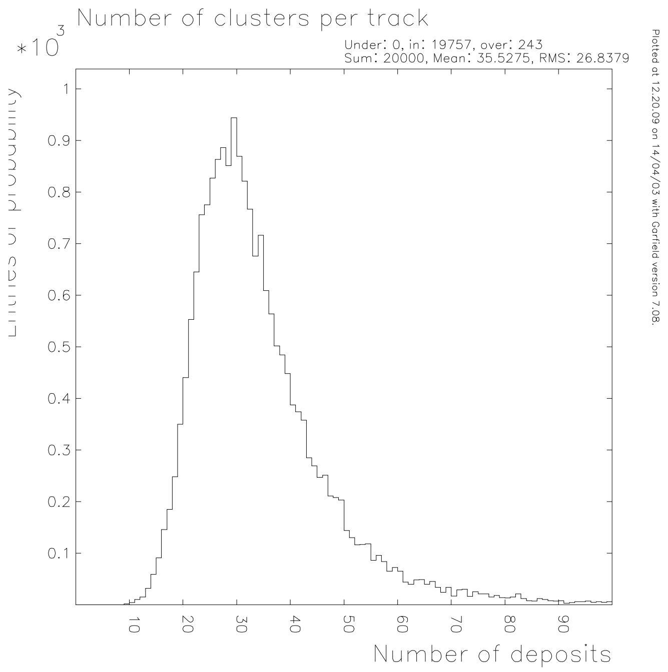

Figure 9: Distribution of drift electron number per $4mm$ for a positron with $E = 50MeV$. δ-electrons, trace δ-electrons, multiple scattering.

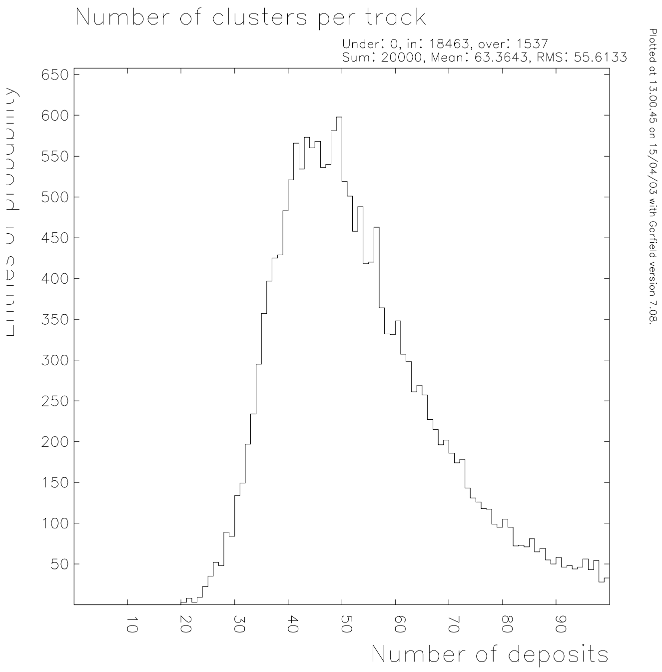

Figure 10: Distribution of drift electron number per $4mm$ for a π^+ with $p = 120MeV/c$. δ-electrons, trace δ-electrons, multiple scattering.

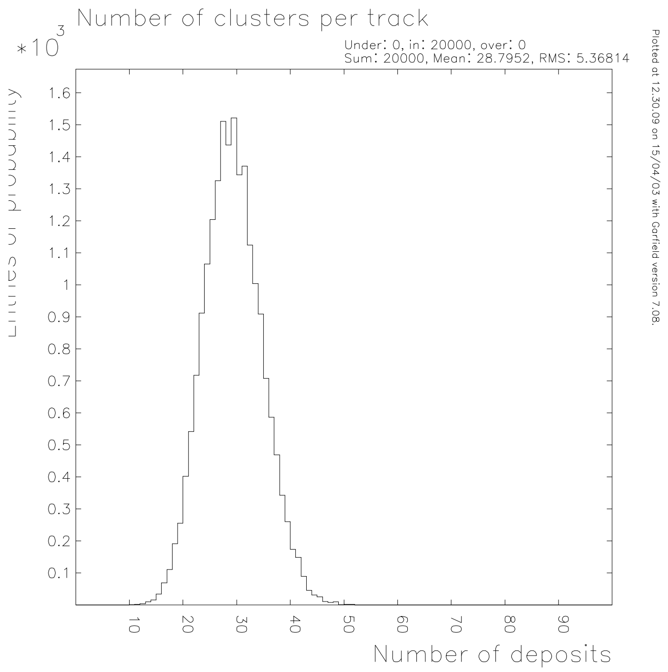

Figure 11: Distribution of drift electron number per $4mm$ for a positron with $E = 50MeV$. No δ-electrons, no trace δ-electrons, multiple scattering.

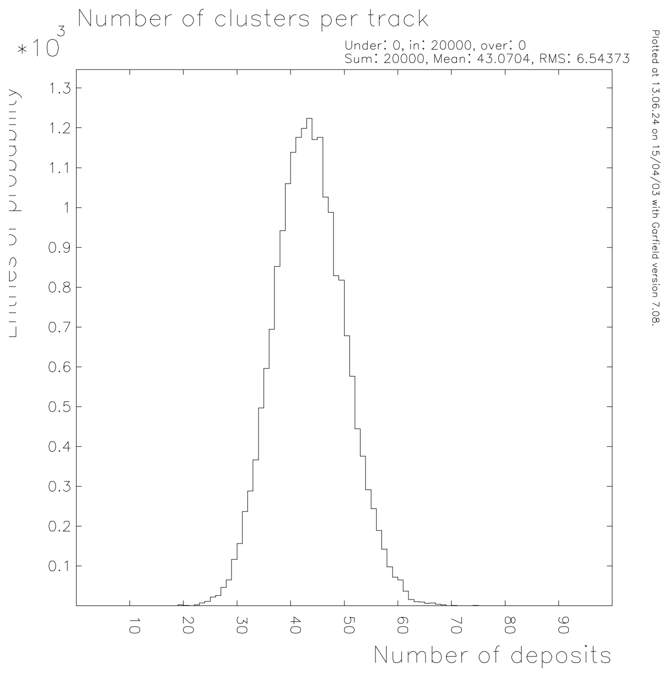

Figure 12: Distribution of drift electron number per $4mm$ for a π^+ with $p = 120MeV/c$. No δ-electrons, no trace δ-electrons, multiple scattering.

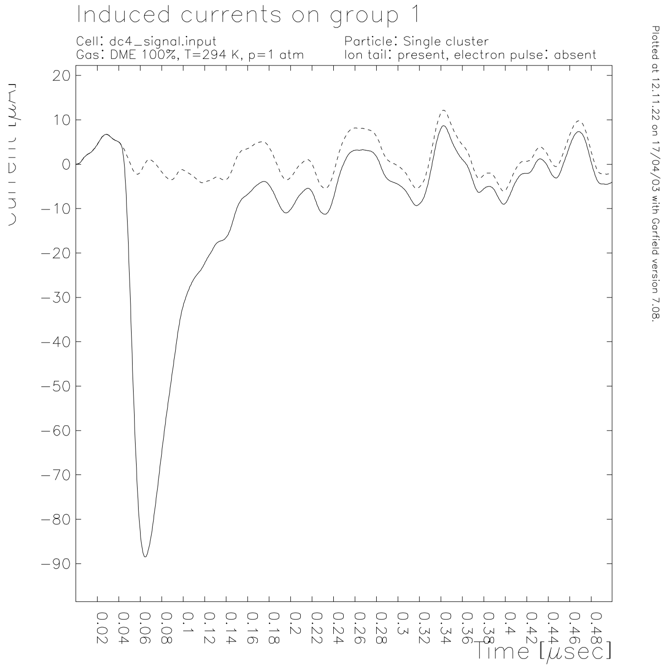

Figure 13: Signal from a single electron in DC4. Vertical axis - mV. Dash line presents a noise.

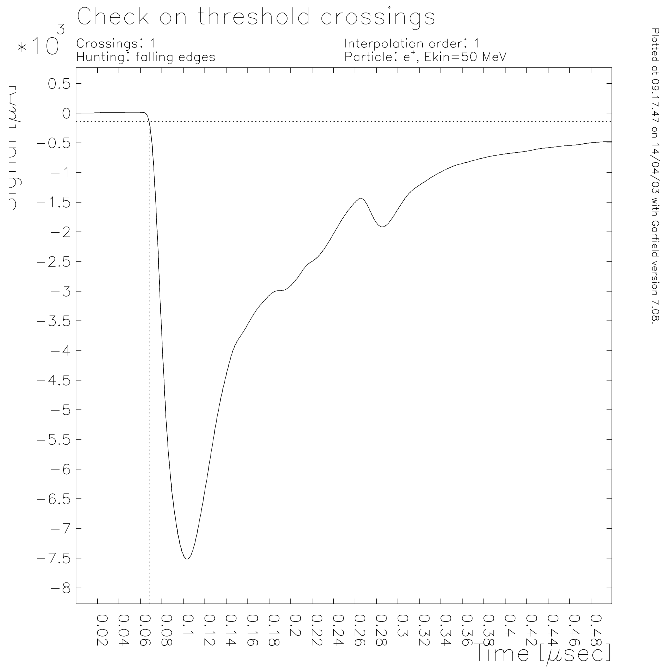

Figure 15: Signal from positron with $E = 50MeV$ goes on distance of $d = 1.6mm$ ($\theta = 0$) from a sense wire. Horizontal dotted line corresponds to threshold of $-140mV$. Vertical dotted line crosses the time axis at $t \simeq 0.07\mu s$ which corresponds to drift time from a delta electron which moves from the track to sense wire as that shown in Fig. 3. Vertical axis - V.

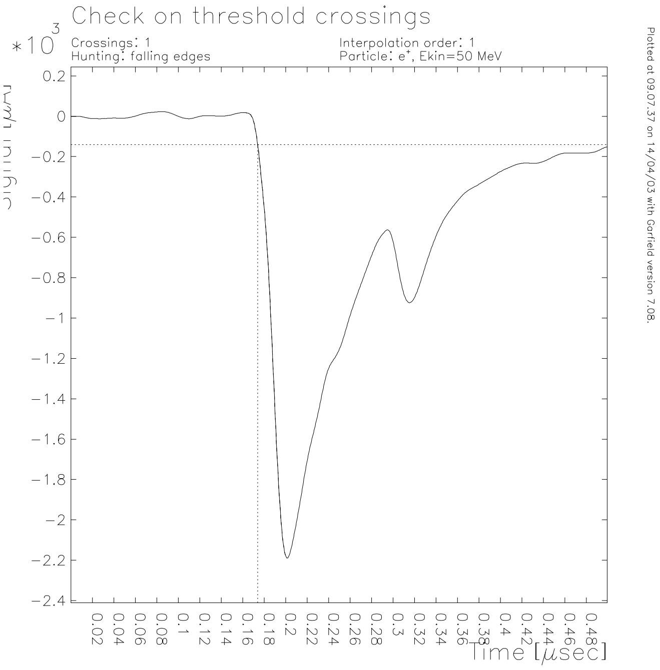

Figure 14: Signal from positron with $E = 50MeV$ goes on distance of $d = 1.6mm$ ($\theta = 0$) from a sense wire. Horizontal dotted line corresponds to threshold of $-140mV$. Vertical dotted line crosses the time axis at $t \simeq 0.18\mu s$ which corresponds to drift time from $d = 1.6mm$. Vertical axis - V.

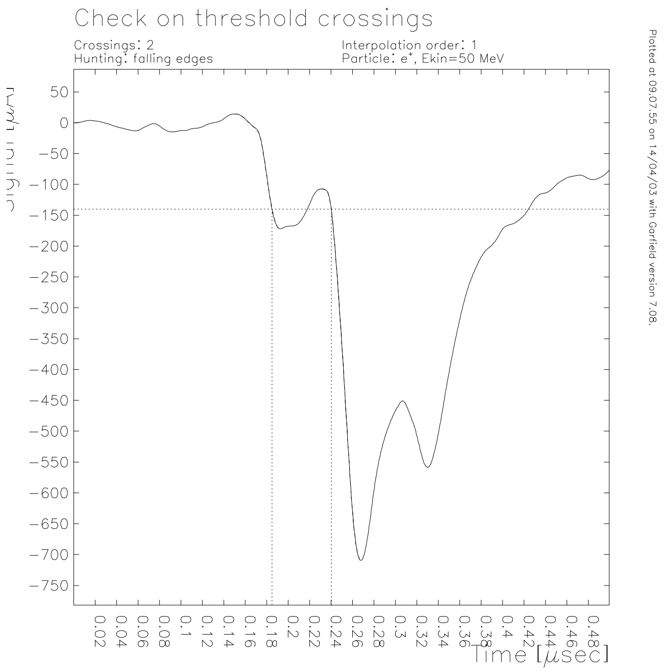

Figure 16: Variety of signal shape. Vertical axis - mV.

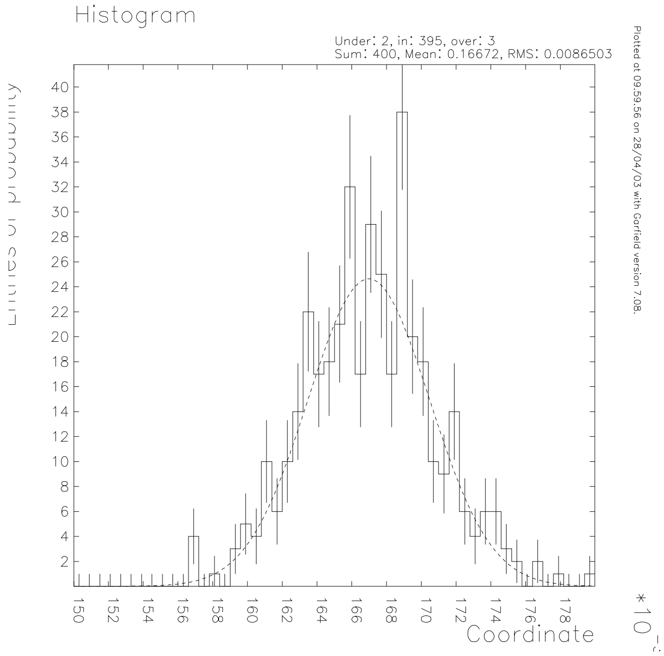

Figure 17: Arrival time distribution of 1st electron from a track with $d = 1.6mm$ and $\theta = 0$. HEED, positron with $E = 50MeV$, δ electrons, trace δ electrons, diffusion, attachment, multiple scattering, Gaussian fit with $t_0 = (166.77 \pm 0.21)ns$ and $\sigma_t = (3.62 \pm 0.15)ns$. Horizontal axis - arrival time in ns.

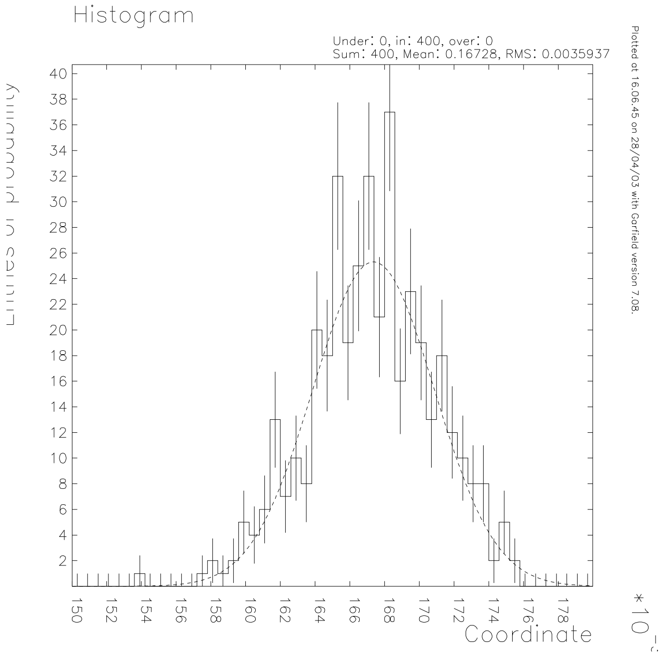

Figure 18: Arrival time distribution of 1st electron from a track with $d = 1.6mm$. Poisson distribution of drift electrons along the track with mean of $\overline{n} = 71e/cm$. Straight track, no scattering, diffusion, attachment, Gaussian fit with $t_0 = (167.37 \pm 0.21)ns$ and $\sigma_t = (3.50 \pm 0.15)ns$. Horizontal axis - arrival time in ns.

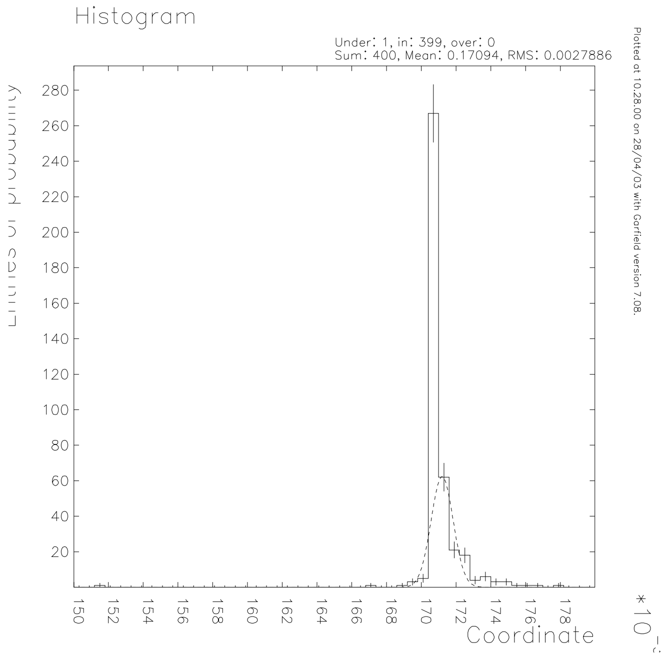

Figure 19: Fig.13 with no diffusion. Horizontal axis - arrival time in ns.

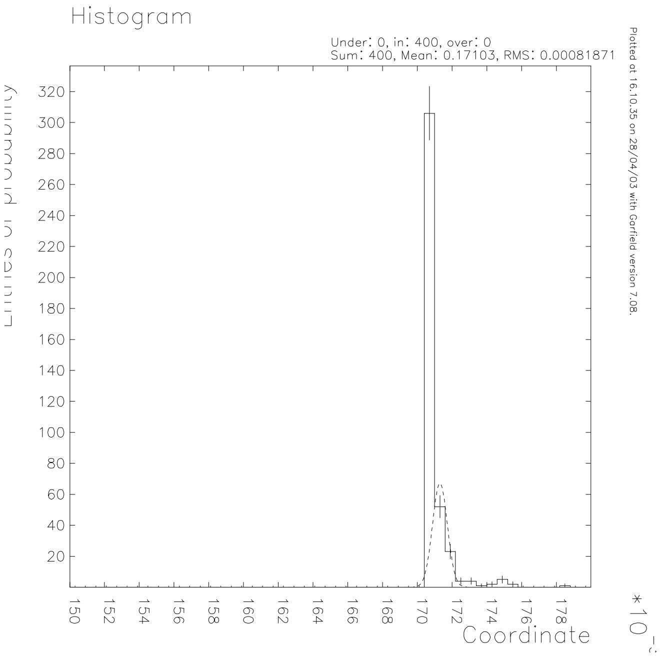

Figure 20: Fig.14 with no diffusion. Horizontal axis - arrival time in ns.

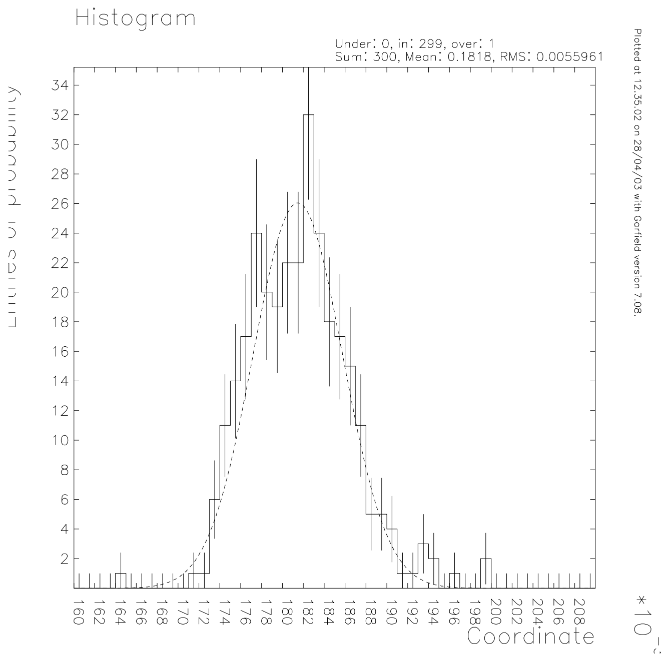

Figure 21: Arrival time distribution of signals from track with $d = 1.6mm$ and $\theta = 0$. Positron with $E = 50MeV$, HEED, δ-electrons, trace δ-electrons, diffusion, attachment, multiple scattering, Polya distribution of gain with $\overline{G} = 15000$ and $\Theta = 0.4$, $threshold = -140mV$, $noise = 1mV$. Gaussian fit with $t_0 = (181.47 \pm 0.24)ns$ and $\sigma)_t = (4.29 \pm 0.18)ns$. Horizontal axis - arrival time in ns.

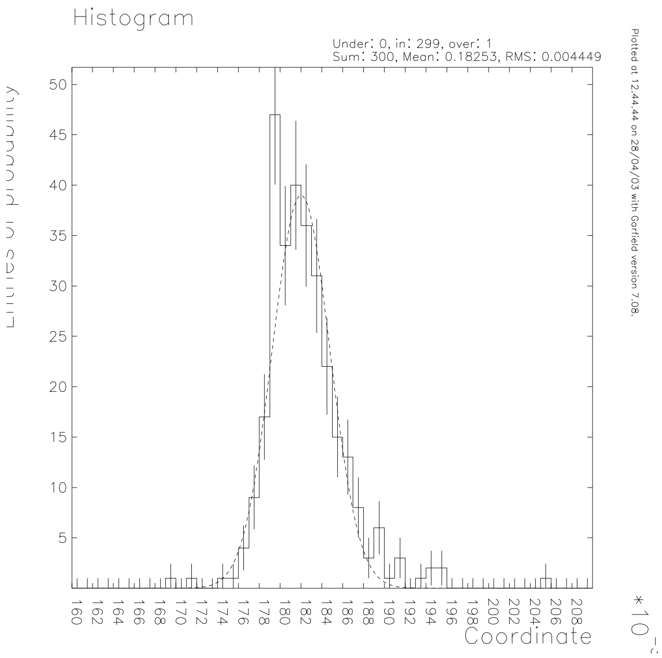

Figure 22: Fig.21 with no diffusion. Gaussian fit with $t_0 = (182.0 \pm 0.16)ns$ and $\sigma_t = (2.77 \pm 0.13)ns$. Horizontal axis - arrival time in ns.

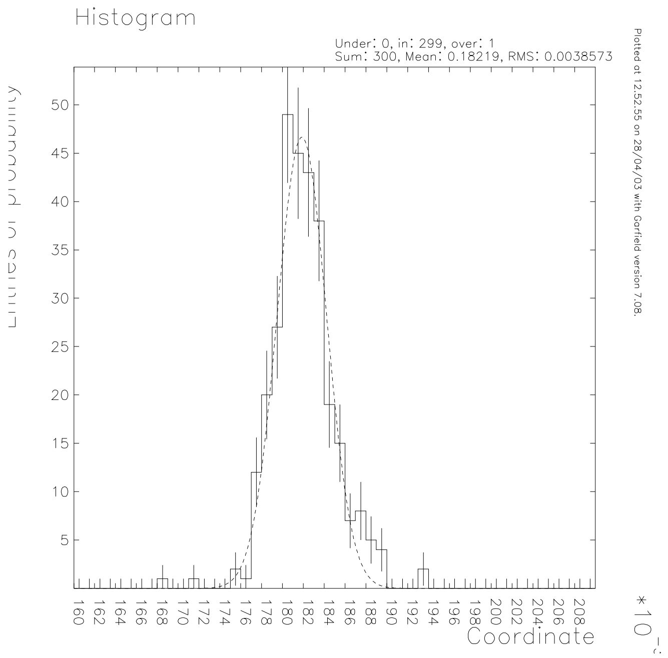

Figure 23: Fig.21 with no diffusion, and fixed gain value of $\overline{G} = 15000$. Gaussian fit with $t_0 = (181.86 \pm 0.13)ns$ and $\sigma_t = (2.37 \pm 0.10)ns$. Horizontal axis - arrival time in ns.

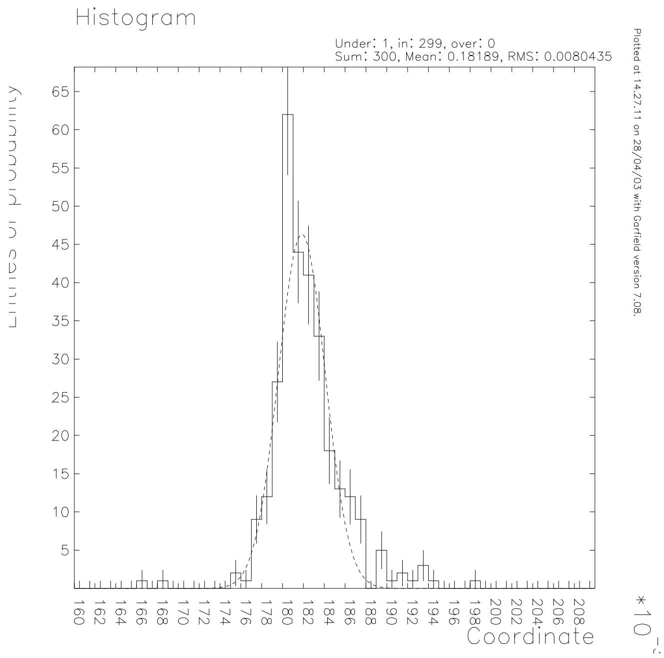

Figure 24: Fig.21 with no diffusion, fixed gain value of $\overline{G} = 15000$, and $noise = 0mV$. Gaussian fit with $t_0 = (181.96 \pm 0.16)ns$ and $\sigma_t = (2.25 \pm 0.16)ns$. Horizontal axis - arrival time in ns.

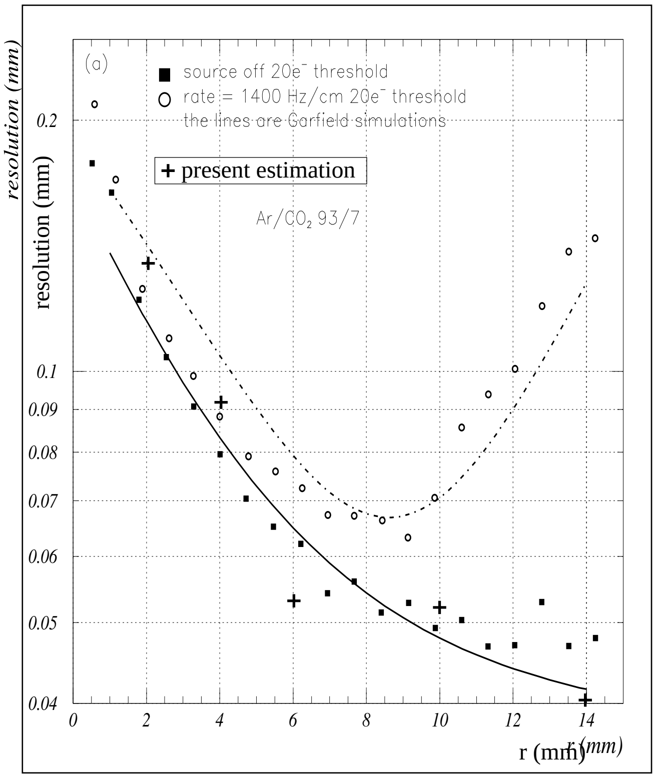

Figure 25: Fig.6 from Ref. [8]. Crosses mark the simulation results.

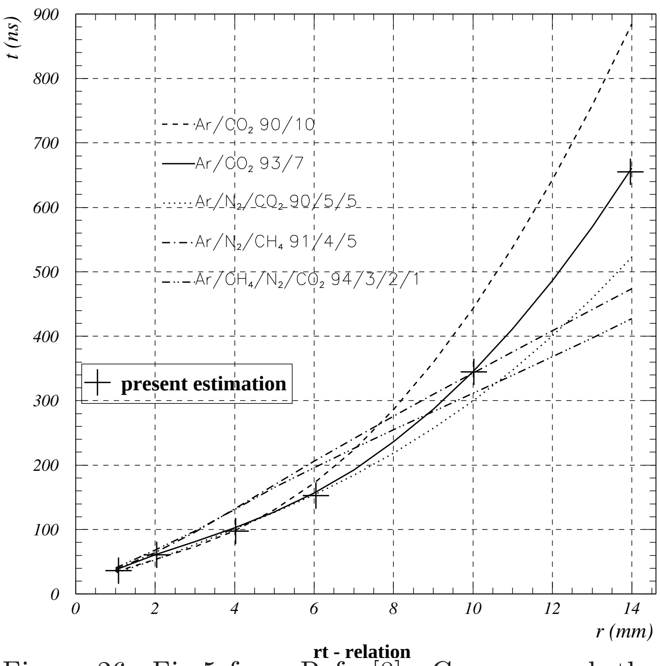

Figure 26: Fig.5 from Ref. [8]. Crosses mark the simulation results for $Ar/CO_2(93/7)$ gas.

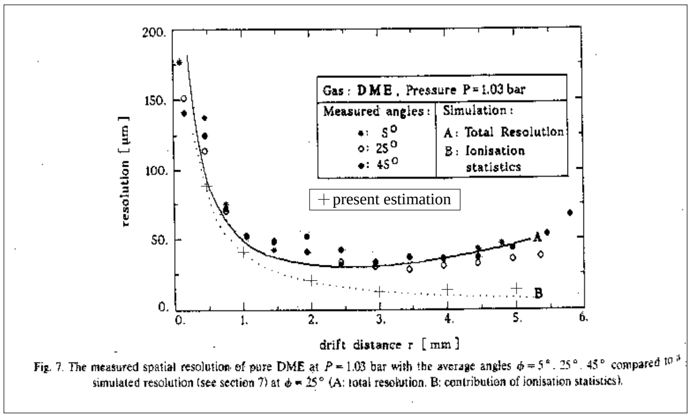

Figure 27: Fig.7 from Ref. [10]. Crosses mark the simulation results. Quotation from [10]: "The simulation of the resolution requires a sizeable constant contribution of about $20\mu m$ which has to be attributed to various imperfections".

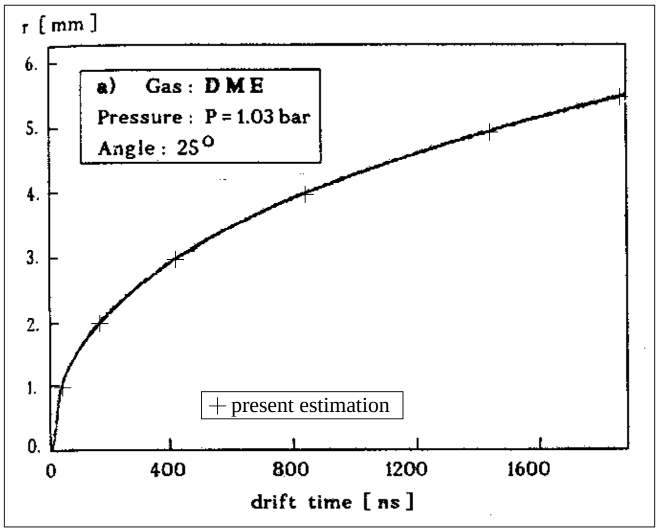

Figure 28: Fig.5 from Ref. [10]. Crosses mark the simulation results.

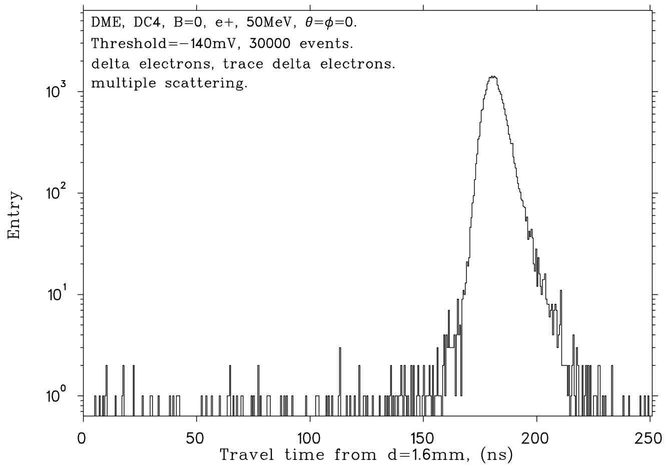

Figure 29: Arrival time distribution from a track with $d = 1.6mm$ and $\theta = 0$. HEED, all interactions are ON, $threshold = -140mV$.

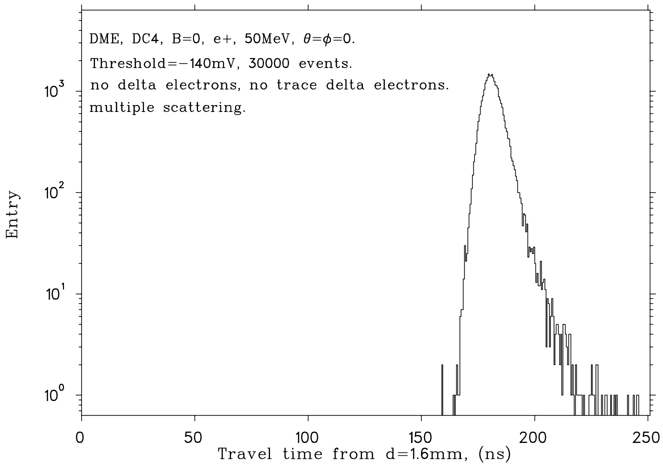

Figure 30: Arrival time distribution from a track with $d = 1.6mm$ and $\theta = 0$. HEED, no δ-electrons, $threshold = -140mV$.

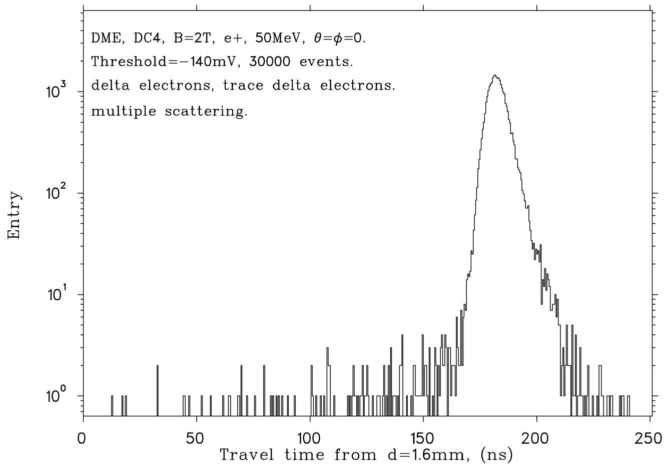

Figure 31: Arrival time distribution from a track with $d = 1.6mm$ and $\theta = 0$. HEED, all interactions are ON, $threshold = -140mV, B = 2T$.

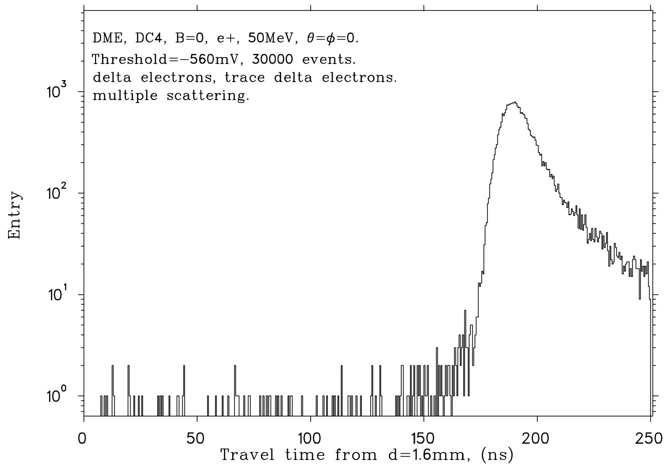

Figure 32: Arrival time distribution from a track with $d = 1.6mm$ and $\theta = 0$. HEED, all interactions are ON, $threshold = -560mV$.

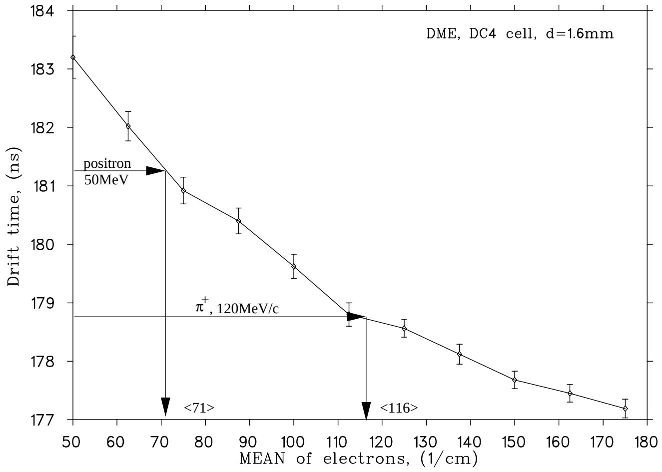

Figure 33: Average arrival time t_0 from track with $d = 1.6mm$ and $\theta = 0$ as a function of mean electron number. Poisson distribution, diffusion, attachment, $threshold = -140mV$.

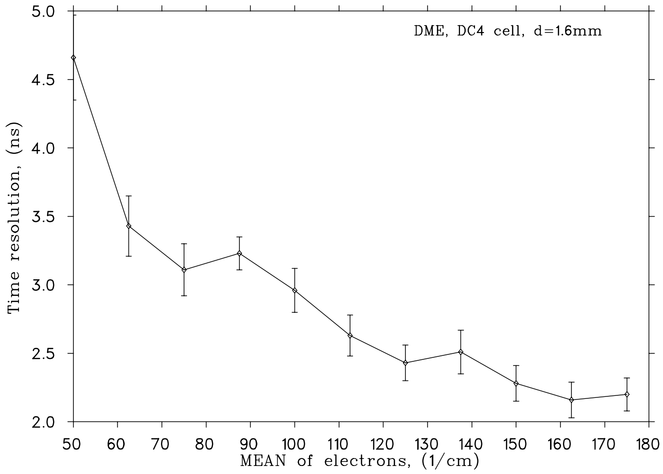

Figure 34: Time resolution σ_t from track with $d = 1.6mm$ and $\theta = 0$ as a function of mean electron number. Poisson distribution, diffusion, attachment, $threshold = -140mV$.

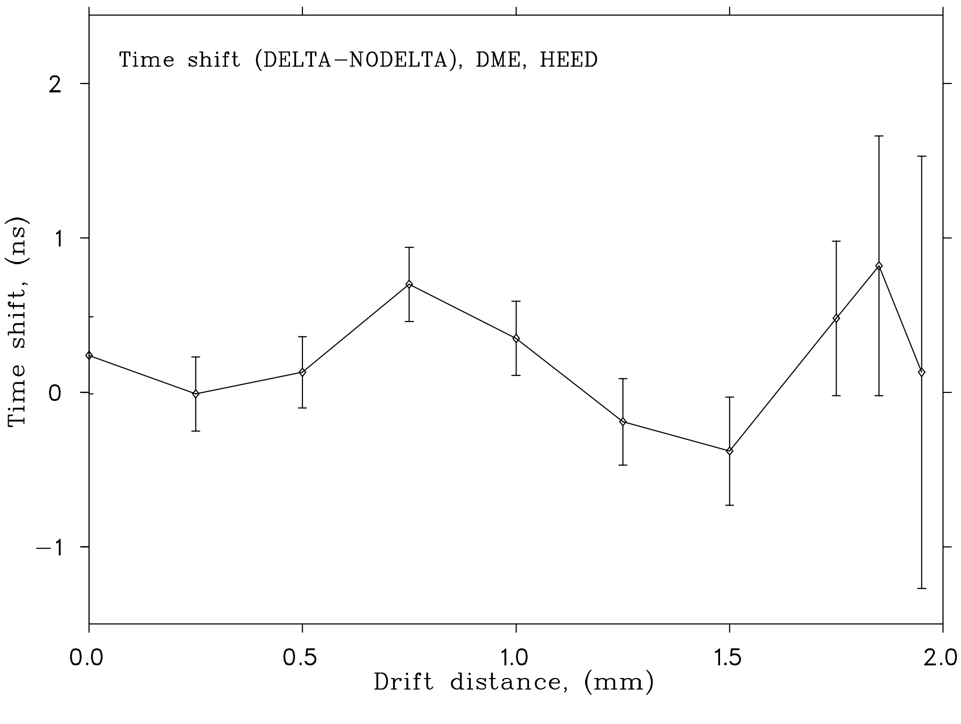

Figure 35: Difference between t_0 calculated by HEED with δ-electrons and with no δ-electrons (MEAN=71e/cm). Positron with $E = 50MeV$, diffusion, attachment, $threshold = -140mV$, $\theta = 0$.

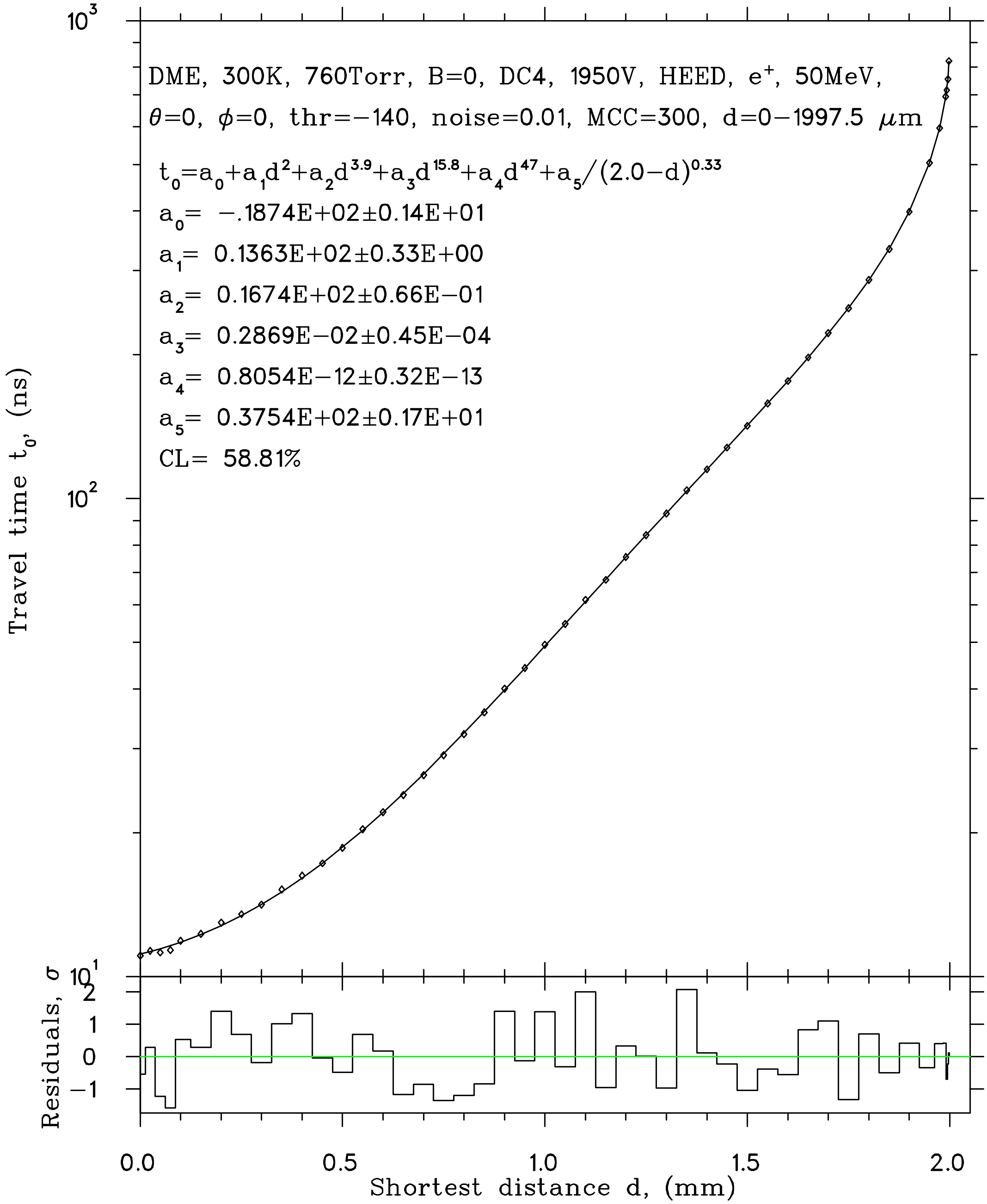

Figure 36: Travel time as function of shortest distance between wire and track. SIGNAL section, all processes are ON, positron with $E = 50MeV$, $\theta = 0$.

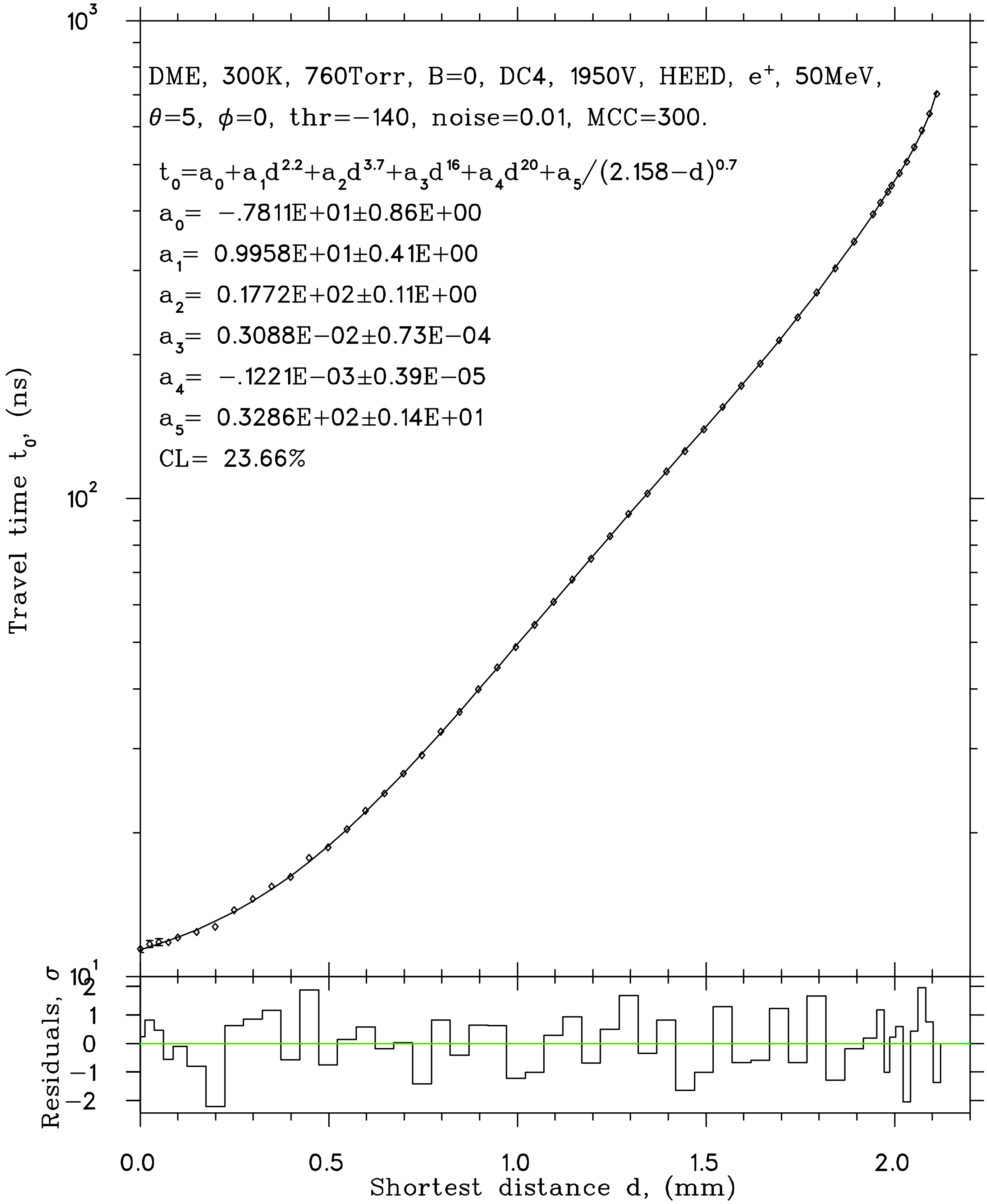

Figure 37: Travel time as function of shortest distance between wire and track. SIGNAL section, all processes are ON, positron with $E = 50MeV$, $\theta = 5°$.

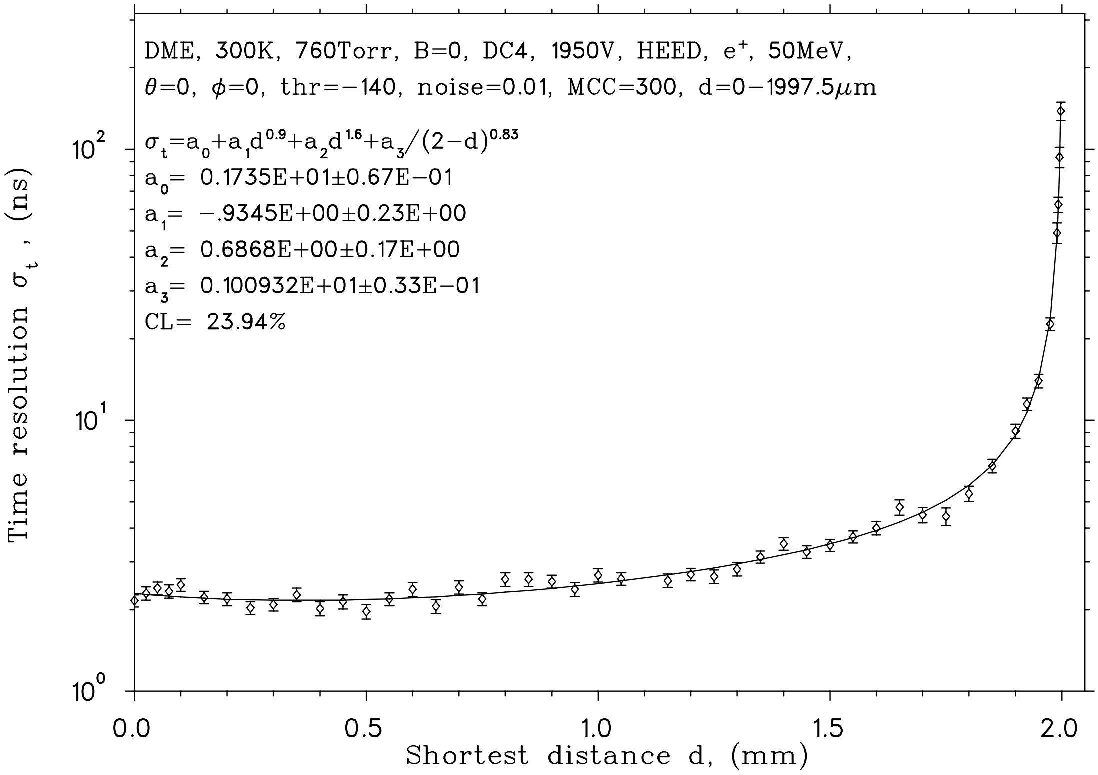

Figure 38: Time resolution as function of shortest distance between wire and track. SIGNAL section, all processes are ON, positron with $E = 50MeV$, $\theta = 0$.

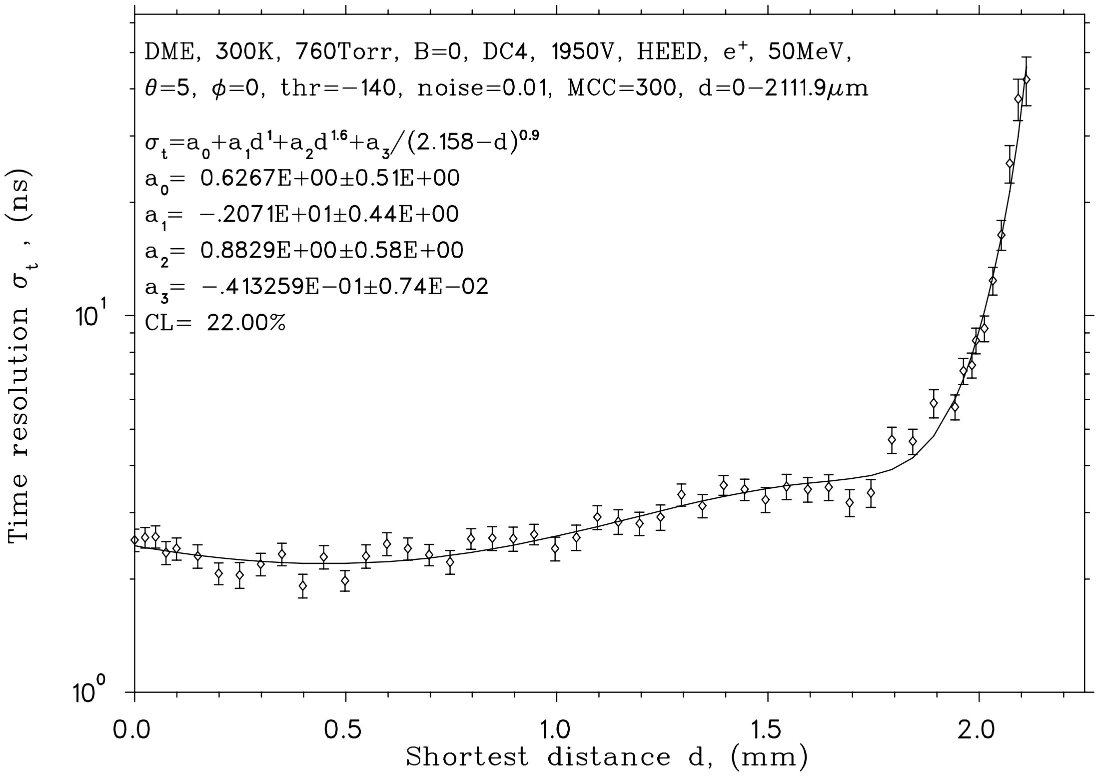

Figure 39: Time resolution as function of shortest distance between wire and track. SIGNAL section, all processes are ON, positron with $E = 50MeV$, $\theta = 5°$.

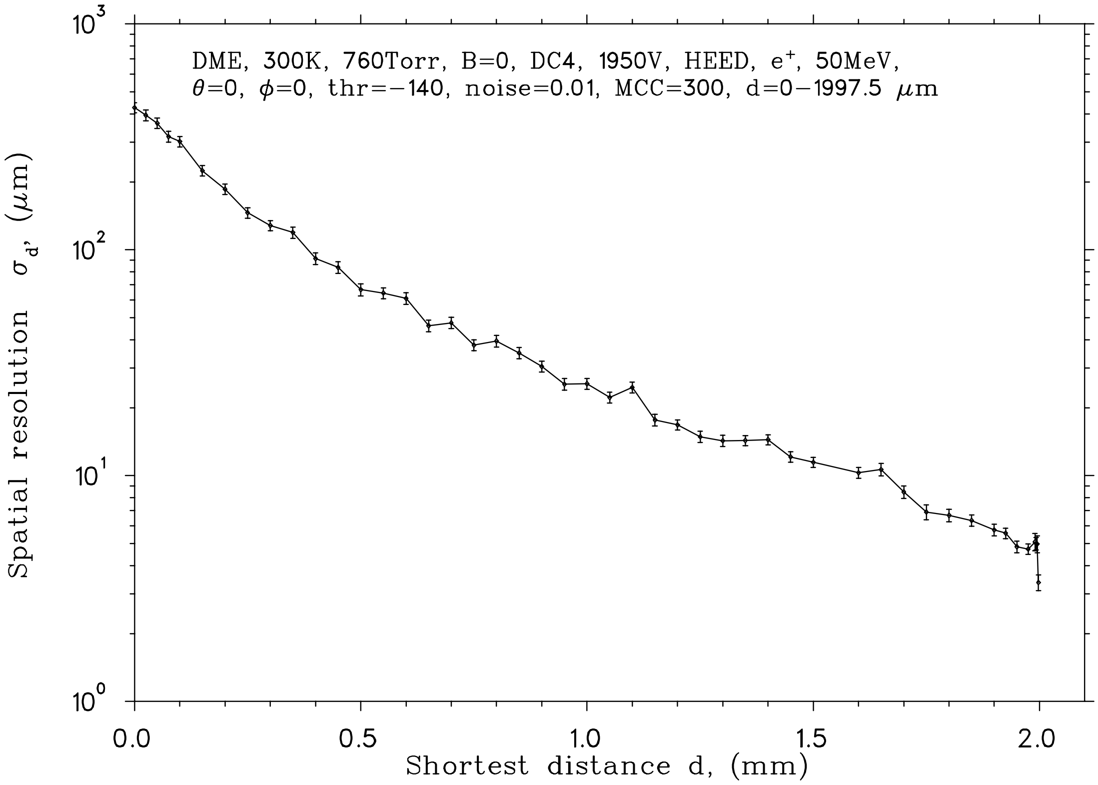

Figure 40: Space resolution as function of shortest distance between wire and track. SIGNAL section, all processes are ON, positron with $E = 50MeV$, $\theta = 0$.

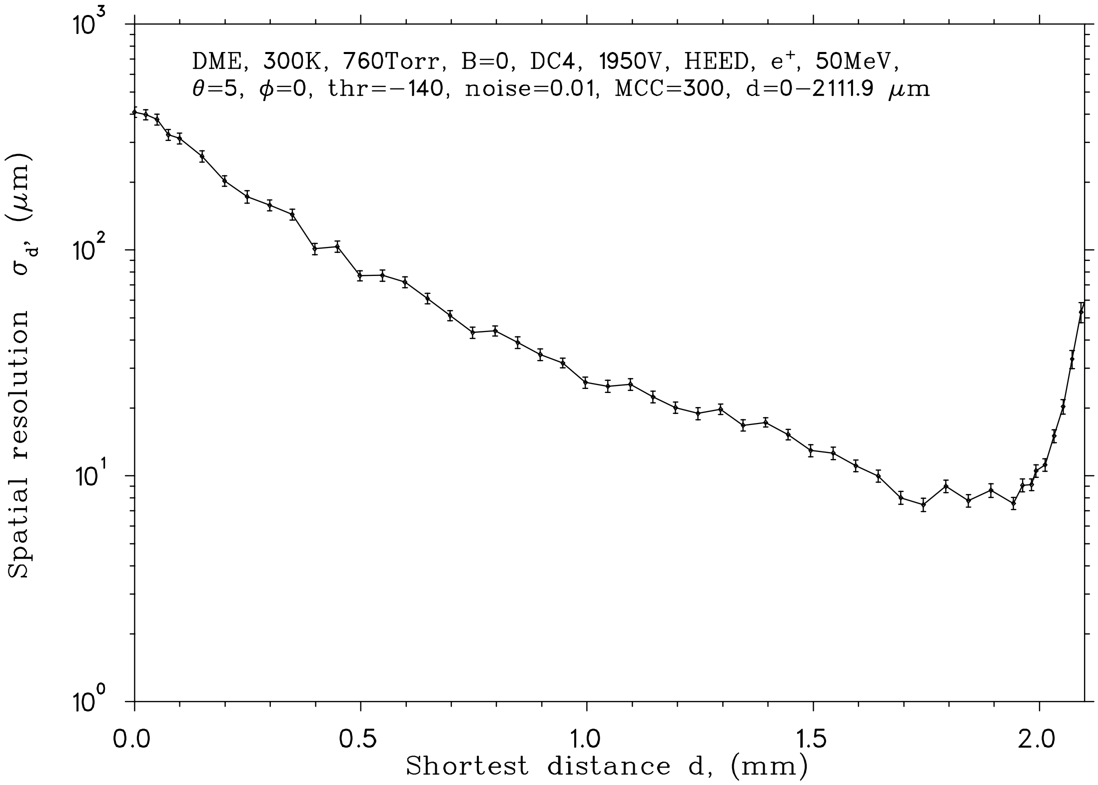

Figure 41: Space resolution as function of shortest distance between wire and track. SIGNAL section, all processes are ON, positron with $E = 50MeV$, $\theta = 5°$.

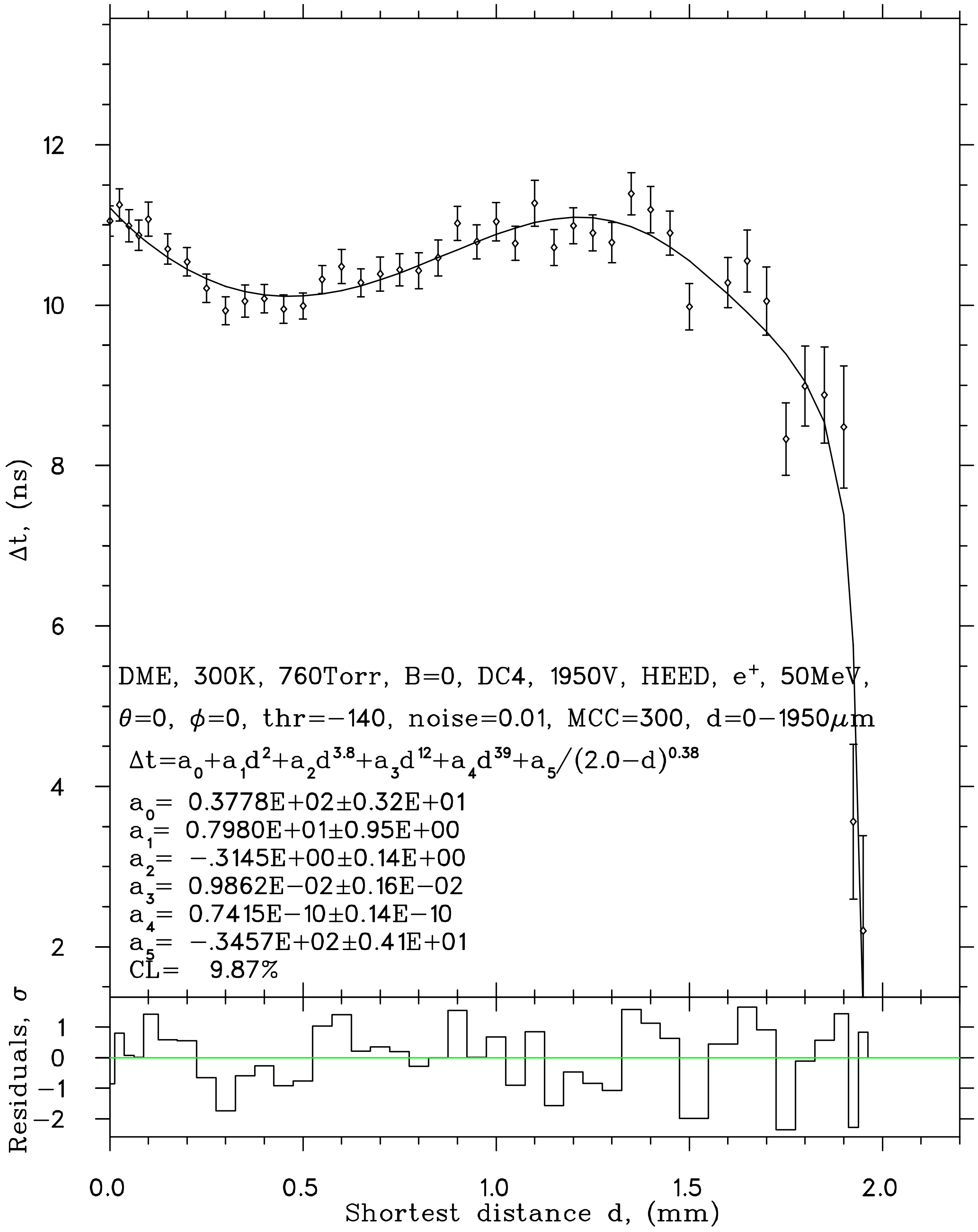

Figure 42: Shift Δt between t_0, calculated by the drift time method as a drift time of a single electron from $(x = d, y = 0)$, and t_0 calculated by the SIGNAL section from a track going at $(x = d, \theta = 0)$. $d = 0 - 1950 \mu m$.

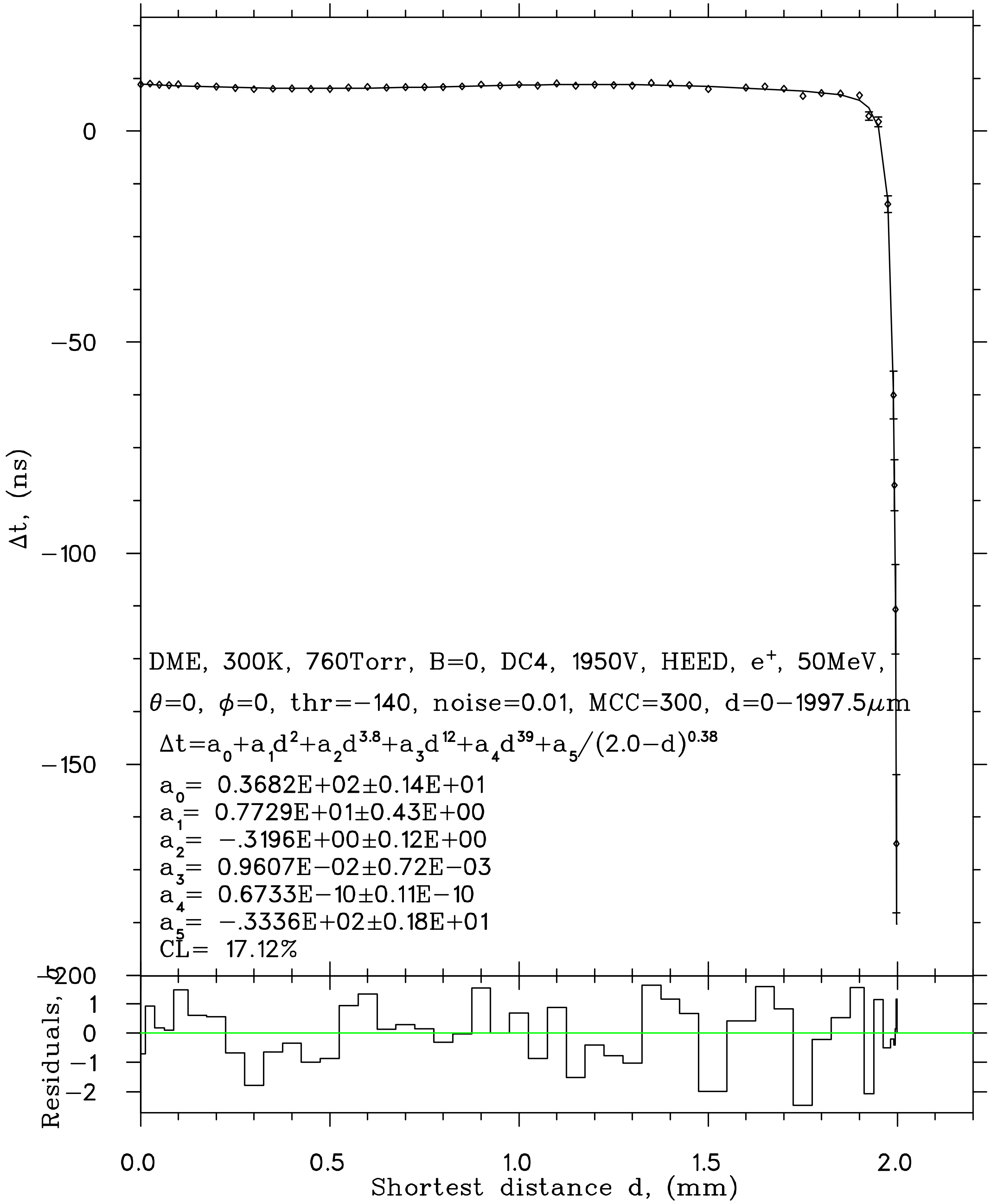

Figure 43: Shift Δt between t_0, calculated by the drift time method as a drift time of a single electron from $(x = d, y = 0)$, and t_0 calculated by the SIGNAL section from a track going at $(x = d, \theta = 0)$. $d = 0 - 1997.5\mu m$.

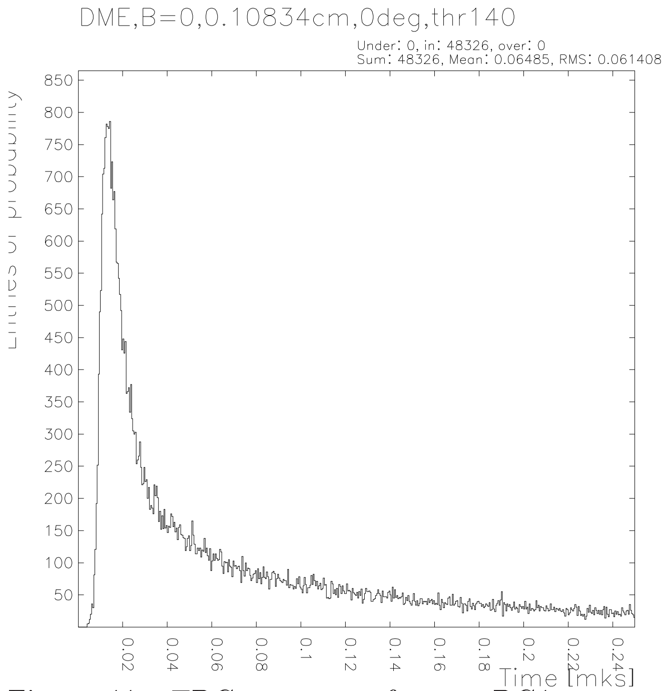

Figure 44: TDC spectrum from a DC4 at random distribution of positrons along drift distance d. HEED, $B = 0$, all processes are ON, angle $\theta = 0$.

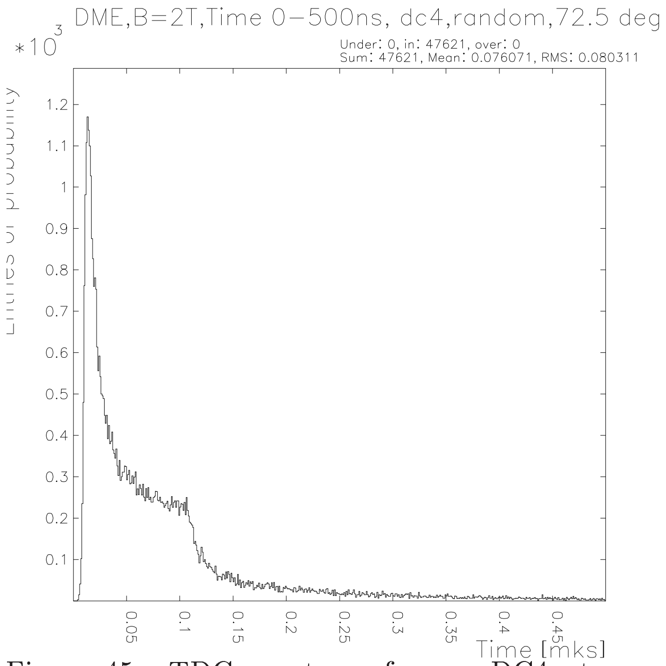

Figure 45: TDC spectrum from a DC4 at random distribution of positrons along drift distance d. HEED, all processes are ON, $B = 2T$, angle $\theta = 72.5°$.

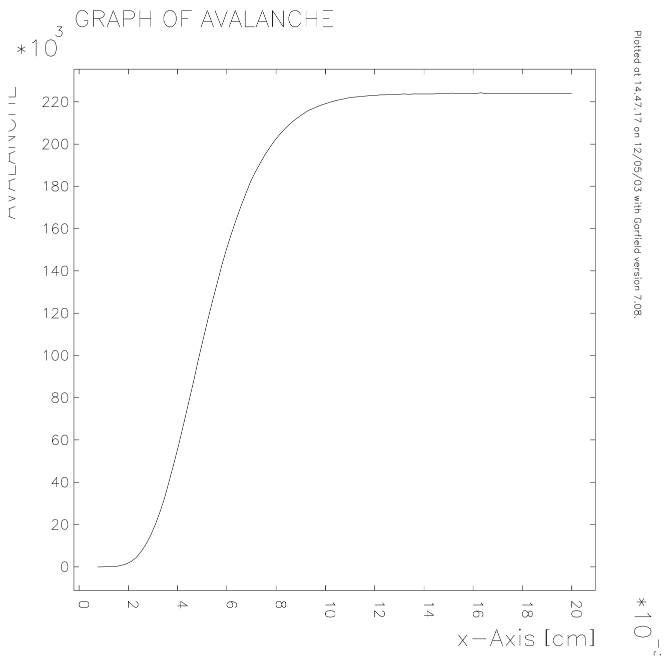

Figure 46: Gain dependance from distance between a drift electron and sense wire. Horizontal axis - distance from wire in $cm \times 10^{-3}$. The curve has been calculated using dependence of Townsend coefficient from electric field E.

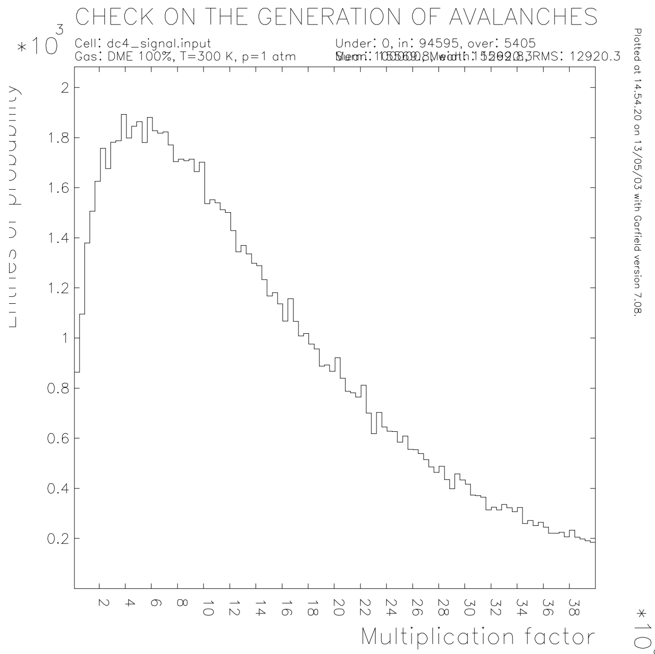

Figure 47: Gain G distribution for Polya function with $\Theta = 0.4$. Horizontal axis - $(Multiplication factor) \times 10^3$. $\overline{G} = 15000$.