Time–to–Distance Relationship for the D0 Proportional Drift Tubes PDTs

usingGarfield

D0–3892

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Contents

Abstract

A detailed computer simulation of a cell of the D0 proportional drift tube chambers PDTs was run to derive a relation for the muon hit position at cell midplane as a function of the incident muon track angle and of the measured electron drift time. A fourth order polynomial function of angle and of drift time was fitted to the X(T) simulated data. For the computer simulation Garfield, a simulation program for drift chambers, was applied to the PDTs operating with the new gas mixture for Run II.

Using the same software and methods, calculations were performed for the old gas used with the PDTs during Run I and compared with cosmic rays measurements. Within the experimental error the simulation coincides with the measured data.

For the present gas mixture the calculations performed with Garfield should be compared with real measurements with cosmic rays passing through PDTs at well defined angles.

1 – Introduction

The upgraded D0 detector for Tevatron Collider Run II has in its central region, as part of the Wide−Angle−MUon−System (WAMUS), the proportional drift tube chambers PDTs with a new gas mixture that requires the determination of an optimal time−to−distance relationship. [1]

For Run I the PDTs used as operating gas a mixture of 90% Ar, 5% CO_2 and 5% CF_4. For this gas a time−to−distance relation was found based on a series of measurements with cosmic rays, reported in D0−Note 2104 "Time to Distance Relationship for D0 Muon Drift Tubes" (H.Haggerty, R.Markeloff, D.Mueller, and Y.Shao, April 8, 1994). [2]

Presently, for Run II, the PDTs use a fast gas in order to reduce the number of crossings which occur during one drift interval: The PDTs are now operating with a non−flammable gas mixture of 88% Argon, 8% Methane and 8% CF_4. With the operating PDT high voltage (2.3 kV for the pads and 4.7 kV for the wires) the estimated drift velocity is ~ 10 cm per micro second, giving a maximum electron drift time of ~ 500 nano seconds. [1]

It is the purpose of this work to derive with a computer simulation of the PDTs a relation for the hit position at cell midplane as a function of the incident muon track angle and of the measured electron drift time.

The computer simulation used is Garfield [3], a CERN package for the detailed simulation of drift chambers.

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2 – Cell layout and electric field

The PDT cells are made of rectangular extruded aluminum tubes with rectangular cross section: width 10.1 cm, height 5.0 cm. The aluminum tube gives the earth of the cell (O Volts). Inside the cell, at 6 mm from the aluminum top and bottom sides, are the cooper vernier pads at 2300 Volts. Inner and outer vernier pads together form a long rectangular cooper strip of 5 cm width. The sense wire in the center of the cell cross section is at 4700 Volts.

The coordinate system used for a cell, a cartesian coordinate system, has its origin in the position of the sense wire, with the Z−axis along the wire, the x−axis along the horizontal 10.1 cm side, the Y−axis along the 5 cm vertical side.

Using the Garfield simulation package, the cell design can be programmed, with geometry, components and voltages as input. Table 1 shows the data used for the cell layout. The electric field and potential are calculated using finite elements techniques and the result is displayed with unit vectors giving the direction of the electric field, with equipotential lines and with a surface representation of the electric potential as a function of X and Y. (See Figures 1 to 7.)

Table 1: PDT cell layout used in the simulation

Description	Value
(Top side of the cell): Infinite plane parallel to the XZ–plane at ...	Y = +2.73 cm
(Bottom side of the cell): Infinite plane parallel to the XZ–plane at ...	Y = −2.73 cm
(Left side of the cell): Infinite plane parallel to the YZ–plane at ...	X = −5.0 cm
(Right side of the cell): Infinite plane parallel to the YZ–plane at ...	X = +5.0 cm
(Top vernier pad): Cooper strip 5 cm wide parallel to the XZ–plane at ...	Y = +2.25 cm from X = −2.5 cm to X = +2.5 cm
(Top vernier pad): Cooper strip 5 cm wide parallel to the XZ–plane at ...	Y = −2.25 cm from X = −2.5 cm to X = +2.5 cm
Sense wire at ...	X = 0, Y = 0

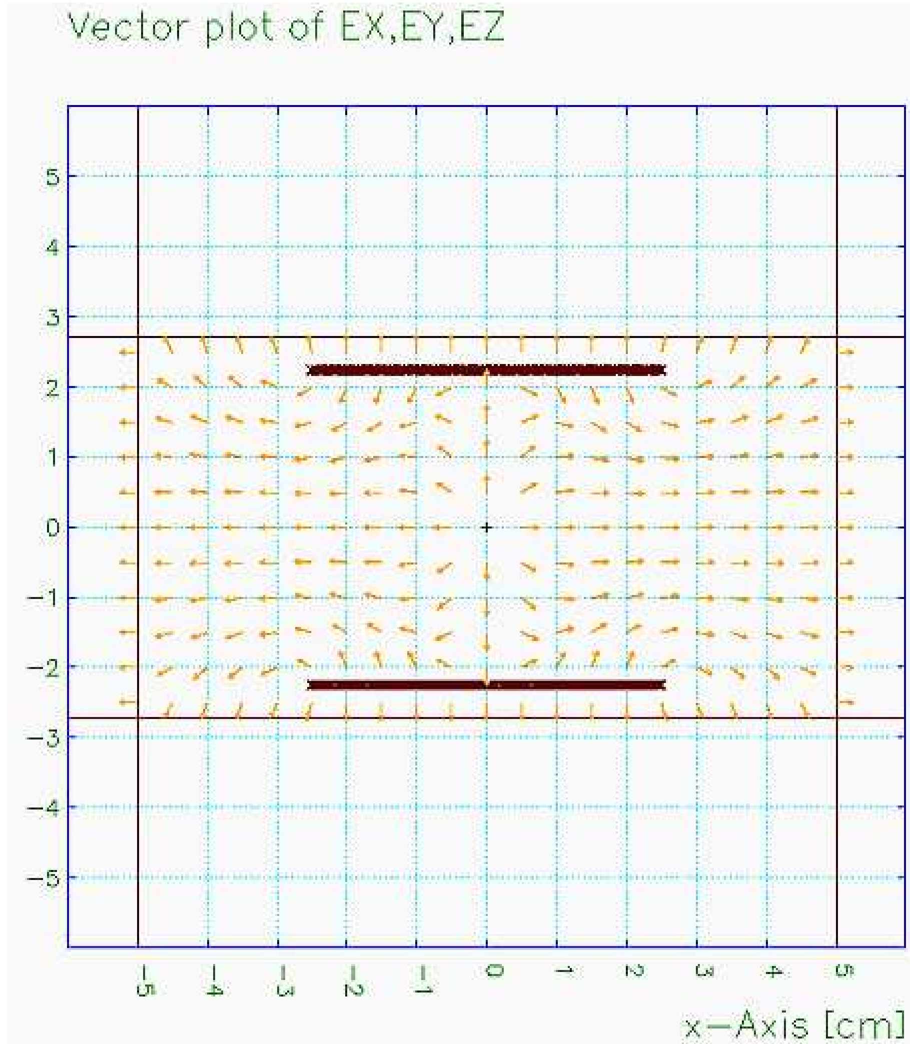

Figure 1: Unit vectors giving the direction of the electric field for the PDT cell. X and Y axis in [cm]

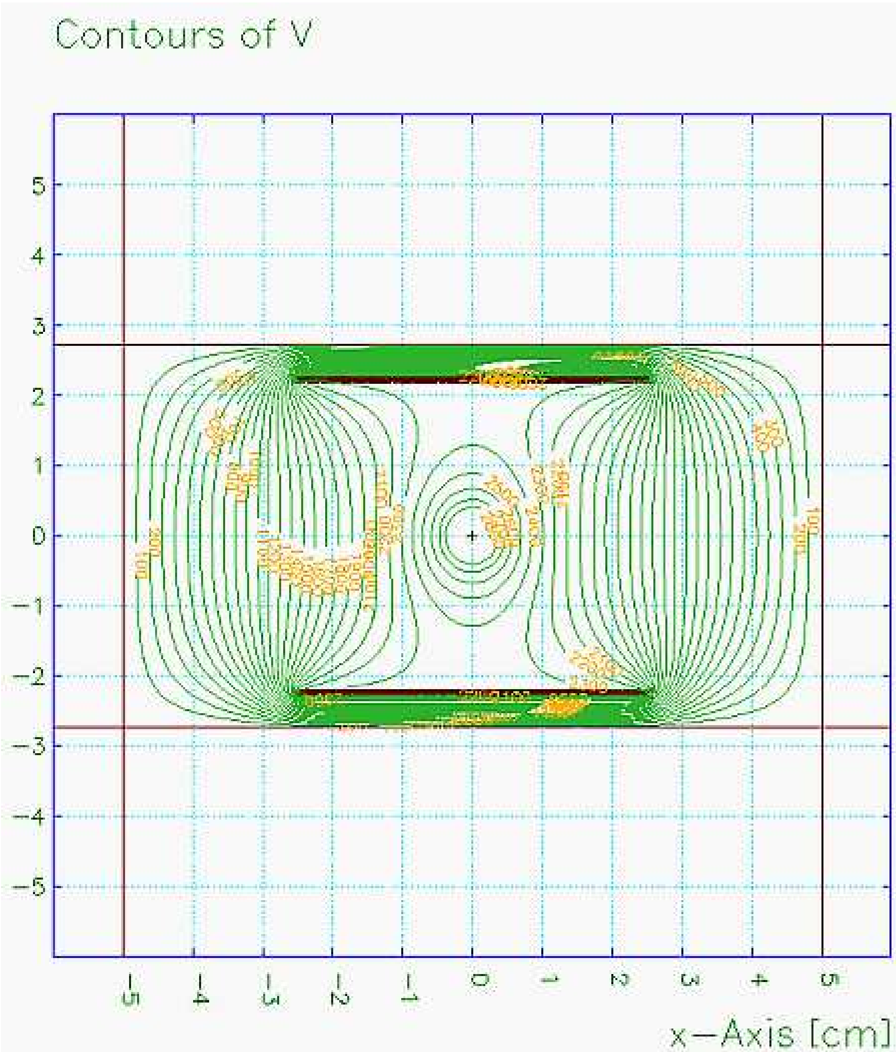

Figure 2: Equipotential lines for the PDT cell. X and Y axis in [cm]

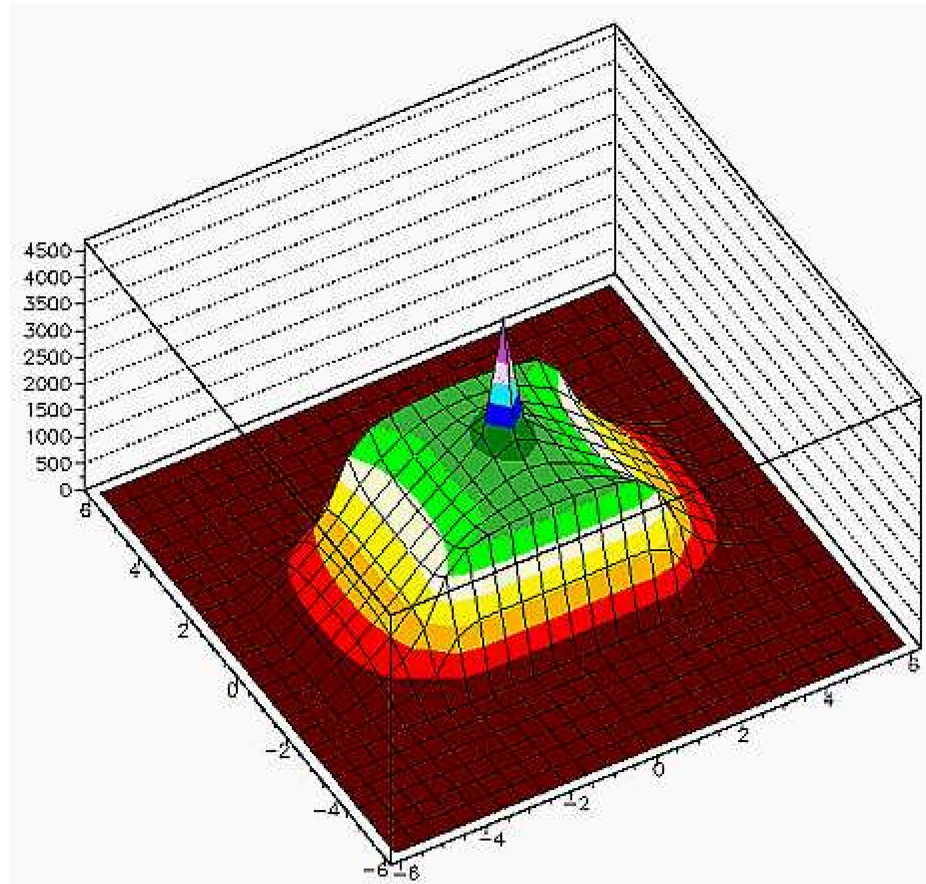

Figure 3: Surface representing the electric potential in the PDT cell.   X and Y axis in [cm]

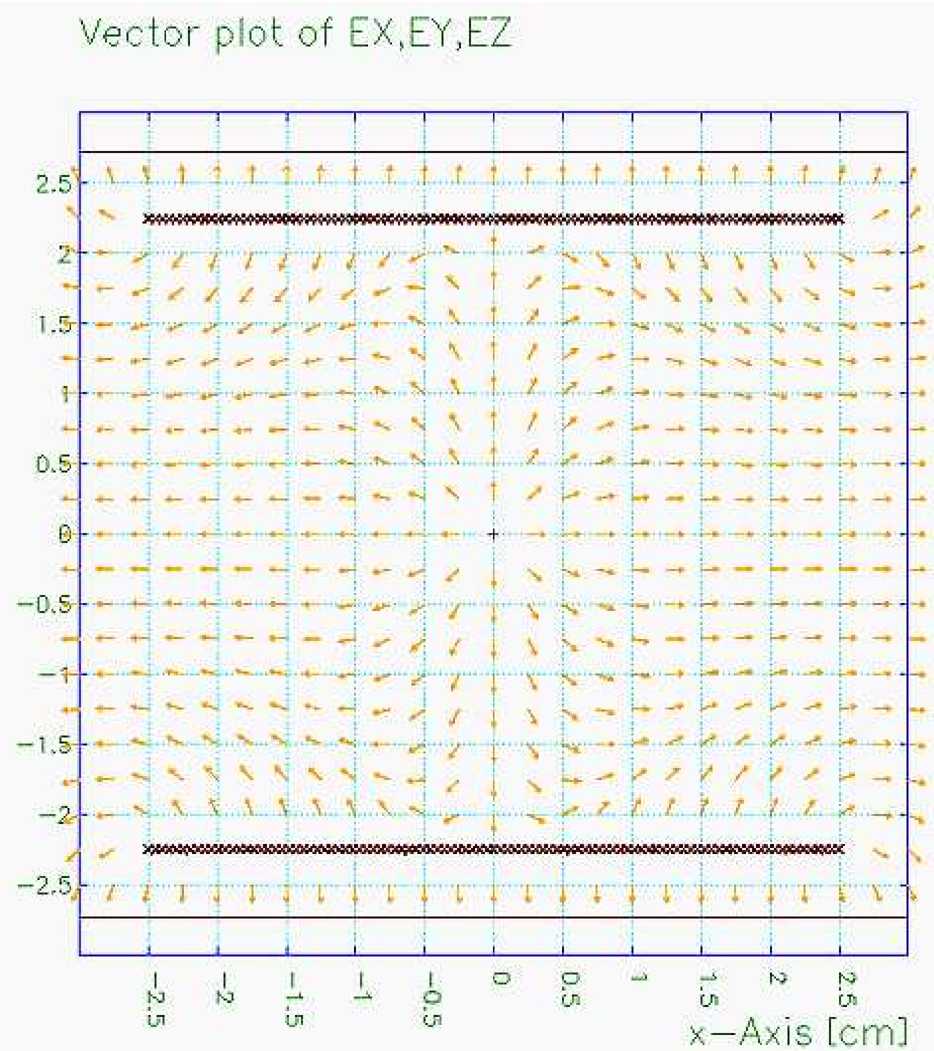

Figure 4: Unit vectors giving the direction of the electric field for the central part of the PDT cell. X and Y axis in [cm]

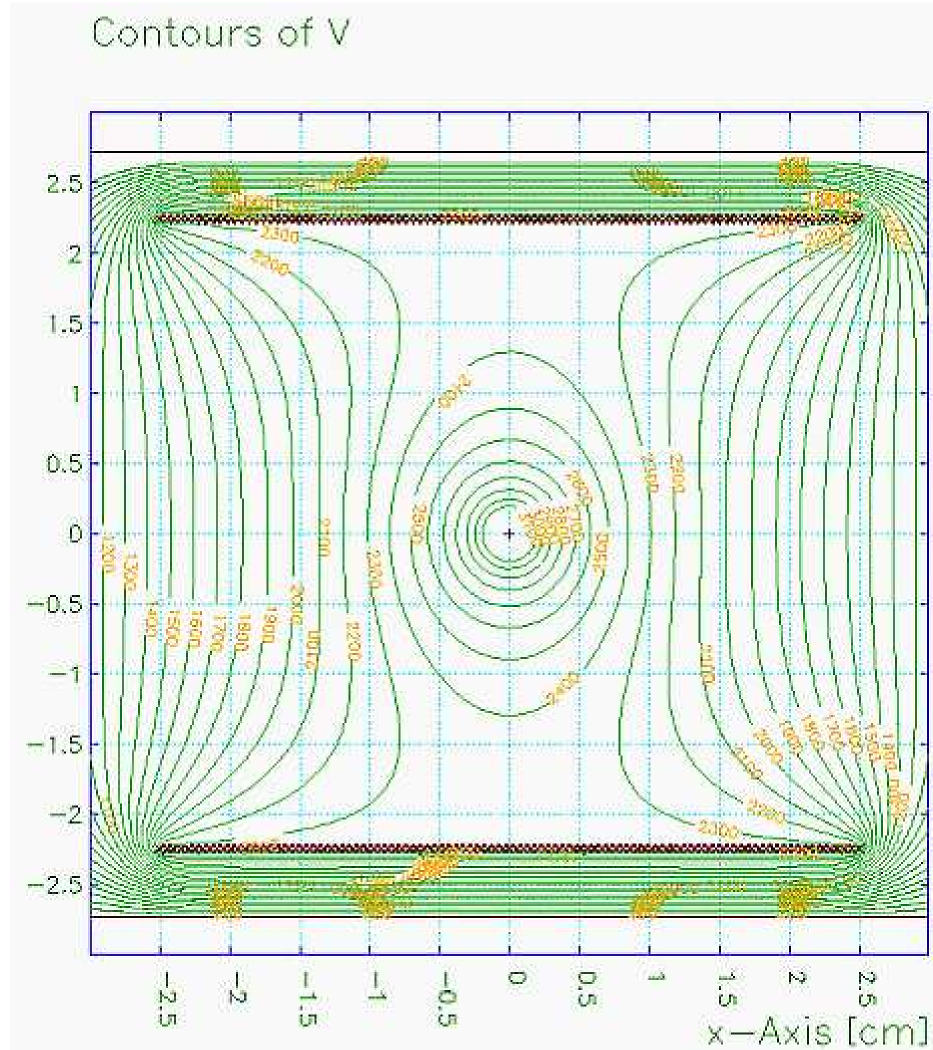

Figure 5: Equipotential lines for the central part of the PDT cell.
X and Y axis in [cm]
Notice an equipotential region at 2300 Volts between pads and wire.

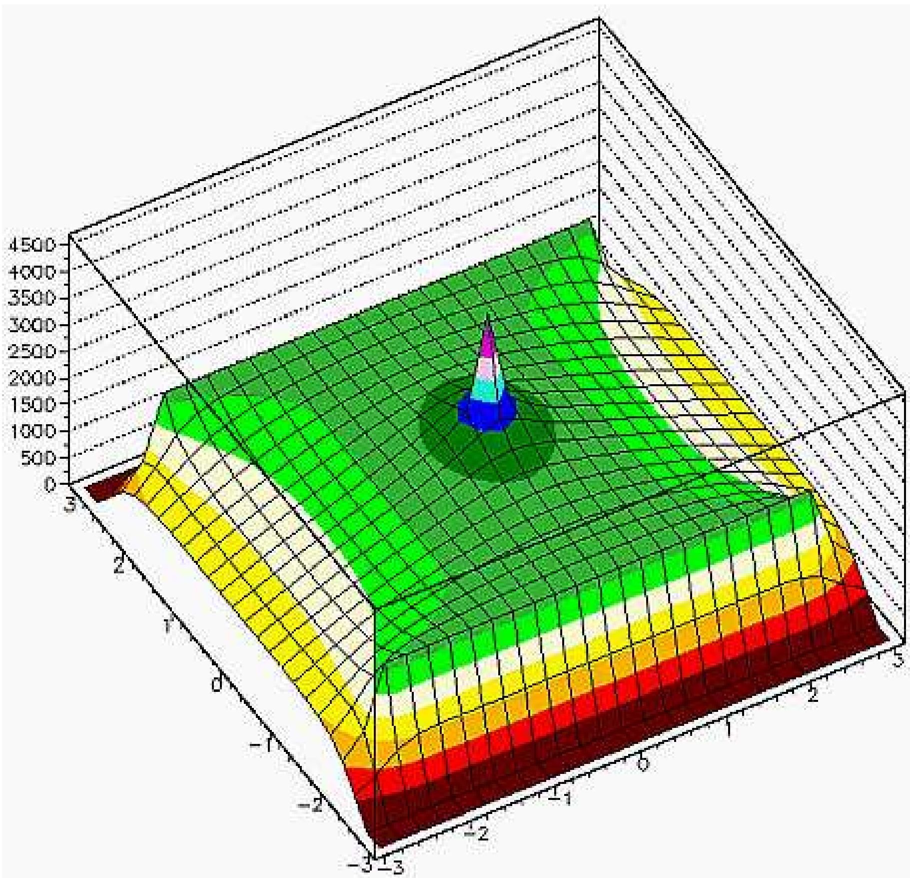

Figure 6: Surface representing the electric potential in the central region of the PDT cell. X and Y axis in [cm]. In this representation of the electric potential a plateau at 2300 V is visible with the high peak of the sense wire potential at 4700 Volts in the center of the cell.

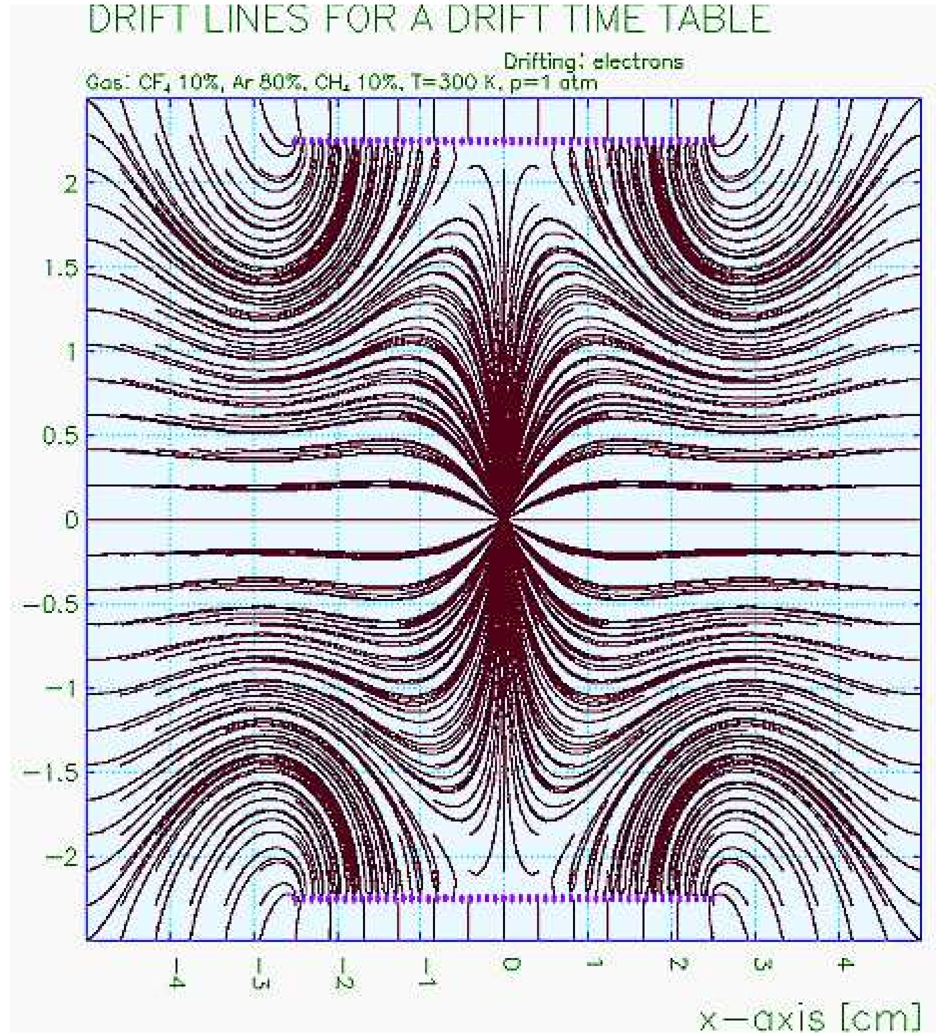

Figure 7: Drift lines for electrons in the central region of the PDT cell following the electric field lines. X and Y axis in [cm]

3 – Gas used in the PDTs

The operating gas in the PDTs for Run II is a fast gas in order to reduce the number of crossings which occur during one drift interval. The PDTs are operating with a non–flammable gas mixture of 88% Argon, 8% Methane and 8% Carbon Tetraflouride CF4.

The gas pressure in the PDT cell is close to atmospheric pressure, approx. 755 Torr. The computer simulation of the gas was run mostly at 760 Torr, but a few runs were done at 755 Torr, giving the same results for this very small change in the pressure value.

The temperature used for the simulation was 300 Kelvin. Table 2 summarizes the gas mixture data used in this work.

Table 2: Gas mixture data used in the simulation

Description	Value
Gas mixture	Ar–CH4–CF4
% Argon Ar	88%
% Methane CH4	8%
% Carbon tetraflouride CF4	8%
Gas pressure	760 Torr
Gas temperature	300 K

The drift chamber simulation program Garfield interfaces with two other programs: Magboltz [4] for the computation of electron transport properties in the gas mixture, and Heed [5] for the simulation of the ionization of the gas molecules by the particles traversing the chamber cell.

These simulations require the knowledge of the cross–sections for the interactions of the charged particles with the gas molecules [6]. For the gas mixture studied here (Ar–CH4–CF4) the cross–sections used are shown in Figures 8 to 10.

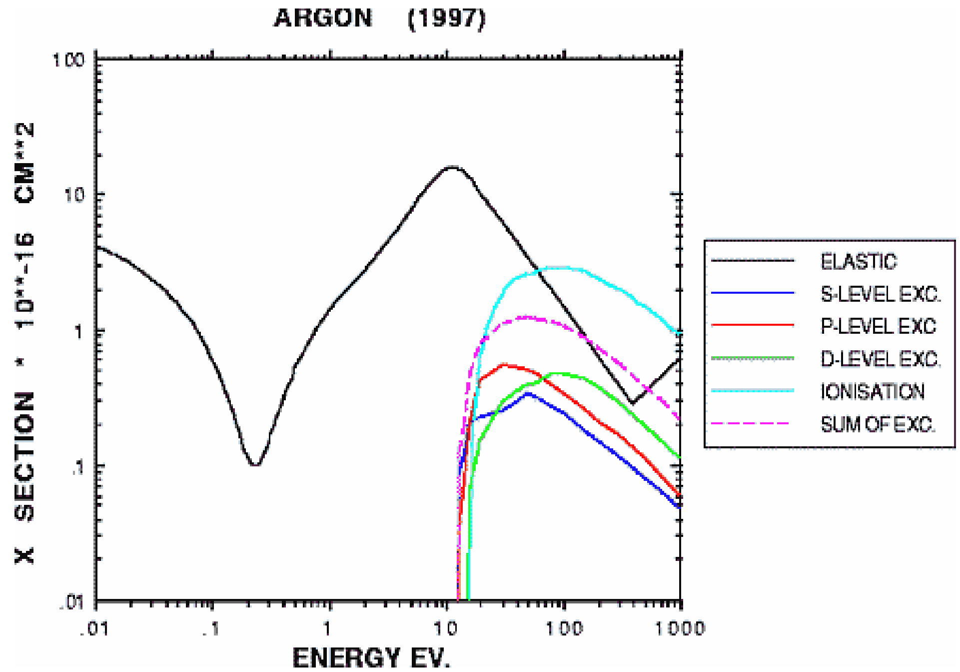

Figure 8: Argon cross–sections.

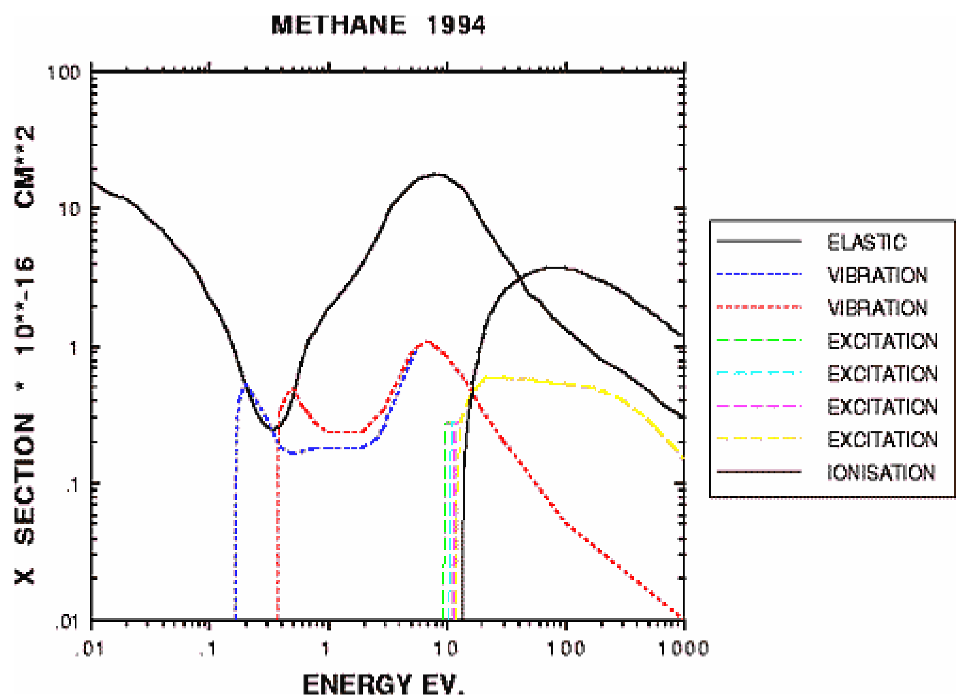

Figure 9: Methane cross–sections.

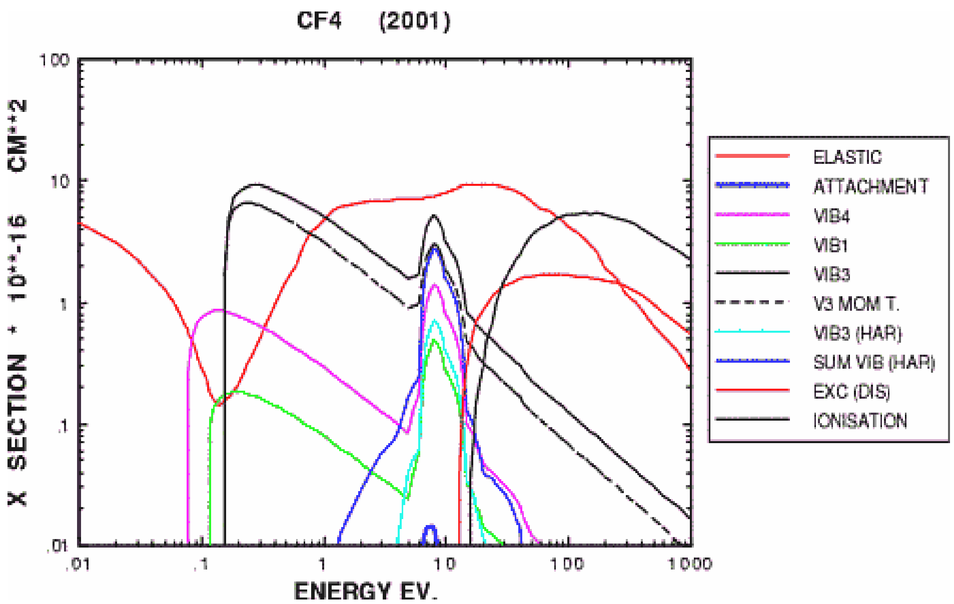

Figure 10: Carbon tetraflouride cross–sections.

These cross–sections were taken from the Magboltz program writeup: http://consult.cern.ch/writeup/magboltz/cross/

4 – Simulation of the detector

The PDT response to muon tracks crossing the cell is simulated the following way:

- First for the given chamber cell layout, for the given pads and wires with their corresponding voltage, the electric field is calculated. The electric field lines originating in the sense wire at the center of the cell give the drift lines for electrons.
- A muon of a given energy and track coordinates is sent through the chamber cell. The ionization along the track is simulated according to the ionization and excitation cross–sections for the operating gas mixture.
- The resulting electrons are tracked in the electric field according to the transport properties, diffusion and drift velocity that are calculated for the operating gas.
- The electrons accelerated in the electric field produce new ionization in the gas, originating avalanches of electrons that will hit the sense wire or the pads.
- The positive ions resulting from the ionization processes, very slow, contribute to generate a positive charge distribution in the cell, a distortion effect of the electric field, in which the electrons are moving very fast.
- The drift times of the electrons to the sense wire are calculated. These drift times are plotted and printed as a function of the starting position of the electrons along the original muon track.
- The minimum of the drift time curve is determined using in the neighborhood of the minimum a parabolic minimization procedure with a limited number of iterations, which is declared to converge if the minimum drift time doesn't change more than the value of an accuracy parameter epsilon (1E–4). The minimum drift time obtained is stored as "the drift time corresponding to the given muon track".

The procedure described above is repeated for a series of parallel muon tracks crossing the PDT cell at a given angle. For each angle a set of 50 parallel muon tracks is simulated, each track at 2 mm separation from its left and right neighbor tracks. This is repeated then for a series of angles between 0 and 85 degrees.

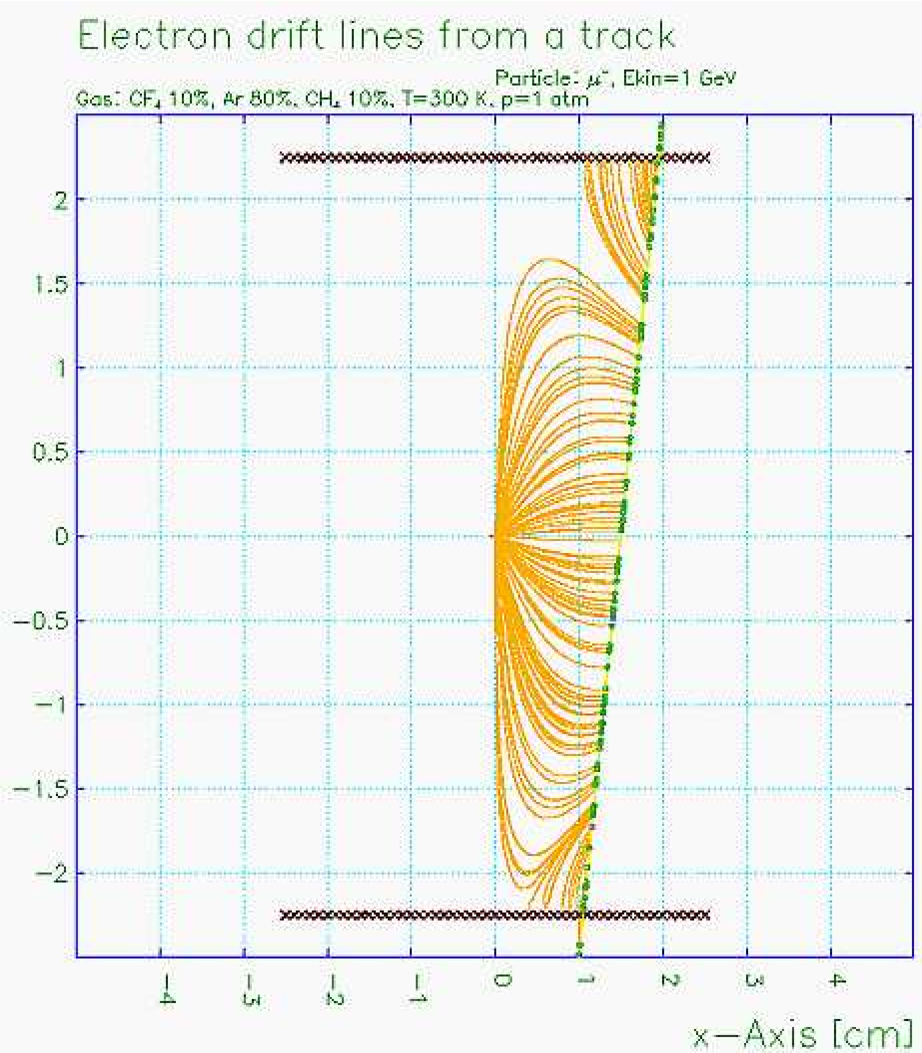

Figure 11: A muon crosses the PDT cell. The electrons resulting from the ionization processes drift along the electric field lines shown in this figure. Most of the electrons drift to the sense wire in the center of the cell, some of them to the pads on top, or bottom of the cell.

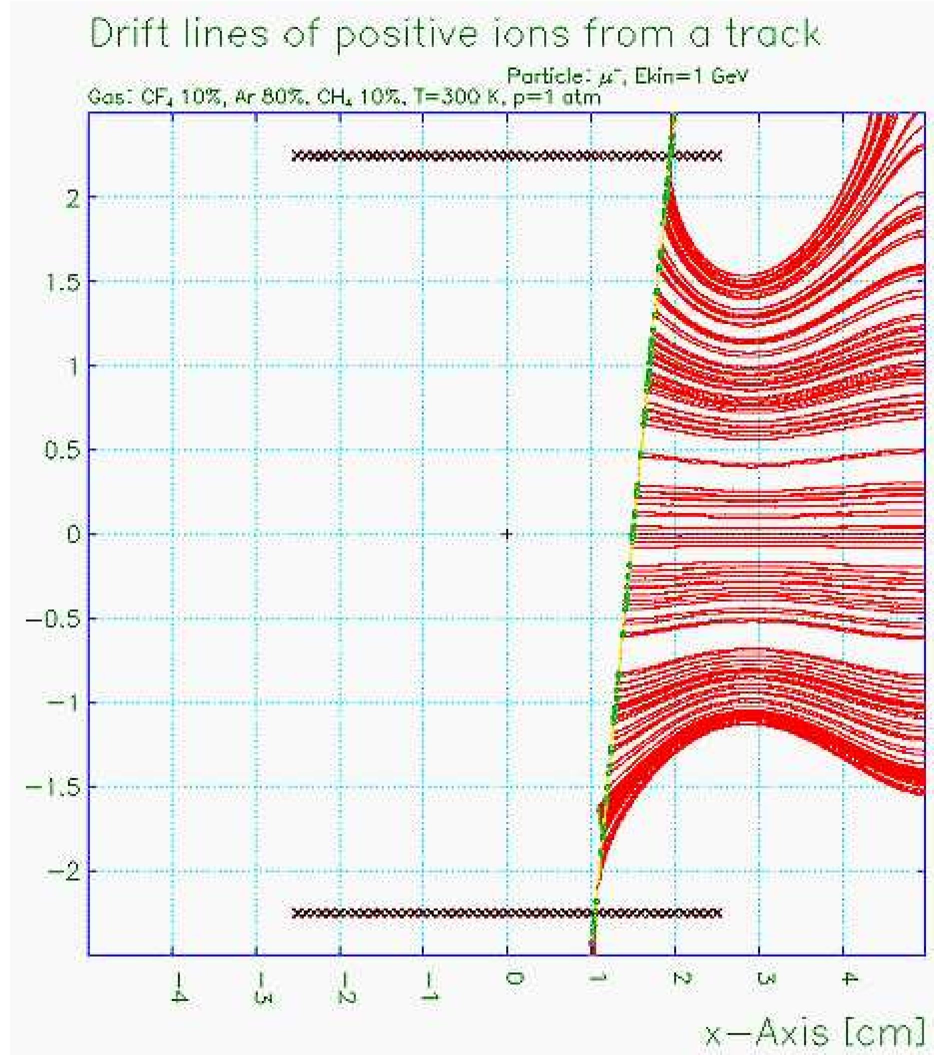

Figure 12: The positive ions resulting from the ionization processes drift towards the regions of lower potential, to the aluminum walls of the cell.

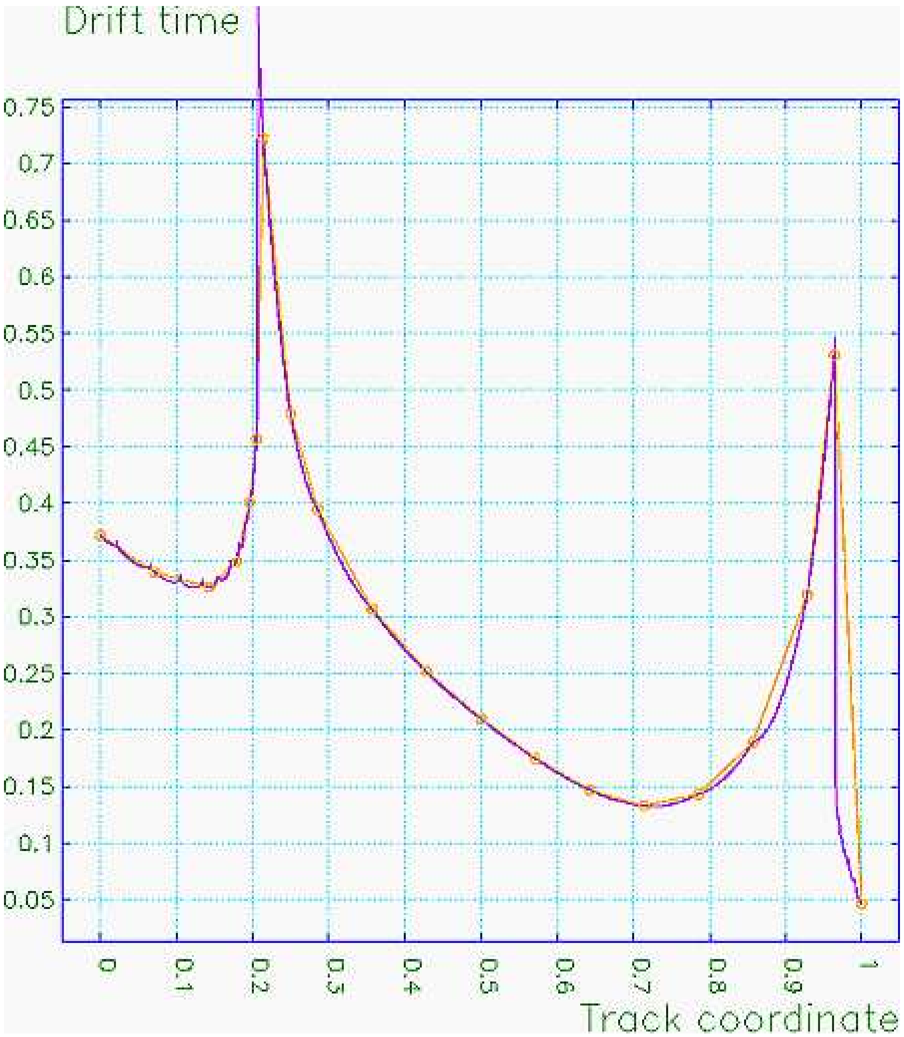

Figure 13: Electron drift times for the muon track of figures 11 and 12. The drift times are given in micro seconds. The minimum drift time for to the sense wire is approx. 0.13 microseconds. Drift times at the extreme left and right of this plot correspond to electrons drifting to the pads.

5 – Drift times for vertical muon tracks

For muons of an energy of 2 GeV from X=–5.0 cm to X=+5.cm 50 tracks were simulated in steps of dX=0.2 cm. For each muon track the minimum electron drift time was obtained as described in the last section. The resulting minimum drift times were plotted and printed as a function of the muon track position X measured with respect to the sense wire at cell midplane. (See Figure 15.)

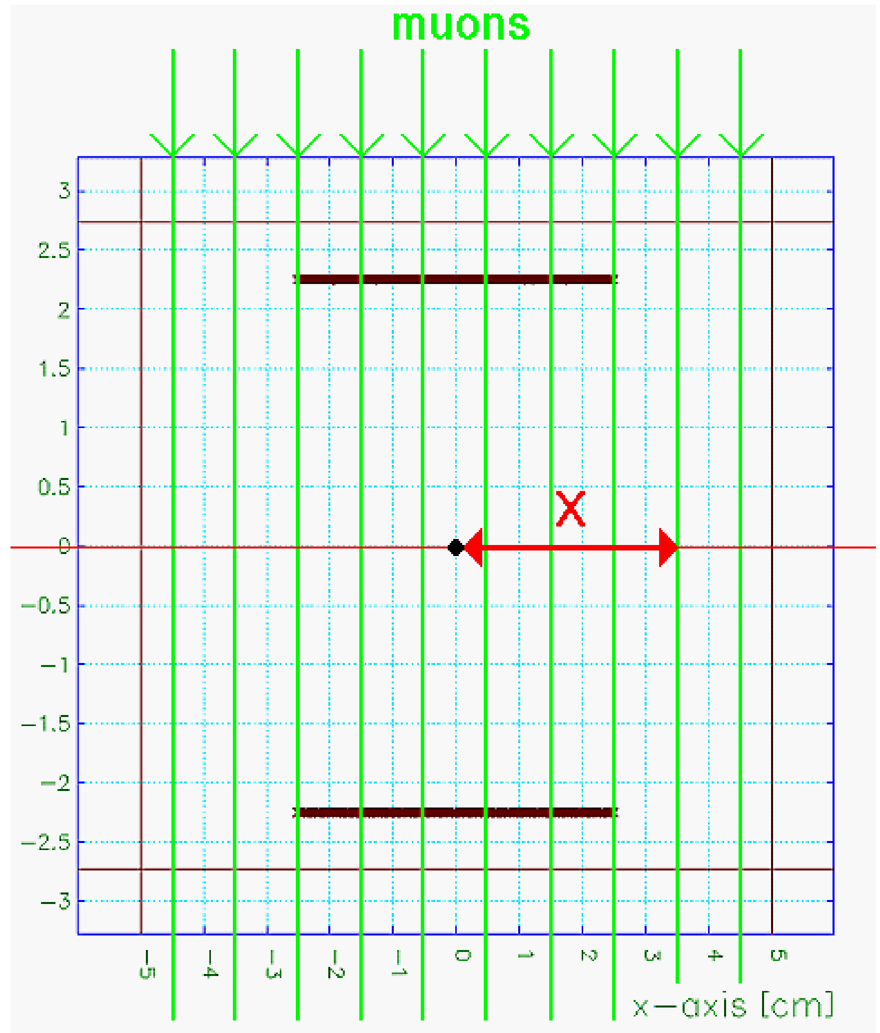

Figure 14: A series of vertical muon tracks crossing the PDT cell.

6 – Drift times for muons tracks at angle θ

Figure 15: The X(t)–correlation plot shown in this figure gives the minimum electron drift time t obtained for vertical muon tracks crossing the cell at a distance X from the wire measured at cell midplane. The drift times (vertical axis) are given in micro seconds. As expected for the fast gas mixture used and for the given PDT cell conditions (voltage, pressure and temperature) the drift times are below 0.5 micro seconds.

Muons of 2 GeV were simulated crossing the PDT chamber at an angle theta with respect to the Y–axis at a distance X from the sense wire measured at cell midplane (Fig.16). For each angle theta 50 parallel muon tracks with 2 mm separation between them were simulated and for each track the minimum electron drift time was obtained. The resulting drift times vs. distance X to sense wire were tabulated and plotted for each angle. (See Table 3 and Figures 17, 18 and 19.) This was completed for a series of 18 angels between 0 degrees and 85 degrees in steps of 5 degrees.

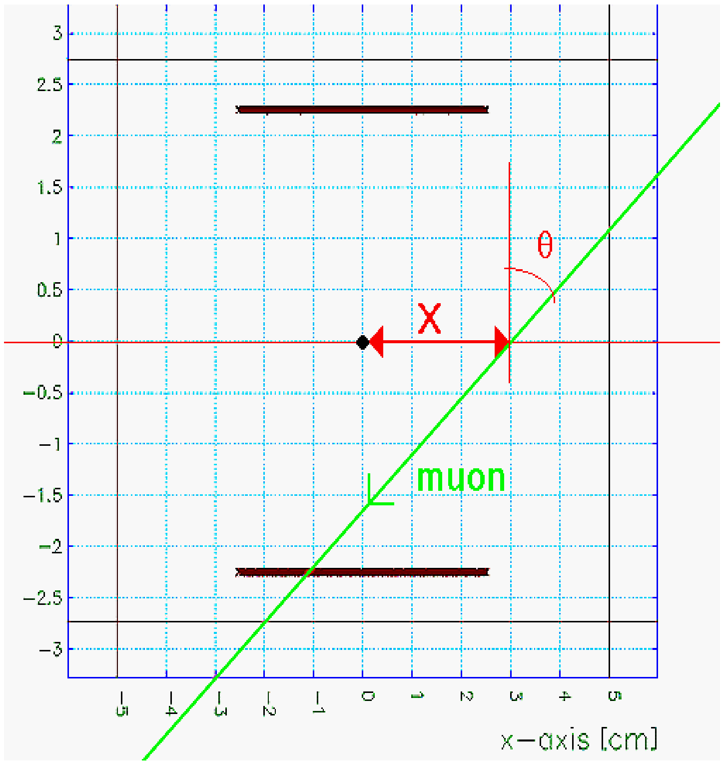

Figure 16: Muon track crossing the PDT cell at an angle theta measured with respect to the Y–axis. Here X gives the distance to the sense wire measured at cell midplane.

Figure 17: Drift times vs. X for muon tracks crossing the PDT cell at theta = 0, 10, 20, 30, 40 50 and 60 degrees with respect to the Y−axis of the PDT cell.

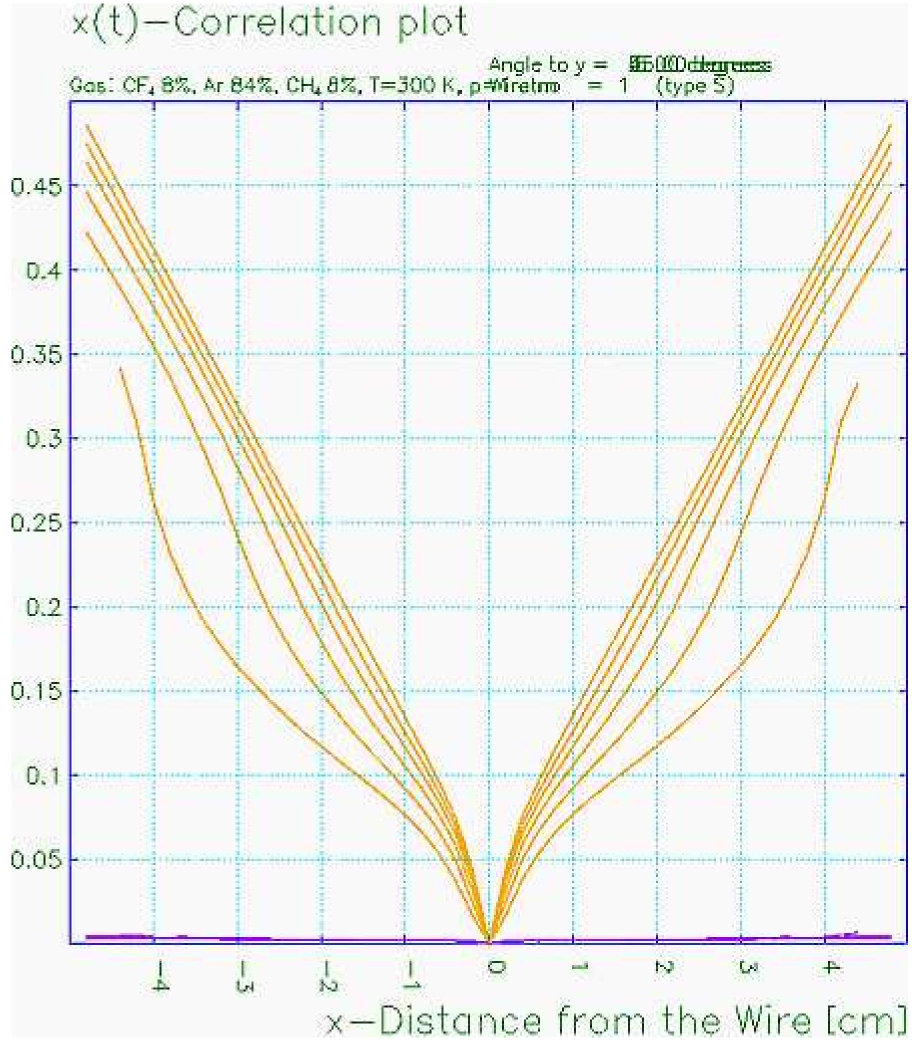

Figure 18: Drift times vs. X for muon tracks crossing the PDT cell at theta = 5, 25, 35, 45, 55 and 65 degrees with respect to the Y−axis of the PDT cell.

θ –>	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°
X	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**
0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	45	45	44	43	42	41	39	37	35	32	29	25	21	17	12	8	4	1
0.4	75	75	74	73	72	70	68	65	62	59	55	50	45	38	31	22	13	4
0.6	97	97	96	95	93	91	88	85	81	77	73	67	61	54	48	35	23	8
0.8	117	116	115	114	112	109	105	101	97	92	87	81	74	66	57	46	32	13
1.0	135	135	134	132	129	126	122	117	111	106	99	92	85	77	67	55	39	18
1.2	154	153	152	150	147	143	138	132	126	119	111	103	95	85	78	63	46	22
1.4	172	172	171	168	165	160	155	148	141	132	123	114	104	94	82	70	52	27
1.6	191	190	189	186	183	178	173	165	157	147	136	125	113	102	89	75	58	31
1.8	209	209	208	205	202	197	191	183	174	162	150	137	123	109	96	81	63	35
2.0	228	227	226	224	220	216	210	202	193	180	165	149	133	117	102	86	67	39
2.2	246	246	245	243	239	235	230	222	212	199	181	162	144	126	108	92	72	43
2.4	265	264	263	262	258	254	249	242	233	219	201	178	155	134	115	97	76	46
2.6	283	283	282	280	277	273	268	263	253	241	222	196	169	144	121	101	79	50
2.8	302	302	301	299	296	292	288	283	274	263	246	218	184	154	128	106	83	52
3.0	321	320	319	317	315	311	307	301	294	284	269	243	201	165	135	110	86	55
3.2	339	339	338	336	333	330	326	320	313	304	292	269	224	177	143	115	90	58
3.4	358	357	356	355	352	348	345	339	332	323	312	293	253	192	151	120	93	61
3.6	376	376	375	374	370	367	363	357	351	342	331	315	287	210	160	125	96	63
3.8	396	394	393	392	389	385	381	375	369	360	350	337	312	232	170	131	100	65
4.0	414	413	412	410	407	403	399	393	387	378	368	355	333	263	181	136	103	68
4.2	432	431	430	428	425	421	417	411	405	396	385	373	353	310	194	142	106	70
4.4	451	450	449	447	443	439	435	430	422	413	402	390	371	333	209	148	109	72
4.6	469	468	467	465	461	457	453	447	439	430	419	406	391	365	227	155	112	74
4.8	488	487	485	483	479	475	471	465	456	447	436	423	407	0	272	162	116	76

Table 3: Drift times table. Each column of the table , corresponding to an angle theta of the muon track with respect to the vertical, gives the electron drift times as a function of the distance of the track to the sense wire, measured at cell midplane. Only the drift time values for positive X are given in this table, since the values for negative X are obtained from the symmetry of the curves. All drift times are given in nanoseconds.

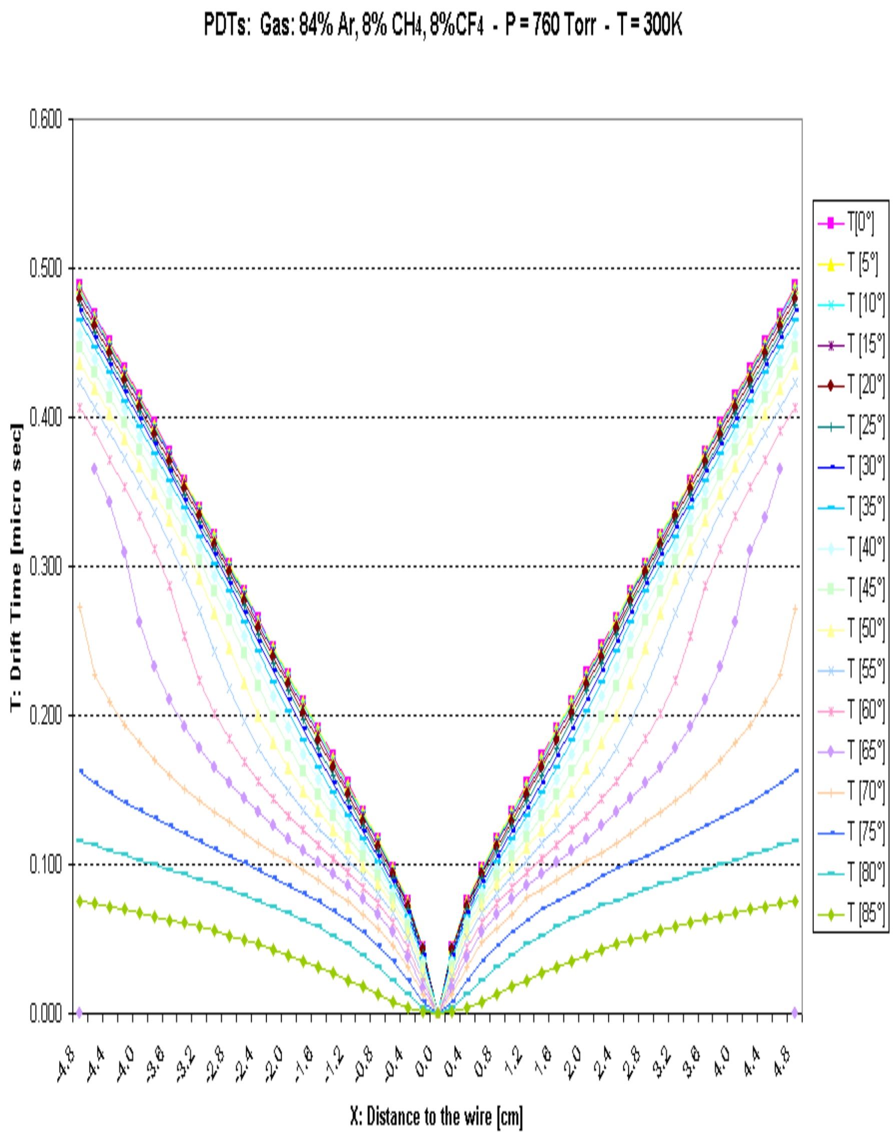

Figure 19: The complete set of curves of drift times T as a function of the hit distance X to the wire for the 25 angles simulated between 0 and 85 degrees. Theses curves correspond to the drift time values given in Table 3. In this plot the drift times are given in microseconds.

7 – Fitting the Time–to–Distance Function

For each angle theta the distance X of the muon track to the sense wire at cell midplane given as a function of the electron drift time T is well described by a function of the form:

```
X(T) = b1*T + b2*T^2 + b3*T^3 + b4*T^4
```

The parameters b1, b2, b3 and b4 are determined from a least squares fit to the Garfield results (Figure 19). The fit results for each angle theta are presented in Table 4. Here the electron drift time values must be given in microseconds and the distance X is obtained in centimeters.

Table 4: Time–to–Distance Relationship for D0–PDTs.

Angle*	b1	b2	b3	b4	R^2
0	2.64	48.56	117.52	99.23	0.9999
5	2.67	48.56	117.99	100.21	0.9999
10	2.78	48.35	118.38	101.19	0.9999
15	2.93	48.97	123.51	108.39	0.9999
20	3.1	49.95	130.05	117.14	0.9998
25	3.4	50.48	136.42	126.52	0.9998
30	3.69	52.75	151.24	146.33	0.9997
35	4.06	55.24	167.93	168.99	0.9995
40	4.21	63.17	209.29	223.04	0.9994
45	4.45	73	261.05	290.84	0.9990
50	4.42	90.79	349.87	406.68	0.9986
55	3.89	121.71	498.2	599.06	0.9985
60	2.78	170.22	727.72	897.63	0.9984
65	0.68	247.73	1094	1384.9	0.9989
70	0	315.57	1357.4	1597.9	0.9984
75	18.86	173.78	3855.6	–14718	0.9997
80	37.31	672.81	11273	–44514	0.9998
85	83.06	1958	35543	–174328	0.9994

Important note: The drift time T must be given in **microseconds**.
X is obtained in **centimeters**.

The fit parameters b1, b2, b3 and b4 depend on the incident angle theta of the muons. They can be fitted as function of the angle theta (θ) , using a polynomial function of fourth order:

```
b1 = a10 + a11*θ + a12*θ^2 + a13*θ^3 + a14*θ^4
b2 = a20 + a21*θ + a22*θ^2 + a23*θ^3 + a24*θ^4
b3 = a30 + a31*θ + a32*θ^2 + a33*θ^3 + a34*θ^4
b4 = a40 + a41*θ + a42*θ^2 + a43*θ^3 + a44*θ^4
```

The fit results are shown in Figure 20 and in Table 5. For known angle theta and drift time T the hit distance X(theta θ, T) is obtained using the fit results to the computed curves. This is valid for a wide range of angles, between 0 and 65 degrees. For angles above 65 degrees the fit is no longer valid.

To include the angle range between 65 and 90 degrees would have required a polynomial fit function of fifth order or higher. These cases of large angles can be treated separately with its own fit function.

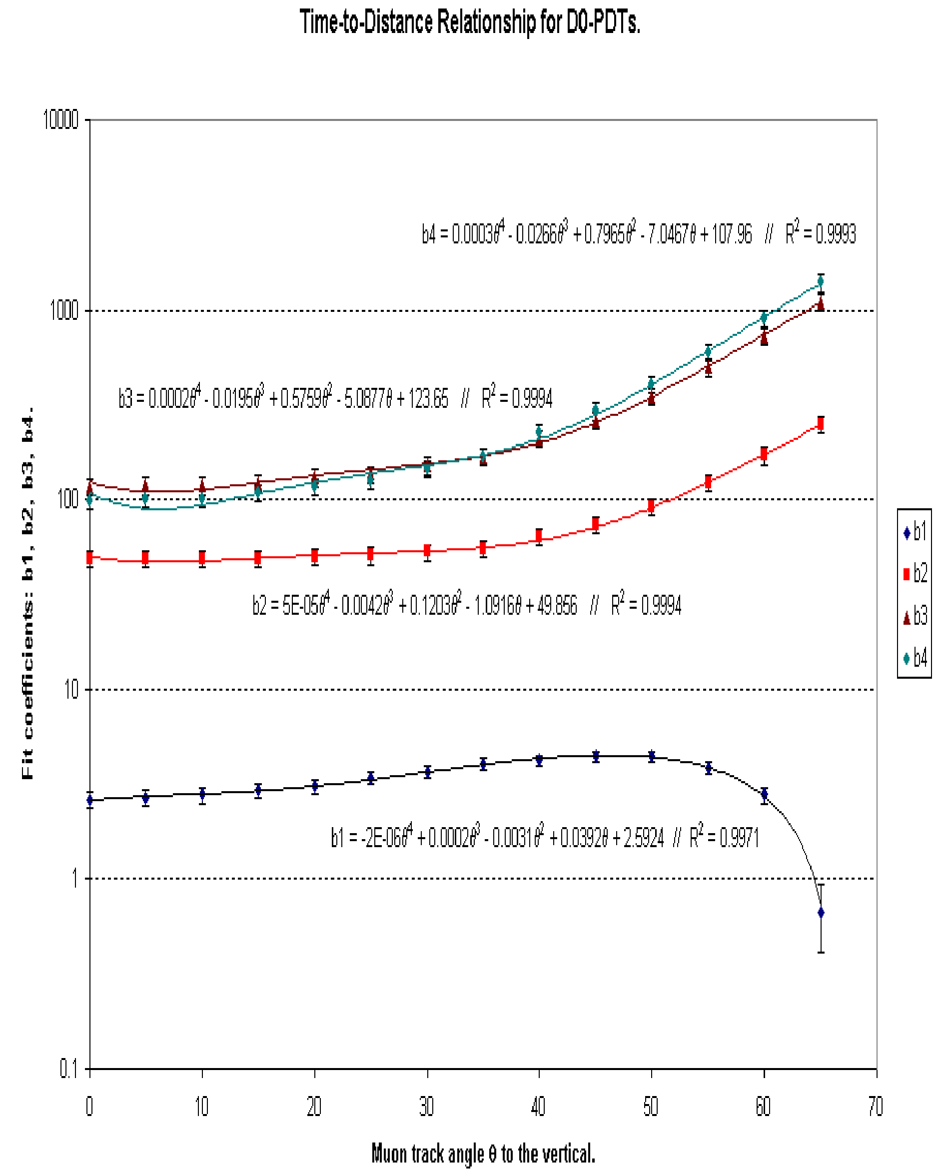

Figure 20: Fit parameters b as a function of the angle theta. The fit is valid in the angle range from 0 to 65 degrees. The least squares fit to the parameters b as a function of theta is given next to each curve. The angle theta must be given in degrees to obtain the correct b1, b2, b3 and b4 values.

Table 5: Results of the least squares fit to the parameters B1, b2, b3 and 4 as a function of he angle theta.

	ai0	ai1	ai2	ai3	ai4
b1	2.59	0.04	0	0	−2.00E−06
b2	49.86	−1.09	0.12	0	5.00E−05
b3	123.65	−5.09	0.58	−0.02	0
b4	107.96	−7.05	0.8	−0.03	0

8 – Comparing with Run I data

In D0−Note 2104, "Time−to−Distance Relationship for D0 Muon Drift Tubes" from H. Haggerty, R. Markeloff, D. Mueller and Y. Shao, April 8, 1994 [2], a report is presented of measurements of the positions of cosmic rays passing through a minichamber proportional drift tube (PDT) prototype. They recorded the corresponding drift times and derived an empirical relation for the hit position at cell midplane as function of incident track angle and drift time.

The gas mixture used consisted of 90% Ar, 5% CO_2 and 5% CF_4, the gas mixture used in the PDTs in Run I.

The minichamber was three driftcells wide by 218 inches long, similar in construction to the muon chambers used in the D0 detector. The minichamber setup used included a pair of proportional wire chambers (PWCs) mounted above and below the minichamber to measure the position of cosmic rays. The PWCs each had 128 parallel wires spaced 1 mm apart. Scintillators and phototubes provided a trigger signal. The PWCs could be tilted at any angle so that the variation of drift time with incident angle could be studied. Figure 21 shows the experimental setup.

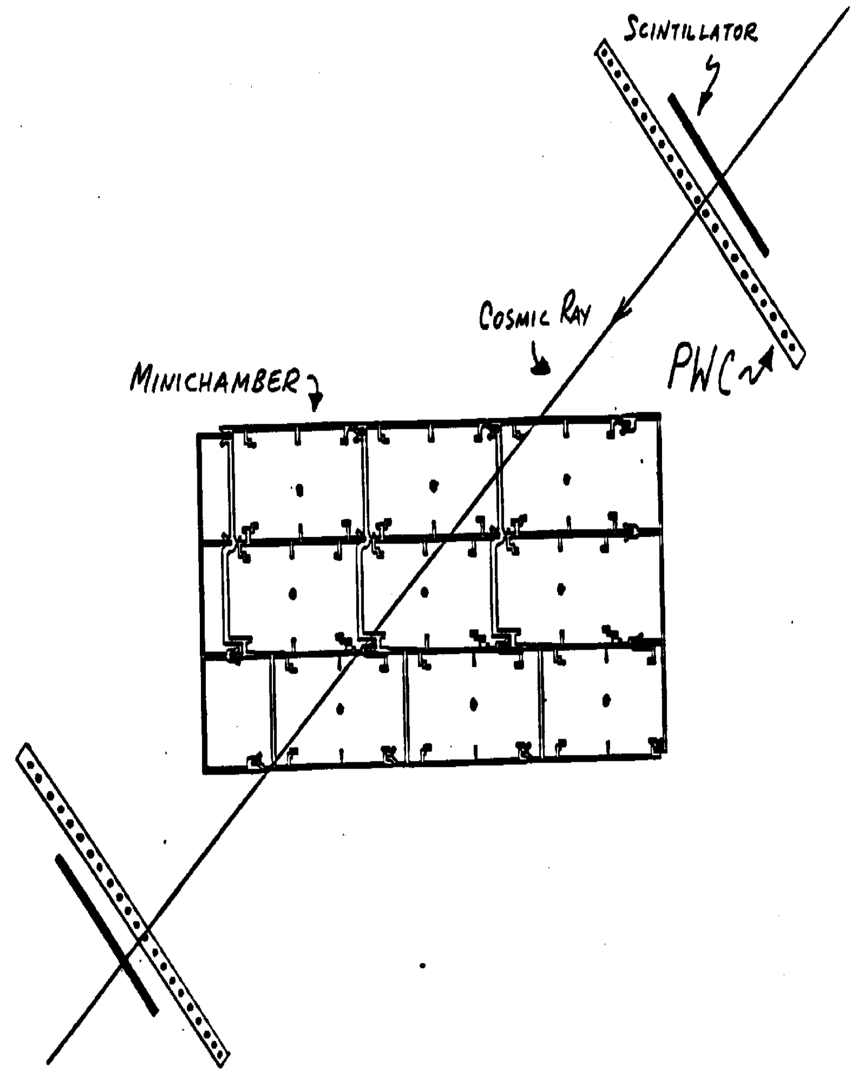

Figure 21: Experimental setup for the cosmic rays measurements with the PDT minichamber prototype.
(Figure taken from that D0−Note 2104, ref. [2])

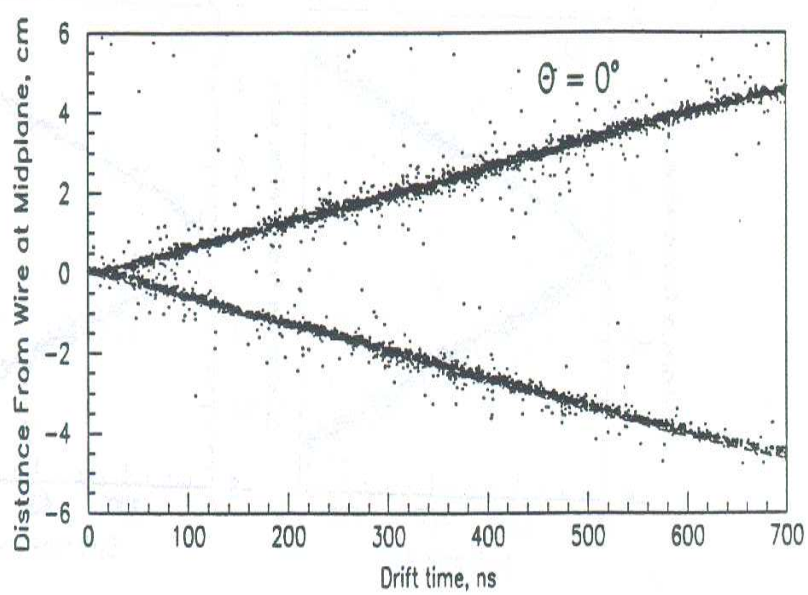

Figure 22: Hit position at cell midplane versus drift time for muons crossing the PDT cell at 0 degrees.
Data taken from D0–Note 2104, ref. [2].

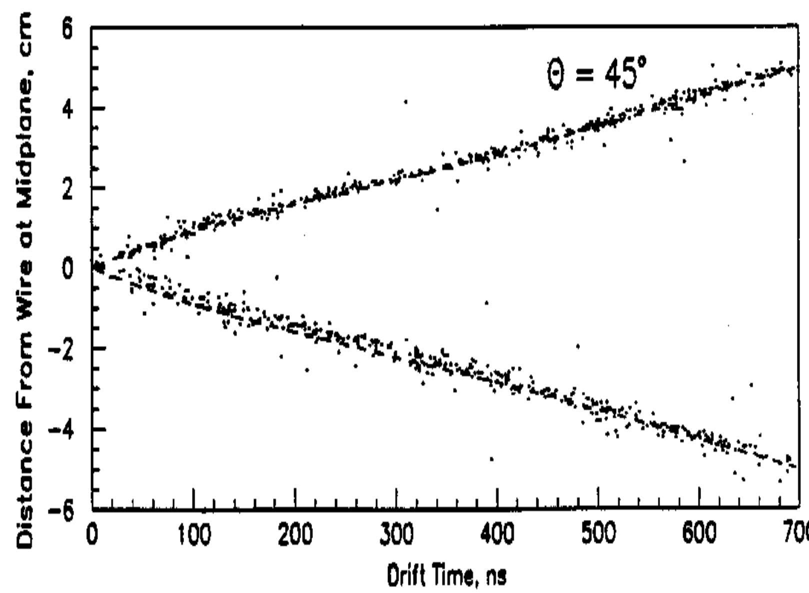

Figure 23: Hit position at cell midplane versus drift time for muons crossing the PDT cell at 45 degrees.
Data taken from D0–Note 2104, ref.[2].

The experimental data obtained in 1994 with this setup were used for a comparison with simulated data, to gain confidence in the methods and its implementation. Applying the same methods described in the sections above, and the same software (Garfield+Heed+Magboltz), by only changing the gas mixture to the one used in 1994, calculated data were obtained and compared with the experiment from 1994, data taken from D0–Note 2104. Figures 22 and 23 show the experimental data from 1994, the the hit position at cell midplane versus drift time for muon tracks crossing the chamber at 0 and 45 degrees. From these plots numbers were extracted, tabulated in Table 6 next to the data simulated with Garfield and plotted together: Figures 24 and 25, X vs. T plots, show that within the error margins of the data the calculated data are in good agreement with the experimental obtained values.

Old Gas (Run I)				
Position to the wire at midplane	Ar–CO2–CF4 mu at **0 deg.** **GARFIELD**	Ar–CO2–CF4 mu at **0 deg.** **MEASUREMENT**	Ar–CO2–CF4 mu at **45 deg.** **GARFIELD**	Ar–CO2–CF4 mu at **45 deg.** **MEASUREMENT**
X [cm]	**T [ns]**	**T [ns]**	**T [ns]**	**T [ns]**
0.200	0.038		0.026	
0.400	0.072		0.053	
0.500		0.080		0.060
0.600	0.101		0.075	
0.800	0.128		0.095	
1.000	0.157	0.150	0.115	0.120
1.200	0.186		0.137	
1.400	0.216		0.161	
1.500		0.230		0.200
1.600	0.246		0.188	
1.800	0.276		0.218	
2.000	0.306	0.300	0.251	0.300
2.200	0.335		0.285	
2.400	0.364		0.318	
2.500		0.360		0.360
2.600	0.393		0.351	
2.800	0.422		0.382	
3.000	0.450	0.450	0.412	0.430
3.200	0.479		0.443	
3.400	0.507		0.472	
3.500		0.530		0.510
3.600	0.536		0.500	
3.800	0.565		0.527	
4.000	0.595	0.600	0.555	0.580
4.200	0.625		0.583	
4.400	0.655		0.608	
4.500				0.640
4.600	0.686		0.636	
4.800	0.716		0.664	

Table 6: Measured cosmic rays data and computer simulation with Garfield for the gas mixture used during Run I: 90% Ar + 5% CO2 + 5% CF4

Note:

The measured data were taken from D0–Note 2104, ref.[2].

Errors for T in [ns] were estimated to be: +–10 ns for mu at 0 deg. and +–20 ns for mu at 45 deg.

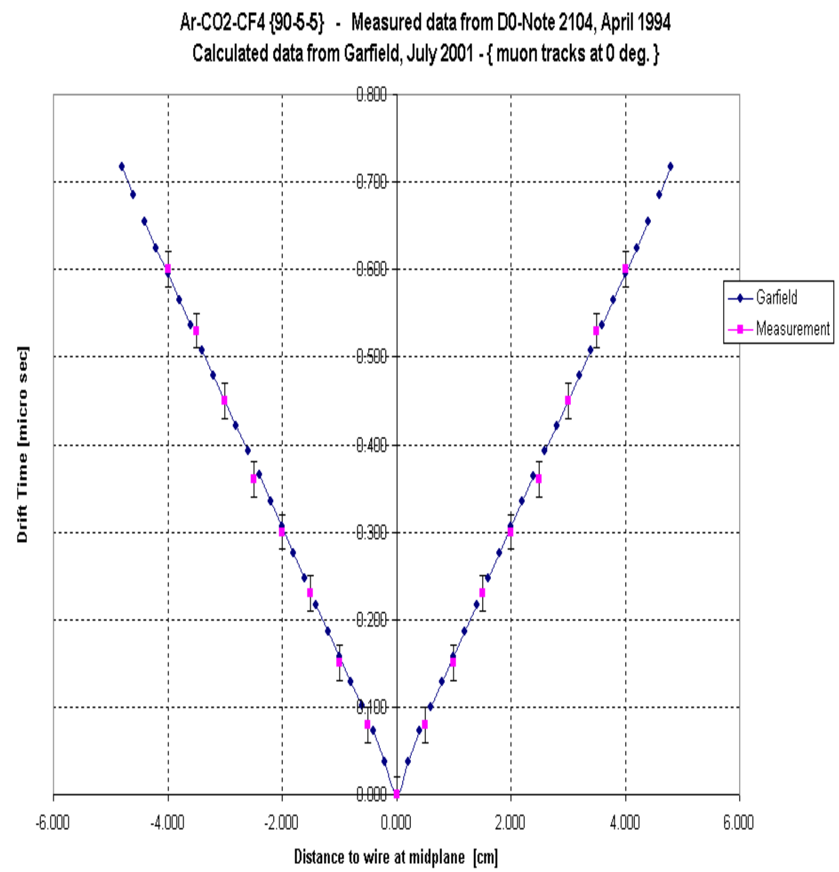

Figure 24: Measured cosmic rays data and computer simulation with Garfield for the gas mixture used during Run I:
90% Ar + 5% CO2 + 5% CF4 .
T vs. X plot for muon tracks crossing the chamber at 0 degrees.
Experimental data taken from D0–Note 2104, ref.[2].

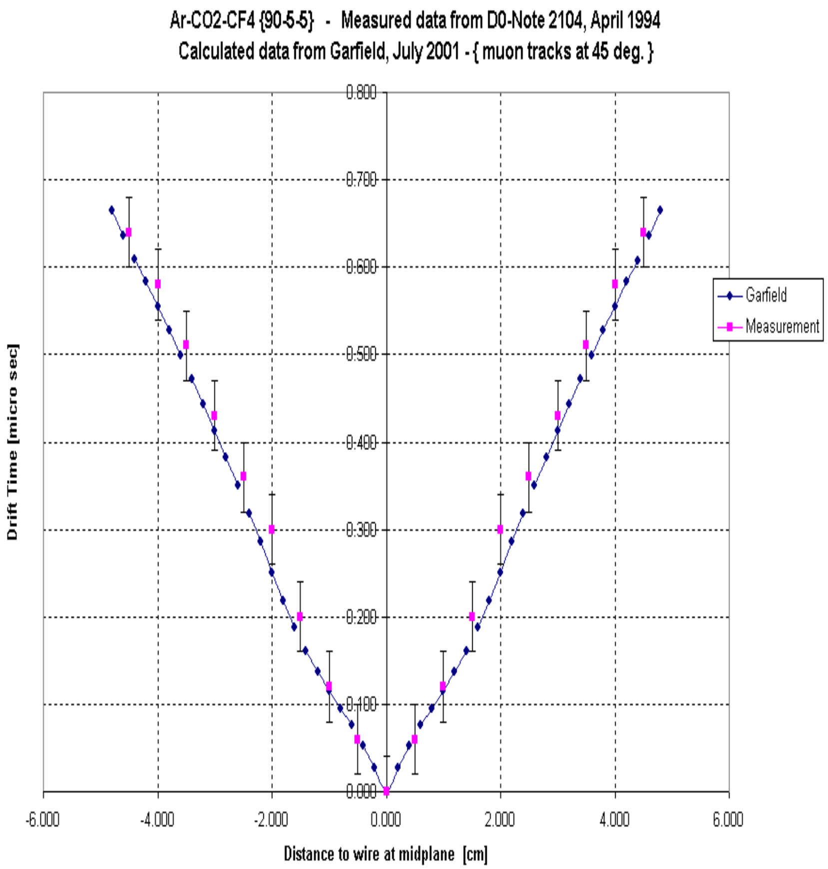

Figure 25: Measured cosmic rays data and computer simulation with Garfield for the gas mixture used during Run I:
90% Ar + 5% CO2 + 5% CF4 .
T vs. X plot for muon tracks crossing the chamber at 45 degrees.
Experimental data taken from D0–Note 2104, ref.[2].

The computer simulated data with Garfield for the gas mixture used in Run I (90% Ar + 5% CO2 + 5% CF4) can be compared with the data for the faster gas mixture used presently in Run II (88% Ar + 8% CH4 + 8% CF4). This is shown in Figure 26, drift time T vs. distance to the wire X. This illustrates the effect of a faster gas used presently for Run II. The effect gives a reduction of the drift time that grows with the distance to the wire, as is shown in Figure 26 and in Table 7.

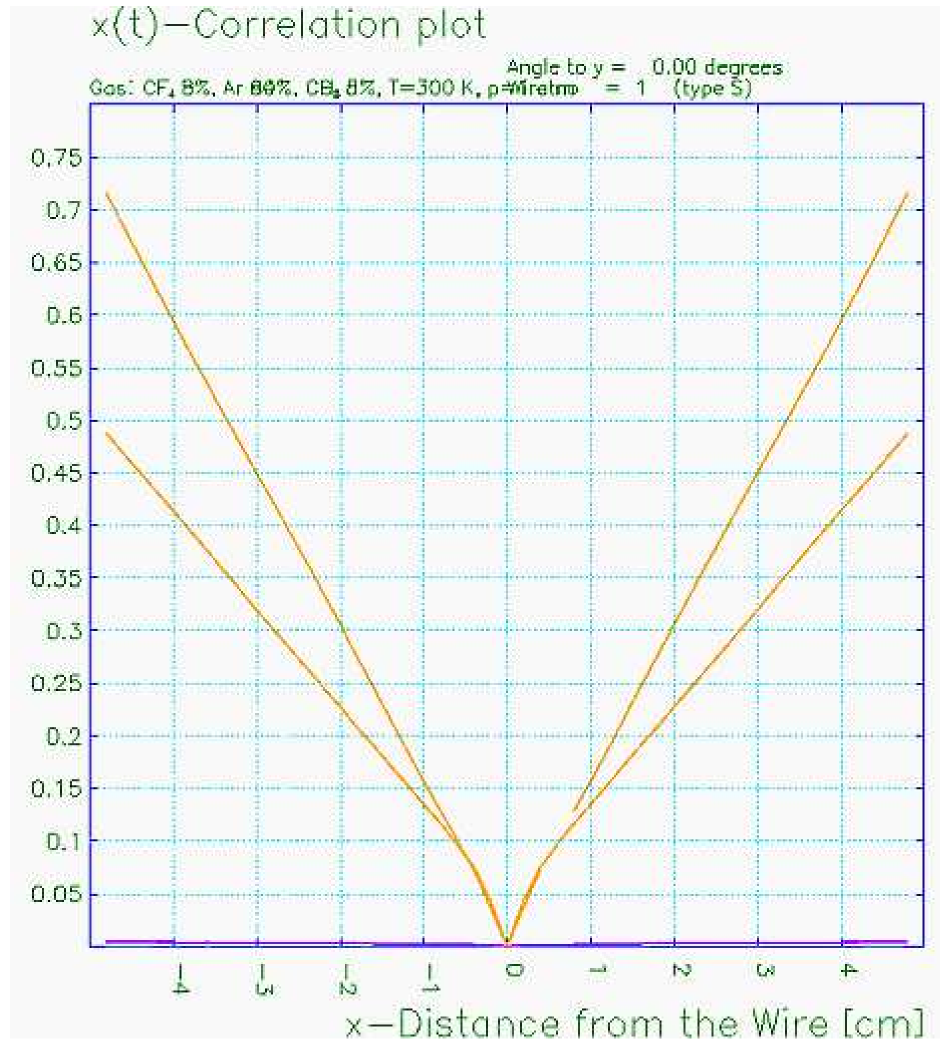

Figure 26: Electron drift time T vs. muon track distance to the wire at cell midplane for two gas mixtures: Ar–CO2–CF4 (90–5–5) and Ar–CH4–Cf4 (88–8–8). Data calculated with Garfield.

Table 7: Reduction of the drift time
for the Ar−CH4−CF4 gas mixture compared to the Ar−CO2−Cf4

Distance X to the wire at cell midplane	% of reduction of the drift time for the Ar−CH4−CF4 (88−8−8) gas with respect to the Ar−CO2−Cf4 (90−5−5−) gas mixture.
1 cm	12%
2 cm	20%
3 cm	28%
4 cm	30%

9 − The software used: GARFIELD

The software used for the PDT simulation was GARFIELD, a program already used at Experiment D−Zero to calculate the Mini Drift Tubes (MDT) Time−to−Distance Relationship, see D0−Note 3797 from November 30, 2000, by D. Denisov and Y. Yatsumenko, [7]. They studied with Garfield the effects of variations in the high voltage, composition of gas mixture and admixture of oxygen and water on the time−to−distance relation for the Mini Drift Tubes.

Garfield

GARFIELD, ref.[3], is a program package from CERN written by Rob Veenhof for the simulation of drift chambers consisting of wires and infinite equipotential planes. This program has been growing since 1984 and is now a very successful package used in most high energy and nuclear physics experiments that require the simulation of drift chambers.

Originally, Garfield was limited to two−dimensional chambers. Currently it accepts two and three dimensional field maps computed by finite element programs such as Maxwell, as basis for its calculations. Also drifting of particles, including diffusion, avalanches and current induction is treated in three dimensions.

The program can calculate field maps, contour plots and 3−dimensional impressions; the wire sag that results from electrostatic and gravitational forces; optimum potential settings to achieve various conditions; plots of electron and ion drift lines; x(t)−relations, drift time tables and arrival time distributions; signals induced by charged particles traversing a chamber, taking both electron pulse and ion tail into account.

Heed

To simulate the initial ionization produced by fast charged particles in gases (the muons in our gas mixture), Garfield includes an interface to HEED, ref.[4], a program written by Igor Smirnov. Heed performs 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 type of atom in the gas mixture is taken into account for each energy transfer. Heed calculates the delta−electron energy and generates cascades of secondary particles emitted by the excited atoms.

Magboltz

For the computation of the electron transport properties in the gas mixture Garfield includes an interface to MAGBOLTZ, ref.[5], a program written by Stephen Biagi. Magboltz solves the Boltzmann transport equations for electrons in gas mixtures. It uses the Monte Carlo integration technique that allows the solution of the transport equations to be independent of the series expansions in Legendre Polynomials or Spherical Harmonics required by analytic solutions of the Boltzmann equations [8], [9]. The technique lends itself easily to use by non–experts since the only inputs required are the electric and magnetic fields, the angle between the fields, the temperature and pressure and the fractional composition of the gases. The program has the option of calculating its own electron energy integration range. Magboltz takes cross–sections for non–elastic processes into account, and also the magnetic field, to compute the transport properties. It computes for electrons, the drift velocity, the longitudinal and transverse diffusion coefficients, the Lorentz angle if there is a magnetic field, as well as the Townsend and attachment coefficients.

Documentation and availability of the software

Garfield is an excellent documented software with extensive, clear and very useful help webpages:

http://consult.cern.ch/writeup/garfield/

Garfield is formally part of the CERN program library. It is a program written in Fortran–77. The source files are available over WWW:

http://consult.cern.ch/writeup/garfield/files

and the author Rob Veenhof gives prompt support to the user's questions.

10 – Conclusions

For drift chambers, in order to optimize its physics parameters like gas mixture, gas pressure, gas gain and electronics parameters like preamplifier peaking time, noise, threshold settings etc., a detailed simulation of the detector response can be performed with Garfield.

Garfield results are reliable as is shown for the PDTs by the agreement between the simulated and the measured data for the Run I gas mixture, and also as is shown in D0–Note 3797 (D. Denisov and Y. Yatsumenko) for the D0 Mini Drift Tubes (MDT). Also extensive documentation is available from the Garfield web pages with examples of the Garfield results for a series of high energy experiments: http://consult.cern.ch/writeup/garfield/examples/

For the D0 PDTs the time T–to–distance X relation is well described by a function of the form

$$X(T) = b1*T + b2*T^2 + b3*T^3 + b4*T^4$$

with fit parameters that can be obtained from the angle q through the relations

$$b1 = a10 + a11*\theta + a12*\theta^2 + a13*\theta^3 + a14*\theta^4$$
$$b2 = a20 + a21*\theta + a22*\theta^2 + a23*\theta^3 + a24*\theta^4$$
$$b3 = a30 + a31*\theta + a32*\theta^2 + a33*\theta^3 + a34*\theta^4$$
$$b4 = a40 + a41*\theta + a42*\theta^2 + a43*\theta^3 + a44*\theta^4$$

The fit parameters obtained with least squares fits of these relations to the with Garfield simulated data can be used for the muon track angle range from 0 to 65 degrees. To extend the fit to cover large angles, up to 90 degrees requires a polynomial function of degree higher than four. A separate fit to the large angle region (65 to 90 degrees) is necessary.

In spite of the confidence gained with the comparison Garfield simulation <–––> experimental data, it is necessary to compare the Garfield results for the Run II PDT gas mixture Ar–CH4–CF4 (88–8–8) with real data, experimental data with cosmic rays muons crossing the PDT chambers at well defined angles.

11 – Acknowledgments

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12 – References

[1] B. Baldin, et al., "Technical Design of the Central Muon System", D0−Note 3365, March 29, 1997; updated November 11, 1997; updated March 12, 1998.

[2] H.Haggerty, R.Markeloff, D.Mueller, and Y.Shao; "Time to Distance Relationship for D0 Muon Drift Tubes", D0−Note 2104, April 8, 1994.

[3] R. Veenhof, "Garfield: Simulation of gaseous detectors", CERN Writeups; http://consult.cern.ch/writeup/garfield/

[4] S. F. Biagi, "Magboltz: Transport of electrons in gas mixtures"; CERN Writeups; http://consult.cern.ch/writeup/magboltz/

[5] I. Smirnov, "Heed: Interactions of particles with gases"; CERN Writeups; http://consult.cern.ch/writeup/heed/

[6] S. Biagi, "Cross−sections used by Magboltz", cross−sections for drift chamber simulation programs, CERN writeup pages, Magboltz program writeup; http://consult.cern.ch/writeup/magboltz/cross/

[7] D. Denisov, Y. Yatsunenko, "Calculations of MDT Time−to Distance Relation with GARFIELD", D0−Note 3797, November 30, 2000.

[8] S.F. Biagi, "A multiterm Boltzmann analysis of drift velocity, diffusion, gain and magnetic−field effects in argon−methane−water−vapor mixtures", Nuclear Instruments & Methods in Physics research, A 283 (1989) 716−722.

[9] S. F. Biagi, "Monte Carlo simulation of electron drift and diffusion in counting gases under the influence of electric and magnetic fields", Nuclear Instruments & Methods in Physics research, A 421 (1999) 234−240.

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