Simulation of Gaseous Detectors by *Garfield* in $\mathcal{TWIST}$

Sun-Chong Wang
TRIUMF, Vancouver, B.C. V6T 2A3, Canada
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Abstract

The use of *Garfield* in $\mathcal{TWIST}$ is to generate a grid table which is directly used by $\mathcal{TWIST}$ GEANT. The same grid table is also processed, in `strs_mod.f90`, to generate the x(t) relation for Kalman tracking in Mofia. The note is a tutorial of how these are accomplished. A section is also devoted to simulating the sensitivity of the STR to variations in gas temperature, pressure, solenoid magnetic field, HV, and jitters in time-zero.

1. **Introduction**

Garfield is a widely used computer program to simulate gaseous detectors in particle/nuclear physics community. It uses *Heed* program to simulate ionization of gas when charged particles traverse through the chamber. Furthermore, it employs *Magboltz* program to simulate drifting of electrons and ions in nearly arbitrary gas mixtures.

Garfield can calculate and plot 1) field maps given the geometry of the cell, 2) electron and ion drift lines, and 3) x(t) relations and drift-time tables. It can also calculate wire sags due to the electric and gravitational force. It also simulates induced wire signals given the electronic response.

Garfield is a command driven program. In $\mathcal{TWIST}$, we store the command lines into files. To simulate, we simply input the file when under the *Garfield* prompt. For a particular gas (e.g., DME) two files are essential. The first one is to generate the (DME) gas data file which will be used in subsequent simulations. The second file is responsible for the creation of drift time grid tables and x(t) curves. In Sec. 2, we describe the input file for gas data. Grid tables for both $\mathcal{TWIST}$ GEANT and Mofia are the subject of Sec. 3 where some field maps and isochrones of our cell are also plotted. Section 4 shows results of the sensitivity study of the chamber to ambient variations. Section 5 describes the Mofia module which preprocesses the *Garfield* output. The last section summaries.

2. **Gas Data File**

Gas properties should be prepared before any simulation. Fortunately, all DME, CF_4, and isobutane are among the default gases provided in *Garfield*. What we have to specify for the gas are the magnetic field, temperature, and pressure. A standard gas input file for $\mathcal{TWIST}$ is listed in Fig. 1. Values of the temperature and pressure are given in the beginning of the file as global constants. *Garfield* commands are grouped into *sections*. In the gas input file in Fig. 1, there are only two sections: magnetic and gas section. `&magnetic` indicates the beginning of the magnetic section, and so on. It is noted that the magnetic section should precede the gas section because gas properties depend on the magnetic field. Lines start with the star sign are comments. In the magnetic section, `Component` is a *Garfield* command. Values/symbols after the command are the arguments. *Garfield* commands are case insensitive. In the file, we've indicated a constant magnetic filed of 2.0 Tesla along the y axis. Note that the coordinate system used here in *Garfield* is not the one of our spectrometer. The choice of the coordinate system will become clear in the next section where the cell geometry is defined.

```
***
*** Program simulates gas data for 3 E/p ranges (linear scale):
*** 0.01 - 9.99 V/cm/Torr (500 points, step 0.02 V/cm/Torr);
*** 10.0 - 19.95 V/cm/Torr (200 points, step 0.05 V/cm/Torr
```

```
*** 20.0 - 600 V/cm/Torr (291 points, step 5 V/cm/Torr)
***

*** Enter gas mixture
*** and fraction and gas id for data set file name

* DME in DC
Global GAS=‘DME 1.0‘
Global GAS_ID=‘DME‘

* CF4/ISO in PC
*Global GAS=‘CF4 .80 ISO .20‘
*Global GAS_ID=‘CF80_ISO‘

*** Enter values of the magnetic field (Tesla), temperature (K),
*** pressure (Torr), ion mobility (cm**2/V*us), average number of
*** clusters per cm (mean)

GLOBAL B=2.0
GLOBAL t=297
GLOBAL p=760

* below will be taken care of by Heed
* GLOBAL cluster=
* { 0. 78.2 7.4 2.1 1.4 0.8 0.7 0.6 0.8 1.1 1.2 0.9 0.7 0.5 0.4}

&magnetic
components 0. {B} 0. tesla

&gas
 pressure {p}
 temperature {t}
 Heed DME 100
* Heed CF4 80. ISO 20.

 magboltz {GAS} E/P-RANGE 0.1 600. N-E/P 20
 interpolations drift-velocity newton 2 townsend newton 2
 extrapolations high-drift-velocity linear ...
 low-drift-velocity constant
 extrapolations high-long-diff constant high-ion-mobility ...
```

```
 constant

 write "{GAS_ID}_B{B*10}_P{p}_T{t}.DAT"

&quit
```

Fig. 1 The gas data input file for $\mathcal{TWIST}$

In the gas section, first of all, the cluster size distribution and cluster spacing are calculated by the *Heed* program. The arguments to the `Heed` command tells that the gas mixture is 100% DME (or 80% of CF_4 plus 20% of ISO in the case of proportional chambers).

The next command in the gas section invokes the *Magboltz* program to compute, for electrons, the drift velocity, the longitudinal and transverse diffusion coefficients as well as the Townsend and attachment coefficients. The arguments to it specify the range of electric field over pressure E/P in V/cm/Torr and the number of E/P points generated. The rest of the commands simply tells *Garfield* how to interpolate and extrapolate when outputting the gas data table. Note that ... is to continue the command to the next line in *Garfield*.

After writing out the gas data table into the file with specified file name, the program quits with &`quit` command.

Note that that since *Garfield* is case insensitive, to output files in capitals, double quotes are used instead of single quotes.

To simulate electron drifts in the cell at various different ambient conditions, namely, magnetic fields, temperatures, pressures, we change the parameters in the gas input file of Fig. 1 and run *Garfield* every time we have different values of the parameters. We then obtain a series of files for the gas at various conditions. These gas data files will be read in to simulate electrons drifts in the procedures described in the next section.

3. Electron Drift Grid Table

Figure 2 shows the input file to generate the grid table which will be used by both $\mathcal{TWIST}$ GEANT and Mofia. Again, first of all, some global variables are assigned constant values, which are also used to compose the file name of the output grid table.

```
*Internal Variables
GLOBAL y=True
GLOBAL n=False

*External use variables
```

```
Global GARFUSER='Sun-Chong Wang'
Global GAS='DME'

GLOBAL B=2.0
GLOBAL t=297
GLOBAL p=760
GLOBAL VOLT=-1900
Global OFILE='DC_{GAS}_B{B*10}_T{t}_P{p}.dat'
Global gridsize=202

*Adding interactive capablilties. Roy Wilds - May 10, 2001
*******Verify current values are proper OR get new ones*******
  say "The current values are:"
  say "User name written to output file= {GARFUSER} "
  say "Bfield= {B}  Temperature= {t}  Pressure= {p}  "
  say "Voltage= {VOLT}  GAS= {GAS}"
  say "MC Output file= {OFILE}"
  say "Grid Size = {gridsize}"
  say "Are these values okay? (y/n)"
  parse Evaluate Terminal choice00
  if choice00 Then
     say "Proceeding with above values"
  Else
     say "New user name for output file="
     parse Terminal GARFUSER
     say "New Bfield="
     parse Terminal B
     say "New Temperature="
     parse Terminal t
     say "New pressure="
     parse Terminal p
     say "New Voltage="
     parse Terminal VOLT
     say "New GAS="
     parse Terminal GAS
     say "New MC Output file="
     parse Terminal OFILE
     say "New Grid Size="
     parse Terminal gridsize
     say " "
```

```
     say "The current values are:"
     say "User name written to output file= {GARFUSER} "
     say "Bfield= {B}  Temperature= {t}  Pressure= {p}  "
     say "Voltage= {VOLT}  GAS= {GAS}"
     say "MC Output file= {OFILE}"
     say "Grid Size= {gridsize}"
  Endif
****************************************************************

&cell
plane y=0.2, v={VOLT}
plane y=-0.2 v={VOLT}
gravity 1 0 1
rows
s  1  0.005   -16.8       0.00   0.     60.  40. 19.4
s  1  0.0025  -16.4       0.000  0.     45.  40. 19.4
s 80  0.0015  -16.0+.4*i  0.000  0.     35.  40. 19.4
s  1  0.0025   16.0       0.000  0.     45.  40. 19.4
s  1  0.005    16.4       0.00   0.     60.  40. 19.4

&field
area -.2 -.2 .2 .2

&optimise
area 0. 0. .2 .2

&magnetic
components 0. {B} 0. tesla

&gas
Global gas_file=`{GAS}_B{B*10}_P{p}_T{t}.DAT`
  Call inquire_file(gas_file,exist)
  If exist Then
     Say "Gas file {gas_file} exists, retrieving ..."
     get {gas_file}
  Else
     Say "Gas file {gas_file} not found, exit ..."
     &quit
  Endif

```

```
opt nogas-pl

&drift
area -0.2 -0.2 .2 .2
*select 43

*The C's in the output are required for the method of read
*in used in MOFIA. In GEANT the file is read in with a
*set number of comment lines ignored at the head of the file.
*If more comment lines are added, then the code will have to
*change.

say "C STRs generated by {GARFUSER}"
say "C Voltage= {VOLT} Bfield={B} Grid Size={gridsize}"
say "C Gas file used is {gas_file}"
say "C Pressure= {p} Temperature= {t} "


*Note on the parameters for the area command.
*The area begins at -0.001 -0.001 with a 9.995 mircometer
*spacing between points. At the moment this 9.995 is treated
*as 10micrometers, and in the GARFIELD source code, there has
*been an adjustment to skip printing the Drift Times for the
*points along x=-0.001 and y=-0.001 The area command starts
*at these points because it was failing to calculate the Drift
*Times along x=0.0 and y=0.0 unless the grid extended past
*these lines. So, the grid dimensions were increased by 1
*increment so that the calcualations would work properly, and
*in the output these extra increments are just ignored. Also,
*the 1 micrometer offset from 0.2 at the other corner of the
*area is necessary, since GARFIELD fails at this location too.
*In the current application, 0.1999 is treated as 0.2

grid {gridsize} {gridsize}
area -0.001 -0.001 0.1999 0.1999
Table table
> {OFILE}
&quit
```

Fig. 2 The input file for drift time grid table

What follows in the input file enable a bit interactivity between the program and the user.

We next enter the cell section beginning with &`Cell`. The cell section which defines the geometry of the cell is usually the first section in most simulations. Here we define the cell boundary at $y = 0.2$ and $y = -0.2$ corresponding to the planes of the cathode foil. The electric potential at these foil planes is also specified. The $x-y$ plane is in fact a cross-section of the cell with the wire along the z-axis. This evolves from the development of *Garfield* since *Garfield* is originally a two-dimensional simulation program. The spacer between arguments can be a comma or space. A line is, however, allowed to have only one command. The direction of gravity is next defined. Note that distances are in centimeter and potentials in Volt in *Garfield*.

The next command `rows` defines the wires in the chamber. The format of this command is,

`label number diameter x y Volt weight length density`

where `label = s` in our case tells that the wire is a sense wire. `number` specifies the number of such wires in the row. Note that the loop variable `i` in the `rows` command starts from zero. The `rows` command ends with a blank line.

We now enter the *field* section which defines the drift area we are looking at. Particles are not allowed to drift outside of this region. Since the whole chamber is composed of supposedly highly symmetrical and identical cells, we can simply simulate drifts within a cell. The `area` command defines such a limited region. The arguments to `area` are `xmin ymin xmax ymax`. Again, numbers are in centimeter.

The next section &`optimize` optimizes the potential and calculation of forces. Here we can further restrict the area of the cell that is considered.

The following two sections &`magnetic` and &`gas` are simply to reconfirm the magnetic field and specify the gas data file to be read in for the drift simulation. `opt nogas-pl` tells *Garfield* not to plot the drift velocity, the ion mobility, the diffusion coefficients, the Lorentz angle, the Townsend coefficient, and the attachment coefficient of the gas.

The final section &`drift` simulates the electron and ion behavior in the chamber. The `area` command changes the area of our concern. As mentioned, we as well focus on simulating one cell. The `select` command in Fig. 2 selects wire 43 as our target. Note that the selected wire should be consistent with the chosen area of drift specified by the `area` command, otherwise, no simulation is performed.

The `grid` command specifies the density of the grid from which drift lines will be drawn and drift times calculated. The arguments to `grid` are the number of steps in x and y direction.

The `Table` command generates the drift lines from the grid. The `table` argument tells *Garfield* to output the table, which will be redirected to a file of name represented by the string `OFILE` in the next command line.

Finally the simulation terminates with &`quit`

When switching from DME to CF_4ISO, it's reminded to change the applied high voltage to the mylar foil from -1900 to -2100, the number of wires in the `rows` command, the x bounds in the `area` command, and the number of grid steps in the x direction. y, the thickness of the module, is the same for both PC and DC.

The input file of this section and the gas input file of the previous section are the two files that are routinely used for the $\mathcal{TWIST}$ chambers. E614slow webpage has links to modified *Garfield* for $\mathcal{TWIST}$ and instructions to run it.

To conclude introduction to *Garfield*, I enclose plots of tracks, isochrones, and x(t) curves of the gas when the magnetic field is off and on. Note the change of the PC drift property with the magnetic field.

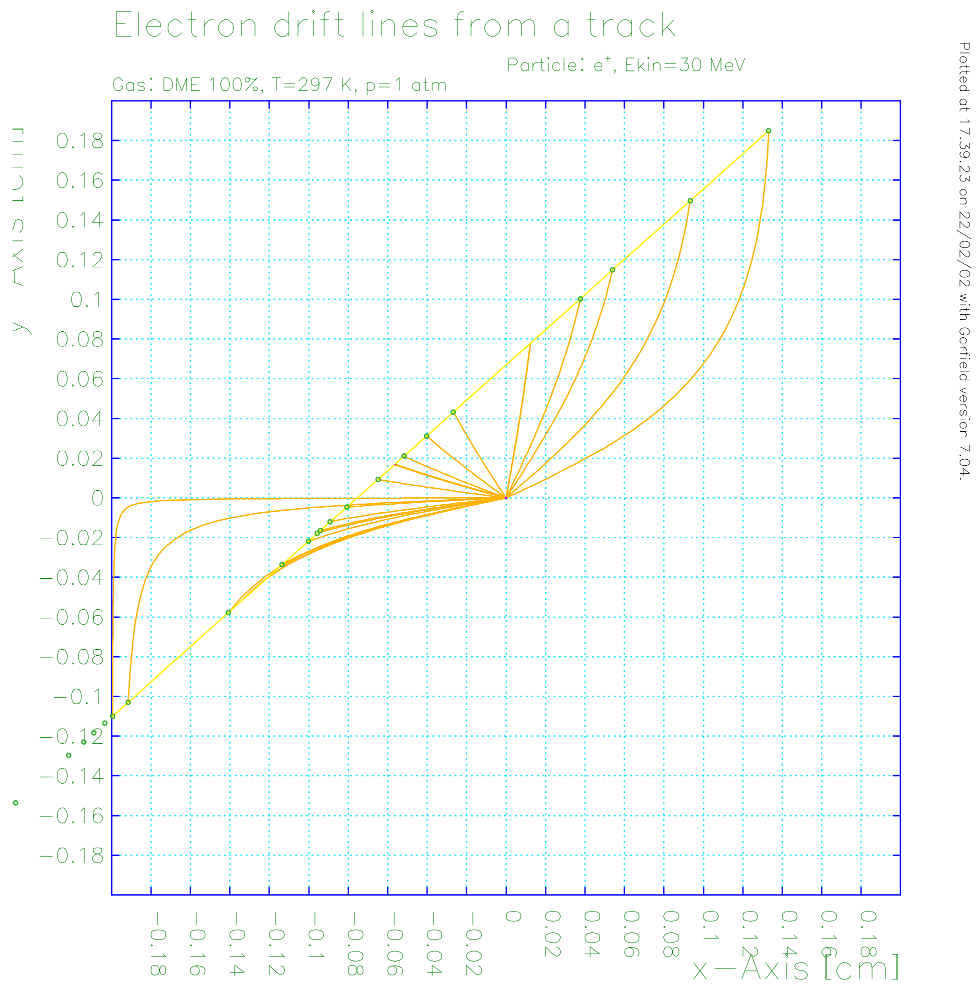

Figure 3: A straight track of positron at 30 MeV through the DC cell. Ground planes are the top and bottom y plane. The cluster size and spacing distributions are calculated by the *Heed* program incorporated in *Garfield*

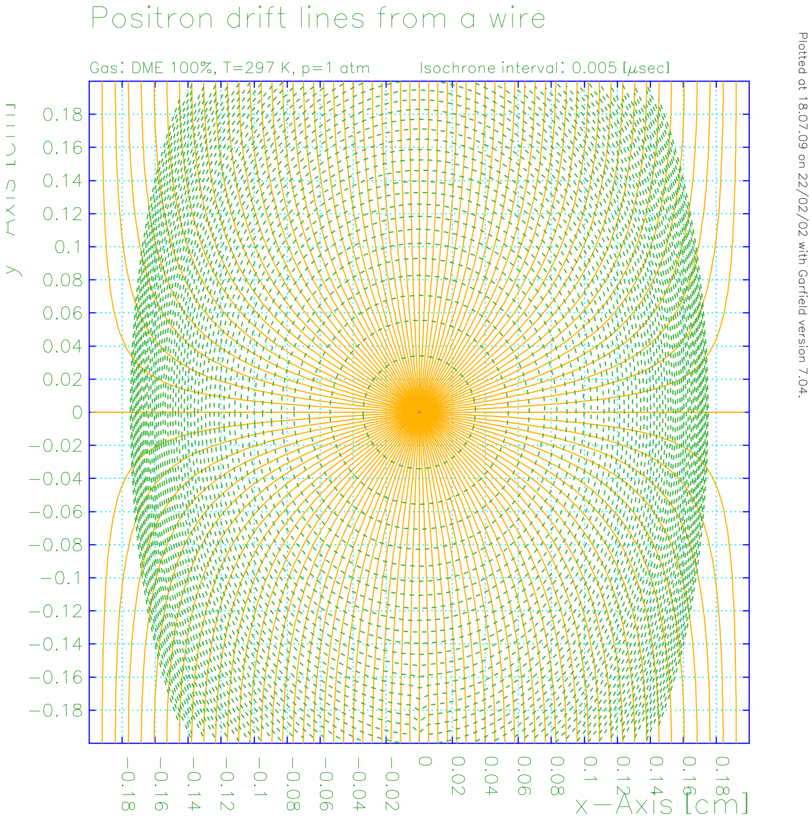

Fig. 4 Drift time isochrones of DME at zero B field

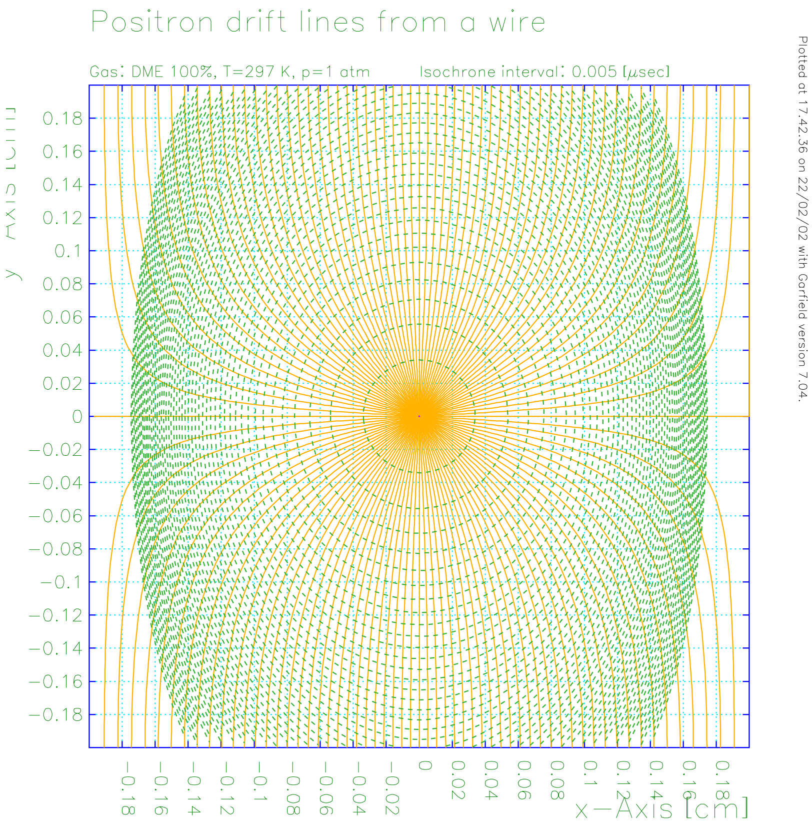

Fig. 5 Drift time isochrones of DME at $B = 2$ Tesla

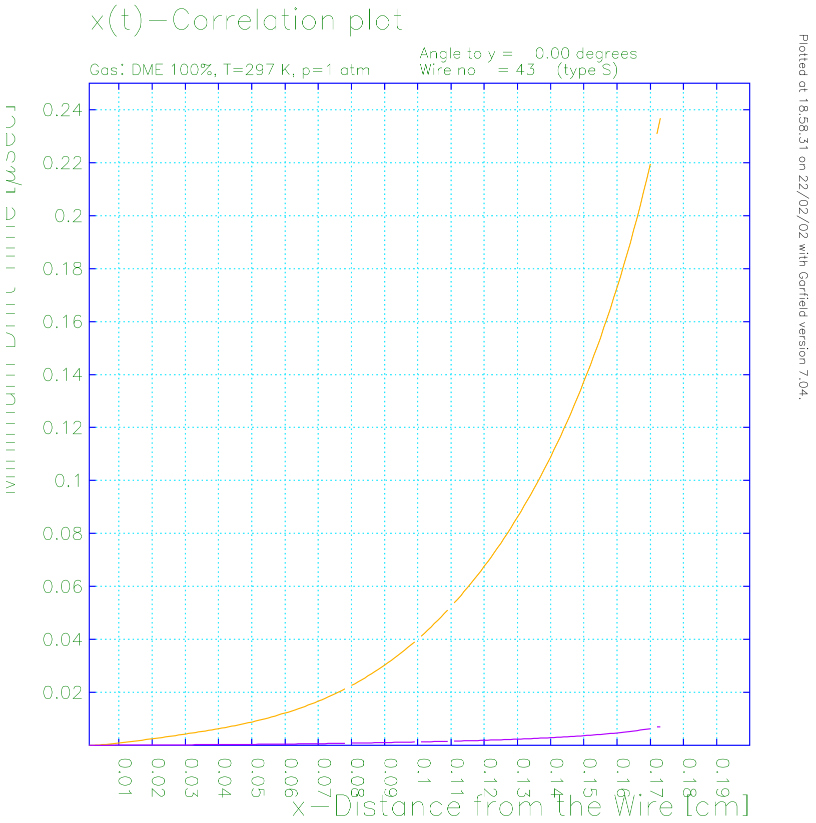

Fig. 6 x(t) relation of DME at zero B field

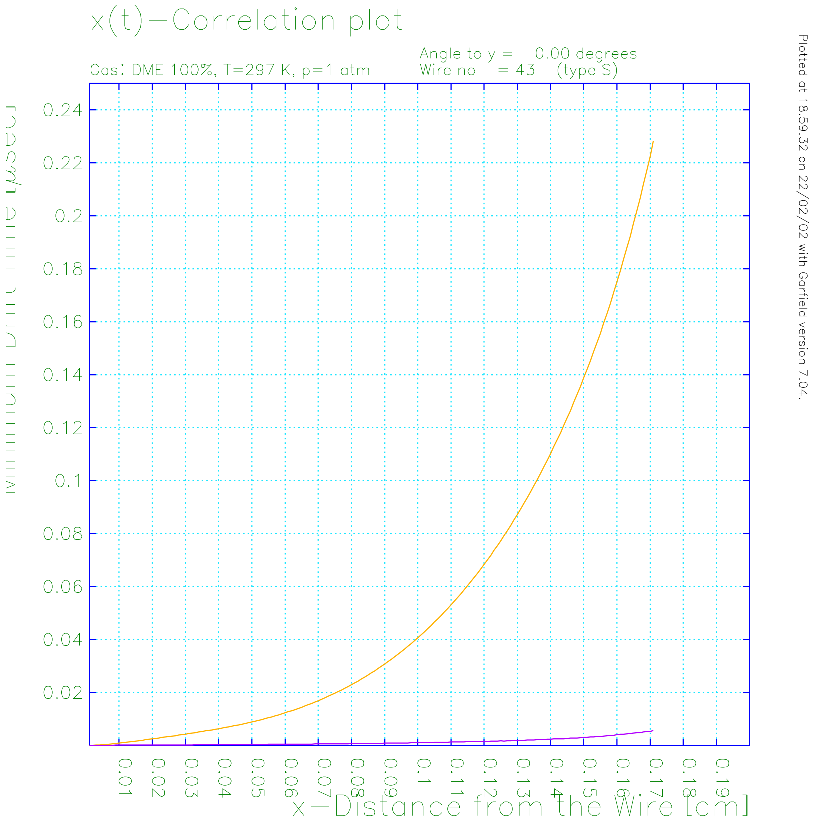

Fig. 7 x(t) relation of DME at $B = 2$ Tesla

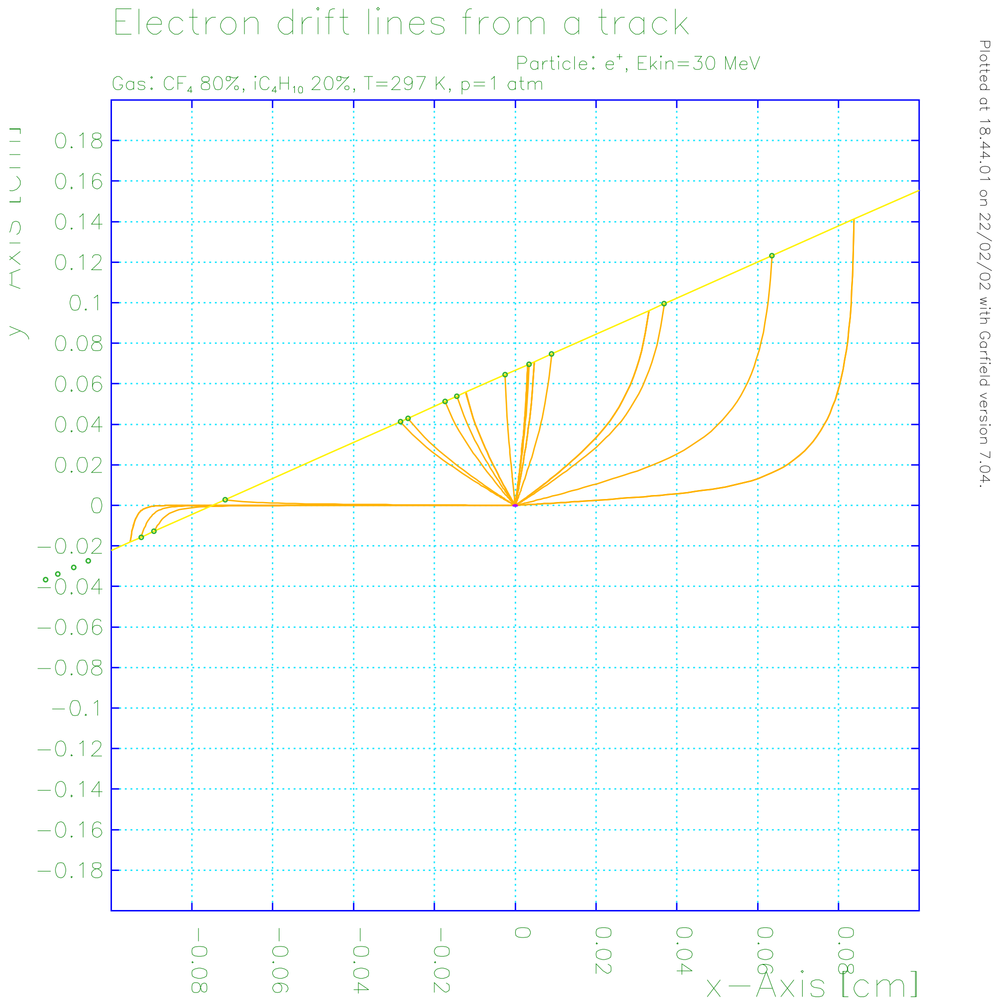

Figure 8: A straight track of positron at 30 MeV through the PC cell. Ground planes are the top and bottom y plane. The cluster size and spacing distributions are calculated by the *Heed* program incorporated in *Garfield*

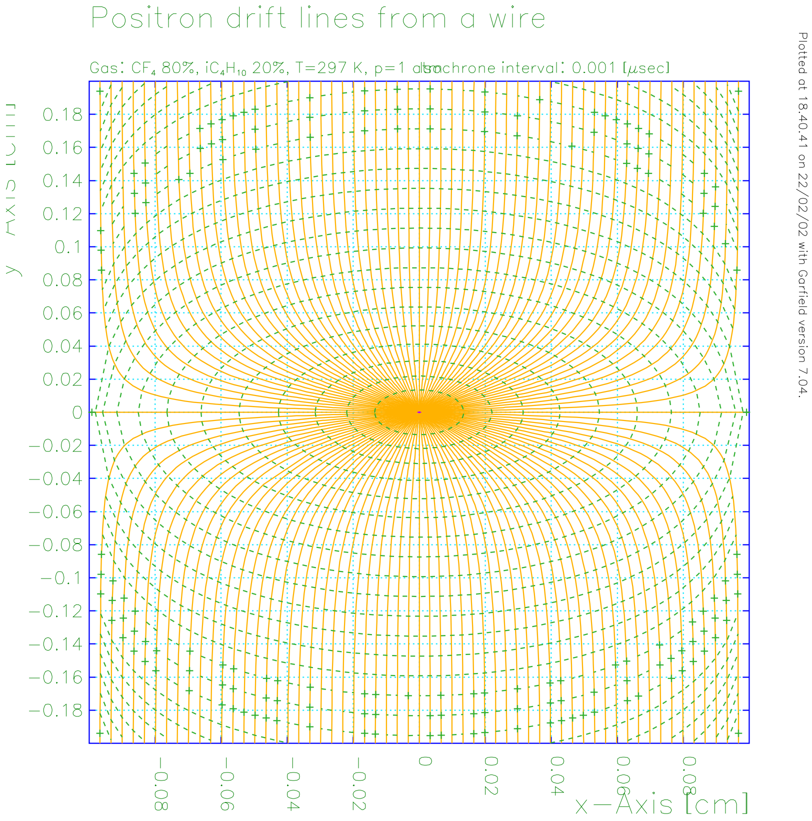

Fig. 9 Drift time isochrones of CF_4/IS0 (80/20) at zero B field

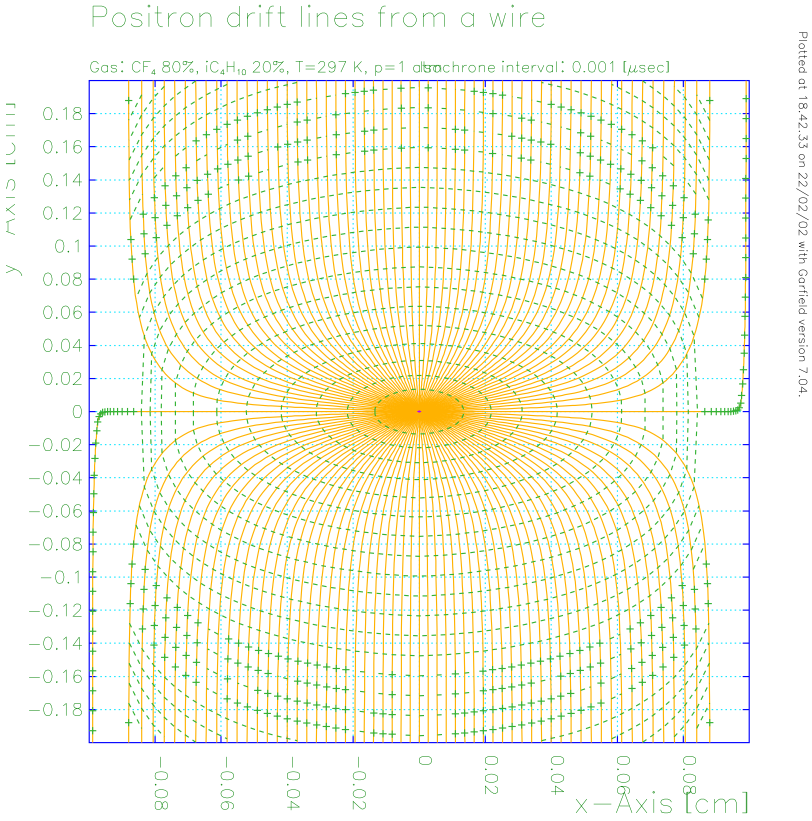

Fig. 10 Drift time isochrones of CF_4/IS0 (80/20) at $B = 2$ Tesla

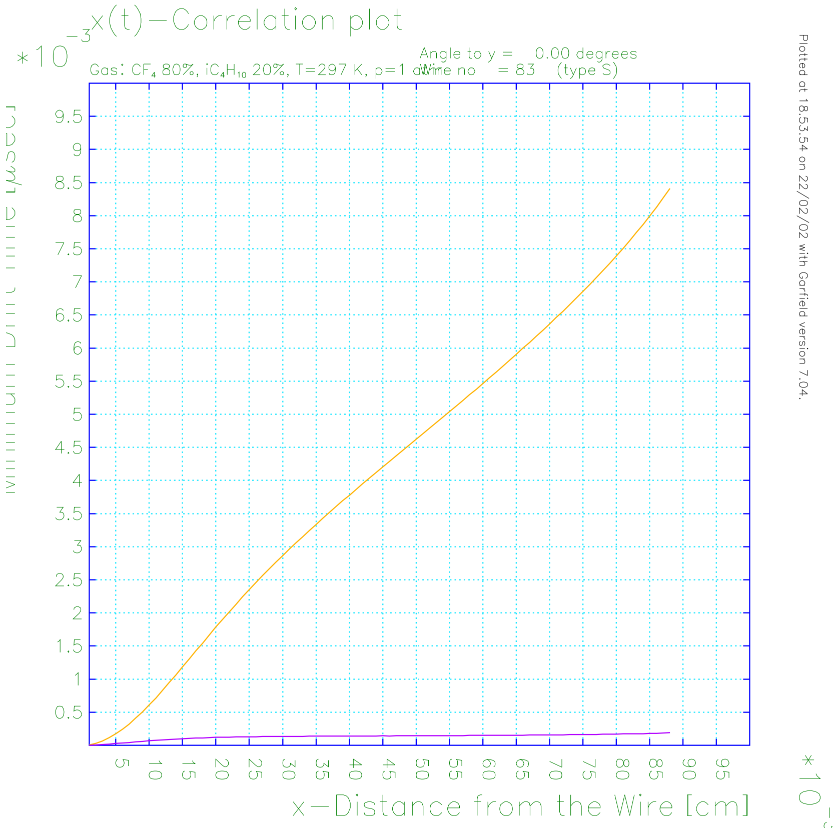

Fig. 11 x(t) relation of CF_4/IS0 (80/20) at zero B field

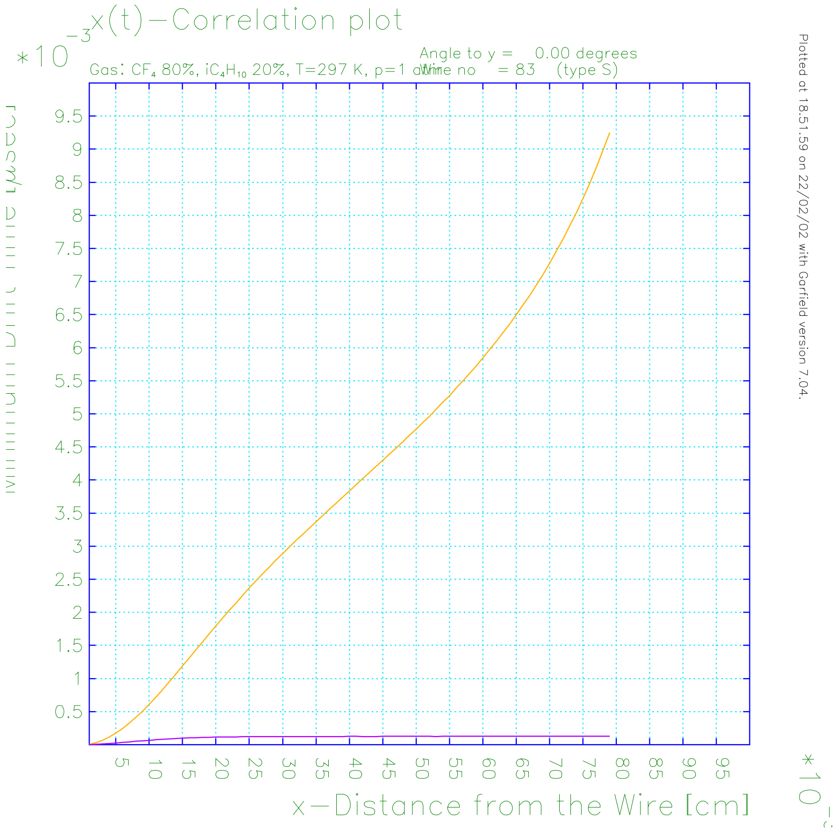

Fig. 12 x(t) relation of CF_4/IS0 (80/20) at B = 2 Tesla

4. **Sensitivity of STR to Temperature/Pressure/B-Field**

In the drift section of the *Garfield*, an `xt-plot` command can be used to prepare for the x(t) table for track reconstruction. *Garfield* calculates x(t) in the following fashion. First of all a number of drift lines are generated backward from the wire. Crossing points of the drift lines with the (straight) track which is at an angle to the y-axis and which intersects the x-axis at x are found. Three crossing points with the minimum drift times are identified. A parabolic minimization procedure proceeds to find the minimum drift time. This finishes one x-t point. An iteration loop is repeated where the track, at the same angle, moves from `xmin` to `xmax` at an increment of `xstep`. After the loop, an x(t) curve is obtained. In $\mathcal{TWIST}$, the Kalman method in Mofia relies on the x(t,angle) table for straight line reconstruction.

I conducted a series of x(t,angle) calculations where the temperature, pressure, and the magnetic field are separately perturbed around the nominal values of T = 24 Celsius, P = 760 Torr, and B = 2.2 Tesla. Deviations of the perturbed x'(t,angle) from the nominal x(t,angle) are found and averaged over angles and drift times,

$$d = < \| \sum_{angle} \sum_{t=0}^{tmax} x'(t, angle) - x(t, angle) \| >$$

Note that the difference between the two 'vectors' x' and x is the Euclidean distance. If the resolution as a function of drift distances is known, we can use the resolution to weight the terms in the above sum. Table 1 shows the mean deviations. It is found that DME is not sensitive to temperature, pressure, and magnetic field variations in the ranges I've tested.

	σ in μm		
	+	–	average
temperature (24 ± 10 C)	16.3	18.4	17.4
pressure (760 ± 23 Torr)	15.2	15.7	15.5
time zero jitter (1 ns)	3.5	3.2	3.4
HV (10^{-3})	0.5	0.6	0.6
B inhomogeneity (10^{-4})	0.8	0.1	0.5

Table 1: First column lists the variables changed in the Garfield simulation. Second are the resulting changes in the drift distance averaged over distances to the sense wire and over track angles (from 0 to 60 per 5 degree). The default STR is the one with DME gas at 24 C, 760 Torr, and in a uniform B field of 2.2 Tesla.

5. strs_mod.f90

In the past, *Garfield* was used to generate separately grid tables for $\mathcal{TWIST}$ GEANT and x(t) tables for Mofia. The x(t) table from *Garfield* needs preprocessing before it can be used in Mofia. This is because, in the x(t) table from the `xt-plot` of *Garfield*, x is evenly spaced (we used a `xstep` of 10 micron). In the experiment, what are measured are tdc's. What is preferable is then a table evenly spaced in time. Given measured time (and the predicted angle), we then look up the table to get the drift distance to the wire. Together with the coordinates of the wire, we get the coordinates of the track crossing the plane. Conversion from the table evenly spaced in x to the one in time was done by interpolation.

It was decided that we output only the grid table. The x(t) table evenly spaced in time is constructed from the grid table. This task is performed in `strs_mod.f90` written by Roy Wilds (May 2001). `strs_mod.f90` has since become part of Mofia.

6. Summary

Input files to run $\mathcal{TWIST}$ *Garfield* are shown and explained. The first file is used to generate gas data table which is later used by the second input file to simulate the drift. Plots of tracks, isochrones, and x(t) curves for DME and CF_4/ISO (80/20) are shown.

Sensitivities of DME to variation in temperature, pressure, HV, jitter in time zero, and inhomogeneity in B were studied. The results are shown in Table 1.

Modification of *Garfield* was made so that the output suits $\mathcal{TWIST}$'s need. The grid tables installed in CFM are generated using the modified *Garfield*.

REFERENCES

(1) Online webpage of *Garfield* is at,
http://consult.cern.ch/writeup/garfield/help/

(2) *Garfield*'s output was modified for $\mathcal{TWIST}$ by Roy Wilds. The latest update is August 2001. Documentation can be found in,
http://e614slow.triumf.ca/e614/offline/garfield/index.html