GateParamterisedPinholeCollimator class for simulation of preclinical SPECT

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Contents

1 Introduction

The GateParametrisedPinholeCollimator class was developed for GATE simulations of a multiple pinhole collimator for preclinical SPECT imaging. In the simulation we use analytical model for the collimator geometry description.

An example of preclinical SPECT with a multipinhole collimator is a nanoSPECT/CT by Mediso shown in Figure 1 and macros can be found in macros on github. It is a four head system with exchangeable collimators adapted to imagning subject. An example of pinhole collimator simulated with GATE is presented in Figure 2.

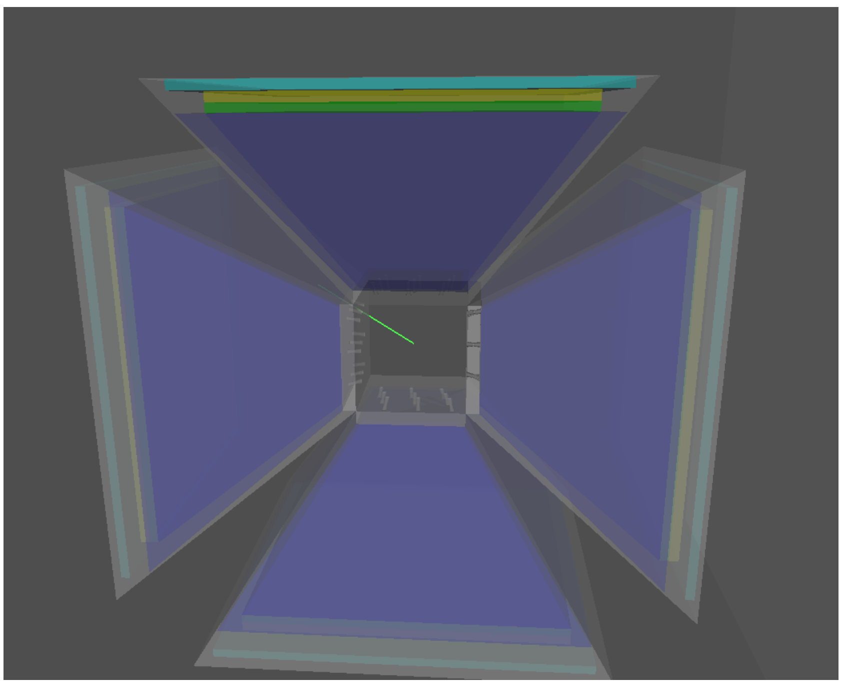


Figure 1: Illustration for simulated nanoSPECT

2 Options and input data

The geometry of pinhole is defined from a G4-pyramid with a subtracted cones (G4Cons) in order to have pinholes drilled from both sides of a colli-

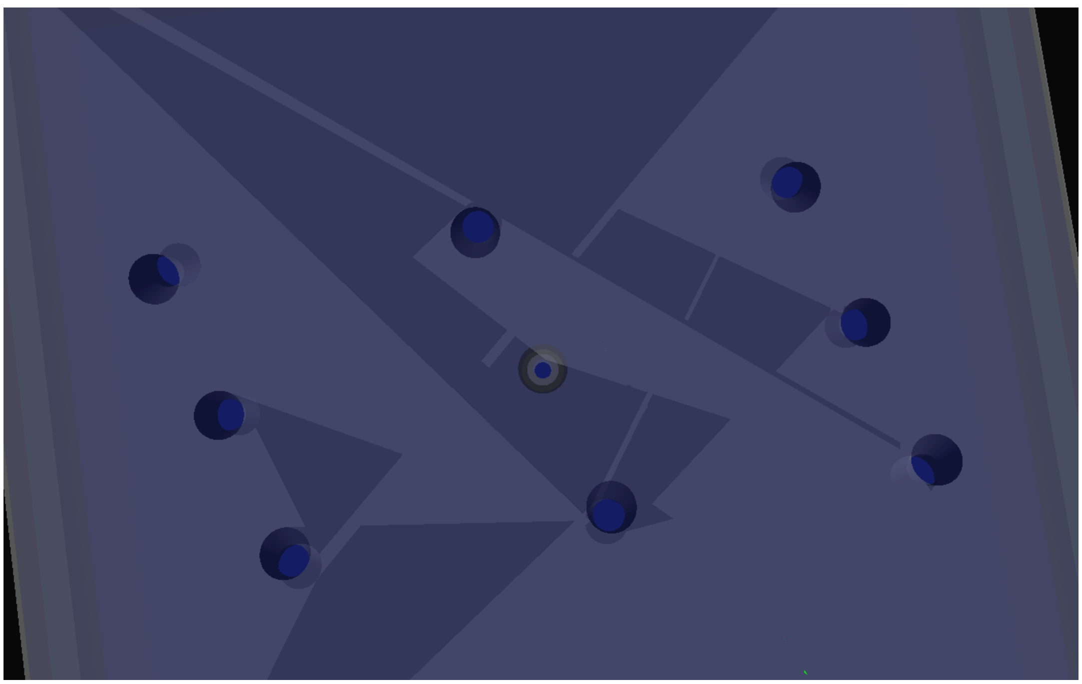


Figure 2: Illustration for pinhole collimator

mator plane.

The pyramid is defied with mac options:

```
/gate/colli/geometry/setDimensionX1 80 mm
/gate/colli/geometry/setDimensionY1 84 mm
/gate/colli/geometry/setDimensionX2 80 mm
/gate/colli/geometry/setDimensionY2 84 mm
/gate/colli/geometry/setHeight 10 mm
```

The collimator rotation radius, i.e. distance from the center of field of view to the pinholes center (see Figure 3 and Figure 4) is defined as:

```
/gate/colli/geometry/setRotRadius 45 mm
```

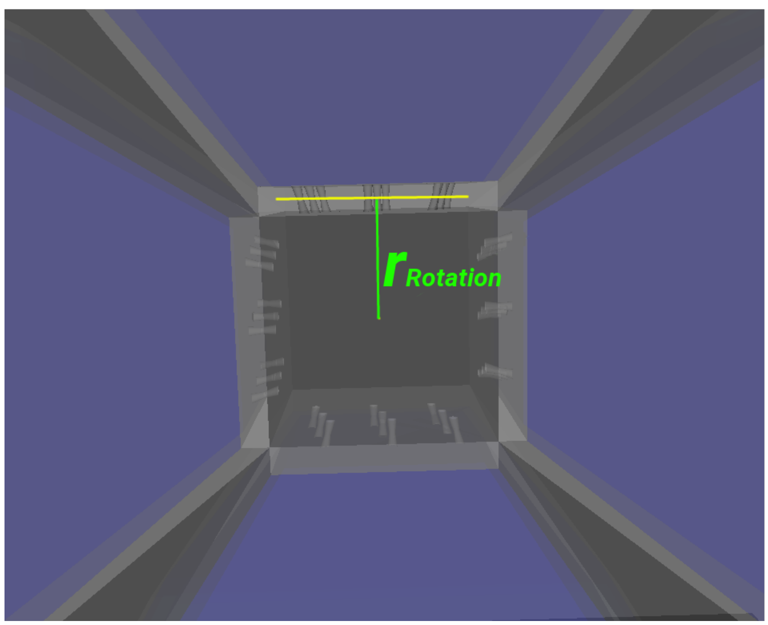


Figure 3: Definition of the rotation radius

The pinholes are defined with an option file:

```
/gate/colli/geometry/input mac/APT2.pin
```

The stricture of the option file, APT2.pin, is the following (an example could be found in Table 1):

# x	y	dia	alpha cone	x_{focal}	y_{focal}
[APT2]					
9					
28.898	11.949	2.5	7.5	20.0002	0
25.19	0	2.5	7.5	15.0274	0
21.464	-11.949	2.5	7.5	10.0315	0
3.743	11.949	2.5	7.5	5.01876	0
0	0	2.5	7.5	0	0
-3.743	-11.949	2.5	7.5	-5.01876	0
-21.464	11.949	2.5	7.5	-10.0315	0
-25.19	0	2.5	7.5	-15.0274	0
-28.898	-11.949	2.5	7.5	-20.0002	0

Table 1: Example of APT2.pin option file

```
Number of pinholes
x y diameter cone_angle x_focal y_focal
```

In Table 1 one can find a description of a collimator called "APT2" with 9 holes. The diameter of pinholes (at the center) is 2.5 mm, the opening cone angle (α) is 7.5 degree. The x and y coordinates are the centers of the pinholes. The focal coordinates are illustrated in Figure 4.

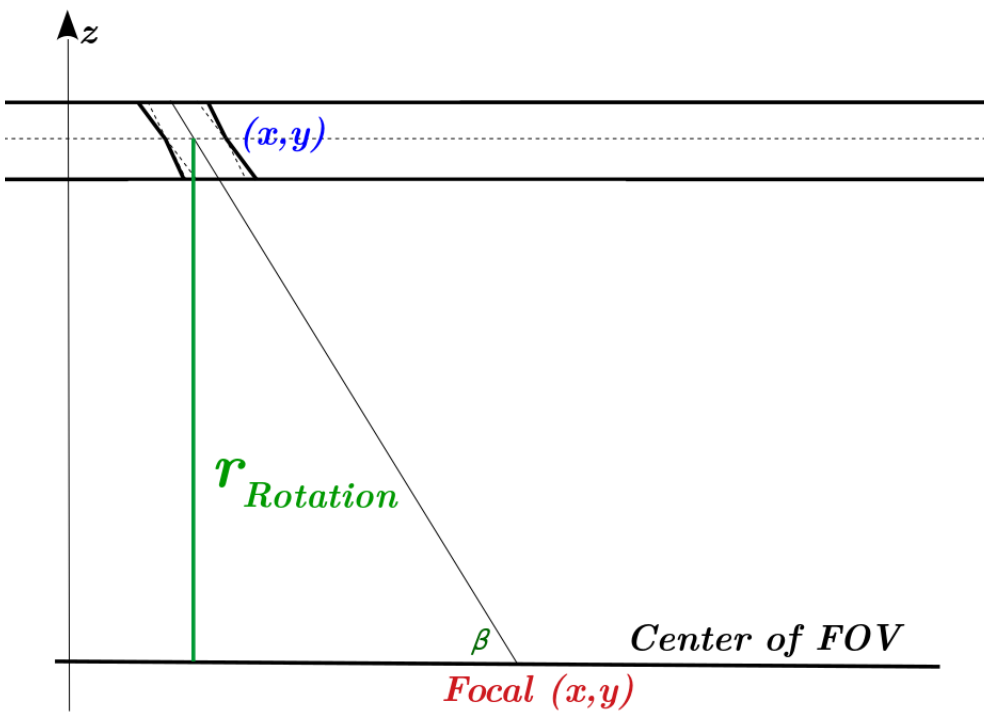


Figure 4: Illustration of parameters defined in APT2.pin option file

3 Pinhole geometry calculations

The result of the following calculations is implemented in GateParametrised-PinholeCollimator class.

The names of the variables in the class are the same as in Figures 5 and 6 and the calculations below. The final results used in the GateParametrised-PinholeCollimator are framed.

The drilled cones of pinholes are simulated as G4Cons. The required and nontrivial parameters are:

- Geometrical cone parameters
  - height of the cone, Dz
  - radius of the cone basis, $rmax$
- Cone tilt
- Displacement correction due to tilt
  - on x (x = the first column read from .pin file) : $x + \Delta x$ for "down cone" or $x - \Delta x$ for "upper cone"
  - on y (y = the second column read from .pin file): $y + \Delta y$ for "down cone" or $y - \Delta y$ for "upper cone"
  - on z (z = collimator rotation radius, Figure 3) : $-\Delta z$ for "down cone" or Δz for "upper cone"

3.1 Geometrical cone parameters

The known parameters are: ***d (= dia)*** – diameter of the pinhole, α = cone opening angle, x and y – center of pinhole, x_{focal} and y_{focal} – focal coordinates, z = rotation radius, h = half of a thickness of collimator plate.

1. Calculation of β

$$\boxed{\beta = |\pi/2 - atan(|x - x_{focal}/z|)|} \tag{1}$$

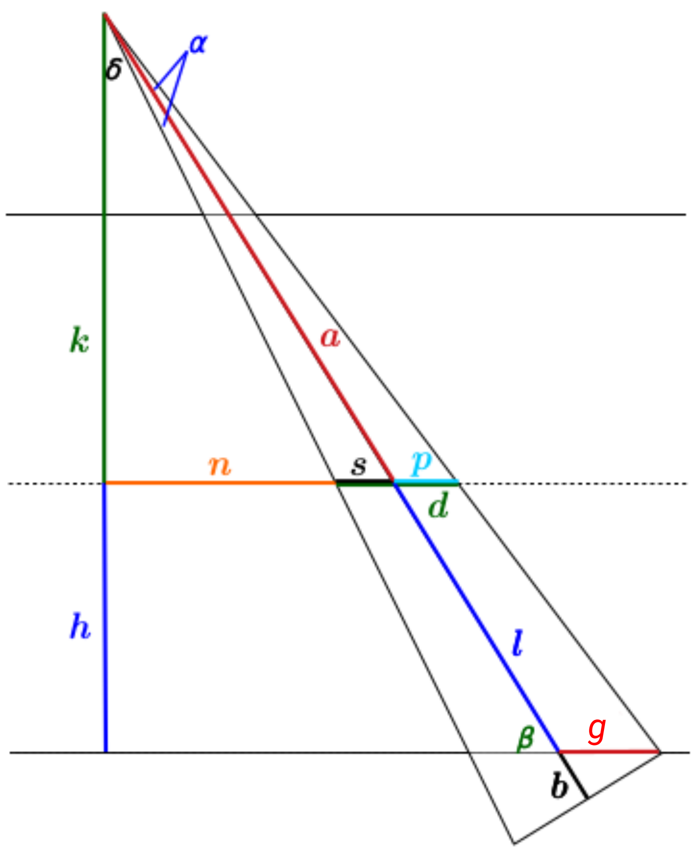


Figure 5: Illustration for pinhole size parameter definitions

2. Calculation of l

$$l = \frac{h}{\cos(\delta+\alpha)} = \frac{h}{\sin\beta}$$

$$\boxed{l = \frac{h}{\sin\beta}} \tag{2}$$

3. Calculation of k and n

$$\delta = 90^o - (\alpha+\beta)$$

$$\begin{cases} \tan\delta = \frac{1}{\tan(\alpha+\beta)} = \frac{n}{k} \\ \tan(\delta+2\alpha) = \frac{1}{\tan(\beta-\alpha)} = \frac{n+d}{k} \end{cases}$$

$$\begin{cases} \tan(\alpha+\beta) = \frac{k}{n} \\ \tan(\beta-\alpha) = \frac{k}{n+d} \end{cases}$$

$$\boxed{k = \frac{d\cdot\tan(\beta-\alpha)\cdot\tan(\alpha+\beta)}{\tan(\alpha+\beta)-\tan(\beta-\alpha)}} \tag{3}$$

$$\boxed{n = \frac{k}{\tan(\beta-\alpha)} - d} \tag{4}$$

4. Calculation of a from k

$$a = \frac{k}{\cos(\delta+\alpha)} = \frac{k}{\sin\beta}$$

$$\boxed{a = \frac{k}{\sin\beta}} \tag{5}$$

5. Calculation of s and b

$$\tan(\delta+\alpha) = \frac{1}{\tan\beta} = \frac{n+s}{k}$$

$$\boxed{s = \frac{k}{\tan\beta} - n} \tag{6}$$

$$p = d - s$$
$$\frac{p}{g} = \frac{a}{a+l}$$
$$g = \frac{(d-s)\cdot(a+l)}{a}$$
$$\cos\beta = \frac{b}{g}$$
$$\boxed{b = \frac{(d-s)\cdot(a+l)\cdot\cos\beta}{a}} \tag{7}$$

6. Calculation of Dz for a chosen direction (x or y)

$$\boxed{Dz_x = a + l + b} \tag{8}$$

$$\boxed{Dz_y = \frac{y - y_{focal}}{\cos\left((y - y_{focal})/z\right)}} \tag{9}$$

7. In 3D:

$$\boxed{Dz = \sqrt{Dz_x^2 + Dz_y^2}} \tag{10}$$

8. Cone radius:

$$\boxed{rmax = Dz \cdot \tan\alpha} \tag{11}$$

3.2 Cone tilt

The tilt is defined with G4RotationMatrix by methods rotateX($rotX$) and rotateY($rotY$).

1. Definition of t

$$t = (x - x_{focal})^2 + (y - y_{focal})^2 + z^2 \tag{12}$$

2. Definitions of normal x, y and z

$$x_{normal} = (x - x_{focal})/\sqrt{t} \tag{13}$$
$$y_{normal} = (y - y_{focal})/\sqrt{t} \tag{14}$$
$$z_{normal} = z/\sqrt{t} \tag{15}$$

3. Definitions of $rotX$ and $rotY$

$$\boxed{rotX = atan(x_{normal}/z_{normal})} \tag{16}$$

$$\boxed{rotY = -atan(y_{normal}/z_{normal})} \tag{17}$$

3.3 Displacement correction due to tilt

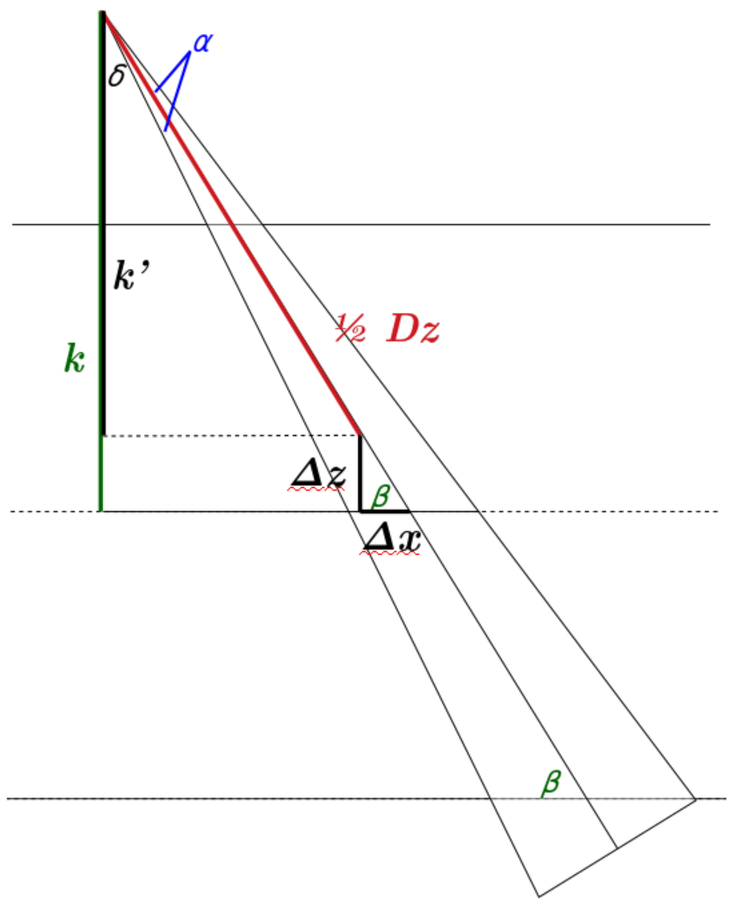


Figure 6: Illustration for pinhole positions definitions

According to illustration in Figure 6 one obtains:

1. Calculation of Δz

$$\Delta z = k - k' \tag{18}$$

$$\cos(\delta + \alpha) = \sin\beta = \frac{k'}{Dz/2} \tag{19}$$

$$k' = (Dz/2) \cdot \sin\beta \tag{20}$$

$$\boxed{\Delta z = k - (Dz/2) \cdot \sin\beta} \tag{21}$$

2. Calculation of Δx or Δy in 3D with ϕ as an azimuthal angle:

$$\boxed{\Delta x = \sin\phi \frac{\Delta z}{\tan\beta}} \tag{22}$$

$$\boxed{\Delta y = \cos\phi \frac{\Delta z}{\tan\beta}} \tag{23}$$

4 How to obtain .pin file

One of tricky steps is to obtain the .pin file, i.e. pinhole parameters: positions, diameters, cone opening angles and focal points positions.

4.1 Input from HiSPECT reconstruction software

Here one can find a description of how it was done for one of projects where the simulation of nanoSPECT/CT by Mediso was done with GATE. It is four head camera with several pinhole exchangeable collimators. In our case we were interested in APT1, a collimator for mouse imagning, and APT2, a collimator for rat imagning.

The best way that we found was to search information in integrated reconstruction software of the scanner. In our case it was **HiSPECT**. The pinhole information was stored in (Figure 7)

`Scivis/HiSPECT/SQL/Install/NanoSPECT_Aperture_4det.sql`

In Figure 7, the lines corresponding to APT1 and APT2 apertures are highlighted.

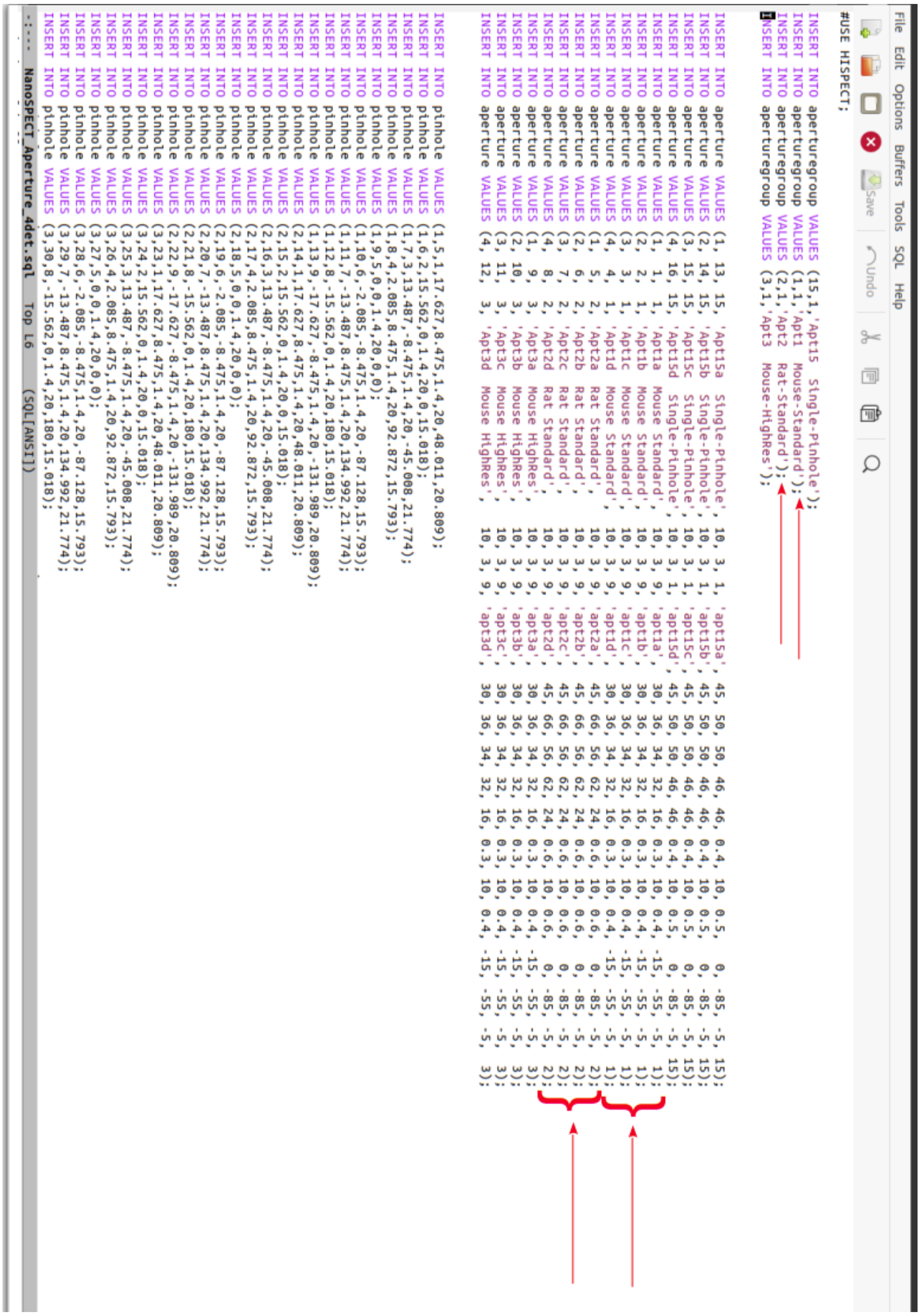
The explanations of corresponding table structures were located in

`Scivis/HiSPECT/SQL/Install/HiSPECT.sql`

and also given in Figure 8.

The pinhole definitions are shown in Figure 9. The most interesting parameters in our case are: yPosition, zPosition, Diameter, ApexAngle, phi and theta.

However, in .pin file one should have focal points positions and not angles phi and theta and, thus, conversion should be done. This conversion is necessary for historical reason: we have in-house reconstruction software developed much earlier than GATE simulations, where .pin files with the defined structure and parameters are used. In order to have the same parameterization files for simulation and reconstruction, we recalculate the focal position from phi and theta. It is done with a tool `HiSPECTtoGATE` described below.



```
File  Edit  Options  Buffers  Tools  SQL  Help
Save  Undo
#USE HISPECT;

INSERT INTO aperturegroup VALUES (15,1,'Apt15  Single-Pinhole');
INSERT INTO aperturegroup VALUES (1,1,'Apt1  Mouse-Standard');
INSERT INTO aperturegroup VALUES (2,1,'Apt2  Rat-Standard');
INSERT INTO aperturegroup VALUES (3,1,'Apt3  Mouse-HighRes');


INSERT INTO aperture VALUES (1, 13, 15, 'Apt15a  Single-Pinhole', 10, 3, 1, 'apt15a', 45, 50, 50, 46, 46, 0.4, 10, 0.5,   0, -85, -5, 15);
INSERT INTO aperture VALUES (2, 14, 15, 'Apt15b  Single-Pinhole', 10, 3, 1, 'apt15b', 45, 50, 50, 46, 46, 0.4, 10, 0.5,   0, -85, -5, 15);
INSERT INTO aperture VALUES (3, 15, 15, 'Apt15c  Single-Pinhole', 10, 3, 1, 'apt15c', 45, 50, 50, 46, 46, 0.4, 10, 0.5,   0, -85, -5, 15);
INSERT INTO aperture VALUES (4, 16, 15, 'Apt15d  Single-Pinhole', 10, 3, 1, 'apt15d', 45, 50, 50, 46, 46, 0.4, 10, 0.5,   0, -85, -5, 15);
INSERT INTO aperture VALUES (1,  1,  1, 'Apt1a  Mouse Standard',  10, 3, 9, 'apt1a',  30, 36, 34, 32, 16, 0.3, 10, 0.4, -15, -55, -5,  1);
INSERT INTO aperture VALUES (2,  2,  1, 'Apt1b  Mouse Standard',  10, 3, 9, 'apt1b',  30, 36, 34, 32, 16, 0.3, 10, 0.4, -15, -55, -5,  1);
INSERT INTO aperture VALUES (3,  3,  1, 'Apt1c  Mouse Standard',  10, 3, 9, 'apt1c',  30, 36, 34, 32, 16, 0.3, 10, 0.4, -15, -55, -5,  1);
INSERT INTO aperture VALUES (4,  4,  1, 'Apt1d  Mouse Standard',  10, 3, 9, 'apt1d',  30, 36, 34, 32, 16, 0.3, 10, 0.4, -15, -55, -5,  1);
INSERT INTO aperture VALUES (1,  5,  2, 'Apt2a  Rat Standard',    10, 3, 9, 'apt2a',  45, 66, 56, 62, 24, 0.6, 10, 0.6,   0, -85, -5,  2);
INSERT INTO aperture VALUES (2,  6,  2, 'Apt2b  Rat Standard',    10, 3, 9, 'apt2b',  45, 66, 56, 62, 24, 0.6, 10, 0.6,   0, -85, -5,  2);
INSERT INTO aperture VALUES (3,  7,  2, 'Apt2c  Rat Standard',    10, 3, 9, 'apt2c',  45, 66, 56, 62, 24, 0.6, 10, 0.6,   0, -85, -5,  2);
INSERT INTO aperture VALUES (4,  8,  2, 'Apt2d  Rat Standard',    10, 3, 9, 'apt2d',  45, 66, 56, 62, 24, 0.6, 10, 0.6,   0, -85, -5,  2);
INSERT INTO aperture VALUES (1,  9,  3, 'Apt3a  Mouse HighRes',   10, 3, 9, 'apt3a',  30, 36, 34, 32, 16, 0.3, 10, 0.4, -15, -55, -5,  3);
INSERT INTO aperture VALUES (2, 10,  3, 'Apt3b  Mouse HighRes',   10, 3, 9, 'apt3b',  30, 36, 34, 32, 16, 0.3, 10, 0.4, -15, -55, -5,  3);
INSERT INTO aperture VALUES (3, 11,  3, 'Apt3c  Mouse HighRes',   10, 3, 9, 'apt3c',  30, 36, 34, 32, 16, 0.3, 10, 0.4, -15, -55, -5,  3);
INSERT INTO aperture VALUES (4, 12,  3, 'Apt3d  Mouse HighRes',   10, 3, 9, 'apt3d',  30, 36, 34, 32, 16, 0.3, 10, 0.4, -15, -55, -5,  3);


INSERT INTO pinhole VALUES (1,5,1,17.627,8.475,1.4,20,48.011,20.809);
INSERT INTO pinhole VALUES (1,6,2,15.562,0,1.4,20,0,15.018);
INSERT INTO pinhole VALUES (1,7,3,13.487,-8.475,1.4,20,-45.008,21.774);
INSERT INTO pinhole VALUES (1,8,4,2.085,8.475,1.4,20,92.872,15.793);
INSERT INTO pinhole VALUES (1,9,5,0,0,1.4,20,0,0);
INSERT INTO pinhole VALUES (1,10,6,-2.085,-8.475,1.4,20,-87.128,15.793);
INSERT INTO pinhole VALUES (1,11,7,-13.487,8.475,1.4,20,134.992,21.774);
INSERT INTO pinhole VALUES (1,12,8,-15.562,0,1.4,20,180,15.018);
INSERT INTO pinhole VALUES (1,13,9,-17.627,-8.475,1.4,20,-131.989,20.809);
INSERT INTO pinhole VALUES (2,14,1,17.627,8.475,1.4,20,48.011,20.809);
INSERT INTO pinhole VALUES (2,15,2,15.562,0,1.4,20,0,15.018);
INSERT INTO pinhole VALUES (2,16,3,13.487,-8.475,1.4,20,-45.008,21.774);
INSERT INTO pinhole VALUES (2,17,4,2.085,8.475,1.4,20,92.872,15.793);
INSERT INTO pinhole VALUES (2,18,5,0,0,1.4,20,0,0);
INSERT INTO pinhole VALUES (2,19,6,-2.085,-8.475,1.4,20,-87.128,15.793);
INSERT INTO pinhole VALUES (2,20,7,-13.487,8.475,1.4,20,134.992,21.774);
INSERT INTO pinhole VALUES (2,21,8,-15.562,0,1.4,20,180,15.018);
INSERT INTO pinhole VALUES (2,22,9,-17.627,-8.475,1.4,20,-131.989,20.809);
INSERT INTO pinhole VALUES (3,23,1,17.627,8.475,1.4,20,48.011,20.809);
INSERT INTO pinhole VALUES (3,24,2,15.562,0,1.4,20,0,15.018);
INSERT INTO pinhole VALUES (3,25,3,13.487,-8.475,1.4,20,-45.008,21.774);
INSERT INTO pinhole VALUES (3,26,4,2.085,8.475,1.4,20,92.872,15.793);
INSERT INTO pinhole VALUES (3,27,5,0,0,1.4,20,0,0);
INSERT INTO pinhole VALUES (3,28,6,-2.085,-8.475,1.4,20,-87.128,15.793);
INSERT INTO pinhole VALUES (3,29,7,-13.487,8.475,1.4,20,134.992,21.774);
INSERT INTO pinhole VALUES (3,30,8,-15.562,0,1.4,20,180,15.018);
-:---  NanoSPECT_Aperture_4det.sql   Top L6    (SQL[ANSI])
```

Figure 7: Part of NanoSPECT_Aperture_4det.sql file with important lines highlighted

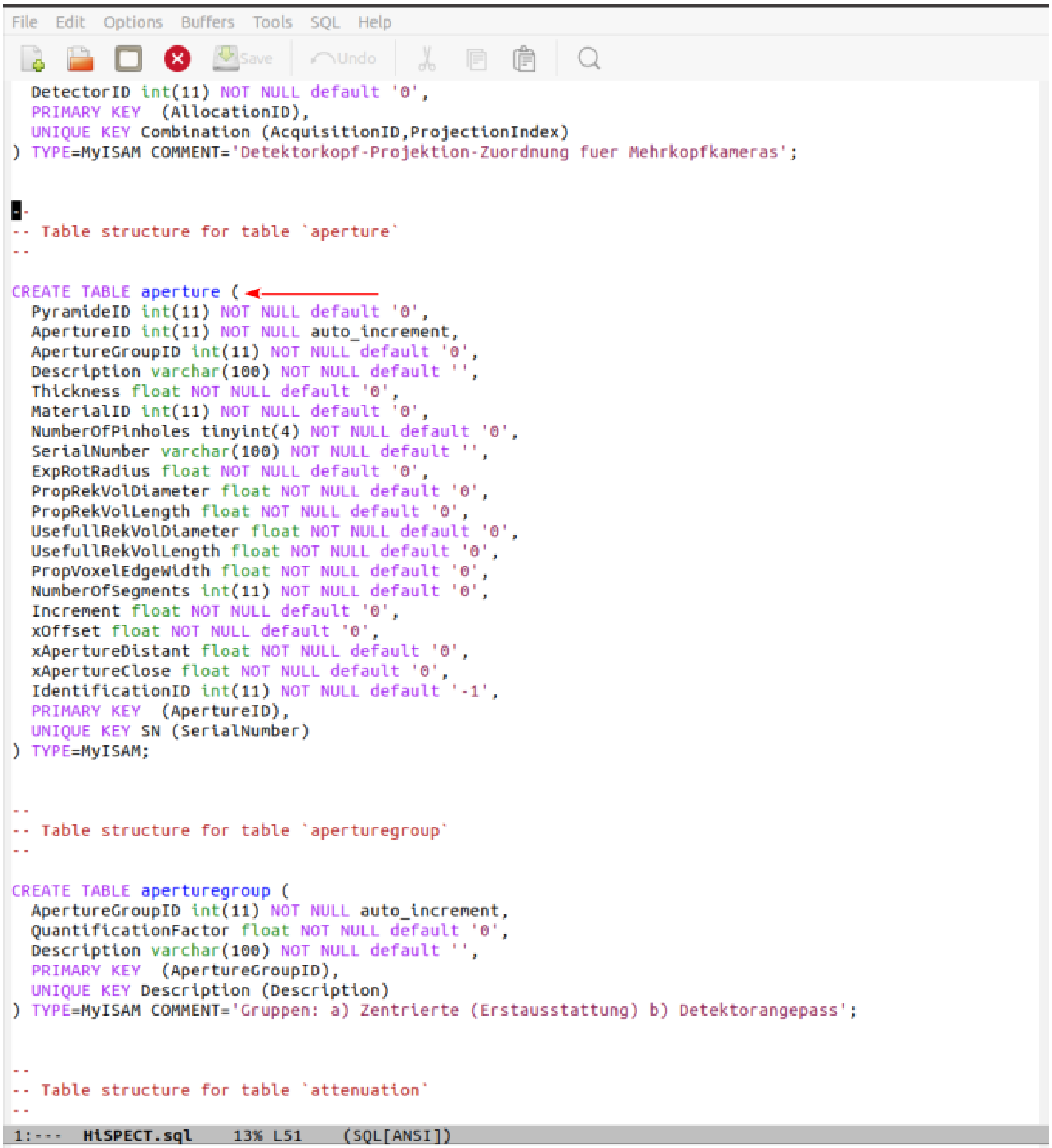


Figure 8: Part of `HiSPECT.sql` file with important lines highlighted

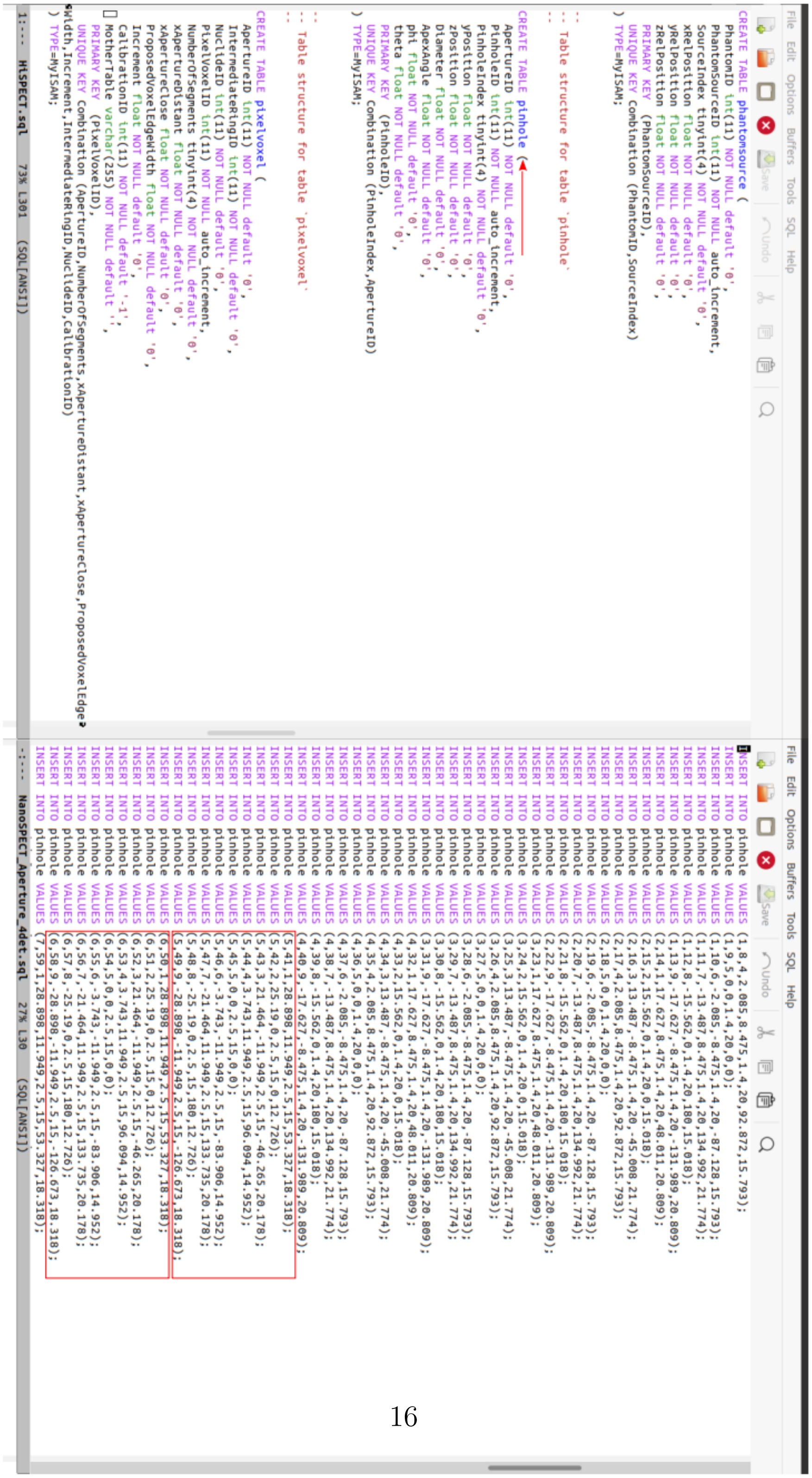


Figure 9: Part of `HiSPECT.sql` and `NanoSPECT_Aperture_4det.sql` file with important lines highlighted: parameters for APT1 are in blue rectangles and in red for APT2.

4.2 HiSPECTtoGate tool

This tool can be found on github: HiSPECTtoGATE on github. We decided to keep this script as simple as possible and not introduce the previous parameters as input options, thus, the script doesn't need a compilation. It is most probably will be used for inspiration.

It is important to notice that one should change some of lines of the script in order to adapt it for specific needs:

- line 16: give the name of your input file
- line 22: give the rotation radius

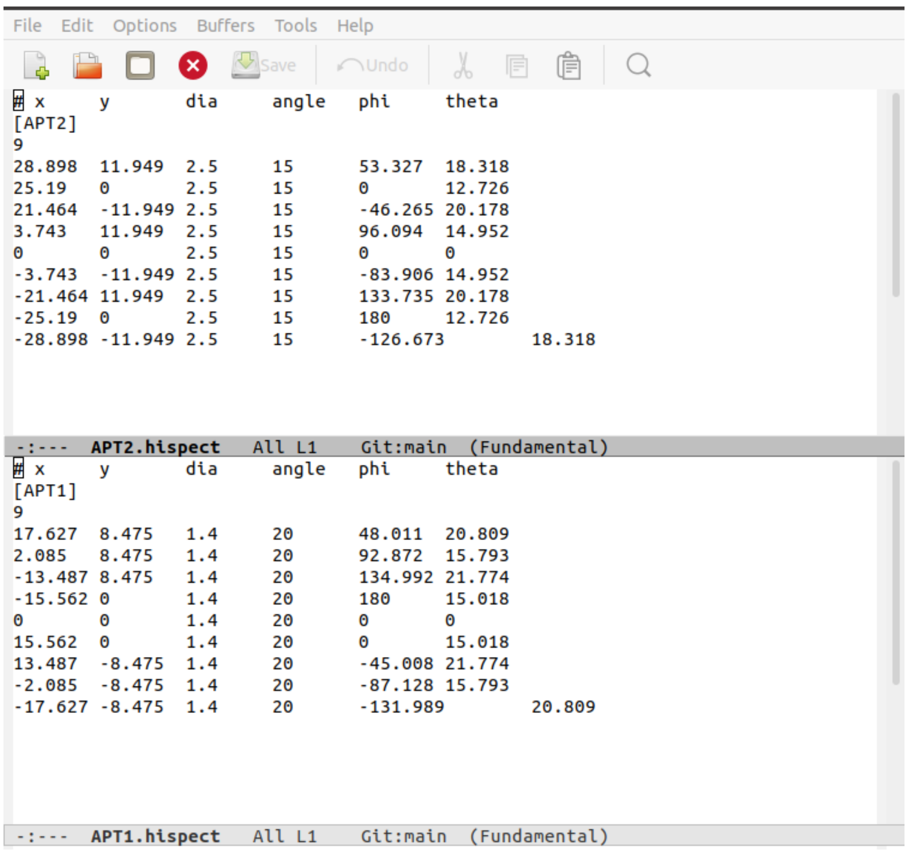
In order to run the script one can simple does:

```
root -l HiSPECTtoGate.C
```

4.3 Input file

As input one should provide information from a text file obtained from HiSPECT (Figure 9) ApertureName.hispect, for example APT1.hispect and APT2.hispect. These are text files produced "by hand". APT1.hispect and APT2.hispect are presented in Figure 10.

The output files, APT1_hispect.pin and APT2_hispect.pin (Figure 11), can be used directly in GATE macros.

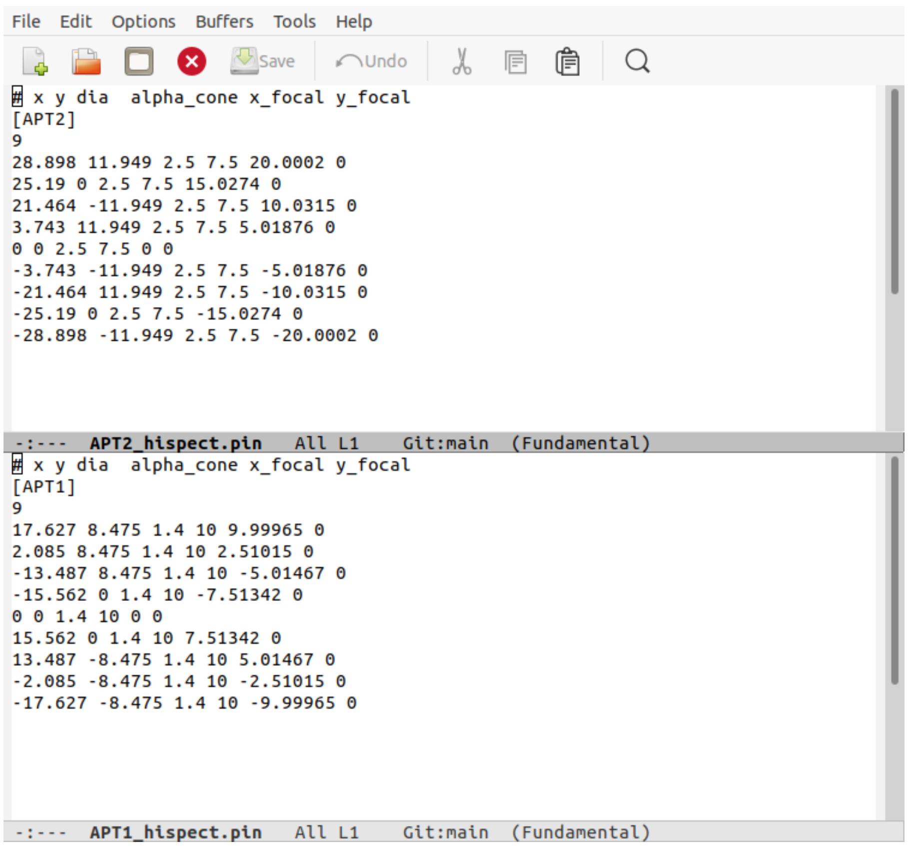


```
File  Edit  Options  Buffers  Tools  Help
Save  Undo
# x     y       dia     angle   phi     theta
[APT2]
9
28.898  11.949  2.5     15      53.327  18.318
25.19   0       2.5     15      0       12.726
21.464  -11.949 2.5     15      -46.265 20.178
3.743   11.949  2.5     15      96.094  14.952
0       0       2.5     15      0       0
-3.743  -11.949 2.5     15      -83.906 14.952
-21.464 11.949  2.5     15      133.735 20.178
-25.19  0       2.5     15      180     12.726
-28.898 -11.949 2.5     15      -126.673        18.318

-:---  APT2.hispect   All L1    Git:main  (Fundamental)
# x     y       dia     angle   phi     theta
[APT1]
9
17.627  8.475   1.4     20      48.011  20.809
2.085   8.475   1.4     20      92.872  15.793
-13.487 8.475   1.4     20      134.992 21.774
-15.562 0       1.4     20      180     15.018
0       0       1.4     20      0       0
15.562  0       1.4     20      0       15.018
13.487  -8.475  1.4     20      -45.008 21.774
-2.085  -8.475  1.4     20      -87.128 15.793
-17.627 -8.475  1.4     20      -131.989        20.809

-:---  APT1.hispect   All L1    Git:main  (Fundamental)
```

Figure 10: APT1.hispect and APT2.hispect




```
# x y dia  alpha_cone x_focal y_focal
[APT2]
9
28.898 11.949 2.5 7.5 20.0002 0
25.19 0 2.5 7.5 15.0274 0
21.464 -11.949 2.5 7.5 10.0315 0
3.743 11.949 2.5 7.5 5.01876 0
0 0 2.5 7.5 0 0
-3.743 -11.949 2.5 7.5 -5.01876 0
-21.464 11.949 2.5 7.5 -10.0315 0
-25.19 0 2.5 7.5 -15.0274 0
-28.898 -11.949 2.5 7.5 -20.0002 0
```



```
# x y dia  alpha_cone x_focal y_focal
[APT1]
9
17.627 8.475 1.4 10 9.99965 0
2.085 8.475 1.4 10 2.51015 0
-13.487 8.475 1.4 10 -5.01467 0
-15.562 0 1.4 10 -7.51342 0
0 0 1.4 10 0 0
15.562 0 1.4 10 7.51342 0
13.487 -8.475 1.4 10 5.01467 0
-2.085 -8.475 1.4 10 -2.51015 0
-17.627 -8.475 1.4 10 -9.99965 0
```


Figure 11: APT1_hispect.pin and APT2_hispect.pin produced by HiSPECT-toGate script and used in macros examples here.