MC Code for the simulation of experiments with AGATA at GSI

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Contents

Introduction

The full simulation is divided into three steps, **a) event generation**, **b) event building** or detector response simulation and **c) event reconstruction**.

In the first step, a heavy ion beam strikes on a target and emits gamma rays. These γ-rays are emitted according to a certain levels and half-life scheme.

In the second step the response of the detection system (for the moment only AGATA) to those gamma rays is simulated.

In the third step, a very basic and simplified analysis is made. Here Doppler corrections are calculated, an ideal event-wise tracking or add-back is performed, the resolution function (in energy and position) of the several detectors is roughly included and raw and Doppler corrected spectra and other histograms are generated.

To split the simulation into these three parts has the advantage that one can e.g. re-evaluate the response of the γ-ray detection system (i.e. AGATA) for different geometric configurations of it, without need to re-generate every time all the primary events. Similarly, the effect of a worse or a better position resolution can be evaluated in the third stage, without need to re-simulate the detector response each time.

Getting started

To run the simulation you will need ROOT [1], GEANT4 [2] and the CLHEP library [3] installed in your computer.

Create a directory for the simulation work, save there the compressed file and unpack it via `tar␣-xzvf␣mc_agata_gsi_v0.tgz`

You should obtain then a directory structure similar to this,

```
drwxr-xr-x   7 cdomingo kp2 4,0K 2009-09-21 13:01 a_event_generator
drwxr-xr-x  21 cdomingo kp2 4,0K 2009-09-22 14:00 b_event_builder
drwxr-xr-x   3 cdomingo kp2   63 2009-09-22 10:48 c_event_reconstruction
drwxr-xr-x   2 cdomingo kp2  107 2009-09-22 14:00 manual
drwxr-xr-x   5 cdomingo kp2   56 2009-09-21 13:02 SimulationResults
```

```
drwxr-xr-x   4 cdomingo kp2   26 2009-09-22 13:55 work
```

The first three directories contain the three parts of the simulation code, splitted as mentioned above.

The directory `manual` contains this manual, both the PDF and the LaTeX-versions. The idea is to update/extend the code and update this changes also in this manual.

`SimulationResults` will contain the results or the output from each part of the simulation. Therefore, it is recommended to create and use a sub-directory structure like the following,

```
cdomingo:~/simulations/agata_gsi/SimulationResults$ ls -lhtr
drwxr-xr-x  3 cdomingo kp2 17 2009-09-21 13:01 Generator
drwxr-xr-x  3 cdomingo kp2 17 2009-09-21 13:02 Builder
drwxr-xr-x  3 cdomingo kp2 17 2009-09-21 13:02 Reconstructor
```

In this way, the output of each simulation step, EventGenerator, EventBuilder or Event Reconstructor, can be saved in the corresponding directory. At the moment only the `Generator` and `Builder` directories are being used, thus the third stage of the simulation does not save any file.

After compilation, the executable of each GEANT4 part will be stored in the `$G4WORKDIR\bin\Linux-g++` directory. I defined my `$G4WORKDIR` equal to the `work` directory (see above), but this depends on yourself.

It is convenient to include the `$G4WORKDIR\bin\Linux-g++` in the `$PATH` variable, so that the executables are accessible from any place.

Chapter 1

Event Generation

This part of the code has been kindly provided by Pieter Doornenbal (RIKEN).

This chapter has been copied from Ref. [4].

The Event Generator is located in the directory `b_event_generator`. Compile the Event Generator with:

`make all`

It will create an executable file called `EventGenerator` in your `$G4WORKDIR/bin/Linux-g++` directory. Please ignore all the warning messages.

1.1 The Input File(s)

To change the parameters of the Event Generator, open the file

`./input/EventGenerator.in`

The file contains keywords, which can be used in the free format and change the default values of the simulation. The available keywords and their parameters are listed in Tab. 1.1. In this table, s, i, and f are used for input string, integer, and floating point values, respectively. Note that in the current version the simulation code is very restrictive, that is, comments and not existing input keywords in this file will cause the program to terminate. The parameters are now discussed subsequently (if not specified differently, the units are cm and degrees):

- BEAMISOTOPE A_P Z_P Q_P

  Contains the information on the type of projectile P in the order mass A_P, the element number Z_P and the charge state Q_P.

- BEAMENERGY E_P $\Delta E(FWHM)_P$

  Gives the total energy of the projectile (E_P before striking on the target) and the width of the energy distribution ($\Delta E(FWHM)_P$) in MeV/u.

Keyword	Parameter(s)
BEAMISOTOPE	$i\ i\ i$
BEAMENERGY	$f\ f$
BEAMPOSITION	$f\ f\ f\ f$
BEAMANGLE	$f\ f\ f\ f$
TARGET	$i\ f\ f\ f$
TARGETANGULARBROADENING	$i\ f$
MASSCHANGE	$i\ i$
BORREL	$i\ f$
GOLDHABER	$i\ f$
THETARANGE	$f\ f$
NUMBEROFEVENTS	i
DEFAULTCUTVALUE	f
OUTPUTFILE	s
DEDXTABLE	$i\ s\ s$
END	

Table 1.1: Parameters of the input file EventGenerator.in.

- BEAMPOSITION X FWHM_X Y FWHM_Y

  Position of the projectile before impinging on the target.

- BEAMANGLE ϑ_P $\Delta(FWHM)\vartheta_P$ ϕ_{Pmin} ϕ_{Pmax}

  Angle of the incoming projectile. The distribution for $\Delta(FWHM)\vartheta_P$ is Gaussian, while the distribution between ϕ_{Pmin} and ϕ_{Pmax} is flat.

- TARGET Type Size_X Size_Y Thickness_Z

  This line specifies the target material and its dimensions. The Type is 1 for Au, 2 for Be, 3 for C, 4 for Fe, 5 for Pb and 6 for LH_2. As density always the standard value for a solid state is given. The value for Thickness_Z is given in mg/cm^2.

- TARGETANGULARBROADENING Option_{ang} $\Delta(FWHM)\vartheta_{target}$

  Angular Broadening caused by the reaction in the target. If $\text{Option}_{ang} = 1$, this option is considered and the broadening is Gaussian distribution defined by $\Delta(FWHM)\vartheta_{target}$.

- BORREL Option_{Borrel} B_n

Velocity shift for a fragmentation process. If Option_{Borrel}=1, the velocity shift is calculated according to the formula from Ref. [5].

$$\frac{v_f}{v_p} = \sqrt{1 - \frac{B_n(A_P - A_F)}{A_P E_F}} \tag{1.1}$$

where the index F stands for the fragment, v is the velocity, and B_n the binding energy (in MeV) per ablated nucleon.

- GOLDHABER $\text{Option}_{Goldhaber}$ σ_0

  Parallel momentum distribution produced in a fragmentation process. If $\text{Option}_{Goldhaber} = 1$, the momentum distribution is calculated according to:

$$\sigma_{||} = \sigma_0^2 \frac{A_F(A_P - A_F)}{A_P - 1} \tag{1.2}$$

  where σ_0 is given in MeV/c.

- GAMMAINPUT $\text{File}_{\gamma-in}$

  The filename specifies the location of the level and decay scheme to be simulated. See section 1.2 for more details.

- THETARANGE $\vartheta_{\gamma min}$ $\vartheta_{\gamma max}$

  Polar angular range in the moving frame of the γ-rays that should be included in the simulation. If your detectors cover only extreme forward angles, $\vartheta_{\gamma min}$ can be set to 0 and $\vartheta_{\gamma max}$ to 90, thereby reducing the simulation time and file size by a factor of two.

- NUMBEROFEVENTS N_{events}

  N_{events} gives the number of reactions to be simulated.

- DEFAULTCUTVALUE L_{cut}

  L_{cut} specifies the default cut-in-range value in mm used in the simulation. Visit the GEANT4 web pages for more information.

- OUTPUTFILENAME $File_{out}$

  Specifies the location of the output root file-name. Additionally an ASCII file with the same name and the `.txt` extension will be created. The latter is formatted as an external event generator for AGATA (next step).

- DEDXTABLE Option$_{dEdX}$ File$_P$ File$_E$

  Instead of letting GEANT4 calculate the energy loss of projectile and ejectile (fragment), if Option$_{dEdX} = 1$ the energy loss can be calculated much faster (for thick targets) according to energy loss tables. $File_P$ and $File_E$ specify the location of these tables for projectile and ejectile, respectively.

- END

  This keyword will end the scan of the input file and can be set at any line within the input file.

1.2 Input of Level Scheme

The variable File$_{\gamma-in}$ specifies the location of the decay scheme of the fragment nucleus to be simulated. It contains two keywords, `LEVEl` and `DECAY`. They are defined as follows:

- LEVEL N$_{Level}$ P_i E_{Level} $T_{1/2}$

  N$_{Level}$ is the identifier of the level, P_i is the relative initial probability of the ejectile (fragment) to end in that state after the initial reaction, E_{Level} is the energy of the level above the ground state in keV, and $T_{1/2}$ is the half-life of the level given in ps.

- DECAY L_i L_f P_γ

  This keyword controls the decay scheme of a initial level L_i into the final level L_f via the relative probability P_γ. Note that any given level may possess up to a maximum five levels that it decays into.

A possible level scheme with two excited states at $L_1 = 1000$ keV and $L_2 = 1500$ keV and an initial level probability of $P_1 = 67$ and $P_2 = 33$ would look as:

```
LEVEL 0 0. 0. 0.
LEVEL 1 67. 1000. 10.
LEVEL 2 33. 1500. 20.
DECAY 1 0 100.
DECAY 2 1 100.
DECAY 2 0 1.
```

In the above example, L_1 has a half-life of $T_{1/2} = 10$ ps, while L_2 has 20 ps. Furthermore, L_2 decays into the ground state (LEVEL 0) with a relative probability of 1/1000 compared to the decay to the first excited state (LEVEL 1).

1.3 Input of the dEdX Tables

The energy loss tables have the structure:

`dEdX Energy SpecificEnergyLoss`

The energy is given in MeV/u and the specific energy loss is given in MeV/(mg/cm^2).

1.4 Starting the Simulation

To start the simulation in the batch mode, type:

`EventGenerator␣run_nothing.mac`

Omitting a filename will bring the Event Generator into the "standard" GEANT4 interactive session, which is not intended to be used in this step.

After running the executable, both a root and an ascii files will be created in the specified directory. One can easily display histograms with the generated events opening a root-session via the TBrowser class. The ascii file will be the input data needed at the next stage of the simulation.

Chapter 2

Event Builder

The event builder is located in the `b_event_builder` directory. Basically it contains the Agata code of E. Farnea plus some macros and geometry files to define a possible geometry of 8-10 AGATA clusters for experiments at GSI. For more details check the Agata code manual of E. Farnea.

To compile it type:

`make`

the executable file `Agata` will be created in your `$G4WORKDIR/bin/Linux-g++` directory.

2.1 Starting the simulation

Once the code is compiled, one can run it in order to visualize the geometry or to run a MC simulation of the events simulated in the previous step.

Macros describing the geometry of AGATA at GSI are placed in the directory

`b_event_builder/macros_prespec`

which is sub-divided into two directories. Visualization macros are placed in

`b_event_builder/macros_prespec/vis`

and macros for running the MC-simulation are placed in

`b_event_builder/macros_prespec/mc`

To visualize the geometry of the AGATA S2 configuration type

`Agata␣-b␣macros_prespec/vis/agataS2.mac`

To run a MC simulation of the γ-ray events generated in the previous step

`Agata␣-Ext␣-b␣macros_prespec/mc/agataS2.mac`

The latter macro is described in more detail below.

2.2 Input file configuration

```
/Agata/file/workingPath␣../SimulationResults/Builder/74ni
/Agata/file/enableLM
/Agata/file/verbose␣1
/Agata/file/info/outputMask␣11100110
/Agata/detector/traslateArray␣0.␣0.␣0.
/Agata/detector/solidFile␣./A180/A180solid.list
/Agata/detector/angleFile␣./A180/A180eulerS2.list
/Agata/detector/wallsFile␣./A180/A180walls.list
/Agata/detector/clustFile␣./A180/A180clust.list
/Agata/detector/sliceFile␣./A180/A180slice.list
/Agata/detector/enableCapsules
/Agata/detector/targetMaterial␣Iron
/Agata/detector/targetSize␣62.25␣62.25␣0.5
/Agata/detector/targetPosition␣0␣0␣0
/Agata/detector/update
/Agata/generator/emitter/eventFile␣../SimulationResults/Generator/74ni/75cu_74ni
/Agata/run/beamOn␣50000
```

In this macro the main commands to change from one simulation to another are the following,

- directory path where the AGATA output ascii file (by default `GammaEvents.0000`) containing all the γ-ray hits and other information will be saved

  `/Agata/file/workingPath ../SimulationResults/Builder/74ni`

- position of AGATA with respect to the target

  `/Agata/detector/traslateArray 0. 0. 0.`

- AGATA geometry (Shell S1, S2, S3 or Cylindrical C1, C2, C3)

  `/Agata/detector/angleFile ./A180/A180eulerS2.list`

- target material

  `/Agata/detector/targetMaterial Iron`

- target size (mm) and thickness (g/cm^2)

  `/Agata/detector/targetSize 62.25 62.25 0.5`

- events file simulated in the previous step

  `/Agata/generator/emitter/eventFile ../SimulationResults/Generator/74ni/75cu_`

- number of events to simulate

  `/Agata/run/beamOn 50000`

After running the simulation, an ascii file with name `GammaEvents.0000` will be written in the `workingPath` directory specified in the last macro. This file should be appropriately renamed and it will be the basic input data for the next step, the Event Reconstruction or analysis.

Chapter 3

Event Reconstruction

At this stage a simplified reconstruction of the events is performed. Add-back and Doppler-corrections are applied and the resolutions of the detectors (spatial, energy) are implemented.

The reconstruction program is placed in the `c_event_reconstruction` directory.

3.1 The input file

The input file, where the information related to the event reconstruction or analysis is specified, is the following

`c_event_reconstruction/input/info_reconstruction.txt`

An example of this file is described in the following.

```
#AGATA Output Ascii File
../SimulationResults/Builder/74ni/g50kEvts0.5ps500mgFe.txt
# Number of Simulated Events or Events to process
50000
#FWHM Spatial Resolution of the AGATA detectors (mm)
5
#FWHM Spatial Resolution of DSSSD (mm)
0.7
#Time Resolution for fragment detection (LYCCA) in (ps)
80
#lower Energy Range for HPGe Pulse Height Spectrum (eV)
500
#high Energy Range for HPGe Pulse Height Spectrum (eV)
2000
```

Canvas	Pad	Content
7	1	g/e-hits multiplicity
	2	Segments multiplicity
	3	Crystals multiplicity
6		Beam Profile
5	1	Raw AGATA Spectrum
	2	Doppler-Corrected AGATA Spectrum
4		Momentum distributions
3		Doppler-shifted γ-ray energy
1		Implemented Energy Resolution for HPGe

Table 3.1: Some of the canvas/histograms created by default in the event reconstruction.

Every line starting with `#` will be considered a comment and hence, ignored by the program. The first line specifies the name and location of the gamma events obtained in the previous step. In this example GammaEvents.0000 has been moved to `g50kEvts0.5ps500mgFe.txt` The rest of lines are self-explicative via the preceding comment lines. No output will be saved, only the spectra should be displayed on the screen when the program is executed.

3.2 To run the program

Open a root session (the program has been tested with root 5.12) and type

```
root[0].L analysis.hh
root[1]plot()
```

after some seconds, depending on the number of events to process, several spectra should be displayed on the screen. In Table 3.2 a summary of some relevant spectra/histograms generated by default is given.

Chapter 4

A simplified illustrative example

I want to test the performance of AGATA for line-shape analysis, in particular the AGATA S2 geometry (a symmetric ring of 10 cluster detectors), in a fragmentation experiment where ^{74}Ni is produced in an excited state at 1024 keV, which decays to the ground state with an unknown halflife, let's say between 0.05 ps and 5 ps.

Event Generation

First I generate the primary events. I go to the `a_event_generator` directory, I compile the code (only once) and I check that in my `$G4WORKDIR\bin\Linux-g++` the `EventGenerator` executable was created. I specify the following input parameters in the `input/EventGenerator.in` file, which describes a secondary beam of ^{75}Cu at 165 MeV/u, with an spread of 6 cm FWHM$_X$ and 4 cm FWHM$_Y$, impinging onto an Iron target 500 mg/cm^2 thick and producing ^{74}Ni with a certain level scheme as described in the second file (see below).

```
BEAMISOTOPE 75 29 29
BEAMENERGY 165   3
BEAMPOSITION 0.0 6.0 0.0 4.0
BEAMANGLE 0.0 0.65 0.0 360.0
TARGET 4 6.25 6.25 500
TARGETANGULARBROADENING 1 0.6
MASSCHANGE 1 1
BORREL 1 8.
GOLDHABER 1 90.
GAMMAINPUT ./input/74Ni.in
NUMBEROFEVENTS 50000
DEFAULTCUTVALUE 0.001
OUTPUTFILE ../SimulationResults/Generator/74ni/75cu_74ni_165mev_500mgfe_1024kev0
```

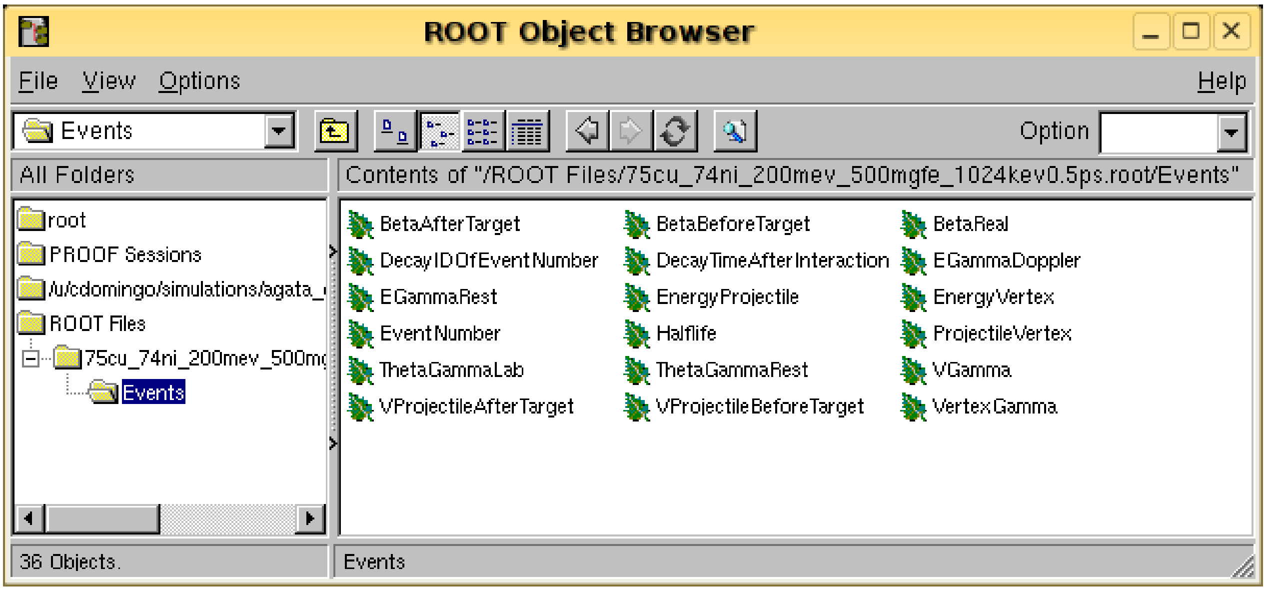
```
DEDXTABLE 1 ./dEdXTables/CuOnFe.in ./dEdXTables/NiOnFe.in
END
```

The level scheme of ^{74}Ni is specified in `input/74Ni.in`

```
LEVEL 0 0.  0. 0.
LEVEL 1 100.0 1024.0 0.5
DECAY 1 0 100.
END
```

I repeat this stage for different values of the half-life (given in 74Ni.in), between 0.05 ps and 5 ps, and I store the corresponding primary events in the `../SimulationResults/Generator/74ni` as shown above.

Opening a root session in the latter directory, via the TBrowser one can quickly check some aspects as the beta distributions before and after the target, etc.



By double-click on the leaves above, one can display e.g. the following histograms,

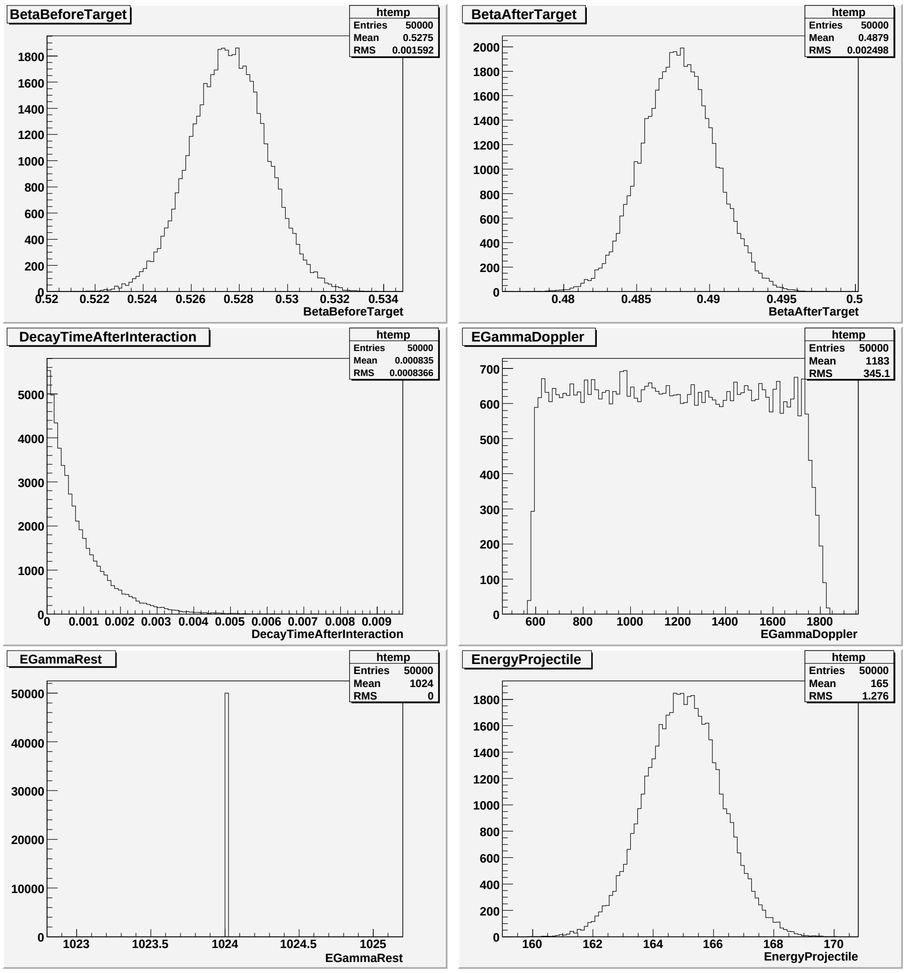


Figure 4.1: Some histograms of the primary events generated via EventGenerator.

Event Builder/AGATA Response

I go to the `b_event_builder` directory, I compile the code (only once), and I check that in my `$G4WORKDIR\bin\Linux-g++` the `Agata` executable was created.

I visualize first the geometry of the AGATA array via (see also Fig. 4):

```
Agata -b macros_prespec/vis/agataS2.mac
```

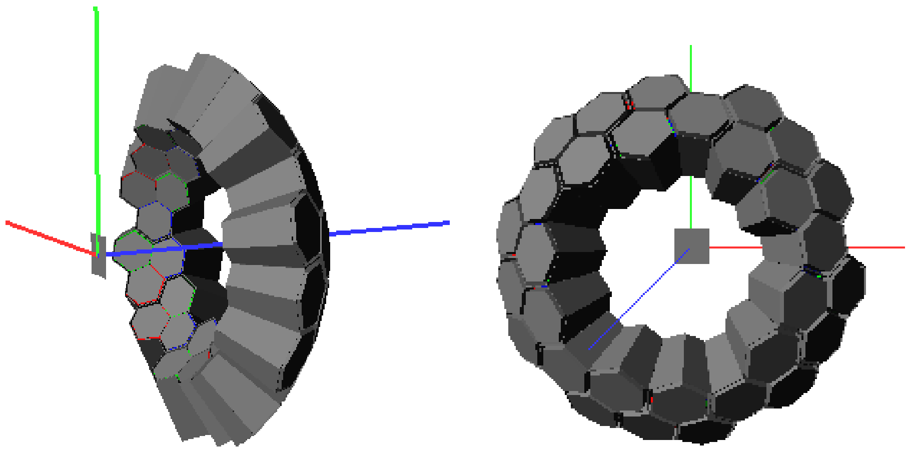


Figure 4.2: AGATA geometry to simulate in this example.

Once I have checked that this is the geometry that I want to simulate, I run the mc-simulation via:

```
Agata -Ext -b macros_prespec/mc/agataS2.mac
```

where the `mc/agataS2.mac` macro contains the following lines,

```
/Agata/file/workingPath ../SimulationResults/Builder/74ni
/Agata/file/enableLM
/Agata/file/verbose 1
/Agata/file/info/outputMask 11100110
/Agata/detector/traslateArray 0. 0. 0.
/Agata/detector/solidFile ./A180/A180solid.list
/Agata/detector/angleFile ./A180/A180eulerS2.list
/Agata/detector/wallsFile ./A180/A180walls.list
/Agata/detector/clustFile ./A180/A180clust.list
/Agata/detector/sliceFile ./A180/A180slice.list
/Agata/detector/enableCapsules
```

```
/Agata/detector/targetMaterial Iron
/Agata/detector/targetSize 62.25 62.25 0.5
/Agata/detector/targetPosition 0 0 0
/Agata/detector/update
/Agata/generator/emitter/eventFile ../SimulationResults/Generator/74ni/75cu_74ni
/Agata/run/beamOn 50000
```

It is important to take care that the target material, thickness and size are the same as the target used in the previous Event-Generation stage.

I run the MC-simulation three times, one for each half life which I want to simulate, 0.05 ps, 0.5 ps and 5 ps. The corresponding primary event files were stored in the previous stage, inside `../SimulationResults/EventGenerator/74ni/`). After each run, I move the AGATA output file `GammaEvents.0000` saved in

`../SimulationResults/Builder/74ni/GammaEvents.0000`

to another name, e.g.

`../SimulationResults/Builder/74ni/g50kEvts0.5ps500mgFe.txt`

Event Reconstruction

I go to the `c_event_reconstruction` directory and specify the following parameters in the `input\info_reconstruction.txt` file,

```
#AGATA Output Ascii File
../SimulationResults/Builder/74ni/g50kEvts0.5ps500mgFe.txt
# Number of Simulated Events or Events to process
50000
#FWHM Spatial Resolution of the AGATA detectors (mm)
5
#FWHM Spatial Resolution of DSSSD (mm)
0.7
#Time Resolution for fragment detection (LYCCA) in (ps)
80
#lower Energy Range for HPGe Pulse Height Spectrum (eV)
500
#high Energy Range for HPGe Pulse Height Spectrum (eV)
2000
```

After running the plot() method for each one of the files in

`../SimulationResults/Builder/74ni/`

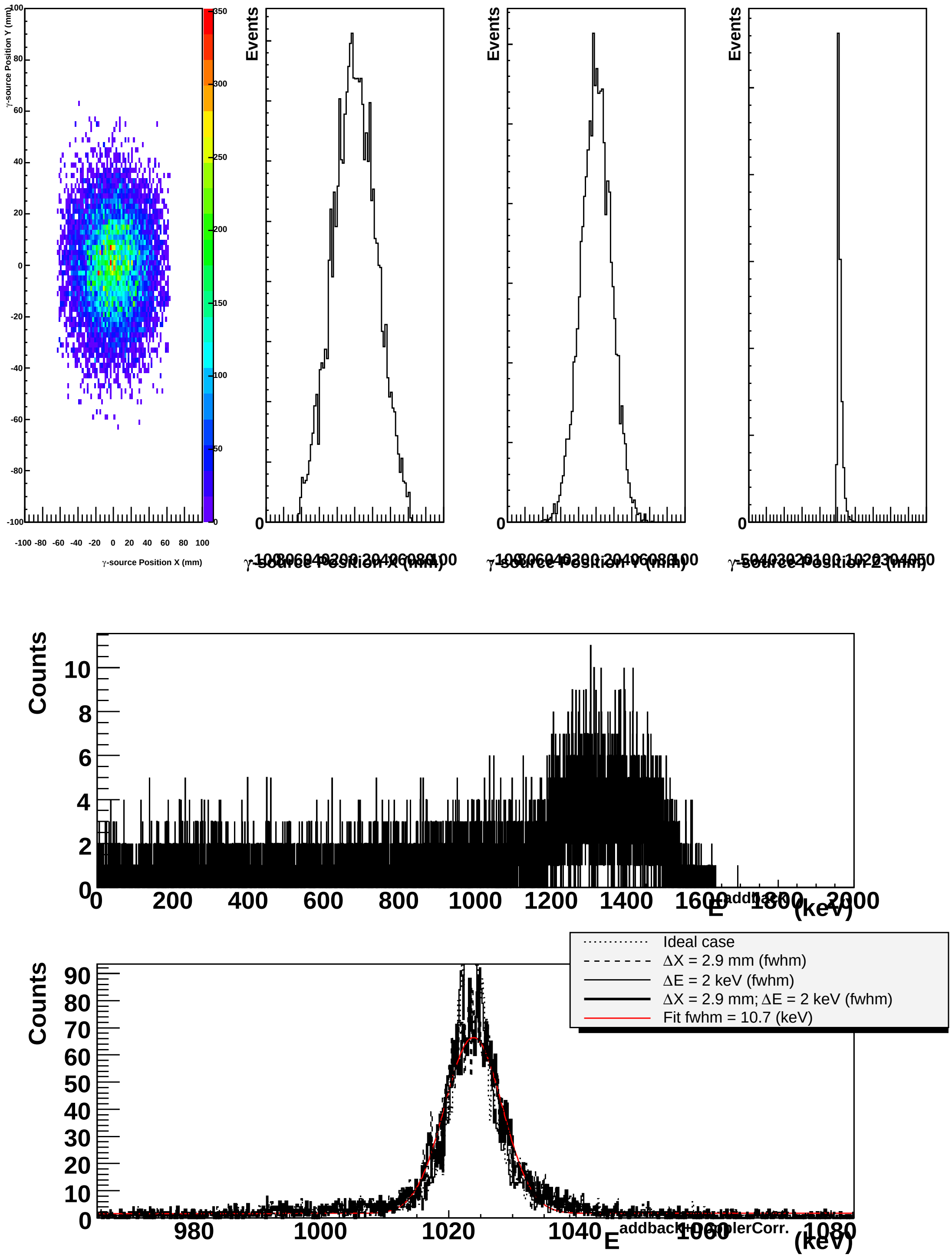


Figure 4.3: Some spectra obtained via analysis.hh→plot().

one obtains some spectra like those shown in Fig. 4 for the primary γ-rays spatial distribution and the AGATA reconstructed pulse height spectra.

One can compare now the Doppler-Corrected lines for the three half-life cases simulated, 0.05 ps, 0.5 ps and 5 ps, thus obtaining the following effect in the line-shape,

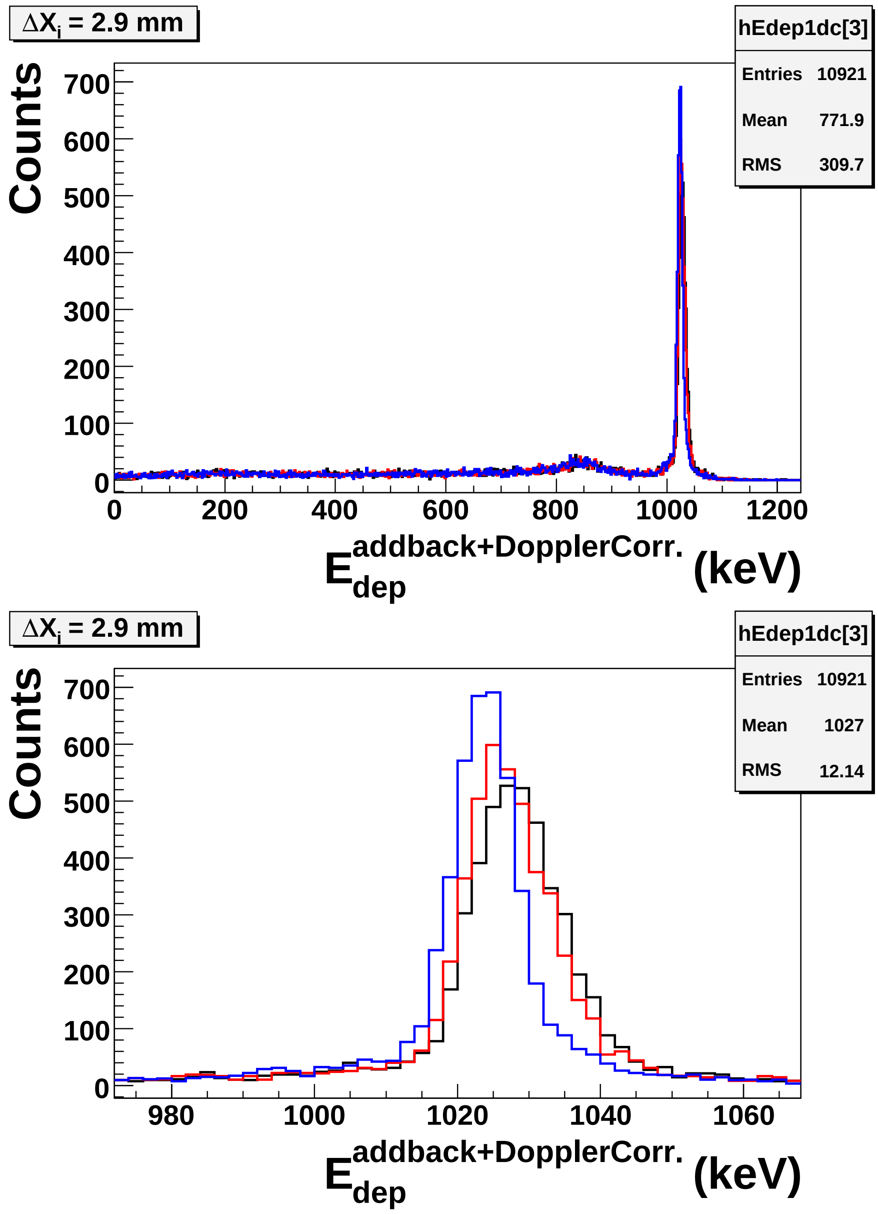


Figure 4.4: Blue, red and black lines correspond to level half-lifes of 5 ps, 0.5 ps and 0.05 ps, respectively.

Bibliography

[1] http://root.cern.ch/.

[2] Geant4 Collaboration, S. Agostinelli, J. Allison, K. Amako, J. Apostolakis, H. Araujo, P. Arce, M. Asai, D. Axen, S. Banerjee, G. Barrand, F. Behner, L. Bellagamba, J. Boudreau, L. Broglia, A. Brunengo, H. Burkhardt, S. Chauvie, J. Chuma, R. Chytracek, G. Cooperman, G. Cosmo, P. Degtyarenko, A. dell'Acqua, G. Depaola, D. Dietrich, R. Enami, A. Feliciello, C. Ferguson, H. Fesefeldt, G. Folger, F. Foppiano, A. Forti, S. Garelli, S. Giani, R. Giannitrapani, D. Gibin, J. J. Gómez Cadenas, I. González, G. Gracia Abril, G. Greeniaus, W. Greiner, V. Grichine, A. Grossheim, S. Guatelli, P. Gumplinger, R. Hamatsu, K. Hashimoto, H. Hasui, A. Heikkinen, A. Howard, V. Ivanchenko, A. Johnson, F. W. Jones, J. Kallenbach, N. Kanaya, M. Kawabata, Y. Kawabata, M. Kawaguti, S. Kelner, P. Kent, A. Kimura, T. Kodama, R. Kokoulin, M. Kossov, H. Kurashige, E. Lamanna, T. Lampén, V. Lara, V. Lefebure, F. Lei, M. Liendl, W. Lockman, F. Longo, S. Magni, M. Maire, E. Medernach, K. Minamimoto, P. Mora de Freitas, Y. Morita, K. Murakami, M. Nagamatu, R. Nartallo, P. Nieminen, T. Nishimura, K. Ohtsubo, M. Okamura, S. O'Neale, Y. Oohata, K. Paech, J. Perl, A. Pfeiffer, M. G. Pia, F. Ranjard, A. Rybin, S. Sadilov, E. di Salvo, G. Santin, T. Sasaki, N. Savvas, Y. Sawada, S. Scherer, S. Sei, V. Sirotenko, D. Smith, N. Starkov, H. Stoecker, J. Sulkimo, M. Takahata, S. Tanaka, E. Tcherniaev, E. Safai Tehrani, M. Tropeano, P. Truscott, H. Uno, L. Urban, P. Urban, M. Verderi, A. Walkden, W. Wander, H. Weber, J. P. Wellisch, T. Wenaus, D. C. Williams, D. Wright, T. Yamada, H. Yoshida, and D. Zschiesche. Geant4-a simulation toolkit. *Nuclear Instruments and Methods in Physics Research A*, 506:250–303, July 2003.

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[4] Pieter Doornenbal. Short manual of a geant4 simulation code for γ-ray detectors used in riken-ribf facility. Technical report, RIKEN, 2009.

[5] V. Borrel, D. Guerreau, J. Galin, B. Gatty, D. Jacquet, and X. Tarrago. Peripheral Ar induced reactions at 44 MeV/u − similarities and deviations with respect to a high energy fragmentation process. *Zeitschrift fur Physik*, 314:191–197, June 1983.