Rabat, Morocco Published date : 09/09/17

G4Linac_MT version 1.0

User Manual

Version1.0 Revision 1.0

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Webpage :https://github.com/EL-Bakkali-Jaafar/G4Linac_MT

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1. Introduction

About this Document

This document refers to G4Linac_MT version 1.0 and contains some instructions and tips which may help user to successfully building their Linac simulations using G4Linac_MT code which is built on the top of the last known stable version of Geant4 Monte Carlo code (at the time of writing this document) namely Geant4.10.03. Users don't need to have a deep knowledge of Geant4 Monte Carlo code nor to consult further documentation since this manual has been built to be self-consistent as well as possible. However, anyone want to contribute in developed of this code must have advanced knowledge of Geant4 code and are welcome.

Anyone have a question about this document, don't hesitate to send me an email at:
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Quick Introduction to G4Linac_MT

The word G4Linac_MT is an acronym of " Geant4 For Linac with Multi Threading mode ", as its name indicates, this code is dedicated to accurately modeling medical linear accelerator used in radiotherapy to treat cancer diseases by employing ionizing radiations. This code has been developed by Dr. Jaafar EL Bakkali, which is actually working as Assistant Professor in Nuclear Physics in Morocco. G4Linac_MT has been written in C++ language from scratch to perform all mandatory tasks required for validating the Monte Carlo Geant4 code for such Linac operating at photon or electron mode. The code supports the following features:

- The code was built on the top of the last known stable version of Geant4 (namely Geant4 .10.3).
- It uses multi-threading option allowing it to start multiple simulations at the same time and it merges data delivered by different threads at the end of a run.
- The code can accurately modeling the physics of all components of treatment head of a Linac.
- The code can accurately modeling the dose distribution either in homogeneous or either in heterogeneous water phantoms.
- The code can read material and geometry specification from .geom file (GEANT4 GEOMETRY FROM TEXT FILE version 1.0) or they can be specified directly by implementing a hard C++ code by the mean of Geant4 APIs.
- It uses a new format of PhaseSpace file based on HDF5 file format by the mean of the HDF5 C++ library and it integrates a set of h5PhaseSpace I/O routines for writing and reading H5Phase-Space files.
- In order to avoiding unecessary time spents by writing data to the physical disk, those data are stored in RAM memory and finally are dumped to the physical disk at the end of a Run.
- It also stores the dosimetric data on a file with binary format, this for each thread. At the end of

a run all dosimetric files are merged together in order to produce a single one.
- The code contains a tool that can be serve at extracting and visualizing data, two kind of files are supported namely: h5PhaseSpace and DosimetricData.

Modules of G4Linac_MT

G4Linac_MT code consists of following three modules:

G4Linac_Head

This module lets user construct model geometry related to all components of a given Linac treatment head include:
- Invariant elements: primary collimator, output window, monitors chamber, mirror and mesh.
- Elements which strongly depend on the selected irradiation energy, namely X-ray target and flattening filter.
- Others that depend on the shape of the beam, namely removable jaws and multileaf system.

The construct of model geometry can be either set directly by implementing required C++ or can be read from a macro file that contains a Geant4 Geometry From Text code. G4Linac_Head module allows one to start its simulation in multi-threading mode, in each thread it will create a h5PhaseSpace file at the end of thread-run, after that all phase-space file will be merged in single one without user intervention, this at the end of a given Run. This code is the only which uses a new phase-space file format based on HDF5 file format and called h5PhaseSpace file. Regarding variance reduction technique, the module uses the technique called BREMSPE for photons bremsstrahlung splitting.

G4Linac_DoseCal

This module lets user simulate doses deposition in either homogeneous or heterogeneous water phantoms. The user can run multiple simulation at the same time, since this code supports multi-threading features. In aim to reduce RAM memory usage, all thread share some copy of h5PhaseSpace file which is used as an input to the Monte Carlo dose calculations. At the end of execution of each run, this module merges DosimetricData per thread in binary file which can be analyzed by G4Linac_DataAnalysis module.

G4Linac_DataAnalysis

This module can be used for data analysis, the data can be either h5PhaseSpace data or either DosimetricData.

For h5PhaseSpace data, this tool can be used for histogramming height physics quantities:

- *Visualizing photon energy spectrum*

```
./G4Linac_DataAnalysis PhaseSpaceData PhaseSpaceFileName.h5 photon_energy_spectrum
```

- *Visualizing electron energy spectrum*

```
./G4Linac_DataAnalysis PhaseSpaceData PhaseSpaceFileName.h5 electron_energy_spectrum
```

- *Visualizing photon angular distribution*

```
./G4Linac_DataAnalysis PhaseSpaceData PhaseSpaceFileName.h5 photon_angular_distribution
```

- *Visualizing electron angular distribution*

```
./G4Linac_DataAnalysis PhaseSpaceData PhaseSpaceFileName.h5 electron_angular_distribution
```

- *Visualizing photon spatial distribution in plane XY*

```
./G4Linac_DataAnalysis PhaseSpaceData  Phase_Space_fileName.h5 photon_spatial_distribution_xy
```

- *Visualizing particle spatial distribution in plane XY*

```
./G4Linac_DataAnalysis PhaseSpaceData  Phase_Space_fileName.h5 spatial_distribution_xy
```

- *Visualizing photon spatial distribution in plane XY in function of its kinetic energies*

```
./G4Linac_DataAnalysis PhaseSpaceData  Phase_Space_fileName.h5
photon_spatial_distribution_xy_with_kinetic
```

- *Visualizing electron spatial distribution in plane XY in function of its kinetic energies*

```
./G4Linac_DataAnalysis PhaseSpaceData  Phase_Space_fileName.h5
```

```
electron_ spatial_distribution_xy_with_kinetic
```

For DosimetricData, this tool can be used for histogramming four physics quantities:

- *Visualizing percentage depth dose curve*

```
/G4Linac_DataAnalysis DosimetricData DosimetricData_fileName.dat pdd x_center_id y_center_id
```

- *Visualizing percentage x profile*

```
/G4Linac_DataAnalysis DosimetricData DosimetricData_fileName.dat xprofile y_center_id z_center_id
```

- *Visualizing percentage y profile*

```
/G4Linac_DataAnalysis DosimetricData DosimetricData_fileName.dat yprofile x_center_id z_center_id
```

- *Visualizing dose heat map*

```
/G4Linac_DataAnalysis DosimetricData DosimetricData_fileName.dat dose_heatmap x_center_id
z_center_id
```

2. Getting started

Getting the source of G4Linac_MT

G4Linac_MT it hosted on github and it can be obtained freely from the following link: https://github.com/EL-Bakkali-Jaafar/G4Linac_MT

by clicking on “clone or download” button.

Prerequisite softwares and libraries

G4Linac_MT was built on the top of Geant4.10.03, so users must have it installed in their operating system. Geant4.10.03 can be downloaded from the following link:

http://geant4.web.cern.ch/geant4/support/source/geant4_10_03_p02.zip

Users must also download all require data and must follow Geant4 installation guide.

G4Linac also needs ROOT data analysis framework (version 6.10) for histogramming, which can be downloaded from:
https://root.cern.ch/download/root_v6.10.04.source.tar.gz

This tool must be configured, compiled and finally installed by following ROOT installation guide.

G4Linac uses HDF5 C++ API for writing and reading h5PhaseSpace files that are based on HDF5 file format. The last version of hdf5 can be downloaded from this link:

https://support.hdfgroup.org/ftp/HDF5/current/src/hdf5-1.10.1.tar

Then, user must configure this tool as follows:

```
./configure --enable-cxx --enable-threadsafe --prefix=/opt/hdf5 --enable-unsupported
```

After that this tool must be compiled (by typing make) and installed (by typing make install).

- **Installing G4Linac_MT**

Installing G4Linac_MT is an easy task, after setup-ping all prerequisite libraries and after downloading the source of G4Linac_MT, users need to extracting the file, by untaring it with any known untar tool, after that users must see three folders namely: G4Linac_Head, G4Linac_DoseCal and G4Linac_DataAnalysis. Users must create a build folder for each ones change directory to the new folder and execute the cmake command. For example:

1. Installing G4Linac_Head module

```
mkdir G4Linac_Head_ Build
cd ./G4Linac_Head
cmake -DGeant4_DIR=/home/user/Geant4/geant4.10.3-install  ~/Geant4/WorkDir/G4Linac_Head
make
```

2. Installing G4Linac_DoseCal module

```
mkdir G4Linac_DoseCal _ Build
cd ./G4Linac_DoseCal
cmake -DGeant4_DIR=/home/user/Geant4/geant4.10.3-install  ~/Geant4/WorkDir/G4Linac_DoseCal
make
```

3. Installing G4Linac_Head module

```
mkdir G4Linac_DataAnalysis_ Build
cd ./G4Linac_DataAnalysis
cmake -DGeant4_DIR=/home/user/Geant4/geant4.10.3-install  ~/Geant4/WorkDir/G4Linac_DataAnalysis
make
```

- **Running an example**

  - **Sample Linac geometry implemented using a hard C++ code**

The G4Linac_MT code comes as default with a sample Linac geometry implemented directly by using C++ programming code and Geant4 APIs. It's about a sample linac operating at 6 MV con figuring a 20 x 20 cm^2 radiation f ield and assembled by the following components: x-ray target, primary collimator, flattening filter, ionization chamber and jaws.
G4Linac_MT code comes with three separated folder namely: G4Linac_Head, G4Linac_DoseCal and G4Linac_DataAnalysis. Users must performing three mandatory tasks:

First task: modeling medical linear accelerator head operating at photon mode X6
create new folder in same directory of G4Linac_Head, rename it to “G4Linac_Head_build”, then open new Linux terminal, cd to “G4Linac_Head_build” folder and execute the following command:

```
cmake  -DGeant4_DIR=/home/user/Geant4/geant4.10.3-install  ../G4Linac_Head
make
```

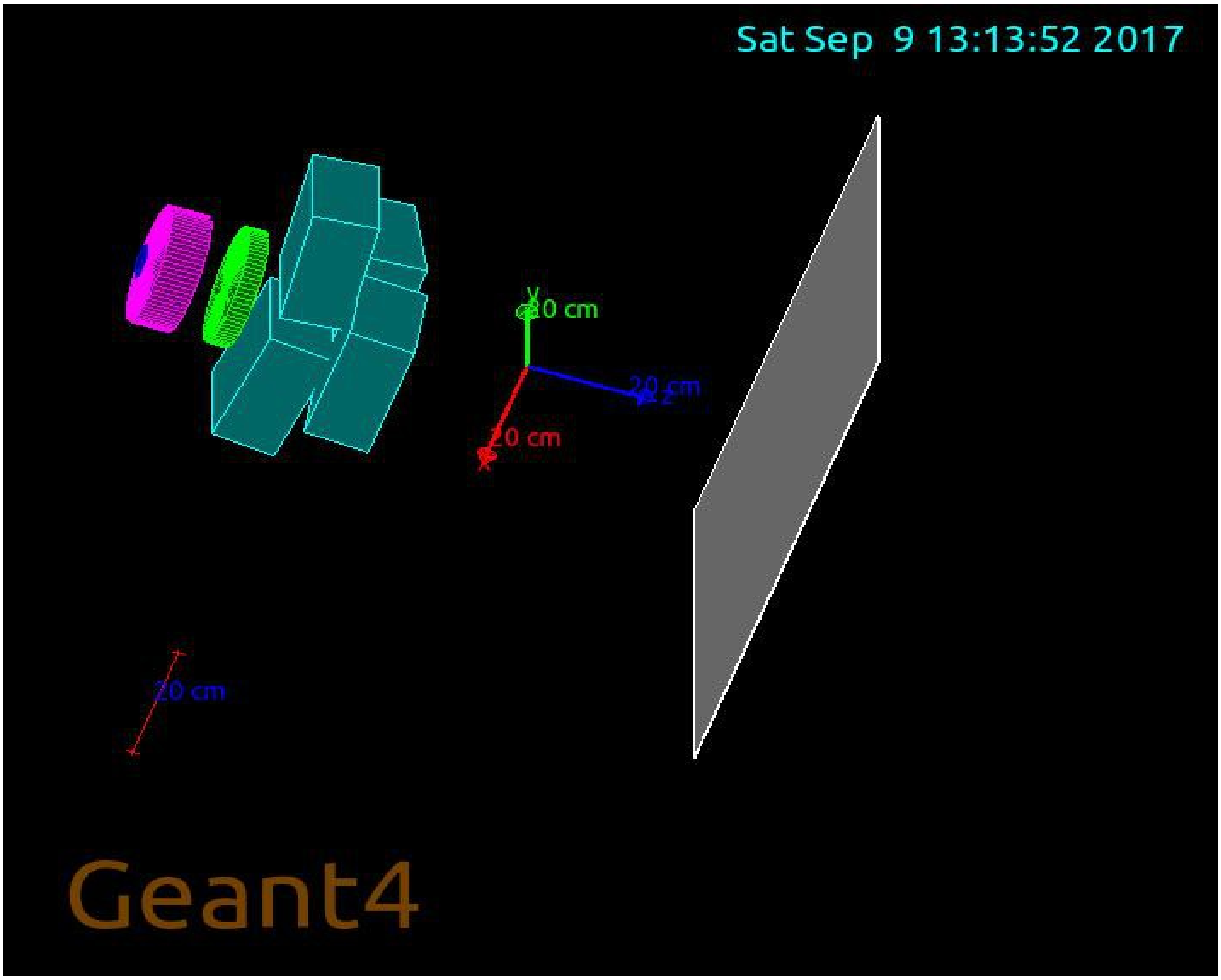
and run the program by typing:

```
./G4Linac_Head  run.mac
```

Users can display linac geometry by typing the following line:

```
./G4Linac_Head
```

The results me be like this:



User can set number of events per thread by changing the following line in “run.mac” file:

```
/Parameters/NumberOfEventsPerThread  _numberOfEventsPerThread
```

At the end of a run, the simulation output is composed by the two following files: PhaseSpace.h5 and PhaseSpace.summary.
The content of PhaseSpace.summary is as follows:

```
#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#
G4LINAC_MT v1.O: A GEANT4 BASED APPLICATION FOR MEDICAL LINEAR ACCELERATOR
DEVELOPED BY DR. JAAFAR EL BAKKALI, BAHMEDJ@GMAIL.COM, RABAT-MOROCCO,  08/ 2017
MULTI_THREADING SUPPORT: YES
#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#=#
```

@DATE_OF_CREATION: Sat Sep 9 12:22:57 2017

@ELAPSED_TIME: 3788.47 seconds.

@PHASE_SPACE_NAME: PhaseSpace.h5

@Z_STOP: 1000 mm.

@REDUCTION VARIANCE TECHNIQUE: BREMSPE

@SPLIT NUMBER: 600

@TOTAL_NUMBER_OF_SIMULATED_HISTORIES: 453600

@TOTAL_NUMBER_OF_ACTIVE_EVENTS: 215397

@ACTIVE_EVENTS_PERCENT: 47.4861 %

@TOTAL_NUMBER_OF_PARTICLES : 2735462

@TOTAL_NUMBER_OF_PARTICLES_PER_SECONDE : 240

@TOTAL_NUMBER_OF_PHOTONS: 2732226

@TOTAL_NUMBER_OF_ELECTRONS: 3054

@TOTAL_NUMBER_OF_POSITRONS: 182

@PHOTONS_PERCENT: 99.8817 %

@ELECTRONS_PERCENT: 0.111645 %

@POSITRONS_PERCENT: 0.00665336 %

@PHOTONS_MAX_ENERGY: 6.31901 MeV

@PHOTONS_MIN_ENERGY: 0.494742 MeV

@PHOTONS_MEAN_ENERGY: 1.63808 MeV

@ELECTRONS_MAX_ENERGY: 5.56064 MeV

@ELECTRONS_MIN_ENERGY: 3.48915 MeV

@ELECTRONS_MEAN_ENERGY: 1.67796 MeV

@POSITRONS_MAX_ENERGY: 3.66707 MeV

@POSITRONS_MIN_ENERGY: 0.989569 MeV

@POSITRONS_MEAN_ENERGY: 1.61236 MeV

@PHOTONS_MAX_WEIGHT: 1

@PHOTONS_MIN_WEIGHT: 0.00166667

@PHOTONS_MEAN_WEIGHT: 0.00166996

@ELECTRONS_MAX_WEIGHT: 0.00166667

```
@ELECTRONS_MIN_WEIGHT: 0.00166667

@ELECTRONS_MEAN_WEIGHT: 0.00166667

__________________________________________________________________________________

@POSITRONS_MAX_WEIGHT: 0.00166667

@POSITRONS_MIN_WEIGHT: 0.00166667

@POSITRONS_MEAN_WEIGHT: 0.00166667

__________________________________________________________________________________
```

Here a phase-space file created of 198.7 Mb that contains 2735462 particles.

Second task: modeling dose distribution in a homogeneous water phantom

Create a new folder in the same directory of G4Linac_DoseCal, rename it to "G4Linac_DoseCal_build", then open new Linux terminal, cd to "G4Linac_Head_build" folder and execute the following command:

```
cmake -DGeant4_DIR=/home/user/Geant4/geant4.10.3-install ../G4Linac_DoseCal
make
```

The h5Phase-Space file created previously need to be copied into this directory. Then open run.mac file and change Phase_Space word to the name of h5PhaseSpace file as follows:

```
/Parameters/H5PhaseSpaceName Phase_Space
```

After that, users should run this module by typing:

```
./G4Linac_DoseCal run.mac
```

At the end of the simulation, a binary file named "dose.dat" will be created which contains dosimetric data and can be analyzed by G4Linac_DataAnalysis module.

Third task: histograming data

Users should create a new folder in the same directory of G4Linac_DoseCal, rename it to "G4Linac_DoseCal_build", then open new Linux terminal, cd to "G4Linac_Head_build" folder and execute the following command:

```
cmake -DGeant4_DIR=/home/user/Geant4/geant4.10.3-install ../G4Linac_DataAnalysis
make
```

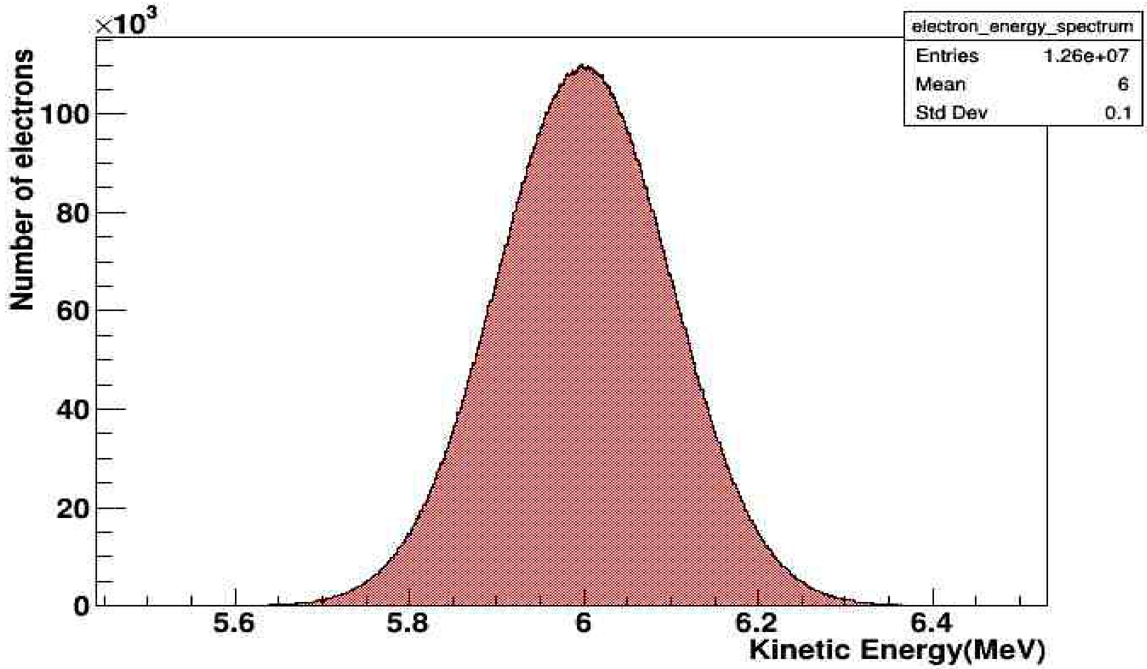
After that , users need to copy h5Phase-Space file and dose.dat to this emplacement in order to perform simulation analysis task. Here we can see a set of histogramms produced for a number of physical quantities thereby extracting data from h5Phase-Space file:

- **Energy spectrum of 6 MeV electron source**

The h5PhaseSpace Zstop parameter must be set to -60 cm . Then uers should run G4Linac_Head module in order to produce a h5PhaseSpace file which need to be moved to build directory of G4Linac_DataAnalysis. The following line must be executed in order to obtain the diserd histogramm:

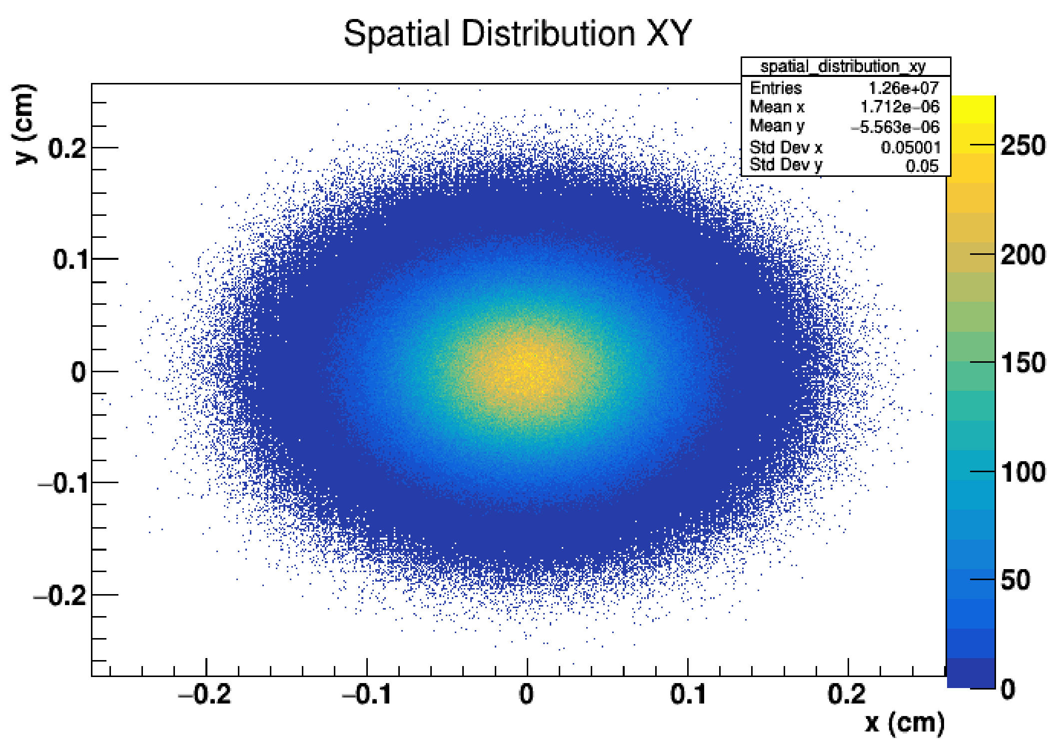
```
/G4Linac_DataAnalysis PhaseSpaceData PhaseSpace.h5 electron_energy_spectrum
```

Users should obtain picture like below.



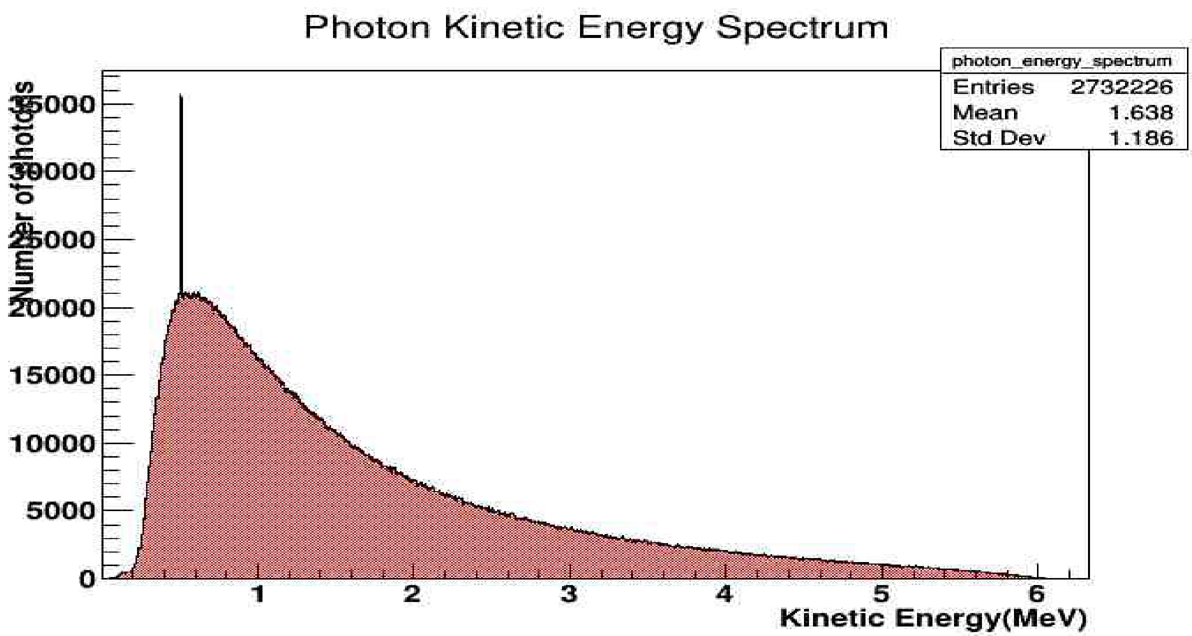
- **Spatial bidistribution of 6 MeV electron source**

```
/G4Linac_DataAnalysis PhaseSpaceData PhaseSpace.h5 electron_spatial_distribution_xy
```



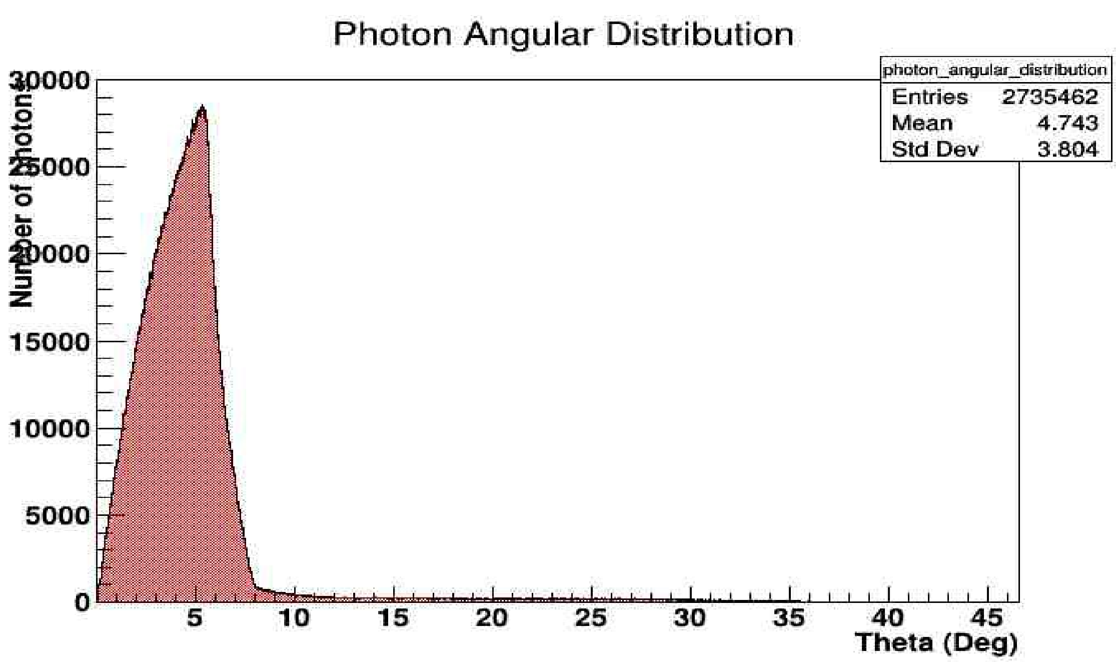
- **6 MV Bremsstrahlung photon energy spectrum**

/G4Linac_DataAnalysis PhaseSpaceData PhaseSpace.h5 photon_energy_spectrum



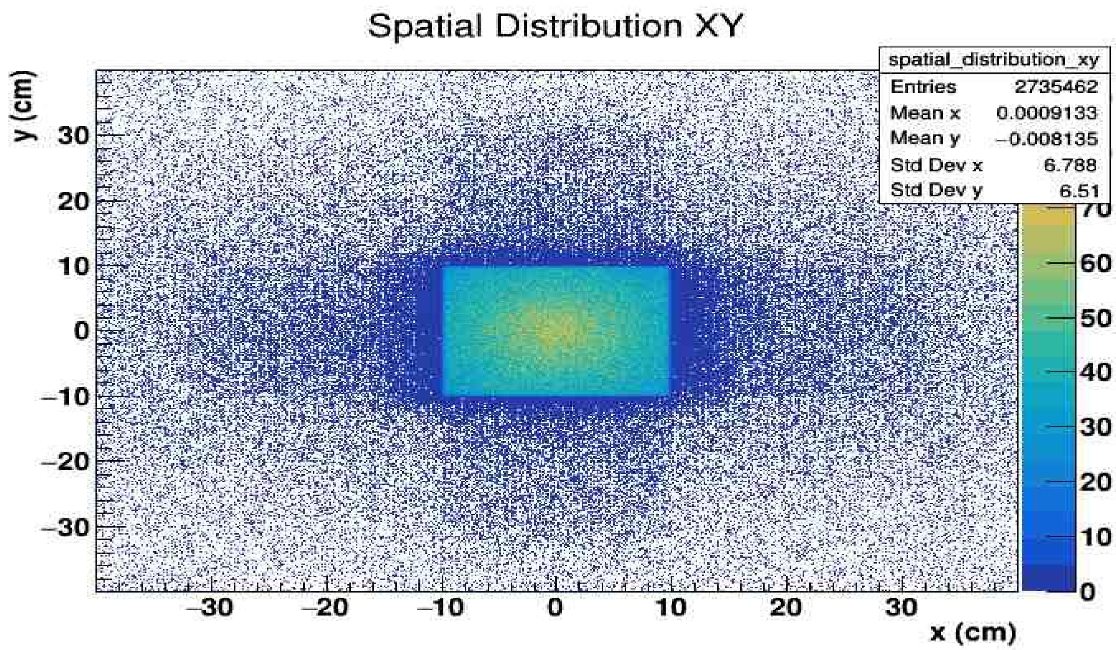
- **6 MV bremsstrahlung Photon angular distribution**

G4Linac_DataAnalysis PhaseSpaceData PhaseSpace.h5 photon_angular_distribution



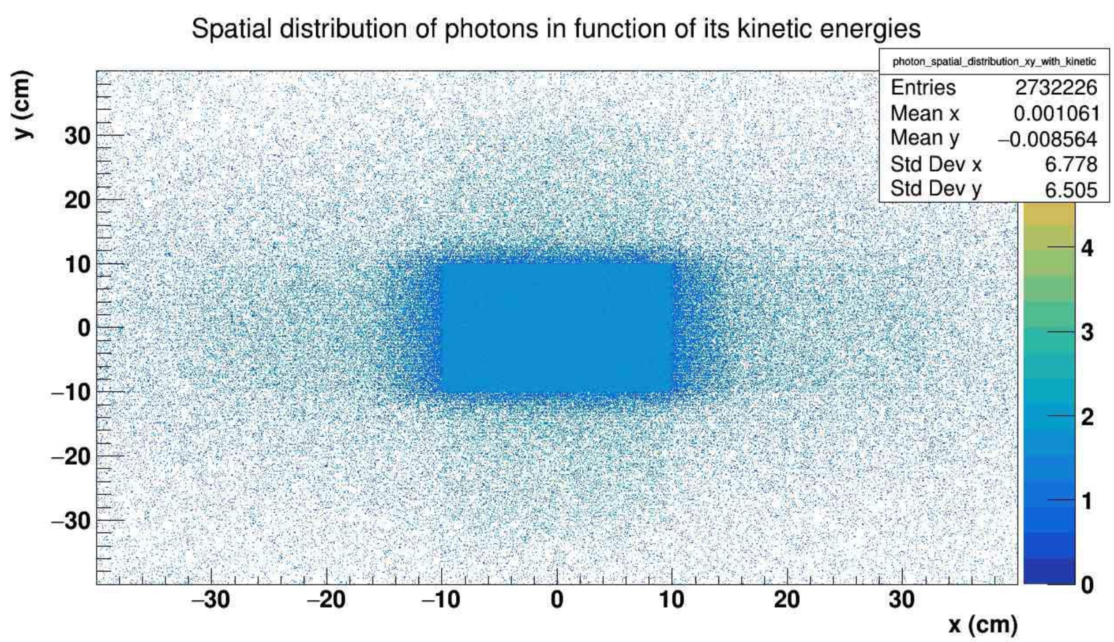
- **Particle spatial bidistribution**

```
./G4Linac_DataAnalysis PhaseSpaceData  Phase_Space.h5 spatial_distribution_xy
```



- **6MV bremsstrahlung photon spatial bi-distribution in function of its kinetic energies**

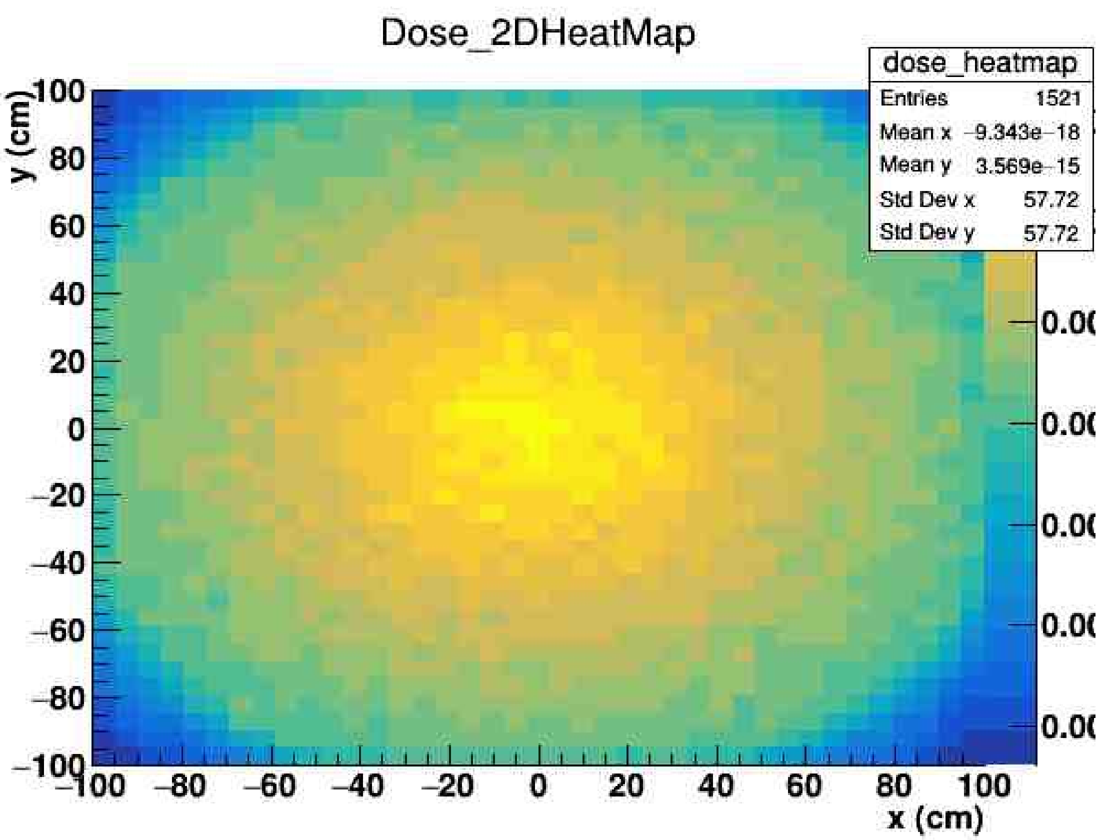
```
./G4Linac_DataAnalysis PhaseSpaceData  Phase_Space..h5 photon_spatial_distribution_xy_with_kinetic
```



Here we can see a set of histogramms produced for a number of physical quantities thereby extracting data from DosimetricData file called dose.dat.

- **Dose 2D heatmap**

```
./G4Linac_DataAnalysis DosimetricData dose.dat dose_heatmap 3
```



3. Troubleshooting

- **Some common errors**

In order to determine the line of C++ code that causes a segmentation fault you should run the following command:

```
valgrind –tool=helgrind nameofModule run.mac
```

where nameofModule should be G4Linac_Head or G4Linac_DoseCal .

I need a help

For any questions, users should contact me at bahmedj@gmail.com

4. For developers

Users who want to contribute in development of this code are welcome !

5. License

G4Linac_MT is an open-source code distributed under the GNU General Public License.