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(H02) Introduction of medical application examples in Geant4  
and  
the Hands-on code

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# Outline

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- Introduction of the Geant4 bundled medical application examples
- How to build and run the Geant4 application [Hands-on]
  - Basics of file structures
  - Basics of user-interface commands
    - /run, /vis, /tracking
- Exercise

## The example medical applications bundled in the Geant4 distribution (1)

---

- `/opt/geant4/src/geant4-v11.1.2/examples/`
  - `basic/B3`
    - B3a and B3b, ( Simple PET system w/ two scoring implementations )
  - `extended/medical/`
    - DICOM (The DICOM handler for building a voxelated CT geometry)
    - DICOM2 (Extended scoring implementation in the DICOM example)
    - GammaTherapy, (A gamma therapy application)
    - dna, (The Geant4-DNA physics/chemistry processes and models)
    - electronScattering (Electron scattering benchmark w/simple condition)
    - electronScattering2 (Electron scattering benchmarks for the NRCC experiment)
    - fanoCavity (The dose deposited ionization chamber by a photon beam)
    - fanoCavity2 (The dose deposited in an ionization chamber by an electron beam)

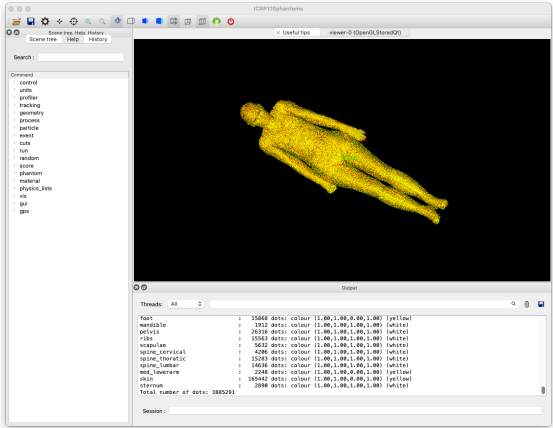
## The sample medical applications bundled in the Geant4 distribution (2)

---

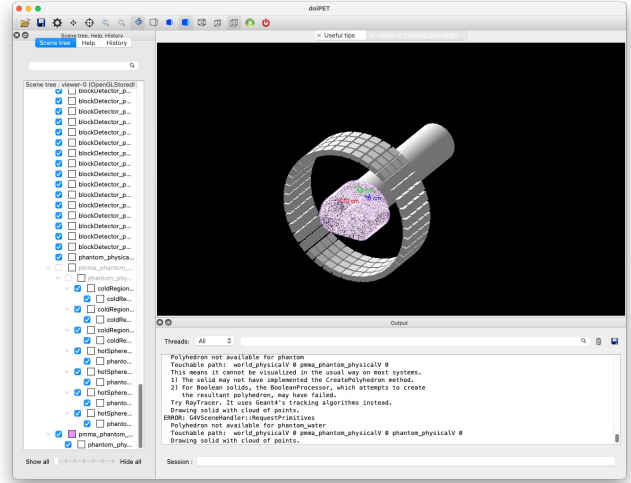
- `/opt/geant4/src/geant4-v11.1.2/examples/`
  - `advanced/`
    - `doiPET`, (The depth-of-interaction enabled PET scanner and NEMA NU phantoms)
    - `ICRP110_HumanPhantoms`, (ICRP110 anthropomorphic phantoms) [See Sep. 27<sup>th</sup> J. Archer]
    - `ICRP145_HumanPhantoms`, (ICRP145 anthropomorphic phantoms) [See Sep. 27<sup>th</sup> J. Archer]
    - `brachytherapy`, (A brachytherapy example w/ a water phantom)
    - `eFLASH_radiotherapy`, (A low-energy electron FLASH beamline in the CPER at Pisa)
    - `gammaknife`, (A Leksell Gamma-knife in Catania for stereotactic radiosurgery)
    - `hadrontherapy`, (A hadron therapy beamline of the passive proton therapy at INFN)
    - `human_phantom`, (Analytical anthropomorphic phantoms of MIRD and ORNL models)
    - `iort_therapy`, (A typical intraoperative electron radiation therapy beamline)
    - `medical_linac`, (A typical medical linear accelerator for IMRT, Varian clinac 2100 accelerator)

# Examples

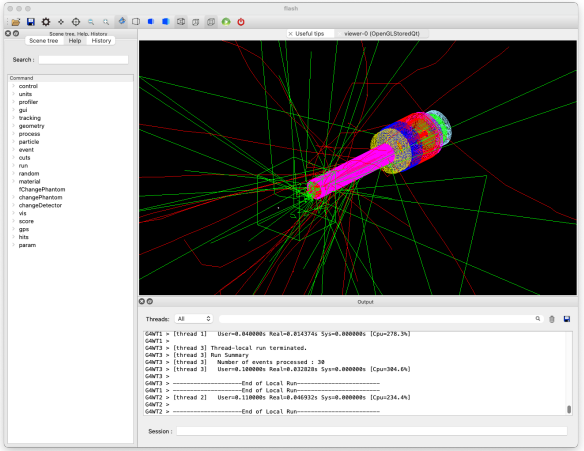
## ICRP110\_HumanPhantoms



## doiPET



## eFLASH\_radiotherapy



# More information about these medical example applications

- The Geant4 documentation

- The detail description about these example applications are [Here](#)

## Geant4 Examples

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### Geant4 Examples

This module collects three sets of user examples aimed to demonstrate to the user how to make correct use of the GEANT4 toolkit by implementing in a correct way those user-classes which the user is supposed to customize in order to define his/her own simulation setup.

The **"basic"** set of examples is oriented to novice users and covering the most typical use-cases of a Geant4 application with keeping simplicity and ease of use.

An **"extended"** set of examples may require some additional libraries besides of Geant4. This set covers many specific use cases for actual detector simulation.

An **"advanced"** set of examples covers the use-cases typical of a "toolkit"-oriented kind of development, where real complete applications for different simulation studies are provided; may require additional third party products to be built.

Most of the examples can be run both in interactive and batch mode, and input macro files (\*.in) and reference output files (\*.out) are provided. Basic and most of the extended examples are considered part of the system testing suite for validation of the official releases of the GEANT4 toolkit. Basic and some of the extended and advanced examples are also used as "acceptance"-tests for the release process.

See more on each examples category pages:

- Basic Examples
- Extended Examples
- Advanced Examples

The previous set of examples oriented to novice users, **"novice"**, has been refactored in "basic" and "extended" examples sets in Geant4 10.0. The information about the original set of these examples can be found at this page .

And more on what is common for all examples:

- How to build and run an example
- Tips how to run an example in multi-threading mode
- How to navigate in the examples documentation

Generated on Mon Jan 9 2023 15:08:56 for Geant4 examples by doxygen 1.9.6

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## Geant4 Advanced Examples

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### Advanced Examples

#### Purpose

The Advanced Examples illustrate realistic applications of Geant4 in typical experimental environments. They are developed in collaboration with user groups expert in the corresponding experimental domain. The code of the developed examples can be downloaded together with the Geant4 toolkit in the directory examples/advanced.

#### Advanced Examples

A short introduction to each advanced example is provided following the appropriate link in the table below. All examples have a README file in the Geant4 distribution where more technical information is provided (e.g. how to compile and run the simulation). For questions, it is suggested to contact directly the responsible Geant4 Collaborator (indicated in the table below as well) and, eventually, the Coordinator/Deputy Coordinator of the Working Group.

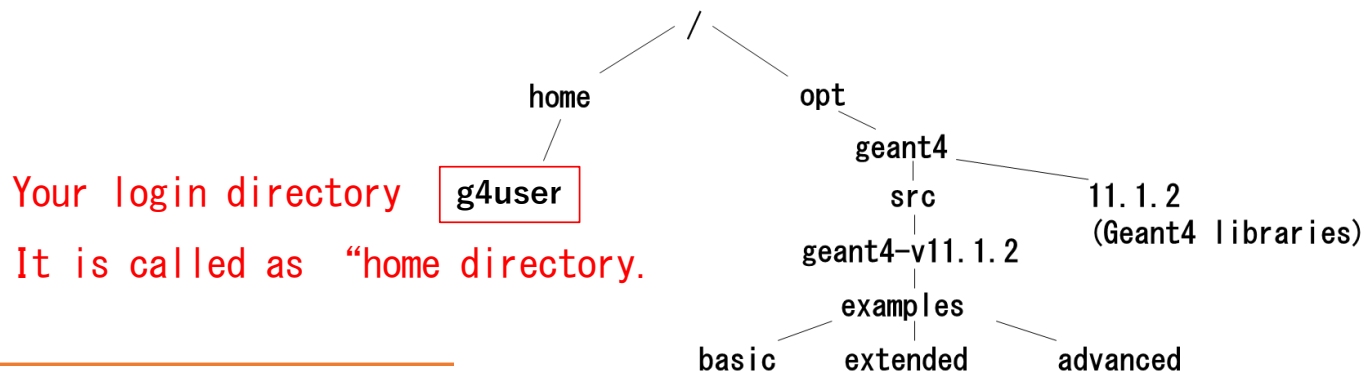
Example name	Responsible Geant4 Collaborator	Short description
air_shower	Bernardo Tomè	Modelling of the ULTRA experiment, EUSO mission
ams_Ecal	Michel Maire	Modelling of the electromagnetic Calorimeter (ECAL) of the AMS-02 experiment
brachytherapy	Susanna Guatelli	Calculation of dose in a phantom, in the context of brachytherapy
CaTS	Hans-Joachim Wenzel	Demonstration of the G4Opticks hybrid workflow for the creation and propagation of optical photons on GPU's
ChargeExchangeMC	Alexey Radkov	Simulation of hadronic physics experiments of the Petersburg Nuclear Physics Institute (PNPI, Russia)
composite_calorimeter	Alberto Ribon	Example of a test-beam simulation used by the CMS Collaboration, CERN, Geneva, Switzerland
dolPET	Susanna Guatelli	Modelling of a PET scintillator system
eFLASH_radiotherapy	Francesco Romano	Modelling of a FLASH radiotherapy beamline
eRosita	Francesco Longo	Modelling of eROSITA astronomical X-ray full-sky survey mission on-board the Spectrum-X-Gamma space mission
fastAerosol	Makoto Asai	Development of a custom geometry class for accurately and efficiently simulating aerosols with many droplets
gammaknife	Francesco Romano	Simulation of an advanced device for Stereotactic Radiosurgery
gammaray_telescope	Francesco Longo	Model of a typical telescope for gamma ray analysis in the context of space exploration
gorad	Makoto Asai	Turn-key application for radiation analysis and spacecraft design built on top of Geant4
hadrontherapy	Pablo Cirrone	Model of hadrontherapy beamlines



## (Tips) Unix commands

---

- \$ pwd (Print working directory )
- \$ ls -l (Show list of files in the current directly )
- \$ cd (Change directory to your home directory. e.g. /home/g4user )
- \$ mkdir *directoryname* (Create a new directory w/ the name of *directoryname* )
- \$ cd *directoryname* (Change directory to *directoryname* )
- \$ cd .. (Change directory to an upper directory)
- \$ less *filename* (Show the file content. scroll by [space]. End by [q] )
- \$ code *filename* (Edit the file in vscode. At first time, you may be required passwd. **!!g4user** )
- \$ cp -r *sourceDir* . ( Copy a directory from the *sourceDir* to the current directory)



## (Tips) Geant4 w/ visualization

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- Depending on machine conditions, we may have problem of visualization such as very slow response, hang-up of application.
- If you have such problem, set the Geant4 RunManager type to serial by:  
**\$ export G4FORCE\_RUN\_MANAGER\_TYPE=Serial**
  - This command forces the Geant4 to run with a single thread mode.
- When you want to use the multithreading mode, clear it by:  
**\$ export -n G4FORCE\_RUN\_MANAGER\_TYPE**



## How to build and run an example application (1) [Hands-on]

---

- We start from a basic example of B3a and assume we work at the home directory
- Check the current directory

```
$ cd
$ pwd (Should be /home/g4user )
```
- Copy the B3a example code from Geant4 source code to your current directory

```
$ cp -r /opt/geant4/src/geant4-v11.1.2/examples/basic/B3/B3a .
```
- Create a build directory

```
$ mkdir B3a-build
```
- Change directory to the building directory. (e.g. /home/g4user/B4a-build )

```
$ cd B3a-build
```
- Prepare the Makefile using cmake command with the source directory of the example code.

```
$ cmake ../B3a
```
- Build the application using the make command

```
$ make
```

## How to build and run an example application (2) [Hands-on]

---

- Check the executable filename

```
$ ls -l
```

(You will find something like ...)

```
-rwxr-xr-x  1 g4user  staff  600263  9  9 12:22 exampleB3a
```

- Run the application

```
$ ./exampleB3a
```

# Qt GUI interface w/ example3a (1) [Hands-on]

- Qt window

(3) Command Help

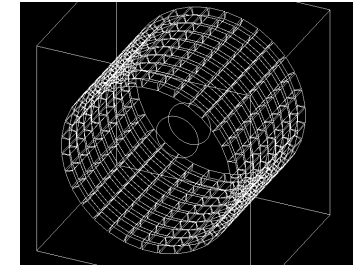
(1-3) icons for display modes

(1) Geometry

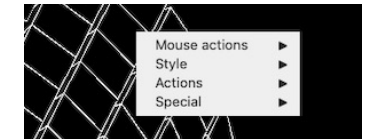
(2) Standard output

(4) Session:  
Command input box

(1-1) Drag, rotate the geometry



(1-2) Right click opens a menu



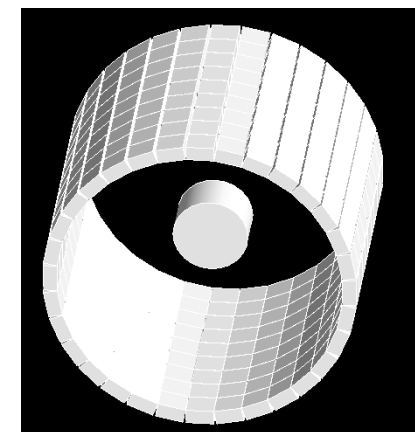
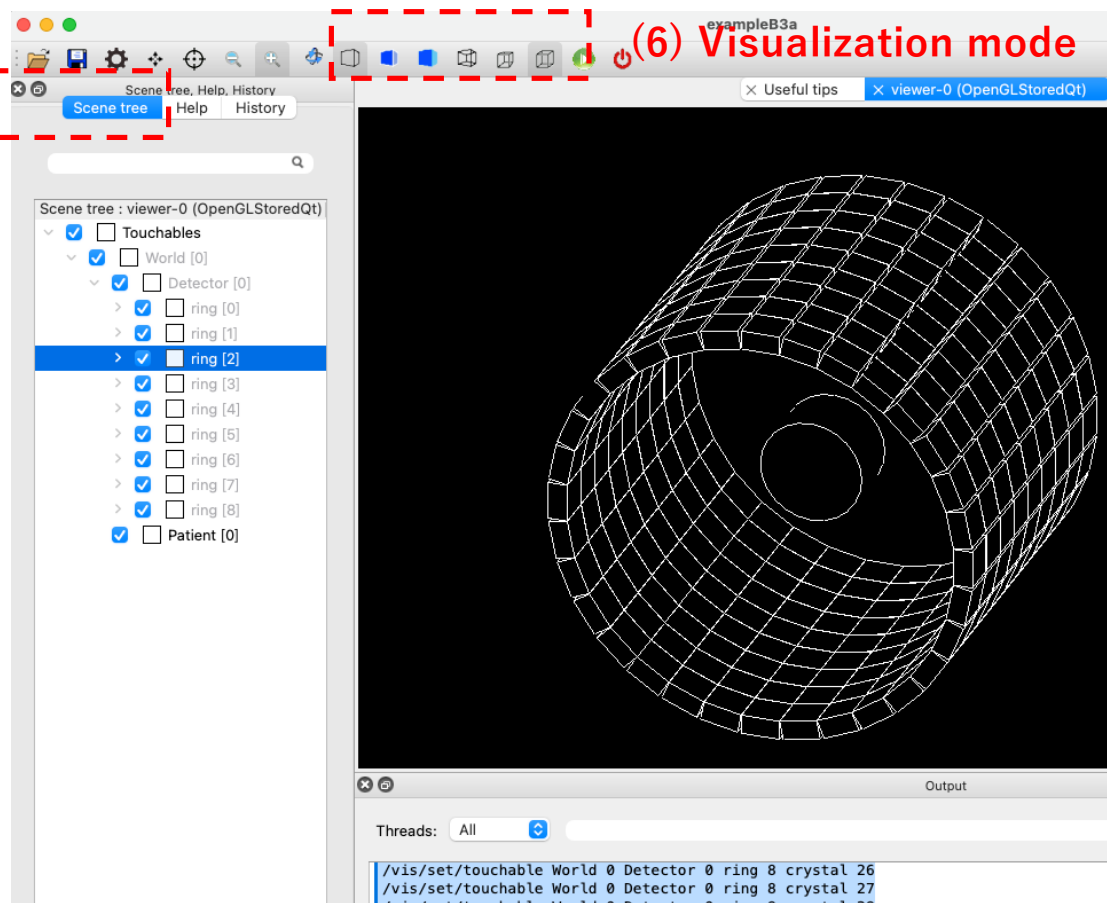
## Qt GUI interface w/ example3a (2) [Hands-on]

- Qt window

(5) Scene tree

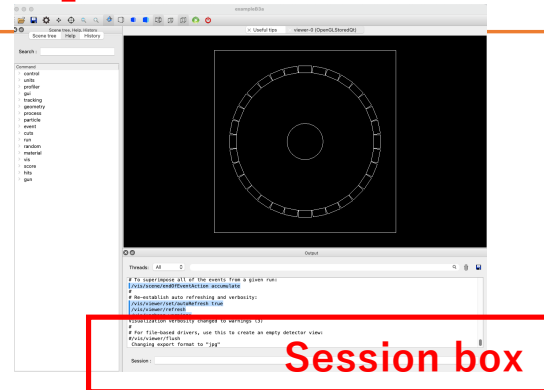
(6) Visualization mode

The geometrical structure



# Geant4 basic commands (1) [Hands-on]

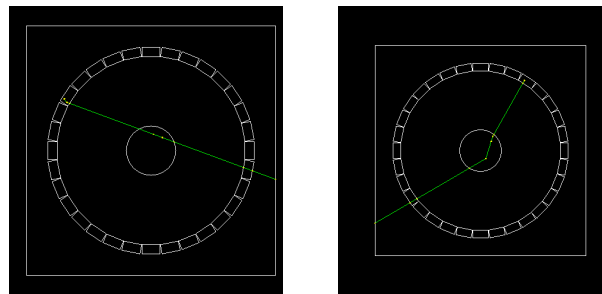
- Try to use the commands in **session box**
- Viewer reset
  - `/vis/viewer/reset`
- Geometry overlapping checker
  - `/geometry/test/run`
- Generate primary particles
  - `/run/beamOn 1`
  - `/run/beamOn 1`
- Visualization OFF/ON
  - `/vis/disable`
  - `/run/beamOn 1`
  - `/vis/enable`
  - `/vis/beamOn 1`



## Geometry overlapping checker

```

/geometry/test/resolution
/geometry/test/recursion_start
/geometry/test/recursion_depth
/geometry/test/run
/geometry/test/run
Running geometry overlaps check...
Checking overlaps for volume Detector:0 (G4Tubs) ... OK!
Checking overlaps for volume ring:0 (G4Tubs) ... OK!
Checking overlaps for volume crystal:0 (G4Box) ... OK!
Checking overlaps for volume crystal:1 (G4Box) ... OK!
Checking overlaps for volume crystal:2 (G4Box) ... OK!
Checking overlaps for volume crystal:3 (G4Box) ... OK!
Checking overlaps for volume crystal:4 (G4Box) ... OK!
Checking overlaps for volume crystal:5 (G4Box) ... OK!
Checking overlaps for volume crystal:6 (G4Box) ... OK!
Checking overlaps for volume crystal:7 (G4Box) ... OK!
Checking overlaps for volume crystal:8 (G4Box) ... OK!
Checking overlaps for volume crystal:9 (G4Box) ... OK!
Checking overlaps for volume crystal:10 (G4Box) ... OK!
Checking overlaps for volume crystal:11 (G4Box) ... OK!
Checking overlaps for volume crystal:12 (G4Box) ... OK!
Checking overlaps for volume crystal:13 (G4Box) ... OK!
Checking overlaps for volume crystal:14 (G4Box) ... OK!
Checking overlaps for volume crystal:15 (G4Box) ... OK!
Checking overlaps for volume crystal:16 (G4Box) ... OK!
Checking overlaps for volume crystal:17 (G4Box) ... OK!
Checking overlaps for volume crystal:18 (G4Box) ... OK!
Checking overlaps for volume crystal:19 (G4Box) ... OK!
    
```



# Geant4 basic commands (2) [Hands-on]

• Dump the track information for debugging purpose

- /tracking/verbose 1
- /run/beamOn 1
- /tracking/verbose 0
- /run/beamOn 1

• Exit the application

- exit

```
G4WT1 > /tracking/verbose 1
=====  
--> G4TaskRunManager::CreateAndStartWorkers() --> Creating 1 tasks with 1 events/task...  
=====  
Adding task 0 to task-group...  
G4WT0 > ### Run 0 starts on worker thread 0.  
G4WT0 > ### Run 0 start.  
G4WT0 > ... set ntuple merging row mode : row-wise - done  
G4WT0 >  
G4WT0 > *****  
G4WT0 > * G4Track Information: Particle = F18, Track ID = 1, Parent ID = 0 *****  
G4WT0 > *****  
G4WT0 > Step#      X          Y          Z          KineE      dEStep    StepLeng  TrakLeng  Volume    Process  
G4WT0 > 0  3.653 cm  4.229 cm  3.895 cm    1 eV      0 eV      0 fm      0 fm      Patient  initStep  
G4WT0 > 1  3.653 cm  4.229 cm  3.895 cm    0 eV      1 eV     1.372 nm  1.372 nm  Patient  ionIoni  
G4WT0 > 2  3.653 cm  4.229 cm  3.895 cm    0 eV      0 eV      0 fm     1.372 nm  Patient  RadioactiveDecay  
G4WT0 >  
G4WT0 > *****  
G4WT0 > * G4Track Information: Particle = e+, Track ID = 4, Parent ID = 1 *****  
G4WT0 > *****  
G4WT0 > Step#      X          Y          Z          KineE      dEStep    StepLeng  TrakLeng  Volume    Process  
G4WT0 > 0  3.653 cm  4.229 cm  3.895 cm  214.2 keV  0 eV      0 fm      0 fm      Patient  initStep  
G4WT0 > 1  3.667 cm  4.227 cm  3.917 cm    0 eV     214.2 keV  467.5 um  467.5 um  Patient  eIoni  
G4WT0 > 2  3.667 cm  4.227 cm  3.917 cm    0 eV      0 eV      0 fm     467.5 um  Patient  annihil  
G4WT0 >  
G4WT0 > *****  
G4WT0 > * G4Track Information: Particle = gamma, Track ID = 6, Parent ID = 4 *****  
G4WT0 > *****  
G4WT0 > Step#      X          Y          Z          KineE      dEStep    StepLeng  TrakLeng  Volume    Process  
G4WT0 > 0  3.667 cm  4.227 cm  3.917 cm   511 keV    0 eV      0 fm      0 fm      Patient  initStep  
G4WT0 > 1  7.487 cm  2.82 cm   2.483 cm   511 keV    0 eV     4.316 cm  4.316 cm  Patient  Transportation  
G4WT0 > 2  29.97 cm  -5.462 cm -5.956 cm   511 keV    0 eV     25.4 cm  29.72 cm  World   Transportation  
G4WT0 > 3  29.97 cm  -5.463 cm -5.958 cm   511 keV    0 eV     42.14 cm  29.72 cm  ring    Transportation  
G4WT0 > 4  32.82 cm  -6.513 cm -7.028 cm   511 keV    0 eV      3.22 cm  32.94 cm  crystal Transportation  
G4WT0 > 5  32.97 cm  -6.57 cm  -7.085 cm   511 keV    0 eV     1.738 mm  33.11 cm  ring    Transportation
```

Primary particle

trkid = 4  
e<sup>+</sup>  
Annihilation

trkid = 6  
gamma

Fluorine  
18  
Primary  
trkid = 1  
parentid = 0

Position

Volume

## Exercise (1) [Hands-on]

---

- Build and run the other example application
  - Recommend **eFLASH\_radiotherapy**
  - Source files: /opt/geant4/src/geant4-v11.1.2/examples/advanced/eFLASH\_radiotherapy

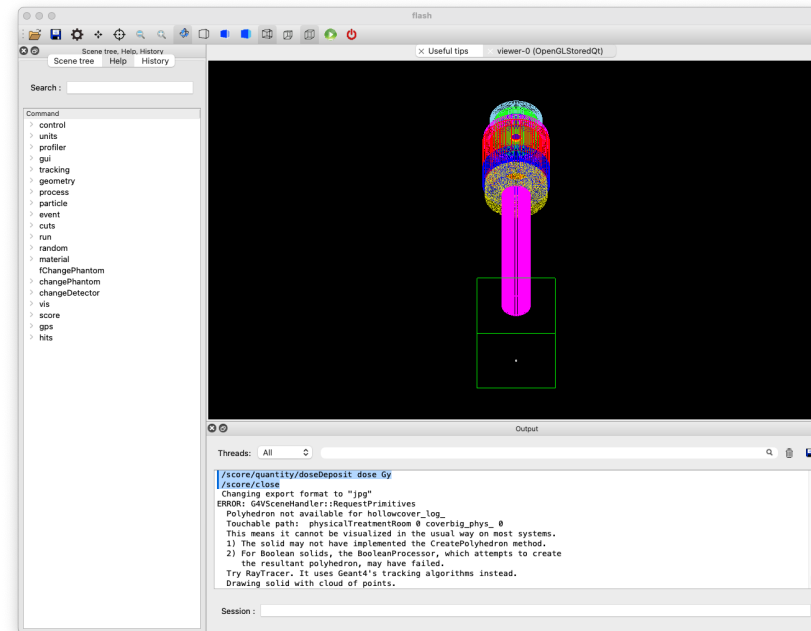
### Answer

```
$ cd
$ pwd (Check the current directory)
$ cp -r /opt/geant4/src/geant4-v11.1.2/examples/advanced/eFLASH_radiotherapy .
$ mkdir eFLASH_radiotherapy-build
$ cd eFLASH_radiotherapy-build
$ pwd (Check the current directory)
$ cmake ../eFLASH_radiotherapy
$ make
$ ls -l (Check the filename of executable)
$ ./flash
```

## Exercise (2) [Hands-on]

- Session:

- /geometry/test/run
- /tracking/verbose 1
- /run/beamOn 1
- /tracking/verbose 0
- /run/beamOn 10
- exit





## A Hands-on example code of this tutorial [\[Hands-on\]](#)

---

- *Galet*, *Geant4 application templet*

- A simple Skelton code for rapid prototyping of a Geant4 application
- Download from the Indico of this lecture using your browser in VM.

- [Galet-v11-MedEx-01.tar.gz](#)

- Then extract the tarball (Ensure you are in your home-directory)

```
$ cd
```

```
$ tar zxvf ~/Downloads/Galet-v11-MedEx-01.tar.gz
```

```
or $ tar xvf ~/Downloads/Galet-v11-MedEx-01.tar
```

- Build the *Galet*

```
$ cd
```

```
$ mkdir Galet-v11-MedEx-01-build
```

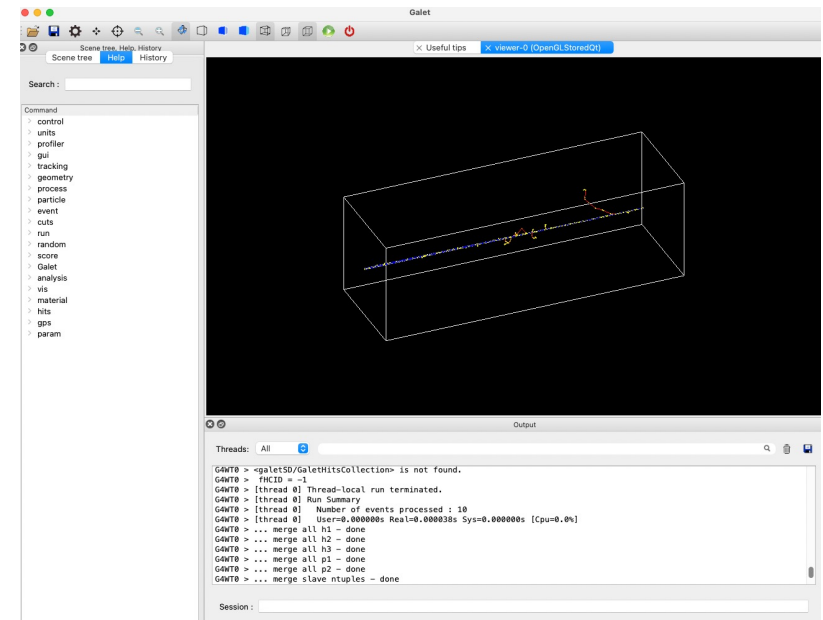
```
$ cd Galet-v11-MedEx-01-build
```

```
$ cmake ../Galet-v11-MedEx-01
```

```
$ make
```

## Galet run options [Hands-on]

- Help of run options  
`$ ./Galet -h`
  - Usage: `$ Galet [-m macro ] [-u UIsession] [-t nThreads]`
- Run the Galet w/ GUI mode  
`$ ./Galet`  
**Session: /run/beam0n 10**  
**Session: exit**
- Run the Galet w/ CUI  
`$ ./Galet -u tcsh`  
**Idle> /run/beam0n 10**  
**Idle> exit**
- Run the Galet in batch mode w/ `run0.mac`  
`$ ./Galet -m run0.mac`
- Run the Galet w/ two threads in batch mode.  
`$ ./Galet -t 2 -m run0.mac`



## Directories and Files [Hands-on]

---

- Directory structure
  - Check files in the source directory

```
$ cd ~/Galet-v11-MedEx-01
$ ls -l
```
  - It shows:
    - REAME.md
    - CMakeLists.txt
    - **Galet.cc** (main program)
    - **init.mac** (Macro for initialization commands)
      - **phys.mac** (Macro for choosing physics constructors)
      - **gps.mac** (Macro for primary particle )
    - **vis.mac** (Macro for visualization commands)
    - **run0.mac** (Sample macro for batch mode)
    - **include/** (Directory for .hh files)
    - **src/** (Directory for .cc files )

# Macro files specialized in Galet

## run0.mac (for batch mode)

```
## Mandatory for initialization
/control/execute init.mac
#
## Start simulation
/run/beamOn 10
```

## init.mac

```
#
# Galet macro: init.mac
#
/control/verbose 2
/control/saveHistory
/run/verbose 1
#
# physics list
/control/execute phys.mac
#
# Initialize kernel
/run/initialize
#
# Primary particle
/control/execute gps.mac
#
```

## phys.mac

```
#####
# EM processes including generic ions.
#####
#/Galet/physics/register G4EmStandardPhysics
#/Galet/physics/register G4EmStandardPhysics_option1
#/Galet/physics/register G4EmStandardPhysics_option2
#/Galet/physics/register G4EmStandardPhysics_option3
#/Galet/physics/register G4EmStandardPhysics_option4
#/Galet/physics/register G4EmLivermorePhysics
#/Galet/physics/register G4EmPenelopePhysics
#/Galet/physics/register G4EmDNAPhysics
#####
..snipped
```

## gps.mac

```
#-----
# Proton pencil beam
#-----
/gps/position 0. 0. 150. cm
/gps/direction 0. 0. -1.
/gps/energy 200. MeV
/gps/particle proton
..snipped
```

# Basics about Directories and Files in Galet-v11-MedEx

---

- File structure (Only important files for the first step are listed here)

- **Galet.cc** (main program)

\$ ls src

**runManager->**  
**SetUserInitializtion()**

- **DetectorConstruction.cc**
- **PhysicsList.cc**
- **ActionInitialization.cc**

**actionInitialization->**  
**SetUserAction()**

- **PrimaryGenaratorAction.cc**
- **RunAction.cc**
- **EventAction.cc**
- SteppingAction.cc
- TrackingAction.cc

## Take a look at the main program, Galet.cc [Hands-on]

\$ less Galet.cc

type [space] to scroll down,  
type [b] to scroll back,  
type [q] to exit

**runManager->**  
**SetUserInitializtion()**

```
//  
// Construct the default run manager  
auto* runManager =  
    G4RunManagerFactory::CreateRunManager(G4RunManagerType::Default);  
#ifdef G4MULTITHREADED  
    if ( nThreads > 0 ) {  
        runManager->SetNumberOfThreads(nThreads);  
    }  
#endif  
  
//  
// Scoring Manager  
G4ScoringManager* scManager = G4ScoringManager::GetScoringManager();  
scManager->SetVerboseLevel(1);  
  
//  
// Set mandatory initialization classes  
// Detector-Construction and ParallelWorld-Construction  
auto detConstruction = new Galet::DetectorConstruction();  
//  
// Parallel world geometry registration.  
//G4String paraWorldName = "paraWorld1";  
//auto* paraWorld = new Galet::ParallelWorldConstruction(paraWorldName);  
//detConstruction->RegisterParallelWorld(paraWorld);  
runManager->SetUserInitialization(detConstruction);  
  
//  
// PhysicsList  
auto physicsList = new Galet::PhysicsList;  
runManager->SetUserInitialization(physicsList);  
  
//  
// ActionInitialization  
auto actionInitialization = new Galet::ActionInitialization();  
runManager->SetUserInitialization(actionInitialization);  
  
//  
// Initialize visualization  
auto visManager = new G4VisExecutive;
```

## Take a look at the ActionInitialization.cc [Hands-on]

\$ less src/ActionInitialization.cc

type [space] to scroll down,

type [b] to scroll back,

type [q] to exit

actionInitialization->  
SetUserAction()

```
/// ActionInitialization
///
/// (Authors)
/// 2023-04-21 T.Aso, C.Omachi, T.Toshito, T. Yamashita
///
#include "ActionInitialization.hh"
#include "PrimaryGeneratorAction.hh"
#include "RunAction.hh"
#include "EventAction.hh"
#include "SteppingAction.hh"
#include "TrackingAction.hh"

namespace Galet{
//....ooo0000ooo.....ooo0000ooo.....ooo0000ooo.....ooo0000ooo.
void ActionInitialization::BuildForMaster() const
{
  SetUserAction(new RunAction);
}
//....ooo0000ooo.....ooo0000ooo.....ooo0000ooo.....ooo0000ooo.
void ActionInitialization::Build() const
{
  SetUserAction(new PrimaryGeneratorAction);
  SetUserAction(new RunAction);
  SetUserAction(new EventAction);
  SetUserAction(new SteppingAction);
  SetUserAction(new TrackingAction);
}
//....ooo0000ooo.....ooo0000ooo.....ooo0000ooo.....ooo0000ooo.
}
}
(END)
```

## Summary

---

- You briefly learn about the medical example applications in the Geant4 distribution
- Now you can build and run these examples
  - make a build directory
  - using commands of cmake and then make
- You can check the simulation on GUI
  - Qt viewer
  - UI commands, `/run/beamOn`, `/tracking/verbose`, `/vis/disable` etc.
- You are ready for the next hands-on with an example code, Galet
  - Galet run options
  - macro files ( and `/control/execute` command)
  - File structure of Galet example code