HADRONTHERAPY

a Geant4 application for proton and ion radiotherapy

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More informations on the Hadrontherapy example can be found in the Hadrontherapy Documentation available at
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INTRODUCTION.

The hadrontherapy example simulates an hadron-therapy beam line. In particular the example models the specific proton therapy beam line installed at Laboratori Nazionali del Sud (INFN) in Catania, Italy. This beam line is modelled inside the PassiveProtonBeamLine.cc file. However any other geometry can be simulated and in the next future an acvive beam line will be also simulated.
In the example directory, inside the "macro" folder two macro files are actually provided for the use of hadrontherapy with proton and carbon beams: proton_therapy.mac and ion_therapy.mac.
The proton_therapy.mac permits to run a simulation with the whole passive beam line installed in Catania.
The carbon_therapy.mac excludes all the elements (moving the origin of the ion beam close to the water phantom) and reproduce a simple passive beam line for the use with carbon beams.

GEOMETRICAL SET-UP.

The idea of *Hadrontherapy* is to provide a tool useful for applications in the field of proton and ion therapy. These can include the simple calculation of dose distribution curves in water or other materials, the derivation of important transport parameters (stopping powers, ranges, etc.) in different geometrical set-ups and for different materials, up to the complete simulation of a real transport beam line for therapy.

The main component of the simulation is the phantom, a box that ca be filled with different material and where the score of different information (at moment only the energy deposited in voxels) can be performed. A more complete description of the phantom is given in the next subsection.

At moment the *Hadrontherapy* include the simulation of the proton beam line for eye-treatments installed at the INFN-LNS facility in Catania. This is a passive beam line and it is simulated in the file PassiveProtonBeamLine.cc.

In the next future an ActiveProtonBeamLine.cc will be provided for the simulation of the active scanning treatment modality.
Moreover the possibility to add a very simple set-up (a beam, a phantom where collect the informations and some simple component) will be also provided.

All these configuration will be setted by macro commands.

The water phantom to collect informations

At the end of the beam line a phantom (a box of uniform material) is reproduced. Inside it, a user-defined region is divided (via the ROGeomtry classes of Geant4) in cubic and identical voxels. The voxels size can be varied as well as the voxelized regio.
At the end of a simulation run the energy deposited by primaries and secondaries in each voxel is collected. This information is available as an .out file or as a .root (if the G4ANALYSIS_USE variable is defined and the AIDA interface is activated).

The default sizes of the active voxelized region are 40x40x40 mm and actually the voxel configuration is 200 x 1 x 1, which means 200 slices with 0.2 mm of thickness.
Of course this default can be modified in order to obtain, for example, a matrix of 80x80x80 cubic voxels each with a lateral dimension of 0.5 mm.

As concern the cut and stepMax values, the default configuration implies a cut value of

0.01 mm in the whole world (use the command /physic/setCuts 0.01 mm) and a stepMax of 0.01 mm just in the phantom (use the command /Step/waterPhantomStepMax 0.01 mm).
In any case it is strongly recommended to use a stepMax value not bigger than 5% of the dose slice thickness.

The Proton passive beam line

The elements simulated in the PassiveBeamLine.cc file are:

1. A scattering system, to spread geometrically the beam;

2. A system of collimators, to avoid the scattering radiation;

3. A modulation system that spreads the beam in energy and produces the so-called spread out Bragg peak; It is constituted by a rotating wheel of different thicknesses. The wheel rotates around is axis (parallel to the proton beam axis) and its movement can be obtained by means of a messenger between runs.

4. A set of monitor chambers (special transmission ionisation chambers used to control the particle flux during the irradiation);

5. A final long collimator and a patient collimator defining the final shape of the beam before reaching the patient.

6. A water phantom: it is a box of water where the energy deposit is calculated. The use of the water phantom is required by the international protocol on the measure of dose in the case of proton and ion beams (IAEA 398, 2000).

PHYSICS

A particular care is addressed to the simulation of the physic processes.
Three different approaches can be used for the choose of the physic models.

Approach 1:

Using the macro command:
/physic/addPhysics/<physics List name>.

In this case the models (for electromagnetic, hadronic elastic and hadronic inelastic) can be
activated directly calling the name of the Physics Lists that are available inside the Geant4 kernel in the directory:

$G4INSTALL/source/physics_lists/builders/include

An example of the use of the Physics List can be found in the macro files:
proton_therapy.mac and ion_therapy.mac

Approach 2:

A set of built-in physic models are also contained inside the Hadrontherapy directory. These
are called Local*.cc and Local*.hh and can be activated using the macro command:
/physic/addPhysics/<name>.

Approach 3:

We developed this approach in order to simplify the choice of the physic models to be used in the application.
With this approach the user must only insert a command line in his/her .mac file using the: /physics/addPackage <PACKAGE_NAME>

This permits to switch-on an already build physic package.
Various packages are already present in the Geant4 tree: they are in the directory: geant4/source/physics_lists/lists/include

In this case hadronic inelastic models are directly activated for every particle.

SUGGESTED PHYSIC FOR ION BEAMS IN THE RANGE 0 - 400 MeV

Two macro files (proton_therapy.mac and ion_therapy.mac) can be used for proton and ion
simulations.

Also the QGSP_BIC package can be used if the *Approach 3* is preferred.

EXPERIMENTAL SET-UP.

The following is the description of the elements of the proton beam line of the Laboatori Nazionali del Sud in Catania (I). This line is completely simulated inside the class PassiveProtonBeamLine.cc.

The main elements are:

- The COLLIMATORS: placed along the beam line to collimate the beam;
- The RANGE SHIFTERS: to decrease the energy of the primary proton beam to a specific value;
- The MODULATOR WHEEL: to modulate the energy of the primary and mono-energetic beam in to a wide spectrum. The energy modulation is necessary to homogeneously irradiate a tumour volume that can extends in depth up to 20 mm;
- The MONITOR CHAMBERS: very thin ionisation chamber that permit the dose monitoring during the patient irradiation;
- The MOPI detector: microstrips, air free detector utilised for the check of the beam symmetry during the treatment;
- The PATIENT COLLIMATOR: a brass, tumour-shaped collimator able to confine the proton irradiation field in order to irradiate just the tumour mass in the transverse direction;

The user has the possibility to vary, via messenger, almost all the geometrical characteristics of the beam line elements (i.e. their position along the beam line, their thickness, etc.). More details on the available user messengers can be found in the Hadronterapy Documentation: http://workgroup.lngs.infn.it/geant4lns/).

SOFTWARE SET-UP

A standard Geant4 example GNUmakefile is provided

README file of Hadrontherapy, a Geant4 application for proton and ion radiotherapy

The following section reports the necessary environment variables
necessary for the run of Hadrontherapy.

Enviroment variables

- G4SYSTEM = Linux-g++
- G4INSTALL points to the installation directory of GEANT4;
- G4LIB point to the compiled libraries of GEANT4;
- G4WORKDIR points to the work directory;
- CLHEP_BASE_DIR points to the installation directory of CHLEP;
- G4LEVELGAMMADATA points to the photoevaporation library;
- G4NEUTRONHPDATA points to the neutron data files;
- G4RADIOACTIVEDATA points to the libraries for radio-active decay hadronic processes;
- G4ABLADATA points to the library of the INCL/ABLA hadronic model;
- G4LEDATA points to the low energy electromagnetic libraries
- LD_LIBRARY_PATH = $CLHEP_BASE_DIR/lib:$LD_LIBRARY_PATH

Visualisation

The user can visualise the experimental set-up with OpenGL, DAWN and vrml

How to run the example

In interactive mode:
> $G4WORDIR/bin/Linux-g++/Hadrontherapy
The defaultMacro.mac is executed

The primary particle beam parameter are:
Radiation: proton beam;
Energy distribution: gaussian;
Mean energy: 62.0 MeV;
Energy spread: 400 keV;

The modulator wheel can be rotated with the following command:

/modulator/angle/xx deg

To produce a Spread Out Bragg Peak using the modulator a macro (modulatorMacro.mac) is provided. With this macro the modulator is rotated of 360 degree at 1 deg steps. In each run 1000 protons are generated as primary particles. Obviously a bigger resolution can be obtained with smaller angles or increasing the protons number in each run.

Modulator wheel can be omitted setting its material air.

run $G4WORKDIR/bin/Linux-g++/Hadrontherapy visualisationMacro.mac
to visualise the experimental set-up with OpenGL

SIMULATION OUTPUT

ASCII file

A .out file os generated at the end of each run (DoseDeposited.out) is its default name that an be changed in the HadrontherapyMatrix.cc file.
The file contains four columns; the first four columns represent the voxel indexs (that univocally identify the voxel volume) while the last column represent the energy deposited in the given voxel.

Use of the AIDA interface

The output is an .hbk file and a .root files. The files are produced if the variable G4ANALYSIS_USE is set to 1 and the analysis tool (AIDA interface) correctly installed.
The file contains histograms and n-tuples.
The histograms contain the Bragg curves: energy deposited
versus the depth in water (in mm) for the primary beam as well as all the secondaries produced.
The n-tuple contains the total 3D energy deposit in the phantom; the information
is energy deposit in each voxel with respect to the position of the voxel.

Setup for analysis: AIDA 3.2.1

Users can download the analysis tools from:
http://aida.freehep.org/

Note that the same information can be stored in different format,
like .root or .xml using the same AIDA interface.

Please contact cirrone@lns.infn.it for more details or suggestions and feedback on this document