Latest developments in GAMOS

P. Arce[1], J.I. Lagares, J.I.[1], L. Harkness-Brennan[2], D. Pérez-Astudillo[3], M. Cañadas[1], P. F. Rato[1], M. de Prado[4], Y. Abreu[5], G. di Lorenzo[6], M. Kolstein[7], A. Díaz[5], A. Glaser[8], L. Desorgher[4], A. Fernández[9]

[1] CIEMAT, Medical Physics Unit, Madrid, Spain
[2] Liverpool, Oliver Lodge Laboratory, Liverpool, UK
[3] Qatar Foundation, Qatar Env. & Research, HBKU, Qatar
[4] Paul Scherrer Institute, Villigen, Switzerland
[5] CEADEN, La Habana, Cuba
[6] SAP SE, Walldorf, Germany
[7] IFAE, Barcelona, Spain
[8] Dartmouth College, Thayer Sch. Eng. New Hampshire, USA
[9] Centro Guadalinfo de Santisteban del Puerto, Jaén, Spain

IVth Geant4 International User Conference
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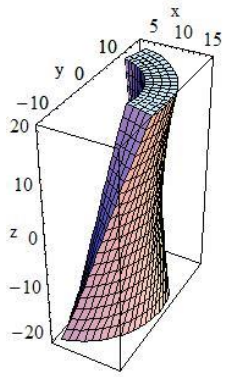
Outline

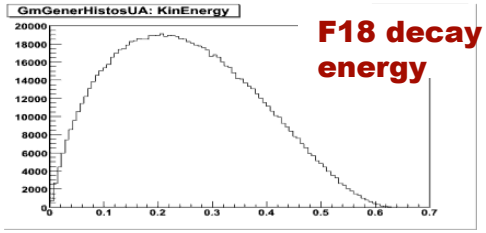
- Introduction: An easy and flexible framework
- 2D detailed visualization
- Biasing: Geant4 biasing + General importance sampling
- DICOM management
- Protontherapy tutorial
- LET+RBE
- Controlling the verbosity
- GAMOS on Windows (native)
  - GAMOS Graphical User Interface
- Nuclear Medicine Dosimetry GUI
- Testing the code robustness
- Summary

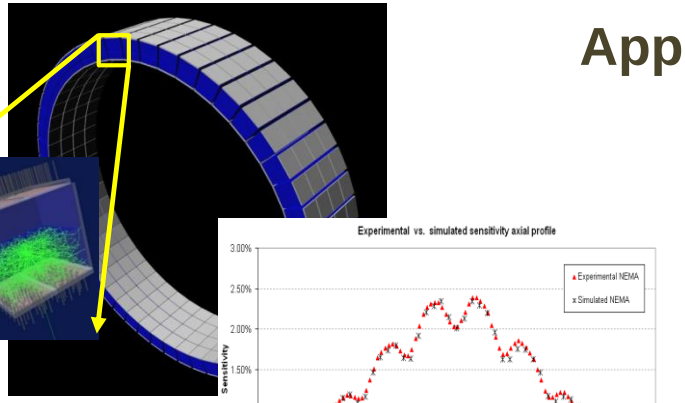
An easy…

A scripting language, instead of C++, plus many tools to facilitate the definition of input and output



- ✓ Any geometry in a text file format
  - ➢ Including superposition's of parallel geometries
  - ➢ Several modules to define in a few lines the most complicated parts (jaws, multi-leaf collimators, range modulators,…)
- ✓ Dozens of distributions for primary particles: position, direction, energy **and time**
- ✓ Any available Geant4 physics
- ✓ + 100 scorers, including error calculation
- ✓ Many optimization options



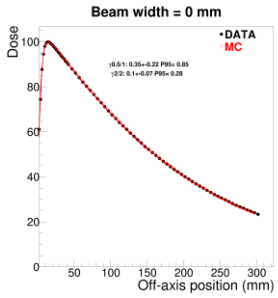


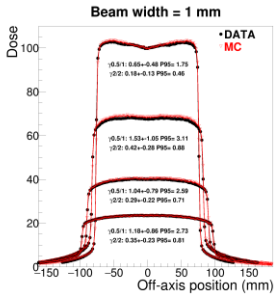
Applications focused of a physics field:

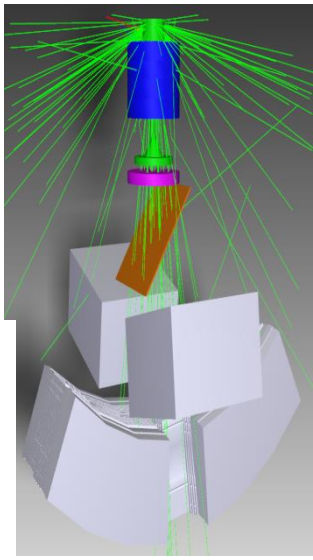
γ/e- radiotherapy,
proton/ion radiotherapy,

PET, SPECT, Compton Camera, tissue

optics, γ spectroscopy, shielding







… and flexible framework

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From its first design: Extensive use of plug-in technology (+800 plug-in's)

= you do not have to understand how GAMOS works to add new code

- ✓ User can easily extend the framework to satisfy a new requirement
- ✓ Any Geant4 example can be transformed into a GAMOS example

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Not behaving as a black box, but letting the user understand in detail each aspect of the simulation

- ➢ A new concept, **GAMOS data**, plus the use of **filters and classifiers**, allows to satisfy with a few user commands requirements as complex as:
  - Write in a file the logarithm of the energy of the gammas that reach the patient only if they have left some energy traversing the jaws
  - Score LET_D using only secondary protons generated in bone
  - ….

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Flexible use of the verbosity of each event/track/step and each package independently

- Choose for which event/tracks to have very detailed information
- Choose independently verbosity of geometry, physics, scoring, …

Obtaining detailed data of your simulation

- Most users are researchers, **it is not enough to provide some final results**, like a dose distribution, or a PET event classification table
  - Want to have a **deep understanding of what happens** in the simulation
  - Want to have the capability to **evaluate the reliability of the results**
  - Want to **choose the best physics configuration**

For example:

- How many gammas traverse completely the jaws? How much energy they lose?
- What is the length travelled by electrons produced by Compton interactions in a crystal?
- Dump in a binary file the position of the gammas as they cross a human body only if in the future this track or one of its descendants will leave a signal in one detector
- Make a histogram of the energy deposited in a water volume by any of the electrons that were created in a Compton interaction in the jaws volumes, only if they have an energy bigger than 1 MeV when they enter the water volume
- …
- Something we GAMOS developers have never imagined…

2D Detailed visualization

- Visualization is often needed to check the correctness of the geometry simulation
- GAMOS allows visualization with any Geant4 drive (although remember that some of them require the installation of an external package)

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☺ GAMOS provides a 2D visualization (ScanVis)

- Based on ray tracing (real tracking)
- Showing dimensions in detail

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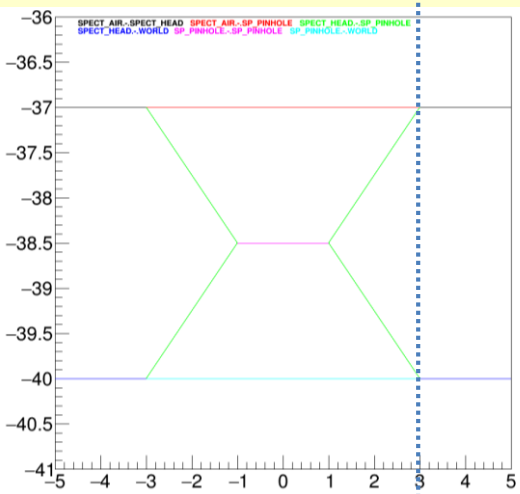
PROBLEM Ex. 1: mistyping some data

```
# Cone of Inner R = 1, Outer R = 2.5
:VOLU CONE 1. 3. 0.25 G4_Al
```

3D VRML view:
everything looks OK

2D GAMOS view:
Wrong pinhole dimensions detected
(should be 2, not 3 mm)



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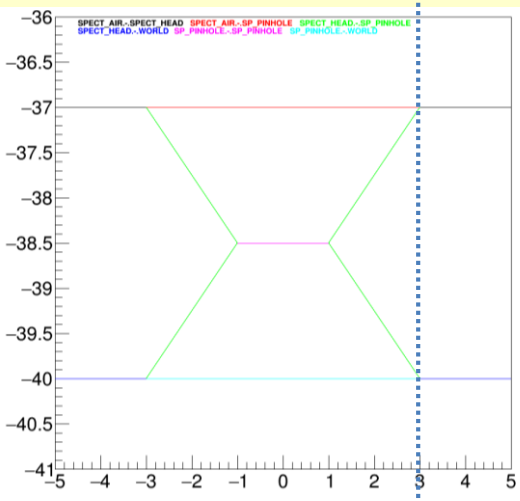
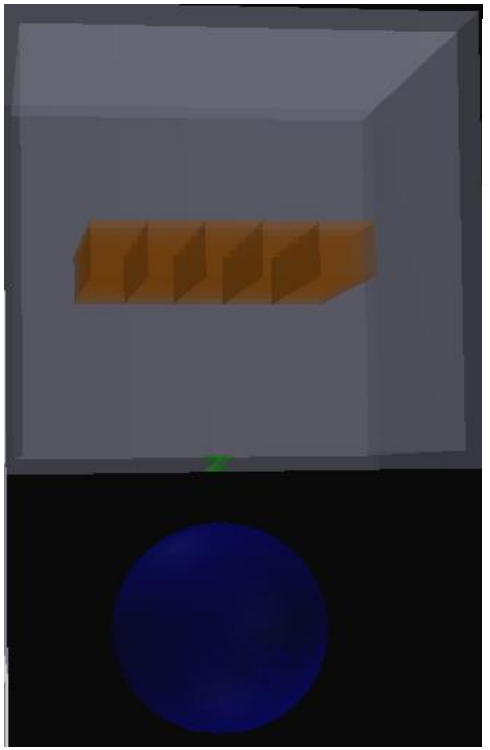
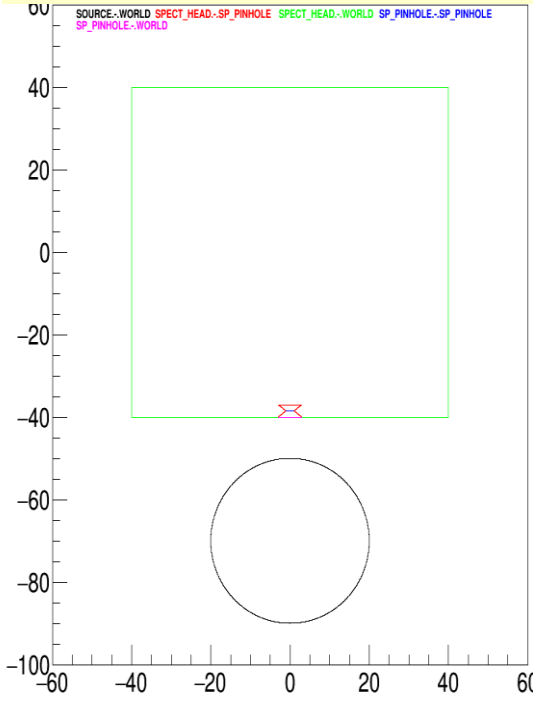


PROBLEM Ex. 2: detecting overlaps not seen by 3D visualization

3D VRML view:
everything looks OK



2D GAMOS view:
Placement in wrong mother detected



Biasing techniques

Biasing techniques

- **Bias generation distribution**
  - Variables to bias: PosX, PosY, PosZ, PosPerp, PosR, PosPhi, PosTheta, DirTheta, DirPhi, Energy, Time
  - User-defined distribution: P(V), V=Variable, P=Probability

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- **Geant4 biasing**
  - ✓ Cross Section change
    - Using a distribution (mult. factors as a function of energy, position, volumen, …)
  - ✓ Force Collision
  - ✓ Bremsstrahlung Splitting
  - ✓ Two more efficient BS techniques
    - ✓ Directional bremsstrahlung splitting
    - ✓ Equal-weight bremsstrahlung splitting
  - User command to choose particle, process and volume

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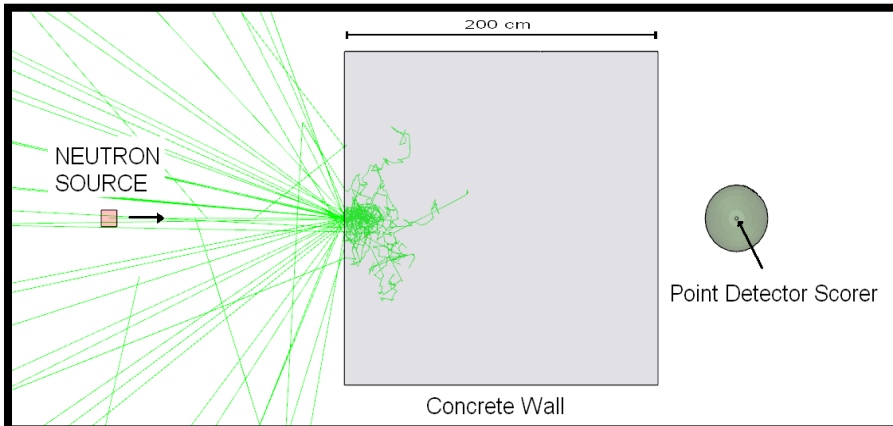
- **Point detector scoring**

- When fraction of particles that reach your detector is many orders of magnitude far from what you can simulate
- **Fundamental for radiation protection**



General importance sampling

/gamos/physics/VR/importanceSampling

- If Splitting Value > 1: particle will be split
- If Splitting Value < 1: Russian roulette will be played with the particle

✓ Define Splitting Value with a GAMOS distribution

- ➢ Different SV as a function of energy, position, volume, log10(posX*posY)*cos(posTheta), …

✓ Apply filters (only for some particle, some volumes, E<1 MeV, …)

✓ If you do not want that particles with very low weights are again and again, you may control it with a parameter

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❑ **Convergence testing** (based on G4ConvergenceTester)

✓ Check how trustable is your result (especially relevant when big weights are used)

➢ The results of eight convergence tests are shown, based on statistical variables of the scores:

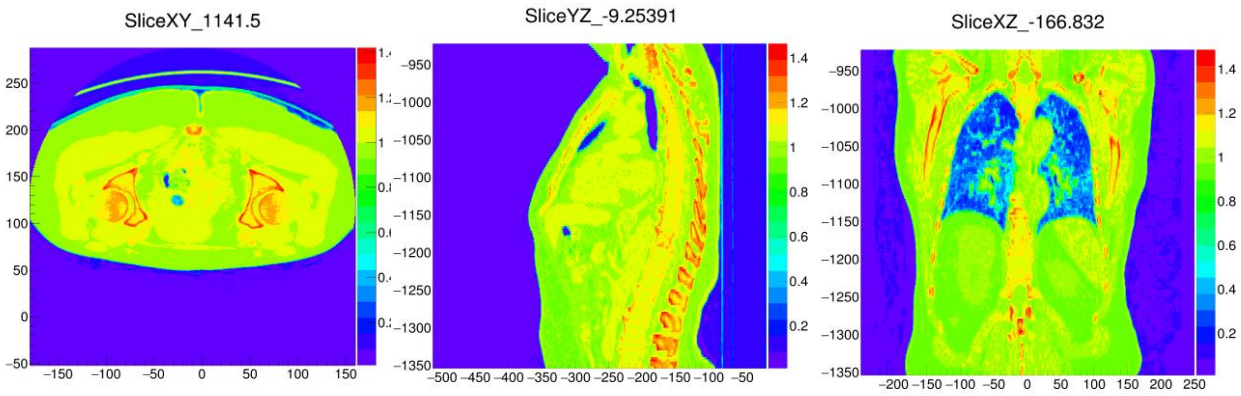
- Mean, estimated relative error (R), Variance, Variance of variance, FOM=1/(R*R)/CPU_time_of_last_event,

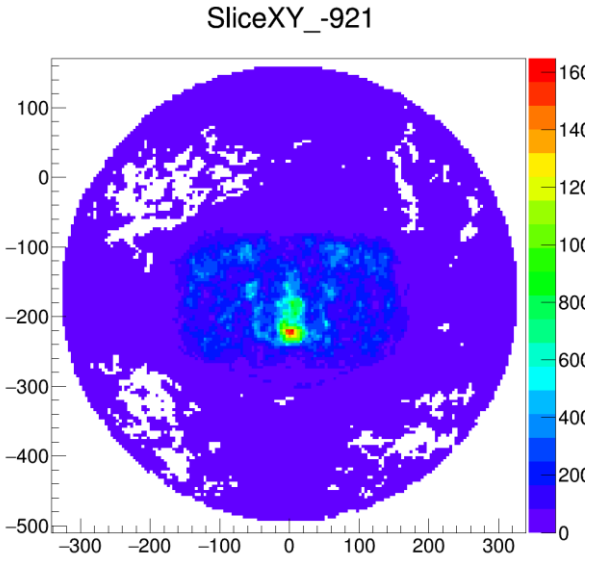
DICOM management

DICOM data processing based on *DcmTk* software

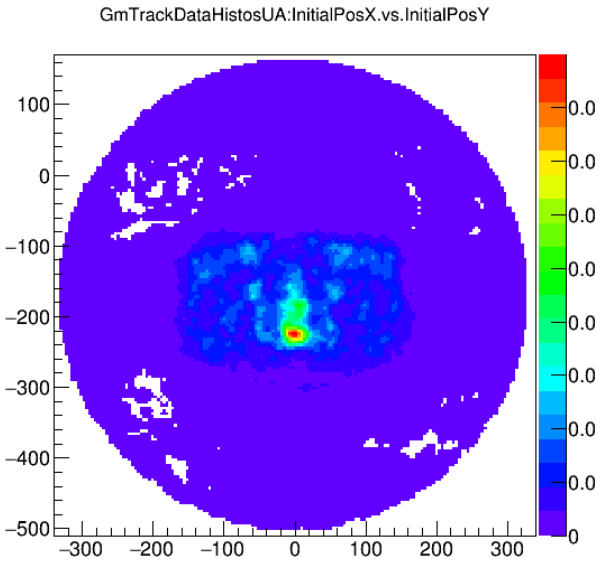
Can process any DICOM CT image, even in compressed format

✓ Tested of dozens of image sets





DICOM PET image

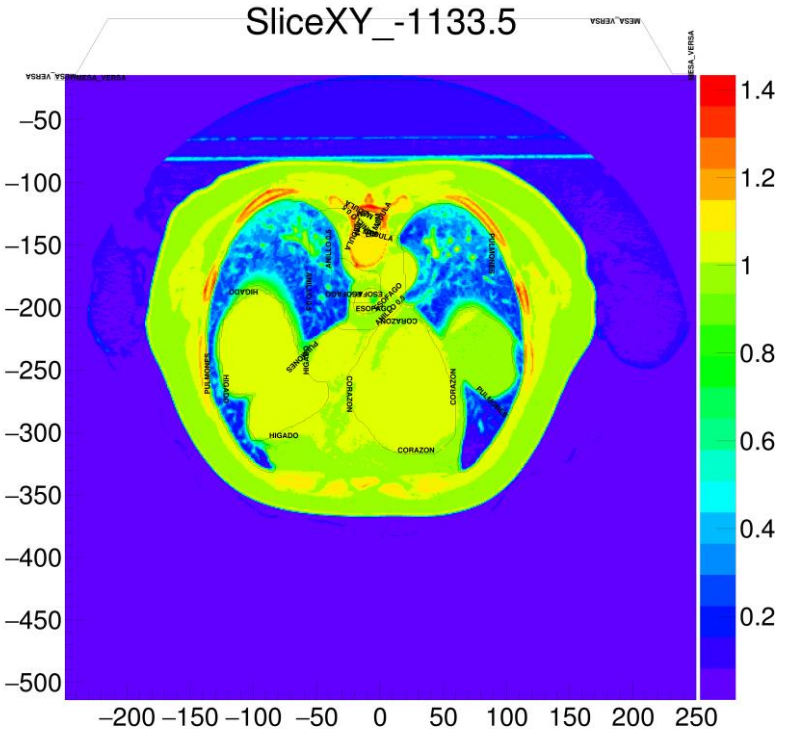


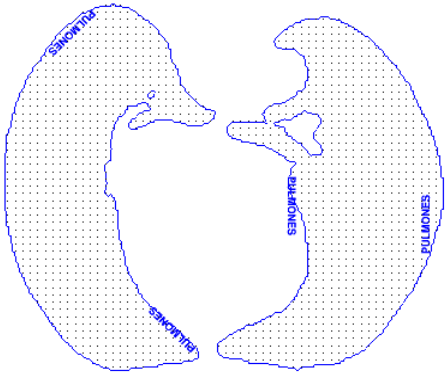
Initial position of GAMOS source particles

Use PET image data as source position

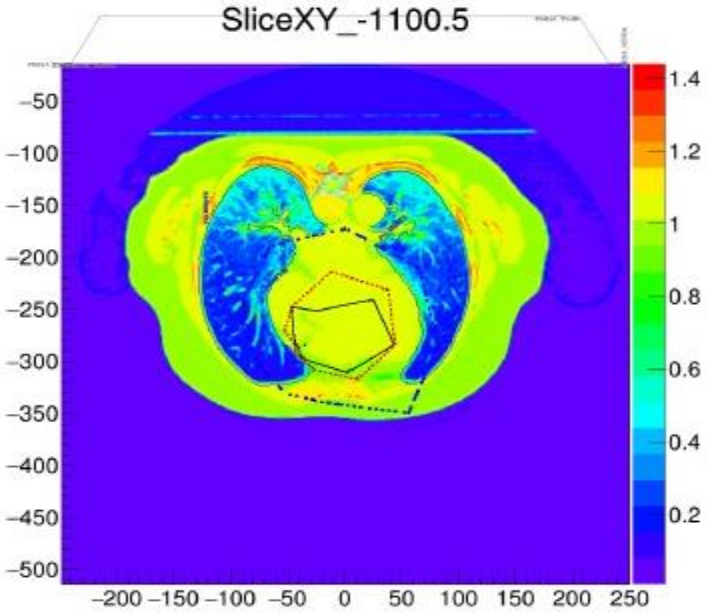
DICOM management

Superimpose RT structures (select line colour, style and width)



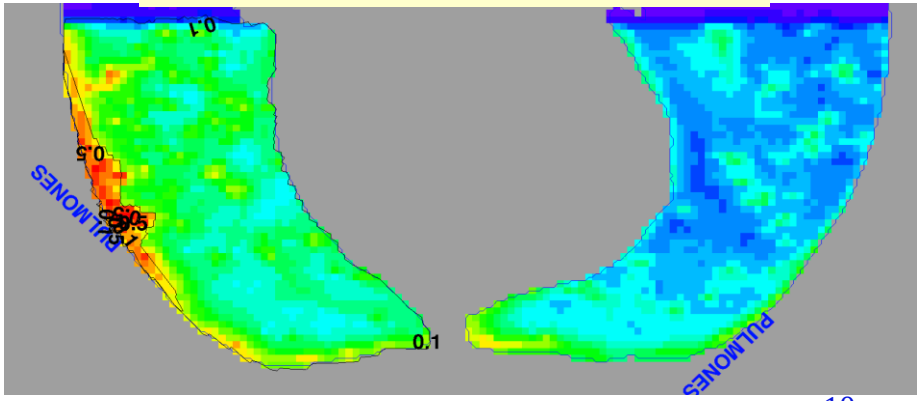


Robust algorithm to identify voxels in structures



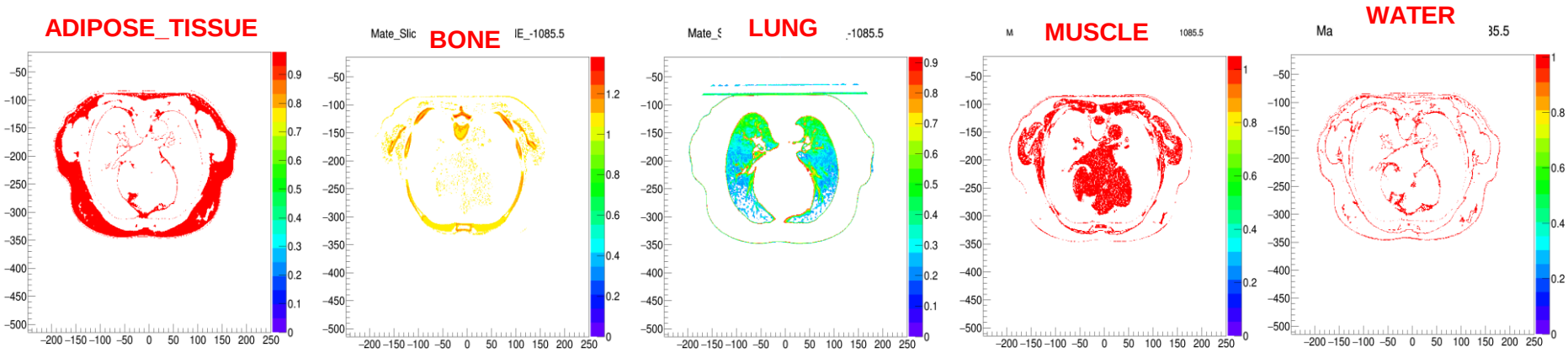
Read RTDOSE and build isodose lines

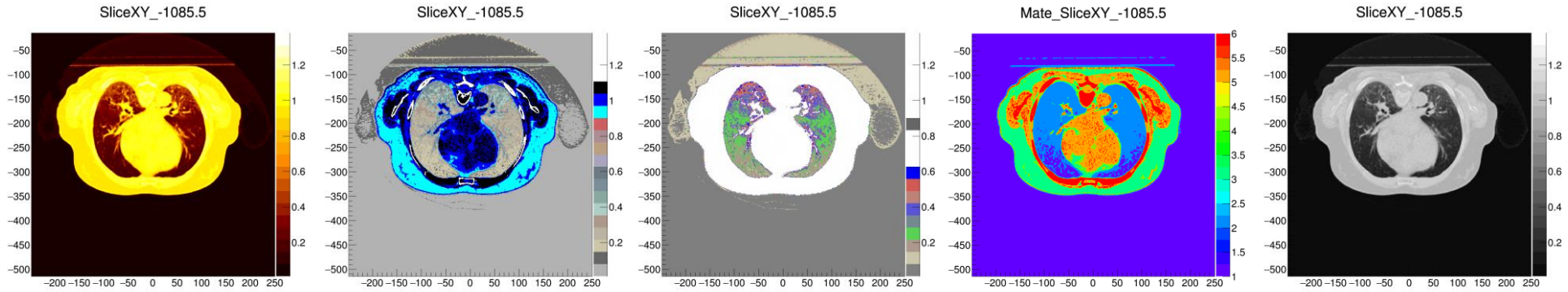
Calculate dose only in selected structures



DICOM management

Draw per material





64 colour palettes

- **Format of the image file: jpg (default), gif, png, eps, ps, pdf, svg, tiff, xpm)**

DICOM management

RTPLAN and RTIonPLAN files

✓ Convert DICOM data to text files, readable by Geant4 ASCII format code

⇨Geometry and beam data is automatically included

RTPlan_1
:P Number 1
:P NumberOfBeams 1
:P NumberOfFractionsPlanned 1

RTIonPlanBeam_1
:P BeamNumber 1
:P NumberOfControlPoints 42
:P NumberOfRangeModulators 0
:P NumberOfRangeShifters 0
:P VirtualSourceAxisDistance 2029.6
:PS BeamType "STATIC“
:PS RadiationType "PROTON"
:PS ScanMode "MODULATED”

RTIonPlanControlPoint_1_2
:P ControlPointIndex 2
:P CumulativeMetersetWeight 30.7095
:P GantryAngle 270
:P IsocenterPosition_Z 58.5
:P NominalBeamEnergy 195.2
:P NumberOfScanSpotPositions 433
:P ScanningSpotSize 9.44015
:P SnoutPosition 650
ScanSpotPositions
-55.0889 60.6304 0.144369
-48.4519 60.6304 0.152257
…

✓ The geometrical parameters can be used directly in the Geant4 ASCII geometry file

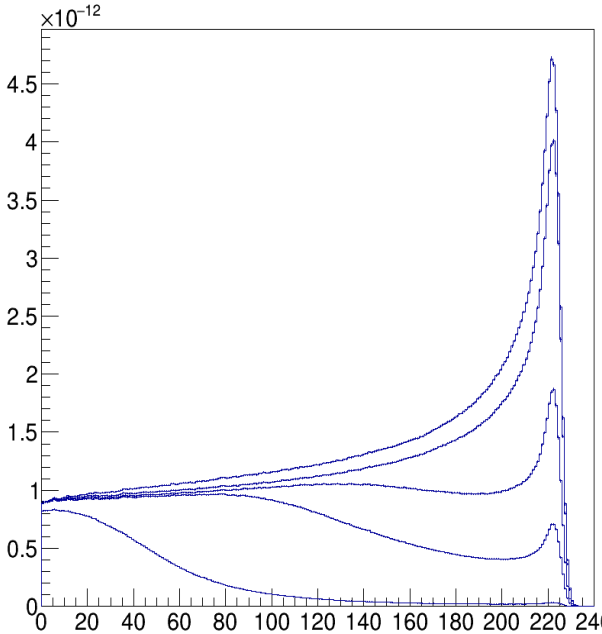
✓ The beam parameters are managed as a GAMOS Particle Source

➢ **Geometry and source are moved** and **energy changed** after a number of events proportional to the “meterset” of each ControlPoint

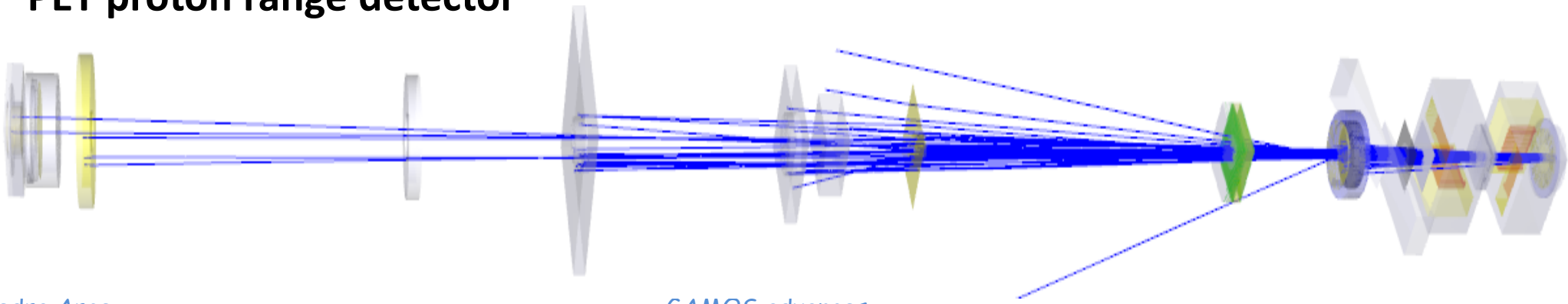
Protontherapy tutorial

A tutorial meant to make the user self-proficient in proton therapy simulation with GAMOS

- 20 exercises of increasing difficulty
- Should be done following instructions in GAMOS User's Guide…
- … but solutions are given for the user to help her/him to become self-proficient



- Any ion/proton therapy setup with simple text commands
- **LET / RBE Scorers**
- **PET proton range detector**



LET / RBE

LET

- Publications use a big variety of LET calculation: LET/LET dose weighted/LET track weighted, step dE/dx average dE/dx from spectrum, restricted/unrestricted, only from primary protons, …

✓ Any of these definitions can be used in GAMOS

✓ You can even define your own definition using GmCompoundScorer

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Phenomenological RBE models

✓ 9 models are available in GAMOS: Carabe, Chen, McNamara, Peeler, Tilly, Rørvik, Wilkens, Wedenberg, Mairani

✓ User may define its own one

✓ PIDE (Particle Irradiation Data ensemble) interfaced

- ➢ + 1,100 in-vitro cell survival experiments

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Mechanistic RBE models

✓ Interface with CATANA's ***Survival*** code will soon be available

- ✓ LEM I,II, III models
- ✓ MKM model

Controlling the verbosity

High verbosity is often necessary

- Find out the reason for a strange behavior
- Better understand some result

But **a too big verbosity output hampers the task**

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⇨ Verbosity should have a high degree of granularity

1. Switch on the verbosity only for a **selected group of events, or event tracks**
2. Control the degree of verbosity of **each simulation field** (geometry, particle generator, scoring, …) individually

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All this can be done in GAMOS

with the extra advantage of keeping a full control through user commands

```
### GAMOS SENSITIVE DETECTOR VERBOSITY IN EVENT 1138
/gamos/userAction GmGamosVerboseByEventUA
/gamos/verbosity/byEvent GmSDVerbosity debug 1138 1138

### GEANT4 VERBOSITY IN EVENT 1138
/gamos/setParam GmTrackingVerboseUA:EventMin 1138
/gamos/setParam GmTrackingVerboseUA:EventMax 1138
/gamos/userAction GmTrackingVerboseUA
```

GAMOS on Windows (native)

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GAMOS can be on used on Windows as a native distribution, **no virtual machine**

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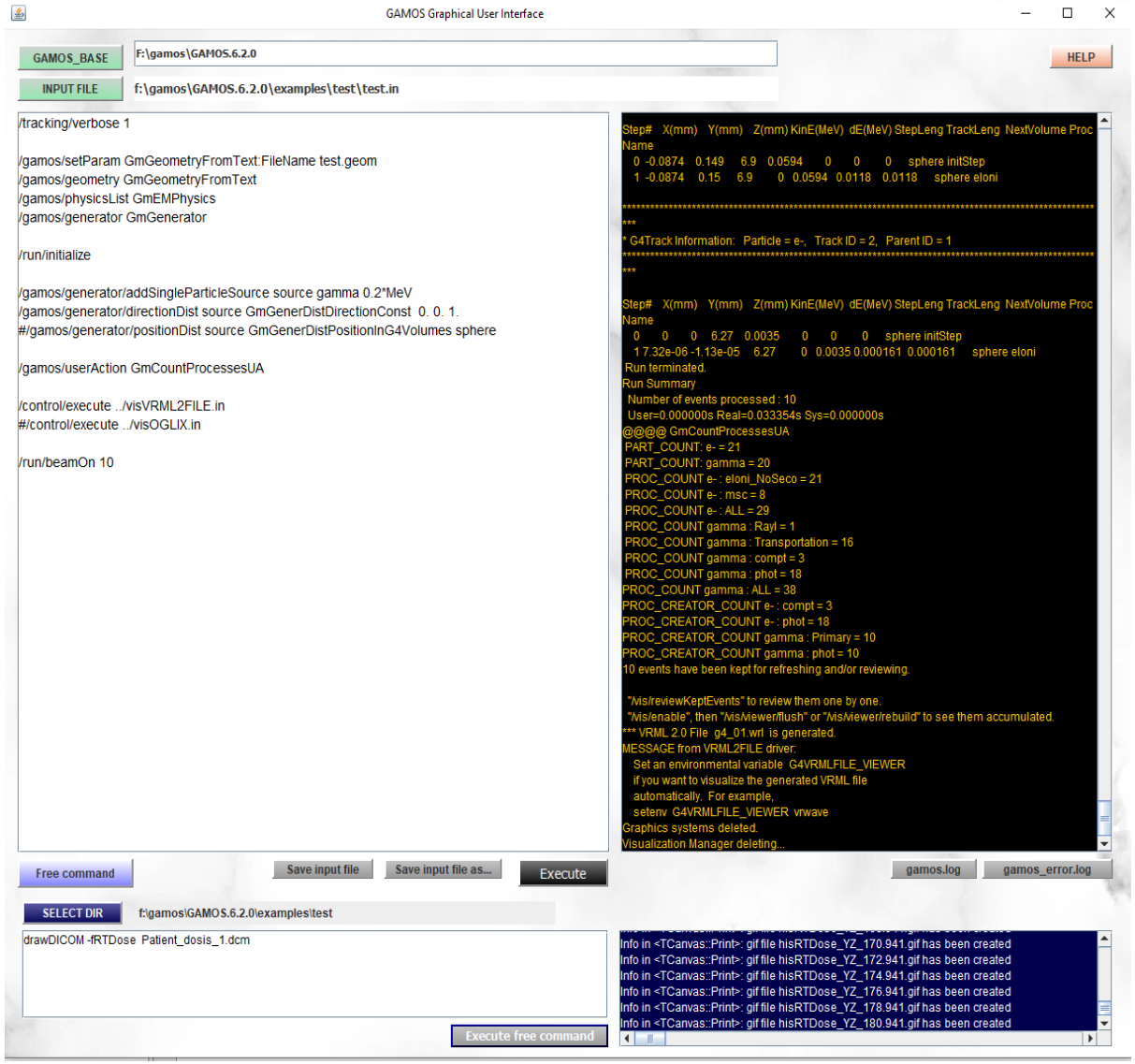
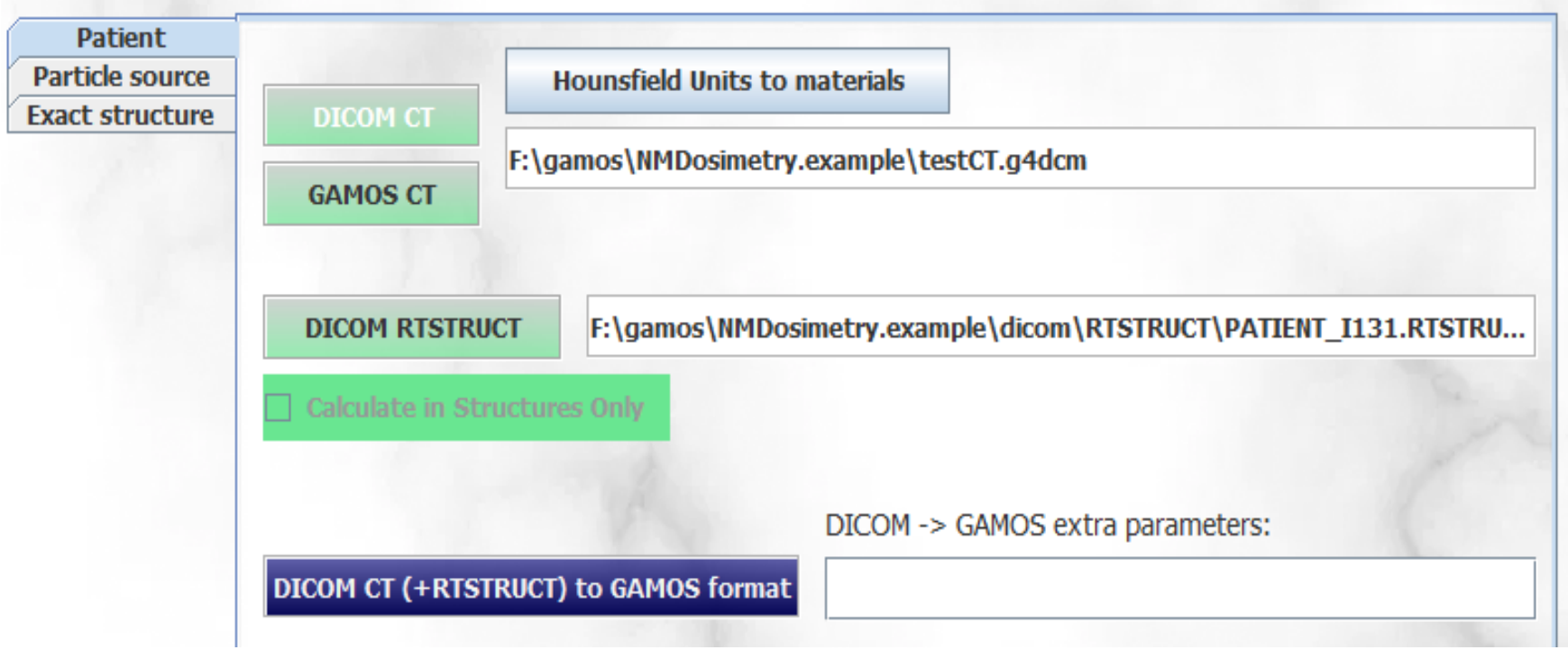
Graphical User Interface for Windows and Linux



Nuclear Medicine Dosimetry GUI (Nguyen Phuong Thao)

Patient CT images:

- ✓ GAMOS CT format or
- ✓ DICOM CT: + transform it to GAMOS format
  - Select table of Hounsfield Units to Materials (default one provided)



Structures/organs:

- ✓ DICOM RTSTRUCT
- ✓ May choose to calculate only in exact structures geometry (not usual convention: only in full voxels)

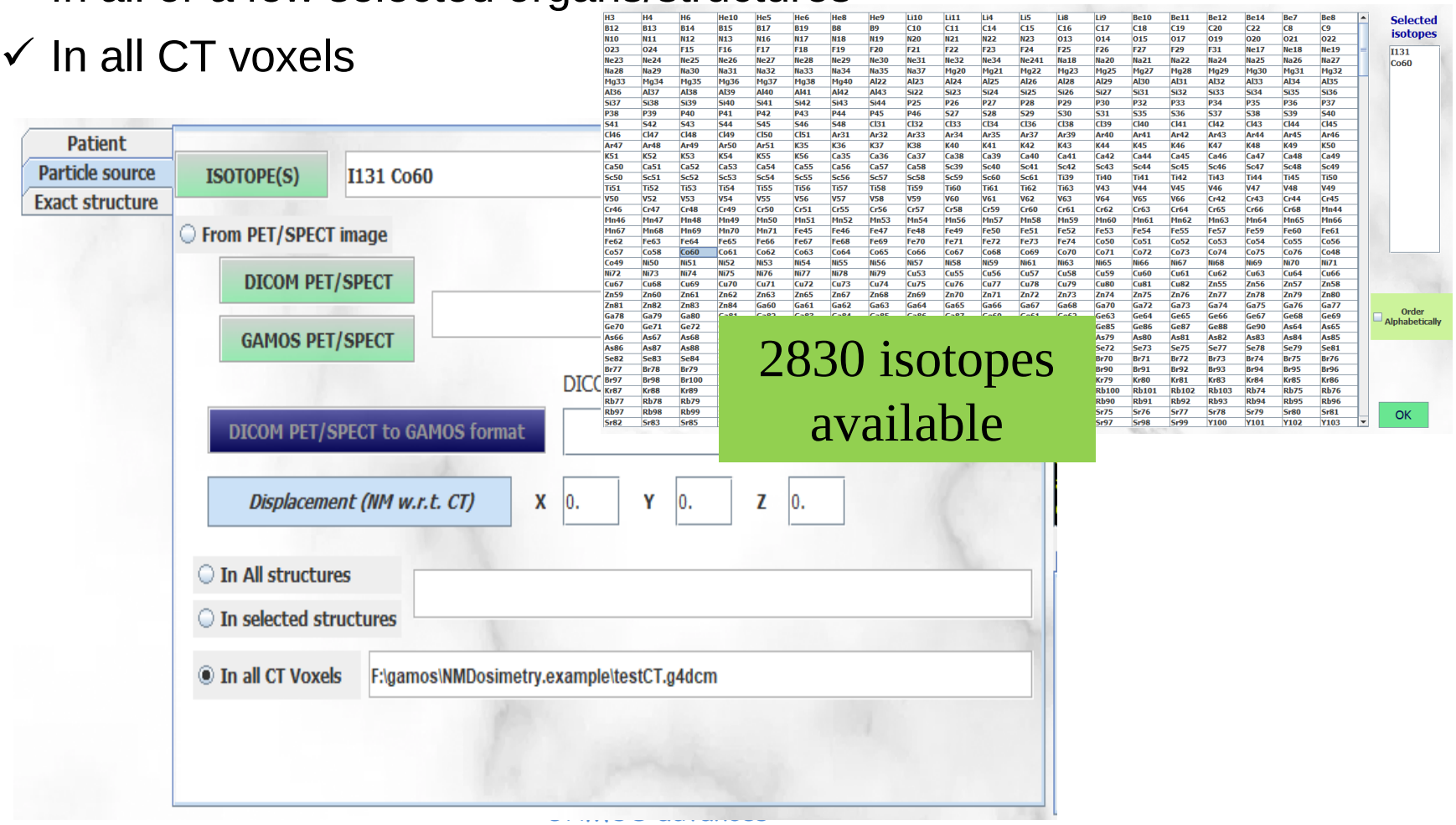
NM Dosimetry GUI: particle source

Isotopes:

- ✓ One or several isotopes
  - ➢ Geant4 will disintegrate them, with full decay chain (ENDSF data)

Where to place the isotope(s):

- ✓ NM image (proportionally to each voxel activity)
- ✓ In all or a few selected organs/structures
- ✓ In all CT voxels



NM Dosimetry GUI: Dose calculations

Two steps:

EXECUTE

- ✓ Run the number of events you want
  - More events → less statistical errors
- ✓ If you have several CPUs/cores you can run N jobs at the same time
- ✓ Select first random seed
  - Different random seed = statistically different dose
- ✓ Can choose dose deposit or energy deposit

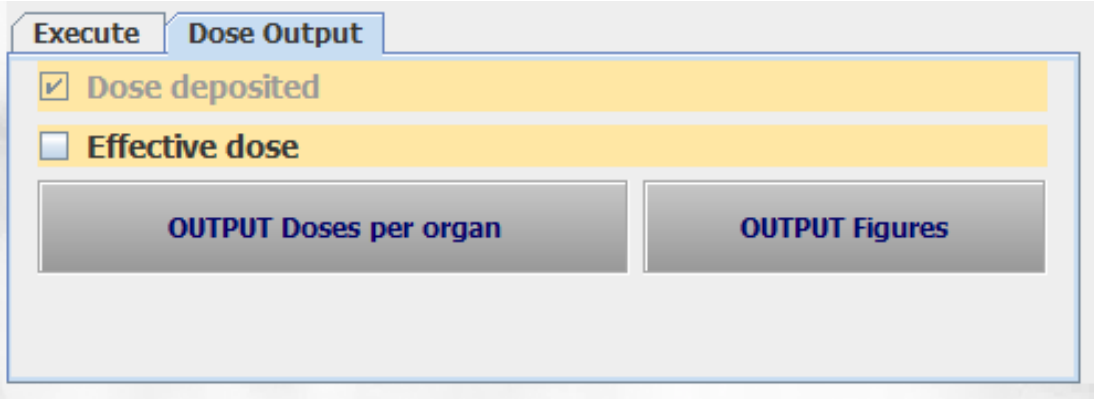
ANALYSE

1. Merge results if several jobs have been run
2. Produce dose results

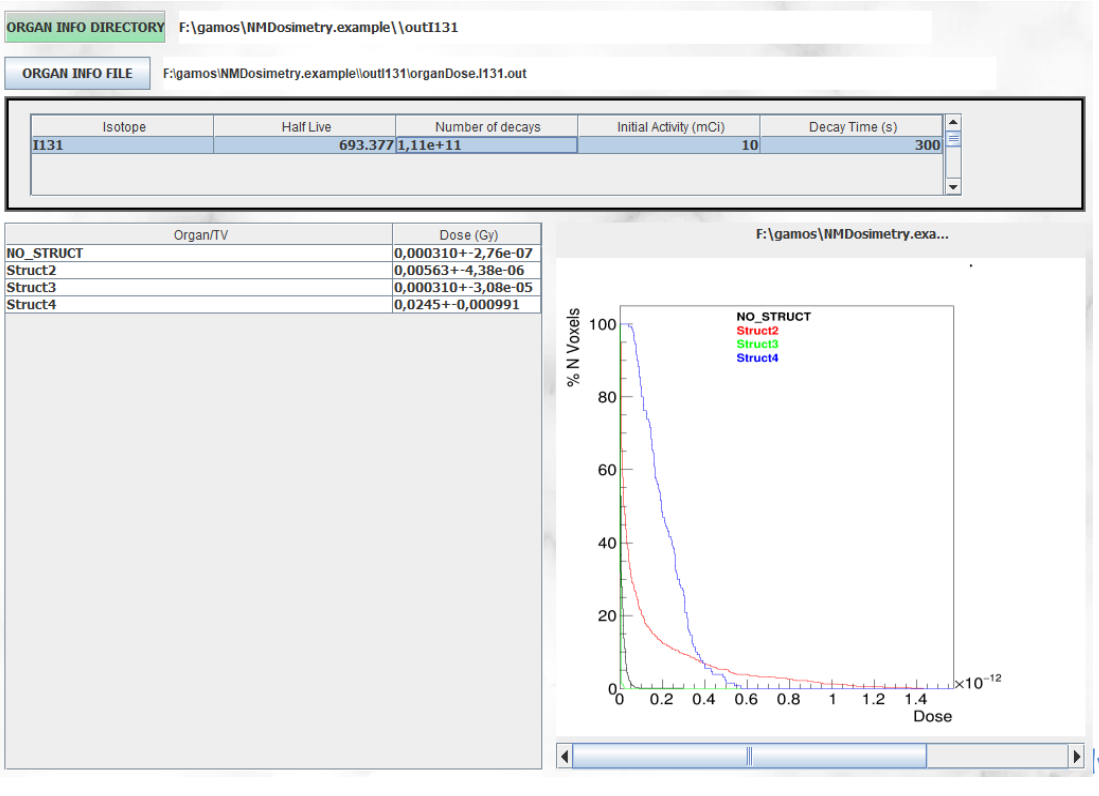
NM Dosimetry GUI: Results

✓ Dose output is provided in DICOM RTDose format, so that it can be analysed with your preferred tool

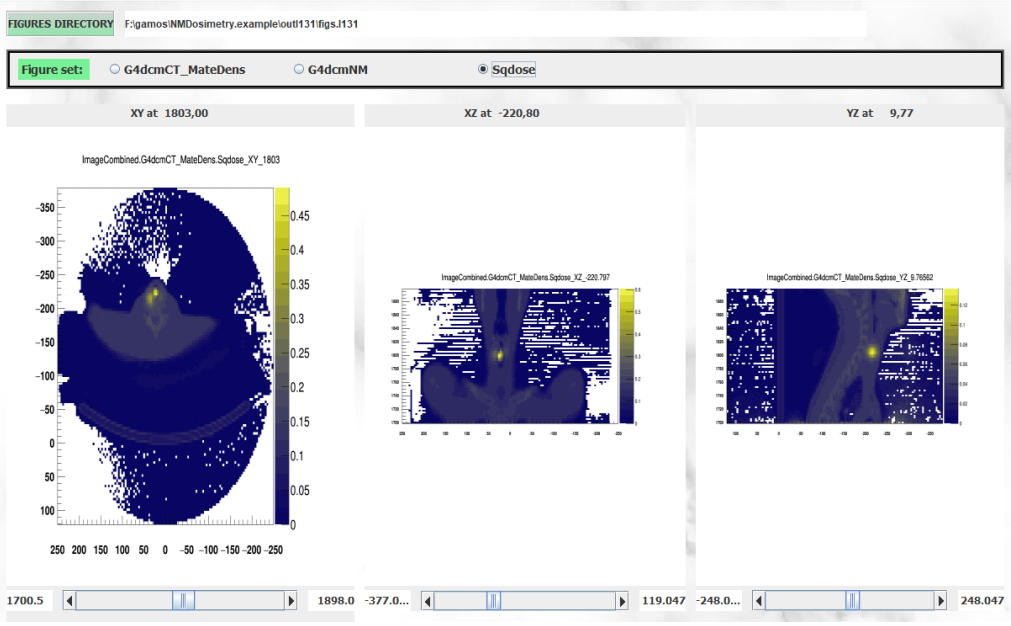
✓ And the GUI also provides some utilities to display the results:



➢ Table of Dose to organs + Dose-Volume histograms



➢ 2-D Gif figures of dose, NM activity and CT



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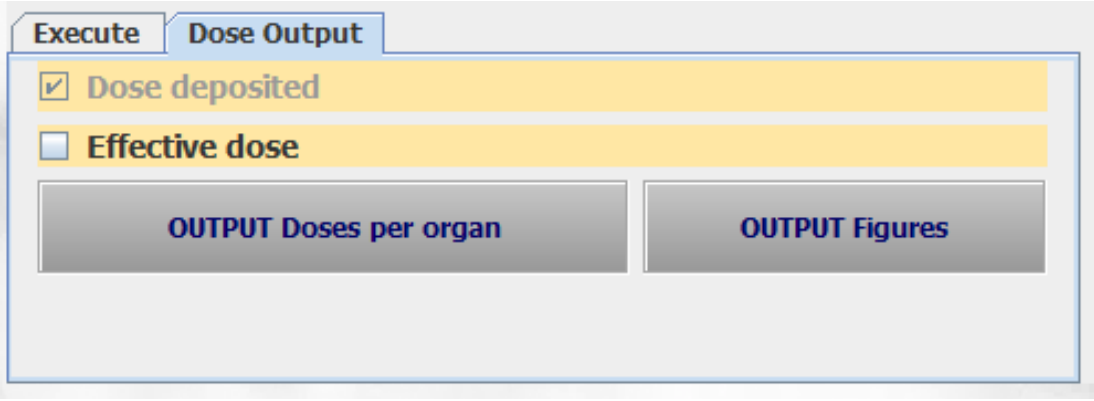

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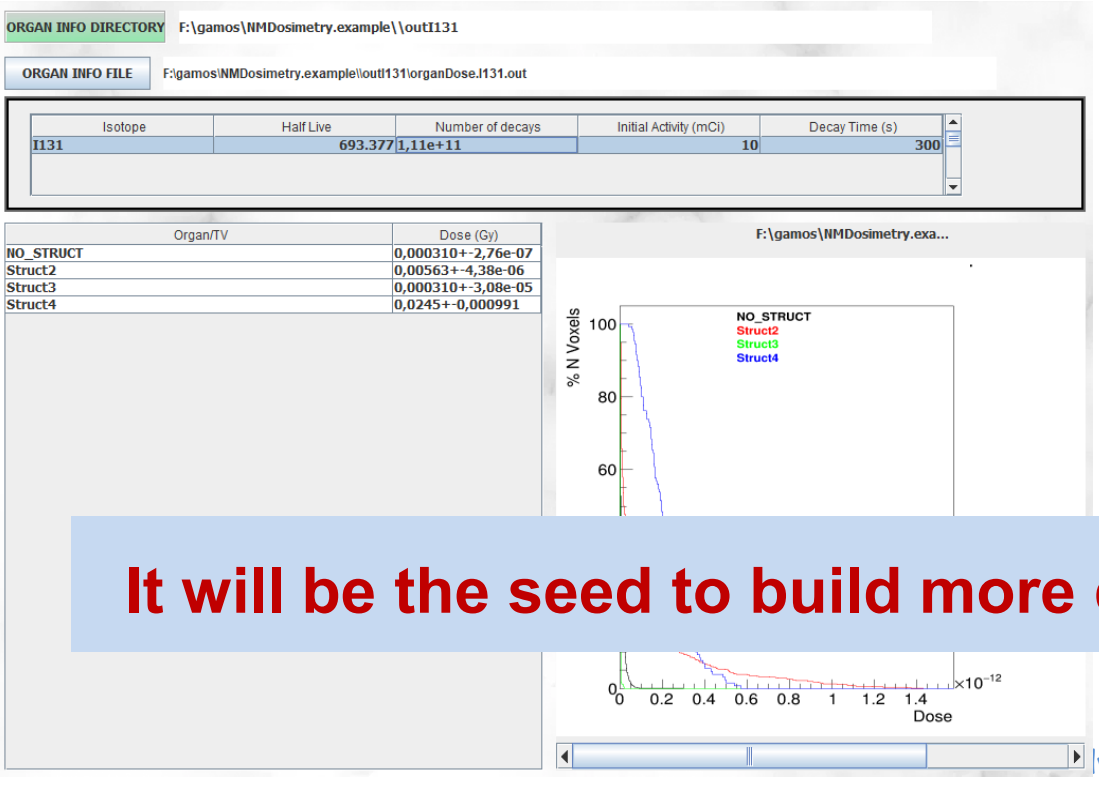

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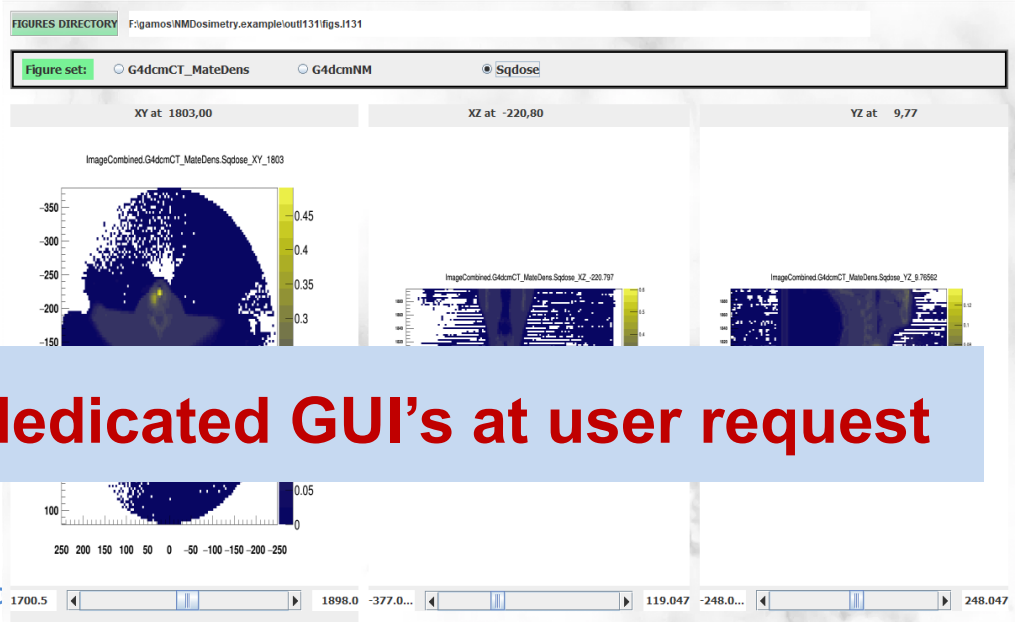

It will be the seed to build more dedicated GUI's at user request

Using GAMOS with your application

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  - A primary generator distribution, moving geometry, SPECT simulation, better understanding/testing your application using GAMOS detailed data, flexible biasing, LET/RBE scoring, …
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- You can easily use your code together with GAMOS:
  - GAMOS commands use the Geant4 interface (all Geant4 commands can be with GAMOS)
  - ✓ Just one line of code to make your physics list, detector, primary generator or user actions GAMOS plugin and then select them with a Geant4 user command
  - ✓ See User Guide + example

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  - You can easily use your code together with GAMOS:

Geant4 example dnadamage1:
- ~20 lines of code added
- ✓ All its functionality is available in GAMOS:
  - ✓ Including chemical phase, ROOT histograms and ntuples, etc.

Testing the code robustness

Installation testing

- Each GAMOS release is tested to be correctly installed in **three different Linux distributions, Windows and MacOS**

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  - **Automatic statistical test** using a Python-based utility (Andrea Dotti)
    - User defines p-value for warning and error
  - Comparison of **over 3,000 variables** and the analysis of **over 8,000 binned Kolmogorov-Smirnov tests of histograms**
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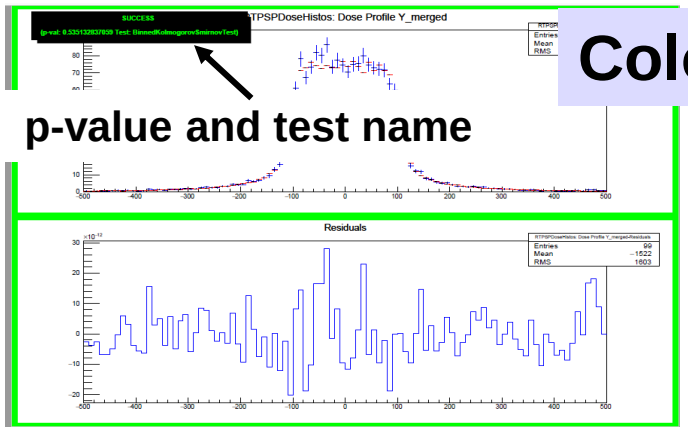
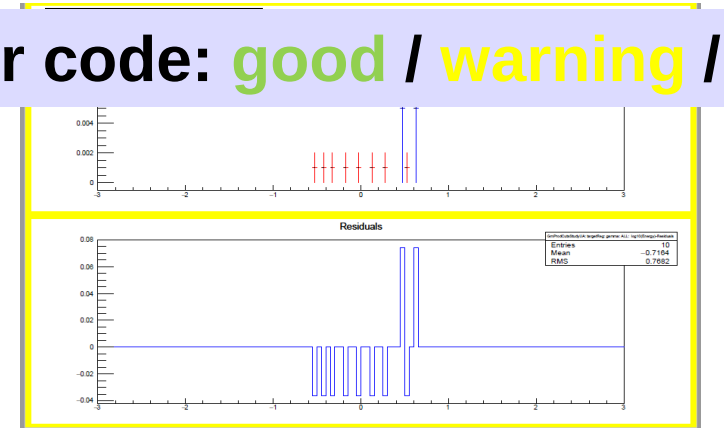
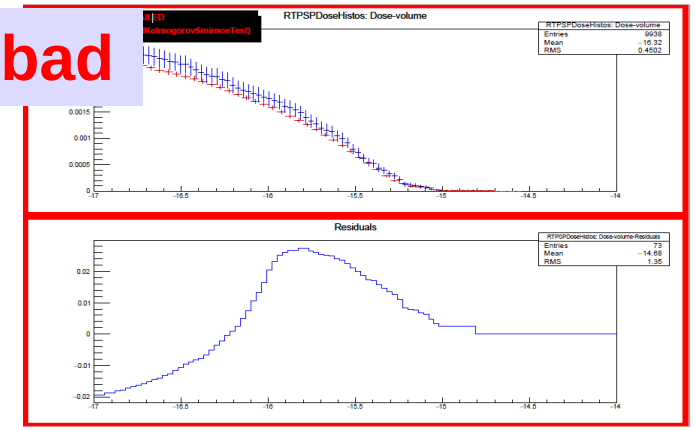


Color code: good / warning / bad





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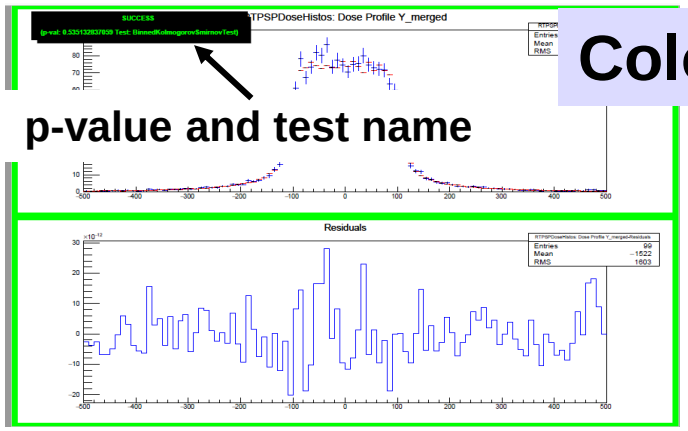

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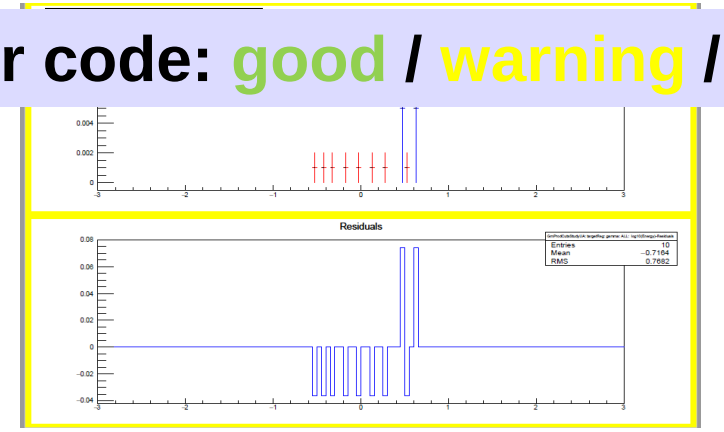
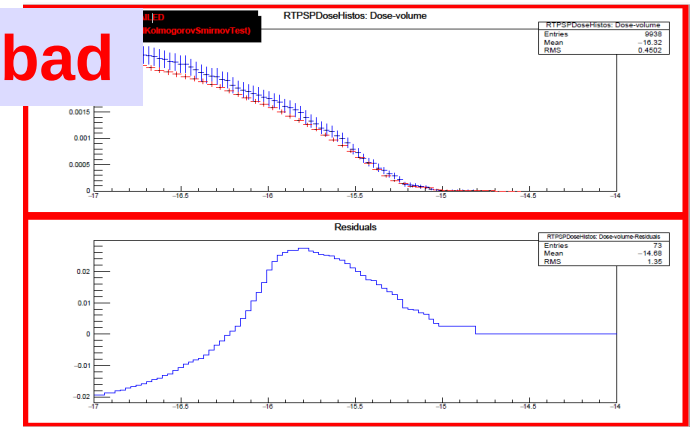




Use GAMOS regression testing tool it for your own simulation statistical tests:

- ✓ **Check vs. experimental data**
- ✓ **Check two jobs with different simulation options**

Summary

- The GAMOS framework has demonstrated to be an easy and flexible tool for Geant4 simulations

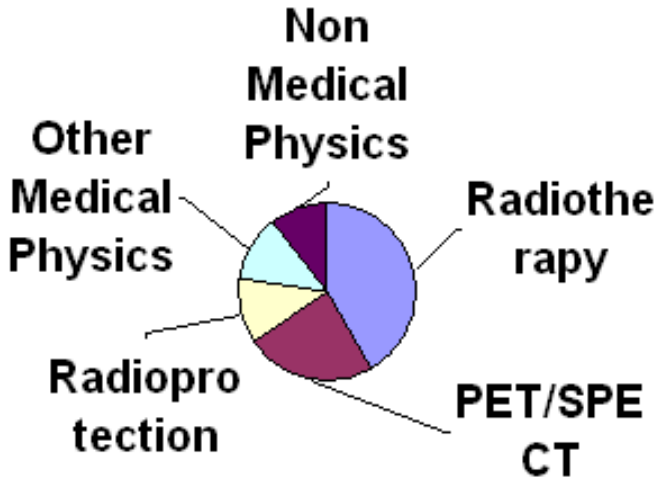
✓ New functionalities **extend its use in several fields**: DICOM management, proton therapy, LET/RBE, …

✓ New protontherapy tutorial

✓ New GUI for Linux and Windows

Geographical distribution of GAMOS users

Physics fields of interest of GAMOS users



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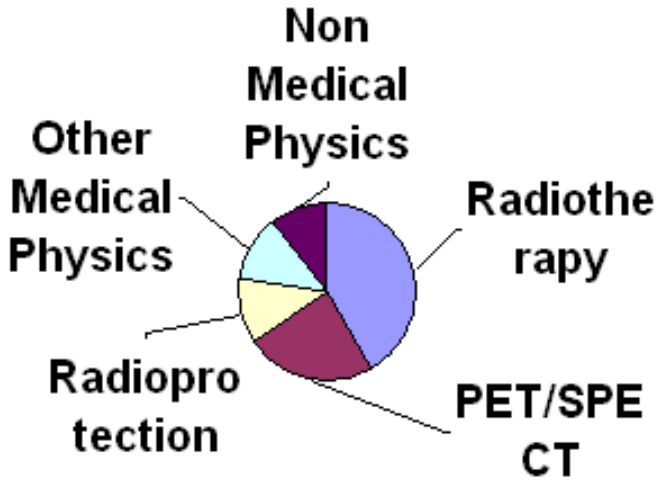

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An active community!

+600 conversations with +2,000 messages in GAMOS User's Discussion Forum

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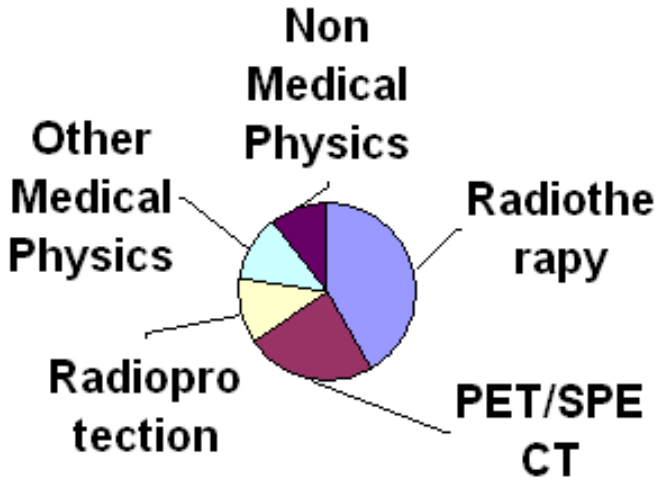
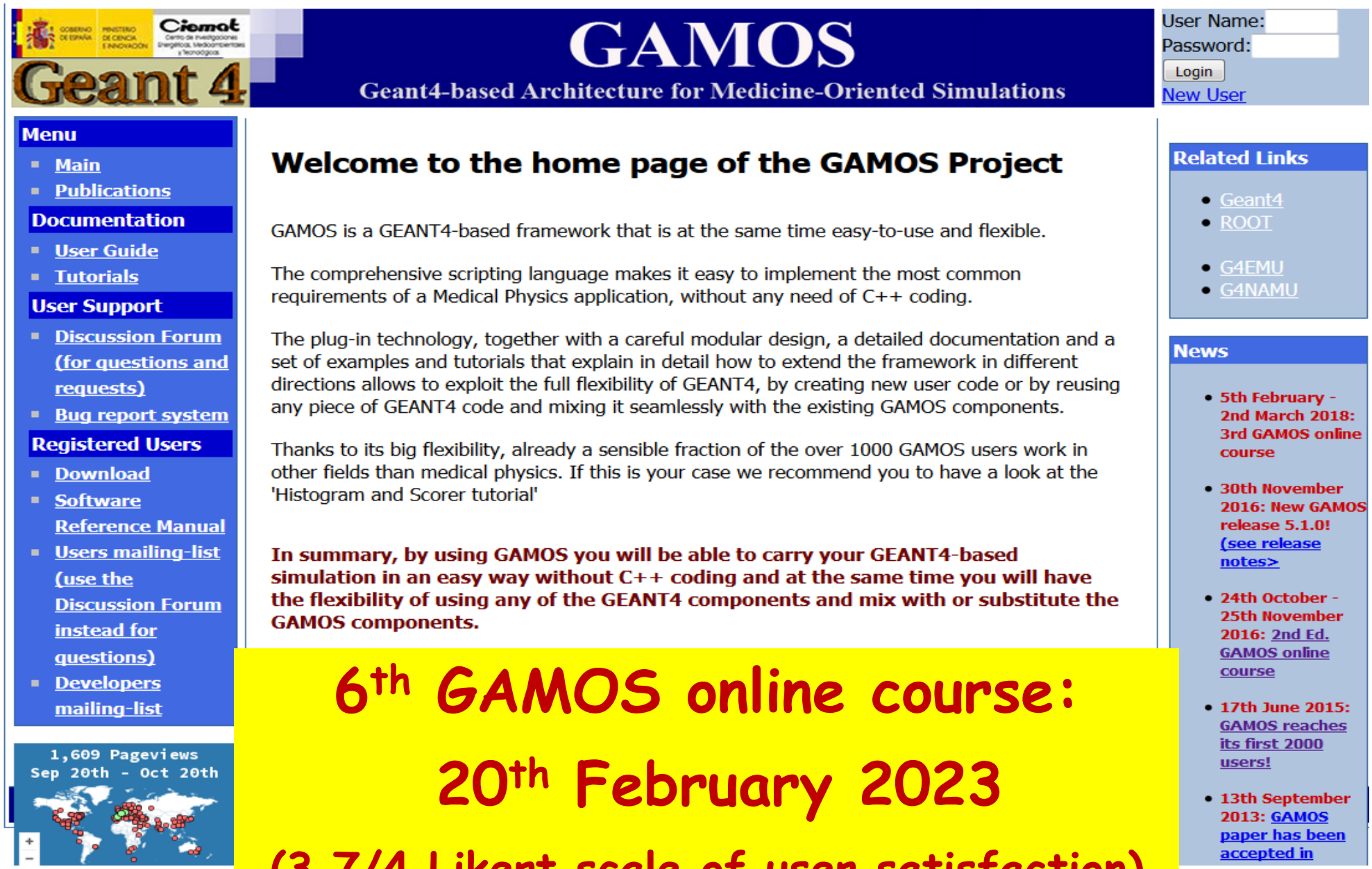


http://fismed.ciemat.es/GAMOS

or Geant4 web (http://geant4.org) → Applications → Medical



6th GAMOS online course:

20th February 2023

(3.7/4 Likert scale of user satisfaction)

Extra slides

Radiotherapy Geometry Modules

Define complex accelerator parts with a few lines

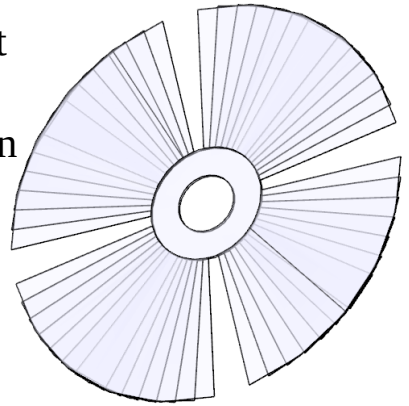
Use radiotherapist point of view

JAWS module:

```
:MODULE JAWS
JAWS_Y  // Name
Y ROUND_DISP // Orientation Leaf_tip_type
10.*cm 10.*cm 40.   / Half-dimensions X/Y/Z
145. 35. // Tip_circle_radius
Tip_circle_centre_Z
12.3 // Half_value_layer
0. 405 100.*cm    // Z_focus Z_centre
Z_isocentre
-10*cm 10*cm  // Field apertures: RIGHT & LEFT
RTUW  ACCEL   // Material Mother_volume_name
```

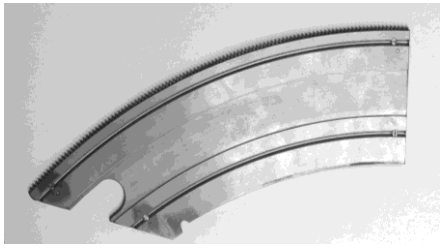
RANGE MODULATOR module:

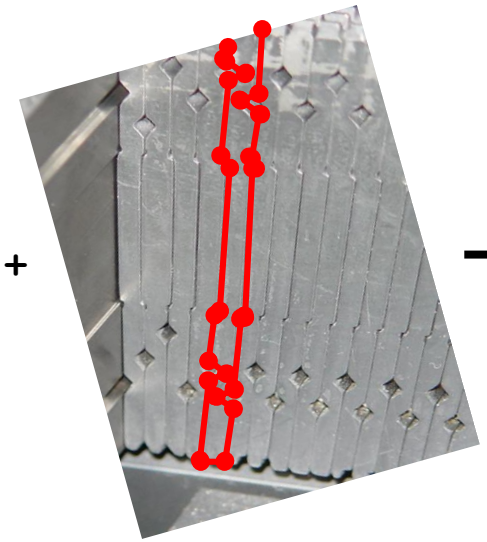
```
:MODULE RANGE_MODULATOR
rangeModulator / Name
85/2 85*2/2 300      // Rcore Rin Rout
4    4    // Nblades  Nsteps
6.5   0.1811111 // thickness angle_span
11    0.12433333
17.1  0.09644444
22.3  0.0953889
```

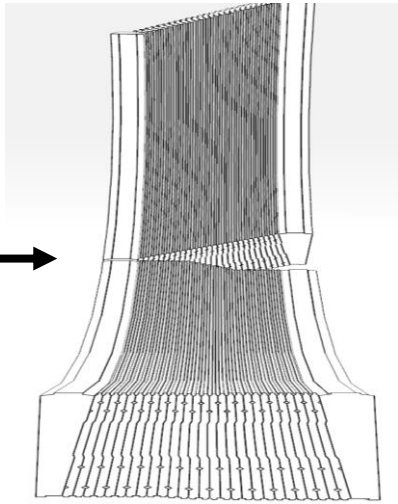


MULTILEAF COLLIMATOR module:

- End leave type Rounded or Straight
- Leaf cross profile as a set of 2D points
- Leaves out-of-focus in cross plane
- Interleaves gap
- Several leaf profiles in one MLC
- Leaves positions calculated from field apertures



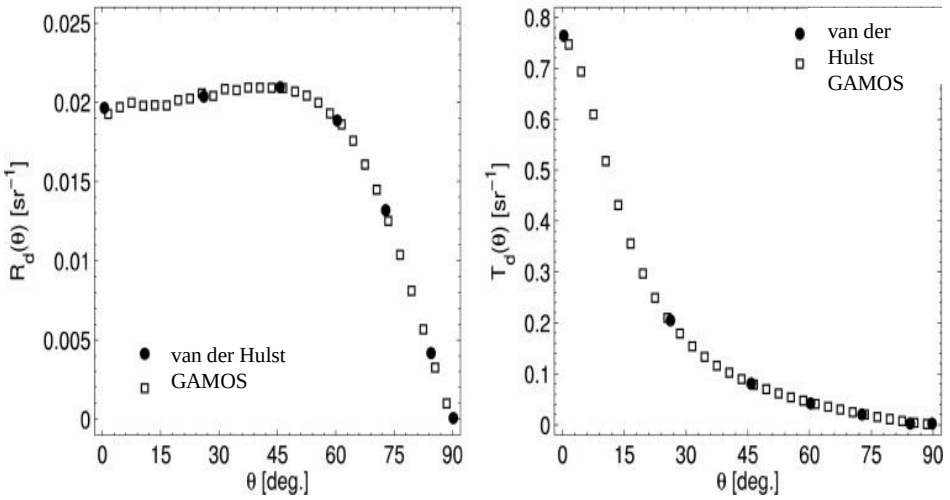




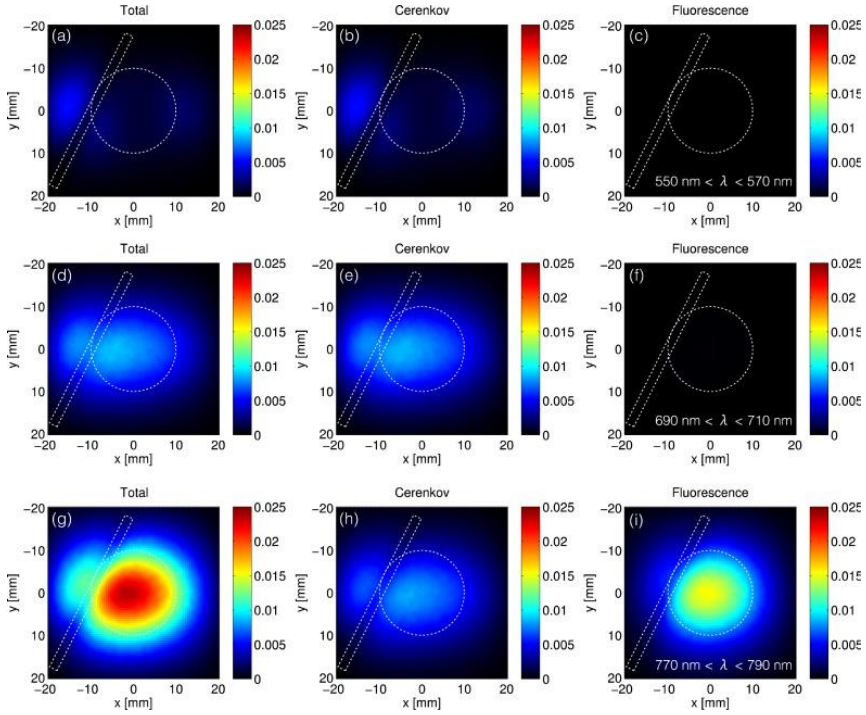
Tissue optics plug-in

- New process for Mie (phase function based upon the Henyey-Greenstein approximation and spectral dependence modulated by the anisotropy)
- Modified Henyey-Greenstein (MHG) scattering (proportional combination of Rayleigh and Mie scattering)

Angularly resolved diffuse reflectance as a function of exit angle



Captured reflectance images for an external radiation beam incident on the tissue volume at different radiation lengths



- User-defined scattering process (wavelength-dependent scattering phase function explicitly defined by the user)
- New source distributions

GAMOS plug-in's

If I want some functionality that GAMOS does not have?

☺ **Best solution for biggest flexibility: plug-in's**

What's is a plug-in?

It is the same in software that USB in hardware:

The easiest way to add a new device (class), without touching the operative system (framework): no need to install a driver (modify framework classes)

How it works in GAMOS:

❖ **If you want to use, for example, your own physics list instead of one of the GAMOS ones**

- Add one line in **user's** code

```
DEFINE_GAMOS_PHYSICS(MyPhysicsList);
```

- Code is transformed into a plug-in
- Automatically it may be selected with a user command

```
/gamos/physics MyPhysicsList
```

GAMOS plug-in's

Advantages of plug-in's:

☺ **No need to understand how GAMOS works internally (how GAMOS would invoke my code?) or modify GAMOS code**

☺ **No need to recompile each time I want to alternate between the GAMOS component and my own one**

☺ **GAMOS has no predefined components: user has full freedom in choosing components**

- Any user written code (geometry, primary generator, physics list, sensitive detector, user actions, …) can substitute any GAMOS component while still using the rest of GAMOS utilities
- If you have a working application, you may still use it, while you take profit of the part of GAMOS you like

☺ **No restrictions on the way to do things: all Geant4 functionality is available to GAMOS users**

Tutorials

Nine tutorials

- Histograms and scorers tutorial
- PET tutorial
- SPECT tutorial
- Compton camera tutorial
- Radiotherapy tutorial
- Shielding tutorial
- Protontheray tutorial
- Gamma spectrometry tutorial
- Plug-in tutorial

- Propose about 10-20 exercises each
  - ❖ Increasing in difficulty
  - ✓ Reference output provided
  - ✓ Solutions provided
  - ⇨ User can do them by her/himself

❑ 22 GAMOS tutorial courses have been given in Europe and America

Documentation

User's Guide:

- Installation
- All available functionality
- How to provide new functionality by creating a plug-in

Software reference manual (doxygen):

- Documentation of the classes and their dependencies

Examples:

- A simple one and a few more complicated ones

test.in:

```
/gamos/setParam GmGeometryFromText:FileName mygeom.txt
/gamos/geometry GmGeometryFromText
/gamos/physics GmEMPhysics
/gamos/generator GmGenerator
/run/initialize
/gamos/generator/addSingleParticleSource my_source gamma 6.*MeV
/run/beamOn 1000
```

and type: *gamos test.in*

Scoring

Scoring may be an important part of a simulation ⇨ **powerful and flexible framework developed, fully based on user commands**:

➢ **Many possible quantities** can be scored in one or several volumes (based on Geant4 scorers)

- Dose
- Current (in/out/passage)
- Number of particles
- Number of steps
- Deposited energy
- Charge
- Number of interactions
- Minimum kinetic energy
- Flux (in/out/passage)
- Step length
- Number of 2^{ary} particles
- Kerma

➢ For each scored quantity **one of several filters** can be used

  ➢ only electrons, only particles with energy in a given interval, …

➢ **Several ways to classify** the different scores

  ➢ One different score for each volume copy, or volume name, or energy bin, …

➢ Results can be printed in **one or several formats** for each scored quantity

  ➢ Standard output, text/binary file, histograms

➢ Scoring can be made **in real or in parallel worlds**

✓ **All scored quantities can be calculated with/without errors**

✓ **All scored quantities can be calculated per event or per run**

- **Taking into account correlations from particles from same event**