22nd Geant4 Collaboration Meeting
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National Physical Laboratory

INFN Istituto Nazionale di Fisica Nucleare

Advanced examples: updates and plan

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Advanced examples

Advanced examples are Users' applications that simulate a specific experimental setup

Wide experimental coverage:

- HEP (15%)
- Space science/astrophysics (20%)
- Medical physics and radiobiology (40%)
- Detector technologies and others (25%)

Wide Geant4 coverage

- Geometry features
- Magnetic field
- Physics (EM and hadronic)
- Biological processes
- Hits & Digits
- Analysis
- Visualisation, UI

- Investigate, evaluate and demonstrate Geant4 capabilities in various experimental environments
- Provide guidance to Geant4 users in realistic experimental applications
- Provide connection between developers and users of GEANT4

Advanced Examples WG

coordinator: Luciano Pandola (INFN-LNS, Italy)
deputy: Francesco Romano (NPL, UK)

- **19 members**
- **21 examples (some examples moved to extended/ since 10.2)**

`https://twiki.cern.ch/twiki/bin/view/Geant4/AdvancedExamples`

TWiki > Geant4 Web > AdvancedExamples (2016-02-04, LucianoPandola)

Edit Attach PDF

The Geant4 Advanced Examples Working Group

Welcome to the **official web site** of the **Geant4 collaboration Advanced Examples working group**.

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 examples code can be downloaded together with the Geant4 Toolkit in the directory geant4/examples/advanced

Examples, responsibles and documentation

Examples and responsibles (I)

Example	Responsible	Description
air_shower	B.Tomè	Detection system for cosmic ray shower simulation
amsEcal	M.Maire	Simulation of an Electromagnetic calorimeter
brachytherapy	S.Guatelli	Dosimetry for endocavitary, interstitial and superficial brachytherapy
composite_calorimeter	A.Dotti	A composite electromagnetic and hadronic calorimeter
ChargeExchangeMC	A. Radkov	Simulation of charge exchange real experiment performed at the Petesburg Nuclear Physics Institute (PNPI, Russia)
eRosita	M.G.Pia, et el.	PIXE simulation with Geant4
gammaknife	F. Romano	A device for Stereotactic Radiosurgery with Co60 sources for treatment of cerebral diseases
gammaray_telescope	F.Longo	A simplified typical gamma-ray telescope (such as GLAST), with advanced description of the detector response
hadrontherapy	G.A.P.Cirrone, F. Romano, et al.	Simulation of a transport beam line for proton and ion therapy
human_phantom	S. Guatelli	Internal dosimetry

Examples and responsibles (II)

Example	Responsible	Description
Iort_therapy	G.Russo	Simulation of a IORT device
lAr_Calorimeter	A.Dotti	Simulation of the Forward Liquid Argon Calorimeter of the ATLAS Detector at LHC
medical_linac	C.Andenna, et al.	A typical LINAC accelerator for IMRT,
microbeam	S.Incerti	Simulation of a cellular irradiation microbeam line using a high resolution cellular phantom
microelectronics	M. Raine	Simulation of tracks of few MeV protons in silicon
nanobeam	S.Incerti	Simulation of a nanobeam line facility
purging_magnet	J.Apostolakis	Electrons travelling through the magnetic field of a strong purging magnet in a radiotherapy treatment head
radioprotection	S.Guatelli, J. Davis	Microdosimetry with diamonds and silicum detectors for radioprotection in space missions
underground_physics	A.Howard	A simplified typical dark matter detector (such as the Boulby Mine experiment)
xray_fluerescence	A.Mantero	Elemental composition of material samples through X-ray fluorescence spectra
xray_telescope	G.Santin	A simplified typical X-ray telescope (such as XMM-Newton or Chandra)

Recent updates and developments

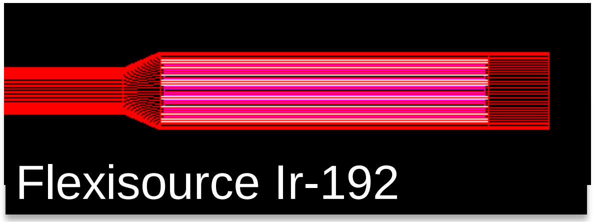
- General maintainance and cleaning of obsolete methods/physics
  - Explicit set of SD to manager in **`air_shower`**, **`gammaray_telescope`**, **`hadrontherapy`** **`human_phantom`**, **`radioprotection`**, **`underground_physics`**, **`xray_fluorescence`**
  - Changed physics in **`air_shower`**, **`gammaray_telescope`**,**`hadrontherapy`**,**`microbeam`**
  - Minor revisions of macro files in: **`gammaknife`**, **`hadrontherapy`**, **`nanobeams`**
- Migration to g4analysis tools and MT
  - 18/21 examples have g4analysis tools
  - 16/21 examples support MT
- Recent/foreseen specific updates on
  - **`Brachytherapy`**, **`Hadrontherapy`**
  - **`STCyclotron?`** → New example proposed by F. Poignant et al. (*University of Adelaide, South Australia*) for the simulation of a solid target system for radioisotope production at SAHMRI cyclotron facility.

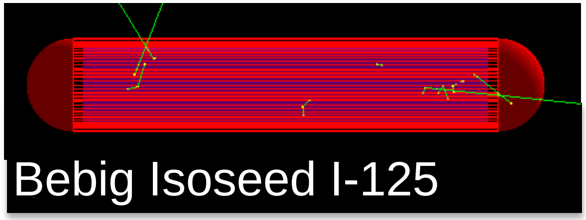
Brachytherapy

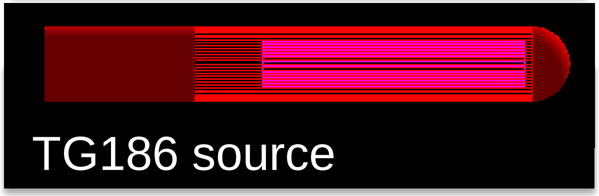
- **Current authors:**
  S. Guatelli and D. Cutajar (CMRP, UOW)

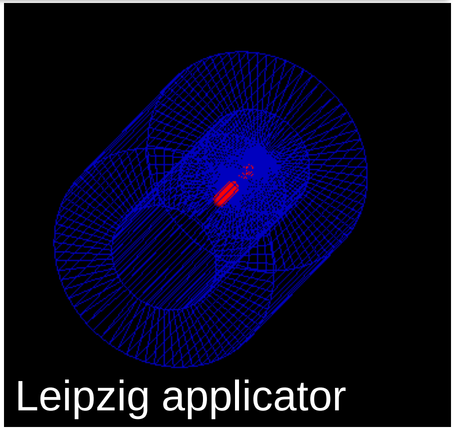
- Calculation of the energy deposition in a water phantom of:
  - Bebig Isoseed I-125
  - Flexisource Ir-192 (*Med. Phys 33(12), 2006, 4578-4582*)
  - Ir-192 TG186 reference source (*Med. Phys. 42 (2015), 3048-3062*)
  - Leipzig applicator

- It shows how to define a radioactive source
  - With the definition of the emitted particles from the radionuclide
  - Or with the Radioactive Decay module









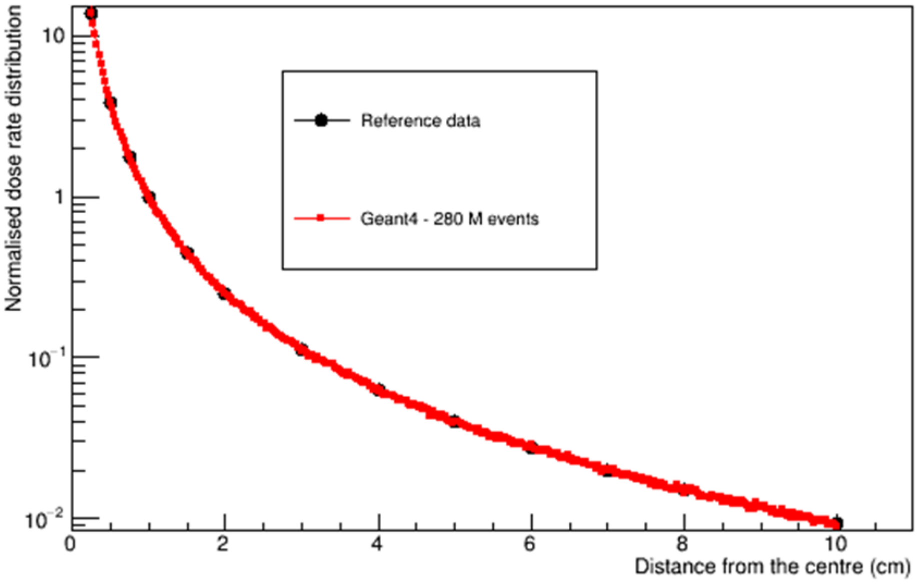
Brachytherapy

"`comparison`" directory

- Since Geant4 10.3, it is possible to calculate the dose rate distribution in a water phantom and compare directly to reference data

$$g(r) = \frac{\dot{D}(r,\theta_0)G(r_0,\theta_0)}{\dot{D}(r_0,\theta_0)G(r,\theta_0)}$$

Example: `root comparison.C`

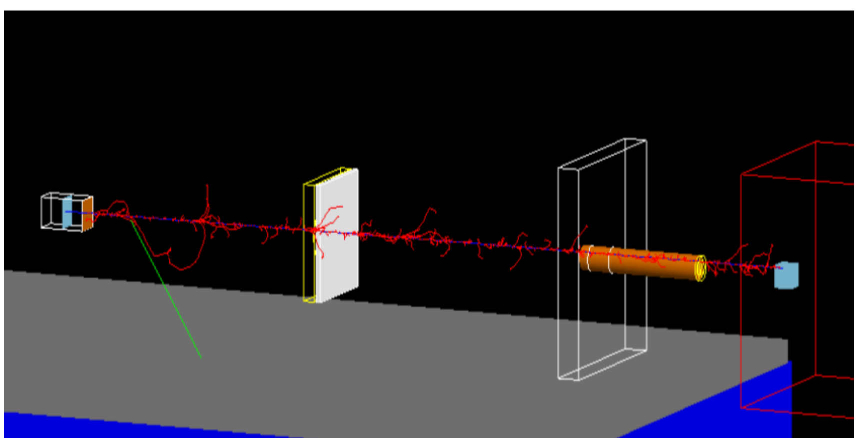


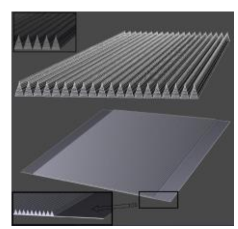
Reference data:

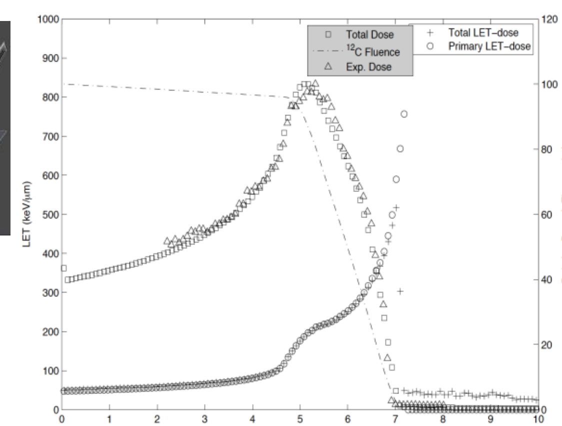
- Granero et al, *Med. Phys 33(12), 2006, 4578-4582*
- Flexisource
  used for source consensus data for TG43 based dose planning systems (ESTRO.org)

Hadrontherapy

- **Current authors**: GAP Cirrone, G. Cuttone, G. Milluzzo, L. Pandola, J. Pipek, P. Pisciotta, G. Petringa, F. Romano
- Paper with recent developments published: *Front. Oncol., in-press, 2017 doi: 10.3389*
- Two beamlines simulated
  - **Proton therapy** facility for eye melanoma treatment
    - Completely **revised modulator class**, with possibility to easily modify the flatness region (*NIM A, Vol. 806, 101-108, 2016*)
  - **Ion transport beam** line for multidisciplinary example.
    - Geometry revised **and new elements** included (ripple filter: *PMB 59 (12):2863-2882 (2014).*)
    - TIFPA beamline added (Trento proton therapy facility).
- **Dose average LET** computations currently based on *PMB 59 (12):2863-2882 (2014).*
  - Recent improvements on track/dose LET computations, studying dependences on simulation parameters
- **Bragg peak validation** for low energy protons (up to 60 MeV) and ions (up to 80 MeV/n)
- **RBE calculations** with LEM
  - Comparisons with proton data in progress
- **In-vivo** simulation studies using the DICOM interface (*NIM A, Vol. 846, 2017*)



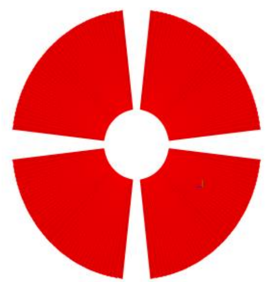




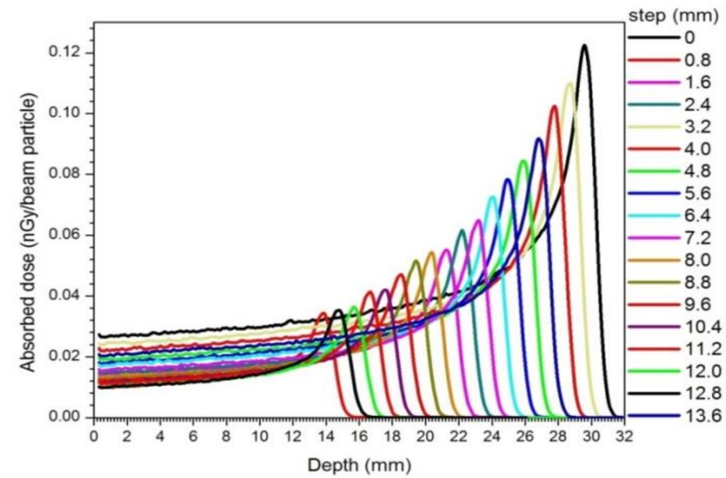
Hadrontherapy (modulator)

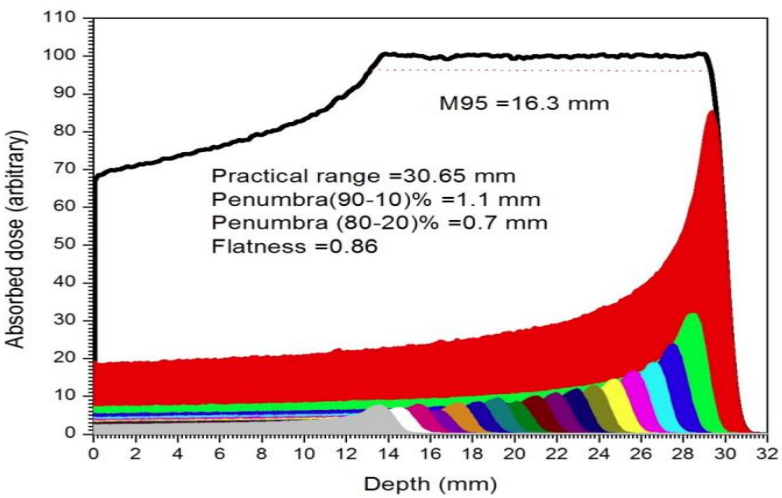
Previous Modulator module
- More than 2000 lines of code
- Changes to be hard coded
- No chance to modify the modulation region

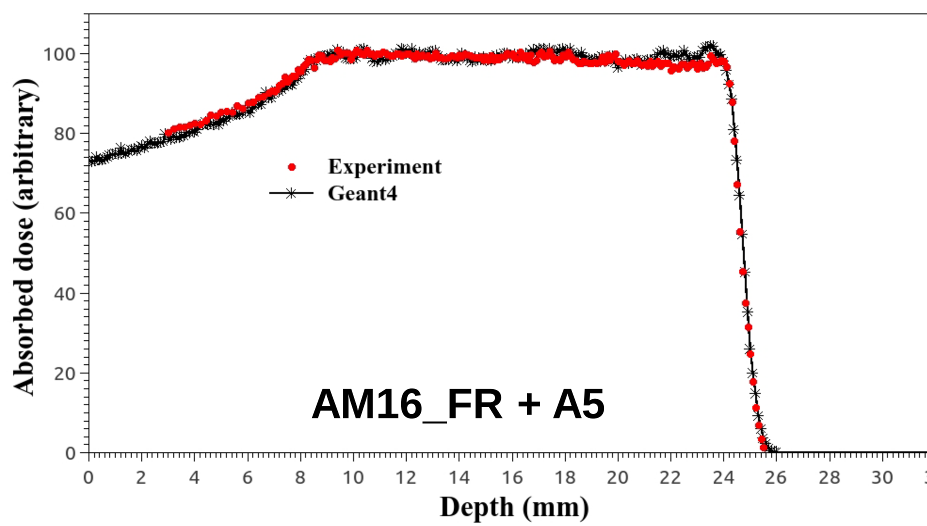
New modulator module:
- About 500 lines of code
- Input loaded by external file activating it by macro command
- Different modulation regions
- Possibility to create new modulators calculating the weights



$$w_1 D_{i1} + w_2 D_{i2} + \cdots w_N D_{iN} = D_{i0} \qquad i = 1,2,\ldots,N$$





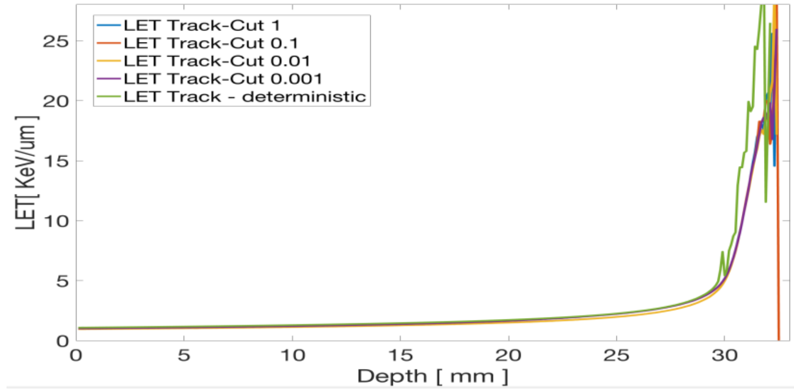


NIM A, Vol. 806 (2016)

Hadrontherapy (LET and RBE)

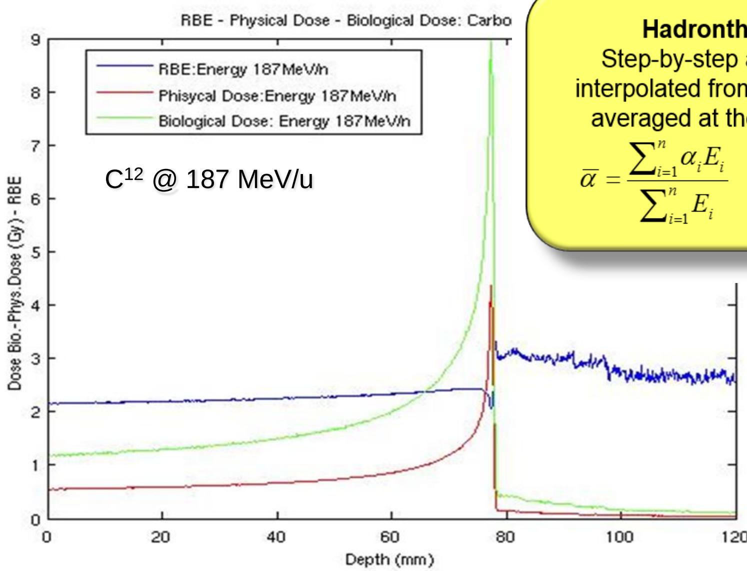
LET

- Currently based on ***PMB 59 (12):2863-2882 (2014).***
- Studies on simulation parameters (**cut**) based on *PMB 60 2645–2669 (2015)*
- Intercomparison of **track**/**dose** average LET



RBE

- Three cell lines simulated at the moment: **CHO**, **AGO1522**, **U87** (extension to a larger cell database in progress)
- Tested for **C12** (**protons** in progress: *Int. J. Rad. Onc.90, 2014*)
- **LEM I** included (extension to LEM II-III and MKM in progress)
- General **code review** and “cleaning” for inclusion in public release



HadrontherapyRBE

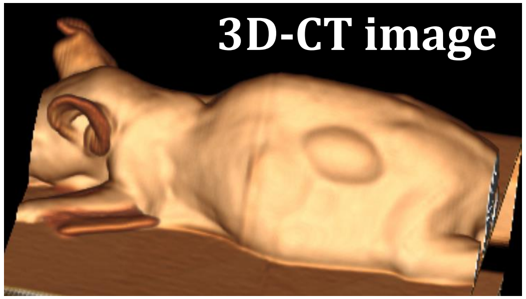
Step-by-step alpha and beta interpolated from LEM tables and averaged at the end of the run

$$\overline{\alpha} = \frac{\sum_{i=1}^{n} \alpha_i E_i}{\sum_{i=1}^{n} E_i} \qquad \overline{\beta} = \left(\frac{\sum_{i=1}^{n} \sqrt{\beta}_i E_i}{\sum_{i=1}^{n} E_i} \right)^2$$

Hadrontherapy (in-vivo studies with DICOM)

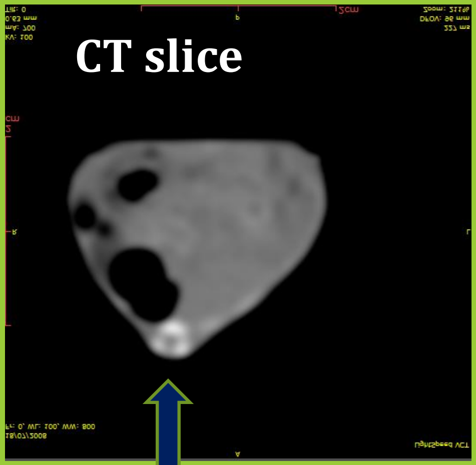
NIM A, Vol. 846 (2017)

DICOM-CT images of mice



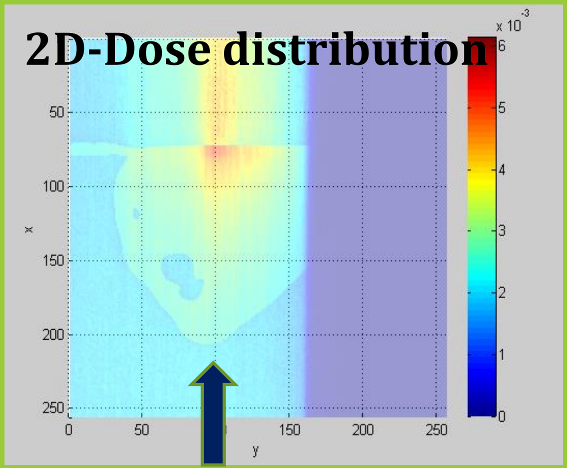
Myelopathy studies implementing small animal treatment plans with two treatment fields

DICOM CT- images



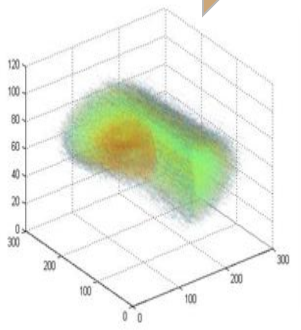
Beam direction

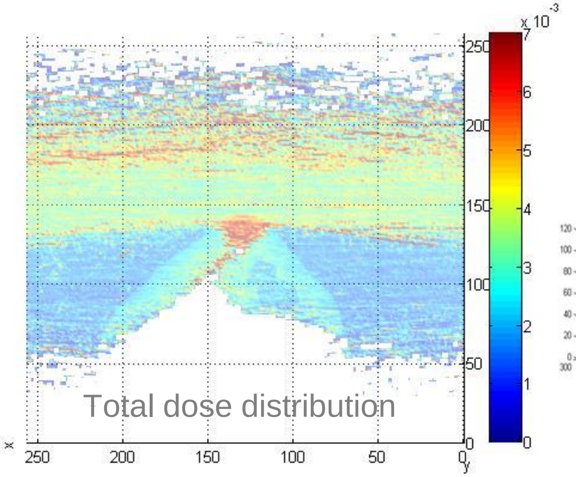
more accurate dose distribution



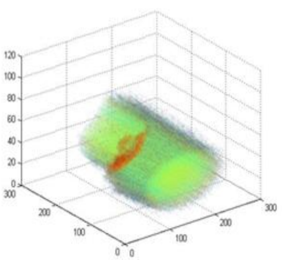
Beam direction

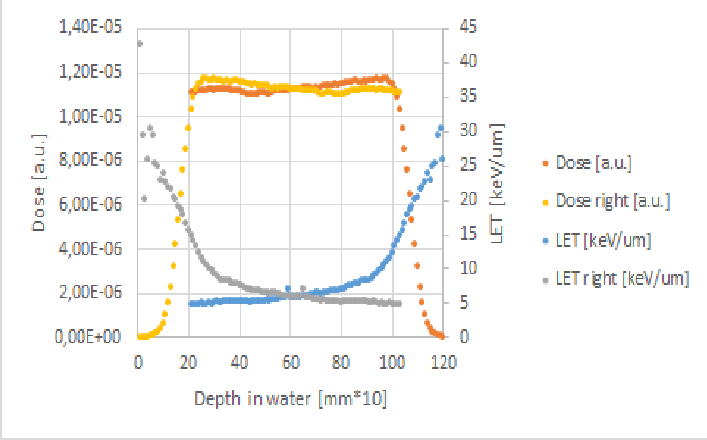
Left field





Right field

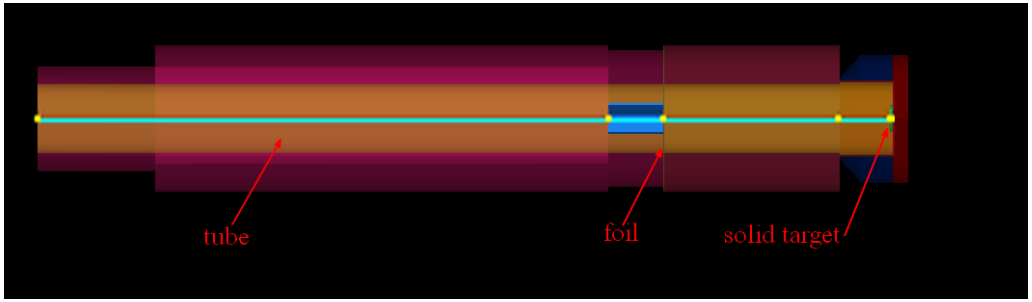




STCyclotron, a new advanced example

- **Objective** :
  - Predict the production of medical radio-isotopes and undesired by-products yields
- **Features** :
  - Modelling of a solid target system based on the GE PETtrace cyclotron from the South Australian Health and Research Institute

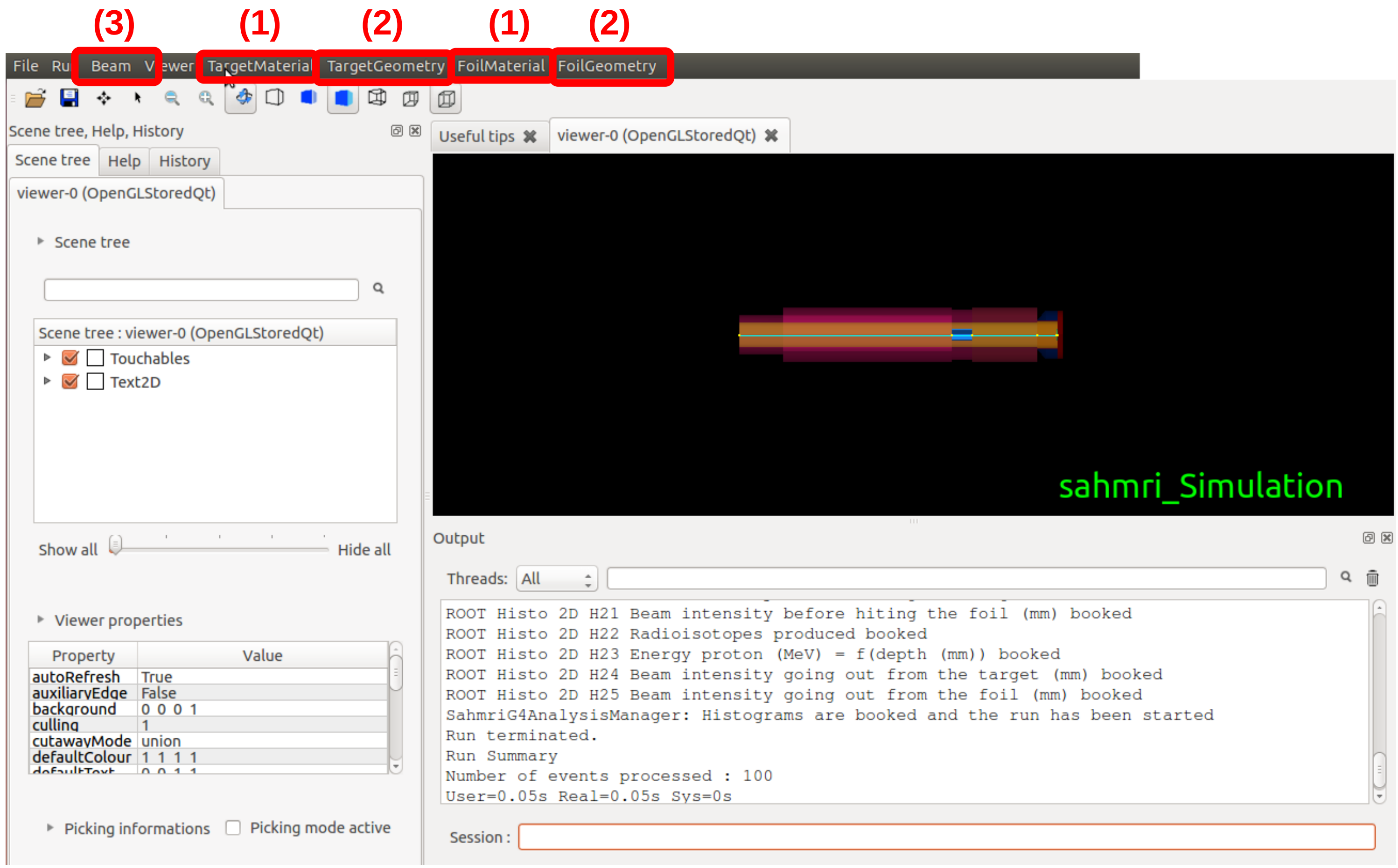
- **Geant4 GUI user-friendly** interface to select parameters
- **AllParticlesHP** physics list : TENDL based cross sections for low energy [MeV] nuclear interaction high precision
- Analysis tool available



[1] : F. Poignant, S. Penfold, J. Asp, P. Takhar, P. Jackson, GEANT4 simulation of cyclotron radioisotope production in a solid target, Physica Medica, Volume 32, Issue 5, 2016, Pages 728-734, ISSN 1120-1797,

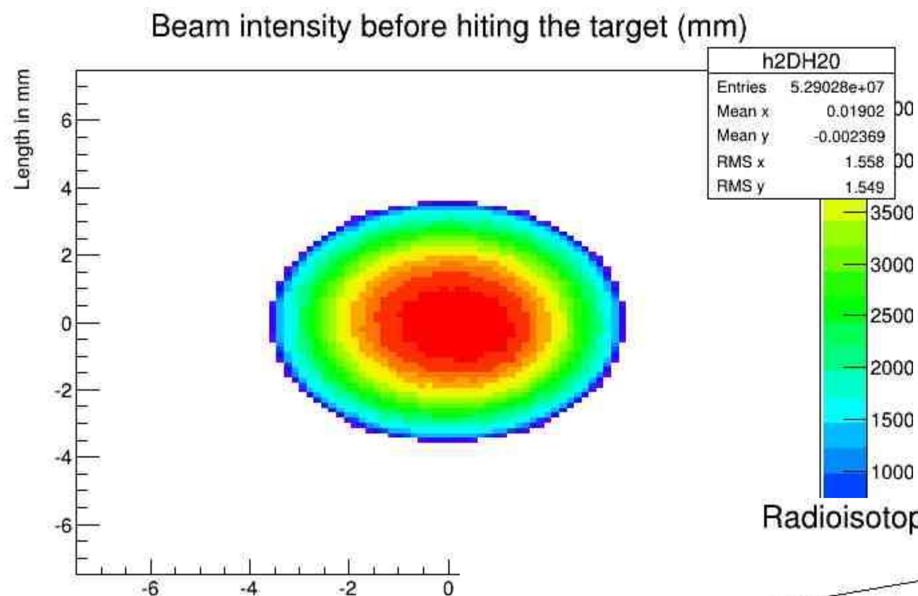
STCyclotron: inputs

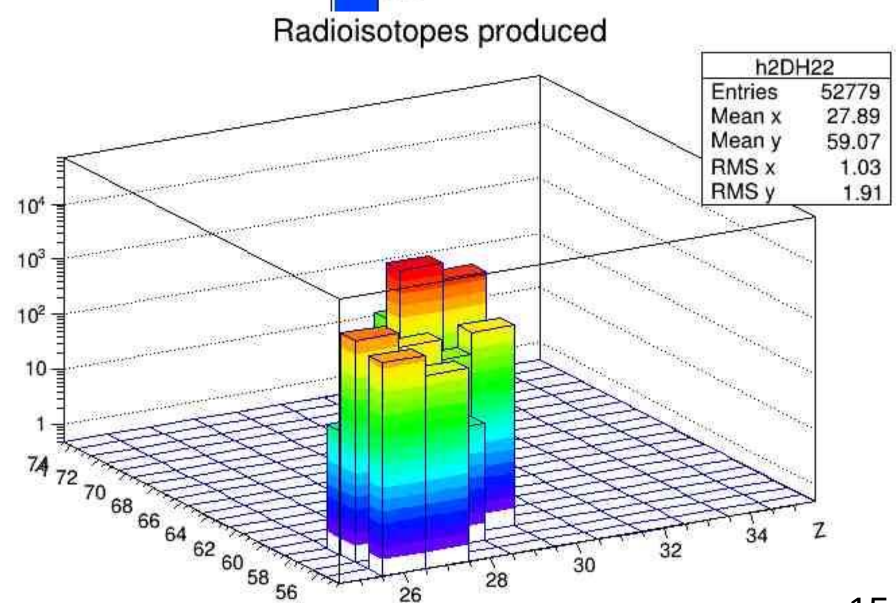
- (1) Foil/target material : NIST based or self-designed
- (2) Foil/target geometry
- (3) Beam : geometry, energy, particle, time of irradiation, current



STCyclotron: outputs

- (1) ROOT 1D/2D histograms : isotopes production, secondary particles production, beam intensity through the componants (and many more!)



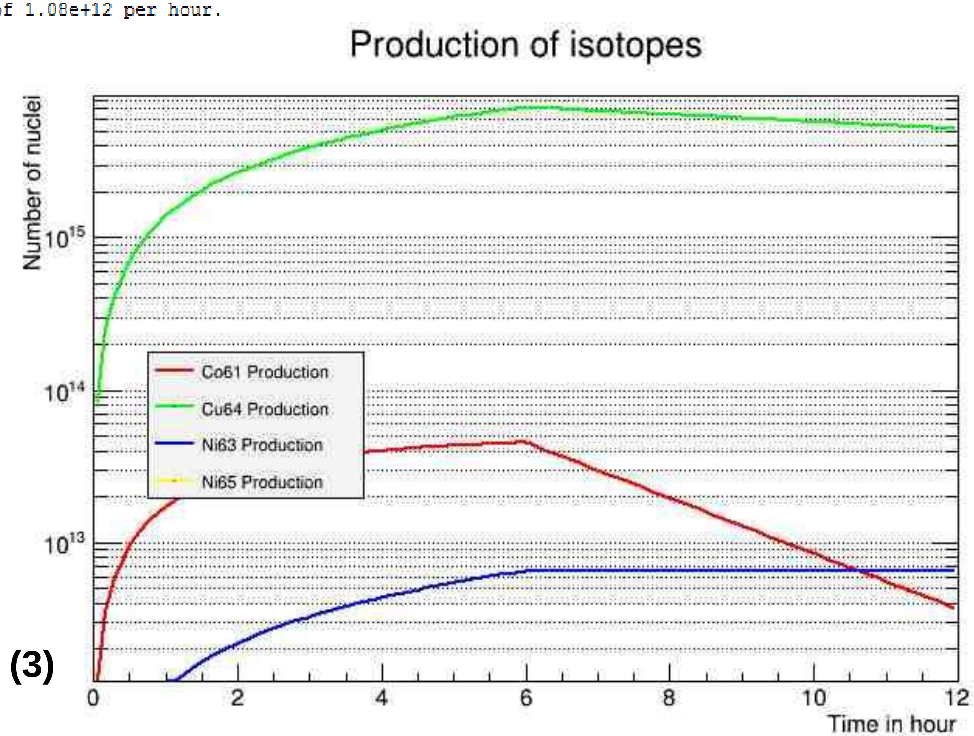


STCyclotron: outputs

(2)

```
****************************************
****** Data from the simulation *******
****************************************
The isotope Co61 has a yield of 4.52339e+13 nuclei at the end of the beam.
The isotope Co61 has a decay constant of 0.420089 hour(s)-1.
The isotope Co61 has a production of 2.0664e+13 per hour.

The isotope Cu64 has a yield of 7.15966e+15 nuclei at the end of the beam.
The isotope Cu64 has a decay constant of 0.0545737 hour(s)-1.
The isotope Cu64 has a production of 1.39928e+15 per hour.

The isotope Ni63 has a yield of 6.47998e+12 nuclei at the end of the beam.
The isotope Ni63 has a decay constant of 7.81353e-07 hour(s)-1.
The isotope Ni63 has a production of 1.08e+12 per hour.

The isotope Ni63[87.150] has a yie
The isotope Ni63[87.150] has a dec
The isotope Ni63[87.150] has a prc

The isotope Ni65 has a yield of 3.
The isotope Ni65 has a decay const
The isotope Ni65 has a production
```

(3)



- (2) Resuming text file
- (3) Plots of radioisotope activity/number of nuclei according to the time

STCyclotron: Study of $^{64}Ni(p,n)^{64}Cu$ production

- **Product of interest ^{64}Cu [1]**

E_{in} (MeV)	E_{out} (MeV)	Sz. Exp. yield (mCi/μA)	TENDL Sim. yield (mCi/μA)	An. yield (mCi/μA)
9	0	79 ± 15	157 ± 1.5	112 ± 19
12	9	117 ± 8	144 ± 1.4	128 ± 9
18	12	118 ± 14	103 ± 1.2	101 ± 15
18	0	315 ± 37	395 ± 2.3	341 ± 42

Table 1: Yields of ^{64}Cu on a 95% enriched target. E_{in} and E_{out} are the energies of protons entering and exiting the target. Sz. Exp. yield and TENDL Sim. yield and An. yield are the Szelecsenyi et al. (1993) experimental yield, the TENDL yield from the simulation and TENDL saturation yield analytically calculated respectively. The experimental cross section values from Szelecsenyi et al. (1993) were used for an analytical calculation to estimate the experimental saturation yield over the energy range of interest.

- **Isotopes contamination [1]**

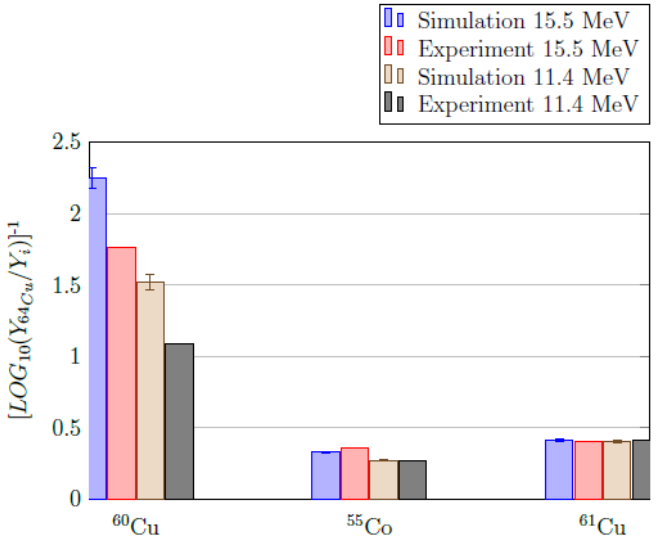


Figure 5: Experimental and simulation relative yields at the EOB on a 95% enriched nickel-64 target by McCarthy et al. (1997). Y_{64Cu} is the yield of ^{64}Cu and Y_i is the yield of the isotope of interest. The EOB time was set to 6 minutes.

[1] : F. Poignant, S. Penfold, J. Asp, P. Takhar, P. Jackson, GEANT4 simulation of cyclotron radioisotope production in a solid target, Physica Medica, Volume 32, Issue 5, 2016, Pages 728-734, ISSN 1120-1797

** Results with Geant4 v9.6 – Improvements are expected with Geant4 10.3 (to be tested)*

Workplan for 2017

- **Maintenance** and **bug fix** (1,2)
- Introduction of some C++11 specific features/utilities in the examples (2)
- Include Low Dose Rate brachytherapy verification suite in the **`brachytherapy`** example (2)
- Validation and implementation in **`hadrontherapy`** of the LET/RBE modelling derived by experimental measurements (1)
- Improve **`air_shower`**, adding the capability of simulating and analysing the air shower fingerprint at ground (2) [*]

Conclusions and critical items

- Advanced examples are typically complex Geant4 applications
  - Maintainance and upgrade **not-so-easy** by people other than the original developer(s)
  - Major and regular developments only in a few examples
  - In general, situation a bit *static*, also due to many orphan examples - Still, some of them are "references" in the respective communities, so not viable to drop them from the release
- **Major work performed** in the past few years with g4analysis and MT migrations
  - The majority of the examples have now g4tools and are MT-compliant
- Basic maintainance and bug fixing are performed and guaranteed
- Difficult to plan major upgrades, especially for the orphans
- Policy for new proposed examples?

Thank you