Open and new requirements: bio-medical applications

URs in progress: tracked in the Geant4 Requirements Tracker

New URs

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Existing URs (1)

- **UR-54:** Physics models for ions below 1 MeV/u for Boron Proton Capture (Ribon)
  - The aim is to compare the hadronic physics models for the p+B11 —> 3 alpha reaction
  - Assigned to Jose` Ramos-Mendez.
  - To start
- **UR-63:** To have an extended example to retrieve directly from the simulation Auger electron energy and associated atomic transition, including in Geant4-DNA processes (Ivantchenko, Guatelli)
  - In progress
  - In Geant4 11.2 model sub-type is added allowing identify Auger electrons. It is needed to check TestEm5 implementation and provide macro files and histograms to demonstrate that the mechanism is working.
- **UR-80:** Isotope production from protons using IAEA medical cross-section (Ribon)
  - IAEA has made an extensive work to cover isotope production for medical applications (https://www-nds.iaea.org/medical/)
  - Review and include IAEA medical cross sections into the Geant4 ParticleHP database
  - To start

Existing URs (2)

- **UR-83:** Webpage, with information about Geant4 for medical applications (Guatelli)
  - Webpage, with information about Geant4 for medical applications
  - Examples
  - G4 medical physics activity
  - Useful information, e.g. how to activate biasing for bremsstrahlung, etc.
  - Promote events (workshops, conferences, schools)
  - Ready to start once it is clear where to have the specific webpage

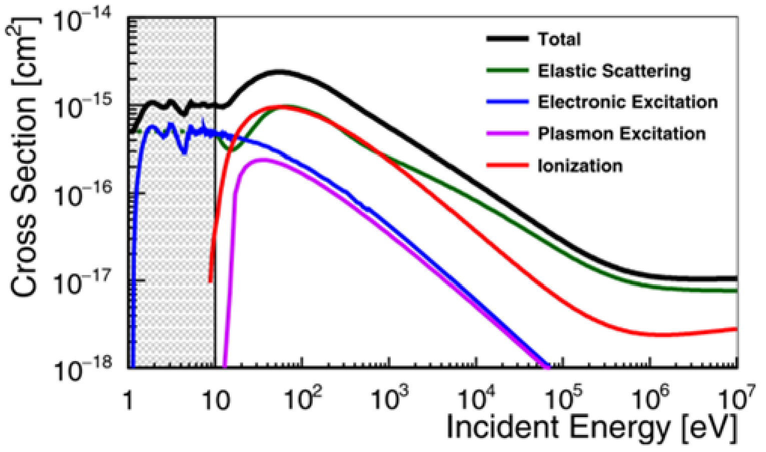
- **UR-94:** Couple Bearden energy lines with ANSTO fluorescence data libraries (Ivantchenko)
  - To start
  - Lack of resources

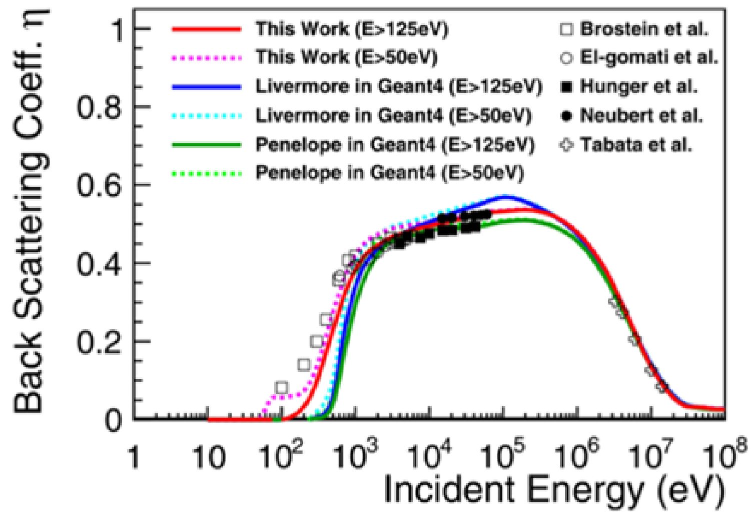
- **UR-95:** Provide documentation on how to include and run tests via geant-val (Konstantinov)
  - Information shared with the G4-Med team
  - Make sure that the documentation is clear
  - Done

Existing URs: Geant4-DNA (1)

- **UR-53:** Extend energy and material coverage of G4-DNA beyond DNA and liquid water (S. Incerti)
  - Liquid water, DNA, amino-acids, boron, gas (micro/nanodosimetry), solid state (e.g. high Z materials for nanoparticle aided radiotherapy, microelectronics)
  - Done for gold (Geant4 11.0)
  - Done for protons in water (extension 100 MeV –> 300 MeV) by M. Cortes-Giraldo et al.
  - In progress for electrons: extension & update of option4 for water (10 keV -> 10 MeV) by I. Kyriakou et al, for DNA materials (by S. Zein et al.), for N2 and O2 (by C. Villagrasa et al., by C. Mancini, F. Nicolanti et al.), extension & update for the dielectric model for gold (10eV-1 MeV), by I. Polopetrakis, I. Kyriakou., D. Sakata et al.)
  - Extensions to MuElec by C. Inguimbert, ONERA, and collaborators
  - In Geant4 11.3 any ion is simulated in DNA physics lists for liquid water. For other materials condense history approach should be used so far.
    - Further validation needed (V. Ivantchenko, H. Tran, J. Archer)

Gold





Sakata et al (2019) Electron track structure simulations in a gold nanoparticle using Geant4-DNA, Physica Medica, 63: 98-104

Existing URs: Geant4-DNA (2)

- **UR-82**: Geant4-DNA physics processes for positrons (Ivantchenko)
  - Positrons are included in the DNA Physics Lists, using standard condensed history approach.
  - No manpower to start developments on discrete models
- **UR-62:** Model for positronium creation and annihilation (Ivantchenko)
  - 1st preliminary version is realized in 11.3beta
  - 1st complete variant is available and will be public with 11.3
- **UR-77**: Multiscale combination. Mixing condensed-history and Geant4-DNA, e.g. for radioprotection in space
  - Done but more validation is required (V. Ivantcheko, H. Tran and J. Archer)
  - BioRad3 Multi-scale prototype framework to be made available (Paolo Dondero et al., SWHARD).
- **UR-78:** Provide an example of physics list activating both Geant4-DNA and hadronic physics, including radioactive decay (Ivantchenko)
  - All components exist in 11.3
  - This needs to be demonstrated in an example with 11.3

Existing URs: Geant4-DNA (3)

- **UR-76**: Provide (external) files to describe geometries of biomolecules (e.g. plasmids, bacterium, cells, etc) (Incerti et al.)
  - On going through BioRad3
  - See "moleculardna" web site : https://geant4-dna.github.io/molecular-docs/

- **UR-79**: Mesoscopic approach development for chemistry / water radiolysis (high dose rates, longer times), including an extended example
  - Under development (high dose rates, longer times) and compared to existing Geant4 (step by step) approaches
  - Activate three Time-Step models (SBS,IRT, IRT-syn) in chem6 example using IU macro.
  - ”scavenger” example for radiolysis simulation in scavengers – released in Geant4 11.0
  - "UHDR" example released in Geant4 11.2 BETA

New URs (1)

MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

Radiation therapy physics

History by history statistical estimators in the BEAM code system

B. R. B. Walters, I. Kawrakow, D. W. O. Rogers

First published: 15 November 2002 | https://doi.org/10.1118/1.1517611 | Citations: 164

- **UR#**: To have example(s) showing how to get statistical uncertainties of additive quantities (e.g. dose) calculated with a scoring mesh using the *"history-by-history"* method
  - **Source:** User forum (see at https://geant4-forum.web.cern.ch/t/history-by-history-method-in-command-based-scoring/11571)
  - Well-known method described by Walters et al., Med Phys 29 (2002), used in PENELOPE, BEAMnrc, etc.
  - Gives a better estimation of statistical uncertainties as compared with the std dev of *N* simulation batches.

$$s_{\bar{x}} = \sqrt{\frac{1}{N-1}\left[\frac{\sum_{i=1}^{N} x_i^2}{N} - \left(\frac{\sum_{i=1}^{N} x_i}{N}\right)^2\right]}$$

  - The **default score writer** G4VScoreWriter **already provides all the info needed** (sum_x and sum_x2) after the migration to G4StatDouble...
  - … but there are no other user score writers which keep sum_x2, including medical examples. This "hides" the possibility of using the default score writer for a beginner.

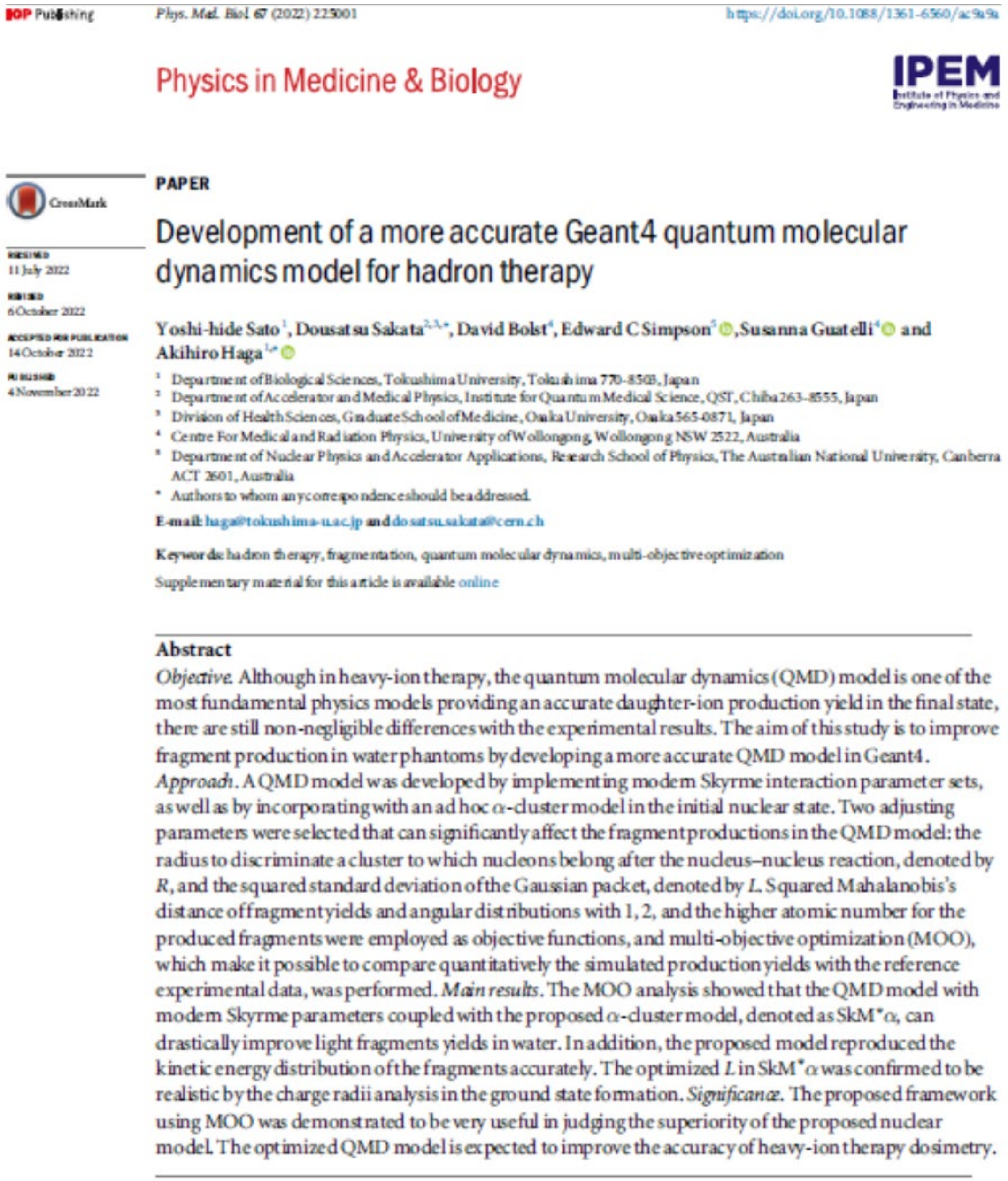
Python wrapping

- **UR#**: contribution to develop the G4 Python wrapping
- Source: David Sarrut
- The current Geant4 python wrapping is not adequate for the needs of GATE.
- A first pybind11-based G4 wrapping has been developed tailored for GATE users. The code is open source and it is here : https://github.com/OpenGATE/opengate/tree/master/core/opengate_core/g4_bindings
- There is strong interest to collaborate to develop further the Geant4 python wrapping for the wider Geant4 community

New URs: benchmarking/validation

New URs: benchmarking(1)

- **UR#**: Validate G4LIQMD against experimental measurements for hadrontherapy
  - Source: Guatelli and Geant4 hadrontherapy community
  - In progress
  - Paper under review in Physica Medica
  - Validate against microdosimetrics experimental data (to start)
  - By Y. Sato, D. Bolst, S. Guatelli, A. Haga and collaborators



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Physics in Medicine & Biology

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PAPER

Development of a more accurate Geant4 quantum molecular dynamics model for hadron therapy

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Keywords: hadron therapy, fragmentation, quantum molecular dynamics, multi-objective optimization

Supplementary material for this article is available online

Abstract

Objective. Although in heavy-ion therapy, the quantum molecular dynamics (QMD) model is one of the most fundamental physics models providing an accurate daughter-ion production yield in the final state, there are still non-negligible differences with the experimental results. The aim of this study is to improve fragment production in water phantoms by developing a more accurate QMD model in Geant4. *Approach.* A QMD model was developed by implementing modern Skyrme interaction parameter sets, as well as by incorporating with an ad hoc α-cluster model in the initial nuclear state. Two adjusting parameters were selected that can significantly affect the fragment productions in the QMD model: the radius to discriminate a cluster to which nucleons belong after the nucleus–nucleus reaction, denoted by R, and the squared standard deviation of the Gaussian packet, denoted by L. Squared Mahalanobis's distance of fragment yields and angular distributions with 1, 2, and the higher atomic number for the produced fragments were employed as objective functions, and multi-objective optimization (MOO), which make it possible to compare quantitatively the simulated production yields with the reference experimental data, was performed. *Main results.* The MOO analysis showed that the QMD model with modern Skyrme parameters coupled with the proposed α-cluster model, denoted as SkM*α, can drastically improve light fragments yields in water. In addition, the proposed model reproduced the kinetic energy distribution of the fragments accurately. The optimized L in SkM*α was confirmed to be realistic by the charge radii analysis in the ground state formation. *Significance.* The proposed framework using MOO was demonstrated to be very useful in judging the superiority of the proposed nuclear model. The optimized QMD model is expected to improve the accuracy of heavy-ion therapy dosimetry.

New URs: benchmarking(2)

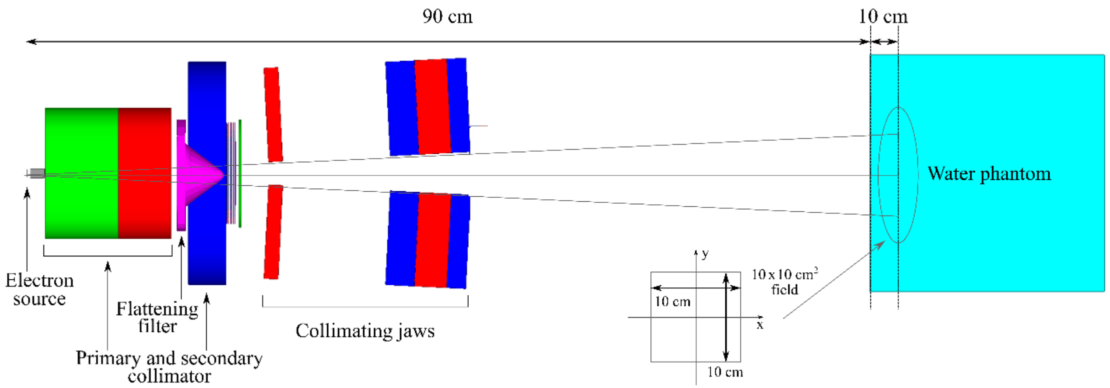
- **UR#**: Benchmark Geant4 for BNCT and neutron field applications against exp data and MCNP and provide "targeted" doc in this topic
- Source: S. Guatelli
- There is work done in this space by the Collaboration and Geant4 users
  - Recent example of this activity: See talk by S. MacLeod on Wednesday, 16:00, in the hadronic physics session
- Aim: enrich the benchmarking tests if needed and develop documentation where papers on this topic are listed

New URs: Investigate the Penelope Brem angular distribution

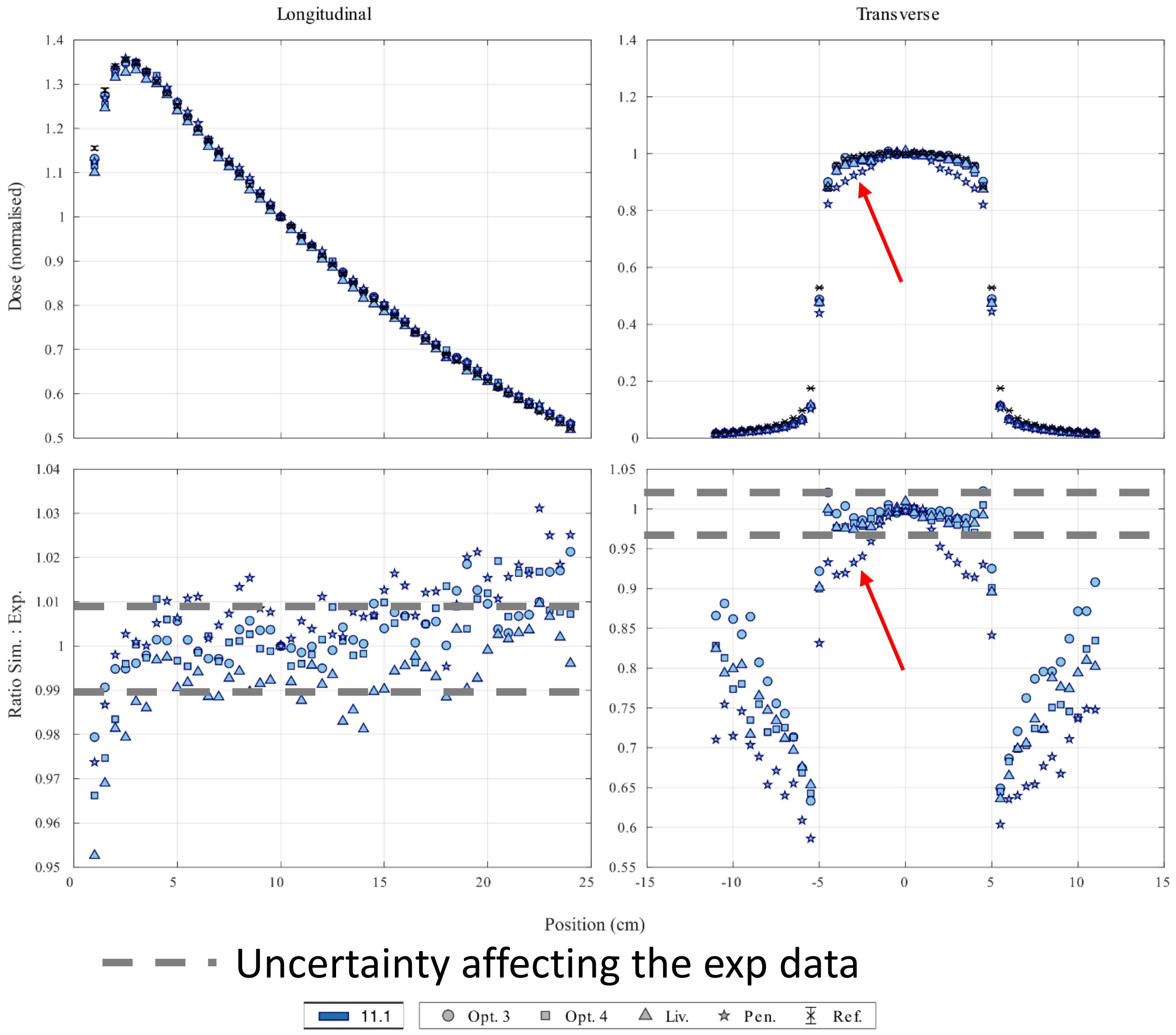
By B. Caccia and S. Pozzi (Istituto Superiore di Sanita', Rome, Italy) and C. Mancini-Terracciano (La Sapienza, Rome,

- Source: G4-Med team
- Geant4 advanced example medical_linac
- Model of a GE Saturne 43 linear accelerator (EURADOS Report Caccia et al, 2020-05)
- 3D dose in a water phantom
- Repeat the sim with Geant4 11.3 and understand if there is a problem in the model

Simulation set-up



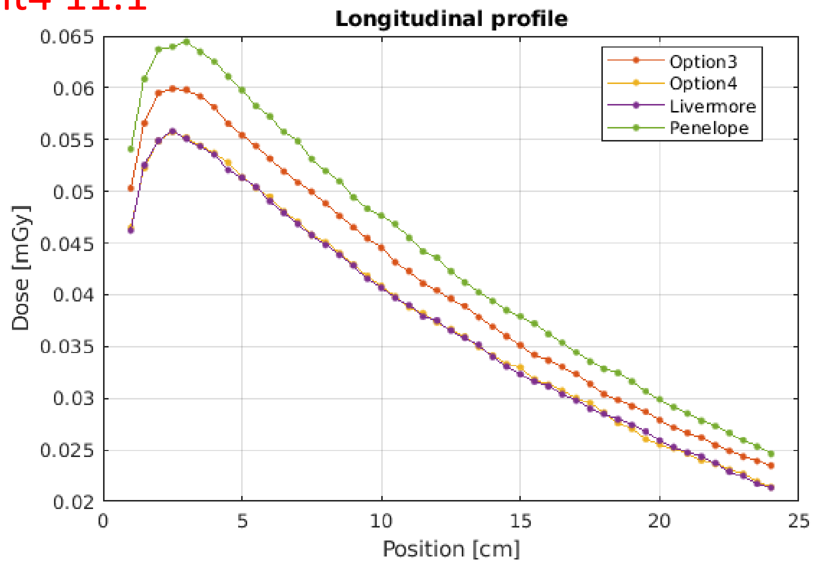
Geant4 11.1

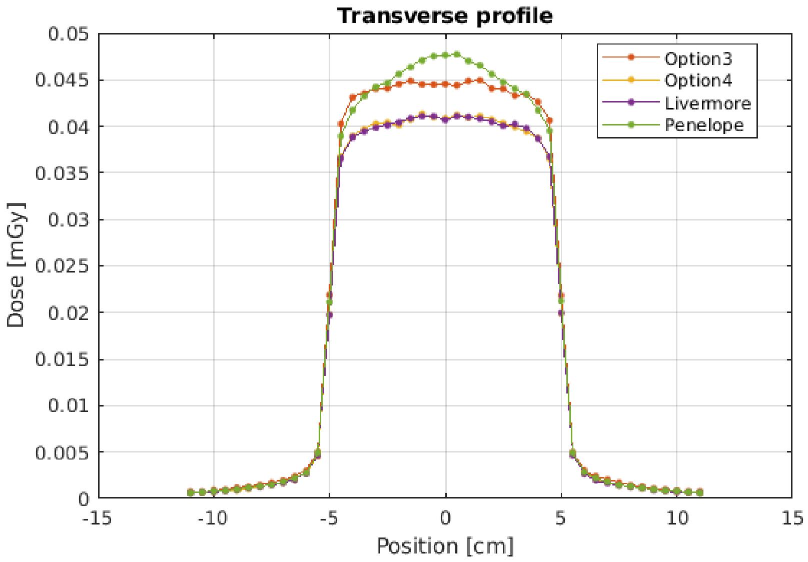


Continued

- In the first 10 cm of water phantom for the longitudinal profiles , differences against Option4 are about 1% for Livermore, between 6% and 10% for Option3, and between 15% and 16% for Penelope.

Geant4 11.1





Validation for radiobiology

On-going verification & validation

- Continue efforts in chemistry under irradiation (LET, doses rates) & radiobiology
- Calculation of G-values, under variety of exp. conditions : T, pH, scavengers, high LET
- Radiobiological damage: beyond strand-breaks towards macroscopic observables (e.g. requiring analytical repair models)
- Addition of related extended and advanced examples for users
- Some of these activities are currently on-going through
  - the ESA BioRad III project (2021-2023): CEA (FR), CHUV (CH), G4AI Ltd. (UK), IN2P3 (FR –coord.), INFN (IT), Ioannina U. (GR), IRSN (FR), Sevilla U. (ES), Swhard (IT)
  - the MAGIC project (2020-2023): CHUV (CH – coord.), LP2i (FR)
  - The FLASHMod project (2021-…): LPC (France), LP2i

Validation for bio-medical applications: the G4-Med suite

- Extend the tests of G4-Med to other medical applications: 23 on geant-val

- More recently added:

- Included Geant4-DNA physics lists where applicable (Microdosimetry and DPK)
- Chemistry / water radiolysis – H. Tran et al.
- EPICS17 data libraries included in the photon attenuation tests
- Validate Medical Linac advanced examples against EURADOS Report 2020-05 – C. Caccia
- Dosimetry for eFLASH radiotherapy

- Later:

- Radioactive decay – L. Desorgher et al, , help needed
- Nuclear medicine tests – A. Malaroda, S. Guatelli et al, help needed
- Neutron cross sections - S. MacLeod and help needed
- Calculation of the wall correction factors, kwall, for two graphite ionization chambers – P. Arce
- Include benchmark against ICRU Report 90: Stopping Powers of electrons (and positrons), protons, α particles and carbon ions for three key materials: graphite, air, and liquid water – M. A. Cortés-Giraldo, help needed
- Include total inelastic cross section tests of production of C-10 and C-11 important for carbon ion in-vivo PET and Prompt Gamma imaging, E. Simpson, ANU – help needed