29th Geant4 Collaboration Meeting

Status and recent developments of Geant4 Advanced Examples for medical applications

Francesco Romano[1] and Miguel Cortes-Giraldo[2]

on behalf of the Geant4 Advanced Example Working Group

[1] *Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Italy*

[2] *Universidad de Sevilla, Spain*

Catania, 8 October 2024

Geant4 Advanced examples

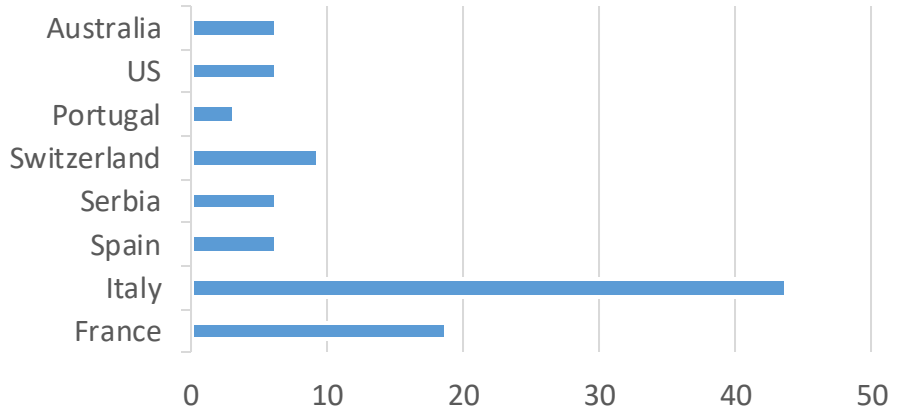
Illustrate realistic applications of Geant4 in typical experimental environments

Coordinator: Francesco Romano

Deputy: Miguel Cortes-Giraldo

Working Group (2024 census)

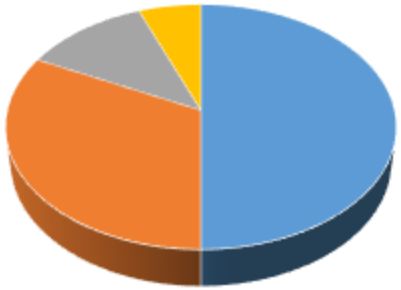
- **26** Geant4 Collaborators (**15%** of G4 Collaboration)
- **5** contributors (**30%** of G4 total)
- **2.78** FTE (2.1 FTE in 2023, 1.8 FTE in 2022)
- + … FTE for external contributors!



Members and Contributors (Census 2024)

1. Francesco Romano (INFN-CT, Catania, Italy) **WG Coordinator**
2. Miguel Cortes-Giraldo (Universidad de Sevilla, Seville, Spain) **WG Deputy Coordinator**
3. Makoto Asai (JLAB, Virginia, US)
4. David Bolst (University of Wollongong, Australia)
5. Pablo Cirrone (INFN-LNS, Catania, Italy)
6. Giacomo Cuttone (INFN-LNS, Catania, Italy)
7. Gabriele Cosmo (CERN, Switzerland)
8. Paolo Dondero (SWHARD, Genpova, Italy)
9. Milos Dordevic (Vinca Institute of Nuclear Sciences, University of Belgrade, Serbia)
10. Susanna Guatelli (University of Wollongong, Australia)
11. Alexander Howard (CERN, Switzerland)
12. Sebastien Incerti (CENBG/LP2I Bordeaux, France)
13. Christophe Inguimbert (ONERA, France)
14. Damien Lambert (CEA, France)
15. Le Anh (Institut de Radioprotection et de Sûréte Nucléaire, Paris, France)
16. Zhuxin Li (CENBG, France) → *contributor*
17. Francesco Longo (INFN-Ts, Trieste, Italy)
18. Carlo Mancini (INFN Rome, Italy)
19. Alfonso Mantero (SWHARD srl, Italy)
20. Claire Michelet (CENBG/LP2I Bordeaux, France)
21. Giuliana Miluzzo (INFN Catania, Catania, Italy) → *contributor*
22. Luciano Pandola (INFN-LNS, Catania, Italy)
23. Giada Petringa (INFN-LNS, Catania, Italy)
24. Ivan Petrovic (Vinca Institute, Belgrad, Serbia)
25. Andrea Polsini (INFN, Ts, Trieste, Italy) → *contributor*
26. Giorgio Russo (CNR-Lato, Cefalù, Italy)
27. Alberto Sciuto (INFN-LNS, Catania, Italy) → *contributor*
28. Ronny Stanzani (SWHARD S.R.L., Genova, Italy) → *contributor*
29. Bernardo Tomè (LIP, Portugal)
30. Hans-Joachim Wenzel (Fermilab, US)
31. Anna Zaborowska (CERN, Geneva, Switzerland)

Medical: 17
Space: 11
HEP: 4
Other: 2



34 examples

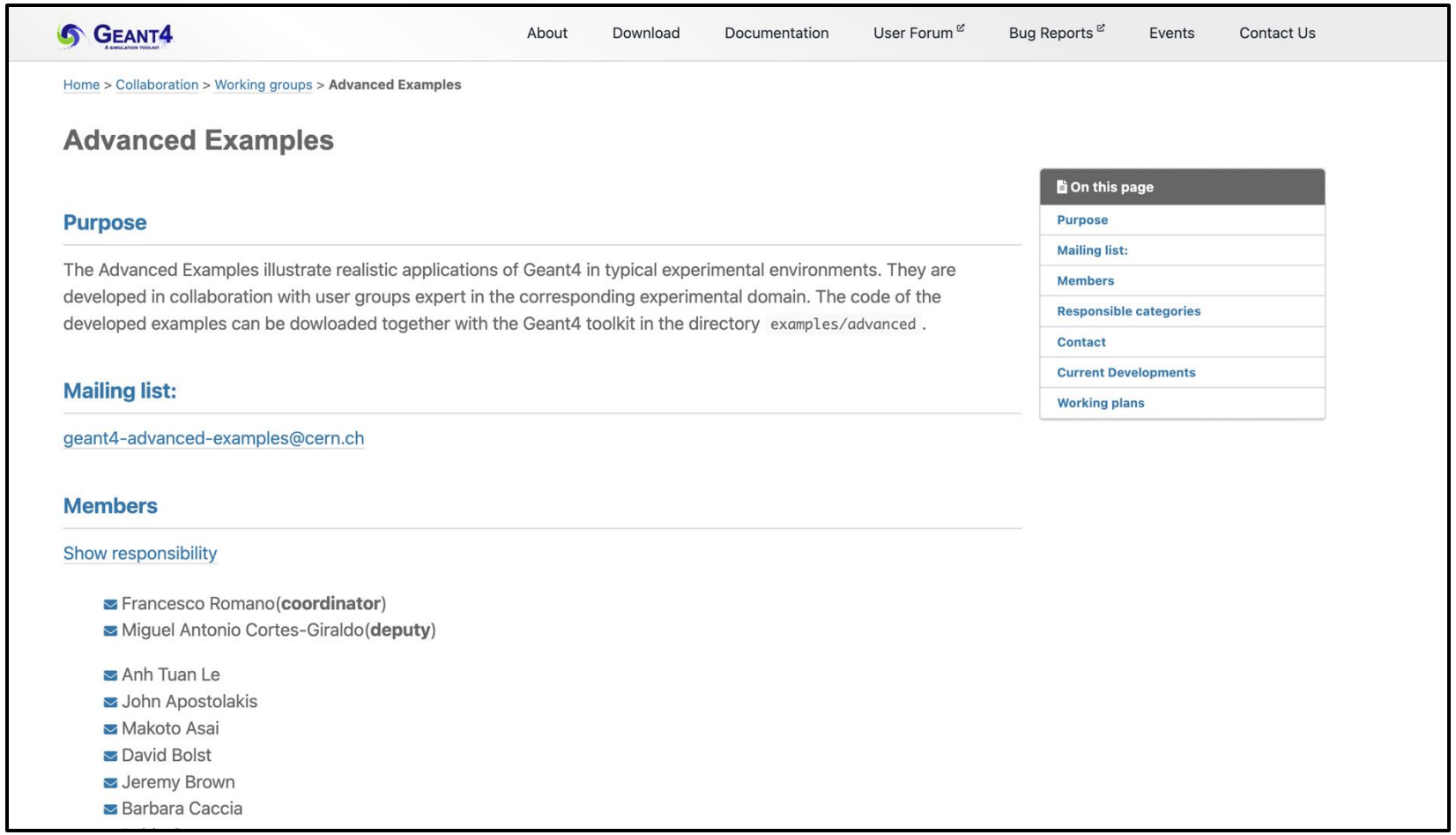
■ Medical 50% ■ Space 33% ■ HEP 12% ■ Other 6%

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
doiPET	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
exp_microdosimetry	Giuliana Milluzzo	Modelling of detectors and their response for microdosimetry for radiation protection in space
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
dsbandrepair	Ahn Tuan Le	Evaluate the early radiation-induced direct and indirect DNA damage (SSBs, and DSBs)

new examples (as respect 2023)

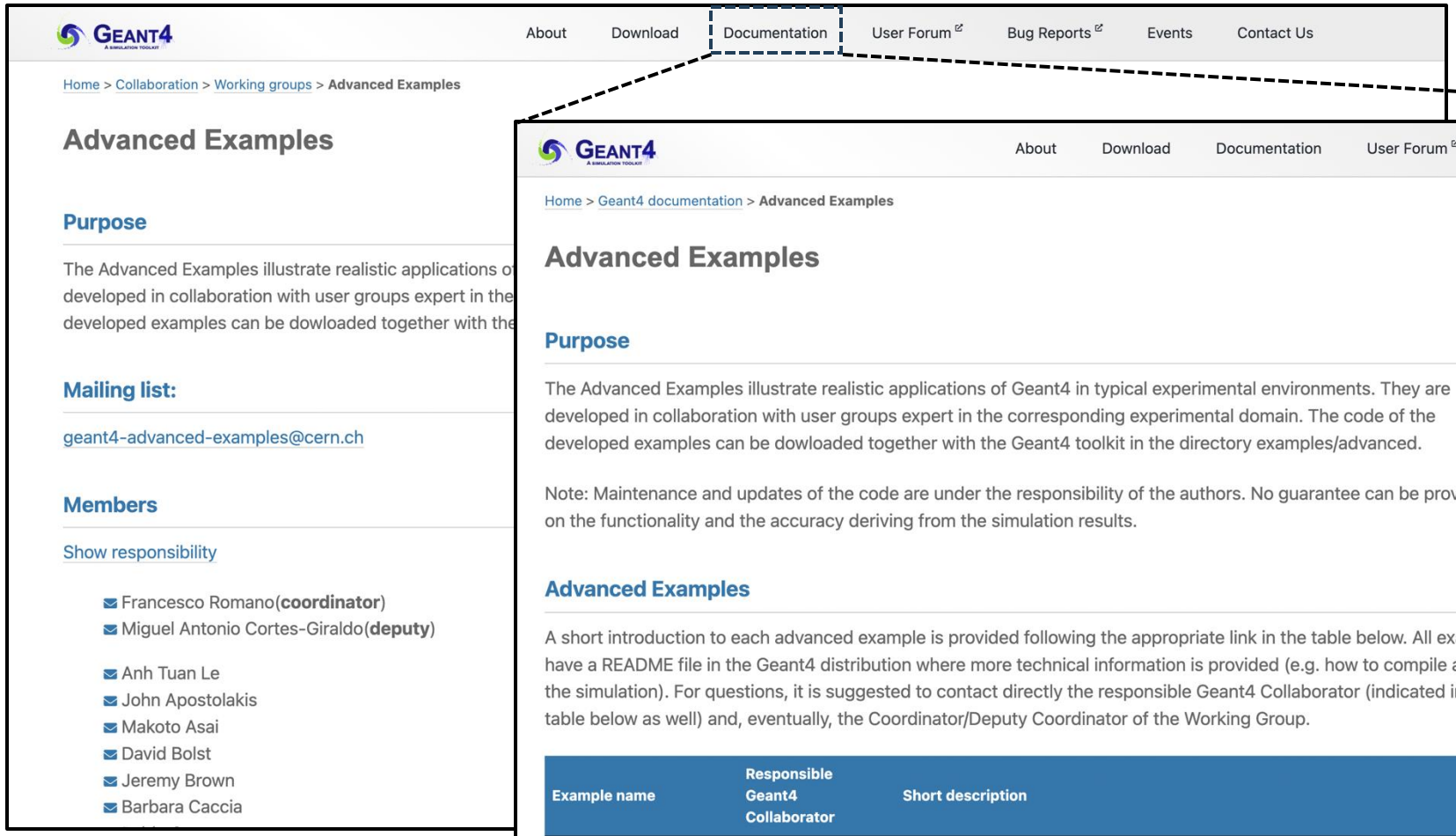
hadrontherapy	Pablo Cirrone	Model of hadrontherapy beamlines
HGCal_testbeam	Anna Zaborowska	Demonstration of a high-end High Energy Physics test beam setup, for the endcap electromagnetic calorimeter of the CMS detector CERN-LHCC-2017-023
human_phantom	Susanna Guatelli	Calculation of dose in analytical anthropomorphic phantoms
ICRP110_HumanPhantoms	Susanna Guatelli	Calculation of dose in ICRP110 anthorpomorphic phantoms
ICRP145_HumanPhantoms	Susanna Guatelli	Calculation of dose in ICRP145 anthorpomorphic phantoms
iort_therapy	Francesco Romano	Model of a typical Intraoperative Radiation Therapy beamline
lAr_calorimeter	Andrea Dotti	Simulation of the Forward Liquid Argon Calorimeter (FCAL) of the ATLAS Detector, CERN, Switzerland
medical_linac	Carlo Mancini Terracciano	Model of a typical medical linear accelerator for Intensity Modulated Radiation Therapy (IMRT)
microbeam	Sebastien Incerti	Simulation of the microbeam cellular irradiation beam line installed on the AIFIRA electrostatic accelerator facility located at LP2i Bordeaux, France
microelectronics	Christophe Inguimbert	Demonstration on how to activate track structure physics models for electrons in a silicon microelectronics device
nanobeam	Sebastien Incerti	Simulation of the beam optics of the "nanobeam line" installed on the AIFIRA electrostatic accelerator facility located at LP2i Bordeaux, France
purging_magnet	John Apostolakis	Modelling of electrons traveling through a 3D magnetic field in the radiotherapy context
STCyclotron	Susanna Guatelli	Model of the solid target of the South Australian Health and Medical Research Institute (SAHMRI), Adelaide, South Australia
stim_pixe_tomography	Claire Michelet	Simulation of three dimensional proton micro-tomography
underground_physics	Alex Howard	Example of an underground dark matter experiment. More details are provided in the README file accompanying the example
xray_fluorescence	Alfonso Mantero	Example reproducing various setups for PIXE and XRF experiments. More details are provided in the README file accompanying the example
xray_telescope	Giovanni Santin	Simulation of a typical X-ray telescope for space exploration
xray_TESdetector	Paolo Dondero	Application of Geant4 in a space environment. Model of an X-ray detector derived from the X-IFU, the X-ray spectrometer designed and developed by the European Space Agency (ESA) for use on the ATHENA telescope.
Xray_SiliconPoreOptics	Paolo Dondero	Model of a single reflective pore used to simulate on a smaller scale the effect of the millions of pores forming the mirror of the ATHENA Silicon Pore Optics (SPO).

Advanced Example web pages



https://geant4.web.cern.ch/collaboration/working_groups/advExamples/

Advanced Example web pages



https://geant4.web.cern.ch/collabor

https://geant4.web.cern.ch/docs/advanced_examples_doc/index

Advanced Example web pages

GEANT4 About Download Documentation User Forum Bug Reports Events Contact Us

Home > Collaboration > Working groups > **Advanced Examples**

Advanced Examples

Purpose

The Advanced Examples illustrate realistic applications o
developed in collaboration with user groups expert in the
developed examples can be dowloaded together with the

Mailing list:

geant4-advanced-examples@cern.ch

Members

Show responsibility

- Francesco Romano(**coordinator**)
- Miguel Antonio Cortes-Giraldo(**deputy**)
- Anh Tuan Le
- John Apostolakis
- Makoto Asai
- David Bolst
- Jeremy Brown
- Barbara Caccia

https://geant4.web.cern.ch/collabor

GEANT4 About Download Documentation User Forum Bug Reports Events Contact Us

Home > Geant4 documentati

Advanced Ex

Purpose

The Advanced Exampl
developed in collaborat
developed examples ca

Note: Maintenance and
on the functionality and

Advanced Exampl

A short introduction to
have a README file in t
the simulation). For que
table below as well) and

Example name
air_shower
ams_Ecal
brachytherapy

https://geant4

Advanced Example brachytherapy

On this page
- Short description
- Comparison to reference data

Responsible Geant4 Collaborator: Susanna Guatelli, Centre For Medical Radiation Physics, Wollongong University, Australia.

Current contributors: Susanna Guatelli (1), Albert Le (1) and Dean Cutajar (1), with the support of Luciano Pandola (2)

1. Centre For Medical Radiation Physics (CMRP), University of Wollongong, NSW, Australia
2. LNS, INFN, Catania, Italy

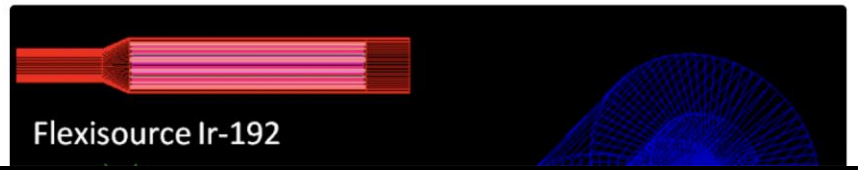
Past contributors: S. Agostinelli (Istituto Tumori, Genova, Italy), S. Garelli (Istituto Tumori, Genova, Italy), S. George (Centre For Medical and Radiation Physics, Wollongong University, Wollongong, Australia), M.G. Pia (INFN, Genova, Italy), M. Tropeano (Universita' di Genova, Italy)

Short description

This example allows to calculate the energy deposition/dose in a water phantom produced by a brachytherapy source. The user can select a source among the following options:

- Iridium sources (Flexisource and TG186).
- Iodine source (Bebig Isoseed I-125 and Oncura).
- Leipzig Applicator with an iridium source (model from the Istituto Tumori, Genova, Italy).

The sources are shown in Figure 1.



Workplan 2024

- Release of a new example showing how to import in Geant4 simulations IAEA Phase Space Files (1,2)[*] *(Cortes-Giraldo) → in progress (see M. Cortes-Giraldo's talk)*
- Improve MicroElec example to show the use of novel electron low energy cross sections for solid state materials beyond silicon (1,2) *(Inguimbert, Lambert) → in progress*
- Implementation of pre-clinical, mice PET images to evaluate a dose distribution for new drugs (1,2) *(Russo) → in progress*
- Upgrade of the medical_linac example (1,2) *(Mancini, Caccia, Pozzi) → done (see S. Pozzi's talk)*
- Design of realistic phantoms of C. elegans in the stim_pixe_tomography advanced example (1,2) *(Michelet) → in progress*
- Add a new geometry reproducing some dosimeters used in FLASH radiotherapy in the eFLASH_radiotherapy example (1,2) *(Milluzzo, Romano, Pensavalle) → done for SiC array and sensitive detector (see G. Milluzzo's talk)*
- Add new detectors, SiC and TEPC microdosimeters, in the exp_microdosimetry example (1,2) *(Milluzzo, Romano) → done for SiC, in progress for TEPC (see G. Milluzzo's talk)*
- Improve the Hadrontherapy example in the simulation of proton, carbon ion and helium ion beam irradiation for the calculation of track- and dose- averaged LET(1,2) *(Cirrone, Petringa, Sciuto, Dordevic?) → done (see G. Petringa's talk)*
- Maintenance of the webpage (1,2) *(Romano) → done (4 examples webpages in progress)*
- Maintenance and code review (e.g. implementation of the extended examples coding guidelines and migration to C++17) in selected examples (1,2) *(Romano) → in progress*

Note

- *[*] Optional, and subject to the availability of manpower*
- *1: aimed to be done in first semester*
- *2: aimed to be done in second semester*

New developments

New examples released in Geant4 11.2

- Development of two examples related to space applications

  By P. Dondero, A. Mantero and R. Stanzani, SWHARD s.r.l., Genova, Italy

  - **`Xray_TESdetector`**
  - **`Xray_SiliconPoreOptics`**

- Development of two examples related to biological aspects
  - **`stim_pixe_tomography:`** by C. Michelet and PhD student Z. Li, Bordeaux University, France
  - **`dsbandrepair:`** by L. T. Anh, Y. Perrot (IRSN), C. Villagrasa (IRSN), S. Meylan, H. N. Tran (LP2I)

stim_pixe_tomography

Proton imaging on biological micro-organism like Caenorhabditis elegans (C. elegans)

Authors: C. Michelet, Z. Li*, A. Rouwane, H. Tran, S. Incerti, H. Seznec (Univ. of Bordeaux and LP2i, CNRS, Bordeaux, France)

Purpose : A benchmark for quantitative imaging

Quantitative imaging = 2D or 3D distributions of the mass content

⇒ **Structure:** using **transmission** techniques (of protons, of X-rays…)

⇒ **Chemical element composition:** using **X-ray emission** techniques, *e.g.,* PIXE: Particle Induced X-ray Emission (proton beam) ; SXRF: Synchrotron X-ray Fluorescence

The experimental data processing may be complex:

⇒ Accuracy of the tomographic reconstruction? Of X-ray attenuation?

⇒ Is the obtained image faithful to the original object?

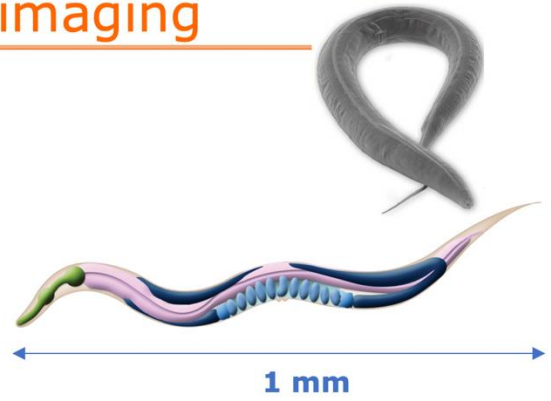
No experimental reference samples available at the microscopic level, with known values of chemical element composition.

⇒ **Geant4 simulation used as a benchmark** to check the accuracy of the data processing chain

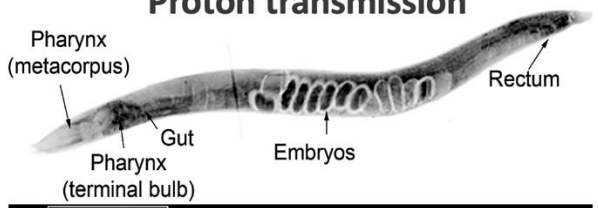
IRiBio research group

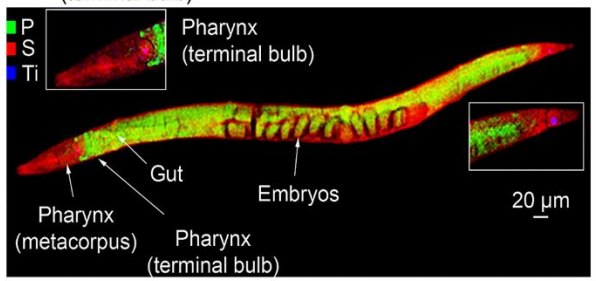
- Interaction of exogenous compounds with cells or micro-organisms
- In-vitro and in-vivo nanotoxicology
- Optimization of therapeutic approaches for proton therapy

Biological model: *Caenorhabditis elegans* (*C. elegans*), a small worm living in temperate soil environments



Proton transmission





X-ray emission

Z. Li

C. Michelet

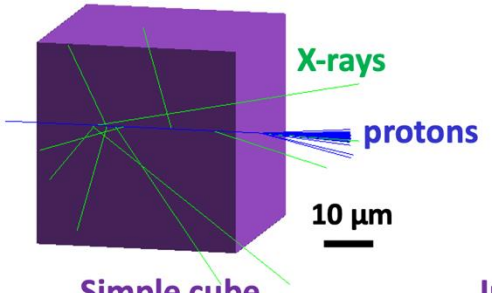
S. Incerti

Slide from C. Michelet

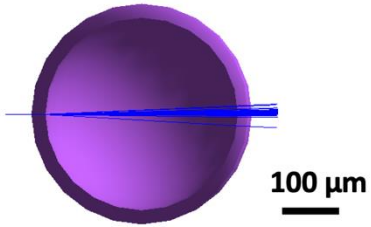
stim_pixe_tomography

2D or 3D imaging of microscopic samples

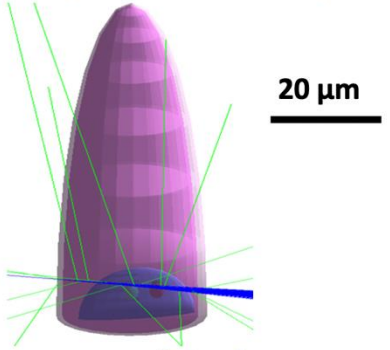
- **Three phantoms are available** in the *stim_pixe_tomography* advanced example => Size, mass density, composition, *etc.*, can be modified
- **Type and energy of incident particles** defined in a macro file => easy to modify. So any source can be used, *e.g.*, proton, ion or X-ray beam. Uses Livermore model with EPICS 2017 update (other PhysicsLists available).
- **User guide** available at: http://geant4.in2p3.fr/styled-4/



Simple cube



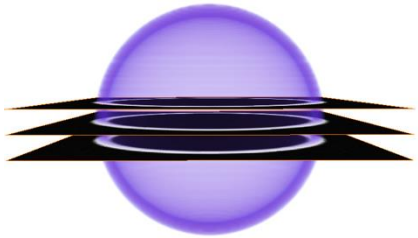
Inertial confinement fusion target
(coll. Fudan University, Shanghai)



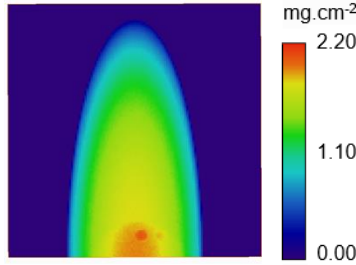
Upper part of *C. elegans*
Simplified phantom made of ellipsoids

References

- *C. Michelet et al., Physica Medica 94 (2022) 85–93, doi: 10.1016/j.ejmp.2021.12.002*
- *Z. Li et al., Nucl. Instrum. Methods Phys. Res. B 536 (2023) 38-44, doi: 10.1016/j.nimb.2022.12.026*



3D transmission tomography



"Classical" (2D) imaging

Perspectives

Construction of a realistic *C. elegans* phantom

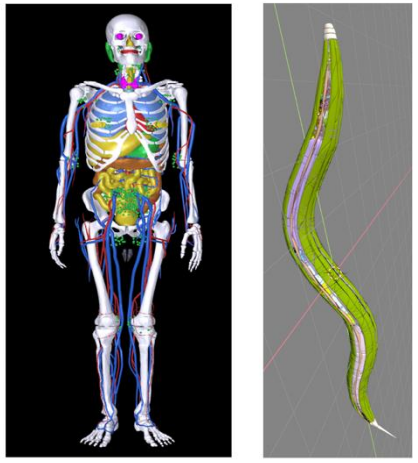
- Similar approach to advanced example ICRP145: Phantom Adult Mesh-type Reference Computational Phantoms

  C.H. Kim, Y.S. Yeom, N. Petoussi-Henss, M. Zankl, W.E. Bolch et al. ICRP. Adult mesh-type reference computational phantoms. ICRP Publication 145. Ann. ICRP 49(3) (2020).

- ***C. elegans* phantom based on a geometrical model developed at Caltech**

  http://canopus.caltech.edu/virtualworm/
  Part of the OpenWorm Project : http://www.openworm.org

  B. Szigeti et al. OpenWorm: an open-science approach to modelling Caenorhabditis elegans. Frontiers in Computational Neuroscience 8, 137 (2014) doi:10.3389/fncom.2014.00137



- The phantom will be made available in the *stim_pixe_tomography* advanced example
- Applications: imaging, radiation biology (dosimetry)…
- Work in progress; public release expected in summer 2025

Slide from C. Michelet

dsbandrepair – new advanced example

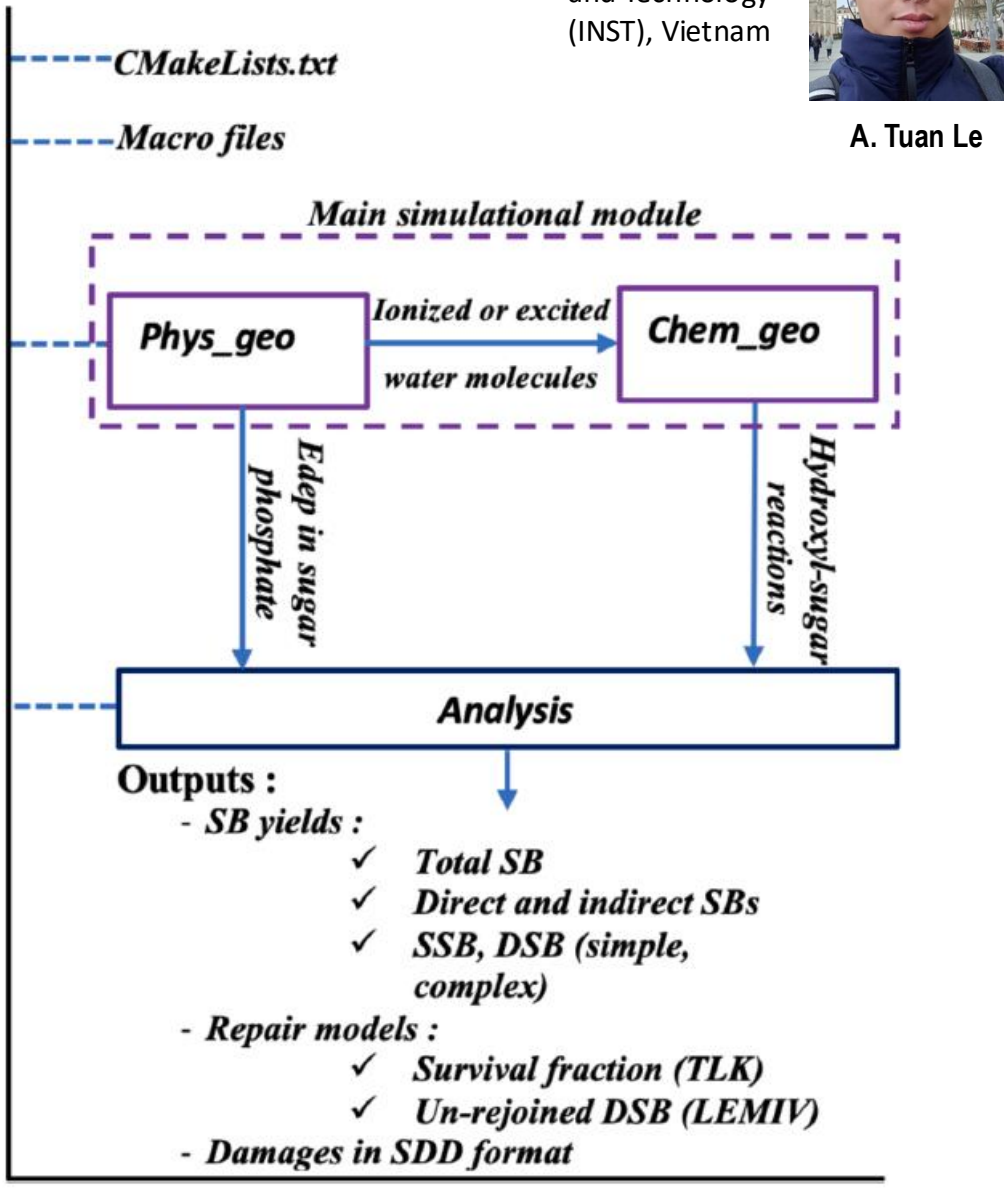
Institute for Nuclear Science and Technology (INST), Vietnam

A. Tuan Le

- The example aims to:
  - Evaluate the early radiation-induced DNA damage
    - Direct and indrect strand breaks (SB)
    - Single strand breaks , double strand breaks (simple, complex)
    - Repair models:
      - Two Lesion Kinetic (TLK): Survival fraction
      - LEM-IV: Un-rejoined DSB

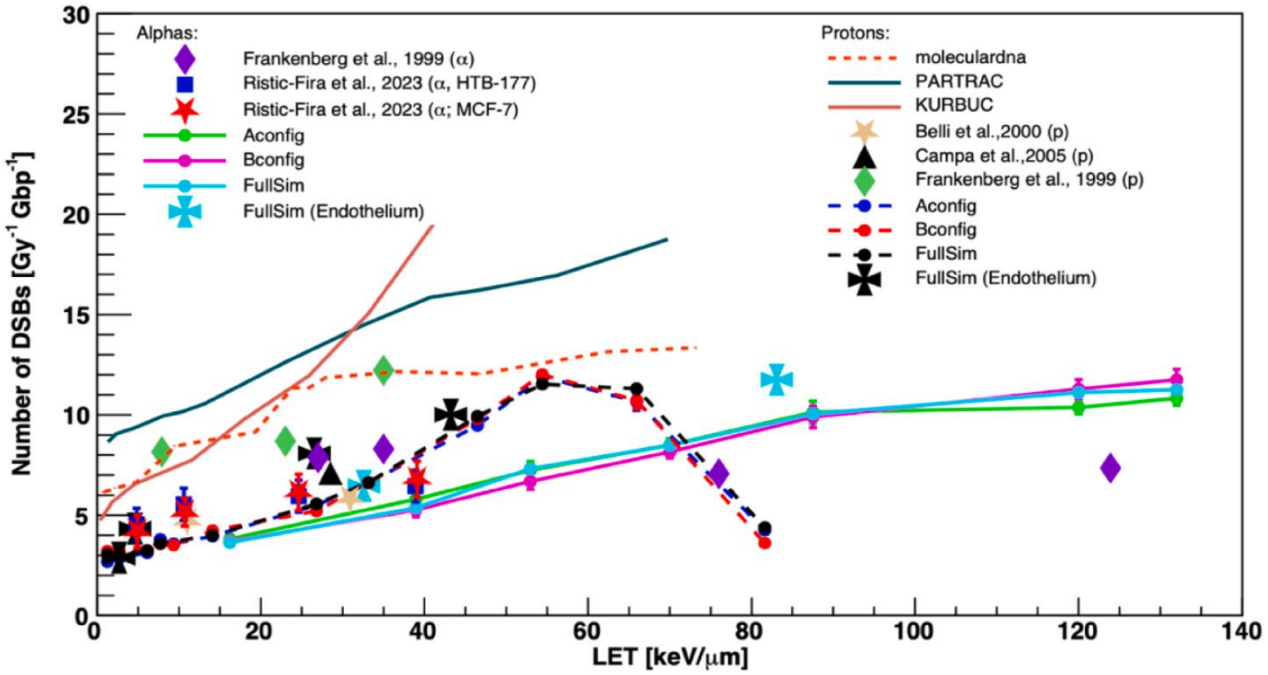
- Coupled to DNA geometries constructed with DnaFabric (Compt. Phys. Comm. 2016 204:159-169)
    - Full genome including bot heterochromatin and euchromatin
    - Yeast, Bacteria, Human nuclei cell

- Three modules: Phys_geo, Chem_geo, & Analysis can be run separately
- Support MPI parallelism
- Please cite: *Meylan et al. Sci. Rep. 7 (2020) 11923*, *Anh et al. Phys. Med. 124 (2024) 103422*



Slide from A. Tuan Le

dsbandrepair - benchmarking results



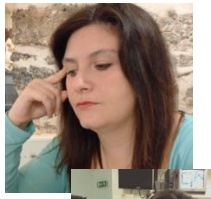
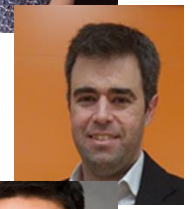
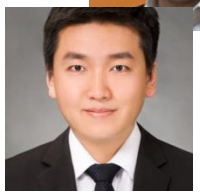
- Fibroblast
  euchromatin (34%), heterochromatin (66%)
- Aconfig: G4DNAPhys_opt2 + G4DNAChem_opt2 (SBS, 5ns)
- Bconfig: G4DNAPhys_opt2 + G4DNAChem_opt3 (IRT_sync, 5ns)

See: Anh et al. Phys. Med. 124 (2024) 103422

Slide from A. Tuan Le

Actual	To be developed
Independent tracks	Dose rate effect: conventional -> UHDR (?)
No impact of chemical enviroment	Oxygen effect, scavengers
G4DNAPhys_opt2 (e- up to 1 MeV)	Benchmark the code for new Geant4-DNA developments - G4DNAPhys_opt4 with e- up to 10 MeV - New models for protons up to 300 MeV
Complex code	Making it easier to understand how things work
2 examples: moleculardna and dsbandrepair	Unified simulation code
Analysis: survival and unrejoined DSB	Other biological endpoints: aberrations, mutation

New developments (covered in the session)

Advanced Examples Summary	*Francesco Romano*	
Hotel Four Points by Sheraton	14:43 - 14:55	
eFLASH_radiotherapy and exp_microdosimetry examples: status and recent developments	*Giuliana Milluzzo*	
Hotel Four Points by Sheraton	14:55 - 15:03	
Hadrontherapy example: Current Status and Future Perspectives	*Giada Petringa*	
Hotel Four Points by Sheraton	15:03 - 15:11	
Status and new developments for the Medical Linac Example	*Silvia Pozzi*	
Hotel Four Points by Sheraton	15:11 - 15:19	
IAEA Phase Space file status	*Dr Miguel Antonio Cortes-Giraldo*	
Hotel Four Points by Sheraton	15:19 - 15:24	
Contributions to Advanced Examples for ICRP Reference Phantoms	*Yeon Soo Yeom*	
Hotel Four Points by Sheraton	15:24 - 15:29	

Summary and Conclusions

- Many advanced examples related to several fields, mainly for medical and space applications
- General improvement of the examples and consolidation of the developments
- Big effort for benchmarking and experimental verifications
- Updating of the web page and code review, update and maintenance
- Relevant number of young collaborators (collaborators, contributors, external)
- First paper on Advanced Examples?










Thank you











Aknowledgements:

Many thanks to all the members of the Advanced Examples Working Group and also external collaborators for providing useful materials