The GATE Monte Carlo simulation platform: The researcher's ally in medical physics

Lydia Maigne, Lydia.Maigne@clermont.in2p3.fr

Associate professor @ Laboratoire de Physique de Clermont, University Clermont Auvergne
Spokesperson the OpenGATE collaboration

Paradigm

- **Development/optimization of medical physics systems**
    - Long term development
    - Need valuable predictive tools

- **Modeling/simulation of systems**
    - Helpful for the experimental set-up
    - Costless (***except with a cat*** or if you need large computing ressources)
    - Step forward to the future

The MC codes in medical physics

GATE
opengatecollaboration.org

mcnp

GEANT4
A SIMULATION TOOLKIT

University of Washington
Division of Nuclear Medicine
SimSET

MCEP

Penelope

The SIMIND Monte Carlo program

LUND UNIVERSITY

GAMOS
Geant4-based Architecture for Medicine-Oriented Simulations

SWORD

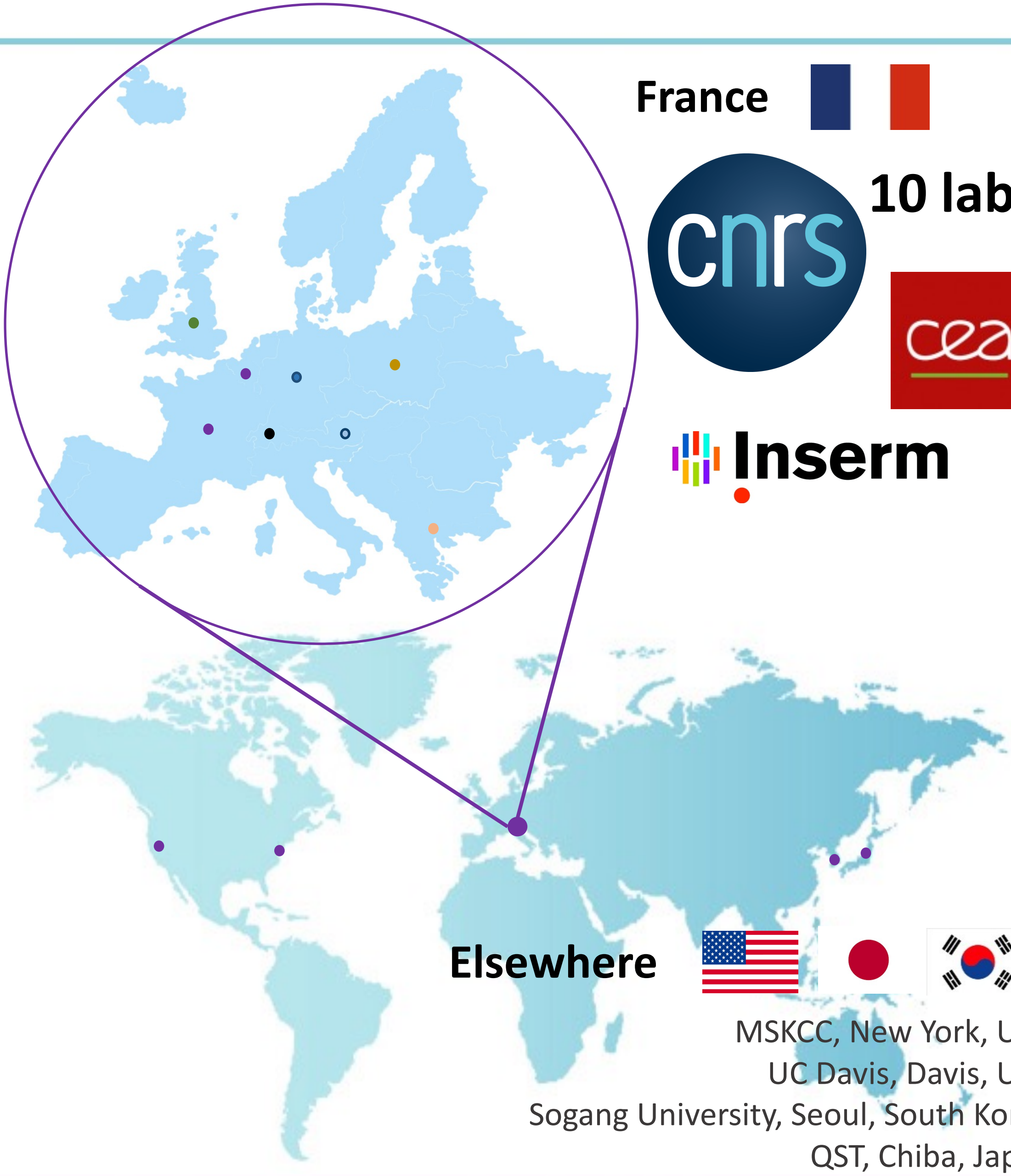
EGSnrc
Toolkit for Monte Carlo simulation of ionizing radiation transport

The collaboration

25 laboratories, companies, clinics developing and validating an open source platform

Spokesperson
Lydia Maigne

Tech. Coord.
David Sarrut



France

10 labs

cnrs

cea

Inserm

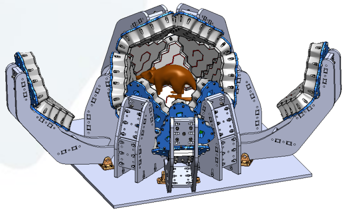
Europe

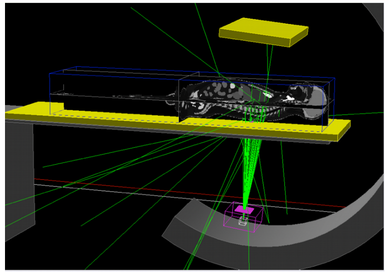
FH Aachen, University of Applied Sciences, Julich, Germany
Medisip, Ghent University, Belgium
Medical University of Vienna, Wiener Neustadt, Austria
MedAustron, Wiener Neustadt, Austria
Christie Medical Physics & Engineering, Manchester, UK
JPET collaboration, Poland
Institute of Nuclear Physics Polish Academy of Sciences, Poland
Univ. of Patras, Dept of Med. Phys., Greece
BioemTech, Athens, Greece
Paul Scherrer Institute (PSI), Switzerland

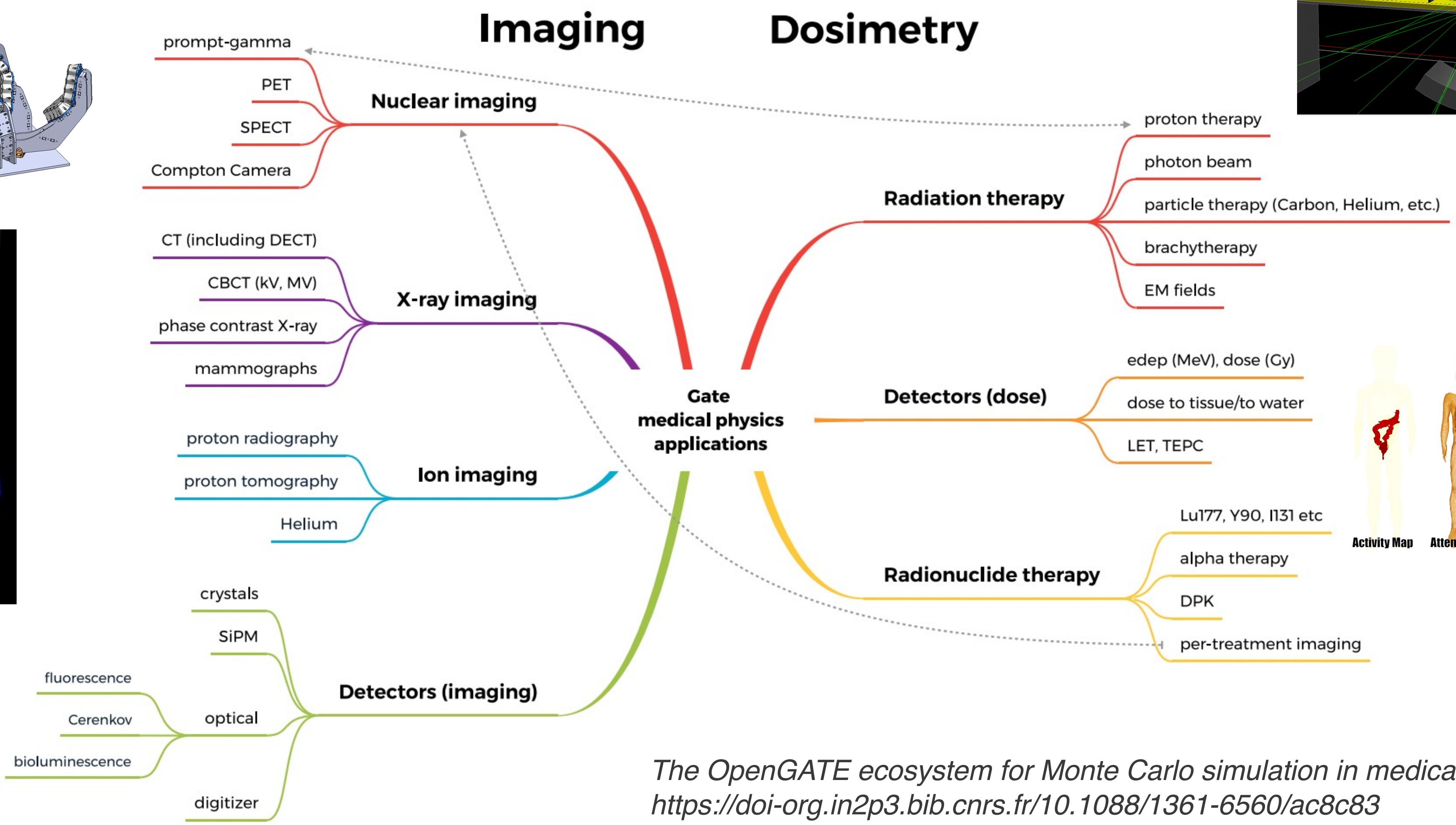
Elsewhere

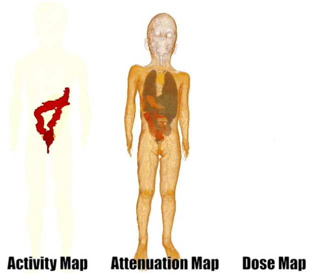
MSKCC, New York, USA
UC Davis, Davis, USA
Sogang University, Seoul, South Korea
QST, Chiba, Japan

4









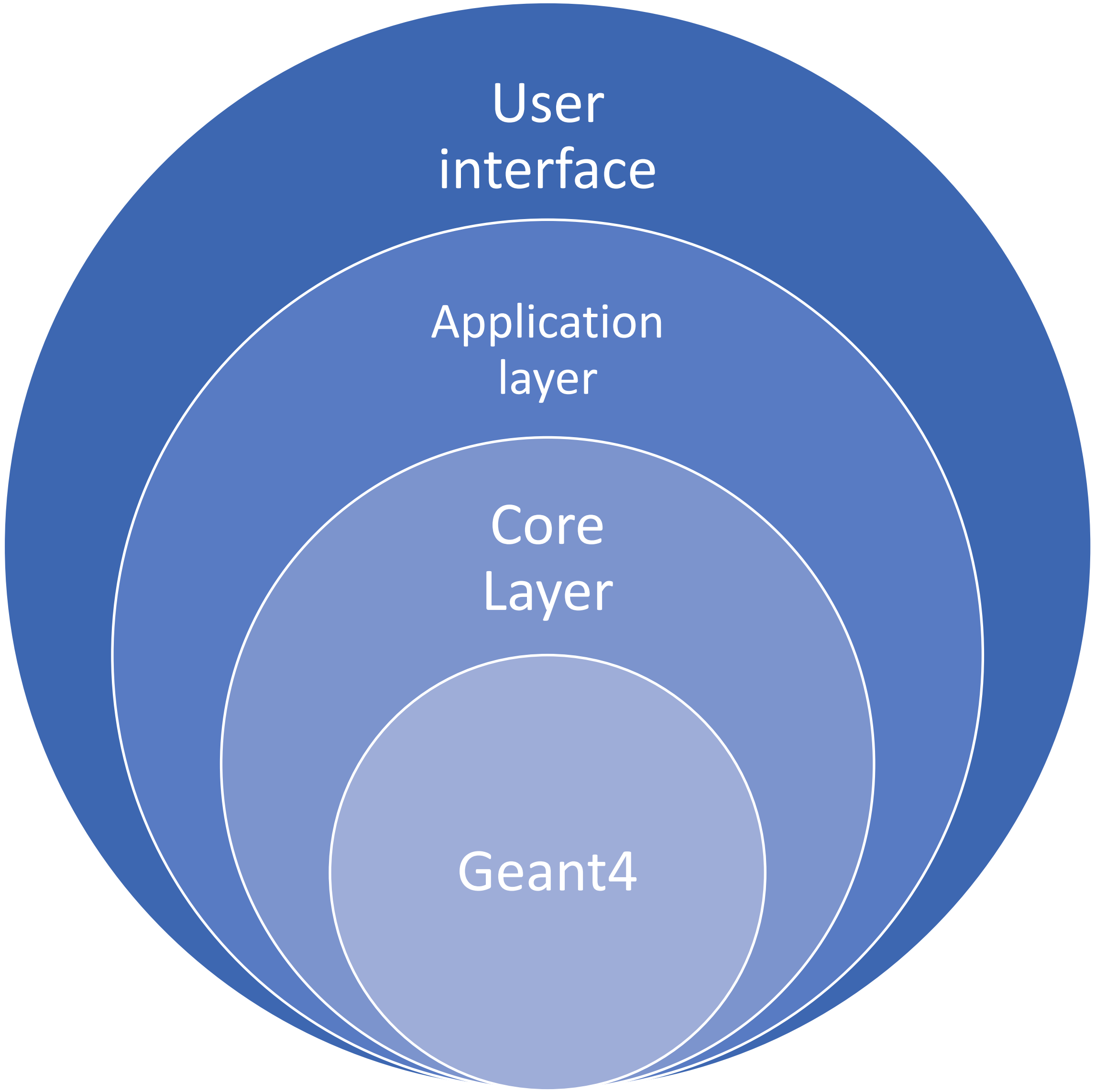
The OpenGATE ecosystem for Monte Carlo simulation in medical physics - https://doi-org.in2p3.bib.cnrs.fr/10.1088/1361-6560/ac8c83

GATE 9.2 (April 2022)

- **17 years of developments & 70 contributors**
- **C++ code: 200 classes, 14000 lines**
- **Based on the Geant4 kernel (current G4 11)**

- **Derived C++ classes**
  - ✓ **Modeling of detectors, sources, patient**
  - ✓ **Movement (detectors and patient)**
  - ✓ **Radioactive decays (mouvement, cinetics…)**

- **Easy to use**
- **Text scripts to define simulation parameters**



GATE 9.2 (April 2022)

- 17 years of developments & 70 contributors
- C++ code: 200 classes, 14000 lines
- Based on the Geant4 kernel (current G4 11)

- Derived C++ classes
  - ✓ Modeling of detectors, sources, patient
  - ✓ Movement (detectors and patient)
  - ✓ Radioactive decays (mouvement, cinetics…)

- Easy to use
- Text scripts to define simulation parameters

```
#=====================================================
# VISUALISATION
#=====================================================
/vis/open OGLSQt
…………….
#=====================================================
# VERBOSE
#=====================================================
/gate/verbose Physic 2
…………….
#=====================================================
# GEOMETRY
#=====================================================
…………….
#=====================================================
# PHYSICS
#=====================================================
…………….
#=====================================================
#  ACTORS
#=====================================================
…………….
#=====================================================
# INITIALISATION
#=====================================================
/gate/run/initialize

#=====================================================
#  S O U R C E
#=====================================================
…………….
#=====================================================
#  R A N D O M   E N G I N E
#=====================================================
…………….
#=====================================================
#   M E A S U R E M E N T   S E T T I N G S
#=====================================================
……………
```

Open-source Code – Examples - Tools

Source code - https://github.com/OpenGATE/**Gate**

Examples - https://github.com/OpenGATE/**GateContrib**

Python tools - https://github.com/OpenGATE/**gatetools**

Docker + VM - https://opengatecollaboration.org

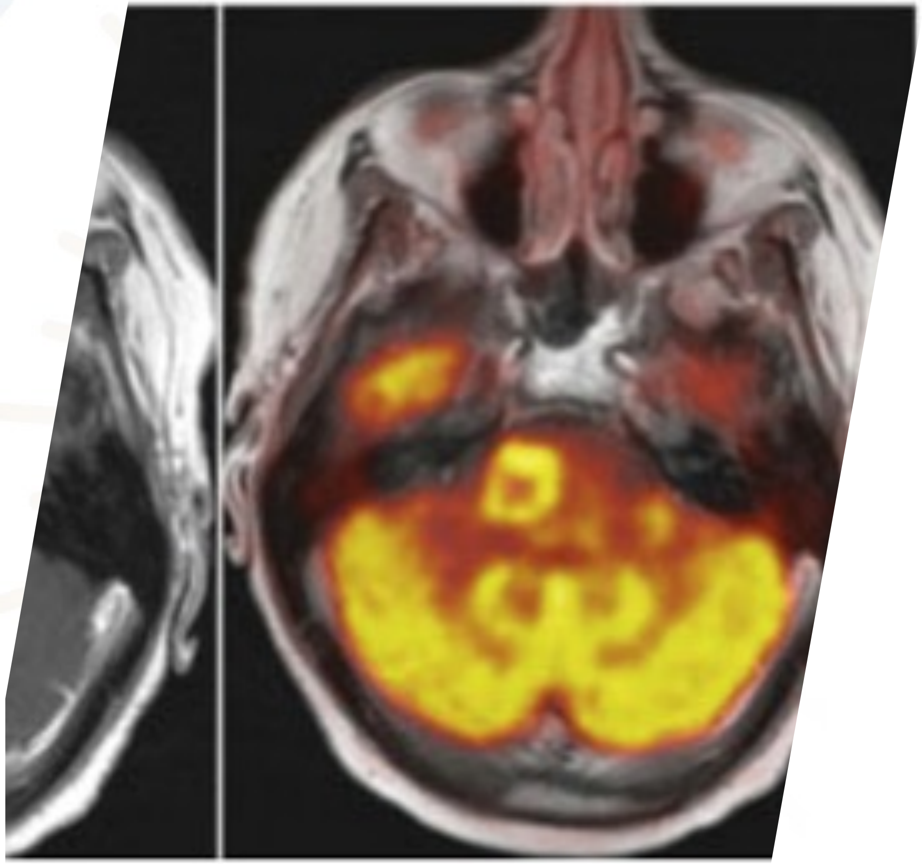
GATE 9.2 release (April 2022)

Compatible with G4 11
More than 70 contributors (since 2012)
25+ benchmarks

GATE10 - https://github.com/OpenGATE/opengate

Official release Mid 2023

GATE USERS MAILING LIST - Information, job offers, bug reports, help http://opengatecollaboration.org/mailinglist

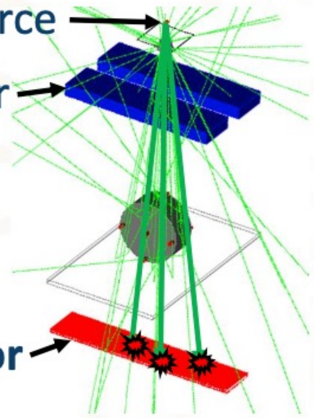


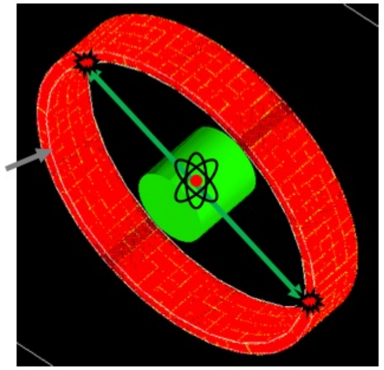
Medical imaging

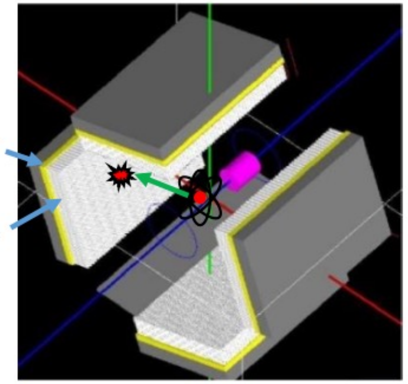
Medical imaging systems

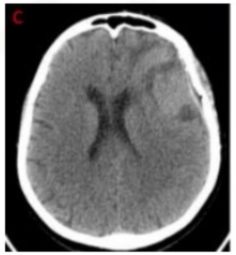
The image quality (resolution, contrast) and radiation exposure (patient dose) are mainly determined by the detector performance

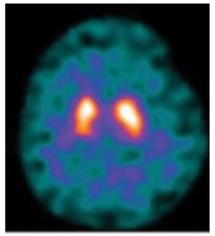
X-ray CT	PET	SPECT
Computed tomography	Positron emission tomography	Single photon emission computed tomography





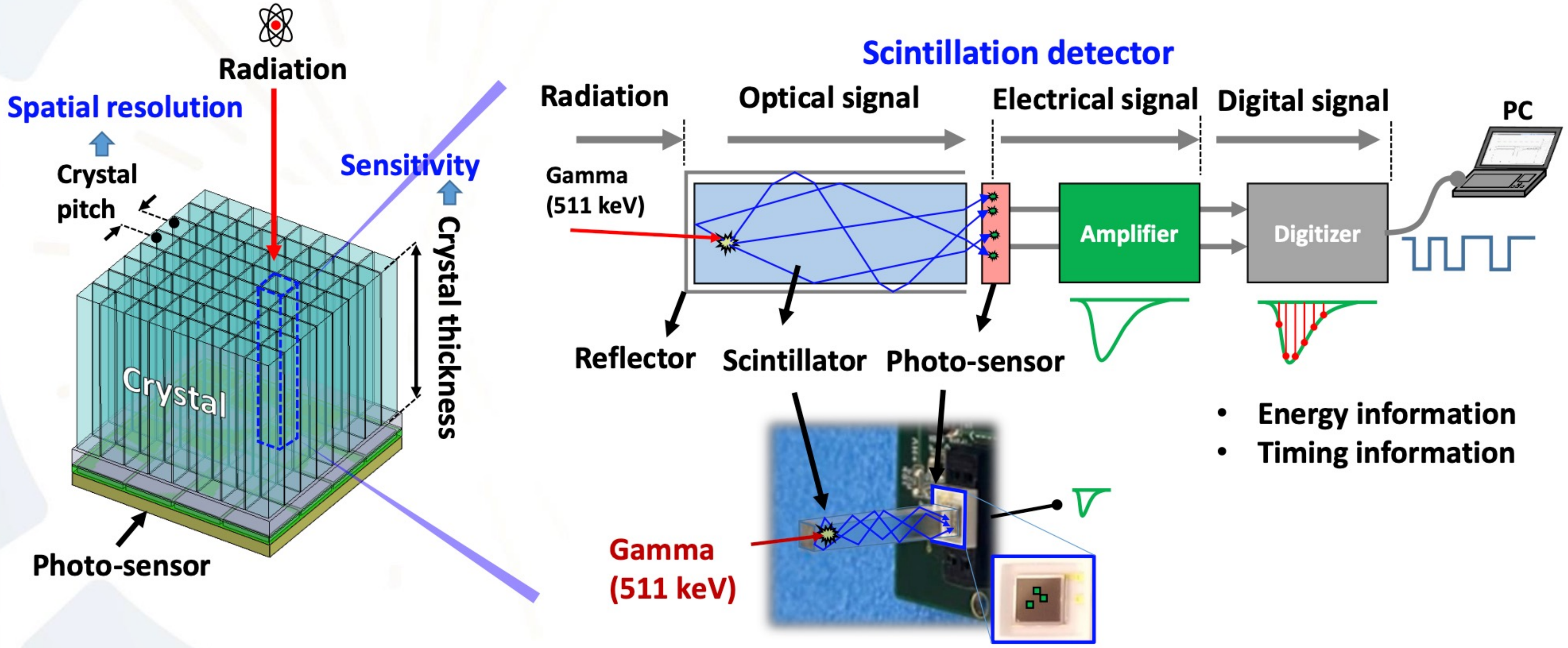






Transmission imaging | **Emission imaging** | **Emission imaging**

Scintillation detector



- Energy information
- Timing information

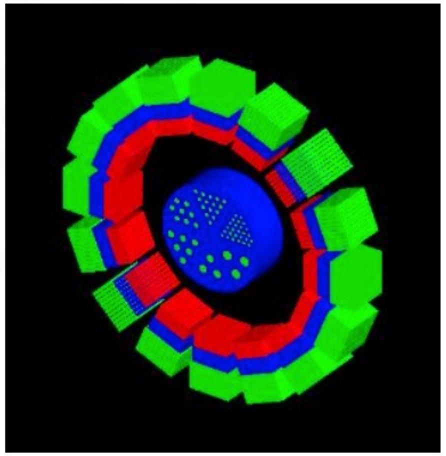
Workflow for medical imaging system development

GATE simulation can be used for
- ✓ **Concept verification** of your new idea
- ✓ **Optimization** of a new imaging system

New idea on imaging system

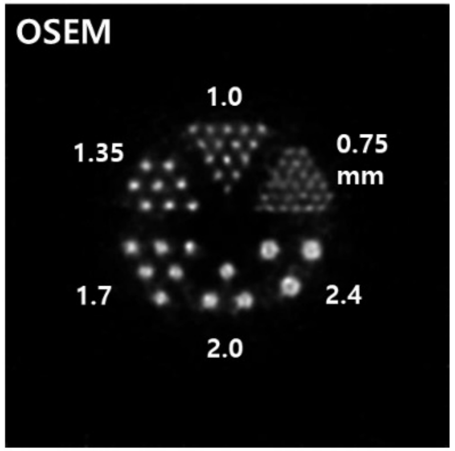
From the perspective of hardware engineers

GATE simulation



- ✓ **Scanner modeling**
- ✓ **Concept verification**

Image reconstruction



- ✓ **Image quality check**
- ✓ **Find any problem**

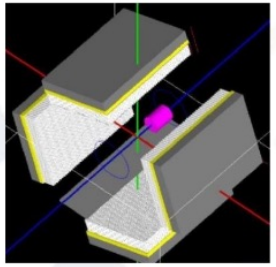
Development of a new PET system*

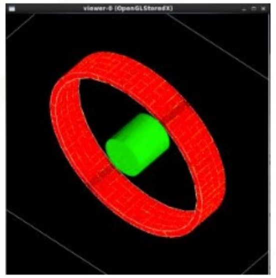
- ✓ **Prototyping**
- ✓ **Performance evaluation**

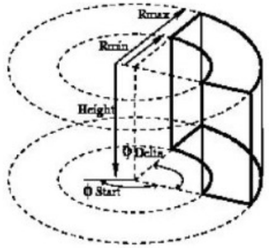
Optimization and debugging

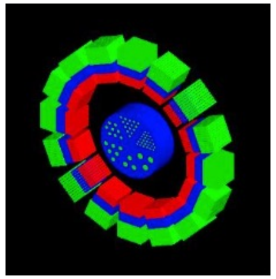
Predefined geometry to simplify the simulation

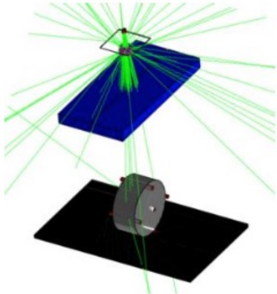
SPECT	PET ECAT	Cylindrical PET	PET scanner	CT scanner	scanner	Optical system
SPECThead	ecat	cylindricalPET	PETscanner	CTscanner	scanner	OpticalSystem
crystal	block	rsector	level1	module	level1	crystal
pixel	crystal	module	level2	cluster	level2	pixel
		crystal	level3	pixel	level3	
		layer0	level4		level4	
		layer1	level5		level5	

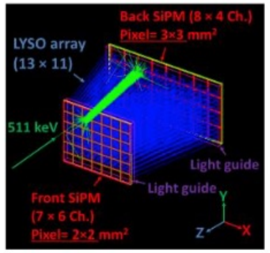


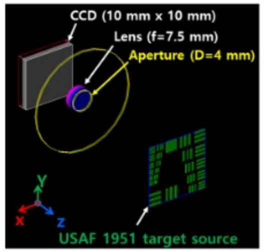






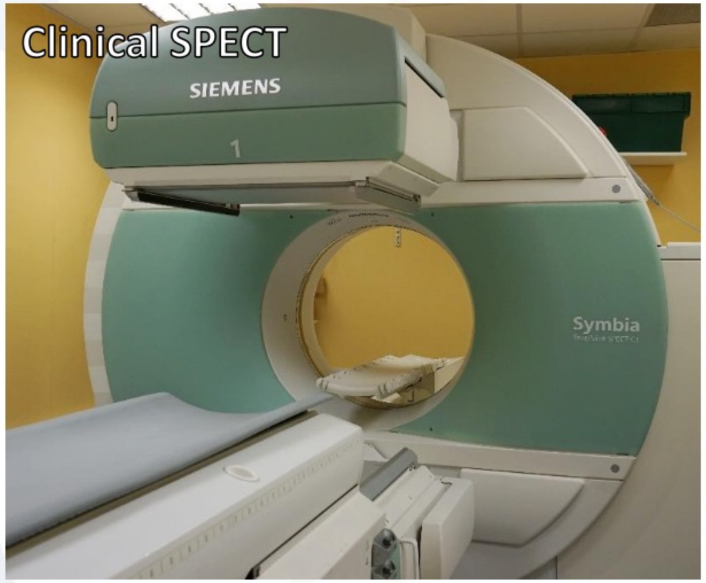




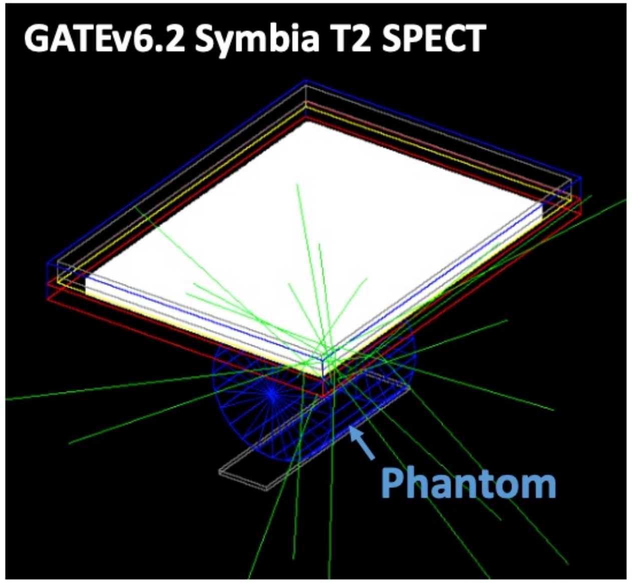


Examples: clinical SPECT simulations

SIEMENS Symbia T2 SPECT/CT



GATE Single head SPECT simulation



What you need to set in GATE

- Collimator
- Scintillator(=crystal)
- Detector response
- Phantom
- Source

GATE projection output (*.sin)

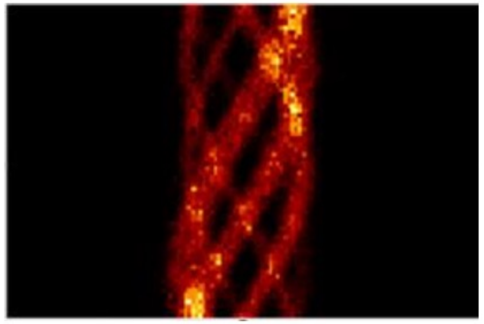
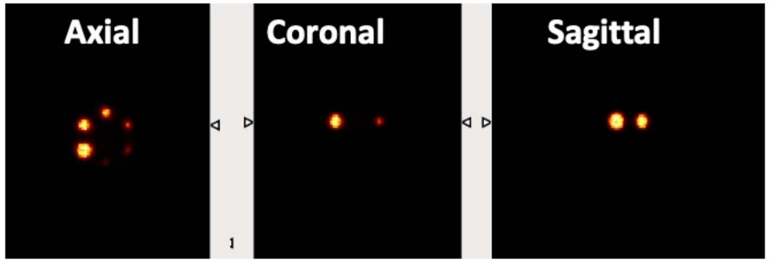
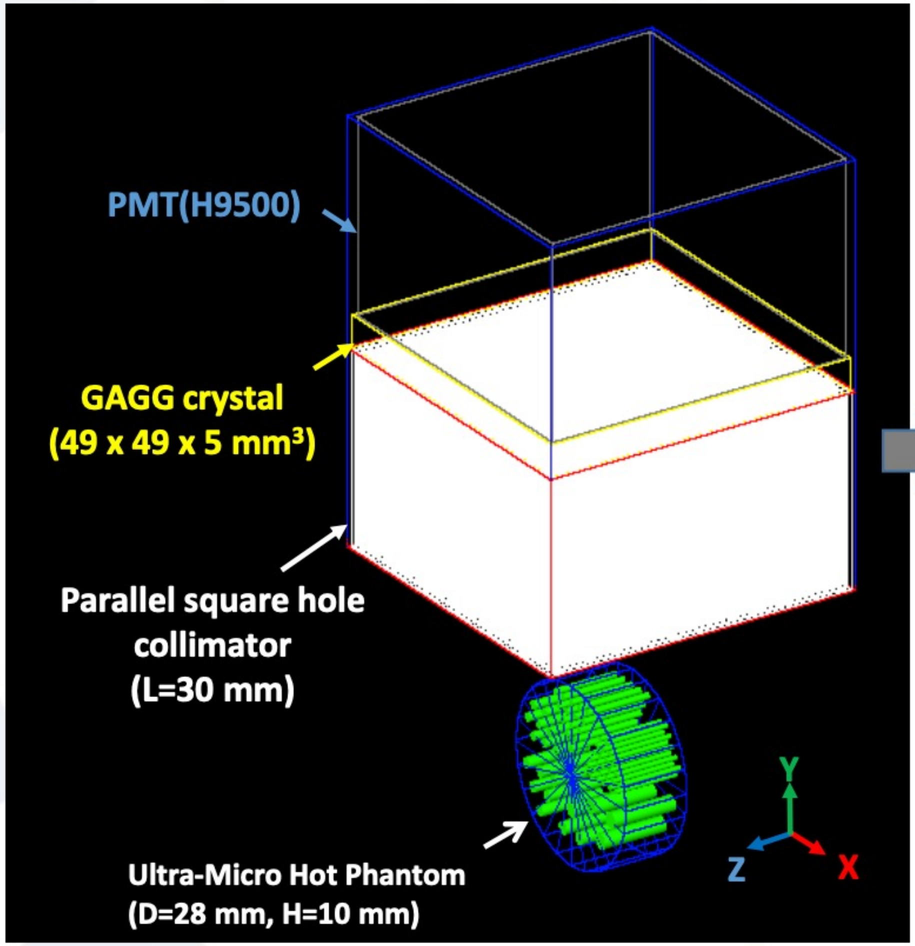


Image reconstruction using STIR*

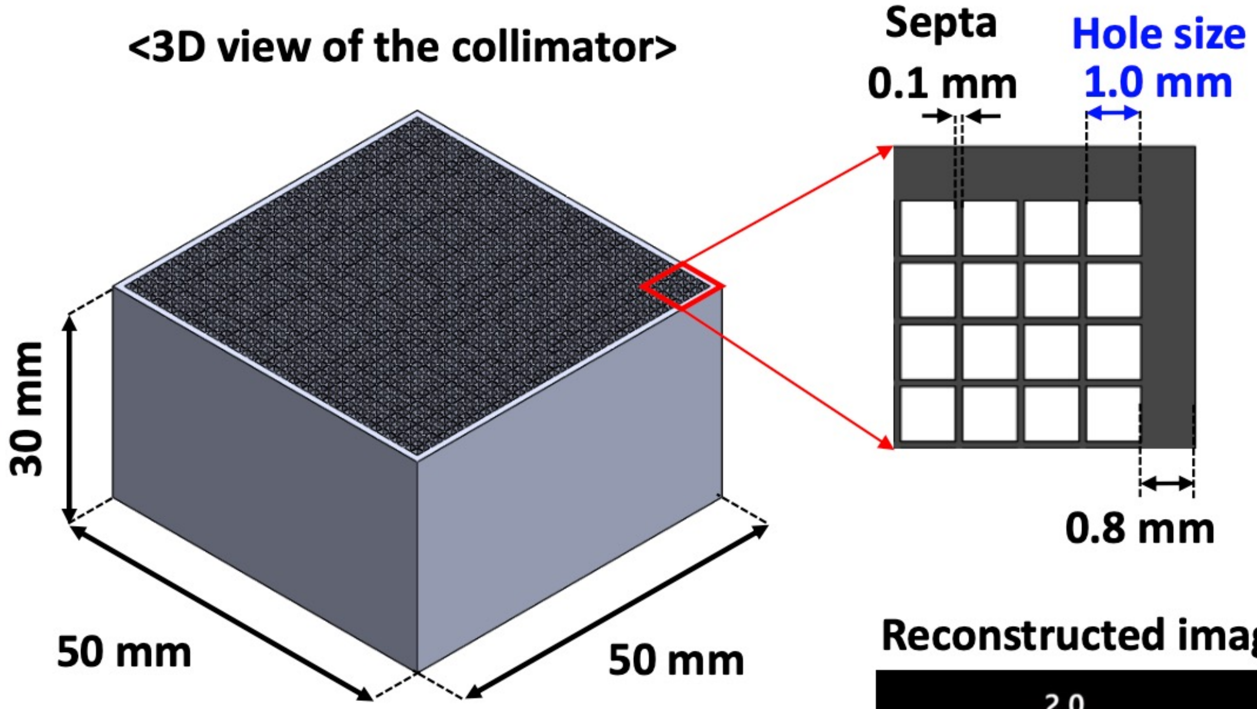


Examples: small animal SPECT imaging

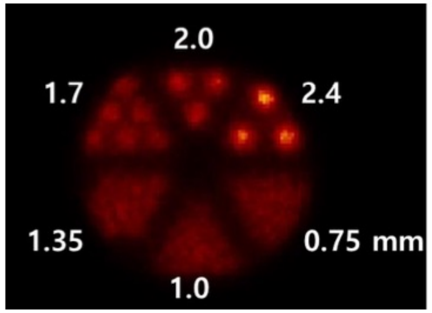
Dedicated small animal SPECT



<3D view of the collimator>



Reconstructed image

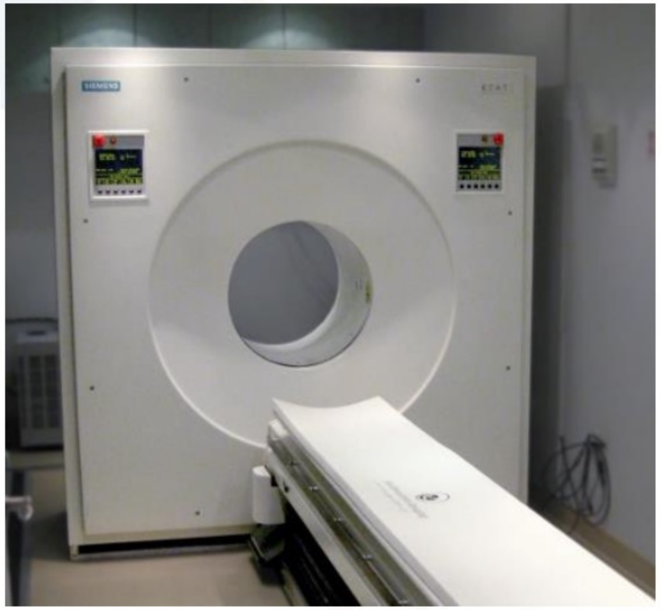


What you need to set in GATE

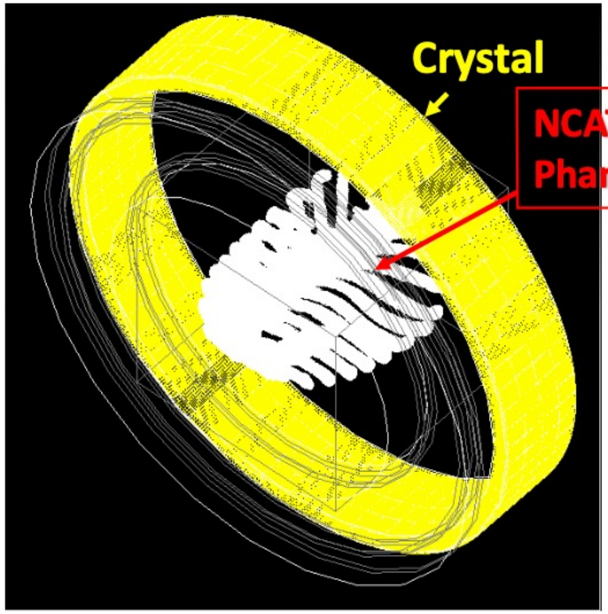
- Collimator
- Scintillator(=crystal)
- Detector response

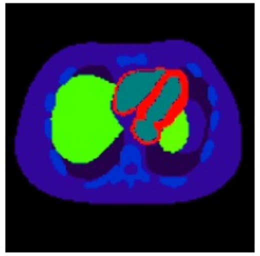
Examples: clinical PET imaging

SIEMENS ECAT PET scanner



GATE ECAT PET scanner



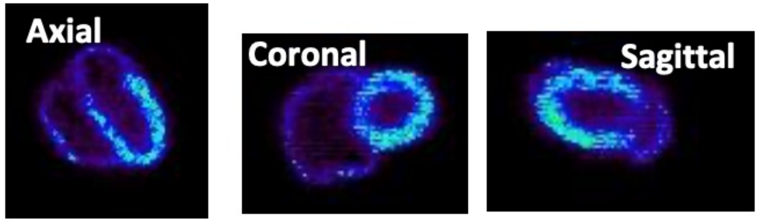


What you need to set in GATE

- Crystal
- Detector response
- Phantom
- Source

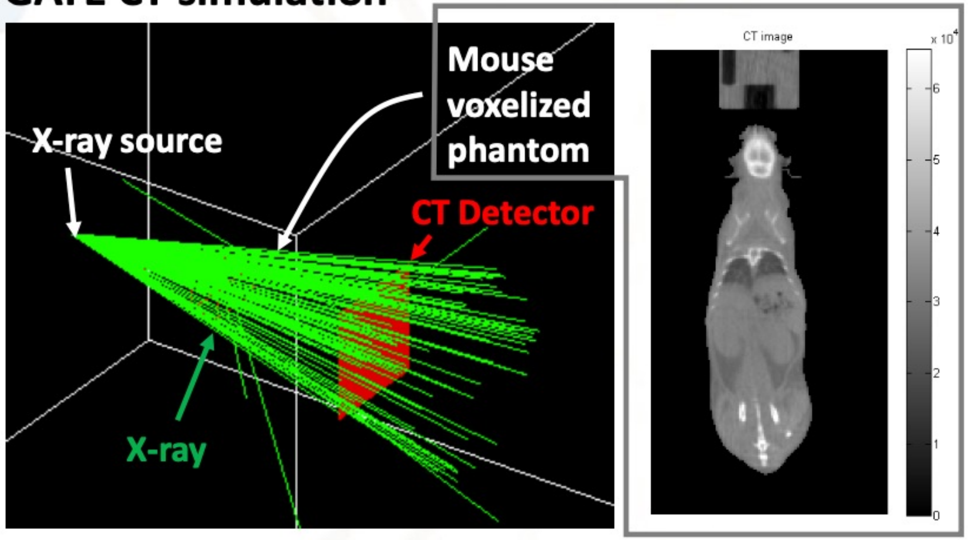
GATE ECAT7 sinogram output(*.S)

Image reconstruction using STIR*



Examples: small animal CT imaging

GATE CT simulation



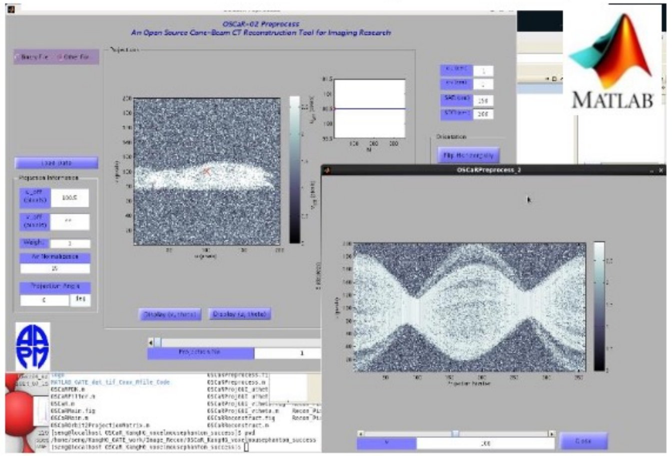
GATE projection output(*.dat)

↓

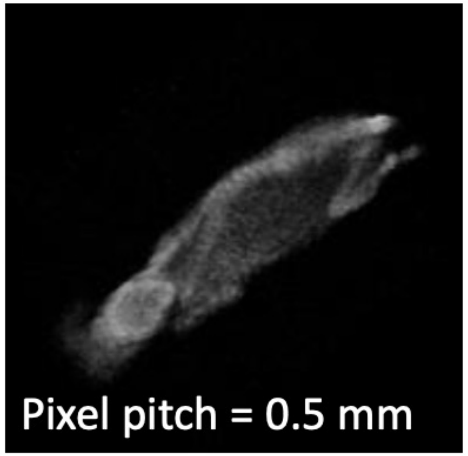
Data format conversion to CSV

↓

OSCaR* software (MATLAB)



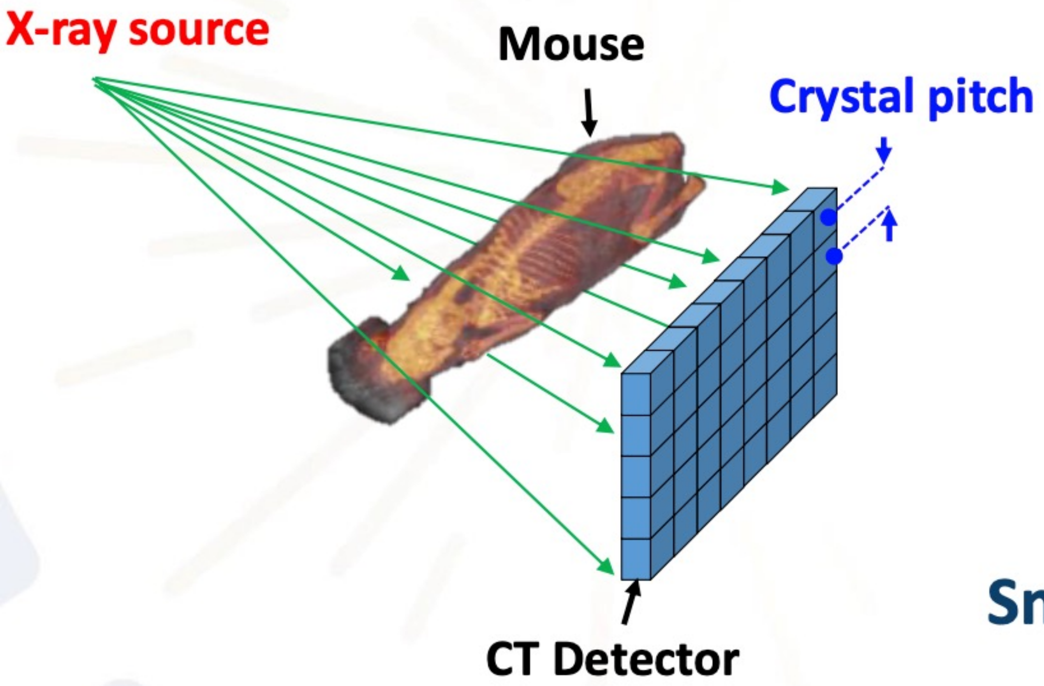
Reconstructed CT image

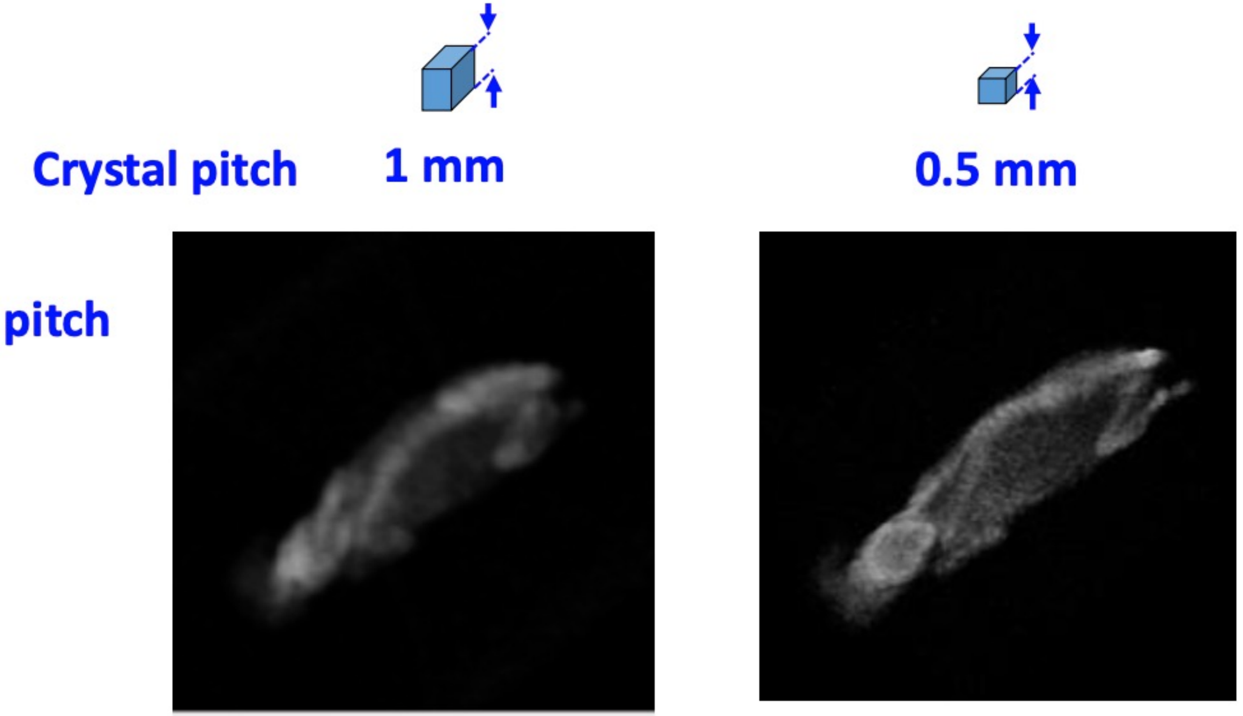


What you need to set in GATE

- X-ray source (SRS78 software)
- Mouse phantom (Voxelized)
- CT detector response

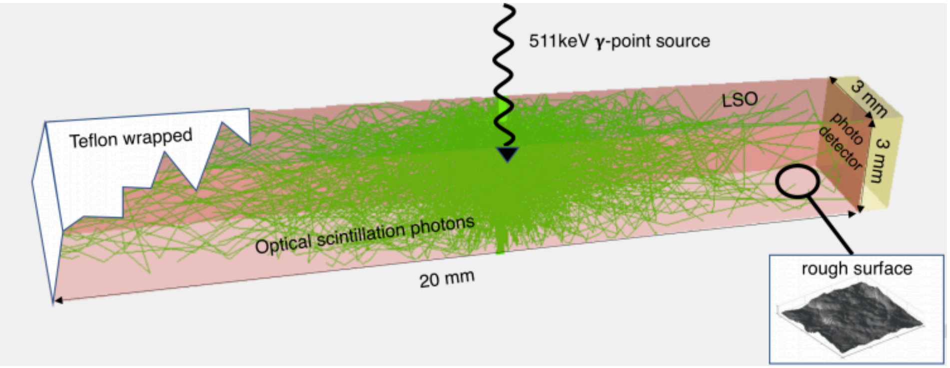
Examples: crystal pitch vs spatial resolution





Small crystal pitch -> High spatial resolution

Examples: simulation of light transport in scintillation detectors



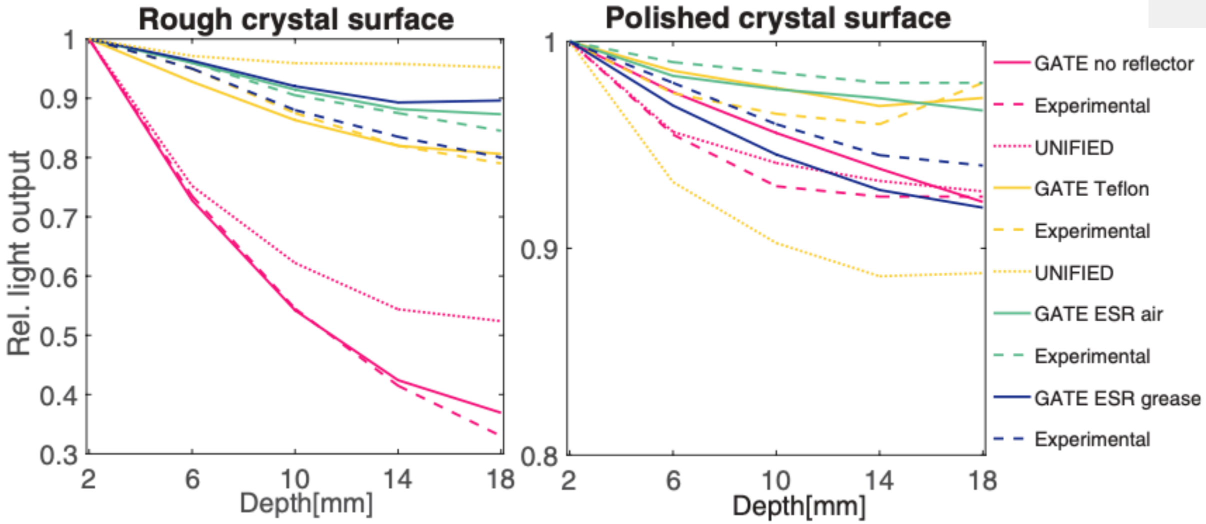


Figure 6. The relative LO as a function of DOI is shown for experimental data and the implemented LUT Davis model in GATE. Trends for different surfaces are normalized by their maximum LO. In contrast, the UNIFIED model shows large variations from the experimental data past the 6 mm DOI position, because inaccuracies in the reflection model add up as the photons undergo more reflections.

IOP Publishing | Institute of Physics and Engineering in Medicine — Physics in Medicine & Biology

Phys. Med. Biol. **62** (2017) L1–L8 — https://doi.org/10.1088/1361-6560/aa7007

Letter

Advanced optical simulation of scintillation detectors in GATE V8.0: first implementation of a reflectance model based on measured data

Mariele Stockhoff[1], Sebastien Jan[2], Albertine Dubois[3], Simon R Cherry[1] and Emilie Roncali[1]

PAPER

An integrated model of scintillator-reflector properties for advanced simulations of optical transport

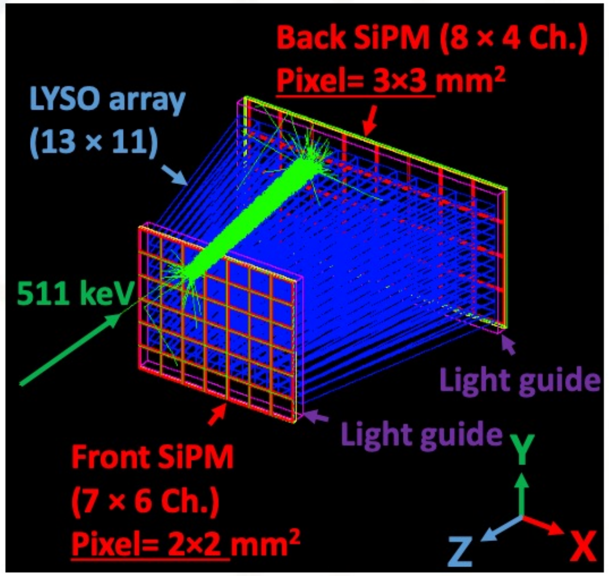
Emilie Roncali, Mariele Stockhoff and Simon R Cherry

Published 18 May 2017 • © 2017 Institute of Physics and Engineering in Medicine

Physics in Medicine & Biology, Volume 62, Number 12

Examples: Simulation of optical photons within a detector

GATE optical simulation



ASCII output (Singles.dat)

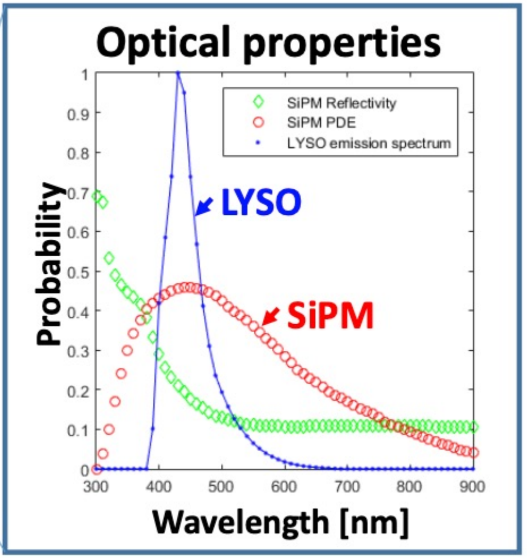
MATLAB code (Custom-written)

- ✓ EventID sorting
- ✓ Assign the SiPM pixel ID
- ✓ Generate the flood map

What you need to set in GATE

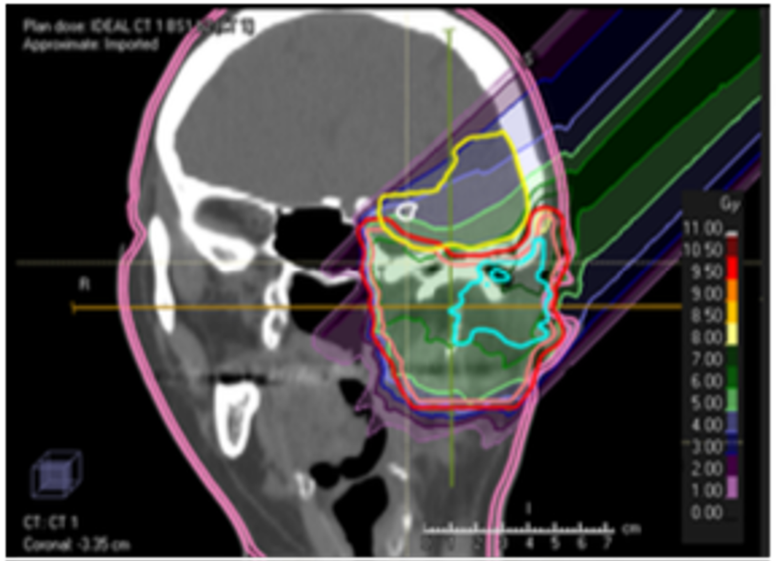
- Optical properties of Crystal (Materials.xml)
- Optical properties of SiPM (Surfaces.xml)
- Digitizer (adder -> opticaladder)

```
/gate/digitizer/Singles/insert adder
/gate/digitizer/Singles/insert  opticaladder
```

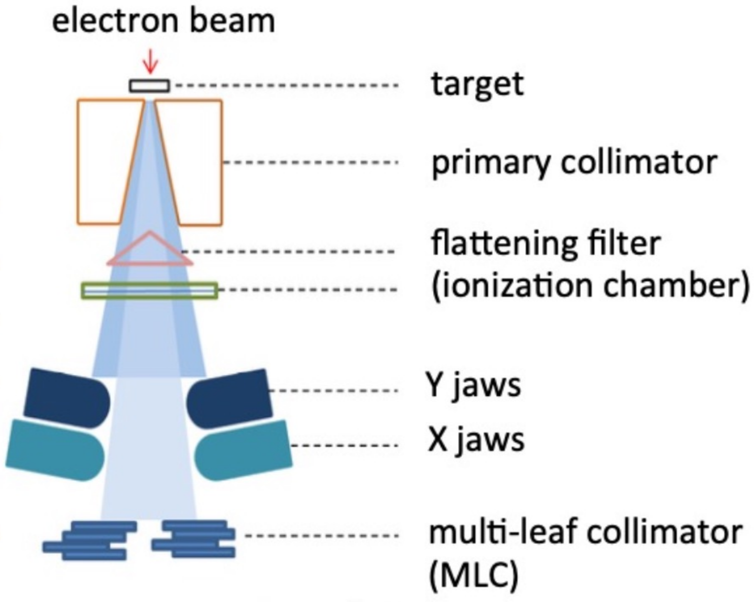


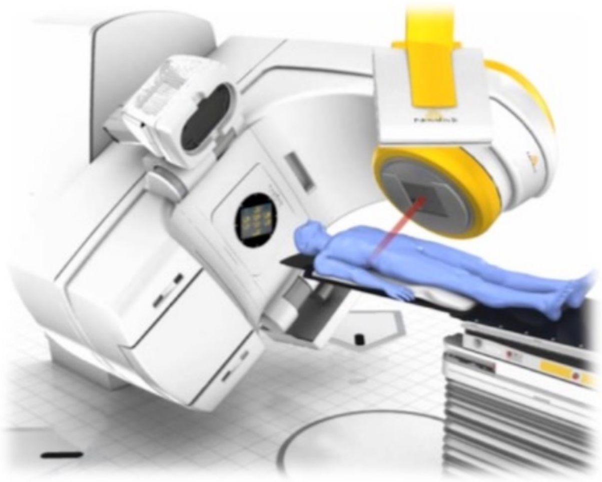
Goal: Modeling of a scintillation detector with dual-ended readout configuration

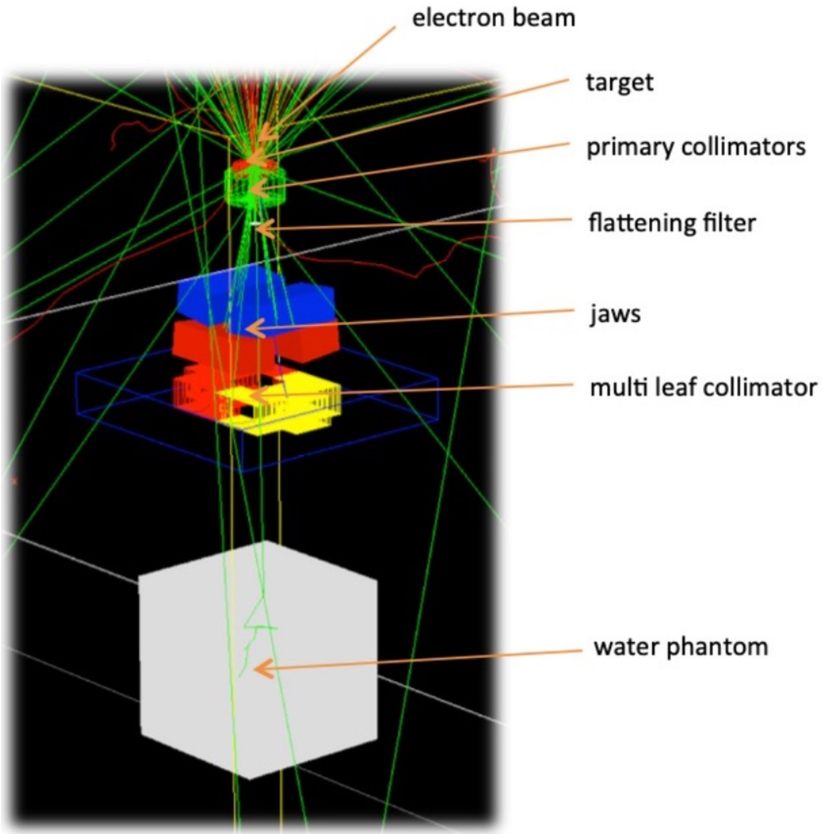
Therapy


Approximate: Imported
Gy
11.00
10.50
9.50
9.00
8.50
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
CT: CT 1
Coronal: -3.35 cm
cm

External RT using electrons and photons







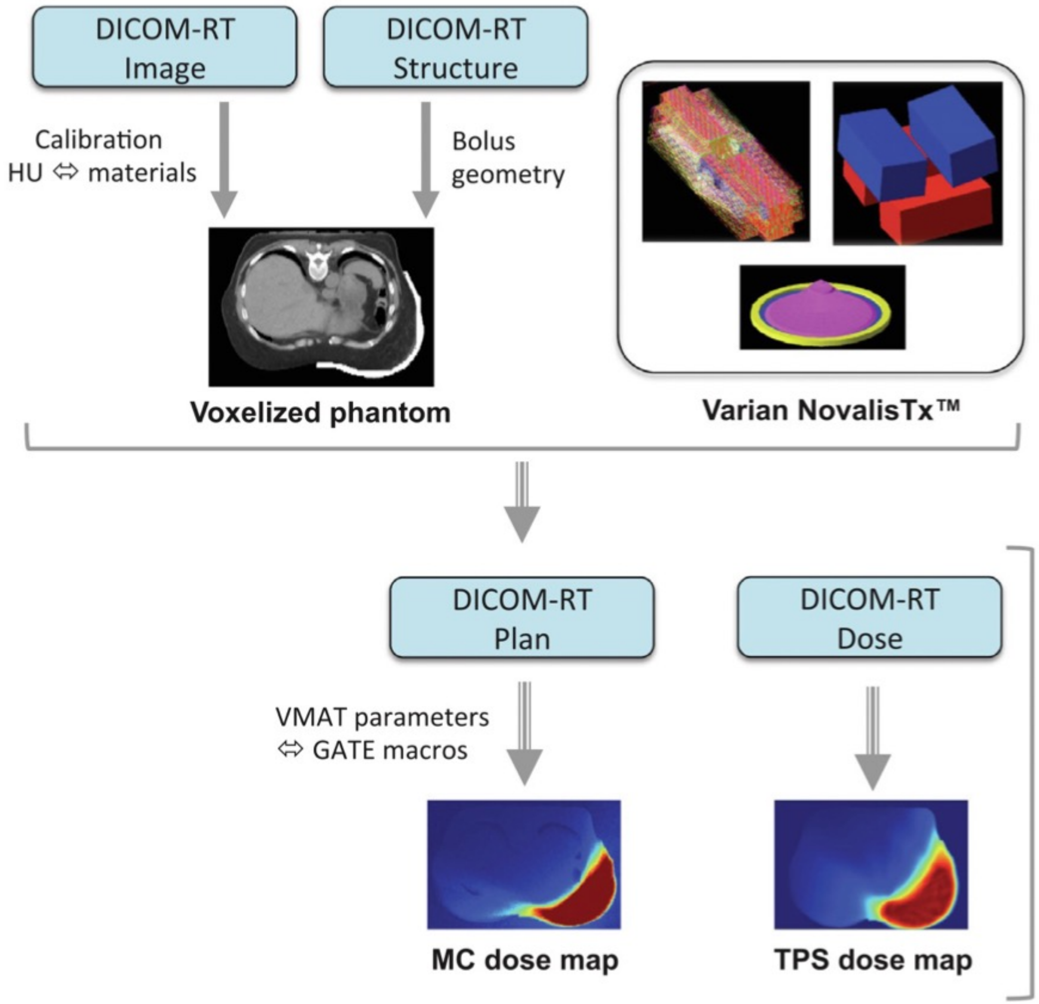
External RT workflow

1. Accelerator modeling
- Geometry
- phase space sources

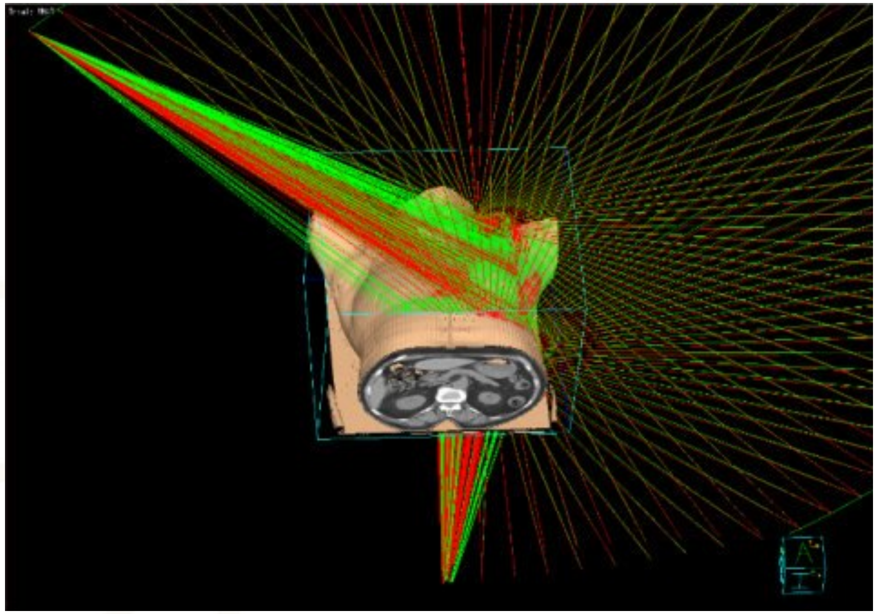
2. **Patient modeling**
- voxelized phantom
- additional structures

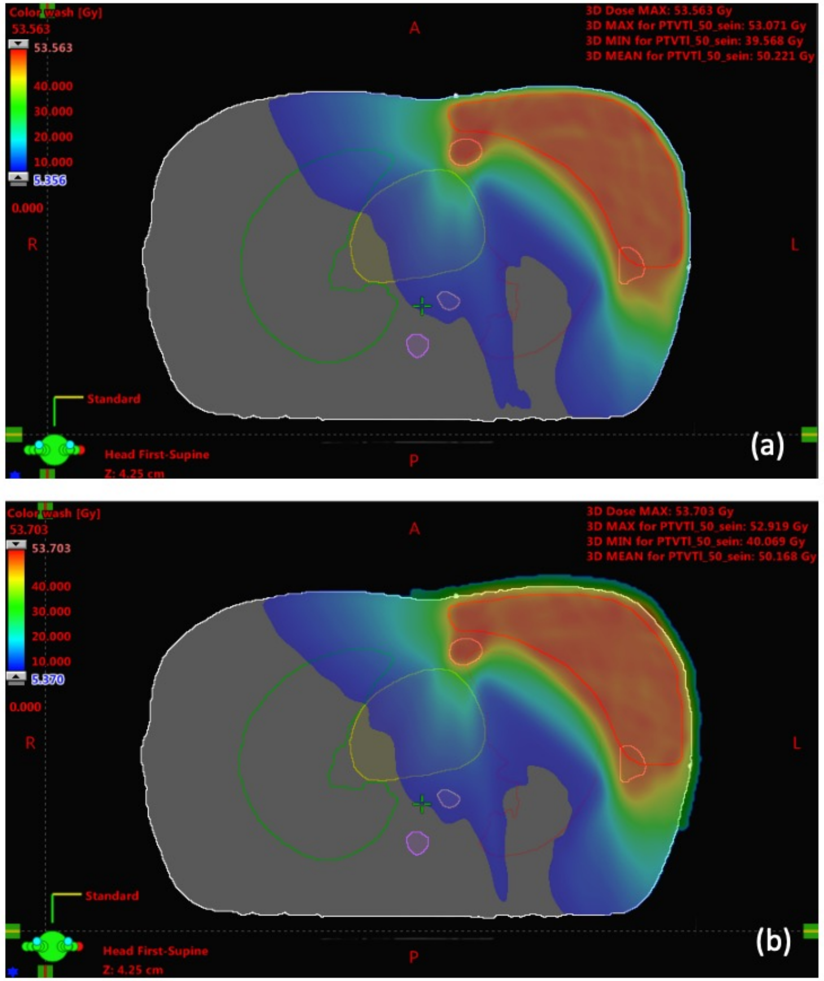
3. **Treatment parameters**
- DICOM-RT Plan

4. **Dose computation**
- dose actor
- analysis tools (Python, ROOT, ITK, ...)



Examples: Evaluating 3D distributions of superficial dose in Volumetric Arc therapy (VMAT)

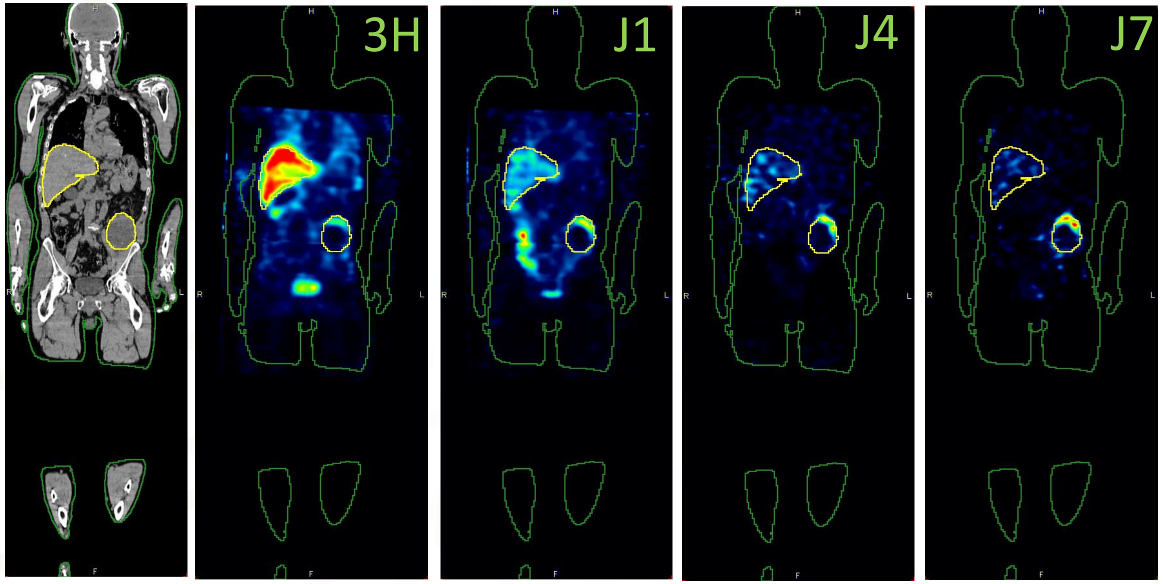


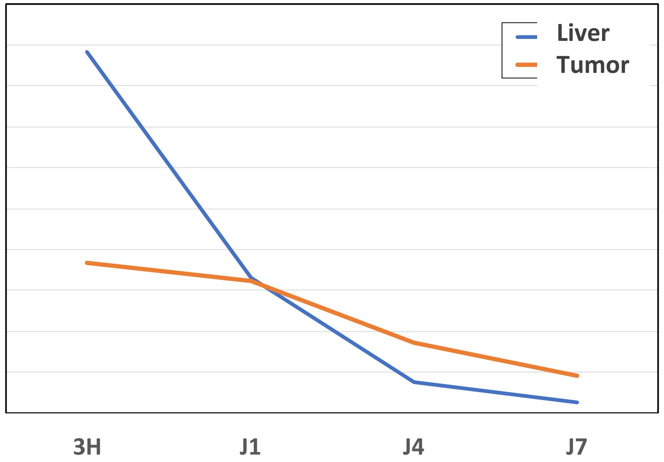


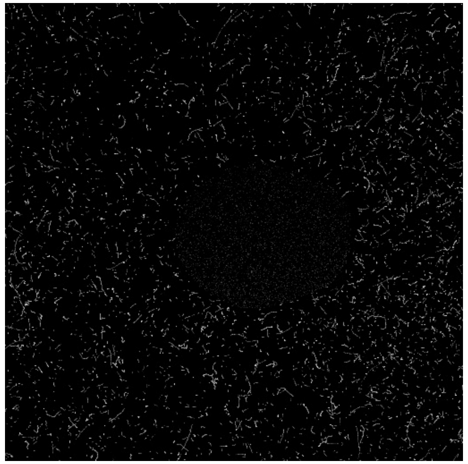
TPS dose maps for VMAT planning without (a) and with a 5 mm bolus (b)

Examples: Internal RT of melanoma

^{131}I-ICF01012

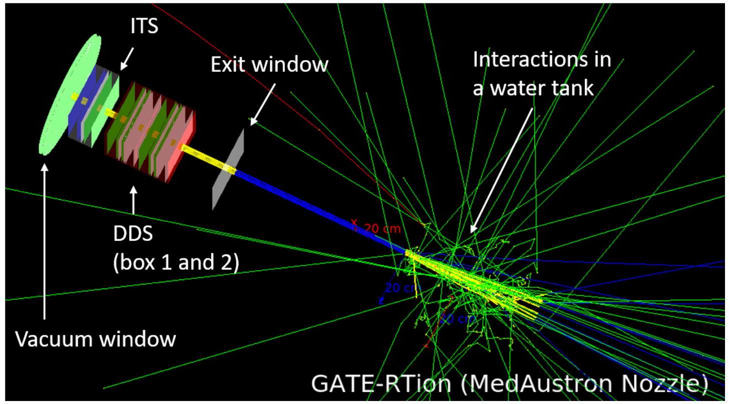




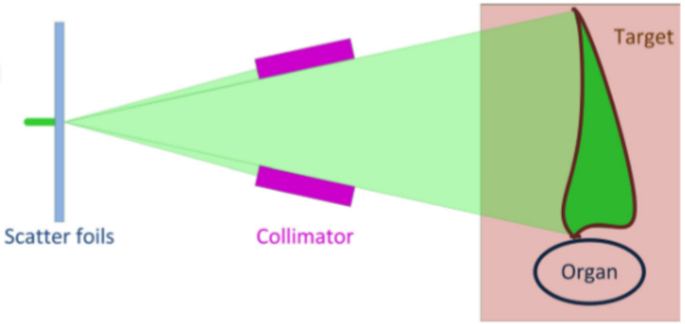


Clinical dosimetry to assess dose to liver and tumor
800 MBq/m^2 till 4000 MBq/m^2 to provide 40 Gy max to the tumor

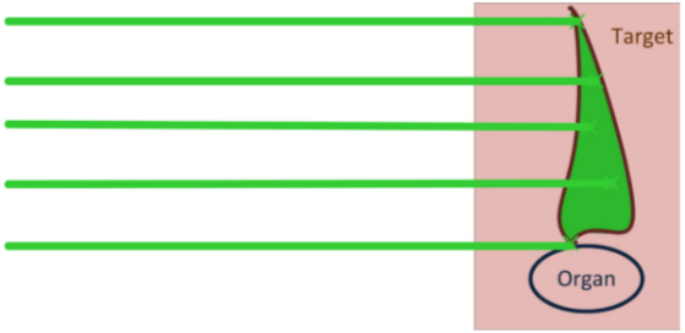
Hadrontherapy



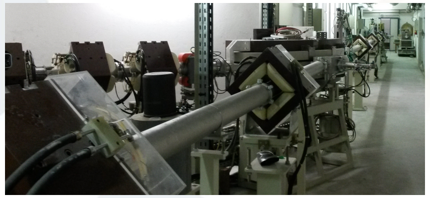
Passive scattering



Pencil beam scanning



Picture: C. Winterhalter, ETH Diss 25698



MediCyc 65 MeV clinical beam line
Centre Antoine Lacassagne

Picture: https://www.psi.ch/en/protontherapy/gantry-3, 05/02/20

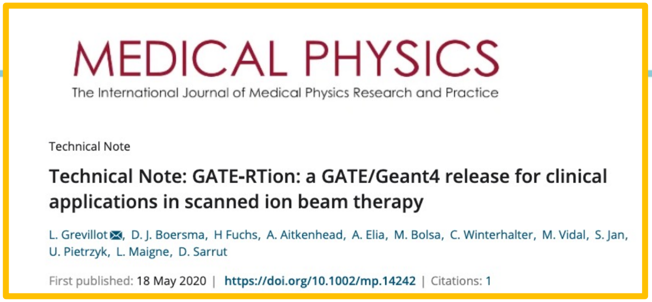
Also: IBA Proteus One
235 MeV

GATE-RTion

- **Goals**
  - Foster collaboration between clinical partners and laboratories to improve treatment delivery
  - Passive and PBS proton and carbon beams quality assurance
  - Clinical applications
  - Cross validation with TPS

- **3 clinical partners involved**
  - **The Centre Antoine Lacassagne** (France): IBA PT Synchro-Cyclotron (S2C2) machine with proton energy range 70-230 MeV
  - **The Christie NHS Foundation Trust** (UK): Varian ProBeam (Cyclotron) machine with proton energy range 70-245 MeV
  - **MedAustron** (Austria) : MAPTA (Synchrotron) machine with proton and carbon ion energy ranges of 60-250 MeV and 120-400 MeV/n, respectively

GATE-RTion – Project Paper (1)


MEDICAL PHYSICS

The International Journal of Medical Physics Research and Practice

Technical Note

Technical Note: GATE-RTion: a GATE/Geant4 release for clinical applications in scanned ion beam therapy

L. Grevillot, D. J. Boersma, H Fuchs, A. Aitkenhead, A. Elia, M. Bolsa, C. Winterhalter, M. Vidal, S. Jan, U. Pietrzyk, L. Maigne, D. Sarrut

First published: 18 May 2020 | https://doi.org/10.1002/mp.14242 | Citations: 1

- **The Centre Antoine Lacassagne (Nice, France): Proton radiography images**
- Proton radiography images of the anthropomorphic human head phantom were compared
  - RayStation 6.0 TPS,
  - GATE-RT-ion
  - Lynx 2D scintillator (IBA)

  - Results compared with MyQA software (IBA)
    - γ-index analysis (2%, 2mm) between GATE-RTion simulations and TPS, more than 95% of the pixels passed the test.

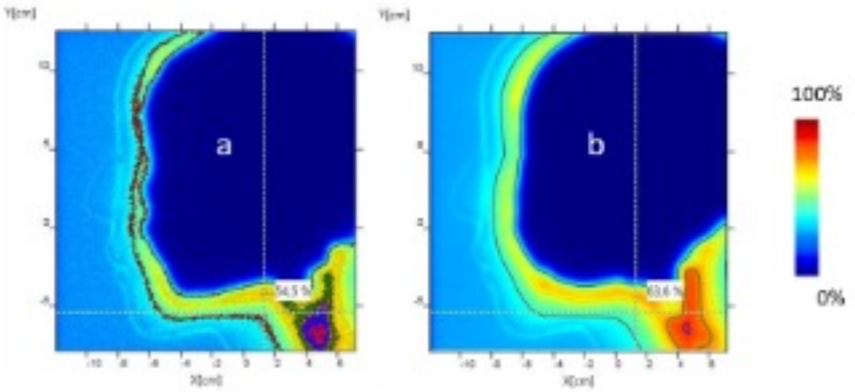


Figure 1: Relative comparison of a GATE dose simulation (a) and a 2D Lynx measurement (b) acquired at the same downstream position for an anthropomorphic phantom. An arbitrary dose scale is used between 100% (red) and 0% (dark blue) - same for both relative dose distributions.

GATE-RTion – Project Paper (2)

- **Independent Dose Calculation of proton beam therapy plans at The Christie**
- Varian Eclipse (version 13.7) TPS
- GATE-Rtion (**AUTOMC,** Aitkenhead, Br J Radiol 2020)

- 23.4 Gy in 13 fractions, delivered using 5 fields: a pair of left/right fields to the brain, and 3 fields to the spine (superior, mid and inferior)

- GATE-RTion simulation was between 1.6% and 2.4% hotter than the TPS in terms of the median dose to the patient.

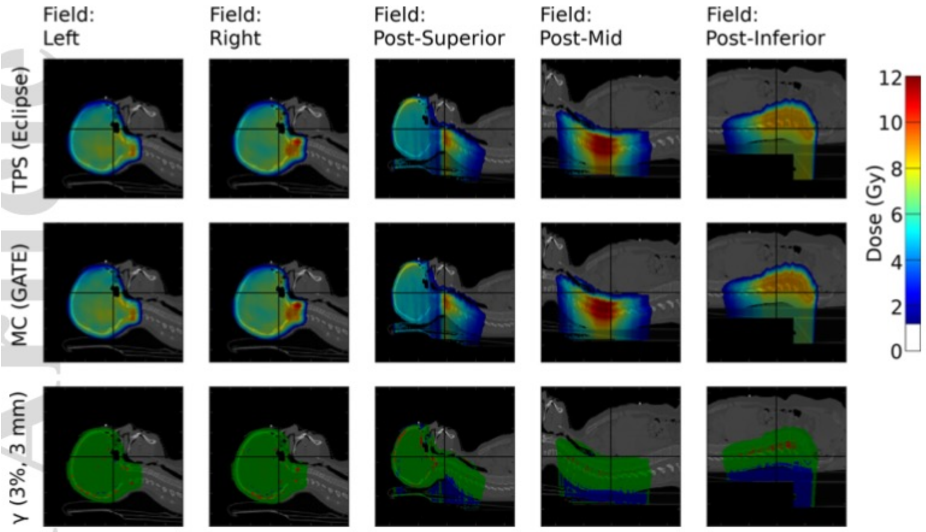
MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

Technical Note

Technical Note: GATE-RTion: a GATE/Geant4 release for clinical applications in scanned ion beam therapy

L. Grevillot, D. J. Boersma, H Fuchs, A. Aitkenhead, A. Elia, M. Bolsa, C. Winterhalter, M. Vidal, S. Jan, U. Pietrzyk, L. Maigne, D. Sarrut

First published: 18 May 2020 | https://doi.org/10.1002/mp.14242 | Citations: 1



Comparison of TPS (Varian Eclipse) and MC (AutoMC / GATE-RTionV1.0) calculations of a 5-field craniospinal axis proton treatment plan, planned at the Christie

MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

Research Article | Open Access

Evaluation of GATE-RTion (GATE/Geant4) Monte Carlo simulation settings for proton pencil beam scanning quality assurance

Carla Winterhalter, Michael Taylor, David Boersma, Alessio Elia, Susanna Guatelli, Ranald Mackay, Karen Kirkby, Lydia Maigne, Vladimir Ivanchenko, Andreas F. Resch ... See all authors

First published: 23 September 2020 | https://doi.org/10.1002/mp.14481

GATE-RTion – Project Paper (3)

MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

Technical Note

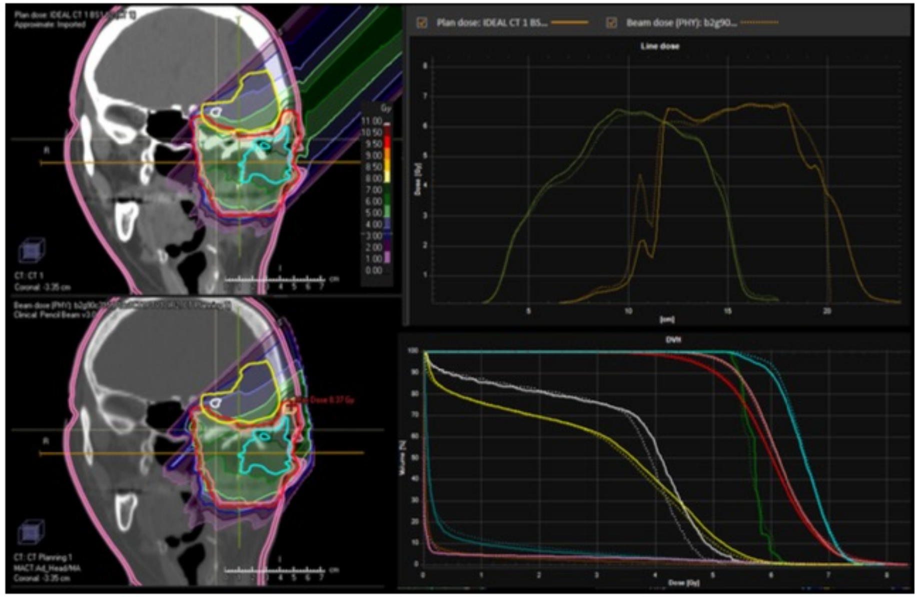
Technical Note: GATE-RTion: a GATE/Geant4 release for clinical applications in scanned ion beam therapy

L. Grevillot, D. J. Boersma, H Fuchs, A. Aitkenhead, A. Elia, M. Bolsa, C. Winterhalter, M. Vidal, S. Jan, U. Pietrzyk, L. Maigne, D. Sarrut

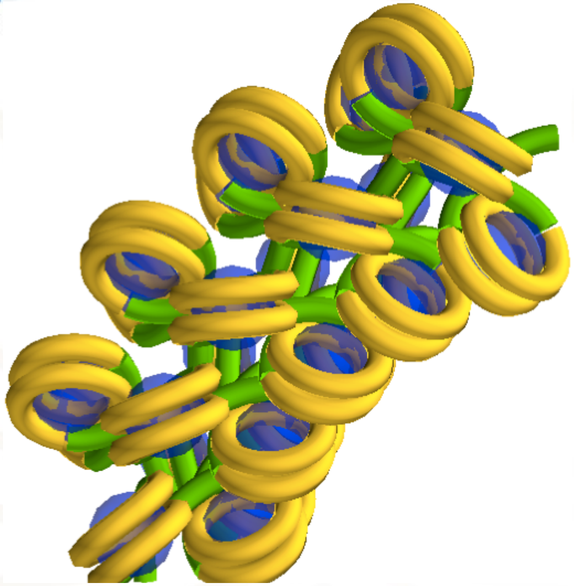
First published: 18 May 2020 | https://doi.org/10.1002/mp.14242 | Citations: 1

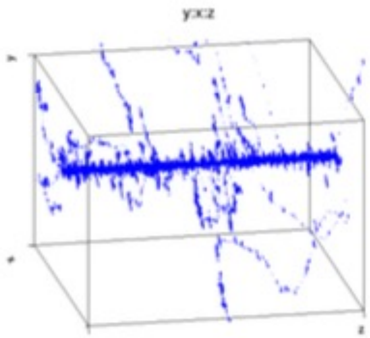
- **Independent Dose Calculation with Scanned Ion Beams at MedAustron**
  - RayStation version 8B from RaySearch Laboratories
    GATE-RTion **(IDEAL: Independent DosE cAlculation for Light ion beam therapy)**
  - 3D-block/24 PinPoint ionization chambers type 31015, PTW, Freiburg

- Curative carbon ion treatment up to 65.6 Gy RBE in 16 fractions of 4.1 Gy RBE (4 fractions per week). The PTV1 is treated with 9 fractions up to 36.9 Gy RBE, using 4 beams with a horizontal beam line and table rotations of 315°, 355°, 320° and 360°



Comparison of the physical dose distribution for a carbon ion beam having an oblique incidence in the head region of a patient. IDEAL/GATE-RTion dose distribution (Top left) is compared to the TPS (bottom left)





Multi-scale simulations

Multi-scale simulations

GEANT4-DNA

The **unique** open source and open access simulation toolkit for micro/nano dosimetry and radiation biology

- **Long term development** fully included in Geant4 releases
- International collaboration composed of 42 collaborators
- **Coordinated by IN2P3/CNRS** since 2008
- Funded by regular support from institutions and international calls
- Fruitful involvement in international conferences & tutorials
  - Geant4 International User Conference at the Physics-Medicine-Biology frontier » series of conferences initiated by IN2P3 in 2005
  - Annual international tutorials (17)
- High rank and highly cited publications (104 since 2007)

DEVELOPMENT ACCESSIBLE TO OTHER TOOLKITS, PARTICULARLY TO GATE

Elementary processes:
- Ionization
- Excitation
- Fragmentation
- Radical production

Sub cellular structures

Nano dosimetry

Death,cycle arrest
Migration /metastases
Mechanical properties
Morphology

Micro dosimetry

Evolution of tumour
- Growing
- Control
- Vascularisation

Bystander

Organ motion
Patient morphology
Cancer induction

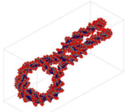
Biological dose

Molecules

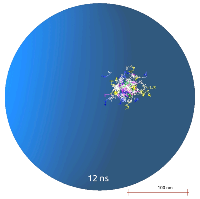
Cell

Clusters of cells / Organ

Patient

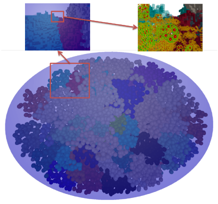


Delage et al. 2015

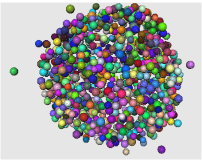


J. Comput. Phys. 274 (2014) 841-882

LPCHEM code

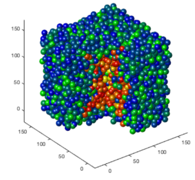


Sc. Rep. 7 (2017) 11923

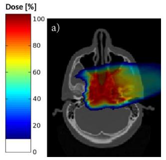


cpop.in2p3.fr

MSB



Dufour A et al, (2018), Modeling the dynamics of oligodendrocyte precursor cells and the genesis of gliomas, *PLoS Comput Biol.*, **14**, e1005977.



NanOx

PMRT

GEANT4-DNA **Open source and open access toolkits** GATE

Estimate the biological dose in hadrontherapy

BIOLOGICAL DOSE = RBE x PHYSICAL DOSE

Nano/micro scale

Predict biological effect at low scale

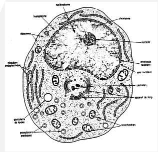
mMKM

(Kase et al., 2006)

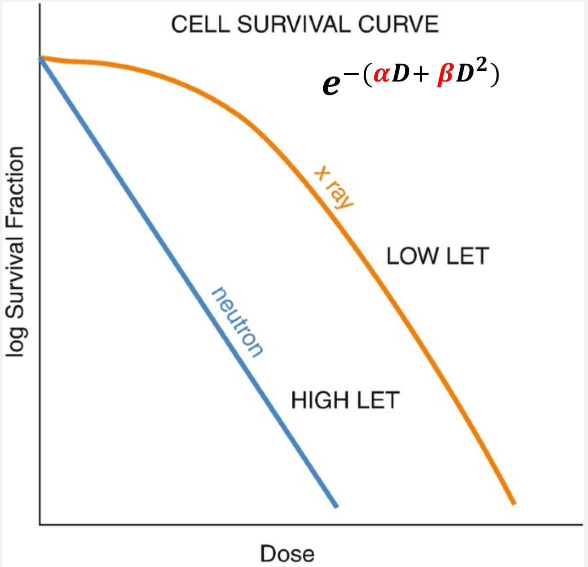
NanOx

(Cunha et al., 2017)

Cellular scale

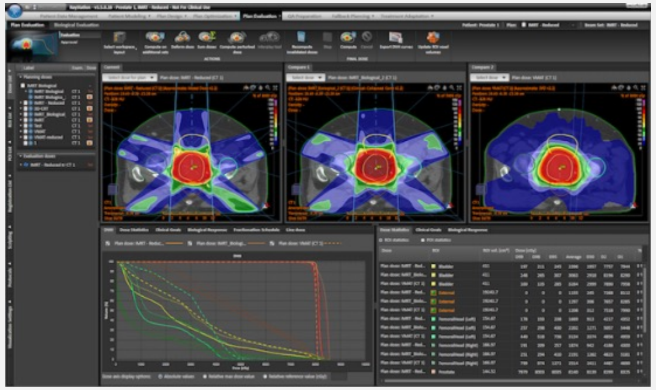


Cell survival estimation



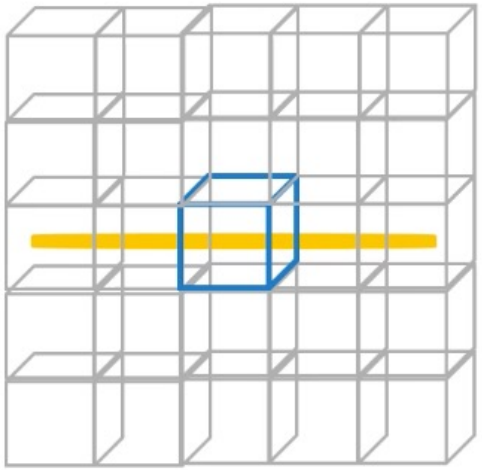
Macro scale

Treatment plan on patient



Estimate the biological dose in hadrontherapy

VOXELIZED TARGET VOLUME

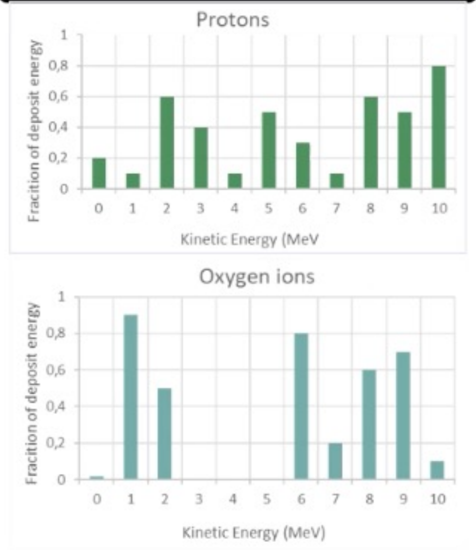


The resolution of the matrix, the size of the voxels, the position of the matrix are initialized via the messenger thanks to the parameters the user set in the macro.

ENERGY DEPOSITION BY STEPS

Is retrieved from each step :
- The particle type
- The kinetic energy (pre step point)
- The energy deposition

PER PARTICLE & PER KINETIC ENERGY



An histogram of the cumulative deposited energy is created for each type of particle as a function of the kinetic energy.

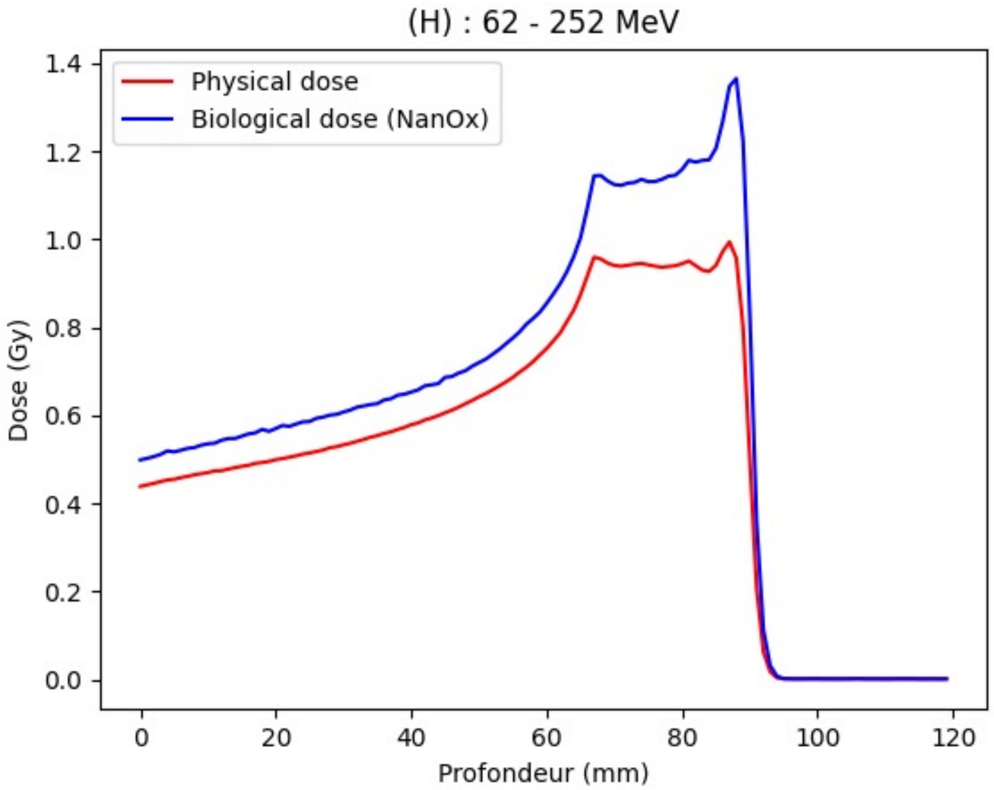
ALPHA BETA MIX CALCULATION

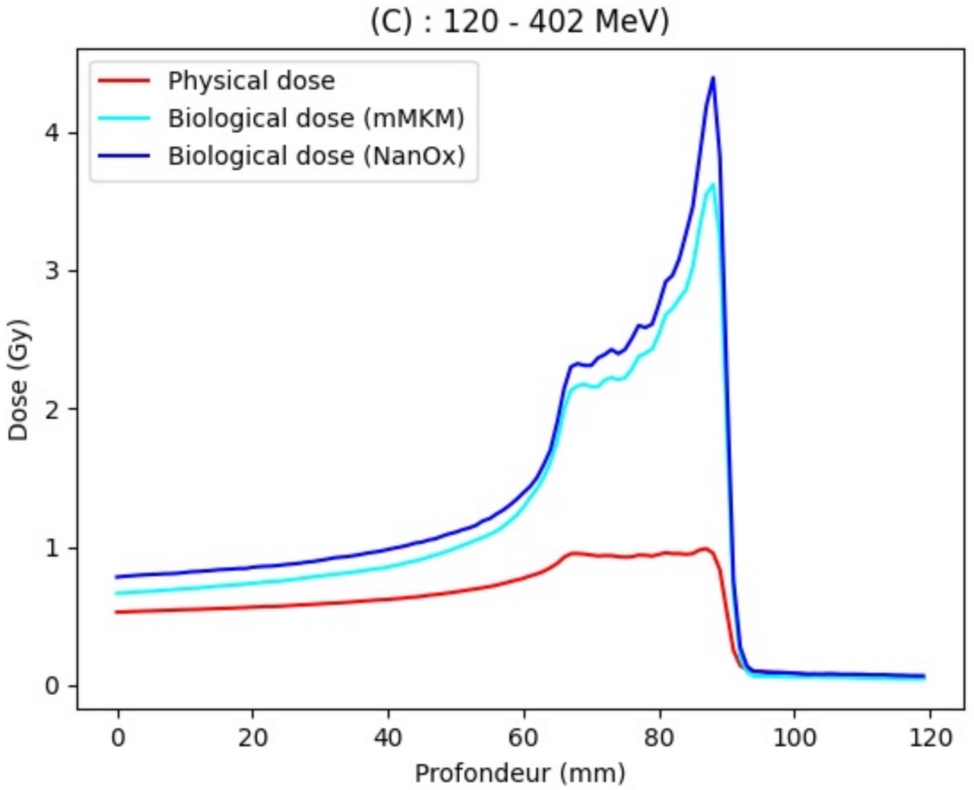
$$\alpha_{mix} = \sum_{k=1}^{N} f_k \alpha_k$$

$$\beta_{mix} = \sum_{k=1}^{N} f_k \sqrt{\beta_k}$$

We weight each alpha/beta values with the deposit energy fraction according to obtain the alpha and beta mix values.

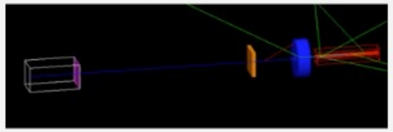
Biological dose estimation for proton and carbon ion beams



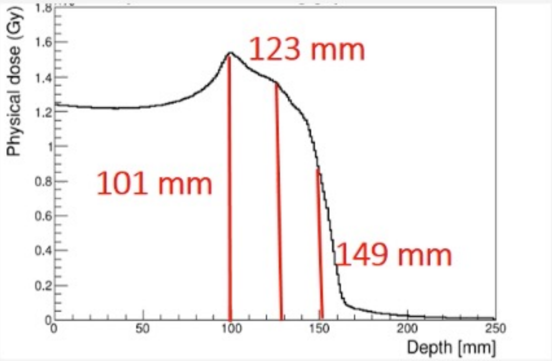


Cell survival estimation

HIMAC LINE



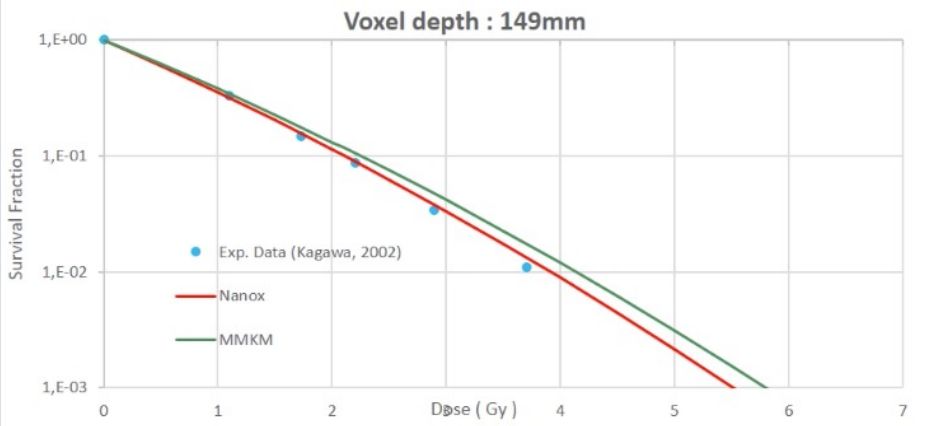
Carbon
Energy: 320 MeV/n
Irradiation mode: passive



HSG cells irradiated at 3 positions of the SOBP, in 2002.

Kagawa et al. (2002)

	NanOx				MMKM
IONS	HSG	CHO-K1	V79	SQ20B	HSG
PROTONS	✓	✓	✓	✓	✓
HELIUM	✓	✓	✓	✓	✓
CARBON	✓	✓	✓		✓
OXYGEN	✓	✓	✓		✓
NEON	✓	✓	✓		✓



LPC Particules pLasmas Univers applicationS Laboratoire de Physique de Clermont

iP2i

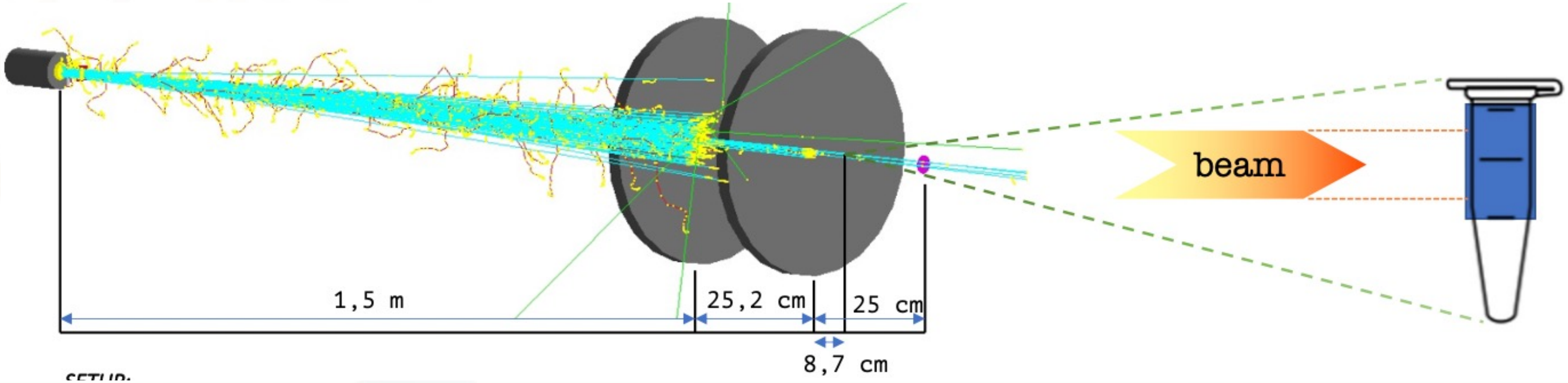
CREATIS

LABEX PRIMES UNIVERSITÉ DE LYON

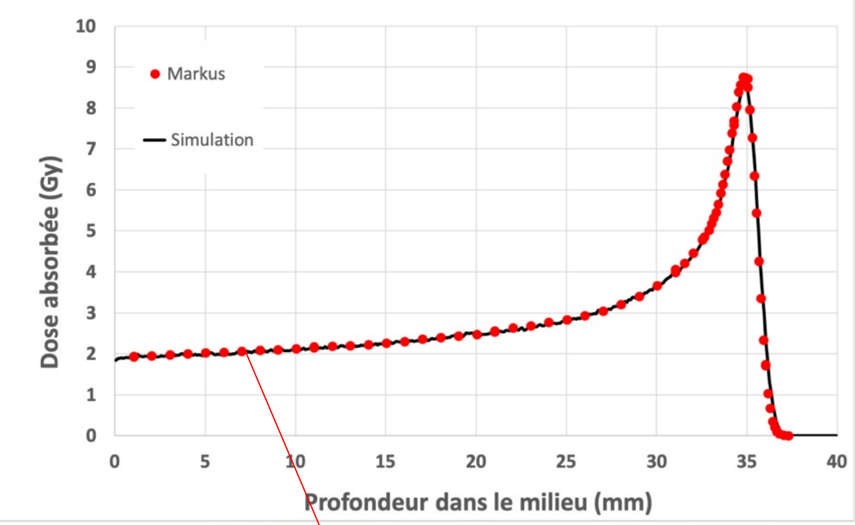
Preclinical proton irradiation at ARRONAX

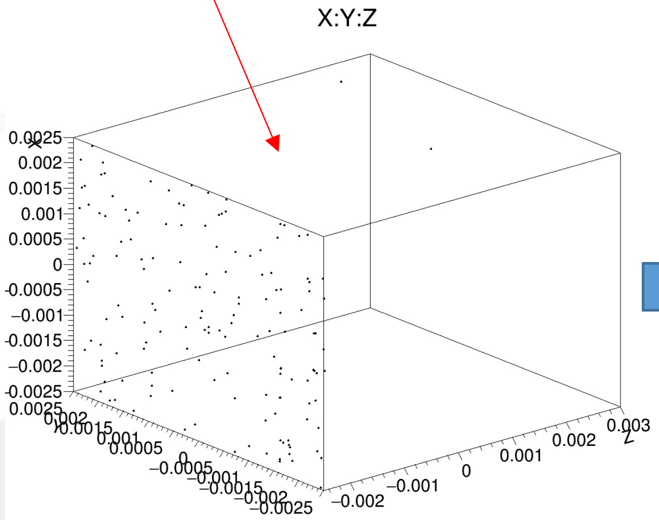
Characterization of the beam line, dosimetry → Water radiolysis + Fricke chemistry H_2O_2 → Radiation biology Zebra fish + human cells → Modeling water radiolysis → Adapted biophysical models

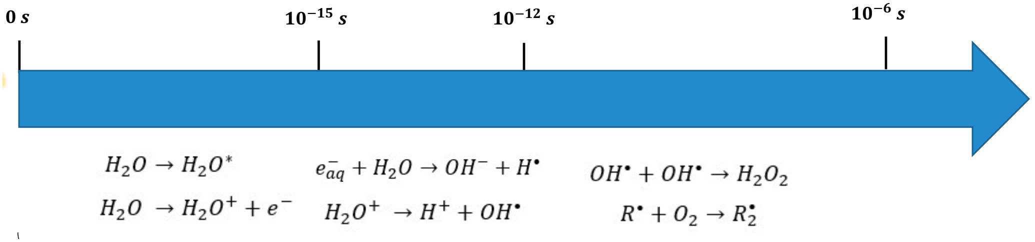
VHDR 67 MeV proton beam
bunches of protons interspaced by 32.84 ns
(micro-pulse, RF = 30.45 MHz)
Pulse dose rate up to 60 kGy/s

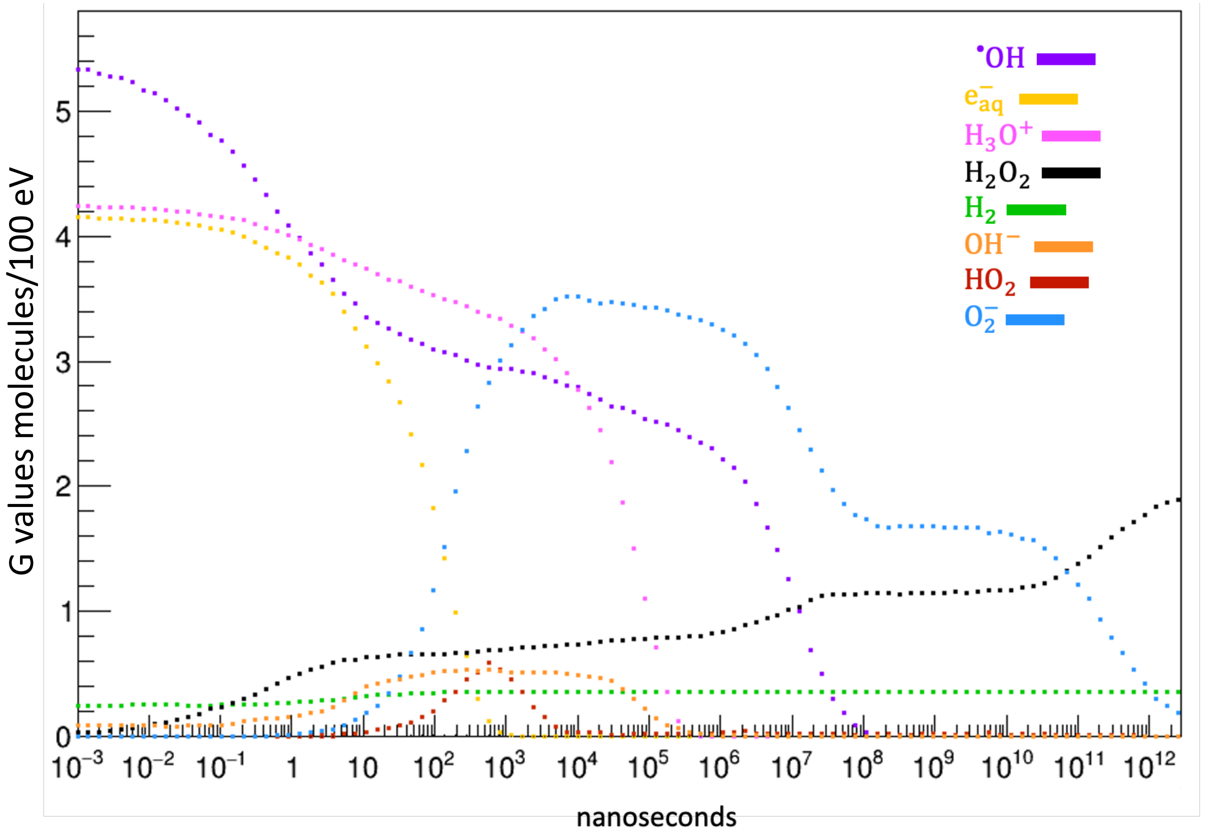


Simulate radical species in water samples









PhaseSpace around the target box

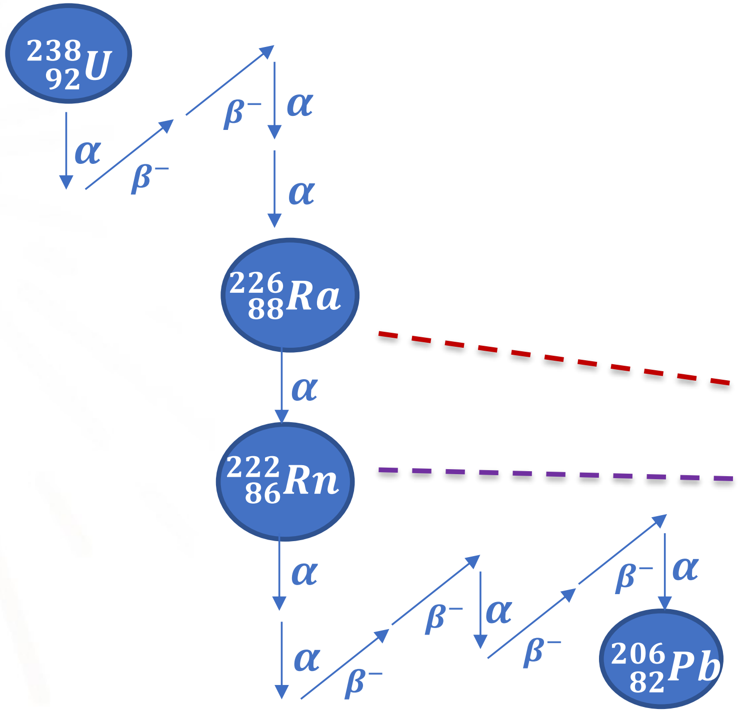
Impact of natural radioactivity in mineral springs

Mineral Springs

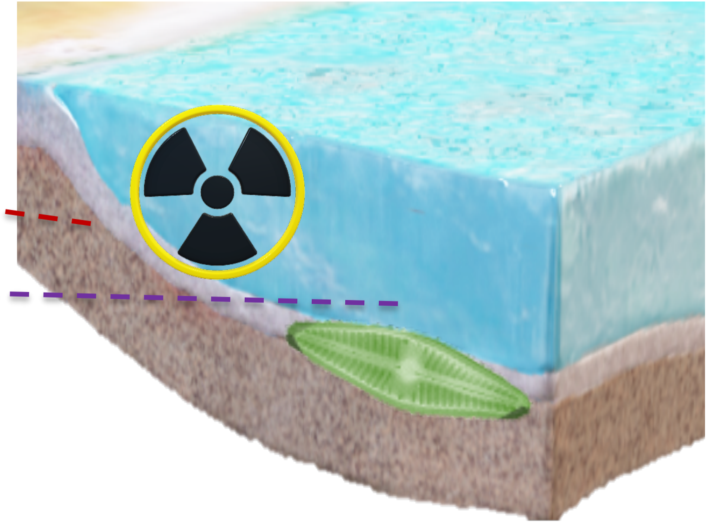
- Isolated ecosystems
- Various physicochemical & radiological properties

Natural Radioactivity

α- emitters : $4 < E_{\alpha} < 9$ MeV

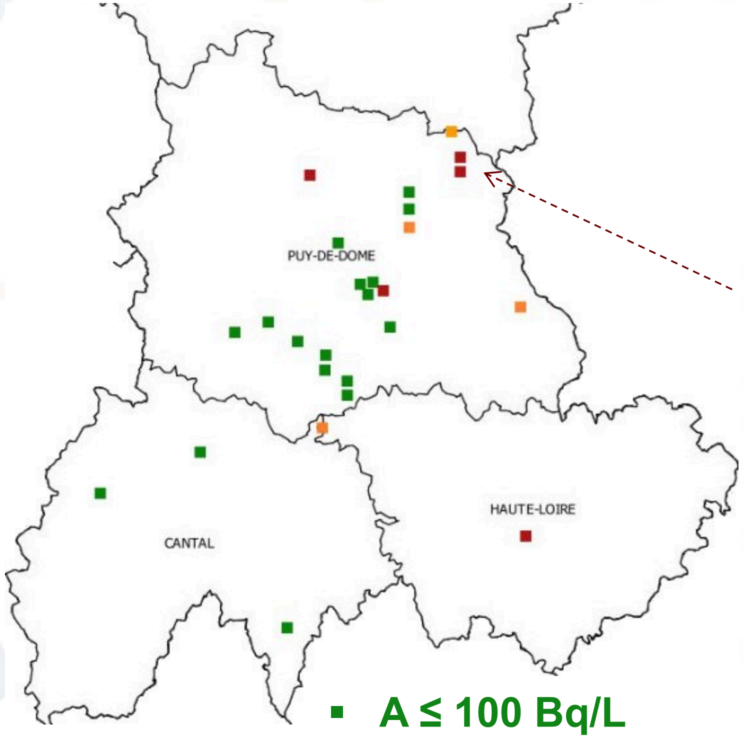


Chronic exposure of microorganisms



^{226}Ra & ^{222}Rn: main dose contributors

27 mineral springs

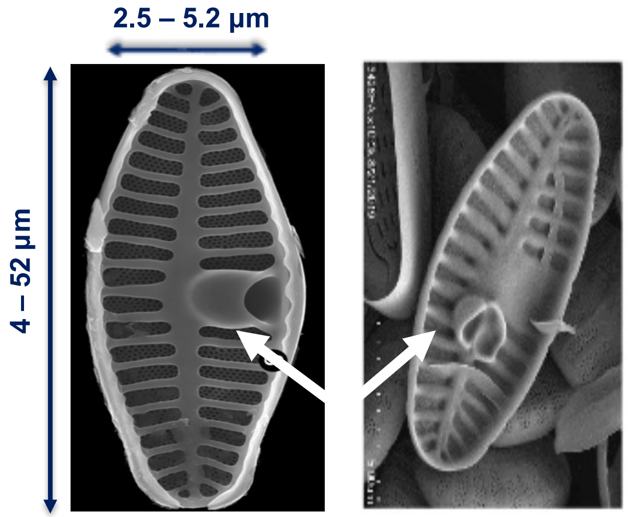


- **A ≤ 100 Bq/L**
- **100 ≤ A ≤ 1000 Bq/L**
- **A ≥ 1000 Bq/L**

La Montagne
~ 4500 Bq / L

Diatoms

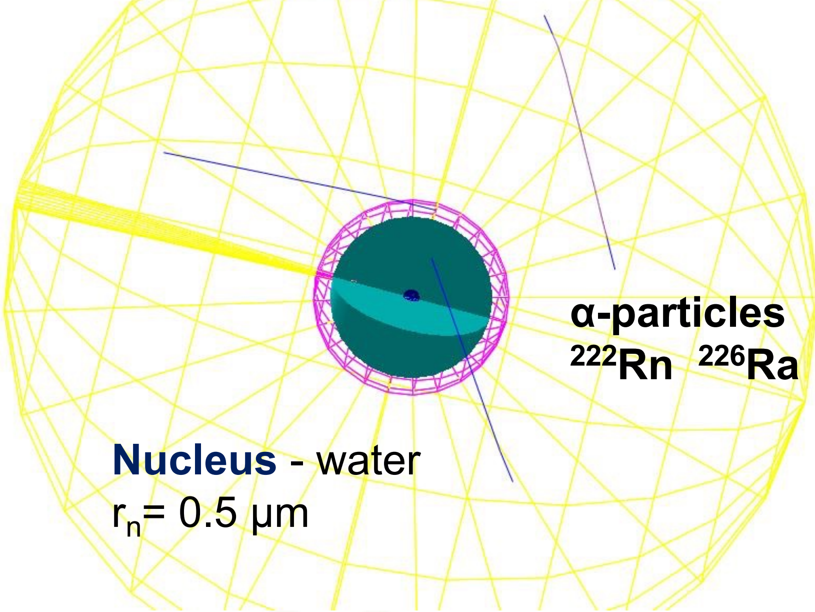
- **Photosynthetic micro-algae (frustule)**
- Water quality indicators
- **Stresses** induce **teratogenic forms**



Credits: M. Potarova, Diatoms.org C. Wetzel, LIST 4

Microdosimetry and DNA damage

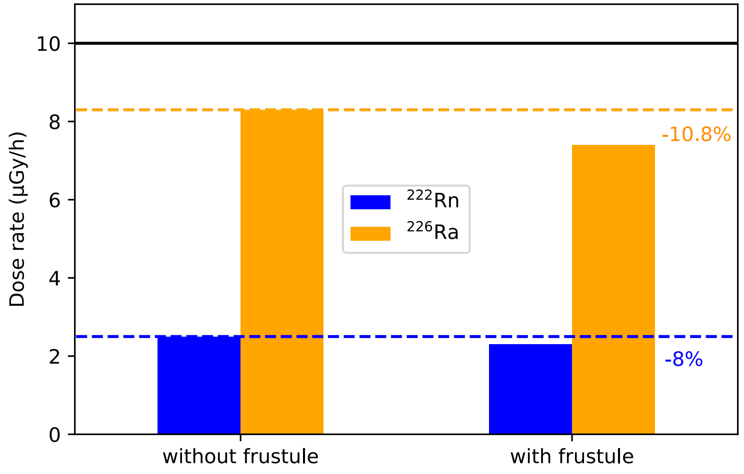
Diatom - water
R_d = 10 µm – with / without 2 µm width **frustule**

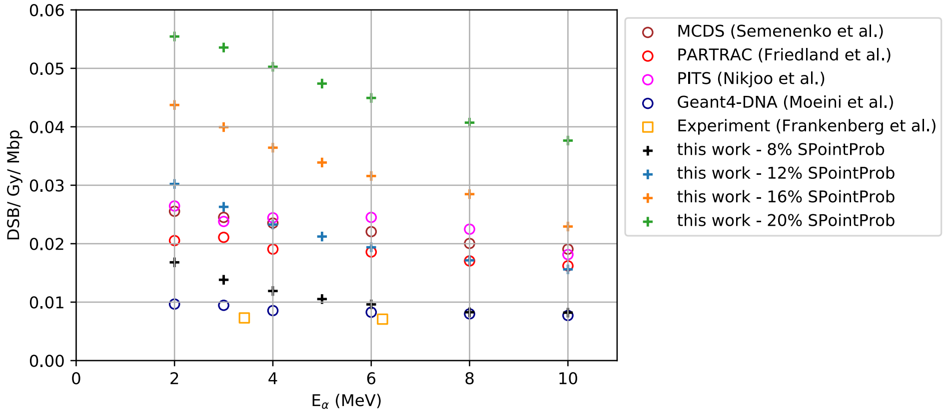


α-particles
^{222}Rn ^{226}Ra

Nucleus - water
r_n= 0.5 µm

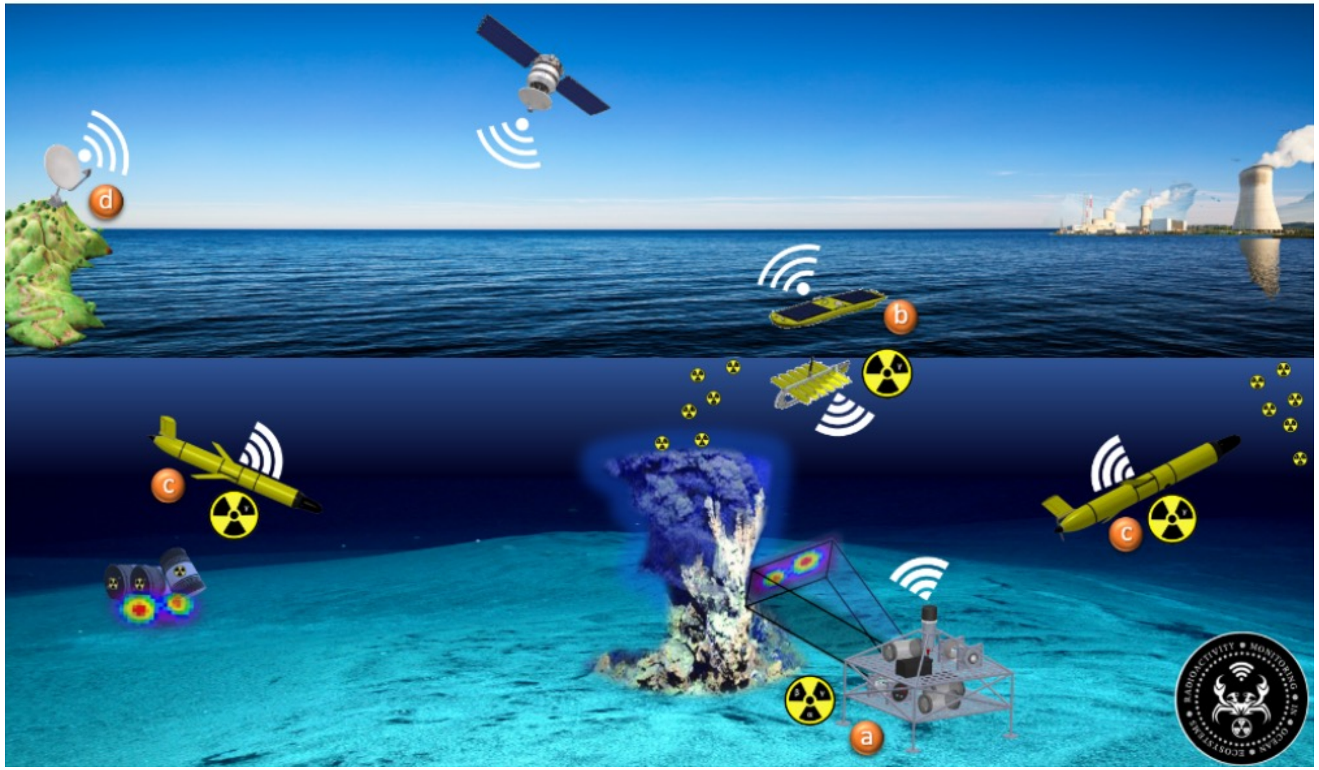
- 90% liquid H_2O
- 10% sediments
- d = 1.02 g / cm^3
- ^{222}Rn in H_2O : 1000 Bq / L
  $E_{\alpha,max}$ = 5.5 MeV
  $Range_{water}$ = 43.5 µm
- ^{226}Ra in sediments: 30 Bq / g
  $E_{\alpha,max}$ = 4.8 MeV
  $Range_{water}$ = 35 µm





V. A. Semenenko *et al.*, Phys. Med. Biol. **51**, 1693 (2006)
W. Friedland *et al.*, Radiat. Phys. Chem. **72**, 279 (2005)
H. Nikjoo *et al.*, Radiat. Res. **156**, 577 (2001)
H. Moeini *et al.*, Int. J. Radiat. Biol. **96**, 767 (2020)
D. Frankenberg *et al.*, Radiat. Res. **151**, 540 (1999)

Radioactivity monitoring in Ocean Ecosystems



Receives funding from European Union under Horizon 2020 FET Proactive Programme via grant agreement No. 101017808

GATE 10 using Python binding for Geant4

- **pip install opengate**
  - Install Geant4 + ITK + QT + GATE + data
- **Writing in Python >> Writing with macros**
  - Simplified sharing : users-developed modules (e.g. IEC phantoms, detectors, linac etc.)
  - Easy access to whole Python ecosystem (AI !)
- **Speed**
  - Python is slow ? NO ! Still same G4 engine: **no time penalty**
  - G4 multithread
- **Faster development time, better separation**
  - Python: user parameters, initialisation, options, I/O etc
  - C++: core processing only
- **Advanced features**
  - Dynamic trigger: call user function during runtime (time penalty)

See: https://github.com/OpenGATE/opengate
Docs https://opengate-python.readthedocs.io (wip)

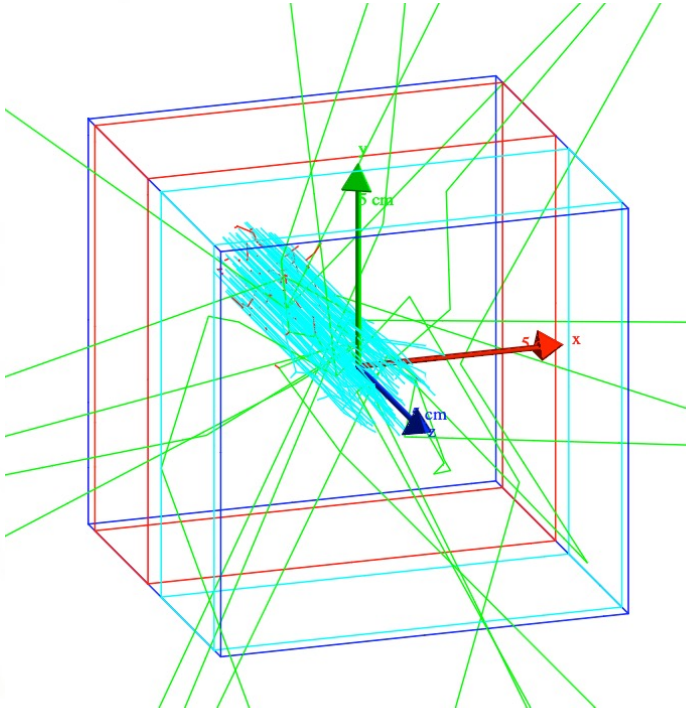
More than 70 tests (example) available

GATE 10 simulation example

```python
#!/usr/bin/env python3
# -*- coding: utf-8 -*-

import opengate as gate

paths = gate.get_default_test_paths(__file__, "gate_test008_dose_actor")

# create the simulation
sim = gate.Simulation()
```

```python
# main options
ui = sim.user_info
ui.g4_verbose = False
ui.g4_verbose_level = 1
ui.visu = False
ui.random_seed = 123456

# units
m = gate.g4_units("m")
cm = gate.g4_units("cm")
mm = gate.g4_units("mm")
MeV = gate.g4_units("MeV")
Bq = gate.g4_units("Bq")
```

```python
#  change world size
world = sim.world
world.size = [0.5 * m, 0.5 * m, 0.5 * m]

# waterbox
waterbox = sim.add_volume("Box", "waterbox")
waterbox.size = [10 * cm, 10 * cm, 10 * cm]
waterbox.material = "G4_WATER"
waterbox.color = [0, 0, 1, 1]

# lungbox
lungbox = sim.add_volume("Box", "lungbox")
lungbox.mother = waterbox.name
lungbox.size = [10 * cm, 10 * cm, 4 * cm]
lungbox.translation = [0 * cm, 0 * cm, 2.5 * cm]
lungbox.material = "G4_LUNG_ICRP"
lungbox.color = [0, 1, 1, 1]

# bonebox
bonebox = sim.add_volume("Box", "bonebox")
bonebox.mother = waterbox.name
bonebox.size = [10 * cm, 10 * cm, 4 * cm]
bonebox.translation = [0 * cm, 0 * cm, -2.5 * cm]
bonebox.material = "G4_BONE_CORTICAL_ICRP"
bonebox.color = [1, 0, 0, 1]
```



```python
# physics
p = sim.get_physics_user_info()
p.physics_list_name = "QGSP_BERT_EMV"
sim.set_cut("world", "all", 1 * mm)
```

```python
# default source for tests
source = sim.add_source("Generic", "mysource")
source.energy.mono = 115 * MeV
source.particle = "proton"
source.position.type = "disc"
source.position.radius = 1 * cm
source.position.translation = [0, 0, -80 * mm]
source.direction.type = "momentum"
source.direction.momentum = [0, 0, 1]
source.activity = 5000 * Bq
```

```python
# add dose actor
dose = sim.add_actor("DoseActor", "dose")
dose.output = paths.output / "test041-edep.mhd"
dose.mother = "waterbox"
dose.size = [10, 10, 50]
mm = gate.g4_units("mm")
ts = [200 * mm, 200 * mm, 200 * mm]
dose.spacing = [x / y for x, y in zip(ts, dose.size)]
print(dose.spacing)
dose.uncertainty = True
dose.gray = True
dose.hit_type = "random"

# add stat actor
s = sim.add_actor("SimulationStatisticsActor", "Stats")
s.track_types_flag = True
```

```python
# create G4 objects
sim.initialize()

# start simulation
sim.start()

# print results at the end
stat = sim.get_actor("Stats")
print(stat)

dose = sim.get_actor("dose")
print(dose)
```

Useful links

GATE version 9.3 coming very soon
1 release/year

Information

Web site http://www.opengatecollaboration.org
GATE user mailing list https://listserv.in2p3.fr/cgi-bin/wa?A0=OPENGATE-L
GATE documentation
To install GATE https://opengate.readthedocs.io/en/latest/installation.html
To use GATE https://opengate.readthedocs.io/en/latest/

Accessible through Github

Source code **https://github.com/OpenGATE/Gate**
Examples **https://github.com/OpenGATE/GateContrib**
Analysis tools **https://github.com/OpenGATE/gatetools**

Scientific meetings:

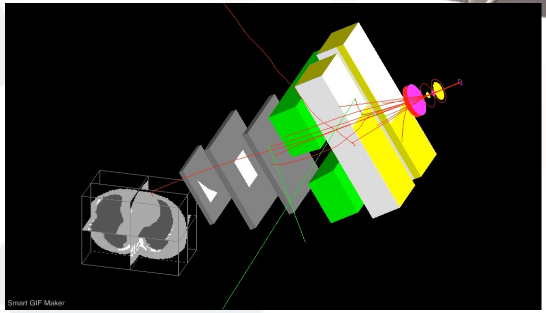
- May 2022 **https://indico.in2p3.fr/e/gate2022**
- **25-26 April 2023, in Krakow (Poland), to register: https://indico.in2p3.fr/e/gate2023**

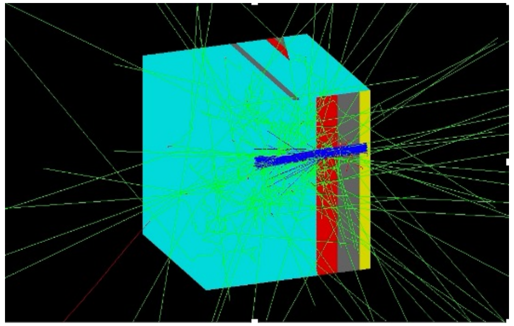
Trainings & Workshops

- **1 workshop @ main conferences : IEEE NSS-MIC, AAPM, MCMA, PTCOG…**
- Trainings : 2/year
  - **GATE training (beginner level): 22-24/11/23**
  - **Python data analysis for GATE simulations: June 2022**

GATE training hub for students

- Server dedicated to training
- 100 simultaneous connections
- For on site or remote tutorials
- Shared course materials
- **Service open since 2021**





THANK YOU

lydia.maigne@clermont.in2p3.fr