GATE
A Geant4-based simulation platform for medical physics

Lydia Maigne on behalf of the OpenGATE collaboration
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The collaboration & Partners

20 members, public laboratories and companies developing an open source platform

Spokesperson: Lydia Maigne
Technical coordinator: David Sarrut

France

- U892 Inserm, Nantes
- U1101 Inserm, Brest
- IMNC - CNRS-IN2P3, Paris-Orsay
- LPC - CNRS-IN2P3, Clermont-Ferrand
- IPHC - CNRS-IN2P3, Strasbourg
- CPPM - CNRS-IN2P3, Marseille
- CREATIS - CNRS, Lyon
- SHFJ - CEA, Paris-Orsay
- CRCT - Inserm, U1037, Toulouse

Soon LPSC

Cross validation with the Geant4 collaboration
Susanna Guatelli & Sébastien Incerti

Europe

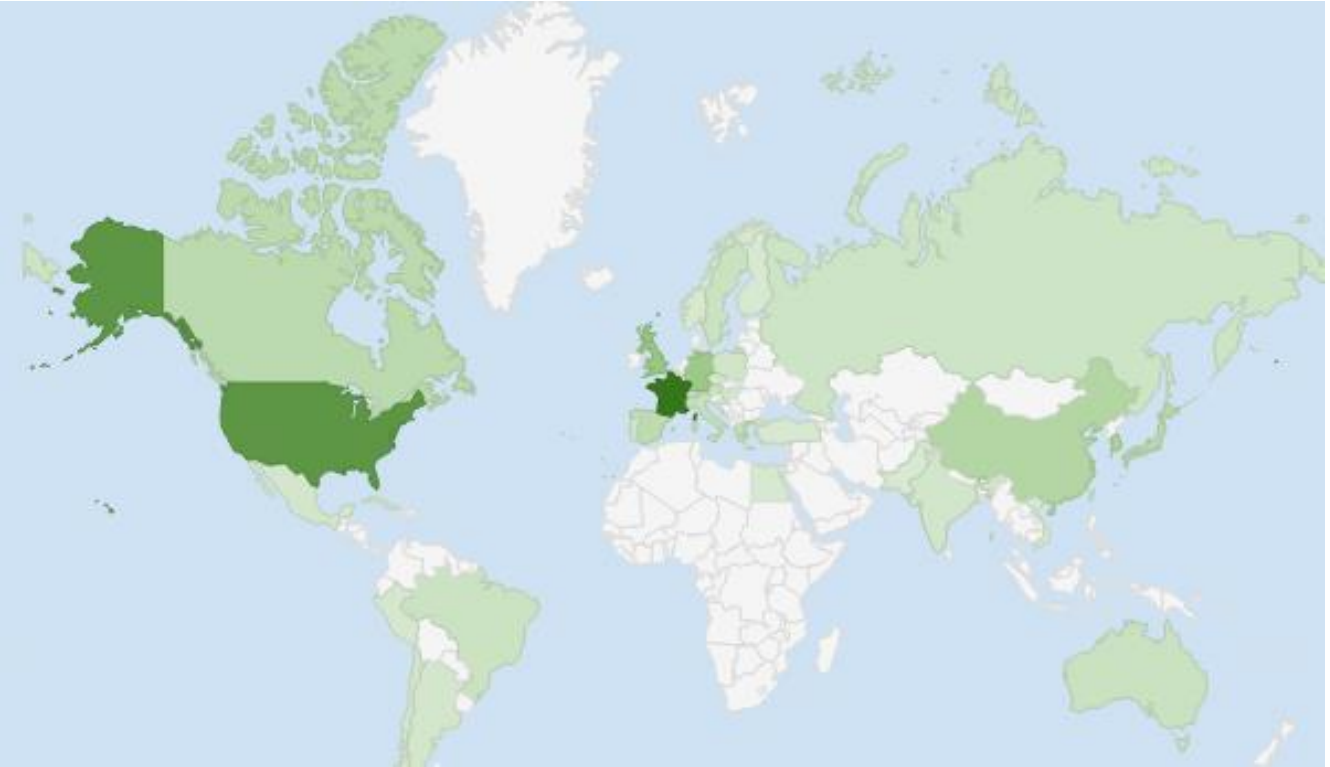
- University of Applied Science, Julich, Germany
- University of Wuppertal, Germany
- The Christie NHS Foundation Trust, Manchester
- Technological Educational Institute of Athens, Greece
- BioemTech, Athens, Greece
- Medical University of Vienna, Wiener Neustadt, Austria
- MedAustron, Wiener Neustadt, Austria
- ACMIT, Wiener Neustadt, Austria

Elsewhere

- Memorial Sloan-Kettering Cancer Center, New York, USA
- UC Davis, Davis, USA
- Sogang University, Seoul, South Korea

The collaboration is always looking for new members

A large community of users



Around 2000 registered users

- Large communities in France and USA
- Increasing number in Asia: China, Japan and South Korea

GATE USERS MAILING LIST

What is for?

- The means for the collaboration to send information about releases, job offers, interesting papers
- The means for users to ask any questions regarding GATE: bugs, compilation problems, good pratice for using or developing the platform

To register to the mailing-list: http://opengatecollaboration.org/mailinglist

What is GATE?

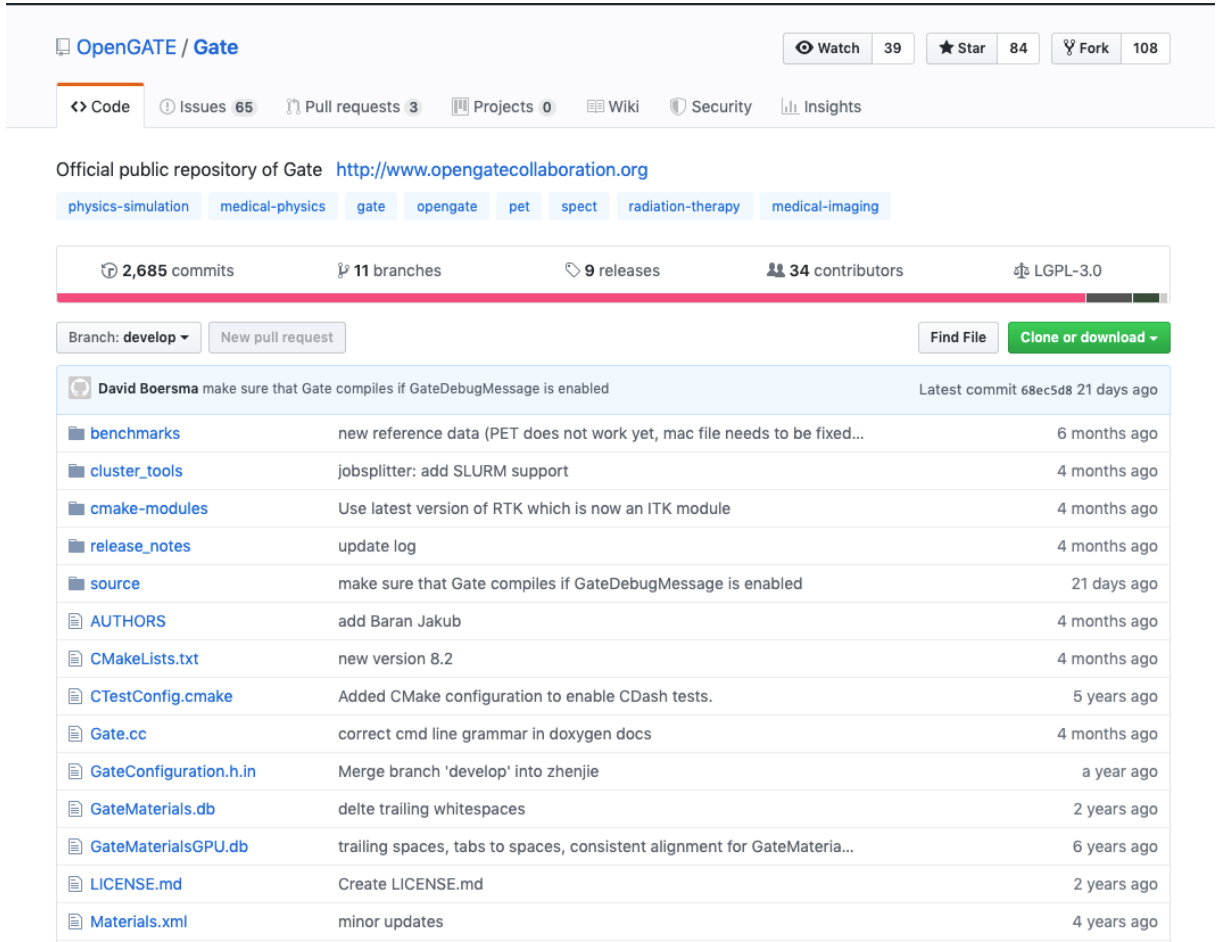
- GATE: **Geant4** Application for Emission Tomography, Transmission Tomography, Radiotherapy and Optical Imaging. For **Medical Physics**
- GATE is an **open source** software (GNU LGPL) fully based on the Geant4 toolbox
- GATE is written in **C++**
- GATE is **user-friendly** as simulations can be designed and controlled using **macros**, without any C++ writing
- GATE can simulate SPECT, PET, CT and optical scans, radiotherapy treatments (internal, external) and **ion beam therapy**
- **1 release / year**, after the Geant4 release, now **GATE 8.2**

GATE source code on GitHub
Release 8.2

How to post your devs?

- Get an account on GitHub
- Fork Gate repository
- Make your fix
- Submit a pull request

https://github.com/OpenGATE/Gate



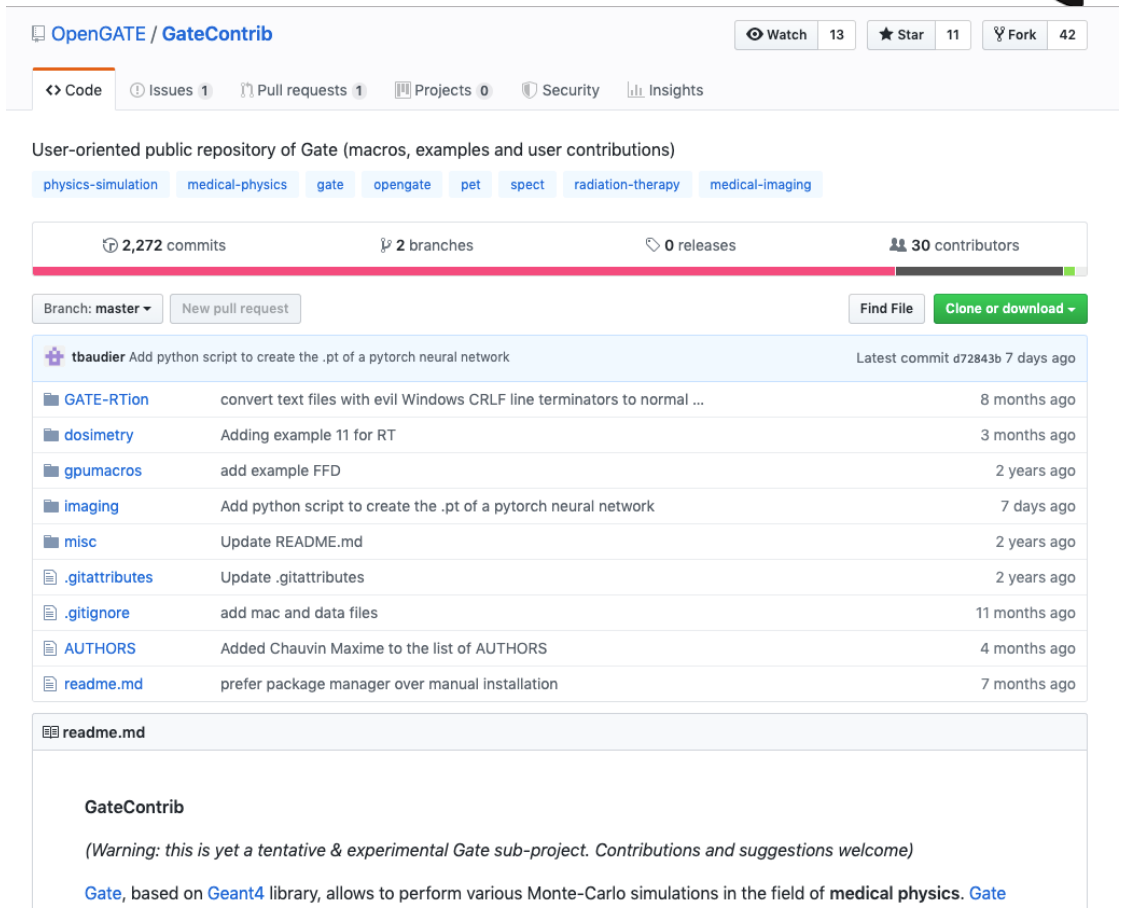
https://github.com/OpenGATE/GateContrib

Play with GATE examples

- **Dosimetry:** Radiotherapy, DNA, LET, doseactor, dosebyregions, …
- **Imaging:** CT, PET, SPECT, SPECT_FFD, fluorescence, ProtonRadiography…
- **Misc:** mesh geometry, STL geometry…

How to contribute?

- **Prepare your example as a pull-request**
- **Clone the repository in your GiHub account**
- **Commit your example**
- **New pull request**



https://github.com/OpenGATE/gatetools

Gate-Tools

- Python scripts and API
- Common process on images, phase-space, gamma-index, etc …
- Open to user contribution

- Still work in progress
- planned for end 2019

OpenGATE / GateTools

Unwatch | Sta

Code | Issues 1 | Pull requests 0 | Projects 0 | Wiki | More | Settings

Tools for Gate

Edit

Manage topics

105 commits | 4 branches | 0 releases | 3 contributors | Apache-2.0

Branch: master | Create new file | Upload files | Find file | Clone or download

dsarrut Update readme.md — Latest commit a0cb731 19 days ago

bin	rename fct	19 days ago
gatetools	update helper	last month
.gitattributes	Initial commit	7 months ago
.gitignore	ignore files	19 days ago
LICENSE	Initial commit	7 months ago
readme.md	Update readme.md	19 days ago
setup.py	rename bin phsp	19 days ago

(Hopefully) useful tools for GATE simulations.

STILL WORK IN PROGRESS : will be released before end 2019

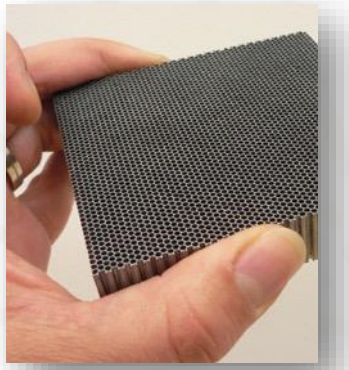
Install with : `pip install gatetools`

Example of usage:

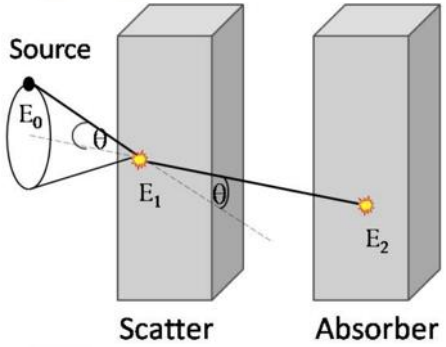
```
gt_image_convert -i input.dcm -o output.mhd
gt_image_convert -i input.mhd -o output_float.mhd -p float
gt_image_arithm -i *.mhd -o output.mhd -O sum
gt_gamma_index data/tps_dose.mhd result.XYZ/gate-DoseToWater.mhd -o gamma.mhd --dd 2 --dta 2.5 -u "%" -T 0
```

Current list of command line tools. Use the flag `-h` to get print the help of each tool.

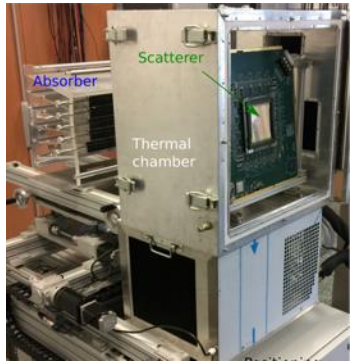
New: Compton Camera module



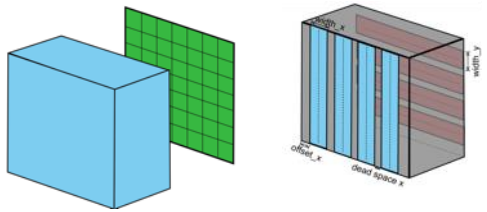
10^{-5}



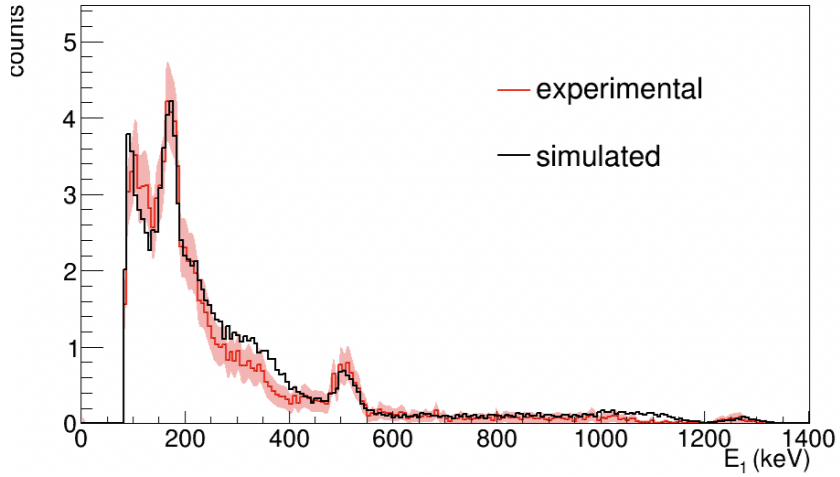
$$\cos(\theta) = 1 - \frac{E_2\, m_e\, c^2}{E_1(E_1 - E_2)}$$



10^{-4}

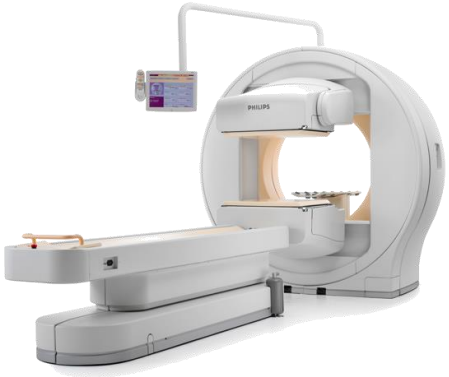


[Extebeste et al 2019]
MCMA
paper soon in PMB

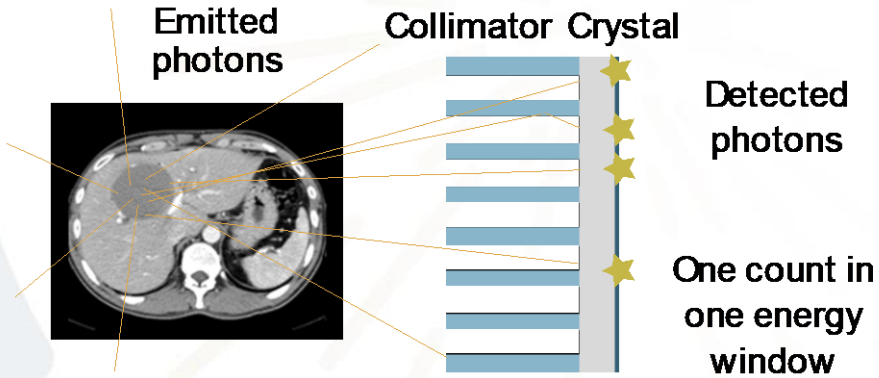


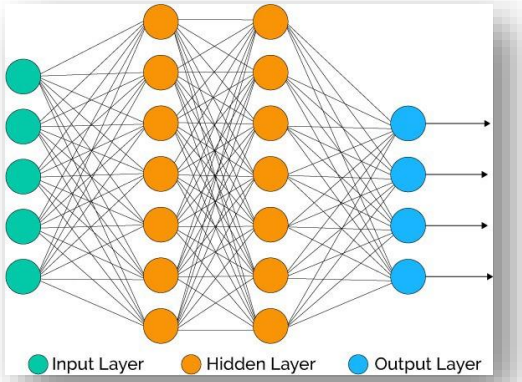
MC simulations and neural networks

Learning SPECT detector response for Monte-Carlo simulations



Angular Response Function

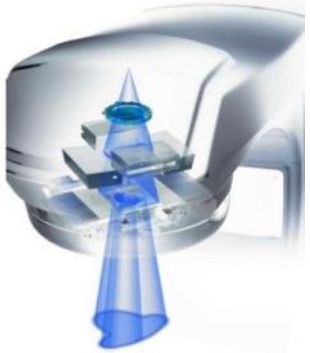


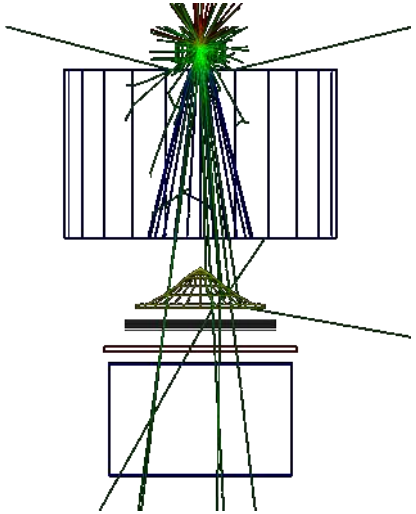


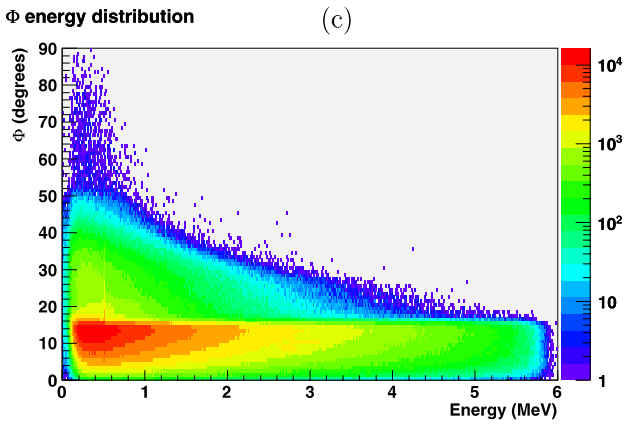
Large speedups (50 – 1000)

[Sarrut et al PMB 2018]

A.I. for Monte Carlo modelling

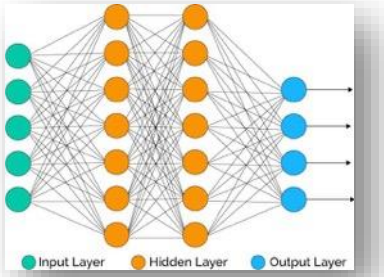




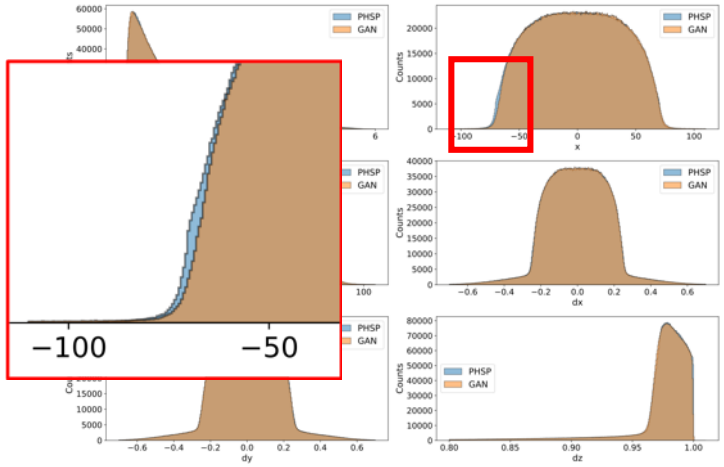


Phase space >3GB

[Sarrut et al PMB 2019]



GAN: Generative Adversarial Network



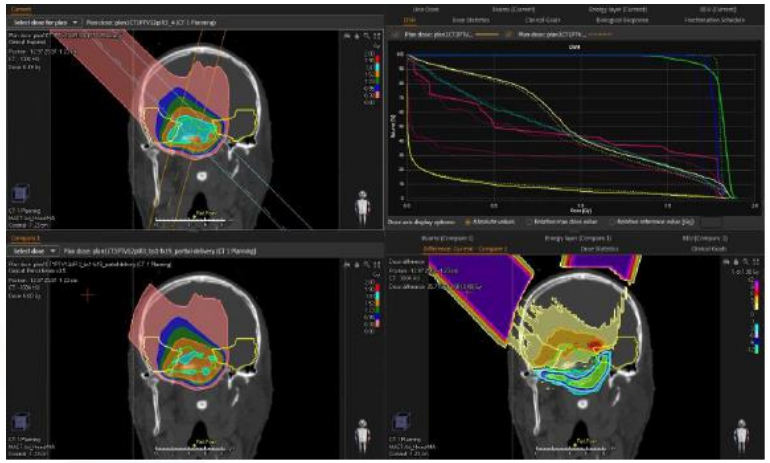
The GATE-RTion project

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



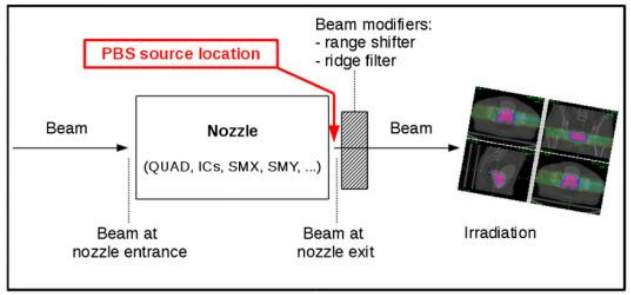
6 ion therapy centers

MedAustron (Austria)
The Christie (UK)
UCLH (UK)
CAL (France)
CPO (France)
Skandion (Sweden)

5 partners

CREATIS CNRS (France)
LPC CNRS (France)
Medical University of Vienna (Austria)
University of Krakow (Poland)
ACMIT (Austria)

The GATE-RTion project



Investigate how simulation parameters can affect results

Tracking and range cuts
Step limiter
Physics settings (MSC models)

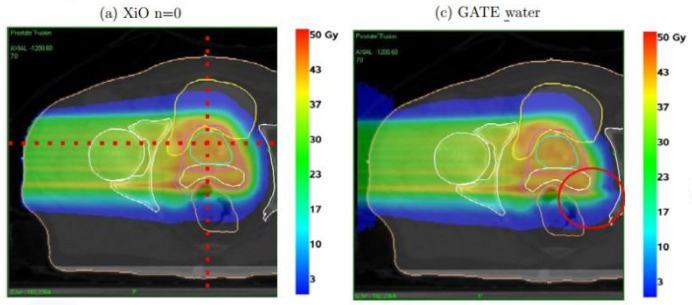
GATE-RTion 1.0: GATE 8.1 & Geant4 10.03.p03

A set of common tools for analysis (mainly using Python)

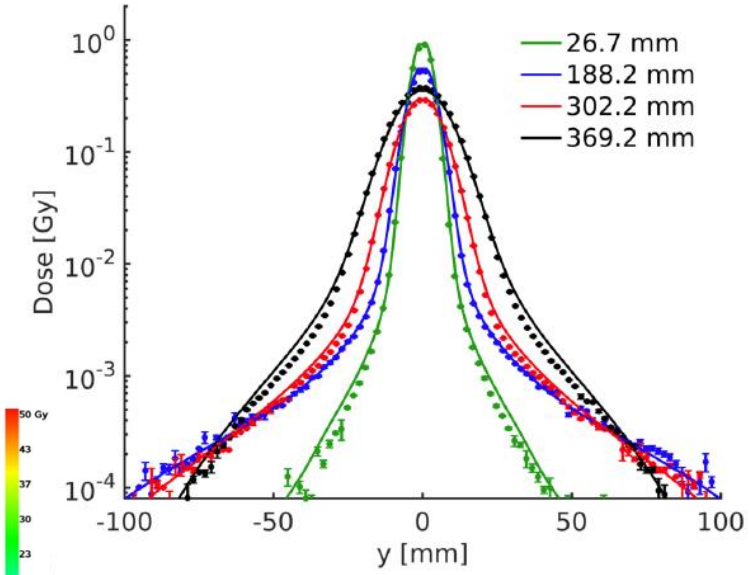
A network of clinical users to validate beam lines

To an independant dose calculation for light ion beam radiotherapy

And the simulation of biological dose?

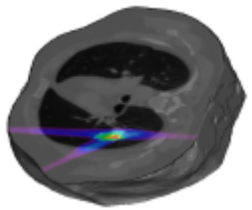


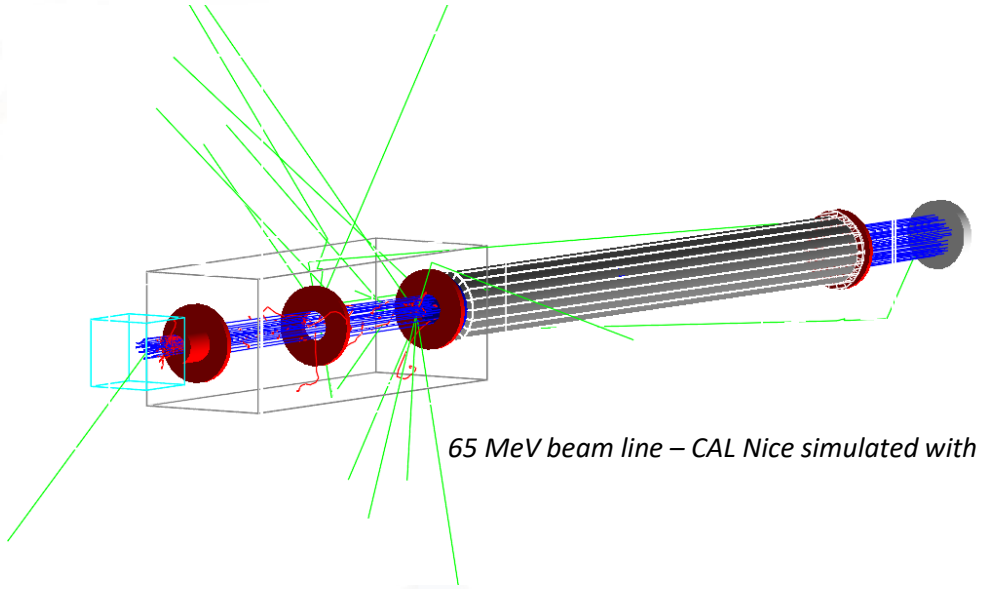
Grevillot et al. 2010



Simulated and measured dose profiles of a central PB at different depths in water. Resch et al. Med. Phys. 2019

Multi-scale simulations for particle therapy





65 MeV beam line – CAL Nice simulated with GATE

Multi-scale simulation schema

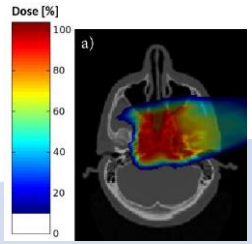
The GATE RT-ion project: a dedicated version for clinical dosimetry

Simulation at lower scales

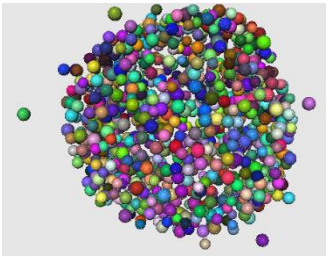
- ***Micro and nano dosimetry***
- ***Radiolysis species production***
- ***Biophysical models***

The picture

Organ motion
Patient morphology
Cancer induction
BIOLOGICAL DOSE



Patient (mm)

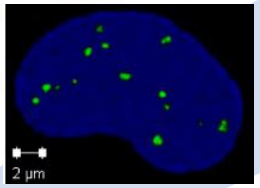


cpop.in2p3.fr

Death,cycle arrest
Migration /metastases
Mechanical properties
Morphology
Micro dosimetry

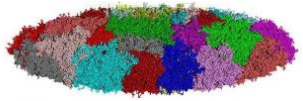
Clusters of cells / Organ (mm)

Evolution of tumour
Bystander



Gruel et al. 2016

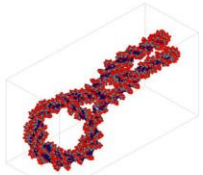
Cell (µm)



Friedland et al. 2008

Elementary processes
Sub cellular structures
Nano dosimetry

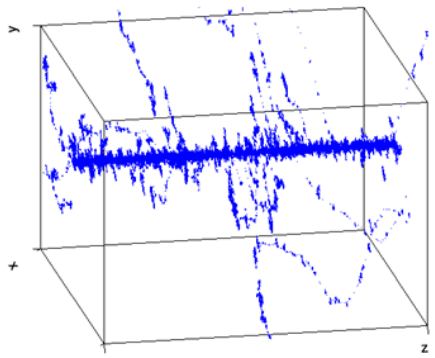
Molecules (nm)



Delage et al. 2015

Friedland et al. 2013

Micro and nano dosimetry



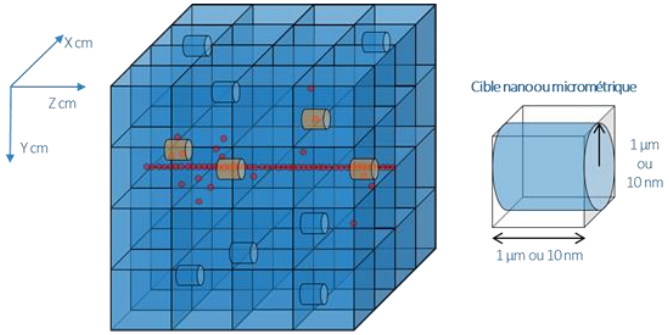
Dedicated Monte Carlo codes : Geant4-DNA, LPCHEM….

Simulation of particle interactions at very low scale

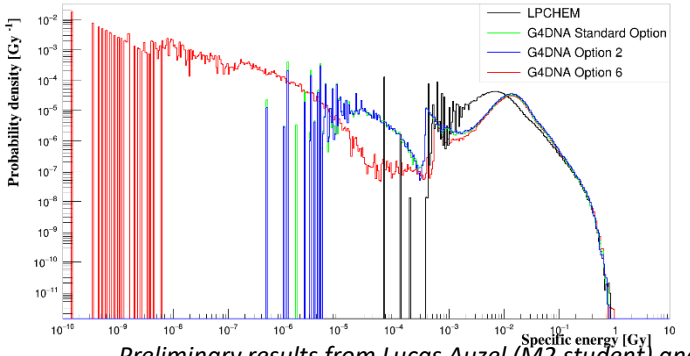
Collection of data in micro and nanometric targets

Plots of lineal and specific energy spectra for protons, electrons, carbon ions covering a large range of energies.

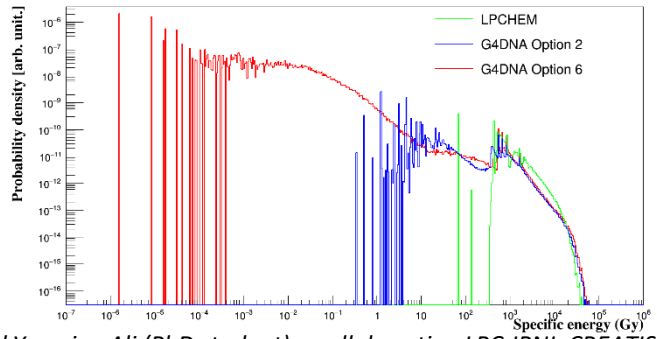
Comparison/validation in water



100 MeV protons, target: 10 nm



100 keV electrons, target: 10 nm



Preliminary results from Lucas Auzel (M2 student) and Yasmine Ali (PhD student) – collaboration LPC-IPNL-CREATIS

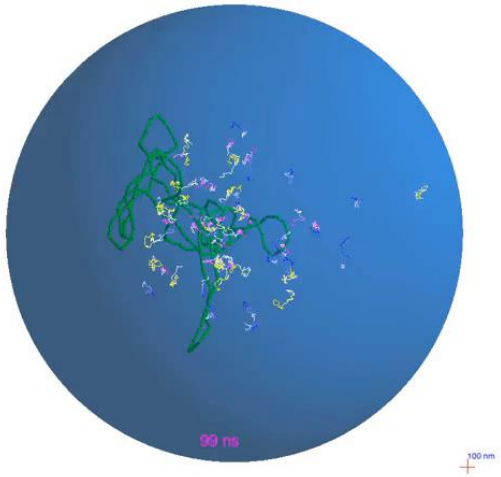
Physico-chemistry and chemistry processes for water radiolysis

Dedicated Monte Carlo codes : Geant4-DNA, LPCHEM….

Simulation of particles with molecules and then between molecules

Production of radiolytic yields

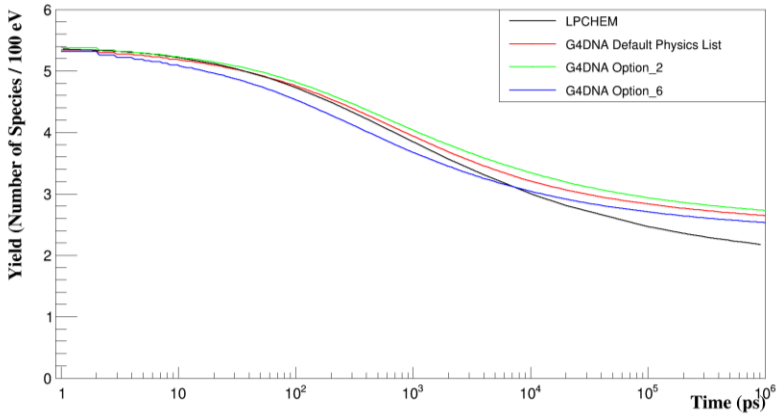
Comparison/validation



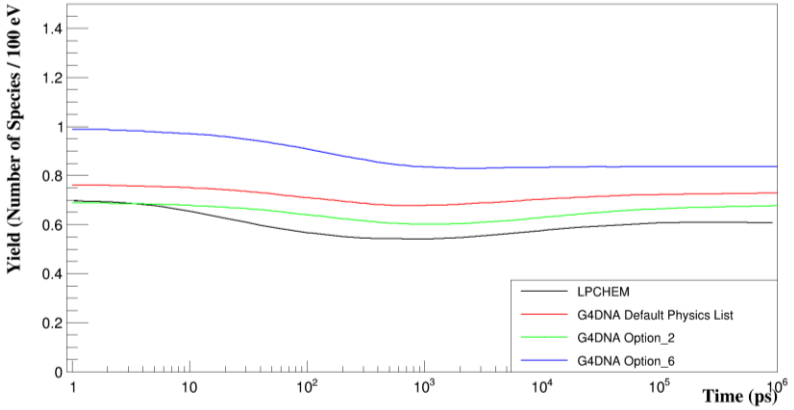
Irradiation of a pBR322 plasmid, including radiolysis
- movie courtesy of V. Stepan (NPI-ASCR/CENBG/CNRS/IN2P3/ESA)
-

Examples for 100 MeV protons

$^{\bullet}OH$



$H^{\bullet}$



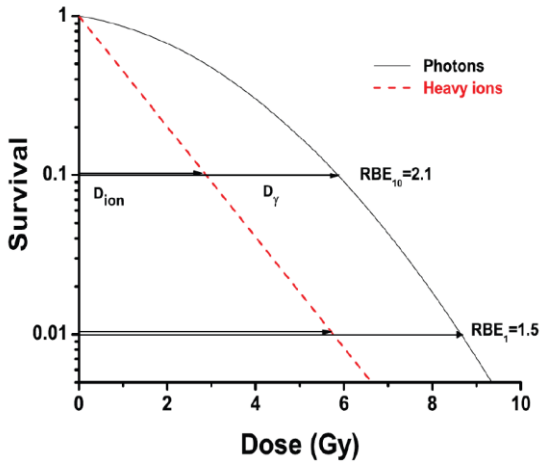
Preliminary results from Lucas Auzel (M2 student) and Yasmine Ali (PhD student) – collaboration LPC-IPNL-CREATIS

Biophysical models

Many models available

From very simplified to more elaborated

Some already used in the clinics (LEM, MKM)

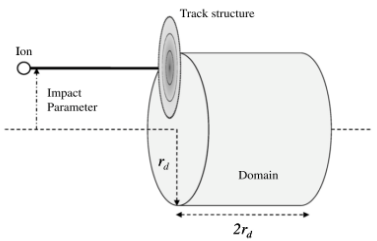


Microdosimetric Kinetic Model

Hawkins et al., Inaniwa et al.

$$S = e^{(-\langle L_n \rangle)}$$

$$\langle L_n \rangle = (\alpha_0 + \beta z_{1D}^*)D + \beta D^2$$



$\langle L_n \rangle$: Number of lethal lesions in the nucleus averaged over cellular population

R_n: radius of the cell nucleus
R_d: radius of the domain

Cell type	α_0(Gy^{-1})	β(Gy^{-2})	R_d(µm)	R_n(µm)
HSG	0.313	0.0615	0.34	4.1
V79	0.184	0.02	0.26	4.1
T1	0.0305	0.0585	0.35	3.5

Tables of z_{1D}^* are produced as a function of the kinetic energy per nucleon for each particle species (H, He, Li, Be, B,C).

NanOx: Nanodosimetry and Oxidative stress

Beuve et al.

$$\bar{S}\,(D) = \sum_{K=0}^{\infty} P(K,D) * \langle {}^{CK}S \rangle_{CK}$$

$${}^{CK}S = {}^{CK}S_{local} * {}^{CK}S_{non-local}$$

Local lethal events: physico-chemical events at local scale
Non-local events: Global events represneted by the production of radical species

How to scale?

The goal is NOT to include MCTS code into GATE BUT access to tabulated data pre-calculated by MCTS in reasonable computation time.

Collection of particle tracks entering each voxel of a 3D patient scan

Convolution of corresponding specific energies AND radiolytic yields (precalculated) as inputs of different biophysical models (NanOx, MKM…)

Optimize calculations to master computing time

Necessitate to work in partnership with biologists (survival parameters) and physico-chemists (experimental evaluation of radiolytic yields)

GATE on social networks

https://www.researchgate.net/project/GATE-Collaboration
Project page updated with the last advances in the fiels of imaging, therapy and computing efficiency
Papers available there

@GATE__MC
Twitts to follow GATE events/talks @ conferences

Coming soon
To be in touch with the user community

Coming soon
To build a network of research labs and companies to connect experts in medical physics using GATE

GATE events in 2019 & 2020

WORKSHOPS:

- October 31 @ **IEEE NSS-MIC conference** in Manchester, registration AVAILABLE
- AAPM 2020

TRAININGS:

- November 19-21 2019 (3 days with 3 teachers): **GATE training for beginners** in Clermont-Fd (France), registration **OPEN**
- March 10-12 2020 (3 days with 3 teachers): **Python data analysis for GATE simulations** in Clermont-Fd (France), programme and registration **OPEN**

TRAININGS FOR BEGINNERS IN ASIA : Japan – University of Tohoku, February 12 to 14 2020
South Korea, Seoul in Spring 2020

EVENTS:

January 22-24 2020 GATE technical meeting & SC meeting, Wuppertal (Germany)

Recent papers in SPECT imaging (2018+2019)

PUBMED search: GATE+Monte Carlo+SPECT

Voxel-Based Dosimetry of Iron Oxide Nanoparticle-Conjugated ^{177}Lu-Labeled Folic Acid Using **SPECT**/CT Imaging of Mice.
Gupta A, Shin JH, Lee MS, Park JY, Kim K, Kim JH, Suh M, Park CR, Kim YJ, Song MG, Jeong JM, Lee DS, Lee YS, Lee JS.
Mol Pharm. 2019 Apr 1;16(4):1498-1506. doi: 10.1021/acs.molpharmaceut.8b01125. Epub 2019 Mar 18.
A **Monte Carlo** Simulation Study of Optimization for Collimator in a Pixelated **SPECT** Camera.
Telikani Z, Sadremomtaz A.
J Med Imaging Radiat Sci. 2019 Mar;50(1):163-170. doi: 10.1016/j.jmir.2018.08.004. Epub 2018 Oct 5.
Performance analysis of a high-sensitivity multi-pinhole cardiac **SPECT** system with hemi-ellipsoid detectors.
Bhusal N, Dey J, Xu J, Kalluri K, Konik A, Mukherjee JM, Pretorius PH.
Med Phys. 2019 Jan;46(1):116-126. doi: 10.1002/mp.13277. Epub 2018 Nov 29.
Learning **SPECT** detector angular response function with neural network for accelerating **Monte-Carlo** simulations.
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PUBMED search: GATE+Monte Carlo+PET

Recent papers in PET imaging (2018+2019)

Scatter Correction based on GPU-accelerated Full **Monte Carlo** Simulation for Brain **PET**/MRI.
Ma B, Gaens M, Caldeira L, Bert J, Lohmann P, Tellmann L, Lerche C, Scheins J, Kops ER, Xu H, Lenz M, Pietrzyk U, Shah NJ.
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Preclinical voxel-based dosimetry through **GATE Monte Carlo** simulation using **PET**/CT imaging of mice.
Gupta A, Lee MS, Kim JH, Park S, Park HS, Kim SE, Lee DS, Lee JS.
Phys Med Biol. 2019 Apr 26;64(9):095007. doi: 10.1088/1361-6560/ab134b.

Implementation and validation of time-of-flight **PET** image reconstruction module for listmode and sinogram projection data in the STIR library.
Efthimiou N, Emond E, Wadhwa P, Cawthorne C, Tsoumpas C, Thielemans K.
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Developing a 'multiPatchPET' system in **GATE** for a **PET** system design with irregular geometries.
Chen G, Weng F, Hong X, Tao W, Zhao Z, Peng Q, Huang Q.
Phys Med Biol. 2018 Sep 6;63(17):17NT02. doi: 10.1088/1361-6560/aad8fd.

A **Monte Carlo** simulation study of the impact of novel scintillation crystals on performance characteristics of **PET** scanners.
Ghabrial A, Franklin D, Zaidi H.
Phys Med. 2018 Jun;50:37-45. doi: 10.1016/j.ejmp.2018.05.010. Epub 2018 May 26.

Systematic study on factors influencing the performance of interdetector scatter recovery in small-animal **PET**.
Lee S, Lee MS, Kim KY, Lee JS.
Med Phys. 2018 May 31. doi: 10.1002/mp.13020. [Epub ahead of print]

The origin and reduction of spurious extrahepatic counts observed in ^{90}Y non-TOF **PET** imaging post radioembolization.
Walrand S, Hesse M, Jamar F, Lhommel R.
Phys Med Biol. 2018 Mar 29;63(7):075016. doi: 10.1088/1361-6560/aab4e9.

PUBMED search: GATE+Monte Carlo+protons+carbon

Recent papers in particle therapy (2018+2019)

Characterization of EBT3 radiochromic films for dosimetry of **proton** beams in the presence of magnetic fields.
Padilla-Cabal F, Kuess P, Georg D, Palmans H, Fetty L, Fuchs H.
Med Phys. 2019 May 4. doi: 10.1002/mp.13567.

Evaluation of electromagnetic and nuclear scattering models in **GATE**/Geant4 for **proton** therapy.
Resch AF, Elia A, Fuchs H, Carlino A, Palmans H, Stock M, Georg D, Grevillot L.
Med Phys. 2019 May;46(5):2444-2456. doi: 10.1002/mp.13472. Epub 2019 Apr 15.

Monte Carlo simulation of the relative biological effectiveness and DNA damage from a 400 MeV/u **carbon** ion beam in water.
Ou H, Zhang B, Zhao S
Appl Radiat Isot. 2018 Jun;136:1-9. doi: 10.1016/j.apradiso.2018.01.038. Epub 2018 Jan 31.

Organ doses from a **proton** gantry-mounted cone-beam computed tomography system characterized with MCNP6 and **GATE**.
Ardenfors O, Henry T, Gudowska I, Poludniowski G, Dasu A.
Phys Med. 2018 Sep;53:56-61. doi: 10.1016/j.ejmp.2018.08.011. Epub 2018 Aug 16.

A beam model for focused **proton** pencil beams.
Almhagen E, Boersma DJ, Nyström H, Ahnesjö A.
Phys Med. 2018 Aug;52:27-32. doi: 10.1016/j.ejmp.2018.06.007. Epub 2018 Jun 18.

A pencil beam algorithm for magnetic resonance image-guided **proton** therapy.
Padilla-Cabal F, Georg D, Fuchs H.
Med Phys. 2018 May;45(5):2195-2204. doi: 10.1002/mp.12854. Epub 2018 Mar 30.

Dosimetric evaluation of a commercial **proton** spot scanning **Monte-Carlo** dose algorithm: comparisons against measurements and simulations.
Saini J, Maes D, Egan A, Bowen SR, St James S, Janson M, Wong T, Bloch C.
Phys Med Biol. 2017 Sep 12;62(19):7659-7681. doi: 10.1088/1361-6560/aa82a5.

Benchmarking **GATE**/Geant4 for ^{16}O ion beam therapy.
Resch AF, Fuchs H, Georg D.
Phys Med Biol. 2017 Sep 5;62(18):N474-N484. doi: 10.1088/1361-6560/aa807e.

Theoretical dosimetric evaluation of carbon and oxygen minibeam radiation therapy.
González W, Peucelle C, Prezado Y.
Med Phys. 2017 May;44(5):1921-1929. doi: 10.1002/mp.12175. Epub 2017 Mar 30.

Optimization of the mechanical collimation for minibeam generation in **proton** minibeam radiation therapy.
Guardiola C, Peucelle C, Prezado Y.
Med Phys. 2017 Apr;44(4):1470-1478. doi: 10.1002/mp.12131. Epub 2017 Mar 11.

Magnetic field effects on particle beams and their implications for dose calculation in MR-guided particle therapy.
Fuchs H, Moser P, Gröschl M, Georg D.
Med Phys. 2017 Mar;44(3):1149-1156. doi: 10.1002/mp.12105. Epub 2017 Feb 28.

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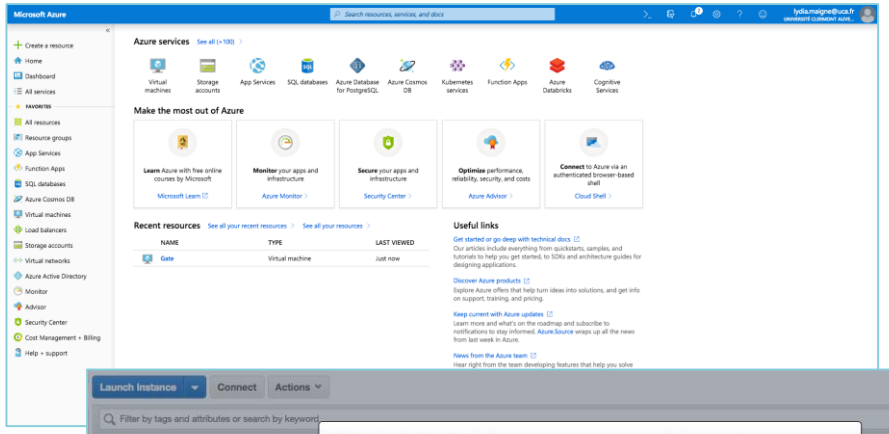
GATE on Microsoft Azure or Amazon Web services

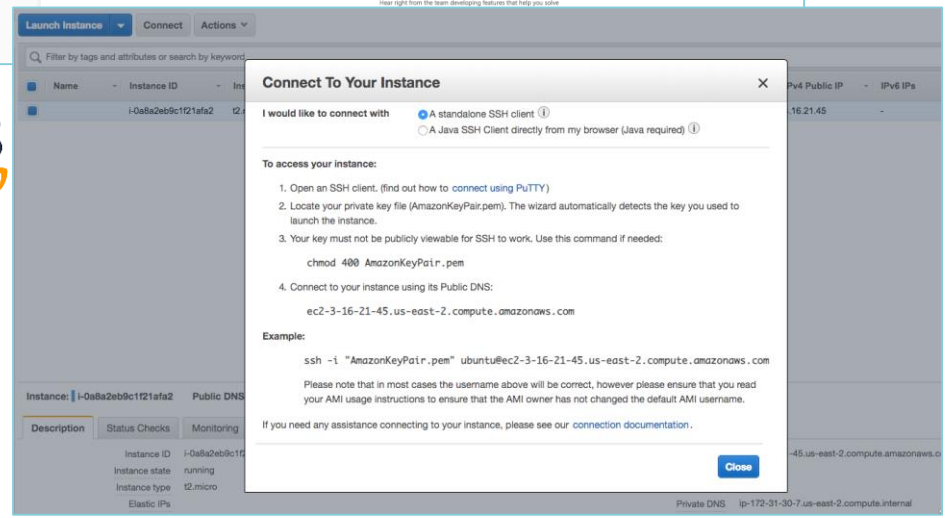
- A new Docker image is proposed following every release
  - https://hub.docker.com/r/opengatecollaboration/gate

- Compatible on every web services providers
  - Create an account on MS Azure or AWS
  - Configure your virtual machine
  - Install Docker
  - Install the GATE Docker image
  - Run your simulations

- Tutorial for installation available on our web site

- Contact the collaboration for any help



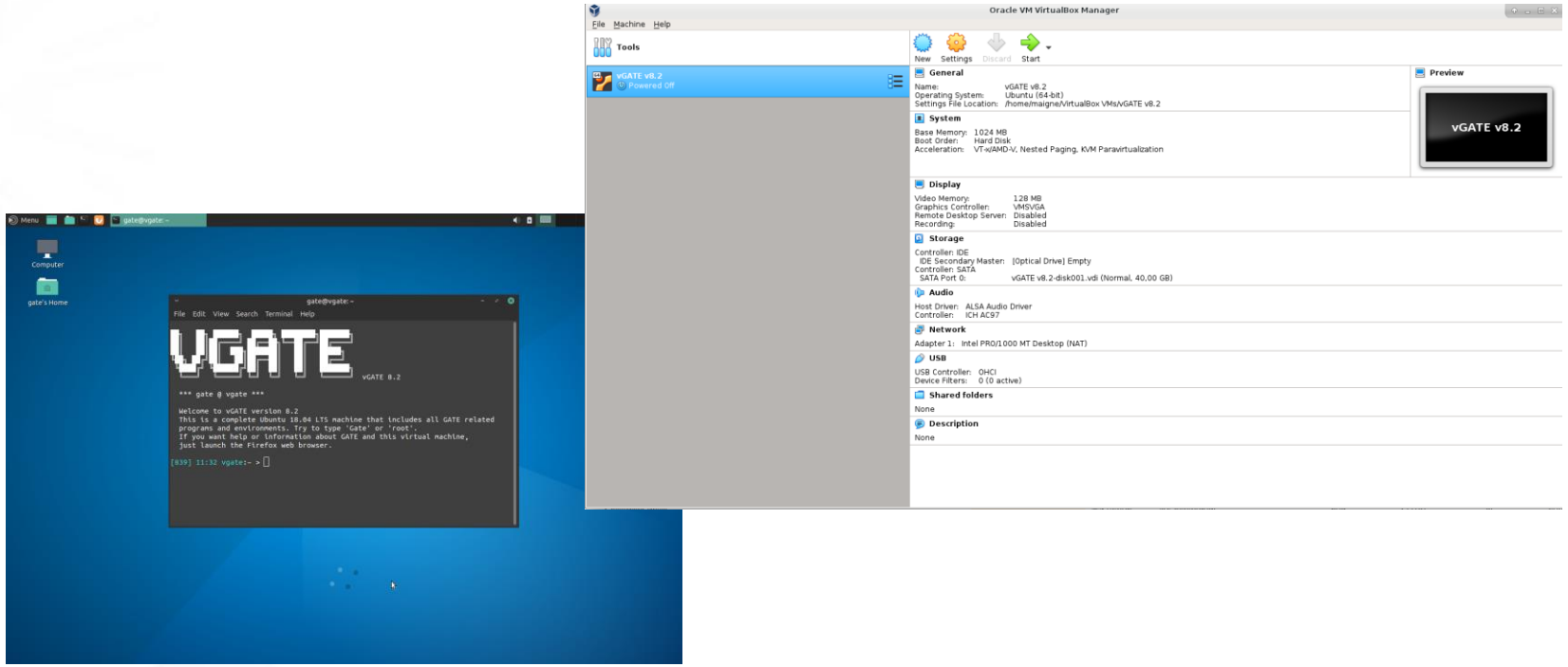


How to use GATE, different ways:

- For beginners: use the GATE virtual machine vGATE8.2
- For advanced users: Install GATE from scratch
  - Compilation instructions available on the Wiki
- When you need large computing resources
  - Install GATE on a cluster (Microsoft Azure, Amazon…) using the Docker framework

vGATE: the GATE virtual machine

- Install VirtualBox on your laptop https://www.virtualbox.org/
- Download and import vGATE on VirtualBox
- Adjust the appliance Import Settings depending on your computer and enable Hardware virtualization



- Login credentials (sudoer):
  - User: gate
  - Password: virtual

New web site coming soon

References

- Web site: http://www.opengatecollaboration.org

- GATE user mailing list: gate-users@lists.opengatecollaboration.org

- GATE documentation (wiki):

To install GATE: http://www.opengatecollaboration.org/InstallingGATE
To use GATE: http://www.opengatecollaboration.org/Documentation

- GitHub:

Through the issue tracker: https://github.com/OpenGATE/Gate/issues
Through the code: https://github.com/OpenGATE/Gate
Through the examples : https://github.com/OpenGATE/GateContrib

- GATE publications: http://www.opengatecollaboration.org/Publications

Thank you

GATE collaborators @ MCMA conference