The GATE platform

Lydia Maigne, Lydia.Maigne@clermont.in2p3.fr
On behalf of the OpenGATE collaboration

Start in 2002 with 2 laboratories: EPFL & LPC

The collaboration & Partners

25 members: laboratories, clinics, and companies developing an open source platform

Spokesperson: Lydia Maigne

Technical coordinator: David Sarrut + Technical board

Cross validation with the Geant4 collaboration

Susanna Guatelli & Sébastien Incerti

France

- **IJCLab - CNRS-IN2P3, Paris-Orsay**
- **LPC - CNRS-IN2P3, Clermont-Ferrand**
- **IPHC - CNRS-IN2P3, Strasbourg**
- **CPPM - CNRS-IN2P3, Marseille**
- **IP2I - CNRS-IN2P3, Lyon**
- **LPSC - CNRS-IN2P3, Grenoble**
- UMR5515 CNRS, CREATIS, Lyon
- BioMaps, CEA Paris-Saclay
- IRCM INSERM, Montpellier, France
- CRCT - U1037 INSERM, Toulouse
- U1101 INSERM, Brest

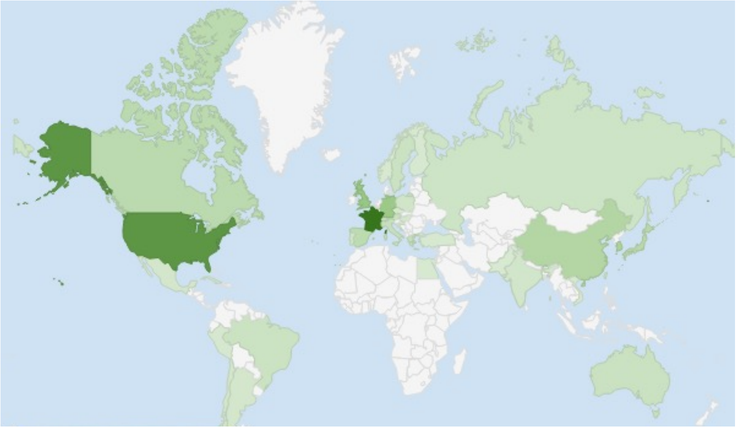
Europe

- University of Julich, Germany
- University of applied Sciences, Aachen, Germany
- Medisip, Ghent University, Belgium
- **Medical University of Vienna, Wiener Neustadt, Austria**
- **MedAustron, Wiener Neustadt, Austria**
- **Christie Medical Physics & Engineering, Manchester, UK**
- JPET collaboration, Jagiellonian University, Krakow, Poland
- Institute of Nuclear Physics Polish Academy of Sciences, Poland
- BioemTech, Athens, Greece
- Univ. of Patras, Dept of Med.Phys., Greece

Elsewhere

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

A large community of users



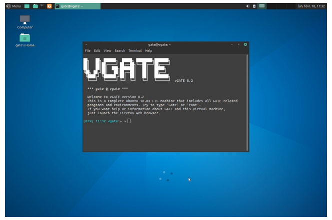
More than 2000 registered users

- Large communities in Europe and USA
- Increasing community: Canada, UK, Australia, China, Japan, South Korea

Open source and open access platform available on Github

The source code: https://github.com/OpenGATE/Gate
The examples: https://github.com/OpenGATE/GateContrib
The tools for analysis: https://github.com/OpenGATE/gatetools

GATE version 9.1
1 release/year

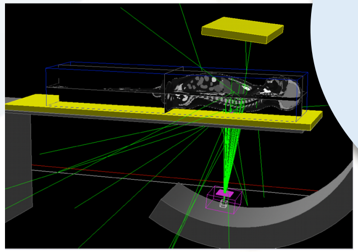


Trainings & Workshops

- 1 workshop / conference of interest: IEEE NSS-MIC, AAPM, MCMA, PTCOG, FRPT…
- Trainings for beginners: 1/year and @ companies
- Advanced trainings: 1/year (Python data analysis…)
- Dedicated trainings for master programs

RESEARCH TOPICS

DOSIMETRY



Interventional radiology
Multimodal nanoparticles
Innovative internal RT (177Lu…)
CT scanner dosimetry
Arctherapy
SBRT – Interplay effect & EPID
Database of S-values (OpenDose)
GATE/G4DNA micro & nanodosimetry

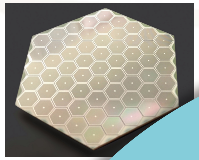
COMPUTING

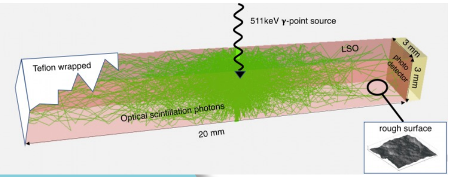
Neural Networks for:
Positioning of γ interactions in monolithic PET detectors
SPECT detector ARF
GAN for compact beam source modeling

HYBRID SIMULATIONS

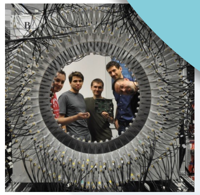
PYTHON data analysis

IMAGING

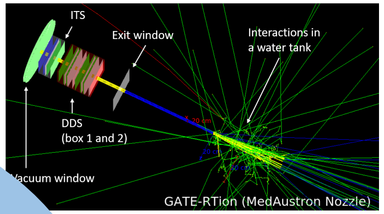




Models to define crystal surfaces
Optical simulation study on timing performance of monolithic crystals
Testing of new camera and crystal designs
New digitizers for SiPM (analogue and digital)
Compton camera
Proton radiography
Non-circular orbit motion in SPECT
JPET (plastic scintillator-based PET)
Metabolic modeling
Digital Photon Counting commercial PET



HADRONTHERAPY



G4 Physics settings
On-line MR-guidance for particle therapy
Neutron dosimetry
Prediction of RBE -> G4DNA
Carbon ion dosimetry
Range monitoring
BNCT & PBCT
FLASH therapy

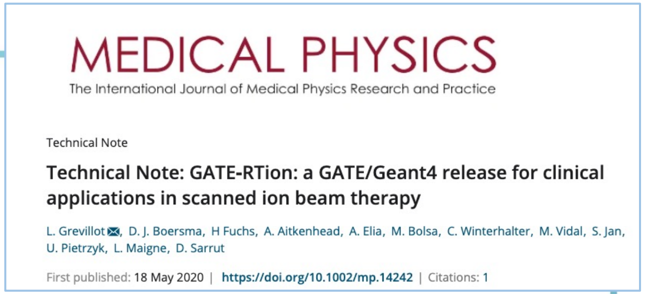
GATE-RTion

- **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

- **« Frozen » version of GATE and common tools for analysis**

- **3 clinical partners involved**
  - **The Centre Antoine Lacassagne** (Nice, France): IBA PT (Louvain-la-Neuve, Belgium) Synchro-Cyclotron (S2C2) machine with proton energy range 70-230 MeV
  - **The Christie NHS Foundation Trust** (Manchester, UK) has a Varian (Palo Alto, California, US) ProBeam (Cyclotron) machine with proton energy range 70-245 MeV
  - **MedAustron** (Wiener Neustadt, Austria) has a 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
  - RayStation 6.0 TPS,
  - GATE-RT-ion
  - Lynx 2D scintillator (IBA)
  - Results compared with MyQA software (IBA) for comparisons
  - γ-index analysis (2%, 2mm) between GATE-RTion simulations and TPS, more than 95% of the pixels passed the test.

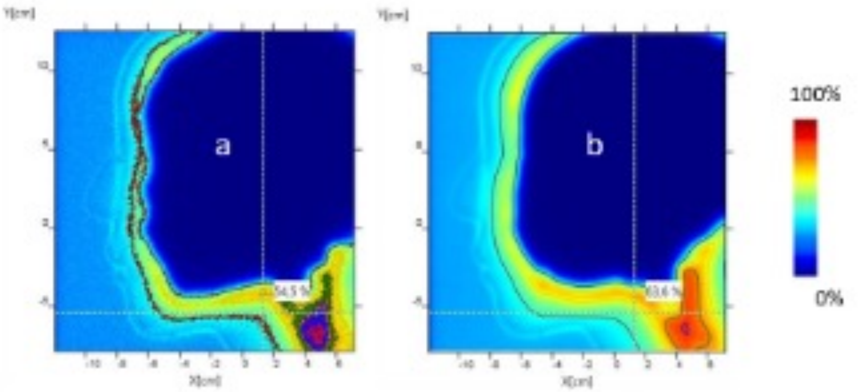
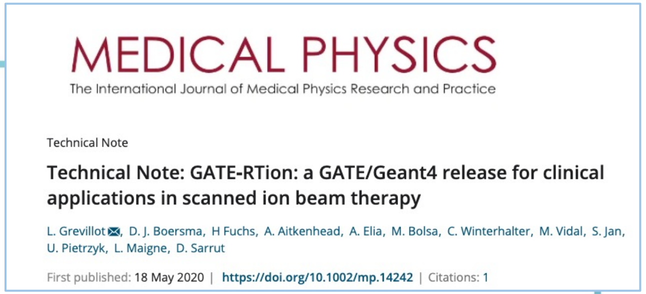


Figure 1: Relative comparison of a GATE dose simulation (a) and a 2D Lynx measurement (b) acquired at the same downstream position for an anthropomorphic phantom. An arbitrary dose scale is used between 100% (red) and 0% (dark blue) - same for both relative dose distributions.

GATE-RTion – Project Paper (2)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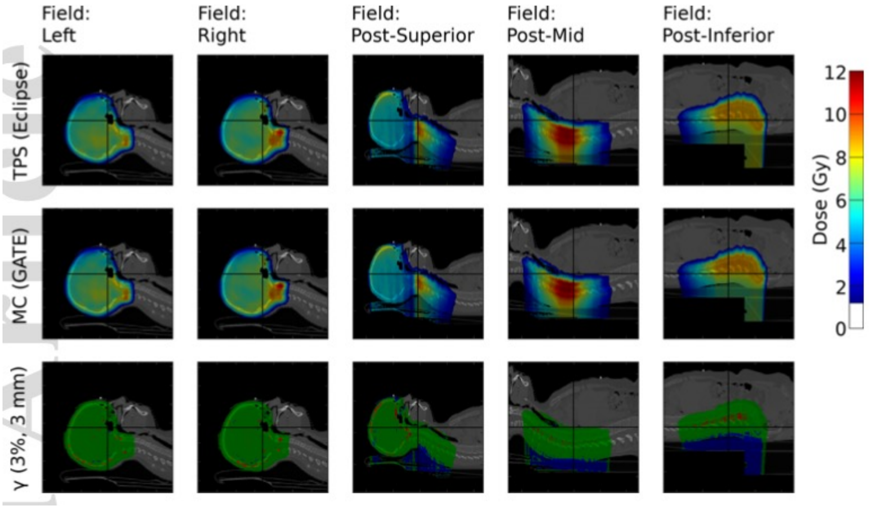
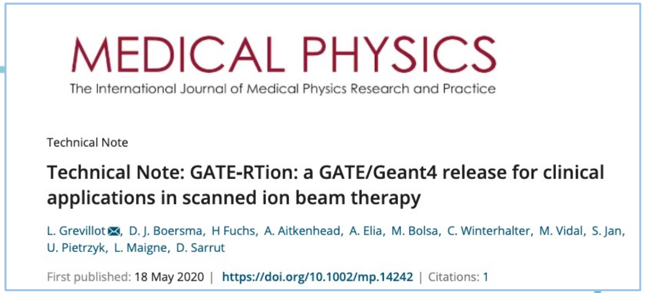
- **Independent Dose Calculation of proton beam therapy plans at The Christie**
- Treatment planning for proton pencil beam scanning
  - Varian Eclipse TPS, proton- convolution-superposition analytical dose calculation algorithm
  - GATE-Rtion (**AUTOMC,** Aitkenhead, Br J Radiol 2020)
- 23.4 Gy in 13 fractions, delivered using 5 fields: a pair of left/right fields to the brain, and 3 fields to the spine

- a 3D gamma analysis at 3%, 3mm, the percentage of voxels in the patient having γ ≤ 1 was between 92.4% and 95.8% for all fields, and the GATE-RTion simulation was between 1.6% and 2.4% hotter than the TPS in terms of the median dose to the patient.



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 for delivery on a Varian ProBeam system.
Top row: TPS;
Middle row: GATE- RTion;
Bottom row:Gamma 3%(local),3mm using a 10% lower dose threshold. Voxels in green have γ≤1,while voxels in (red/blue) have γ > 1 and are (hotter/colder) than the TPS respectively.

GATE-RTion – Project Paper (3)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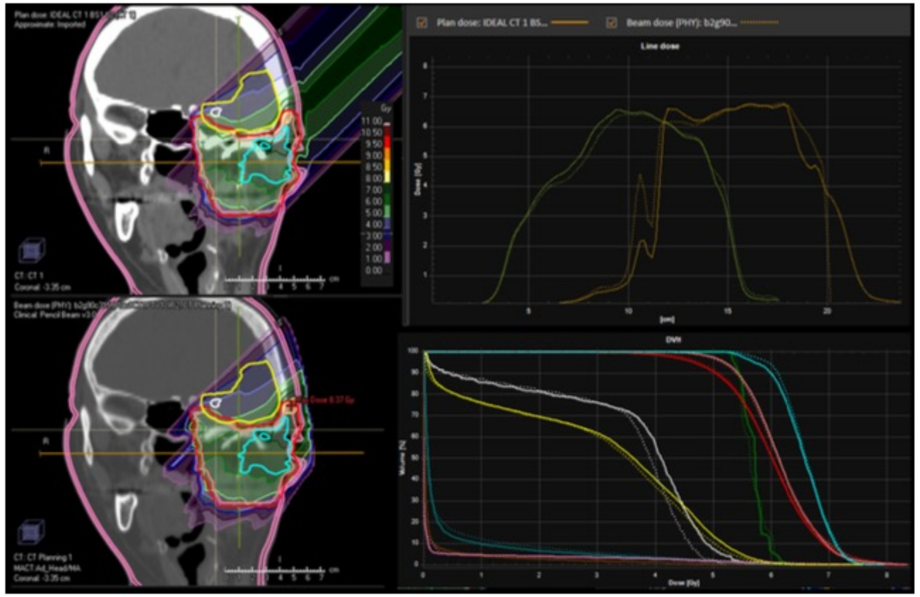
- **Independent Dose Calculation with Scanned Ion Beams at MedAustron**
- Treatment planning for carbon pencil beam scanning
  - RayStation version 8B from RaySearch Laboratories (Stockholm, Sweden) with MC 4.2
  - GATE-RTion **(IDEAL: Independent DosE cAlculation for Light ion beam therapy)**
  - 3D-block/24 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) in terms of Dose Volume Histogram (DVH, bottom right) and dose profiles (top right).

For DVH and dose profiles, solid lines correspond to IDEAL/GATE- RTion and dotted lines to the TPS. The positions of the two orthogonal dose profiles in the patient are visible in the patient images on the left side (orange and green lines).

GATE-RTion – Validation paper for PBS

- **Comparisons of physics lists in proton PBS treatments**
  - QGSP_BIC, QGSP_BIC_EMY, QGSP_BIC_EMZ, QGSP_BIC_HP_EMZ
  - Cuts varying form 0.1 to 1 mm
  - Maximum step size: 0.1 mm, 1 mm, none
- **Recommendations**
  - Patient specific quality assurance measurements:
    - No step limiter on proton tracks; production cuts of 1 mm for electrons, photons and positrons (in the phantom and range-shifter) and 10 mm (world); best agreement to measurement data was found for QGSP_BIC_EMZ
  - Considering the patient CT model,
    - No step limiter on proton tracks; production cuts of 1 mm for electrons, photons and positrons (phantom/range-shifter) and 10 mm (world) if the goal is to achieve sufficient dosimetric accuracy to ensure that a plan is clinically safe; or 0.1 mm (phant om/range-shifter) and 1 mm (world) if higher dosimetric accuracy is needed (increasing execution times by a factor of 2); most accurate results expected for QGSP_BIC_EMZ

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

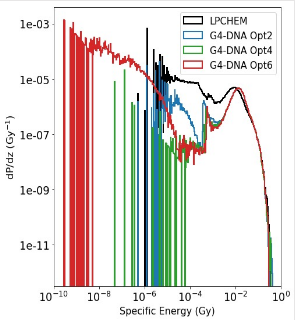
Carla Winterhalter, Michael Taylor, David Boersma, Alessio Elia, Susanna Guatelli, Ranald Mackay, Karen Kirkby, Lydia Maigne, Vladimir Ivanchenko, Andreas F. Resch ... See all authors

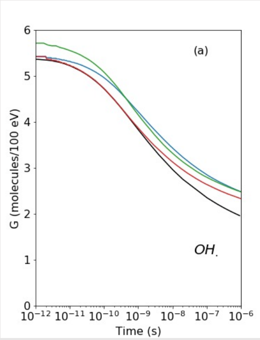
First published: 23 September 2020 | https://doi.org/10.1002/mp.14481

Evaluation of the biological dose in hadrontherapy

BIOPHYSICS MODELS

PRE CALCULATED DATA WITH TRACK SCTRUCTURE MC CODES





Evaluation of alpha and beta parameters for mono-energetic ion beams using data such as specific energy and water radiolysis

mMKM and NanOx models

CLINICAL BEAM MODELING

HIMAC BEAM LINE GEOMETRY IN GATE

BIODOSE ACTOR

The biodose actor uses the biophysics models predictions to calculate the biological quantities for an SOBP in a voxelized target

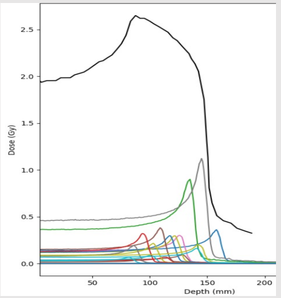
RBE

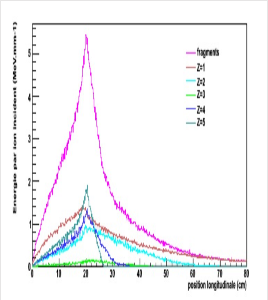
BIOLOGICAL DOSE

SURVIVAL FRACTION

SOBP

IRRADIATION FIELD WITH PRIMARY IONS AND NUCLEAR FRAGMENTS OF DIFFERENT LET

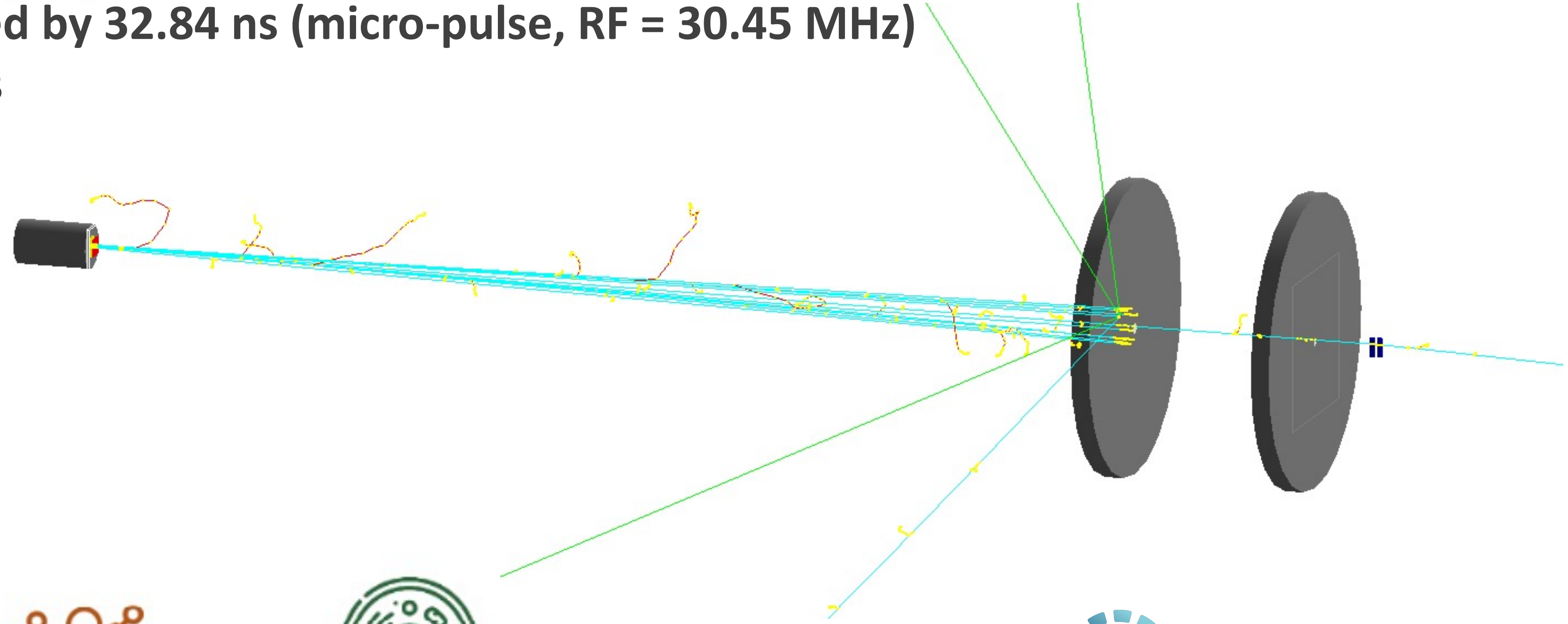




The physical dose deposition is simulated for the clinical beam line as an SOBP using PBS or passive modulation

Preclinical proton FLASH irradiation at ARRONAX

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



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

Conclusion

- GATE is being used and validated over different applications:
  - G4 Physics settings
  - Neutron dosimetry
  - Carbon ion dosimetry
  - Range monitoring
  - Prompt gamma ray imaging
  - BNCT & PBCT
  - FLASH therapy
  - RBE evaluation

  (BNCT & PBCT, FLASH therapy, RBE evaluation:) Multi-scale simulations using Geant4-DNA

- GATE has to be validated over other irradiation beams (CNAO) and with other MC codes (FLUKA)