Benchmarking micro- and nanodosimetry spectra and free radicals simulated with GEANT4DNA and LPCHEM for ion beams

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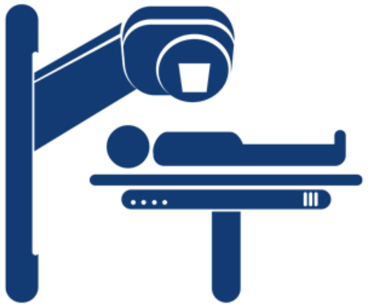
Context

Biophysics models for treatment optimizations

For hadrontherapy applications,
biological dose prediction will enhance treatments optimization.



Why using an approximative RBE value for ions isn't relevant?

What would be the tools for an accurate RBE estimation?

In which ways our work contribute to this purpose?

Biophysics Models

The biophysics models requires several types of data to lead to the relative biological effectiveness

Microkinetic model

Cell survival fraction

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

Number of damages in the nucleus

$$\langle L_n \rangle = (\alpha + \beta z)D + \beta D^2$$

Inaniwa T. et al. (2010)

NanOx

Cell survival fraction

$$S = S_{local\ events} \cdot S_{non\ local\ events}$$

LOCAL EVENTS

Effective lethal function

$$F(z) = -N \ln(1 - f(z))$$

NON LOCAL EVENTS

Oxidative stress

$$F(Y) = e^{(-\langle \alpha Y + \beta Y^2 \rangle)}$$

C. Monini et al. (2017)

Biological data

α, β : constants of the linear and quadratic components of cell killing

Physical data

z: specific energy deposited in a target

N : targets distributed in sensitive volume

Chemical data

Y : yield of OH· the sensitive volume

Models implementations

Our methodology

To estimate the biological effectiveness, Monte Carlo simulations go hand in hand with biological, physical, chemical data.

EXPERIMENT

Biological data

The survival fraction constants α and β are extracted from the cell survival fraction estimations.

GEANT4 LPCHEM

Data tables

Biological, physical and chemical data are stored under data tables.

GEANT4-DNA

Physical data

The dose mean specific energy distribution, the restrictive specific energy are simulated for micrometric and nanometric targets.

Chemical data

The radiochemical species yields are simulated and calculated.

GATE 8.2

Data tables

Biological, physical and chemical data.

Biophysics Models

The models use the data tables data to then estimate the RBE.

Biological dose

Gate models the 3D biological dose distribution

Physical dose

Gate models the 3D physical dose distribution

Physical data simulation

LPCHEM and G4DNA

We use simular simulation parameters for both LPCHEM and GEANT4DNA, however a few differences can be noted between the codes.

	Physics Models	Simulated interactions		**Stored interactions**	**Energies**	
		Electrons	Protons		Electrons	Protons
LPCHEM 1.11	CDW-EIS calculations	Ionizations Electronic excitation Vibrational excitation Attachment	Ionization Excitation	80% of deposited energy, events relevant for the biological effect of radiation	10 keV to 100 keV	10 MeV to 250 MeV
G4DNA 10.5	G4DNA_Option0 G4DNA_Option 2 G4DNA_Option 6	Ionizations Electronic excitation Vibrational excitation Attachment	Ionization Excitation	100% of deposited energy	10 keV to 100 keV	10 MeV to 100 MeV

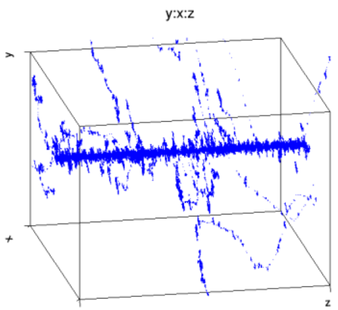
TED

Transfered Energy Deposition

A code to calculate specific and lineal energy distributions in micrometric and nanometric targets

ENERGY TRANSFERT POINTS

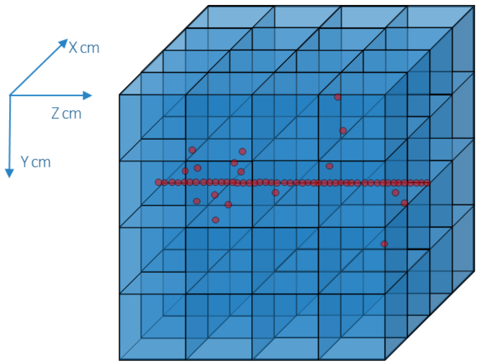
From LPCHEM or G4DNA



The LPCHEM and G4DNA physical modules simulate the energy transfer points.

THE MESH AND 3D MATRIX

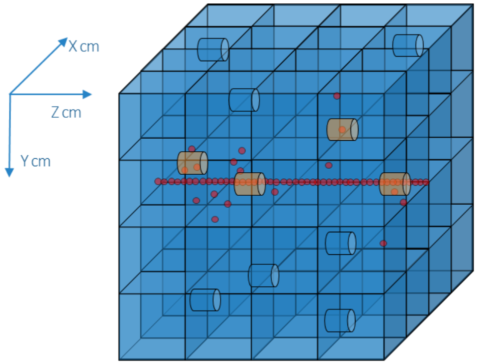
Calculation time saving biased method



TED uses the same track volume. The track volume is devided into voxels.

THE TARGETS

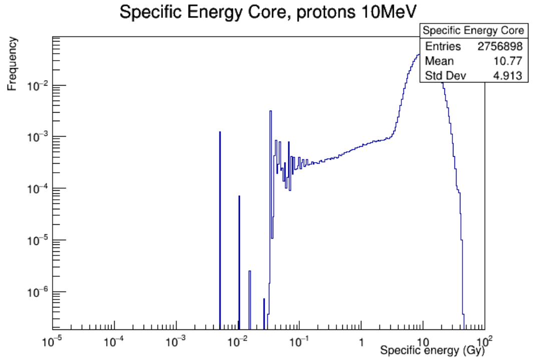
1µm micrometric and 10nm nanometric targets



Targets are generated in the voxels containing energy transfert points.

PROBABILITY DISTRIBUTIONS

Specific energy



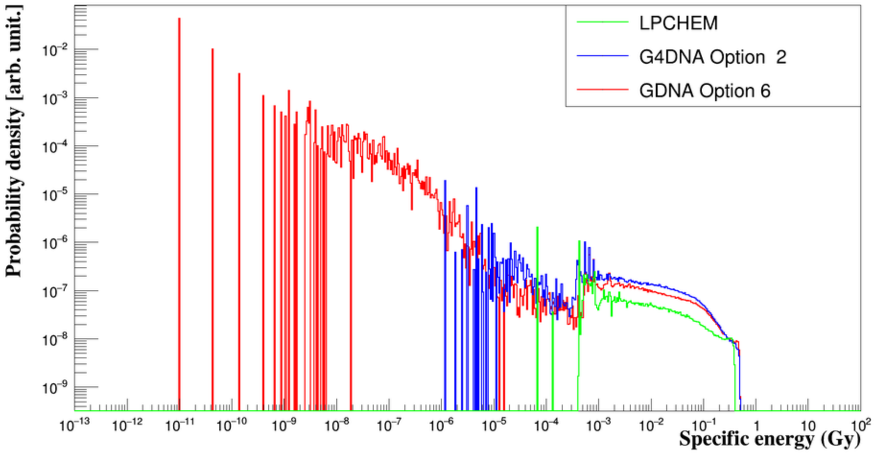
The probability distributions of specific energy are calculated.

Specific energy probability distribution

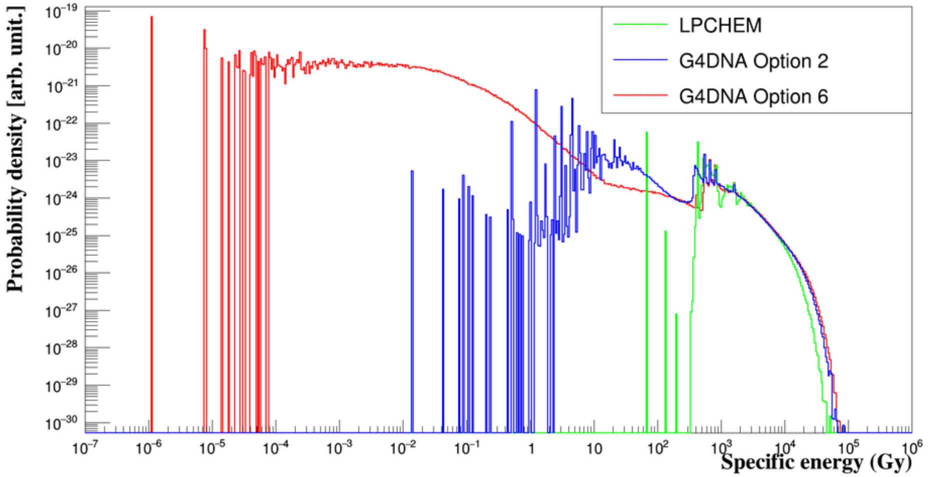
for 1µm micrometric and 10nm nanometric targets

Electrons 10 keV

Micrometric

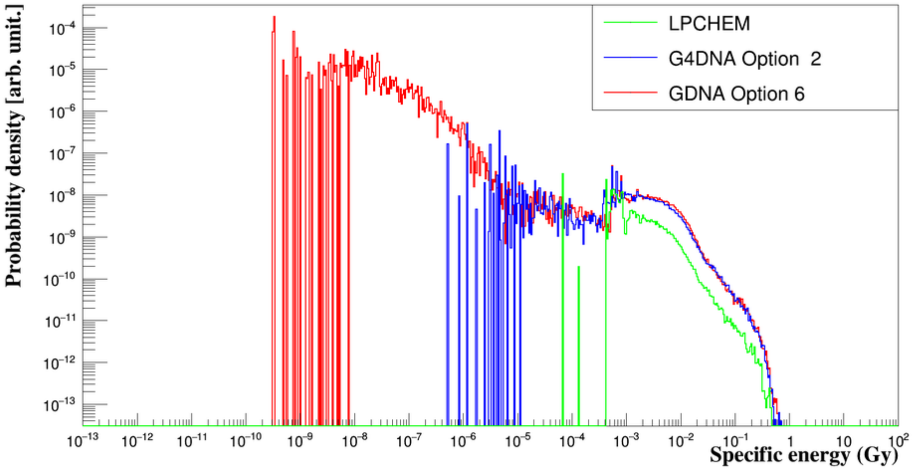


Nanometric

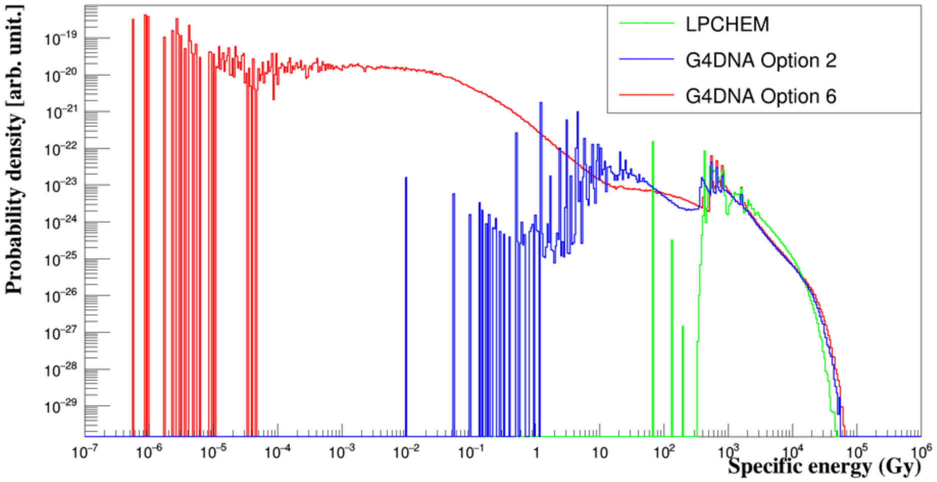


Electrons 100 keV

Micrometric



Nanometric

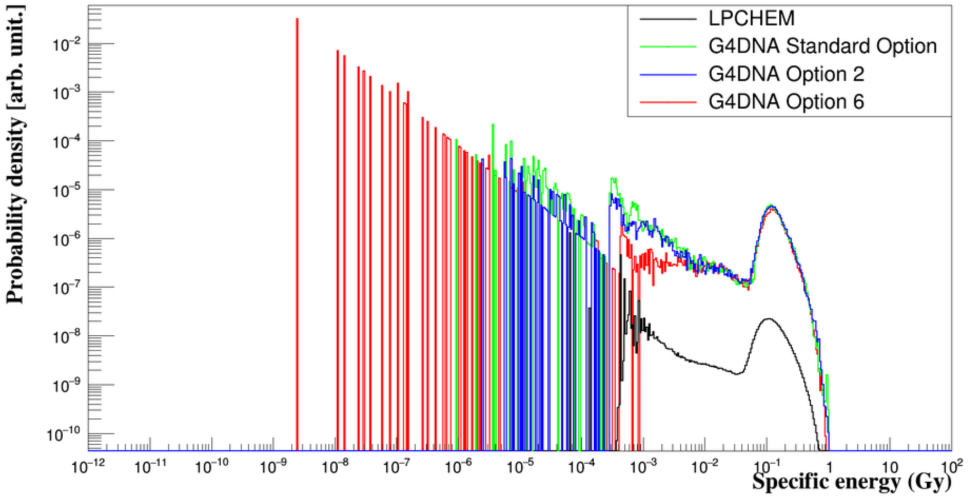


Specific energy probability distribution

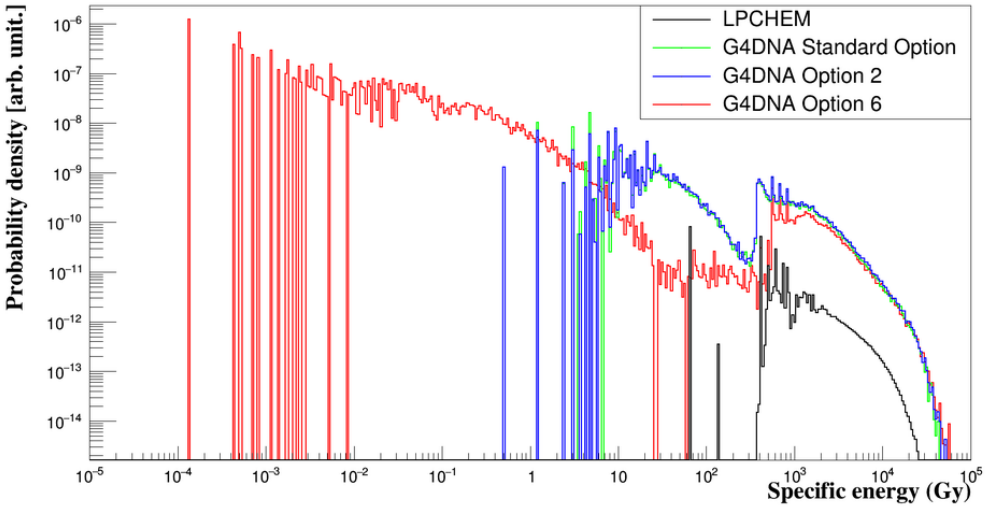
for 1µm micrometric and 10nm nanometric targets

Protons 10 MeV

Micrometric

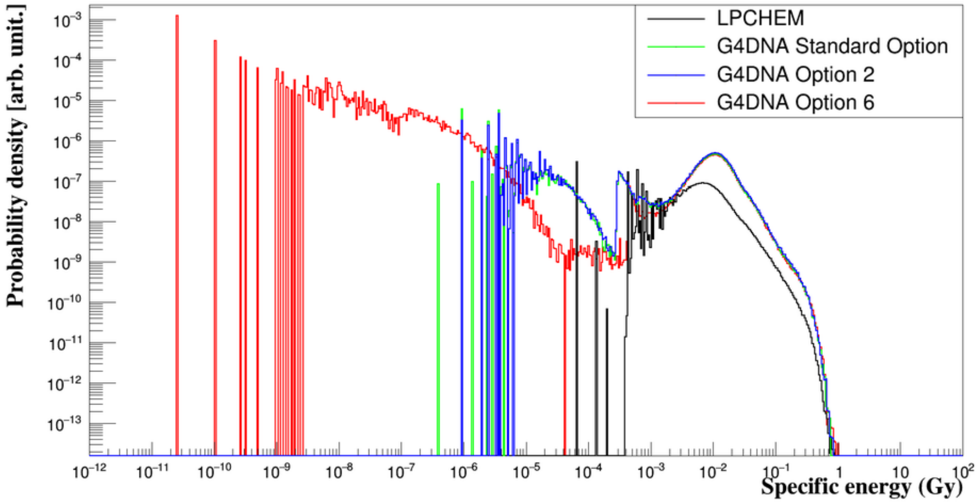


Nanometric

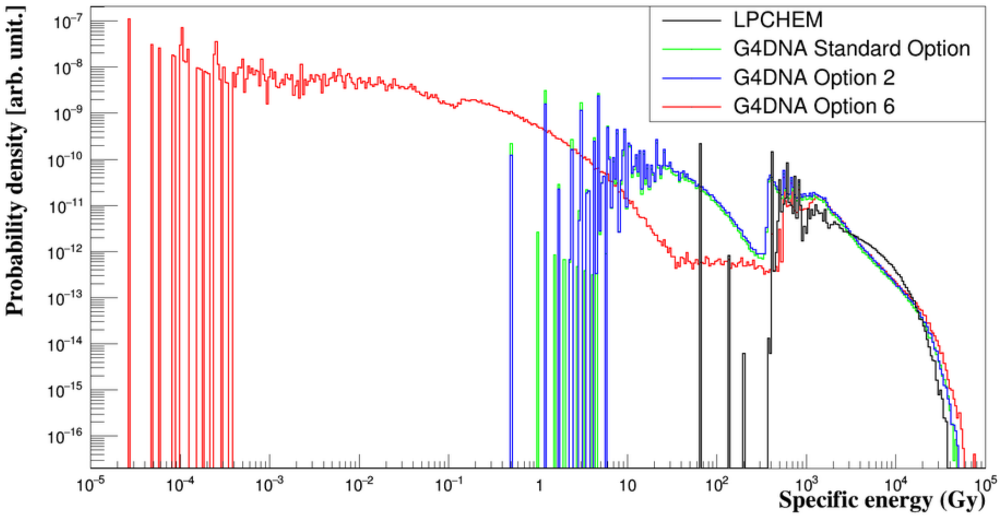


Protons 100 MeV

Micrometric



Nanometric



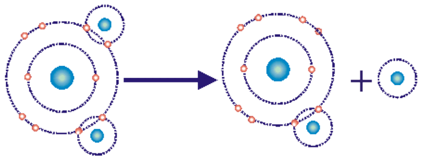
LPCHEM AND G4DNA

Radiochemical products simulation

To estimate the type, the quantity of free radicals with the chemistry modules

RADIOCHEMICAL PRODUCTS

By LPCHEM and G4DNA



In the physicochemical stage of LPCHEM and G4DNA chemistry modules, the radiochemical products are generated.

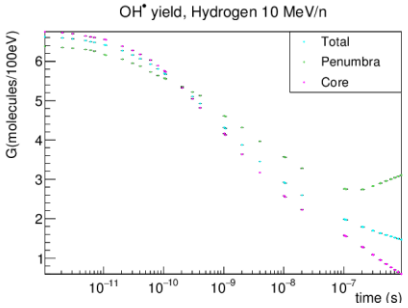
INTERACTIONS AND DIFFUSION

Radiochemical products

In the chemical stage, the radiochemical products interactions and their diffusion are simulated.

RADIOCHEMICAL YIELDS

OH Yield

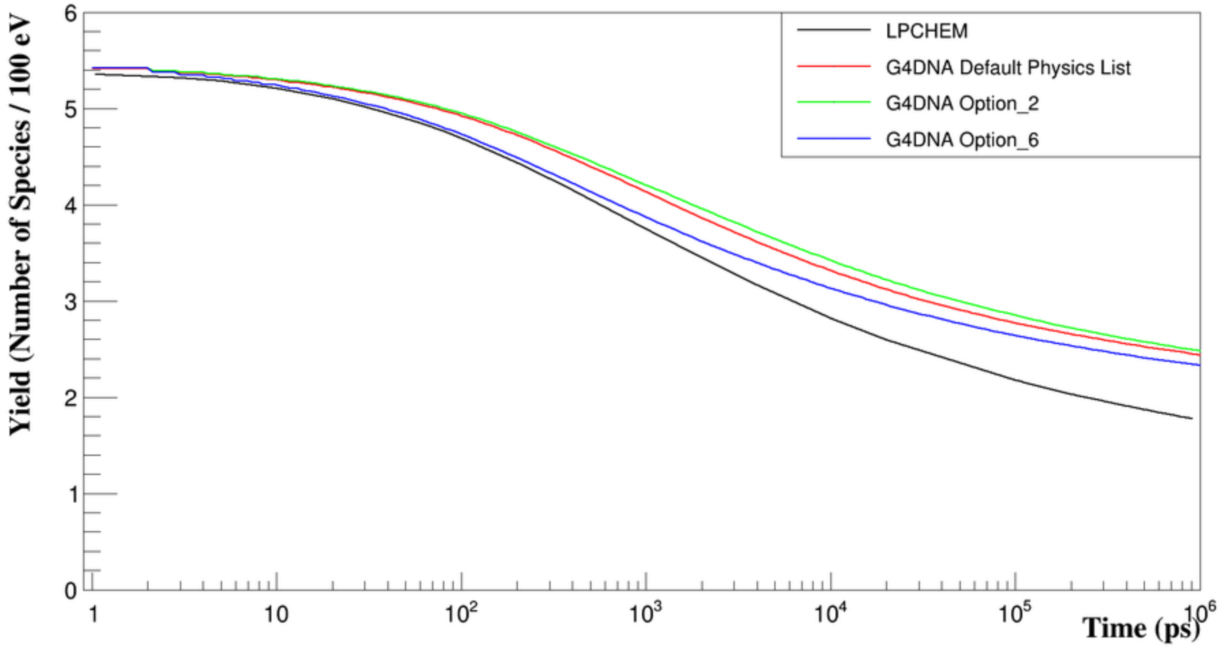


The average yield of OH molecules between 10^{-12} and 10^{-06} second for a 100eV deposited energy is estimated.

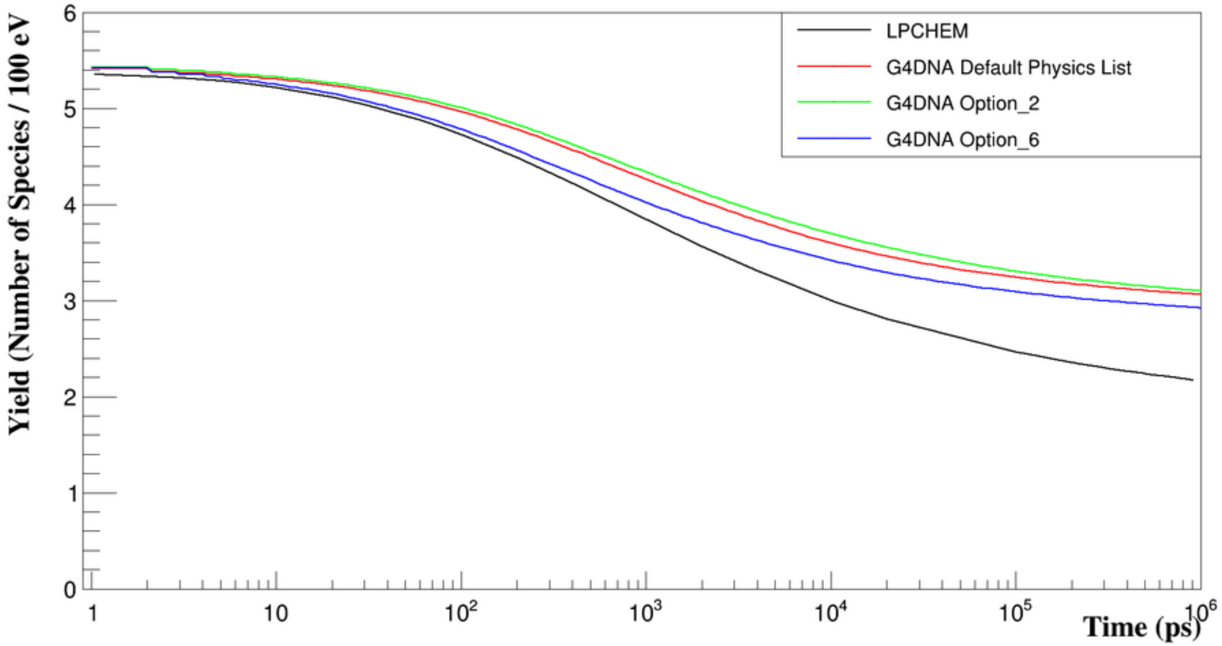
Hydroxyl radical yield

OH radical products yield for a 100 eV deposited energy

Protons 10 MeV



Protons 100 MeV

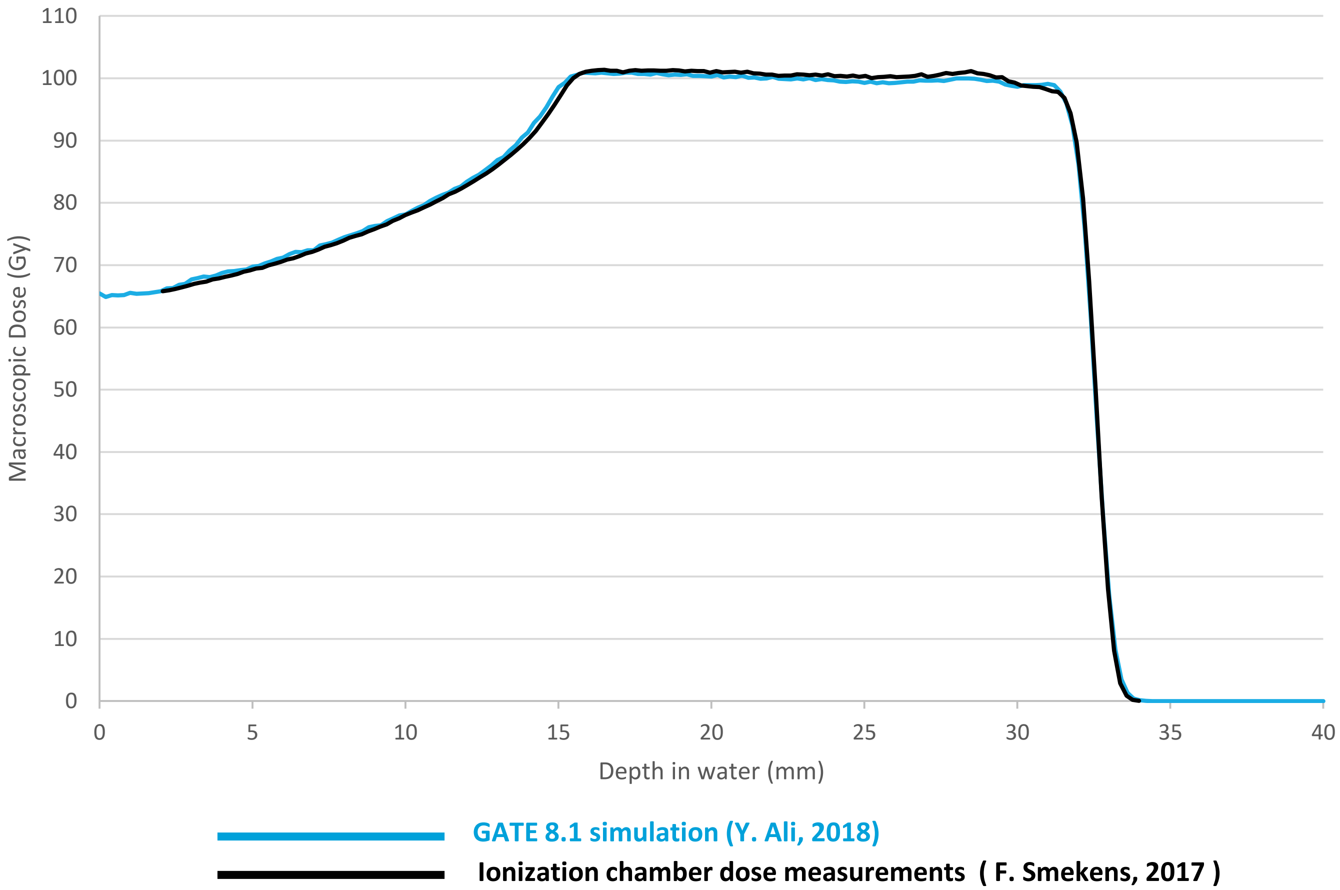


Spreak out bragg peak

Our methodology

Physical and chemical data have been simulated for monoenergetic beams, the next step will be to perform the same work for a clinical beam SOBP.

Spread out bragg peak for 65 MeV protons.



GATE ACTOR

The actor collects, for each voxel :

- the particles atomic number
- the deposited energy for each particle
- the proportion of each type of particles

DATA TABLES

We use data tables of biological, physical and chemical data calculated for monoenergetic beams, summed, to obtain the equivalent data for a SOBP.

Collaborations

We would like to thank

LPC – Particules pLasmas Univers applicationS – Laboratoire de Physique de Clermont

GATE & GEANT4

iPNL

NanOx, LQD, PHYCHEML

Antoine Lacassagne – CENTRE DE LUTTE CONTRE LE CANCER DE NICE

Protons beam

GEANT4DNA
GATE

CENBG

GEANT4DNA

MedAustron

Carbon ions beam

LIDYL

Experimental Radiolysis products

fondazione CNAO

Carbon ions beam

THANK YOU.