Monte Carlo simulations of charged particle beams for radiobiology experiments at IFIN-HH

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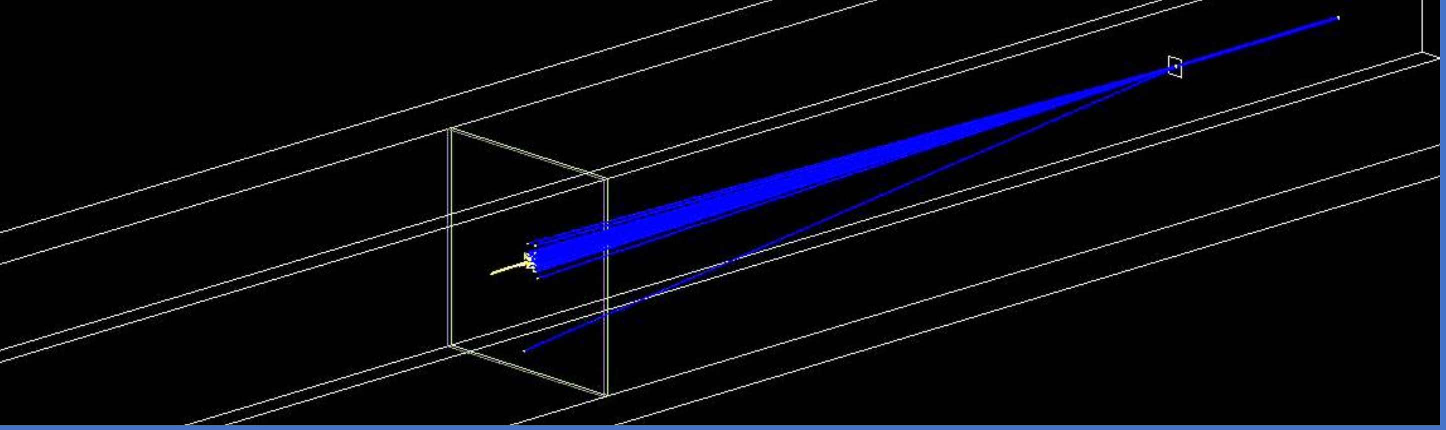
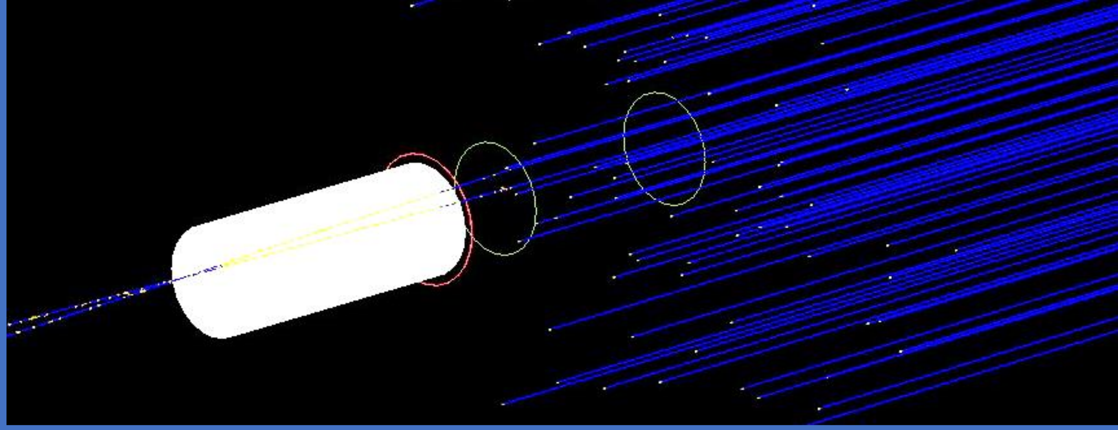
Charged particle accelerated beam-based cancer therapy is an accurate radiotherapy technique, very effective in delivering the desired (or expected) doses to target volumes. The improved local control of the beam allows a more efficient sparing of the healthy tissue.

The 3 MV (*I. Burducea et al.*, *2015*) Tandetron and TR19 cyclotron facilities at IFIN-HH have been adapted to be used for charged particle irradiation of biological samples in in vitro radiobiology studies.

To optimize the irradiation protocols, we employed a Monte Carlo object-oriented particle tracking strategy, implemented with the Geant4 simulation toolkit (*Geant4 Collaboration*, *2017*).





3 MV Tandetron^{TM} simulation parameters

Two envelope volumes representing – vacuum tube and air section

Vacuum tube

- **Particle source**

  Geant4 General Particle Source disc-shaped circular plane proton/alpha source

  Mono energetic channel energy of 3 MeV for protons (8.5 MeV for alpha)

  Energy spread of 5 keV for protons (15 keV for alpha)
- **Thin gold/aluminum foil** *used to scatter the protons along the beam propagation axis.*

Thick graphite *collimator with a 6 mm in diameter circular window*

1 µm thick Si_3N_4 window

Material compositions and physical parameters were obtained from the NIST material database. The **physical processes** inside the volumes were described using the **electromagnetic option 4** physics lists constructor with default parameters. It is classified as the most accurate model for standard and low-energy simulations (*V. Beaudoux et al., 2019; Y. Wang et al., 2019*).

Air section

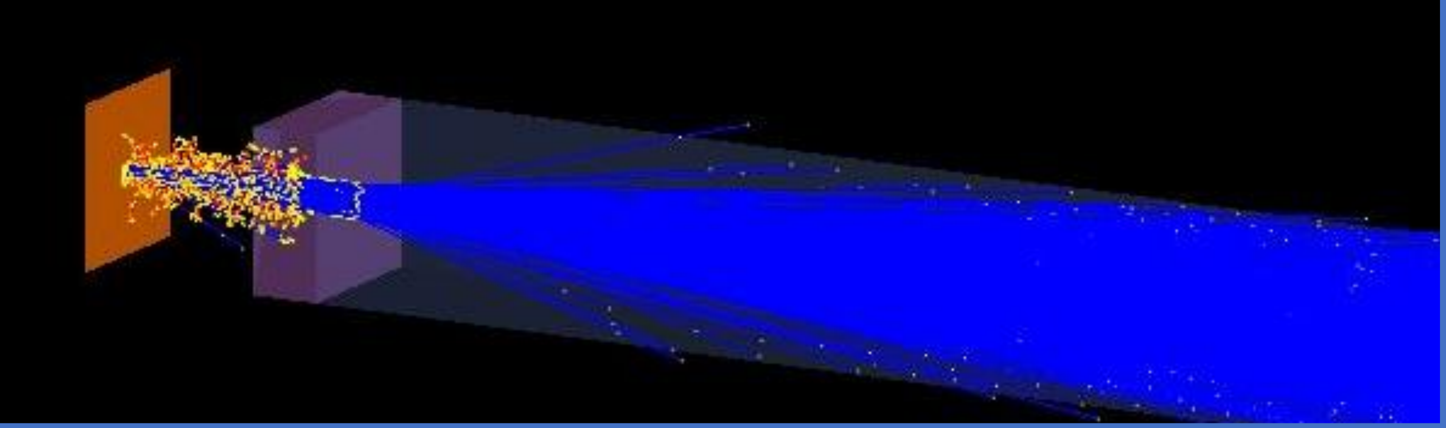
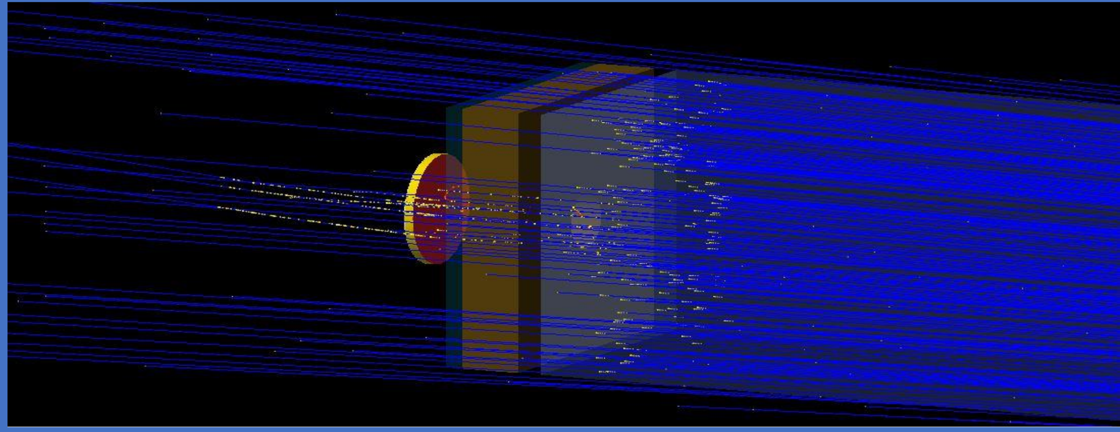
- **Mylar layer**

  6 µm thickness and 7 mm diameter as support for cell culture
- **1 µm thick water scoring volume**

  Diameter of 6 mm.

  LET in replicas of volume, generated horizontally along the beam line up to 100 times.

  Depth resolution of 1 µm for the Bragg peak.

TR19 cyclotron simulation parameters

Three envelope volumes representing – 2 air sections and a vacuum tube

First air section

- **Particle source**
  Geant4 General Particle Source [2] disc-shaped circular plane proton/alpha source
  Mono energetic channel energy of 18 MeV (protons)
  Energy spread of 200 keV

- **Thin wolfram foil** *used to scatter the protons along the beam propagation axis.*

Vacuum tube *of 1,3 m*

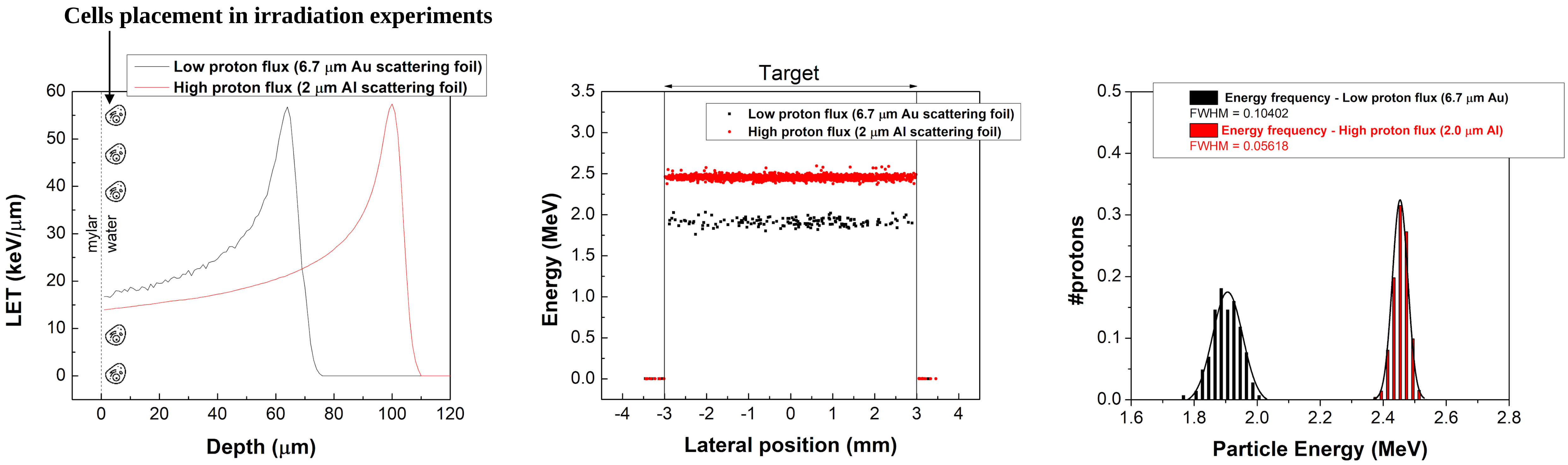
- **Starts with**
  ***Aluminum** foil (0.04 mm) and collimator (5 mm)*
- **Ends with**
  ***Aluminum** collimator (30 mm) and foil (0.04 mm)*

Material compositions and physical parameters were obtained from the NIST material database. The **physical processes** inside the volumes were described using the **electromagnetic option 4** physics lists constructor with default parameters. It is classified as the most accurate model for standard and low-energy simulations (*V. Beaudoux et al., 2019; Y. Wang et al., 2019*).

Second air section

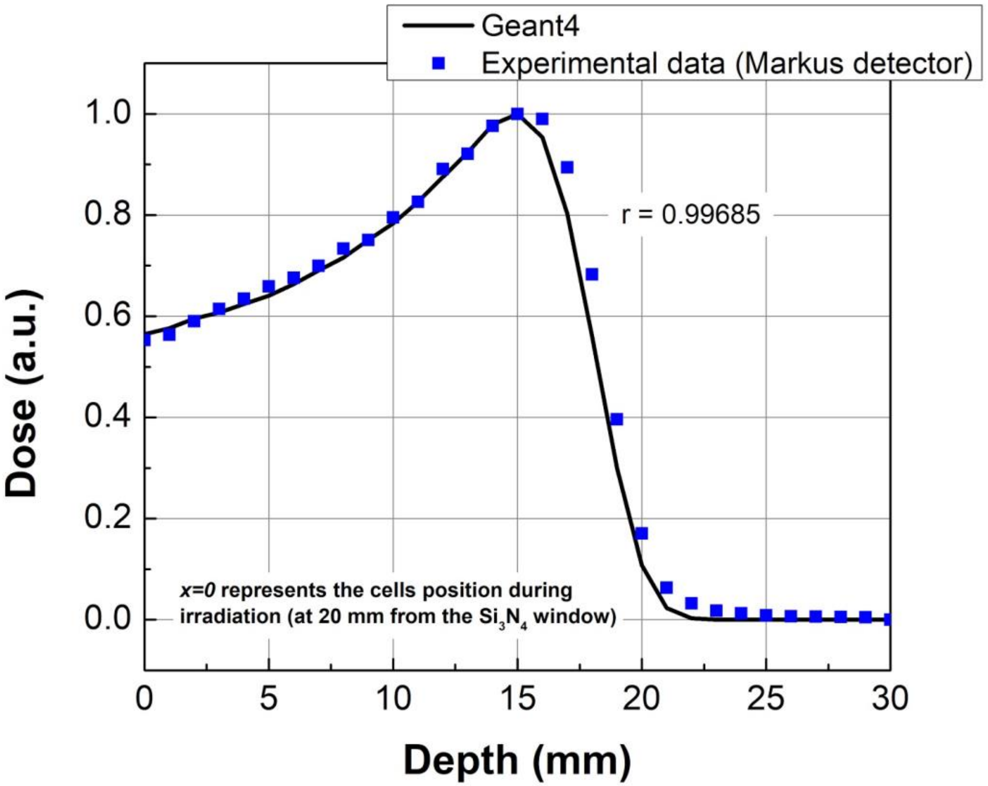
- **PMMA+aluminum** *collimators (21 mm)*
- ***Mylar foil** of 0.018 mm applied over the bottom of the culture well (polystyrene; 1.5 mm thick)*
- **1 µm thick water scoring volume**
  Diameter of 21 mm.
  LET in replicas of volume, generated horizontally along the beam line up to 100 times.
  Depth resolution of 1 µm for the Bragg peak.

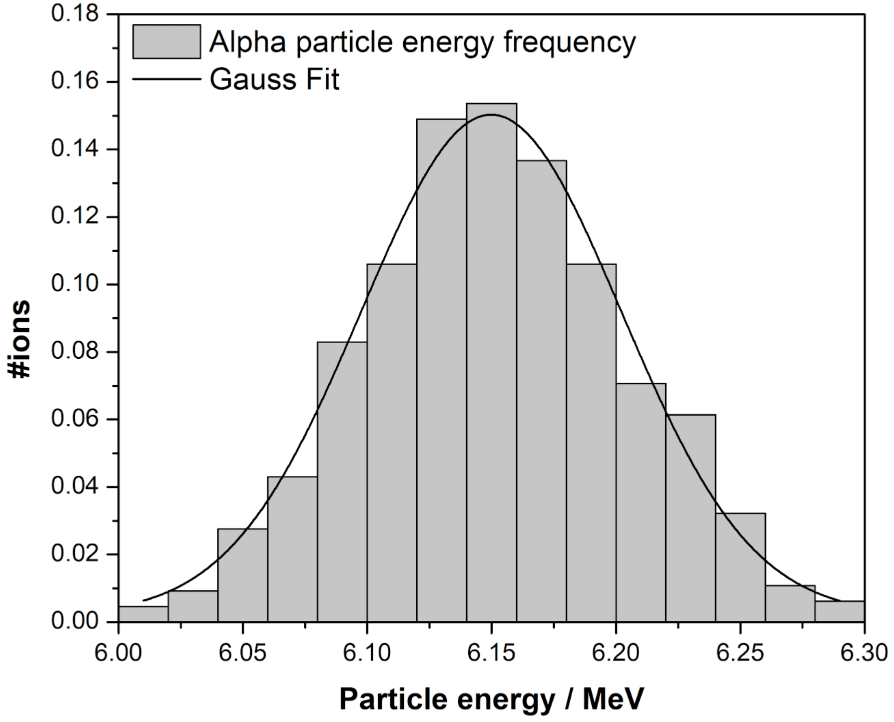
Simulation of high and low flux proton irradiation at 3 MV Tandetron™ facility



GEANT4 simulation of Bragg peaks in water, simulated energy profiles along the diameter at the air target interface and energy distributions of the high and low flux proton beams at the mylar-water interface. (mean energy = 1.9 MeV – low flux, 2.45 MeV – high flux, FWHM = 104.02 keV – low flux, 56.18 keV – high flux)

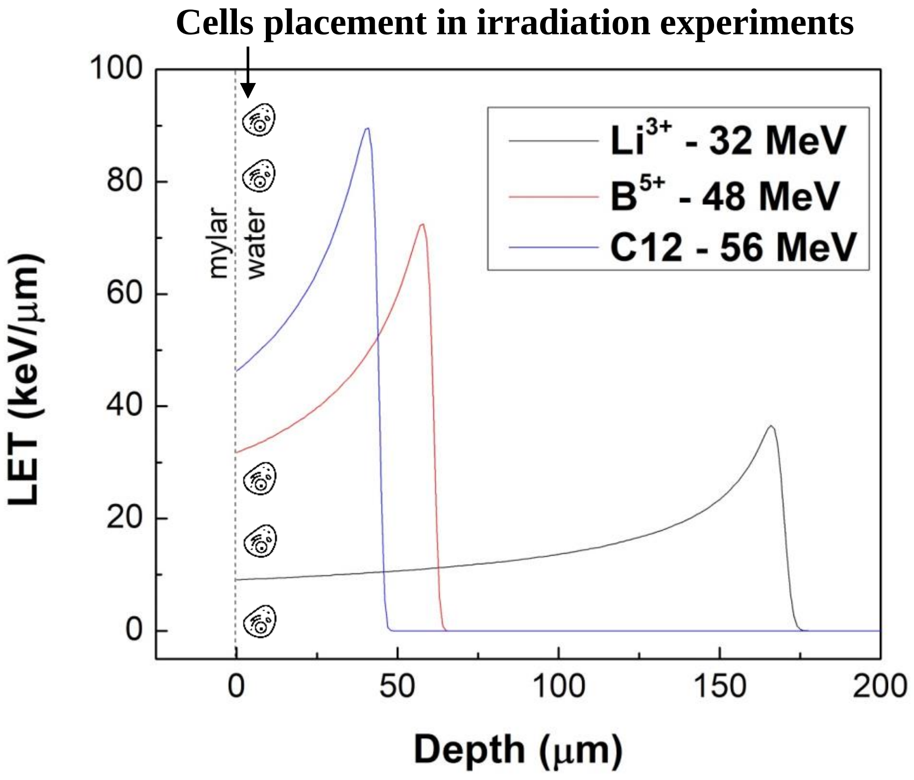
Simulation of alpha particle beam irradiation at 3 MV Tandetron^{TM} facility

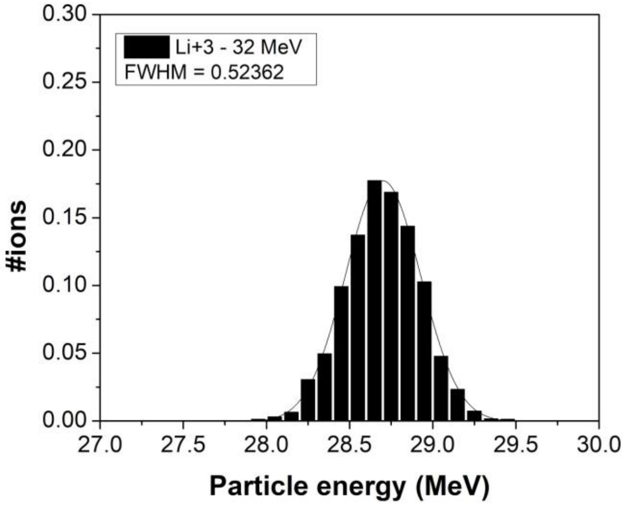


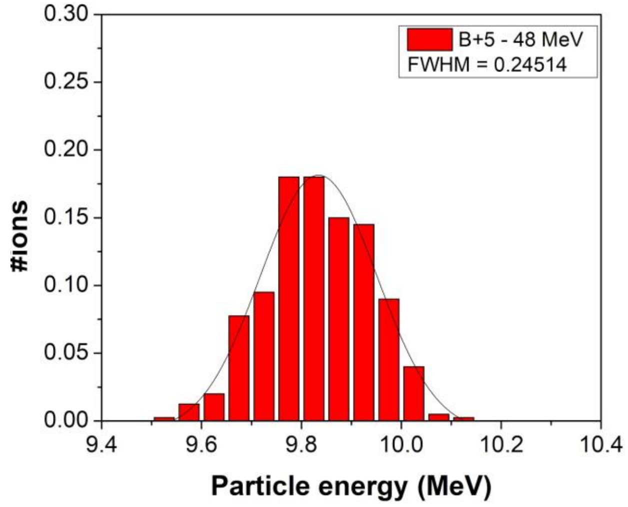


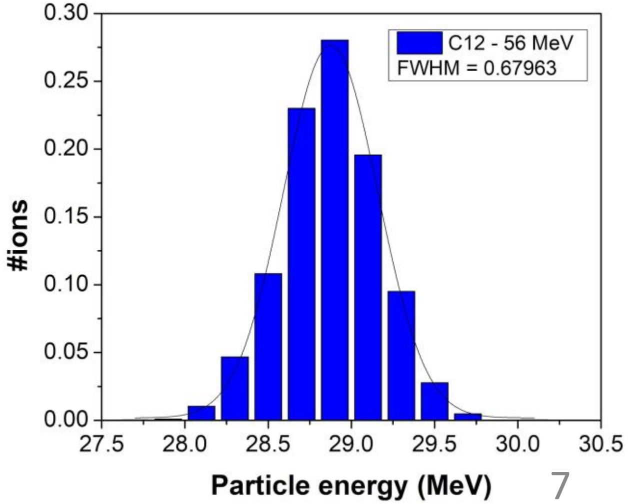
GEANT4 simulation of alpha particles Bragg peak in water against experimental data acquired using the Markus detector and the energy distribution of the alpha particles beam at the mylar-water interface (mean energy = 6.15 MeV, FWHM = 123 keV)

Simulation of other heavy ion beams irradiation at 9 MV Tandem facility of IFIN-HH



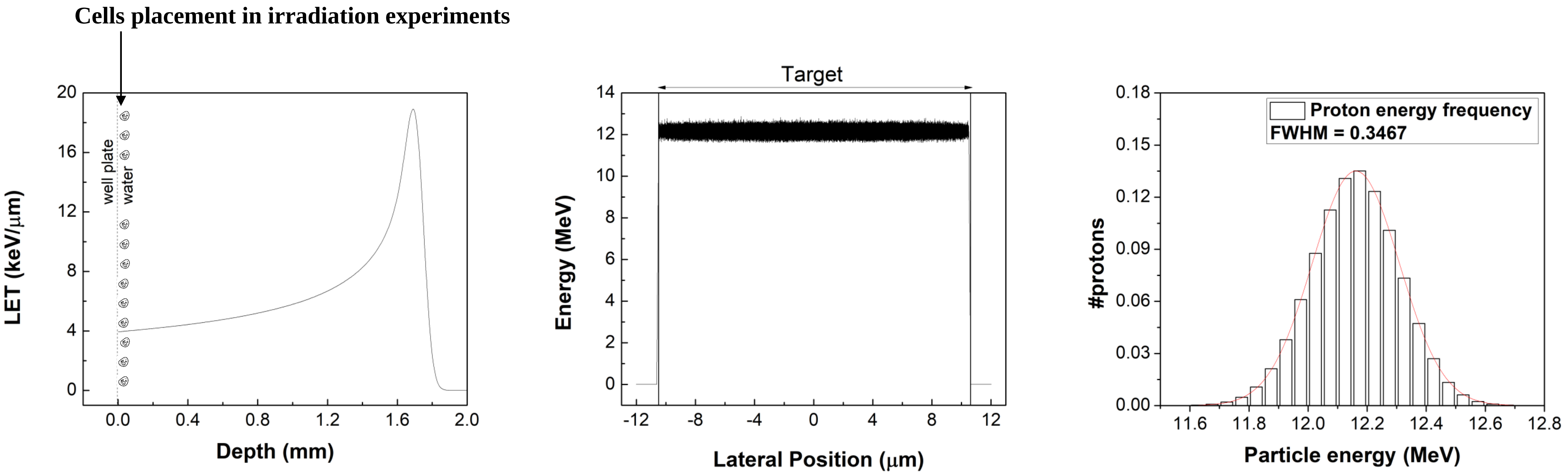






GEANT4 simulation of heavy ion beams Bragg peaks in water and the energy distributions at the mylar-water interface (mean energy = 28.75 MeV – Li+3, 9.8 MeV – B+5, 28.9 MeV – C12, FWHM = 523.62 keV – Li+3, 245.14 – B+5, 679.63 – C12)

Simulation of proton beam irradiation at TR19 cyclotron facility



GEANT4 simulation of the Bragg peak in water, simulated energy profile along the diameter at the air target interface and energy distributions of proton beams at the plate-water interface. (mean energy = 12.2 MeV, FWHM = 346.7 keV)

Conclusions

Geant4 simulations proved to be useful in validating the feasibility of heavy ions irradiation experiments from 3 MV / 9MV Tandem accelerators and TR19 cyclotron facility of IFIN-HH. The model provides a high-fidelity representation of the geometry, source parameters and physical processes, as well as flexible dose and energy estimations.