IL NUOVO CIMENTO **41 C** (2018) 211
DOI 10.1393/ncc/i2018-18211-8

Colloquia: SIRR 2018

Preliminary test of Bragg application for proton therapy using the Geant4 toolkit

Filomena Loffredo(1)(2)(*) and Mariagabriella Pugliese(1)(2)

(1) *Dipartimento di Fisica "E. Pancini", Università di Napoli Federico II - Naples, Italy*
(2) *Istituto Nazionale di Fisica Nucleare, Sezione di Napoli - Naples, Italy*

received 4 December 2018

Summary. — In the treatment of tumors, the advantage of proton therapy is the sparing of dose to healthy tissue surrounding the target one, saving it from unnecessary damage. For protons, the dose increases with increasing penetration depth up to the Bragg peak that occurs near the end of the particle's range. This work shows the first results obtained with a specific application, Bragg, which has been developed with the use of the Geant4 package. This application aims to contribute to develop and test innovative treatment planning models for particle therapy. The results from the numerical simulation have been compared with the experimental data in the literature. The validation of models against experimental data is a prerequisite for the use of any application and, therefore, highly demanded.

1. – Introduction

The major clinical advantage of proton therapy compared to traditional radiotherapy concerns the absorbed dose distribution within the tissue, as a function of depth. The main purpose is to kill tumor cells. Another important aspect is the sparing of surrounding healthy tissue. This aspect is crucial if vital organs or tissues are directly adjacent to the tumor. Among the used hadrons employed for radiotherapy purposes, *i.e.*, neutrons, protons and light ions (such as helium, carbon, oxygen and neon), protons show similar low LET (Linear Energy Transfer) as a conventional photon and electron beams when they enter the treated body, but have an increasing LET at the end of their path in tissues. The depth of the Bragg peak depends on the initial energy of the protons and its width on the energy spread of the beam.

In fact, the protons are charged particles that penetrate the tissues without deviating much from the initial direction by depositing much of their energy in the last centimeters

(*) E-mail: `filomena.loffredo@unina.it`

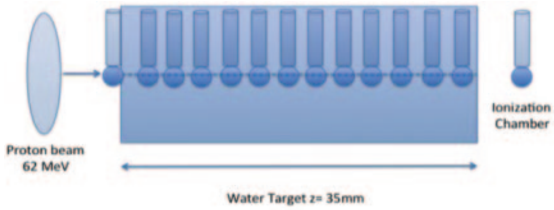

Fig. 1. – Schematic representation of the experimental setup. The figure shows some of the different positions of the ionization chamber used for the different simulation runs.

of the path. This circumstance makes it possible to preserve the crossed healthy tissue. Moreover, the tissue located in the beam direction behind the tumor receives almost no dose since the proton is stopped within the tumor.

Because the natural width of the Bragg peak of proton beams is small, it is essential to spread out the Bragg peak, since the extension in depth of many tumors can be as large as 10 cm.

The use of proton beams in the range between 60–70 MeV and 200–250 MeV allows conformal treatments both for tumors located near the skin and of deep seated tumors, respectively. To verify the reliability of the numerical results, the simulated data (proton beam of 62 MeV) obtained with this preliminary test were compared with the experimental data shown in an example of Geant4, obtained at *Centro di AdroTerapia e Applicazioni Nucleari Avanzate* (CATANA), that is the first Italian protontherapy facility [1-3].

2. – Materials and methods

2˙1. *Geant4*. – Geant4 is a versatile and powerful toolkit to simulate the passage of particles through matter. It is a toolkit written in C++ and developed by an international collaboration of researchers coming from worldwide important institutes.

It includes a large variety of physics functionalities for each particle type in the energy range from a few eV to several TeV. It is possible to construct a detailed geometry that reproduces the irradiation conditions [4]. Geant4 allows users to choose among a wide range of either theoretical or data-driven models describing the different physical phenomena in turn depending on particle type and energy range.

With respect to other particle transport simulation tools, Geant4 allows the investigation of a significant larger variability of physical modeling options.

Users are responsible for selecting the physical configuration of their experimental applications; the nature of Geant4 as a toolkit prevents the definition of any "default" physical configuration.

The task of optimizing the physical configuration for a given experimental scenario is guided by the body of knowledge of Geant4 physical validation available in the literature [5]. This task entails both validation tests of the fundamental components of Geant4 models (*e.g.*, cross-sections, stopping powers, secondary-particle production, etc.) and comparisons of complex simulated observables (*e.g.*, energy deposition patterns) with experimental measurements.

2˙2. *Bragg applications*. – The application Bragg has been updated starting from a previous work concerning the validation of a code that simulates the interaction of

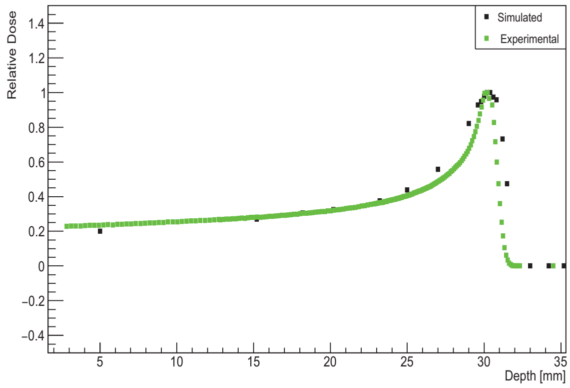

Fig. 2. – Comparison between experimental and simulated data. Bragg peak for 62 MeV protons.

protons of 1 GeV with a target for space applications [6-8]. Differently from the code used for spatial application, the tests were performed considering the physical processes involved for interactions between protons of lower energy and target. The geometry considered for these tests consists in a proton beam with energy of 62 MeV in air hitting a water target $z = 35\,\text{mm}$.

To measure the dose, an equivalent tissue ionization chamber, mounted at each run at different target thicknesses, was used. The setup is schematically shown in fig. 1.

The simulated values were compared with the experimental data reported in one of the examples of Geant4 (hadrontherapy) [1, 2].

3. – Results

The validation of physical processes with Monte Carlo simulation is the most precise approach for the calculation of dose deposition in the human tissues. In particular in this study we simulated the Bragg curve distribution using the physical models available in Geant4: the standard electromagnetic model "emstandard_opt3", in particular the

Table I. – *Comparison between simulated and experimental data with respect to the same depth (mm).*

Depth (mm)	Relative dose simulated data	Relative dose experimental data
5	0.20	0.24
15	0.27	0.28
18	0.29	0.30
20	0.33	0.32
30	0.99	0.99
30.1	0.99	0.99
30.2	1	1
30.4	0.99	0.97
∼31	0.37	0.36
34	0	0

QGSP_BIC_EMY package. The comparison was performed between simulated data and the experimental data for 62 MeV proton beam with water target.

Figure 2 shows the behavior of the proton beam in the water target and the comparison between experimental and simulated data. For each point the computed absorbed dose was measured with an ionization chamber, and all values were normalized to the maximum value within the Bragg peak. Table I shows the data that can be observed in fig. 2.

4. – Conclusion

In this work we have presented the development of a code *Bragg* to study the behavior of a proton beam in a water target. This configuration can be considered, to the first order, as a proxy for proton therapy applications. We demonstrated the good agreement between the simulated results, computed by the presented tool, and the experimental data.

REFERENCES

[1] Cirrone G. A. P. *et al.*, *IEEE Trans. Nucl. Sci.*, **51** (2004) 3.
[2] Cirrone G. A. P. *et al.*, *Front Onc.*, **7** (2017) 247.
[3] Cirrone G. A. P. *et al.*, *Nucl. Phys. B*, **150** (2006) 54.
[4] Ivantchenko A., Nieminen P., Incerti S. *et al.*, in *40th COSPAR Scientific Assembly, 2–10 August 2014, Moscow, Russia* (2014).
[5] Agostinelli S. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **506** (2003) 250.
[6] Loffredo F. *et al.*, *Am. J. Environ. Prot.*, **4** (2015) 275.
[7] Loffredo F. *et al.*, *Adv. Space Res.*, **59** (2017) 393.
[8] Loffredo F. *et al.*, *Mater. Res. Express*, **6** (2019) 1.