First microdosimetric characterization of nuclear interaction events, and assessment of their effect on the dose-mean lineal energy uncertainty.

G. Parisi[1,2] G. Schettino[1,2], F. Romano[3]

[1]Department of Physics, University of Surrey, Guildford, United Kingdom).
[2]NPL-National Physical Laboratory, Teddington, United Kingdom).
[3]INFN-Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Catania, Italia).

Background: Microdosimetry is a radiation detection technique measuring the energy deposited by radiation into cell-like volumes, taking into account the stochastic nature of radiation interaction. If applied to hadron therapy, microdosimetry could bring important benefits both to quality assurance, as the radiation quality of the radiation beam could be uniquely characterised, and to the treatment effectiveness, since it could be successfully used to estimate the Relative Biological Effectiveness linking microdosimetric quantities to dedicated radiobiological models. However, standard protocols and codes of practice, necessary for a clinical transition of microdosimetry, are still missing. It is in this framework that the use of particle-tracking Monte Carlo simulations could have a fundamental role in supporting microdosimetry experiments and in the understanding of underlying processes. Geant4 is widely used in medical applications as it has been validated for the particles and energy range of interest [1].

Material and Methods: A systematic uncertainty analysis focused on the effects of counting statistics was carried out using data from Geant4 simulations, [2]. The uncertainty propagation into the final dose-mean lineal energy uncertainty was performed according to the numerical method described in Evaluation of Measurement Data – Supplement 1 [3] by BIPM (Bureau International des Poids et Mesures). Several ion species (protons, helium and carbon ions) and energies relevant to hadron therapy, were studied as detected by a diamond-based microdosimeter. Since the study pointed out a significant impact of nuclear interactions on microdosimetric quantities, the code was later improved to obtain, together with the energy deposited in the diamond detector and its path length, the atomic number of the particle depositing energy, when generated by a nuclear interaction, and the kinetic energy it was generated with. Hence, nuclear interaction events could be accurately characterised.

Preliminary results: The dose-mean lineal energy uncertainty was found to be strongly affected by nuclear interaction events, as shown in Figure 1, [2]. Nuclear reactions occurring into the detector sensitive volume produce, indeed, low energy fragments with very high LET, resulting in events with lineal energy much higher than the primary's. These events have a significant effect both on the dose-mean lineal energy value, that could differ up to one order of magnitude if nuclear interactions are considered or not, and to its uncertainty, which could require a total number of collected events up to 5e7 to be lower than 10%. It is therefore important to study and characterise them thoroughly. A typical proton beam in the entrance region was chosen as reference case since it was found to be the most affected by nuclear interactions effects. The part of the microdosimetric spectrum due to nuclear interaction events was characterised in terms of fragment type and path length. Results will be compared against nuclear reaction cross-sections found in literature and the impact of using a detector material different than tissue will be assessed by comparing results obtained in the same conditions but simulating sensitive volumes of different materials (e.g. diamond, silicon, tissue, …).

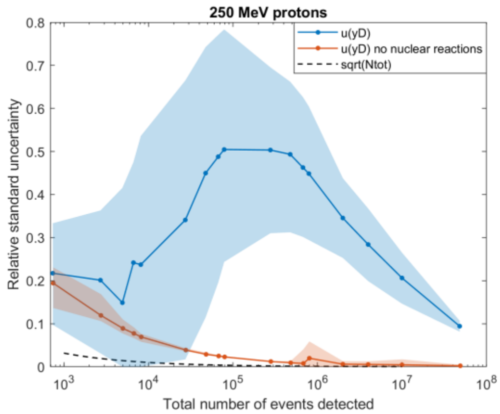

Figure 1: Dose-mean lineal energy relative uncertainty as a function of the number of collected events, for a 250MeV proton beam detected by a 1µm thick diamond detector placed at 10mm depth in water. Figure taken from [2].

[1] P. Arce *et al.*, Med. Phys., 48 (2020) 19-56.

[2] G. Parisi *et al.*, Phys. Med. Biol., 67 (2022) 155002.

[3] Evaluation of measurement data - Supplement 1 to the "Guide to the expression of uncertainty in measurement" - Propagation of distributions using a Monte Carlo method, https://www.bipm.org/documents/20126/2071204/JCGM_101_2008_E.pdf