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Advanced Simulation Tools for Medical Imaging and Radiation Therapy at the University and INFN Naples

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Shaping the Future: Strategic Roadmap for Ultrafast Radiation Biology with laser-driven radiations

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Microdosimetric spectra evaluation for proton Minibeam Radiotherapy through Monte Carlo Geant4 simulations

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Microdosimetric spectra evaluation for proton Minibeam Radiotherapy through Monte Carlo Geant4 simulations

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Currently, one of the primary limitations of radiotherapy lies in the maximum dose that can be safely tolerated by surrounding healthy tissues, often making treatments ineffective for advanced lesions located in critical organs such as the lungs and brain. Spatially fractionated radiotherapy (SFRT) represents a promising alternative technique in which the deposited dose alternates regularly between high-dose and low-dose regions and allows the reduction of the toxicity to the healthy tissue while preserving the same tumoral control of conventional radiotherapy. In vivo/in vitro experiments of SFRT technique show potential reductions of healthy tissue damage guaranteeing at least the same tumor damage as conventional radiotherapy. Minibeam radiotherapy (MBRT) combines spatial dose fractionation with highly collimated, parallel beams of 0.5-1 mm size, separated by comparable spaces resulting in a not uniform dose distribution with alternating peaks and valleys. The use of proton beams, known for their low scattering and maximum energy deposition at the end of their path (Bragg peak), combined with the unique properties of spatial modulation, makes proton minibeam radiotherapy (pMBRT) a potentially more effective and safer treatment option for cancer patients in the future clinical perspective of this technique.
The presented study was performed in the framework of the INFN MIRO (MInibeam RadiOtherapy) project, financed by the Committee 5 of the INFN, with the goal to address key questions related to the radiobiological minibeam effect with both electron and proton beams and explore potential clinical implications through the correlation with the dosimetric and physical quantities.
At this aim, the quality of proton minibeam radiation at a clinical energy and its variation along the peak-to-valley pattern and in depth was evaluated by means of Monte Carlo Geant4 simulations. In

particular, the microdosimetric spectra and the related average quantities have been estimated for specific minibeam configurations and compared to the ones obtained simulating an equivalent homogeneous proton beam, i.e. without the spatial modulation. Microdosimetry is, in fact, particularly relevant for minibeams where spatial modulation in the dose distribution requires a micrometric-scale description to further investigate their biological effect.
The "exp_microdosimetry"Geant4 advanced example developed by the INFN Catania division was used to perform Montecarlo simulations of 100 MeV gaussian proton beam impinging on a tungsten 5 mm thick collimator with different geometrical configuration (width and center-to-center distance). An array of silicon microdosimeters was simulated to simultaneously acquire the microdosimetric spectra at different positions along the minibeam pattern and reduce as much as possible the computation time. In particular, the single microdosimeter simulated was the simplified silicon detector already implemented in the code and developed at the Centre for Medical Radiation Physics (CMRP), University of Wollongong.
Results regarding the microdosimetric spectra (in frequence and in dose) and the average quantities yF and yD between the peak and the valley and at different water depths for the most relevant minibeam configuration will be presented in this contribution.
This preliminary study lay the groundwork for future calculations of the RBE in radiobiological models and open the way to a more complete microdosimetric and radiobiological characterization of pMBRT.

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INFN-4LS: Ongoing Activity and Development Projects

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Geant4-DNA Chemistry Modelling: General Overview, Current Status and Future Developments

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The accurate simulation of radiation-induced chemical processes is essential for understanding biological damage at the molecular and cellular levels. Since version 10.1, Geant4 has included a dedicated chemistry module within Geant4-DNA to simulate water radiolysis following exposure to ionising radiation. This module enables time- and space-resolved tracking of chemical species, supporting the calculation of radiolytic yields (G-values) and the modelling of early DNA damage.
Over the years, the chemistry module has undergone substantial improvements aimed at enhancing computational efficiency and broadening applicability, most notably through the inclusion of homogeneous chemical kinetics in bulk solutions. These developments have led to a growing number of applications and publicly available Geant4 examples, showcasing how to implement chemical reaction models in diverse scenarios.
This presentation will provide a comprehensive overview of the current capabilities of the Geant4-DNA chemistry module, highlight recent advancements, and discuss ongoing efforts to extend the