Study of biological effects of LWFA electrons

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Over the past few years, impressive advances have been reported in the field of Laser Wakefield Acceleration (LWFA), in terms, e.g., of electron beam energy end energy spread, transverse and longitudinal emittance, pointing stability and reproducibility (see [1, 2] and references therein). Whilst very high quality electron bunches currently require the use of tens to hundreds TW class lasers to be obtained, a few MeV to a few tens of MeV energy electron beams produced using TW class systems already allow promising applications to be foreseen.

The group operating at the Intense Laser Irradiation Laboratory of the INO-CNR in Pisa is currently investigating a regime of electron acceleration whose resulting electron bunches exhibit kinetic energy and delivered dose per unit time suitable for the radiotherapic treatment of cancer [3]. In particular, performances and figures have been attained very close to the output of conventional RF-driven conventional accelerators used for Intra-Operatory Radiation Therapy (IORT). However, before going toward a clinical use of laser-driven accelerators, a fundamental issue has to be deepened, concerning the effects of laser accelerated electron bunches on biological samples. Indeed, electron bunches delivered by a LWFA have a duration of the order of a picosecond or less, namely one million times shorter than microsecond bunches delivered by a RF machine. Since the dose content of each bunch is comparable for the two techniques, the peak current (or electron density) released in the laser case is one million times higher than in the RF case. The biological consequence of such a huge difference in peak current is basically unknown and needs to be investigated. Recently, a project has been funded by the Italian Ministry of Health specifically aimed at the study, at a pre-clinical level, of the effects induced by ultrashort, laser-driven electron bunches on biological matter, using established biomedical protocols. In particular, the project is aimed at: a) validating with non-clinical tests the effectiveness of the dose delivered with the laser-based experimenal device, also in comparison with the effect of dose delivered by current RF-based commercial device; b) investigate the possibility of a deeper dose release at higher kinetic energy; c) explore potential different effects due to the extremely different electron peak current available with the Laser and RF based techniques. The project will take advantage of well-established collaborations among collegues from the same Research Campus of the CNR in Pisa, as well as from the Medical Physics Unit of the Santa Chiara Hospital in Pisa, active in the fields of laser-driven acceleration, medical biology and radiotherapy. The project will use a combined approach by integrating in vitro and in vivo studies in order to investigate the potential biomedical applications of innovative laser-plasma accelerators. In radiobiology and radiotherapy, it is known that the early spatial distribution of energy deposition following ionizing radiation interactions with DNA molecule is crucial for the prediction of damages at cellular or tissue levels and during the clinical responses to this irradiation. The evaluation of the radiobiological effects obtained with electron bunches from a laser-driven electron accelerator and from bunches coming from a IORT-dedicated medical Radio-frequency based linac on human cells will be performed by a variety of biological assays.

A laser-linac (L-linac) has been setup at the Intense Laser Irradiation Laboratory of the INO-CNR (http://www.ino.it) and a preliminary characterization of the produced electron pulses has been carried out in the past few months. In particular, the following features have been studied and consolidated:

- bunch total charge: about 100 pC/per laser shot (the L-linac based source could in principle be operated at a 10Hz repetition rate)
- bunch transverse homogeneity: the bunch features a gaussian angular spread with typical aperture of a few degrees. Possible setups leading to the required homogeneity on the sample have been being studied by means of Monte Carlo simulations (see below)
- bunch spectrum: electron bunches with kinetic energy up to around 25 MeV can be reliably obtained; the exact spectral shape can be already controlled to some extent
- shot-to-shot stability and reproducibility: an acceleration regime in which close to a 100% reproducibility in terms of accelerated energy and charge has been steadily reached. Furthermore, the possible spatial nonhomogeneities of the delivered dose arising from the shot-to-shot small (mrad) pointing deviations have been observed to be fully ruled out over an area of interest by integrating the dose over about ten L-linac shots

In the past few weeks, the L-linac based e-source has been used to carry out preliminary test experiments on different biological samples.

Recent efforts have been also devoted to the design and study, by means of Monte Carlo simulations, of a vacuum-air interface for the produced e-bunches as well as to the design of a plastic collimator and homogeneizer [4]. As an example of the obtained results, Figure 1 shows the changes experienced by the electron pulse passing through a 500-micron thick Cu-made vacuum-window interface.

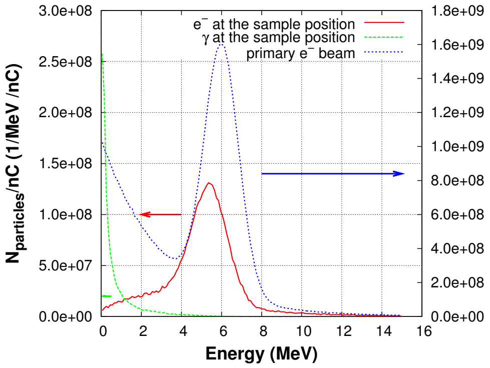

Figure 1: Electron and γ-ray spectrum after crossing a Cu vacuum-air window.

Figure 2 shows the available equivalent dose in water available to a sample in air just after the window. At the same time, based upon such a kind of simulations, a mechanical system allowing the irradiation of biological samples in air has been designed and is currently in operation. The system enables controlled and reproducible e-bunch irradiation in air of samples a few cm^2 surface. Finally, dose measurements are ongoing within the present irradiation setup in collaboration with the Pisa Hospital and the University of Pisa.

References

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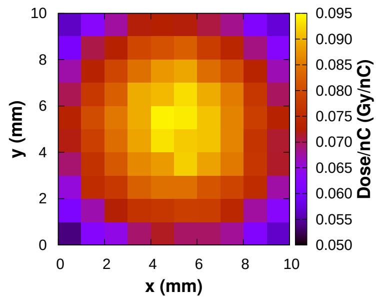

Figure 2: Available equivalent dose in water deliverable in air.