Production of alpha particles sources through proton-boron nuclear reactions initiated by relativistic lasers

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The landscape of attainable radio-isotopes with medical cyclotrons is limited due to the low energy of particles accelerated. Only a few radio-isotopes with low energy particles are produced at hospitals, except with the ARRONAX cyclotron in Nantes which produces heavier isotopes with lower lifetimes for a broad range of medical applications. A new way of producing those radio-isotopes has been studied, that is, using secondary alpha particles sources as a way to generate those relevant isotopes. Proton-Boron nuclear reactions have been actively studied these last few years as a possible way of producing secondary alpha particles sources. Proton acceleration by interaction of ultra-high intense lasers with hydrogenated targets is the preferred way to initiate those type of reactions. [1] The versability of such laser systems is the preferred way to complement conventionally used medical cyclotrons.

The two main mechanisms of ion acceleration studied for this nuclear scheme are the Target Normal Sheath Acceleration (TNSA) and the Hole-Boring (HB) process. In the first case, protons are accelerated at the rear side of the target via the electrostatic field induced by laser driven electrons escaping from the target. The exponential shape of the proton energy spectrum induces a great number of nuclear reactions throughout a Boron secondary target despite a decrease of the cross-section above the main resonance at 675 keV.

For the Hole-Boring process, ions are accelerated at the front side thanks to the electric field induced by the electrons pushed by the radiation pressure of these high laser intensities. Accelerated protons interact directly with boron atoms contained within the same target [2]. Different types of targets have been studied both numerically and experimentally for Hole-Boring based alpha production.

Particle-in-Cell (PIC) and Monte-Carlo simulations have been conducted to better understand experimental campaigns done on the VEGA-III laser at CLPU, Salamanca, Spain in november 2022 and march 2023. This laser is characterized by a short pulse duration, 30fs and a high-repetition rate of 1Hz. The two ion acceleration schemes have been studied numerically to better understand the experimental data and to further the analysis. Angular analysis of particle bunches (protons, carbon ions and alpha) has been done to support experimental results obtained on CR-39 track diagnostics. Simulations have thus allowed to discriminate traces found on these diagnostics and given confidence on the number of alpha particles obtained.

[1] Margarone Daniele, Alessio Morace, Julien Bonvalet et al. « Generation of α-Particle Beams With a Multi-KJ, Peta-Watt Class Laser System ». Frontiers in Physics 8 (9 septembre 2020): 343. https://doi.org/10.3389/fphy.2020.00343.
[2] Margarone, Daniele, Julien Bonvalet, Lorenzo Giuffrida, et al. « In-Target Proton–Boron Nuclear Fusion Using a PW-Class Laser ». Applied Sciences 12, no 3 (28 janvier 2022): 1444. https://doi.org/10.3390/app12031444.