MODELING PROTON BEAM BEHAVIOR DRIVEN BY LASER-PLASMA ACCELERATION IN THE PRESENCE OF RELATIVISTIC AND SUPRATHERMAL ELECTRONS

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In High Intensity Laser Accelerated Beams (HILAB), numerous phenomena influence considerably various stages of the acceleration process, impacting beams quality. This study aims to analyze the Bragg-peak dose distribution behavior by characterizing the maximum energy, proton count, and dose distribution in HILAB, focusing on the interaction between suprathermal and relativistic electrons. These events arise from the strong plasma nonlinearity induced by intense laser fields. We employ a theoretical models to simulate proton acceleration combined with Monte-Carlo methods for dose investigation. It is shown that the competition between these factors leads to significant improvements in proton beam stability, producing a high-quality energy spectrum and an optimal Bragg-peak dose distribution, within the range of values for the electron suprathermality and relativistic parameters (κ, θ) *that were optimized numerically.*

Keywords: Laser Accelerated Beams, Bragg Peak, dose distribution, Relativistic and Suprathermal Electrons.

1. Introduction. The field of Laser-Plasma Acceleration (LPA) has seen remarkable advancements over the past few decades, emerging as a promising technology for generating high-energy particle beams with applications ranging from fundamental research to clinical applications, namely in radiation therapy [1]. HILAB represent one of the most compelling innovations, offering the potential for more precise and effective in future medical technology, where dose accuracy is a crucial factor. Since S. V. Bulanov and V. S. Khoroshkov [2]

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proposed their scheme in 2002, demonstrating the feasibility of using laser ion accelerators in proton therapy, significant improvements have been made worldwide [3, 4]. Various models have been suggested to reconstruct the SOBP using laser-accelerated proton beams [5]. For example, L. Tao et al. [6] proposed an analytical model for the reconstruction of two-dimensional SOBPs, while Y. F. Li et al. [7] proposed a promising method for generating monoenergetic beams, ideal for laser proton therapy. They demonstrated theoritically that a single-shot proton beam can achieve a flat clinical SOBP distribution with doses up to several Gy. The acceleration of particles using high-intensity laser pulses in a plasma medium involves a complex interplay of physical phenomena. Among these, relativistic and suprathermal effects are significant contributors to the acceleration dynamics and resulting beam characteristics [8]. These two phenomena arise from the high particle velocities influenced by intense laser fields [9–11]. In the context of LPA, the TNSA mechanism is a well-studied process where ions are accelerated by the strong electric fields generated by relativistic electron clouds at the rear surface of a thin foil target. A significant portion of the incoming laser energy is absorbed on the target's front surface, generating powerful electromagnetic fields that accelerate electrons to relativistic speeds. These relativistic electrons travel through the target, with the most energetic ones escaping from the rear surface into vacuum. This creates the charge separation that forms a strong electrostatic sheath, which subsequently accelerates ions from the target surface normal to the rear side. Recently, S. Singh et al. [12] showed that the energy spectrum describing the efficiency of relativistic electron generation and bremsstrahlung radiation depends on several parameters, such as the focused intensity and pre-plasma level.

The suprathermal event, on the other hand, involves the generation of particles with energies significantly higher than the thermal equilibrium distribution. These phenomena often result from non-linear laser-plasma interactions and instabilities...

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