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CONICAL COIL FOCUSING OF LASER-PLASMA ACCELERATED PROTON BEAMS FOR BIOMEDICAL APPLICATIONS

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The major advances in laser-plasma acceleration techniques for charged particle beams have generated significant interest in the development of laser-based solutions for proton beam therapy [1, 2]. The particularities of laser-plasma accelerated ion beams that could benefit the biomedical field feature ultra-short pulse durations, down to tens of picoseconds, and high fluxes, with peak values ranging from 10^{11} to 10^{13} particles per shot. These properties enable the potential delivery of ultra-high dose rates far exceeding 40 Gy/s, the threshold for FLASH therapy. To benefit from these features, the scientific community needs to overcome the more challenging aspects of employing ultra-short accelerated hadrons in clinical applications, which stem from their broadband energy spectrum and large divergence.

In this work we present a simulation-based study that investigates the feasibility of employing high-current solenoid-generated magnetic fields for focusing a proton beam characterised by a broad angular divergence of 21.25 degrees and an energy spectrum ranging from 4 to 20 MeV. The proposed focusing solution consists of a conical solenoid, oriented with its narrow opening facing the proton beam, followed by a coaxial cylindrical one. High currents of 20 and 16 kA were applied to the solenoids, generating peak axial magnetic fields of 9 T and 6 T, respectively. Two versions of the dual-solenoid configuration are compared in terms of focused beam size and position, as well as capturing efficiency, to identify the optimised focusing solution. Protons of over 16 MeV were captured with a 94% efficiency, in a focus spot of 9 mm diameter, located at 1 m from the source.

Additionally, using the optimised dual-solenoid configuration, a 16 to 20 MeV focused proton beam was employed in a dose deposition study targeting a millimeter-scale cylindrical water phantom, resembling a superficial tumour, to explore its potential for therapeutic applications within the flash therapy regime. The study monitored the spatial distribution of the absorbed dose across transverse planes at various depths within the sample. Due to the beam exposure, the total absorbed dose received by the water phantom was 25 mGy with a rate of $1.2 \cdot 10^7$ Gy/s, reaching the FLASH therapy regime.

This work provides valuable insight into beam modulation techniques that support the development of laser-based solutions for proton beam therapy.

Keywords: laser-plasma acceleration, proton beam, dose deposition, FLASH effect.

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