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Hybrid Proton Acceleration Scheme with Dual-Laser Pulses

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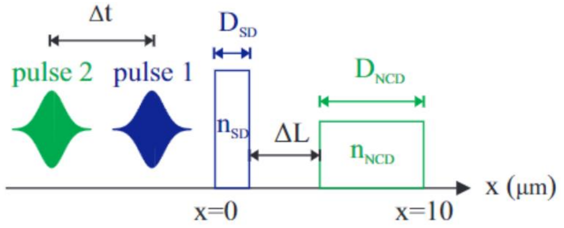
Laser-driven proton acceleration has garnered significant attention due to its potential applications in cancer therapy and proton-boron fusion [1]. The two primary schemes, TNSA and RPA, have been extensively studied. TNSA involves an ultra-intense laser pulse interacting with a thin foil target, creating a hot electron cloud that generates a strong electrostatic sheath field, accelerating protons and ions. RPA uses an intense, circularly polarized laser pulse to push the electron layer of a thin foil target, creating a strong electrostatic field that accelerates ions. Recent advancements have explored hybrid schemes to enhance proton acceleration efficiency. For example, combining RPA and LWFA mechanisms using tandem solid and underdense plasma targets has been studied. Near-critical density (NCD) targets have also been used to produce highly energetic proton beams. In 2021, Isayama et al. proposed a novel hybrid acceleration scheme using dual-laser pulses with energies of only a few joules [2]. This method uses a tandem arrangement of SD and NCD targets, separated by a vacuum gap, as shown in Fig. 1. The initial laser pulse generates a high-energy proton beam through RPA in the SD target. These protons are then injected into the NCD target, where the second laser pulse further accelerates them via LWFA, creating a snow-plow field that significantly boosts their energy. Finally, the TNSA mechanism provides additional acceleration at the rear of the NCD target. Our simulations for Isayama's hybrid scheme, considering the NCU 100-TW laser system, show proton energies up to 75.1 MeV, as shown in Fig. 2. Detailed parametric studies optimize laser pulse intensities, target densities, and vacuum gap length to maximize acceleration efficiency. These results highlight the potential of this hybrid scheme to develop compact, high-efficiency proton sources for various scientific and medical applications.



Physics quantities	Symbol (unit)	Values (NCU)
Laser wavelength	λ_L (nm)	810
Laser energy	ε_L (J)	1.5
Pulse duration	$\tau_L(fs)$	30
Focal spot size	$w_L(\mu m)$	5
Laser strength	a_L	6.3
Pulse 1 timing	t_1 (fs)	60
Pulse 2 timing	t_2 (fs)	220
Time delay	Δt (fs)	160
Solid target density	n_{SD} (n_c)	100
Solid target thickness	D_{SD} (nm)	18
NCD target density	n_{NCD} (n_c)	5.5
NCD target length	D_{NCD} (μm)	2
Vacuum space	ΔL (μm)	8

Figure 2. Simulation setup and the parameter set.

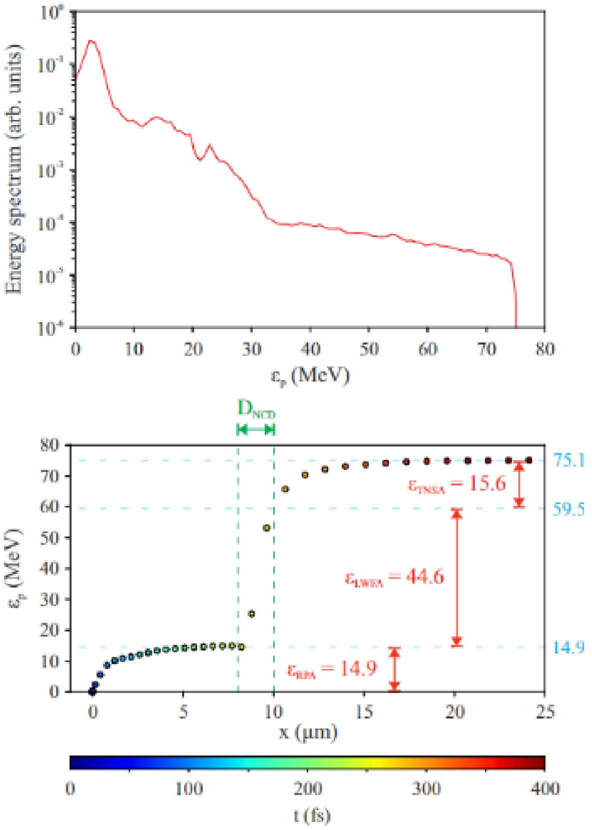


Figure 1. The proton energy spectra and the track of the maximum proton energy.

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