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Impact of the gas species and optical ionization effects in kHz laser-wakefield acceleration

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Laser-wakefield acceleration (LWFA) of electrons at a kHz repetition rate holds significant promise for medical and industrial applications. Until recently, kHz laser systems have been limited to few-mJ pulses, necessitating sharp focusing and strong temporal compression to achieve relativistic intensities [Guénot 2017]. Continuous operation of a kHz laser-plasma accelerator requires specialized target systems capable of sustaining a continuous gas flow, previously demonstrated only in N2 [Rovige 2020]. However, recent studies indicate that lighter gases, such as H2, promise superior performance [Salehi 2021].
We present our latest study on optical ionization effects in kHz LWFA with few-mJ, few-cycle pulses [Monzac 2024]. We confirm and elucidate the improved performance of H2 compared to other gases, including He: the ionization effects significantly distort the laser pulse, negatively impacting the accelerator performance. These effects are minimal in hydrogen plasma, thereby enhancing beam quality. Utilizing 4 fs pulses with 2.5 mJ on-target energies at the Salle Noire facility (LOA), we achieved low-divergence electron beams with narrow spectra peaking around 5-10 MeV. These beams exhibited remarkable shot-to-shot stability in beam pointing, charge and energy spectrum. To achieve these results, we implemented a differential pumping scheme enabling continuous operation at kHz repetition rates in light gases.

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