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Development of a two-chamber LWFA target for fine electron injection control

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Laser wakefield acceleration (LWFA) has seen great improvements in recent years, demonstrating the ability to generate high-energy, ultrashort electron beams in compact setups.
However, reproducibility remains a major challenge, with beam properties often affected by shot-to-shot fluctuations [1], caused by fluctuations in the laser system, inconsistencies in the plasma density profile, and stochastic processes in the electron injection and acceleration stages. Such limitations hinder the reliability and applicability of LWFA-based electron sources, particularly in precision-demanding fields like medical therapy [2] or advanced radiation sources such LWFA-driven X-FELs.
To address this, we present a novel two-chamber gas cell design that enables precise and tunable control over the plasma density profile along the laser propagation axis. By independently regulating the gas temperature in each chamber, longitudinal gas density modulation is achieved, allowing for a down-ramp injection scheme that supports reproducible, charge-tunable electron beam generation.
The cell's adjustable length further enhances control over the acceleration process, facilitating energy tuning and compatibility with a wide range of experimental conditions. This flexible, 10Hz-compatible design also enables real-time, automated optimization of LWFA performance (in line with previous successful experiments such as [3] and more recently [4]).
Computational fluid dynamics (CFD) simulations performed using OpenFOAM [5] suggest that the target can produce the desired gas density profiles. Additionally, a Bayesian optimization approach was applied to OSIRIS [6] particle-in-cell simulations to explore optimal laser and plasma density parameters within experimentally achievable ranges.

References

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