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Long-duration ion motion effects in beam-driven plasma-wakefield accelerators

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High-repetition-rate operation of plasma-wakefield accelerators is essential for their suitability in the design of colliders and FELs. Energy remaining in the plasma after the wakefield acceleration event can limit the ultimate repetition rate of the plasma accelerator as the plasma takes time to relax to its initial state. This relaxation is limited by two ion-driven effects: their redistribution after the wakefield event and potential further collisional ionisation caused by this motion, as was observed at FACET [Nat. Commun 11, 1–11]. A tens-of-nanoseconds recovery of the original on-axis plasma density directly from ion motion was measured for standard FLASHForward operational settings [Nature 603, 58–62], prompting further investigations into possible ionisation effects. In this work, we investigated hydrogen and argon plasmas at a variety of working points with two different diagnostics: the pump-probe electron-beam-based technique and optical emission spectrometry. In some regimes, both diagnostics indicated additional ionisation happening on the nanoseconds-microseconds timescale, which elongated the recovery time. The dependency of the exact evolution rate of ion-motion-driven ionisation on the initial plasma conditions, namely plasma density and the degree of ionisation, was explored, which will inform the design of the highest repetition rate plasma sources for future colliders and FELs.

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