Developing a novel platform for investigating intense near-critical-density laser plasma interactions

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The interaction of high-intensity lasers with near-critical density (NCD) plasmas underpins many applications, such as the generation of ultra-high peak current ion beams [1]. However, diagnosing NCD plasmas remains challenging due to their high density, short timescales, and small spatial structures. Without being able to experimentally verify the laser plasma interaction, typically particle-in-cell simulations are relied on to elucidate experiments in this regime. However, these simulations can be limited by poor understanding of the experimental inputs, reduced dimensionality and simplified physics models. This issue restricts the extension of these promising experiments to applications.

We address these challenges by employing a high-power, long-wave infrared CO_2 laser at the Accelerator Test Facility, Brookhaven National Laboratory. The longer drive wavelength reduces the critical density, allowing the use of gas jet targets to easily scan the plasma density over the near critical density regime. Furthermore, the increased wavelength results in increased spatial and temporal scales of the relevant physics, enabling the use of standard optical plasma probing techniques with a synchronised near infrared optical laser.

Here, we discuss new femtosecond probing capabilities and their application to investigating near-critical-density laser plasma interactions. We focus on experimentally elucidating laser-plasma phenomena of relevance to particle acceleration, including the transition between front-surface and sheath acceleration regimes of ion acceleration, revisiting our earlier work on radiation-pressure driven shock acceleration [2]. Furthermore, we have made direct optical measurements of the Weibel-like current filamentation instability of laser driven electrons in plasma exceeding the critical density, demonstrating their density dependence and using the long-term evolution to evaluate the overdense plasma temperature [3]. We have also investigated the channelling of relativistic lasers in NCD plasmas, enabling precise measurement of sub-luminal channel velocities previously only observed in simulations. Our novel platform can be further extended to provide new insights into a wide range of intense laser-plasma phenomena.

References

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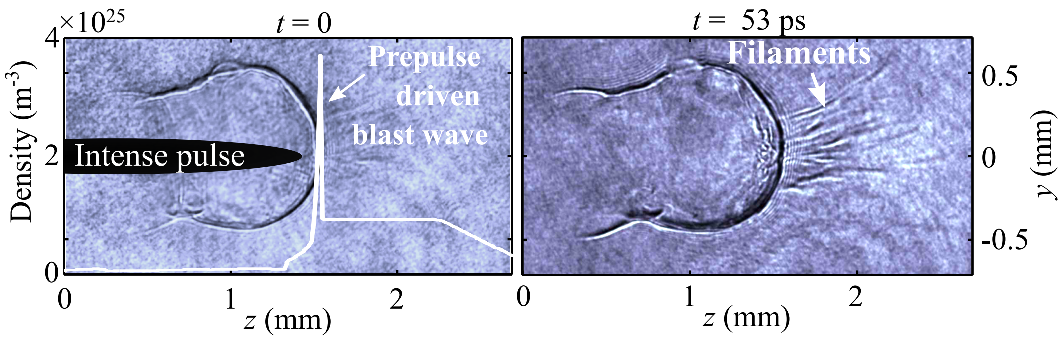

Figure 1: Adapted from [3]. Example shadowgraphy images of plasma before (left) and after (right) irradiation by intense longwave infrared pulse. Clear filamentation is observed in the downstream plasma, caused by Wiebel-like current filamentation instability of electron beams generated in the laser plasma interaction.