Programmable-Velocity Dephasingless Laser Wakefield Acceleration

M. V. Ambat, J. P. Palastro, P. Franke, H. G. Rinderknecht, D. H. Froula, and J. L. Shaw

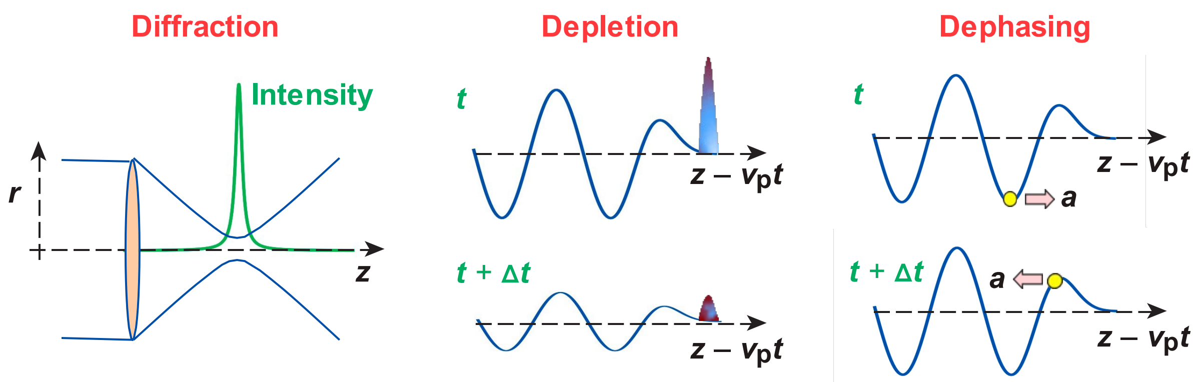
University of Rochester, Laboratory for Laser Energetics

Introduction

In a laser wakefield accelerator (LWFA), the ponderomotive force of an intense laser pulse propagating through a plasma excites a large-amplitude plasma wakefield that can trap and accelerate electrons [1]

Three fundamental challenges limiting LWFA performance are

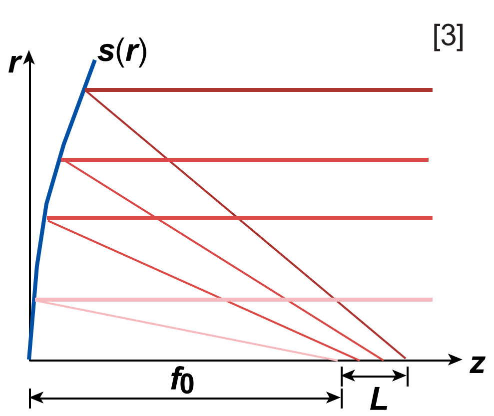
- Diffraction: the laser pulse diffracts as it propagates, decreasing its intensity and thus its ability to drive a wake
- Depletion: the laser pulse loses energy to the wakefield, decreasing its intensity
- Dephasing: electrons ($v_z \sim c$) outrun the accelerating phase of the wakefield and are no longer accelerated



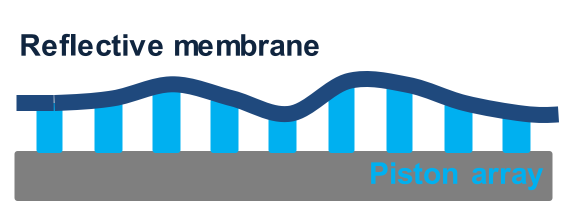
Electron dephasing can be circumvented by using custom optics to produce a flying focus: an intensity peak with a controlled velocity which sets the phase velocity of the driven wakefield [2]. This poster presents simulations of a novel optical configuration for spatiotemporal pulse shaping that combines a reflective axiparabola, deformable mirror (DM), and a spatial light modulator (SLM).

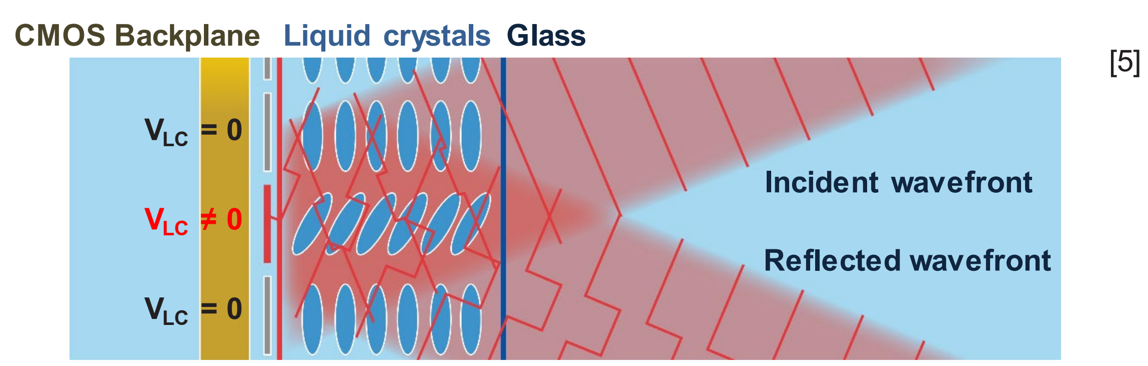
Advanced Optics for Spatiotemporal Control

An axiparabola (below, left) is a reflective optic that focuses light rays at different near-field radial locations to different far-field axial locations [3].



A deformable mirror (below) is an adaptive optic consisting of pistons or piezoelectric segments that can shape a flexible, reflective membrane.



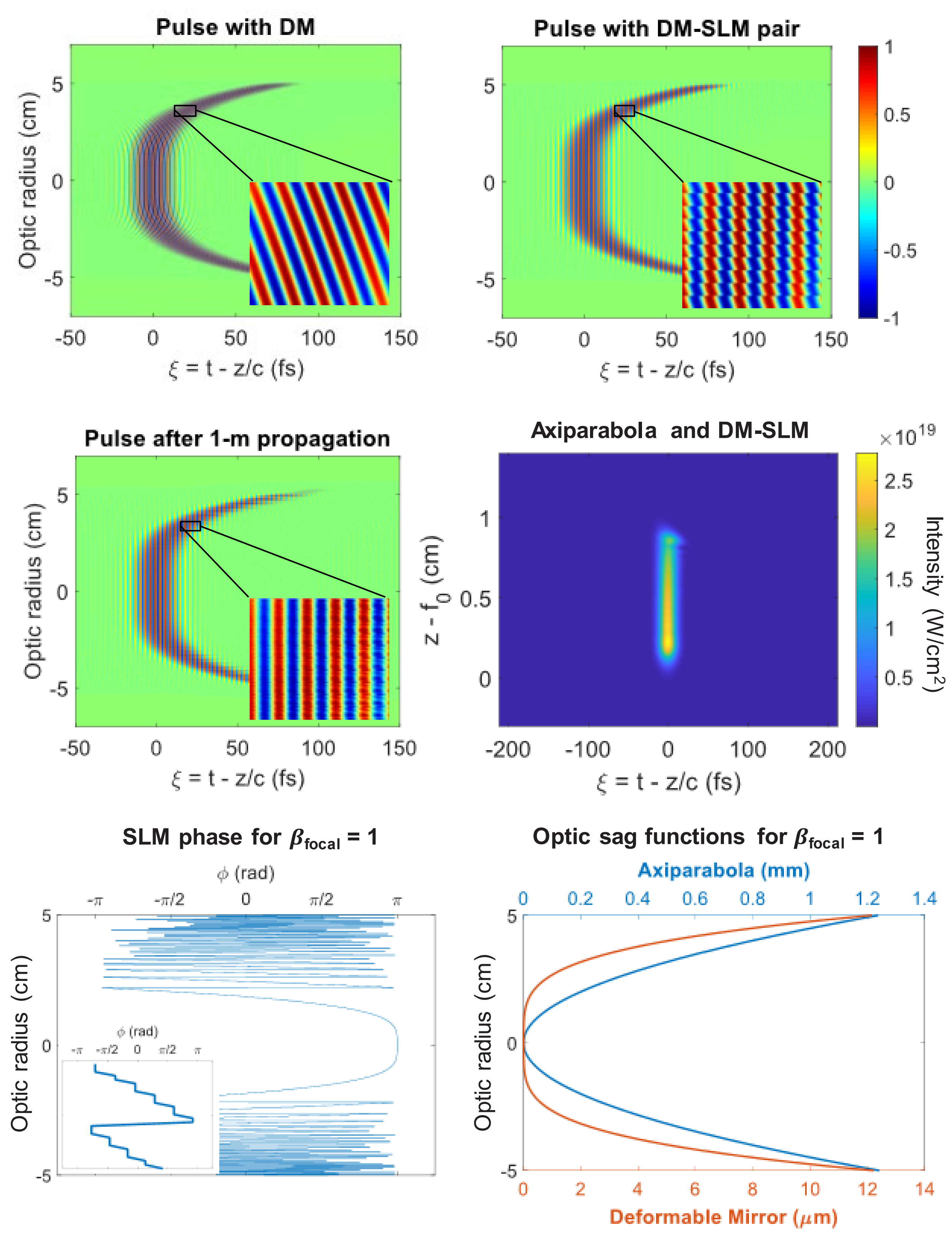


A spatial light modulator (above) consists of an array of liquid crystals (LCs). Applying some voltage (V_{LC}) to a LC causes the LC to rotate. The rotation of the LCs results in changes in the local refractive index.

Programmable-Velocity Flying Focus for Dephasingless Laser Wakefield Acceleration

A combination of an axiparabola, deformable mirror (DM), and spatial light modulator (SLM) can produce a focus that propagates at $\beta_{focal} = v_{focal}/c = 1$ in a plasma over distances much greater than a Rayleigh range, thereby mitigating electron dephasing in LWFA.

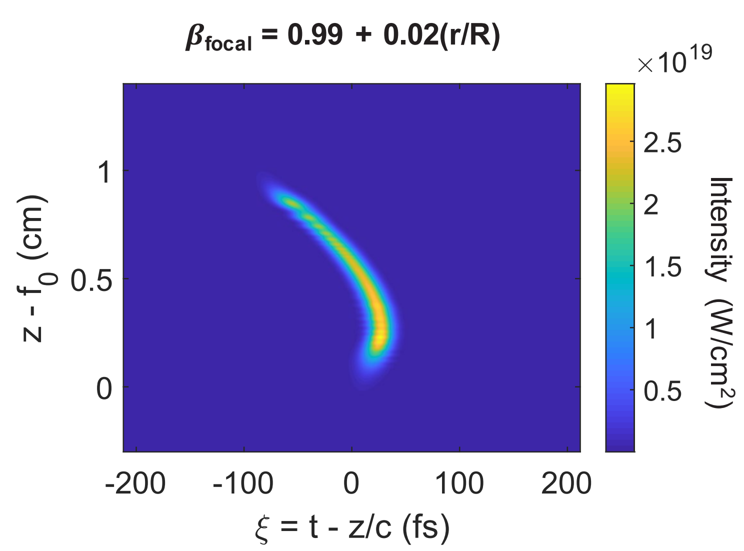
- The axiparabola controls the longitudinal location at which each radius focuses.
- The DM imparts a radial group delay (*i.e.,* pulse front curvature) that controls the time at which each radius reaches its focus [6].
- The SLM corrects the unwanted phase front curvature imparted by the DM while retaining the desired pulse front curvature [6].



Insets illustrate fine structures in a small region of 2 mm × 15 fs.

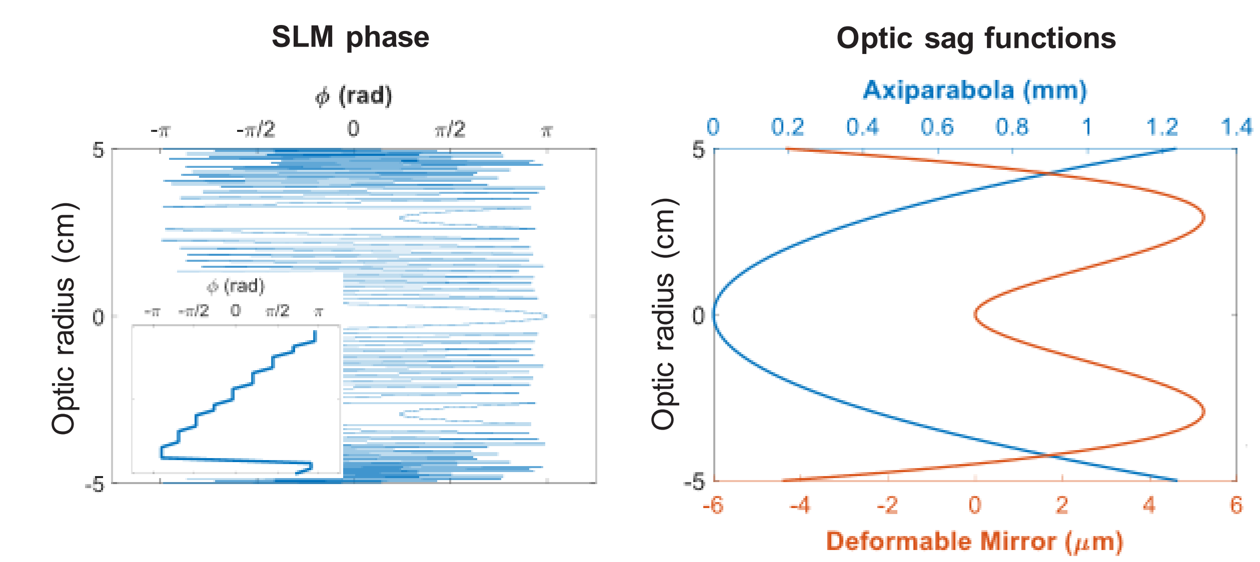
In these simulations, f_0 = 50 cm, $f/\#$ = 5, L = 1 cm, and n_e = 1.25 × 10^{19} cm^{-3}

Exotic Programmable-Velocity Flying Foci



The DM-SLM pair offers rapid, tunable exploration of exotic flying foci, which improves upon the previously proposed static reflective echelon [2].

An example of an exotic focal velocity is one shown on the left. Initiating the flying focus with $\beta_{focal} < 1$ allows for controlled trapping of background charge; subsequent acceleration of the focus beyond $\beta_{focal} = 1$ mitigates dark current and wave breaking.



Conclusions

- An axiparabola, deformable mirror, and spatial light modulator can create a flying focus that circumvents electron dephasing in a laser wakefield accelerator.
- The programmable nature of the DM and SLM offers rapid fine-tuning of the focal trajectory, which is of interest for rep-rate experiments.
- This configuration enables exotic flying foci such as an accelerating focus that can control electron trapping in a laser wakefield accelerator.

References

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Acknowledgements

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