What is going on in a laser plasma wakefield accelerator (LPWFA)? - a theoretical perspective on the hybrid concept

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The combination of laser wakefield acceleration (LWFA) with plasma wakefield acceleration (PWFA) provides a miniaturized testbed for the study of PWFA. Since the first experimental implementation of this hybrid concept, various driver generation methods and witness injection have been investigated. Extensive simulation studies accompanied these experiments and provided insights into the complex interplay between the individual stages and the processes occurring within them. This real-world implementation allowed us to revisit and refine the original concepts. Here we present this revised implementation guide for LPWFA.

Derived from these simulation campaigns, we present a theoretical analysis of the processes relevant to LPWFA hybrid accelerators. Requirements and possible methods for generating a driver package in the LWFA stage are discussed, and different laser extraction techniques are compared. The driver evolution in the PWFA stage is studied and the implications for performance limits relevant to current experiments are discussed. Different witness generation methods are also compared in terms of reproducibility and beam quality.

The analysis is based on 3D3V particle-in-cell simulations performed with PIConGPU. Its 3D capability and efficiency allows studying non-rotational effects such as oblique density profiles of shocks and higher laser modes originating from experimental measurements. Their influences are briefly discussed, as well as general requirements on start-to-end simulations.