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First Optimization of Plasma-Wakefield Acceleration in Virtual FLASHForward

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Introduction

Recent developments in plasma wakefield technology have enhanced the potential of compact particle accelerators with high energy efficiency and minimal energy spread. At the FLASHForward facility at Deutsches Elektronen-Synchrotron (DESY), researchers have experimentally validated optimal beam loading in a nonlinear plasma wakefield, achieving excellent energy-transfer efficiency and minimal energy spreads [1]. Locating more optimal plasma wakefield acceleration working points virtually is important to increase the efficacy of plasma wakefield acceleration research and consequently to enhance the results of these experiments. By doing this, we can increase the depth of our experimental discoveries and shorten the duration of our investigations.

This study focuses on optimizing three key parameters in virtual FLASHForward: notch width, notch position, and plasma density, crucial for analyzing the witness electron bunch and enhancing the effectiveness of plasma wakefield acceleration. Virtual FLASHForward aims to replicate actual experiments through computational tools Ocelot for beamline tracking and Wake-T for plasma simulations.

Optimization Parameter

The analysis of the witness electron bunch was carried out using an optimization parameter P. This parameter P was aimed at making the witness bunch have a very high energy gain, high witness charge, and a low energy spread [1].

\begin{equation}
P = \frac{\Delta E_{\text{acc}}^2 \cdot Q_{\text{acc}}}{\sigma_E}
\end{equation}

where ΔE_{acc}, Q_{acc}, and σ_E represent the energy gain, charge, and energy spread of the witness bunch.

Results

We present the results of the first optimization of plasma wakefield acceleration in virtual FLASHForward, achieving the ideal acceleration regime using a trailing bunch and 500 simulations of a 3D parameter scan varying plasma density, notch position, and width. Points 1 and 2 on the scan show low values for the optimization parameter P, indicating insufficient beam loading. At point 3, high plasma densities result in strong acceleration and field flattening with the highest P value. This point represents optimal beam loading with a charge of 59.75 pC, an energy gain of 100 MeV, and an energy spread of 13.44 MeV. This point can be further investigated for more experimental working points at higher plasma density profiles.

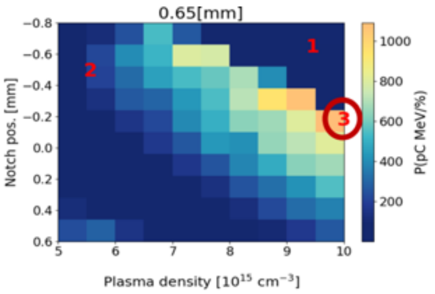

Fig. 1: 3D parameter scan of plasma density versus notch position as a function of notch width at point 3.

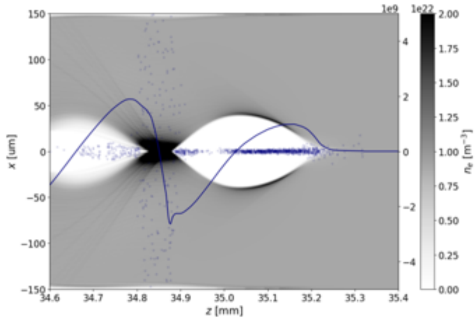

Fig. 2: Wakefield simulation for the witness bunch at point 3.

Figure 1: Description of the image

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References

[1] Lindstrøm, C. A., Garland, J. M., Schröder, S., Boulton, L., Boyle, G., Chappell, J., … & Osterhoff, J. (2021). Phys. Rev. Lett. 126, 014801. https://doi.org/10.1103/PhysRevLett.126.014801

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