Instability and Efficiency in Beam-Driven Plasma Wakefield Accelerators

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Abstract

Plasma-wakefield acceleration can sustain very large (GV/m) accelerating fields. However, because of the strong focusing fields present in the plasma channel, small transverse offsets can give to rise to transverse instabilities. Without mitigating these instabilities, emittance preservation will not be possible and the beam might ultimately be destroyed. Recent results have indicated that high efficiency and transverse instabilities might be interlinked. We simulate the magnitude of this effect using a start-to-end simulation framework which combines multiple PIC Codes. We will measure the effect and quantify the performance of mitigation techniques with the E302 experiment at the FACET-II facility.

Motivation

Emittance preservation and efficiency are crucial for next generation PWFAs.

- Need to mitigate transverse instabilities.
- Growth rate of transverse instabilities and efficiency inherently linked [3],

$$\text{->}\ \eta_t = \frac{\eta_p^2}{4(1-\eta_p)}.$$

η_t -> Ratio between transverse force and focusing force.

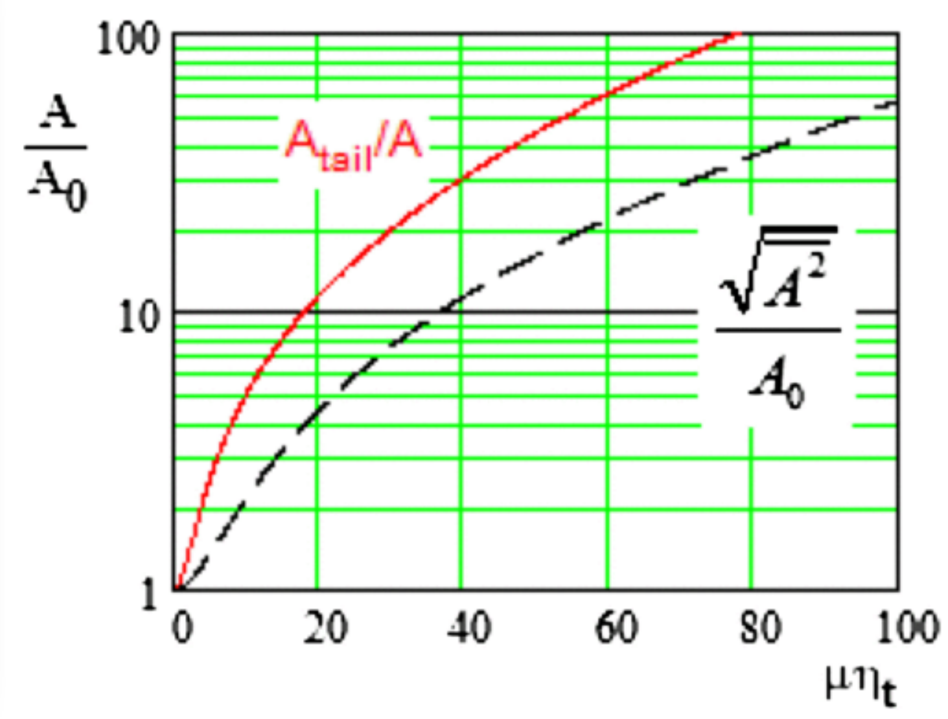
η_p -> Power transfer efficiency from driver to witness.

FACET-II facility

- High-energy electron beam facility at SLAC (California, USA).
- Upgraded from FACET.
- 10 GeV electron bunches.
- Laser-ionized plasma.
- Emittance reduced by two orders of magnitude from FACET [1].
- Exchangeable gas species.

The E302 experiment

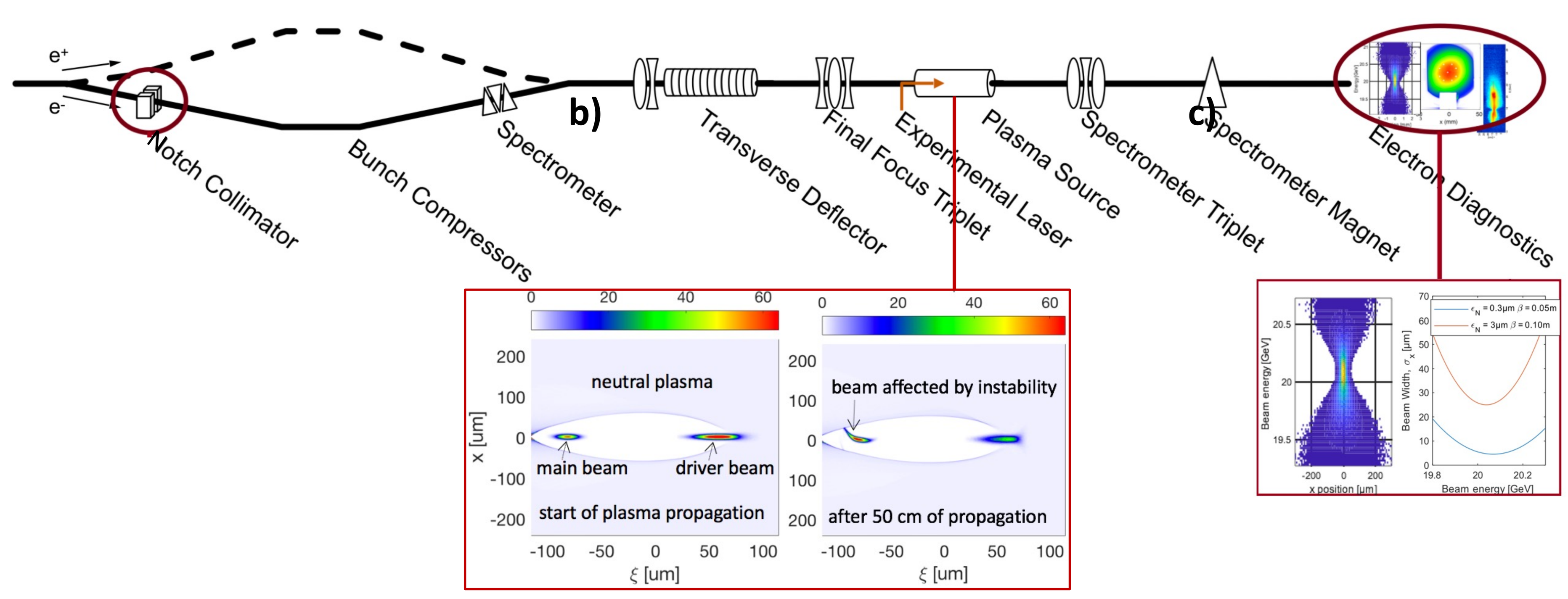
- Study transverse instabilities in a beam-driven PWFA.
- Will measure instability growth rate using transverse profile of the trailing beam at the spectrometer screens.
- Record efficiency by measuring bunch charge and energy before and after acceleration.



Tail and rms amplitude growth versus betatron phase advance times normalised transverse wakefield strength. Image credit: Ref. [3]

Imaging spectrometer

- Point-to-point imaging: cancelling the effect of angular kicks and divergence from the plasma stage.
- FACET-II spectrometer [1]:
  - Focusing quadrupole triplet and dipole magnet.
  - In-vacuum OTR and phosphor screens.
  - 4 micron spatial resolution and 0.4% energy resolution.
- Imaging effects must be taken into account when measuring the transverse instabilities.

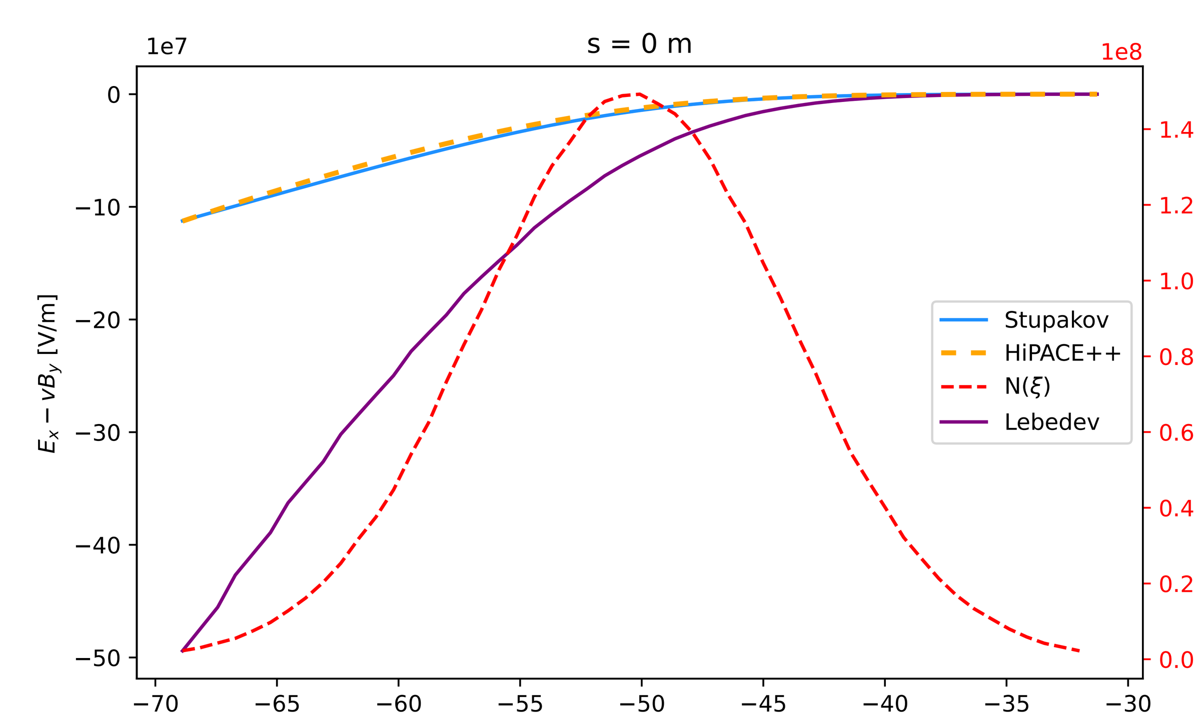


Predicting the transverse wakefields

We compare Stupakov's [2] formalism $W_r(\xi'-\xi,\alpha) = \frac{2}{\pi\epsilon_0}\frac{(\xi'-\xi)}{(r_b(\xi')+\alpha k_p^{-1})^4}\theta(\xi'-\xi)$

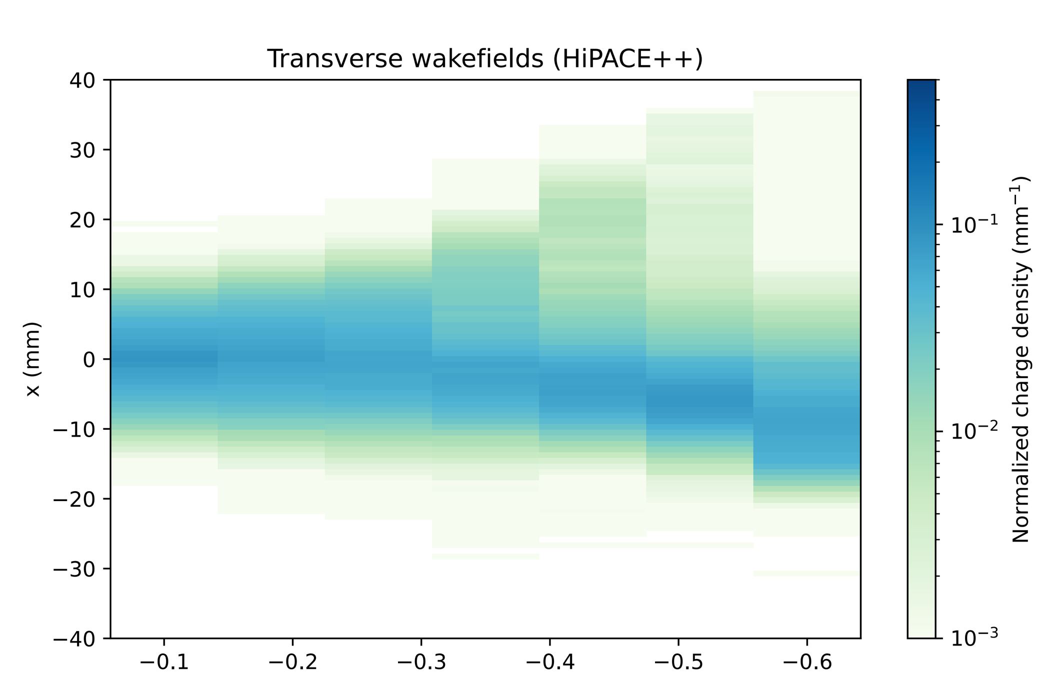
and Lebedev's [3] $$W_r(\xi'-\xi) = \frac{2}{\pi\epsilon_0}\frac{(\xi'-\xi)}{r_b(\xi')^3 r_b(\xi)}\theta(\xi'-\xi),$$

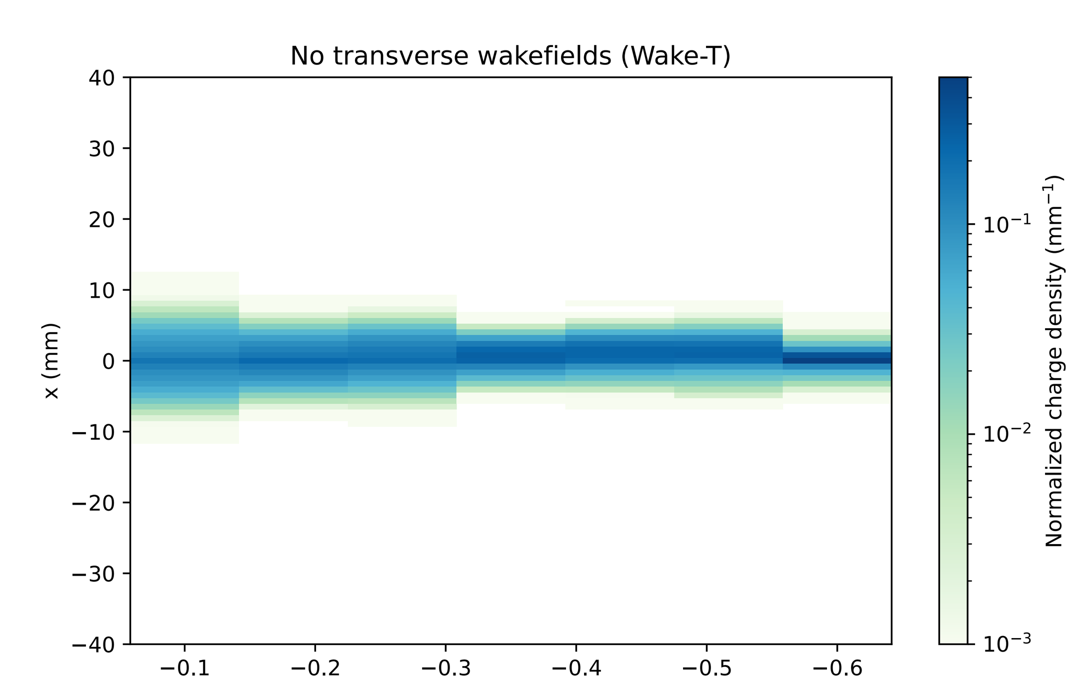
to predict the transverse wakefields for a simulation using similar values to those available at FACET-II [1]. Using the quasi-static PIC code HiPACE++ we find a good agreement with the analytical model as shown here.



Simulation results

As part of planning the E302 experiment, we use a start-to-end simulation framework consisting of various PIC codes and reduced models to observe transverse instabilities from a misaligned trailing bunch with predicted FACET-II parameters and a simulated imaging spectrometer. We increase the charge of the trailing bunch to simulate an increase in efficiency and observe the difference in the transverse profile of the trailing bunch with and without transverse wakefields included in the model.





* Presenter

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[2] G. Stupakov. Short-range wakefields generated in the blowout regime of plasma-wakefield acceleration. Phys. Rev. Accel. Beams, 21:041301, Apr 2018.
[3] V. Lebedev, A. Burov, and S. Nagaitsev. Efficiency versus instability in plasma accelerators. Phys. Rev. Accel. Beams, 20:121301, Dec 2017.

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