Optimisation of high transformer ratio plasma wakefield acceleration at PITZ.

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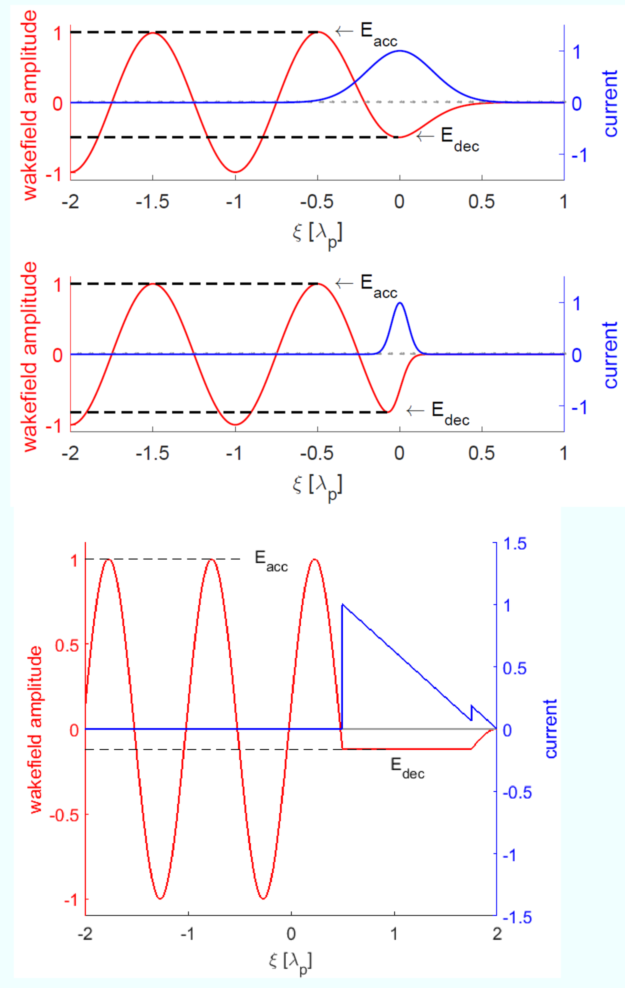
Abstract

The transformer ratio, the ratio between maximum accelerating field and maximum decelerating field in the driving bunch of a plasma wakefield accelerator (PWFA), is one of the key aspects of this acceleration scheme. It not only defines the maximum possible energy gain of the PWFA but it is also connected to the maximum percentage of energy that can be extracted from the driver, which is a limiting factor for the efficiency of the accelerator. Since in linear wakefield theory a transformer ratio of 2 cannot be exceeded with symmetrical drive bunches, any ratio above 2 is considered high.
After the first demonstration of high transformer ratio acceleration in a plasma wakefield at PITZ, the photoinjector test facility at DESY, Zeuthen site, limiting aspects of the transformer ratio are under investigation. This includes e.g. the occurrence of bunch instabilities, like the transverse two stream instability, or deviations of the experimentally achieved bunch shapes from the ideal. Experimental data as well as simulations are presented.

High transformer ratio PWFA

- Ratio between acceleration (witness) and deceleration (driver)
- Defines possible energy gain / necessary drive beam energy
- TR ~ Energy efficiency
- For symmetrical bunches limited < 2
- TR of ramped bunches ~ L_{bunch} / λ_p
- BUT: long bunches in PWFA subject to strong instabilities (SMI / TTS, Hosing)

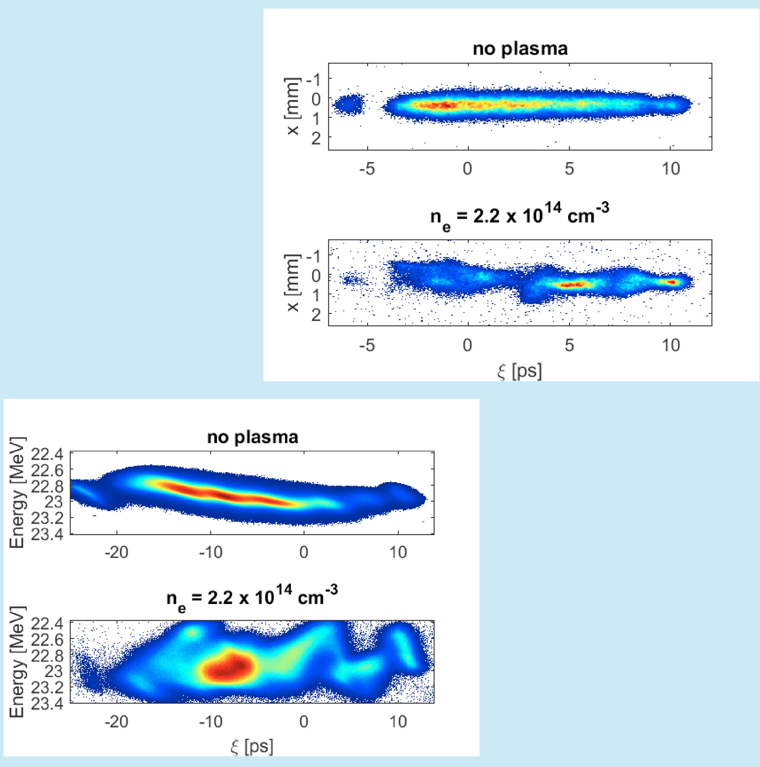


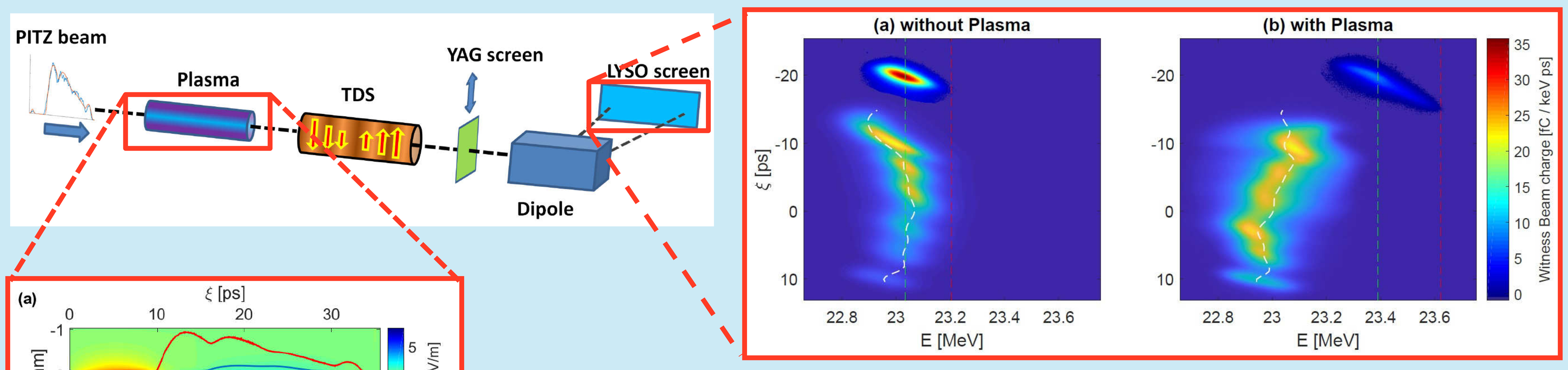
First demonstration of HTR PWFA

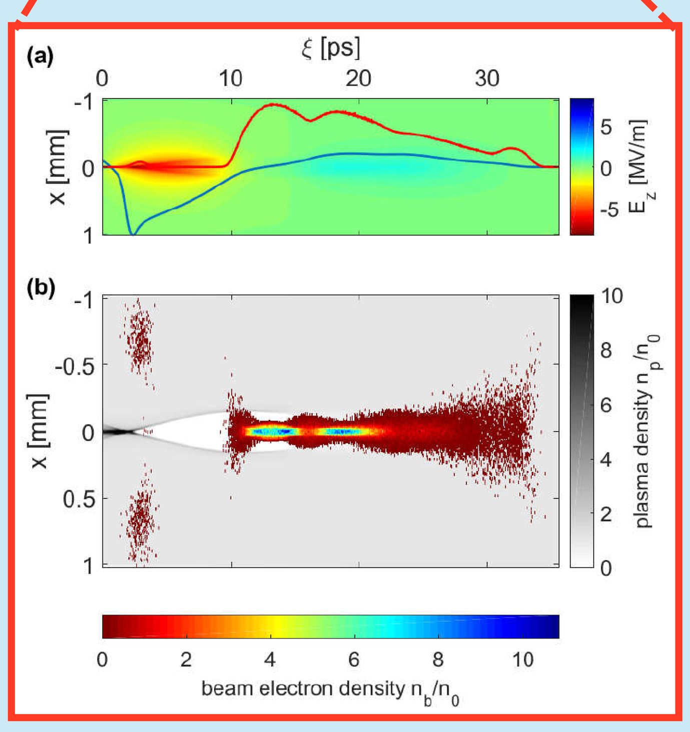
- Production of triangular bunches with new photocathode-laser based method

Loisch et al., Nucl. Instr. Methods Phys Res. A, in press, 2018

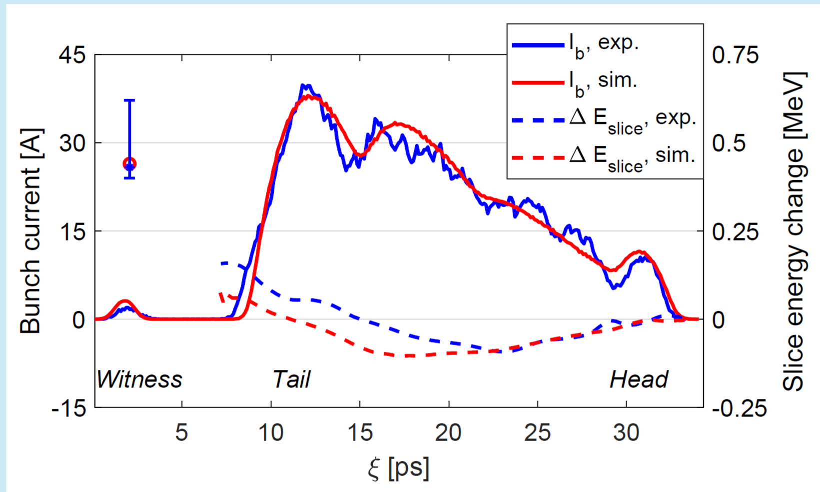
Observed instabilities for $\lambda_p << L_{bunch}$ (here: SMI)







- **Demonstrated transformer ratio of** $4.6^{+2.2}_{-0.7}$
- Mitigation of beam-plasma instabilities by operation in nonlinear regime
- bunch shapes not ideal due to complexity of current bunch shaping method implementation



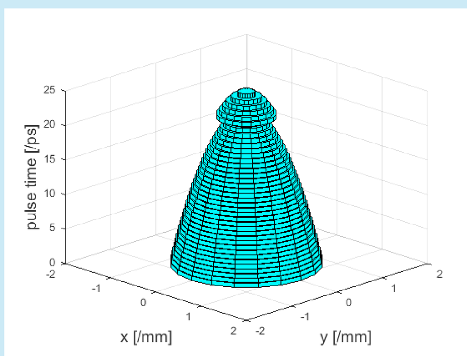
Loisch et al., subm. Phys. Rev. Lett. 2018

Increasing the transformer ratio

- Increasing TR is possible by:
  - Higher L_{bunch} / λ_p
    - higher n_p but still nonlinear interaction
    - → Better control of bunch slice parameters
  - Bunch shapes closer to ideal
    - Better control of bunch shape at linac end
    - → Higher shaping flexibility

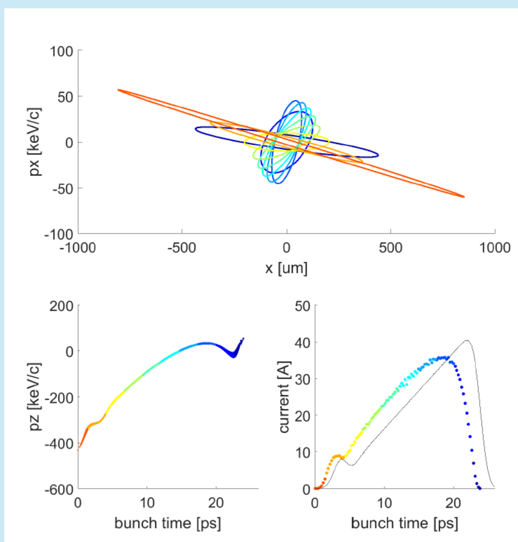
→ Need better bunch shape and slice phase space control
→ New laser shaping method based on spatial light modulators (SLM)
→ Control of longitudinal and transverse laser pulse shape

See also WEPMF059

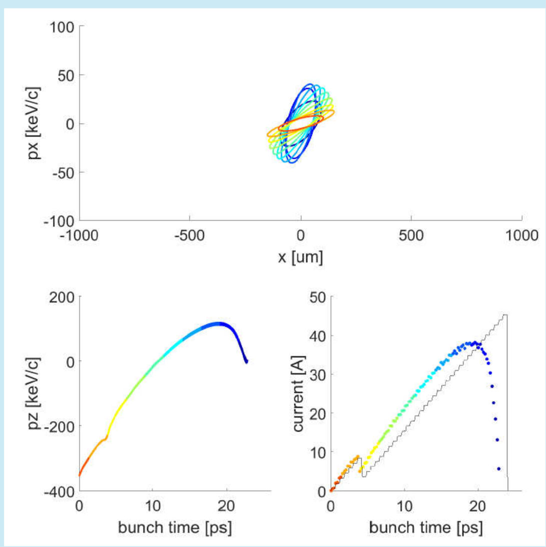


Assumed possible laser pulse/ bunch shape with SLM-based shaping

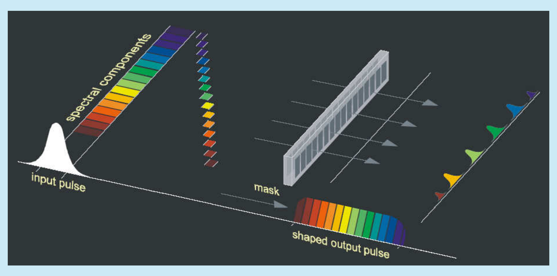
Phase space simulation for current, crystal based shaping



Phase space simulation for SLM-based bunch shaping



SLM based shaping principle



Outlook

- Demonstration of stable transport of HTR-capable bunches allows planning future PWF accelerators
- Measure dependency of TR on bunch shapes
- Improved photocathode-laser based bunch shaping will allow high energy HTR PWFA

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PITZ Photo Injector Test Facility Zeuthen