Employing double-achromats for plasma-wakefield acceleration

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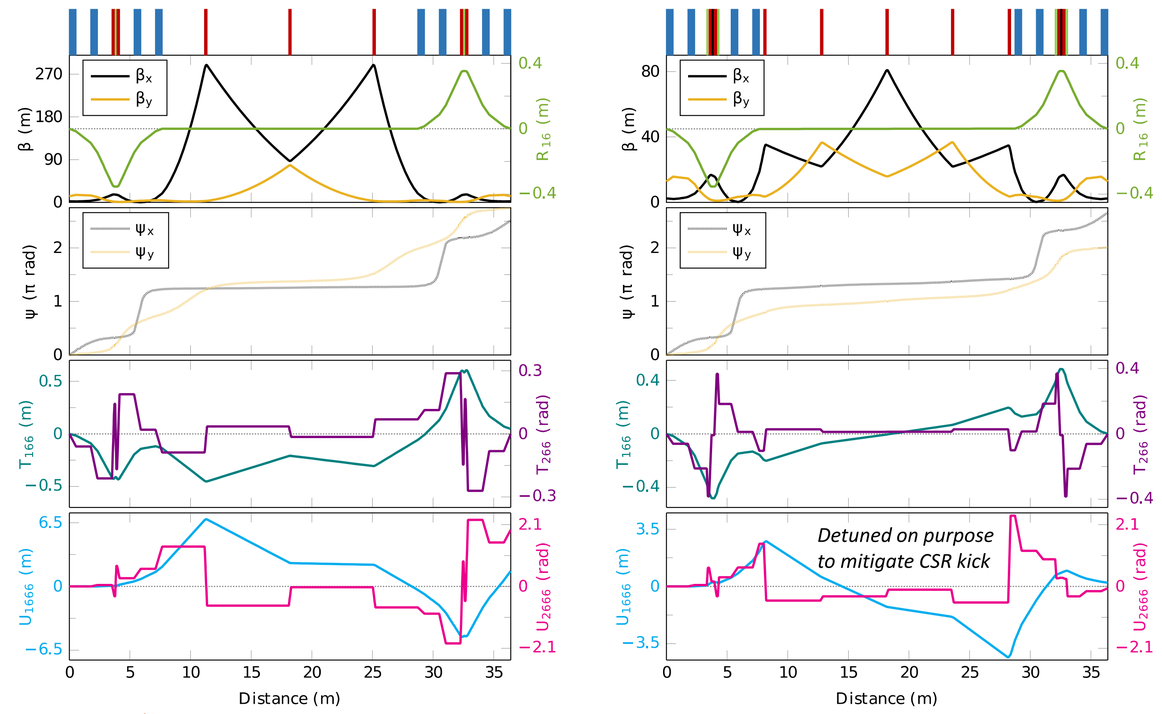
Introduction

Beam-driven plasma-wakefield acceleration (PWFA) is an acceleration scheme promising accelerating fields of at least two to three orders of magnitude higher than in conventional radiofrequency accelerating structures. The scheme relies on using a charged particle bunch (driver) to drive a non-linear plasma wave, into which a second bunch (witness) can be injected (internally or externally) to receive a boost in energy.

A current challenge for PWFA, particularly when moving toward low-emittance beam drivers, will be to avoid the beam hose instability. Here, an offset, or tilt, of the beam with respect to its propagation axis can induce large oscillations along the beam which can disturb or destroy the wake. Such offsets can be generated by leaking higher-order transverse dispersion from e.g. bunch compressors, as well as coherent synchrotron radiation (CSR) in any dipole magnet.

We have improved upon the concept of double-achromat bunch compressors to close the higher-order dispersion and mitigate CSR kicks, making them a very suitable candidate for e.g. future PWFA machines.

Improved compressor design



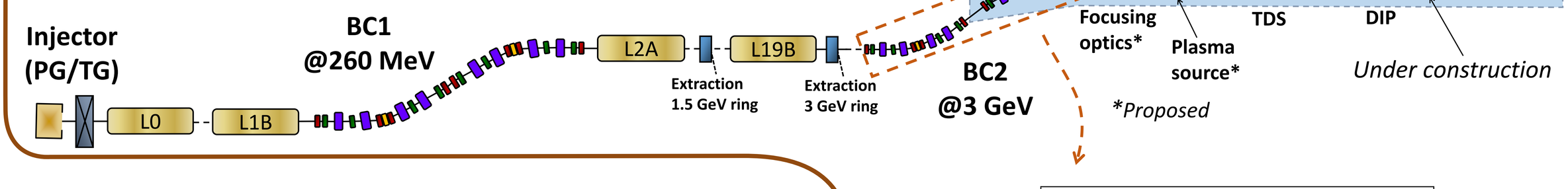
Changes

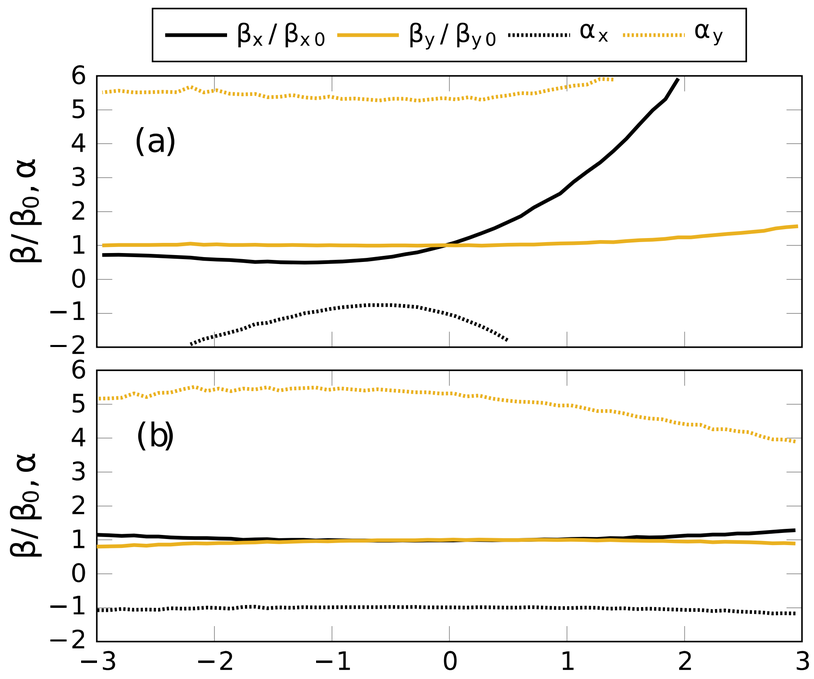
2 QP's added in straight section - control of e.g. phase advance and chromaticity
1 SXP family added per achromat, original SXPs moved - control of second-order terms
1 OCT family added to achromat center - some control of third-order terms

Higher-order dispersion can be tuned to mitigate CSR kicks

The MAX IV Linac

The MAX IV Linac is a warm S-band electron linac, nominally providing beams at ≳3 GeV, at an emittance of <1 mm mrad, bunch duration of <100 fs and charge of 100 pC nominally. Compression is done using two double-achromat bunch compressors and longitudinal phase space linearization is done using the optics alone.

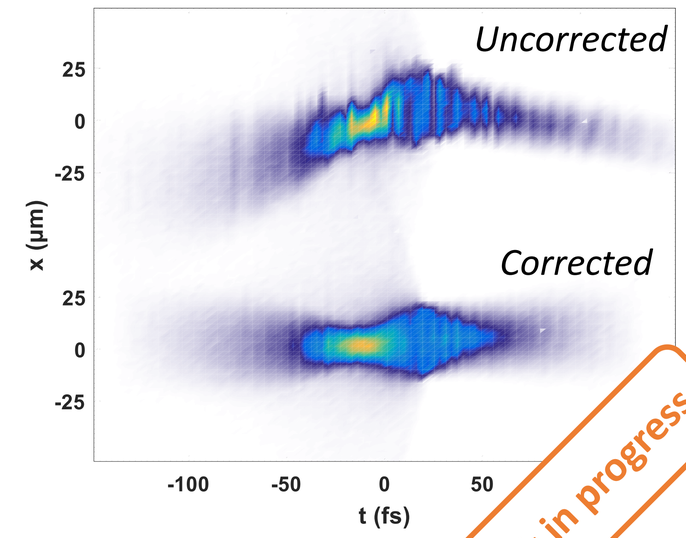




Twiss function response of BC2. Additional quadrupoles decrease chromaticity.

Start-to-end simulation

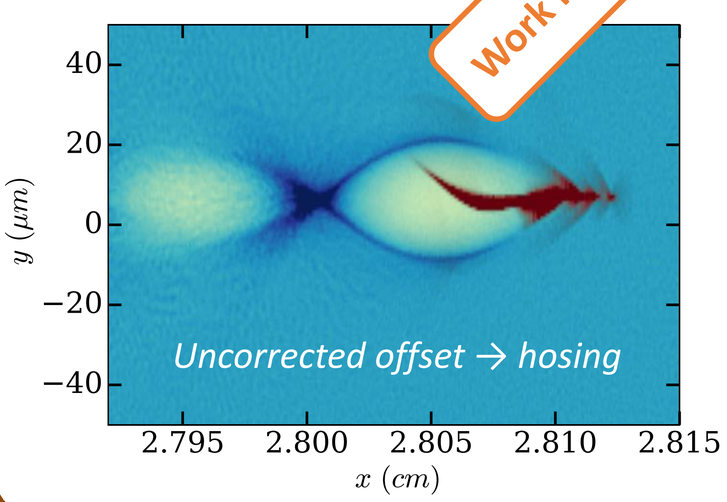
Start-to-end simulations are being performed using ASTRA, Elegant and CALDER 3D, for the photocathode gun, accelerator and beam-plasma interaction, respectively. The single-bunch beam has 200 pC of charge, compressed to 80 fs fwhm for a peak current of 2.2 kA. The focused spot size at the plasma entrance is 10 μm fwhm.



Beams at BC2 exit

Time (energy) dependent beam width from chromatic aberrations in upstream optics. Correcting this is on the to-do-list.

Work in progress



PIC simulation of beam-plasma interaction

Plasma density
$n_e = 1 \times 10^{17}$ cm^{-3}
2.8 cm into plasma
Simulations with corrected beam currently under way

Conclusions

Owing to the higher-order achromatic and quasi-apochromatic properties, in combination with the possibility to optically mitigate CSR kicks and tune the bunch current profile, double-achromat bunch compressors could be a useful tool for demanding applications, such as future PWFA machines. Simulations are currently ongoing with the aim to demonstrate the feasibility of the MAX IV linac as a driver for a PWFA experiment, as well as a general demonstration of the capabilities of the improved double-achromat bunch compressors.

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