Optimization and transport of electron beam for self-modulation experiments at PITZ.

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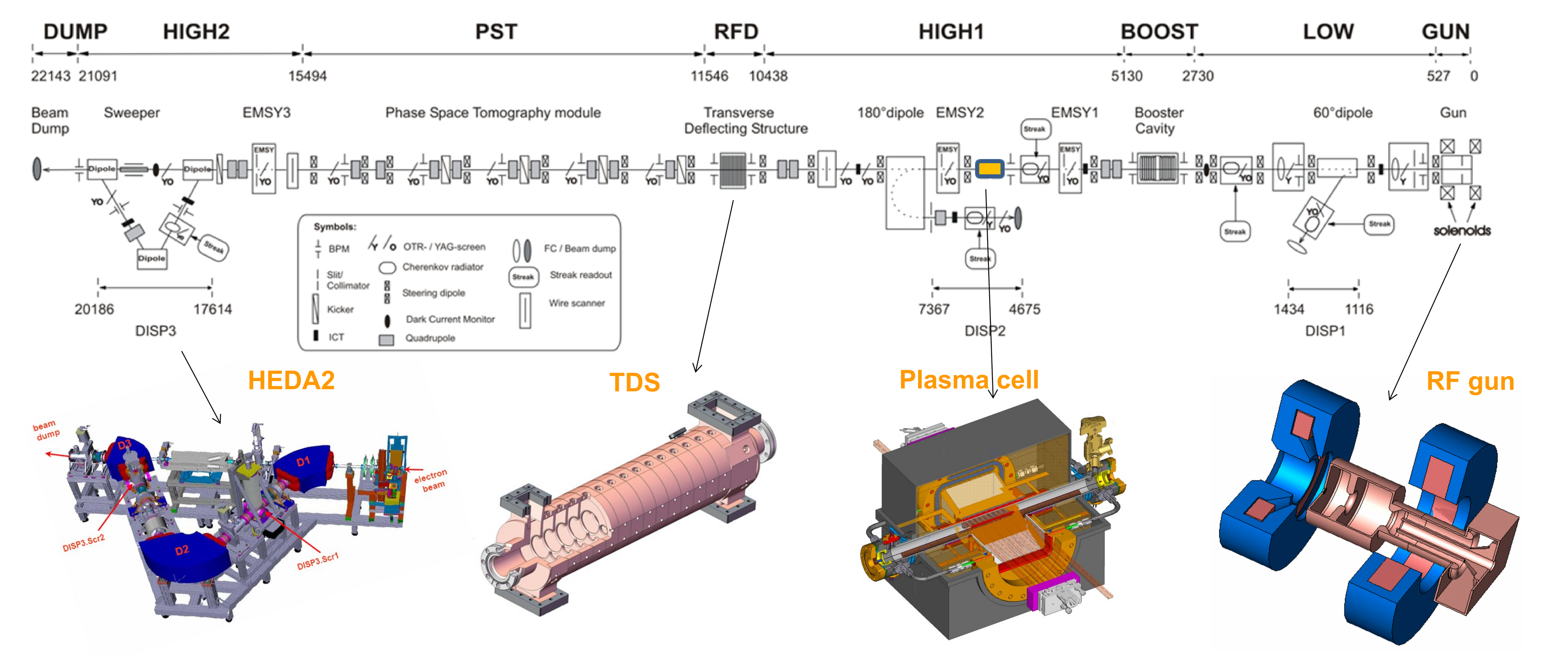
Introduction

The Photo Injector test facility at DESY, Zeuthen site (PITZ) is generating and optimizing high brightness electron sources for linac based free electron lasers such as the European XFEL. Beside the different measurements related to the characterization of the high quality electron beams, the self-modulations experiments are planned to be carried out at PITZ. Such experiments will be the first demonstration of the so called self-modulation effect where the long electron bunch (bunch length much longer than the plasma wavelength) gets energy (density) modulated by the interaction with plasma. The period of above mentioned modulations is in the order of the plasma wavelength. In this work start-to-end simulations have been performed for an electron bunch starting from the cathode up to the point of beam longitudinal phase space measurements. The simulations were carried out in different steps. In the first part the electron beam was matched to the point for beam-plasma interaction. Next the plasma simulations have been performed proving the existence of the self-modulation effect. The electron bunch was afterwards transported along the whole PITZ beamline to the HEDA2 section for phase space measurements. The results of such studies as well as remaining challenges are presented and discussed.



PITZ setup for self-modulation studies (e-beam propagation from the right to the left).

Self-modulation: Setup and electron beam longitudinal phase space

Aims / requirements for self-modulation studies

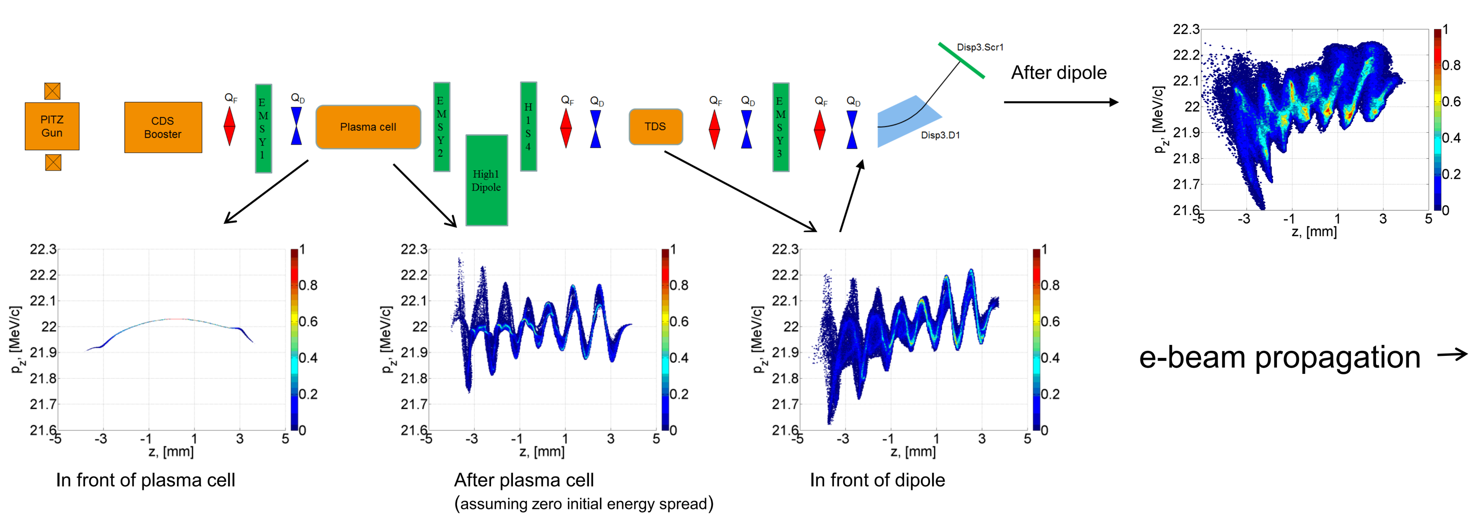
Requirements for 100 pC electron beam:

- Smooth beam transverse focusing at the entrance / middle of plasma cell (z = 6.25 m)
- Transverse beam rms size while entering plasma → $\sigma_{xy} = \sqrt{\sigma_x \cdot \sigma_y} \leq 50\mu m$
- Beam output after plasma (simulations by Alberto) → input for further beam transport up to HEDA2
- Vertical beam size through TDS (~11 m) → as small as possible induced energy spread by TDS
- Horizontal phase space while entering Disp3.Dipole1 (~17.2 m) → best momentum resolution
- Vertical beam size at Disp3.Scr1 (~18.6 m) → best temporal resolution

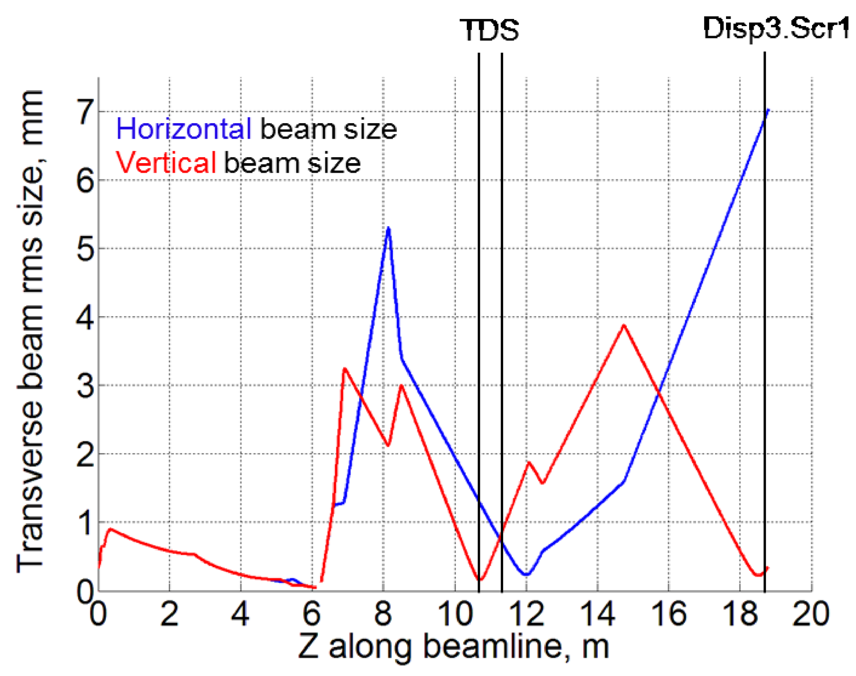
Simulation setup:

- Laser: Longitudinally flat-top → 2/22\2 ps. Transverse rms spot size on the cathode → 0.3 mm
- Gun: Gradient of 61 MV/m (6.73 MeV/c after gun at on-crest phase), phase fixed to on-crest
- Booster: Gradient of 17.5 MV/m (22 MeV/c final beam momentum for gun and booster on-crest phases), phase fixed to on-crest
- Solenoid scan for e-beam focus on EMSY1 (Z=5.34 m)
- Many quadrupoles for further beam transport until HEDA2
- 100pC charge (200kp in ASTRA)

PITZ setup of self-modulation



Setup of self-modulation experiments at PITZ.

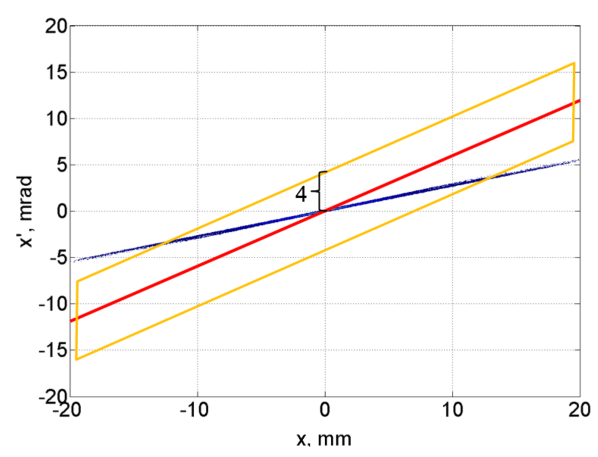


Beam transport for beam-plasma interaction and further matching for LPS measurements.

- ❑ Slight readjustment of quadrupole currents needed to get an electron beam waist at Z=6.25 m
- ❑ Plasma simulations should be done assuming non-zero beam energy spread
- ❑ Beam transport after plasma until HEDA2 still can be improved:
  - a. Better vertical beam matching in TDS
  - b. Special beam orientation in horizontal phase space for as good as possible momentum resolution

Resolution issues due to the beam transport for phase space measurements

Momentum resolution



$$x_1 = R_{11}x_0 + R_{12}x'_0 + D\delta p_0$$

$R_{11} = -0.516$

$R_{12} = 0.867$

$D = 0.905$

$$|R_{11}x_0 + R_{12}x'_0| < D\delta p_0$$

$$x' = x\frac{R_{11}}{R_{12}} = 0.595x$$

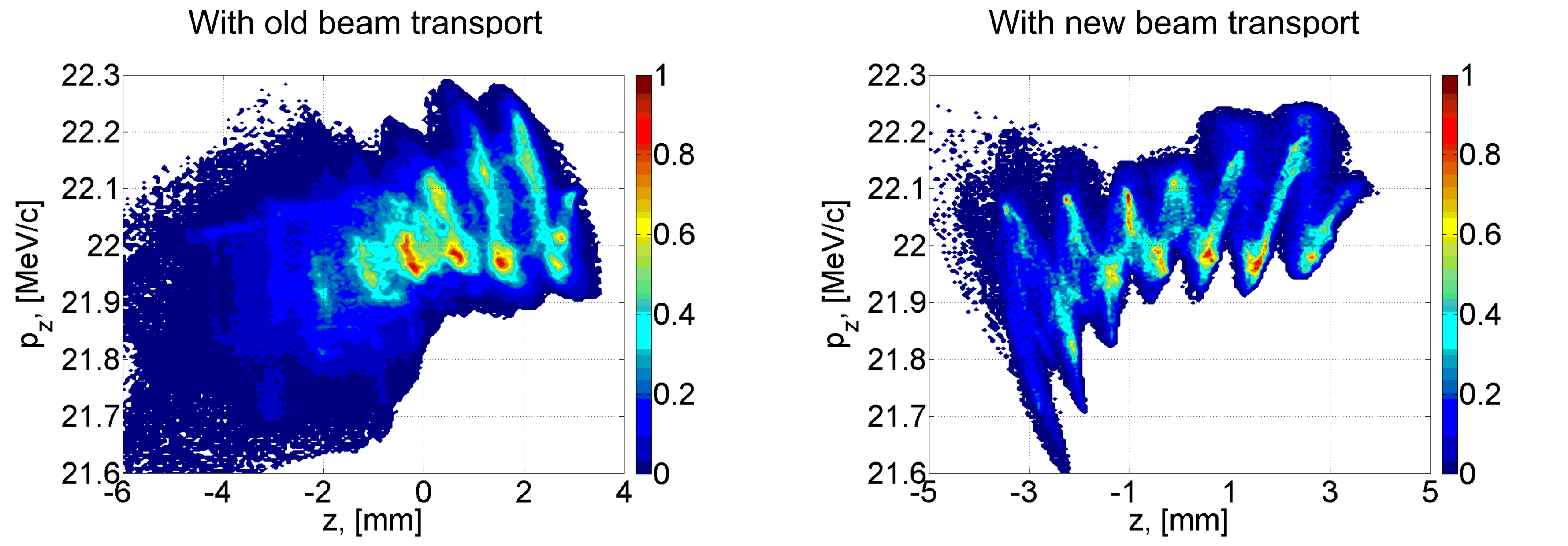
Current case → $x' \approx 4 \cdot 10^{-3} \Rightarrow \delta p_0 = x'\frac{R_{12}}{D} \approx 3.8 \cdot 10^{-3} \Rightarrow \Delta p = \delta p_0 \cdot p_0 \approx 84\, keV/c$

Best case → $x' \approx 0.2 \cdot 10^{-3} \Rightarrow \Delta p = \delta p_0 \cdot p_0 \approx 1\, keV/c$

Temporal resolution

Temporal resolution → $\delta z = \frac{\varepsilon_y}{\sigma_y \cdot \sin(\varphi_{y)}} \cdot \frac{p_0 c}{eV_0 k} \Rightarrow \delta z \approx 0.2mm$

TDS induced momentum spread → $\delta p = \frac{eV_0 k}{p_0 c}\sigma_y \Rightarrow \Delta p \approx 37\, keV/c$



Simulated electron beam longitudinal phase space at the point of measurement.

Summary

Start-to-end simulations have been done for the PITZ setup proving the principle of self-modulation for long electron bunches. The picture of electron beam longitudinal phase space was significantly improved with respect to the previous studies. Studies are ongoing in order to simulate the beam behaviour in plasma assuming non-zero energy spread. The momentum and temporal resolutions estimated from the current beam transport setup were found to be ~ 100 keV/c and ~ 0.2 mm correspondingly. More accurate studies are to be performed in order to improve the resolution (momentum as well as temporal) of beam phase space measurements planned for the upcoming year.

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