Start-to-end simulations of the self-modulation experiment at PITZ

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**Photo Injector Test facility @DESY Zeuthen site**

**Self-modulation experiment layout**

- Flexible photocathode laser system
  - Arbitrary longitudinal pulse shape
  - Up to 24 ps FWHM long, 2 ps fronts
- Electron beam momentum up to 25 MeV/c after Booster
- Electron beam charge up to 5 nC
- Longitudinal phase space measurement employing a transverse deflecting cavity (TDS) and a dipole spectrometer. Temporal resolution up to 0.3 ps, momentum resolution up to 10 keV/c
Next generation plasma cell

Entrance electron window: 0.9 \text{ um} \mu \text{m} \text{ PET foil coated with 37.5 nm Al both sides}
SMI Experimental Results: 1) Time Resolved Beam

- The first direct time-resolved experimental observation of a self-modulated electron beam

Q=970 pC
Plasma density: $\approx 10^{14}$ cm$^{-3}$
Simulations of the SMI experiment at PITZ | Osip Lishilin | 2018-03-22

SMI Experimental Results: 2) Longitudinal Phase space

- Momentum modulation with 200 keV/c amplitude

Q=970 pC
Plasma density: $\approx 1.3 \times 10^{14} \text{ cm}^{-3}$
SMI Experimental Results 3): Self-Modulation vs plasma density

- Measured time resolved electron bunch for different delays of the electron bunch arrival time relative to the ionization laser pulse

**Gross et al., accepted for publication at Physical Review Letters**
Start-to-end simulations

Astra+HiPACE

- ASTRA: tracking from cathode plane to the plasma cell
- HiPACE: beam-plasma interaction
- ASTRA: tracking the electron beam to the measurement stations
Focusing into the plasma

Imain = 385 A

Imain = 393 A

Imain = 396 A
Beam evolution

Imain = 385 A. The beam head is overdense -> nonlinear field evolution

Imain = 393 A. The beam is overdense -> plasma focusing, SMI is suppressed

Imain = 395 A. The beam density is relatively homogeneous -> SMI is developed
The overfocused beam behaves as predicted by the SMI theory

Simulations of the measurements

PST.Scr1:
\[ \sigma_{xy} = 0.343 \text{ mm} \]

High2.Scr2:
\[ \sigma_x = 0.39 \text{ mm} \]
\[ \sigma_y = 0.44 \text{ mm} \]
Summary

- Simulations demonstrate:
  - Three regimes of beam-plasma interaction are possible for the experimental conditions
  - Measurements downstream the plasma cell reflect beam properties and allow to distinguish these regimes
- Combination of the longitudinal beam profile and longitudinal phase space measurements indicate on the self-modulation instability
- This summer: experiment with a higher plasma density and a variable plasma channel length (direct observation of the saturation length)