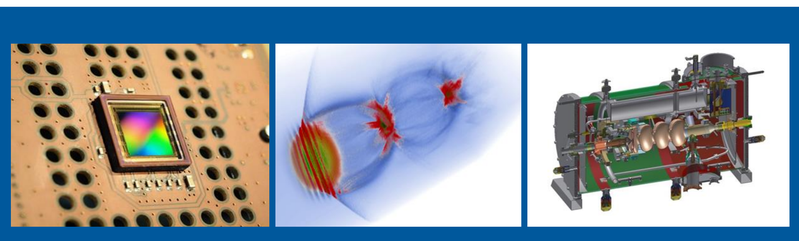
Program Matter and Technologies

Studies of Longitudinal Dynamics in the Micro-Bunching Instability using Machine Learning



T. Boltz*, M. Brosi, E. Bründermann, P. Schönfeldt, M. Schwarz, M. Yan, A.-S. Müller

*tobias.boltz@kit.edu

Motivation

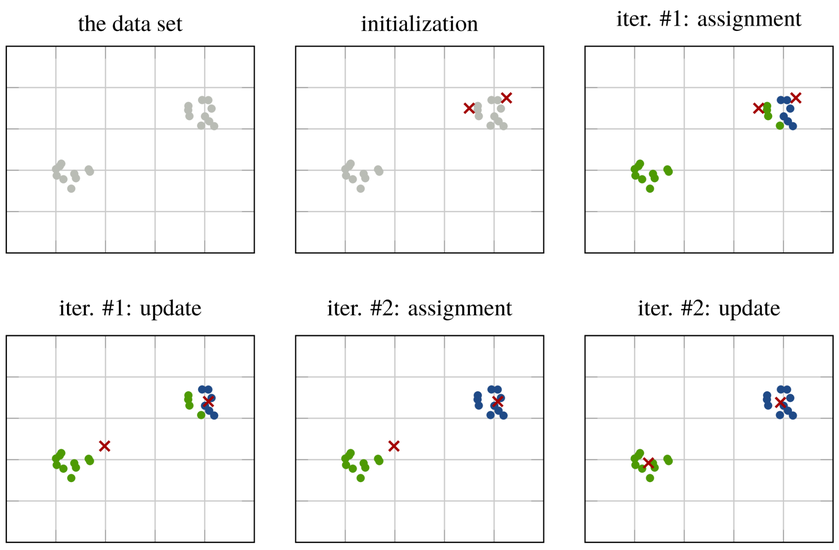
Introduction

Due to the self-interaction with its own coherent synchrotron radiation (CSR), short electron bunches in a storage ring are subject to complex longitudinal dynamics. Above a given threshold current, this results in the formation of dynamically changing, but persistent, micro-structures within the electron bunch. As the longitudinal charge distribution varies, this also leads to major fluctuations in the emitted CSR power and is thus called micro-bunching instability.

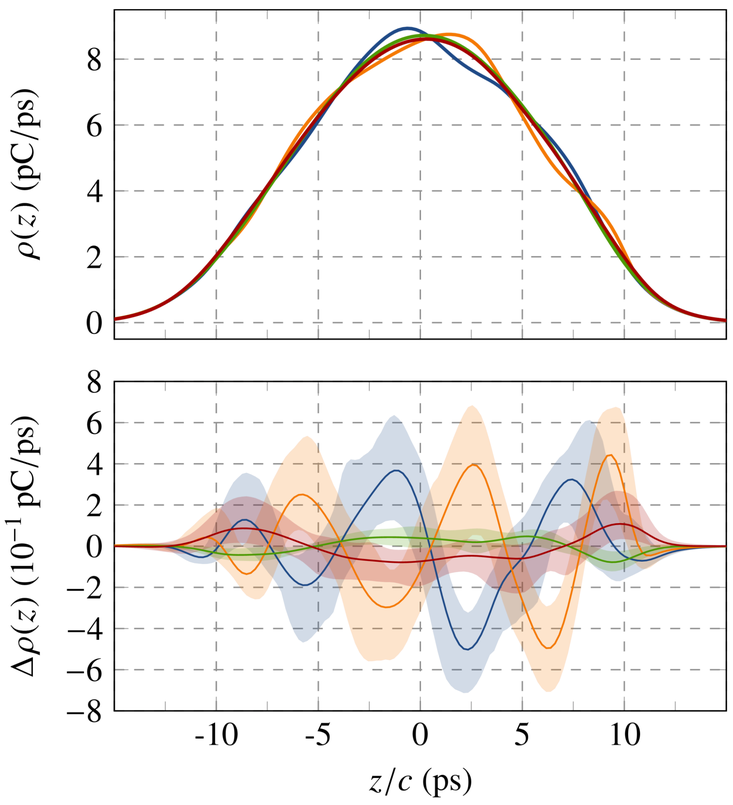
This contribution focuses explicitly on the longitudinal dynamics above the threshold current and places special emphasis on the characteristics of the occurring micro-structures. Therefore, the dynamics are simulated across multiple bunch currents using the in-house developed Vlasov-Fokker-Planck solver *Inovesa* [1].

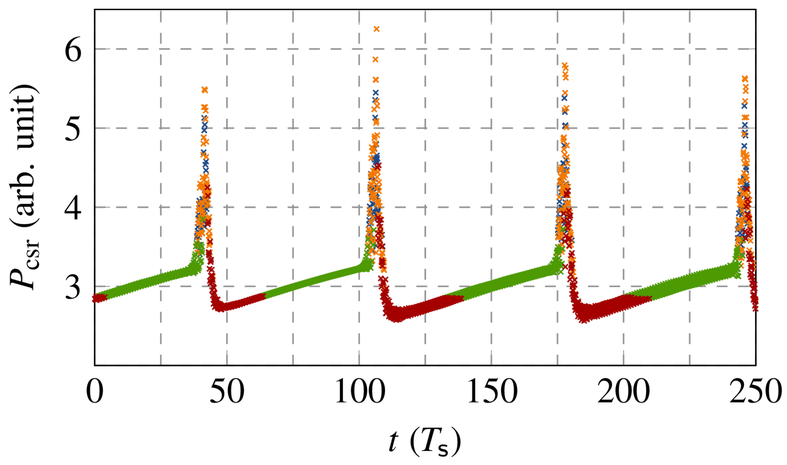
Application of Clustering Method *k*-means

- Data sets of terabytes in size
- Identification of dominant micro-structures
- Cluster centers can be used as reasonable representatives
- Aimed at describing the longitudinal dynamics by merely a few discrete states



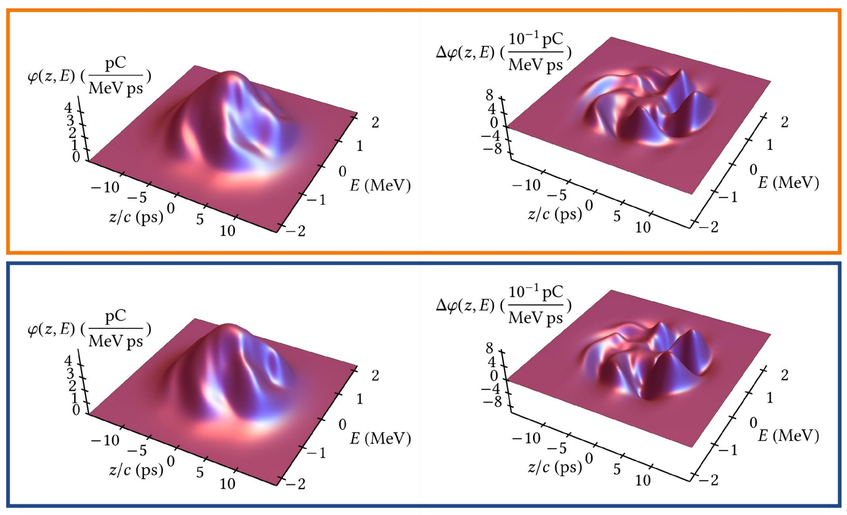
Analysis of Micro-Structure Dynamics





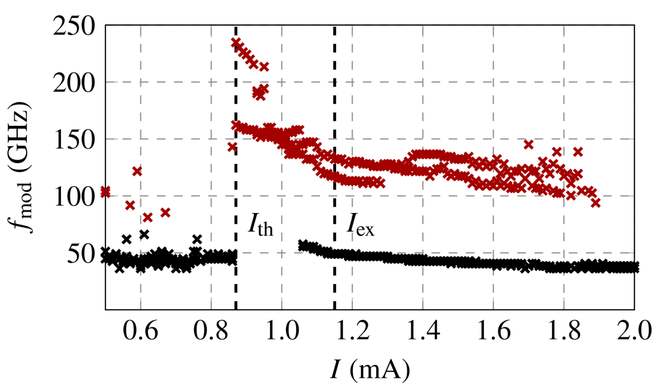
- Blue & orange cluster: phase and paraphase of an almost sinusoidal modulation on the longitudinal profiles
- Red & green cluster: describe mainly changes in bunch length
- Shaded areas denote the standard deviation within the respective cluster

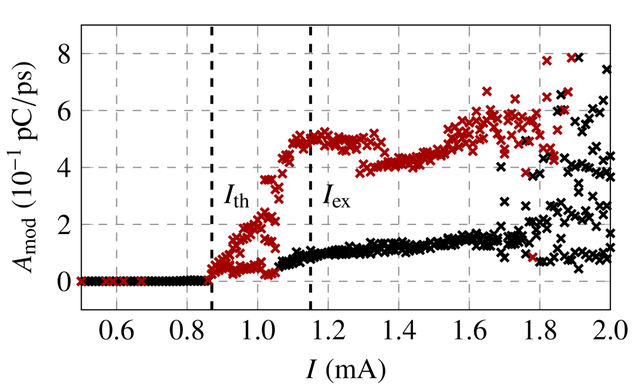
- Micro-structures of high amplitude coincide perfectly with bursts of emitted CSR
- Modulations on the longitudinal profiles correspond to distinct micro-structures in phase space



A more detailed discussion can be found in [2].

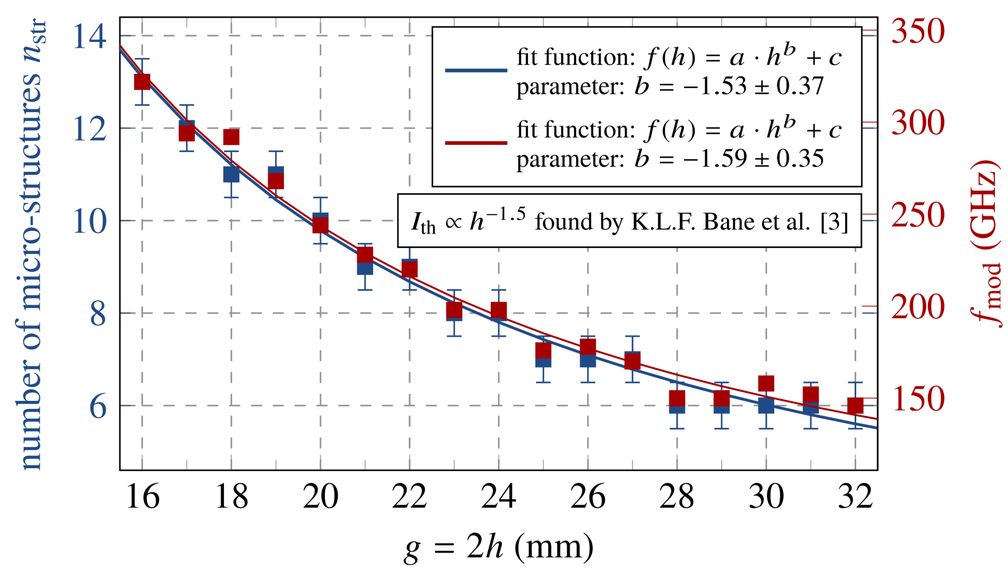
Micro-Structure Characteristics





- Modulation frequencies at 50 GHz correspond to changes in bunch length
- Slightly decaying (mainly due to bunch lengthening) higher modulation frequencies indicate constant number of micro-structures in phase space across different bunch currents above the threshold
- Modulation amplitudes start rising exactly at threshold current and eventually reach a saturation value at roughly 1.1 mA
- Changes in bunch length lead to relatively small modulation amplitudes until higher currents are reached

- Machine parameters can influence micro-structures
- Number of micro-structures shows interestingly a similar dependence on the vacuum gap as found for the threshold current by K.L.F. Bane et al. [3]
- Observed steps indicate an intrinsic discretization of the occurring micro-bunching



[1] P. Schönfeldt et al., *Phys. Rev. Accel. Beams* **20**, 030704 (2017)
[2] T. Boltz, Master's Thesis, doi: 10.5445/IR/1000068253 (2017)
[3] K.L.F. Bane et al., *Phys. Rev. ST Accel. Beams* **13**, 104402 (2010)

MT ARD | KIT Karlsruhe Institute of Technology | HELMHOLTZ RESEARCH FOR GRAND CHALLENGES