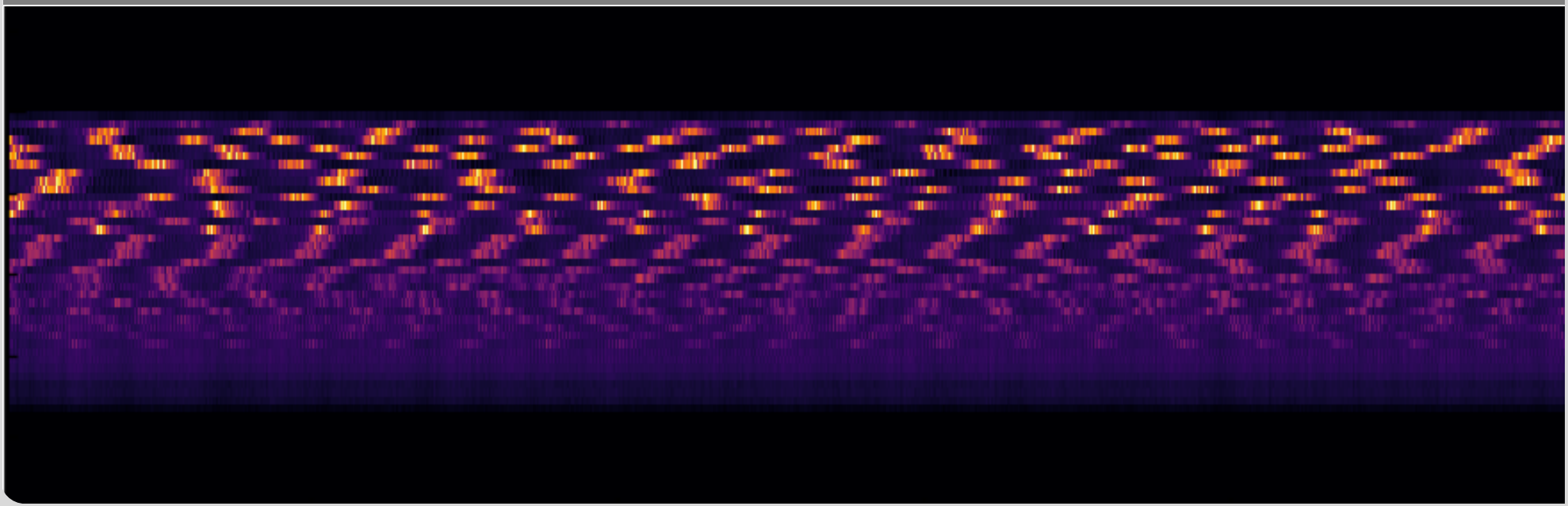
Karlsruhe Institute of Technology

MT ARD | MT DTS

Synchronous Studies of the Longitudinal Micro-Bunching Instability at KARA

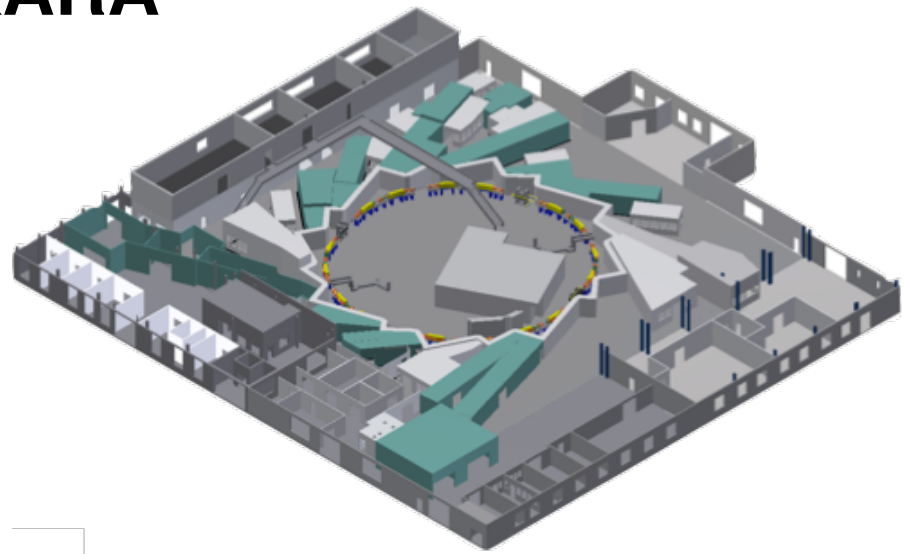
Miriam Brosi, T. Boltz, E. Bründermann, S. Funkner, B. Kehrer, G. Niehues, M.J. Nasse, M.M. Patil, P. Schreiber, J. L. Steinmann and A.-S. Müller | October the 17th, 2019

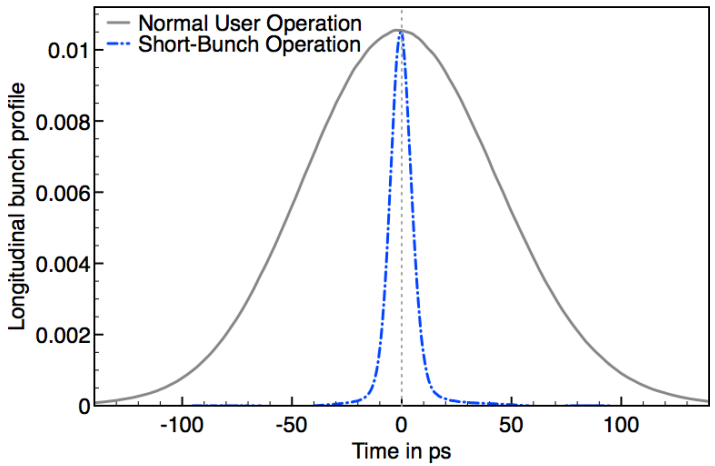
INSTITUTE FOR BEAM PHYSICS AND TECHNOLOGY (IBPT)



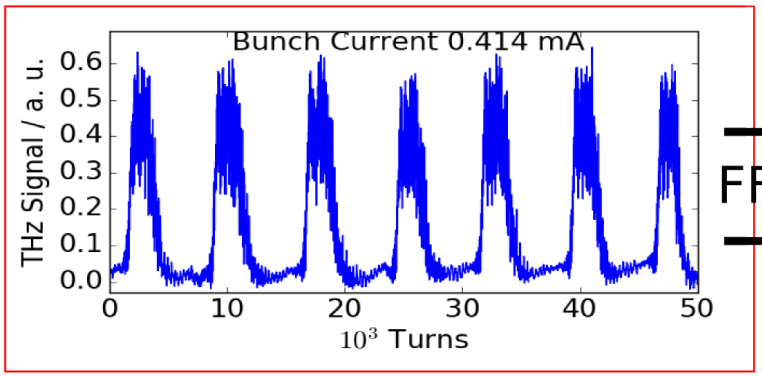
Introduction: short-bunch operation at KARA

- Circumference: 110.4 m
- Revolution frequency: 2.715 MHz
- RF-frequency: 500 MHz
- Filling pattern: single- or multi-bunch (min. bunch spacing 2 ns)
- Energy: 0.5 - 2.5 GeV (1.3 GeV during short-bunch mode)
- RMS bunch length: 45 ps (for 2.5 GeV), down to a few ps (for short-bunch mode at 1.3 GeV)
- Generation of coherent synchrotron radiation (CSR)
  $\Rightarrow$ Micro-bunching instability





Micro-bunching instability



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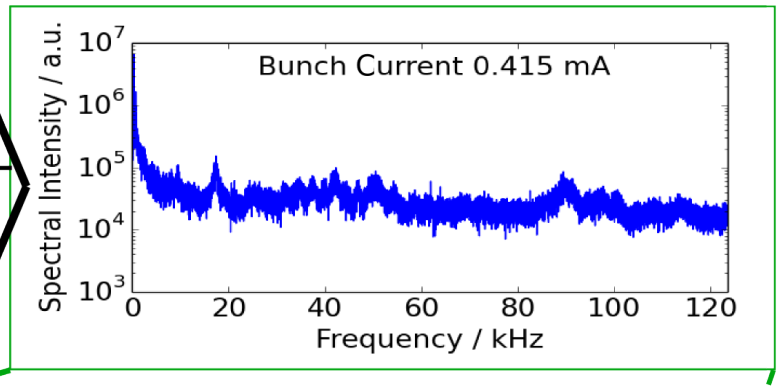
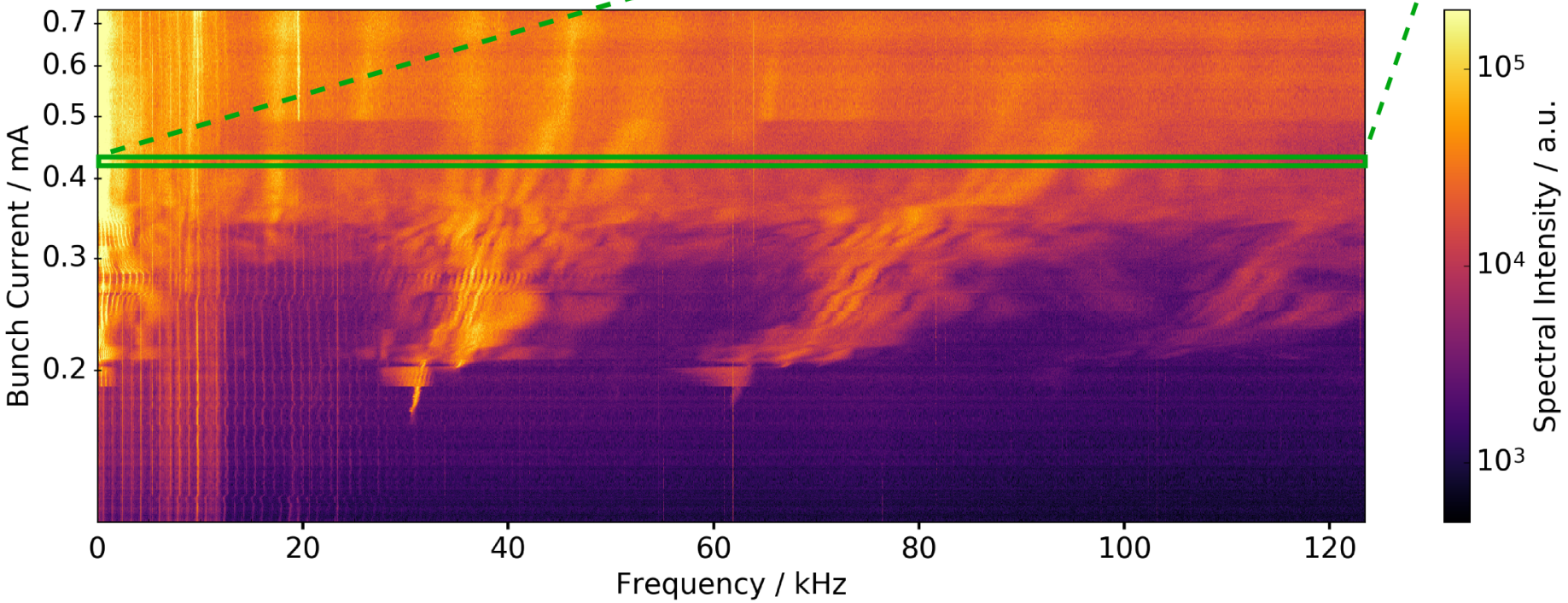
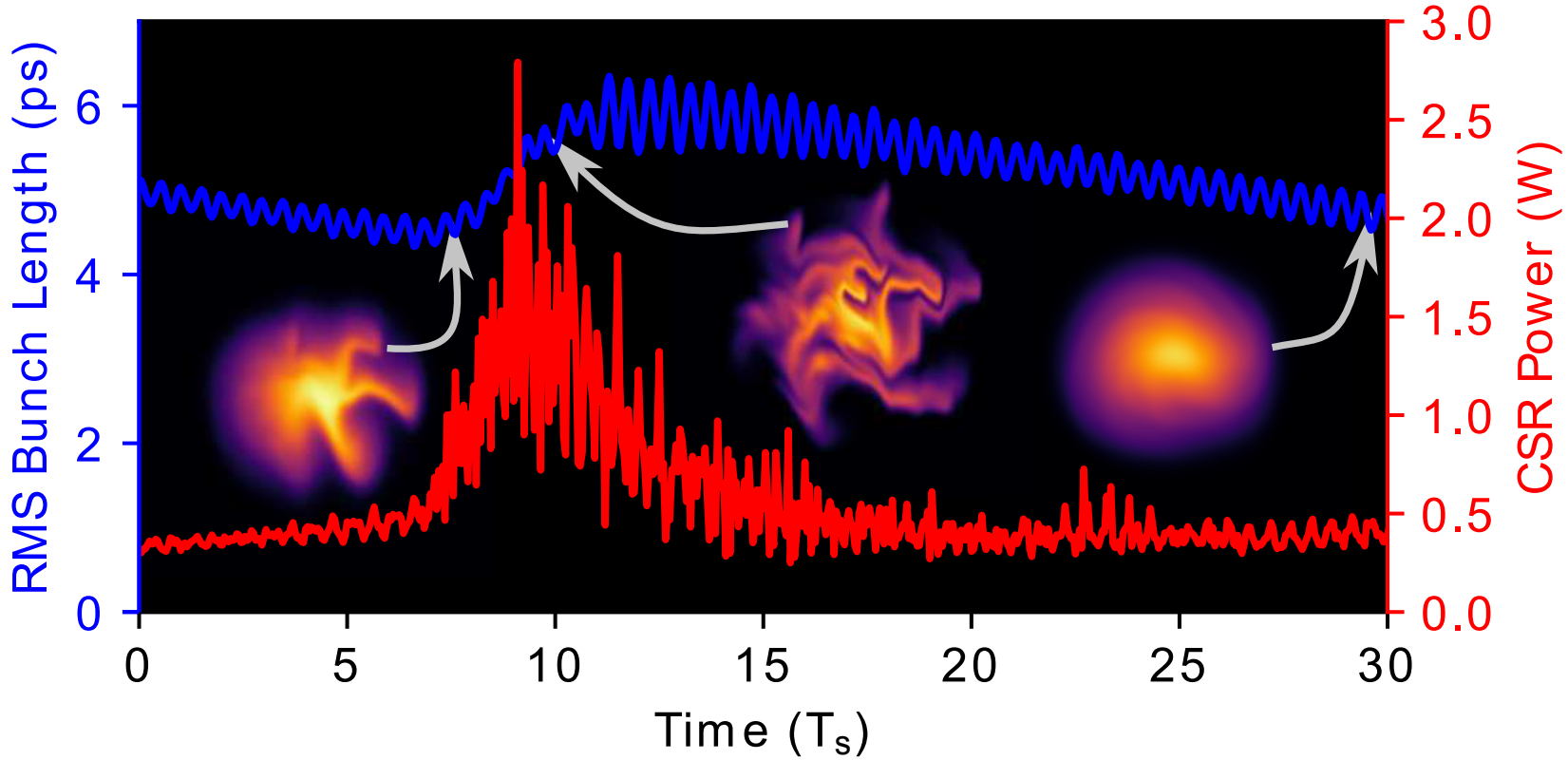




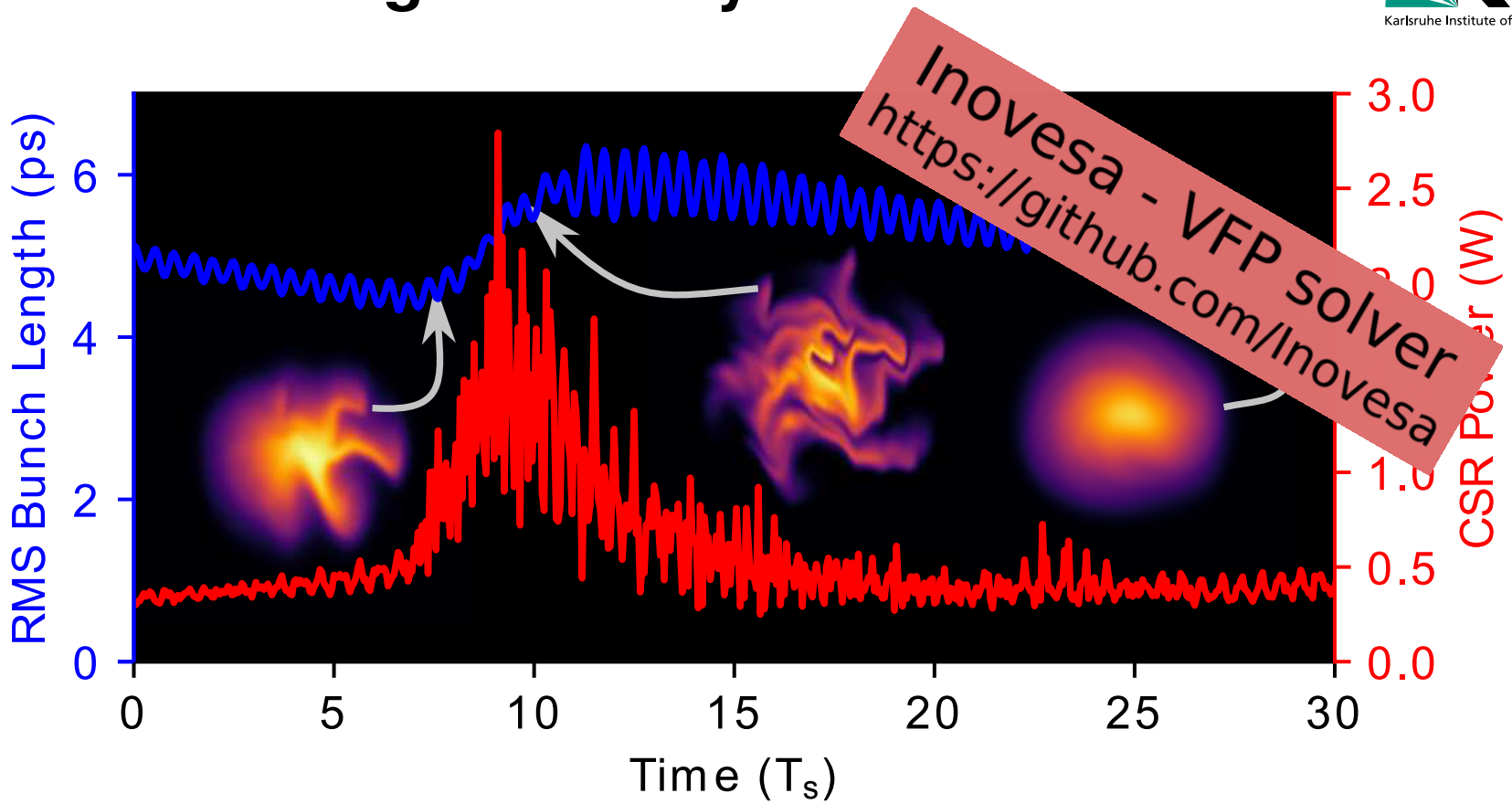
Micro-bunching instability



The instability leads to changing micro structures on the bunch profile which emit coherent synchrotron radiation in the THz frequencies

$\Rightarrow$ Fluctuations in THz CSR emission correspond to dynamics in phase space

Micro-bunching instability



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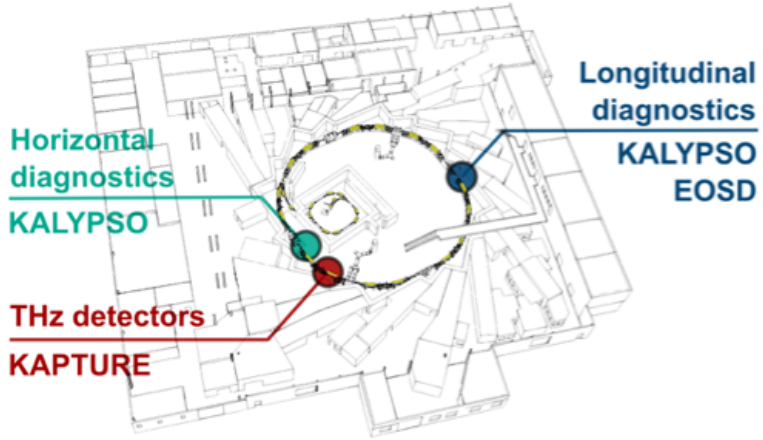
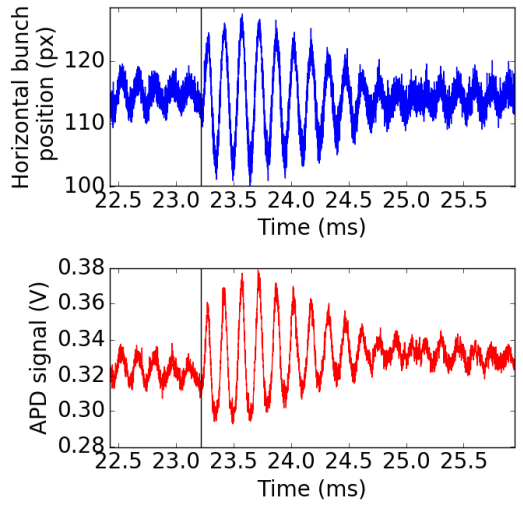
Diagnostics at KARA

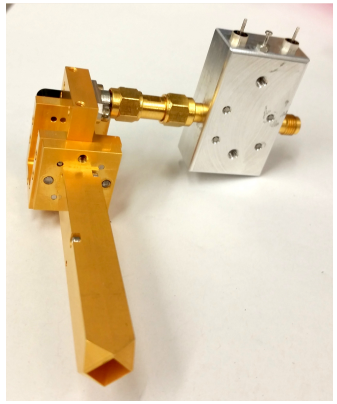


- Observation of longitudinal dynamics
  - Emitted coherent radiation (THz range)
  - Longitudinal bunch profile ($<$ ps resolution)
  - Horizontal bunch size
- Relevant time scales
  - Size of sub-structures (sub-)ps
  - Bunch spacing / rev. time 2 ns / 368 ns
  - Repetition rate of bursts $\sim$ ms
  - Current dependent changes $\sim$ seconds/hours
- Diagnostic requirements:
  - High resolution (ps)
  - High repetition rate (500 MHz / 2.7 MHz)
  - Long term observation (secs - hr)
  - Possibility for synchronised accquisition



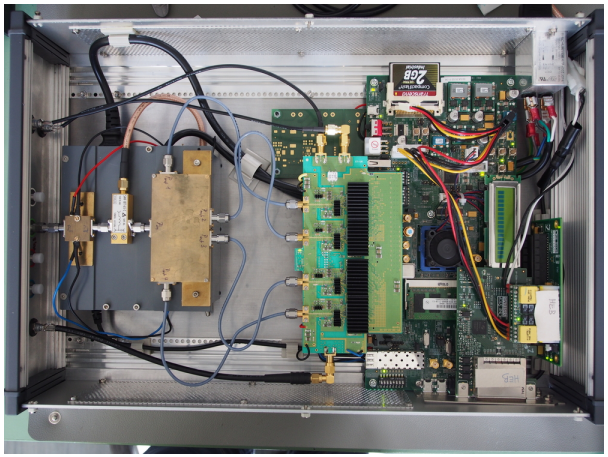
Fast THz detector and acquisition

Quasi-optical broadband Schottky diode (ACST GmbH)
Narrowband Schottky diodes (Virginia Diodes, Inc.)



- Room temperature
- Covering 50 GHz - 1 THz
  $\rightarrow$ Used 220 GHz - 325 GHz
- $>$ 4 GHz bandwidth $\rightarrow$ Resolves intensity of each bunch

KAPTURE - KArlsruhe Puls Taking and Ultrafast Readout Electronics



FPGA - four ADC board
(M. Caselle, IPAC 2014 Dresden, THPME113)

- Simultaneous monitoring of all 184 buckets
- Continuous turn-by-turn read-out of each bucket (500 MHz) $\rightarrow$ 32 Gb/s
- Four sampling channels with 12-bit ADC each
- Adjustable delay for each channel in 3 ps steps
- Alternative: read out multiple detectors simultaneously

Online monitoring of each bucket at every turn (500MHz)

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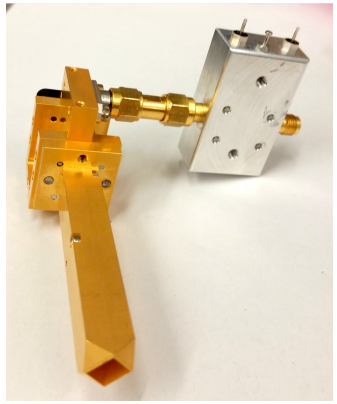

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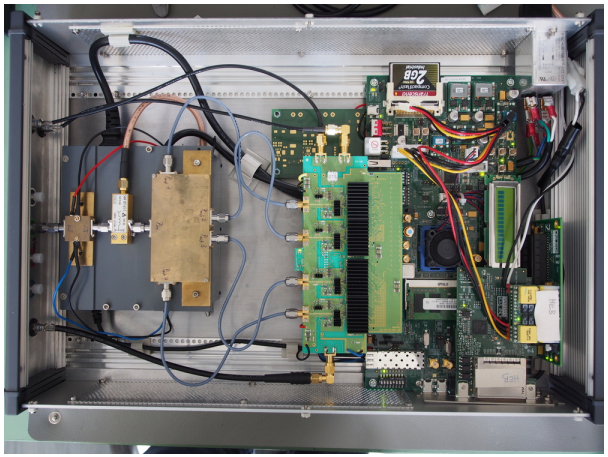

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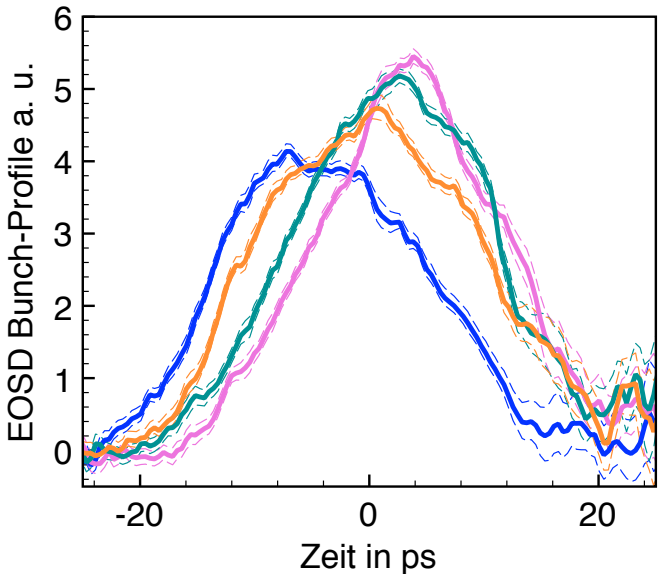
Poster this afternoon
A. Ebersoldt

Online monitoring of each bucket at every turn (500MHz)

Longitudinal bunch profile measurement

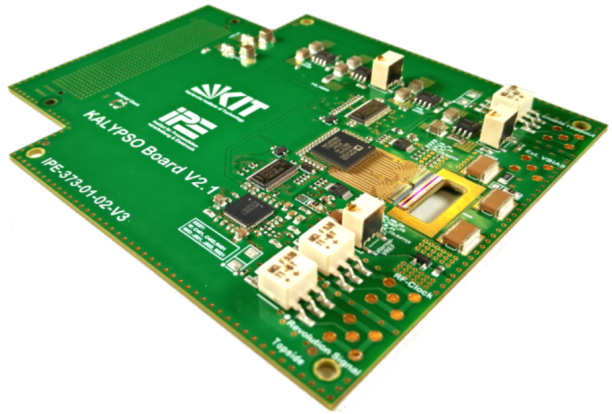
Electro-Optical Spectral Decoding



(N. Hiller, et al., IBIC 2014, MOPD17)

- Samples near field of electron bunch
- Initially developed for single-pass linacs
- Permanently installed in the KARA storage ring
- Operational in single-bunch operation
- Measures single-shot bunch profiles

KALYPSO KArlsruhe Linear arraY detector for MHz-rePetition rate SpectrOscopy

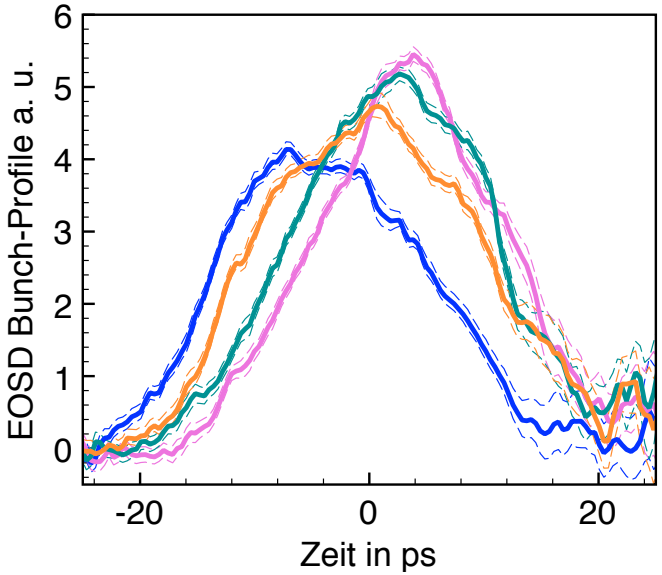


(L. Rota PhD thesis doi:10.5445/IR/1000082349)

- Line array (512, 1024 or 2048 pixel)
- Up to 10 Mfps @ 512 pixel
- Continuous data aquisition
- Combined with grating used as spectrometer

Longitudinal bunch profile measurement

Electro-Optical Spectral Decoding



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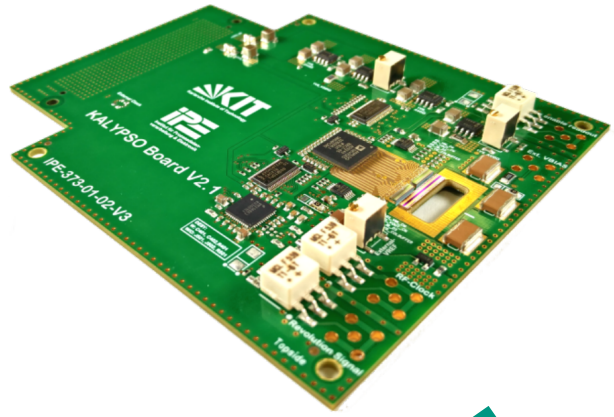

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- Line array (512, 1[illegible] pixel)
- Up to 10 M[illegible]ixel
- Contin[illegible]quisition
- Co[illegible]with grating used as spect[illegible]meter

Poster this afternoon
M. M. Patil

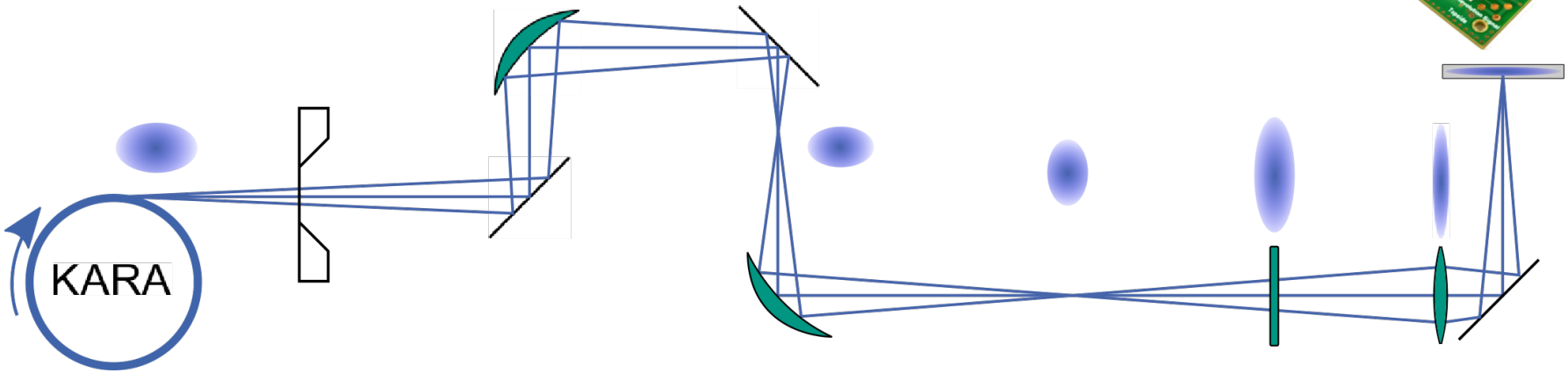
Energy spread studies

- Measure the horizontal bunch size σ_x in dispersive section of storage ring

$$\sigma_\delta = \frac{1}{D_x}\sqrt{\sigma_x^2 - \beta_x \cdot \epsilon_x}$$

- Incoherent synchrotron radiation (visible range)
- Radiation from 5° port at dipole magnet
- KALYPSO as fast line array detector
- turn-by-turn

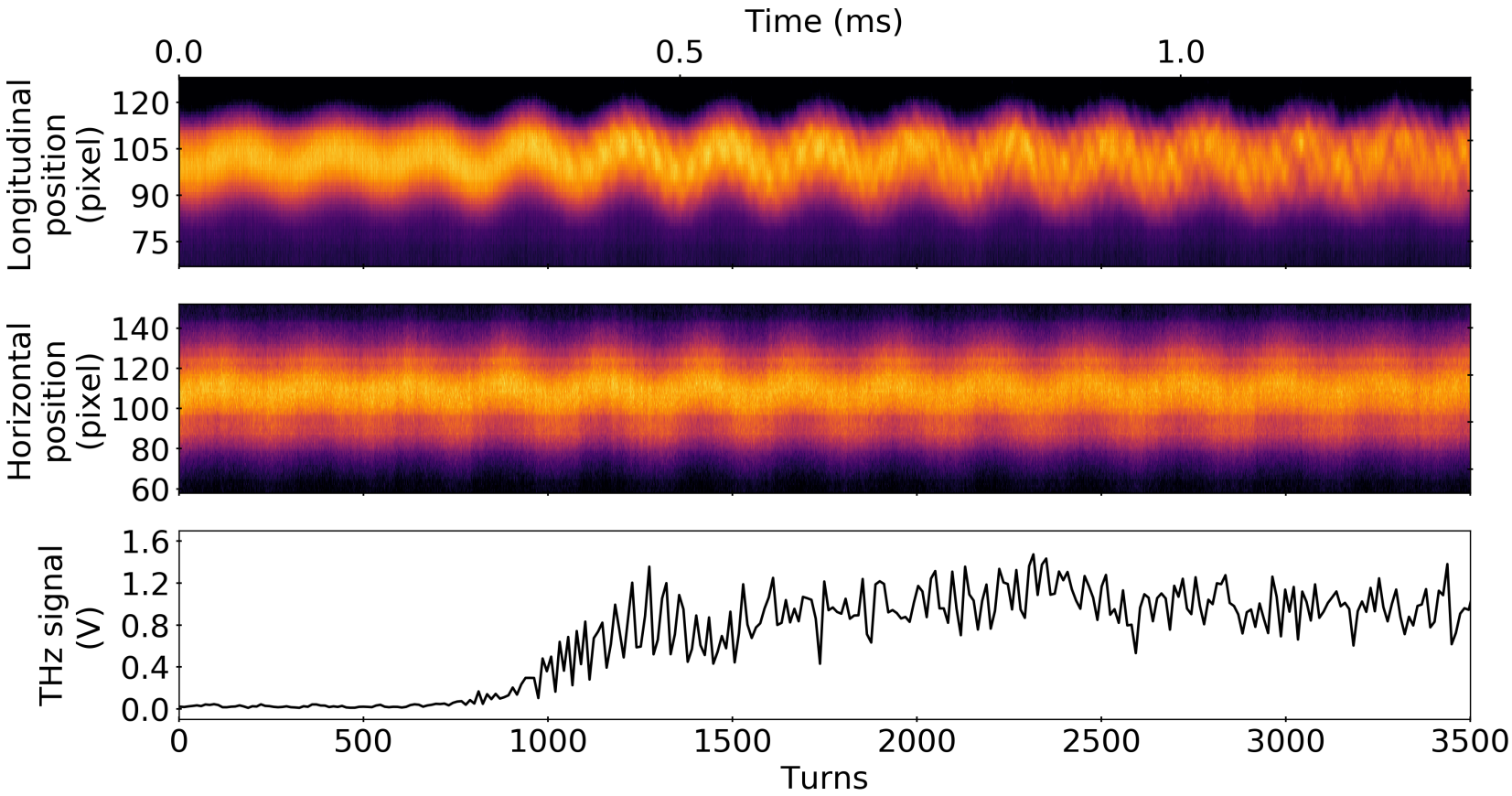
KALYPSO



B. Kehrer, et al., IPAC19, doi:10.18429/JACoW-IPAC2019-WEPGW016

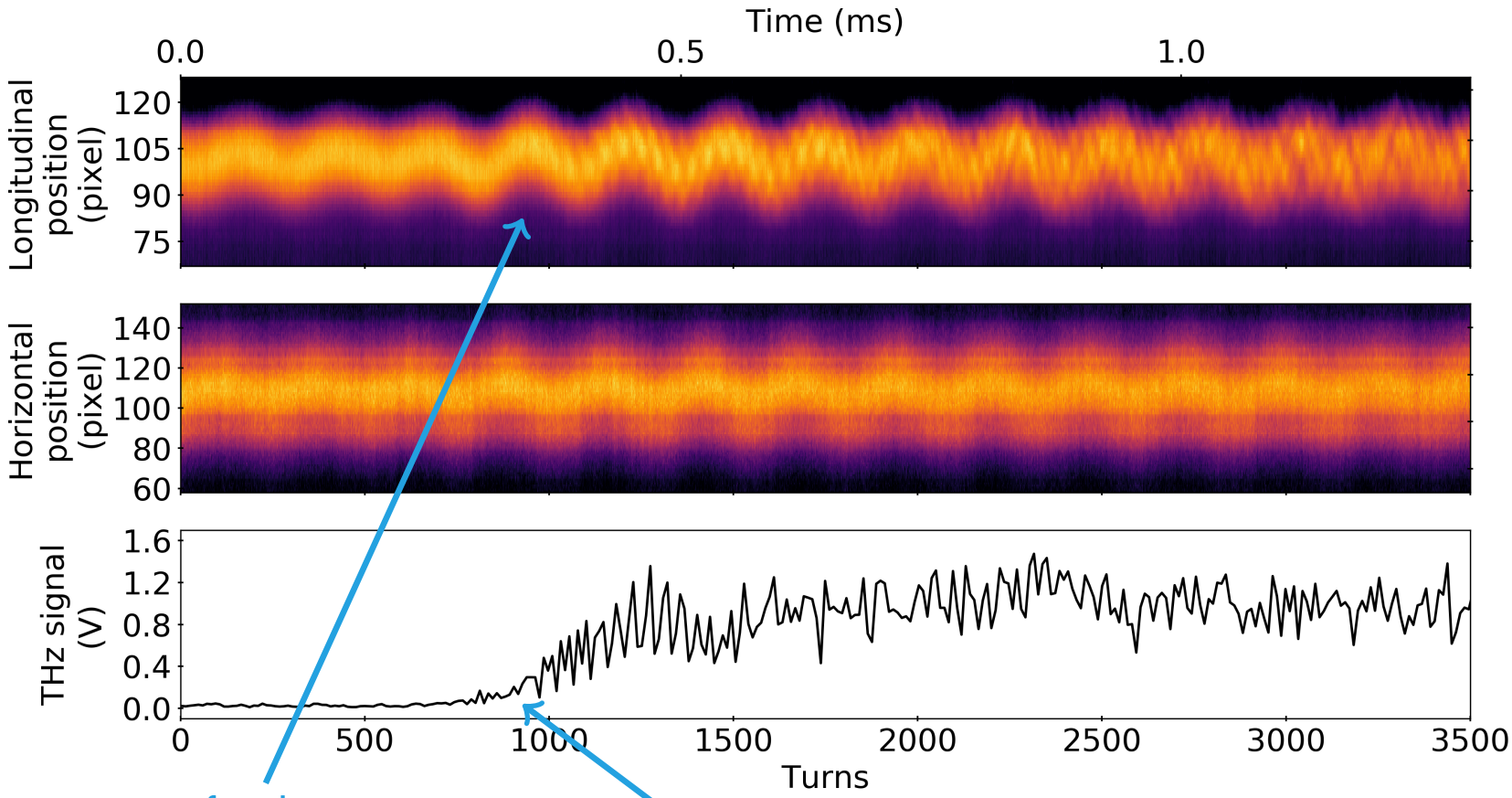
sketch, courtesy by Paul Schütze

Synchronous measurements



M. Brosi, et al., IPAC19, doi:10.18429/JACoW-IPAC2019-WEPTS015

Synchronous measurements



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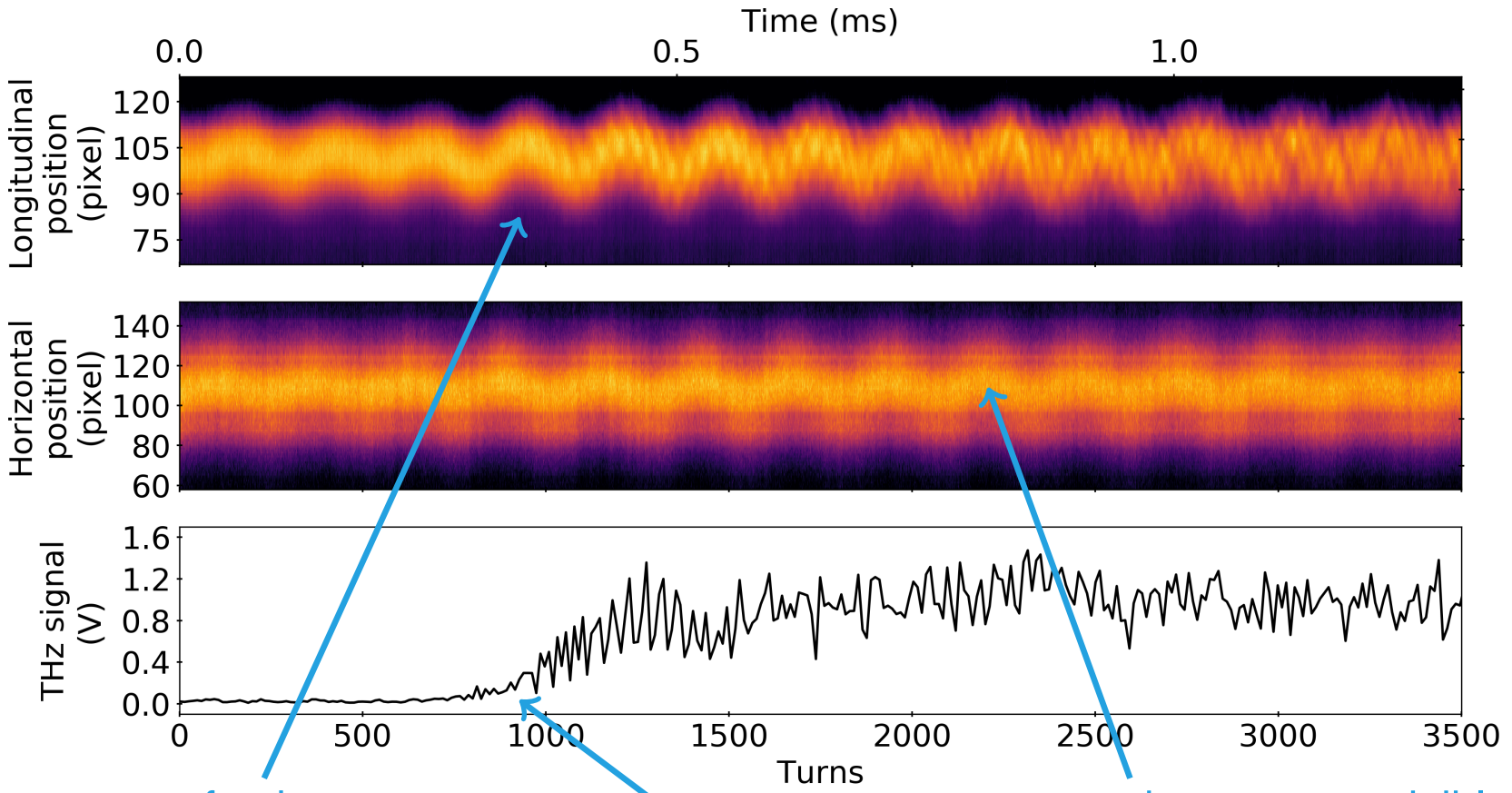

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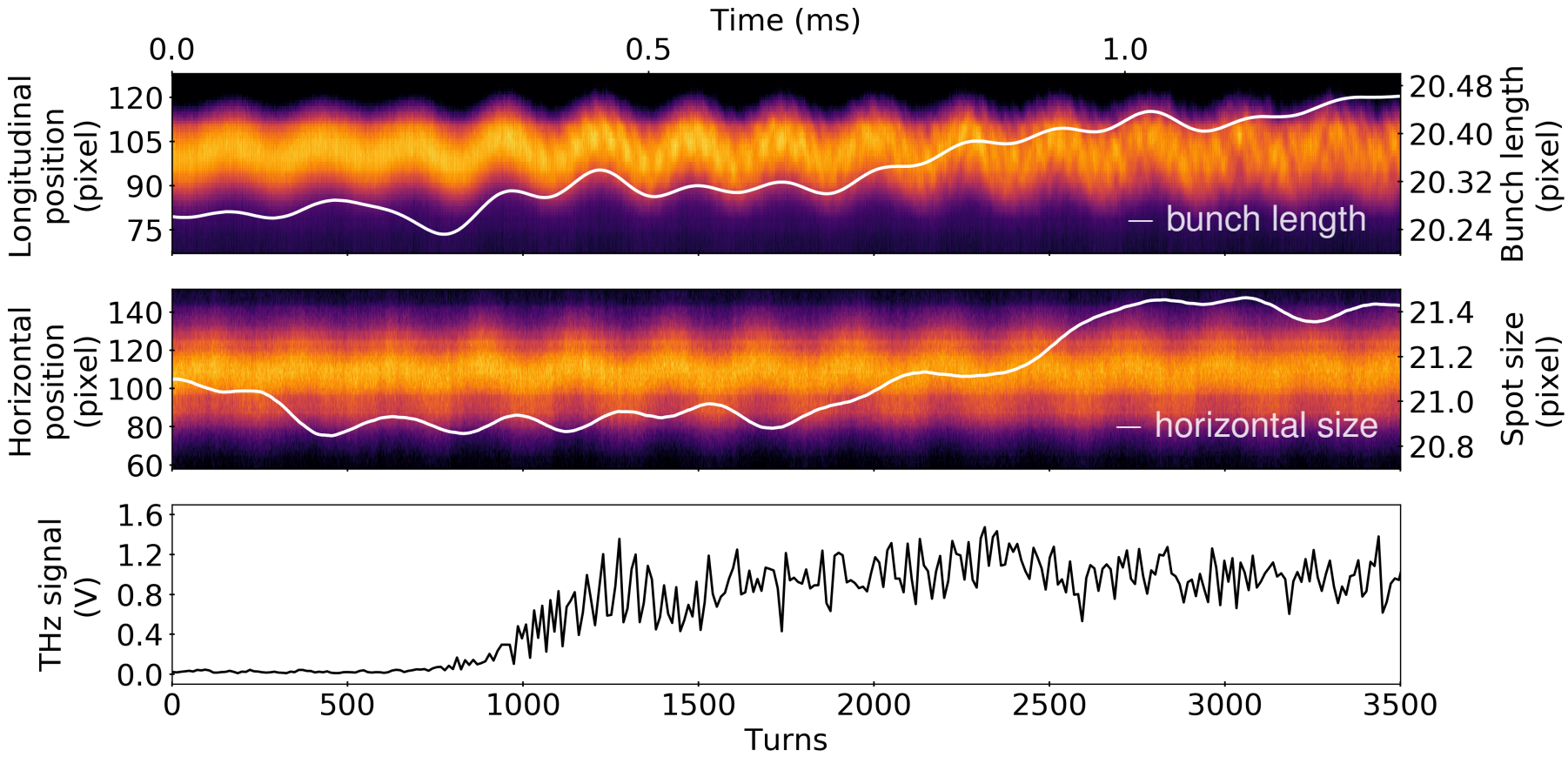
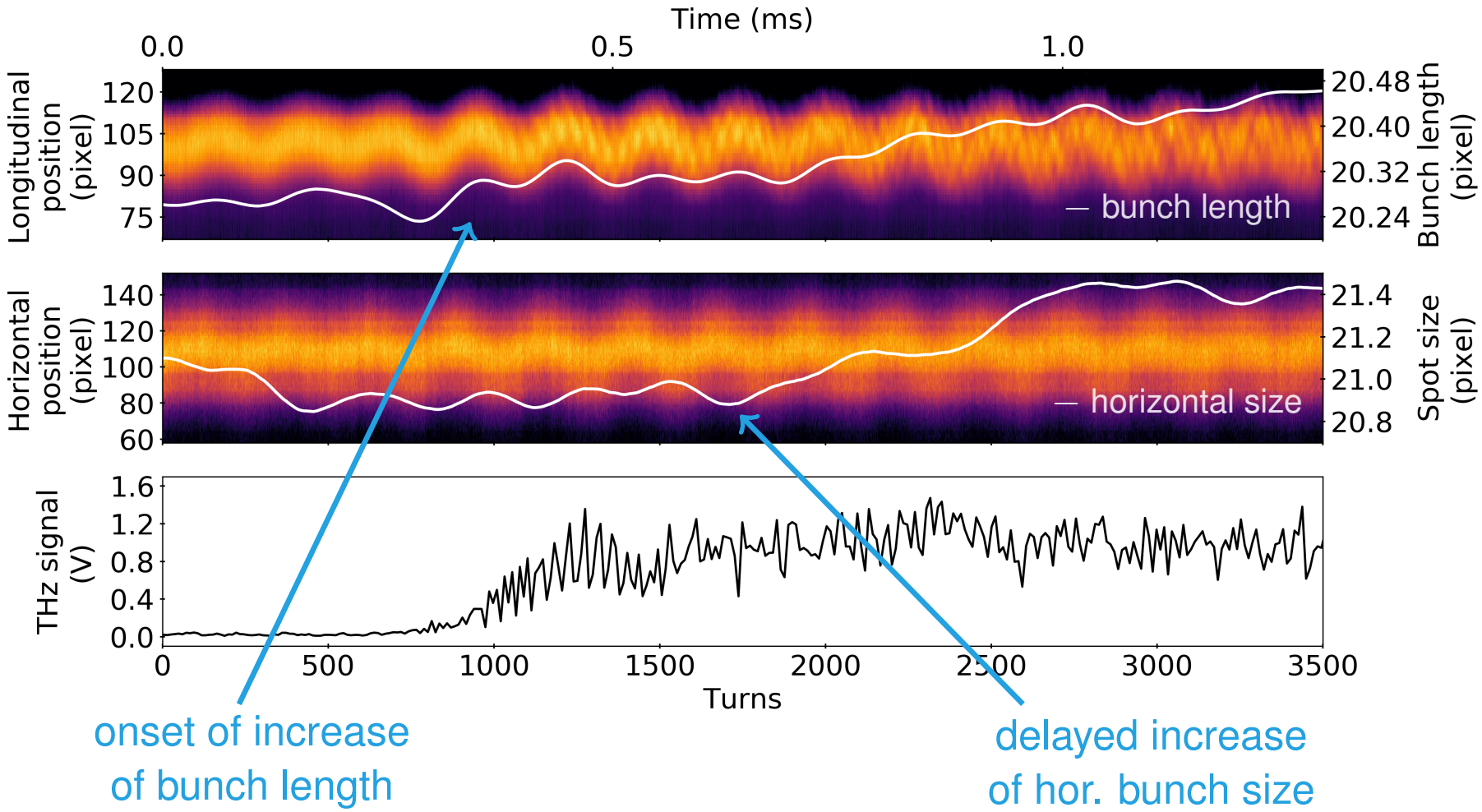


bunch length and horizontal bunch size increase during burst

Synchronous measurements



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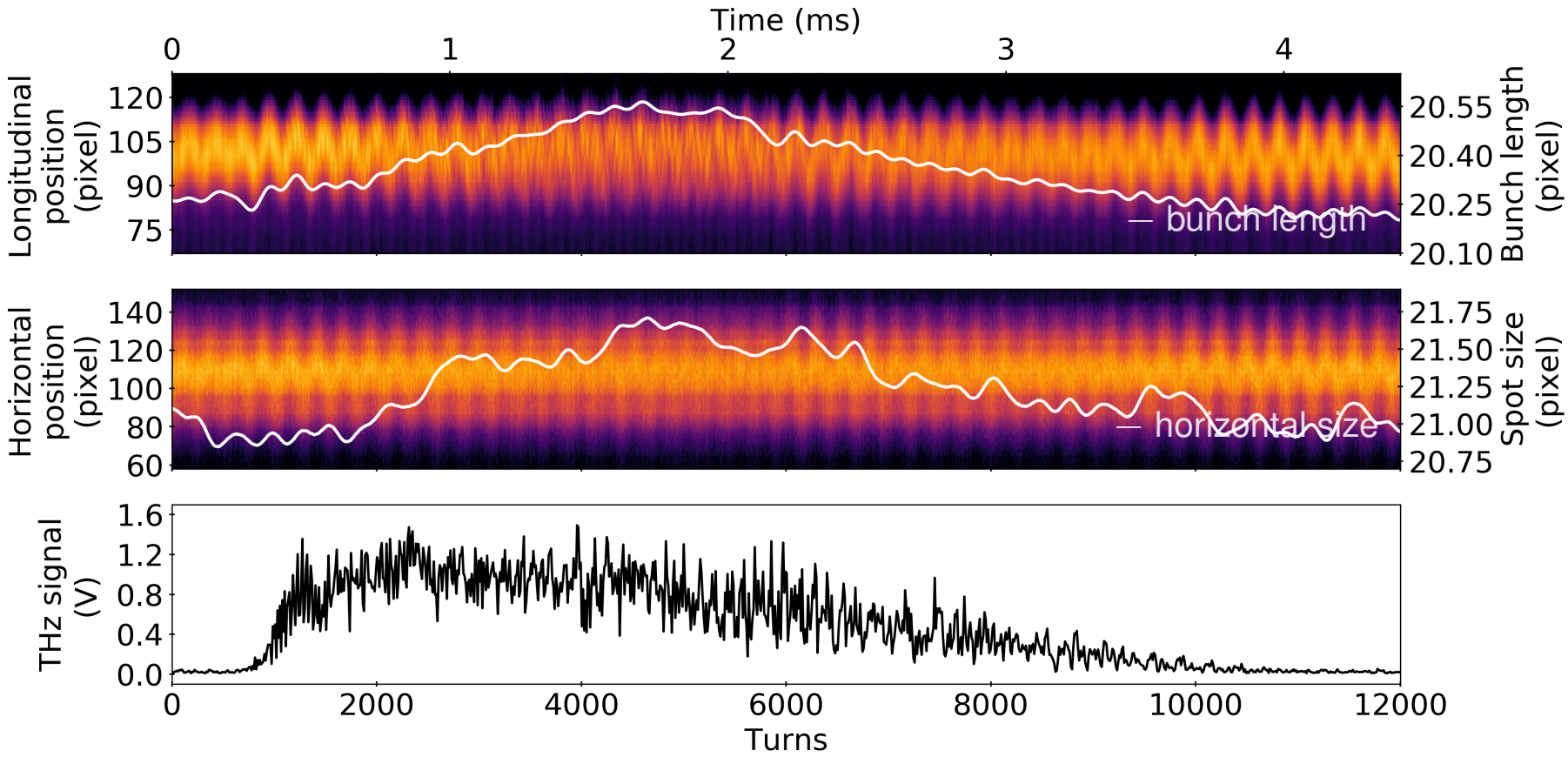

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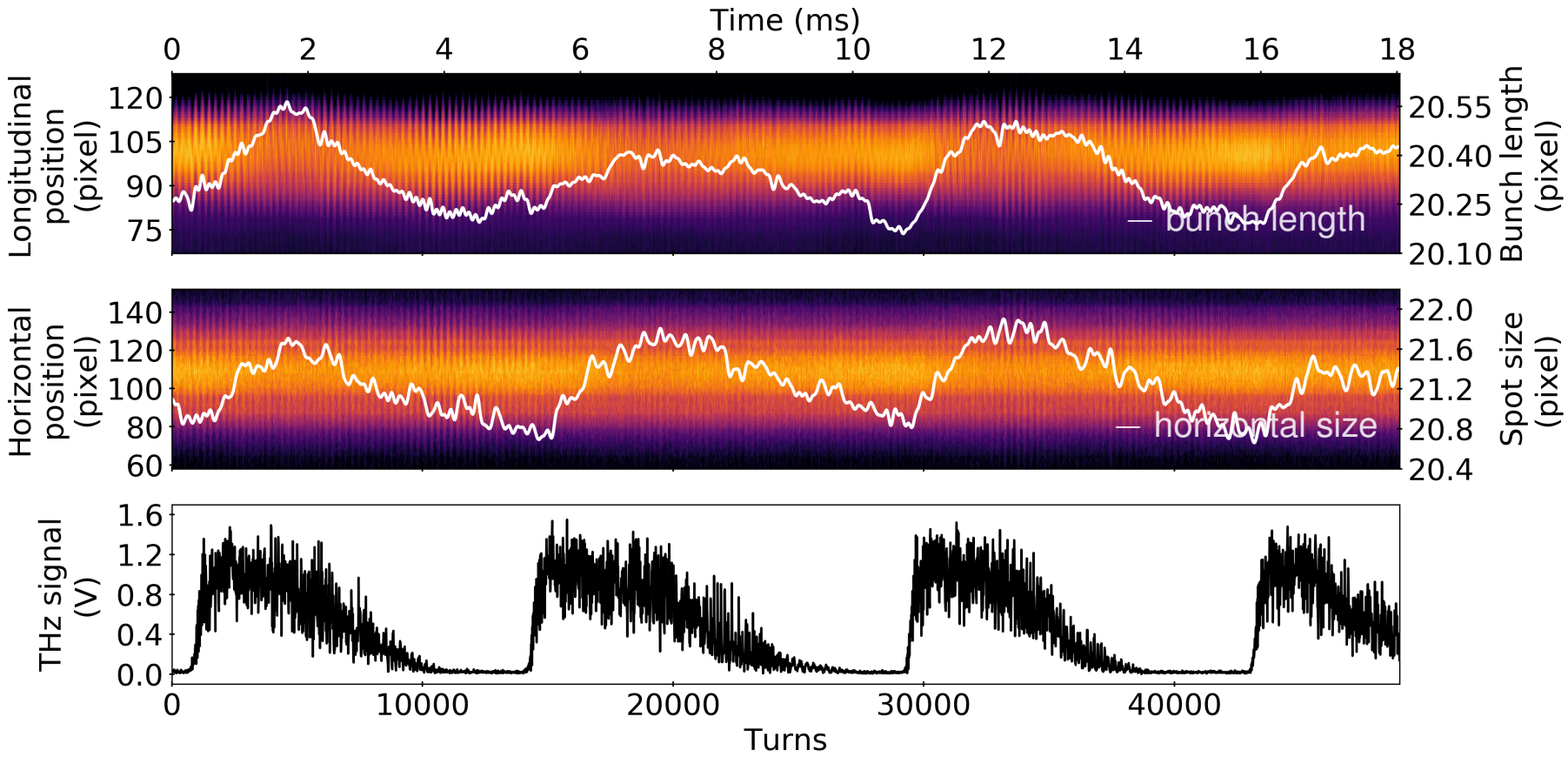
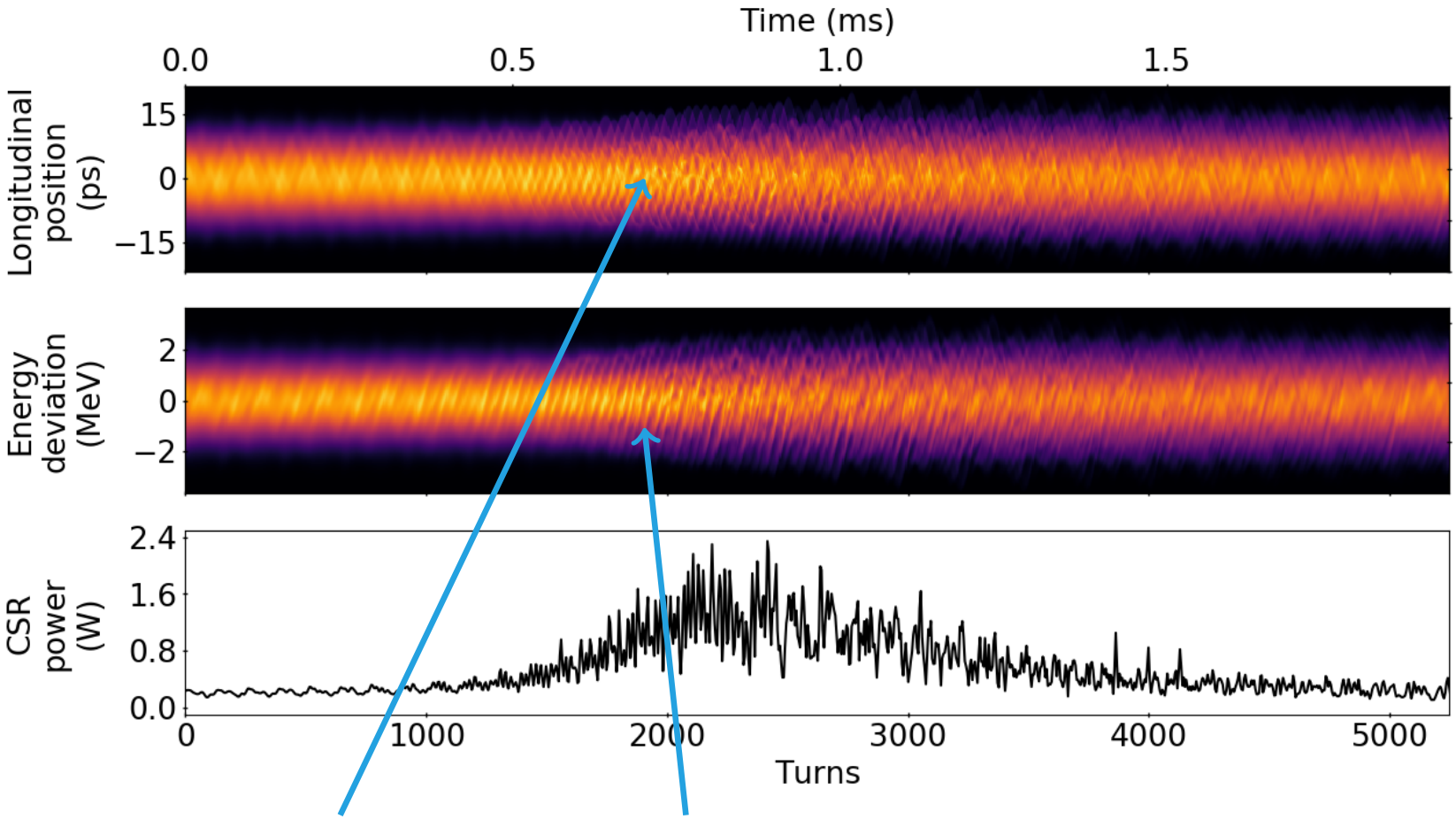


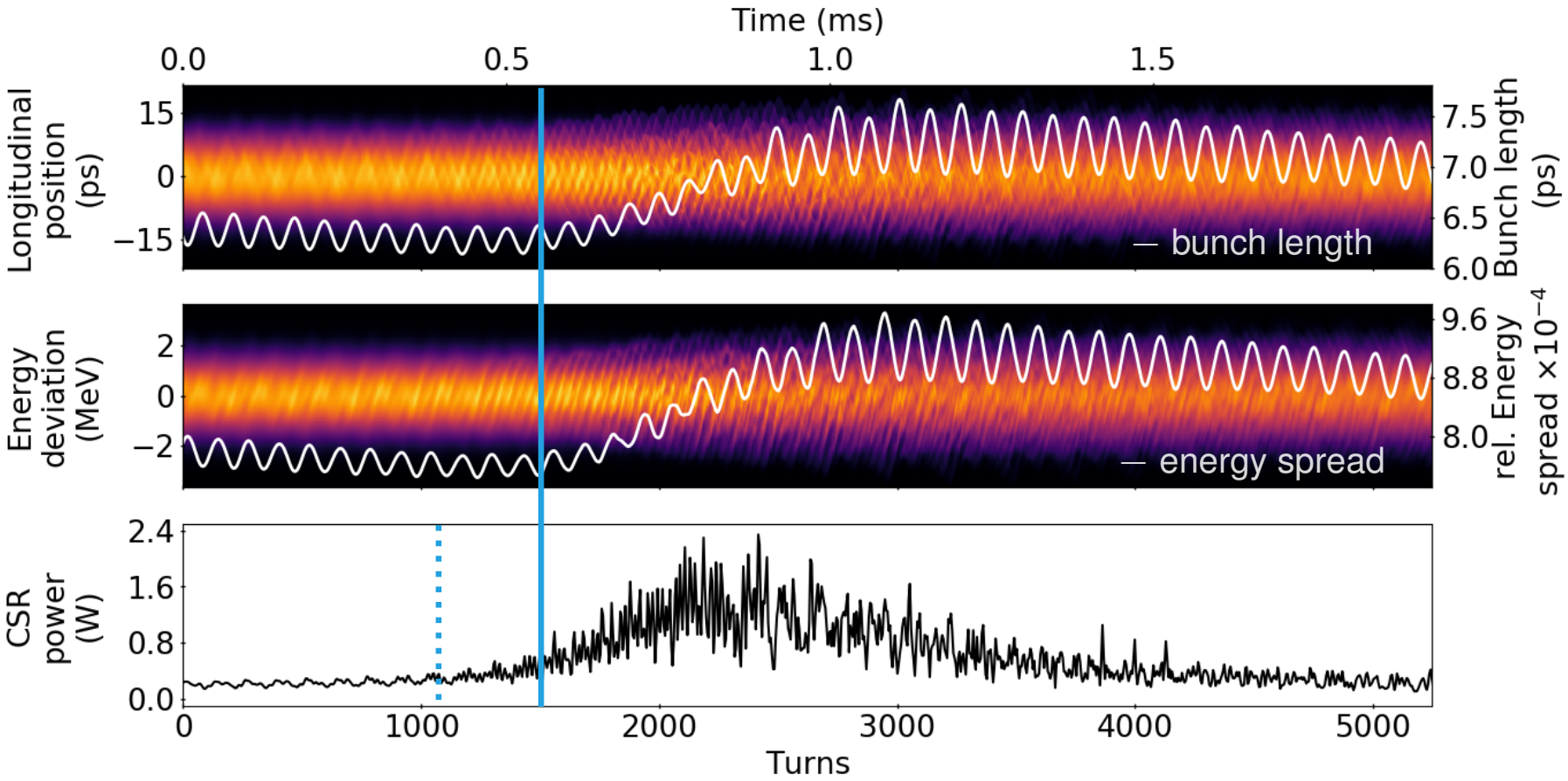
slightly different shape but same repetition rate

Simulations with Inovesa



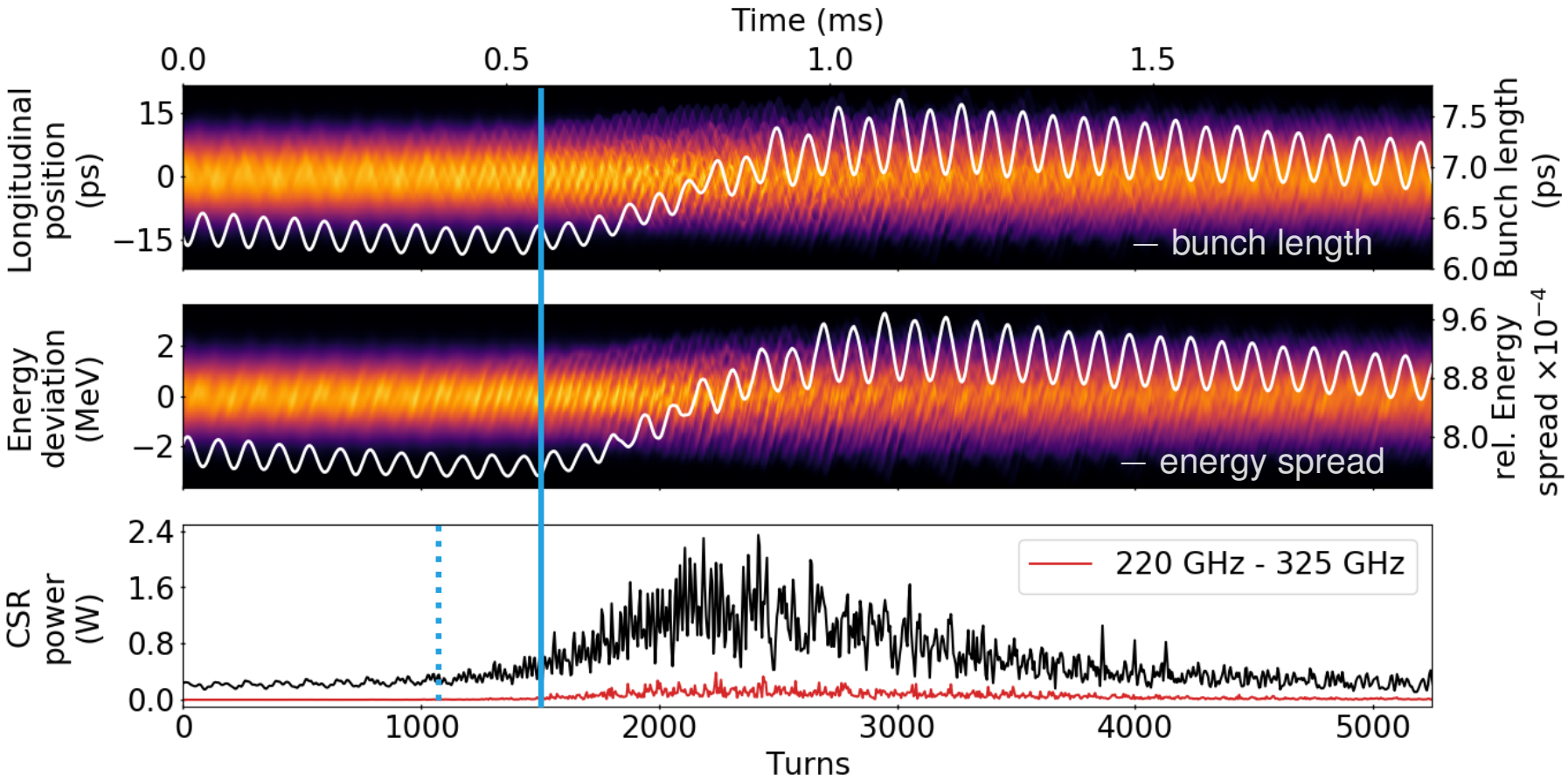
longitudinal as well as energy profile show substructures

Simulations with Inovesa



bunch length and energy spread increase simultaneously
but slightly after CSR power, in contrast to the measurement

Simulations with Inovesa



onset of CSR depends on observed frequency range

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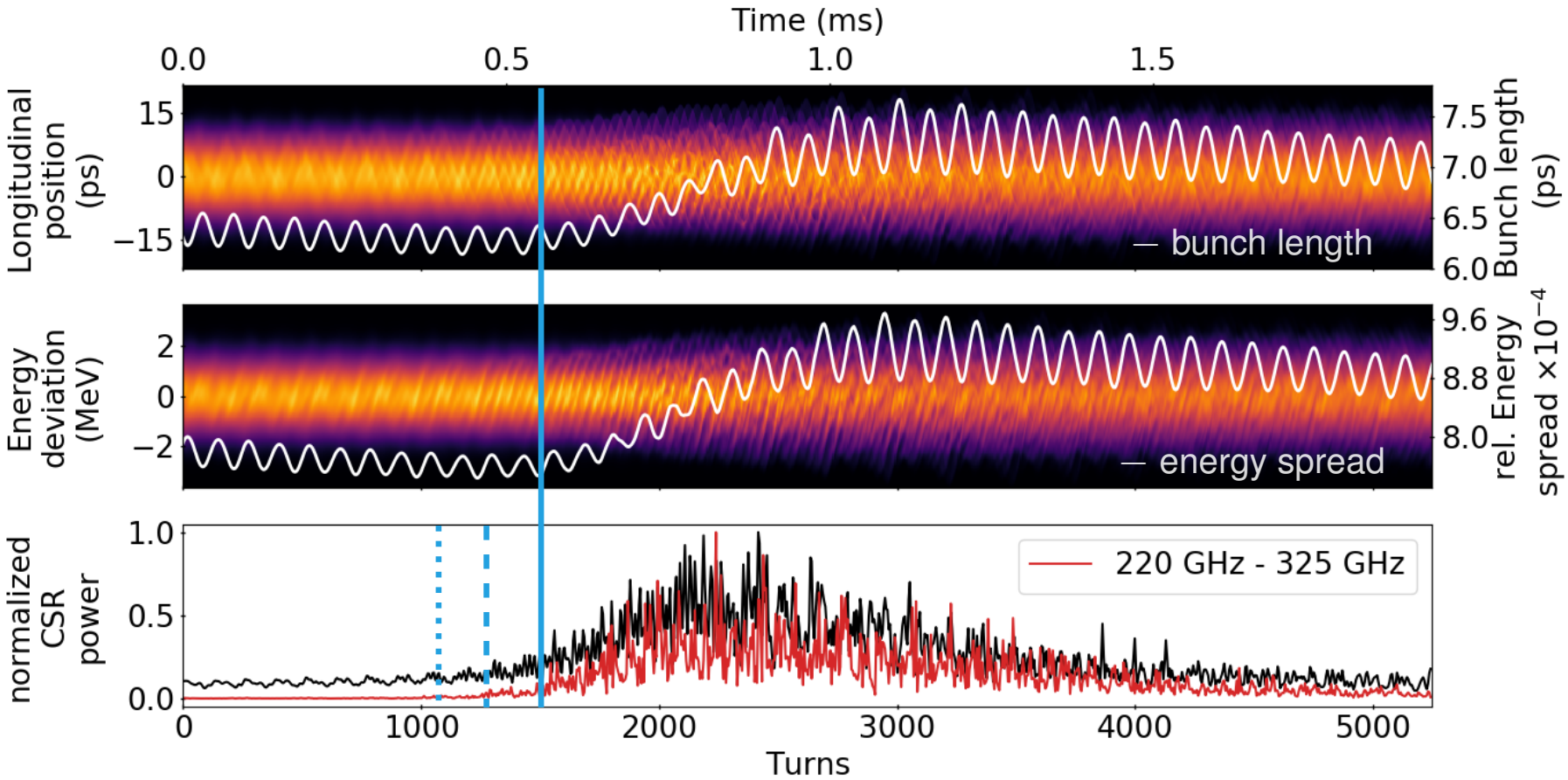

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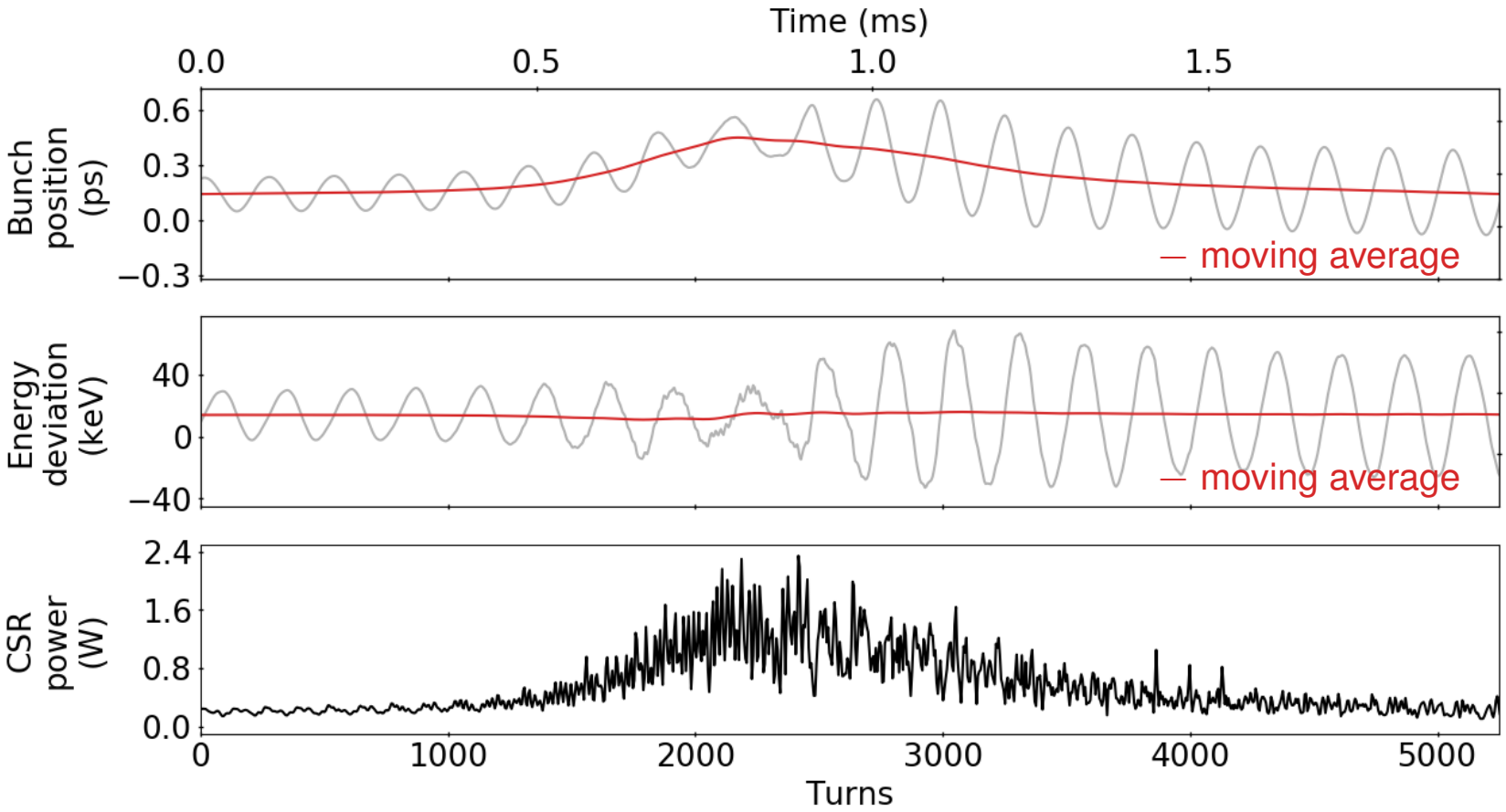
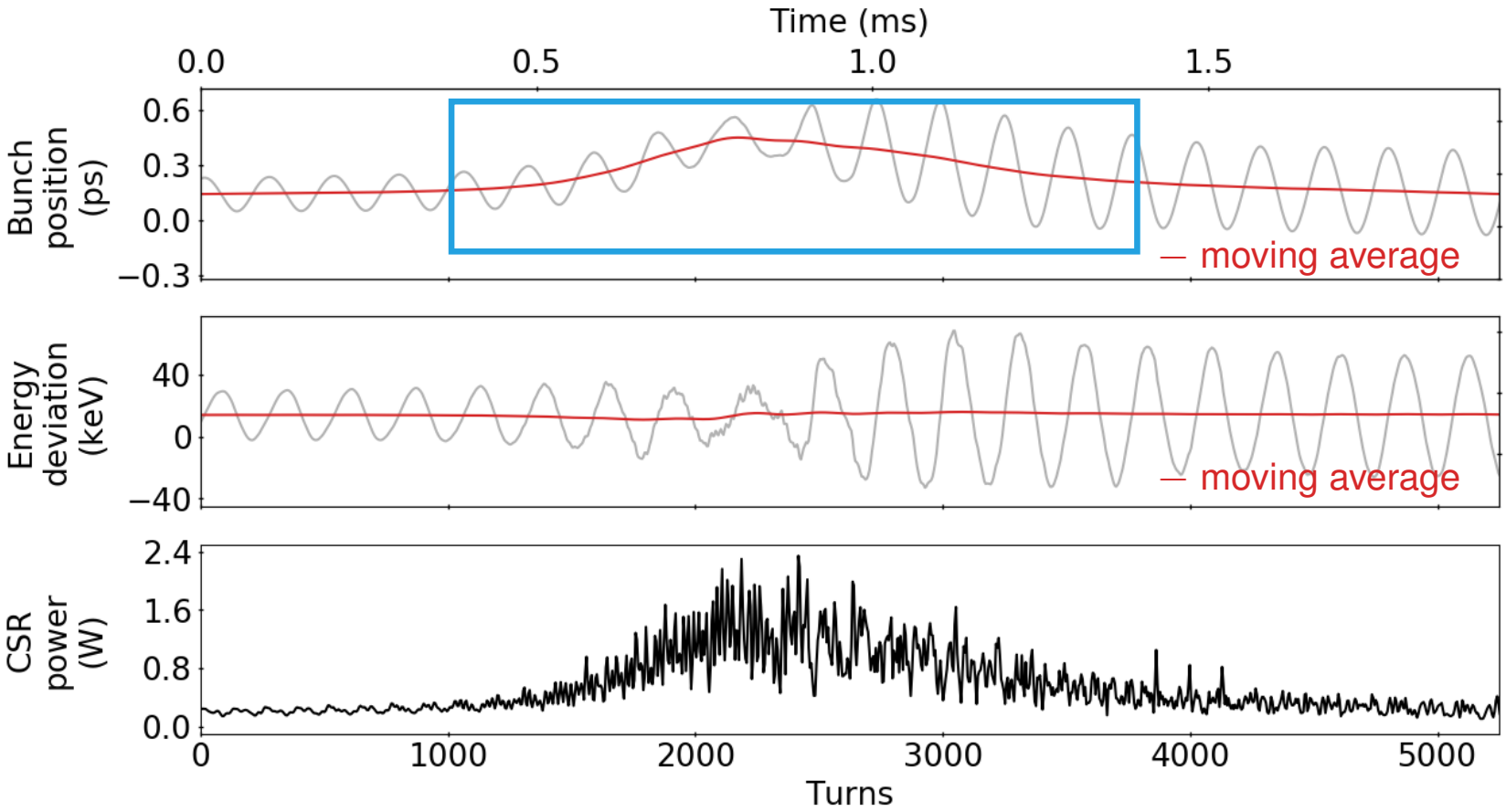


shift of long. position due to increased emission
and resulting increase in oscillation amplitude

Simulations with Inovesa



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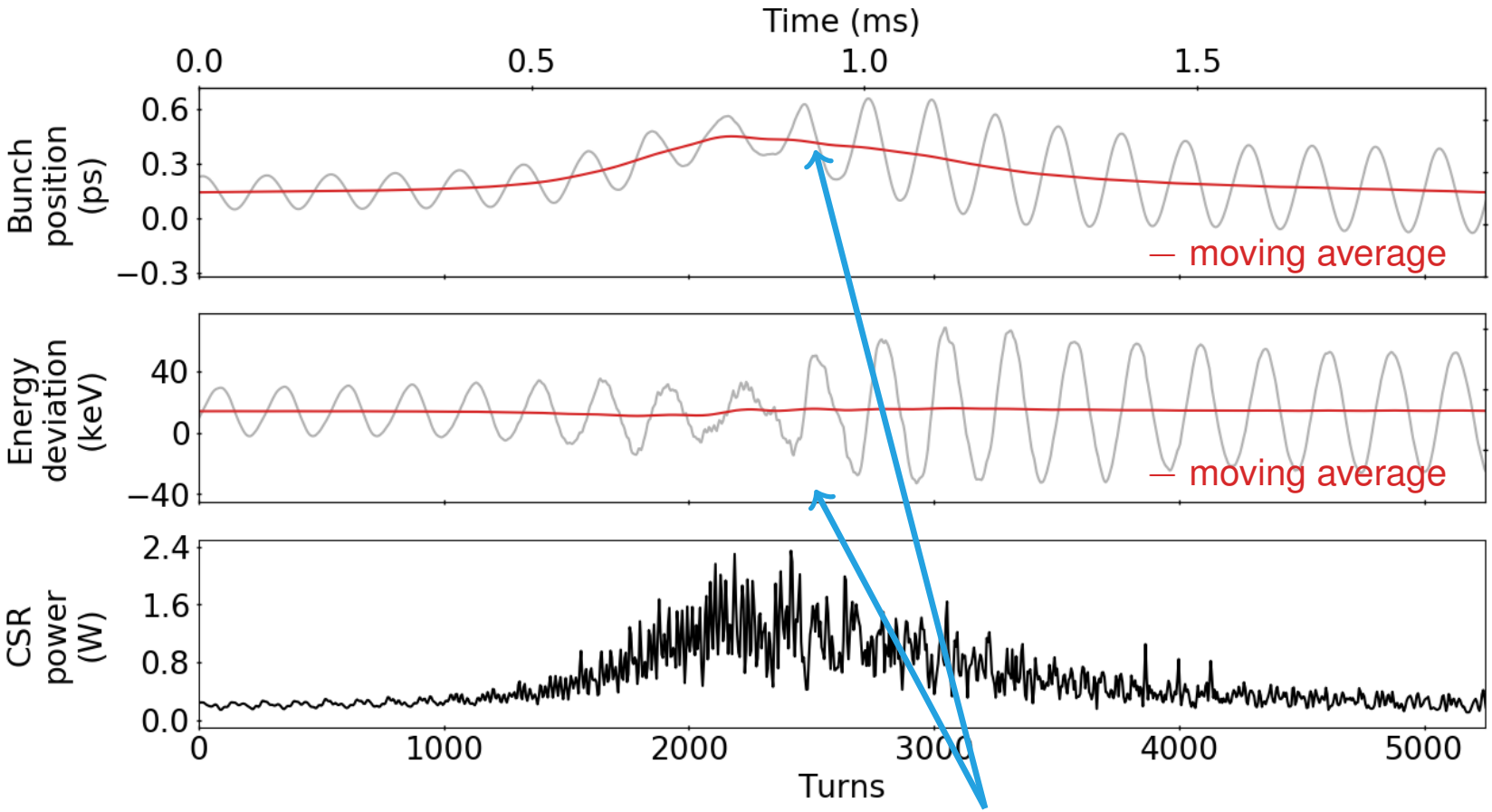

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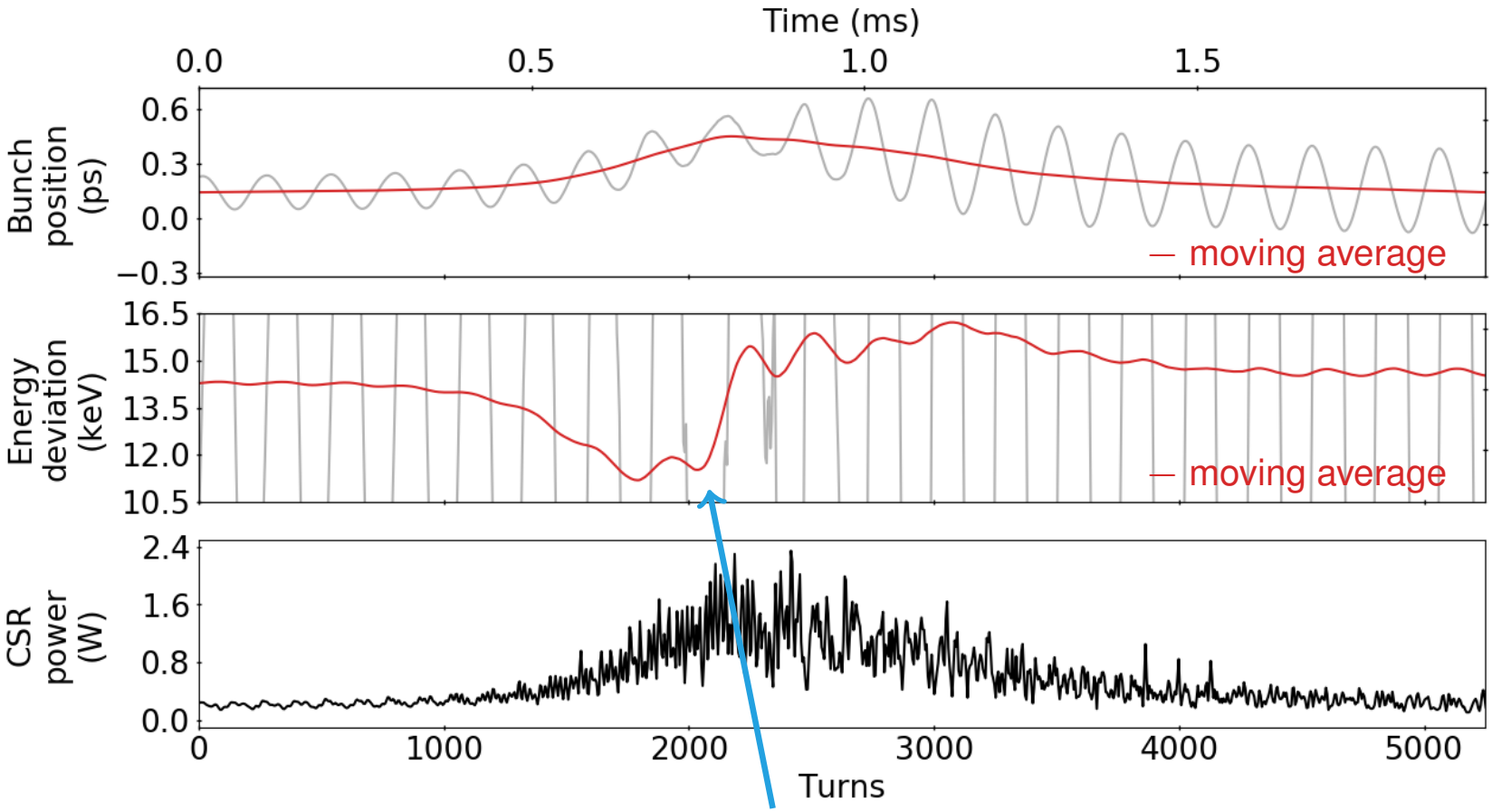
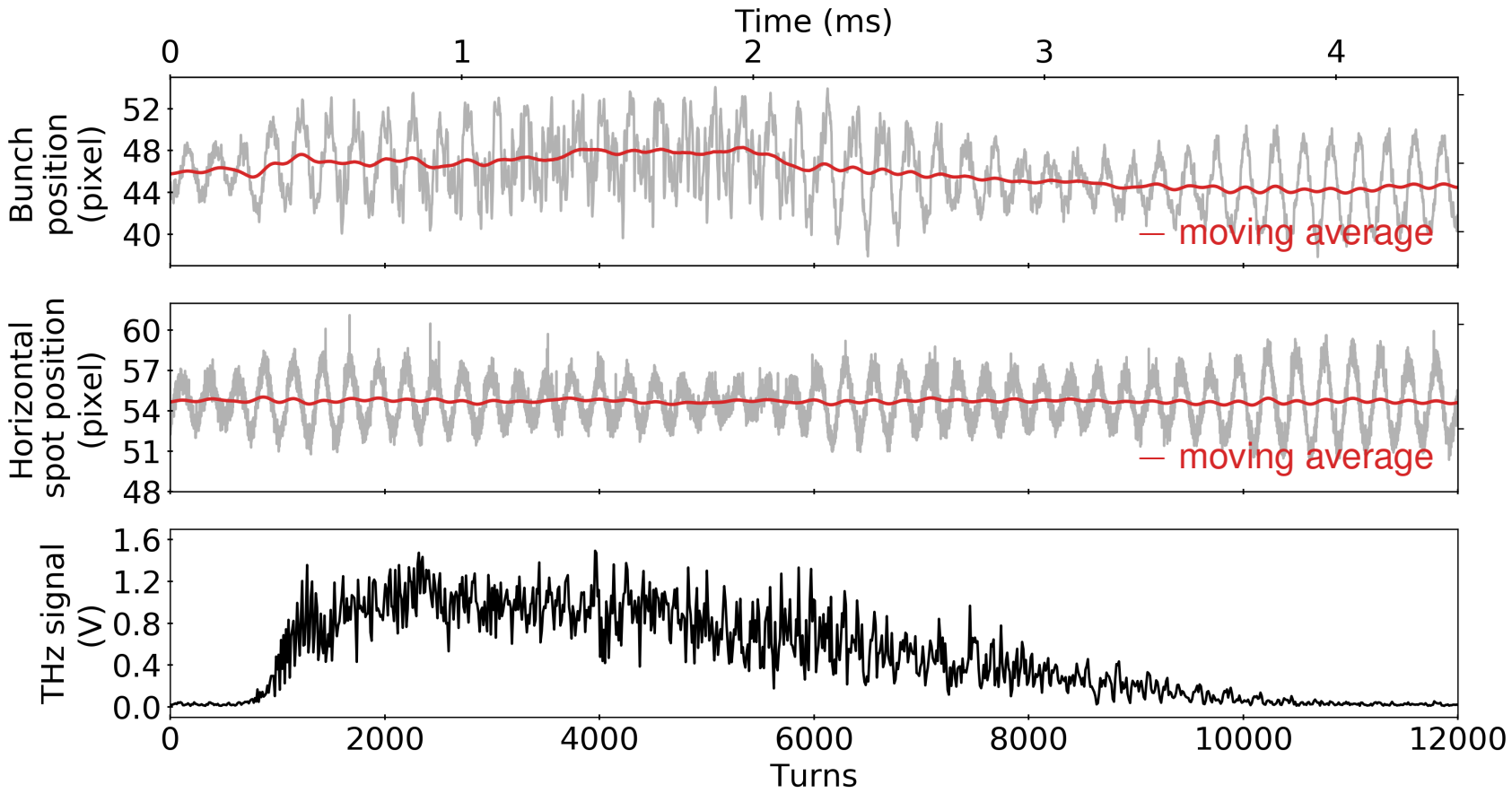


small shift in energy
which is soon compensated by shift of long. position

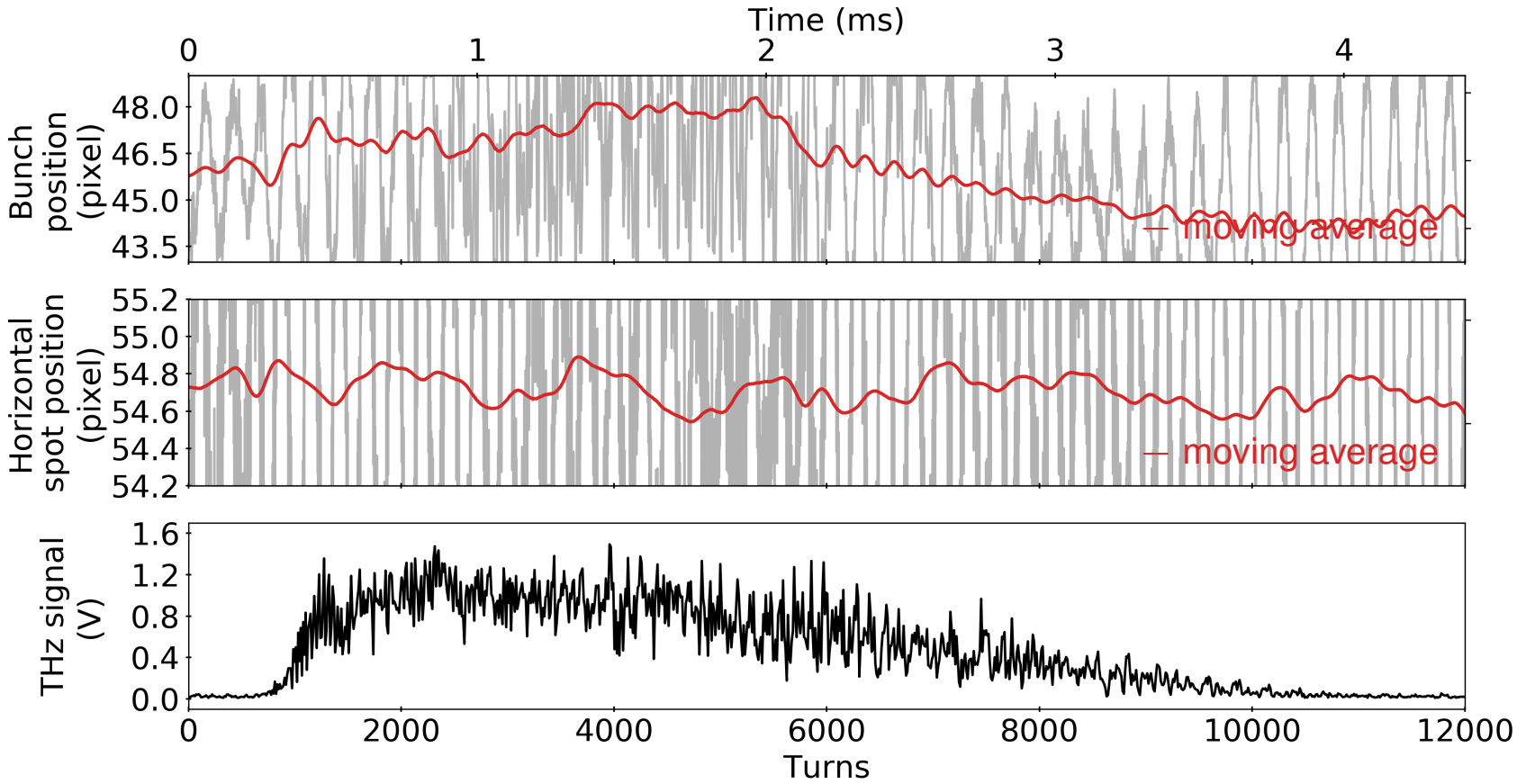
Synchronous measurements



small shift of long. position during burst

variation of oscillation amplitude seems uncorrelated to burst

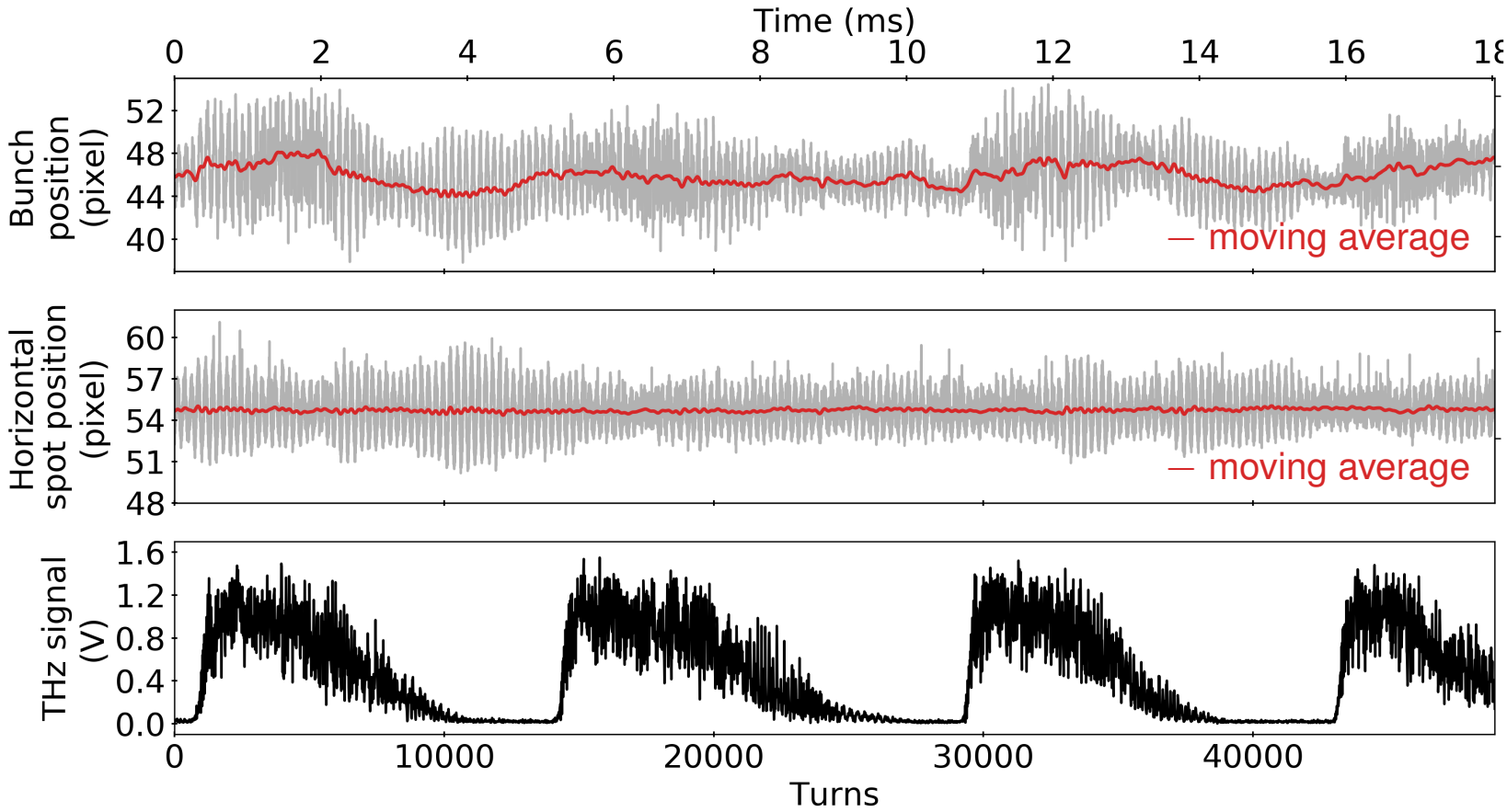
Synchronous measurements



small shift of long. position during burst

no energy shift resolvable?

Synchronous measurements



small shifts of long. position during bursts

variation of oscillation amplitude seems uncorrelated to bursts

Summary

- Micro-bunching measurement techniques allow to study the complex and nonlinear dynamics in longitudinal phase space
- Diagnostics requirements:
  - High resolution (ps)
  - High rate (500 MHz)
  - Long term observation (secs - hrs)
  - Synchronisation
- KAPTURE + KALYPSO allow synchronous observation of
  - CSR emission (THz)
  - Longitudinal bunch profile
  - Horizontal bunch profile / energy spread

$\Rightarrow$ Effect of instability visible in longitudinal as well as horizontal plane

- Substructures visible on longitudinal profile
- Increase of bunch length and energy spread during burst
- Small phase shift due to increased emission during burst
- Results supported by simulation with Valsov-Fokker-Planck solver Inovesa

Acknowledgements

MT ARD | MT DTS
ATP KIT Accelerator Technology Platform
KIT Karlsruher Institut für Technologie

Involved KIT Institutes:

Institute for Beam Physics and Technology (IBPT)
Laboratory for Applications of Synchrotron Radiation (LAS)
Institute for Photon Science and Synchrotron Radiation (IPS)
Institute for Data Processing and Electronics (IPE)
Institute of Micro- und Nanoelectronic Systems (IMS)

Beam dynamics and diagnostics students