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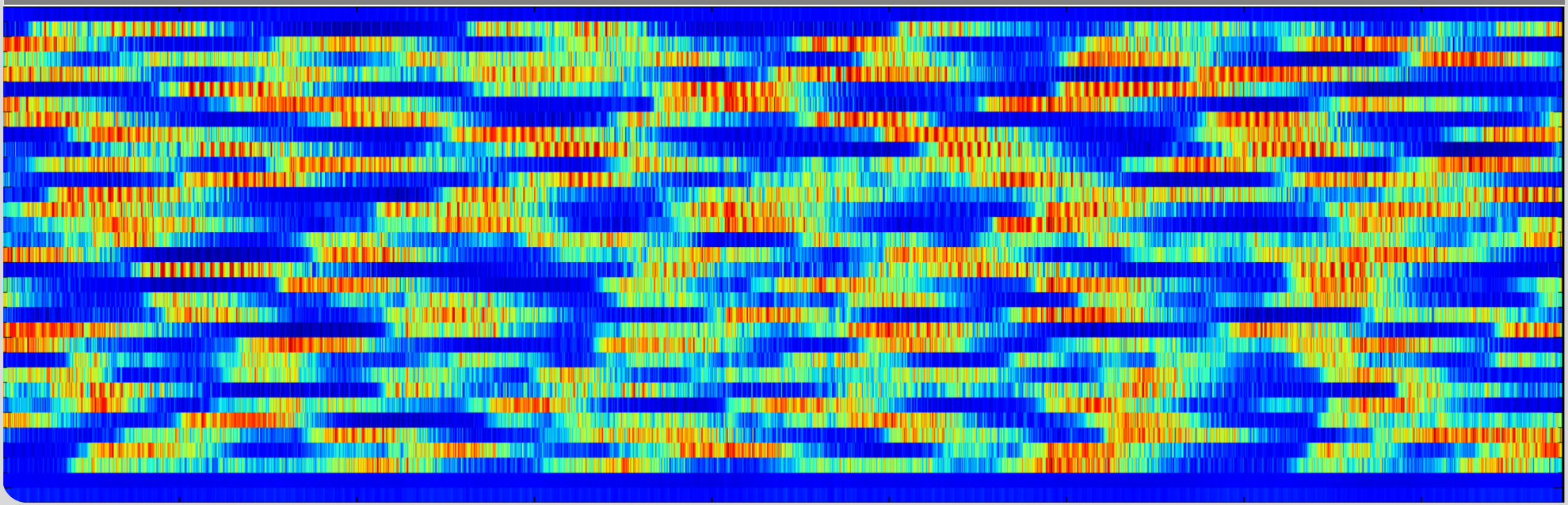
ANKA THZ GROUP

Studies of the Micro-Bunching Instability in Multi-Bunch Operation at ANKA

Miriam Brosi, E. Blomley, E. Bründermann, M. Caselle, B. Kehrer, A. Kopmann, L. Rota, P. Schönfeldt, M. Schuh, J. L. Steinmann, M. Weber and A.-S. Müller | May the 17th, 2017

INSTITUTE FOR BEAM PHYSICS AND TECHNOLOGY (IBPT)



Outline

ANKA & micro-bunching instability

Motivation multi-bunch effects

THz Detectors & readout system KAPTURE

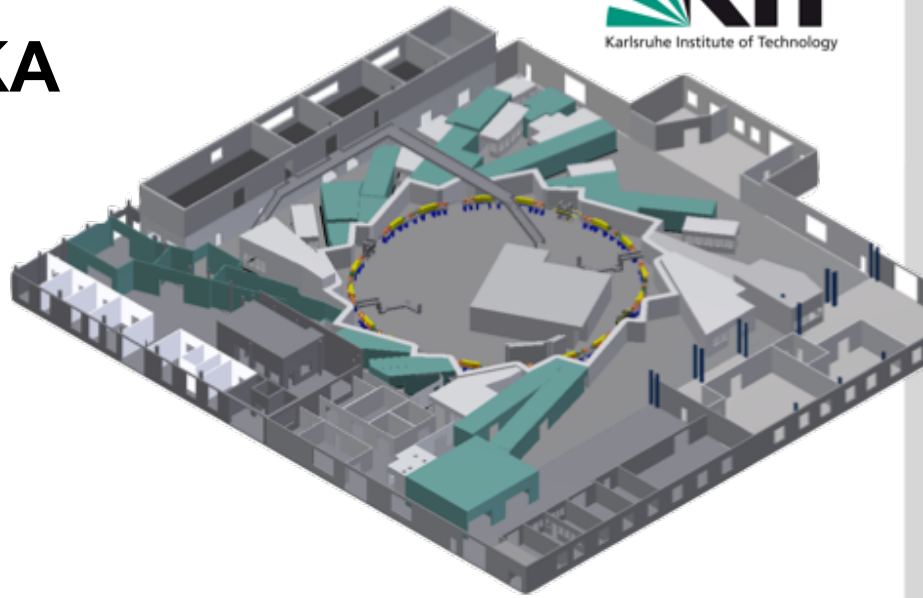
Determination of instability threshold

Bunch current measurement & dead-time effect

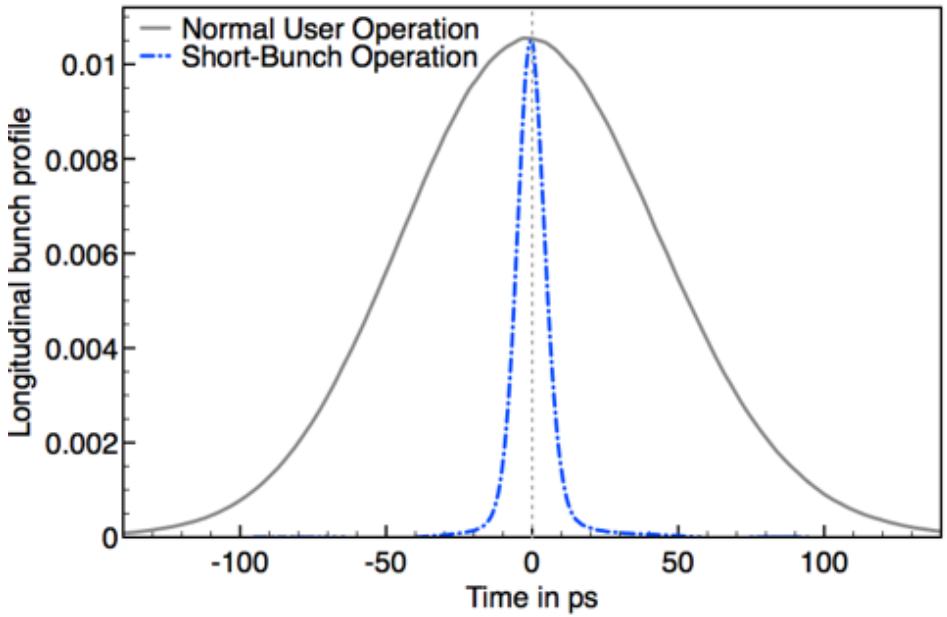
Individual threshold currents

Summary and outlook

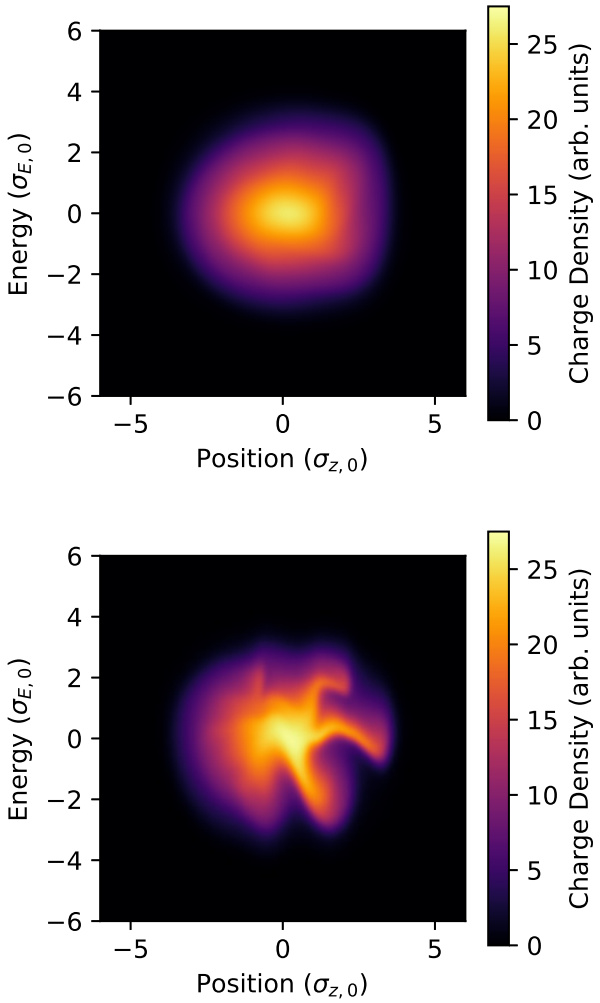
Introduction: short-bunch operation at ANKA

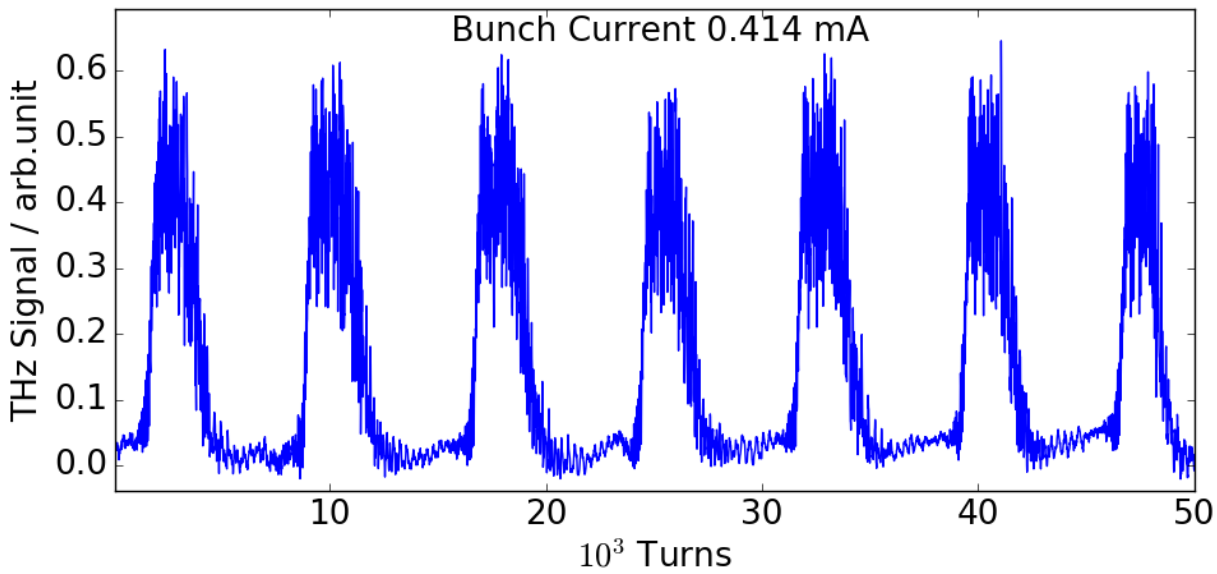


- Circumference: 110.4 m
- Revolution frequency: 2.715 MHz
- RF-frequency: 500 MHz
- Filling pattern: **single- or multi-bunch (min. bunch spacing 2 ns)**
- Energy: 0.5 - 2.5 GeV (0.8 - 1.6 GeV during short-bunch mode)
- RMS bunch length: 45 ps (for 2.5 GeV), **down to a few ps (for 1.3 GeV)**
- **Generation of coherent synchrotron radiation (CSR)**
  ⇒ Micro-bunching instability



Micro-bunching instability





The instability leads to micro structures on the bunch profile corresponding to THz frequencies
$\Rightarrow$ Fluctuating CSR emission for THz frequencies

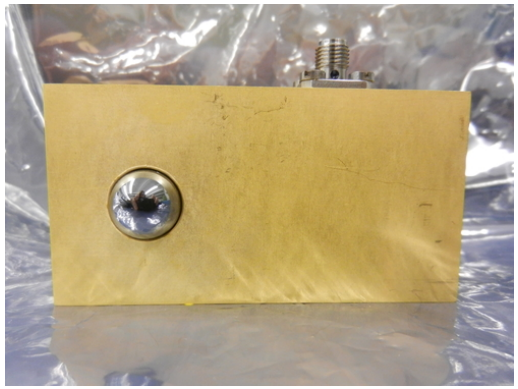
P. Schönfeldt et al.,"Parallelized Vlasov-Fokker-Planck solver for desktop personal computers", Phys. Rev. Accel. Beams, 2017, Vol. 20, Nr.3, DOI:10.1103/PhysRevAccelBeams.20.030704.

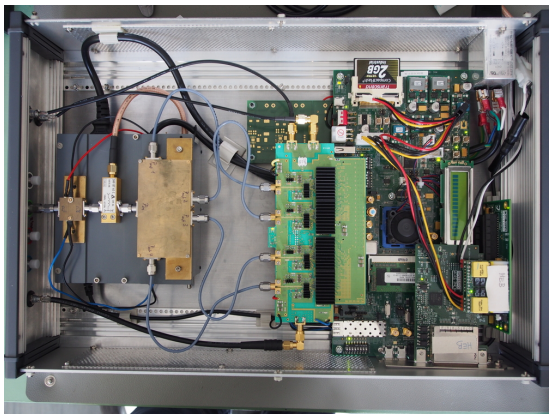
Experimental requirements

- CSR intensity once per turn and bunch (bunch spacing 2 ns)
- High acquisition rate and long acquisition duration

Fast THz detectors: Schottky barrier diodes

- Room temperature
- Response time $<$ 200 ps
- 50 GHz up to 1 THz, narrowband detectors
- Commercially available (ACST, VDI)



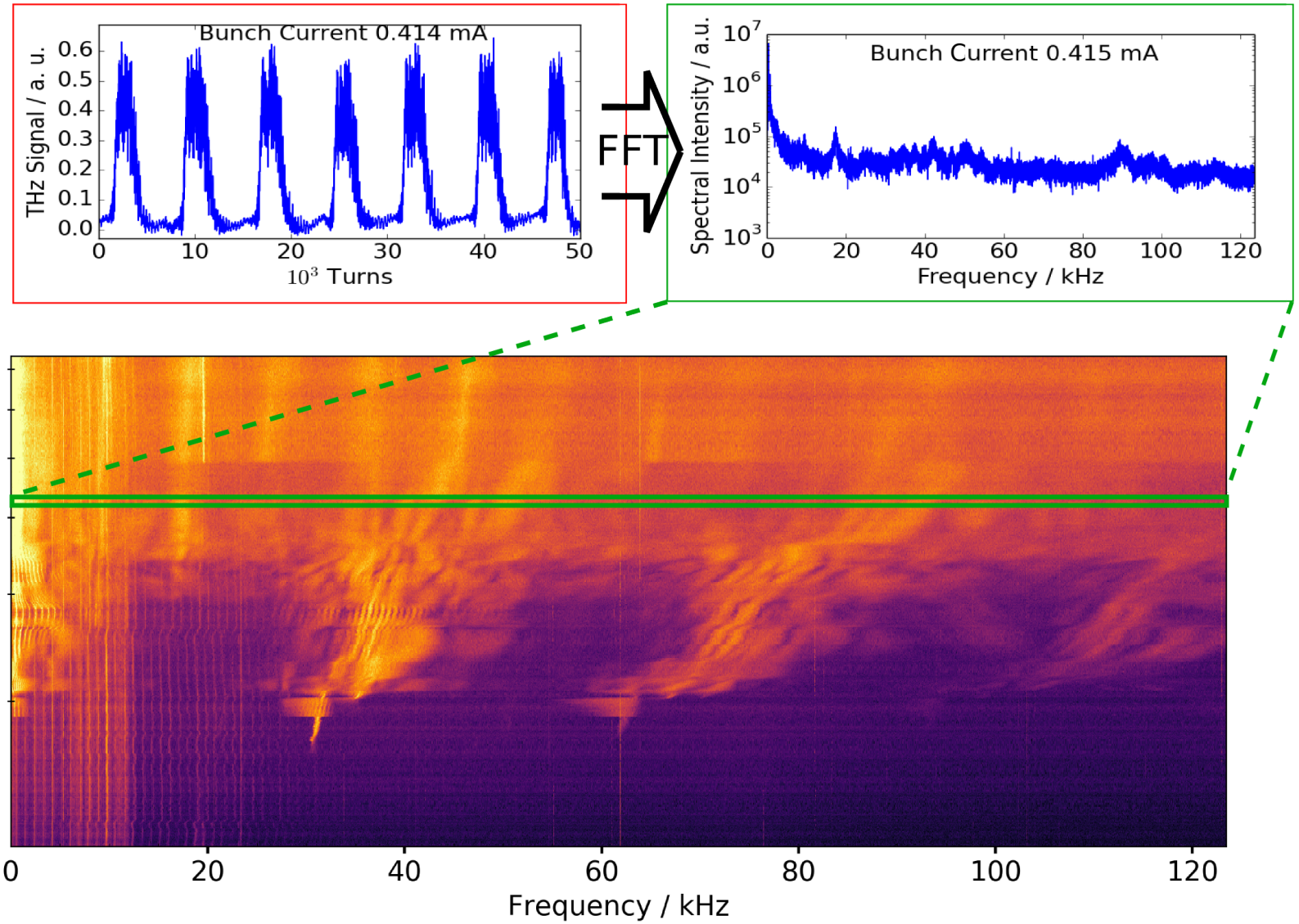


DAQ: KAPTURE

- In-house developed DAQ system
- 4 ADC channels with turn-by-turn and bunch-by-bunch capability (sampling with fixed phase)
- Continuous read-out

M. Caselle, IPAC 2014 Dresden, THPME113

Micro-bunching instability



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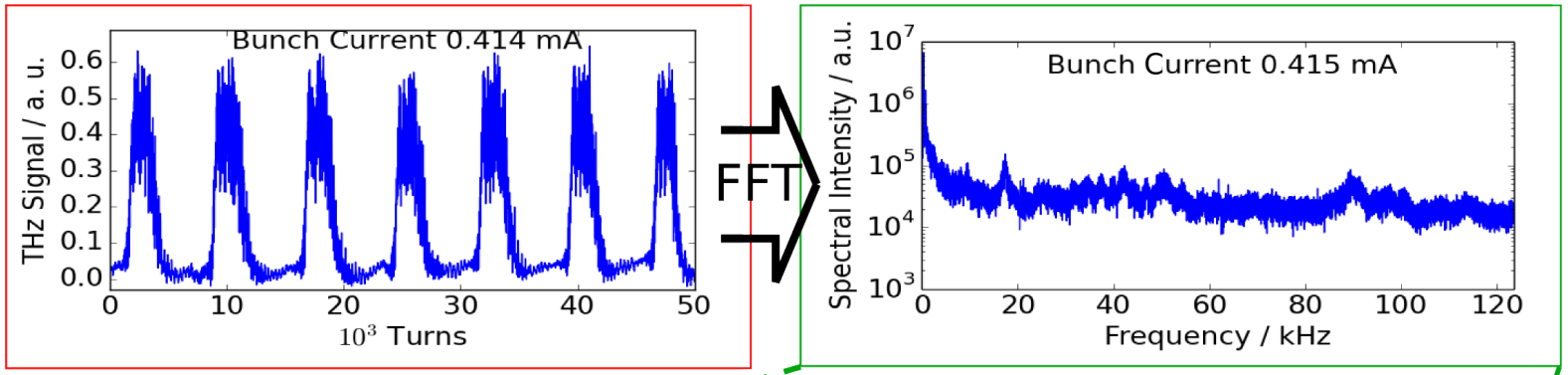
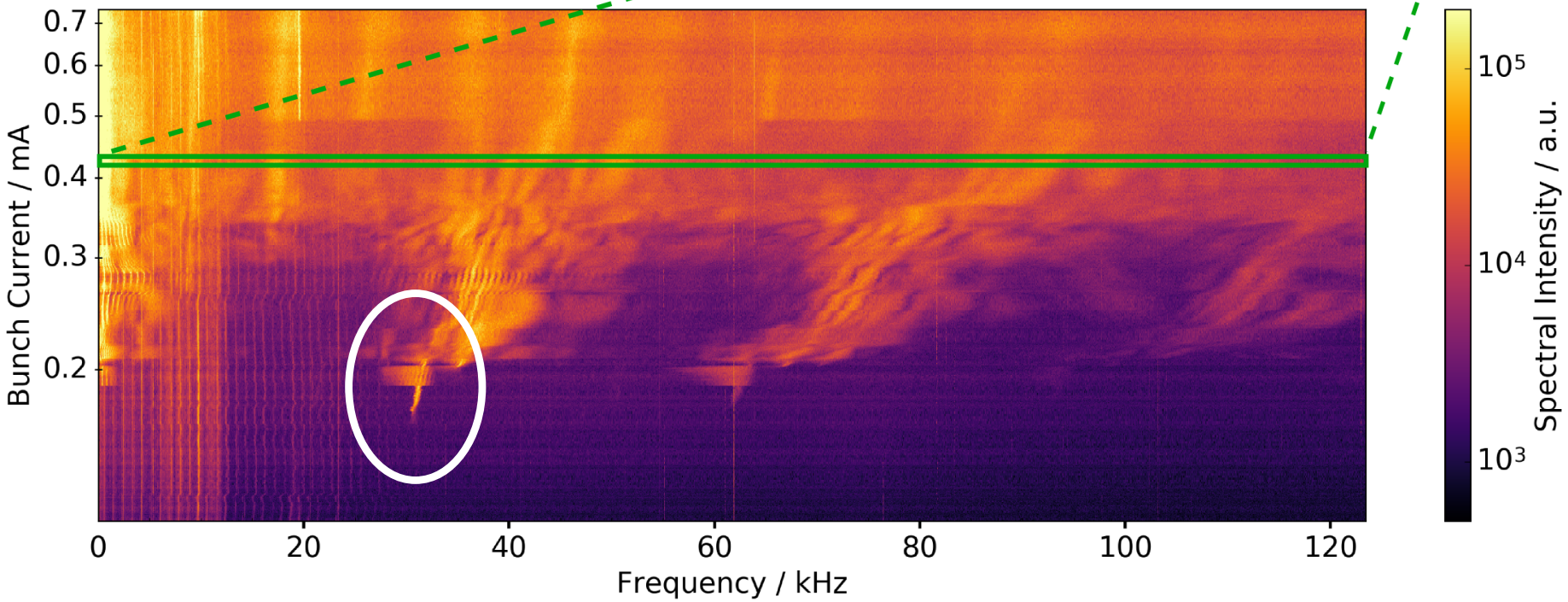
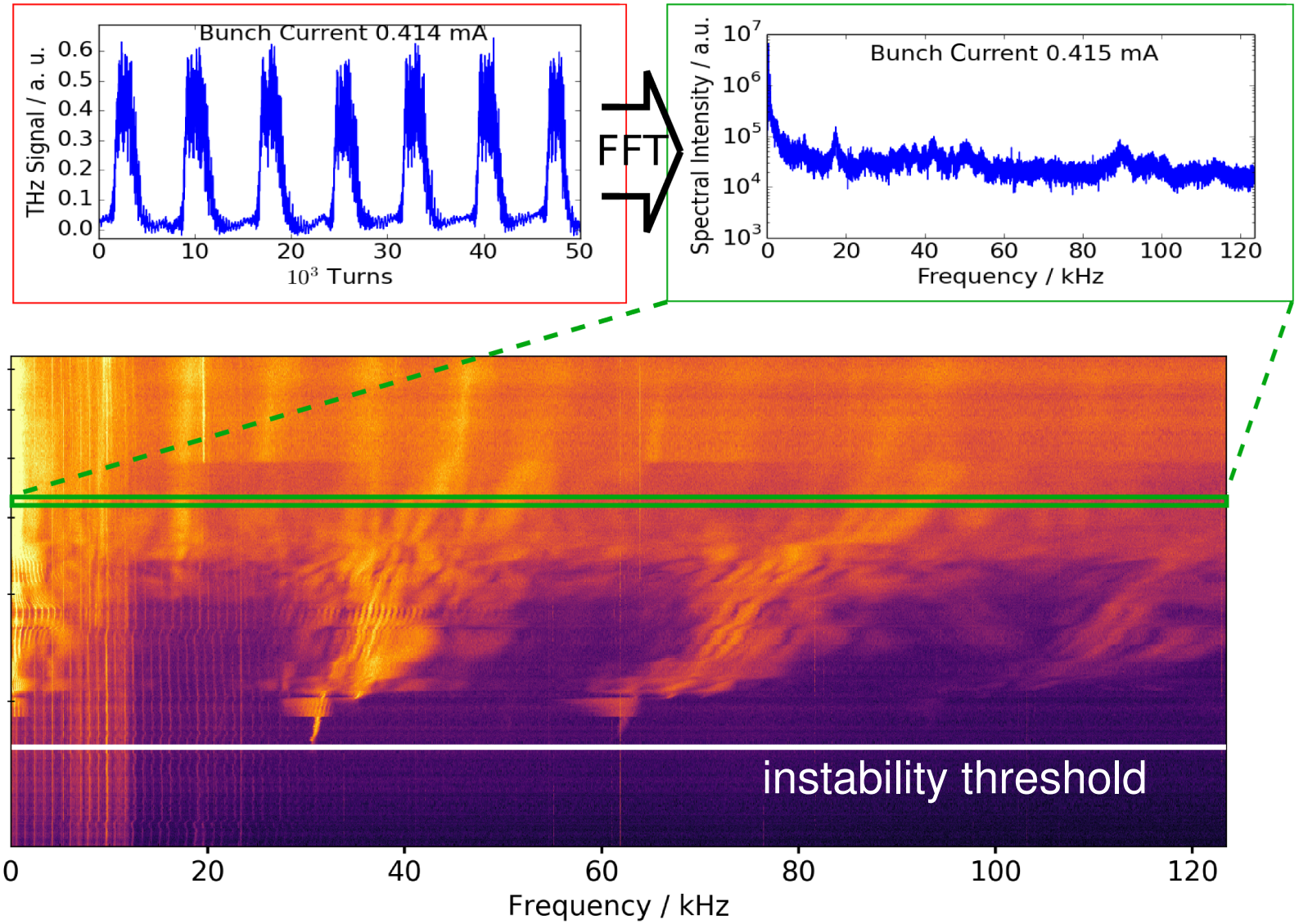


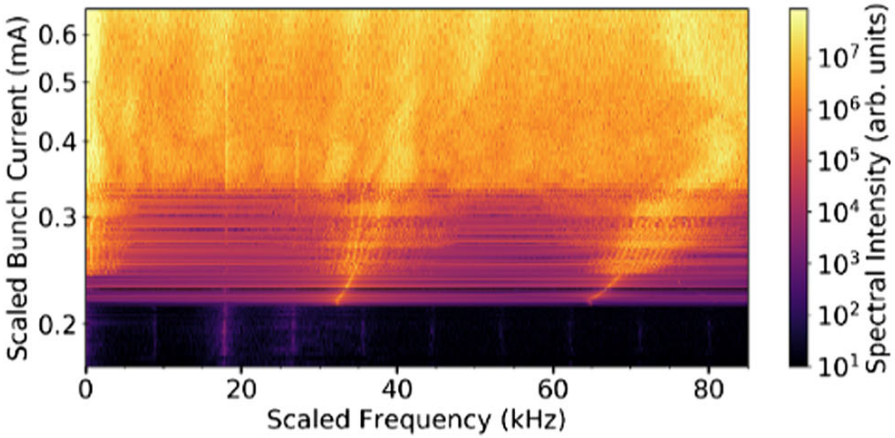


Micro-bunching instability

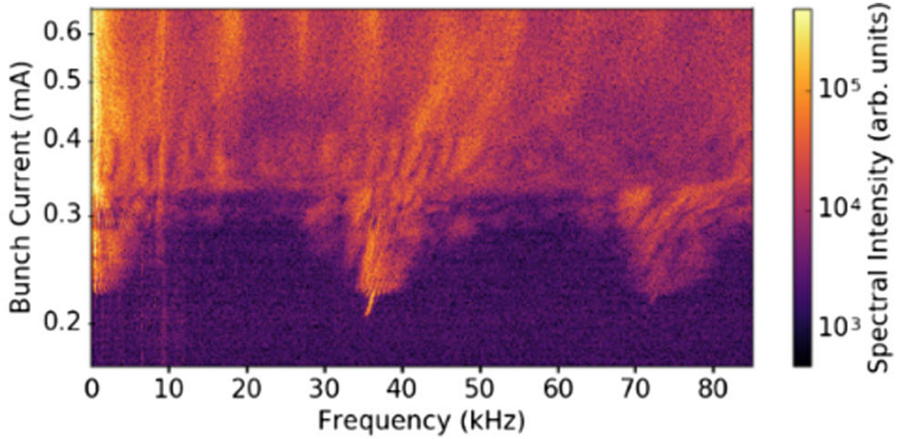


Motivation - multi-bunch effects

- Parallel plates CSR impedance model describes instability for single bunches [1, 2]
- No long range effects included in model



Simulation



Measurement

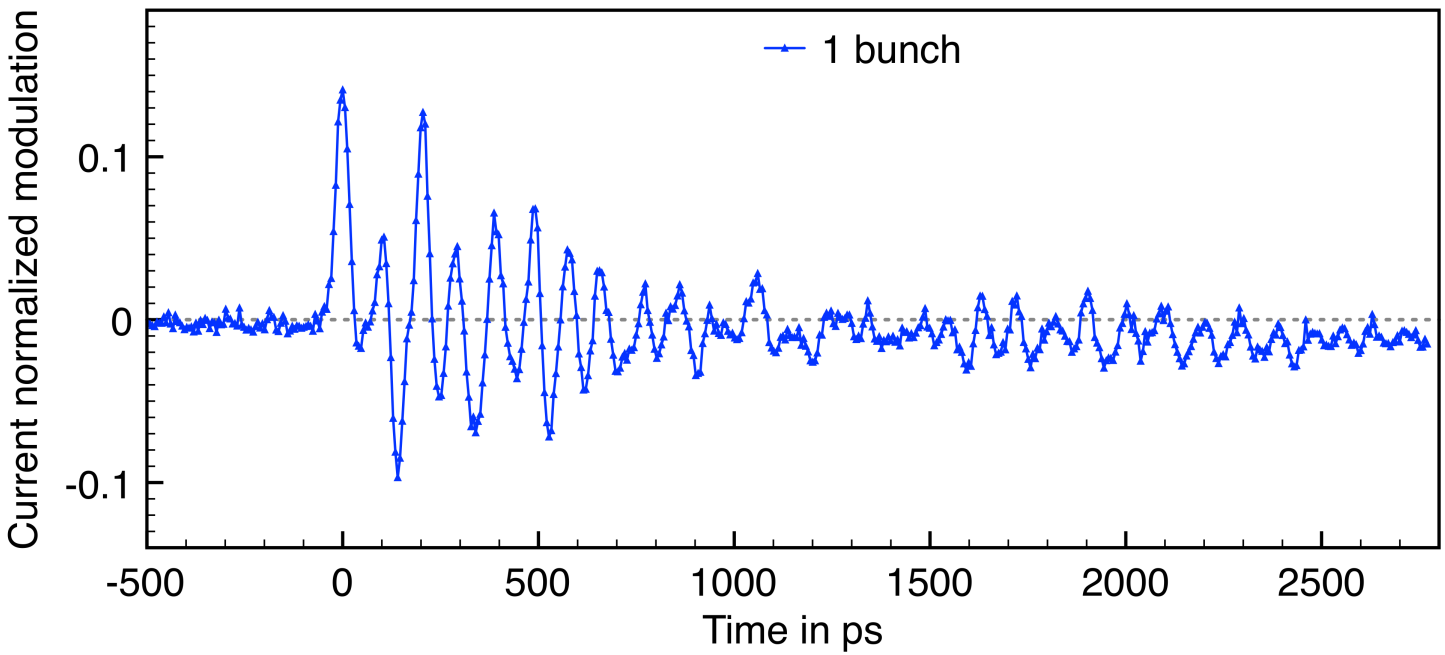
What about multiple bunches?

[1] M. Brosi et al., Phys. Rev. Accel. Beams, 2016, Vol. 19, Nr.11.
[2] P. Schönfeldt et al., Phys. Rev. Accel. Beams, 2017, Vol. 20, Nr.3.

Motivation - multi-bunch effects

- Indications for long range effects seen in previous measurements

Electro-optical measurement:

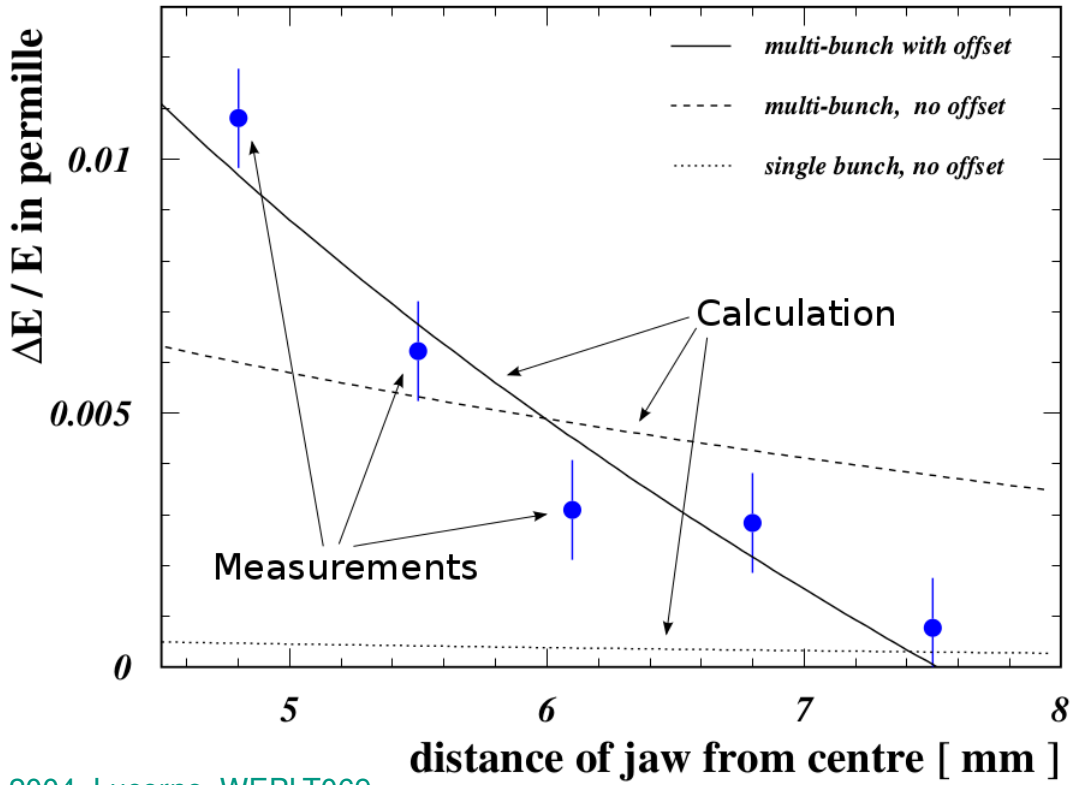


N. Hiller et al., "Single-Shot EOSD Measurements at ANKA", WEOBB02 talk, IPAC'14 Dresden, Germany.

Motivation - multi-bunch effects

- Indications for multi-bunch effects seen in previous measurements and simulations [3, 4, 5]

Energy loss due to impedance of scraper jaw [3]:

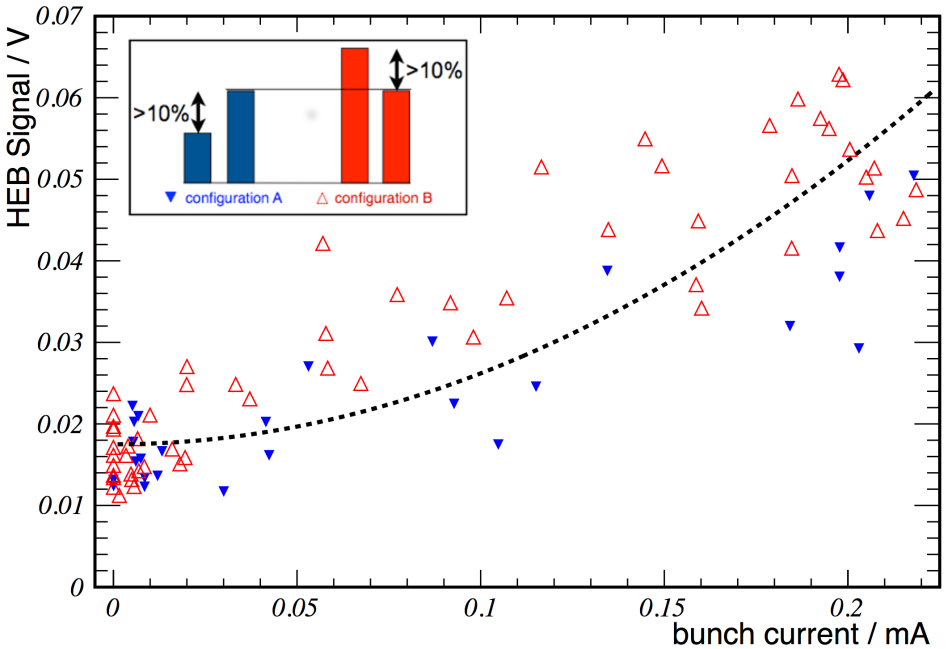


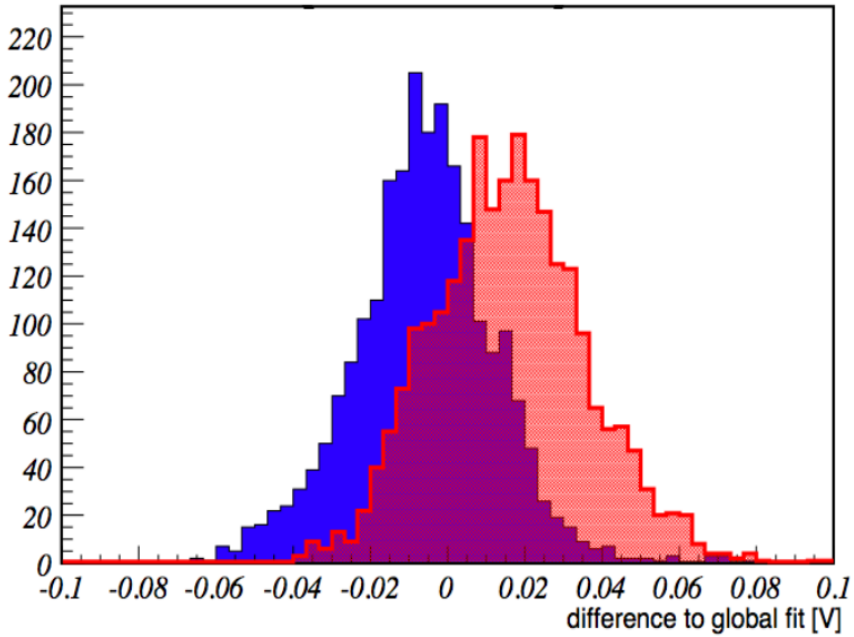
[3] A.-S. Müller et al., EPAC 2004, Lucerne, WEPLT069.
[4] A.-S. Müller et al., ICFA Beam Dynamics Newsletter No. 57, 2012, pp. 154–165.
[5] R. Warnock et al., North American Particle Accelerator Conference 2013, Pasadena, CA.

Motivation - multi-bunch effects

- Indications for multi-bunch effects seen in previous measurements and simulations [3, 4, 5]

Difference in THz power below threshold [4]:





[3] A.-S. Müller et al., EPAC 2004, Lucerne, WEPLT069.
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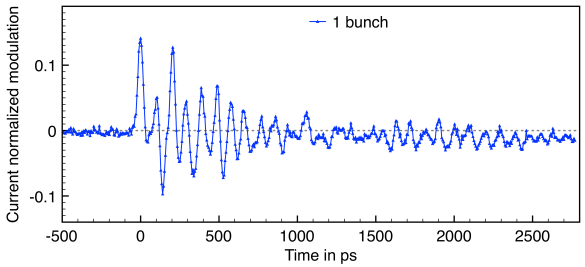
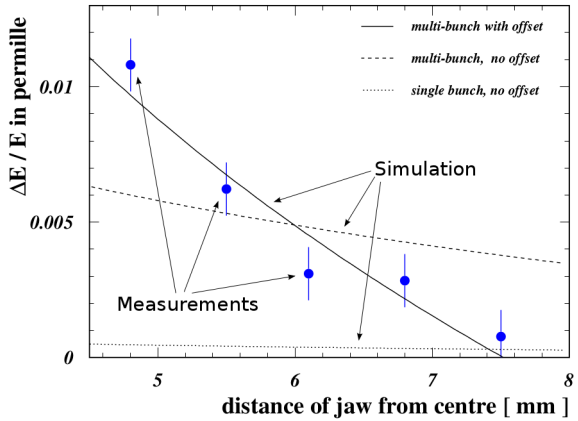
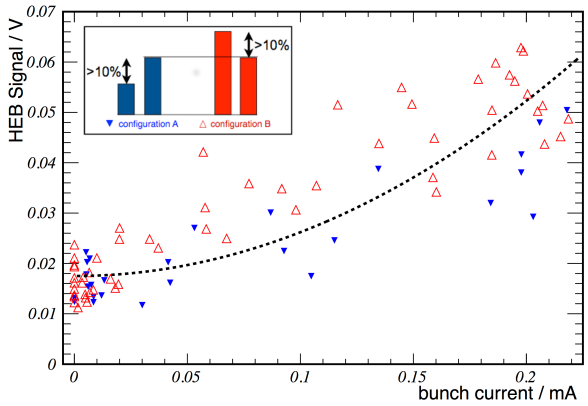
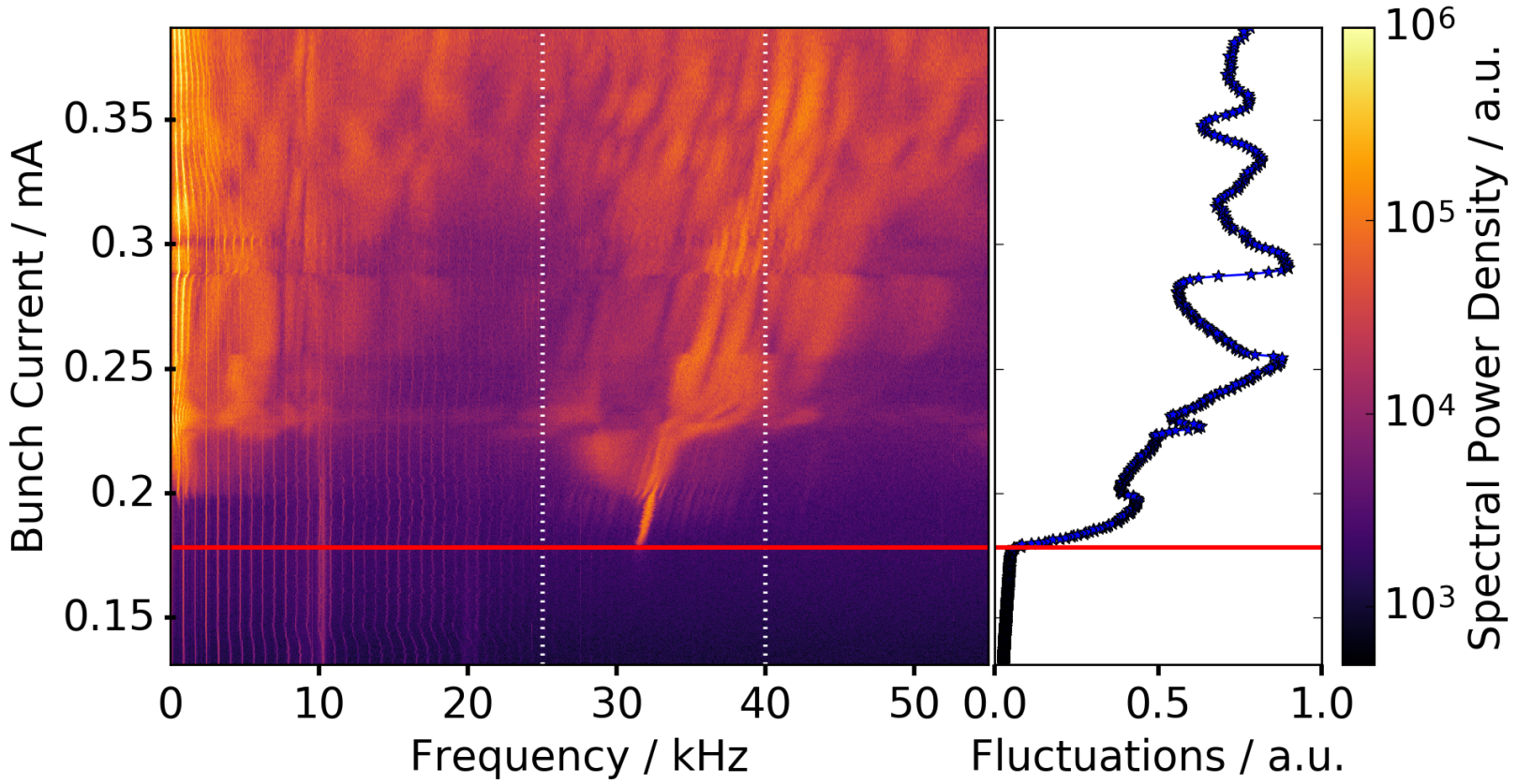






⇒ Is the micro-bunching instability threshold current sensitive to multi-bunch effects?

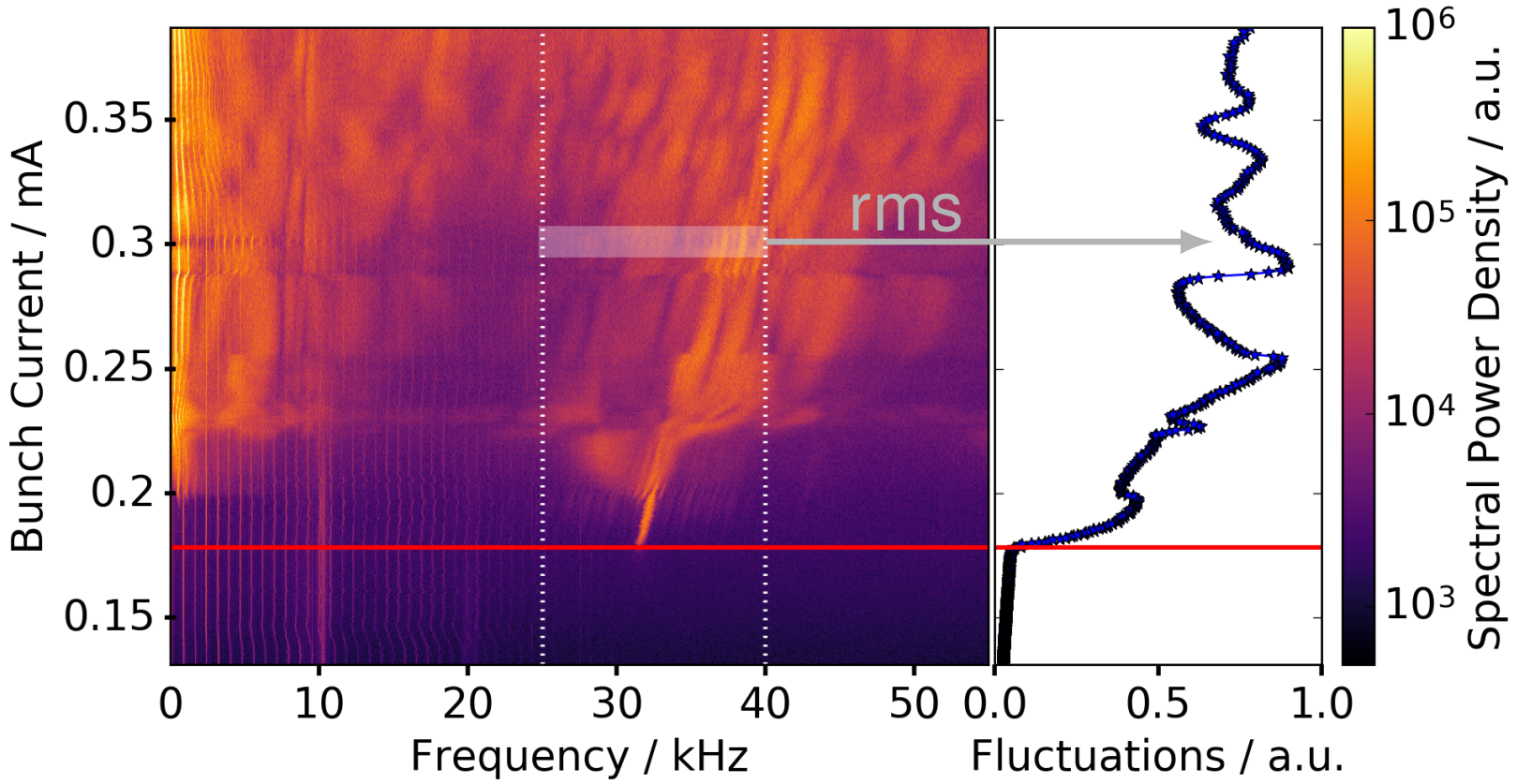
Instability threshold



Instability threshold = first increase of fluctuations:
Power in fluctuations of specific frequency range gives strong indication for threshold current

Miriam Brosi et al., “Fast mapping of terahertz bursting thresholds and characteristics at synchrotron light sources”, Phys. Rev. Accel. Beams 19, 110701, DOI: 10.1103/PhysRevAccelBeams.19.110701

Instability threshold



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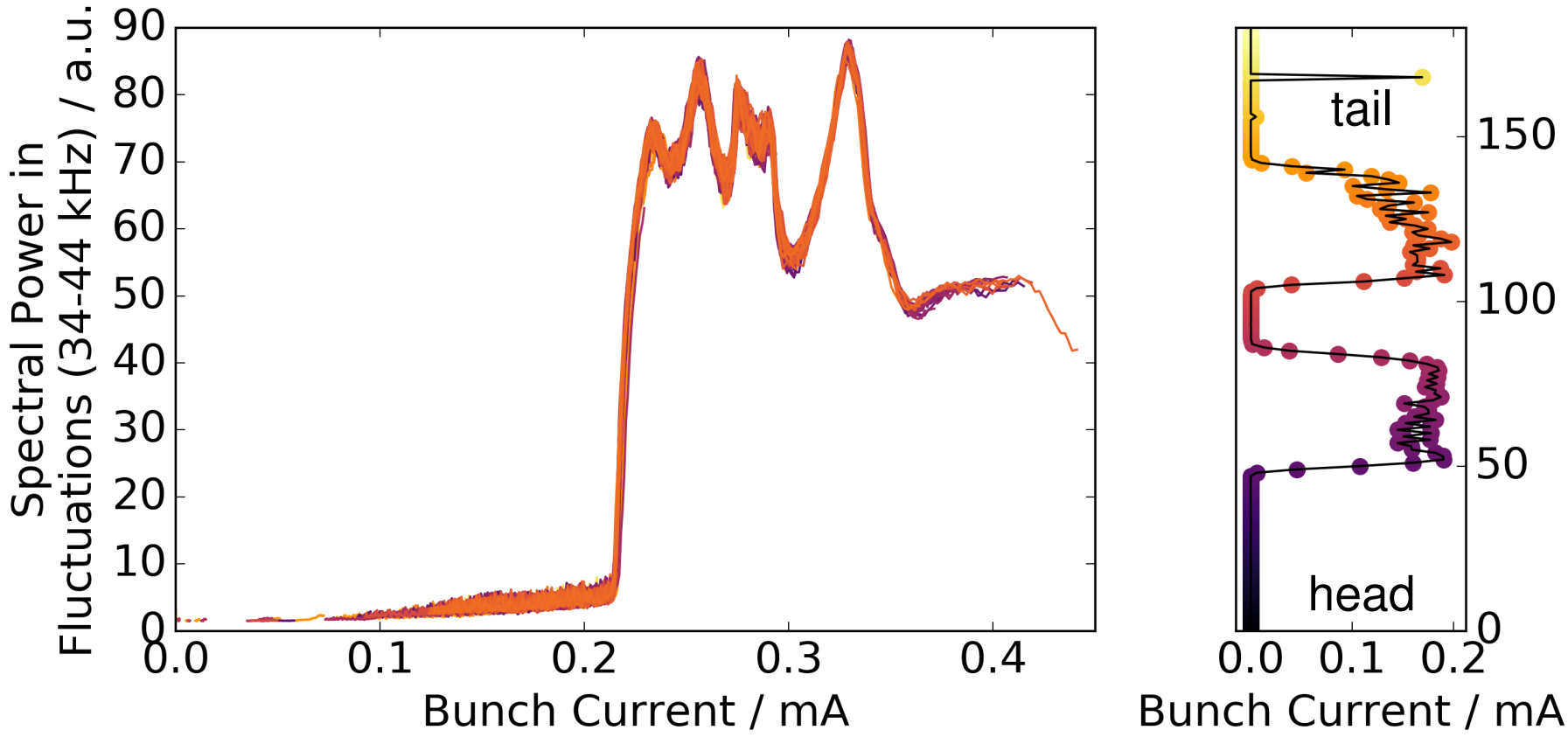
Instability threshold in multi-bunch

Threshold currents of all bunches in a multi-bunch fill



- Roughly the same threshold currents for all bunches of one fill
- Uncertainty of the measured bunch current is an important parameter

Instability threshold in multi-bunch

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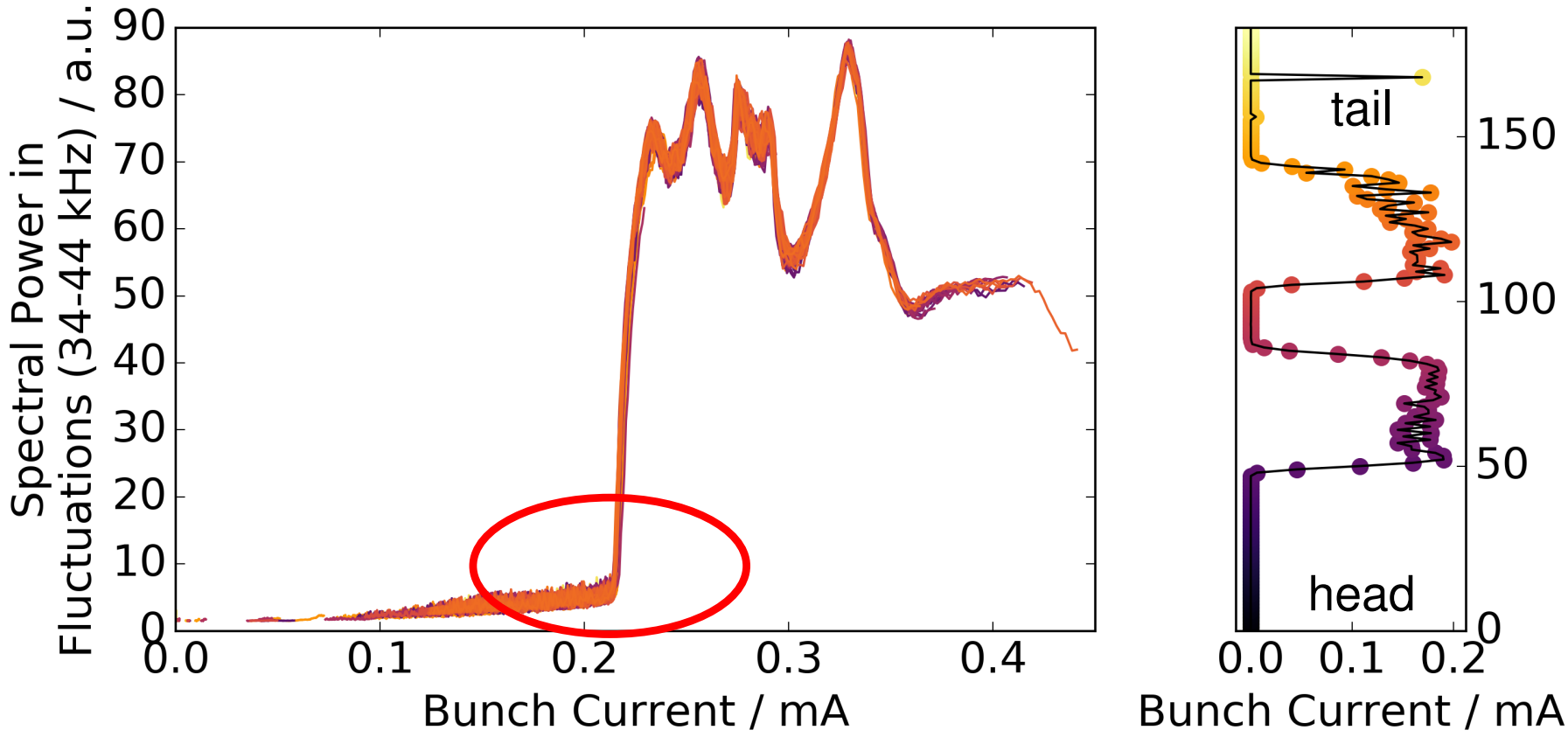

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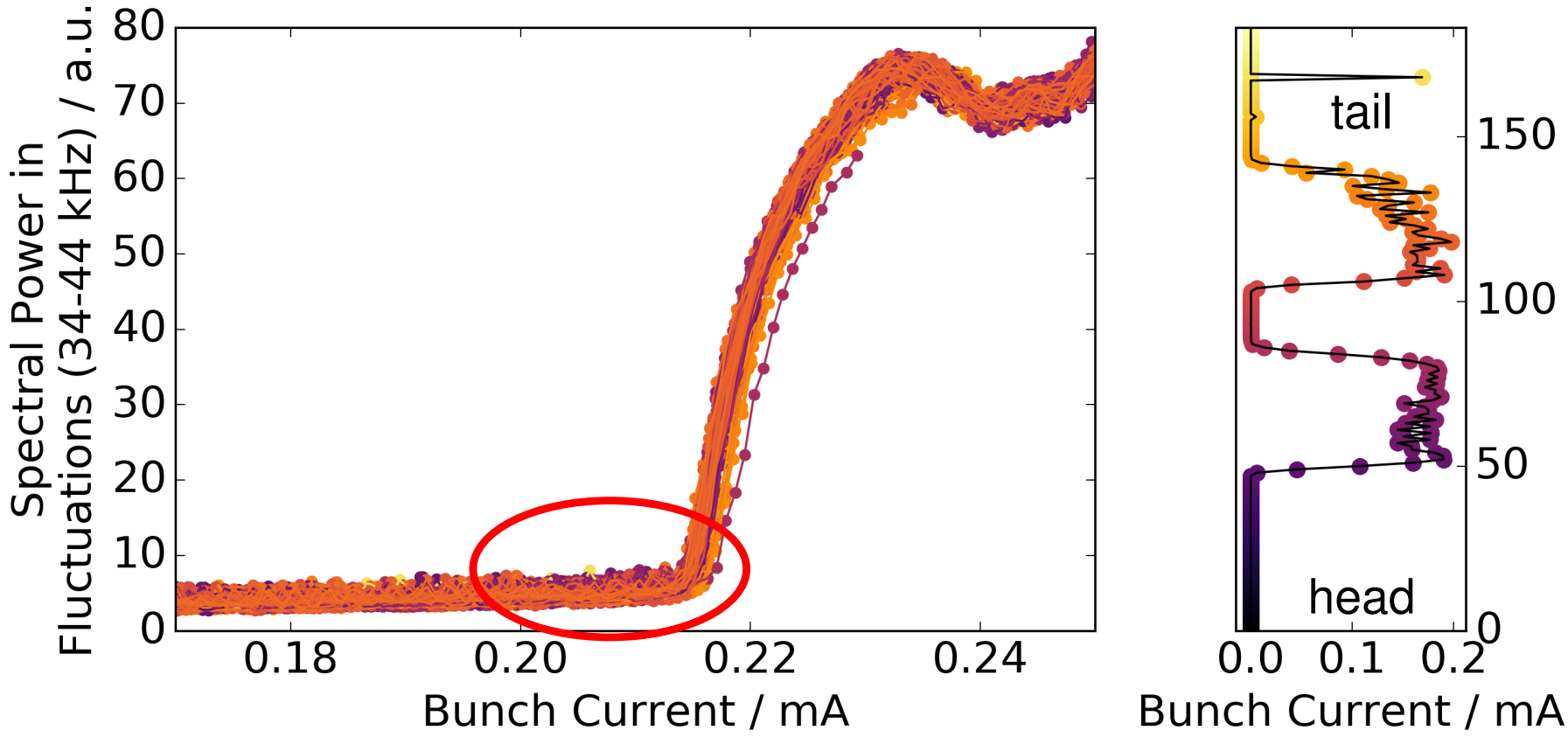

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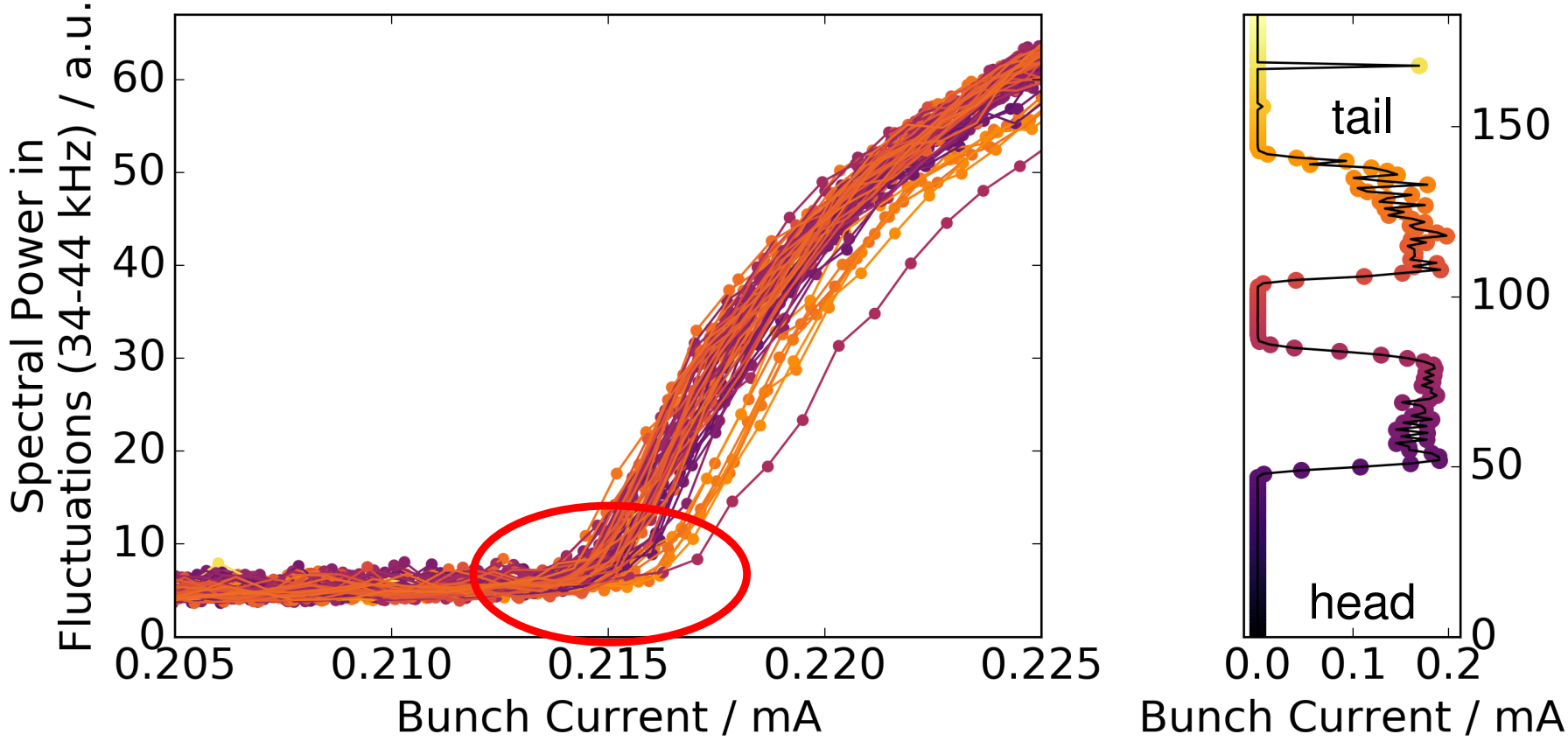

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Bunch current measurement

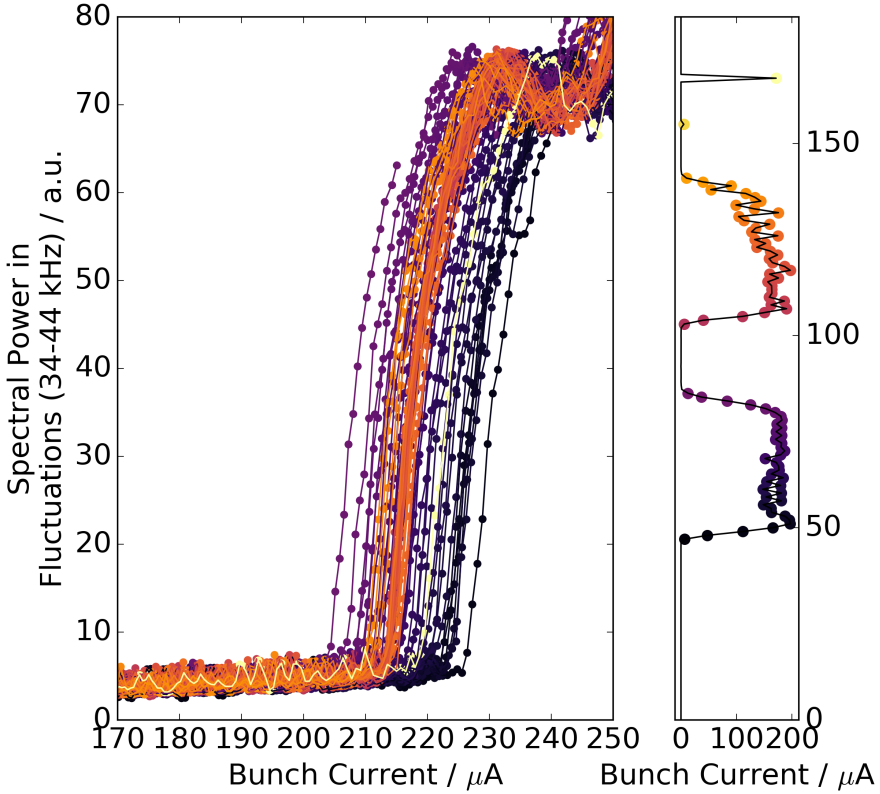
- Absolute beam current
  $\rightarrow$ DCCT (DC Current Transformer)
- Relative distribution over bunches
  $\rightarrow$ Time-Correlated Single Photon Counting
  - Use incoherent synchrotron radiation (I $\propto$ Ne)
  - Reduce intensity to less than a photon per turn
  - Measure arrival time distribution relative to ANKA revolution clock
- Setup at ANKA:
  - Single Photon Avalanche Diode (SPAD)
  - PicoHarp 300
- Statistical error on measured bunch current I_b dominated by Poisson statistics (with counts N):

$$\frac{\sigma_{I_b}}{I_b} \propto \frac{1}{\sqrt{N}}$$

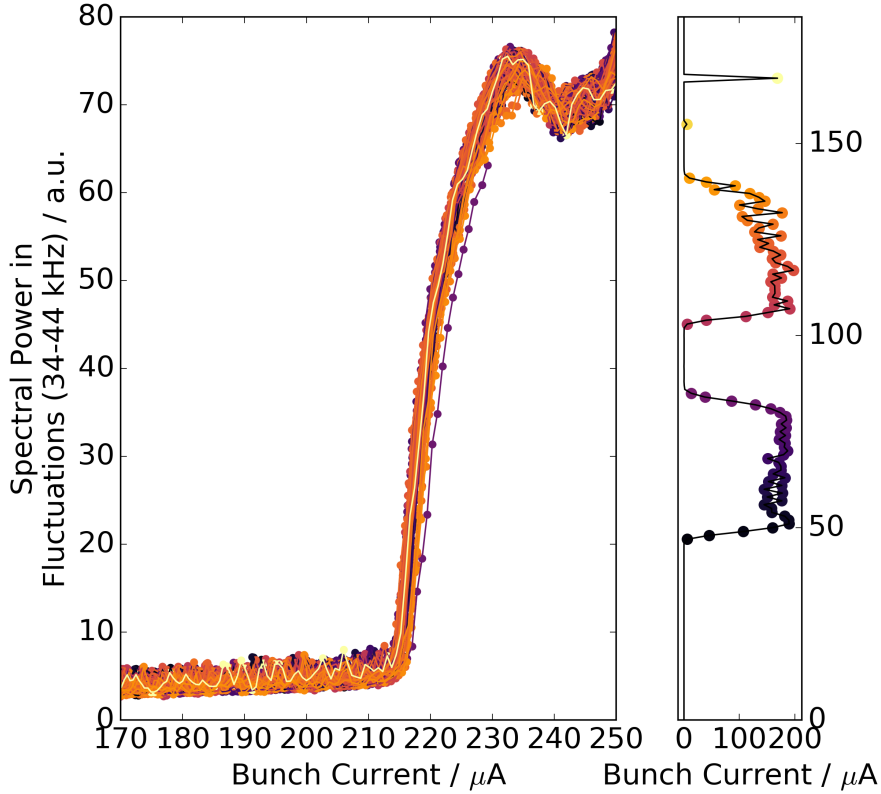
- Caution: Dead time correction might be necessary

B. Kehrer et al., “Visible light diagnostics at the ANKA storage ring”. IPAC2015, 866-868(2015)

Influence of dead time correction

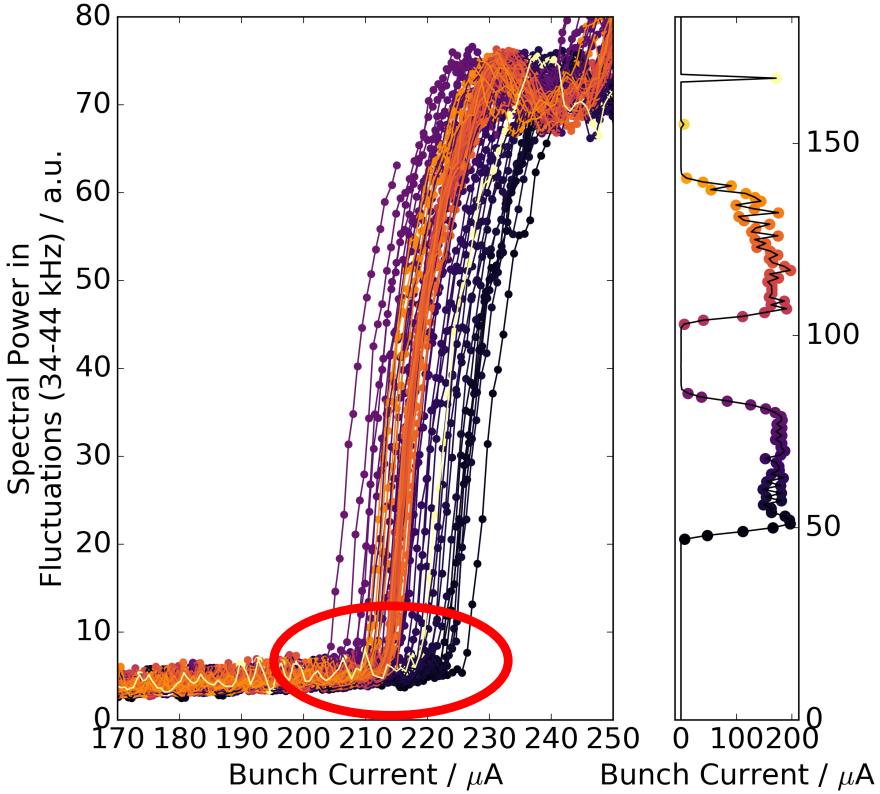


Before

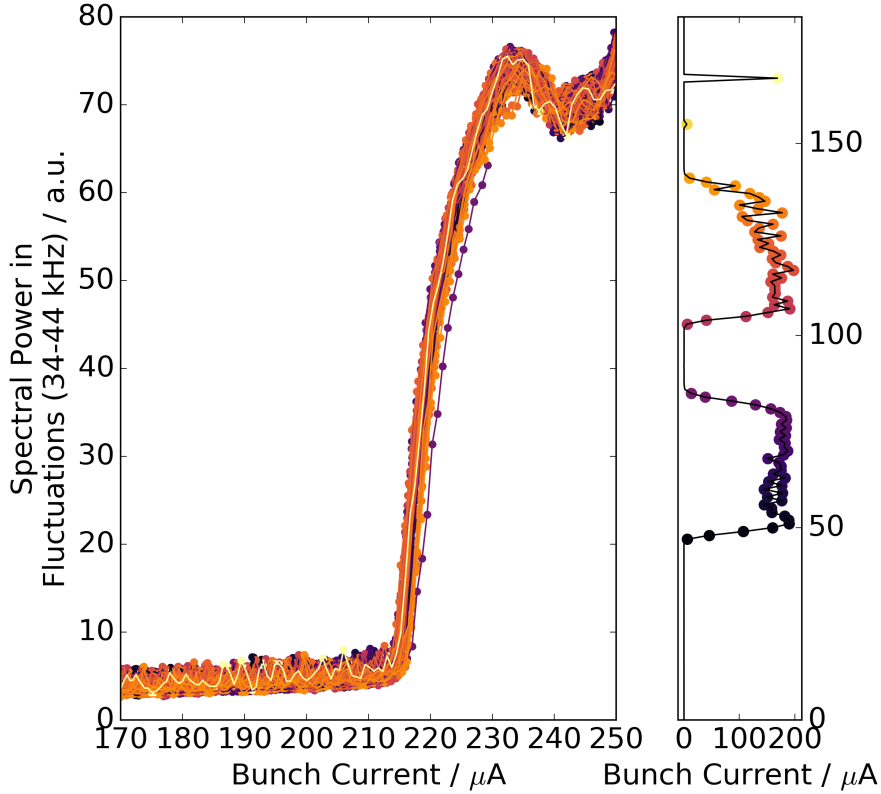


After

Influence of dead time correction



Before



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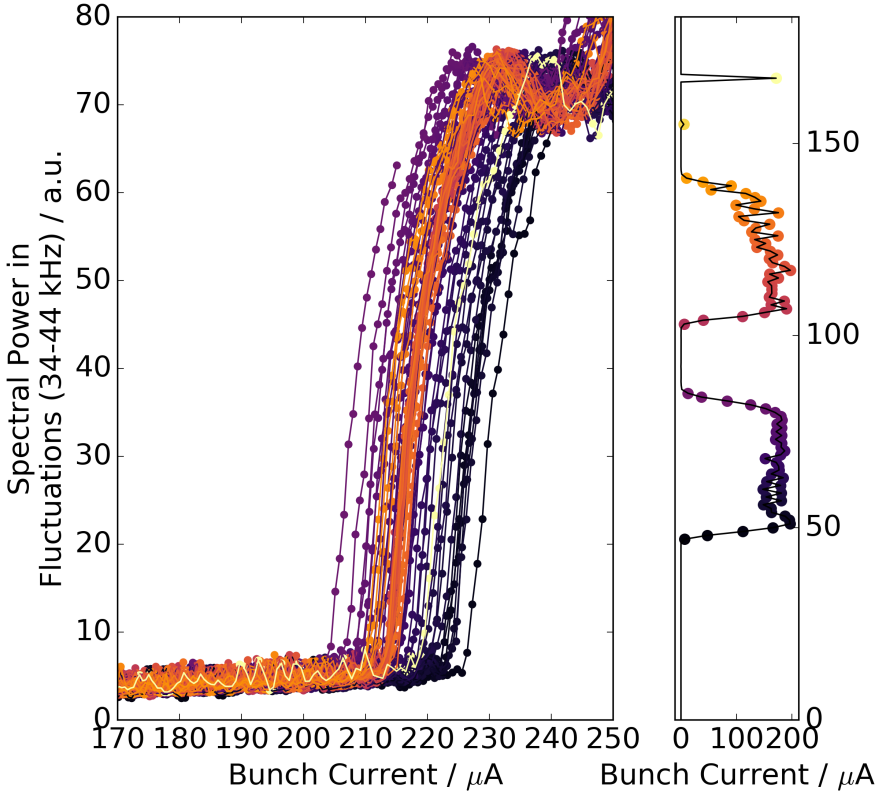

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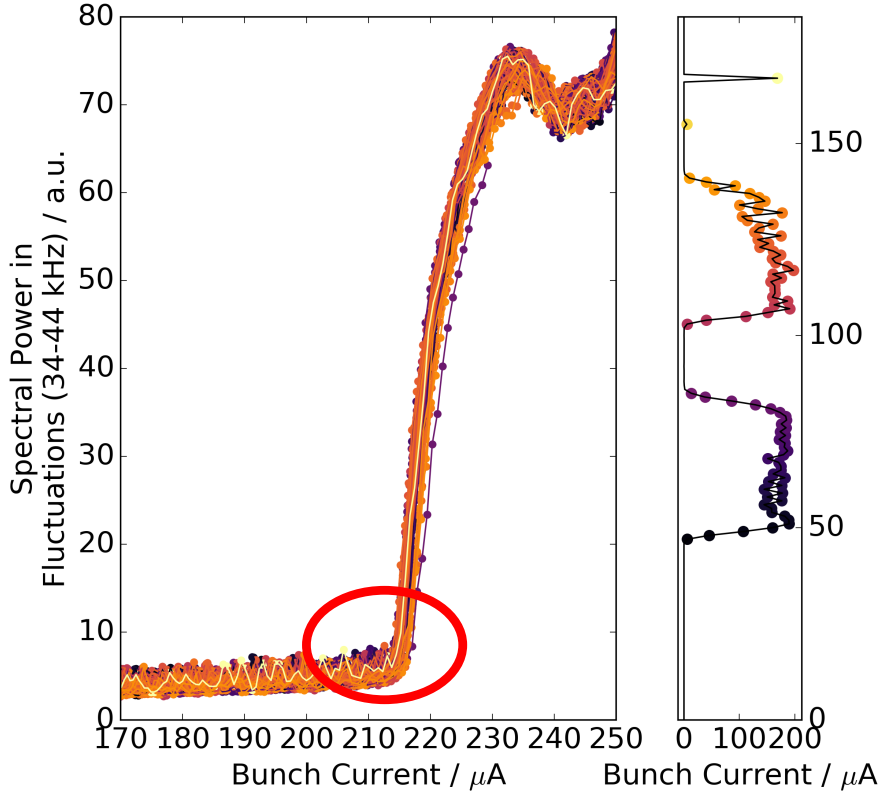
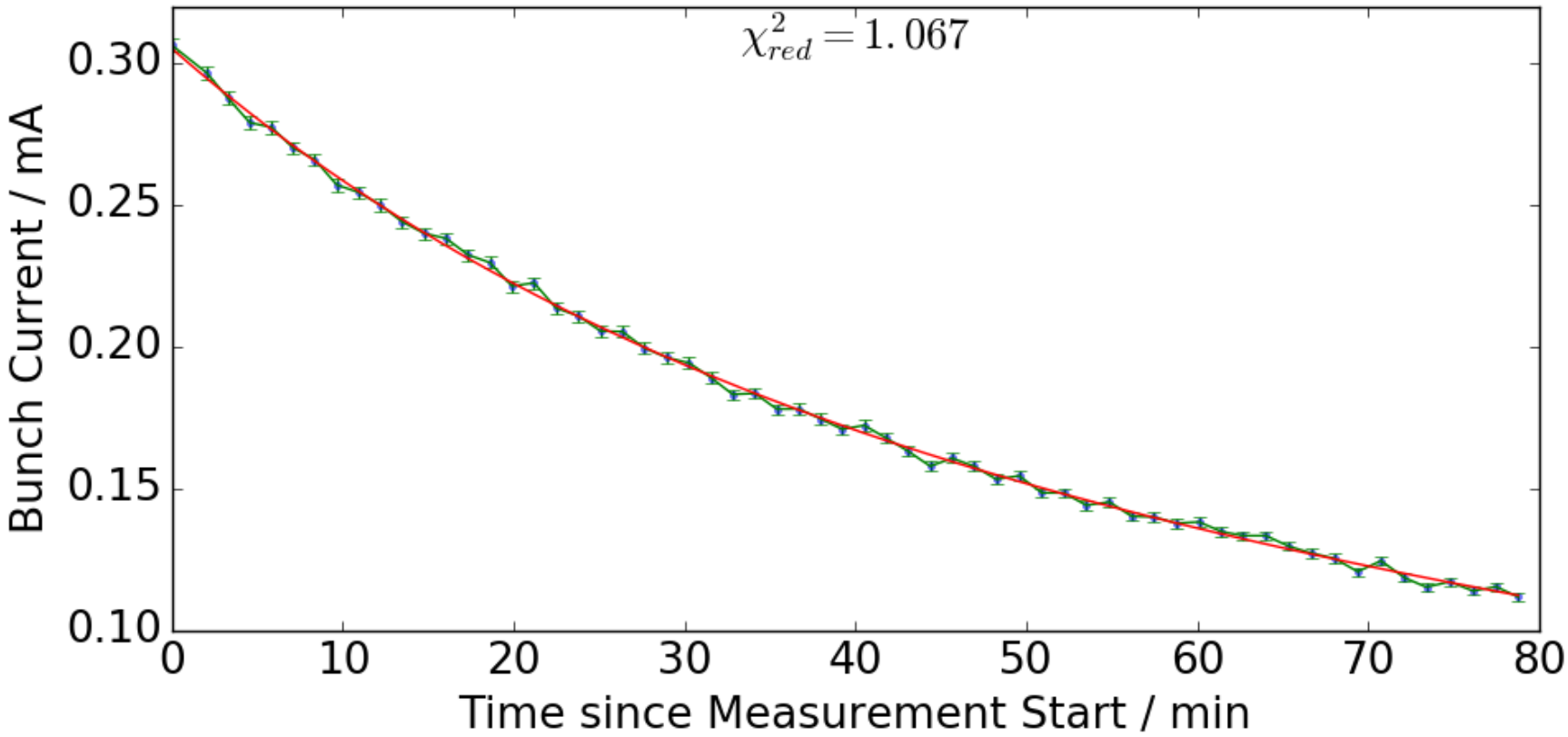


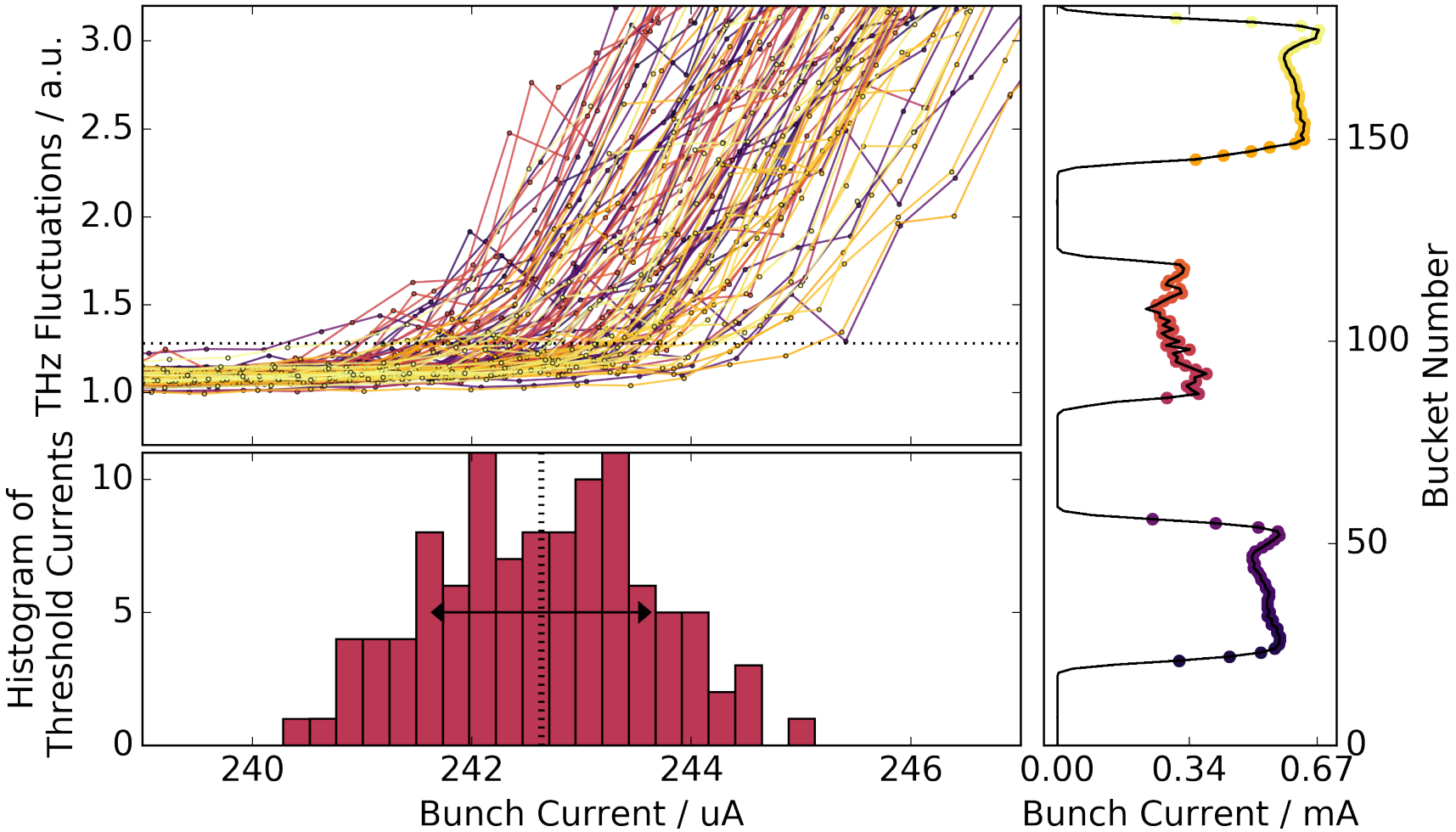
After

Bunch current interpolation

- Filling pattern measurements available every 30 s (due to integration)
- Interpolation necessary to determine bunch current at threshold for each bunch



Comparison of threshold currents



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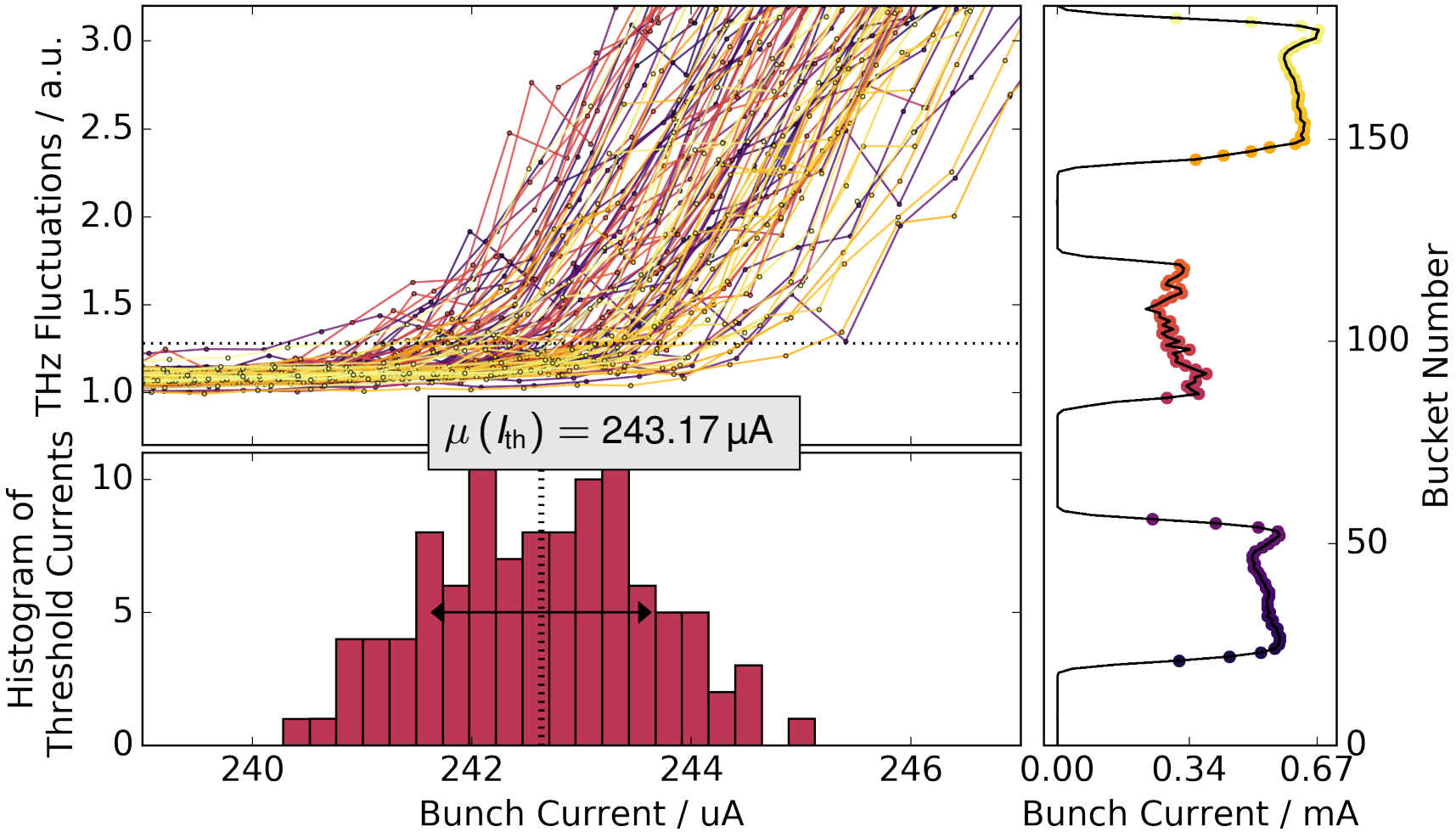

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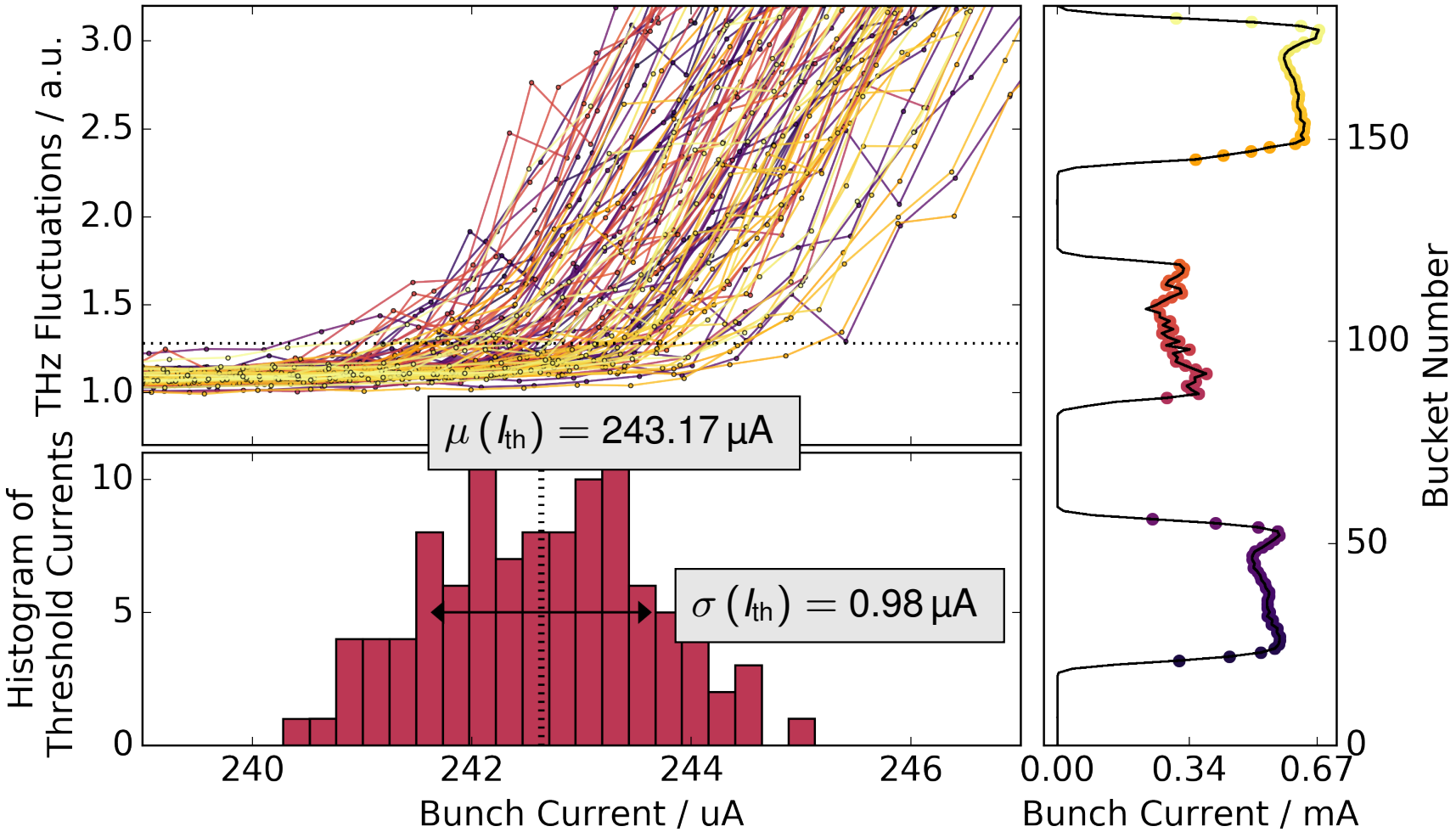

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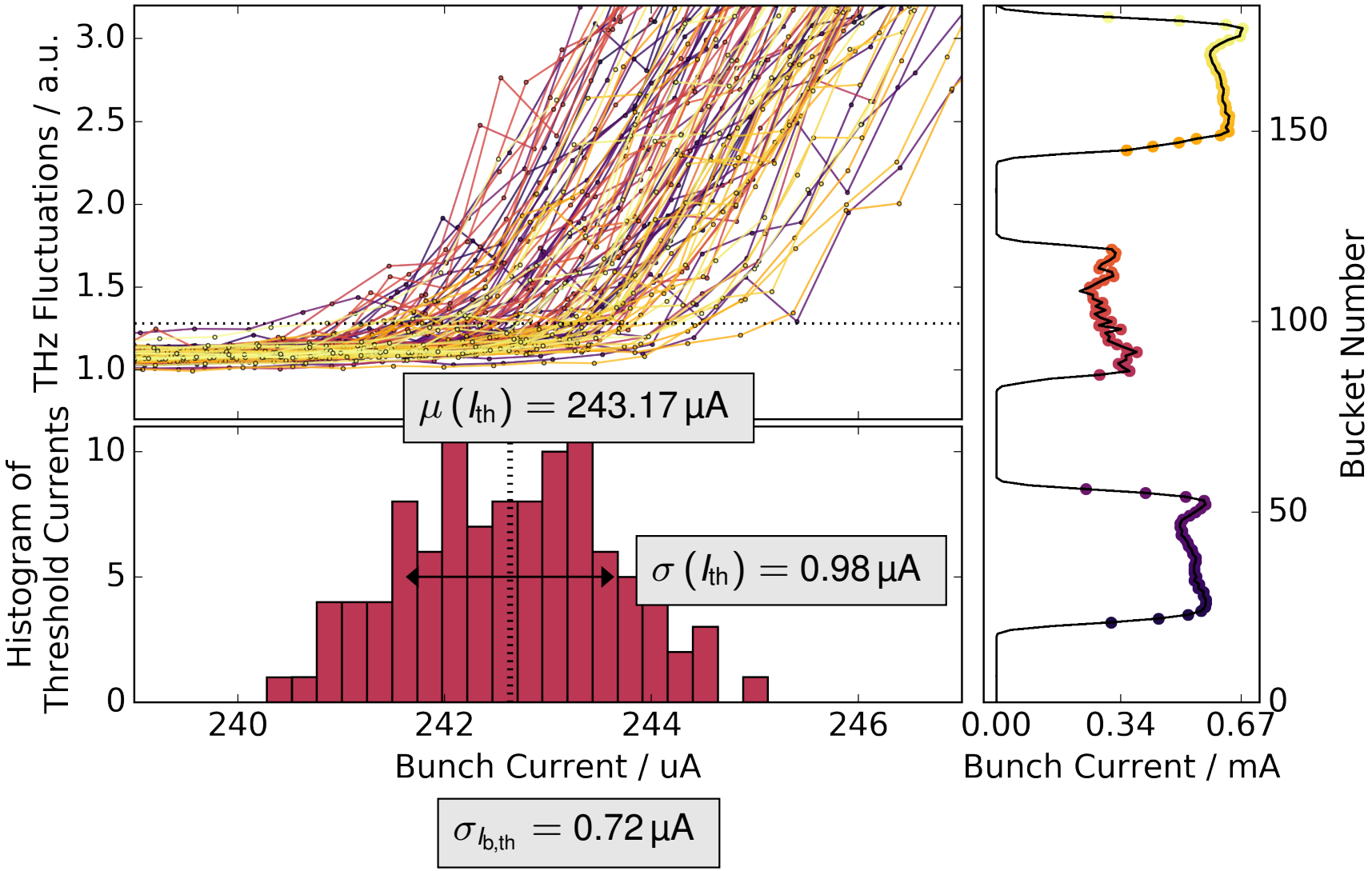
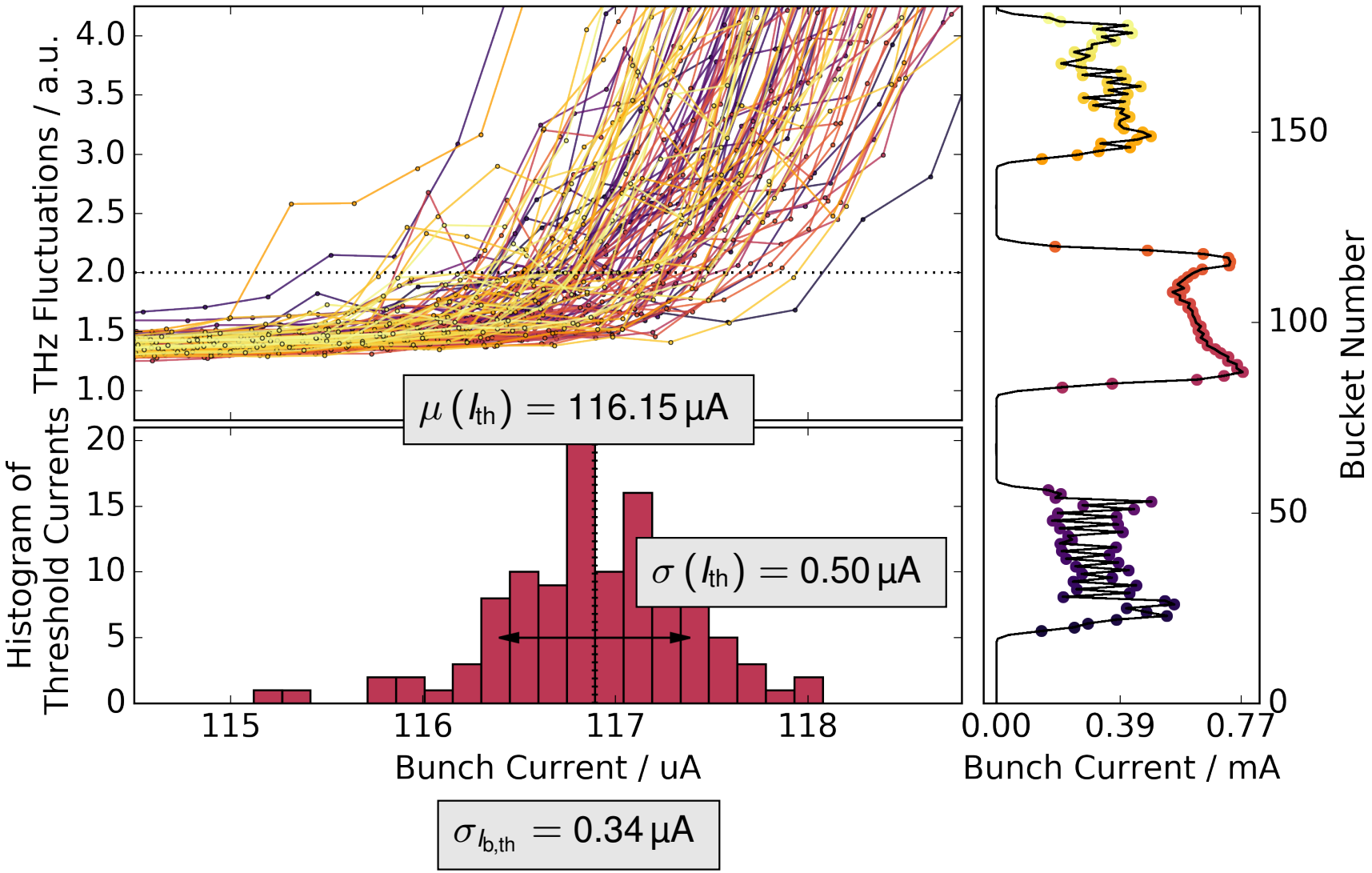


Comparison of threshold currents

Different beam conditions:



Results for different Fills

Different mean threshold currents due to different beam conditions

Fill number	6212	6283	6284	6288	6292	6296
$\mu\left(I_{\mathrm{th}}\right)$ / µA	106.02	179.44	67.64	116.15	128.13	243.17
$\sigma_{I_{\mathrm{b,th}},\,\mathrm{Fit}}$ / µA	0.48	0.62	0.29	0.34	0.29	0.72
$\sigma\left(I_{\mathrm{th}}\right)$ / µA	0.55	1.065	0.49	0.50	0.43	0.98
$\sqrt{\sigma\left(I_{\mathrm{th}}\right)^2 - \sigma^2_{I_{\mathrm{b,th}}}}$ / µA	0.27	0.87	0.39	0.37	0.32	0.66

Part of spread not explained by bunch current uncertainty

$\Rightarrow$ additional contribution?

Even better current resolution necessary.

Summary

- Aim was to look for multi-bunch effects, required:
  - Turn-by-turn and bunch-by-bunch resolution
    $\rightarrow$ Provided by fast THz detector & in-house developed DAQ
  - Highest possible resolution for all properties, in particular bunch current
- Small but systematic difference between threshold currents of bunches in multi-bunch environment
- Still higher bunch current precision needed

- Next steps:
  - Systematic studies with additional sources of long-range wakefields
  - Systematic studies on absolute emitted THz Power

Acknowledgements

- **KIT THz-Team** (from IBPT, IMS, IPE, IPS and LAS):
  M. Balzer, E. Blomley, T. Boltz, A. Borysenko, E. Bründermann, M. Caselle, C. Chang*, N. Hiller*, S. Höninger, M. Hofherr, E. Huttel, K.S. Ilin, V. Judin*, B. Kehrer, M. Klein*, S. Marsching, Y.-L. Mathis, M.J. Nasse, G. Niehues, A. Plech, J. Raasch, L. Rota, R. Ruprecht, M. Schedler*, A. Scheuring, P. Schönfeldt, M. Schuh, P. Schütze*, M. Schwarz*, M. Siegel, N.J. Smale, J. Steinmann, P. Thoma*, M. Weber*, S. Wuensch, M. Yan, and A.-S. Müller
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