Impedance Characterization and Collective Effects in the MAX IV 3 GeV Ring

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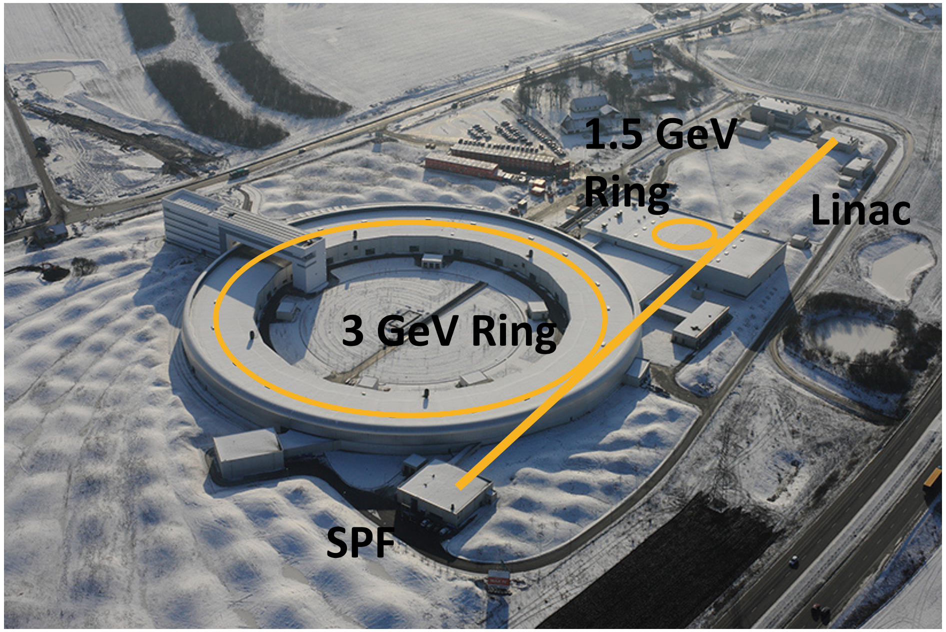
MAX IV Laboratory

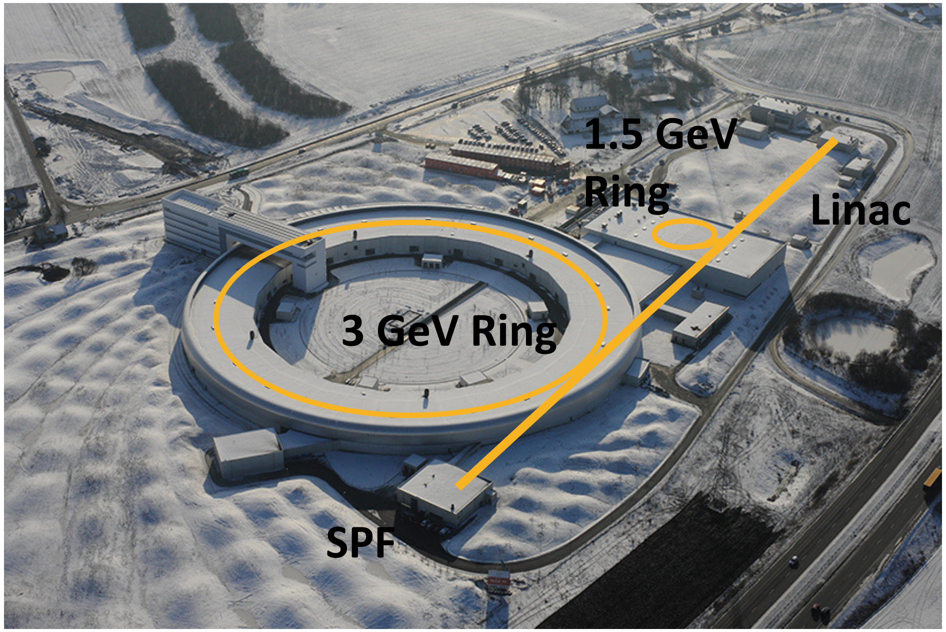
- Light source facility, currently under commissioning in Lund, Sweden [1]
- 3 GeV ring based on multibend achromat lattice



Parameter	Value
Horizontal emittance (pm)	300 (200 with IDs)
Design current (mA)	500
RF frequency (MHz)	99.931
Bunch length (ps)	40 (196 with harmonic cavities)

MAX IV Laboratory

- Small vacuum chamber aperture to accommodate strongly focusing, small-bore magnets
  - increases both resistive wall and geometric impedances



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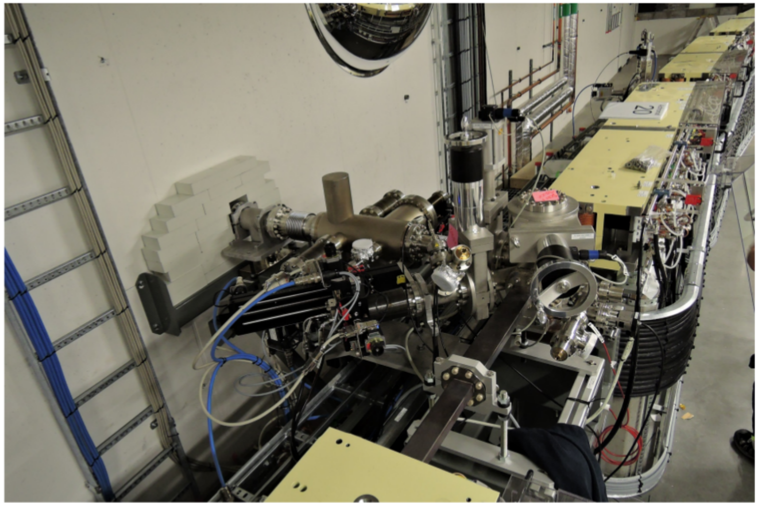
Outline

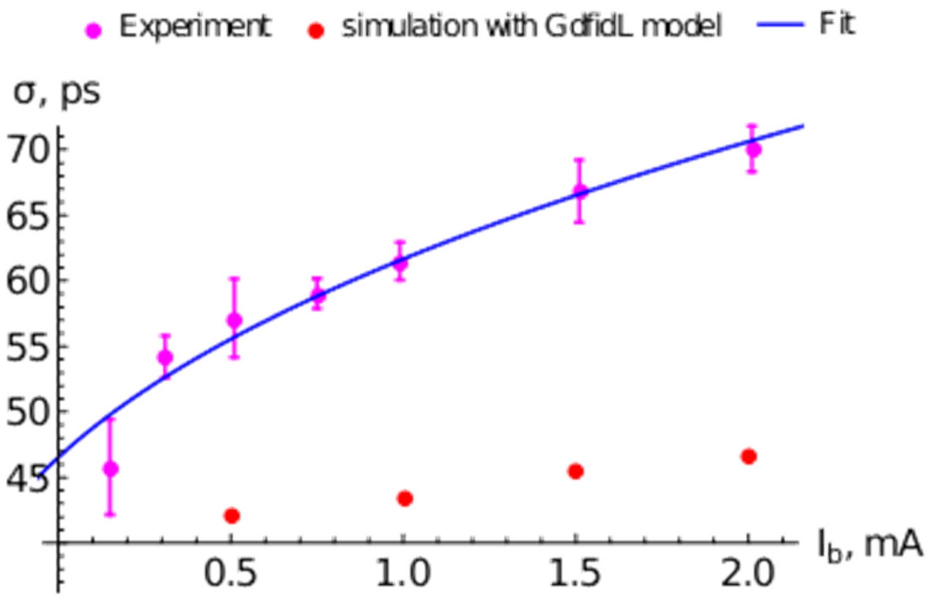
- First measurements of collective effects have been made
  - Bunch lengthening with single-bunch current
  - Shift of vertical tune with single-bunch current
  - Transverse mode-coupling instability
  - Multibunch instabilities – resistive wall and ion driven
- Impedance model [3][4]
  - Averaged resistive wall
  - GdfidL simulations of all major vacuum components fitted to a number of resonators plus resistive and inductive longitudinal impedance

Longitudinal

- Diagnostics beamline taking synchrotron radiation from a dipole bending magnet [5]
- Effective impedance from simulation about 2 times smaller than estimated from measurement
- 6 GHz resonator fit to reproduce lengthening:
  - Shunt impedance = 732 Ω
  - Quality factor = 1

Beam line inside ring tunnel

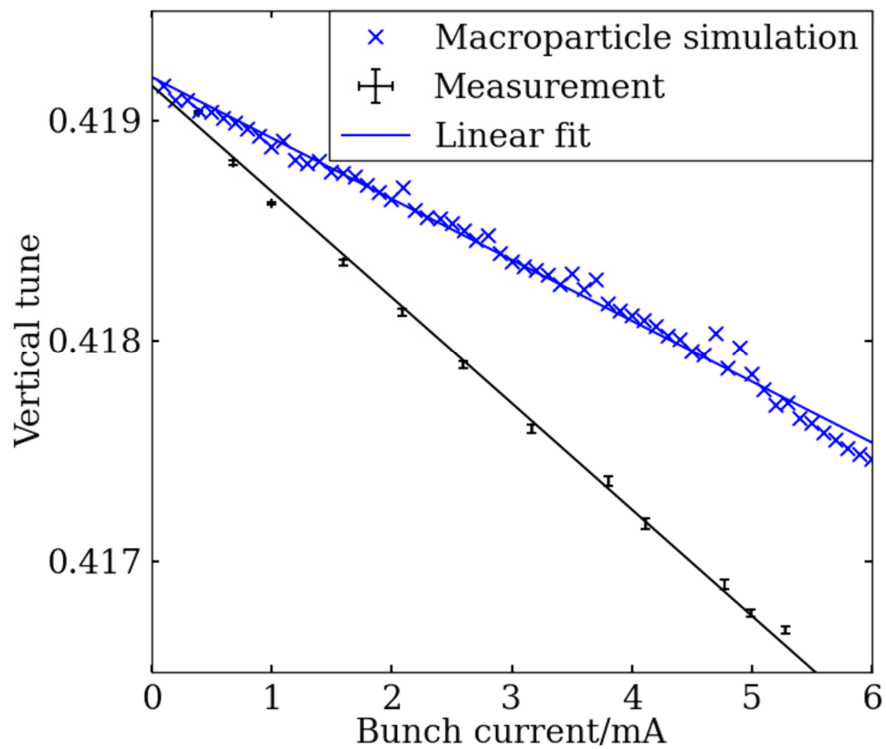




SOLEIL SYNCHROTRON MAX IV

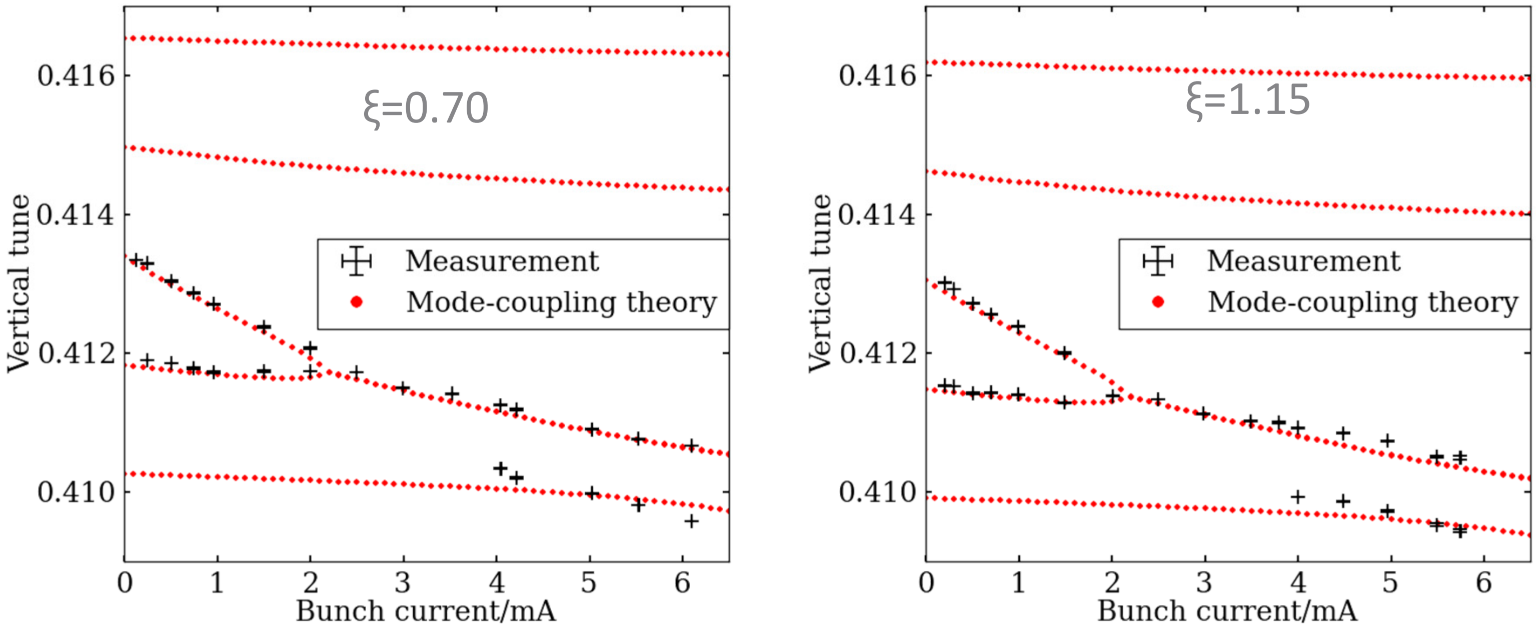
Single-Bunch Transverse – Tune Shift

- Close to zero chromaticity
- Vertical tune shift with bunch current measured using turn-by-turn BPM data
  - Detuning: -0.481±0.002 A^{-1}
- Detuning about a factor of 1.8 larger than predicted in simulation
  - Similar discrepancy to longitudinal plane
- No clear signs of TMCI such as hard limit on injection or sudden beam loss
  - Simulation predicts threshold of 5.5 mA



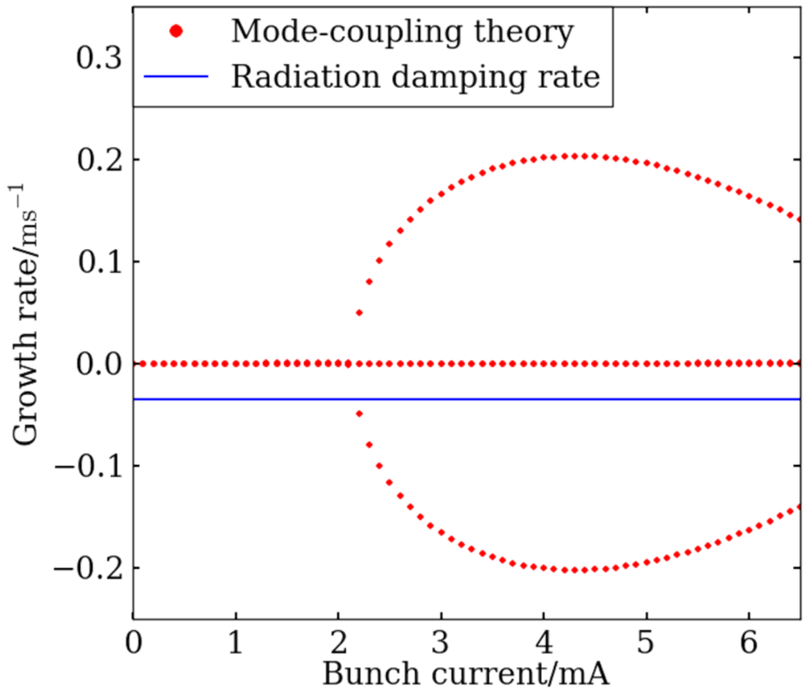
Single-Bunch Transverse – Mode Coupling

- Increase chromaticity to make head-tail modes visible to BPM
- Modes appear to merge in frequency and couple
- Use single resonator at 6 GHz and resistive wall to reproduce detuning using mode-coupling theory [8]
  - Shunt impedance: 360 Ω mm^{-1}, Quality factor: 1
- Bunch lengthening included



Single Bunch Transverse – Growth Rates

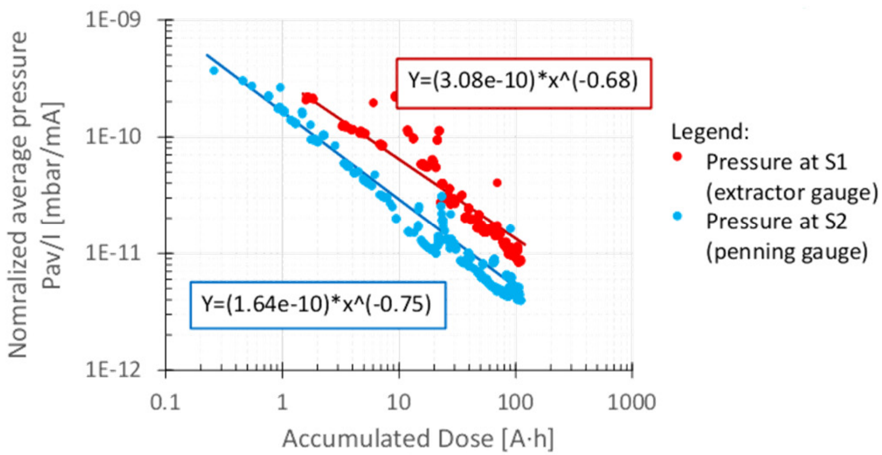
- Using imaginary tune-shift from mode-coupling theory
- Growth rates remain within the same order of magnitude as radiation damping time
- Decoherence due to amplitude dependent tune shift could be limiting saturation of instability



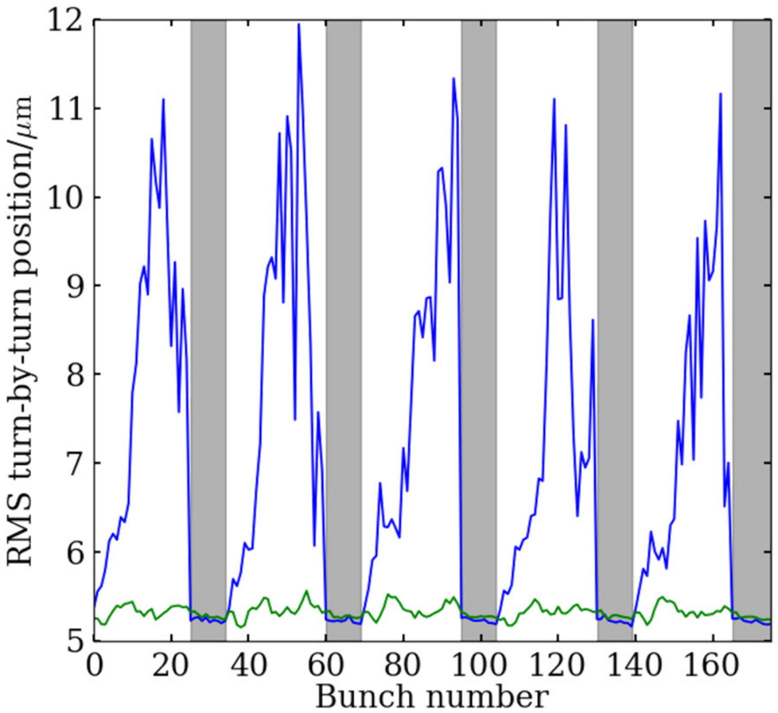
Transverse Multibunch – Ion Instability

- Ion instabilities seen in multibunch filling patterns as low as 40 mA
- Vacuum still in conditioning phase

Marek Grabski, ALERT workshop 2016:

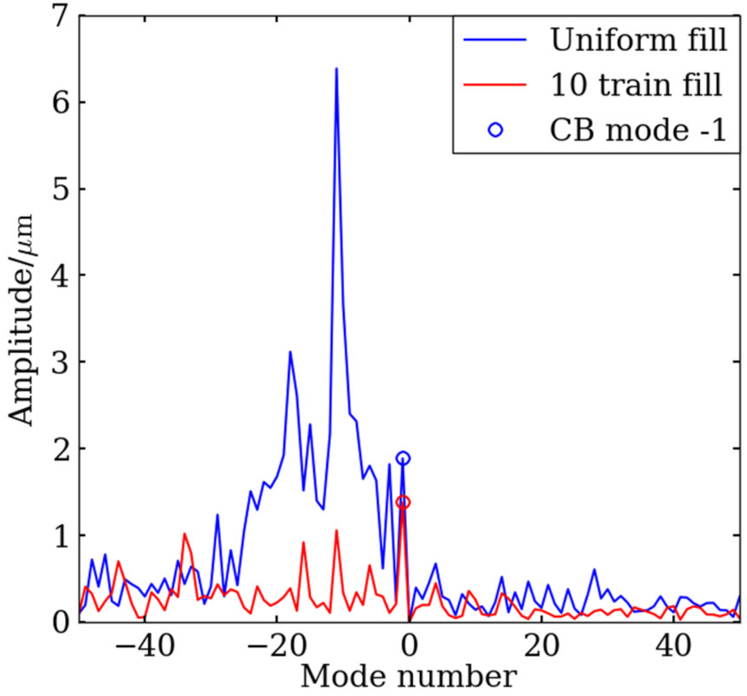


Shorter bunch trains suppress instability



Transverse Multibunch – Modes

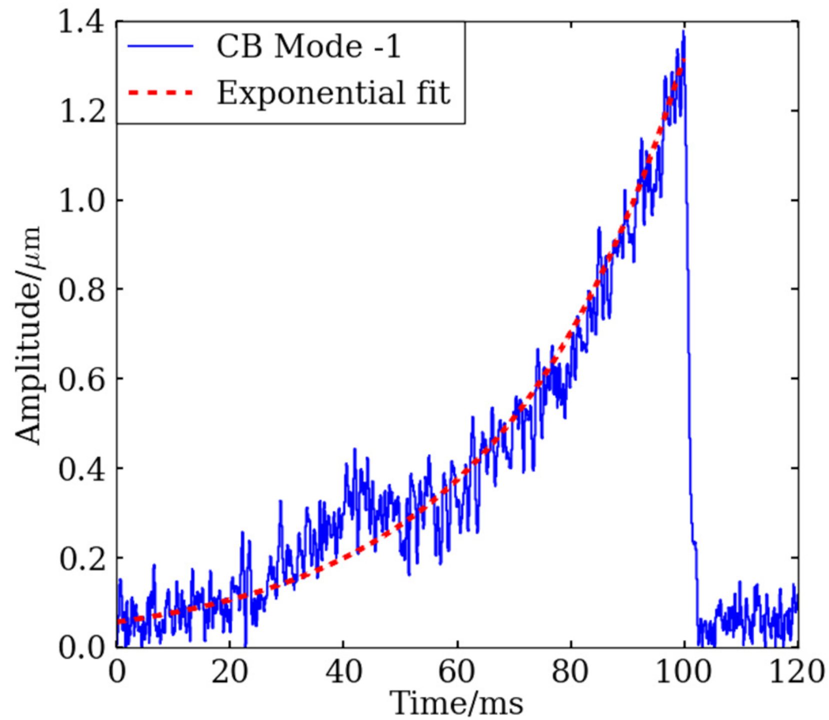
- Decompose motion of multiple bunches into coupled-bunch modes
- Filling pattern of 5 trains of 25 bunches, each with gap of 3 in center of each
  - Ion peak is suppressed
- Coupled-bunch mode -1 dominates suggesting resistive wall
  - Other peaks are due to noneven fill



Transverse Multibunch – Resistive Wall

- Slightly positive chromaticity
- Grow-damp measurement with ion-free filling pattern
  - Bunch-by-bunch feedback turned off for 100 ms
- Small amplitude growth
  - Measured growth time: 31.6 ms
- Assuming
  - Growth rate proportional to current
  - 29 ms radiation damping time

	RW threshold/mA
Experiment	27.4
Frequency domain	21.6
Macroparticle tracking	21.9



Conclusion

- Single bunch collective effects have been measured
  - Same discrepancy seen between experiment and simulation in vertical (tune shift) and longitudinal (bunch lengthening) planes
- No clear signs of TMCI seen up to 6 mA
  - Decoherence due to amplitude-dependent tune shift is a possible explanation
- Multibunch instabilities investigated
  - Ion-driven instability dominates for uniform filling patterns
  - First estimate for threshold current of resistive-wall instability
- Mitigation
  - Bunch-by-bunch feedback in 3 planes [6]
  - Harmonic cavities [9]
- Injection of up to 200 mA achieved with no feedback but unstable longitudinally

References

[1] P. F. Tavares et al., ¨The MAX IV storage ring project¨, J. Sync. Rad., Vol. 21, pp. 862-877, 2014.
[2] G. Skripka et al., ¨Simultaneous computation of intrabunch and interbunch collective beam motions in storage rings¨, Nucl. Instr. Meth. Vol. 806, pp. 221-230, 2015.
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[4] M. Klein et al., ¨Study of Collective Beam Instabilities for the MAX IV 3 GeV Ring¨, presented at the 4th Int. Particle Accelerator Conf. (IPAC'13), Shanghai, China, May 2013, paper TUPWA005, unpublished.
[5] J. Breunlin and Å Andersson, ¨Emittance Diagnostics at the MAX IV 3 GeV Storage Ring¨, presented at the 7th Int. Particle Accelerator Conf. (IPAC'16), Busan, Korea, May 2016, paper WEPOW034, unpublished.
[6] Dimtel, San Jose, USA,
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Acknowledgements

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