Beam instabilities measurements and analysis in MAX IV 3 GeV ring

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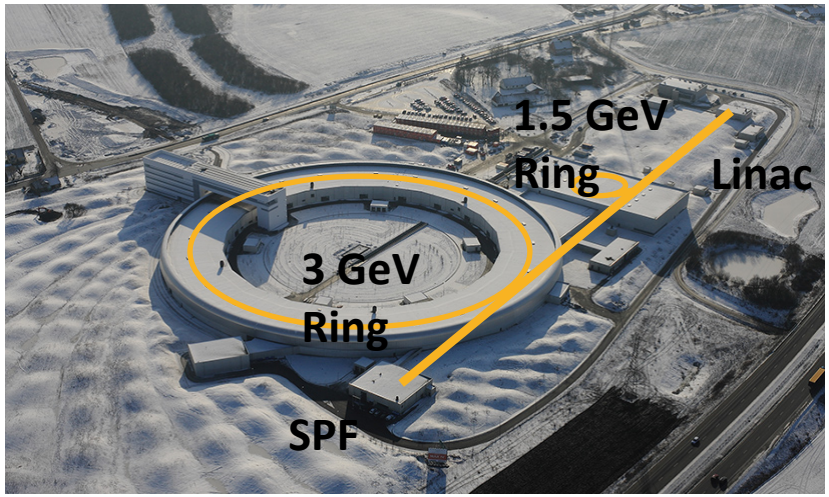
MAX IV Laboratory

- Currently under commissioning in Lund
- 3 GeV ring based on multibend achromat lattice:
  - Ultralow emittance
  - High beam intensity
- Technical parameters:
  - Strong compact quadrupoles
  - Small vacuum chambers



Parameter:	Value
Horizontal emittance (pm)	328 (200 with IDs)
Design/reched current (mA)	500 / 198
RF frequency (MHz)	99.931
Bunch length (ps)	40 (196 with HCs)

Increased resistive wall and geometric impedances

Mitigation of instabilities by harmonic cavities (HC)

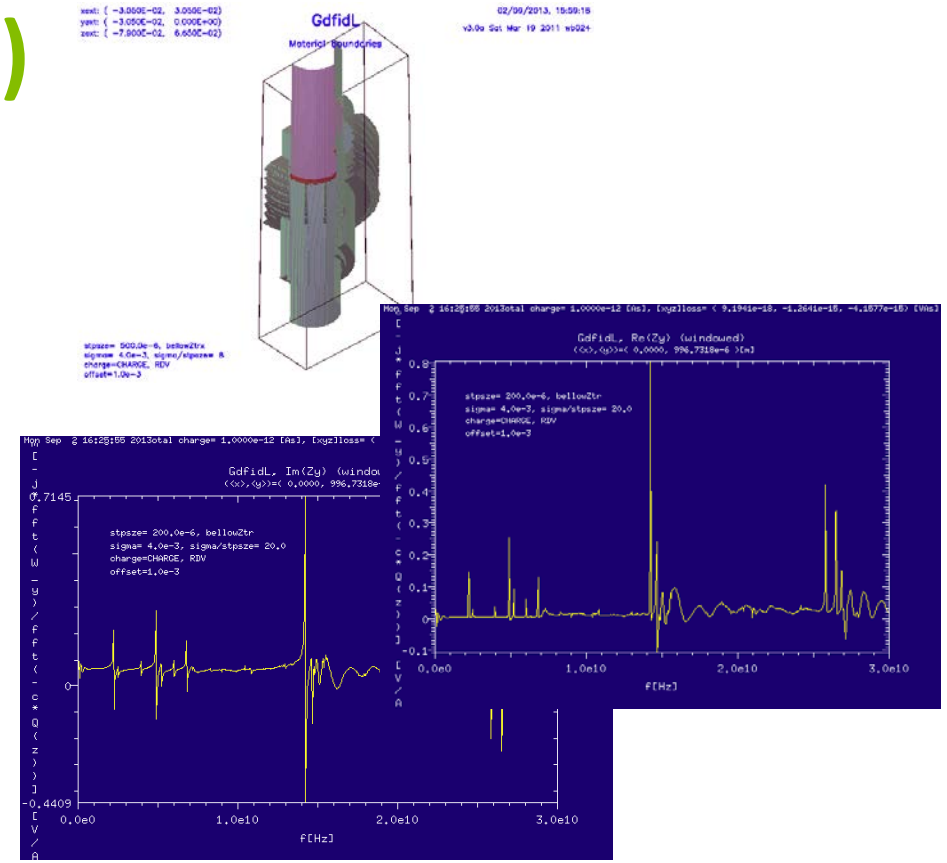
Outline

- Impedance model
- Measurements of collective effects
  - Single bunch instabilities
    - Bunch lengthening
    - Tune shift and TMCI
  - Multibunch instabilities
    - Resistive wall
    - Ions
    - Longitudinal coupled bunch motion

Impedance model (I)

- Geometric impedance (GdfidL) for 23 machine components:
  - 4 mm bunch length
  - Longitudinal: sum of all the components considering the repetitions
  - Transverse: sum of all the 'weighted' components

$$W_i = \frac{\sum_i \beta_i l_i}{l \beta_0}$$



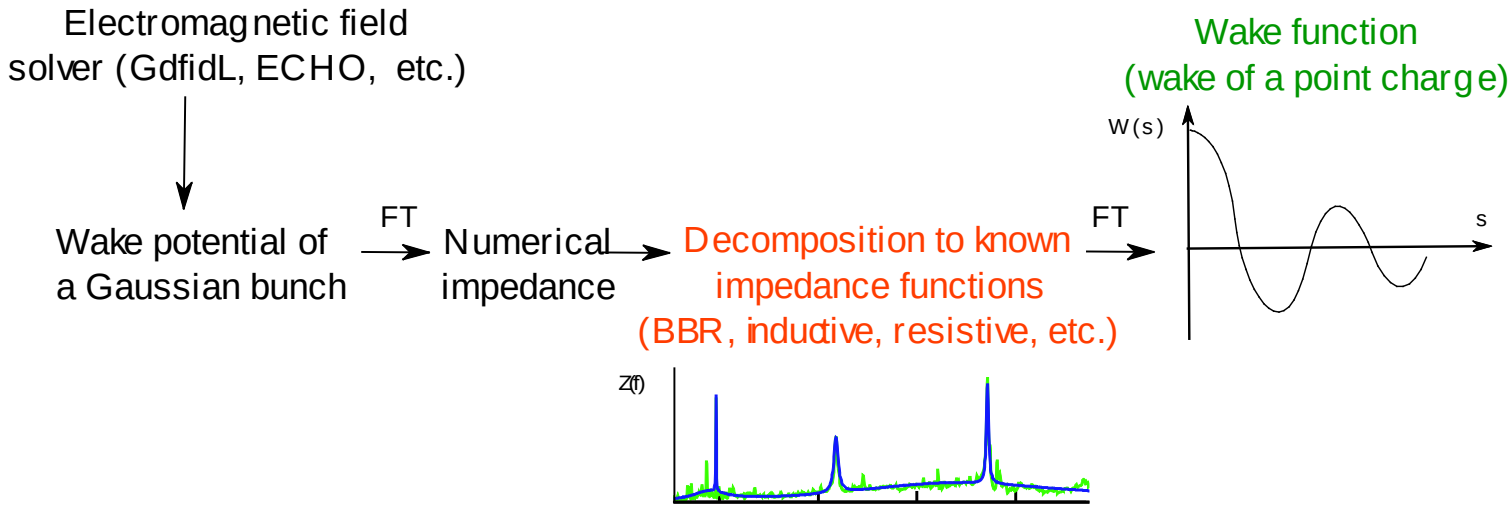
- Post processing of numerical impedance

Impedance model (II)

- GdfidL calculated wake potential
- Tracking code uses wake function

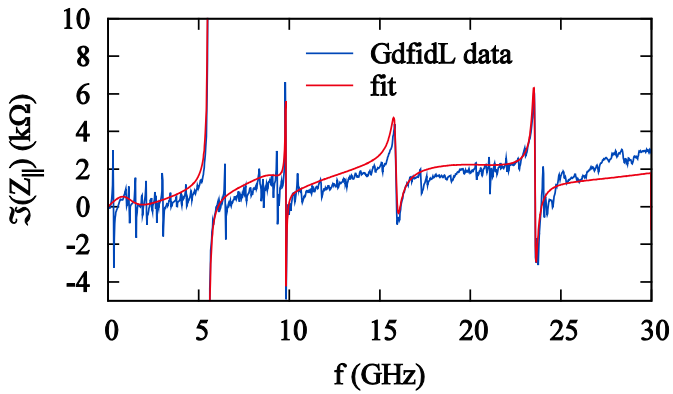
Some post processing required

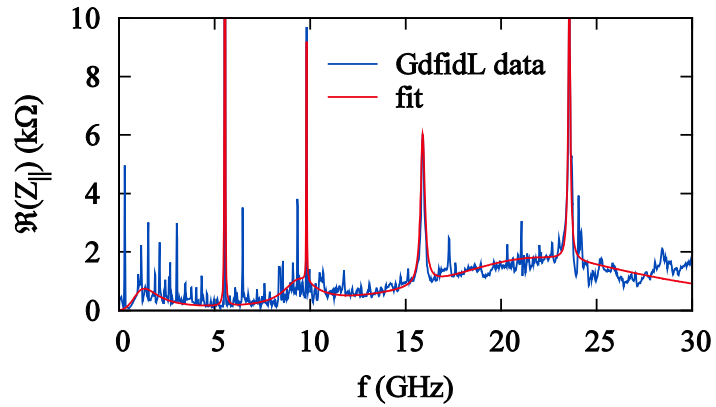
- Reduce bunch length → increase CPU time
- Impedance processing



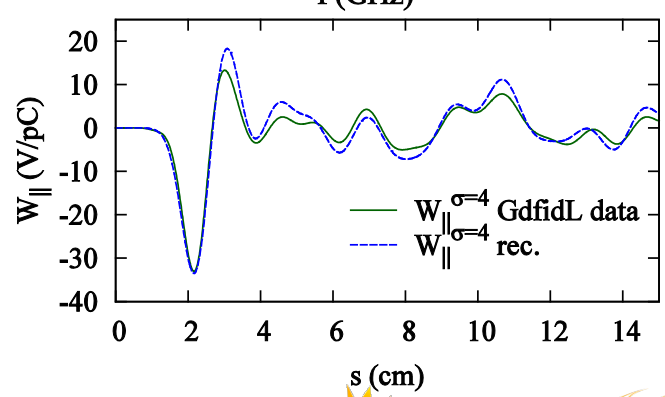
Impedance model (II)

- Geometric impedance budget is fitted with:
  - Longitudinal: resonators, resistive and inductive components
  - Transverse: resonators





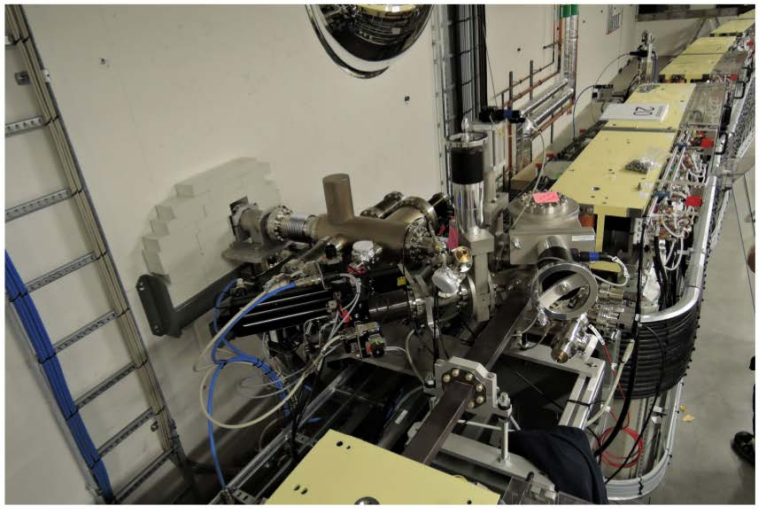
- Tracking
  - Short range effect of the geometric wake can be simulated
  - Resistive wall impedance included



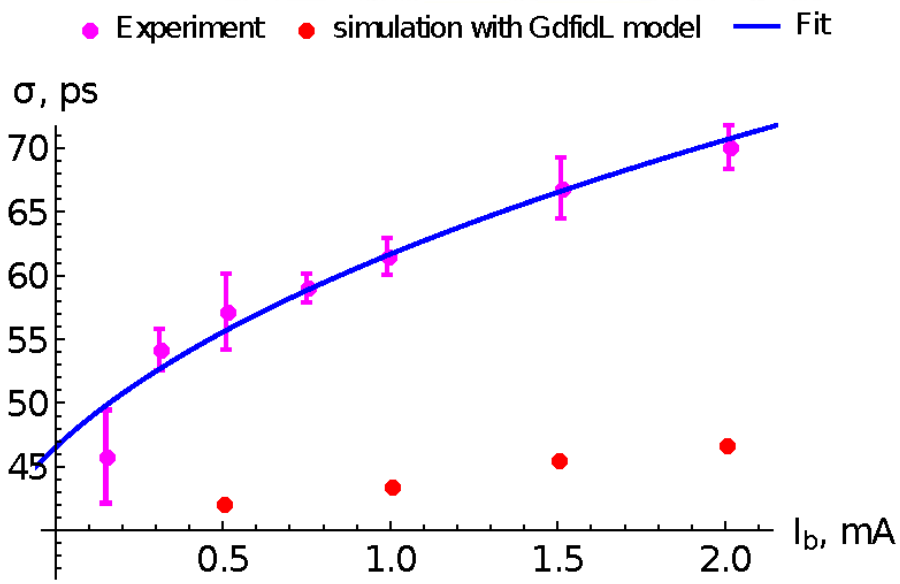
Longitudinal single-bunch

- Diagnostics beamline taking synchrotron radiation from a dipole bending magnet:
  - Bunch length
  - Transverse beam sizes
- Second diagnostic beamline for σ_δ will be installed in 2017

Beam line inside ring tunnel

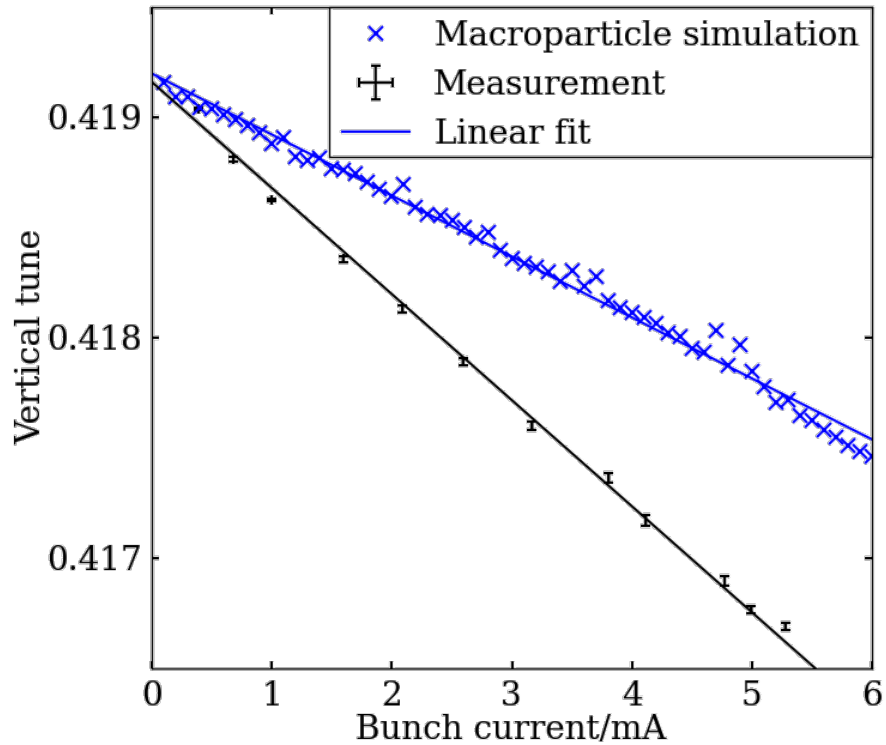


- Bunch lengthening assuming only potential well distortion:
  - Fitted with a single resonator (blue)
  - Numerical effective impedance about 2 times smaller than estimated from measurements



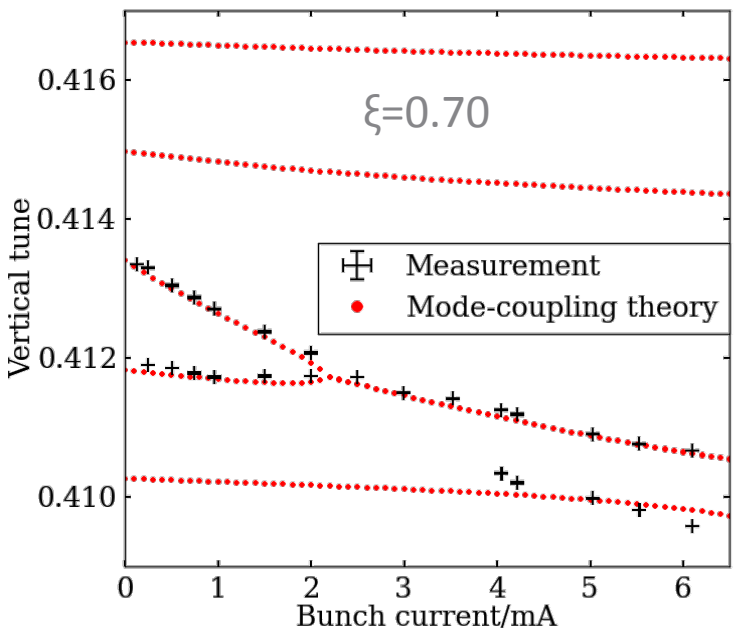
Single-Bunch Transverse – Tune Shift

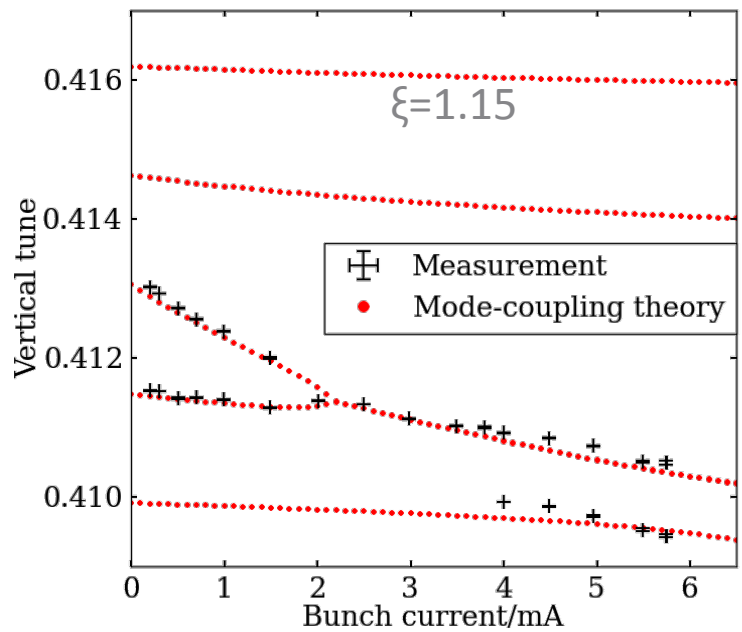
- Close to zero chromaticity
- Vertical tune shift with bunch current measured using turn-by-turn BPM data
  - Detuning: -0.481±0.002 A^{-1}
- Detuning about a factor of 1.8 larger than predicted in simulation
  - Similar discrepancy to longitudinal plane
- Detuning is larger than one synchrotron tune



Single-Bunch Transverse – Mode Coupling

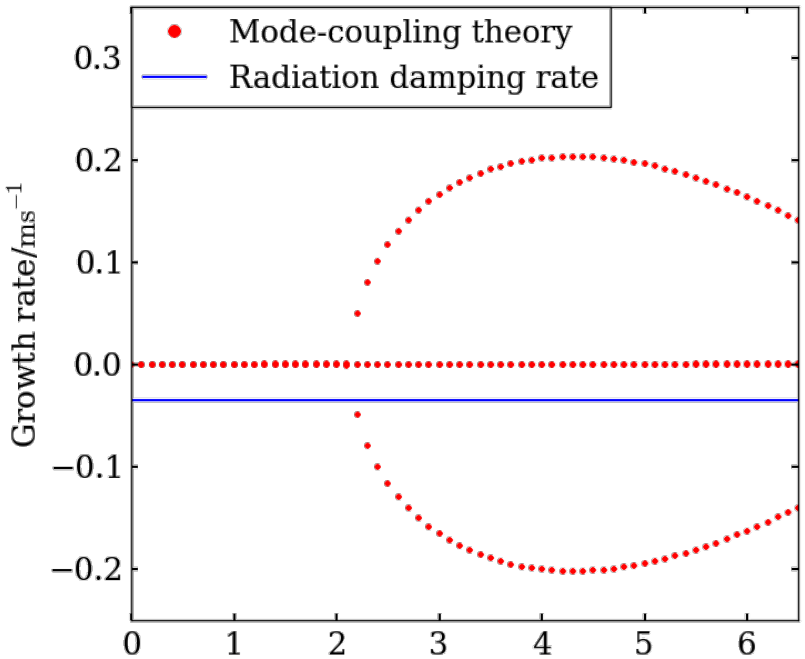
- Increase chromaticity to make head-tail modes visible to BPM
- Modes appear to merge in frequency and couple
- Use single resonator and resistive wall to reproduce detuning
- Bunch lengthening included
- No TMCI such as hard limit on injection or sudden beam loss
  - Simulation predicts threshold of 5.5 mA





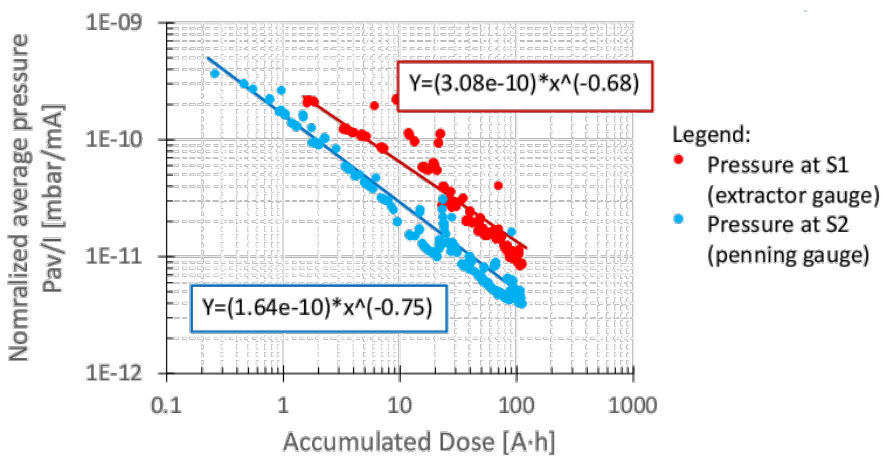
Single Bunch Transverse – Growth Rates

- 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



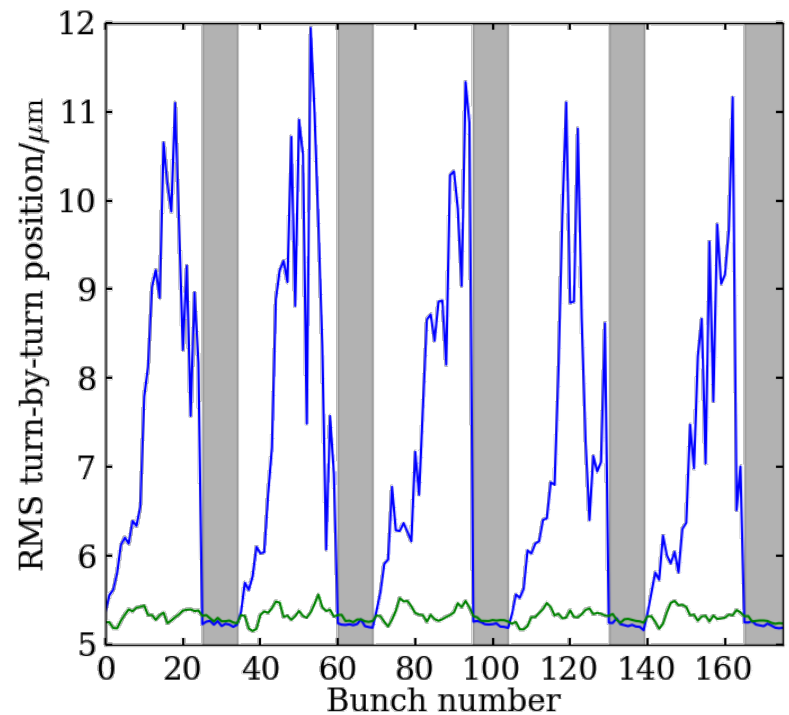
Transverse Multibunch – Ion Instability

- Different filling patterns
- Ion instabilities seen in multibunch filling patterns as low as 40 mA:
  - Gaps of 10 empty buckets
- Vacuum still in conditioning phase



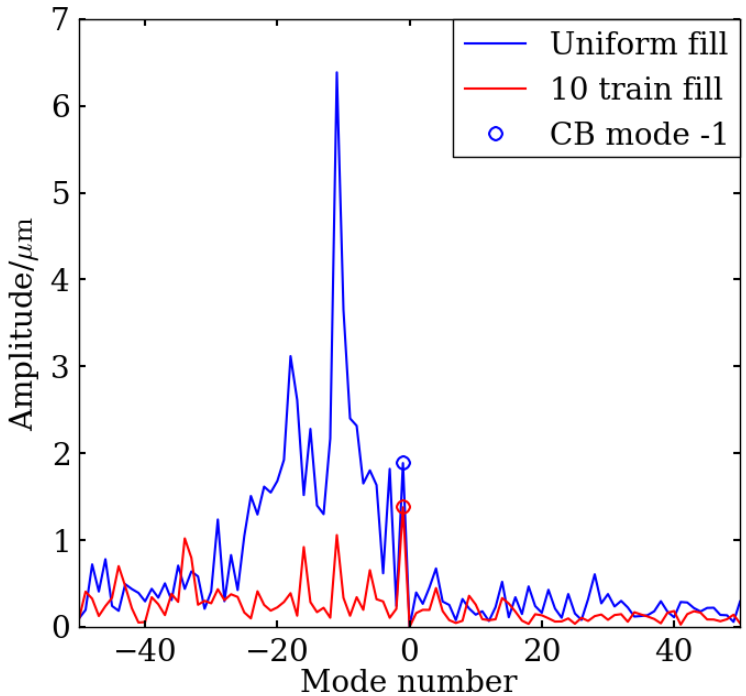
Marek Grabski, ALERT workshop 2016

Shorter bunch trains suppress instability: 25f -10e and 11f-3e-11f-10e fills



Transverse Multibunch – Modes

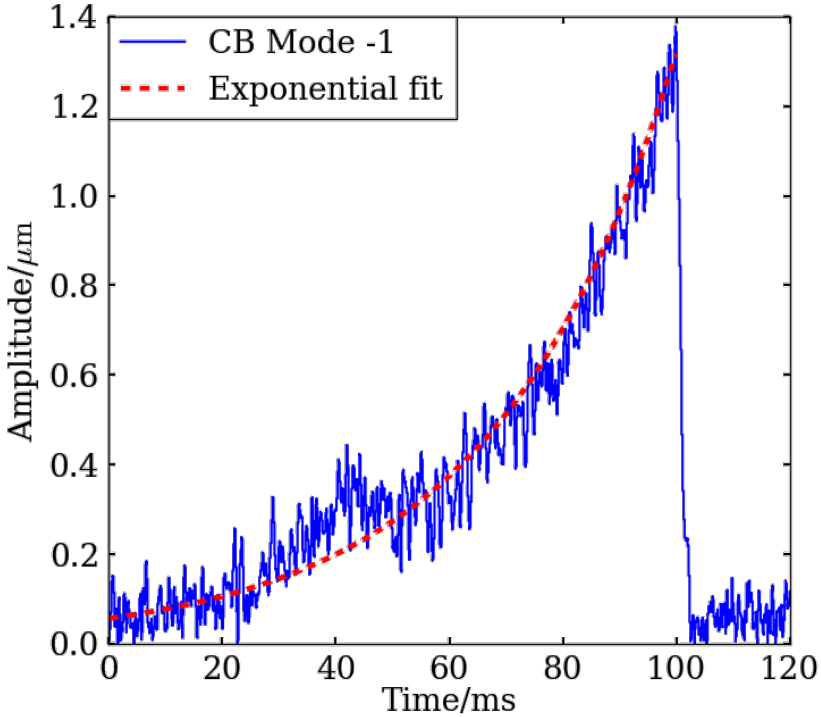
- Decompose motion of multiple bunches into coupled-bunch modes
- Filling pattern of 5 trains of 25 bunches, each with gap of 3 in center of each
  - Ion peak is suppressed
- Coupled-bunch mode -1 dominates suggesting resistive wall
  - Other peaks are due to uneven fill



Transverse Multibunch – Resistive Wall

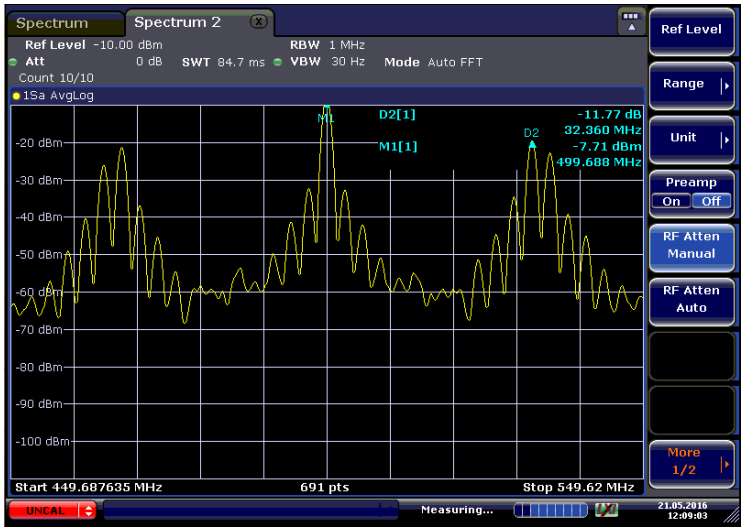
- Slightly positive chromaticity
- Grow-damp measurement with ion-free filling pattern
  - Bunch-by-bunch feedback turned off for 100 ms
- Small amplitude growth
  - Measured growth time: 31.6 ms
- Assuming
  - Growth rate proportional to current
  - 29 ms radiation damping time

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



Longitudinal Multibunch

- HOMs in cavities
  - Beam unstable at 3 mA in even fill
  - With feedback (stripline) stable up to 90mA
- Temperature tuning
  - Possible to tune HOMs away from a synchrotron sideband
  - Bad control and long temperature stabilization time
- Stabilization with HCs
  - 100 mA beam, not loaded enough to reach flat potential condition
  - 140 mA beam, fields corresponding to flat potential condition
  - At 125mA a single mode left (mode119)
- Longitudinal feedback (cavity kicker)
  - Designed



Conclusion

- Single bunch collective effects have been measured
  - Similar discrepancy between experiment and simulation in vertical (tune shift) and longitudinal (bunch lengthening) planes
- No TMCI up to 8.5 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
  - Longitudinal coupled bunch motion can be suppressed by temperature tuning and HCs
- Mitigation
  - Bunch-by-bunch feedback in 3 planes
  - Harmonic cavities
- Injection beam of 198 mA achieved with no feedback but longitudinally unstable beam

More measurements will be done before 2017

Acknowledgements

We thank the MAX IV commissioning team for their support during the experiments and Dmitry Teytelman for instability-related discussions and for tuition in the use of the Dimtel bunch-by-bunch feedback system.

Thank you