# Vacuum Instabilities at MAX IV

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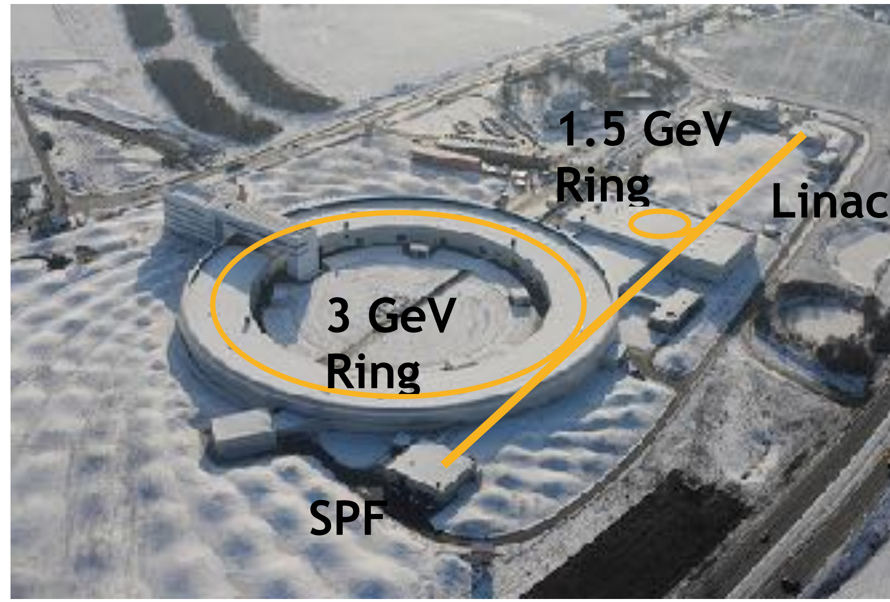
# Outline

- Introduction to MAX IV
- Impedance sources
- Bunch lengthening
- Single-bunch transverse instabilities
    - Head-tail modes
    - Detuning and TMCI
    - Effect of NEG coating
- Multibunch transverse instabilities
    - Ion driven
    - Resistive-wall driven

# 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 |
| Vacuum chamber radius (mm) | 11 |
| Natural bunch length (ps) | 40 |

# Impedance Sources

Resistive-wall

- From vacuum chamber, small-gap insertion devices
- Scaling with chamber radius b
  - Transverse: $b^{-3}$
  - Longitudinal: $b^{-1}$
- Estimated using known formulae (K.L.F Bane & M. Sands, AIP Conf. Proc., 1996)

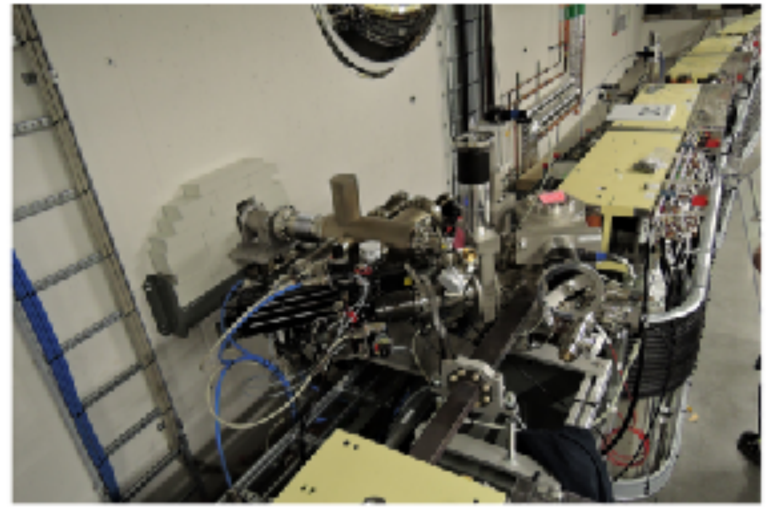
Geometric

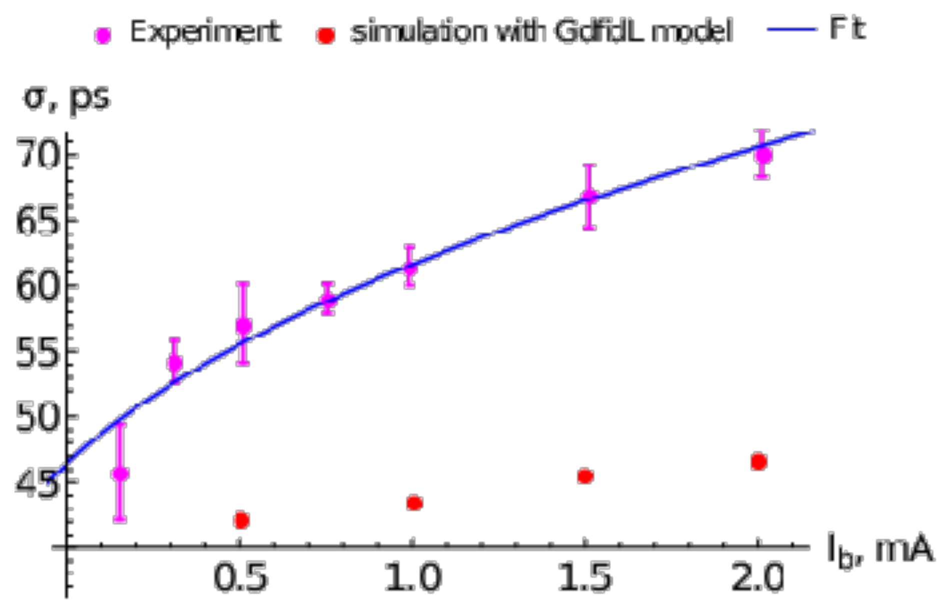
- From discontinuities in the vacuum chamber (tapers, flanges, BPMs)
- Scaling depends on element but always larger for smaller vacuum chamber apertures
- Estimated using electromagnetic simulations of vacuum geometry using codes such as GdfidL

# Longitudinal

- Energy lost to longitudinal impedance by individual particles distorts potential from RF cavities
- Diagnostics beamline taking synchrotron radiation from a dipole bending magnet
- Effective impedance from simulation about 2 times smaller than estimated from measurement

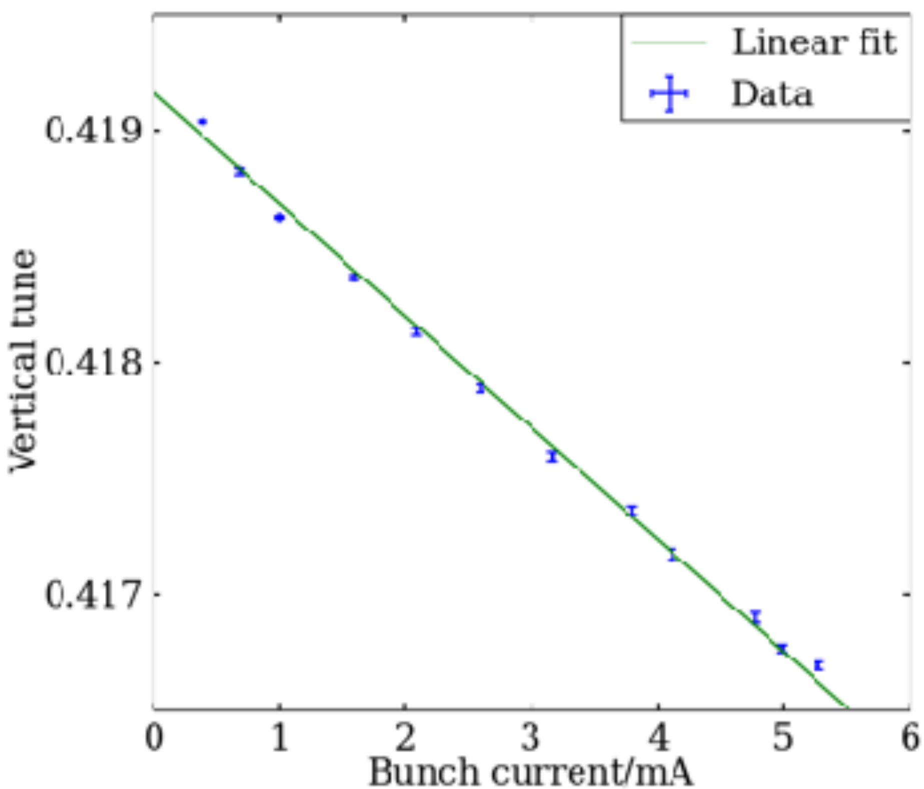
Beam line inside ring tunnel





# Transverse

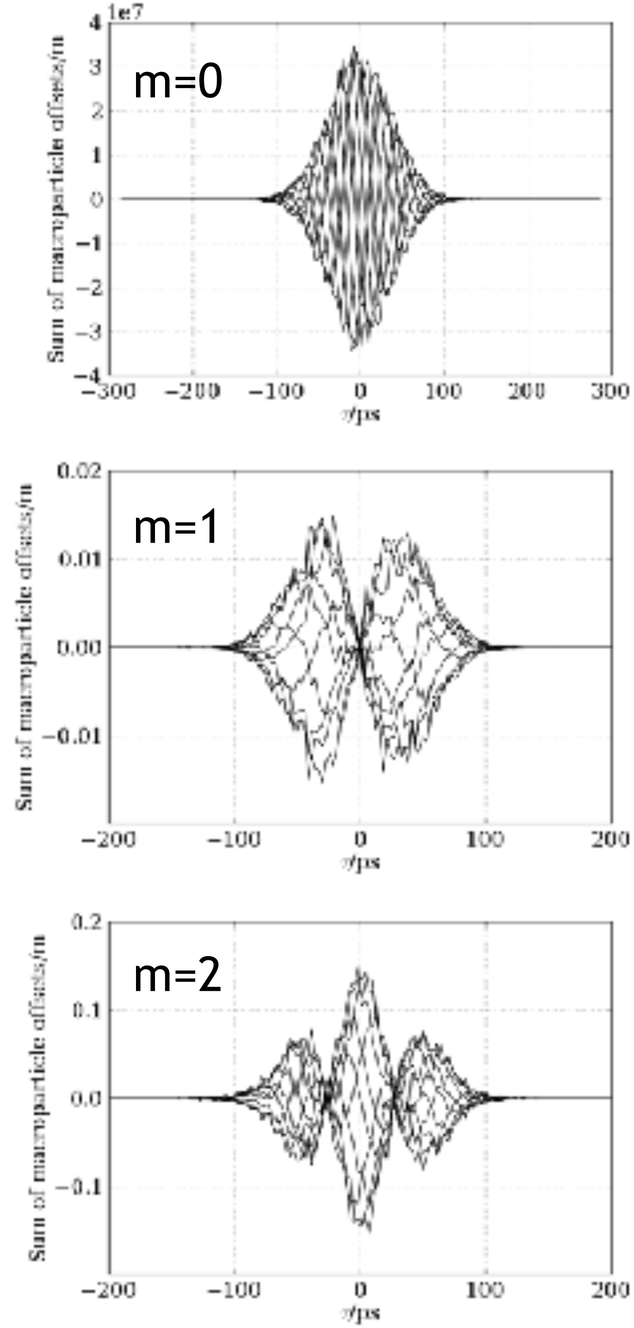
- Measure frequency of transverse oscillation as a function of current
- Slope gives effective impedance




- Effective impedance from measurement: 215 Ω $mm^{-1}$
- Effective impedance from model: 137 Ω $mm^{-1}$
- Underestimates of around 2 common but good agreement can be achieved (eg. M. Carlà et al., Phys. Rev. Accel. Beams, 2016)

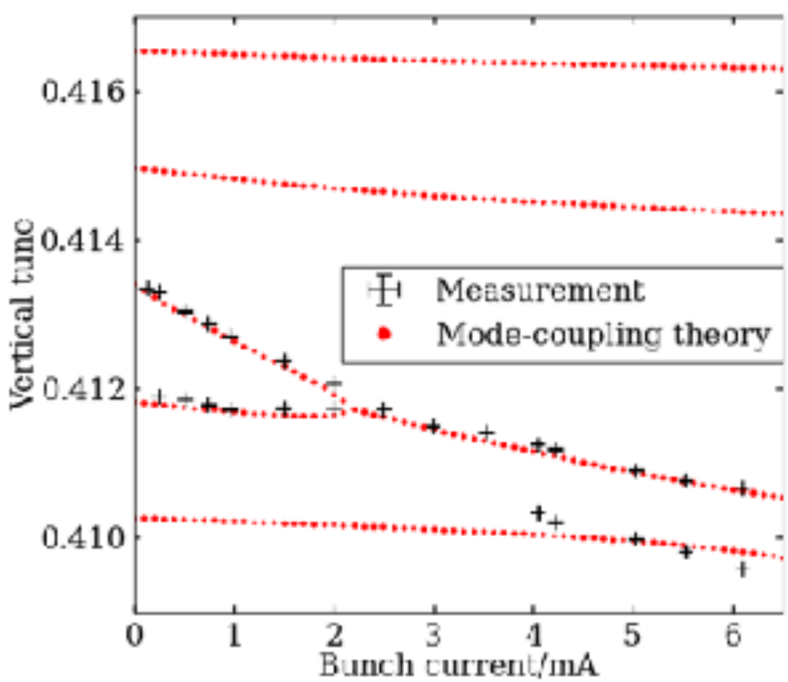
# Transverse Head-Tail Modes

- Important for transverse instabilities
- Head-tail mode order equivalent to number of nodes in position profile
- Particles oscillate between head and tail - synchrotron oscillation
- Frequencies of neighbouring head-tail modes are separated by one synchrotron frequency



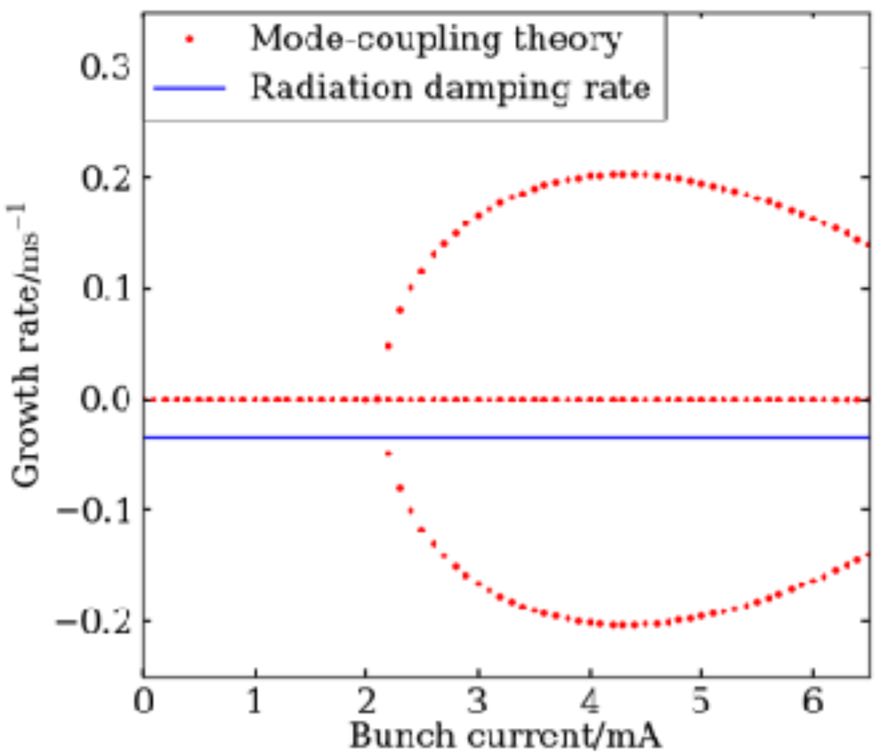
# Single-bunch Tune Shift

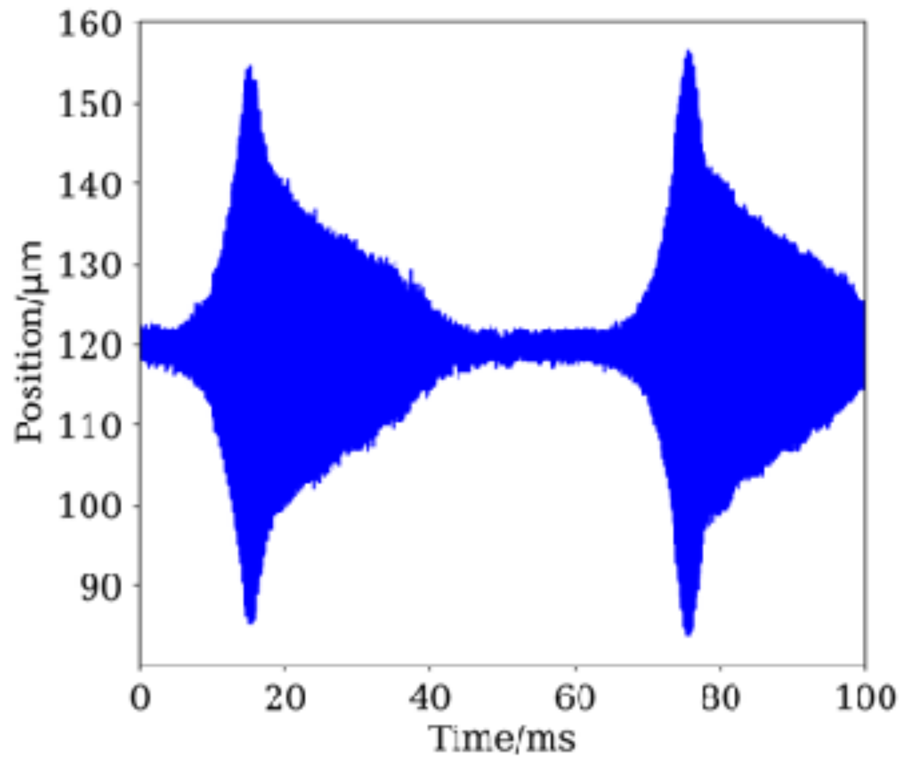
- We are able to follow the frequencies of different head-tail modes
- When the frequencies of two head-tail modes meet, a very strong instability is expected



# Transverse Mode-Coupling Instability

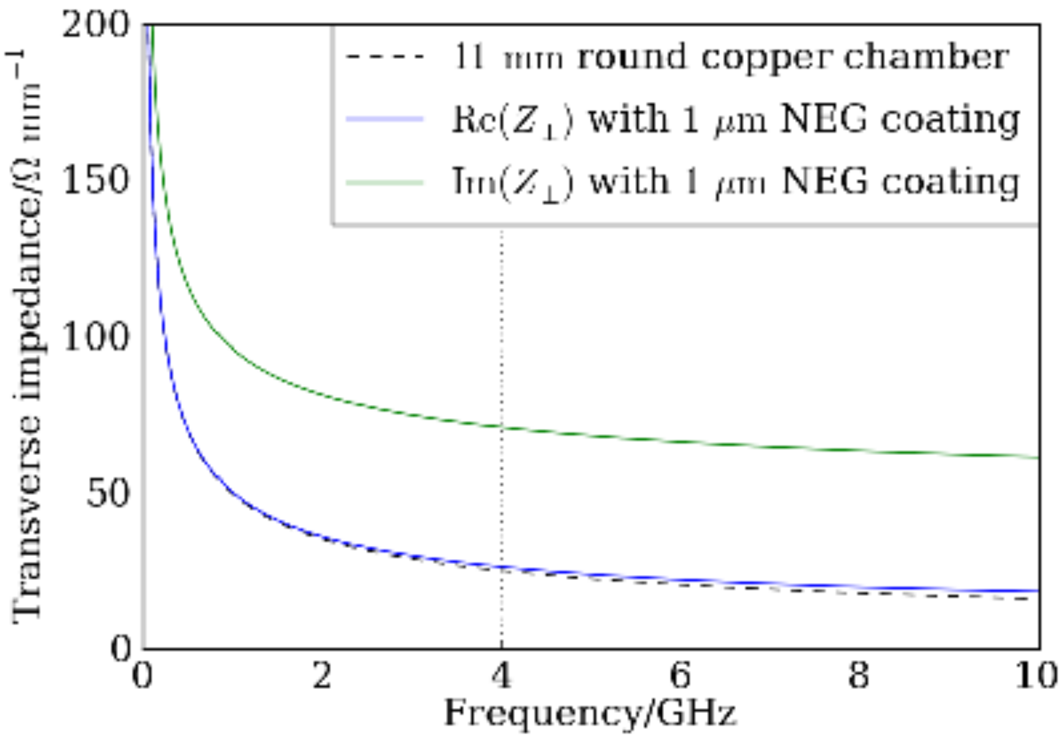
- When frequency of two head-tail modes meet, there is a mode-coupling instability
- Instability can be very strong but not in the case of MAX IV



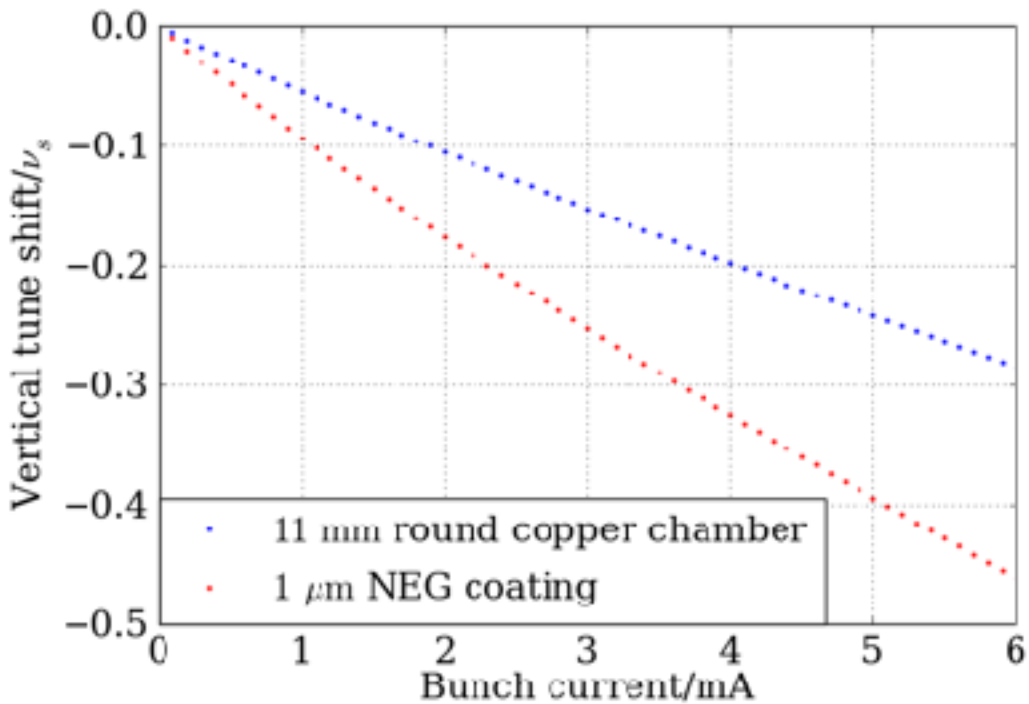
# Effect of NEG Coating

- NEG has large effect on the imaginary impedance
- This will in turn, have a nonnegligible effect on detuning
- NEG conductivity: 1e-6 Ω m

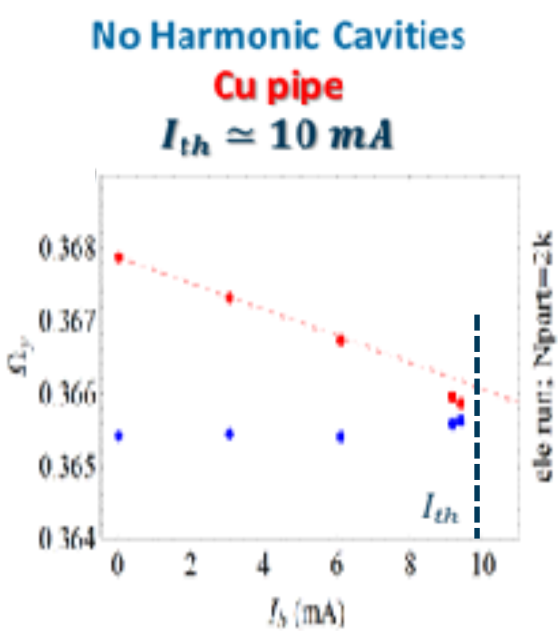


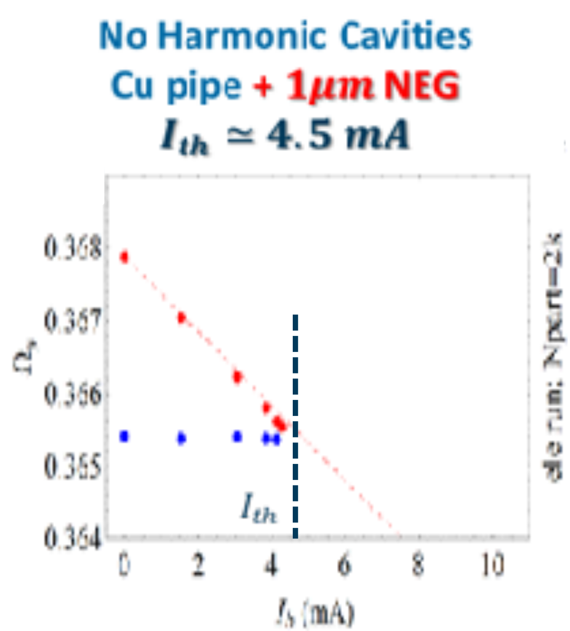
# Effect of NEG Coating

- Detuning in presence of NEG
- Effective impedance from resistive-wall without NEG: 38 Ω $mm^{-1}$
- Effective impedance from resistive-wall with NEG: 64 Ω $mm^{-1}$
- 67 % increase on RW component (19 % of total)

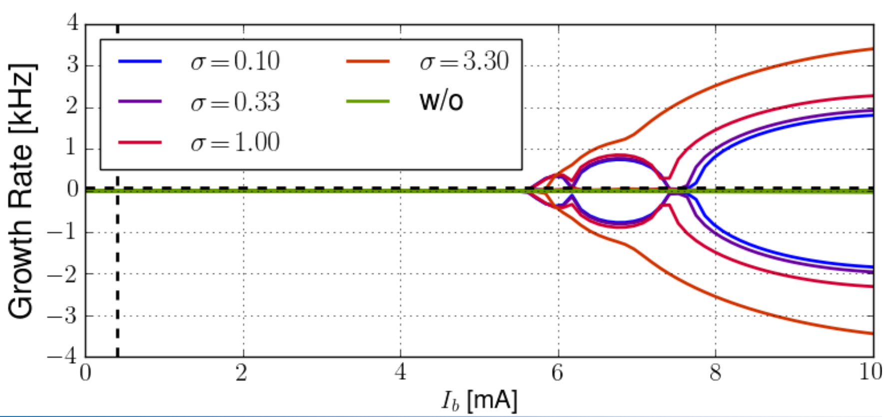


# Other Machines (RW only)



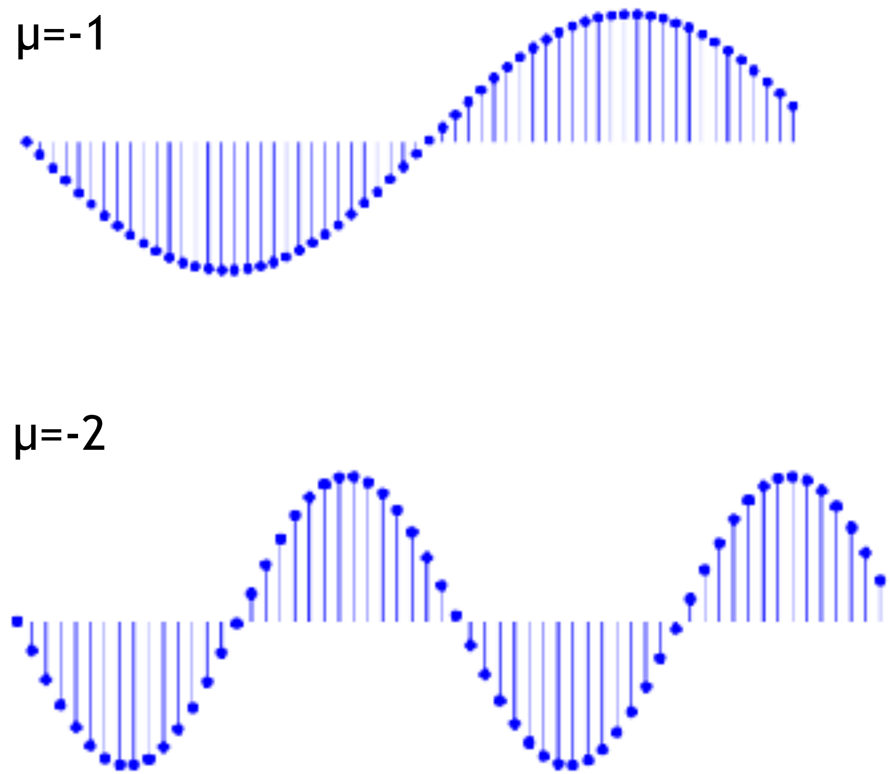

ALSu:
M. Venturini, LER 2016




SIRIUS:
F. De Sà, LER 2016

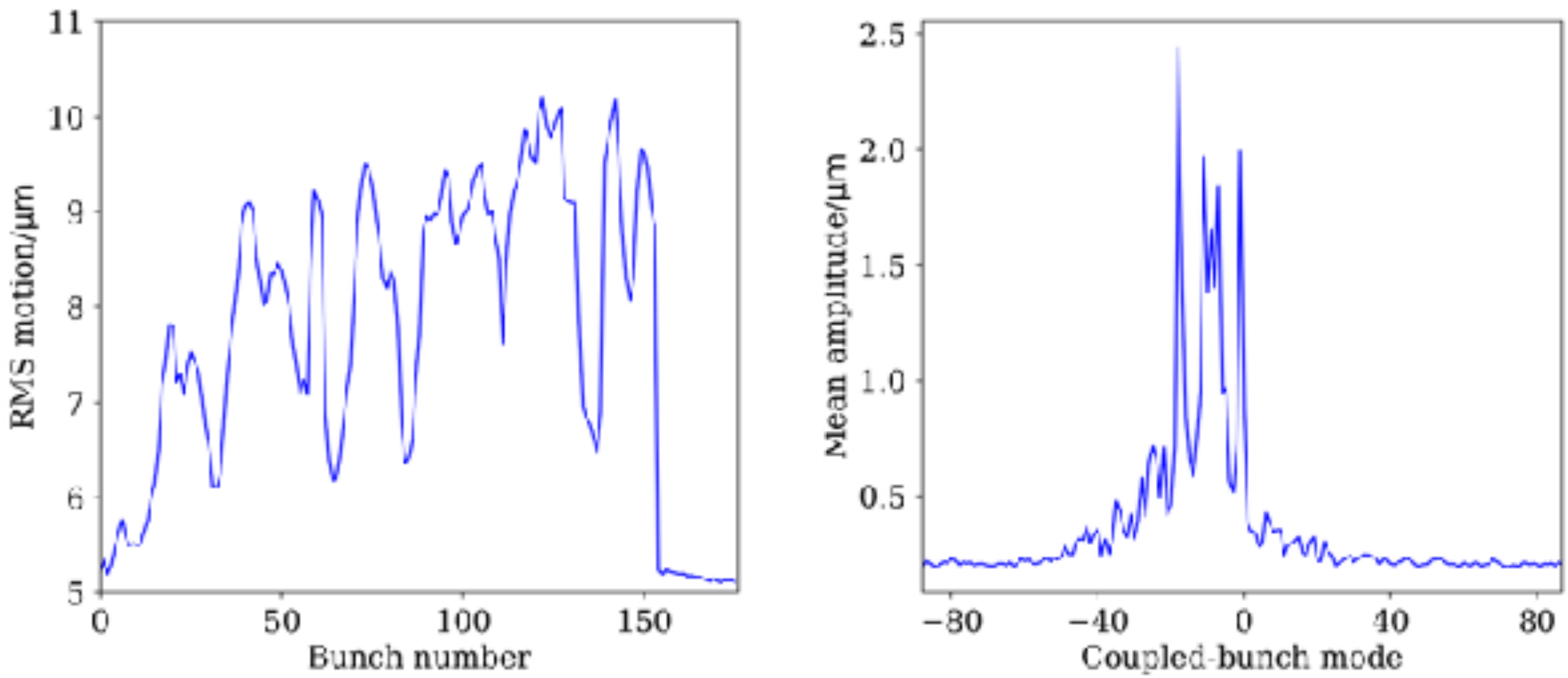
# Multibunch Instabilities - Coupled-Bunch Modes

- The oscillation of each bunch can be out of phase
- Each coupled bunch mode separated by one revolution frequency
- Can be used to identify frequencies where impedance is large



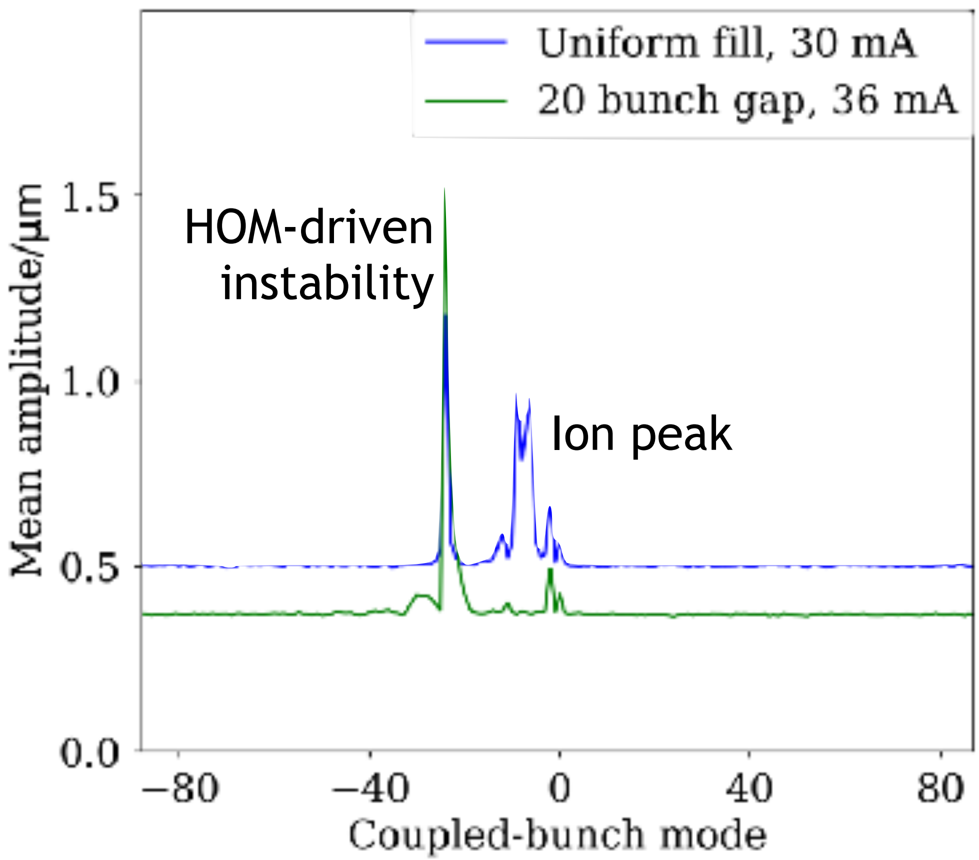
# Ion-driven - July 2016

- Fast-ion instability
    - Amplitude of beam motion grows along the train
- Wide band of low-frequency, coupled-bunch modes excited



# Ion-driven - February 2017

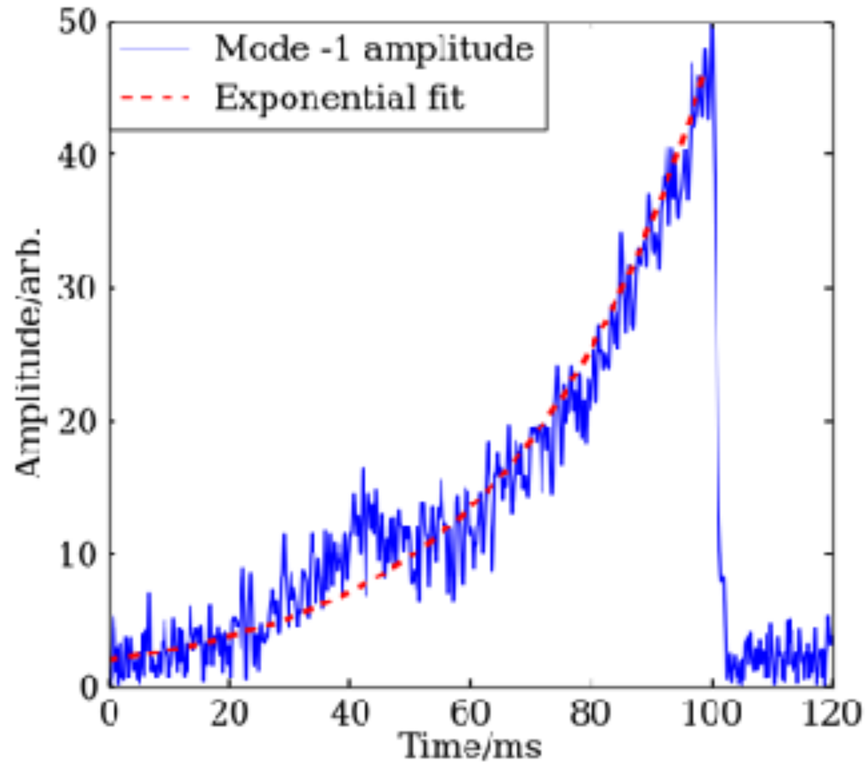
- Ions only seen in horizontal plane with uniform filling pattern at low current



# Resistive-wall driven

- One measurement performed of resistive wall
- Transverse higher-order modes are now dominant

- From measurement, estimated threshold current of resistive-wall instability: 27 mA
- Prediction from macro particle tracking and frequency domain calculations: 22 mA



# Conclusion

- Trend towards smaller vacuum chambers means an increase in the machine impedance
- NEG coating has a nonnegligible effect, particularly in single-bunch
- Residual ions can drive instabilities
- Mitigation:
    - Chromaticity (TMCI, Multibunch)
    - Harmonic cavities (Multibunch)
    - Bunch-by-bunch feedback (TMCI, Multibunch)

MAX IV

# Method

Determine resistive-wall impedance using known analytical formulae

Determine geometric impedance using electromagnetic simulation codes, eg. GdfidL

Estimate effect on measurable quantity, eg.

- Bunch length
- Frequency of beam oscillations (tune)
- Instability threshold currents

Tools:

- Analytical formulae
- More complex numerical calculations
- Macroparticle tracking

Comparison with experiment