Investigation of transverse beam instabilities in the MAX IV 3 GeV ring using the multibunch code *mbtrack*

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Overview

The macro-particle multi-bunch code *mbtrack*

- Considered effects
- Geometric ring impedance treatment
- Resistive wall impedance
- Passive harmonic cavity

The MAX IV 3 GeV ring as an example, status of the studies

- Introduction MAX IV 3 GeV ring
- Objectives of the project
- Ring impedance determination and present impedance budget
- Longitudinal single-bunch runs
- Transverse single- and multi-bunch runs
- Summary and outlook

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The macro-particle multi-bunch code *mbtrack*

- **6D macroparticle tracking code** for multiple bunches
  - internal motions and micro-structures can be followed
  - allows for an arbitrary filling pattern
- **Single- (Intra-) bunch effects**: geometric ring impedance, wall resistivity
- Quantum excitation and radiation damping
- **Multi- (Inter-) bunch effects**:

  transverse resistive wall impedance, **passive harmonic cavity (HC)**
- Multiple active (powered) cavities possible
- Damping from gradient dipoles + insertion device radiation losses
- Current scans: Bunch length, energy spread, trans. beam size
- Ion-beam interaction and transverse feedback
- Parallelized code:
  - Master task: organizes the data exchange by MPI
  - Slave tasks: each corresponding to one present bunch

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Geometric ring impedance & wall resistivity

Goal: Treat numerically computed wakes (as single bunch effect)

Impedance inputs:

- Series of resonators, broad- or narrow-band
- Additional purely resistive components
- Additional purely inductive components
- Resistive wall contribution: round pipe, radius a, conductivity σ

Determination of the self-field:

- Determination of Green's functions
- Longitudinal binning and smoothening of distribution
- Transverse determination of dipole moment per bin
- Calculation of effects per longitudinal bin

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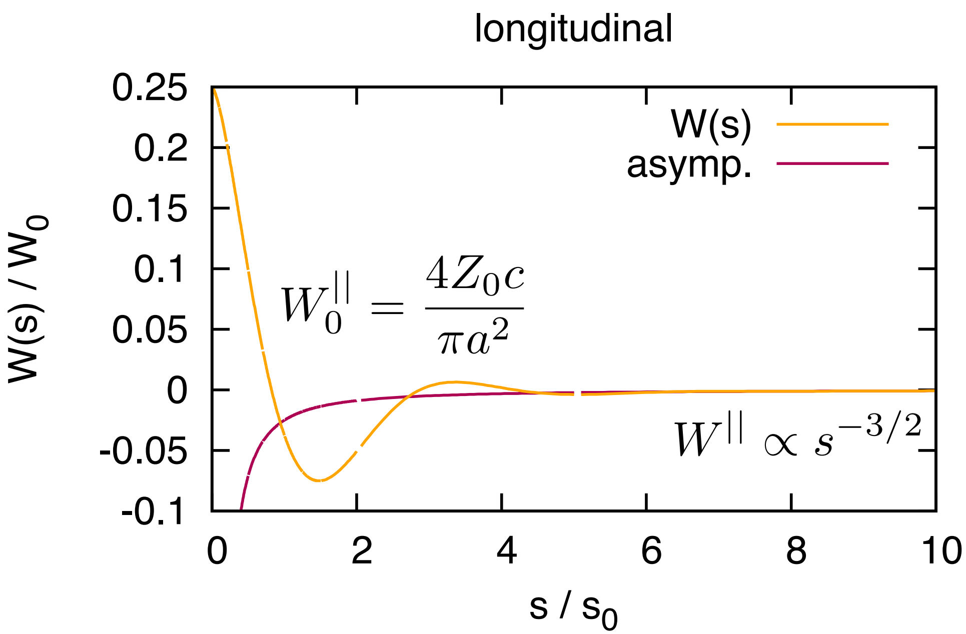
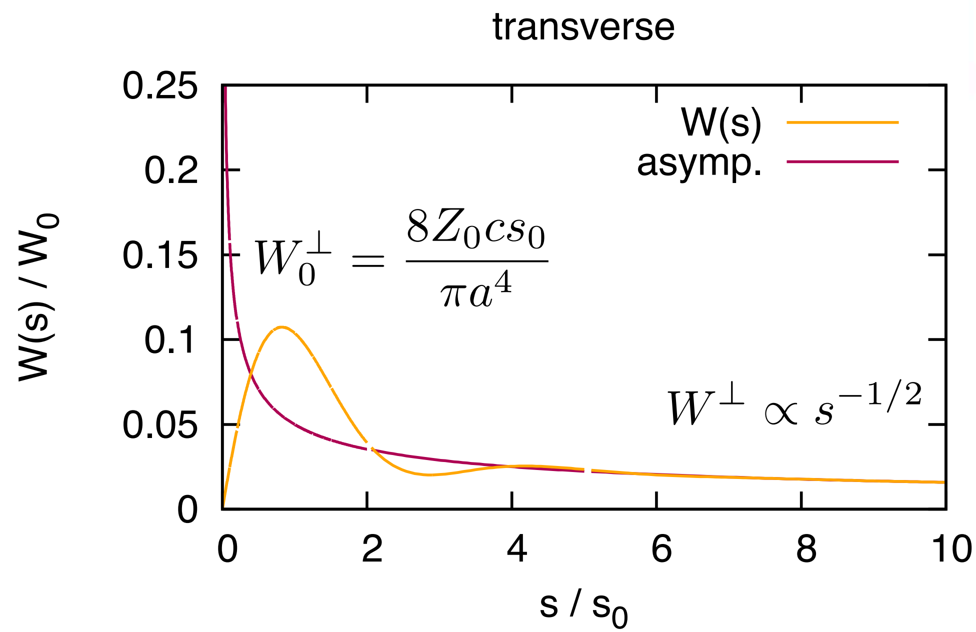
Resistive wall wake





Characteristic distance: $s_0 = \left(\frac{2a^2}{Z_0 \sigma} \right)^{1/3}$

Single-bunch contribution:

- Averaging field over first bin, asymptote for the following bins

Longrange effect:

- Transverse RW, approximated by asymptotes
- Storing of CM position of all bunches over several turn

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Passive harmonic cavity: Phasor scheme

- Beam voltage of the passive HC as phasor $\tilde{V}$:

$$\tilde{V}_{j+1} = \tilde{V}_j \exp\left[(i\omega_r - (\omega_r/2Q))\Delta t\right] - 2kq_j$$

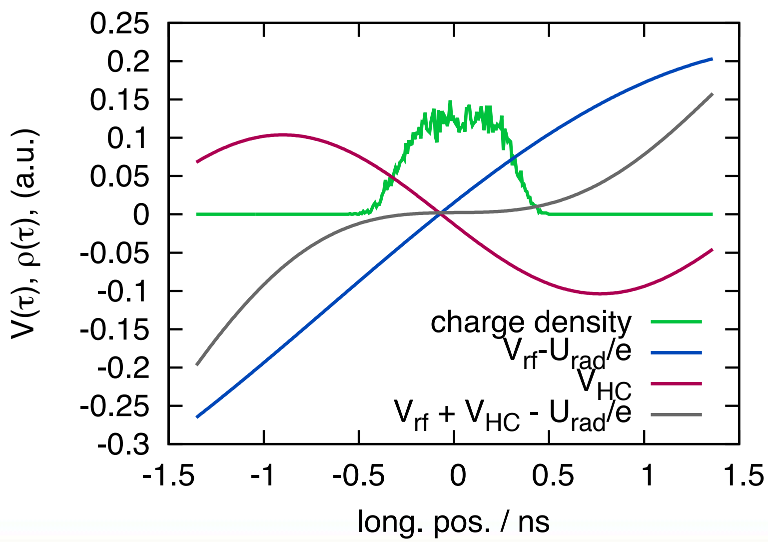
rotation decay induction

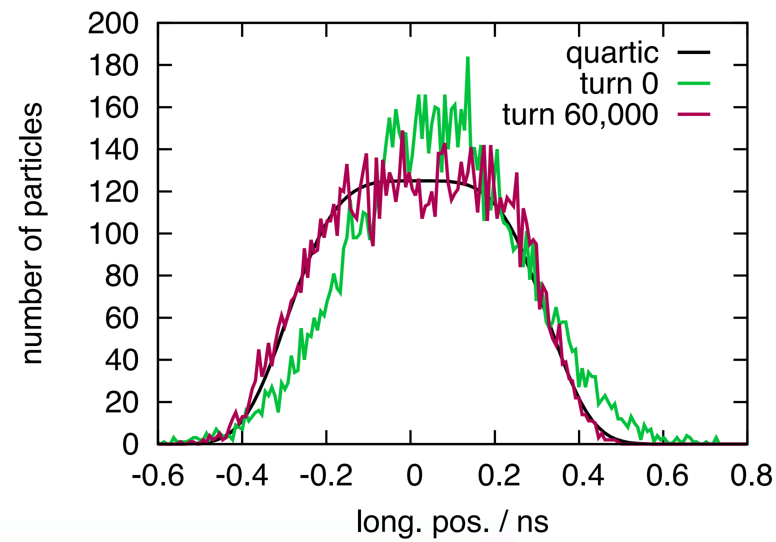
$$\Delta t = t_{j+1} - t_j$$
$$k = \omega_r R/2Q$$

J. M. Byrd et al., Phys. Rev. ST Accel. Beams 5, 092001 (2002)

- Update phasor after every bin
- Actual voltage in HC is the real part of $\tilde{V}$

(Scheme not possible for RW, no exponential decay)





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MAX IV 3 GeV storage ring

Beam energy	E_0	3.0	GeV
Beam current	I	500	mA
Ring length	L	528.0	m
Harmonic number	h	176	
Bunch length w/o HC	σ_τ	40	ps
Bunch length at 500 mA	σ_τ	195	ps
Peak rf-voltage	V_{rf}	1.02	MV
rf- frequency	f_{rf}	99.931	MHz
Energy loss per turn	U_{rad}	360	keV
Higher harmonic of HC	n	3	
Quality factor HC	Q_f	21600	
HC detuning	Δf	48.1227	kHz
Total shunt impedance HC	R_s	2.36441	MΩ

- Multibend achromat lattice
- Ultra-low horizontal emittance: 0.2 - 0.4 nm rad
- Round beam pipe, small radius: 11 mm
- High beam intensity: 500 mA
- Passive harmonic cavities
  - Relax the Touschek life-time and intrabeam scattering
  - Fight collective beam instabilities via Landau damping

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Planned Studies

Major Objectives of the Studies:

- Verification of no critical impedance issues related to beam instabilities
- Evaluation of single bunch and multibunch instability thresholds
- Special efforts to be made in tracking simulations in order to use the whole of numerically evaluated (GdfidL) wake fields and incorporate the effect of harmonic cavities (transient effects)

Single bunch tracking:

- Are all instability thresholds well above the nominal bunch current?
- Microwave instability in the longitudinal plane
- TMCI and head-tail instabilities in the transverse plane

Multibunch tracking:

- Can we overcome resistive-wall instabilities with Landau cavities and chromaticity shifting?
- Inclusion of both resistive-wall and broadband impedances
- Simulation of harmonic cavity effects

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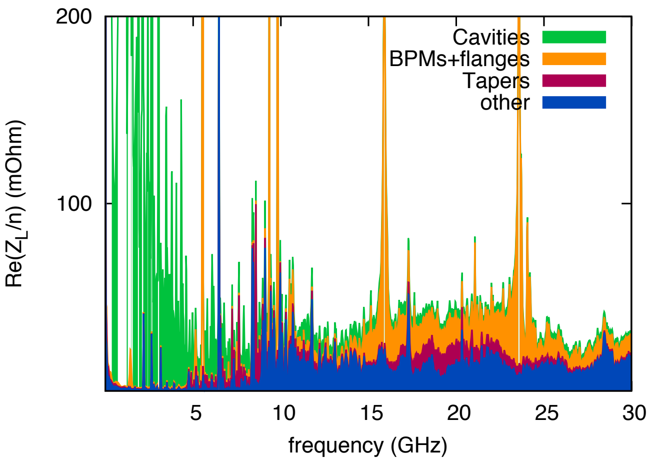
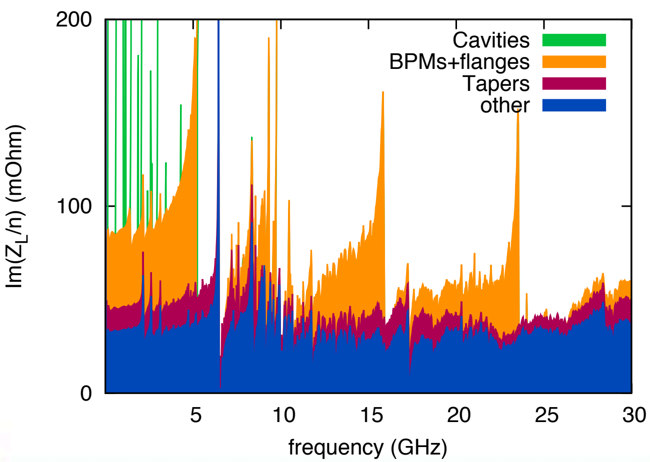
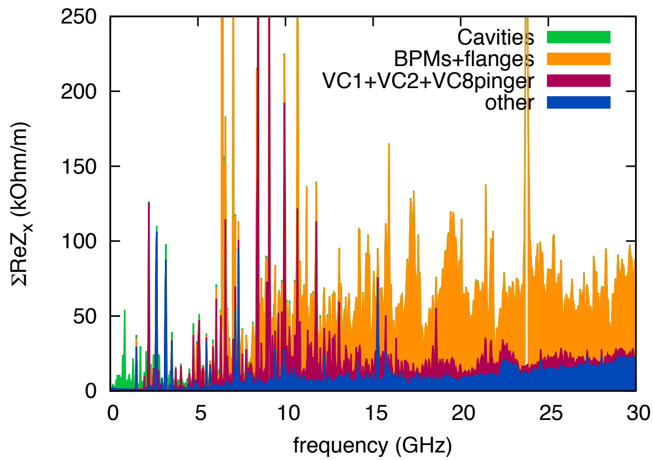
Determination of the ring impedance (3D)

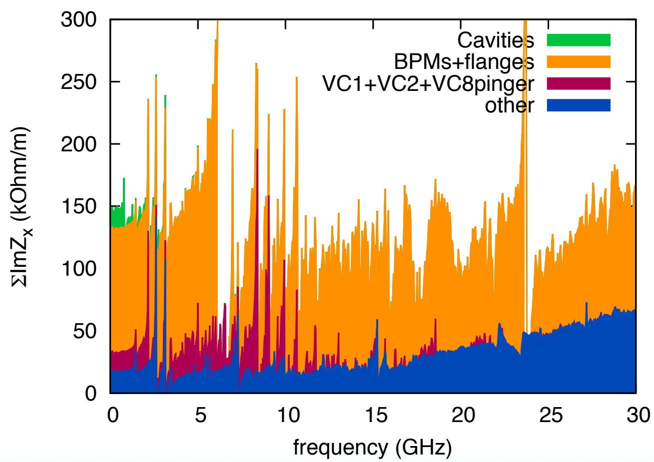
longitudinal



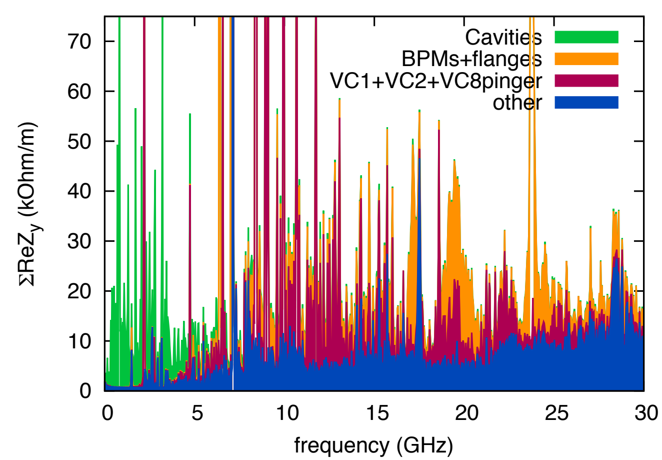


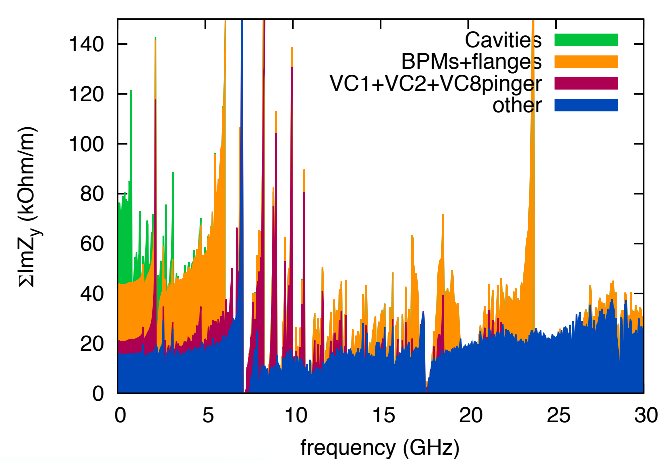
horizontal





vertical





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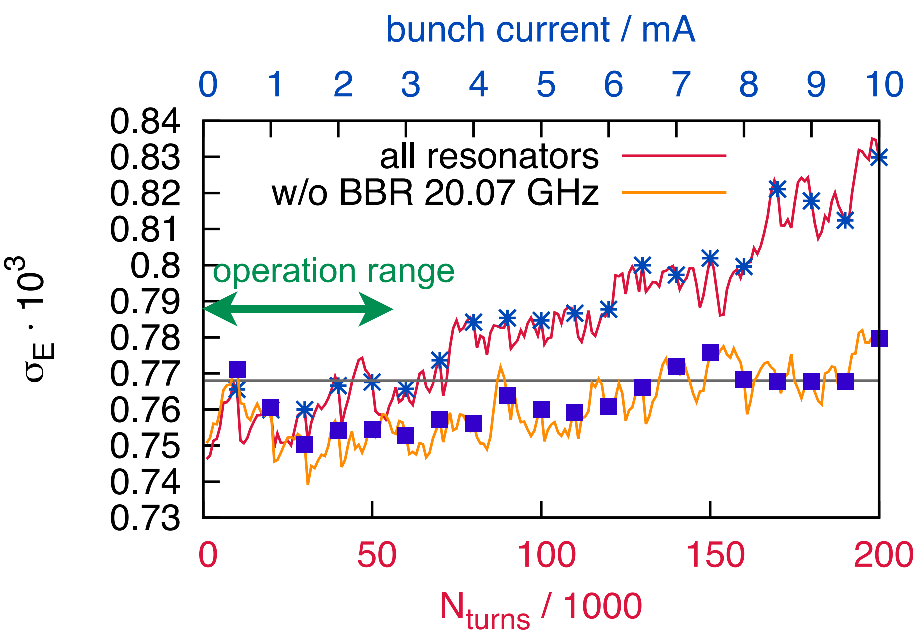
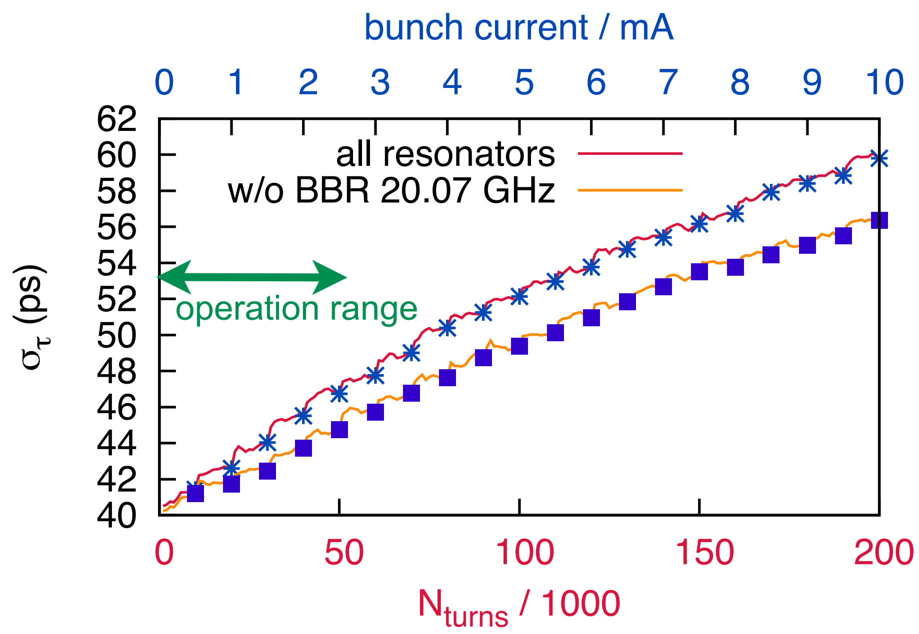
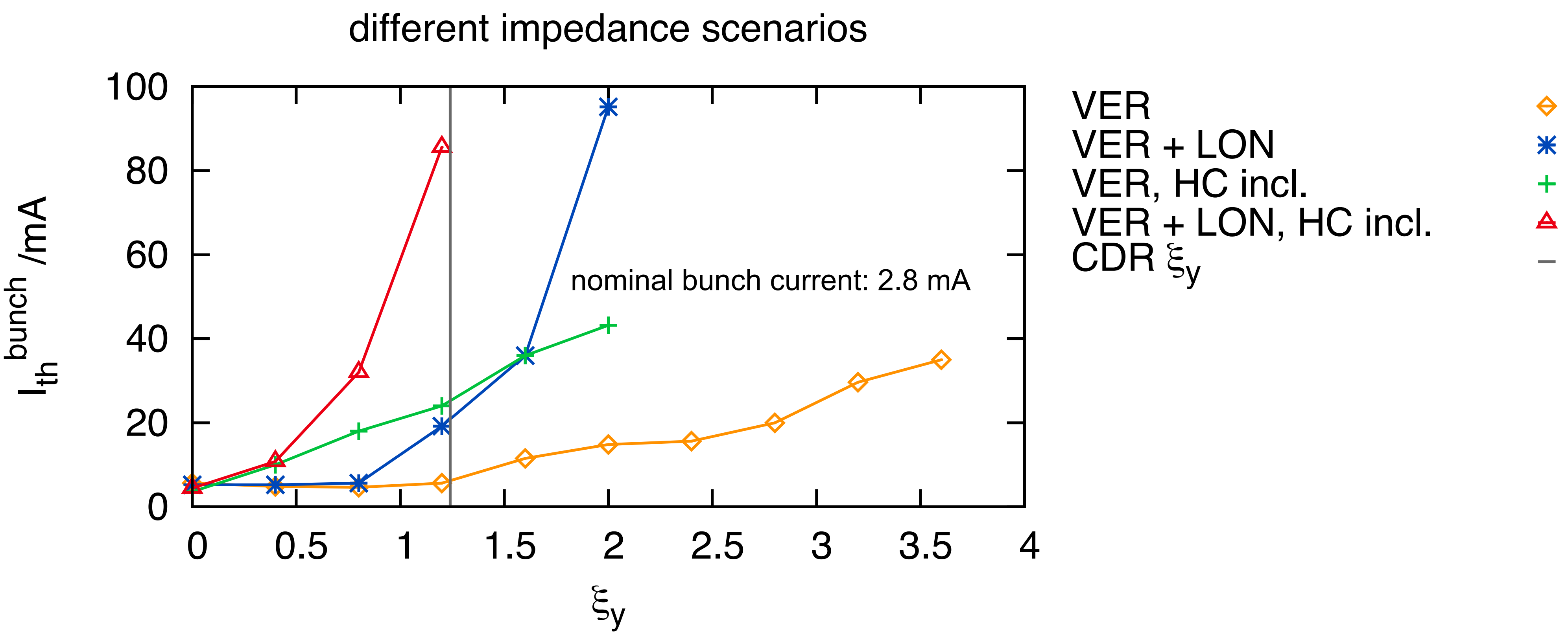
Single bunch instability calculations, longitudinal





- Included effects: geometric impedance; no harmonic cavity
- Biggest contributor: BBR at 22.07 GHz (from flanges and BPMs)
  - Only this BBR: unstable at 5 mA / bunch
  - w/o this BBR: unstable at 9.5 mA / bunch
- **No instability in the operation range even without HC**

Single bunch instability calculations, vertical



- Transverse instabilities are damped by bunch lengthening and tune spread
  - Longitudinal impedance relaxes the situation for medium chromaticities
  - The HC (here modeled static, ideal potential) can increase this effect

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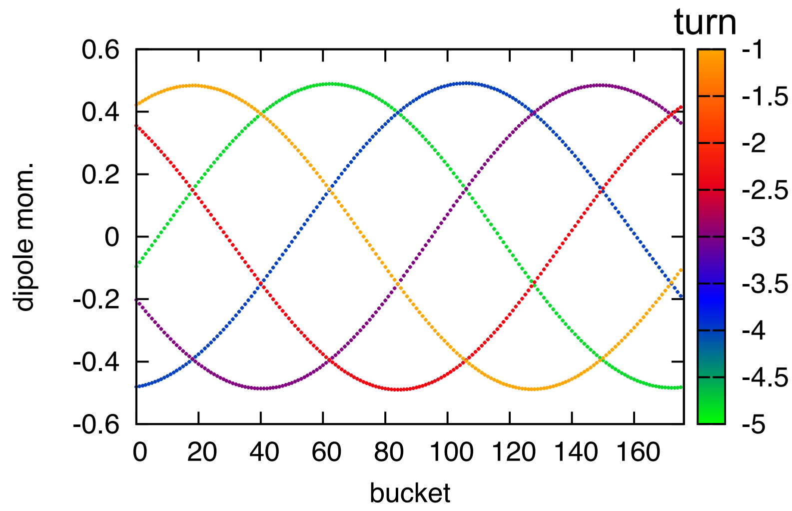
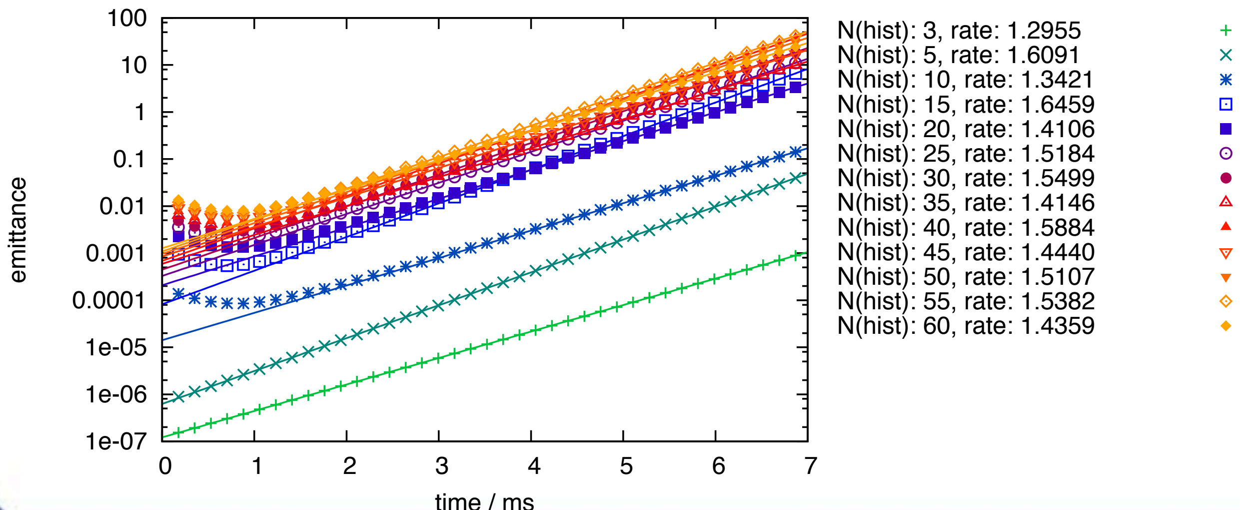
Multi-bunch calculations: Resistive wall impedance



- CM history of each bunch stored in an array
- Resulting effect is supposed to be the same for all particles in one bunch

- Growth rates of beam size can be determined from monitored emittance
- Growth rates depend on history length



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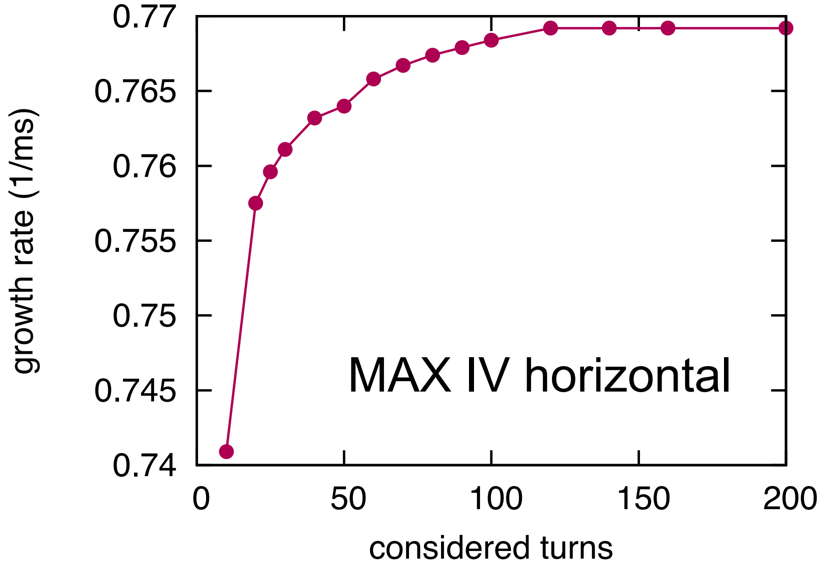
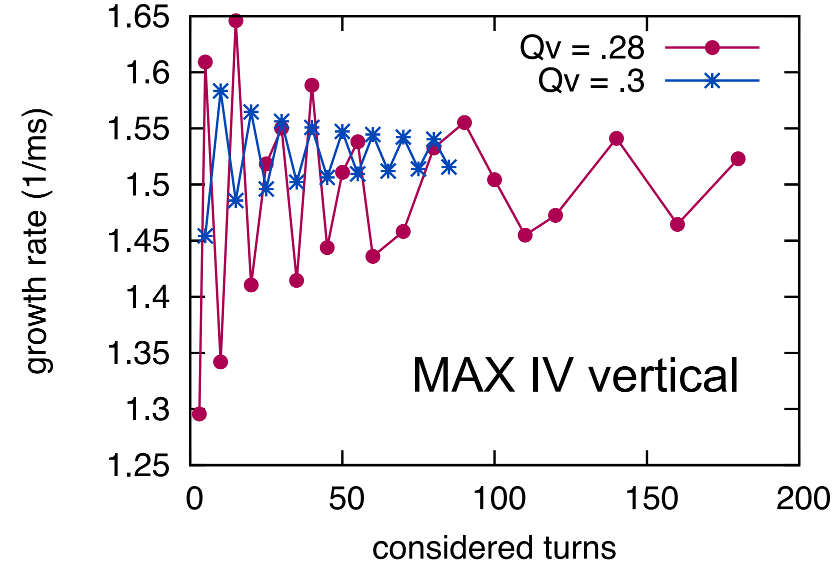
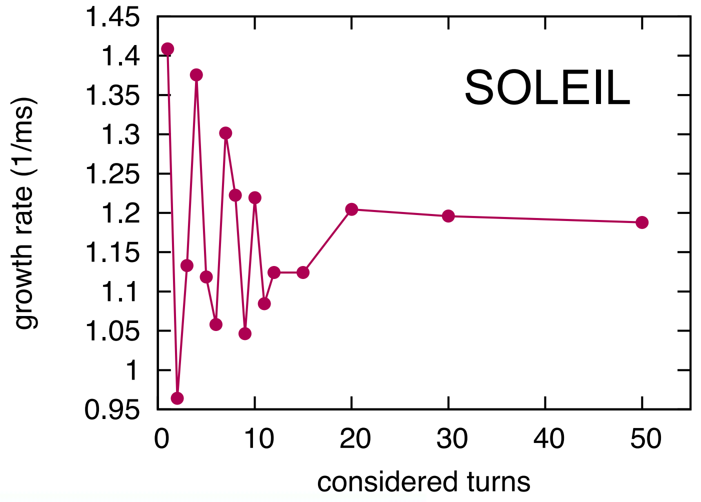




- Growth rates as function of history length:
  - Effect at MAX IV 10 times longer as expected
  - Reasons under investigation



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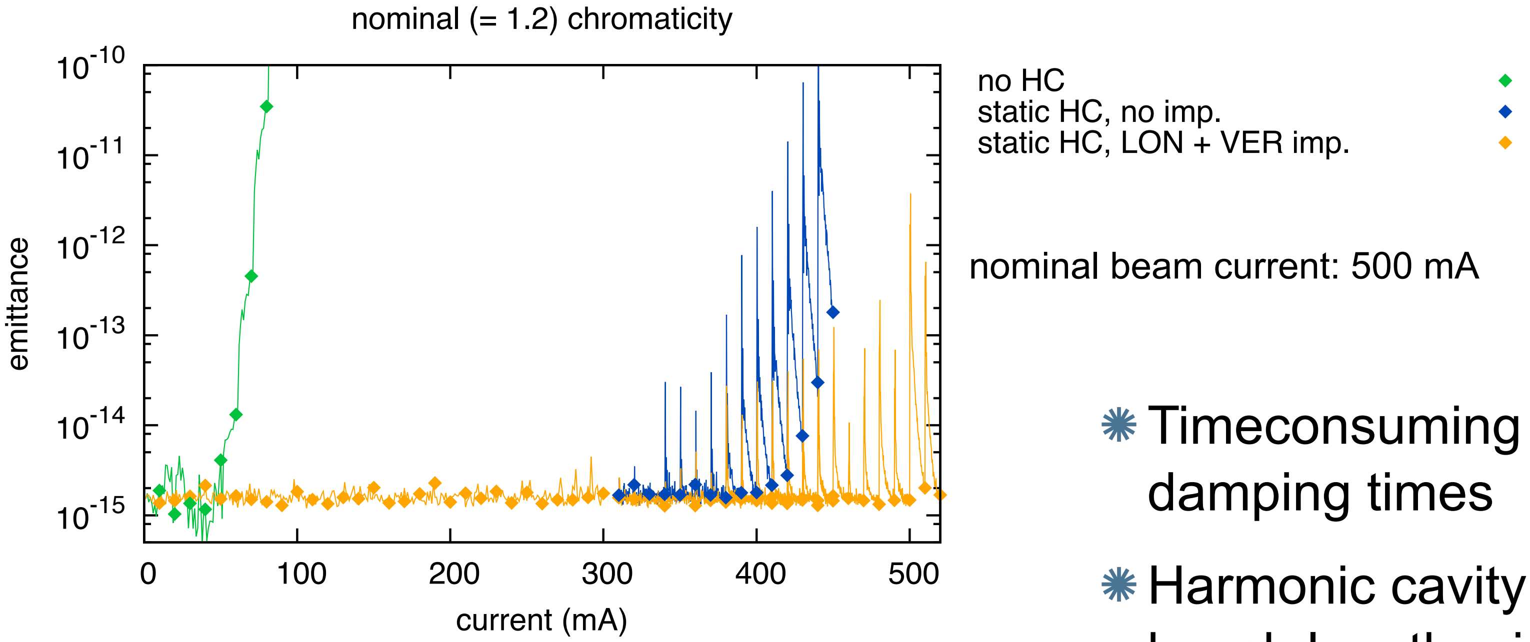
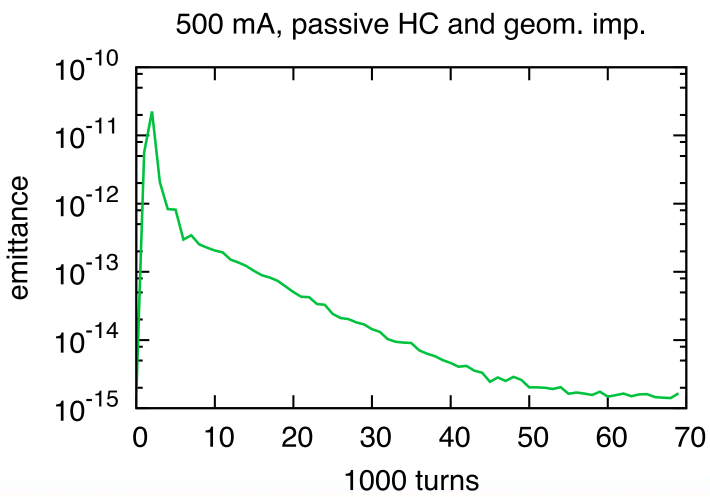
Multi-bunch calculations: Resistive wall impedance



nominal beam current: 500 mA



- Timeconsuming runs due to long damping times
- Harmonic cavity tuning for maximum bunch lengthening needed
- Vertical geom. impedance helps relaxing the situation
- Passive HC allows operation at the nominal 500 mA

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Conclusion and outlook MAX IV

- Longitudinal & transverse impedance budget was determined

- Longitudinal instability studies finished
  - No energy spread blow-up was observed in the planned operating current range

- Transverse beam instabilities studies launched

- Single bunch effects (vertical):
  - Chromaticity shifting and HC leads to sufficiently hight instability thresholds in the vertical plane
- Multi-bunch effect of the wall resitivity (vertical):
  - Very longlasting effect (100-200 turns), reason under investigation
  - The presence of the the geometric impedance and the HC allow stable operation at the aimed beam current (500 mA)

- Studies of the horizontal plane are to come

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