Simulations on multi bunch dynamics at FLASH with different damping of the HOM at 3,9GHz cavities

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Problem description

- The 3rd harm cavity is planned to be installed in order to provide better bunch qualities.
- HOM could affect the transverse MB dynamics of the bunches thus causing an additional MB emittance.
- HOM are planned to be suppressed by the HOM couplers with an average damping factor of 10^{-5}
- The question in this context: how strong should be the damping of the HOM of the 3,9GHz cavities to provide the suitable multi bunch dynamics (i.e $\varepsilon_{MB} << \varepsilon_{SB}$) and to verify if it is a possible option to use the 3,9GHz cavities without HOM couplers.

Background

- HOM of the 3,9GHz cavities: described in

  „*A Design of a 3rd Harmonic Cavity for the TTF 2 Photoinjector*“ J. Sekutowicz, R. Wanzenberg

  „*Higher Order Modes of a 3rd Harmonic Cavity with an Increased End-cup Iris*“ T. Khabibouline, N. Solyak, R. Wanzenberg

- HOM of the 1,3GHz cavities:

  „*Monopole, Dipole and Quadrupole Passbands of the TESLA 9-cell Cavity*“ R. Wanzenberg

- Passage between cavities:

  „Matlab Functions for Calculations of the Linear Beam Optics of FLASH Linac“ V. Balandin, N. Golubeva.

Main Formulas of the Model

Wake fields:

$$W_{\parallel}^{(m)}(s) = -\sum_n \omega_n \left(\frac{R^{(m)}}{Q}\right)_n \cos\left(\omega_n \cdot s/c\right)\exp\left(-1/\tau_n \cdot s/c\right)$$

$$W_{\perp}^{(m)}(s) = c\sum_n \left(\frac{R^{(m)}}{Q}\right)_n \sin\left(\omega_n \cdot s/c\right)\exp\left(-1/\tau_n \cdot s/c\right)$$

Energy deviation due to wake fields:

$$\Delta E\left(s_j\right) = -eq\sum_{i<j} W_{\parallel}^{(0)}\left(s_j - s_i\right) - eq\sum_{i<j}\left(x_j x_i + y_j y_i\right)W_{\parallel}^{(1)} + \ldots$$

Transverse kick due to wake fields:

$$\vec{\theta}_j = \frac{eq}{E_j}\sum_{i<j}\left(x_i \vec{e}_x + y_i \vec{e}_y\right)W_{\perp}^{(1)}\left(s_j - s_i\right)$$

Damping of the HOM: $\tau_n \rightarrow dampingfactor \cdot \tau_{n0}$

Assumptions

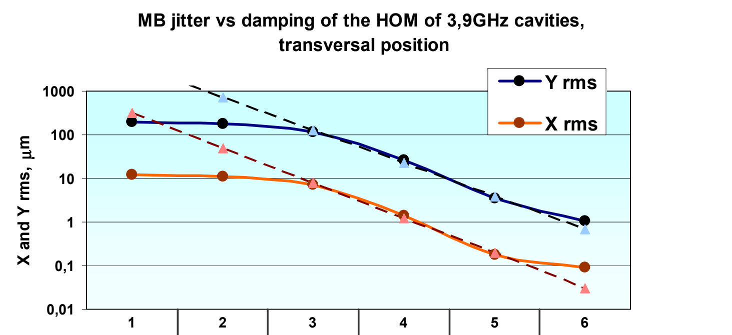
- Simulation region: from the quadrupole Q9ACC1 at 13,5827m (right after the ACC1) to the entrance into the Undulator 1 at 203,3288m (Q22SEED)
- Supposed place for the 3,9GHz cavities: between V10ACC1 at 14,0177m and 1UBC2 at 19,235m.
- Amount of 3,9GHz cavities: 4 cavities with 9 cells each.
- HOM of the 1,3GHz cavities are damped by the order of 10^{-5}
- Decouple single bunch effects from MB effects
- All monopole and dipole modes from the first four passbands for both cavities (1,3GHz and 3,9GHz) have been taken into account.
- Inject bunches on crest ideally i.e. without slope divergence and without transverse offsets.

Parameters for Simulations

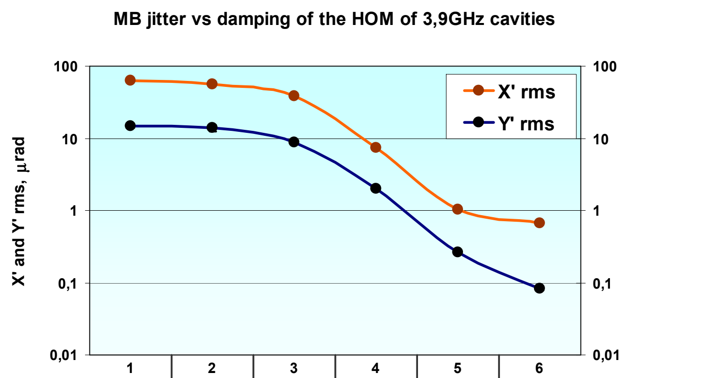
bunch charge	1nC
pulse length	120μm
bunch spacing	200ns
number of bunches per train	600
cavity misalignment	0,5mm rms
cavity detuning	0,1% rms
normalized SB emittance	1,4mm mrad

- 100 linacs have been simulated and averaged for each measurement.

MB Jitter as a Function of Damping of the HOM in the 3,9GHz Cavities



	1	2	3	4	5	6
Y rms	197,81658	182,04911	115,95185	26,42996	3,53766	1,0568
X rms	12,093302	10,76564	7,24337	1,39923	0,18022	0,09095
Trend Y	4154	725,4	126,7	22,12	3,863	0,6747
Trend X	311,5	49,13	7,748	1,222	0,1927	0,0304



	1	2	3	4	5	6
X' rms	62,899	56,193	38,071	7,277	1,0388	0,6725
Y' rms	14,992	13,796	8,774	2,0012	0,26631	0,08322

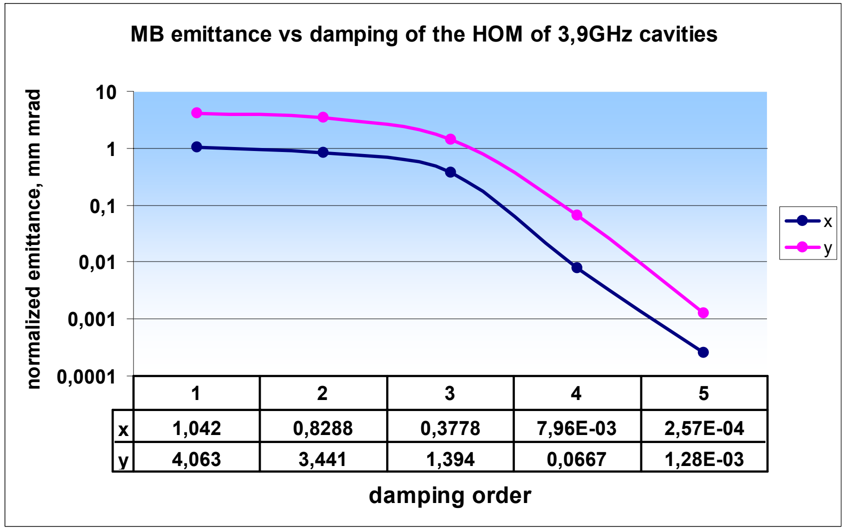
- Almost no influence of damping on MB emittance up to damping factor of 10^{-3}
- Linear dependence of the MB rms size on the damping of the HOM in the region $10^{-3} - 10^{-5}$. It could be approximately described by the equation:

$$y_{rms} = 27787 \cdot (0{,}1746)^{1/dampingfactor} \quad \mu m$$

$$x_{rms} = 1975 \cdot (0{,}1577)^{1/dampingfactor} \quad \mu m$$

- The effect of damping decreases after 10^{-5} → comprehensible since 1,3GHz cavities are damped only by the order of 10^{-5}.

MB emittance as a function of damping

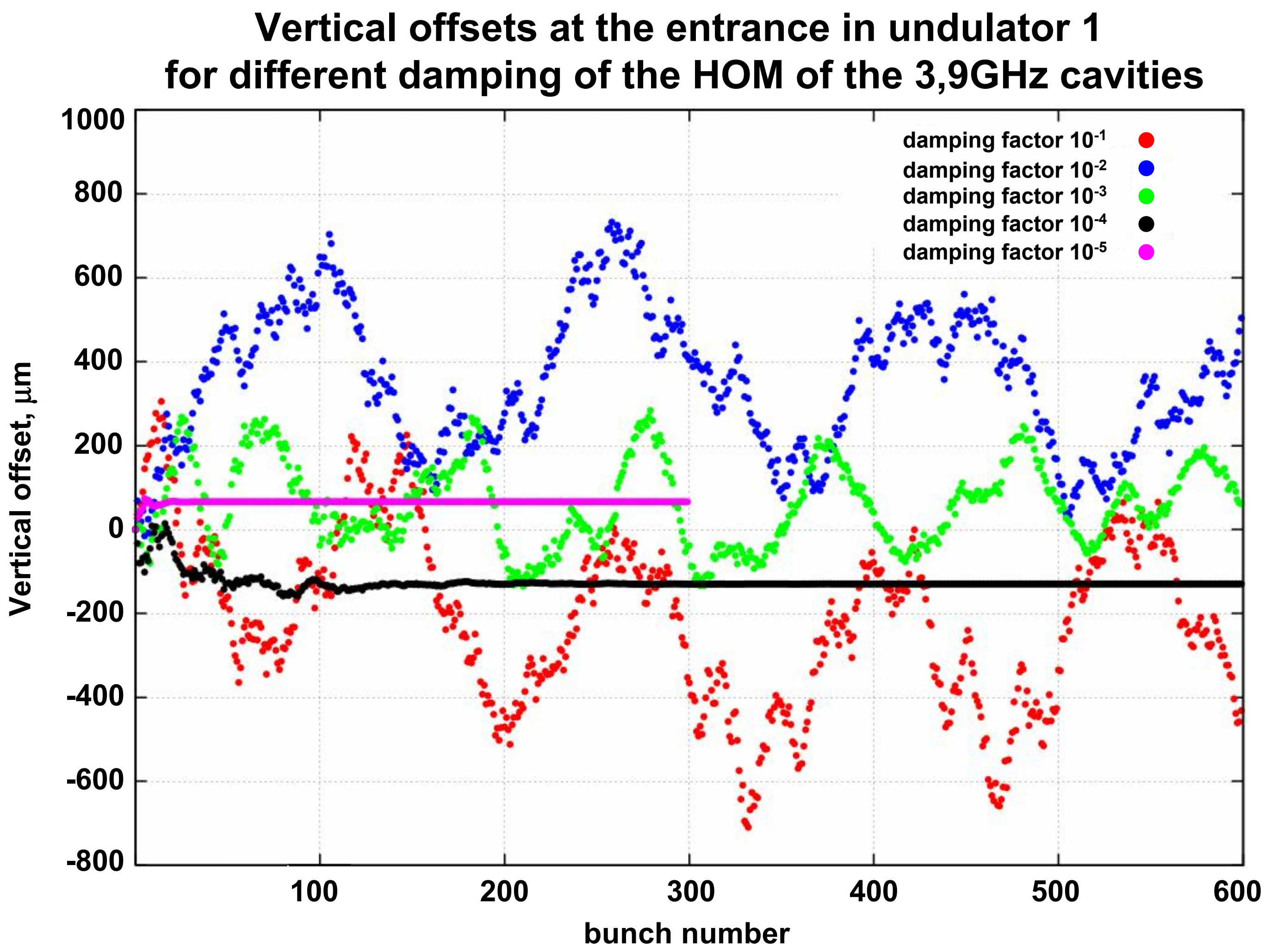


Design normalized single-bunch emittance 1,4mm mrad assumed. Combined emittance calculated according to

$$\varepsilon = \sqrt{\varepsilon_{MB}^2 + \varepsilon_{SB}^2}$$

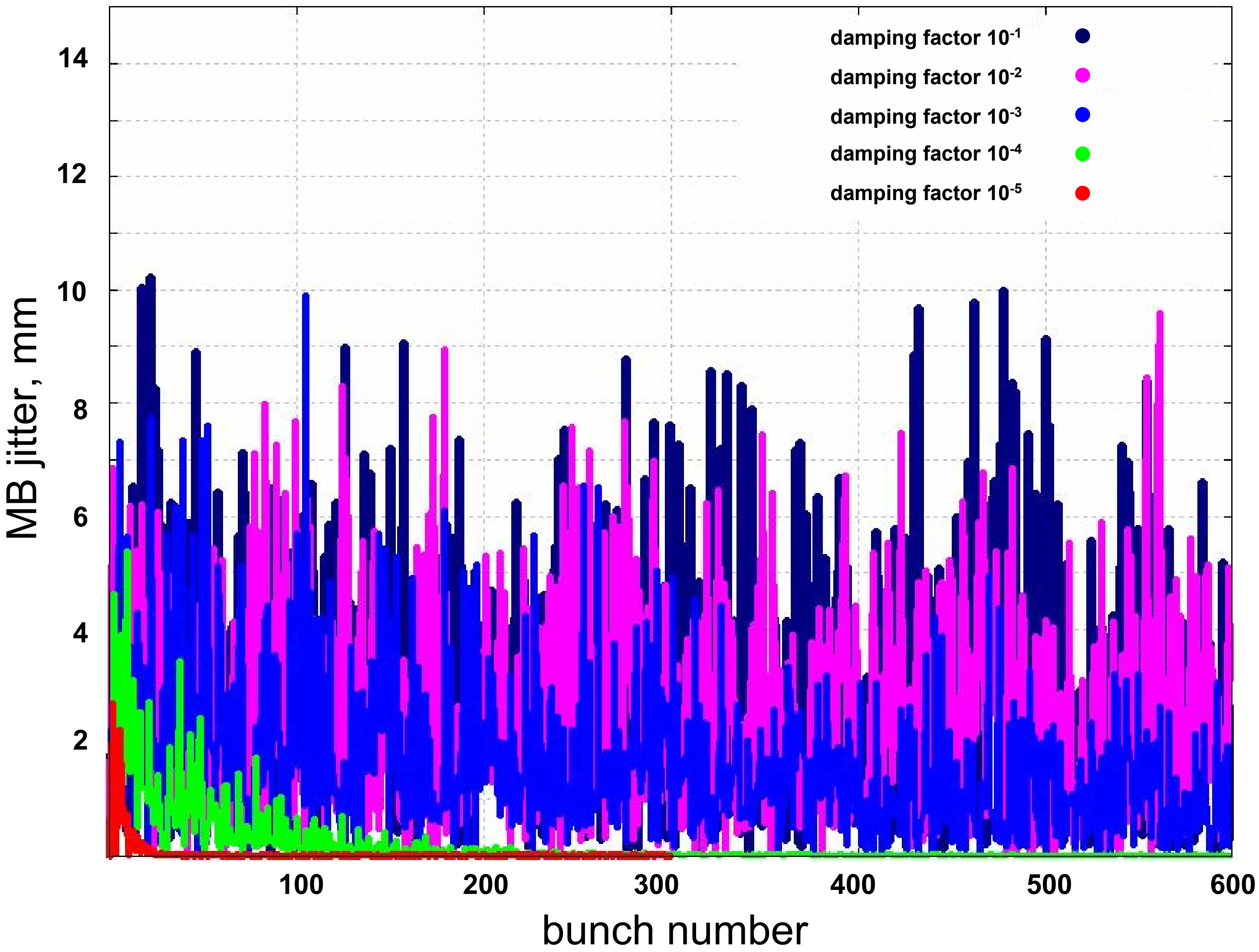
Table: Emittance blow up vs damping of the HOM of the 3,9GHz cavities
Design emittance of 1,4mm mrad assumed

Damping	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
$\Delta\varepsilon_x$, %	24,66	16,21	3,58	1,616e-3	1,642e-6
$\Delta\varepsilon_y$, %	206,96	165,35	41,12	0,113	4,171e-5



Vertical offsets at the entrance in undulator 1
for different damping of the HOM of the 3,9GHz cavities
Vertical offset, µm
bunch number
damping factor 10-1
damping factor 10-2
damping factor 10-3
damping factor 10-4
damping factor 10-5
1000
800
600
400
200
0
-200
-400
-600
-800
100
200
300
400
500
600

MB jitter in vertical direction at the entrance in undulator 1



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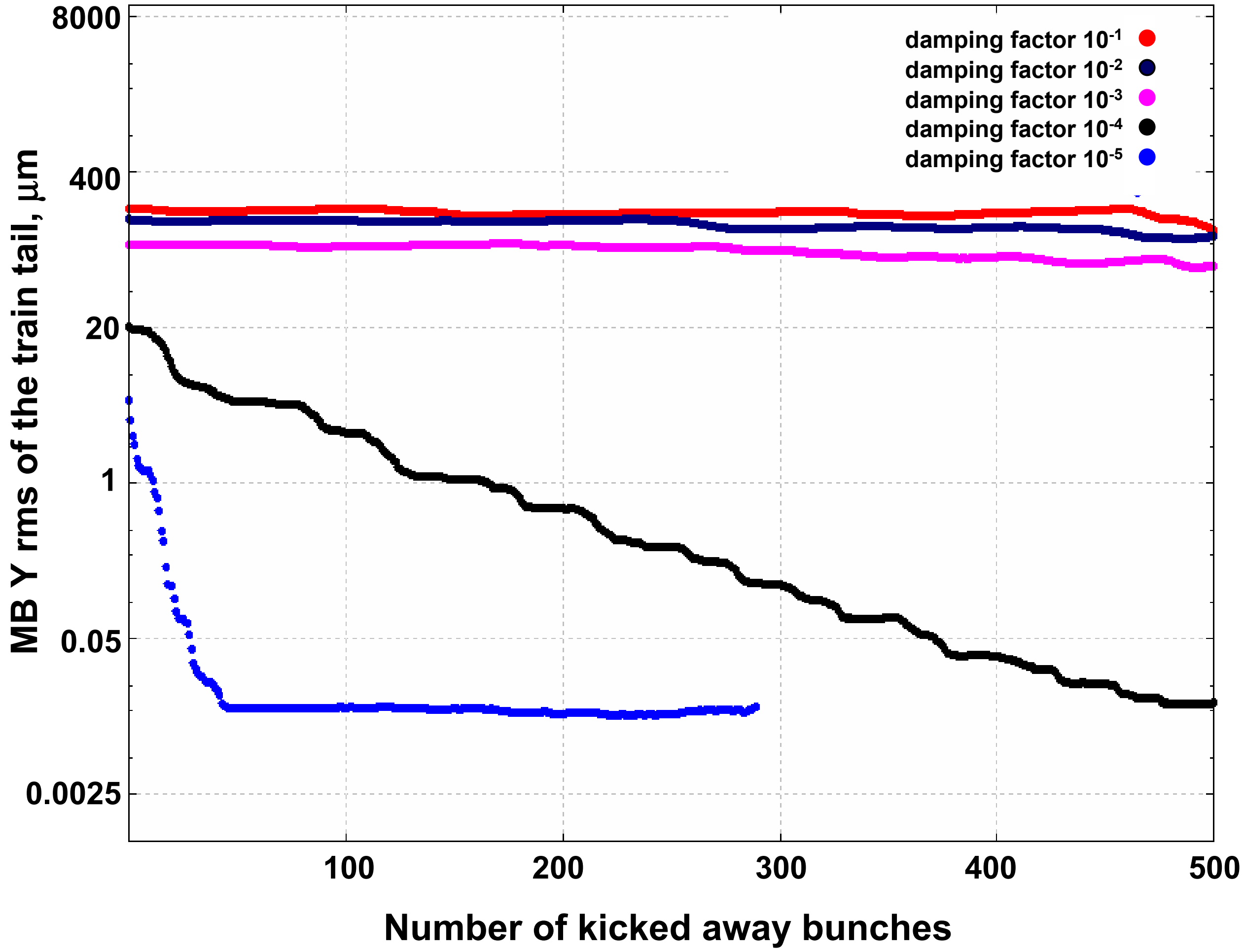
Vertical MB rms after cutting off the first bunches



Simulation settings:

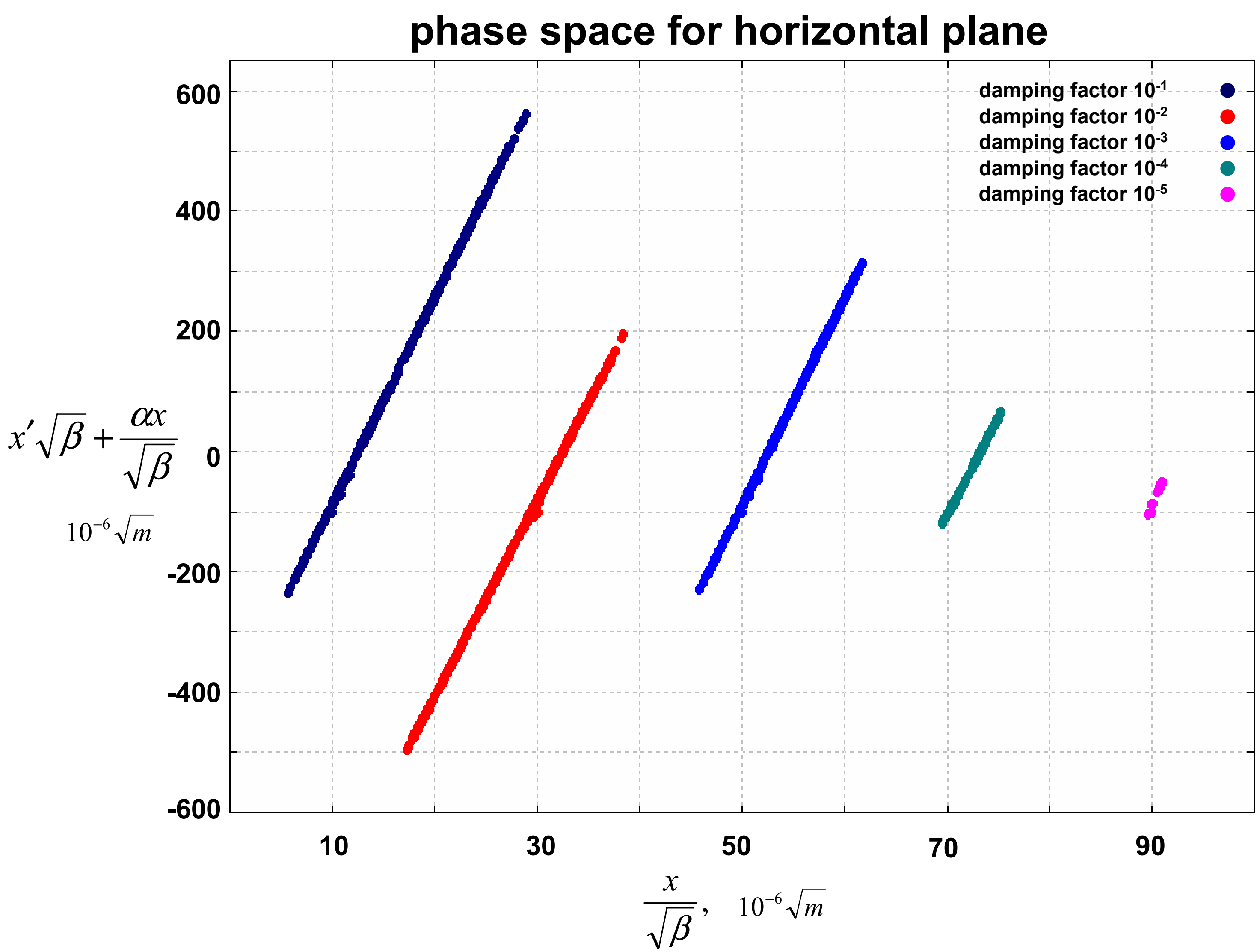
Bunch train: 600 bunches
Bunch spacing: 200ns
Bunch charge: 1nC

Vertical mb rms calculated after kicking away the first bunches of the train head

Results:

for the design damping of the HOM:
Kicking away the first 50 bunches leads to absolutely stable conditions. The jitter of the whole bunch train is in any case negligible.

Damping by the order of up to 10^3:
doesn‘t lead to significant effect by suppressing the MB jitter.



Phase space for different cases of damping of the HOM of the 3,9GHz cavities

Conclusions

- MB emittance blow up of up to 200% is possible if the 3rd harmonic cavities are operated without HOM couplers.
- Damping of the HOM by 10^{-4}-10^{-5} required for the stable operating conditions with negligible mb effects. Since HOM couplers provide the damping of 10^{-5} no problems about mb dynamics are expected in this case.