Impedance Budget and collective effects study for Sirius

Fernando Henrique de Sá
Accelerator Physics Group

on behalf of the LNLS Impedance Team

6th Low Emittance Rings Workshop (LOWeRING 2016)
Synchrotron SOLEIL, France, October 26th-28th, 2016.

Summary

- Sirius main parameters
- Modelling of the components:
  - Standard Vacuum Chamber
  - BC Chamber
  - Undulators Chamber
  - Other Components
- Impedance Budget Summary
- Instabilities analysis:
  - Longitudinal Instabilities
  - Transverse Instabilities

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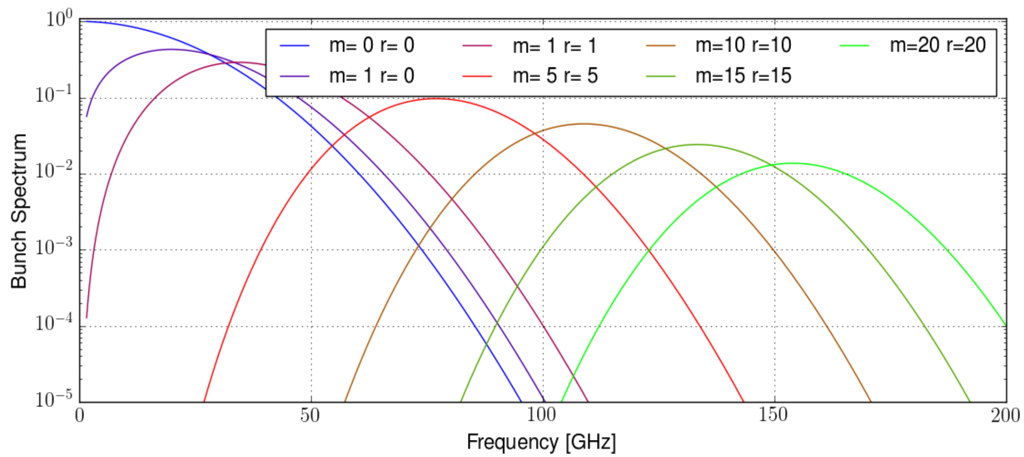
Sirius main parameters

Beam energy	3.0 GeV
Circumference	518.4 m
Revolution Frequency	578.3 kHz
Harmonic Number	864
RF Voltage	3 MV
tunes (H / V / L)	49.11 / 14.17 / 4.7 x 10^{-4}
Momentum Compaction	1.6 x 10^{-4}
Natural bunch length	2.5 mm
Natural energy spread	8.5 x 10^{-4}
Energy loss/turn (dipoles)	532 keV
Damping times (H/V/L)	15.5 / 21.5 / 12.8 ms

	Comm. (P0)	Phase 1 (P1)	Phase 2 (P2)
Nom. Cur. [A]	0.02	100	350
RF Cavity	PETRA 7-cell	2 SC	2 SC
3rd HC	-	-	1 SC
Ins. Dev.	0	3 SGU	14 SGU + 04 BGU

SGU: Small gap undulators
BGU: Big gap undulators



Bunch Spectrum for several azimuthal (m) and radial (r) modes.

In the longitudinal plane:

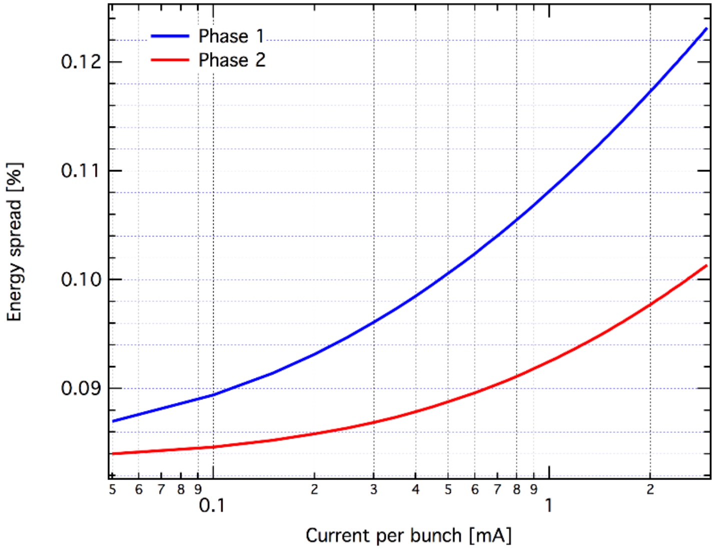
$$m, r \sim 20 \quad \Rightarrow \quad -200\ GHz < f < 200\ GHz$$

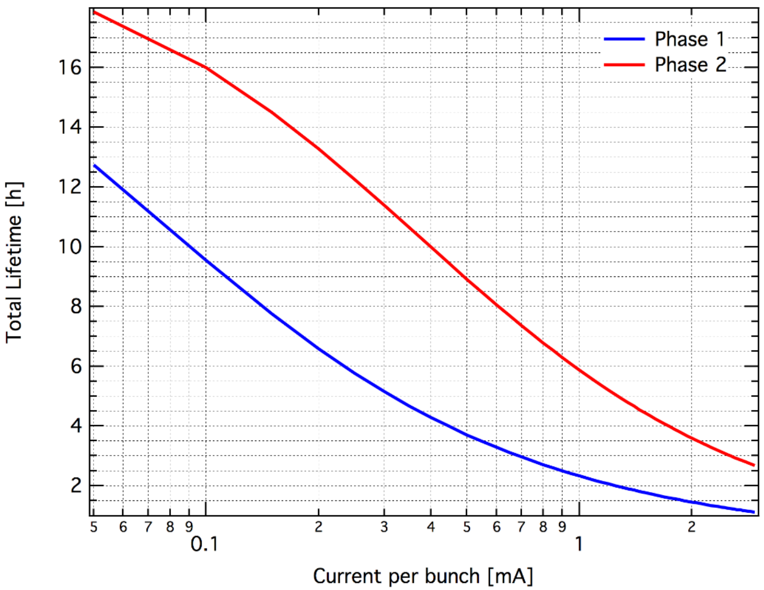
In the transverse plane:

$$m, r < 3 \ \text{ and } \ f_\xi = \frac{\xi}{\eta} f_0 \approx 34 \text{ GHz}$$

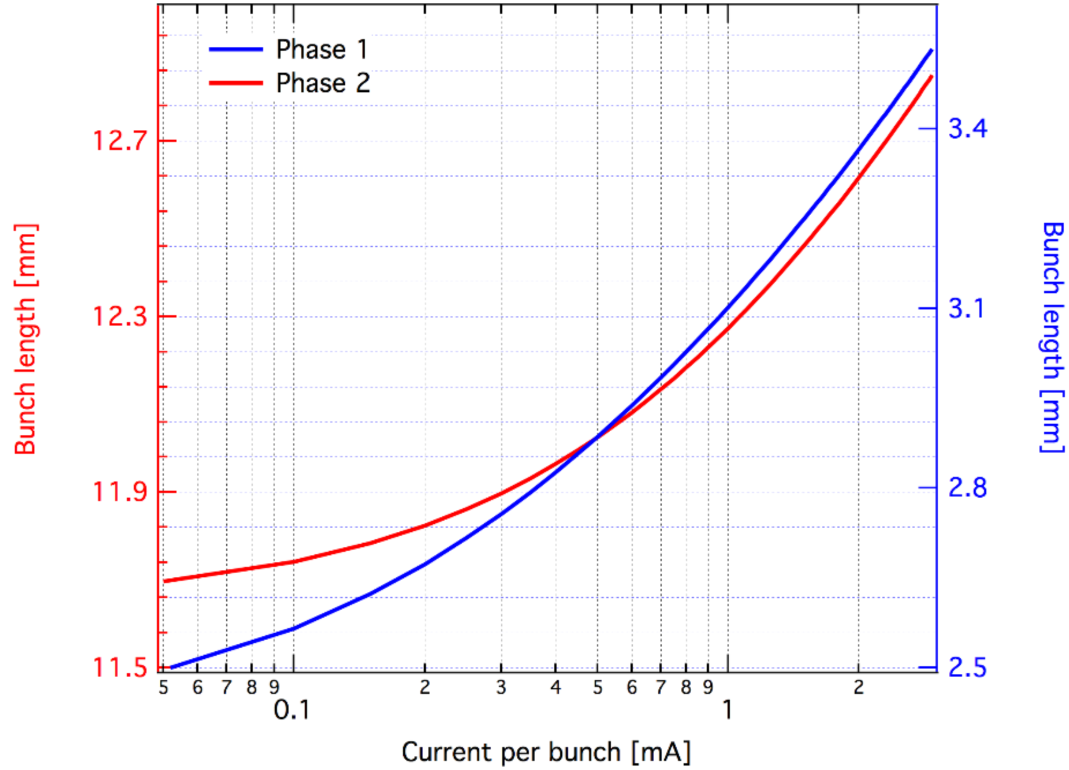
$$\text{for } \xi = 10 \quad \Rightarrow \quad -100 \text{ GHz} < f < 100 \text{ GHz}$$

Sirius main parameters





Figures: equilibrium parameters and total beam lifetime as function of the current per bunch considering IBS effects. All calculations take into account the presence or not of a passive 3rd harmonic cavity.



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Standard Vacuum Chamber

- NEG coated round pipe;
- Impedance was calculated using N. Mounet formulas for multi-layer round pipes.
- Uncertain about NEG conductivity: values in literature vary from ~0.1 to 5 MS/m;
- We also varied ε_r, but for values up to 10^4 no significative changes were observed;

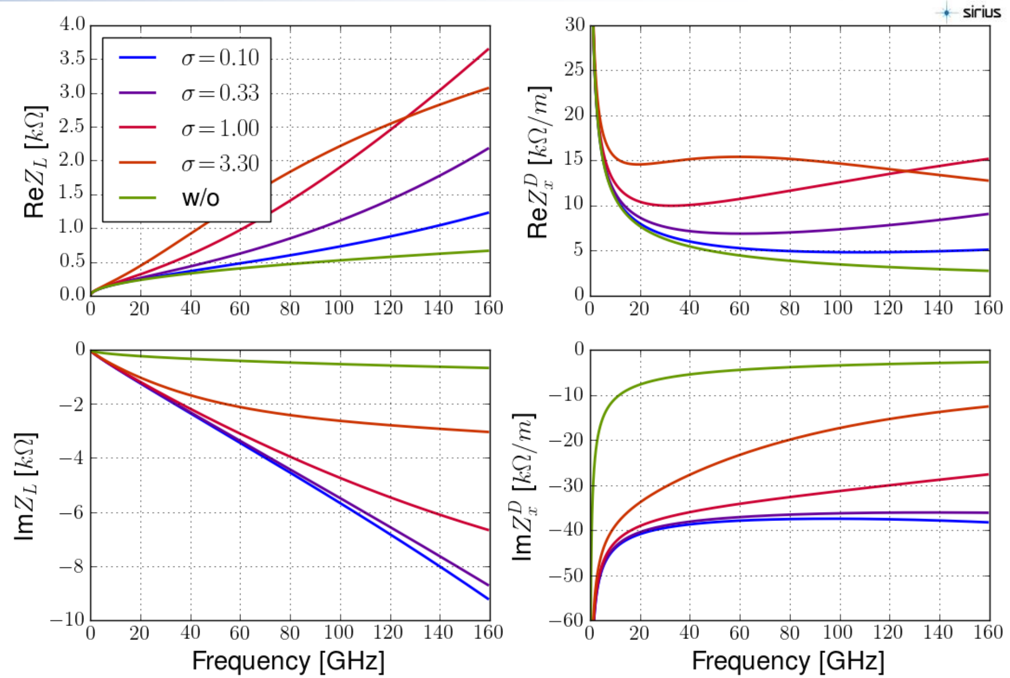

Figure: Longitudinal and Horizontal impedance for the Sirius standard vaccum chamber considering several values of NEG conductivity. Notice that small conductivities have higher impaginary impedance, while bigger conductivities have stronger real impedances.

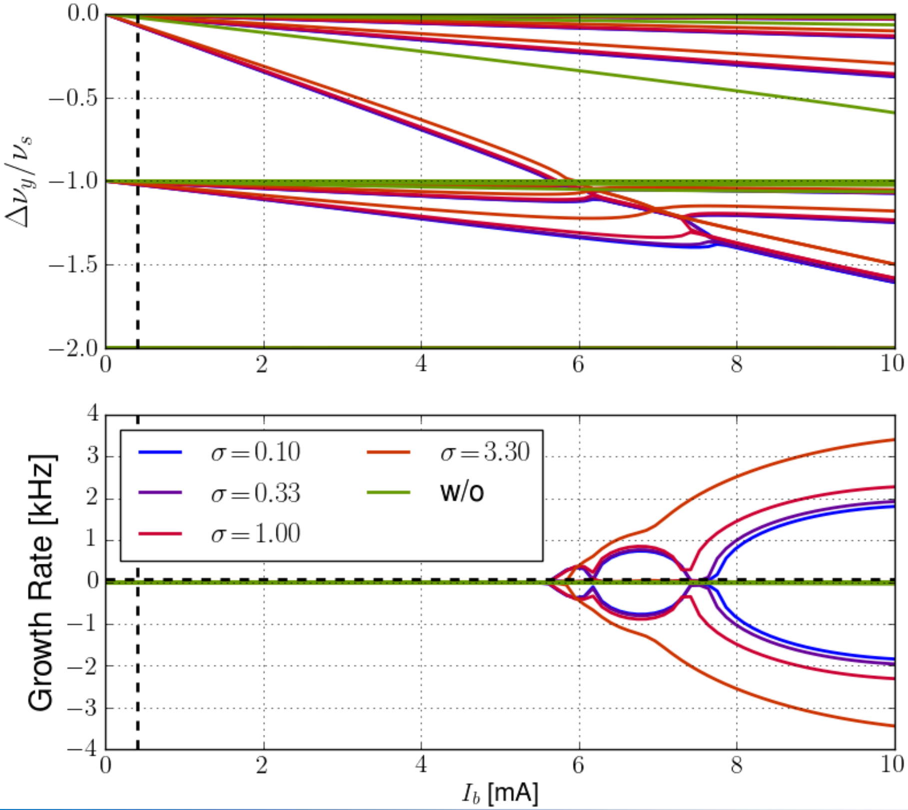

Figure: Mode-coupling istability for a 3mm bunch at zero chromaticity considering the chamber impedance with different values of NEG conductivity (values in MS/m).

Parameter	Value
NEG cond [MS/m]	0.5
NEG Thickness [μm]	1
Copper cond. [MS/m]	59
Radius [mm]	12
Length [m]	480

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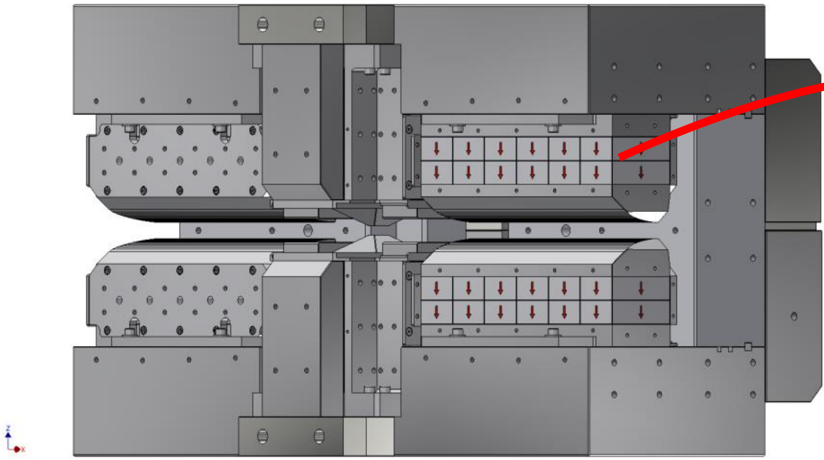
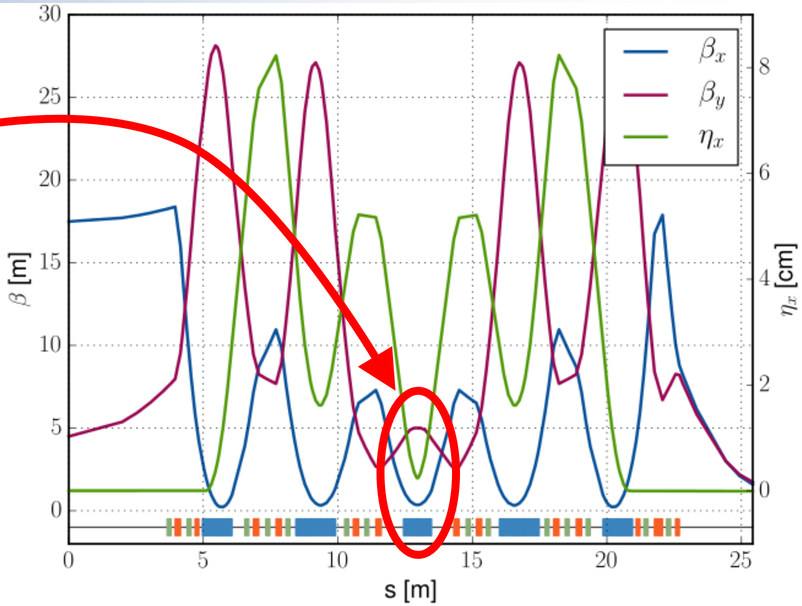
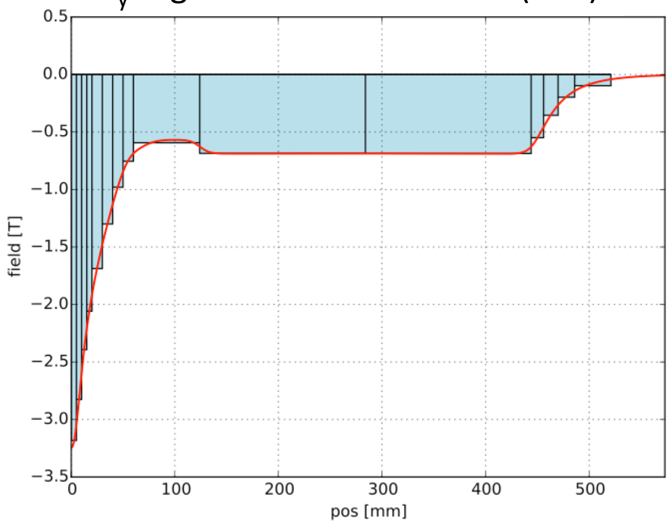
BC Magnet

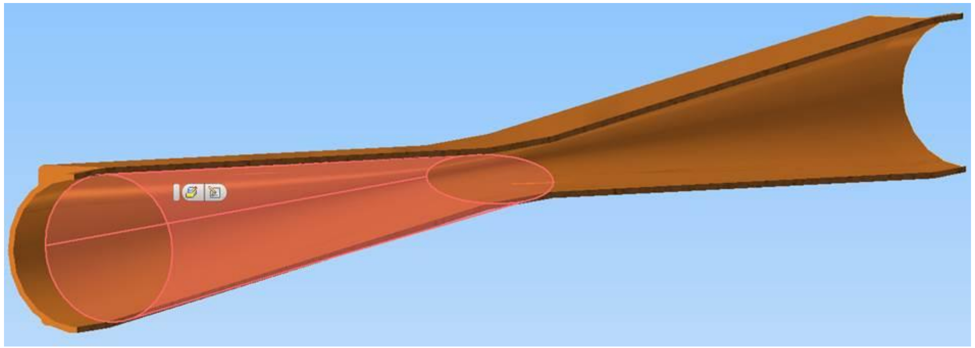




B_y segmented model for BC (half)



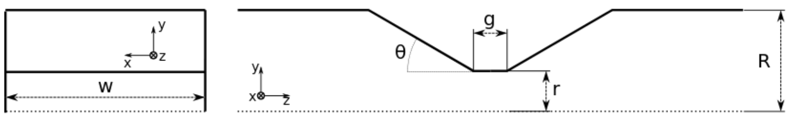
- High field (3.2 T) permanent dipole at the center of each dispersive unit cell;
- Hard x-ray (~19keV critical energy) beamline
- To produce the high field, the gap is reduced to 10 mm (8 mm for the beam).
- Sirius will have 20 units of these magnets;



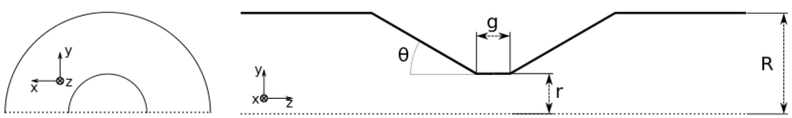
BC Chamber

We investigated two possibilities:

- the original proposal, with an eliptical cross section at the minimum gap



- a round cross section at the middle of the chamber



The transitions were calculated in ECHOzR for the rectangular model and ECHOz1 and ECHOz2 for the round model. We assumed a linear taper.

Parameter	Value	Parameter	Value
g [mm]	20	w [mm]	24
R [mm]	12	$t = 1/\tan(\theta)$	15
r [mm]	4		

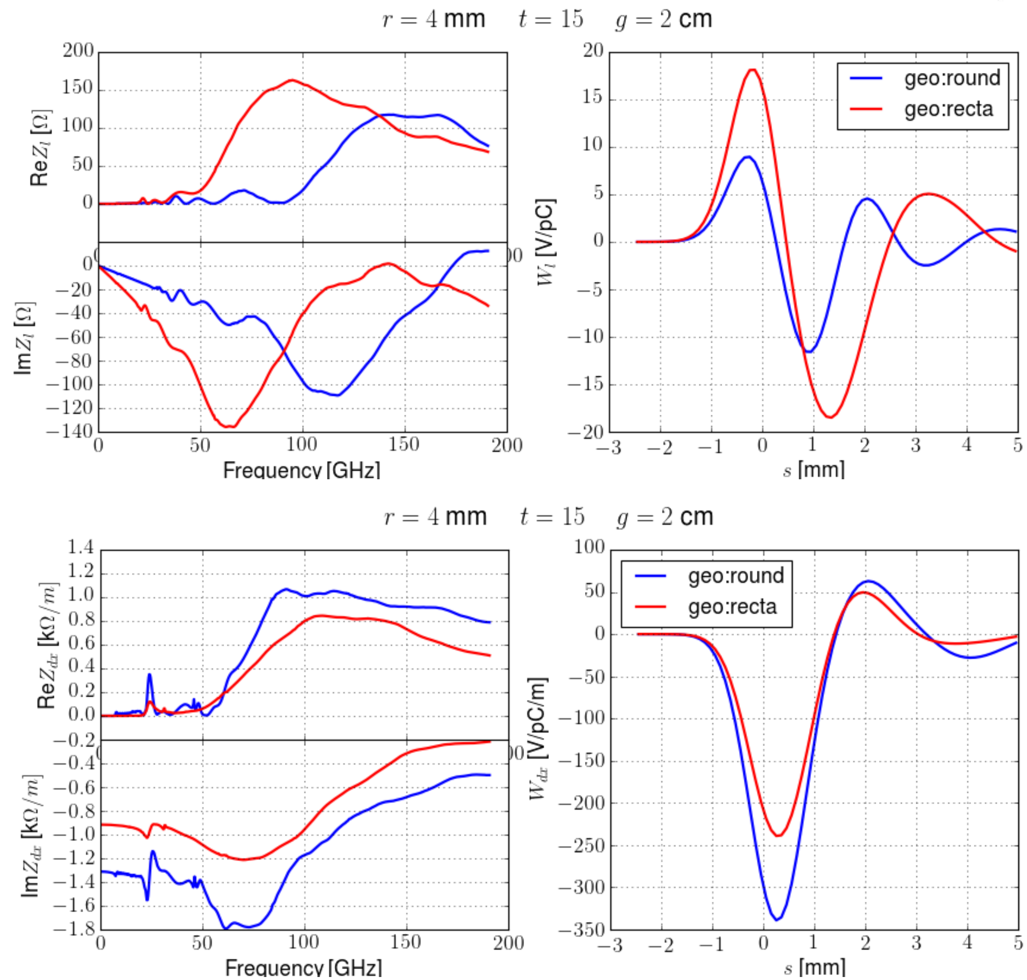


Figure: Longitudinal and Driving Horizontal impedances for the two models studied for the BC magnet vacuum chamber.

BC Chamber

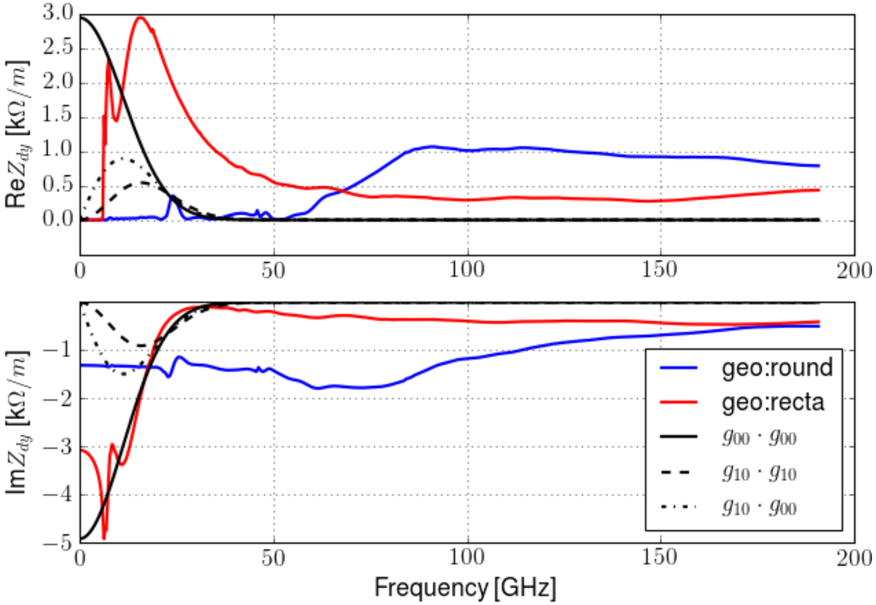


Figure: Vertical Impedance of one BC magnet chamber.

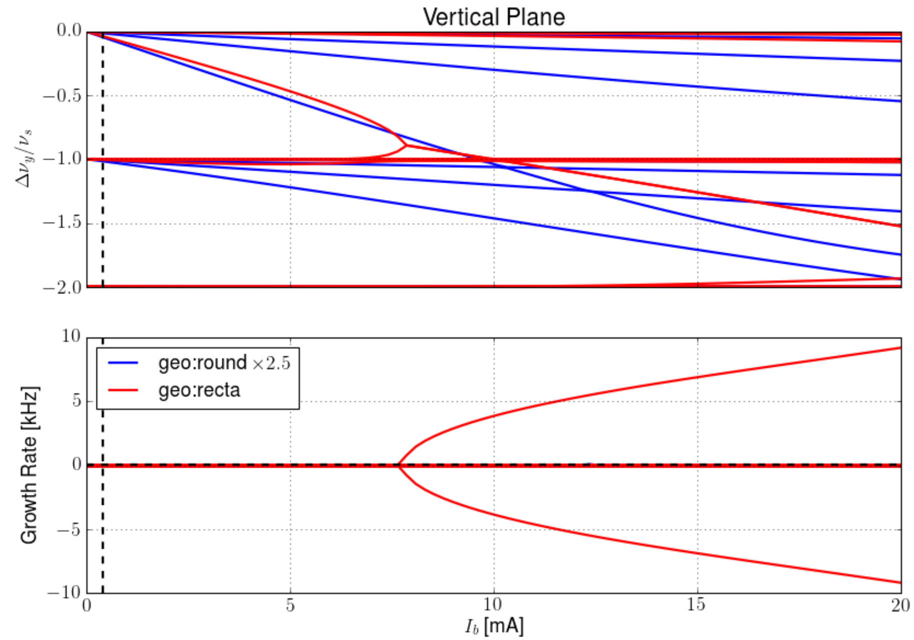


Figure: Single bunch modes at $\xi = 0$ for a 3mm bunch considering the 20 BC magnet chamber in the ring and the local value of the betatron function.

With only modes 0 and -1, the mode-coupling matrix is of the form:

$$\begin{pmatrix} I_1 - \frac{1}{N} & R_1 \\ -R_1 & I_0 \end{pmatrix} \Rightarrow \lambda_{1,2} = \frac{I_0 + I_1 - \frac{1}{N}}{2} \pm \frac{1}{2}\sqrt{\left(I_1 - \frac{1}{N} - I_0\right)^2 - 4R_1^2}$$

$$I_i \propto \int \mathrm{Im}\{Z_y^D\} g_{i0} g_{i0} \, \mathrm{d}\omega$$

$$R_1 \propto \int \mathrm{Re}\{Z_y^D\} g_{10} g_{00} \, \mathrm{d}\omega$$

Where N is the number of particles in the bunch.

The instability happens if: $2|R_1| \geq |I_1 - \frac{1}{N} - I_0|$

Based on these results we decided to change the original design of the chamber by a cilyndrical transition;

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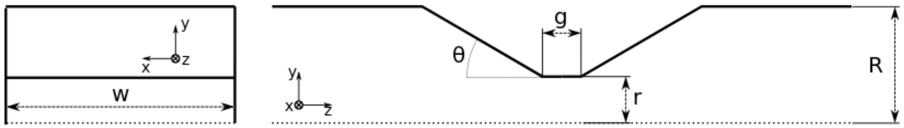
Undulators Chamber

- Undulators with 2 different gaps:
  - Small Gap Undulators (SGU) with 4.5 mm gap;
  - Big Gap Undulators (BGU) with 12 mm gap;
- We don't know the type of the undulators;
- For the SGUs:
  - in-vacuum → no NEG coating, rect. chamber;
  - Delta or DHSCU → NEG coating, round chamber.



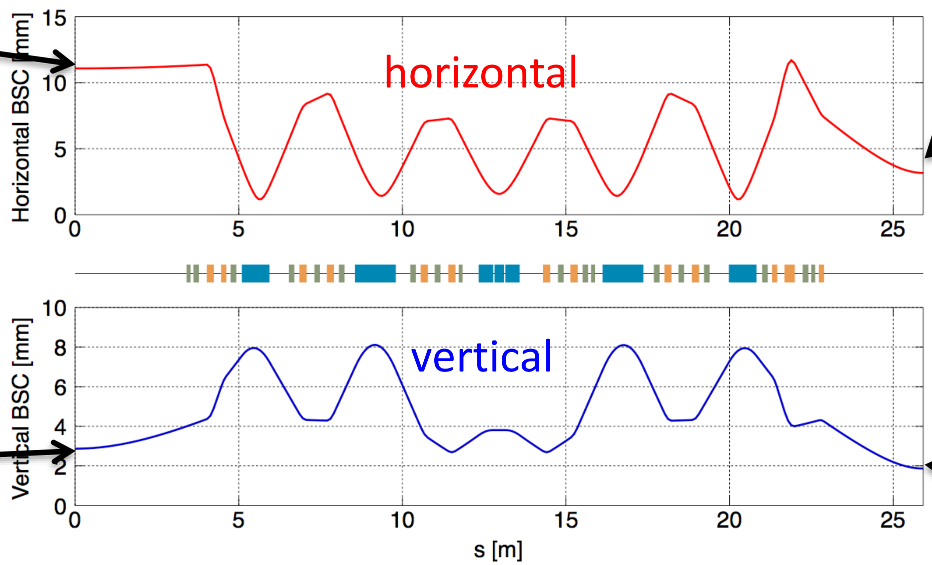
Parameter	SGU	BGU
g [m]	2.0	3.6
R [mm]	12	12
r [mm]	2.25	6.0

Parameter	SGU	BGU
w [mm]	24	24
$t = 1/\tan(\theta)$	20	20

Storage Ring Beam Stay Clear

< 11 mm @ 1m from center

< 4 mm @ 1m from center

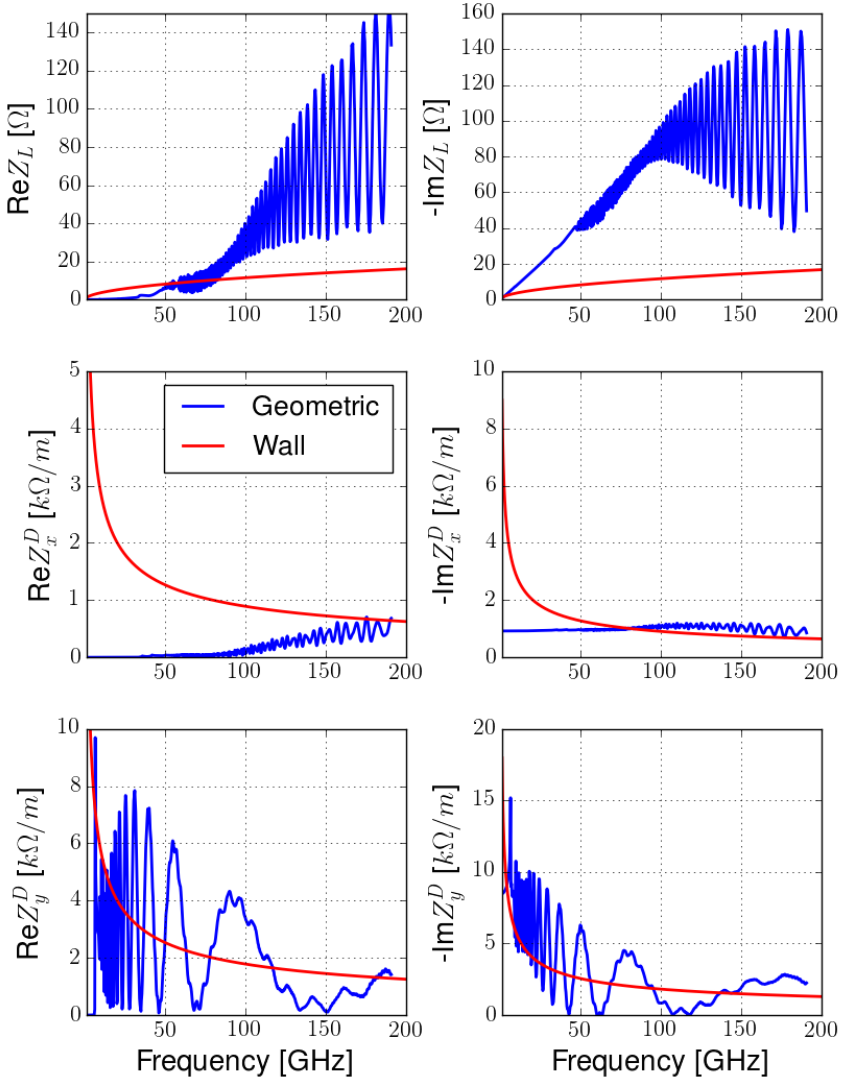


< 3.2 mm @ 1m from center

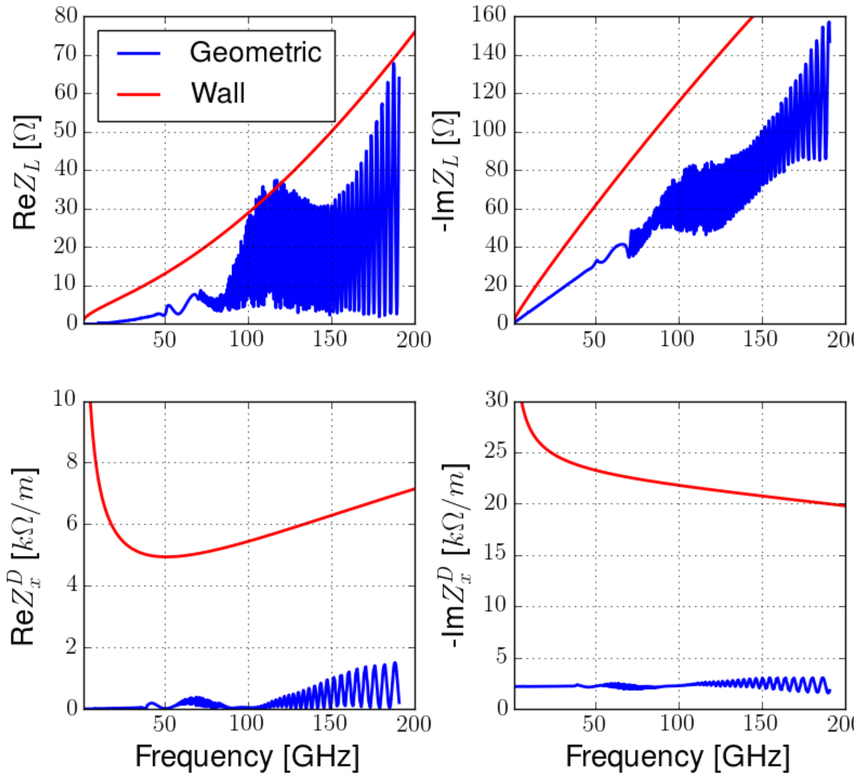
< 2.3 mm @ 1m from center

Undulators Chamber

In-Vacuum

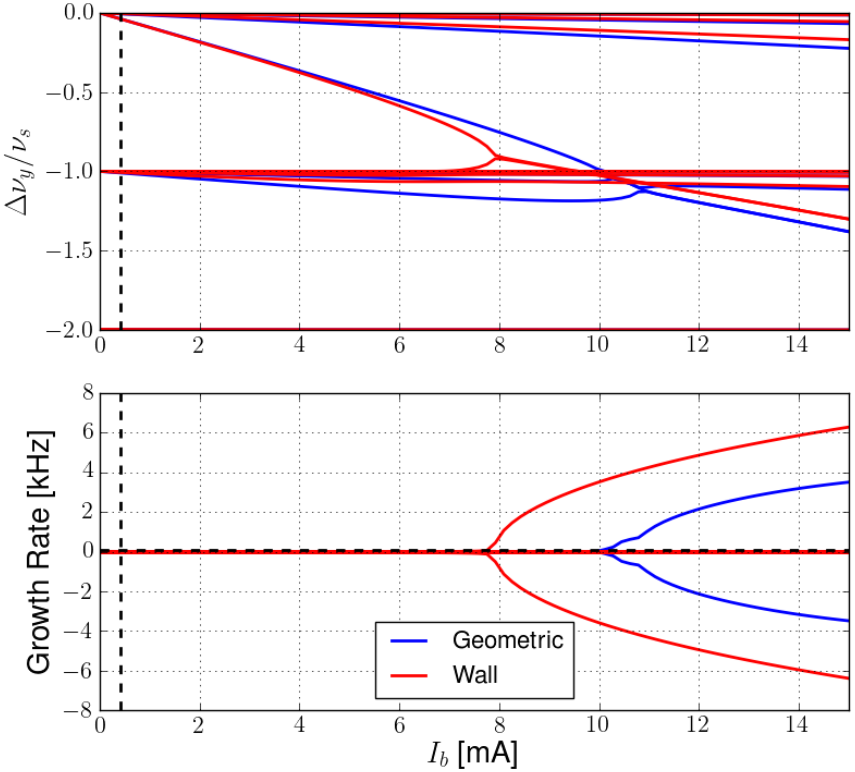


Delta or DHSCU



Undulators Chamber

In-Vacuum



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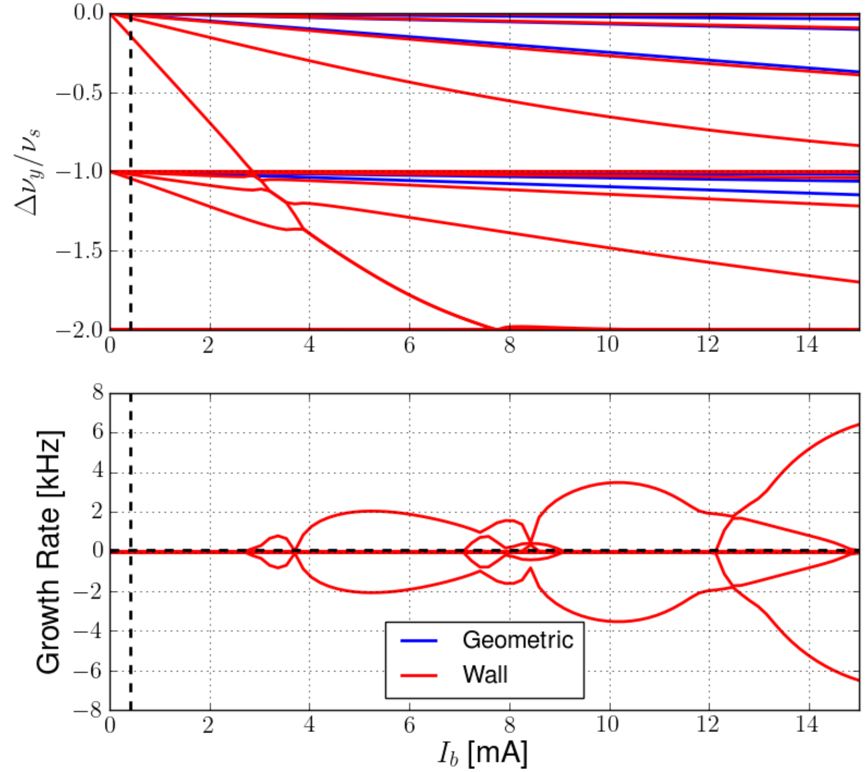

Mode-coupling instability at zero chromaticity for a 3 mm bunch simulated considering 14 elements in the ring, with betatron function of 2.5m at the position of the undulator.

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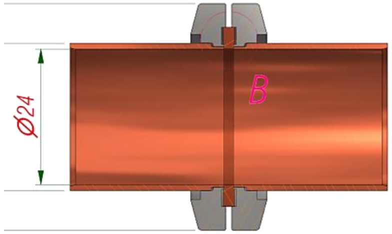
Other elements

- RF Cavity: A simple pair of tapers was calculated in ECHO2D;

- Injection Section: Sirius injection system will have a Non-linear Kicker (NLK) for off-axis injection and one Dipolar Kicker (DIPK) for commisioning. So far we simulated the transitions for these components and its resistive wall. We are planing to have a keyhole chamber for the injected beam, in such a way that the impedance is minimized for the acummulated beam;

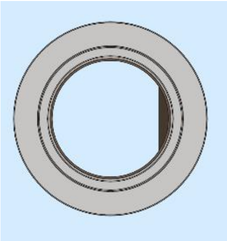
- Fast orbit correctors (FOC): Will have a special chamber (0.3mm SS) due to the high repetition rate (10 kHz). We modelled them as infinite round chambers with length of 0.1 m;

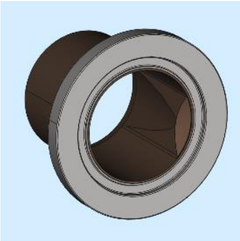
- Flanges: Sirius flanges will have “zero” impedance;



Other elements

- Radiation Masks: they are not axisymmetric. Their shape was optimized for impedance;





Courtesy of Duarte, H.O.C.

- BPMs: All BPMs will have one bellows in each side. Their Impedance were calculated with GdfidL for the complete 3D set;

- Valves: A 2D axisymmetric model was calculated with ECHO2D;

- Other elements such as: dipole chamber, scrapers, vacuum pumps and striplines were designed and had their impedance calculated, but were not added to the budget yet;

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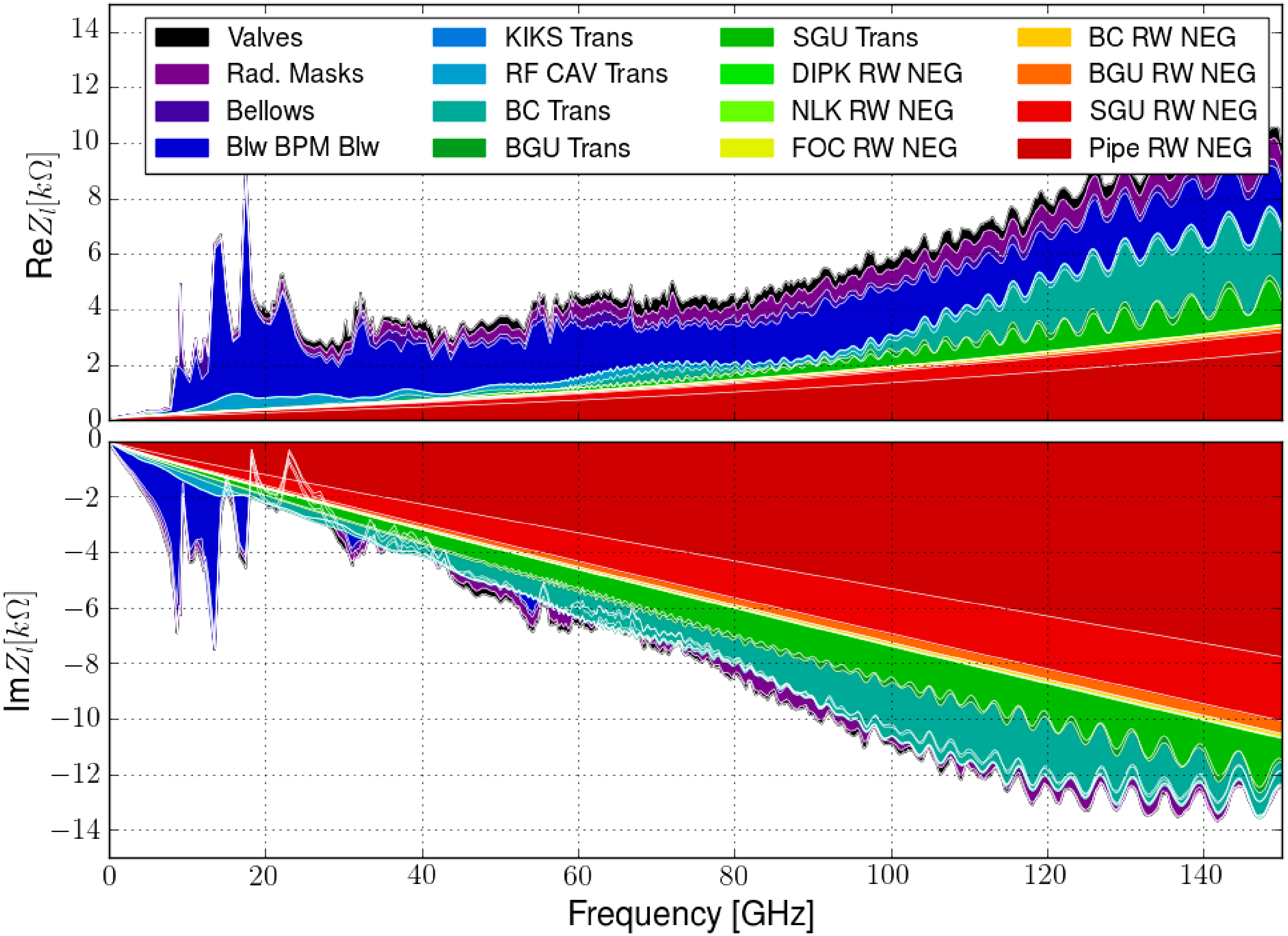
Impedance Budget Summary



Element	Quant.	Bx [m]	By [m]
Pipe RW NEG	1	6.0	11.0
SGU RW NEG	14	2.2	2.2
BGU RW NEG	4	17.8	5.0
BC RW NEG	20	0.4	5.2
FOC RW NEG	80	7.2	6.5
NLK RW NEG	1	18.2	7.3
DIPK RW NEG	1	18.0	6.7
SGU Trans	14	2.4	2.4
BGU Trans	4	17.8	5.0
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RF CAV Trans	1	7.3	7.3
KIKS Trans	1	18.2	7.1
Blw BPM Blw	160	6.6	8.8
Bellows	80	6.6	8.8
Rad. Masks	350	6.6	11.0
Valves	40	6.6	11.0

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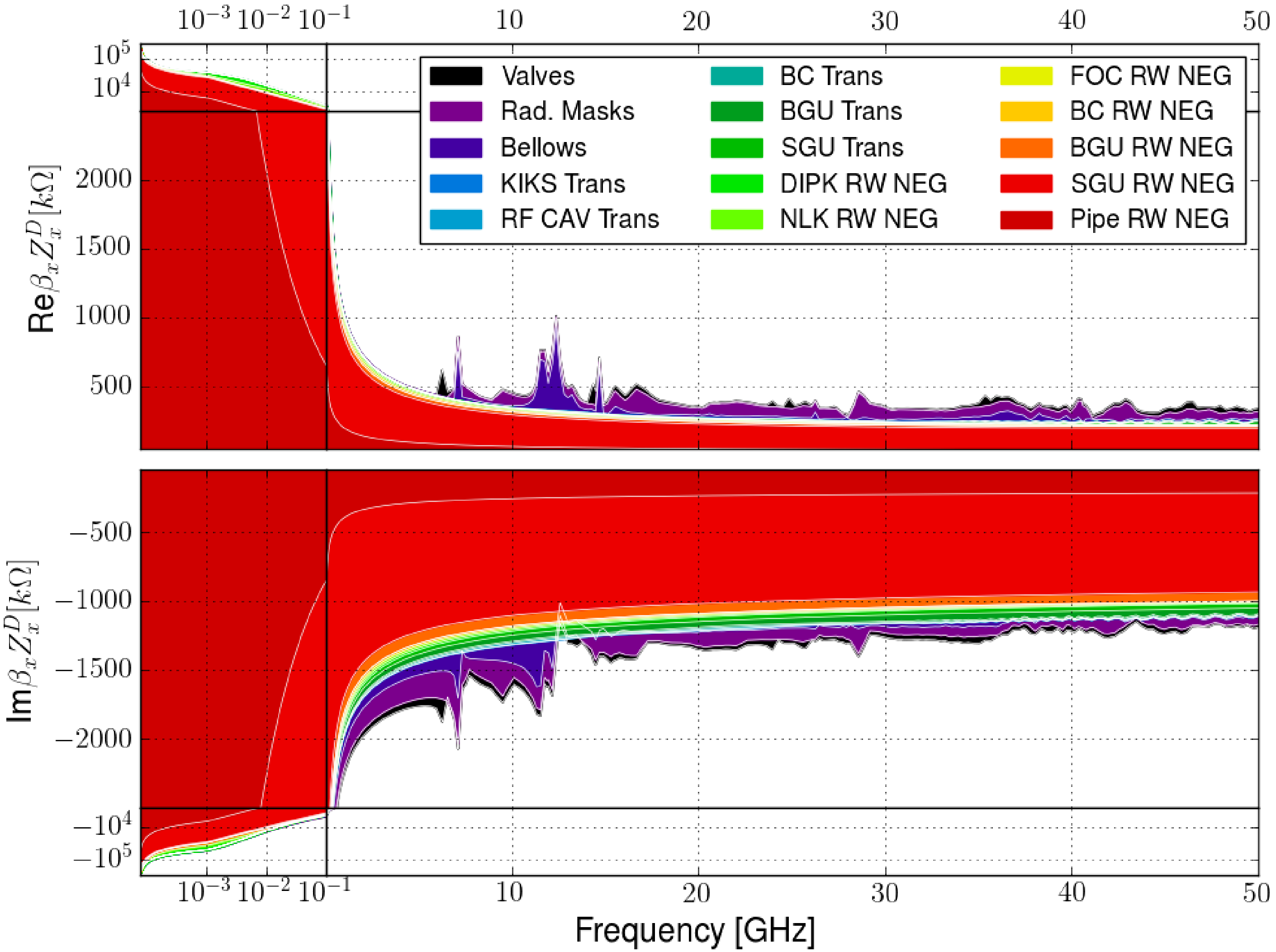

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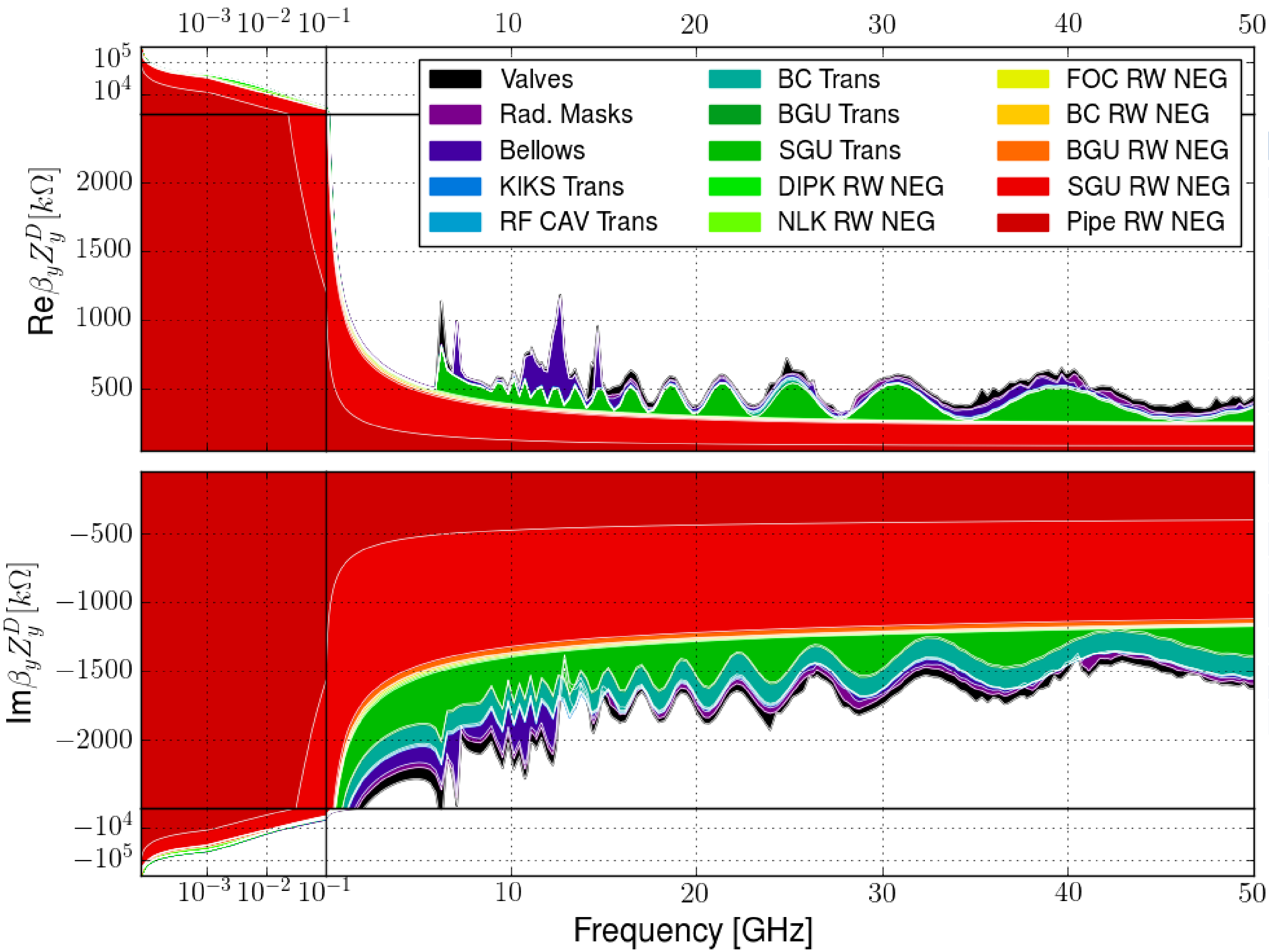

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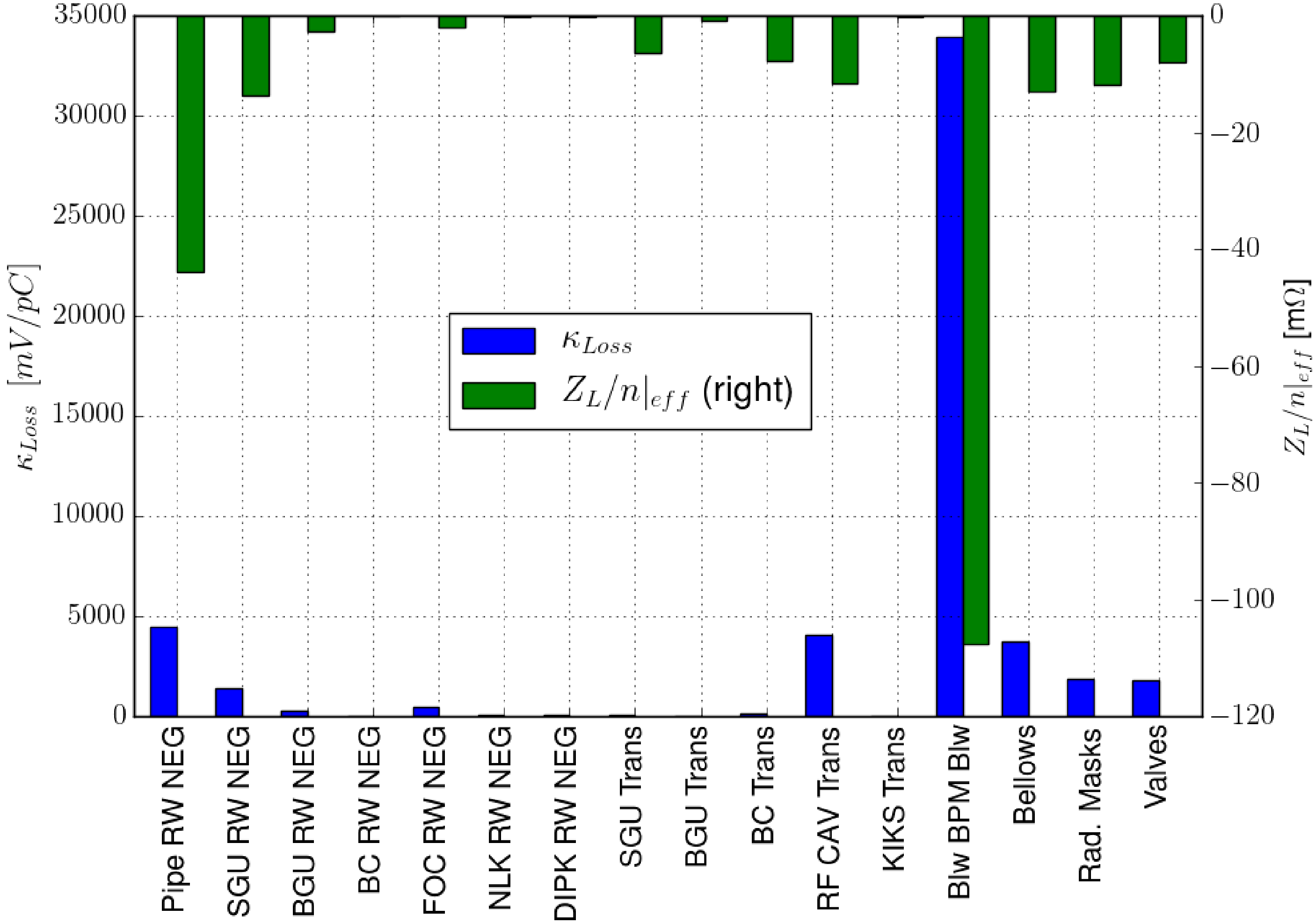

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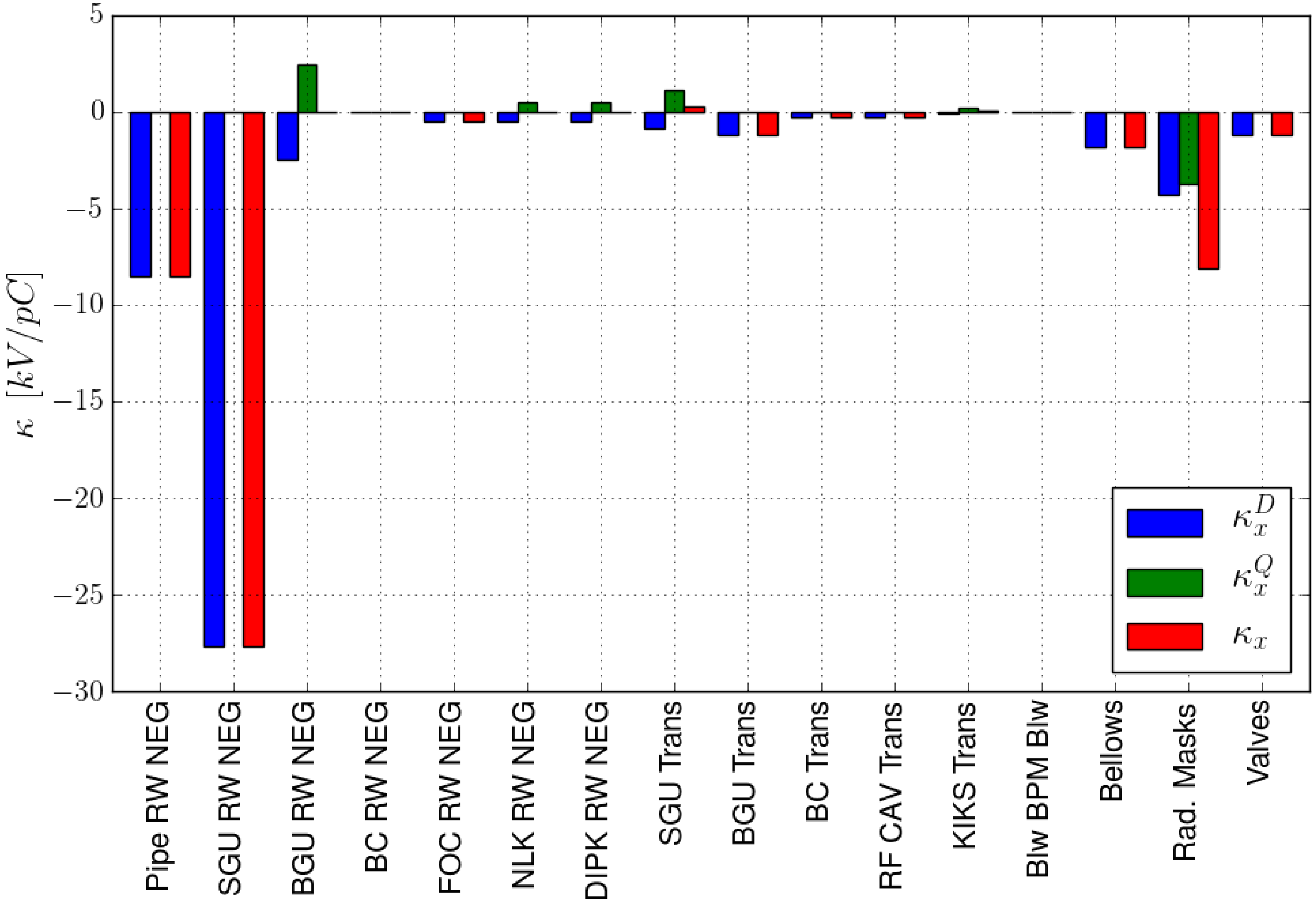
$\left.\frac{Z_L}{n}\right\|_{\text{eff}}$ $[m\Omega]$	κ_{Loss} $\left[\frac{V}{pC}\right]$
-230.4	52.3

Values calculated using a 3 mm single bunch in the machine.

Impedance Budget Summary



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	$\left[\frac{kV}{pC}\right]$
κ_x^D	-50.3
κ_x^Q	1.1
κ_x	-49.2

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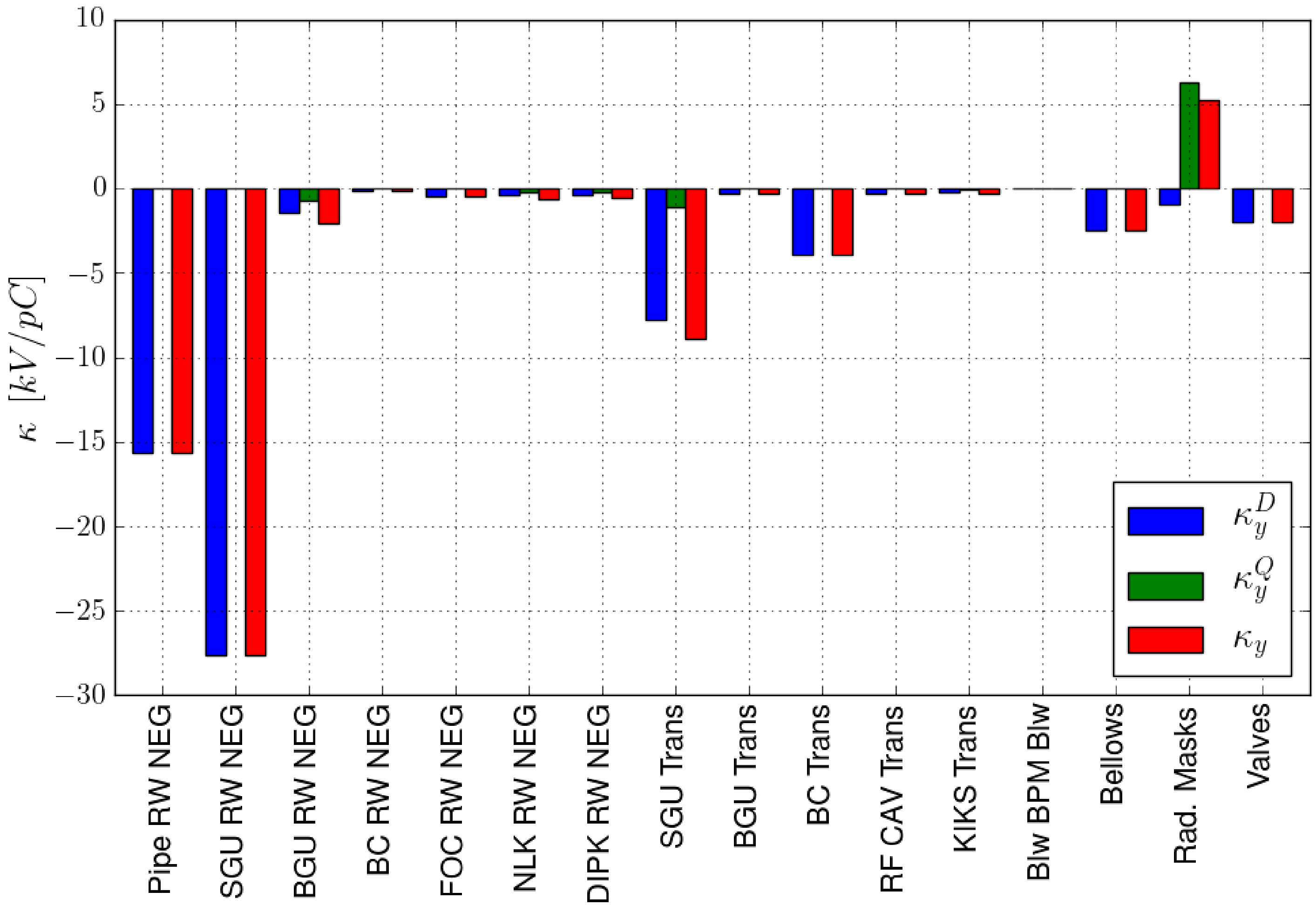

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	$\left[\frac{kV}{pC}\right]$
κ_y^D	-64.2
κ_y^Q	4.0
κ_y	-60.2

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Longitudinal Instabilities

- First We need to simulate the longitudinal plane to get the bunch length as function of current for the transverse plane simulations;
- Creation of a model for the longitudinal impedance: Five broad band resonators;

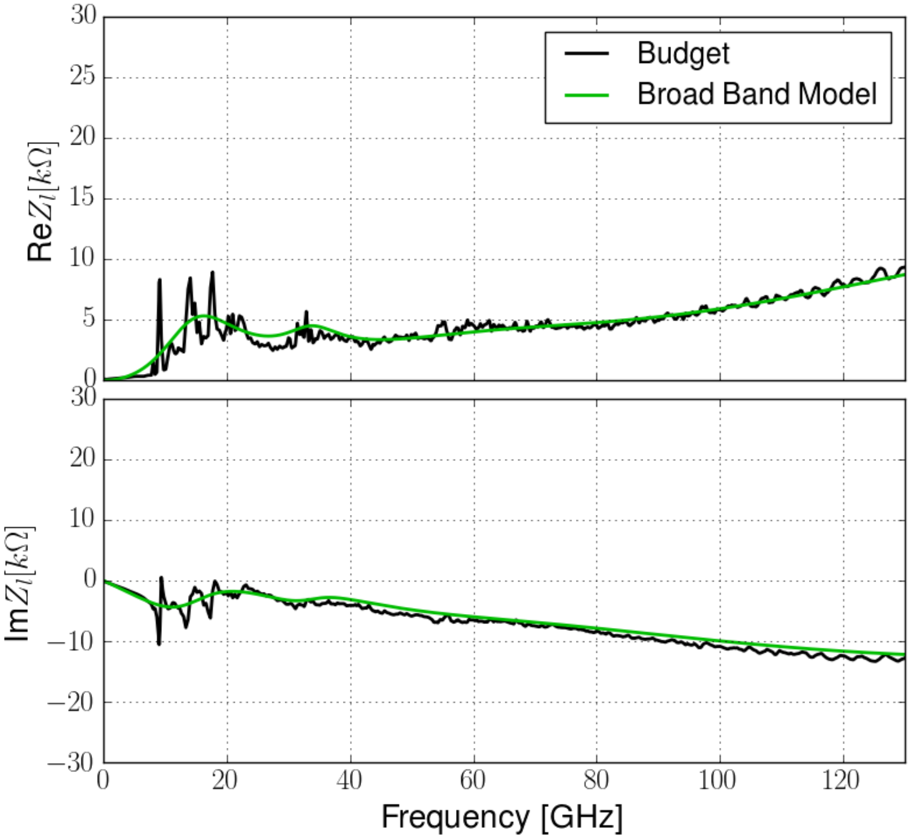


Figure: Longitudinal impedance of the Sirius budget for phase 2 of operation of the storage ring and the impedance of a broad band model with five resonators.

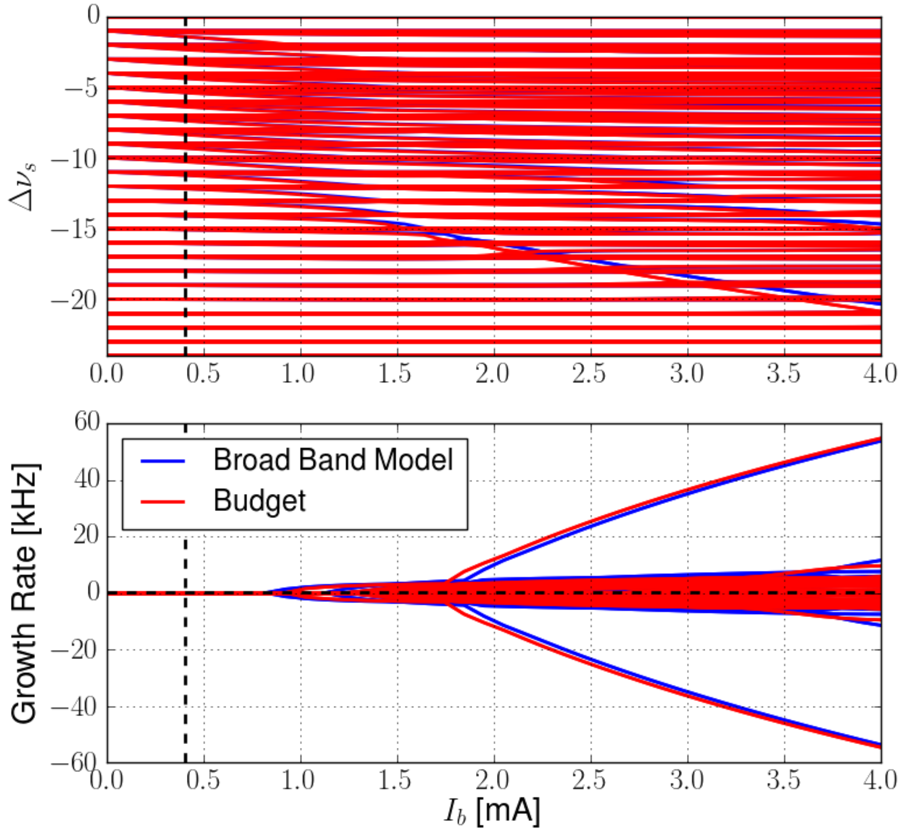


Figure: Longitudinal mode-coupling instability for a 3 mm bunch calculated with the longitudinal impedance of the Sirius budget for phase 2 of operation and the impedance of a broad band model with five resonators. Notice that the broad band model reproduces qualitatively and quantitatively the behavior of all modes.

Longitudinal Instabilities

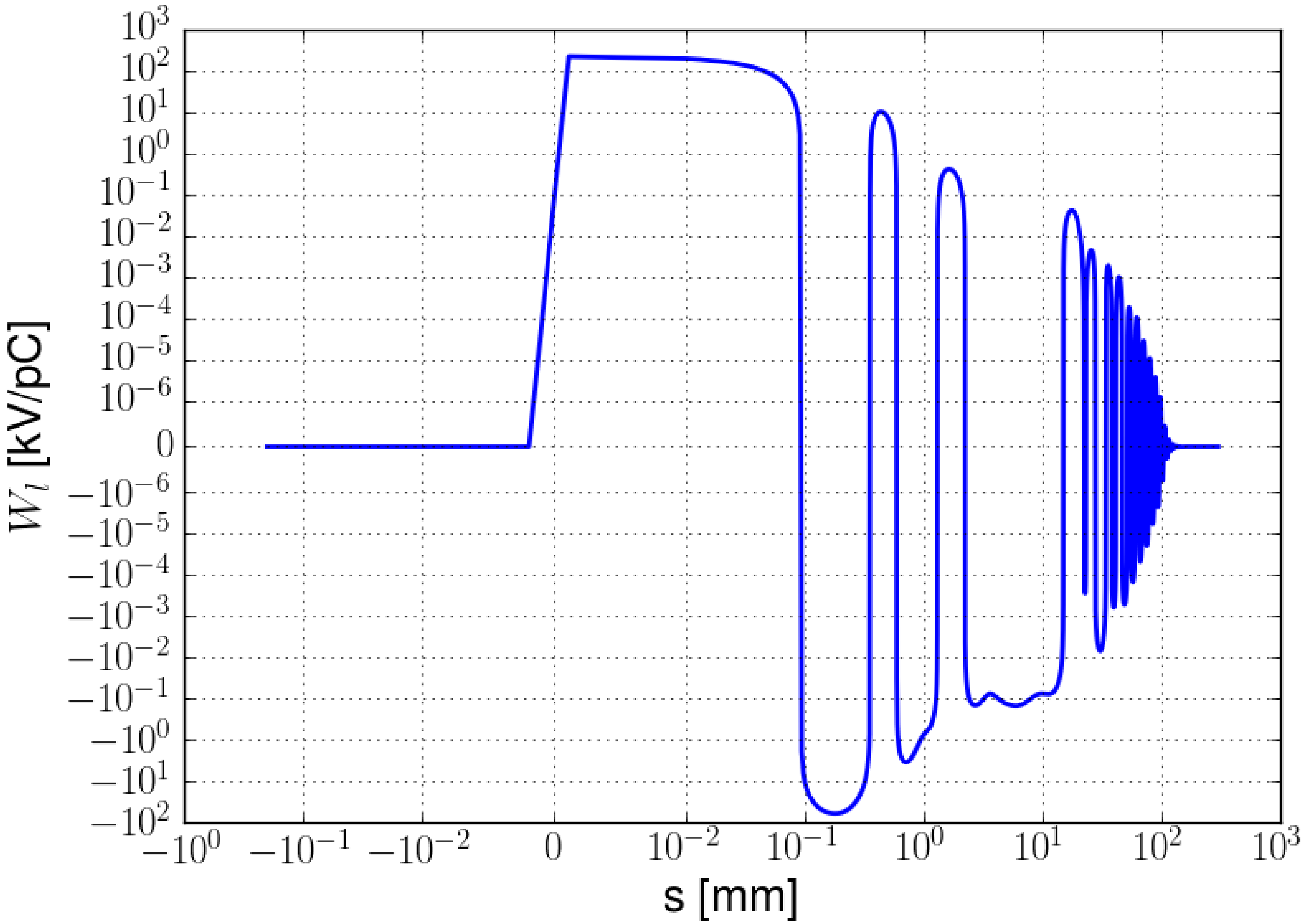


Figure: Longitudinal wake function of a broad band model for the Sirius impedance budget with five resonators.

Table: Parameters of the five resonators which compose the model.

f_r [GHz]	R_s [kΩ]	Q
650	54	1
170	7.5	1
64	2	1
16	5	1
34	2	3

Longitudinal Instabilities

P0

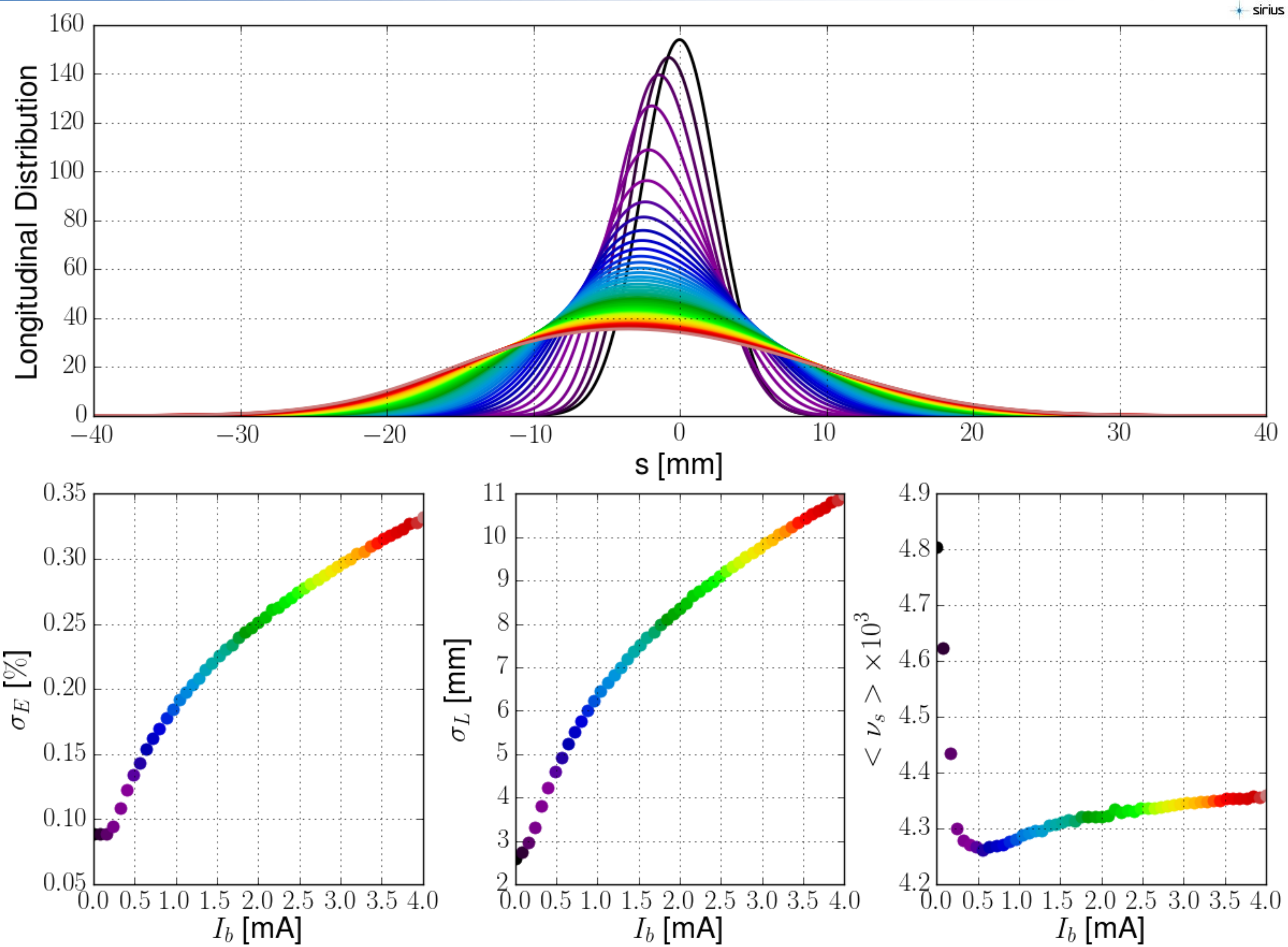


Figure: Longitudinal beam parameters considering the effect of the Sirius phase 0 wake-function model. The simulation was done with a Hassinski solver with relaxing energy spread, assuming the bunch will reach equilibrium.

Longitudinal Instabilities

P2

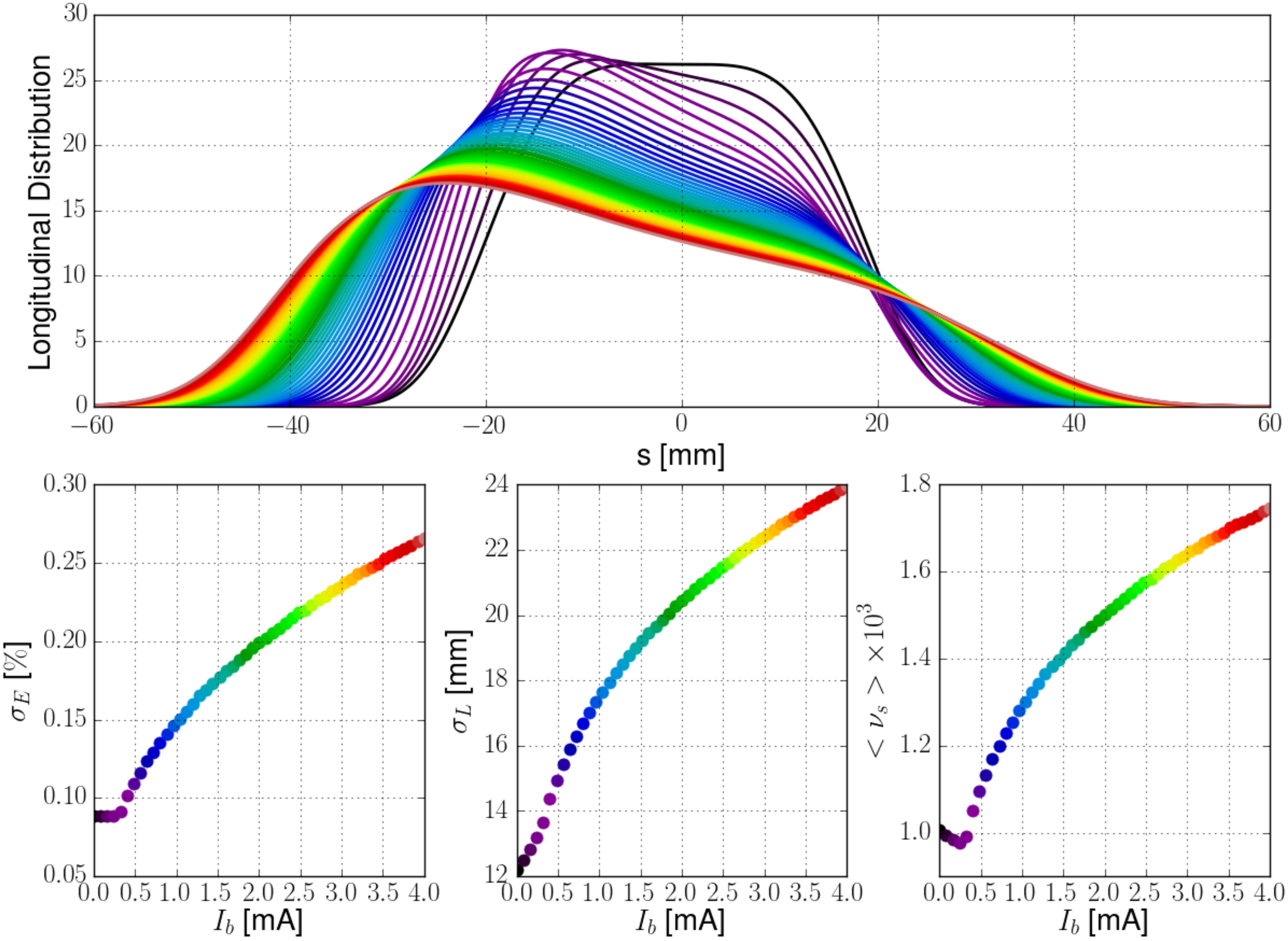


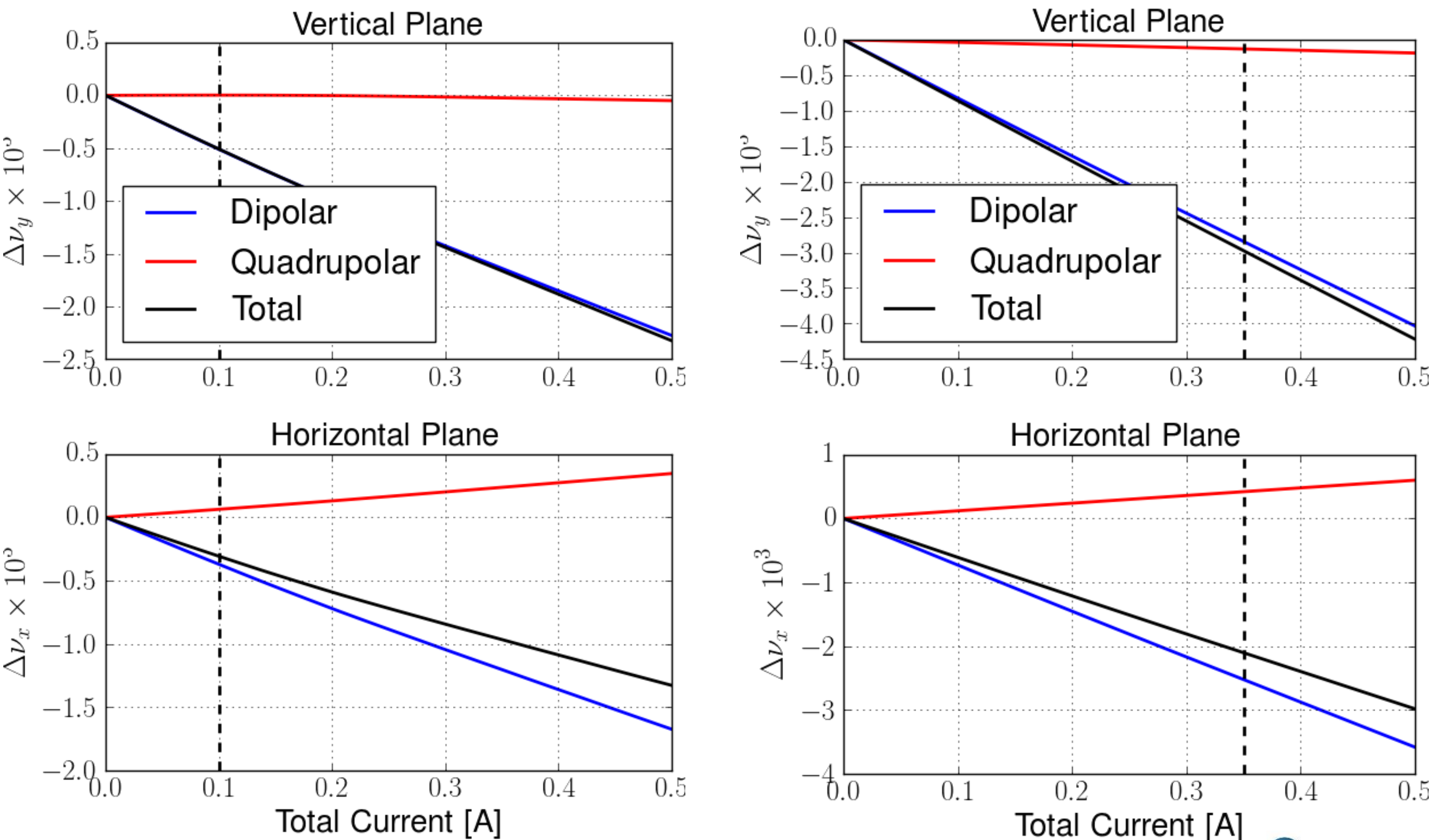
Figure: Longitudinal beam parameters considering the effect of the Sirius phase 0 wake-function model. The simulation was done with a Hassinski solver with relaxing energy spread, assuming the bunch will reach equilibrium. The initial distribution is obtainded from an artificial sum of the Equilibrium landau cavity potential for ideal operation with uniform filling with the RF voltage.

Summary

- Sirius main parameters
- Modelling of the components:
  - Standard Vacuum Chamber
  - BC Chamber
  - Undulators Chamber
  - Other Components
- Impedance Budget Summary
- Instabilities analysis:
  - Longitudinal Instabilities
  - Transverse Instabilities

Transverse Instabilities

P0 P2



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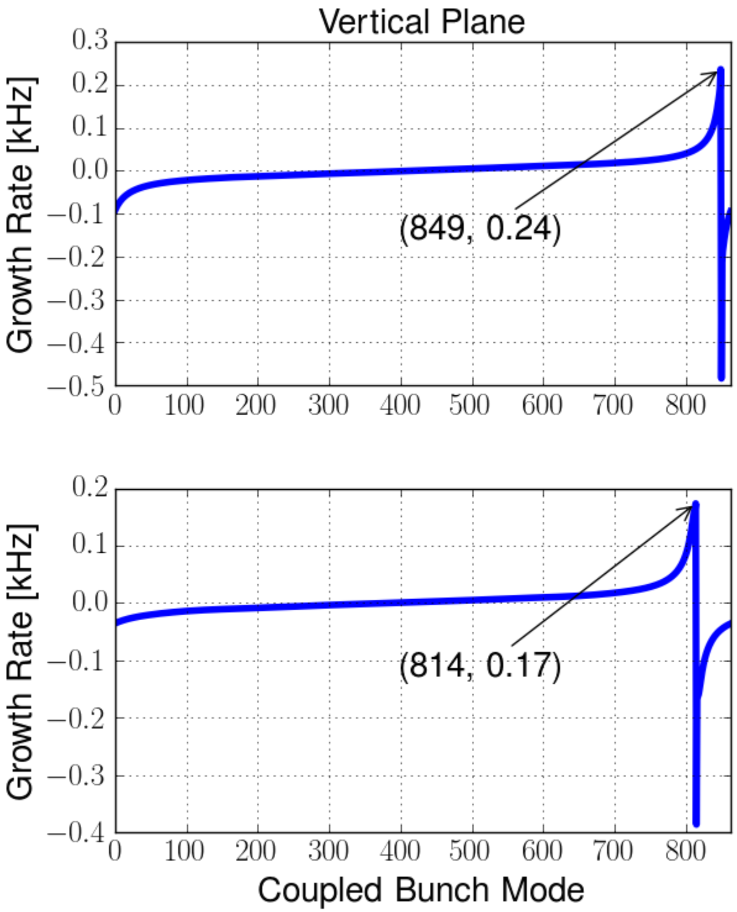
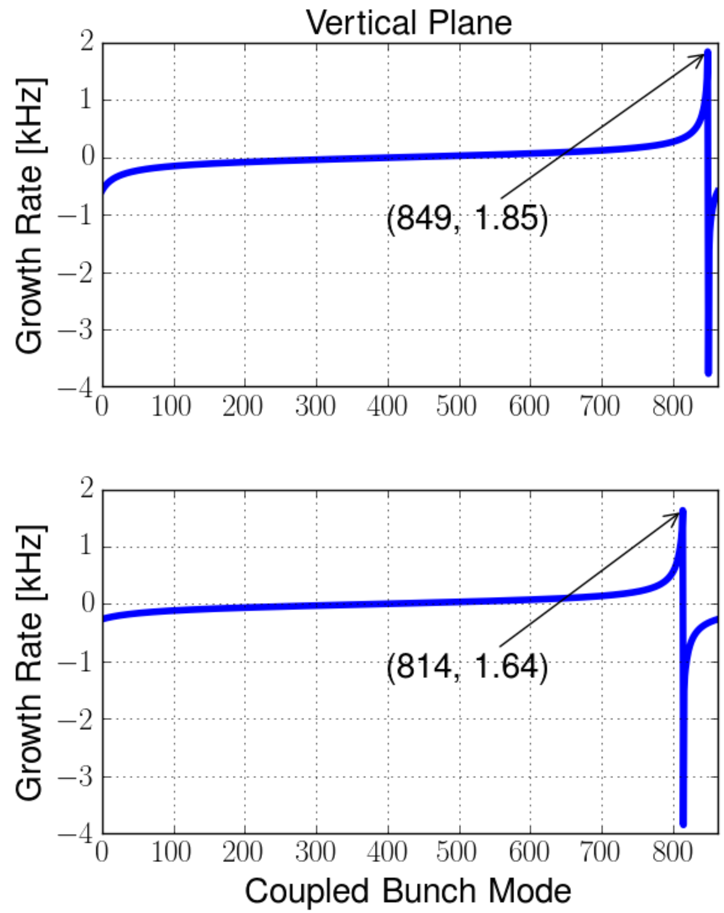
Transverse Instabilities



P0

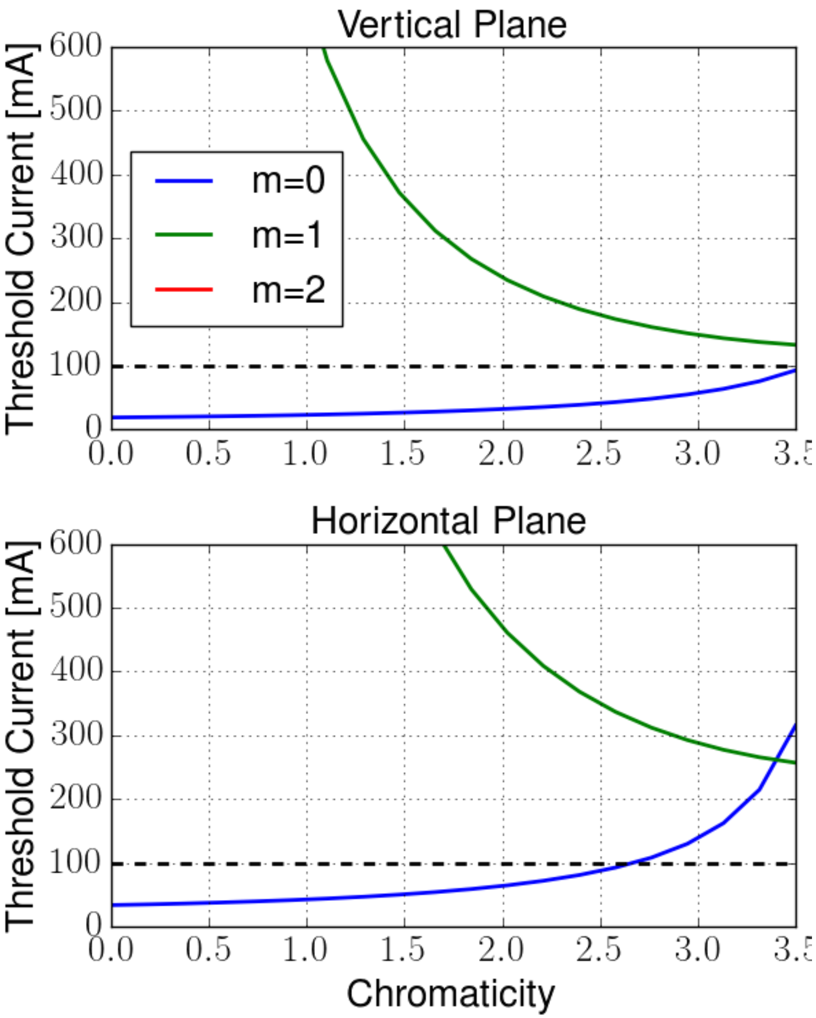


P2

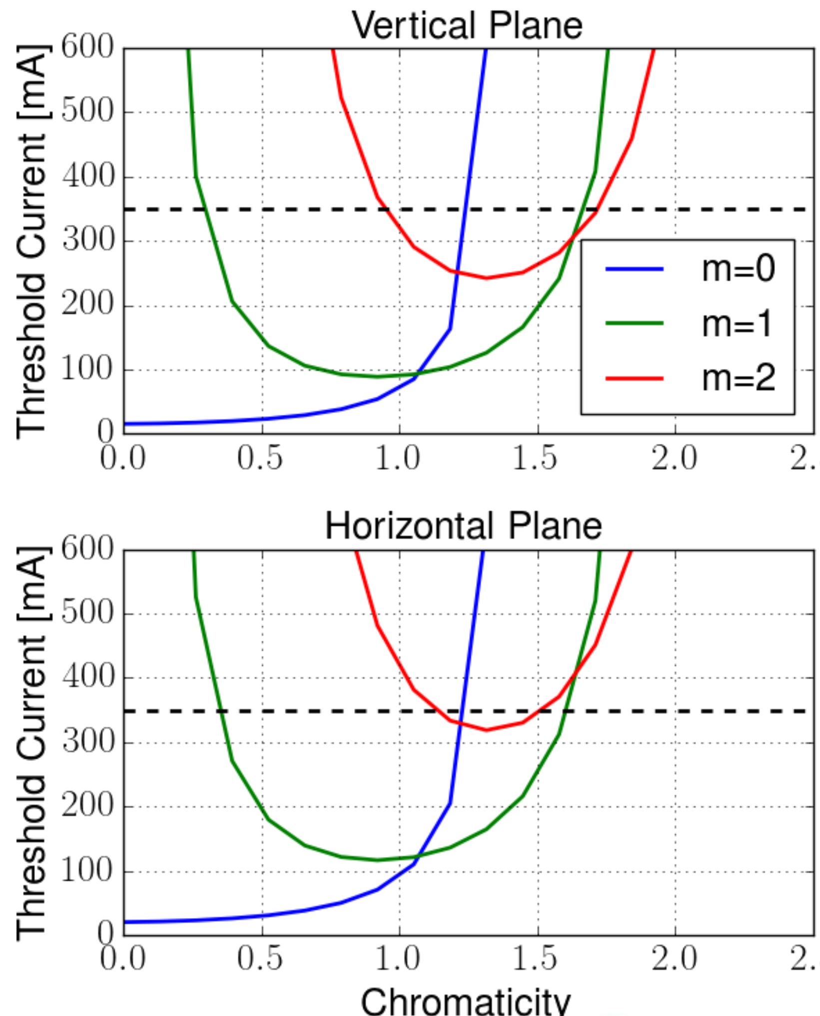
I_{th} [mA] @ $\xi = 0$	P0	P2
Horizontal	34	20
Vertical	19	15

Transverse Instabilities

P0

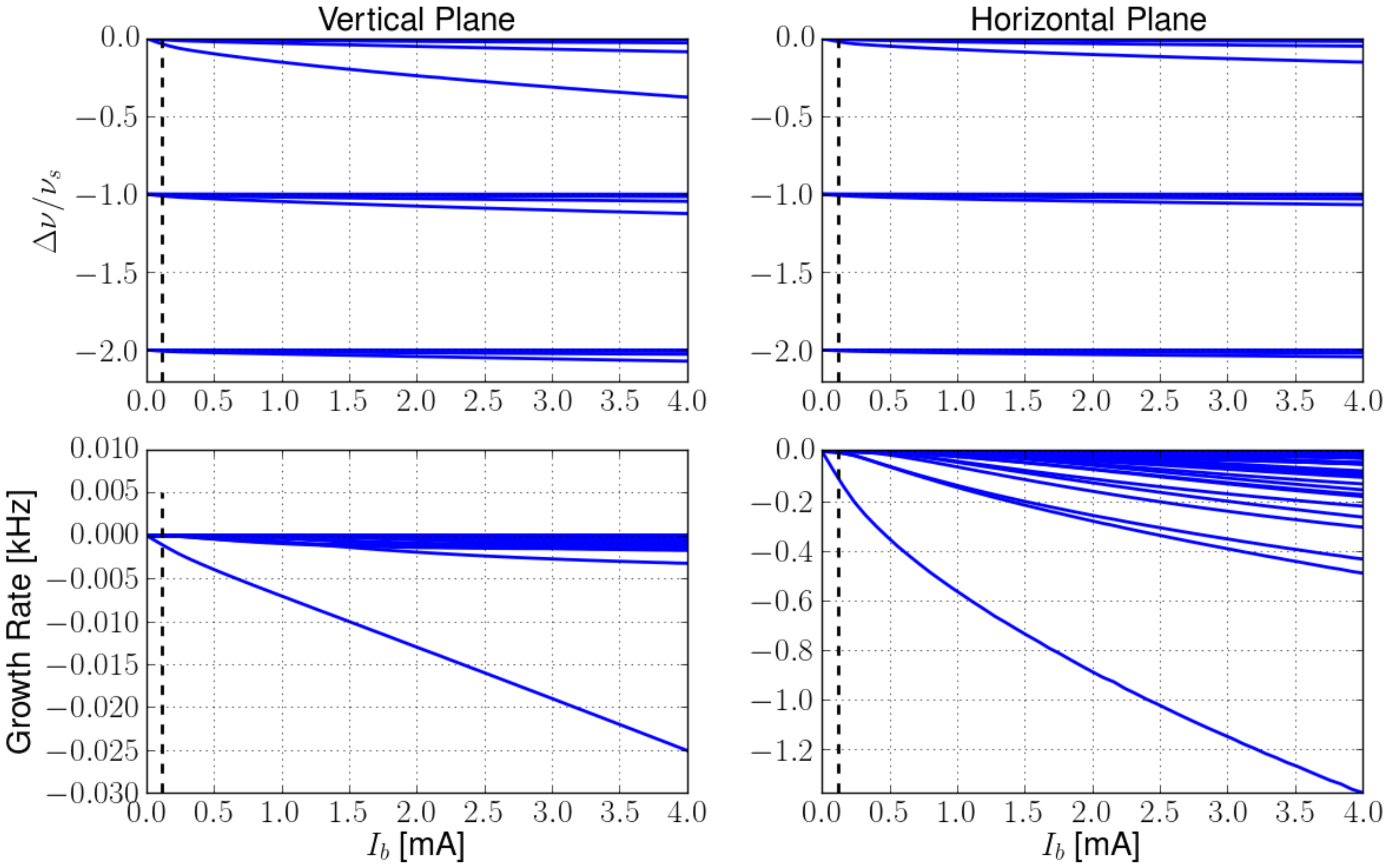


P2

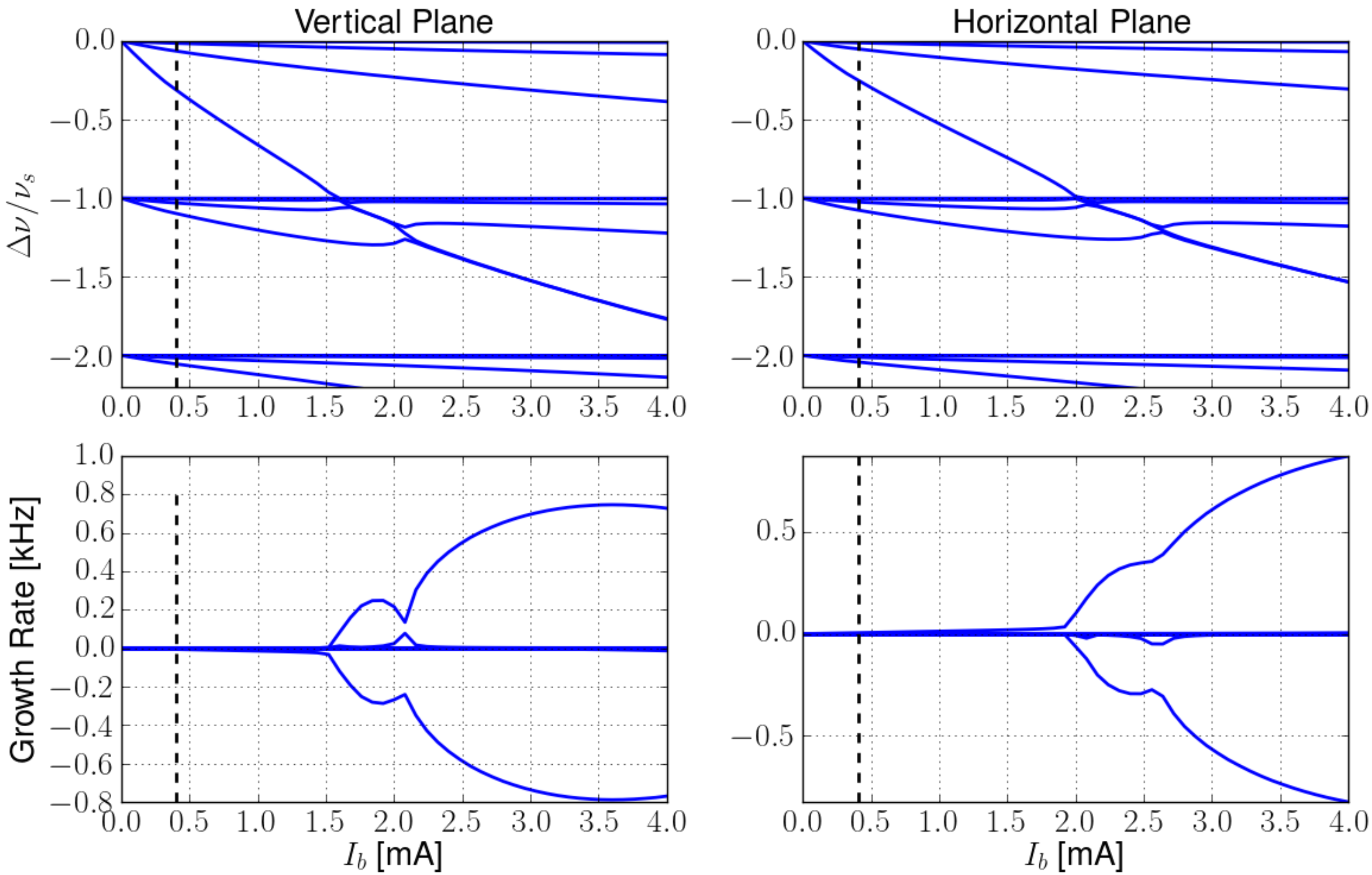


Transverse Instabilities

P0



P2


Vertical Plane
Horizontal Plane
$\Delta\nu/\nu_s$
Growth Rate [kHz]
I_b [mA]
I_b [mA]

Conclusions

- Our impedance budget is not complete yet, but a reasonable part of it was already determined or at least studied;

- The instabilities thresholds were estimated, but further calculations are necessary, mainly for the case with the landau cavity. A tracking code is being developed for this purpose.

Thank you for your attention!