Damping Rings

HeadTail simulations for the impedance in the CLIC-DRs

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Damping Rings

Outline

- DRs parameters
- Head tail simulations for impedance
- Results
- Conclusions
- Studies on the resistive wall from a chamber with coating
- Future steps

Updated list of parameters with the new lattice design at 3 TeV

Parameter	Symbol	Value
Energy	p_0 (GeV)	2.424
Norm. transv. emitt.	$\epsilon_{xn,yn}$ (nm)	381, 4.1
Bunch length	σ_z (mm)	1.53
Momentum spread	σ_δ	1.43 $\times 10^{-3}$
Bunch spacing	ΔT_b (ns)	0.5
Bunch population	N_b	4.1×10^9
Circumference	C (m)	365.2
Coupling	(%)	0.13
Mom. compact.	α	8×10^{-5}
Number of bunches	n_b	312
Tunes	$Q_{x,y,s}$ (m)	69.82, 33.80
Store time/train	T_{st} (ms)	20
Energy loss	ΔE (MeV/turn)	3.857
Damping times	$\tau_{x,y,z}$ (ms)	1.5, 1.5, 0.74
RF frequency	f_{rf} (GHz)	2
RF voltage	V_{rf} (MV)	4.115
Bend length	L_{bend} (m)	0.545
Bend chamber rad.	R_{bend} (cm)	2
Number of bends	N_{bend} (m)	96
Wiggler length	L_w (m)	2
Wiggler field	B_w (T)	2.5
Number of wigglers	N_w (m)	76
Wiggler radius	r_w (mm)	9

With combined function magnets

Parameter	Symbol	Value
Energy	p_0 (GeV)	2.86
Norm. transv. emitt.	$\epsilon_{xn,yn}$ (nm)	480, 4.7
Bunch length	σ_z (mm)	1.4
Momentum spread	σ_δ	1 $\times 10^{-3}$
Bunch spacing	ΔT_b (ns)	0.5
Bunch population	N_b	4.1×10^9
Circumference	C (m)	493.05
Coupling	(%)	0.1
Mom. compact.	α	6×10^{-5}
Number of bunches	n_b	312
Tunes	$Q_{x,y,s}$ (m)	58.2, 18.8
Store time/train	T_{st} (ms)	20
Energy loss	ΔE (MeV/turn)	5.9
Damping times	$\tau_{x,y,z}$ (ms)	1.6, 1.6, 0.8
RF frequency	f_{rf} (GHz)	2
RF voltage	V_{rf} (MV)	7.2
Bend length	L_{bend} (m)	0.4
Bend chamber rad.	R_{bend} (cm)	1
Number of bends	N_{bend} (m)	96
Wiggler length	L_w (m)	2
Wiggler field	B_w (T)	2.5
Number of wigglers	N_w (m)	76
Wiggler radius	r_w (mm)	9

$\Rightarrow$ Advantages: DA increased, magnet strength reduced to reasonable, reduced IBS

$\Rightarrow$ Relative to collective effects (main changes):

- Higher energy, larger horizontal emittance (good)
- Longer circumference (bad)

From Y. Papaphilippou, G. Rumolo, CLIC'09

New update of the lattice design at 3 TeV

Parameter	Symbol	Value
Energy	p_0 (GeV)	2.86
Norm. transv. emitt.	$\epsilon_{xn,yn}$ (nm)	480, 4.7
Bunch length	σ_z (mm)	1.4
Momentum spread	σ_δ	1×10^{-3}
Bunch spacing	ΔT_b (ns)	0.5
Bunch population	N_b	4.1×10^9
Circumference	C (m)	493.05
Coupling	(%)	0.1
Mom. compact.	α	6×10^{-5}
Number of bunches	n_b	312
Tunes	$Q_{x,y,s}$ (m)	58.2, 18.8
Store time/train	T_{st} (ms)	20
Energy loss	ΔE (MeV/turn)	5.9
Damping times	$\tau_{x,y,z}$ (ms)	1.6, 1.6, 0.8
RF frequency	f_{rf} (GHz)	2
RF voltage	V_{rf} (MV)	7.2
Bend length	L_{bend} (m)	0.4
Bend chamber rad.	R_{bend} (cm)	1
Number of bends	N_{bend} (m)	96
Wiggler length	L_w (m)	2
Wiggler field	B_w (T)	2.5
Number of wigglers	N_w (m)	76
Wiggler radius	r_w (mm)	9

1 GHz option

Parameter	Symbol	Value
Energy	p_0 (GeV)	2.86
Norm. transv. emitt.	$\epsilon_{xn,yn}$ (nm)	480, 4.5
Bunch length	σ_z (mm)	1.6
Momentum spread	σ_δ	1.3×10^{-3}
Bunch spacing	ΔT_b (ns)	1
Bunch population	N_b	4.1×10^9
Circumference	C (m)	420.56
Coupling	(%)	0.1
Mom. compact.	α	7.6×10^{-5}
Number of bunches per train	n_b	156
Number of trains	n_t	2
Distance between trains	τ_t (ns)	545
Tunes	$Q_{x,y,s}$	55.4, 11.6, 0.00387
Store time/train	T_{st} (ms)	20
Energy loss	ΔE (MeV/turn)	4.2
Damping times	$\tau_{x,y,z}$ (ms)	1.88, 1.91, 0.96
RF frequency	f_{rf} (GHz)	1
RF voltage	V_{rf} (MV)	4.9
Harmonic number	h	1402
Dipole length	L_{dip} (m)	0.43
Dipole chamber rad.	R_{dip} (cm)	1
Number of dipoles	N_{dip} (m)	102
Wiggler length	L_w (m)	2
Wiggler field	B_w (T)	2.5
Number of wigglers	N_w (m)	52
Wiggler gap	r_w (mm)	13
Wiggler width	h_w (mm)	65
Average β_x in wigglers	$\langle\beta_{xw}\rangle$ (m)	4.787
Average β_y in wigglers	$\langle\beta_{yw}\rangle$ (m)	4.185

$\Rightarrow$ Lattice has been redesigned to reduce the space charge effect (ring circumference shortened). However, higher order cavities will also help in this sense (simulations foreseen)

$\Rightarrow$ The 1 GHz option has been considered because:

- it is better for the RF design (less impedance)
- it could relieve constraints due to e-cloud, ions, coupled-bunch instabilities, ...

From Y. Papaphilippou

Damping Rings

HeadTail simulations for impedance

- Use of HeadTail code
- Simulates single bunch phenomena
- Broadband impedance model
- Tuneshift in horizontal and vertical plane
- Transverse shunt Impedance range: 0-20 MOhm/m
- 0 and different positive values in chromaticity
- Round and flat geometry

Damping Rings

CLIC-DR parameters used in the simulations

Tunes Qx/Qy/Qs	55.4/11.6/0.00387
Ring circumference (m)	420.56
Number of turns	20000
Energy (GeV)	2.86
N_b	4.1×10^9
Geometry	round/flat
<βx> (m) wigglers	4.787
<βy> (m) wigglers	4.185

1 GHz
or 2GHz

Damping Rings

- **Transverse**

In a round chamber the TMCI threshold is given (chromaticity 0, coupling mode 0 and -1 assumed) :

$$\xi < \frac{Q_s}{\omega_r \sigma_t} \quad \text{if} \quad \omega_r \sigma_t \leq 1$$ → short bunch

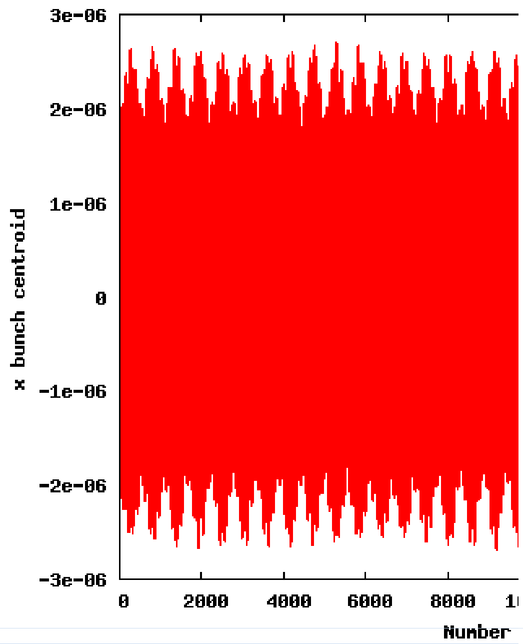
$$\xi < \sqrt{2} Q Q_s (\omega_r \sigma_t)^2 \quad \text{if} \quad \omega_r \sigma_t \gg 1$$ → long bunch

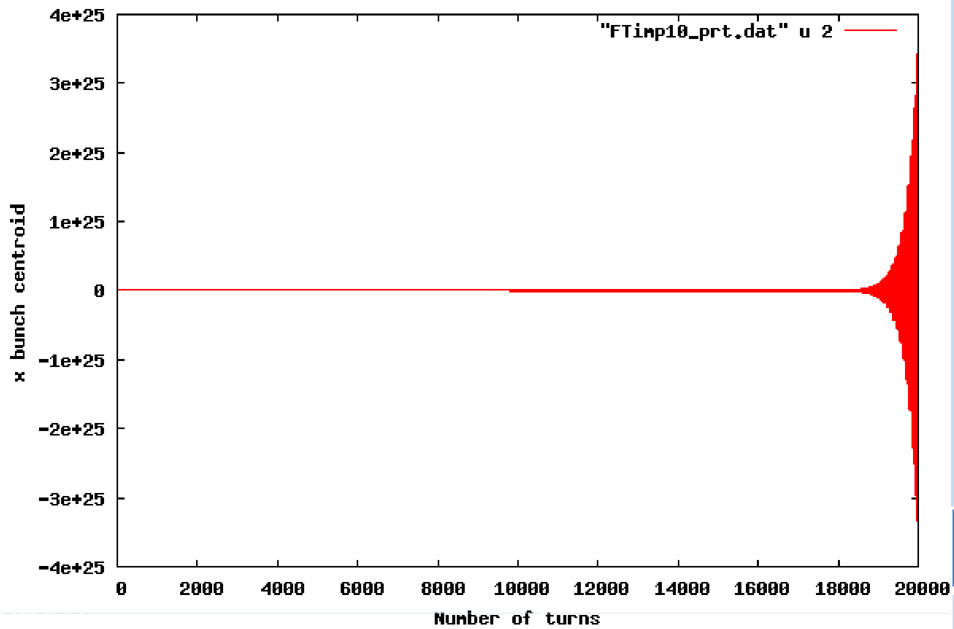
where

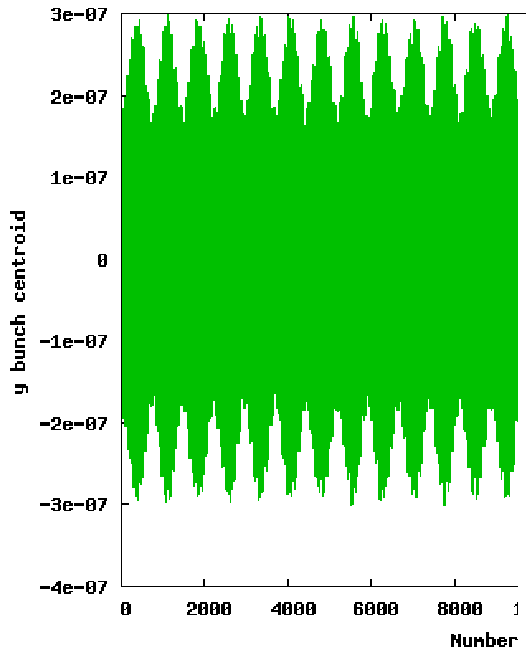
$$\xi = \frac{\omega_r / 2\pi < \beta_y > R_T N_b \mathrm{e}}{3.75\, QE/\mathrm{e}}$$

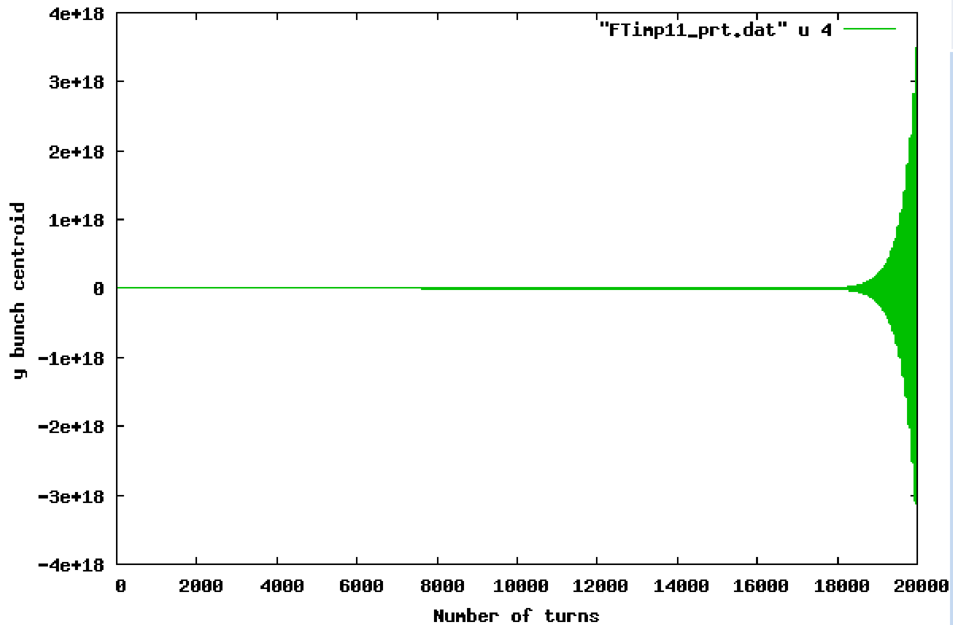
CLIC-DRs: impedance value of ≈12 MOhm/m if $\omega_r = 2\pi \times 7$ GHz

Horizontal and vertical motion in a round chamber









- Centroid evolution in x and y over the number of turns, for different values in impedance

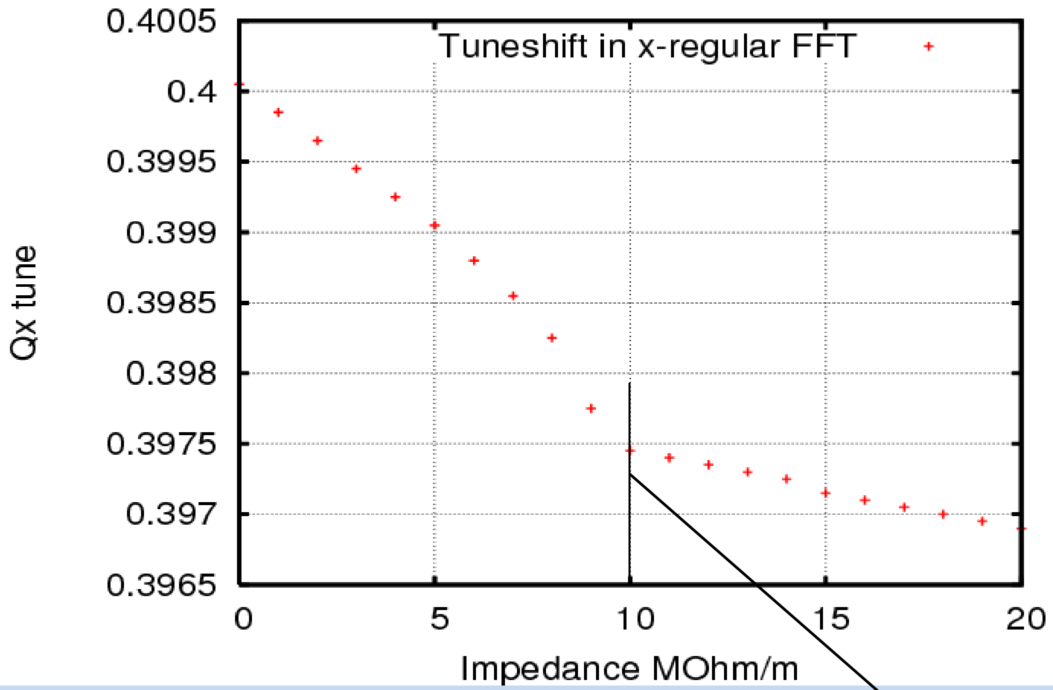
	0
vert. chrom. Q y	0
	Round

- As the impedance increases an instability occurs

Horizontal plane

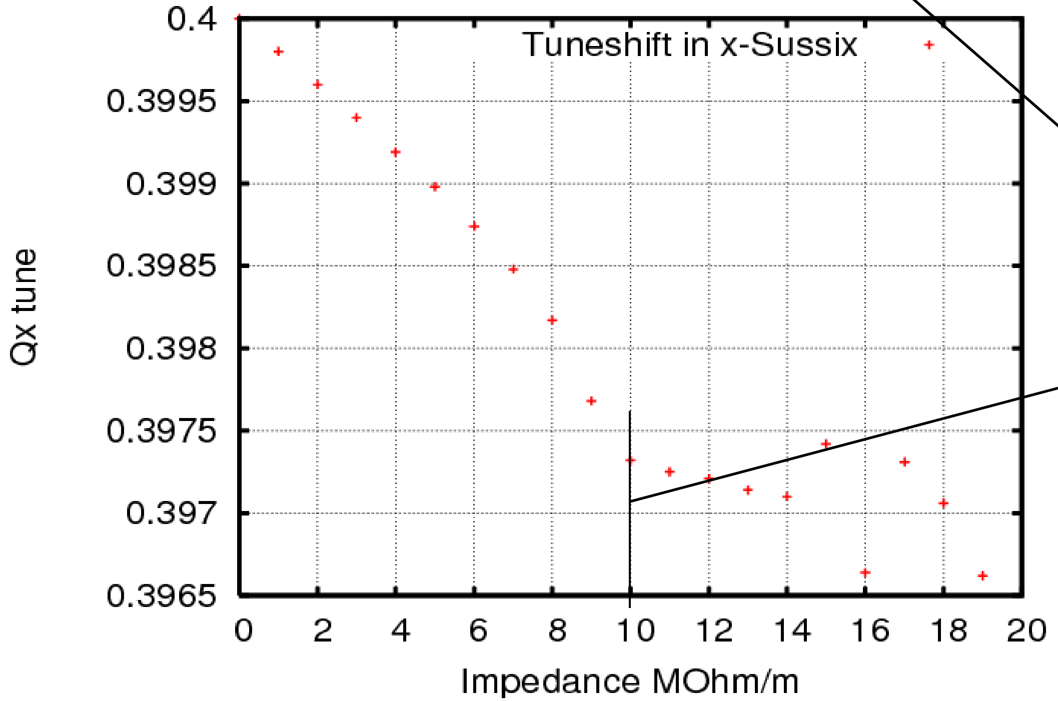
- To observe a TMCI, the betatron frequency is measured , i.e. the frequency of the mode 0

- Classical and Sussix algorithms used for Fourier analysis of the coherent horizontal motion



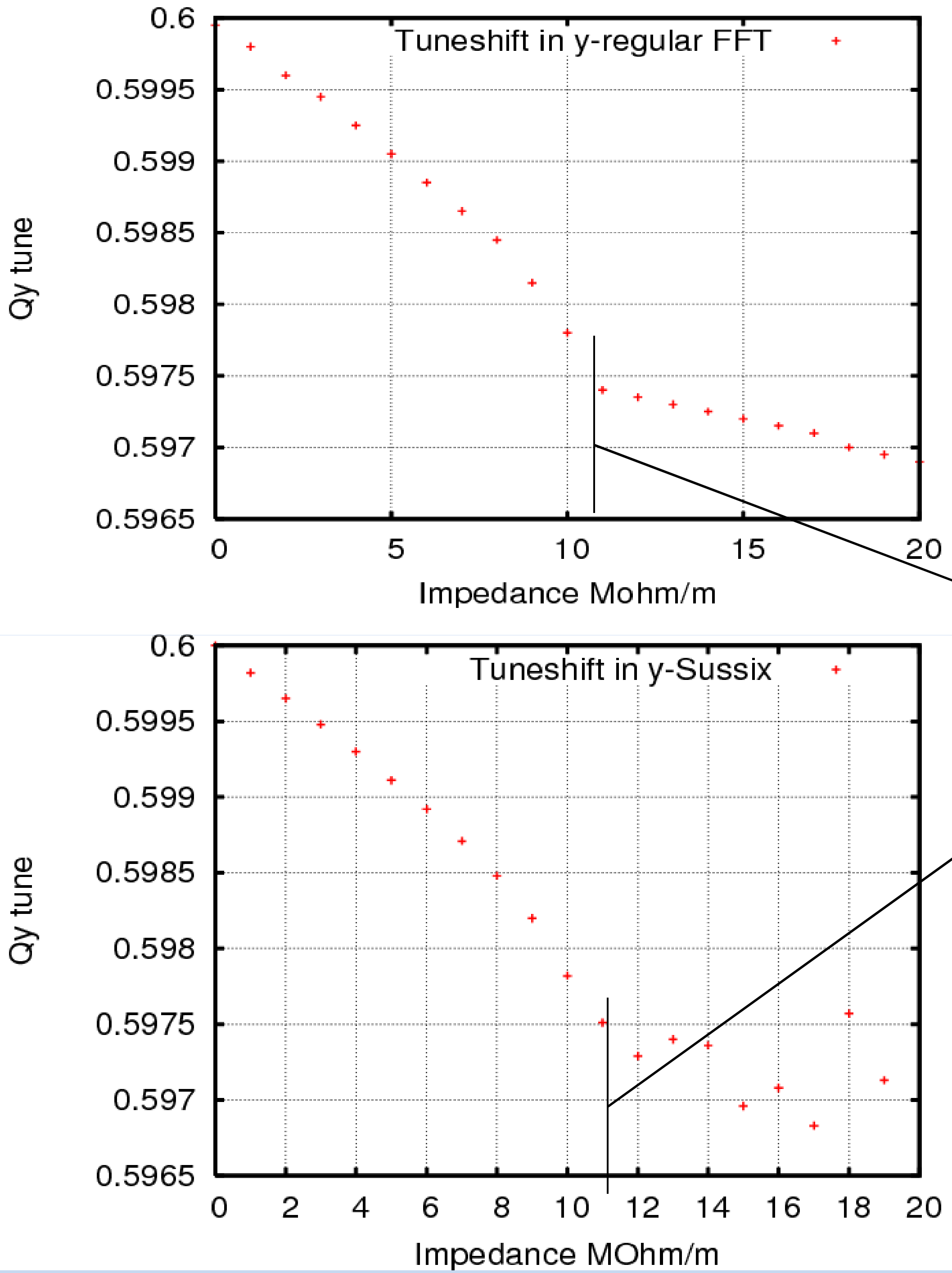
Regular FFT

•Instability threshold (TMCI) 10 MOhm/m



Sussix FFT

Vertical plane

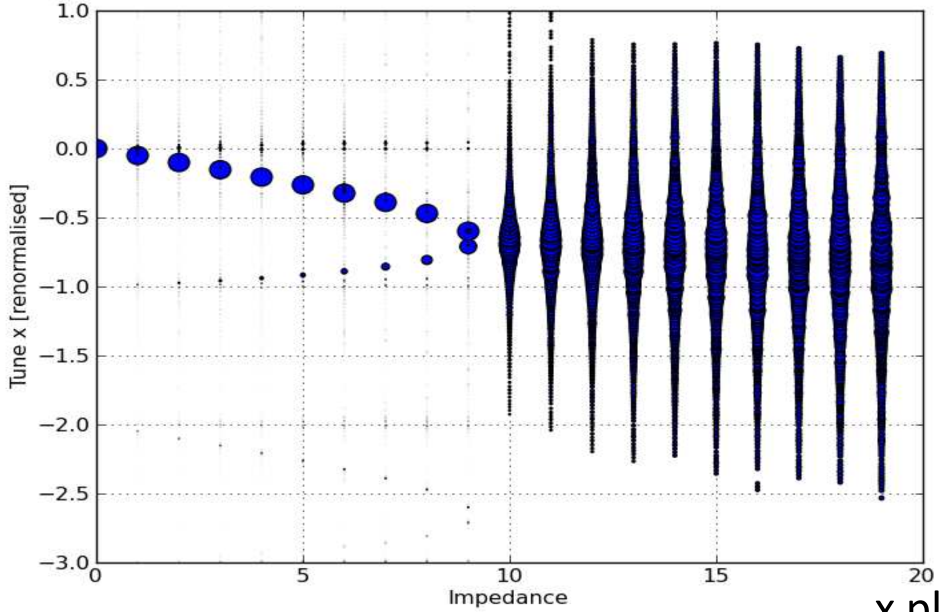


- Classical and Sussix algorithms used for Fourier analysis of the coherent vertical motion

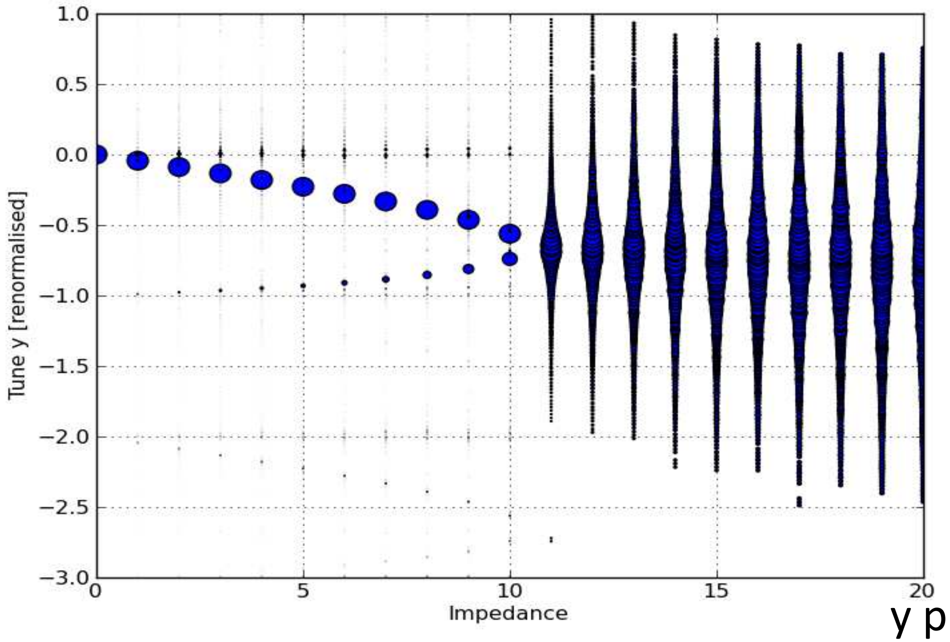
Regular FFT

- **Instability threshold (TMCI) 11 MOhm/m**

Sussix FFT



x plane



y plane

Mode spectrum of the horizontal and vertical coherent motion as a function of impedance

- Plot all the tunes (Q-Qx)/Qs and (Q-Qy)/Qs with impedance, from the Sussix results
- Mode spectrum represents the natural coherent oscillation modes of the bunch
- The movement of the modes due to impedance can cause them to merge and lead to an instability

❑The mode 0 is observed to couple with mode -1 in both planes
❑Causing a TMCI instability

Damping Rings

$$\gamma_{tr} = \frac{1}{\sqrt{a_c}} = \frac{1}{\sqrt{7.6x10^{-5}}} = 115$$

$$\gamma_{rel} = 5597$$

$$\gamma_{rel} >> \gamma_{tr}$$

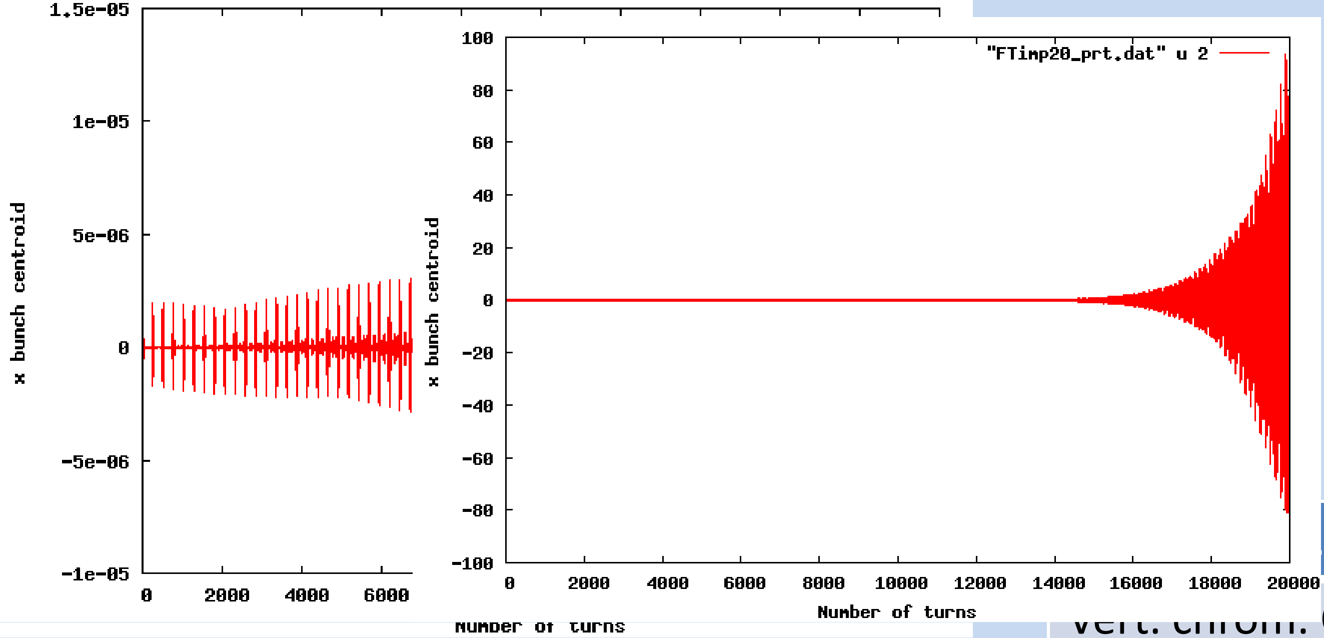
↓

Above transition

positive chromaticity ↓

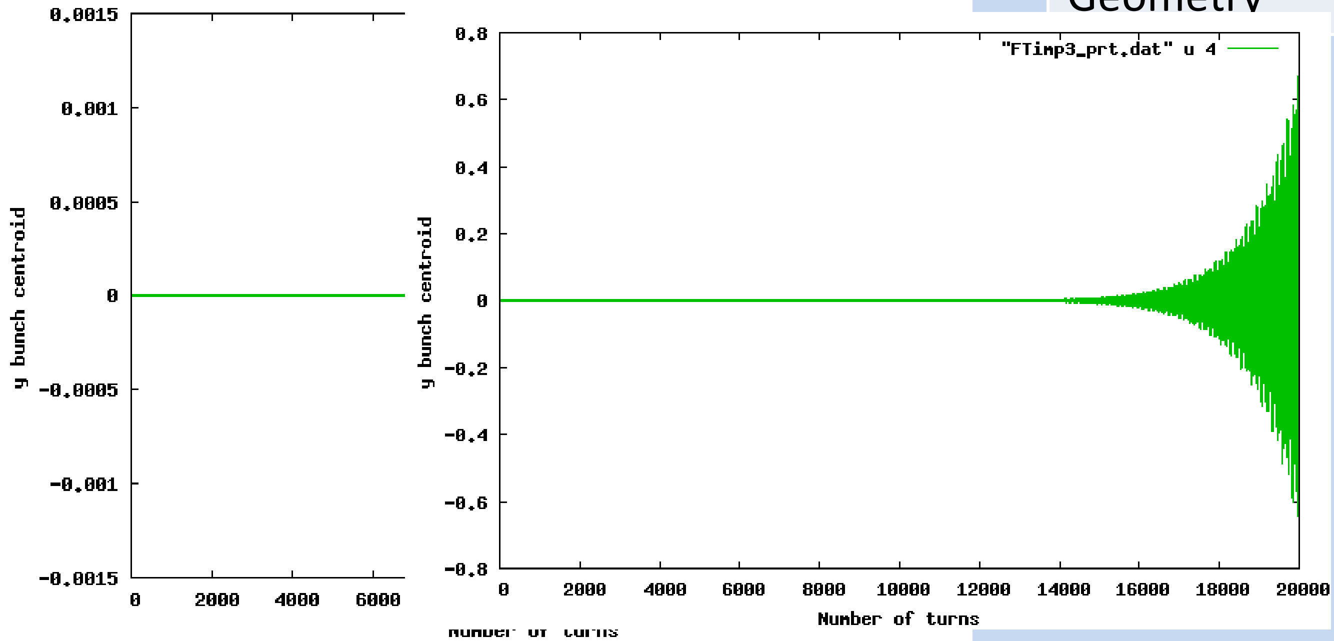
damping

Horizontal and vertical motion in a round chamber

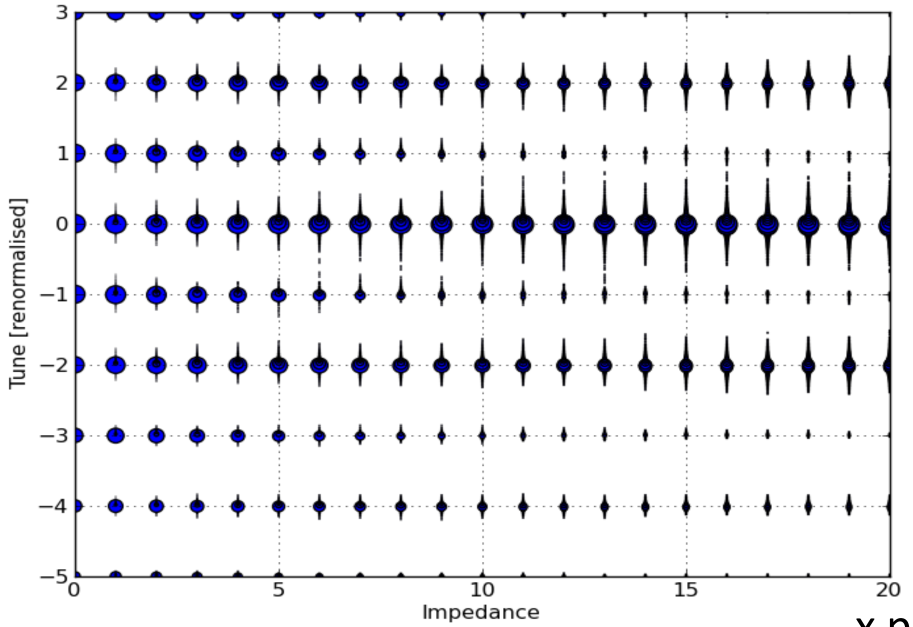


Instability
growth

Q’x	9.2
Vert. chrom. Q’y	1.9
Geometry	Round

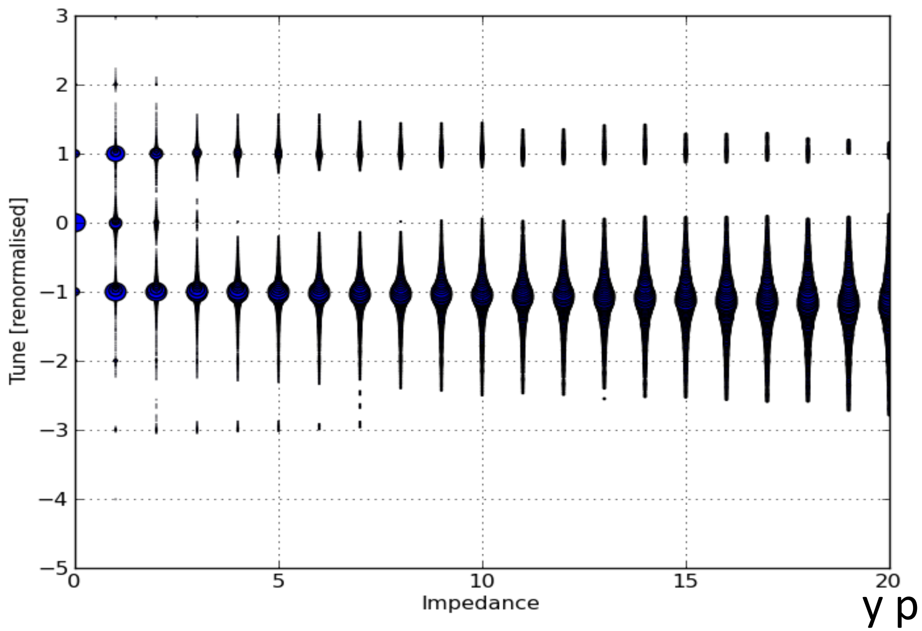


Mode spectrum of the horizontal and vertical coherent motion as a function of impedance



x plane

•no mode coupling observed, no TMCI



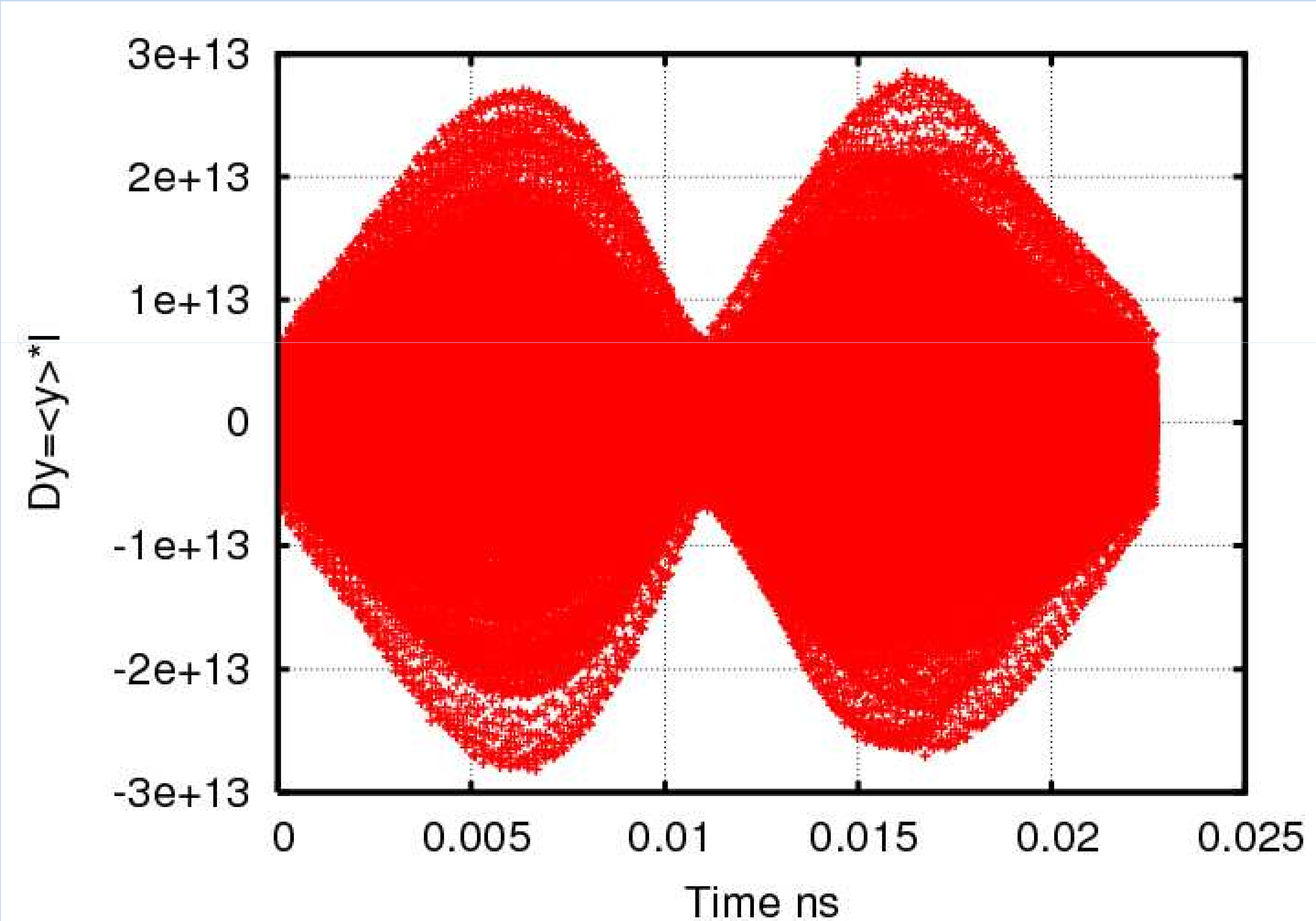
y plane

•no mode coupling
•mode 1 is damped
•mode -1 gets unstable

➢Presence of chromaticity makes the modes move less, good for coupling
➢Another type of instability

Damping Rings

Looking at hdtl.dat file (information along the bunch)

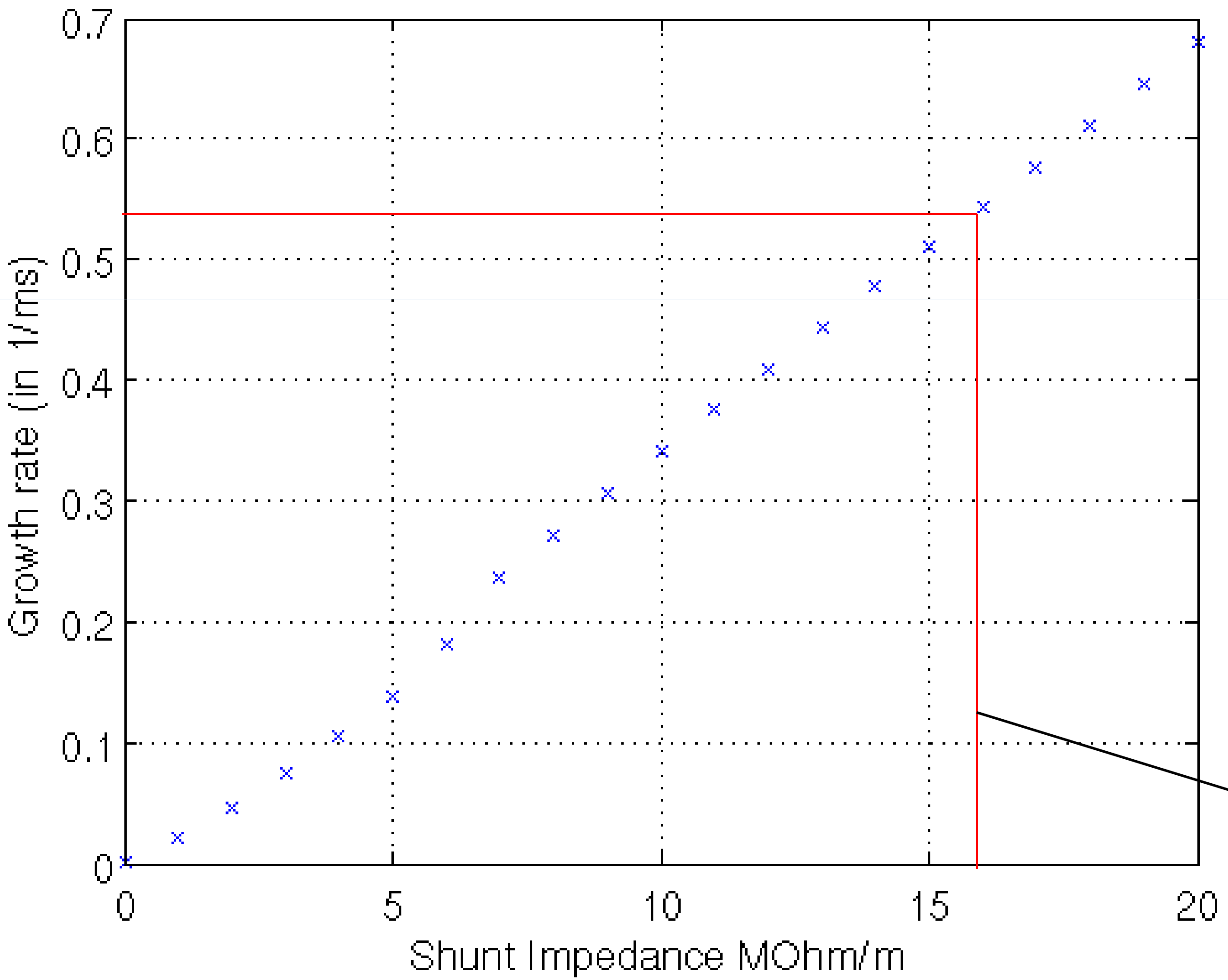


bunch length

- y plane
- mode -1

Damping Rings

Growth rate – x plane

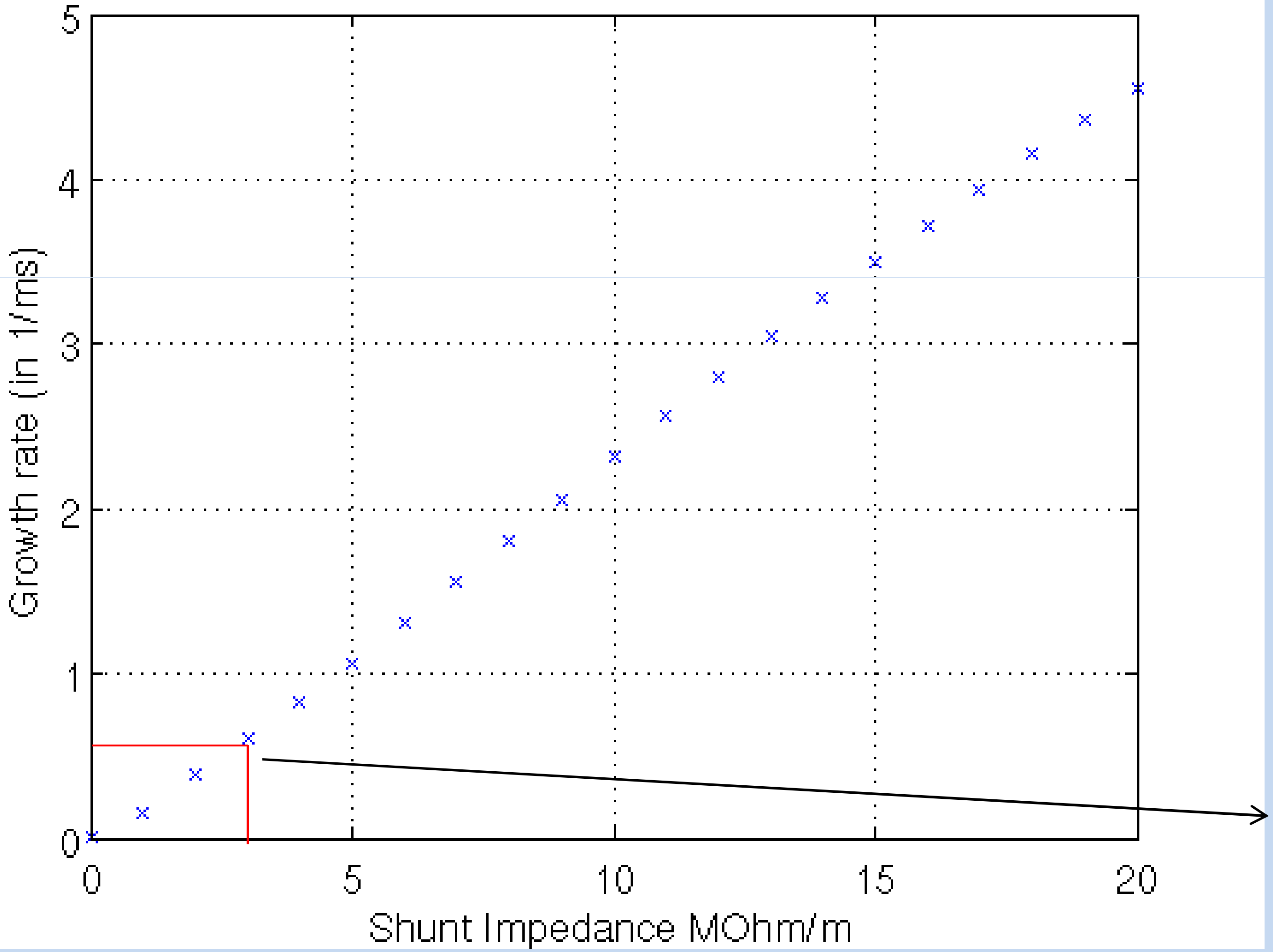


- Damping time τx=1.88ms
- >~16MOhm/m rise time < τx unstable

Threshold ~16MOhm/m

Damping Rings

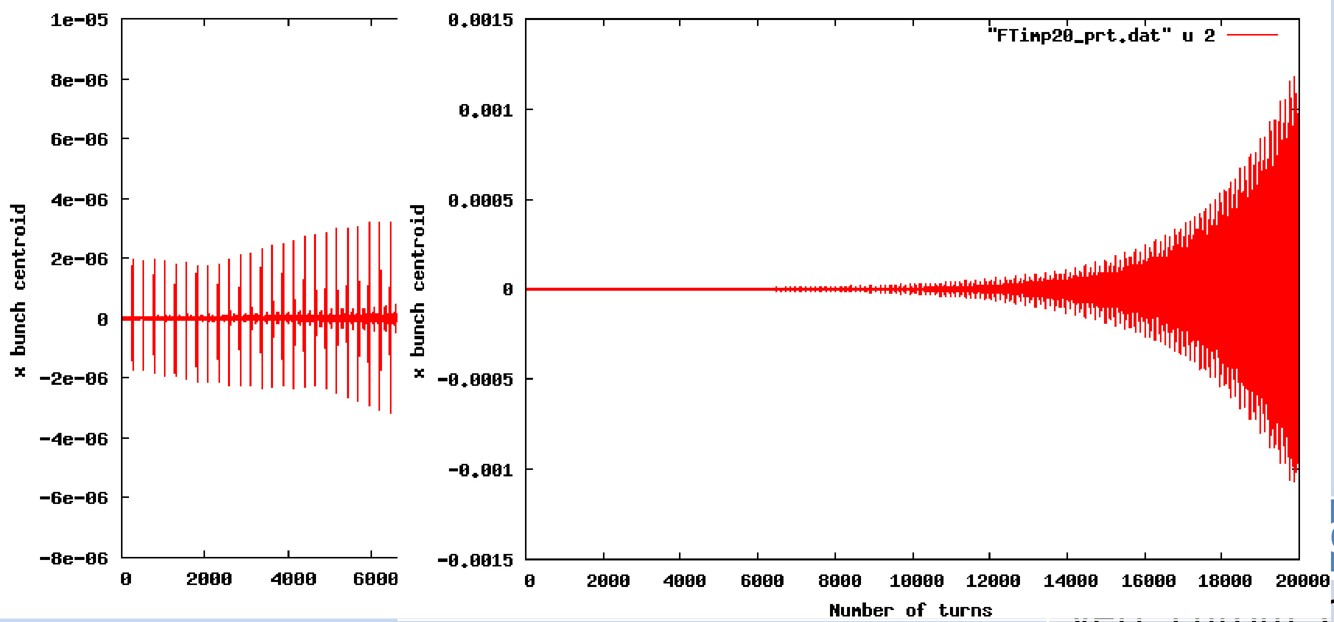
Growth rate – y plane



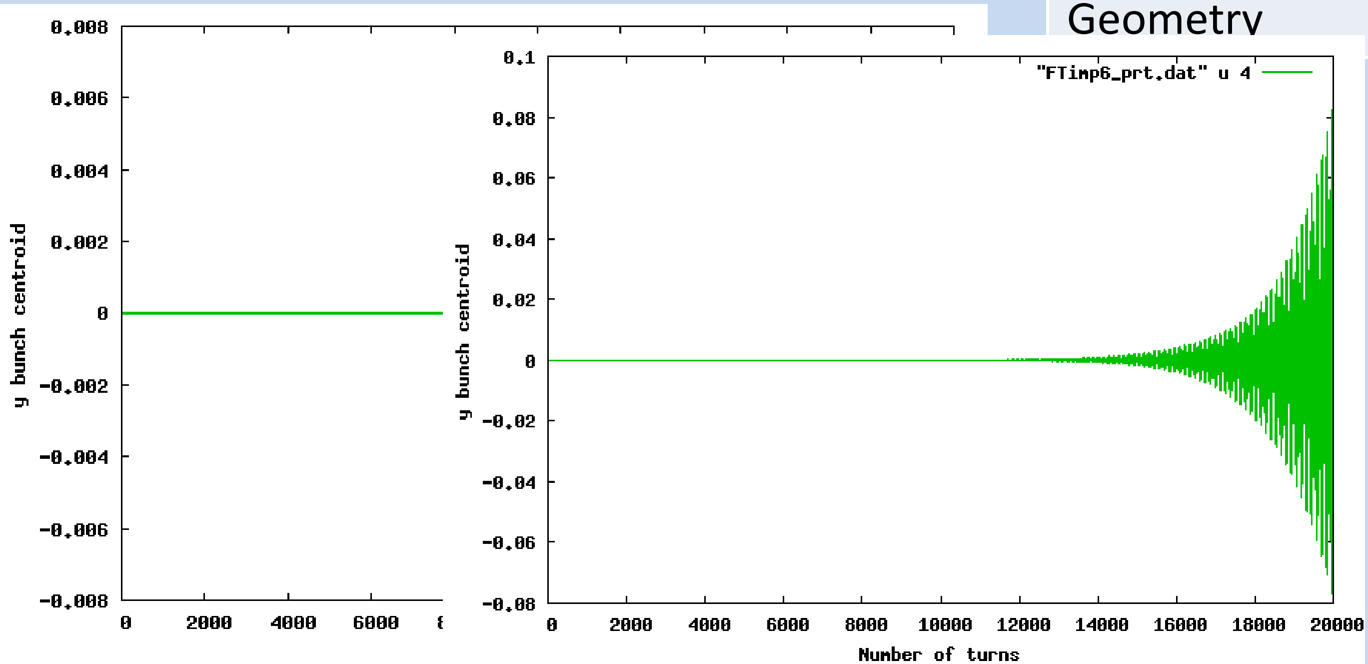
- Damping time τy=1.91ms
- For impedances above ~3MOhm/m, rise time < τy
- mode -1 is dangerous leading to instablity

Threshold ~3MOhm/m

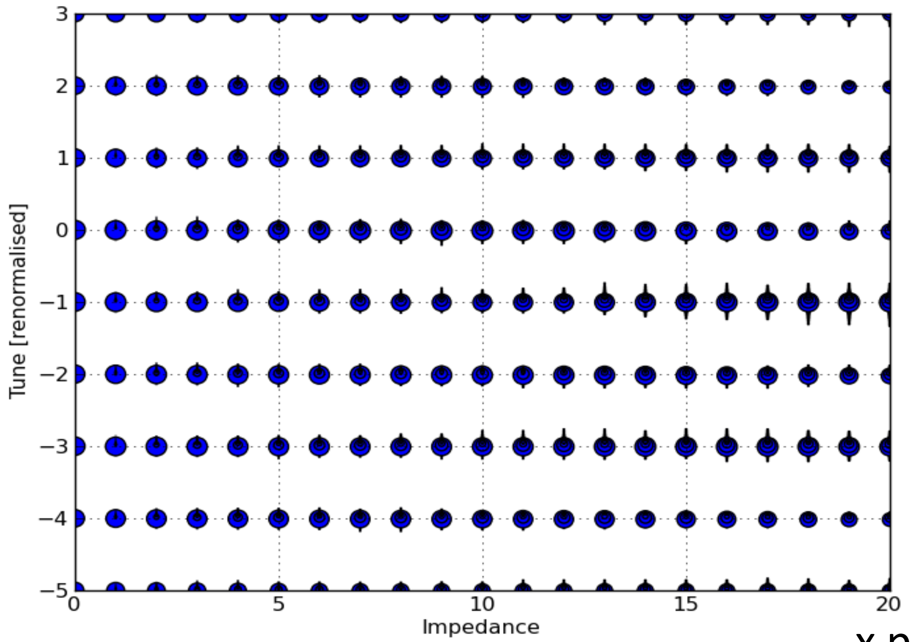
Horizontal and vertical motion in a round chamber



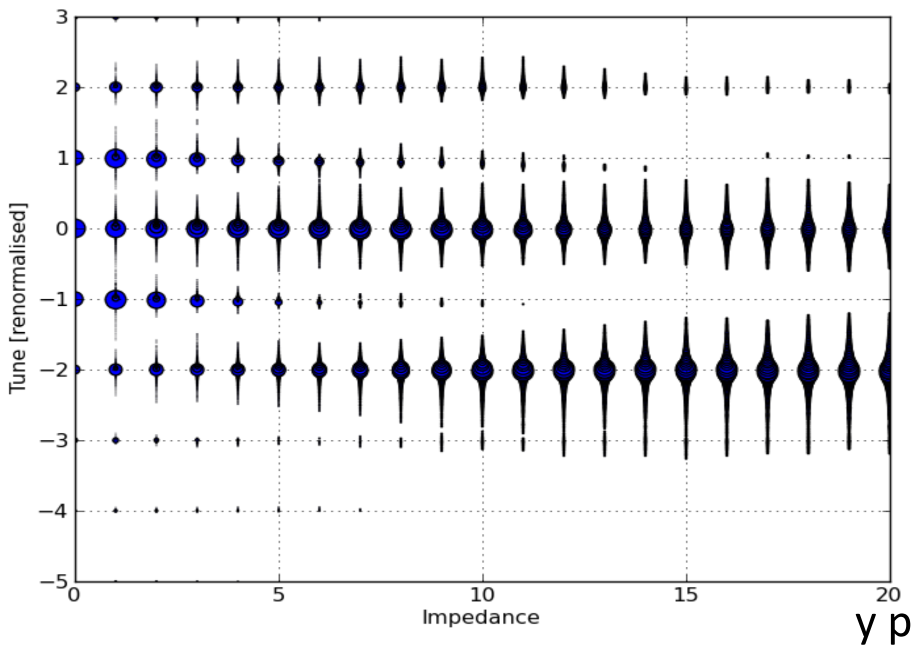
Q’x	18.4
Vert. chrom. Q’y	3.8
Geometry	Round



Mode spectrum of the horizontal and vertical coherent motion as a function of impedance



x plane



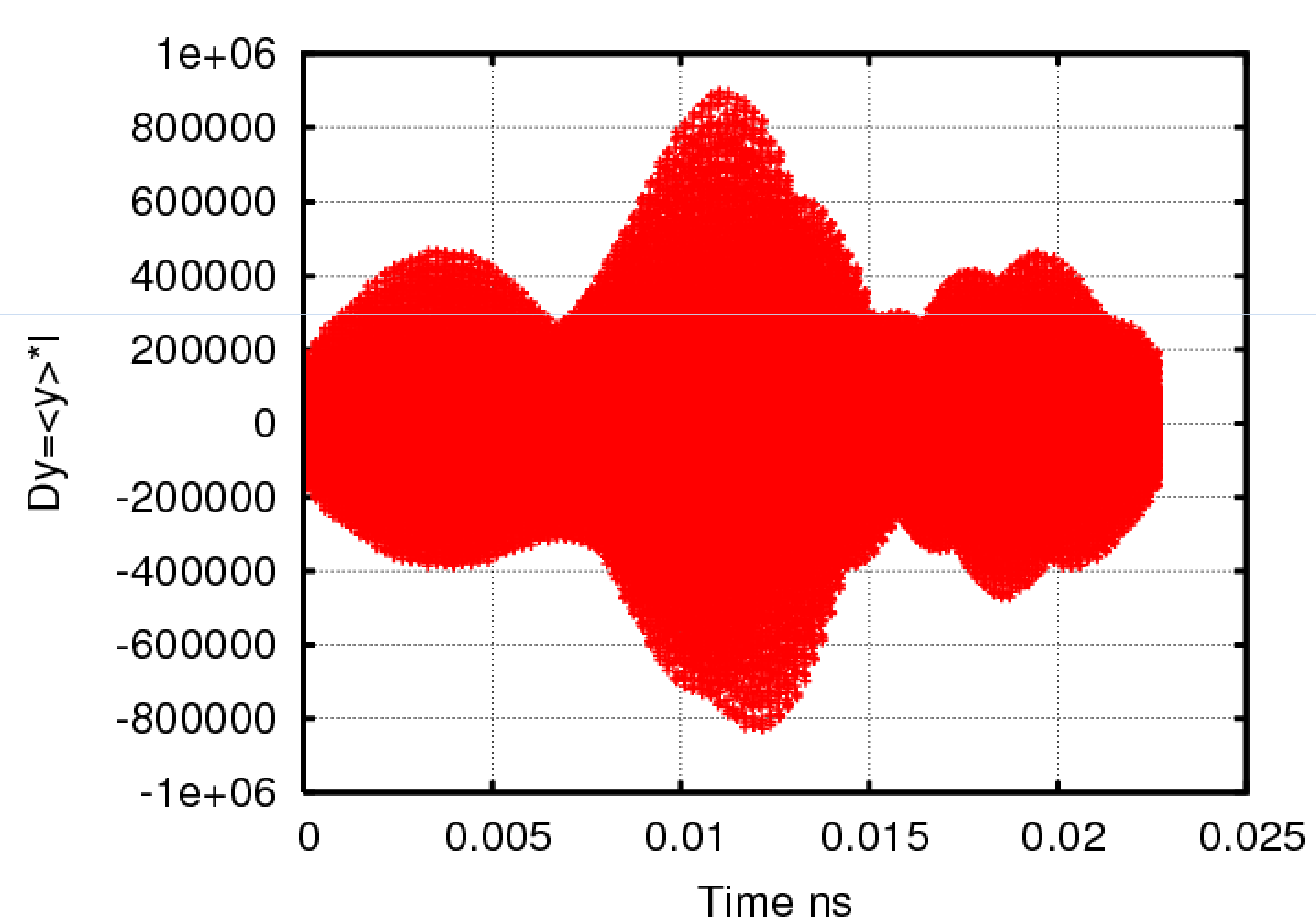
y plane

- no mode coupling (TMCI)

- As the chromaticity is increased , the main unstable mode changes
- mode -2 gets unstable in the y plane

Damping Rings

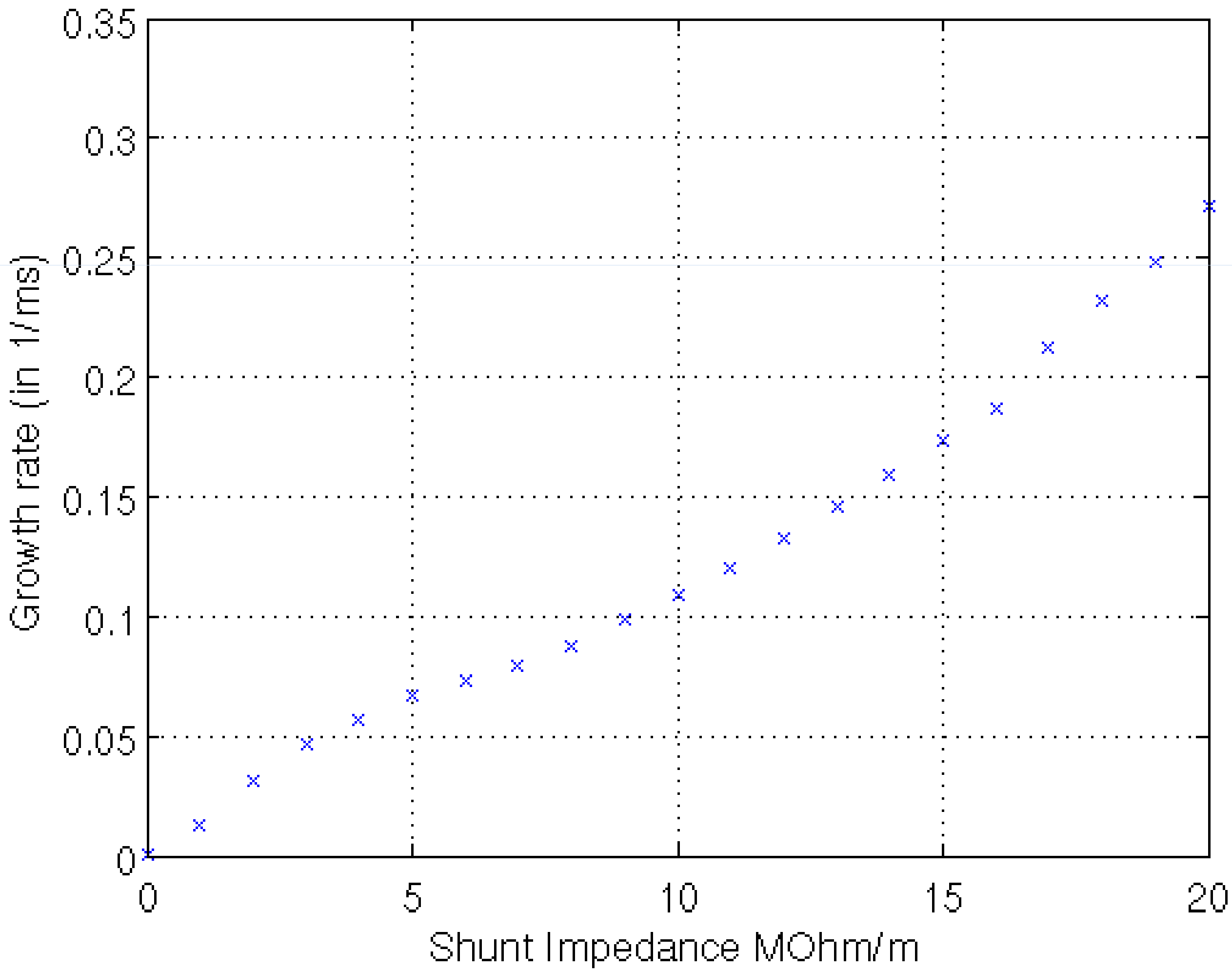
Looking at the hdtl.dat file



- y plane
- mode -2
- another higher order mode

Damping Rings

Growth rate – x plane

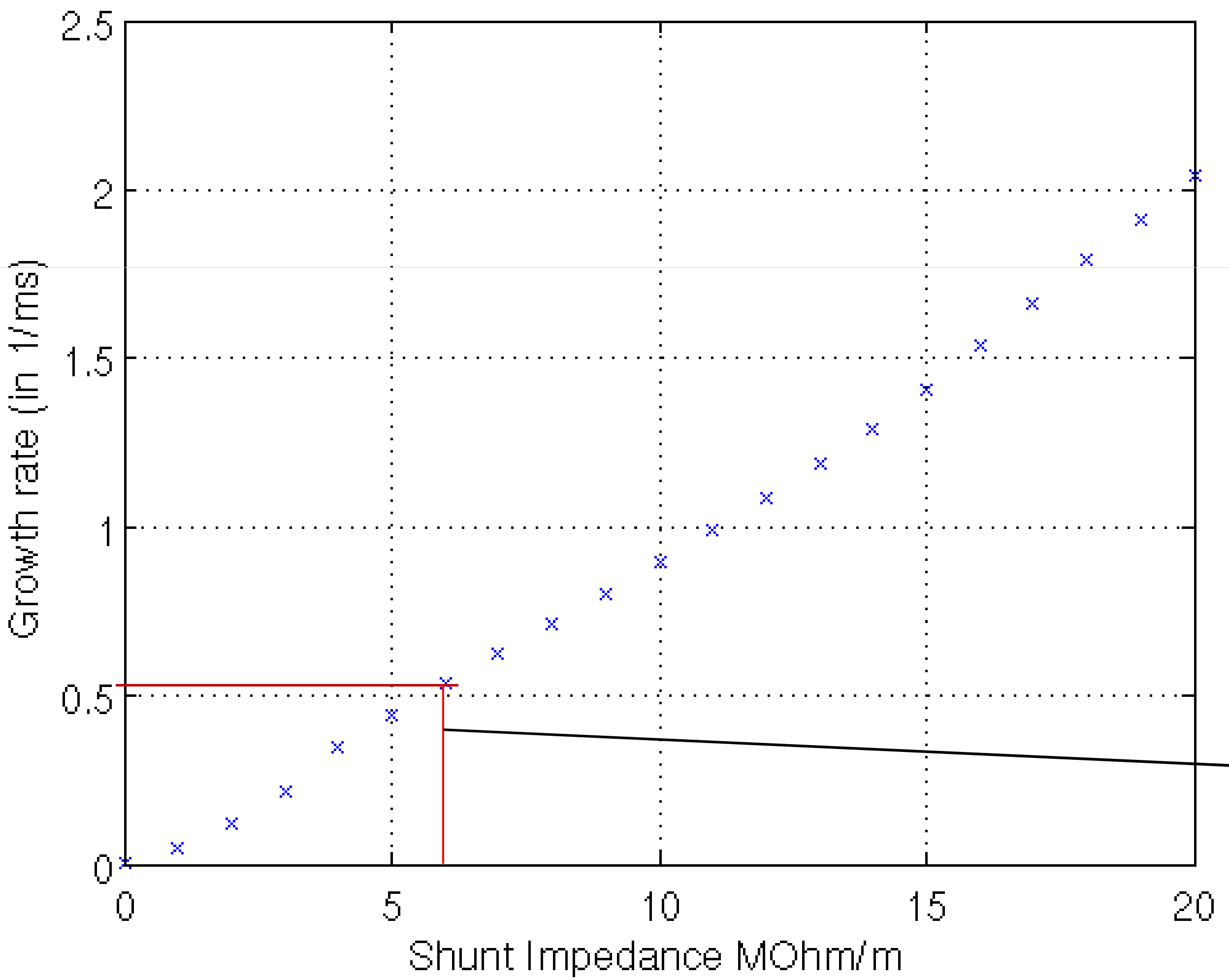


- Damping time τx=1.88ms
- rise time > τx

stable

Damping Rings

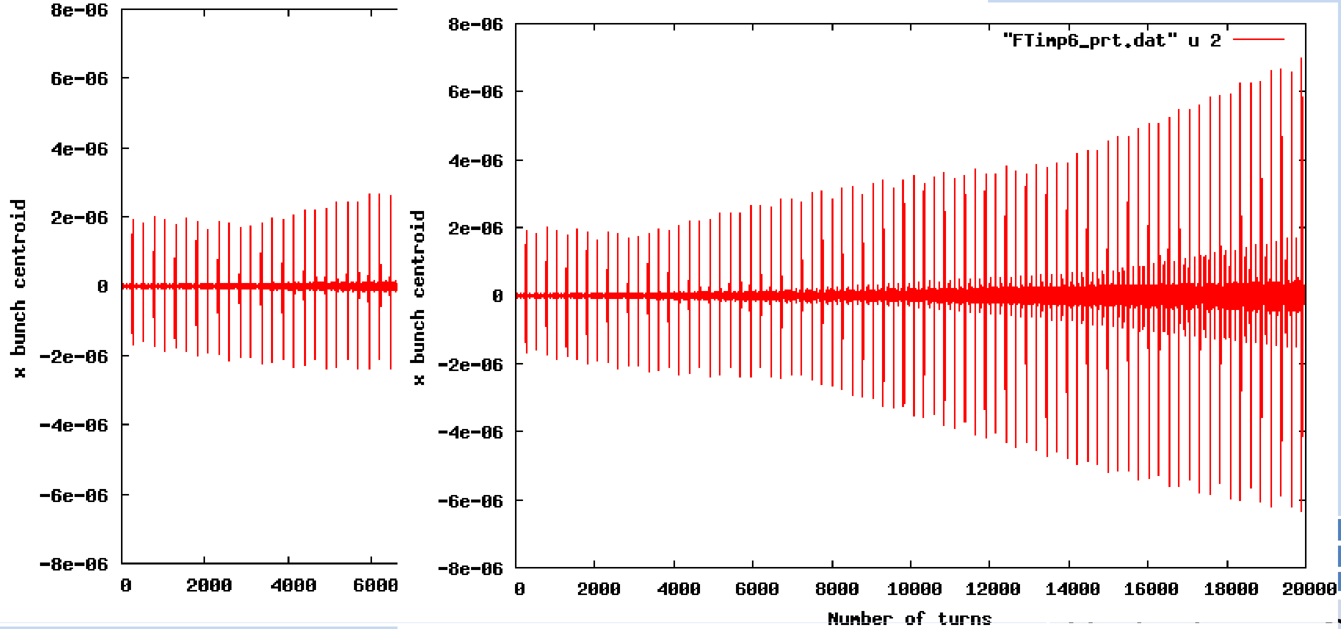
Growth rate – y plane



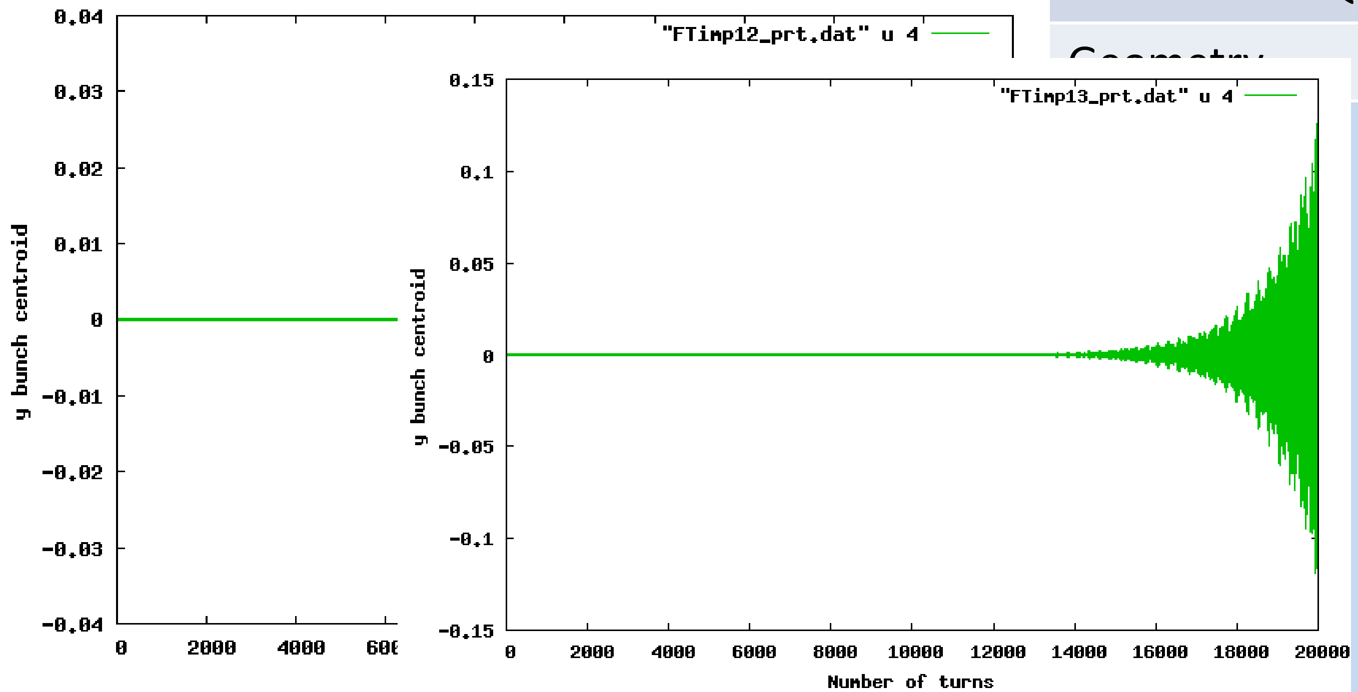
- Damping time τy=1.91ms
- >~6MOhm/m rise time < τy unstable

Threshold ~6MOhm/m

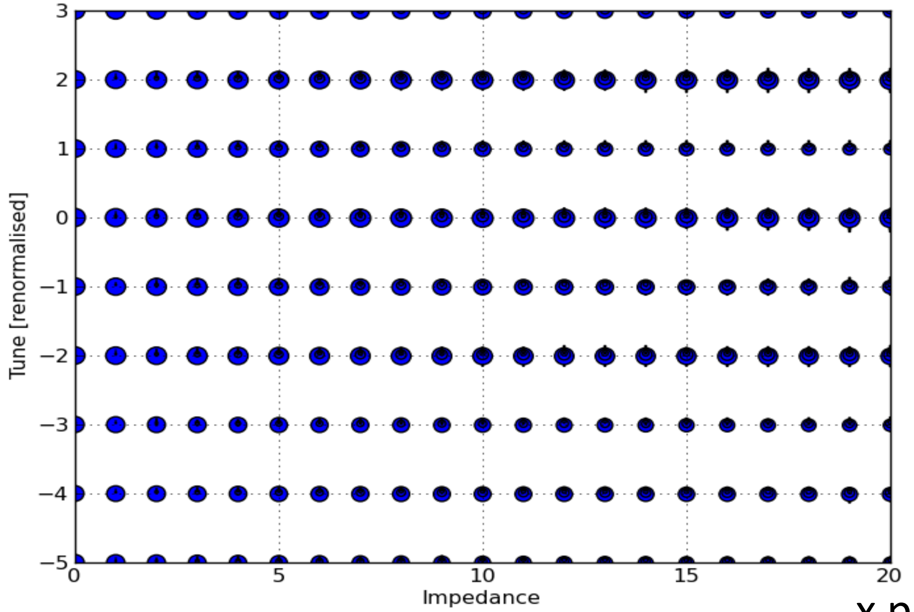
Horizontal and vertical motion in a round chamber



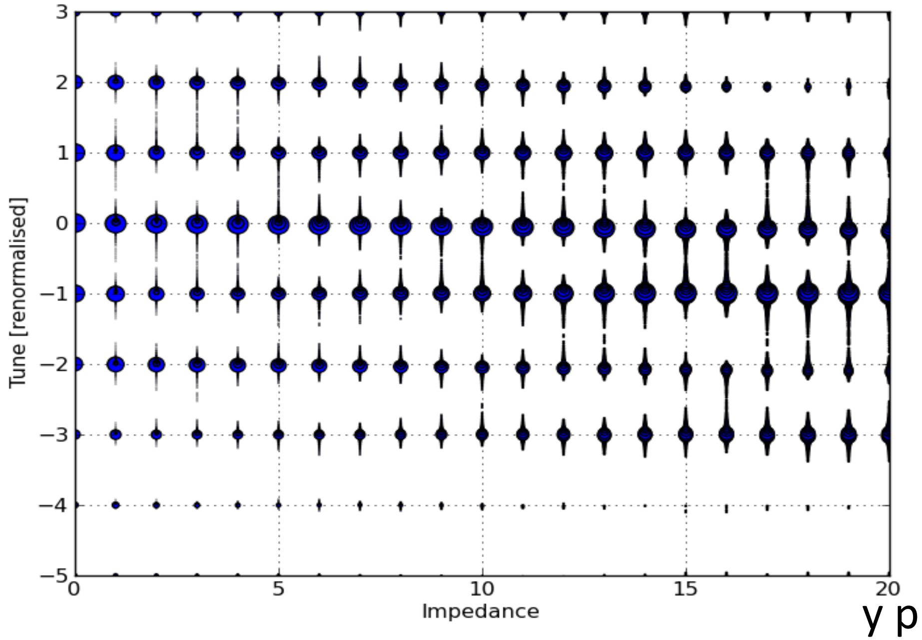
Q'x	27.6
Vert. chrom. Q'y	5.7
Geometry	Round



Mode spectrum of the horizontal and vertical motion as a function of impedance



x plane



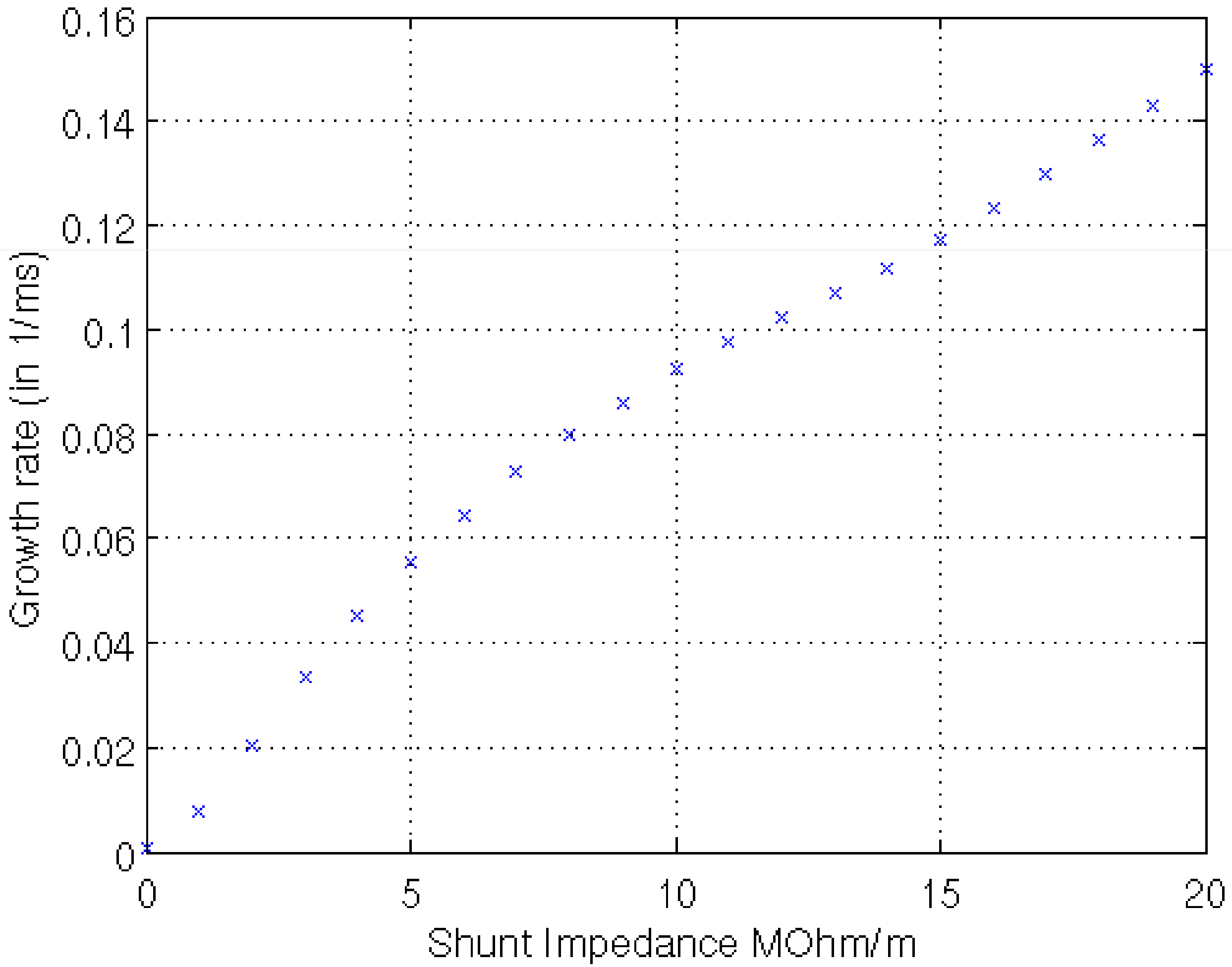
y plane

- Gets harder to see the cause of the instability

➢As the chromaticity is increased, higher order modes are excited

Damping Rings

Growth rate – x plane

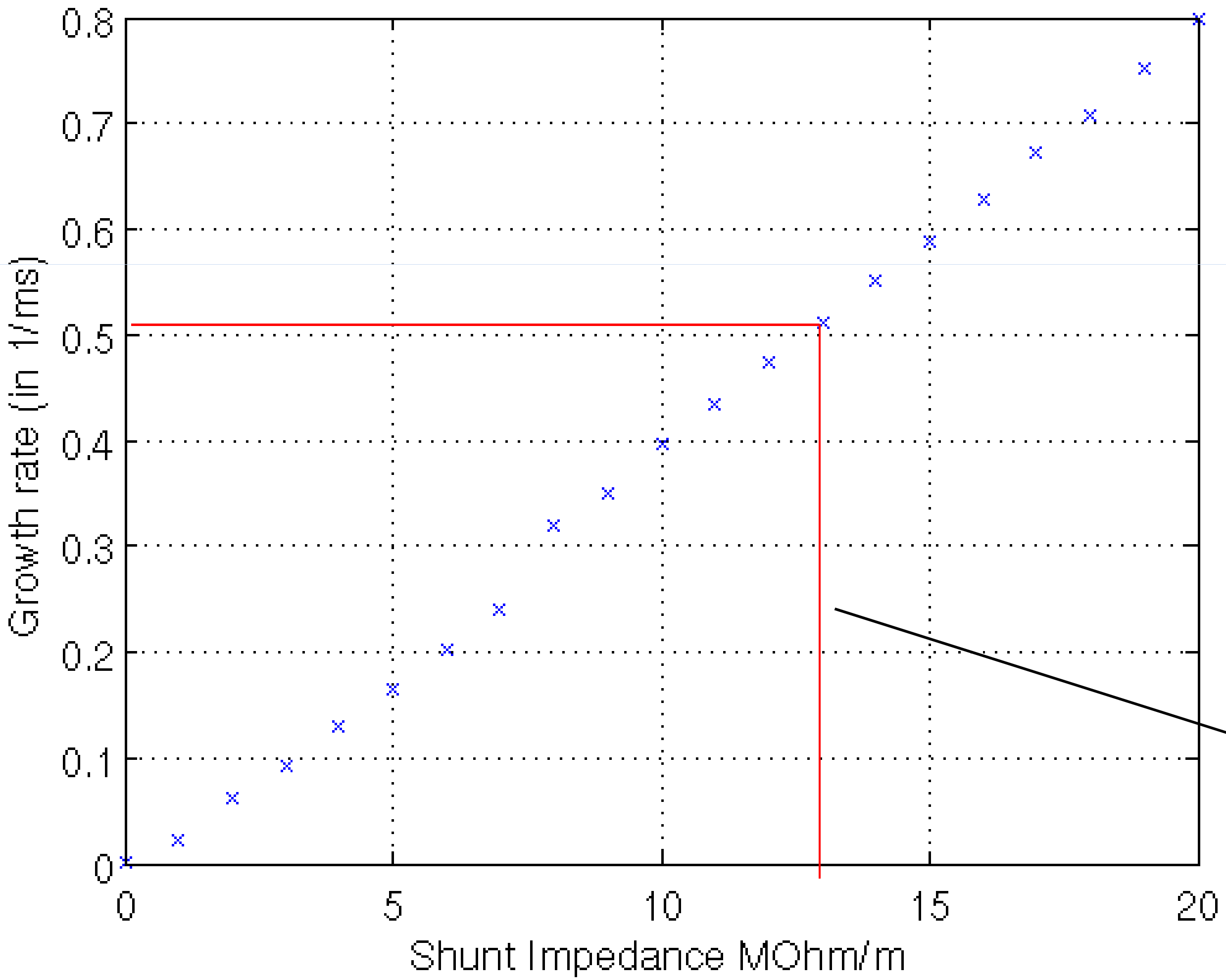


- Damping time τx=1.88ms
- rise time > τx

<u>stable</u>

Damping Rings

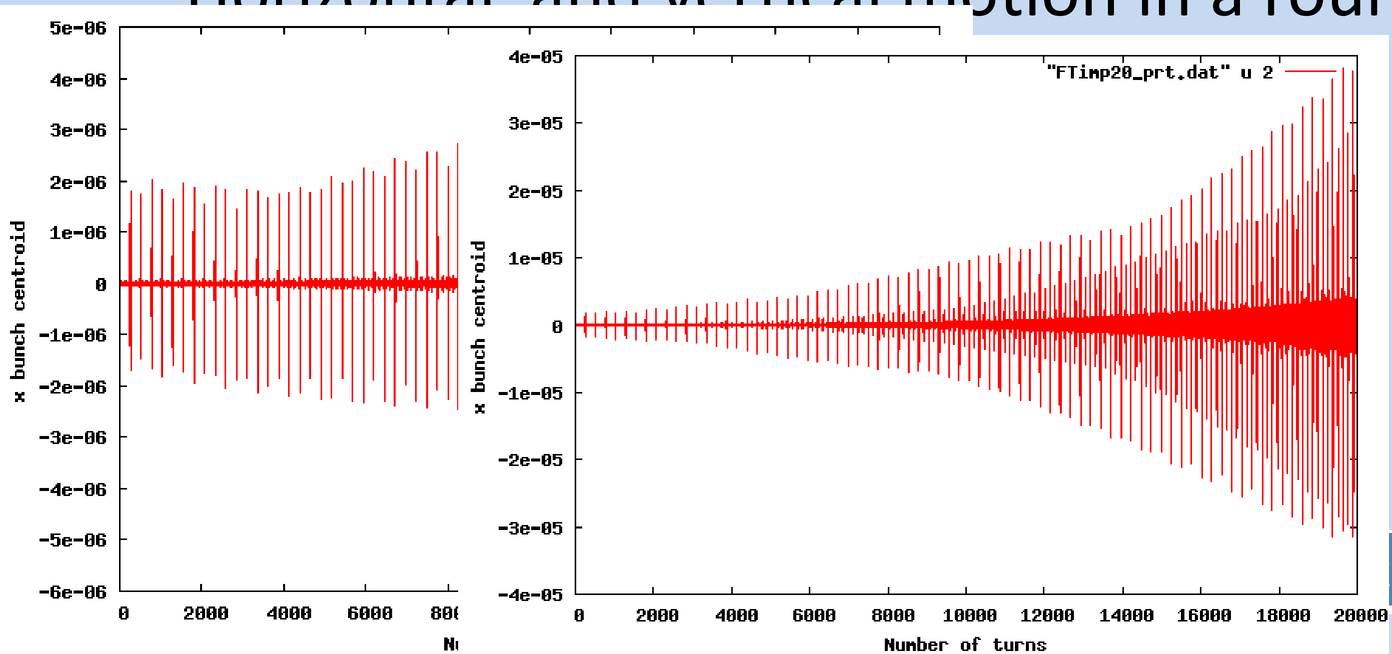
Growth rate – y plane



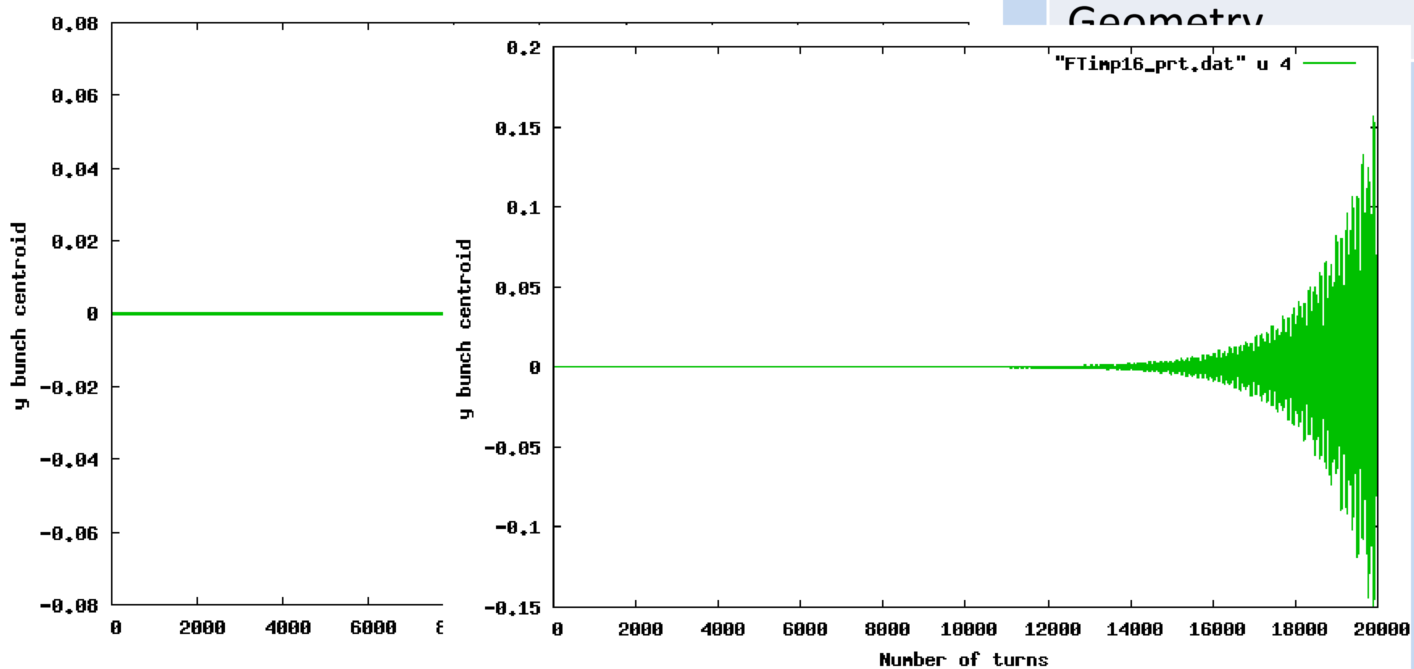
- Damping time $\tau y=1.91ms$
- >~13MOhm/m rise time < τy unstable

Threshold ~13MOhm/m

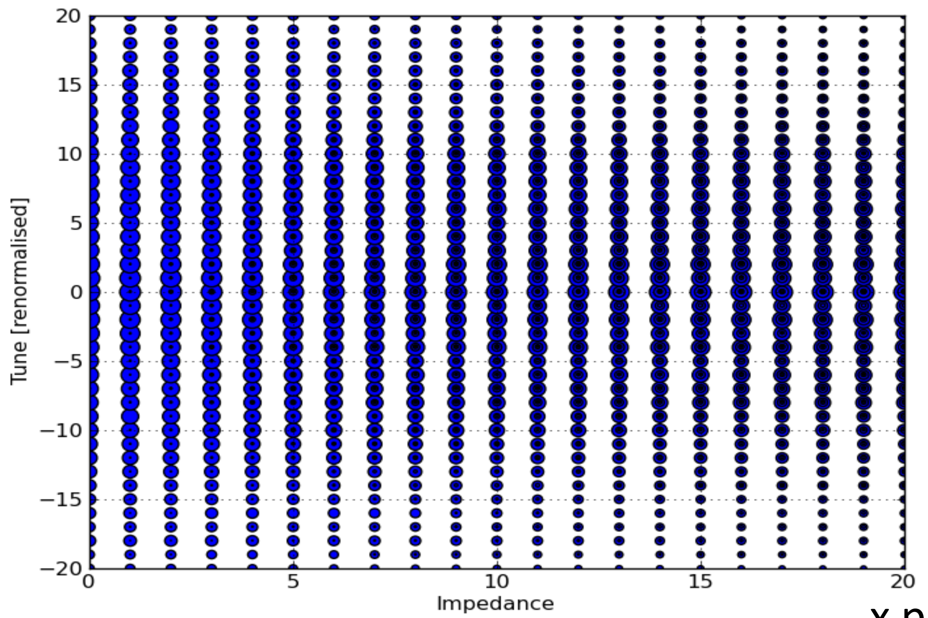
Horizontal and vertical motion in a round chamber



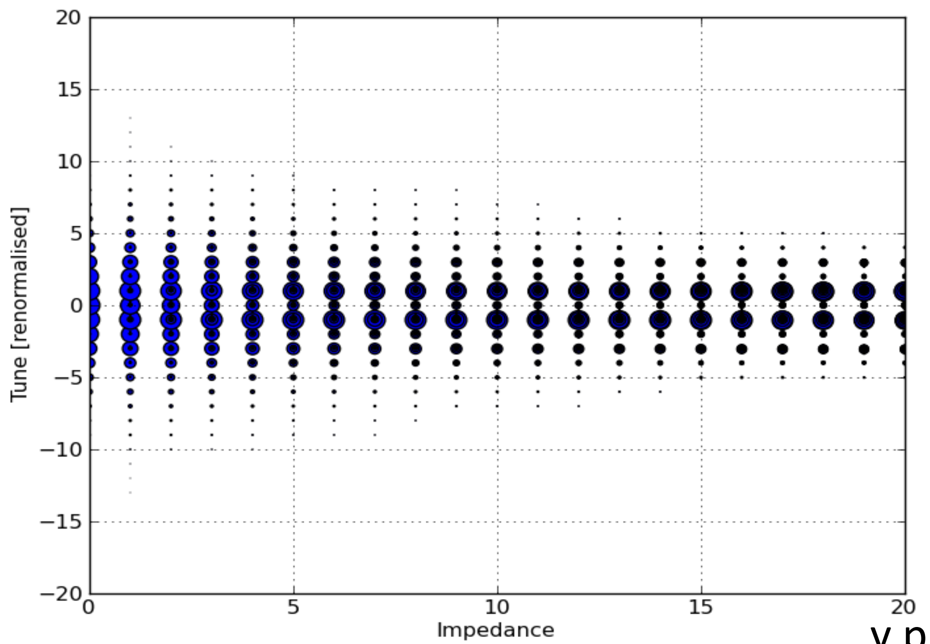
	36.8
Vert. chrom. Q y	7.6
Geometry	Round



Mode spectrum of the horizontal and vertical motion as a function of impedance



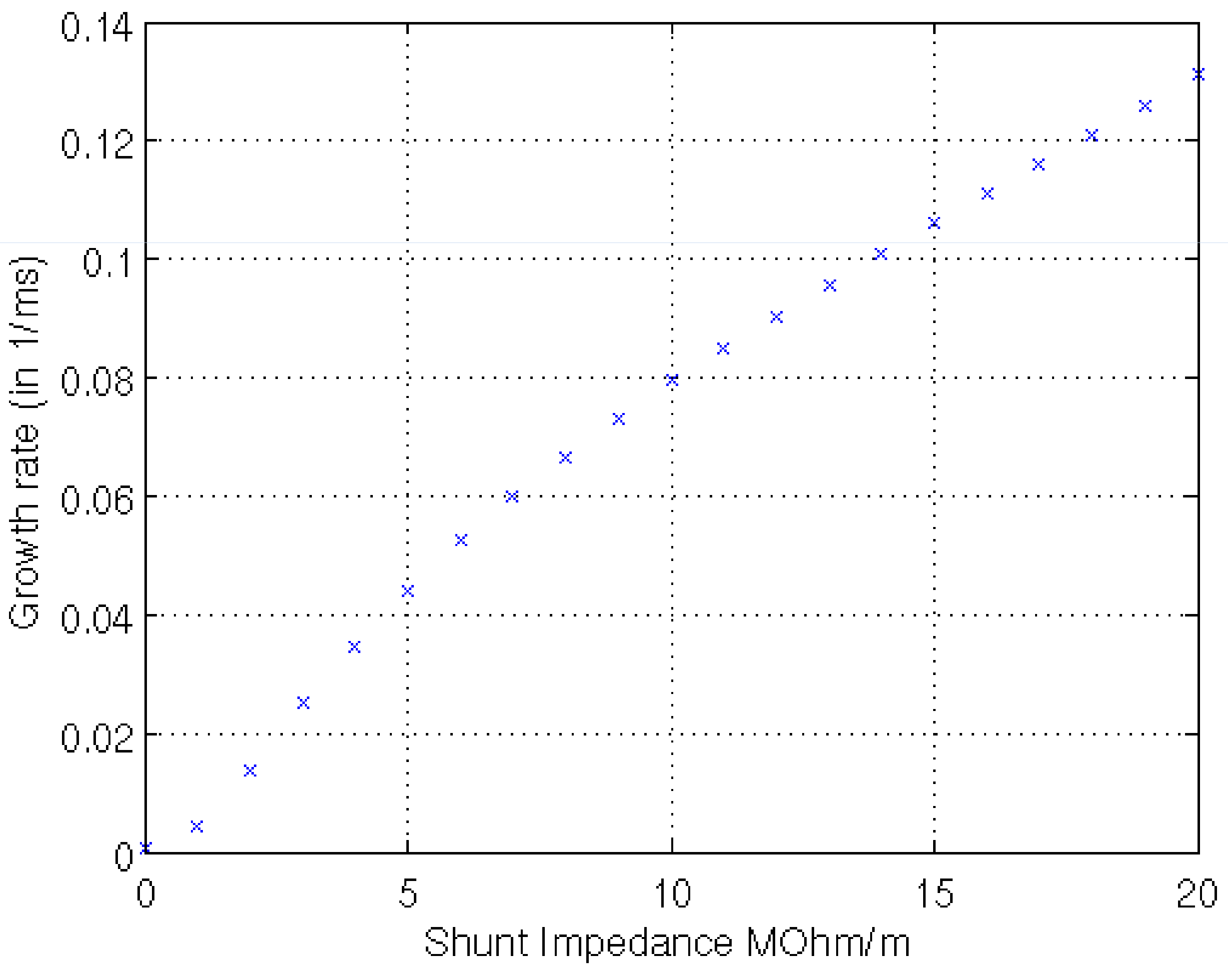
x plane



y plane

Damping Rings

Growth rate – x plane

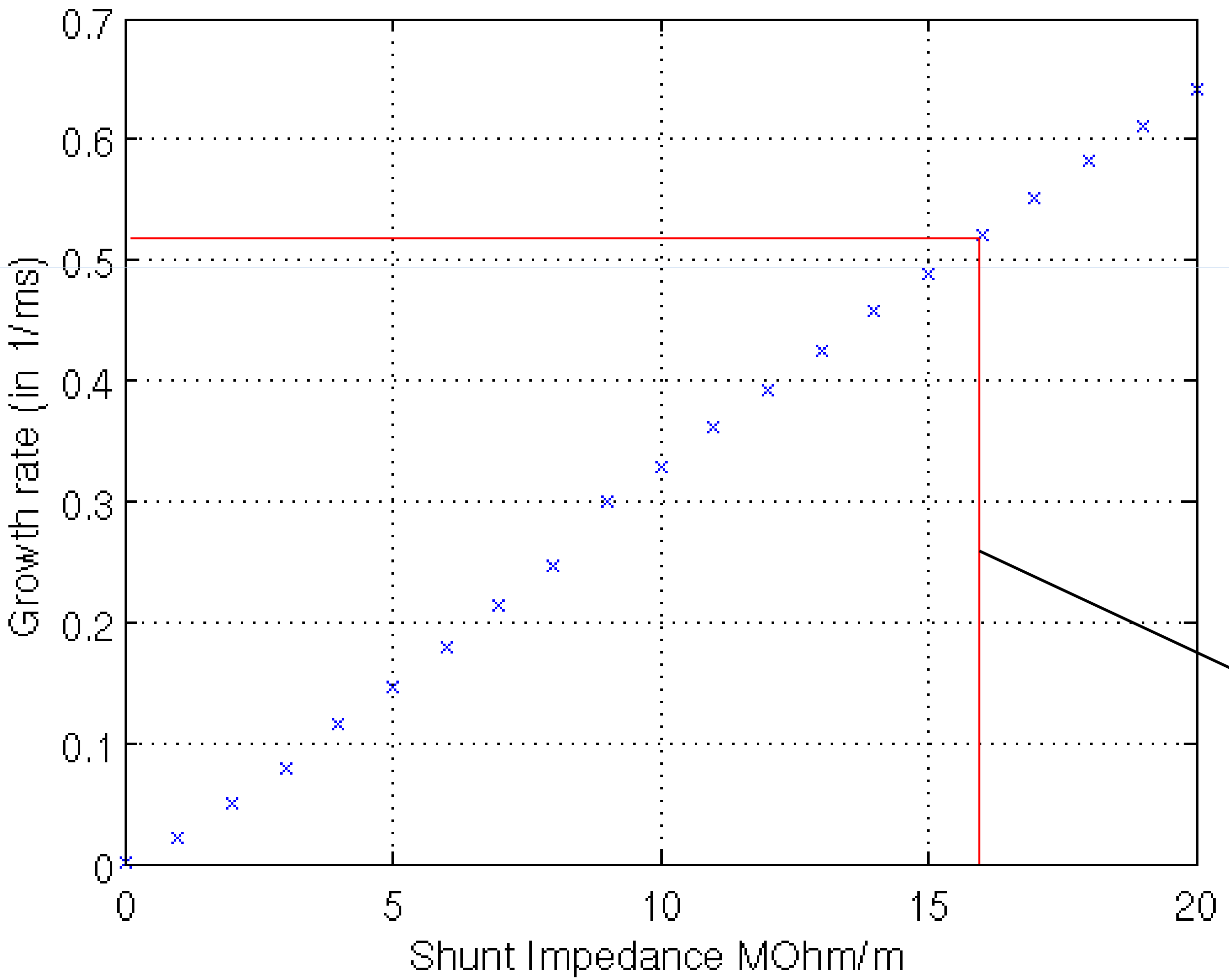


- Damping time τx=1.88ms
- rise time > τx

stable

Damping Rings

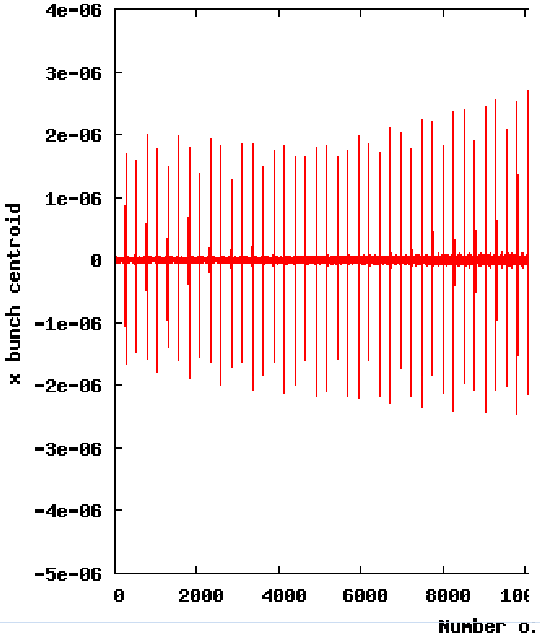
Growth rate – y plane

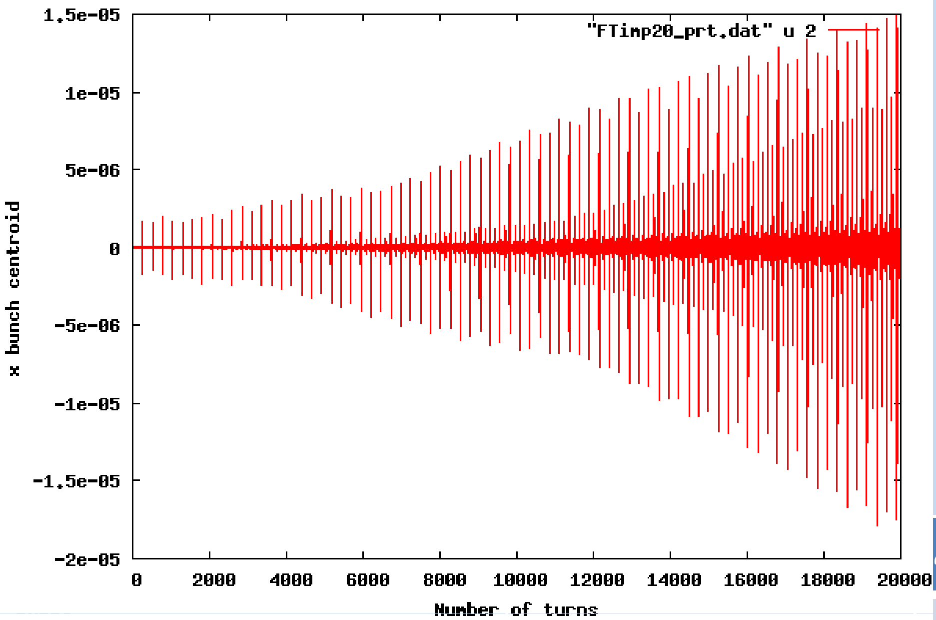


- Damping time τ_y=1.91ms
- >~16MOhm/m rise time < τ_y unstable

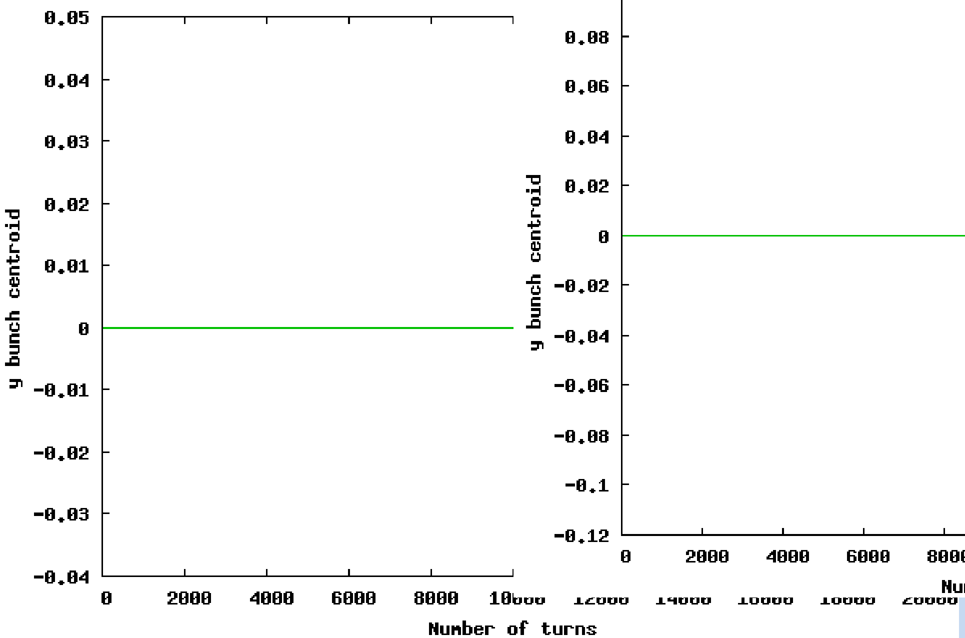
Threshold ~16MOhm/m

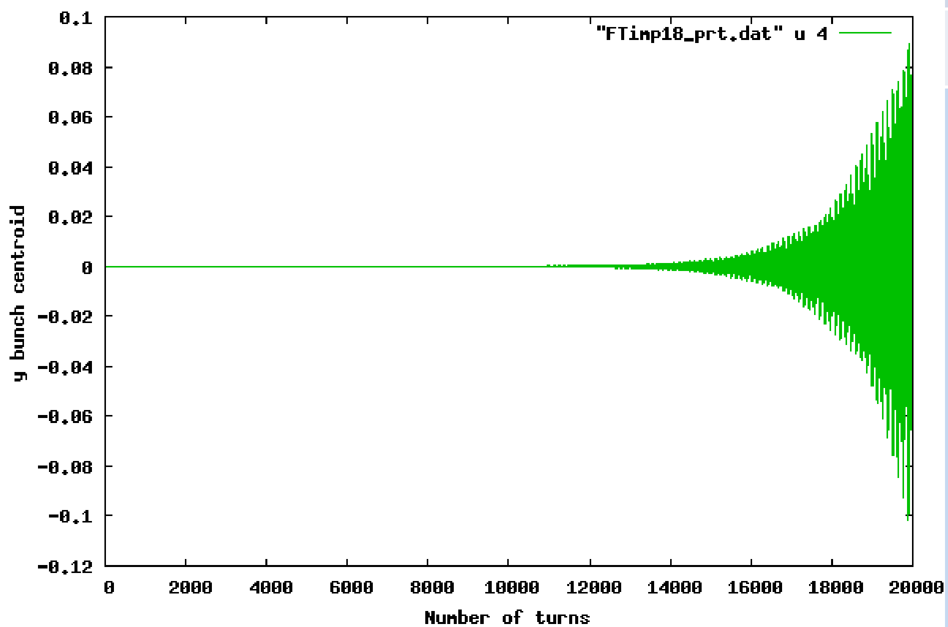
Horizontal and vertical motion in a round chamber



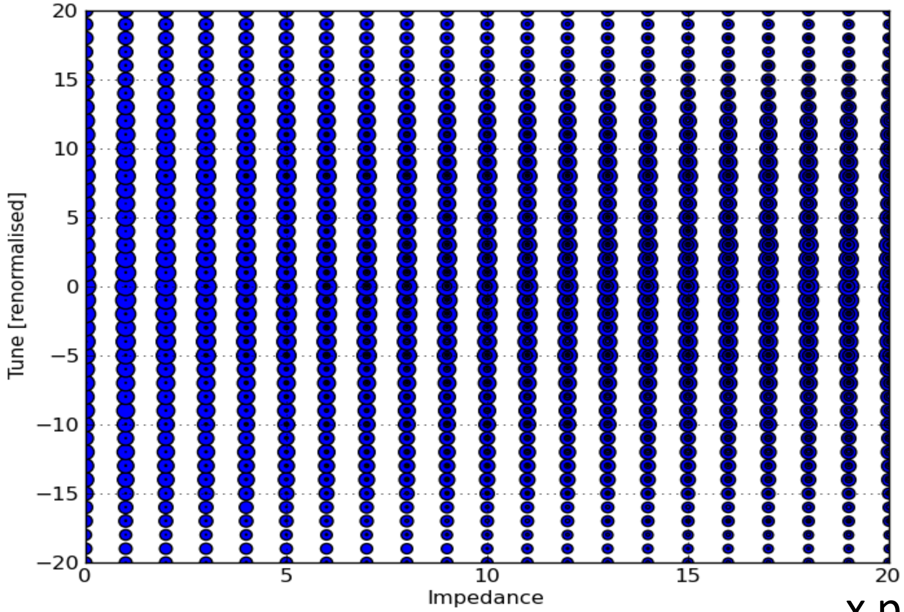


	46
Vert. chrom. Q'y	9.5
	Round

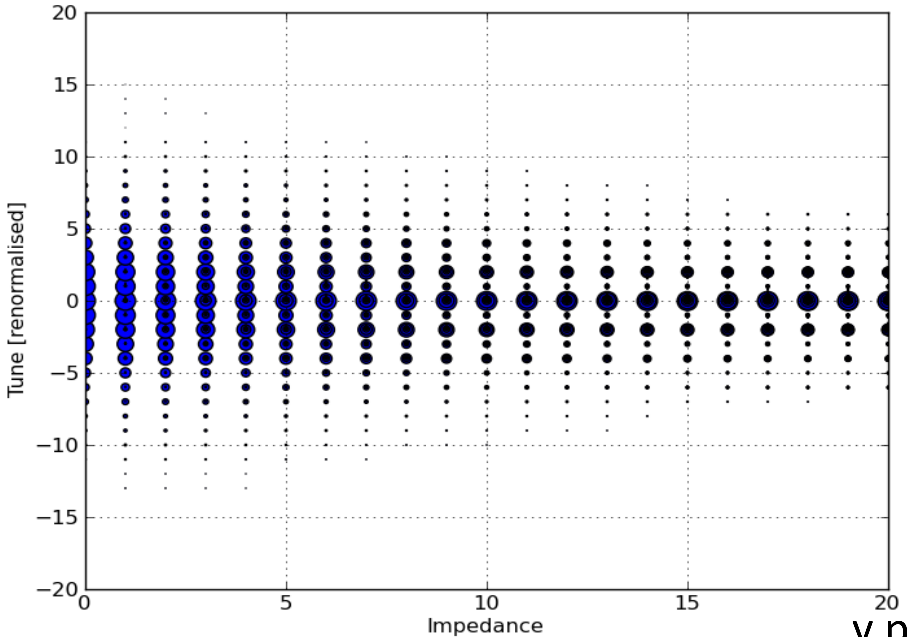




Mode spectrum of the horizontal and vertical motion as a function of impedance



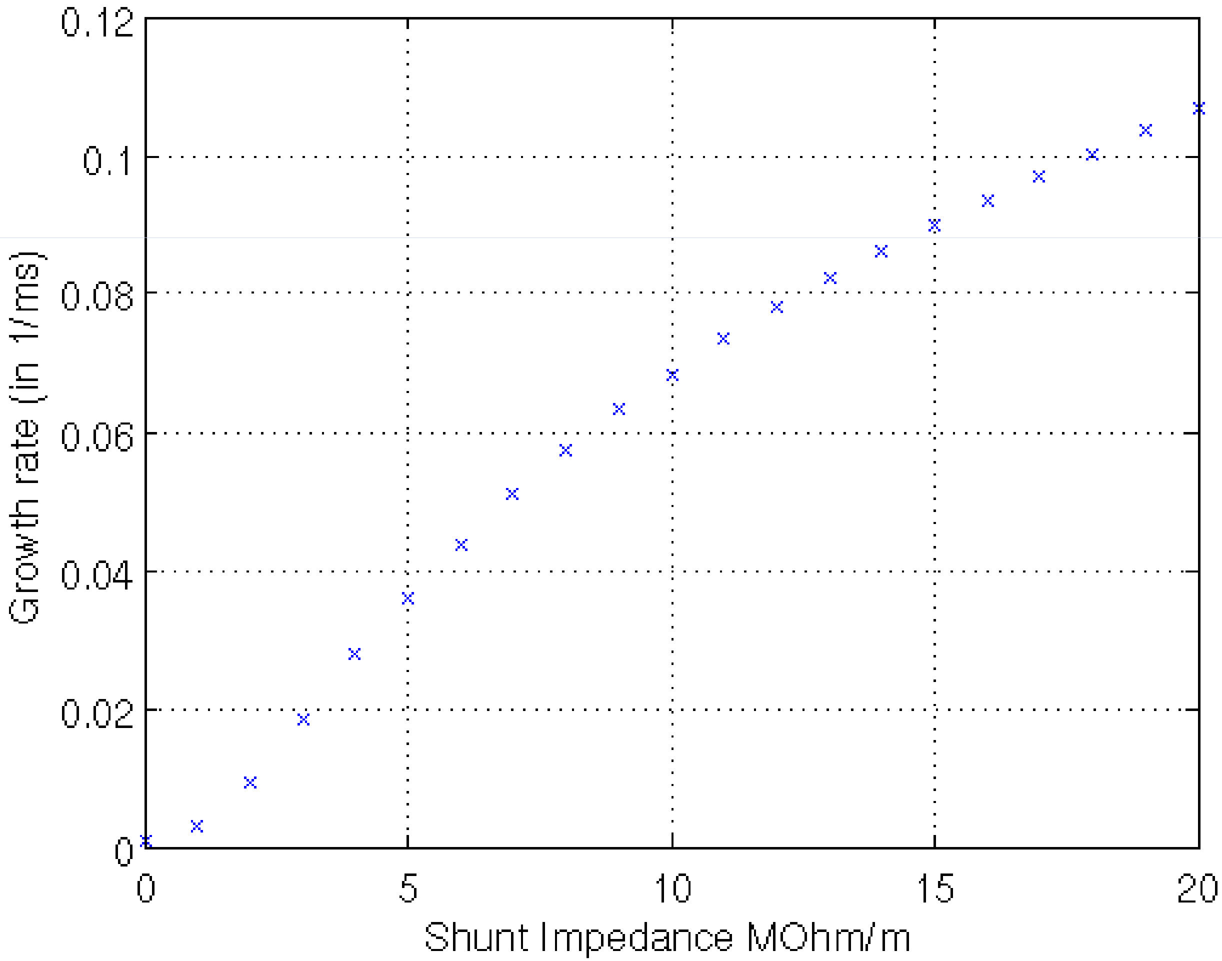
x plane



y plane

Damping Rings

Growth rate – x plane

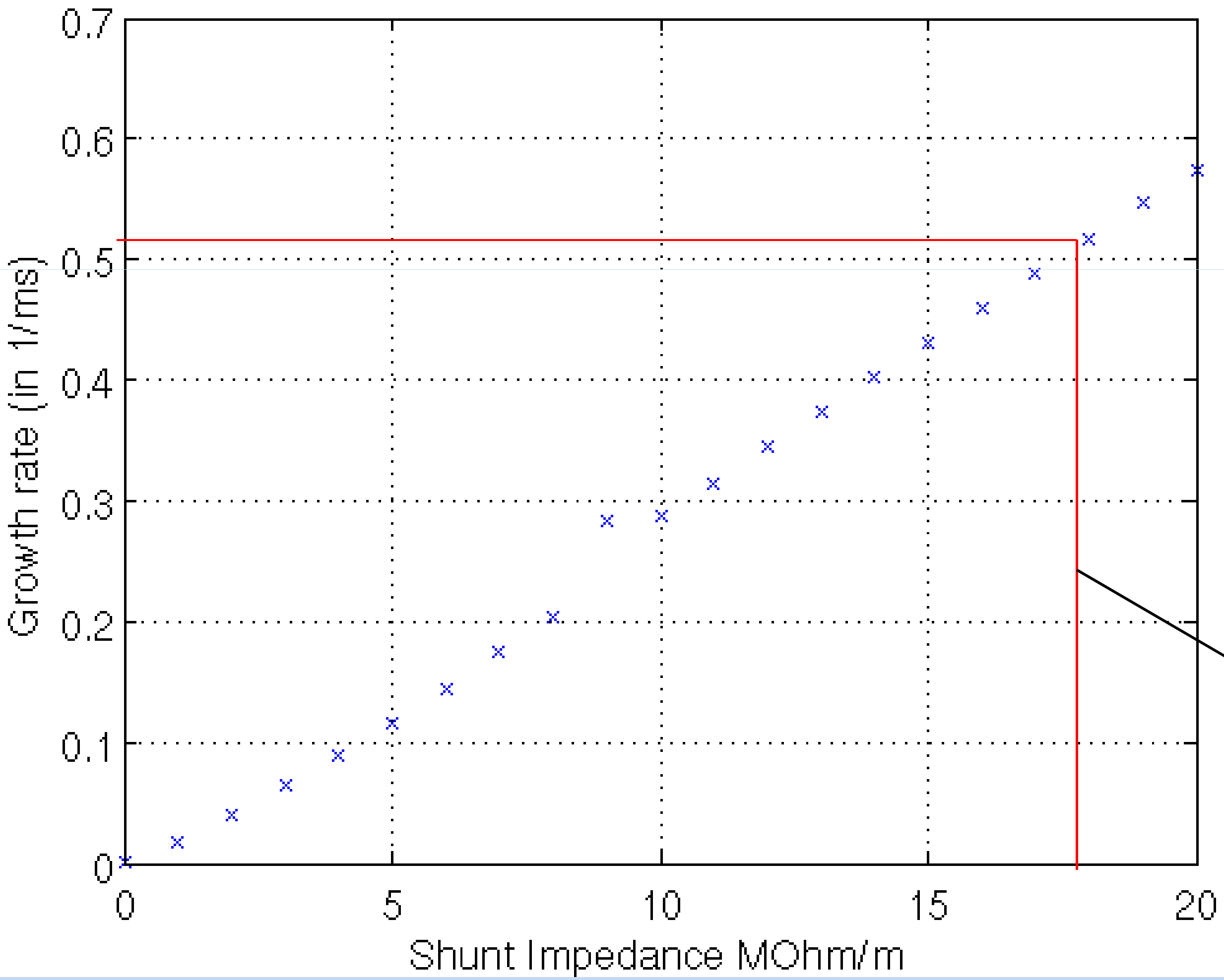


- Damping time τx=1.88ms
- rise time > τx

stable

Damping Rings

Growth rate – y plane



- Damping time τ_y=1.91ms
- >~18MOhm/m rise time < τ_y unstable

Threshold ~18MOhm/m

Damping Rings

Results for round chamber

	x	y	x	y
Chromaticity Q'x/ Q'y	Threshold MOhm/m		Rise time (ms) τx=1.88, τy=1.91	
0/0	10	11	0.38	0.49
9.2/1.9	16	3	1.92	2
18.4/3.8	stable	6	stable	1.81
27.6/5.7	stable	13	stable	1.81
36.8/7.6	stable	16	stable	1.81
46/9.5	stable	18	stable	1.81

- For chromaticity 0, the TMCI threshold is at 10 and 11 MOhm/m for x,y respectively
- For positive chromaticity, there is no TMCI but another instability occurs.
- As the chromaticity is increased, higher order modes get excited, less effect, move to higher instability thresholds

Damping Rings

Results for round chamber

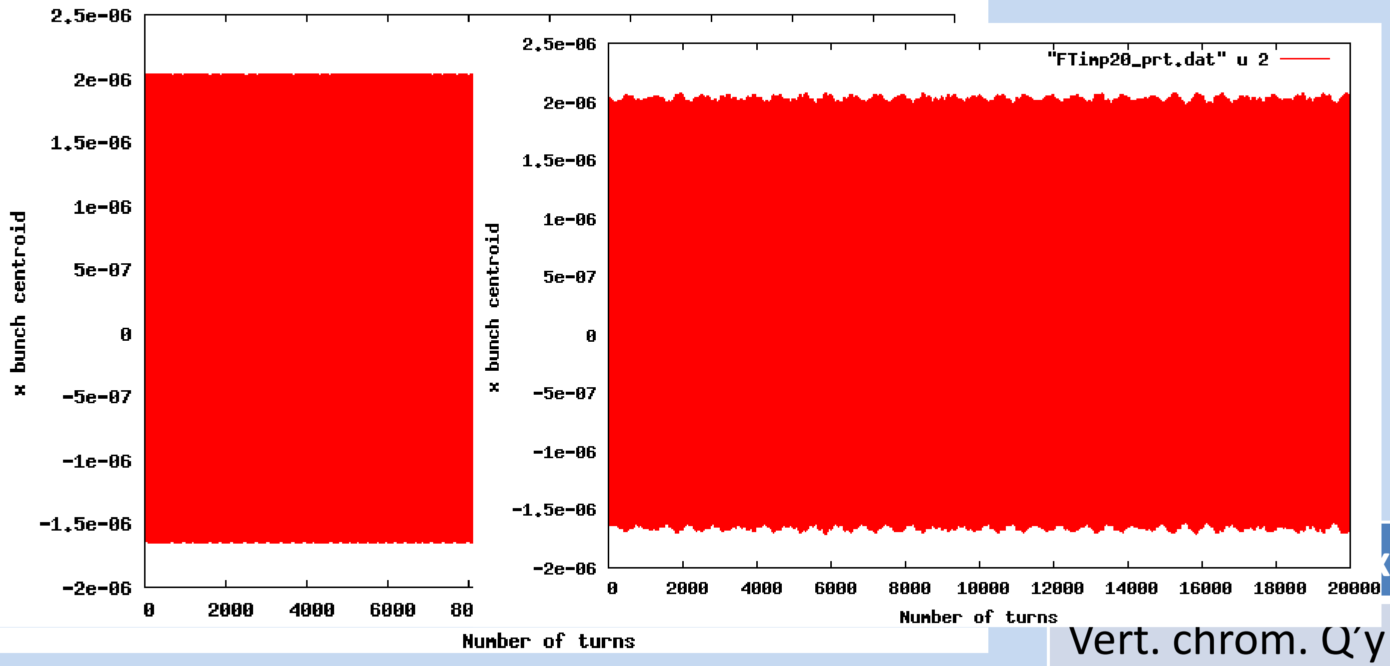
- Impedance cause bunch modes to move and merge, leading to a strong TMCI instability
- Chromaticity make the modes move less, therefore it helps to avoid the coupling (moved to a higher threshold)
- Still some modes can get unstable due to impedance

- As the chromaticity is increased, higher order modes are excited (less effect on the bunch)

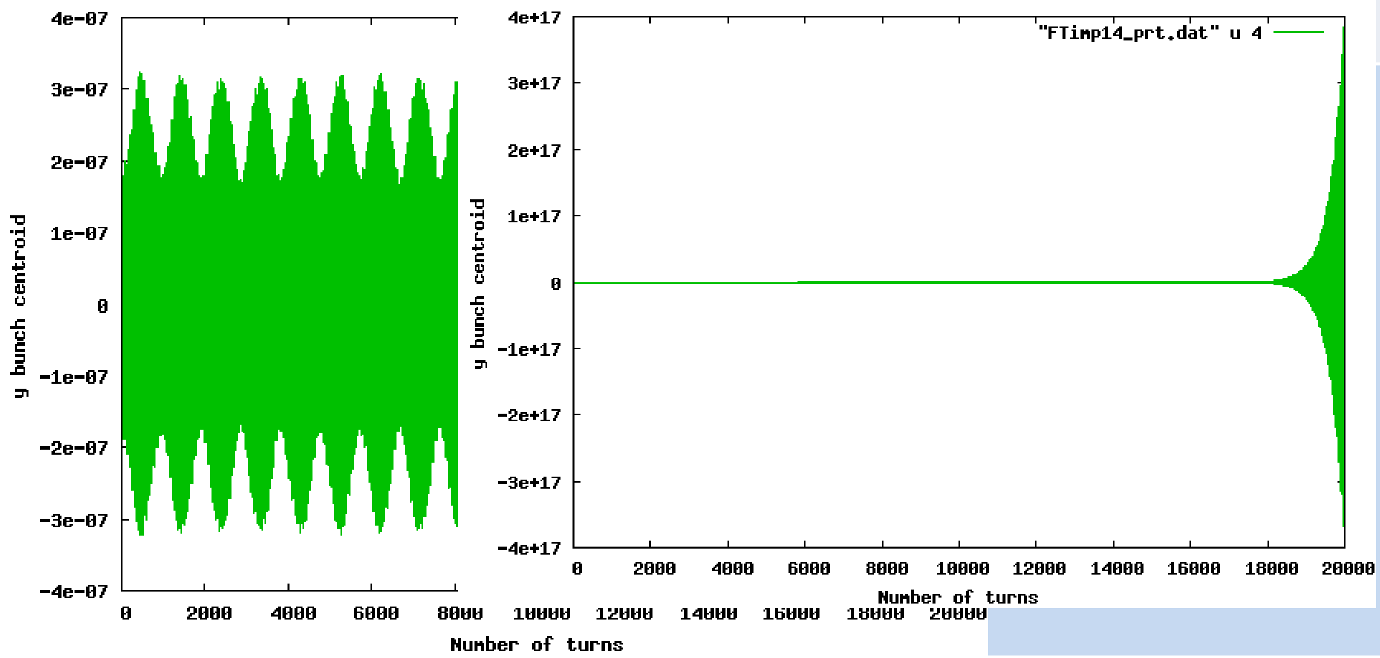
Conclusion

➢ Either we correct the chromaticity and operate below the TMCI threshold or sufficient high positive chromaticity must be given so that mode -1, or -2 or maybe higher order mode is stable for the damping time

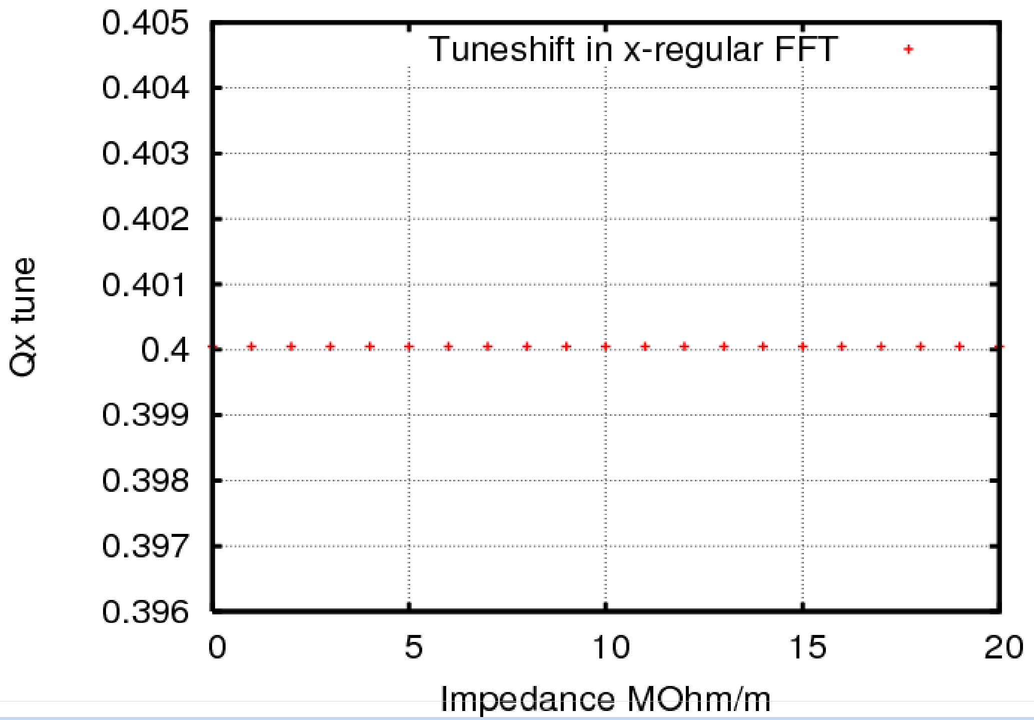
Horizontal and vertical motion in a flat chamber



x	0
Vert. chrom. Q'y	0
	Flat

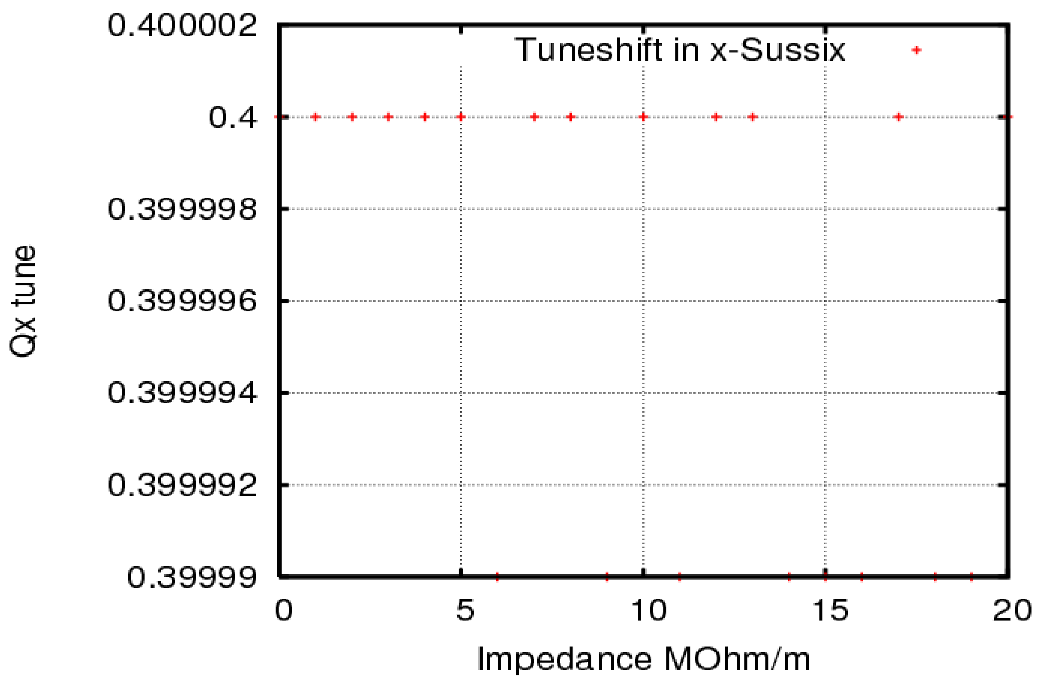


Horizontal plane



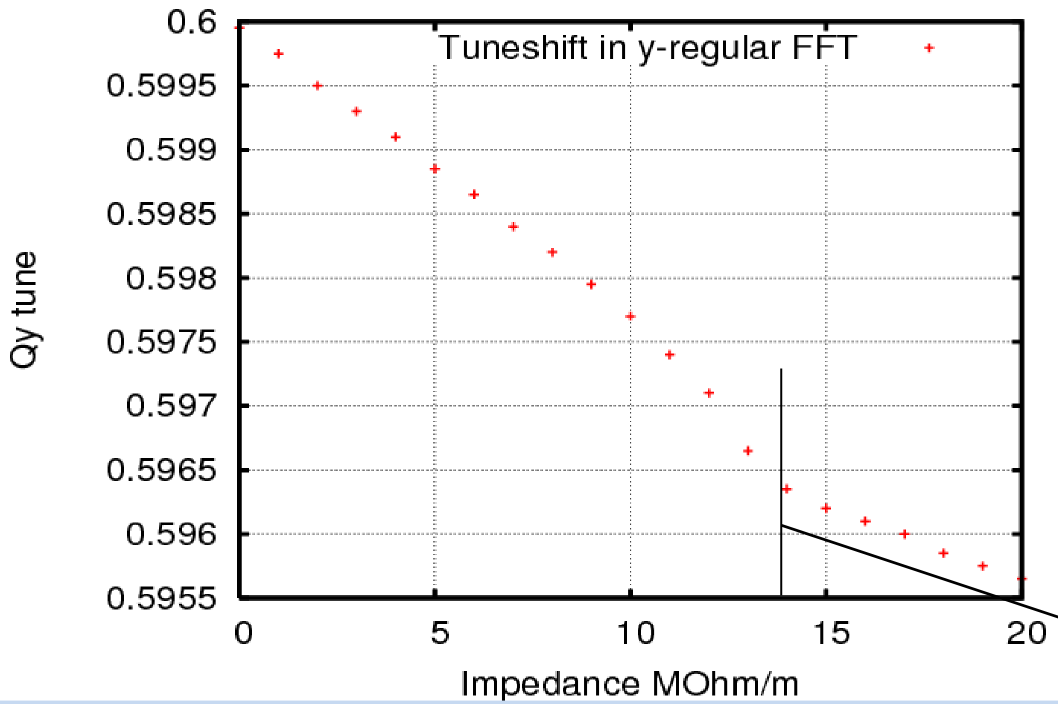
Regular FFT

Stable beam



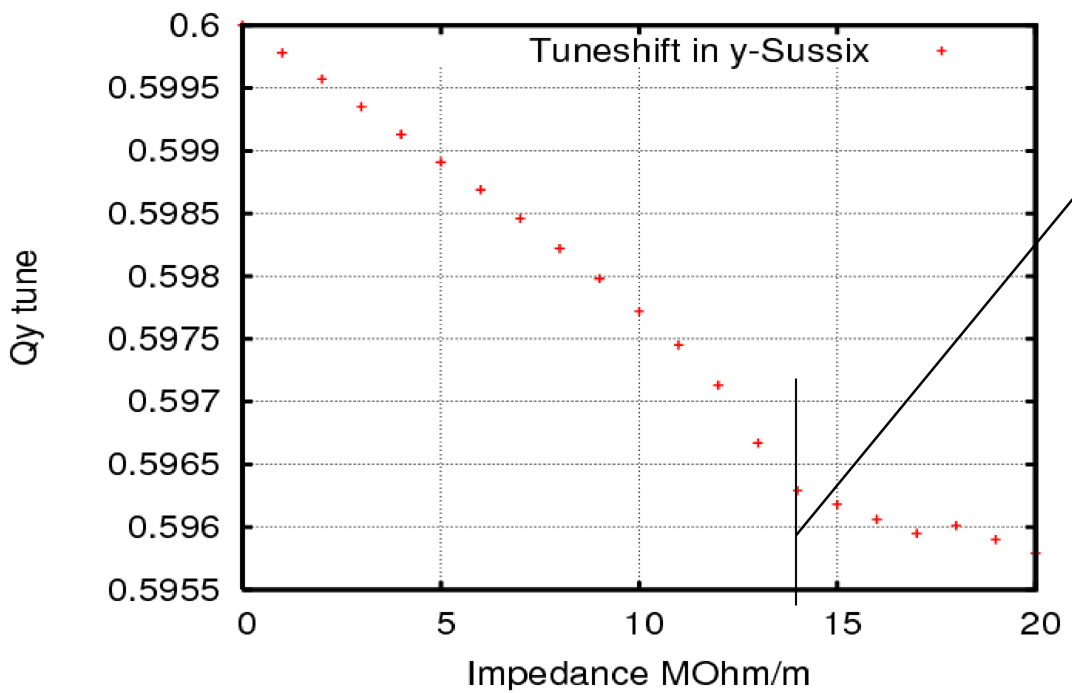
Sussix FFT

Vertical plane



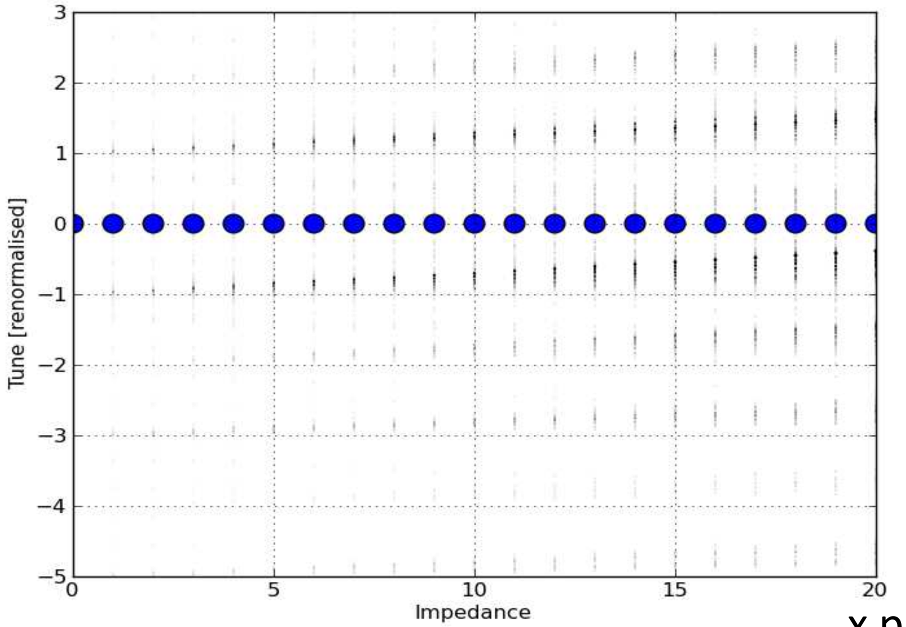
Regular FFT

Instability threshold (TMCI) 14MOhm/m



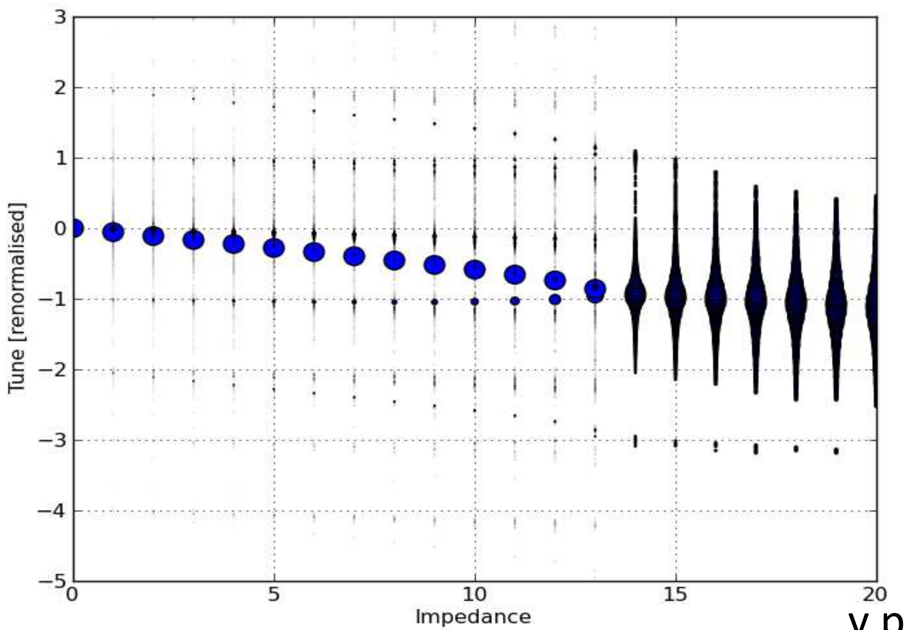
Sussix FFT

Mode spectrum of the horizontal and vertical motion as a function of impedance



x plane

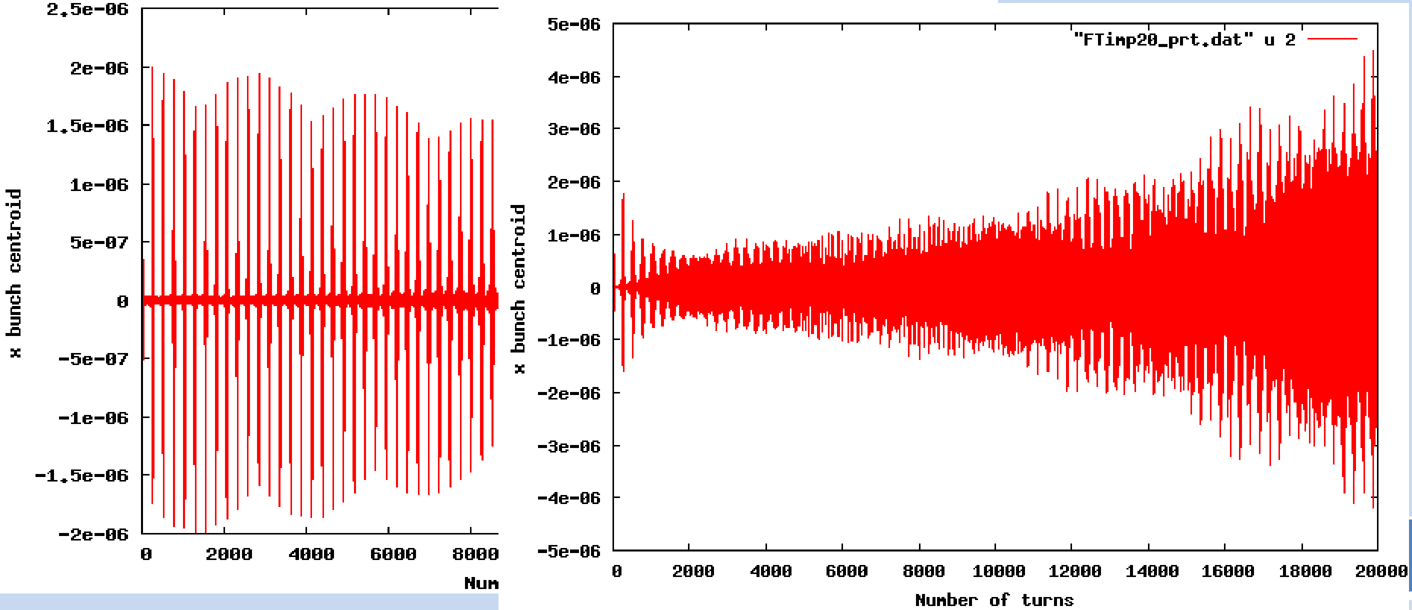
- mode 0 stable
- others shift
- later coupling between 0 and -1



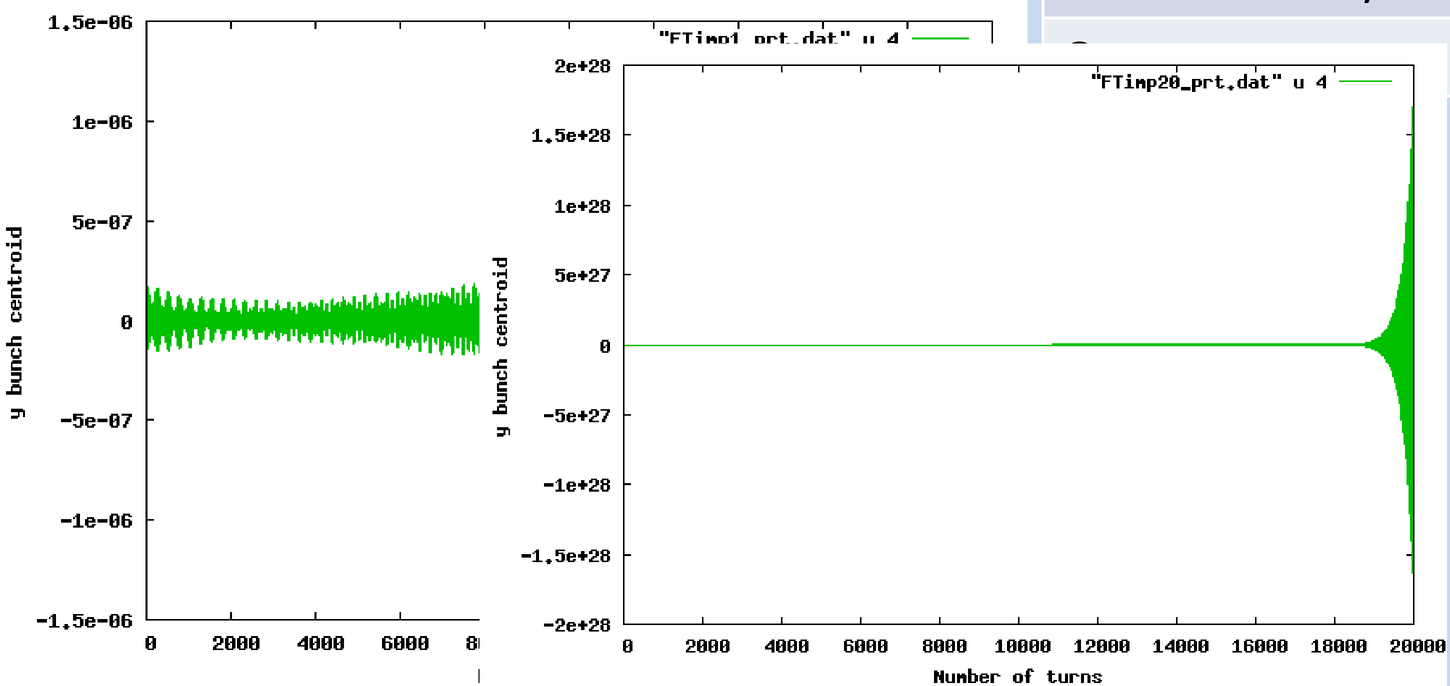
y plane

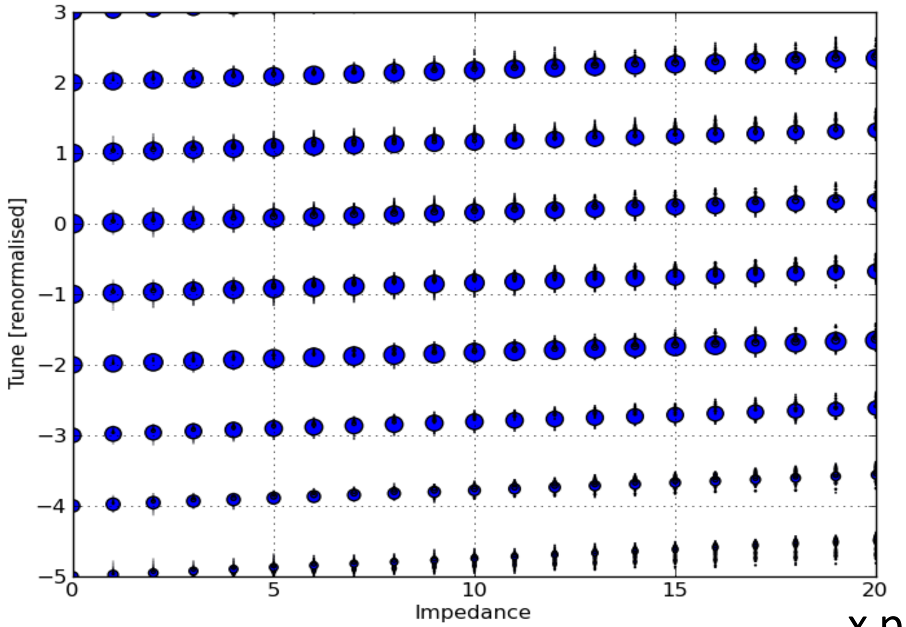
- mode 0 and mode -1 couple
- TMCI instability

Horizontal and vertical motion in a flat chamber

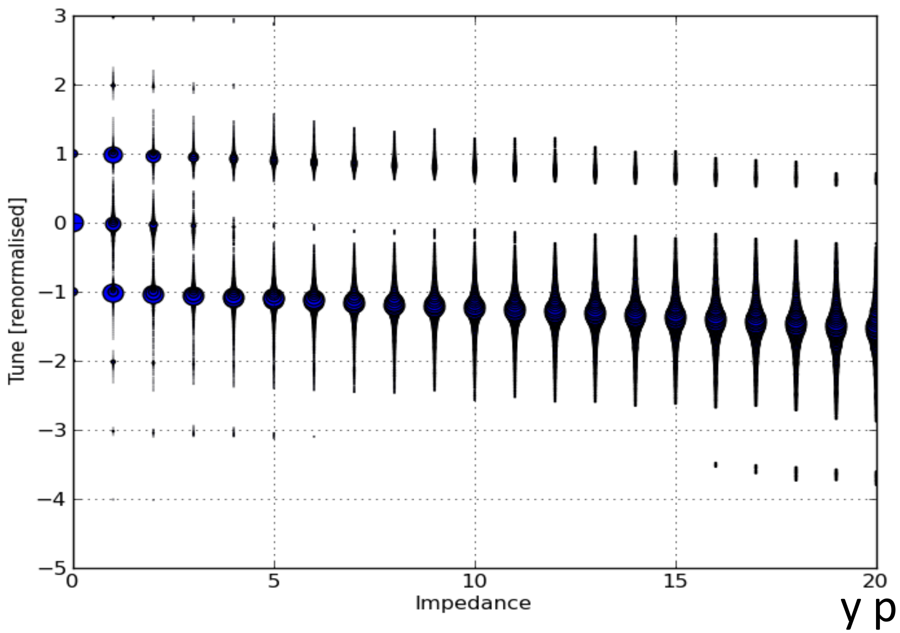


	9.2
Vert. chrom. Q’y	1.9
	Flat





x plane



y plane

Mode spectrum of the horizontal and vertical motion as a function of impedance

- no mode coupling
- no TMCI instability
- hard to tell the cause of instability

- mode 1 is damped
- mode -1 gets unstable

Damping Rings

Conclusions for the flat chamber

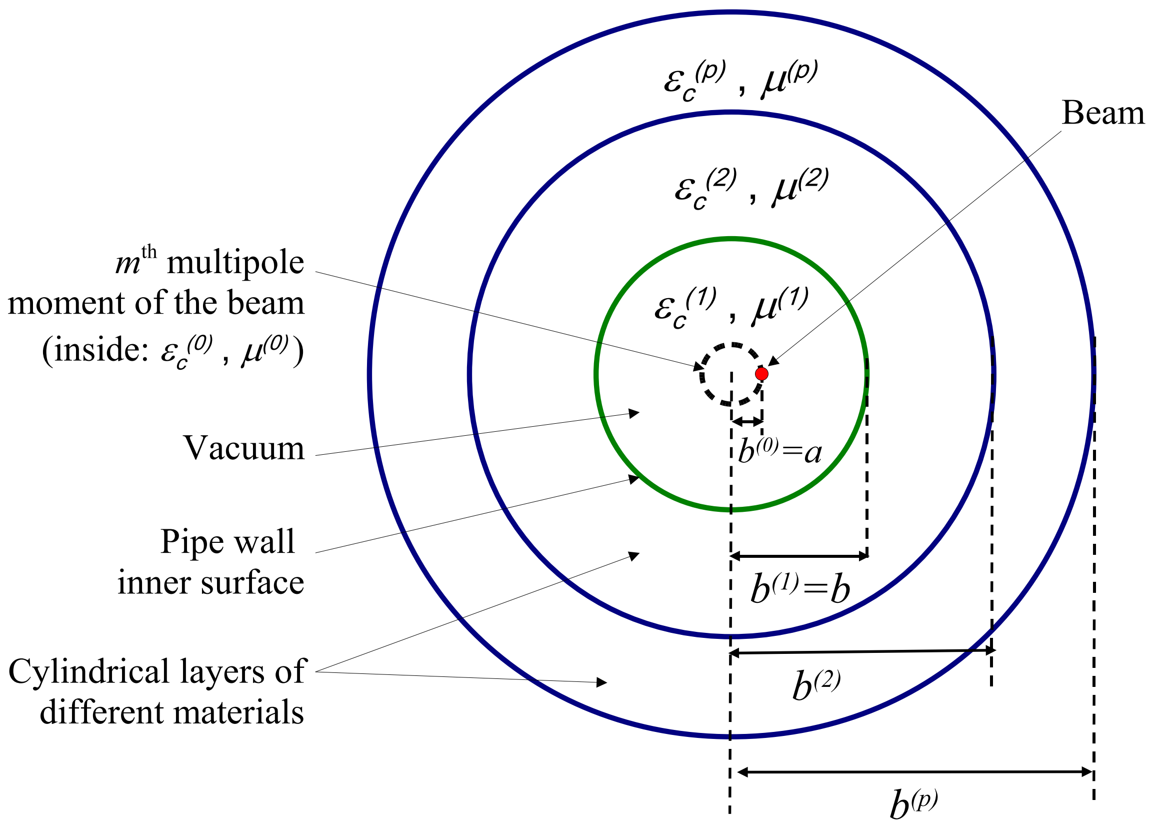
	threshold (MOhm/m)			
	Round		Flat	
Chromaticity	x	y	x	y
0	10	11	stable	14

•Calculate the growth rate for the cases with chromaticity and compare with the round chamber

Resistive wall in the CLIC-DR regime

- Layers of coating materials can significantly increase the resistive wall impedance at high frequency
  - Coating especially needed in the low gap wigglers
  - Low conductivity, thin layer coatings (NEG, a-C)
  - Rough surfaces (not taken into account so far)

Pipe cross- section:



N. Mounet

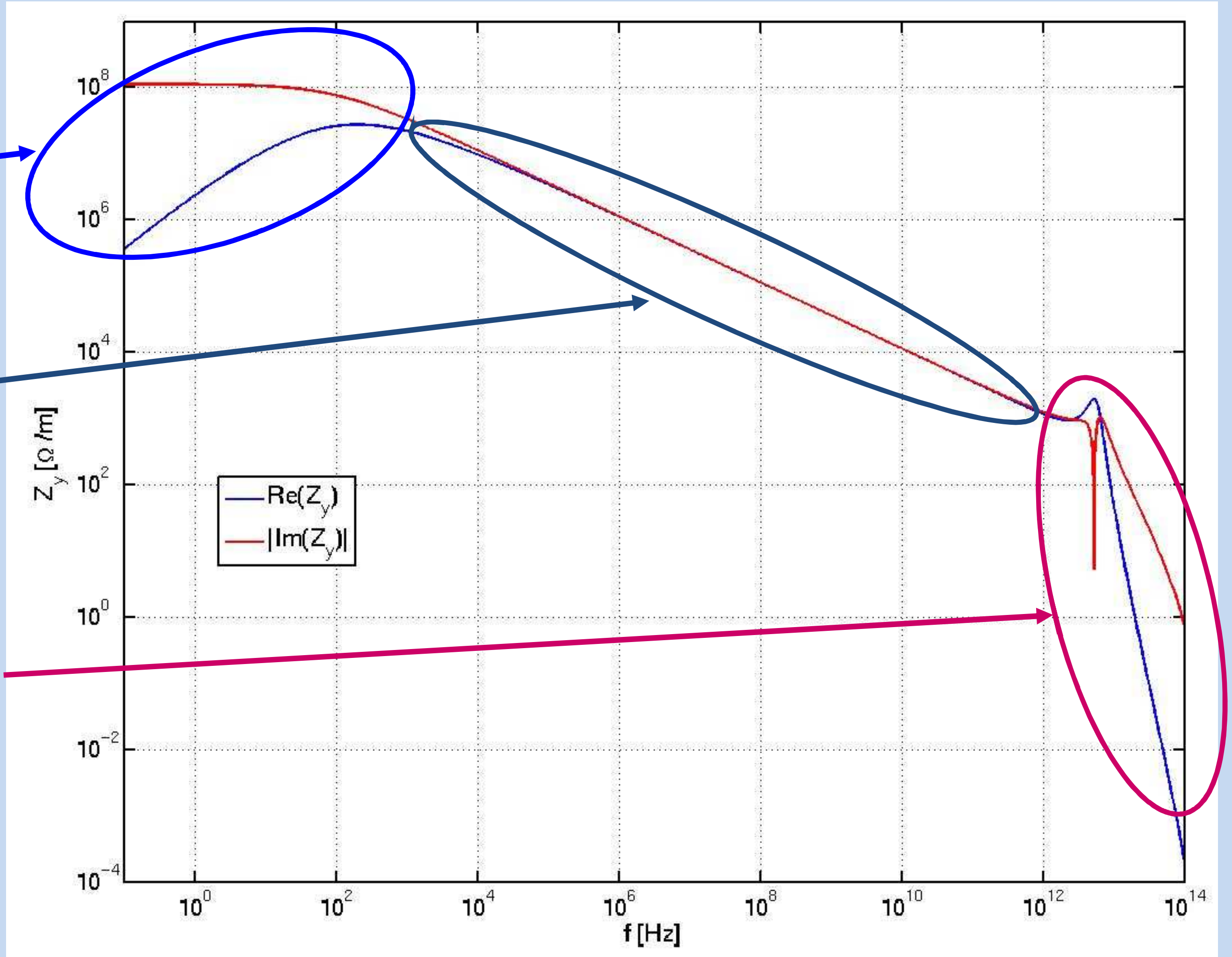
General Resistive Wall Impedance: Different Regimes

- Vertical impedance in the wigglers (3 TeV option, pipe made of copper without coating)

Low frequency or "inductive-bypass" regime

"Classic thick-wall" regime

High frequency regime

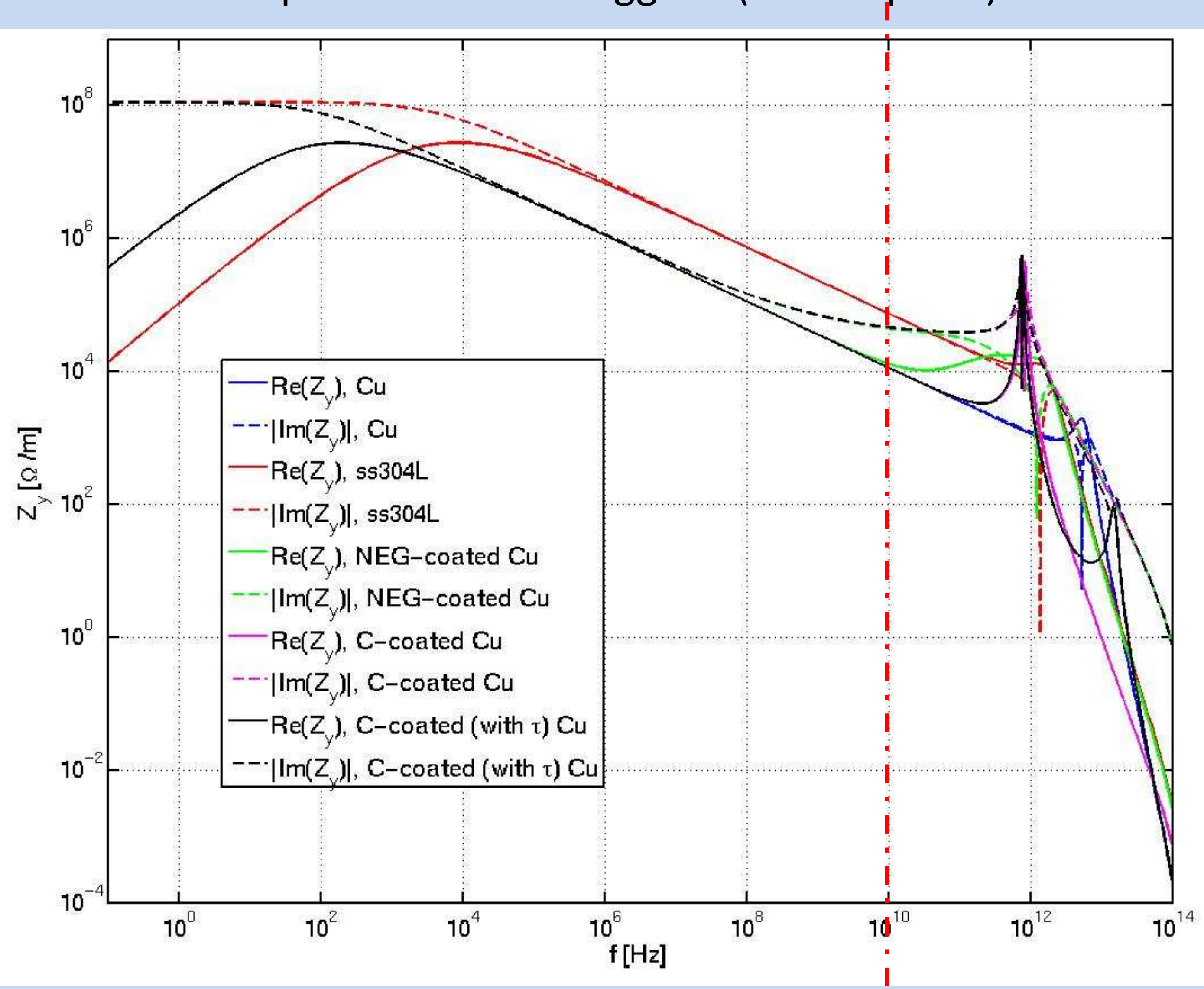


Note: all the impedances and wakes presented have been multiplied by the beta functions of the elements over the mean beta, and the Yokoya factors for the wigglers

N. Mounet

Resistive Wall Impedance: Various options for the pipe

- Vertical impedance in the wigglers (3 TeV option) for different materials



⇒ Coating is "transparent" up to ~*10* GHz

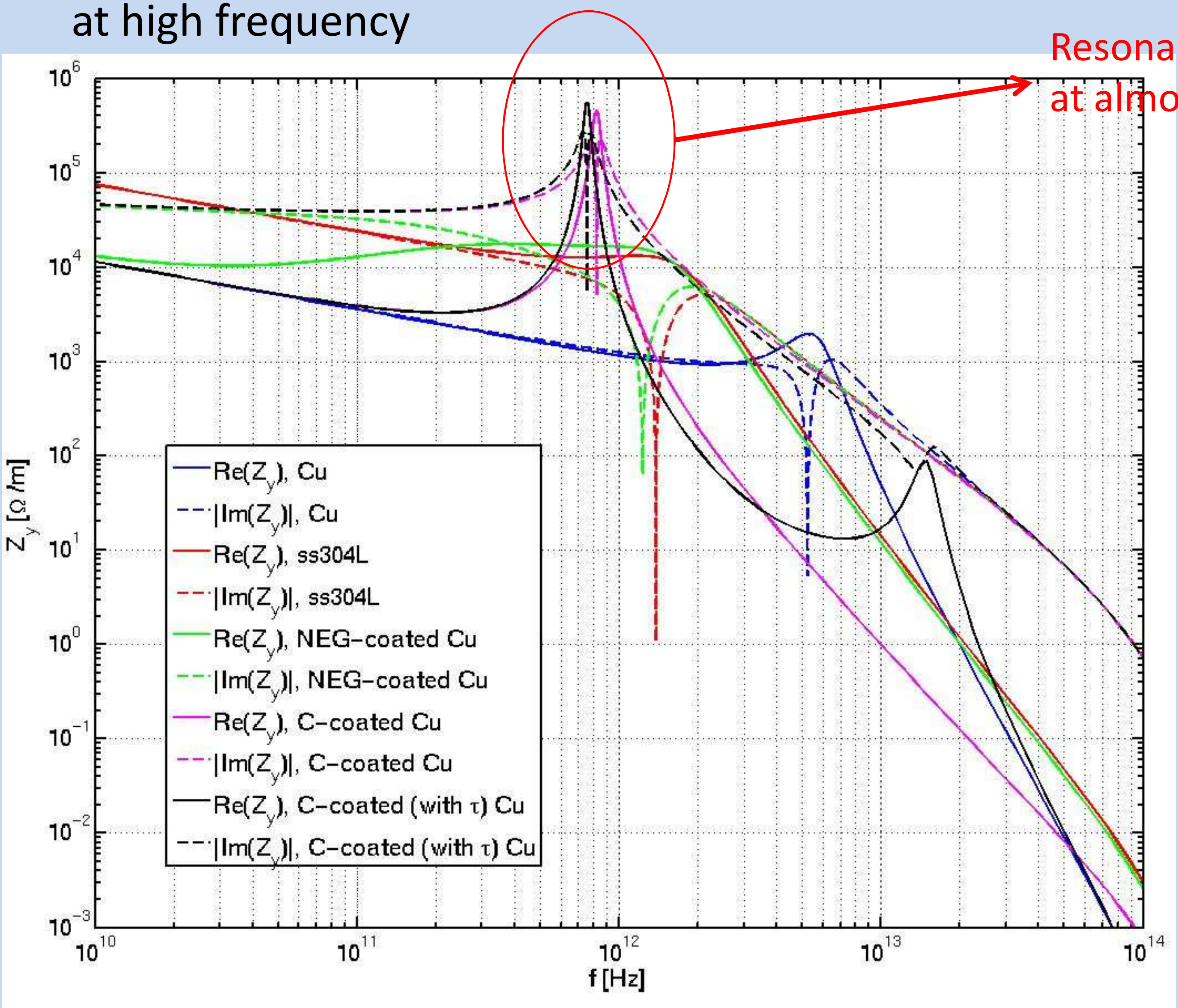
⇒ But at higher frequencies some narrow peaks appear!!

⇒ So we zoom for frequencies above 10 GHz →

N. Mounet

Resistive Wall Impedance: Various options for the pipe

- Vertical impedance in the wigglers (3 TeV option) for different materials: zoom at high frequency

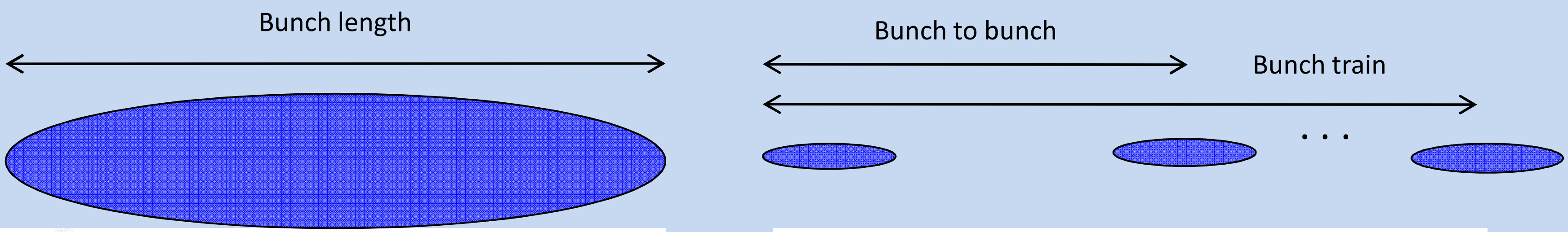


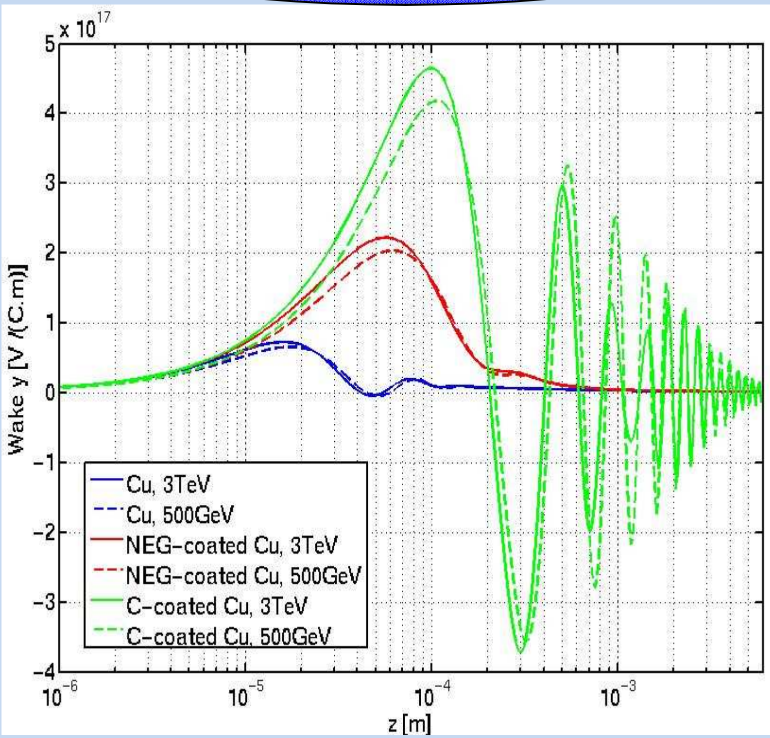
⇒ Above *10* GHz the impact of coating is quite significant.

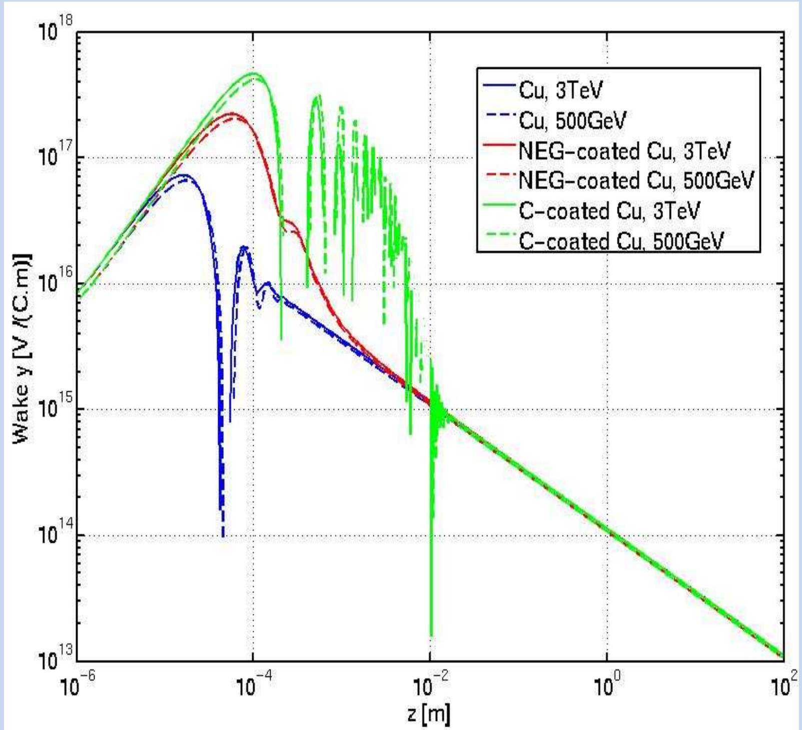
⇒ Relaxation time (as taken from graphite) does not seem to make a large difference on the main peak

N. Mounet

In terms of wake field, we find







- The presence of coatings strongly enhances the wake field on the scale of a bunch length (and even bunch-to-bunch)
- The single bunch instability threshold should be evaluated, as well as the impact on the coupled bunch instability
- This will lower the transverse impedance budget for the DRs

Damping Rings

Next steps…

- Use the average beta functions for the DRs (<βx>=4.568, <βy>=7.568)
- Growth rate for the flat chamber
- Theoretical calculation of the tune shift and the growth rate of the headtail modes
- Check for negative chromaticity (mode 0 would be the only one getting unstable but also it's the easiest one to be corrected-damped with a use of a feedback system/ check on the growth time of the instability)
- Include the effect of octupoles in the simulation (detuning with amplitude), but check for the emittance growth
- Include damping in the HeadTail code
- Include the wake field from the resistive wall with coating and other impedance sources in the HeadTail simulation

Damping Rings

Parameter	Symbol	Value
Energy	p_0 (GeV)	2.86
Norm. transv. emitt.	$\epsilon_{xn,yn}$ (nm)	480, 4.5
Bunch length	σ_z (mm)	1.6
Momentum spread	σ_δ	1.3 $\times 10^{-3}$
Bunch spacing	ΔT_b (ns)	1
Bunch population	N_b	4.1×10^9
Circumference	C (m)	420.56
Coupling	(%)	0.1
Mom. compact.	α	7.6×10^{-5}
Number of bunches per train	n_b	156
Number of trains	n_t	2
Distance between trains	τ_t (ns)	545
Tunes	$Q_{x,y,s}$	55.4, 11.6, 0.00387
Store time/train	T_{st} (ms)	20
Energy loss	ΔE (MeV/turn)	4.2
Damping times	$\tau_{x,y,z}$ (ms)	1.88, 1.91, 0.96
RF frequency	f_{rf} (GHz)	1
RF voltage	V_{rf} (MV)	4.9
Harmonic number	h	1402
Dipole length	L_{dip} (m)	0.43
Dipole chamber rad.	R_{dip} (cm)	1
Number of dipoles	N_{dip} (m)	102
Wiggler length	L_w (m)	2
Wiggler field	B_w (T)	2.5
Number of wigglers	N_w (m)	52
Wiggler gap	r_w (mm)	13
Wiggler width	h_w (mm)	65
Average β_x in wigglers	$\langle\beta_{xw}\rangle$ (m)	4.787
Average β_y in wigglers	$\langle\beta_{yw}\rangle$ (m)	4.185

Backup Slides

Damping Rings

Theoretical tune shift

$$\Omega^{(l)} - \omega_\beta - l\omega_s \approx -\frac{1}{4\pi}\frac{\Gamma\left(l+\frac{1}{2}\right)}{2^l l!}\frac{Nr_0c^2}{\gamma T_0\omega_\beta\sigma}i\left(Z_1^\perp\right)_{\text{eff}}.$$

$$\left(Z_1^\perp\right)_{\text{eff}} = \frac{\sum_{p=-\infty}^{\infty} Z_1^\perp(\omega')h_l(\omega'-\omega_\xi)}{\sum_{p=-\infty}^{\infty} h_l(\omega'-\omega_\xi)}.$$

Backup Slides