Final Impedance Budget of the ALBA Storage Ring

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Outline:

Longitudinal $\frac{Z}{n}$ budget

Longitudinal resonances

Global approach of transverse impedance

- Resistive wall impedance (RW)
  - Effect of multi-layer chambers
  - Budget and thresholds
- Geometrical (broadband) impedance
- TMC-instability
- Head-Tail instability

Conclusions

Longitudinal $\frac{Z}{n}$ budget

The main risk is that the onset of the microwave instability enhances the energy spread.

Potential well distortion below the onset of the microwave instability normally is not a problem since longer bunches and created synchrotron spread can even stabilize (other instabilities) the beam.

For bunched beam the Boussard-criterion has to be used which has according to A.Chao's book the following form:

$$|\frac{Z}{n}| \leq \sqrt{\frac{\pi}{2}}\frac{Z_0}{Nr_e}\gamma\alpha\sigma_z\sigma_E^2 = 873\,m\Omega$$

for homogeneous filling at 400mA (=0.89mA/bunch)

Longitudinal $\frac{Z}{n}$ budget con't

universal and strict application of the same criterion:

$$|\sum \frac{Z}{n}| \leq \sum |\frac{Z}{n}| \qquad |\sum \frac{Z}{n}|_{eff} \leq \sum |\frac{Z}{n}|_{eff} \leq 873 m\Omega$$

the contributions:

- vacuum chamber elements
  determination of sets of (f_r, R_s, Q_r) by a fit of several resonators to the impedance spectrum. Computation of $|Z/n|_{eff}$
- RF-cavity
  fit of a $Z/n^{3/2}$ function to the spectrum
- long. reduced RW-impedance
  Analytical computation of $|Z/n|_{eff}$ from the geometrical parameters of the different low-gap and standard chambers.

Longitudinal $\frac{Z}{n}$ budget con't

constellation	RW	different vacuum elements	cavities	total
virgin machine(VM)	181.2	145.8	685.20	1012.2
VM+wiggler chamber	180.5	149.6	685.20	1015.3
VM+wiggler+3NEG/Al	179.5	160.5	685.20	1025.2
VM+wigg+3invacs	180.2	163.3	685.20	1028.7
VM+wigg+3invacs+3NEG/Al	179.3	175.2	685.20	1039.7

Installation of NEG/Al-chambers respectively in-vacuum undulators does not increase the RW-part of |Z/n|. Better conductivity cancels out more narrow chamber.
the BBR-part of |Z/n| only increases moderately with more low-gap chambers.

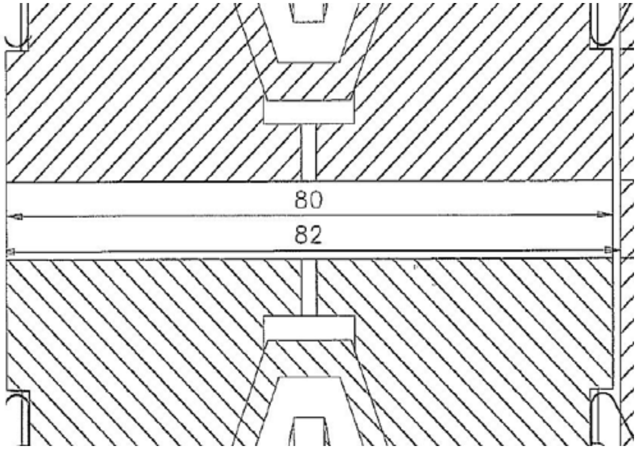
The cavities provide the largest contribution but also the most uncertain one. The integral over |Z/n| has to be cut off somewhere before the its lower border reaches 0. Worst case was assumed.

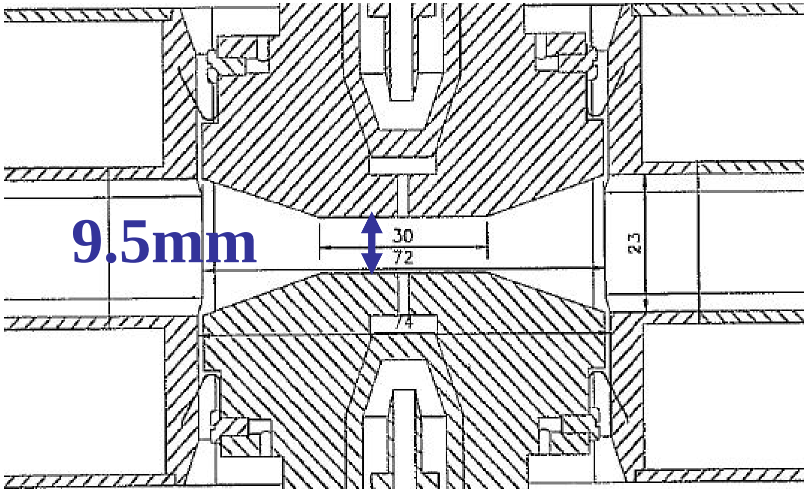
the threshold of the Boussard-criterion is slightly exceeded partly due to its more strict interpretation. Tracking simulations have shown that in general the onset of the MW-instability is typically much higher than the one given by Boussard.

Resonance behaviour
study of longitudinal beam stability

About 2/3 of all elements have been examined on possible generation of dangerous HOMs.

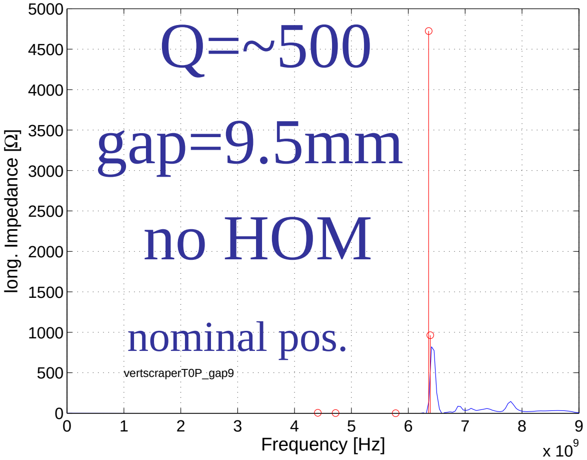
Example: vertical scraper(nominal 9.5 x 80mm^2)

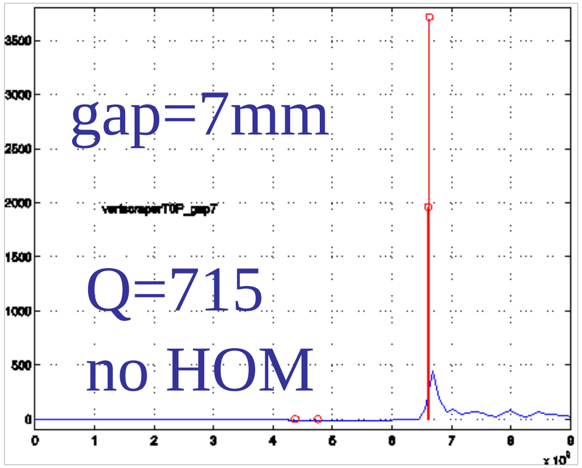


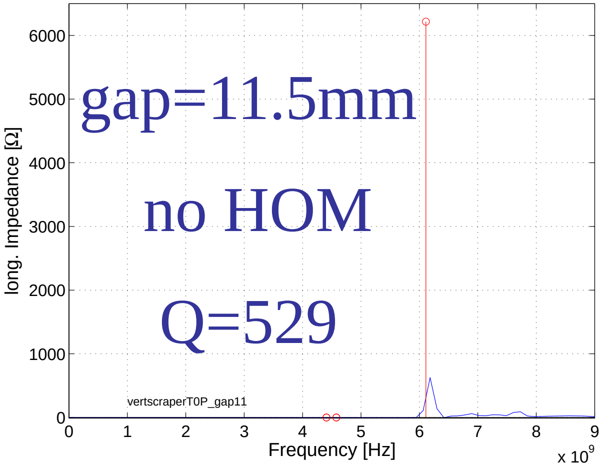


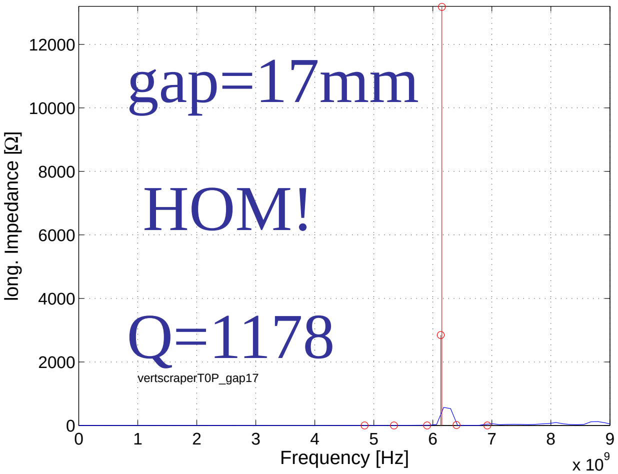
Resonance behaviour

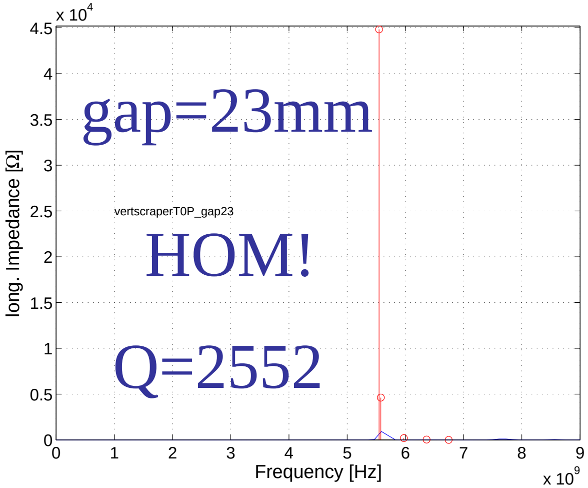
Overlay of long. Impedance(t-domain) and eigenmodes(f-domain)









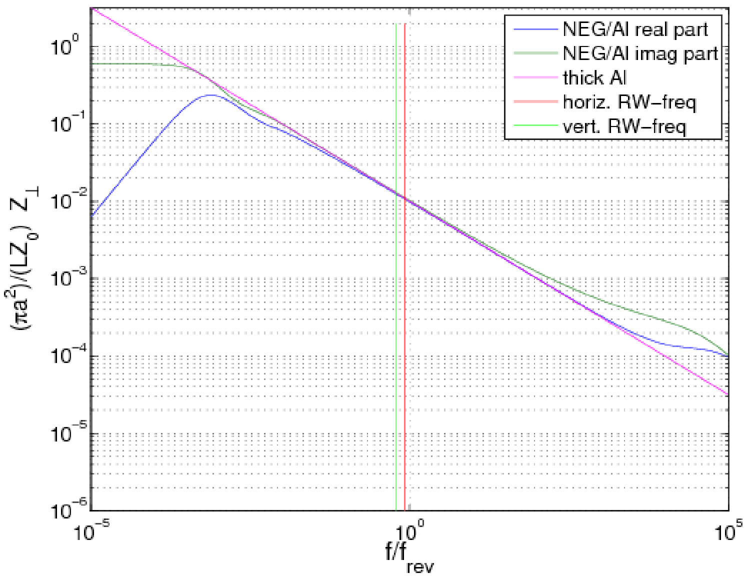


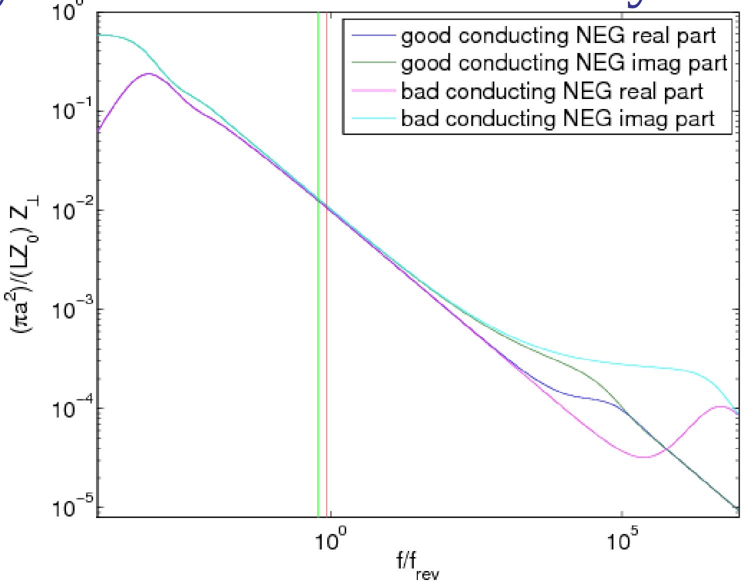
the scraper in withdrawn state can generate a HOM, in normal position no.

Effects of multi-layer chambers on the transverse impedance

NEG-coated Al-chambers

Study of the effect of NEG-layers on the RW-instability





according to Burov, Lebedev EPAC'02, Paris, p.1452

NEG only increases impedance at relative high frequency
only relevant for single bunch effects like TMCI, HT etc.

Furthermore, low conducting NEG
only has effect on high frequencies
no effect at the excitation freq. of RW

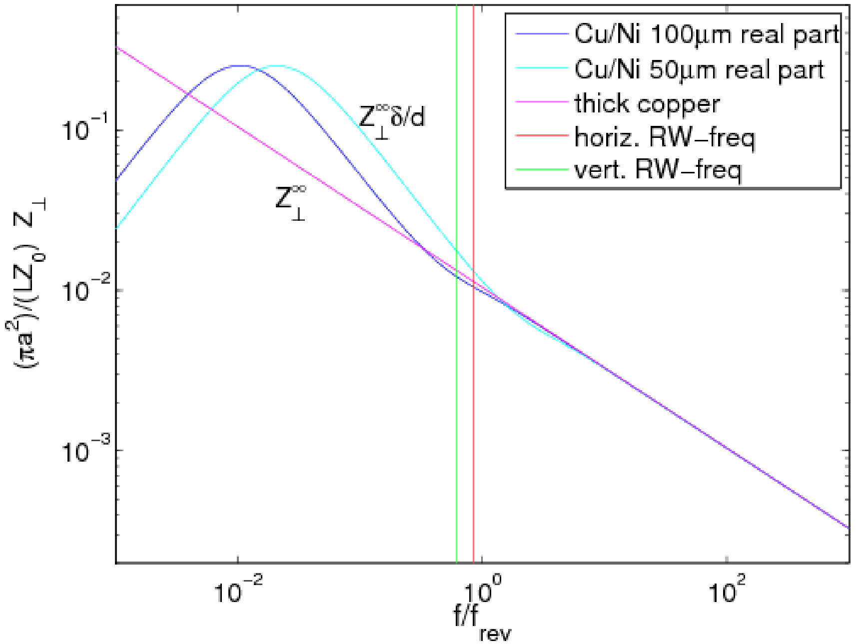
Possible effects of surface roughness have not been studied yet, but will be done if necessary.

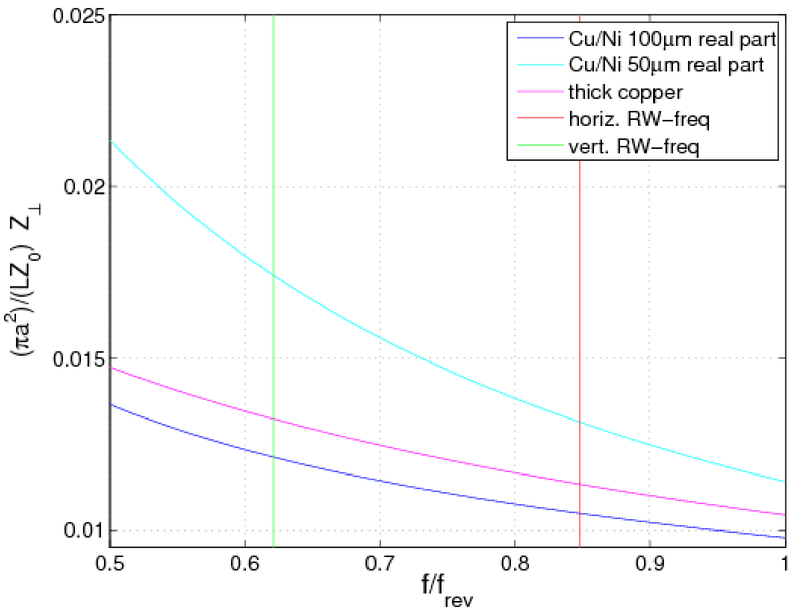
Effects of multi-layer chambers on the transverse impedance

Metal sheets covering the jaws of the in-vacuum undulator

Model of its transverse impedance given by Cu/Ni-layer in air

the impedance' real part of a single layer on a magnet and in air have very similar values



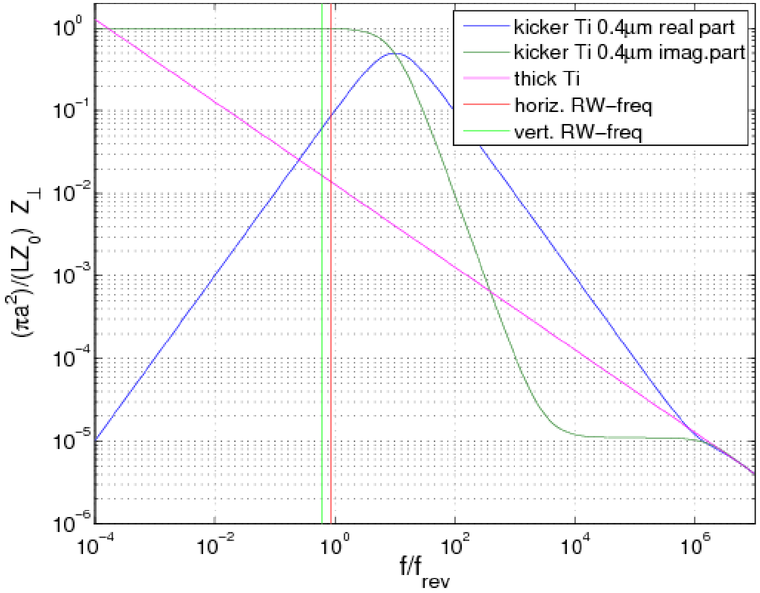


according to Burov, Lebedev EPAC'02, Paris, p.1452

Originally 50µ sheets were forseen, finally they will be 100µ thick for the benefit of the beam stability.

Effects of multi-layer chambers on the transverse impedance

ceramic kicker chamber with
400nm Titanium cover



according to Danilov, Henderson, Burov, Lebedev EPAC'02, p.1464

other descriptions, for instance the one of Piwinski
(PAC'77, p.1364) predict lower values at the RW-frequencies

To the contrary of the other multi-layer chambers, the kickers have enhanced impedance' real part at the RW-excitation freq.

Resistive wall transverse impedance budget

thresholds and growth rates of mode m=0 at zero chromaticity

constellation	A_V[kΩ√GHz]	I_{th} [mA]	τ^{-1} [s^{-1}]	A_H [kΩ√GHz]	I_{th} [mA]	τ^{-1} [s^{-1}]
virgin machine(VM)	1723.1	38.8	1942.69	626.6	161.4	604.58
VM+wiggler chamber	1734.7	38.6	1955.77	634.3	159.4	612.01
VM+wiggler+3 NEG/Al	1802.3	37.1	2031.99	677.1	149.3	653.30
VM+wigg+3 invacs	1815.6	36.9	2046.98	688.4	146.9	664.21
VM+wigg+3 invacs+3NEG/Al	1883.2	35.5	2123.20	731.2	138.3	705.50

phase I

$$\beta Z_{\perp} = \frac{A_{\perp}}{\sqrt{\omega_0 (1 - Q_{\perp})}}$$

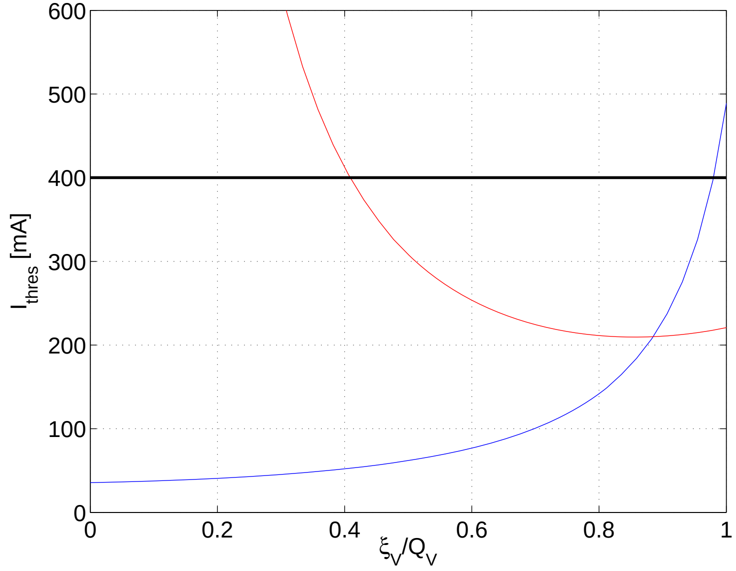
The increase of RW-impedance is only moderate upon installation of low-gap chambers, the standard beam chamber 14x72mm^2 of SS makes up the largest part

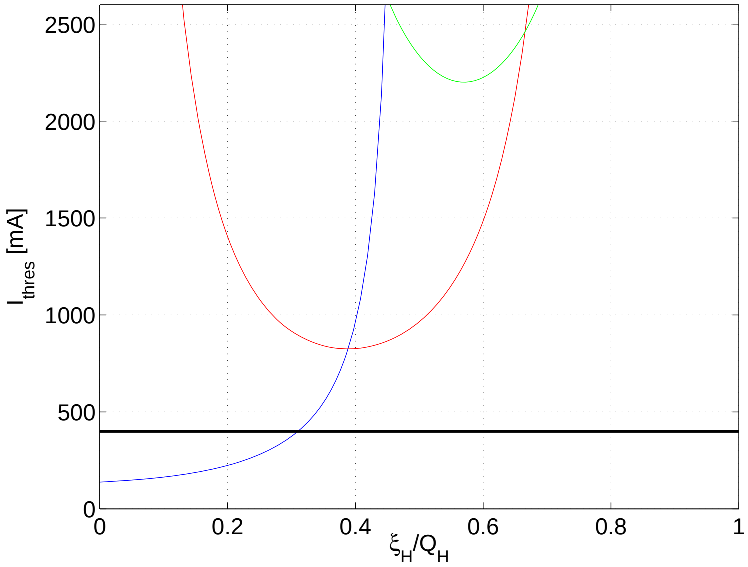
Resistive wall instability

the thresholds as a function of the normalized chromaticity

calculated with a modified version of ZAP

phase I constellation

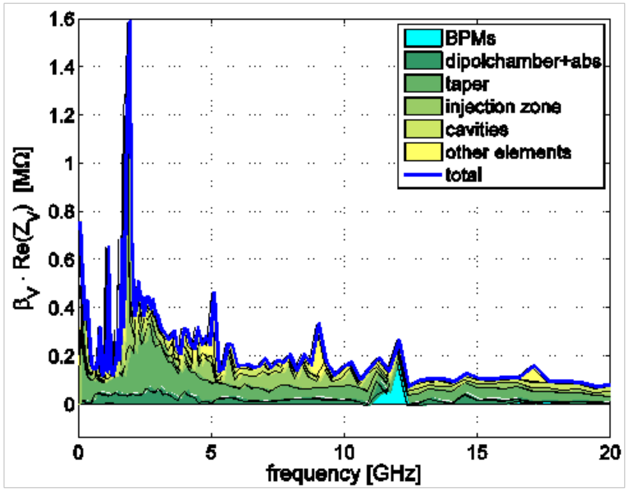


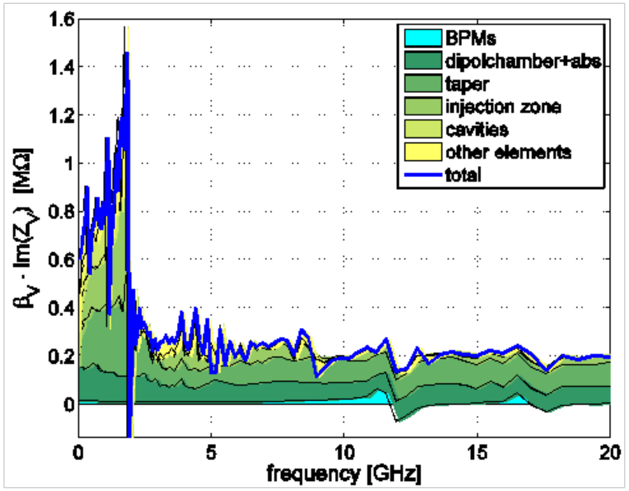


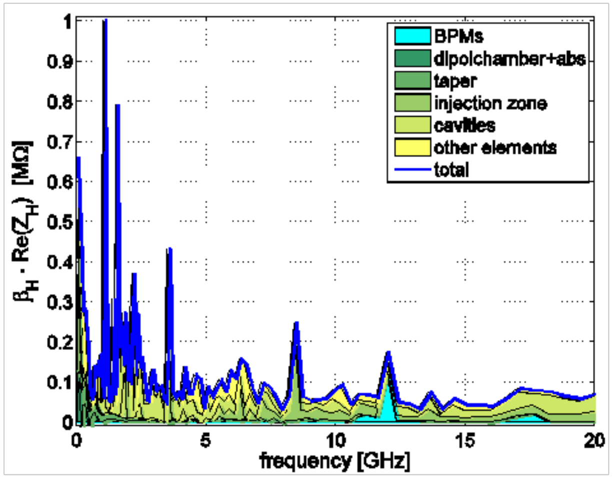
In the vertical plane the threshold is ~35.5mA
in the horizontal one ~138.3mA.

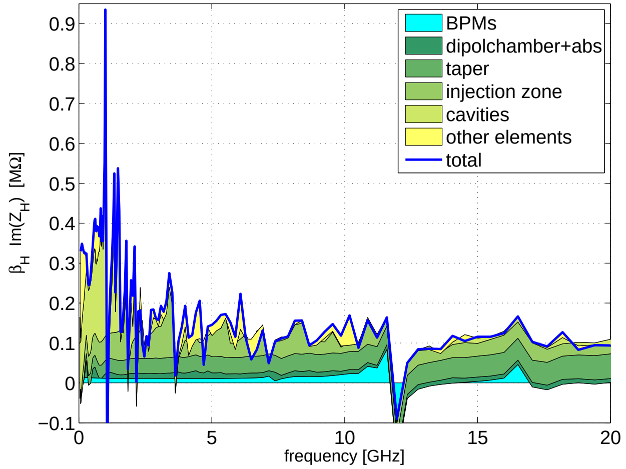
transverse feedback system will be installed to cure it.

spectra of the broadband impedance phase I









computed with GdfidL(W.Bruns)

TMCI thresholds

Single bunch threshold of TMCI is computed by combining RW-impedance and geometrical impedance. Modified MOSES versions(H.Y.Chin, CERN-TH,1988) were used for this computation where different RW-models (as shown above) were implemented.

constellation	vertical I_{thres} [mA]	I_{geo} [mA]	I_{RW} [mA]	I_{RW} / τ_{RW}	horizontal I_{thres} [mA]	I_{geo} [mA]	I_{RW} [mA]	I_{RW} / τ_{RW}
virgin machine(VM)	21.5	73.3	30.42	59.10	48.0	154.2	69.74	365.51
VM+wiggler chamber	21.1	69.6	30.18	59.03	46.8	149.6	68.11	374.55
VM+wiggler+3NEG/Al	19.1	61.8	27.64	56.16	42.8	139.1	61.82	426.81
VM+wigg+3invacs	18.7	51.5	29.36	60.10	42.4	122.4	64.87	441.17
VM+wigg+3invacs+3NEG/Al	17.0	47.1	26.6	56.48	40.1	115.3	61.48	497.73

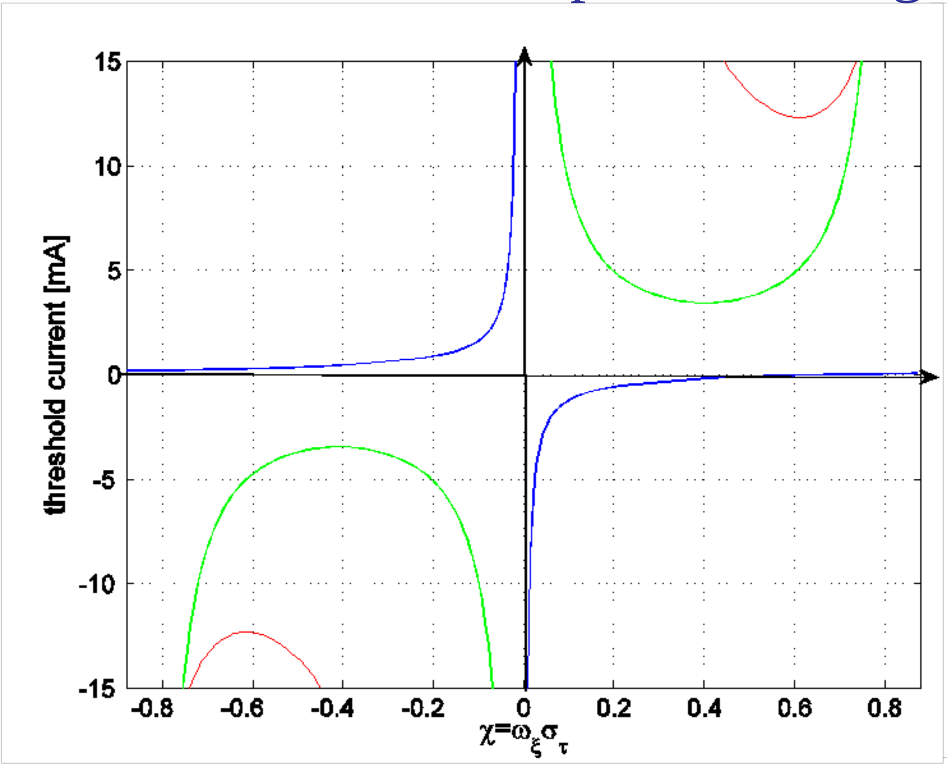
To see the effect of multi-layer vacuum chambers, measure the ratio of the imaginary to the real part of the RW-contribution to total impedance

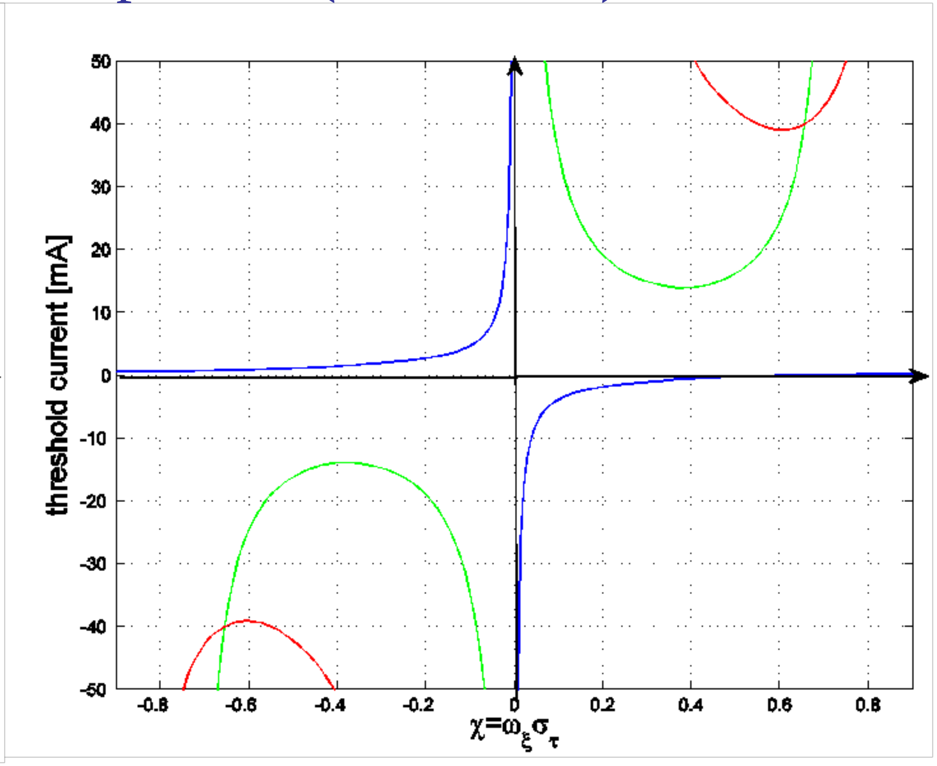
imaginary part represented by I_{RW}^{TMCI}, real part by growth rate τ of the resistive wall instability

$$\frac{1}{I_{TMCI}} \approx \overbrace{\frac{\mathrm{Im}(\beta_\perp Z_\perp)_{geo}}{4\sqrt{\pi}(\omega_s\sigma_\tau)(E/e)}}^{\frac{1}{I_{geo}^{TMCI}}} + \overbrace{\frac{\mathrm{Im}(\beta_\perp Z_\perp)_{RW}}{4\sqrt{\pi}(\omega_s\sigma_\tau)(E/e)}}^{\frac{1}{I_{RW}^{TMCI}}}$$

Head-Tail instability

transverse impedance budget of phase I (BBR+RW):





no problem at 400mA homogeneous filling

In the vertical plane the threshold is ~3.6mA
in the horizontal one ~15mA.
smaller than the TMCI-thresholds, with Landau damping they might increase.

Conclusions

- The impedance values are much more exact as they were 3years ago
- However, the Z/n-values, in particular of the cavity have still to be improved.
- Search for dangerous long. HOMs in the vacuum system revealed 1 HOM in the outlets of the injection kickers, it’s cured by installation of RF-fingers.
- Interesting proposal for the detection of the enhancement of RW-impedance of chamber walls with several layers.
- Some optimisations in the computations of the thresholds can still be done, apart from that we are ready to test the impedance model with beam.