ESRF | The European Synchrotron

Investigation on an unexpected resonant mode affecting BPM measurements

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ESRF (Grenoble, France)

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OUTLINE

Part I: Introduction - BPM issue

Part II: Resonance characterization

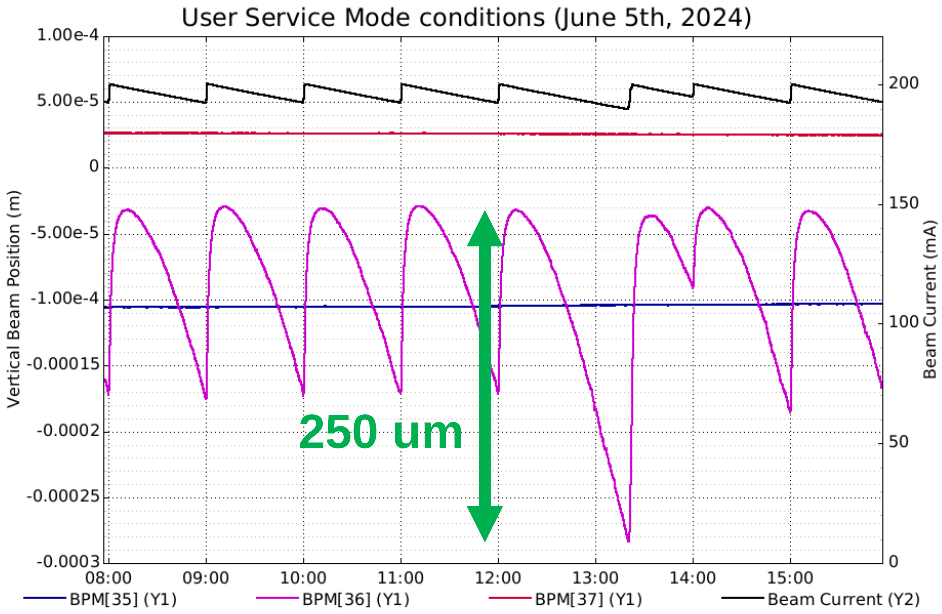
Part III: A possible explanation

Part IV: Solutions

Part I: Introduction - BPM issue

THE ISSUE WITH SOME BPM MEASUREMENTS

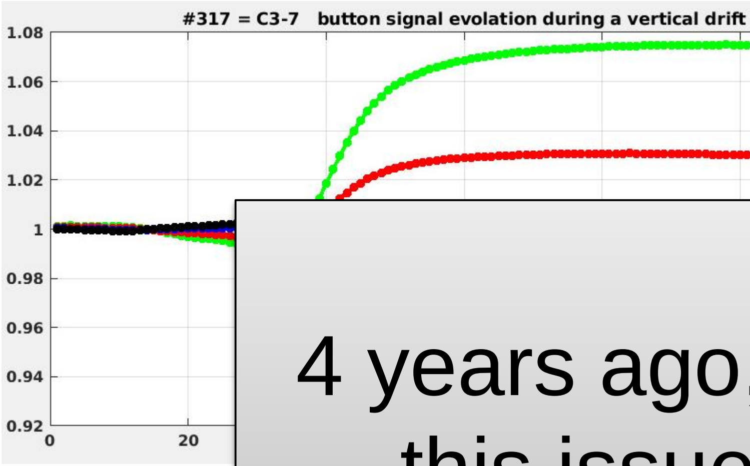
Approximately 12 BPMs among the 320 BPMs are affected by a phenomenon which generates un-physical measurements:



It is not physical:

- Neighboring BPMs are perfectly stable (red and blue curve)
- Large incoherency associated with this effect
- Position sensors were installed in the tunnel and did not measure a chamber displacement

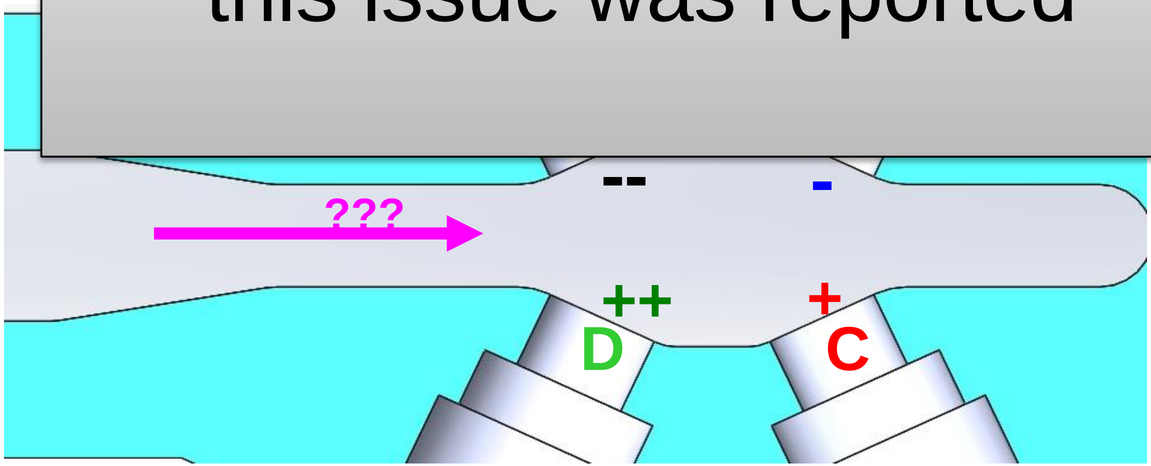
STRANGE BEHAVIOR ON SOME 7TH BPMS



this is NOT coherent … !
i.e. it can NOT be explained by
neither beam motion
nor block motion

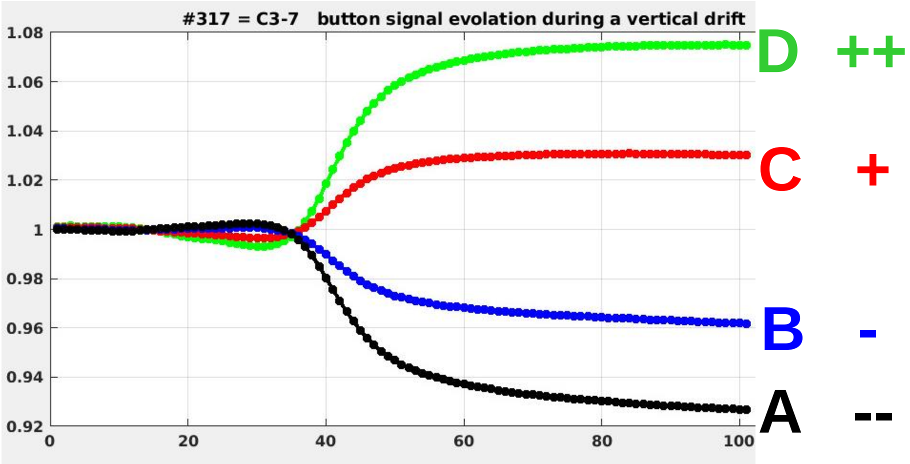
ne

nals with
mplitudes



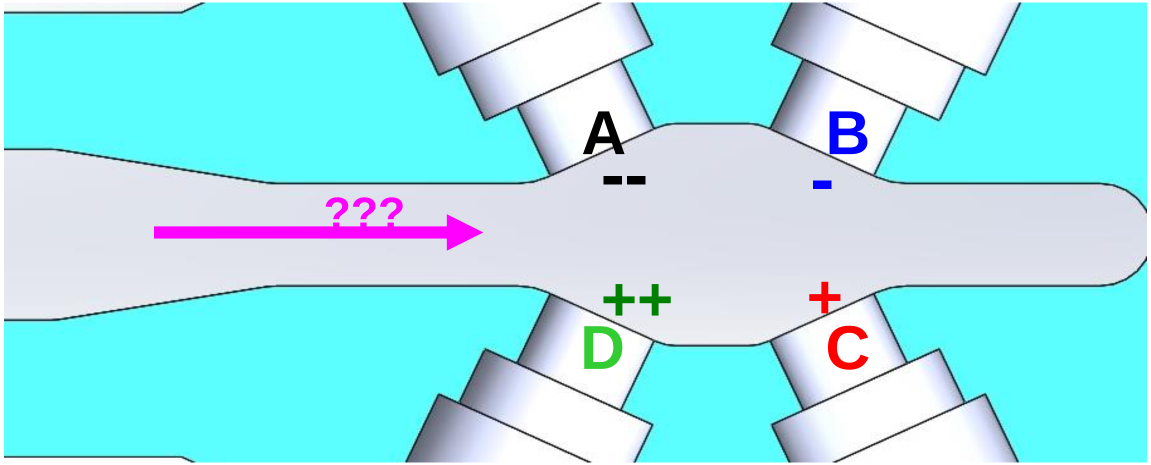
4 years ago, at DEELS 2020 this issue was reported

STRANGE BEHAVIOR ON SOME 7TH BPMS



this is NOT coherent … !
i.e. it can NOT be explained by neither beam motion nor block motion

RF mode coupled to the buttons?
adding to buttons' signals with different phases and amplitudes



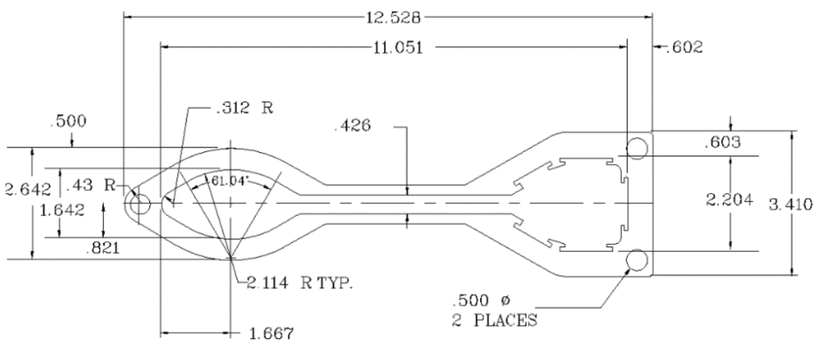
DEELS 2020

SIMILAR ISSUE AT APS

We suspected a RF resonance, but where???

Similar issue was already reported at APS [Kang1999]:

<u>**Damping spurious harmonic resonances in the APS storage ring beam chamber**</u>
Y. Kang, G. Decker, and J. Song
Proceedings of the Particle Accelerator Conference, New York, 1999



"The structure behaves like a ridge waveguide so that the cut-off frequency of the waveguide mode becomes lower."

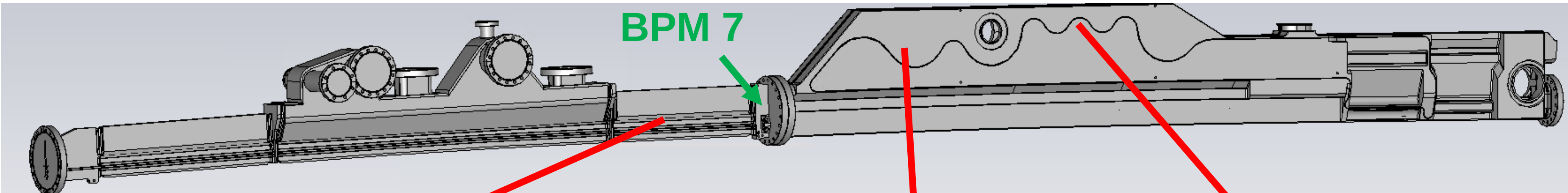
→ There was a resonant mode at 350 MHz in the whole vacuum chamber

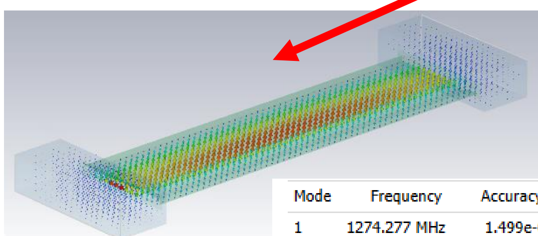
Are we affected by a similar effect?

CST SIMULATIONS TO FIND THE RESONANT MODE

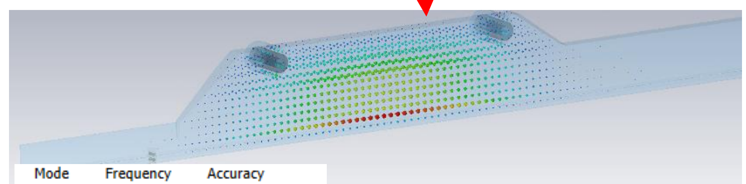
Despite an intensive simulation effort, no possible candidate was found considering just the vacuum chamber shape.

BPM 7



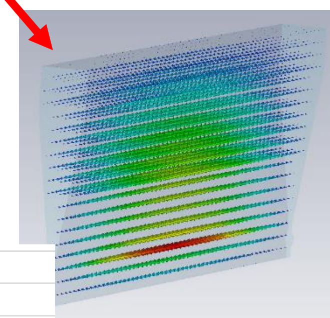


Mode	Frequency	Accuracy
1	1274.277 MHz	1.499e-08
2	1326.997 MHz	3.405e-07
3	1451.333 MHz	6.035e-07



Mode	Frequency	Accuracy
1	453.1753 MHz	4.988e-09
2	454.8202 MHz	5.408e-09
3	474.4779 MHz	4.878e-08
4	475.3486 MHz	2.118e-08
5	578.6466 MHz	0.0004794
6	614.2488 MHz	0.0001052
7	664.1759 MHz	1.821e-05
8	726.8071 MHz	2.493e-06

Marked 2313 of 107519 for refinement.

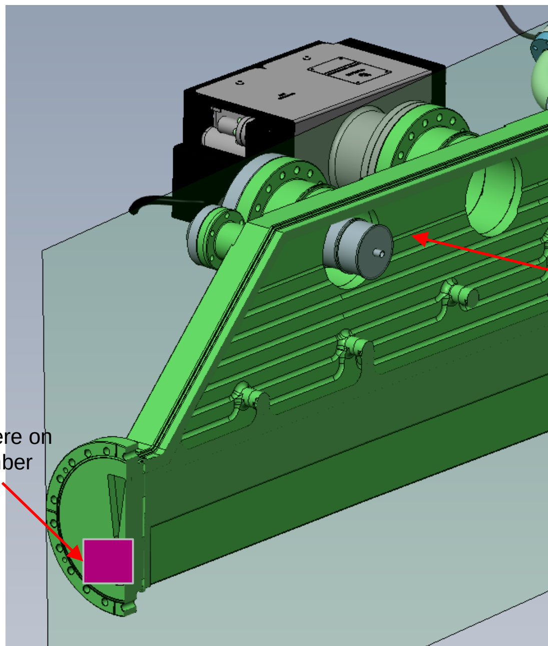


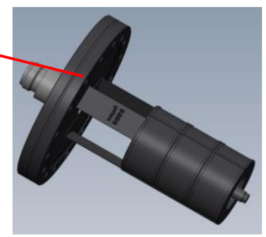
Eigenmode solver results:

Mode	Frequency	Accuracy
1	582.053 MHz	4.518e-07
2	637.1837 MHz	2.259e-09
3	720.0596 MHz	1.414e-08
4	822.2688 MHz	1.249e-08
5	937.2439 MHz	2.95e-08

NEG PUMP RESONANCE

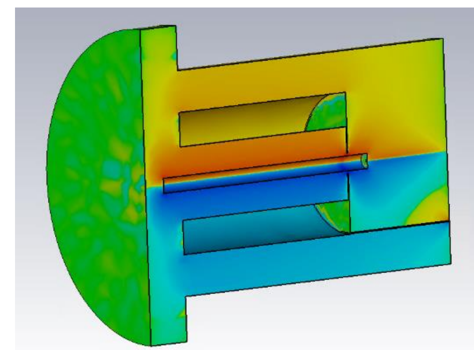
We started including more details in the simulation to find this mode… and there was a first candidate!





This NEG pump (completely passive device) can be modeled in such a way that a mode close to 350 MHz could be found!

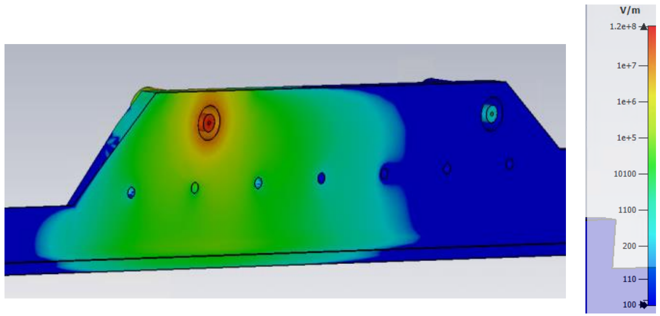
CST simulation:



NEG PUMP RESONANCE

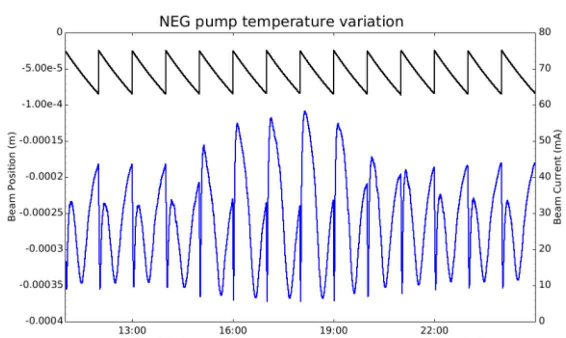
That was encouraging, but:

- **The mode was strongly attenuated at the location of the BPM**



The E-M field is reduced at a level of 10^{-6} at the BPM location

- **Temperature changes was showing very little effect**

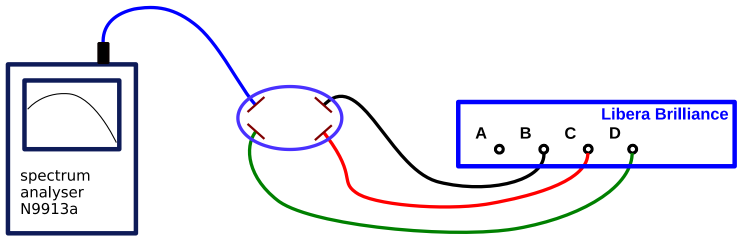


Here we increased the NEG pump temperature up to 117 °C, the effect was much smaller than expected if the resonance was located there
(04 Dec. 2023)

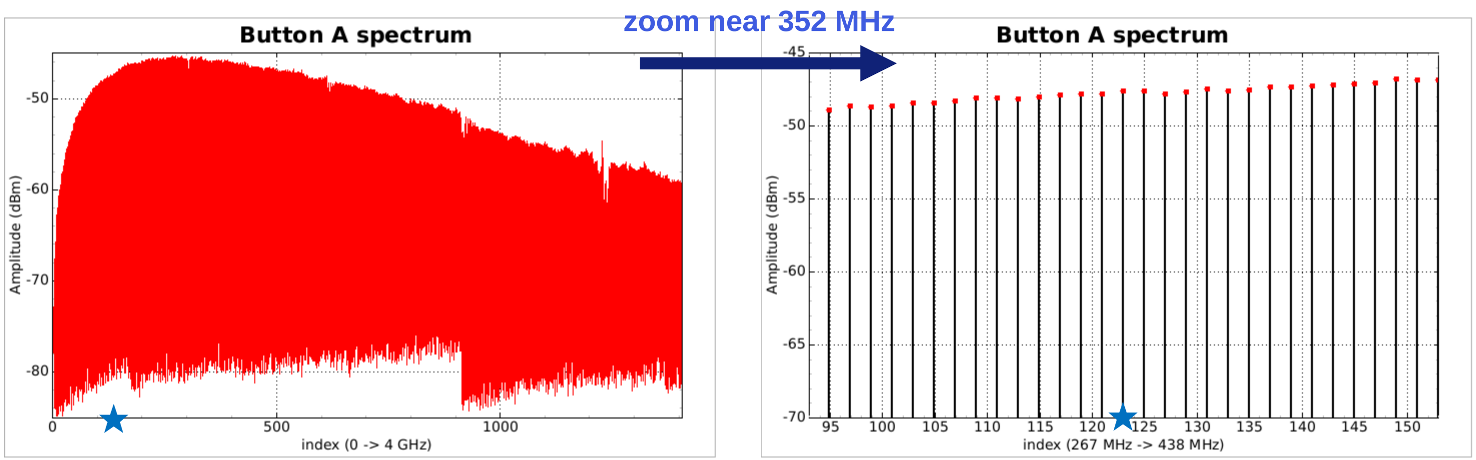
Part II: Resonance characterization

MODE SPECTROSCOPY USING A SPECTRUM ANALYSER

In parallel with the simulations, we wanted to "see" the mode:



As mentioned in [Kang1999], this measurement has to be done with a small number of bunches in the ring to have a richer beam spectrum



16-bunch mode
Δf = 5.68 MHz

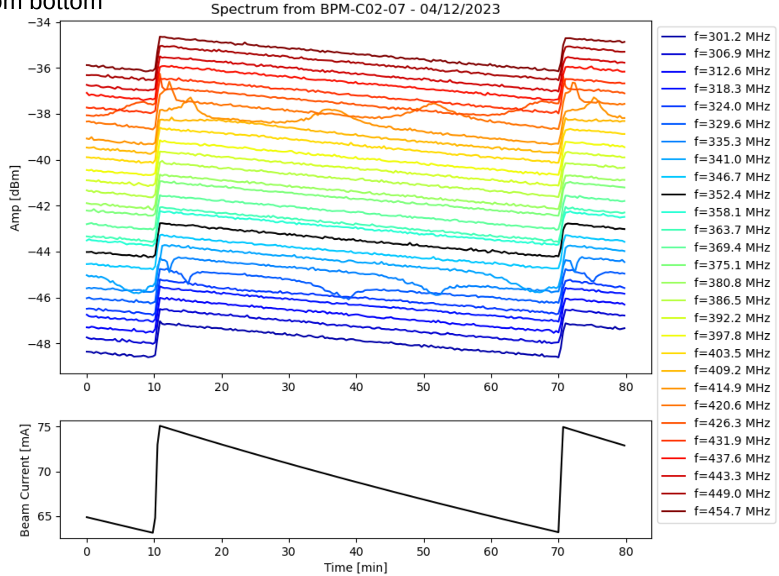
★ 352.374 MHz, at which Libera Brilliance performs BPM measurement

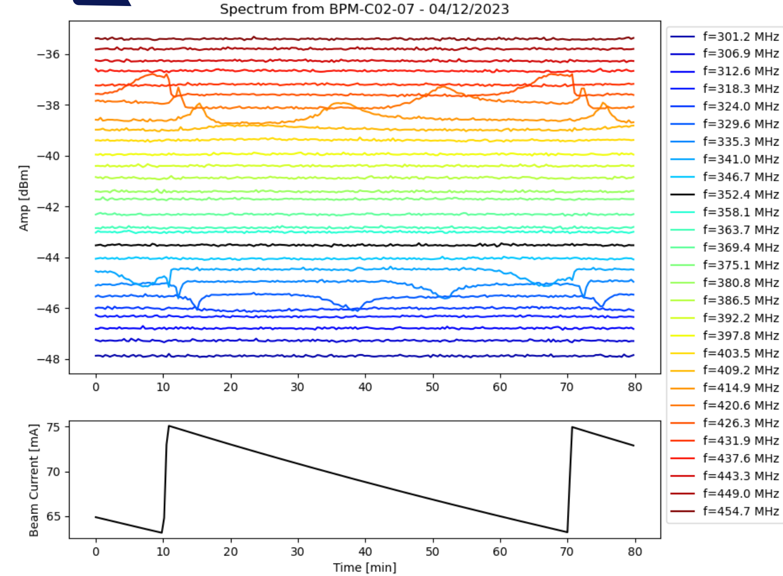
MODE SPECTROSCOPY USING A SPECTRUM ANALYSER

The spectrum is recorded during a few hours, and plotted with time:

renormalization with beam current

traces are
shifted by 0.4 dB
from bottom



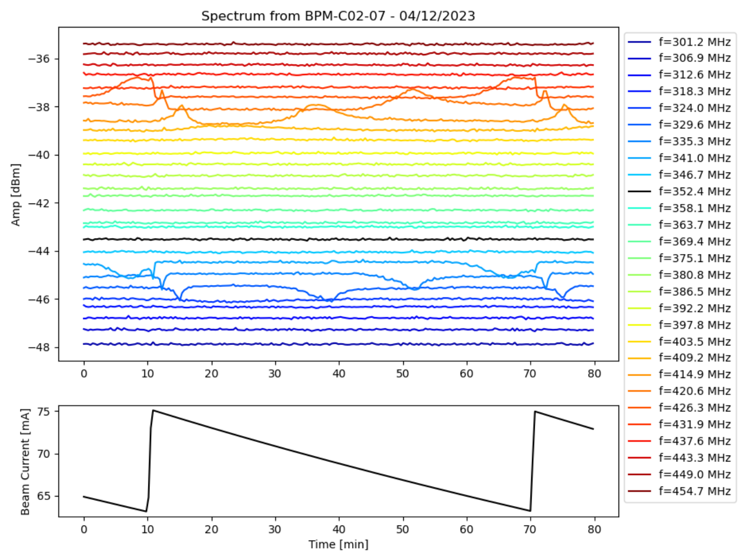


MODE SPECTROSCOPY USING A SPECTRUM ANALYSER

We can see two modes (but other affected BPMs only have one mode), whose exact frequency moves by ~15 MHz during a normal decay

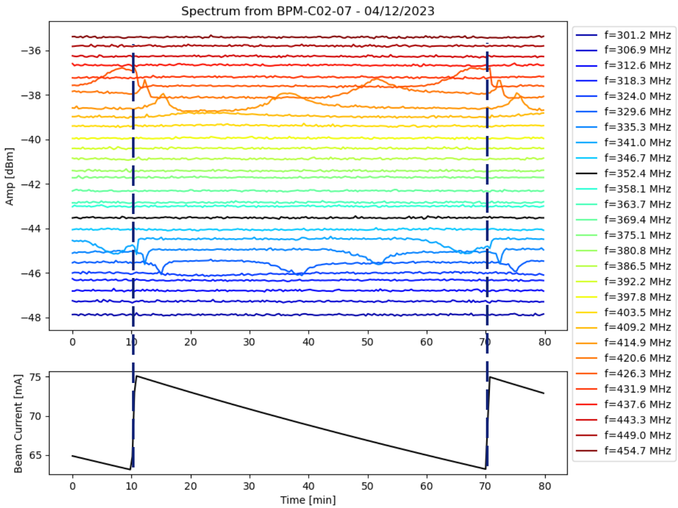
When the mode crossed 352.374 MHz (black line), it affects BPM measurement.

Below BPM measurement was not affected, but the issue was present in a different filling mode



MODE SPECTROSCOPY USING A SPECTRUM ANALYSER

There is a lag between beam current and mode frequency, which indicates that the frequency change is due to a thermal effect.

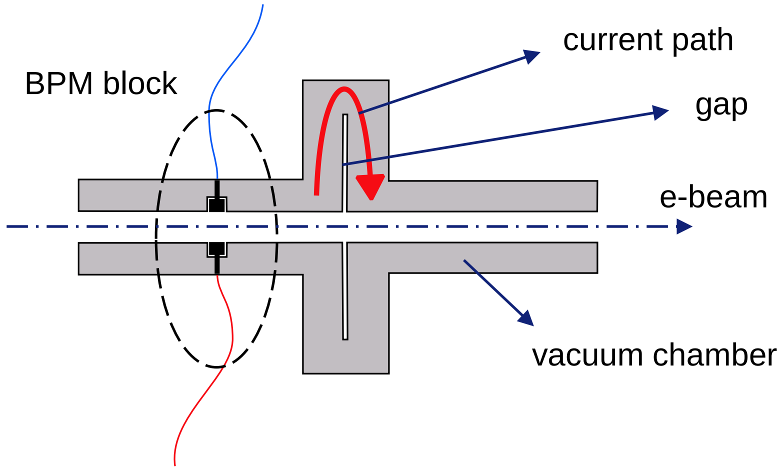


→ The effect of temperature was studied and has indeed a strong effect (see supplementary slides)

Part III: A possible explanation

THE GAP THEORY

The idea to explain the resonance was to search for a resonant structure like this:



The gap itself behaves like a capacitor, the path around the gap has an inductance

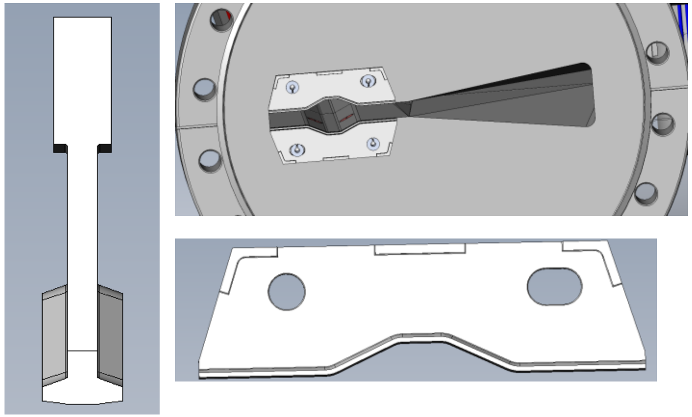
→ this makes a resonating LC circuit

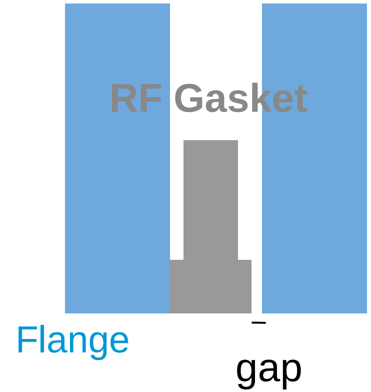
It would explain:

- **How the resonant frequency can change so much with temperature**
- **How we can have a resonance in a narrow place, next to the BPM block**

FIRST CANDIDATE FOR A GAP: RF GASKET

The first candidate for such a gap was the RF gasket between the flanges:



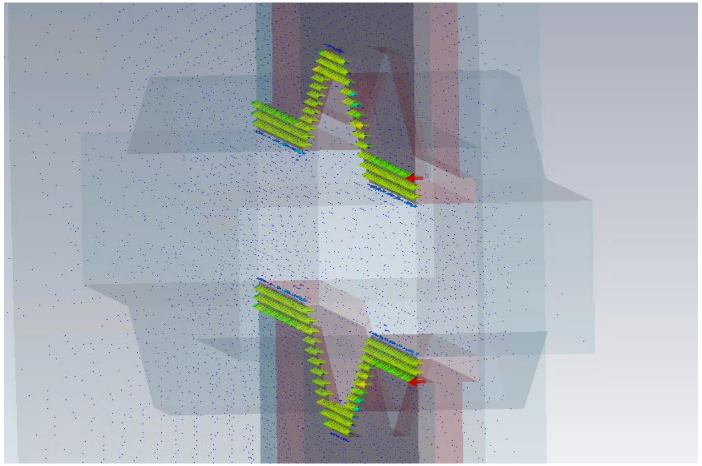


It is a piece of aluminium placed between the flanges, and compressed to ensure electrical contact and shield the beam from any unwanted impedance sources.

<u>Hypothesis:</u> during the bake out, a small gap is created because the aluminium gasket expands more than the stainless steel flange, resulting in plastic deformation.

FIRST CANDIDATE FOR A GAP: RF GASKET

CST simulations of this possible gap showed that a **gap opening of 2.8 µm** would create a resonance frequency close to 352 MHz

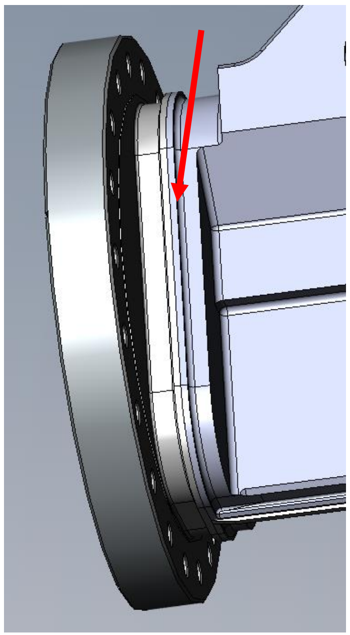


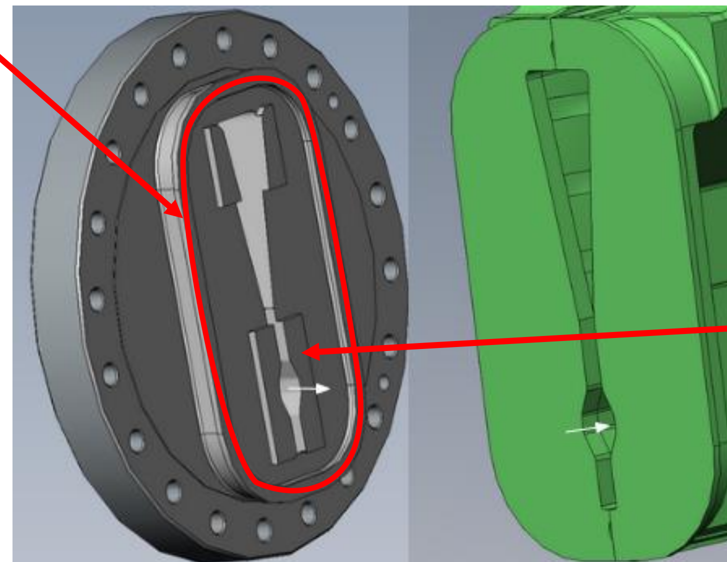
After several discussions with mechanical engineers and some thermo-structural simulations (ANSYS), we are still not sure that this gap exists…

SECOND CANDIDATE FOR A GAP: WELDING JOINT

Second candidate: a stainless steel flange attached to an aluminum chamber by welding joint

Weld around outside





stainless steel flange   aluminum chamber

this surface is supposed to touch the aluminum chamber, but can leave a gap if dimensions are not perfect

SECOND CANDIDATE FOR A GAP: WELDING JOINT

$A = 555.4\ mm^2$

$g = 15.7\ \mu m$

$C = 313.2\ pF$

$\omega_0 = 2\pi * 352.863\ MHz$

$L = 0.65\ nH$

$Q = 275$

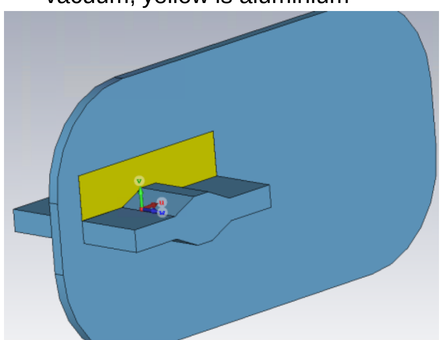
$R/Q = 1.4\ Ohms$

$R_s = 385\ Ohms$

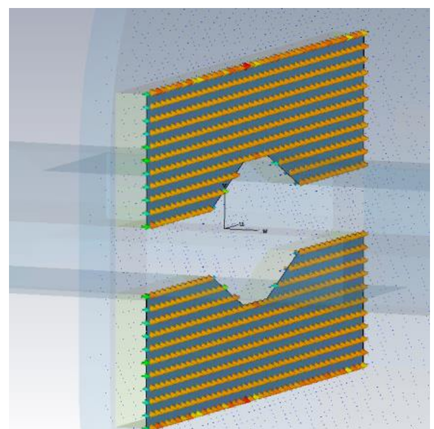
$P_{loss} = 1.7\ W$ (4x10mA)

- Tolerances were not specified, so a variance due to manufacturing errors of the gap size is expected. Achieving <20 µm alignment considered very difficult.

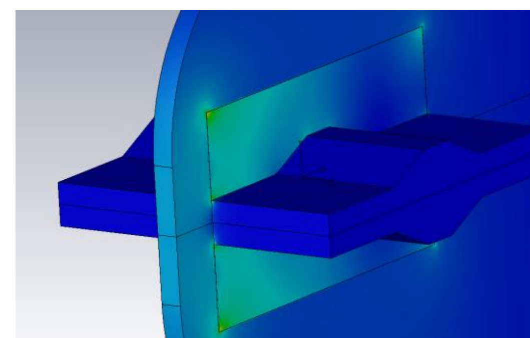
CST simulation model, blue is vacuum, yellow is aluminium



E-field vectors showing capacitive gap



Abs(H-field) showing stronger field on part closest to outer flange



Part IV: Solutions

POSSIBLE SOLUTIONS

Possible solutions to cure a BPM:

- **Change the vacuum chamber**

  → very heavy intervention, not really an option

- **Control the temperature around the gap**

  → tested (see supplementary slides)

- **Squeeze the vacuum chamber to reduce/close the gap**

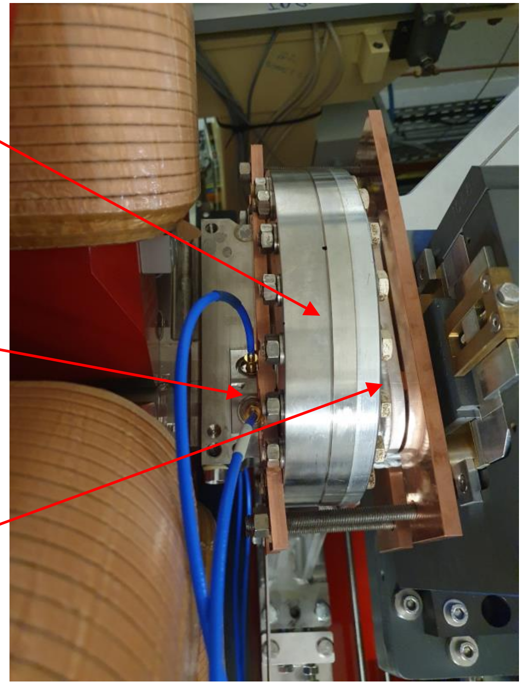
  → a “clamp” was designed, more effective than temperature control (see next slides)

Two clamps were fabricated to reduce/close the gap (#1 or #2):

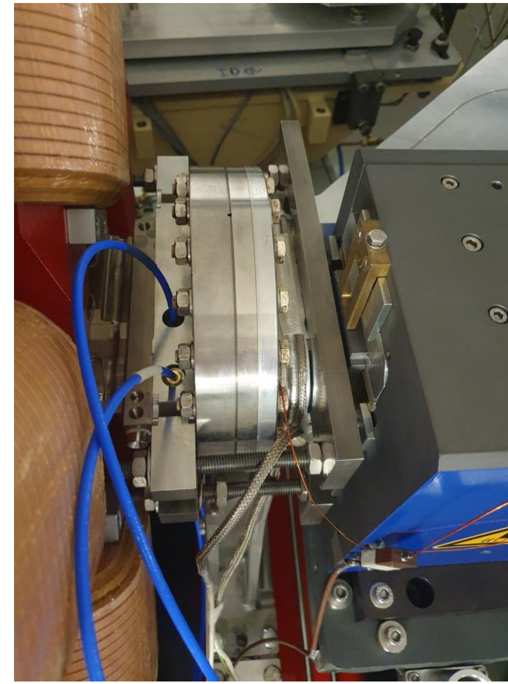
gap #1

BPM

gap #2



Clamp v1
(CuCrZr)

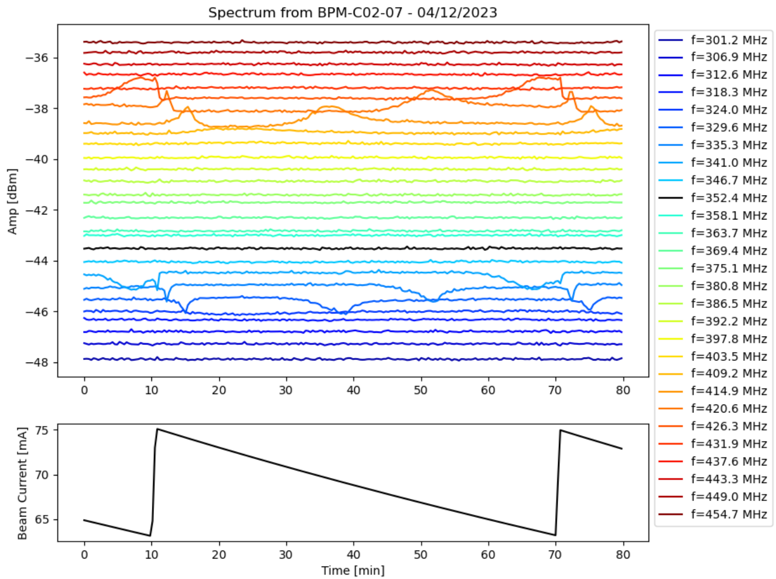


Clamp v2
(thicker, stainless steel)

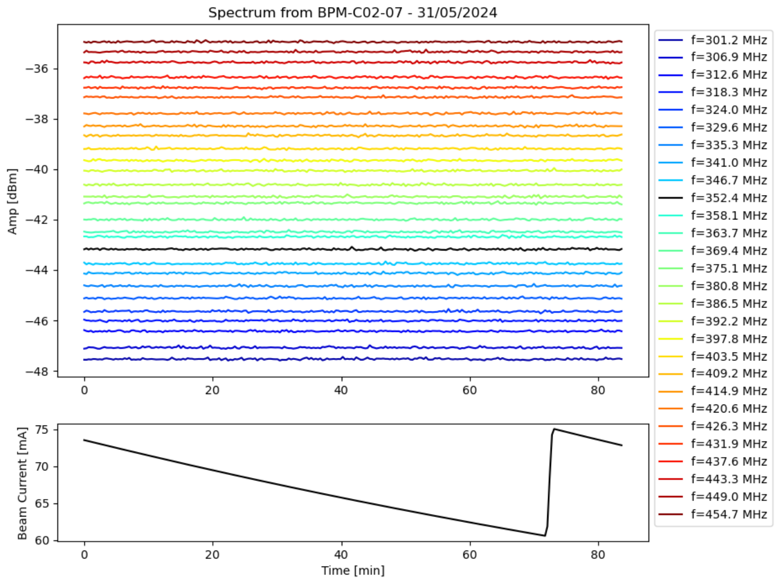
EFFECT OF CLAMP V2 ON C02-07

with clamp v2, both modes are completely suppressed

No clamp



Clamp v2

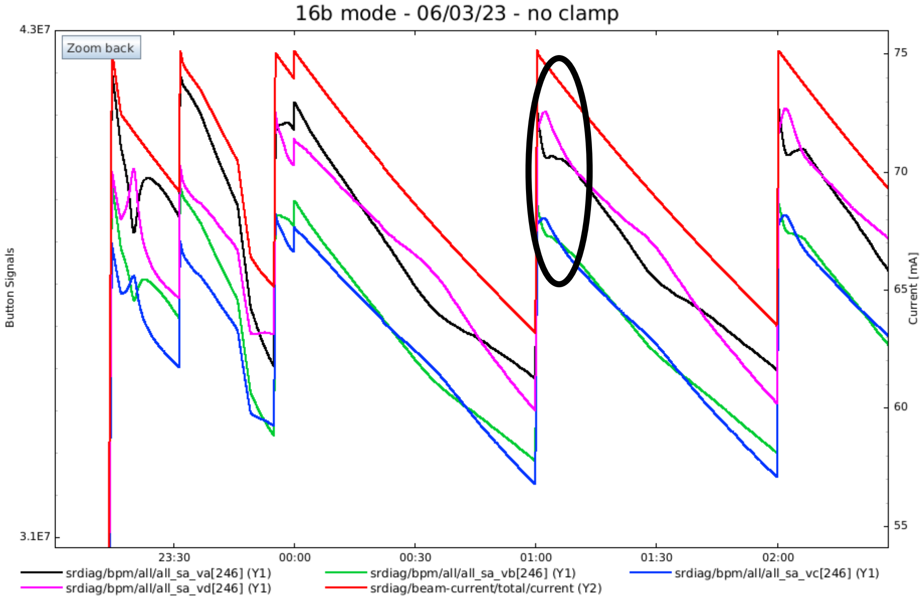


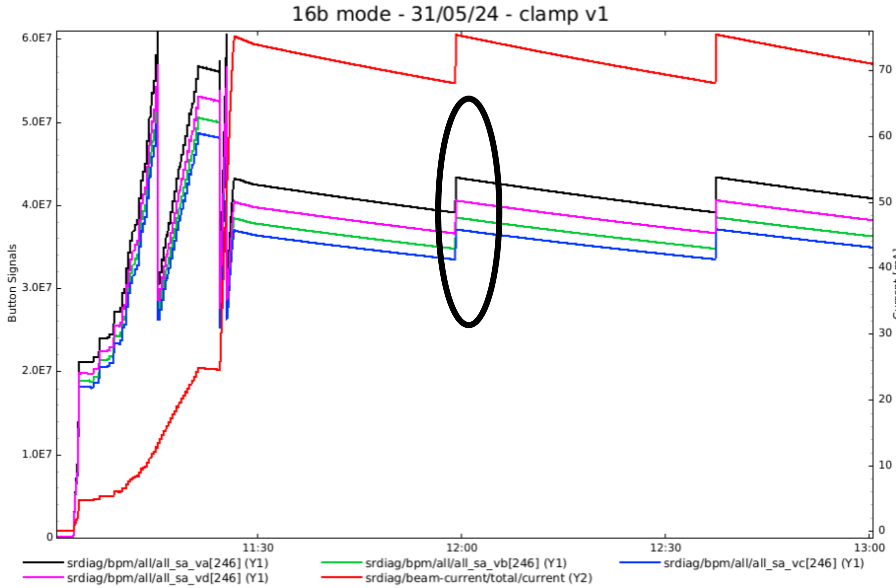
clamp v1 was not strong enough for this BPM (see supplementary slides)

EFFECT OF CLAMP V1 ON C28-07

The first clamp was installed on a different BPM.

Spectroscopy of the BPM not done yet, but BPM measurement looks perfect now





CONCLUSION

We think a ~15 µm gap in the vacuum chamber in the vicinity of BPM blocks is responsible for a 352 MHz RF resonance, affecting BPM measurement

A clamp was designed to close this gap and shows very good results: 2 BPM are now completely resonance-free

ALBA, DESY, Diamond, Elettra, SOLEIL, SLS: are there possible gaps in the vicinity of your BPMs for your upgraded machine?

Thank you for your attention

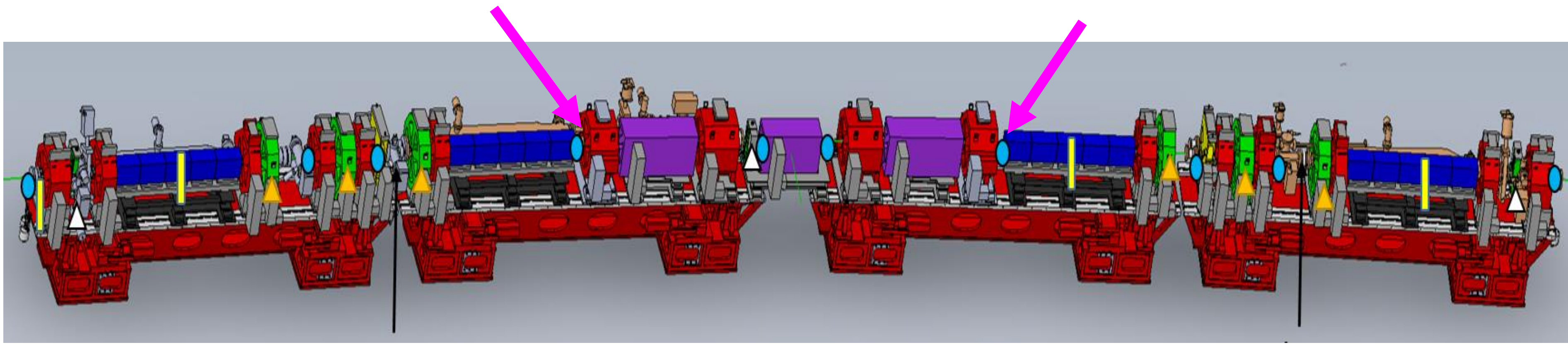
Questions?

Supplementary slides

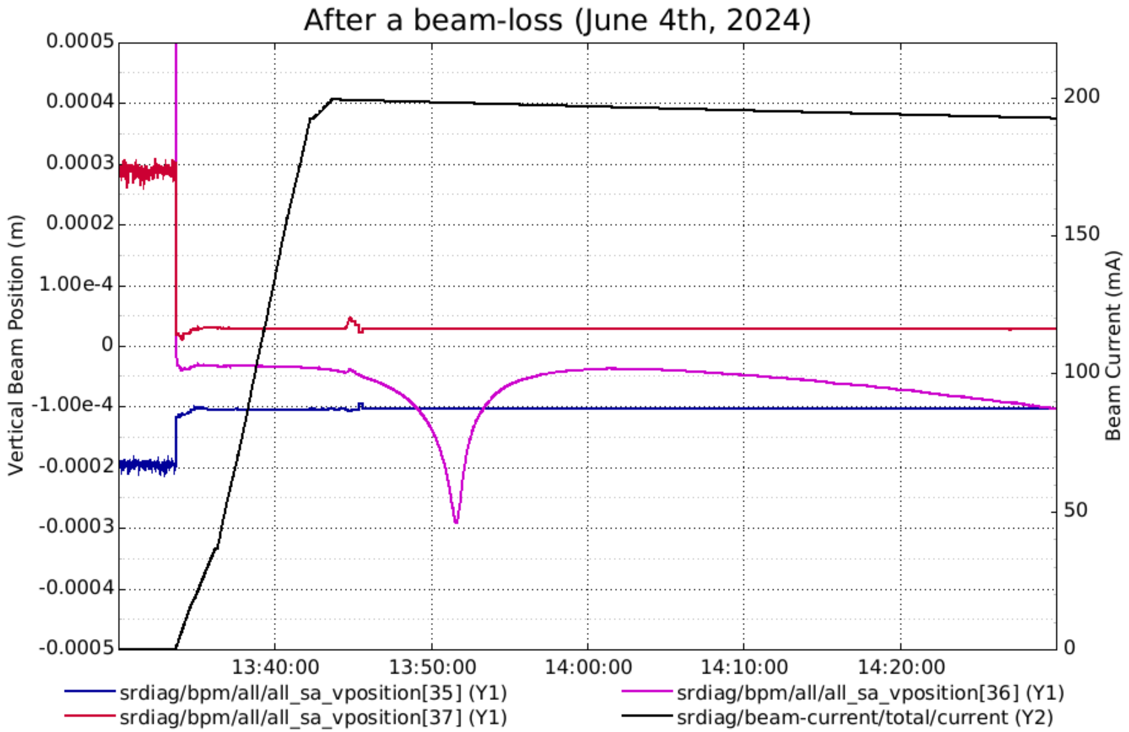
POSITION OF AFFECTED BPMS IN THE CELL

BPM #4, 1 block affected by the resonance

BPM #7, 11 blocks affected by the resonance



We suspected a RF resonance, because we can see a resonant shape-like



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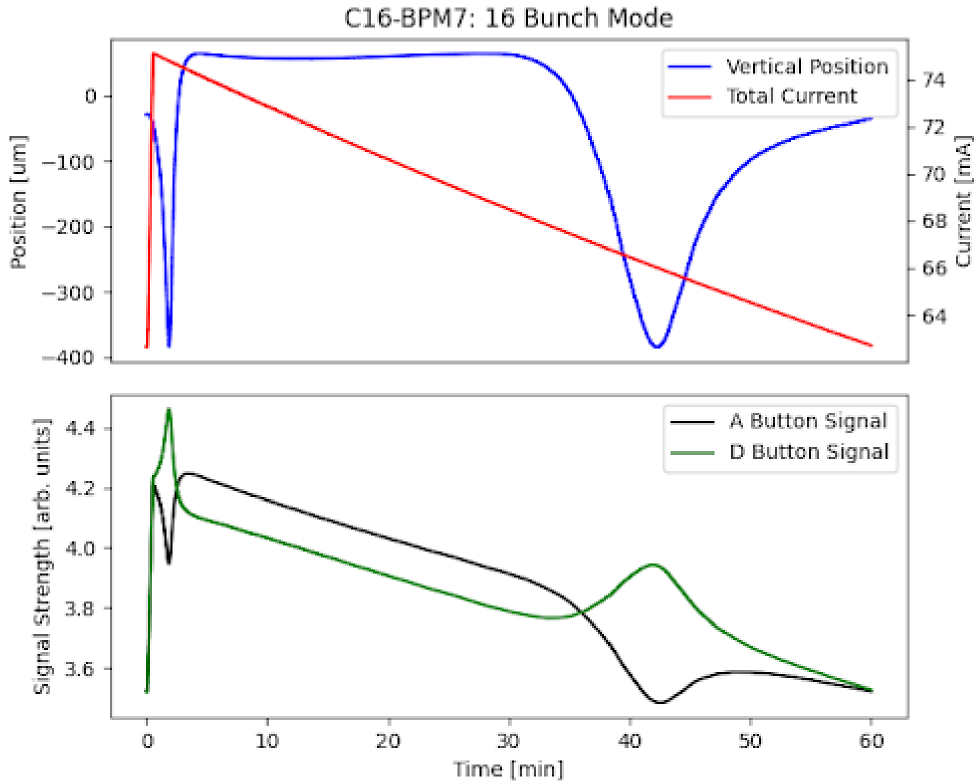
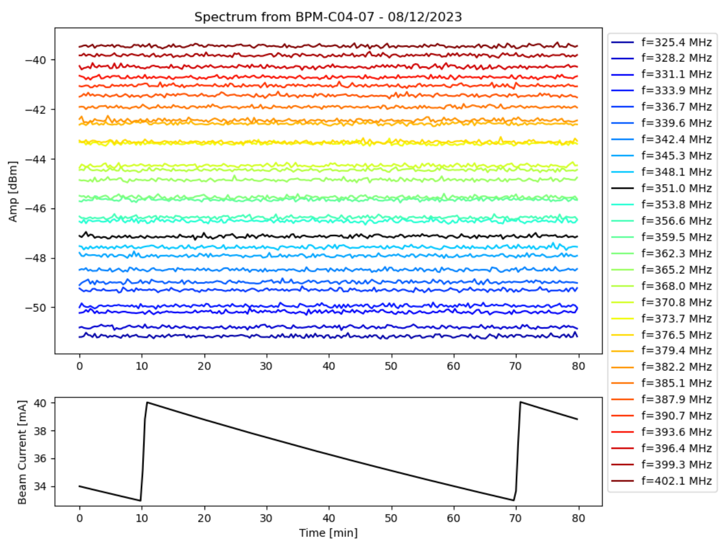


Why not all BPM 7 are affected?

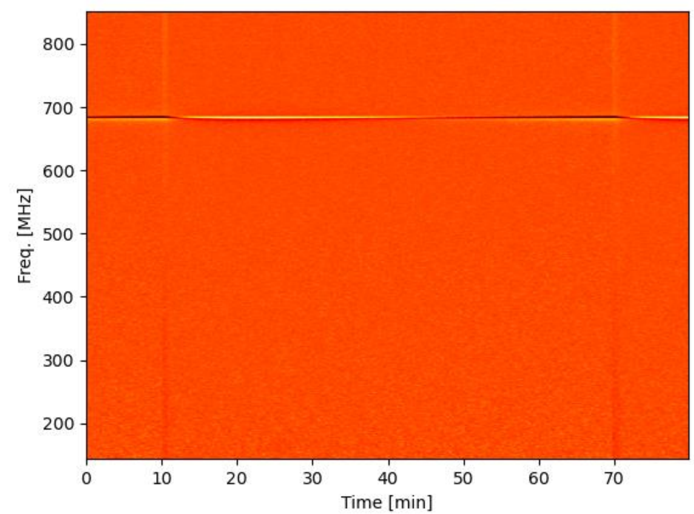
WHY NOT ALL BPM 7 ARE AFFECTED?

BPM C04-07 is a perfectly fine BPM: beam position is stable for all modes.

We selected randomly this BPM, and measured its spectrum with the network analyser



The spectrum is clean around 352 MHz



But there is a resonance close to 700 MHz (shown in colormap for clarity)

WHY NOT ALL BPM 7 ARE AFFECTED?

We did not measured all BPM 7 with the spectrum analyser because it is quite time consuming

Based on this single measurement on a random working BPM, we can guess that the variability of gap dimension explains why some BPM are not affected by this phenomenon

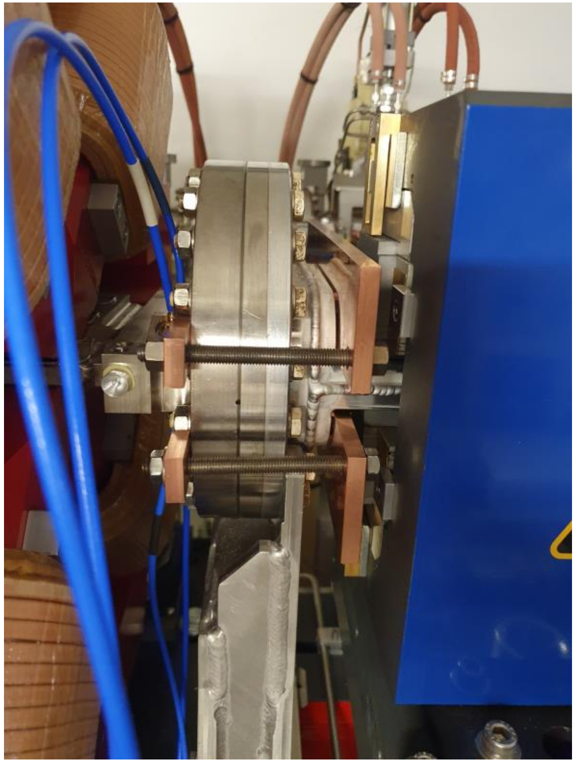
Since f_{res} scales with sqrt(g), the gap for BPM 7 could be 21 µm, instead of 15 µm.

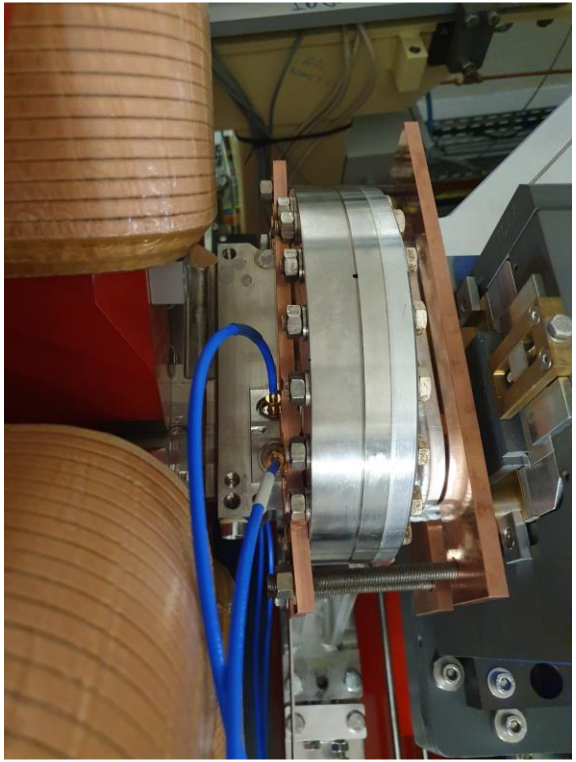
- 15 µm $\rightarrow f_{res} \approx$ 350 MHz
- 21 µm $\rightarrow f_{res} \approx$ 700 MHz

Effect of the two clamps on the BPM C02-07 (in chronological order)

CLAMP - V1

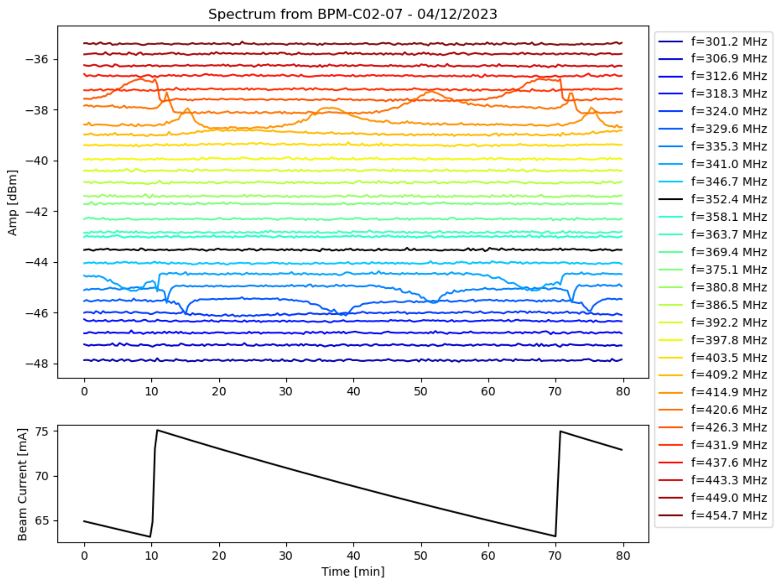
A first prototype was installed during the March shutdown (in copper-beryllium-zirconium)



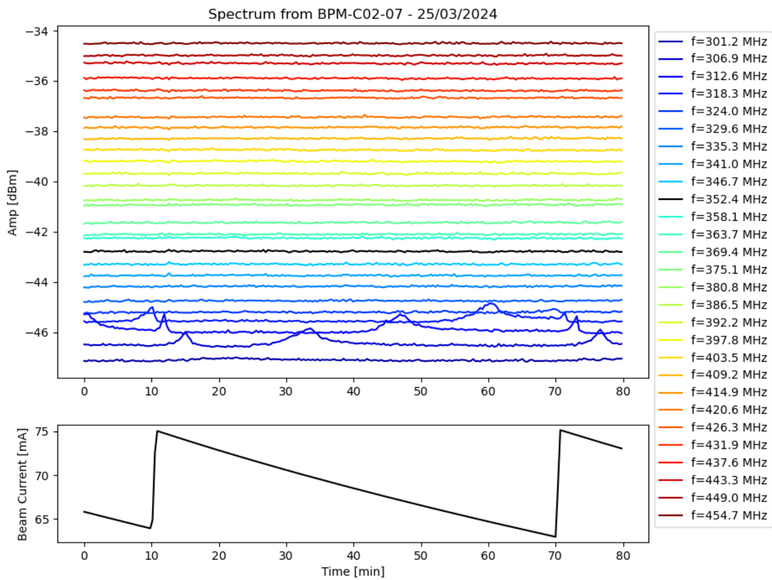


Clamp v1 had an effect, but not enough to kill the mode

before any clamp installation



clamp v1 installed



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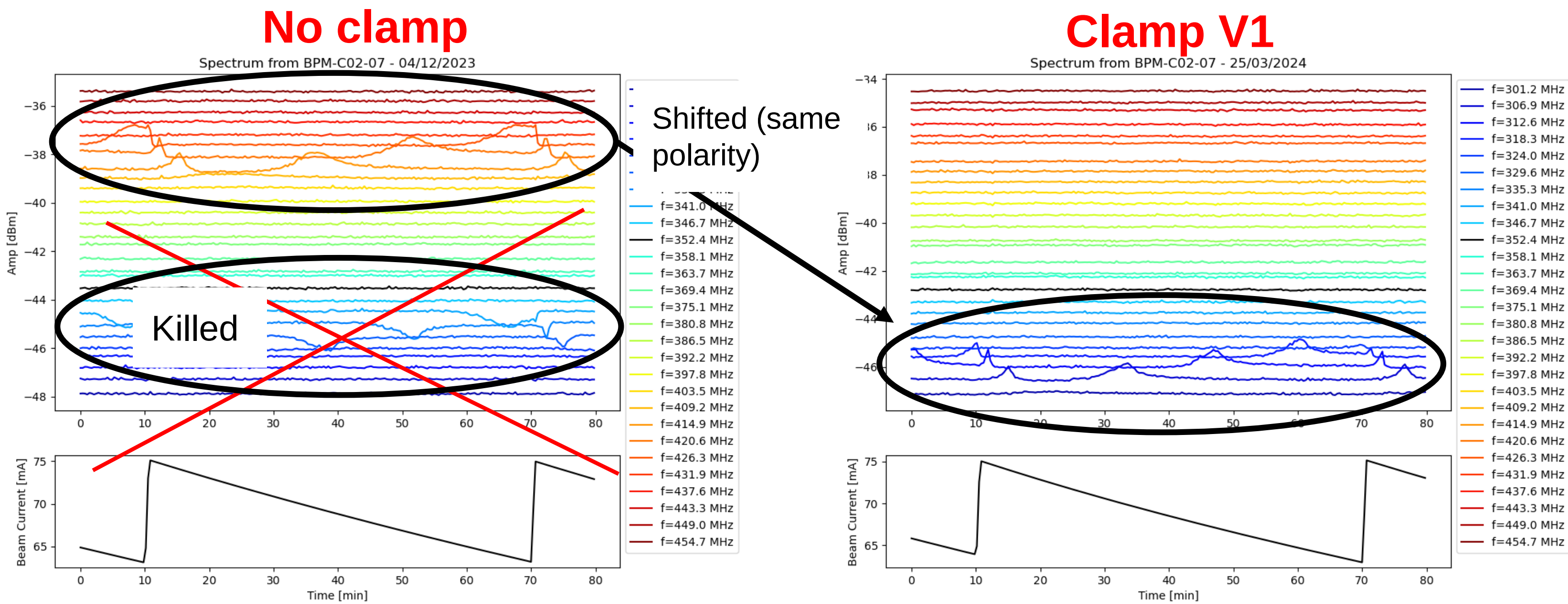
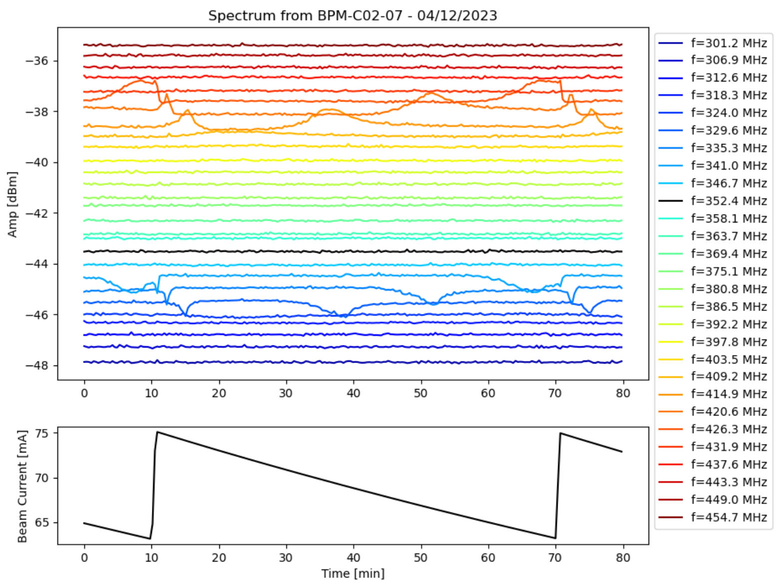


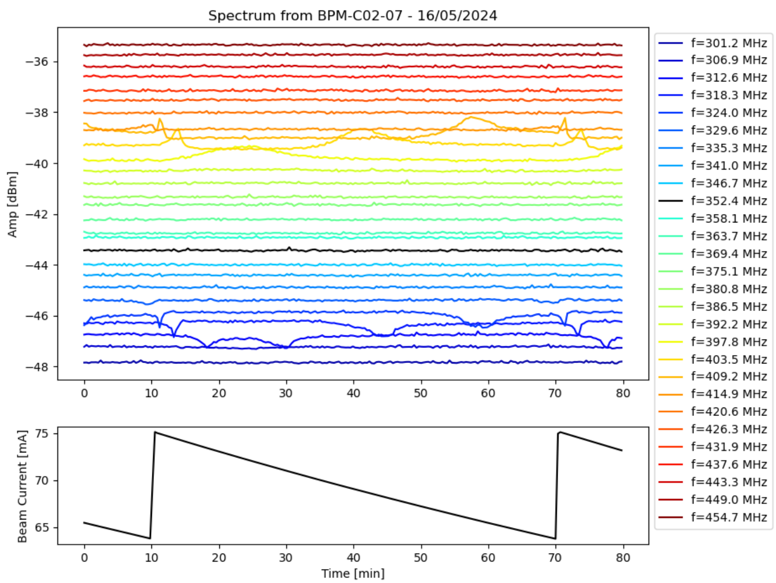
Seemed to do what we expected (smaller gap -> lower frequency) but not enough clamping force.

Clamp effect is reversible: clamp v1 was removed, we recovered 2 resonances (slightly shifted)

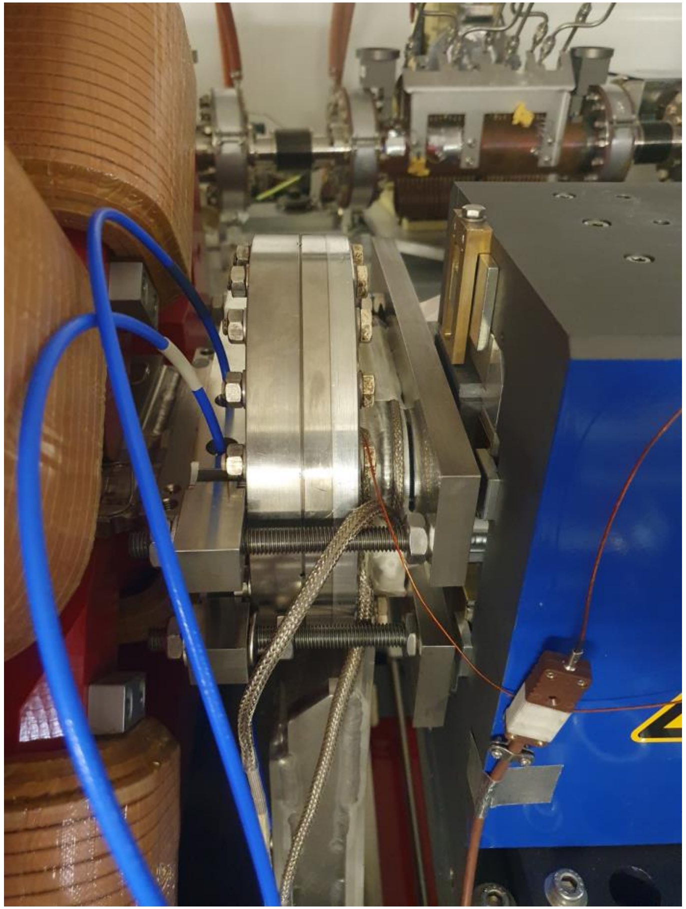
before any clamp installation

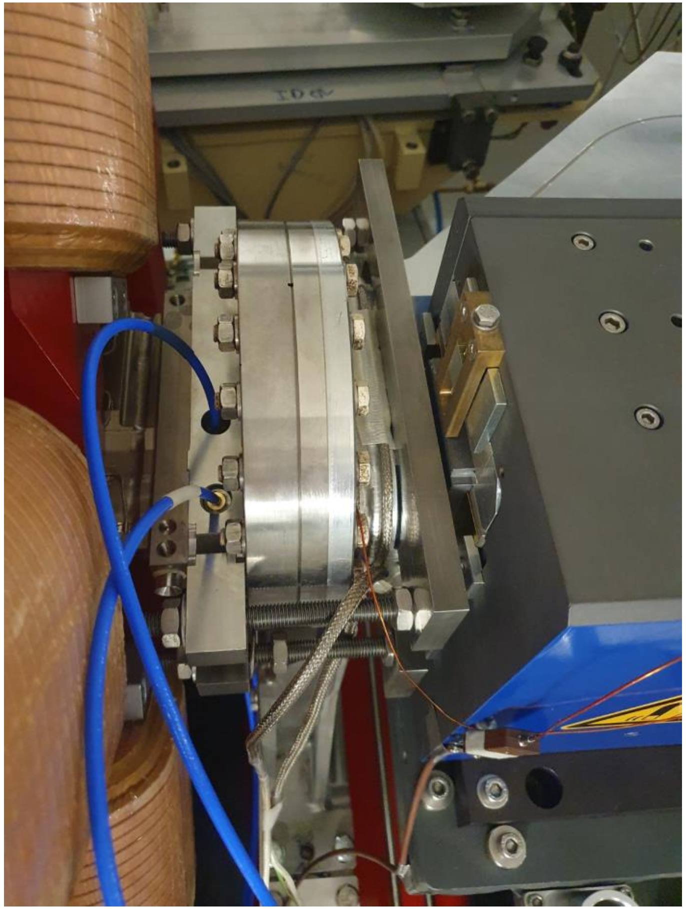


clamp v1 removed



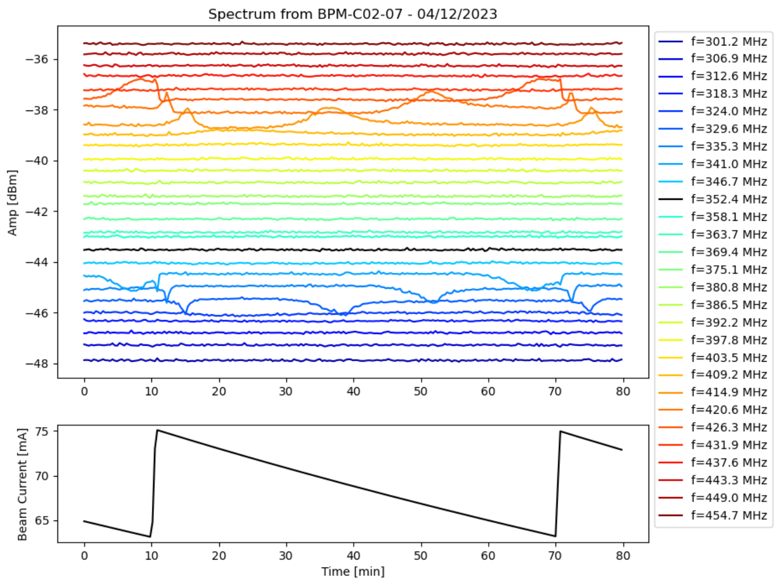
CLAMP - V2



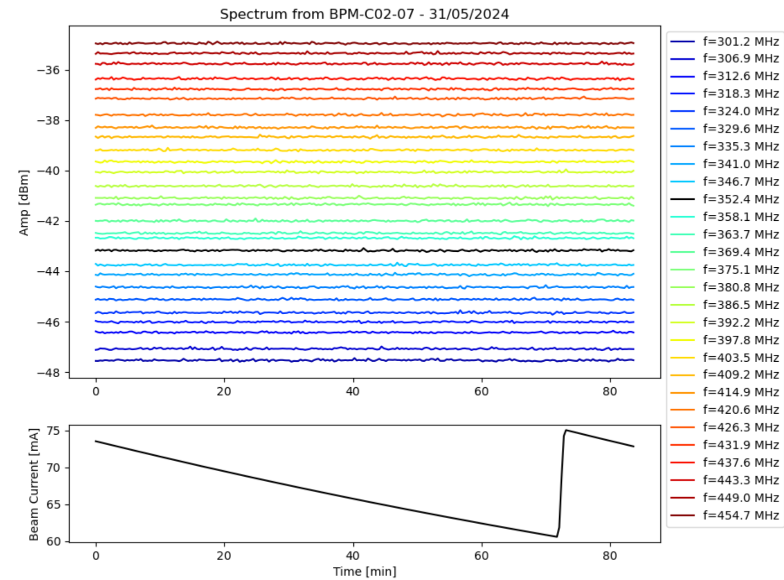


Clamp v2 completely killed both resonances

before any clamp installation

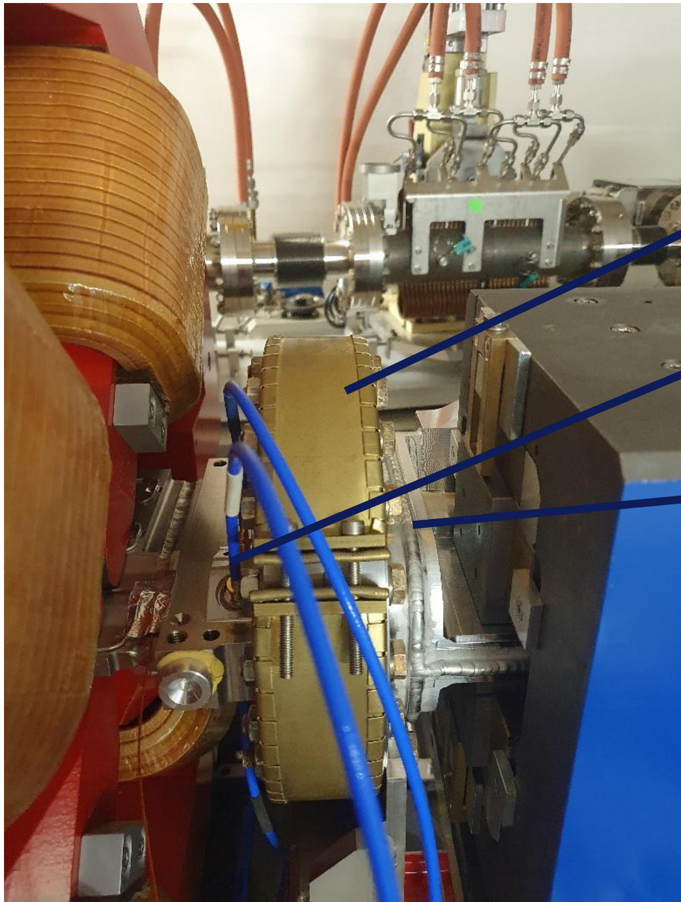


clamp v2



Effect of flange temperature on the resonance

EFFECT OF FLANGE TEMPERATURE ON THE RESONANCE



Bakeout heating collar

BPM 7

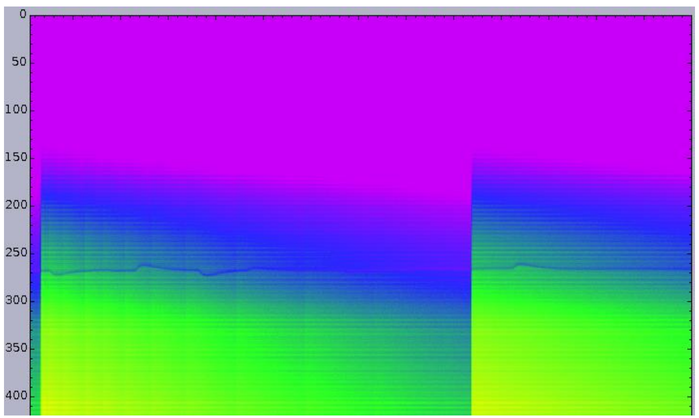
Suspected resonant gap

EFFECT OF FLANGE TEMPERATURE ON THE RESONANCE

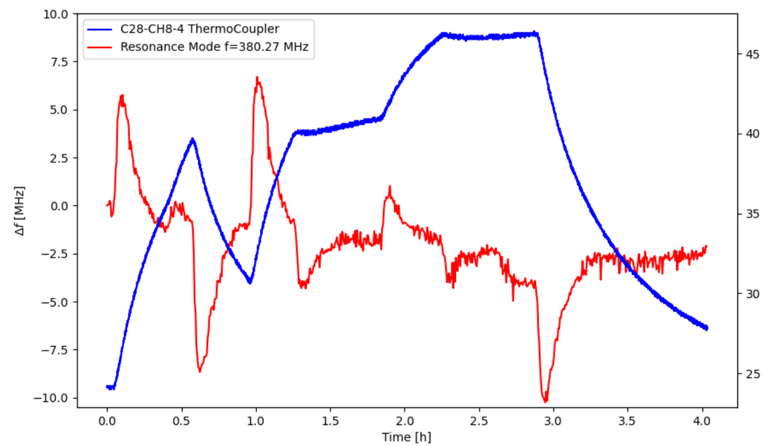
We use the bakeout heating collar to change the temperature of the flange, and monitor the effect on the resonance

We extract resonance frequency (red curve)

380 MHz →



Raw spectrum in colorscale



EFFECT OF FLANGE TEMPERATURE ON THE RESONANCE

It was found that whenever the heating collar power was changed, a strong deviation of the mode was seen. However it quickly recovered after.

A small frequency shift remains after a thermal equilibrium is reached, but seems too small to be a solution for this resonance issue.

Frequency shift with absolute temperature