DEELS 2025
Diagnostics Experts of European Light Sources Workshop
Elettra Sincrotrone Trieste | Italy | 12 – 13 May 2025

SOLEIL SYNCHROTRON

SOLEIL II BPM development progress

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Outline

- SOLEIL II PROJECT
  - SOLEIL II MAIN PARAMETRES
  - SOLEIL II BPM SPECIFICATIONS
- BPM SIMULATION
  - BEAM PROFILE AND POWER SIMULATIONS
  - THERMAL SIMULATIONS
- BUTTON PROTOTYPE TEST
  - CURRENT MACHINE INSTALLATION SETUP
  - MEASUREMENTS WITH BEAM
- CONCLUSIONS AND PERSPECTIVES

SOLEIL II Storage Ring Key Parameters

1. Non-standard MBA lattice: 12 x 7BA + 8 x 4BA / 2.75 GeV / 354 m / 500 mA
2. ~83 pm.rad (~53 pm.rad round beam as ultimate goal).
3. 22 straight sections (7 different lengths).
4. NEG coated very small vacuum chamber diameter (12 mm)
5. Extensive use of permanent magnets (all dipoles, RB and main quadrupoles).
7. Miniaturization.
8. Off-axis injection with Multipole Injection Kicker (MIK).
9. Energy savings and reduced energy footprint.

Parameters	SOLEIL	SOLEIL II
Energy [GeV]	2.75	2.75
Circumference [m]	354.10	353.97
Maximum Beam Current [mA]	500	500
Lattice Type	DBA	**7BA-4BA**
Cell Number	24	20
Natural Emittance [pm.rad] Round beam (100% coupling)	3 900 -	83 53
Energy Spread	1.02 E-3	0.91 E-3
Natural RMS Bunch Length [ps]	16.1	8.6
Transverse Damping Times, $\tau_x/\tau_y/\tau_s$ [ms]	6.9 / 6.9 / 3.5	7.8 / 14.3/ 12.4
Momentum Compaction Factor	4.2 E-4	1.06 E-4
Energy Loss per Turn [keV]	917	453
Overall RF Voltage [MV]	2.6	1.8
RF Frequency [MHz]	352.20	352.33
RF Power into the Beam [kW]	575	245
Synchrotron Frequency [kHz]	4.2	1.8

Parameters without insertion devices nor harmonic cavity

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SOLEIL II BPM SPECIFICATIONS

Beam Position Monitor main requirements

- **High Resolution** at nominal operating conditions
- **High S/N Ratio** at low current for optimal resolution during first turns
- **Long-Term Stability** to ensure operation for users

Type	Data	Spec.	Conditions
Resolution	Fast acquisition (~100 kHz, DC-2kHz bandwidth)	100 nm rms	Nominal current / Nominal filling pattern (500 mA / 416 bunches)
	Turn by Turn	1 µm rms	
		100 µm rms	0.1-1 mA in 1 quarter (commissioning)
	Slow Acquisition (~10 Hz)	1 µm rms	
Beam Current Dependence	-	10 µm	From 0.1 mA – to nominal current
Absolute accuracy	-	< 500 µm	Before BBA
		< 5 µm	After BBA
Long term Stability	-	500 nm	Day drift
		1 µm	Week drift

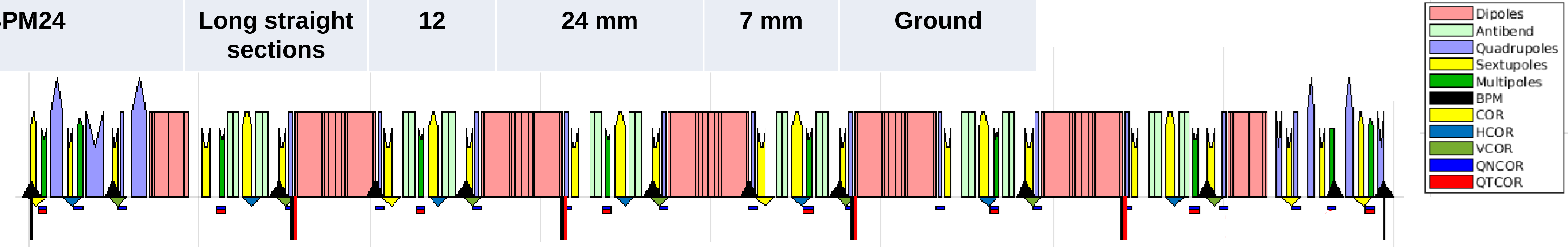
SOLEIL II BPM Types

- A large number of BPM types:

SOLEIL II BPMs	Location	Nb. of units	Chamber inner diameter	Button diameter	Fixation
BPM16	**Arcs**	**128**	**16 mm**	**6 mm**	**Girder**
	Arcs, behind BM source points	**16**			**Welded on dipole vacuum chamber**
BPM20	**Standard straight and SD01L/SD11L matching sections**	**40**	**20 mm**	**7 mm**	**Ground (SS) or girder (matching)**
BPM24	**Long straight sections**	**12**	**24 mm**	**7 mm**	**Ground**

Design Features for Maximum Stability

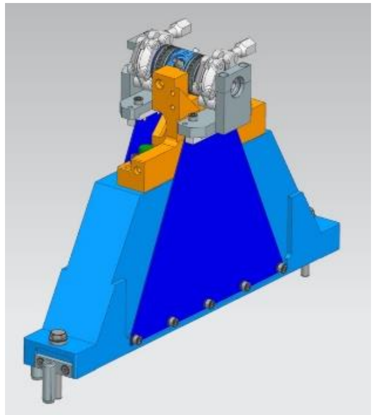
- **Enlarged tapered sections** for BPMs within SR shadow
- **Rigid mechanical supports** to minimize displacement due to temperature fluctuations
- **Bellows** to reduce vacuum chamber constraints



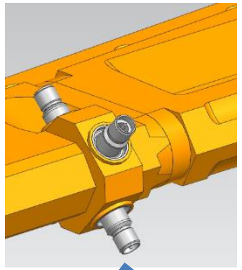
Schematics of the 7BA achromat

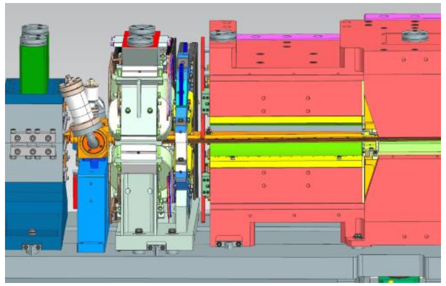
BPM Mechanical Implantation

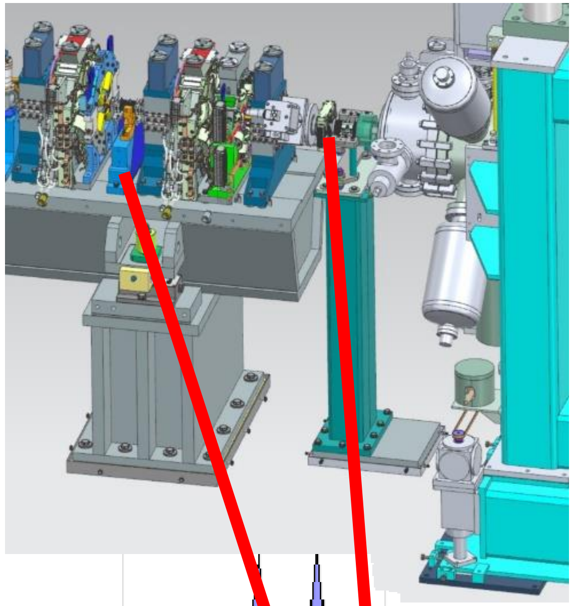
Standard arc BPM16 (x128):

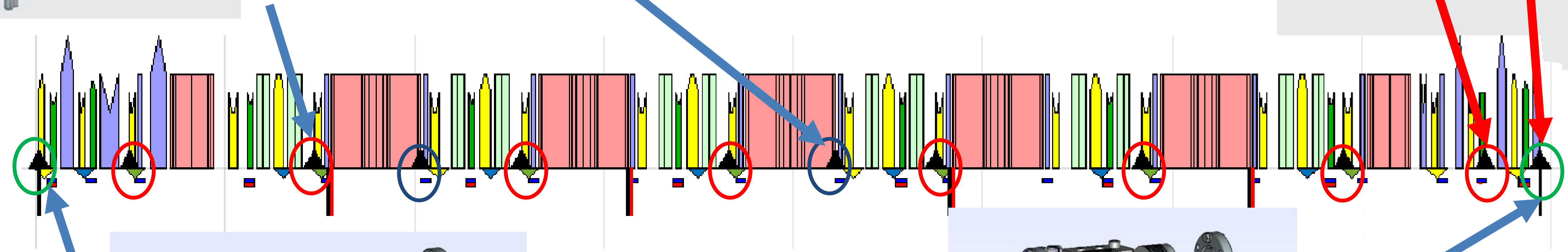


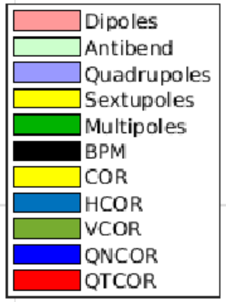
Integrated arc BPM16 (x16): **Welded** on the dipole vacuum chamber

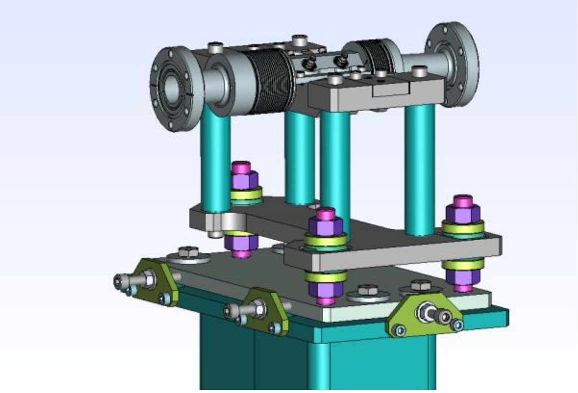




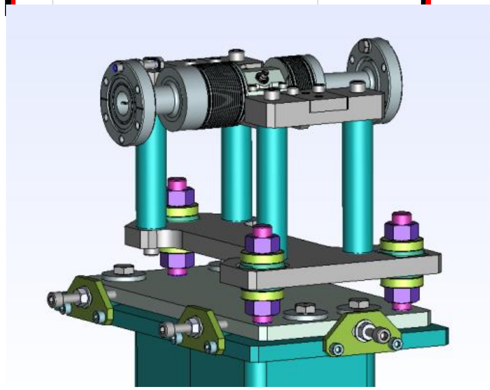








Long straight section BPM24 (x12)



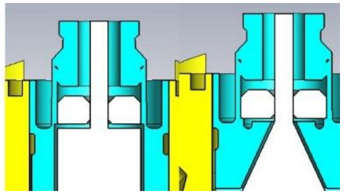
Standard straight section BPM20 (x40)

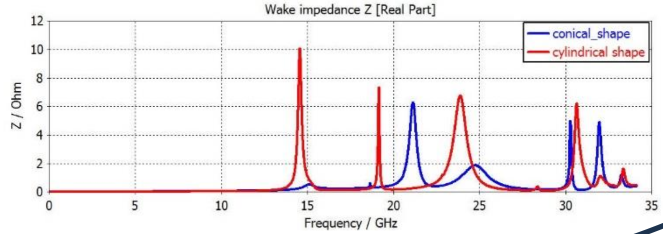
SIMULATION WORKFLOW

Conical buttons shift the first resonance to higher frequency:
Shape adopted for SOLEIL II

longitudinal impedance simulation

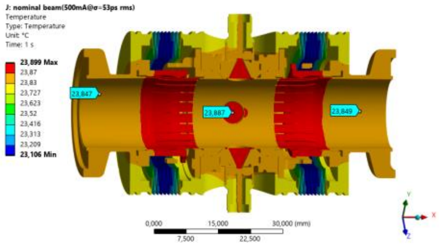
CST PARTICLE STUDIO

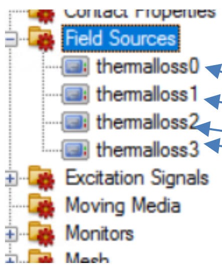




Thermal simulation

Ansys

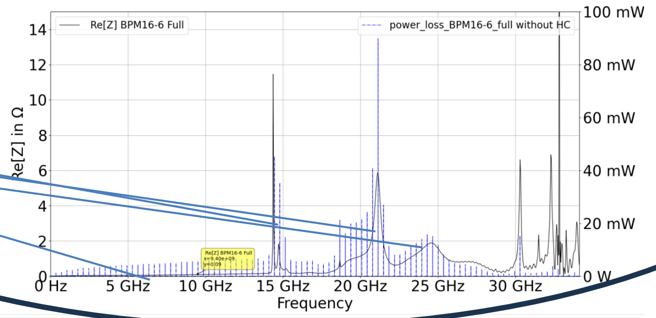




Importing CST field maps into ANSYS thermal solver with the appropriate coefficients allows for calculating the total heating and the contribution of each resonance

Power loss calculation

mbtrack II



MBTrackII models power loss by simulating beam interactions with longitudinal impedance

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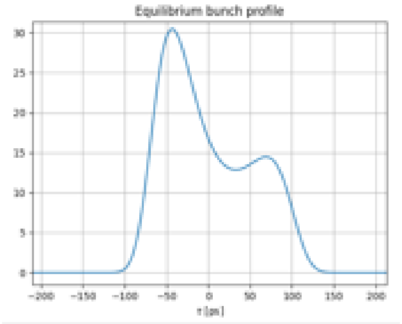
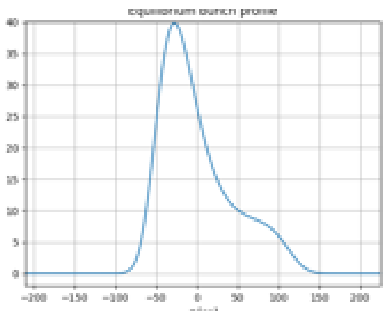
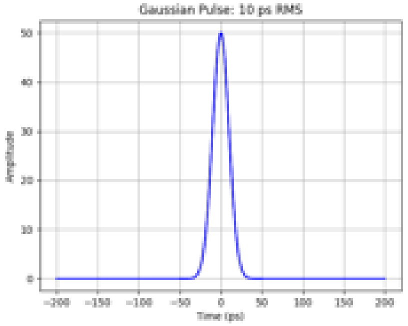
Filling patterns for SOLEIL II

	Uniform mode with HC	32 bunches mode	Degraded uniform mode without HC
Current(mA)	500	200	300
Nombre of bunches	416	32	416
Bunch length (ps rms)	53	55-60	10
Bunch profile	No gaussian 	No gaussian 	Gaussian 

When the harmonic cavities(HC) are active, the bunch profile becomes long and non-Gaussian, whereas with the HC inactive, the bunch profile is short and Gaussian.

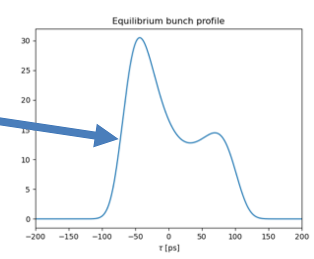
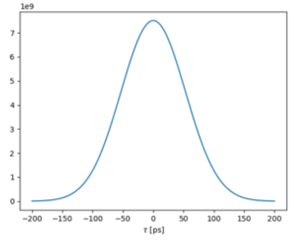
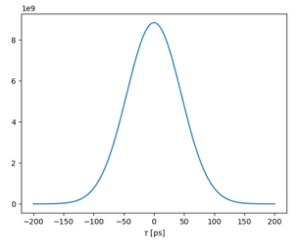
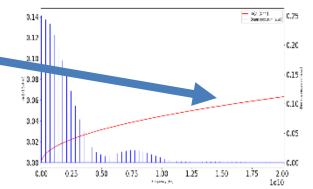
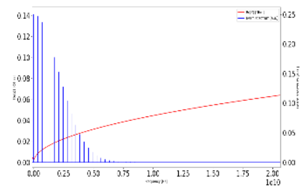
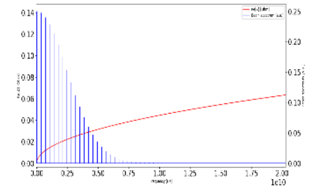
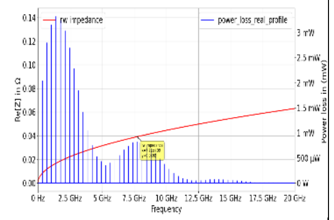
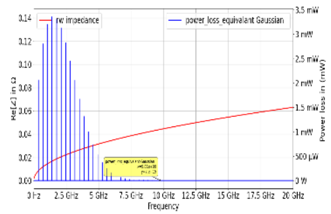
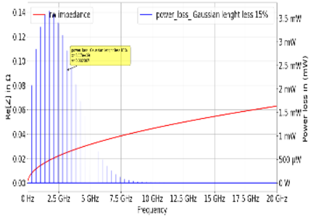
Effect of bunch longitudinal profile

$$\Delta P = (f_0 e N_{beam})^2 \sum_{p=-\infty}^{p=+\infty} |\Lambda(p\omega_0)|^2 Re[Z_{\parallel}(p\omega_0)]$$

in the case of a constant impedance as RESISTIVE WALL :
Example of RW for beam pipe 7cm length and diameter = 16mm equivalent to BPM16 size.

The non-Gaussian beam delivers the same amount of power as a Gaussian beam that's 15% shorter.

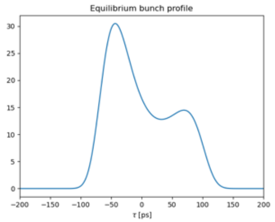
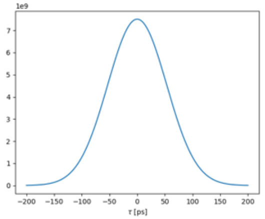
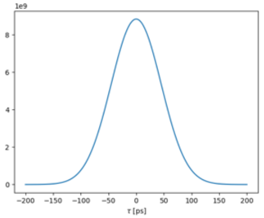
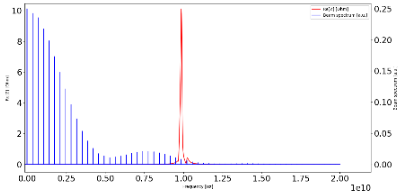
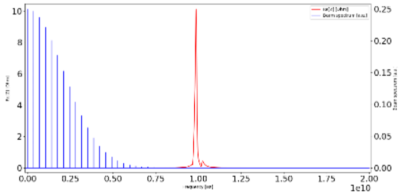
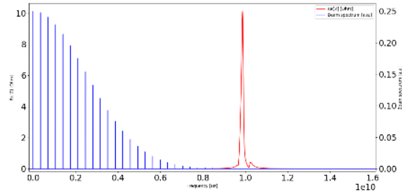
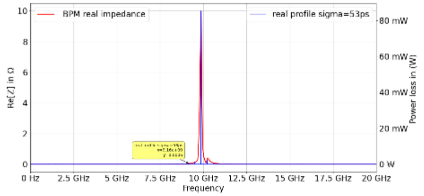
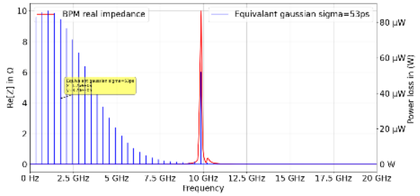
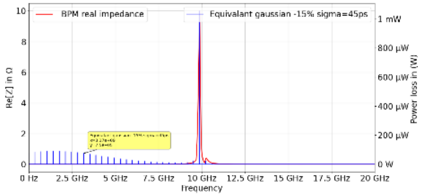
by courtesy of Alexis Gamelin

Distribution	Real profile	Equivalent Gaussian	Equivalent Gaussian of reduced size 15 %
Lenght RMS	53 ps	53 ps	45 ps
Bunch Profile			
Impedance and beam Spectrum			
Spectral power distribution			
Power dissipation	77 mW	62 mW	80 mW

Case of impedance with resonance pick

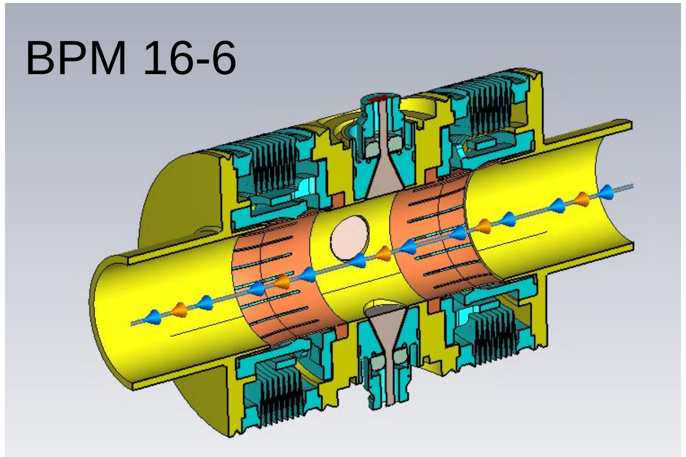
The previous assumption is **not applicable for a non-constant impedance, like in the case of trap modes**. Resonances in the 5 to 20 GHz range must be considered seriously.

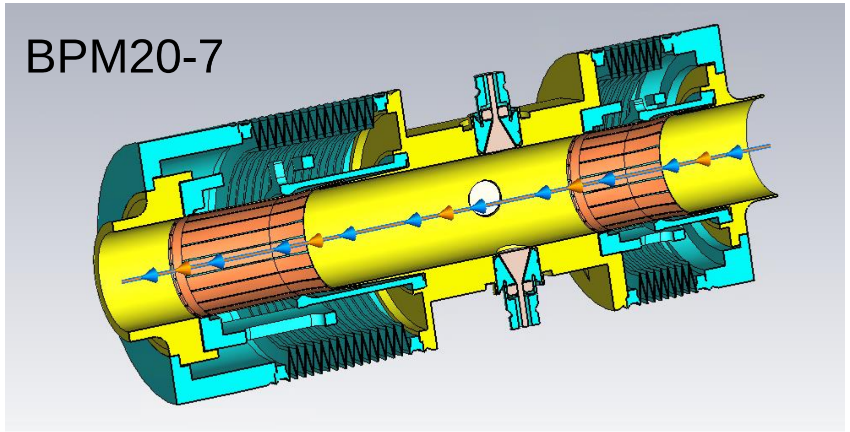
Exemple : BPM with trap modes @10GHz and 10Ω

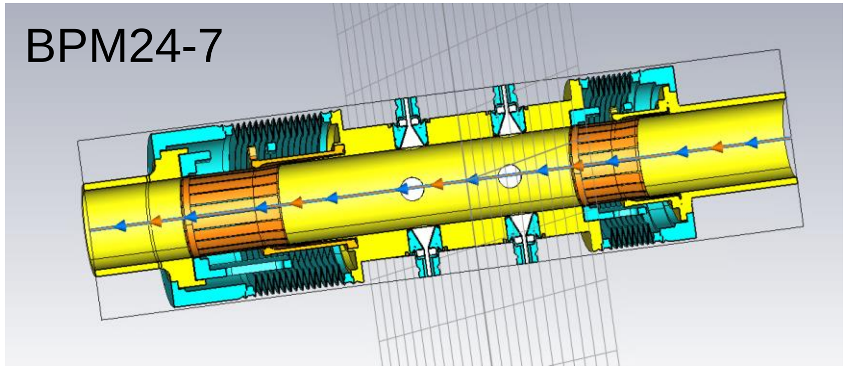
Distribution	Real profile	Equivalent Gaussian	Equivalent Gaussian of reduced size 15 %
Lenght RMS	53 ps	53 ps	45 ps
Bunch Profile			
Impedance and beam Spectrum			
Spectral power distribution			
Power dissipation	184 mW	2 mW	5 mW

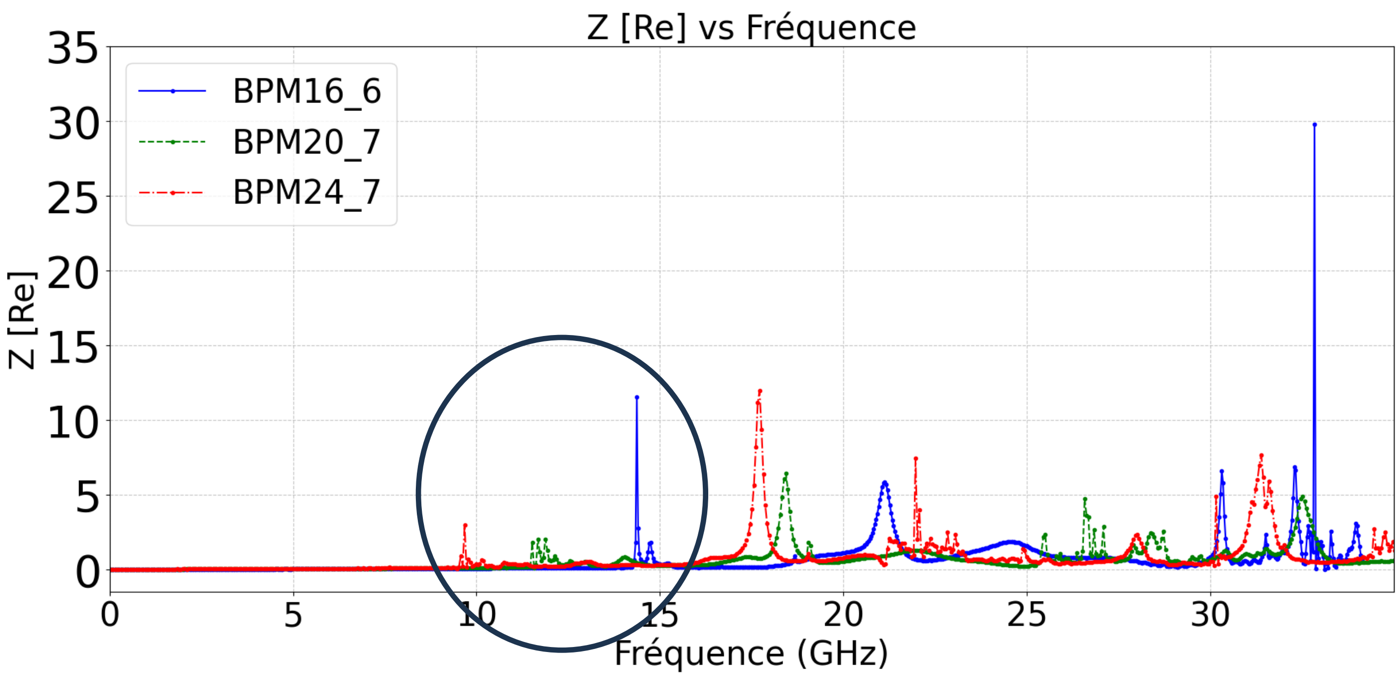
by courtesy of Alexis Gamelin

Electromagnetic Simulations







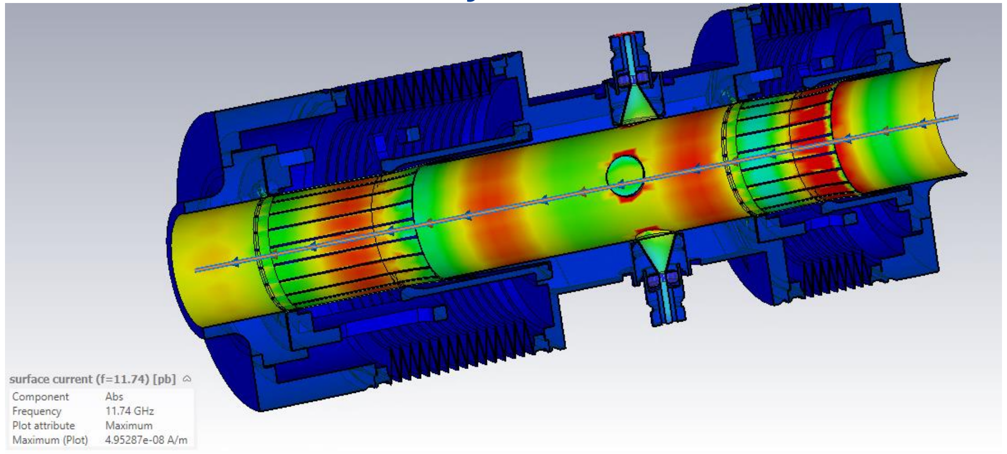


Resonance between 10 GHz and 15 GHz

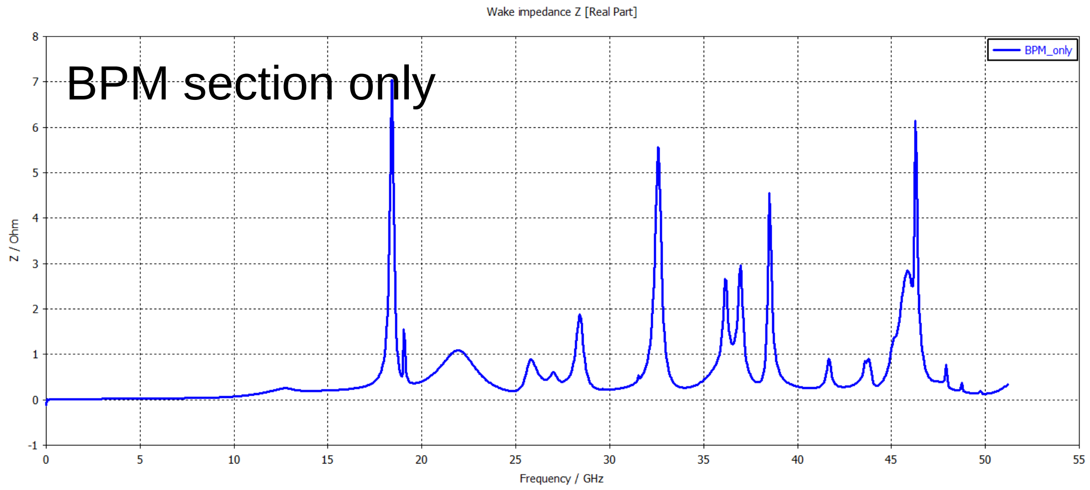
- Simulation of full BPM block
- Were not present simulating the BPM section only

Investigation of the first resonance

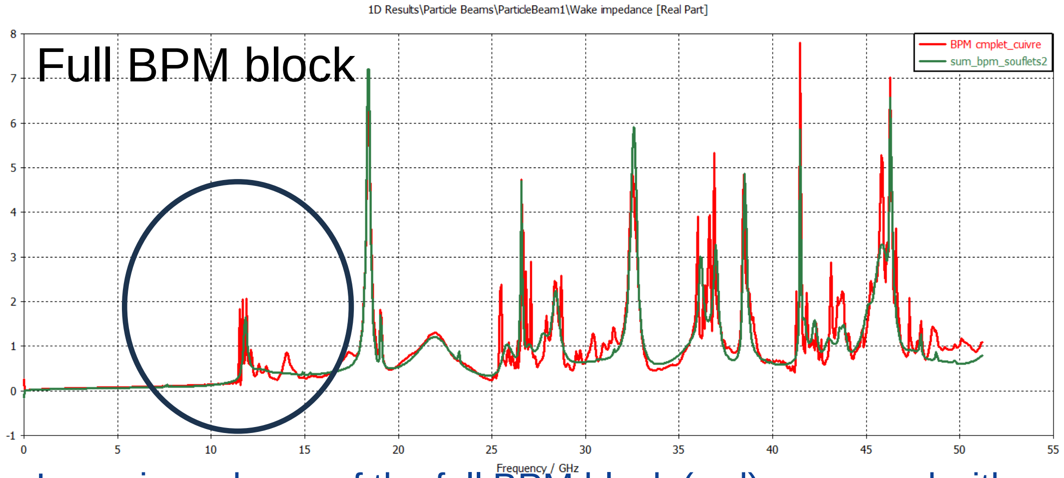
- BPM20-7 case study:



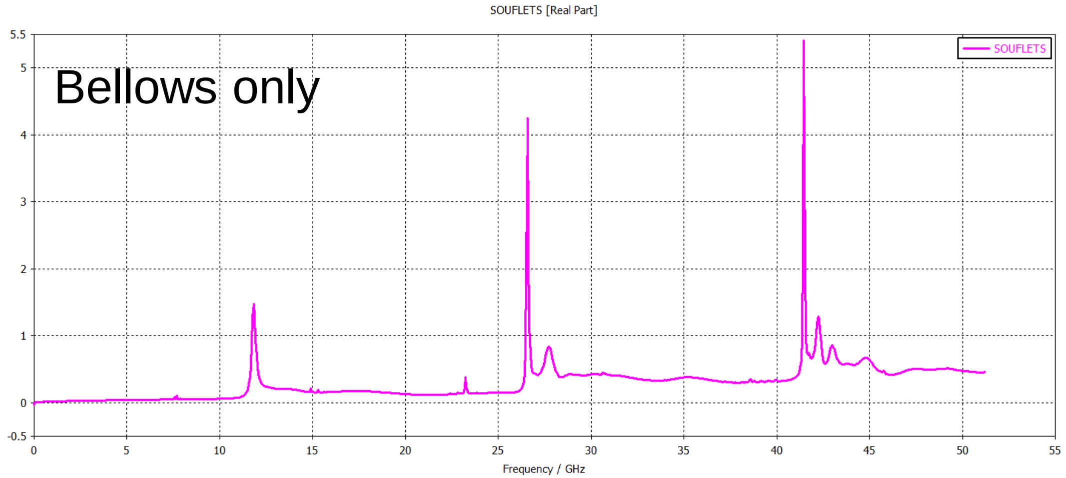
A field monitor positioned at these frequencies indicates power deposition at the bellows (surface current visualization).



Long. impedance of the BPM section



Long. impedance of the full BPM block (red) compared with the sum of independent simulation of BPM section and bellows (green).



Long. impedance of the bellow.

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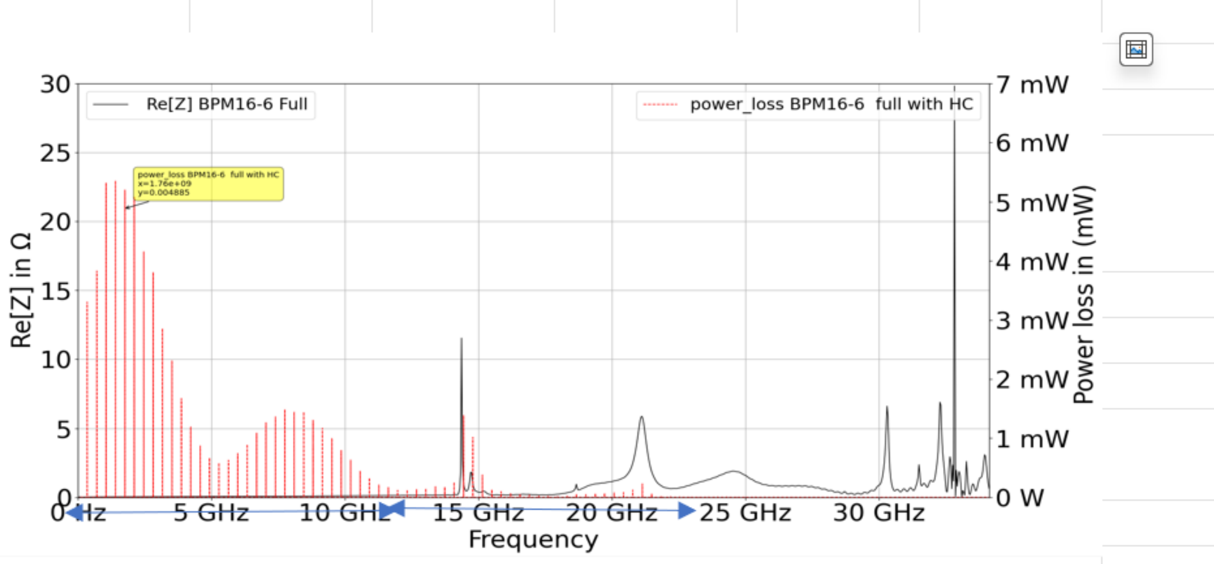
Total Power Loss

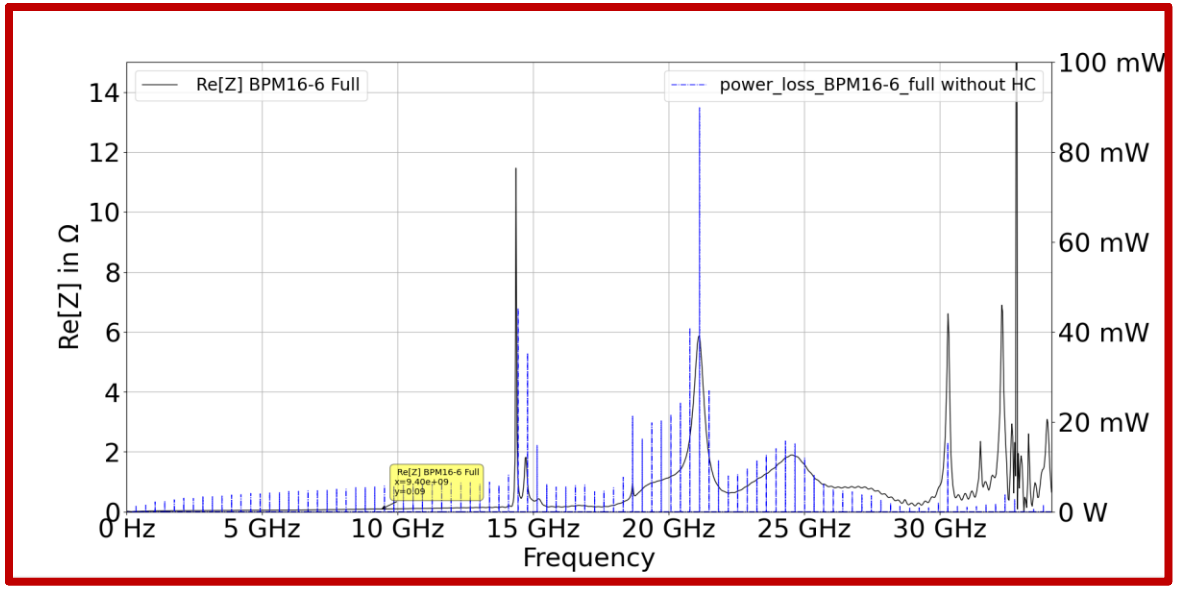
- Resulting power loss on the complete BPM blocks:
  - Very limited (max 0,21 W) in the nominal operational mode
  - Stronger (up to 2,4 W) in case we should operate without HC (degraded mode)

Power loss (W)	BPM16	BPM20	BPM24
Nominal w. HC (σ=53ps)	0.14	0.21	0.21
Degraded mode w/o. HC (σ=10ps)	1.6	2	2.4

- BPM16-6 case study:



Power loss distribution in nominal mode



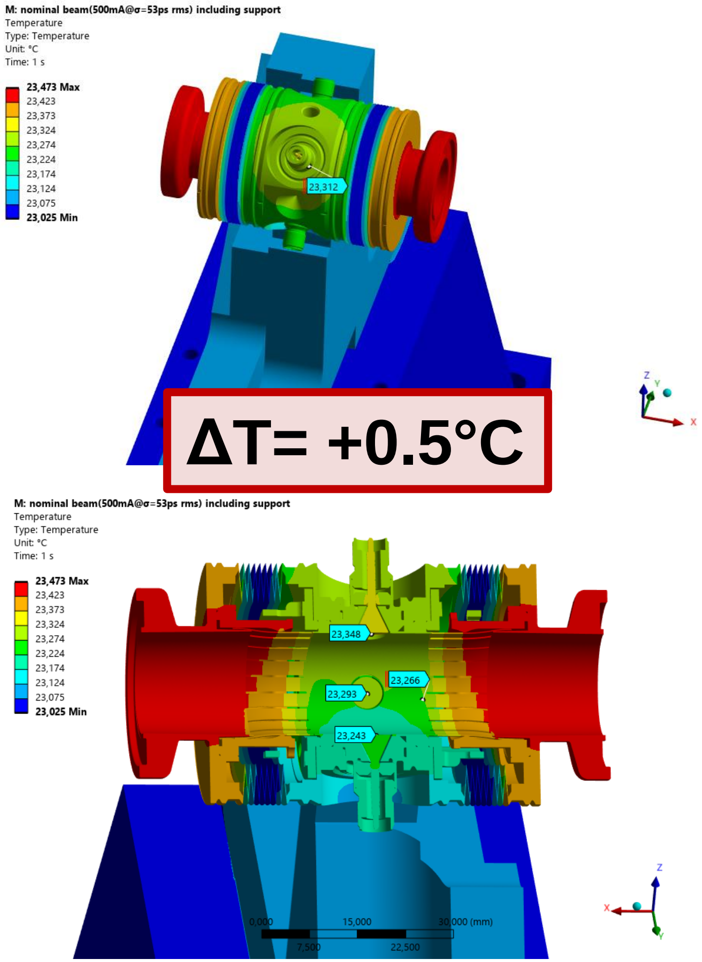
Power loss distribution in degraded mode

- Very small contribution from the bellows in nominal mode
- Stronger interaction with the beam in degraded mode coming both from the bellows but also from the first trap mode around the buttons.

Thermal simulations

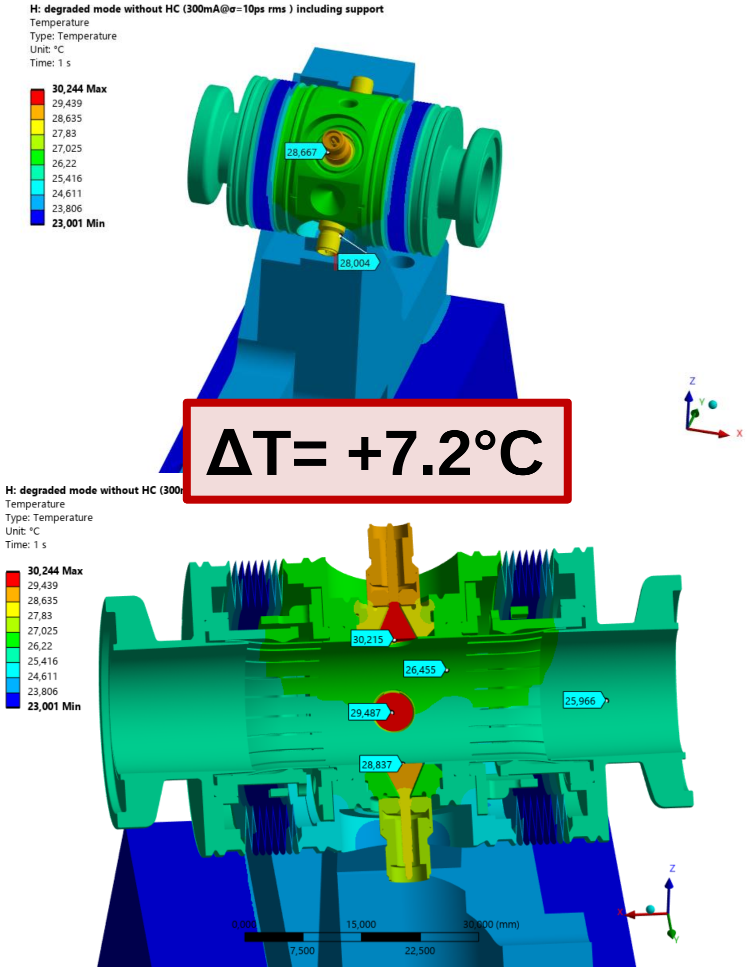
- BPM16-6 :

Nominal operational mode:
500mA, σ=53 ps with HC.



ΔT= +0.5°C

Degraded operational mode:
300 mA, σ=10 ps without HC



ΔT= +7.2°C

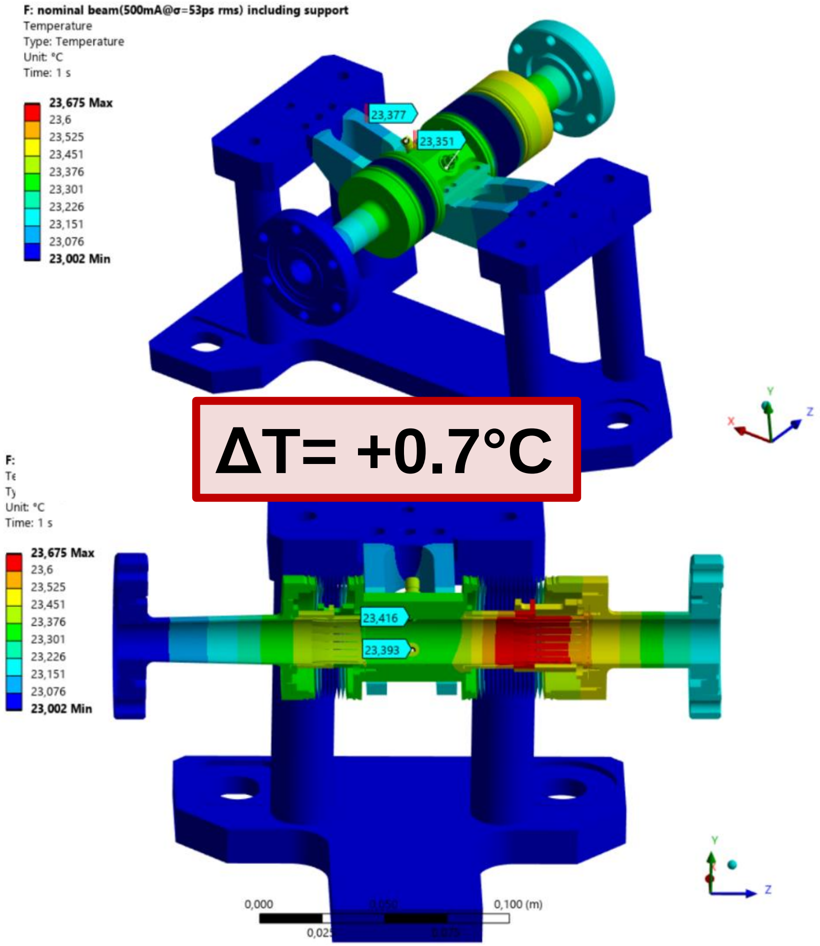
Natural convection coefficient=**10 W/m²·K / ambient temperature = 23°C**

BPM **support** equipped with a **forced water-cooling system**

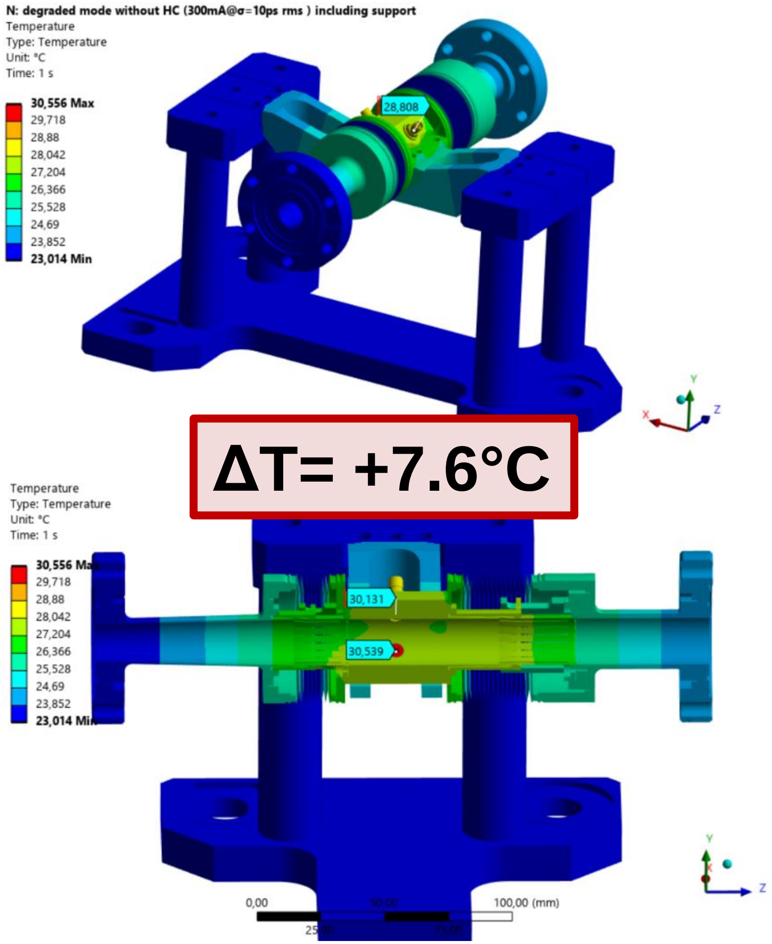
Thermal simulations

- BPM20-7 :

Nominal operational mode:
500mA, σ=53 ps with HC.



Degraded operational mode:
300 mA, σ=10 ps without HC

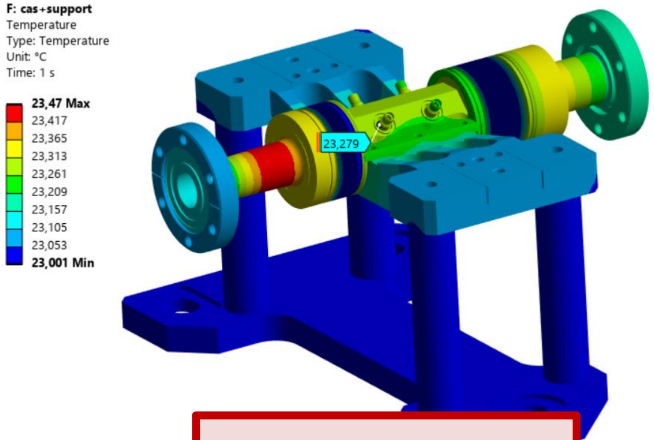


Natural convection coefficient=**10 W/m²·K / ambient temperature = 23°C**

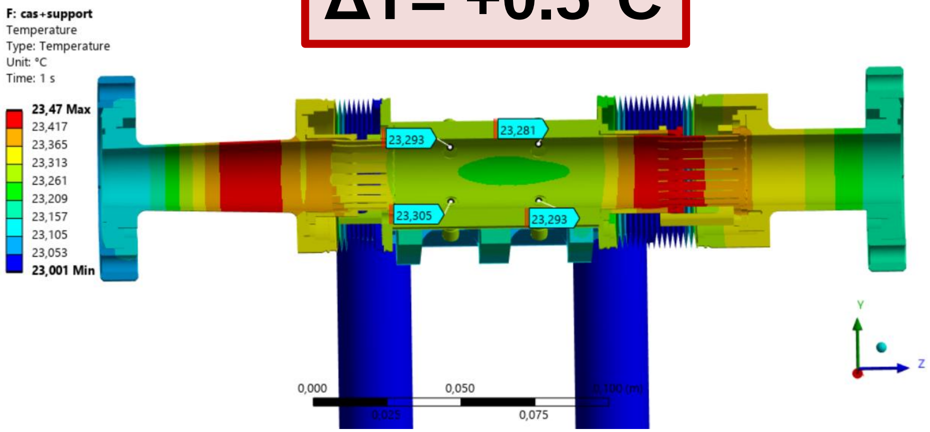
Thermal simulations

- BPM24-7 :

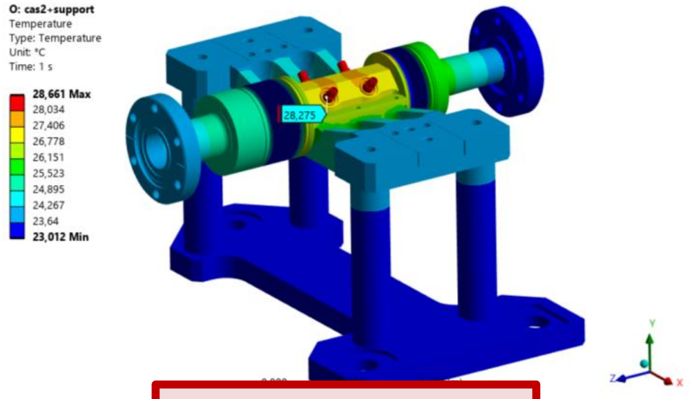
Nominal operational mode:
500mA with σ=53 ps with HC.



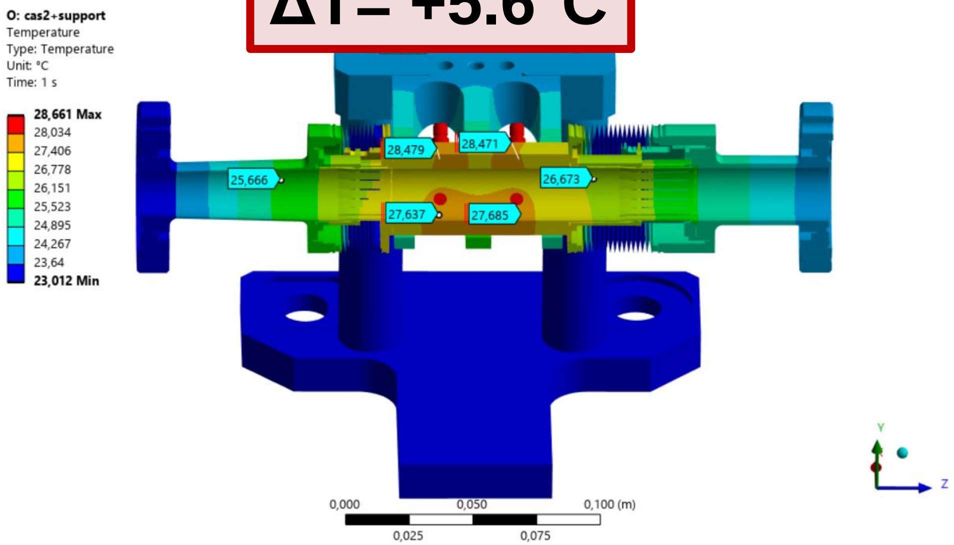
ΔT= +0.5°C



Degraded operational mode:
300 mA, σ=10 ps without HC

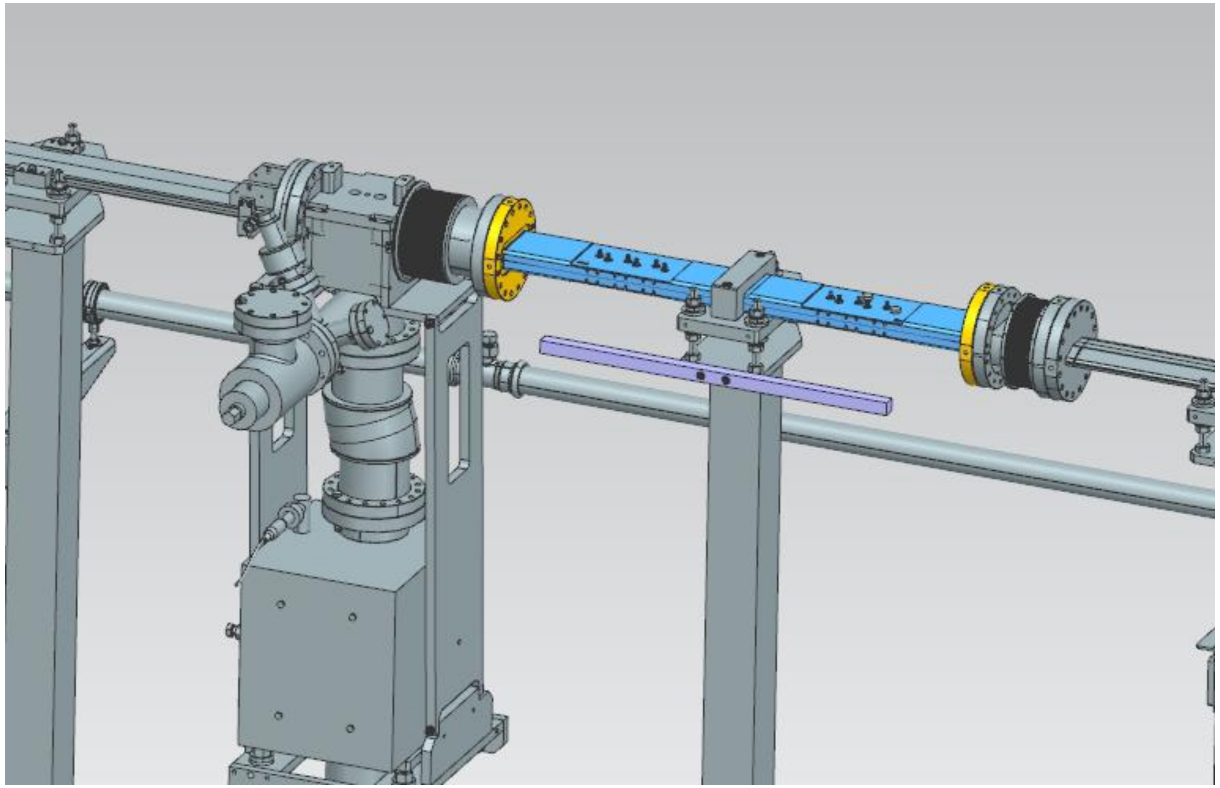


ΔT= +5.6°C



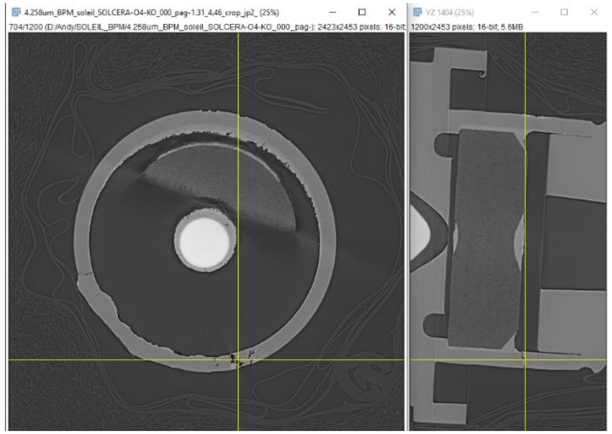
Natural convection coefficient=**10 W/m²·K / ambient temperature = 23°C**

Buttons test on the current machine

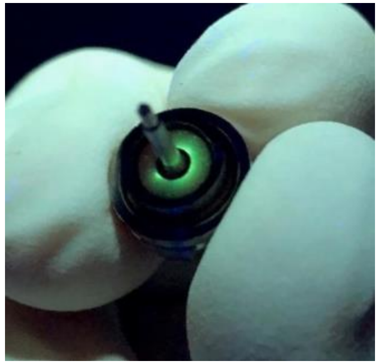


Installation of two sets of 12 feedthroughs supplied by two different manufacturers

One batch was withdrawn after leakage problems during the soldering and bake-out phase



CT scan by ESRF BM18. Crack is visible on the upper part (in-air) of Manufacturer 2.

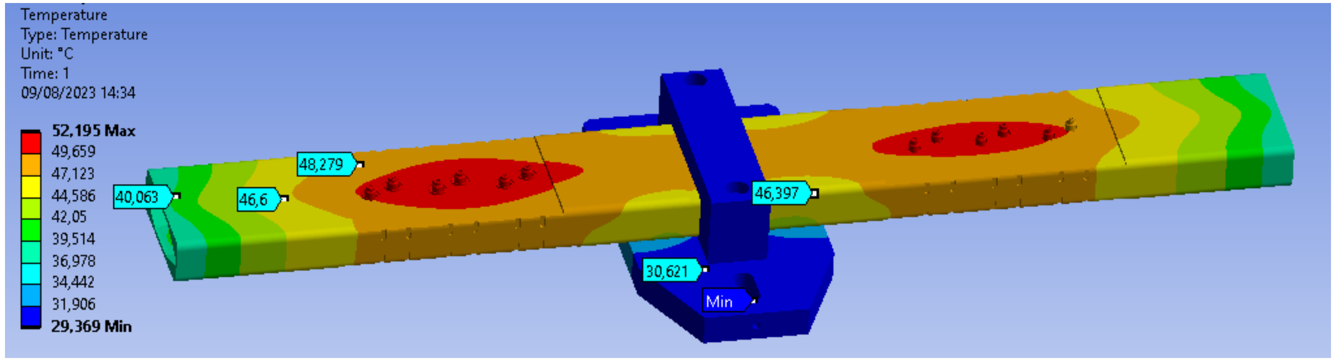


Fluorescent oil shows transversal (top) or radial (bottom) cracks

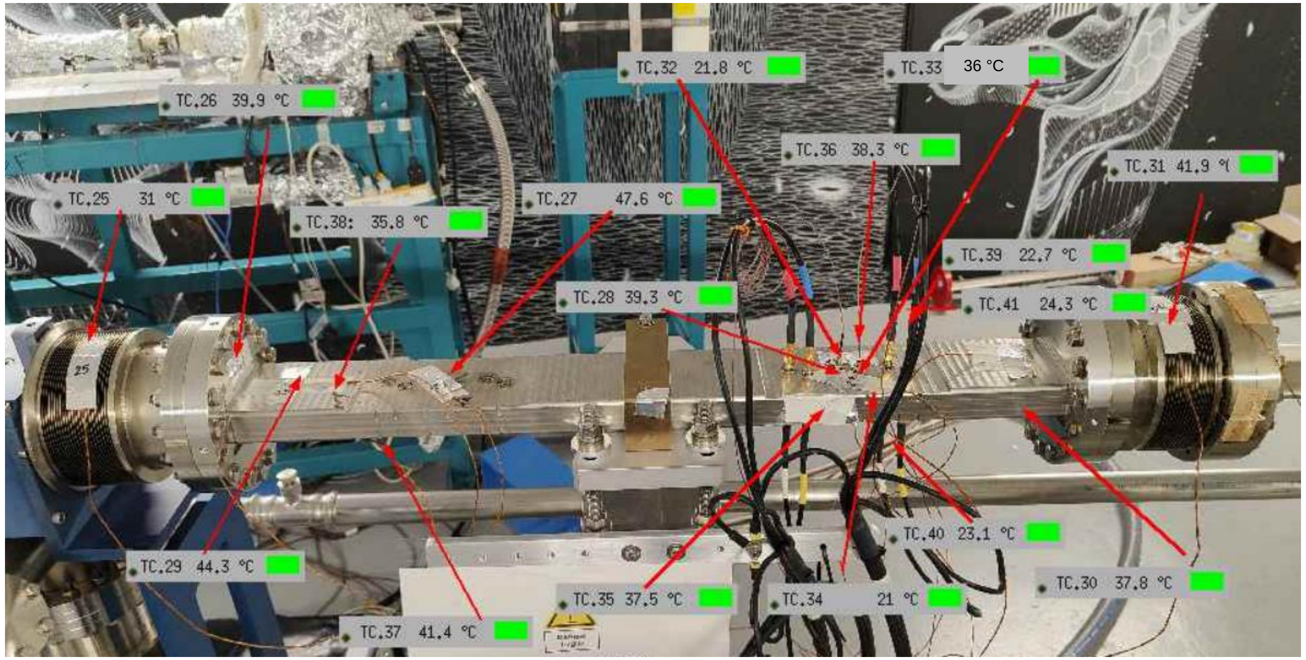
For more details, please refer to Nicolas Hubert presentation during the BPM workshop at ALBA
https://indico.cells.es/event/1542/contributions/2943/

Button prototypes: beam tests

- Temperature measurements:
  - Sensors distributed on the VC body and on some feedthrough pins.
  - Measurements in good agreement with simulations!
    - Observed temperatures are ~15% lower than expected.
    - Probably due to an overestimation of heat exchange with environment in simulations



Thermal simulation. Maximum expected temperature @ 500 mA is 52 °C

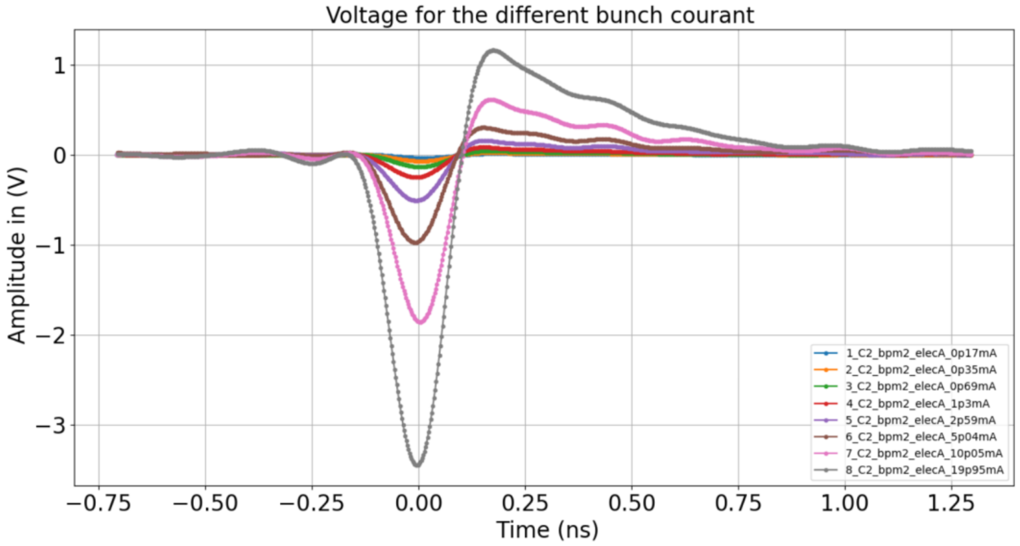


Maximum measured temperature @ 500 mA is 47.6 °C

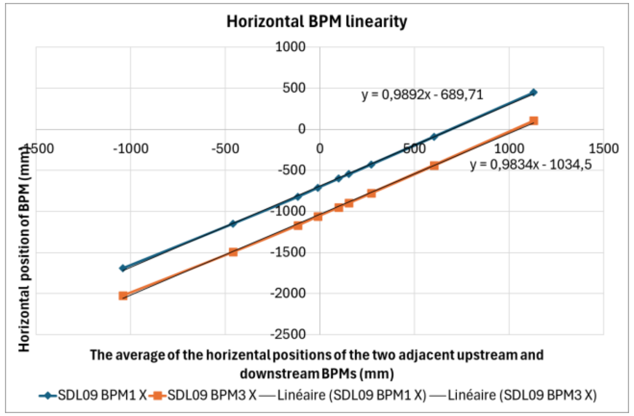
Button prototypes: beam tests

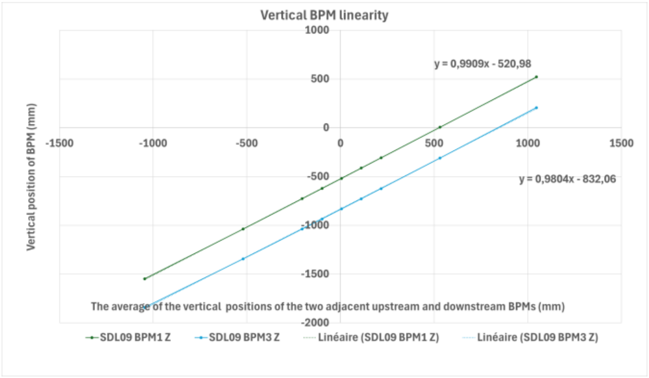
- Collected signal:
  - Measurement conditions:
    - Scope: 4GHz BW
    - 32-meter cable (4dB attenuation at 352 MHz)
    - Additional 15 dB attenuator
  - Collected signal at 500 mA is -5 dBm
    - In good agreement with analytical calculation (expected -7 dBm)
  - Long term monitoring does not show any glitches that could be a sign of multipactor.
    - Observed temperatures are ~15% lower than expected.
    - Probably due to an overestimation of heat exchange with environment in simulations

SOLEIL II BPM button conical design is validated by the beam tests.



Oscilloscope pulse amplitude acquisition vs. bunch current





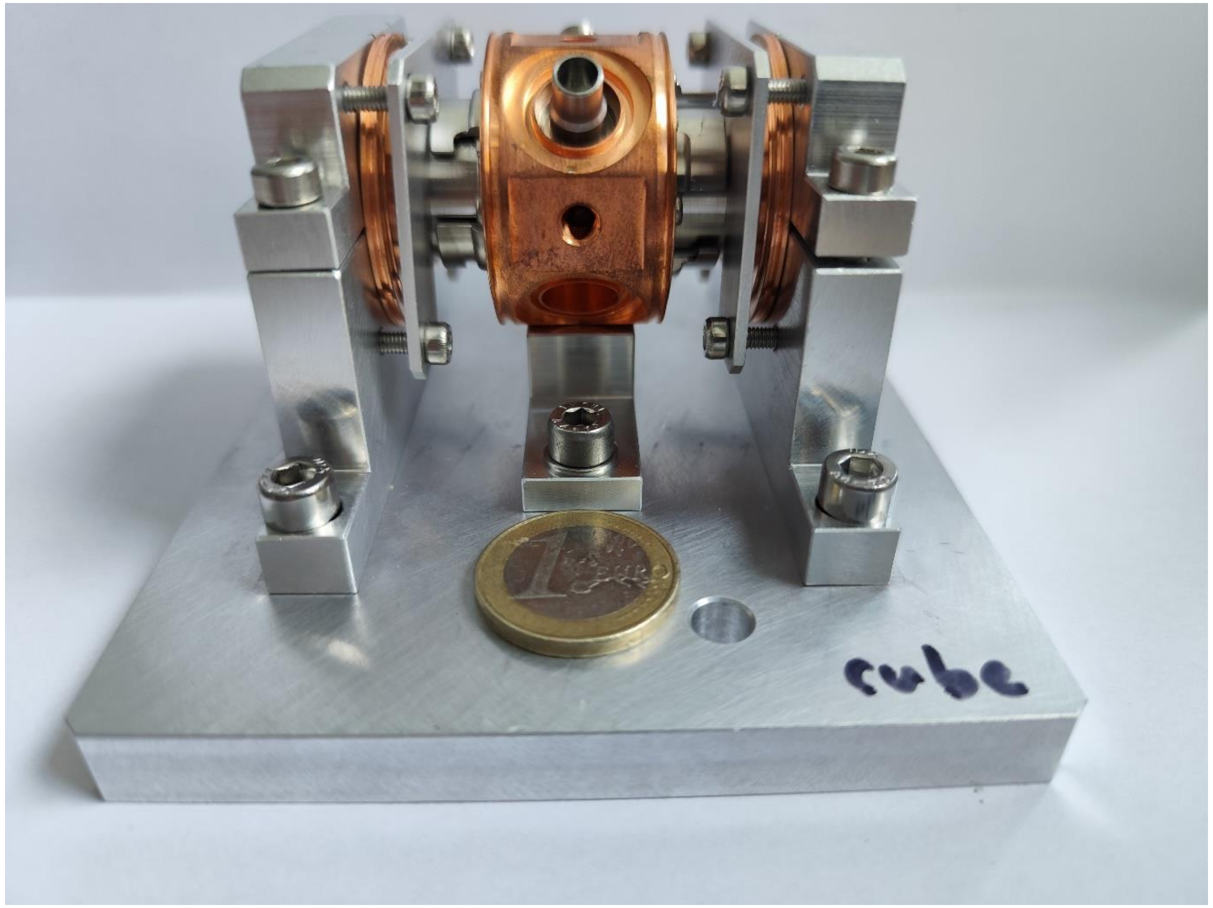
BPM response vs beam position in horizontal plane (left) and vertical plane (right).

Conclusion

- BPM simulations are almost terminated.
- Thermal simulations give acceptable temperature increase (+0.5°C in nominal operational mode).
- Thermal measurements on the chamber confirm that the simulation methodology is accurate.
  - Buttons have been positioned 8 mm from the beam, which matches the SOLEIL II BPM16.
  - Collected signal is compliant with theoretical calculation.
  - Button temperature does not exceed 40 °C, which is below the simulation predictions

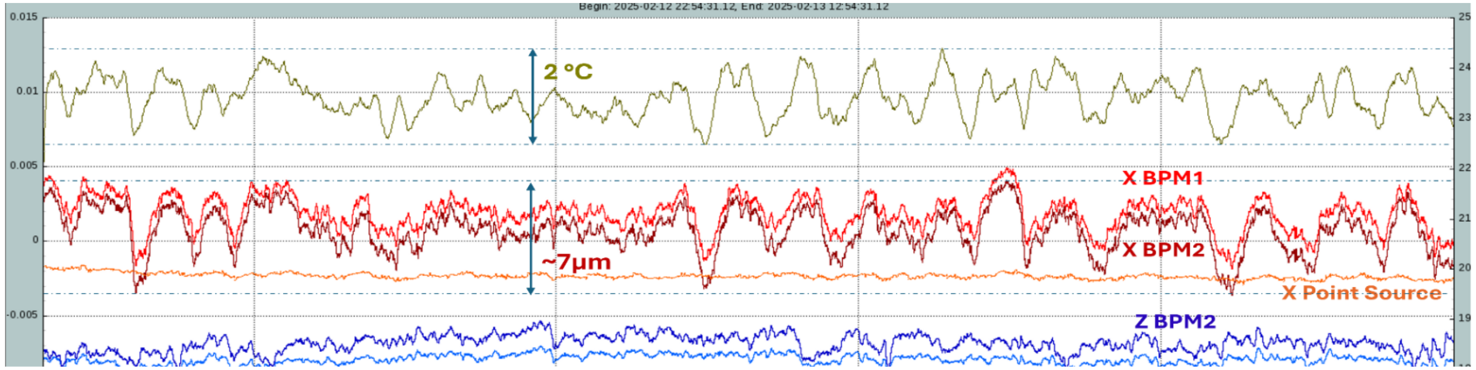
Next steps:

- Manufacturing of two 6 mm button batches after design modifications (better robustness to bake-out expected)
  - Validation of laser welding on CuCrZr (for BPMs integrated on bending magnet VC)
  - Conduct bake-out tests to validate ceramic robustness



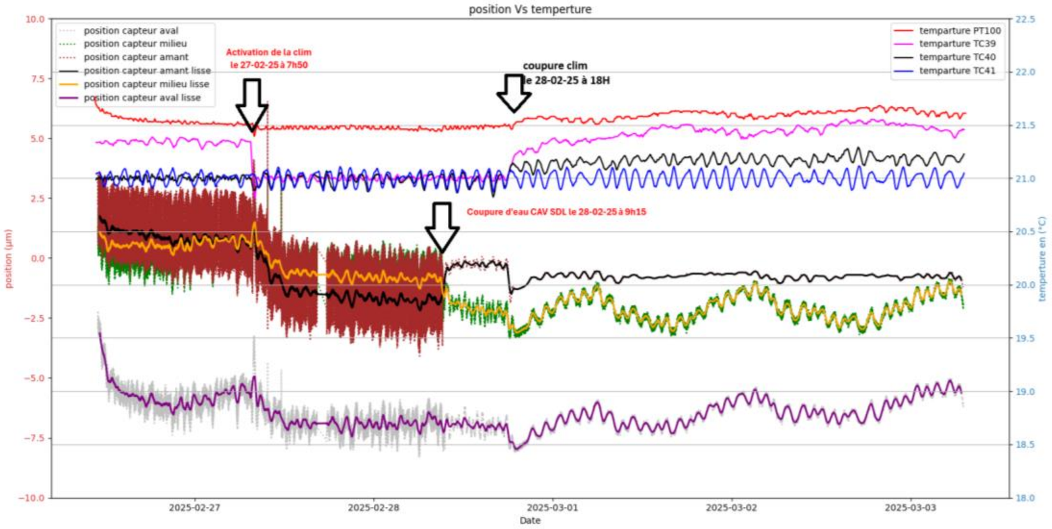
Thank You for Your Attention

Setup stabilities



Displacements observed in the H plane are correlated with significant temperature variations in the area (around 2°C).

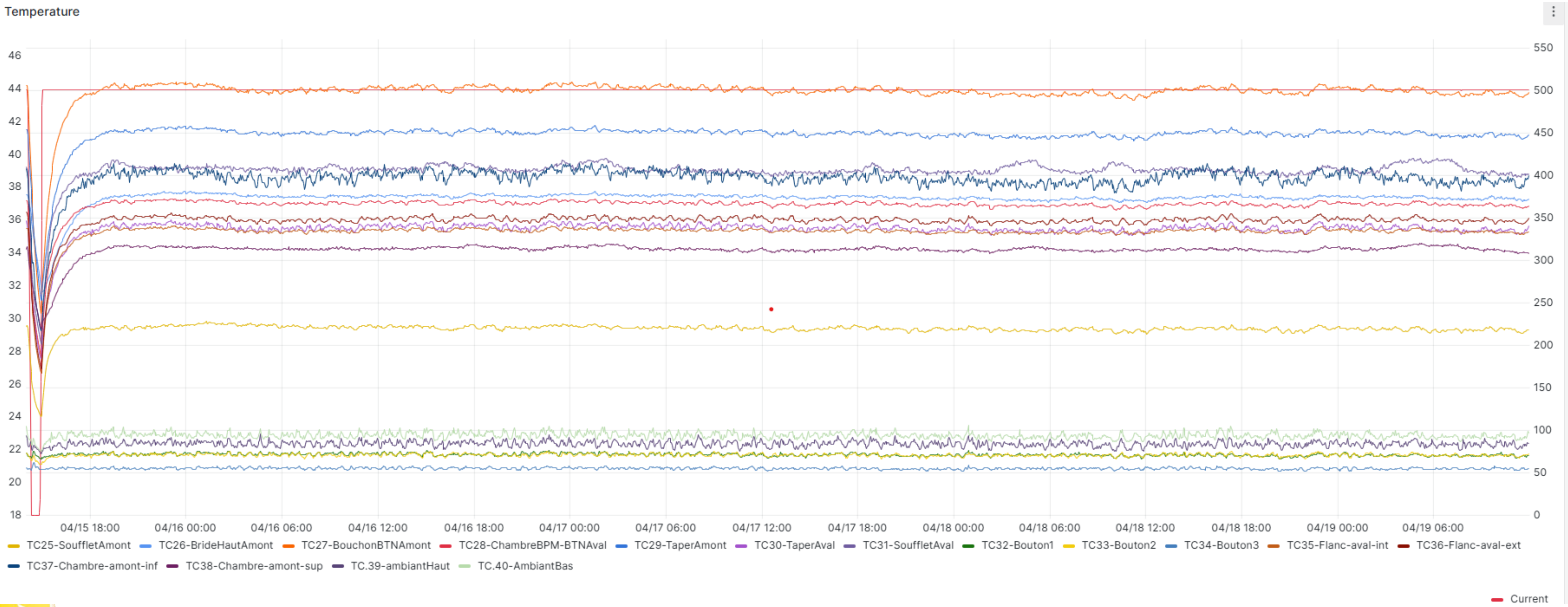
Installation of a second supplementary support to eliminate disturbance



Investigation during technical shutdown : installation of three position sensor

"A combination of two disturbances is observed: a slow variation due to temperature changes, and a fast one linked to the cooling system of the vacuum chamber."

Temperature stability



Position stability

Positions