ESS spoke cavities tuning

N. Gandolfo

On behalf of ESS Spoke cryomodule team

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Outline

- Why do we need a tuner?
- How does look the design phase?
- ESS double spoke tuner, how does it work?
- Preliminary results at room temperature

Why do we need a tuner?

Main actions of a tuner (or Cold Tuning System)

- Tuning : Adjust and control the cavity resonant frequency during operation
- Detuning : In some failure case, it may be useful to detune the cavity in order to not let the beam interfere with it

Identified perturbations to compensate

Perturbations	Speed	Repetition	Amplitude
Fabrication incertitude	Static	Once	Large (~10s kHz)
Cooling down Incertitude	Quasi-static (~ hours)	Once	Large (~10s kHz)
Pressure variations	Slow (~ seconds)	Random / hours	Medium (~100s Hz)
Lorentz forces	Fast (~ milliseconds)	Each beam pulse	Medium (~100s Hz)
Microphonics	Fast (~ milliseconds)	Random / continous	Medium to small (~100s Hz to ~10s Hz)

How does look the design phase?

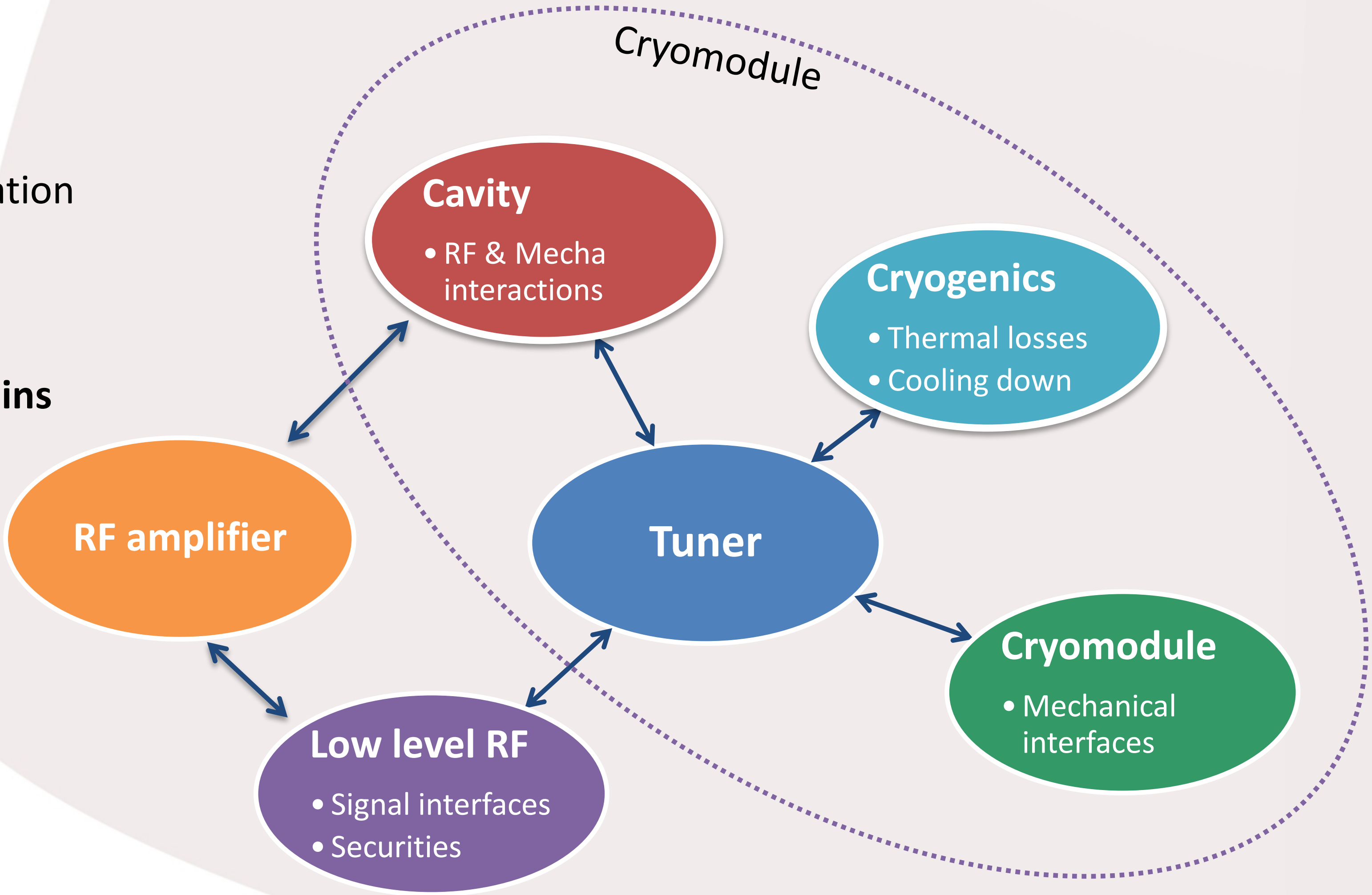
Tuner interaction overview

Different skills

- Electronics
- Mechanics
- Instrumentation
- Simulation
- And more…

Multiple domains

- Vacuum
- Cryogenics
- RF
- Magnetic
- Control
- And more…

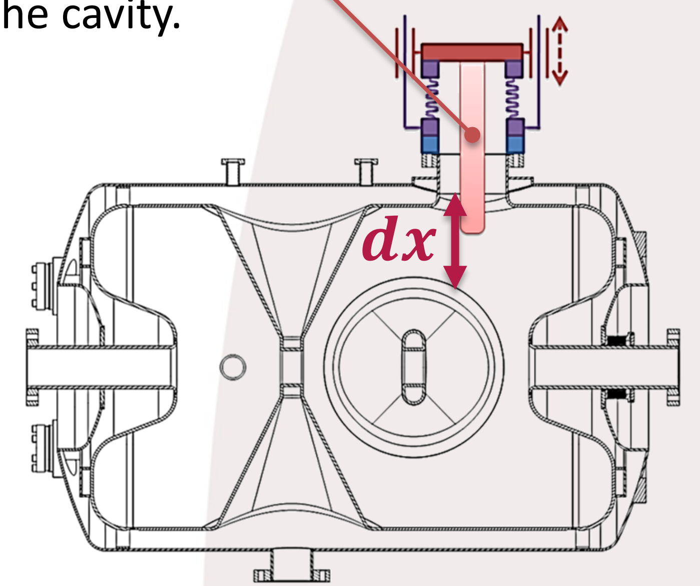


How to tune?

Two ways of tuning well identified

By insertion

…of a superconducting plunger inside the cavity.

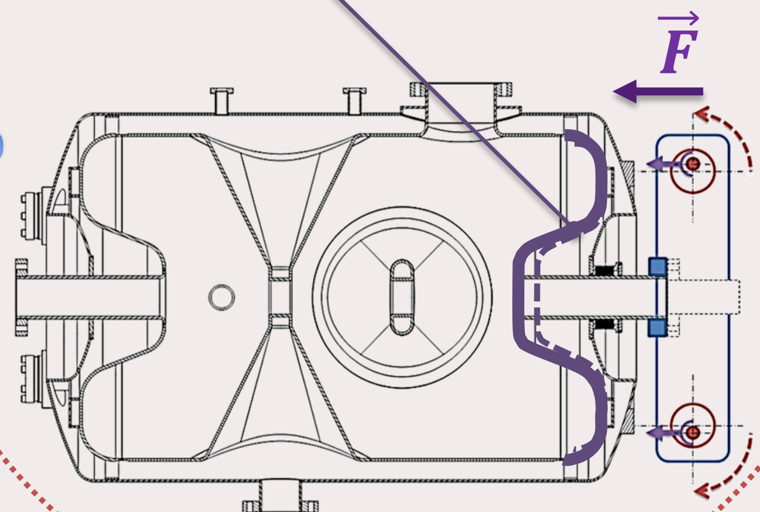


- No risk to damage the cavity
- Not mature yet
- Additional risk of pollution / quench
- Clean room assembling
- Must be integrated to LHe circuit
- Fast tuning seems to be an hard task

Vs.

By deformation

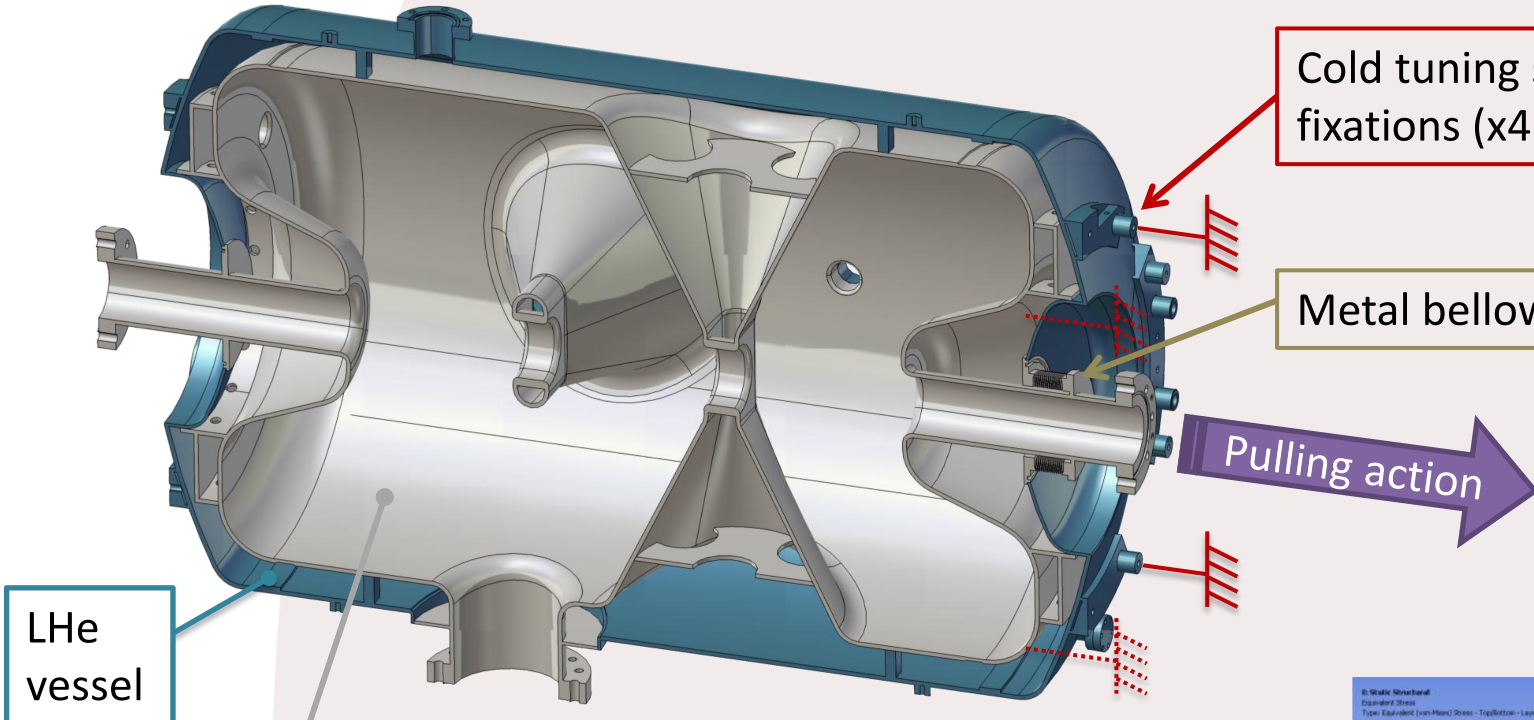
…of a local area of the cavity.



- No interaction with inside of the cavity
- Reliable
- Cooling down is long
- Additional space along the beam axis
- High forces involved
- Risk of plastic deformation of the cavity

Design study : Cavity parameters

Double spoke cavity

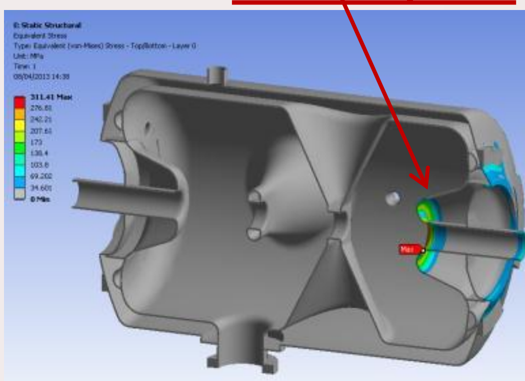


Cavity RF/Mecha computation results

- Tuning sensitivity : **135 kHz/mm**
- Cavity stiffness : **20 kN/mm**

➔ "Tuning challenge coefficient" : **148 N/kHz**

- Max displacement @2K (400 MPa) : **1.28 mm**



Design study : Cavity parameters

Cavity frequency requirement

- Q_L = 1.77e+5
- Resonant frequency = 352.2 MHz
- Cavity bandwidth = 1,990 Hz

➔ Looking for a resolution of at least 100 Hz (0.74 µm)

Sensitivity to Helium bath pressure fluctuation

K_P without CTS (free ends)	**+16.5 Hz/mbar**
K_P with greatly stiff CTS*	**+26.0 Hz/mbar**

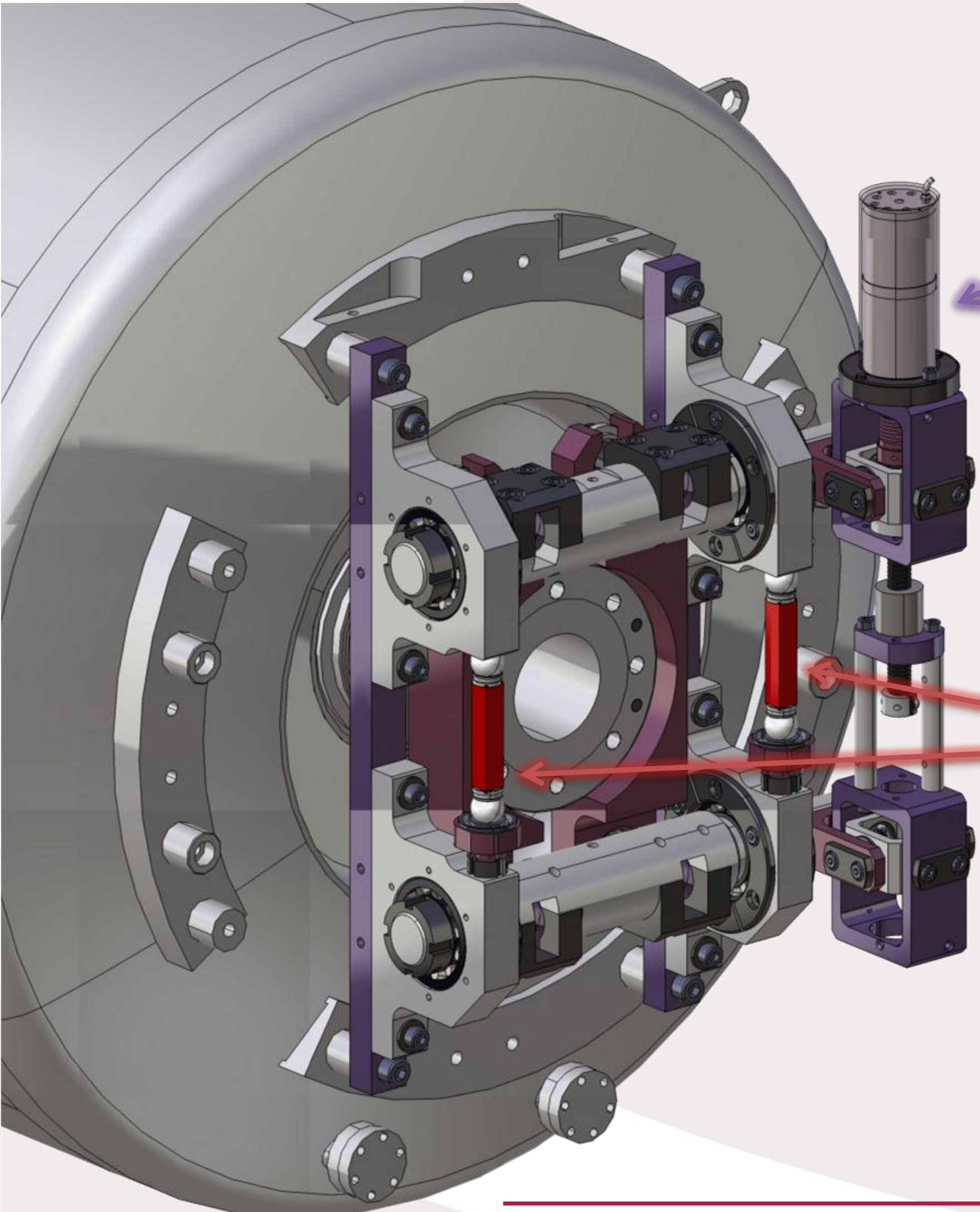
*The beam tube is connected rigidly to the helium vessel at the level of the 4 CTS supports (along the beam axis)

Notice the Lorentz forces detuning are small in regard to the cavity bandwith

Sensitivity to Lorentz forces detuning

For 9 MV/m		
K_L without CTS (free ends)	**-5.13 Hz/(MV/m)²**	Δf = -415 Hz
K_L with stiff CTS	**-4.4 Hz/(MV/m)²**	Δf = -356 Hz

ESS Double Spoke tuner



Slow tuner

Main purpose : Compensation of **large** frequency shifts with a **low** speed

Actuator used : Stepper motor with planetary gearbox (1:50)

Fast tuner

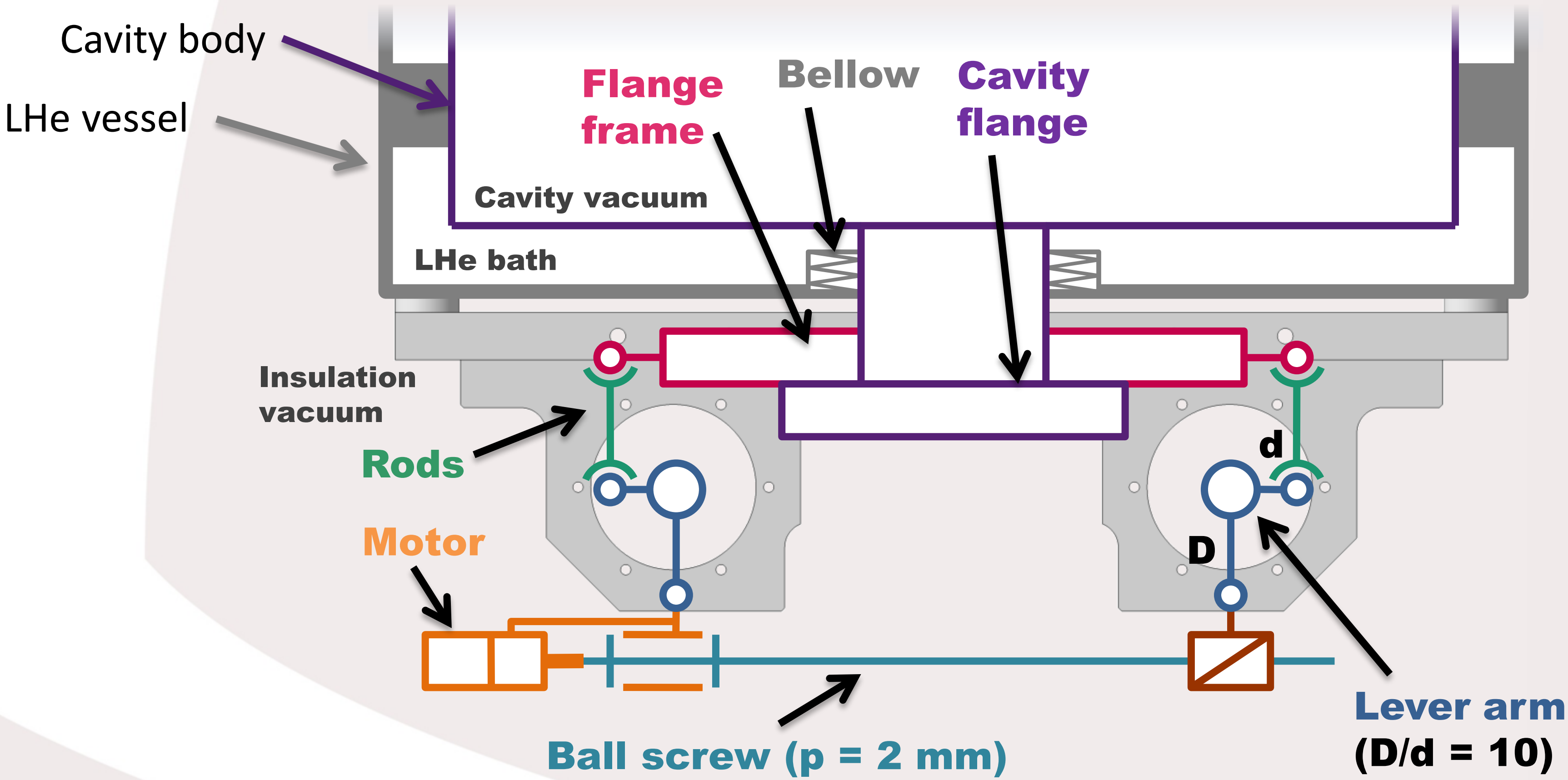
Main purpose : Compensation of **small** frequency shifts with a **high** speed

Actuator used : Piezoelectric actuators (no load displacement : ~ 50 µm @ RT)

Slow tuner

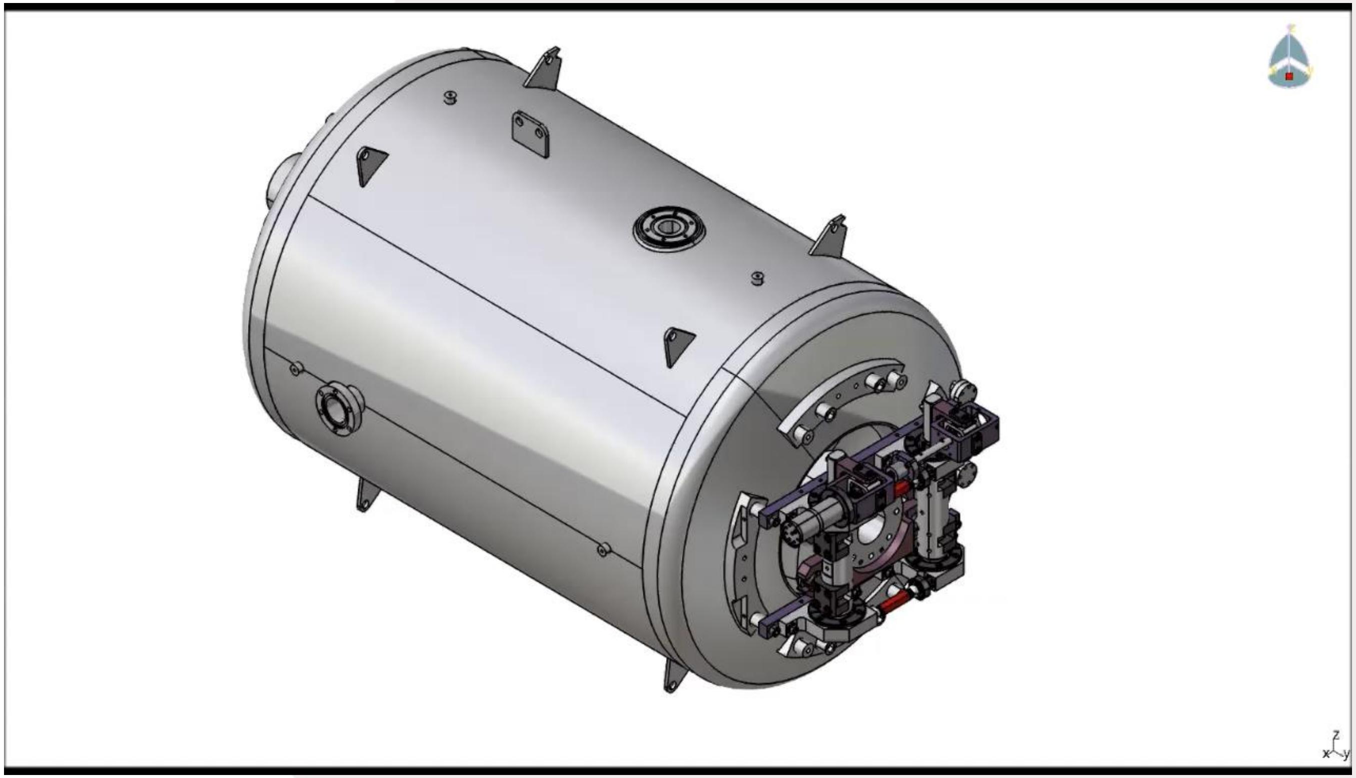
Slow tuner principle

A ball screw system driven by a stepper motor acts on a double lever arm mechanism to provide a significantly reduced displacement of the cavity flange along the beam axis.



Slow tuner

Slow tuner in motion



Cavity sensitivity

- 135 kHz/mm

CTS tuning range

- 135 kHz

Cavity stiffness :

- 20 kN/mm

CTS stiffness estimated :

- 110 kN/mm

CTS theoretical resolution :

- 10 nm/step (full step mode)

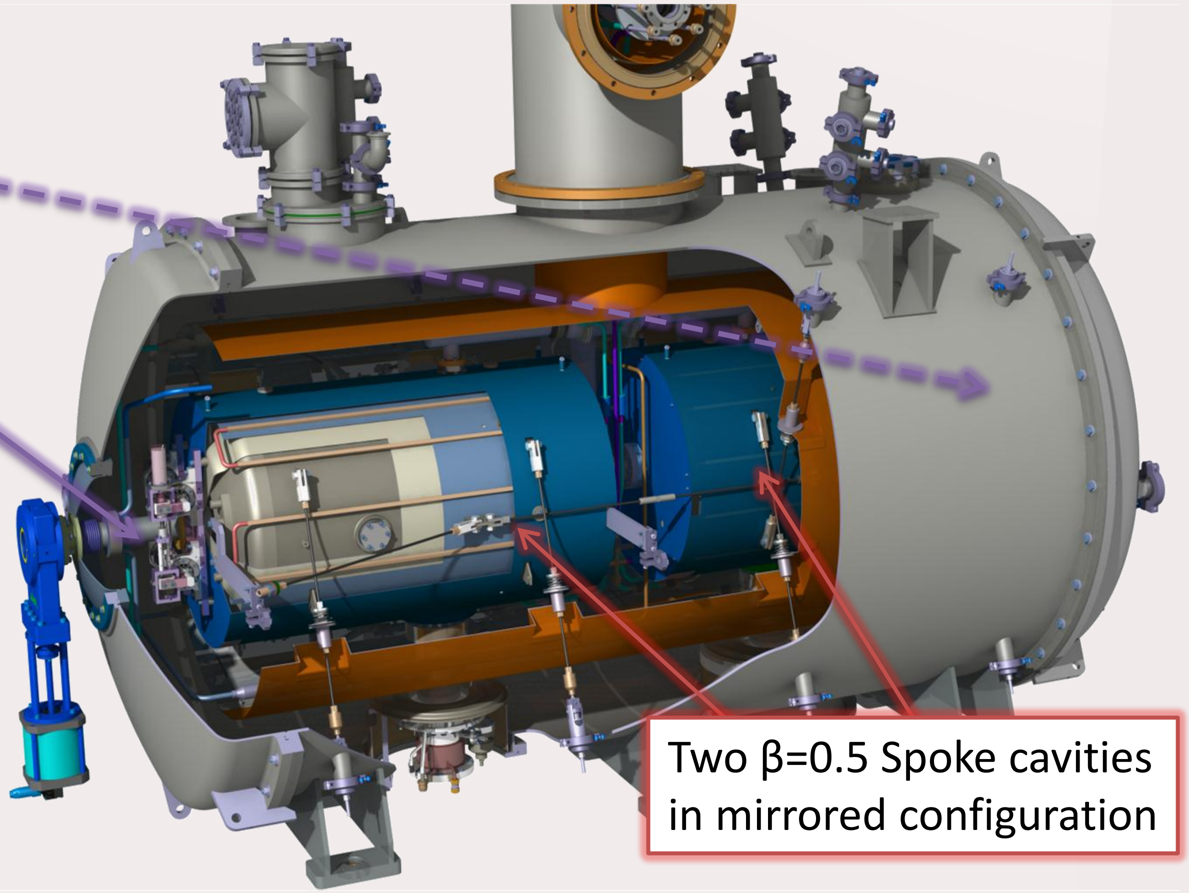
Final Tuning resolution :

- 1.14 Hz/step (full step mode)

Cryomodule integration

ESS Spoke cryomodule

CTS are located on each side of the cryomodule
Additional mass : 2x 14 kg



Two β=0.5 Spoke cavities in mirrored configuration

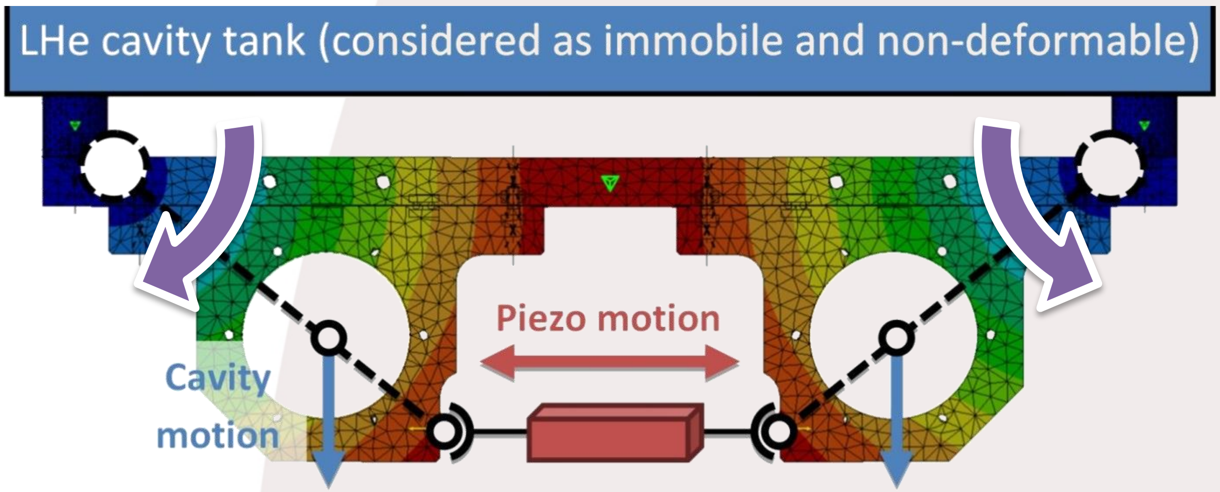
Transmission & motorization

Two options identified :

- From outside the cryomodule
- From inside the cryomodule

Inside avantages		Outside avantages
• **Less thermal losses** (if the motor is only powered when it is running) • **Less interaction with cryomodule :** • Design // Risks // Assembly	Vs.	• **Maintenance of the motor** • Motor is cheaper (but cost for additionnal parts must be taken in account)

Fast tuner



Fast tuner principle

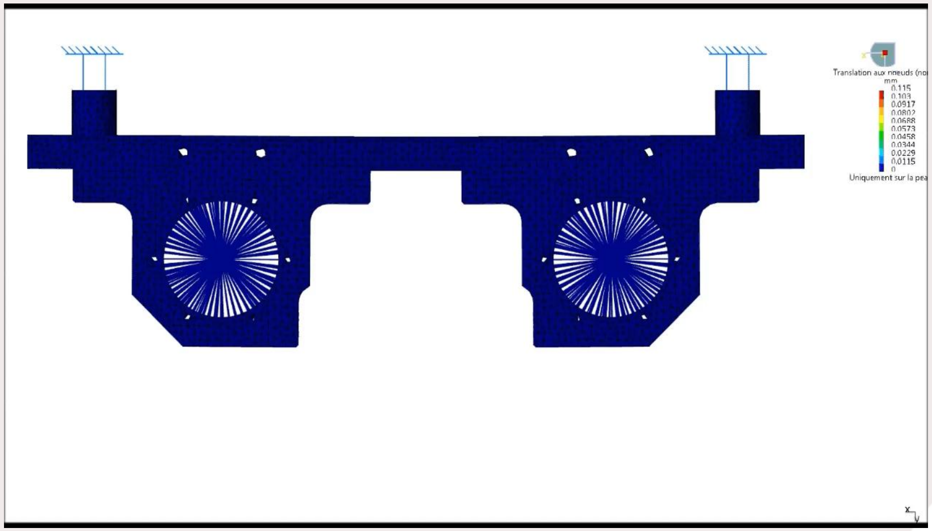
- Rigid lever arm concept
- 38% of dual piezos motion is transmitted along the beam axis
- Quasi independent from the slow tuner action

About preload force

Value targeted : ~20 MPa (2kN)

Comes from 3 identified sources :

- Thermal shrinks (small contribution)
- Slow tuner (small contribution)
- Manual preloading during assembly



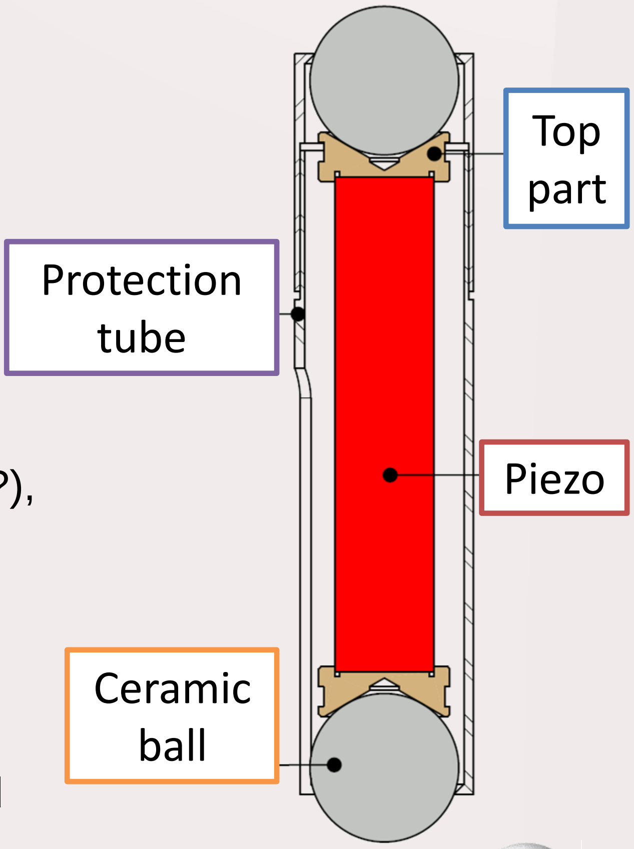
Fast tuner

Piezo assembly

Two different manufacturers have been selected to compare performances : Noliac & Physik Instrument.

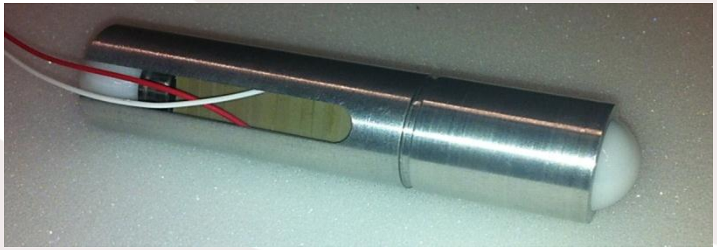
Main differences between Noliac & PI is the way to build stacks :

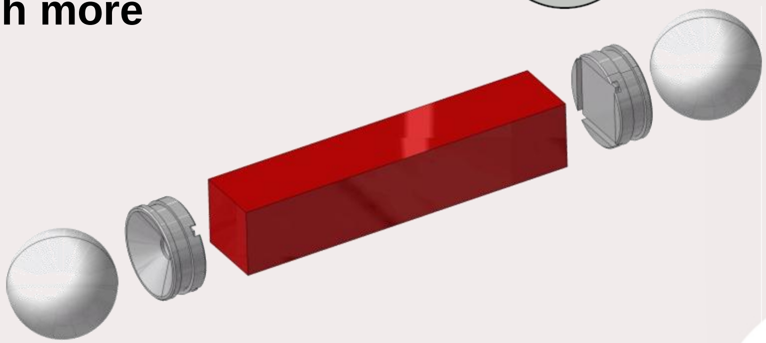
- Noliac build multilayers actuators of 2 mm height, then stack them with glue, **this allow fabrication of very long piezos** (>100 mm)
- PI **build directly multilayers** of defined height (more reliable ?), but 36 mm max from catalogue



<u>Tricks and Tips</u>:

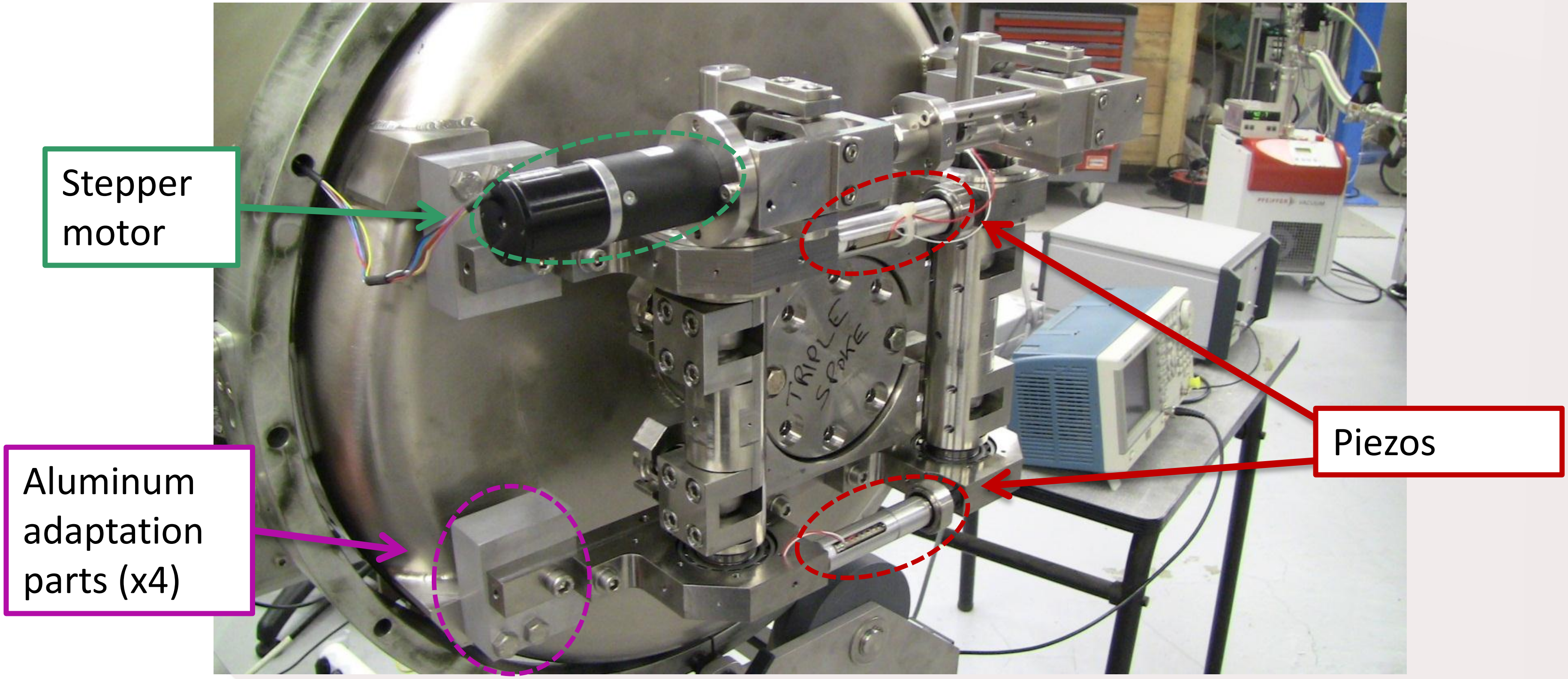
- Think to **attach the cables rigidly** to a fix part of the tuner to avoid over stress at the welding of the piezo electrodes
- Ring stacks piezo actuators exist but if they seem more adapted to interface with spherical joints, they can be also **much more expensive** (up to 3 times for similar performances)





Preliminary results (at room temp.)

Tuner put on a triple spoke resonator (EURISOL prototype)



Similar cavity parameters

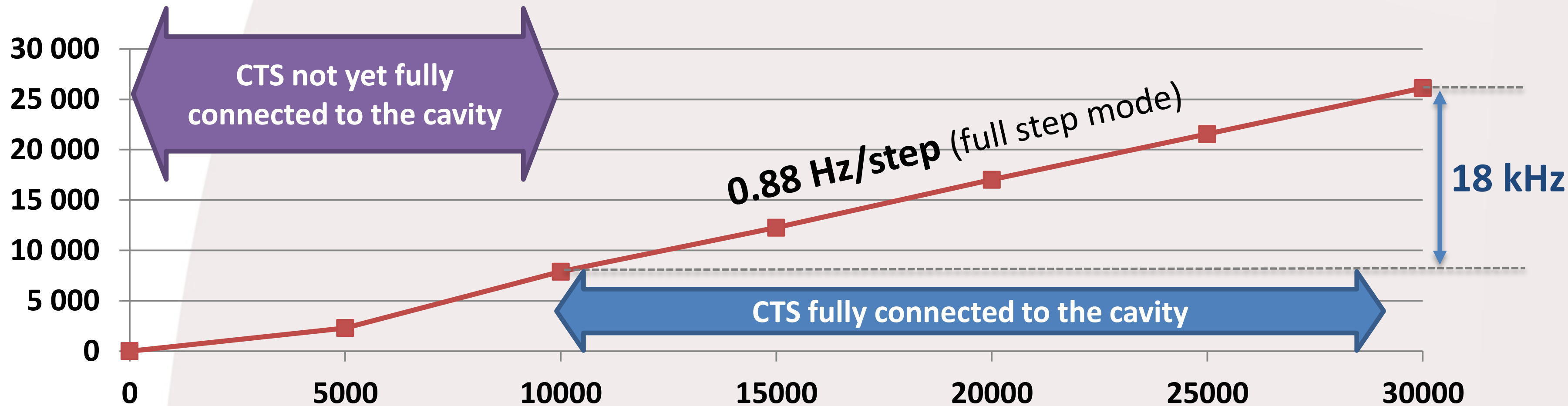
	ESS spoke cavity	Triple spoke cavity
Stiffness	20 kN/mm	19.3 kN/mm
Tuning sensitivity	135 kHz/mm	180 kHz/mm

Preliminary results (at room temp.)

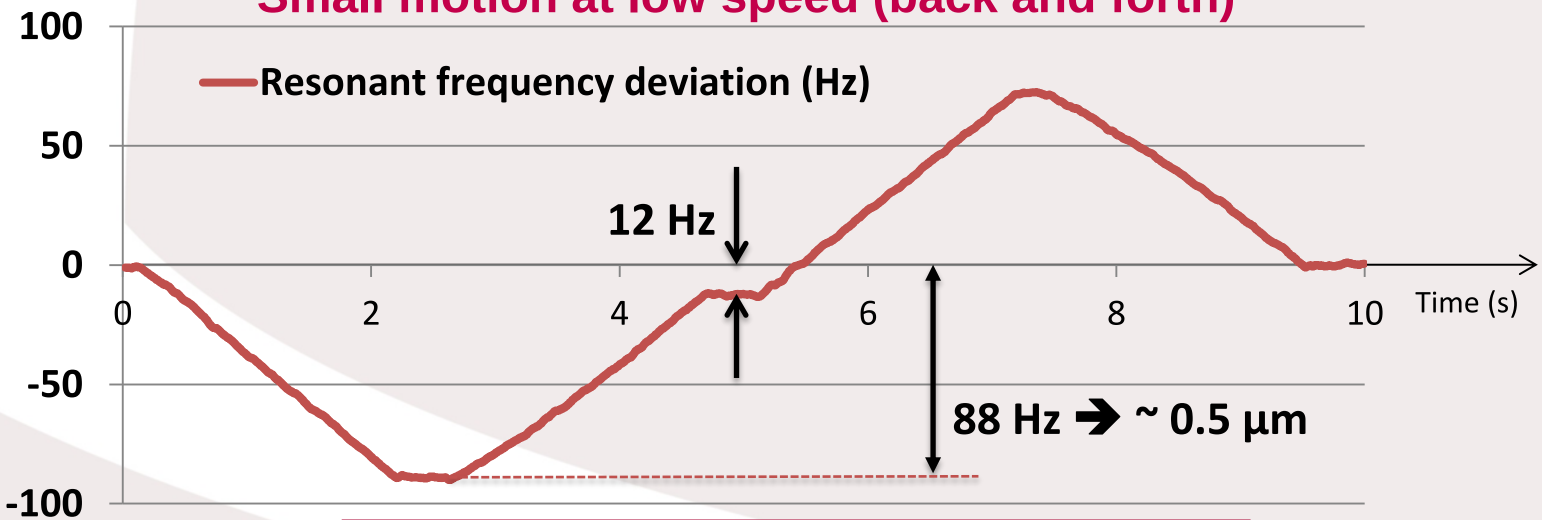
Slow tuner test on triple spoke cavity

Max range limitation :
@300K : 30k steps

Frequency shift (Hz) Vs motor displacement (step)

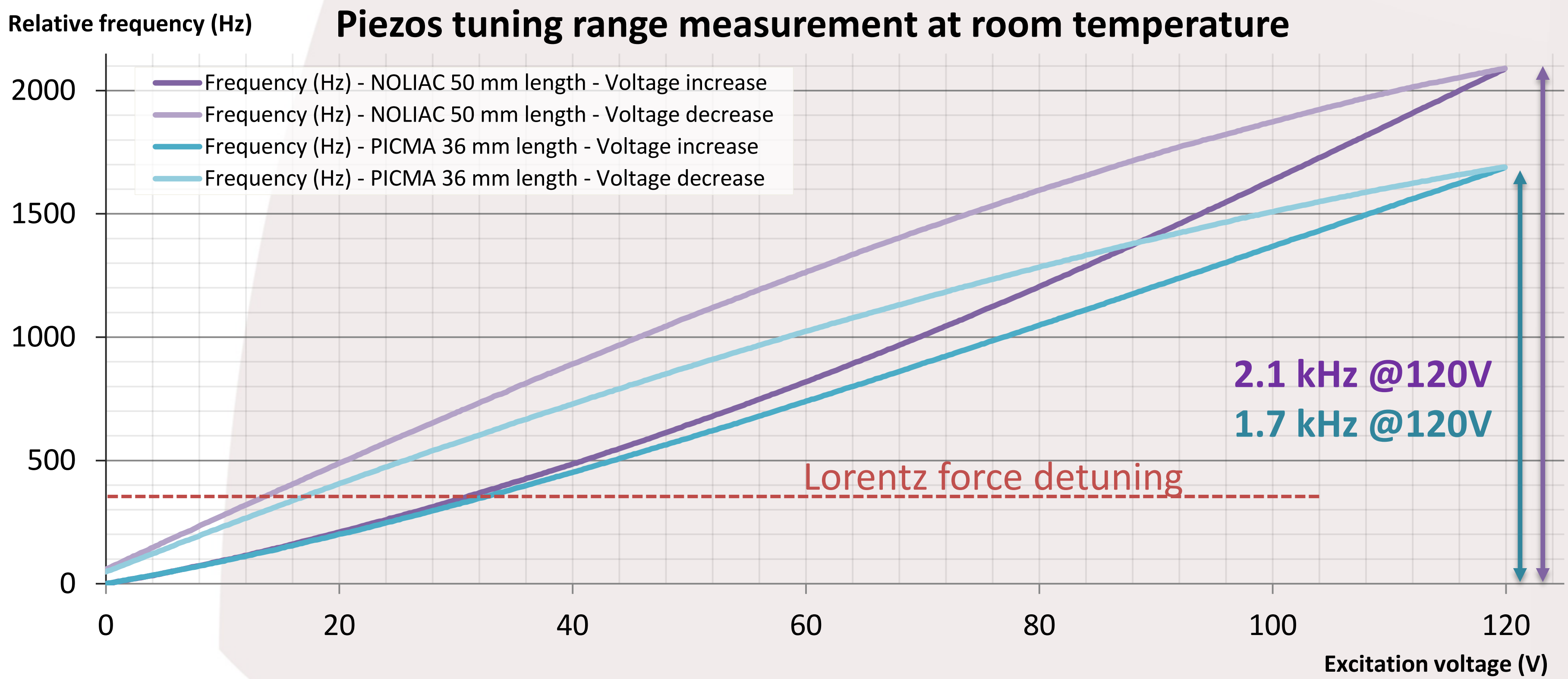


Small motion at low speed (back and forth)



Preliminary results (at room temp.)

Fast tuner test



Reminder :

- Here the cavity sensitivity is 180 Hz/µm instead of 135 Hz/µm for double spoke
- At low temperature, piezo can be driven with full bipolar range [-120 V to +120 V]
- At low temperature, piezo stroke is expected to drops at around 25% from 300 K

Summary

Actual tasks

- Make a cryogenic test @2K
- Improve the design thanks to the experience from prototypes
- Piezo cryogenic test campaign
- Preparing the mass production (Quality stuff, procedures, etc.)

And also… one tricky issue is remaining

- Integration of system to disengage the tuner from the cavity if it get stuck

Few personal feelings I want to share

- Slow and fast tuner linked together cause some interferences on both design and operation phases. Maybe a good thing would be to **physically separate** these two functions, especially when the cavity is very stiff.
- In the ESS spoke cavity case, maybe the piezo are not necessary (low LFD, high bandwidth) **BUT** they may significantly improve the slow tuner lifetime and performances with a smart control process.

☺ Thanks you for your attention ☺

piezos 50x10x10 mm Noliac :
- 70 µm @ 200 V

piezos 36x10x10 mm PI:
- 38 µm @ 120 V