Frequency tuning of the HIE-ISOLDE high-β quarter-wave resonator

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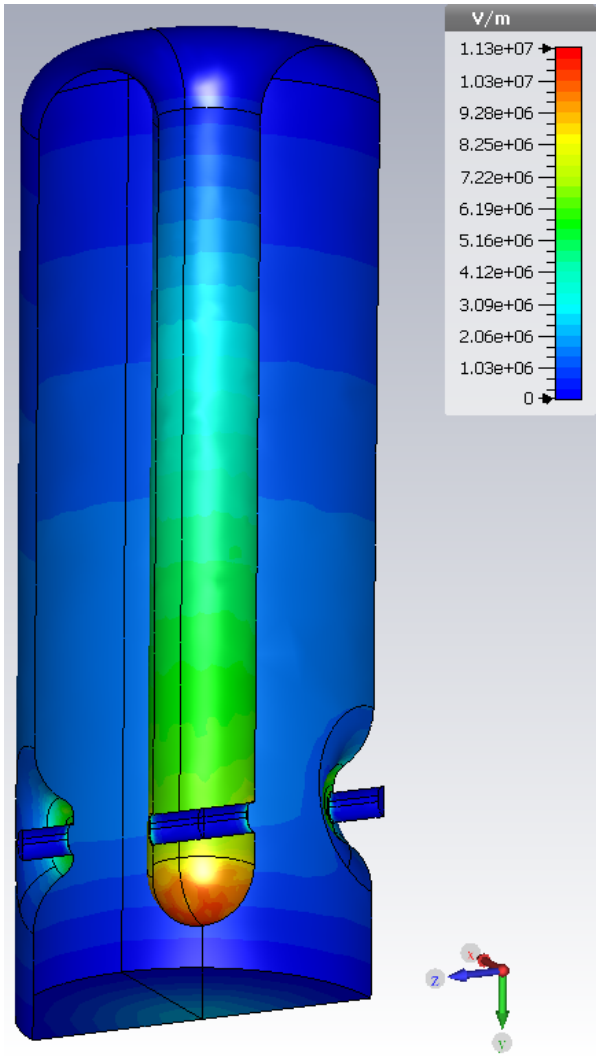
Outline

- Brief introduction to the cavity
- Why the frequency need to be tuned?
- How the frequency is tuned?
- Summary

High-β quarter wave resonator

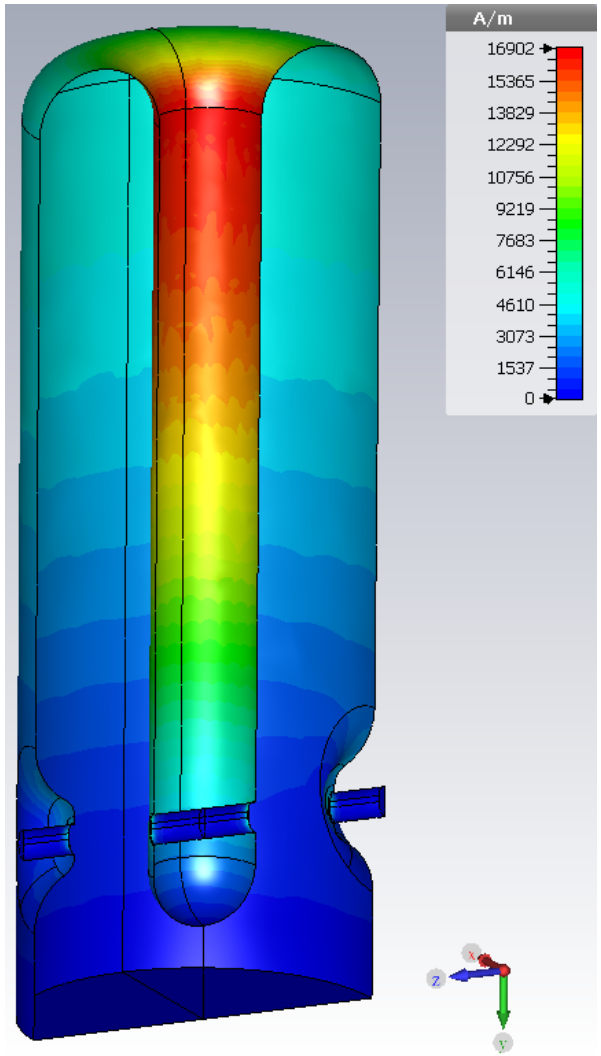
|E| field



Niobium coated on copper

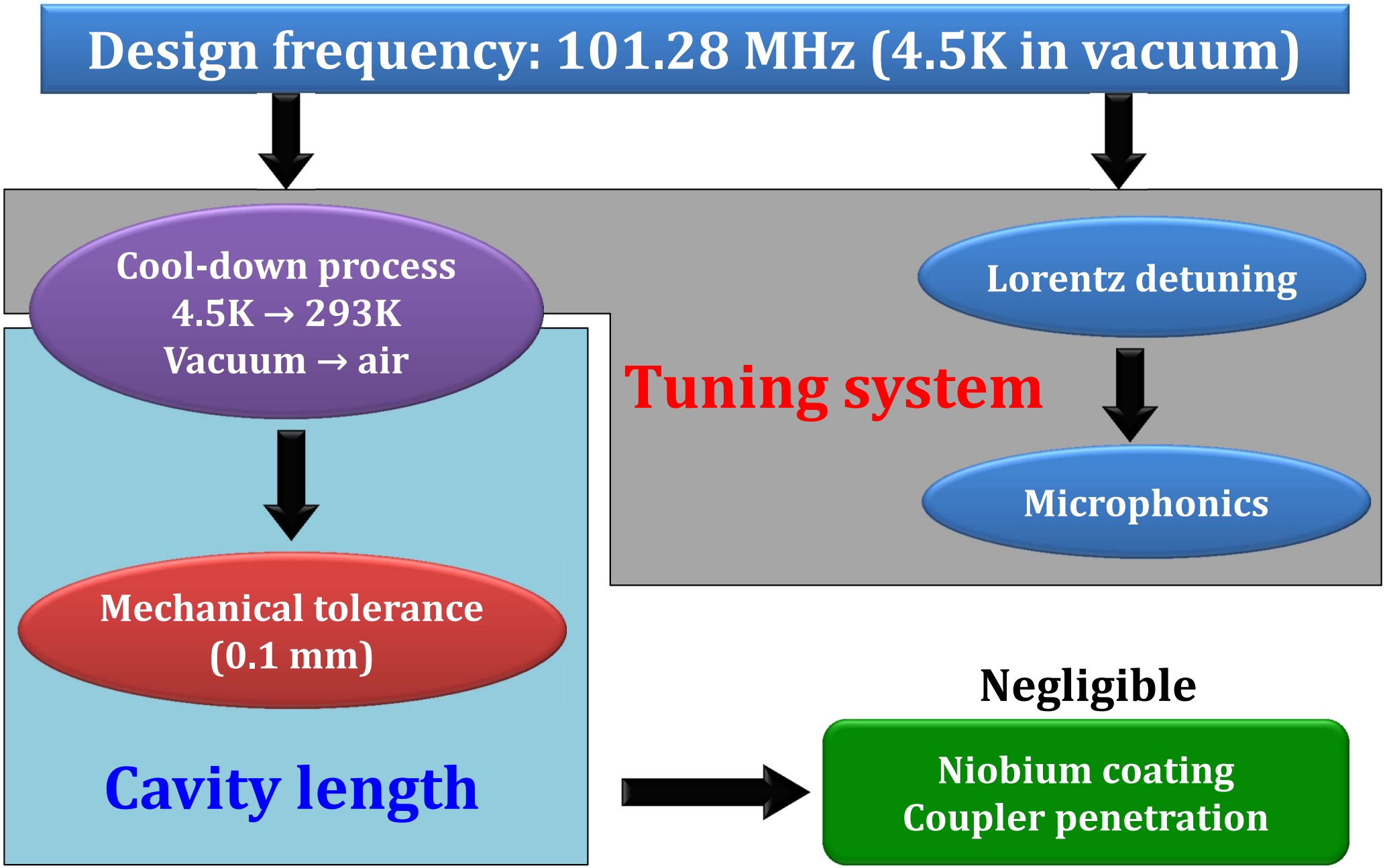
Frequency	101.28 MHz
E_{acc}	6 MV/m
$\beta_{optimum}$	10.9%
R/Q	553 Ω
E_{peak}/E_{acc}	5.0
H_{peak}/E_{acc}	95.6 G/(MV/m)
$G=R_sQ$	30.7 Ω
P_c	7.7 W

|H| field

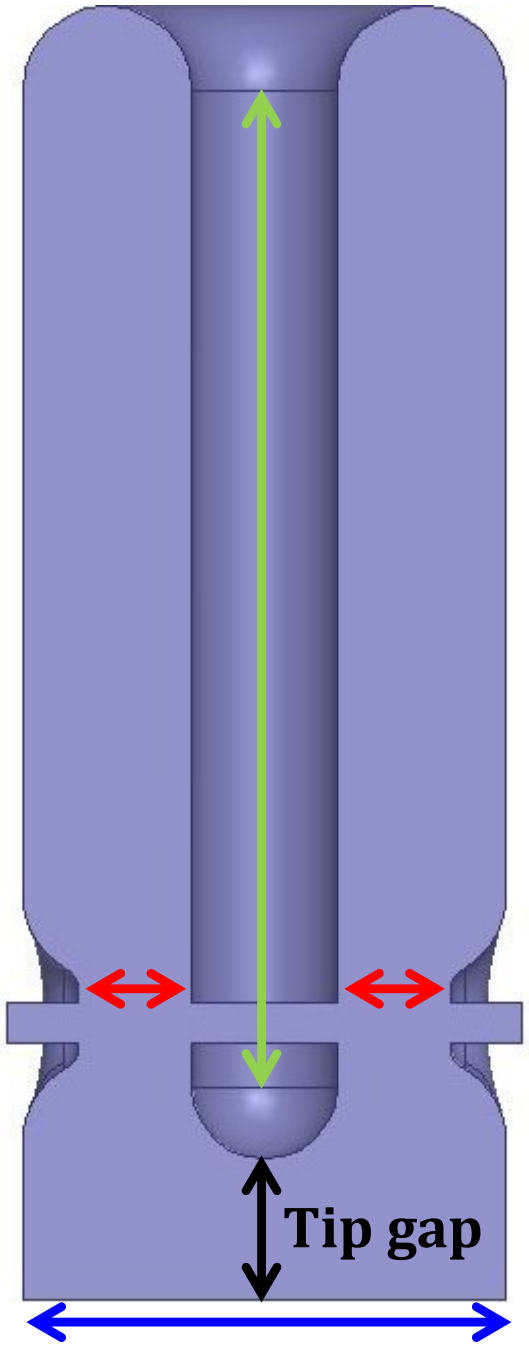


All plots are normalized to 1J of stored energy

Decouple the frequency tuning



Δf due to mechanical tolerance



Type of error	Δf (kHz/mm)
Inner conductor length	160
Cavity diameter	65
Nose length	50

- **Δf due to mechanical tolerance of 0.1mm**
  - **28 kHz in worst case**
- Frequency sensitivity of changing tip gap
  - **18kHz/mm** (@ tip gap 77.5mm)
- Use **tip gap** as a free parameter to **compensate** the mechanical tolerance

A tuning method is required.

The target frequency

101.28 MHz

-370 kHz (vacuum at 4.5K → air at 293K, 50%)

100.91 MHz

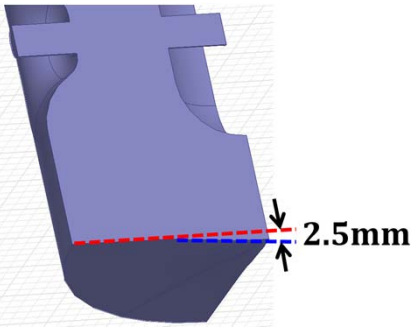
-19 kHz (Tuning plate: 0 position → flat plate)

100.891 MHz

-41.8 kHz (pikcup perturbation)

100.849 MHz

Rest position



Flat plate

Pickup perturbation

Frequency vs. temperature & humidity

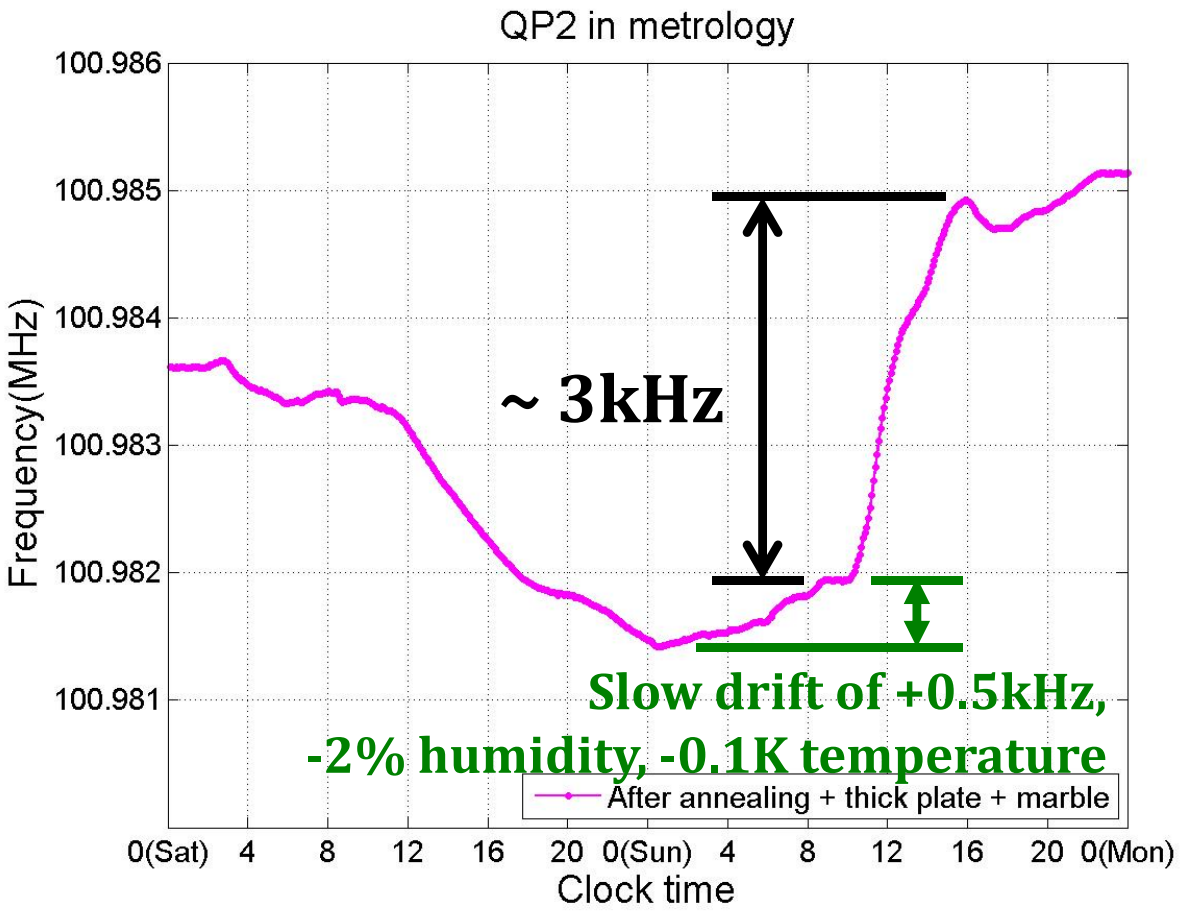
	Δ	Sunday	Δf (calculation)
Temperature	- 1.2K	9:00 – 11:00	+2.4 kHz
Humidity	- 5%	11:00 – 15:00	+0.5 kHz

1 hour delay observed for the frequency to respond the temperature changes

Correct every measured frequency to 20°C and 50% humidity

From calculation

	Δf
Humidity **± 10%** (nominal: 50%)	**∓ 1 kHz**
Temperature **± 1K** (thermal + ε_{air})	**∓ 2 kHz**



The tuning of QP2.1

Trimming	Measured Freq.	Ideal Freq.	Δf	Tip gap
0 mm	**101.0059 MHz**	**100.9953 MHz**	+10.6 kHz	87.5 mm
10 mm	**100.8544 MHz**			77.5 mm
10.3 mm	**100.849 MHz**			77.3 mm

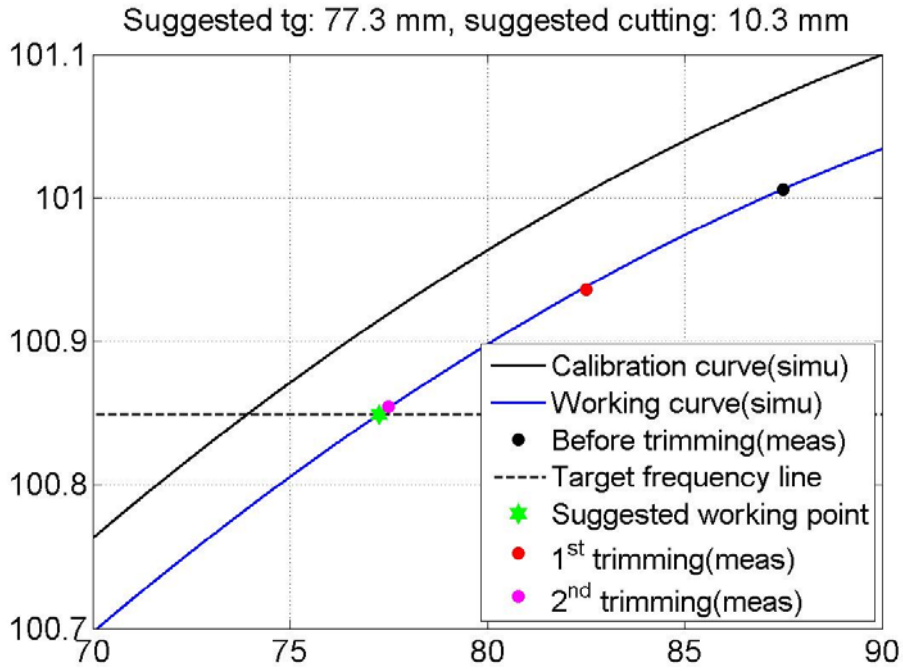
Δf = **100.8544** – **100.849** = **5.4kHz**

77.9 mm

0.3mm * 18kHz/mm = **5.4kHz** (@tg = 77.5mm, the sensitivity is 18kHz/mm)

In summary, if we cut the cavity by **exactly 10.3mm**, the frequency measured will be less than **1kHz** away from the target.

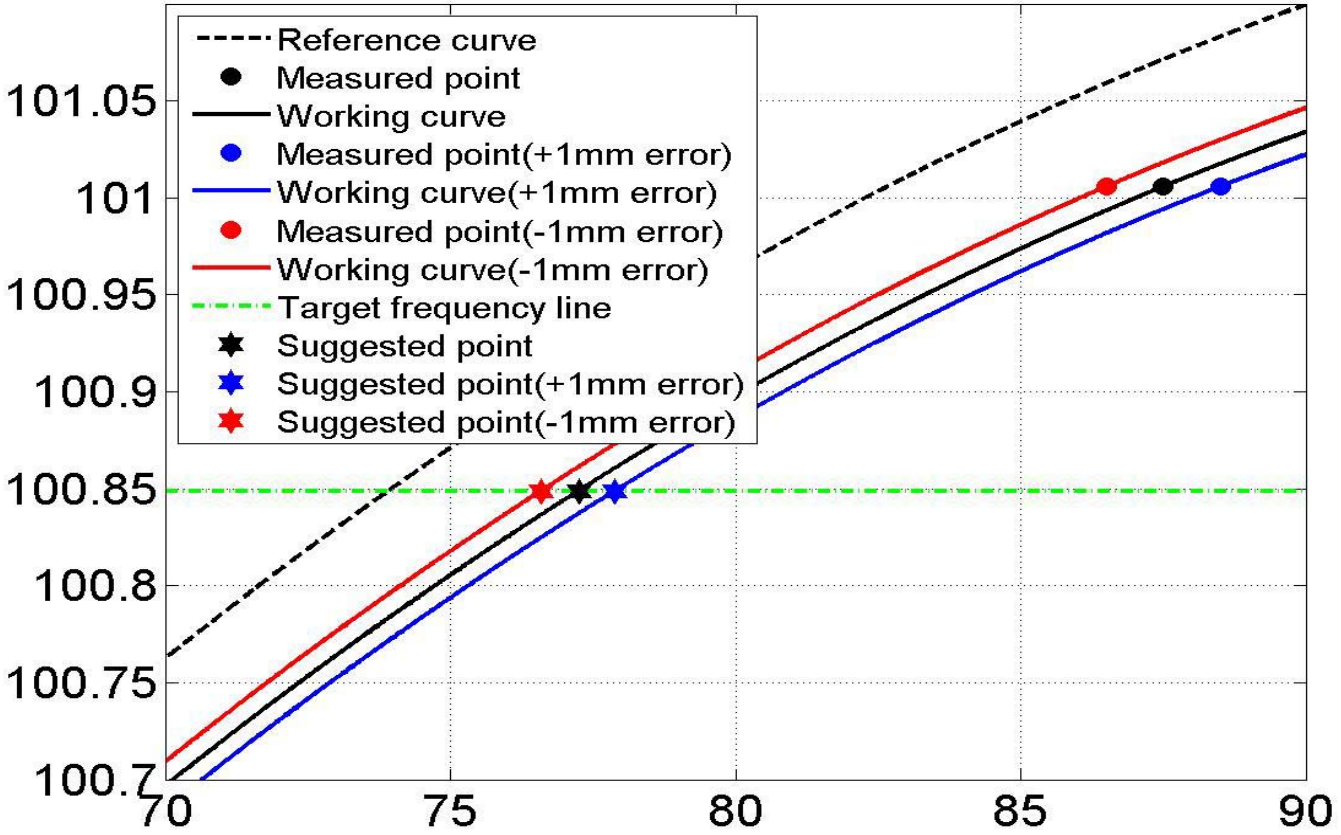
The tuning of QP2.1 is complete.



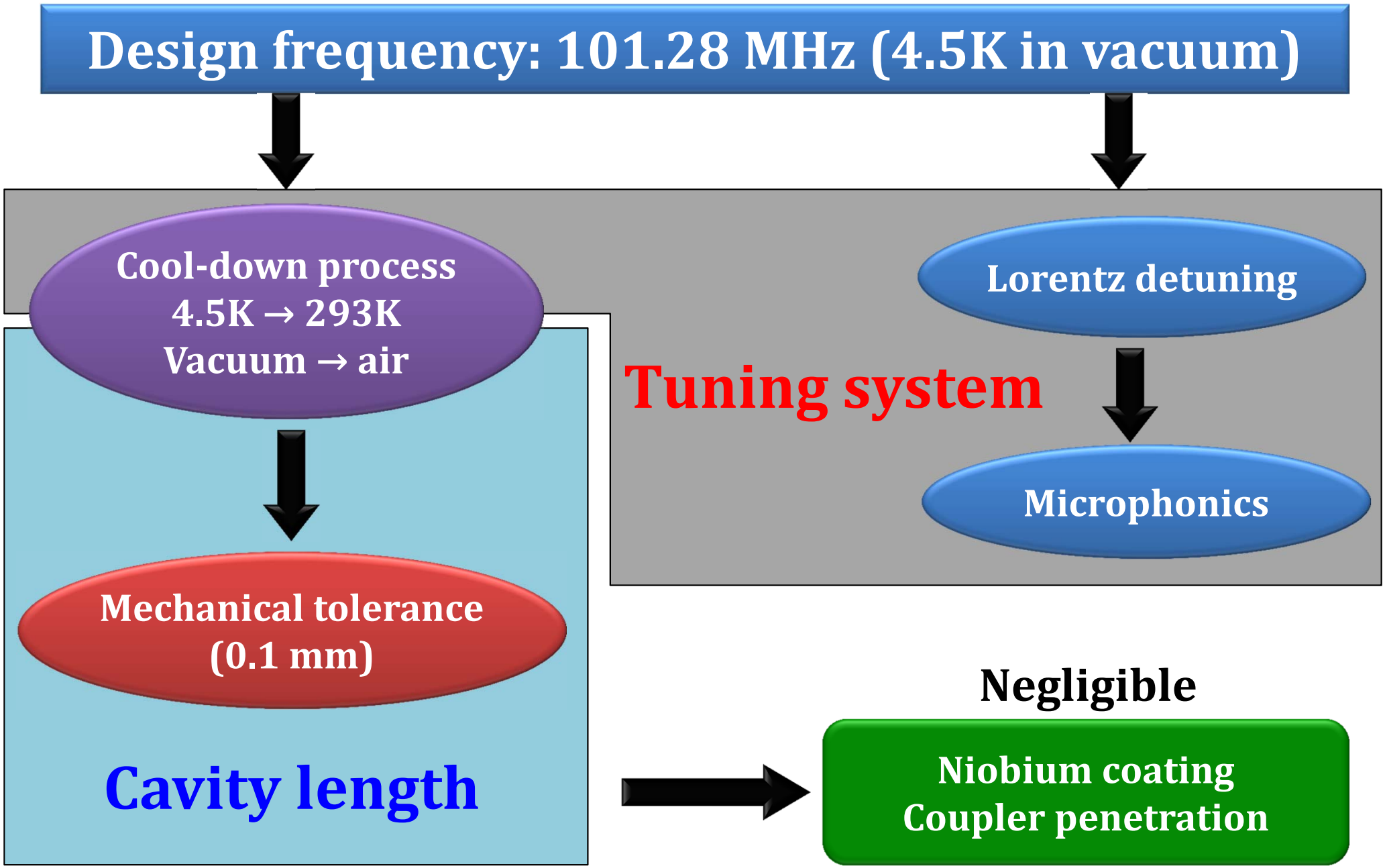
Error estimation

Initial tip gap error	Suggested trimming error	Frequency error
1 mm	0.7 mm	12 kHz
0.1 mm	**0.1 mm**	**~2 kHz**

Can be well covered by tuning system



Decouple the frequency tuning



The tuning system

Original tuning plate

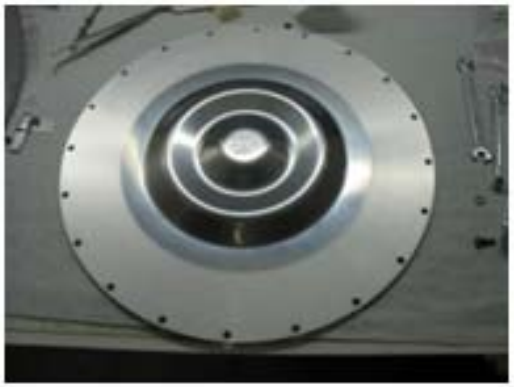
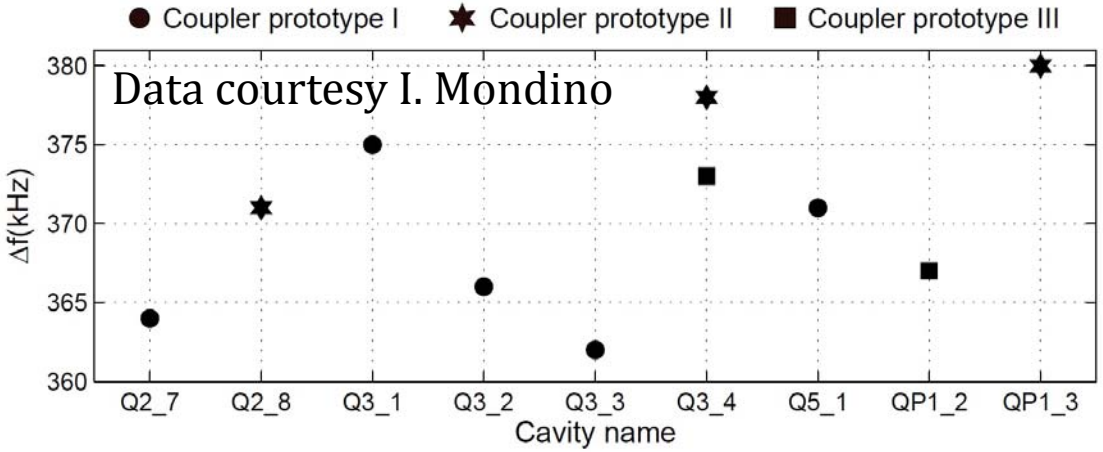


Plate type	Coarse range	Sensitivity
Original	220 kHz	11 kHz/mm
New (R=100mm)	**37 kHz**	**7.4 kHz/mm**

The new simplified plate drastically reduced the production cost.

Variability during the cool-down process

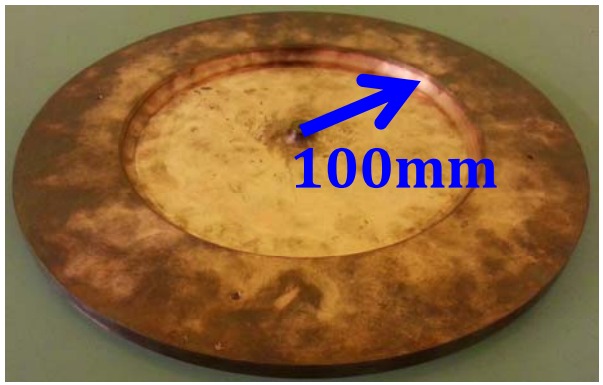


18kHz → **Coarse range**

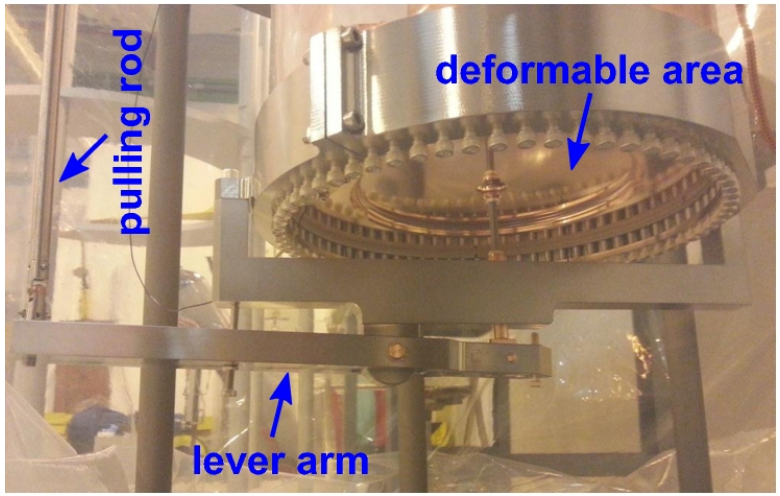
LLRF requested 0.5Hz/step → **Favor low sensitivity**

The first tuning plate prototype

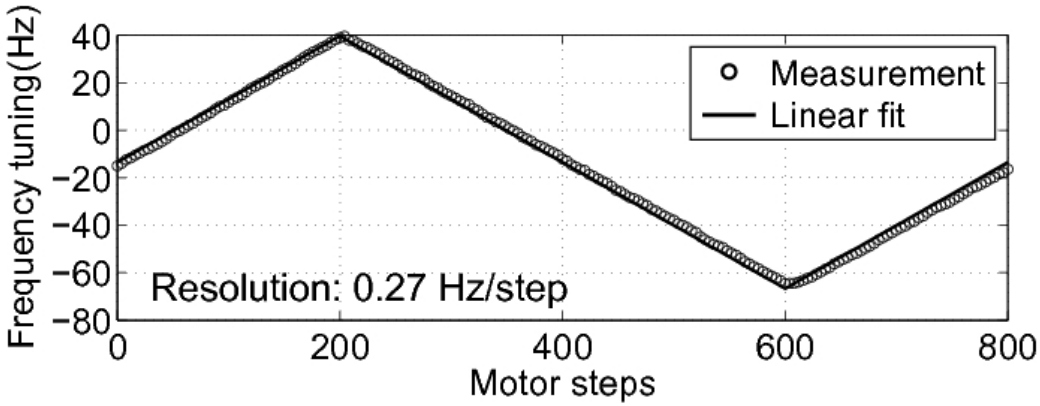
New simplified plate

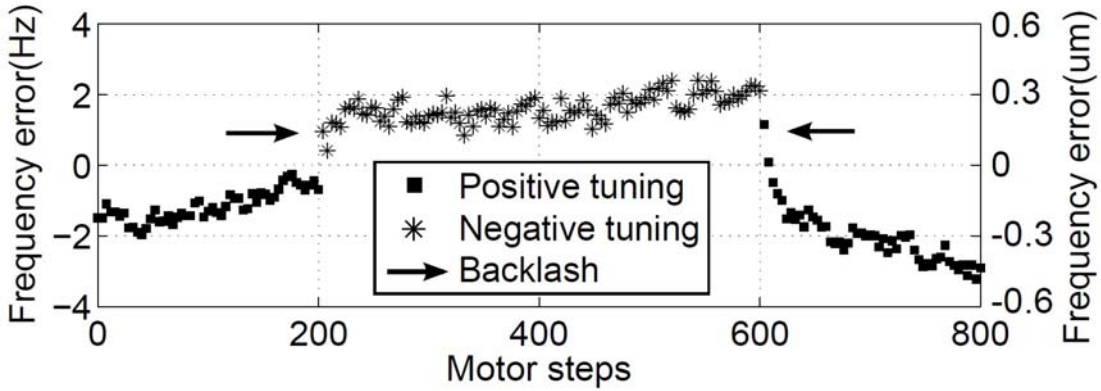


First prototype



- Measurement achieved:
  - **Coarse range: 37kHz**
  - **Tuning sensitivity: 0.3Hz/step**
- Development is ongoing





Data courtesy D. Valuch

Summary

- **The frequency tuning of QWR has been decoupled**
  - **pre-tuning** to recover mechanical tolerance
  - **tuning system** to compensate cool-down variability, Lorentz detuning and microphonics
- **The pre-tuning of the first two QP cavities completed**
- **The tuning system has been simplified**
  - the first prototype tested and fulfilled specifications

Reference

[1] A. D'Elia, "Frequency scaling from …", HIE-ISOLDE-PROJECT-Note-0007, 2010.

[2] A. D'Elia, "Coarse tuning range of …", HIE-ISOLDE project note, to be submitted.

[3] P. Zhang *et al.*, "The tuning system for …", SRF2013, THP084, 2013.

[4] P. Zhang *et al.*, "Frequency pre-tuning of …", HIE-ISOLDE project note, to be submitted.