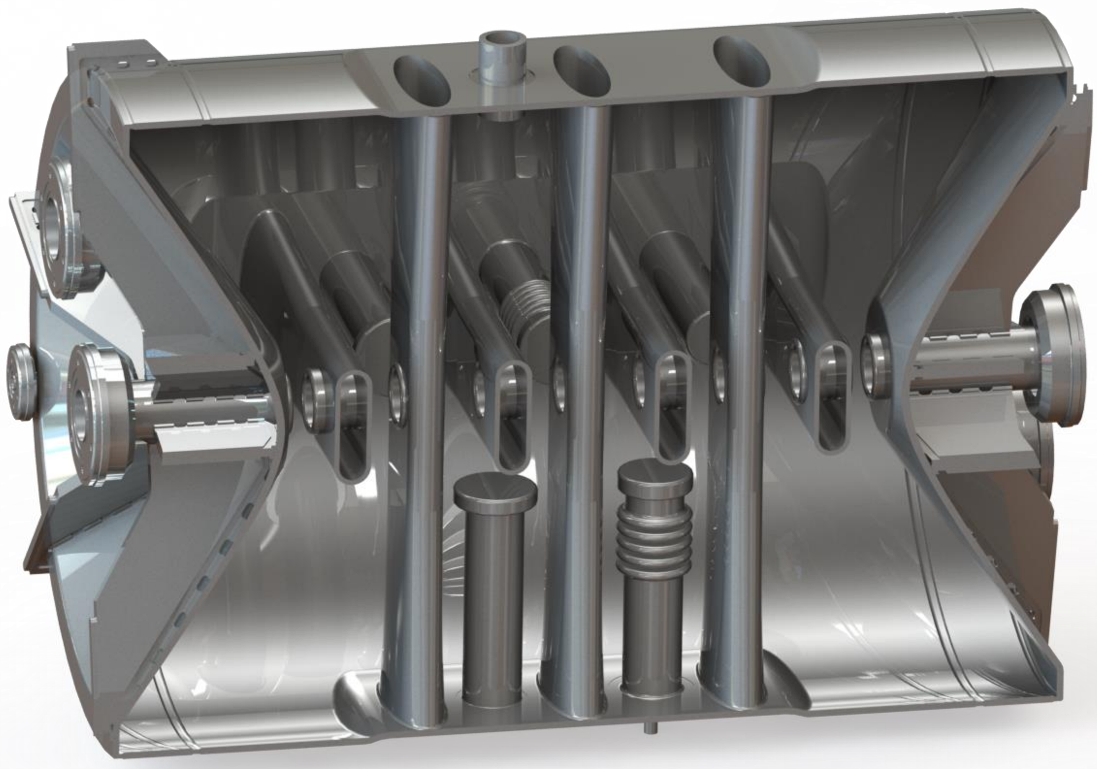
# Cavity development and measurements on the cw heavy Ion LINAC@GSI



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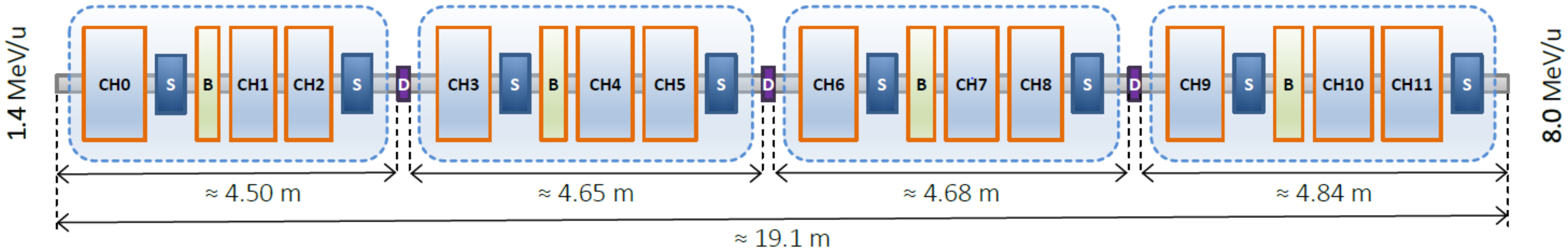
# Inhalt?

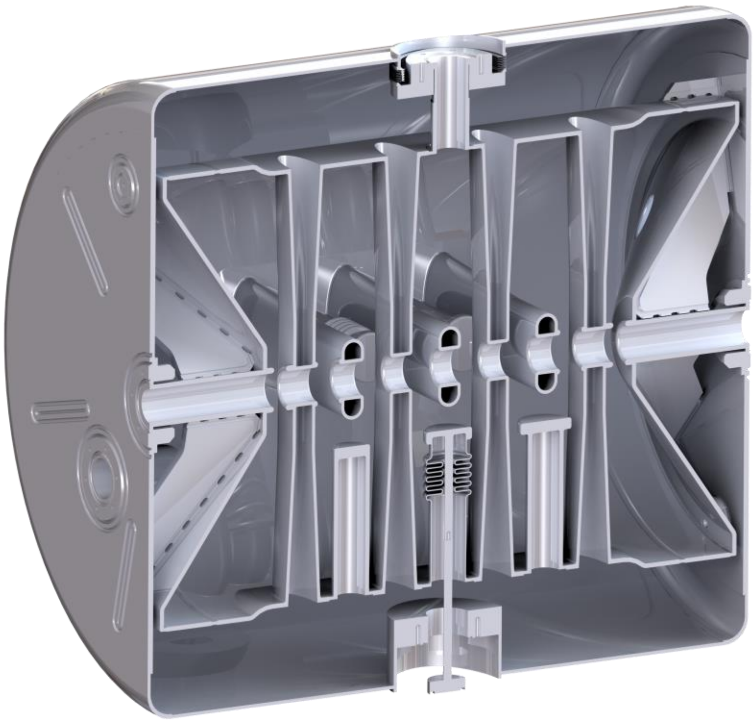
- Design of the cw heavy ion LINAC
- Development of CH1&2
  - Cavity parameter optimisation
  - Drift tube optimisation
  - Production Design
  - Frequency change through oversize erosion
- First intermediate measurements
  - Characterization of dynamic bellow tuners
  - Tuning stroke from static tuners
- Last measurements on factory side
  - Determine the length of power coupler and pickup
  - Measuring the pressure sensitivity of the cavity
  - Estimating the frequency change induced by thermal shrinking

# Design of the cw heavy ion LINAC@GSI



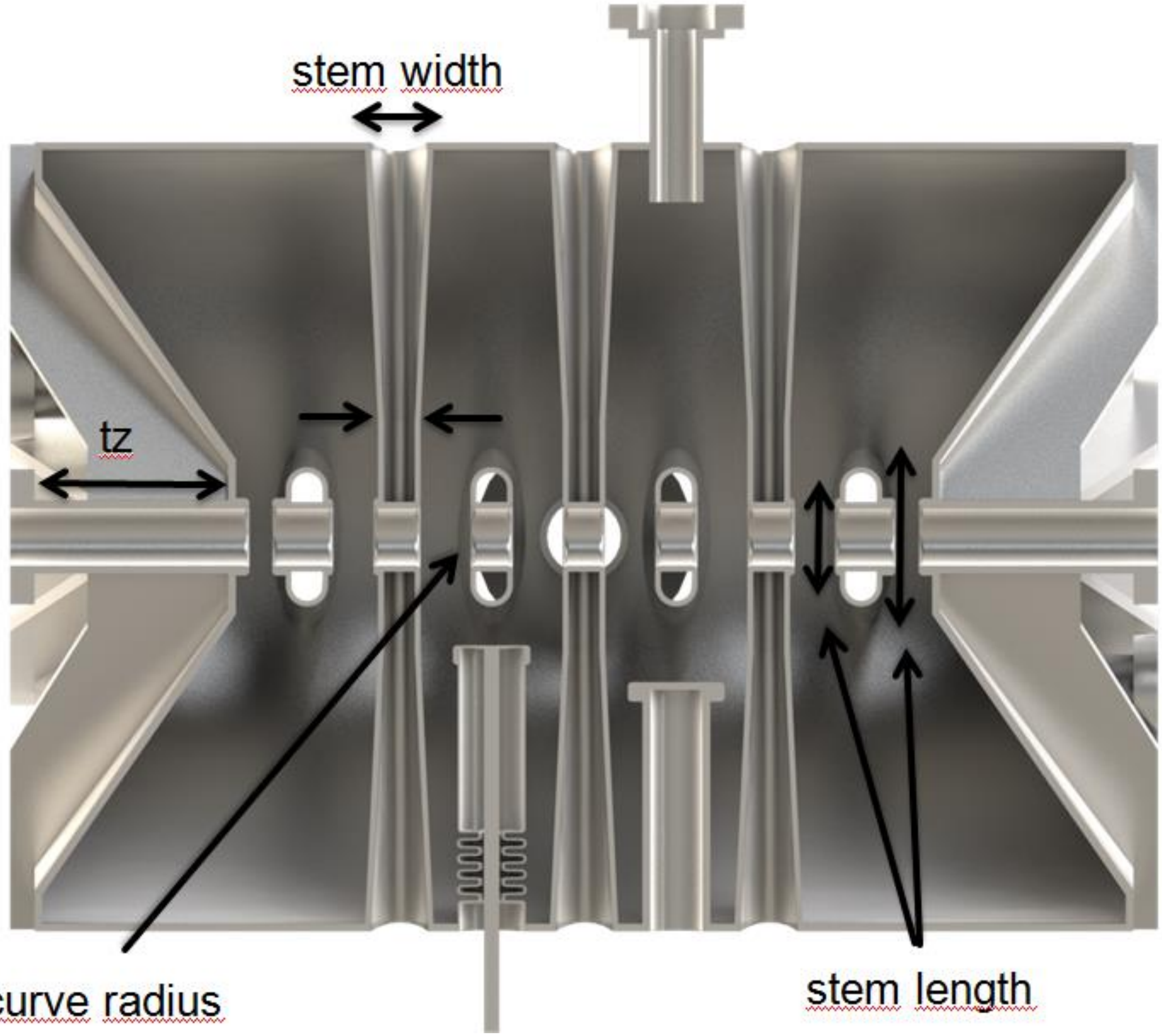

- Basic design of CH1 and CH2 is used for all cavities up to CH11
- Each cryomodule contains 3 CH-cavities two solenoids and a buncher
- Acceleration for Ions with A/q ≤ 6 with acceleration gradients up to 7.1 MV/m in each CH-cavity
- Maximum length of each cryomodule is 5 m
- Solenoids with B < 9T

# Development of CH1&2

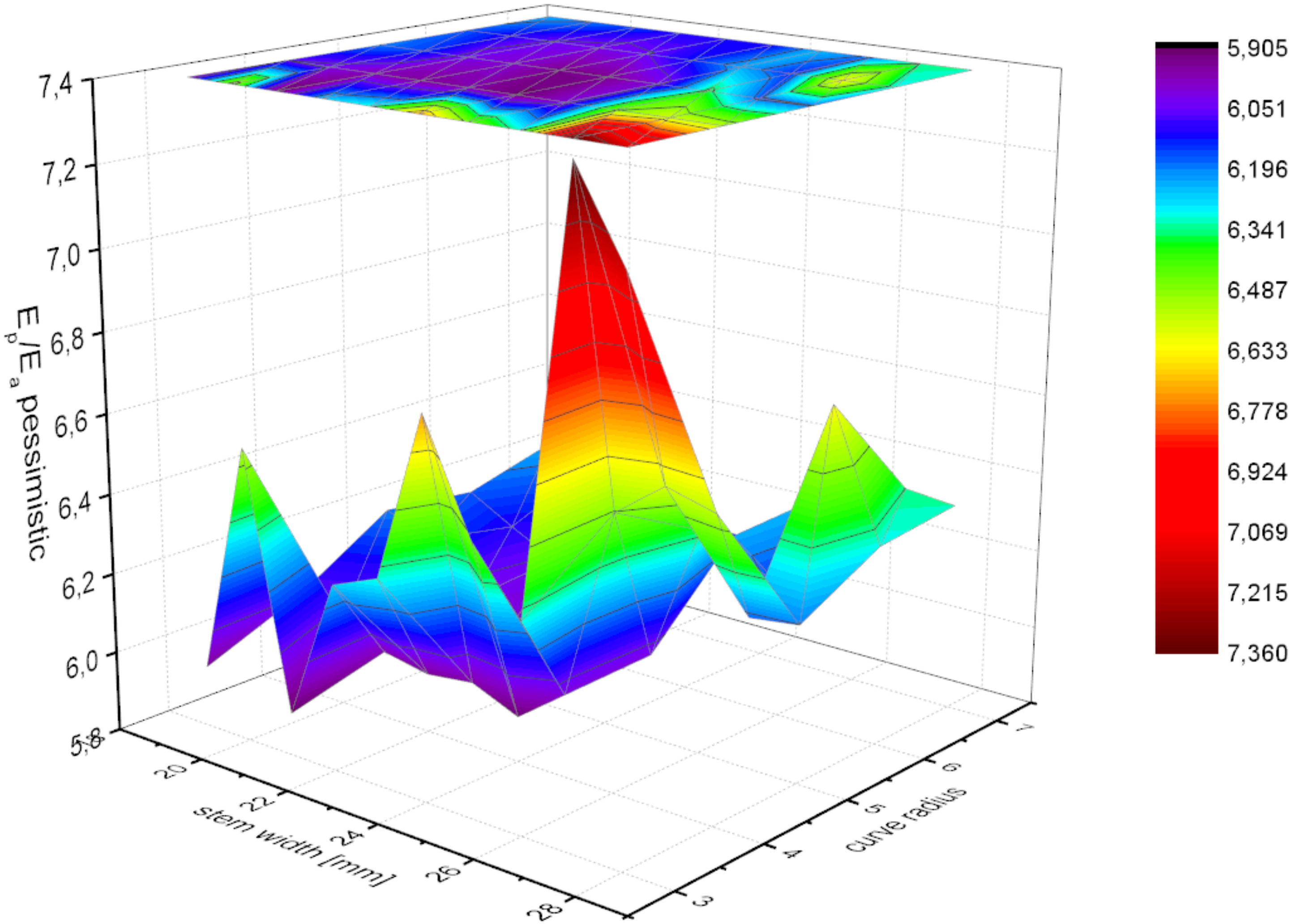


| Parameter | Unit | |
|---|---|---|
| β | | 0.069 |
| Frequency | MHz | 216.816 |
| Cavity diameter | mm | 407 |
| Cavity length | mm | 593 |
| Aperture diameter | mm | 30 |
| Cell length | mm | 47.7 |
| Static tuner | | At first 3 now 0 |
| Dynamic bellow tuner | | 2 |
| Accelerating gradient | MV/m | up to 7.1 |
| $E_P/E_a$ pessimistic | | 8.5 |
| $E_P/E_a$ optimistic | | 6.3 |
| $B_P/E_a$ pessimistic | mT/MV/m | <10 |
| G | Ω | ≈50 |
| $R_a/Q_0$ | | ≈1000 |

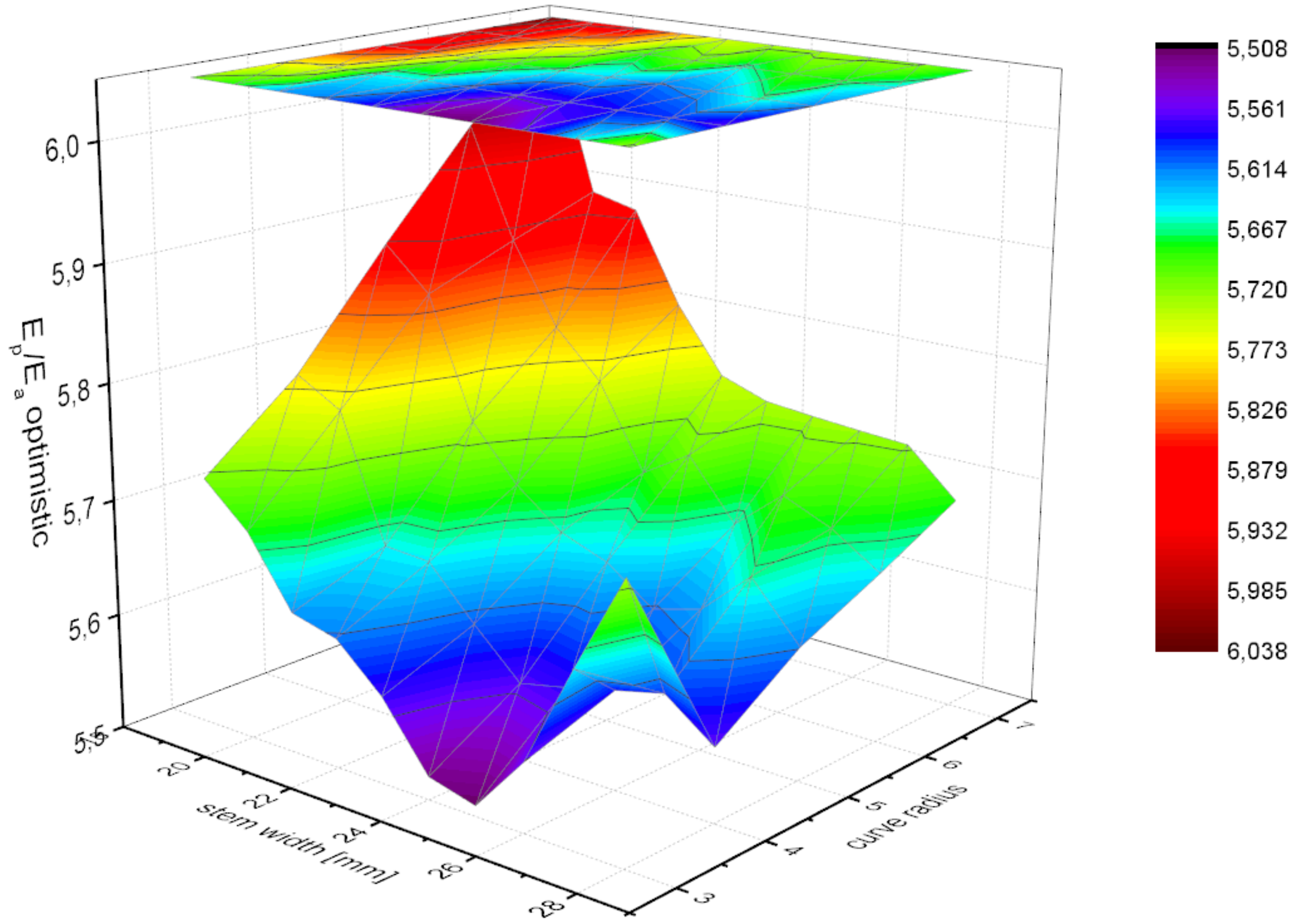
# Cavity parameter optimisation



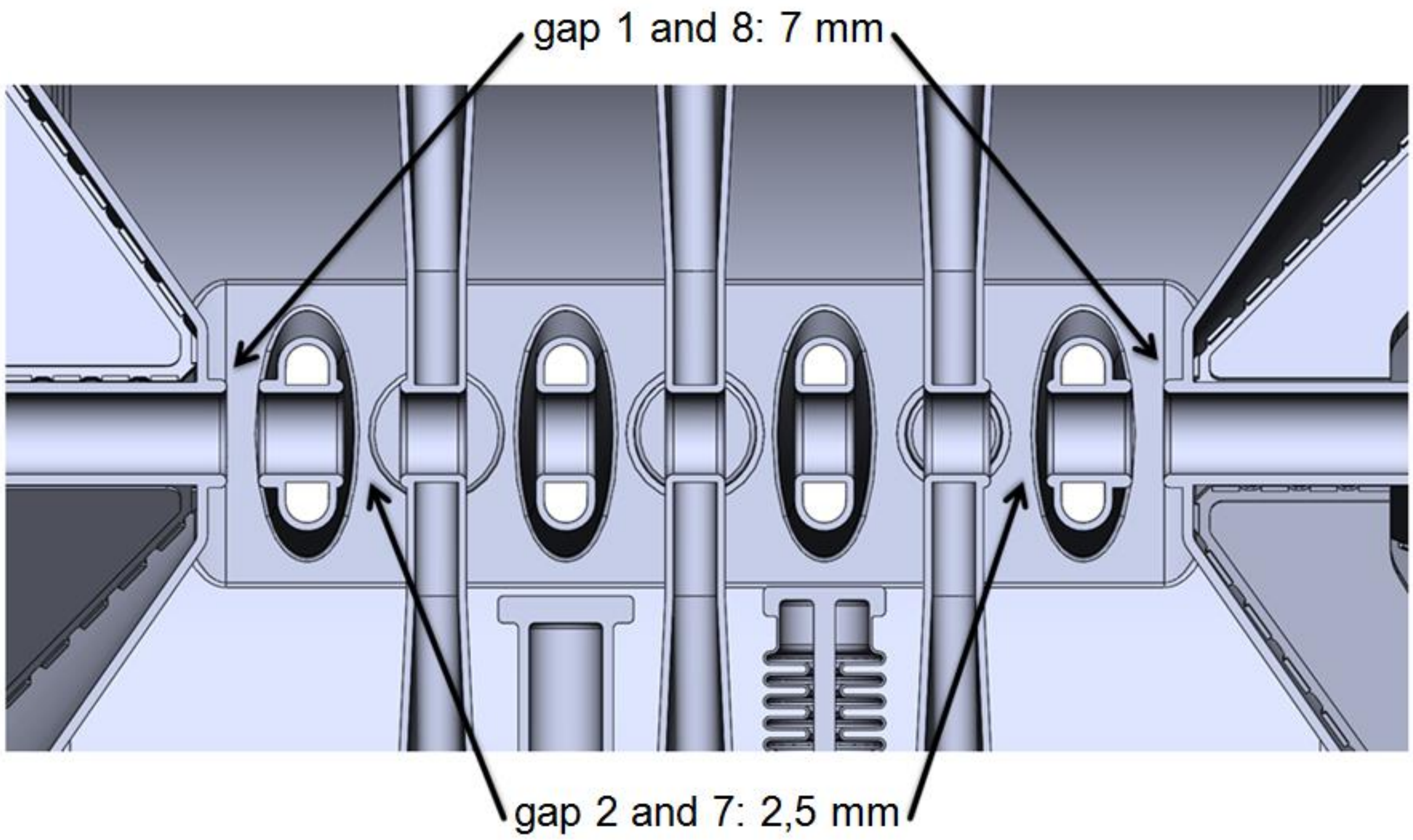
# Electric peak fields



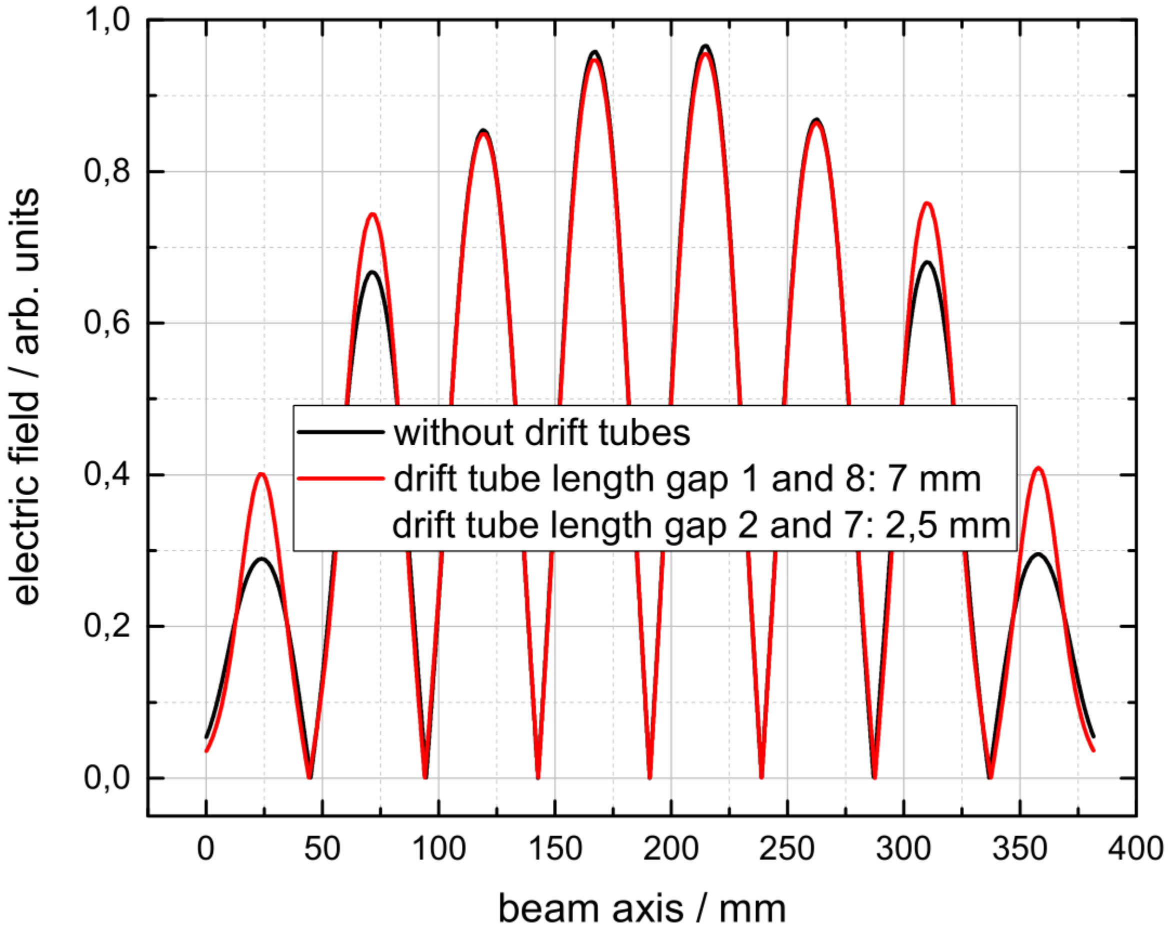
# Electric peak fields



# Drift tube optimisation

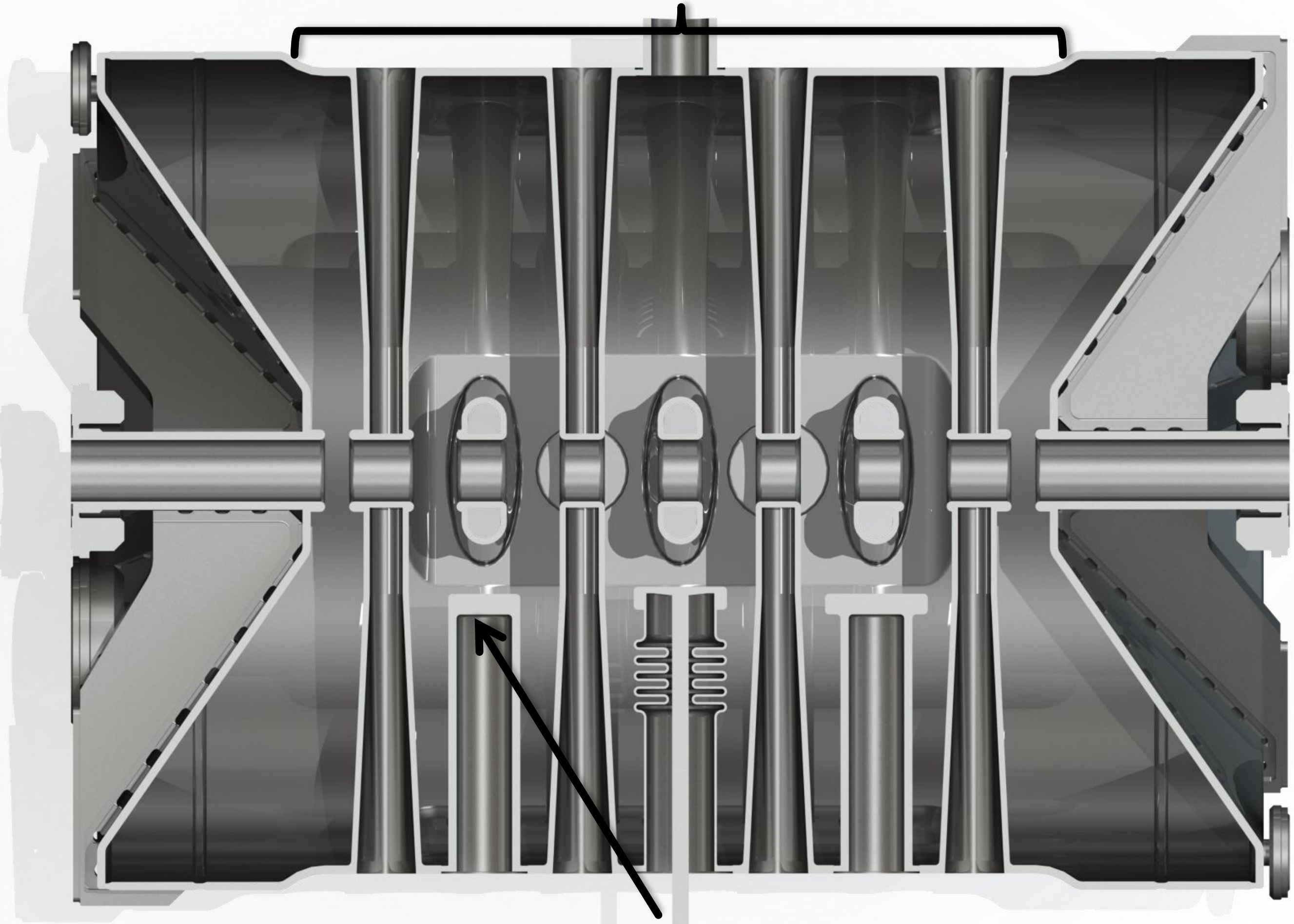


# Electric field with and without drifttubes



# Production Design

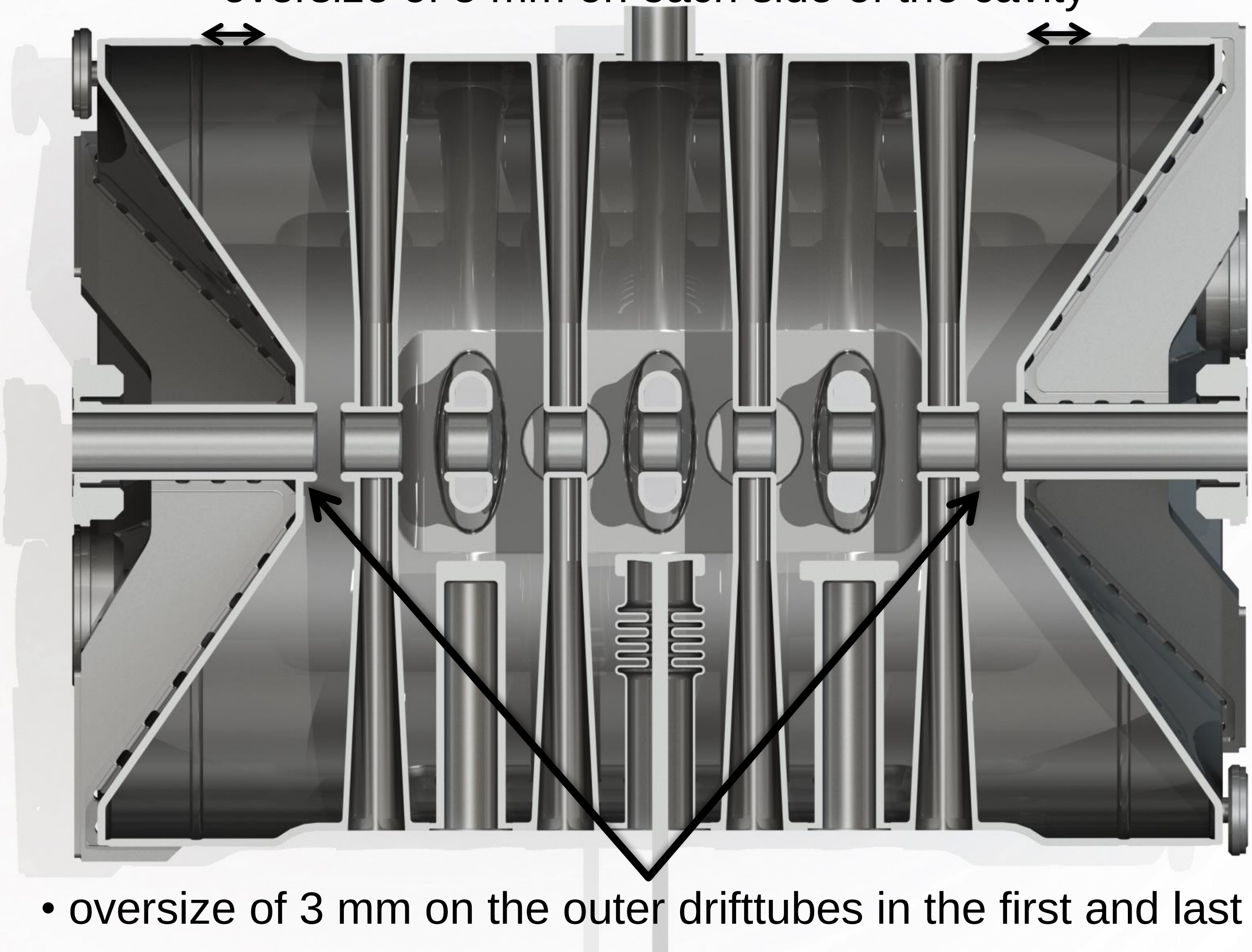
• flat parts in the cavity shell for constant welding depth



• static tuner withouth tunerhead for installation into closed cavity

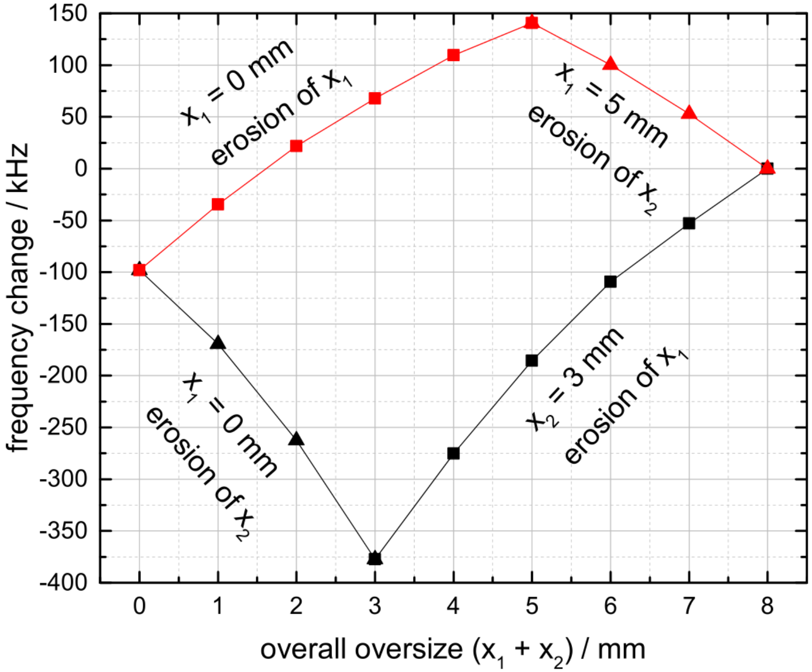
# Production Design

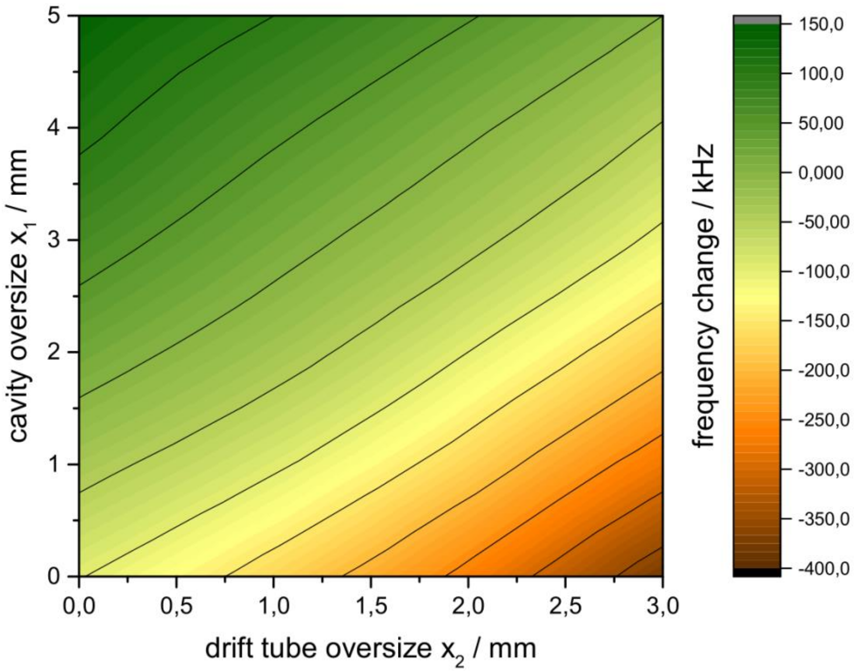
• oversize of 5 mm on each side of the cavity



• oversize of 3 mm on the outer drifttubes in the first and last gap

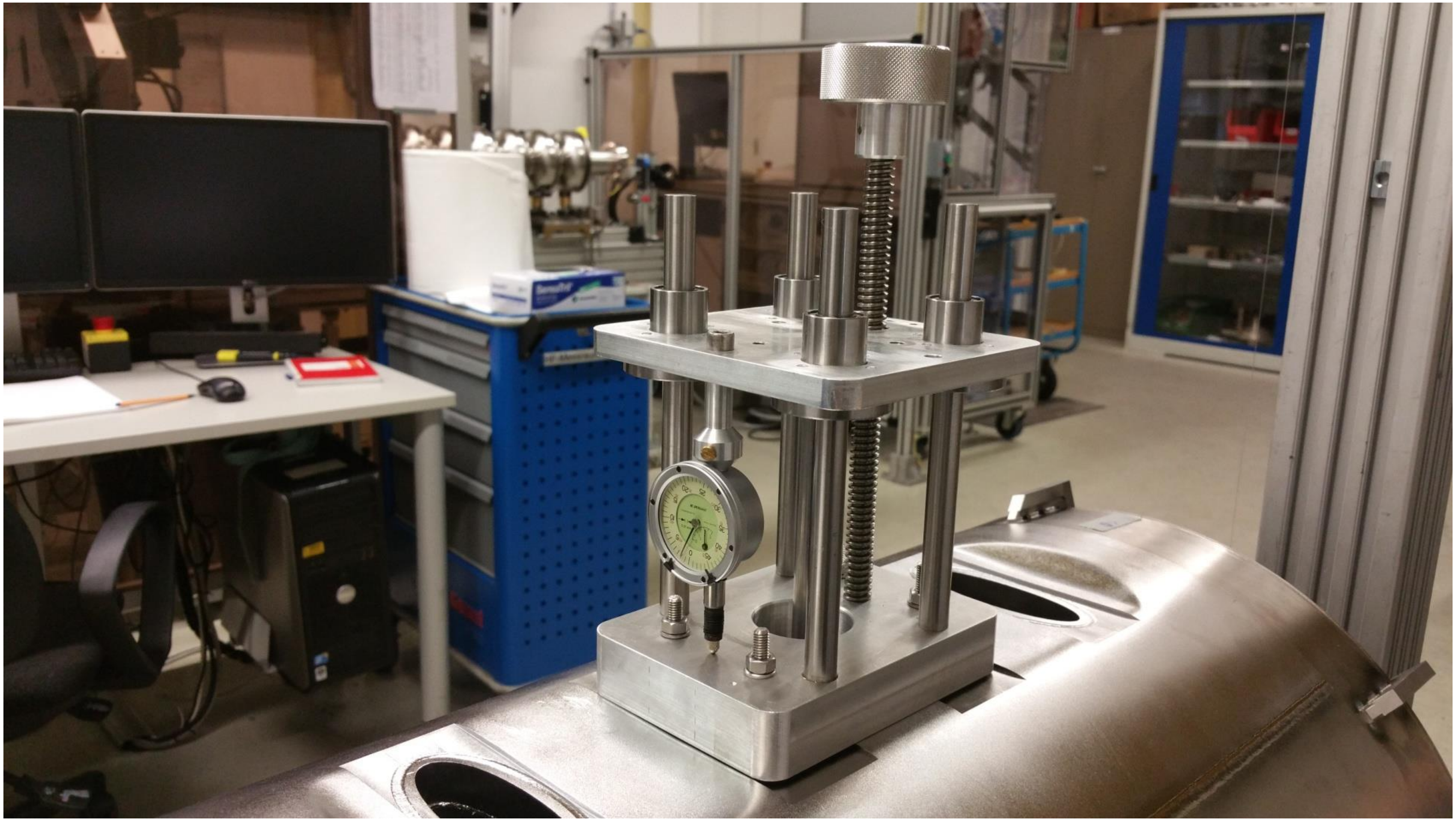
# Frequency change through oversize erosion



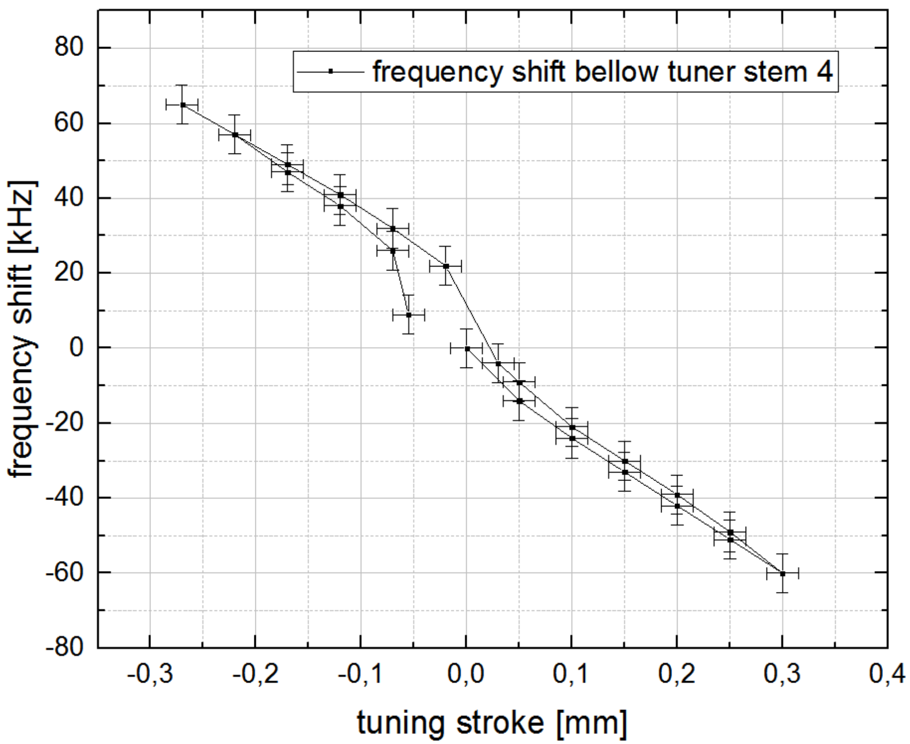



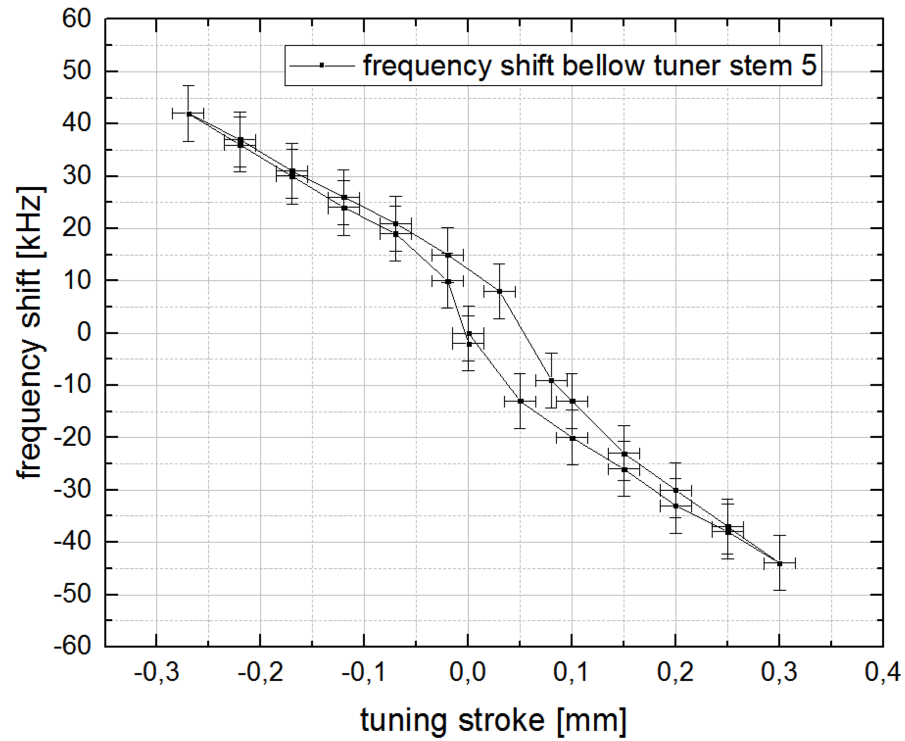
# Intermediate measurements

# Tuning stroke induced by trapezoidal thread spindle



# Tuning stroke induced by trapezoidal thread spindle



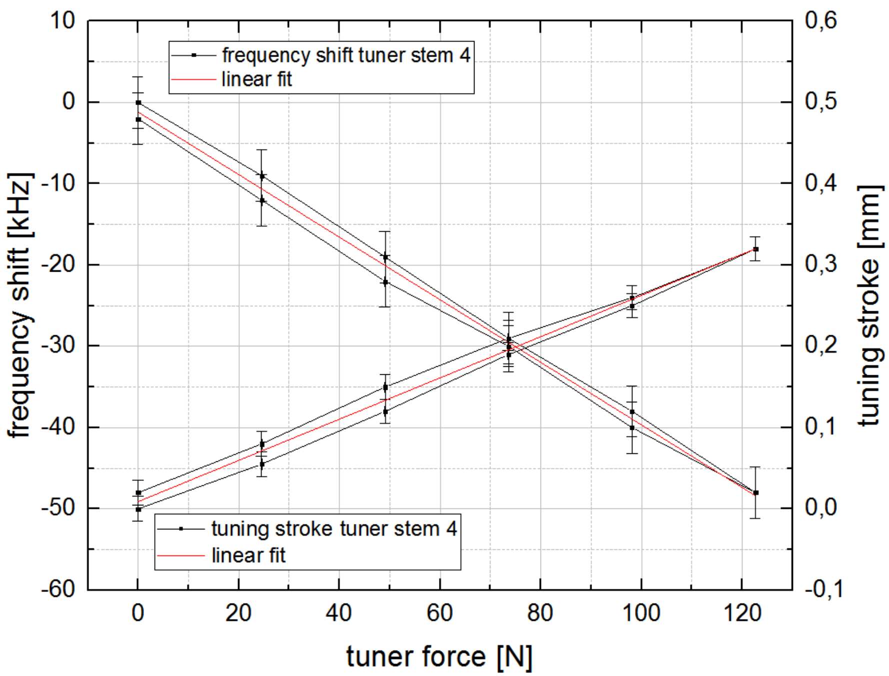



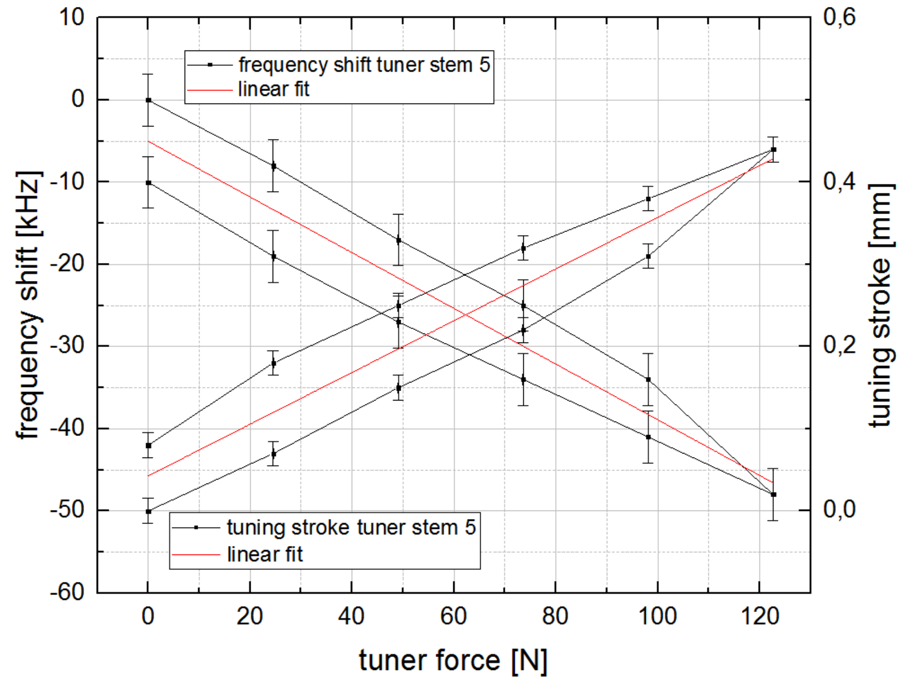

- Δ f ≈ -183 ± 9 kHz/mm measured
- Δ f ≈ -140 kHz/mm simulated
- Δ f ≈ -100 - 190 kHz/mm first cavity

- Δ f ≈ -124 ± 8 kHz/mm measured
- Δ f ≈ -130 kHz/mm simulated
- Δ f ≈ -80 - 140 kHz/mm first cavity

# Tuning stroke induced by tuner force

# Tuning stroke induced by tuner force



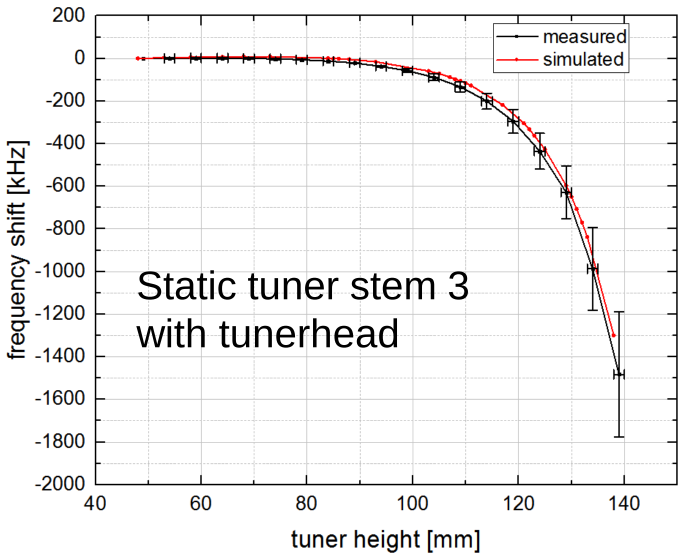

- Δ x ≈ 2,5 ± 0,1 µm/N measured
- Δ x ≈ -2,1 µm/N simulated
- Δ f ≈ -0,39 ± 0,01 kHz/N measured
  ≈ -156 ± 10,2 kHz/mm
- Δ f ≈ -140 kHz/mm simulated
- Δ f ≈ -183 ± 9 kHz/mm (spindle)

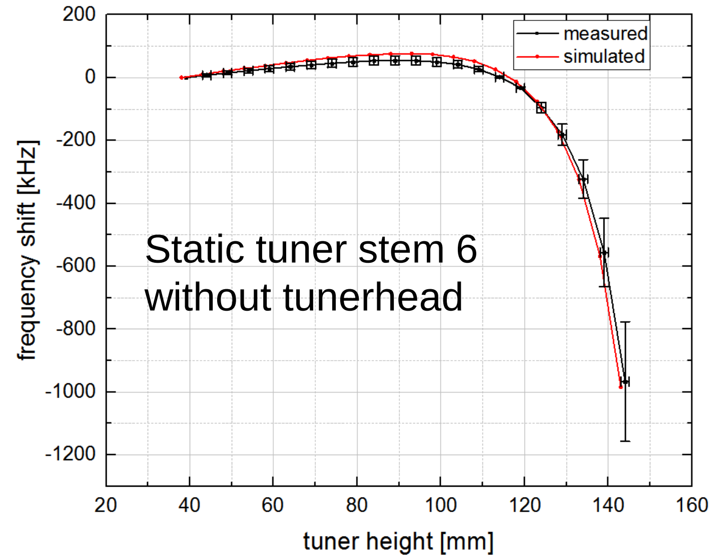
- Δ x ≈ 3,2 ± 0,4 µm/N measured
- Δ x ≈ -2,1 µm/N simulated
- Δ f ≈ -0,34 ± 0,04 kHz/N measured
  ≈ -106 ± 25,7 kHz/mm
- Δ f ≈ -130 kHz/mm simulated
- Δ f ≈ -124 ± 8 kHz/mm (spindle)

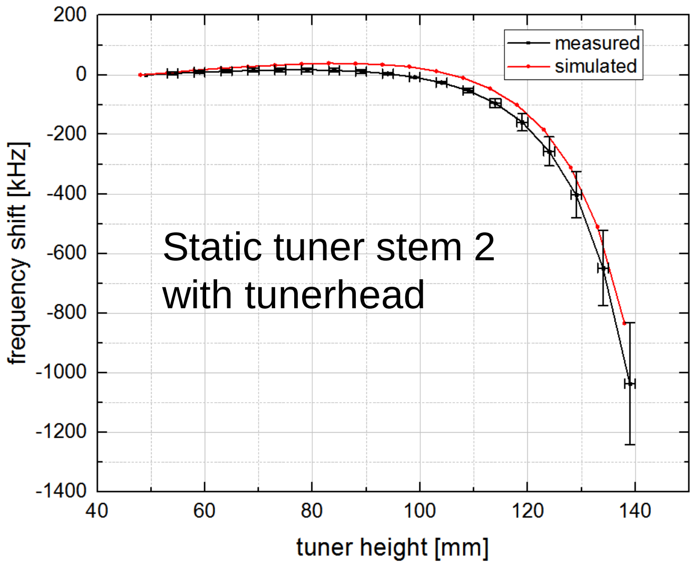
# Inner parts of the CH-cavity

# Brass Dummy Tuner with mount

# Measured and simulated tuning range



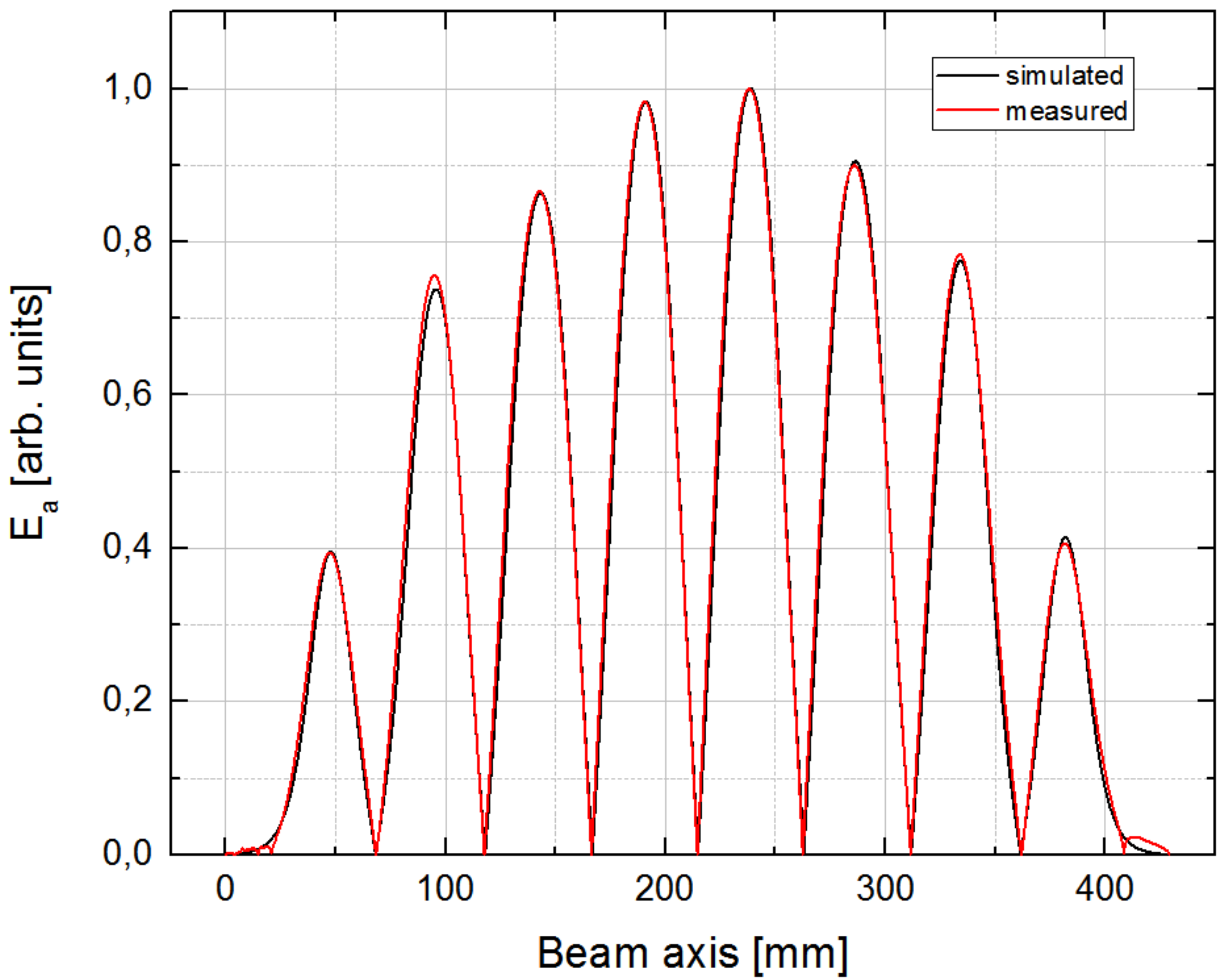




- Measured frequency  214,835
- 1,981 MHz until design frequency of 216,816 MHz
- After erosion of oversize and concerning the pressure sensitivity and thermal shrinking 1,76 MHz to design frequency

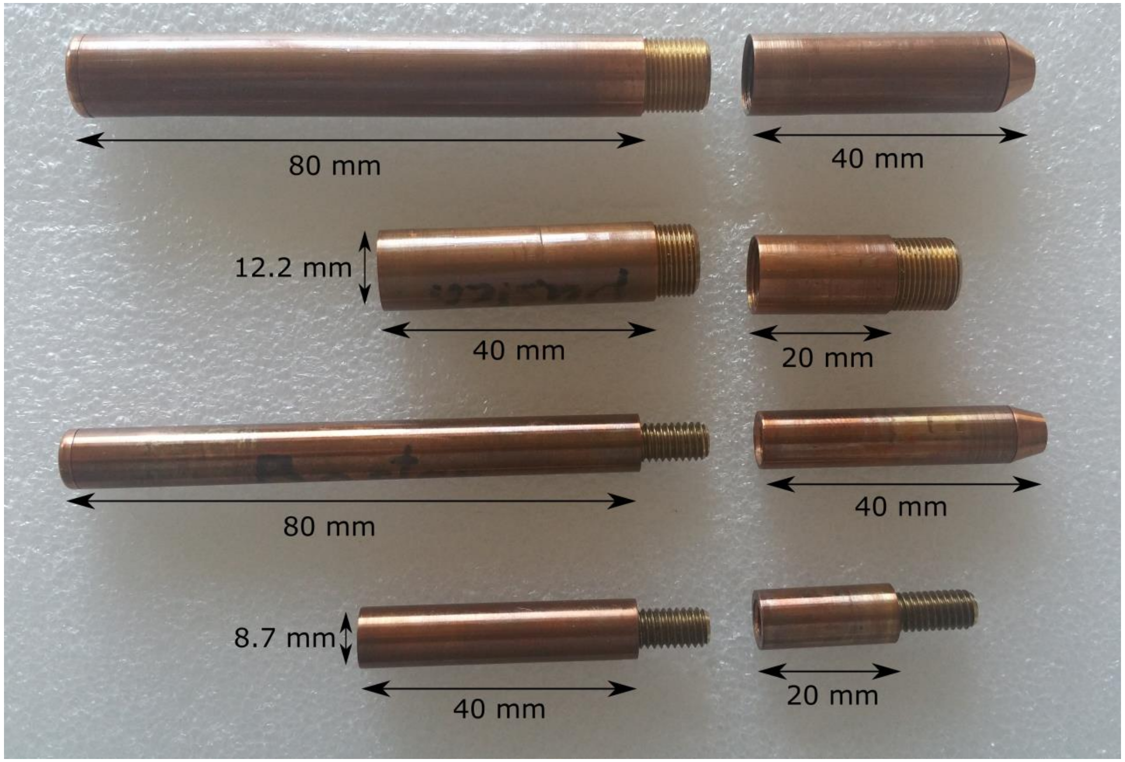
| | simulated | measured | Measurements on CH 1 up to now |
|---|---|---|---|
| | [MHz] | [MHz] | |
| 14.03.2017 | 218,118 | 217,416 | 1. Measurement done by RI with attached end caps, oversize and no static or dynamic tuners |
| 10.04.2017 | 215,094 | 214,953 | 2. Measurement done by us with attached end caps, oversize and welded dynamic tuners |
| 22.06.2017 | 215,026 | 214,835 | 3. Measurement done by RI right before welding the first end cap to the cavity body, oversize removed completely |
| 13.07.2017 | 215,026 | 214,839 | 4. Measurement done by RI after welding both end caps to the cavity body |
| 26.10.2017 | 215,252 | 215,144 | 5. Measurement done by RI after first 50 µm BCP (Δf = 317 kHz) |
| 20.11.2017 | 215,478 | 215,454 | 6. Measurement done by RI after second 50 µm BCP (Δf = 311 kHz) |
| 24.11.2017 | 215,704 | 215,779 | 7. Measurement done by RI after third 50 µm BCP (Δf = 325 kHz) |
| 18.01.2018 | 215,704 | 215,887 | 8. Measurement done by us to determine pressure sensitivity, thermal shrinking and external Q-value |

# Last measurements before final BCP-treatment

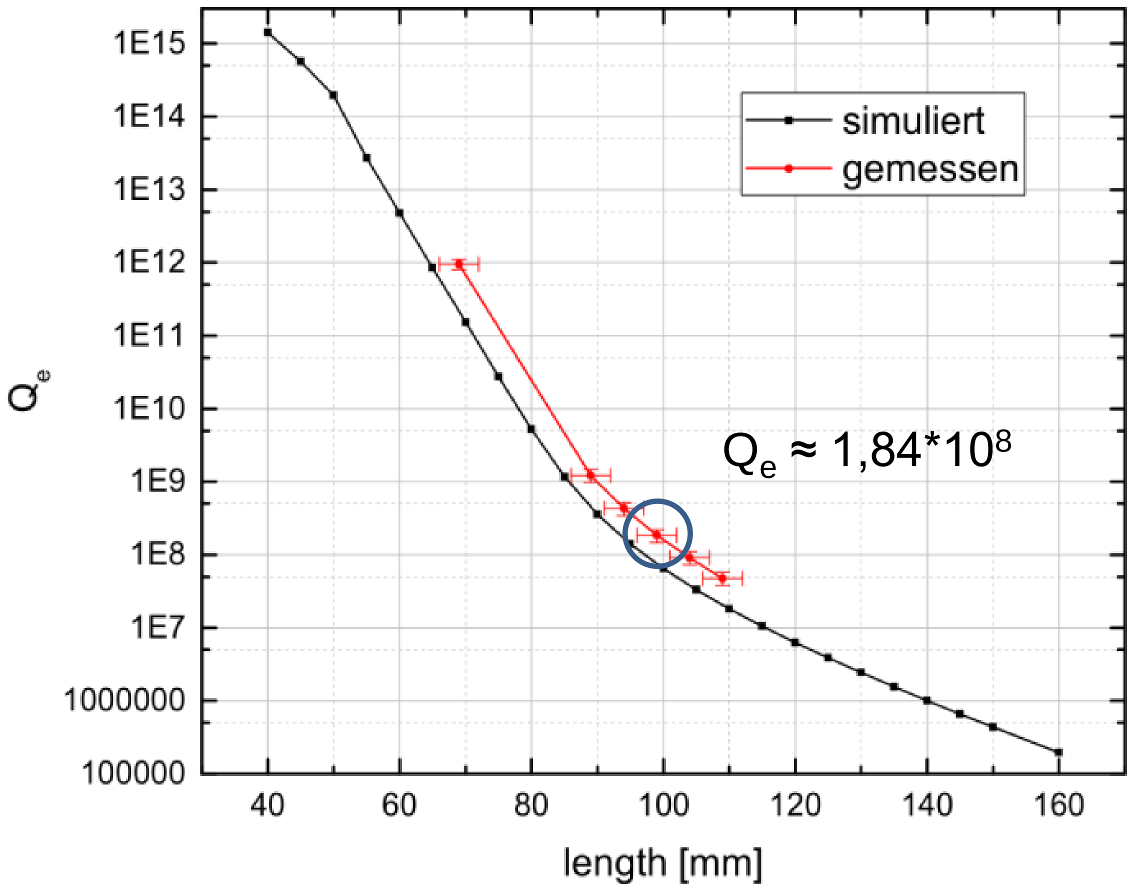
# Last measurements before final BCP-treatment



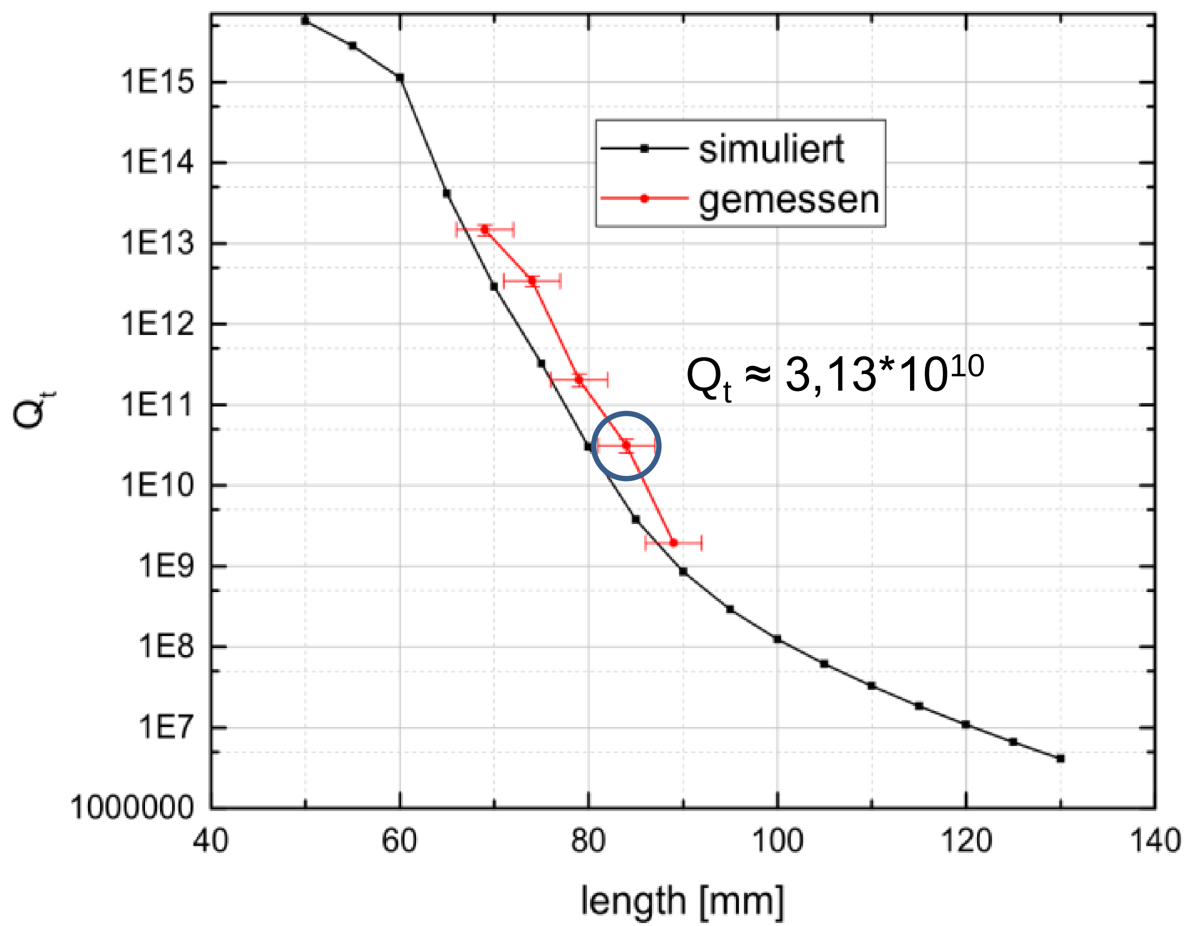
# Copper-Couplers with variable lengths



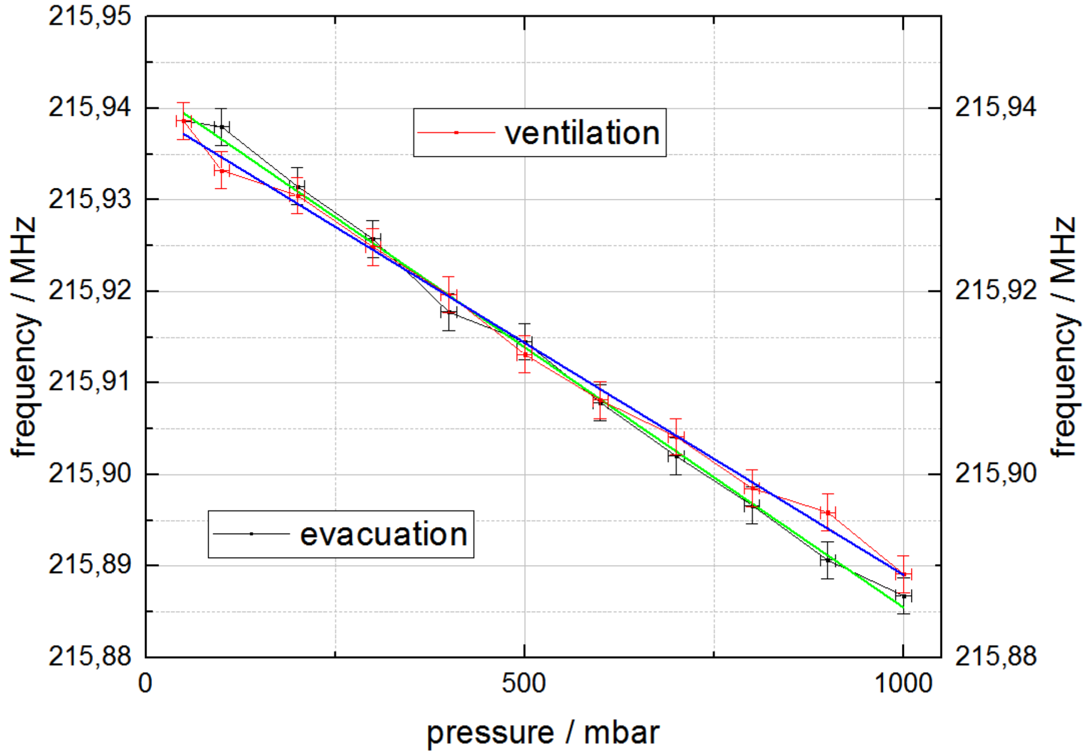
# External Q-value for power coupler



# External Q-value for pickup

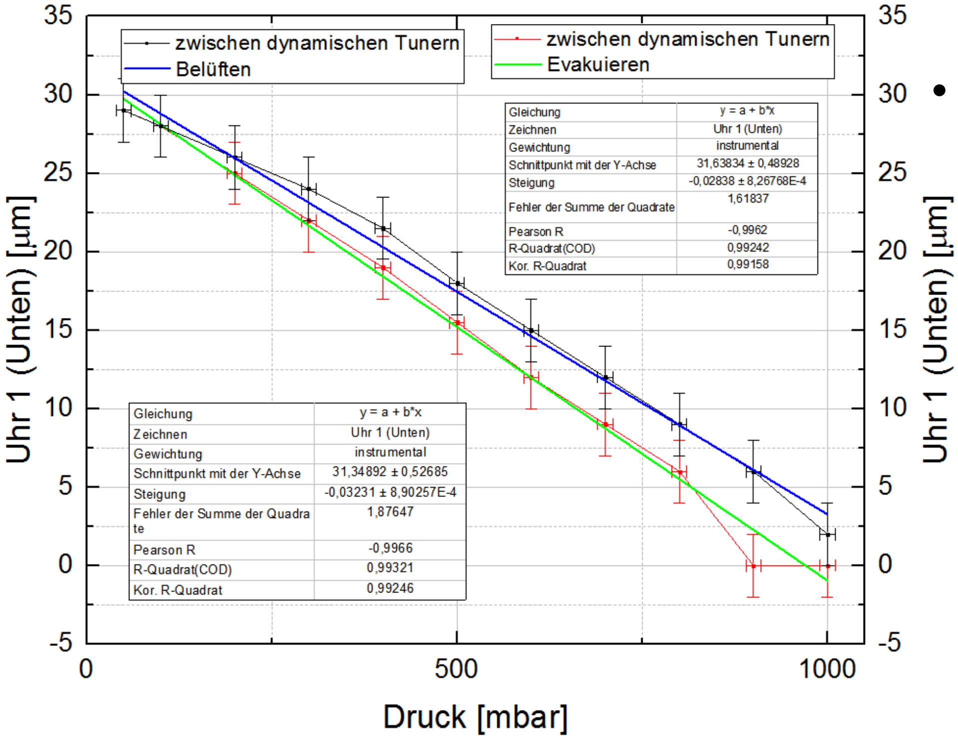


# Pressure sensitivity CH 1



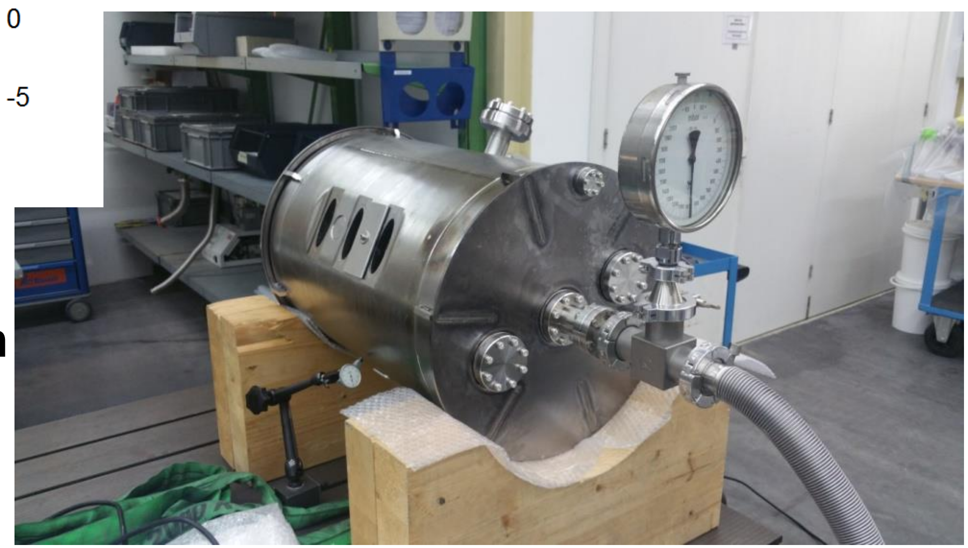

- approx. **Δ f = +56,86 ± 1 Hz/mbar** during evacuation
- approx. **Δ f = +50,73 ± 1,1 Hz/mbar** during ventilation
- change of $\varepsilon_r$ should result in approx. **Δ f = +63,6 kHz**
- measured pressure sensitivity during evacuation approx. **Δ f = -6,74 ± 1 Hz/mbar**
- measured pressure sensitivity during ventilation approx. **Δ f = -12,87 ± 1,1 Hz/mbar**
- simulated pressure sensitivity approx. **Δ f = +4,61 Hz/mbar**

# Measured deformation CH 1

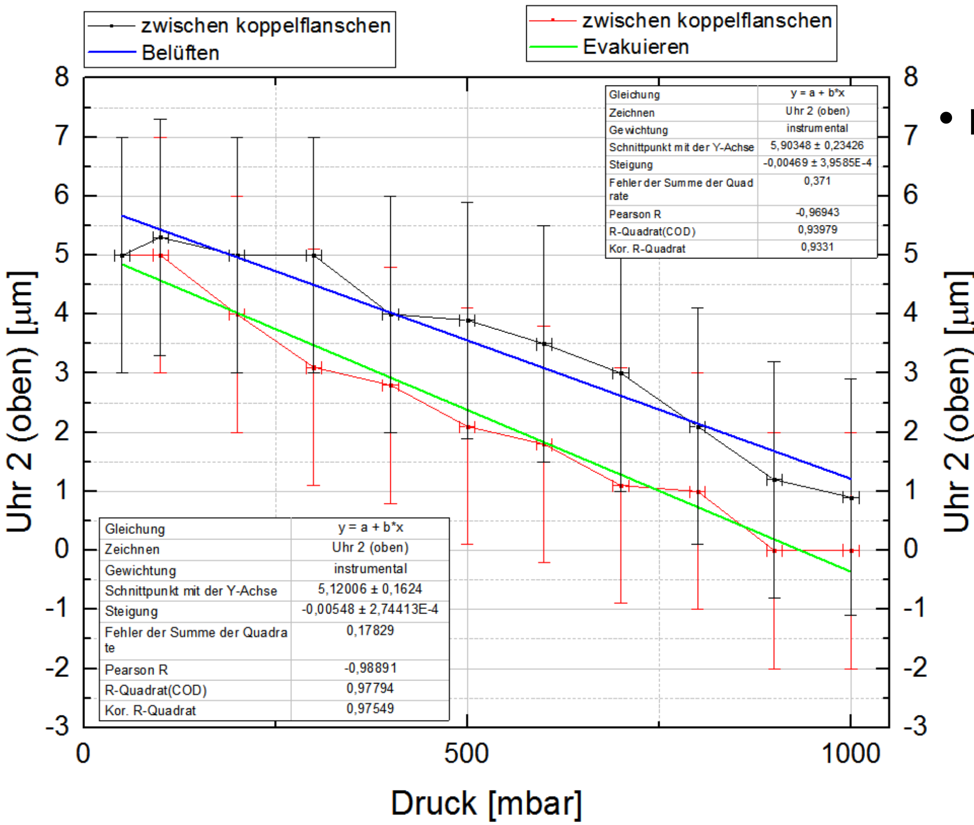



- measured deformation up to **Δ x = 30 µm**

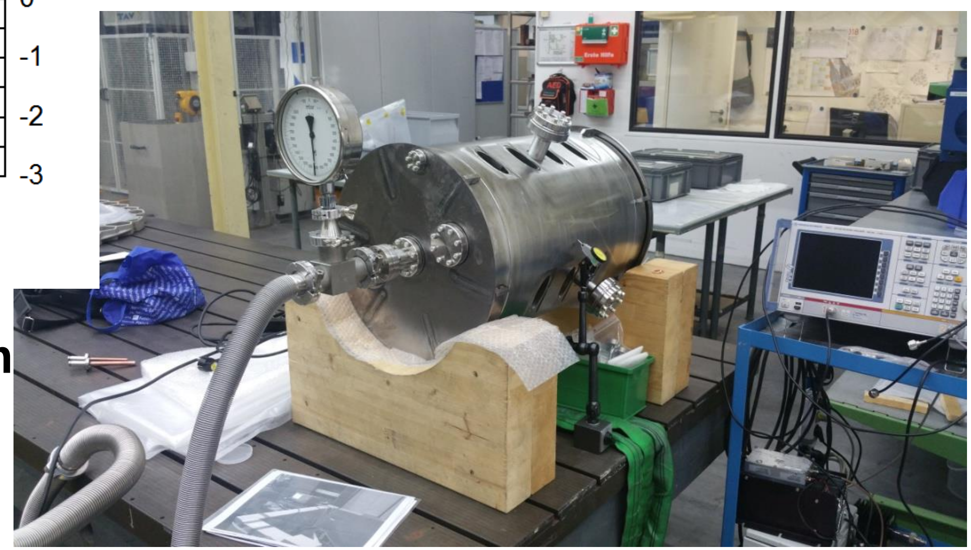
- simulated deformation up to **Δ x = 65 µm**



# Measured deformation CH 1

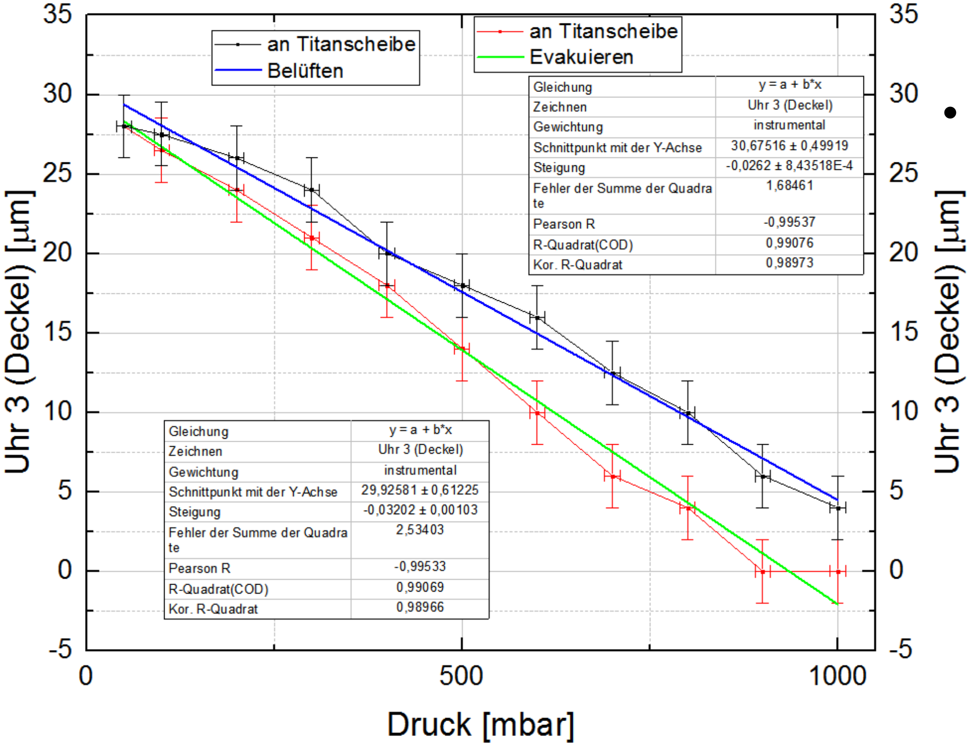



- measured deformation up to **Δ x = 5-6 µm**



- simulated deformation up to **Δ x = 35 µm**

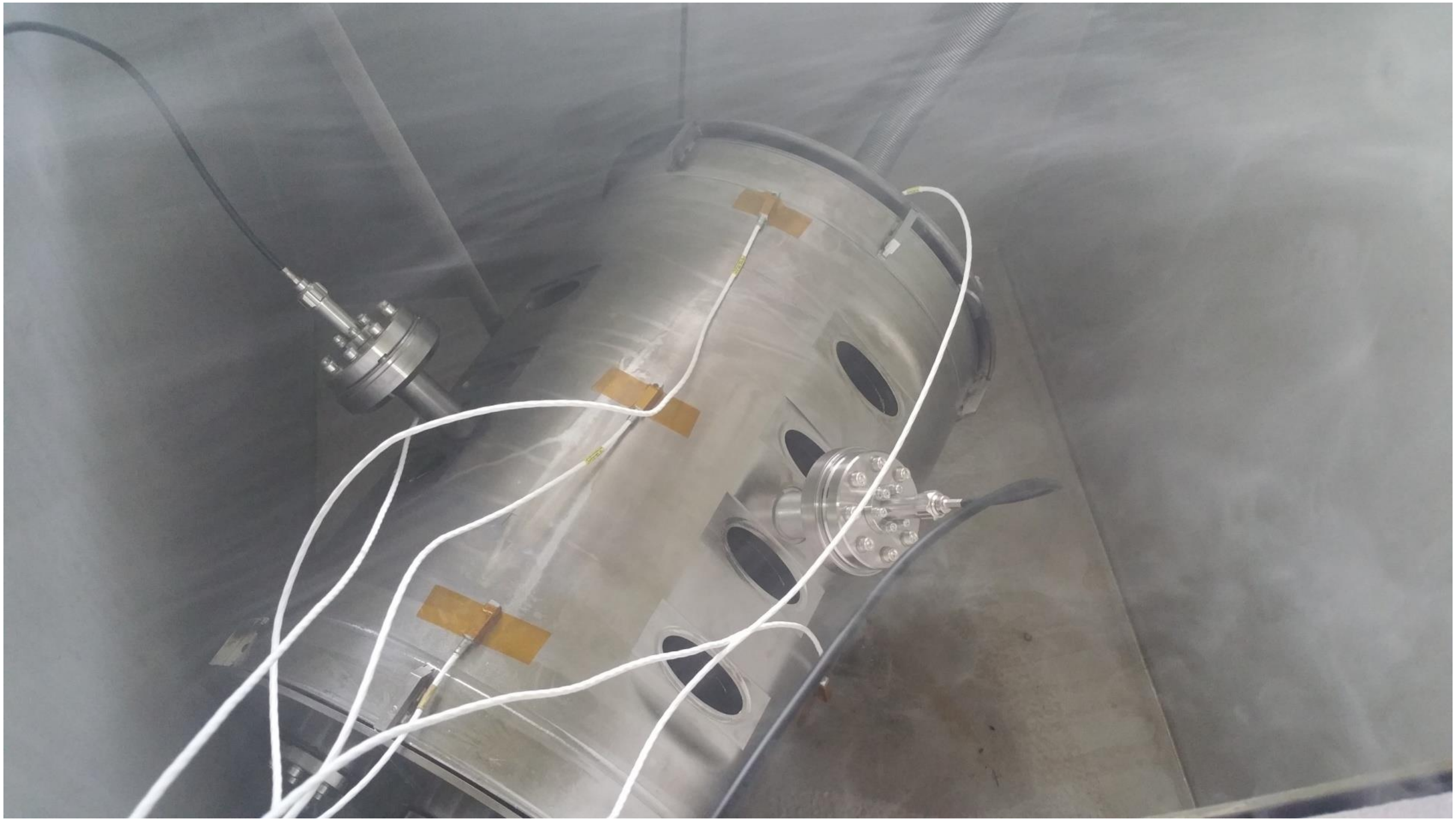
# Measured deformation CH 1



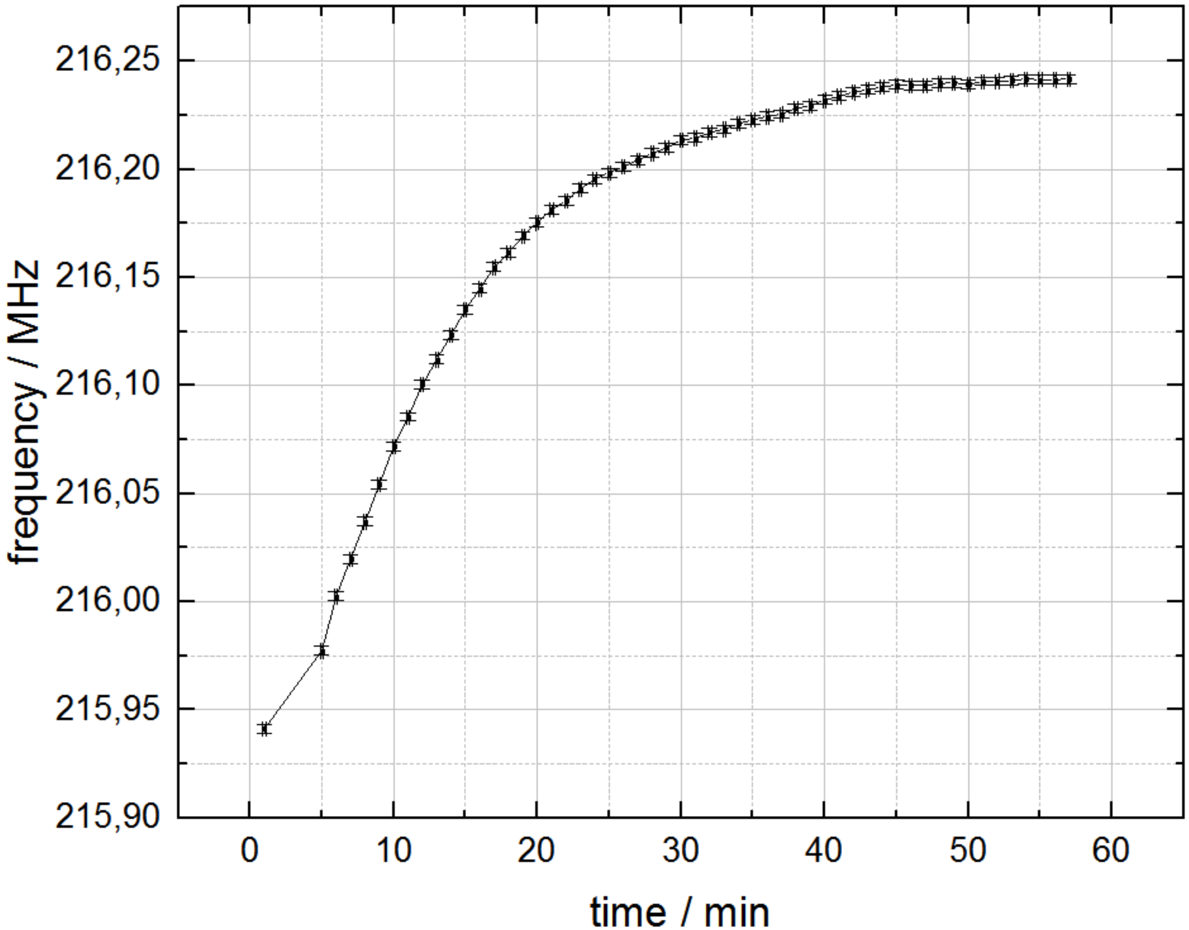

- measured deformation up to **Δ x = 28 µm**

- simulated deformation up to **Δ x = 93 µm**

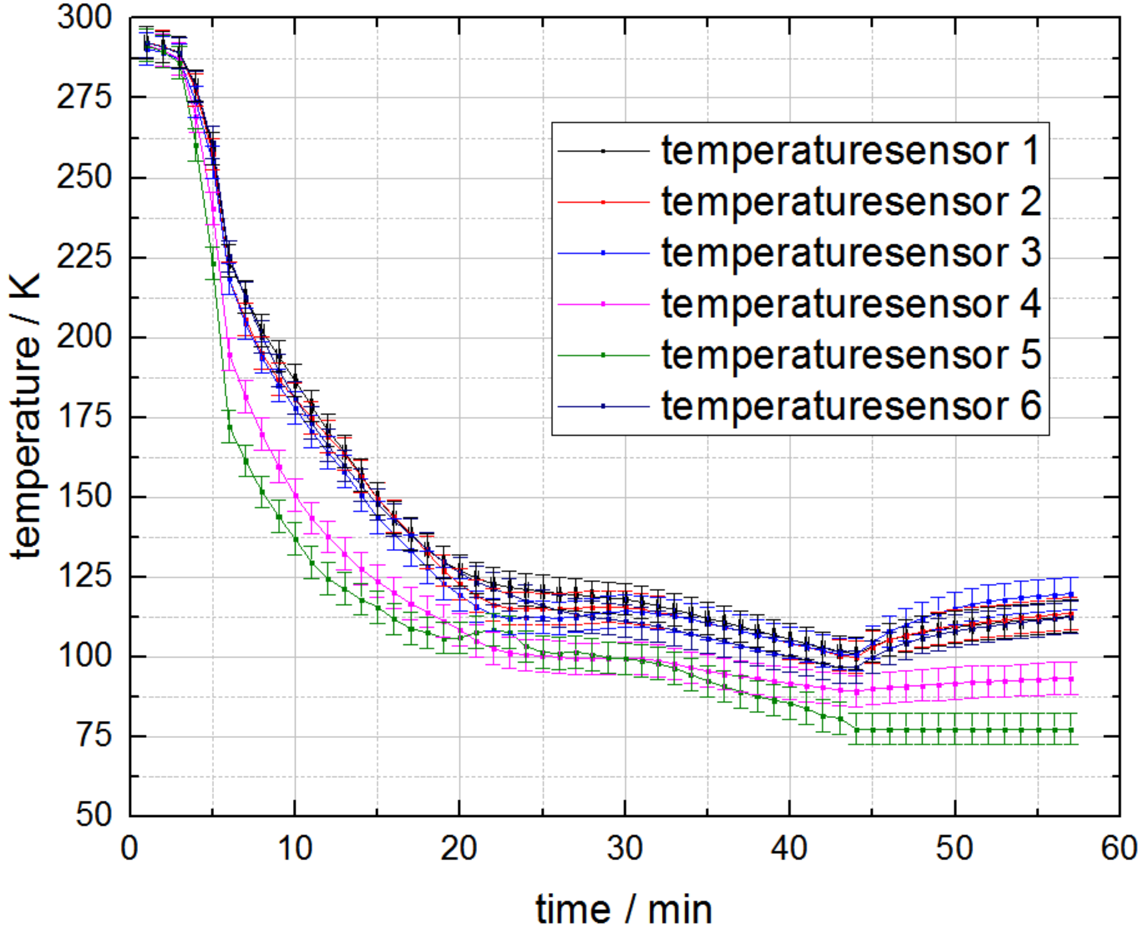
# First cold test to determine thermal shrinking



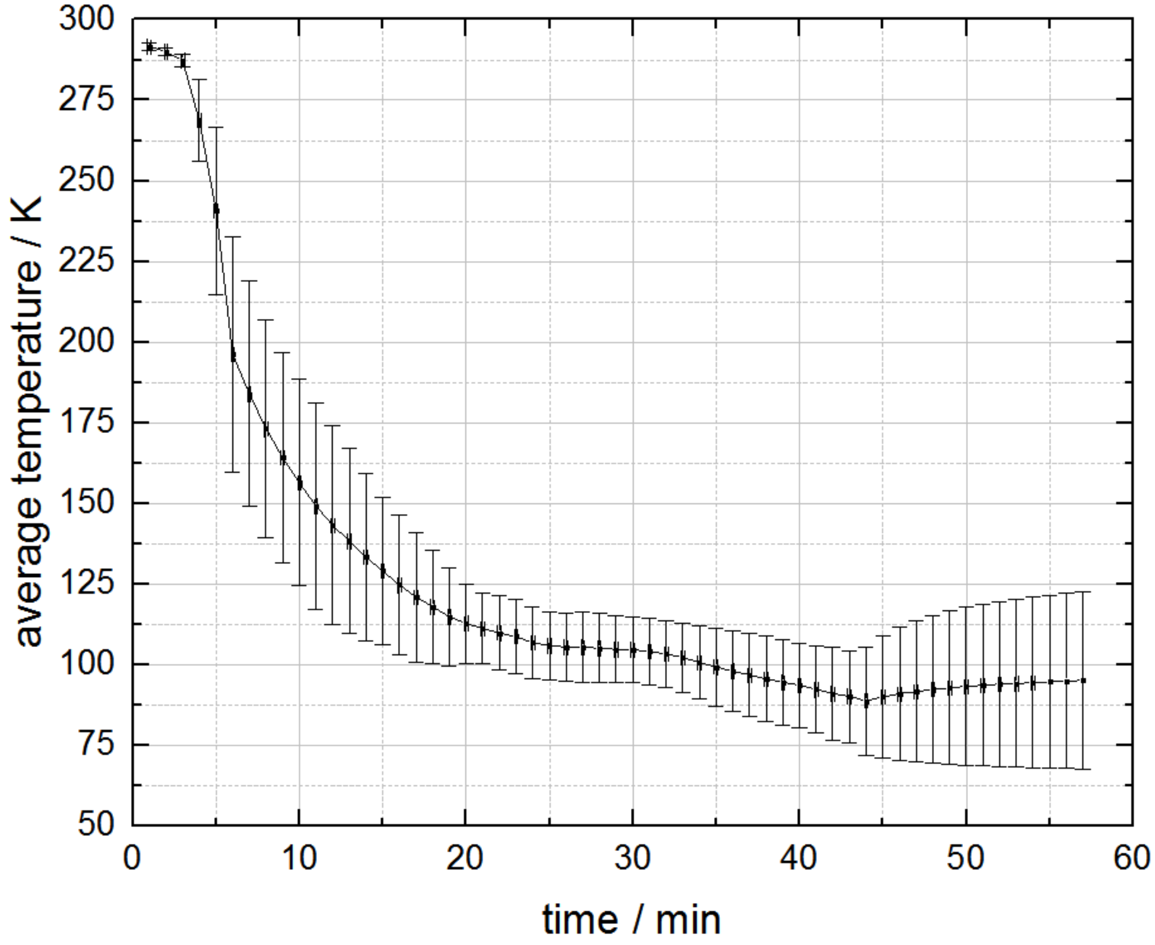
# First cold test to determine thermal shrinking CH 1



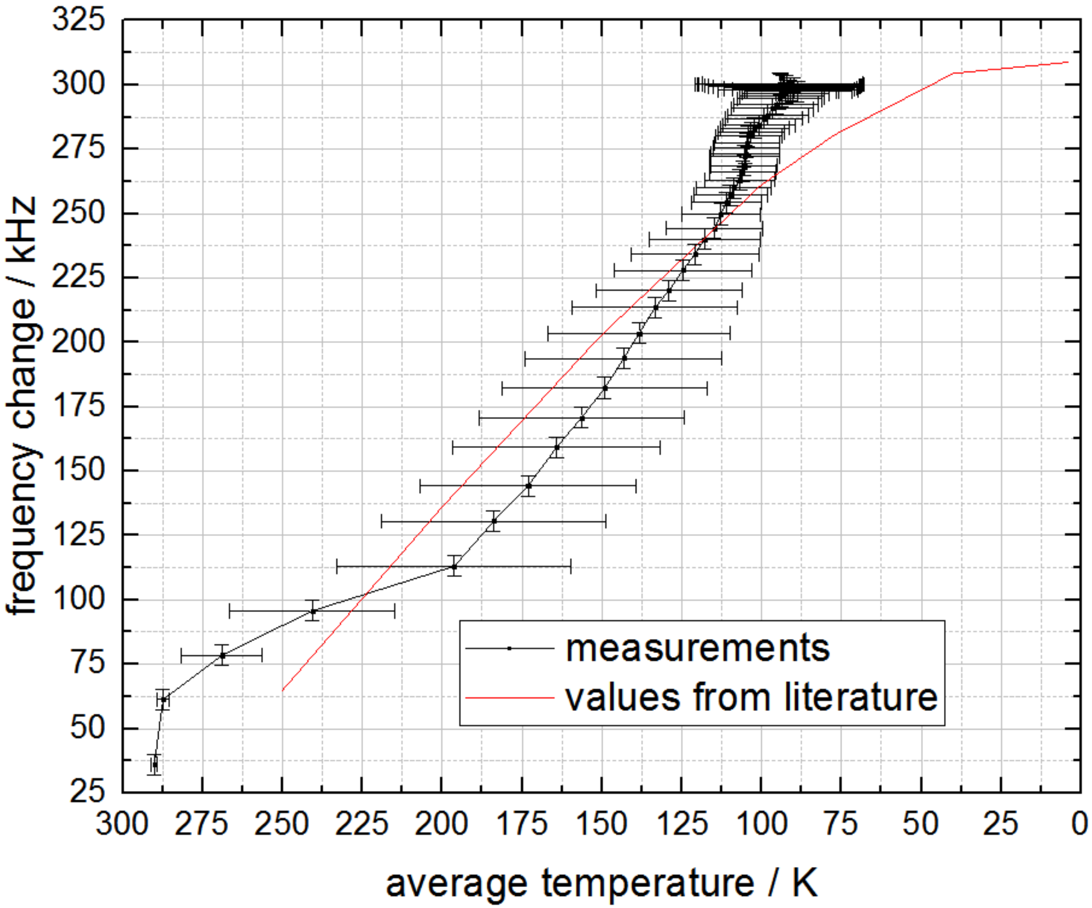
# First cold test to determine thermal shrinking CH 1



# First cold test to determine thermal shrinking CH 1



# First cold test to determine thermal shrinking CH 1




- The frequency change at an average temperature of approx. 95 K was 293,5 kHz
- This is 34,37 kHz (approx. 13,3%) more than values from literature
- In consideration of these results we expect a frequency change of approx. +350 kHz at a temperature of 4 K

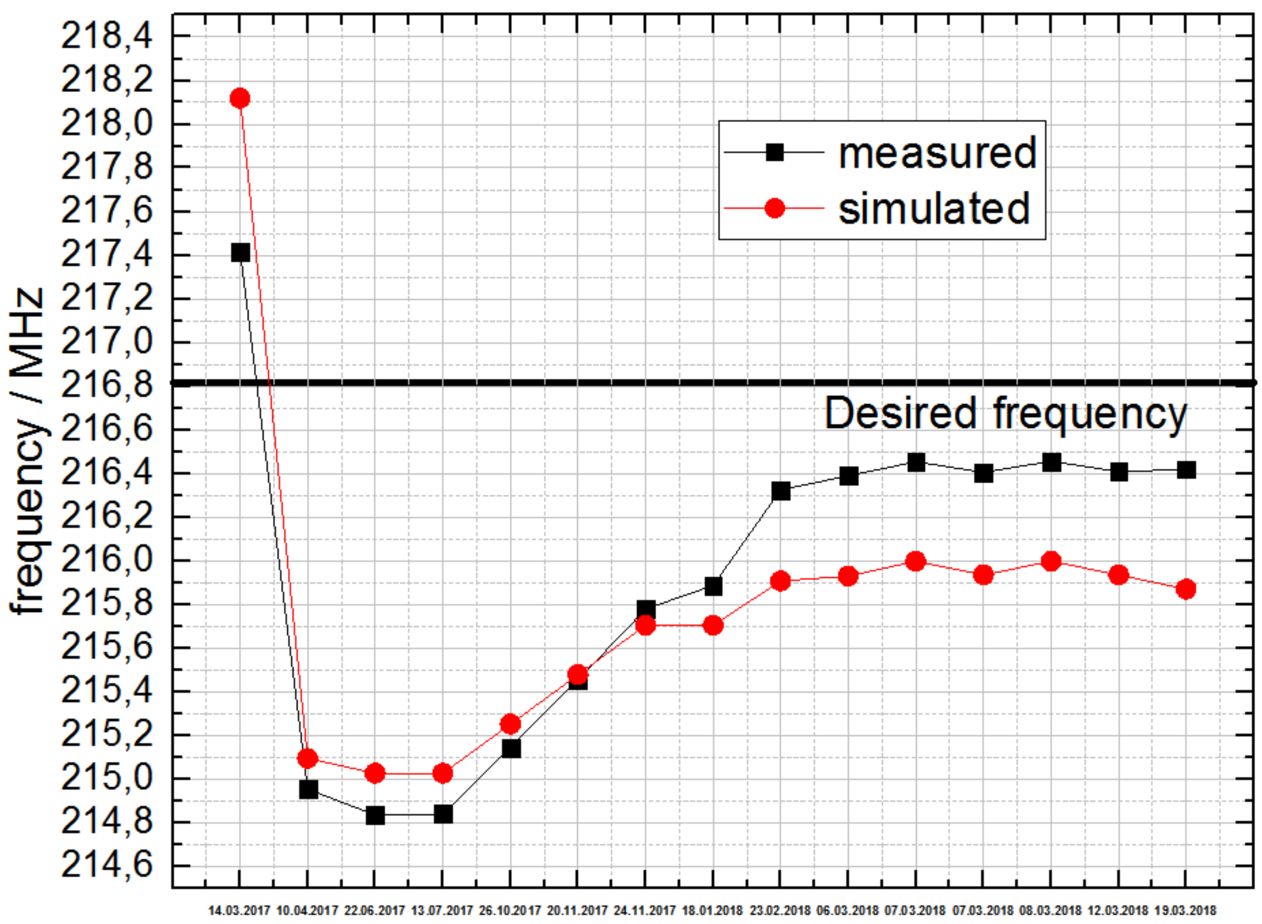
# Final BCP-Treatment of CH 1

- If we consider all impacts on the frequency we are still approx. 524 kHz below the design frequency of 216,816 MHz

  215,887 + 0,35 + 0,054 = 216,291 MHz
- This would mean we need another approx. 83 µm BCP which should be performed in two steps
- Due to technical failure of the BCP-system, the first BCP step resulted in a frequency change of approx. 438 kHz
- This would mean a BCP of approx. 70 µm instead of planned 45 µm
- To stay below the design frequency we decided to perform just a minimalistic BCP-treatment of 5 µm to reach the desired surface quality

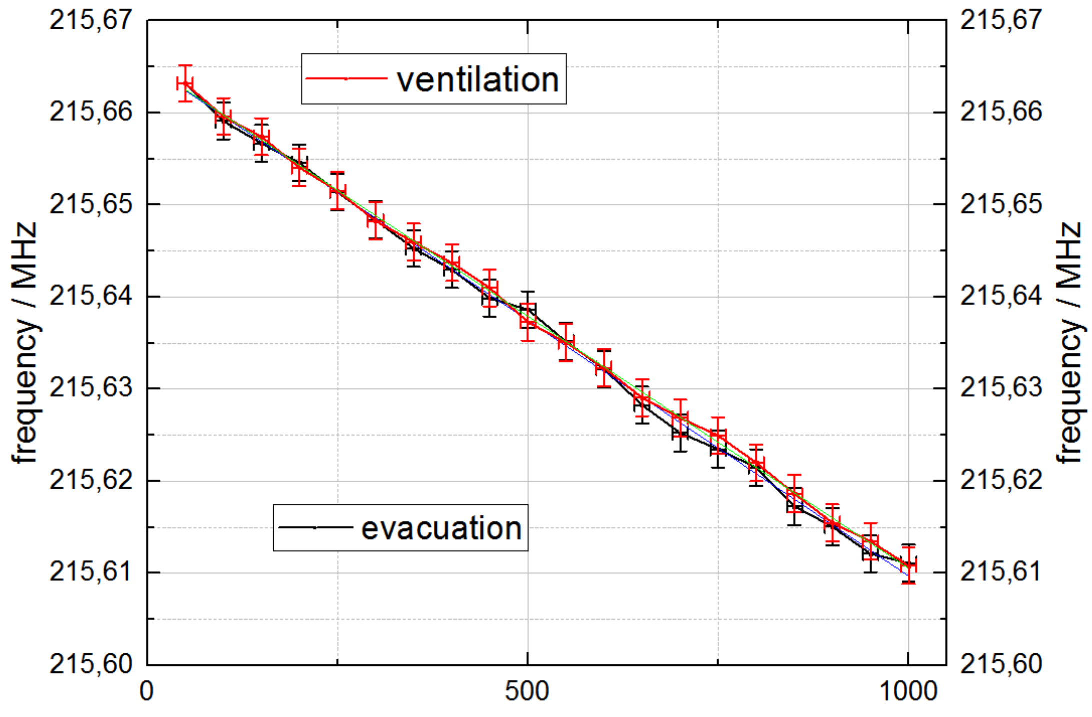
| | simulated | measured | Measurements on CH 1 up to now |
|---|---|---|---|
| | [MHz] | [MHz] | |
| 14.03.2017 | 218,118 | 217,416 | 1. Measurement done by RI with attached end caps, oversize and no static or dynamic tuners |
| 10.04.2017 | 215,094 | 214,953 | 2. Measurement done by us with attached end caps, oversize and welded dynamic tuners |
| 22.06.2017 | 215,026 | 214,835 | 3. Measurement done by RI right before welding the first end cap to the cavity body, oversize removed completely |
| 13.07.2017 | 215,026 | 214,839 | 4. Measurement done by RI after welding both end caps to the cavity body |
| 26.10.2017 | 215,252 | 215,144 | 5. Measurement done by RI after first 50 µm BCP (Δf = 317 kHz) |
| 20.11.2017 | 215,478 | 215,454 | 6. Measurement done by RI after second 50 µm BCP (Δf = 311 kHz) |
| 24.11.2017 | 215,704 | 215,779 | 7. Measurement done by RI after third 50 µm BCP (Δf = 325 kHz) |
| 18.01.2018 | 215,704 | 215,887 | 8. Measurement done by us to determine pressure sensitivity, thermal shrinking and external Q-value |
| 22.02.2018 | 215,907 | 216,325 | 9. Measurement done by RI after fourth planned 45 µm BCP, which turned out to be roughly 70 µm (Δf = 438 kHz) |
| 06.03.2018 | 215,93 | 216,389 | 10. Measurement done by RI after last BCP of planned 5 µm, which was in reality roughly 10 µm (Δf = 64 kHz) |
| 19.03.2018 | 215,87 | 216,419 | 11. Measurement done by me at IAP after delivery, ventilated with nitrogen |

# Measurements on CH 1 up to now



| | simulated | measured | Measurements on CH 2 up to now |
|---|---|---|---|
| | [MHz] | [MHz] | |
| 30.06.2017 | 215,094 | 214,686 | 1. Measurement done by us with attached end caps, oversize and welded dynamic tuners |
| 05.09.2017 | 215,026 | 214,647 | 2. Measurement done by RI right before welding both end caps to the cavity body, oversize removed completely |
| 21.09.2017 | 215,026 | 214,723 | 3. Measurement done by RI after welding both end caps to the cavity body |
| 23.02.2018 | 215,026 | 214,72 | 4. Measurement done by RI after welding the flanges onto the cavity |
| 22.03.2018 | 215,252 | 214,987 | 5. Measurement done by RI after first 50 µm BCP (Δf = 267 kHz) |
| 28.03.2018 | 215,478 | 215,287 | 6. Measurement done by RI after second 50 µm BCP (Δf = 300 kHz) |
| 11.04.2018 | 215,704 | 215,575 | 7. Measurement done by RI after second 50 µm BCP (Δf = 288 kHz) |
| 18.04.2018 | 215,704 | 215,613 | 8. Measurement done by us to determine pressure sensitivity and thermal shrinking |

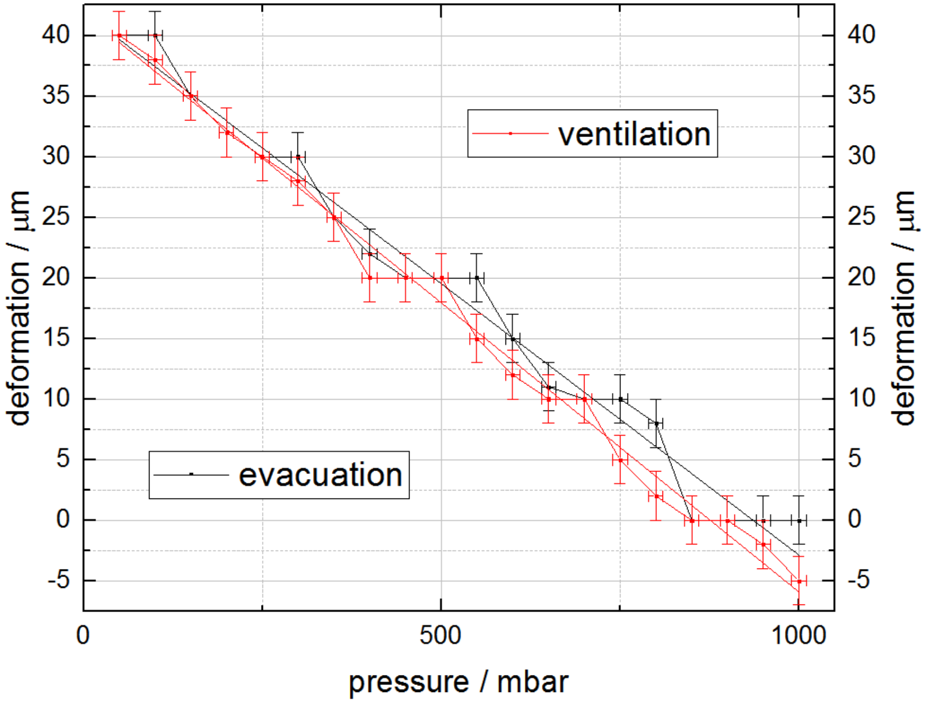
# Pressure sensitivity CH 2

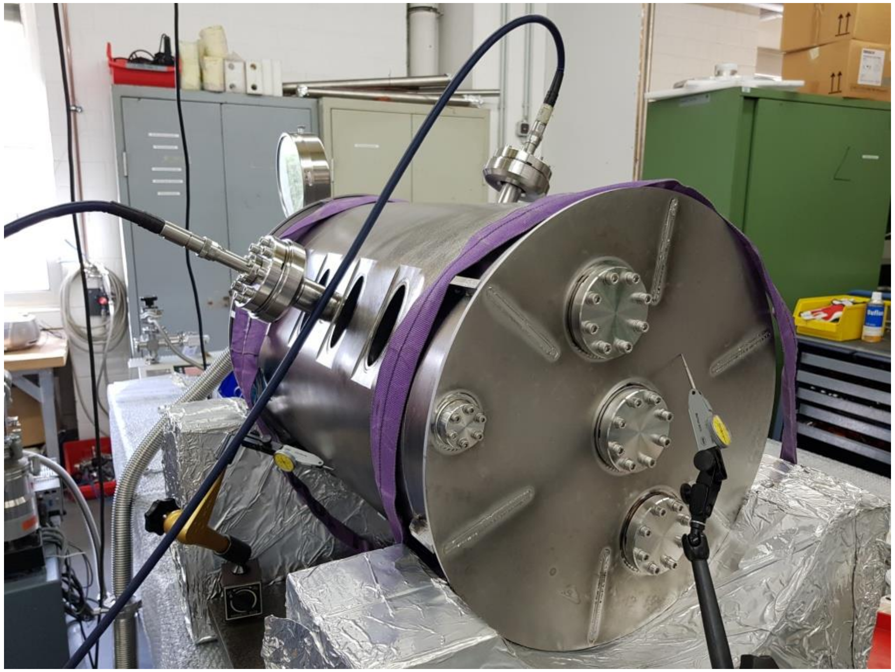



- approx. **Δ f = +55,52 ± 0,5 Hz/mbar** during evacuation
- approx. **Δ f = +54,75 ± 0,3 Hz/mbar** during ventilation
- change of $\varepsilon_r$ should result in approx. **Δ f = +63,6 kHz**
- measured pressure sensitivity during evacuation approx. **Δ f = -8,08 ± 0,5 Hz/mbar**
- measured pressure sensitivity during ventilation approx. **Δ f = -8,85 ± 0,3 Hz/mbar**
- simulated pressure sensitivity approx. **Δ f = +4,61 Hz/mbar**

# Measured deformation CH 2

- measured deformation evacuation **Δ x ≈ 45 µm**
- measured deformation ventilation **Δ x ≈ 48 µm**

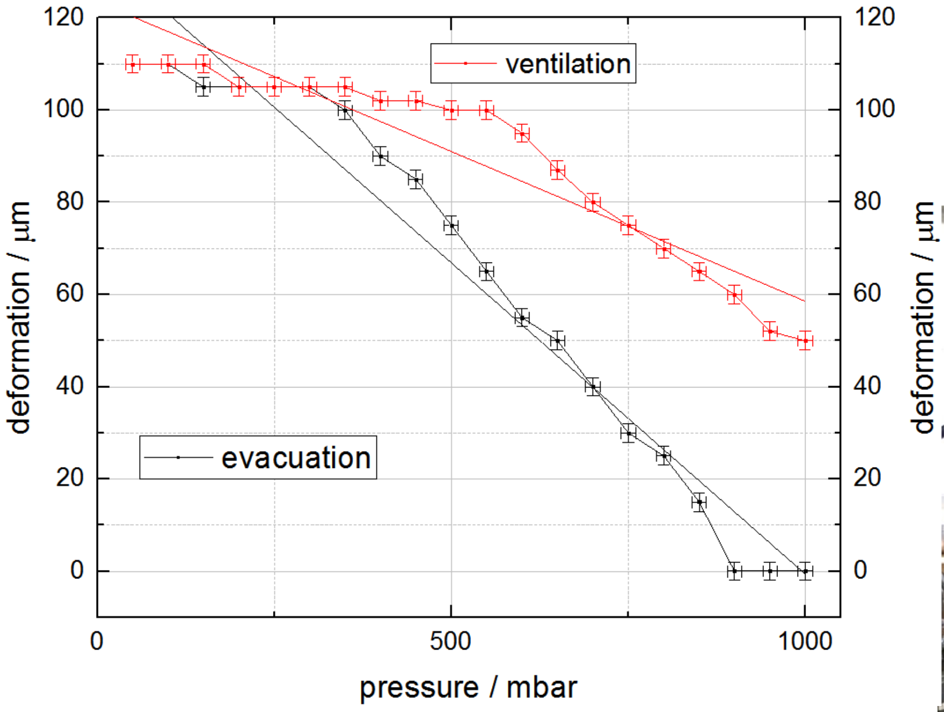


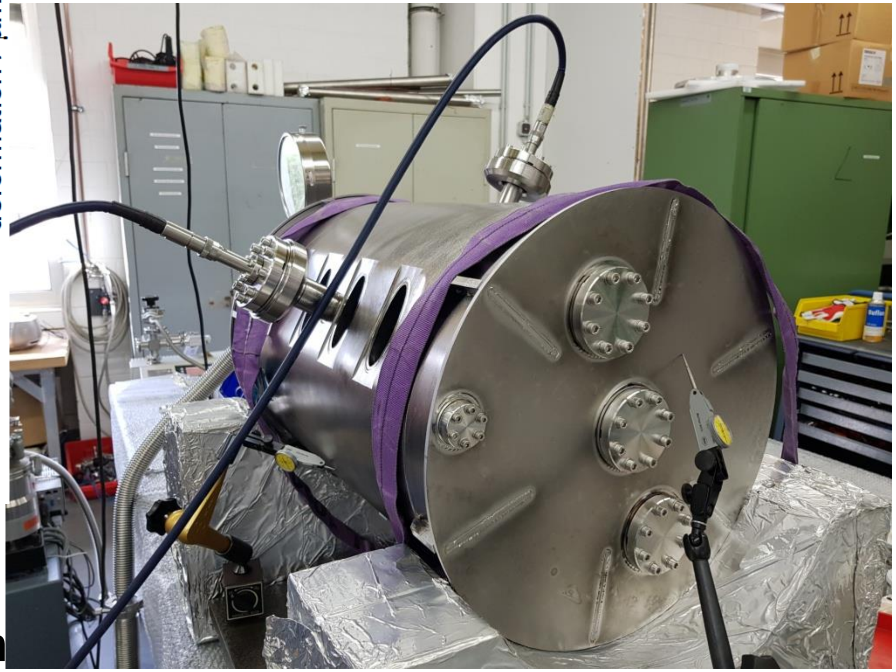



- simulated deformation up to **Δ x = 50 µm**

# Measured deformation CH 2

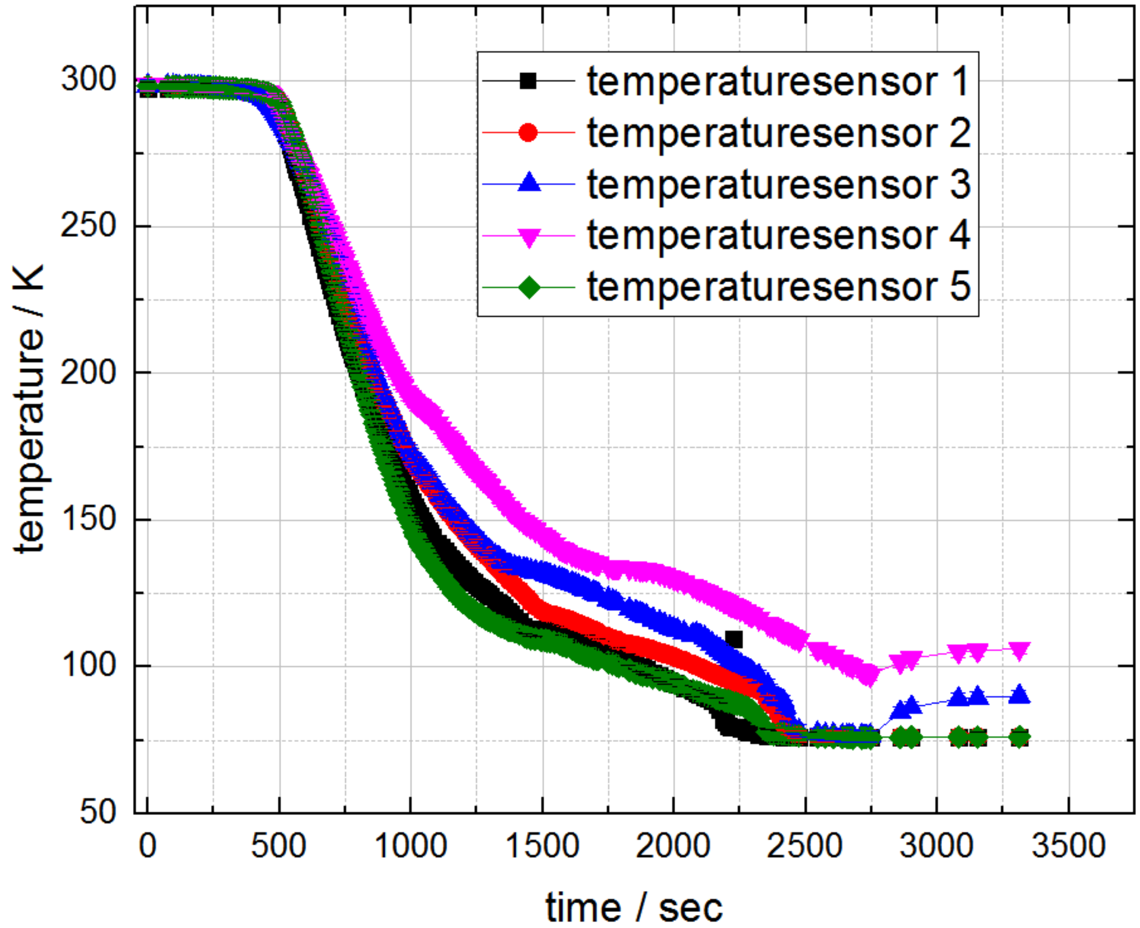
- measured deformation evacuation **Δ x ≈ 137 µm**
- measured deformation ventilation **Δ x ≈ 66 µm**



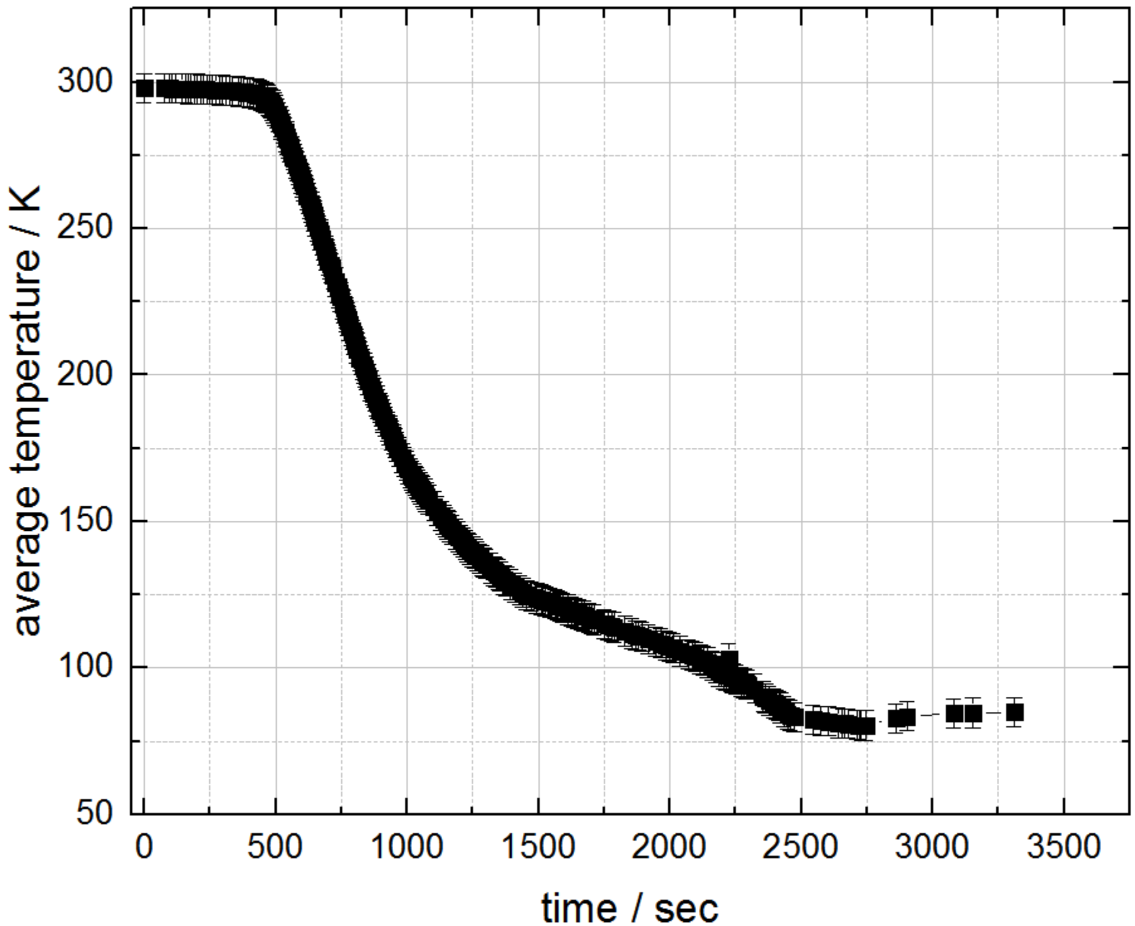



- simulated deformation up to **Δ x = 100 µm**

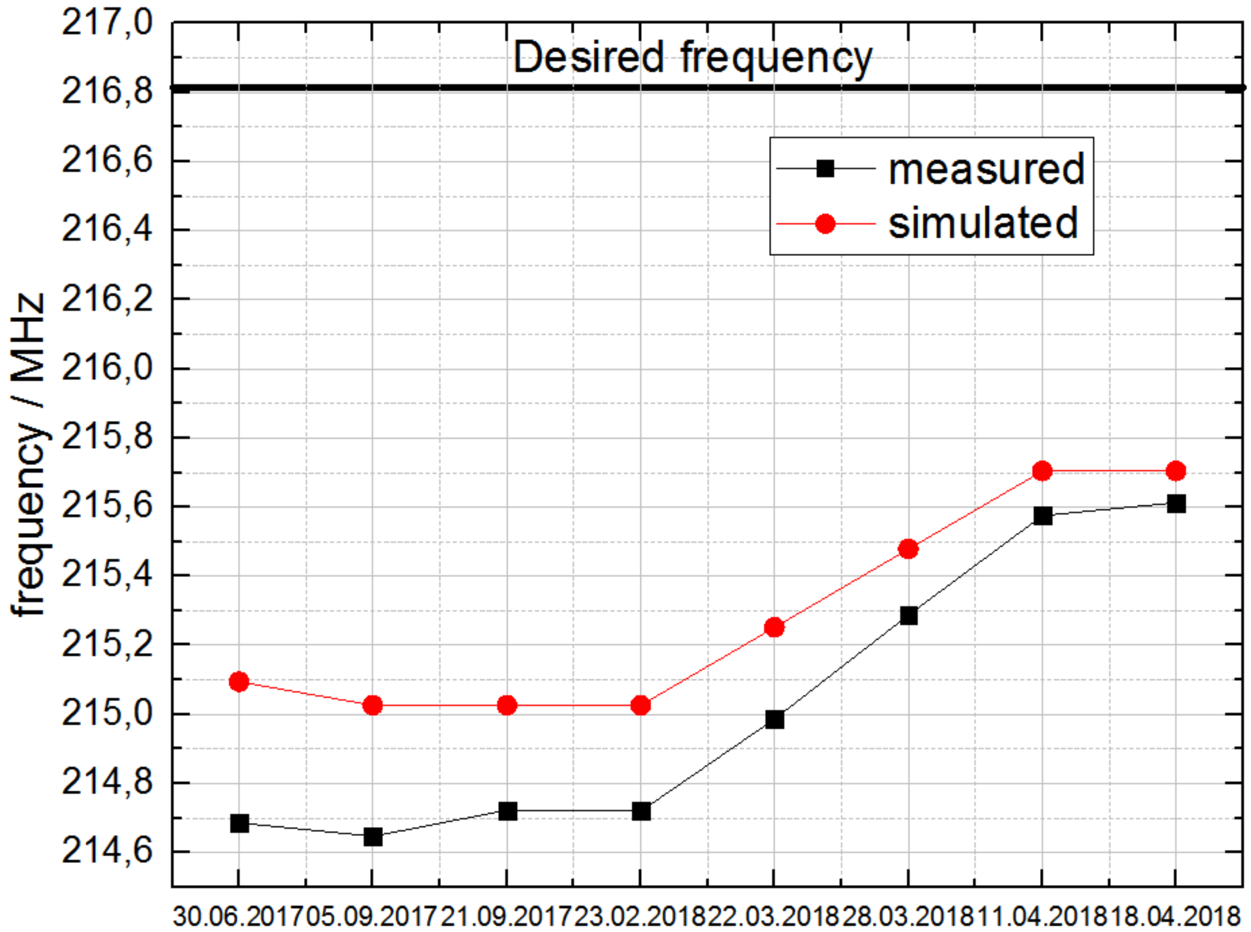
# First cold test to determine thermal shrinking CH 2



# First cold test to determine thermal shrinking CH 2



# Measurements on CH 2 up to now



# Status of both CH-cavities

| Measurement on factory site | CH1 | CH2 |
| --- | --- | --- |
| Attached end caps, oversize and no tuners | ✓ | |
| Attached end caps, oversize and dynamic tuners | ✓ | ✓ |
| Attached end caps, oversize removed before welding | ✓ | ✓ |
| After welding both end caps | ✓ | ✓ |
| After first 50 µm BCP | ✓ | ✓ |
| After second 50 µm BCP | ✓ | ✓ |
| After third 50 µm BCP | ✓ | ✓ |
| Before final BCP | ✓ | ✓ |
| After final BCP ventilated with nitrogen | ✓ | |

# Thank you for your attention