Characterisation of a 3D aluminium cavity for the QSHS experiments

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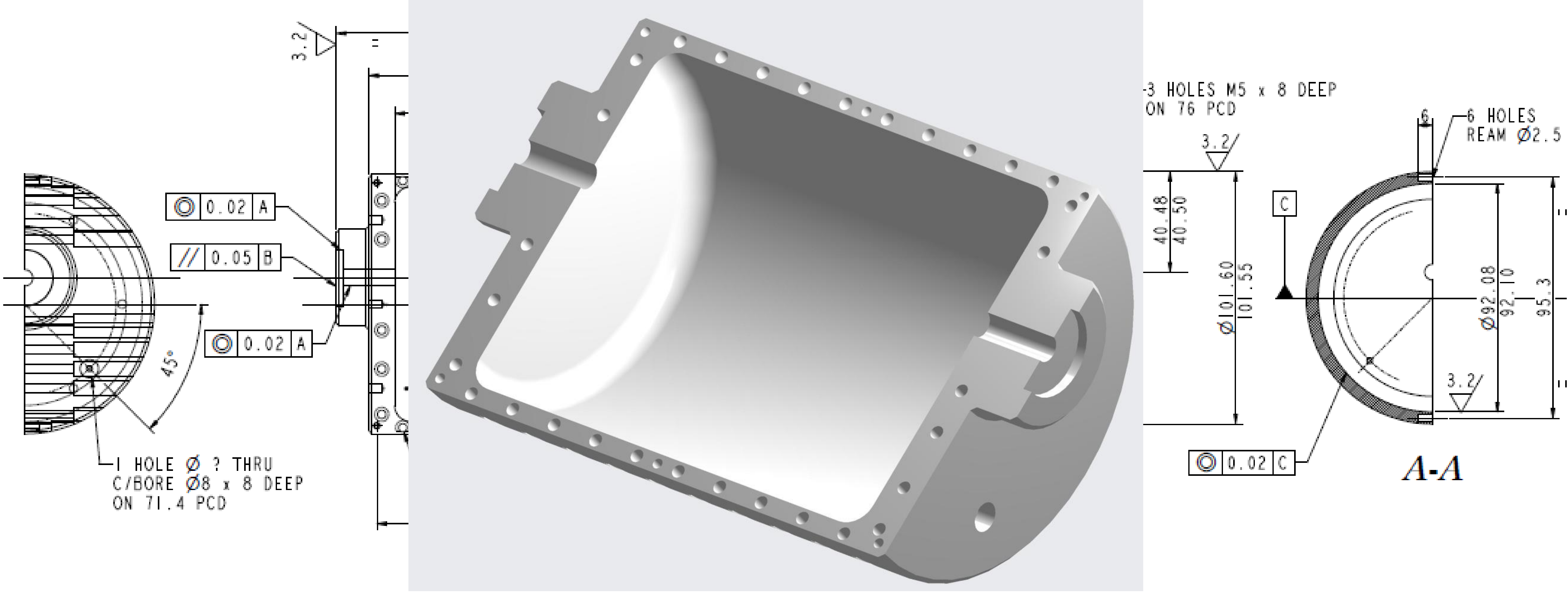
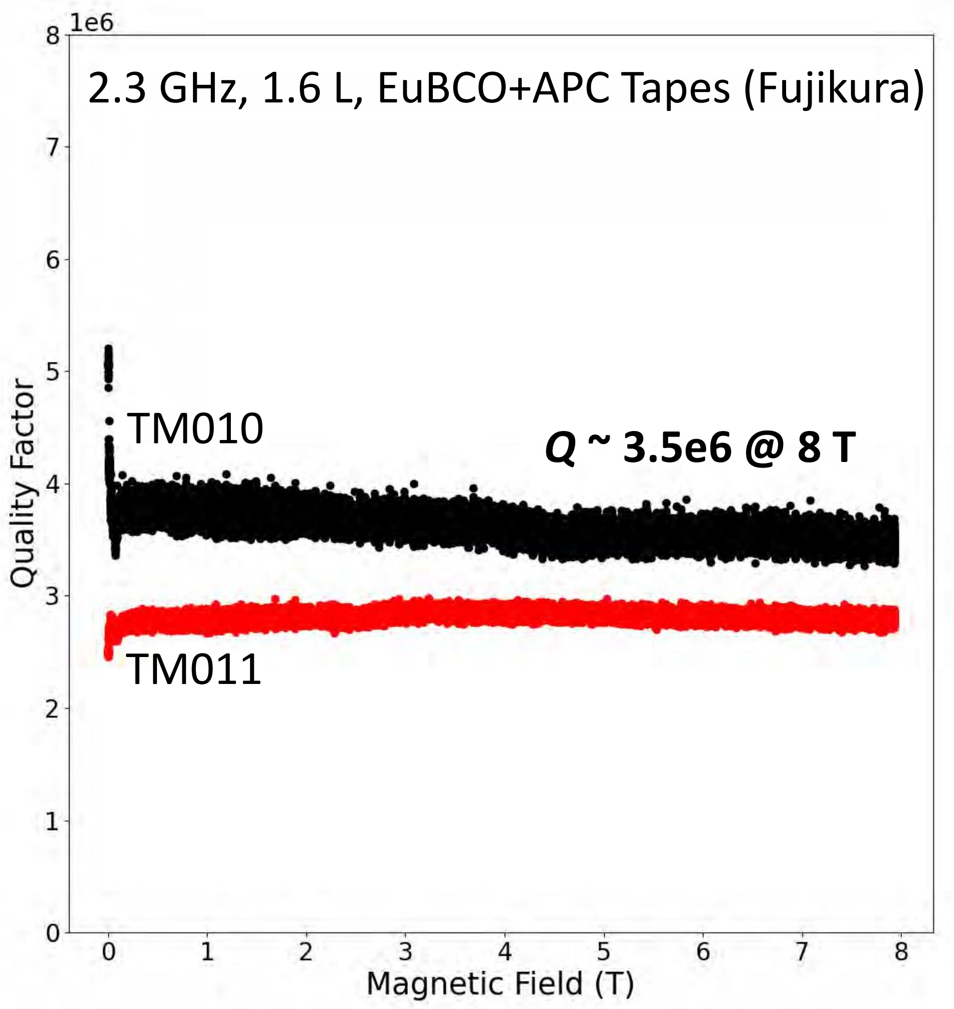
Al cylindrical cavity drawing



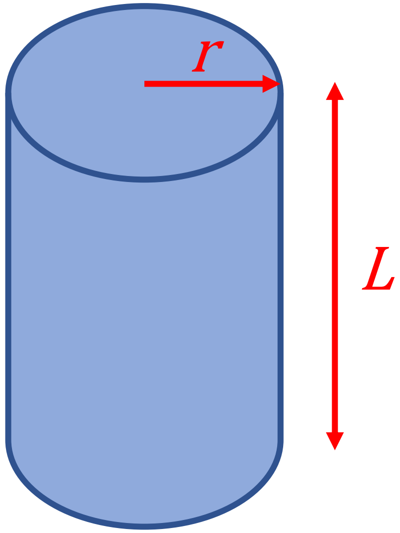
Material: Al grade 6061   Chemical composition (%): **Mg** 0.8 – 1.2; **Si** 0.4 – 0.8; **Cu** 0.15 – 0.4

Al cylindrical cavity with HTS coating



Courtesy of Dahno Ahn, CAPP IBS, Korea

Cylindrical cavity resonant modes



Transverse Magnetic (TM)

$$\omega_{mnp} = \frac{1}{\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{X_{mn}}{r}\right)^2 + \left(\frac{p\pi}{L}\right)^2}$$

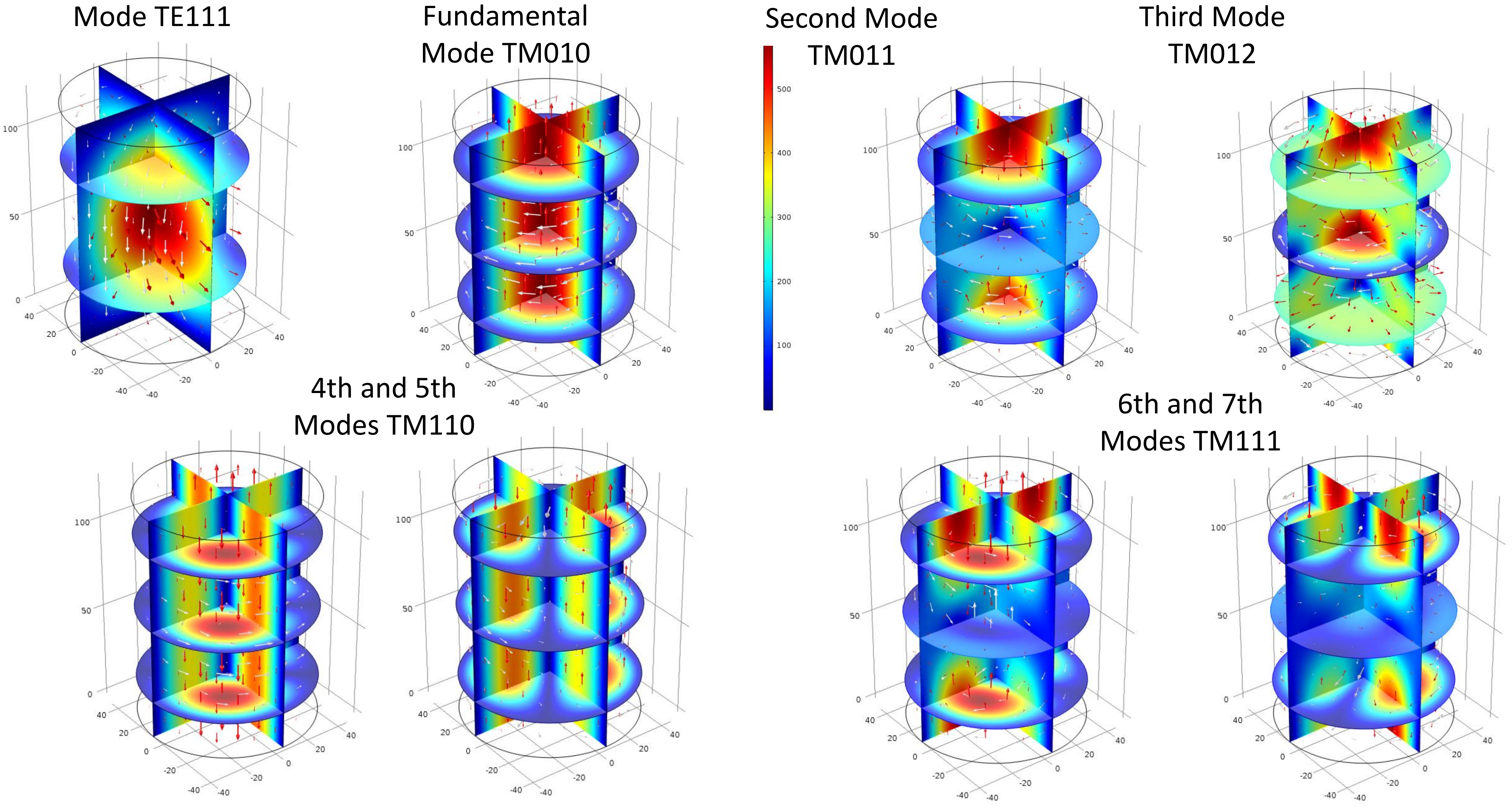
Transverse Electric (TE)

$$\omega_{mnp} = \frac{1}{\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{X'_{mn}}{r}\right)^2 + \left(\frac{p\pi}{L}\right)^2}$$

X_{mn} and X'_{mn} are the zeroes of the Bessel functions of the first and second kind
ε is the relative permittivity of the cavity filling
μ is the relative permeability of the cavity filling

Nodal indices:
m – the number of nodal diameters in the circular degree of freedom
n – the number of nodal circles in the circular degree of freedom
p – the number of nodal planes along the length of the cavity

Resonant modes



Equilibration time of superconducting aluminium

The heat equation: $$\frac{\partial T}{\partial t} = \alpha \quad T$$

$\alpha = \frac{\kappa}{\rho C_p}$ is the thermal diffusivity coefficient
κ is the thermal conductivity
ρ is the mass density
C_p is the specific heat capacity

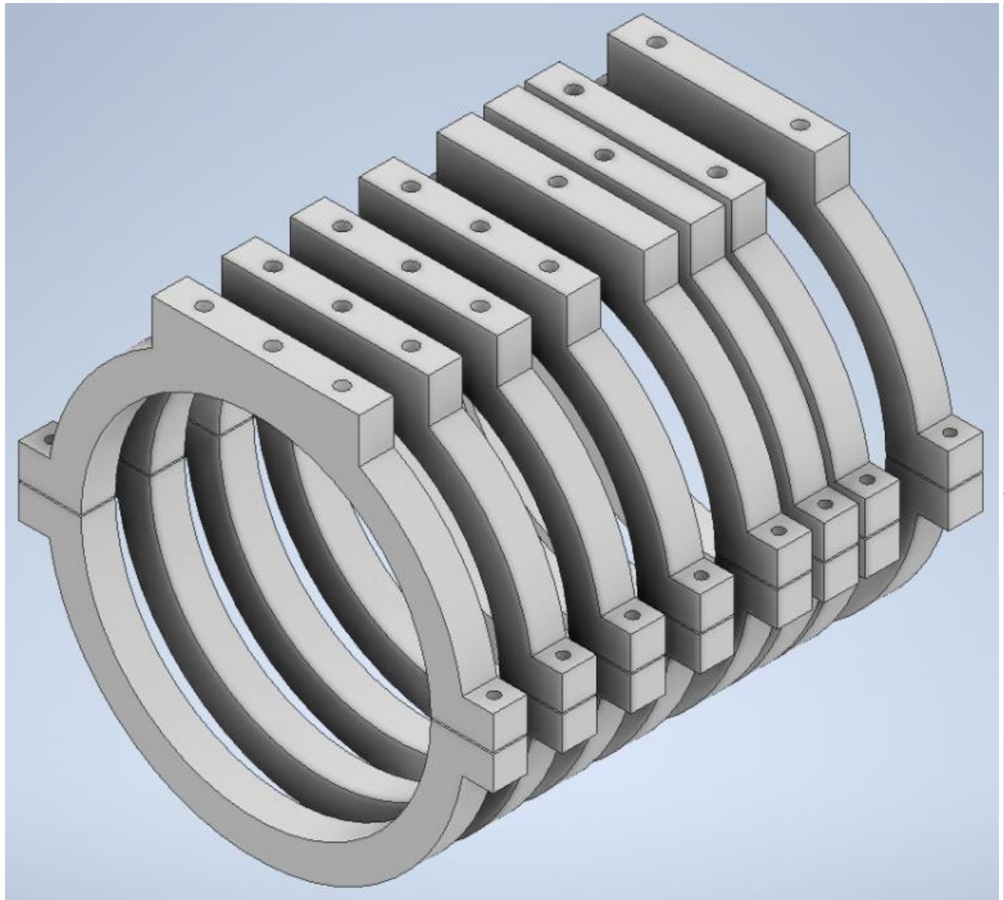
The solution to the above differential equation has a term $e^{-\frac{\tau}{t}}$, where $\tau \sim \frac{L^2}{\alpha}$

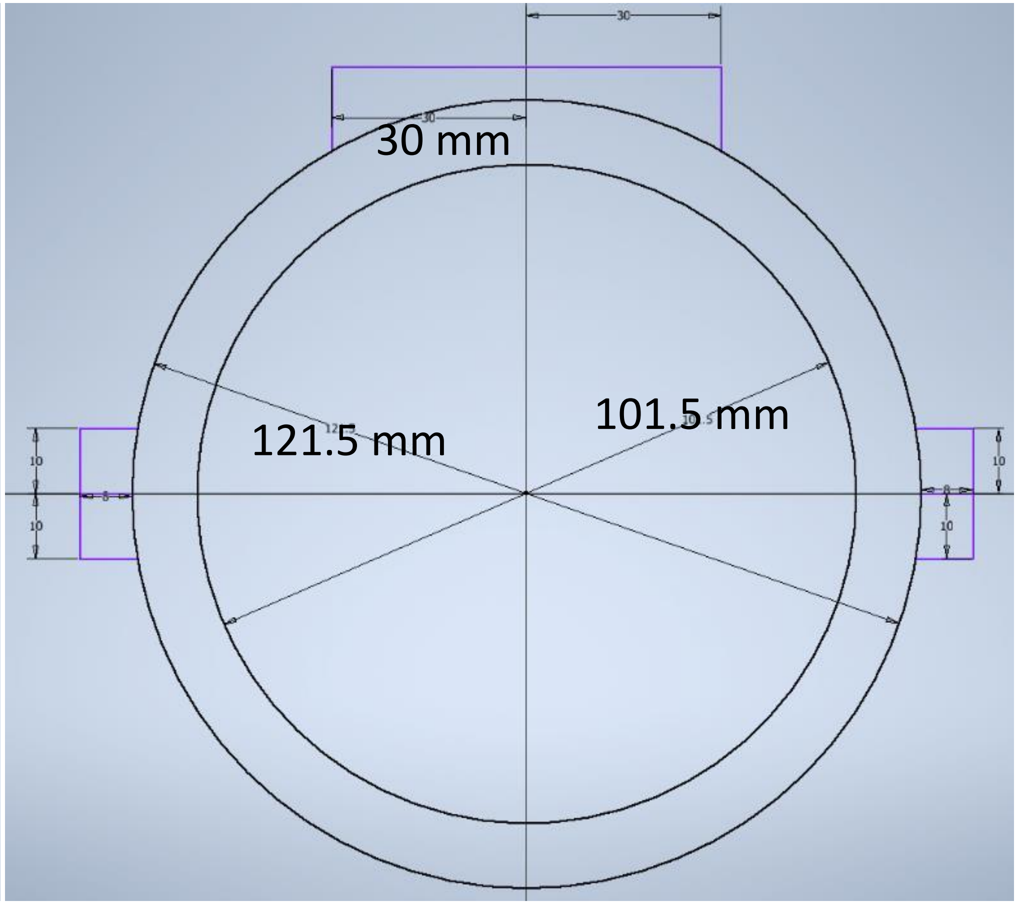
Assume $L = 10^{-1}$ m

Just at *T*c (Pobell's book)
$C_p = 2 \times 10^{-1}$ J/kg K
$\kappa = 5 \times 10^{2}$ W/Km
$\rho = 2700$ kgm^{-3}
→ $\tau \sim 10^{-2}$ s

Plausible combination at 100 mK
$C_p = 10^{-6}$ J/kg K (Sahling, Abens 2001)
$\kappa = 10^{-3}$ W/Km (Pobell's book)
$\rho = 2700$ kgm^{-3}
→ $\tau \sim 3 \times 10^{-2}$ s

Cavity holders



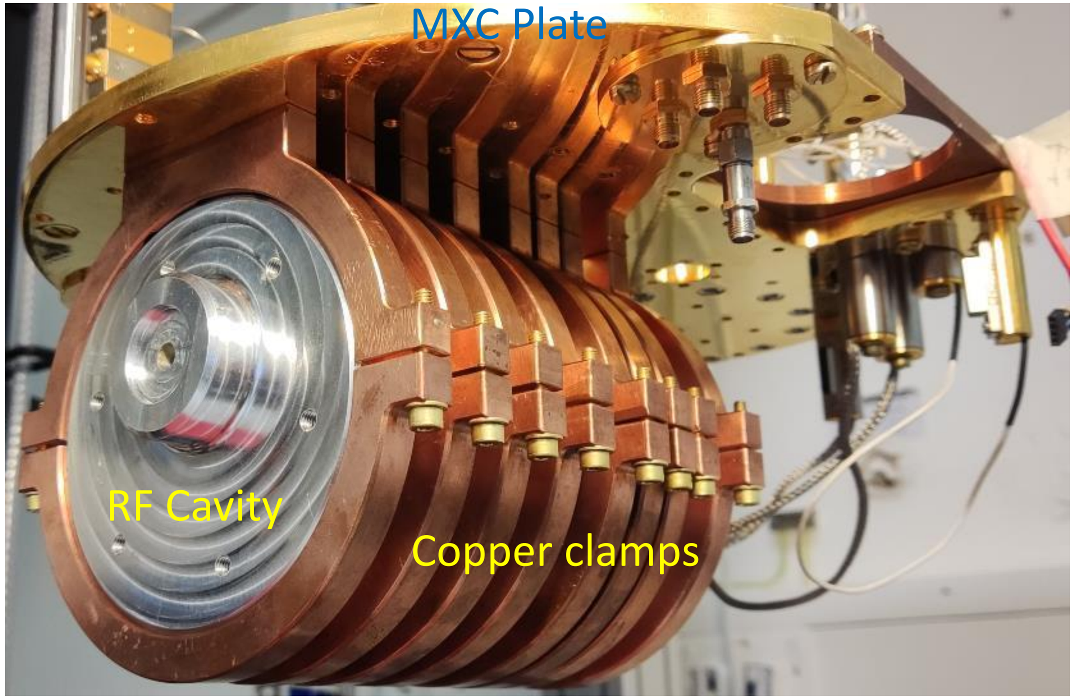


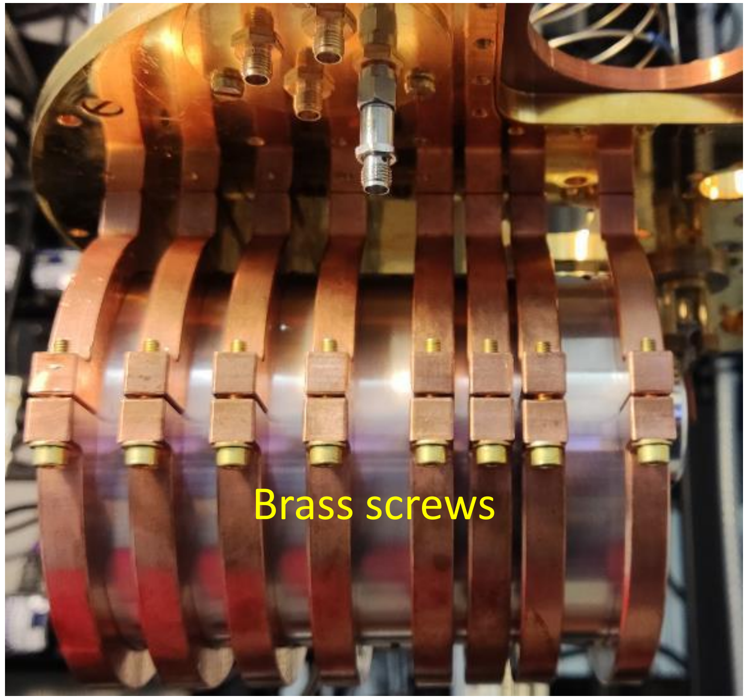
10 mm

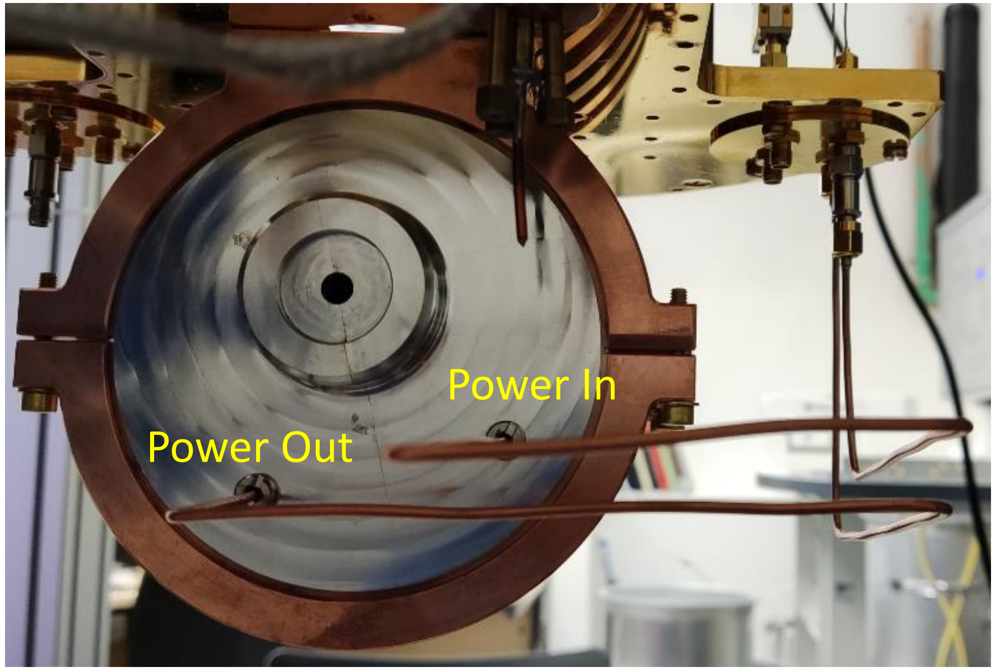
Eight 1 cm thick clamps consisting of two brackets each
1 mm gap in between the top and bottom brackets

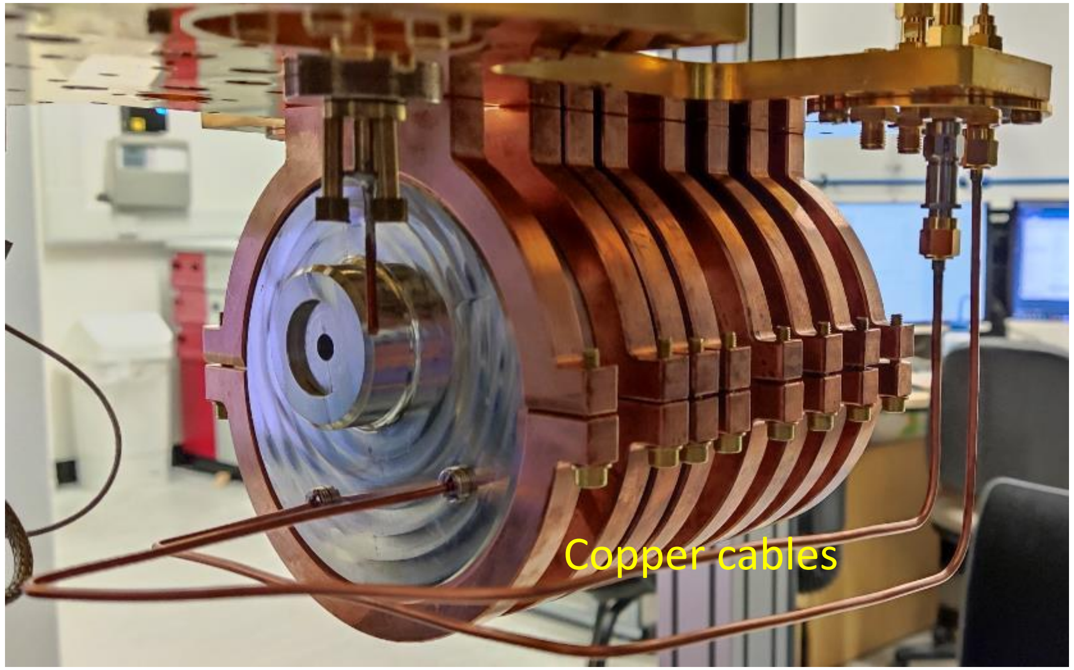
Al cavity attached to the MXC plate

All measurements performed with minimal antenna insertion



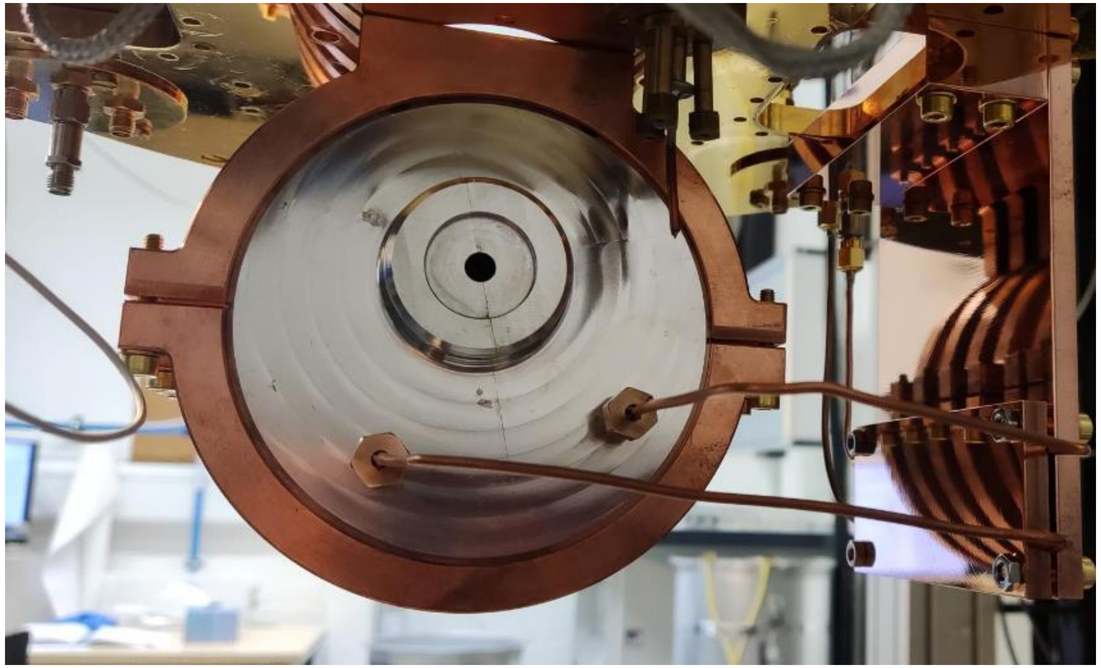






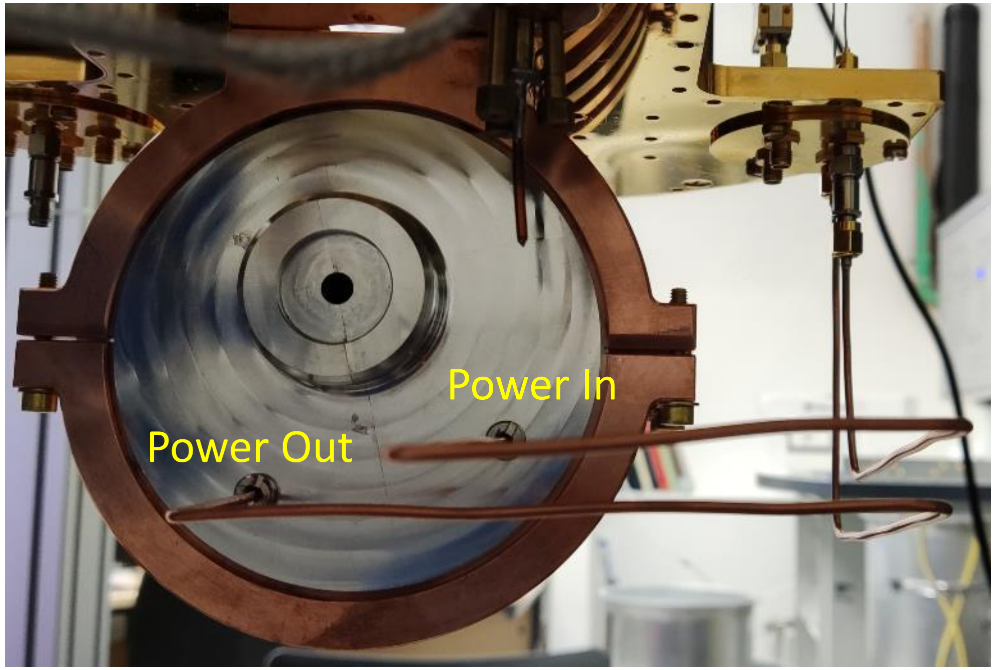
Al cavity attached to the MXC plate

All measurements performed with the minimal antenna insertion

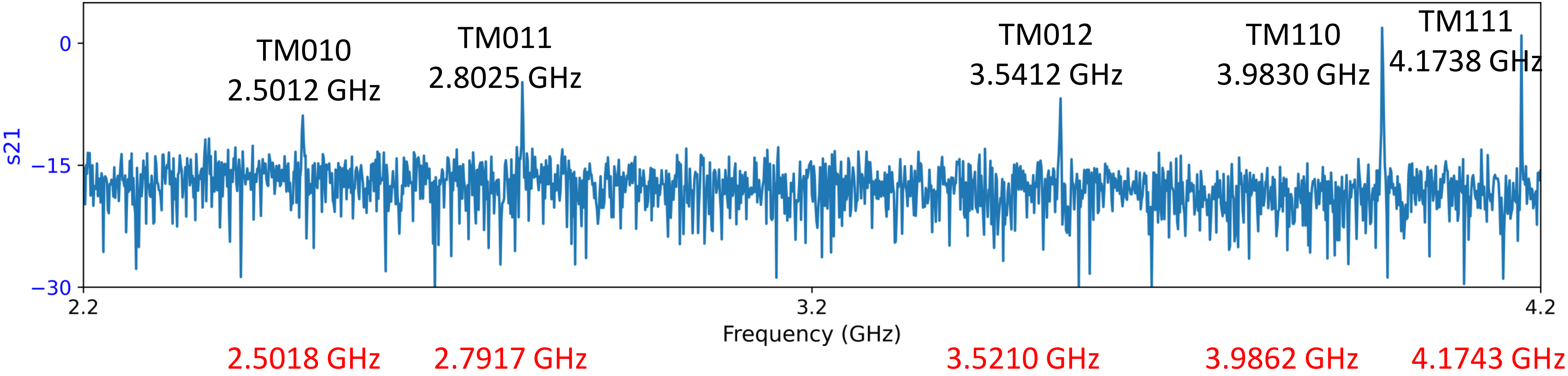


Copper plate to fix the coax lines

Collet mechanisms to hold the ends of coax lines

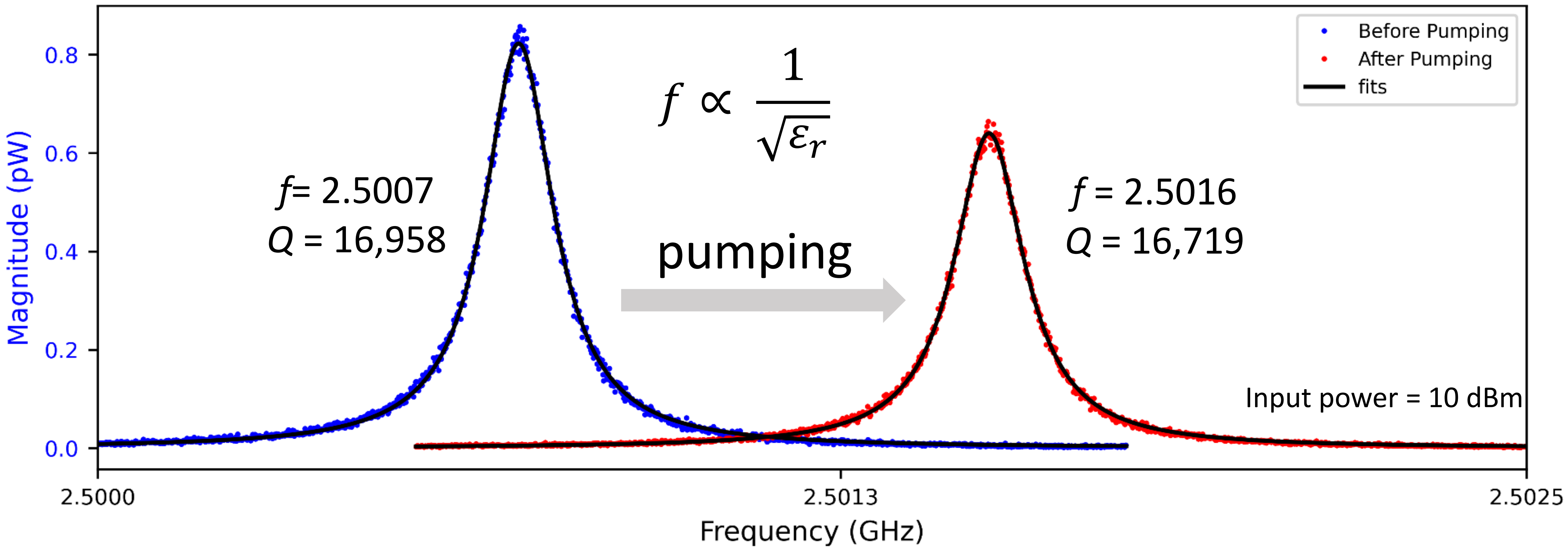


Wideband scan at room *T*



Resonance frequencies obtained from COMSOL modelling

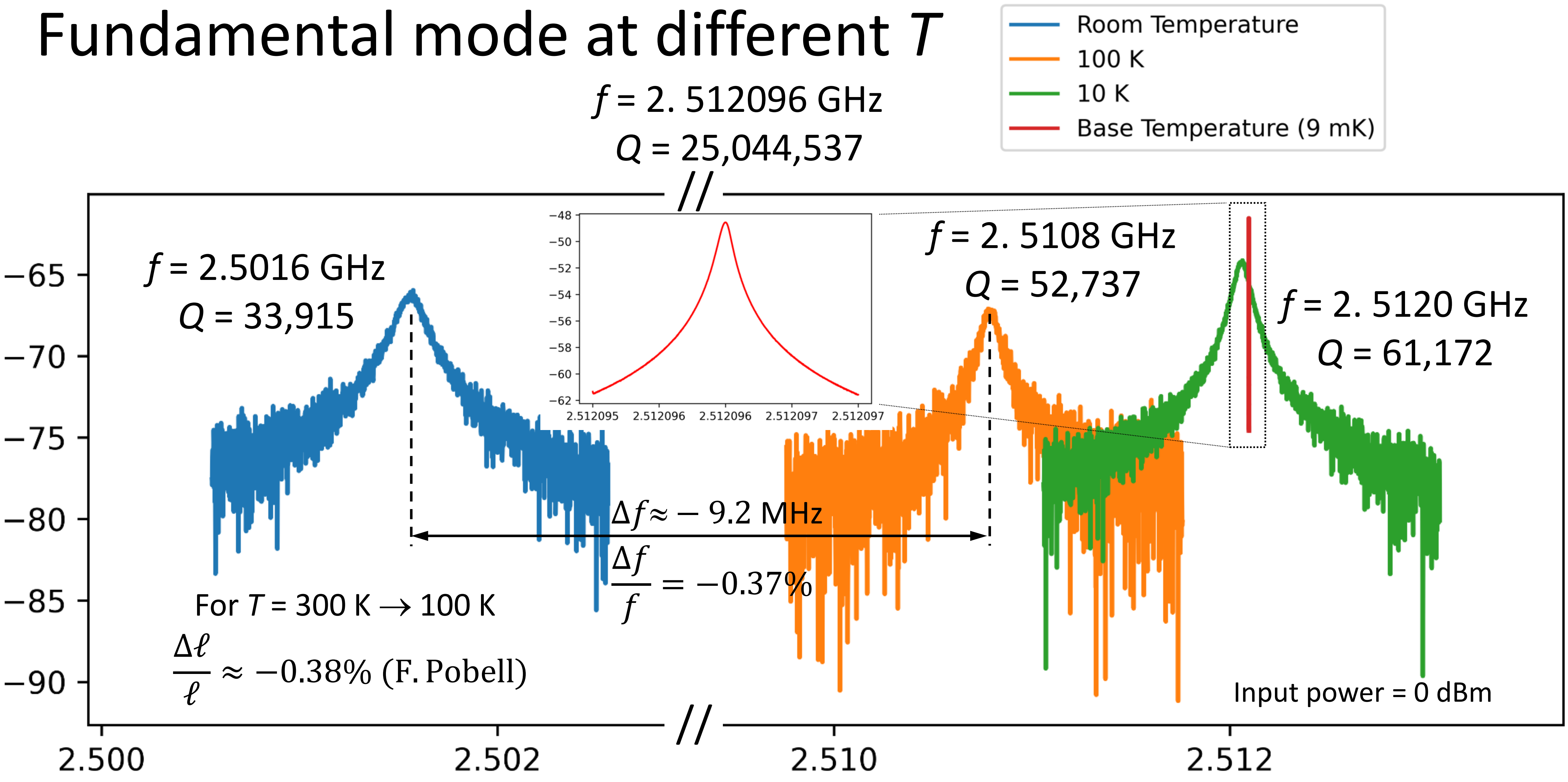
Before and after pumping at room T



Prediction: $\frac{f_{vac}}{f_{air}} = \sqrt{\varepsilon_{air}} = \sqrt{1.00059} \approx 1.00030$

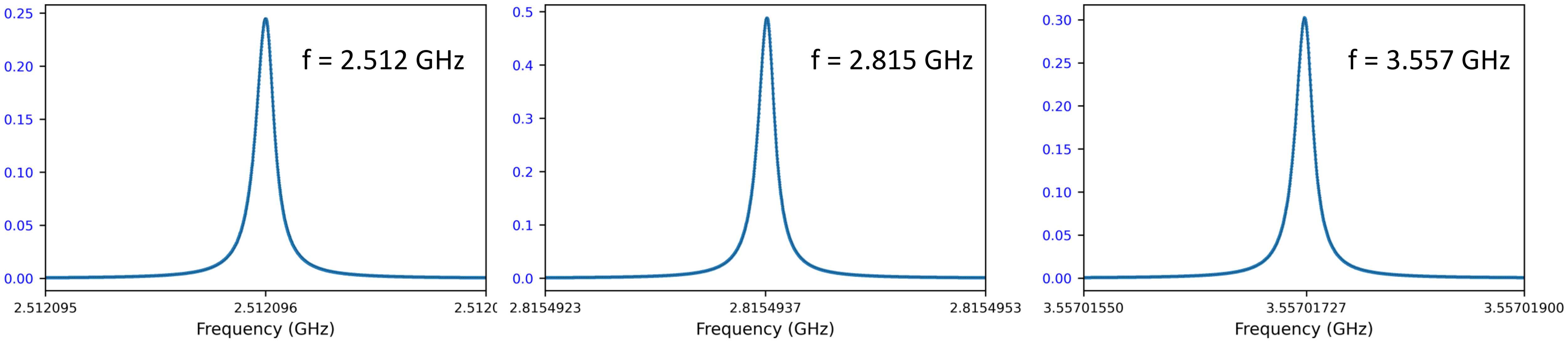
Measurement: $\frac{f_{after\ pumping}}{f_{before\ pumping}} \approx 1.00033$

Fundamental mode at different T

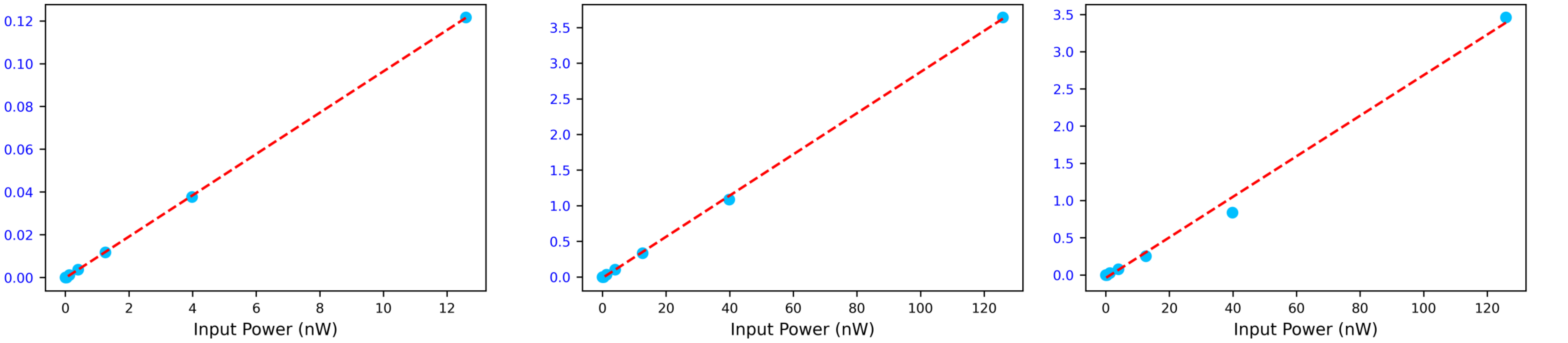


Note: Baselines for each curve were adjusted to be equal for presentation

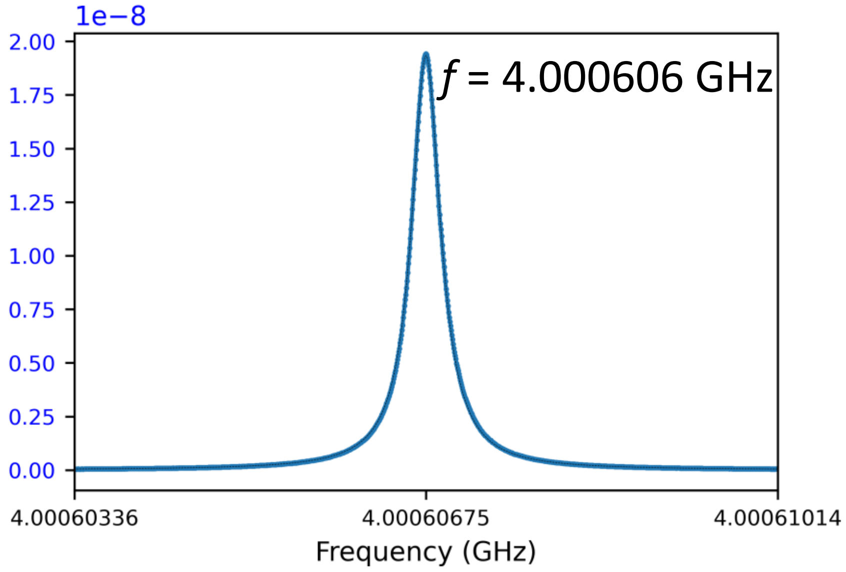
Lowest three modes at base *T*



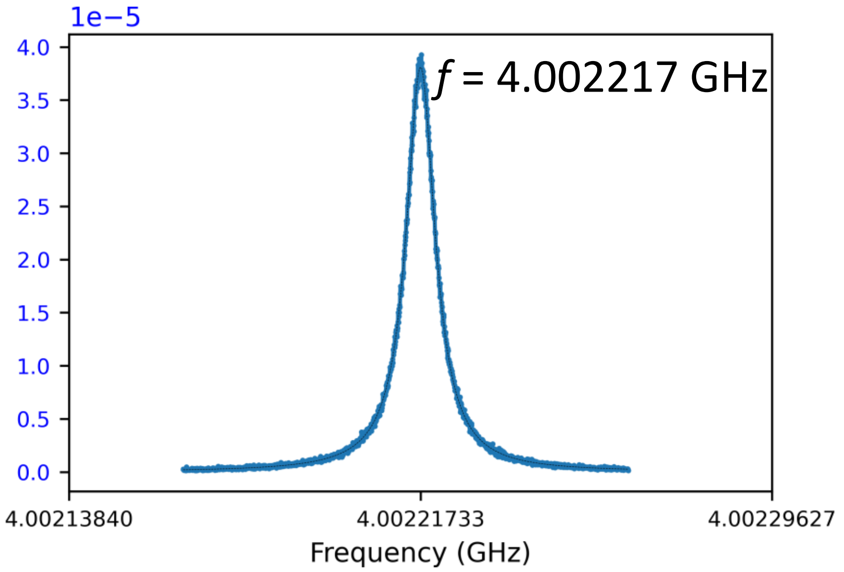
FM: Q = 25,044,537 | 2nd mode: Q = 20,353,042 | 3rd mode: Q = 21,063,194



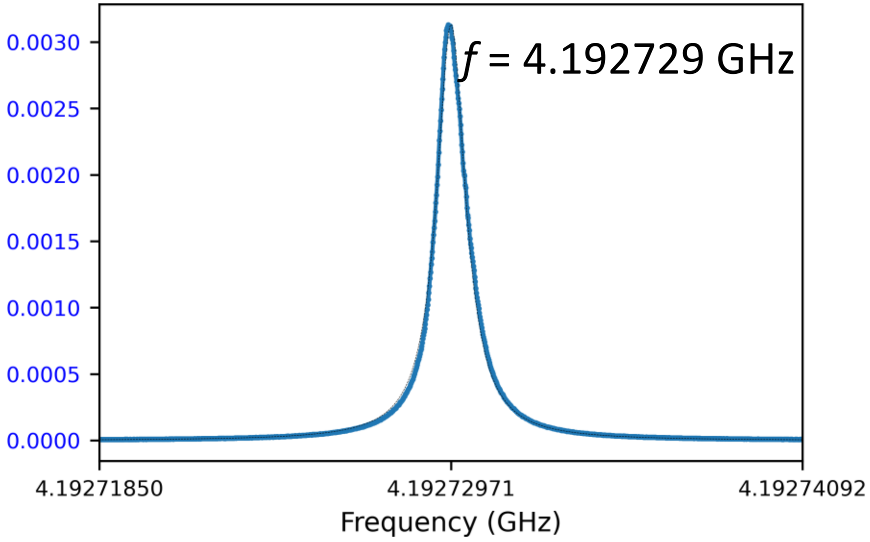
Splitting of higher deg. modes



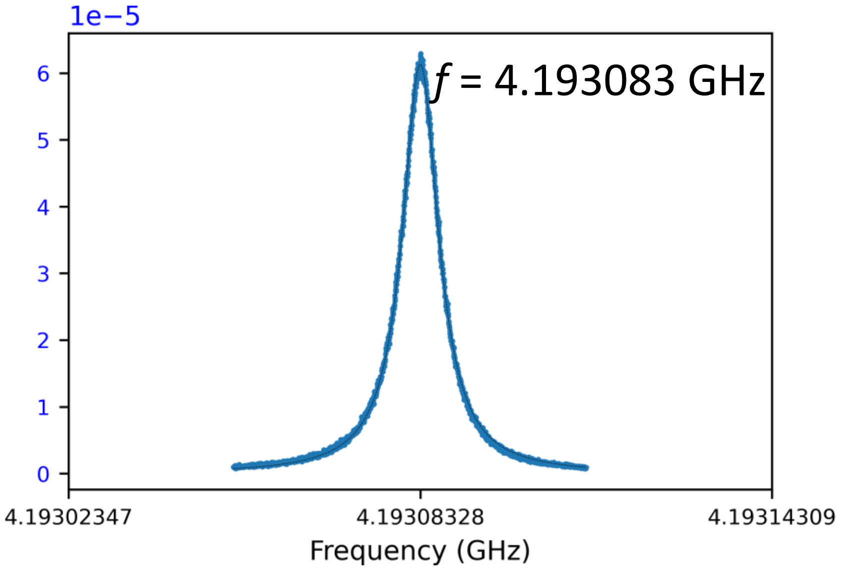
4th mode: Q = 11,803,640 at -15 dBm



5th mode: Q = 507,029 at -15 dBm

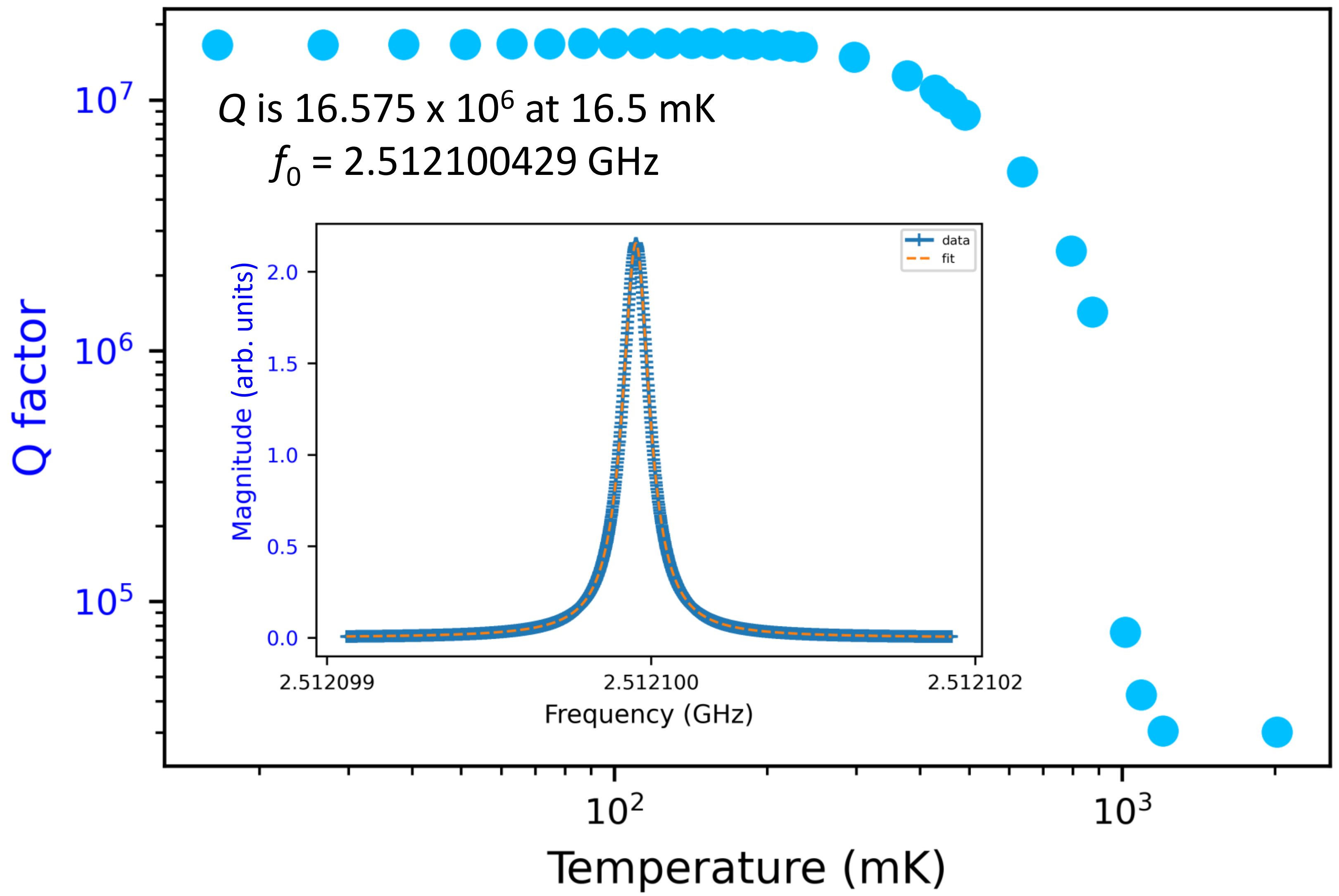


6th mode: Q = 3,739,055 at -15 dBm



7th mode: Q = 560,843 at -15 dBm

Q vs T



$$\frac{1}{Q} = \frac{1}{Q_i} + \frac{1}{Q_c}$$

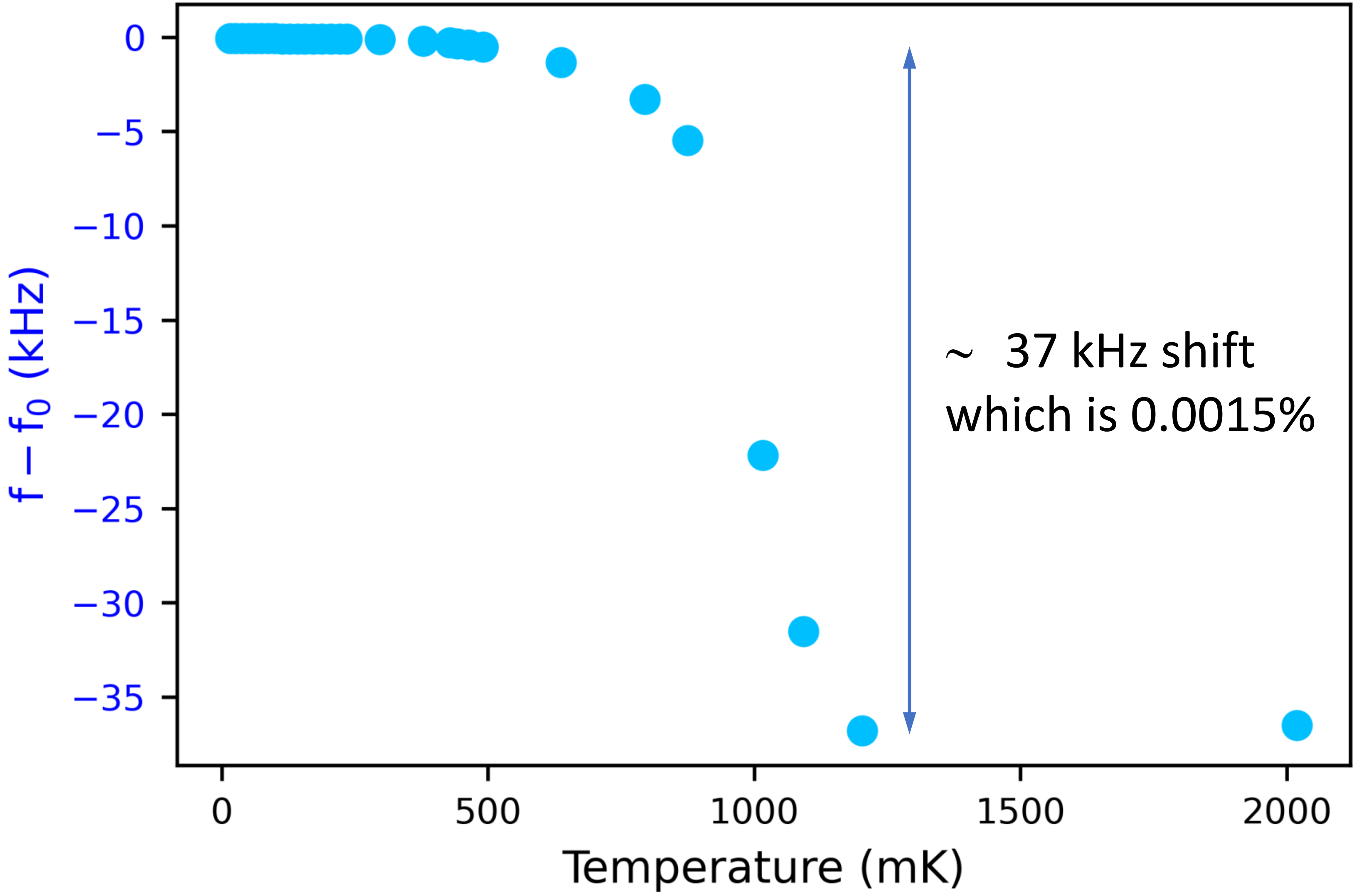
$$\frac{1}{Q_i} = \frac{1}{Q_{\mathrm{BCS}}} + \frac{1}{Q_{\mathrm{TLS}}}$$

$$\frac{1}{Q_{\mathrm{TLS}}} \propto \tanh \frac{\hbar\omega}{2k_B T}$$

WA Phillips (1987)

$$\frac{1}{Q_{\mathrm{BCS}}} \propto \frac{1}{T} \exp\left(-\frac{\Delta(T)}{k_B T}\right)$$

Δf vs T



$$\Delta\omega \approx -\omega_0 \frac{L_k}{L}$$

$$L_k = \frac{\hbar R_n}{\pi \Delta(T)} \tanh\left(-\frac{\Delta(T)}{2k_B T}\right)$$

$T \ll T_c$

$$L_k = \frac{\hbar R_n}{\pi \Delta(0)}$$

$T \sim T_c$

$$\Delta(T) \propto \left(1 - \frac{T}{T_c}\right)^{1/2}$$

Summary

- ✓ Al cavity characterised in a wide temperature range, $Q \sim 20$ million
- ✓ Sharp changes of in Q and ω_0 observed at about T_c
- ✓ Q vs T dependence dominated by BSC and TLS losses
- ✓ Frequency shift caused by changes of the total inductance of the cavity