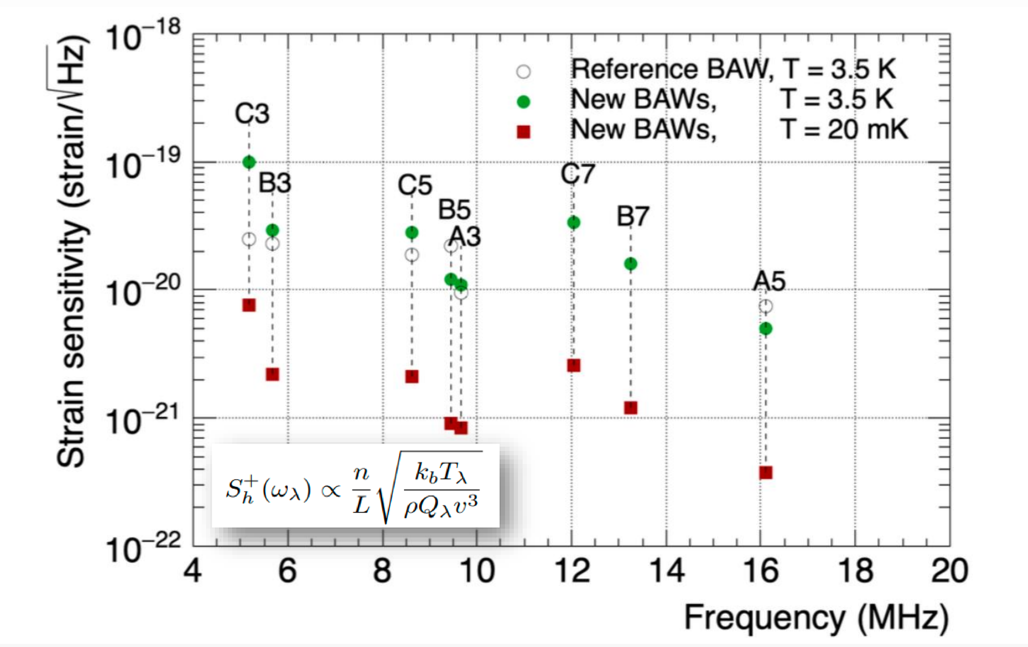
Characterization of SiO_2 crystals for a multimode gravitational wave antenna

Riccardo Maifredi on behalf of the BAUSCIA experiment

First BicoQ Conference: from Gravity to particles

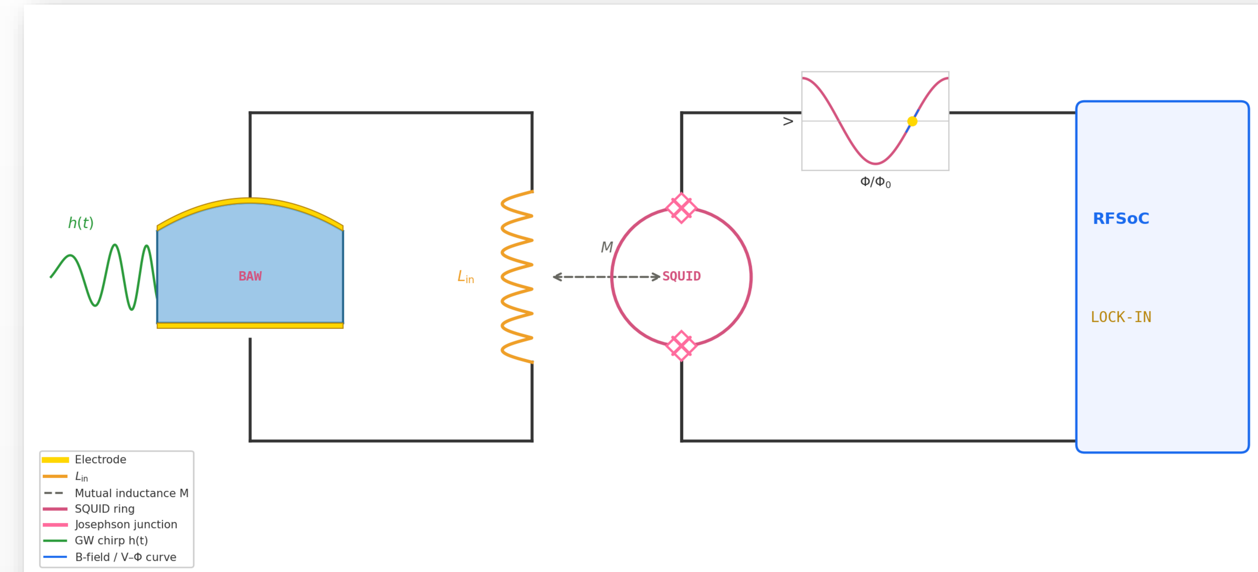
Strain sensitivity



Putative Sources

- **PBH-PBH mergers** (G. Franciolini et Al. Phys. Rev. D 106, 103520)
- **Axion clouds collapse into MBH** (A. Arvanitaki et Al., Phys. Rev. D 83, 044026)
- **Phase Transitions in nascent NS** (K. Bleau et Al., arXiv:2603.18153 (2026))
- **QCD phase transitions following NS mergers** (D. Blas et Al., Phys. Rev. Lett. 136, 101401)

Readout scheme

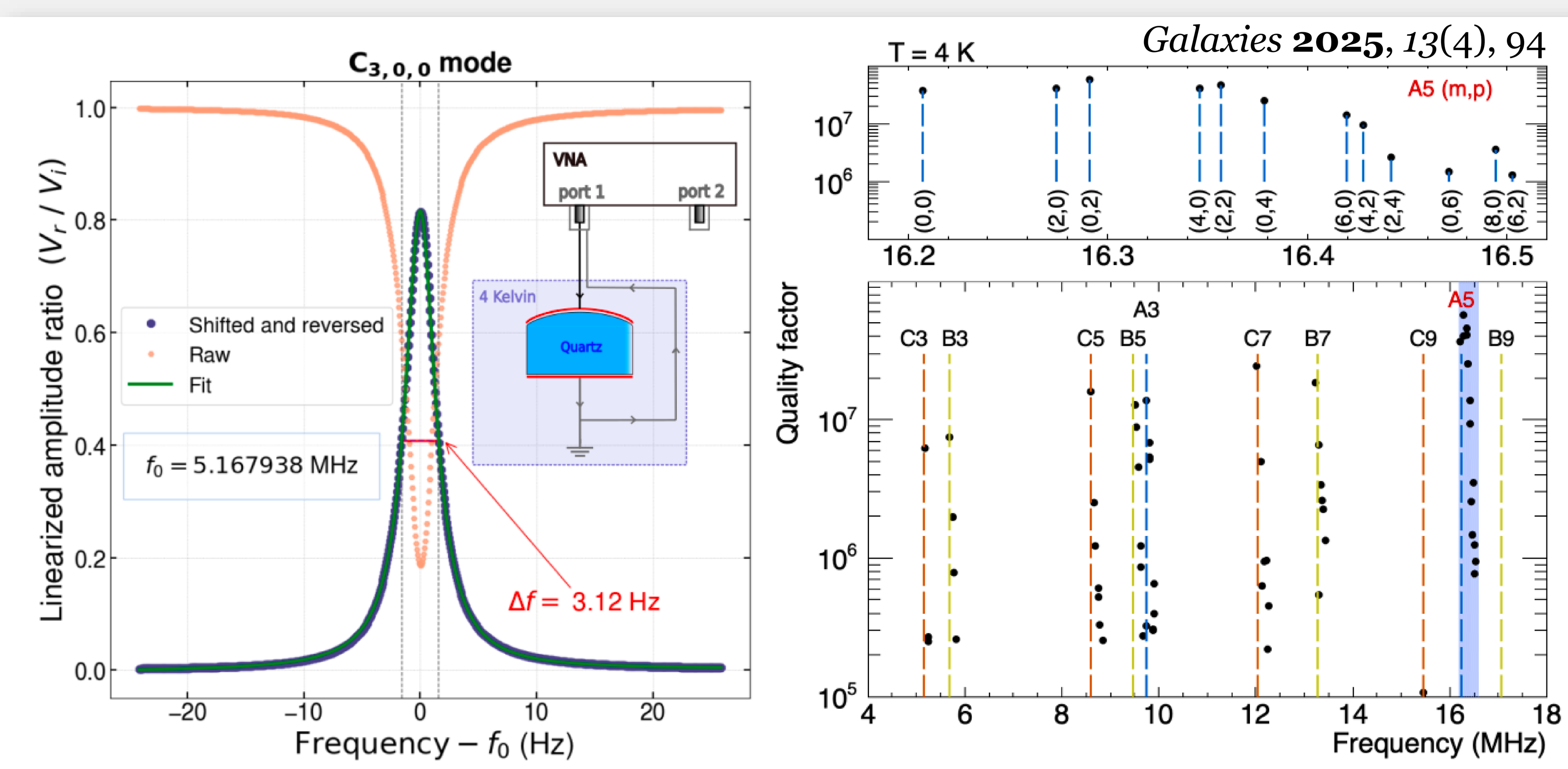


BAUSCIA dedicated dilution cryostat

Rakon Commercial Crystals for the BAUSCIA experiment

❖ Commercial crystals characterisation

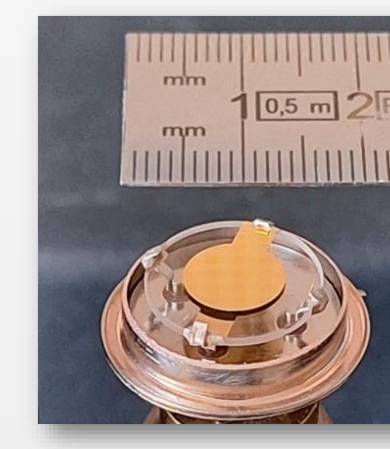
The resonator characterisation relies on impedance measurements performed through a calibrated Vector Network Analyzer (VNA). For example, the VNA can be coupled to the resonator in a reflection geometry, with one electrode connected to one port and the other to ground.
A typical resonance scan is shown. Resonators' quality factors are derived from the unfolding of the coupling coefficient and stand at 10^7 at T = 4K.

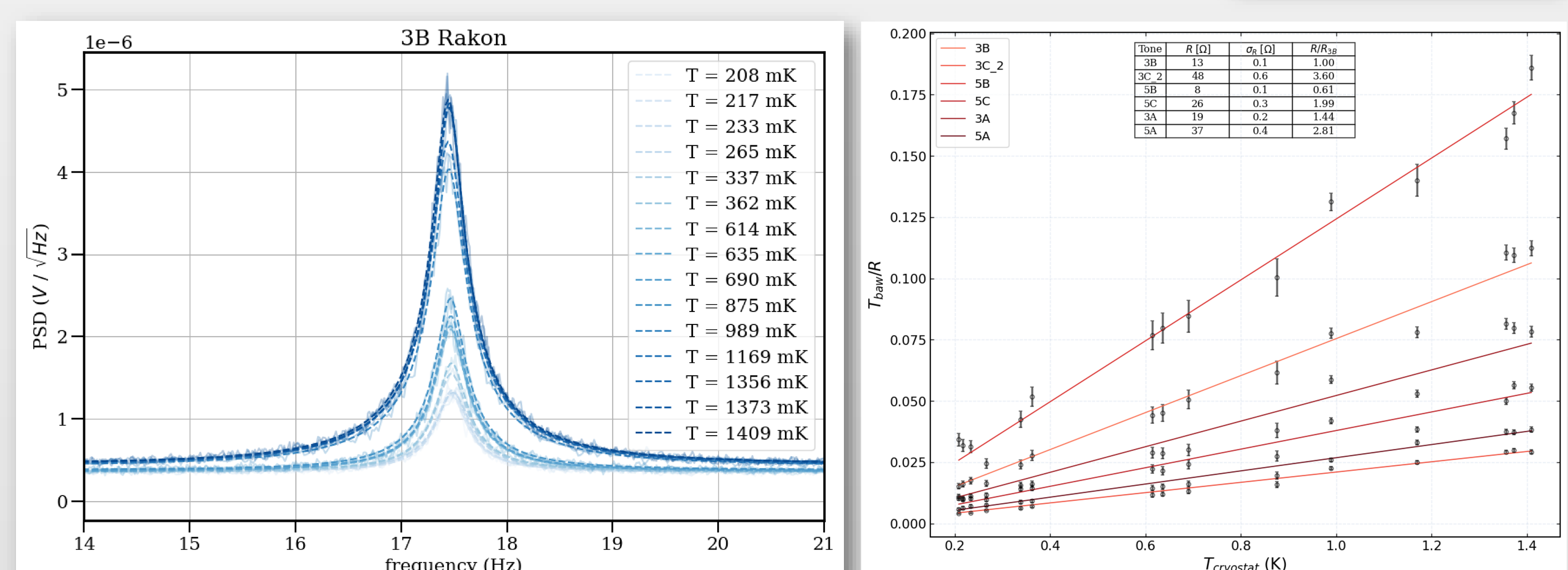


$$f_\lambda \sim n f_{\{X,1,0,0\}} + \frac{n-1}{2}(\Delta f_x + \Delta f_y) + m\Delta f_x + p\Delta f_y$$

❖ BAW modes thermal noise assessment

A study of BAW mode thermal noise has been performed. In the left panel below, a resonance mode temperature dependence is shown.
The mode temperatures have been measured by fitting the resonance profiles as a function of the cryostat plate temperature.
As shown in the bottom-right panel, the mode temperatures and the cold plate temperatures show a strong linear relationship.
The motional resistance values extrapolated from the linear fit are in good agreement with independent measurements.





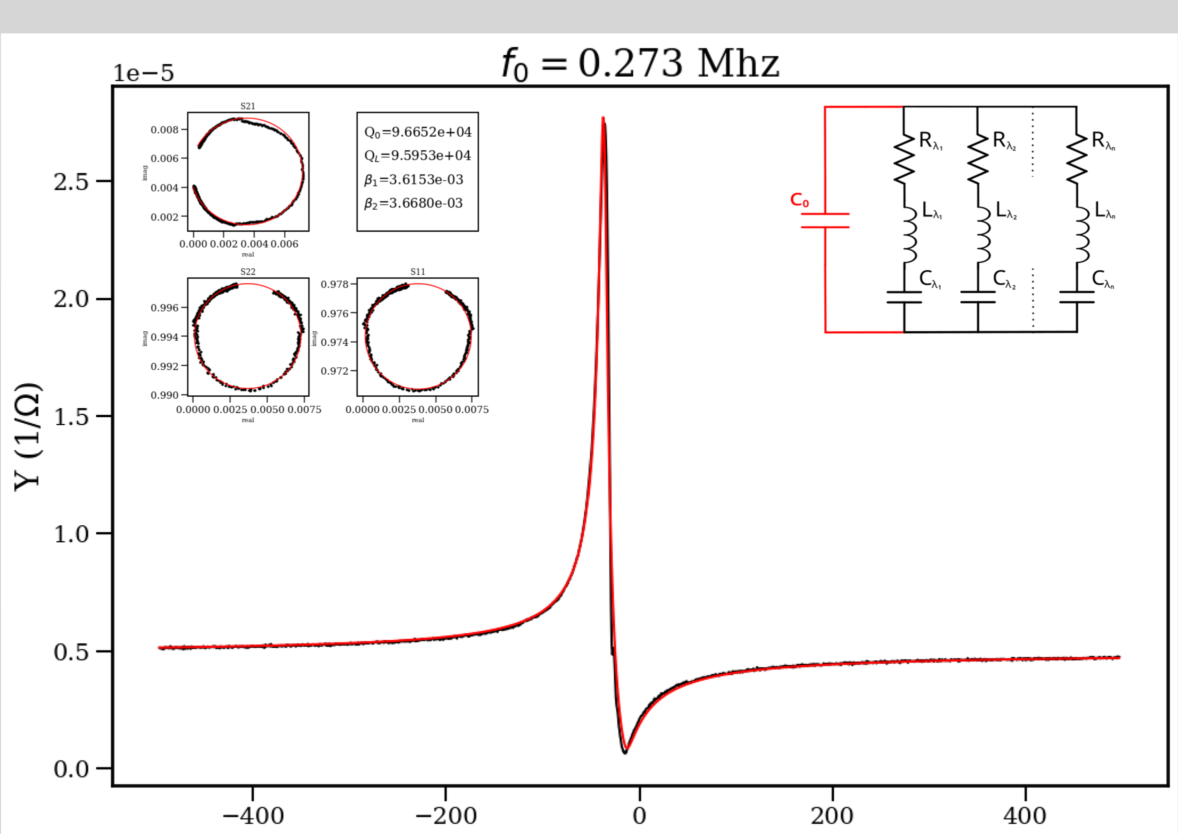
$$S_{vv}(\omega) \approx \frac{(M_{\rm in} G V_\Phi)^2\, 4K_b T R_\lambda}{\left|R_\lambda + j\left(\omega(L_\lambda + L_{\rm in}) - \frac{1}{\omega C_\lambda}\right)\right|^2}, \quad \text{for } \omega \ll 2\pi \times 200\text{MHz}$$

Ready for Data Taking!
(Summer 2026)

Custom Crystals R&D

❖ Room temperature characterisation

Two SC-cut quartz crystals with thicknesses of 9,13 mm were characterised at room temperature in vacuum via a transmission measurement performed with a VNA. A fit of every resonance was performed leveraging the Butterworth-Van Dyke electrical model in order to extract resonance parameters.

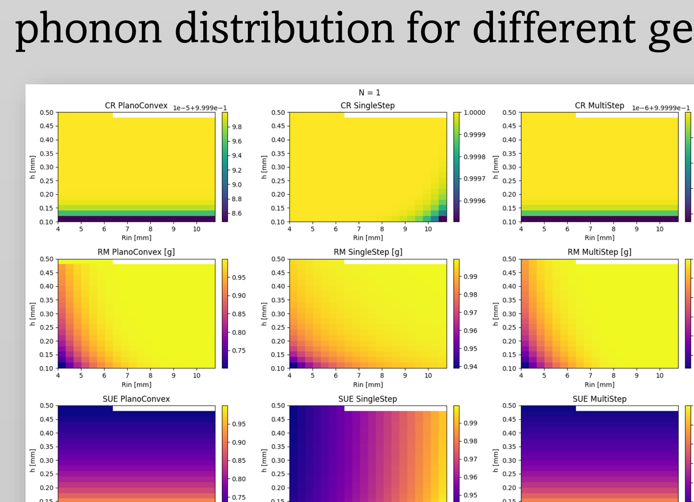


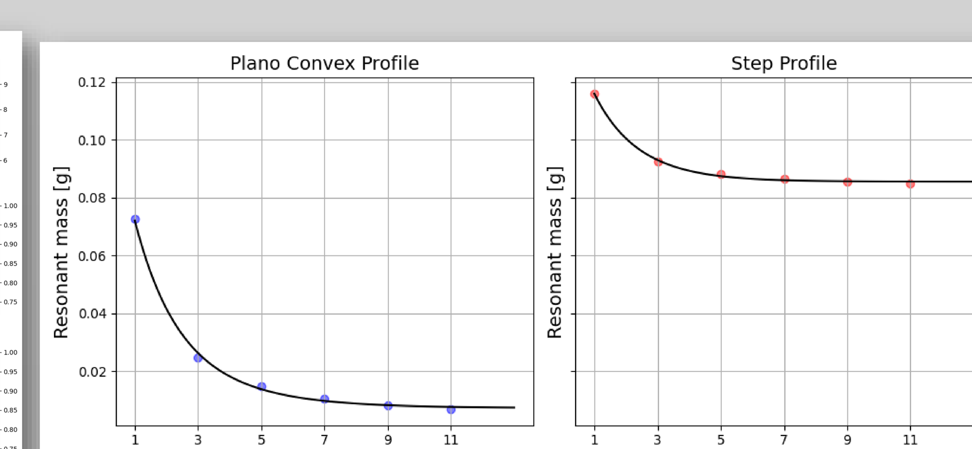
❖ Strain sensitivity optimisation

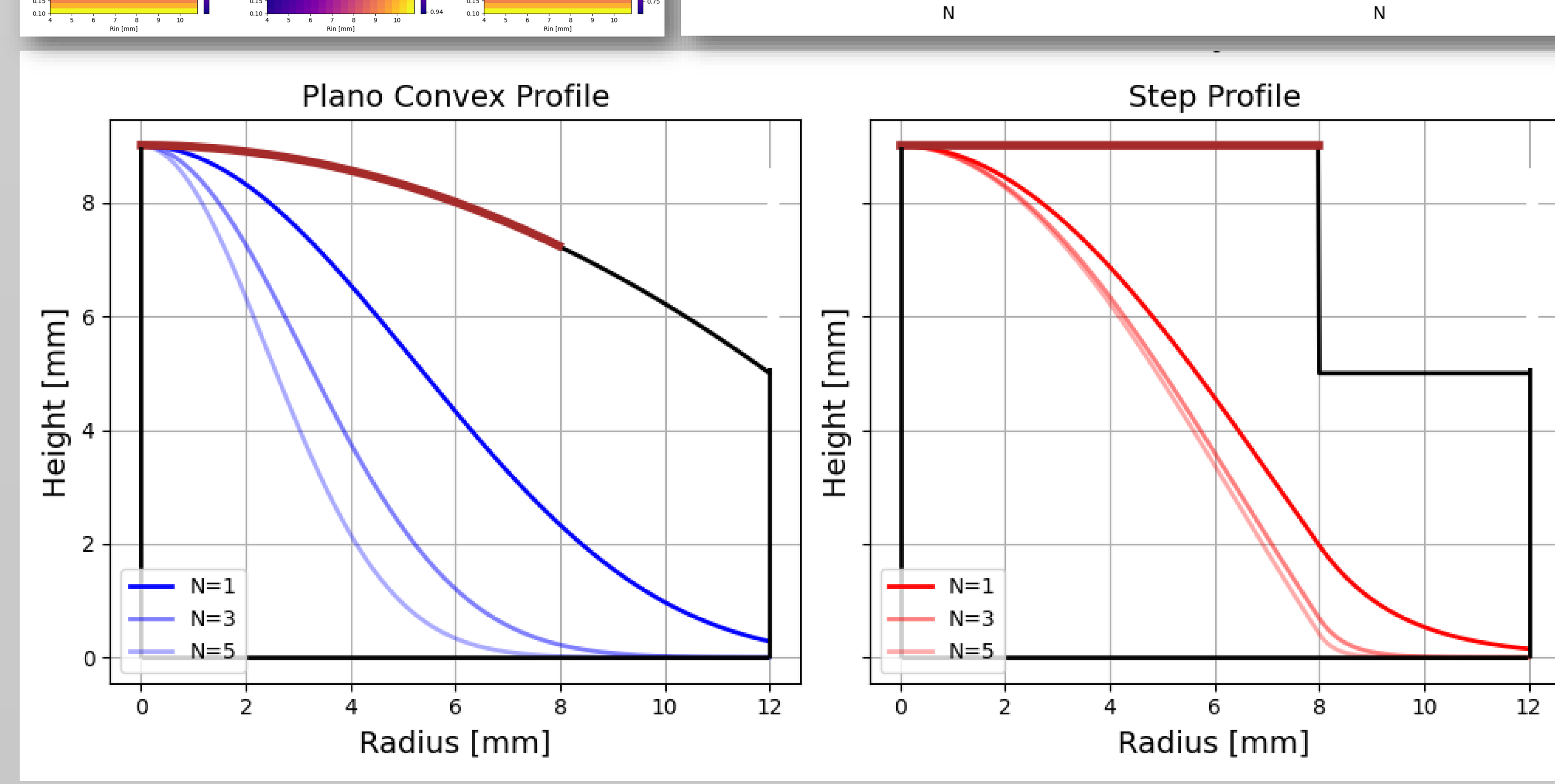
The crystal's top surface geometrical profile acts as a **potential barrier** which governs how well phonons are trapped inside the bulk of the crystal.

$$\frac{\partial^2 \boldsymbol{u}}{\partial t^2} \approx c_l^2\,\nabla(\nabla\cdot\boldsymbol{u}) - c_t^2\,\nabla\times\nabla\times\boldsymbol{u} \longrightarrow \delta f(r,\theta) = \left[-\frac{c_t^2}{2\omega_n^2}\nabla_\perp^2 + \frac{h\omega_n^2}{L_0}\Delta(r)\right] f(r,\theta)$$

By optimising the top surface geometrical properties, it is possible to trap phonons of the first overtone of the resonant modes, enhancing strain sensitivity.
Inspired by the work of T.Trickle (T. Trickle, Phys. Rev. D **112**, 055043, 2025), we have numerically solved the acousto-elastic wave equation, gaining knowledge on the phonon distribution for different geometrical cuts.







Outlook and future prospects for BAUSCIA