Bulk Acoustic Wave cavities for high-frequency gravitational wave antennas

G. Albani[1], M. Borghesi[1,2,3], L. Canonica[1,2], R. Carobene[1,2,3], F De Guio[1,2], M. Faverzani[1,2,3], E. Ferri[2], R. Gerosa[1,2], A. Ghezzi[1,2] A. Giachero[1,2,3], M. Malberti[2], A. Nucciotti[1,2,3], G. Pessina[2], D. Rozza[1], T. Tabarelli de Fatis[1,2]

[1]*University of Milano - Bicocca*, Milan, Italy; [2]*INFN Milano - Bicocca*, Milan, Italy; [3]*Bicocca Quantum Technologies (BiQuTe) Centre*, Milan, Italy

Frontier Detectors for Frontier Physics

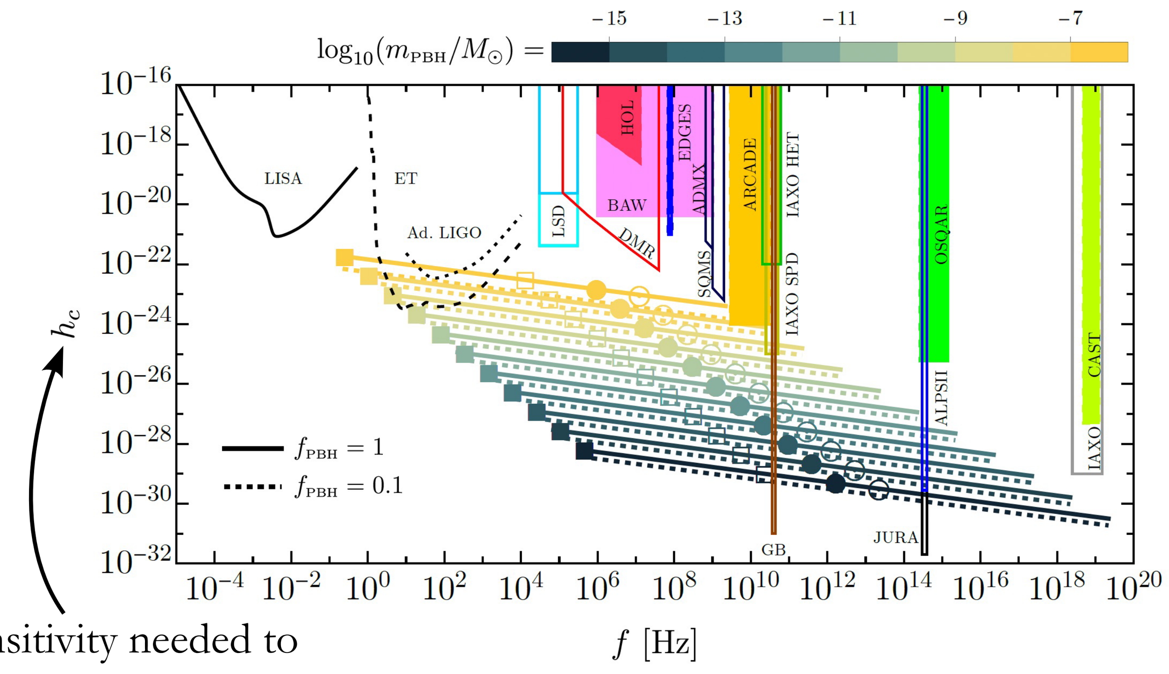
High-frequency gravitational wave (GW) detection based on a cryogenic bulk acoustic wave (BAW) cavity coupled to a superconducting quantum interference device (SQUID) has been under investigation at the University of Western Australia for several years. A recent paper reported the observation of rare events of uncertain origin using the first antenna of this type. In this report, we describe the work towards the construction of a similar GW antenna at the University of Milano Bicocca, including the characterisation of commercially available BAWs and plans to tailor the BAWs to sample multiple frequencies from about 0.5 MHz to a few tens of 1 MHz. Potential GW sources in this range include scenarios involving dark matter candidates such as primordial black hole binaries and axion-black hole interactions.

Physics case

Why searching for High Frequency Gravitational Waves?

- f_{GW} limited so far at ~ 10 kHz (spectrometers)
- exploration of other frequency ranges
- search for other sources of GW ⟶ dark matter candidates
  - Primordial black holes
  - axion annihilation (black hole superradiance)

as a bonus: direct detection of axions with same devices



sensitivity needed to detect 1 event/yr

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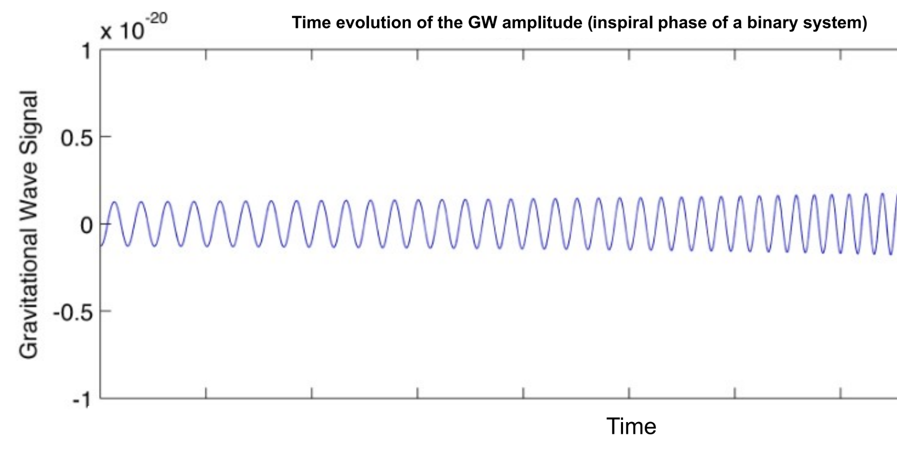
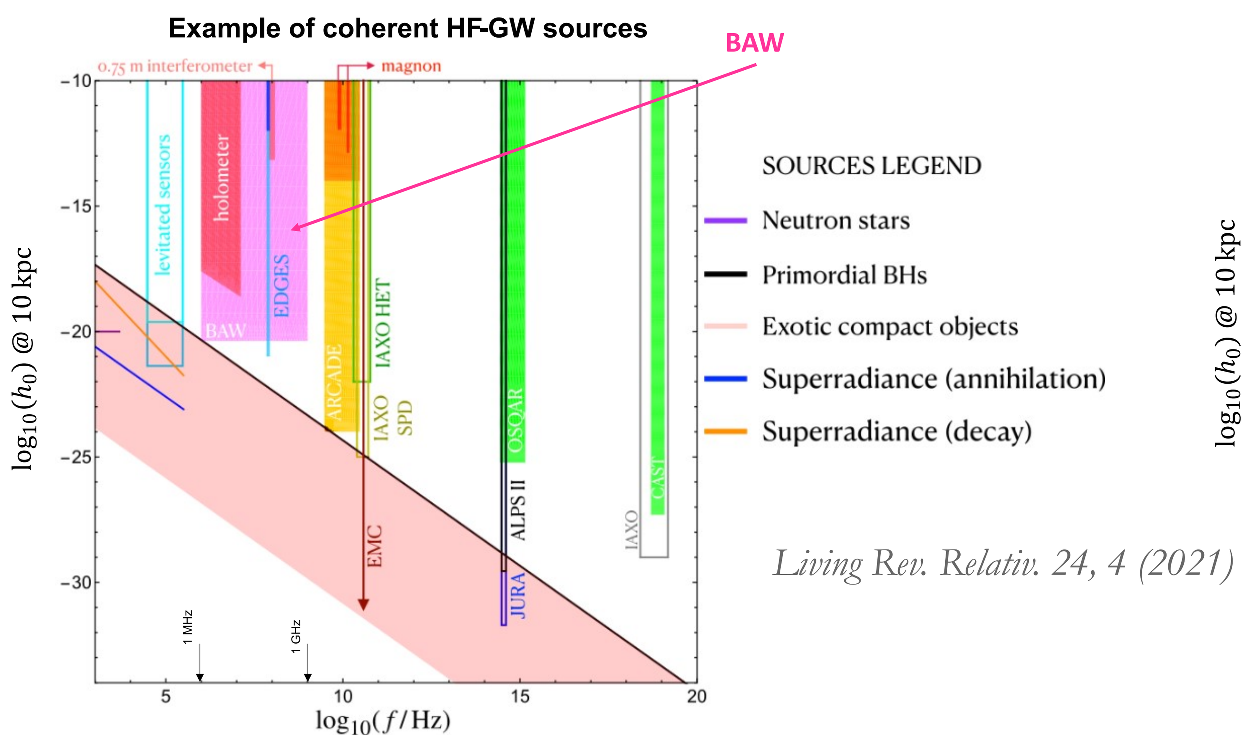


$$S_h^+(\omega = \omega_\lambda) = \sqrt{\frac{4\, k_b T_\lambda \omega_\lambda}{Q_\lambda M_\lambda}} \left(\frac{1}{\omega_\lambda^2 (\Delta s/2) \Xi_\lambda} \right)$$



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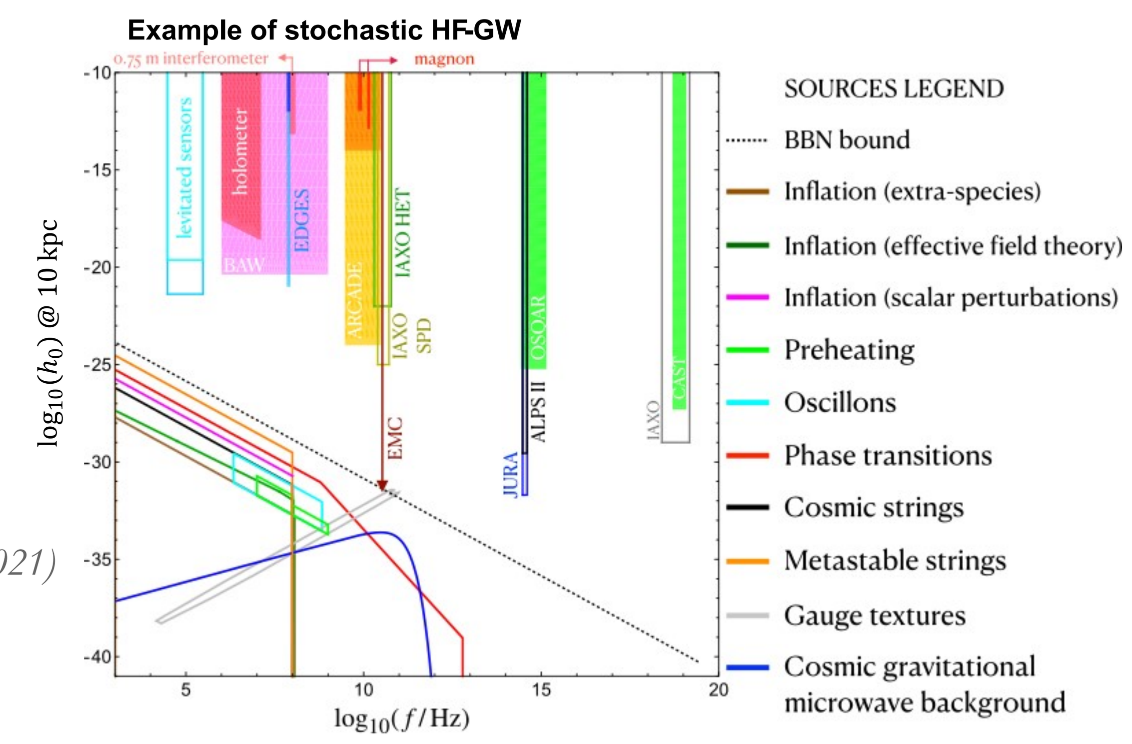
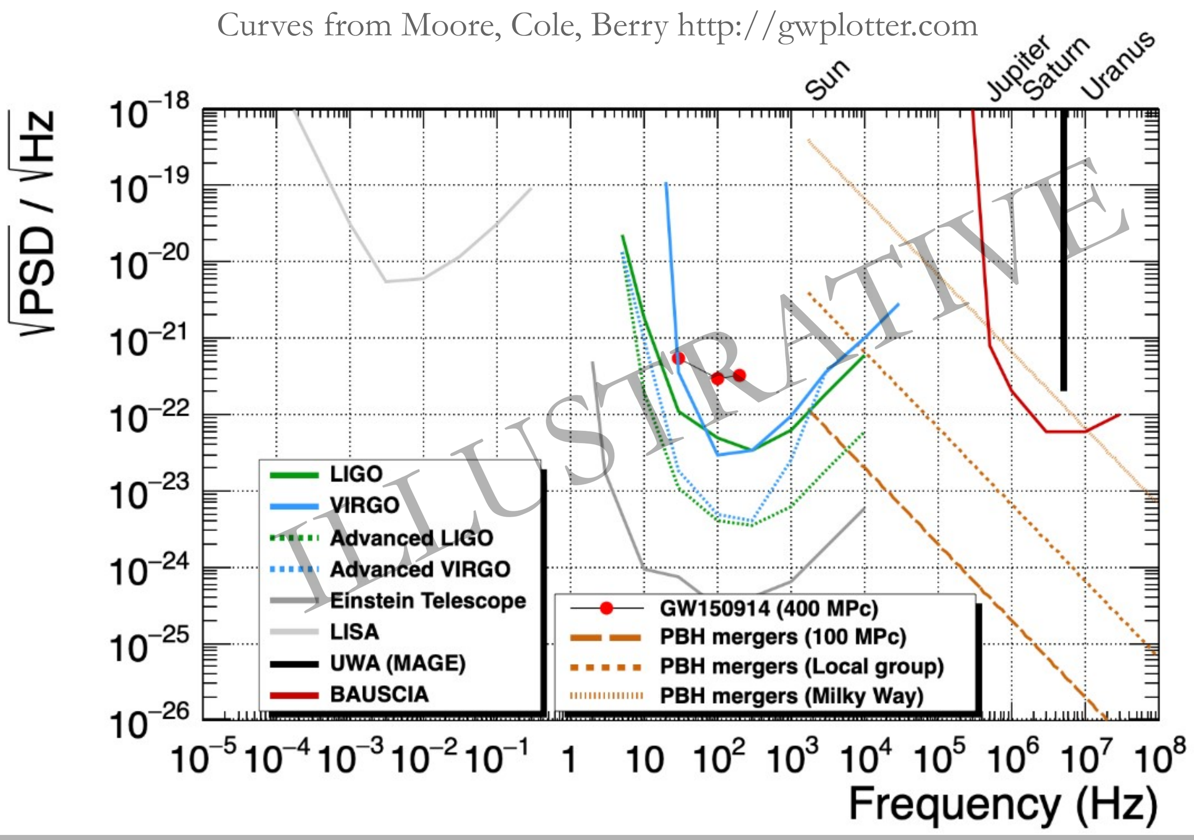


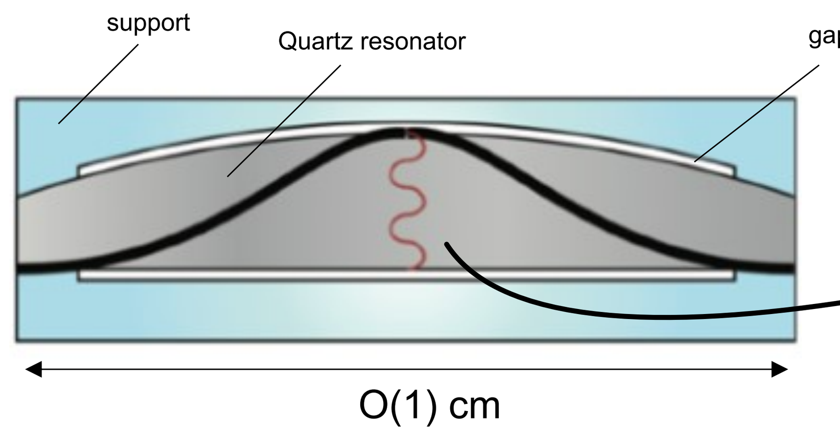
Curves from Moore, Cole, Berry http://gwplotter.com

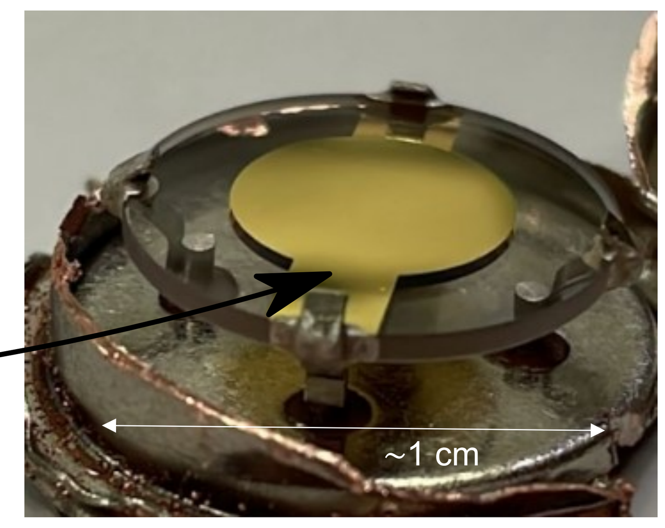


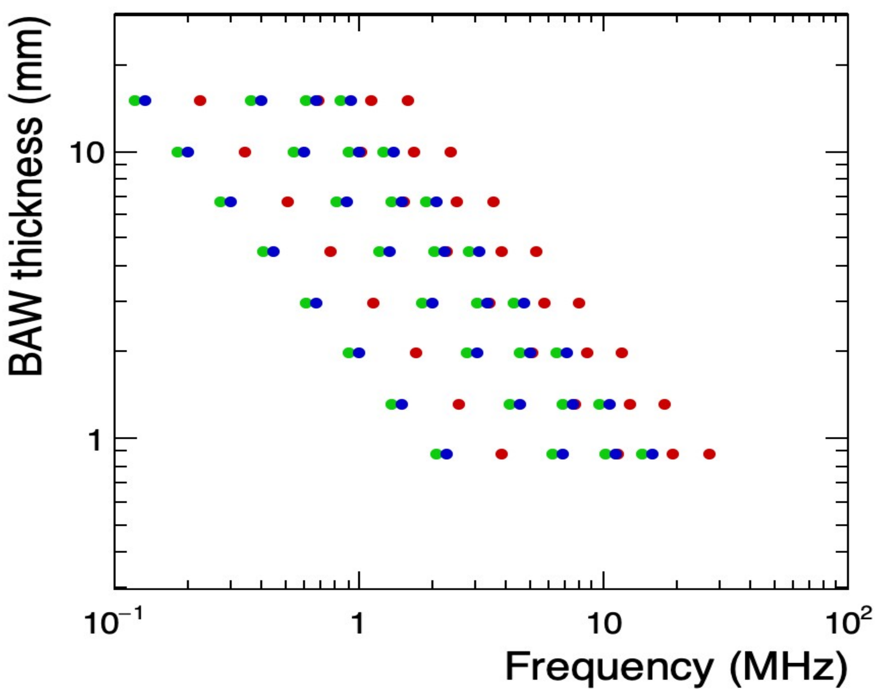
Bauscia

Concept: probe the ~(0.1 - 20 MHz) frequency range with Bulk Acoustic Wave (BAW) resonators

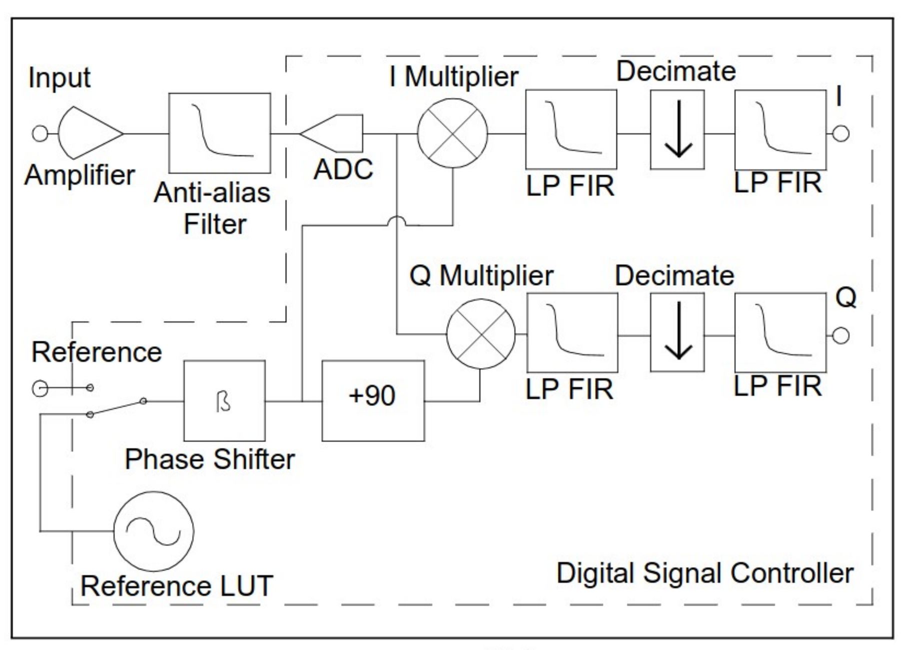
- each resonator has three oscillation modes (1 longitudinal + 2 transverse)
- the oscillation is transduced in electrical signal by piezoelectric effect
- each mode has multiple harminics (only the odd ones are visible due to the piezoelectric effects)
- high quality factors Q ⟶ the signal survives for a long time before decaying
- devices scalable ⟶ with just 8 resonators the entire rage of frequency can be covered

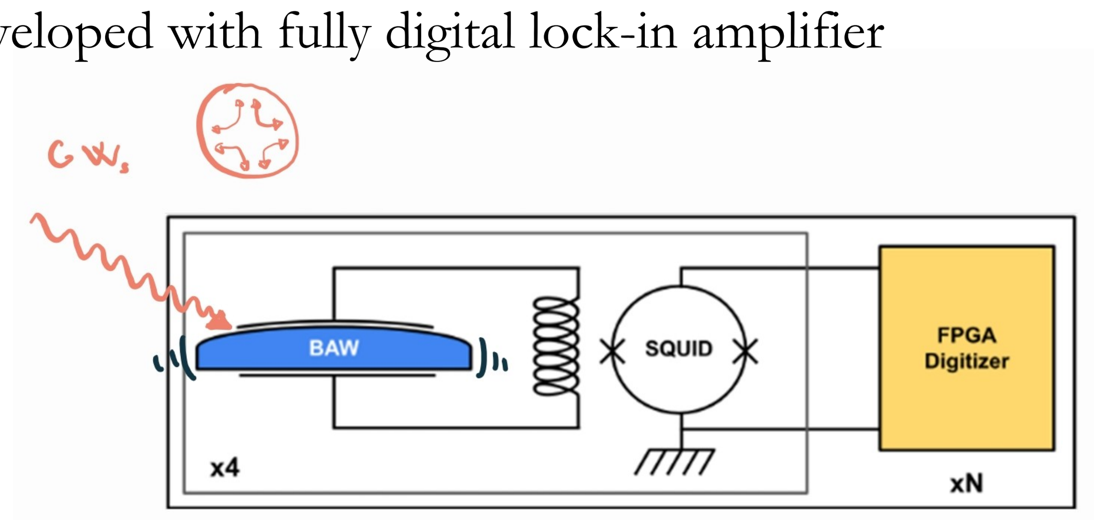






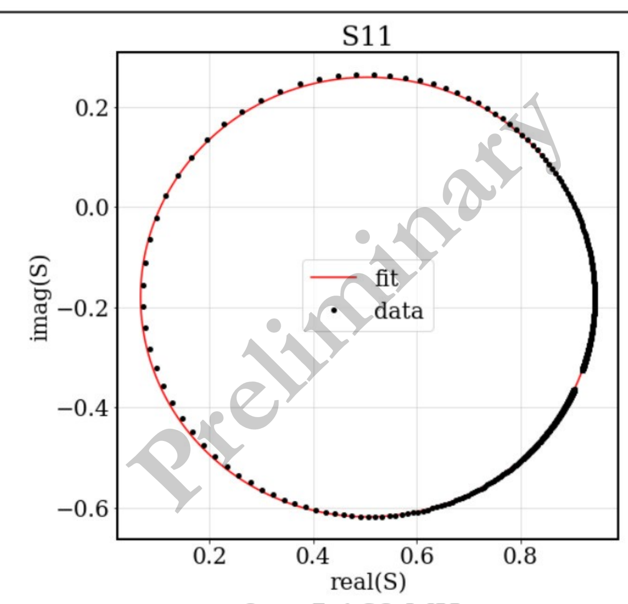
Multiplexing being developed with fully digital lock-in amplifier





- tested with a RFSoC4x2 by Xilinx
- flexible firmware: both with trigger and in continous mode

characterization of commercially available BAWs in progress

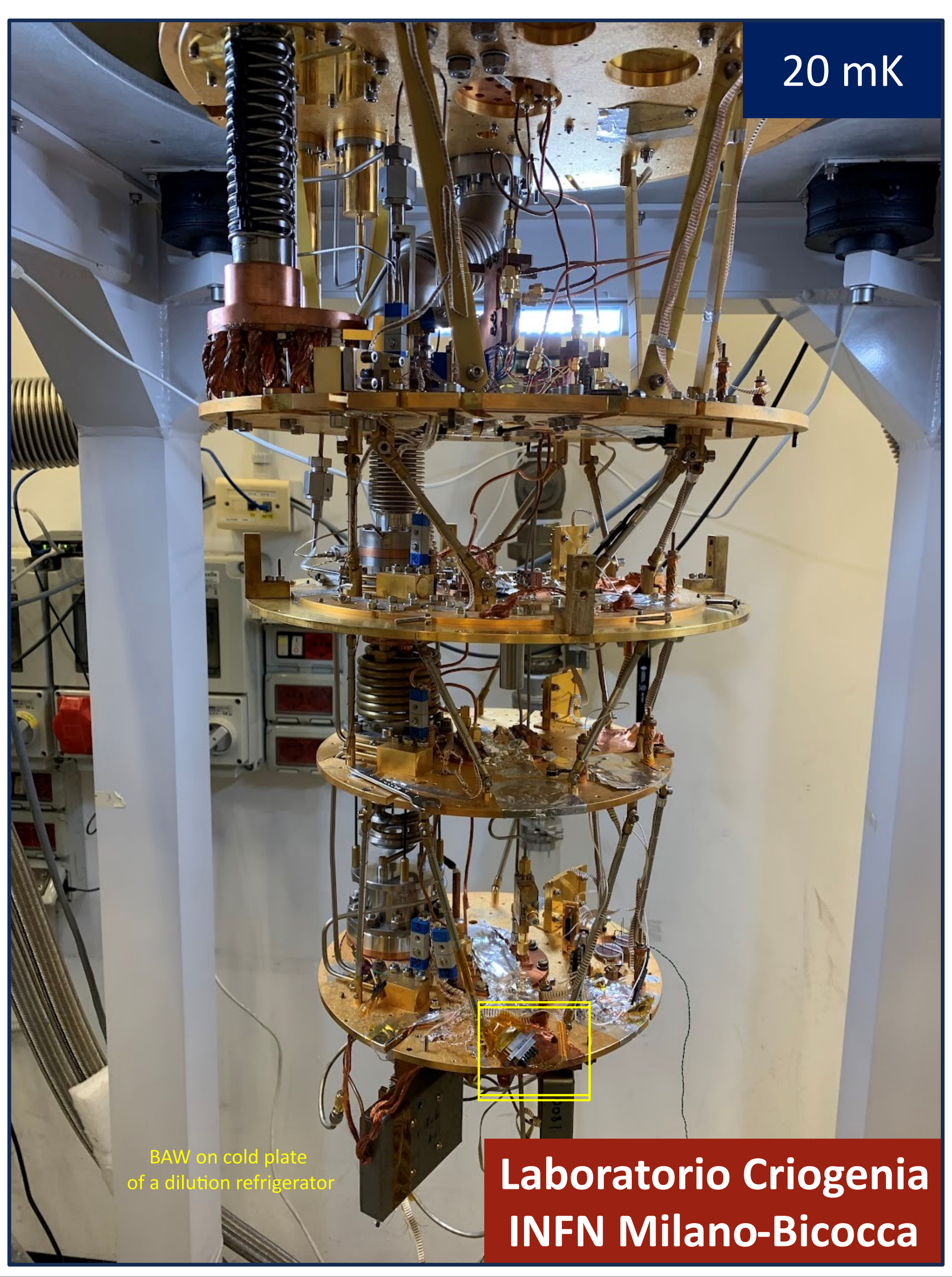


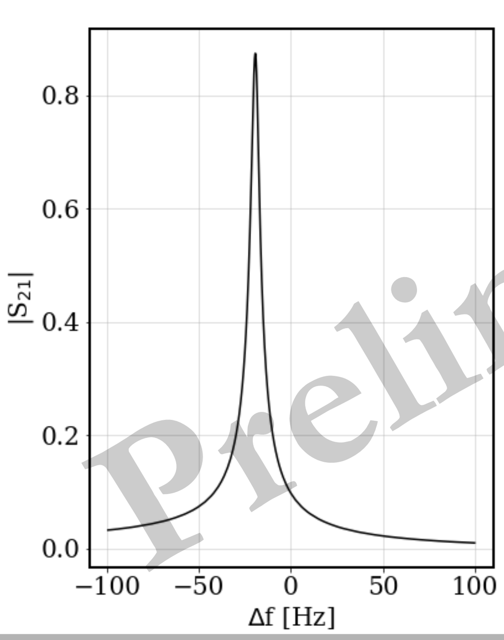
f_0 = 5.168 MHz

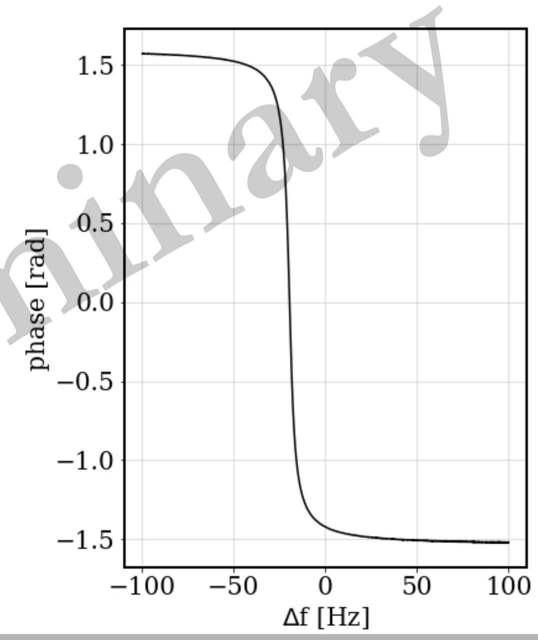
several contributions to Q:

- phonon-tunneling though electrodes, supports, etc.
- thermoelastic dissipation from compression/decompression
- scatter on surfaces roughness and impurities
- Two-Level-Systems (TLS)
- phonon-phonon scattering

design/quality (first three); temperature-dependent (last two)







Q_0 (unloaded) measured with Network Analyzer

max Q_0 measured ~ 3x10^7 at low temperature