Mechanical Quality Factor of

1. Beryllium cylinder
2. CuAl6% sphere

as function of temperature
for gravitational wave experiments

By Amy Shumack

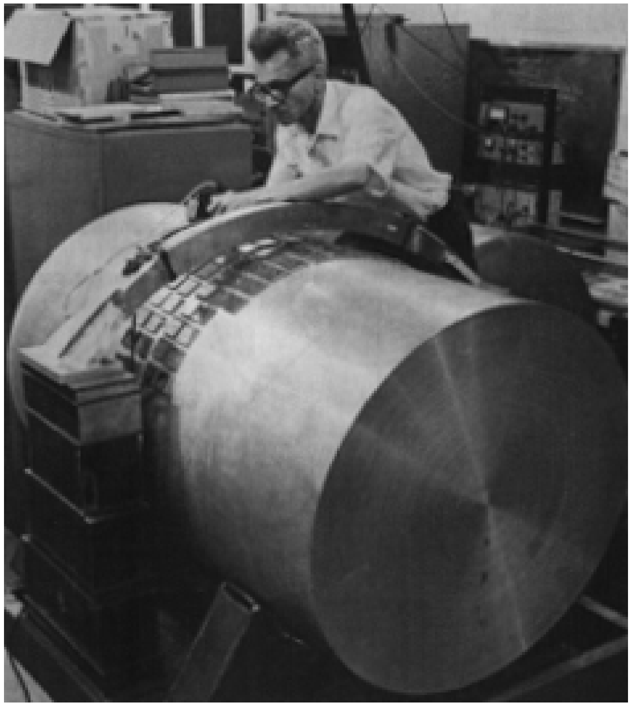
The four generations of resonant gravitational wave detectors

1. Room temperature bar antennas

2. Cryogenic bar antennas

3. Ultra-cryogenic bar antennas

4. Spherical ultra-cryogenic antennas



"Explorer"
(CERN, Switzerland)
- Cryogenic antenna (2.6K)
- Al5056 bar
- Measuring since 1989
- Sensitivity: $h = 6*10^{-19}$

(with a bandwidth of 0.5hz)

John Weber
- Room temp. antenna
- aluminium bar
- constructed 1966
- Sensitivity: $h \sim 10^{-16}$

h is sensitivity for SNR=1 of a burst signal of ~1ms

“Minigrail” (Leiden)
- Spherical ultra-cryogenic antenna (20mK)
- CuAl6% sphere
- Measuring in 2003?
- Expected sensitivity: $h = 4*10^{-21}$ (assuming quantum limited squid)
- Bandwidth: 230Hz

“Nautilus” (Frascati, Italy)
- Ultra-cryogenic antenna (0.1K)
- Al5056 bar
- Measuring since 1994
- Sensitivity: $h = 3*10^{-19}$ (with a bandwidth of 0.5Hz)

Energy Cross-section

$$\sigma = \lambda \frac{G}{c^3} M v^2$$

M – Mass of detector

– Sound velocity in antenna material

$G = 6.6*10^{-11}$

$c = 3.0*10^{8}$

is 2.98 for the fundamental spherical quadrupole mode of a sphere

$$\sigma = 7.28 \cdot 10^{-36} \cdot M\nu^2$$

for spherical detector

Normalised cross-section calculated for a sphere with resonant frequency of 3kHz

Material	Density ( )	SoundVelocity ($_{sound}$)	Normalised cross-section (at 3kHz) [= M ^{2}]
Beryllium	1800 kg/m^3	**13000 m/s**	**53.9**
CuAl6%	8000 kg/m^3	4000 m/s	0.66
Al5056	2700 kg/m^3	5400 m/s	1

EFFECTIVE TEMPERATURE (T_{eff})

Minimum energy detectable by an antenna

$$E_{\min} = k_B T_{eff}$$

Effective temperature

$$T_{eff} = 2\sqrt{2}T_N \left(1 + \frac{2T}{\beta Q T_N}\right)^{\frac{1}{2}}$$

$$\frac{2T}{\beta Q T_N} < 1$$

$$Q > \frac{2T}{\beta T_N}$$

$$Q > 1.3 \cdot 10^6$$

T_N - Noise of squid → $1.5 \cdot 10^{-7} K$ → For quantum limited squid at 3.1kHz :

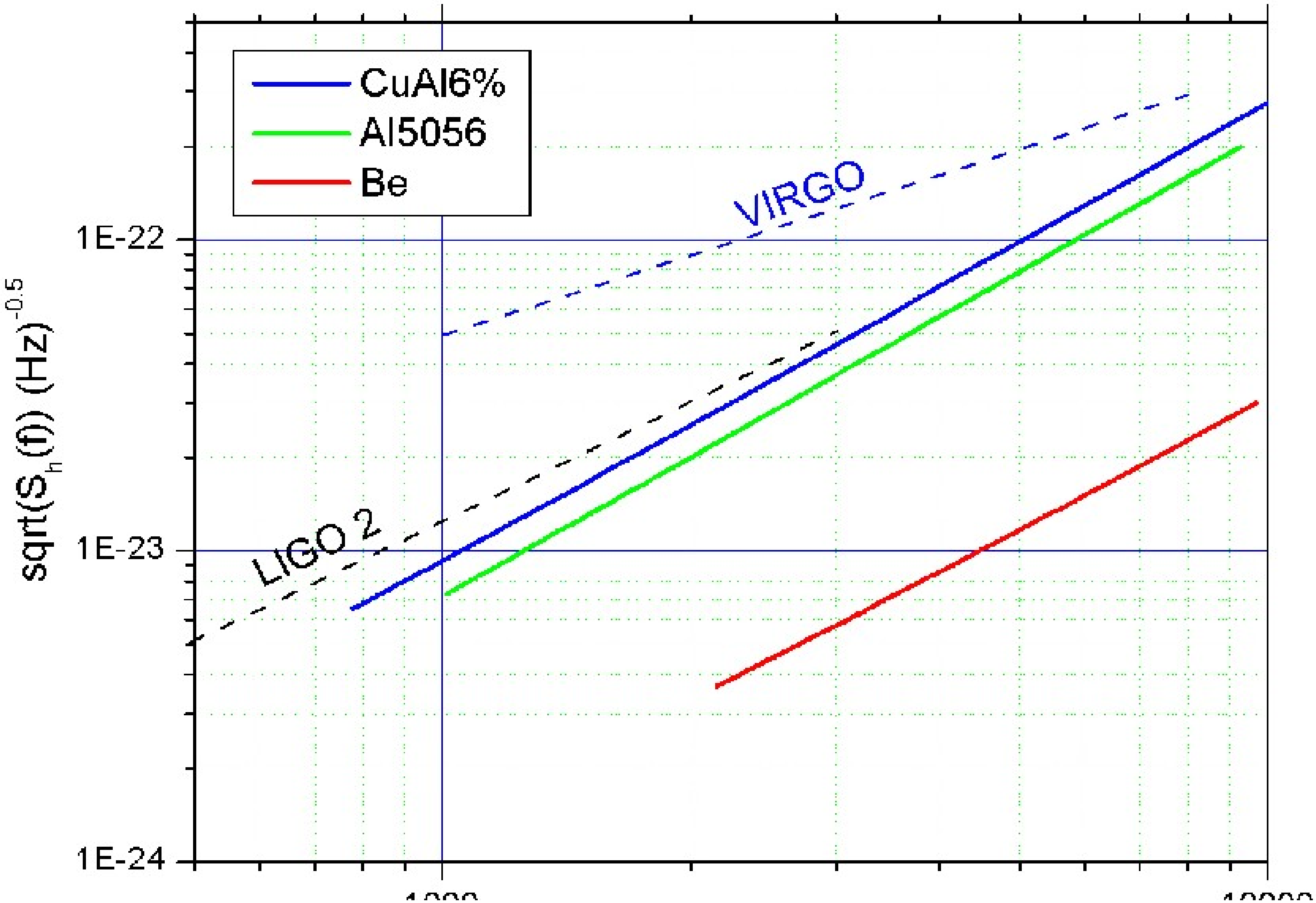
$$k_B T_N = 1 \cdot h\upsilon$$

Q – Mechanical quality factor

T – Thermodynamic temperature → $10mK$

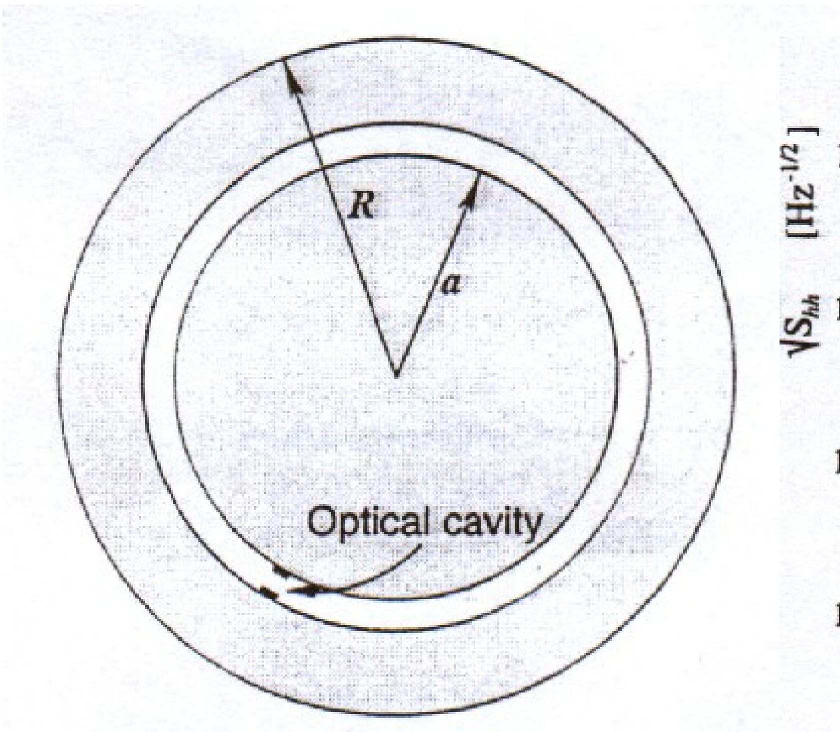
– Fraction of energy transferred from antenna to squid. → 0.1

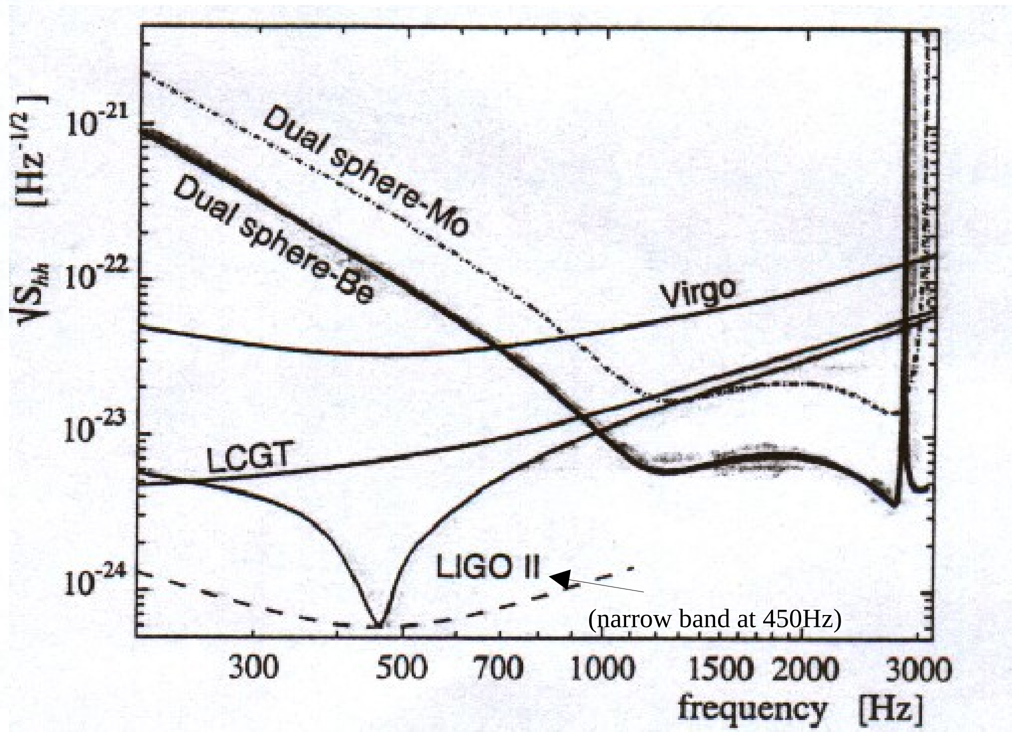
Spectral sensitivity as a function of frequency



Wideband Dual Sphere Detector of Gravitational Waves

M. Cerdonio, L. Conti, J.A. Lobo, A. Ortolan, L. Taffarello, and J.P. Zendri





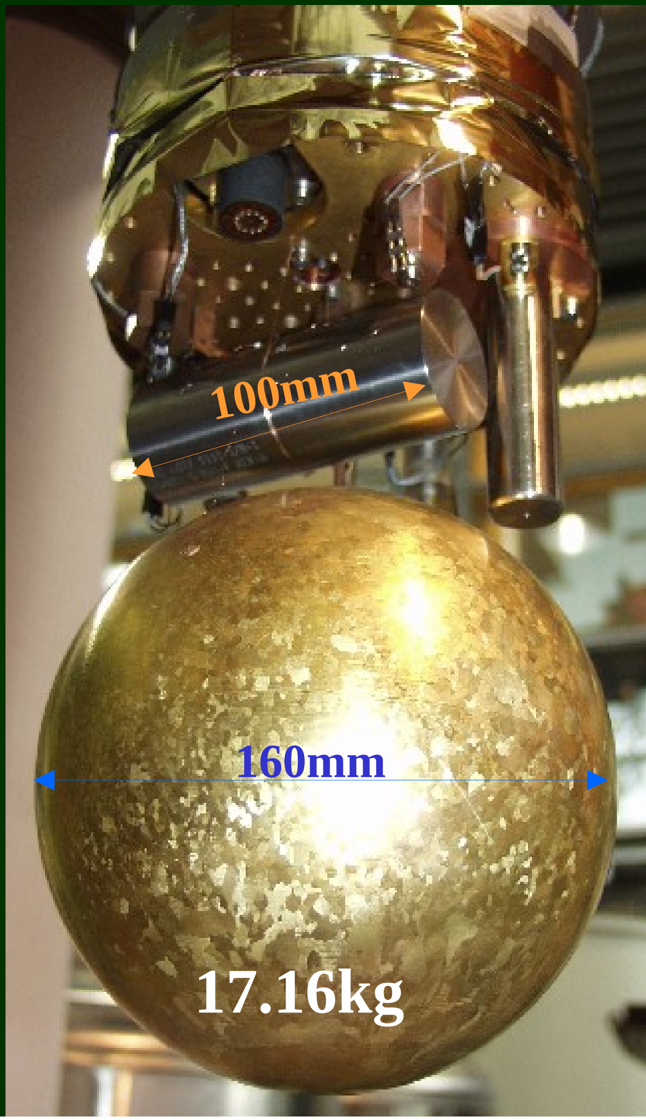
Material: Beryllium

R = 0.95

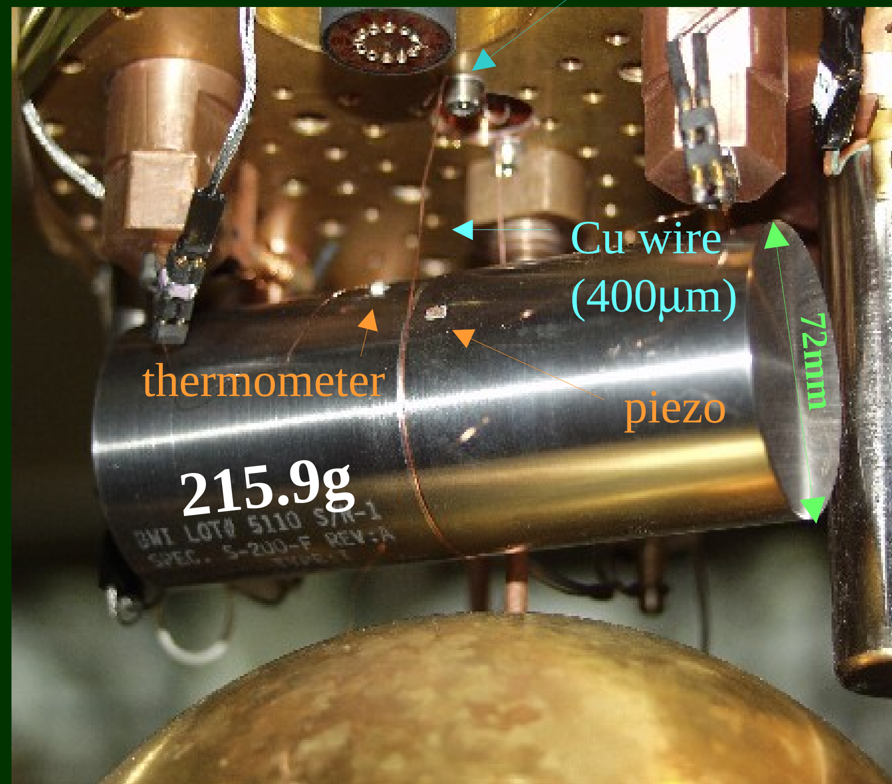
Assuming that:

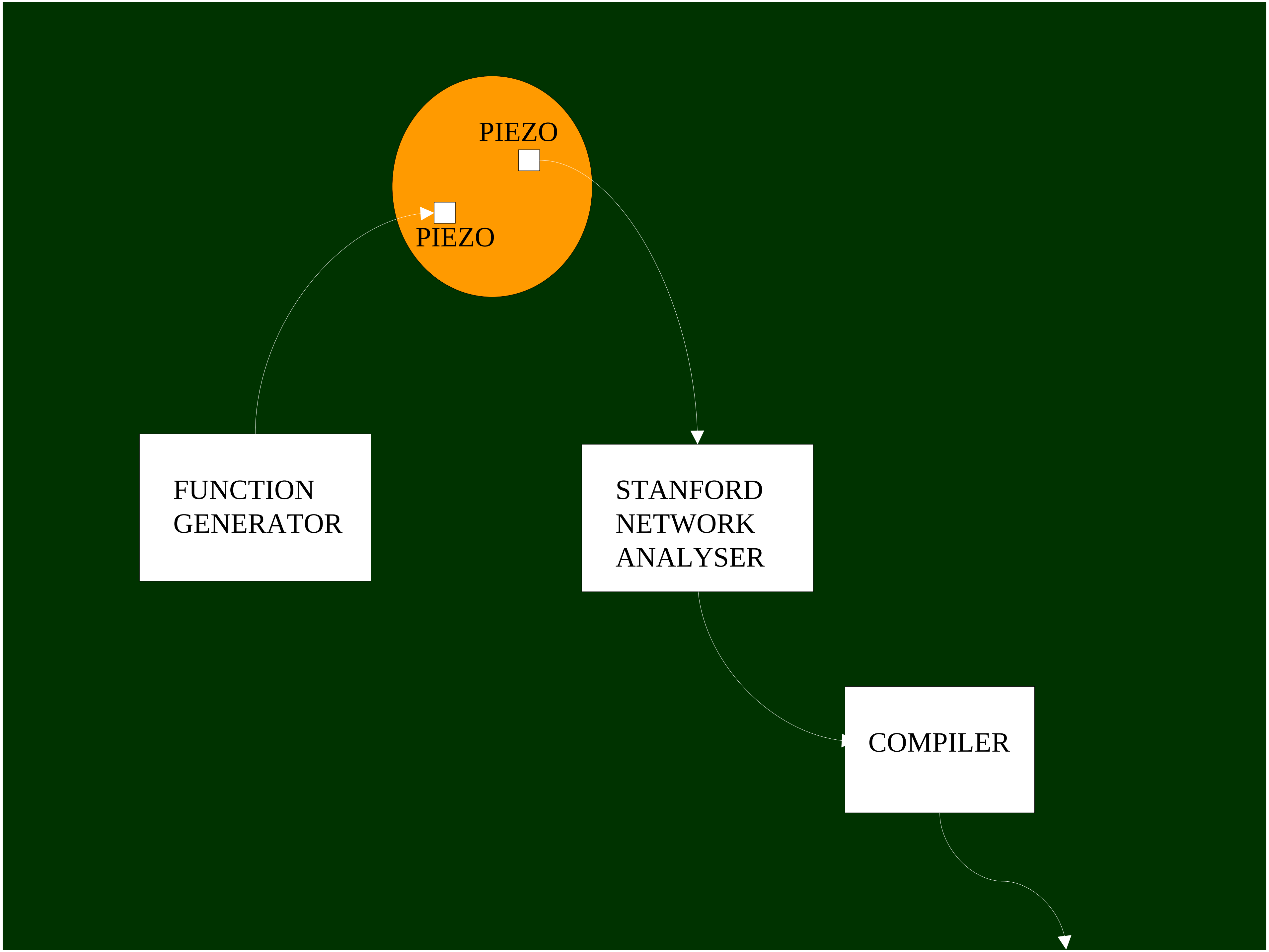
$$\frac{Q}{T} \geq 2 \cdot 10^{8} K^{-1} \quad \xrightarrow{\text{At 10mK}} \quad Q \geq 2 \cdot 10^{6}$$

Experimental Set-up of Low Temperature Q-factor Measurements

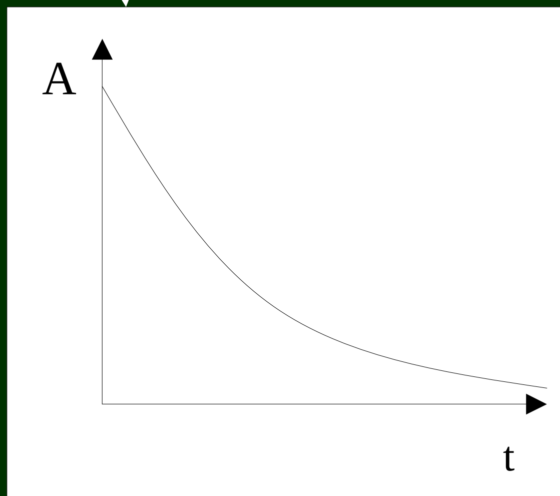


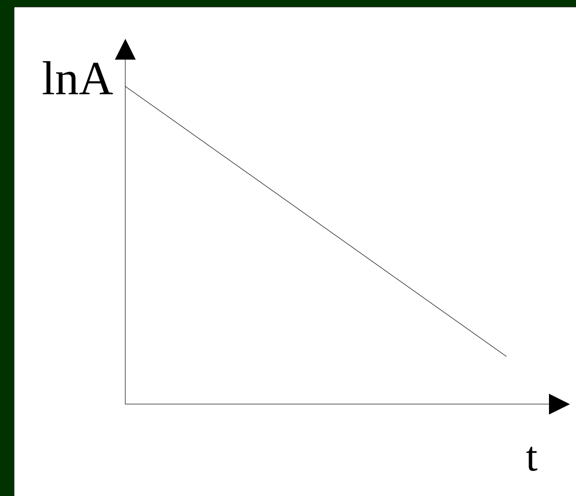
Thermal anchoring to cold plate of mixing chamber




PIEZO
PIEZO
FUNCTION GENERATOR
STANFORD NETWORK ANALYSER
COMPILER

Calculation of τ and Q





$$A = A_0 e^{-\frac{t}{\tau}}$$

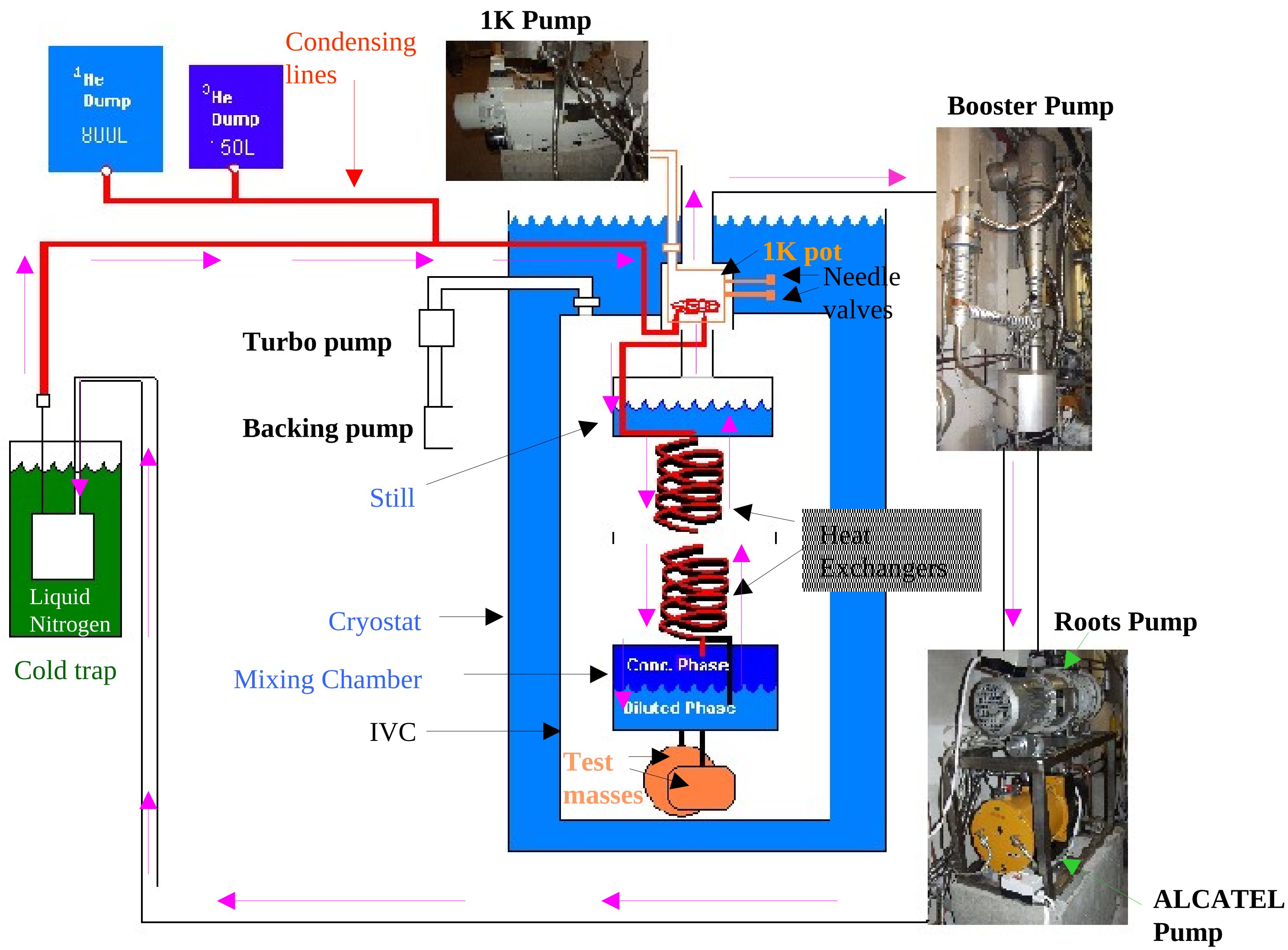
$$\ln A = \ln A_0 - \frac{t}{\tau}$$

$$Q = \pi \upsilon \tau$$

= resonant frequency

= relaxation time

Set-up for cooling



THE DILUTION REFRIGERATOR

Still

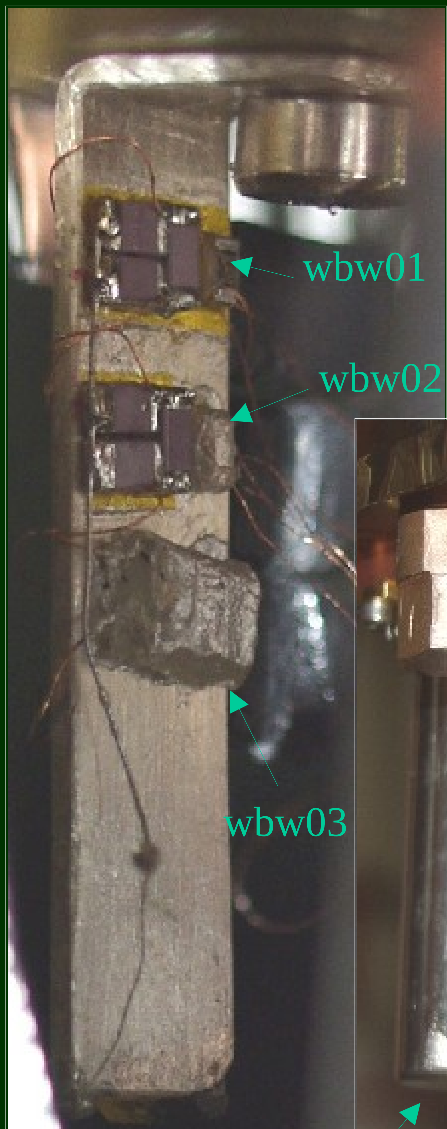
Continuous heat exchangers

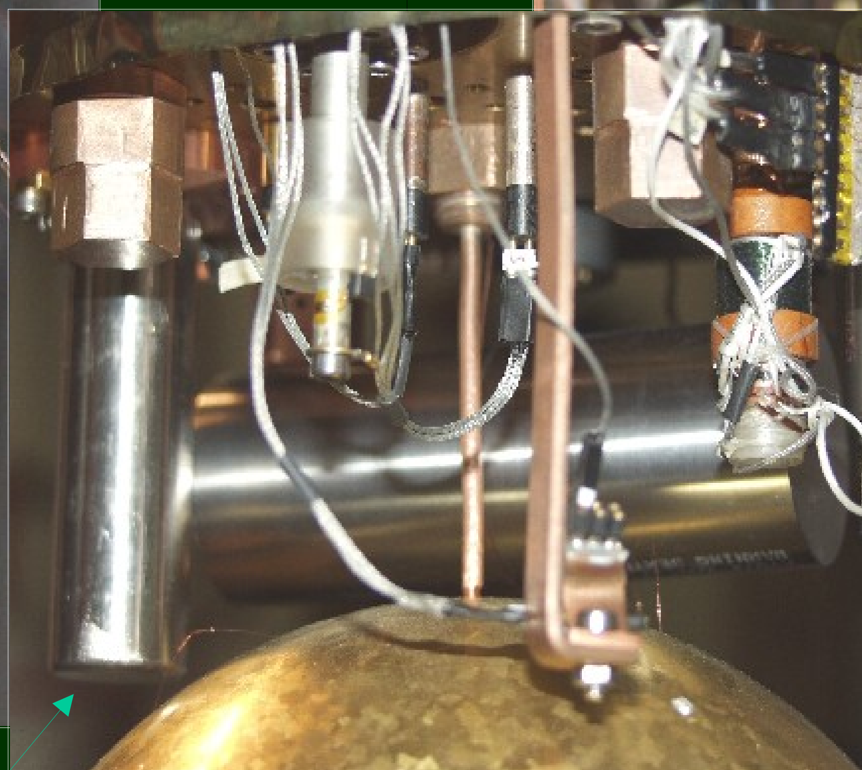
50mK plate

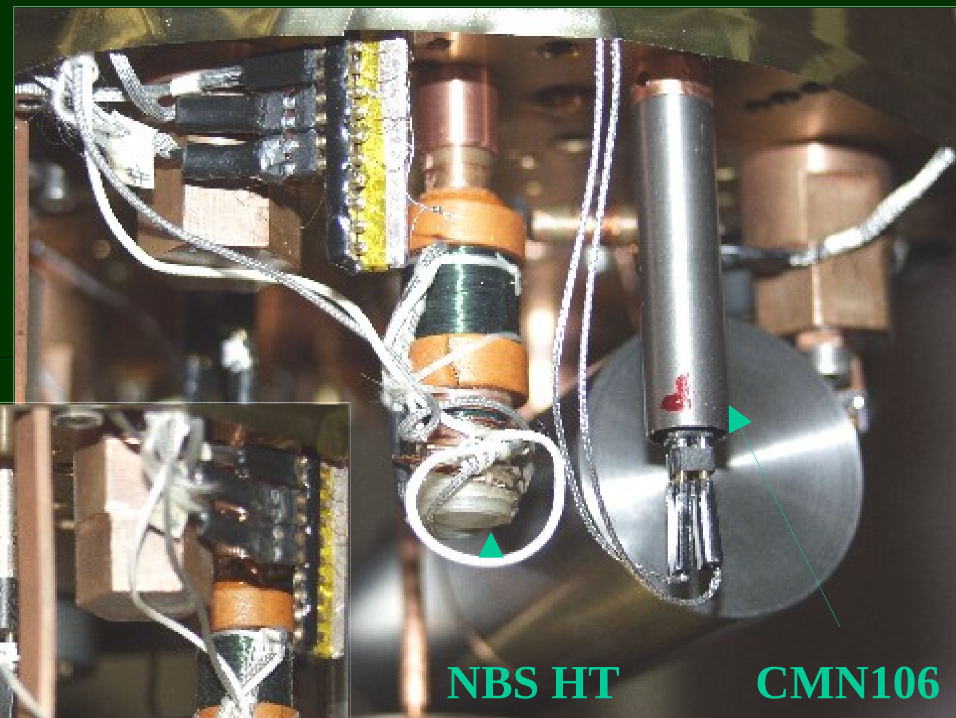
Sintered heat exchangers

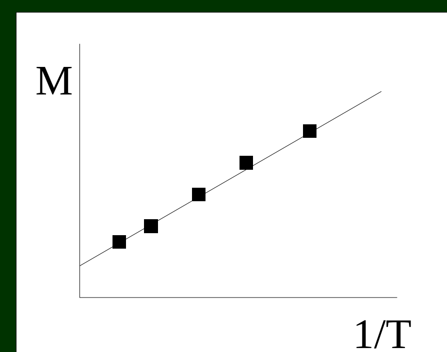
Mixing chamber

THERMOMOMETRY

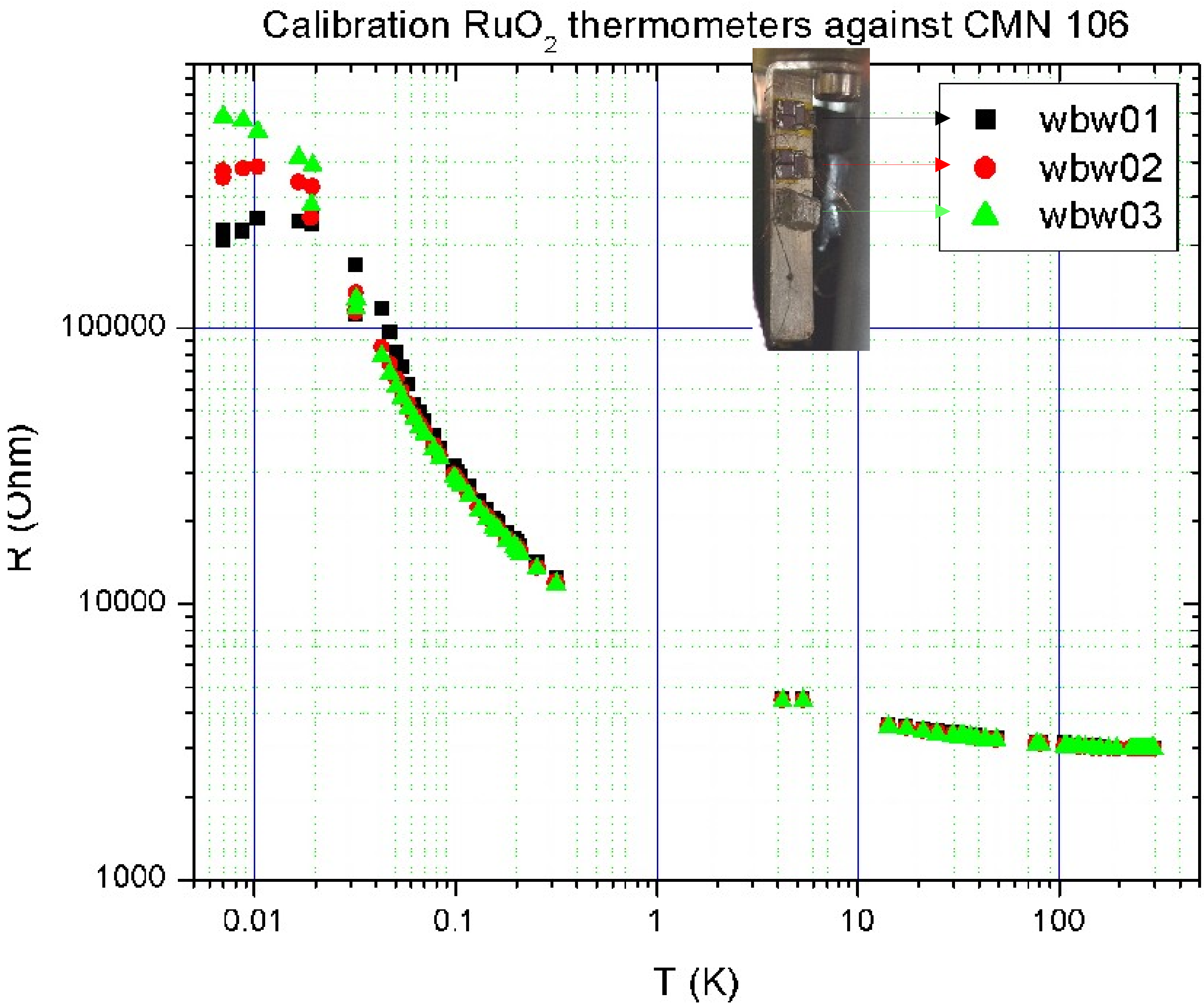




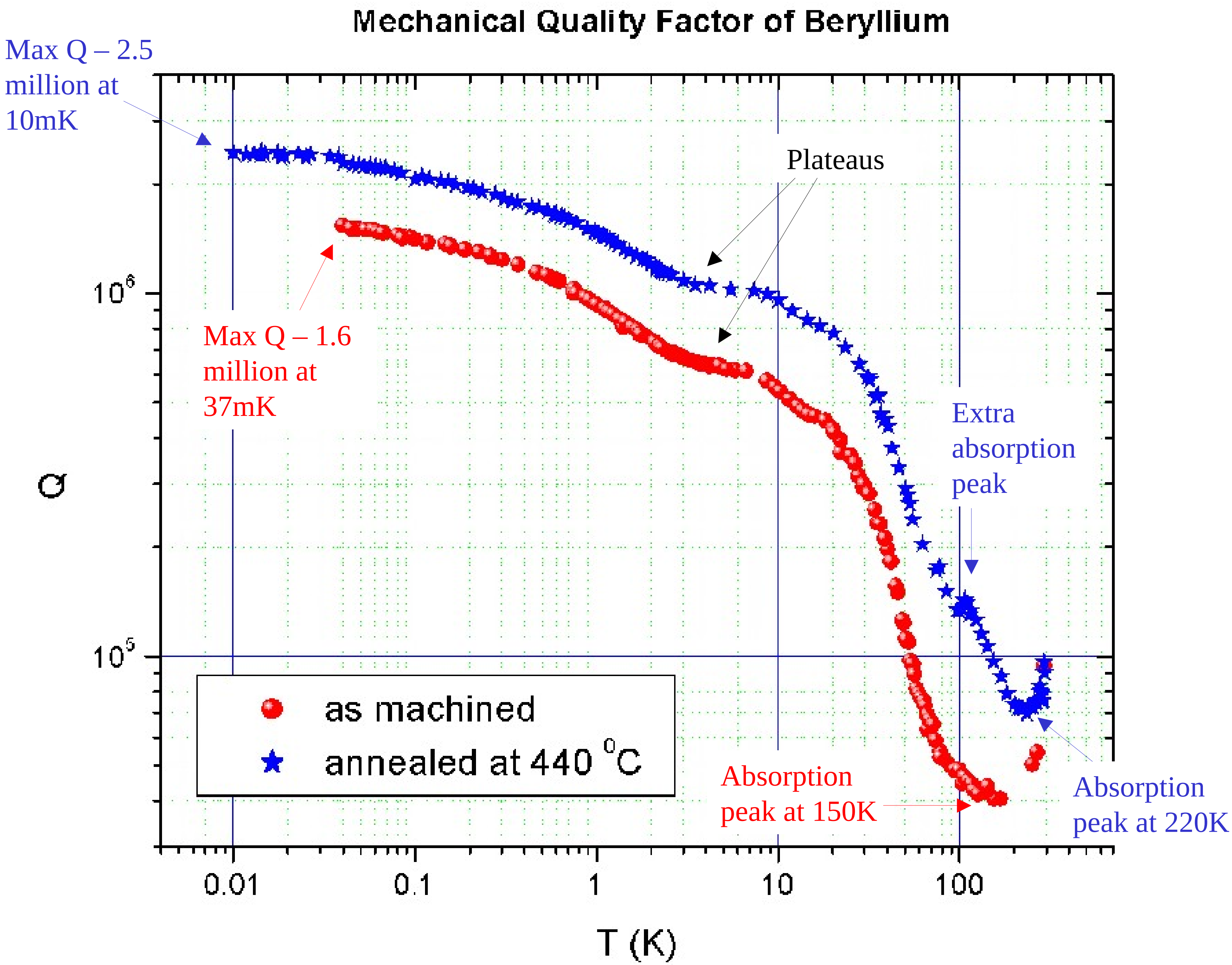




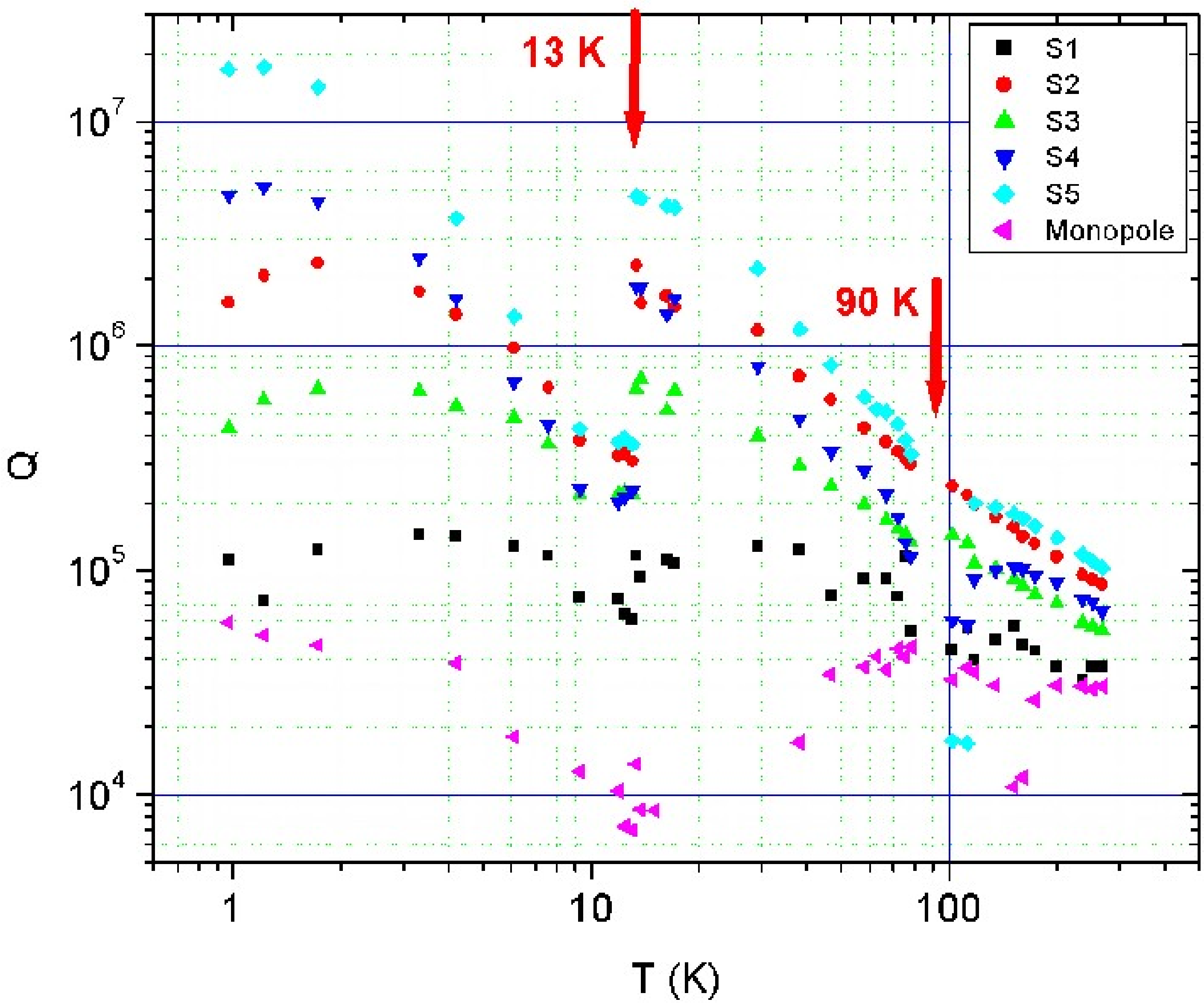
Calibration of CMN with fixed points



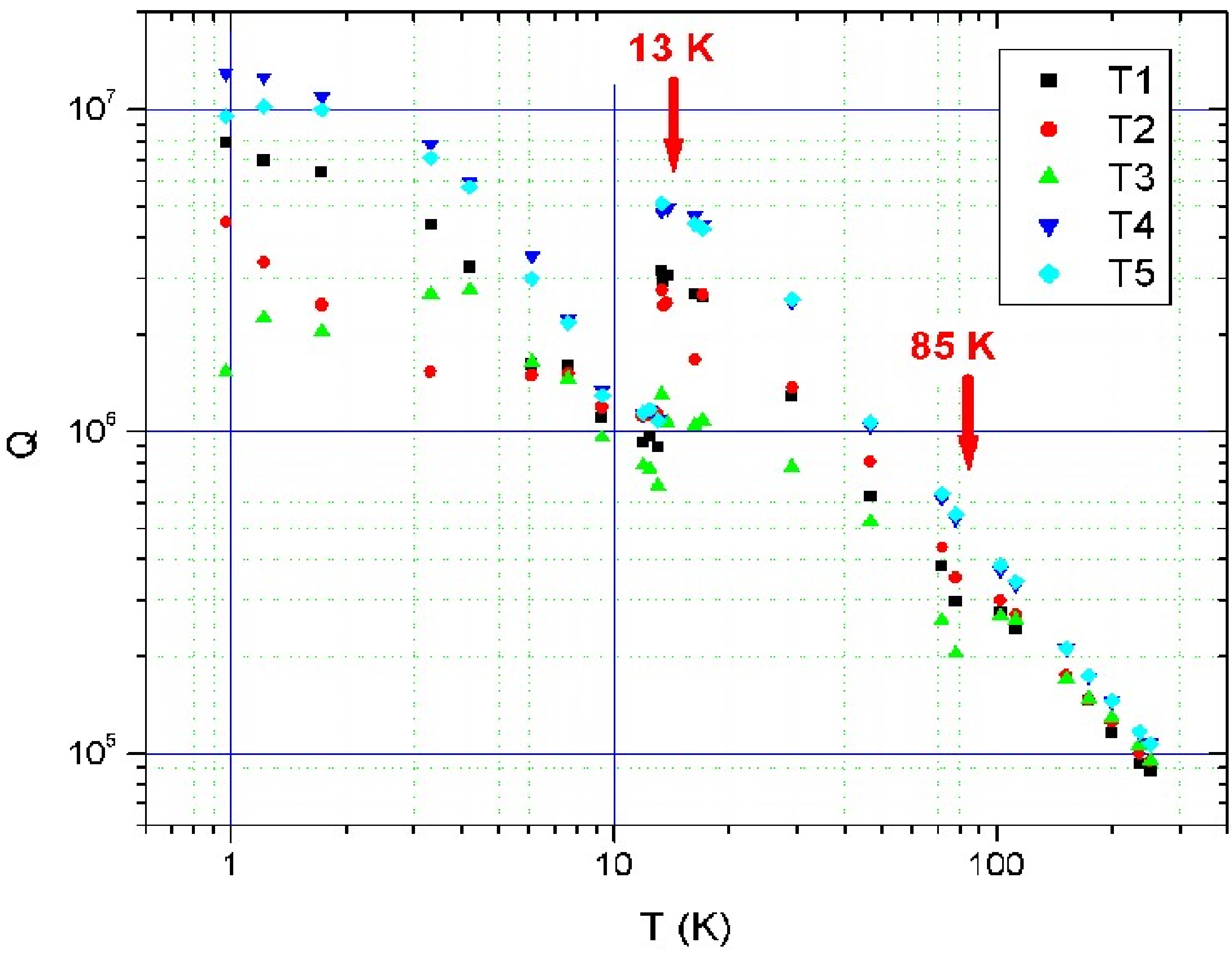
Calibration RuO_2 thermometers against CMN 106
wbw01
wbw02
wbw03
R (Ohm)
100000
10000
1000
T (K)
0.01
0.1
1
10
100


Mechanical Quality Factor of Beryllium
Max Q – 2.5 million at 10mK
Plateaus
Max Q – 1.6 million at 37mK
Extra absorption peak
Absorption peak at 150K
Absorption peak at 220K
as machined
annealed at 440 °C
Q
T (K)
0.01
0.1
1
10
100
10^6
10^5

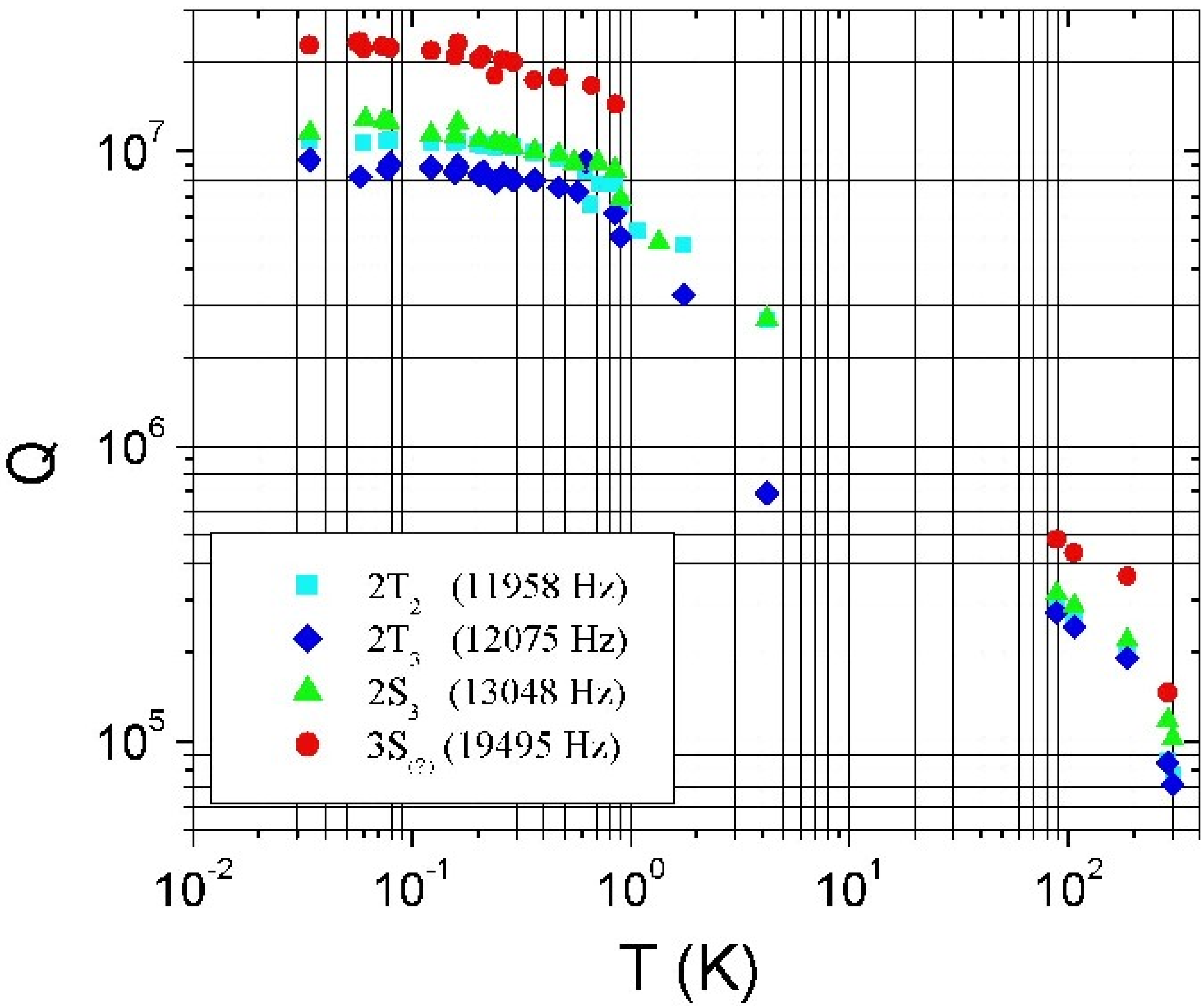
Spheroidal modes (suspended from surface)



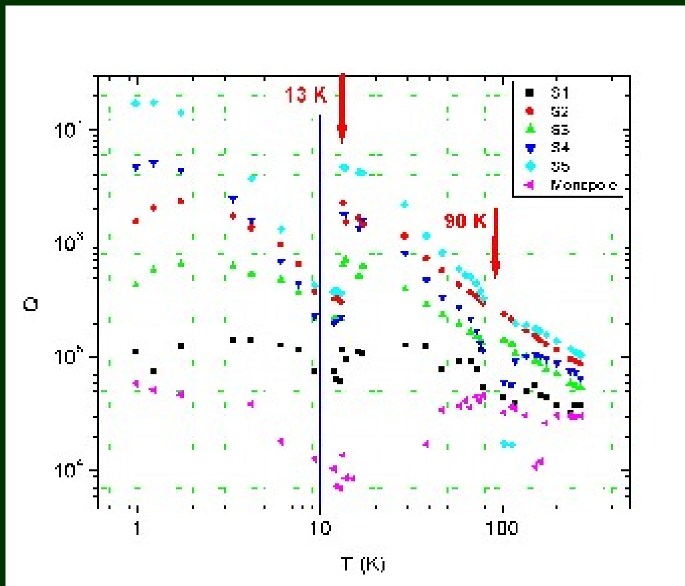
Toroidal Modes (suspended from surface)



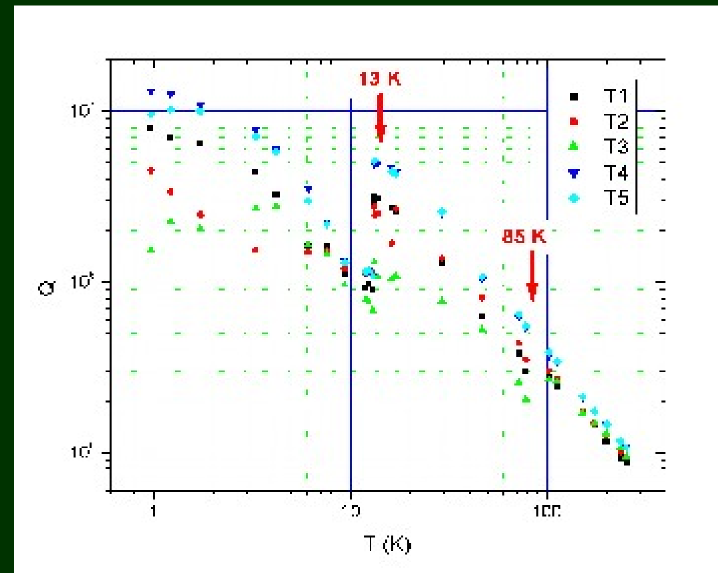
Modes (suspended from centre)



SPHERE SUSPENDED FROM SURFACE

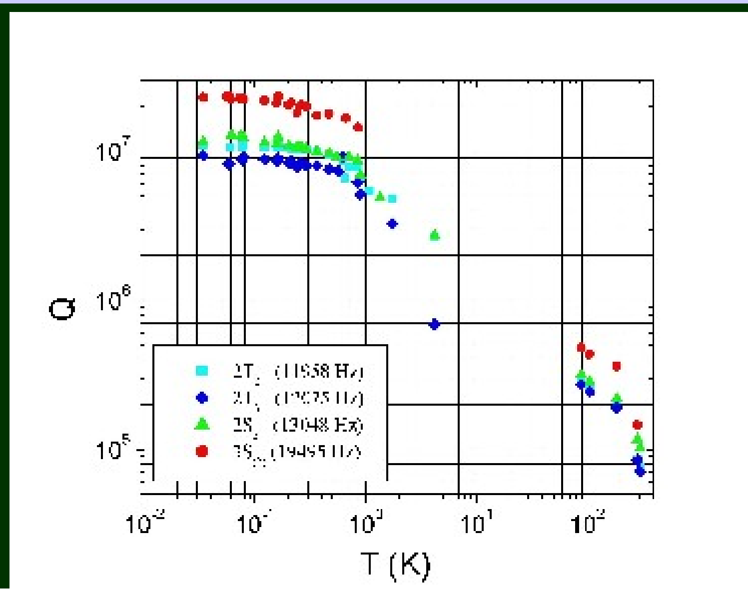


Spheroidal Modes



Toroidal Modes

SPHERE SUSPENDED FROM CENTRE



CONCLUSION

BERYLLIUM

Possibilities:

- **Sphere of 2m in diameter**
- **Dual sphere**

Disadvantages:

- **Highly toxic**
- **Very expensive (a 2m sphere would cost $2 million)**

SUSPENSION FROM SURFACE

- **All modes are damped but one**
- **Further experiments are needed to see if it is possible to reduce the damping of all of the modes**