Rivelazione
Acustica
di Particelle

Rivelazione Acustica di Particelle in cilindri di alluminio e niobio

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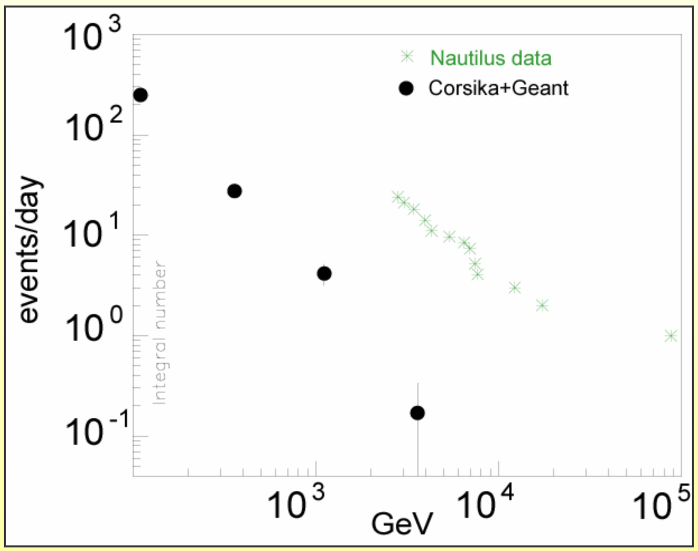
Scientific Motivations

The NAUTILUS Gravitational Wave Antenna has recorded signals due to the passage of cosmic rays.

Interaction between CR and the antenna is described by the so-called Thermo-Acoustic model



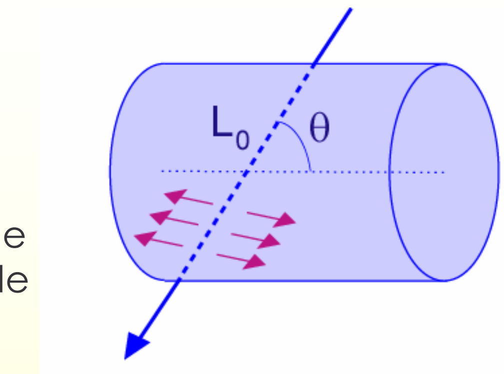
Green: NAUTILUS measurements
Black: expected data for the hadronic component with the Thermo-Acoustic model

NAUTILUS measurements are in good agreement with the model when T > Tc, but large signals of high energy CR at higher rate than expected (2-4 orders of magnitude) have been observed in the superconductive state of the antenna.

→ *RAP*

Scientific Motivations

Thermo-acoustic model
for cylindrical bars



CR crossing the antenna loss energy

→ *warming up of the material*

↓

local thermal expansion

↓

mechanical vibrations

This model has been verified for the Al at T = 300 K

The amplitude of the 1st longitudinal mode of oscillation is

$$B_{TH} = B_0(1+\varepsilon)$$

$$B_0 = \frac{2}{\pi}\frac{\alpha}{C_V}\frac{L}{M}W$$

accounts for:

a) $O[(R/L)^2]$ corrections

b) beam shape

$\rightarrow \varepsilon = -0.04$ for Al

Grüneisen parameter (γ)

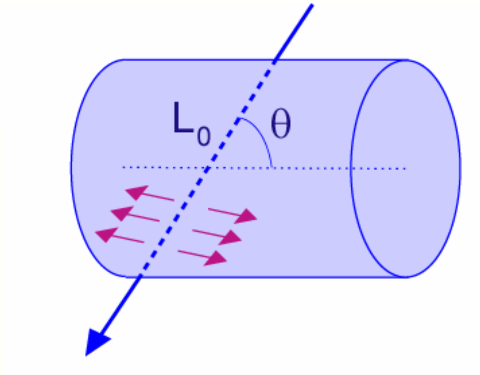
- ✓ *is proportional to* α/C_V
- ✓ *is nearly constant between* $T = 10 \div 300$ K
- ✓ *but, in superconductive state?*

$$E_n \propto \gamma^2 W^2 F_n^2$$

Scientific Motivations

$$B_0 = \frac{2}{\pi}\frac{\alpha}{C_V}\frac{L}{M}W$$

Thermo-acoustic model
In superconducting state?



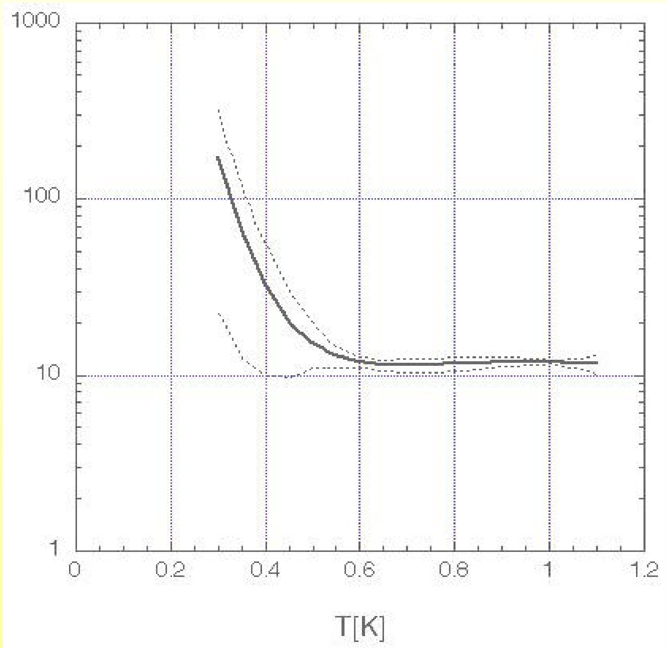
$$r = \sqrt{\frac{dW/dx}{\pi C_V \rho \Delta T}} \approx 100\ \mathring{A}\ (\text{per Al}) \qquad \Rightarrow \qquad \Delta T \approx 30\ \text{K}$$

At low temperature γ has 2 components: 1 from the lattice and the other from the conduction electrons.
The first is assumed to be not dependent on the conduction state (NC or SC)

$$\gamma_n^e\left(T \to 0\right) = 1.6$$

But, calculation of α as a function of the derivative of the critical field versus P and T gives a different value of γ in the range $\mathrm{T} < 1\ \mathrm{K}$ (see the figure)

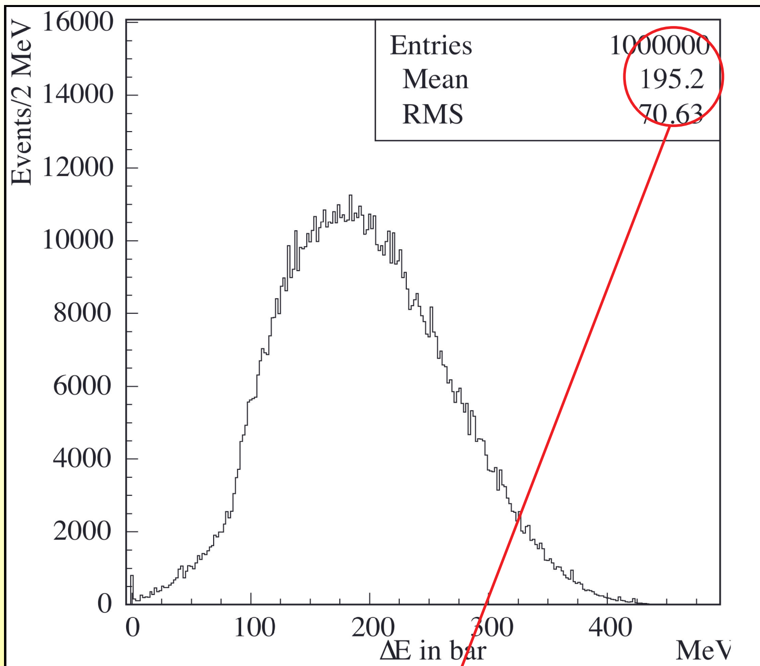
Measurement is needed!

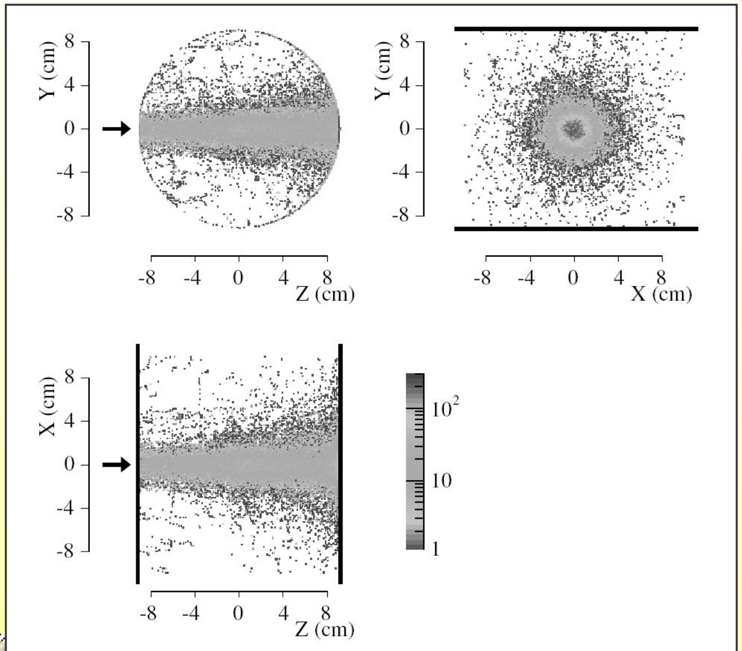


Expected $\left|\gamma_s^e\right|$ vs T for pure Al

Beam Interaction Simulations

$$B_0 = \frac{2}{\pi}\frac{\alpha}{C_V}\frac{L}{M}W$$





Monte Carlo simulations

*Mean energy released by the particles for a **510MeV** e- impinging the Aluminum antenna*

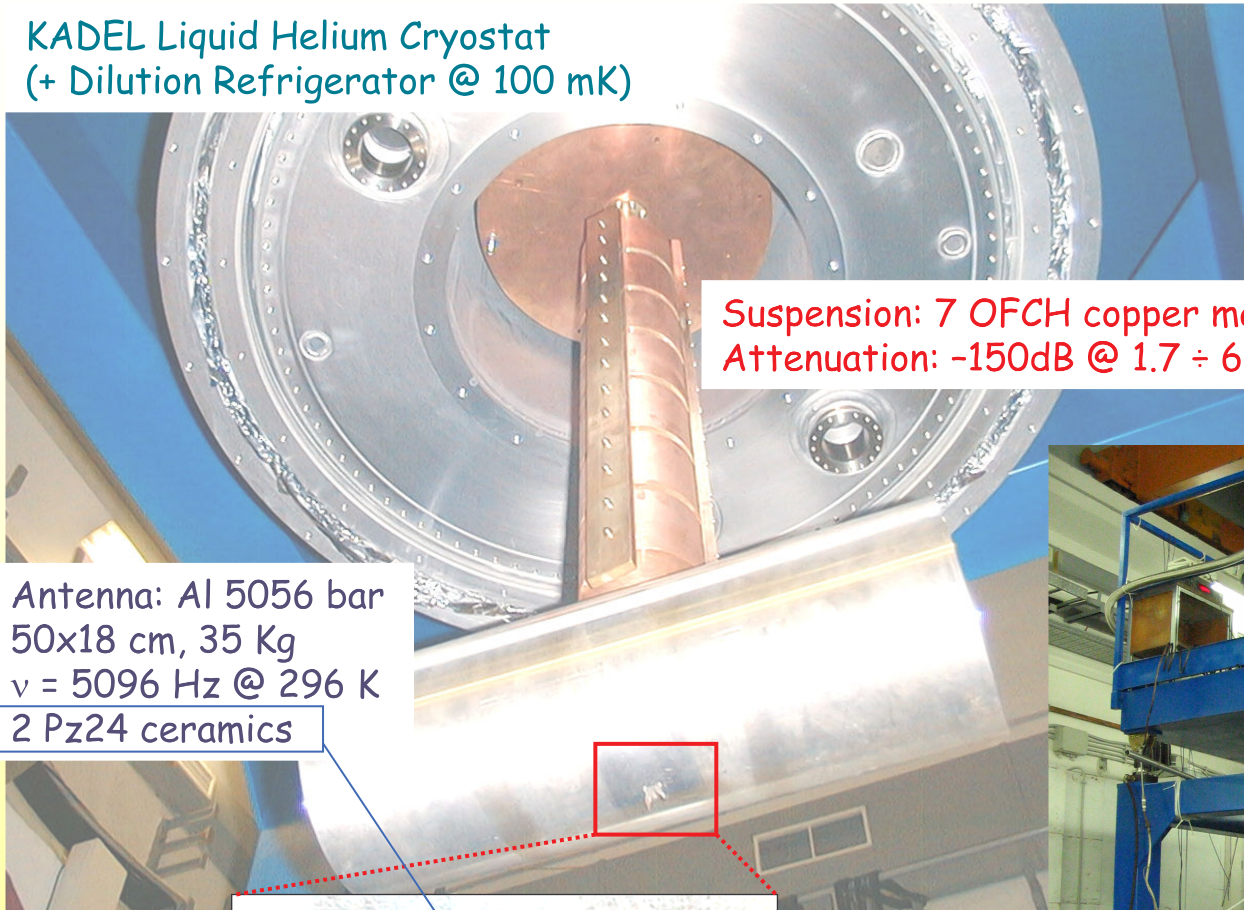
$$\langle \Delta E \rangle \pm \sigma_{\Delta E} = 195 \pm 70 \quad \mathrm{MeV}$$

$$W = N\langle \Delta E \rangle \qquad \sigma_W = \sqrt{N}\sigma_{\Delta E}$$

Secondary particle distribution for a 510MeV primary e- impinging on the bar

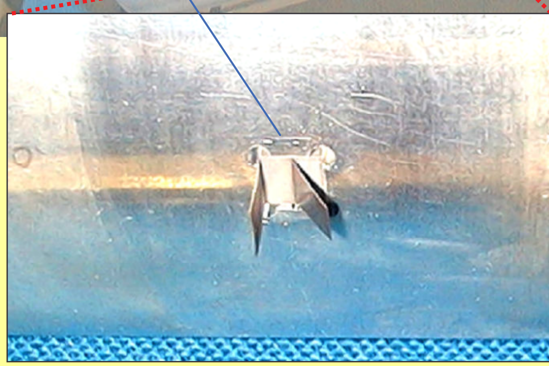
Experimental Setup

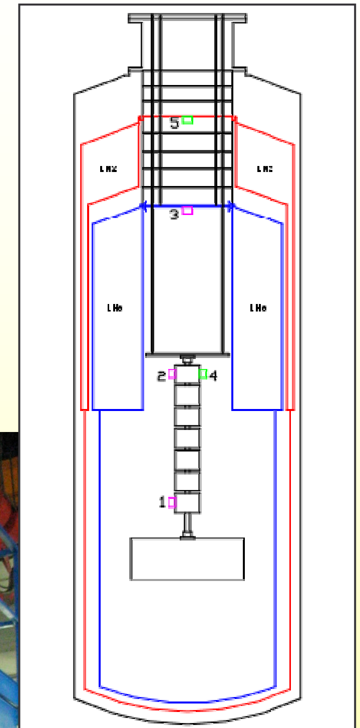
KADEL Liquid Helium Cryostat
(+ Dilution Refrigerator @ 100 mK)



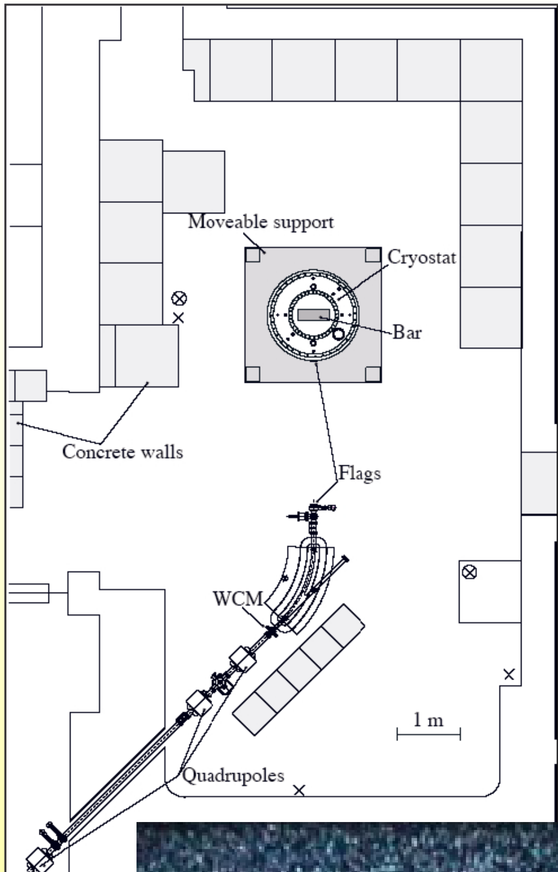
Suspension: 7 OFCH copper masses
Attenuation: -150dB @ 1.7 ÷ 6 KHz

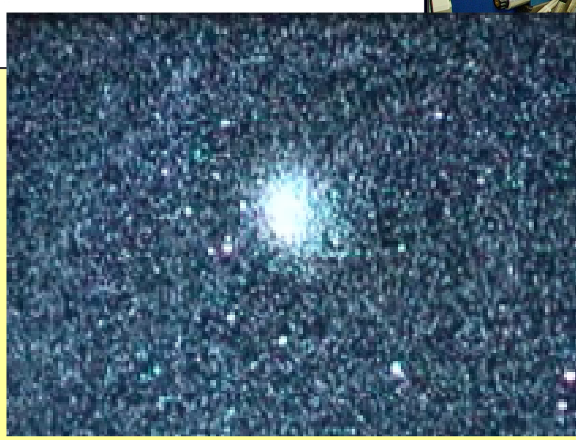
Antenna: Al 5056 bar
50x18 cm, 35 Kg
ν = 5096 Hz @ 296 K
2 Pz24 ceramics





DAΦNE BTF Run





Al5056 Measurement Results

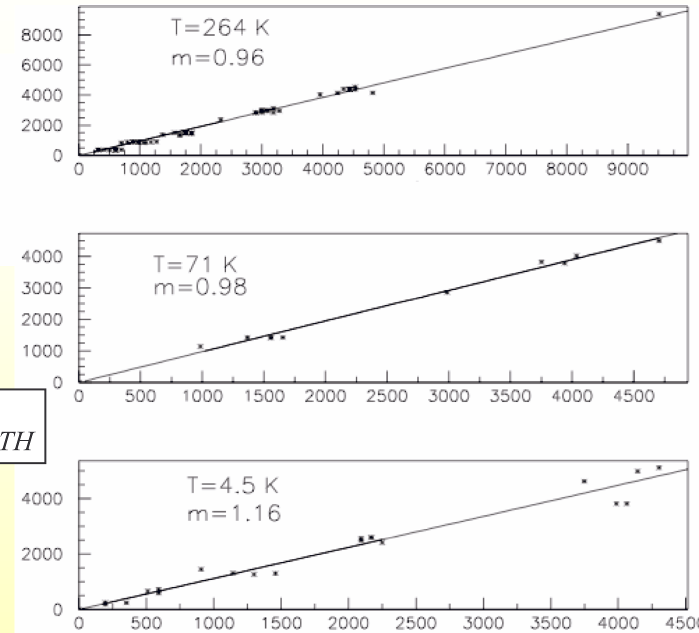
*AstroParticle Physics, **24**, 65-74 (2005)*

Devices systematic accuracy

- Beam monitor: 3%
- PZ24: 6%
- → Total = 7%

$T[K]$	$f_o[Hz]$	$\tau_o[s]$	$\lambda[10^7 V/m]$
264	5143.7	6.25	1.32
71	5397.3	24	1.48
4.5	5412.7	84	1.32

$$B_{MIS} = mB_{TH}$$

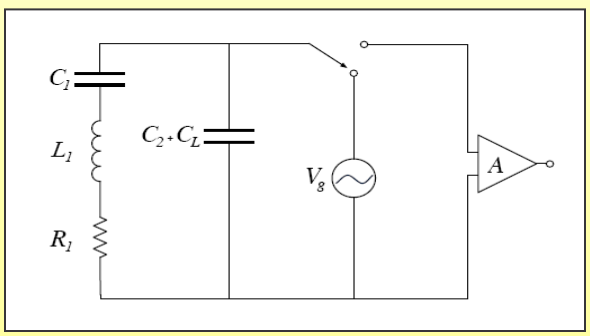


B_{MIS} vs B_{TH} (10^{-16} m)

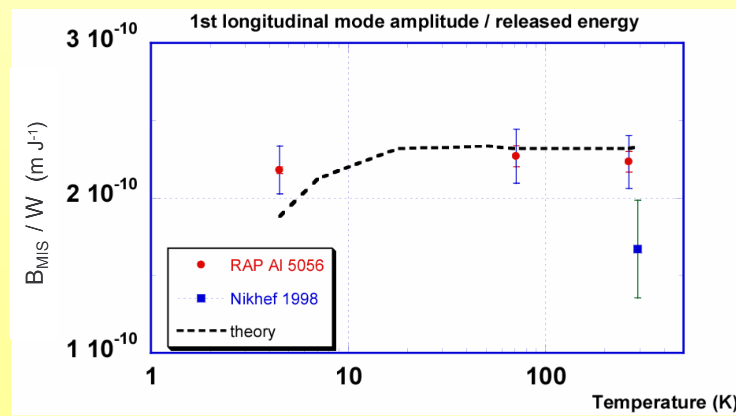
PZ24 Calibration

$$B_{mis}[m] = \frac{V}{\lambda}, \quad \lambda = \sqrt{\frac{2\pi f_0 M V_0}{(C_2 + C_L) V_g \Delta t}}$$

$$V \approx 10^{-6} \text{ V}$$
$$\lambda \approx 10^{7} \text{ Vm}^{-1}$$



the auto-calibration method shows good agreement with a calibrated accelerometer

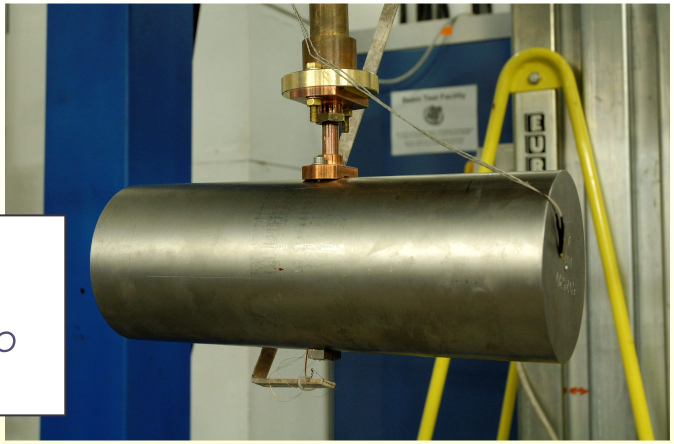


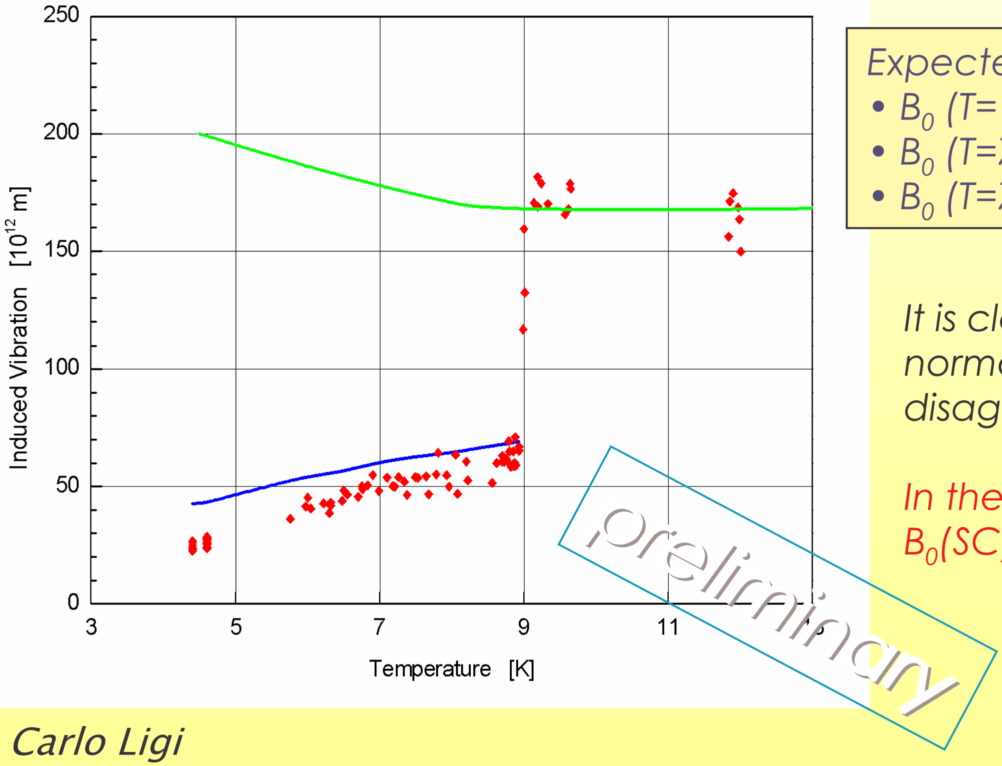
Niobium Measurement Results

Due to the delay in the dilution refrigerator delivery, we decided to make measurement with a material different from Aluminum. We used a Niobium bar ($T_c \approx 9$ K)

$T[K]$	$f_o[Hz]$	$\tau_o[s]$	$\lambda[10^6 V/m]$
275	6377.50	6	1.80
81	6513.30	14	1.71
12.5	6569.28	100	1.57
4.5	6569.38	107	1.50

- *27.4x10 cm*
- *annealed, purity > 99%*
- *2 PZ ceramics in parallel glued to the bottom center*





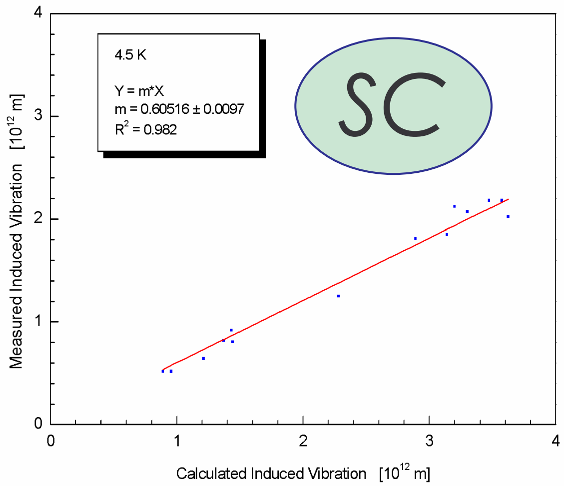
Expected B_0:
- *B_0 (T=10 K) = 1.7 10^{-10} mJ^{-1}*
- *B_0 (T=7 K,normal c.) = 1.8 10^{-10} mJ^{-1}*
- *B_0 (T=7 K,superc.) = 0.6 10^{-10} mJ^{-1}*

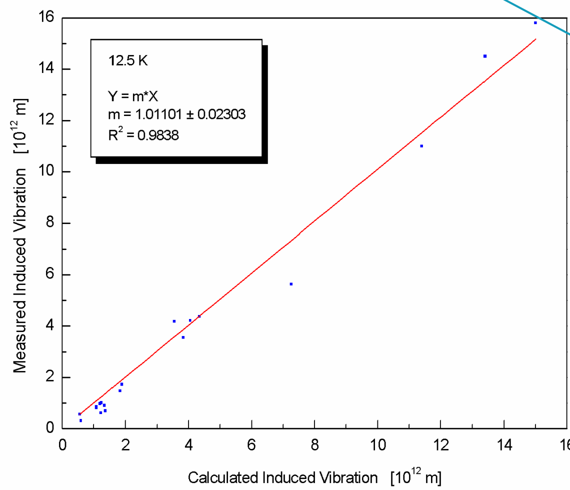
It is clear that the $T < T_c$ extrapolation of the normal conducting calculation of B is in strong disagreement with the measured data!

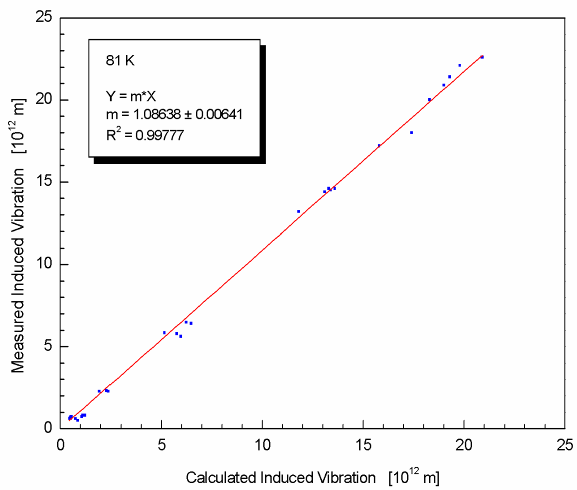
In the case of Aluminum, calculation gives $B_0(SC) > B_0(NC)$ at $T < T_c$

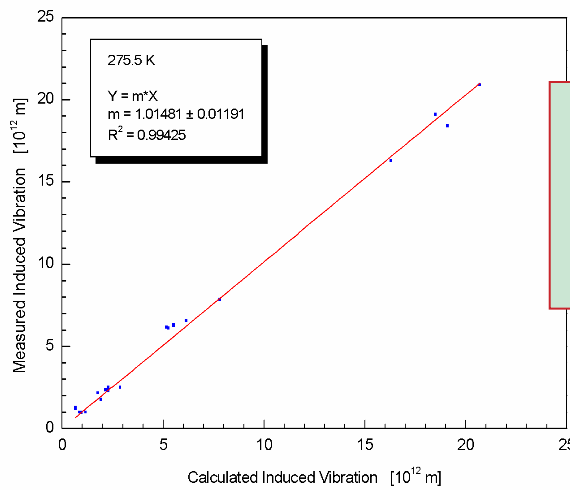
Niobium Measurement Results

preliminary









m (4.5K) = 0.605 (SC)
m (12.K) = 1.011 (NC)
m (81K) = 1.086 (NC)
m (275K) = 1.015 (NC)

Conclusions

Measurements with 5056 Aluminum alloy:

✓ *results show agreement with the Thermo-Acoustic model in the 4-300 K range at the 10% level, but*

✓ *measurement below 1 K is needed in order to understand the behaviour of the material in superconducting state*

Measurements with Niobium:

✓ *preliminary results show good agreement with the Thermo-Acoustic model in the 10-300 K range (normal conducting state)*

✓ *an evidence of the transition (not expected!) has been seen.*

Next steps…

✓ *Publication of the Niobium measurements.*

✓ *Measurements with Al5056 in superconductive state (we are waiting for the dilution refrigerator…)*