Rivelazione Acustica di Particelle in materiali massivi superconduttivi

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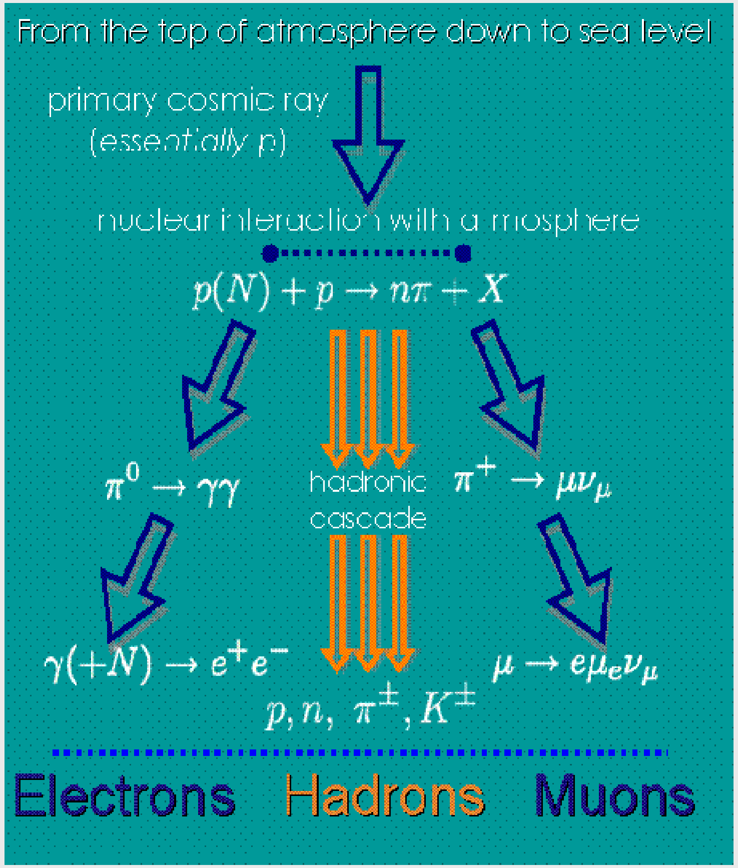
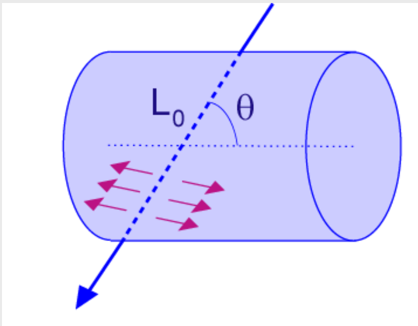
Cosmic Rays & Gravitational Wave Detectors

- High energy cosmic rays (CR) passing the atmosphere can produce showers, which loss energy when hitting bulk materials, exciting their resonant modes
- In 1998 the NAUTILUS Gravitational Wave Antenna detected for the first time signals due to the passage of cosmic rays.
- Interaction between CR and the antennas has been so far described by the so-called Thermo-Acoustic Model
- NAUTILUS measurements are in good agreement with the model when the antenna is in normal-conducting state, but <u>large signals of high energy CR</u> at higher rate than expected have been observed when antenna was operating in superconductive state.
- Investigation was needed in order to better understand the interaction process → An experiment (RAP) has been proposed to measure the interaction between relativistic charged particle beams and massive cylinders



The *Thermo-Acoustic* Model

CR crossing the antenna interact with the lattice and loss energy →
This energy gets warm the antenna around the particle trajectory →
The warming up causes an impulsive local thermal expansion →
The pulse diffuses in the bulk and generates mechanical oscillations



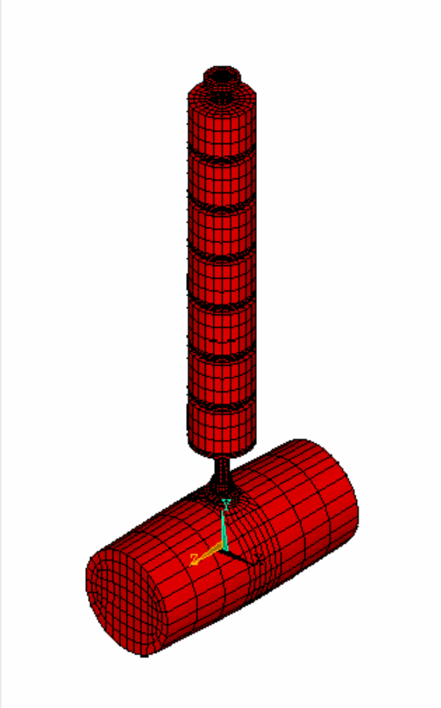
- The max amplitude of the 1st longitudinal mode of oscillation is given by

$$B_{TH}[m] = \frac{2}{\pi} \frac{\alpha}{C_V} \frac{L}{M} W(1+\varepsilon)$$

(*Grassi Strini A.M. et al. – J. Appl. Phys. 51, 948 - 1980*)

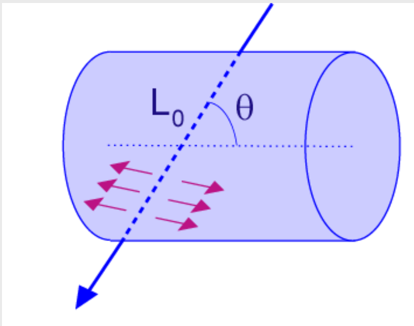
where α is the linear thermal expansion coefficient, C_V is the specific heat, L e M are length and mass of the bar and W is the total energy released by the beam to the bar. The term ε accounts for corrections estimated by MC simulations due to $O[(R/L)^2]$ and to the beam structure.

- The model has been verified for the Al5056 at ambient temperature, but RAP made the first measurement at cryogenic T.
- B is a function of T on α/C_V, but this ratio is nearly constant in T < 300 K



The *Thermo-Acoustic* Model <u>in SC State</u>

What happens? Two possible approaches:



1) The beam <u>does NOT cause any transition</u> in the material →

The process should be described by the Thermo-Acoustic model using the thermophysical parameters of the material in the SC state (α e C_V)

(*Grassi Strini A.M. et al. – J. Appl. Phys. 51, 948 - 1980*)

2) The beam <u>causes a transition</u> in the material →

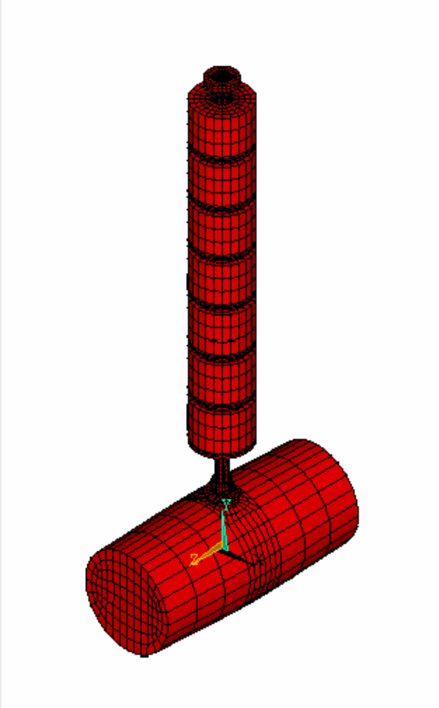
so, two different processes contribute in the energy release in the material:

i) the energy released by a particle interacting with the bulk determines a *s-n* local transition, which causes a pressure pulse in the material due to the different energies between the *s* and *n* state

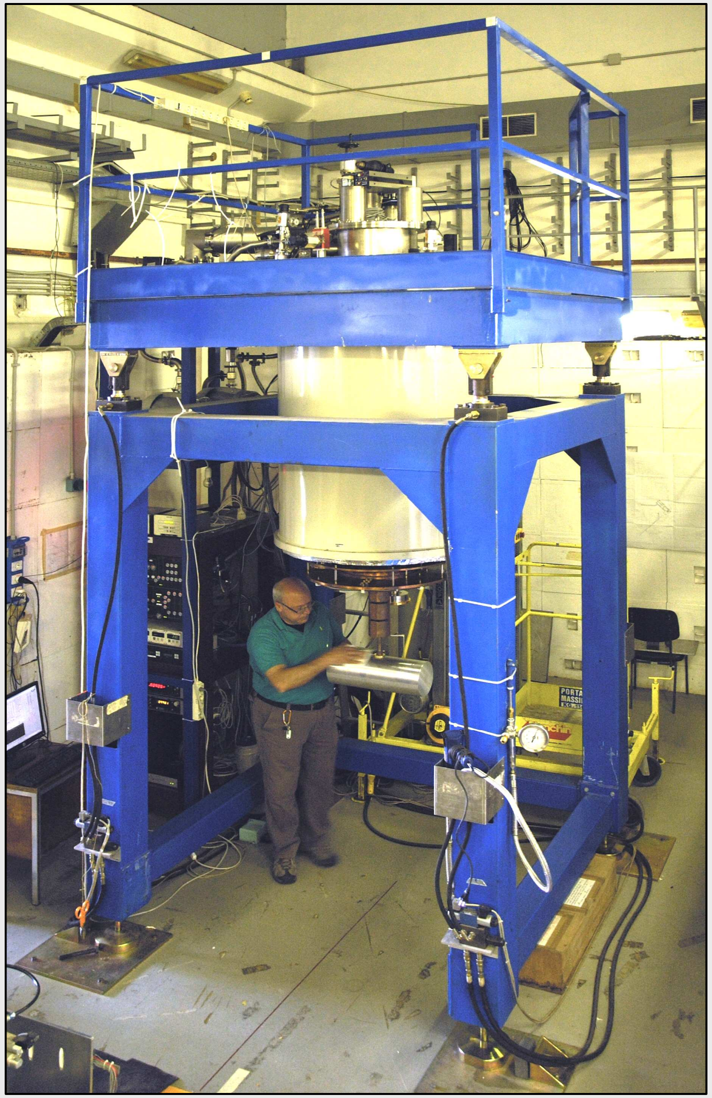
ii) then the material gets warm same as in the previous case, but now the heating of the material should be treated with the Thermo-Acoustic model at $T < T_C$, but using the thermophysical parameters of the material in the <u>normal-conducting state</u>

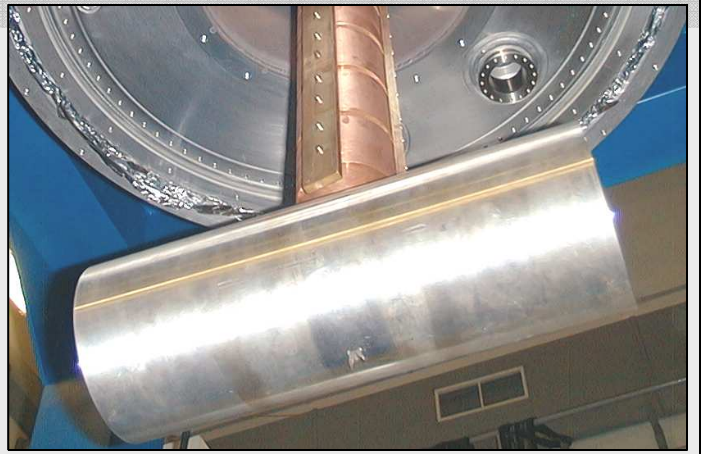
These two effects could have <u>different sign</u>!

(*Allega-Cabibbo – Lett. N. Cimento 38, 263 - 1983,*
Bernard et al. – Nucl. Phys. B 242, 93 - 1984)



Experimental Setup



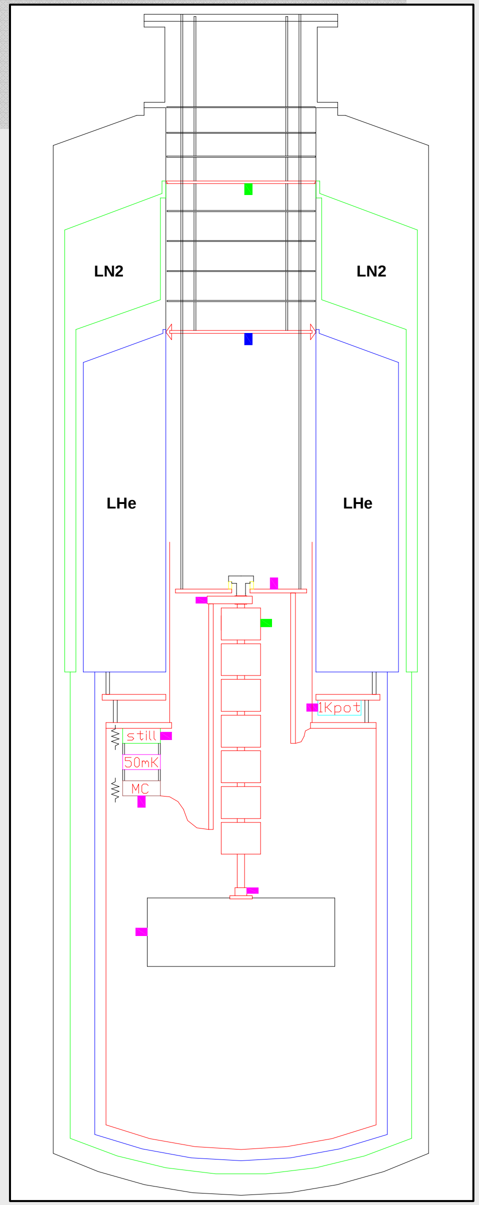


KADEL Cryostat
LEIDEN CRYOG. dilution refrigerator

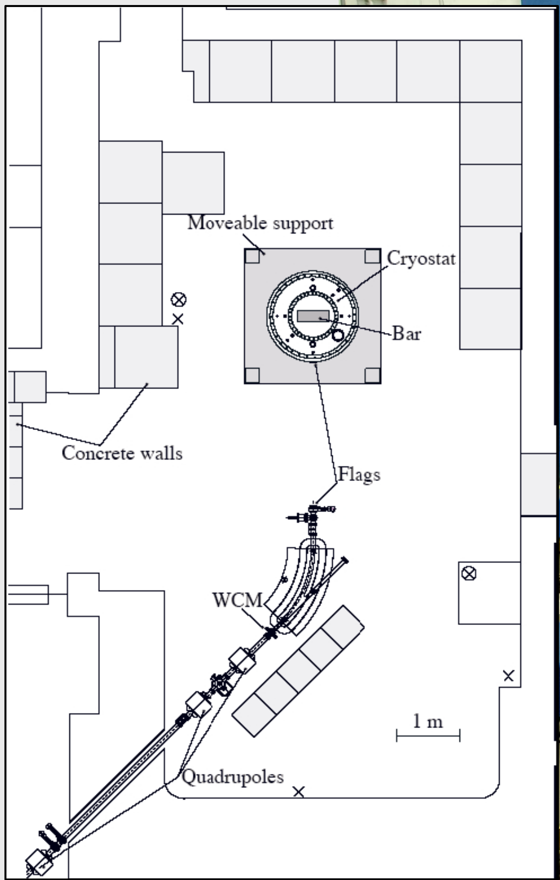
Suspension: Cu tube + 7 Cu masses
attenuation –150dB @ 1.7÷6kHz

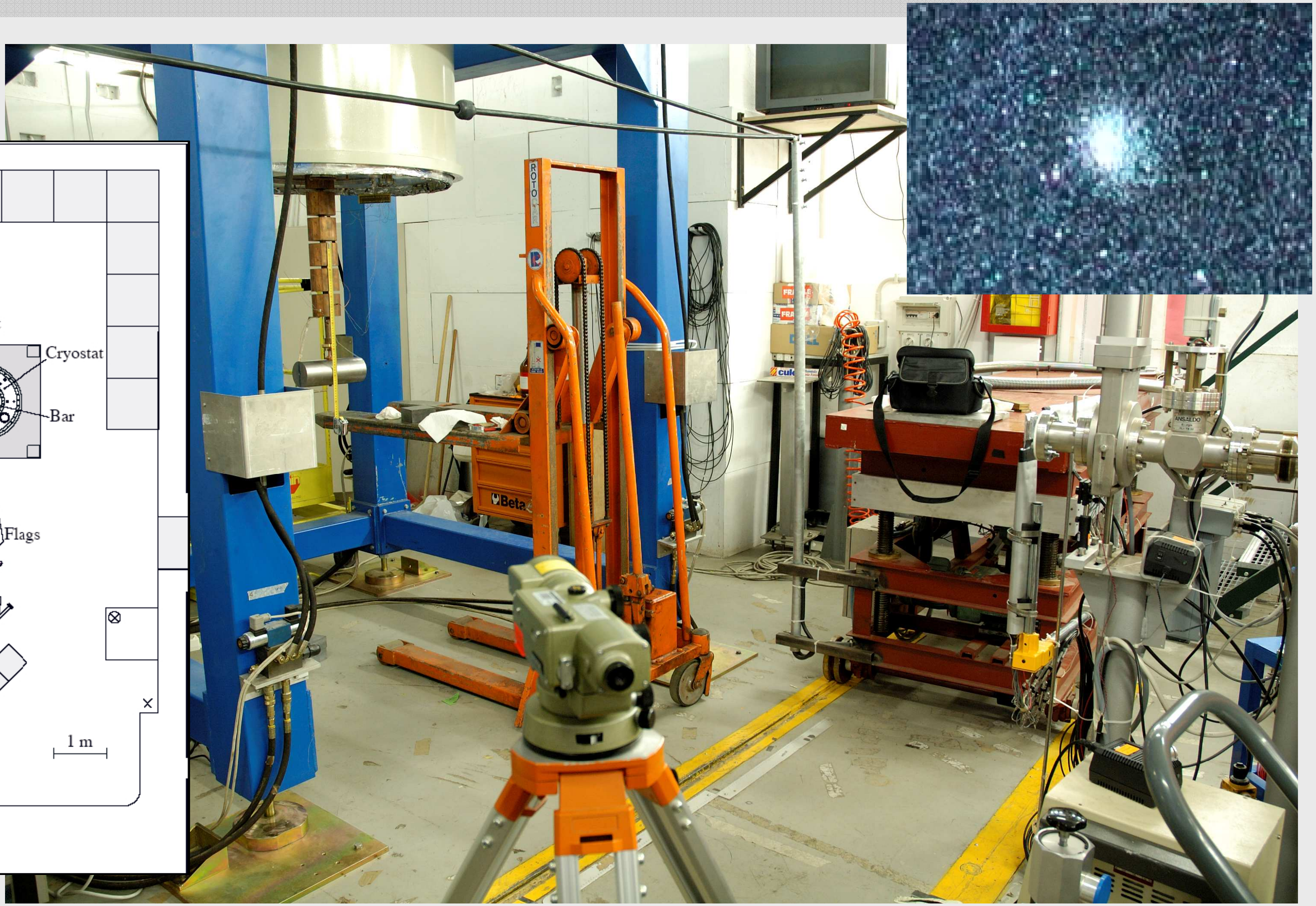
Antennas:
Al 5056 50x18.1cm, 34.1 kg
f_0 = 5096 Hz @ 296 K
Nb 27.4x10cm, 18.4 kg
f_0 = 6373 Hz @ 290 K

Sensors: 2 ceramic PZs in parallel
$\lambda = 10^6 \div 10^7$ V/m



The DAΦNE Beam Test Facility



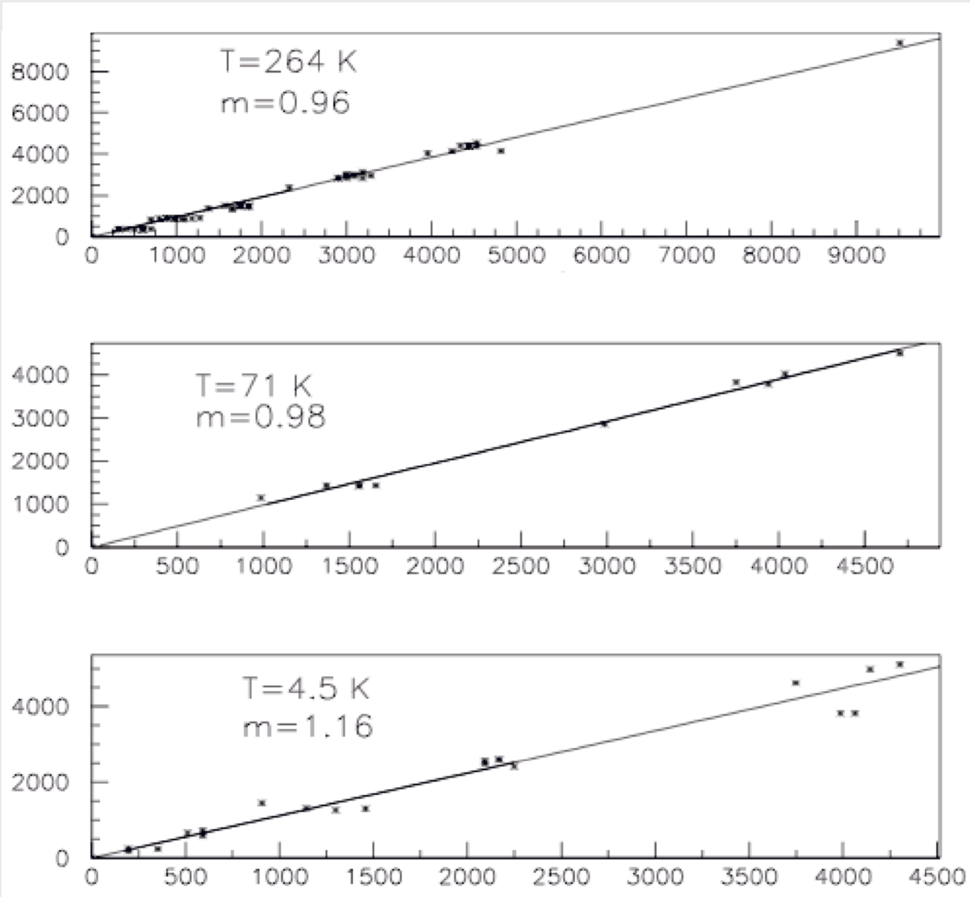


Measurement with Al5056 Antenna

Normal Conducting State

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

$$B_0 = mB_{TH}$$



T [K]	B_{TH} [10^{-10} m/J]	m	Δm
264	2.32	0.96	0.01
71	2.32	0.98	0.03
4.5	1.88	1.16	0.03

- Better agreement with the model with respect to the previous measurements
- First assessment of the model at cryogenic temperatures
- Small disagreement at liquid helium temperature, probably due to the lack of knowledge of the thermophysical parameters (α e C_V) at low T
- Linearity of the response with the energy released by the beam

Measurement with Niobium Antenna

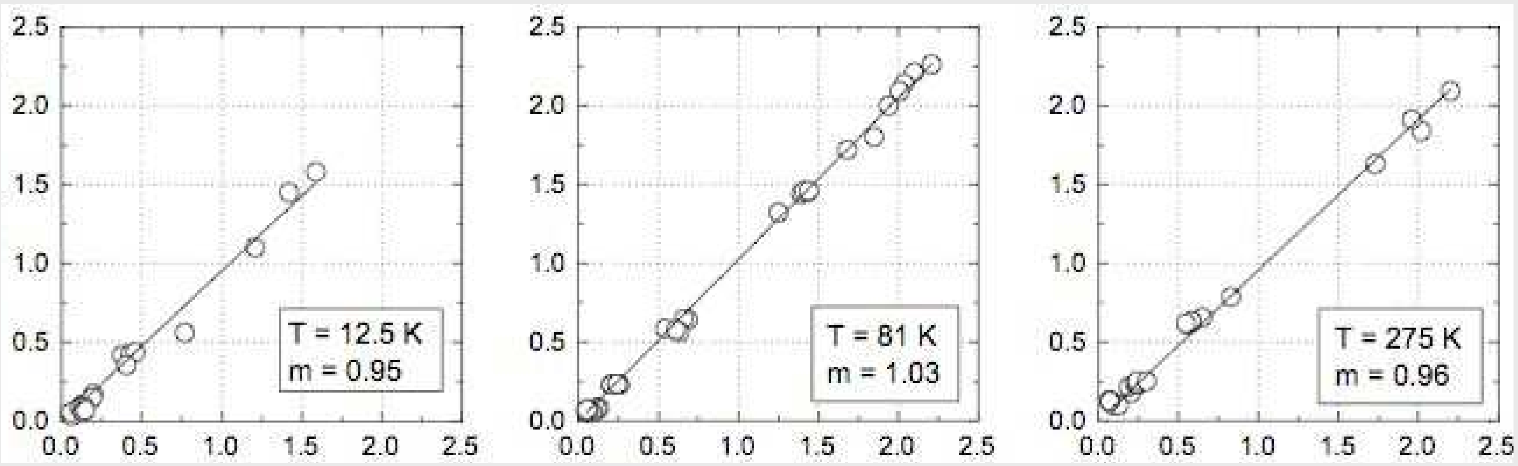
Normal Conducting State

Europhysics Letters **76**, 987-993 (2006)

- Very good agreement with the model also due to the very well known thermophysical parameters of the pure Niobium as a function of T
- Linearity of the response with the energy released by the beam

T [K]	B_{TH} [10^{-10} m/J]	m	Δm
275	2.31	0.96	0.01
81	2.30	1.03	0.01
12.5	1.55	0.95	0.02

$$B_0 = mB_{TH}$$



Superconducting State

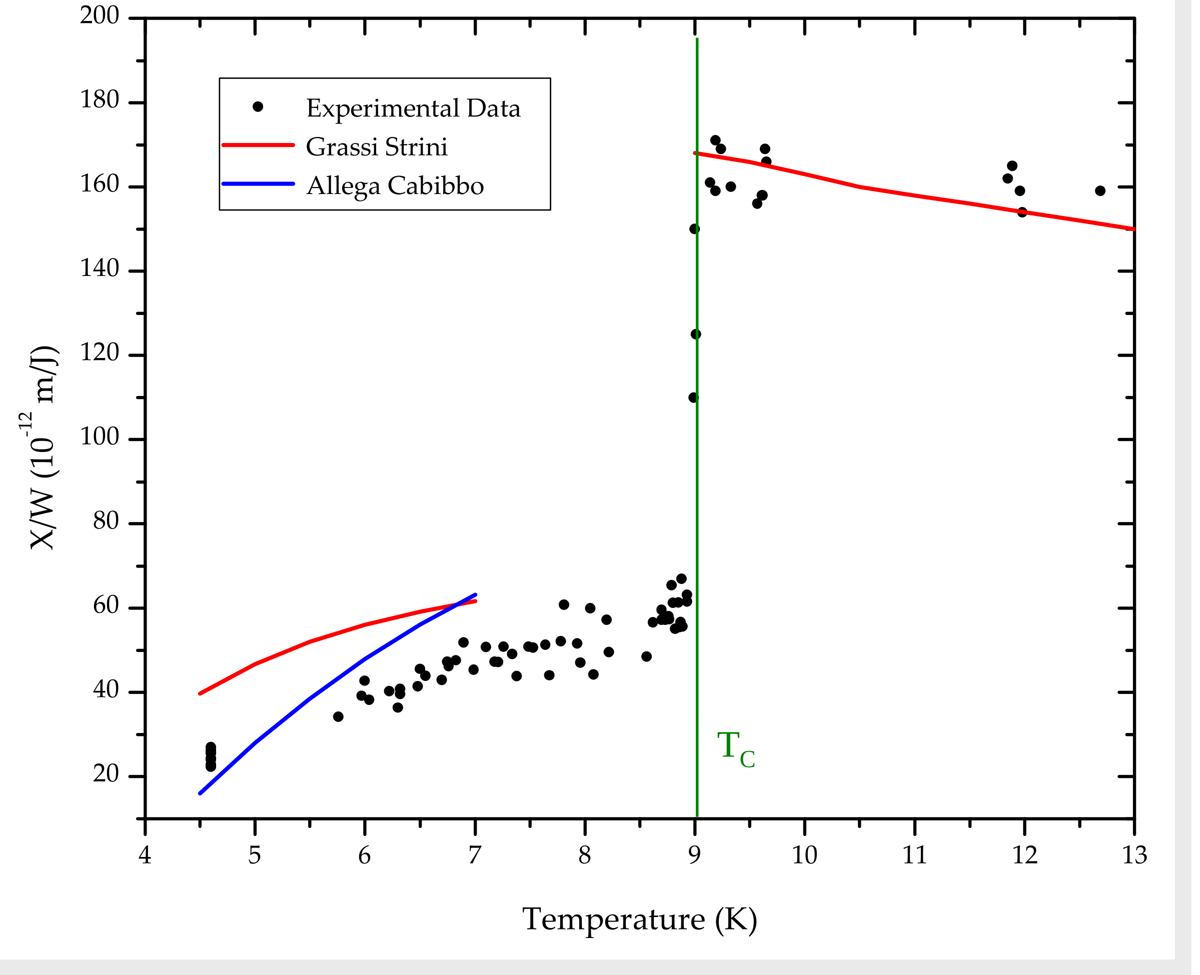
Measurement with Niobium Antenna

Europhysics Letters **76**, 987-993 (2006)

•For the first time has been experimentally verified that the amplitude of the longitudinal oscillation of a bar, when hit by a ionizing particle, depends on the conduction state of the material

•A possible agreement of the data with the predictions of the AC model is found

•The direct extension of the application of the GS model to the SC state seems to fail

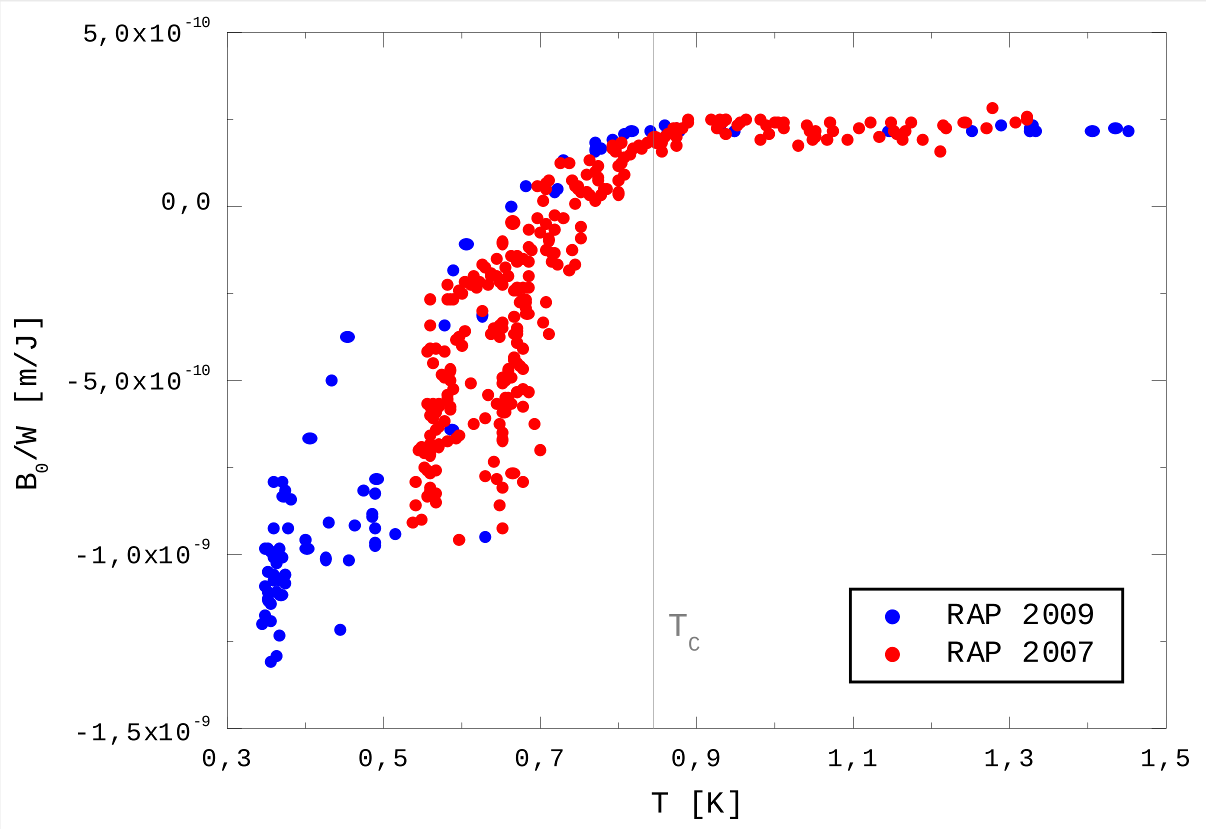


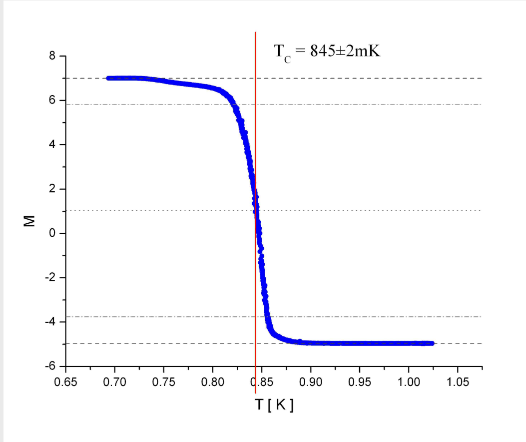
Superconducting State

Measurement with Al5056 Antenna

Physics Letters A **373,** 1801-1806 (2009)

Al5056 alloy: 5.2 w% Mg, 0.1 w% Cr, 0.1 w% Mn





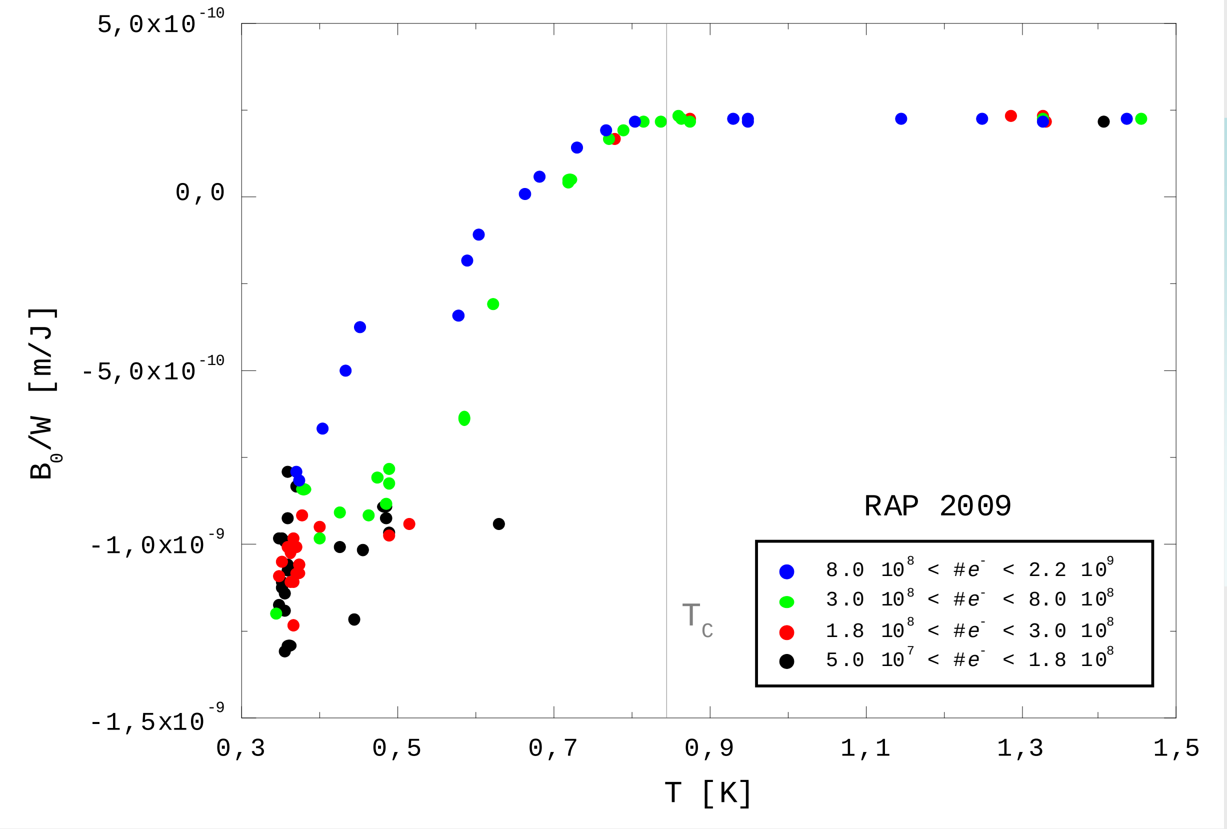
- Measurement of transition temperature using mutual inductance method gives
  T_C = 0.845 ± 0.002 K

- Good agreement between the 2007 and the 2009 data

Superconducting State

Measurement with Al5056 Antenna

2009 data – preliminary



- Below T_C is confirmed the behaviour seen in 2007
- At very low T, data seems to stabilize to a value around -1×10^{-10} f
- In the transition zone, between T_C and very low T, the behaviour depends on the beam multiplicity

Superconducting State

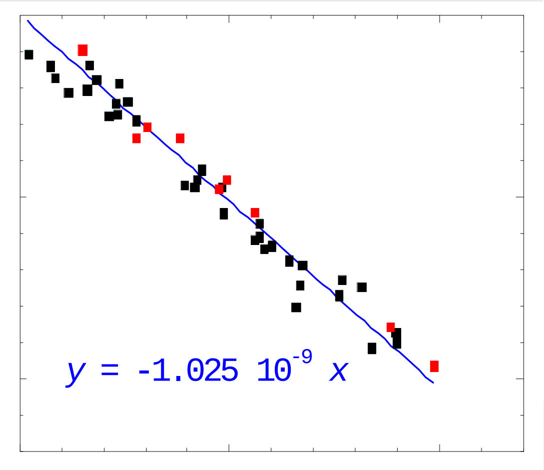
Measurement with Al5056 Antenna

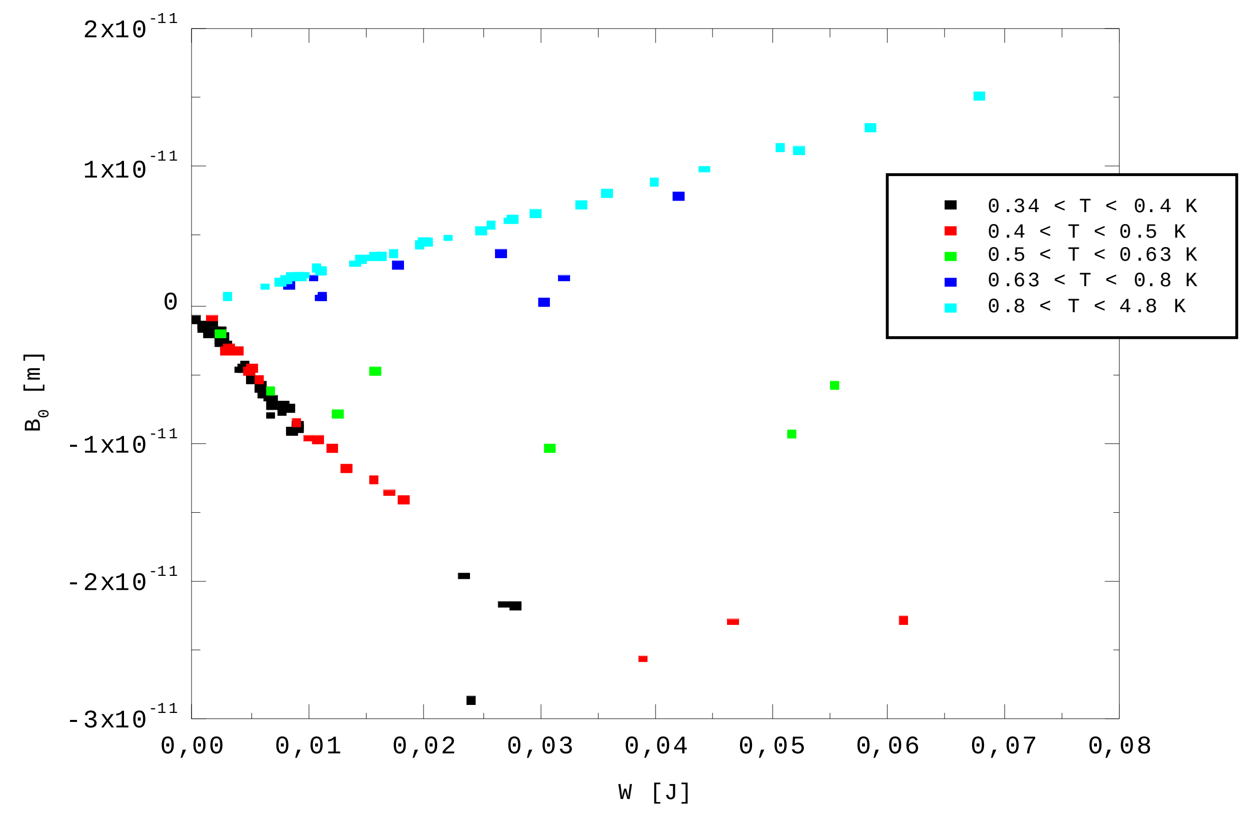
2009 data – preliminary

- Linearity at:

1) $T > T_C$
2) $T < 0.5$ K, $W < 0.01$ J

- Non linearity elsewhere





Conclusions

- NAUTILUS CR 1998 detections brought us to a discussion about if is correct to extend the use of Thermo-Acoustic Model in SC materials.
  → RAP has been proposed to verify the model.
- Measurements in NC state have verified the model within the 10% level, using both Nb and Al5056 alloy bars, also at cryogenic T.
- Measurements in SC state show that:

1) The 1st longitudinal mode of oscillation amplitude definitely depends on the conduction state of the material
2) The transition zone width between the NC and the pure SC behavior depends on the material superconductivity and its purity
3) Al5056 measurements at the lowest T seem to be in agreement with the NAUTILUS data.
4) Thermo-Acoustic Models are in good agreement with the measurement in NC state, also at low T, but seem to be unsuited to describe the SC state, at least in the transition zones of impure materials → Measurements are needed for the material characterization
5) Other resonance modes could be taken in account