RAP

Rivelazione Acustica di Particelle in materiali massivi superconduttivi

Carlo Ligi

On behalf of the RAP collaboration:

M. Bassan, B. Buonomo, G. Cavallari, S. D'Antonio, V. Fafone, C. Ligi, A. Marini, G. Mazzitelli, G. Modestino, G. Pizzella, L. Quintieri, F. Ronga, P. Valente, S. Vinko

INFN – LNF

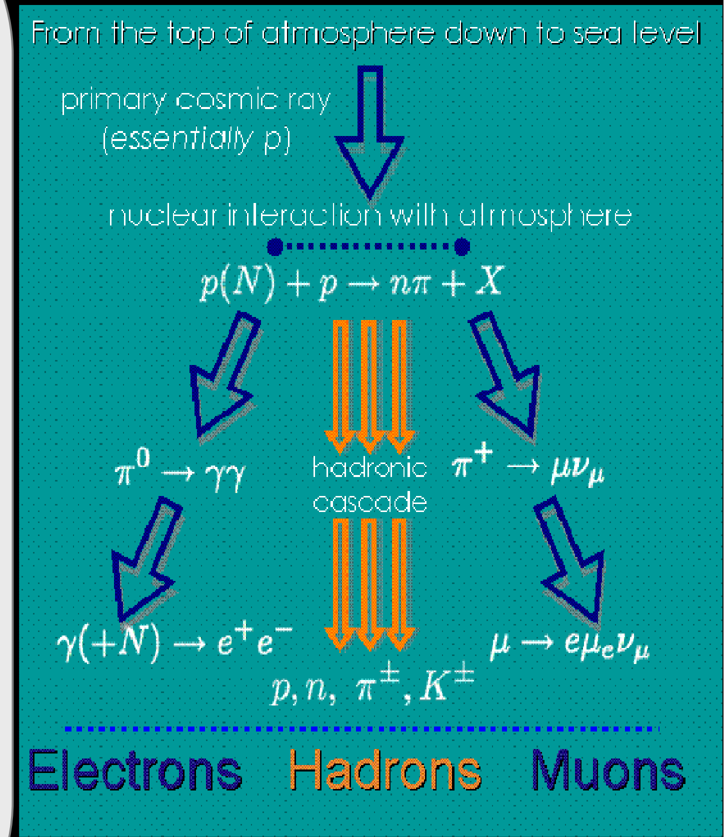
INFN – sez. di Roma Tor Vergata

Univ. di Roma Tor Vergata

RAP is partially supported in the framework of the ILIAS/STREGA E.U. program (6^{th} F.P.) and from the PRIN MIUR Univ. Tor Vergata / INFN-LNF

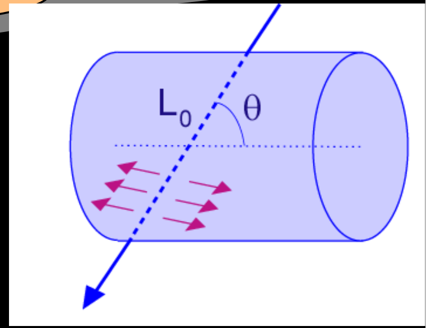
Cosmic Rays & Gravitational Wave Detectors

- High energy cosmic rays (CR) passing the atmosphere can produce showers, which can 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 antenna 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 large signals of high energy CR 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 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



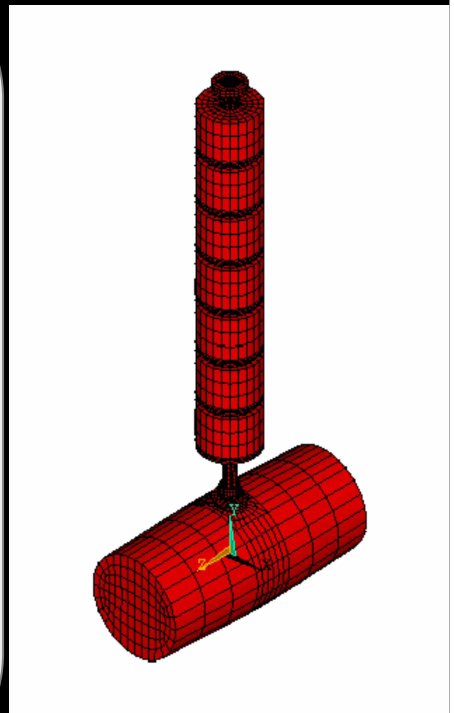
The max amplitude of the 1st longitudinal mode of oscillation is given by
(*Grassi Strini A.M. et al. – J. Appl. Phys.* **51**, *948 (1980)*)

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

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

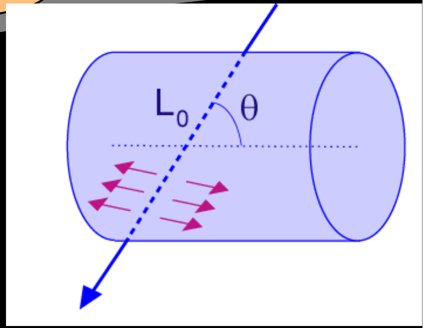


The *Thermo-Acoustic* Model in SC State

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)



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

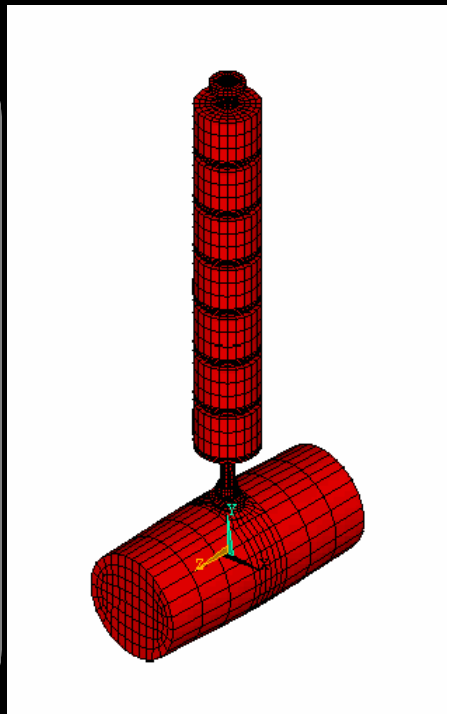
(*Allega-Cabibbo – Lett. N. Cimento **38**, 263 (1983)*
*Bernard et al. – Nucl. Phys. B **242**, 93 (1984)*)

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>



Experimental Setup

KADEL Cryostat with a *LEIDEN CRYOGENICS* dilution refrigerator

Suspension: tube + 7 Cu masses

attenuation −150dB @1.7÷6kHz

Antennas:

Al 5056 50x18.1cm – 34.1 kg

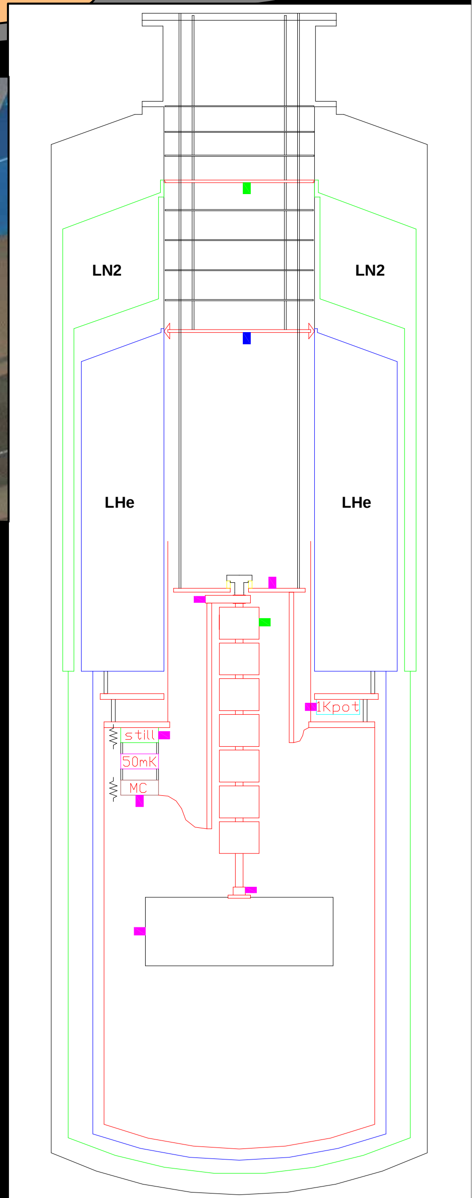
f = 5096 Hz @ 296 K

Nb 27.4x10cm – 18.4 kg

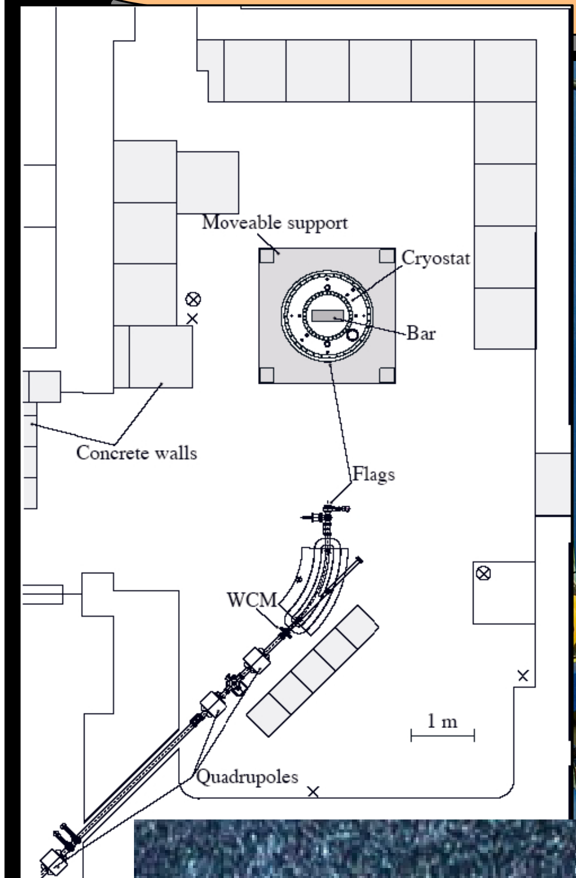
f = 6373 Hz @ 290 K

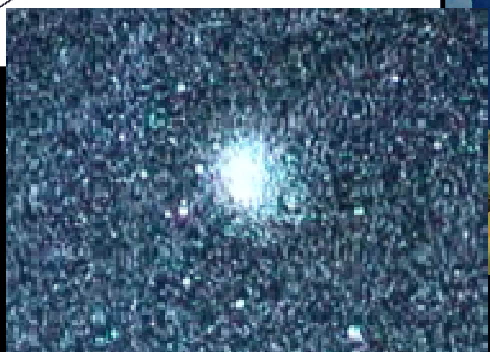
Sensors: 2 ceramic PZs in parallel

$\lambda = 10^6 \div 10^7$ V/m



The DAΦNE Beam Test Facility



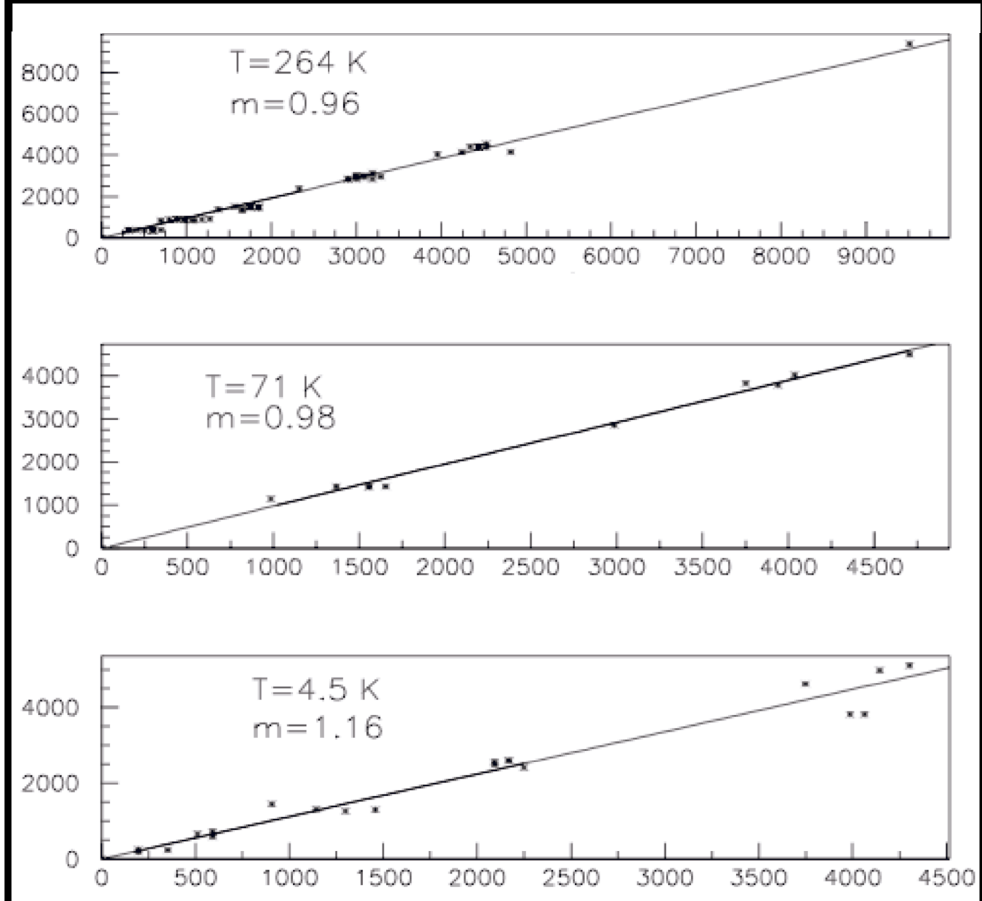


Measurement with Al5056 Antenna

Normal Conducting State

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

$$B_{MEAS} = mB_{TH}$$



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

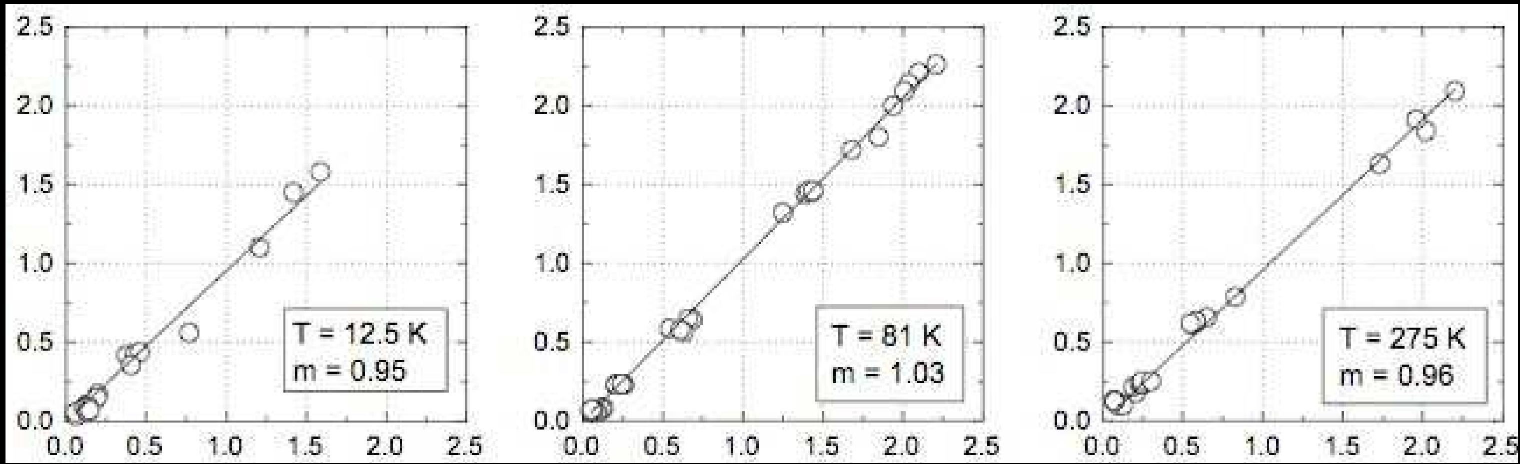
Europhys. Lett. **76**, 987-993 (2006)

$$B_{MEAS} = mB_{TH}$$

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

✓Very good agreement with the model also due to the very well known thermophysical parameters of the pure Niobium as a function of the temperature

✓Linearity of the response with the energy released by the beam



Measurement with Niobium Antenna

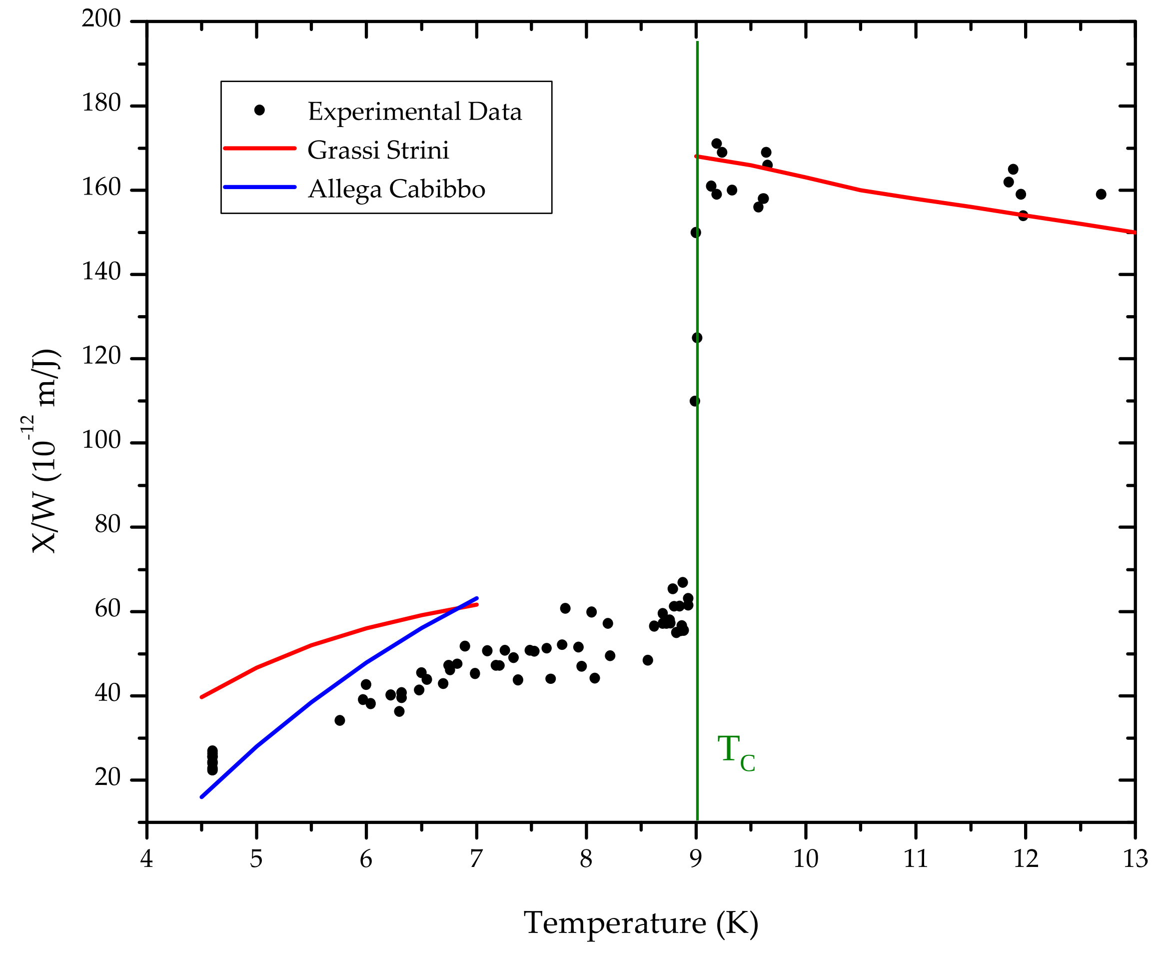
SuperConducting State

Europhys. Lett. **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 ACB model is found

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



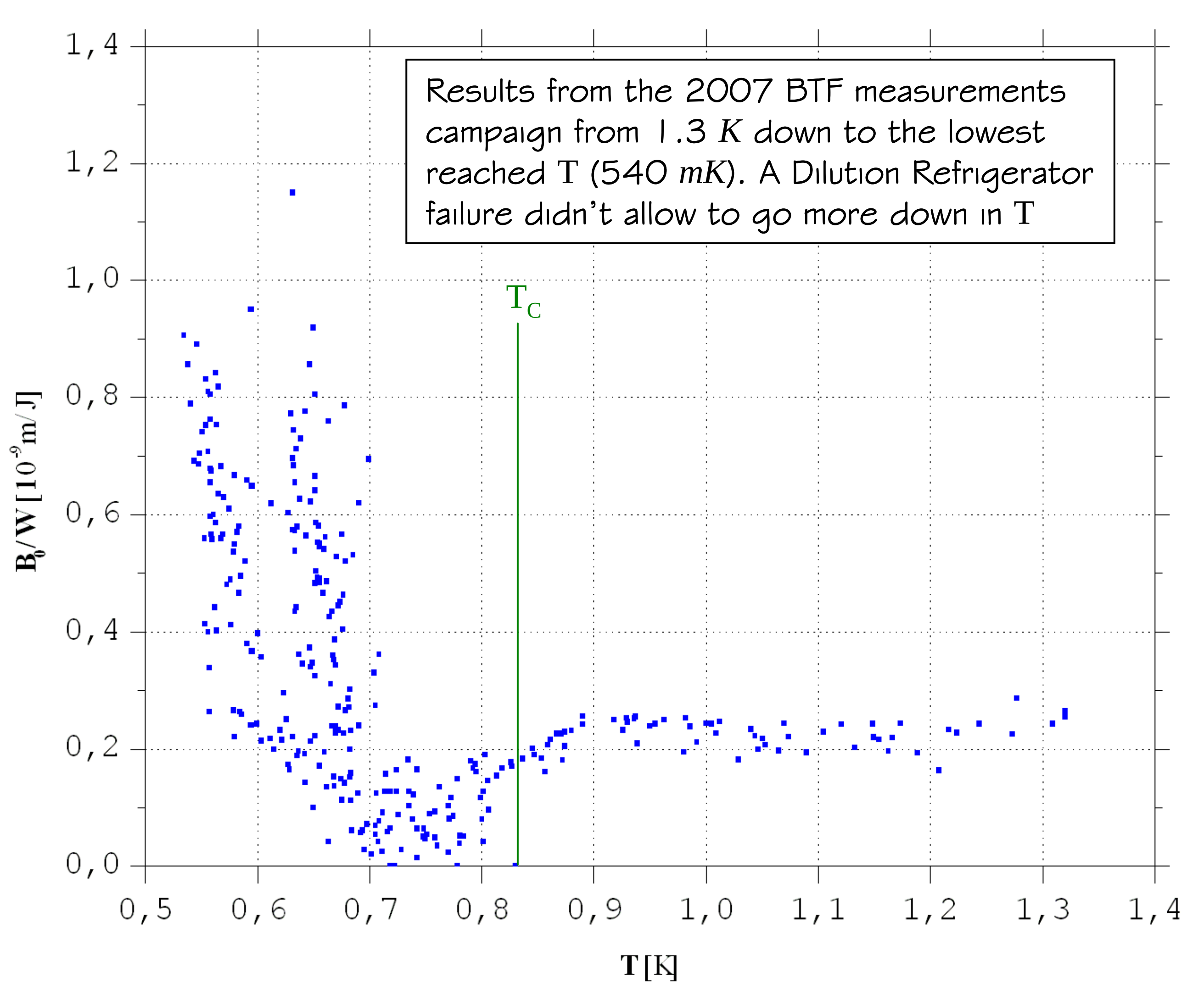
Measurement with Al5056 Antenna

SuperConducting State

✓Has been confirmed that the amplitude of the longitudinal oscillation depends on the conduction state of the material

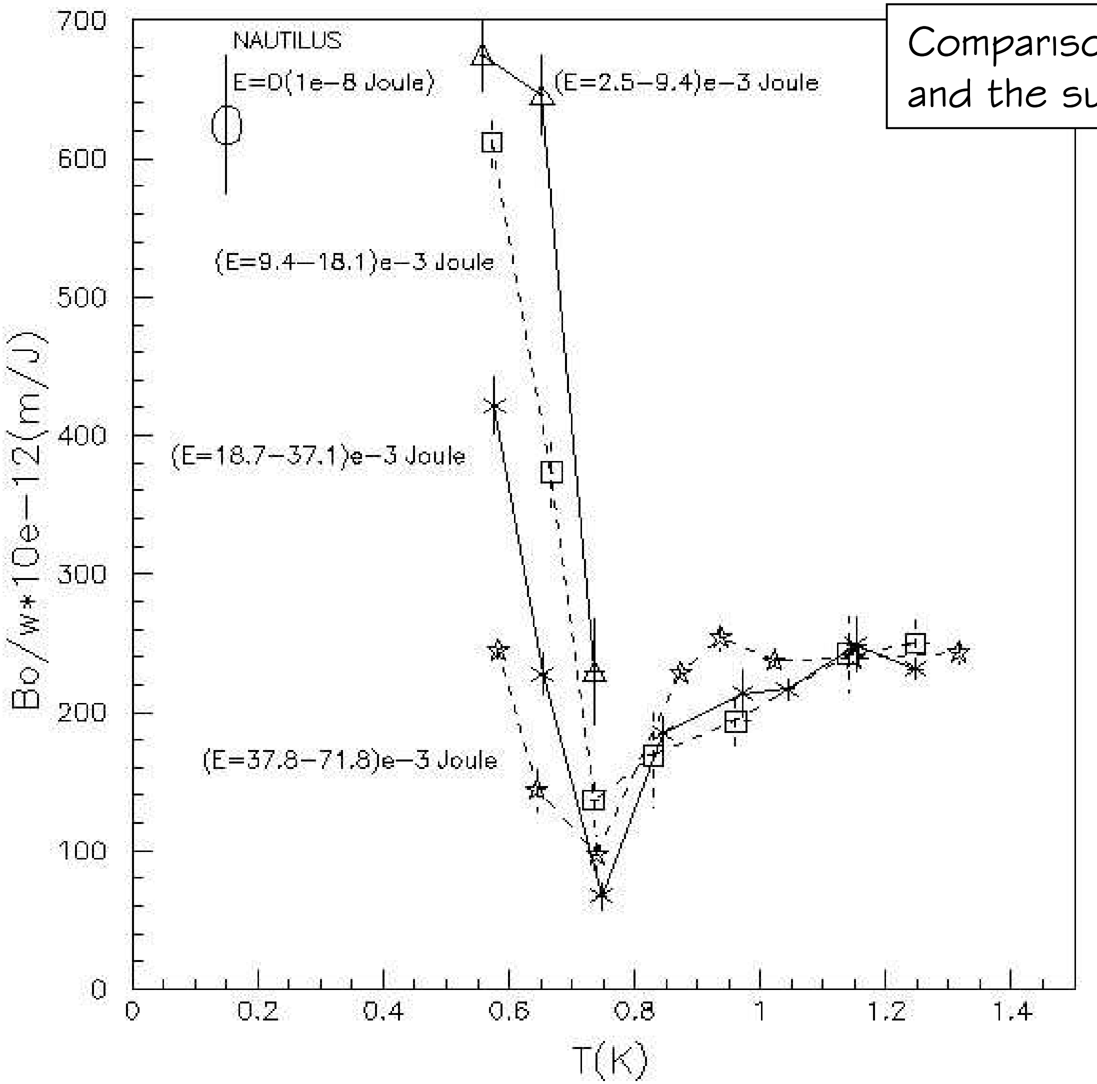
✓As predicted, there is a trend to a raising of the bar oscillation amplitude in SC state

✓However, a not explained quite complicated structure of the amplitude near the transition temperature has been observed!!



Measurement with Al5056 Antenna

SuperConducting State



Comparison between the RAP measurements and the superconducting NAUTILUS data

- ✓Single shots are grouped in different released energy ranges. In this way a released-energy-dependence has been pointed out
- ✓Measurements at the lowest T seem to be compatible with the cosmic rays NAUTILUS measure
- ✓At present the response depression at $0.7\ K < T < 0.9\ K$ has not yet well understood, even though it could be related to a two-components process

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 gave us a number of information, some of them not yet completely understood:

- The 1^{st} longitudinal mode of oscillation amplitude definitely depends on the conduction state of the material
- The Grassi-Strini Model seems to fail in the prediction in SC state. The two-components Model (Bernard) seems to be in better agreement with the data for the Nb bar. A poor knowledge of the thermophysical parameter of the Al5056 does not allow to give a final result. It must be also stressed that the model should in principle be applied only to pure materials!
- Al5056 measurements at the lowest T seem to be in a qualitative agreement with the NAUTILUS data
- The Al5056 data shows some unpredicted behaviour, such as a non linear dependence of the oscillation amplitude from the released energy in the SC state.

→ *Measurements at $T << T_C$ might help to improve our knowledge of the bar behaviour in SC state, and might give information about the open tasks*