B. Buonomo, G. Delle Monache, D. Di Gioacchino, V. Fafone, C. Ligi, A. Marini, G. Mazzitelli, G. Modestino, G. Pizzella, L. Quintieri, F. Ronga

R. Lenci and DAΦNE Cryogenic Group

INFN – Laboratori Naz. di Frascati

In collaboration with:
INFN – sez. di Roma2
Univ. di Roma Tor Vergata
Kamerlingh Onnes Laboratory, Leiden Univ.

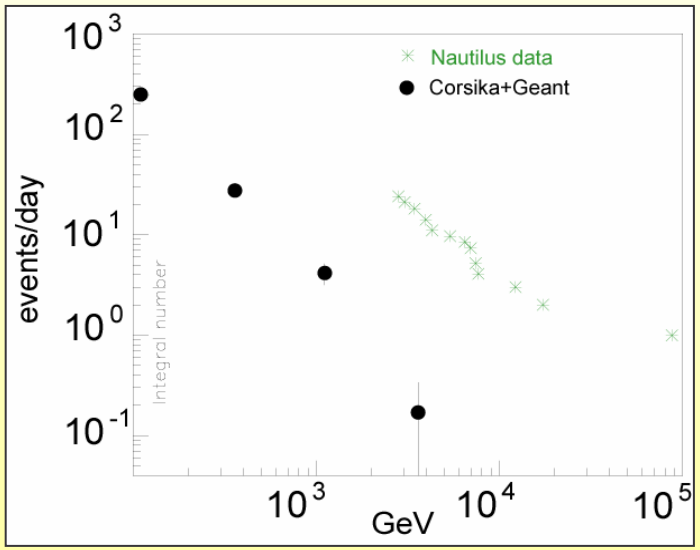
RAP is partially supported in the framework of the ILIAS/STREGA E.U. program (6th F.P.)

STREGA (Study for Thermal Noise Reduction for European Gravitational wAve detectors) is a 5-years mission that wants to coordinate many labs in different projects in the study on thermal noise research (CNRS, INFN, IFN, Leiden Univ., Glasgow Univ.)

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



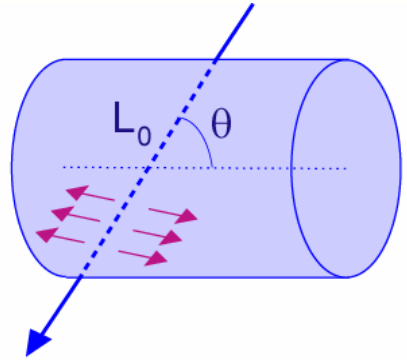
Green: NAUTILUS measurements
Black: expected data for the hadronic component with the Thermo-Acoustic model

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 structure
→ $\varepsilon = -0.04$

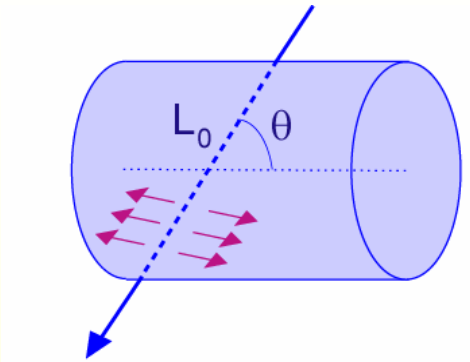
Grüneisen parameter (γ)

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

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

Scientific Motivations

Thermo-acoustic model
In superconducting state?



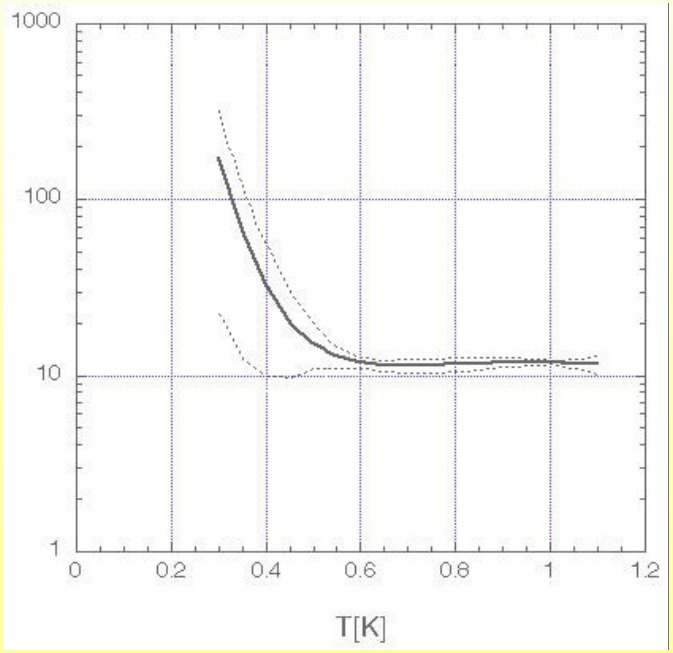
$$r = \sqrt{\frac{dW/dx}{\pi C_V \rho \Delta T}} \approx 100 \text{ Å (per Al)}$$

$$\Rightarrow \Delta T \approx 30 \text{ K}$$

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

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 $T < 1$ K *(see the figure)*

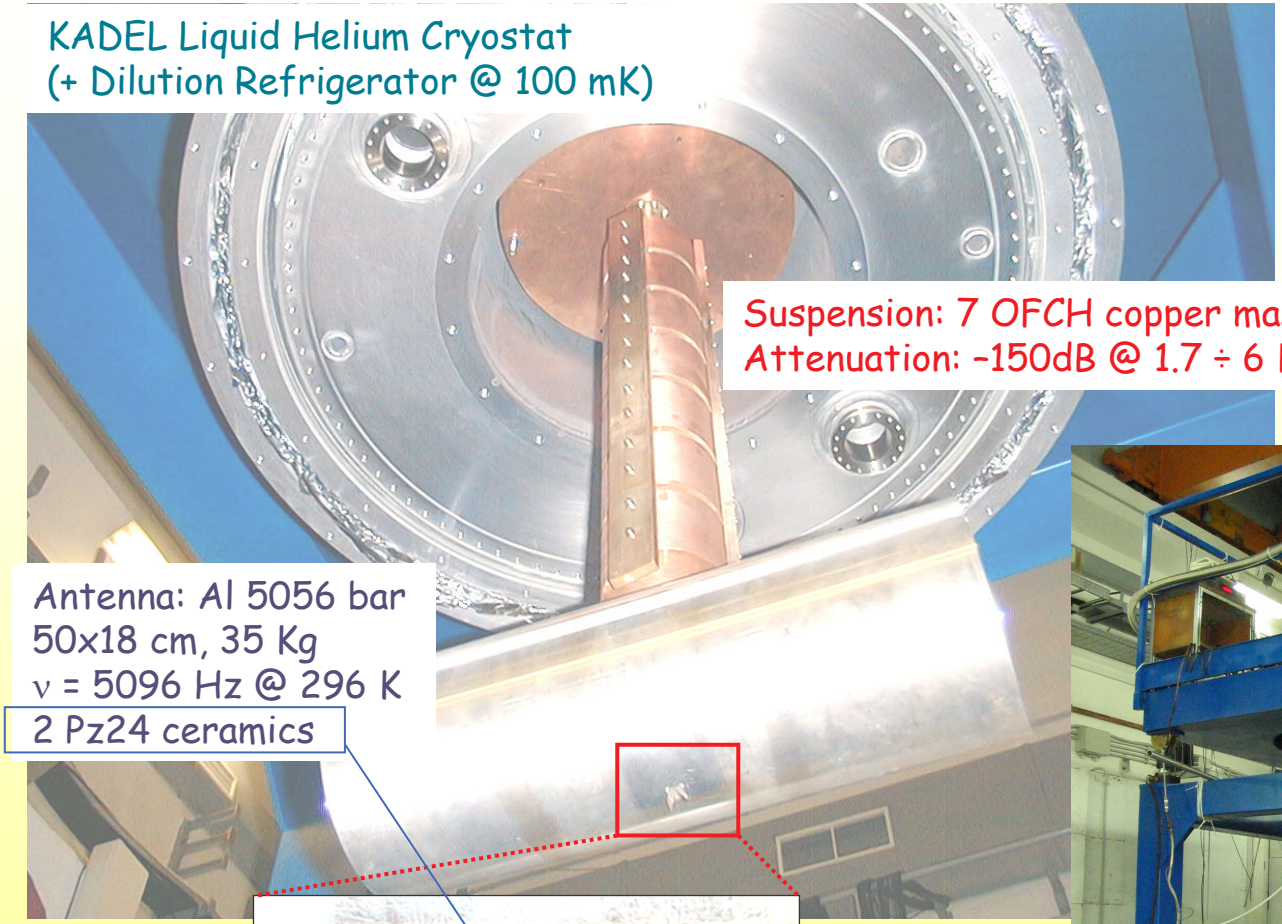
Measurement is needed!



Expected $\left|\gamma_s^e\right|$ *vs T*

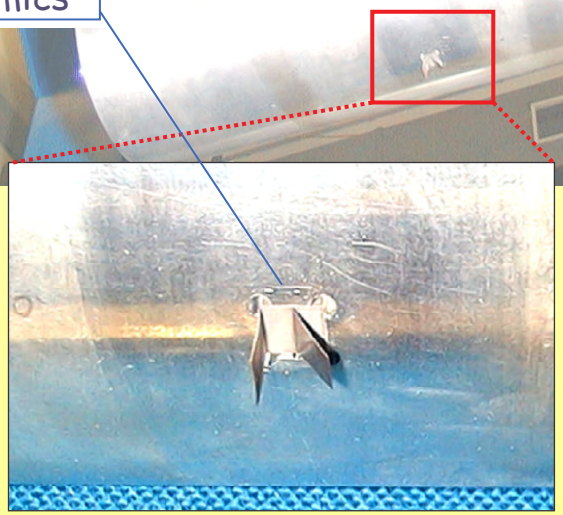
Experimental Setup

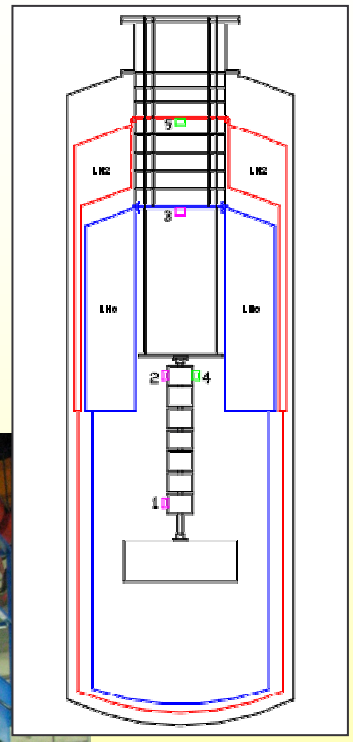
KADEL Liquid Helium Cryostat
(+ Dilution Refrigerator @ 100 mK)



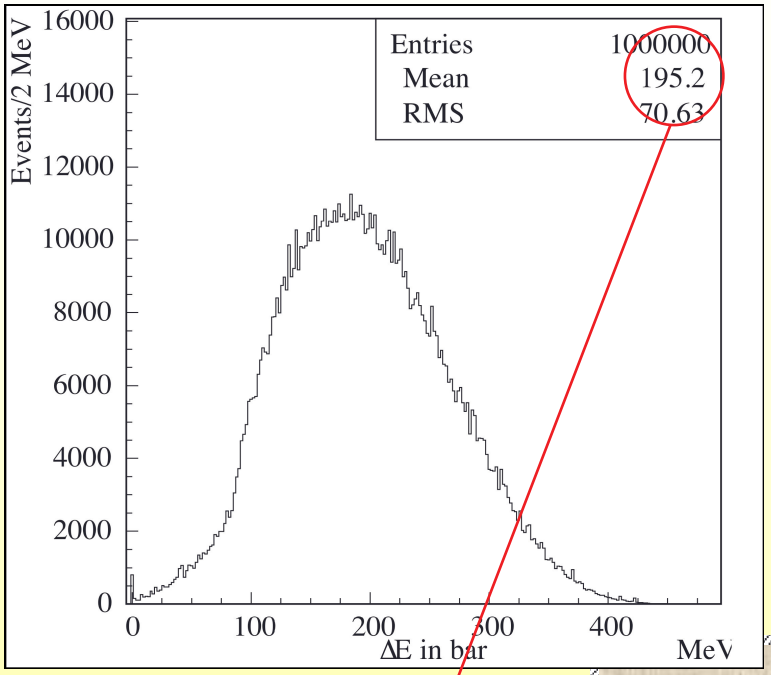
Suspension: 7 OFCH copper masses
Attenuation: -150dB @ 1.7 ÷ 6 KHz

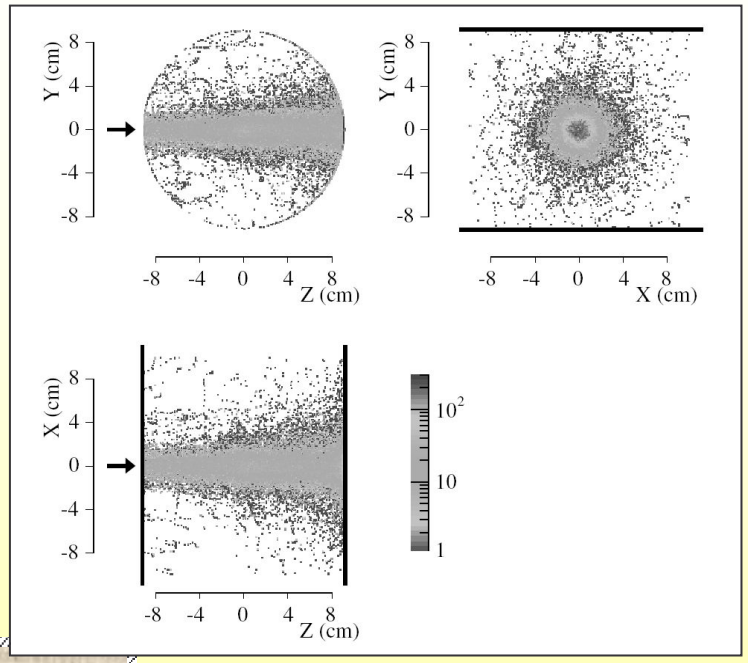
Antenna: Al 5056 bar
50x18 cm, 35 Kg
ν = 5096 Hz @ 296 K
2 Pz24 ceramics





Beam Interaction Simulations



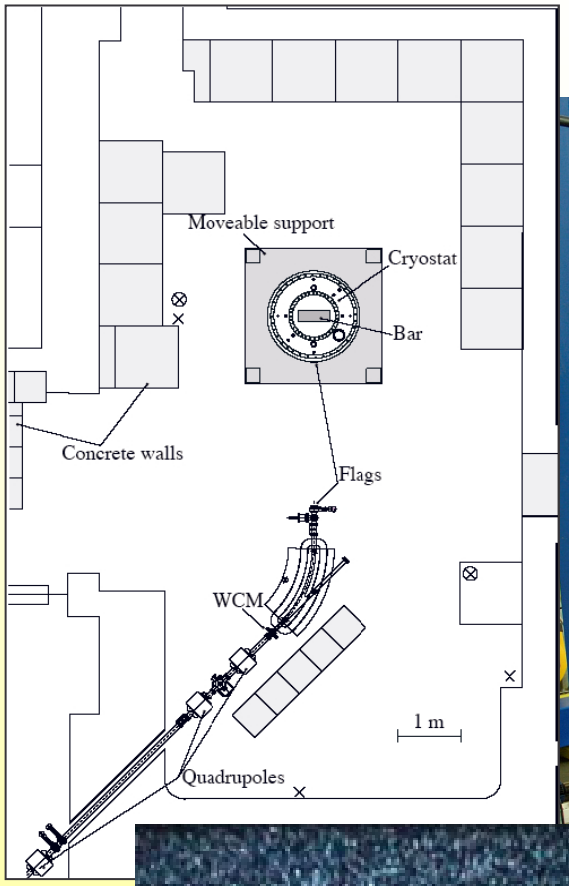


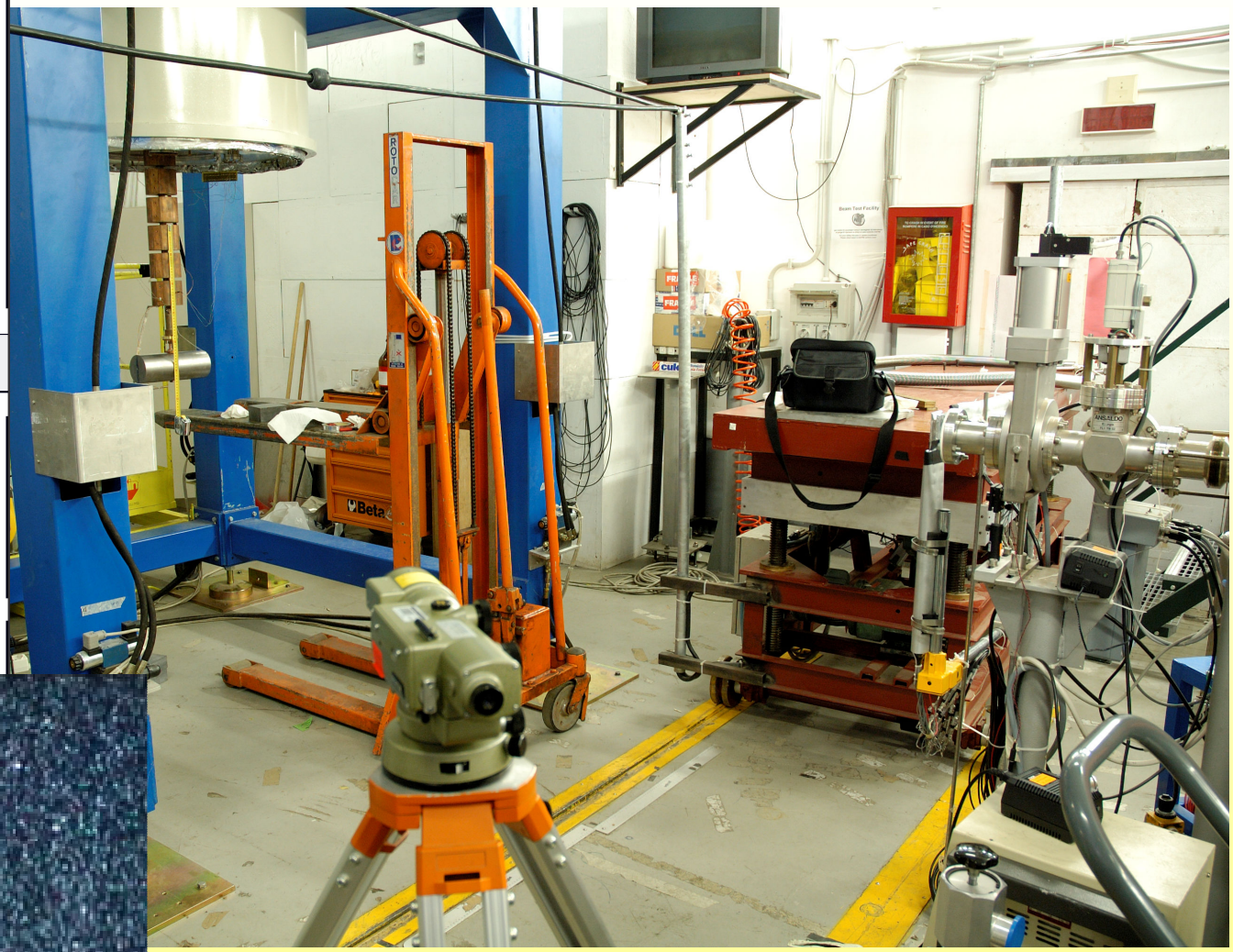
Monte Carlo simulations

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

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

DAΦNE BTF Run



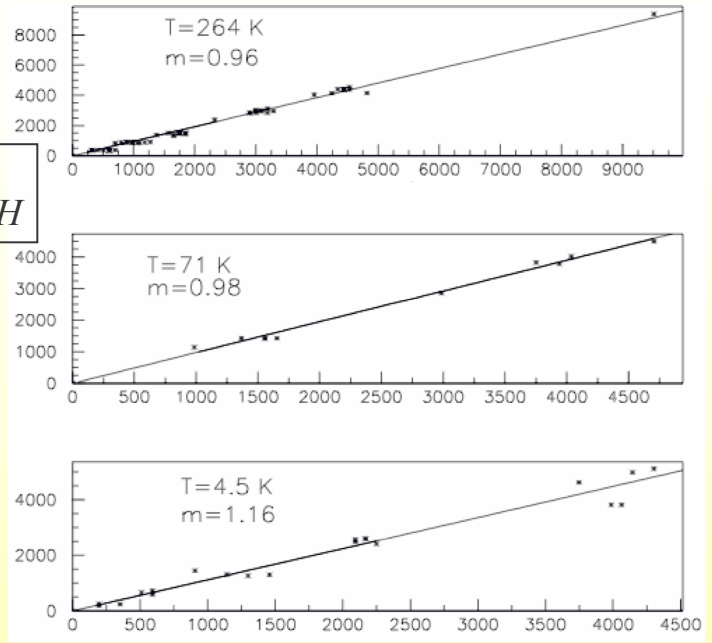


Al5056 Measurement Results

Devices systematic accuracy

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

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



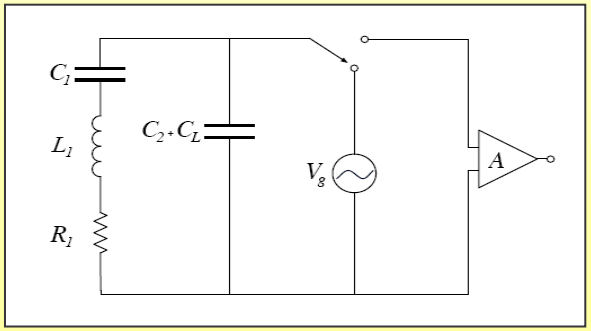
B_{MIS} vs B_{TH} (10^{-16} m)

PZ24 Calibration

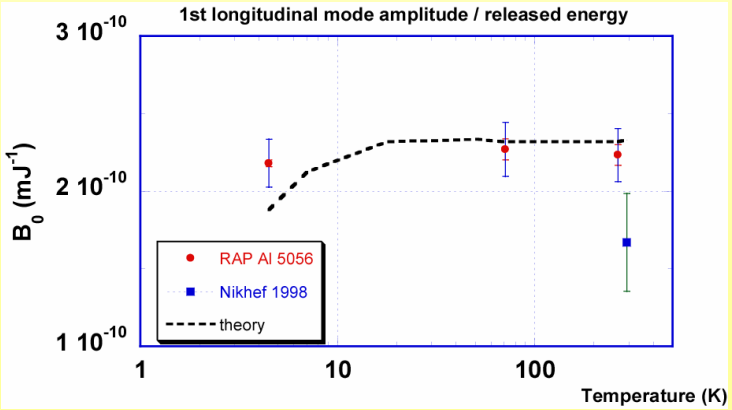
$$B_{mis}[m] = \frac{V}{\lambda}, \quad \lambda = \sqrt{\frac{2\pi f_0 M V_0}{(C_2 + C_L) V_g \Delta t}}$$

$$V \approx 10^{-6}\ \text{V}$$

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

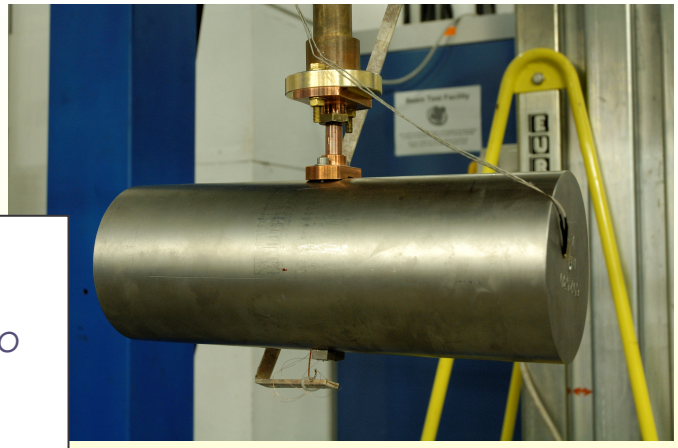


the auto-calibration method shows good agreement with a calibrated accelerometer

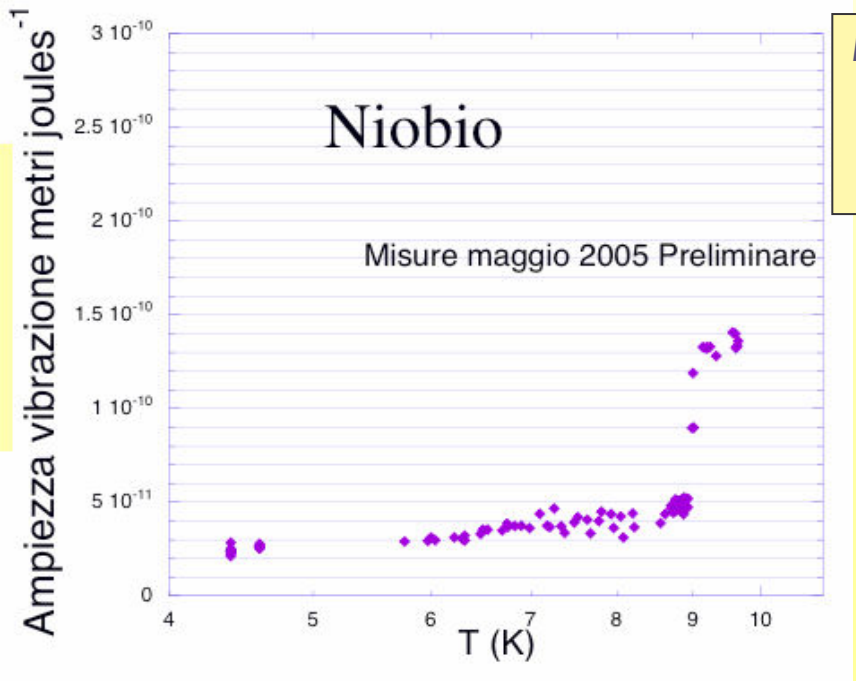


Niobium Measurement Results

Due to the delay in the dilution refrigerator delivery, we decided to make measurement with a material different from Aluminum. We then tried to use a Niobium bar (T_c = 9 K)
(note that Nb is a type II superconductor, while Al is a type I SC!)



- *27.4x10 cm*
- *f(1 long.) = 6373 Hz @ T = 290 K*
- *2 PZ ceramics in parallel glued to the bottom center*
- $\lambda \sim 10^6\ Vm^{-1}$



Expected B_0:
- *B_0 (T=10 K) = 1.8 10^{-10} mJ^{-1}*
- *B_0 (T=8 K,normal c.) = 2.0 10^{-10} mJ^{-1}*
- *B_0 (T=8 K,superc.) = 0.7 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 $T < T_c$

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 (α is never measured at ultralow temperature).*

Measurements with Niobium:

- ✓ *data analysis is in progress.*
- ✓ *from the on-line data an evidence of the transition (not expected!) can be seen.*

Next steps…

- ✓ *Publication of the Niobium measurements.*
- ✓ *Measurements with Al5056 in superconductive state (we are waiting for the dilution refrigerator…)*

Publications (end 2004 – early 2005)

Particle acoustic detection in gravitational wave aluminum resonant antennas,
RAP Collaboration – ***Astroparticle Physics***
Accepted

RAP - Acoustic Detection of Particles: First Results at 4.2 K
RAP Collaboration – IJMPA (Proc. Of 19th ECRS Conf.)
Accepted

Conferences (end 2004 – early 2005)

C. Ligi – LTD11 Conf. 2005 (Tokio)
G. Mazzitelli – Amaldi6 Conf. 2005 (Okinawa)
L. Quintieri – SIF 2004 (Brescia)
C. Ligi – 19th ECRS Conf. 2004 (Firenze)

Attività prevista

- Caratterizzazione del refrigeratore a diluizione
- Misure con barra di alluminio in stato superconduttivo

Partecipazioni LNF

- Ricercatori & Tecnologi :	11 (3.8 FTE)
- Tecnici:	1 (0.2 FTE)
- Servizio criogenico di DAΦNE	12 mesi/uomo

Preventivo di spesa 2006

	Missioni est.	Mat. consumo	Trasporti e facchinaggio	Costr. apparati
Assegnazioni 2005 (K€)	4	24.5	4.5	5.5
Richieste 2006 (K€)	4	28	5	5

RAP on the WEB

www.lnf.infn.it/esperimenti/rap/