Rivelazione Acustica di Particelle

TASK M6 report: Particle Acoustic Detection

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Task M6 plan (last meeting, Nov 2004)

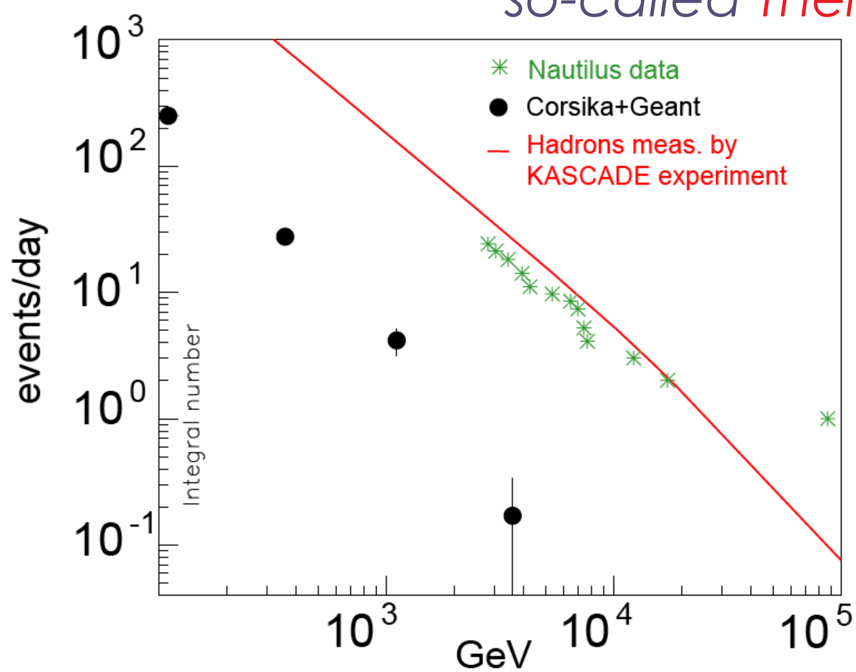
9.R3 - Table 2 – STREGA - First 18 months Implementation Plan			
Tasks and Deliverables	1^{st} To 6^{th} Month	7^{th} To 12^{th} Month	13^{th} To 18^{th} Month
WP 1 - Task M 6: Study of thermo-elastic effects caused by absorption of cosmic rays			
Tasks:			
6.1 - Modification of the cryogenic facility in Frascati	completed		→ waiting for refrigerator
6.2 - Design and implementation of the acoustic emission detector	completed		
6.3 - Room temperature acoustic measurements on Al		completed	
6.4 - Starting of low T measurements on Al and Si			started
Deliverables:			
- Modified cryogenic facility in Frascati operative - Report on room temperature measurements on Al using an electron beam		In progress	

Task M6 have completely achieved the milestones. We have already started part of the low temperature measurements, and by the beginning of 2005 we will start the ultralow temperature test and final measurements.

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 (task M6)*

Scientific Motivations

Thermo-acoustic model for cylindrical bars

CR crossing the antenna loss energy

→ *warming up of the material*

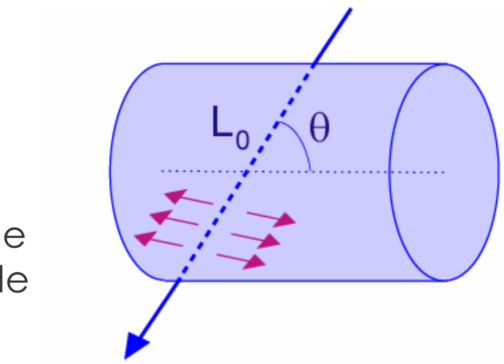
↓

local thermal expansion

↓

mechanical vibrations

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



The amplitude of the 1[st] 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

→ ε = – 0.04 for Al

→ ε = – 0.08 for Nb

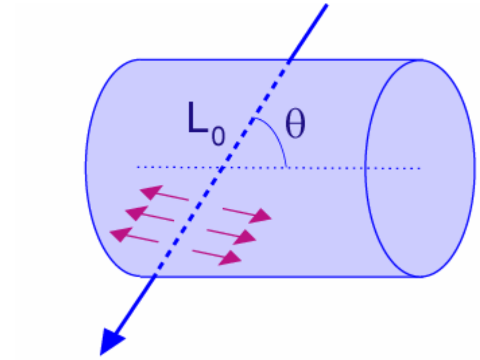
Grüneisen parameter (γ)

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

Scientific Motivations

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

Thermo-acoustic model
In superconducting state?



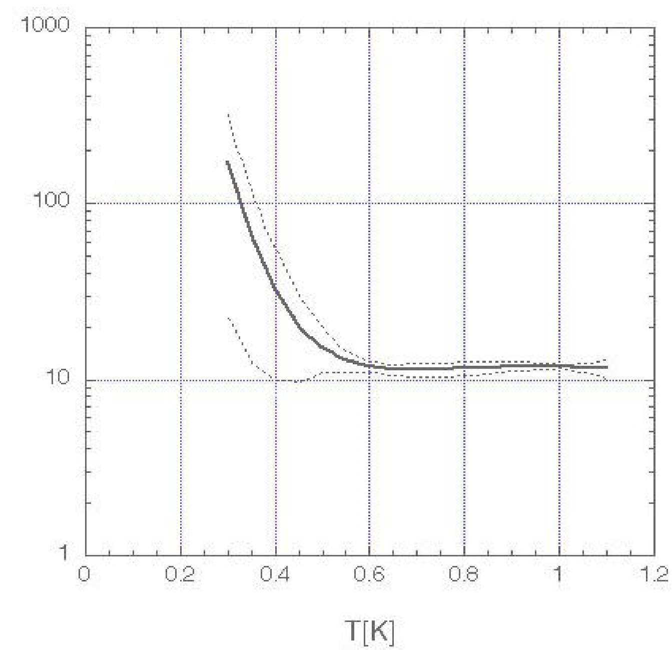
$$r = \sqrt{\frac{dW/dx}{\pi C_V \rho \Delta T}} \approx 100\ \mathring{A}\ \text{(per Al)} \quad \Rightarrow \quad \Delta T \approx 30\ \mathrm{K}$$

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)

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

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)

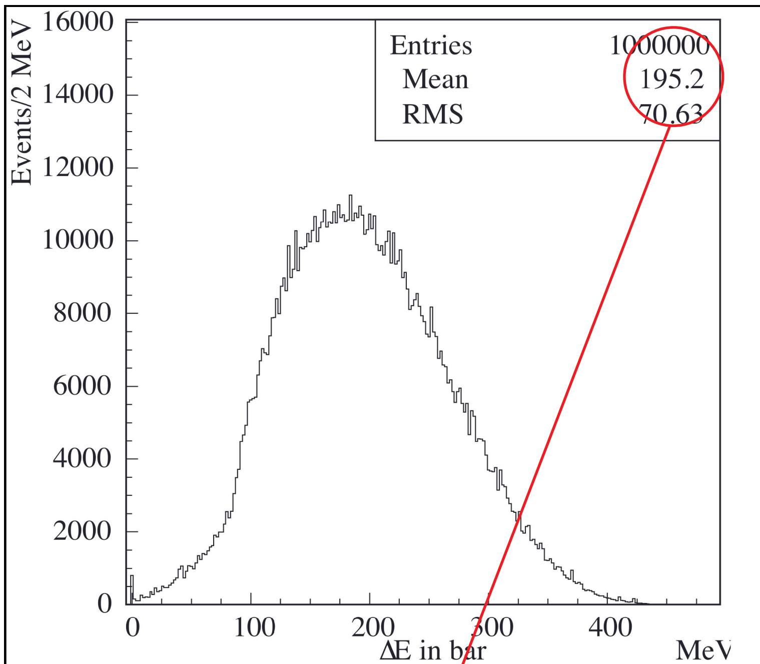
Measurement is needed!

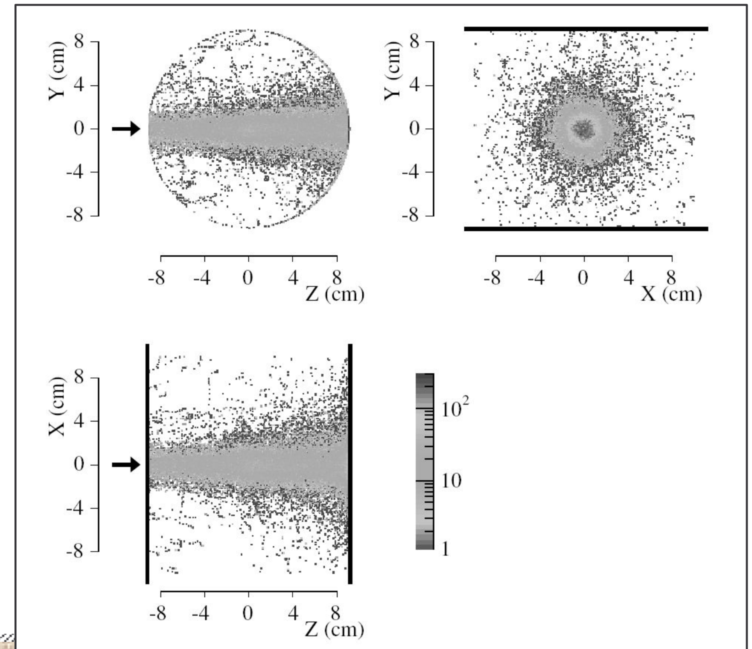


Expected $|\gamma_s^e|$ vs T for pure Al

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*

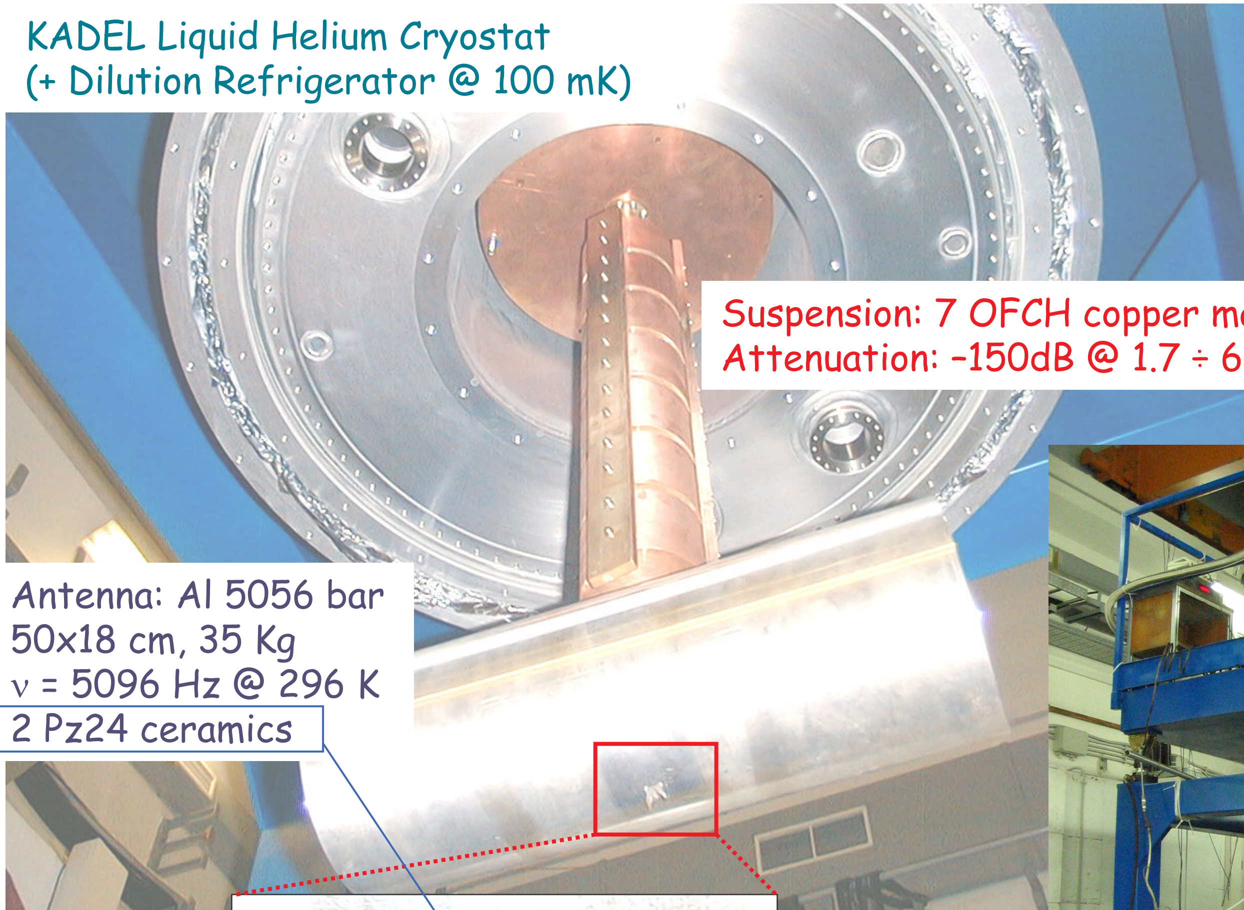
$$\langle \Delta E \rangle \pm \sigma_{\Delta E} = 195 \pm 70 \quad \text{MeV}$$

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

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

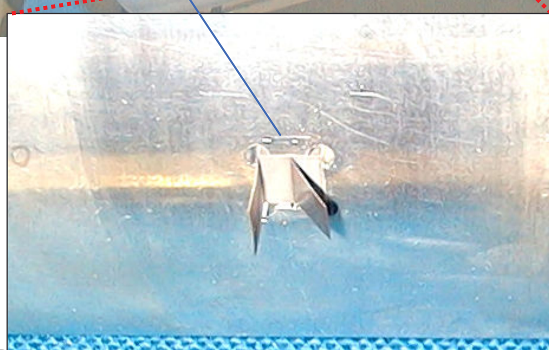
Experimental Setup

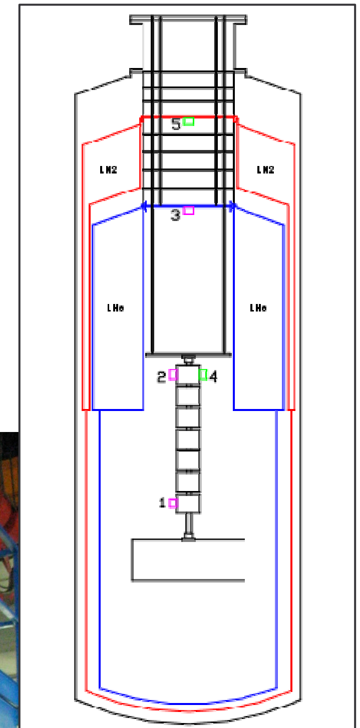
KADEL Liquid Helium Cryostat
(+ Dilution Refrigerator @ 100 mK)



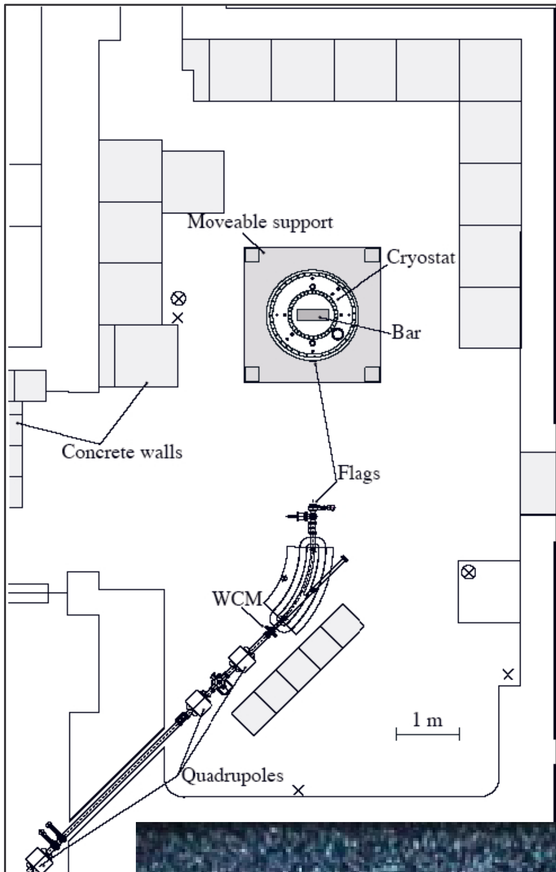
Suspension: 7 OFCH copper masses
Attenuation: -150dB @ 1.7 ÷ 6 KHz

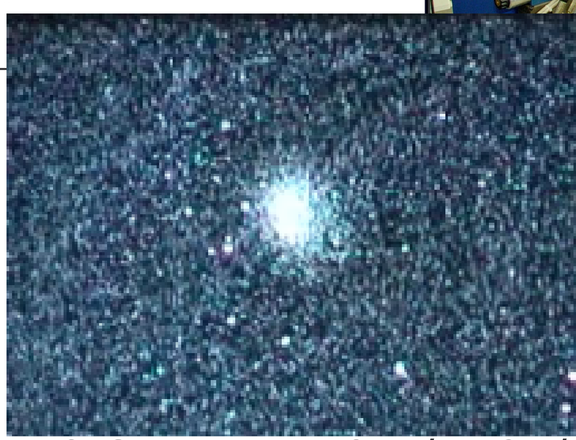
Antenna: Al 5056 bar
50x18 cm, 35 Kg
ν = 5096 Hz @ 296 K
2 Pz24 ceramics





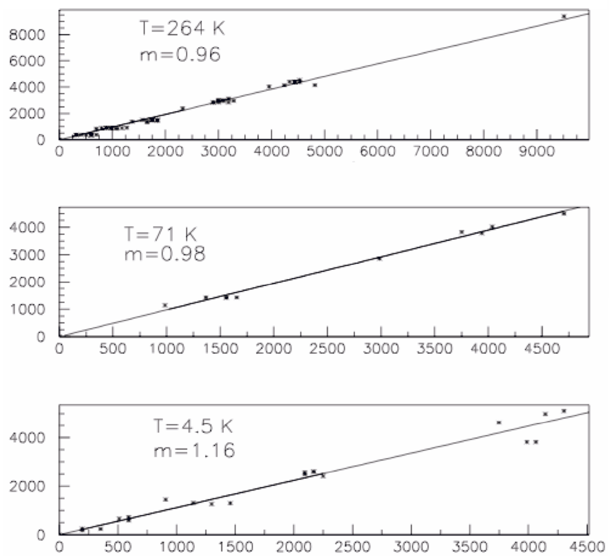
DAΦNE BTF Run



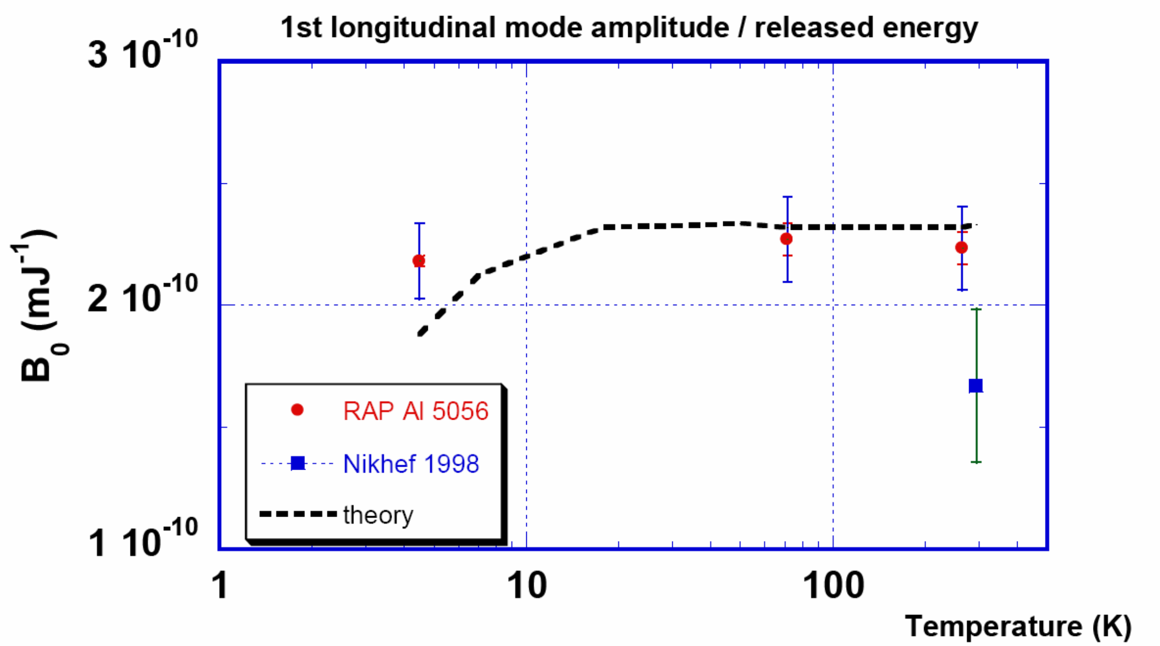


Al5056 Measurement Results
(the first measurements of thermo-acoustic model at low temperature)

Astro Particle Physics,
***24**, 65-74 (2005)*



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



Devices systematic accuracy

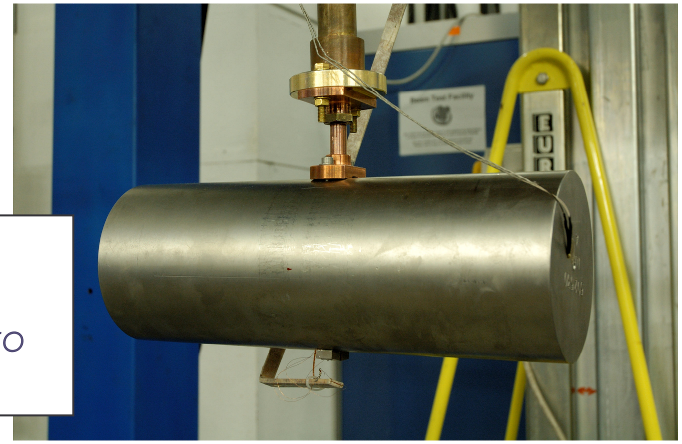
- ***Beam monitor: 3%***
- ***PZ24: 6%***
- → ***Total = 7%***

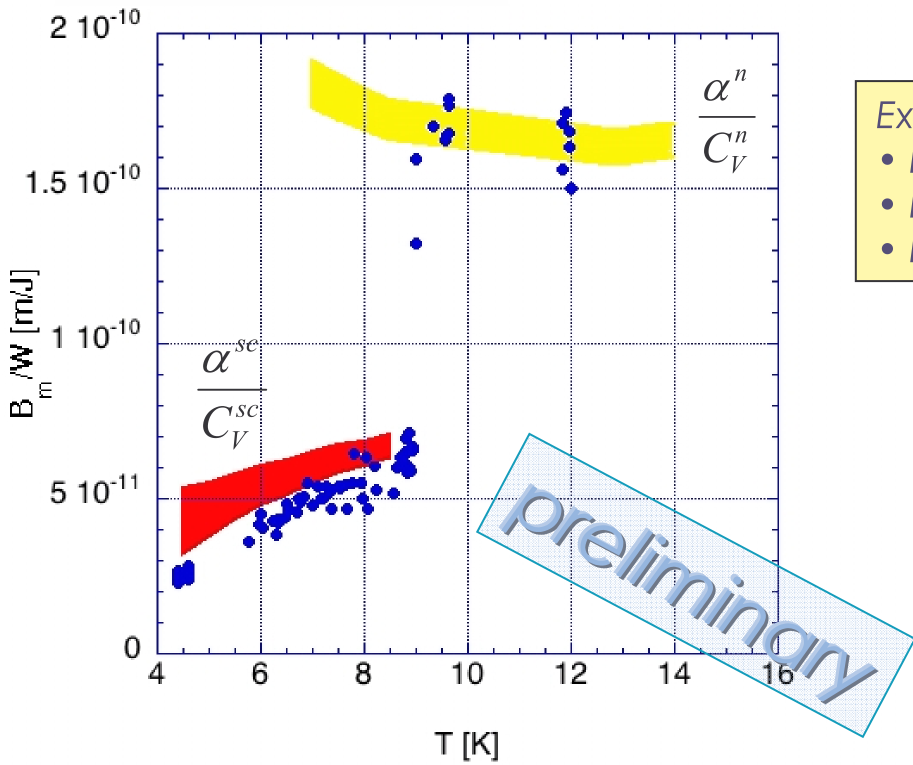
Niobium Measurement Results

(the first measurements of thermo-acoustic model in superconducting state)

$T[K]$	$f_o[Hz]$	$\tau_o[s]$	$\lambda[10^6 V/m]$
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*



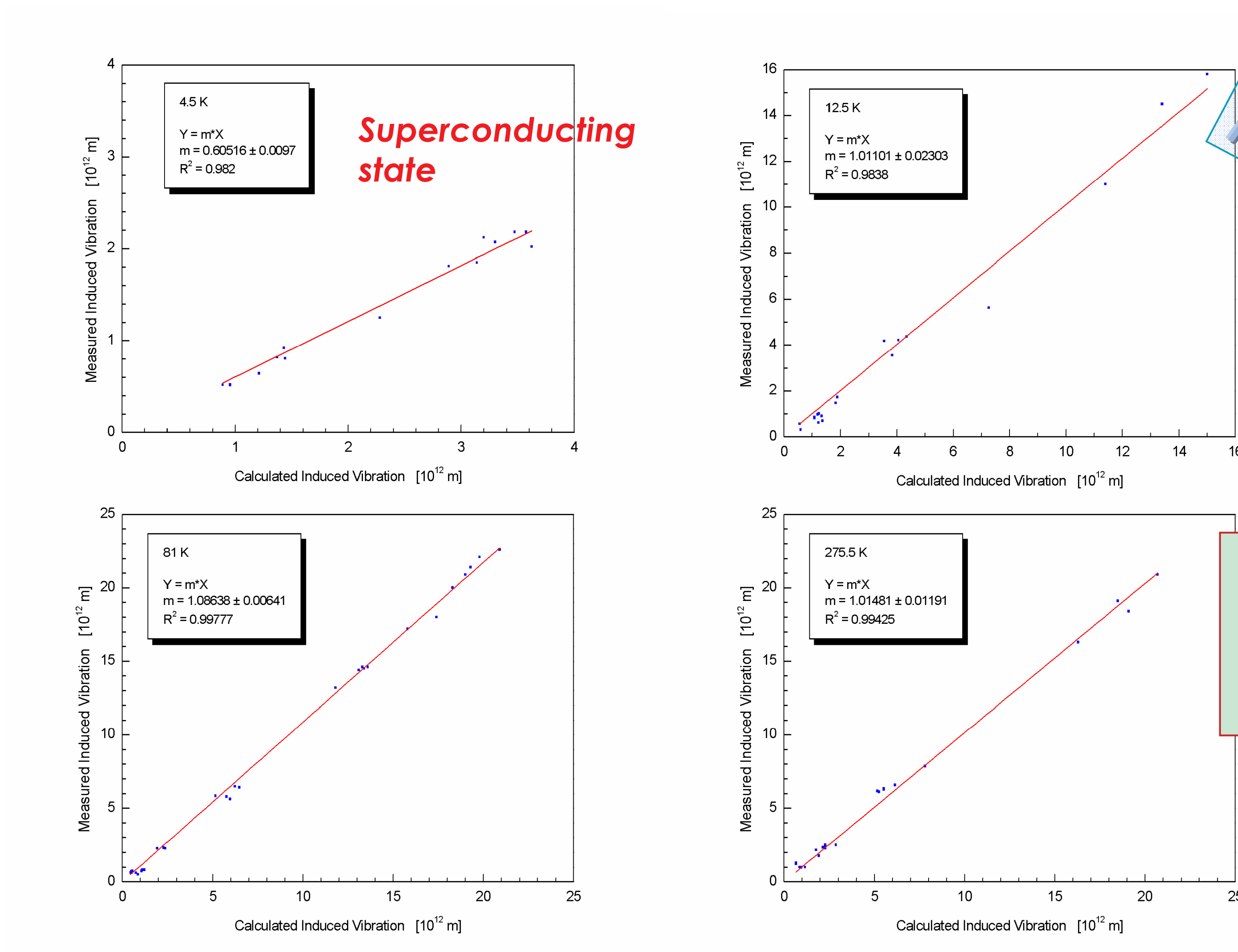


Expected B_0:
- *B_0 (T=10 K) = 1.7 10^{-10} mJ^{-1}*
- *B_0 (T=7 K,normal c.) = 1.8 10^{-10} mJ^{-1}*
- *B_0 (T=7 K,superc.) = 0.6 10^{-10} mJ^{-1}*

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)

Task M6 implementation plan

9.JRA3 - Table 2 - months 13 to 30 Implementation Plan			
Tasks and Deliverables	13th to 18th month	19th to 24th month	25th to 30th month
WP 1 - Task M 6: Study of thermo-elastic effects caused by absorption of cosmic rays			
Tasks:			
6.1 **- Modification of the cryogenic facility in Frascati , installation of the dilution refrigerator**	→ Still waiting for refrigerator…		
6.2 **- Design and implementation of the acoustic emission detector**	ENDED		
6.3 **- Room temperature acoustic measurements on Al**			
6.4 **- Low T measurements on an Al bar**	4K done: first measurements of Thermo acoustic effect at low temperature → <1K delayed		
6.5 **- Design and implementation of the acoustic emission detector for measurements on a Nb bar**	ENDED		
6.6 **- Design and implementation of the acoustic emission detector for measurements on Si and Cu bars**			
Deliverables:			
- Report on low temperature measurements on Al using an electron particle beam		partially done	

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 behavior of the Al material in superconducting state*

(WARNING: the deliverable must be achieved before the end of march 2006)

Measurements with Niobium:

✓ *Results show good agreement with the Thermo-Acoustic model in the 10-300 K range.* ***Data in superconducting state show a behavior not expected: superconducting parameters should be apply in the Thermo-Acoustic model***

Next steps…

✓ *Publication of the Niobium measurements.*

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

RAP on the WEB

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

spare

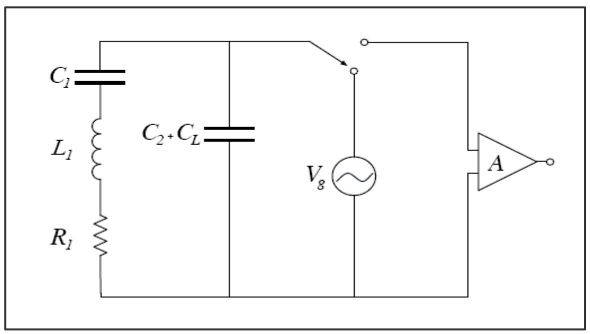
Calibration

PZ24 Calibration

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

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

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



1. Auto-calibration: a well known signal is apply to the bar via the PZ. The procedure has been applied to any data taking at any temperature
2. Accelerometer calibration: an accelerometer, mounted at the end of the bar is exited by a know signal the procedure as been used only at room temperature

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

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

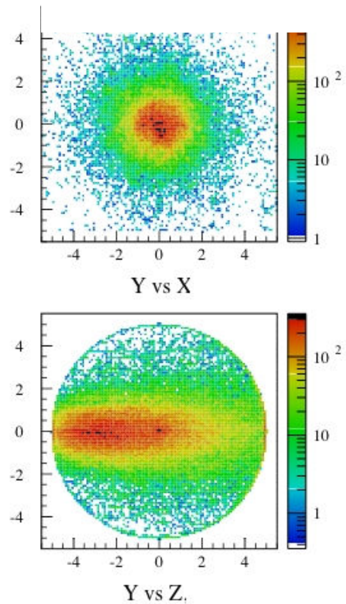
Misure con barra Nb nell'intervallo 4-275 K

Caratteristiche barra:
Nb (purezza >99%)
Ø 0.100 m, lunghezza 0.274 m, massa 18.4 kg)

$T[K]$	$f_o[Hz]$	$\tau_o[s]$	$\lambda[10^6 V/m]$
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

MC simulation and B_{th}

Longitudinal shower development



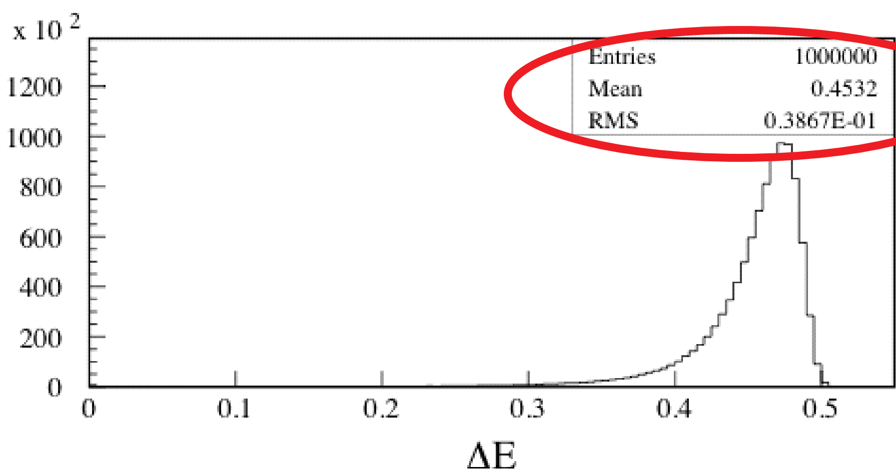
beam →

~ 9 r.l.
r.l.(Nb)=1.1 cm

$$W = N < \Delta E > \ , \ \sigma_W = \sqrt{N} \ \sigma_{\Delta E}$$

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

Energy lost per electron

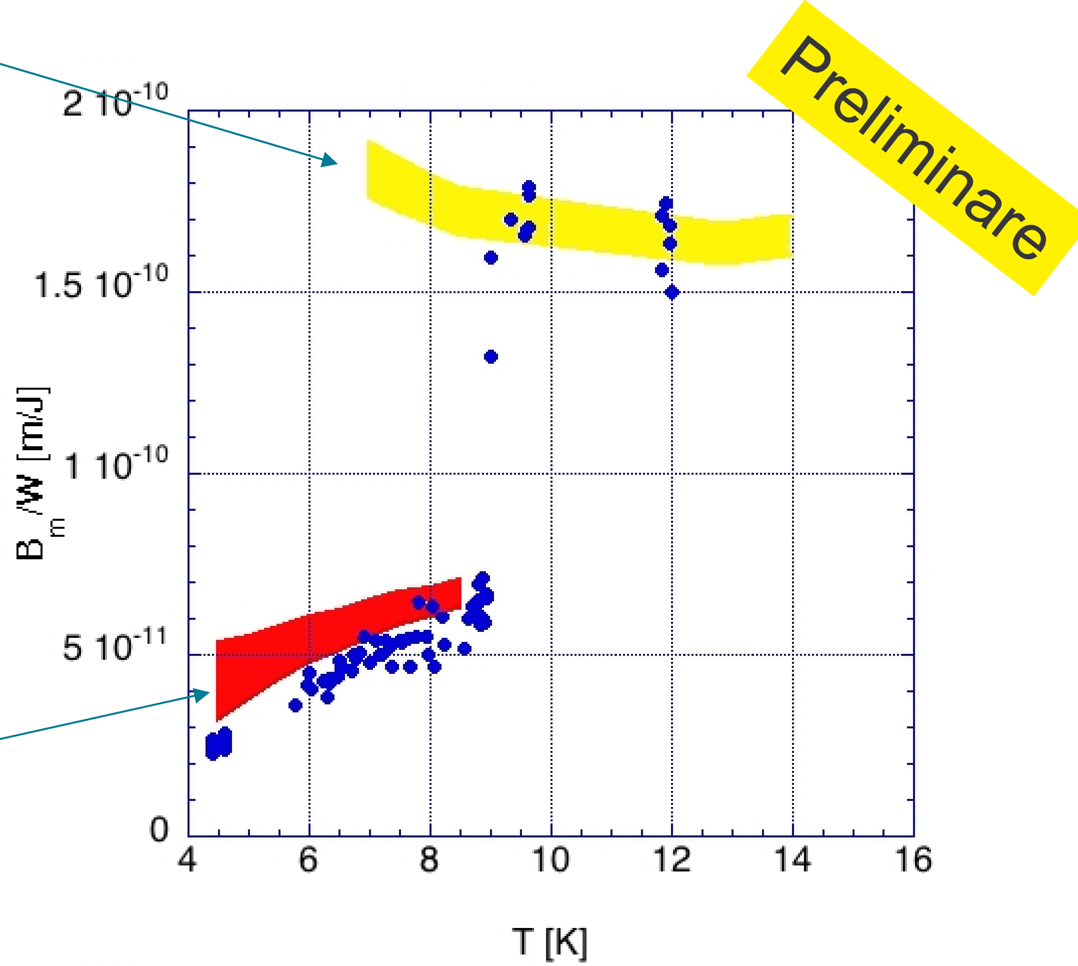


$$B_{th} = B_0 \ (1 + \epsilon)$$

Da MC: ε = -0.08

Nb - Misure a bassa temperatura

proporzionale a $\frac{\alpha^n}{C_V^n}$



proporzionale a $\frac{\alpha^{sc}}{C_V^{sc}}$

4-275 K

$B_{mis}=m(B_0*0.92)$ →

T(K)	m	Δm
275.5	1.01	0.01
81.0	1.09	0.01
12.5	1.01	0.02
4.5	0.60	0.01

Preliminare

$$\gamma_{mis} = 3\left(\frac{\alpha}{c_V}\right)_{mis} K_T V_m$$

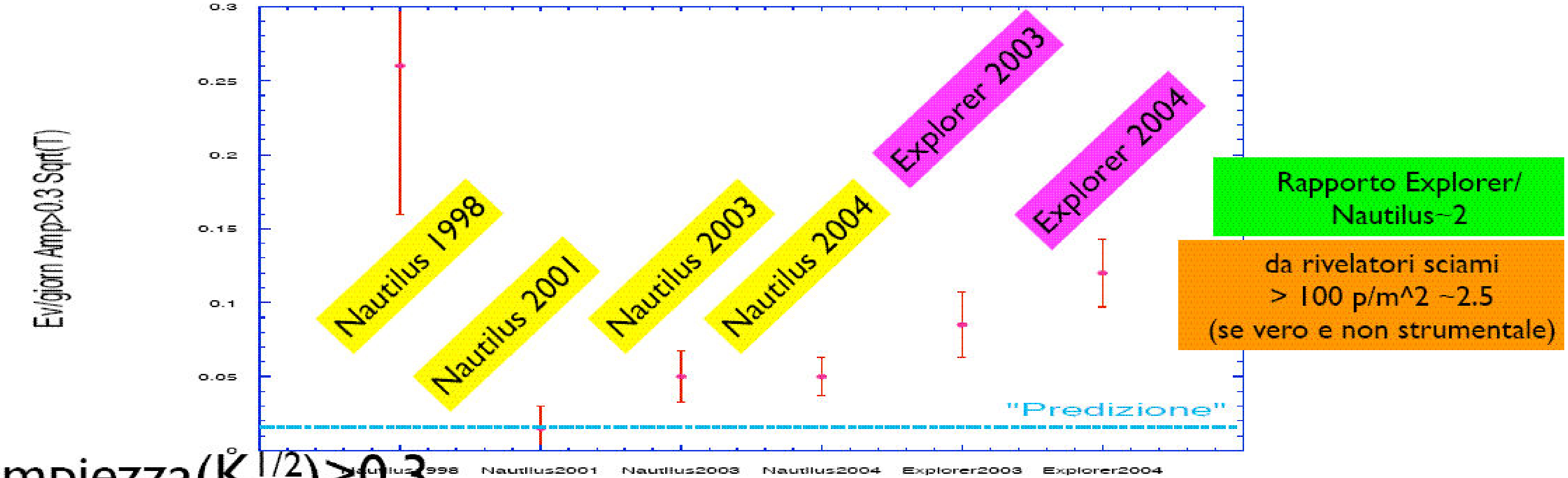
$$\left(\frac{\alpha}{c_V}\right)_{mis} = \frac{\pi M}{2L}\frac{0.92 * m * B_0}{W}$$

T(K)	γmisurato	Δ γ	Rif
275.5	1.48(n)		1.6
81.0	1.60(n)		*(1.59)*
12.5	1.00(n)		*(1.07)*
4.5	0.16(s)		0.30(*)

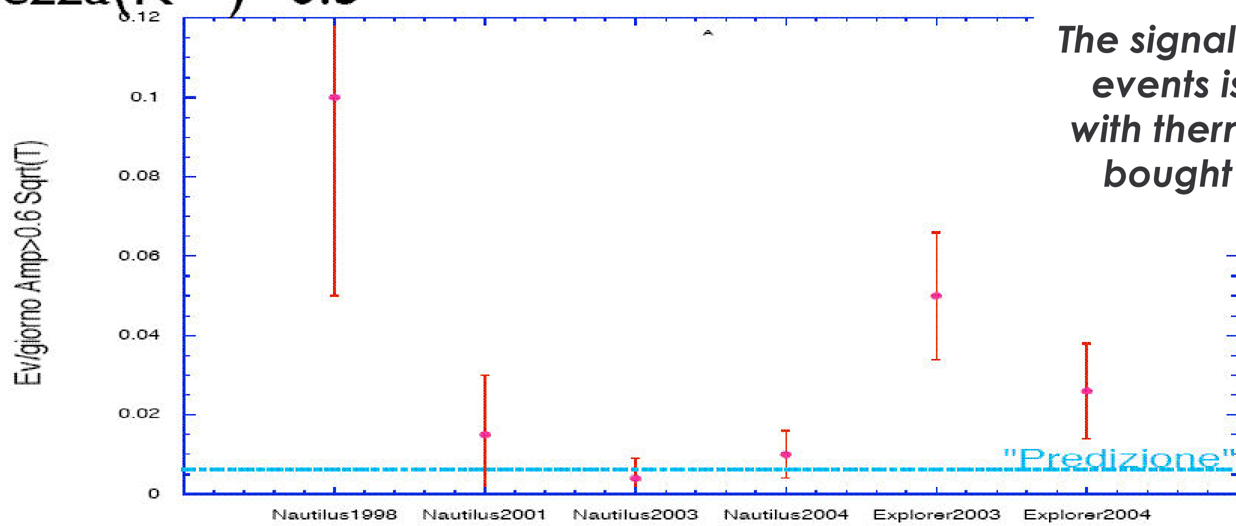
(*) γ e' definito come la media pesata sui calori specifici di γ_e e γ_l

Per lo stato normale:
$\gamma_e(T \to 0) = 1.5$
$\gamma_l(T \to 0) = 0.90$

Per lo stato SC a T=4.5 K:
$\gamma_e(4.5K) = 0$ perche' $\alpha_{e,sc} = 0$
$\gamma_l(4.5K) \sim \gamma_l(T \to 0) = 0.90$
$\gamma(4.5K) = c_{l,sc} / c_{sc} * \gamma_l = 0.33*0.90$



Ampiezza($K^{1/2}$)>0.3



The signal for small amplitude events is well in agrement with thermo-acoustic model bought for NAUTILUS and EXPLORER

Ampiezza($K^{1/2}$)>0.6