# RAP-RD

# Acoustic Detection of Particles at the DAFNE Beam Test Facility (BTF)

Rivelazione Acustica di Particelle

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*In collaboration with :*
*Kamerlingh Onnes Laboratory, Leiden Univ.*

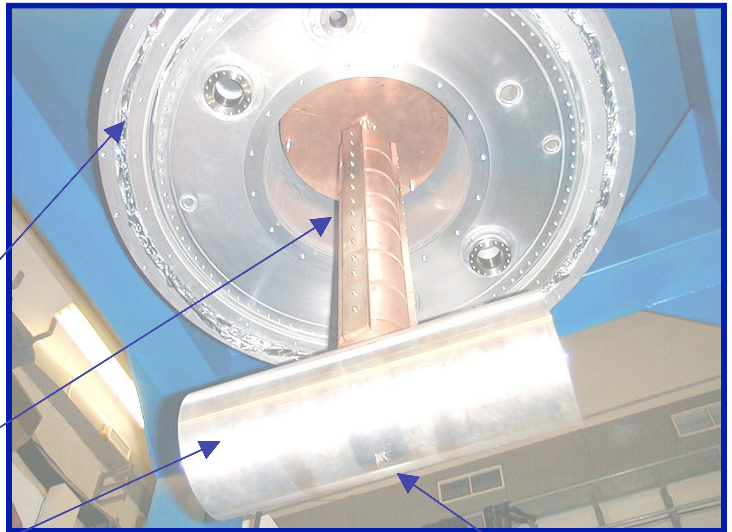
Goal of the experiment :

To measure the amplitude X of the first longitudinal mode of vibration of a suspended bar, when it is excited by the interaction with a beam of electrons .

Motivation:

The rate of high energy cosmic rays detected by the NAUTILUS g.w. antenna, when operating in superconducting regime (T=0.14K), turned out to be larger than the rate detected in the normal conducting regime.

The test masses for RAP can be operated both above and below the transition temperature $T_c$ , in order to verify whether the amplitude of oscillation depends on the conduction state of the material.



# Highlights of previous activity

❖ Thermoelastic models (Grassi Strini et al., Liu and BarishAllega, Cabibbo; De Rujula, Laudrup et al.) for excitation of vibrations is well validated above $T_c$

## Niobium bar – Normal state

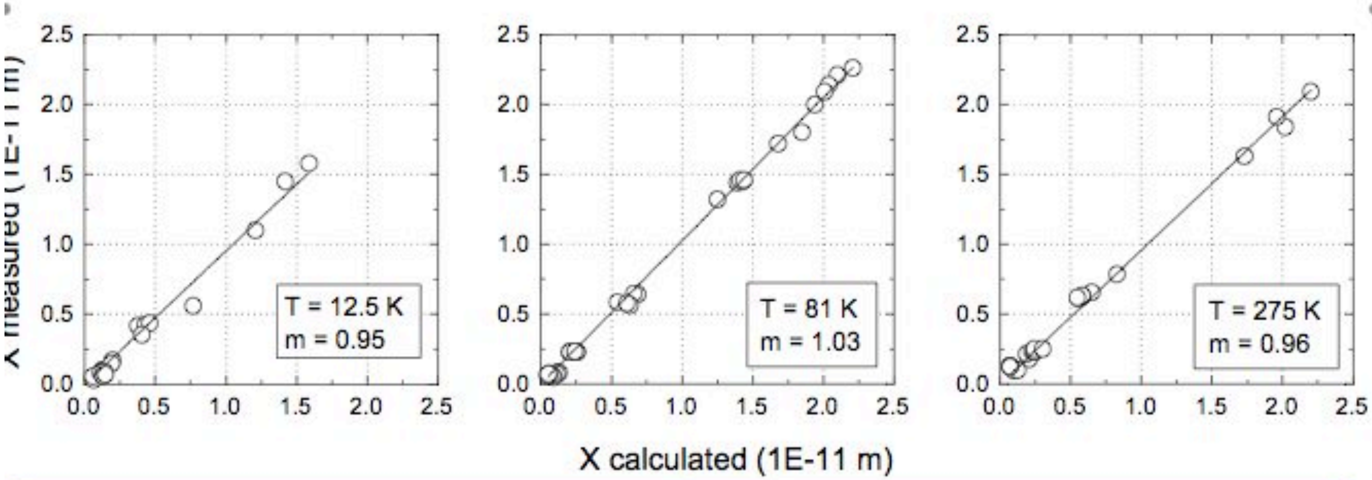
RAP

Europhys. Lett., 76 (6), pp. 987-993 (2006)

- 0.274 m long, 0.1 m in diameter, mass of 18.44 kg
- Critical temperature around 9 K

$$X_{\text{measured}} = m X_{\text{calculated}}$$

| T [K] | m | Δm |
|---|---|---|
| 275 | 0.96 | 0.01 |
| 81 | 1.03 | 0.01 |
| 12.5 | 0.95 | 0.02 |



# Activity since last meeting (Nov 2006- Jul 2007)

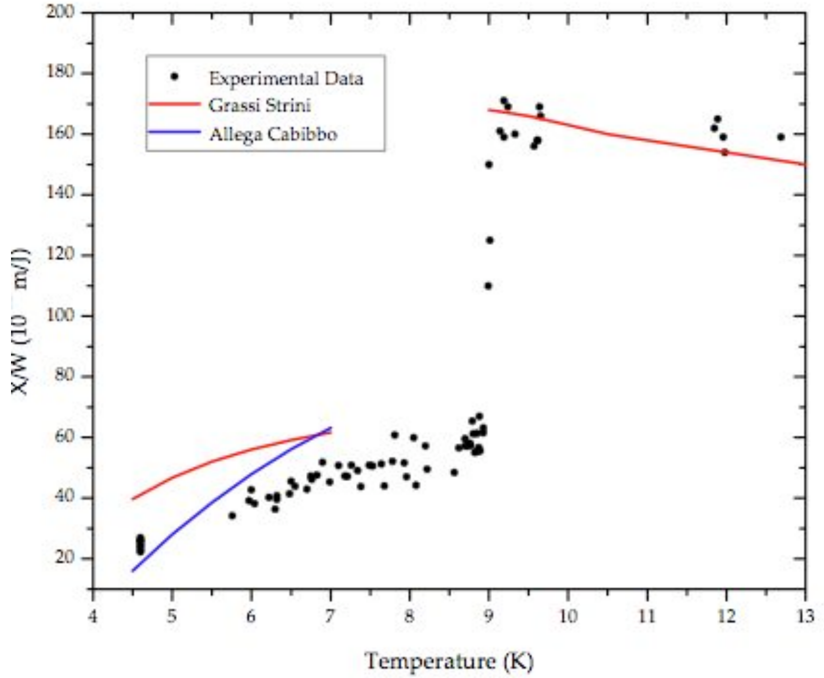
**Published the data collected with a Nb bar in both normal and SC state**
(Europhys. Lett., 76 (6), pp. 987–993 (dec 2006))

- The amplitude of oscillation (X) of the bar depends on its conduction state:
  amplitude in N state > amplitude in SC state

- Fair agreement with models that predict local transitions (SC-N) around the particles trajectory. In these models the max amplitude X normalized to the total energy W lost in the bar by the beam is given by:

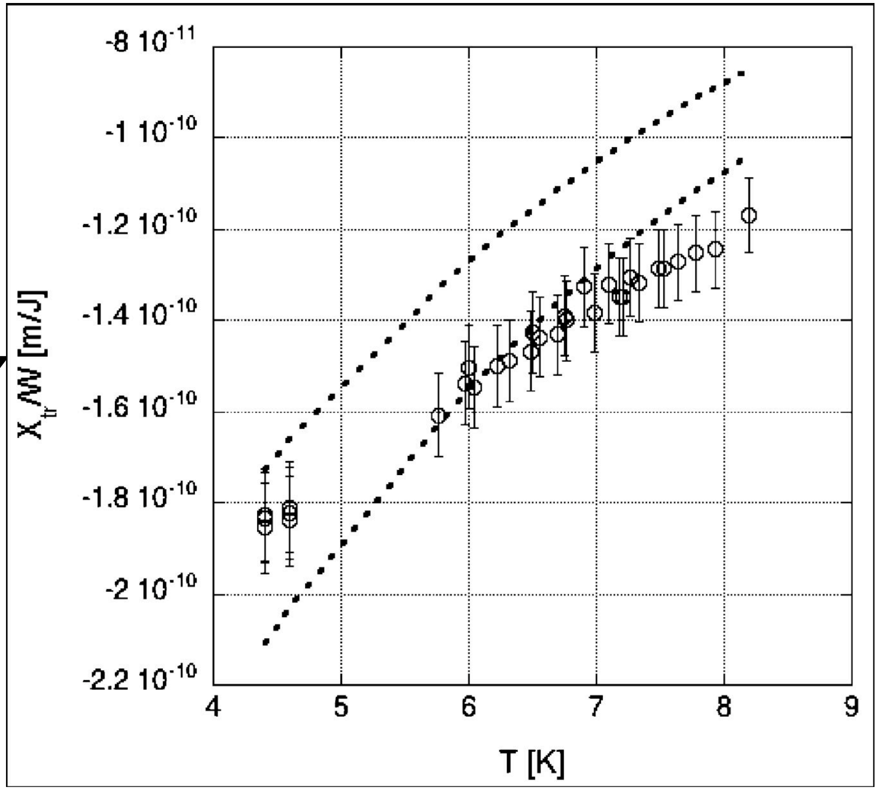
$$\frac{X}{W} = \left[\left(\frac{X}{W}\right)_{trans}\right] + \left[\left(\frac{X}{W}\right)_{norm}\right] =$$

$$= \left[\mathcal{F}\left(H_c, \frac{\partial H_c}{\partial T}, \frac{\partial H_c}{\partial P}\right)\right] + \left[B\left(\frac{\alpha}{c_V}\right)_{norm}\right]$$



# Niobium

NOTE :
normal contribution
subtracted




Between dotted lines : Expected values for the transition term
Dots and error bars : Observed values
Temperature interval : 0.5< $T/T_c$ < 0.8 (Tc~9 K)

# Measurements on Aluminium 5056

**Preparing for a BTF run with an Al 5056 bar in the normal and SC state ($T_c$~1K)**

- Assembly of the Dilution Refrigerator and ancillary control systems completed. controllo.

- During a commissioning test we found operating problems, localized to a heat exchanger between the Still and the Mixing Chamber.

- Temporary fix of this problem by operating the DL in a 3He evaporation mode. In this way we were then able to run a measurement (May 25th to Jun 6th) on the Al5056 bar down to $T_{min}$~0.5 K < Tc with interesting results.

**Characterization of the material in both N e SC regimes: measurement of $C_V^{N,SC}$**

- with the help of INFN Firenze.


EUROPA

# Results for the Al5056 bar

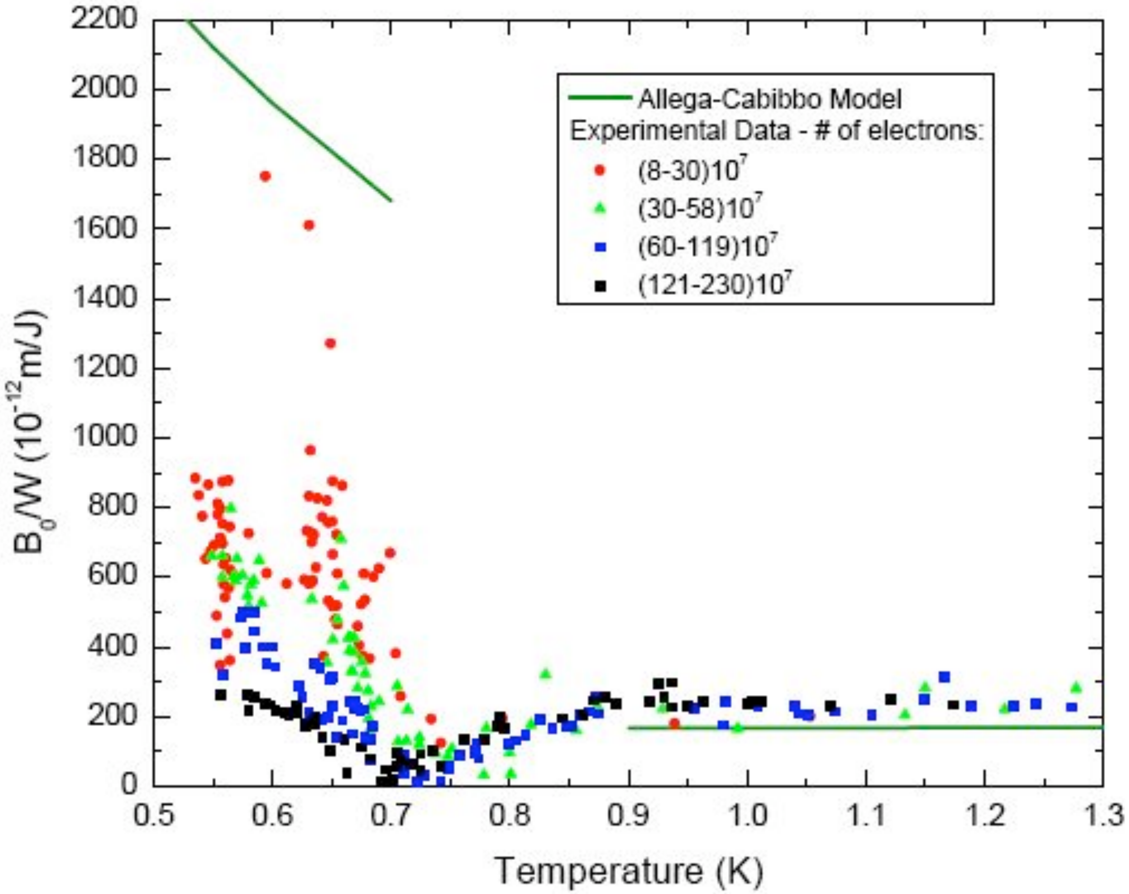
T$\gtrsim$ 0.9 K - The amplitude X takes values consistent with the expected ones for the Normal state.

T$\lesssim$0.9 K - Effects due to the SC state arise

For T$\lesssim$0.7 K we observed larger amplitudes than in the normal state.

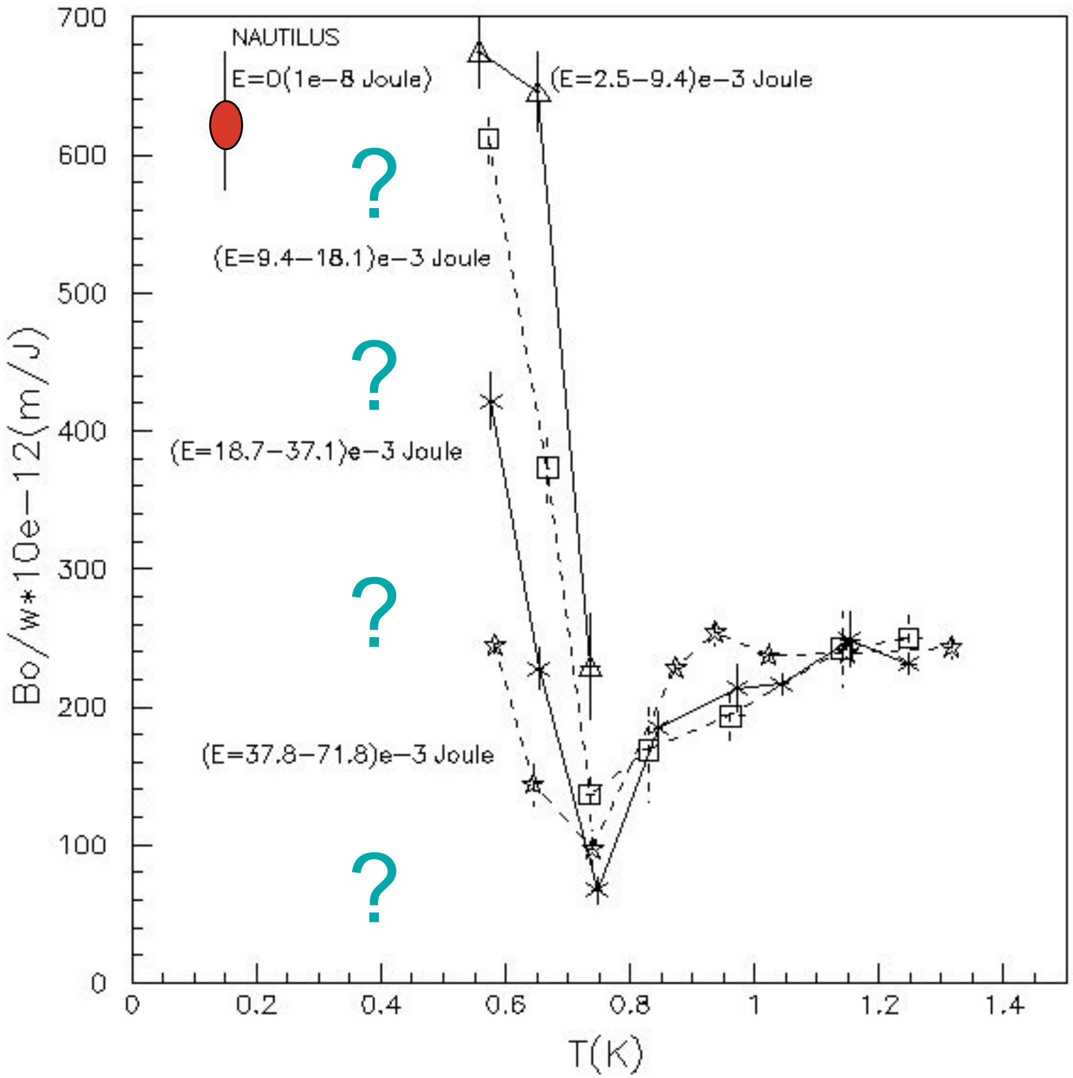
Models predict, for pure AL in the SC state, larger X than in the N state.

It is yet to be understood the attenuation of the response X in the temperature range 0.6-0.9 K as well as its dependence on the elctron beam intensity.




Max amplitude of oscillation, normalized to the energy deposited by the $e^-$ beam, vs Temperature for 4 different ranges of beam current.

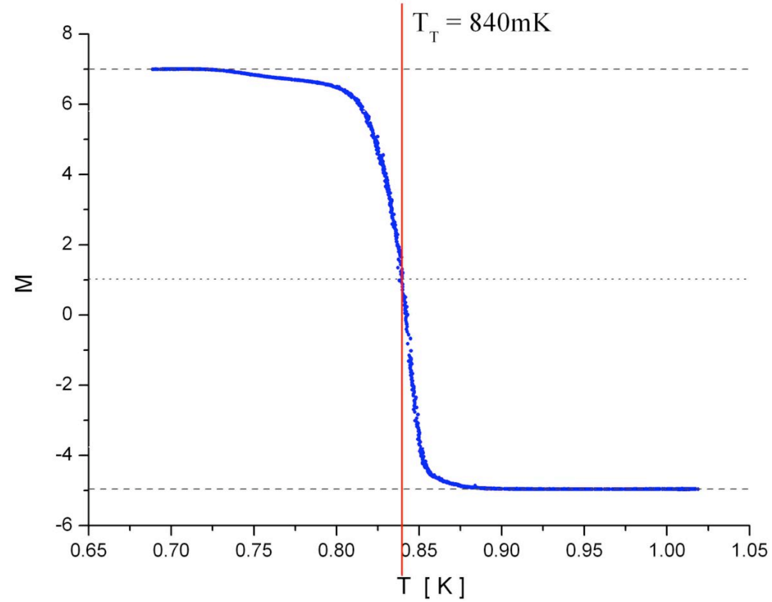
What will happen
At T < 0.5 K ?




Same as previous, but with data grouped in 50 mK Temperature bins
The red data point is induced from observation on the Nautilus gw antenna

## Characterization of the material (Fi)

- Measurements on $C_V$ is underway
- $T_c$ measured via a mutual inductance bridge in a carefully shielded environment.




$T_c$(50%)=0.84 K, $T_c$(100%)=0.73 K
Compare with Tc (pure Al) = 1.14 K

The transition is intrinsically wide (~100 mK)
The alloy is characterized by ~ 5% Mg and 0.1% Mn (magnetic effects)

# Summary (so far) for Al5056

1) The amplitude of vibration generated by the energy release by a beam of particles depends on the conduction state of the bar.

2) Well below the transition temperature this amplitude is larger than in the N state (unlike Niobium)

→ This finding is a qualitative support to explain the observed effects due to cosmic rays on Nautilus when this was operating in the SC state (T - 0.14 K)

→ Quantitative conclusions can be derived after exploring the effect at temperatures below 0.5 K.

→ Moving farther away from $T_c$, as well as a better knowledge of the material characteristics at those temperatures would allow a more accurate comparison with the model predictions.

Supported by EU under contract RII3-CT-2004_506222

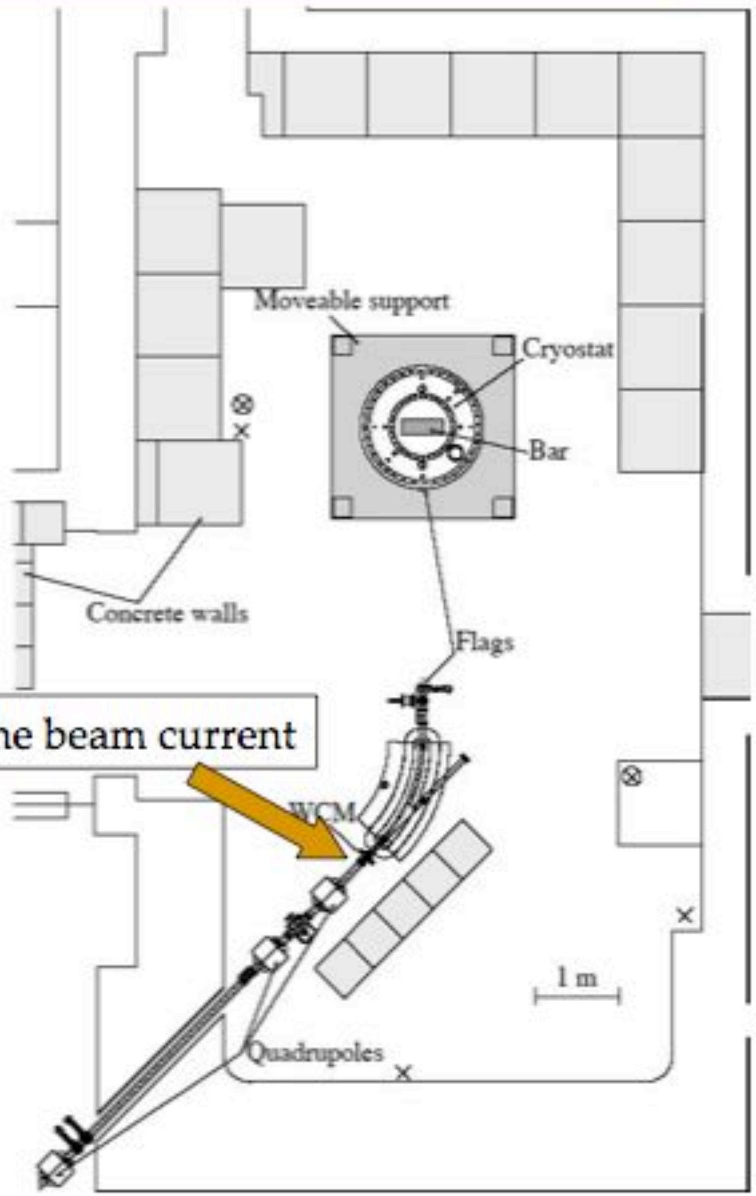
# Spare slides

(just in case)

# Electron Beam

The electron beam used for the experiment is provided by the DAΦNE Beam Test Facility (BTF):

- electron energy of 510 MeV
- pulse duration of 1 or 10 ns, with a fairly uniform distribution
- intensity of $10^7 - 10^9$ particles per bunch
- Single impulses are used, spaced by about 3 $\tau$ (Al5056 @ 0.8 K, $\tau$ = 120 s)



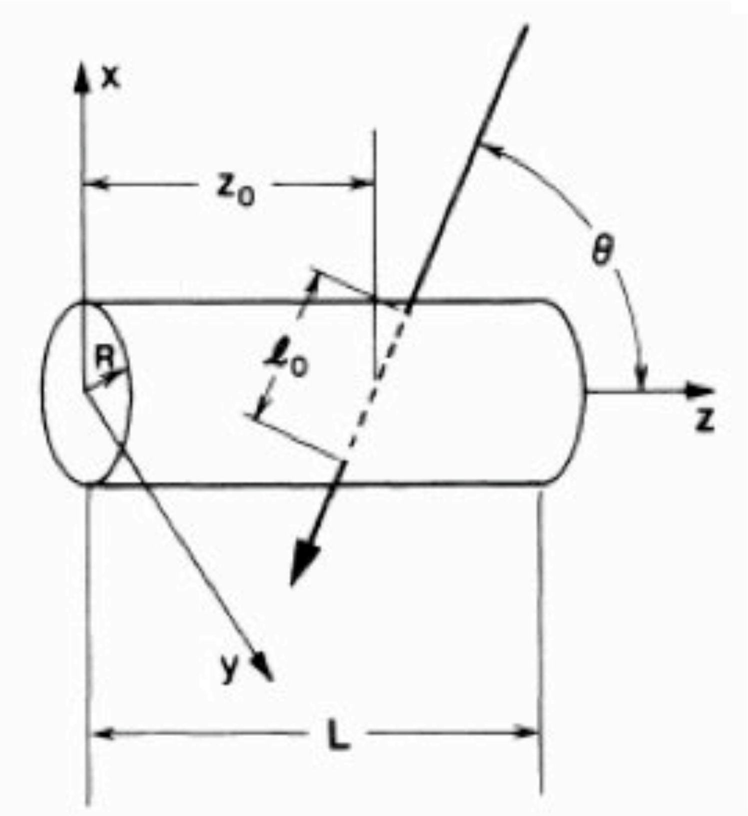

GEANT simulations for the energy loss of a single electron give:

$$\Delta E_{Al} = 195 \pm 70\text{MeV}$$

$$\Delta E_{Nb} = 450 \pm 40\text{MeV}$$

$$W = N\Delta E \pm \sqrt{N}\sigma_{\Delta E}$$

# Thermo-acoustic Model
(Grassi Strini, Strini, Tagliaferri; 1979)




Relates the energy lost by the particle to the energy installed in the various normal modes of vibration of the cylindric bar:

$$E_n \propto \left(\frac{\alpha}{C_V}\right)^2 \cdot \left(\frac{dE}{dx}\right)^2 \cdot F_n^2(L,R)$$

$$\Rightarrow \quad B_0^{therm} = \frac{2}{\pi}\frac{\alpha W L}{C_V M}$$

The quantity $\alpha/C_V$ (proportional to the Grüneisen parameter $\gamma$) is practically constant between 10-300 K;

What happens in the superconducting state?