International Journal of Modern Physics A
Vol. 20, No. 29 (2005) 7054–7056

RAP — ACOUSTIC DETECTION OF PARTICLES: FIRST RESULTS AT 4.2 K

C. LIGI,[1*] M. BASSAN,[2,3] S. BERTOLUCCI,[1] B. BUONOMO,[1] E. COCCIA,[3,4]
G. DELLE MONACHE,[1] S. D'ANTONIO,[2] D. DI GIOACCHINO,[1] V. FAFONE,[1]
A. MARINI,[1] G. MAZZITELLI,[1] G. MODESTINO,[1] L. QUINTIERI,[1] G. PIZZELLA,[1,3]
S. ROCCELLA,[5] F. RONGA,[1] L. SPERANDIO,[1] P. TRIPODI,[1] and P. VALENTE[1]

[1] *Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali di Frascati, Frascati (Rome), Italy*
[2] *Istituto Nazionale di Fisica Nucleare – section of Roma 2, Rome, Italy*
[3] *Department of Physics, Tor Vergata University, Rome, Italy*
[4] *Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Gran Sasso, Assergi (AQ), Italy*
[5] *Department of Structural Engineering and Geotechnics, La Sapienza University, Rome, Italy*
[*] *carlo.ligi@lnf.infn.it*

Received 25 October 2004

RAP (Rivelazione Acustica di Particelle) is a small cylindrical aluminum bar ($l = 500$ mm, $d = 181.7$ mm) placed at the DAΦNE Beam Test Facility, where it is hit by a 510 MeV electron beam, coming from the DAΦNE Linac. Aim of the experiment is to measure the mechanical vibrations of the bar caused by the interaction with the beam. On June, 2004 RAP successfully collected data for the first time at cryogenic temperature. Several runs at different temperatures (4.5, 70 and 273 K) have been performed and a number of shots in normal-conducting state of the bar were detected. The preliminary results are in good agreement with the Thermo-Acoustic Model. In the next months the mounting of a dilution refrigerator and the data taking of the bar in the superconducting state ($T = 100$ mK) have been planned.

Keywords: Cosmic rays; Cryogenics; Gravitational waves; Relativistic electron beam.

1. Introduction

It is well known that gravitational wave detectors are sensitive to effects due to the passage of the cosmic rays. The interaction between an energetic particle and a massive detectors produces a release of energy from the particle to the antenna, with a consequent temporary local increase of temperature and pressure inside the antenna itself. This pressure pulse generates acoustic vibrations in the material and excites the resonant vibrational modes of the detector.

This behaviour is well explained by the so-called Thermo-Acoustic Model,[1–3] and some experiments[4,5] have confirmed its validity, at least at room temperature.

During the runs performed in 1998 and 2000, the gravitational wave detector NAUTILUS has recorded signals of cosmic rays passage[6] whose amplitude was in strong disagreement with the prediction of the Thermo-Acoustic Model. The "anomalous" measurements were taken with the antenna in superconducting state ($T = 0.14$ K).

It is not clear how to interpret this phenomenon. Nevertheless, there are some aspects of the Thermo-Acoustic Model that are not yet well defined, like the behaviour of the Grüneisen parameter below 1 K and the possibility of an enhancement of the energy conversion at low temperatures. RAP[7,8] is intended to investigate these topics, making measurements at different temperatures, from 300 K down to significantly below 1 K, i.e. both in normal-conducting and in superconducting regime. This study is important for the evaluation of the noise induced by cosmic rays in the next generation of gravitational wave detectors, both of interferometric and resonant mass type. In particular it can drive the choice of an underground site for the future projects of large resonant mass detectors at ultralow temperatures.

2. Operations

During the year 2003, the commissioning and the first runs at room temperature on the beam have concluded the first phase of the RAP schedule. In 2004, the cryogenic tests and the runs at liquid helium temperature (4.2 K) were planned. Unfortunately, in February a severe cryostat failure (a big crack of a welding in the nitrogen dewar) occurred, and the cryogenic test was stopped for the repair. Then, in May, after the fixing, the cryostat was directly placed in the DAΦNE Beam Test Facility for the cryogenic runs with the electron beam.

The cryogenic operation started with the filling of the cryostat with liquid Nitrogen, both in the Nitrogen and in the Helium dewars, followed by the final cool-down to 4.2 K with liquid Helium. A very slow cool-down was made between 300 and 77 K to avoid as much as possible fast contraction of the cryostat material.

During the cool-down, the space surrounding the bar was filled with about 1 mbar of gaseous Helium, in order to allows the detector cooling. This was indeed the only thermal link between the bar and the liquid Helium, the bar being mechanically disconnected from the cryostat, with the exception of three thin stainless steel wires.

During the period May 26 – June 17 a number of shots, with the bar at different temperatures, were recorded by the data acquisition system. The signal of the piezoelectric, enhanced by a factor 10^3 by a low noise amplifier, has been sent both to a 60 kHz 16 bit ADC of the DAQ system for the data storage and to a spectrum analyzer for a visual analysis.

3. Data analysis

The data analysis is still in progress. The relationship between the measured signal and the amplitude of the first longitudinal mechanical oscillation (B_0) of the bar per unit of released energy W is

$$\frac{B_0}{W} = \frac{V}{NE\,\alpha(T)} \quad [\mathrm{m\,J^{-1}}] \tag{1}$$

where V is the amplified piezoelectric signal, N is the number of electrons of the beam, E is the mean energy released from every electron to the bar (Monte Carlo simulation gives an estimate of 195 ± 7 MeV/electron for the 510 MeV electrons coming from the DAΦNE Linac) and $\alpha(T)$ is the electro-mechanic conversion factor.

Figure 1 shows the results of the visual analysis performed during the 2004 data taking together with the results obtained in 2003, in comparison with the results obtained by past experiment[5] adapted to the RAP geometrical parameters. The lines show the theoretical

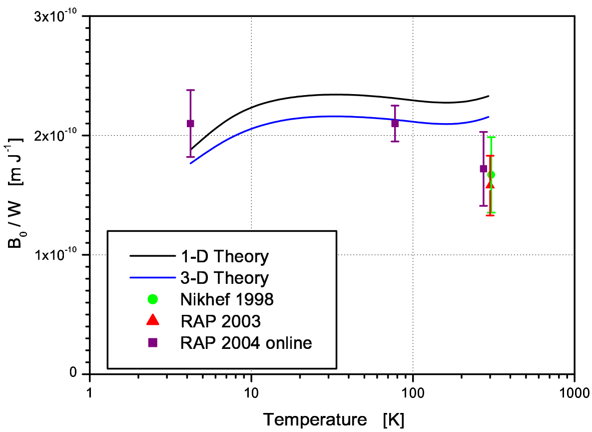

Fig. 1. Plot of the first longitudinal mode amplitude per unit of released energy versus T.

prediction of the Thermo-Acoustic model. 1-D line is the result of an analytical calculation, whose expression is

$$\frac{B_0}{W} = \frac{2}{\pi} \frac{\lambda L}{C_v M} \quad [\mathrm{m\ J^{-1}}] \tag{2}$$

where λ is the linear thermal expansion, C_v is the specific heat, L and M the length and the mass of the bar, while 3-D line is obtained from a finite element simulation. These first results show a quite good agreement with the theory. Nevertheless, a more accurate offline analysis is now in progress.

This will be the last step before the data taking with the bar in superconducting state, which is the main purpose of this experiment. These measurements are planned during the next year (2005), after the dilution refrigerator mounting.

References

1. A. M. Allega and N. Cabibbo, *Nuovo Cim. Lett.* **38**, 263 (1983).
2. C. Bernard, A. De Rújula and B. Lautrup, *Nucl. Phys.* **B242**, 93 (1984).
3. G. Liu and B. Barish, *Phys. Rev. Lett.* **61**, 271 (1988) and references therein.
4. A. M. Grassi Strini, G. Strini and G. Tagliaferri, *J. Appl. Phys.* **51(2)**, 948 (1980).
5. G. D. van Albada *et al.*, *Rev. Sci. Instr.* **71**, 1345 (2000).
6. P. Astone *et al.*, *Phys. Lett.* **B540**, 167 (2002).
7. S. Bertolucci *et al.*, *INFN-LNF Note*, **LNF-01/027** (2001).
8. G. Mazzitelli *et al.*, *Class. Quantum Grav.*, **21**, S1197 (2004).