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PROCEEDINGS
SUPPLEMENTS

Cosmic-Ray-Induced Cascades on the Ultracryogenic Antenna NAUTILUS

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The gravitational wave antenna NAUTILUS has been provided with a cosmic-ray veto system.The expected number of events from the interactions of high-energy hadrons and muons and multihadron showers with the antenna are shown together with examples from the data analysis of the search for coincidences between the two detectors.

1. Introduction

The ultracryogenic antenna NAUTILUS [1] , operating at Frascati INFN National Laboratory, is at present the most advanced detector for the detection of gravitational radiation caused by a variety of events: the coalescence of binary black holes or neutron stars, the collapse of white dwarfs or neutron stars and supernova explosions. The detector consists of a resonant Al 5056 cylindrical bar (L=3 m. Ø=0.6 m.), whose vibrational normal modes should be excited by gw bursts. While the sensitivity reached at present by this kind of detector is at the level of $h \approx 7 \times 10^{-19}$, corresponding to our galaxy and the local group of galaxies, the final goal of NAUTILUS is to extend the range of observable distances up to the Virgo Cluster and at gw amplitudes of the order of $h \approx 10^{-21}$ that require a noise temperature near the quantum limit ($T_n \approx 10^{-7}$ K). In order to clearly assign the signal detected by the antenna to gw bursts, the usual strategy is to make coincidences between similar detectors and use seismic and electromagnetic veto systems. NAUTILUS also has been equipped with a cosmic-ray veto system.

2. Cosmic-Ray Detector and Montecarlo Simulation

The cosmic-ray detector is described elsewere [2]. It was designed to maximize acceptance for high-energy particles and extensive air showers (EAS), taking into account the severe space constraints. It consists of seven layers of limited streamer tubes (LST's), three (6×6 m^2) above the cryostat and four (6×2.75 m^2) at ground level. The analogic readout of the LST wires allows measurement of the multiplicity of the particles impinging on the detector.

We performed a full simulation of the interaction of single hadrons and muons with the NAUTILUS bar. The energy lost by a cosmic ray is converted into a local expansion of the bar, due to the temperature increase. This effect was studied experimentally by Grassi et al.[2] using a 30 Mev proton beam. The relation between particle energy loss and the innovation of the vibrational

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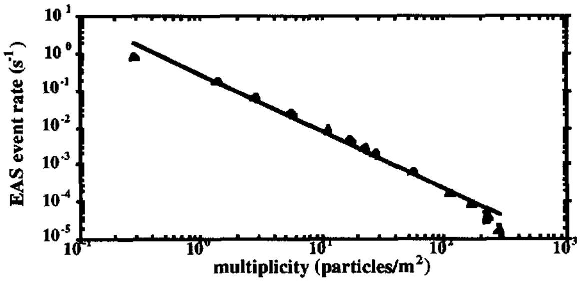
energy of the bar can be found in [3,4].

In simulating the effects due to hadron interaction, we used two different parametrizations for the experimental data: for hadrons of energy exceeding 300 GeV, we used the differential vertical spectrum at sea level given by Sihoan et al.[5], up to a max. of 10 TeV. Below 300 GeV, we used the Arvela et al. [6] parametrization with a minimum energy cut of 1 GeV. A factor of $e^{-\frac{h}{\Lambda_N}}$, where h is the atmospheric depth crossed by the particle and $\Lambda_N \simeq 140\ \frac{g}{cm^2}$, accounts for the hadron angular distribution. The muon interaction contribution was evaluated using, for the flux, the theoretical estimation of Dar[7], which is in good agreement with the available experimental data and a μ^+/μ^- charge ratio of 1.25. The Table 1gives the results on the expected number of events/day from hadrons and muons as a function of the minimum vibrational energy change detectable by the gravitational detector, expressed in kelvin. Also reported are an analytical estimation of the contribution due to EAS, as suggested by Amaldi and Pizzella[8], and an estimation of multiple hadron events based on the Arvela et al. Monte Carlo results.

Note that our evaluation at high energy is based on measurements affected by large errors.

3. Detector Performance and Preliminary Results

The NAUTILUS antenna is active at the Frascati Laboratory; a record thermodynamic temperature of 95 mK has been reached. Since the last cooling in November 1994, a major effort has been made to search for any source of excess noise, mainly nonstationary, so as to operate the antenna at a stable noise temperature. Meanwhile, data have been collected from the cosmic-ray detector. Figure 1 shows the measured EAS multiplicity rate and the best fit [9] to the results of some sea-level cosmic-ray detectors. The agreement is good: the small discrepancy in the low range of particle density is due to the trigger request of at least 20 particles in the bottom module; while at high density the data are affected by the ADC saturation effect.



Since the basic problem of gravitational-wave research is the detection of short bursts and extremely small signals due to gravitational collapses embedded in an ideally flat noise spectrum, different filtering procedures are applied to the antenna data. However, details about the data processing procedures can be found in [10,11]. Here, we report an example of the search for coincidences between the gravitational and cosmic-ray detectors for 141 hours of almost stable conditions during the period 24 Feb.-4 March 1995. A threshold of 250 mK was applied to the useful gravitational data sampled at a rate of 3.44 Hz and processed following the the so-called "slow" procedure [11]. We used a $\pm 0.29\ s$ coincidence time window and considered two samples of cosmic-ray events: a) EAS selected with the requirement of more than 50 $\frac{particles}{m^2}$ on the top module; b) single interacting particles with the requirement of zero or one particle in the top module and more than 500 particles in the bottom module. For a) we found 22 coincidences with an expected number of accidentals $< n >_{acc}$=25.8 corresponding to an upper limit at 90% CL of 1.3 concidences per day; for b) 94 coincidences with $< n >_{acc}$=90.5 corresponding to an upper limit at 90% CL of 2.7 coincidences per day. The $< n >_{acc}$ is obtained by shifting all the occurence times of the cosmic-ray events 1000 times by 7-s steps in a ± 3500 s window.

These are the first results of the cosmic-ray (hadrons, muons and EAS) effects on a cryogenic antenna at sea level. The past experiments was sensible to EAS only.

The experiment of Ezrow et al [13] with a room

Table 1
Events/day as a function of the minimum detectable vibrational energy change

Energy (kelvin)	muons	hadrons	EAS	multi hadrons	total
10^{-7}	1540	3310	137	– – –	4987
10^{-6}	155	463	35	– – –	653
10^{-5}	12.7	55.7	7	5.5	80.9
10^{-4}	1.2	6.2	1.3	3.7	12.4
10^{-3}	0.18	0.56	0.24	1.2	2.18
10^{-2}	0.002	0.035	0.04	0.1	0.18

temperature bar has given an upper limit for EAS of 1 ev/day at 90% confidence level with an antenna threshold of the order of 200 Kelvin. The Stanford cryogenic antenna [14] was under a 1-m concrete shield with an attenuation factor for EAS of about 20. The upper limit obtained scaling for a factor 20 the original Stanford limit is 4.2 events/day at 90% confidencel level with an antenna threshold of the order of .25 Kelvin. So our preliminary results for EAS (with a very small data sample) are already better than the existing published limits.

From the Montecarlo simulation, at 250 mK, we expect less than $10^{-2}\ \frac{events}{day}$ to give detectable signals in the antenna. Hence, higher statistics and better sensitivity are required in order to reach a significant excess of coincidences.

4. Conclusions

The cosmic-ray veto system has demonstrated good performance, well in agreement with the physics requirements of the experiment and with the simulation results. Analysis of data on the search for coincidences between the two detectors is still in progress.

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