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Air Microwave Yield (AMY): An experiment for measuring the GHz emission from air shower plasma

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Summary. — The AMY experiment aim is to measure and characterize the microwave emission from plasmas induced in air by an electron beam. The study of this phenomenon could provide the development of new techniques for detecting high-energy cosmic rays over large area with a 100% duty cycle. We present the results of a first test beam done at the electron Beam Test Facility (BTF) of the Laboratori Nazionali di Frascati (LNF, Roma Italy) in November 2011. The measurements were performed with an electron beam of 510 MeV energy. A frequency range between 1 and 20 GHz has been investigated.

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PACS `95.55.Jz` – Radio telescopes and instrumentation; heterodyne receivers.
PACS `96.50.sd` – Extensive air showers.
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1. – Introduction

The ultra-high-energy cosmic rays (UHECR) are investigated in several experiments mainly using two detection techniques: ground-based particles arrays and fluorescence detectors (see Pierre Auger Observatory [1]). The operation of fluorescence telescopes is however limited by the fact that this can only work on clear, moonless nights leading to a net yearly duty cycle of $\simeq 14\%$.

The observation of a microwave continuum emission from air shower plasmas [2] has raised the interest in a possible new technique for detection of cosmic-ray extensive air showers that may be able to provide the longitudinal profile measurement with a 100% duty cycle.

The plasma is created after the release of the energy of the shower into the atmosphere and it is made of electrons at temperatures of about 10^5 K. A small part of the plasma energy can be released through Bremsstrahlung emission by the collision of the electrons with the neutral molecules [2] of the atmosphere. This emission mechanism (Molecular Bremsstrahlung Radiation MBR) produces radiation in the microwave frequency band which is expected to be isotropic and proportional to the shower energy deposit. This property of the MBR opens the possibility to develop a radio telescope which is able to reconstruct the full shower longitudinal development and provide a calorimetric measurement of the shower energy with two main benefits: 100% duty cycle and a weak, negligible dependence on atmospheric conditions.

Several groups around the world are involved in many activities to study in detail the process of microwave emission using prototype telescopes with different designs (see AMBER [2], MIDAS [3], EASIER [4], CROME [5], MAYBE [6]). The primary goal of the AMY experiment is to confirm and measure the absolute rate emission of microwave radiation and its frequency spectrum in the range between 1 and 20 GHz. The idea is to study the process in a well controlled environment using an electron beam impinging on a showering media, and to observe the emission at different stages of shower development.

2. – Experimental setup and first measurements

The AMY experiment uses the BTF of the LNF laboratory in Frascati (Italy) where an anechoic Faraday chamber ($2 \times 2 \times 4\,\mathrm{m}^3$) was installed (see fig. 1, left). In order to prevent the detection of the electromagnetic radiation coming from the experimental area and to avoid reflection, the inner walls of the chamber are covered with RF absorbers, providing a good shielding from 2 up to 20 GHz (above 4 GHz better than 85 dB). The chamber is designed to host antennas in five different places. Three positions are in the central part of the chamber (up, left and right with respect to the beam direction), two positions are at the corners of the entrance wall and oriented in such a way that the centre of the chamber falls in the field of view of the antenna.

The first test beam was performed in November 2011 with 15 days of data taking. The e-beam was delivered with the following features: electrons of 510 MeV energy each, 1–2 Hz repetition rate, 10 ns pulse duration with ~ 30 microbunches in each pulse, up to $\sim 10^9$ particles/bunch.

The antennas used are of two types: two log-periodic antennas Rohde & Schwarz HL050 (range: 0.25–26.5 GHz; gain: ~ 8.5 dBi) and one horn antenna DRH20 RFSPIN (range: 1.7–20 GHz; gain 14–16 dBi). Each antenna was connected to a Mini-Circuit amplifier (ZVA-183-S+) covering a frequency range of 800 MHz–21 GHz with a gain of ~ 26 dBi. The signals from the three antennas together with the signal from the pickup

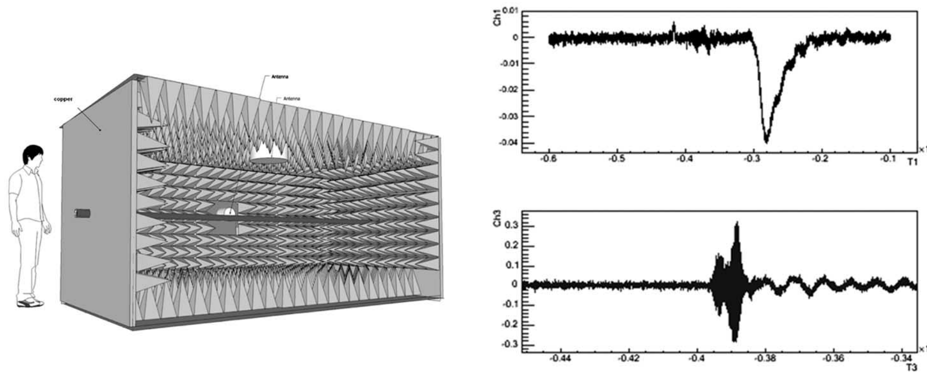

Fig. 1. – Left: schematic view of the AMY chamber. Right: typical signals registered by the LeCroy oscilloscope during a run without target. Top: signal from the pick-up coil. Bottom: signal measured by a log-period antenna.

coil of the beam have been acquired by an oscilloscope LeCroy SDA 830Zi-A whose main features are: 4 channels, 20 GHz real time bandwidth, 40 GS/s. The showering target was made by small pieces of alumina (90% Al_2O_3, 10% SiO_2) that could be piled up to have different target thickness.

Measurements were done with the three antennas in different positions inside the chamber and with the polarization plane orthogonal (cross-polarized) and parallel (co-polarized) to the beam axis. In this first test only a few runs were taken with 20 cm of showering target. We decided to run without target, planning for a remote handling mechanical system for the next test.

In fig. 1, right, typical signals for a run without target are shown. The channel-1 signal is from the pick-up coil. From this we could calculate the charge. Moreover while the data was being taken we could change the beam intensity (*i.e.* the overall charge). In the figure a log-periodic antenna signal is also shown. Comparing this signal with the one from the horn (fig. 2, left) it is possible to see that for the log-periodic antenna, oscilatory behaviour appears after the central part of the signal. This can be attributed to a chamber resonance below 1 GHz affecting log-periodic antennas. In fact the chamber shield below 1 GHz decreases down to 40 dB affecting the log-periodic

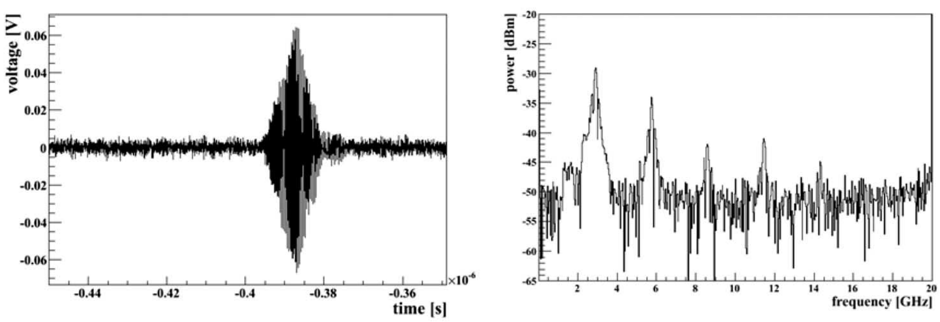

Fig. 2. – Typical signals registered by the horn antenna with polarization plane containing the beam axis (left) and power spectrum of the signal as a function of the frequency (right).

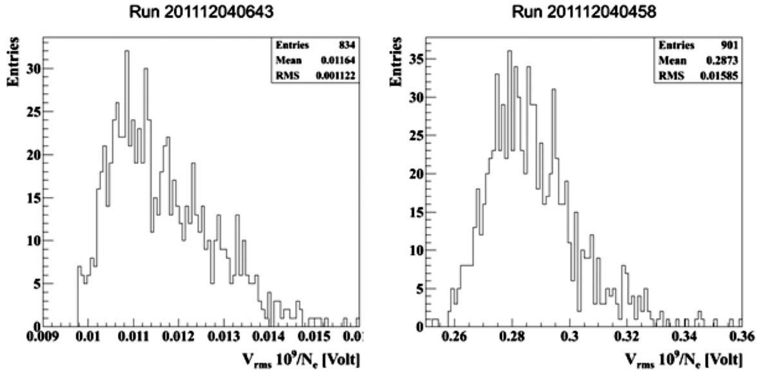

Fig. 3. – Voltage r.m.s. distribution normalized to the beam intensity obtained with antenna cross-polarized (left) and co-polarized (right) with respect to the beam axis.

antenna detection, while the horn antenna is not sensitive below 1.7 GHz. This problem can be overcome with the spectrum analysis of the signal through Fast Fourier Transform (FFT) filtering.

In fig. 2, right the FFT of the horn signal is shown. It is possible to recognize several peaks produced by the fine structure of the LINAC beam inside the chamber (see ref. [7]).

Figure 3 shows the voltage r.m.s. distribution normalized to the beam intensity obtained with the antenna cross-polarized (left) and co-polarized (right) with respect to the beam axis. As expected there is a significant difference between the signal intensities in the two configurations.

Moreover looking at the power of the signal over the full bandwidth, a quadratic dependence with the beam intensity is observed independently of the antenna polarization plane.

3. – Conclusions

Preliminary results of the first AMY test beam have been presented. The analysis is in progress and it proceeds together with an accurate simulation of the electric and magnetic field produced by the beam close to the antenna. This can lead to the understanding of the physical emission mechanism and of the detector response.

The data shows the presence of a strong and fast radiation produced directly from the relativistic beam. By taking data with different orientations with respect to the antenna polarization plane, this radiation has been found to be polarized in the plane defined by the beam axis and the Poynting vector.

The experimental apparatus needs to be optimized for the next test: remote interaction target control, and improvements on geometrical precision of the camera (antenna positioning and orientation of the polarization plane).

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