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The AMY experiment to measure GHz radiation for Ultra-High Energy Cosmic Ray detection

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Abstract. The Air Microwave Yield (AMY) project aims to measure the emission in the GHz regime from test-beam induced air-shower. The experiment is using the Beam Test Facility (BTF) of the Frascati INFN National Laboratories in Italy. The final purpose is to characterize a process to be used in a next generation of ultra-high energy cosmic rays (UHECRs) detectors. We describe the experimental apparatus and the first test performed in November 2011.

1. Introduction

The current observatories of ultra-high energy cosmic rays (UHECRs) (e.g. Pierre Auger Observatory [1]) achieved its sensitivity utilizing a so-called "hybrid" observation i.e. the combination of two detection techniques: air shower arrays and fluorescence detectors. Air shower arrays consist of a large number of particle detectors that cover large area. The shower triggers the array by coincidental hits. The direction of the primary particle can be reconstructed quite well from the timing of the different hits, but the shower energy requires extensive Monte Carlo work with hadronic interaction models that are extended orders of magnitude above the accelerator energy range. The fluorescence method uses the fact that the charged particles of the passing showers excite nitrogen molecules in the atmosphere, which emit fluorescence light. The fluorescence light is emitted isotropically and can be detected independently of the shower direction. Since optical detectors follow the shower track, the direction of the primary cosmic ray is also

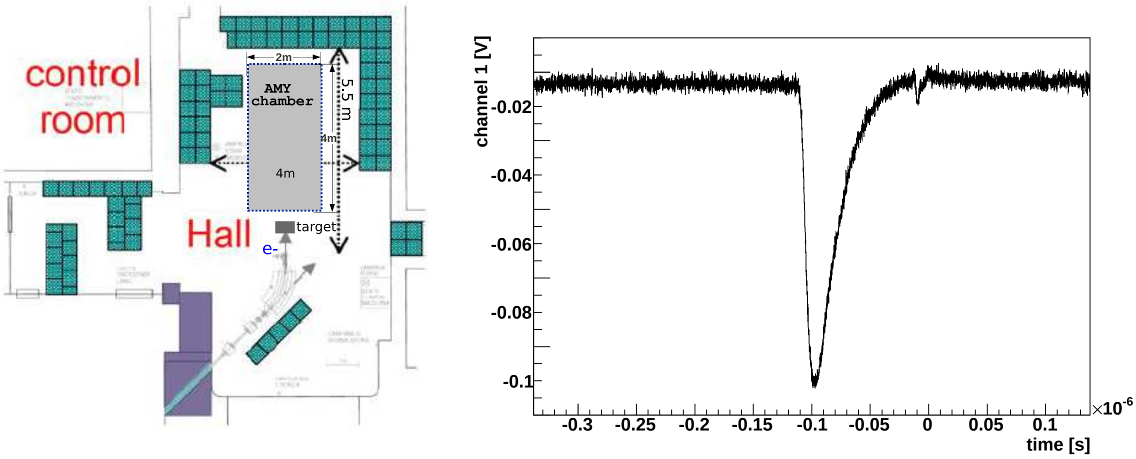

Figure 1. Left: schematic view of the AMY experimental hall. Right: The signal from the Integrating Current Transformer was recorded by the LeCroy scope for each event. It allows to measure the intensity of the beam event by event.

relatively easy. 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 the order of 10%.

Evidence for radio emission in the GHz regime from test-beam induced air showers was originally proposed and reported by Gorham et al [2]. During the development in the atmosphere, an air shower releases its energy through ionization, producing a plasma with an electron temperature of about 10^5 K. Emissions of Molecular Bremsstrahlung Radiation (MBR) in the microwave range are predicted as a result of interactions between free electrons and atmospheric molecules. MBR can be treated classically as a result of thermal processes of electrons of less than 10 eV kinetic energies. From this treatment the emissions are expected to be isotropic and un-polarized [2].

The results from Gorham indicate that MBR from EAS is strong enough to be detected from a remote 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]). The AMY experiment together with MAYBE[6] is studying the emission from a test-beam induced air shower, in order to observe the different stages of shower development in a well controlled environment.

2. Experimental Setup

The AMY experiment uses the BTF of the LNF laboratory in Frascati (Italy) where an anechoic Faraday chamber ($2 \times 2 \times 4$ m^3) was installed (see fig.1-left). The inner walls of the chamber are covered with Radio Frequency 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 positions. Three positions are in the central part of the chamber, while the others are at the corners of the entrance wall oriented toward the center of the chamber.

The first test beam was performed in November 2011. The electrons beam with an energy of 510

MeV [7] was delivered with 1-2 Hz repetition rate, 10 ns pulse duration with ∼30 microbunches in each pulse and up to $\sim 10^9$ particles/bunch.
The antennas used are of three different types: log-periodic antenna Rohde & Schwarz HL050 (range: 0.25-26.5 GHz; gain: ∼8.5 dBi), horn antenna DRH20 RFSPIN (range: 1.7-20 GHz; gain 14-16 dBi), and commercial LNBF in C-Band. A large band amplifier (Mini-Circuit ZVA-183-S+) was connected to the log-periodic and horn antenna. The signals from the antennas have been acquired by an oscilloscope LeCroy SDA 830Zi-A (4 channels, 20 GHz real time bandwidth, 40 GS/s). The scope was also acquiring the signal from an Integrating Current Transformer, available in the BTF area allowing for a simultaneous measure of the beam intensity. 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.

3. Results from the first Test Beam

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, since the remote handling of the target was not available.
In fig.1-right the signal from the Integrating Current Transformer is shown. From this signal, the beam intensity (i.e. the overall charge) can be calculated for each event. The trigger to the scope was defined respect to the RF signal from the LINAC accelerator, and its timing was therefore very stable.

The oscilloscope trace of the horn antenna signal is shown in Fig.2-left, together with his Fourier Transform in Fig.2-right. From the Fourier Transform it is possible to recognize several peaks corresponding to the frequencies multiple of the LINAC frequency ($f_L = 2.856\ GHz$ see ref: [7]).
Above 20 MeV the electrons in air emit Cherenkov radiation. The Cherenkov radiation is polarized in the plane defined by the Poynting vector and the electron velocity. A detailed simulation of the prompt radiation for studying the detector response and its calibration is in progress. A preliminary result is shown in Fig.3-left. This picture shows the spectral analysis of a simulated prompt radiation signal as recorded by the Horn antenna. From this simulation it appears that the simulated spectrum qualitatively reproduces the observed signal. Nevertheless at the stage of the analyis we can not exclude that the MBR contribution would have the same structure, and for this a more precise simulation and estimation is needed. The power of the signal over the full bandwidth as a function of the beam intensity is shown in Fig3-right. The signal shows a strong correlation with the beam, evidencing a quadratic scaling, but the analysis in frequency of the signals is dominated by the peaks structure. A more detailed simulation together with the data analysis is underway.

4. Conclusions

The first test of the AMY experiment has been performed at the Beam Test Facility (BTF) of the Frascati INFN National Laboratories in November 2011. The data show the presence of a strong and fast radiation produced directly from the relativistic beam. By taking data with different orientations of the antenna polarization plane, this radiation has been found polarized in the plane defined by the beam axis and the Poynting vector. A detailed simulation of the prompt radiation is in progress for studying the detector response and its calibration and to understand the background for the MBR measurement.

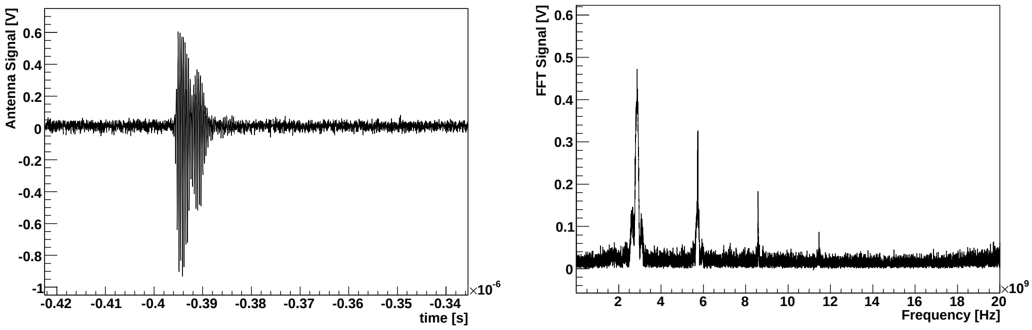

Figure 2. (Left) A signal registered by the horn antenna in the central position and (Right) his Fourier Transform as a function of the frequency.

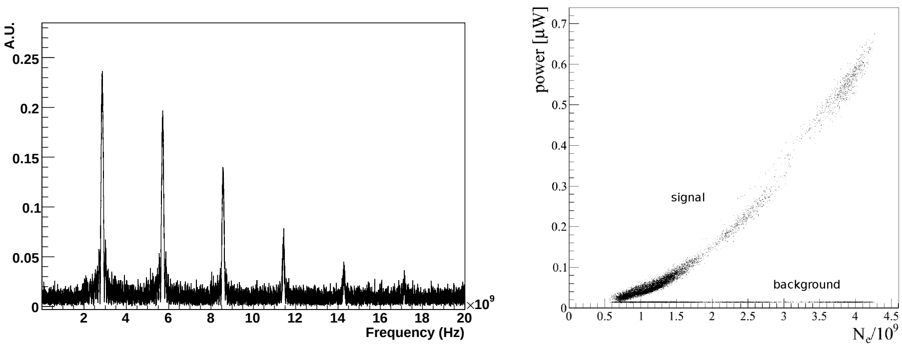

Figure 3. (Left) Fourier transform of a simulated prompt radiation signal, as seen by the horn antenna in the central position. (Right) Correlation between the power of the signal and the beam intensity given in number of electrons per bunch

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