CosMic: Detection of Cosmic Rays with microwawes

Research Program funded by the University of Salento (budget 5‰)

G. Cataldi[3], M. R. Coluccia[1,3], F. Congedo[2], L.Corchia[2], A. Corvaglia[3] P. Creti[3], R. De Paolis[2], G. Marsella[1,3], A. Miccoli[3], M.Panareo[1,3], L.Perrone[1,3], C. Pinto[3], V. Scherini[1,3]

[1] Dipartimento di Matematica e Fisica "Ennio De Giorgi", Università del Salento, Italy
[2] Dipartimento di Ingegneria dell'Innovazione Università del Salento, Italy
[3] Istituto Nazionale di Fisica Nucleare sez. di Lecce, Italy

1. Abstract and main goals

Aims of this proposal are the study and the detection of the highest energy cosmic rays (E > 10^{18} eV) by observing and measuring the electromagnetic radiation emitted in the microwave band between a few GHz and 20 GHz. The most likely hypothesis is that this radiation is due to the Bremsstrahlung emission by low energy electrons (few eV) interacting with the molecules of the atmosphere. In this hypothesis we expect the radiation to be non-polarized and isotropically emitted, as for the emission of fluorescence light from excited nitrogen molecules.

The detection of isotropic radiation in the microwave frequency band would allow, similarly to what happens for the fluorescence telescopes, the direct observation of the longitudinal development of the extensive air showers, a key measurement for establishing the chemical composition and the energy spectrum of the highest energy primary cosmic rays. But, unlike the fluorescence technique, available only during the dark and moonless nights, the microwave technique would provide a nearly 100% duty cycle. Moreover the absorption in the atmosphere is negligible in this frequency range.

A confirmation of the reported evidence would have a significant impact on high-energy cosmic ray physics by delivering to the scientific community a low-cost and high duty-cycle measurement technique, with comparable or even better performance compared to the fluorescence telescopes.

This proposal aims to the construction of a prototype telescope for the observation of microwave radiation emitted along the path of cosmic rays through the atmosphere. The operating schedule can be summarized in three steps:

- Phase 1: Simulation and studies of the physical process and estimate of expected signals.
- Phase 2: Construction and optimization of a prototype telescope consisting of a parabolic dish with a matrix of microwave antennas placed at its focal surface.
- Phase 3: Data acquisition and analysis of the observed signal.

2. Research Sectors according to the ERC scheme

PE Physical Sciences and Engineering

- PE9 Universe sciences: astro-physics/chemistry/biology; solar system; stellar, galactic and extra-galactic astronomy, planetary systems, cosmology; space science, instrumentation
- PE9_10 High energy and particles astronomy: X-rays, cosmic rays, gamma rays, neutrinos
- PE9_17 Instrumentation: telescopes, detectors and techniques
- PE2 Fundamental constituents of matter: particle, nuclear, plasma, atomic, molecular, gas, and optical physics
- PE2_2 Particle physics

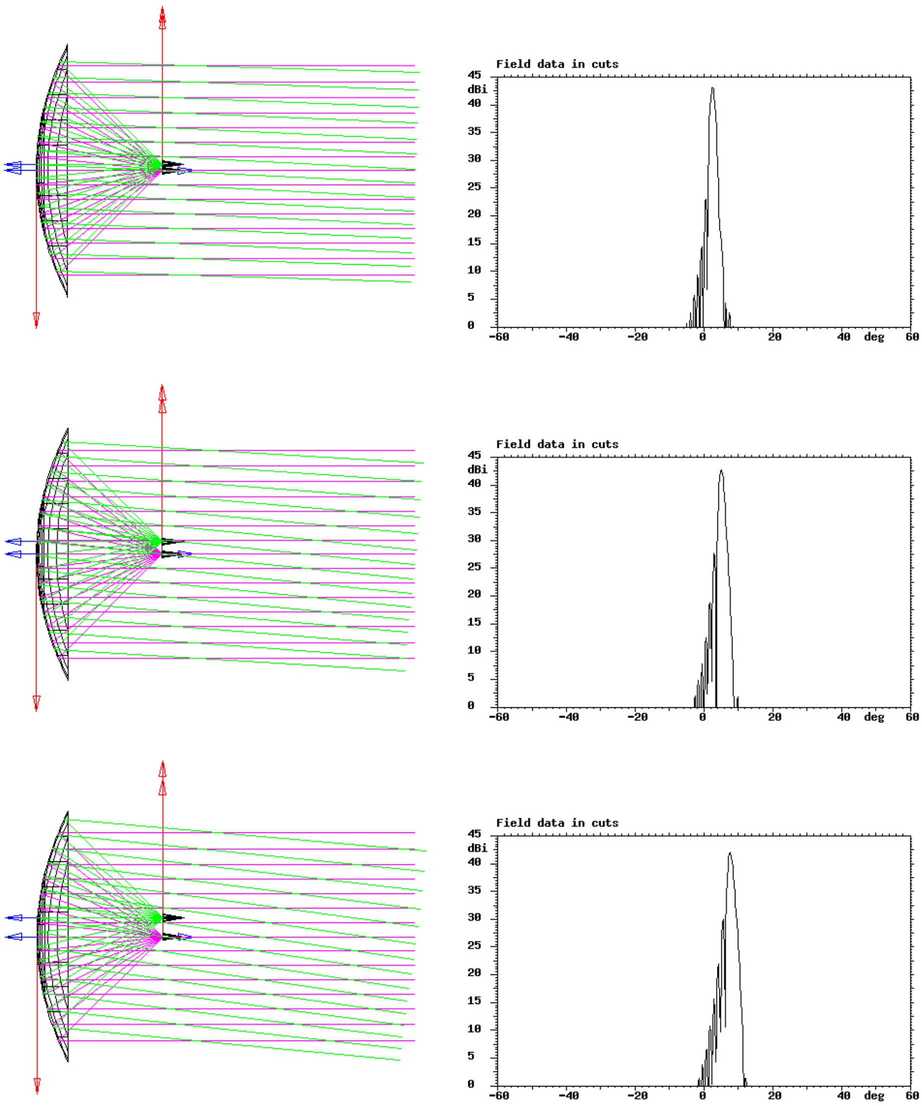

Figure 1. Response of a 10 cm feed at 4GHz as a function of the angle to the optical axis, for a parabolic dish with focal distance and rim angle of 2 m. The feed is placed at 10 (top panel), 20 (middle panel) and 30 cm (bottom panel) from the focal point of the dish in the direction perpendicular to the optical axis.

3. Description and development of the project

The progress since the beginning of the project (July 2011) can be summarized as in the following:

- Study of the design of the optical system
  The student edition of the simulation code GRASP9 (available at *http://www.ticra.com/free-downloads/grasp9-se/*) has been used to derive the expected response of a feed placed at the focal plane of a parabolic dish of given curvature. Fig. 1 shows the signal amplitude at 4 Ghz as a function of the angle between the direction along the feed and the optical axis, assuming a dish with focal distance and rim radius of 2m. The top, middle and bottom panels refers to the case of a feed placed at 10, 20, and 30 cm from the dish focal point in the direction perpendicular to the optical axis.

  Simulations support a design based on an array of feeds at the focal surface to observe the longi-

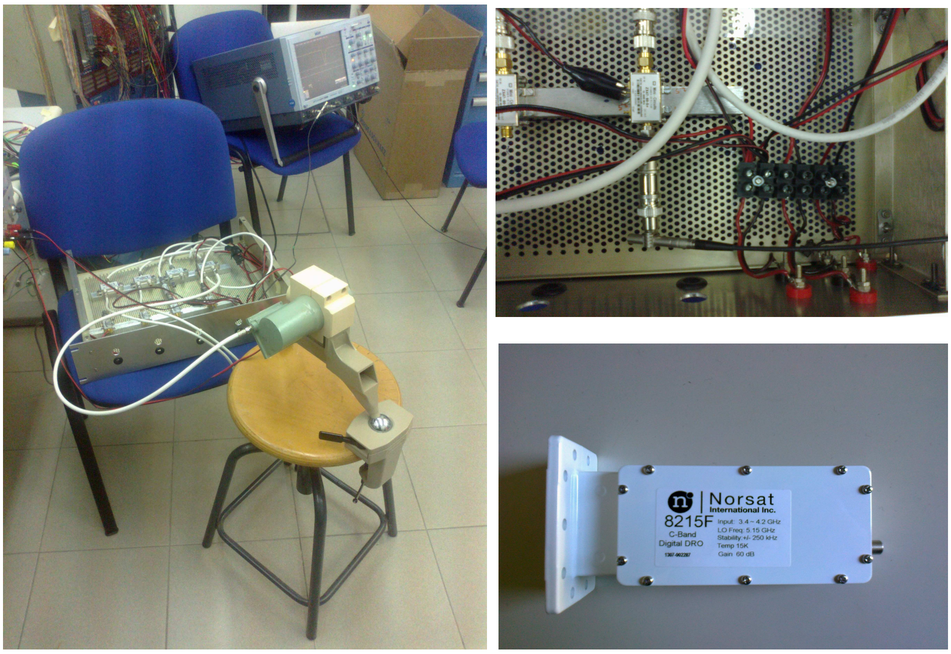

Figure 2. Experimental setup for feed characterization including the electronics box and the oscilloscope (left). Shows in figure is also the power detector (right top) and the LNB chosen for the construction of the prototype (right bottom).

tudinal profile of an extensive air shower propagating through the atmosphere. As shown in the figure, each feed would in fact provide the image of a segment of the longitudinal profile, giving overall a complete reconstruction of both geometry and particle number evolution.

- Participation to AMY
  An important contribution to this project comes from the participation to the experiment AMY approved and funded independently by INFN. It aims to derive an absolute calibration of the physical process of microwave emission and to measure the spectrum of the emitted radiation in the frequency range between 2 and 25 GHz. This experiment is performed at the Beam Test Facility (BTF) of the Laboratori Nazionali di Frascati. The first measurement campaign has been carried out between November 21st and December 4th 2011, using electron beams of 500 MeV on fixed target. Data are being analyzed. The outcome of this experiment will be relevant to the knowledge of the physical process and to the consequent optimization of the telescope design.

- Electronics for Data Acquisition.
  A study of the appropriate design for the DAQ electronics has been started. We will adopt use fast analog-to-digital converters with high sampling frequency (100 MHz) and large dynamical range (14 bit) combined with power detectors to enhance the signals which are expected to be very weak.

- Feeds characterization.
  A dedicated campaign of measurements has been carried out in order to study the response of the feeds candidate to be employed in the construction of the prototype. The experimental setup (shown in figure 2, left) consisted of a Rohde-Schwartz signal generator, a "biquad" antenna optimized for emission in C-Band (at about $\sim$ 4GHz), an LNBF (Low Noise Block Feed) receiver and an oscilloscope Le Croy for data acquisition and analysis. We measured the angle to feed axis at which the signal is reduced by 3 dB (*taper angle*), see figure 3, top. This value is relevant for a realistic simulation of the antenna response. We also measured the feed sensitivity and the delay introduced by the cables along the distance between the astroparticle physics laboratory and the antenna installation site (the roof of the building hosting the Physics Department), see figure 3, bottom. The feeds that we decided to use are produced by the North American manufacturer Chaparral,

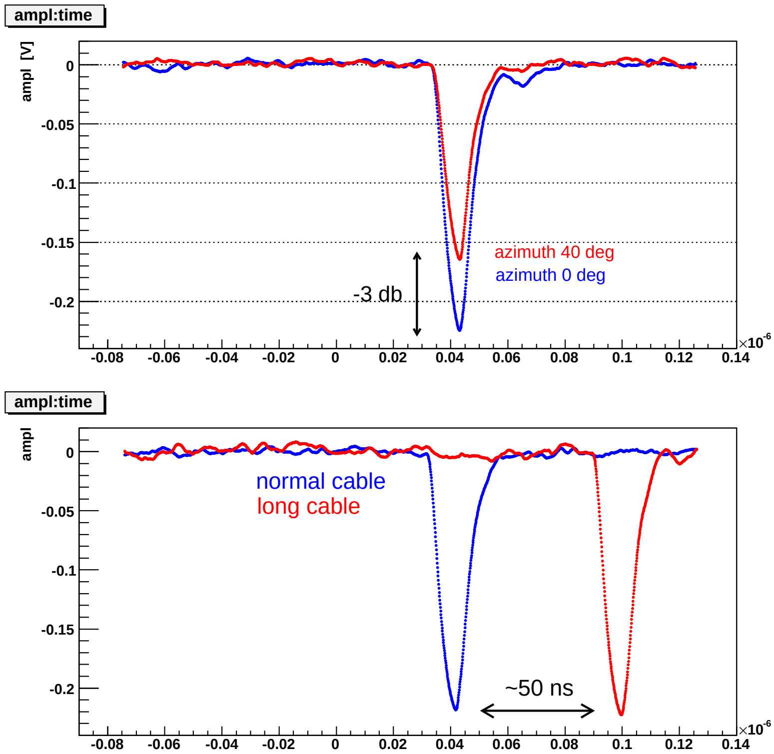

Figure 3. Measurement of *taper* angle (top) and cables delays (bottom). See text for details.

a leader company in the production of C-band receiver. The radio signal is converted to a lower frequency (about 1 GHZ) with low noise ($\sim$ 15 K) blocks, designed to have a very low background in faint signal measurement. The selected LNB are produced by the English manufacturer Norsat, see figure 2, right bottom.

- Parabolic dish.
  The choice of the parabolic dish has been very delicate. The experience gained within the community working on microwave detection of cosmic rays, and in particular the interaction with the group of Forschungszentrum di Karlsruhe, was very fruitful. We finally identified the parabolic dish fulfilling the requirements of quality, cost and efficiency from the proposal. It is distributed by the company ApexSat of Pforzheim (Germany) and produced by the North American manufacturer Prodelin. The dish has a diameter of 3.7 m and it consists of a 8 glas fiber slices. A picture taken on the day of delivery of is shown below 4.

4. Status

All components, i.e. feeds, LNBs, dish, electronics for DAQ, cables and connectors, have been acquired. The technical department of the University is now proceeding with the installation of the antenna on the roof of the Physics Department. This will require a dedicate effort, given the size and the weight of the antenna. The site has been already identified and the entity of the work quantified.

5. Impact of the project

The main motivation is the study and the detection of the highest energy cosmic rays (E>10^{18} eV) by observing and measuring the electromagnetic radiation emitted in the microwave C-band. Besides to this, the antenna will be capable of observing astrophysical sources emitting in this frequency band, such as the sun and the crab nebula. The instrument will be then an interesting tool for astronomical

Figure 4. Picture taken on the day of the antenna delivery by Physics Department

observation, appealing for the astrophysics group of the Department. It will also be an excellent tool for didactical and outreach purposes.

6. Acknowledgments

We want to thank the administrative staff of the Engineering Department (in particular Gabriella Panareo, Francesco Angiulli and Alessandra Bartolomeo) for help with invoices and related bureaucracy. A special thanks goes to the technical staff of the Mathematics and Physics Department and to INFN for the support along this phase (and in advance for the support they will be providing in future).