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Extensive air showers and diffused Cherenkov light detection: The ULTRA experiment

G. Agnetta[a], P. Assis[b], B. Biondo[a,c], P. Brogueira[b], A. Cappa[d,e], O. Catalano[a,c], J. Chauvin[f], G. D'Alí Staiti[a,c,g], M. Dattoli[d,e,h], M.C. Espirito-Santo[b], L. Fava[d,e], P. Galeotti[d,e], S. Giarrusso[a,c], G. Gugliotta[a,c,✠], G. La Rosa[a,c], D. Lebrun[f], M.C. Maccarone[a,c], A. Mangano[a,c], L. Melo[b], S. Moreggia[f], M. Pimenta[b], F. Russo[a], O. Saavedra[d,e], A. Segreto[a,c], J.C. Silva[b], P. Stassi[f], B. Tomè[b], P. Vallania[e,h,*], C. Vigorito[d,e], The ULTRA Collaboration

[a]*Istituto di Astrofisica Spaziale e Fisica Cosmica di Palermo, Istituto Nazionale di Astrofisica, Via Ugo La Malfa 153 - 90146 Palermo, Italy*
[b]*Laboratório de Instrumentação e Física Experimental de Partículas, Av. Elias Garcia 14, 1°, 1000-149 Lisboa, Portugal*
[c]*Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Viale A. Doria 6-95125 Catania, Italy*
[d]*Dipartimento di Fisica, Generale dell'Università di Torino, via P.Giuria 1-10125 Torino, Italy*
[e]*Istituto Nazionale di Fisica Nucleare, Sezione di Torino, via P.Giuria 1-10125 Torino, Italy*
[f]*Laboratoire de Physique Subatomique et de Cosmologie, 53, avenue des Martyrs-38026 Grenoble Cedex, France*
[g]*Dipartimento di Fisica e Tecnologie Relative, Università degli Studi di Palermo, Viale delle Scienze, Edificio 18-90128 Palermo, Italy*
[h]*Istituto di Fisica dello Spazio Interplanetario dell'Istituto Nazionale di Astrofisica, corso Fiume 4-10133 Torino, Italy*

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Abstract

The Uv Light Transmission and Reflection in the Atmosphere (ULTRA) experiment has been designed to provide quantitative measurements of the backscattered Cherenkov signal associated to the Extensive Air Showers (EAS) at the impact point on the Earth surface. The knowledge of such information will test the possibility to detect the diffused Cherenkov light spot from space within the Ultra high-energy cosmic ray observation. The Cherenkov signal is necessary to give an absolute reference for the track, allowing the measurement of the shower maximum and easing the separation between neutrino and hadronic showers.

In this paper we discuss the experimental set-up with detailed information on the detection method; the in situ and laboratory calibrations; the simulation of the expected detector response and finally the preliminary results on the detector performance.

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1. Introduction

The Uv Light Transmission and Reflection in the Atmosphere (ULTRA) experiment [1] has been designed in the context of the Extreme Universe Space Observatory (EUSO) project as a propaedeutic experimental supporting activity to study the possibility of detecting from Space the Cherenkov signal associated to the highest-energy tail of the cosmic ray spectrum. The aim of the EUSO project [2–4] is to detect the Ultra High-Energy Cosmic Rays (UHECR) by measuring the fluorescent light produced by the interaction with the Earth atmosphere. With this method, the particle track can be measured together with its relative depth, but not its absolute position. During its development through the atmosphere, the $e^{\pm}$ belonging to the Extensive Air Shower (EAS) produce a huge amount of

*Corresponding author. Istituto di Fisica dello Spazio Interplanetario dell'Istituto Nazionale di Astrofisica, corso Fiume 4-10133 Torino, Italy. Tel.: +390116707349; fax: +390116707493.
E-mail address: Piero.Vallania@to.infn.it (P. Vallania).
✠Deceased.

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Cherenkov photons emitted in a narrow cone along the shower axis. At the impact with the Earth surface, this light is partially absorbed and partially diffused, giving the possibility, if detected together with the main fluorescent signal, of having an absolute reference for the track, thus allowing the measurement of the shower maximum. Aim of the ULTRA experiment is to provide quantitative measurements of the reflectively diffused signal produced by the EAS impact on the Earth surface, overcoming the lack of information in this specific field.

The detection of EAS through the Cherenkov light reflected by snow was indeed firstly proposed by Chudakov [5] in 1972 and performed at the Big Alma-Ata Lake [6] (Kazakhstan) and other sites [7,8] since 1983, but only snowed surfaces were used without any measurement of the related EAS. For our purposes, since the Earth surface is covered by more than 70% of water, we need to study the diffusing properties of this medium. The study of the feasibility of the fluorescent light detection and the atmospheric background measurement by balloon borne experiments have been done elsewhere [9]; the goal of the ULTRA experiment described in this paper is to verify the possibility of detecting the reflected/diffused Cherenkov light produced by the EAS impacting on sea water. A scintillator array and an UV light detector will operate in coincidence to detect the electromagnetic component of EASs and the associated UV photons. In order to fully characterize the impinging signal, both direct and diffused light are measured. We have decided to perform these measurements in real conditions, using the same signal (i.e. lateral distribution, energy spectrum and time spread of incoming photons) that will be visible from Space, not only to have the exact features, that in any case could be reproduced in laboratory, but mainly to study the effect of the accompanying particle shower on the impacting surface. For this reason we have prepared a laboratory facility to test the properties of the incident light of fixed wavelength on different surfaces.

2. Detector layout

The ULTRA apparatus is a hybrid system composed by three main parts named ETscope, UVscope and Belenos, respectively. ETscope is a small array of scintillators which measures the shower size and the arrival direction of incoming EAS; near the centre of the array are located two couples of wide field Cherenkov light detectors, called "Belenos",[1] pointing to zenith and nadir to measure in coincidence the direct and diffused Cherenkov light.

Outside the array is sited UVscope, made by a couple of narrow field Cherenkov detectors pointing to the centre of the array; it is used to give the most accurate measurement of the diffusion coefficient. The first tests were performed during October 2002 and June–July 2003 at Mont-Cenis (France, 1970 m a.s.l.) and during 2004 at LPSC, Grenoble (France, 250 m a.s.l.) to test, calibrate and optimize the detectors [10]; in May 2005 the experiment was carried out at sea level in a small private harbour in Capo Granitola (Italy) [11]. In this paper we describe the characteristics and performances of the final experimental set-up.

2.1. ETscope: the electromagnetic detector

The electromagnetic detector ETscope is a small EAS array made by five particle detection stations. Each station includes a plastic NE102A scintillator ($80 \times 80\,\mathrm{cm}^2$ area and 4 cm thick) with an expected light yield of $\sim$40 photoelectrons/m.i.p. (minimum ionizing particle). Two photomultipliers XP3462, with high voltage power supplies set to work at different gains (High Gain (HG) and Low Gain (LG) photomultipliers) are located below each scintillator at a distance of 30 cm. Both the scintillators and the photomultipliers are contained in a pyramid-shaped box made of stainless steel and coated with white diffusing paint. All the equipment is finally housed in a $1\,\mathrm{m}^3$ plastic container to provide total insulation. The main goal of this detector is to determine the arrival direction, size and core location of the impinging shower. This information, together with the UV-light measurements and an accurate Monte Carlo simulation, will determine the diffusion features of the selected surface.

Designed to be operated on different environments including the sea, the ETscope has been optimized as a portable, floating and waterproof detector. At the Capo Granitola site four out of five stations were placed at the vertexes of a trapezoid at different heights on the shore surrounding the bay as illustrated in Figs. 1 and 2. Being the bay very well protected from waves, tides and winds, we managed to place the fifth scintillation counter on a raft in the middle of the experimental area.

2.2. UVscope: the narrow field of view optical device

The UVscope optical device, as shown in Fig. 3, consists of two separate units (telescopes) placed on a tripod. The telescopes are mechanically aligned to have parallel optical axes; each telescope is made of a common Fresnel lens of 0.46 m diameter having a large Photo-Multiplier Tube (PMT) on its focal plane. The lens provided by Fresnel Tecnologies Inc. [12] is made of UV transmitting acrylic material which offers a good optical quality with bulk transmittance approaching 90% in the wavelength band of

Fig. 1. The ULTRA experiment at Capo Granitola, Italy.

[1]Belenos was the Celtic god of light, a Gallo-Roman nickname for Apollo, often invoked by Asterix and the other Gauls.