The Scientific Baseline to have an Atmosphere Sounding System coupled to the *EUSO* Detector

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Abstract

The atmosphere provides the active target for the detection of the Extreme Energy Cosmic Rays ($EECR$) and Neutrinos ($EE\nu$), as well as for the signals induced by other physical phenomena (lightning, meteors,...), addressed by the $EUSO$ experiment. The detection technique is based on the time and space imaging of the fluorescence, emitted in the UV wavelength range 300÷400 nm and induced, in the atmosphere, by the passage of the secondary ionizing particles which constitute the Extensive Air Showers. The EASs induced by $EECRs$ and $EE\nu$ also produce an intense Čerenkov beam, collimated around the shower axis, whose reflection/diffusion can be detected as well. The transport of both the fluorescence and of the Čerenkov signal is conditioned by the atmospheric conditions. This paper addresses the issue of directly monitoring the conditions of the atmosphere, during the $EUSO$ mission.

Introduction

The atmosphere is, as seen from $EUSO$ (Extreme Universe Space Observatory" [1,7,8], an active target, whose composition, density and thermodynamical state determines, for a given shower, the intensity of the detectable signal. The correct reconstruction of the parent EAS longitudinal profile depends on a detailed knowledge of the atmosphere's actual condition and on the capability of deconvolving the distortion introduced by it.

Since the ISS covers the whole Earth surface in the latitude range -51^o+51^o and moves at a speed of 7 km/sec, the variability of the scene seen by $EUSO$ is much higher than that observed by a ground-based experiment. On the other hand, the large distance from which $EUSO$ looks at the Earth($>\sim$ 400km) with respect to the thinness of the atmosphere layer where the shower develops ($>\sim$40 km) turns out into a large advantage, together with the almost vertical direction of the line of sight($EUSO$ field of view FoV, $\pm 30^o$ around the vertical). The former feature has, as a consequence, that the proximity effect is in fact rather small (all the different segments of the shower lie approximately at the same distance ($\pm$10 %) from the detection optics, the latter ensures that the traversed depth of the

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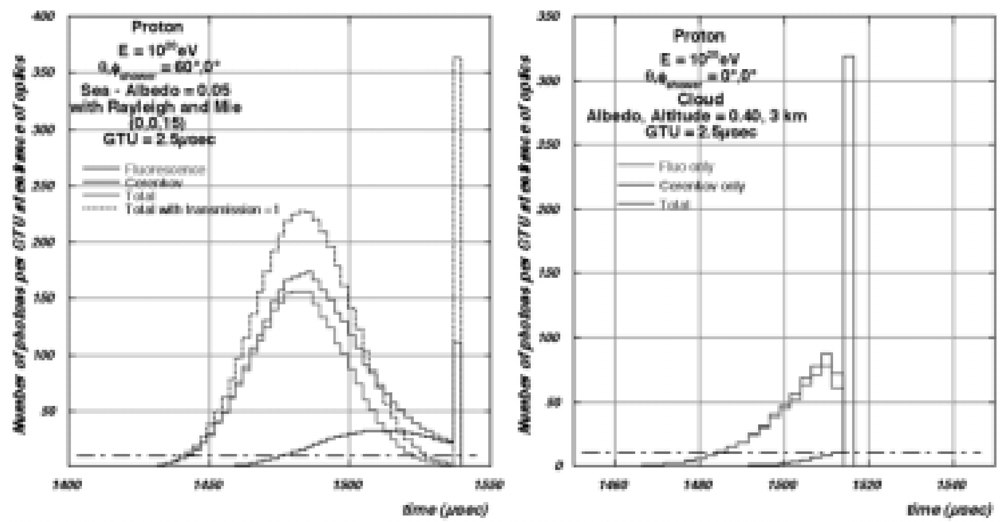

Fig. 1. Number of photons arriving at the *EUSO* optics[6] for a proton showers at (E = 10^{20} eV) for **left**, inclined direction, $\theta = 60^o$ in a "clear sky" condition, **right** vertical direction $\theta = 0^o$in the presence of a dense cloud at 3 km altitude.

absorbing/scattering medium is minimized from the light source to the detector position. Clouds will eventually obscure the lower part of the atmosphere with the double effect of hiding the evolution of the shower, but also of enhancing the albedo of the surface and thus strengthening the light (mainly due to the Čerenkov beam) scattered toward *EUSO*. The *EUSO FoV* includes a region of the Earth atmosphere of $>\sim$ 200km in radius, thus covering areas where the atmosphere condition can be rather different. A direct sounding of the atmosphere is therefore under study[8], by the use of a LIDAR, as a part of the *EUSO* Instrument. The LIDAR will scan the full *FoV* and, upon occurrence of a trigger, will point the region where the event comes from and probe, locally, the atmosphere.

Ideal atmosphere and real atmosphere observations

Fig. 1[6](left), shows an ideal shower profile, as induced by a primary proton of energy E$>10^{20}$ eV, impinging at an angle of 60^o from the vertical, as it should be seen by the *EUSO* optics, within a "clean atmosphere". This spectrum shows the number of photons arriving at the entrance of the *EUSO* optics as a function of time. The details of the simulation are given in Ref. 4. The grey curves show the yield associated to the fluorescence production and to the Čerenkov photons. The full black curve gives the sum of both. The dot-dashed curve represents the average background noise per pixel. The black dotted curve shows the number of photons that would arrive at the *EUSO* optics if the atmosphere would be completely transparent (no diffusion or absorption). It is only this curve that has some relation to the initial *EECR* energy. An energy

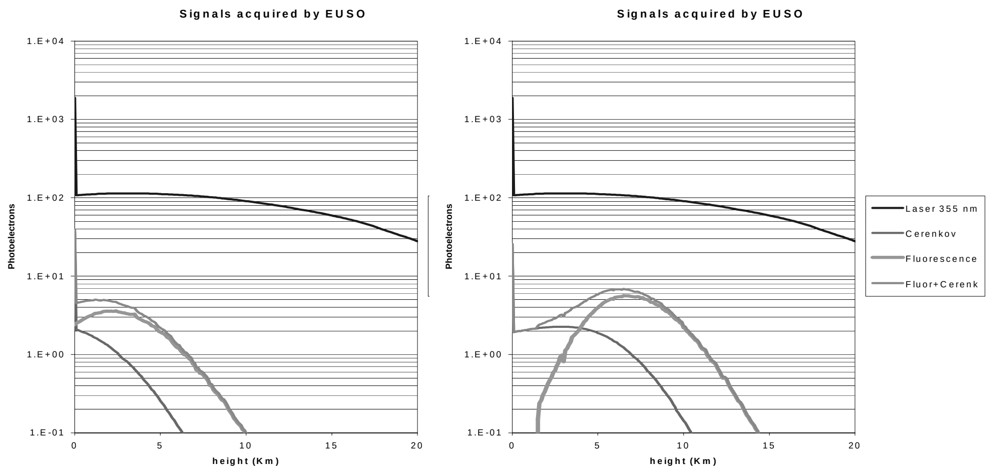

Fig. 2. Expected number of photoelectrons detected by *EUSO* for a E = 10^{20} eV proton (orange curves) and for a 50 mJ LIDAR shooting, in a "clear sky" condition: **left**, vertical shower, **right**, inclined shower, $\theta = 60^o$.

measurement by *EUSO* would therefore imply a correction to compensate for the atmosphere transmission, working out the dotted curve from the black full one. And the compensation is strongly dependent on the atmospheric conditions. Fig. 1 shows also (right) another almost "clean situation", when a vertical shower of the same energy hits an optically thick cloud, at a height of 3000m a.s.l. The shower maximum is now hardly recognizable in the profile, before that the shower enters the cloud. The Čerenkov peak is on the other hand strongly enhanced. The chance to get relevant information about an event like this one depends on the knowledge of the height and the optical depth of the cloud. This information should be provided by the LIDAR[8] response analysis.

The LIDAR option

A worthwhile initial consideration facing the data retrieval problem of *EUSO* is the assessment of the role of clouds and aerosol. Based on available meteorological statistics [9,10] the annual average clear sky frequency (limited to visual reports of clouds only) is 18 % over land and 3 % over seas. The total cloud cover amounts on the average to 64.8 % over ocean areas, whereas for the land is 52.4 %. Moreover there is a high probability of simultaneous occurrence of aerosol layers and different cloud types at different heights in the atmosphere [4,5]. Fig. 2[8] shows the expected number of photoelectrons recorded by *EUSO* as induced by an energetic proton (E = 10^{20} eV), either vertical (right), or inclined (left) and the corresponding signal of a typical LIDAR, as a function of the altitude, in a clear sky situation. Fig.3[8] shows the same profiles, worked out when the transmission medium is a possible atmospheric profile, as registered, in a real

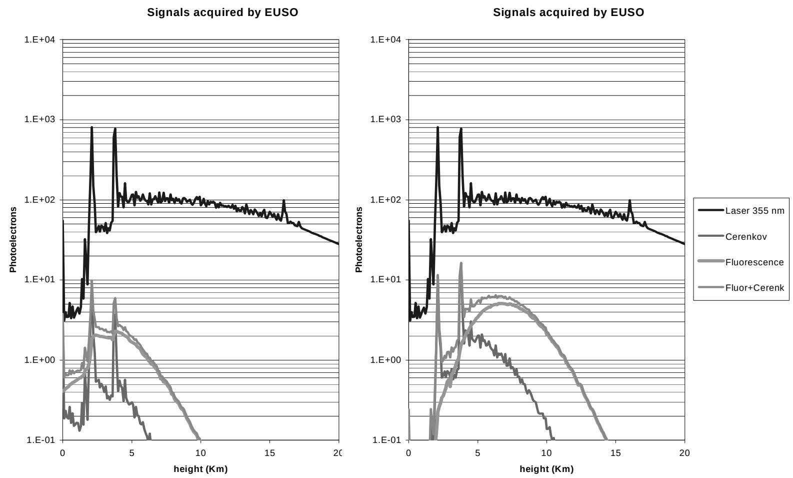

Fig. 3. Expected number of photoelectrons detected by *EUSO* for a E = 10^{20} eV proton and for a 50 mJ LIDAR shooting, in a real atmospheric condition [3]: **left**, vertical shower, **right**, inclined shower, $\theta = 60^o$.

atmospheric data acquisition run [3]. The calibration curve given by the LIDAR is in this case of utmost importance, to measure and interpret the shower induced signal and to disentangle the distortion introduced by real atmosphere.

Conclusion

The evaluation of the real atmospheric situation in the EUSO experiment is needed in order to correct for the influence of its features on the detected signal, minimize the systematic errors and evaluate the real duty cycle and acceptance.

The connection to the existing databases and meteorological satellites will give the possibility of an average correction of the duty cycle and acceptance.

The use of a dedicated LIDAR system, as a part of the EUSO Instrument, will allow to correct, on an event-by-event basis, the detected signal, or to isolate the most doubtful triggers, reducing thus the systematics in the data analysis.

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