Simulation and Data Analysis for EUSO

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Abstract

The *"Extreme Universe Space Observatory - EUSO"* is the first Space mission devoted to the investigation of Extreme Energy Cosmic Rays/Neutrinos (EECR/ν), using the Earth's atmosphere as a giant detector. The detection is based on the innovative approach of the well-known technique of capturing the UV fluorescence radiation emitted by Extensive Air Shower (EAS): the UV fluorescence will be detected after its propagation upward from the atmosphere to the *EUSO* telescope accommodated on board the International Space Station.

This approach implies a dedicated effort for the evaluation of the expected features of the detected signals and the reconstruction of its space-time development, energy and composition, namely from the simulation and data analysis point of view. Physics process simulation, active target simulation, detector simulation, event reconstruction all contain peculiarities due to the *EUSO* observational strategy.

1. Introduction

The scientific objective of the *EUSO* [2,11] mission is to observe and measure, with high statistical significance, the cosmic rays spectrum in the energy region $E > 5 \times 10^{19} eV$, the highest range ever investigated for Cosmic Rays, the so-called Extreme Energy Cosmic Ray region. *EUSO* will also be able to open a window on the Neutrino Astrophysics in the same energy range [5].

EUSO as a mission [5] has been approved by the European Space Agency for an accommodation on the International Space Station (ISS), and is undergoing at the moment a Phase A detailed feasibility study. The *EUSO* telescope set-up is described elsewhere, as well as the details of the expected detector performances [5]. The aim of this paper is to discuss the problems posed by the innovative approach of *EUSO* (as it is the first experiment which will detect EASs from space and in particular through their fluorescence emission), as far as the simulation and event reconstruction are concerned.

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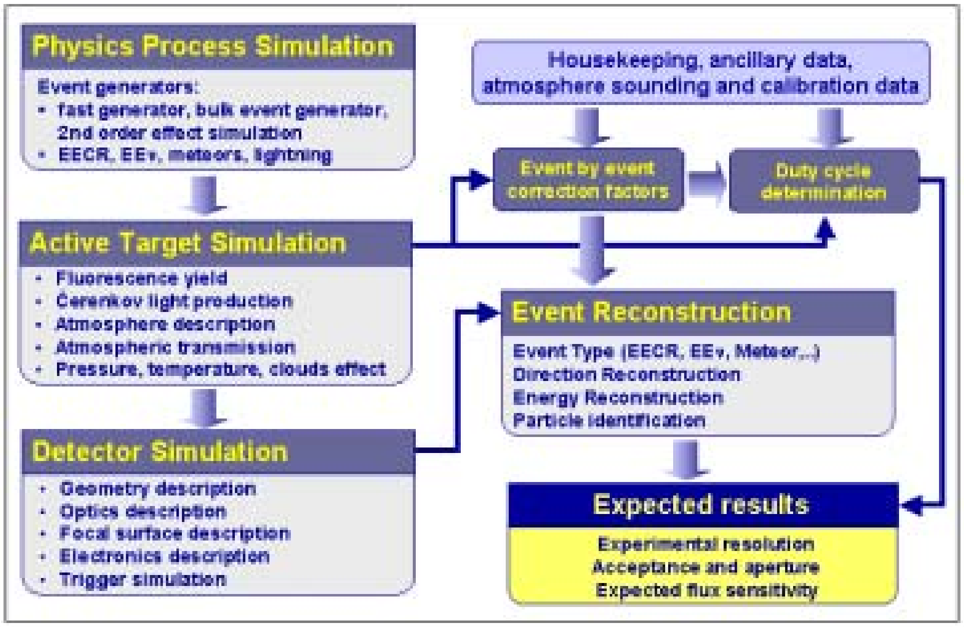

Fig. 1. Flow-chart of the *EUSO* simulation and analyis scheme.

2. The Simulation and Data Analysis for *EUSO*

The flow-chart in Fig.1 summarizes the most important items that the *EUSO* Simulation and Data Reduction software has to face.

The trade-off of EAS generation is between the desirable detailed description of the most common and sophisticated Montecarlo programs (CORSIKA [6], AIRES [12]), paid with a very high computing time, even in the "thinning" version and a less detailed simulation, focused on the correct treatment of the longitudinal shower profile, the fluorescence yield and Čerenkov light emission, leaving apart the development of all the secondary particles produced in the shower. A library of simulated events is being constructed using a less detailed generator of the hybrid category, called UNISIM [1], based on a full Montecarlo approach according to the SYBILL [4] minijet model for high energy hadronic interactions. Particles are followed down a given threshold ($E = 10^{17} eV$); below that, a library of existing showers is used, to work out the longitudinal profile. Some analytical code to generate the longitudinal profile and the Čerenkov light beam (GIL [3], SLAST [10]) is also used to allow a fast overlook to the gross feature of the events. At each relevant step of the generation process, a cross-check of the results with a reference Montecarlo code (CORSIKA) is performed.

The atmosphere is, as seen from *EUSO*, an active target, whose composition, density and thermodynamical state determine the intensity of the detectable signal. Its detailed modeling and the simulation of the UV light production and transport from the light source (the EAS) to the detection device (*EUSO* telescope) is therefore mandatory for a correct deconvolution of the effect of the atmosphere from the recorded signal to the parent EAS longitudinal profile.

Since the ISS covers the whole Earth surface in the latitude range $\pm 51^o$ and moves at a speed of $7\,km\,s^{-1}$, the variability of the scene seen by *EUSO* is much higher than that observed by a ground-based experiment. A lot of works have been published and are still in progress to parameterize the fluorescence yield [5]; its wavelength dependence, in the range $330 \div 400\,nm$ is duly taken into account within the simulation chain, according to [9]. We use the LOWTRAN7 package [7] as a software tool to measure the effect of the atmospheric transmission. On the opposite, the fact that *EUSO* is looking to the Earth from a large distance ($\sim 400\,km$) together with the thinness of the useful atmosphere layer ($<\sim 40\,km$) turns out into a large advantage, as the proximity effect is rather small; moreover, the fact that *EUSO* looks at the EAS scene from almost a vertical direction ($FoV = \pm 30^o$ around the vertical) minimizes the light path in the absorbing/scattering medium, from the light source to the detector position.

The most difficult aspect, both from the simulation and from the data analysis points of view is, by far, the distortion effect due to the clouds. A detailed analysis of the problem is given elsewhere [5]. An in-flight monitoring of the actual atmospheric conditions will be performed thanks to an "Atmosphere Sounding" device, a LIDAR probe, as a part of the *EUSO* Instrument, which will explore the region of the sky where the trigger comes from, on an event-by-event basis. Here again the largest simulation effort is devoted to the exploitation of a deconvolution algorithm, able to estimate the parent fluorescence/Čerenkov UV light profile, starting from the recorded signal.

The detector simulation, providing the expected recorded signal, has been set-up within ESAF (EUSO Simulation and Analysis Framework [5]), where a detailed description of the detector is given, taking into account the effect of its different components, both in terms of geometry and efficiency. The ESAF output is intended to be a raw-like simulated event.

The *EUSO* detection system is based on the imaging of the shower through the single photon counting (with a double pulse resolution of $10\,ns$) in any pixel ($< 1\,km^2$ on ground), within a very short time window (the experiment Gate Time Unit, GTU, $\Delta t \leq 3\,\mu s$). The space-time image of the triggering shower will be thus given in terms of X-T and Y-T projection of the collected photons, X and Y being the coordinates inside the FoV, T the time coordinate measuring the shower development in depth, thus giving the length in the third direction (the height in the atmosphere). The shower appears as a "single track" event in the *EUSO*

FoV. The reconstruction of the two projections X-T, Y-T will therefore give, in the ideal case, an unambiguous estimate of the shower direction, to the extent that the reconstruction algorithm is able to recognise the sequence of correlated space-time pixels out of the uncorrelated background ($\sim 500\, ph\, ns^{-1}\, sr^{-1}\, m^{-2}$). The preliminary results, as far as the expected angular resolution is concerned, are presented elsewhere and have been worked out either using linear fitting [5] or dedicated pattern recognition techniques [8].

The ultimate goal of *EUSO* is measuring the energy spectrum of the EECRs. Thus, the energy reconstruction and the achievable resolution appears as a priority in the development of the simulation chain and the reconstruction algorithms. An energy resolution of $\Delta E/E \leq 20\%$ is the experimental requirement. Some preliminary result is discussed in [5]. The reconstructed maximum shower size $N_{max} = N(s = 1)$, the estimate of the track integral and the shower elongation X_{max} are used as indicators, both to derive the energy of the primary and the expected elemental composition resolution power. Extreme Energy Neutrinos will instead be clearly tagged by the value of the depth of the shower maximum $X_{max} > 1400\, g\, cm^{-2}$, within the sample of quasi-horizontal showers ($\theta \geq 70^o$).

3. Conclusions

An end-to-end simulation chain for *EUSO* is being developed, which goes from the physical process simulation to the event reconstruction, through the atmosphere transport equation and a detailed detector performance simulation. A particular effort will be devoted to the deconvolution algorithm, to estimate the expected shower longitudinal profile, with reference to the distortion introduced by the variability of the atmospheric condition as seen from *EUSO* on the ISS.

4. References

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