29th International Cosmic Ray Conference Pune (2005) **00**, 101–104

The Euso Simulation and Analysis Framework

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ESAF is the simulation and analysis software framework developed for Euso experiment. ESAF's scope is the whole process of data simulations and data-analysis, from the primary particle interaction in atmosphere to the reconstruction of the event. Based on the ROOT package and designed using Object Oriented technology, is organized in two main programs: the full montecarlo simulation and the reconstruction framework. The former includes all the relevant physical contributions, shower development in atmosphere, light transport to the detector pupil and detector response, while the latter comprises basic data cleaning, track direction, shower profile and energy reconstruction algorithms. Here we describe the software architecture and its main features.

1. Introduction

The experiments aiming to study Extensive Air Showers (EAS) generated in the atmosphere by Ultra High Energy Cosmic Radiation with energy above 10^{19} eV requires detectors with huge sensitive area.

In order to achieve a larger geometrical aperture an approach alternative and complementary approach to the ground based experiment has been proposed for the first time by John Linsley more than 20 years ago. An EAS can be detected by observing the fluorescence light emitted by nitrogen. Instead of looking at this UV light from ground, the same signal can be watched from above, using a space-borne wide angle telescope on orbit around the earth. The fluorescence light is produced isotropically and, at any depth in the shower, is proportional to the number of charged particles.

The "Extreme Universe Space Observatory - EUSO" [1] was proposed as free-flyer satellite in winter 1999. EUSO was accepted for an Accommodation Study on the ISS (end 2000) and then approved for Phase A (study report and conceptual design), successfully completed in summer 2004.

ESAF, the EUSO Simulation and Analysis Framework, has been developed during the EUSO Phase A study as the full End-to-end simulation and analysis chain. A flexible and detailed MonteCarlo simulation is the fundamental tool to understand the effects contributing to the detected signal and to the background. A powerful event reconstruction is necessary to disentangle the signal from the background, to extract the shower parameters and the primary particle features.

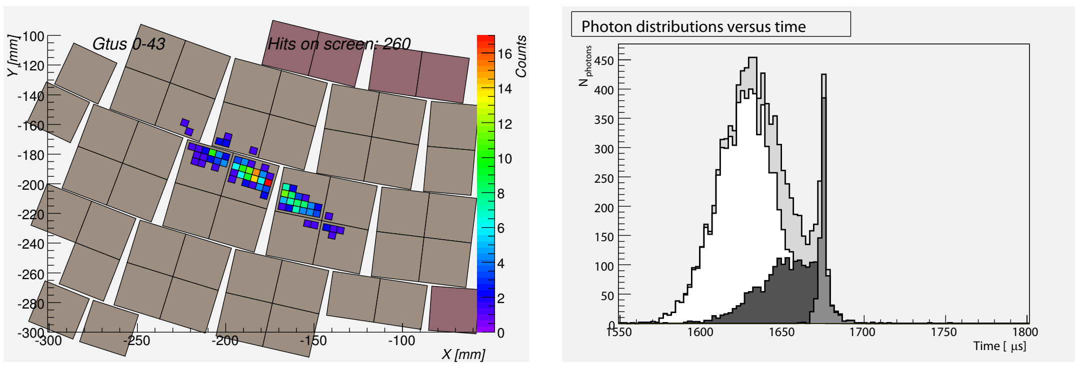
Flexibility is a key point. Therefore ESAF was conceived to be easily adaptable to any space-borne detector design. The ESAF package is written in C++ and based on ROOT [3] framework.

The simulation has been organized in two main subsystems, the light generation and the detector response. The output is written as a standard ROOT file, with detailed information of each simulated effect along with the detector configuration used. To inspect the output an advanced event viewer has been implemented (fig:1). The

ROOT file acts also as interface between the simulation and the reconstruction. The reconstruction is designed as a set of modules driven by a common framework. Each module implements a different algorithm.

2. Light Generation and atmosphere transmission

The detected shower signal depends critically on the atmospheric parameters. The monitored volume of atmosphere is continuously and rapidly changing, spanning many degrees in latitude and strongly variable weather conditions. Clouds may affect and distort or even enhance the shower signal. Also, many different kind of backgrounds are expected, including night-glow, man-made lights, lightnings, reflected moonlight.



(a) (b)

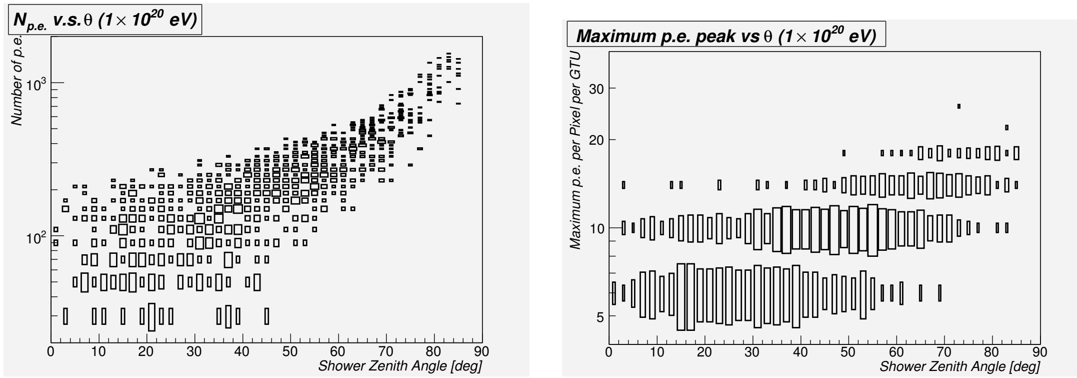
Figure 1. (a) Front-end counts generated by a 1.5×10^{20} eV, proton shower developing in clear sky atmosphere on the EUSO focal surface. The night glow background hits are not shown. (b) Number of photons reaching EUSO pupil versus time. Different contributions are shown: the fluorescence light transmitted directly to the detector (white), Čerenkov beam scattered by the atmosphere (dark gray) and reflected by the ground (ash gray) and the overall profile (light gray).

The simulation of light toward the detector has been split in three parts, according to the involved processes: the physics event generation, the production of light and the transport of light through the atmosphere:

1. Each primary physical phenomenon is coded into a Even Generator module. Several shower generators have been implemented, both as integrated part of ESAF or as interfaces to well established stand-alone generators (UNISIM [4], SLAST[5] and Corsika[6]). Lightnings and Meteors generators are foreseen.

2. The description of the physical event is given to the Light Source module to be converted into photons. Shower's fluorescence and Čerenkov signal spectra are simulated according the local atmosphere and electrons distributions. Nitrogen fluorescence yield data by Kakimoto[7] and Nagano[8] are used.

3. Eventually the photons are propagated from the creation point to the pupil of the detector by the Radiative Transfer module. Nitrogen fluorescence and Čerenkov radiation are treated separately. The former, isotropic, is transmitted directly to the detector, the latter, strongly forward beamed, is scattered in the air and diffusely reflected by the earth surface or clouds at the impact point (fig.1b). Transmission coefficients are computed for each wavelength as a function of the local atmosphere using the LOWTRAN[9] package. Several atmospheric profiles are supported: US Standard, MSISE, Lowtran, Corsika. The reflection of Čerenkov light on simple uniform cloud layers has been implemented.



(a) (b)

Figure 2. (a) Number of counts on the EUSO focal surface generated by 10^{20} eV showers as a function of the shower zenith angle. (b) Number of counts in the most populated pixel on EUSO focal surface as a function of shower zenith angle.

3. The detector

The Instrument must collect as many photons as possible, in order to be able to detect the faint signal from the less energetic EAS and to discriminate it from the background. All the components must be carefully assembled to minimize any possible signal loss. Dead areas on the focal surface, optics design, fluctuations in photo detectors response, background rate dependence on the position on the focal surface affect the performances of the instrument if not correctly taken into account.

The role of the detector's simulation is twofold:

1. Provide a fast and reliable tool to simulate a parameterized detector. The possibility to test the response as a function of optics field of view, optics transmittance, point spread function, photo detector pixel size and many other parameters is fundamental for any feasibility study of future space-borne UHECR detectors.

2. Support a full Monte Carlo simulation of the advanced instrument design. Currently, EUSO Phase A configuration has been successfully implemented: Large field of view Fresnel optical system, modular focal surface design, photo sensors assembled in 2x2 elementary cells (fig. 1a). All sensors are supplied with an UV bandpass optical filter and each elementary cell is connected to its own front-end chip. Elementary cells are grouped into logical triggering units (Macrocells) and several first level trigger patterns based on the space-time coherence of the shower signal has been included.

4. Reconstruction

The event reconstruction can be accomplished following multiple paths. ESAF reconstruction supports this approach via a modular framework where the module's chain can be easily configured by the user. Each module has been devoted to a specific task:

Pattern recognition : Disentangling of the signal from the incoherent background is committed to the Hough transform and clustering algorithms.

Track finding : the shower direction is computed with robust numerical and analytical approaches.

Energy : The primary particle energy is, in principle, proportional to the number of detected photo electrons. Nevertheless many effects can lead to a wrong estimation, if not taken into account. The energy module uses the information on atmosphere optical depth, detector's optics and focal surface dead areas to recover the shower longitudinal profile and then extrapolate the initial energy.

5. Conclusions

ESAF is a stable, powerful and flexible simulation and reconstruction tool for UHECR space-based UV telescopes.

ESAF, thanks to its flexibility, will also play a key role in feasibility studies for future experiment proposals within the ESA Cosmic Vision 2015-2025 program.

References

[1] G. D'AlìStaiti, "EUSO A Space mission searching for Extreme Energy Cosmic Rays and neutrinos", Proceedings of the CRIS 2004 Conference, Catania, Italy, May 31 - June 4 2004
[2] Euso collaboration, this conference, several contributions.
[3] ROOT Homepage, http://root.cern.ch/
[4] Bottai S. 2001, Proc. of the 27th ICRC, Hamburg.
[5] Naumov D. 2003, EUSO Report SDA-REP-015.
[6] Heck D. et al.. 1998, Report FZKA6019, Forschungszentrum Karlsruhe
[7] F. Kakimoto et al., NIM A372 (1996) 527.
[8] M. Nagano et al., Astropart. Phys. 22 (2004) 235-248.
[9] Kneizys F.X. et al. 1996,The MODTRAN 2/3 Report and LOWTRAN 7 MODEL, ed. L.W.Abreu and G.P. Anderson