THE ESAF SIMULATION FRAMEWORK FOR THE JEM-EUSO MISSION

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Abstract: ESAF, the EUSO Simulation & Analysis Framework, was originally developed as the simulation and analysis software for the Extreme Universe Space Observatory - EUSO mission of ESA. More recently, ESAF has been extended and modified to simulate the JEM-EUSO mission. ESAF consists of several independent modules, which perform the shower simulation, the light transport in the atmosphere, the instrument and telemetry simulation, and eventually the analysis of the observed track in order to reconstruct the energy, arrival direction and Xmax of the event. In this paper, we present the ESAF event simulation structure. In particular we describe the shower generators, the atmospheric modeling, the simulation of the JEM-EUSO optics, sensors and electronics including the trigger algorithms developed to discriminate the good event signals from the background, allowing a fake trigger rate compliant with the JEM-EUSO telemetry constrains. We will also show some event describing it step by step through the entire detector.

Keywords: JEMEUSO, Simulation, Analysis, ESAF

1 Introduction. ESAF the Euso Simulation and Analysis Framework

The Euso Simulation and Analysis Framework (ESAF) is currently used as the simulation and analysis software for the JEM-EUSO mission [1][2]. It has been developed in the framework of the ESA-EUSO mission [3][4]. ESAF performs the simulation of the shower development, atmospheric transport, detector optics and electronics simulation. Furthermore, algorithms and tools for the reconstruction of the shower properties are included in the ESAF package. In the framework of the JEM-EUSO Phase-A study, we took all the necessary steps to implement the JEM-EUSO mission configuration. This is carried out in a coordinated effort between several groups which are actively collaborating in the software development and on the mission performances assessment. A general sketch of the ESAF structure is given in fig 1. ESAF is a C++, Object Oriented, root[1] based software. It has been written in a modular way in order to cope with the high complexity of the mission and with the rapidly changing instrumental design and science requirements. It consists of several independent modules: the LightToEuso, the EusoDetector, the Reco and the Analysis module. The LightToEuso module allows the simulation of the shower development and of the light transport through the atmosphere to the detector. The EusoDetector includes the simulation of all the detector components from Optics to the Electronics of the JEM-EUSO telescope. Once the trigger algorithms issued a trigger signal, the event is sent through telemetry to Earth for the event reconstruction. At this stage (the Reco framework) the reconstruction of the arrival direction, energy and type of primary particle is performed. The Analysis module is being developed. The executables of the software

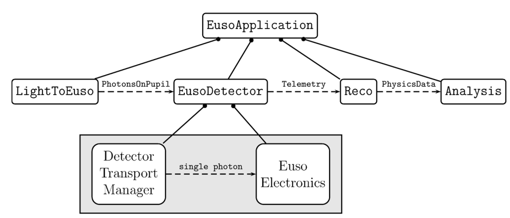

Figure 1: Basic ESAF scheme. Taken from [6]

1. Package developed at CERN for particle physics data analysis. [5]

have been divided in two parts: the Simu and the Reco file. The first performs the simulation of the real event from shower generation to telemetry while the second takes care of the reconstruction. This has been done in view of a future utilization of the reconstruction module which could be used for the analysis of real data.

2 The Simulation framework

In this section we will describe the simulation framework of the ESAF software. This part is meant to simulate all the physical processes which are related to the shower development, the light production and propagation, the detector and eventually the telemetry.

2.1 Event generators

Several shower simulators are implemented in ESAF, following parametrical and Monte Carlo approach. As parametrical generator, the Gaisser-Ilina-Linsley (GIL) function [7], is used to reproduce the profile as function of Energy and slant depth. Other generators such as the Monte Carlo simulator Corsika [8] and the Monte Carlo Conex simulator [9] are interfaced with ESAF. Consistency studies between all the different approaches have been performed and the appearance of some small inconsistency between the parameterization and the Monte Carlo simulators is still under investigation. With the different shower generators we are now able to generate showers of different primary. Neutrino showers can now be generated with the Conex generator and then analyzed by ESAF. Lidar events can be now generated in ESAF: specific methods have been developed and implemented to simulate photons at 355 nm emitted by laser sources, in parallel to methods in use for showers. Other sources of light (lightnings, TLEs[2], cities, meteors) cannot be simulated yet although test light sources can reproduce the effect of those events up to first approximation.

2.2 Atmospheric transport

Both Fluorescence and Cherenkov production is taken into account in ESAF. The simulated Fluorescence spectrum according to Nagano et al [10] is shown in Fig. 2. The Cherenkov production is taken into account following the standard Cherenkov theory. Both the ground reflected and the backscattered component are considered. All the photons are affected by Rayleigh scattering and ozone absorption. Furthermore, photons can reach the detector in indirect way after scattering. Optionally clouds can be simulated as constant layer of variable altitude thickness and optical depth. Non uniform cloud coverage is also included in ESAF. The effect of aerosols and dust has not been included in ESAF yet.

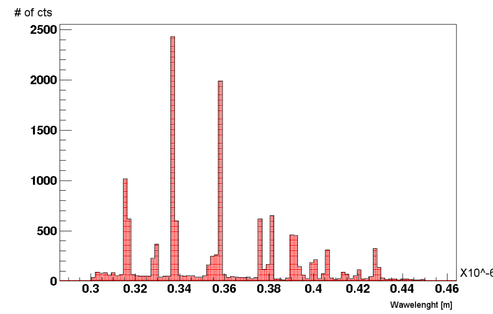

Figure 2: Photon spectrum simulated with ESAF. Both the typical Fluorescence emission lines and the Cherenkov (low level continuous spectrum) spectrum are visible. Fluorescence is calculated according to Nagano et al. [10]

2.3 Detector

Once the photons reach the detector they are taken over by the optics module. Several optics simulation approaches have been considered. The parametrical simulation module calculates analytically the position of the photon on the focal surface and adds to this position a random spread. This is intended to be the first approximation of the optics simulation and is basically the fast working tool to test the features of the different optics designs. Furthermore, the optics simulation code developed in RIKEN [11] is included in the simulation code. This ray-trace code is interfaced with the ESAF framework in order to transport every photon within the optics through a Monte Carlo simulation. In Fig. 3 an example of the generated RIKEN ray-trace Point Spread function can be seen. Several optics configurations have been included in the course of time to assess the performances. Another optics module is the Geant 4 optics module [12] which uses an interface with the Geant simulator to transport the photons from pupil to the focal surface.

In Fig. 4 we analyze the composition of the photon spectrum arriving at the pupil. As can be seen both direct fluorescence, reflected and backscattered Cherenkov are visible. Moreover we can observe in Fig. 5 the event through the entire detector from the pupil to detected counts regardless of the photon's kind.

Once the photons reach the focal surface they are transported through the filter and the optical adaptor before of reaching the photocathode. All the relevant effect including geometrical losses, inefficiencies of the adaptor (the BG3) and of the filter are taken into account. A parameteriza-

2. TLE: Transient Luminous Event. Transient event in the high atmosphere responsible for the production of huge amounts of light in the UV range. In this category we can consider Sprites, Jets, Elves and many other phenomena.

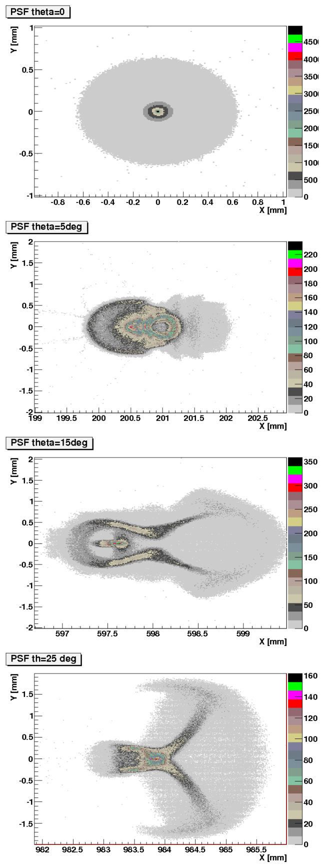

Figure 3: Point spread functions simulated with the RIKEN ray-trace code interfaced with ESAF for several inclination angles (0, 5, 15, 25 deg). On the axes the position in mm on the FS can be read.

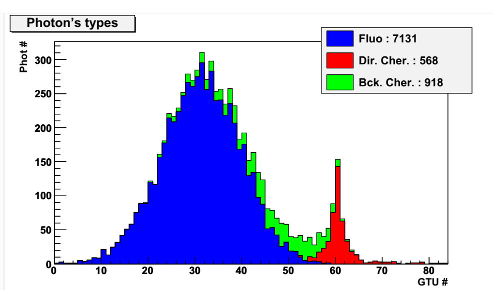

Figure 4: Composition of the photons at the detector pupil. Standard shower (10^{20}eV 60 deg) as simulated by ESAF with the GIL parameterization.

tion of the photomultiplier is included in the electronics part. All the effects like quantum efficiency (and its dependence from the photon inclination), collection efficiency and cross talk are also taken into account pixel by pixel within one Photomultiplier (PMT). The implemented Photomultiplier is the M64 Photomultiplier of Hamamatsu. In table 1 we give a resume of the most relevant parameters of

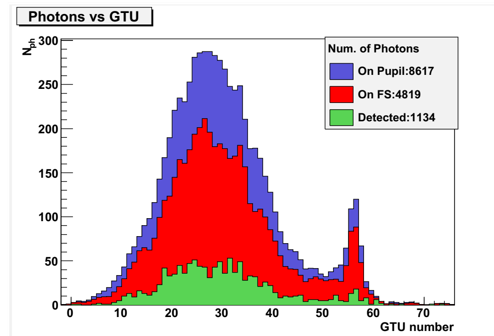

Figure 5: The event as seen through the detector. The Blue curve gives the number of photons as function of GTU # at the pupil. The red one tells how many photons reach the FS. The green one represents the counts. Standard shower (10^{20}eV 60 deg) as simulated by ESAF with the GIL parameterization.

the detector. More details can be found in [13]. The signal

Quantum Efficiency	$\sim$ 39.6%
Collection Efficiency	$\sim$ 80%
Cross talk	Negligible
Pixel Area	9 mm^2
Number of Pixels	64

Table 1: The most relevant parameters for the implemented M64 Photomultiplier

is then amplified by a parameterized gain and the resulting output current is collected and treated by the Front End Electronics. A threshold is set on the PMT output current in order to accept or reject the signal count.

2.4 Trigger

The trigger algorithm's duty is to filter the background in order to increase the signal to noise ratio. Being the telemetry limited, the instrument cannot afford the transmission of the entire Focal Surface data to Earth. The entire triggering scheme is therefore organized in a multiple step filtering. After the Front End Electronics identified a photon count a first search for persistency is done at the level of PDM [3]. This is called the first level trigger (L1). After at this level a trigger signal is issued data are sent at the next level: the so called Cluster Control Board [4] trigger. This is also called second level trigger (L2). Here the Fake Trigger Rate must be further reduced to fit with the telemetry constraints (from $\sim$ 1kHz to 0.1Hz on the entire Focal Surface). Several algorithms have been implemented and tested: the so called Linear Tracking Trigger (LTT) scheme and the Progressive Tracking Trigger (PTT) as well as the so called

3. Part of the Focal Surface consisting of 36 Photomultipliers.
4. Electronics board which operates on 324 Photomultipliers.

Cluster Control Board LTT trigger (CCB_LTT) [14]. Several combinations of trigger schemes have been tested and compared. Triggering efficiency for several detectors and different GTU length have been produced. Once the trigger has been produced the triggered events are sent through telemetry to the reconstruction framework. A more comprehensive review on the trigger scheme is given in [15].

2.5 Tilted mode

In order to further increase the exposure it might be useful to tilt the instrument. In this way the surveyed area will be increased by a large factor. Unfortunately the larger distance at which showers are observed under these conditions will significantly increase the energy threshold. Therefore tilting must be carefully studied in order to optimize the inclination of the instrument. The tilting angle also deeply affects the scientific output of the mission. Low tilting angles are more favorable to study Cosmic Rays in the GZK region while higher inclinations give us a larger exposure above 10^{20}eV. We started some preliminary activity to assess the most proper mission configuration and as a further step the tilted mode will be implemented in ESAF.

3 The Reconstruction framework

Aim of this framework is to analyze the detector response in order to identify the direction of arrival, the energy and the type of the primary. The first step consists in the identification of the signal inside the transmitted data. For this purpose both a clustering and a Hough module have been implemented. Then through fits procedures the direction of the primary is calculated. Several different fits algorithms have been included in ESAF. As last step the profile, X_{max} and the energy are reconstructed. A more comprehensive review of the reconstruction module is given in [16]. In Fig. 6 we see how the signal is treated after having been identified. A fit procedure is applied in order to find the arrival direction of the shower.

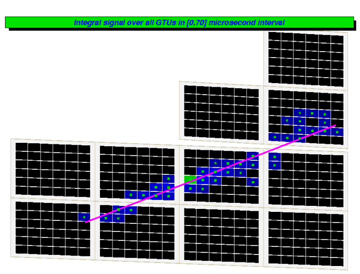

Figure 6: The standard event arrival direction is here reconstructed. The event is seen after the clustering procedure while a fit is performed in order to find the arrival direction. (T. Mernik)

4 Conclusions

In this paper we described the ESAF simulation framework. After the short historical introduction we described the structure of the software and the physical models implemented in it. We showed how an event is treated by the ESAF simulation software by showing the key plots of the simulated event through the various steps of the detector simulation and of the reconstruction. Moreover we wish to remember that the ESAF package is available under the svn repository based in Lyon. We encourage interested people to contact the accounts manager at the address naumov@numail.jinr.ru.

Acknowledgments

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