An ESAF approach to JEM-EUSO end-to-end simulation studies

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***Abstract*. JEM-EUSO stands for Extreme Universe Space Observatory on-board the JEM Exposure Facility of the International Space Station (ISS). The aim of JEM-EUSO is to detect the UV tracks emitted by Extreme Energy Cosmic Ray showers (EECR), with $E > 5 \times 10^{19}$ eV, traversing the earth's atmosphere.**

ESAF stands for EUSO Simulation & Analysis Framework and was developed in the context of the EUSO mission to perform End-to-End simulations of EECR observed from space.

We present in this paper a study performed to update the ESAF framework to the JEM-EUSO mission. We introduced in the code 1.) a parameterization of the optics that is a parameterization of the effective area and of the point spread function; 2.) the focal surface layout designed for the mission and the parameterizations of the advanced photomultiplier; 3.) several trigger algorithms which aim at reducing the fake trigger rate to match the telemetry constrains.

After summarizing the current status of ESAF updating, we will present some preliminary results on JEM-EUSO trigger efficiency obtained comparing different trigger algorithms.

***Keywords*: JEM-EUSO, Simulation, ESAF**

I. INTRODUCTION

The JEM-EUSO observatory, led by Japan, is a space based mission devoted to the observation of EECRs to be accommodated on the Japanese Experiment Module (JEM) of the International Space Station (ISS). It mainly consists of an UV camera attached to the ISS pointing toward the earth along Nadir to observe the fluorescence tracks generated by cascades of particles scattering on atmosphere's atoms. More details on the mission can be found in Ebisuzaki et al. [1].

For space-based missions like JEM-EUSO is of crucial importance the assessment of the performances of the instrument in the designing phase. End-to End simulations are powerful tools to carry out this kind of preliminary study. For this purpose different independent approaches are being used in the framework of the JEM-EUSO mission. Here we focus on ESAF studies of the mission performances.

The ESAF acronym stands for EUSO Simulation and Analysis Framework [2]. This was the End-to-End simulation framework developed in the context of the ESA studies of the EUSO mission concept. After the re-orientation of the EUSO mission to JEM-EUSO, several aspects like the optics, the sensor quantum efficiency, the trigger scheme have been improved. Consequently, also the simulation and analysis framework needed to be updated to the new concept of the mission. In this paper we present our studies to include the current design of JEM-EUSO in ESAF.

After briefly summarizing the main features of ESAF, we focus on how the new JEM-EUSO configuration (optics, focal surface, triggering schemes, etc.) has been introduced in the code. We will also present some preliminary study on the triggering efficiency of the instrument based on ESAF.

II. ESAF

ESAF has been designed to simulate the whole chain of processes involved in EECR observation from space, from shower generation to reconstruction of the direction and energy of the detected track. The End-to-End framework includes: shower development, light production, propagation to the instrument, instrument simulation, telemetry transmission and eventually event reconstruction. The software is written in C++ using an Object Oriented Programming (OOP) approach. This allows very high modularity making easy to reuse already written code, or to change modules without impacting on the entire code. ESAF runs on the ROOT package. The software is organized in separated and independent units. The basic scheme of the two highest layers is summarized in Fig. 1. The *EusoApplication* coordinates all sub-applications of the second layer which are more specialized.

A. Shower production.

The *LightToEuso* application is devoted to the shower development, light production and transport to the detector. Several parameterizations for shower production can be used like SLAST [3] or UNISIM [4]. Recently the interface with Conex (hybrid shower simulator) has been implemented by the JEM-EUSO collaboration [5].

B. Light production and transport.

Once the shower has been generated a list of photons is produced and delivered to the radiative transfer part. The fluorescence yield is modeled following [6]. Mie, Rayleigh scattering and Ozone absorption may be taken into account. Cherenkov production and scattering is considered. The atmosphere profile is typically US 1976 standard. In fig. 2 the time profiles of light components reaching the detector are shown for an event with $E \sim 10^{20}$ eV and $\theta = 60°$. Three components contribute to the observed light: 1.) The direct fluorescence component; 2.) the scattered Cherenkov component; 3.) the so called Cherenkov ”bump” associated to the diffuse reflection of primary Cherenkov light on ground.

C. The Instrument response.

The *EusoDetector* performs the detector simulation including the processing through the optical system, the focal surface and the electronics. Optics can be implemented via a full ray tracing approach or through parameterization: each photon is, in this last case, propagated according to its position and inclination on the entrance lens according to a predefined function. A simple two-dimensional Gaussian defines the approximated Point Spread Function (PSF). The width of the Gaussian is function of the incidence angle. This solution, although simplified, allows to test very efficiently many different kinds of optics with reduced computing time. Once a stable version of the optical system design is reached ray-tracing can be used. Photons which survive absorption are propagated then to the focal surface. Then it is decided in which Elementary Cell (a combination of four PMTs), and Photo-Detector Module (PDM, a macrocell combination of 9 elementary cells) lies the activated Photomultiplier (PMT). ESAF needs 3 vectors to define the position of the PMT: the position of the uppermost left corner, the local y axis of the photomultiplier and the normal to the photomultiplier surface. A key aspect of *EusoDetector* is the treatment of the trigger. Trigger algorithms are discussed in Section III-C.

D. Reconstruction

The *RecoApplication*, after receiving a *Telemetry* object from the instrument, reconstructs the characteristics of the event like its direction, energy and depth of the maximum. More details can be found in [7].

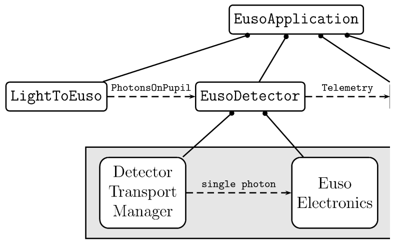

Fig. 1. Structure of ESAF [2]. The meaning of each one of these blocks is described in section II.

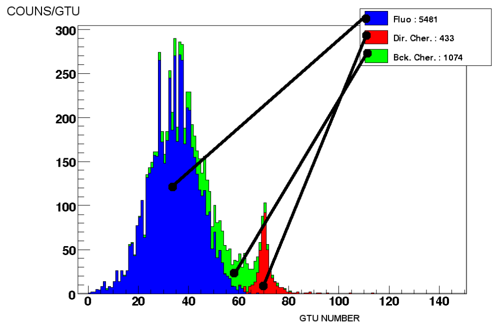

Fig. 2. Profile of the different light components reaching the JEM-EUSO pupil. The event shown has an energy of $E \sim 10^{20}$ eV and incidence angle $\theta = 60°$. The fluorescence component contributes to 78% of the observed light. The peak on the right correspond to the diffusively reflected Cherenkov light. The Gate Time Unit (GTU) is 2.5 μs.

III. Toward JEM-EUSO

To include the JEM-EUSO configuration in ESAF we introduced in the code 1.) a parameterization of the optics that is a parameterization of the effective area and of the point spread function; 2.) the focal surface layout designed for the mission and the parameterizations of the advanced photomultiplier; 3.) two trigger algorithms which aim at reducing the fake trigger rate to match the telemetry constrains.

A. Implementation of the optics

As a first approximation we implemented a parametrical optics. This allows us the efficient testing of different configurations. In the long term a full Monte Carlo simulation will be used. Using the ray tracing package developed at RIKEN the effective area of the optics has been obtained. The optics efficacy, expressed in mm^2 is shown in fig. 3. This is an expression of the effective area, in other terms the product between optics efficency and area of the detector. The width of the spot generated by a point-like source has been calculated. The radius within which 39% of the photons are contained is chosen as the σ of a two-dimensional Gaussian representing the PSF. A third parameterization was necessary to take into account the fraction of photons falling too far from the

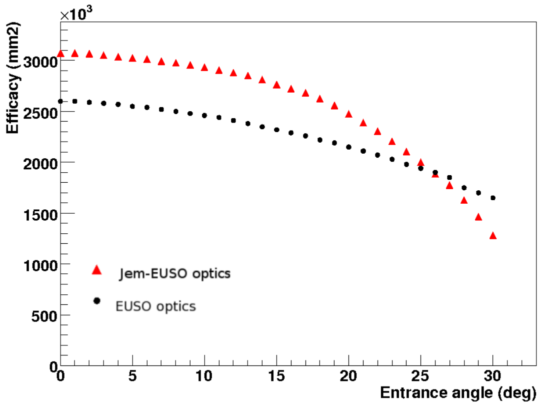

Fig. 3. Effective area of JEM-EUSO (Triangles) compared with EUSO (Dots).

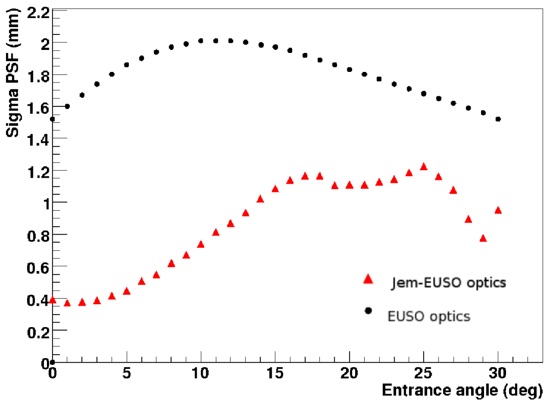

Fig. 4. Sigma of the spot of JEM-EUSO (Triangles) compared with EUSO (Dots).

spot center because of large scattering with irregularities of the Fresnel Lens. All the photons falling outside this area are treated as absorbed since they are scattered by a large angle and are as a matter of fact not distinguishable from background. However this component is less than the 5% of the total number of photons.

B. Layout implementation

The JEM-EUSO focal surface layout as provided by RIKEN was implemented in the code. This is a X-Y layout with very high filling factor. The more recent side-cut design of the optics has been also parameterized, included in ESAF and is in the debugging phase. A detail of the focal surface showing the modular approach of elementary cells and PDM is given in Fig. 5. The sensor was implemented according to the measurements performed on the real Hamamatsu R8900-M36 at RIKEN. The detector efficiency is of about 27%

C. Trigger algorithms

The very high background rate of $\sim 10^{11} - 10^{12}$ cts/sec on the focal surface poses a serious challenge to the JEM-EUSO mission. An unacceptable high fake trigger rate can be predicted while we expect few real events per day consisting of some thousand counts each. To reduce the fake trigger rate the devoted electronics must be very carefully designed and tested. The trigger algorithm must be capable of selecting the real event triggers from those generated by background. For this purpose the signal is filtered by a multiple stages process each one of them reducing the trigger rate. The first trigger selection is performed at the Front-End level. This level discriminates between noise and real counts and sets a digital threshold on the counts obtained in each pixel within an integration time. The second filter operates at PDM level and tries to recognize a track pattern in the count image. The signal will most likely generate a track since it is a spot moving on the focal surface while background generates pixels above threshold distributed in a random way. If some track is found it is much more likely that this has been generated by a shower rather than by background. At this stage, the trigger algorithm must reduce the fake trigger rate from MHz to kHz level on the whole focal surface. For more details see [8]. The third level trigger operates on the Cluster Control Board. This also looks for patterns on the focal surface but on a larger scale. At this stage the fake trigger rate must be reduced to some mHz on the focal surface. Different trigger algorithms have been studied with ESAF. The so called Chip Tracking Trigger Algorithm looks for clusters of active pixels. We also used the LBL trigger which looks for signal persistency in neighboring pixels. We eventually implemented the so called Linear Tracking Trigger conceived by Bertaina. et al. [9]. This will be probably the second level trigger algorithm and basically tries to integrate the signal spot along certain tracks. More details can be found in [9]. We implemented also a third level trigger algorithm that performs a further filtering at Cluster Control Board level. This will lead to a loss in the efficiency but to many orders of magnitude reduction in the fake trigger rate.

IV. CONCLUSIONS

We prepared the software in order to simulate the new JEM-EUSO instrument. Further studies will be presented in the ICRC conference.

ACKNOWLEDGEMENTS

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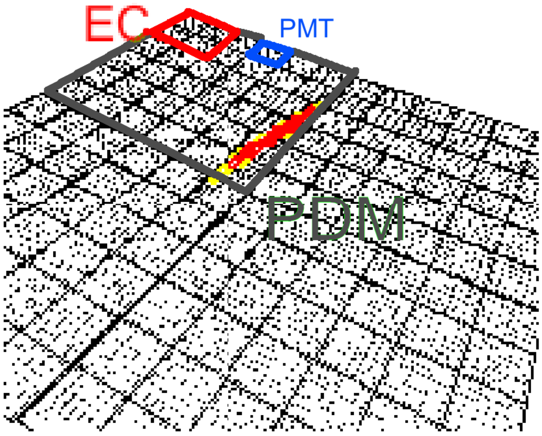

Fig. 5. Integrated track of a 8×10^{20} eV. The detail of the Elementary Cell (EC), of Photo Detector Module (PDM) and of Photomultiplier (PMT) is shown.

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