Calibration and testing of a prototype of the JEM-EUSO telescope on Telescope Array site

M. Casolino\(^1,2\), J. Adams\(^3\), P. Barillon\(^3\), J. Bayer\(^4\), J. Belz\(^5\), M. Bertaina\(^6,7\), F. Borotto\(^8\), M. J. Christl\(^9\), G. Distrait\(^9\), A. Ebersold\(^9\), T. Ebisuzaki\(^1\), T. Fujii\(^1\), M. Fukushima\(^8\), G. Giraudo\(^10\), D. Gottschall\(^4\), D. Ikeda\(^8\), A. Jung\(^9\), F. Kajino\(^10\), Y. Kawasaki\(^1\), M. Marengo\(^11\), J. N. Matthews\(^3\), T. Nonaka\(^8\), S. Ogio\(^7\), G. Osteria\(^10\), A. Pesoli\(^11\), P. Picozza\(^1,2\), L. W. Piotrowski\(^1\), H. Sagawa\(^8\), V. Scotti\(^10,2\), T. Shibata\(^8\), K. Shinozaki\(^1,4\), N. De Simone\(^2,11\), P. Sokolsky\(^8\), M. Takeda\(^8\), Y. Takizawa\(^1\), Y. Takeda\(^8\), C. Tenzer\(^4\), G. B. Thompson\(^8\), H. Tomono\(^12\), T. Tomida\(^1\), Y. Tsunesada\(^12\), and the JEM-EUSO collaboration.

1 RIKEN, Wako, Japan
2 Istituto Nazionale di Fisica Nucleare, Italy
3 LAL, University of Paris-Sud, CNRS/IN2P3, Orsay, France
4 University of Tubingen, Germany
5 Institute for High Energy Astrophysics and Department of Physics, University of Utah, Salt Lake City, UT 84112-0830, USA
6 Karlsruhe Institute of Technology (KIT), Germany
7 Osaka City University, Faculty Administration Department, Sagimoto-ku, Osaka, 558-8585
8 Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 277-8582, Japan
9 Ehwa Womans University, Seoul, South Korea
10 University of Napoli, Italy
11 University of Rome Tor Vergata
12 Graduate School of Science and Engineering, Tokyo Institute of Technology, Meguro, Tokyo 152-8551, Japan
13 Istituto Nazionale di Fisica Nucleare, Sezione di Torino, Italy
14 Department of Physics, Konan University, Okamoto 8-9-1, Higashinada, Kobe 658-8501, Japan
15 University of Alabama in Huntsville, Huntsville, USA
16 NASA - Marshall Space Flight Center, USA

casolino@riken.jp

Abstract: The aim of the EUSO-TA project is to install a prototype of the JEM-EUSO telescope in the Telescope Array (TA) site in Black Rock Mesa, Utah, USA and perform observations of ultraviolet light generated by cosmic-ray showers and artificial sources. The detector consists of one Photo Detector Module (PDM), identical to the 137 that will be present on the JEM-EUSO focal surface. The PDM is composed of 36 Hamamatsu multi-anode photomultipliers (64 channels per tube), for a total of 2304 channels. Front-End readout is performed by 36 ASICs, with trigger and readout tasks performed by two FPGA boards that send the data to a CPU and storage system. Two, 1 meter side square Fresnel lenses provide a field of view of 8° × 8°. The telescope is housed in a shed located in front of one of the fluorescence detectors of the Telescope Array collaboration, pointing in the direction of the ELF (Electron Light Source) and CLF (Central Laser Facility). The aim of the project is to calibrate the response function of the EUSO telescope with the TA fluorescence detector in presence of a shower of known intensity and distribution. An initial run of about one year starting from summer 2013 is foreseen, during which we expect to observe, triggered by TA electronics, a few cosmic ray events which will be used to further refine the calibration of the EUSO-TA with TA. Medium term plans include the increase of the number of PDM and therefore the field of view.

Keywords: JEM-EUSO, EUSO-TA, UHECR, cosmic rays, particles, EAS

1 Introduction

The Extreme Universe Space Observatory on the Japanese Experiment Module (JEM-EUSO) of the International Space Station (ISS) is the first mission that will study Ultra High-Energy Cosmic Rays (UHECR) from space\(^5,7\). JEM-EUSO will observe Extensive Air Showers (EAS) produced by UHECRs traversing the Earth’s atmosphere from above. For each event, the detector will make accurate measurements of the energy, arrival direction and nature of the primary particle using a target volume far greater than what is achievable from ground. The corresponding increase in statistics\(^2\) will help to clarify the origin and sources of UHECRs as well as the environment traversed during production and propagation. Possibly, this will bring new light onto particle physics mechanisms operating at energies well beyond those achievable by man-made accelerators. The spectrum of scientific goals of the JEM-EUSO mission includes the detection of high-energy gamma rays and neutrinos, the study of cosmic magnetic fields, and tests of relativity and quantum gravity effects at extreme energies. In parallel JEM-EUSO will systematically perform observations of the surface of the Earth in the infra-red and ultraviolet ranges, studying atmospheric phenomena (Transient Luminous Effects). The apparatus is a 2 ton detector using Fresnel-based optics to focus the ultraviolet (UV) light from EAS on a focal surface composed of about 6,000 multianode photomultipliers for a total of ~3 · 10^5 channels. In the framework of the EUSO project, a number of prototype detectors are being realized to calibrate the detector response, test its performance in air and space, raise
The Technological Readiness Level of some of the components and improve our knowledge of the various detectors. These projects include a series of stratospheric balloon flights (EUSO-BALLOON) and a ground calibration with the Telescope Array collaboration (EUSO-TA).

2 EUSO-TA

The EUSO-TA project aims to install a fully functional prototype of JEM-EUSO in Black Rock Mesa, the site of one of the fluorescence light detectors of the Telescope Array collaboration. From there it will observe artificial light (laser and electron-generated UV) and events coming from cosmic rays.

The aim of the project is to calibrate this Ground-EUSO detector prototype using the signals of UV light coming from known sources. They include artificial light coming from fluorescence emitted by electrons accelerated at the Electron Light Source (ELS, a compact electron linear accelerator) and from a laser at the CLF (Central Laser Facility). The response to artificial light will be correlated with that of the TA fluorescence light telescope in order to calibrate the response with that of TA and reduce the systematic errors of the measurement.

Also, UV light coming from cosmic ray events will be detected by Ground-EUSO with an external trigger coming from TA. In this case studies of the transversal profile of the shower will be performed. Note that in the first stage of the project, the use of one PDM will only allow to see part of the shower (Figure 1), albeit with a higher spatial resolution than TA Fluorescence detector. In subsequent stages the addition of other PDM detectors (with the same optics) will be considered, to enlarge the field of view.

The Ground-EUSO telescope is housed in a container about 20 m in front of the TA fluorescence detector of Black Rock Mesa. As mentioned, both the ELS and the CLF lie in the telescope field of view, so that light from these sources is seen by the two double sided Fresnel lenses optical system. The optical signal is focused on and detected by the PDM (Figure 2). The PDM is attached to the telescope with alignment accuracy better than 0.1°.

The optical system consists of two square Fresnel lenses, 1 meter side (Figure 3), focusing the light in a ±4° field of view on one PDM (Photo-Detector-Module) of 2304 pixels. Each PDM has a focal surface of 13.6 × 13.6 cm and is composed of 36 Hamamatsu multi-anode photomultipliers (64 channels per tube), for a total of 2304 channels. They are arranged in a 6 × 6 element array, with front-end readout performed by 36 ASICs (SPACIROC, Spatial Photomultiplier Array Counting and Integrating Readout Chip). Readout tasks are performed by an FPGA board that stores the data in a 100 GTU (Gate Time Unit. 1 GTU = 2.5 μs) round buffer.

In case of an event (trigger, pedestal or calibration) data are sent to a second FPGA for further processing and interfacing with the CPU. Note that the electronic system and the 2.5 μs sampling rate are designed for observation of UHECR showers from the altitude of 400 km of the ISS. Therefore the relative proximity of cosmic ray events and the limited field of view seen from ground is such that the shower is visible only in one - two time frames (GTUs), compared to dozens of GTUs for JEM-EUSO. Therefore, a dedicated trigger system for the ground detector will be realized. However, given the limited number of GTUs available, this solution is expected to be of low efficiency – therefore an external trigger, generated from TA trigger electronics, will be used for the main cosmic ray acquisition.

2.1 Data Acquisition and Reduction

The data acquisition system (Figure 4) is an architecture capable of reducing data at each level through a series of triggers controlling an increasingly growing area of the focal surface [1, 4]. On ground it is necessary to reduce...
the 1 Gbyte/s background output of the Focal Surface (FS) to 10-100 Gbyte/day which can be stored for off-line analysis. Each board and data exchange protocol is therefore capable of handling the data and sending them to the higher level of processing if they satisfy the trigger conditions. This structure is similar to that expected on board the International Space Station, where most of the triggers will be due to noise.

An ASIC chip performs photo-electron signal readout and conversion for the 64 channels of the MAPMT. It has two main purposes: counting the number of photons reaching each pixel of the MAPMTs and measuring the intensity of photon flux by performing charge to time (Q-to-T) conversion. The first version of the ASIC is the result of the collaboration between OMEGA/LAL-Orsay, France, RIKEN, ISAS/JAXA and Konan University, Japan. It has 64 channels preamplifier with independent gain (8-bit) adjustment in order to correct for the non-uniformity of the 64 MAPMT anodes; photon counting for each channel with a system managing 100% trigger efficiency for a charge greater than 50 fC (1/3 p.e for a MAPMT gain of $10^6$) and a double pulse resolution as close as possible to 15 ns. The Q-to-T converter has an input charge range of 2 - 200 pC (12.5 - 1250 p.e.). The last dynode signal, produced by the MAPMT, as well as 8 internal channels corresponding to the sum of up to 8 channels signals, have to be processed. The chip has a low power consumption of about 1 mW/channel.

An FPGA (Xilinx XC6VLX240T) board handles first level trigger data on a PDM level (reading 36 MAPMTs). Background events are reduced by a factor $10^3$. Second level triggering algorithms are implemented by the CCB (Cluster Control Board), DSPs with about 1 Gflop computing capability which further process the data. At this level background is rejected by another factor $10^3$. The CPU has a relatively low processing power (100 MHz) since it is in charge of the general handling of the experiment. The CPU is part of the Storage and Control Unit System (SCU), the evolution of a similar system used for PAMELA and composed of a number of boards devoted to different tasks: CPU main board, mass Memory (8 Gbyte), internal and external housekeeping interfaces (CAN bus), Hard Disk storage. Data acquisition and status of the apparatus can be monitored remotely from a PC in the counting room of the TA building. All hardware and software resets, as well as power cycling, can be performed remotely in order to avoid access to the EUSO-TA container during data acquisition in case of malfunction. Only high level data, coming from artificial light sources and cosmic ray events will be transferred via network, whereas the calibration and pedestal raw data will be physically transferred to a higher (Grid-based) link location.

### 2.2 Slow control and Housekeeping

The housekeeping module is connected to the CPU with the task to distribute commands to the various detectors and to collect telemetry for them in order to monitor in real-time the status of the experiment and optimize its observational parameters. The module is capable of handling, single, periodic and time-tagged instruction according to the CPU commands. For instance all relays to toggle secondary power supplies and subsystems are controlled by high level signals. This approach has the advantage of a great degree of flexibility keeping at the same time a strong robustness and reliability.
3 Initial integration and tests of the EUSO-TA detector

In January 2013 a first integration of the whole detector, from optics to read-out systems was performed in RIKEN, Japan. The data processing elements, produced by different institutions in different countries, were connected and configured to work with each other. This completed the chain of data acquisition, starting with the request for data sent from CPU, through CCB, PDM and EC-ASIC to MAPMT, detecting single photons with the MAPMT and sending back the photon counts through all the electronics to the CPU which then stored them in an appropriate file. The task required adjusting the hardware interfaces between the elements but also developing proper protocol for the exchange of commands and data between the hardware elements. For the purpose of these tests only a single MAPMT was used.

Upon successful completion of tests of the electronics with MAPMTs illuminated by an artificial light source in light-sealed conditions, we performed tests in an environment close to the final experiment site conditions. The whole telescope was assembled, including the focal surface consisting of a single MAPMT and the two Fresnel lenses. The mechanical frame of the telescope allows changes in the vertical pointing, which was crucial for measuring different types of signal, as well as for properly focusing the image on the focal surface.

First, we acquired single expositions of the night sky in order to measure the ultraviolet background on-site. The second task was a continuous exposure to a variable light source, resembling the conditions of the EAS observation. For this purpose we used a spot of the fast moving laser projected on the wall surrounding the roof of the building (Figure 5). The whole data acquisition process was successful and the signal was stored by the CPU for further analysis. The detector registered the changes in the illumination due to the spot of the laser coming in the field of view. Apart from the laser signal, we could see the constant UV background registered by the MAPMT pixel (Figure 6). From these measurements it was possible to estimate the UV background in cloudy conditions in the Wako area to be about 8 photons/GTU, with signal from the laser reaching up to 35 photons/GTU. A more precise measurement of the background will have to be performed in Utah.

4 Installation and tests of EUSO-TA in the TA site

Between February and March 2013 the telescope housing, mechanical structure of the TA-EUSO telescope and its optical system were installed in Black Rock Mesa, on the site of the TA fluorescence telescope. The two Fresnel lenses (Figure 7) were installed and aligned. Preliminary tests with a single MAPMT connected to a test system were performed to test the installation. The second stage of the installation, scheduled for summer 2013, will be dedicated to installing the full focal surface and data processing hardware. This will allow for the target, automatic data gathering and analysis, with initial tests performed remotely from the TA control room.

5 Conclusion

JEM-EUSO aims to perform a high-statistic UHECR measurement from space for the first time. Due to the innovative character of the experiment, a number of tests with prototype detectors have been performed. EUSO-TA is an on-ground, smaller version of JEM-EUSO, built to observe EAS from the Telescope Array site in Utah, USA. In RIKEN we have successfully integrated the full chain of the data acquisition data processing system with optics. The tests performed on the roof of the building in RIKEN were successful, showing the ability to register variable UV light source and store the data for offline analysis. The optics of the telescope have been installed at the destination site of TA and night background data was acquired with a test readout. Currently we plan to install the electronics and start systematic data taking in summer 2013.

Acknowledgment: This work was partially supported by 1) Basic Science Interdisciplinary Research Projects of RIKEN and JSPS KAKENHI Grant (22340063, 23340081, and 24244042). 2) Italian Ministry of Foreign Affairs grant. Part of the MonteCarlo simulations were performed using the RIKEN Integrated Cluster of Clusters (RICC) facility.

References


