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Preliminary analysis of EUSO–TA data

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Abstract.

The EUSO–TA detector is a pathfinder for the JEM–EUSO project and is currently installed in Black Rock Mesa (Utah) on the site of the Telescope Array fluorescence detectors. Aim of this experiment is to validate the observation principle of JEM–EUSO on air showers measured from ground. The experiment gets data in coincidence with the TA triggers to increase the likelihood of cosmic ray detection. In this framework the collaboration is also testing the detector response with respect to several test events from lasers and LED flashers. Moreover, another aim of the project is the validation of the stability of the data acquisition chain in real sky condition and the optimization of the trigger scheme for the rejection of background. Data analysis is ongoing to identify cosmic ray events in coincidence with the TA detector. In this contribution we will show the response of the EUSO–TA detector to all the different typologies of events and we will show some preliminary results on the trigger optimization performed on such data.

1. Introduction

The EUSO–TA [1] detector, a pathfinder of the JEM–EUSO project [2], is currently operating at the Black Rock Mesa (BRM) site of the Telescope Array in Utah [3]. The detector is monitoring a fraction of the sky and aims at the detection of Cosmic Ray (CR) showers and artificial sources in coincidence with the BRM fluorescence detector. Purpose of the project is the study of the



systematics and the calibration of the EUSO-TA detector. For this reason we also use LEDs, lasers and other sources of calibration.

The massive amount of data produced forces us to apply some real-time selection. In normal conditions EUSO-TA uses the trigger signal from the TA-BRM detector to increase the chance of a correlated detection. The possibility to receive a trigger signal reduces the rate of acquisition to the order of ~ 4 Hz, well within the electronics and storage limits. We also tested an autonomous trigger algorithm.



Figure 1. EUSO-TA detector (front) and the Telescope Array fluorescence detector (back) at Black Rock Mesa (Utah).

In this contribution we want to describe the detector, give an update of the status of the project and show some preliminary results. We will therefore show some example of detected test events and some CR candidates.

2. The EUSO-TA detector

EUSO-TA is a prototype of the planned JEM-EUSO detector [2] and consists of a system of two Fresnel lenses focusing the light on a Photo-Detector Module (PDM) of 36 Multi Anode Photomultipliers (MAPMT or PMT) each consisting of 64 channels. PMTs are organized in groups of four in so called Elementary Cells (EC). The lenses measure 1×1 m and are squared. The PDM 17×17 cm active surface contains 2304 pixels, each 3×3 mm². The FOV of the PDM is roughly $11^\circ \times 11^\circ$ (0.19° per pixel) and can be extended by adding more PDMs. The instrument is sensitive in the 300–400 nm range and integrates the counts in the Gate Time Unit (GTU) which corresponds to $2.5 \mu\text{s}$. The elevation of the instrument can be manually changed from 0 to 25° whereas the azimuth is fixed.

Several acquisition modes are available for EUSO-TA: external, CPU and autonomous mode. In the external mode EUSO-TA receives the trigger signal from the TA-BRM detector and starts acquisition of a 128 GTUs packet. In this way we increase the probability of a correlated detection. The detector can operate also in so called CPU mode for testing purposes. In this configuration the detector acquires 128 GTUs in fixed intervals of time. We can in such way assess the sky condition and test the instrument independently of the TA trigger. We also successfully tested the JEM-EUSO trigger algorithm. Such algorithm described in [5] looks for excesses of signals with respect to the background in real time. In this way we can autonomously trigger events like CRs, lasers or LEDs which are developing on a time scale of few μs .

3. The EUSO–TA calibration

A first instrumental calibration is done in the laboratories in RIKEN and ICRR in Japan. The calibration of EUSO–TA is now being performed on–site through observation of stars, test sources and airglow background [6]. The detector is operating together with TA–BRM and common measurements of background and other sources are used to estimate the relative uncertainties.

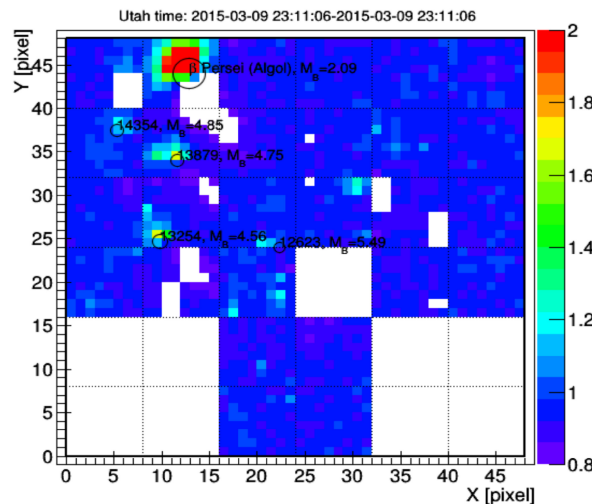


Figure 2. The integrated image of 1280 GTUs. Stars are visible and clearly identifiable. For the most off–axis stars the point spread function is not symmetric due to aberration like coma or astigmatism. The two white ECs are temporarily non operating.

The presence of bright stars in the FOV gives the opportunity to use very well known point–like sources. Thanks to the known brightness and spectrum of stars we can give an estimate of the atmospheric attenuation and the efficiency of the detector. We can also give a very good estimate of the point spread function. We show in Fig. 2 an example of an averaged 1280 GTUs acquisition where stars are detected. The color code indicates the intensity of the signal in counts per pixel per GTU.

For the calibration of the detector we used also laser sources [4]. If a laser beam crosses the EUSO–TA FOV part of the light will be scattered and will reach the detector. This generates a spot moving on the focal surface. In such a way we aim to create an artificial shower–like event of known energy and distance. We can see in Fig. 3 (left panel) an example of the integrated image of a Central Laser Facility ¹ event as seen by EUSO–TA. The spot needs 5–6 GTUs to cross the entire FOV being the CLF source in 21 km distance from EUSO–TA and the beam being vertical. The value for each pixel is averaged over 250 laser shots and corrected for a flat field value.

On the right panel of Fig. 3 we can see the signal of a portable 85 mJ laser deployed 100 km away from the detector. In this case only one GTU of a single laser event is shown. Unlike the Telescope Array CLF this laser can be oriented in various directions to simulate showers of different inclinations.

A very extensive campaign of laser shots has been performed. Different distances from the detector, energies and inclinations along both rotation axes have been tested. In this way a very complete assessment of the detector performances is being prepared.

¹ The Central Laser Facility (CLF) of Telescope Array is a laser facility used for the calibration of the Telescope Array collaboration.

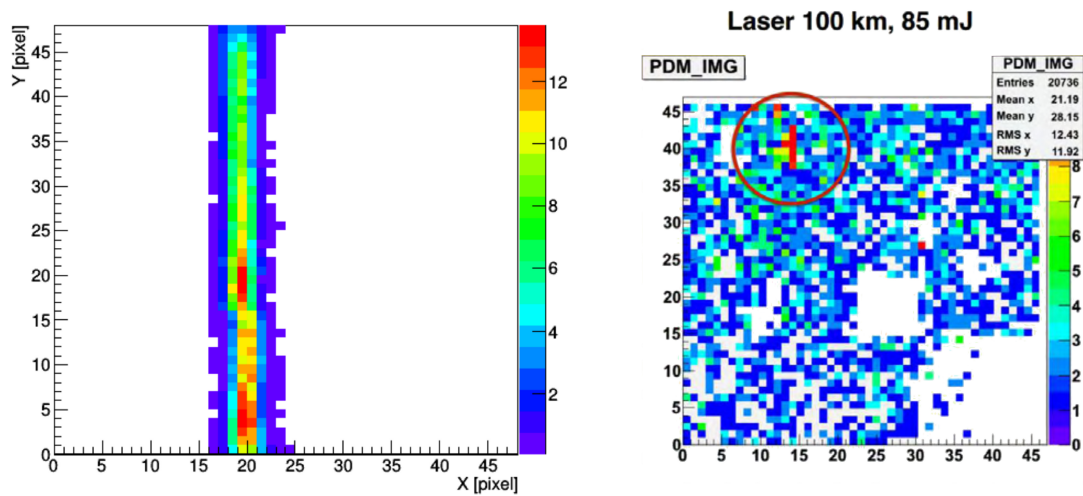


Figure 3. Left panel: 250 integrated CLF shots with flat field correction applied and sky background removed. Right panel: a single GTU of a laser event shot 100 km away from the detector.

4. Cosmic Rays detected by EUSO–TA

Five shifts have been performed in 2015 and several CR event candidates have been found. We show in Fig. 4 (left panel) just one candidate which has been detected by EUSO–TA together with TA–BRM. The energy of the event was estimated to be $\sim 10^{18}$ eV and the impact point 2.5 km from the detector.

As it can be expected the event of Fig. 4 is visible on just 1 GTU in the EUSO–TA FOV given the small distance from the detector. This also affects the quality of the event with respect to TA since the JEM–EUSO electronics was designed for detection from 400 km. The GTU of $2.5 \mu\text{s}$ is in fact not appropriated for the detection from ground.

Several other events have been detected by EUSO–TA and their analysis is ongoing. Extensive simulations are being performed to reconstruct the parameters of the showers both by the TA and JEM–EUSO collaborations.

5. The JEM–EUSO trigger test

At the EUSO–TA site we performed tests of the JEM–EUSO trigger electronics. We used for this purpose both the CLF and EUSO–TA laser facilities. We first confirmed that we can trigger on the CLF with more than 90% efficiency. We then performed a study to assess the energy threshold of the instrument with the EUSO–TA portable laser. We see in Fig. 4 (right panel) the efficiency of the trigger as function of the laser energy. It can be clearly seen how the trigger efficiency increases with the energy. Simulations are being carried out to evaluate the EUSO–TA energy threshold with respect to CRs.

6. Conclusions

The EUSO–TA detector is currently taking data in Utah together with TA. The detector has been successfully assembled and is being tested. The calibration is ongoing through the detection of stars and laser pulses of known energy. Several CR events have been detected thanks to the trigger signal of TA–BRM. The detailed analysis is ongoing. We successfully tested the first level trigger of JEM–EUSO.

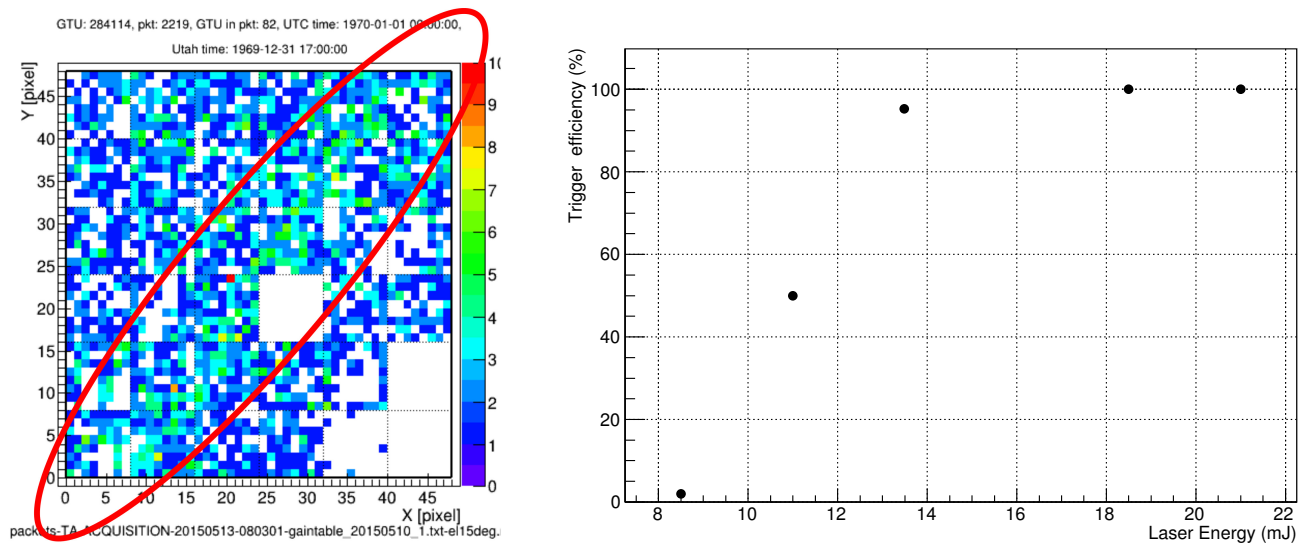


Figure 4. Left panel: a CR, crossing the EUSO–TA field of view diagonally from right–top to left–bottom (marked by the red ellipse). This event was detected in coincidence of EUSO–TA with TA–BRM. **Right panel:** the efficiency of the trigger as function of laser energy.

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