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Central Laser Facility Analysis at The Telescope Array Experiment

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Abstract. The Central Laser Facility (CLF) is the laser device which shoots the vertical laser. CLF is located at the Center of the Telescope Array (TA) experiment site. The TA has three fluorescence detectors. CLF is equidistant from three FD stations. We made the CLF simulation using the same program as the cosmic-ray simulation. Using the CLF simulation, we reconstruct the energy shot by the CLF. In this paper, we describe some results of CLF reconstruction comparing the difference of reconstructed energy between two fluorescence telescopes.

Introduction

The Telescope Array (TA) is the hybrid detector that consists of Fluorescence Detectors (FDs) and Surface Detectors (SDs)[1] to observe ultra-high energy cosmic rays. The TA is located in Utah, and hybrid observation started in March 2008. At the "Black Rock Mesa"(BRM) and "Long Ridgh"(LR) sites in the southern part of the TA, we constructed new detectors designed specifically for the TA experiment. Each station has 12 telescopes. One set of six telescopes has a lower field of view from 3 to 17 degrees, and anogher set has an upper field of view from 17 to 31 degrees. The "Middle Drum" site in the northern part of the TA is instrumented with 14 refurbished telescopes from the HiRes-I site of the High Resolution Fly's Eye experiment.

In order to monitor the atmospheric condition, the Central Laser Facility (CLF) has been placed in the center of the TA site. The distances from the CLF to three FD stations are 20.85 km each. The CLF is a laser device which shoots the laser vertically [2]. The CLF uses third harmonic of a Nd:YAG of 355nm wavelength.

We made the CLF simulation and reconstruct the CLF laser energy using the simulation and observation data. This paper describes some results of the CLF energy reconstruction. In addition, the new laser device "Portable Laser" was shot vertically first at the CLF position and was observed with the FD in September 2010. We reconstructed the energy of the shot from the Portable Laser and descrive the results.

Laser simulation and energy reconstruction

We generated the CLF Laser simulation using the same program of cosmic ray simulation, calibration data and geometry. Fig.1 shows event displays of data and simulation. There are no signals from PMTs pointing towards upper elevation because these signals are cut by the time window of data taking. Using the CLF simulation, we reconstruct the energy shot by the CLF laser. Fig. 2 shows the waveforms of a CLF event. Here one event consists of about 300 shots at one CLF-shooting time. The horizontal axis shows the time and 1bin corresponds to 100ns. The vertical axis shows the pedestal subtracted Flash ADC counts observed at the BRM FD station. Red lines show the waveform of data and blue lines show the waveforms of simulation. Since a fluorescence detector is composed of an upper and a lower field of view, there are two waveforms for early timing and late timing in Fig. 2.

Using FADC counts from the simulation and data, reconstructed energy is obtained by the following equation:

$$\text{reconstructed energy} = \text{simulation energy} \times \frac{\text{integrated FADC counts (data)}}{\text{integrated FADC counts (simulation)}} \quad (1)$$

"integrated FADC counts" means the integrated value of FADC counts in Fig. 2 and "simulation energy" means the shot energy used in the simulation.

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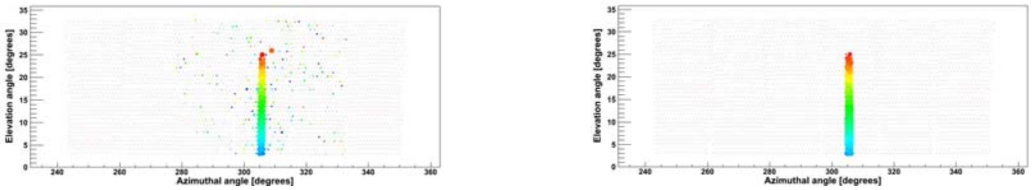

Fig.1 Event display of the CLF laser. Lefthand graph is data and righthand graph is simulation. Size of the point means signal strength and color means timing. Larger size point means strong signal, and red point is later than blue point.

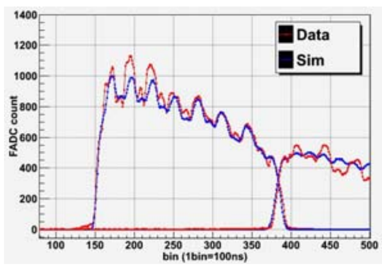

Fig.2 Waveforms of the CLF event on a clear day. The horizontal axis shows the time (1bin=1ns) and the vertical axis shows the FADC counts. Red is data and blue is simulated waveform.

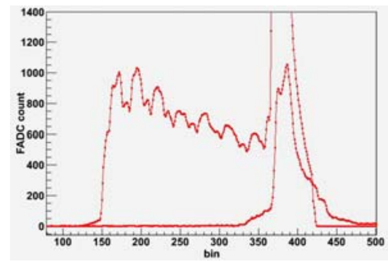

Fig.3 Waveforms of the CLF event on a cloudy day. The spikes are caused by cloud.

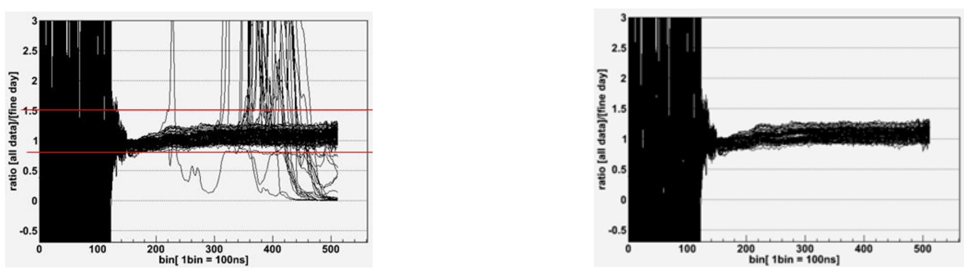

Fig.4 (FADC value for all events in October 2009)/(FADC value on a clear day) versus time bin. Lefthand graph is before the cut and righthand graph is after the cut. Large deviation in the regin below 140th bin are caused by background because there are no signals.

Atmosphere

For the CLF simulation, we used two types of atmospheric model. One is typical atmosphere and another is measured atmosphere. For both cases, the atmospheric temperature and pressure in radiosonde data are used. Typical atmosphere uses aerosol attenuation length of 29.4km on the ground and aerosol scale height of 1.0km. These values mean that the transmittance of the aerosol scattering from height h2 to h1 ($T_{aer}(h1 > h2)$) is described as

$$T_{aer}(h1 > h2) = \exp\left\{\frac{1.0}{29.4}\exp\left(-\frac{h1}{1.0}\right) - \frac{1.0}{29.4}\exp\left(-\frac{h2}{1.0}\right)\right\} \quad (2)$$

The attenuation length of 29.4km is the median of the distribution of the attenuation lengths measured by LIDAR observation for the available period [3]. In the case of measured atmosphere, height-dependent Vertical Aerosol Optical Depth (VAOD) values from LIDAR observations are used [4]. Using the height-dependent VAOD as $\tau(h)$, we can calculate the transmittance of the aerosol scattering ($T_{aer}(h)$) as the following equation:

$$T_{aer}(h) = \exp\left(-\tau(h)\right) \quad (3)$$

And we assume that atmosphere spread flat for both models.

Cloud cut

We need to cut the CLF events on cloudy days because we do not include the effect of cloud in CLF simulation. We usually use the following two methods to cut cloud: one is IR camera and another is the check by eye during FD observation. Here we introduce a new method of

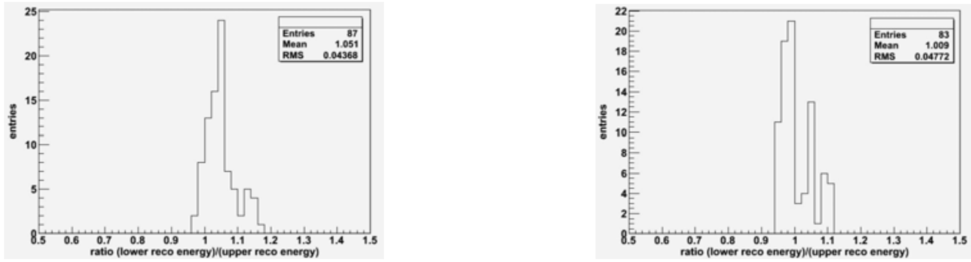

Fig.5 Distribution of (reconstructed energy in lower view)/(reconstructed energy in upper view) in October 2009. The lefthand figure shows the result of typical atmospheric simulation, and the righthand figure shows the result of measured atmospheric simulation.

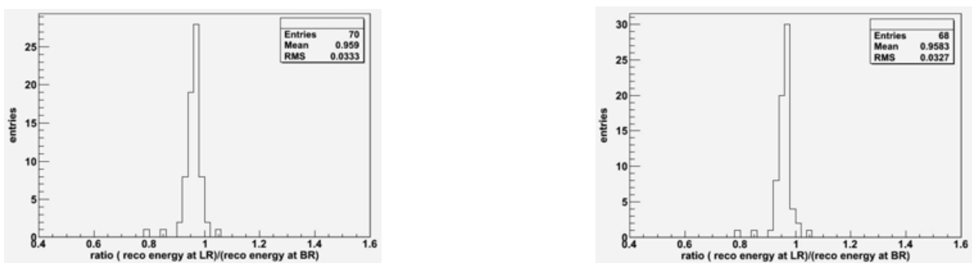

Fig.6 Distribution of (reconstructed energy at BRM)/(reconstructed energy at LR) in October 2009. The lefthand figure shows the reconstructed energy ratio using typical atmosphere for the simulation, and the righthand figure shows the reconstructec energy ratio using measured atmosphere for the simulation.

cloud cut which uses the waveform of signals from CLF laser.

Fig. 3 shows the waveform of CLF data on a cloudy day. Large spikes in the waveform in the Fig.3 are caused by cloud. To cut clouds, we calculate the ratio of the FADC counts on cloudy events to the FADC counts on clear event bin by bin. The lefthand graph in Fig. 4 is the result of the ratio for one month (Oct 2009). There are 114 events in the figure. Since there are no signals in the region below 140^{th} bin, large deviations from one are caued by background. The large spikes on the lefthand figure of Fig.4 are caused by cloud, so we can cut these spikes determining the appropriate threshold. In October 2009, we cut the events whose ratios exceed 1.5 or fall below 0.8 (Red line of Fig.4). And then, we got 80 events without clouds in October 2009 (righthand figure of Fig.4).

Reconstructed energy comparison

Differences between upper and lower view camera

The fluorescence detectors view using two-tiered cameras. So there are two cameras to be used for the reconstruction of CLF events in one FD station. Fig.5 shows the ratio of energy reconstructed in the lower view to that in the uppwer view. In the left figure, we use typical atmospheric conditions, which uses aerosol attenuation of 29.4km and scale height of 1.0km. In the right figure, measured atmospheric conditions are used to the CLF simulation. The difference in reconstructed energy between the upper view and the lower view is 5% using typical atmospheric simulation. And the ratio of the reconstructed energy becomes almost 1 using measured atmospheric simulation.

Differences between BRM and LR station

We compared the reconstructed energy at the BRM station with LR station. Fig.6 shows the ratio of reconstructed energy at the LR station to reconstructed energy at the BRM station. The reconstructed energy at BRM is about 4% lager than that of LR for both (typical, measured) results. We assume that atmosphere spreads flat for both models, so the locality of the atmosphere (difference between BRM and LR) might appear as the same result in both models.

Portable Laser

The Portable Laser is a new laser device which shoots the laser anywhere. So the Portable Laser will calibrate all cameras. The wavelength of the laser is 355nm. The Portable Laser was firstly shot and observed at the CLF position in September 2010.

The angle of the Portable Laser is determined using three stars and this alignment determines the angle within an accuracy of 0.1 degrees.

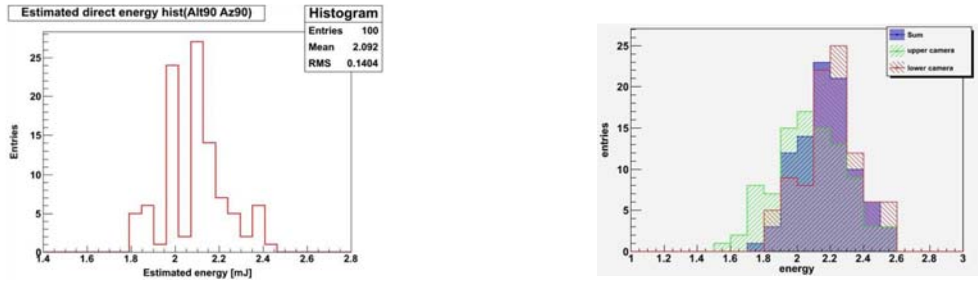

Fig.7 Left figure shows the measured energy[mJ] at the portable laser energy probe. And right figure shows the results of reconstructed energy using the measured FADC at BRM station. Red means the reconstructed energy using the lower view telescope, green means the reconstructed energy using the upper view telescope, and blue means the reconstructed energy using both telescopes.

Energy reconstruction of the Portable Laser

Because the first shot of the Portable Laser was carried out at the CLF position, we can easily reconstruct the Portable Laser energy using the same method of the CLF energy reconstruction. Fig.7 shows the results of measured energy with a energy probe of the portable laser and reconstructed energy with the BRM station. Mean of the measured energy is 2.09 ± 0.01mJ, and mean of the reconstructed energy using both telescopes (blue) is 2.18 ± 0.02mJ. So measured energy and reconstructed energy agree within 4%.

Summary

We made the CLF simulation and reconstruct the CLF laser energy. Reconstructed energy at lower view camera is about 5% higher than upper view camera if we use typical atmospheri values for the simulation. And if we use measured atmospheric values, the reconstructed energy difference between upper and lower camera becomes 1%.

Reconstructed energy at BRM station is 4% higher than LR station.

The first shot of new laser device called "portable laser" was carried out at September 2010. We reconstructed the first portable laser event. The measured energy at portable laser energy probe and reconstructed energy agree within 4%.

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