The Central Laser Facility at the Telescope Array

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Abstract: Atmospheric monitoring is indispensable to calibrate the reconstruction of extensive air shower that observed by air fluorescence telescope. The Telescope Array experiment is using an air fluorescence technique along with a shower array system to observe the ultra-high energy cosmic ray. And we adopted two laser systems measuring the atmospheric transmittance to calibrate the Fluorescence Detector. One is a LIDAR system which will be reported other-where in this conference and another is a Central Laser Facility. The Facility located near the middle of three Fluorescence stations is equipped with a UV laser and optical components that direct a calibrated pulsed beam into the sky. The scattering light from this beam observed by telescopes becomes a good calibration source of total attenuation caused by atmosphere. We will describe this system along with some measurements briefly.

Introduction

Although the Ultra-High Energy Cosmic Ray (UHECR) is been observing through several cosmic ray experiments, its spectrum is not known clearly still now. The AGASA experiment that selected air shower sampling technique presented the possibility of absence of the GZK cut-off effect [6]. On the other hand, HiRes claimed that the GZK effect appears on the energy spectrum which they observed with fluorescence telescopes [1]. To investigate this inconsistency, the Telescope Array experiment (TA) had started with both of fluorescence and air shower techniques. The TA almost finished construction of two of three Fluorescence Detector (FD) stations and deployment of Surface air shower Detector array (SD) as of Mar. 2007, and is ready to start operation. About calibration systems, construction of one of LIDAR which establishment is planned on every FD station was also finished at Black Rock Mesa (BRM) station [3].

The Central Laser Facility (CLF) located at the middle of three FD stations has a 355 nm wavelength laser as test beam for FD telescopes. It has a close color to second prominent wavelength 357 nm of the fluorescence light caused by air shower. Furthermore, we are expecting that the amount of scattered light from emitted 5 mJ laser at a height of 2 km is roughly equal to the fluorescence light generated by 10^{20} eV cosmic ray. Therefore the information about atmospheric transmittance induced from the ratio between scattered and detected light should be able to apply to transmittance of air fluorescence light. For this end, we prepared the energy calibration system to know emitted laser power. Since features above are basically common with the CLF of the Pierre Auger experiment especially around the laser energy calibration system, the CLF will be a standard candle for both experiments [2].

Hardware

The CLF uses a third harmonic beam of Nd:YAG laser as a spurious air shower event to calibrate the FD telescope. This 355 nm laser extracted from original IR laser contains spectral contaminations of less than 10 %, these ingredients possibly affect the measurement of emitted laser power. In

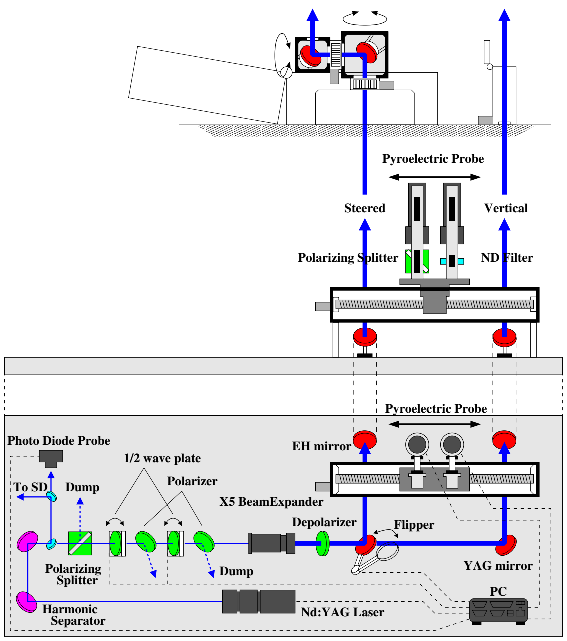

Figure 1: Top view (bottom) and side view (top) of the optical components of the TA CLF. The beam passed two harmonic separators is split into main path and extra path, then the extra path goes to simplified SD module to make SD event trigger. After going through the attenuation system which is using polarization mechanism, the main beam that expanded and depolarized is sent to vertical paths to the sky.

the optical configuration shown by Fig. 1, two harmonic separator mirrors are placed to remove unnecessary frequencies. As a result, the frequental purity is improved on to better than 99 %.

After two harmonic separators, the beam is split into main and extra paths. Less than 10 % of the beam is conducted to the extra path, it is split into the paths to energy probe and to SD trigger system again. The photo-diode probe placed here measures the fractional energy of the laser at all times, will be used for relative energy calibration source. The SD trigger system will contain simplified SD components, whole of the electronics, small scintillater, PMT and wireless communication system. (See [4] for configuration about SD.)

Generally the third harmonic of Nd:YAG laser just after emitted has linear polarization. We were planning to use this characteristic to attenuate the power of beam. A half-wave plate resolves incident linearly polarized beam into two waves, parallel and perpendicular to the optical axis of the plate, and delays this parallel wave exactly half of a wavelength relative to the perpendicular wave. Now a linearly polarized beam incidents to a half-wave plate with the angle θ to the plate's optical axis, the direction of polarization at the far side of the plate will be turned from initial direction to 2θ. Next the beam is conducted to the polarizer to pick out particular polarization and reflect another. The polarization of incident beam and which is picked by polarizer out are fixed, then only the rotation of half-wave plate controls the strength of the beam picked out by polarizer. These half-wave plates are mounted on motorized rotary stage, and two set of this system realizes over 200 times attenuation. For this performance, polarization splitter is placed on front of this system to make purely linear polarization.

After go through the beam expander and the depolarizer, the beam is sent to two selectable vertical beam paths. One goes directly to the sky and the other enters a mechanism with two mirrors on rotating orthogonal axes that can steer the beam in any direction above the horizon. The covers of both nozzles and steering mirror mechanism are operated by PC controlled stepper motors.

On the vertical paths, two pyroelectric probes set upped on the slider mechanism are located. One probe has polarizing splitter for polarization analysis and another has ND filters to weaken the beam. Keeping random polarization is required to make the Rayleigh scattering light equal as for azimuth, and to measure the same amount of light through the FDs. Though a depolarizer imparts a variable phase shift across the beam aperture to linear polarization beam, we should optimize the angle between the beam polarization and the optical axis of depolarizer. Fig. 2 is a variation of polarization of “depolarized” beam when the optical axis is rotated each 30 °. Vertical axis shows ratio between the amplitude of variation and the average power measured by pyroelectric probe equipped with polarization splitter that makes a rotation.

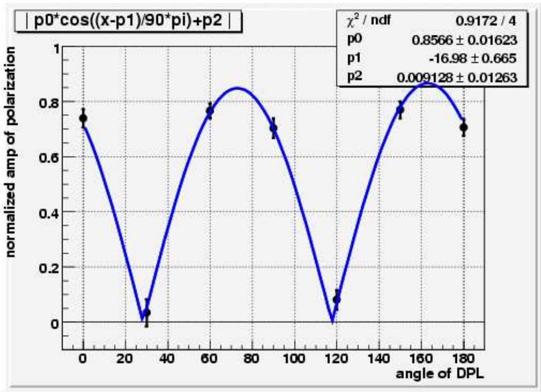

Figure 2: The horizontal axis shows relative rotation angle of depolarizer, and the vertical axis indicates degree of polarization of the incident beam. In general, the net polarization represented through ellipse shape, the vertical in this figure corresponds to $(major)/(minor) - 1$ of ellipse.

When these probes measure the beam energy directly, the photo-diode probe measures part of that energy on same time. Even when the beam are released to the sky, we can estimate the real energy of emitted laser using the measurement of the photo-diode probe.

Simulation and Test shot

To confirm the amount of light scattered out of the beam and the total number of photon detected by FD telescope, toy simulation is performed. Since it is required that the simulation includes atmospheric attenuation, we gave up adopting ray-tracing method to the simulation. In place of the ray-tracing, the simulator traces the change of number of photon which is included in certain solid angles each 10 ns, and reproduces attenuation caused by local aerosols. Fig. 3 shows two simulation results. One is the result of the case that assumed pure-Rayleigh condition. Another includes the result of Vertical Aerosol Optical Depth (VAOD) measured by the LIDAR system at BRM station [3]. That features the total amount of attenuation caused by aerosols which is 0.65 during 0 $\sim$ 10 km from ground height. The assuming of the exponential shape to the aerosol distribution appears to the difference between figures. Although the photon numbers of both figures are obviously different in the lower view, it seem almost same in the upper view.

Strictly speaking, the location in which this VAOD can be applied is only around the LIDAR site. That is, the result of simulation is an approximation assumed one-dimensional distribution so far, and requires more study about the aerosol distribution model after this.

On May 2007, we started the test observation with two FD stations, BRM and Long Ridge (LR) [7]. The facility is not on site yet, but the laser for CLF would be carried near the site and be shot to the sky in the near future. Even if the shot might be not calibrated, depolarized and well aligned though, it is meaningful test for both the confirmation of FD stereo trigger system and estimation of the amount of detectable light from CLF.

Future Prospect

Now the CLF housing and whole components are in SLC. The CLF would be constructed in this summer, and start the periodical calibration shot as soon as possible. Although this calibration shot aims at the measurement of the VAOD around FDs, the problem is that the measurement needs to assume one-dimensional aerosol distribution. It is unavoidable limitation on this calibration method, but combination with the VAOD measured by LIDAR enables to integrate more complex models.

On the other hand, the TA is developing the Linear Accelerator (LINAC) to calibrate between well-known electron beam energy and emitted fluorescence photons [5]. The LINAC will be set upped 100 m away from the BRM FD station, and makes a small air shower event which is similar to far, and energetic real event. The fluorescence photons generated by these "air shower"s should be detected by FD telescope equally, except atmospheric attenuation effect. Therefore, if a scale-down copy of the CLF is put side by side with LINAC, original energy of air shower is connected with the number of photons indirectly. Whole pre-detector calibration system is completely established within the next one year, and expected to work useful to reconstruct the primary energy of UHECRs.

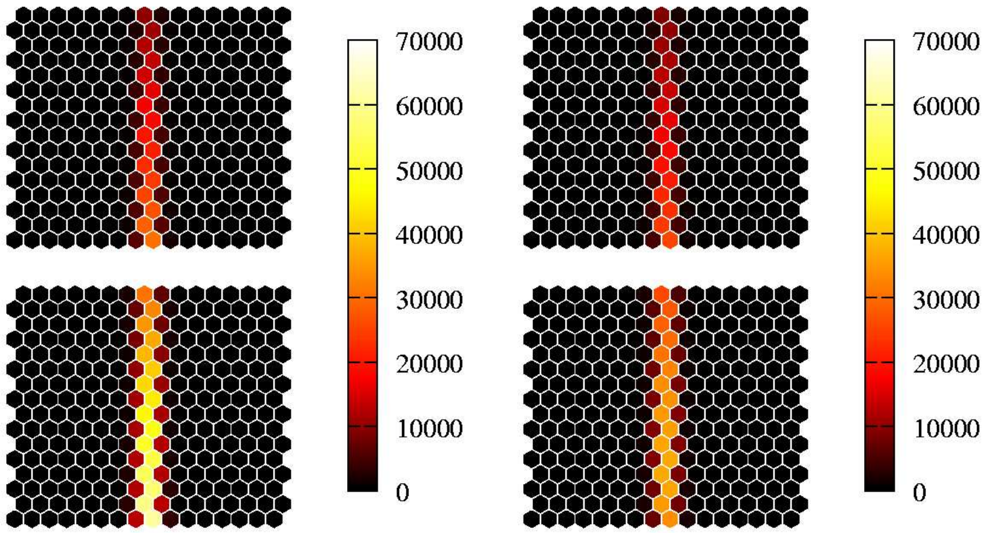

Figure 3: The result of the CLF simulation that assumed laser energy 10 mJ. Color bar shows number of photons which was detected by each PMT. The image when the pure Rayleigh condition applied is shown in left, right image shows the result that simplest aerosol distribution is assumed.

Acknowledgments

This work is supported in part by Grants-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology in Japan. We would like to thank the Millard County Council and Fillmore BLM.

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