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# 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 [1]. On the other hand, HiRes claimed that the GZK effect appears on the energy spectrum which they observed with fluorescence telescopes [2]. 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 [4].

## 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 the optical configuration shown by Fig.1, two harmonic separator mirrors are placed to remove un-

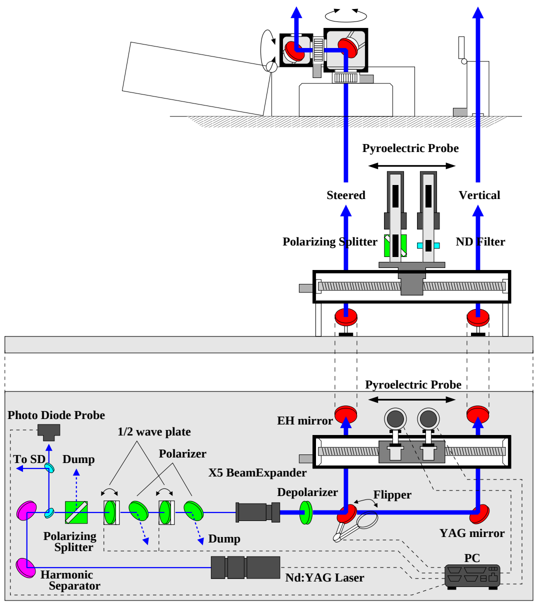


Figure 1: Top view (bottom) and side view (top) of the optical components of the TA CLF. The beam passed two harmonic separators is split into main path and extra path. After going through the attenuation system which is using polarization mechanism, the main beam that expanded and depolarized is sent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

necessary 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, see [5] 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 rotates a linearly polarized beam $2\theta$, as if the $\theta$ is the angle between polarization and the optical axis of the plate. After that, rotated 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.

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.

After go through 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 these 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. 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. 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.2 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.

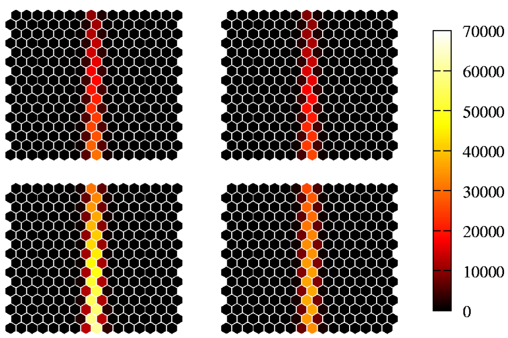


Figure 2: The result of the CLF simulation that assumed laser energy 10 mJ. Color bar shows number of photons which was detected by each PMT. The image when the pure Rayleigh condition applied is shown in left, right image shows the result that simplest aerosol distribution is assumed.

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 [6]. The facility is not on site yet, but the laser for CLF was carried near the site and was shot to the sky on this June. Fig.3 shows the real image of the laser shot which was detected by FD telescope at BRM station. It was meaningful test for both the confirmation of FD stereo trigger system and the estimation of the amount of detectable light from CLF, even if the beam was not calibrated, depolarized and well aligned.

The laser energy was supposed to be about 20 mJ, it is double energy assumed at simulation. And we assume the conversion factor between FADC outputs and photoelectron to be 0.37 p.e./counts and

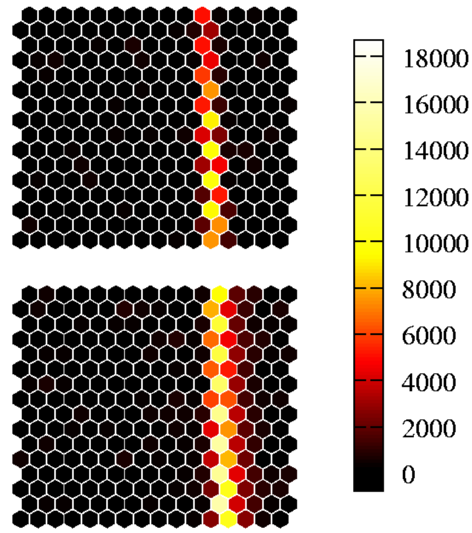


Figure 3: The real laser shot observed by the FD at BRM site. Colorbar shows the integral of FADC counts. Since the laser had not been fixed solidly, the beam truck tilted.

Q.E. & C.E. of PMTs to be 0.2. Then 40,000 ph. of the result of simulation correspond to 22,000 counts. It seems to be not bad consistency with 18,000 counts of the Fig.3, if we consider about polarization and energy fluctuation.

As to polarization, we put the half-wave plate in front of beam nozzle and turned the plate to change the polarization of the emitted beam. As mentioned before, the polarization of the beam is changed 2 $\theta$ when the plate is rotated $\theta$. And the intensity of light scattered by Rayleigh scattering makes 180°-cycle sinusoidal curve which has the lower peak at the direction of emitted beam polarization. Therefore the polarization would be gone around when the half-wave plate was turned 180°, then it would be observed as 2 cycles of the intensity variation of Rayleigh scattered light by each FD station. In the Fig.4 which shows the correlation between the angle of half-wave plate and light intensity observed by two FD stations, we can find the gap in phase of BRM and LR. Both top (BRM) and bottom (LR) panels are showing the variation of FADC output in each three dominant PMTs, and each peak are located on 67.2° $\sim$ 67.6° (BRM) and 104.1° $\sim$ 104.4° (LR). Now, the opening angle which viewed from the laser shooting point from BRM to LR is 107.7°. It roughly coincide with the double angle from first peak of LR to latter peak of BRM, $[(67° + 90°) - 104°] \times 2 = 106°$. Absolute intensities are not consistent between two stations, because the ratio of the lights distribute to adjoined PMTs is uncertain for tilted truck.

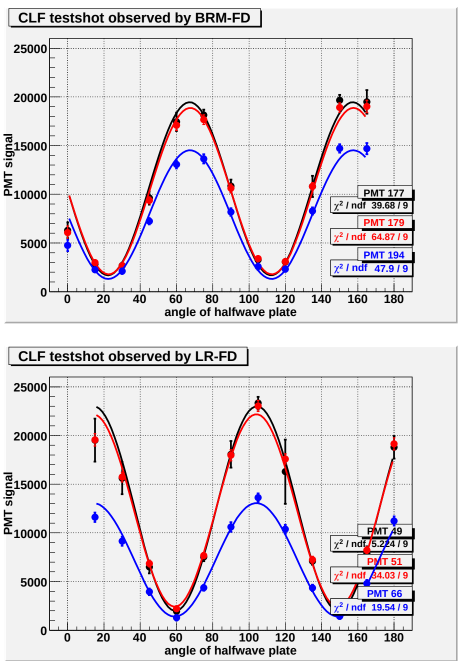


Figure 4: Intensity variation of Rayleigh scattering light observed by BRM (top) and LR (bottom) FD station. Three PMTs that have a certain output were selected for each station. Solid lines show best fitted sinusoidal curve with 90°-cycle.

## Future Prospect

Now we are moving the CLF housing and whole components to LR FD site for final adjustment. The foundation work at the site would be started in this summer, and the periodical calibration shot will be started 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, we are developing the Linear Accelerator (LINAC) to calibrate between well-known electron beam energy and emitted fluorescence photons [7]. The fluorescence photons generated by both of the air shower and LINAC 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 can be connected with the number of photons.

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.

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## References

[1] Takeda, M., *et al.*, Phys. Rev. Lett. 81 (6) (1998) 1163–1166.
[2] Abbasi, R.U., *et al.*, Phys. Rev. Lett. 92 (15).
[3] Chikawa, M., *et al.*, Proc. 30th Int. Cosmic-Ray Conf. Merida H.E.1.5.
[4] Arqueros, F., *et al.*, Proc. 29th Int. Cosmic-Ray Conf. Pune 8 (2005) 335–338.
[5] Ozawa, S., *et al.*, Proc. 29th Int. Cosmic-Ray Conf. Pune 8 (2005) 177–180.
[6] Tokuno, H., *et al.*, Proc. 30th Int. Cosmic-Ray Conf. Merida H.E.1.5.
[7] Shibata, T., *et al.*, Proc. 30th Int. Cosmic-Ray Conf. Merida H.E.1.5.