Progress in optimizing the detection surface structure of CRAFFT

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Abstract

An observatory for the next generation of ultra-high energy cosmic rays (UHECRs) should be expanded for clarifying the origin and nature of UHECRs. In order to realize a huge UHECR observatory, we are developing Cosmic Ray Air Fluorescence Fresnel lens Telescope (CRAFFT), which is a low-cost fluorescence telescope. We tested a performance of prototype CRAFFT at Telescope Array (TA) site, and succeeded to detect UHECR air showers synchronized with TA detectors in 2017. We are currently developing a reconstruction method based on waveform fitting with sufficient analysis accuracy, and optimizing the detector configuration to improve its performance with low cost. Progress in detector optimization, reconstruction method, and calibrations such as uniformity of PMT sensitivity are discussed.

CRAFFT : Cosmic Ray Air Fluorescence Fresnel lens Telescope

A simple structure fluorescence detector for the next generation of ultra-high energy cosmic ray observatory

For the next generation of ultra-high energy cosmic ray observations, the number of telescopes needs to be increased to significantly increase the observation volume. Therefore, cost reduction is inevitable. In order to measure the mass composition to reveal the mass composition of ultra-high energy cosmic rays, a fluorescence detector that can measure *X*max is preferable.

Large-scale observation to increase statistics

- Estimation of mass composition by *X*max observation.
- Fluorescent telescope with a simple structure using a refracting telescope instead of a reflecting telescope.

Low cost for Large-scale observation

- Reduction of construction costs by reducing the number of pixels.
- Reduction of operating costs by automatic observation system.

Fig. 1: Deployed CRAFFT prototype detectors.

Fig. 2: A test of the automatic observation system

Uniformity of PMT sensitivity

We have developed a calibration system for the CRAFFT detector and measured the non-uniformity of the sensitivity of the PMT. As shown in Figure 3, we moved the LED on the PMT and recorded the signal from the PMT every 5 mm, totaling 1569 points.

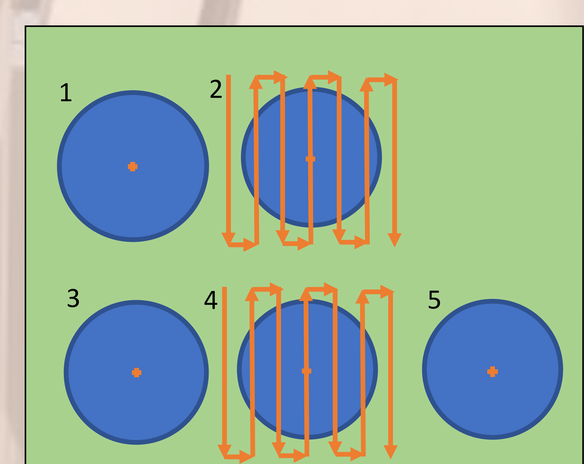

Fig. 3: LED calibration track

Figure 4 and 5 shows the results of two measurements to check the repeatability. Figures 6 show ratios between the first and second measurements. The results of the measurements show that the PMT sensitivity changes significantly depending on the incident position. We have established a two-dimensional non-uniform measurement method for PMT.

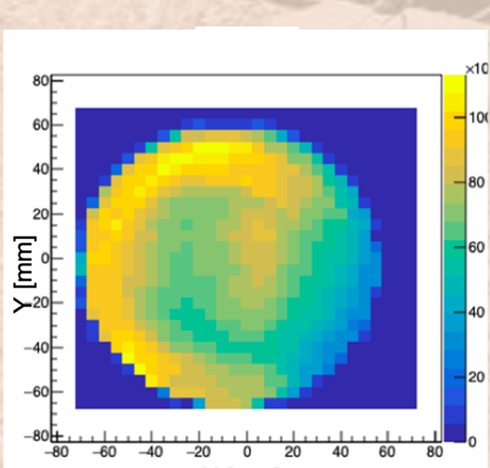

Fig. 4: Results of the first measurement

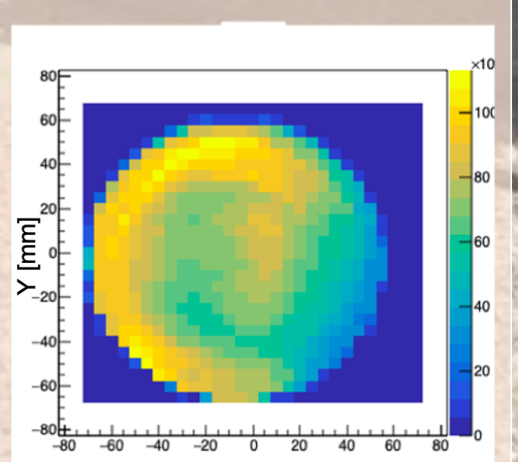

Fig. 5: Results of the second measurement

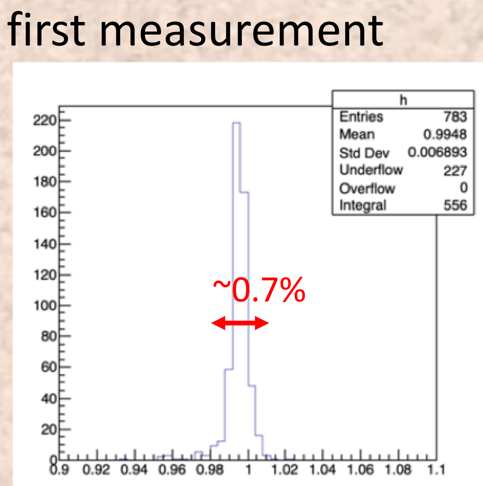

Fig. 6: Ratio between first and second measurements.

Reconstruction method based on waveform fitting

We are currently developing a reconstruction method based on waveform fitting with sufficient analysis accuracy.

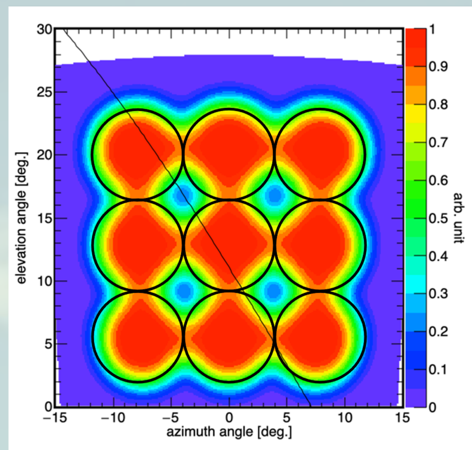

Fig. 7: Sensitivity map of PMTs.

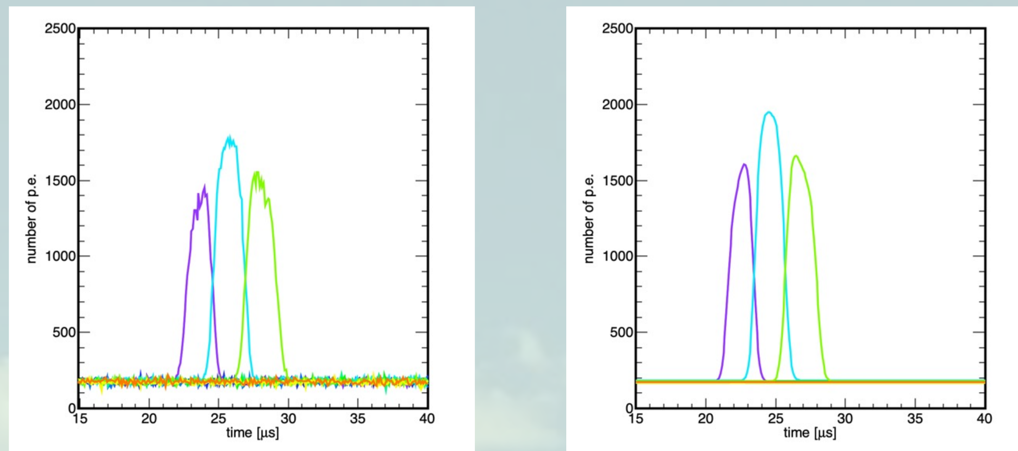

Fig. 8: Waveforms obtained by simulation. Left: Artificial data. Right: Fitted waveform.

Figure 7 is a sensitivity map of PMTs obtained by convoluting the spot size with the shape of PMT. The waveforms of artificial data is compared with the expectation generated by the various air shower parameters. We search for waveforms that base reproduces the data by minimizing the following χ^2.

$$\chi^2 = \sum_i \left(\frac{x_i - \mu_i}{\sigma_i}\right)^2$$

x = Npe of artificial data in i-th bin
μ = Npe of expected waveform in i-th bin
σ = Standard deviation of artificial data in i-th bin

Optimizing the detector configuration

Optimizing the detection unit to improve performance at a low cost.

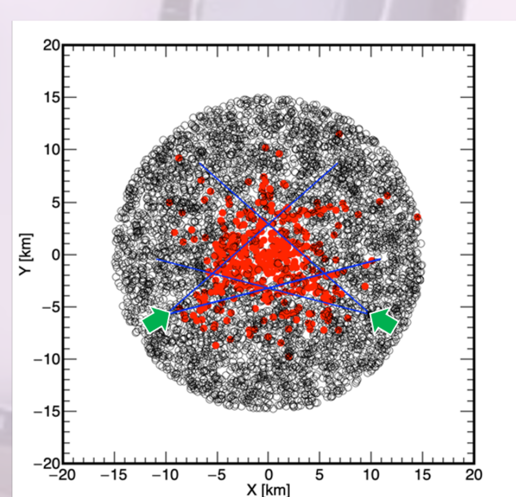

Fig. 9: The core locations of the air showers that arrived in the simulation.

Simulations were performed under the following conditions to evaluate the two types of detectors. ;the energy of the primary cosmic ray is $10^{19.5}$ eV, the Xmax is 700 g/cm^2, the zenith angle is less than 70 degrees, and the azimuth angle is uniform. The thrown core positions are shown in Figure 9, uniformly arriving within a circle of 15 km radius containing two stereo detectors. The detectors have a field of view toward the center of the circle as shown in the blue line. The red circles indicate the triggered air showers, which are triggered when both of detector have signals with signal-to-noise ratios above 6.

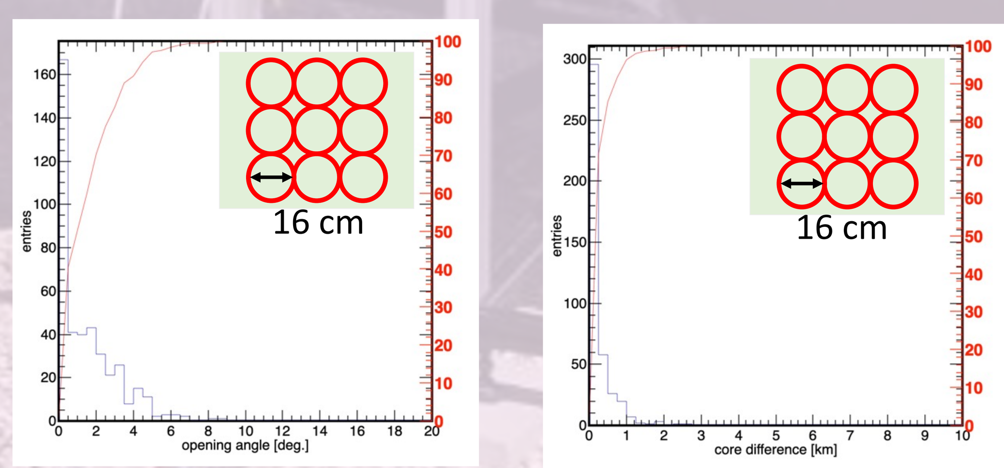

Fig. 10: The results for a detection plane with 9 PMTs of 16 cm diameter arranged in a square

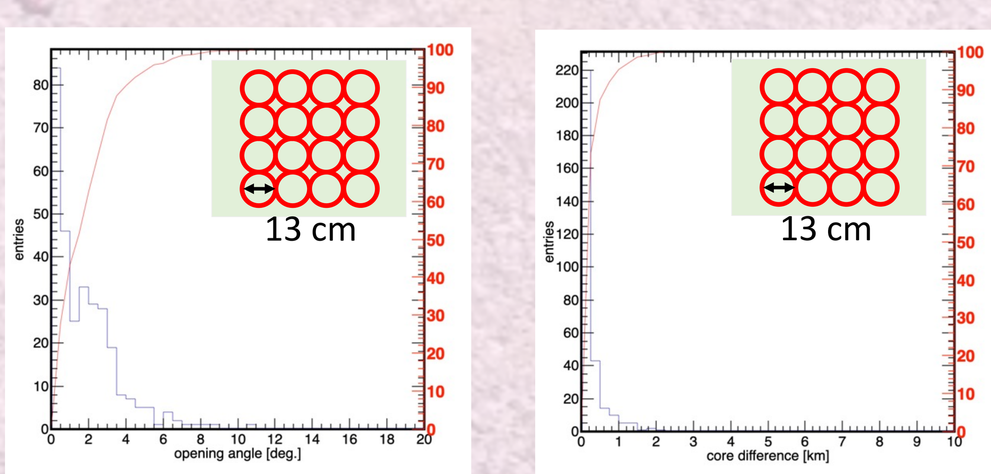

Fig. 11: The results for a detection plane with 16 PMTs of 13 cm diameter arranged in a square

Figures 10 and 11 show the differences between the thrown geometries and reconstructed those using the two types of detectors. Figure 10 shows the results for a detection plane with 9 PMTs of 16 cm diameter arranged in a square, and Figure 11 shows the results for a detection plane with 16 PMTs of 13 cm diameter arranged in a square. From the simulation study, it is found that the the resolutions are about 2 degrees in arrival direction and about 500 meters in core position, respectively of both types of detectors.