LHAASO simulation: LIACTs in the LHAASO project at 4300 a.s.l

L. L. MA*, **Z. Cao***, **H. H. He***, **E. Carmona**† **and M. Teshima**† **for LHAASO collaboration**

*Institute of High Energy Physics, Beijing 100049
†Max-Planck-Institute for Physics, D-80805 Munchen, Germany

***Abstract*. The Large High Altitude Air Shower Observatory (LHAASO) project is designed for gamma ray source survey using 90,000m^2 water Cherenkov array and 1km^2 air shower array and morphology measurement of sources using Large Imaging Air Cherenkov Telescopes (LIACTs), like MagicII telescopes. Temporal features and energy spectra of sources confirmed using the telescopes will be also investigated thoroughly. Detector performances including effective area, angular resolution and discrimination power of background hadronic showers are investigated using a detailed detector simulation package. The sensitivity of two LIACTs combined with the air shower arrays on the ground is estimated at the LHAASO site in Tibet at 4300m a.s.l.**

***Keywords*: IACT, Gamma ray astronomy, Cherenkov telescope**

I. Introduction

Large High Altitude Air Shower Observatory (LHAASO)[1] is a new project located at YangBajing Tibet (longitude 90.5E altitude 30.11N atmosphere depth 606g/cm^2). One of main goals of LHAASO is searching for new gamma ray sources using 90,000m^2 Water Cherenkov Detector Array (WCDA) and a 1km^2 air shower array (KM2A). With an energy threshold of about 30TeV, a sensitivity of 1% crab unit, large field of view (FOV) and high duty cycle, KM2A are expected to discover many Galactic gamma ray sources and to measure the high energy end of their spectra [2]. At TeV region, WCDAs will survey the whole northern sky with a sensitivity of 2% of Crab unit and monitor any transient phenomenon[3]. Neither KM2K nor WCDAs can measure the source spectrum at TeV region due to not very well energy resolution, which can be done by Large Imaging Atmosphere Cerenkov Telescope (LIACT). Furthermore, LIACT can do detailed morphologic study of the source region because of it high angular resolution, energy resolution and strong power in gamma and hadron separation. In order to study properties of LIACTs at the altitude of YangBajing, detailed simulations have been done using Magic simulation software[4].

The Monte carlo simulation is divided into three stages. The first step is to simulate air showers initiated by either high energy gammas or hadrons using CORSIKA program[5]. The second step is reflector simulation. In this stage the Cherenkov light absorption and scattering in the atmosphere are considered and then is performed the reflection of surviving photons to record their locations on the camera and arrival time. The final stage is camera simulation including the response of PMTs, trigger system and data acquisition system. A total of 2.2×10^6 gammas with energies between 20GeV and 30 TeV are simulated, as well as 4.6×10^7 protons with energy between 30GeV and 40 TeV according to power law spectra with a spectral index of -2.0 in order to get more statistics of high energy events. The primary zenith angles of both gammas and protons are sampled from 6° to 30°. If the primary particles are gammas, telescopes are always pointing to the primary directions, while in case of protons, the telescopes pointing directions are scattered isotropically within 6° around the primary directions. The maximum impact parameters are 700m and 1000m for gammas and protons respectively. In order to optimize the distance of the two telescopes, 6 telescopes are placed in the simulation, with one in the center and the other five located at distances of 60m, 80m, 90m, 100m, 120m to the center. In order to study the influence of the geomagnetic field, two configurations are simulated with the 6 telescopes placed along the North-South and East-West directions respectively.

II. effective area

The trigger conditions used are: threshold = 4mV (4 photonelectrons(phe)) for each PMT and at least 4 pixels with topology II (4NN)) which means close-impact neighbor pixels are triggered for each event. The trigger efficiency $P(E, r)$ is a function of energy E and impact parameter r. The integration of this function in its space coordinates gives the effective area $S(E)$ which determines the telescope's capability for the detection of gammas and protons[4]. The effective area for gammas can be seen in figure 1. In the case of protons the trigger efficiency also depends on the angle between the shower axes and the telescope pointing directions, due to the fact that the protons come isotropically from different sky directions. As the distance between the two telescopes become larger, the effective area becomes smaller according to Fig. 1. The effective area can reach up to 10^{5}m^2 when gamma's energy is above 1TeV.

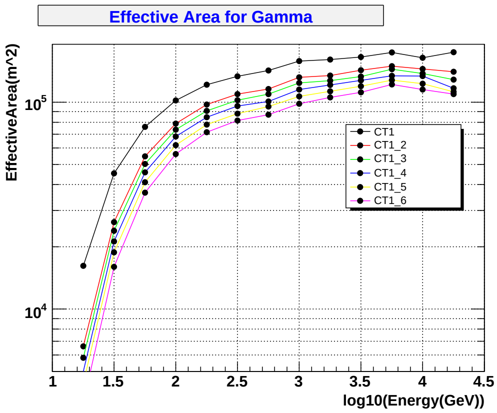

Fig. 1: The effective area for gamma with different distances between the two telescopes of 60m (CT1_2), 80m (CT1_3), 100m (CT1_4), 120m (CT1_5), 140m (CT1_6). CT1 indicates the effective area of one telescope.

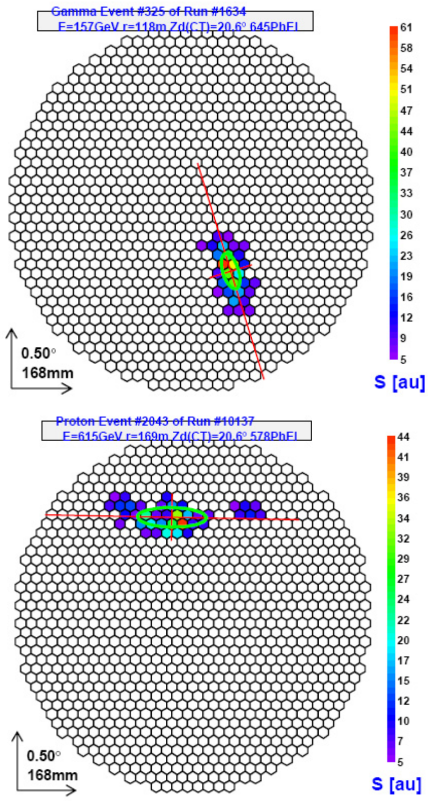

Fig. 2: Typical images of a gamma shower (upper) and a proton one (bottom).

III. DATA ANALYSIS

Before image parametrization image cleaning should be done requiring signals higher than a pre-defined number of phe for each PMTs within a time window. The image cleaning procedure uses a threshold signal value q_1 to select core pixels, namely all those with charge above q_1 and which have at least one neighbor fulfilling the same condition. Then all pixels which have at least one core neighbor, and whose charge is above q_2 (with $q_2 < q_1$) are included in the image called boundary pixels[6]. The night sky background can be effectively suppressed using the time information. Four sets of values (6,3),(7,4),(8,5),(9,6) of q_1 q_2 are used to optimize the image cleaning threshold. Fig.2 shows typical images of gamma and proton showers after image cleaning.

After image cleaning, data analysis can be done by Hillas parametrization[7]. A set of Hillas parameters including Size, Length, Width etc are used to reconstructed arrival directions, shower core positions and energy etc of primary particles and to do gamma and hadron separation.The Size is the total number of phe in shower image. Width and Length are the second moments of the light distribution along the major and minor axes of the image. Using the images of the two telescopes, three dimensional reconstruction can be done. The intersection point of the major axes of the two ellipses recorded by the two telescope cameras indicates the directions of primary particles. The image center of gravity (COG) can be considered as the projection of Hmax on the camera plane with Hmax being the height of shower maximum, thus the intersection of COG and shower direction in the telescope coordinate can be considered as the Hmax. The core position can be also obtained from the intersection of image axes on the ground. The reconstructed energy is the function of image Size and impact parameters. Energy reconstruction can be done through a table built from Monte Carlo gamma showers and averaged over the two telescopes.

IV. GAMMA AND HADRON SEPARATION

For gamma and hadron separation the most useful parameters are Width and Length. At fixed image Size the Width and Length are smaller for gamma induced image than that for hadron induced shower. Width and Length depend on the impact parameter so they are normalized by subtracting their means and then divide the results by their RMSs. The mean value and RMS are the functions of Size and impact parameters are gotten from Monte Carlo gamma images. In order to combine the two parameters from both telescopes, the average values of normalized Width and Length are used, namely Mean Scaled Width and Mean Scaled Length[8]. The distributions of the two new parameters for gammas have a mean value 0 with RMS 1, while the distributions for hadrons are much broader (see Fig.3).

In our data analysis Random Forest method (RF) is used to do gamma and hadron separation[9]. RF method is based on a collection of decision trees, built up with some elements of random choices. RF creates a set of largely uncorrelated trees, and combines their results to form a generalized predictor. The trees are trained by Monte Carlo gammas and hadrons. Each event will be given a label called hadronness distributed from 0 to

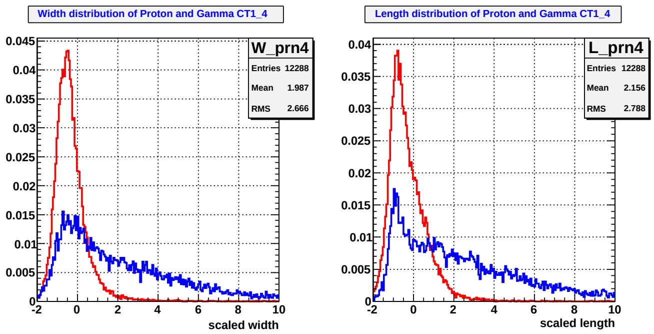

Fig. 3: Distributions of scaled Width and Length for gammas and hadrons. The red line indicates gammas and the blue one is hadrons.

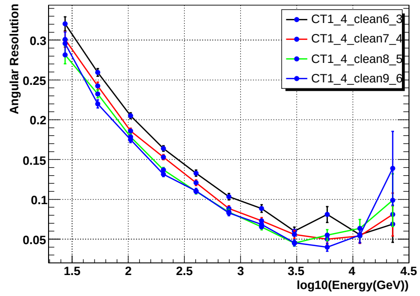

Fig. 5: The angular resolution for different image cleaning parameters. The distance between the two telescopes is 100m.

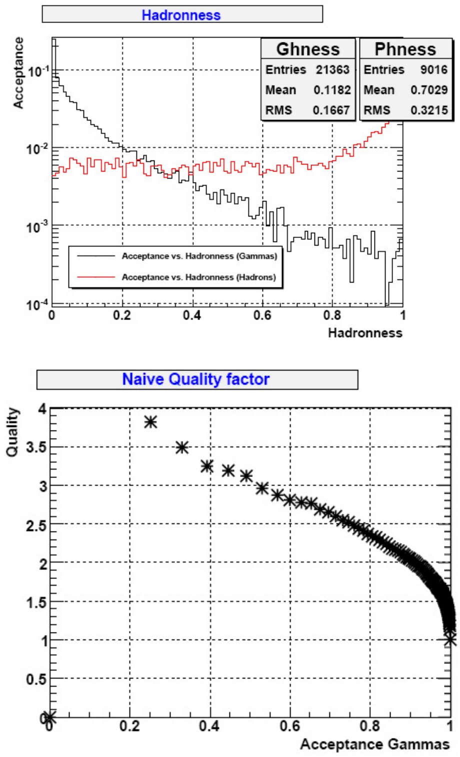

Fig. 4: The upper plot are distributions of hadronness for gammas and hadrons. The black line indicates gammas and the red one is hadrons. The bottom one is the Q factors varying with gamma acceptance.

1. Events with value closer to 0 are gamma-like, while those with value closer to 1 are hadron-like.

In the RF method several parameters are used including mean Size, Mean Scaled Width, Mean Scaled Length, reconstructed Hmax, reconstructed energy and average number of Islands which indicates the compactness of images. The ability of separating gammas and hadrons can be indicated by a quality (Q) factor which can be seen in Fig.4. The Q factor at 50% acceptation of gamma can reach up to 3.2.

V. Results

Two telescopes with distance 100m are chosen to optimize image cleaning parameters q_1, q_2 which based on angular resolution and sensitivity. The angular resolution is defined as the angle within which 50% of reconstructed gammas from a point source should be contained. The angular resolution becomes better for higher image cleaning level and it is also a function of gamma ray's energy as shown in Fig.5. The sensitivity is defined as the minimum gamma ray flux which can be detected with 5 sigma in 50 hours. The sensitivities for different image cleaning levels can be seen in Fig.6, from which one can see the image cleaning parameters 8phe and 5phe for q1, q2 respectively are best. These image cleaning parameters are used to telescopes with different distances to optimize the distance of the two telescopes. The angular resolution, energy resolution of the two telescopes with different distances can be seen in Fig.7, from which one can see that angular and energy resolution are not only the function of energy but also the function of the distance of the two telescopes. The larger for the distance between the two telescopes, the energy resolution and the angular resolution the better. But on contrary the effective area becomes smaller as the distance of the two telescopes becomes longer (sen Fig.1).

Finally the sensitives are calculated for different distance telescopes as shown in Fig.8. From Fig. 8 one can see that the best sensitivity is the two telescopes with distance 100m.

VI. conclusion

Detailed simulations have been done for two MAGICII telescopes at YangBajing site. The angular resolution can reach to 0.05° and the energy resolution can reach up to 15% for showers with energy above 1TeV. The mode energy for the two telescopes with an optimize distance of 100m is about 48GeV. The angular resolution of telescopes along East-West direction is better than the ones along North-South direction due to influence of geomagnetic field, so it is better for

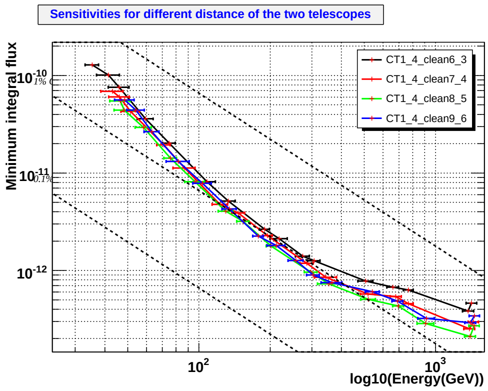

Fig. 6: The sensitivities of the two telescopes with distance 100m for different image cleaning parameters. From this plot the image cleaning parameter 8phe for core pixels and 5 for boundary pixels should be best.

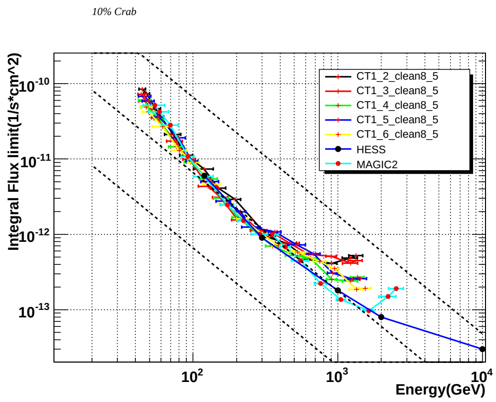

Fig. 8: This plot shows the sensitivities of the two telescopes with different distance. The bright blue line shows MagicII sensitivity and the blue line shows Hess sensitivities.

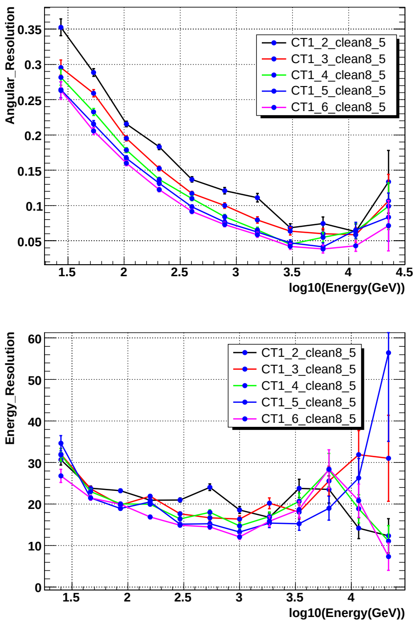

Fig. 7: The upper plot shows angular resolution and the bottom plot shows energy resolution. The angular and energy resolution become better when the distance of the two telescopes becomes longer.

the two LIACTs placed along East-West direction. Two LIATs are to be placed near one of the Water Cherenkov Detector Arrays in the LHAASO project to perform hybrid observation of air showers, by which performances of both detectors may be improved. Detailed simulation on that are undergoing. With a sensitivity of 1% Crab unit, the two telescopes can be used to do detailed morphology study of gamma ray sources to be discovered by LHAASO KM2A and WCDAs.

VII. Acknowledgements

The authors thank MAGIC group in Munich for valuable discussion and help. This work is supported by Knowledge Innovation fund (H85451D0U2) of IHEP, China.

References

[1] Z. Cao, H. H. He In these proceedings, 31th International Cosmic Ray Conference
[2] S. W. Cui In these proceedings, 31th International Cosmic Ray Conference
[3] Z. G. Yao In these proceedings, 31th International Cosmic Ray Conference
[4] T. Bretz and the MAGIC collaboration 29th International Cosmic Ray Conference
[5] D. Heck, J. Knapp, J.N. Capdevielle, G.Schatz and T. Thouw. Techincal Report FZKA 6019, Forschungszentrum Karlsruhe,1998.
[6] E. Aliu et al. arXiv:0810.3568v2 [astro-ph] 27 Nov 2008
[7] A. M. Hillas. 19th International Cosimc Ray Conference, 1985
[8] E. Carmona, P. Majumdar 30th International Cosmic Ray Conference, 2007
[9] J. Albert etc. arXiv:0709.3719v2 [astro-ph] 8 Nov 2007