PROCEEDINGS OF SCIENCE

Comparison of measured and simulated data with LHAASO-WCDA run data

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LHAASO-WCDA has finished its first pool installation in the beginning of 2019. Since then the detector start to take test run data. Based on these data, a lot of update has been implemented in both detector simulation and reconstruction method. In this work, a lot of comparison between data and MC samples have been processed, some preliminary results, such as lateral distribution of air shower data , are shown.

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1. Introduction

In very-high-energy (VHE) gamma-ray astronomy, the water Cherenkov technique has the unique advantage of background rejection power. This characteristic has been well demonstrated by simulations and in practice by the Milagro experiment. New generation facilities, such as HAWC [1] and LHAASO [2], that adopt this technique and with larger area can achieve a sensitivity of more than one order of magnitude better than current experiments.

A water Cherenkov detector array(WCDA) has been built since 2017 at Mountain Haizishan (altitude, 4410 m asl), Daocheng, Sichuan Province, China. This array will cover an area of 78,000 m^2 and contain 350,000 tons of purified water. The main purpose of the WCDA will primarily survey the northern sky for sources of VHE gamma ray. The whole WCDA will be divided into 3120 detector cells and consist of three ponds, two of which will cover areas of 150 m × 150 m, and the other of 300 m × 110 m (Fig. 1). The water in each pond will be subdivided into cells with areas of 5 m × 5 m, portioned by black plastic curtains to prevent the cross-talk of lights between cells. Additionally, 2 PMTs will be placed at the bottom of each cell. The PMTs will face upwards with effective water depth 4 m above the photo-cathode.

The firstly built pool has 900WCD units, 25 m^2 each, equipped by a large (8 inch) PMT for timing and a small (1.5 inch) PMT for pulse size at the center of each cell, and measures shower directions with a resolution better than 0.2° above 10 TeV and 1.0° above 600 GeV. A gold event detected by the array as shown in Fig. 2.

In order to enhance the gamma ray detecting sensitivity at low energies, enlarging the sensitive photo-cathode of the PMT is one effective way to catch the faint signals. LHAASO upgrading plan is to replace the 8" PMTs by 20" PMTs in the rest two pools of 55,500 m^2 in total. The customized design of the PMTs using multi-channel-plate (MCP) in stead of the traditional dynodes enables good uniformity between PMTs as well as the Transit Time Spreads (TTS) less than 7 ns, Cathode Transit Time Distribution (CTTD) less than 2 ns and long lifetime. The photo cathode is a factor of 6.25 larger than the 8" tube, therefore the dynamic range is also shrunk by the same factor. In order to compensate the loss, a 3" PMT is installed beside the large PMT in each unit, read out only for the pulse size.

In Section 2, the details of simulations is described. In Section 3, comparison between data and MC samples have been proceed. Finally the study is summarized.

2. Details of simulations

2.1 Shower simulation

In this simulation, the air shower events are generated by CORSIKA v75000 [4]. The EPOS-LHC and FLUKA libraries are used for high energy hadronic interactions and for interaction cross-section in low energy regions, respectively. The loss of the shower information is avoided by setting the kinetic energy cut to lower values than Cherenkov production threshold in the water for secondary particles in CORSIKA, that is, 50 MeV for hadrons and muons and 0.3 MeV for pions, photons and electrons [5]. The detector is supposed to be built at an altitude of 4300 m asl, and geomagnetic field components are set to 34.5 μT and 35.0 μT for north and downward vertical components of geomagnetic field respectively.

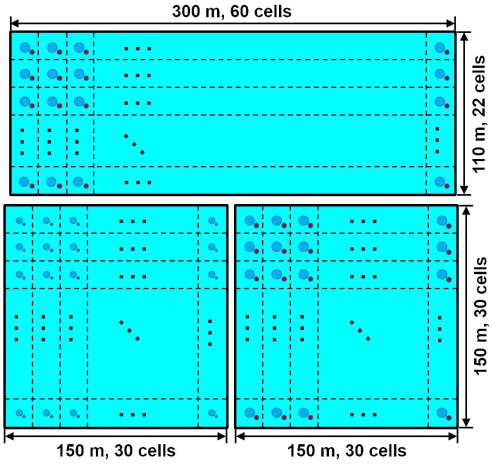

Figure 1: Schematic drawing of the WCDA layout [3].

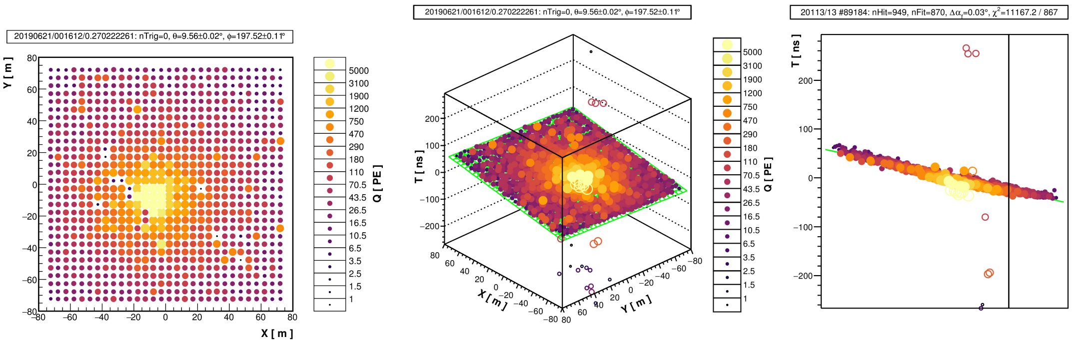

Figure 2: A gold event detected by the array.

Five different primary cosmic ray nuclei (proton/helium/CNO/MgAlSi/Fe) are used in simulation. The primary energy is sampled in the range from 10 GeV to 100 TeV, at zenith angles 0° – 60°, and uniformed azimuth angle 0° – 360°. The fluxes and spectral index of Horandel model [6] is used. The Horandel model is used to consider the composition of primary cosmic ray as shown in Fig.3. Table 1 lists two important CORSIKA input parameters, energy range and corresponding spectral index, used in the simulation.

Table 1: Two important parameters of the five primary particles in simulation.

CR	energy range (TeV)	spectral index
P	$0.01 - 10^2$	-2.71
He	$0.1 - 10^2$	-2.58
CNO	$0.1 - 10^2$	-2.60
MgAlSi	$0.1 - 10^2$	-2.63
Fe	$0.1 - 10^2$	-2.63

2.2 GEANT4 simulations

The GEANT4 toolkit with 10.3.3 [7] version is employed to track the secondary particles of

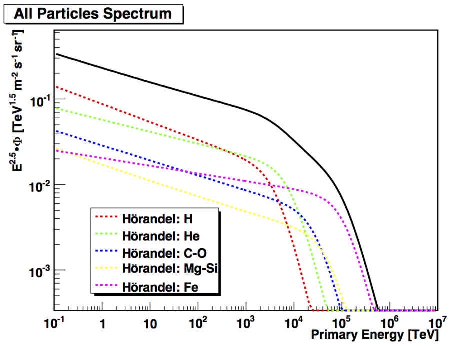

Figure 3: Primary cosmic ray composition.

shower and their productions in the detector, where the PMT models are taken from GenericLAND software library [8].

The so-called G4WCDA programe which is based on the Geant4 is used to consider the detector geometry, particle interaction with materials in the WCDA detectors. The realistic experimental hall including the columns, beams and roof materials are all taken into account properly in this code.

For water Cherenkov detector simulation, most of CPU time is consumed in Cherenkov light production, transparency and absorption, for example in one cm step length, around 300 Cherenkov lights will be produced and tracked. In order to improve the simulation efficiency, two steps simulation are adopted in our MC simulation procedure. The first step is to deal with secondary particles interaction inside the water pool without any water absorption consideration, And the information of secondary particles, mostly Cherenkov light, hitted in a limited volumed around PMT ($80 \times 80 \times 80\ cm^3$) are all stored in ROOT file for the second step simulation. In this way, once some changes happened on water absorption length or other properties, a very quick parameter-tuned in second step can be easily re-produce realistic MC samples without simulation on the first step. Fig. 4 is a sketch map of this idea. And in the work, each shower is re-used 10 times and the projection area is 2000 m × 2000 m around the pool center.

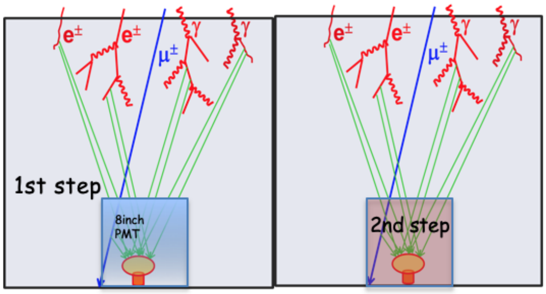

Figure 4: Sketch map of G4WCDA.

2.3 Reconstruction

The events are reconstructed by first fitting the spatial charge distribution to identify the location of the primary particle trajectory as projected onto the array, which we refer to as the shower "core", and then fitting the times of the hits to a shower plane hypothesis. An accurate core fit is important to properly account for the curvature of the shower front and achieve the most accurate possible angle fit. Fig.5 is MC result on core and angular resolution.

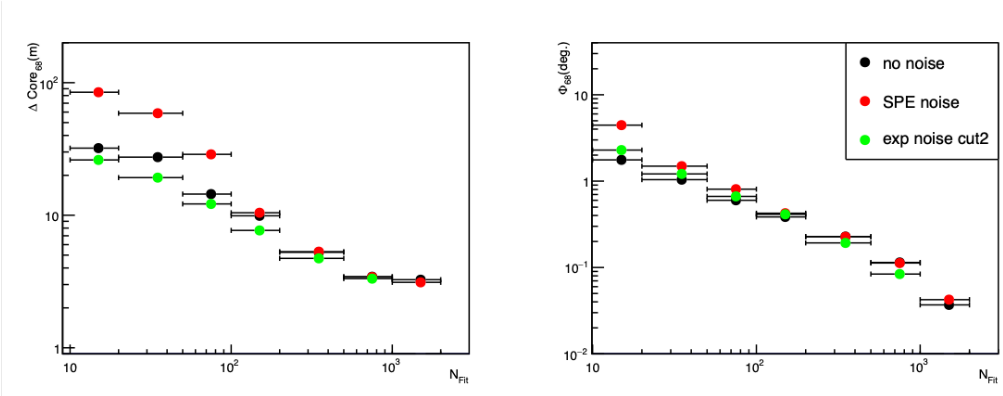

Figure 5: The core and angular resolution from MC.

Fig. 6 shows the energy distribution with the different PMT multiplicities. The PMT multiplicity is the number of PMTs required to be in coincidence during a time window of 300 ns.

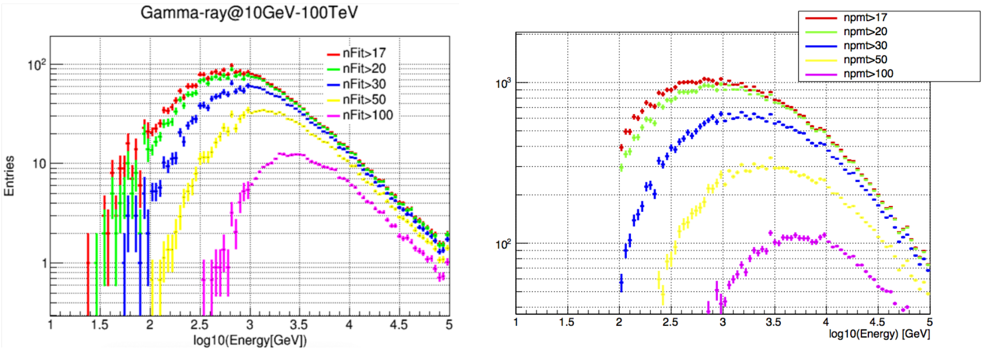

Figure 6: The energy distribution with the different PMT multiplicities.Top is for the Gamma, and the bottom is for the background.

3. Some simulation results

3.1 The trigger rate

The trigger rate has certain relationship with the distribution of incident primary cosmic rays due to the atmosphere absorption. Fig. 7 show the distribution of incident zenith and azimuth angle, it is obvious to see the distribution of M.C sample is quite consistent with experimental data as $\theta < 45°$. Because of the simulation statistics, the simulation data fluctuates greatly.

And the trigger rate has dependent on many details, such as primary cosmic ray compsition, interaction models used in air shower. Based on our simulated conditions, the M.C. trigger rate from different species are shown in Table 2 . The trigger rate of shower are dominated by primary proton and helium, contributing to nearly 90% of total trigger rate. Other components totally share

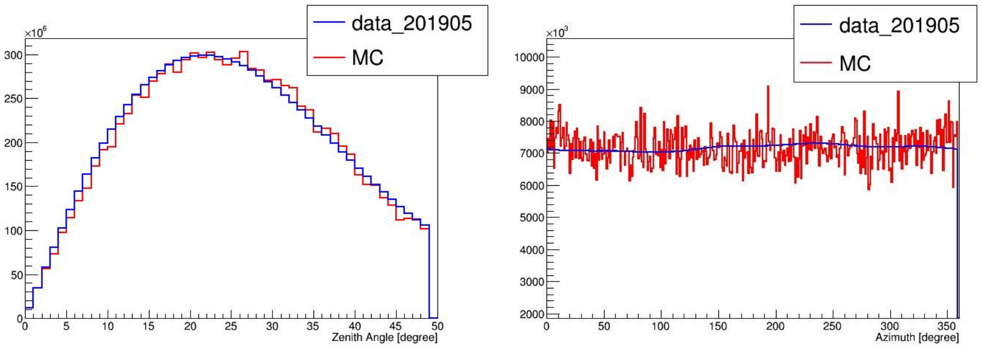

Figure 7: The distribution of the zeniths (left) and azimuths (right) for the shower directions.

10%. The data trigger rate from one selected file is about 22.1 KHz and the M.C is 20.5 KHz, thus the M.C. trigger rate is consistent with data within 8% level.

Table 2: Trigger rate versus the PMT multiplicity for the simulation data. Different components of showers from MC simulation are shown..

CR	>17 (NHit)	>20 (NHit)	>30 (NHit)	>50 (NHit)	>100 (NHit)
P	13.2 kHz	9.7 kHz	4.7 kHz	1.9 kHz	0.6 kHz
He	4.9 kHz	3.5 kHz	1.7 kHz	0.8 kHz	0.3 kHz
CNO	1.3 kHz	0.9 kHz	0.4kHz	0.2 kHz	0.07 kHz
MgAlSi	0.6 kHz	0.4 kHz	0.2 kHz	0.08 kHz	0.03 kHz
Fe	0.5 kHz	0.3 kHz	0.16 kHz	0.07 kHz	0.02 kHz
All (8m)	20.5 kHz	15.0 kHz	7.2 kHz	2.9 kHz	1.0 kHz

3.2 Even odd angular resolution

One of main topic of WCDA is gamma ray astronomy, a good angular resolution is an crucial point. A even-odd cell unit has been used to undertand the angular resolution both for data and MC samples, their results are shown in Fig. 8. The angular resolution as a function of nfit (number of fiting PMT in the reconstruction) are reported in this figure, one can see a good agreement between MC and experimental data is evident.

Based on the same reconstruction data, a preliminary result on moon shadow has been observed. Fig. 9 shows the displacement along RA direction is around 0.2 in different nfit ranges, this value is bascially consistent with the MC simulation.

3.3 Shower size comparison

Besides gamma ray astronomy, WCDA detector can also do some interesting work on typical cosmic ray physics, such as energy scale calibration based on moon shadow[9] and light component (Proton + Helium) energy spectrum measurement. Thus preliminary comparsion refering to Npe, number of recorded photonelectrons, and the average lateral distributin of recorded Ne are shown in Fig. 10. A consistent agreement can be found in both cases.

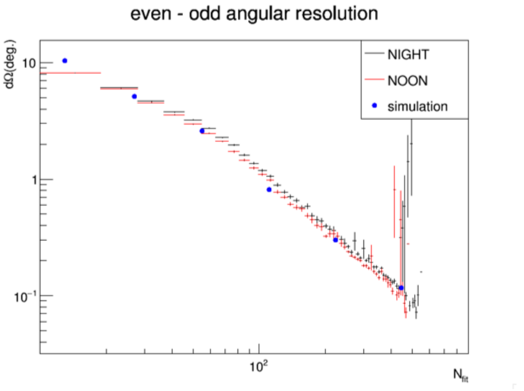

Figure 8: Even odd method to determine the angular resolution.

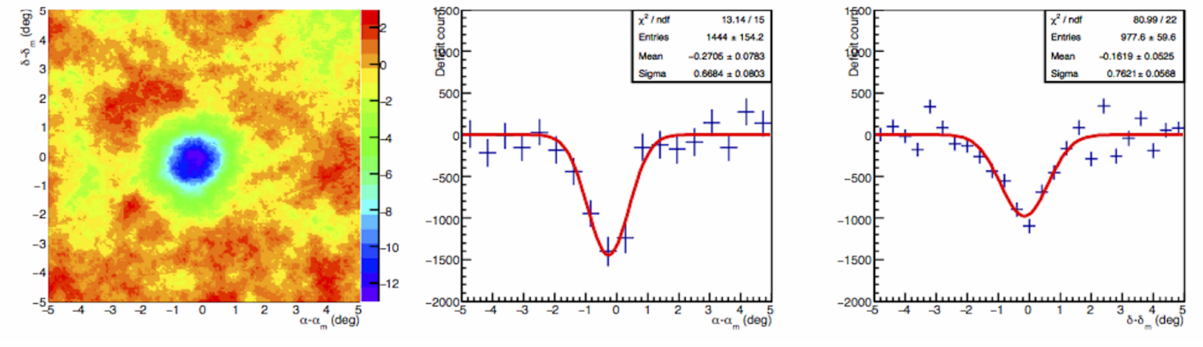

Figure 9: The data moon shadow significance and one-dimensional projection case distribution(nfit range: 100-200.

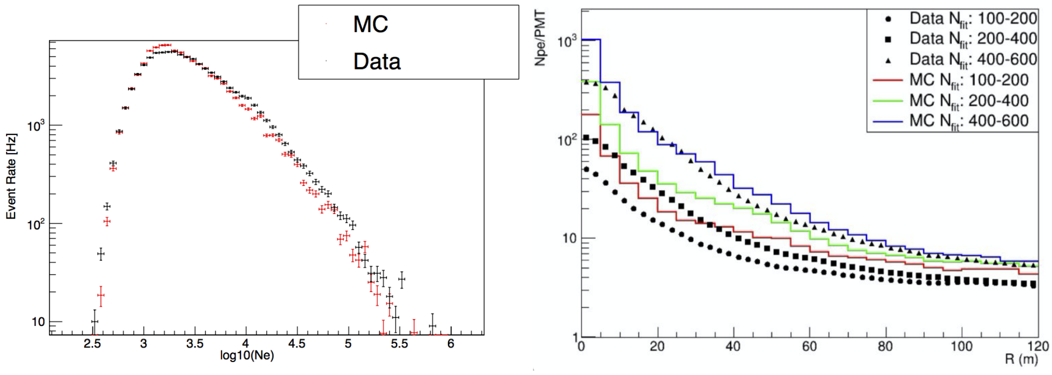

Figure 10: Left panel is the distribution of recorded number of PEs, right panel is the average lateral distribution in 3 different Nfit intervals

4. Discussions

In this study, the MC sample shows good consistency compared with the experimental data of the first WCDA array. For the trigger rates at 17 Npmt multiplicities, the experimental data is about 22.1 KHz and the M.C is 20.5 KHz, thus the M.C. trigger rate is consistent with data within 8% level. A even-odd cell unit has been used to understand the angular resolution both for data and MC samples. A good agreement between MC and experimental data is evident. The lateral distribution is not good agreement between MC and experimental data. More studies for this are in progress and will be discussed somewhere.

References

[1] T. DeYoung, Nucl. Instrum. Methods Phys. Res. A, 692(2012): 72–76.

[2] Z. Cao, Chin. Phys. C, 34 (2)(2010): 249–252.

[3] H.C. Li, *et al*, Chin. Phys. C, 41 (2)(2017): 026002.

[4] http://www-ik.fzk.de/corsika

[5] H.C. Li, *et al*, Chin. Phys. C, 38 (1)(2014): 016002.

[6] J.R. Horandel, Astroparticle Physics, 19 (2003): 193–220.

[7] S. Agostinelli, *et al*, Geant4 Collaboration, Nucl. Instrum. Methods Phys. Res. A, 506(2003): 250–303.

[8] http://neutrino.phys.ksu.edu/∼GLG4sim.

[9] Yanjing Wang et al. for the LHAASO Collaboration, "The energy calibration using the moon shadow of LHAASO-WCDA detector" ICRC2019.