PROCEEDINGS OF SCIENCE

Study on improving the gamma ray discrimination from cosmic ray detected by LHAASO

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Detection of Gamma ray source is one important approach for searching galactic cosmic ray origins, meanwhile the high energy diffuse gamma ray is expected to be produced by astrophysical objects, including dark matter annihilation and decay emissions in galactic or extragalactic structures. The large high altitude air shower observatory (LHAASO) is a hybrid detector array. It does not have only 1 km^2 detection area, but also powerful background discrimination. It has been the best observatory for the all sky survey for the gamma-ray sources and diffuse gamma ray above several TeV. we propose one characteristic variables to discriminate the gamma ray from hardon based on the feature of LHAASO. The lateral distribution of extensive air shower is divided into different sizes of rings, then the particle density is calculated. We extract characteristic variable ($\rho_{w200-220}/\rho_{k0-20}$) which is the ratio between density of the ring from 200 meters to 220 meters in the water Cherenkov detector array and that from 0 meter to 20 meters in the 1 kilometer squarer array. In this paper, we present preliminary results for the abilities of the variables.

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1. Introduction

The gamma ray source is relevant to the cosmic ray origins and we can detect the gamma ray to locate the position of the source[1]. Meanwhile the astrophysical objects, including dark matter annihilation an decay emissions in galactic or extragalactic structures can produce the high energy diffuse gamma ray according to the study. The large high altitude air shower observatory (LHAASO) is a hybrid detector array. It does not have only 1 km^2 detection area, but also powerful background discrimination. It has been the best observatory for the all sky survey for the gamma-ray sources and diffuse gamma ray above several TeV.[2].

There are three parts in the LHAASO, the 1 kilometer squarer array (KM2A), the water Cherenkov detector array (WCDA) and Wide field of view Cherenkov telescopes array (WFCTA) respectively[3]. The KM2A is made of two different kinds of detectors, one is the electron-magnetic particle detector and the other is the muon detector. The MD array plays an important roles in discriminating the gamma-rays from protons.

Previously, the detection threshold of the KM2A is about 30 TeV[4]. Above the energy, the KM2A can discriminate the gamma-rays from protons by the number of muons, because the hadrons, for example protons, can produce a lot of muons. Generally, the variable (N_μ/N_e) which is the ratio between the number of the muons and the number of the electrons generated by the air shower is an powerful tools.

2. Method

The WCDA is in the middle of the LHAASO, in order to obtain the reasonable complete events, the events whose shower cores are near the boundaries between two array are abandoned. On the other hand, the hadrons which are below 30 TeV will produce so little muon that the KM2A cannot separate gamma-rays from protons. Therefore, we define a new variable base on the hybrid arrays configuration.

2.1 Discrimination Variable

The lateral distribution of extensive air shower is divided into different sizes of rings, then the particle density is calculated. Here, the new discrimination variable is the ratio ($\rho_{w200-220}/\rho_{k0-20}$) between density of the ring from 200 meters to 220 meters in the WCDA and that from 0 meter to 20 meters in the KM2A. It is an example in the figure 1, the red (ED) and blue (MD) dots are KM2A, and the green rectangles are WCDA. The red star is the shower core, and the brown circle is an imaginary air shower particle distribution on the ground. These two rings in the brown circle are selected area of particles, the inner ring is from 0 to 20 meters and the outer one is from 200 meters to 220 meters. In order to use the events which can trigger the WCDA, the shower cores cannot locate far from the boundary. We adopt the simulation of the CORSIKA and the LHAASO to test the variable.

2.2 Simulation

There are two steps in the simulation, the first one is CORSIKA, the second one is LHAASO-KM2A and LHAASO-WCDA simulation. The CORSIKA version number is 7.4000, and the

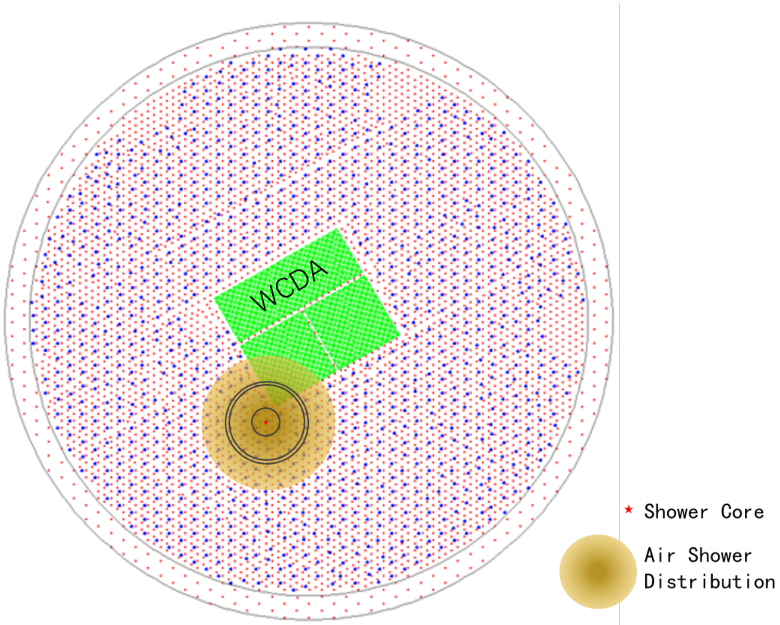

Figure 1: Two parts of LHAASO layout are shown above, the red (ED) and blue (MD) dots are KM2A, and the green rectangles are WCDA. The red star is the shower core, and the brown circle is an imaginary air shower particle distribution on the ground. These two rings in the brown circle are selected area of particles.

model is QGSJET-II-04 and FLUKA. The components gamma-ray and proton are simulated with the energy from 10 Tev to 1 PeV. The shower cores are located from -300 meters to 300 meters on both east to west and north to south and the center is at the left-down corner of the WCDA, and the zenith angle is from 20^o to 40^o.

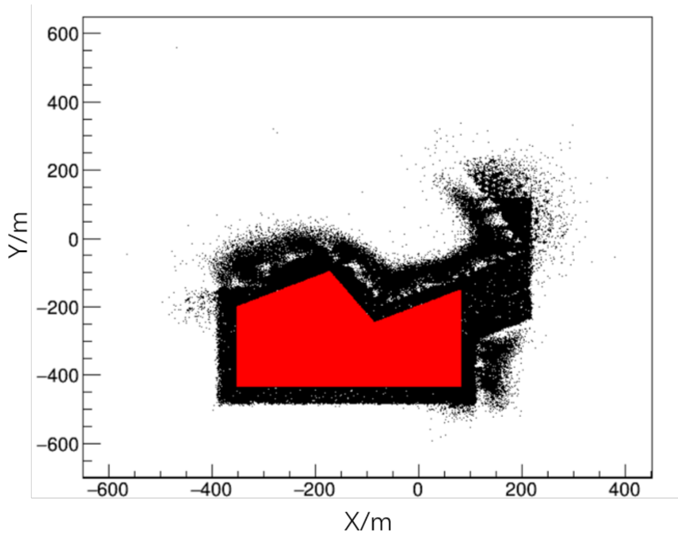

Figure 2: The shower cores distribution of simulation events are in the KM2A. The dark dots are the reconstruction core positions and the red dots are the selected events.

We adopt the G4KM2A to simulation KM2A, it was developed based on Geant4[4], the situation is the same for WCDA simulation[5]. In order to make full use of the CORSIKA events, each events are simulate 20 times at different position. The figure 2 shows the shower cores distribution of simulation events are in the KM2A. The dark dots are the reconstruction core positions and the red dots are the selected events. When more than 60 EDs are fired, the air shower is triggered.

3. Discussion and Result

3.1 Discrimination result

We extract the discrimination variable from the simulation data to study the ability of separating gamma-rays from protons. The figure 3 shows the result of the ratio between density of the ring from 200 meters to 220 meters in the WCDA and that from 0 meter to 20 meters in the KM2A. The red one is gamma-ray and the blue is proton. The density (ρ_{k0-20}) of inner ring is very sensitive to the shower core position and zenith angle, so it is necessary to adapt the density based on these parameters.

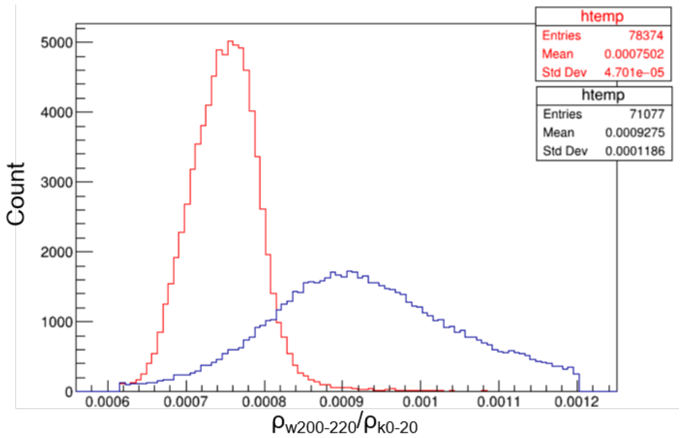

Figure 3: The discrimination variable is the ratio between density of the ring from 200 meters to 220 meters to in the WCDA and that from 0 meter to 20 meters in the KM2A. The red one is gamma-ray and the blue is proton.

To find the best cut position, we adopt the Q-factor to assess the variable[6]. The Q-factor is defined as shown $Q = \frac{\eta_\gamma}{\eta_{cr}}$, where η_γ and η_{cr} are the efficiencies of simulated gamma-rays and cosmic rays for a variable value less than a certain value. The result is shown in figure 4, and it indicates that the Q-factor increase rapidly with the density ratio, reach the maximum about 2.2 then decrease. Obviously, the new variable can discriminate the gamma-rays from protons.

As mentioned above, the N_μ/N_e is one powerful tool to separate the gamma-rays and protons. Therefore, we inspect correlation between the new variable and the N_μ/N_e. The figure 5 shows the result, the two dimensions distribution of the two variables, one is the ratio between the number of the muons detected by MD and the number of the electrons detected by ED, the other is the ratio between density of the ring from 200 meters to 220 meters in the WCDA and that from 0 meter to 20 meters in the KM2A. The upper and the right picture are the one dimension distribution of both variable respectively. It indicates that correlation is very weak. Even though the ability is not as good as N_μ/N_e, we can realize that the new variable can provide further discrimination.

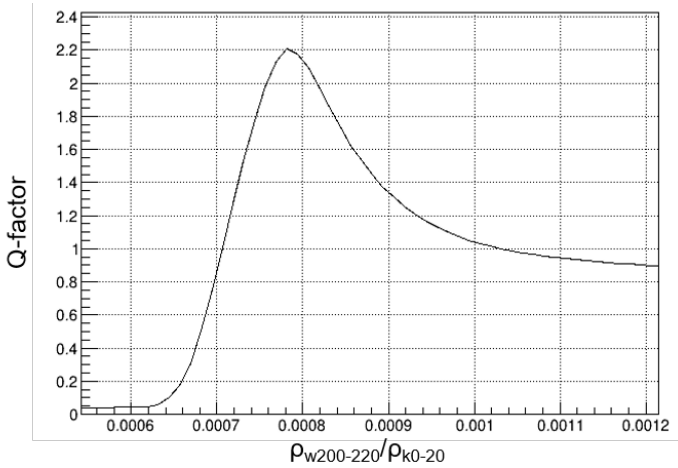

Figure 4: The Q-factor changes with the discrimination variable which is the ratio between density of the ring from 200 meters to 220 meters in the WCDA and that from 0 meter to 20 meters in the KM2A.

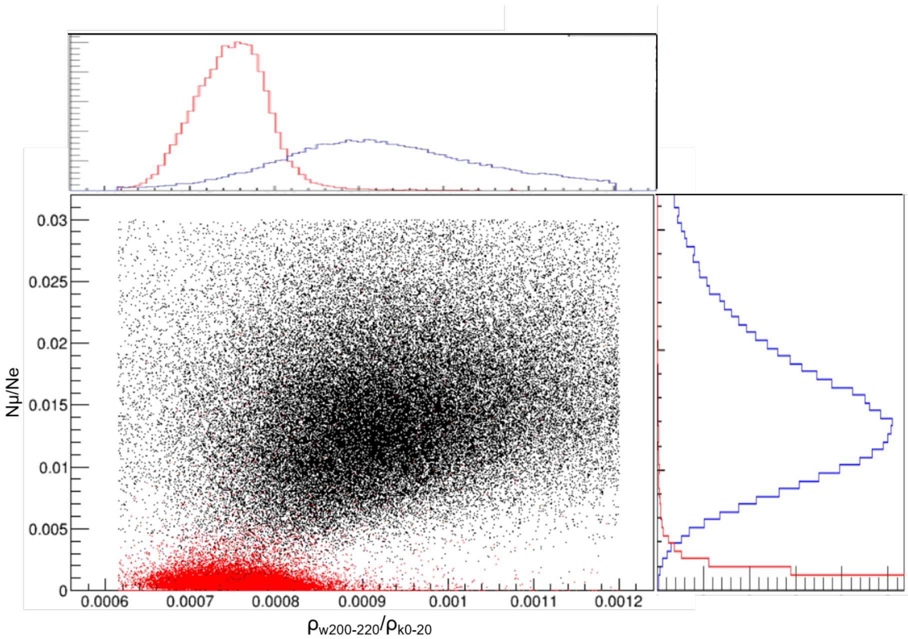

Figure 5: The two dimensions distribution of the two variables, one is the ratio between the number of the muons detected by MD and the number of the electrons detected by ED, the other is the ratio between density of the ring from 200 meters to 220 meters in the WCDA and that from 0 meter to 20 meters in the KM2A. The upper and the right picture are the one dimension distribution of both variable respectively. The red dots and lines are gamma rays, the black dots and blue lines are protons.

In order to verify the capacity of the new variable on the basis of the traditional N_μ/N_e, we carry on the further research, especially for the low energy range from 10 TeV to 100 TeV. We narrowed the shower cores scopes from the figure 2 to figure 6. The shower cores locate nearer the WCDA than before.

The same method is utilized for the simulation data, the distribution of the new variable is

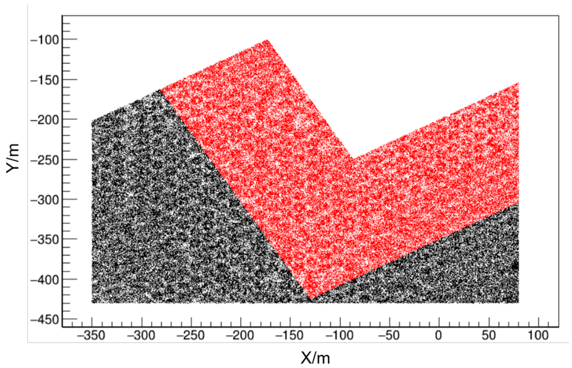

Figure 6: The selected shower cores of events (red dots) are applied for the low energy range from 10 TeV to 100 TeV.

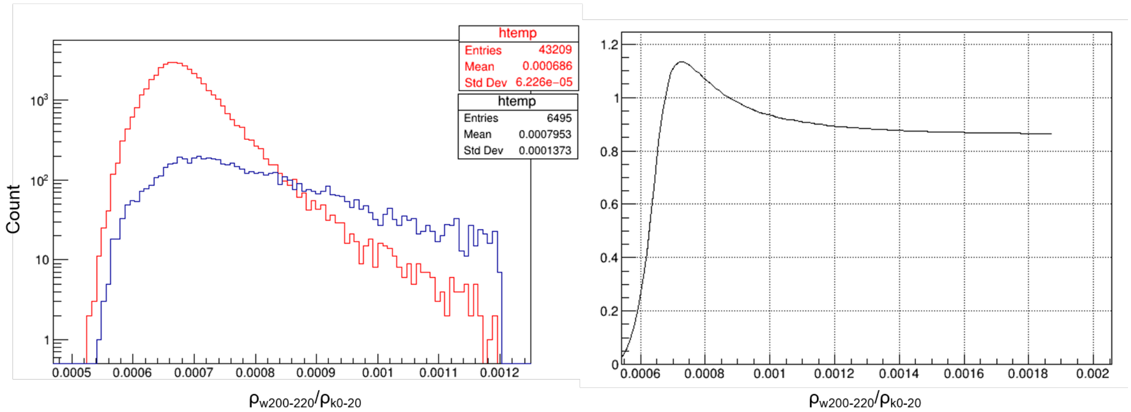

Figure 7: After considering the ratio between Nu and Ne, the discrimination variable is the ratio between density of the ring from 200 meters to 220 meters in the WCDA and that from 0 meter to 20 meters in the KM2A. The red one is gamma-ray and the blue is proton.

shown at the left in figure 7. It shows that after the N_μ/N_e get rid of the protons dramatically, the new variable can still play a role in discrimination. The Q-factors are also calculated for the new variables, the result is displayed at the right in figure 7. We can see that the maximum is larger than 1, it further illustrates that the new variable can improve the gamma-ray discrimination from cosmic ray detected by LHAASO.

4. Conclusion

We propose one characteristic variable to discriminate the gamma-ray from hardon based on the feature of LHAASO. The lateral distribution of extensive air shower is divided into different sizes of rings, then the particle density is calculated. We extract characteristic variables which is the ratio ($\rho_{w200-220}/\rho_{k0-20}$) between density of the ring from 200 meters to 220 meters in the WCDA and that from 0 meter to 20 meters in the KM2A. Firstly we show the discriminate ability of the new variable, the Q-factor can reach 2.2. Secondly, we compare it with the traditional N_μ/N_e, it indicates that even though considering the N_μ/N_e, the new variable reveal the capacity of discrimination that the Q-factor can reach larger than 1.

The new variable is adopted, we can not only make use of more data which is near the boundary, but also decrease the discrimination threshold less than 30 TeV hopefully. It is an attempt to take maximum advantage of the hybrid array of the LHAASO.

References

[1] Cao, Z., Aharonian, F. A., An, Q., Bai, L. X., Bai, Y. X., Bao, Y. W., ... Sun, Q. N. (2021). Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 -ray Galactic sources. Nature, 594(7861), 33-36.

[2] Neronov, A. , Semikoz, D. . (2020). Lhaaso telescope sensitivity to diffuse gamma-ray signals from the galaxy.

[3] Wang, L., Ma, L., Zhang, S., Feng, C., Cao, Z., Yin, L., ... Chen, S. (2023). Cosmic ray mass independent energy reconstruction method using Cherenkov light and muon content in LHAASO. Physical Review D, 107(4), 043036.

[4] Aharonian, F., An, Q., Bai, L. X., Bai, Y. X., Bao, Y. W., Bastieri, D., ... Wang, B. D. (2021). Observation of the Crab Nebula with LHAASO-KM2A a performance study. Chinese Physics C, 45(2), 025002.

[5] LHAASO collaboration. (2021). Performance of LHAASO-WCDA and observation of crab nebula as a standard candle. arXiv preprint arXiv:2101.03508.

[6] Aharonian, F., Alekseenko, V., An, Q., Bai, L. X., Bao, Y. W., Bastieri, D., ... Wu, S. (2020). Prospects for a multi-TeV gamma-ray sky survey with the LHAASO water Cherenkov detector array. Chinese Physics C, 44(6), 065001.