PROCEEDINGS OF SCIENCE

Expected performance of the prototype experiment for the ALPACA experiment

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ALPACA (Andes Large area PArticle detector for Cosmic-ray physics and Astronomy) experiment is a collaboration project between Bolivia and Japan. It is going to be located at the Mt.Chacaltaya plateau (16° 23′ S, 68° 08′ W) in Bolivia, at high altitude of 4,740 m (572.4 g/cm^2). As the prototype experiment of ALPACA, ALPAQUITA experiment is going to start in 2019. We evaluate the performance of ALPAQUITA with an MC simulation and give as results the detection efficiency of the ALPAQUITA AS array and the difference of muon distribution of gamma-ray induced air showers and cosmic-ray induced ones. The calculation of the sensitivity optimization for gamma-ray signals is now ongoing.

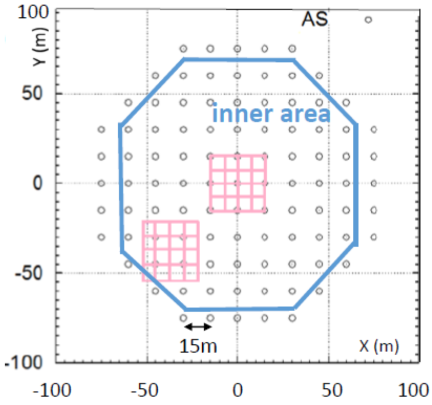
1. Introduction

ALPAQUITA has a surface air shower array (AS array) with 25% of the size of the ALPACA array, and consists of 97 plastic scintillators. The construction of the ALPAQUITA array is going to start in August 2019. An underground water Cherenkov muon detector pool (MD pool) will be constructed in 2020 after a 1 year operation of the ALPAQUITA AS array to improve the rejection power of background cosmic rays and the sensitivity to gamma-ray signals.

2. Array design

The design of the ALPAQUITA AS array is illustrated in Fig.1 (Left). The array consists of 97 plastic scintillators which are arranged in 15m intervals. Each scintillator has an area of 1 m^2 and 5 cm thickness, and a lead plate of 5 mm thickness is placed on it.

The MD pool consists of 16 MD cells, and the design of the MD cell is illustrated in Fig.1 (Right). Particles entering into the water in the pool emit Cherenkov light. We can evaluate the number of particles passing the pool by collecting the Cherenkov light with a PMT suspended at the ceiling of the pool. Since the MD pool will be placed 2.2 m beneath the surface, only the muons with energies above 1.2 GeV can penetrate the soil layer, and we get muon signals with almost no contamination from the electromagnetic component of air showers. It enables us to discriminate gamma-ray signals and background (BG) cosmic rays in an effective way.



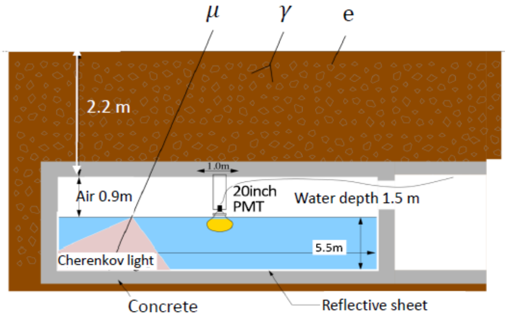


Figure 1 Left : ALPAQUITA AS array (black) and 2 possible locations of the MD pool (pink : each consists of 16 cells). The region surrounded by a blue line is called an inner area. Right : design of an MD cell.

3. Simulation condition

We executed an MC simulation for evaluating the performance of the ALPAQUITA AS array + MD pool, using CORSIKA 76400 code and GEANT4.10.04.p02 code.

3. 1. Gamma-ray source

We assumed RX J1713.7-3946, the bright gamma-ray source in the southern hemisphere, as the gamma-ray object in this simulation. We fitted the flux points of RX J1713.7-3946 observed by H.E.S.S. [1] with a broken-power law spectrum, and adapted for the simulation the spectral model bending at 6 TeV.

3. 2. Simulation code and simulated MD locations

In this simulation study, we used CORSIKA 76400 code [2] for air shower generation, and GEANT4.10.04.p02 [3] for detector responses. In CORSIKA code, we generated signal gamma-rays and BG cosmic rays from the trajectory of RX J1713.7-3946. Modifications of the gamma-ray spectrum to the model described above and the BG angular distribution isotropic around the source were executed in the analysis stage.

In GEANT4 code, we simulated two location of the MD pool. In case 1, AS array and only the lower-left MD pool were used (see Fig.1. (Left)). In case 2, AS array and only the center MD pool were used. For each case, we determined the event-cut criterion depending on the number of muons contained in air showers, and evaluate the rejection power of BG cosmic rays and the detection significance of the gamma-ray events from RX J1713.7-3946 in three energy ranges ≥ 10TeV, ≥ 50TeV, and ≥ 100TeV.

3. 3. Trigger condition and selection cut

In this simulation, we defined the energy deposit of one particle on a plastic scintillator as 9.4 MeV. Using this definition of one particle, we adopt as a hardware trigger condition that at least 4 plastic scintillators detect more than 0.5 particles within 600 nsec. In addition, we further selected the events passing through the trigger condition by applying following 5 selection criteria for each event:

1. At least 4 plastic scintillators detect more than 0.8 particles.
2. 5 out of 6 hottest detectors (detecting the largest number of particles) are located in the inner area region, which is surrounded by the blue line in Fig.1 (Right).
3. Residual error that indicates the precision of determination of incoming direction of the event is smaller than 1.0.
4. Zenith angle of the incoming direction of the event is smaller than 40° except the study in Sec.4.1.
5. The angular distance between the source and the incoming direction of the event is smaller than $6.9°/\sqrt{\Sigma\rho}$, where $\Sigma\rho$ is the total number of particles detected by the AS array in each air-shower event.

4. Results

4. 1. Effective area

Fig.2 presents the effective area of the ALPAQUITA AS array for gamma rays. The filled squares are for the events with zenith angle $\theta < 45°$, and the open circles are for those with $45° \leq \theta < 60°$. Horizontal line drawn at 12,600 m^2 corresponds to the area of the inner region. Full effective area is achieved above 20 TeV and 200 TeV for $\theta < 45°$ and $45° \leq \theta < 60°$, respectively. We can see that in the case of $\theta < 45°$, the effective area becomes larger than the inner area of the ALPAQUITA AS array in the energy range of > 20 TeV. This means that some fraction of events having their shower cores outside the inner area pass through the selection criteria described in 3.3. Improvement of event selection criteria is under way.

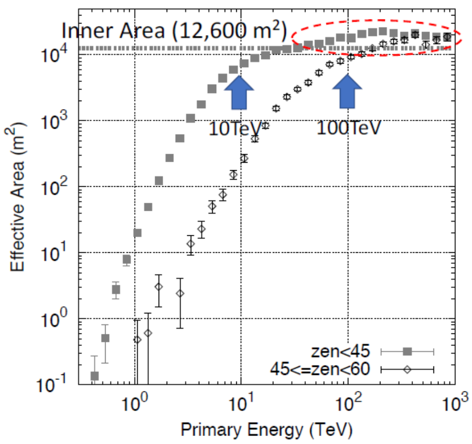


Figure 2 Effective area of the ALPAQUITA AS array for gamma-ray signals. The curve of filled squares is for the events of θ<45°, and the curve of empty circles is for that of 45°≤θ<60°.

4. 2. Muons abundance of gamma-ray showers and cosmic-ray showers

In Fig.3 we show the simulation results for the muon abundance of gamma-ray induced showers and cosmic-ray induced ones. Two panels show the results in $20 \le \Sigma\rho < 50$ and $200 \le \Sigma\rho < 500$, corresponding to the gamma-ray energies of about 10 TeV and 100 TeV, respectively. The red and green points are muon densities for gamma-ray and cosmic-ray induced showers, respectively. As we can see, in the both $\Sigma\rho$ regions, cosmic-ray induced showers contain about 50 times more muons than gamma-ray induced showers within 100m from the cores. By locating the MD within approximately 100 m from any place in the array and counting the number of muons contained in air showers, we can discriminate gamma-ray signals from BG cosmic rays in an effective way.

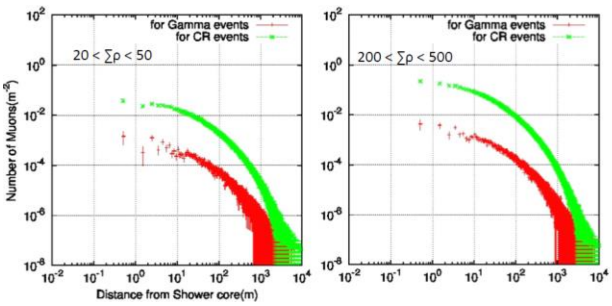


Figure 3 Number of muons per unit area contained in air showers is shown for two $\Sigma\rho$ bins. Horisontal axis indicates the distance from the core of an air shower. $20 \le \Sigma\rho < 50$ and $200 \le \Sigma\rho < 500$ correspond to the gamma-ray energies of ~10 TeV, and ~100TeV, respectively. The red and green graphs are for gamma-ray induced air showers and cosmic-ray induced ones, respectively.

4. 3. Sensitivity for gamma-rays from RX J1713.7-3946

Fig.4 shows the number of events to be observed in 1 year as a function of the total number of muons in each air shower. The black and red histograms are for gamma-ray events from RX J1713.7-3946 and BG cosmic-ray events, respectively. This is the case of $158 \le \Sigma\rho < 251$ in the case 2 (using AS array and only the center MD pool), which corresponds to the energy range of 50 TeV. In 100 TeV, ALPAQUITA can observe a few gamma-ray events from RX J1713.7-3946. Note that this is a very preliminary result. Because we are going to optimize the analysis method for event-reconstruction such as energy, arrival direction and core location, we can expect the performance of ALPAQUITA to be improved. The optimization of the MD pool location also improves the performance. Analysis of other energy bins and the other sources, having harder energy spectrum than RX J1713.7-3946, are also in progress.

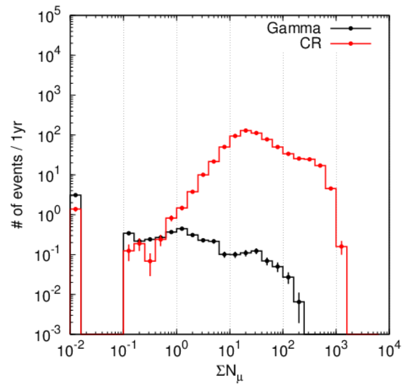


Figure 4 Histogram of the events observed in 1year. The black and red histograms are for gamma-ray signals from RX J1713.7-3946 and BG cosmic-ray events, respectively. This is the case of $158 \le \Sigma\rho < 251$ in the case 1, corresponding to the energy range of 50 TeV.

Summary

The construction of the ALPAQUITA AS array is going to start in 2019 summer. To improve the sensitivity to the gamma-ray signals from astronomical sources, we are going to construct an MD pool in 2020 and distinguish between gamma-rays and BG cosmic rays. In this paper, we presented a sensitivity to detect 50-100 TeV gamma-rays from RX J1713.7-3946. We also note that there is still a room to improve the analysis method for event reconstruction and to optimize the design of the array. Further studies are in progress.

Reference

[1] H.E.S.S. Collaboration, A & A 612, A6 (2018).

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