Expected performance of the prototype experiment for the ALPACA experiment

C. Calle,[a] **K. Hibino,**[b] **N. Hotta,**[c] **Y. Katayose,**[d] **C. Kato,**[e] **S. Kato**∗**,**[f] **K. Kawata,**[f] **W. Kihara,**[e] **Y. Ko,**[e] **H. Kojima,**[g] **R. Mayta,**[h] **P. Miranda,**[a] **H. Mitsui,**[i] **K. Munakata,**[e] **H. Nakada,**[i] **Y. Nakamura,**[j] **M. Nishizawa,**[k] **S. Ogio,**[h] **M. Ohnishi,**[f] **T. Ohura,**[i] **A. Oshima,**[l] **M. Raljevich,**[a] **H. Rivera,**[a] **T. Saito,**[m] **T. Sako,**[f] **T. K. Sako,**[f] **Y. Sengoku,**[i] **S. Shibata,**[l] **A. Shiomi,**[n] **M. Subieta,**[a] **N. Tajima,**[o] **W. Takano,**[b] **M. Takita,**[f] **Y. Tameda,**[p] **K. Tanaka,**[q] **H. Tsuchiya,**[r] **Y. Tsunesada,**[h] **S. Udo,**[b] **K. Yagisawa,**[i] **Y. Yokoe,**[f]

[a] *Instituto de Investigaciones Físicas, Universidad Mayor de San Andres, La Paz* 8635, *Bolivia*

[b] *Faculty of Engineering, Kanagawa University, Yokohama, Kanagawa* 221 − 8686, *Japan*

[c] *Utsunomiya University, Utsunomiya, Tochigi* 321 − 8505, *Japan*

[d] *Faculty of Engineering, Yokohama National University, Yokohama, Kanagawa* 221 − 8686, *Japan*

[e] *Department of Physics, Shinshu University, Matsumoto, Nagano* 390 − 8621, *Japan*

[f] *Institute for Cosmic Ray Research, the University of Tokyo, Kashiwa, Chiba* 277 − 8582, *Japan*

[g] *Faculty of Engineering, Aichi Institute of Technology, Toyota, Aichi* 470 − 0392, *Japan*

[h] *Graduate School of Science, Osaka City University, Osaka, Osaka* 558 − 8585, *Japan*

[i] *Graduate School of Engineering Science, Yokohama National University, Yokohama, Kanagawa* 240 − 8501, *Japan*

[j] *Institute of High Energy Physics, Chinese Academy of Science, Shijingshan, Beijing* 100049, *China*

[k] *National Institute of Informatics, Chiyoda, Tokyo* 101 − 8430, *Japan*

[l] *College of Engineering, Chubu University, Kasugai, Aichi* 487 − 8501, *Japan*

[m] *Tokyo Metropolitan College of Industrial Technology, Arakawa, Tokyo* 116 − 8523, *Japan*

[n] *College of Industrial Technology, Nihon University, Narashino, Chiba* 275 − 8576, *Japan*

[o] *Riken, Wako, Saitama* 351 − 0198, *Japan*

[p] *Faculty of Engineering, Osaka Electro − Communication University, Neyagawa, Osaka* 572 − 8530, *Japan*

[q] *Graduate School of Information Sciences, Hiroshima City University, Hiroshima, Hiroshima* 731 − 3194, *Japan*

[r] *Japan Atomic Energy Agency, Tokai − mura, Ibaraki* 319 − 1195, *Japan*

E-mail: katosei@icrr.u-tokyo.ac.jp

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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 this year. 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 this year. In addition, we have decided to construct an underground water Cherenkov muon detector pool (MD pool) after the 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 put 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.

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.

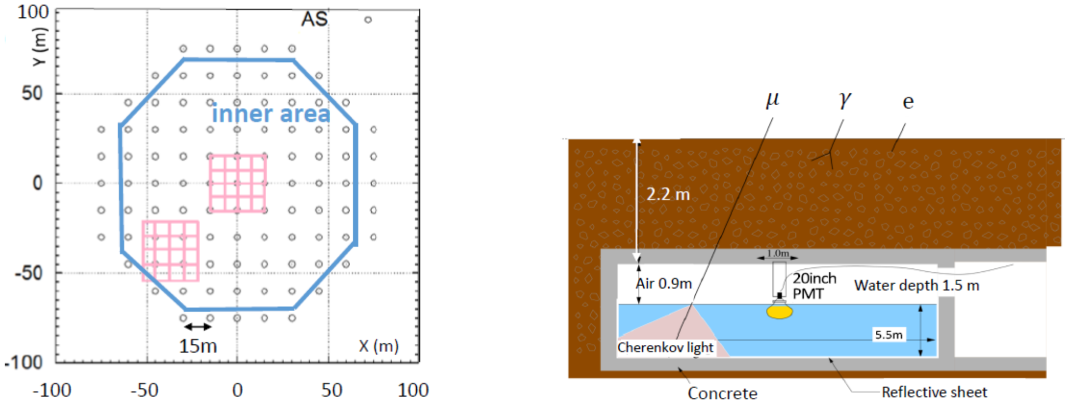

Figure 1 Left : ALPAQUITA AS array (black) and 2 MD pools (pink : each consists of 16 cells). The region surrounded by a blue line is called an inner area. Right : design of MD cell.

3. Simulation condition

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

3. 2. Simulation code and simulated cases

In this simulation study, we use CORSIKA 76400 code [2] for air shower generation, and GEANT4.10.04.p02 [3] for detector responses. In CORSIKA code, we generate signal gamma-ray events and BG cosmic rays from the trajectory of RX J1713.7-3946. Modification for the gamma-ray spectrum to the real one and the isotropic distribution of BG cosmic rays are executed in the simulation analysis.

In GEANT4 code, we simulate three cases. In case 1, AS array and only the lower-left MD pool are used (see Fig.1. (Left)). In case 2, AS array and only the center MD pool are used. In case 3, AS array and both MD pools are used. For each case, we determine 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 $\geq$ 10TeV, $\geq$ 50TeV, and $\geq$ 100TeV.

3. 3. Trigger condition and selection cut

In this simulation, we assume the energy deposit of one particle on a plastic scintillator as 9.4 MeV. Using this definition of one particle, we adopt as a trigger condition that at least 4 plastic scintillators detect more than 0.5 particles. In addition, we further select 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 (detect 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°.
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 we present 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 the events 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 though the selection criteria described in 3.3. Improvement of event selection criteria is under way.

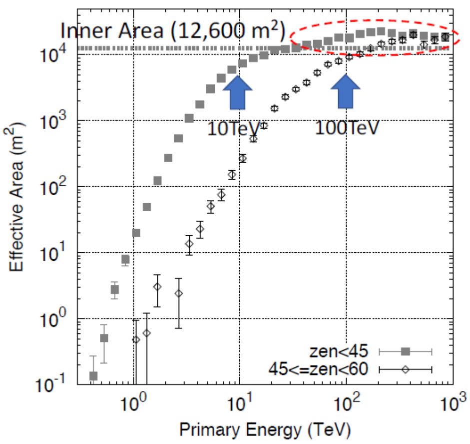

Figure 2 Effective area of the ALPAQUITA AS array for gamma-ray signals. The curve of filled squares is for the events of θ<45°, and the curve of empty circles is for that of 45°≤θ<60°.

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 one. Two panels show the results in$20 \leq \Sigma\rho < 50$ and $200 \leq \Sigma\rho < 500$, corresponding to the gamma-ray energies of about 10 TeV and 100 TeV, respectively. The red and green graphs are for gamma-ray induced showers, cosmic-ray induced ones, 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 ones in a circle of 100m radius centered on their cores. Therefore 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 a very effective way.

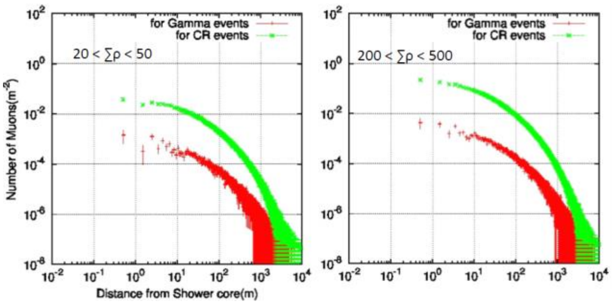

Figure 3 Number of muons per unit area contained in air showers is shown for two $\Sigma\rho$ bins. Horisontal axis indicates the distance from the core of an air shower. $20 \leq \Sigma\rho < 50$ and $200 \leq \Sigma\rho < 500$ correspond to the gamma-ray energies of ~10 TeV, and ~100TeV, respectively. 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 histogram of the events observed in 1 year which takes as its horizontal axis the total number of muons counted in each air shower. 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 $158 \leq \Sigma\rho < 251$ 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 few gamma-ray events from RX J1713.7-3946. Note that this is a very preliminary result, because we are going to brush up the analysis method for event-reconstruction such as energy resolution and angular resolution, and the design of the ALPAQUITA AS array and MD pool, so we can expect the performance of ALPAQUITA to become highly improved. Also, the analysis to other energy bins is now ongoing, and the sensitivity to the integral gamma-ray flux is expected to be better than that to the differential flux.

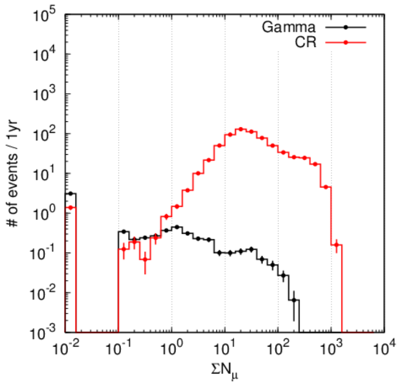

Figure 4 Histogram of the events observed in 1year. The black and red histograms are for gamma-ray signals from RX J1713.7-3946 and BG cosmic-ray events, respectively. This is the case of $158 \leq \Sigma\rho < 251$in the case 1, corresponding to the energy range of 50 TeV.

Summary

The construction of the ALPAQUITA AS array is going to start in this summer. To improve the sensitivity to the gamma-ray signals from astronomical sources, we need to construct use the MD and distinguish between them and BG cosmic ray. Furthermore, we also need to brush up the analysis method for event reconstruction and optimize the design of the array.

Reference

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[3] S. Agostinelli et al., Nucl. Instrum. Methods Phys. Res. A 506, 250 (2003).