Iranian Journal of Astronomy and Astrophysics
Vol. 7, No. 1, Spring 2020
©Available online at http://journals.du.ac.ir
DOI:10.22128/ijaa.2020.402.1082

Iranian Journal of Astronomy and Astrophysics

Simulation of Performance of SURA Particle Detectors as an External Trigger

Alibakhsh, Maryam[1] · Rastegarzadeh, Gohar[2]

[1] Faculty of physics, Semnan University, Semnan,P.O.Box 35131-364 Iran; email:m-alibakhshi@semnan.ac.ir

[2] Faculty of physics, Semnan University, Semnan, P.O.Box 35131-364 Iran; email: grastegar@semnan.ac.ir

Abstract. Semnan University Radio Array (SURA) with 4 LPDA antennas is recording the cosmic ray event on the roof of the University. As an external trigger, we are going to add three scintillator detectors to this array. In this work, by using CORSIKA code, simulation has been carried out for primary proton in the 100TeV-100PeV range of energies for different zenith angle. For this set of simulated showers, reconstructed zenith angle and its uncertainty are obtained and the effect of distance between the detectors on the zenith angle reconstruction investigated. Because the structure of the shower (thickness and curvature of the disk) affects the determination of the arrival direction, the angular resolution vs core distance is also studied. We have shown that by increasing zenith angle and distance from the shower core, uncertainty increases.

Keywords: Cosmic ray, particle detector, SURA, external trigger

1 Introduction

At energies above $10^{14}eV$, the flux of cosmic rays is about a few particles per square meter per year; For this reason, they cannot be directly detected. High-energy cosmic rays can be studied with the help of indirect detection, i.e., detection of secondary particle cascades from primary cosmic ray interactions with the atmosphere. The extensive air showers (EAS) array covers up from several km^2 to several thousands of km^2 and detects cosmic rays in a wide range of energies.

Using ground-based detectors, three observables of EASs can be studied, the nature of a shower (hadronic or electromagnetic), mass [1, 2], and the arrival direction of EAS. There are several types of ground-based detectors, including scintillation detectors [3], Cherenkov [4] and radio detectors [5]. Some observatories, such as Auger [6], use a combination of several types of detectors to achieve better results. Despite significant advances in state-of-the-art detectors (ground-based and satellite), fundamental questions about the origin of cosmic rays and their acceleration mechanism remain.

At the present, we have deployed Semnan University Radio Array (SURA) [7]consist of 5 radio antennas placed at the Semnan university campus ($35°34'22''$ N $53°23'50''$ E, 1130 m a.s.l= 904 gcm^{-2}) is designed to study the ultra-high-energy cosmic rays and the possible sources with radio signal properties. In the first stage, we tried to install 5 antennas and receive possible cosmic rays candid with the help of radio signals. 5 radio antennas include 4 logs periodic dipole and one Inverted-V dipole antennas working in a self-trigger array.

In the second stage, three particle detectors will be added to the array to work as an external trigger which will increase the accuracy of detection of cosmic rays. In this work, we will describe its scintillation detector and consider the reconstruction techniques and accuracies. Fig1. Possible layout for the second phase of the SURA experiment. In the future, 15 radio detectors will be added to the set to detect cosmic rays with higher accuracy and expand the range of energy.

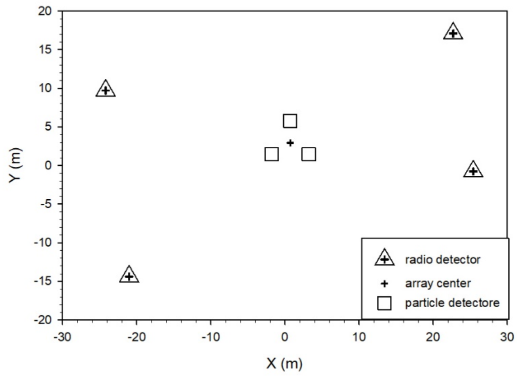

Figure 1: The SURA array. triangles show the current locations of the LPDA antennas and squares show particle detector for this study.

2 Simulation Specifications

EAS experiment cannot be exposed to a test beam for calibration, so Monte Carlo simulation of particle interactions and transport in the atmosphere have been used to compare the experimental data with the prediction of the shower development in the atmosphere. Since scintillation detectors are only able to measure the time lag between detectors, the CORSIKA simulation code is used to reconstruct the arrival direction and angular resolution. For this simulation, CORSIKA version 7.74 [8] was used and QGSJETll [9] and GHEISHA [10]models were selected respectively for hadronic interactions with energy above and under $E_{lab} = 80GeV$.
A sample of 2400 shower for primary proton in the $100TeV - 100PeV$ range of energies for $0°, 15°, 30°$ and $45°$ zenith angle and azimuth angle from to was generated. For 10^{15},5×10^{15}-$10^{16}eV$ energies 100 showers were used and for 5×10^{16} -$10^{17}eV$ energies 50 showers were used in all mentioned zenith angels. We simulated these EAS events based on the characteristics of our site, SURA observatory, with an observation altitude 1130m above sea level and the values of geomagnetic field components,$B_x = 39.53\mu T, B_z = 28.1\mu T$, which Were obtained from U.S. Geomagnetic Data Center [11]. The arrangement of the scintillations is simulated in a equilateral triangular shape with sides of 5 and 10 meters.
In the following, we will discuss these sets of simulated shower reconstructed zenith angle and their uncertainty are obtained and the effect of distance between the scintillations on the zenith angle reconstruction, core position, and the angular resolution.

3 Results

3.1 Reconstruction of the arrival direction

Due to the interaction of cosmic rays with magnetic fields [12] to their arrival directions is completely distorted. In general, the direction of the shower axis (arrival direction of primary particle towards Earth's atmosphere) can be determined by the arrival time of secondary particles in an EAS. The difference in the velocity of the particles as well as their path lengths causes the thickness of the shower disk and as a result different arrival times of the particles in the atmosphere. The EAS thickness can be determined from changes in the arrival time of particles at a particular point of the EAS lateral extension and also, from the time difference between the shower core to the curvature of the EAS front, its arrival direction can be obtained. The surface array of Pierre Auger Observatory has used the above method to reconstruct and study the characteristics of the highest-energetic cosmic rays. They examined the arrival direction reconstruction for event with a zenith angle $\theta < 60°$, and after the fit with the distribution has been fitted with a weighted sum of two Rayleigh distributions, they found that in 68% of the events, arrival directions which agree to within $0.40°$[6].

Reconstruction of the arrival direction cosmic rays by fitting the arrival time and coordi-

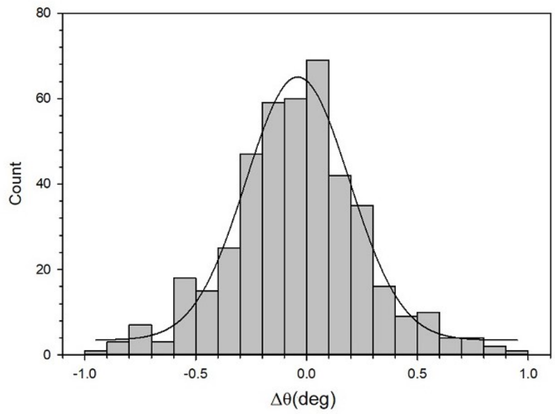

Figure 2: Histogram fluctuation of zenith angle in energy $10^{17}eV$ and $45°$ radiation angle and for 50 showers and Gaussian function fit.

nates of the detectors with a flat plate is obtained. Figure 2 is shown the error histogram in determining the zenith angle at energy $10^{17}eV$ and the radiation angle of $45°$ and a equilateral triangular arrangement with sides of 10 m. After fitting with the Gaussian function, the width of the curve was obtained and then by repeating this work for different angles of radiation and different energies, an error in calculating the arrival direction in each case was obtained.

Figure 3 shows the error of the zenith angle in terms of radiation beams for $0°, 15°, 30°$ and $45°$, and energies of 5×10^{15}, 10^{16},5×10^{16} and $10^{17}eV$in two equilateral triangular arrangements of 5 and 10 meters. As it can be seen, the error increases with the increasing angle for both arrangements, and at high energies, the fluctuations decrease significantly.

Both technical and physical fluctuations are effective in determining the arrival directions. Figure 4 shows the error diagram vs energy at the angles $0°, 15°, 30°$ and $45°$ for both

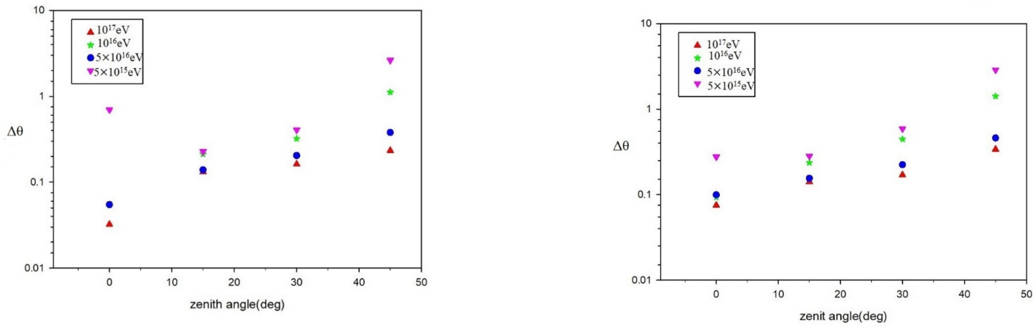

Figure 3: Error in the determinations of EAS arrival direction vs zenith angle (right and left for equilateral triangular arrangement with sides of 5 and 10 meters, respectively).

arrangements, with increasing energy and radiation angle, a better order is shown and fluctuations are reduced.

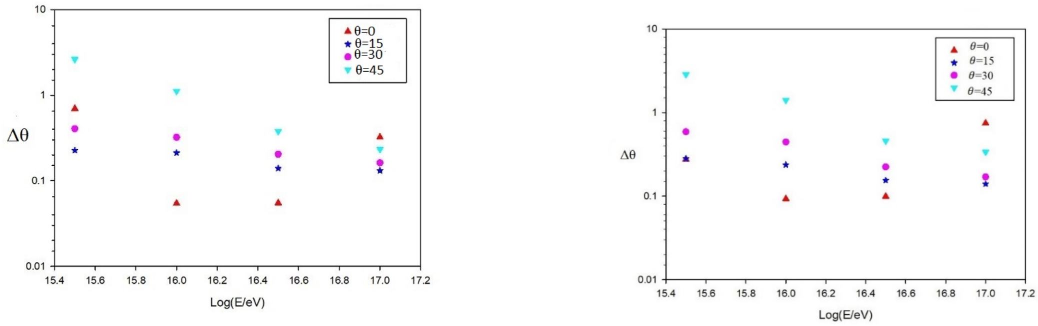

Figure 4: Error in the determinations of EAS arrival direction vs energy (right and left for triangular arrangement with sides of 5 and 10 meters, respectively).

3.2 Core position

Valuable information about the spectrum of cosmic rays can be extracted from the hadron component (the lightest component, i.e., the protons) of EAS. In addition, understanding the EAS hadronic cores helps us to study the models of hadronic interaction. It should be noted that this observation is based on the deposit energy of the incoming beam. The deposit energy is determined based on characteristics such as total cross-section and inelasticity in high-energy hadronic interactions.

The position core obtained from the intersection of the shower axis with the shower particle disk, is obtained fitting the lateral density distribution of the secondary particles to a modified Nishimura-Kamata-Greisen (NKG) function [13]. Therefore, it can be concluded that the position core is more at the edge or outside the array.

Using algebraic methods, the places with the highest particle density are known as core location. Figure 5 (left) shows the core coordinates. An error bar ($0 < \sigma < 1$) is considered zero error bar, which means that it is the real core and in the other cases the core position is simulated. In most EAS experiments, the value of the lateral particle distribution function, i.e., particle density, has been calculated as a function of distance R from the shower axis to determine the shower core. (Fig 5 right) The particle density as a function of the distance from the shower axis for the SURA event is shown on the left.

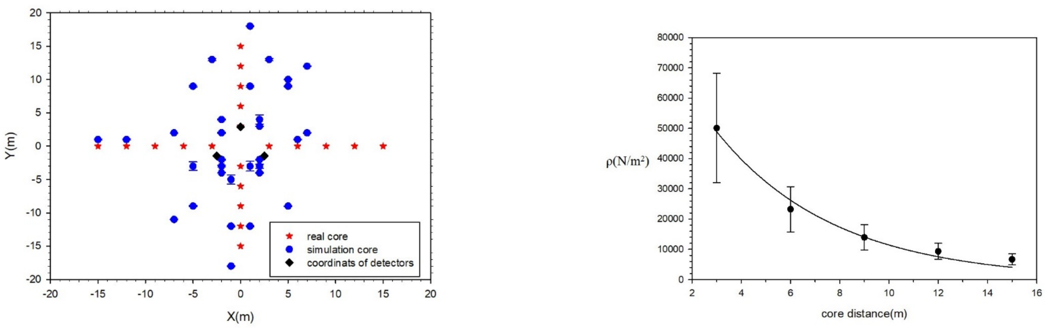

Figure 5: Left A simulated core position. The geometry is similar to that of the SURA array. Right The particle density as a function of the distance from the shower axis for the event shown on the left.

3.3 The angular resolution

To check the angular resolution, its internal compatibility with the data must first be checked. Shower structure (curvature and thickness disk) affects the measurement of the arrival direction EAS. The delay of the shower particles, and also the tangent surface on the front of shower, cause an error in determining the arrival direction, which depends on the distance from the core arrays. The structure of EAS is such that the effect of particle sampling on the curvature of the disk and the distance from the core is sensational. Figs.7 shows the behaviors of such the angular resolution as a function of the core distance, giving, energy $10^{17} eV$ for our geometry. As can be seen, at distances close to the core, the angular resolution shows better accuracy and decreases with the distance from the core.

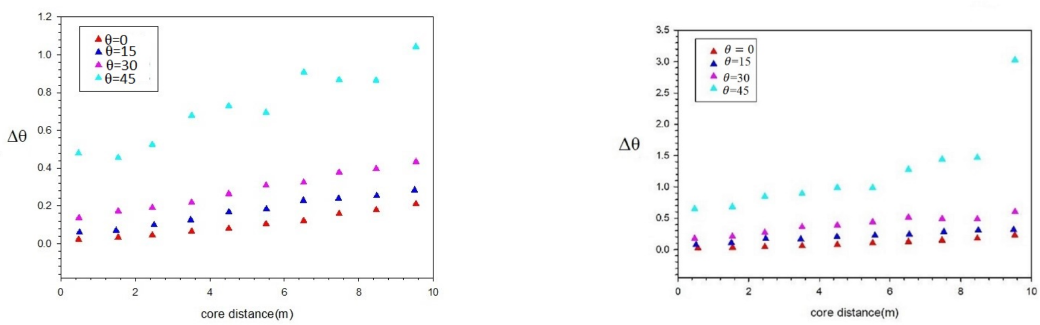

Figure 6: Errors in angular resolution vs core distances (right and left for equilateral triangular arrangement with sides of 5 and 10 meters, respectively).

4 Discussion

In the SURA radio array, three scintillation detectors will be added as external trigger to detect more accurately cosmic rays. In this work, by using CORSIKA code, simulation has

been carried out for primary proton in the $100TeV - 100PeV$s range of energies for different zenith angle. The arrangement of the scintillations is simulated in a equilateral triangular shape with sides of 5 and 10 meters.
In this work, for this set of simulated showers, the effect of distance between the scintillations on reconstruction of the arrival direction, core position, the angular resolution and its uncertainty are obtained. The above characteristics in a equilateral triangular arrangement with sides of 5 and 10 meters do not show a significant difference.

References

[1] Rastegarzadeh, G., & Nemati, M. 2018, Adv. Space Res., 61, 1181.

[2] Rastegarzadeh, G., & Nemati, M. 2016, Adv. Space Res., 361, 104.

[3] Bahmanabadi, M., Rastegarzadeh, G., & Mortazavi Moghaddam, S. 2020, Nucl. Instrum. Methods Phys. Res., 962, 163703.

[4] Sbrizzi, A. 2011. Nucl. Phys. B, 215, 232.

[5] Torres Machado, D., & CODALEMA collaboration. 2013, J. Phys. Conf. Ser., 409, 012074.

[6] Aab, A., & et al. 2020, J. Instrum., 15, 10021.

[7] Rastegarzadeh, G., & Sabouhi, M. 2020, Exp. Astron, 49, 21.

[8] Heck, D., & et al. 1998, Report FZKA 6019, Karlsruhe, Forschungszentrum, https://www.ikp.edu/corsika/70.php

[9] Kalmykov, N. N., & Ostapchenko, S. S. 1993, Yad. Fiz, 56, 105.

[10] Scholten, O., Werner, K., & Rusydi, F. 2008, APh, 29, 94.

[11] http://www.ngdc.noaa.gov/seg/potfld/geomag.html.

[12] Rastegarzadeh, G., Parvizi, B., & Sabouhi, M. 2015. Eur. Phys. J. Plus, 130, 1.

[13] Gerision, K., & Ann, J. 1960, Revs. Nucl. Sic., 10, 63.