Süleyman Demirel Üniversitesi Fen Edebiyat Fakültesi Fen Dergisi
Süleyman Demirel University Faculty of Arts and Sciences Journal of Science
2018, 13(2): 1-8
DOI: 10.29233/sdufeffd.419878

Angular Dependence Study of the Cosmic Ray Flux at 900 Meters above Sea Level

Ali YILMAZ*[1], Kaan Yüksel OYULMAZ[2], Haluk DENİZLİ[2]

[1]*Giresun University, Engineering Faculty, Department of Electrical and Electronics Engineering, 28200, Giresun, Türkiye*
[2]*Abant Izzet Baysal University, Faculty of Arts and Sciences, Department of Physics, 14280, Bolu, Türkiye*
**corresponding author e-mail: aliyilmaz@giresun.edu.tr*

(Received: 30.04.2018, Accepted: 02.07.2018, Published: 30.11.2018)

Abstract: In this study, the zenith angle distribution of the ground level cosmic ray flux has been measured at 900 meters above the sea level by using the developed prototype detector. The measurements have been done in Experimental Particle Physics Laboratory, Department of Physics, Abant Izzet Baysal University (AIBU) Bolu. The method used to carry out the experiment is by using simultaneous particle hits on two scintillator boxes that are arranged in tower mode then counts will accumulate in the scintillator counter boxes. This detector prototype provides a simpler, cheaper and suitable alternative to the common cosmic ray detectors for the detection of particles at ground level. The orientation of module is in the south-east direction. The fluxes and rates were measured for different zenith angles between 0^o and 90^o. The attenuation effect of the architectural components on the measured cosmic ray flux was carried out by using GEANT4 simulation program and this effect was taken into account in the given results.

Key words: Cosmic ray flux, Angular dependence, Geant4

Deniz Seviyesinin 900 Metre Üstünde Kozmik Işın Akısının Açısal Bağımlılık Çalışması

Özet: Bu çalışmada, zemin seviyesindeki kozmik ışın akısının zenit açısı dağılımı, geliştirilen prototip detektörü kullanılarak deniz seviyesinden 900 metre yukarıda ölçülmüştür. Ölçümler, Bolu Abant İzzet Baysal Üniversitesi Fizik Bölümü Deneysel Parçacık Fiziği Laboratuvarında yapılmıştır. Ölçümleri gerçekleştirmek için kullanılan yöntem, kule modunda düzenlenmiş iki sintilatör kutusu üzerindeki eş zamanlı parçacık izlerini kullanmaktır, daha sonra sayımlar sintilatör sayaç kutularında birleştirilmektedir. Bu detektör prototipi, parçacıkların yer seviyesinde tespit edilebilmesinde bilinen kozmik ışın detektörlerine göre daha basit, daha ucuz ve uygun bir alternatif sunmaktadır. Parçacık akı ve oranları, 0^o ve 90^o arasındaki farklı zenit açıları için ölçülmüştür. Sistem geometrisinin ölçülen kozmik ışın akısı üzerindeki zayıflama etkisi, GEANT4 simülasyon programı kullanılarak gerçekleştirilmiş ve bu etki verilen sonuçlarda dikkate alınmıştır.

Anahtar kelimeler: Kozmik ışın Akısı, Açısal bağımlılık, Geant4

For citation: A. Yılmaz, K. Y. Oyulmaz and H. Denizli, "Angular Dependence Study of the Cosmic Ray Flux at 900 Meters above Sea Level", *Süleyman Demirel Üniversitesi Fen Edebiyat Fakültesi Fen Dergisi*, 13(2), 1-8, 2018.

1. Introduction

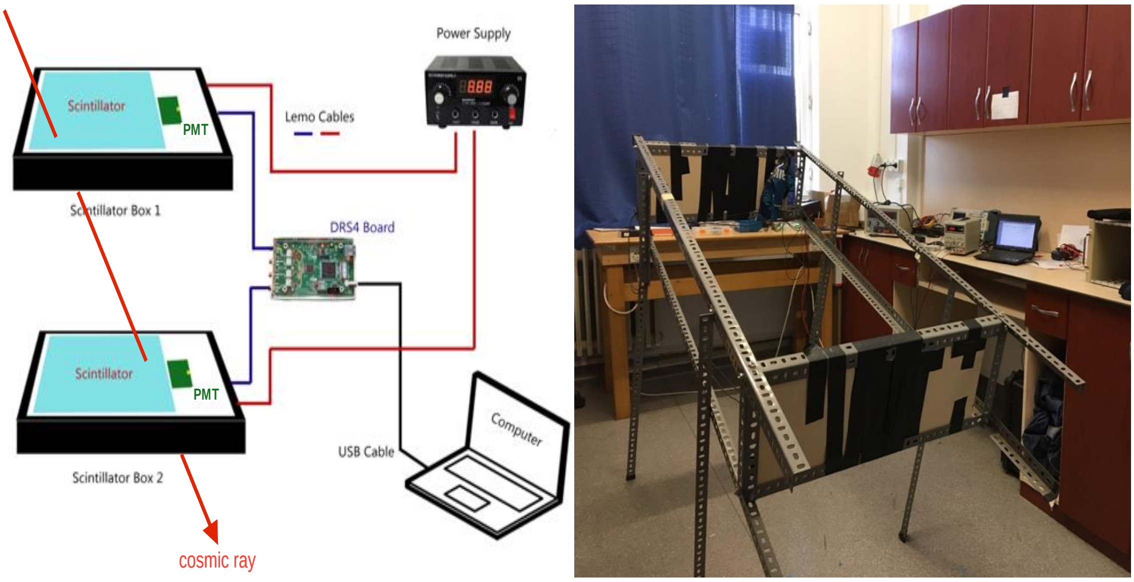
The study of cosmic rays has been a major and attractive subject in the field of high energy physics [1]. Cosmic rays are originated in the upper atmosphere by the energetic protons and other particles from outer space and produce a shower. The shower mainly consists of hadronic (pions, muons, etc.) and electromagnetic (electrons, positrons, photons, etc.) components with different energies and moving in different directions. It is a very important to detect these showering particles at Earth's surface. A lot of the experiments are performed at Earth surface or top-edge of the atmosphere, airplanes and balloons. These measurements show that the most numerous charged particles are muons at the Earth surface [2]. The majority of the muons are created in the upper atmosphere (≈ 15 km) and loose about 2 GeV of energy for ionization before arriving to the surface of the Earth. Their angular and energy distribution indicate a convolution of yielding spectrum, energy loss in the atmosphere, and decay. For instance, 2.4 GeV muons have a decay length of 15 km, which is lowered to 8.7 km by energy loss. The average energy of muons at the surface is ≈ 4 GeV [3]. The behaviour of the atmospheric muons energy scale is one power steeper than the initial spectrum. The integral intensity of vertical muons above 1 GeV/c at sea level is ≈ 70 $m^{-2}s^{-1}sr^{-1}$ [4, 5]. The muon density from the ground plane at lower energies is inherently decreased in consequence of muon decays and absorption effects in the denser atmosphere at bigger zenith angles. Higher energetic primary particles of muons pass comparatively longer space part of the atmosphere. As a result, their interaction probability is decreased compared to the decay probability.

The detector setup used in this study and the track reconstruction method are given in section 2. The simulation setup and measured cosmic muon flux results are discussed in section 3.

2. Material and Method

The experimental setup consisted of two scintillator boxes, separated by 160 cm, named as "Tower". The tower designed to recognize single particles as well as determine the direction of motion (up/down). Each box (or Tile) consists of a Kuraray Organic Scintillator (20×20 cm^2, 1.4 cm thick) which is attached by one low voltage R5783 Hamamatsu Photomultiplier (PMT) [6]. Moreover, the boxes are mounted on a metal frame which can be rotated to point for different zenith angles, allowing the selection of particles from a given direction as shown in Figure 1.

The relation between threshold voltage and rate is important to determine the optimum operating voltage for each scintillator box. This relation was found by changing threshold voltage for each box. According to Figure 2, the rate changes at −40 mV threshold voltage is acceptable for being insensitive to the spurious triggers which cause to oscillation on the cosmic ray flux. −40 mV threshold voltage is obviously fine for measuring the Time of Flight (TOF) and estimating the flux.



(a) Block diagram (b) Experimental setup

Figure 1. Block Diagram of the experimental setup at 0° and the experimental setup at 50° are used for data acquisition shown in (a) and (b), respectively.

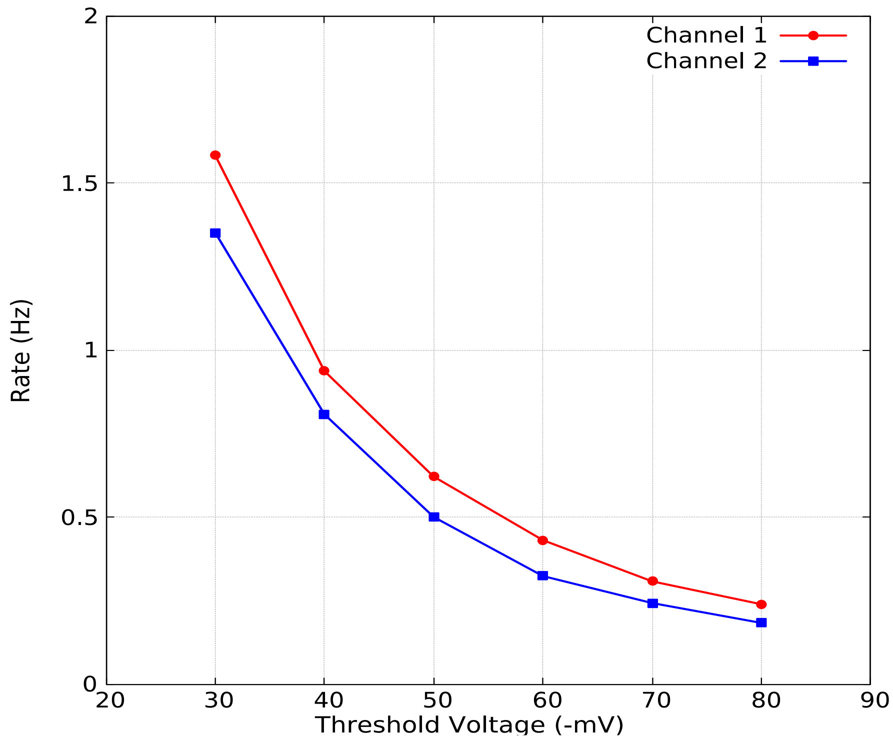
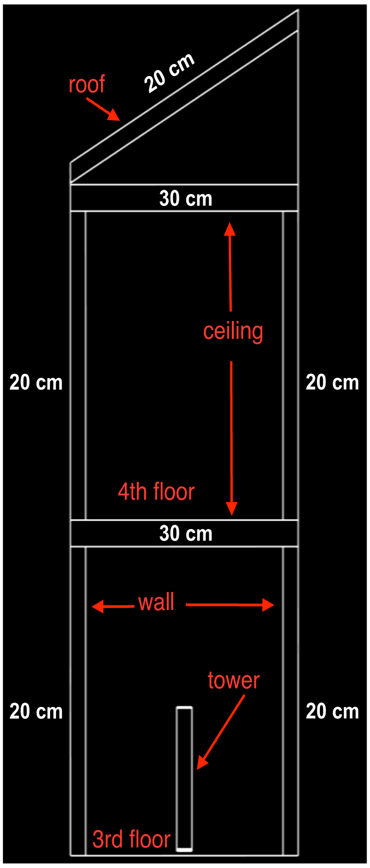


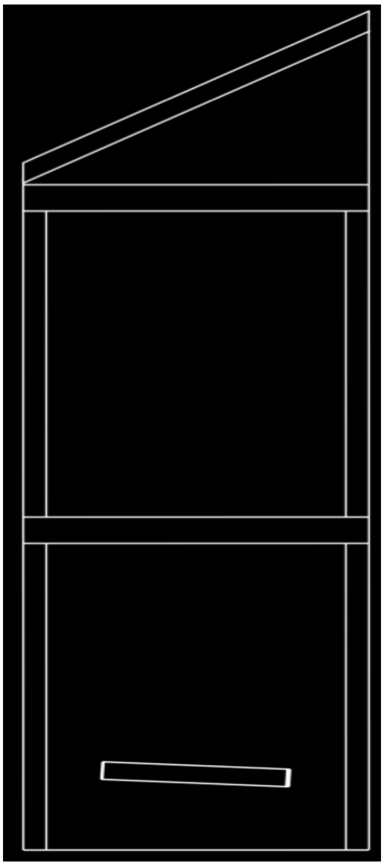
Figure 2. Relation between threshold voltage and rate for scintillator box channel 1 and 2.

2.1. Simulation

Geant4 is a toolkit for simulating the passage of particles through matter which includes geometry, tracking, physics models and hits functionality [7, 8]. Geant4, (version 10.04.p01) have been used for simulating the detector setup and the interactions of the primary particle with the air nuclei, and architectural elements. The tower simulated in this study is the prototype cosmic ray detector located in the building of the Faculty of Arts and Science in Abant Izzet Baysal University-Bolu. It is located in the third floor at the center of the room, where one more floor and roof above the detector. The faculty building did not construct with all rooms, the roof, fourth floor and third floor have been considered in Geant4 simulation as shown in Figure 3.



(a) at 0°



(b) at 87.5°

Figure 3. Tower orientation setup inside the building where there is one floor and roofover the tower. The tower located in (a) at 0° and (b) 87.5° from vertical axis, respectively.

These architectural elements such as walls (20 *cm* thick brick) or roof (20 *cm* thick concrete) and ceilings (2 × 30 *cm* thick concrete) are leading to the loss of detectable particles since they were stopped. The output signal known as trigger is needed for registering the data. This trigger is taken into account in the simulation to provide more realistic measurements and results. It includes some electronic devices (readout-circuit, DRS4, etc.) and processing delays in a more qualitative way:

Trigger: it is established by the two scintillator boxes, also called detection triggers. If the upper scintillator box firstly fired and then the bottom scintillator box records the hit of a passing particle with a time difference smaller than a certain value (∼ 20 *ns*), a coincidence trigger is recorded. The cosmic particles live approximately 5.3 *ns* to cross the whole tower (assuming they are traveling at the speed of light). Therefore, the time window selected with the coincidence circuit will depend on the delay of the signals caused by elements such as cables. This trigger is used to measure the angular dependence of the cosmic ray flux. The tower is rotated for determined angles (0°, 50°, 70°, 87.5°) and the number of coincidences is registered.

3. Results

Particles pass through the scintillators that produce a photon so that creates photo-electrons and then the electrons are multiplied by dynode inside of PMTs. These electrons create a negative output signal which can be observed from Domino Ring Sampler Evaluation Board 4, revision 3.0 (DRS4) [9]. Shortly, incoming signals from PMTs are transferred to DRS4 Board which digitize and write to computer for offline analysis with Data Acquisition (DAQ) program which is written C++. DAQ program selects an event based on the triggering box, threshold voltage and time gate. As shown in Figure 4, with the time difference between the two signals, one can calculate where the cosmic rays go through the scintillator box. TOF is also evaluated to select the direction of incoming particles by using DAQ program.

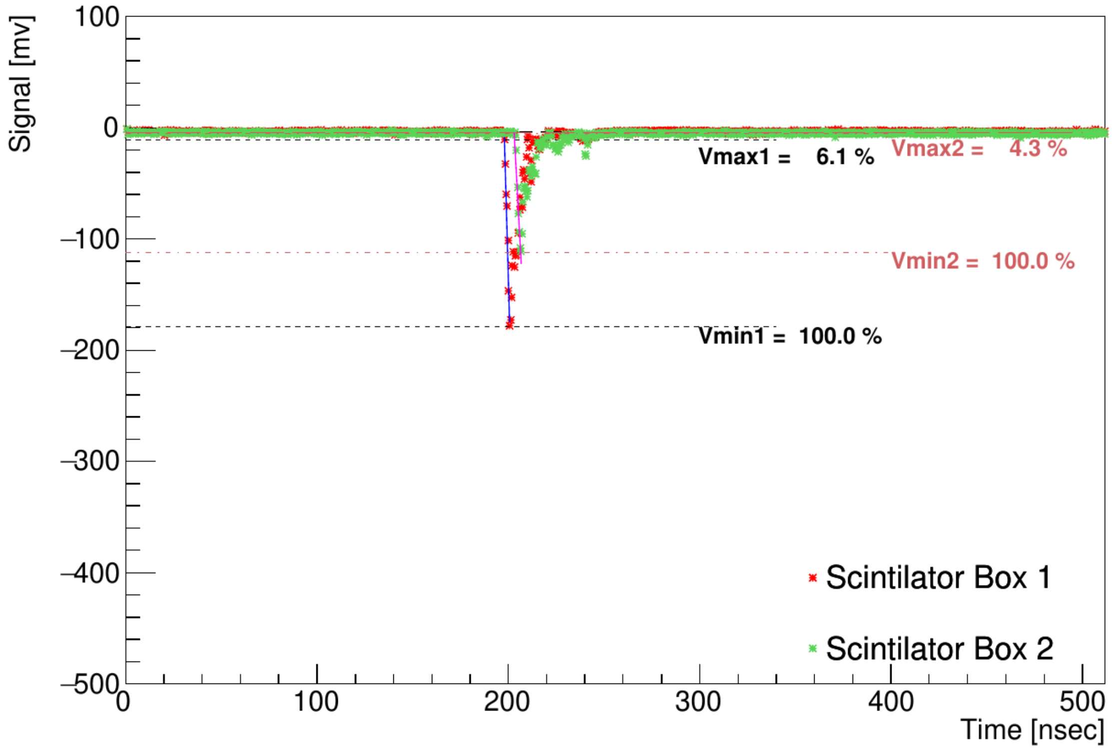


Figure 4. Time of Flight (TOF) evaluated by using DAQ program. Magenta and blue lines indicate the fitted lines according to the method works forward direction from 20% until 70% of the amplitude of the reconstructed signals coming from Tile #1 and Tile #2 scintillation boxes.

To determine the starting point of the signal, which gives the timing information of the particle (called as t_0), the least square method was implemented in the analysis program [10]. The mathematical procedure can be applied for obtaining the well-fitting line to an established particular point via minimizing the residuals of the points from the line. By getting the difference of this t_0 time information one can calculate the TOF value of a particle. Figure 5 shows that the TOF distribution of the cosmic rays when the tower oriented at 0° from the zenith angle.

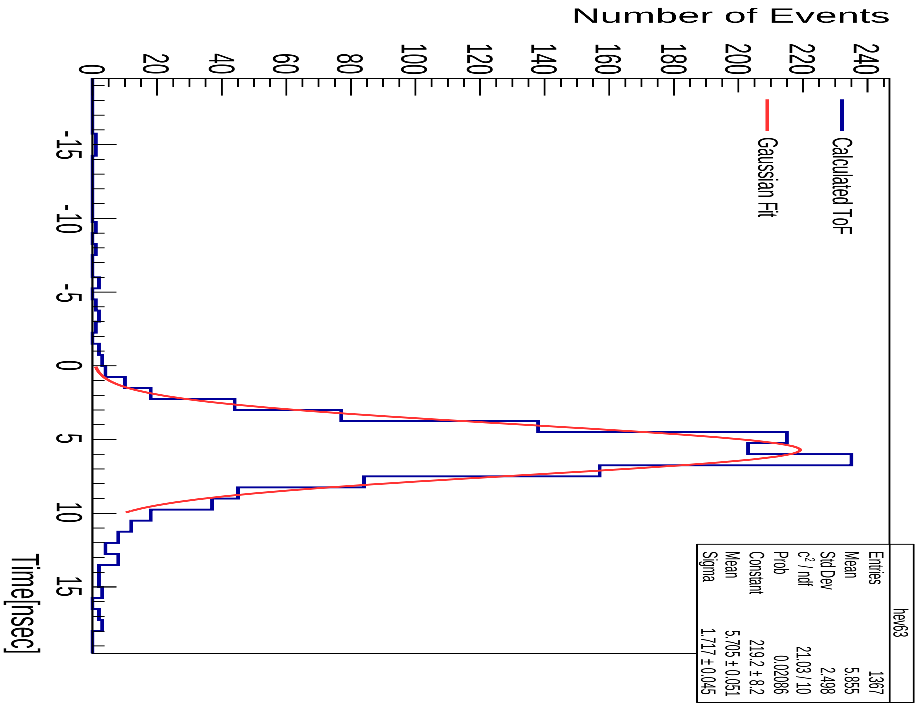


Figure 5. Time of Flight (TOF) histogram evaluated by using DAQ program at 0°.

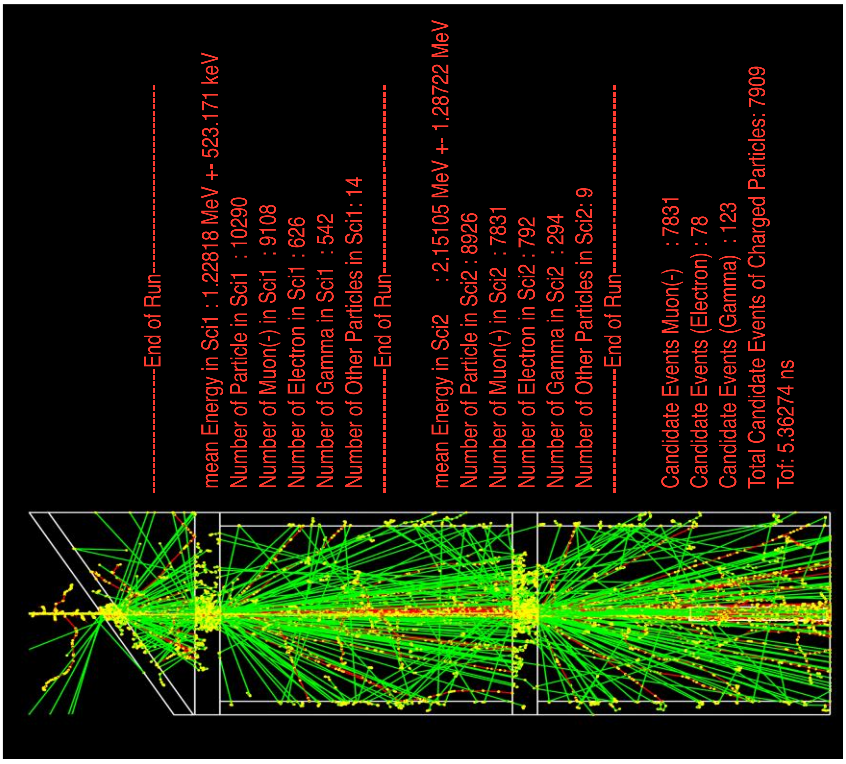


Figure 6. Geant4 simulation of the cosmic rays through from the roof to the tower detectors.

In the simulation program, each scintillator box is a counter which is counting the particles with their identities, and registering the coincident events with their (TOF) value. The results at 0^o of zenith angle configuration are shown in Figure 6, when 10000 particles were fired from the roof with 4 *GeV* average energy, 79% of them were passed through from both scintillator boxes. That means 21% were absorbed from the roof or concrete walls. This 21% attenuation effect was taken into account in the given results.

All the measurements have been done for predetermined zenith angles. Also, the results showed that changing zenith angles is decreasing rate and coincident events. Results compared with literature of flux values (see Figure 7) [11, 12].

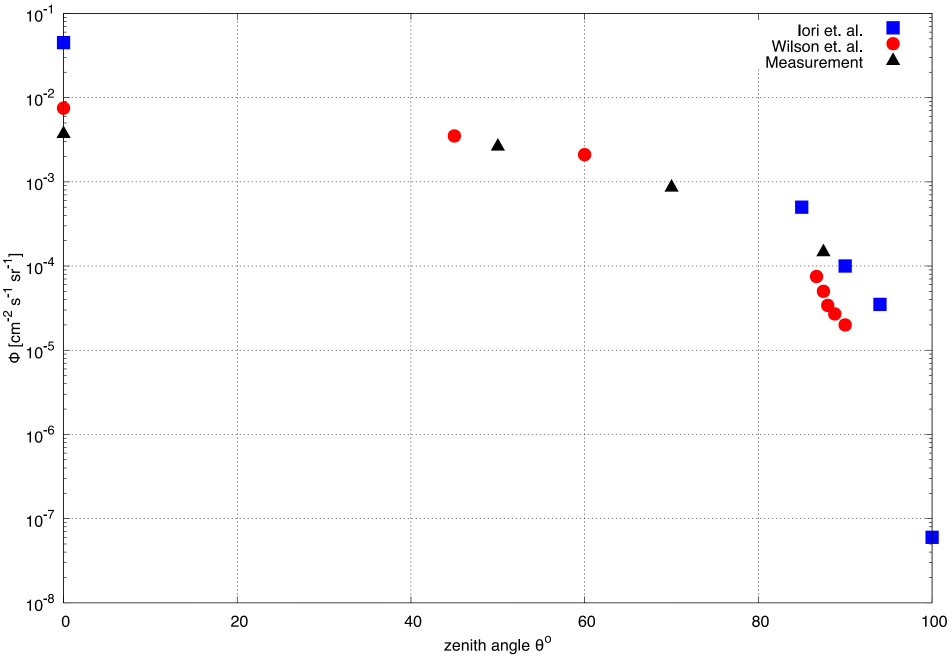


Figure 7. Measurements of cosmic ray fluxes for different zenith angles at 900 m a.s.l., compared with results from the literature [11, 12].

4. Conclusion and Comment

The knowledge of the cosmic ray, the properties of the cosmic ray flux at ground level and the attenuation process of cosmic rays while penetrating through the materials is crucial significance for scientific purposes and imaging feasibility studies. In order to carry out the angular distribution of cosmic rays, dedicated prototype cosmic ray detector has been constructed. The detector consists of two scintillator boxes with one side ended readout, which enable the use of time of flight method. At 0°, 21 % of the particles were attenuated by the architectural elements located above the detector setup, and the angular dependence of the flux distribution was carried out for predetermined angles. Distribution of flux depends on altitude of detector placement and the measured flux values decrease from high altitude to sea level. The results, reported by Iori et. al. [11], was done at 3800 m. a.s.l. In this study, the measured flux at 900 m a.s.l., is in accordance with the literature [11, 12].

Acknowledgement

The authors express our gratitude to Maurizio IORI and the INFN-Labe-Roma1. We thank Scientific Research Projects Unit (BAP-2012.03.02.512) for partial support by Abant Izzet Baysal University.

References

[1] B. Rossi, "Interpretation of cosmic-ray phenomena," *Reviews of Modern Physics*, vol. 20, no. 3, p. 537, 1948.

[2] R. Bellotti, F. Cafagna, M. Circella, G. De Cataldo, C. De Marzo, N. Giglietto, P. Spinelli, R. Golden, S. Stephens, S. Stochaj, *et al.*, "Measurement of the negative muon spectrum between 0.3 and 40 gev/c in the atmosphere," *Physical Review D*, vol. 53, no. 1, p. 35, 1996.

[3] K. Nakamura, "K. nakamura et al. (particle data group)," *Journal of Physics G.*, vol. 37, p. 075021, 2010.

[4] M. De Pascale, A. Morselli, P. Picozza, R. Golden, C. Grimani, B. Kimbell, S. Stephens, S. Stochaj, W. Webber, G. Basini, *et al.*, "Absolute spectrum and charge ratio of cosmic ray muons in the energy region from 0.2 gev to 100 gev at 600 m above sea level," *Journal of Geophysical Research: Space Physics*, vol. 98, no. A3, pp. 3501–3507, 1993.

[5] P. K. Grieder, *Cosmic rays at Earth*. Gulf Professional Publishing, 2001.

[6] M. Iori, E. Arslan, H. Denizli, M. Kaya, A. Yilmaz, and J. Russ, "Electron–muon identification by atmospheric shower in a new concept of an eas detector," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 692, pp. 285 – 287, 2012. 3rd Roma International Conference on Astroparticle Physics.

[7] S. Agostinelli, J. Allison, K. a. Amako, J. Apostolakis, H. Araujo, P. Arce, M. Asai, D. Axen, S. Banerjee, G.. Barrand, *et al.*, "Geant4 a simulation toolkit," *Nuclear instruments and methods in physics research section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 506, no. 3, pp. 250–303, 2003.

[8] J. Allison, K. Amako, J. Apostolakis, H. Araujo, P. A. Dubois, M. Asai, G. Barrand, R. Capra, S. Chauvie, R. Chytracek, *et al.*, "Geant4 developments and applications," *IEEE Transactions on nuclear science*, vol. 53, no. 1, pp. 270–278, 2006.

[9] S. Ritt, "The drs chip: cheap waveform digitizing in the ghz range," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 518, no. 1, pp. 470 – 471, 2004. Frontier Detectors for Frontier Physics: Proceeding.

[10] E. W. Weisstein, "Least squares fitting. from mathworld-a wolfram web resource," 2002.

[11] M. Iori, A. Sergi, and D. Fargion, "Test results of a prototype designed to detect horizontal cosmic ray flux," *arXiv preprint astro-ph/0409159*, 2004.

[12] B. G. Wilson, "A study of μ-mesons incident at large zenith angles," *Canadian Journal of Physics*, vol. 37, pp. 19–29, Jan 1959.

Ali YILMAZ, aliyilmaz@giresun.edu.tr, ORCID: https://orcid.org/0000-0001-5963-8306
Kaan Yüksel OYULMAZ, kaan.oyulmaz@gmail.com, ORCID: https://orcid.org/0000-0002-5533- 9621
Haluk DENİZLİ, denizli_h@ibu.edu.tr, ORCID: https://orcid.org/0000-0003-1570-0344