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Study of Shielding Effects on Cosmic Ray Rate

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Abstract: In this study, the effect of the lead (Pb) shielding on the rate of cosmic rays generally charged particles coming through the atmosphere were studied. The measurements were all done indoors by using a prototype detector consisting of a 20 × 20 × 1.4 cm^3 KURARAY organic scintillator read by 3 mm^2 SensL silicon photomultiplier. The measurements were carried out by using lead plates of different thickness in order to shield the charged particles and investigate Rossi transition curve by using this system. The detector was placed under the lead block and then recorded the coincidence only when both detectors were triggered simultaneously. The Cosmic ray fluxes over the building (sea level firstly simulated by using the CRY software and then the attenuation effect of the construction elements on the measured cosmic ray rate was carried out by using GEANT4 simulation program and this effect was taken into account in the given results.

***Keywords**:* Rate of cosmic rays, Rossi transition curve, CRY, Geant4

Kozmik Işın Oranına Kalkanlamanın Etkilerinin Çalışılması

Özet: Bu çalışmada kurşun (Pb) blok çoğunlukla yüklü parçacıklardan oluşup atmosferden gelen kozmik ışın oranı üzerindeki etkisi çalışmıştır. Ölçümler 3mm^2 SensL silikon fotoçoğaltıcı tarafından okunan 20 × 20 × 1.4 cm^3 KURARAY organik sintilatörden oluşan bir prototip detektörü kullanılarak bina içinde yapılmıştır. Farklı kalınlıklardaki kurşun tabakalar yüklü parçacıklara karşı kalkan görevi görmesi ve Rossi geçiş eğrisini elde etmek amacıyla ölçümlerde kullanılmıştır. Kurşun blok detektörler arasına yerleştirilerek her iki detektörden gelen eş zamanlı tetiklenmeler kaydedilmiştir. İlk olarak kozmik ışın üretim, CRY yazılımı kullanılarak binadaki (deniz seviyesi) kozmik ışın akısı benzetim edilmiş ve daha sonra yapı malzemelerinin ölçülen kozmik ışın oranı üzerindeki zayıflatma etkisi dikkate alınarak GEANT4 programında benzetimi yapılmış ve bu etki verilen sonuçlarda dikkate alınmıştır.

***Anahtar kelimeler**:* Kozmik ışınların oranı, Rossi geçiş eğrisi, CRY, Geant4

1. Introduction

When a primary cosmic rays smashes to an atmospheric nucleus which produces a few of secondary cosmic ray particles. They are mostly made up of protons (p), neutrons (n), and pions ($\pi^{\pm}$), their secondary particles proceed to smash to the atmospheric nuclei, yielding further more secondary particles. Except the generation of $\pi^{\pm}$'s, these nuclear collisions are disposed to yield in increasingly more nucleons. Due to the higher cross sections and energy losses normal in that smashes, these energetic particles decay quickly with downward distance from atmosphere and just a few parts of them are get through to ground level. The life of the pions ($\pi^{\pm} \rightarrow \mu^{\pm} + \nu\ (\bar{\nu})$) produced in primary collisions is about 10^8 s just before they pass to self-degradation into muons ($\pi^{\pm} \rightarrow \mu^{\pm} + \nu\ (\bar{\nu})$. These

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muons may also be self-destructible ($\mu^{\pm} \rightarrow e^{\pm} + \nu + \bar{\nu}$), so that owing to their comparatively long-life span ($\sim 10^{6}$ s) and high penetration power, a large percentage generally reaches the sea level. The part of the secondary cosmic particle made up of $\pi\pm$ and $\mu\pm$ is frequently referred to as a meson shower [1]. Eventually, the neutral pions decay very quickly to the photons ($\pi^{0} \rightarrow 2\gamma$) that are rarely involved in the interactions. Thanks to the repeated processes of bremsstrahlung ($e^{\pm} \rightarrow e^{\pm} + \gamma$) and pair production ($\gamma \rightarrow e^{+} + e^{-}$), that photons give rise to an electromagnetic cascade. A great portion of these electrons, positrons and photons arrive to the sea level, while they have considerably lesser penetration than muons. The collection of multiple secondary elements can generate huge number of particles scattered over a radius of hundreds of meters. Still the main situation is reasonably simple. Only one primary particle leads to 3 sets of secondary particles (electromagnetic shower, nucleonic shower and mesonic cascade). The nucleons hardly arrive to the sea level because of decaying very quickly. The mesonic cascade produces a great number of penetrating muons, a lot of them arrive to the sea level. And the electromagnetic cascade is made up of photons that diffusing lesser than electrons, positrons and muons, however a lot of them arrive to the sea level (or ground). [2, 3]. The Cosmic Ray Generator (CRY) simulation package is developed for creating a particle spectrum from cosmic rays that interact with the atoms in Earth's atmosphere. The software produces cosmic ray particle showers from 3 different heights such as sea level, 2100 m and 11300 m. In order to transport and detector simulations, produced showers can be used as an input data. By using the data tables a broad range of energies (1 GeV-100 TeV) are simulated for initial and secondary particles. Production of a shower is accomplished within an area specified until to $300m \times 300m$. Generation of particles contains p, $\mu^{\pm}$'s, n^{o}, $e^{\pm}$, γ and $\pi^{\pm}$. [4]. The rate of triple coincidences as a function of the thickness of lead block was measured by Bruno Rossi (1930-1940) [5, 6]. A plot of this rate as a function of thickness known as the Rossi curve, showed a rapid increment as the thickness of lead block was increased, and that followed by a slow decrease. Rossi's experiment indicated that the ground level cosmic rays consisted of 2 blocks: a soft block that allows abundant production of various particle events and a hard block that can cross a large thickness of lead [7–9].

The objectives in this study are firstly measure the rate of cosmic rays at sea level, secondly find the rate at the location of the building by using CRY simulation software, thirdly obtain the Rossi curve as a function of the lead absorber thickness, and then correlate it with GEANT4 simulation program.

2. Material and Method

2.1. Experimental Setup

Figure 1 depicts that the hardware of the scintillation counter telescope constructed with two identical scintillator plates, called *Tile* 1 and *Tile* 2, separated by one lead block between two tiles like a sandwich between them. Each box consists of a KURARAY organic scintillator plate ($20 \times 20 \times 1.4$ cm^{3}). The scintillator has great properties to obtain precise time information, such as giving light in the blue region of the visible spectrum, the emission peak is around 430 nm [10]. Each scintillator panel was covered by aluminum foil to spread the reflection, and a SensL SiPM (3×3 mm^{2}) was contacted to read the generated signal. The bias voltage of this device is about 27.5 V with the dynamic range of $\sim$2 V. The gain of the SiPM is 2.3×10^{6} [11] that is competitive with traditional Photo Multiplier Tubes (PMTs). The produced signal is digitized by Domino Ring Sampler Board (DRS4), developed by Stefan Ritt [12]. Data Acquisition (DAQ) program is based on the setup schematically shown in Figure 1. It is controlled by a shell script that controls the two main C++ programs. One of the programs is managing the Arduino so that reads temperatures from the SiPM readout circuit and adjust the operating voltage in order to keep constant the gain of the SiPM on each tile. The other program manages the DRS4 board which digitizes the signal detected by the SiPM and stores in ROOT binary format for further analysis. The DAQ is based on waveform sampling at 2 GS/s [13]. To investigate effect of a lead block over the detector which influence the count rates that will be recorded.

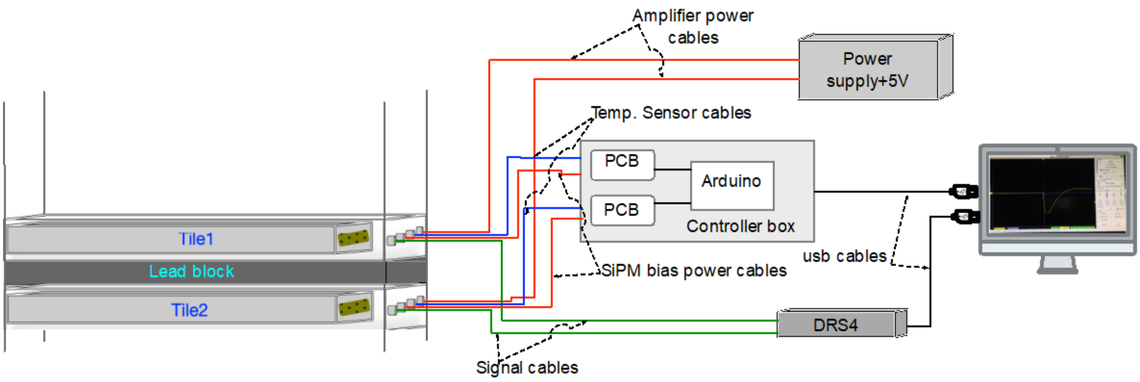


Figure 1. Schematic view of data acquisition.

2.2. Simulations

Cosmic-ray particle showers at the sea level generated by using the CRY software. The showers are used as input data for transport and detector simulation codes in GEANT4 simulation code. Shower generation is done within an area defined by $1m \times 1m$ above the roof of the building. Produced secondary particles include muons, neutrons, protons, electrons, photons and pions. The input parameters of the CRY software for the location is $40°54'52''N$ and $38°19'26''E$ with the elevation of 30 m above the sea level. 10^6 primary particles are required to generate by CRY software.

GEANT4 is a toolkit for simulating the passage of particles through matter which includes geometry, tracking, physics models and hits functionality [14, 15]. GEANT4(10.4.2) have been used for simulating the detector setup and the interactions of the primary particle with the air nuclei, and construction elements. The tower simulated in this study is the prototype cosmic ray detector located in the building of the Faculty of Engineering in Giresun University, Giresun-Turkey. 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 the simulation as shown in Figure 2.

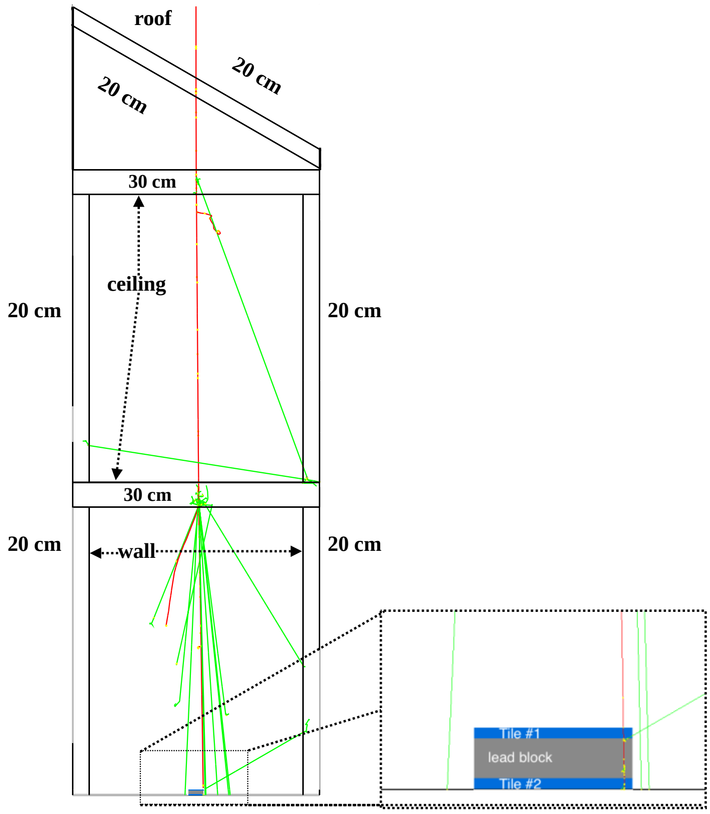
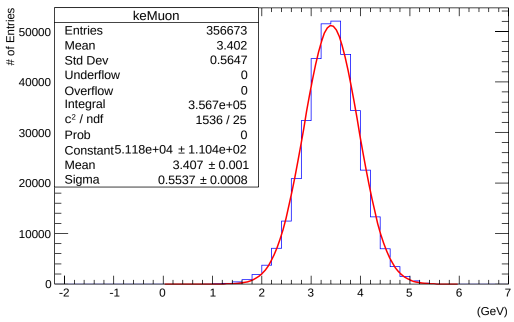


Figure 2. Detector setup inside the building where there is one floor and roof over the tower. The tower located at 0° from vertical axis. Geant4 simulation of the cosmic rays passing from the roof to the detector.

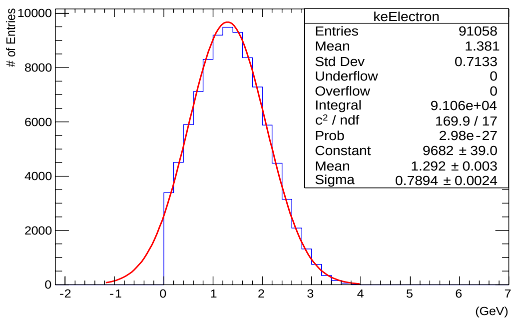
Construction elements such as walls (20 *cm* thick brick) or roof (20 *cm* thick concrete) and ceilings (2 × 30 *cm* thick concrete) or are leading to the loss of detectable particles since they were dumped.

3. Results

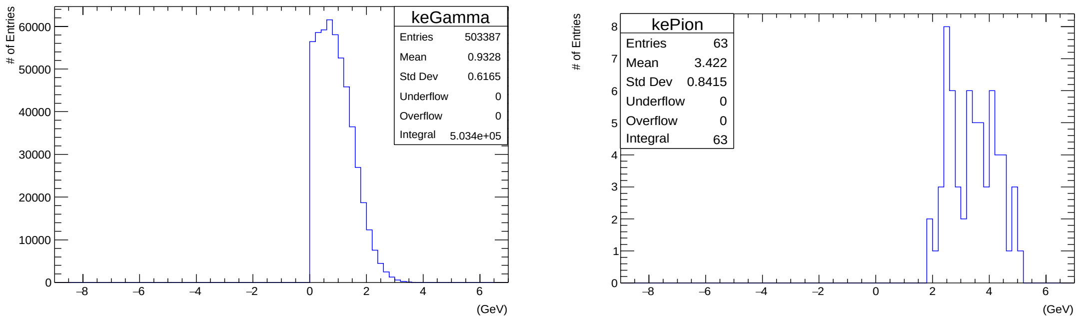
Figure 3 shows the results of CRY simulation. The produced secondary particles ($u^{\pm}$, $e^{\pm}$, γ and $\pi^{\pm}$) and their mean energies are used as an input for the GEANT4 simulation codes.



(a)



(b)



(c) (d)

Figure 3. Produced secondary particles ((a) for Muon, (b) for Electron, (c) for Gamma and (d) for Pion) versus their mean energies in the sampling area of 1 m^2 on the roof of the building using CRY software.

The measured rate of the cosmic rays versus thickness of the lead shielding block is depicted in Figure 4. In the GEANT4 simulation program, each scintillator box is a counter which is counting the particles with their identities, and registering the coincident events. A coincidence count plot as a function of the shielding thickness gives a "shower transition curve", which indicates a sharp rising and then a slower decrease seen in Figure 4 for both measurement and simulation.

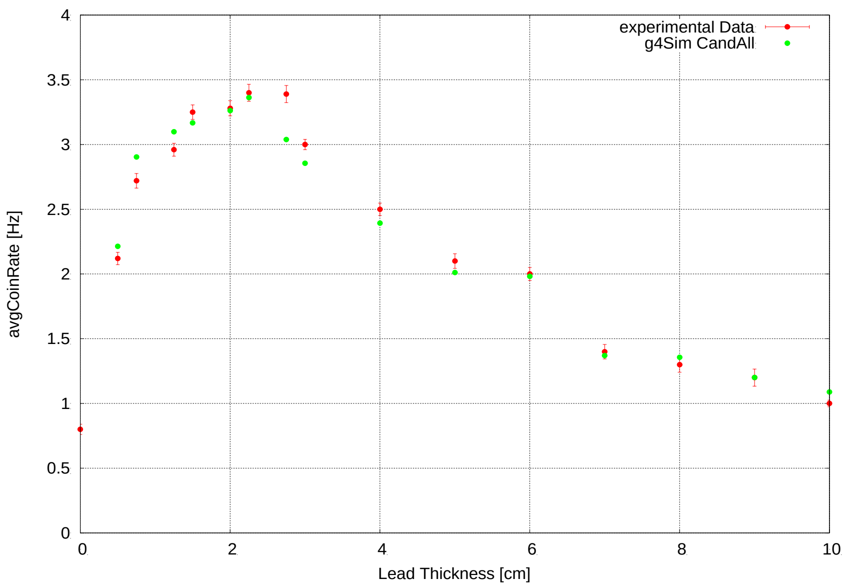


Figure 4. Average coincidence counting rate of cosmic rays as a function of lead block thicknesses.

The behavior of this function can be explained as follows. The showers are initiated by interactions between the incident particle and a lead atom. For this reason, when the thickness of the lead shield gets bigger, the number of showers should also grow. This increased number of showers will cause the counting rate to increase, as long as the shower parts pass through the lead completely. However, since the energy of the incoming particle is split between all shower parts, these thicknesses are more likely to be absorbed due to the increased shielding thickness. Thus, the increase in coincidence counts due to the increasing number of showers is followed by a reduction in the number of coincidences of the lead absorption.

4. Conclusion and Comment

The effect of lead block thickness upon the cosmic ray count rate in the vertical direction by using the prototype detector with total thickness of Pb ~10.0 *cm*, at University of Giresun, Turkey from June to September 2018 were studied and analyzed. Figure 4 depicts the results of the experiment after collection of all data. A slow decrease can be obviously seen following a typical sharp increase. Rossi curve for Pb is obtained by using the prototype detector and it is confirmed by GEANT4 simulation. The obtained results agree well with values from frequency analysis experiments.

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