Simulating background characteristics of low-level gamma-spectrometers: a Monte Carlo approach

Robert Breier, Pavel P. Povinec

Comenius University, Faculty of Mathematics, Physics and Informatics, Bratislava, Slovakia

ABSTRACT

An increasing number of experiments have been devoted in modern physics to the detection of very rare events. Their common feature is a utilization of high sensitive low-level counting spectrometers operating very often underground. A computing code based on the CERN's GEANT4 has been used to compute cosmic-ray background components of low-level Ge-spectrometers, optionally equipped with an anticosmic shield made of a plastic scintillation detector. The results show that it is advantageous to operate Ge detectors in shallow and/or medium depth underground laboratories with anticosmic. Background of the Ge detector placed at 100 m w.e. has been decreased by a factor of 30 and 99 without and with the anticosmic shielding, respectively, when compared with a surface laboratory without anticosmic shielding.

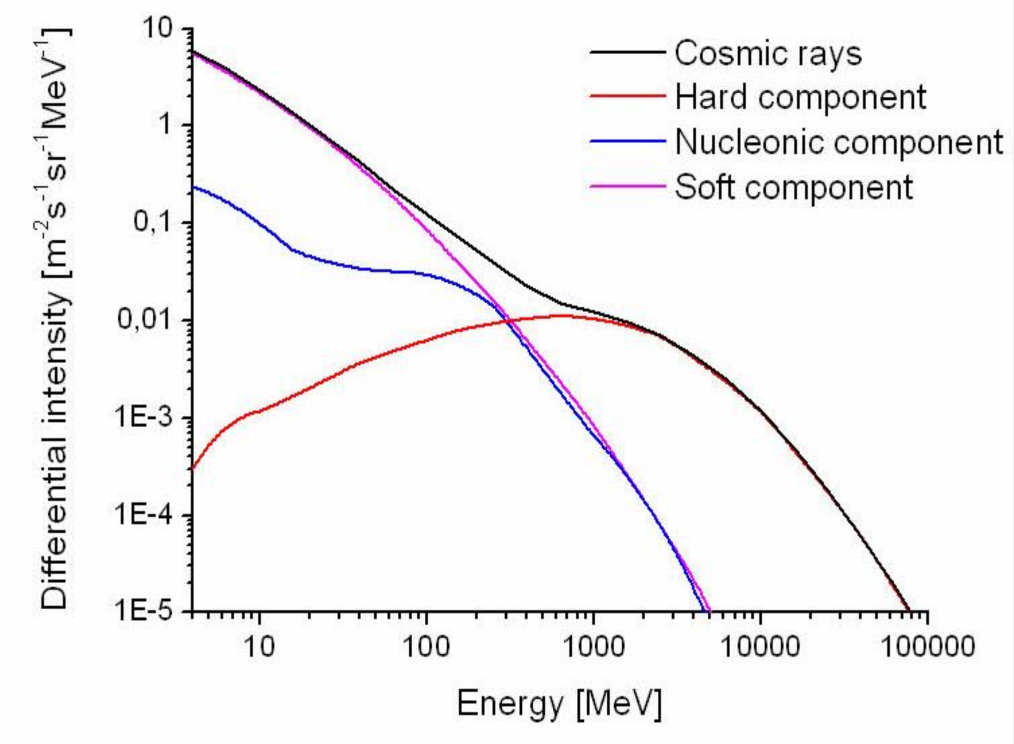

Figure 1. Differential intensity of different components of comic rays.

The cosmic-ray shower library (CRY) (http://nuclear.llnl.gov/) has been used as a generator of cosmic-ray particles, which has been implemented in three different CERN codes: GEANT4, MCNPX and FLUKA. This simulation code library generates a momentum, a direction and an energy distribution of cosmic-ray particles at sea level at a given time and geographic location. The flux spectra of different components of cosmic rays, which are inducing Ge detector's background, are shown in Fig. 1. The dominant components which can be observed on the earth surface are the hard and soft components, while the nuclear component is less intensive.

For simulating a Ge-detector background we used the GEANT4 code, as it simulates both the high energy and low energy particle transport through the matter (Allison et al., 2006). The simulations were carried out at various thickness of lead shield, without and with anticosmic shielding. The simulations were done for Ge detector placed in a surface as well as in a shallow underground laboratory.

Experimental

The counting system consisted of the Ge detector (7.2 cm in diameter and 7.0 cm in length; the total volume of 285 cm) which was placed in a rectangular lead shield of internal size of 30x30x30cm^3. The efficiency of the Ge detector (relative to 7.6 cm in diameter and 7.6 cm long NaI(Tl) crystal) for the 60Co line of 1.33 MeV was 70 %. The resolution of the detector (FWHM) was 1.08 keV for 122 keV of 57Co, and of 2.6 keV for 1.33 MeV of 60Co. The Ge-detector construction parameters such as the Ge dead layer (5µm), the active Ge layer and the copper cryostat (0.5 mm thick window) have been taken into account during simulations as well.

The second detector was a plastic scintillation sheet of square form of 34x36x5cm^3, placed above the Ge detector in the lead shield, and connected with the Ge detector in anticoincidence. This anticosmic shielding formed a zenith angle of approximately 70°.

Result and discussion

The first simulation run was done with the Ge detector placed in a lead shield with thickness of 20 cm. Simulated low energy background spectra are shown in Fig. 2, as induced by various components of cosmic rays. As we can see, the majority of background is from cosmic muons. The peak at 511 keV, which is due to the annihilation of electron-positron pairs, dominates in all spectra. The peak around 250 keV, which we can observe in all spectra (a black line), and the hard component of the single and anticosmic spectra (a red line), is due to interactions of cosmic muons with construction parts of the Ge detector (a dead Ge layer and a copper window).

High energy background spectra presented in Fig. 3 also show a dominating muon component of the background. The peak at 54 MeV corresponds to the most probable interaction length of muons in the sensitive layer of the Ge detector. Energy losses of a minimum ionizing particle in germanium are 7.3 MeV cm^{-1}, what corresponds to a muon track in the Ge of detector of 7.4 cm.

A fraction of the background

$$f = \frac{B_c}{B_t}$$

(B_c represents the component background and Bt is the total cosmic ray background) induced from different components of cosmic rays is presented in Fig.4. We can see that the fraction of the background induced by the hard component increases with the lead thickness. On the other hand, the fractions of soft and nucleonic components decrease with thickness of lead. This fact correlates with higher cross-sections of interaction particles of the soft and nucleonic component with lead.
The efficiency of the anticosmic shielding, defined as

$$\varepsilon = \frac{B_{ac}}{B_s}$$

(B_{ac} and B_s represent the background with and without anticosmic shielding, respectively) simulated for the full energy spectrum (0-3000 keV) is presented in Fig. 5. The nucleonic and soft components of cosmic rays have already been filtered by the lead shield. The background with anticosmic shielding has been suppressed by a factor of 3. The maximum efficiency is predicted between 50 and 400 keV. The minimum is observed around 500 keV (this should be due to a contribution from annihilation process), and it slowly increases at higher energies.

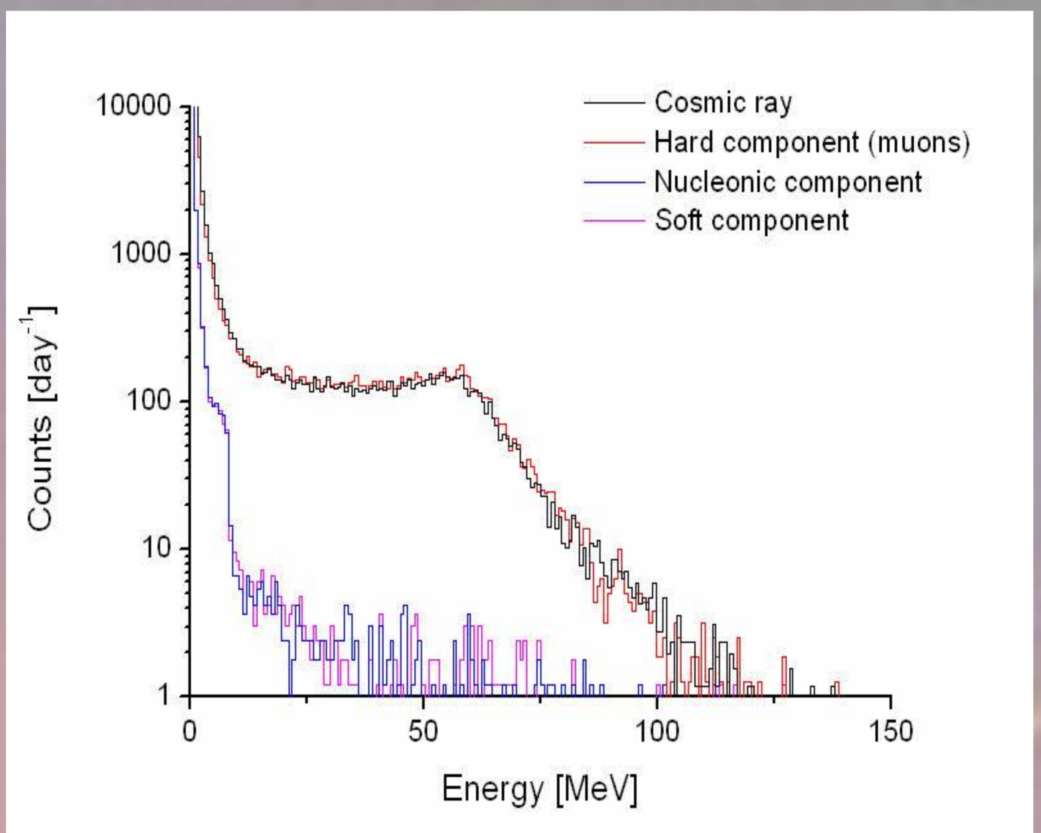

Figure 3. High- energy spectra of different components of comic rays at sea-level with anticosmic shielding predicted by Monte Carlo simulation.

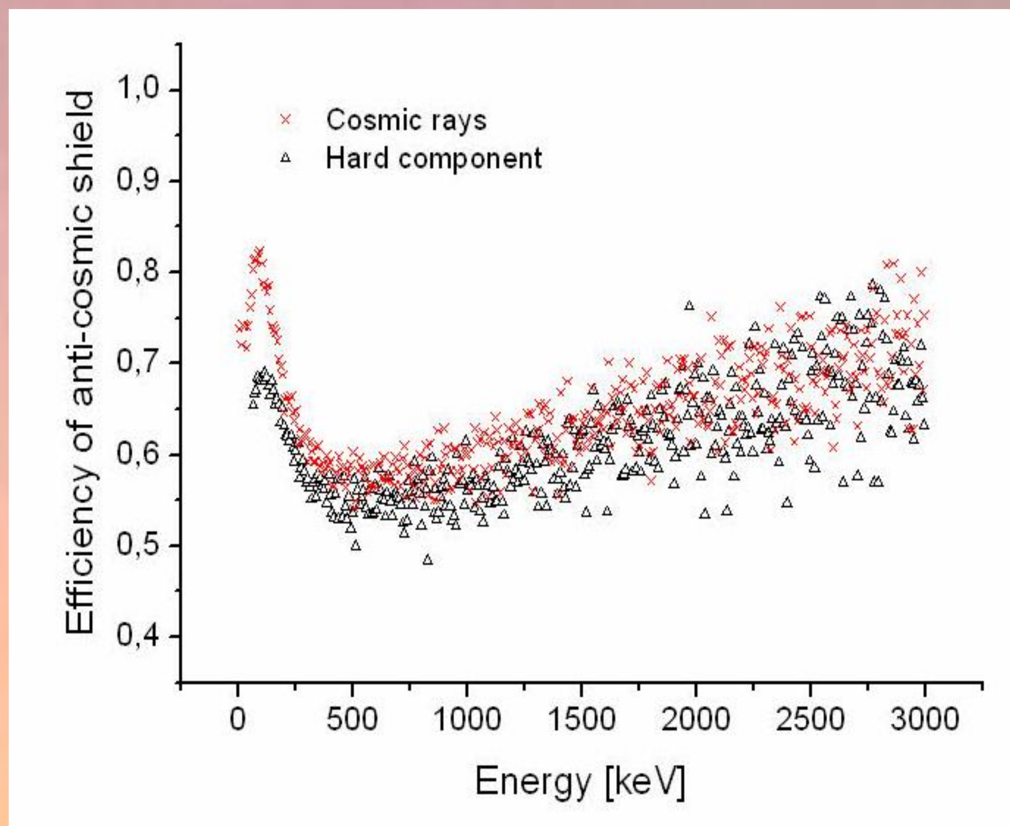

Figure 5. Efficiency of the anticosmic shielding as a function of the energy for hard component and all cosmic rays.

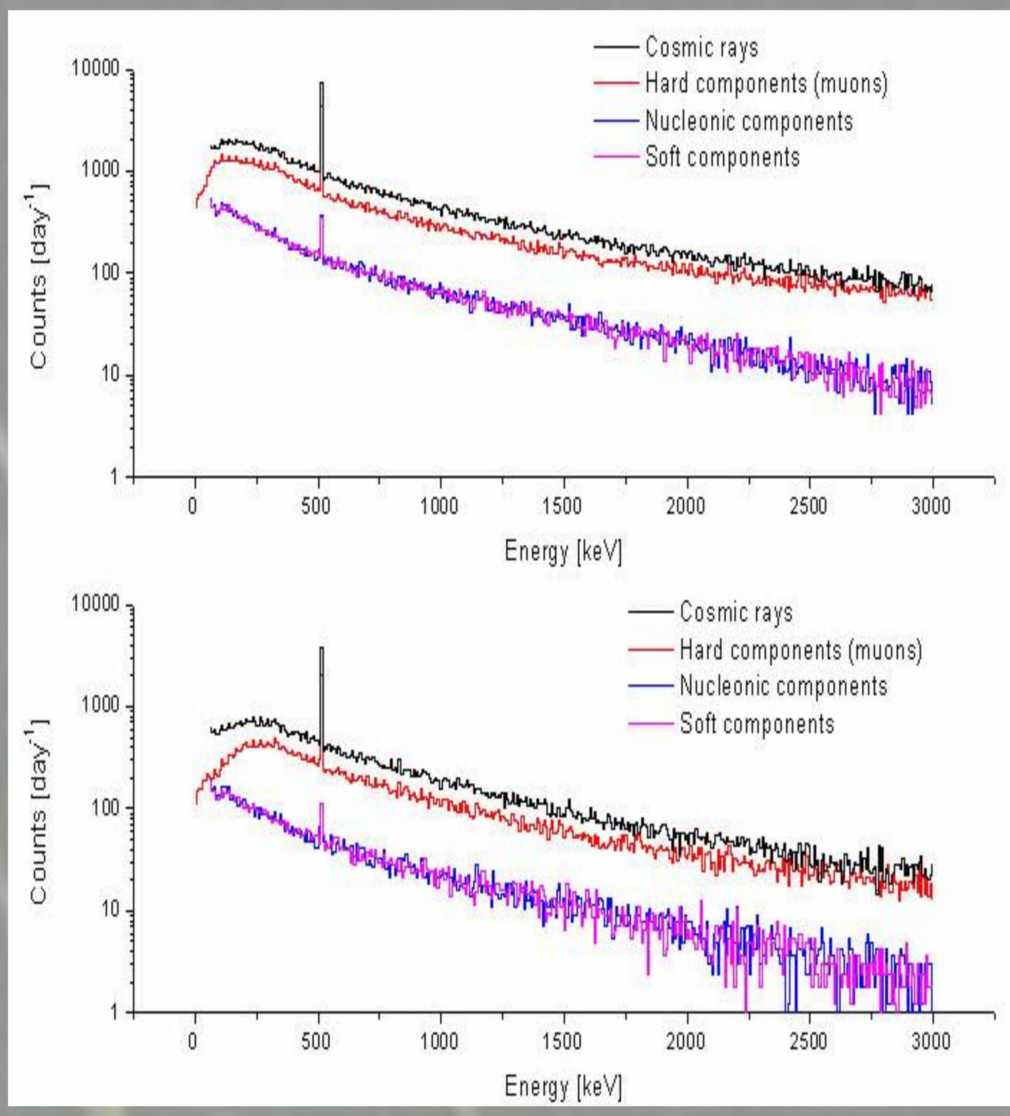

Figure 2. Low-energy spectra of different components of comic rays at sea-level in a single Ge spectrometer (top), and with anticosmic shielding (bottom) as predicted by Monte Carlo simulation.

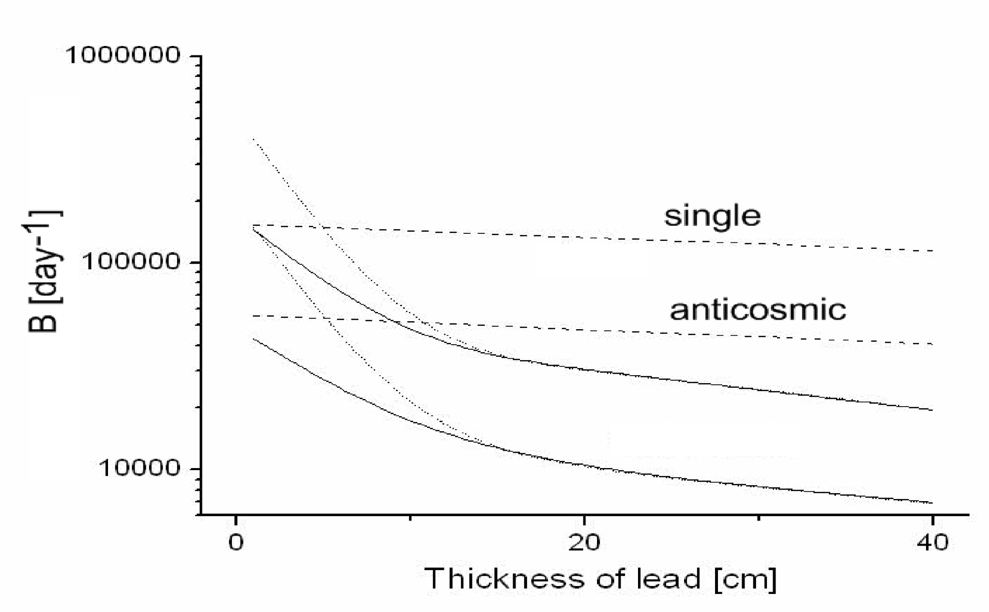

Figure 4. Total background counts (0-3000 keV) due to hard (broken line), soft (dotted line) and nucleonic (solid line) components.

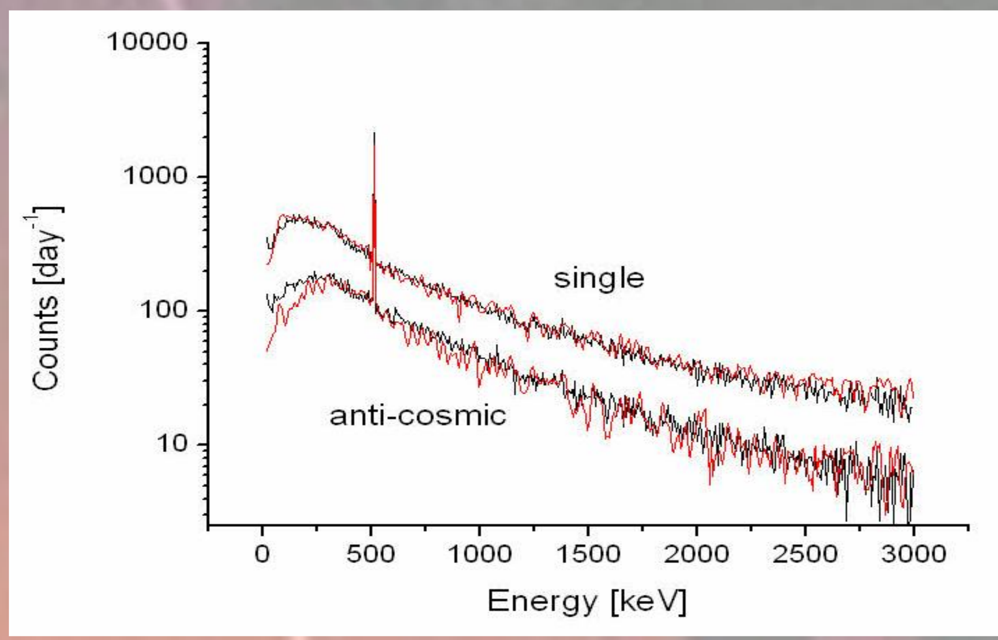

Figure 6. Low-energy spectra of hard component (red line) and all of cosmic rays (black line) at 10 m w.e. underground for a single and anticosmic spectrometer.

The most effective decrease of the flux of cosmic-ray particles is by placing a detector deep underground. The simulated energy spectrum of the Ge detector shielded by a standard rock of 10 m w.e. (water equivalent) thickness is shown in Fig. 6. The dominant peak in the spectrum is still the annihilation peak at 511keV, however, the background integrated over 0-3000 keV in the anticosmic mode has decreased by a factor of 4. The soft and nucleonic components have been considerably eliminated even by such a shallow shielding. This was the reason why next simulations were done with the hard component only. The background of the Ge detector shielded by 20 cm of lead in the underground laboratory at 100 m w.e. depth with anticosmic shielding has decreased by a factor of 99 (a factor of 30 without the anticosmic shielding), when compared with the surface laboratory without the anticosmic shielding.

Conclusions

The Monte Carlo simulation of the Ge-detector background has shown that the application of anticosmic shielding is important prerequisite for obtaining a low detector background. While shallow depths (10 m w.e.) are good enough to eliminate contributions from soft and nucleonic cosmic-ray components, deeper installations are necessary to decrease a contribution from the hard (muon) component of cosmic rays. Placing the Ge detector at 100 m w.e., and using anticosmic shielding made of plastic scintillation sheet, it is possible to decrease the detector background by a factor of 99 when compared with a surface laboratory without anticosmic shielding.

http://www.theresilientearth.com/files/images/Cosmic_ray_shower.jpg