Registration of Particles Delayed by 400 – 1000 Microsec after EAS

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Abstract

Particles are detected up to 2 milliseconds after the EAS front. These are likely to be neutrons. The scenario that these neutrons originate due to EAS hadron interactions is discussed. Neutrons evaporated from excited target nuclei diffuse and get thermalized and then diffuse and can be detected. The relation between number of detected neutrons and EAS hadron content is being investigated. We found that the time distribution of registered neutrons does not match distribution predicted by simulations using MCNP code.

1. Introduction

Neutrons were registered after the passage of Extensive Air Shower (EAS) front [1, 5, 6, 4, 3], however, the effect still needs to be studied in details. This "observable" of EAS event might be related to number of hadrons crossing the detector or to the energy of hadronic component deposited at observation level. The registration method is inexpensive and may be efficient enough to be used as the "effective hadron calorimeter" for EAS.

The method of studying the effect requires the EAS array equipped with neutron detectors and computer simulation tools to deal with high energy processes as well as thermal energy interactions of neutrons. As most of EAS particles are passing within about 100 nsec, the delay of a few hundred of microsec between the EAS front and particle registration can be diffusion time of neutrons. (Process of excitation and decay of nuclei is not relevant here as nuclei nearby detectors have no isotopes which decay in related time scale).

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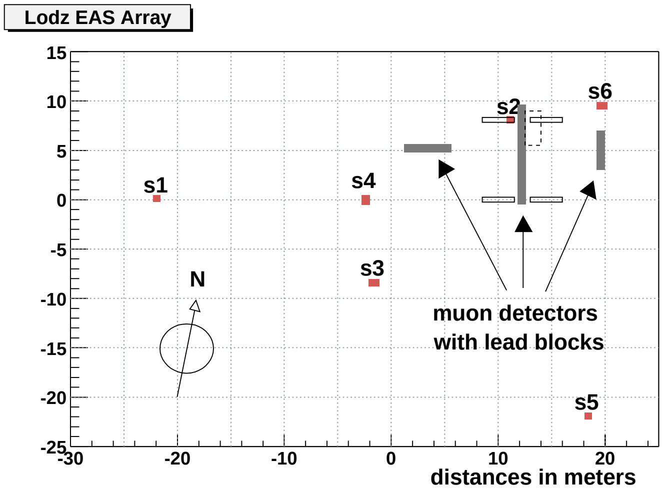

Fig. 1. The schematic layout of Łódź EAS array. Central muon detector is used for neutron registration. The boron counter is placed at the side of lead block.

2. Detection Methods.

The Łódź EAS array at altitude 200 m a.s.l. is registering EAS with trigger frequency about 1 per minute. Trigger condition requires 0.5 particle signal within 200 nsec from 3 scintillation detectors separated by about 30 m, 0.5 m^2 each, (labelled s1, s2, s5 in the Figure 1.) and 1 m^2 scintillation detector in the center (labelled s4). For bigger showers most of soft component detectors are saturated and shower size can be estimated from hodoscopic registration of muon density (muon energy threshold 0.5 GeV) using Geiger–Müller counters (5 GM tubes form a unit of the area of 0.137 m^2; there are 104 GM units for muons). Muon detectors are covered by 10 cm layer of iron and 40 cm layer of lead. These materials emit a lot of neutrons under the hadronic shower penetration. Under the counters there is 2 cm of iron, then 5 cm of lead and then the concrete base. To register neutrons Łódź EAS array was equipped with additional detectors and electronics for registrations of signals within several hundreds of microseconds around the time of EAS front. The 56 (out of 104) GM units are connected to CAMAC block counting delay signals (counting starts 5 microsec after the trigger time and counts are summed in 12 periods of 100 or 200 microsec long).
Additionally, near to main lead block we have placed boron proportional counter (with 1 atm. of BF_3, nearly 90% of ^{10}B, area of 120 cm^2), small stilben scintillation counter (area of 38 cm^2), and 3 plastic scintillation detectors of 0.5 m^2 each. Each of these detectors is connected to 10 MHz FADC (8 bit) with 32 kB “circular” memory which stops registration 2 millisec after the EAS trigger time (so we have amplitude data from about 1 millisec before the EAS and 2 millisec after

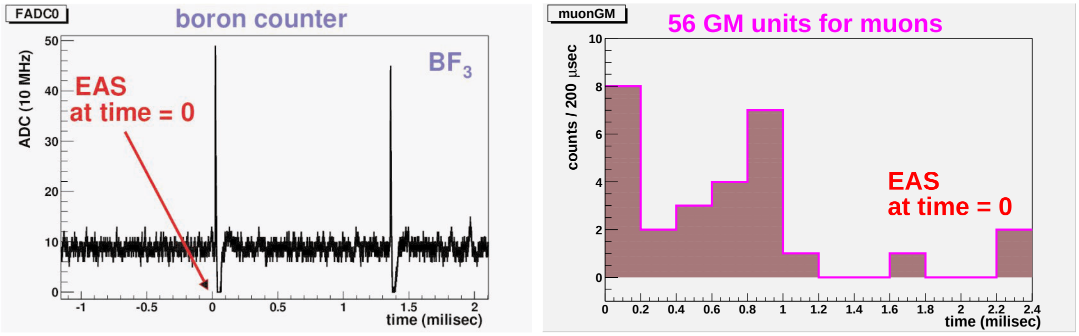

Fig. 2. Example of EAS event with delayed signals. Left figure shows two neutron peaks from BF_3 counter at the time of 20 μ-sec and 1.356 millisec after EAS front and the right figure shows histogram of 56 muon GM counters hit in 200 μ-sec bins (expected noise is 0.9/bin for time $>$ 0.2 millisec). 83% of muon GM units were hit at EAS passage time=0, which corresponds to muon density 11 μ/m^2 and primary CR energy about $2 \cdot 10^7$ GeV. Thermal neutron density is $\approx 120/m^2$.

the EAS with 100 ns resolution). The BF_3 counter is surrounded by 30 litres of water (to thermalize neutrons). In this paper we concentrate on results from GM and BF_3 counters. In the Fig 2. we present very rare event when two neutrons were registered in the Boron counter and the GM muon counters have counted several particles long time after the EAS front.

3. Simulation Methods.

We assume that the only process which is responsible for large time difference between EAS front and registered delayed signals is the diffusion/thermalization of neutrons. These neutrons originate in the lead block or in the vicinity of the array as product of EAS hadron component interaction with lead, iron or soil nuclei at the time of EAS front registration (time = 0).

To produce a signal in GM muon counters neutron needs to produce a gamma photon in ^{56}Fe(n,γ)^{57}Fe process and the gamma needs to convert to e^+e^- which can be detected. The cross section for gamma production [2] can be parameterized as $\sigma = 0.4149 \cdot E_n^{-0.496}$ barn, where E_n is neutron kinetic energy in eV ($\sigma \approx 1/v$, v - neutron velocity). The GEANT 4.5 simulations show that the dominant neutron registration capability reaches 1.3% per GM unit (for upward going neutrons).

The boron proportional counter reacts for ^{10}B(n,α)^{7}Li. Cross section [2] can be parameterized in low energy region $\sigma = 660.7 \cdot E_n^{-0.475}$ barn.

For neutron diffusion simulation we have used the MCNP v.4b code (Monte–Carlo N–Particle code by Transport Methods Group, Los Alamos National Laboratory). This is a code for neutron protection studies. The geometry of detectors and surroundings were included together with building walls and soil (also organic top

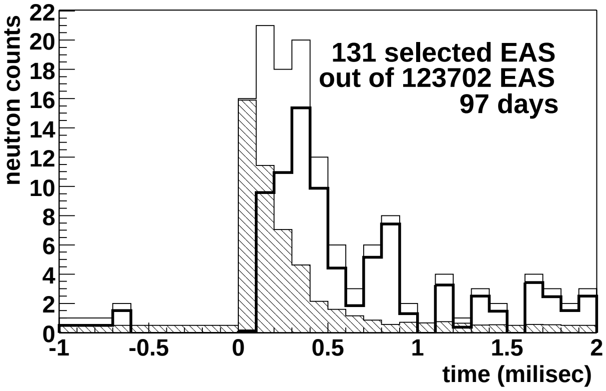

Fig. 3. Time distribution of neutrons in the boron counter: observed (thin solid line), expected (shaded area) and the resulting excess of delayed signals (thick solid line).

layer). Neutrons started with energy 1–10 MeV from inside the lead block or (separately) from the soil around the central muon detector. As a result we obtained the time distribution and the neutron fluxes (with different neutron energy bands) across some layers or within some volumes.

4. Results and Discussion

In the Fig 3. we plotted the time distribution of neutron signals relative to EAS trigger time obtained in nearly 100 days of registrations. As the counter is small the events are very rare. Only 3 EAS events have more than one neutron signal registered. Detector was effectively always ready to register neutron signal. Similar plots were presented for muon GM units [3].

We were not able to reproduce the time distribution of signals in the simulations. The MNCP results for GM unit area and for boron counter predict the maximum of thermal neutron intensity near to 50–150 μsec after the EAS (for dominant neutrons with energy 0.01 – 1 eV) and the exponential fall later.

One of the possible explanations of the observed excess of delayed signals is that some neutrons are produced in lead long time after the EAS event.

5. References

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