The 2nd International Symposium on Cosmic Rays and Astrophysics (ISCRA-2019)

Simulation of the response of the URAN and PRISMA-32 facilities to thermal neutrons from the EAS hadronic component

Izhbulyakova Z.T., Bogdanov A.G. Bogdanov F.A., Bouchama L., Gromushkin D.M.,
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute),
Scientific and Educational Center NEVOD, Moscow , Russia

Annotation

Hadrons are one of the main components of EAS which is formed in the interactions of high-energy primary cosmic rays (CR) with the atmosphere. Recently a new method for studying the hadron component of EAS was developed. This method is based on registration of thermal neutrons that are generated as a result of interactions of shower hadrons with atomic nuclei in the atmosphere and at the surface of the Earth and then thermalized. An advantage of the thermal neutron component is that the time profile of EAS in thermal neutrons is of the order of 10 ms, which is about 10^6 times longer than the time profile of charged particles in the near-core region of shower. This allows us to measure the number of neutrons in a wide dynamic range of up to 1000 neutrons per detector in each event.

At the Scientific and Educational Center NEVOD (MEPhI) , PRISMA-32 array [1] and URAN array [2] were created to detect the neutron component of EAS corresponding to $E \sim 10^{15}$ eV energy range of primary particles. For the correct interpretation of the experimental data obtained by these facilities, it is necessary to carry out model calculations.

PRISMA-32 and URAN arrays

The PRISMA-32 array consists of two independently operating clusters of 16 en-detectors in each and covers an area of about 500 m^2. En-detectors are installed inside the experimental complex building at the 4th floor of distances of 2.5 or 5 m from each other. The effective area of each detector is 0.36 m^2. Thin layer of inorganic scintillator ZnS(Ag) and LiF (enriched up to 90% of ^{6}Li) is used for detecton of EAS neutrons. Thermal neutrons Are registered via the following reaction:

$$^6\text{Li} + n \rightarrow \text{T} + \alpha + 4.78\ \text{MeV}$$

The URAN array includes 72 en-detectors. The detectors are located on the roofs of two laboratory buildings and are combined into cluster structures. On each roof, three clusters (36 en-detectors) are deployed. The total area of the array is about 10^3 m^2. Registration of thermal neutrons in the scintillator ZnS(Ag)+B_2O_3 occurs due to the following reactions:

$$^{10}\text{B} + n \rightarrow {}^7\text{Li}^* + \alpha + 2.792\ \text{MeV}$$

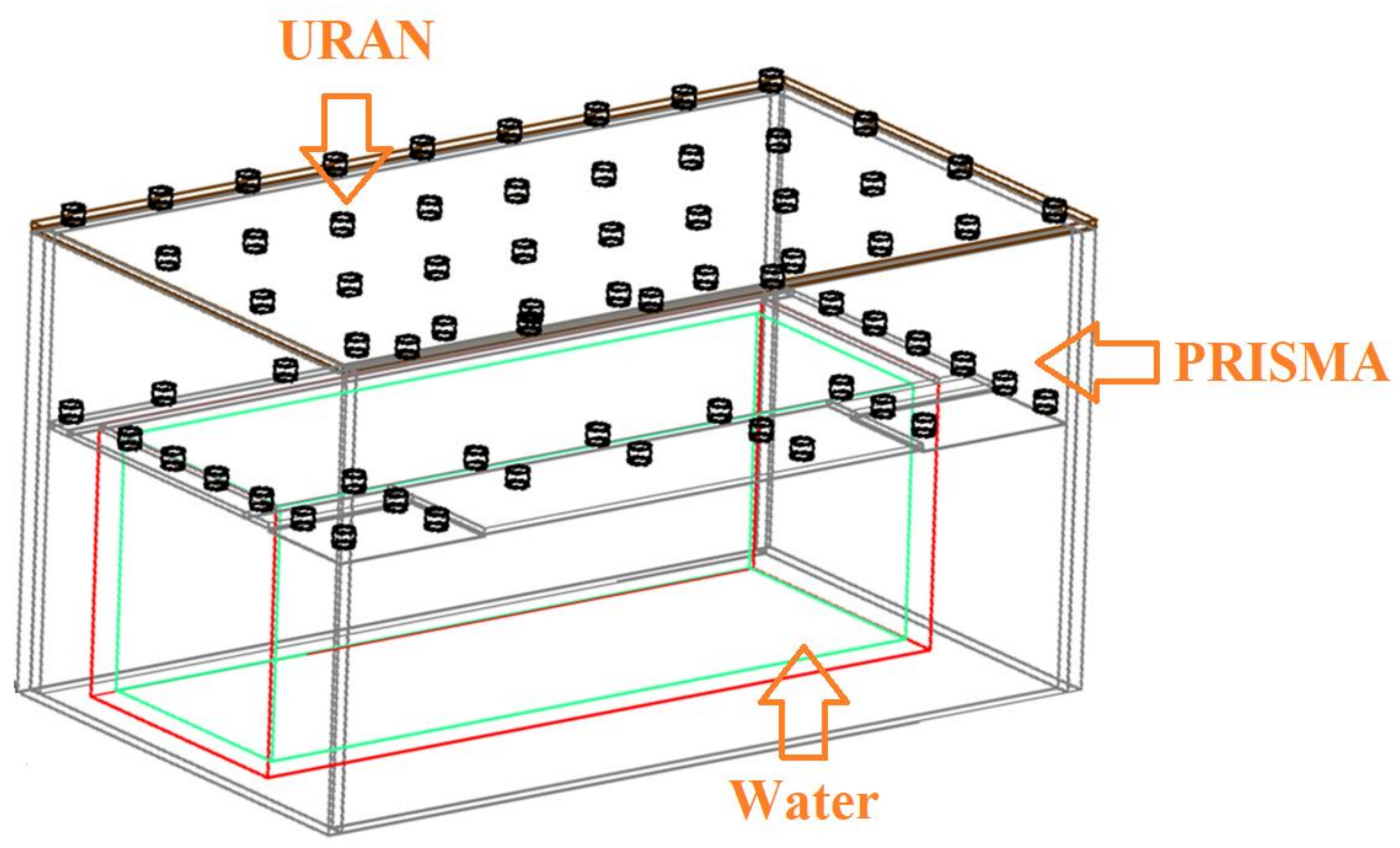
$$^{10}\text{B} + n \rightarrow {}^7\text{Li}^* + \alpha + 2.31\ \text{MeV}$$

$$^7\text{Li}^* \rightarrow {}^7\text{Li} + \gamma + 482\ \text{keV}.$$

The formed nuclei cause luminosity of ZnS(Ag) in the visible wavelength range.

Model geometry

For The correct interpretation of the experimental data obtained from these Facilities, models of PRISMA-32 and URAN arrays were created on the basis of the Geant4.10 simulation toolkit [3]. The geometry of the installations and the environment, the chemical composition of materials are defined. ' Geometry of installations is close to real conditions. The geometry model includes features of the building frame, a water tank and a simplified model of PRISMA-32 and URAN facilities. A soil layer was modeled, according to the real composition of the soil in the Moscow region. For better reliability of model of neutron propagation in the environment, a neighboring building was simulated. The Geant4 model Visualization is shown below. The included physical processes take into account the features of the interaction of thermal neutrons with matter. The physics list used in this simulation is QGSP_BIC_HP.

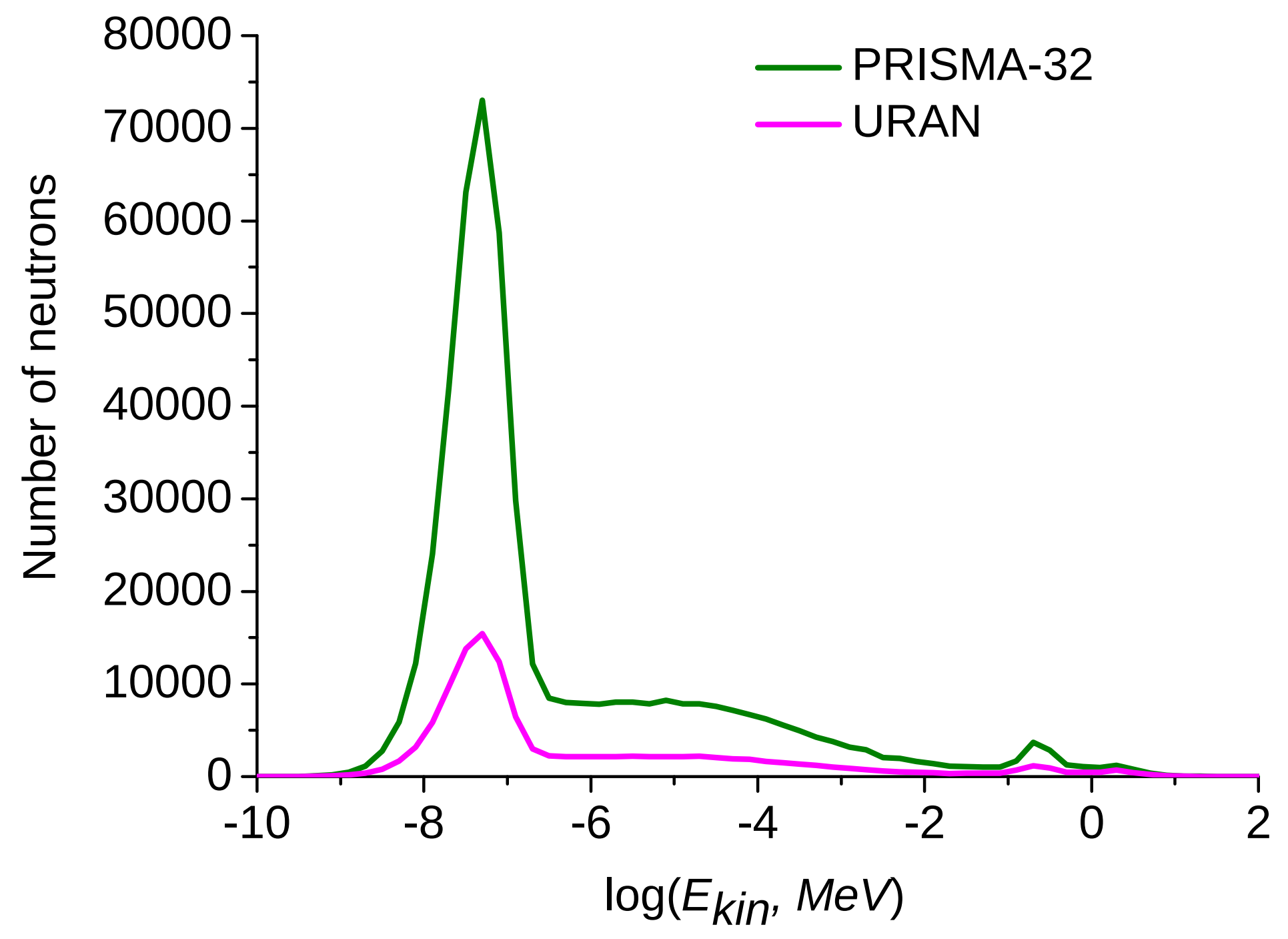


Installation model

A simplified model of the detector represents a scintillation layer with the size and characteristics of real LiF+ZnS(Ag) scintillator. The installation response was considered as appearance of triton and α in the scintillator substance.

Influence of the location

One of the important tasks is to compare the influence of the location of the PRISMA-32 and URAN arrays on the registration of thermal neutrons. For this purpose, the responses of installations to single pions and neutrons of various energies generated above the building roof were calculated.



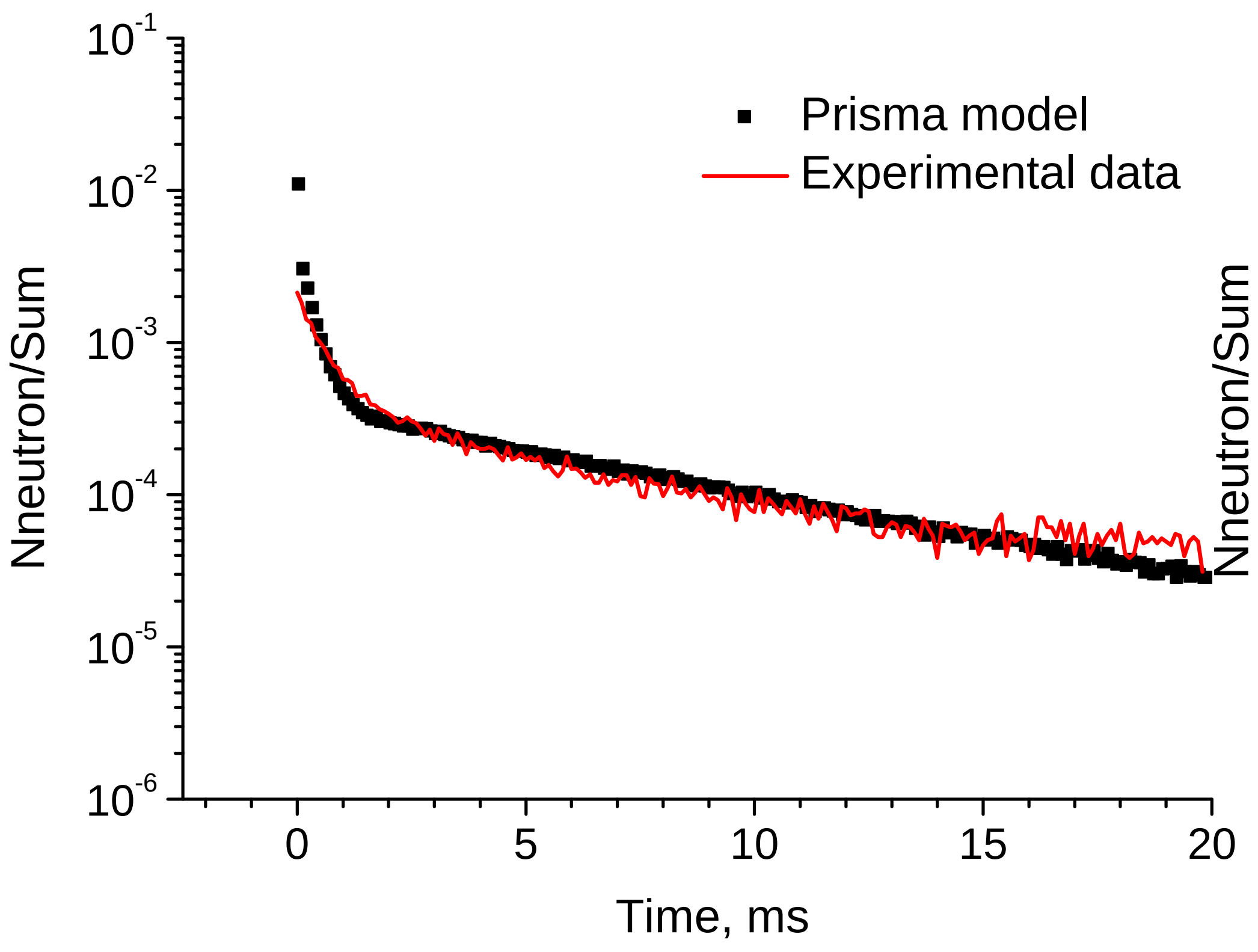
The distributions of thermal neutrons in the kinetic energies

The figure shows the distributions, by the kinetic energies of thermal neutrons registered in the scintillator.

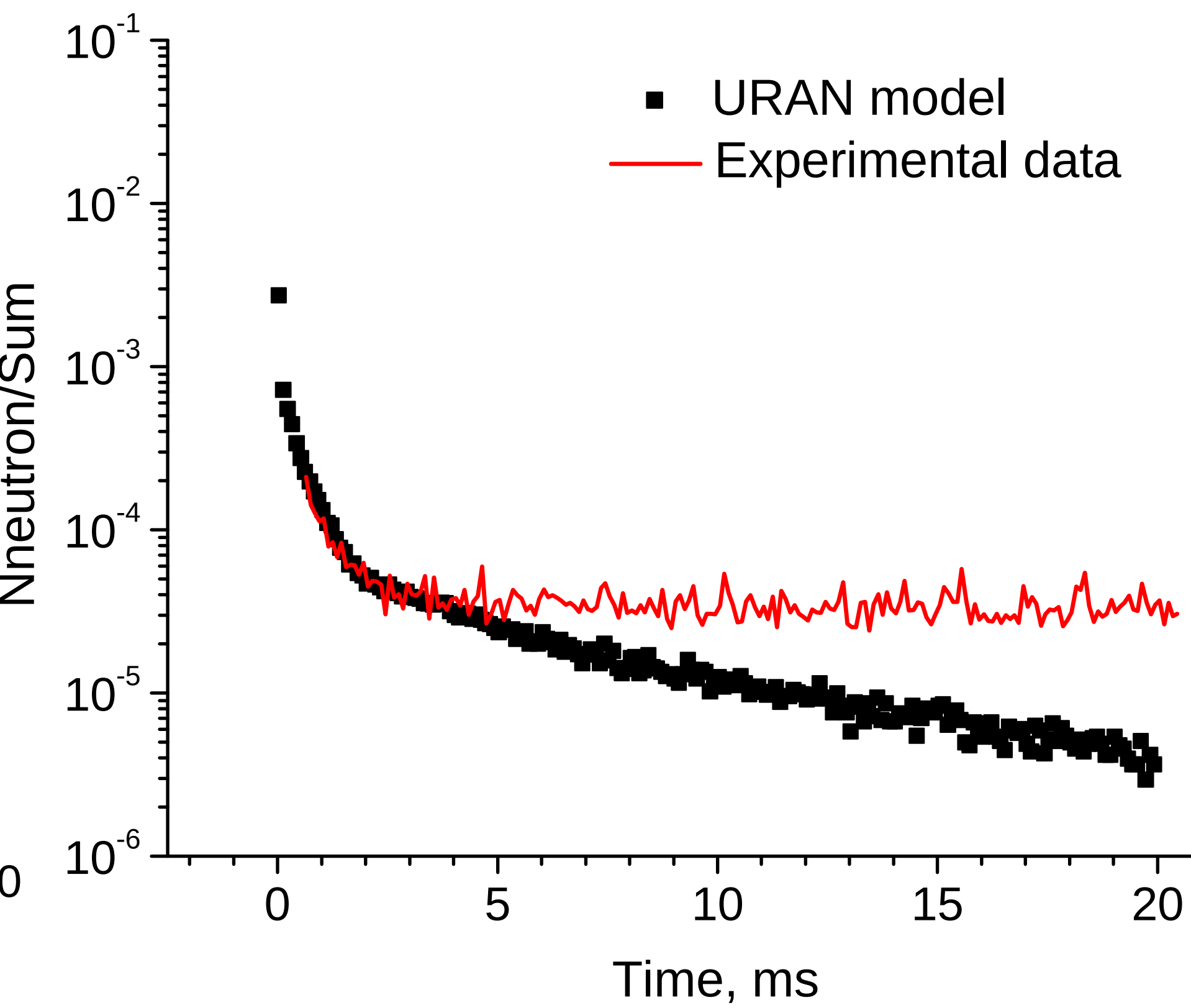
As seen, the location of the facilities has a great influence on the detection of thermal neutrons. The response of the PRISMA-32 array model is 5-6 times higher than the response of the URAN array model.

Temporal distribution

One of the important characteristics of the detector response is the temporal distribution of thermal neutrons. In the experiment the trigger for neutron registration , is the passage of EAS. In the model, π-meson with an energy of 10 GeV was chosen as the initial particle that interacts with the roof of the building. The figure shows a comparison of simulated and experimental temporal distributions of thermal neutrons registered by PRISMA-32 and URAN arrays. These distributions can be described by a superposition of two exponents.



Temporal distribution of thermal neutrons registered by PRISMA-32 array (red line is experimental data, black line is result of simulation)



Temporal distribution of thermal neutrons registered by URAN array (red line is experimental data, black line is result of simulation)

A comparison of the temporal distributions of thermal neutrons according to the results of simulation and experiment is shown in the figure above.

Experiment

t_{1PrEx} = (0.49 ± 0.01)
t_{1UEx} = (0.65 ± 0.20)

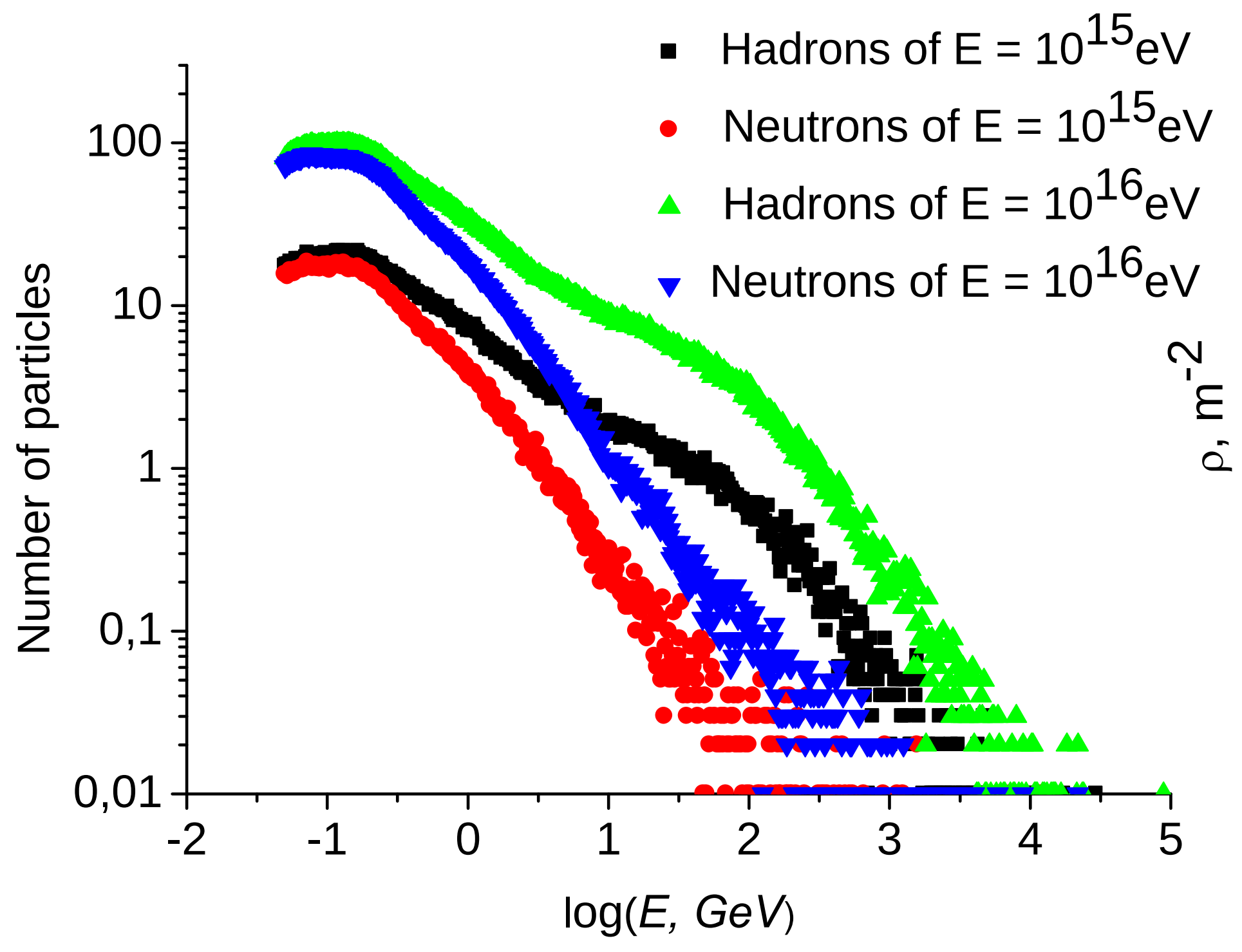
Simulation

t_{1PrMod} = (0.289 ± 0.001)
t_{1UMod} = (0.367±0.004)

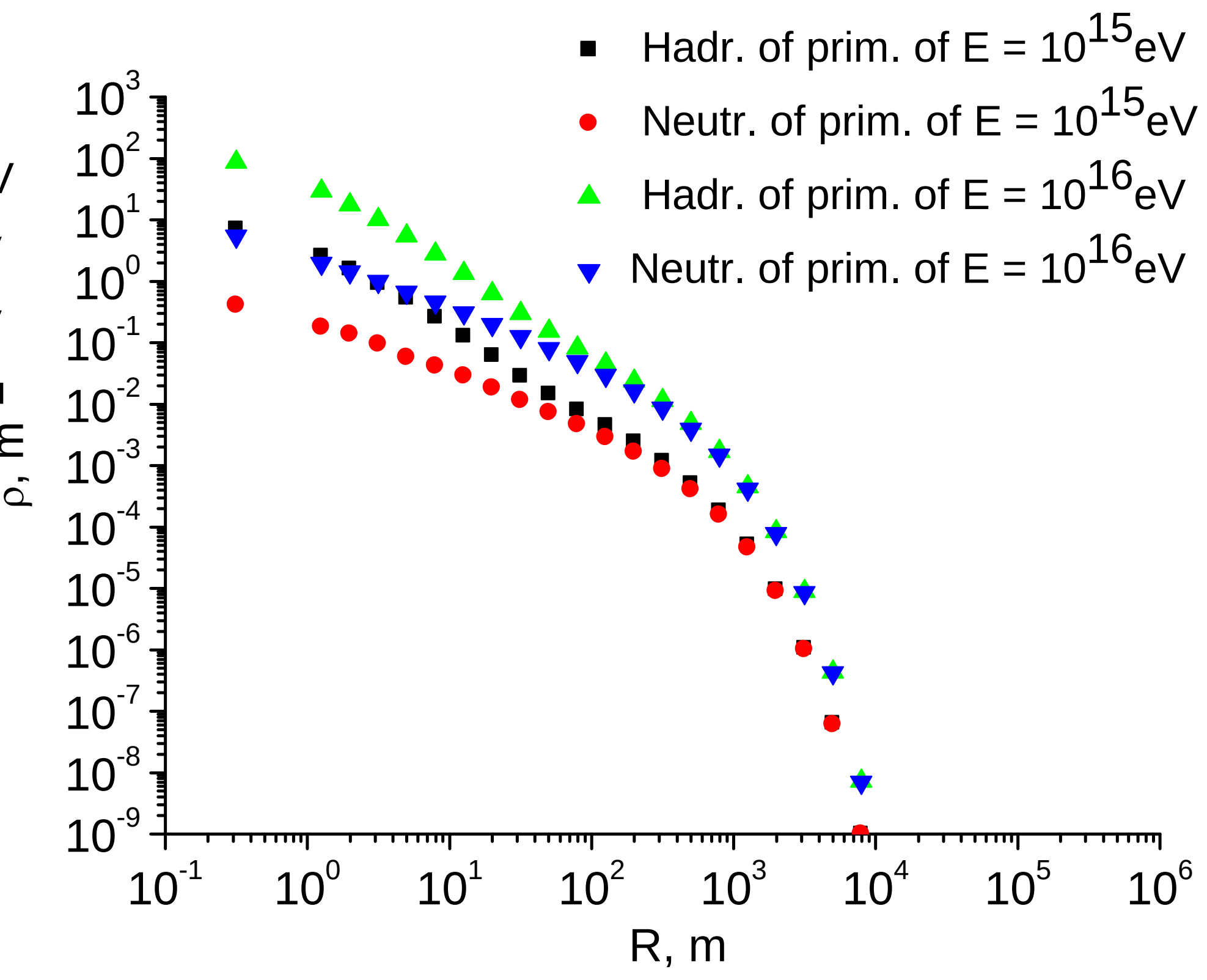
It is seen, temporal distribution of thermal neutrons has a agreement with the simulation results for the first exponent [4], [5]. The absence of the second exponent in the experimental data can be explained by the presence of background.

CORSIKA simulation

Simulation of EAS is carried out using the CORSIKA 7.6900 program [5]. To solve our tasks, the models QGSJET-II-04 (for high-energy interactions) and FLUKA2011 (for lower energies) were chosen. Air showers were simulated for primary protons and iron nuclei for the observation level of of 170 m. The energy ranges of simulated protons are from 1 TeV to 30 PeV, and iron nuclei from 1 TeV to 30 PeV. The energy and spatial distributions of secondary hadrons formed at the building roof level of the are presented below.



Energy distribution of secondary hadrons

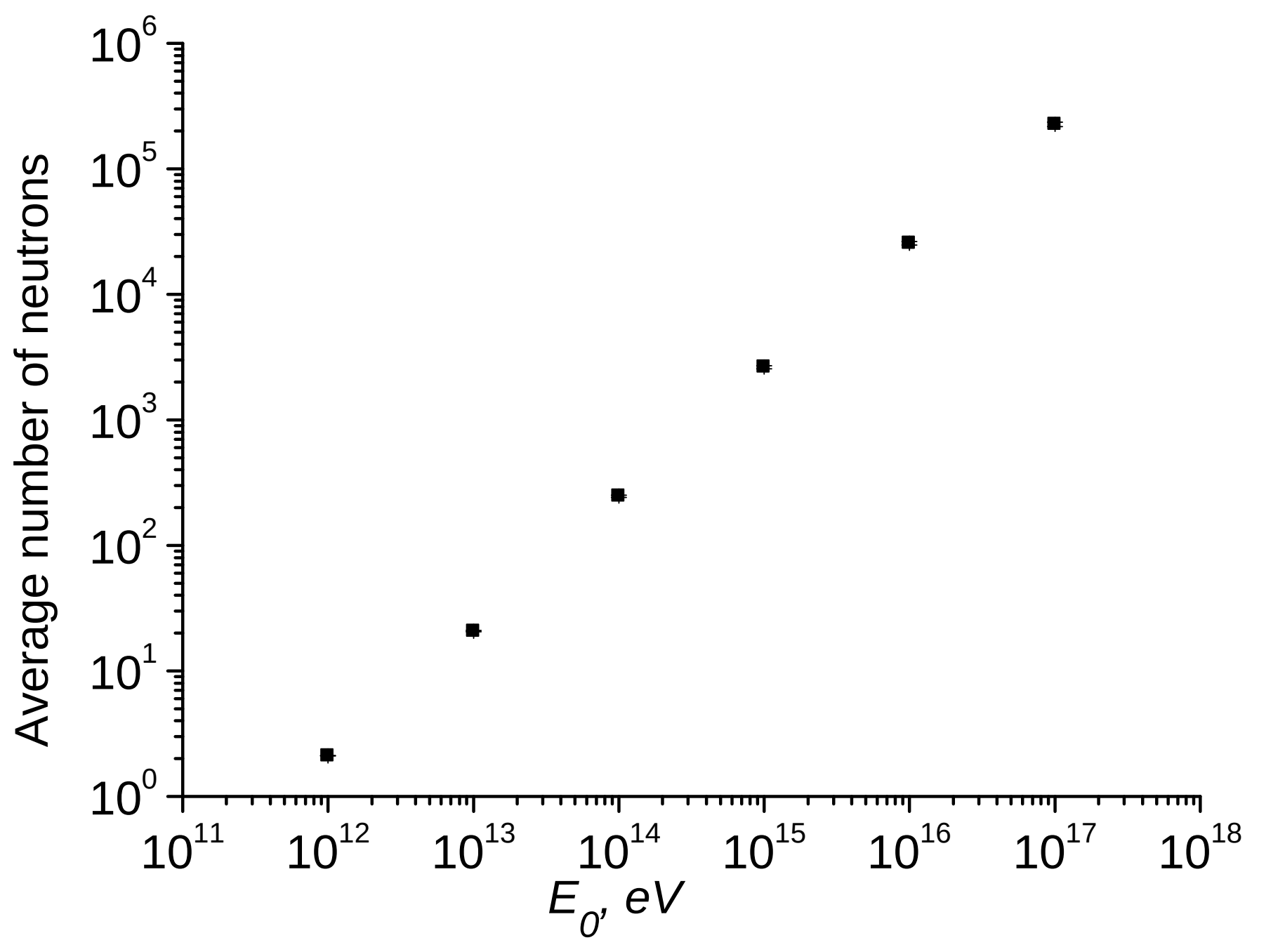


Spatial distribution of secondary hadrons

Typical energies of secondary hadrons are ~ 500 MeV. Particle density at a distance of 1 m from the EAS axis is ~ 1 m^{-2}.

The figure shows the dependence of the average number of neutrons on the energy of the primary particle.

As seen, it is linear on a logarithmic scale.



Dependence of the average number of neutrons on the energy of the primary particle

Conclusions

Thus, in the course of this work we compared the efficiency of neutron registration above and below the roof. The number of neutrons under the roof for the pion energy of E = 10 GeV is about 6 times greater than above it. Temporal distribution calculated by the model is an exponential one, as well as in the experimental data.

For more accurate results, an results of modeling EAS will be used in the future.

Bibliography:

1) Gromushkin D.M. et al. J. Instrumentation 2014 9 C08028
2) Yurin K.O. et al J. Phys.: Conf. Ser. 2017 798 012048
3) http://geant4.web.cern.ch
4) Gromushkin D.M. et al. J. Phys.: Conf. Ser. 2017 798 012202
5) Yashin I.I. et al J. Phys.: Conf. Ser. 2019 1181 012081
6). https://www.ikp.kit.edu/corsika/