

Cosmic ray study using air shower time coincidence arrays ("The Knowledge Showers")

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Introduction

Radiation of all kinds reaches the top of the Earth's atmosphere from outer space. Traditionally, that is astronomy what is the science which studies the electromagnetic radiation of any energy from radio waves through visible light to gamma rays coming from the sky. When we observe particles or atomic nuclei, it is called the cosmic ray physics or since recently "the particle astrophysics". Cosmic rays provide us the information about the high-energy processes in distant stars, thus allowing to study the fundamental particles and forces of nature under conditions far beyond the reach of man-made particle accelerators. The cosmic rays incident upon the Earth are intercepted by the atomic nuclei high in the atmosphere. The "blanket" of air surrounding the Earth acts as a very thick (equivalent to about 3 meters of concrete) radiation shield. As soon as a cosmic particle reaches the atmosphere of the Earth it collides with atmospheric nuclei (oxygen or nitrogen). The products of this collision collide again and so on, thus producing a particle cascade, or air shower (Fig 1 and 2).

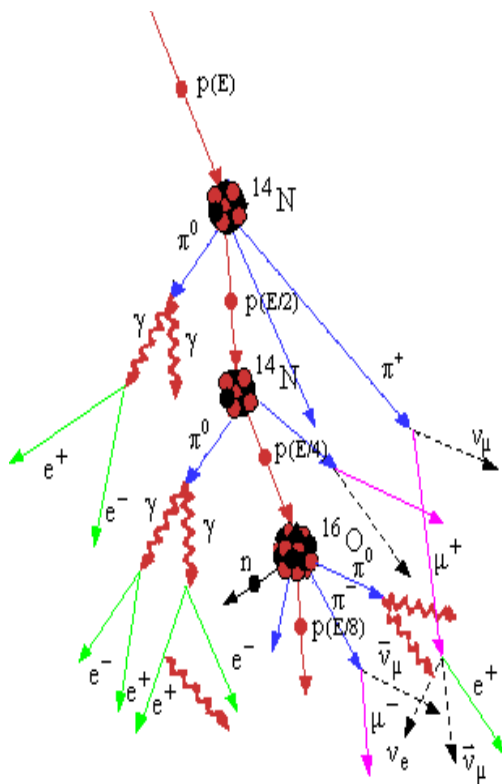


Fig. 1

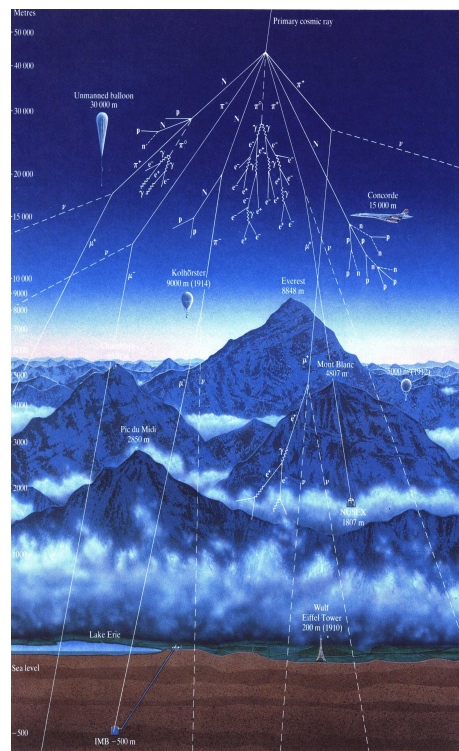


Fig. 2

The more energy a primary cosmic particle possesses, the larger number of secondary particles are produced. Many of these particles reach the sea level and can be detected. Particles originating from a single primary cosmic ray arrive at sea-level almost simultaneously. While developing the cascade, the secondaries are spread over a large area. This area raises along with energy of the primary cosmic ray. Therefore, by detecting particles at sea-level over larger area one probes only

highly energetic primary cosmic rays.

The highest energy rays create spots over the area of more than 10 square kilometers. Naturally, one cannot make a single detector of this size and therefore it is common practice to sample a large area using an array of small detectors to measure the particle density at several locations. These density measurements are combined to calculate the total number of particles at sea-level so that the energy of the primary particle can be estimated. Furthermore, the direction of the primary particle can be determined if precise timestamps are added to each density measurement. This follows from the fact that the secondary particles form a flat pancake moving at the speed of light towards the ground in the direction of the original particle. This pancake will hit the detectors at the ground level at different times when it is not exactly parallel to the ground surface.

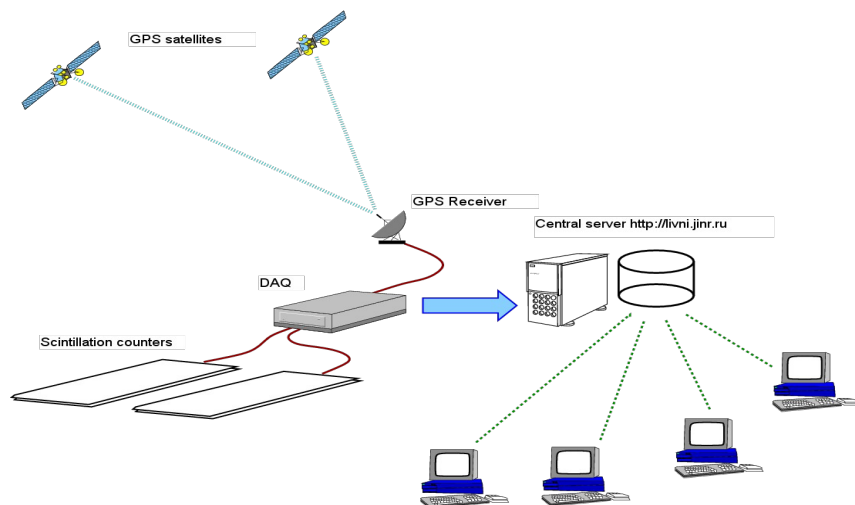
The distributed system for detection of air showers RUSALKA has been constructed at JINR site and takes data continuously since 2009. This project is aimed on learning the principles of the air shower time coincidence array operation, the relevant experimental hardware and the data analysis techniques.

RUSALKA: the distributed system for detection of air showers

The main element of the distributed detector array is a base detection station. The layout of the base station is shown in Fig. 3. The station consists of

- two scintillation counters;
- a GPS receiver, which provides precise absolute timing (<50 ns);
- the data acquisition (DAQ) box, which includes
 - a QNet readout card to obtain the signals from the scintillation detectors and to match them against the timestamp from the GPS receiver;
 - high voltage power supply;
 - low voltage power supply;
 - single board computer connected to the Internet.

Each station measures the absolute time of arrival of particles to the scintillation counters and the signal duration. Requirement of the coincidence of signals from two counters allows to reduce dramatically the random signals caused by the PMT noise or single cosmic muons.



3: Layout of a base detection station

Fig

Currently the distributed system consists of nine base stations, spread around the site of the Laboratory of Nuclear Problems of JINR (Fig. 4). They cover the area within the circle with the

diameter of approximately 300 meters. Such a compact cluster allows to detect air showers with the energy about 10^{13} eV or higher and to determine the direction of primary cosmic particle with an accuracy of about 5 degrees.

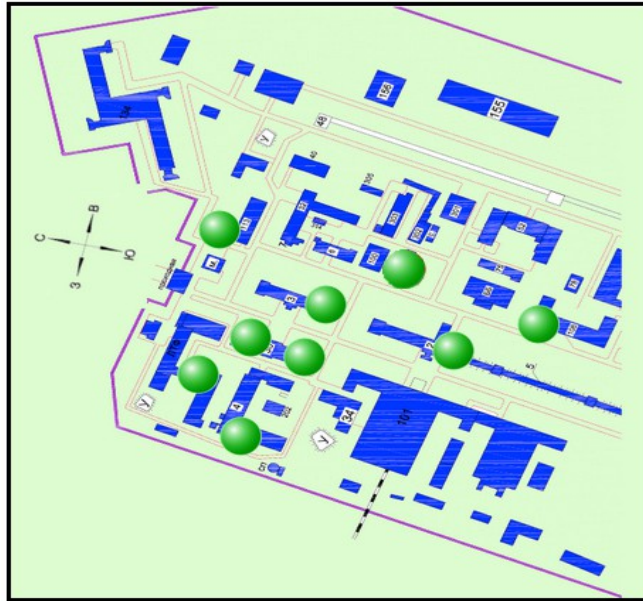


Fig 4: Schematic location of RUSALKA base stations at LNP site.

General research program

Students will learn the following topics:

- General information about cosmic rays
- The idea of air shower detection by the time coincidence arrays.
- Principles of operation of a local RUSALKA detection station including its main elements:
 - Scintillation detector
 - Photomultiplier
 - GPS receiver
 - QNET DAQ card
 - On-line and off-line software

The data analysis is largely done via the web-portal <http://livni.jinr.ru>.

Knowledge of C++ programming language and the ROOT software (<http://root.cern.ch>) is very welcome, but not obligatory.

References

<http://livni.jinr.ru> the site of the project 'The Knowledge Showers'

Introductory books on cosmic ray physics

1. Pierre Auger, *What are cosmic rays*, University of Chicago Press, 1945.
2. R.W.Clay and B.R.Dawson, *Cosmic Bullets*, Allen and Unwin, Sydney, 1987; Helix Books, Addison Wesley, Reading (Mass.), 1998.
3. M.W.Friedlander, *A thin cosmic rain. Particles from outer space*, Harvard University Press, Cambridge 2000.
4. Malcolm S. Longair, *High Energy Astrophysics*, Cambridge University Press; 3 edition, 2011

General papers in cosmic ray physics

1. Bruno Rossi, Interpretation of cosmic-ray phenomena, Rev. Mod. Phys. 20(1948)537

A reference paper with a survey of a vast study of cosmic rays worldwide and some data which can employed for student analysis is

- 2.A.H.Compton, A geographical study of cosmic rays, Phys. Rev. 43(1933)387

Recent review papers of general interest on cosmic ray physics are the following

- 3.J.W. Bieber et al., Cosmic Rays and Earth, Space Science Review 93(2000)1
4. J.A.Simpson, The cosmic ray nucleonic component: the invention and scientific uses of the neutron monitor, Space Science Review 93(2000)11
5. H.V.Cane, Coronal mass ejection and Forbush decreases, Space Science Review 93(2000)55
6. K.Kudela et al., Cosmic rays in relation to space weather, Space Science Review 93(2000)153
7. M.A.Shea and D.F.Smart, Cosmic ray implications for human health, Space Science Review 93(2000)187
8. M.L.Dulding, Muon observation, Space Science Review 93(2000)207
9. M.A.Shea and D.F.Smart, 50 years of cosmic radiation data, Space Science Review 93(2000),229