Measurement of composition of ultra-high energy cosmic rays

The project aims at an experimental study of ultra-high energy cosmic rays (above 1 EeV= 10^{18} eV). Cosmic rays are particles arriving to the Earth from deep space. Most of them have relatively low energies, but some have enormous energies of 100 EeV - more than 10 million times higher than the energies obtained in the largest particle accelerators on Earth. The origin of particles of such high energies is so far unknown. We do not know where in the universe are their sources, nor how they are accelerated to the observed huge energies. This is one of the greatest mysteries of modern astrophysics.

The highest-energy cosmic rays are extremely rare. Therefore, it is necessary to build a huge detector to be able to observe them. The Pierre Auger Observatory located on the Argentine pampa and extending over an area of approximately 3000 km^2 is such a detector. It is currently the largest ultra-high energy cosmic ray observatory in the world. It is not possible to observe the ultra-high energy cosmic rays directly. Cosmic rays penetrating the Earth's atmosphere interact with the air and create cascades of secondary particles that are called extensive air showers. Secondary particles produced by a shower reach the Earth's surface where they are recorded by a network of ground-based detectors. Additionally, we can observe the fluorescence light generated in the atmosphere by the charged particles of the air shower through excitation of nitrogen molecules. Designed as a hybrid detector, the Pierre Auger Observatory uses both methods.

The results obtained so far with the Pierre Auger Observatory have dramatically advanced our understanding of ultra-high energy cosmic rays, however some of the findings are very surprising and their interpretation is difficult within the current cosmic rays paradigm. Undoubtedly, there is an evidence of the suppression of the cosmic rays flux above 40 EeV. While about one particle with an energy of 1 EeV falls on one km^2 of the Earth's surface per year, the flux of particles with energies greater than 100 EeV decreases to less than one particle per km^2 per millennium. Such a suppression was predicted 50 years ago as a result of the particle energy losses en route to the Earth due to interactions with the cosmic microwave background (which is a remnant of the Big Bang) and is known as the Greisen-Zatsepin-Kuzmin cutoff. However, the dependence of the mass composition on energy suggests that the observed suppression of the spectrum can be rather characteristic of the sources of cosmic rays (where the maximum energy to which particles can be accelerated increases with their charge) and not the result of propagation. The knowledge about the composition of cosmic rays is of fundamental importance for interpretation of the Auger data and discriminating between different models of the cause of the observed flux suppression. It follows that very accurate measurement of the mass composition (possibly on event-by-event basis) is essential to understand the nature of cosmic rays.

Currently there are two methods for determining the mass composition of cosmic rays: the study of muon component of extensive air showers via the network of ground detectors and observation of the shower maximum development in the atmosphere by observation of a fluorescence light. However, at present the accuracy of determining these parameters is insufficient to resolve the problem of the nature of flux suppression of the cosmic rays.

The aim of this project is the identification of the primary particles of cosmic rays by studying the muon component of extensive air showers at the Pierre Auger Observatory. In addition, we plan to participate in the upgrade of the Pierre Auger Observatory, to increase the accuracy of determining the mass composition of cosmic rays.