Referee report
on the JINR participation in the

Project TAIGA:
Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy

Gamma ray observatory TAIGA is designed to study gamma-radiation and charged cosmic rays in the energy range of 10^{13} eV – 10^{18} eV. For this energy range there are many fundamental questions with still unknown answers. The first and foremost one is the question about the galactic cosmic rays sources with energies about 1 PeV – the region immediately adjacent to the classical "knee" in the spectrum of all particles ($3{\cdot}10^{15}$ eV), the most likely limit of the acceleration of protons in the galactic accelerators. The energy of gamma rays originated in such accelerators would extend up to 300 TeV, however so far there was not registered a single photon with energy greater than 100 TeV. The flux of gamma-quanta strongly decreases with increasing energy and therefore it is necessary to increase sensitive area of arrays to move towards higher energies.

Up to now, the vast majority of the data of gamma-ray astronomy in the TeV and sub-TeV energy range has been obtained using several imaging atmospheric Cherenkov telescopes (IACT) operating as a stereo systems with a rather small distance of the order of 100 m between IACTs. In such an approach a large number of Cherenkov telescopes is needed in order to build arrays with large sensitive area. The approach is used in the international Cherenkov Telescope Array (CTA) project in which 70 telescopes are distributed over an area of 7 km^2.

In the TAIGA project the IACTs are located at much larger distances of order 600-700 m supplemented by simple and relatively cheap non-imaging Cherenkov stations. Therefore the observatory TAIGA is a hybrid array, combining the imaging with the non-imaging technique of the Extensive Air Showres (EAS) Cherenkov light measurements. The advantage of IACT telescopes (TAIGA-IACTs) combined with a wide-angle timing array (TAIGA-HiSCORE) is a possibility to use information about the characteristics of EAS such as core position, direction, and energy reconstructed by timing array for a separation of events originated from charged cosmic ray particles and gamma quanta by IACT. This allows even for a distance between the IACTs of up to 600 m to maintain a level of hadronic background rejection by a factor ~0.01 at the energy of 100 TeV. Such an approach of the imaging and timing arrays combination to observe the same events is proposed for the first time for gamma ray astronomy.

The main aim of the TAIGA project is to cover a large area of approximately 5 km^2 and to reach the sensitivity for the local source flux of photons at the level of 10^{-13} erg cm^{-2} s^{-1} in the energy range of 30 -200 TeV. At such sensitivity, the TAIGA will compete in this energy range with the largest gamma-ray observatory CTA , the Chiness LHAAS0 project and already operating American-Mexican HAWC array. The TAIGA observatory will be the northernmost gamma-ray observatory, and its location provides advantages for observation of sources with large declinations. So, gamma-ray source in the Tycho SNR, virtually inaccessible for HAWC and LHAASO, will be in the field of view of the TAIGA for 500 hours per year.

TAIGA can make a significant contribution to the understanding of the origin of cosmic rays in the region around the knee in the spectrum of cosmic rays. Moreover it can be done much earlier than the direct satellite experiments will start to operate in this energy region. The TAIGA scientific targets include also searching for photon-axion oscillation, indications of

Lorentz invariance violation etc. giving a link to particle physics experiments in laboratories.

Technical realization of the TAIGA project is quite successful. The main goal of the previous stage, the construction of the first telescope and joint operation of the telescope with wide-angle Cherenkov optical stations, is successfully completed. Also, a number of interesting results were obtained including the energy spectrum of charged cosmic rays, the excess of events from the Crab nebula, the registration of the light signal from the International Space Station. It demonstrates a good quality level of the array hardware and data processing algorithms.

Over the next three years the TAIGA collaboration plans to increase by a factor of 4 (from 0.25 km^2 to 1 km^2) the array area and to deploy an additional 2-3 IACTs. This installation will be the full-fledged prototype of the TAIGA observatory. The expected integral sensitivity of this array for 200 hours source observation in the energy range of 30 – 200 TeV will be about 10^{-12} erg cm^{-2} sec^{-1}, extending the energy range of the existing experiments. The combined operation of the first Cherenkov telescopes of TAIGA-IACT and the TAIGA-HiSCORE array in the energy range of 30-200 TeV is expected to give a good chance to measure the energy spectrum of gamma rays from the Tycho SNR as the main candidate for Pevatron.

The collaboration includes representatives from 7 Russian (MSU, Irkutsk University, JINR, MEPHY, INR, IZMIRAN, Novosibirsk University) and 4 EU (Hamburg University, DESY, Max-Plank Institute for Physics (Munich), Torino University , Institute of Space Science (Bucharest, Romania, which is the JINR member state)) institutions. The TAIGA collaboration consists of experts in the field, thus there is a good reason the believe that the challenging goals can be really achieved.

The JINR group includes 17 scientists and engineers. The main responsibility of the JINR group is the IACT's mechanics manufacturing including the IACT power and motion control electronics. It is planned to produce not less than 3 telescopes at JINR workshop for the time period of 2018 to 2020 without cameras and mirrors. The cameras and mirrors are the responsibility of the other participants of the TAIGA collaboration. However, the JINR group plans to design a cheap variant of the mirror to be used in future. The JINR group also plans to participate in the software development and Monte-Carlo simulation, in data taking and in the off-line analysis. The working plan of the group for the time period of 2018 to 2020 is reasonable and achievable. One can recommend the group to increase its participation in the data processing.

Financial request for 2018-2020 is 50 kUSD per year including 35 kUSD for IACT fabrication and 15 kUSD for scientific trips to participate in the commission, shifts, and conferences. In addition 30 kUSD per year is expected from the Russian, Romanian, Polish, and German grants. The financial request looks reasonable.

In summary, the project TAIGA is very interesting and, in my opinion, the continuation of JINR participation in the project should be approved and fully supported.

EBoos

E.Boos
Professor
Member of PAC