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ЛИСТ СОГЛАСОВАНИЙ ПРОЕКТА

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О Д О Б Р Е Н

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Abstract

For the cosmic gamma-quanta above 30 TeV (high-energy gamma astronomy) there are a number of fundamental questions which presently have no answers, and first of all this is the question of the sources of Galactic CR with ~PeV energies. It should be noted that to date there was not detected a single photon with an energy more than 80 TeV.

Up to now, most data of gamma astronomy in the TeV and sub-TeV energy range have been obtained using imaging atmospheric Cherenkov telescopes (IACT), in particular with stereo systems of several of such telescopes. The gamma-ray observatory TAIGA (Tunka Advanced Instrument for cosmic-ray and Gamma-ray Astronomy) which is under construction in the Tunka Valley, targets the energy range above 30 TeV. The observatory combines several IACTs with a net of comparatively cheap wide-angle non-imaging optical detectors. This allows to extend the area of the device up to several square kilometers and to considerably suppress the background from charged cosmic rays due to the superior angular resolution (~0.1° at energies above 100 TeV). The combination of two complementary methods of gamma-ray separation allows building a device with large area for a relatively low price. TAIGA is the first detector of this kind.

The gamma-ray Observatory TAIGA will include a network of 500 wide field of view (0.6 sr) timing Cherenkov light HiSCORE detectors and up to 16 IACTs with shower image analysis (FOV 10×10 degrees), covering an area of 5 km^2, and the muon detectors with a total sensitive area of 2000 m^2, distributed over an area of 1 km^2. The observatory is placed in the Tunka Valley (50 km from Lake Baikal), at the same place where the EAS Cherenkov array Tunka-133 is located. JINR full responsibility is the IACT's mechanics manufacturing. In addition JINR team participates in shifts in the data taken in Tunka area, MC simulation and physical analysis.

During the nearest 3 years, it is planned to increase the area of TAIGA-HiSCORE 4 times: from 0.25 km^2 to 1 km^2, deploy two new IACTs and 200 m^2 of new muon detectors. With such prototype it would be possible to have a serious scientific program:

1. Study of high-energy edge of spectrum of the most bright galactic gamma-ray sources.
2. Search for Galactic Pevatrons.
3. Apply the new hybrid approach (common operation of IACTs and wide-angle timing array) for study of cosmic rays mass composition in the “knee” region (10^{14}-10^{16} eV).
4. To explore the high energy region of the energy spectrum of the brightest extragalactic source Mkr421.
5. Study of CR anisotropy in the energy region 100 – 3000 TeV.

TAIGA international collaboration consists of more than 70 authors from the 13 scientific groups of Russia, Germany, Italy and Romania that have many years of research experience in the astroparticle studies. Besides the scientific group of Warsaw University participates via JINR. The JINR group includes 17 scientists and engineers. Financial request is ~ 50 k$/year: 35 k$ for IACT fabrication and 15 k$ for scientific trips (Tunka IACT commission, shifts, conferences).

Introduction

The progress in understanding the nature of sources of high-energy cosmic rays from our Galaxy and from the Metagalaxy is going along with experiments registered 3 types of particles: charged cosmic rays, gamma-quanta and neutrinos. The study of secondary gamma quanta, produced by cosmic rays (CR) in the vicinity of the source, where particles are accelerated (experiments H.E.S.S. [1], VERITAS [2], MAGIC [3] , MILAGRO [4], HAWC [5] etc.) is possible to clarify a mechanism of the galactic CR acceleration. About 10 sources with gamma-ray spectra extending up to several tens of TeV have been discovered. This implies that the parent protons or electrons must have been accelerated to several hundreds of TeV.

For the energy range of gamma quanta above 30 TeV there are a number of fundamental questions which presently have no answers. First of all, there is the question of the sources of Galactic cosmic rays with energies around 1 PeV, the energy region approximately adjoining the classical knee in the all-particle energy spectrum. It should be noted that no single photon with an energy of more than 80 TeV has been detected till now.

Up to now, most data of gamma astronomy in the TeV and sub-TeV energy range have been obtained using imaging atmospheric Cherenkov telescopes (IACT), in particular with stereo systems several of such telescopes. The gamma-ray observatory TAIGA (Tunka Advanced Instrument for cosmic-ray and Gamma-ray Astronomy [6, 7] which is under construction in the Tunka Valley, targets the energy range above 30 TeV. The observatory combines several IACTs with a net of comparatively cheap wide-angle non-imaging optical detectors. This allows to extend the area of the device up to several square kilometers and to considerably suppress the background from charged cosmic rays due to the superior angular resolution (~0.1° at energies above 100 TeV). The combination of two complementary methods of gamma-ray separation allows building a device with large area for a relatively low price. TAIGA is the first detector of this kind.

TAIGA observatory will include a network of 500 wide field of view (FOV ~0.6 sr) timing Cherenkov light detectors, named TAIGA-HiSCORE (High Sensitivity Cosmic Origin Explorer [8]), and up to 16 imaging atmospheric Cherenkov telescopes (IACTs) with shower image analysis (FOV ~10×10 degrees), covering an area of 5 km^2, and muon detectors with a total sensitive area of 2000 m^2, distributed over an area 1 km^2. The advantage of IACT telescopes combined with a wide-angle timing array is the possibility to use the image information about the EAS characteristics (core position, direction, energy) for a separation of the CR events from the gamma events that can be better reconstructed by the timing array than by a single IACT. This allows, even for a distance between the IACTs of up to 600 m, to maintain a level of rejection ~0.01 of showers induced by CRs at the energy of 100 TeV. The detection sensitivity for local sources of a 5 km^2 observatory in the energy range of 30 – 200 TeV is expected to be 10^{-13} erg cm^{-2} sec^{-1} for 500 h of observation or 10 detected events which is comparable with planned sensitivity of the main gamma-ray astronomy projects (CTA [9], LHAASO [10]) in this energy range.

Currently array consists of 28 wide-angle optical stations in the area of 0.25 km^2 and one IACT. Up to the end of 2017 it is planned to add additional 32 optical stations. With such prototype of TAIGA array it would be possible to demonstrate advantage of hybrid approach for selection EAS from gamma-rays and study high-energy edge of the most bright galactic sources on the sensitivity level of 10^{-12} erg cm^{-2} sec^{-1} for 200 h of observation. During the 2018-19 the number of wide-angle stations will be increased to 100 in the area of 1 km^2 and 2 additional IACTs will be deployed.

Detailed plans are presented below. Plans in short:

2018.

MC simulation of common operation of IACT telescope. The prototype TAIGA observatory in hybrid mode (common observation by HiSCORE and IACT). Upgrading of software for IACT+HiSCORE data analysis. Study of gamma rays from the Crab nebula. Observation of the brightest extragalactic gamma-ray source Mrk-421. Taking into operation the second IACT. Development and production of IACT mirror facets. Design, fabrication and tests of the third IACT mechanics in JINR workshop.

2019.

Comparison TAIGA-prototype sensitivity with MC – expectation. Selection of the optimal distance between IACTs. Search for gammas E>30 TeV from Mkr-421 in the hybrid mode. Participation in the data taking in Tunka and data analysis. Taking into operation third IACT. Design, fabrication and tests of the fourth IACT.

2020.

Participation in the data taking in Tunka and data analysis. Monitoring of galactic gamma-rays sources. Search for extragalactic ELB and axion-like particles. Design, fabrication and tests of the fifth IACT. Prepare a detailed project of the extension of the prototype to the full TAIGA gamma-ray observatory.

Status of world investigation. Motivation.

Ground-based gamma-ray astronomy. Ground-based gamma-ray astronomy has established itself as an astronomical discipline. Imaging Atmospheric Cherenkov telescopes (IACT) lead to the groundbreaking discovery of TeV gamma-rays from the Crab Nebula. Subsequently, high-resolution PMT cameras with fast readout were developed and the stereoscopic technique with multiple Cherenkov telescopes was introduced by HEGRA. These advances have led to state-of-the-art experiments, such as H.E.S.S. [1], VERITAS [2], and MAGIC [3]. Today, near to 200 sources are listed in the TeV-catalog [11] in the energy range from 100 GeV to a few tens of TeV, but two source with the energy of gamma-rays more than 100 TeV (Fig.1).

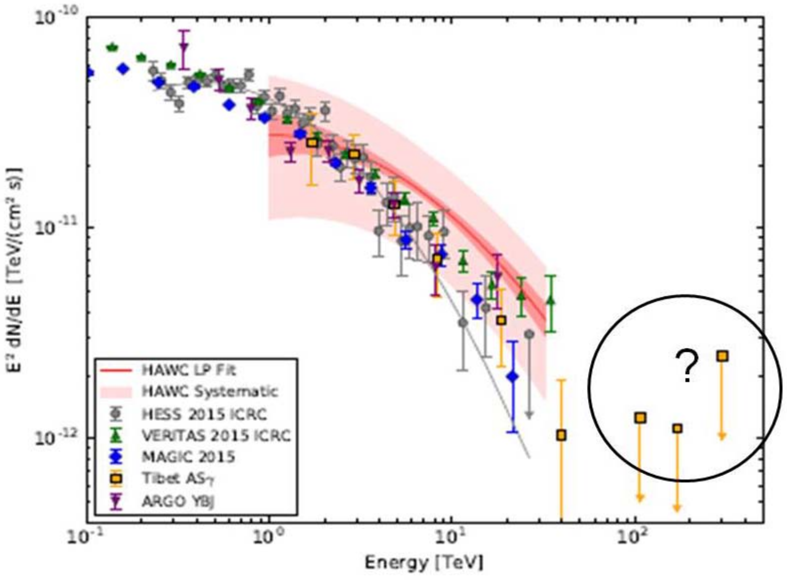

Fig.1 Photon spectral energy distribution (SED) from one the brightest gamma-ray source – Crab nebula.

In this energy range, the stereoscopic (multi-telescope) IACT technique is the most sensitive detection method and is used by the existing instruments and by the planned Cherenkov Telescope Array (CTA) [9]. CTA will provide optimal coverage up to several tens of TeV. Beyond these energies, at multi-TeV to PeV energies, the gamma-ray universe is so far only poorly explored by existent IACT experiments. Multi-TeV observations are particularly important to measure the precise spectral shape of known sources and, finally, to discover the accelerators of Cosmic Rays (CR) up to the knee-region of the all-particle CR spectrum. Based on our current knowledge of the gamma-ray sky up to few tens of TeV, a clear potential can be deduced for gamma-ray observations above these energies. Spectroscopic studies of known objects over a wide range of energy will allow better conclusions and shed light on the underlying acceleration mechanisms. Therefore, observations well beyond the multi-TeV to PeV are necessary.

In the widely adopted view, the Galactic component of charged CR is accelerated in shock fronts at the boundaries of expanding shells of Supernova Remnants (SNR) in the interstellar medium. The interactions of the accelerated particles with the ambient medium produce gamma-rays and neutrinos at very high energies. In order to understand the production of CR in our Galaxy, the cosmic accelerators need to be identified over the full energy range usually attributed to the Galactic CRs. The corresponding Galactic gamma-ray and neutrino signals can be expected to span the energy range from the MeV/GeV range up to several 100 TeV. While the detection of galactic CR neutrinos is a difficult task for IceCube, ANTARES and BAIKAL neutrino experiments, galactic gamma-rays were detected from several SNR.

At MeV/GeV energies, two SNR could be positively identified as accelerators of hadrons via the measurement of the spectral signature for neutral pion decay by Fermi-LAT [12]. In the TeV energy range, no such unambiguous identification was possible so far. The ambiguity results from plausible alternative radiation scenarios, in which accelerated leptons emit synchrotron and inverse Compton radiation up to few tens of TeV[13]. This ambiguity is resolved at higher energies, where the inverse Compton process becomes inefficient. Thus, a gamma-ray spectrum reaching up to few 100 TeV would represent an unambiguous signature for nucleon acceleration. Such energy spectra are expected from the accelerators of PeV cosmic rays, the Pevatrons [14]. In order to compensate for the rapidly dropping CR flux at these energies, a detector area of 5-10 km^2 is necessary.

Higher energy particles can be expected to be released earlier from their acceleration region. This scenario is supported by observations of TeV gamma-rays from molecular clouds in the neighborhood of SNR. Similar measurements at higher energies will help to understand the energy dependence of propagation and the release of CR from their acceleration region.

Another aspect of CR propagation that can be studied with the highest energy gamma-rays is the attenuation of gamma-ray signals due to their absorption by electron-positron pair production in low energy photon fields. The gamma-ray spectra are modified by the absorption effect, making an estimation of the density and shape of the low energy photon field possible. Depending on the energies of the gamma-rays, the absorption effect takes place in different energy bands. With Fermi-LAT and the current generation of IACT experiments, measurements of the extragalactic background photon field were successful in the 0.1-5 m wavelength range. In the region of the cosmic microwave background (CMB), the absorption band is in the several 100 TeV to few PeV range. Here, even Galactic objects will suffer significant absorption, adding to the problem of dropping photon statistics. However, also interesting new possibilities arise: the absorption feature is expected to be sharp and only dependent on the distance to the object. Measuring this sharp CMB absorption feature then allows to measure the distance to the object from the gamma-ray energy spectrum. Finally, high energy photons could be converted into axion-like particles propagating without attenuation through the interstellar medium, therewith reducing or modulating the CMB absorption effect.

A question that recently arose is the acceleration in ultra-relativistic plasma, as occurring in pulsar winds or in the jets of active galactic nuclei. For example, it appears that in the Crab Nebula system electrons are accelerated up to PeV energies within hours, giving rise to transient gamma-ray fluxes. Such transient events can be expected to occur in other systems as well. Their observation requires large effective detector areas of the order of 5 km^2 or more.

Ground-based gamma-ray experiments. Beyond 10 TeV, the rapidly decreasing fluxes require a large effective detector area. Further requirements are a good directional resolution for pinpointing the observed accelerators or for resolving source morphologies, good energy resolution for spectroscopic studies, and a good gamma-hadron separation. However, due to the requirement of a very large instrumented area, the feasibility of a large stereoscopic IACT array is limited by the implied very large number of (PMT) channels per km^2. Ground-based non-imaging air-shower detectors require less channels per area (about a factor 10 less), and are used by most existing and planned experiments accessing the multi-TeV energy regime. These detectors measure the arrival-time distribution and density of particles or photons on the ground. While approaches such as HAWC [5], and LHAASO [10], located at an altitude above 4 km, mainly use charged particle detectors (the latter experiment also planning to use IACTs at low energies), the timing of the air shower front is best measured using the Cherenkov photons emitted by the secondary air shower particles. Such Cherenkov timing-arrays fulfill most of the above mentioned requirements, providing an angular resolution of the order of 0.1◦ and energy resolution of better than 15%, as compared to 1◦ and 100% for particle shower front sampling techniques (also see [15]).

Previous timing array experiments were realized on a smaller scale, e.g. THEMISTOCLE [16], AIROBICC [17], Tunka-25[18]. With an instrumented area of less than 0.1 km^2 no source detections above 10 TeV were possible then. While the currently operating Tunka-133 experiment [19,20] does implement the Cherenkov timing-array technique, its energy threshold is too high for gamma-ray astronomy. Presently the Tunka-133 experiment data have a common recognition of the CR community. The TAIGA collaboration aims at a combination of the Cherenkov timing-array, the Cherenkov imaging, and the particle detector techniques.

The subject of investigation, data taking and off-line analysis methods, theoretical models, JINR responsibility, plans and expected results.

TAIGA observatory [6,7] will include a network of 500 wide field of view (FOV ~0.6 sr) timing Cherenkov light detectors, named TAIGA-HiSCORE (High Sensitivity Cosmic Origin Explorer), up to 16 Imaging Atmospheric Cherenkov Telescopes (IACTs) with shower image analysis (FOV ~10×10 degrees), covering an area of 5 km^2, and muon detectors with a total sensitive area of 2000 m^2, distributed over an area 1 km^2. The advantage of IACT telescopes combined with a wide-angle timing array is the possibility to use the image information about the EAS characteristics (core position, direction, energy) for a separation of the CR events from the gamma events that can be better reconstructed by the timing array than by a single IACT. This allows, even for a distance between the IACTs of up to 600 m, to maintain a level of rejection ~0.01 of showers induced by CRs at the energy of 100 TeV (Fig.2 A). The array sensitivity for local sources of a 5 km^2 observatory in the energy range of 30 – 200 TeV is expected to be 10^{-13} erg cm^{-2} sec−1 for 500 h of observation or 10 detected events (Fig. 2 B).

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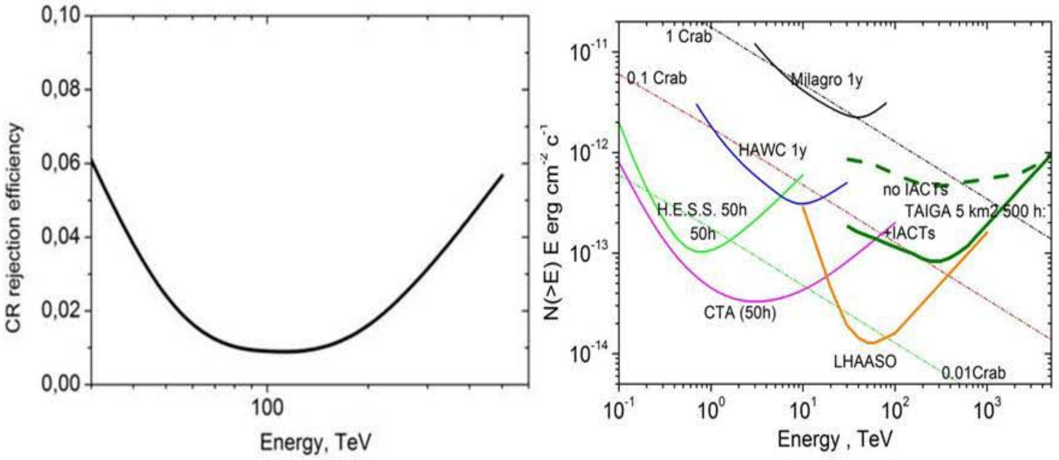

A B

Fig. 2. A: Cosmic rays rejection efficiency. B: Integral sensitivity for point-like sources for a 5 km^2 observatory. The dashed line marks the sensitivity without IACTs.

Comparison of the sensitivity of existing and planned facilities shows that the sensitivity of the TAIGA observatory for registration of gamma-quanta with energies above 100 TeV is not worse than the most ambitious modern projects (LHAASO, CTA).

The main scientific topics of TAIGA array:

- Gamma-ray astronomy - one of the most intriguing questions in high-energy astroparticle physics is a search for galactic objects for accelerating of particles up to PeV-energies (the so-called Pevatrons); Very High Energy (VHE) spectra of known sources: where do they stop; absorption in Infrared Radiation (IR) and Cosmic Microwave Background (CMB); diffuse emission from the galactic plane and local supercluster.
- Charged CR physics – the energy spectrum, mass composition and cross-section measurements from 10^{14} to 10^{18} eV.
- Particle physics - axion/photon conversion; hidden photon/photon oscillations; Lorentz invariance violation; pp cross-section measurement; search for quark-gluon plasma phenomena.

TAIGA-IACT.

The Imaging Atmospheric Cherenkov Telescope (IACT) is of Davis-Cotton type with 34 mirrors, 60 cm diameter each, the focal length is 4.75m, the IACT camera comprises 560 PMTs of XP1911 type with 2 cm photocathode diameter. The FOV of the camera is 10^{o} × 10^{o}[21]. The camera consists of identical clusters, each with 28 PMTs (Fig. 3, left). The basis of the cluster electronics is a 64-channel ASIC MAROC-3. Each channel includes a preamplifier with adjustable gain, a charge sensitive amplifier and a comparator with adjustable threshold. This chip has a multiplexed analog output signal which is proportional to the input charge. The chip is connected to a 12-bit external ADC. The signals from each PMT go to 2 channels with gains different by a factor 30. This results in a full dynamic range of 3000 photoelectrons. In December 2016 the first TAIGA-IACT was put into operation (Fig. 3, right).

Fig. 3. Left figure: Cluster of 28 PMTs. Right figure: The first TAIGA-IACT.

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The main technical requirements for the IACT are given in the following list:

1. The spherical shape mirror facets of D~60 cm and with a total mirror area of ~ 9 m^2.
2. Focal distance ~4750 mm and FOV ~ $\pm 5^o$.
3. Turn range around the horizontal axis (zenith angle) $-10+95^o$.
4. Turn range around the vertical axis (azimuthal angle) $0-420^o$.
5. Setting angular accuracy 0.01^o.
6. The photo camera block of 750x750x400 mm^2 size consists of ~560 PMT matrix with FE and DAQ electronics. The 15 mm useful diameter of the PMT photocathode will be used together with 30 mm input and 15 mm output size Winston cones. It provides the IACT angular resolution at the level of $0.02-0.03^o$.
7. The camera weight is ~200 kg and fixed by carrier support at the focal 4500±1 mm distance from the mirror at the common with the mirror support structure.
8. Service conditions – temperature from minus 40 till plus 30^o C, wind up to 15 m/sec.

The IACT camera and electronics design, tests and production are a responsibility of the MSU, MEPhI members of the TAIGA collaboration. JINR group participates in the production and tests of the IACT electronics. JINR full responsibility is the IACT's mechanics manufacturing including the IACT power and motion control electronics.

The mirror facets are supposed to be bought in a specialized company-producer that has already an experience. Simultaneously JINR plans to develop of IACT mirror facets production itself.

TAIGA-HISCORE

Currently, the TAIGA-HiSCORE array is composed of 28 optical stations distributed in a regular grid over a surface area of 0.25 km^2 with an inter-station spacing of 106 m. Each optical station contains four large area PMTs with 20 or 25 cm diameter, namely EMI ET9352KB, or Hamamatsu R5912 and R7081. Each PMT has a Winston cone with 0.4 m diameter and a 30^o viewing angle (field of view is 0.6 sr). The anode signals of all 4 PMTs of the station are summed up. It leads to additional lowering of the energy threshold by a factor of 2. Each station is connected with the DAQ center by a fiber optic cable for data transfer and synchronization. The synchronization stability of the optical stations reaches about 0.2 ns. Precision calibration is achieved by external light sources. Reconstruction of shower parameters was performed using algorithms developed for the Tunka-133 array [20]. Arrival directions of showers are determined by the relative delay of Cherenkov light at each station. In a first step, the arrival direction is reconstructed with a plane wave model of the front. This reconstructed direction is used in the reconstruction of the EAS core. The pulse amplitude is fitted by a parameterization of the Amplitude Distance Function (ADF) [20]. The final EAS arrival direction is reconstructed for the found core position assuming a curved front of the shower.

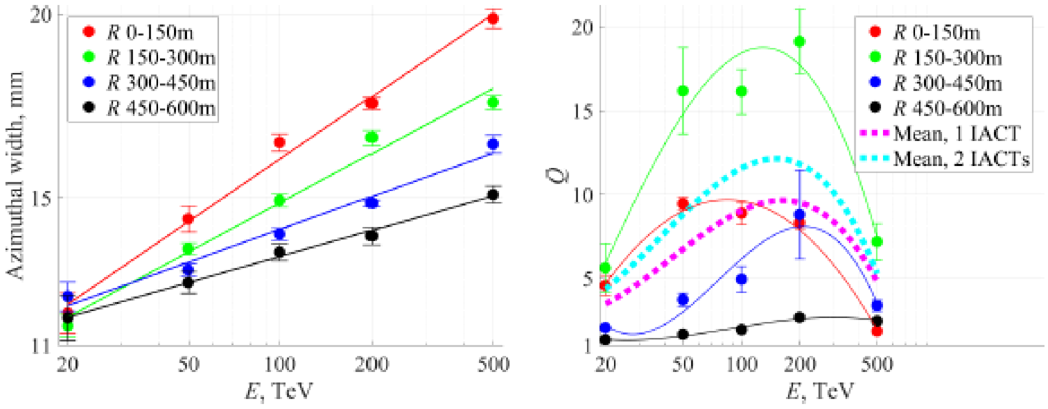
Scientific background

MC simulation of common operation of TAIGA-HiSCORE and IACTS [22,23]. The modeling of the telescope data has been done in two consecutive steps: firstly the simulation of the EAS using the program package CORSIKA [24], and secondly the calculation of the number of resulting Cherenkov photons which are reflected by the mirror of the IACT and registered by a camera of 560 PMTs in its focal plane. The input data from the non-imaging device are parameters which had been derived from the relative arrival times of the photons recorded by different detector stations: the primary energy, the direction and the position of the EAS. The direction of the primary gamma ray was fixed according to the investigated point source location, and the angle of the simulated background proton showers was varied within 0.4^o around that direction, considerably wider than the actual angular resolution of the device. For each EAS in the data bank different image parameters in the IACT have been calculated, and for each configuration of these parameters we calculated the factor of background suppression:

$$Q = \varepsilon_\gamma \ / \ \sqrt{\varepsilon_{proton}}$$

where ε_γ and ε_{proton} are the fraction of events, classified as gamma-ray events from samples of true gamma-ray events and of proton-induced air showers, respectively.

The optimum parameters of the IACT image are its width perpendicular to the direction towards the center of the camera (*azwidth* [25], from “azimuthal width”), and the width in the direction perpendicular to the direction of the axis of the shower (*azcorewidth*, from “azimuthal core width” which is introduced in the [22]. The efficiency of the second parameter depends on the accuracy with which the shower axis is determined. For an accuracy of 10-15 m, the Q-factor from this parameter exceeds the Q-factor from the parameter *azwidth* only for events at more than 450 m distance of the shower axis. The optimum parameters from the non-imaging detectors to be combined with the IACT parameters are all three investigated parameters: the primary energy, the position of the shower axis, and the EAS direction. The optimum way to combine these two groups of parameters – imaging and non-imaging – is to include in the gamma-ray separation procedure the dependence of the threshold values of *azwidth* and *azcorewidth* from energy and shower axis distance (Fig.4 left). Thereby we reach Q > 5 for energies 100-200 TeV and distances up to 450 m (Fig. 4b).



A B

Fig.4 A: Selection cut depending on energy for different distances.
B: Q factor depending on energy and distance. The dashed lines are averaged over the whole installation area with one or two IACTs.

As follows from the Q factor dependence on the core distance, we can successfully use only one single IACT for efficiently selecting gamma ray showers up to ~450 m in a hybrid installation. This situation differs from a stand-alone IACT, when the distance ~100–150 m is a limit. Therefore, the distance between two or more IACTs (if any) as parts of a hybrid installation can be significantly greater than in a stereoscopic system of IACTs. In particular, the expected location of the second IACT in TAIGA is supposed to be ~300 m apart from the first one.

Results from the first season of TAIGA-HiSCORE operation.

Energy spectrum [26,27]. About 10 million EAS with simultaneous hits in 4 or more stations were recorded during the 35 clean moonless nights of the 2015-2016 winter season. The total time of data acquisition was 210 hours. The energy spectrum obtained by above described procedure is shown in Fig. 5. The energy threshold of almost 100% efficiency of registration is about 250 TeV. Events with zenith angles less than 15^o are used to reconstruct the CR spectrum below 10^{15} eV and events with zenith angles less than 40^o are used for higher energies. Our preliminary spectrum is compared with the results of previous experiments in the Tunka Valley, as well as with the results of the direct balloon experiment ATIC-2[28] and the satellite experiment NUCLEON[29] in Fig. 5. Data taking of the latter experiment is ongoing and one can expect increased statistics by at least a factor of 5 by the end of its operation. Presently the extrapolation of our spectrum to the lower energies does not contradict the results of the direct experiments within their statistical errors.

Search for gamma rays from Crab. The Crab Nebula with the pulsar at its center is the most prominent and most studied source of TeV gamma-ray astronomy. Therefore, it is used as a standard candle for calibration of gamma - ray telescopes. The maximum full observation time of the source for the described HiSCORE array is about 230 hours per year. The typical observation time is two times less due to bad weather. In the winter of 2015-2016 the achieved observation time was about 60 hours. The expected number of gamma quanta from the Crab is 10-25 events for 100 hours of observation, depending on the used extrapolation of the spectrum from low energies. The experimental measured event excess within a 0.4^o bin around the Crab direction is compatible with those expectations.

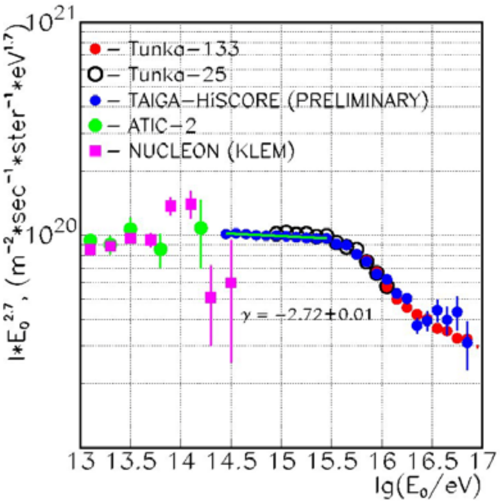


Fig. 5.The energy spectrum of primary cosmic rays from the data of the TAIGA-HiSCORE array in comparison with the results of other experiments.

Signal from Lidar and ISS [30]. The first fast moving point similar to a CR source was detected with TAIGA-HiSCORE, while observing the night sky during this winter-season: a LIDAR operating on board of the ISS. This ISS light source is an interesting object for TAIGA detectors calibration.

The first images in TAIGA-IACT. In December 2016 the first TAIGA-IACT was put into operation. The more systematic registration of EAS was started at the end of January. They were already found showers registered both by IACT and by TAIGA-HiSCORE. Example of such event is in Fig 6. The energy of these showers is 700 TeV. Core position at 200 m from IACT, the expected rate of such events are in good agreement with MC simulation. Data processing is going on and the first results of hybrid analysis will be presented at summer conferences.

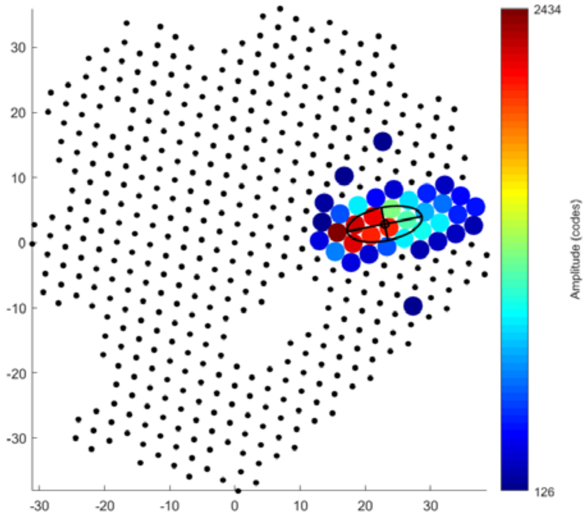


Fig.6. One of the images of showers from 30.01 2017

Plans for 2018-2020

During this year we plan to deploy additional 32 optical stations. Array configuration at the end of this year is presented in Fig.7. Yellow point – position of the first IACT.

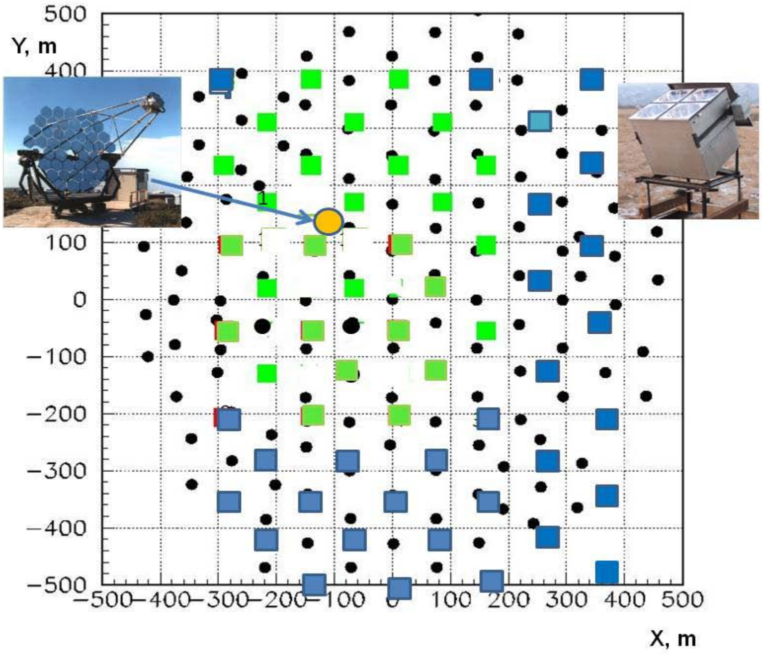


Fig.7 Array configuration at the end of 2017.

Presently the second IACT fabrication is underway at the JINR with the purpose to install it in Tunka area in this year autumn after the general combined mechanical tests at the JINR workshop. It is planned to install this telescope at the end of this year in Tunka. During 2018-19 it is planned to deploy additional 40 stations (100 stations on 1 km^2 area) and put into operation more IACTs.

2018.

1. MC simulation of common operation of IACT telescope and wide-angle Tunka-HiSCORE array and optimization approach to background rejection in selection events from gamma-rays.
2. To conduct the monitoring sessions of the brightest gamma-rays source by the prototype TAIGA observatory in hybrid mode (common observation by HiSCORE and IACT). Upgrading of software for IACT+HiSCORE data analysis.
3. Study of gamma rays from the Crab Nebula in the energy range of 2 – 10 TeV (during the autonomous operation of the telescope) and prove thereby the correctness of the telescope and data-processing procedures. Observation of the brightest extragalactic gamma-ray source Mrk-421.
4. Taking into operation the second IACT.
5. Design, fabrication and tests of the third IACT mechanics in JINR workshop.

2019.

1. Compare experimental sensitivity of TAIGA-prototype with MC –expectation. Select the optimal distance between IACTs.
2. Search for gamma-rays with energy more that 30 TeV from an extraterrestrial source Mkr-421 in Hybrid mode of observation.

3. Participation in the data taking in Tunka and data analysis.
4. Taking into operation the third IACT.
5. Development and production of IACT mirror facets.
6. **6.** Design, fabrication and tests of the fourth IACT mechanics, including mirror facet production in JINR workshop.

2020.

1. Participation in the data taking in Tunka and data analysis.
2. Monitoring of galactic gamma-rays sources.
3. Search for extragalactic ELB and axion-like particles on the basis of observations of high energy edge of gamma-ray spectrum from Mkr-421.
4. Design, fabrication and tests of the fifth IACT mechanics, including mirror facet production in JINR workshop.
5. **5.** Prepare a detailed project of the extension of the prototype to the full TAIGA gamma-ray observatory.

Difficulties:

1. According to the plan, TAIGA project has 60 k$ for 2017 for the second IACT fabrication. Presently (May 2017) it was possible to obtain ~420 kRub or 6.5 k$. With no financial support as now it will be impossible to fulfill our plans.
   We hope to sign a contract with IGU group of TAIGA to get some financial support and we suppose to send an application for BMBF grant of Germany.
2. There is a danger that there will be no money in collaboration to buy mirror-facets in the GALACTIC company in Armenia - a specialized company-producer. It will be crucially important to JINR group to produce the mirror ourselves. This activity is underway in JINR.
3. Presently ~800 PMTs are available for IACT. This is not sufficient and is unknown where will be obtained additional PMTs.

TAIGA international collaboration consists of the 13 scientific groups of Russia, Germany, Italy and Romania.

1. Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia
   - data analysis, IACT camera fabrication , DAQ , MC-simulation
2. Institute of Applied Physics, ISU, Irkutsk, Russia
   - Tunka infrastructure, data taken, control electronics for IACTs and HiSCORE ,deployment of new stations
3. Institute for Nuclear Research of RAS, Moscow, Russia
   - IACT camera fabrication, muon detectors
4. Dipartimento di Fisica Generale Universiteta di Torino and INFN, Torino, Italy
   - HiSCORE MC-simulation and data analysis
5. Max-Planck-Institute for Physics, Munich, Germany
   - Methodical question IACTs construction and calibration , data analysis, HiSCORE PMTs
6. Institut für Experimentalphysik, University of Hamburg, Germany
   IACT mirror facet production, HiSCORE and IACT MC-simulation
7. IZMIRAN, Moscow Region, Russia
   - theoretical support
8. DESY, Zeuthen, Germany
   - IACTs PMTs, data analysis, MC-simulation
9. National Research Nuclear University MEPhI, Moscow, Russia
   - data analysis, IACT camera fabrication , MC-simulation
10. JINR, Dubna, Russia
    - full responsibility in design, fabrication and tests of IACTs mechanics in JINR workshop, participation in the software development and Monte-Carlo simulation, in data taking in Tunka area and in off-line analysis. Development and production of IACT mirror facets
11. Novosibirsk State University, NSU, Novosibirsk, Russia
    - design and fabrication muon detectors
12. Budker Institute of Nuclear Physics SB RAS, Novosibirsk, Russia
    - design and fabrication muon detectors

13 ISS, Bucharest, Romania
   - IACT electronic components, made a financial contribution as JINR member-state

Besides group of Warsaw University express their interest to join TAIGA and made a financial contribution as JINR member-state.

Spokepersons: L. Kuzmichev, SINP MSU and R.Mirzoyan, MPI Munich.

Full JINR responsibility for design, fabrication and tests of the IACTs (including mirror facet production since 2019) at JINR workshop. The JINR group supposes to participate in the software development and Monte-Carlo simulation, in data taking in Tunka area and in off-line analysis (including mirror facet production since 2019) at JINR workshop. JINR responsibility for HiSCORE and muon detectors are limited by assistance with customs problems due to JINR-BMBF agreement of scientific collaboration.

List of the TAIGA project participants

Name	employment	involvment	PhD	Age
1. V. Boreyko	engineer	100%	no	>40
2. A.Borodin	senior scientist	100%	yes	>40
3. A.Demenko	designer	100%	no	>40
4. N.Gorbunov	head of sector	10%	yes	>40
5. V. Grebenyuk	senior scientist	70%	yes	>40
6. A. Grinyuk	engineer	50%	in preparation	<40
7. A. Kalinin	engineer	50%	yes	>40
8. M. Lavrova	engineer	30%	no	<40
9. S. Porokhovoy	engineer	20%	no	>40
10. V.Romanov	designer	10%	no	>40
11. Ya.Sagan	graduated student	100%	no	<40
12. B. Sabirov	scientist	20%	no	>40
13. S. Slepnyov	senior scientist	20%	yes	>40
14. M. Slunecka	senior scientist	10%	yes	>40
15. V.Temirbulatov	engineer	50%	no	<40
16. A. Tkachenko	scientist	20%	in preparation	<40
17. L. Tkachev	head of sector	80%	yes	>40

Presentation at TAIGA collaboration meetings : A.Borodin, A.Grinyuk, L.Tkatchev
Presentation of TAIGA at conferences : A.Grinyuk, L.Tkatchev

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Form № 29

Expenditure for project (K$)

Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy (TAIGA)

Expense items	Total	2018	2019	2020
Direct expenditure				
1. LNP Design bureau (hours)	1000	800	100	100
2. LNP Workshop (hours)	2400	800	800	800
3. NPO “Atom” (hours)	60	20	20	20
4. Materials	45	15	15	15
5. Equipment	45	15	15	15
6. Research work (contracts)	15	5	5	5
7. Business trips, including:				
- to states outsides rouble zone	24	8	8	8
- to states insides rouble zone	21	7	7	7
Total direct expenditure	150.0	50	50	50

Project leader	L.Tkachev
LNP Director	V.Bednyakov
Leading economist engineer	G.Usova

Form № 26

Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy (TAIGA)

Proposed time-schedule and necessary resources for implementation of project (k$)				
Parts and systems of set-up , resources and sources of financial support	Costs of parts of set-up. Required financial support	2018	2019	2020
LNP Design. Bureau, hours LNP Workshop, hours NPO "Atom", hours	1000 2400 60	800 800 20	100 800 20	100 800 20
Project total	150.0	50	50	50
JINR budget	150.0	50.0	50.0	50.0
Extra-budgetary: from grants, agreements (Russia, Romania, Poland, Germany grant BMBF)	90.0	30.0	30.0	30.0

Project leader	L.Tkatchev
LNP Director	V.Bednyakov
Leading economist engineer	G.Usova

Форма № 26

Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy (TAIGA)

Предлагаемый план-график и необходимые ресурсы для осуществления проекта ТАЙГА

Наименование узлов и систем установки, ресурсов, источников финансирования			Стоимость узлов установки (тыс. долларов) Потребности в ресурсах	Предложения Лабораторий по распределению финансирования и ресурсов.		
				2018	2019	2020
Необходимые Ресурсы	Нормо-часы	КБ ЛЯП	1000	800	100	100
		НПО АТОМ	60	20	20	20
		ООЭП ЛЯП	2400	800	800	800
Источники финансирования	Бюджет	Затраты из бюджета	150.0	50.0	50.0	50.0
	Внебюджетные средства	ИГУ* грант РФ Румыния грант Польша грант ФРГ, грант BMBF	90.0	30.0	30.0	30.0
	ИТОГО		240.0	80.0	80.0	80.0

* Договор между ИГУ(Иркутск) и ОИЯИ из средств по грантам Правительства РФ.

Руководитель проекта	Л.Г.Ткачев
Директор ЛЯП	В.А.Бедняков
Ведущий инженер-экономист Лаборатории	Г.А. Усова