PROCEEDINGS OF SCIENCE

The TAIGA-1 – a hybrid complex for gamma-ray astronomy, cosmic ray physics and astroparticle physics

A. Vaidyanathan[a,*] **for the TAIGA Collaboration**
(a complete list of authors can be found at the end of the proceedings)
[a] *St. Thomas College (Autonomous), Thrissur, India*
E-mail: arunneelakandaiyer@hotmail.com

The physical motivations and performance of the TAIGA (Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy) project are presented. The TAIGA astrophysical complex addresses ground-based gamma-ray astronomy at energies from a few TeV to several PeV and cosmic ray physics from 100 TeV to several EeV and astroparticle physics. The pilot TAIGA-1 complex is located in the Tunka valley, ~50 km west of the southern tip of lake Baikal. It includes a timing Cherenkov TAIGA-HiSCORE array with 120 wide-angle optical stations distributed over an area of about 1 square kilometer and three 4-m class Imaging Atmospheric Cherenkov Telescopes of the TAIGA-IACT array. The latter array has a shape of a triangle with side lengths of about 300m, 400m and 500m. There are three approaches to selecting gamma quanta from the hadron background in the TAIGA experiment: (1) IACT operation in standalone mode; (2) Stereo mode operation of two or more IACTs; (3) Hybrid mode operation -joint operation of TAIGA-HiSCORE and IACTs. The main advantage of the hybrid operation of the IACTs and timing is their good gamma/hadron separation, even with only a few telescopes on the large area. Present status of the project, the first experimental results and plans for the future 10-20 km^2 TAIGA are presented.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

ICRC2023
38th International Cosmic Ray Conference
The Astroparticle Physics Conference

PoS(ICRC2023)269

---

[*] Speaker

1. Introduction

The experimental data necessary to understand the nature of the sources of high-energy cosmic rays are obtained both by methods of gamma astronomy and neutrino astrophysics, studying the flux of neutral particles generated by cosmic rays in the immediate vicinity of the source, and by the remote methods of cosmic ray physics, studying the energy spectrum and the mass composition of cosmic rays near the Earth.

The TAIGA (Tunka Advanced Instrument for cosmic rays and Gamma-ray Astronomy) astrophysical complex [1, 2] allows the nature of CR sources to be investigated within both gamma-ray astronomy and cosmic ray physics methods. A unique feature of the facility consists in combining arrays with detectors of different types into a unified system to detect all EAS components in the energy range from 10^{12} to 10^{18} eV.

This will allow one to search for PeVatrons, i.e., galactic objects in which protons are accelerated to energies ~10^{14}–10^{17} eV, to find the energy limits for particle acceleration in supernova remnants and PWNs, and to carry out a search for correlations with neutrino events detected by the Ice- Cube [3] and Baikal-GVD [4] neutrino observatories.

The paper has the following structure. The installations currently operating as part of the complex are briefly described in section 2. The third section discusses the scientific program of the astrophysical complex. The last results in study cosmic rays are presented in section 4. Status and main results in the field of gamma-ray astronomy are presented in section 5. In section 6, we will summarize and discuss the future of the experiment.

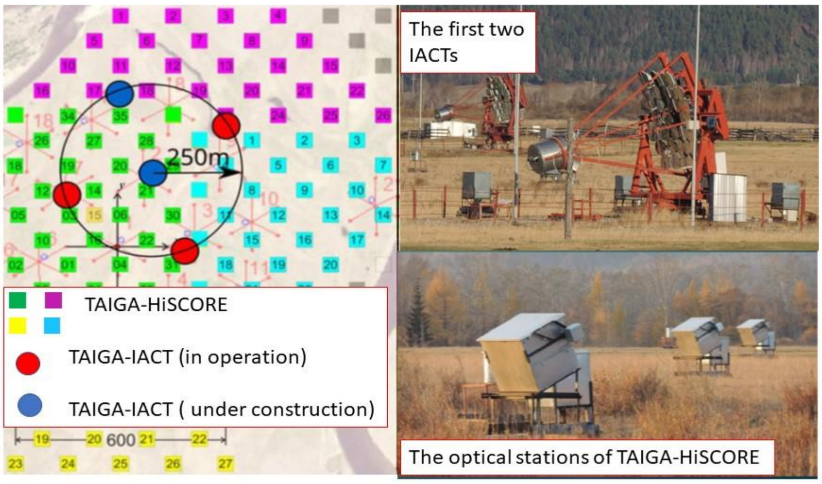


Figure 1: TAIGA-HiSCORE and TAIGA-IACTs

2. Status of experimental installations of the TAIGA complex

The experiments to detect EASs by their Cherenkov radiation in the Tunka valley 50 km to the west from Lake Baikal (51.49 N, 103.04 E) were begun in 1993. The first experimental array Tunka-4 consisted of four optical detectors [5] on the base of Hybrid QUASAR-370 phototube, designed for the Baikal neutrino telescope NT200 [6]. Below, we describe the arrays that are operating in the astrophysical facility now, very briefly about Tunka-133, Tunka-Grande, TAIGA-MUON and in some more detail about TAIGA-HiSCORE and TAIGA-IACT. All these arrays are synchronized with one another with a 10-ns precision [7].

2.1 Tunka-133 array

The Tunka-133 array consists of 175 Cherenkov detectors [8, 9] arranged over an area of 3 km2. The detectors are grouped into 25 clusters of seven detectors each — six detectors at the vertices of a regular hexagon and one at the center. The detector spacing in one cluster is 85 m, each detector contains a PMT with a photocathode diameter of 20 cm.

2.2 Tunka-Grande array

The Tunka-Grande array [10] is a network of scintillation detectors combined into 19 stations, each of which consists of the ground and underground parts. The ground part contains 12 counters with a total area ~8 m^2 that detect charged EAS particles. The underground part located under a 1.5-m-thick layer of soil consists of 8 counters with a total area ~5 m^2 and is designed to detect the EAS muon component.

2.3 TAIGA-Muon array

A new array, TAIGA-Muon [11], is being created to investigate the mass composition of CRs with energies above 10^{16} eV and to suppress the hadron background when detecting gamma-ray with energy more that 1 PeV. The design of scintillation counters ([12]) allow them to be buried in the soil without any additional protection. The area of the muon detectors in the TAIGA-Muon array is planned to be increased to 150 m^2 by 2024.

2.4 TAIGA-HiSCORE array

The TAIGA-HiSCORE (High Sensitivity Cosmic Rays and gamma Explorer) array [13, 14] is a network of wide-field optical stations (0.6 sr) to detect the Cherenkov radiation from EASs. The array consists of 120 stations arranged on an area of 1.1 km^2, with the station spacing being 106 m (Fig. 1). The stations are grouped into 4 clusters with independent data acquisition centers. The effective energy threshold of the array when four or more stations are triggered is ~80 TeV for EASs from charged CR particles and ~40 TeV for EASs from gamma-ray photons. The angular resolution of the array changes from 0.4–0.5° near the array threshold to 0.15° when more than 10 stations are triggered [15].

2.5 TAIGA-IACT installation.

The TAIGA-IACT installation includes now three 4-m class imaging air Cherenkov telescopes (IACT) (the third IACT was put in operation in April 2022). The distance between the telescopes is 300, 400 and 500 m respectively. They have an optical design of the Davies-Cotton type with 34 mirrors, each of the 60-cm diameter and a focal length of 4.75 m. The imaging camera comprises 600 PMTs of the XP1911 type (Photonics) with the 19-mm diameter. The FoV of the camera is 9.6∘ (each pixel has an aperture of 0.36°). The detailed description of the camera electronics and trigger conditions could be found in [16,17].. A CCD camera Prosilica GT1380 is installed on the telescope dish for telescope pointing calibration and real-time monitoring.

3. Scientific program of the TAIGA astrophysical complex.

3.1 TAIGA Complex and gamma-ray astronomy.

The main tasks of the TAIGA-1 in the field of gamma-ray astronomy:

1.Study of energy spectrum of gamma-rays from galactic sources and search for new sources.

The TAIGA experiment will measure the energy spectrum of gamma-rays for certain sources in the energy range important for understanding the gamma-ray production mechanism. About 40- 60 gamma-rays with energies above 100 TeV are expected for the Crab Nebula gamma-ray source in 300 hours of observation, according to result of LHAASO [18]. It is planned to reconstruct the gamma-ray spectrum from galactic sources (such as the Crab Nebula, Dragonfly Nebula (MGRO J2019+37), HAWC J2227+610 (G106.3+2.7), J2031 +415 (Cygnus Cocoon), CTA-1 and SNR Tycho) important for understanding the origin of cosmic rays.

2.Monitoring of gamma-ray quantum flux from close extragalactic sources.

The study of the shape of the spectrum of gamma-ray with an energy above 8-10 TeV will allow us to obtain upper limits on the density of extragalactic background radiation (EBL), to search for transitions of photons into "axion-like" particles, with which the high transparency of the Universe for high-energy photons can be associated. Due to the absorption on the EBL, for our installation to monitor the closest blazars and galaxies (1ES1959+650, Mrk501, Mrk421, etc.). All these sources can be observed for 70-100 hours per year and 2-3 seasons of observation of these sources will give interesting information about both the variability of the flow and its spectra.

3.Search for gamma-rays of the TeV range from GRB.

The recent discovery of gamma-rays with an energy of about 1 TeV in several gamma-ray bursts [19, 20, 21] deepened the understanding of the physics of gamma-ray bursts and opened a new energy range in their observation. The flux and energy spectrum of gamma-rays from these GRBs, shows the possibility of detecting gamma-rays in the range of 3-10 TeV from nearby gamma-ray bursts ($z<0.1$) by IACTs of the TAIGA-1.

4.Search for gamma-rays associated with energetic neutrinos.

The discovery of the connection between high energy neutrinos and the flare activity of bazaars (for example, TXS 0506+056 [3]) showed the importance of searching for gamma-ray quanta correlated in the direction of high-energy neutrinos detected by the Baikal-GVD and IceCube neutrino telescopes. It is planned to search for such gamma-rays, both with the help of TAIGA-IACT and TAIGA- HiSCORE.

5.Search for nanosecond optical transients.

A unique feature of the TAIGA-HiSCORE is the simultaneous observation of a very large area of the sky, thanks to a wide FOV, which makes the detection of rare events in the optical range more likely. Based on a number of signatures, a technique will be developed to distinguish nanosecond optical flashes from astrophysical sources from events caused by EAS [22].

3.2 TAIGA complex and study of charged cosmic rays

Over the past 10 years of operation of the astrophysical complex, a large amount of experimental material has been accumulated and important results have been obtained on the spectrum and the mass composition of cosmic rays. The new capabilities of the complex - a system of IACTs, the expansion of the area of muon detectors and the development of a methods of data processing using machine learning, will make it possible to advance in solving the following tasks:

1.To confirm the existence of a breakage in the CR spectrum at an energy of 50 TeV detected by the HAWC [23] by reconstructing the CR spectrum in this range using the system of IACTs.

2.In the energy range of 100 – 3000 TeV, using a hybrid technique reconstruct the energy spectrum of the main nuclei in the composition of CR. To check the existence of a breakage in the spectrum of the light component at an energy of 700 TeV, detected by the Argo-YBJ [24] and to understand which component dominates the area of the classical "knee" in the energy spectrum.

3.According to experimental data from a number of installations, including Tunka-133, there is an "ankle" in the energy spectrum of the CR in the range of 10 – 30 PeV, where the slope index varies from 3.3 to 3.0. We plan to reconstruct the spectrum of the main nuclei in the composition of CR of s in this energy range, and perhaps this will give a clue to the nature of this feature.

4.In the energy range of 10^{17} eV, a "second knee" is observed in the spectrum of cosmic rays, where the slope index of the spectrum varies from 3 to 3.4. It is believed that in this range there is a transition from CR of galactic origin to extragalactic. More than 10 years ago, a hypothesis was formulated that the "second knee" is associated with a fracture in the spectrum of iron nuclei. The latest data from the Tunka-133 installation casts doubt on the result of the dominance of heavy nuclei at an energy of about 100 PeV and such an explanation of the second knee. Using these Tunka-133 and Tunka-Grande installations, we plan to reconstruct component spectrum of nuclei in this area, which will allow us to understand the astrophysical cause of the "second knee".

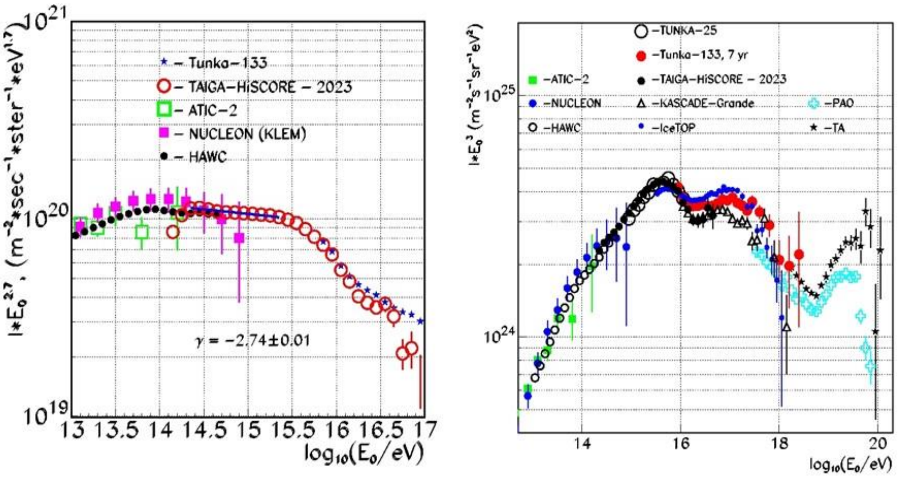
4. Cosmic-ray energy spectrum from the data of TAIGA complex

In this section latest results of the reconstruction of the energy spectrum according to the TAIGA-HiSCORE installation is presented. The reconstruction of EAS parameters (zenith θ and azimuth φ angles, coordinates of the EAS core on the observation plane, and steepness of the LDF) for the Tunka-133 array is described in [9]. The same technique is used to process the data from the TAIGA-HiSCORE array [25]. To reconstruct the energy, we used the recalculation from the parameter Q200, which is a flux of Cherenkov light at a core distance of 200 m. For the TAIGA-HiSCORE array in the previous work [26], the average light flux density parameter for two stations closest to a shower core was used for energy reconstruction. This parameter provided decreasing of the energy threshold. However, further analysis of the calculations showed that the better precision at the same threshold can be reached using the light flux density at the EAS core distance of 100 m -Q100. This parameter for fixed particle energy depends on shower zenith angle [27]. The differential energy spectrum obtained by recalculation from Q100 according to the TAIGA-HiSCORE data from the season 2022-2023, when the stations were oriented vertically, is shown in Fig. 2 A. This spectrum is compared with the spectra from direct measurements on a balloon [28], a satellite [29], and in the mountains [23]. One can see good agreement of all spectra in the 200 – 300 TeV energy range, despite the significant difference in the experimental technique. Fig. 2 B shows the corrected spectrum of the Tunka-133 array compared to the spectra of the TAIGA-HiSCORE and Tunka-25 arrays and also with results KASCADE-Grande, IceTop, PAO and Ta+Tale. A decrease in the power law index of the spectrum at $2 \cdot 10^{16}$ eV is observed also from the data of the TAIGA-HiSCORE (black circles).

For the Tunka-Grande array the primary particle energy is reconstructed from the EAS particle flux density at a distance of 200 m from the core ($\rho(200)$). The correlation of $\rho(200)$ with the primary energy is determined using the experimental results of Tunka-133 array [34]. At this conference energy spectrum based on five years of Tunka-Grande operation is presented [35].

5. The last results in Gamma-ray astronomy

To study the entire energy range available for observation, the TAIGA experiment uses three modes of detecting EAS from gamma-rays. Stand-alone mode is used to detecting gamma-rays with energies of more than 2-3 TeV with only one IACT [36]. To detect gamma-rays with energies above 10 TeV, it is possible to use a stereo mode, when - EAS is detected by two or more IACTs [37]. The hybrid mode is to use joint data obtained with the help of IACTs and HiSCORE stations [38]. In this method, the reconstruction of the energy of the primary particle, the direction and position of the EAS core is carried out by analyzing the data of the HiSCORE. To determine the type of the primary particle that gave rise to the EAS, the data of the IACTs are used [36].



a *b*

Figure 2: Comparison of the CR energy spectra obtained in various experiments in a wide energy range: ATIC-2 [28], NUCLEON [29], HAWC [23], Tunka-25, TAIGA-HiSCORE, Tunka-133, KASCADE-Grande [30], IceTop [31], PAO [32] and Ta+Tale [33].

According to the data from the first IACT collected during the deployment of the installation, the flux of gamma-rays from the Crab Nebula has been detected at significance level of 12 sigma, the spectrum of gamma-rays in the range of 3-100 TeV has been reconstructed [39, 40].

Two more IACTs will start operating within the next 2 years (see Fig.1). The MC simulation of such a configuration [41] showed that the accuracy of energy reconstruction 10%, $\sigma X_{max} = 28$ g/cm^2. The relative suppression of protons in the energy range from 2 to 200 TeV is equal to 10^{-4}. The effective area after using selection cuts at energy more 100 TeV is near 1 km^2.

The use of a hybrid method allowed, according to data from half of the HiSCORE installation (58 station) and the first telescope, to select 7 gamma-like events with energy more than 100 TeV from Crab Nebula in 250 hours of observation [42].

Since the end of 2022, the search for gamma-rays in TeV energy range from GRB with 3 IACTs has been started [43]. During the winter season the TAIGA GCN monitor program triggered 5 follow-up observations issued by notices from FERMI GBM, FERMI LAT and SWIFT BAT instruments.

6. Conclusion and future plans

In the coming years, we plan to continue observations of gamma-ray sources of galactic and extragalactic origin, with priority on observations of the Crab Nebula and the CTA-1 source – the galactic source with the highest declination. To search for gamma-ray of the TeV energy range from GRB, from binary systems and gamma-rays associated with energetic neutrinos.

During the next three years, 2 more IACTs with a mirror diameter of 4 m and one IACT with a mirror diameter of 6 m will begin to work. To increase the effective area for the energy above 300 TeV up to 2 km^2, outside the complex along the perimeter, 10 - 15 stations of the TAIGA-HiSCORE array will be installed.

The further aim is to create a complex TAIGA-10 for the study of the origin of cosmic rays in the energy range of 0.1-10^3 PeV, by detecting gamma-rays in the Tev-PeV energy range. The effective area of the installation for detecting gamma-rays with PeV energy will be near to 20 km^2. The new TAIGA-10 experimental complex will include detectors whose design has been tested for a long time as part of the TAIGA-1. So the basis of the complex will be about 1000 optical stations of the TAIGA-HiSCORE installation and about 10 IACTs.

Acknowledgments

The work was performed at the UNU "Astrophysical Complex of MSU-ISU" (agreements 13.UNU.21.0007, EB-075-15-2021-675). The work is supported by the Russian Science Foundation (grants 23-72-00019 (Section 2, 3.1, 5), 23-72-00016 (Section1, 3.2. 4), the Russian Federation Ministry of Science and High Education (projects FZZE-2020-0024, FZZE-2023-0004, FSUS-2022-0015and FSUS-2020-0039).

References

[1] N. M. Budnev, et al. (TAIGA Collaboration) NIM A 958, 162113 (2020).

[2] L. A. Kuzmichev, et al., (TAIGA Collaboration) *Phys. At. Nucl.* **81**, 497 (2018)

[3] M. G. Aartsen, M. et al, (Ice_Cube Coll) Science 361, 6398 (2018)*; arXiv*: 1807.08816

[4] A. D. Avrorin*, et al.(Baikal Collaboration) JETP Lett. 108, 787 (2018*); arXiv*:* 1810.10966

[5] S. V. Bryanski, G. N. Dudkin, O. A. Gress*, et al., ICRC, Roma (1995), Vol. 2, p. 724.*

[6] R. Bagduev, V. Balkanov, I. Belolaptikov*, et al., NIM.* A **420**, 138 (1999*).*

[7] O. Gress, I. Astapov, N. Budnev*, et al., NIM.* A **845**, 367 (2017).

[8] S. Berezhnev *et al.,(TAIGA Collaboration) NIM.* A **692**, 98 (2012).

[9] N. Budnev *et al., (TAIGA Collaboration) Astropart*. Phys. **117**, 102406 (2020)

[10] R. Monkhoev *et al., (TAIGA Collaboration) Bull. Russ. Acad.Sci.:* Phys. **83**, 959 (2019).

[11] A. Ivanova, N. Budnev, A. Chiavassa*, et al., J. Instrum*. **15**, C06057 (2020).

[12] I. Astapov, P. Bezyazeekov, A. Borodin, et al., NIM. A **936**, 254 (2019).

[13] M. Tluczykont et al., Astropart. Phys. **56**, 42 (2014).

[14] I. Astapov et al, (TAIGA Collaboration) Bull. Russ. Acad. Sci.: Phys.**81**, 460 (2017).

[15] L. Kuzmichev, et al., (TAIGA Collaboration) EPJ Web Conf. **145**, 01001 (2017).

[16] Budnev N et al. (TAIGA Coll.) 2020 JINST 15 C09031

[17] Lubsandorzhiev N et al. (TAIGA Collab.) 2017 Proceedings of the ICRC 2017 757Jefhj

[18] Z.Cao et al. (LHAASO Coll.) Science 373 (2021) 6553, 425-430

[19] Acciari, V.A et al (MAGIC Coll.) Nature **2019**, 575, 459–463.

[20] H.Abdalla et al (HESS Coll) Science 372 (2021) 6546, 1081-1085

[21] Z.Cao et al. (LHAASO Coll.) Science 380 (2023) 6652, adg9328

[22] A.D. Panov et al et a (TAIGA coll.) Phys.At.Nucl. 84 (2021) 6, 1037-1044 arXiv: 2109.09637

[23] R. Alfaro, C. Alvarez, R. Arceo et al. Phys. Rev. D. V. 96. P. 122001 (2017)

[24] B. Bartoli, P. Bernardini, X. J. Bi et al., Phys. Rev. D. D 92, 092005 (2015)

[25] V.Prosin et al. (TAIGA Collab.) Phys. of Atomic Nucl. 2021. V. 84. P. 1653.

[26] V. Prosin, et al., (TAIGA Collab.) Bull. Russ.Acad. Sci.: Phys. **83**, 1016 (2019).

[27] V. Prosin, et al., (TAIGA Collab.) Bull.of the Russ. Acad. Scie: Phys. (2023).

[28] Panov, A.D, Adams, J.H., Jr., Ahn, H.S., et al., Bull.Russ. Acad. Sci.: Phys., 2007, vol. 73, p. 564.

[29] Turundaevskiy, A.N. et al, Bull. Russ. Acad. Sci.: Phys., 2021, vol. 85, p. 353.

[30] W. Apel, J. Arteaga Velбzquez, K. Bekk, et al., Astropart. Phys. **36**, 183 (2012).

[31] M. G. Aartsen et al, (Ice Top Collaboration) Phys. Rev. D **88**, 042004 (2013).

[32] J. Abraham, et al., (Auger Collaboration) Phys. Lett B **685**, 239 (2010).

[33] R. Abbasi et al (TA Collaboration) Astrophys. J. **858**, 76 (2018).

[34] R.Monkhoev et al (TAIGA coll,) Bull.of the Russ. Acad. Scie: Phys. (2023). 87, 954-961

[35] A. Vaidyanathan et al. (TAIGA coll. PoS (ICRC2023) 256.

[36] L Sveshnikova et al (TAIGA Coll.) Bull. Russ .Acad. Sci.: Phys. 2021 85, 529-533

[37] A.Grinyuk et al. (TAIGA Coll.) PoS ICRC2021 (2021), 713, DOI: 10.22323/1.395.0713

[38] L Sveshnikova et al. (TAIGA Coll.) Bull. Russ. Acad. Sci. Phys. 2019. 83. P. 922-966

[39] L Sveshnikova et al (TAIGA Coll.) Bull. Russ .Acad. Sci.: Phys. 2023 87, 966-972

[40] M. Blank et al. Mon.Not.Roy.Astron.Soc. (2023) stad276

[41] R. Togoo, P. Volchugov, et al.,(TAIGA Coll), PoS ICRC2023 (2023) 686

[42] A.Sh.M. Elshoukrofy, E.V.Okuneva et al (TAIGA Coll.) POS (ICRC2023) 685

[43] Gress O., Togoo R._and Zhurov D. et al (TAIGA Coll.) POS (ICRC2023) **444**, 939

Full Authors List: TAIGA Collaboration

A. Vaidyanathan[1,13], A. L. Ivanova[1, 2], I.I. Astapov[3], P.A. Bezyazeekov[2], E.A. Bonvech[4], A.N. Borodin[5], N. M. Budnev[2], A.V. Bulan[4], D.V. Chernov[4], A. Chiavassa[6], A.N. Dyachok[2], A. R. Gafarov[2], A. Yu. Garmash[1,7], V. M. Grebenyuk[5,8], E.O. Gress[2], O.A. Gress[2], T.I. Gress[2], A.A. Grinyuk[5], O.G. Grishin[2], A. D. Ivanova[2, 9], M.A. Iliushin[2], N.N. Kalmykov[4], V.V. Kindin[3], S.N. Kiryuhin[2], R.P. Kokoulin[3], N. I. Kolosov[2], K.G. Kompaniets[3], E.E. Korosteleva[4], V.A. Kozhin[4], E.A. Kravchenko[1,7], A.P. Kryukov[4], L.A. Kuzmichev[4], A.A. Lagutin[10], M.V. Lavrova[5], Yu. E. Lemeshev[2], B.K. Lubsandorzhiev[11], N Lubsandorzhiev[4], S.D. Malakhov[2], R.R. Mirgazov[2], R.D. Monkhoev[2], E.A. Okuneva[4], E.A. Osipova[4], A.L. Pakhorukov[2], L. V. Pankov[2], A. Pan[5], A.D. Panov[4], A.A. Petrukhin[3], D.A. Podgrudkov[4], E.G. Popova[4], E. B. Postnikov[4], V.V. Prosin[4], V.S. Ptuskin[12], A.A. Pushnin[2], R.I. Raikin[10], A.V. Razumov[4], G.I. Rubtsov[11], E.V. Ryabov[2], V.S. Samoliga[2], I. Satyshev[5], A.A. Silaev[4], A.A. Silaev (junior) [4], A.Yu. Sidorenkov[11], A.V. Skurikhin[4], A.V. Sokolov[1,7], L.G. Sveshnikova[4], V.A. Tabolenko[2], L.G. Tkachev[5,8], A.B. Tanaev[2], M.Yu. Ternovoy[2], N.A. Ushakov[11], P.A. Volchugov[4], N.V. Volkov[10], D.M. Voronin[11], A.V. Zagorodnikov[2], D.P. Zhurov[2,14] and I.I. Yashin[3]

[1]Novosibirsk State University, Pirogova str. 2, Novosibirsk, 630090 Russia.[2]Irkutsk State University, Karl Marx str. 1, Irkutsk, 664003 Russia. [3]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe hwy 31, Moscow, 115409 Russia. [4]Skobeltsyn Institute of Nuclear Physics MSU, Leninskie gory 1 (2), GSP-1, Moscow, 119991 Russia. [5]Joint Institute for Nuclear Research, Joliot-Curie str. 6, Dubna, 141980 Russia. [6]Dipartimento di Fisica Generale Universiteta di Torino and INFN, Via P. Giuria 1, Turin, 10125 Italy. [7]Budker Institute of Nuclear Physics SB RAS, Ac. Lavrentiev Avenue 11, Novosibirsk, 630090 Russia. [8]Dubna State University, Universitetskaya str. 19, Dubna, 141982 Russia. [9]Moscow Institute of Physics and Technology, Institutskiy per. 9, Dolgoprudny, 141701, Russia. [10]Altai State University, pr. Lenina 61, Barnaul, 656049 Russia. [11]Institute for Nuclear Research RAS, prospekt 60-letiya Oktyabrya 7a, Moscow, 117312 Russia. [12]IZMIRAN, Kaluzhskoe hwy 4, Troitsk, Moscow, 4108840 Russia. [13]St. Thomas College (Autonomous), Thrissur, India. [14]Irkutsk National Research Technical University, Lermontov str. 83, Irkutsk, 664074 Russia.