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

1. Goals of the experiment:

1a. Give a short description of the goals of the experiment - limited to ½ page.

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 100 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).

1b. Explain what the project adds to the international scenario: limited to ½ page.

The progress in understanding the nature of sources of high-energy cosmic rays from our Galaxy and from the Metagalaxy is going along such directions as: study of secondary gamma quanta, produced by CR in the vicinity of the source, where particles are accelerated, and precise determination of the energy spectrum, mass composition and anisotropy of CRs by detailed measurements of all EAS parameters.

The expected integral sensitivity of TAIGA complex for detecting gamma radiation with an energy of 100 TeV, given the 300-hour observation of the source, will reach approximately 2.5×10^{-13} TeV cm^{-2} s^{-1}, which is higher than the sensitivity of the currently active and planned arrays in this range of super-high energies. TAIGA array allows the following tasks to be solved:

1. Studying the high-energy end of the spectrum of the brightest galactic gamma ray sources and searching for galactic PeVatrons.
2. Applying the new hybrid approach to studies of the mass composition of the CR in the "ankle" region (10^{14}–10^{16} eV).
3. Studying the high-energy range in the spectrum of bright extragalactic sources (Mkr421).
4. Studying the CR anisotropy in the energy range of 100–3000 TeV.

As the TAIGA will be the northernmost gamma observatory, its location provides some advantages for observing the sources with large declinations. For example, the gamma ray source in the Tycho Brahe supernova remnant, being almost inaccessible for the HAWC and LHAASO arrays, will remain within the field of view of the TAIGA detectors for 500 hours per year.

2. Contributions of the JINR group:

2a. Give an itemized list of the specific contributions of the JINR group in hardware (including use of JINR computing resources for the project), software development and physics analyses - limited to 1 page.

1. JINR full responsibility is the IACT's design, mechanics manufacturing and tests. Two IACTs are produced up to now (Fig.1). The first IACT takes data since 2016 and its preliminary results were presented at the ICRC2017 and other astroparticale international conferences.
2. Besides, the JINR is responsible for PMT tests and its calibration for IACT’s cameras. More than 1200 PMTs were tested and calibrated in total.
3. Additionally JINR team participates in shifts for the data taken at Tunka area, MC simulation and physical analysis

Fig.1. Left: the first TAIGA IACT, it takes data since 2016. Right: the second IACT was delivered from Dubna to Tunka in August 2018.

2b. Give a list of the responsibilities of JINR group members within the management structure of the collaboration, if any, giving the name of the JINR member, the managerial role and the appointment period.

L.Tkachev is a member of the TAIGA collaboration group-leader committee

3. Plans. *Give a short description limited to ½ page of the JINR group plans (in data taking, analysis, detector R&D, upgrade activities…) till the end of the currently approved project.*

1. The third IACT redesign taken into account the experience of first IACTs operation in the Sibirian conditions. IACT-3 fabrication of mechanics and mechanical tests during 2018-2019. IACT-3 mechanics delivery to Tunka site at August 2019.
2. The R&D of focusing mirror facets production is going on in JINR. The polishing machine has been buyed and the first mirror facet prototypes were fabricated by the bending glass technology – see Fig. 2. We plan to produce 30-35 mirror facets to equip them the IACT-3 telescope.
3. During 2018-2019 TAIGA collaboration has plan to increase the area of TAIGA-HiSCORE to 1 km^2, deploy two new IACTs and 200 m^2 of new muon detectors. With such an array it will be possible to start realization the following scientific program and to obtain the preliminary results:
    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.

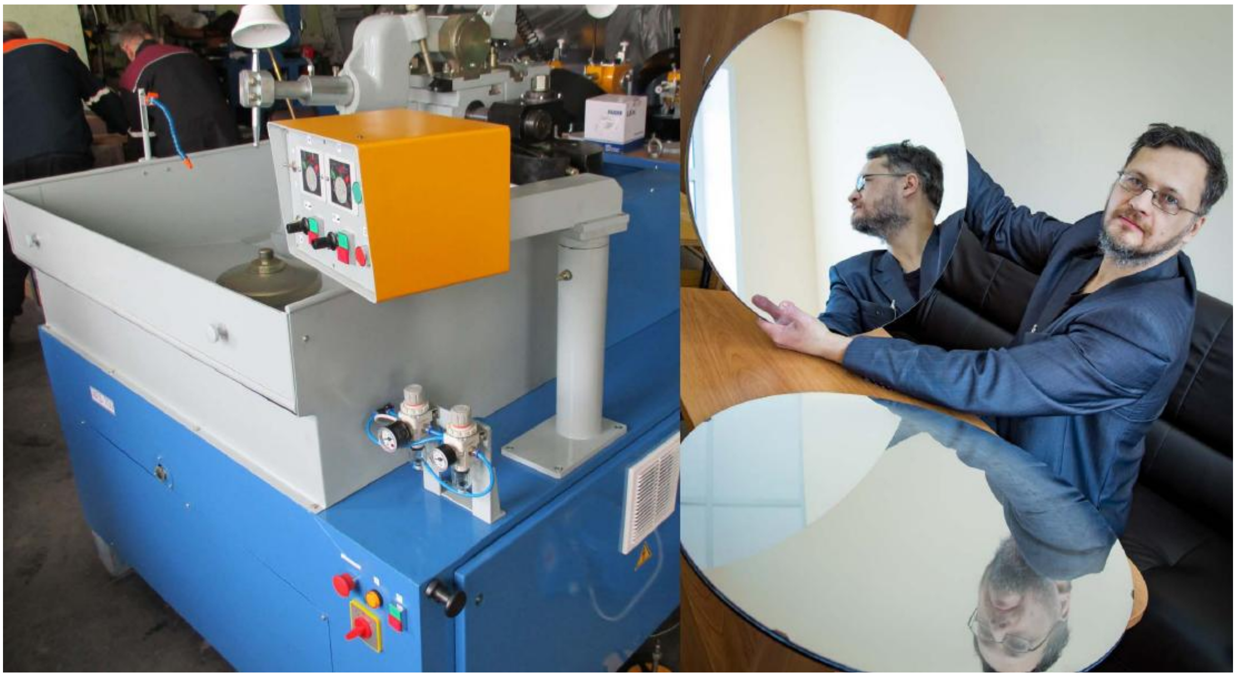

Fig.2. Left: the polishing machine. Right: the first mirror facet prototypes were fabricated

4. Publications: *List the papers published in 2016, 2017 and 2018 in the refereed literature (no conference proceedings) in which the JINR group had a major contribution (e.g. author of the analysis, promoter of the experiment, corresponding author, realization of a key equipment etc.). Give title of paper, reference and describe in 1-2 sentences the JINR contribution.*

1. TAIGA experiment: present status and perspectives, Budnev N.M., Astapov I.I., Bezyazeekov P., Boreyko V., Borodin A., Brückner M., Chiavassa A., Gafarov A., Grebenyuk V., Gress O., Gress T., Grinyuk A.A.,Grishin O., Dyachok A., Fedorov O., Haungs A., Horns D., Huege T., Ivanova A., Kalmykov N., Kazarina Y., Kindin V., Kiryuhin S., Kokoulin R., Kompaniets K.,Kostunin D., Korosteleva E.E., Kozhin V., Kravchenko E., Kunnas M., Kuzmichev L., Lemeshev Yu, Lenok V., Lubsandorzhiev B., Lubsandorzhiev N.,Mirgazov R., Mirzoyan R., Monkhoev R., Nachtigall R., Osipova E., Pakhorukov A., Panasyuk M., Pankov L., Poleschuk V., Popesku M., Popova E.G., Porelli A., Postnikov E., Prosin V., Ptuskin V., Petrukhin A., Pushnin A., Rjabov E., Rubtsov G., Sagan Y., Samoliga V., Semeney Yu, Sidorenkov A., Schröder F,Silaev A.A., Silaev Alexey A., Skurikhin A., Slunecka M., Sokolov A., Spiering C., Sveshnikova L., Tabolenko V., Tarashansky B., Tkachenko A., Tkachev L.G.,Tluczykont M., Wischnewski R., Yashin I.I., Zagorodnikov A., Zhurov D., Zurbanov V., Journal of Instrumentation, Institute of Physics (United Kingdom), 12, № 08, c. 08018-1-08018-17 DO:I 0.1134/S1063779618040172 (JINR is one of the crucial institution for realization of this key equipment)

2. TAIGA GAMMA OBSERVATORY - STATUS AND PROSPECTS (in Russian). By TAIGA Collaboration, Yad. Phys. (ЯДЕРНАЯ ФИЗИКА), 2018, 81, № 4, p. 1-11, DOI: 10.1134/S0044002718040104 (JINR is one of the crucial institution for realization of this key equipment)

Mention the total number of papers published by the project in the same time period.

In SPIRE HEP list ~40 publications

5. PhD theses: *List the PhD theses completed within the last 3 years, or expected to be completed within 2019, by JINR students within the project, giving the student name, thesis title and graduation year.*

Yaroslav Sagan – post-graduate student 2016-2019. Preliminary title: "Cherenkov TAIGA gamma telescope of the experiment: development, production, tests, data acquisition and their physical analysis."

6. Talks:

6a. List the invited plenary talks given by members of the JINR group in 2016, 2017 and 2018 at international conferences, workshops…: give name and date of the Conference, title of talk and speaker name.

1. International Conference on Ultra High Energy Cosmic Rays (UHECR2016), 11-14.10 2016. Kyoto, Japan. The status of the TAIGA project, L.Tkachev (JINR, Dubna) for the TAIGA collaboration.

2. New Trends in High-Energy Physics, 24-30 September 2018, Montenegro, Budva, Becici, Tunka Advanced Instrument for cosmic rays and Gamma Astronomy (TAIGA): status, results and perspectives, A.Borodin

3-4. Cherenkov gamma telescope IACT experiment "TAIGA". VI Annual Conference of Young Scientists and Specialists, Alushta-2017/2018. 12-19 June 2017/11-18 June 2018. Y.Sagan

5. Design, fabrication and tests of IACT telescope for the TAIGA experiment. The XXI International Scientific Conference of Young Scientists and Specialists (AYSS-2017). JINR, 2 - 6 October 2017. Y.Sagan

6. The IACT optical system of the TAIGA observatory. The XXII International Scientific Conference of Young Scientists and Specialists (AYSS-2018). JINR, 23-27 April 2018. Y.Sagan

6b. Give a similar list for parallel talks.

1. Control of the telescope moving. TAIGA Collaboration Meeting (Session-5a: IACT hardware and software). SINP MSU, 01-03 June 2016. Y.Sagan
2. Status of telescope control system. TAIGA Collaboration Meeting (Session-2c: IACT control system). SINP MSU, 15-17 December 2016. Y.Sagan
3. PMT calibration. TAIGA Collaboration Meeting (Session-3b: The second telescope). SINP MSU, 11-14 December 2017. Y.Sagan

7. Group size, composition and budget.

7a. Present in a Table the list of JINR personnel involved in the project, including name, status (e.g. PI, researcher, post-doc, student, engineer, technician…) and FTE. Mention the total number of people in the collaboration.

The total number of people in the TAIGA collaboration author list - 72 people

List of the JINR TAIGA project participants :

Name	employment	involvment	PhD

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1. A.Borodin	senior scientist	100%	yes
2. A.Demenko	designer	100%	no
3. V. Grebenyuk	senior scientist	60%	yes
4. A. Grinyuk	engineer	50%	in preparation
5. A. Kalinin	engineer	50%	yes
6. V.Kovalchuk	technicien	100%	-
7. M. Lavrova	engineer	30%	no
8. A.Pan	engineer	30%	no
9. S. Porokhovoy	engineer	20%	no
10. V.Romanov	designer	10%	no
11. Ya.Sagan	postgraduated student	100%	no
12. B. Sabirov	scientist	10%	no
13. M. Slunecka	senior scientist	10%	yes
14. L. Tkachev	head of sector	60%	yes

7b. Indicate the expected changes in the group size, if any, till the end of the currently approved project.

Expected changes in the group size ±2 persons

7c. Present the JINR group budget from 2018 till the end of the currently approved project in a Table specifying the main budget items (equipment, computing, salaries, common funds, travel…)

Expenditure for project TAIGA

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

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

7d. Indicate the use of JINR computing resources for the group and for the project if any.

LIT computer farm