In total the completed form should not exceed 20 pages (together with tables).

Annex 3.

Form of opening (renewal) for Project / Sub-project of LRIP

APPROVED

JINR DIRECTOR

____________/__________________

"_____" ______________________ 202_ г.

PROJECT PROPOSAL FORM

Opening/renewal of a research project/subproject of the large research infrastructure project within the Topical plan of JINR

1. General information on the research project of the theme/subproject of the large research infrastructure project (hereinafter LRIP subproject)

1.1 Theme code / LRIP (for extended projects) - *the theme code includes the opening date, the closing date is not given, as it is determined by the completion dates of the projects in the topic.*
1081

1.2 Project/LRIP subproject code (for extended projects)**: 02-0-1081-2024**

1.3 Laboratory: DLNP, VBLHEP, MLIT

1.4 Scientific field: 02 EPP and RNP

1.5 Title of the project/LRIP subproject: ATLAS. Physical researches at the LHC

1.6 Project/LRIP subproject leader(s): V.A. Bednyakov

1.7 Project/LRIP subproject deputy leader(s) (scientific supervisor(s)): E.V. Khramov and A.P. Cheplakov

2 Scientific case and project organization

2.1 Annotation

The main purpose of the international ATLAS experiment is to investigate proton-proton interactions at unprecedented energies at the LHC collider (from 7 to 14 TeV center-of-mass energy). In particular, detailed study of the Standard Model, its application limits, search for answers to the key problems in particle physics and astrophysics, such as origin of elementary particles masses, nature of the dark matter in the Universe, existence of extra dimensions, are carried out with the ATLAS detector.

Absolutely new and unique data will be obtained based on multifaceted and comprehensive studies of the proton-proton scattering processes. These data analyses will allow to address several fundamental problems in particle physics. Within current project, scientists from JINR are going to participate in these analyses.

Scientists from JINR will obtain new results leading to publications in all mentioned above areas. The most important tasks include studies of the proton structure and of hadron spectra, tests of the Standard Model at the LHC energies, searches for Supersymmetry, searches for new heavy particles and new interactions. Apart from new physics searches, JINR scientists will work on the precision frontier and will measure with greater accuracy the properties of known elementary particles, such as W and Z bosons, top quark, and heavy baryons.

The requested project budget is 2360 kUSD for 2025-2028.

2.2 Scientific case (aim, relevance and scientific novelty, methods and approaches, techniques, expected results, risks)

The ATLAS international collaboration was established more than 30 years ago to carry out a new-generation multipurpose experiment designed to study fundamental properties of matter in proton-proton collisions at the center-of-mass energy of 14 TeV at the Large Hadron Collider (LHC). Nowadays, the Collaboration includes 2929 authors and overall ~5900 participants from 182 institutes in 42 countries. During these 30 years, very complex ATLAS detector systems were designed, constructed, commissioned, and used to successfully investigate a variety of physics phenomena, including a long-awaited Higgs boson discovery in 2012.

JINR contribution to this achievement looks very remarkable compared to other institutions. It is worth to stress that the following very important works has been carried out at JINR in full compliance with the responsibilities imposed upon JINR by the ATLAS collaboration:

1. Creation, mounting and adjustment of the elements of the ATLAS Muon Detector System.
2. Creation, mounting and adjustment of the elements of the Liquid-Argon Calorimeter for the ATLAS (LAr).
3. Creation, mounting and adjustment of the elements of the Barrel Tile Calorimeter for the ATLAS.
4. Participation in the development and adjustment of the ATLAS Inner Detector.
5. Calibration of the ATLAS calorimeters and preparation for data-taking.
6. Participation in the development on the ATLAS Trigger DAQ (TDAQ).
7. Creation of the ATLAS GRID at JINR (one of the best in Russia).
8. Modeling and optimization of the ATLAS magnet system.
9. Preparation and planning of JINR participation in the ATLAS physics research program.

It is remarkable that only Italy, USA, CERN and JINR have contributed to all main subsystems (Tile-Cal, Muon, LAr, TRT, TDAQ) of the ATLAS detector. In 2009, JINR ATLAS project leaders explicitly stated (when the first part of the project was approved) that the outstanding JINR contribution to design, construction, assembly and commissioning of the ATLAS detector systems should not have been in vain for JINR. Therefore in 2020-2023 the main goal of JINR ATLAS management was to transform the above-mentioned JINR achievements into exciting physics results obtained by (or with important contribution of) the JINR scientists. Despite several complications, this goal was successfully achieved. The extended report on the JINR ATLAS team contribution to ATLAS operation and physics results during 2020-2023 is under preparation for publication.

In short, during these 4 years in the scope of the project the JINR team strongly participated in ATLAS physics results preparation including data taking, data preparation, Monte Carlo simulation and data analysis. The team took relevant part in obligatory ATLAS Common Operation Tasks, including shifts in the CERN-ATLAS and JINR-remote-ATLAS control rooms, on-call expert jobs, data quality control (remote), etc. Standard ATLAS maintenance and operation (M&O) support was supplied by JINR experts over these years. JINR has upgraded the JINR LHC computing Grid facilities and supplied computing resources which allowed successful exploitation of the JINR-based Tier-2 ATLAS Grid fragment. The JINR team has also defined its participation scope in the general ATLAS upgrade programme for the HL-LHC.

Furthermore, during realization of the ATLAS project at JINR in 2009-2023, the JINR ATLAS management has carried out its inner reorganization. The reason was a general change from construction, assembly and commissioning of the ATLAS detector sub-systems (Tail and LAr Calorimeters, Muon systems, inner TRT detectors, etc) to the ATLAS detector operation via new Common Operation Tasks (OT) like, for example, shifts in ATLAS control room, on-call expertise, data preparation, data quality tests and physics analysis. These new requirements forced some optimization of the ATLAS author list as well. Currently, participation in both Operation Tasks and Physics analyses is (as a rule) obligatory for an ATLAS author (from JINR). To strengthen responsibility of JINR people and to enhance the JINR contribution in the ATLAS project it was necessary to impose a new requirement for a membership in the JINR-ATLAS team. To fulfil it, one first had to become "visible" at the general ATLAS collaboration level before becoming an official ATLAS author. The main practical goal of this rule was to create at JINR a new efficiently working ATLAS team which can solve ambitious problems at a level of the whole ATLAS collaboration. JINR ATLAS management believes that during 2020-2023 the goal was reached in general. In particular, the JINR team contributed substantially to ATLAS physics output on the main topics of the Standard Model, QCD, searches for Higgs boson and Supersymmetry, and general study of physics beyond the Standard Model (Exotics physics). Several new directions for physics research were proposed and put into development by JINR team members.

Physical motivation for continuation of JINR participation in the ATLAS project relies on the main conceptual points in the Long-Term Plan of JINR development (the JINR Road-map). The Plan starts from description of the main developing directions of the modern Particle Physics and the urgent problems to be solved in the field. In particular, despite the Standard Model of particle physics explains to a high accuracy almost all relevant experimental observations, nevertheless, it is not a fundamental theory, but a low-energy limit of some underlying theory which originates from the very high energy scales. The main problems beyond the Standard Model can be cast into the following list (not complete):

1. What is the origin of the particle masses, are they due to a Higgs boson?
2. What is the nature of new particles and new principles beyond the Standard Model? Are there undiscovered principles of Nature – new symmetries, new laws?
3. Do all the forces of nature become one? How does gravity fit in? Is there a quantum theory of gravity?
4. Why are there so many types of quarks and leptons, and how can one understand their weak mixing and CP violation?
5. What is the dark matter that makes up about one quarter of the contents of the Universe? How can we make it in laboratory?
6. What is the nature of the dark energy that makes up almost three quarters of the Universe? How can we solve the mystery of dark energy?
7. Why is the universe as we know it made of matter, with no antimatter present? What is the origin of this matter-antimatter asymmetry? What happened to the antimatter?
8. What are the masses and properties of neutrinos and what role did they play in the evolution of the Universe? How are they connected to matter-antimatter asymmetry?
9. How did the universe form? How did the universe come to be?
10. Are there extra dimensions? String theory predicts seven undiscovered dimensions of space that give rise to much of the apparent complexity of particle physics, etc.

Addressing the above-mentioned central questions of the Particle Physics requires a broad, strongly integrated, program of theoretical and experimental research using a wide variety of modern tools and techniques that can be classify mainly into four interrelated directions – the **Energy-increasing accelerator** direction (the Energy Border); the **Intensity-increasing accelerator** direction (the Intensity Border), the Accuracy-increasing non-accelerator direction (the Accuracy Border) and the **Particle astrophysics** (the Cosmic Border).

At the Energy Border, using both hadron and lepton high-energy colliders, one will discover new physics of the **Terascale** (a TeV energy scale) and **directly** probe the properties of nature. At the Intensity Border, using intense beams, one will uncover the elusive properties of neutrinos and spread light on the problem of CP-violation, etc. At the Accuracy Border, investigating the rare processes by means of high-sensitivity, low-background experiments, one will observe new phenomena beyond the Standard Model and probe **indirectly** the properties of the nature far beyond any opportunities of modern and future accelerators. At the Cosmic Frontier one will reveal the natures of dark matter and dark energy and using high-energy particles from space (in particular neutrinos) one will probe the most far corners of the universe and make unique contribution in particle astrophysics. These four directions of the particle physics research join tightly together into a common framework that addresses all fundamental questions about the laws of nature and the cosmos.

Accelerators and experiments at the **Energy Border** are expected to make major discoveries. They will address key questions about the physical nature of the universe: the origin of particle masses, the existence of new symmetries of nature, extra dimensions of space, and the nature of dark matter.

In 2009 the **Large Hadron Collider (LHC)** at CERN (European Organization for Nuclear Research, Geneva, Switzerland) has achieved the highest collision energies. Significant participation in the full exploitation of the LHC has the highest priority in any national particle physics program. The LHC is the biggest and most powerful particle accelerator ever built. Colliding beams of protons generate about 1000 million collisions per second. Each proton flying around the LHC has energy of 7-14 Tera electron volts (TeV) to give proton-proton collision energy up to 14 TeV. Four major particle detectors – ALICE, ATLAS, CMS and LHCb – successfully observe the collisions during 5 years. The LHC experiments record about 1000 Gigabytes of data every day. Particle physicists are working with computer scientists around the world to develop and use new grid **networking technology**, which links computing and data storage resources from around the world into a seamless whole. The Grid is obviously inevitable for all the other modern experiments in Particle Physics, as well as for any research in all other fields of modern Science and Technology.

The future of Particle physics for decades is dominated by the LHC at CERN. JINR physicists participate in the general purpose experiments, **ATLAS** and **CMS**, which are designed to make excellent measurements of the many possible (known and unknown) products of collisions at the unprecedented centre-of-mass energy of 14 TeV. The experiments have already spread the light on the problem of particle mass genesis through the discovery of the Higgs boson, etc.Physics program of LHC experiments is, however, much more complex and it contains precision physics of CP violation, SUSY particles searches, extra dimensions and unexpected new phenomena.

Being in course of modern Particle Physics, JINR participates in generation of sources and tools for technological innovations with profound benefits for the sciences and society. Being in touch with (and/or in direct access to) a completely mystery substances as the dark matter and dark energy, JINR will take part in a science revolution, not just in particle physics but in the way human beings see the universe.

The Particle Physics near-the-corner opportunity for discovery about the fundamental nature of the universe that we never expected, the real work with unique best-level equipment and networking will make JINR very prestigious and most attractive for young generation of scientists and will allow the JINR Member States to be honest and generous with JINR financial support. This is also very attractive for rising the importance and prestige of high-quality education. Only such kind of very interesting, prestigious, front-end scientific work will attract young people in JINR and will copiously generate highly qualified personal for science industry, education, and all the other fields.

JINR, being in the course of modern Particle Physics, will inevitable participate in science international cooperation and will have access to most promising achievements and technologies (such as remote control systems, cryogenic and accelerator facilities, sophisticated power supply and control apparatuses, etc). Very good working example is the Grid – the new generation computing and networking system, which appeared at JINR due to its involvement in the LHC physics program. The future of the Grid is very difficult to overestimate.

This concludes description of advantages from (and motivation for) JINR participation in the Particle Physics development in general and in the ATLAS experiment, in particular.

JINR participation in the ATLAS physics and software development in 2025-2028

During the next 5 years the two main directions are planned under this type of the ATLAS project:

1. Participation in Running of the ATLAS experiment (M&O, Shifts, Common Operation Tasks, etc)
2. Physics research and data analysis.
3. Participation in the software maintenance and development.

As already noted since 2013 the JINR participation in the ATLAS and LHC Upgrade program is under a specialized JINR-ATLAS upgrade project (leader Dr. A.P.Cheplakov).

Participation in Running of the ATLAS experiment

JINR will continue its taking relevant part in obligatory ATLAS Common Operation Tasks. It includes shift work of JINR people in the CERN-ATLAS control rooms, fulfillment of on-call expert jobs, and data quality control, etc. Standard ATLAS maintenance and operation (M&O) support will be supplied by JINR over these years as well. In particular, JINR will continue participation in the running of the **Hadronic Tile Calorimeter** (Irakli Minashvivli (JINR) and Stano Nemecek (Prague) are the two main leaders of the Tile Calorimeter detector Maintenance). The LAr JINR ATLAS team will continue exploitation and support of the **Liquid Argon hadronic calorimeter**. The JINR M&O obligations include repairing and put in order electronic blocks, monitoring of quality of read-out channels, participation in shifts as “expert-on-call” and “HEC local expert”, etc. In the future 5 years some members of JINR ATLAS team will continue supporting the systems of АТЛАС **Distributed Computing** (including Grid, etc). Also it is planned to increase the participation in the detector maintenance and operation via the software development.

JINR will continue to participate in ATLAS **Safety control** efforts. In particular JINR members (V. Batusov, I. Kostyukhina, M.Shiyakova) will work as SLIMOS (Shift Leader in Matter of Safety). Furthermore they will care on Radiation Gate Monitors, where the main problem is SLIMOS to be able to prevent people to get out if they are detected with radioactive material in the underground cavern, etc.

JINR in the ATLAS Physics

The strategical idea of JINR participation in the ATLAS physics program is “visibility” of the JINR-team contributions. Contrary to the previous stage of the project (2020-2023, *with so-called JINR-based ATLAS preliminary activities*) any local activity in the field of ATLAS physics will not be supported at JINR if it has no clear plans to be considered, accepted and supported for development within the whole ATLAS Collaboration (or relevant ATLAS working groups).

In the light of the point, in the following directions JINR plans to strongly participate in 2025 – 2028:

1. Investigation of the applicability of the Standard Model and verification of SM predictions (including interactions of heavy ions), defining the structure of the proton at ultra-high energies (PDFs), tuning and improvement of relevant computer codes and events generators etc.
2. Search for the chiral Z*/W* bosons in the two-jet decays as well as in process with more complex topology of their associative production including heavy b and t quarks.
3. Search for (supersymmetric) charged Higgs bosons via their specific decay modes (3-leptons, etc).
4. Analyses on associated productions of the SM Higgs with $t\bar{t}$ pair and search for production with single top.
5. Search for a valence-like nonperturbative component of heavy quarks in the proton (intrinsic heavy quarks) via specific final state topology in the pp-interactions.
6. Search for new hadrons and baryons containing heavy c- and b-quarks, study the properties.
7. A new comprehensive study of the gluon structure of the proton, etc.
8. Search for quantum black holes in lepton+jet channel at 13 TeV.
9. Participation in the event triggers indexing infrastructure development.
10. Maintenance and development of the TDAQ system.

It is important to stress, that many of the points were proposed for ATLAS at JINR.

JINR in the ATLAS Standard Model Working group

SANC-group

Within this WG JINR is visible thanks to the international SANC Project (Support of Analytical and Numerical Calculations for Experiments at Colliders, site: http://brg.jinr.ru/). The work on application of the SANC results to LHC physics has been carried out since 2004 (under leadership of D.Yu.Bardin). The SANC group at JINR (D. Bardin, A. Arbuzov, S. Bondarenko L. Kalinovskaya, A. Sapronov, et al.) works very successfully in the ATLAS Collaboration over the years.

They develop and apply theoretical predictions for practically all three-particle and many four-particle processes of the Standard Model at the one-loop accuracy level. The main aims of SANC are preparation for very accurate physical analysis (including loop corrections), for example of single top quark production in pp collisions at LHC within SANC. Implementation of the SANC products into the ATLAS analysis software is of highest importance for JINR.

In 2025-2028 the SANC group plans to continue theoretical support with calculation of the electro-weak and QCD (EW&QCD) NLO corrections to the Drell-Yan-like processes for ATLAS data. In particular it concerns high-order EW-corrections for Drell-Yan neutral current events; fit of the Standard Model effective parameters and related Monte Carlo simulation; implementation of the impact of the photon-induced subprocesses in the generator and investigation of the effect on the final results.

A development of the SANC/PHOTOS software for ATLAS is also planned by A. Arbuzov et al and Z. Was. They plan to start from careful comparison of SANC/PHOTOS calculations off- and on-resonance cases and study the production of light fermion pairs.

Other members of the team will upgrade the famous HERAFitter code for ATLAS purposes, so that in particular the evolution of photonic PDFs will be included.

In addition, the members of the group (leader A.Sapronov) plan to deal with the following topics:

1. Measurement of the parameters of the Standard Model based on data on the longitudinal asymmetry of the lepton decay modes of a single Z-boson. Existing calculations of electro-weak

corrections in the approximation of NLO, implemented in the form of a Monte Carlo integrator MCSANC, permit, together with the approximation of the parton distributions of the proton, to measure a number of parameters of the electro-weak SM. The latter include the effective Weinberg angle, the so-called rho-parameter, and, in the long term, the effective coupling constants.

2. Analysis of the Drell-Yan-like processes in the context of QCD. The purpose of this analysis is to clarify the parton distribution functions based on experimental data of proton-proton collisions. Application of HERAFitter code for data of Run-I allows to get more information on the densities of momentum distributions of s-quark at small values of x and gluons at large x. The research will continue for wider kinematic ranges and higher statistics of Run-II.

Nowadays the SANC's machinery for ATLAS Run-II data analysis is developed. It is necessary for the Run-III to adopt the code of the interface for the new format and extend the code functionality.

Study of the proton structure

In the years 2025-2028 it is planned to continue the study of the structure of the proton in experiment ATLAS. It is supposed to test the JINR born hypothesis of existence of the valence-quark states in the proton, the so-called intrinsic charm and strangeness, in the pp processes with direct production of photons or vector bosons (W, Z), accompanied by the c- or b-jets.

The hypothesis will be checked by comparing the spectra of direct photons and vector bosons obtained from the data of Run-I and Run-II and taken from the theory [V.A. Bednyakov, M.A. Demichev, G.I. Lykasov, T. Stavreva, M. Stockton, hep-ph/1305.3548, Phys.Lett.B 728 (2014) 602].

Experiments at the LHC can be interpreted as "the factory of gluons" because at energies of several TeV, in pp collisions, the transfer momenta are so large that a large number of gluons is produced which manifest itself experimentally as jets of hadrons, mostly heavy, c- and b-jet.

It was shown by JINR team that from ATLAS data on the spectra of hadrons at small and large transverse momenta one can extract information about the distribution of gluons, which depend on the internal longitudinal and transverse momenta as well as the transfer squared four-momentum in pp collisions.

From the analysis of ATLAS data on the spectra of light charged hadrons, π- and K-mesons produced in pp collisions in the central rapidity region and the wider range of initial energies (from SPS until the LHC), the gluon distribution function at small internal transverse momenta was found for the first time [V.A.Bednyakov, A.A. Grinyuk, G.I. Lykasov, M.Poghosyan, Intern. J. Mod.Phys., A 27 (2012) 1250042; A.A. Grinyuk, A.V. Lipatov, G.I.Lykasov, N.P. Zotov, Phys.Rev. D87, 074017(2013); G.I. Lykasov, A.A. Grinyuk, V.A. Bednyakov, Phys.Part.Nucl. 44 (2013) 568-572; A.V. Lipatov, G.I. Lykasov, N.P. Zotov, hep-ph/1310.7893, Phys.Rev.D, 89 (2014) 014001].

It is planned to conduct a detailed analysis of ATLAS data on the production of heavy hadrons containing b- and c-quarks, and heavy jets in pp collisions by using QCD calculations in order to find the form of the gluon distribution at medium and large transverse momenta.

In other words, we plan to monitor of the gluon density in a wide range of variables on which it depends, using a set of ATLAS data obtained during the 2015-2025 period.

Heavy hadrons and baryons

One of the important research directions at the LHC is investigation of baryons containing c- and b-quarks. It is not possible to do at the B-factories, and the majority of baryons with two (and/or three) heavy quarks have not yet been observed. In the period of 2025 – 2028 JINR team plans the following:

1. Study of semi-leptonic and hadronic Bc decay modes in data of RUN-II, in particular for searching for a vector states $B_c^* \to B_c + \gamma$ (earlier it was not observed in other experiments), and also for searching for possible reproducing the analysis of Run-I/II for searching of $B_c^*(2S)^+$ in semi-leptonic B_c decay mode, as in Run-I, but aiming on more precise measurement of $B_c^*(2S)^+$ production cross section using higher statistics.

2. Search for a double-charged tetraquark state decaying to B_c^+ and π^+.

3. Measurement of the relative B_c^+/B^+ production cross section.

4. As the next step of the analysis performed during previous project (Phys.Lett. B751 (2015) 63-80) it is planned to measure the helicity amplitudes and parity violating asymmetry parameter α_b for $\Lambda_b^0 \to J/\psi\ \Lambda^0$ and $\Lambda_b^0 \to \Psi(2S)\ \Lambda^0$ decay channels. It is expected that polarization effects for the $\Lambda_b^0 \to \Psi(2S)\ \Lambda^0$ decay channel will be measured for the first time.

5. Search for various exotic states in $\Lambda_b^0 \to J/\psi\ \varphi\ \Lambda^0$ or/and $\Lambda_b^0 \to J/\psi\ K_S^0\ \Lambda^0$ processes. For example, the $(J/\psi,\Lambda^0)$ mass spectrum can be used to search for the hidden charm pentaquark with S=-1 in the mass range 4.35 – 4.55 GeV

6. Study of exotic structures $X \to J/\psi\ \varphi(1020)$ in $B^+ \to J/\psi\ \varphi\ K^+$ decays.

7. Measurement of $B_c \to J/\psi\ D$ decays. Totally five decays, with $D = D_s^+, D^{*+}_s, D^+, D^{*+}, D_{s1}(2536)^+$. First two were observed in Run-I, a more precise measurement is possible with Run-II. The other decays have not been observed yet.

To study the decays with J/ψ in the final state the existing trigger will be used after its adaptation to the increased luminosity of the LHC. JINR team is going to continue maintenance and development of the package for one- and di-muon trigger efficiency and scale-factors measurement, in particular for the analysis on B^+ cross section measurement.

Bose-Einstein correlations

Studies of the dependence of BEC on particle multiplicity and transverse momentum are of special interest. They help to understand the multiparticle production mechanism. The size of the source emitting the correlated particles has been observed to increase with particle multiplicity. This can be understood as arising from the increase in the initial geometrical region of overlap of the colliding objects: a large overlap implies a large multiplicity. While this dependence is natural in nucleus–nucleus collisions, the increase of size with multiplicity has also been observed in hadronic and leptonic interactions. In the latter, it is understood as a result of superposition of many sources or related to the number of jets. High-multiplicity data in proton–proton interactions can serve as a reference for studies of nucleus–nucleus collisions. The effect is reproduced in both the hydrodynamical/hydrokinetic and Pomeron-based approaches for hadronic interactions where high multiplicities play a crucial role. The dependence on the transverse momentum of the emitter particle pair is another important feature of the BEC effect. In nucleus–nucleus collisions the dependence of the particle emitter size on the transverse momentum is explained as a “collective flow”, which generates a characteristic fall-off of the emitter size with increasing transverse momentum while strong space–time momentum–energy correlations may offer an explanation in more “elementary” leptonic and hadronic systems where BEC measurements serve as a test of different models (Eur. Phys. J. C75 (2015) 466; Phys. Lett. B 758 (2016) 67).

JINR team is going to continue measurements of the BEC in one- and three-dimensional cases as well as investigations of charged-particle distributions in Run-II/III data.

JINR in the ATLAS Higgs Working group

VH process study with Higgs to bb decay

The results of this study were briefly presented in the "ATLAS Upgrade" chapter. Working together with our colleagues from the "Higgs to complex states" working group we will complete soon this analysis on the full dataset from Run-II. The present analysis is based on the so called "Simple template" approach, but more complicated multivariable methods will be applied once higher statistics will be available in Run-III.

ttH measurements in multilepton channel

The study of the origin of electro-weak symmetry breaking is one of the key goals of the LHC. In the Standard Model, the symmetry is broken through the introduction of a complex scalar field doublet, leading to the prediction of the existence of one physical neutral scalar particle, commonly known as the Higgs boson. The discovery of a Higgs boson with a mass of approximately 125 GeV by the ATLAS and CMS Collaborations was a crucial milestone. Measurements of its properties performed so far are consistent with the predictions for the SM Higgs boson.

JINR team in collaboration with IEAP Czech Technical University in Prague is going to continue ttH study with full Run-II dataset:

1. Fake Lepton Analysis in the Same-sign Lepton+Tau hadronic Channel (2lSS+1τ had)
2. Contribution to Group Framework 1 (GFW1)
3. Upgrade the ABCD Fake factor method for fake lepton estimation
4. Apply Template Fit for fake estimation and compare with results of updated FF method
5. Contribution to combination of channels

tH production

The Higgs boson production in association with a single top-quark (tH) is searched using Higgs decays into b quark pairs. In the Standard Model the cross-section of this process is predicted to be an order of magnitude smaller than for the Higgs production with a pair

of top quarks (ttH). Due to the very small event yield, the SM tH process can not be discovered with the Run-II statistics, only an upper limit can be set. On the other hand, this channel is sensitive to the sign (or, more generally, to the complex phase) of the top Yukawa coupling. In particular, in the BSM model with inverted top coupling (ITC) the cross-section is enhanced by more than an order of magnitude. The Run-II statistics is sufficient to observe the ITC tH channel, or to rule out this model.

So far, a generator-level Monte-Carlo study of the tH channel has been undertaken by the JINR team. A brief summary can be found O.A.Koval, I.R.Boyko and N.Huseynov, EPJ Web Conf., 201 (2019) 04003. The further plans are:

1. Improve the event selection by applying a Neural Network instead of the event selection by sequential cuts;

2. Analyze the Full Simulation Monte-Carlo using the experience gained with the generator-level study;

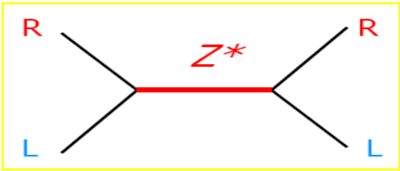
3. Study the tH (H→bb) channel using the ATLAS Run-II data and set limits if no signal is observed

JINR in the ATLAS Exotics Working group

Prospects for the search for Z*/W*

The existence of excited bosons has been suggested in the early papers of M.V. Chizhov [Mod. Phys. Lett. A 8 (1993) 2753], at present a senior researcher at Dzhelepov Laboratory of Nuclear Problems. The project for their search at the LHC has been proposed in [Phys. Atom. Nucl. 71 (2008) 2096; Nuovo Cim. C 33 (2010) 343] also by scientists of Dzhelepov Laboratory:

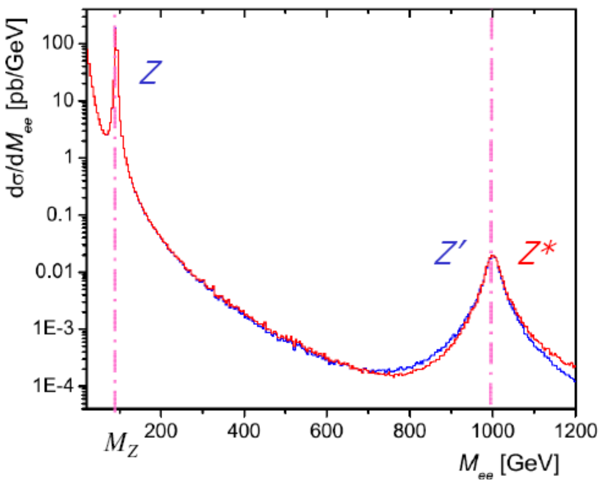
M.V. Chizhov, V.A. Bednyakov and J.A. Budagov. The project has been accepted by the ATLAS Collaboration in 2009.

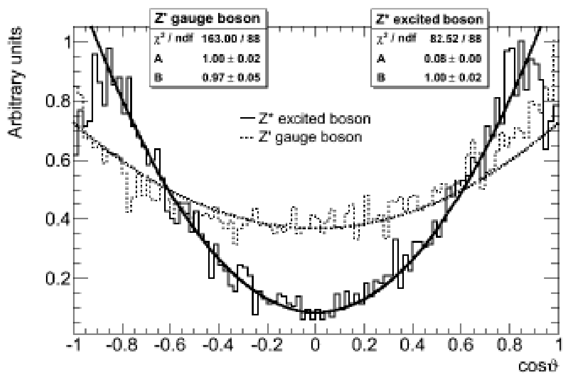


excited Z^* :

$$\mathcal{L}_{\text{exited}} = \frac{g}{\sqrt{2}\Lambda}\left(\bar{\ell}\sigma^{\mu\nu}\ell + \bar{d}\sigma^{\mu\nu}d\right)\partial_\mu Z^*_\nu$$

JINR team (Leader M.V.Chizhov) together with ATLAS team from St.Petersburg INR (Leader O.Fedin) within Lepton+X Exotics WG have carried out research on general topic “Search on inclusively produced chiral Z* bosons via their decay into lepton-antilepton pairs”. The obtained data is collected at special Twiki page https://twiki.cern.ch/twiki/bin/view/AtlasProtected/ZstarEleEle. In general, the Z* analysis is very similar to the Z’ analysis. However, the peculiar features of the excited bosons result in many differences in comparison with the Z’ results (**Figure below**). This will help to distinguish them an ambiguously from the other neutral resonances with different spins.



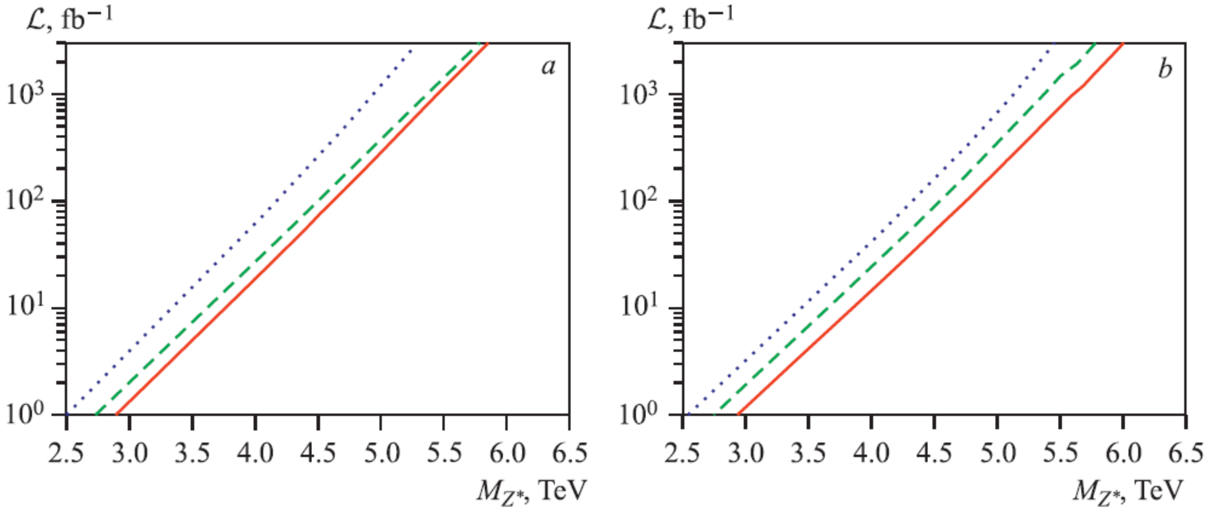


$$A + B\cos^2\vartheta_{CS}$$

Experimental searches for these heavy excited bosons with ATLAS detector in the first period of the LHC data analysis were based on proton-proton collision energies of 7 (8) TeV and integrated luminosity of 5(20) fb-1, respectively. The results of these studies were the new upper limits for the cross sections and the masses of the new bosons. The observed mass limits Z*(W*) are 2.85 (3.21) TeV.

Prospects for further Z*, W* searches related, are based primarily on the plans to increase the energy of the proton-proton collisions at the LHC to 13-14 TeV and increase the luminosity of proton beams. Expected number of events with Z*, W* increases proportionally integrated luminosity of the collider, and for large masses of the new bosons significantly increases with the energy of the colliding beams.

The **figure below** shows the dependence of the integrated luminosity necessary for detection (left) or exclusion (right) with a confidence level of 95% of the Z* boson depending on its mass for energy of pp collisions 13 TeV.



The integrated luminosity of the proton-proton collisions with energy 13 TeV required for detection (left) or exclusion of the existence (right) of the boson Z depending on the mass of the latter.*

It should be noted that the increase in energy collision greatly increases the potential for the search of the new physics. For instance, for the pp-collisions with energy of 14 TeV the integrated luminosity smaller than 1fb^{-1} is required to improve the existing restrictions on the Z* mass in required, while the analysis of 100 fb^{-1} data will test the hypothesis of Z* existence up to it mass of 4.5 TeV.

The next 5 years the JINR team will continue searches for the Z* boson. Then the search will start for charged chiral W* boson, produced inclusively and decaying into electron-neutrino pair (pp→W*→μν). Due to the missing neutrino energy this analysis seems more complicated. We plan to attract our PhD students for its fulfillment.

JINR team holds leading positions in this analysis direction and attracts for cooperation the others ATLAS members. The leaders of the research (M.V.Chizhov and G.Dvali) have recently showed a deep connection between introduced chiral bosons and fresh ideas beyond the SM, such as SUSY and physics of extra dimensions.

Therefore, during 2025-2028 JINR team plans to continue the search for the excited bosons not only in the dilepton channels, but also in the dijets final states as well as in associated production with the heavy quarks [M.V. Chizhov, V.A. Bednyakov, J.A. Budagov, Phys. Atom. Nuclei 75 (2012) 90; ATLAS Collaboration, Phys. Rev. D 91, 052007 (2015); M.V. Chizhov, V.A. Bednyakov, Phys. Atom. Nucl. 79 (2016) 721]. To prepare for the full Run-II, new Monte-Carlo simulations of productions of the excited bosons should be done in the ATLAS software framework for different channels. This task is a direct responsibility of our Institute. JINR group plans to continue also the data analysis in the muon channel.

Mixing and mass of Z’ bosons from resonant di-boson searches

Neutral vector bosons Z are among the best motivated scenarios of physics beyond the Standard Model (SM). Many new physics models beyond the SM, including superstring and left-right-symmetric models, predict the existence of such bosons. They might actually be light enough to be accessible at current and/or future colliders. The search for such neutral Z’ gauge bosons is an important aspect of the experimental physics program of present and future high-energy colliders.

Depending on the considered theoretical model, Z’ masses of the order of 4.5 TeV [3,4] and Z-Z’ mixing angles at the level of 10^{-3} are already excluded. These constraints come from the very high-precision Z pole experiments at LEP and the Stanford Linear Collider (SLC), including measurements from the Z line shape, from the leptonic branching ratios (normalized to the total hadronic Z decay width) as well as from leptonic forward-backward asymmetries. While these experiments were virtually blind to Z' bosons with negligible Z-Z' mixing, precision measurements at lower and higher energies (away from the Z pole) attainable at TRISTAN and LEP2, respectively, were able to probe the Z' exchange amplitude via its interference with the photon and the SM Z boson. However, as was shown, at the LHC at nominal collider energy of $\sqrt{s}$ = 14 TeV and integrated luminosity of $L_{int} \approx 100\ fb^{-1}$ a high potential exists to improve significantly on the current limits on the Z-Z' mixing angle in the di-boson channel: pp → ($Z_2 \rightarrow W^+ W^-$) + X.

In contrast to the Drell-Yan (DY) process pp → Z' → $l^+ l^-$ + X, with l = e, μ, the di-boson process is not the principal discovery channel, but can help to understand the origin of new gauge bosons.

The JINR team plans are:

1. Set limits on W-W' mixing angle in the WZ-bosons production processes in Run-I/II/III
2. Set limits on Z-Z' mixing angle in the di-boson production processes in Run-II/III
3. Perform a search for resonant and interference effects of the new calibration bosons, the di-lepton production processes and to set limits on the dynamical parameters and masses in Run-II/III

Quantum Black Holes

Models for physics beyond the SM, such as the ADD-model, postulate the existence of extra dimensions which could lead to an energy scale of quantum gravity in the TeV region. And also Randall Sundrum-1 (RS1) model postulates the existence of extra dimensions leading to low gravity at the TeV scale. Quantum black holes are predicted in low-scale gravity models which offer a possible solution to the mass hierarchy problem of the SM by lowering the scale of gravity (MD) from the Planck scale (∼ 10^{16} TeV) to a value of about 1-10 TeV. Here MD is the multi-dimensional Planck scale. The multi-dimensional paradigm has been developed into models such as that proposed by Arkani-Hamed, Dimopoulous and Dvali (ADD-model). In models with large extra spatial dimensions, like the ADD model, only the gravitational field is allowed to penetrate the n extra spatial dimensions, while all the SM fields are localized in the usual four-dimensional space-time. The model used in this note includes the following features. QBHs have masses above MD and have spin=0. The production and decay needs to conserve total angular momentum, color and electric charge. The QBH decay into two particles final states. In other words, the QBHs show quasi-particle behavior in contrast with semi-classical black holes that decay via Hawking radiation to a large number of particles. In these models baryon and lepton numbers can be violated in the QBH production.

JINR team going to finalize analysis using Run-II data and after re-optimizations and some preparation work start to analyze Run-III data.

JINR in the ATLAS SUSY Working group

SUSY related charged Higgs search (complex final states)

JINR has very strongly motivated plans to continue study of discover possibility of charged Higgs boson from MSSM. To prove SUSY discovery one coherently has to find as many SUSY particles as possible, and the charged Higgs boson is one of the main “player” of SUSY. This search will be carried out via charged Higgs boson decay into SUSY final states, charginos and neutralinos. Such final states allow one to search for and discovery the charged Higgs boson when all other his decay channels into ordinary SM particles (non-SUSY) are forbidden. This SUSY decay channel assumes rather large mass of this Higgs boson (large than 250 GeV/c^2), where associate charged Higgs and top quark production dominates. All neutralinochargino Higgs decay channels are considered, where one can find in the final state three charged leptons, two neutral stable invisible neutralinos and some neutrinos.

Preliminary study has shown good prospects of the selected process for discovery of the charged Higgs boson predicted for rather wide parameter space of tan β and $m_{H\pm}$. Nevertheless it is possible only for well defined values of the other important MSSM parameters μ and M_2. Therefore, JINR team plans first to study the 4-dimension MSSM parameter space to select the best search strategy on the basis of simulated samples generated for benchmark SUSY points by the ATLAS Higgs WG. First real low luminosity ATLAS data will be used for real background determination (including SUSY backgrounds), later with increase of data first signal search are scheduled (Leader A.P.Cheplakov, F.Ahmedov. A.A.Soloshenko).

JINR work and plans on charged Higgs search are approved by HSG5 WG and were discussed at two Workshops of the WG (2010 and 2011) in Dubna.

In general, a study of SUSY with ATLAS detector, discovery of SUSY and coherent (SUSY) solution of the dark matter problem are between the primary goals of JINR participation in the ATLAS experiment.

JINR in the ATLAS software development

Events indexing

The EventIndex is a complete catalog of all ATLAS events, keeping the references to all files that contain a given event at any processing stage. It takes event information from various data sources, such as CERN and Grid sites. It is also checks data for corruption and consistency, provides information about overlap of events or datasets by different trigger chains as well as fast data overview. JINR team during next 5 years is going to participate in development and support of the control system of the data indexing on the GRID servers, system parameters and production monitoring and as well as full support of the EventIdex system. It is also planned to develop EventIdex system using BigData technologies for the Run-III datataking period.

TDAQ system

JINR team will participate in support of components of the real time TDAQ system, development of the operational monitoring systems and networks monitoring. It is also planned to participate in the development and maintenance of the TDAQ system for the Run-III.

SWOT Analysis

The approach developed by our colleagues from the ATLAS-JINR Upgrade Team was used as a good starting point for the present analysis.

Strength

1. Participation in a large and challenging international projects in a competitive and high-tech, internationally oriented, research arena
2. Excellent scientific publication and citation records
3. Collaborations with groups at the leading international scientific center (CERN) in particle physics and other physics laboratories
4. Large interest of the general public and media

Weaknesses

1. The growing age of staff scientists and engineers

- The efforts are undertaking to attract young students to join the project
- JINR and CERN are the founder of the Russian Physics Teacher Programme

2. Many analyses in the ATLAS Collaboration have publication deadlines due to the high class conferences date. This is especially important for the search analyses. But nonetheless, it is rather hard to precisely predict and therefore perform the definite plan of the analyses work, publications and expenses for working trips.

Opportunities

1. LHC shows huge discovery potential which attracts scientists at all levels (master students, PhD students, postdocs and staff physicists)
2. JINR experiments often require completely new and challenging analysis methods, data acquisition and production requirements and ATLAS offers all those possibilities and contacts with new research and analysis communities
3. The experience gained in the ATLAS experiment is shared with our colleagues from the other projects of the Institute
4. The Big Grid - e-science grid–project JINR-LCG2 - provides researchers at JINR with state-of-the-art computing services and an opportunity to establish contacts and/or collaborations with many other research disciplines.

Threats

No threats are identified

2.3 Estimated completion date: 2028

2.4 Participating JINR laboratories: DLNP, VBLHEP, MLIT

2.4.1 MICC resource requirements

Computing resources	Distribution by year				
	1st year	2nd year	3rd year	4th year	5th year
Data storage (TB) - EOS - Tapes	200	200	200	200	
Tier 1 (CPU core hours)					
Tier 2 (CPU core hours)	200	200	200	200	
SC Govorun (CPU core hours) - CPU - GPU					
Clouds (CPU cores)					

2.5. Participating countries, scientific and educational organizations

Organization	Country	City	Participants	Type of agreement
Foundation ANSL	Armenia	Yerevan	G. Akopyan	Collaborative work
IP ANAS	Azerbaijan	Baku	N. Huseynov + 5	Collaborative work
GSTU	Belarus	Gomel	A.A. Pankov + 3 I.A. Serenkova + 1	Visits exchange

GSTU	Belarus	Gomel	A.A. Babich + 1	Collaborative work
GSU	Belarus	Gomel	N.V. Maksimenko	Visits exchange
GSU	Belarus	Gomel	V.V. Andreev + 2	Collaborative work
IAP NASB	Belarus	Minsk	R.G. Shulyakovsky + 2	Visits exchange and collaborative work
IP NASB	Belarus	Minsk	Yu.A. Kurochkin + 3	Visits exchange and collaborative work
INP BSU	Belarus	Minsk	A.A. Solin A.V. Solin P.M. Starovoitov + 5	Visits exchange
INP BSU	Belarus	Minsk	A.V. Grinevich	Collaborative work
JIPNR-Sosny NASB	Belarus	Minsk	V.V. Gilevsky + 2	Visits exchange and collaborative work
SU	Bulgaria	Sofia	M.V. Chizhov	Collaborative work
UdeM	Canada	Montreal	C. Leroy	Collaborative work
TRIUMF	Canada	Vancouver	L.L. Kurchaninov	Collaborative work
CERN	CERN	Geneva	M. Vincter A. Hoecker K. Jacobs	Cooperation agreement
CU	Czech Republic	Pargue	I. Wilhelm	Collaborative work
LPC	France	Clermont-Ferrand	F. Vasey	Collaborative work
LAL	France	Orsay	D. Fournier	Collaborative work
HEPI-TSU	Georgia	Tbilisi	T. Djobava + 3	Cooperation agreement
MPI-P	Germany	Munich	S. Menke	Collaborative work
DESY	Germany	Zeuthen	W. Loman Y. Schrieber	Collaborative work
WIS	Israel	Rehovot	G. Mikenberg	Collaborative work
INFN	Italy	Pisa	T. Del Prete	Collaborative work
NIKHEF	Netherlands	Amsterdam	H. Van Der Graaf	Collaborative work

ITEP	Russia	Moscow	I. Tsukerman	Collaborative work
LPI RAS	Russia	Moscow	A. Snesarev + 1	Collaborative work
MSU	Russia	Moscow	L. Smirnova	Collaborative work
IHEP	Russia	Protvino	S. Denisov A. Zaytsev	Collaborative work
NOSU	Russia	Vladikavkaz	I. Tvauri	Collaborative work
CU	Slovakia	Bratislava	A. Dubnickova S. Tokar	Collaborative work
IP SAS	Slovakia	Bratislava	S. Dubnicka + 3	Collaborative work
IFAE	Spain	Barcelona	M. Cavalli-Sforza	Collaborative work
ANL	USA	Lemont, IL	L. Price	Cooperation agreement
SSU	Uzbekistan	Samarkand	A. Artikov U. Salikhbaev	Collaborative work

2.6. Key partners *(those collaborators whose financial, infrastructural participation is substantial for the implementation of the research program. An example is JINR's participation in the LHC experiments at CERN).*

3. Manpower
3.1. Manpower needs in the first year of implementation

№№ n/a	Category of personnel	JINR staff, amount of FTE	JINR Associated Personnel, amount of FTE
1.	research scientists	26.5	1
2.	engineers		
3.	specialists		
4.	office workers		
5.	technicians		
	Total:		

3.2. Available manpower
3.2.1. JINR staff

No.	Category of personnel	Full name	Division	Position	Amount of FTE
1.	research scientists	Prof. L. Kalinovskaya	DLNP	Head dep.	1
		PhD A. Sapronov	DLNP	Sen. scientist	1
		Y. Dydyshka	DLNP	Sen. scientist	1
		Yu. Yermolchyk	DLNP	Engeneer	1
		V. Yermolchyk	DLNP	Sen. scientist	1
		PhD A. Soloshenko	VBLHEP	Head dep.	1
		T. Turtuvshin	VBLHEP	Scientist	1
		Prof. G. Lykasov	DLNP	Chief sc.	1
		PhD A. Lipatov	DLNP	Sen. scientist	1
		PhD st. A. Prokhorov	DLNP	Jr. scientist	1
		Prof. L. Gladilin	DLNP	L. scientist	0.5
		PhD V. Lyubushkin	DLNP	Sen. scientist	1
		T. Lyubushkina	DLNP	Jr. scientist	1
		PhD F. Ahmadov	VBLHEP	Sen. scientist	1
		M. Manashova	VBLHEP	Jr. sc	1
		PhD E. Khramov	DLNP	Head dep.	1
		PhD S. Karpov	DLNP	Sen. scientist	1
		PhD Z. Karpova	DLNP	Sen. scientist	1
		PhD I. Yeletskikh	DLNP	Sen. scientist	1
		PhD N. Huseynov	DLNP	Sen. scientist	1
		PhD I. Boyko	DLNP	Sen. scientist	0.5
		M.Sc. O. Dolovova	DLNP	Jr. scientist	0.5
		A. Didenko	DLNP	Tr. researcher	1
		A. Tropina	DLNP	Lab. Assistant	1
		Prof. Y. Kultchitsky	DLNP	Head dep.	1
		P. Tsiareshka	DLNP	Scientist	1
		E. Plotnikova	DLNP	Scientist	1
		PhD I. Alexandrov	MLIT	Head dep.	0.4
		E. Aleksandrov	MLIT	Scientist	0.2
		A. Kazymov	MLIT	L. programmer	0.2
		M. Mineev	MLIT	Scientist	0.2
2.	engineers				
3.	specialists				
4.	technicians				
	Total:				**26.5**

3.2.2. JINR associated personnel

No.	Category of personnel	Partner organization	Amount of FTE
1.	research scientists	Prof. M Chizhov	1

2.	engineers		
3.	specialists		
4.	technicians		
	Total:		**1**

4. Financing

4.1 Total estimated cost of the project/LRIP subproject

The total cost estimate of the project (for the whole period, excluding salary).
The details are given in a separate table below.

We would like just to make some comments regarding two largest positions. The first one is the "Materials" with 300 kUSD per year. This amount should cover JINR contribution to the Collaboration for our 34 active authors. The second position "Working trips/Travel allowance" should cover Collaboration request for Operation Tasks of Class 1 and 2 that requires permanent presence of three shifters at CERN that is approximately 3*12*4kUSD = 144 kUSD per year. The rest ~86 kUSD of this position should cover travel expenses for coverage of the Operation Tasks of Class 3, for physics analyses purposes and for conferences.

4.2 Extra funding sources

Expected funding from partners/customers – a total estimate.

Project (LRIP subproject) Leader __________/___________/

Date of submission of the project (LRIP subproject) to the Chief Scientific Secretary: __________
Date of decision of the laboratory's STC: __________ document number: __________

Year of the project (LRIP subproject) start: _________________

(for extended projects) – Project start year: _______

Proposed schedule and resource request for the Project / LRIP subproject

Expenditures, resources, funding sources		**Cost (thousands of US dollars)/ Resource requirements**	**Cost/Resources, distribution by years**				
			1st year	2nd year	3rd year	4th year	5th year
	International cooperation	920 k$	230 k$	230 k$	230 k$	230 k$	
	Materials	1200 k$	300 k$	300 k$	300 k$	300 k$	

		Equipment, Third-party company services						
		Commissioning						
		R&D contracts with other research organizations	200 k$	50 k$	50 k$	50 k$	50 k$	
		Software purchasing	40 k$	10 k$	10 k$	10 k$	10 k$	
		Design/construction						
		Service costs (*planned in case of direct project affiliation)*						
Resources required	**Standard hours**	Resources						
		- the amount of FTE,	110	27.5	27.5	27.5	27.5	
		- accelerator/installation,						
		- reactor,…						
Sources of funding	**JINR Budget**	JINR budget *(budget items)*	2360 k$	590 k$	590 k$	590 k$	590 k$	
	Extra fudning (supplementary estimates)	Contributions by partners Funds under contracts with customers Other sources of funding						

Project (LRIP subproject) Leader_________/________________/

Laboratory Economist _________/________________/

APPROVAL SHEET FOR PROJECT / LRIP SUBPROJECT

TITLE OF THE PROJECT/LRIP SUBPROJECT

SHORT DESIGNATION OF THE PROJECT / SUBPROJECT OF THE LRIP

PROJECT/LRIP SUBPROJECT CODE

THEME / LRIP CODE

NAME OF THE PROJECT/ LRIP SUBPROJECT LEADER

AGREED

JINR VICE-DIRECTOR	SIGNATURE	NAME	DATE
CHIEF SCIENTIFIC SECRETARY	SIGNATURE	NAME	DATE
CHIEF ENGINEER	SIGNATURE	NAME	DATE
LABORATORY DIRECTOR	SIGNATURE	NAME	DATE
CHIEF LABORATORY ENGINEER	SIGNATURE	NAME	DATE
LABORATORY SCIENTIFIC SECRETARY THEME / LRIP LEADER	SIGNATURE	NAME	DATE
PROJECT / LRIP SUBPROJECT LEADER	SIGNATURE	NAME	DATE

APPROVED BY THE PAC

SIGNATURE	NAME	DATE