

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

APPROVED

JINR DIRECTOR

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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 - 02-2-1081-2009

1.2 Project code – 02-2-1081-1-2010/2025, 02-1-1081-2-2013/2025

1.3 Laboratory – DLNP, VBLHEP, MLIT, FLNP, BLTP

1.4 Scientific field – High energy physics of elementary particles and heavy ions

1.5 Title of the project/LRIP subproject – ATLAS. Detector upgrade and physics at LHC

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

1.7 Project/LRIP subproject deputy leader(s) (scientific supervisor(s)) – Yeletskikh I.V.,
Cheplakov A.P.

2 Scientific case and project organization

2.1 Annotation

The primary goal of the ATLAS experiment is to explore proton-proton collisions at record-breaking energies (7 – 14 TeV in c.m.f.) at Large Hadron Collider (LHC). The physics program of the experiment includes precision measurements of the Standard model (SM) parameters, investigating limits of its applicability and aims at addressing the fundamental questions of the modern physics such as nucleon structure, top-quark physics, existence of the dark matter particles, possible manifestations of quantum-gravity effects and additional space dimensions, observations of new properties of the known fundamental interactions.

JINR scientists (as in previous years) plan to obtain and publish new results related to all major parts of the ATLAS physics program. New data that are going to be collected in collisions of proton beams of high luminosity will allow performing high-precision observations and measurements of rare processes, obtain inputs for improving simulation of the studied processes, extend sensitivity to processes beyond SM. Studies of heavy hadron properties, such as CP-violation in *B*-meson decays, search for new hadronic states in decay spectra, measurements of exotic tetraquark and pentaquark states; top-quark physics, proton structure and modeling of the charm and beauty hadron production

are planned. Within the Higgs physics program the studies of its production in association with top-quarks and vector bosons as well as new measurements of Higgs-boson couplings to SM particles will be performed. Searches for beyond SM physics such as manifestations of quantum black holes at TeV scale in pp-collisions are going to continue.

JINR plans to continue active participation in ATLAS software (SW) development and support. These activities, in particular, include development and support of databases for the experiment, trigger system software, support for the event reconstruction and simulation performance in all detector subsystems.

The High-Luminosity LHC (HL-LHC) physics program will be crucial for deepening our understanding of fundamental physics, enabling in particular precision studies of the Higgs sector and enhancing sensitivity to rare processes and potential new physics signals. With unprecedented integrated luminosity, it will offer a unique opportunity to probe the Standard Model (SM) with extreme accuracy and explore connections to open questions in particle physics, astroparticle physics, and cosmology. The HL-LHC legacy measurements of many SM parameters are expected to remain relevant for decades, even during the operation of a next future collider. Until then, our understanding of key SM sectors will rely on the ultimate precision achieved by the HL-LHC experiments.

The HL-LHC conditions require unprecedented detector technologies in terms of radiation hardness, high detection granularity and resolution, precision track timing, and powerful triggers. To meet these challenges, ATLAS pursues an ambitious upgrade program. The JINR group is actively engaged in upgrading several subsystems of the ATLAS detector, making significant contributions to the modernization of the muon spectrometer, liquid argon calorimeter and construction of a novel High-Granularity Timing Detector (HGTD).

2.2 Scientific case

JINR participation in ATLAS physics program

The international ATLAS collaboration has been founded over 30 years ago to design and construct the new-generation multi-purpose facility aiming at investigations of the fundamental properties of matter in pp-collisions with energies up to 14TeV at LHC. Currently the ATLAS collaboration involve 2632 authors and overall around 6000 participants from 187 institutions in 42 countries. Since it's foundation the collaboration designed, produced and tested the highly complex experimental equipments, the unprecedented precision of detector simulation and physics processes in it have been achieved. This led to the discovery of a new Standard Model particle—the Higgs boson—in 2012 and the measurements of its crucial properties. In 2025, the participants of the ALICE, ATLAS, CMS, and LHCb experiments were awarded the Breakthrough Prize in Fundamental Physics for "precise measurements of the Higgs boson's properties confirming the symmetry-breaking mechanism of mass generation, the discovery of new strongly interacting particles, the study of rare processes and matter-antimatter asymmetry, as well as the exploration of nature at the smallest scales and most extreme conditions at CERN's Large Hadron Collider."

A list of works and studies conducted at JINR made a decisive contribution to the results obtained by the collaboration. This list includes:

1. Production, installation and setup of all main detector subsystems including works within detector upgrade
 - a) Elements of the muon spectrometer
 - b) Elements of the liquid argon calorimeter and central part of tile calorimeter
 - c) Calibration of ATLAS calorimeters and their preparation to data taking
 - d) Contribution to data acquisition and trigger systems development
 - e) Participation in development and production of the High Granularity Timing Detector (HGTD)
2. Development and support of several important ATLAS software componets:

- a) Development of the distributed computing system at JINR and development and support for detector conditions databases and event databases;
 - b) Development of the trigger software;
 - c) Development and support of the reconstruction and simulation software for the different detector subsystems, including configuration software, fast calorimeter simulation, tuning of calorimeter simulation using test beam facilities, etc.;
3. Studies within the physics program of the experiment and their implementation during all periods of data taking:
- a) Higgs boson physics studies, including measurements of cross sections of Higgs boson produced in association with gauge vector bosons (F.Ahmadov); studies of Higgs boson produced via gluon-gluon fusion processes associated with W-bosons (E.Ramakoti); exploration of top-quark Yukawa coupling via Higgs-boson + top-quarks production processes (I.Boyko, N.Huseynov, I.Yeletsikh, A.Didenko, O.Dolovova, A.Tropina);
 - b) Development of the theoretical models of heavy gauge bosons with masses of TeV-scales and search for their manifestations in dilepton final states (V.Bednyakov, M.Chizhov, I.Yeletsikh); contribution to searches for heavy bosons decaying to W/Z/H-boson plus gamma photon (E.Khramov); participation in searches for supersymmetric particle decays (V.Bednykov, D.Kazakov, A.Gladyshev, Yu.Budagov, D. Khubua, E.Khramov, S.Karpov, A.Soloshenko); search for quantum black holes in proton-proton collisions (S.Karpov, Z.Karpova);
 - c) Investigations of proton structure including the contribution of intrinsic charm and transversely polarized gluons (G.Lykasov, V.Bednyakov, A.Lipatov);
 - d) Measurements of the properties and spectra of the beauty hadrons and light states, search and studies of exotic tetraquark and pentaquark states (L.Gladilin, A.Vasyukov, I.Yeletsikh), studies of the resonant production of charmonium pairs and fully charmed tetraquarks (I.Yeletsikh, A.Didenko, L.Gladilin), study of B_c -meson decays (L.Gladilin, T.Lyubushkina), measurement of differential cross sections of charmed and beauty hadrons (L.Gladilin);
 - e) Measurements of the associated production of vector boson pairs and two high-invariant mass jets (E.Soldatov); measurements of Z + heavy jets production cross sections (S.Turchikhin);
 - f) Study of Bose-Einstein correlations in the events with high-multiplicity of tracks (Yu.Koultchitski, P.Tsiareshka, E.Plotnikova);
 - g) Participation in data acquisition activities, control and measurements of object reconstruction quality in detector (muons, electrons, photons, jets) (S.Turchikhin, E.Soldatov);
 - h) Development of Monte-Carlo generators (SANC, ReneSANCe), theoretical description of experimental processes (L.Kalinovskaya, E.Dydyshka, V.Yermolchyk, S.Bondarenko).

The motivation for continuing work and research within the ATLAS collaboration is based on the key provisions of the long-term development plan of JINR (the JINR Roadmap). In particular, this plan includes the main directions of modern particle physics and the most topical challenges in this field today. Despite the Standard Model's ability to describe experimentally observed phenomena with high precision, even up to TeV energy scales, it is clear that it is not a complete theory. Rather, it represents only a low-energy approximation of a more general theory that incorporates gravitational interaction and provides a description of physical phenomena up to Planck mass energies. The most crucial questions that cannot be resolved within Standard Model have to be addressed by physics research of the nearest future:

1. Are there new fundamental phenomena in the energy range between the electroweak unification scale (a few hundred GeV) and the Planck scale that determine the limits of the Standard Model's applicability? Is there an energy scale for the unification of fundamental interactions, and what is it?

2. What is the source of masses of elementary particles and what causes their hierarchy in the Standard model? Is there a ‘fine tuning’ of the Standard Model parameters?
3. What is the nature of dark matter and dark energy? Is it possible to explore them at particle colliders?
4. What is the source of baryonic asymmetry in the universe?
5. Are there extra spacial dimensions and fundamental forces and symmetries related to them?

In addition, the study of proton structure at LHC energies remains highly relevant. These unique energies make research on known Standard Model particles, especially massive ones like the top quark and the Higgs boson, a particularly significant direction. A thorough investigation of these objects will not only refine their key properties but also pave the way beyond the Standard Model.

Answers to these and a number of related questions are the primary objectives of elementary particle physics in the nearest future. The most promising research directions are associated, on the one hand, with accelerator physics (including increasing energies, as well as improving reconstruction accuracy and accelerator luminosities) and, on the other hand, with observational astrophysics. Increasing accelerator energies up to hundreds of TeV will enable direct searches for new physics at corresponding scales. Boosting the luminosity of existing accelerators and improving the precision of reconstructed processes will allow searches for manifestations of new physics through corrections to observed phenomena—such as coupling constants and phases between particles.

JINR plans for participation in physics analysis during 2026-2030

During the next five years the major planned directions of JINR team participation in ATLAS collaboration (aside of detector upgrade) are the following:

1. Contributions to detector exploitation and management (M&O, Shifts, Common Operation Tasks);
2. Physics studies (data preparation and processing, experimental analyses, modeling, theoretical support);
3. Participation in software development and support;

JINR participation in detector exploitation and management

JINR staff will continue to participate in the operation of the ATLAS experimental facility. These activities include shifts at control and monitoring stations, on-call expert shifts, data quality control tasks, and more.

1. Hadronic Scintillator Calorimeter Operation:
JINR plans to continue its involvement in managing the operation of the hadronic scintillator calorimeter (I. Minashvili);
2. Liquid Argon Calorimeter Operation:
JINR will maintain its participation in the operational tasks of the liquid argon calorimeter. The institute's responsibilities include the repair and recommissioning of electronics modules, monitoring readout channel quality, and taking part in on-call expert shifts;
3. Distributed Computing Support for ATLAS:
In the coming years, JINR staff will continue to support distributed computing for the ATLAS experiment;
4. Safety Operations at the detector:
JINR intends to remain involved in safety-related operations at the facility. JINR staff (V. Batusov, I. Kostyukhina, M. Shiyakova) will continue to serve as Shift Leaders in Matters of Safety (SLIMOS). Additionally, they will oversee radiation safety and manage access control in the ATLAS cavern;

JINR participation in physics research

In the coming years, the JINR (Joint Institute for Nuclear Research) group plans to continue its participation in all major areas of the ATLAS physics program. The analysis of data collected by the detector in 2022–2025, as well as data expected to be collected in the future, will significantly enhance sensitivity to observable parameters or set new limits on their values in a range of physics studies. The main research directions are as follows:

1. Search for Higgs boson production in association with top quarks (N. Guseynov, I. Boyko, A. Didenko, O. Dolovova, A. Tropina, et al.) in the Higgs boson decay channel to a pair of b-jets. The goal is to obtain and analyze data directly sensitive to the magnitude and phase of the Higgs boson-top quark coupling constant. The phase difference between the WH and tH couplings, predicted by the Standard Model, leads to destructive interference between different contributions to Higgs boson production in association with top quarks, suppressing the cross-section. Possible corrections to this phase difference from Beyond the Standard Model (BSM) effects could increase the observed cross-section by several times.
2. Study of Higgs boson production via gluon and vector boson fusion (E. Ramakoti). Like other Higgs boson property measurements, this is an important test of the Standard Model and is sensitive to potential deviations from its predictions.
3. Measurements of Higgs boson production cross-sections in gauge boson-associated channels (F. Akhmadov). New data are expected to significantly refine previous measurements, particularly in improving the precision of Higgs boson coupling constants with beauty and charm quarks.
4. Search for manifestations of BSM physics models, particularly quantum black hole (QBH) production in the lepton+jet channel (S. Karpov, Z. Karpova). Analyzing new data in this channel will provide new constraints on QBH model parameters and serve as an important test of both the Standard Model's validity at multi-TeV energies and the quality of existing simulation methods.
5. Investigation of excited B_c -meson properties and spectra (T. Lyubushkina) is of significant interest for understanding different heavy quark flavour interactions and their bound states.
6. Measurement of the CP-violating phase in B_s -meson decays (V. Lyubushkin). CP violation in $B_s \rightarrow J/\Psi\phi$ decays arises from interference between direct decay and decay with B_s - $anti$ - B_s oscillations. The Standard Model predicts a small phase ($\phi_s \sim -0.04$), determined by Cabibbo-Kobayashi-Maskawa mixing angles. BSM effects could substantially alter this phase. Current experimental measurements of ϕ_s show discrepancies, necessitating further refinement.
7. Study of tetraquark and pentaquark states in B-meson decays (A. Vasyukov, I. Yeletskikh). Recent experimental efforts focus on hidden-charm tetraquarks (Z_c, Z_{cs}) and pentaquarks (P_c, P_{cs}). Pentaquark contributions to Λ_b -baryon decay chains were first observed in 2015 by LHCb and confirmed by ATLAS. Current research aims to precisely measure their parameters, determine spins and parities, and discover new decay channels, shedding light on their internal structure and interaction dynamics.
8. Investigation of double charmonium production and fully charmed tetraquark states (I. Yeletskikh, A. Didenko). In 2021–2022, LHC experiments discovered resonances near the J/Ψ - J/Ψ and J/Ψ - $\Psi(2S)$ thresholds, consistent with fully charmed tetraquark hypotheses. Future tasks include refining spectral modeling, analyzing angular distributions, and determining spin-parity. Increased ATLAS data statistics will enhance measurement sensitivity.
9. Measurement of differential B^\pm -meson production cross-sections (L. Gladilin). This is crucial for understanding heavy meson production and hadronization mechanisms.

10. Proton structure studies at LHC energies (G. Lykasov, A. Lipatov), including intrinsic charm contributions to parton distribution functions and polarized gluon effects. Measurements of vector boson production with heavy jets, angular distributions in heavy-flavor hadron production, and heavy jet spectra will constrain theoretical proton structure models proposed at JINR.
11. Search for W -boson decay in the $J/\Psi + \pi$ channel (L. Gladilin).
12. New measurements of single and double Z -boson production cross-sections (E. Soldatov).
13. Data quality monitoring and reconstruction validation (E. Soldatov).
14. Measurements of total and differential cross-sections for W -boson production in association with top-quark pairs (A. Maslennikov).

JINR's Contribution to ATLAS Software Development and Theoretical Support

In recent years, JINR's involvement in ATLAS software development and support has expanded considerably. The efficiency of reconstruction, simulation, triggering, event selection, and analysis software directly impacts physics results. For 2025–2029, JINR plans to continue and expand its contributions in key areas:

1. Development of the ReneSANCe Monte Carlo generator, including calculations of radiative corrections and refined modeling of LHC physics processes, such as polarized W -boson production in proton-proton collisions.
2. Theoretical studies of proton structure at LHC energies, including intrinsic charm and transversely polarized gluon contributions to observable processes, e.g., calculations of angular asymmetries in D -meson pair production.
3. Development and maintenance of the EventIndex database, critical for analyses requiring non-standard reconstruction (e.g., excited B_c -meson studies). Tasks include data integrity checks, duplicated event handling, registered by different triggers.
4. Support for ATLAS calorimeter software, including response simulation, calibration, and detector condition database maintenance.
5. ATLAS trigger system software support.
6. Development of statistical analysis tools, such as a pseudo-data generator for multidimensional kinematic spectrum analysis.
7. Creation and testing of multivariate analysis software, including custom mathematical models, machine learning algorithms, and neural network training tailored to high-energy physics data.

This comprehensive program ensures JINR's continued leadership in ATLAS physics and software contributions.

JINR participation in ATLAS upgrade program

The ATLAS and CMS experiments at LHC are unique drivers of fundamental understanding of nature at the energy frontier. With a collected luminosity of 3ab^{-1} per experiment, ATLAS and CMS can achieve, in particular [*ATL-PHYS-PUB-2025-018, CMS-HIG-25-002*]:

1. The observation of the $H \rightarrow \mu^+ \mu^-$ and $H \rightarrow Z\gamma$ rare processes and the determination of the corresponding couplings with a precision of 3% and 7%;
2. The measurement of the other main Higgs boson couplings to fermions and vector bosons with a precision between 1.6% and 3.6%;
3. The observation of the SM di-Higgs-boson production with a significance exceeding 7σ ;
4. The measurement of the Higgs boson trilinear self-coupling λ_3 with a precision better than 30%;

5. The measurements of extremely rare processes, such as simultaneous four-top-quark production, with a precision of 6%;
6. Constraints on anomalous interactions between the top quark and the Z boson, probing new physics at energy scales up to 2 TeV, etc.

To achieve such accuracies, a large statistical sample of experimental data is required, so efforts are being made to increase the LHC luminosity, which necessitates the modernization of the detectors and elements of the CERN accelerator complex. The first stage of the detector modernization (Phase 1) was carried out during the second Long Shutdown of the LHC (LS2), when instantaneous luminosity of the LHC more than doubled (Fig. 1); after LS3 and completion of the Phase-II of the LHC and detector upgrades, the luminosity will increase fivefold compared to the nominal value of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$.

Phase-I of the ATLAS detector upgrade

The preliminary schedule for the LHC project, updated in March 2025, is presented in Figure 1.

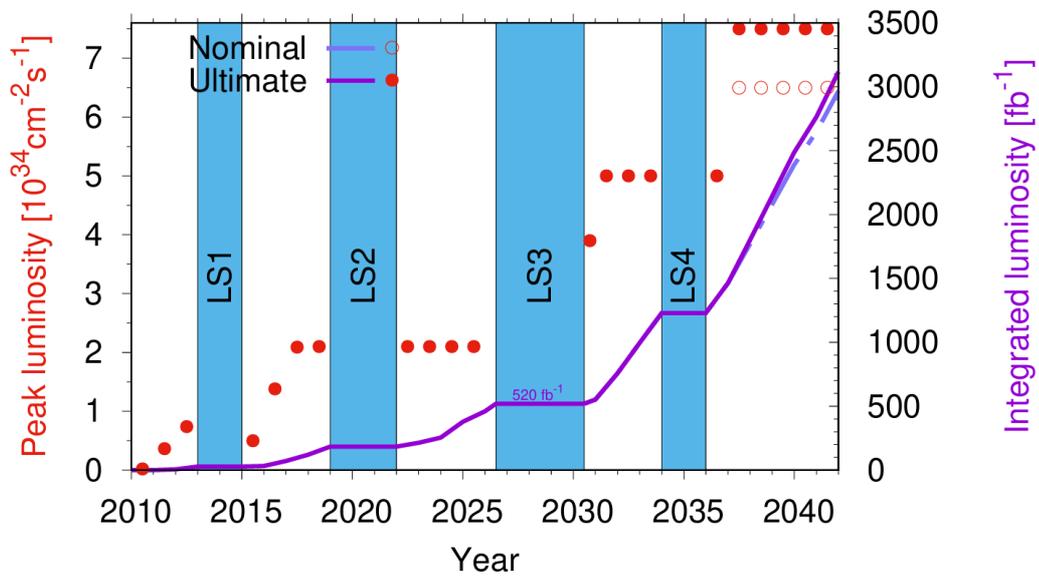


Fig. 1: A preliminary schedule showing the delivered peak (integrated) luminosity in red (purple) as a function of year. The periods of long shutdown are shown by the blue bands. The nominal scenario (light purple, open red circle) in Run 5 corresponds to an average number of pp interactions per bunch crossing (pileup) of about 173, and the ultimate scenario (dark purple, solid red circle) corresponds to a pileup of 200. Both Run 5 scenarios include heavy ion data taking.

The Phase-I of the ATLAS detector upgrade was completed by the end of 2022. The JINR team played important role in realization of the New Small Wheel (NSW) project for the Muon spectrometer, we made contributions in development of the Demonstrator for the Tile calorimeter readout electronics. For the Tile subsystem we also performed radiation tests of new scintillators and contributed to the production and assembly of the new modules. Our engineers designed baseplane for readout crates and designed preshower board for the LAr trigger electronics. The radiation tests were done for readout boards, cables and optical patch-cords at the IBR-2m pulsed neutron reactor.

Muon spectrometer (Phase-I)

The most significant contribution of the JINR within the Phase-I of the ATLAS Upgrade project was made for the upgrade of the Muon spectrometer. The JINR group was responsible for the fabrication and testing of Micromegas modules for the outer part of the large sectors of the NSW - LM2 (see Fig. 2). All 64 (plus 4 additional spares) readout panels with a total area of 384 m² out of 1200 m² NSW were manufactured and tested at JINR. Using drift panels produced at Aristotle University of Thessaloniki, Greece (AUTH), the group also produced and tested 32 Micromegas modules (plus 1 spare module).



Fig. 4. Various stages of the RO panels and modules production and testing, and the new prototypes.

After production and testing, the MM modules were shipped to CERN, where they were tested, integrated into the NSW structures and commissioned by DLNP JINR group (Fig. 5). Currently, the MM modules are successfully operating in the ATLAS muon spectrometer. By May 2024, the MM trigger was fully integrated, achieving $>95\%$ efficiency across all NSW sectors and reducing fake rates further. Fake MM trigger segments are now at sub-% levels.



Fig. 5. Members of the DLNP JINR team during the integration of the LM1 and LM2 modules (BB5 area at CERN) and in front of the fully assembled NSW wheel.

This way the modern Micromegas technology was brought to JINR. Nowadays two production lines for Micromegas chambers are used for the ATLAS R&D and provide the institute employees with the opportunity to use the chambers in different physics experiments and in applied studies, including experiments at the NICA complex.

Liquid argon calorimeters (Phase-I)

The scope of the LAr Phase-I upgrade project was to design, build and install new trigger readout electronics. The objective of this upgrade was to provide higher-granularity, higher-resolution and longitudinal shower information from the calorimeter to the Level 1 trigger processors. The 10-fold increase in granularity improved the trigger energy resolution and efficiency for selecting electrons, photons, τ -leptons, jets, and missing transverse momentum, while enhancing discrimination against backgrounds and fakes in an environment with high instantaneous luminosity.

The upgrade to the trigger branch of the LAr system begins with the signal which is produced by the linear mixer in the front-end electronics, as shown in the block diagram in Fig. 6. This signal is sent over the baseplane to the new LAr Trigger Digitizer Board (LTDB), where it undergoes digitization.

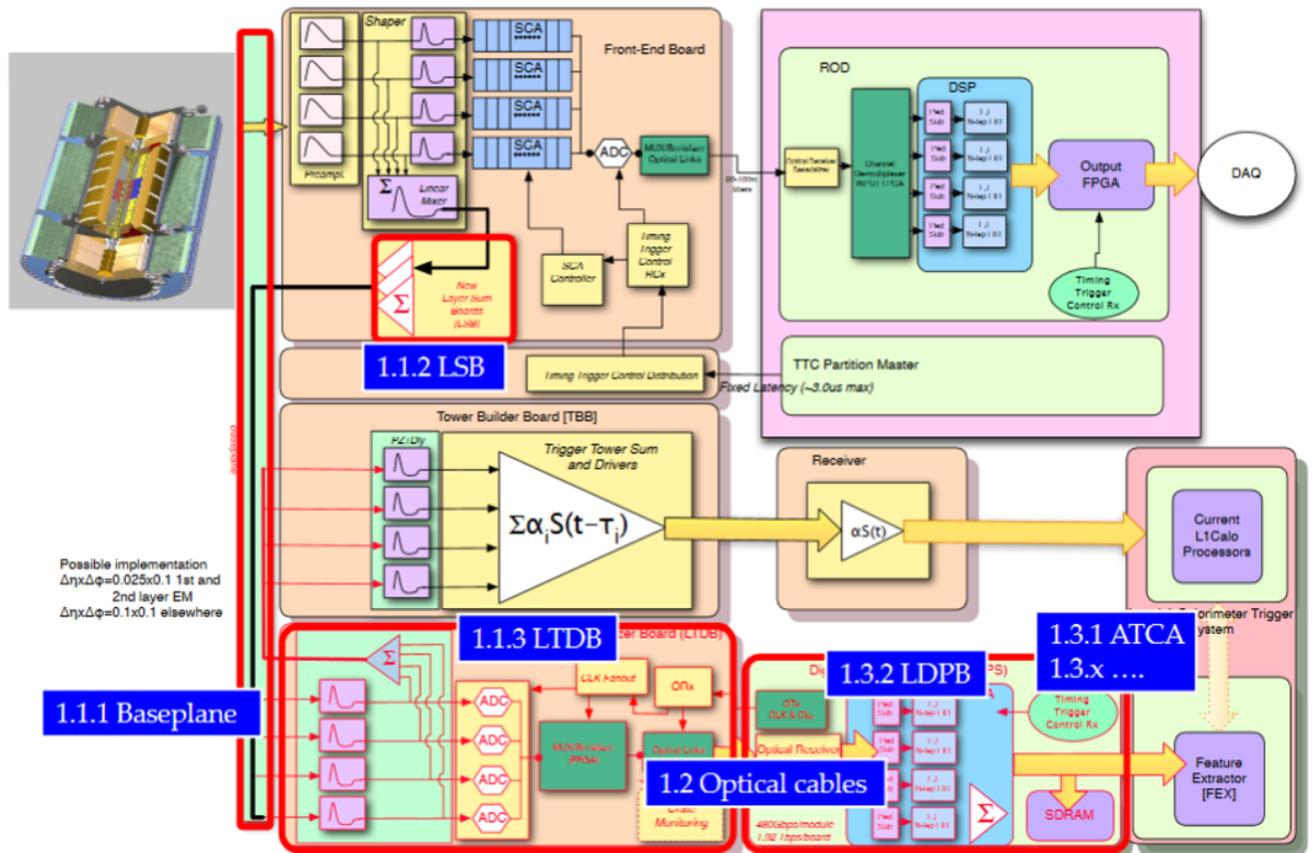


Fig. 6. Schematic block diagram of the Phase-I upgrade LAr trigger readout architecture. The new components are indicated by red outlines and arrows

Baseplane for the Hadronic Endcap Calorimeter (HEC) front-end readout crate was developed by the JINR team and produced in collaboration with colleagues from TRIUMF (Canada). We also proposed design for the prototype of the preshaper of LTDB, it was produced and successfully tested (Fig. 7).

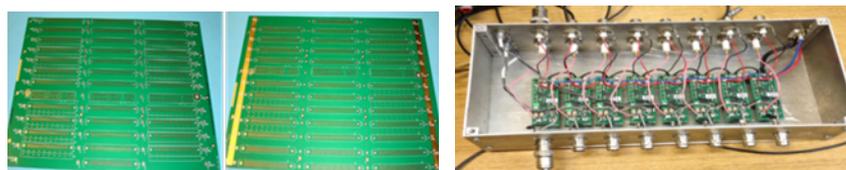


Fig. 7. Baseplane and pre-shaper prototype and test board for LTDB.

A series of radiation tests of the LAr calorimeter readout boards and cables were conducted at the irradiation channel 3 of the IBR-2 reactor. The JINR group took part in a test beam at SPS CERN to study the effects of space charge with minimodules of the FCal forward calorimeter.

Phase-II of the ATLAS detector upgrade

To fully exploit the discovery potential of the HL-LHC, the ATLAS Collaboration has proposed a Phase-II upgrade programme of the ATLAS Detector, consisting of modifications and replacements of existing sub-systems as well as new additions to the Detector [CERN-LHCC-2015-020].

To cope with the demanding conditions at the HL-LHC, the ATLAS collaboration is upgrading its detectors with state-of-the-art instrumentation and technologies. These new detectors need to withstand a much harsher environment with high radiation, high data-rates, larger event sizes, and high-occupancy with up to 200 proton-proton interactions per proton bunch crossing. Key improvements include changes to the trigger and data acquisition system, a completely new all-silicon inner tracker, a new silicon timing detector, as well as upgrades to the calorimeter electronics, additional muon chambers and electronics, and forward detectors as shown in Figure 8.

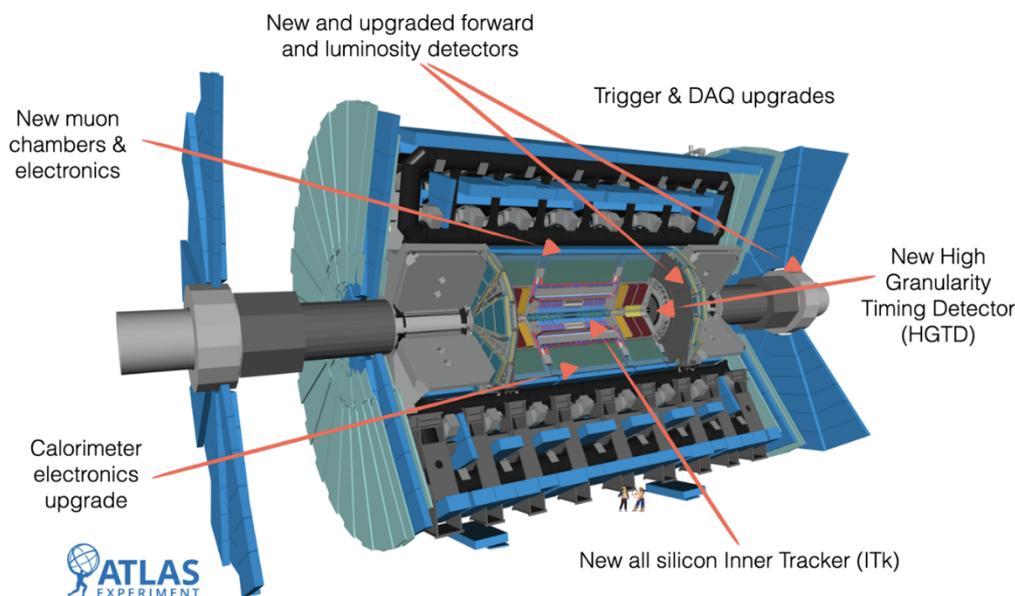


Fig. 8. Schematic of the major upgrades to the ATLAS detector for the HL-LHC era including a trigger and data acquisition (DAQ) upgrades with increased read out rates, a new all-silicon inner tracker (ITk), a new high granularity timing detector (HGTD), calorimeter electronics upgrades, new muon chambers and electronics with improved coverage and new and upgraded forward and luminosity detectors [JINST 19 (2023) P05063].

In 2019 the JINR signed several Memoranda of Understanding for Collaboration in the Construction of the ATLAS Detector (Phase-II Upgrade) that define the obligations of the JINR group to participate in the upgrade of the muon spectrometer, LAr calorimeter and construction of the HGTD. In addition, the procurements of parts and hardware components are foreseen for these subdetectors as well as for TDAQ system. The total CORE¹ cost of all the items is about ~2.7 MCHF. These expenses are foreseen in the Seven Year Plan for the Development of JINR (2024-2030). Our goal is to maximize the JINR in-kind contribution.

Resistive Plate Chambers (RPC) for muon spectrometer (Phase-II)

In accordance with the MoU for the ATLAS Phase-II Upgrade the DLNP ATLAS group is involved in the development and production of the new resistive plate chambers (RPC) for the ATLAS Muon spectrometer. It includes, in particular:

- RPC Singlet assembly and testing;

1 * The CORE (Cost of Resource Exchange) value identifies only the deliverable's direct cost; it excludes associated manpower costs, exchange rate fluctuations, prototyping cost, R&D costs, etc. It includes items such as components, industrial stuff (but not institute staff) for production, outsourced parts of assembly, installation, test and commissioning.

- Strip panels production and testing;
- Gas system design, production, installation;
- Power distribution design, production and installation;
- Surface commissioning, installation in the pit and final commissioning.

The present ATLAS Resistive Plate Chamber (RPC) system represents the first level trigger in the ATLAS barrel region. It consists of 6 concentric cylindrical layers providing independent space-time measurements along the track with a resolution of $1\text{ ns} \times 1\text{ cm}$. For the HL-LHC programme, this system will undergo a major upgrade, which will consist of installing three additional next-generation full-coverage RPC layers in the inner region of the barrel. This upgrade will increase trigger acceptance (from 78% to 92% and up to 96% by requiring the inner and outer layers to match) and improve time resolution for time-of-flight measurements (0.4 ns for the new thin-gap RPCs and 1.1 ns for the old RPCs). The new thin-gap (1 mm) RPCs will occupy an area of 472 m^2 and will be organized into 306 triplets. A singlet (Fig. 9) is the assembly of a gas volume enclosed between two readout panels with strips parallel to the long side of the chamber. In turn, the gas volume of the resistive plate chamber consists of a gas gap enclosed between two high-pressure laminate (HPL) plates. A layer of graphite is applied to the outer surface of each HPL plate. The total thickness of the gas volume is approximately 4.5 mm.

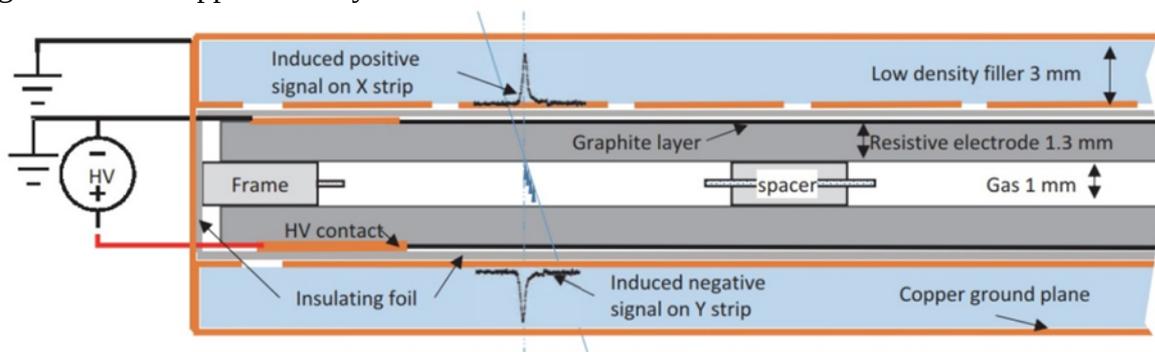


Fig. 9. Schematic view of the RPC Singlet.

The production area of NSW LM2 Micromegas (Phase-I) was adapted for production of BI RPC readout panels. Two vacuum tables technology is used for production. This technology allows gluing both sides of the panels in one pass and the panel thickness does not depend on variation of the material (PCB+Honeycomb) thickness (Fig. 10).



Fig. 10. Technological stages of the RPC panel production process

Three test readout BIL type panels were produced and tested for geometric characteristics. The tests showed a high quality of production (Fig. 11). All produced panels satisfy requirements with a large margin. Moreover, a 3-axis linear module with a measuring optical probe made it possible to measure the absolute dimensions of the panel and the strips on it and confirmed high quality.

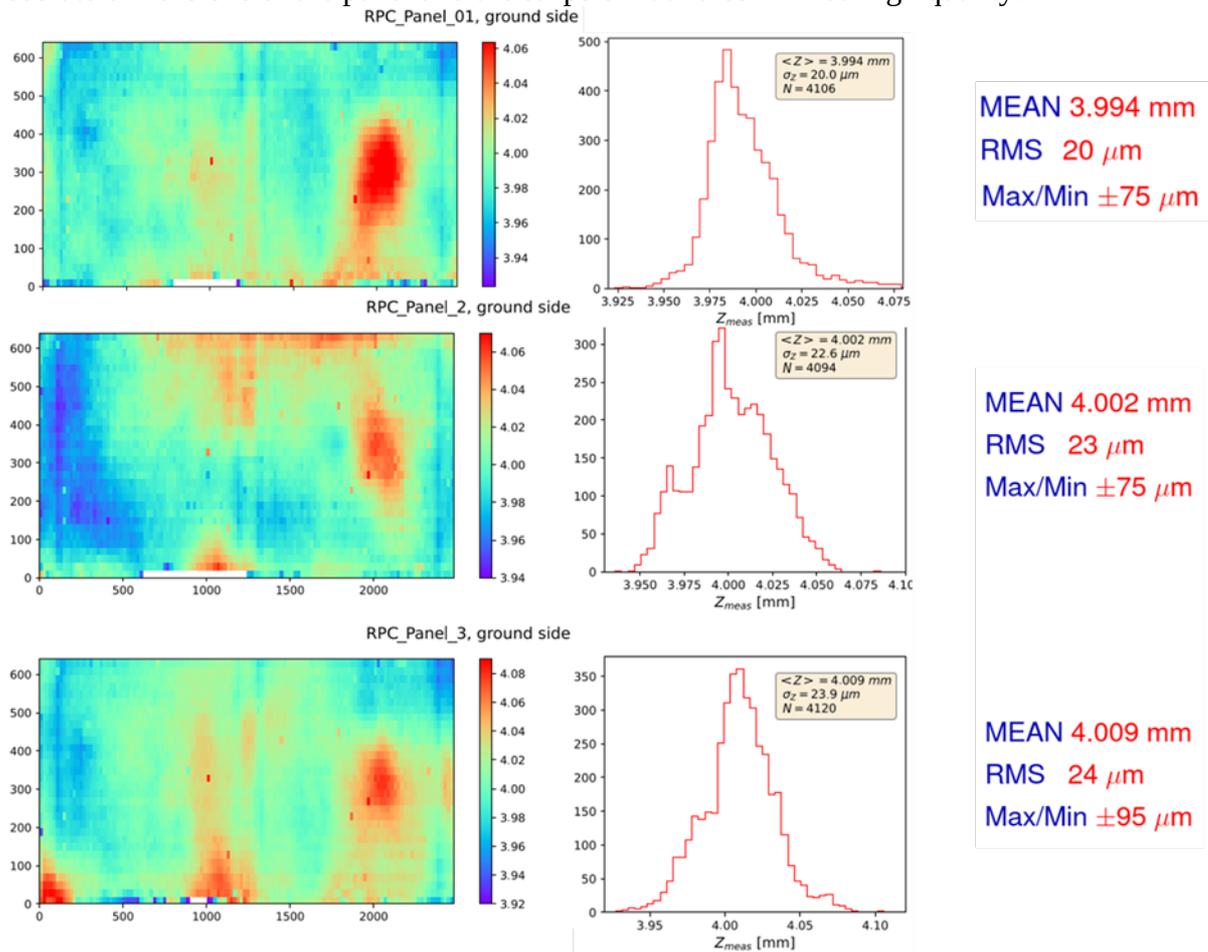


Fig. 11. Results of measuring the geometrical characteristics of the panels.

While realization of the RPC production at JINR remains uncertain, the first full production cycle site in Russia and Eastern Europe for the development and testing of modern Micromegas Micro Pattern Gas Detectors (MPGD) has been established at DLNR JINR. It provides the opportunity to carry out new developments, produce and test prototypes and small batches of detectors, and participate effectively in the implementation of major physics experiments, such as AMBER project at SPS at CERN, MPD and SPD experiments at the NICA accelerator complex.

High-Granularity Timing Detector (Phase-II)

The large increase of pileup interactions is one of the main experimental challenges for the HL-LHC physics programme. A powerful new way to mitigate the effects of pileup is to use high-precision timing information to distinguish between collisions occurring close in space but well-separated in time. A High-Granularity Timing Detector, based on low gain avalanche detector technology, is therefore proposed for the ATLAS Phase-II upgrade (Fig. 12). Covering the pseudorapidity region between 2.4 and 4.0, this device will improve the detector physics performance in the forward region. The typical number of hits per track in the detector was optimized so that the target average time resolution per track for a minimum-ionising particle is 30 ps at the start of lifetime, increasing to 50 ps at the end of HL-LHC operation. The high-precision timing information improves the pileup reduction to improve the forward object reconstruction, complementing the capabilities of the upgraded Inner Tracker (ITk) in the forward regions of ATLAS and leading to an improved performance for both jet and lepton reconstruction.

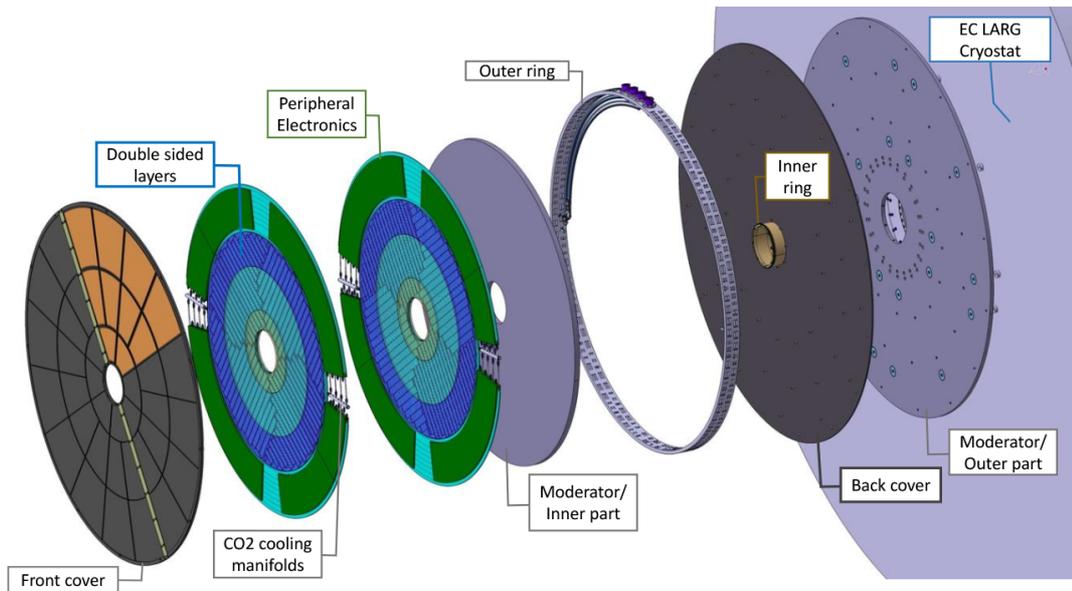


Fig. 12. Global view of the HGTD to be installed on each of two end-cap calorimeters. The various components are shown: hermetic vessel (front and rear covers, inner and outer rings), two instrumented double-sided layers (mounted in two cooling disks with sensors on the front and back of each cooling disk), two moderator pieces placed inside and outside the hermetic vessel.

The JINR group was involved in the HGTD project from the very beginning. Our employees occupy a number of coordinating positions in the collaboration. The official MoU for collaboration in construction of HGTD was signed in 2022. The JINR obligations include:

- Development and production of the DCS system;
- Design, development, production and testing of the half-disk instrumentation stand;
- Design, development, production and testing of tool for half-disk installation;
- Participation in testbeam activities, assembly of components, installation and integration work.

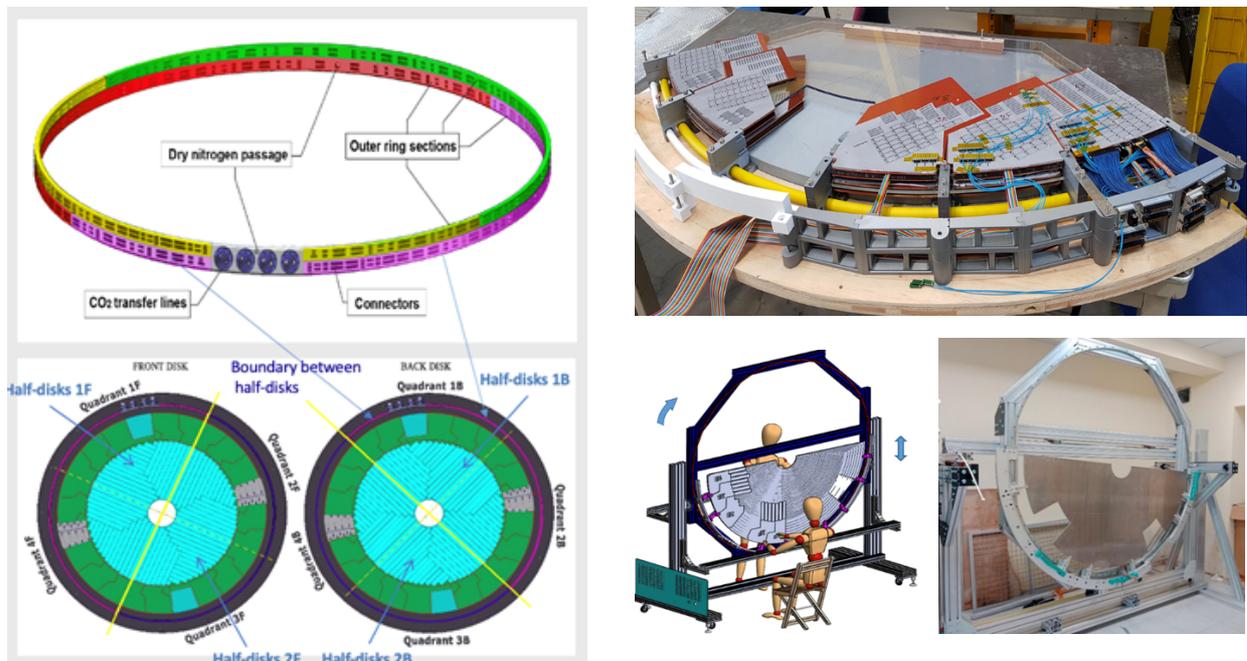


Fig. 13. Details of the HGTD services, the mock-up and prototype of the stand for the HGTD half-disk instrumentation.

The JINR team developed an optimal scheme for the arrangement of the modules and peripheral electronics in order to maximize the number of identical components. A concept for the outer ring of the detector and connecting services was also proposed and realized in a prototype (Fig. 13). The HGTD detector comprises:

- ~300 cables and 40 optical cables connected to each vessel at outer ring
- 281 pigtailed + 80 optical fanouts per vessel interconnect peripheral electronics boards with cables
- HV, LV, NTC pigtailed all are identical, fanouts are the same length.

To optimize the layout of electrical and optical services inside the HGTD case, 3D model of services inside the detector case was developed and mock-up was constructed. It was used to determine the locations and dimensions of electrical and optical services for their further manufacture.

We proposed the concept and designed a stand for instrumentation of HGTD half-disks. The prototype of the stand was manufactured at JINR and is being prepared for shipment to CERN. The group continues to work on developing DCS control system (hardware and software). We are participating in the development of the HGTD Demonstrator. Module-0 comprises 1 peripheral board with 54 modules (108 ALTIROC ASICs) and other detector systems – mechanics, cooling, HV, LV, etc. Beam tests of the modules are foreseen at the SPS and DESY.

The most significant in-kind contribution of the JINR team in the project will be manufacturing additional stands and mechanical components for HGTD support frame followed by participation in the assembly of HGTD half-disks using stands manufactured in Dubna.

Liquid argon calorimeters (Phase-II)

The plans for the JINR group participation in the upgrade of LAr calorimeters included:

- Design and testing of Preamplifier-Shaper and HEC Preshaper ASICs;
- Production and testing of optical pigtailed;
- Development and testing of analog circuit.

In addition to the trigger electronics replaced during Phase-I, the complete replacement of the remaining readout electronics will be completed in Phase-II. Much of the work to upgrade the calorimeter electronics was carried out in parallel with our Phase-I commitments. In particular, the test board for high-frequency operational amplifiers of the analog part of the trigger digitizer LTDB was designed (Fig. 14). The amplifiers demonstrated good linearity up to 8 μ A of input current.

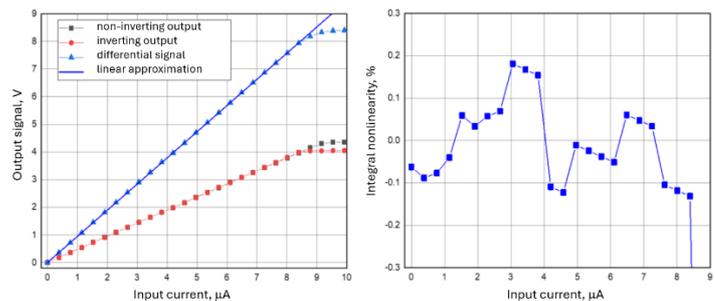
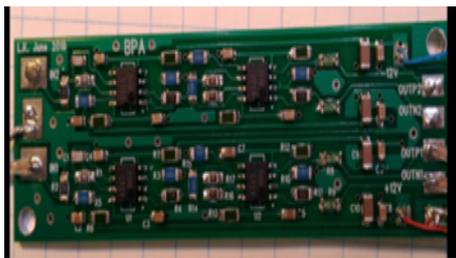


Fig. 14. Test board and results of the linearity measurements.

At the IBR-2 reactor we continued the programme of irradiation tests for the LAr calorimeters. The optical patch-cords were exposed to the fluence of fast neutron $8 \cdot 10^{15}$ n/cm². Subsequent analysis of the reflectograms revealed no deviations from the original shape. We have designed and tested a set of patch-cords for the half-crate tests at CERN which are focused on testing the full chain of the LAr readout electronics. These cables were manufactured at the Unicord firm (Moscow) and shipped to CERN.

For the moment, design, testing and mass-production of the optical cables is considered as the main in-kind contribution of our team to the LAr Phase-II upgrade. We also participate in the FCalPulse R&D project.

At the HL-LHC the ATLAS Forward Calorimeter (FCal) energy response will be compromised due to excessive ionization rates. The current pulses will shrink and the shape will distort as a function of the luminosity over the previous few milliseconds and of the location within the module. To assess the degradation in a controlled way, the FCalPulse R&D was proposed. The project employs a single electrode, part of which is subject to constant β radiation to simulate the flux from pileup at the HL-LHC. This electrode, and a control electrode that is not exposed to β 's, is then placed in a high-energy electron beam. The response is recorded in a variety of conditions, allowing correction factors to be derived that will recover much of the degradation. We helped our colleagues from Arizona University to manufacture 100 mCi source of Sr-90 in Obninsk and participated in the testbeam. Testbeam data were collected in the H2 beamline of the CERN North Area in August 2022. The FCal module was exposed to the beam of 180 GeV electrons (Fig. 15).

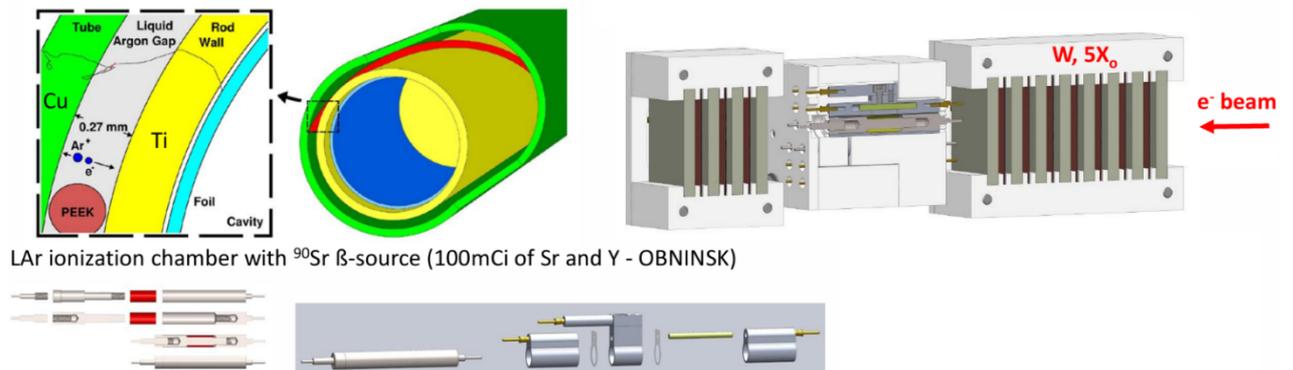


Fig. 15. Details of the FCalPulse testbeam setup.

The JINR group provides GEANT4 simulation of the testbeam. We compared results of our simulation with calculations made in Arizona for the energy deposited in the LAr gap (tube) at various locations of the electron beam for 350 GeV beam energy (Fig. 16).

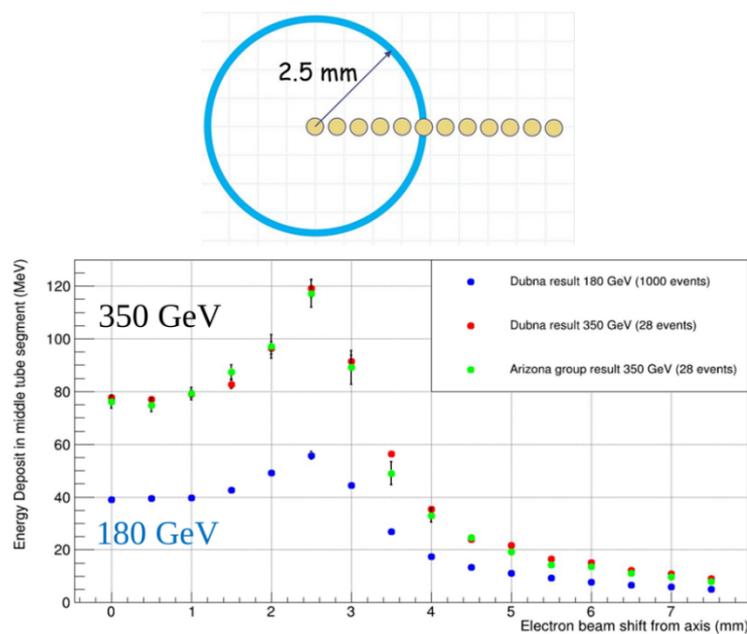


Fig. 16. Deposited energy in LAr volume for various positions of the electron beam of 350 GeV and 180 GeV.

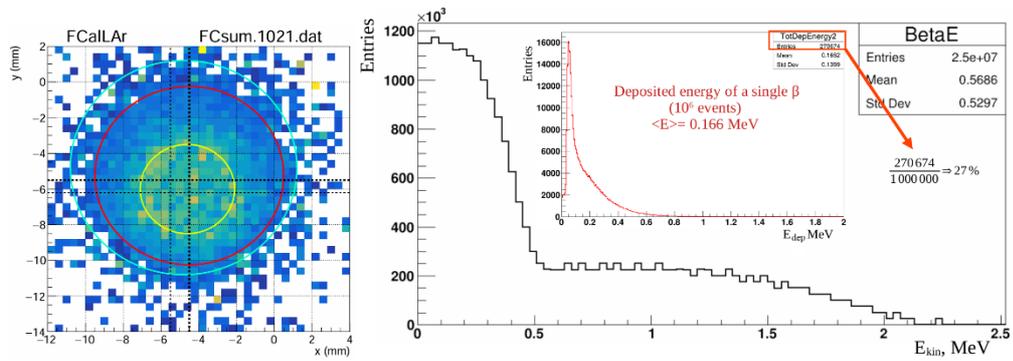


Fig. 17. Testbeam profile and GEANT4 simulation results (initial spectrum of Sr-source and deposited energy). Monte Carlo simulations are ongoing with real electron beam parameters (Fig. 17). It was shown that about 30% of the β -electrons deposit energy in the LAr gap. The analysis is ongoing with the aim of publication in the near future.

Participation in the NICA project at JINR

Mega-science project of a complex of superconducting rings on colliding beams of heavy ions is a flagship project of the JINR aimed at a study of the nuclear matter in a state of maximum baryonic density, inaccessible to research in other laboratories of the world. The study of the spin structure of the proton and deuteron and the other spin-related phenomena with polarized proton and deuteron beams is one of the main topics of the NICA experimental programme. These ambitious goals will be achieved by conducting experiments using the most modern detector technologies. Many detector technologies adopted in the ATLAS experiment are applicable for use in the NICA experiments.

As part of the future upgrade of the TPC chambers for MPD NICA, the robustness of a new resistive coating (DLC) to discharges has been investigated. The robustness of the detector to electric discharges was demonstrated by accumulating about 10^4 discharge events at a gas gain of 4×10^4 without any visible impact on the operation of the detector.

The JINR team is engaged in the Micromegas-based central tracker (MCT) project for the SPD NICA. The MCT will be located as close as possible to the beam interaction region and will improve pulse resolution and track finding efficiency in the absence of a vertex detector in the initial setup of the SPD. To date, a simulation and gas mixture optimization study has been carried out and the primary and backup solutions have been identified. The discharge resistance of the DLC protective layer has been tested, the technology has been refined, and the first cylindrical prototype has been built (Fig. 18). Several prototypes with different configurations were tested and the main parameters of the future detector were determined.

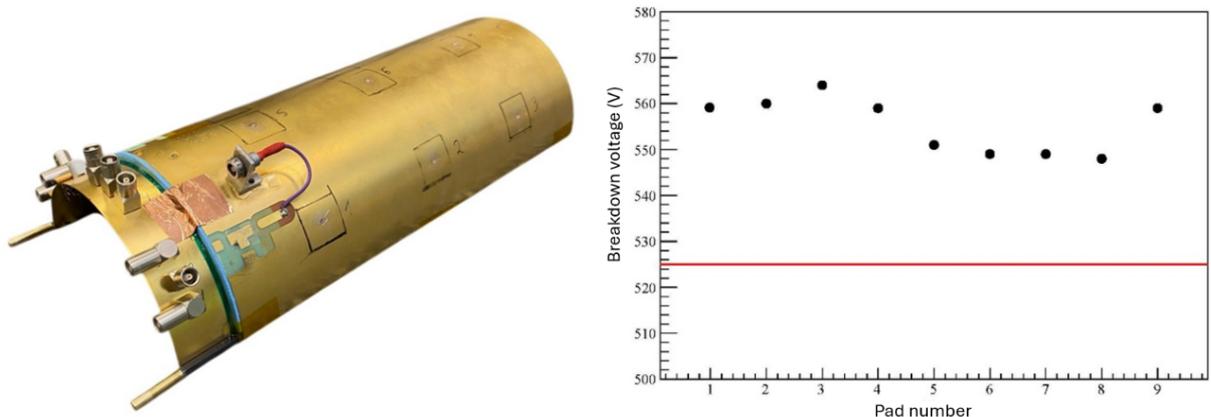


Fig. 18. General view of semi-cylindrical prototype of the MCT (left) and breakdown voltage (right) measured separately **for all sites**. The red line represents the operating voltage for gas gain of 10^4 .

Four MRPCs were manufactured for prototyping TOF system of the SPD detector. The analog front-end electronics based on the constant fraction discrimination method was designed and optimized for the MRPC timing measurements. The total time resolution of ~ 40 ps has been achieved for MRPCs

with 10 and 12 gaps using cosmic test setup and muon beam at IHEP U-70 accelerator in Protvino (Fig. 19). Obtained result satisfies the requirements of the SPD experiment at NICA (60ps).

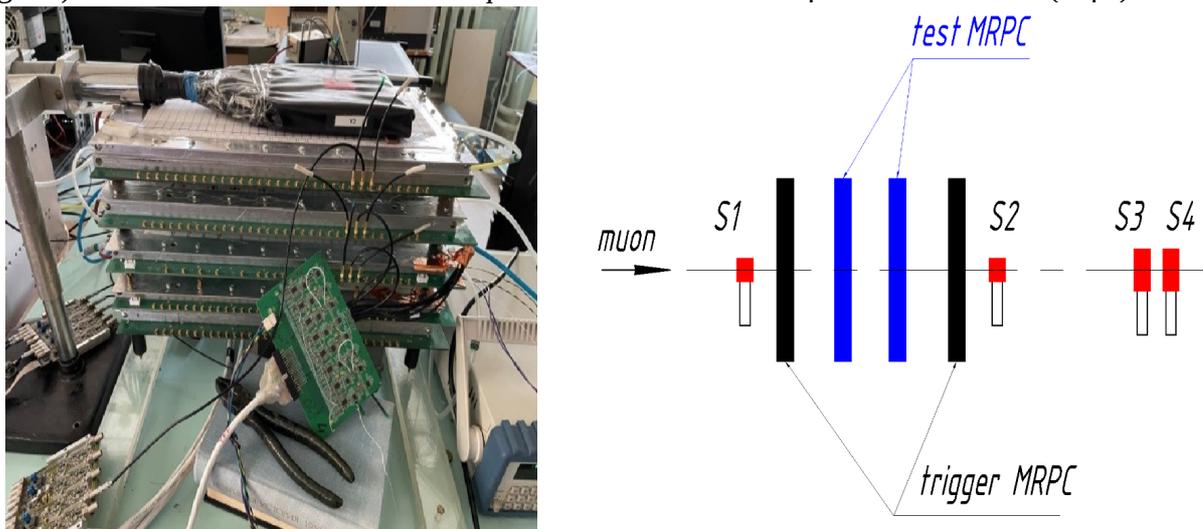


Fig. 19. Cosmic test setup (left) and MRPC test setup (right) at the muon beam at the U-70 accelerator.

The JINR group continues to participate in the upgrade and maintenance of superconducting toroids of the ATLAS magnetic system. During the LS3 cryogenic pump replacement, bus-bar upgrades, scaffolding installation and other work in the cavern for the technical coordinator services are planned.

SWOT Analysis

Strength

- Participation in a large and challenging international project in a competitive and high-tech, internationally oriented, research arena.
- Excellent scientific publication and citation records.
- Collaborations with groups at the leading international accelerator center (CERN) and other physics laboratories.
- Great interest from the public and mass-media.

Weaknesses

- The growing age of staff scientists and engineers.
- Difficulties in registration of new people at CERN.

Opportunities

- LHC shows huge discovery potential which attracts scientists at all levels (master students, PhD students, postdocs and staff physicists alike).
- JINR experiments often require completely new and challenging technologies and ATLAS offers our technical departments possibilities and contacts with new research communities. New technology of Micromegas has already been brought to JINR.
- The experience gained in the ATLAS experiment is shared with our colleagues from the NICA project.
- 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

- Expensive and complicated logistics, extremely difficult bank transactions.

In 2024, CERN terminated Cooperation Agreements with institutes from Russia and Belarus, and restrictions were introduced in the Agreement with JINR. Even before that, due to the uncertainty of the situation, the ATLAS Collaboration decided to revise JINR's obligations to participate in Phase-II, some of which were redistributed among other institutes. Negotiations are currently underway to clarify JINR's commitments and prepare a new MoU.

2.3 Estimated completion date – 2030

The start of the long shutdown LS3 for the LHC is now scheduled for early July 2026, seven and a half months later than originally planned. The total duration of the shutdown will increase by approximately four months. Combined, these changes will delay the launch of the High-Luminosity LHC (HL-LHC) (Run 4) by about a year, moving it to June 2030. By that time, the production, assembly, and commissioning of all ATLAS detector subsystems will be completed. In addition to the main tasks, the ATLAS teams are also involved in the experimental program at the NICA facility.

2.4 Participating JINR laboratories

The main participants in the ATLAS physics studies and upgrade program are scientists from the Dzhelepov Laboratory of Nuclear Problems and the Veksler and Baldin Laboratory of High Energy Physics. The project also involves researchers from the Meshcheryakov Laboratory of Information Technologies (responsible for experimental data processing and simulations, including the use of Tier-2-level grid infrastructure) and the Frank Laboratory of Neutron Physics (radiation testing of materials and electronic components). Theoretical support for the project (and related topics) is traditionally provided by the N.N. Bogolyubov Laboratory of Theoretical Physics.

2.4.1 MICC resource requirements

Computing resources	Distribution by year				
	1 st year	2 nd year	3 rd year	4 th year	5 th year
Data storage (TB) - EOS - Tapes	200	200	200	200	200
Tier 1 (CPU core hours)					
Tier 2 (CPU core hours)	200	200	200	200	200
SC Governor (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
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.Vincent, A.Hoecker, K.Jacobs	Cooperation agreement
CU	Czech Republic	Prague	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
INFN	Italy	Genova	S.Turchikhin	Collaborative work
NIKHEF	Netherlands	Amsterdam	H. Van Der Graaf	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
BINP	Russia	Novosibirsk	L.Maslennikov, V.Bobrovnikov	Collaborative agreement
MEPhI	Russia	Moscow	E.Soldatov	Collaborative agreement

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

No n/a	Category of personnel	JINR staff, amount of FTE	JINR Associated Personnel, amount of FTE
1.	research scientists	29.9	6
2.	engineers	5.3	1
3.	specialists	0.3	

4.	office workers		
5.	technicians	1	
Итого:		36.5	7.0

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.	0.5
		Y.Dydydshka	DLNP	Sen.scientist	0.4
		V. Yermolchik	DLNP	Sen.scientist	0.4
		PhD A.Soloshenko	VBLHEP	Head dep.	1
		T.Turtuvshin	VBLHEP	Scientist	1
		Prof. G.Lykasov	DLNP	Chief sc.	0.8
		PhD A.Lipatov	DLNP	Sen.scientist	0.8
		PhD A.Prokhorov	DLNP	Scientist	1
		PhD V.Lyubushkin	DLNP	Sen.scientist	1
		T.Lyubushkina	DLNP	Scientist	1
		PhD F.Ahmadov	VBLHEP	Sen.scientist	1
		M.Manashova	VBLHEP	Jr.scientist	1
		PhD S.Karpov	DLNP	Sen.scientist	1
		PhD Z.Karpova	DLNP	Sen.scientist	1
		PhD I.Yeletsikh	DLNP	Head dep.	1
		PhD N.Huseynov	DLNP	Sen.scientist	1
		PhD I.Boyko	DLNP	Sen.scientist	0.5
		O.Dolovova	DLNP	Jr.scientist	0.5
		A.Didenko	DLNP	Jr.scientist	1
		A.Vasyukov	DLNP	Jr.scientist	1
		A.Tropina	DLNP	Lab.Assistant	1
		Prof. Y.Kultchitsky	DLNP	Head dep.	1
		P.Tsiareshka	DLNP	Scientist	0.8
		E.Plotnikova	DLNP	Scientist	0.8
		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
		E.Ramakoti	DLNP	Scientist	1
		PhD A. Gongadze	DLNP	Head of sector	0.5
		I. Potrap	DLNP	Scientist	1
		PhD I. Minashvili	DLNP	Jr.scientist	0.5
		PhD A. Cheplakov	VBLHEP	Sc. secretary	0.7
		PhD V. Kukhtin	VBLHEP	Sen scientist	1
		PhD E. Ladygin	VBLHEP	Sen scientist	0.3
		PhD N. Zimin	VBLHEP	Sen scientist	1
		N. Atanov	DLNP	Scientist	0.3
		A. Boikov	DLNP	Jr.scientist	0.2
		PhD Yu. Davydov	DLNP	Head of dept	0.3
		K. Gritsay	DLNP	Scientist	0.4
		S. Malyukov	DLNP	Scientist	1
		V. Moskalenko	DLNP	Jr.scientist	0.3
		S.Bondarenko	BLTP	Prof.	0.4
2.	engineers	I. Gongadze	DLNP	Engineer	0.7
		L. Gongadze	DLNP	Engineer	0.5
		N. Kaurtsev	DLNP	Engineer	0.5
		T. Rudenko	DLNP	Engineer	0.5
		O. Atanova	DLNP	Engineer	0.4
		V. Rogozin	DLNP	Engineer	0.4
		A. Shaikovskii	DLNP	Engineer	0.3
		I. Troeglazov	DLNP	Engineer	1
		S. Mokrenko	DLNP	Engineer	0.4
		I. Fomichev	DLNP	Engineer	0.3
		A. Shutov	DLNP	Engineer	0.3
3.	specialists	N. Ponomarenko	VBLHEP	Specialists	0.3
4.	technicians	M. Serochkin	DLNP	Technician	1
	Total:				36.5

3.2.2. JINR associated personnel

No.	Category of personnel	Partner organization	Amount of FTE
1.	research scientists	Budker INP (Novosibirsk)	3
		TSU (Tomsk)	3
2.	engineers	LPI (Moscow)	1
3.	specialists		
4.	technicians		
	Total:		7

4. Financing

4.1 Total estimated cost of the project

Currently, the ATLAS collaboration author list includes 48 JINR staff members and JINR-associated scientists. The institute's commitments consist of approximately 2 FTE (Full-Time Equivalent) for detector shifts and operation, and 9-10 FTE for software support and related tasks. The corresponding expenses for JINR's participation in the collaboration amount to a total of $770 \times 5 = 3,810$ k\$ over the project's five-year implementation period. This includes $300 \times 5 = 1,500$ k\$ in collaboration membership fees. The remaining $470 \times 5 = 3,350$ k\$ covers travel expenses for JINR staff to CERN to fulfill the institute's operational commitments (shifts, detector operation, and software support).

Costs related to participation in the second phase of the detector upgrade include expenses for sending personnel to CERN for test runs of detector systems at CERN accelerators, assembly and installation work, equipment placement in the experimental cavern and other joint activities. These activities will total 1,160 k\$. Most of the work will be carried out at JINR, with approximately 900 k\$ allocated for material procurement. The corresponding JINR contribution will be around 12 FTE.

Over the project's duration, its total cost will be 5,040 thousand dollars. A detailed breakdown is provided in a separate form.

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: _____

APPROVAL SHEET FOR PROJECT / LRIP SUBPROJECT

TITLE OF THE PROJECT/LRIP SUBPROJECT
ATLAS. Detector upgrade and physics studies at LHC
 SHORT DESIGNATION OF THE PROJECT / SUBPROJECT OF THE LRIP
ATLAS
 PROJECT/LRIP SUBPROJECT CODE
02-2-1081-1-2010/2025
 THEME / LRIP CODE
02-2-1081-2009
 NAME OF THE PROJECT/ LRIP SUBPROJECT LEADER
Bednyakov V.A.

AGREED

JINR VICE-DIRECTOR

_____ SIGNATURE	_____ NAME	_____ DATE
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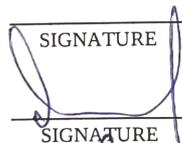
CHIEF SCIENTIFIC SECRETARY

_____ SIGNATURE	_____ NAME	_____ DATE
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CHIEF ENGINEER

_____ SIGNATURE	_____ NAME	_____ DATE
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LABORATORY DIRECTOR

 SIGNATURE	<i>Исупов Е.А.</i> NAME	<i>24.05.25</i> DATE
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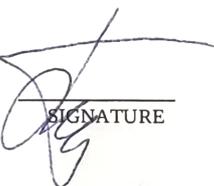
CHIEF LABORATORY ENGINEER

 SIGNATURE	<i>Симонова С.А.</i> NAME	<i>24.05.25</i> DATE
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LABORATORY SCIENTIFIC SECRETARY
THEME / LRIP LEADER

 SIGNATURE	<i>Симонова И.</i> NAME	<i>24.05.25</i> DATE
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PROJECT / LRIP SUBPROJECT LEADER

 SIGNATURE	<i>Bednyakov</i> NAME	<i>13.05.2025</i> DATE
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APPROVED BY THE PAC

_____ SIGNATURE	_____ NAME	_____ DATE
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