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) **- 01-3-1137-2019/2023**

1.2 Project/LRIP subproject code (for extended projects)

1.3 Laboratory Bogoliubov Laboratory of Theoretical Physics

1.4 Scientific field Theoretical Physics

1.5 Title of the project/LRIP subproject Nanostructures and nanomaterials

1.6 Project/LRIP subproject leader(s) V.A. Osipov, E.A. Kochetov

1.7 Project/LRIP subproject deputy leader(s) (scientific supervisor(s))

2 Scientific case and project organization

2.1 Annotation

It is planned to conduct research in the field of physics of nanostructures and nanomaterials, in particular using the software packages for modeling physical and chemical processes and for analysis of physical characteristics. First of all, these are modern two-dimensional materials, such as graphene, transition metal dichalcogenides, etc., including their modification and chemical functionalization for subsequent use in the design of new devices for nanoelectronics, spintronics, etc. Partly, these studies are focused on experiments held at the FLNR Center for Applied Physics JINR, the Institute of Semiconductor Physics SB RAS and a number of other laboratories of the JINR Member States. It is planned to analyze topological superconductivity in strongly correlated electronic systems in order to find possible applications for the transmission and storage of quantum information. The physical properties of stacks of Josephson junctions and various Josephson nanostructures will be studied in detail.

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

At this stage, the development of electronics has reached a limit, which is primarily due to the properties of the material basis of microelectronic devices, that is, due to the properties of standard semiconductors. In this regard, there is a request to fundamental science regarding the further development of the base for computing technology. One of the answers is the proposal of the fundamentally new materials with unique properties and the development of the ways to use of them to create new efficient microelectronic devices. Graphene is one of the main candidates for the role of a basic material for a new type of electronics owing to a number of advantages over standard semiconductors. The most important is the extremely high mobility of charge carriers (this characteristic is directly responsible for performance of electronic devices). In addition, the very fact that graphene is two-dimensional (2D) creates the possibility for a compact layout (miniaturization). However, this material also has some disadvantages. If we omit the technological aspects, then they should include the absence of a band gap and the inability to localize electrons in graphene due to the Klein paradox. The development of fundamental principles for the operation of electronic devices, which, on the one hand, use the advantages of graphene, and on the other hand, allow avoiding the difficulties associated with its shortcomings, is an extremely urgent and very interesting scientific task.

Recent years have seen a surge in superconducting quantum electronics, with rapidly rising number of promising devices and systems enabling quantum coherent manipulation. Topological order in strongly correlated systems, including quantum spin liquids, quantum Hall states in lattices and topological superconductivity is one of the key topics. Various metallic non-Fermi-liquid states including fractionalized Fermi-liquid and phase string theories are being intensively researched. Classification of topological states and differences between quantum and classical topology are of particular interest. Along with important practical applications the new topological paradigm may contribute to our understanding of fundamental questions of nature.

The Josephson effect finds numerous applications in various fields of science, technology, and medicine. In particular, devices based on it are used in superconducting electronics for measuring ultra-weak magnetic fields, in quantum metrology as modern voltage standards, and in medicine for recording magnetoencephalograms of the brain. This effect is the basis for generating and detecting coherent electromagnetic radiation in the terahertz region. Until recently, it was not possible to combine superconductivity and magnetism, since these phenomena are antagonistic: a magnetic field destroys superconductivity, and superconductivity pushes out a magnetic field. However, in hybrid Josephson structures they have been brought close enough to allow superconductivity to control magnetism and magnetism to influence superconductivity. One of the main directions in this area is the solution of fundamental problems of superconducting spintronics - the development of fundamentally new methods for controlling the magnetization of magnets, as well as a radical reduction in energy consumption during the operation of spintronic devices.

The **main goal** of the project is a theoretical study of the properties of new promising materials, primarily nanostructures and nanomaterials. Particular attention will be paid to the analysis of the transport characteristics of two-dimensional and few-layer structures, taking into account their functionalization and structural modification. An important place will be occupied by the study of such phenomena as topological superconductivity in strongly correlated systems and the manifestation of the Josephson effect in hybrid heterostructures. This is explained not only by the fundamental nature of the physical properties of these materials, but also by their practical importance for designing new electronic devices, as well as devices for storing, processing and transmitting information, sensors and biosensors, and others.

Scientific **novelty and relevance** lies in the analysis of a wide range of physical characteristics of new materials in order to identify the most promising for the development and creation of devices in the field of nanoelectronics, spintronics, photonics, etc.

General methods of theoretical research and approaches to solving the formulated problems are based on the use of quantum solid state physics, statistical mechanics, physical kinetics, numerical methods, as well as the use of standard software packages for quantum chemical calculations, molecular dynamics, etc.

The project is aimed at solving tasks in the following areas:

1. In order to identify materials with promising properties for use as a component base for a new generation of electronics, it is planned to study thermal and electron transport in low-dimensional materials of various configurations and chemical composition. An analysis will be made of the role of functionalization, structural modification, the influence of thin layers, polycrystalline, structural defects, and other factors. Experimental studies are carried out in cooperation with the Institute of Semiconductor Physics SB RAS (synthesis, characterization, functionalization) and FLNR JINR (ion irradiation to create nanopores).
2. Analysis of topological superconductivity in strongly correlated electronic systems in order to search for possible applications for the transmission and storage of quantum information and for the study of non-standard quantum transport, insensitive to local noise sources.
3. Study of dynamic, transport and chaotic phenomena in hybrid Josephson nanostructures with magnetic materials for the purposes of superconducting spintronics. Modeling of quantum phenomena in Josephson qubits (memory elements).
4. Study of the properties of polarons in low-dimensional materials and nanostructured objects. Analysis of plasmon-phonon interaction and plasmons in nanoscale and massive objects.

Both employees of JINR laboratories and representatives of scientific institutions and universities of Russia, the JINR Member States and a number of other countries are involved in solving the problems of the project.

2.3 Estimated completion date 2028

2.4 Participating JINR laboratories

- Meshcheryakov Laboratory of Information Technology (I. Sarhadov, S.I. Serdyukova, E.B. Zemlianaya);
- Flerov Laboratory of Nuclear Reactions (V.A. Skuratov);
- Laboratory of Radiation Biology (A.N. Bugay).

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					
Tier 1 (CPU core hours)					

Tier 2 (CPU core hours)					
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
IP NASB	Belarus	Minsk	Kilin S.Ya. +5	visits
SPMRC NASB	Belarus	Minsk	Saiko A.P. +3	visits
IIP UFRN	Brazil	Natal, RN	Ferraz A.	joint work
CU	Egypt	Giza	El Sherbini T.M.	joint work
IACS	India	Kolkata	Sengupta K.	joint work
IASBS	Iran	Zanjan	Kolahchi M.	joint work
IPT MAS	Mongolia	Ulaanbaatar	Sangaa D.	visits
WUT	Poland	Wroclaw	Mierzejewski M.	joint work
NIIC SB RAS	Russia	Novosibirsk	Okotrub A.V. +3	visits
ISP SB RAS	Russia	Novosibirsk	Antonova I.V.+2	visits
SSU	Russia	Saratov	Kolesnikova A.S.	joint work
UB	Romania	Bucharest	Nemnes G.A.	joint work
INS “VINCA”	Serbia	Belgrade	Tekic D.	joint work
CU	Slovakia	Bratislava	Plecenik A.	joint work
IEP SAS	Slovakia	Kosice	Pudlak M. +1	visits
UNISA	South Africa	Pretoria	Bota A.E.	joint work
UU	Japan	Utsunomiya	Irie A.	joint 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	14	
2.	engineers		
3.	specialists		
4.	office workers		
5.	technicians		
	Total:	14	

3.2. Available manpower
3.2.1. JINR staff

No.	Category of personnel	Full name	Division	Position	Amount of FTE
1.	research scientists	Osipov V.A	SDTCM	Head of the department	1.0
		Kochetov E.A.	SDTCM	Head of the sector	1.0
		Shukrinov Yu.M.	SDTCM	Leading researcher	1.0
		Anghel D.	SDTCM	Leading researcher	1.0
		Katkov V.L.	SDTCM	Senior researcher	1.0
		Krasavin S.E.	SDTCM	Senior researcher	1.0
		Kulikov K.V.	SDTCM	Senior researcher	1.0
		Matsko N.L.	SDTCM	Senior researcher	1.0
		Rahmonov I.R.	SDTCM	Senior researcher	1.0
		Nashaat M.	SDTCM	Research assistant	1.0
		Kesharpu K.K.	SDTCM	Research assistant	1.0
		Belgibaev T.	SDTCM	trainee	1.0

				researcher	
		Mazanik A.A.	SDTCM	trainee researcher	1.0
2.	engineers				
3.	specialists				
4.	technicians				
	Total:				**13**

3.2.2. JINR associated personnel

No.	Category of personnel	Partner organization	Amount of FTE
1.	research scientists		
2.	engineers		
3.	specialists		
4.	technicians		
	Total:		

4. Financing

The project will be funded through the theme "Theory of complex systems and advanced materials"

Project (LRIP subproject) Leader __________/___________/

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: 13.04.2023 document number: 14

Year of the project (LRIP subproject) start: 2024

(for extended projects) – Project start year: _______

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

PROJECT / LRIP SUBPROJECT LEADER

SIGNATURE	NAME	DATE

APPROVED BY THE PAC

SIGNATURE	NAME	DATE