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

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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 / 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.*

02-2-1151-1-2025/2025 Development of advanced detectors and analysis methods, hadronic and rare leptonic processes

1.2 Project/LRIP subproject code (for extended projects)

02-2-1151-1-2025/2025

1.3 Laboratory
Dzhelepov Laboratory of Nuclear Problems

1.4 Scientific field
Elementary Particle Physics and High-Energy Heavy-Ion Physics (02)

1.5 Title of the project/LRIP subproject
Development of a physics program and detectors for experiments at electron-positron colliders

1.6 Project/LRIP subproject leader(s)
Yuri Davydov

1.7 Project/LRIP subproject deputy leader(s) (scientific supervisor(s))
Yuri Kulchitsky
Andrej Arbuzov

2 Scientific case and project organization

2.1 Annotation

At the 60th session of the PAC for Particle Physics, we presented a new project "Development of a method for detecting particles in future experiments with the participation of JINR". PAC supported the proposal to open this new project. In its recommendation, the PAC noted: "However, the PAC considers that the program presented is too general. The PAC encourages the team to prepare a more elaborate program outlining the specific goals and objectives of the project and to submit it to the PAC in one year." This project specifies the goals and objectives set out in the previous project, in accordance with the recommendation of the PAC, and also extends to the physical tasks that the development of particle detection methods aims to solve.

The Standard Model (SM) of particle physics is a theory that describes three of the four known fundamental forces in the Universe and classifies all known elementary particles. At the same time, SM remained an incomplete theory, unable to answer many questions: it does not predict parameters in the Higgs potential, such as the mass of the Higgs boson, there is no complete understanding of the nature of the electroweak phase transition, etc. The discovery of the spin-zero Higgs boson in 2012 marked the beginning of a new era in particle physics and at the same time exacerbated these questions. Obviously, any attempt to resolve these issues will involve new physics beyond the SM (BSM). Precise measurement of the properties of the Higgs boson will be a major development in high-energy physics in the coming decades. New physics BSM may lead to observed deviations of the Higgs boson properties from SM expectations.

The High Luminosity LHC (HL-LHC) will measure the Higgs boson production cross sections with an accuracy of about 5%. Probing new physics well beyond the LHC's reach will require measurements of the Higgs boson's properties to sub-percentage-level precision. To achieve such precision, we will need new instruments such as the proposed electron-positron colliders, the Circular Electron-Positron Collider (CEPC) in China and the Future Electron-Positron Collider (FCC-ee) at CERN, which are Higgs boson factories. The CEPC will operate at center-of-mass energies of $\sqrt{s} \sim 240$ GeV, around 91.2 GeV, around 160 GeV and ~360 GeV acting as a Higgs factory, Z factory or Z pole, and WW threshold scan, and a top factory, respectively.

The CEPC gives impressive opportunities to study the properties of the Higgs boson. With an expected integrated luminosity of ~20 ab^{-1} over 10 years of operation, about $\sim 4\cdot 10^6$ Higgs bosons will be obtained. It will provide an unprecedented opportunity to detect the invisible decay of the Higgs boson, with an accuracy of detecting the upper boundary of the invisible decay branching ratio down to 0.3%.

The processes occurring with the formation of the Higgs boson at the CEPC at the energy $\sqrt{s}\sim 240-250$ GeV are $e^+e^-\to ZH$, $e^+e^-\to \nu_e\bar{\nu}_e H$, and $e^+e^-\to e^+e^-H$. Higgs boson candidates can be identified using a mass recoil method, without labeling their decays. The branching ratios of the Higgs boson decay can be determined by studying its individual decay modes. To study the inclusive formation of the Higgs boson, the reactions $e^+e^-\to ZX$ with the decay of the Z boson in the modes will be studied using the Monte Carlo method with a full simulation of the detector. Higgs boson decays, which can be identified by their unique signatures, will be studied in the following modes: 1) $H\to b\bar{b}/c\bar{c}/gg$, 2) $H\to WW^*$, 3) $H\to WZ^*$, 4) $H\to W\gamma$, 5) $H\to \tau^+\tau^-$, 6) $H\to \mu^+\mu^-$, 7) $H\to inv$.

There is a large and unique potential for B-physics studies at CEPC. The CEPC offers an unmatched opportunity for precision measurements in *B*-Physics. It gives us a unique possibility to measure CP-violating phase ϕ_s in decay $B_s^0 \to J/\psi\, \phi(1020)$ with unprecedented accuracy.

Our group has a large experience in Higgs boson and flavor physics studies with the ATLAS collaboration at LHC and, earlier, with the ZEUS collaboration at HERA, giving us all needed competences.

The concepts of basic and alternative detectors are proposed to meet the physical requirements of CEPC. The basic concept utilizes an ultra high granular calorimetry system, a low-material tracking system, and a large volume 3 Tesla solenoid. Innovative Detector for Electron-positron Accelerator (IDEA) is an alternative detector concept. It has a lower solenoidal field of 2 Tesla, but compensates with a large tracking volume. The IDEA concept adopts a calorimeter based on the dual readout technique to achieve excellent energy resolution for both electromagnetic and hadronic showers.

The option of using of a $PbWO_4$ crystal based electromagnetic calorimeter is under consideration. The $PbWO_4$ crystals form two segments. The front segment is 5 cm long (~5.4 X_0), while the rear segment is 15 cm long (~16.3 X_0). A timing layer consisting of LYSO crystals is located in front of $PbWO_4$ crystals and should provide time resolution on the level 20-30 ps.

The muon system of the IDEA consists of layers of muon chambers embedded in the magnet yoke. Large area chambers based on the μ-RWELL are considered for use in tracking muons outside the calorimeter volume. These chambers should cover large surfaces and have energy resolution up to 20%, and a spatial resolution up to 200 μm.

Our group has extensive experience in the development, construction, and testing of hadron and crystal electromagnetic calorimeters and plans to participate actively in this area within the CEPC. The group is actively involved in the development and construction of microstructure gas detectors, including the μ-RWELL microstructure gas detector, and plans to contribute to this activity.

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

The main goal of the project is to develop new innovative detectors for future electron-positron colliders and prepare a program of physical research on them.

The Standard Model (SM) of particle physics is a theory that describes three of the four known fundamental forces (electromagnetic, weak, and strong interactions - excluding gravity) in the Universe and classifies all known elementary particles. At the same time, SM remained an incomplete theory, unable to answer many questions. In particular, it does not predict parameters in the Higgs potential, such as the mass of the Higgs boson. The huge difference between the Planck scale and the weak scale remains a major mystery of modern physics. There is no complete understanding of the nature of the electroweak phase transition. The discovery of the Higgs boson in 2012 by the ATLAS and CMS collaborations [1] at the Large Hadron Collider (LHC) at CERN was the result of many years of effort by a large number of experimental and theoretical groups and marked the beginning of a new era in particle physics. The discovery of the spin-zero Higgs boson only exacerbates these questions. Obviously, any attempt to resolve these issues will involve new physics beyond the SM (BSM). Precise measurement of the properties of the Higgs boson will be a major development in high-energy physics in the coming decades. New physics BSM may lead to observed deviations of the Higgs boson properties from SM expectations. Typically, such deviations can be parameterized as $\delta = cv^2/M_{NP}^2$, where v and M_{NP} are the vacuum expectation value of the Higgs field and the typical mass scale of new physics. The High Luminosity LHC (HL-LHC) will measure the Higgs boson production cross sections with an accuracy of about 5%.

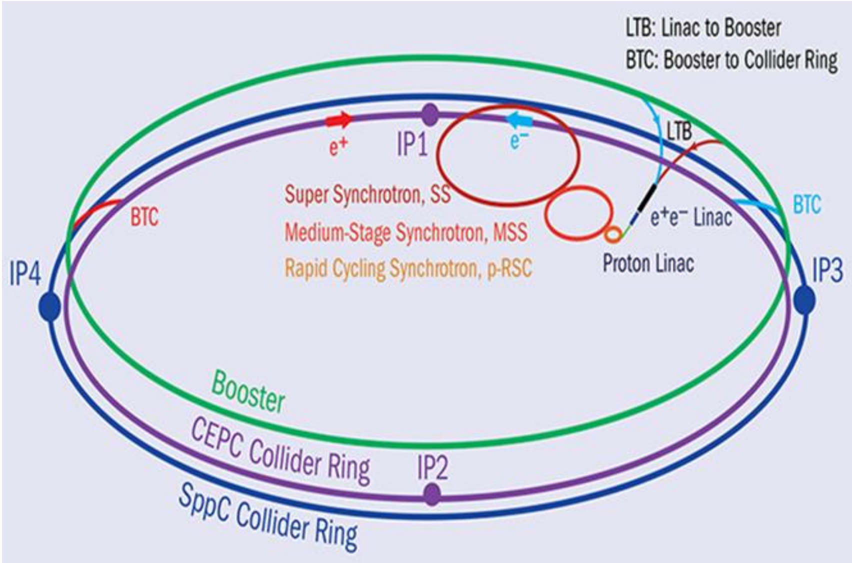

Figure 1. Layout of the CEPC [2].

Probing new physics well beyond the LHC's reach will require measurements of the Higgs boson's properties to sub-percentage-level precision. To achieve such precision, we will need electron-positron colliders, which are the Higgs boson factory. The Circular Electron-Positron Collider (CEPC) [2] in China and the Future Electron-Positron Collider (FCCee) [3] at CERN are such possible instruments. The CEPC layout is shown in Figure 1. In particular, the CEPC will be housed in a tunnel with a circumference of approximately 100 km and will operate at a center-of-mass energy of $\sqrt{s} \sim 240$ GeV, close to the maximum cross section for the production of the Higgs boson in the reaction $e^+e^-\rightarrow ZH$ (Higgs factory), around 91.2 GeV (Z factory or Z pole), and around 160 GeV (WW threshold scan). The cross sections of the main physics processes of the SM at the electron positron collider at center-of-mass energies $\sqrt{s}$ in the range of 50-400 GeV are presented in Figure 2. The operation modes of CEPC, as well as the expected parameters of the collider and event yields over 10 years of operation are given in Table 1 [4].

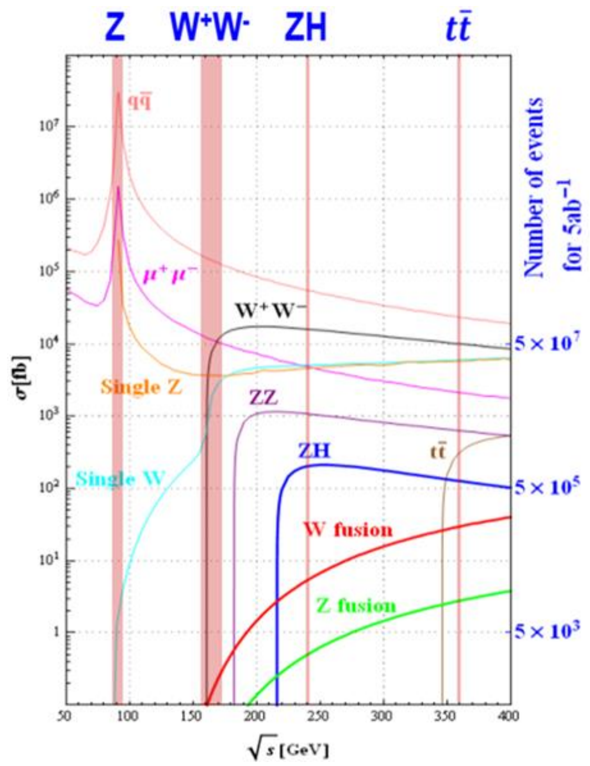

Figure2. Cross sections for major SM physics processes at the electron positron collider.

Operation mode	E_{CM} GeV	L per IP 10^{34} $cm^{-2}s$-1	Years	Total $\int L$ ab^{-1}, 2 IP	Event yields
H	240	3	7	5.6	$1x10^6$
Z	91.5	32	2	16	$7x10^{11}$
W^+W^-	158-172	10	1	2.6	$2x10^7$

Table 1. CEPC operating modes, expected collider parameters and event results over 10 years of operation.

In the CEPC experiments, unlike the LHC experiments, Higgs boson candidates can be identified using a method known as the mass recoil method, without labeling their decays. Therefore, the production of the Higgs boson can be separated from its decay in a model-independent way. Fewer background events at the e^+e^- collider allow for much more accurate measurements of exclusive Higgs boson decay channels. All this gives the experiments at the CEPC impressive opportunities to study the properties of the Higgs boson. With an expected integrated luminosity of ~20 ab^{-1} over 10 years of operation, about ~$4\cdot10^6$ Higgs bosons will be obtained. The statistics collected in the experiments at the CEPC will provide an unprecedented opportunity to detect the invisible decay of the Higgs boson, with an accuracy of detecting the upper boundary of the invisible decay branching ratio down to 0.3%. It is important to emphasize that the e^+e^- Higgs factory can also perform model-independent measurements of the Higgs boson width. This unique feature, in turn, allows for model-independent determination of the Higgs boson couplings.

The Higgs boson provides a unique sensitive probe of physics beyond the SM (BSM) which may manifest itself as observable deviations in the Higgs boson couplings relative to the SM expectations. The couplings and other electroweak physics parameters, can be measured at electron-positron colliders with very high precision.

The future electron-positron colliders can also be used to search for a variety of new particles. Running as both a Higgs factory and a Z factory, the exotic decays of the Higgs and Z bosons can be used to search for new physics, such as those associated with a light dark sector.

The processes occurring with the formation of the Higgs boson at the CEPC at the energy $\sqrt{s}\sim 240-250$ GeV are the following: $e^+e^-\to ZH$, $e^+e^-\to \nu_e\bar{\nu}_e H$ and $e^+e^-\to e^+e^-H$ (Fig. 1).

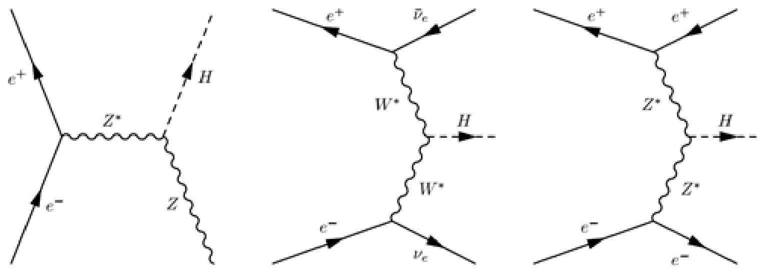

Figure 3. Feynman diagrams for the processes of Higgs boson production in electron-positron interactions: $e^+e^-\to ZH$, $e^+e^-\to \nu_e\bar{\nu}_e H$ and $e^+e^-\to e^+e^-H$.

The difference between e^+e^- collisions and hadron-hadron collisions is that electrons are fundamental particles, while hadrons are composite particles, therefore the energy of e^+e^- collisions is known. Using conservation laws, the energy and momentum of the Higgs boson can be determined from other particles in the event without examining the Higgs boson itself. Tagging of $e^+e^-\to ZH$ events using the recoil mass method, independent of Higgs boson decay, is unique to lepton colliders. For a Higgs boson production event, where the Z boson decays into a pair of visible fermions (ff), the recoil mass can be calculated, assuming the event has a total energy $\sqrt{s}$ and zero total momentum:

$$M_{rec}^2 = (\sqrt{s} - E_{ff})^2 - p_{ff}^2 = s - 2E_{ff}\sqrt{s} + m_{ff}^2,$$

where E_{ff}, p_{ff} and m_{ff} are the total energy, momentum and invariant mass of the fermion pair. The M_{rec} distribution should have a peak at the Higgs boson mass m_H for $e^+e^-\to ZH\to ffH$ and $e^+e^-\to e^+e^-H$ processes, and is expected to be smooth without a resonance structure for background processes around 125 GeV. The Higgs boson mass can be determined from the position of the resonance in the spectrum. The best precision of the mass measurement can be achieved from the leptonic decays $Z\to e^+e^-$ and $Z\to\mu^+\mu^-$.

The branching ratios of the Higgs boson decay can be determined by studying its individual decay modes. To study the inclusive formation of the Higgs boson, the reactions $e^+e^-\to ZX$ with the decay of the Z boson in the modes will be studied using the Monte Carlo method with a full simulation of the detector for signal and background events: 1) $Z\to l^+l^-$ $(l=e,\mu)$, with leading backgrounds ZZ, WW and $Z\gamma$ for $Z\to\mu^+\mu^-$ and additional background from Bhabha scattering for $Z\to e^+e^-$; 2) $Z\to q\bar{q}$, with leading backgrounds WW and $Z\gamma$.

Higgs boson decays, which can be identified by their unique signatures, will be studied in the following modes: 1) $H\to b\bar{b}/c\bar{c}/gg$, 2) $H\to WW^*$, 3) $H\to WZ^*$, 4) $H\to W\gamma$, 5) $H\to\tau^+\tau^-$, 6) $H\to\mu^+\mu^-$, 7) $H\to inv$

There is considerable interest in the processes occurring with the formation of heavy (c, b) flavors and their bound states in e^+e^- annihilation. Such processes, in particular, are background for many processes of new physics BSM, which will be studied at the CEPC. Their cross sections are quite large, for example, near the Z-boson mass they are two orders of magnitude larger than the cross section of the process $e^+e^-\to e^+e^-Z$. The gauge theory of strong interaction, quantum chromodynamics (QCD), plays a key role in the theoretical description of reactions involving heavy flavors. It is important that direct information on the fragmentation functions of heavy quarks into mesons can be obtained as a result of precision measurements of the total and differential cross sections for the production of D and B mesons in e^+e^- annihilation, which will allow us to qualitatively improve the accuracy of measuring the fragmentation functions. Experimental studies of reactions in collisions of virtual photons produced in e^+e^- interactions, along with the study of the processes of formation of bound states of heavy quarks (quarkonia), will allow us to obtain information on the dynamics of the quark-gluon interaction in a new kinematic region. It is by studying these reactions that we can extract new information on the behavior of electromagnetic form factors in the time like region of transferred momenta, $Q^2 > 0$.

The CEPC TDR [5] states the current plan is to operate in Higgs mode for the first 10 years. Afterward, the CEPC will operate at Z-pole for two years, generating about $2.5\cdot 10^{12}$ Z bosons at 30 MW synchrotron radiation (SR) power per beam. Consequently, vast amounts of $b\bar{b}$ final states will be produced from the decay of these Z bosons, thanks to large Br(Z $\to b\bar{b}$) $\simeq$ (15.12$\pm$0.05)%. Thus, the CEPC offers an unmatched opportunity for precision measurements in B-Physics, serving concurrently to HL-LHCb and future B-factories. In particular, the background level is expected to be much smaller than in LHCb. The abundant energy from Z decays will also generate a large sample of B_s^0 and B_c^+ mesons as well as *B*-hadrons (in contrast to *B*-factories, operating at the Υ(4S) pole).

The latter gives us a unique possibility to measure CP-violating phase ϕ_s in decay $B_s^0 \to J/\psi\ \phi(1020)$ with unprecedented accuracy, see preliminary studies from [6]. The weak phase ϕ_s arises from the CP violation (CPV) in the interference between decays with and without mixing in B_s^0 - $\bar{B}_s^0$ system. In the Standard Model (SM), neglecting contributions from higher-order penguin diagrams, $\phi_s \simeq -2\beta_s = -2\arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$, where V_{ij} are the elements of the Cabibbo–Kobayashi–Maskawa matrix and β_s represents one of the angles within the unitary triangles. Global fits to experimental data, under the assumption of the CKM paradigm, give $\phi_s = -36.96^{+0.72}_{-0.82}$ mrad (CKMFitter). The best available at the moment measurement by LHCb [7] gives us ϕ_s=−39.0±22(stat)±6(syst) mrad with the uncertainty being approximately 20 times larger than that of the SM prediction. The current status of ϕ_s measurement and expected sensitivity of Tera-Z CEPC are shown in Fig. 4.

Accurate measurement of ϕ_s serves as a critical test for the Standard Model. Preliminary studies from [6] show the ϕ_s resolution at the 10-Tera-Z CEPC can reach the current precision of SM prediction. Moreover, the excellent particle identification, highly accurate track and vertex reconstruction, and extensive geometric acceptance of the planned detectors at the CEPC will make it possible to measure the phase ϕ_s in other B_s^0 decay channels, such as $B_s^0 \to J/\psi\pi^+\pi^-$ or even $B_s^0 \to D_s^+ D_s^-$.

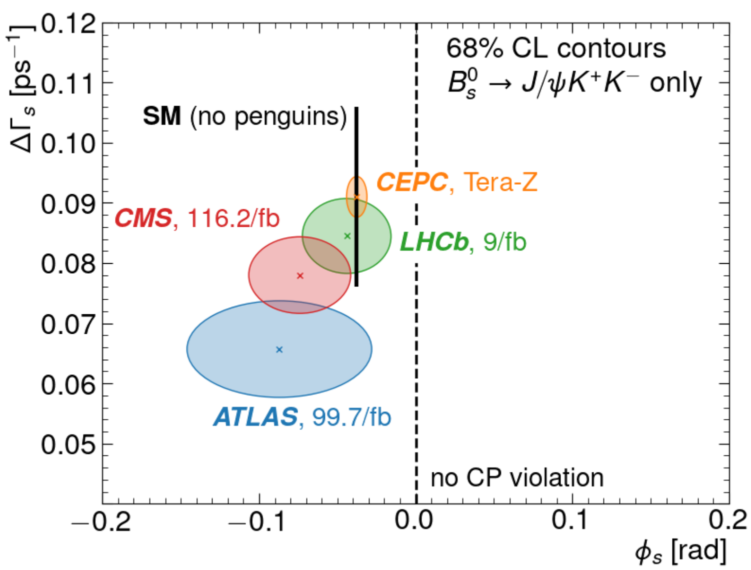

Figure 4. Results of the time-dependent angular analyses for $B_s^0 \to J/\psi\ \phi$ decay on the (ϕ_s, $\Delta\Gamma$) plane. Individual 68% confidence-level contours of ATLAS [8], CMS [9] and LHCb [7] are shown. The expected values of $\sigma(\phi_s) = 4.6$ mrad and $\sigma(\Delta\Gamma_s)=0.72\ ns^{-1}$ for Tera-Z CEPC are taken from [6].

There is a large and unique potential for B-physics studies at CEPC. The most promising conditions for the studies can be expected in the running mode with e^+e^- collisions at energy ~91 GeV, i.e. in the peak of Z-boson production (Tera-Z mode). During 2 years of such operation CEPC will produce up-to one trillion highly-boosted B-hadrons with all possible quark contents (and a similar amount of directly produced charmed hadrons). During operation at other energies, statistics up-to one million B-hadrons per year can be collected. Additional advantages for B-physics studies at CEPC are the clean environment of e^+e^- collisions, the absence of pile-up, and expected high-precision tracking with reliable particle identification. Our group has a large experience in flavor physics studies with the ATLAS collaboration at LHC and, earlier, with the ZEUS collaboration at HERA, giving us all needed competencies. The following B-physics studies at CEPC are of interest for our group:

1. Measurements of the b- and c-quark fragmentation fractions and fragmentation functions. Tuning the fragmentation functions with NNLO and higher-order QCD predictions.
2. Verification of evidence for anomalies in B-hadron decays. The anomalies are currently seen in the ratio of branchings $R(D^{(*)}) = Br(B^0 \to D^{(*)-}\tau^+\nu_\tau)/Br(B^0 \to D^{(*)-}\mu^+\nu_\mu)$ and in the angular distributions of the $B^0 \to K^*(892)\mu^+\mu^-$ (and a similar) decays. In addition to the verification of these anomalies, it will be possible to probe the decay $B^0 \to K^*(892)\tau^+\tau^-$ for the first time.
3. Measurements of the ground and excited B_c states, their production and decays. In particular the decay $B_c^+ \to \tau^+\nu_\tau$ can be probed for the first time. Production of the ground and excited B_c states can be effectively studied during the CEPC running with collision energies of 91 GeV, 160 GeV and 240 GeV [1]. The Higgs boson decays to the ground and excited B_c states can be probed [2].
4. Studies of exotic hadrons (tetraquarks, pentaquarks and so on) in B-hadron decays.
5. Studies of doubly and triply heavy baryons.
6. Measurements of rare B decays. In particular the decay $B_s^0 \to \tau^+\tau^-$ can be probed for the first time.
7. Measurements of the CP violation in B decays.

The concepts of basic and alternative detectors are proposed to meet the physical requirements of CEPC. The basic concept utilizes an ultra-high granular calorimetry system to efficiently separate the final state particle showers, a low-material tracking system, and a large volume 3 Tesla solenoid that encloses the entire calorimetry system. The default option is a combination of a silicon tracker and a Time Projection Chamber (TPC).

Innovative Detector for Electron-positron Accelerator (IDEA) is an alternative detector concept. It has a lower solenoidal field of 2 Tesla, but compensates with a large tracking volume. The structure of the IDEA detector is shown in Figure 3. The IDEA concept adopts a calorimeter based on the dual readout technique to achieve excellent energy resolution for both electromagnetic and hadronic showers. This technology allows the electromagnetic and hadronic calorimeters to form a single package, providing excellent discrimination between hadronic and electromagnetic showers.

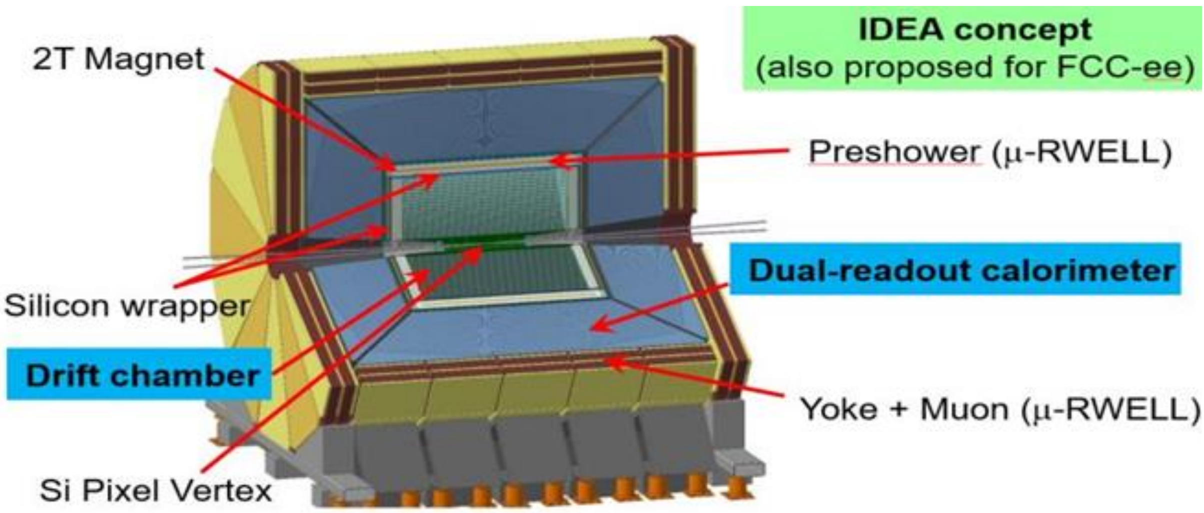

Figure 5. The structure of the IDEA detector.

The dual readout approach involves developing a combined, homogeneous detector with excellent performance for both electromagnetic and hadronic particle showers. When using conventional calorimeters, the results of hadronic energy measurements are significantly worse than when using electromagnetic calorimeters. Hadron showers develop an electromagnetic component that exhibits large fluctuations from event to event and is dependent on particle type and energy. The variation of the *em* fraction is intrinsic to hadronic showers. The average *em* fraction $<f_{em}>$ increases with the energy and with the depth of the shower. Compensation and double readout (DR) methods were used to solve this problem.

The dual-readout method directly measures f_{em} on an event-by-event basis. Showers are detected by two independent processes, scintillation (*S*) and Cherenkov (*C*) light emissions. Cherenkov (C) light is produced by highly relativistic particles only, almost exclusively found inside the *em* shower component. The independent sampling of hadronic showers, through scintillation and Cherenkov light emission, allows one to fully reconstruct, at the same time, energy and f_{em} of hadronic showers. A fiber-sampling calorimeter, even without longitudinal segmentation, may meet the requirements of the CEPC physics.

The structure of the dual readout calorimeter is shown in Figure 6. It comprises scintillation and Cherenkov fibers placed in the same absorber volume. Copper, lead, brass and iron are considered as absorber materials. The Cherenkov light has a larger yield for copper absorber, resulting in a better hadronic resolution. But lead is easily and accurately extruded, unlike copper.

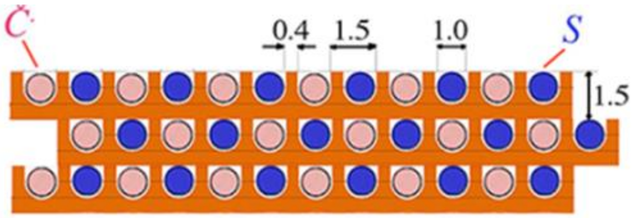

Figure 6. Structure of a dual readout calorimeter.

The dual readout calorimeter is designed with a projective layout as shown in Figure 7. It covers with no cracks the full volume up to $|cos(\theta)| = 0.995$, with 92 different types of towers. The total number of fibers is of the order of 10^8 for a complete 4π calorimeter.

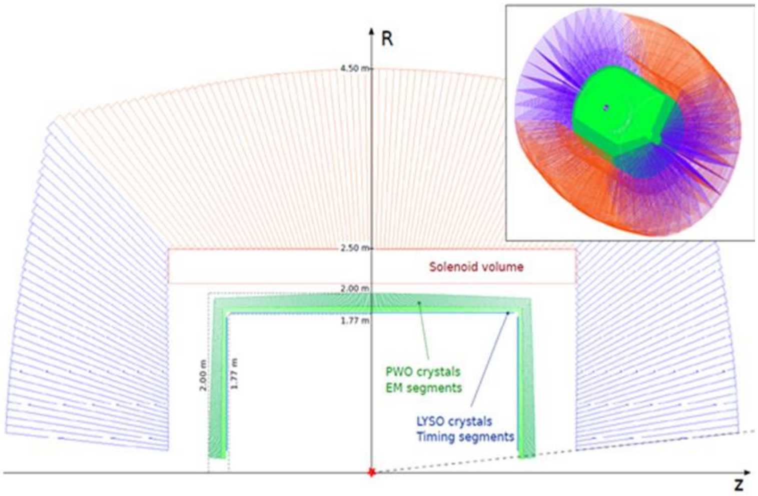

Figure 7. The layout of the IDEA dual readout calorimeter

Option of using a crystal electromagnetic calorimeter, as shown in Figure 7, is under consideration. It consists of $PbWO_4$ crystals measuring 1x1x20 cm^3 that form two segments.
The front segment is 5 cm long (~5.4 X_0), while the rear segment for the core shower is 15 cm long (~16.3 X_0). A timing layer consisting of LYSO crystals is located in front of $PbWO_4$ crystals. All crystals are read out with SiPM. LYSO crystals should provide time resolution on the level 20-30 ps.

Our group has extensive experience with hadron and crystal electromagnetic calorimeters and plans to actively participate in this area within the CEPC.

The muon system of the IDEA consists of layers of muon chambers embedded in the magnet yoke. Recent developments in micro-pattern gas detector technology, such as μ-RWELL Micropattern Gas Detector [], can significantly reduce the cost of large area tracking chambers to be used for tracking particles. Large area chambers based on the μ-RWELL are considered for use in tracking muons outside the calorimeter volume. These chambers should cover large surfaces and have gas gain on the level greater than 20000, energy resolution up to 20%, spatial resolution up to 200 μm. It is required to develop technology for the production of microstructured gas detector μ-RWELL type

Expected results

The following results are expected with the participation of the JINR group:

A systematic study of the $e^+e^-\to ZX$ processes will be carried out with the aim of determining the properties of the Higgs bosons with the best possible accuracy using Monte Carlo simulations with full detector simulations for signal and background events. As a result, algorithms will be developed for the best signal-to-background ratio in the selected events. Based on this analysis, values of the Higgs boson characteristics will be obtained with an accuracy an order of magnitude better than in the experiments at the HL-LHC.

A large sample of B_s^0 and B_c^+ mesons allows us to measure CP-violating phase ϕ_s in decay $B_s^0 \to J/\psi\ \phi(1020)$ with unprecedented accuracy. The excellent particle identification, accurate track and vertex reconstruction, and extensive geometric acceptance of the planned detectors at the CEPC will make it possible to measure the phase ϕ_s in another B_s^0 decay channel $B_s^0 \to J/\psi\pi^+\pi^-$.

Prototypes of dual readout calorimeters with lead and copper/brass absorbers will be built and tested using SiPM readout. The resolution of the dual readout calorimeter as a function of granularity will be assessed by simulations and measurements in beam tests.

Prototypes of a PWO-based crystal electromagnetic calorimeter will be built and tested together with LYSO:Ce crystals used for timing purposes. A SiPM preamplifier will be developed for use with LYSO:Ce crystals, providing 30 ps timing resolution.

Technology for creating μ-RWELL detectors with DLC resistive layers larger than 20x20 cm^2 will be developed. Prototypes of the μ-RWELL detectors with DLC coating larger than 20x20 cm^2 will be built and tested.

Risks

SWOT-Analysis

Helpful	Harmful
STRENGTHS ● Electron-positron colliders are factories of *Z*, *W*, and Higgs bosons ● Extensive experience in simulation methods and development of software ● Expertise in developing various types of innovative detectors and electronics	**WEAKNESSES** ● Possible delay with electron-positron collider construction ●
OPPORTUNITIES ● Development of new detectors and technologies ● The project provides an opportunity to play an important role for young scientists and their professional growth.	**THREATS** ● change of plans or significant reduction in the budget for preparation of experiments ● Major changes in the world situation

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2.3 Estimated completion date
2030

2.4 Participating JINR laboratories
Dzhelepov Laboratory of Nuclear Problems (DLNP), Bogolyubov Laboratory of Theoretical Physics (BLTP), Veksler and Baldin Laboratory of High Energy Physics (VBLHEP)

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	Kurochkin Yu.A. +5	Collaboration
INP BSU	Belarus	Minsk	Misevich O.V. +3 Makarenko V.V.+3	Collaboration
IE NASB	Belarus	Minsk	Baev V. +3	Collaboration
LNF	Italy	Frascati	Sarra I. + 4	Collaboration
INFN	Italy	Pisa	Bedeschi F. + 3	Collaboration

IHEP CAS	China	Beijing	J.G. da Costa +5	Collaboration

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	16.9	
2.	engineers	0.9	
3.	specialists	-	
4.	office workers	-	
5.	technicians	-	
	Total:	**17.8**	

3.2. Available manpower
3.2.1. JINR staff

No.	Category of personnel	Full name	Division	Position	Amount of FTE
1.	research scientists	Yuri Davydov	DLNP	Head of department Project leader	0.7
2.	research scientists	Yuri Kulchitsky	DLNP	Head of sector Deputy project leader	0.7
3.	research scientists	Andrej Arbuzov	BLTP	Head of sector Deputy project leader	0.4
4.	research scientists	Akram Artikov	DLNP	Leading researcher	0.7
5.	research scientists	Davit Chokheli	DLNP	Senior researcher	0.6
6.	research scientists	Nikolay Atanov	DLNP	Researcher	0.7
7.	research scientists	Ilia Zimin	DLNP	Researcher	0.7
8.	research scientists	Viktoria Kiseeva	DLNP	Junior researcher	0.6
9.	research scientists	Elena Plotnikova	DLNP	Researcher	0.5
10.	research scientists	Pavel Tereshko	DLNP	Researcher	0.5
11.	research scientists	Vladimir Baranov	DLNP	Researcher	0.7
12.	research scientists	Aleksandr Boikov	DLNP	Junior researcher	0.5
13.	research scientists	Ilya Vasilyev	DLNP	Researcher	0.7
14.	research scientists	Viktoriya Moskalenko	DLNP	Junior researcher	0.7
15.	research scientists	Aleksandr Simonenko	DLNP	Senior researcher	0.6
16.	research scientists	Igor Suslov	DLNP	Senior researcher	0.5
17.	research scientists	Nazim Huseinov	DLNP	Senior researcher	0.5
18.	research scientists	Gennady Lykasov	DLNP	Chief Researcher	0.5
19.	research scientists	Artem Lipatov	DLNP	Senior researcher	0.5
20.	research scientists	Vladimir Lyubushkin	DLNP	Senior researcher	0.5
21.	research scientists	Oksana Dolovova	DLNP	Junior researcher	0.5
22.	research scientists	Anastasiya Tropina	DLNP	Junior researcher	0.6
23.	research scientists	Leonid Gladilin	DLNP	Senior researcher	0.3
24.	research scientists	Ivan Eleckih	DLNP	Head of sector	0.3
25.	research scientists	Tatiana Lyubushkina	DLNP	Junior researcher	0.3

26.	research scientists	Konstantin Afanaciev	DLNP	Researcher	0.7
27.	research scientists	Vladimir Malyshev	DLNP	Researcher	0.6
28.	research scientists	Alexi Gongadze	DLNP	Head of sector	0.4
29.	research scientists	Serge Bondarenko	BLTP	Head of sector	0.3
30.	research scientists	Uliana Voznaya	BLTP	Trainee researcher	0.3
31.	research scientists	Valery Chmill	VBLHEP	Leading researcher	0.4
32.	research scientists	Faig Ahmadov	VBLHEP	Senior researcher	0.4
33.	engineers	Olga Atanova	DLNP	engineer	0.5
34.		Andrey Shalyugin	DLNP	Senior engineer	0.4
3.	specialists				
4.	technicians				
	Total:				**17.8**

3.2.2. JINR associated personnel

No.	Category of personnel	Partner organization	Amount of FTE
1.	Students	NRNU “MEPhI”	2
2.	Students	Dubna State University	2
	Total:		**4**

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.

820 k$ for five years

4.2 Extra funding sources

Expected funding from partners/customers – a total estimate.

Project Leader __________/Yu.Davydov/

Date of submission of the project (LRIP subproject) to the Chief Scientific Secretary: _________
Date of decision of the laboratory's STC: _19.11.2024___ document number: _________

Year of the project (LRIP subproject) start: ___2026_________

(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	410	60	80	80	90	100
		Materials	260	60	50	50	50	50
		Equipment, Third-party company services	100	20	20	20	20	20
		Commissioning						
		R&D contracts with other research organizations						
		Software purchasing	50	10	10	10	10	10
		Design/construction						
		Service costs (*planned in case of direct project affiliation)*						
Resources required	**Standard hours**	Resources						
		– the amount of FTE,						
		– accelerator/installation,						
		– reactor,…						
Sources of funding	**JINR Budget**	JINR budget *(budget items)*	820	150	160	160	170	170
	Extra fudning (supplementary estimates)	Contributions by partners Funds under contracts with customers Other sources of funding						

Project Leader __________/Yu. Davydov/

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

Annex 4.

Project (LRIP subproject) report form

PROJECT REPORT

1. General information on the project / LRIP subproject

1.1. Scientific field

1.2. Title of the project / LRIP subproject

1.3. Project (LRIP subproject) code
Example (04-4-1140-1-2024/2027)

1.4. Theme / LRIP code
Example (theme 04-4-1140-2024, **MIP** *04-4-1140-2024)*

1.5. Actual duration of the project/ LRIP subproject

1.6. Project / LRIP subproject Leader(s)

2. Scientific report

2.1. Annotation

2.2. A detailed scientific report

2.2.1. Description of the mode of operation and functioning of the main systems and equipment (for the LRIP subproject).
2.2.2. A description of the conducted experiments (for experimental projects).
2.2.3. A description of the research undertaken and the results obtained.
2.2.4. A list of the main publications of the JINR authors, including associated personnel on the results of the project (list of bibliographical references).
2.2.5. A complete list of publications (electronic annex, for journal publications with journal impact factor).
2.2.6 List of talks given at international conferences and meetings (electronic annex).
2.2.7. Patent activity (if any)

2.3. Status and stage (TDR, CDR, ongoing project) of the project (subproject) (including percentage of implementation of the declared milestones of the project (LRIP subproject) *(if applicable)*

2.4. Results of related activities

2.4.1. Research and education activities. List of defended dissertations.
2.4.2. JINR grants (scholarships) received.
2.4.3. Awards and prizes.
2.4.4. Other results (expert investigation, organizational, outreach activities).

3. International cooperation

Actually participating countries, institutions and organizations

Organization	Country	City	Participants	Type of agreement

4. Analysis of planed vs actually used resources: manpower (including associated personnel), financial, IT, infrastructure

4.1 Manpower (actual at the time of reporting)

No.	Personnel category	JINR staff, amount of FTE	JINR associated personnel, amount of FTE
1.	research scientists		
2.	engineers		
3.	specialists		
	Total:		

4.2 The actual estimated cost of the project/ LRIP subproject

<table>
<tr><th colspan="2" rowspan="2">Names of costs, resources, funding sources</th><th rowspan="2">Cost (thousands of US dollars) / Resource request</th><th colspan="5">Proposal from the laboratory for allocation of funding and resources</th></tr>
<tr><th>1 year</th><th>2 year</th><th>3 year</th><th>4 year</th><th>5 year</th></tr>
<tr><td rowspan="8"></td><td>International cooperation</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Materials</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Equipment, Third-party company services</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Commissioning</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>R&D contracts with other research organizations</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Service costs (planned in case of direct project affiliation)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Resources required Standard hours</td><td>Resources</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>– the amount of FTE,</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>– accelerator/installation,</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

		– reactor,…						
Sources of funding	**JINR Budget**	JINR budget *(budget items)*						
	Extra fudning (supplementary estimates)	Contributions by partners Funds under contracts with customers Other sources of funding						

4.3 Other resources

Computer resources consumed MICC	**Distribution by years**				
	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)					

5. Conclusion

6. Proposed reviewers

Theme / LRIP Leader

______________/________________/
"______"____________________ 202_г.

Project leader (project code) / LRIP subproject
______________/_____/
"______"_____________ 202_г.

Laboratory Economist
_______/________/
"______"_____________ 202_ г.