Form No. 24

Precision Laser Metrology for Accelerators and Detector Complexes
Prolongation of the project for 2022-2023

Topic ID: 01-0-1127-2016/2023 DLNP Laboratory
Direction: Physics and Technology of Accelerators
Topic name: Research in the field of e + / e- linear accelerators and new generation colliders for fundamental and applied purposes.

JINR

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PROJECT APPROVAL SHEET

Precision Laser Metrology for Accelerators and Detector Complexes

APPROVED BY THE JINR DIRECTOR ____________________ ___ / __ / 2021

AGREED

JINR VICE-DIRECTOR ________________________________ ___ / ___ / 2021

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APPROVED

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Form No. 26

Proposed plan timeline and resources required for the implementation of the Project

Precision Laser Metrology for Accelerators and Detector Complexes

Name of nodes and installation systems, works, resources, funding sources			The cost nodes installation (thousand USD)	Laboratories' proposals for funding allocation and resources		
				1год 2022	2год 2023	
Main nodes and equipment	1Compact Precision Laser Inclinometer 2 Laser Fiducial Line 3.Interferometric Distance Meter 4.Suismic isolated platform		132 20 20 20	66 12 8 10	66 8 12 10	
Resources required	Normalized hours	JINR Experimental Workshop mechanical work electronics KB OOEW DLNP	800 (hours)	400 (hours)	400 (hours)	
		accelerator (type) reactor Computer (type)				
		Operating costs				
Sources of financing	Budget	Costs from the budget, including funding from BMBF, Armenia	192	96	96	
	Extrabudgetary	Contracts: Grants:				

Form number 29

Project cost estimate

Precision Laser Metrology for Accelerators and Detector Complexes

№ Name of cost items	Full cost	1year 2022	2year 2023	
Direct Project Costs				
1 Computer communication				
2 DB				
3 OOEP (in standard hours)	800	400	400	
4 Materials	10	5	5	
5 Equipment	92	46	46	
6 Payment for research, performed under contracts	30	15	15	
7 Travel expenses, incl.	60	30	30	
a) to countries of the non-ruble zone	54	27	27	
b) to the countries of the ruble zone	6	3	3	
c) according to protocols				
Итого по прямым расходам:	192	96	96	
Including: from the DLNP budget	160	80	80	
Budgetary from BMBF and from the Plenipotentiary of Armenia at JINR	32	16	16	

Project Manager Yu.A. Budagov

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Annotation

The main achievements of the project "Precision Laser Metrology for Accelerators and Detector Complexes" for 2019-2021 are presented. It is shown that the use of project developments is growing every year.

In the second extension of the Project an innovative compact monolithic[1] Precision Laser Inclinometer will be created, with characteristics sufficient for its use in Interferometric Gravitational Antennas (VIRGO, possibly Telescope Einstein), in creating an angular seismic isolation system for NIKA, LHC colliders and - expectably - FCC and for creating PLI networks in Armenia and Uzbekistan for earthquake prediction.

The actively developed metrological toolkit - Laser Reference Line, Interferometric Distance Meter and Seismic Insulated Platform - in the second extension of the Project goes to experimental testing.

Introduction

Modern metrology forms a new approach to conducting large-scale physical experiments: with the help of metrological tools, it is possible not only to fine-tune the physical installation, but also to stabilize it in space from external influences during the experiment. This makes it possible to achieve a significant reduction in background noise during experiments.

The project "Precision Laser Metrology for Accelerators and Detector Complexes" is aimed specifically at creating the necessary metrological instruments for conducting experiments in seismic conditions protected from angular vibrations of the Earth's surface. The Project provides for the creation of a Precision Laser Inclinometer (PLI), a Laser Reference Line (LRL), an Interferometric Distance Meter (IDM) and a Seismic Insulated research Platform (SID) seismically isolated from angular vibrations of the Earth's surface.

Of the listed metrological tools, the Precision Laser Inclinometer [1-20] should be distinguished. In the last two extensions of the Project we have created a set of more advance samples of it.

Using the fact that the vertical of gravity is one of the most stable benchmarks in nature (Accuracy~ 10^{-10} rad per year), using PLI, we can connect the coordinates of the controlled points and determine their mutual displacement. This makes it possible to measure the movement of the Earth's surface and thereby determine the deformation of large-scale physical installations.

The result of the Project is the achievement of sufficient sensitivity for such control:

[1] Inclinometer elements do not move relative to each other

The Precision Laser Inclinometer will have an online measurement accuracy of about 10^{-9} rad,

the Laser Reference Line should have an accuracy of a few microns at a distance of 130m,

the Interferometric Distance Meter should measure 16 m with an accuracy of the order of 10 microns and

the Seismic Insulated research Platform must be horizontalized with an accuracy of the order of 10^{-8} rad.

Works on Laser metrology are protected by four state patents of the Russian Federation [17,18,25,27].

Results of work on the project for a 3-year period

1. Creation of the Metrological Laboratory (ML) DLNP

One of the most important achievements of the metrology group during the period of two project extensions was the creation of the DLNP Metrological Laboratory.

The Metrological Laboratory provides conditions for conducting all experiments that are currently planned within the framework of the extended Project.

The Metrological Laboratory is a temperature-stabilized room 24 m long and 6 m wide

(Fig. 1).

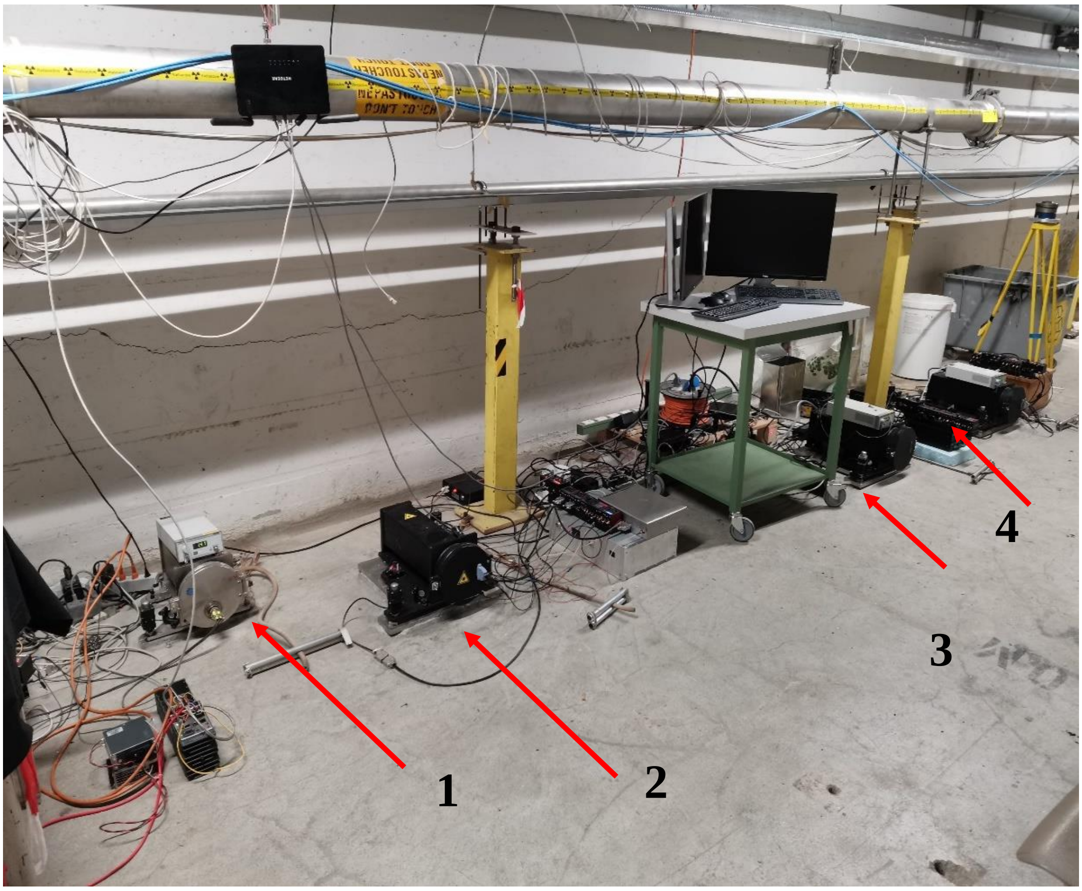
Fig. 1 The Metrological Laboratory DLNP JINR

A professional precision air conditioner stabilizes the indoor temperature with an accuracy of ± 1^0C. The Laboratory has five optical tables, contains with basic optical equipment, conditions have been created for conducting experiments within the framework of the extended Project.

These works were not foreseen in the plans of the previous extension and were for the Metrological group an over fulfillment of the tasks of the JINR Research Plan and the current Project.

2. Creation of a network of four PLIs at CERN (CERN-JINR Agreement[2]).

A network of four PLIs is designed to measure the deformation of the floor of the LHC Tunnel. All four PLIs (1,2,3,4) have been tested (Fig. 2) in the LHC Transport Tunnel No. 1 and in the spring of 2021 they will be placed in the LHC tunnel.



[2] The second Agreement is in the preparation stage.

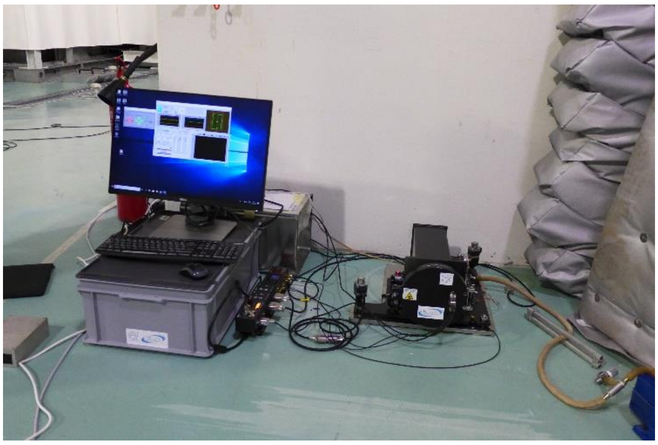
Fig. 2 Four PLI (JINR) in Transport Tunnel No.1 (CERN)

Simultaneous registration of signals from inclinometers will allow visualizing the passage of surface seismic waves under the collider and also registering a slow change in the geometry of the LHC tunnel. The data obtained will make it possible to take into account the deformations of the collider and, in the future, will be used to stabilize its position in order to increase its luminosity.

In the previous extension of the Projectit was planned to create a network of 6 PLIs. These plans, at the request of colleagues from CERN, were changed to 4 PLIs in connection with the use of two PLIs in the operation of the VIRGO Interferometric Antenna. This part of the work will be carried out planned in the second quarter of 2021, i.e. within the first extension of the project.

3. Creation of a monitoring system for angular oscillations of the Earth's surface on the territory of the VIRGO Interferometric Gravitational Antenna (IGA)

One of the key achievements of the Metrological Group is the installation of two Precision Laser Inclinometers[3] on the territory of the VIRGO Interferometric Gravitational Antenna (Fig. 3)[4] [21]. This work was done in excess of the obligations of the JINR Research Plan.



[3] **Proposed by ac. V.A. Matveev**
[4] **INFN-JINR-CERN Agreement**

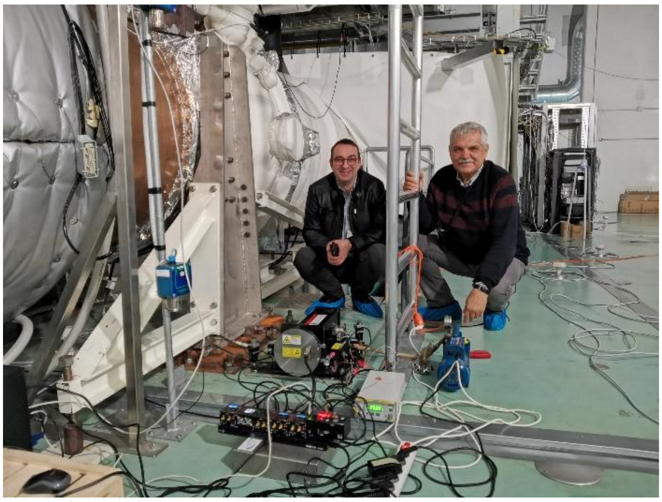


Fig. 3 Two PLI of JINR in the room of the North Mirror of the VIRGO Interferometric Gravitational Antenna

The main task of using PLI on IGA VIRGO is stabilization of its sensitive elements from angular microseismic noises. The placement and continuous operation of two PLIs for more than one year was a major breakthrough in experiments on the IGA VIRGO. They demonstrated the reliability and the required accuracy of measurements, which made it possible to proceed to the next stage of using a compact PLI directly in the vacuum of the IGA.

Currently, two PLIs are used in the noise reduction system of the IGA VIRGO North Mirror.

These extra works were not planned in the first extension of the project and are an achievement comparable to the creation of a network of 4 PLIs in the LHC tunnel.

4. Forecast of earthquakes using the PLI network

Work is underway to use the inclinometer for earthquake prediction tasks at the Garni International Geophysical Observatory (Armenia) (Fig. 4)

Fig. 4 Precision Laser Inclinometer Of JINR at the Garni International Geophysical Observatory (Armenia)

This observatory houses one PLI and a network of four inclinometers is being created in the geophysical centers of Gyumri and Garni.

These works were also not planned in the first extension of the project and are an additional important activity of the DLNP Metrological Group on the application of PLI. In connection with this application of PLI, we note the beginning of work with Uzbekistan on earthquake prediction[5].

5. Laser Fiducial Line 130m long

The creation of the 130m Laser Fiducial Line is being completed. A system of vacuum volumes was put into operation, connected by vacuum tubes with a total laser beam propagation Distance of 130m (Fig. 5).

[5] Agreement between JINR and AnRUz Uzbekistan

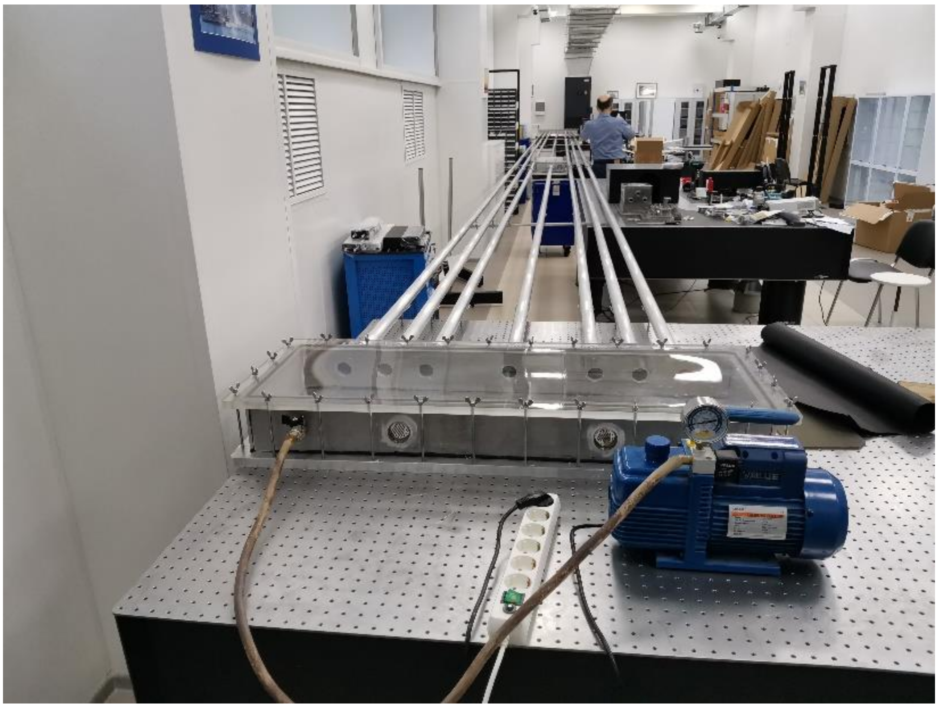


Fig. 5 Laser Vacuum Reference Line 130m long at DLNP Metrological Laboratory

Experiments at a Distance of 18 m revealed a strong dependence of the parameters of a single-mode laser beam on the quality of mirror surfaces in the laser beam collimation system. Currently, preparations are underway for the production of such mirrors.

The LRL will be operational by the end of 2021 in accordance with the previous extension of the project.

6. Interferometric Distance Meter

Work on the Interferometric Distance Meter revealed a strong dependence of the sensitivity of the interferometer on the parameters of the air environment. Experiments were carried out at a Distance of 0.1m (Fig. 6). The reach Distance measurement accuracy was ± 10 μm. To achieve greater accuracy, Distance measurement experiments are transferred to a vacuum volume. An experiment will be carried out under vacuum conditions by the end of the year.

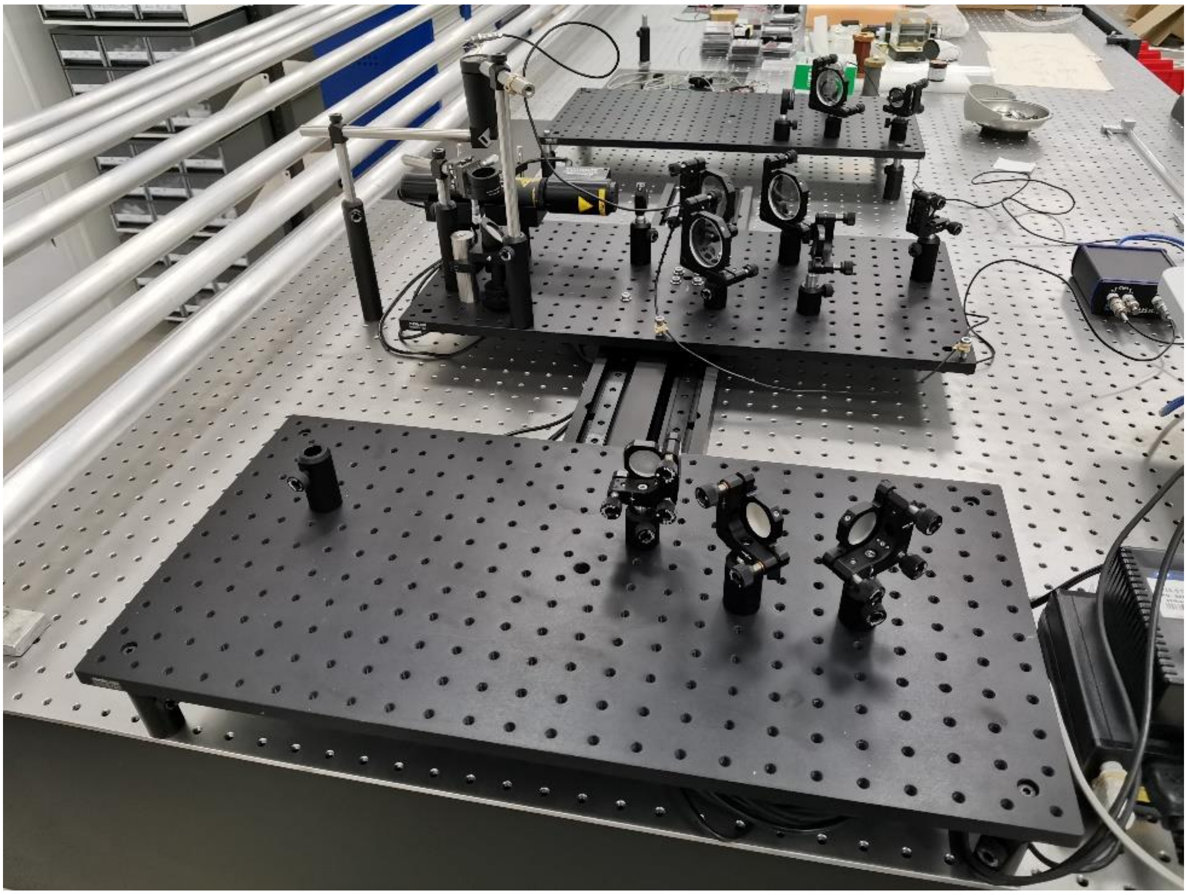


Fig. 6 DLNP Metrological Laboratory: Interferometric Distance Meter JINR

When creation of the Interferometric Distance Meter, currently , the results have been achieved on measuring distances up to 10 cm with the accuracy required for use in CERN (in accordance with the JINR Research Plan).

Measurements up to 16m will be carried out in the proposed extension of the project.

7. Research platform seismically isolated from angular vibrations of the Earth's surface

A research platform isolated from angular microseismic vibrations (SIP) is being created. The platform should be kept in a horizontal position by the feedback system with the Precision Laser Inclinometer. The creation of such a platform in future projects is necessary for fundamental physical experiments (more accurate measurement of Newton's gravitational constant G, Majoran's experiment to search for gravitational-like forces, etc. [22]).

At present, the measurements of the SIP inclinations were carried out using the MINILEVEL inclinometer with calibration inclinations $\approx 10^{-5}$ rad (Fig. 7). Measured SIP slopes are consistent with the Calibration.

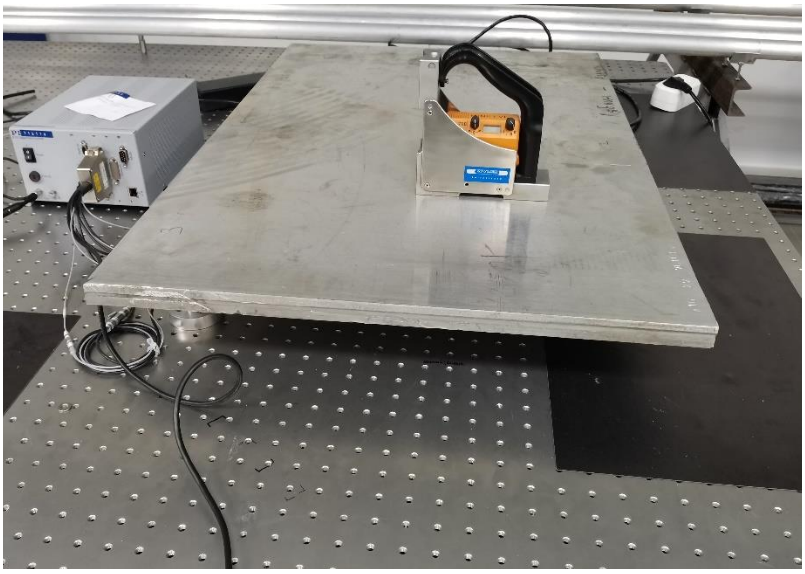


Fig. 7 The Research Platform in the DLNP Metrological Laboratory

This activity is additional in the current project. For the effective implementation of this part of the Project it is necessary to create a Compact PLI.

We plan to continue this activity and complete it in the proposed second extension of the Project.

Tasks for the second extension of the Project

1. Compact monolithic Precision Laser Inclinometer (CPLI)

Compact Monolithic Precision Laser Inclinometer Concept

The experience of developing a Precision Laser Inclinometer has shown: to create an effective inclinometer with an online sensitivity of ~ 10^{-9} rad, it is necessary to significantly reduce the influence of external and internal noise sources. Sufficiently intense and broadband noise penetrates into the PLI registration system through the influence of atmospheric air on the propagation of the laser beam. The use of vacuum more than 100 times [11, 22]) allowed us to reduce the PLI noise in the range of 10^{-3}-10 Hz.

An external change in the air temperature deforms the PLI structure, as a result of which a low-frequency noise (less than 10^{-4} Hz) of parasitic angular tilts appears. For stable operation of the PLI, thermostable conditions are required. The system for recording PLI signals also requires stable operating conditions for the recording ADCs and stabilization of the laser beam power.

Modern conditions for conducting a scientific experiment with the use of PLI require the elimination of the influence of all of the above noise sources with the additional requirement of ensuring the inclinometer's small size.

This is especially important when using PLI in the VIRGO Interferometric Gravitational Antenna. One of the key features of the IGA VIRGO is the use of a suspension for interferometer mirrors. This is due to the suppression of the sound transmission channel of noise oscillations to the Interferometric Gravitational Antenna. At the same time, the natural frequencies of the suspension *are resonant* to the microseismic waves passing over the Earth's surface. The sources of microseismic vibrations are sea waves (Microseismic peak) and industrial noises (vehicles, operation of vacuum pumps and mechanisms, etc.) Surface waves move at a speed of 2 km/s in the frequency range 0.1-1 Hz to 400 m/s at frequencies of 4-20 Hz. Since the distance between the mirrors in the IGA is 3 km or more, the effects of microseismic waves on the sensitive elements of the IGA are not correlated and, therefore, *their independent stabilization is required*.

In fact, it is required to measure the angular noise movement of the platform on which the suspension of the Interferometric mirror is mounted. The situation is complicated by the fact that the system of suppression of vertical and longitudinal seismic vibrations introduces additional noise of angular tilts, which also needs to be recorded.

Since the base for hanging of the VIRGO mirrors has small dimensions, it is necessary to reduce the overall dimensions and weight of the PLI. At the moment, it is required[6] to create a PLI with overall dimensions of 20x20x20 (cm) and weighing no more than 10 kg. *This is more than 8 times less in volume than the previous version (50x40x30cm) and more than 6 times less in weight (65kg).*

Compact monolithic Precision Laser Inclinometer

The second extension of the Project proposes the creation of a monolithic CPLI. The following tasks will be solved in this new generation inclinometer:

- achieving reduced linear dimensions (less than 20x20x20cm) and small weight (less than 10kg);

-Significant decrease in the dependence of CPLI readings on temperature (introduction of thermoresistive elements)

-use of the position-sensitive method of dividing plates (a significant reduction in the dimensions of the optical scheme of the PLI, a decrease in the influence of the positional noise of the photodetector);

[6] Second INFN-CERN-JINR Agreement

- ensuring the solidity of the PLI design (all PLI elements are connected using anaerobic glue, which excludes temperature-dependent changes in the direction of laser beams)

-use of a new method of PLI calibration, based on interferometric measurement of the piezomodule value of the calibration piezo staker.

In a conventional PLI, a quadrant photodetector is used to register the position of the laser beam reflected from the surface of the liquid. The presence of a dielectric gap separating the photodetectors with a width of 30 µm requires focusing the laser beam into a region with a diameter of 100 µm. Using the formula for the diameter of a focused laser beam

$$d = \frac{4}{\pi} \lambda \frac{F}{D} \qquad \{1\}$$

where F is the focal Distance, D is the diameter of the collimated laser beam in front of the lens, λ is the waveDistance of the light for D = 1cm, we get the focal Distance F = 100cm. It is this circumstance that creates the current dimensions of the PLI (50x40x30). Moreover, the weight of such a PLI exceeds 60 kg.

We propose to radically reduce the overall dimensions and weight of the PLI using a relatively new position-sensitive photometric method of dividing plates [23-25]. It is based on the use of specially made dividing plates (Fig. 8).

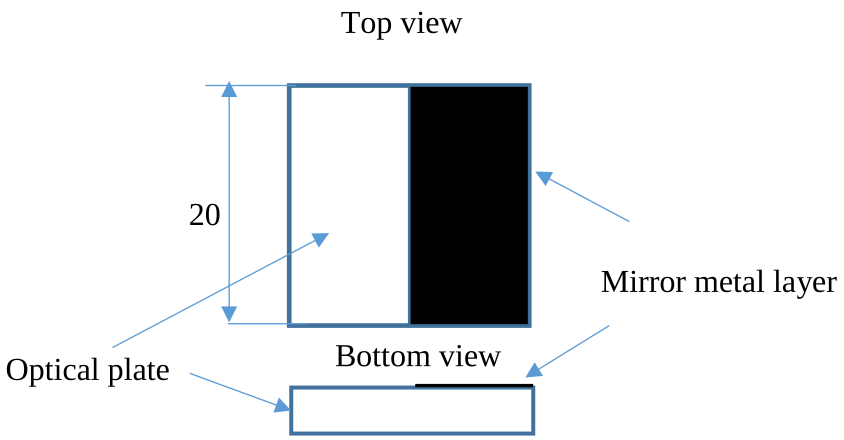


Fig. 8 Arrangement of a metal reflective layer on a plane-parallel dielectric plate

A layer of metal is sprayed onto the surface of a plane-parallel plate so that the line of connection between the metal and the dielectric surface of the plate is straight. By focusing the laser beam on this line, it is possible to divide it into two parts - one passes through the transparent plate, the other part of the laser beam is reflected (Fig. 9).

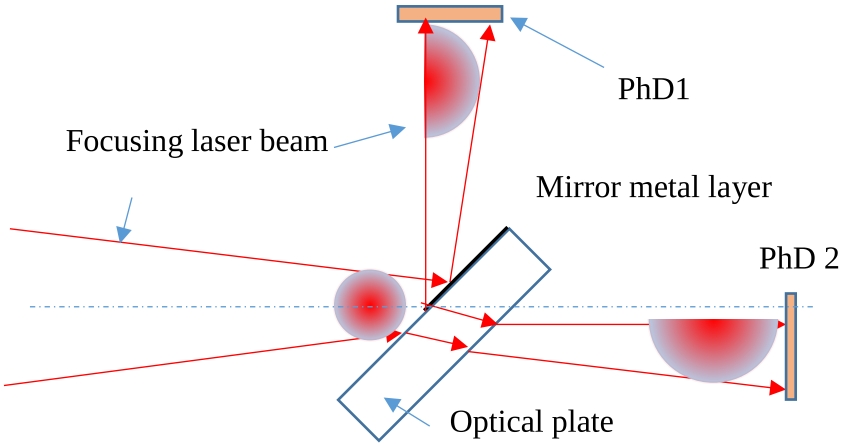


Fig. 9 Dividing a focused laser beam with a dividing plate

The displacement of the laser beam spot on the dividing plate changes the intensities of the transmitted and reflected laser beams. By measuring the change in the intensity of the separated laser beams, we obtain a position-sensitive photodetector (PSD). In this device there is no limitation on the diameter of the laser beam and, accordingly, on the focal Distance of the laser beam. According to preliminary estimates {1} it is possible to reduce the focal Distance of the laser beam to 7.5 cm and, accordingly, to reduce the dimensions of the PLI to 20x20x20 (cm)

As the focal Distance of the laser beam decreases, the focus diameter decreases. This increases the difficulty of precision alignment of the PLI.

To achieve the necessary stability in a compact PLI, we propose the creation of a monolithic structure, with the simultaneous use of thermoresistive elements (Fig. 10) (our RF patent [25]).

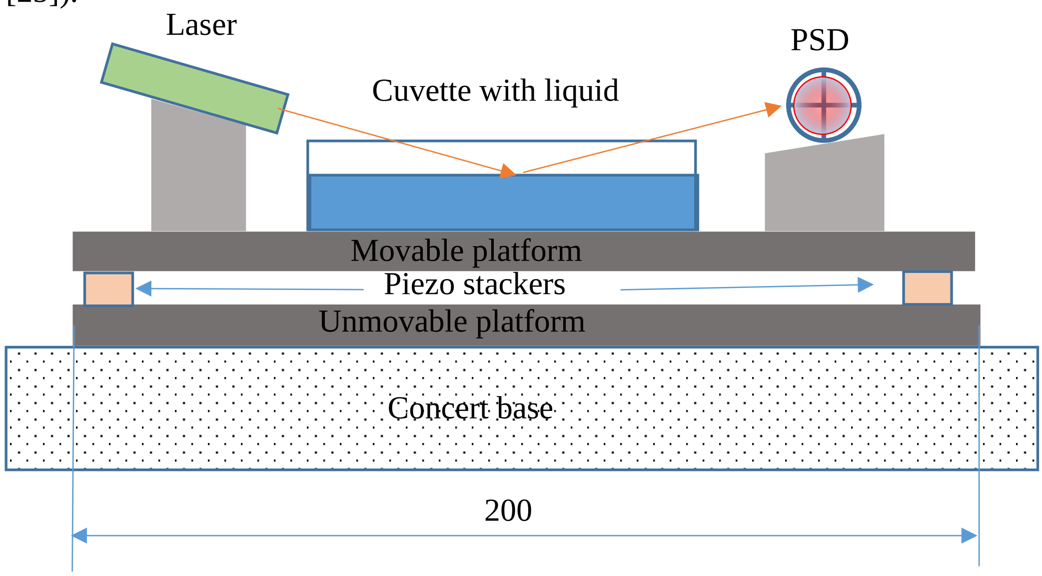


Fig. 10 Arrangement of piezo stackers (thermoresistive elements) in the Compact PLI

In this case, all elements of the CPLI are held together with anaerobic glue on a fixed base. The CPLI movable platform is connected to the fixed platform using piezo stackers of the same size. In this case, a change in temperature changes the dimensions of the piezo stackers, but does not cause parasitic tilts of the CPLI. Our proposed creation of a monolithic structure using thermal resistance will improve the performance of the CPLI and reduce its noise.

To align the laser beam in a monolithic PLI, we propose to align the PFC relative to the center of the focal spot of the laser beam (Fig. 11).

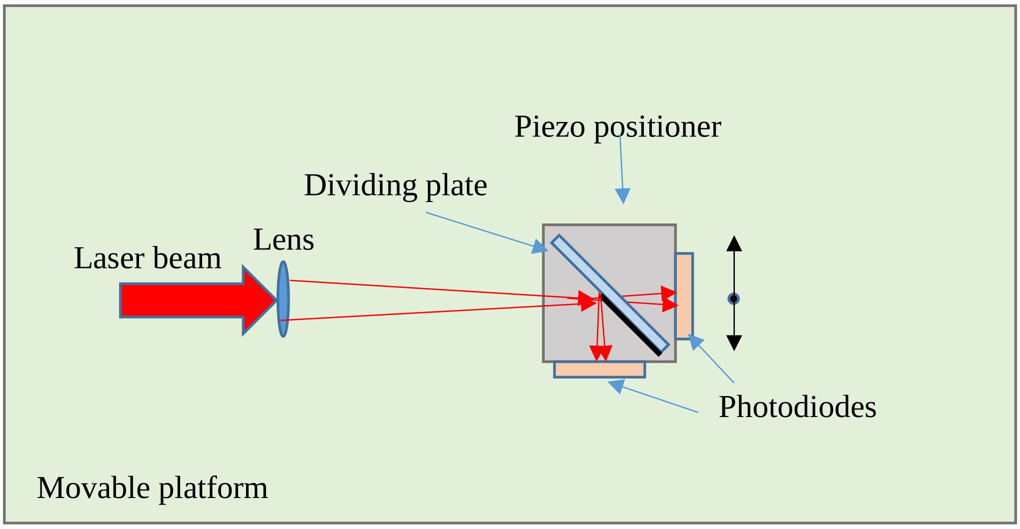


Fig. 11 Adjusting the position of the focus of the laser beam on the dividing plate using the piezo positioner

It is proposed in the design of a monolithic CPLI to place the PSD on the piezo positioner and adjust the PSD to the focus of the laser beam in the CPLI. This will avoid the escape of the laser beam after evacuating air from the vacuum volume.

For CPLI, a control board will be developed that will provide remote control, calibration, instrument adjustment and signal recording.

The creation of a CPLI will significantly reduce the labor costs in manufacturing the inclinometer and the cost of its necessary electro-optical components.

Table1

Stages	Beginning	The ending
CPLI design and manufacturing	2021	2022
Testing in the IGA VIRGO and in the LHC Tunnel	2022	2023
CPLI testing for earthquake prediction (Armenia, Uzbekistan)	2022	2023

The use of a monolithic CPLI in the operation of the VIRGO Interference Gravitational Antenna[7]

To ensure the operation of IGA VIRGO up to 10 CPLI units are required.

The operation of the CPLI as part of the IGA VIRGO requires significant adaptation of the CPLI to the conditions of deep vacuum (it is necessary to use special vacuum positioners, create a sealed cuvette with a liquid, etc.). The necessary work to create an agreed design will begin after preliminary approbation of the CPLI in the area where the IGA VIRGO is located.

Table 2

Stages	Beginning	The ending
Testing as part of IGA VIRGO	2022	2023
Design and manufacture of CPLI for work in high vacuum	2022	2023
CPLI testing for stabilizing VIRGO mirrors	2023	2023

Development of a cryogenic compact PLI for the IGA of the third generation "Einstein's Telescope"

The work of the CPLI as part of the IGA VIRGO is extremely important, but only the first stage in the use of the PLI in the IGA of the third generation - "Einstein's Telescope" (the Second Agreement between INFN-CERN-JINR) [26].

This gravitational antenna requires operation of the PLI in cryogenic conditions at liquid Ne temperature (23-24 ^{0}K). Liquid Ne is used as the horizontalizing fluid.

It is proposed in the extended Project to start creating prototypes of CPLI based on liquefied gases:

• Ethanol (room temperature),

• liquefied carbon dioxide (-58^{0}C),

[7] Second INFN-CERN-JINR Agreement

• liquid nitrogen (77^0K)

• Next, the transition to liquid Neon (23-24 ^{0}K) in CPLI will be carried out. This will ensure the operation of the third generation IGA in isolation from microseismic angular noise.

For this, the concept of a cryogenic CPLI conceptual design will be developed. Specifically, this is: ensuring the operability of piezomotors and piezo stackers and photodetectors at low temperatures.

Table 3

Stages	Beginning	The ending
Development of a closed cell design for ethanol	2021	2022
Testing CPLI with a closed cell in a vacuum	2022	2023
Development of the design of a closed cell for liquefied carbon dioxide	2022	2023

System for visualization of angular microseismic tilts of the earth's surface for the NIKA[8] collider and LHC[9] using CPLI

Microseismic slopes of the earth's surface exist in a wide frequency range from 10-6 Hz to 20 Hz. In fact, two microseismic phenomena dominate in different frequency ranges:

-high-frequency surface microseismic waves. These are surface waves from the wind load on the surface of the oceans and seas (Microseismic Peak) and industrial noises (the movement of railway and road transport, the operation of a vacuum pump, etc.)

-low-frequency change in the slopes of the Earth's surface (the influence of the Moon and the Sun), ground subsidence (underground rivers under the LHC), seasonal movement of groundwater (NIKA).

The system for visualizing the angular microseismic tilts of the earth's surface (PLI network) is, first of all, a system that can monitor the angular parameters of the earth's surface for a long time. The system will make it possible to visualize the movement of the accelerator modules of the collider from the action of the sources of angular motions of the first and second types.

Thus, it is necessary to simultaneously solve two problems.

• *First task*

Visualization of angular microseismic oscillations of surface microseismic waves in the frequency range 10^{-2}-20 Hz. In the range of 1-10 Hz oscillations of the Earth's surface, maximum

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[8] Proposed by ac. G.V. Trubnikov
[9] CERN-JINR Agreement

displacements of beams of colliding particles occur both at the NIKA collider and at the LHC, as a result of which the focuses of the particle beams in the collider diverge.

At a certain amplitude of such oscillations ($\approx 5\cdot 10^{-6}$ rad by our estimated), the divergence of particle beams can be significant. Therefore, it is necessary to develop not only a system for registering the position of the Earth's surface under the collider, but also a system for stabilizing the collider during its deformation by surface waves.

• *Second task*

To obtain the maximum luminosity of the collider, it is extremely important to register the slow motion of the Earth's surface - the so-called Ground Motion. This movement of the earth slowly deforms the collider. In this case, the motion of the beams, due to their passage in gradient magnetic fields, changes its parameters, which may go beyond the design tolerances. Under these conditions, it is important to stop the collider deformation and stabilize it. Such an visualization system seems to be necessary for both the NIKA collider and the LHC collider and the future FCC collider.

Solving the aforementioned tasks requires the participation of a team of accelerator specialists, which is beyond the scope of this project extension.

The extended Project provides for the placement of a compact PLI directly in the area of the NIKA collider (Fig. 13).

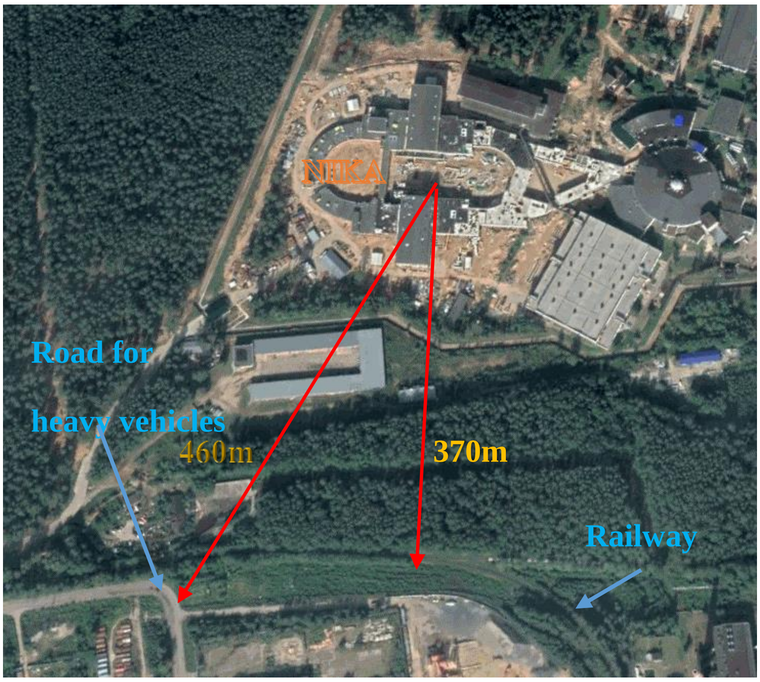

Fig. 13 Location of the NIKA collider relative to the main sources of microseismic noise (road and railways)

Angular microseismic noise will be measured over a wide frequency range. These studies will help determine the parameters of the future network of Precision Laser Inclinometers.

Table 4

Stages	Beginning	The ending
Installation of CPLI on the floor of the NIKA collider	2021	2022
Determination of angular microseismic activity in the area of the NIKA collider	2022	2023
Development of a conceptual design of the CPLI network for the NIKA collider	2022	2023

Creation of a network of four Monolithic PLIs in Armenia for earthquake prediction

One of the important areas of PLI application is earthquake prediction.

In this case, the Precision Laser Inclinometer operates in the mode of recording low-frequency and very low-frequency oscillations of the Earth's surface. The frequency range of the recorded oscillations is 10^{-8}-10^{-3} Hz. In this case, it is necessary to observe the movement of the Earth's surface in the range of one year with a time resolution of about 20 minutes.

Such a possibility will allow to determine the angular slopes at the points of the PLI placement and then, knowing the distance between the inclinometers, to quantitatively determine the movement of the earth's crust. Analysis of the movement of the earth's crust makes it possible to detect zones of accumulation of seismic energy (areas of future earthquakes). Knowing the location of the seismic energy accumulation zones, their formation process, it seems possible to predict the development of seismic activity in the area of the PLI network location.

In the future, this zone can be observed using conventional seismometers and seismophones, which will determine the presence of seismic activity on the earth's surface before earthquakes. These are the so-called foreshocks. Foreshocks are earthquake harbingers. Their appearance means that a primary crack is forming, along which the earthquake will develop. As a rule, foreshocks occur before earthquakes in a day and this makes it possible to organize the evacuation of people from a dangerous area.

In the conditions of Armenia, there are several large faults in the earth's crust. In the area of these faults, it is planned to place several inclinometers and conduct joint observation of the movement of the earth's crust.

This use of PLI has a theoretical justification given by the academician of the Academy of Sciences of Armenia L.A. Agolovyan. On this basis, he was shown in his report at a seminar at DLNP on November 2019. the ability to predict earthquakes using high-precision inclinometry. The use of monolithic PLI due to the possibility of organizing long-term observations of the earth's surface tilts, from his point of view, is extremely important for the organization of quantitative earthquake prediction.

To create a network for observing the slopes of the earth's surface, it is necessary to place the PLI on the territory with an average step corresponding to the size of the action of an earthquake with a Magnitude of more than 6 Mw (starting from this magnitude, especially large destruction of houses, roads and objects of the national economy is observed). Experimental observation data of such earthquakes indicate an earthquake action zone of up to 10 km.

It is proposed in the extended Project to create a primary network of four compact PLIs. The deployment of such a network will make it possible to experimentally carry out long-term observation of the angular motions of the Earth's surface, prepare the necessary infrastructure for servicing the inclinometers of the network, and develop software for servicing the network. On the prototype of the network, consisting of four monolithic PLIs, it is planned to determine the parameters of the future network: the average distance between inclinometers, measurement frequency, etc.

After the completion of the work on the Compact monolithic Precision Laser Inclinometer, it is planned to produce the required number of CPLIs for earthquake forecasting and place the primary network in Armenia in the next three years.

Table 5

Stages	Beginning	The ending
Installation of CPLI at Garni International Geophysical Observatory	2021	2022
Monitoring of microseismic activity in the fault zone of the earth's crust at GARNI	2022	2023
Production of 3 samples of CPLI (if funding is available) and placing them in geophysical centers in Armenia	2022	2023

2. Associated metrological activities

Laser Fiducial Line 130 m long

In the manufactured and assembled vacuum volumes of the Laser Reference Line, it is planned to conduct a laser beam to a Distance of 130 m and begin physical experiments.

Planned list of experiments on LRL:

1. *Determination of the positioning accuracy of the laser beam in vacuum at a Distance from 18m to 130m*

In the experiment, it is planned to investigate the behavior of a laser beam under the action of angular microseismic vibrations.

2. *Determination of the accuracy of long-term measurements of LRL at a Distance of 130m*

In the experiment, it is planned to determine the long-term stability of the LRL at a Distance of 130 m over a long period (day).

3. *Determination of measurement accuracy using seismically isolated platforms.*

The experiment will find the maximum positioning accuracy of the LRL in the absence of angular microseismic vibrations.

4. *Measurements of the displacement of the test object relative to the stable LRL.*

When the maximum stability is reached in the LRL, the displacement of the test object relative to the LRL will be investigated. It is planned to measure the long-term motion of the test object with respect to a stable laser reference line.

5. *Comparison of the motion of a laser beam in pipes at atmospheric pressure relative to vacuum.*

The experiment will continue the study of the previously found effect of laser beam stabilization in closed tubes [27]. The parameters of such an attenuation of a relatively stable LRL in vacuum will be determined.

Carrying out experiments with a laser reference line will end with the determination of its accuracy and time characteristics (study of the accuracy of LRL measurement from the time of continuous measurements).

After the experiments, it is planned to defend two dissertations of Ph.D.

Table 6

Stages	Beginning	The ending
Carrying out experiments on LRL without angular stabilization of LRL platforms	2021	2022
Carrying out experiments on LRL with angular stabilization of LRL platforms	2022	2023
Experimental comparing of the propagation of a laser beam in a closed tube and in a vacuum	2022	2023

Interferometric Distance Meter

To overcome the influence of the atmosphere on the measurement accuracy, experiments are planned to measure distance in vacuum in order to obtain the maximal measurement accuracy.

For these purposes, all elements of the Interferometric Distance Meter will be placed in a vacuum box.

To increase the distance of the measurement, a processing program will be created, which online determines the current coordinate of the carriage movement in the IDM. The use of a processing program will allow one to avoid information overflow in the measurement system and increase the measurement distance to a distance of 2m. After testing the IDM at a distance of 2m, it will be placed on the floor of the Metrological Laboratory on metrological rails for carrying out full-scale measurements of distances up to 16m.

Let us recall that an Interferometric Distance Meter is necessary for connecting coordinate systems of accelerators (collider), separated by detector complexes.

Table 7

Stages	Beginning	The ending
Carrying out experiments on the Interferometric distance Meter in vacuum	2021	2022
Writing a program for online processing of IDM signals	2022	2023
Experiments with a new online program at a distances of 2m - 16m	2022	2023

Research platform seismically isolated from angular vibrations of the Earth's surface

After the manufacture of a compact monolithic PLI, it is planned to conduct experiments on the Seismic Insulated research Platform (SIP) with dimensions of 1 x1 (m).

The main purpose of such experiments is to demonstrate the angular seismic isolation of the platform, to determine the spread of angular oscillations of the stabilized platform and the possibility of angular seismic isolation of an optical table with dimensions of 3x1.5m. The second stage of the experiments is the seismic isolation of the optical table.

The SIP experiments will be completed during the second extension of the Project.

In the future, it is planned to carry out fundamental physical experiments on an optical table seismically isolated from angular vibrations of the Earth's surface (measurement of Newton's gravitational constant G with greater accuracy, Majoran's experiment on the search for gravitational-like forces, experiments with Kibble weights, etc. [20,26,28]).

Table 8

Stages	Beginning	The ending
Experiments on a small Seismically Isolated Platform with CPLI	2021	2022
Experiments on a large Seismically Isolated Platform (optical table) with two CPLI	2022	2023
Seismic isolation of optical LRL tables using SIP	2022	2023

Conclusion

The second extension of the Project is taking place under the conditions of intensive improvement of the parameters of the Precision Laser Inclinometer. The successes achieved with the PLI open up the possibility of using this device in several research directions. The most important direction of PLI application is its use for registration of angular microseismic vibrations of large-scale physical installations.

With a new extension of the Project it is planned to put into operation a unique new device - a monolithic Compact PLI. This device can investigate angular microseisms in a wider frequency range (expectedly 10^{-8}-20Hz), which will significantly expand the field of application of the Precision Laser Inclinometer in physics experiments.

The new device will make it possible to start systematic work on the creation of a network in order to predict earthquakes in seismic zones of Armenia and Uzbekistan.

For the NIKA, LHC and FCC colliders, the use of CPLI as its seems will make it possible improve the parameters of their beams spatial stability.

The use of CPLI for stabilization of Interferometric Gravitational Antennas is very promising. Without this device, it is practically impossible to stabilize angular microseisms, both for the existing VIRGO, LIGO, and for the future Interferometric Gravitational Antenna - the Einstein telescope.

For the IGA of the third generation, it is planned to develop CPLI for operation in cryogenic conditions. In the Projectit is planned to start R&D for a CPLI that will operate on cryogenic liquids, and we hope that in the future JINR will take part with the cryogenic Compact Precision Laser Inclinometer method in the third generation IGA project - the Einstein Telescope.

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Table 9

Employment of the Metrological group (Sec.No. 3, group No. 1 of NEOMAP DLNP JINR) in the work of the project "Precision Laser Metrology for Accelerators and Detector Complexes"

№	Name	FTE	Positon	Work (apart common duties like shifts)
1	Lyablin M.V.	1	Senior Researcher	optics, general management
2	Atanova O.S.	1	engineer	PLI data visualization
3	Atanov N.S.	1	Researcher	Seismically isolated platform
4	Batusov V.Yu.	0.2	Researcher	PLI at CERN
5	Bednyakov I.V.	1	engineer	PLI programming
6	Budagov Yu.A.	0.6	Chief Researcher	general leadership
7	Klemeshov Yu.V.	1	engineer	PLI programming
8	Krasnopyorov.A	0.9	Researcher	PLI programming
9	Kuzkin A.M.	1	senior engineer	production, adjustment of PLI
10	Ni R.V.	1	engineer	optics, PLI adjustment
11	Pluzhnikov A.A.	1	engineer	Laser Fiducial Line Adjustment, PLI

12	Torosyan G.T.	1	Senior Researcher	Earthquake forecast with help. PLI
13	Seletsky A.A.	0.3	engineer	PLI design
14	Studenov S.N.	1	mechanic	Mechanical work
15	Artikov A.M.	0.1	Senior Researcher	earthquake forecast
	Total FTE	**12.1**		