**Questionnaire**

The second extension of the project "PRECISION LASER METROLOGY FOR ACCELERATORS AND DETECTOR COMPLEXES"

**A. Scientific merit**

An innovative method has been developed and created for precision registration of angular oscillations of the Earth's surface under the influence of microseismic phenomena: surface microseismic waves, deformation of the Earth's surface by the Moon and the Sun, irregular movements of the earth's crust.

**1. Goals of the experiment:**

• Online measurements of the spatial change in the position of the base of the collider by surface microseismic waves.

• Registration of angular oscillations of the Earth's surface in the area of the VIRGO Interferometric Gravitational Antenna.

• Registration of irregular inclinations of the earth's surface in an area of increased seismic hazard.

**1a. A short description of the objectives of the experiment**

• Online measurements of the spatial position of the collider will make it possible to reduce the effect of microseisms and increase the luminosity.

• Online measurements of the angular tilts of the earth's surface will make it possible to stabilize the spatial position of the IGA VIRGO elements and increase the sensitivity of the gravitational antenna.

• Online measurements of the angular inclination of the earth's surface in the zone of increased seismicity will make it possible to determine the zones with the accumulation of seismic energy and earthquakes forecast.

**1b. The international scenario**

The implementation of the project ensured the participation of JINR in the LHC, VIRGO and the NIKA collider Megasciense programs. In the future, application of the project results will allow JINR to participate in the forthcoming Interferometric Gravitational Antenna - "Einstein's Telescope".[[1]](#footnote-1)

**B. Achievements**

1. Currently, two PLIs are working as part of the IGA VIRGO. The data from the PLI are used in the IGA VIRGO microseismic vibration suppression system on the northern mirror.

2. Completed testing of five PLIs in Transport Tunnel No. 1 of CERN and installation of four PLIs on the ALISA and CMS spectrometers.

3. One PLI works at the International Geophysical Observatory GARNI (Armenia).

2. Contribution of the JINR group:

**2a.**

The hardware and software complex "Precision Laser Inclinometer" has been developed, which includes:

• Design and manufacture of mechanical elements of PLI.

• Assembly and adjustment of PLI

• Precision Laser Inclinometer software and PLI network software.

• Installation and subsequent maintenance of PLI at CERN, VIRGO and Armenia

**2b.**

The JINR metrological group is focused on the development and creation of hardware and software systems for PLI. These devices are installed and serviced by us at LHC, IGA VIRGO and in Armenia.

**3.Publications**

Over the past 3 years, **12 articles** have been published in peer-reviewed journals and **three State Patents** for inventions of the Russian Federation have been received.

1. B. Di Girolamo, J.-Ch. Gayde, D. Mergelkuhl, M. Schaumann, J. Wenninger, Switzerland N. Azaryan, J. Budagov, V. Glagolev, M. Lyablin, G. Shirkov, G. Trubnikov, Russia The monitoring of the effects of earth surface inclination with the precision laser inclinometer for high luminosity colliders Proceedings of RuPAC2016, St. Petersburg, Russia, P. 210-212

2. N. Azaryan, J. Budagov, J-Ch. Gayde, B. Di Girolamo, V. Glagolev, M. Lyablin

D. Mergelkuhl, G. Shirkov The Innovative Method of High Accuracy Interferometric Calibration of the Precision Laser Inclinometer Physics of Particles and Nuclei Letters, 2017, Vol. 14, No. 1, pp. 112-122. 2017

3. N. Azaryan, V. Batusov, J. Budagov, V. Glagolev, M. Lyablin, Trubnikov, G. Shirkov, J.-Ch. Gayde, B. Di Girolamo, A. Herty, H. Mainaud Durand, D. Mergelkuhl, V. Rude Comparative Analysis of Earthquakes Data Recorded by the Innovative Precision Laser Inclinometer Instruments and the Classic Hydrostatic Level System Physics of Particles and Nuclei Letters, 2017 , Vol. 14, No. 3, pp. 480-492. © 2017 Pleiades Publishing, Ltd.

4. N. Azaryan, J. Budagov, M. Lyablin, A. Pluzhnikov, B. Di Girolamo, J.-Ch. Gayde, D. Mergelkuhl Determination of the maximum recording frequency by the Precision Laser Inclinometer of an earth surface angular oscillation Physics of Particles and Nuclei Letters November 2017, Volume 14, Issue 6, pp 920-929

5. N. Azaryan, J. Budagov, M. Lyablin, A. Pluzhnikov, B. Di Girolamo, J.-Ch. Gayde, D. Mergelkuhl The compensation of the noise due to angular oscillations of the laser beam in the Precision Laser Inclinometer Physics of Particles and Nuclei Letters November 2017, Volume 14, Issue 6, pp 930-938

6. Azaryan, N .; Budagov, J .; Lyablin, M .; Pluzhnikov, A .; Gayde, J.-Ch .; Di Girolamo, B .; Mergelkuhl, D. The temperature stability of 0.005 ° C for the concrete floor in the CERN Transfer Tunnel # 1 hosting the Precision Laser Inclinometer Physics of Particles and Nuclei Letters, Volume 14, Issue 6, pp.913-919

7. Professional Precision Laser Inclinometer: the Noises Origin and Signal Processing

N. Azaryan, J. Budagov, V. Glagolev, M. Lyablin, A. Pluzhnikov, A. Seletsky, G. Trubnikova, B. Di Girolamo, J.-C. Gayde & D. Mergelkuhlb Physics of Particles and Nuclei Letters volume 16, # 3 pages 264–276 (2019)

8. The Seismic Angular Noise of an Industrial Origin Measured by the Precision Laser Inclinometer in the LHC Location Area N. Azaryan, J. Budagov, V. Glagolev, M. Lyablin, A. Pluzhnikov, A. Seletsky, G. Trubnikov, B Di Girolamo, J.-C. Gayde & D. Mergelkuhl Physics of Particles and Nuclei Letters volume 16, No. 4 pages343–353 (2019) /

9. Position-Sensitive Photoreceivers: Sensitivity and Detectable Range of Displacements of a Focused Single-Mode Laser Beam N. S. Azaryan, J. A. Budagov, M. V. Lyablin, A. A. Pluzhnikov, B. Di Girolamo, J.-Ch. Gayde & D. Mergelkuhl Physics of Particles and Nuclei Letters volume 16, # 4 pages 223

10. Colliding Beams Focus Displacement Caused by Seismic Events N. S. Azaryan, J. A. Budagov, M. V. Lyablin, A. A. Pluzhnikov, G. Trubnikov, G. Shirkov, O. Bruning, B. Di Girolamo, J.-Ch. Gayde, D. Mergelkuhl & L. Rossi Physics of Particles and Nuclei Letters volume 16, # 4 pages377–396 (2019)

11. The compact nanoradian precision laser inclinometer - an innovative instrument for the angular microseismic isolation of the interferometric gravitational antennas Julian Budagov, Beniamino Di Girolamo, Mikhail Lyablin PEPAN Letters Vol 17, No 7 (2020)

12. The methods to improve the thermal tolerance of the Compact Precision Laser Inclinometer Julian Budagov, Beniamino Di Girolamo, Mikhail Lyablin PEPAN LettersVol 17, No 7 (2020)

13. State Patent for the invention of the Russian Federation 2734451 C1 Device for measuring the angles of inclination of the surface Budagov Yu. A. Lyablin MV

14. State Patent for invention of the Russian Federation No. 2510488 C1 "Device for measuring the angle of inclination." Budagov Yu. A. Lyablin M. V.

15. State Patent for invention RF 2740489 C1 Laser inclinometer for long-term registration of angular tilts of the earth's surface Budagov Yu. A. Lyablin M.V.

The total number of articles published during the work on the project is **16.**

**4. Dissertations**

One Ph.D. and one doctoral dissertation are expected to be defended based on the results of work on the project.

**5. Reports at conferences:**

5a

Over the past three years, there have been reports at the following conferences

• J.A. Budagov et al., "The Precision Laser Inclinometer", 12th International Particle Accelerator Conference - IPAC '21, 24-28 May 2021, Campinas, Brazil

• I. V. Benyakov at al., NEC'2019 XXVII International Symposium on Nuclear Electronics & Computing 30 September - 4 October 2019

**6. Plans**

In the next two years 2022-2023 it is planned:

• Put into operation the innovative Compact Precision Laser Inclinometer, the next generation of PLI.

• Deploy a network of five PLIs in the LHC tunnel and obtain the world's first online visualization of the passage of surface seismic waves under the LHC collider.

• To test the Compact PLI in the conditions of the IGA VIRGO.

• To test a Compact PLI for recording seismic activity in Armenia and Uzbekistan.

**7. Group size, composition and budget.**

Tab.1 shows the direct participants in the implementation of the project.

Tab. 1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| № | 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. | 0.7 | Chief Researcher | general scientific 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 | Management support |
| 13 | Seletsky A.A. | 0.3 | engineer | PLI design |
| 14 | Studenov S.N. | 1 | mechanic | Mechanical work |
| 15 | Artikov A.М. | 0.1 | Senior Researcher | Tarthquake forecast, Management support |
|  | **Total FTE** | **12.2** |  |  |

The total number of participants in the collaboration is 62.

7a.

Project budget for 2022-2023 **$ 192,000.**

7b.

Tab. 2 provides detailed information on the items of expenditure of the project budget.

Tab.2

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 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: |  |  |  |  |

**7c.**

The project does not provide for the use of JINR computing power.

1. This international cooperation follows the "AGREEMENT+ATTACHMENTS+AMENDMENTS"

   Signed By CERN Director General Prof. F.Gianotti, ,JINR Directors Prof. V. Matveev, Prof. G. Trubnikov and INFN President Prof. Antonio Zoccoli. [↑](#footnote-ref-1)