Приложение 2

**Questionnaire**

for the extraordinary session of the PAC for Condensed Matter Physics for the assessment of related JINR projects

 **PART A: Achievements of the JINR project: New semiconductor detectors for fundamental and applied research (04-2-1126-2015 / 2023)**

The goal of the project is scientific and methodological research on the creation of new types of detectors both for experimental installations for studies in the field of experimental physics of the atomic nucleus and elementary particles, and in applied research, primarily in biomedicine. In order to fulfill these tasks, the project is developing in two parallel directions. One of them is devoted to the study of the properties and possible applications of modern pixel semiconductor detectors (we will call this direction "Pixels") and the second one is related to the study of the properties of new Gallium Arsenide semiconductor material “GaAs” as detector’s sensor and their application in experimental physics.

Contributions of the JINR group:

1. Pixels activities. As a member of Medipix4 Collaboration JINR group:
2. The GaAsPix system for detecting and monitoring the radiation situation in the ATLAS cavern in CERN has been proposed, created and it is successfully operating. First results were published at JINST. All 10 GaAs Timepix detectors have been tested at JINR, installed in the ATLAS cavern and serviced from 2017 to the end of Run 2 by the JINR group.
3. The JINR group contributed 250 kCHF (50% from the JINR budget and 50% from a grant from the Ministry of Science of Russia) to the development by Medipix Collaboration of the most modern pixel chip Timepix4. This entitles JINR to develop its own detectors using these Hi-tech pixel chips. The first trial batch of the most recent generation Timepix4 was made.
4. The installation and commissioning of the main elements of the operating prototype of the X-ray tomograph with a rotating sample has been completed, and its adjustment and calibration has begun at LNP JINR.
5. An agreement on joining the efforts of JINR, MIPT and MSU in carrying out research in medicine and biology was reached. A unique MARS microtomograph was transported from JINR to the Phystech School of Biological and Medical Physics (FMBF).
6. Single-photon emission computed tomography (SPECT) allows obtaining tomographic images of the biodistribution of radiolabeled compounds, both throughout the patient’s body and in separate organs. A system based on the coded aperture and the hybrid pixel Timepix detector with the CdTe sensor has been used to obtain images of different gamma ray sources.
7. The JINR group takes part in R&D for the Transition Radiation Detector prototype at SPS, CERN. Response simulation and estimates for resolution of GaAs-Timepix3 detector are being done .
8. GaAs activities. As a member of FCAL collaboration JINR group:
	1. The creation and testing of a full-scale prototype of the FCAL module including readout electronics. Together with the TSU group (Tomsk), research continued on the creation and testing of new semiconductor radiation-resistant materials on particle beams at JINR.

In all listed collaborations (Medipix, FCAL), the role of JINR scientists is quite noticeable. All the governing bodies of the collaborations - the Bord Institute - have JINR representatives.

# Publications in 2018 – 2021

Articles

1. H. Abramowicz, A. Abusleme, K. Afanaciev, G. Chelkov, et.al. Measurement of shower development and its Molière radius with a four-plane LumiCal test set-up, //Eur. Phys. J. C (2018) 78:135 (The JINR group made a significant contribution to this work by providing GaAs PAD sensors and tungsten absorber plates, taking part in assembly, beam testing at DESY, analysis of the data and preparation of the publication.)
2. G.Chelkov, B.Bergmann, S.Kotov, P. Smolyanskiy, U.Kruchonak, D.Kozhevnikov, Y.Mora Sierra, I.Stekl, A Zhemchugov. Properties of GaAs:Cr-based Timepix detectors, // Journal of Instrumentation. Vol. 13, no. 02. T02005. (2018) (The JINR group made a decisive contribution to this work by providing GaAs sensors and testing this GaAsTimepix detectors at semiconductor testing laboratory at the LNP JINR).
3. Savelyeva, E. N., Burikova, T. V., Masagutov, R. K., & Kozhevnikov, D. A. Compacting processes and their effect on reservoir properties of the Pashian horizon in Kitayamskoye field (Russian), // *Oil Industry Journal*, *2018*(04), 26-28 (The JINR group made a decisive contribution to this work, since all measurements were performed on the MARS microtomograph at the LNP JINR).
4. Kozhevnikov D., Smolyanskiy P. Equalization of Medipix family detector energy thresholds using X-ray tube spectrum high energy cut-off, // Journal of Instrumentation. 2019. Т. 14. №. 01. С. T01006. (This work was carried out only by the LNP JINR scientists and is devoted to a very original method proposed and implemented by them).
5. F. Dachs,J. Alozy,N. Belyaev,B.L. Bergmann,M. van Beuzekom,T.R.V. Billoud,P. Burian,P. Broulim,M. Campbell,G. Chelkov,M. Cherry,S. Doronin,K. Filippov,P. Fusco,F. Gargano,B. van der Heijden,E.H.M. Heijne,S. Konovalov,X.L. Cudie,F. Loparco et al. Transition radiation measurements with a Si and a GaAs pixel sensor on a Timepix3 chip, // Nuclear Instruments and Methods in Physics Research Section A, Vol. 958. 2019 (In this article, the contribution of the authors of the LNP JINR is very significant, since we provided one of the two investigated (Si and GaAs) detectors, namely GaAs.)
6. M.Krmar, Y.Teterev, A.Belov, S.Mitrofanov, S.Abou El-Azm, M.Gostkin, V.Kobets, U.Kruchonak, A.Nozdrin, S.Porokhovoy, M.Demichev. Beam energy measurement on LINAC200 accelerator and energy calibration of scintillation detectors by electrons in range from 1 MeV to 25 MeV. Nuclear Instruments and Methods in Physics Research Section A, Vol. 935. 2019 (This work was carried out entirely on JINR equipment and only by JINR specialists.)
7. 7. Abramowicz, H. et al. FCAL Collaboration Performance and Molière radius measurements using a compact prototype of LumiCal in an electron test beam. Eur. Phys. J. C 79 (2019) 579 (The contribution of the JINR group is very significant, since when the prototype was sucked, GaAc sensors and tungsten absorber plates provided by JINR were used.)
8. V. Rozhkov1, G. Chelkov1, I. Hernández2, O. Ivanov3, D. Kozhevnikov1, A. Leyva1,4, A. Perera2, D. Rastorguev1,5, P. Smolyanskiy1, L. Torres2, A. Zhemchugov1. Visualization of radiotracers for SPECT imaging using a Timepix detector with a coded aperture. 2020 JINST 15 P06028.3.   (The JINR researchers developed and tested an SPECT system with a submillimeter spatial resolution based on the Timepix hybrid pixel detector. The system can be used both for obtaining scintigrams and for carrying out tomographic studies.)

# D Rastorguev, D Kozhevnikov and P Smolyanskiy. Study of charge sharing effect in a GaAs:Cr-based Timepix3 detector. 2020 J. Phys.: Conf. Ser. 1690 012184. (Estimates on detector spatial and energy resolution, governed by charge sharing in GaAs sensor, are obtained via Monte-Carlo simulation. This work was performed by LNP JINR scientists.)

# J Alozy et al. Registration of the transition radiation with GaAs detector: Data/MC comparison. 2020 J. Phys.: Conf. Ser. 1690 012041. (JINR group is in charge for the GaAs usage in the test setup. This work was performed by LNP JINR scientists.)

1. Boyko1, P. Burian5,6, M. Campbell2, G. Chelkov1,4, E. Cherepanova1, B. Di Girolamo2, A. Gongadze1, J. Janecek5, D. Kharchenko1, U. Kruchonak1 et al. Measurement of the radiation environment of the ATLAS cavern in 2017–2018 with ATLAS-GaAsPix detectors. Published *JINST* **16** P01031. 2021 (The overwhelming majority of this work was performed by LNP JINR scientists.All 10 GaAs Timepix detectors have been tested at JINR, installed in the ATLAS cavern and serviced since 2017 was carried out by JINR scientists.)

Patents

1. Abdelshakur S., Demichev M. A., Zhemchugov A. S., Kozhevnikov D. A., Kotov S. A., Kruchonok V. G., Smolyansky P. I., Shelkov G. A. SEMICONDUCTOR PIXEL DETECTOR OF CHARGED STRONGLY IONIZING PARTICLES (MULTI-CHARGED IONS), Patent (RU) 2659717, dated 03.06.2018, JINR.

2. Kozhevnikov D.A., Kotov S.A., Kruchonok V.G., Leiva F.A., Smolyansky P.I., Shelkov G.A., Zhemchugov A.S. PLANAR SEMICONDUCTOR DETECTOR, Patent (RU) 2672039, 11/08/2018, JINR.

PhD theses

1. P.I. Smolyansky KFMN (01-04-01) 2018 (supervisor A.S. Zhemchugov) “The study of pixel arsenide-gallium detectors based on the Timepix chip”

2. D.A. Kozhevnikov KFMN (01-04-01) 2019 (supervisor G.A.Shelkov) “Development of the method of multi-energy x-ray tomography using detectors based on microchips of the Medipix family”

Masters Degrees

1. E.A. Cherepanova (MIPT) 2019 (supervisor G.A.Shelkov)

“Analysis of the structure of the radiation background in the underground hall of the ATLAS installation based on data from the detectors of the ATLAS-GaAsPix system”

2. V. Andriyashen (MIPT) 2019 (supervisor A.S. Zhemchugov) “Development of a method of multi-energy iterative tomographic reconstruction”

3. D. Rastorguev (MIPT) 2021 (supervisor P.I.Smolyanskiy ) “Simulation of a GaAs-Timepix3 detector response on gamma radiation”.

**Talks**:

1. "Stack of Si, GaAs:Cr and CdTe based detectors for spectral micro-CT". Oral presentation. Petr Smolyansky. 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference 10-17 November 2018 International Convention Center, Sidney, Australia.
2. "Use of semiconductor pixel detectors with GaAs:Cr sensorand Timepix readout for control of neutron flux". E. Cherepanova. Oral presentation. The 61th Moscow Institute of Physics and Technology Scientific Conference, Dolgoprudnyy, Russia Nov. 19-25, 2018.
3. "Stack of Si, GaAs:Cr and CdTe based detectors for spectral micro-CT". Danila Kozhrevnikov. Oral presentation. MARS spectral CT workshop in Christchurch, New Zealand on the 8 November 2018. University of Otago.
4. «Visualization of distributed medical gamma sources using Timepix detector», Oral presentation. V. Rozhkov, 20th Anniversary Symposium on Medipix and Timepix. 18.09.2019, CERN.
5. “High resolution SPECT/CT method using a Medipi detector”. Oral presentation. V. Rozhkov, Reporting conference on the results of joint projects RFBA-CITMA, Habana, Cuba 05.02.2020
6. “ATLAS-GaAsPix Network for radiation background measurements”. E. Cherepanova. Talk at ATLAS Background Simulation Working group meeting 15.09.2020. <https://indico.cern.ch/event/954720/>
7. “Measurement of the Radiation Environment of the ATLAS Cavern in 2017-2018 with ATLAS-GaAsPix Detector” E. Cherepanova. Talk at Medipix Collaboration meeting 23.09.2020
<https://indico.cern.ch/event/952738/>
8. «A portable Timepix based camera with a coded aperture for gamma ray imaging» Oral presentation. V. Rozhkov, IX summer conference for young scientists and specialists, Russia, Alushta 27.09.2020
9. «Pixel detectors with GaAs sensor and Timepix chip for radiation background measurements in the ATLAS cavern» Oral presentation. E.Cherepanova, IX summer conference for young scientists and specialists, Russia, Alushta 27.09.2020
10. “Study of charge sharing effect in a GaAs:Cr-based Timepix3 detector.” D. Rastorguev. 5th International Conference on Particle Physics and Astrophysics (ICPPA-2020). 07.10.2020.
11. «TimePix detector with a coded aperture for small animal SPECT», Oral presentation. V. Rozhkov,LXX International conference "NUCLEUS – 2020" . St. Petersburg, Russia. 14.10.2020
12. «Visualization of radiotracers for SPECT imaging using a Timepix detector with a coded aperture», Oral presentation. V. Rozhkov, V International Symposium on «Physics, Engineering and Technologies for Biomedicine» Moscow, Russia, 10.11.2020
13. “MicroSPECT with system based on Timepix detector and coded aperture” Oral presentation. V. Rozhkov. The School-Conference for Young Scientists "Ilyinsky Readings 2020" Moscow, 24.12.2020.

**PART B: Plans and requests**

5.   Plans

|  |  |  |  |
| --- | --- | --- | --- |
|  | 1-st year | 2-nd year | 3-d year |
| Radiation resistant semiconductors  |  |  |  |  |  |  |  |  |  |  |  |  |
| New semiconductor material samples  |  |  |  |  |  |  |  |  |  |  |  |  |
|  Test cycle at reactor and Linac-200 |  |  |  |  |  |  |  |  |  |  |  |  |
|  Data analyses  |  |  |  |  |  |  |  |  |  |  |  |  |
| FCAL R&D |  |  |  |  |  |  |  |  |  |  |  |  |
|  RO system design and test |  |  |  |  |  |  |  |  |  |  |  |  |
|  Sector module R&D and design |  |  |  |  |  |  |  |  |  |  |  |  |
|  Beam test |  |  |  |  |  |  |  |  |  |  |  |  |
| Timepix4 R&D |  |  |  |  |  |  |  |  |  |  |  |  |
|  FPGA-based electronics and software |  |  |  |  |  |  |  |  |  |  |  |  |
|  Detector R&D  |  |  |  |  |  |  |  |  |  |  |  |  |
|  Detector sample construction & test |  |  |  |  |  |  |  |  |  |  |  |  |
| Full scale “head” CT prototype |  |  |  |  |  |  |  |  |  |  |  |  |
|  R&D and design |  |  |  |  |  |  |  |  |  |  |  |  |
|  Construction & test |  |  |  |  |  |  |  |  |  |  |  |  |
| Research with MIPT Bio on the MARS CT |  |  |  |  |  |  |  |  |  |  |  |  |

-Describe the plans of the JINR group within the project, in physics analysis, data taking, software development. detector R&D, detector operation and maintenance, upgrade activities… for the period of time of the requested extension.

6.   Group size, composition and budget

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| № | Name | Laboratory | Status | FTE |
| 1 | Shelkov G. | LNP | PhD Project leader | 0,8 |
| 2 | Rozhkov V. | LNP | Deputy project leader | 1,0 |
| 3 | Smolyansky P.I. | LNP | PhD Detectors group leader | 0,2 |
| 4 | Zhemchugov А.S. | LNP | PhD FCAL group leader  | 0,1 |
| 5 | Gostkin M. I. | LNP | PhD Deputy FCAL group leader | 0,6 |
| 6 | Rastorguev D.D. | LNP | Master Student. Detector R&D. Simulation. | 1,0 |
| 7 | Lapkin A.V. | LNP | Engineer. FPGA and electronic designer | 1,0 |
| 8 | Cherepanova E.A. | LNP | Junior researcher. MARS, GaAsPix, data analysis. | 0,8 |
| 9 | Abdelshakur S | LNP | PhD. Radiation hardness tests. Beam tests at LNR. | 0,8 |
| 10 | Leiva F.A. | LNP | PhD. Computer modeling  | 0,8 |
| 11 | Kozhevnikov D.A. | LNP | PhD. Tomography reconstruction | 0,2 |
| 12 | Kuznetsov N.K. | LNP | Mechanical Engineer. | 0,5 |
| 13 | Kruchonak V.G. | LNP | Electronic Engineer. Radiation hardness tests. | 0,6 |
| 14 | Gongadze A. | LNP | Detector R&D | 0,1 |
| 15 | Porokhovoy S.I. | LNP | PhD. Researcher. | 0,1 |
| 16 | Rudenko T.O. | LNP | Electronic Engineer. | 0,2 |
| 17 | Mitrofanov S.V. | FLNR | PhD. Researcher. Tests at FLNR beams. | 0,2 |
| 18 | Teterev Yu.G. | FLNR | PhD. Researcher. Tests at FLNR beams. | 0,2 |
| 19 | Isatov A.T. | FLNR | Researcher. Tests at FLNR beams. | 0,2 |
| 20 | Kopach Yu.N. | FLNP | PhD. Researcher. Tests at IBR2 beams. | 0,1 |
| 21 | Telezhnikov S.Yu. | FLNP | PhD. Researcher. IBR2 tests results analys | 0,1 |
| 22 | Akhmedov A.A. | FLNP | Researcher. Tests at IBR2 beams. | 0,1 |
|  |  |  | **FTE** | **9,7** |

# Medipix 4 Collaboration – 16 Participant Institutes ~ 90 members.

# FCAL Collaboration – 15 Participant Institutes ~ 70 members.

- List the JINR personnel involved in the project, including name, status (e.g. PI, researcher, post-doc, student, engineer, technician…) and FTE. Mention the total number of people in the collaboration.

# Cost estimates for the Project

For the program implementation in 2021-2023 the next JINR resources are needed:

1. 180 K$ - the TPX4 chips purchase, creation of detector prototypes, conclusion of contracts to carry out R&D works.
2. 110 K$ - creation of working prototype of the “head” scanner, computing infrastructure.
3. 200 K$ - Microfocus X-ray tube, microfocus scanner prototype.
4. 40 K$ - Measuring equipment.
5. 60 K$ - Semiconductor sensors.
6. 90 K$ - Participation in test beams, meetings and conferences.

Total sum 680 k$

- Present the JINR group budget for the period of time of the requested extension, specifying the main budget items (equipment, computing, salaries, common funds, travel…)

-Indicate the use or needs of JINR computing resources for the group and for the project if any.