Форма № 24

НОВЫЕ ПОЛУПРОВОДНИКОВЫЕ ДЕТЕКТОРЫ ДЛЯ ФУНДАМЕНТАЛЬНЫХ И ПРИКЛАДНЫХ ИССЛЕДОВАНИЙ

Продление проекта на период 2021-2023 гг.

NOVEL SEMICONDUCTOR DETECTORS FOR FUNDAMENTAL AND APPLIED RESEARCH

PROJECT EXTENSION FOR THE PERIOD 2021-2023

Шифр темы: 04-2-1126-2015/2023

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РУКОВОДИТЕЛЬ ПРОЕКТА - Г.А.Шелков.

ЗАМЕСТИТЕЛЬ РУКОВОДИТЕЛЯ ПРОЕКТА - В.А.Рожков

ДАТА ПРЕДСТАВЛЕНИЯ ПРОЕКТА В НОО _________

ДАТА НТС ЛАБОРАТОРИИ 21/04/2020. НОМЕР ДОКУМЕНТА _________

ДАТА НАЧАЛА ПРОЕКТА - 2015 год

Дата представления физического обоснования на семинаре ЛЯП: 14/04/2020

Форма № 25

ЛИСТ СОГЛАСОВАНИЙ ПРОЕКТА

Новые полупроводниковые детекторы для фундаментальных и прикладных исследований

Продление проекта на период 2021-2023 гг.

Novel Semiconductor Detectors for Fundamental and Applied Research

Project extension for the period 2021-2023

Г.А.Шелков

Шифр темы: 04-2-1126-2015/2023

УТВЕРЖДЕН ДИРЕКТОРОМ ОИЯИ	ПОДПИСЬ	ДАТА
СОГЛАСОВАНО		
ВИЦЕ-ДИРЕКТОР ОИЯИ	ПОДПИСЬ	ДАТА
ГЛАВНЫЙ УЧЕНЫЙ СЕКРЕТАРЬ	ПОДПИСЬ	ДАТА
ГЛАВНЫЙ ИНЖЕНЕР	ПОДПИСЬ	ДАТА
НАЧАЛЬНИК НОО	ПОДПИСЬ	ДАТА
ДИРЕКТОР ЛАБОРАТОРИИ	ПОДПИСЬ	ДАТА
ГЛАВНЫЙ ИНЖЕНЕР ЛАБОРАТОРИИ	ПОДПИСЬ	ДАТА
РУКОВОДИТЕЛЬ ПРОЕКТА	ПОДПИСЬ	ДАТА
ЗАМ. РУКОВОДИТЕЛЯ ПРОЕКТА	ПОДПИСЬ	ДАТА
ОДОБРЕН		
ПКК ПО НАПРАВЛЕНИЮ	ПОДПИСЬ	ДАТА

Форма № 26

Предлагаемый план-график и необходимые ресурсы для осуществления проекта: Новые полупроводниковые детекторы для фундаментальных и прикладных исследований

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<tr><td rowspan="4">Основные узлы и оборудование</td><td colspan="2">Микросхемы TPX4, создание прототипов детекторов, НИР и НИОКР</td><td>180</td><td>60</td><td>60</td><td>60</td></tr>
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<tr><td colspan="2">Измерительное оборудование</td><td>40</td><td>10</td><td>20</td><td>10</td></tr>
<tr><td>Мате-риалы</td><td colspan="2">Сенсоры из полупроводников</td><td>60</td><td>20</td><td>20</td><td>20</td></tr>
<tr><td rowspan="2">Необходимые ресурсы</td><td>Нормо-час</td><td>Ресурсы ОП ЛЯП</td><td>10</td><td>700</td><td>700</td><td>700</td></tr>
<tr><td>Тыс. $</td><td>Участие в test-beams, рабочих совещаниях и конференциях</td><td>90</td><td>30</td><td>30</td><td>30</td></tr>
<tr><td rowspan="2">Источники финансирования</td><td>Бюджетные средства</td><td>Затраты из бюджета, в том числе инвалютные средства</td><td>680</td><td>280</td><td>210</td><td>190</td></tr>
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РУКОВОДИТЕЛЬ ПРОЕКТА Г.А.Шелков

Novel Semiconductor Detectors for Fundamental and Applied Research

Project extension for the period 2021-2023

G.A.Shelkov

Index: 04-2-1126-2015/2023

JINR DLNP: A.Gongadze, V.Gostkin, A., V.Kruchonok, D.Kozhebnikov, N.Kuznetsov, A.Lapkin, A.Leyva, D.Rastorguev, V.Rozhkov, N.Rudenko, P.Smolyanskiy, E.Cherepanova, S.Shakur, G.Shelkov, A.Zhemchugov

JINR FLNR: A.Isatov, S.Mitrofanov, Yu.Teterev.

JINR FLNP: A.AkhmedovYu.Kopach, S.Telegnikov.

Project leader - G.Shelkov.

Deputy project leader - V.Rozhkov

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Brief annotation of the project

The success of a scientific experiment depends primarily on the equipment’s use. Progress in understanding the physical picture of the world that has occurred over the past century has been largely provided by technological advances that have allowed the creation of more advanced experimental facilities and improved methods of processing the obtained data. Scientific and methodological studies on the creation of new types of detectors are a prerequisite for the further development of experimental physics of the atomic nucleus and elementary particles, as well as possible applied projects.

Semiconductor devices in our time are being used increasingly when dealing with both fundamental problems and in the production of the equipment used in technology and medicine.

The project under consideration aims at developing this field. During the project realization since 2015, a modern base has been created at LNP JINR to study the parameters of semiconductor materials and detectors based on them. For 2017-2020, a number of interesting results were obtained: a) in the study of radiation hardness of semiconductor sensor materials; b) in the development and research of compact electromagnetic calorimeters for future colliders as part of the FCAL collaboration;(пункты а и b не содержат именно полученного результата, поэтому плохо согласуются с остальными пунктами. В русской версии так же) c) a system for detecting and monitoring the radiation situation in the ATLAS cavern in CERN has been created and it is successfully operating; d) a stable electron beam with energy up to 200 MeV was obtained at the LINAC-200 electronic accelerator, which is being put into operation; e) development is being completed and the first samples of the unique Timepix4 chip were obtained in cooperation international Medipix collaboration. This entitles JINR authors to conduct their own development of modern detectors and systems that detect X-ray radiation(в русской версии опечатка). The results are documented in 7 publications, two patents, two Ph.D. theses of young employees and two master's degrees.

The main tasks of the project in 2021-2023:

1. Continuation of researches on the creation and testing of new radiation-resistant semiconductor materials on JINR particle beams together with a group of TSU.

2. Participation in the creation and testing of a full-scale prototype of the FCAL module including readout electronics.

3. Development and setting up of existing prototypes of pixel detectors based on the Timepix4 chip.

4. Completion of work on the creation of a prototype “head” CT and energy-sensitive microtomograph with spatial resolution better than 10 microns.

5. Together with specialists from the Faculty of Biological and Medical Physics of the Moscow Institute of Physics and Technology, the establishment of a group to carry out joint biomedical research using the JINR MARS microtomograph.

Introduction

The goal of the project is a comprehensive study of the properties of semiconductors from the point of view of their use in particle and gamma radiation detection devices and the creation of new versions of semiconductor detectors and devices that use them both for the needs of particle physics and for applied purposes.

The development of semiconductor detectors is largely determined by technological advances in industry. For the needs of high-energy physics, practically there is no semiconductor crystals growing directly in laboratories as well as reading microcircuits, etc. are not produced, since all this equipment is much simpler, cheaper, and better manufactured at electronic enterprises. In most centers of high-energy physics, the main emphasis has been shifted from production itself to the formulation of requirements for detectors, the design and sometimes assembly of prototypes or small-scale samples from manufactured elements. The study of new detectors characteristics is a central issue in the development cycle of new detectors. That provides feedback to the manufacturer of sensitive elements.

Particle physics, in its development, is steadily moving in the direction of researches requiring more and more intense particle beams. Therefore, the first two tasks of the project are very relevant: the continuation of the search in the creation of new radiation-resistant modifications of semiconductors of materials together with specialists and the creation of detectors based on these materials (work as part of the FCAL scientific and methodological collaboration).

Currently, there is a rapid development and use of digital diagnostic systems. Digital systems are increasingly replacing film and other image carriers. The success in creating digital diagnostic systems is largely determined by the progress in the development of solid-state coordinate detectors (sensors) with direct conversion of particle energy into an electrical signal, which are suitable for recording x-rays and gamma radiation.

X-ray computed tomography is now used in many fields of material science, life science, earth science, historical heritage researches and others. For this reason, great efforts are being made to develop methods and equipment for such studies.

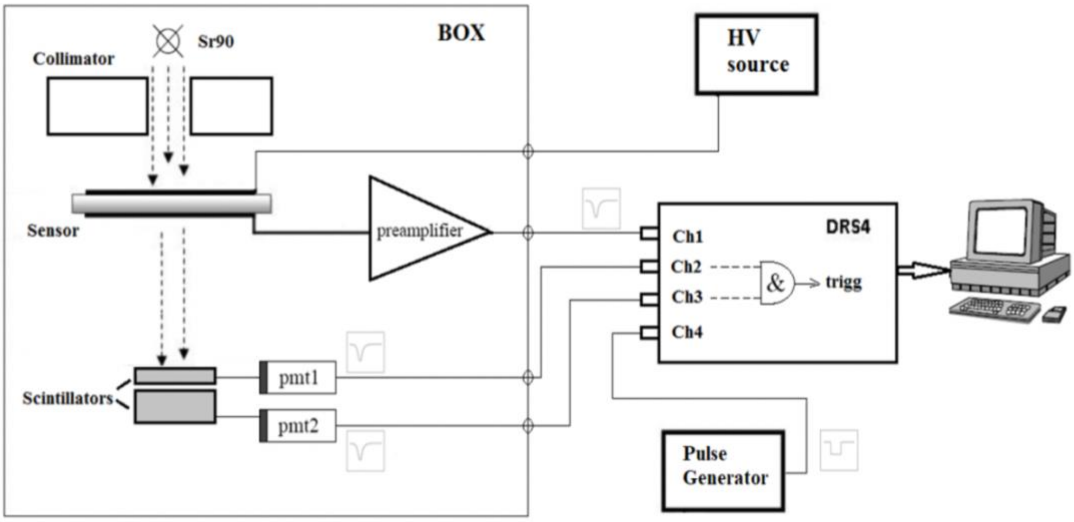
The next ambitious goal of the project is the transition from the creation of small methodological stands to the fully functioning laboratory prototypes of full-scale computer energy-sensitive tomographs using modern pixel chips of the Medipix/Timepix series. As a rule, x-ray tomography reveals the shape and boundaries of the components composing an object and allows one to measure the absorption coefficient of the x-ray radiation of these components. However, to fully characterize the object, it is necessary to identify the substances that make it up. In most cases, sources of a polychromatic X-ray detector are used paired with an integrating detector that records the intensity of the transmitted radiation. Such detectors have a number of disadvantages: information about the emission spectrum is lost, noise is integrated with the signal, the contribution of a photon to the signal depends on its energy. Hybrid pixel detectors with single-photon counting and energy discrimination, such as Medipix-based detectors, do not have these drawbacks. They make it possible to carry out multi-energy tomography, which, in turn, allows us to determine not only the spatial distribution of x-ray density in the studied sample, but also spatial distribution of some chemical elements. The authors of the project obtained a number of interesting results recorded in a series of publications, two patents and two candidate dissertations and set as their goal the further development of these studies. It is extremely important that the authors became full-fledged participants in the development and creation of the Timepix4 chip, that is unique in the set of parameters, as part of the international collaboration Medipix. This entitles the authors to conduct their own development of modern detectors and X-ray detection systems. Based on these developments, it is planned to create working prototypes of multi-energy “head” tomograph and tomograph with high spatial resolution (several microns).

Project results and future plans

During project execution there were several stands created in LNP JINR to study semiconductors and semiconductor detector properties as well as devices that use such detectors.

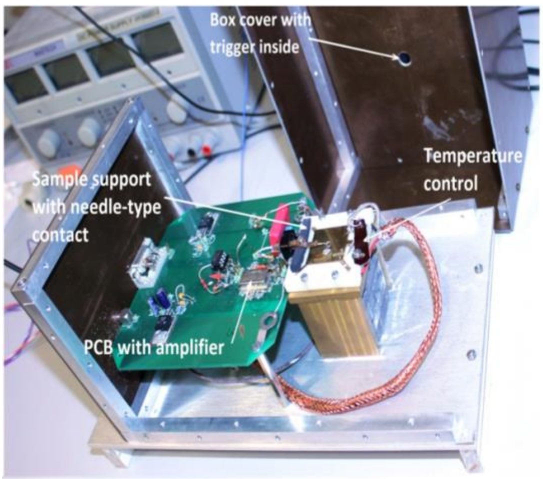
Station for measuring charge collection efficiency (CCE)

Station for measuring charge collection efficiency (CCE) in sensor material of a detector.

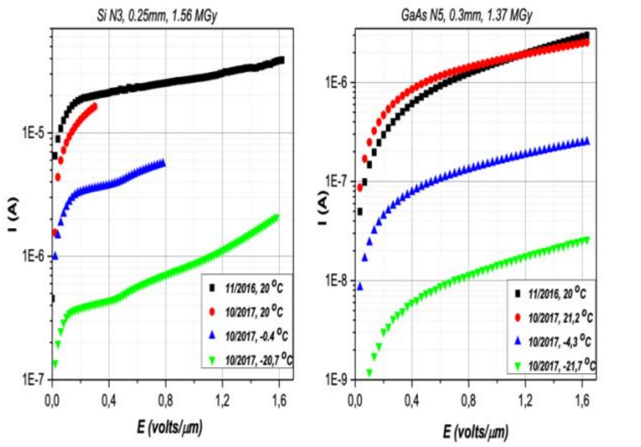


Block diagram of CCE measurement setup.

This station allows measuring CCE and volt-ampere (I-V) characteristics of semiconductor in temperature range of ± 50$_0$ C



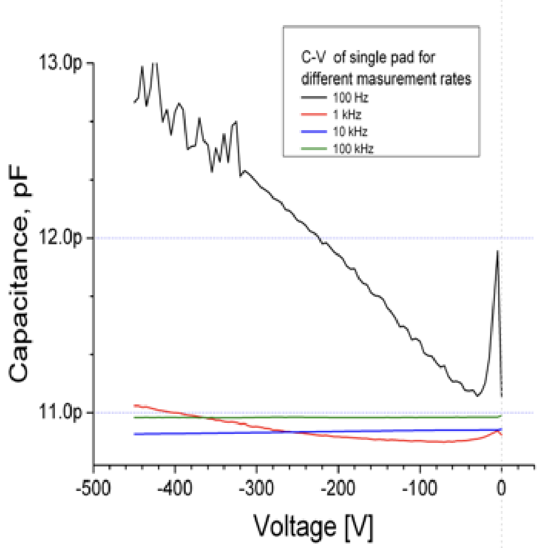
A photography of the setup for CCE and I-V measurements.



I-V characteristics measured at different sensors temperatures: Si _N3 (type1) after irradiation dose of 1.56 MGy (left) and GaAs:Cr N5 after irradiation dose of 1.37 MGy (right).

Probe station

The probe station is equipped with multifunctional meter – characteristic tracer Keysight B1505A, which allows to measure precisely volt-ampere and volt-capacitance semiconductors' characteristics for voltage up to 3 kV.

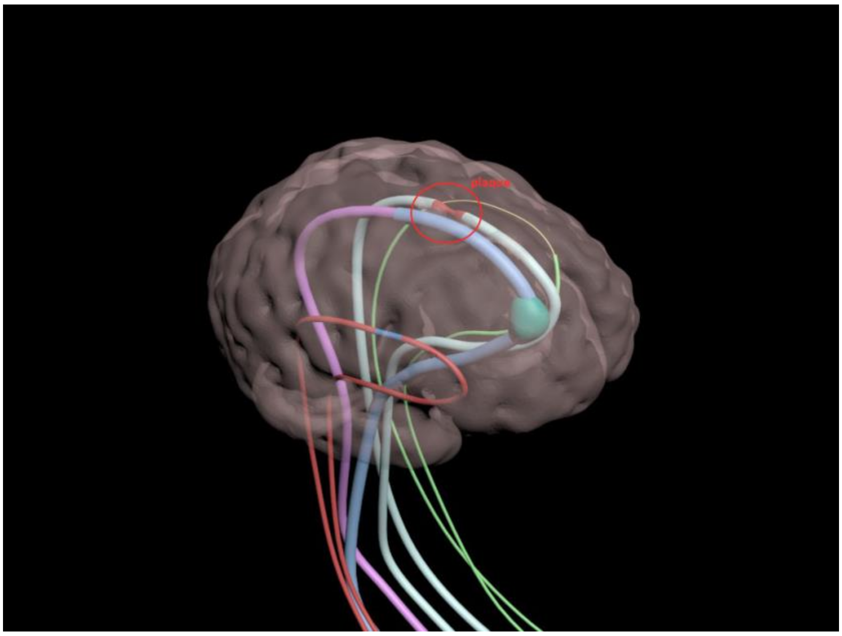


Stand for X-ray tubes operation

For multi-energy tomographic scanning operations of different objects with high geometric magnification a large safety cabinet was acquired. This has all basic elements for computer tomography with rotating sample.

Motorized translators and their controllers of STANDA company were used. Programming opportunity of the devices allows setting up an apparatis which is suitable for a specific research sample at minimal cost.

In addition, a human head phantom with was ordered to compare objects that are closed to real ones. The phantom has five vessels with different diameters:
Red - 2mm, Blue – 5mm, Purple - 4mm, Green - 1.5 mm, Gold color - 0.5 mm



The GaAsPix-Network for background measurements in the ATLAS cavern

The system was built together with Medipix collaboration. It has worked stably since 2017. It was shown that: a) the distribution of the relative level of radiation load is stable over time. b) By comparing the ratio of count rates in detectors of different thicknesses, it was possible to estimate the ratio of neutral and charged components at different points in the cavern. c) The distribution of the integral neutron flux at the locations of the detectors can be estimated from the level of the background activity induced by neutrons in the GaAs material.

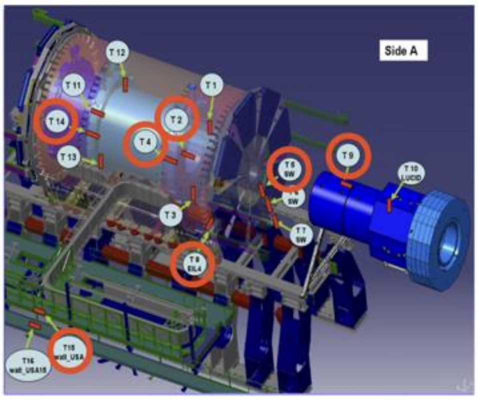


Table 1. The positions of ATLAS-GaAsPix devices in the ATLAS detector cavern.

Detector ID	Sensor thickness, μm	X, m	Y, m	Z, m
GPX1	500	-5.98	0	7.22
GPX2	1000	-5.80	0	7.22
GPX3	1000	-16.69	-0.06	5.07
GPX4	500	0	-0.28	-6.74
GPX5	500	0	1.57	-12.86
GPX6	1000/500	-1.12	-0.21	3.53
GPX7	1000/500	0.65	-1.45	7.8
GPX8	1000/1000	0	1.57	15.09
GPX9	1000/500	-3.46	-0.92	2.84
GPX10	1000/500	-3.46	-0.92	-2.84

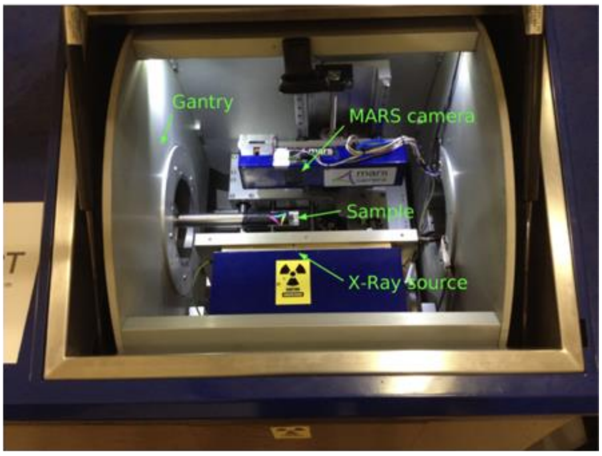
Table 2. Detector (GPXi) count rate normalized to count rate of GPX7 detector layer with corresponding thickness.

Detector #	$N_{tot}(GPXi)/N_{tot}(GPX7)$
1	0.032 ± 0.001
2	0.031 ± 0.002
3	0.029 ± 0.002
7-1	1
7-2	1
8-1	0.08 ± 0.01
8-2	0.08 ± 0.01
9-1	0.499 ± 0.007
9-2	0.522 ± 0.008
10-1	0.57 ± 0.01
10-2	0.584 ± 0.006

Table 3. The ratio between charge and neutral components of background from comparison of count rates relation at thin (500μm) to thick (1000μm) GaAs detectors located in the same point in ATLAS cavern. The ratio between GPX8-1 and GPX8-2 sensors with equal thickness (1000μm) is taken for self-assessment.

Detector #	$N_{tot}(1000\mu m)/N_{tot}(500\mu m)$	$N_{Charged}$	$N_{Neutral}$
1 2	1.62 ± 0.04	0.26 ± 0.03	0.74 ± 0.03
7-1 7-2	1.7 ± 0.1	0.17 ± 0.09	0.83 ± 0.09
9-1 9-2	1.7 ± 0.1	0.18 ± 0.08	0.82 ± 0.08
10-1 10-2	1.676 ± 0.008	0.194 ± 0.006	0.806 ± 0.006
8-1 *8-2*	*0.96 ± 0.08*	-	-

Studies using MARS CT Scanner

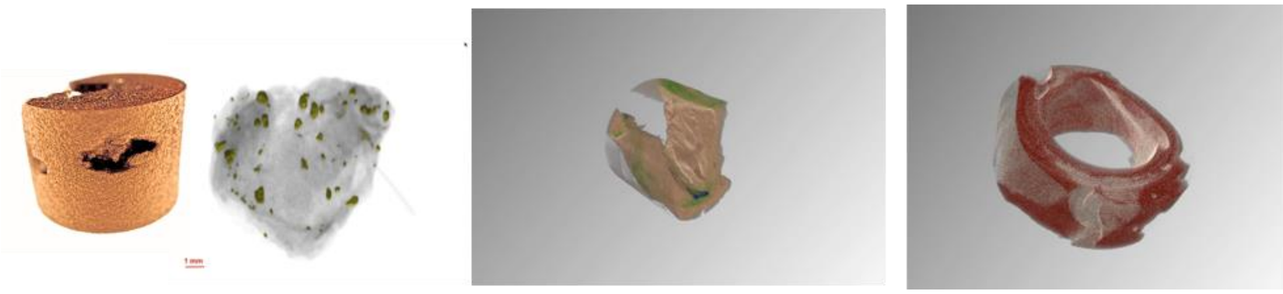


The MARS Scanner was upgraded significantly during 2019: control PC was replaced, new reconstruction server was installed, software was updated to version 19.04. The scanner was equipped with MARS v5 Medipix3RX CZT 2 mm 110 um camera. Camera's field of view is 14 mm x 42 mm (was 14 mm x 14 mm).

After the camera repair (replacing FPGA) the whole cycle of detector's setting was conducted: DAC scans, bias voltage scans, equilization, energy calibration.

The MARS Vision software together with 3D monitor Z-Space was purchased. This software with MARS MD tool make it possible to visualize the multi-energy reconstruction results in 3D.

In collaboration with medics from St-Petersburg and geophysics several searches were carried out. The results were presented at international conferences and in published in articles.



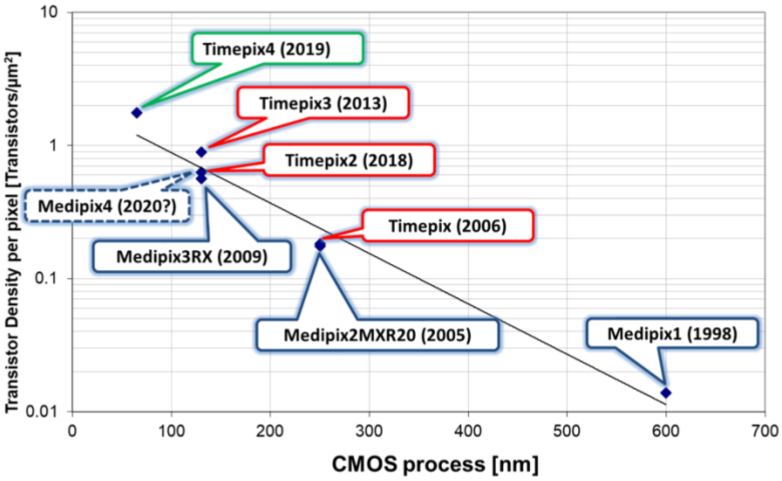
Examples of scans made with MARS.
From left to right: 1 – Oil core sample; 2 – ore with magnesite disseminations; 3 - Часть part of a human artery with atherosclerotic lesions; 4 – part of a pig's healthy artery.

Currently JINR and MIPT have an agreement about creation of a group for collaboration work in MIPT Molecular and Biological Physics Department to increase the efficiency of usage the equipment available for both.

Joint work with Medipix Collaboration for the new generation Timepix-4 chip design.

As a rule, X-ray tomography captures the shape and boundaries of the components that make up an object and allows one to measure the absorption coefficient of the x-ray radiation of these components. However, to fully characterize the object, it is necessary to identify the substances. In most cases, sources of a polychromatic X-ray detector are used paired with an integrating detector that records the intensity of the transmitted radiation. Such detectors have a number of disadvantages: information about the emission spectrum is lost, noise is integrated with the signal, the contribution of the photon to the signal depends on its energy.

Medipix4 Collaboration (from 2016)



CEA, Paris, France
CERN, Geneva, Switzerland,
DESY-Hamburg, Germany
Diamond Light Source, Oxfordshire, England, UK
IEAP, Czech Technical University, Prague, Czech Republic
JINR, Dubna, Russian Federation
NIKHEF, Amsterdam, The Netherlands
University of California, Berkeley, USA
University of Houston, USA
University of Maastricht, The Netherlands
University of Canterbury, New Zealand
University of Oxford, England, UK
University of Geneva, Switzerland
- IFAE, Barcelona, Spain
- University of Glasgow, UK

Timepix4: A 4-side tillable large single threshold particle tracking detector chip with improved energy and time resolution and with high-rate imaging capabilities

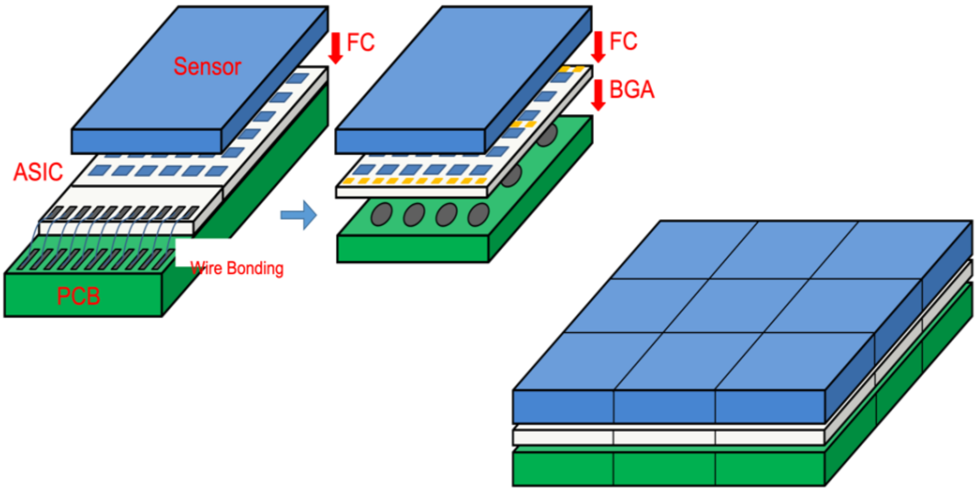
15 members

The hybrid pixel detectors with single photons counting and energy discrimination, what are Medipix chips-based detectors, do not have such deficiencies. These detectors make it possible to carry out multi-energy computed tomography, which allows to determine not only spatial distribution of X-ray density in the sample, but also the spatial distribution of some chemical elements.

Timepix3 → Timepix4

			Timepix3 (2013)	Timepix4 (2019)
Technology			130nm – 8 metal	65nm – 10 metal
Pixel Size			55 x 55 µm	55 x 55 µm
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448 **3.5x**
Sensitive area			1.98 cm²	**6.94 cm²**
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA	
		Event Packet	48-bit	64-bit **33%**
		Max rate	0.43×10^{6} hits/mm²/s	**3.58×10^{6} hits/mm²/s** **8x**
		Max Pix rate	1.3 KHz/pixel	**10.8 KHz/pixel**
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit)
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr)
		Max count rate	~0.82×10^{9} hits/mm²/s	~5×10^{9} hits/mm²/s **5x**
TOT energy resolution			< 2KeV	**< 1Kev** **2x**
TOA binning resolution			1.56ns	**195ps** **8x**
TOA dynamic range			409.6 µs (14-bits @ 40MHz)	**1.6384 ms** (16-bits @ 40MHz) **4x**
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	**≤163.84 Gbps** (16x @10.24 Gbps) **32x**
Target global minimum threshold			<500 e-	<500 e-

4-side buttable pixel arrangement



- Target to build **large area detectors** by combining smaller modules
- The through-silicon vias (TSVs) is the key technology for this paradigm shift

During the period of collaboration with Medipix group the authors of the project have got a series of interesting results which are published in seven papers, two patents and two candidate dissertations. The authors aim to the further development of these searches. It is extremely important that the authors have become full-fledged participants in the development and creation of a unique Timepix4 chip in terms of a set of parameters. This gives the right to the authors to conduct their own development of modern detectors and X-ray detection systems.

Publications in 2018 – 2020

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

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Patents

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ПОЛУПРОВОДНИКОВЫЙ ПИКСЕЛЬНЫЙ ДЕТЕКТОР ЗАРЯЖЕННЫХ СИЛЬНО ИОНИЗИРУЮЩИХ ЧАСТИЦ (МНОГОЗАРЯДОВЫХ ИОНОВ),
Патент (RU) 2659717, от 03.06.2018, ОИЯИ.

2. Жемчугов А.С., Кожевников Д.А., Котов С.А., Кручонок В.Г., Лейва Ф.А., Смолянский П.И., Шелков Г.А.
ПЛАНАРНЫЙ ПОЛУПРОВОДНИКОВЫЙ ДЕТЕКТОР,
Патент (RU) 2672039, от 08.11.2018, ОИЯИ.

PhD dissertations

1. Smolyanskiy, P.I. (2017). *Investigation of GaAs pixel detectors based on Timepix chip* (Doctoral dissertation, name of University, city, Russia).
2. Kozhevnikov, D.A. (2019) *Development of the multi-energy CT method using detectors based on Medipix chip family* (Doctoral dissertation, name of University, city, Russia).

Master's dissertations

1. Cherepanova, E.A. (2019). *Analysis of radiation background structure in the ATLAS cavern using the ATLAS-GaAsPix Network data* (Master's thesis, Moscow Institute of Physics and Technologies, Dolgoprudnyy, Russia).
2. Andriyashen, V. (2019) *Development of the iterative reconstruction method for multi-energy CT* (Master's thesis, Moscow Institute of Physics and Technologies, Dolgoprudnyy, Russia).

The Project implementation plan for 2021-2023

1. Creation of radiation-hardened semiconductor materials for particle detectors.
    a. Continue collaboration work with Tomsk State University including search for radiation-hardened GaAs modifications and their radiation hardness measurement at neutron and electron beams in JINR.

2. Creation of a full-scale module prototype of compact radiation-hardened electromagnetic calorimeter together with the FCAL collaboration.

3. Development of pixel detectors and their usage.
    a. Development of detectors and electronics based on FPGA and software for Timepix4.
    b. Prototype and software development for the “head” tomograph and the scanner with high resolution (~ 10μm).
    c. Collaborations with:
        i. MIPT biophysicist using the MARS scanner;
        ii. LNP genetics using the high-resolution scanner.

	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												
High space resolution CT												
R&D and design												
Construction & test												
Research with MIPT Bio on the MARS CT												

List of the Project participants

Among the actual members of the LNP Project four PhD of physical and mathematical sciences with large experience of particle detectors creation (including pixel semiconductor detectors). Some success has already been achieved in development software for semiconductor detectors' operational work simulation, also in work with X-ray scanners, including their calibration and software development. There are several young staff members as well.

#	Name	Laboratory	Tasks	FTE
1	Shelkov, G.A.	LNP	Project leader	0,8
2	Akhmedov, A.A.	FLNP	Tests at IBR-2 beams	0,1
3	Cherepanova, E.A.	LNP	MARS, GaAsPix, data analysis	0,8
4	Gongadze, A.	LNP	Detectors study	0,1
5	Gostkin, M.I.	LNP	FCAL group leader	0,6
6	Isatov, A.T.	LNR	Tests at LNP beams	0,2
7	Kruchonok, V.G.	LNP	Radiation tests. Electronics	0,6
8	Kozhevnikov, D.A.	LNP	КТ, ПО, MARS	0,2
9	Kopach, Yu.N.	FLNP	Tests at IBR-2 beams	0,1
10	Kuznetsov, N.K.	LNP	Engineer	0,5
11	Lapkin, A.V.	LNP	FPGA electronics for Tomepix4	1
12	Leyva, A.	LNP	Computer simulation	0,8
13	Mitrofanov, S.V.	LNR	Tests at LNP beams	0,2
14	Rastorguev, D.D.	LNP	Detectors, simulation	1
15	Rozhkov, V.A.	LNP	Deputy Project Leader	1
16	Rudenko, T.O.	LNP	Electronic engineer	0,2
17	Smolyanskiy, P.I.	LNP	Detectors group leader	0,8
18	Shakur, A.	LNP	Radiation tests. Measurements work in LNR	0,8
19	Telizhnikov, S.Yu.	FLNP	Tests at IBR-2 beams	0,1
20	Teterev, Yu.G.	LNR	Tests at LNP beams	0,2
21	Zhemchugov, A.S.	LNP	Detectors study	0,1
			Total LNP	9,3
			Total	10,2

Short SWOT analysis

Strengths. The authors have considerable experience and best practices that allow complete tasks of the Project. There are accelerators and a reactor which could fulfil necessary tests in JINR. Also, JINR has required infrastructure and significant part of necessary equipment. The authors have long-standing and productive ties with colleagues of closely related subjects in Russia and abroad as well.

Weaknesses. The need to involve high level IT experts for conducting R&D tasks.

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: 680 K$

Form № 29

Cost estimates for the Project: Novel Semiconductor Detectors for Fundamental and Applied Research

No	Expenditures	Total amount	2021	2022	2023
1.	Accelerator, reactor	-	-	-	-
2.	Computers	-	-	-	-
3.	Computer network тыс. долл.	10	3	3	4
4.	Design office				
5.	ООЭП ЛЯП (нормочасы)	2100	700	700	700
6.	Materials (k$.)	90	30	30	30
7.	Equipment (k$)	380	150	120	110
9.	R&D (k$.)	110	40	40	30
10.	Travel expenses (k$) a) countries of the non-ruble zone б) countries of the ruble zone в) under the protocols	 81 9	 27 3	 27 3	 27 3
	Total direct costs:	680	253	223	204

PROJECT LEADER

HEAD OF THE LABORATORY

LEAD ENGINEER-ECONOMIST OF THE LABORATORY