Project 04-2-1126-2015/2023

“Novel Semiconductor Detectors for Fundamental and Applied Research”

PAC CM 15 June 2023

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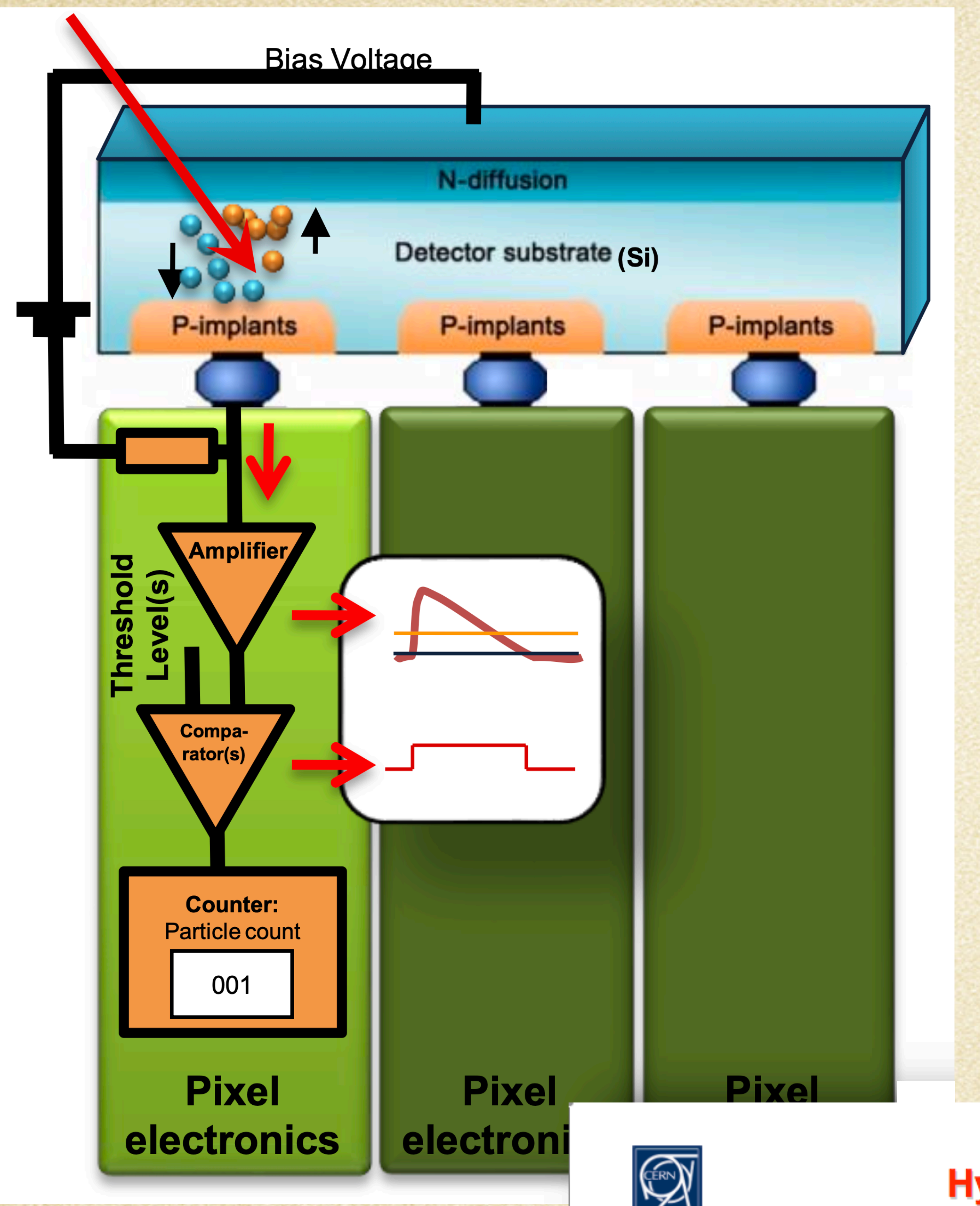
In 2015, topic 1126 was opened.

The main goal of the project is the R&D of a new class of physical devices - hybrid pixel semiconductor detectors operating in the single-photon counting mode.

These devices first appeared at the turn of the 2000s and differ from other pixel detectors by the ability to process and digitize the signal directly in the pixel.



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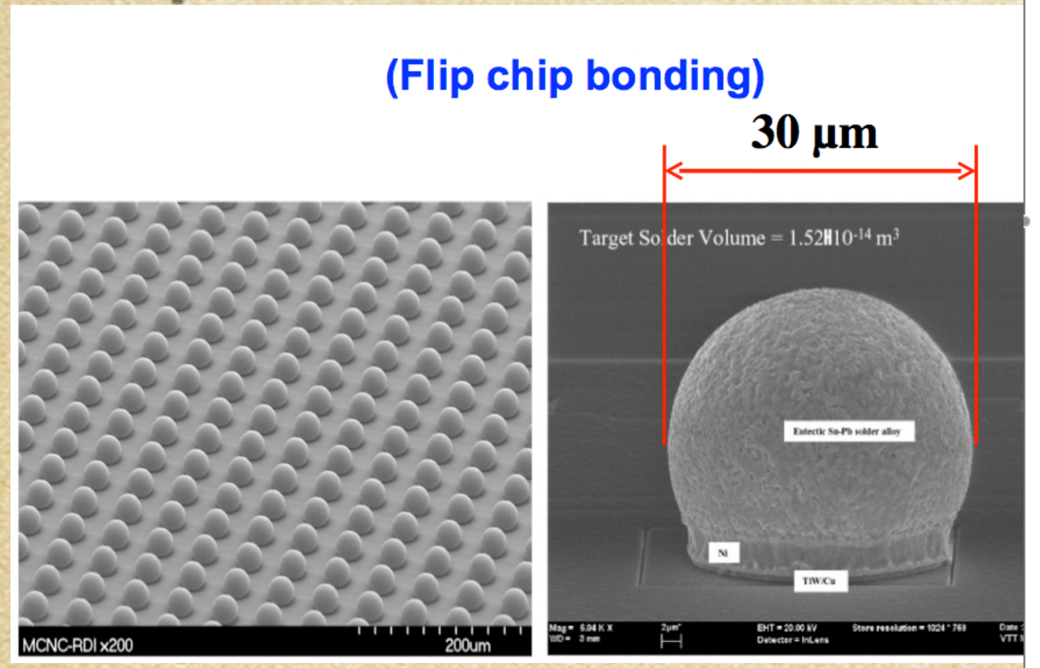

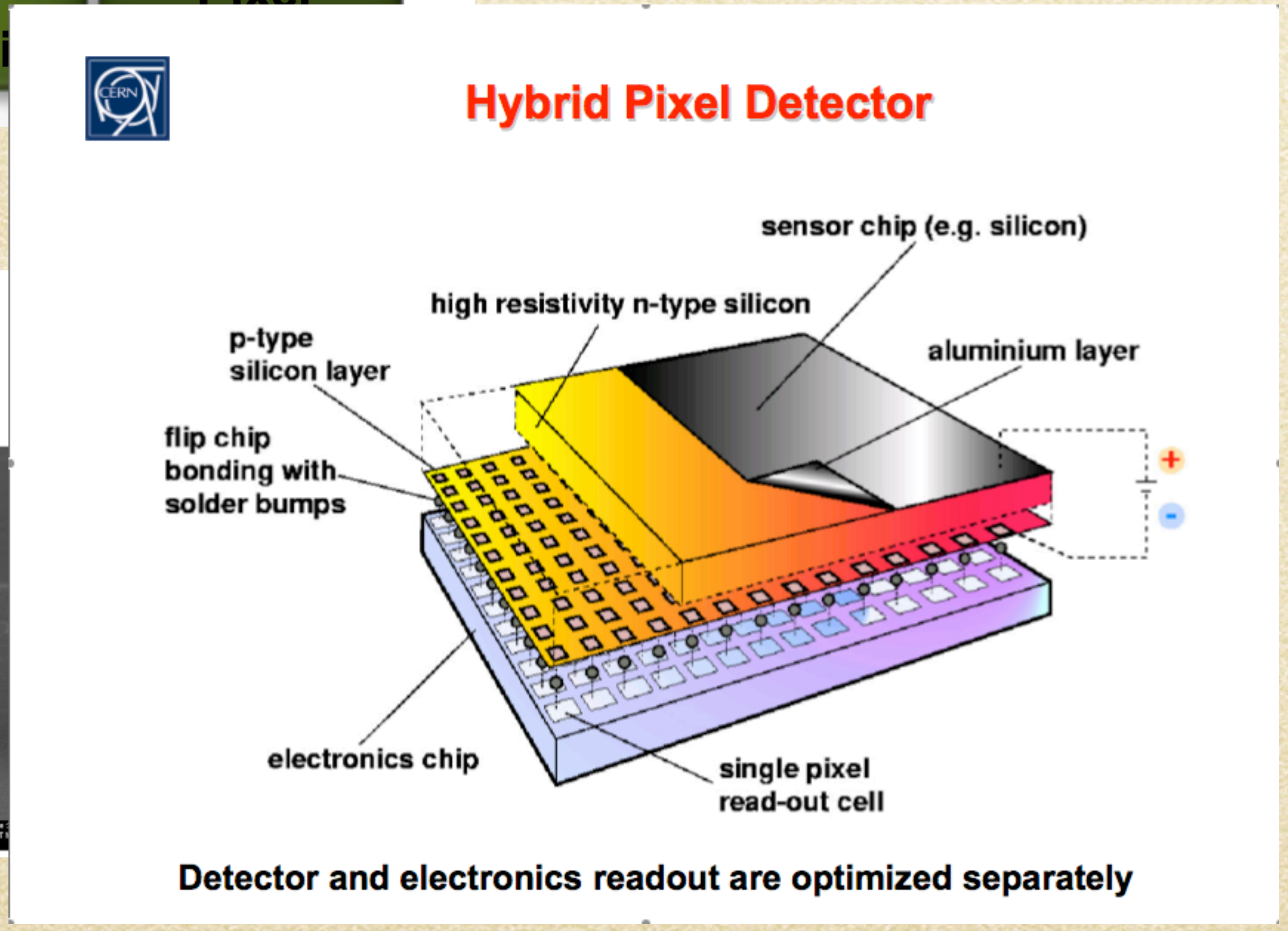

Advantages:

- **Direct conversion:**
  X-ray Photon => Electric pulse => Digital count
- **Provide energy sensitive imaging (spectral too)**

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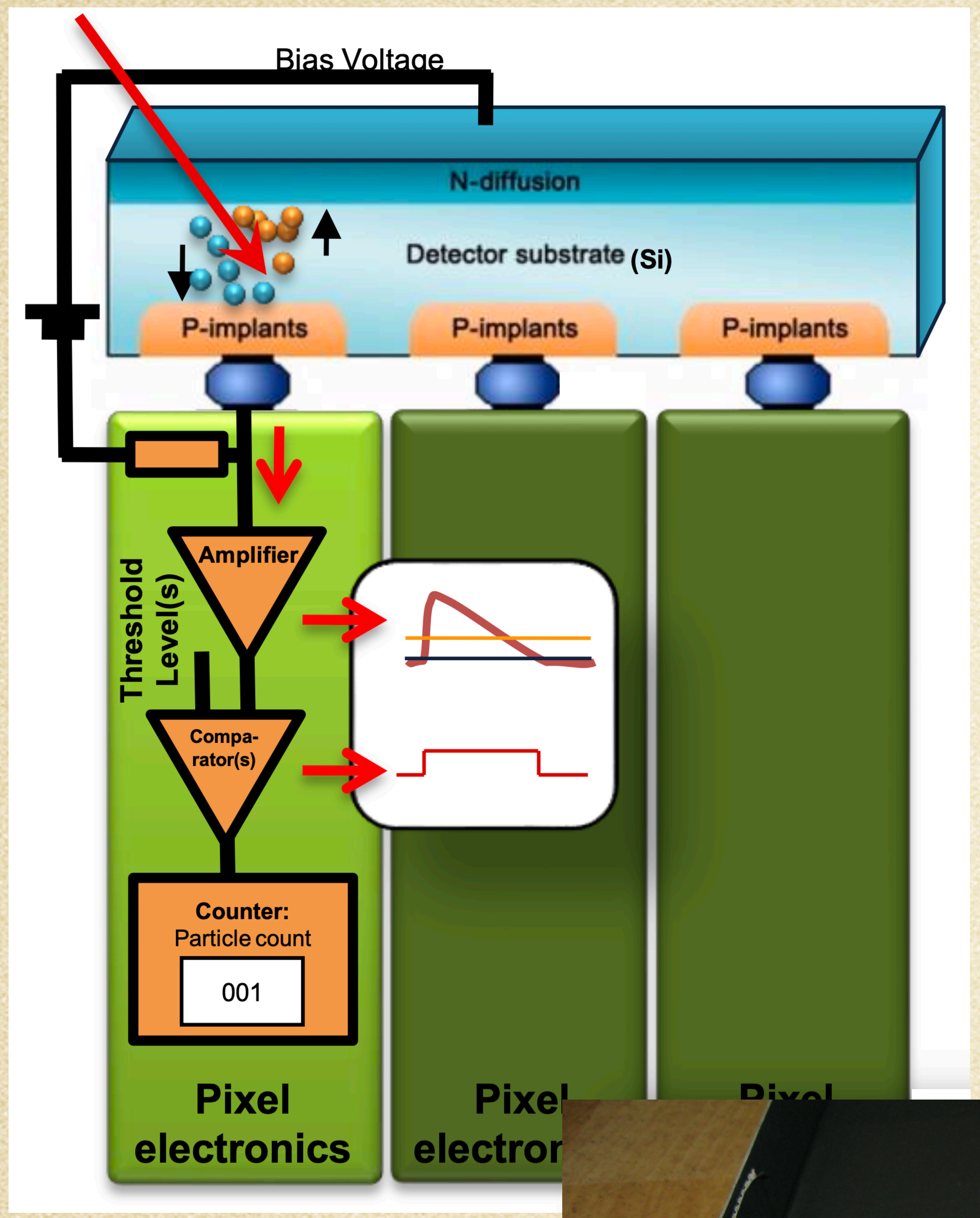

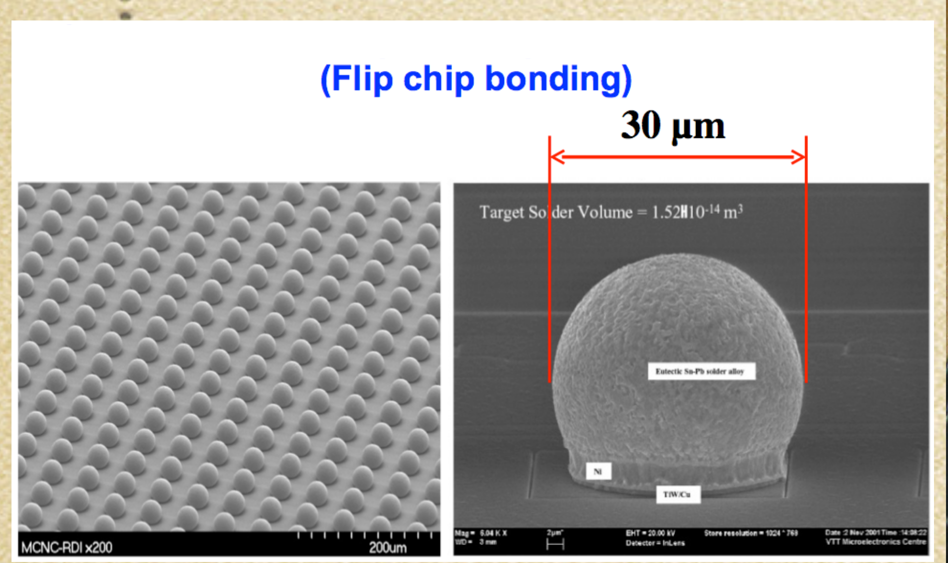

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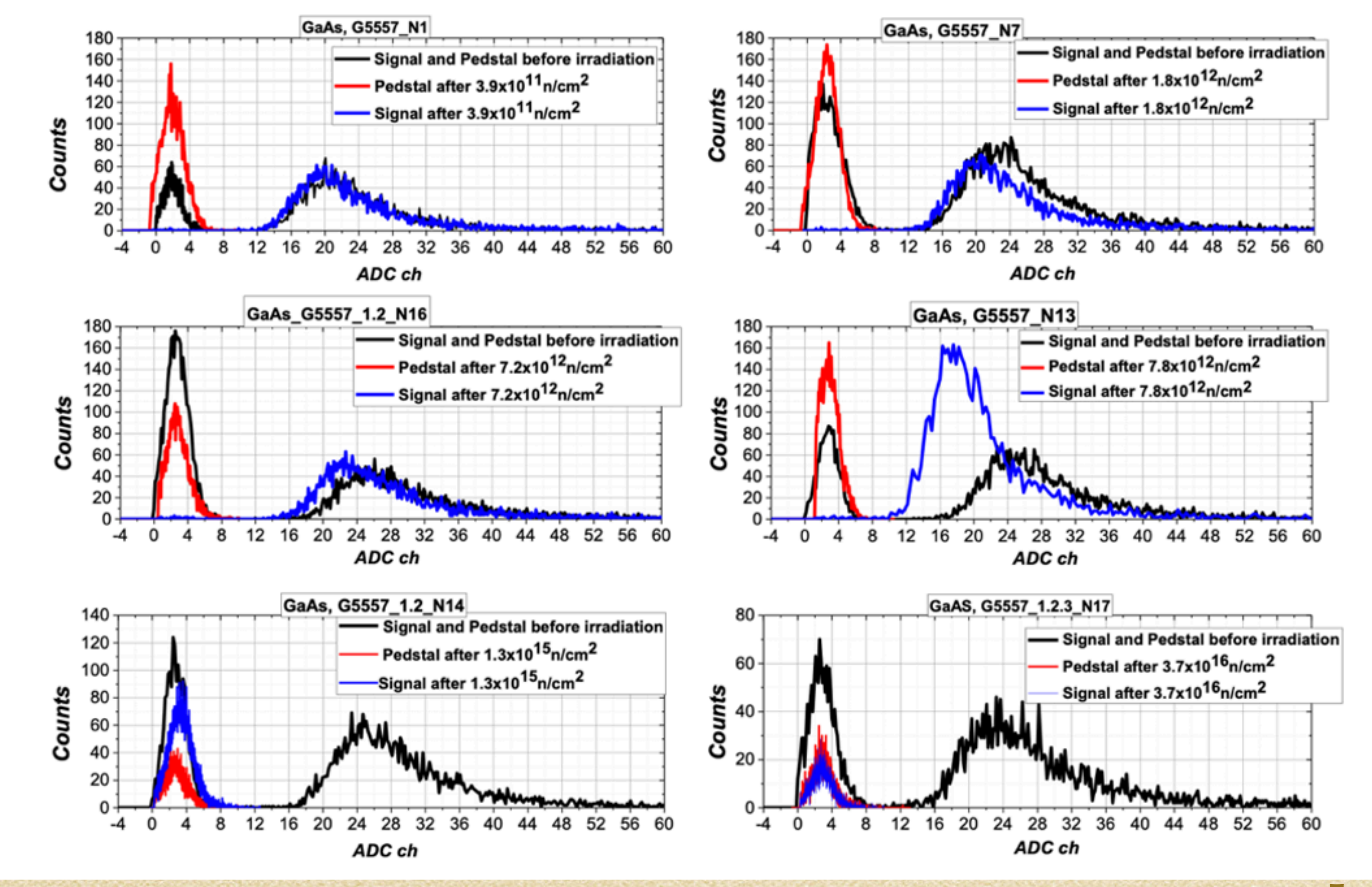
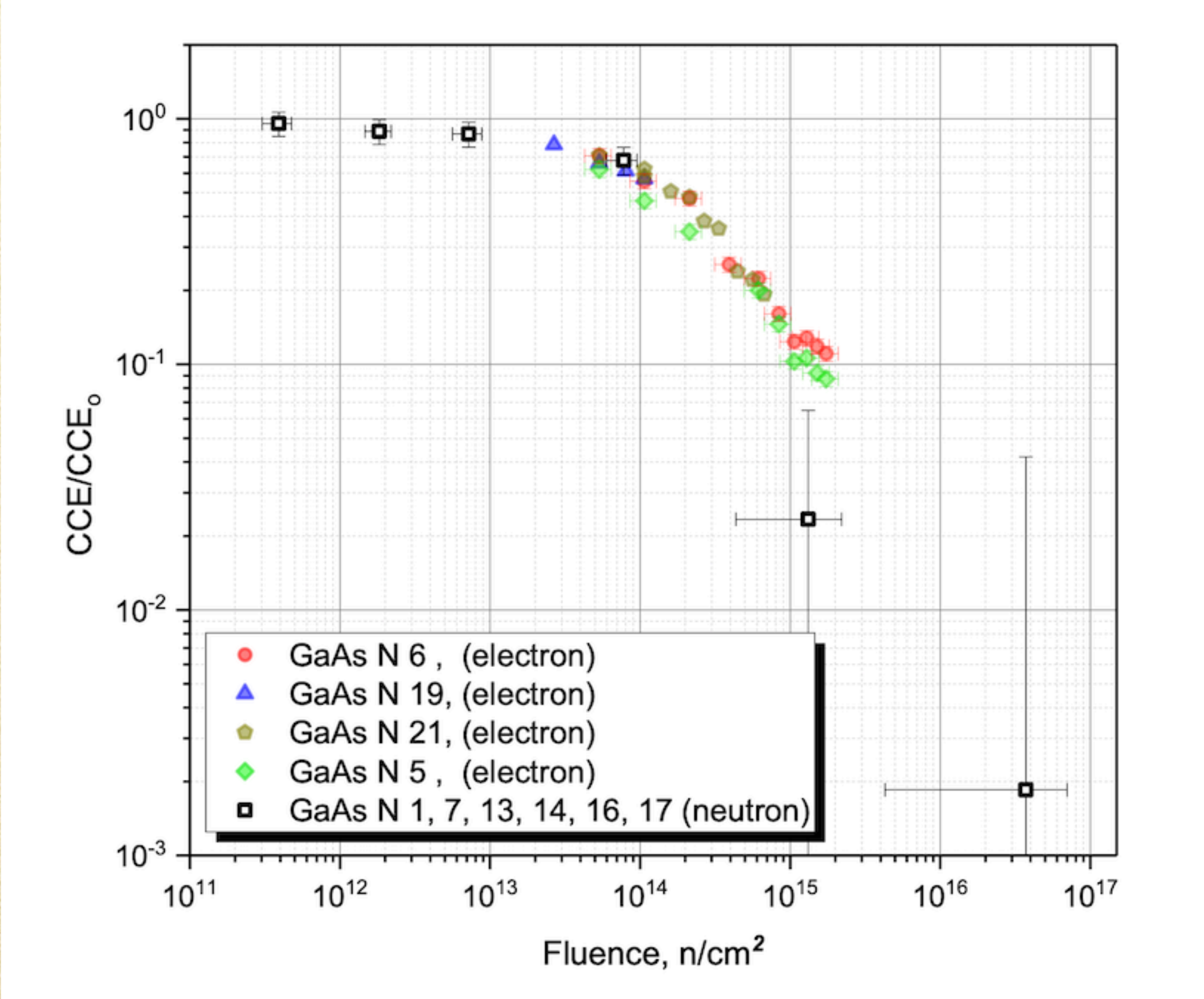
Studies have been carried out in the past:

Radiation resistance of new modifications of GaAs on neutron and electron beams at JINR together with physicists from Tomsk State University;

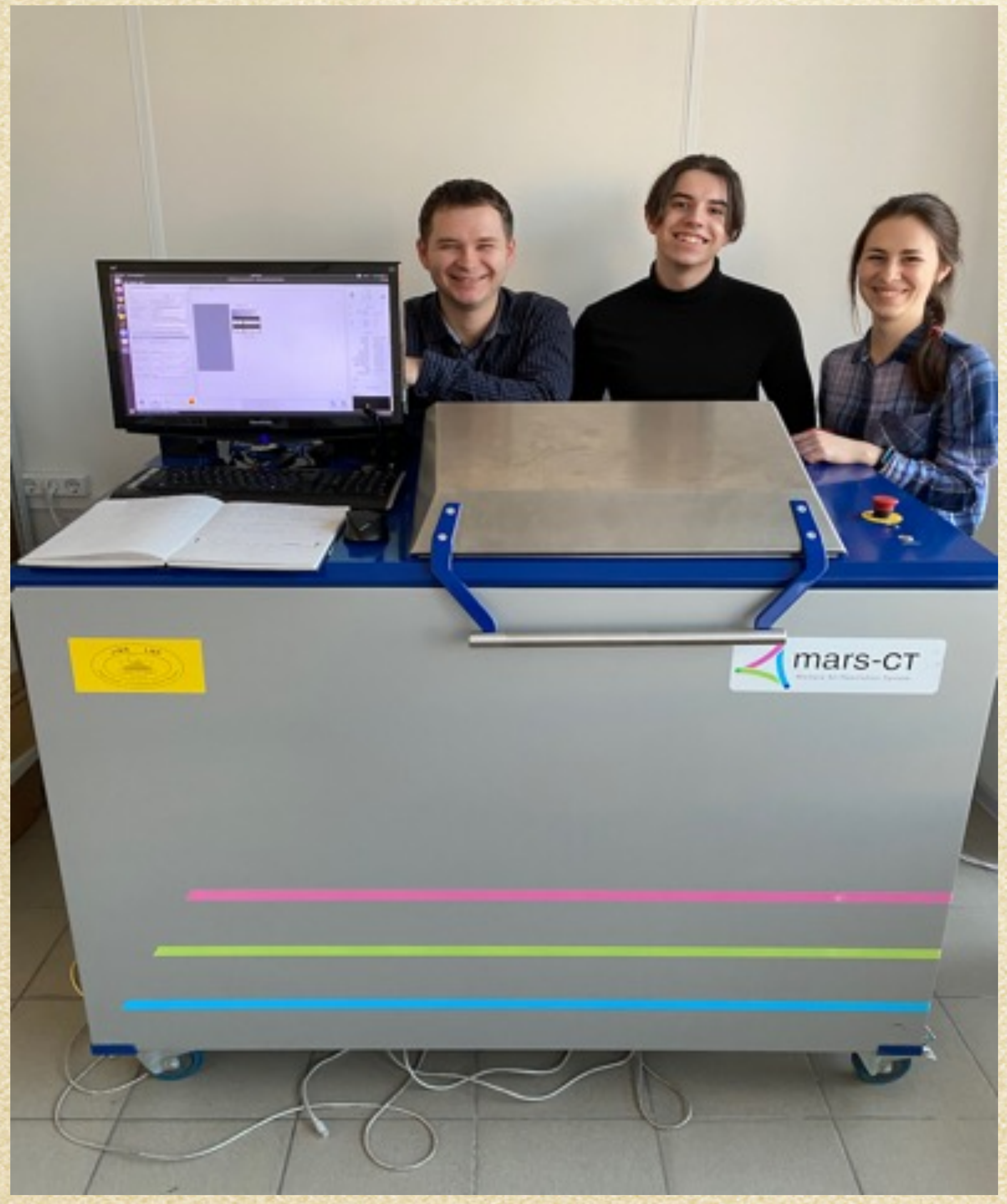




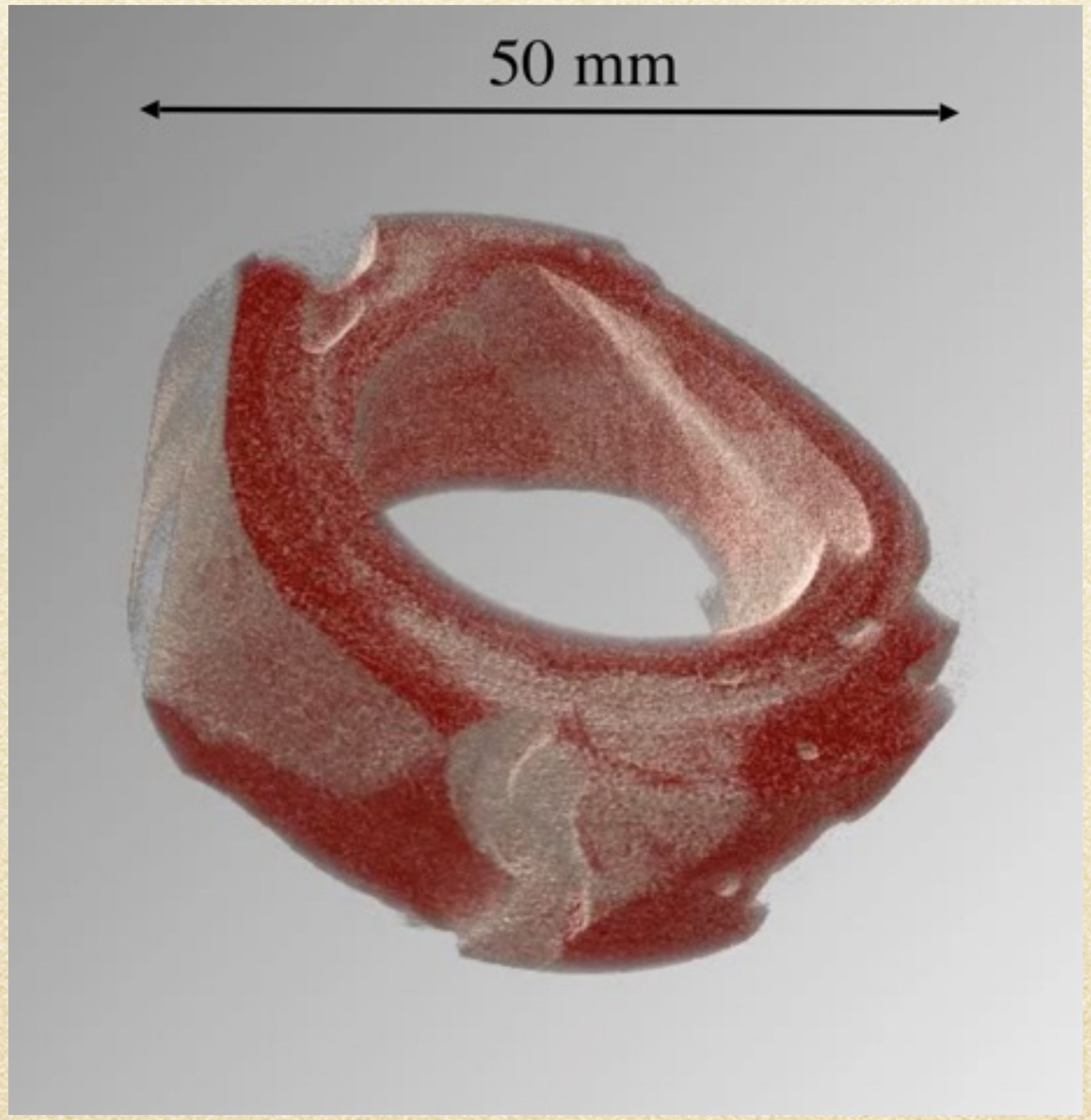
Studies have been carried out in the past:

Biological samples were scanned on the MARS μ-tomograph (MARS Bioimaging Ltd), which uses hybrid pixel energy-sensitive semiconductor detectors Medipix3RX, in collaboration with doctors from the T. Topper Center for Vascular Surgery in St. Petersburg, as part of a program to study the mechanism of aortic aneurysm.

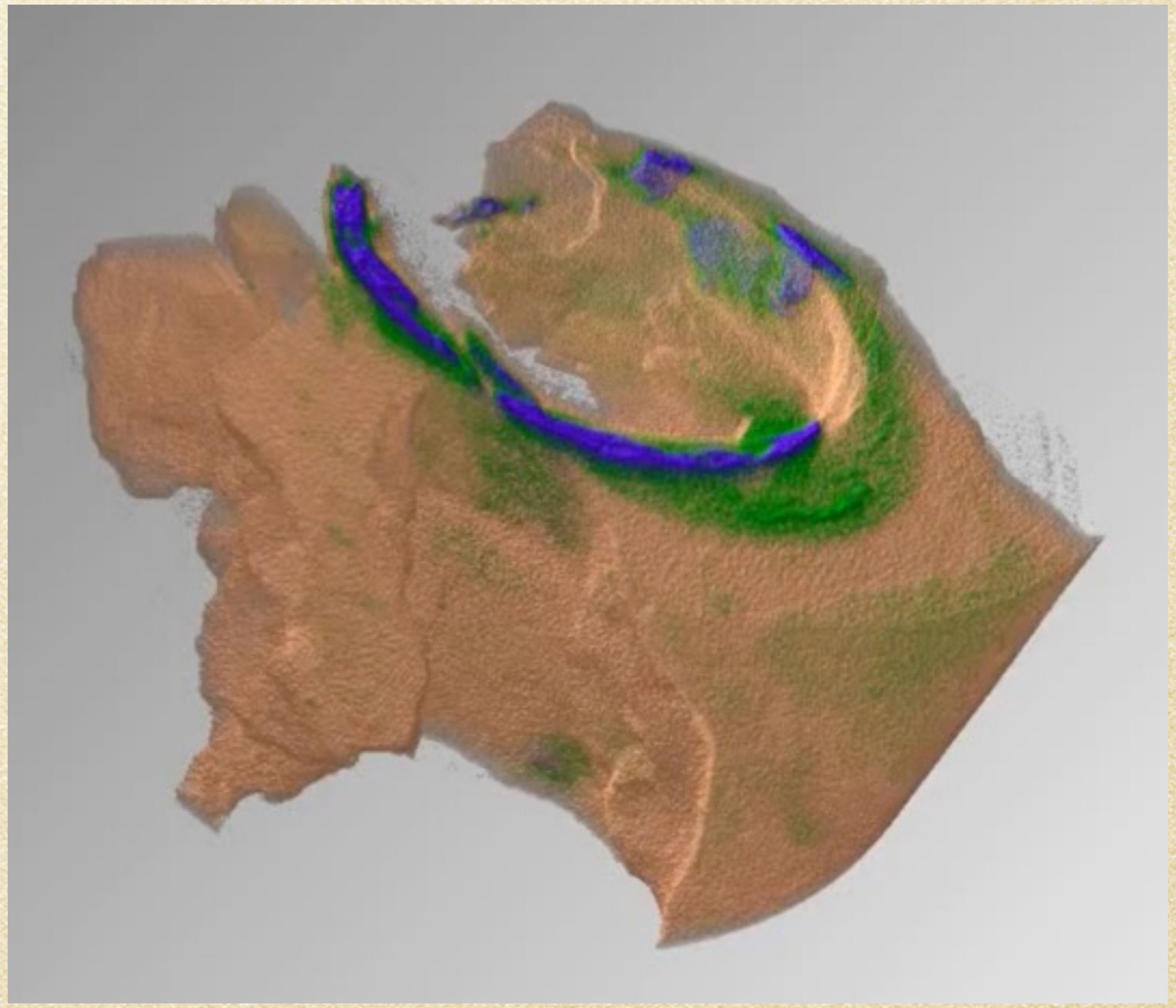
Doctoral dissertation of Svetlikov A.V. - Head of the Center for Vascular Surgery St. Petersburg.



MARS μ-tomograph



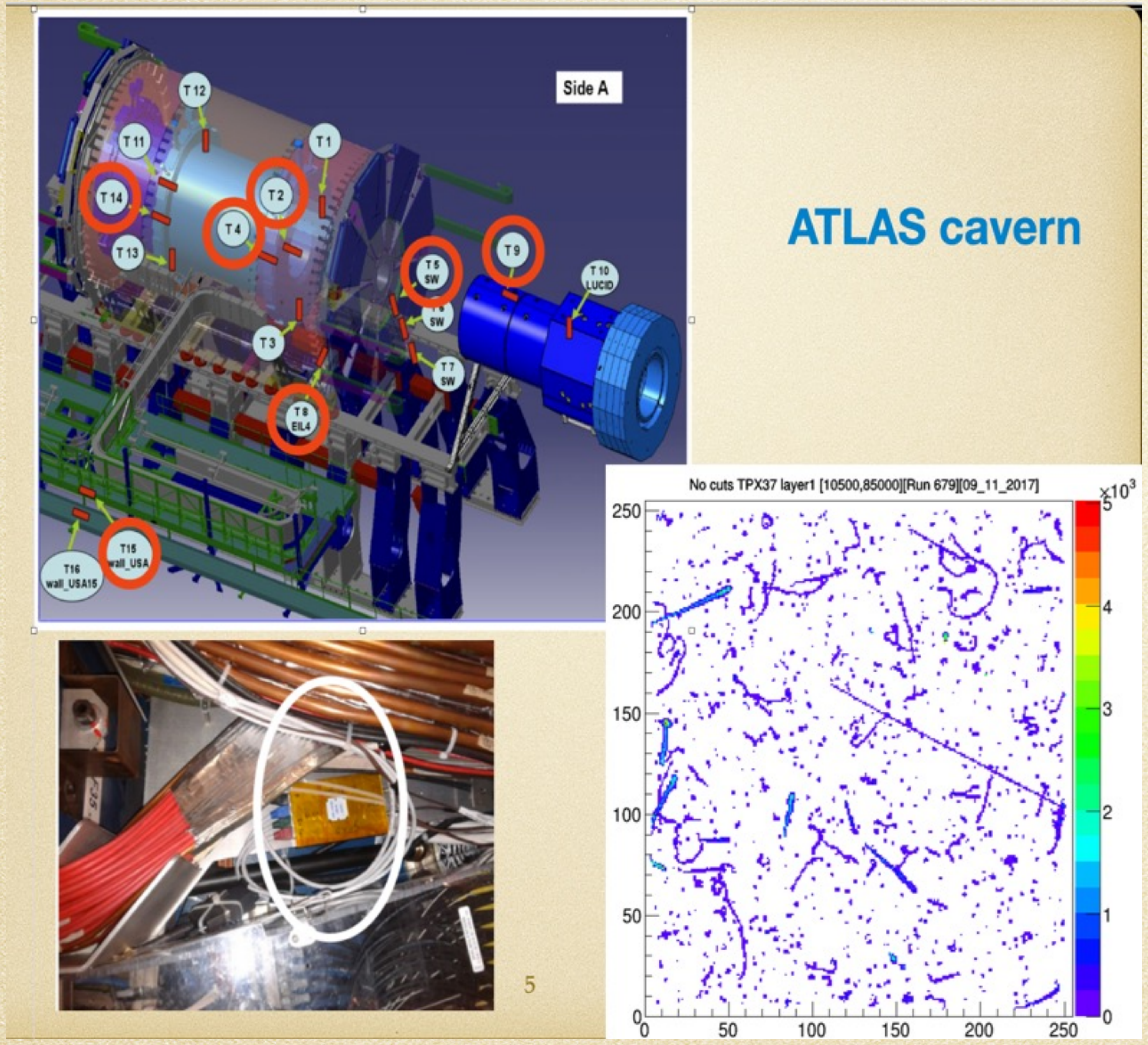
CT of a healthy aorta.
(Pig)



Aortic aneurysm CT
(Human patient)

Studies have been carried out in the past:

Radiation environment in ATLAS cavern at CERN



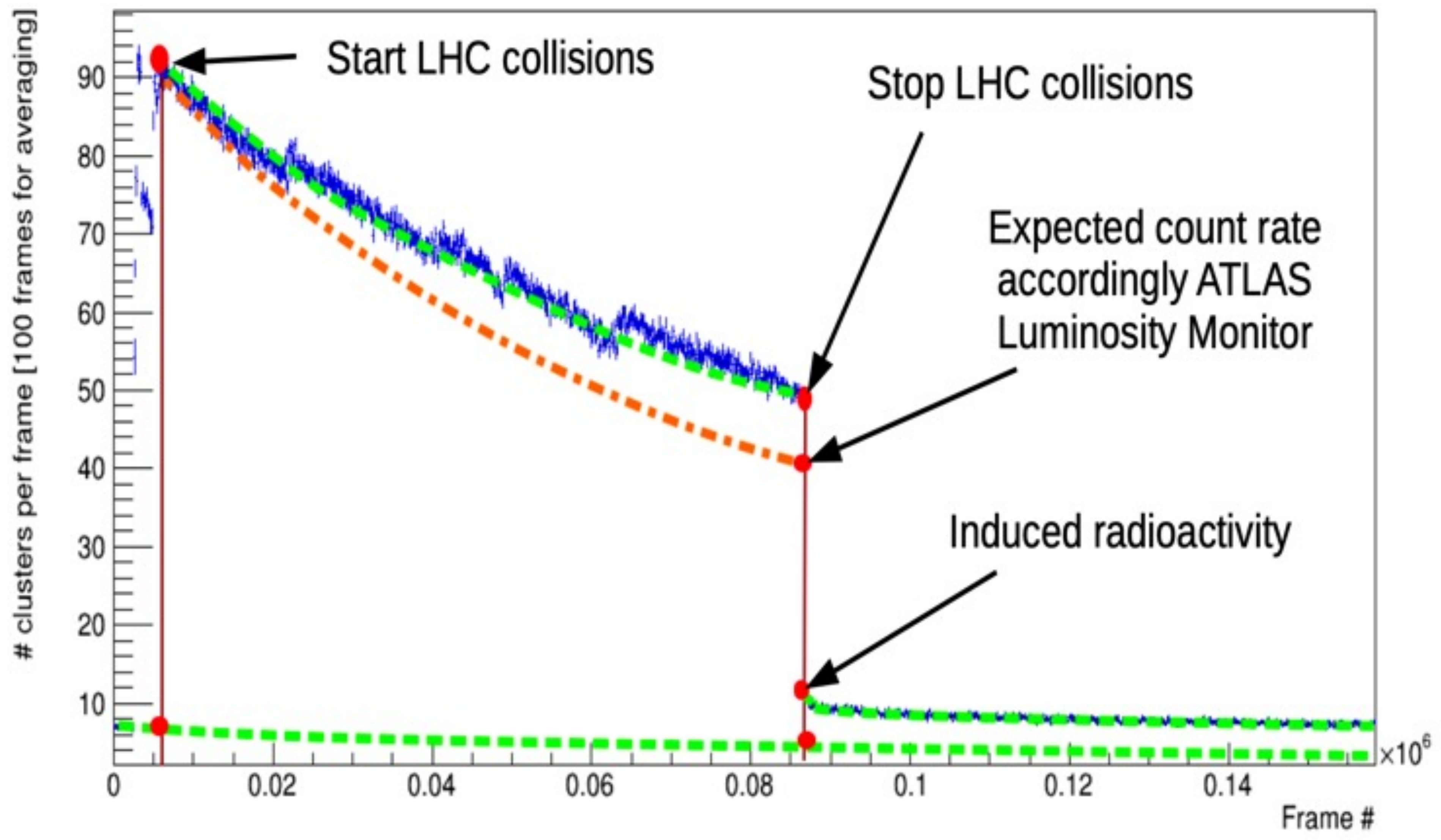
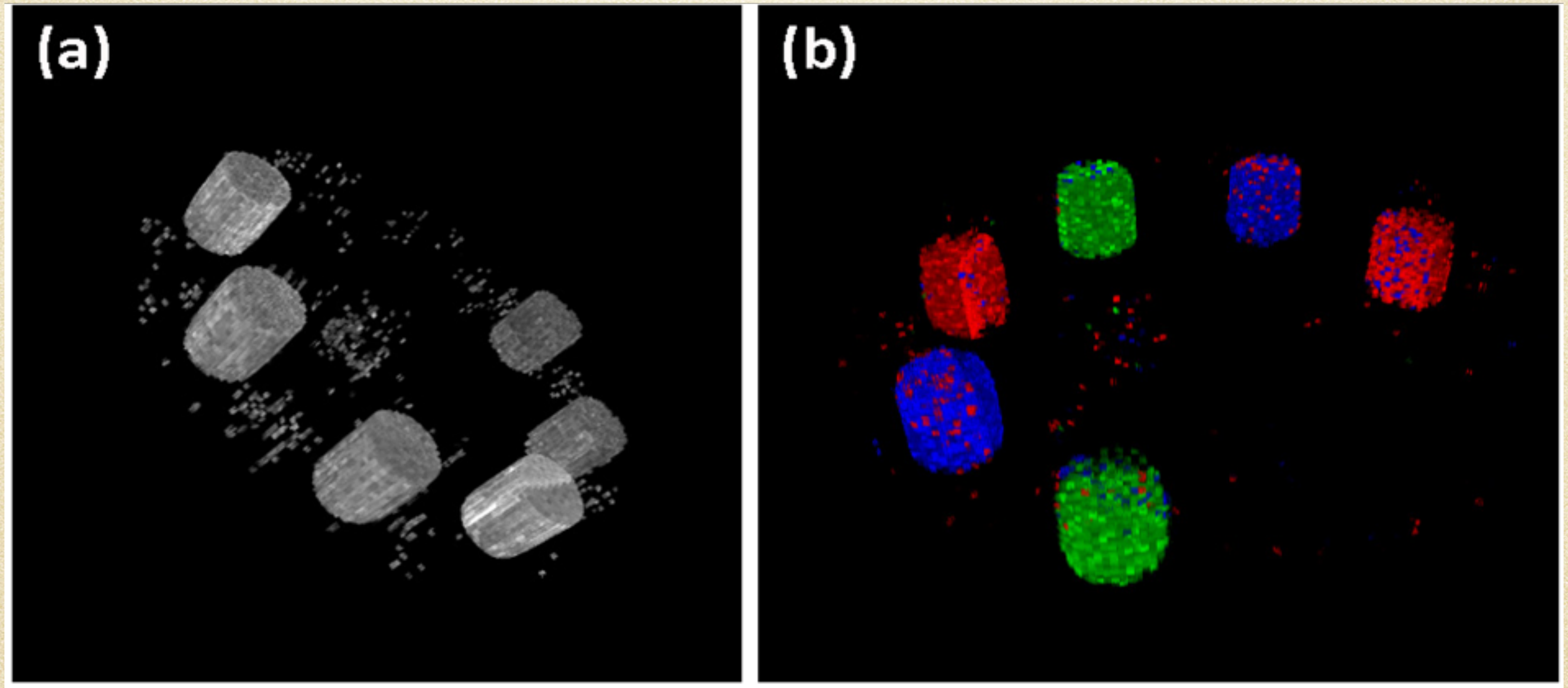


Figure 6: The cluster (event) rate of the GPX1 detector (blue markers) in collisions-on and collisions-off periods. The orange line is the expected cluster rate calculated in accordance with luminosity level at the ATLAS luminosity monitor. The green lines are fitted curves on the experimental data.

Studies have been carried out in the past:

Algorithms for selection in radiography/tomographic images of various materials using information about the energy of registered photons.
Together with chemists from Moscow State University, work is underway to create new types of contrast agents based on lanthanides. (RNF grant 22-15-00072)



Classic grey 3D phantom reconstruction with La, Nd and Gd samples

The same data reconstructed taking into account energy information:
La - red; Nd - blue and Gd - green.

During the initial period of the project, we mastered in detail the work with a promising new class of hybrid pixel semiconductor detectors. But all these detectors were developed by other laboratories.

Based on our experience, we came to the conclusion that the **next task of the project should be to create our own ready-made kits (detector + software package) in-house.**

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Based on our experience, we came to the conclusion that the **next task of the project should be to create our own ready-made kits (detector + software package) in-house.**

This will make it possible to preserve and develop the ten-year experience accumulated at JINR and implement it in the form of a hybrid pixel semiconductor energy-sensitive detector and a software package that ensures its operation and data reconstruction. This will allow the production of X-ray equipment specialised for various applications (medicine, biology, geology), which will differ from the devices currently on the market by the ability to analyse data using information about the energy of gamma rays. **A key element in the design of such detectors is a pixel chip.**

This is rarely said but in the history of JINR there is a very positive experience in the development and small-scale production of "own" custom chips. These chips were created in cooperation of various JINR groups with chipmaker **Solin A.V.** from INP BSU (Minsk)

Chip's name	Experiment	Amount	Year	Purpose and specifications
Tetrode-BT, Tetrode-JFET	CMS ECAL, CERN TESLA, DESY Astrophysical Observatory RAS, N. Arkhyz "ISTRA", IHEP	**10000**	**1997**	Single-channel CSA with p-n-p (Tetrode-BT) and p-JFET (Tetrode-JFET) head transistors
AS01T	Tower ECAL, IHEP (Protvino)	**5000**	**2004**	One channel: CSA-Slow Shaper-50-Ohm buffer, detectors up to 200 p
AS01PDA	TESLA THCAL DESY	**5000**	**2004**	One channel: CSA-Slow Shaper-50-Ohm buffer, detectors up to 200 p
MIC32, MIC1024	Si pixel detectors, SVD-2, IHEP (Protvino)	**2000**	**2012**	MIC32: 32 channels; MIC1024: 32x32 matrix Chips channel: CSA-Shaper-ADC
AST-1-1	Straw детекторы NA64, CERN and Test area, NICA, JINR	**10000**	**2015**	8 channels: Diff. CSA-Fast Shaper-BLR-Discriminator-Monostable-LVDS
AST-1-2	Study of Straw detector and Micro-pattern gaseous detectors, JINR and INP BSU (Minsk)	**1000**	**2015**	8 channels: Differential CSA-Fast Shaper-Differential 50-Ohm buffer
OKA-2BC	Пропорциональные и дрейфовые камеры установки «ОКА», ИФВЭ, Протвино	**15000**	**2017**	8 каналов: ЗЧУ-Формирователь-BLR-Дискриминатор-Одновибратор-LVDS
Ampl-8.10, Ampl-8.11 Ampl-8.52	Muon systems PANDA, FAIR and NICA-SPD, JINR	**2000**	**2021**	Ampl-8.10, Ampl-8.11: 8-channel current amplifiers based on the Rush stage Ampl-8.52: 8-channel current amplifiers based on the Rush stage with fast shaper
In total, more than 20 different chips have been developed and more than 70,000 pieces have been produced.				

2.4. Results of related activities

2.4.1. Research and education activities. List of defended dissertations. (2020-2023).

The results of these works were published in 22 articles in scientific journals and presented in 16 reports at international conferences.

19 master's degrees

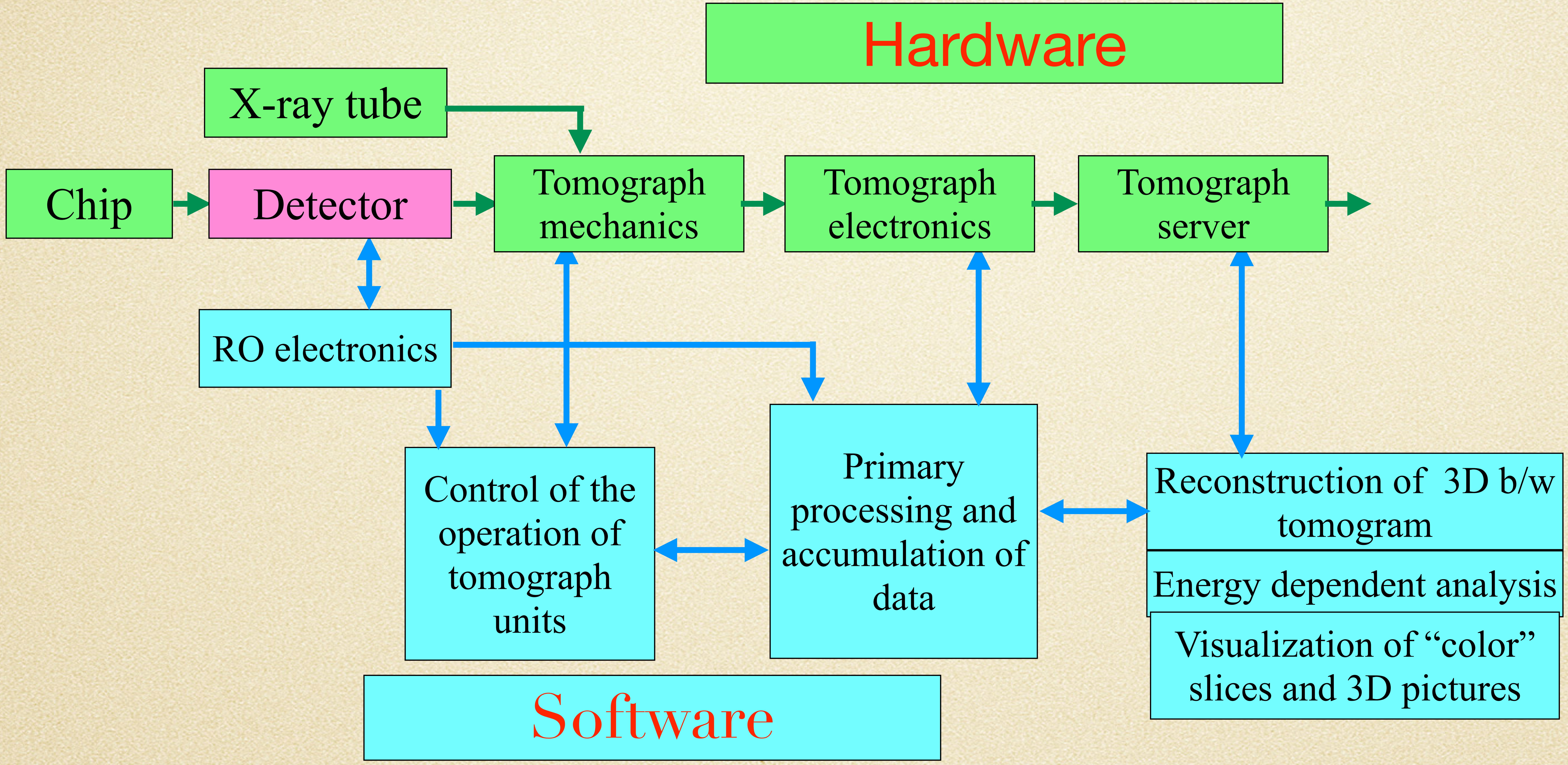
3 Ph.D. dissertations were prepared and successfully defended.

3 patents received. (see Attachment)

4.1 Manpower

Personnel category	JINR staff, amount of FTE
Research Scientists	5,1
Engineers	2,6
Total	7,7

Chip production is the most important but not the only task that needs to be solved at creating "your own" tomograph



The risks of the project are inadequate funding and possible problems in placing developments with manufacturers of custom chips.

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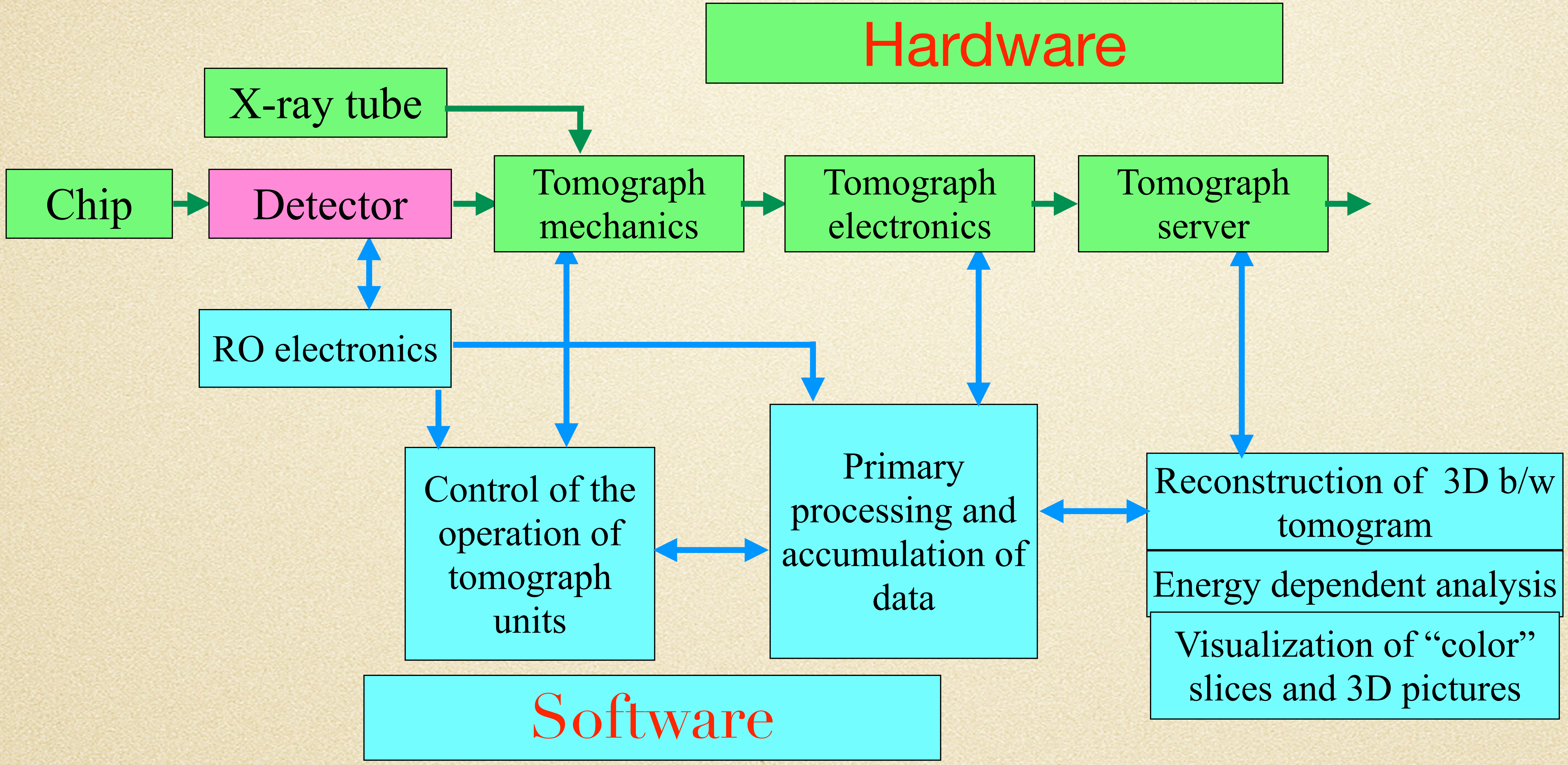


The risks of the project are inadequate funding and possible problems in placing developments with manufacturers of custom chips.

The main tasks of the next stage of the project will be:

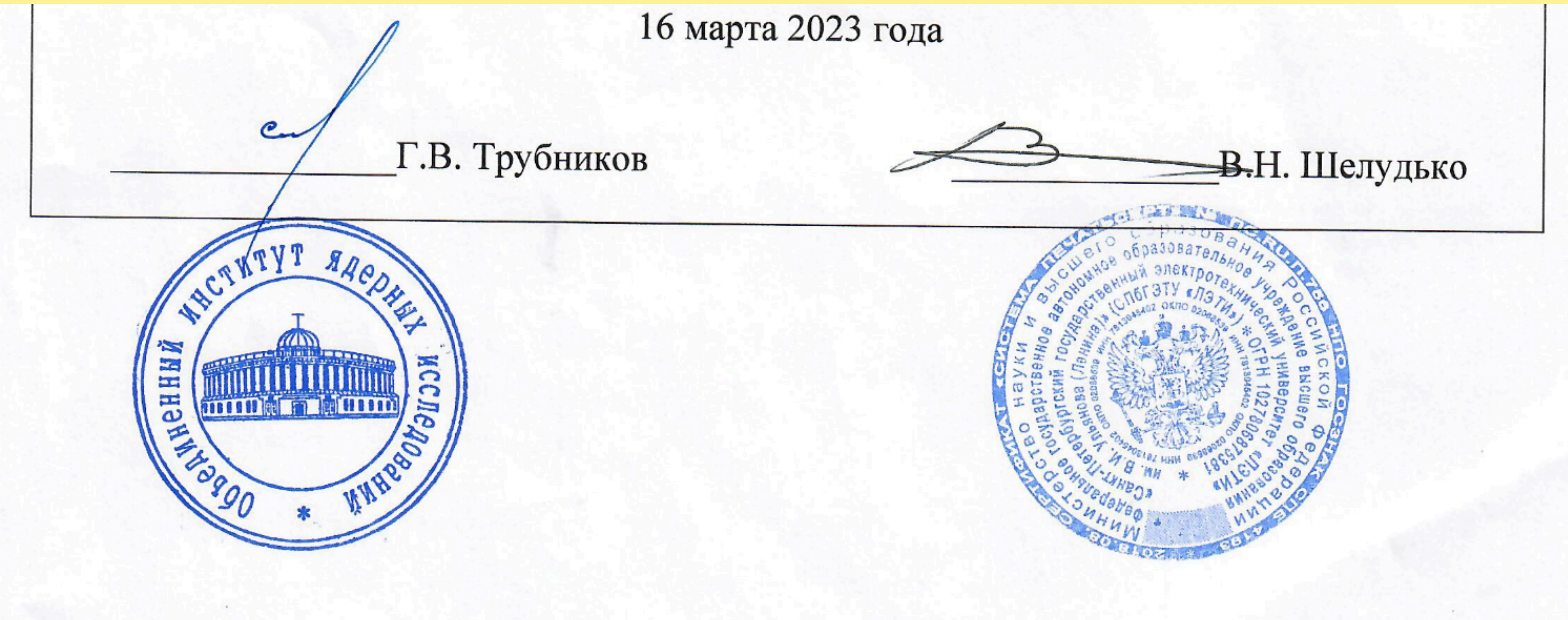
1. development of a custom chip
2. formation of a wide group of interested project participants

2.5. Participating countries, scientific and educational organizations

Institution	Country	City	Type of agreement
St. Petersburg State Electrotechnical University "LETI."	RF	St.Petersburg	Cooperation Agreement
Moscow State University	RF	Moscow	Grant RSF 22-15-00072
Institute of Nuclear Problems BSU	Belarus	Minsk	Cooperation Agreement
Institute of Semiconductor Physics SB RAS	RF	Novosibirsk	Cooperation Agreement
Federal State Budgetary Institution " Northwest District Scientific and Clinical Center FMBA"	RF	St.Petersburg	Cooperation Agreement
Design Center "Crystal" Joint Stock Company	RF	Moscow	Cooperation Agreement
Tomsk State University	RF	Tomsk	Cooperation Agreement
BRS Limited Liability Company	RF	Moscow	Cooperation Agreement
Institute of Crystallography RAS	RF	Moscow	
National Center for Radiation Research and Technology, Egyptian Atomic Energy Authority	Egypt	Cairo	
Department of Reactor Research Center, Egyptian Atomic Energy Authority	Egypt	Cairo	

Each text of the Cooperation Agreement signed by the Heads of the Institutes contains the phrase:

The Parties have determined that they are striving to achieve the following results of cooperation: Search or development of solutions for the creation of an energy-sensitive semiconductor X-ray image detector operating in the single photon counting mode, which, among other applications, can be used as a detector in medical diagnostic instruments


16 марта 2023 года

Г.В. Трубников

В.Н. Шелудько

2.4 Participating JINR Laboratories

FLNP - Akhmedov G., Berikov D., Kopatch Yu.

LRB - Bugay A., Chizhov A.

FLNR - Isatov A., Mitrofanov C., Teterev Yu.

Proposed schedule and resource request for the Project

Expenditures, resources, funding sources			Cost (thousands of US dollars)/ Resource requirements	Cost/Resources, distribution by years				
				1st year	2nd year	3rd year	4th year	5th year
		International cooperation	150	30	30	30	30	30
		Materials	100	20	20	20	20	20
		Equipment, Third-party company services	600	100	150	200	100	50
		Commissioning						
		R&D contracts with other research organizations	80	15	15	20	20	10
		Software purchasing						
		Design/construction						
		Service costs *(planned in case of direct project affiliation)*						
Resources required	Standard hours	Resources						
		– the amount of FTE,						
		- accelerator/installation,						
		– reactor,…						
Sources of funding	JINR Budget	JINR budget *(budget items)*	930					
	Extra fudning (supplementary estimates)	Contributions by partners Funds under contracts with customers Other sources of funding	Grant RSF 22-15-00065	7 MRuR	7 MRuR			

We have a dream!

In case of successful implementation of the project and the production of a new generation custom chip - JIMed (JINR Medicine), specialists from the JINR Member States will be able to purchase these microchips at a low price, and free access to documentation and the necessary software for their own R&D of medical equipment using X-ray imaging spectroscopic detectors with JIMed chip.

JIMed

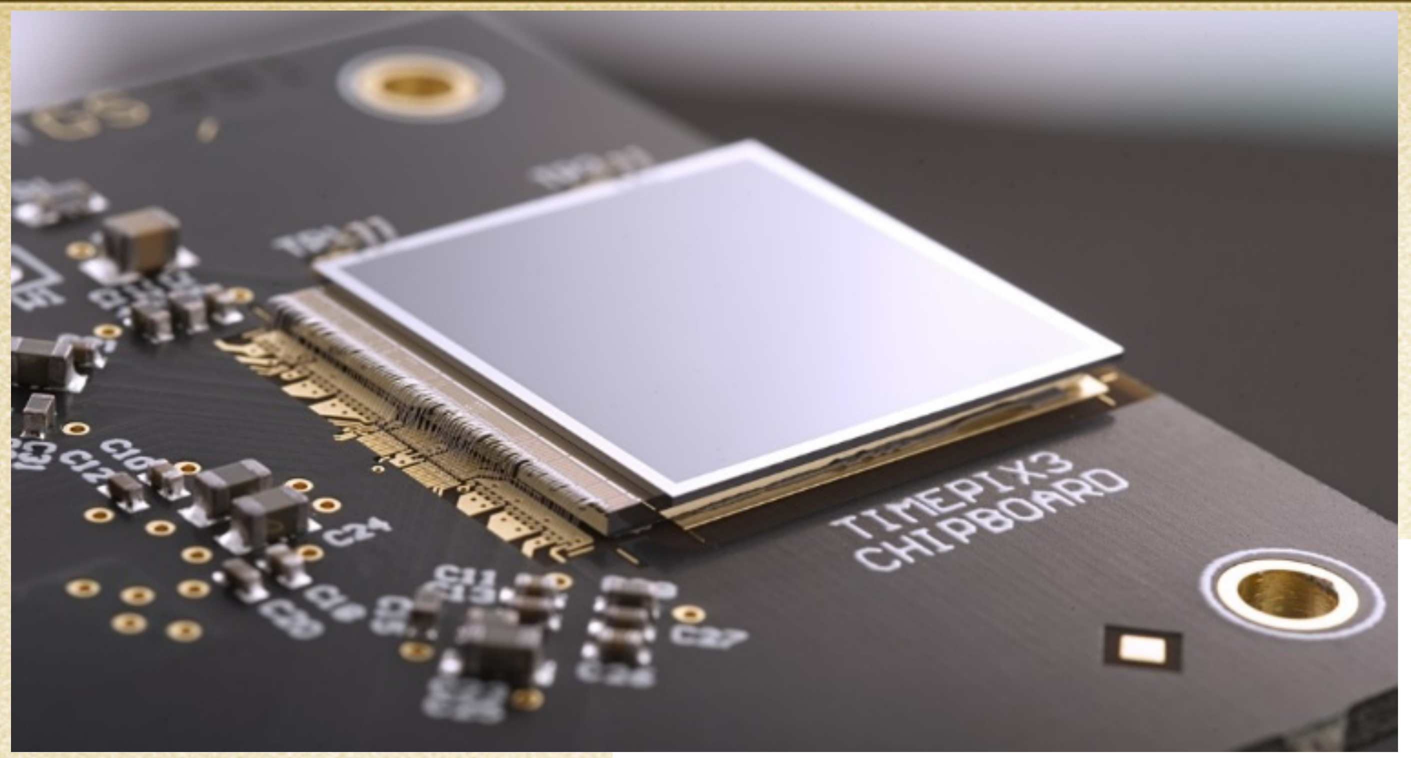
Publications for 2020-2022гг.

Year	Title	Authors	DOI	Reference
2022	New Composite Contrast Agents Based on Ln and Graphene Matrix for Multi-Energy Computed Tomography	E.Syslova, A.Kozlov, D.Shahurin, V.Rozhkov, R.Sotenskii, S.Maximov, S.Savilov, O.Medvedev, G.Chelkov	10.3390/nano12234110	Nanomaterials 2022,12(23),4110 **(Q1)**
2022	Development of La-graphen composit contrasting agents for photon-counting compudet tomography.	E.Syslova, D.Shahurin, A.Kozlov, S.Maximov, V.Rozhkov, R.Sotenskii, S.Savilov, J.Medvedev, G.Chelkov	10.1142/S1793604722500291	Functional Materials Letters. Vol.15 No.07n08. **(Q3)**
2021	Measurement of the radiation environment of the ATLAS cavern in 2017–2018 with ATLAS-GaAsPix detectors	I. Boyko, P. Burian, M. Campbell, G. Chelkov, E. Cherepanova, B. Di Girolamo, A. Gongadze, J. Janecek, D. Kharchenko, U. Kruchonak, A. Lapkin, Y. Mora Sierra5, M. Nessi, L. Pontecorvo, S. Pospisil, D. Rastorguev, V. Rozhkov, P. Smolyanskiy, M. Suk, I. Stekl, O. Tolbanov, A. Tyazhev and A. Zarubin	10.1088/1748-0221/16/01/P01031	JINST Vol.16 P01031 **(Q2)**
2021	Timepix pixel detector data pre-processing for SPECT	V. Rozhkov, A. Zhemchugov, A. Leyva, P. Smolyansky.		Journal of Physics: Conference Series
2020	Transition radiation measurements with a Si and a GaAs pixel sensor on a Timepix3 chip	F. Dachs a b, J. Alozy a, N. Belyaev c, B.L. Bergmann d, M. van Beuzekom e, T.R.V. Billoud , P. Burian, P. Broulim, M. Campbell, G. Chelkov … S. Pospisil …A. Romaniouk …P. Smolyanskiy …	10.1016/j.nima.2019.03.092	NIMA Vol.958, 162037 **(Q2)**
2020	Visualization of radiotracers for SPECT imaging using a Timepix detector with a coded aperture	V. Rozhkov, G. Chelkov, I. Hernandez, O. Ivanov, D. Kozhevnikov, A. Leyva, d, A. Perera, D. Rastorguev, e, P. Smolyanskiy, L. Torres and A. Zhemchugov	10.1088/1748-0221/15/06/p06028	JINST Vol.15 P06028 **(Q2)**
2016	Experimental X-ray microtomograph MARS as the future new tool for the evaluation of infrarenal aneurysms rupture risk	A.Svetlikov, A.Zhemchugov, D.Kozhevnikov, G.Shelkov, V.Gurevich, G Khubulava	10.1007/s00270-016-1405-3	CardioVascular and Interventional Radiology **(Q2)**
2020-2022	During this period, the project participants made over 20 reports/presentations at various conferences and schools			

Thanks for your attention!

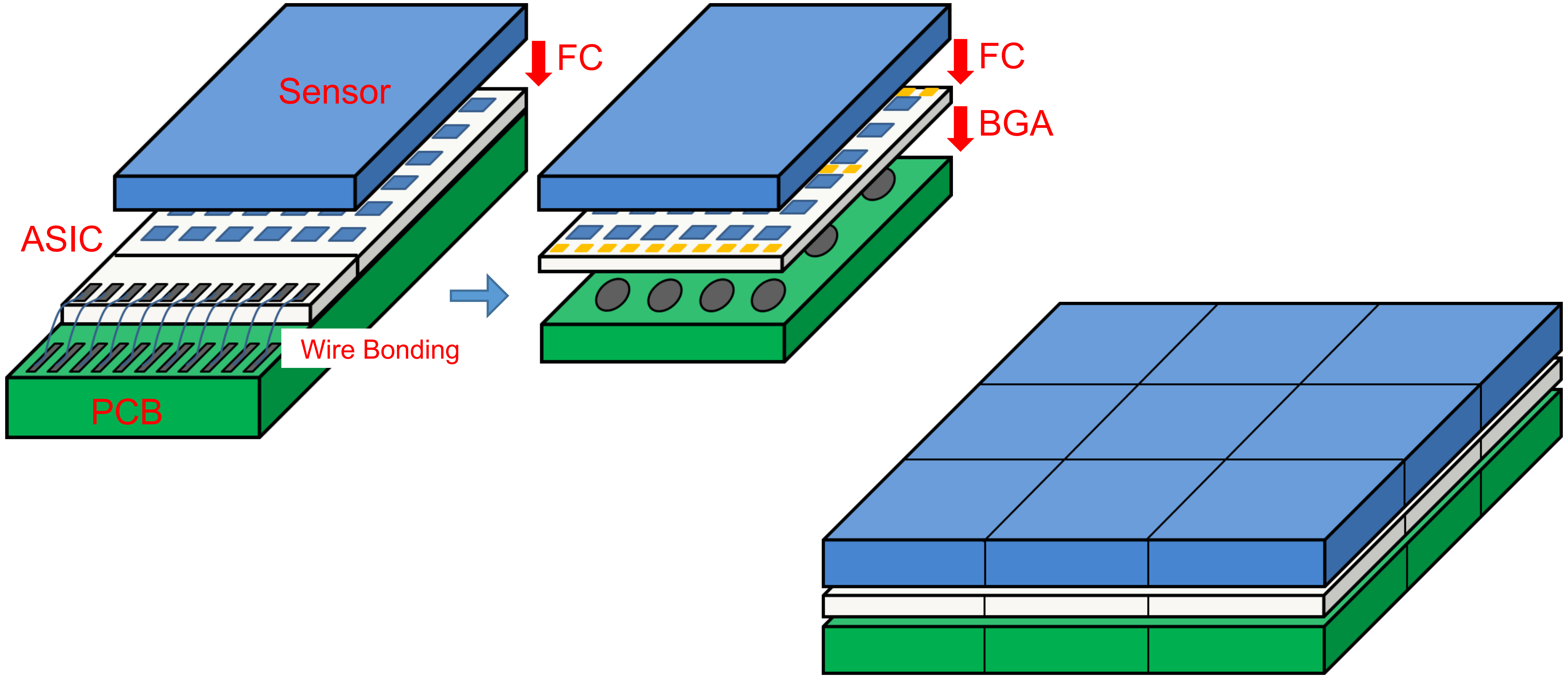
Timepix3 → Timepix4

			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 cm^2	**6.94 cm^2**	
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA		
		Event Packet	48-bit	64-bit	**33%**
		Max rate	0.43×10^6 hits/mm^2/s	**3.58×10^6 hits/mm^2/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 x 10^9 hits/mm^2/s	~5 x 10^9 hits/mm^2/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^-	



Сборка детекторов Medipix4 большой площади

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