National research center
«KURCHATOV INSTITUTE»

CREMLIN PLUS
Connecting Russian and European Measures
for Large-scale Research Infrastructures

4th generation synchrotron complex with X-ray free electron laser (general overview of the USSR project)

Marchenkov Nikita

01.12.2021

Federal program for synchrotron-neutron research

In accordance with the Decree, the NRC "Kurchatov Institute" was designated as the **head scientific organization** for the implementation of the Federal Scientific and Technical Program

УКАЗ

ПРЕЗИДЕНТА РОССИЙСКОЙ ФЕДЕРАЦИИ

О мерах по развитию синхротронных и нейтронных исследований и исследовательской инфраструктуры в Российской Федерации

В целях комплексного решения задач ускоренного развития синхротронных и нейтронных исследований, необходимых для создания прорывных технологий, а также обеспечения создания и развития исследовательской инфраструктуры в Российской Федерации п о с т а н о в л я ю:

1. Правительству Российской Федерации:

а) в 3-месячный срок разработать и утвердить Федеральную научно-техническую программу развития синхротронных и нейтронных исследований и исследовательской инфраструктуры на 2019 - 2027 годы (далее - Программа);

б) обеспечить при разработке и реализации Программы:

определение основных направлений исследований, касающихся решения принципиально новых фундаментальных и крупных прикладных задач в целях реализации приоритетных направлений научно-технологического развития и достижения национальных

Decree of the President of the Russian Federation on the development of synchrotron and neutron research (25.07.2019)

УТВЕРЖДЕНА
постановлением Правительства
Российской Федерации
от 16 марта 2020 г. № 287

ФЕДЕРАЛЬНАЯ НАУЧНО-ТЕХНИЧЕСКАЯ ПРОГРАММА
развития синхротронных и нейтронных исследований и исследовательской инфраструктуры на 2019 - 2027 годы

П А С П О Р Т

Федеральной научно-технической программы
развития синхротронных и нейтронных исследований
и исследовательской инфраструктуры на 2019 - 2027 годы

Наименование Программы	-	Федеральная научно-техническая программа развития синхротронных и нейтронных исследований и исследовательской инфраструктуры на 2019 - 2027 годы
Основание для разработки Программы	-	Указ Президента Российской Федерации от 25 июля 2019 г. № 356 "О мерах по развитию синхротронных и нейтронных исследований и исследовательской инфраструктуры в Российской Федерации"

Federal program for the development of synchrotron and neutron research until 2027 (16.03.2020)

Vladimir Putin's visit to the National Research Center "Kurchatov Institute" (10.04.2018)

Infrastructure of synchrotron researches in the world

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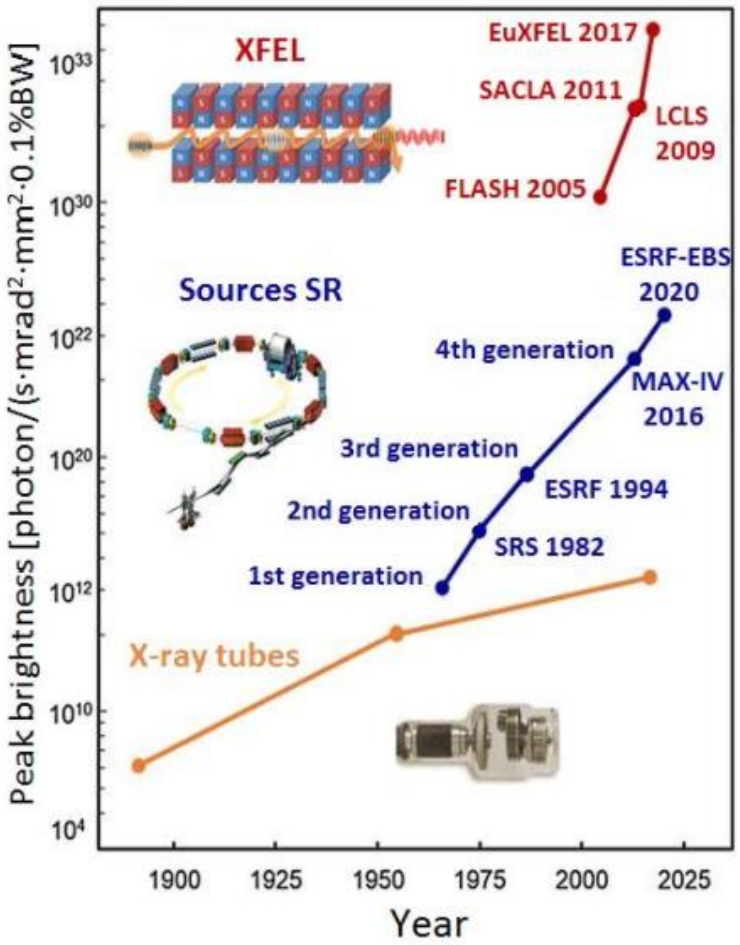

Increase in peak brightness of synchrotron radiation sources and free electron lasers

BREAKTHROUGH TECHNOLOGIES

APS - USA
Spring-8 - Japan
ESRF - EBS - France
Petra III + XFEL - Germany

ESRF (6 GeV)
France

FLAGSHIP SYNCHROTRONS

6 - 8 GeV (~1000 m)

Technological independence

Spring – 8 (8 GeV)
Japan

BASIC SYNCHROTRONES

(technological and specialized)

«Workhorses» - 1,5-3 GeV (>70 units)

KISI-Kurchatov (2,5 GeV)
Russia

ALBA (3 GeV)
Spain

Support and development of existing technologies

Concept of synchrotron-neutron facilities landscape in Russia

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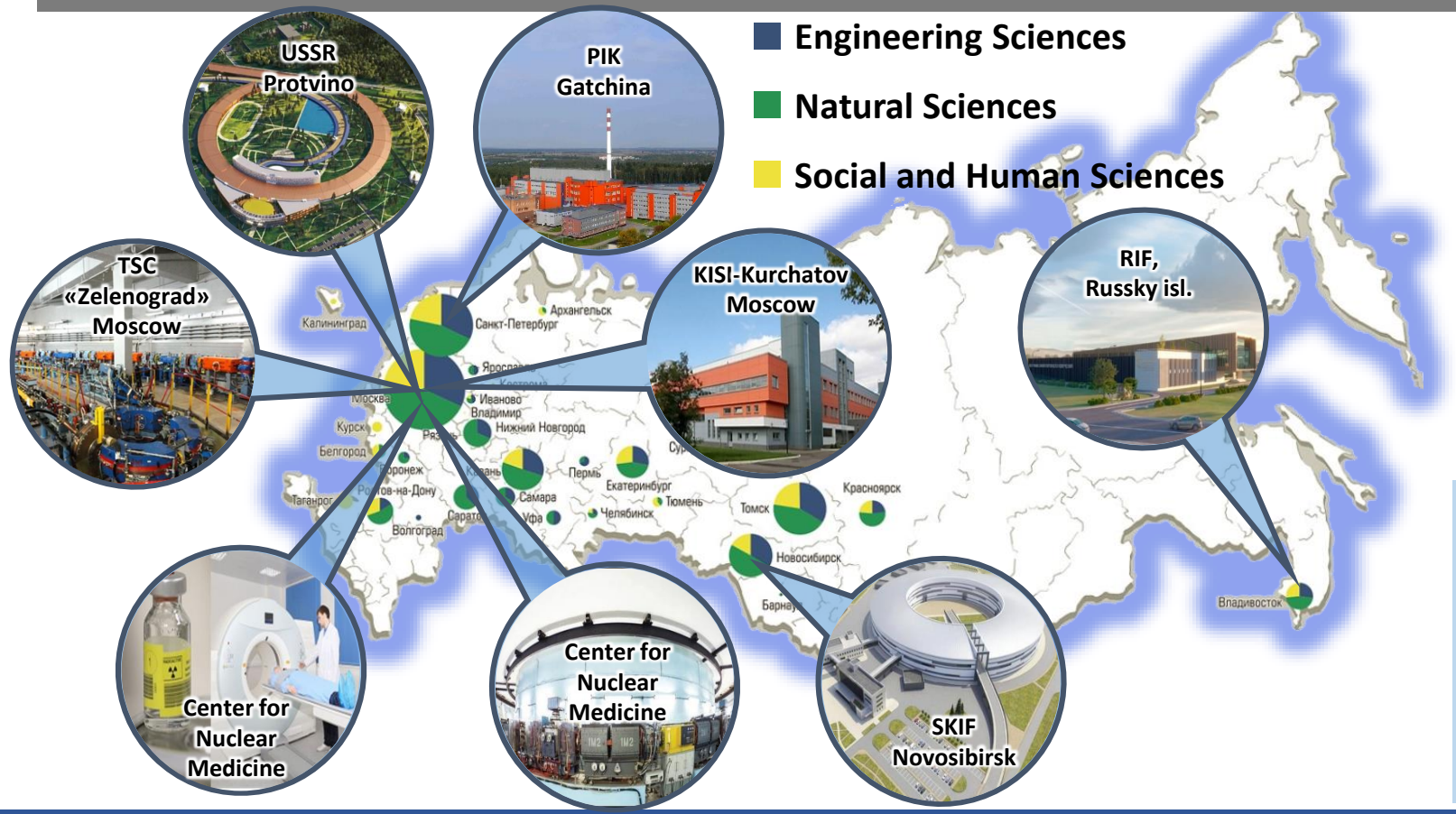
INTEGRATION AND COMPLETENESS OF THE FACILITIES SCIENTIFIC TASKS, EFFECTIVE DISTRIBUTION OF RESOURCES

- Obtaining breakthrough scientific results
- Regional development, including education, science and industry
- Transfer of scientific results to technology
- Development of nuclear medicine technologies



Facilities are divided into 3 basic categories:

- **Leading the world level**
  USSR, PIK, OMEGA
- **Basic facilities**
  SKIF, KISI-Kurchatov, RIF
- **technological facilities and specialized** including **nuclear medicine facilities**

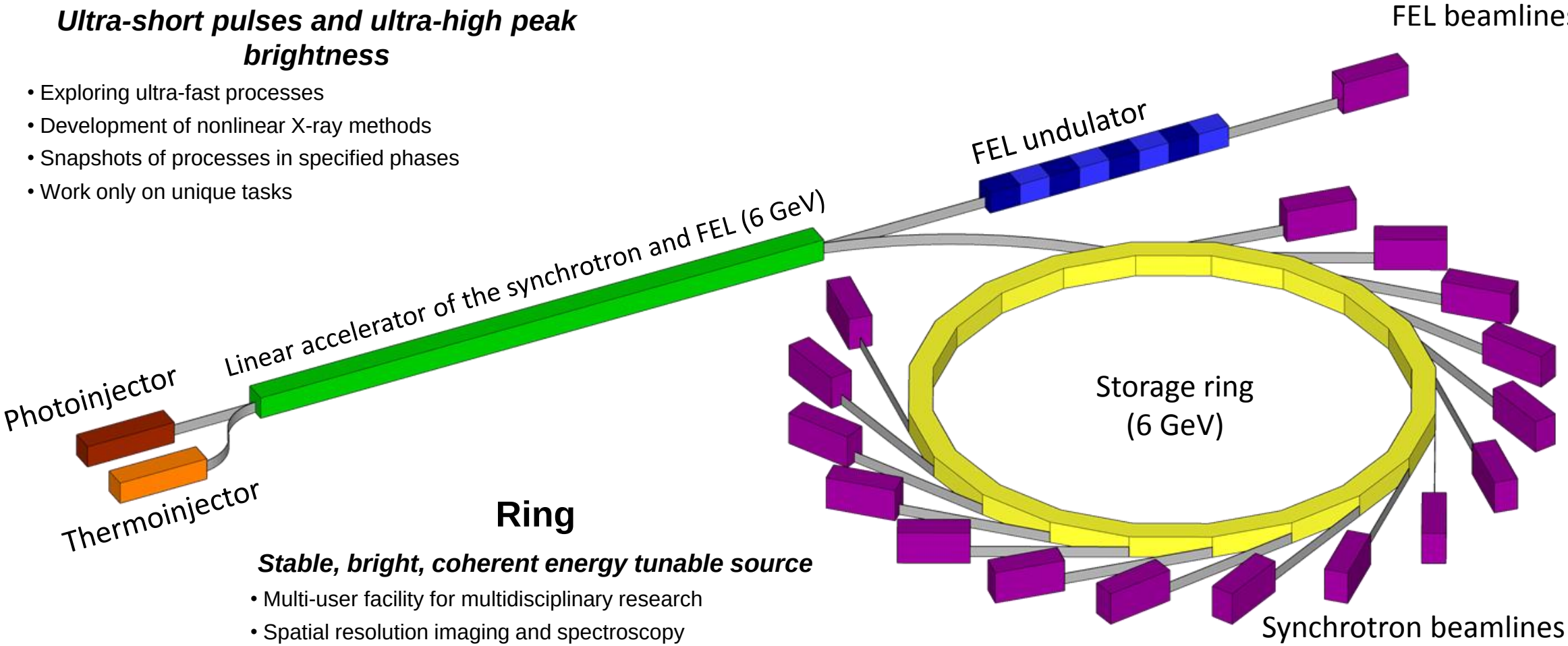
- **Concepts developed for megascience-class facilities**
- The basic technical characteristics of the installations **are approved by the scientific and technical council**

Scheme of the accelerating-storage complex

Free Electron Laser

Ultra-short pulses and ultra-high peak brightness

- Exploring ultra-fast processes
- Development of nonlinear X-ray methods
- Snapshots of processes in specified phases
- Work only on unique tasks



Ring

Stable, bright, coherent energy tunable source

- Multi-user facility for multidisciplinary research
- Spatial resolution imaging and spectroscopy
- Studying the behavior of a system in dynamics

USSR synchrotron complex parameters

A fundamentally new and promising USSR source – 4th generation synchrotron source (6 GeV) + X-ray free electrons laser

Key parameters	
Perimeter (circumference of the electron beam trajectory):	**more than 1100 m**
Energy e- in the storage ring (the higher the energy, the higher the brightness):	**6 GeV**
Emittance (the product of the beam size by its divergence - the "quality" of the SR):	**70 pm×rad**
Brightness (the brighter, the less time it takes to perform an experiment, less sample volume is required): Average brightness of the ring storage Peak brightness of a free electron laser (FEL)	**10^{23}** (ph/s/mm^2/0.1% BW) **10^{33}** (ph/s/mm^2/0.1% BW)
Spectral composition of radiation (range of available SR energies):	**200 eV – 500 keV**
Maximum number of experimental beamlines (including FEL beamlines):	**52 (6)**
Full coherence of radiation (self-consistency of the phases of the X-ray waves that make up the radiation beam)	**investigation of disordered objects**

USSR – on the way to the diffraction limit

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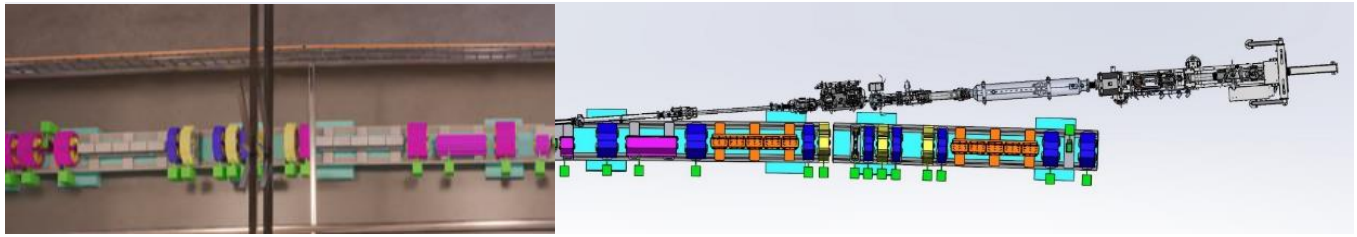
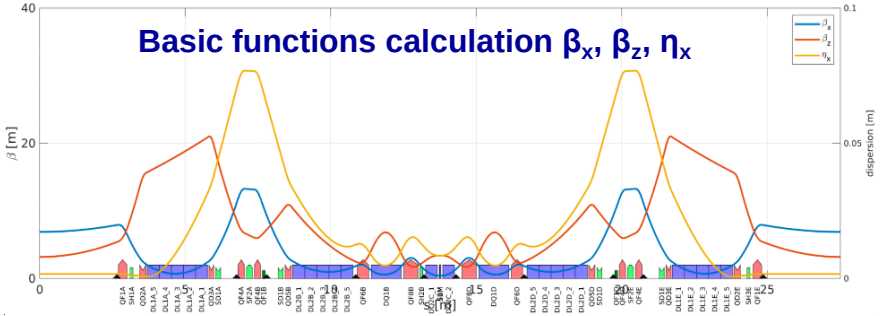
Modified 9BA configuration - 6 GeV, emittance < 70 pm×rad
40 super periods, sections and linear intervals (1100 m)



Superperiod structure	
Dipole	9
Quadropole	16
Sextupole	10
Octupole	2



Electron beam size

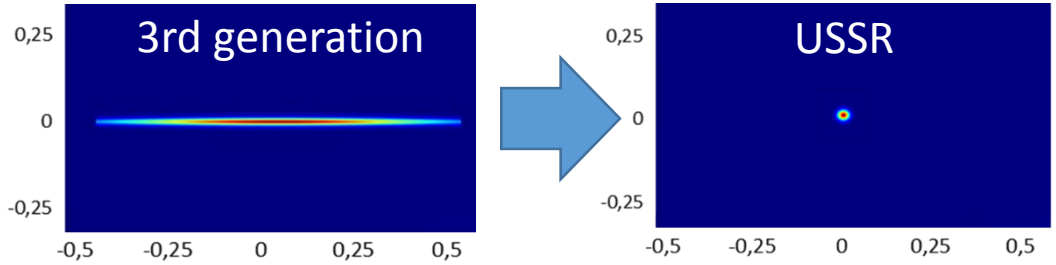
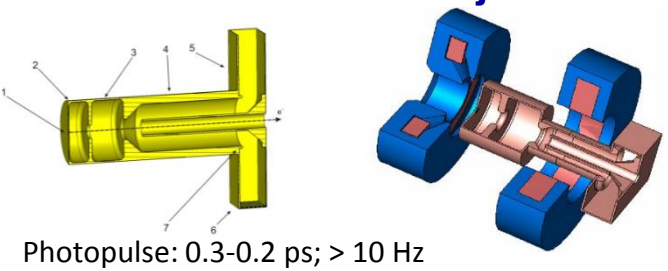
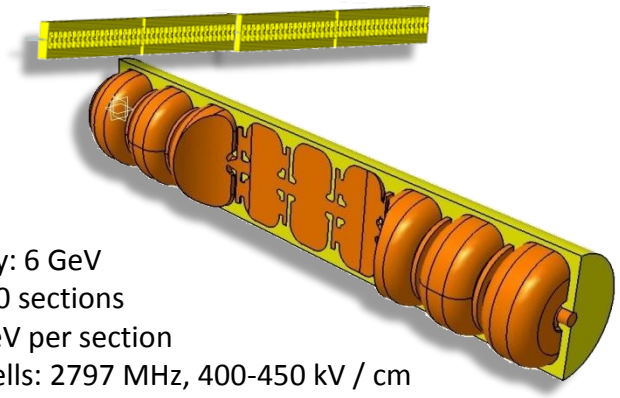


Photo and thermal injector



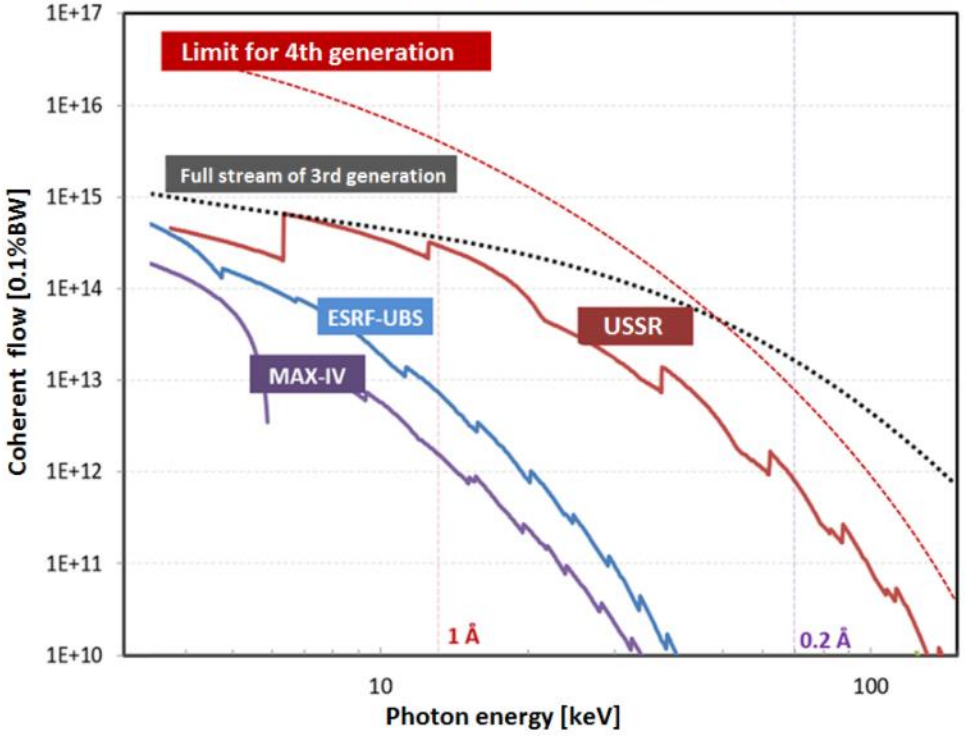
Photopulse: 0.3-0.2 ps; > 10 Hz
Bunch charge:> 1 nC
Photocathode: Cs_2Te
Accelerating field: 400-800 kV / cm
Thermal pulse: up to 600 ns; > 30 Hz; 120 keV

Linear accelerator



Energy: 6 GeV
80-100 sections
80 MeV per section
BAS cells: 2797 MHz, 400-450 kV / cm

Coherent photon flux [0.1%BW]



International cooperation in the framework of the CremlinPlus project

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Development of the **main ring magnetic structure** of the USSR synchrotron

ESRF-EBS

Synchrotron USSR **beam monitoring and diagnostics system**

Simulation of the elements of the channel in order to determine the **impedances** and their influence on the **stability of the electron beam** of the USSR synchrotron

INFN LNF Istituto Nazionale di Fisica Nucleare

DESY.

Development of the USSR **synchrotron** photogun - an electron source for a free electron laser

DESY.

Development of the USSR synchrotron **linear accelerator** for accelerating an electron beam up to 6 GeV energy and top-up injection

INFN LNF Istituto Nazionale di Fisica Nucleare

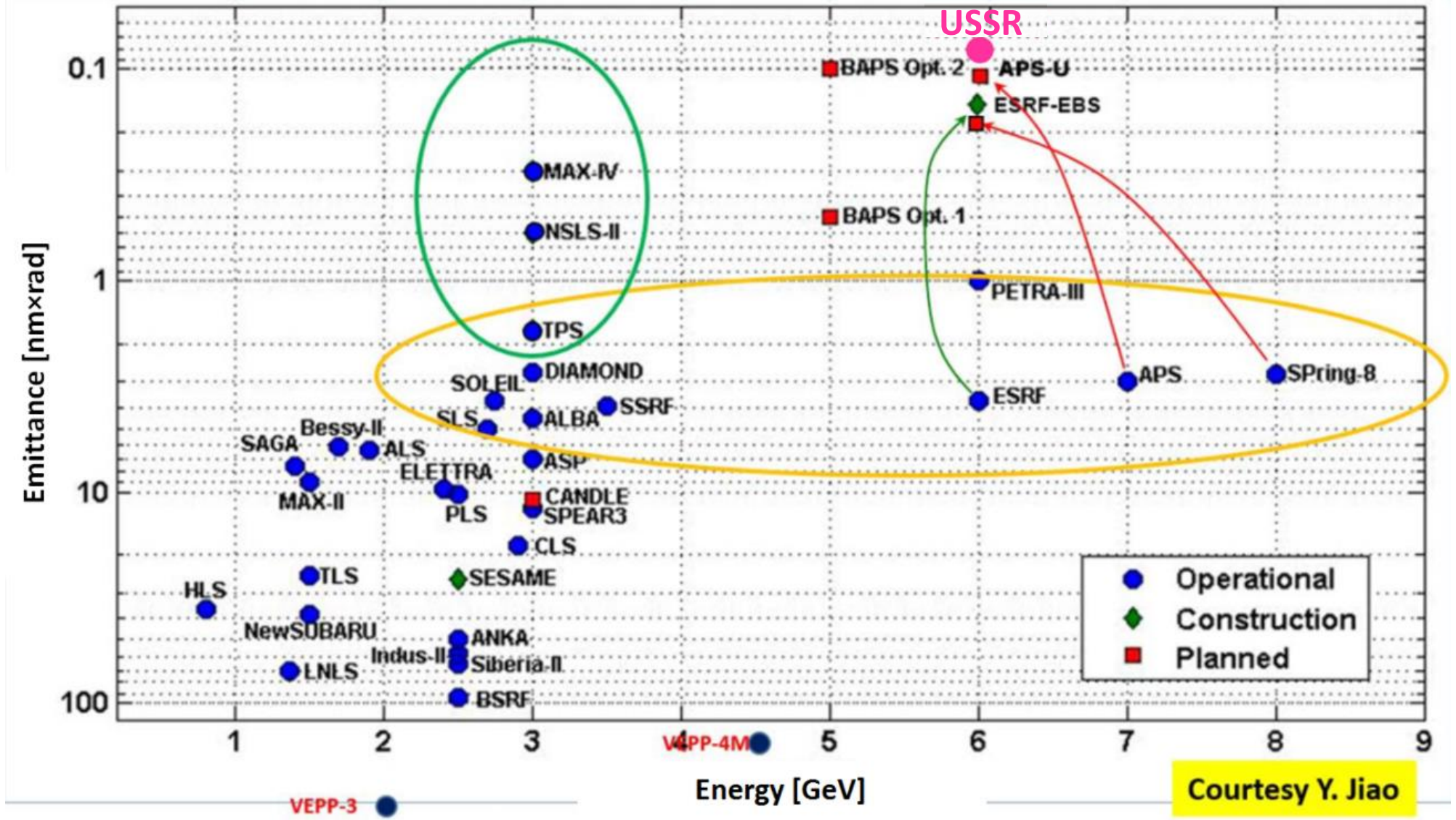
European XFEL

Development of **beamlines projects** of the USSR synchrotron

ESRF-EBS

DESY.

World-wide landscape of SR sources



4th generation synchrotron radiation sources

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USSR, Russia, 70 pm*rad (6 GeV)

	Horizon. Emittance [pm * rad]	Energy [GeV]	Circumference (m)	Year
USSR	70 (60)	6	1100	2027
ESRF-EBS	147	6	850	2020
PETRA-4	20	6	2200	2027
APS-U	50	6	1100	2025
SPring-8	67	6	1400	
HEPS	60	6	1296	2025
TeVUSR	2	11	6210	---
PEP-X	11	4.5	2199	---
SKIF	75	3	477	2024
MAX - IV	330	3	530	2019
Sirius	250	3	518	2019

Operating sources of SR

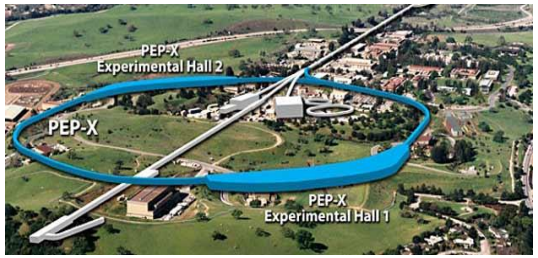
ESRF-EBS, France, 130 pm*rad (6 GeV)

MAX-IV, Sweden, 250 pm*rad (3 GeV)

Planned / under construction

APS-U, USA, 42 pm*rad (6 GeV)

PEP-X, USA, 11 pm*rad (6 GeV)



Spring-8 II, Japan, 67 pm*rad (6 GeV)

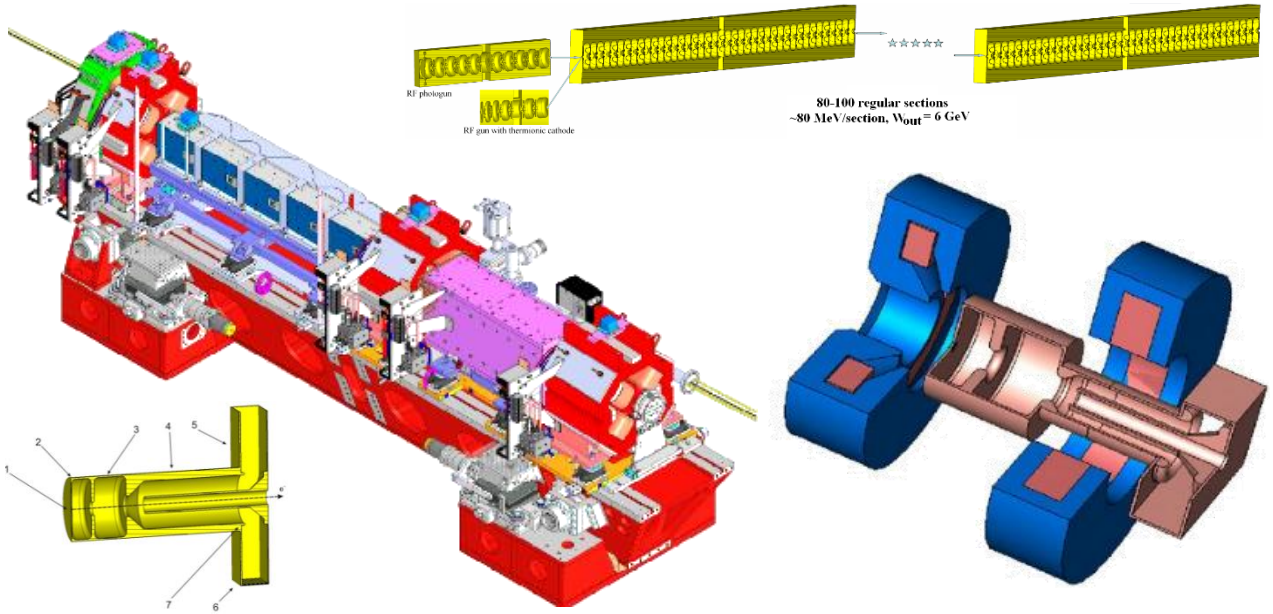
PETRA-IV, Germany, 15 pm*rad (6 GeV)

Prototypes

Based on the results of R&D, set of **working prototypes**
and documentation will be developed for the following units and systems:

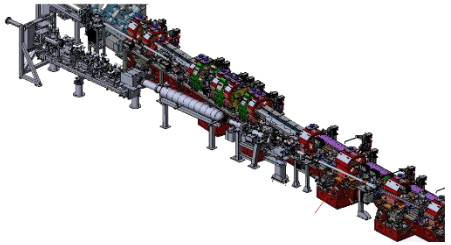
Accelerator storage complex:

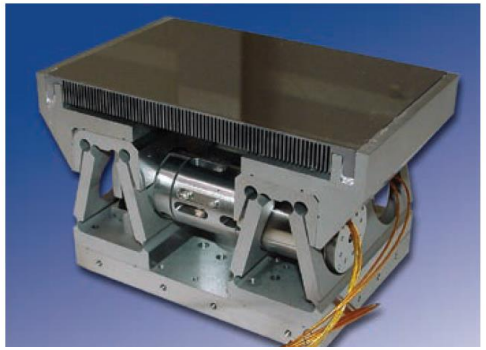
- Photogun
- Regular Linear Accelerator Section
- Regular section of the main ring
- Vacuum section
- Control, beam monitoring and diagnostics system

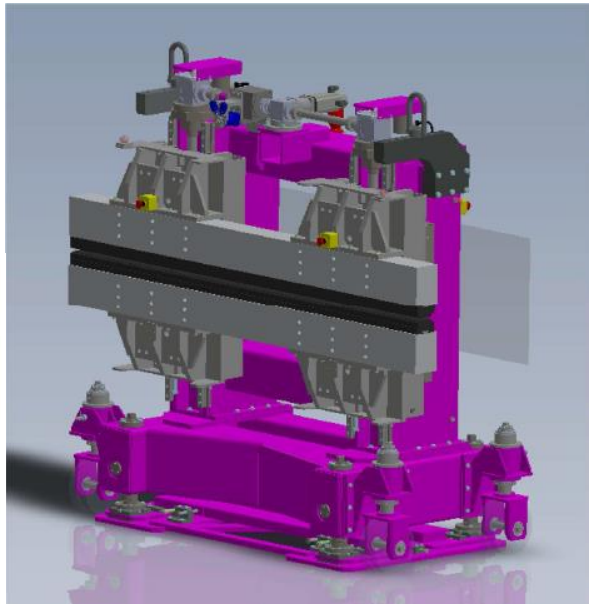


Beamlines:

- Typical frontend for an undulator line
- Typical undulator
- X-ray optics elements
- SR detection systems
- Mechanical and kinematic systems







XX CENTURY - The era of crystallography
XXI CENTURY - Research of disordered objects

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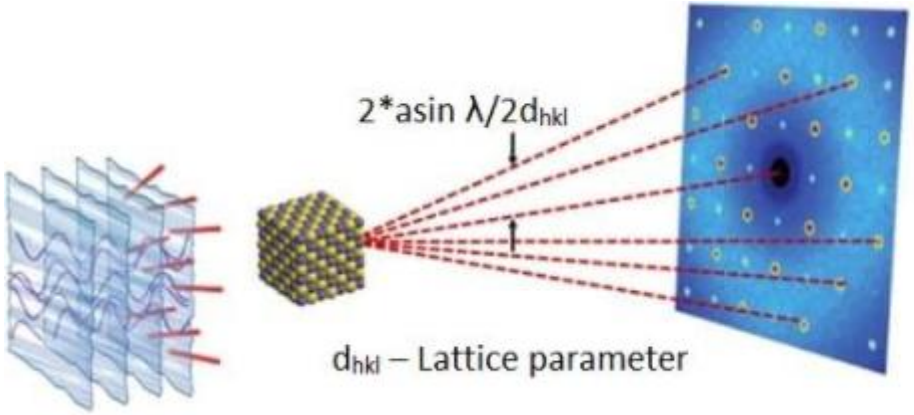
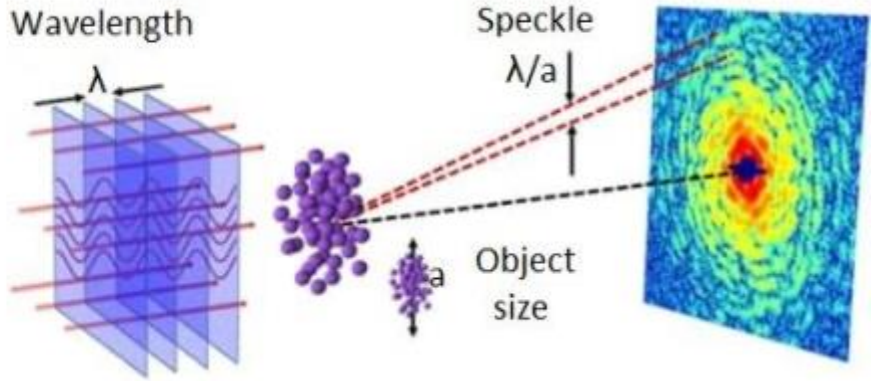
The structure of disordered objects (nano-objects)

Incoherent scattering and an ordered object



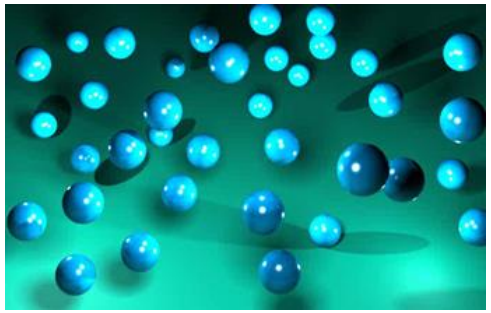
Coherent scattering and disordered object



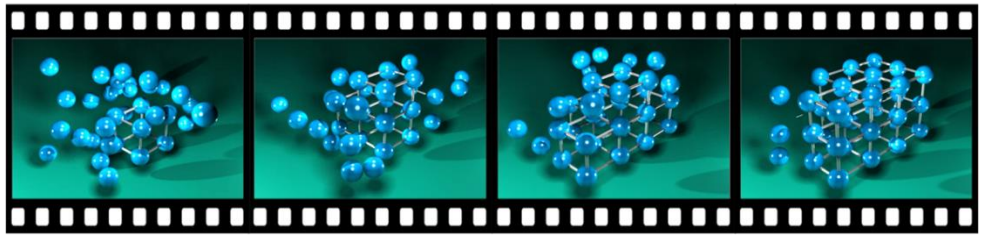
The interference pattern allows you to determine the structure of the sample!

Dynamics of the nanoworld at a fundamental level

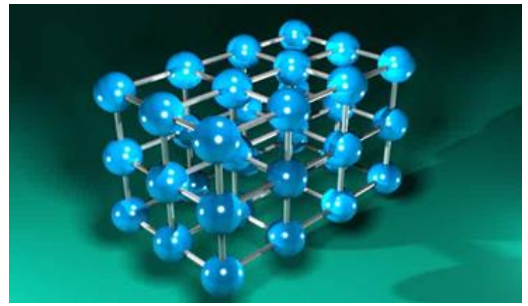
Chaos



4-d crystallography



Order



Benefits from the principally new facility

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- **Wide energy range (200 eV - 500 keV):** spectroscopy of light and heavy elements in the bulk of the material. The brightest source in the hard range. 3D mapping and visualization in depth of the sample.
- **Peak brightness (more than 10^{22} for SR, more than 10^{31} for XFEL):** nanoscale objects, atomic resolution. Multiscale visualization. Fast mapping with chemical and magnetic contrast.
- **Short impulse (duration from ns to fs):** ultra-high resolution structural diagnostics.
- **Coherence (30 - 100% depending on the wavelength):** atomic resolution for disordered structures, including single molecules, viruses. Lensless imaging for hard range. Phase contrast imaging.

Scientific case

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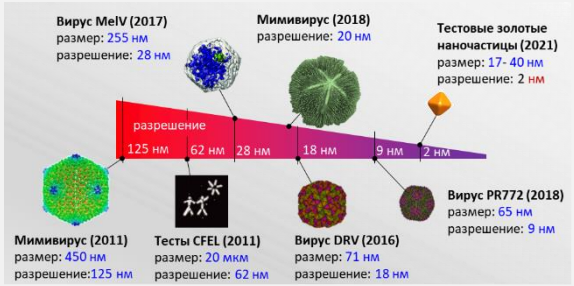
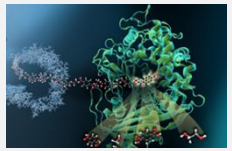
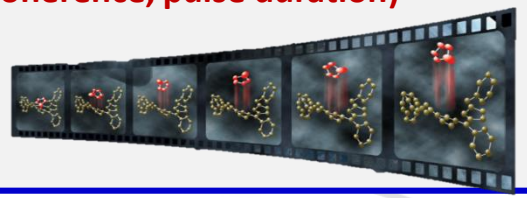
Single particle visualization
(brightness, coherence)



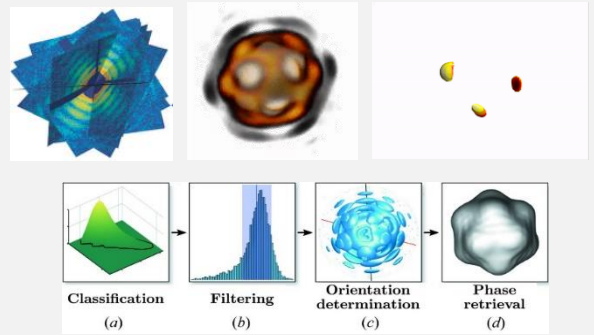
Dynamics of the nanoworld with femtosecond resolution, quantum systems
(brightness, coherence, pulse duration)



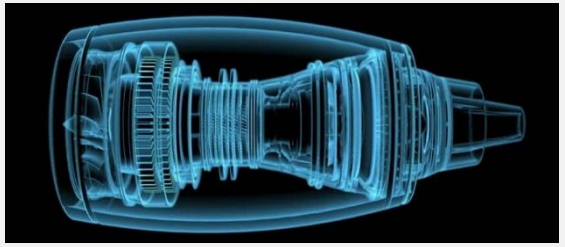


- **Nature-like technologies**
  (bioorganic, hybrid materials, artificial cell)
- **Personalized medicine and diagnostics**
- **Electronic component base**
  (magnetic materials, nanoelectronics, neuromorphic systems)
- **Construction materials and products**
  (massive machine parts, welds, titanium, coatings, shape memory)
- **Additive technologies and materials**
- **Materials with unique properties**
- **New energy**
  (superconductors, thermo-photo-electricians, electromotion)

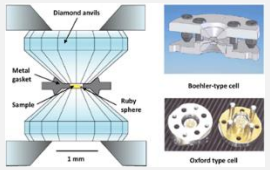
Research of biological objects
(brightness, coherence, energy)



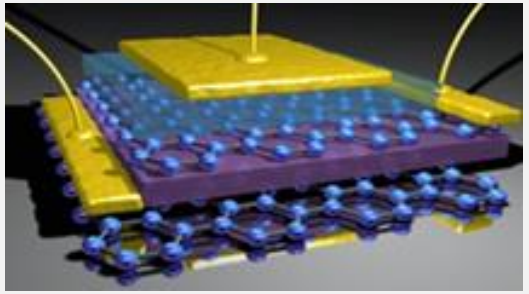
Massive objects visualization
(energy, brightness, coherence)



Extreme state of matter
(brightness, coherence, energy, power and pulse width)



Research of electronic and magnetic properties
(brightness, coherence, energy)



USSR beamlines: stage 1

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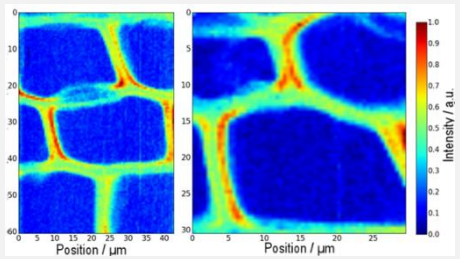
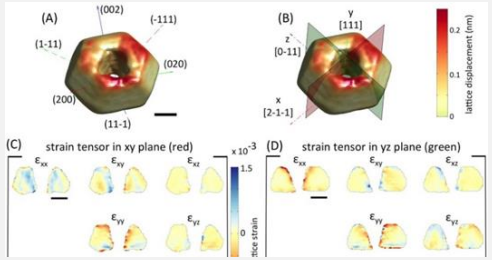
Nanodiffraction beamline

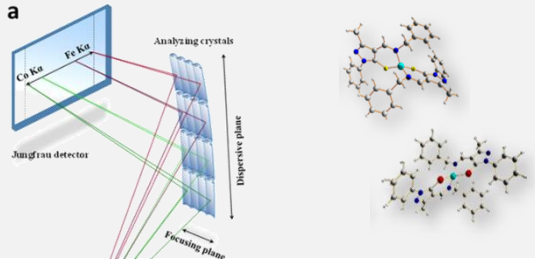
(Materials Science, NBIKS technologies, Microelectronics)

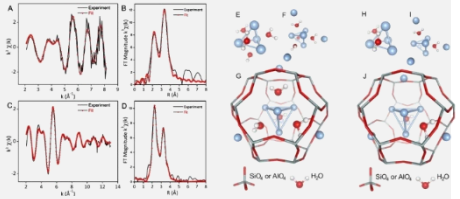




X-ray spectroscopy beamline

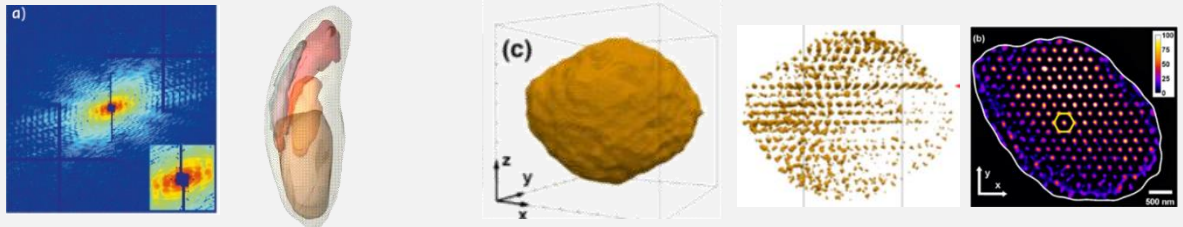
(Structural Chemistry and Materials Science, Biology and Geology)





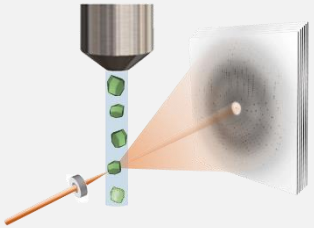
Coherent application beamline

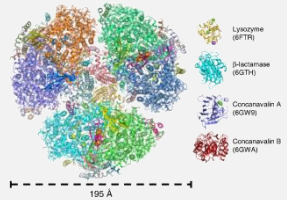
(Nature-like technologies, Materials Sciences)



Serial crystallography beamline

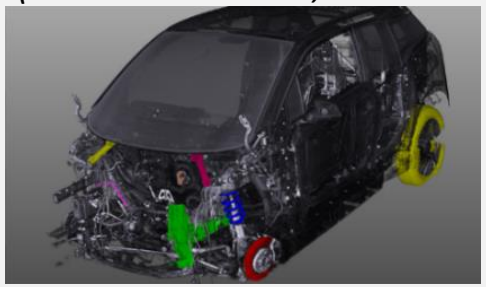
(Structural biology, nature-like technologies)





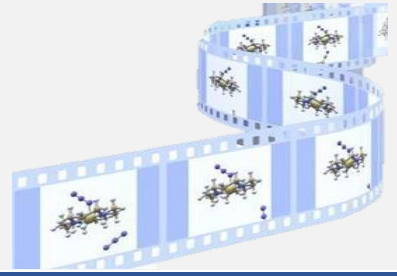
Multi-scale imaging beamline

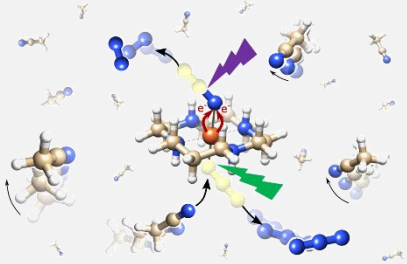
(Materials Science, Socio-humanitarian Technologies, Medicine)



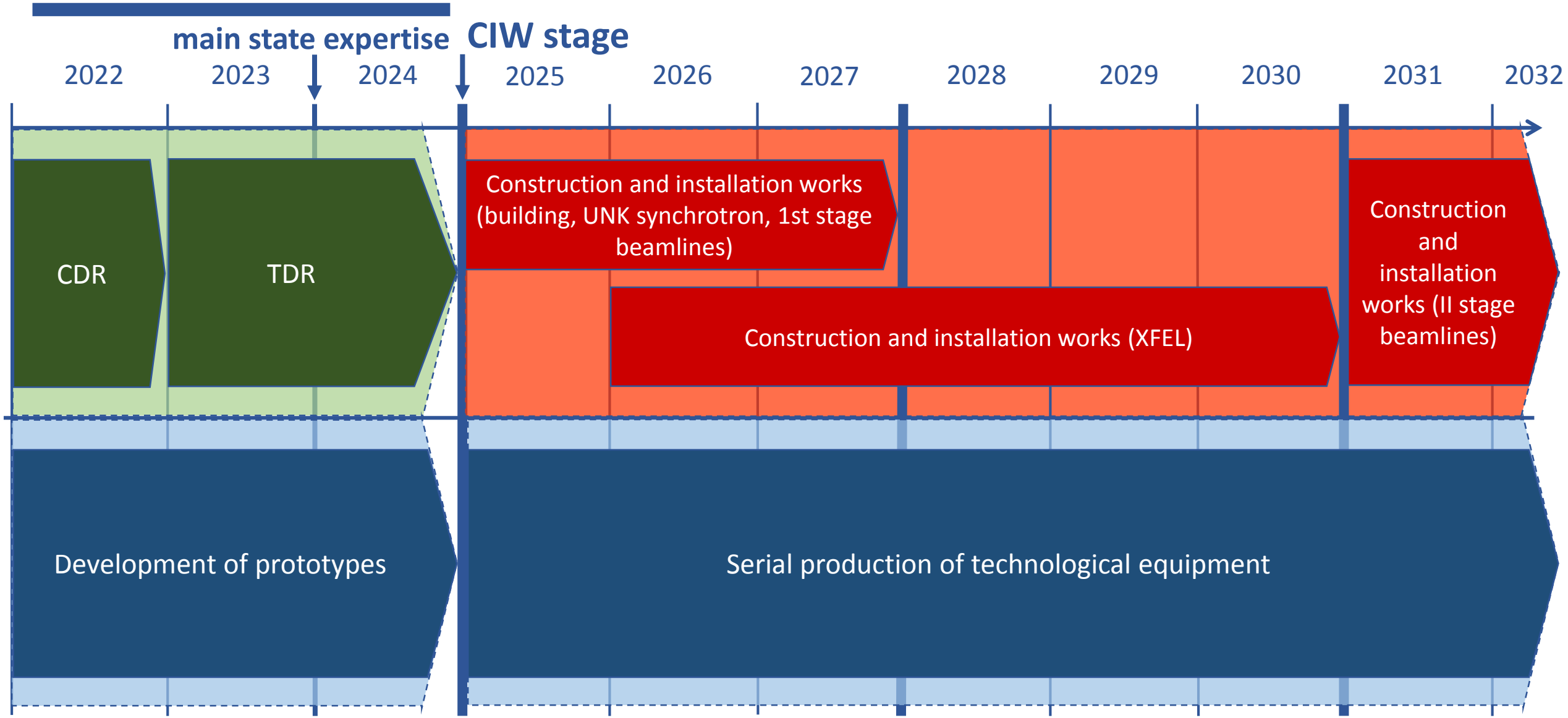
Time resolution beamline

(Materials Sciences, Nature-like technologies)





Roadmap of the USSR project



Conclusion

The creation of a USSR synchrotron radiation source will determine **Russia's leadership** in the field of synchrotron research **for several decades** and will ensure the creation of breakthrough technologies that form a fundamentally new basis of the Russian economy.


THANK YOU FOR THE
ATTENTION!