НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ЦЕНТР
«КУРЧАТОВСКИЙ ИНСТИТУТ»

Concept of a New Kurchatov Synchrotron Radiation Source

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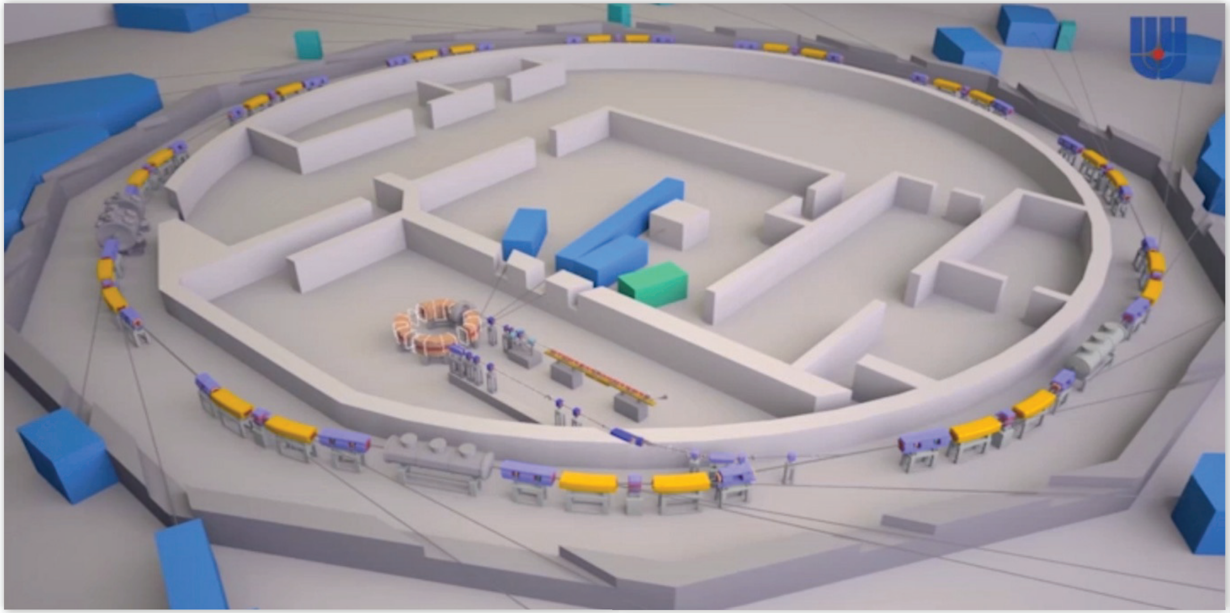
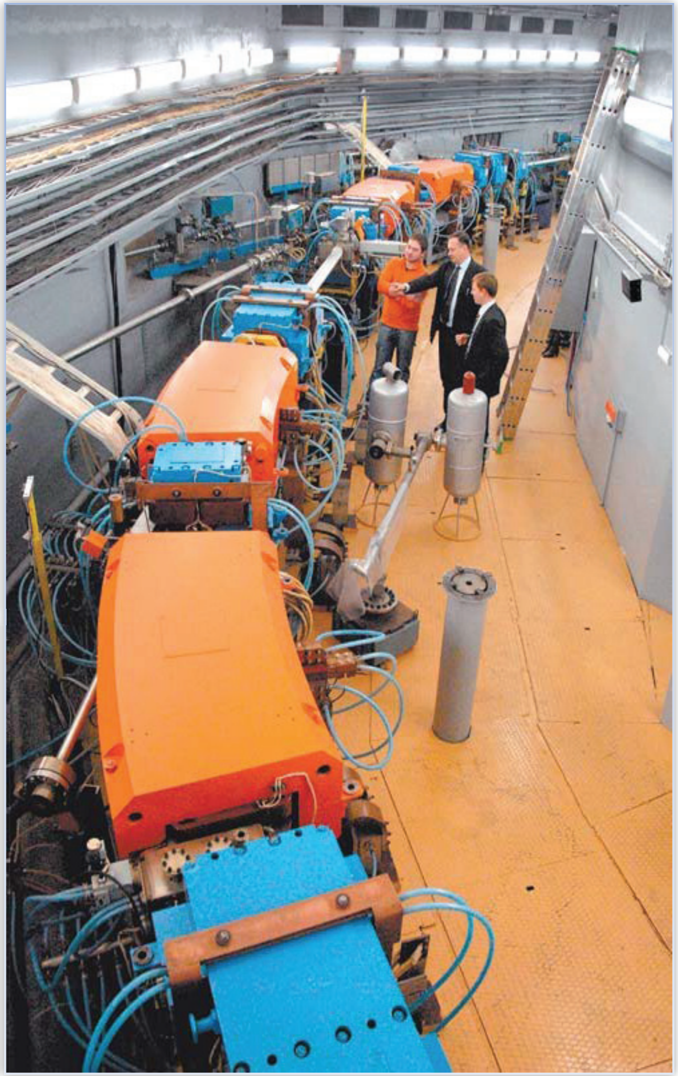
NRC KI,

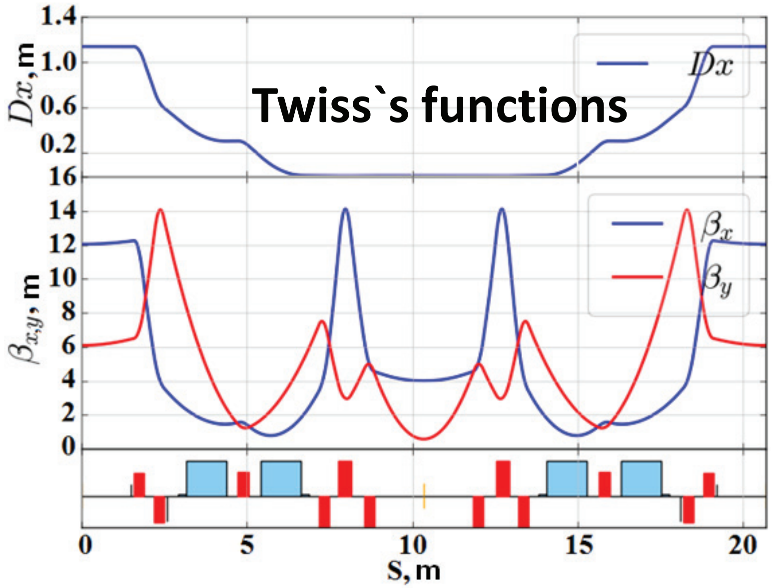
RUPAC 2021 26.09-02.10/2021

KSRS-1 Overview





KSRS-1 Status



KSRS-1 main parameters

Energy	2.5 GeV
Perimeter	124.130 m
Superperiods	6
Emittance	98 nm-rad
Electron current	~150 mA
Life time	15-20 hrs
Betatron numbers	7.775 / 6.695
Chromaticities, x/y	-16.9 / -12.9

Structure - Modified DBA

Earlier studies had shown that with existing magnetic structure of SR Source "Siberia-2" it is possible to achieve:

- **emittance 55-65 nm · rad when keeping zero dispersion function, but an injection factor was limited due to lower DA and large emittance of "Siberia-1" (800 nm-rad)**
- **emittance 13-18 nm · rad - reinstallation of sextupoles and work with non-zero dispersion function in the straight sections. Limitations: it is impossible to operate with strong field SCW, small DA and large injected emittance.**

Content of the KSRS-1 modernization project. Decree of the Russian Federation Government on March 20, 2020

1. Development and creation of a new injection complex, consisting of:

1.1. A new booster synchrotron (BS) - an electron injector with an energy of 2.5 GeV for a new SR source;

1.2. a new 200 MeV linear electron accelerator (LUE) - injector for BS;

1.3. the electron transport lines (EOK-1, EOK-2)

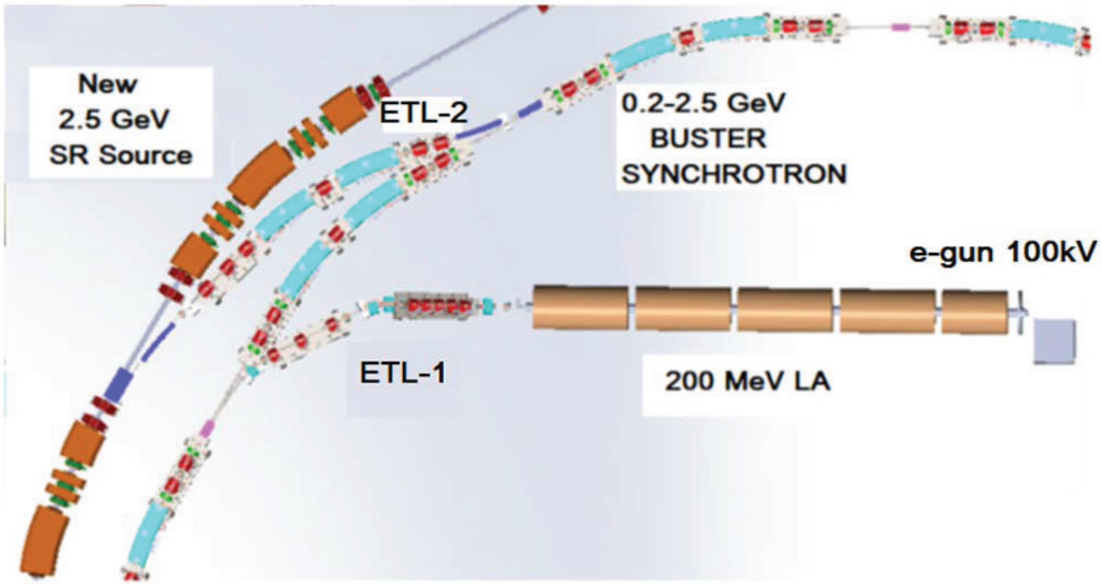
2. Creation of a new 2.5 GeV SR source ring with the natural emittance of 2-4 nm-rad:

- **to bring closer the SR fluxes and SR brightness to the values typical for SR sources of the 3rd generation;**
- **to keep the perimeter of the old SR source and the coordinates of the existing SR channels.**

3. Main features for KSRS:

- **All three KSRS accelerators disassembling**

New injection complex of KSRS-2: BS+LA

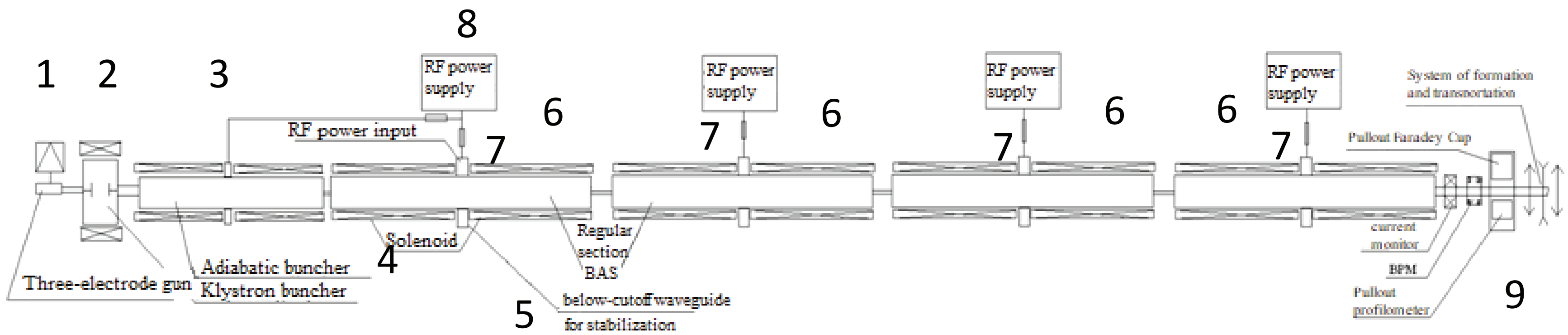


- Aim for KSSR-2^
- Average beam current 200 mA
- The beam lifetime is 20 h.
- Separatrix number 75
- Total beam charge 100-120 nC

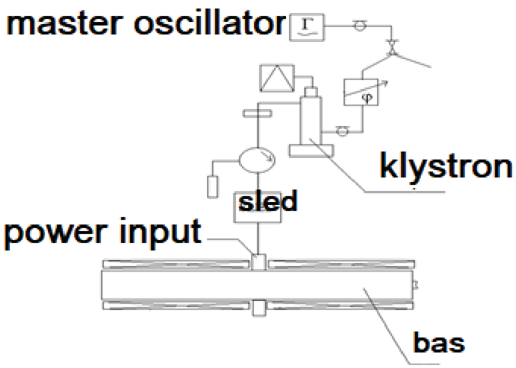
KSRS-2 injection complex scheme

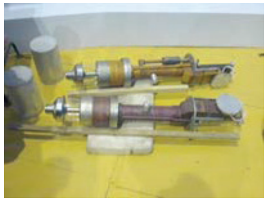
- New electron gun with buncher (max 3 A, 100 keV, Δt ~ 5 ns)
- new linear accelerator (max 2 A, 200 MeV, Δt ~ 5 ns)
- new booster synchrotron (10-15 mA, 0.2-2.5 GeV)
- new main storage (200 mA, 2.5 GeV)

A new pre-injector - 200 MeV, 2797 MHz Linear Accelerator



Schematic diagram of microwave power supply





Friazino,
"НПП «Исток»"

COMPOSITION OF LA:

1. 3-electrode electron gun, 100-120 keV
2. Klystron buncher
3. Adiabatic buncher, 10 MeV, capture coefficient in LA - 70-75%
4. Solenoids for transverse focusing
5. Transcendental waveguide for symmetrization
6. Regular section BAS
7. Microwave power input
8. Microwave power supply
9. Retractable Faraday Cylinder
10. System of formation and transportation
11. Current sensor
12. BPM
13. Retractable profilometre

**Biperiod accelerating structure - BAS - standing voltage wave,
4 Klystrons KIU-53A, 18-20 MW, 2797 MHz, section ~ 2.4 m, acceleration rate 25-30 MeV / m**

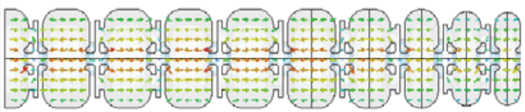
Status LA. The beam dynamics simulation in 200 MeV linac

Adiabatic buncher

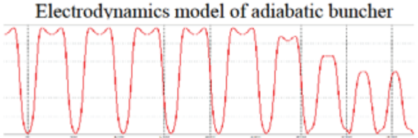
$W \sim 10$ MeV. $F = 2800$ MHz. $N_{periods} = 26$.

Beam dynamics simulation results at the exit of the adiabatic buncher.

Parameter	Value
Electric field amplitude, E_{max}, kV/cm	150
Full output energy W_{out}, MeV	10.15
Output current I_{out}, mA	447.3
Transmission coefficient, %	74.5
Longitudinal losses, %	24.5
Transverse losses, %	0.9
Width of the energy spectrum FWHM, %	±1.5

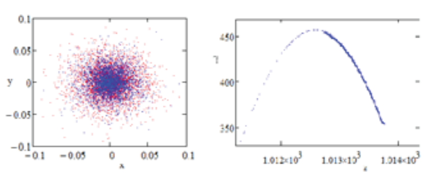


Electrodynamics model of adiabatic buncher

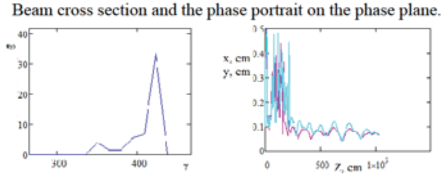


Electric field distribution in adiabatic buncher

Front-to-end simulation



Beam cross section and the phase portrait on the phase plane.



The energy spectrum and beam envelope

Regular sections

The biperiodical accelerating structure (BAS) operating on a standing wave was chosen as an accelerating structure.

Beam dynamics simulation results at the output of the fourth regular section depending on the injection phase.

Parameter	Value		
Injection phase, $d\varphi$	0,75	0	-0,75
Full output energy, MeV	196.0	215,7	214,2
Output current I_{out}, mA	354.2	325.3	348.9
Transmission coeff., %	59.0	54.2	58,2
Longitudinal losses, %	39.7	44.8	40,9
Transverse losses, %	1.2	2.6	1
FWHM, %	±2.6	±2.2	±1.7

Eelectrodynamics characteristics:
$K_{co} = 11\%$;
$r_{sh.ef.} = 96$ MOhm/m;
Q-factor: 12800;
group velocity: 0.165c;
$E_{max}/E_{acc} = 3.66$.

Maximum field strength on axis: 450 kV/cm. Output energy is near about 215 MeV. Energy acceleration rate: 50-55 MeV/section. The transverse emittance at the output of the linac will be about 10 nm rad.

Linear Accelerator project status

- The geometric and electrical parameters of the electron gun, the adiabatic buncher were found;
- the geometrical elements for inputting microwave power into the accelerating cells were determined;
- mathematical modeling of the dynamics of the electron beam in the LA was carried out, the optimal parameters of the resonant accelerating structure with high impedance were found;
- the microwave power supply scheme was determined.
- A set of defining geometric parameters (form of accelerating sells) for the start of specific design studies of microwave systems has been found.

- SEE: Poster

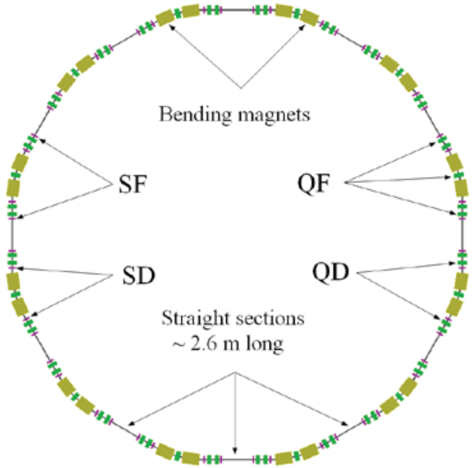
200 MEV LINEAR ELECTRON ACCELERATOR – PRE-INJECTOR FOR A NEW KURCHATOV SYNCHROTRON RADIATION SOURCE

02-2.5 GeV Booster Synchrotron Project

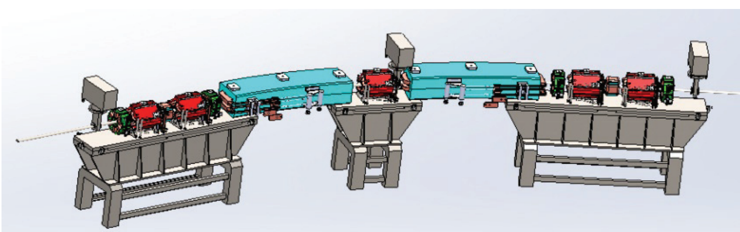
Planed:

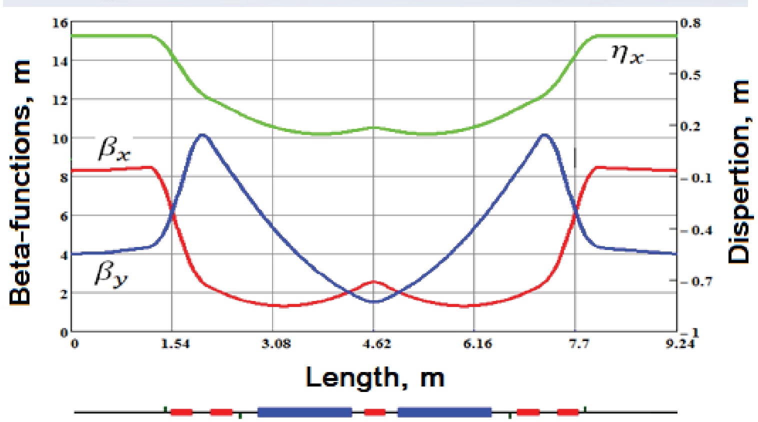
- to inject from the BS an electron beam with low emittances (ex ~ 50 nm-rad) at a total energy of 2.5 GeV with high efficiency (low radiation load);
- to exclude in the KSSR-2 ring the periodic process of accumulation of electrons at low energy, which interrupts the use of SR beams at X-ray stations, leads to temperature problems of orbit stabilization, transient electronic-magnetic processes when the electron energy rises in the storage ring, when working with SCW and other plug-in devices;
- to achieve the effect of "infinite" lifetime of the electron beam;
- to work with much higher stability of the spatial position of photon beams;
- to improve the reliability of the SR source with the help of new technologies, and more stabilized power supplies.

BS Project:: Optical structure of BS - 12-fold symmetry



12 s / periods, 24 BMs, 60 Qs, 46 Ss, 12 straight sections 2.6 m long





Energy, GeV	0.200	2.5
Super-periods	12	
Circumference, m	**110.873**	
Operation cycle, Hz	1	
Electron beam current, mA	10	
Revolution frequency, MHz	2.704	
RF system frequency, MHz	**181.1**	
RF harmonic number	67	
RF acceptance, ε_{RF}, %	1.7	0.7
Betatron number: Q_x/ Q_y	**7.178/4.367**	
Synchrotron numder: Q_s	$8\cdot10^{-4}$	$9\cdot10^{-4}$
Max./Min. lattice functions: $\beta_{xmax}/\beta_{xmin}$, m $\beta_{ymax}/\beta_{ymin}$, m h_{xmax}/h_{xmin} , m	xx 8.472/1.323 10.156/1.528 0.715/0.147	
Chromaticity: x/y	**–9.0186/–8.5569**	
Momentum compaction factor, *a*	0.00997	
Horizontal emittance, e_x, nm-rad	300 (Lin. Acc.)	**43.4**
Energy spread, s_E/E, %	1.5 (Lin. Acc.)	**0.084**
Energy loss/turn, U_0 , keV	0.022	**538.6**
Oscillation damping times:: horizontal, t_x vertical, t_y Longitudinal, t_s	 6.9 c 6.7 c 3.3 c	 3.53 мс 3.43 мс 1.69 мс
Damping factors: J_x J_y J_s	 0.995 1.000 2.005	

Status of BS Project

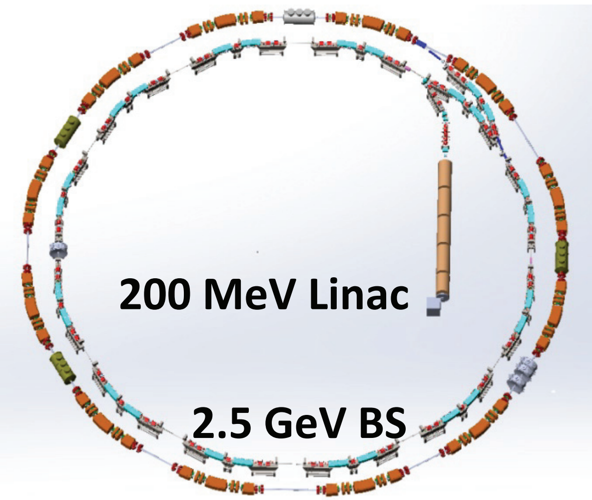
- 3D calculations of magnetic fields in BS laminated magnets were carried out: the relative integral inhomogeneity of the magnetic field in the "good field" region for the dipole component does not exceed 1 · 10-4, for the quadrupole component - 2 · 10-4, for the sextupole component - 5 · 10-4.
- Terms of reference for all magnetic elements of the BS have been worked out sufficient to begin the design, taking into account the technology being laid for the production of laminated magnets.
- *See* A. Smygacheva. Posters 06 ID: 2084, Poster 07 ID: 2085

New KSRS-2 Project

- **Requirements:**

- saving all experimental stations
- minimization of emittance
- preservation of the spectral range of SR
- preservation of the number, lengths and coordinates of the axes of straight sections with a zero dispersion function
- providing the possibility of injection of an electron beam from a booster synchrotron, placed "concentrically" relative to the ring of the SR source in the same tunnel
- reaching the lifetime of an electron beam of at least 10 h at a current of up to 200 mA
- saving the perimeter of the main storage ring
- meeting technological constraints on the part of all systems

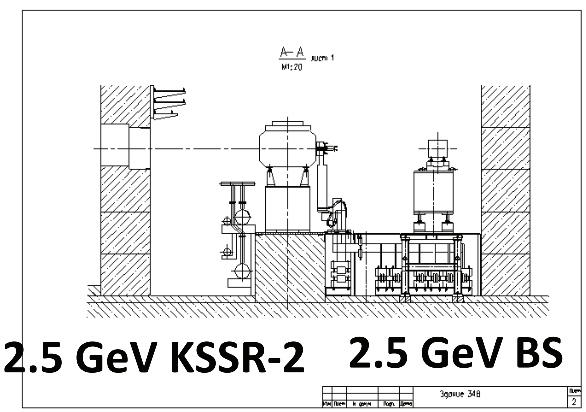
Location of new SR Source and Booster Synchrotron

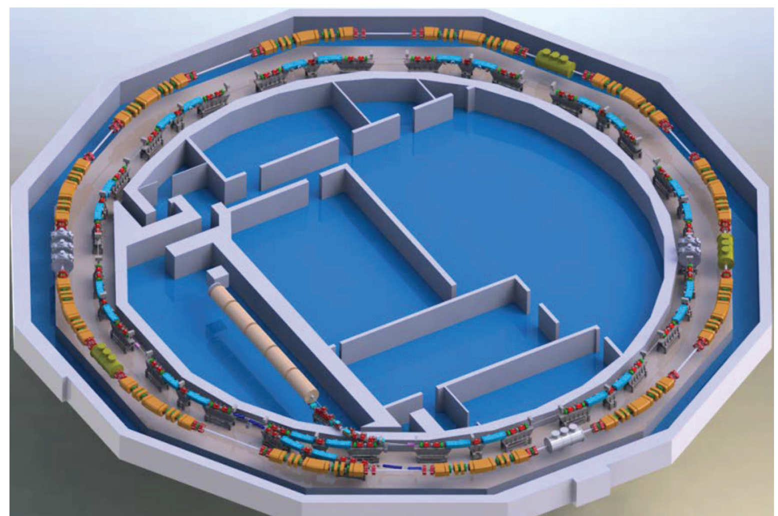


2.5 GeV KSSR-2

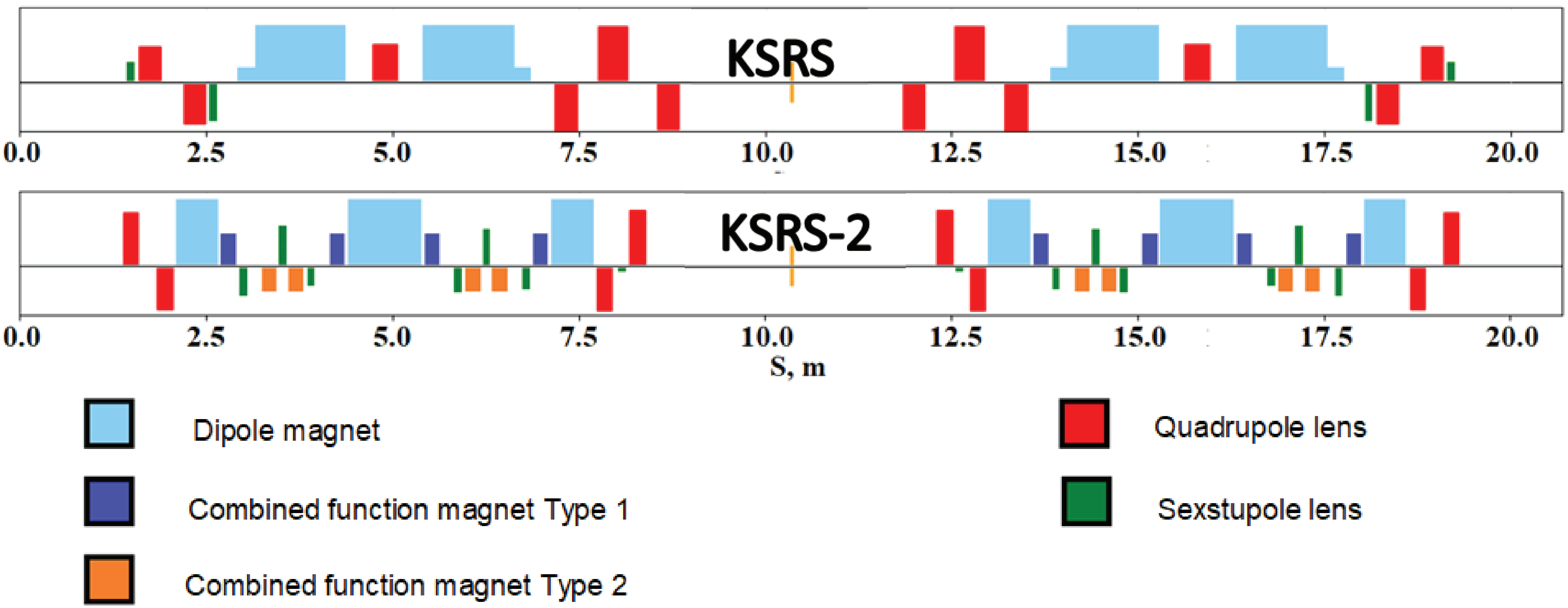
KSSR-2 complex scheme

- New electron gun with buncher (max 3 A, 100 keV, Δt ~ 5 ns)
- new linear accelerator (max 2 A, 200 MeV, Δt ~ 5 ns)
- new booster synchrotron (10-15 mA, 0.2-2.5 GeV)
- new main storage (200 mA, 2.5 GeV)

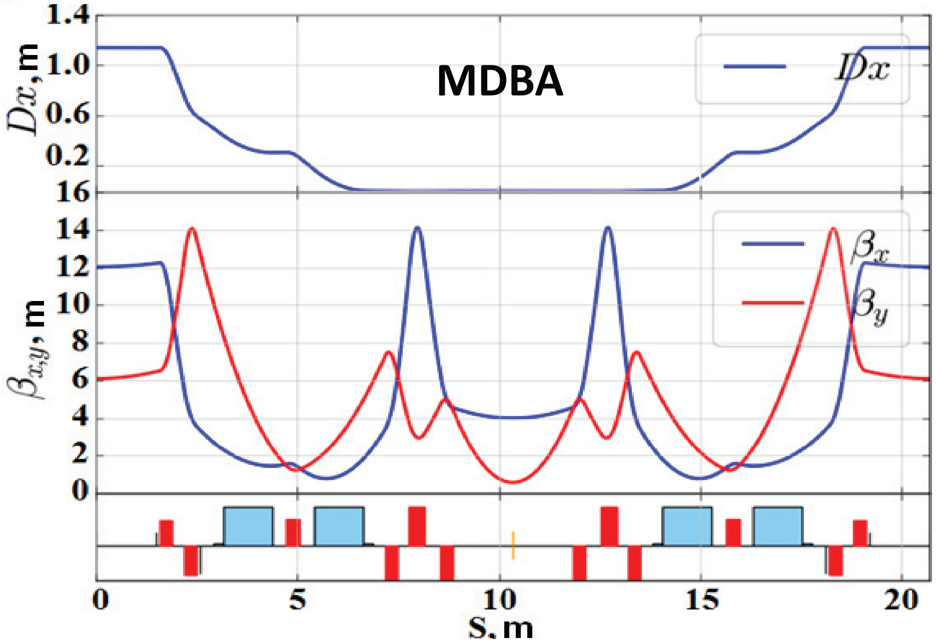




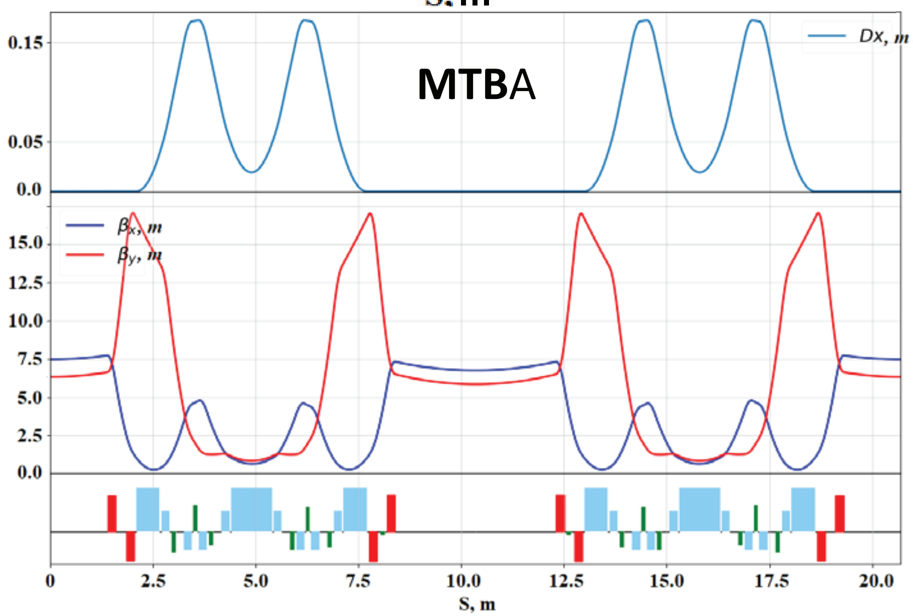
Location of magnets in KSRS and KSRS-2 at one super-period

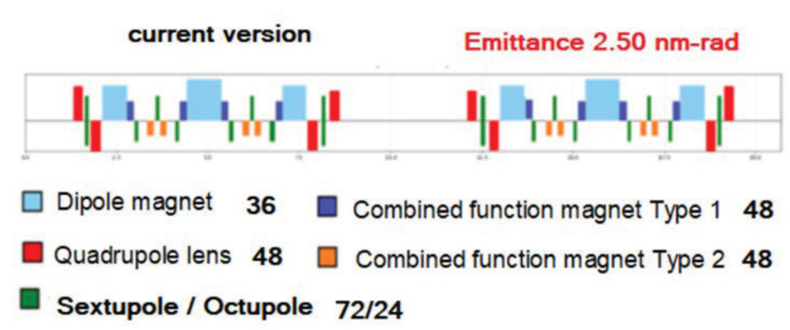


Optical function comparison of KSSR and KSSR-2 latticies



	KSSR		KSSR-2
Perimeter	124.130 м		124.174 м
Emittance	98 нм·рад		2.86 нм·рад
Frequencies	7.775 / 6.695		14.852 / 6.759
Chromaticity	-16.9 / -12.9		-29.3 / 27.0





Parameters of the Kurchatov`s SR source before and after modernization

Parameter	At present	After modernization
Energy, GeV	0.45-2.5	2.5
Circumference, m	124.1304	124.174
Super-periods number	6	
Emittance, nm-rad	97.7	2.86
Betatron numbers, ν_x / ν_y	7.78771 / 6.69652	14.85274 / 6.75948
Natural Chromaticity, ξ_x / ξ_y	-16.7 / -12.8	-29.3 / -27.1
Energy loss per turn, keV	680.7	925.4
Damping times, $\tau_x / \tau_y / \tau_s$, ms	3.172 / 3.041 / 1.490	0.955 / 2.238 / 3.404
Energy spread	$0.95 \cdot 10^{-3}$	$1.76 \cdot 10^{-3}$
Momentum compaction factor	$1.0 \cdot 10^{-2}$	$3.2 \cdot 10^{-4}$
Electron beam current, mA	до 200	
Beam lifetime, h	20-30	∞
RF Frequency, MHz	181.135599	181.071371
HF multiplicity	75	
Straight sections number for Insertion devices	up to 5 wigglers and up to 4 undulators	up to 9 wigglers or up to 9 undulators
Possible number of experimental stations	up to 24 from BM up to 9 from ID	up to 36 from BM up to 9 from ID
Magnetic lattice type	modified DBA	modified TBA
Coupling factor, %	1-10	1-100
Dynamical aperture, mm	±45	±12

Man Ring – KSSR-2 Project work

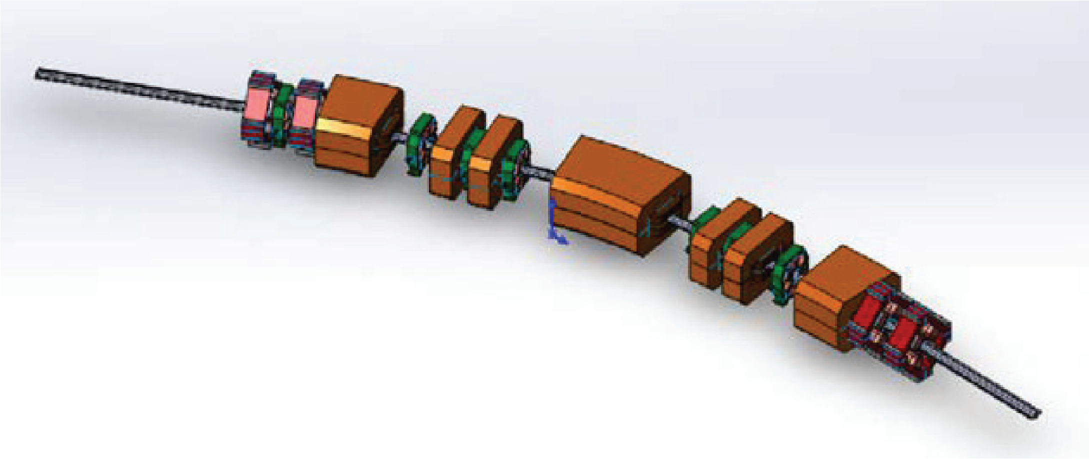
During September 2020 - August 2021, optimization of the new brighter magneto-optical structure of the source were continued.

The current magneto-optical structure provides:

- natural emittance of the electron beam is 2.5 (2.9) nm · rad while maintaining the dynamic aperture with dimensions HxV=12x8 mm sufficient for injection even in the presence of errors in the position of the magnetic elements at the level of 35-50 microns;
- keeping the positions of the beam lines for the SR from the bending magnets with an accuracy of fractions of one millimeter;
- the lengths of the straights for setting superconductive wigglers have been increased from 3m to 3.5m;
- the length of the straights intended for the injection of the electron beam decreased from 3m to 2.6m.

Such a redistribution of the lengths of straight sections is a payment for a significant decrease of the emittance. Nevertheless, the length of the 2.6 m will be quite enough for the installation of insertion devices, similar to those installed on the main ring at the present time.

Arrangement of KSSR-2 magnets at half of the super- period

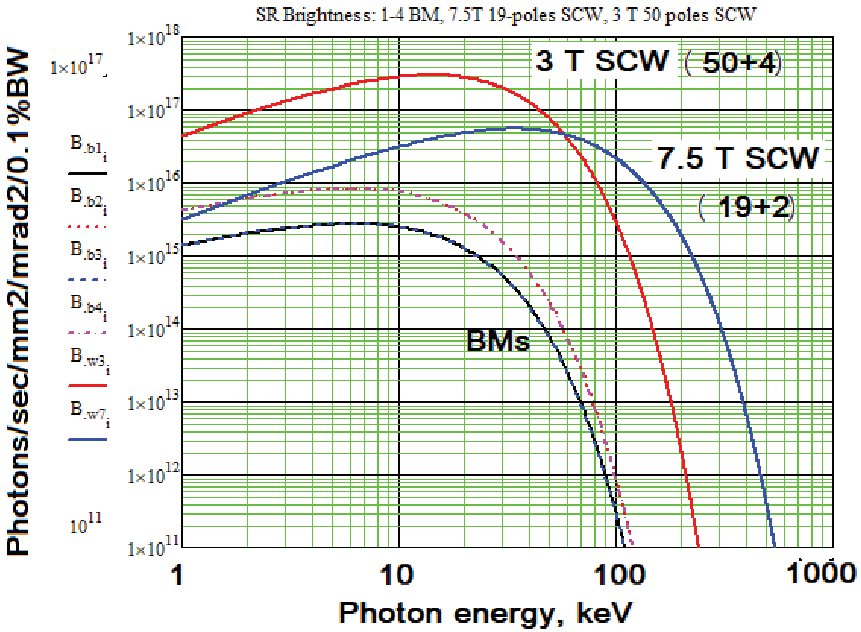


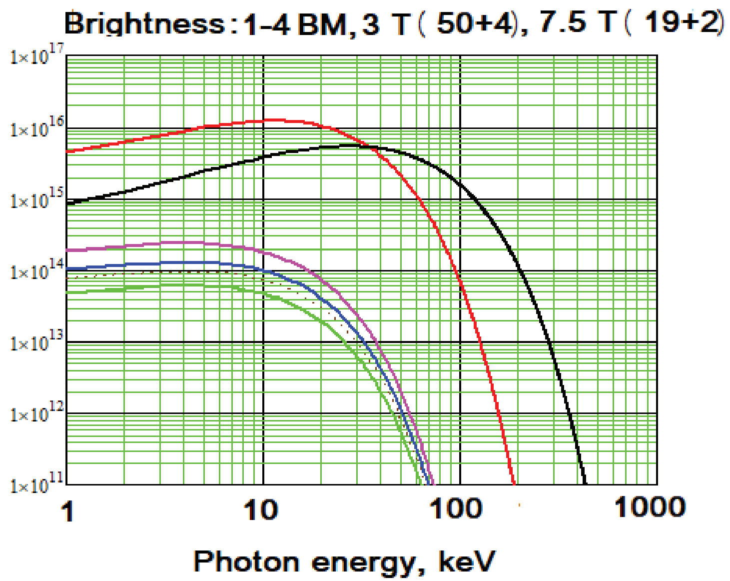
6 super-periods

1/2 superperiod:
3 dipole magnets with a field of 2 T:
4 dipoles - defocusing quadrupoles (DQ, type 1);
4 anti-bend dipoles- focusing quadrupoles (DF, type 2);
4 standard quadrupoles;
6 chromatic sextupoles;
2 harmonic sextupoles and 2 octupoles.

All magnetic elements will be made of non-laminated soft magnetic iron (Armco). The minimum area of good field in all magnets is ± 10 mm horizontally and ± 5 mm vertically accordinally with DA.

SR parameters comparison of old and new structures at 2 .5 GeV, 100 mA





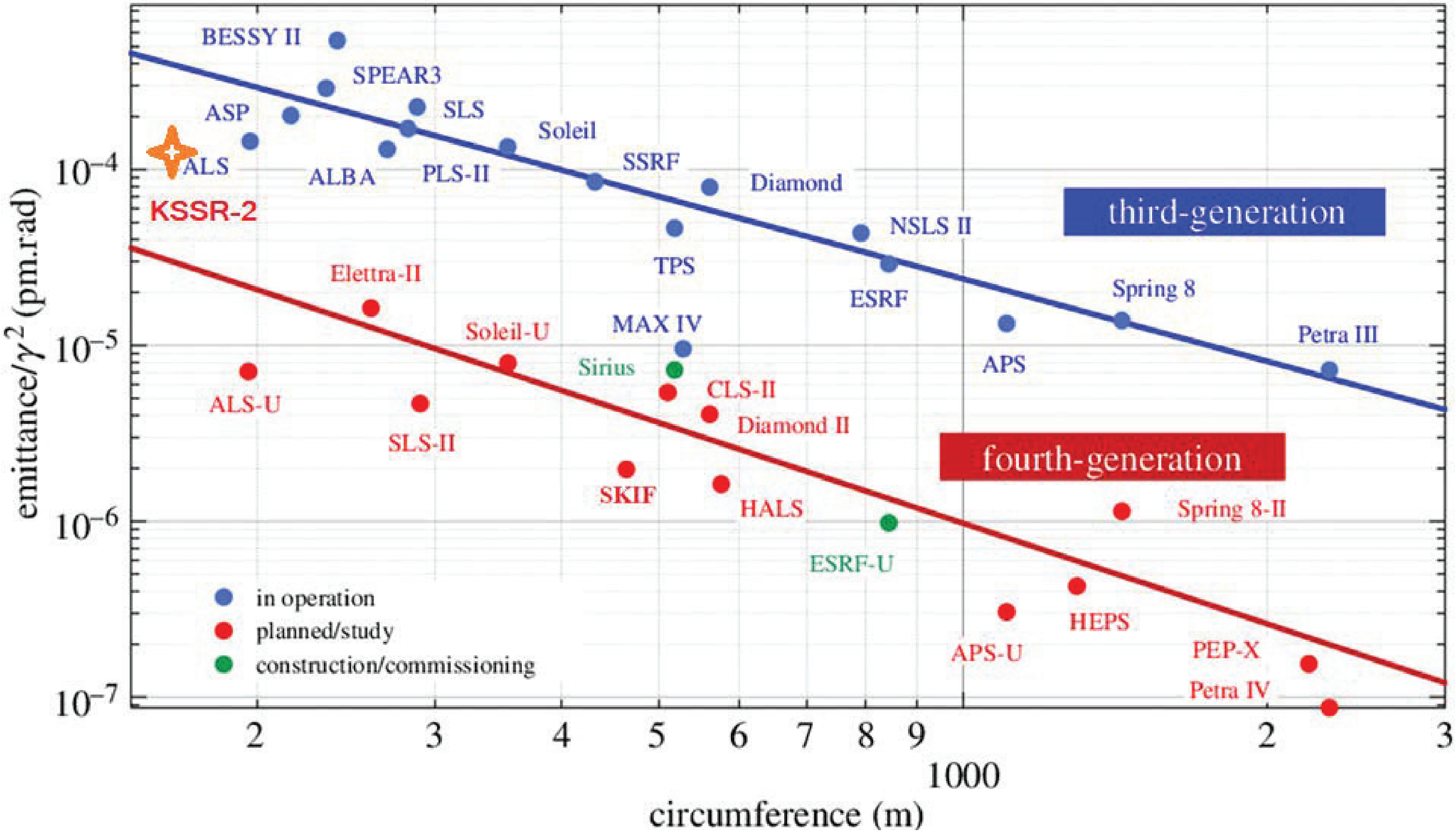
New storage ring: ~3*10^17 **Old storage ring: ~1.03*10^16**

Note that the transition from modified DBA structure, available in the operating SR source "Siberia-2", to modified TBA structure in the new KSRS , creates an additional advantage, allowing, in principle, to increase the number of SR beam lines from bending magnets by one and a half times. Another new feature (advantage) of the new structure is the "zeroing" of the dispersion function in all long (from 2.5 m) straight sections, which also allows increasing the number of special emitters on the ring.

SR Sourses – world experience

Estimation of the electron beam emittance in the new structure based on scaling:

- **MAX-IV (3 GeV, 528 m, 7BA) -> 17 nm-rad**
- **ESRF EBS (6 GeV, 844 m, 7BA) -> 8 nm-rad**
- **SLS-2 (2.4 GeV, 290 m, 7BA) -> 2 nm-rad**
- **ANKA (2.5 GeV, 110 m,, 4BA) -> 6 nm-rad**



KSRS-2 - challenges

- Large number of complex precision magnetic elements
- High precision of magnetic elements alignment in narrow tunnel
- Dense packing of elements on the rings leads to unwanted interaction of edge magnetic fields of different types of neighboring magnets.
- Complex vacuum system – small cross-section of vacuum chamber and its articulation with many and dissimilar devices provided they are tightly packed
- Long-term temperature stabilization of the tunnel and main storage ring
- Numerous power supplies for magnetic elements and others
- Distribution of electrical, water- cooling communications and …

CONCLUSIONS

- **Main Ring.** The calculated magnetic structure of the new SR source at the Kurchatov Institute has a ~ 30 times lower natural emittance, which will ensure the parameters of synchrotron radiation beams (brightness and intensity) at the level of the 3rd generation SR sources. Electromechanical calculations of the KSRS-2 magneto-vacuum system are being carried out. The RF system is being manufactured. The magnets 3D calculations are in progress

- **BS.** The stage of calculations of all magnetic elements of the booster synchrotron has been completed. Terms of reference for all magnetic elements and the RF system of the BS have been developed, sufficient to start work on the development of design documentation, taking into account the technology for the production of BS magnets.

- **Linear Accelerator.** The work carried out on the prototyping and optimization of the parameters of a 200 MeV linear accelerator - pre-injector. A set of defining geometric parameters for the start of specific design studies of microwave systems has been found.

Thank you
for your attention!