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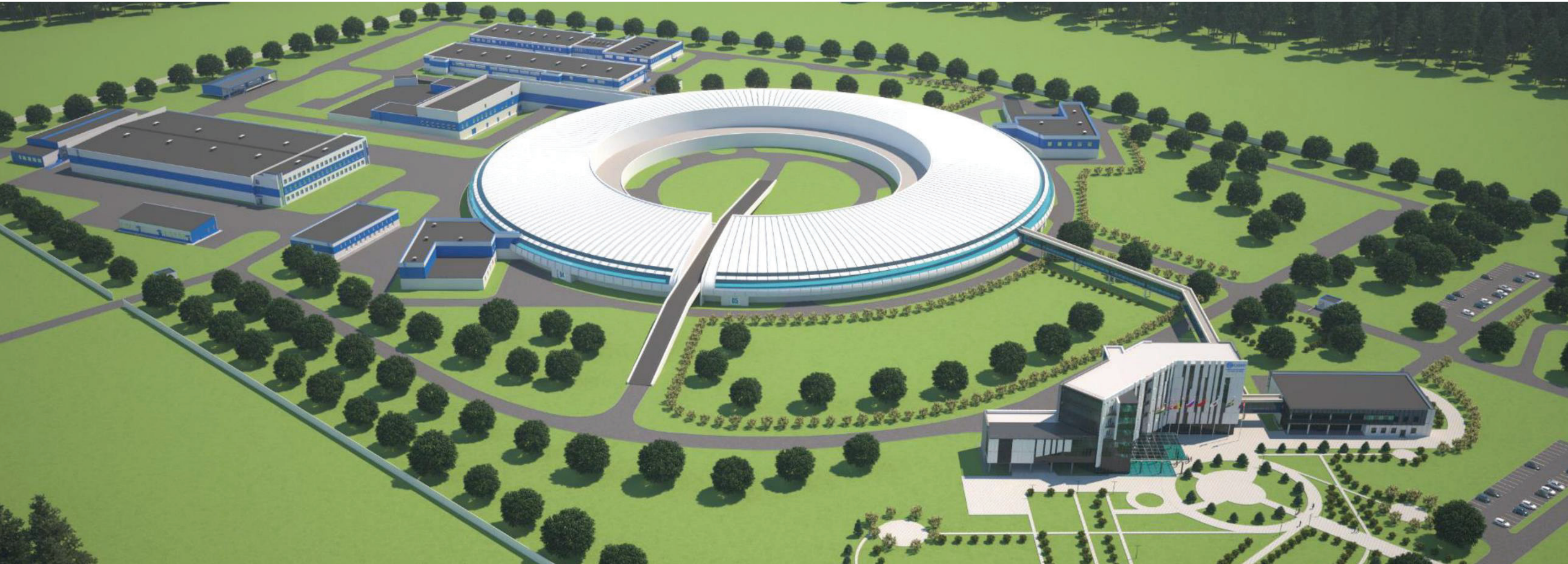
ИНСТИТУТ КАТАЛИЗА
им. Г.К. БОРЕСКОВА

Status of the Novosibirsk Fourth-Generation Light Source SKIF



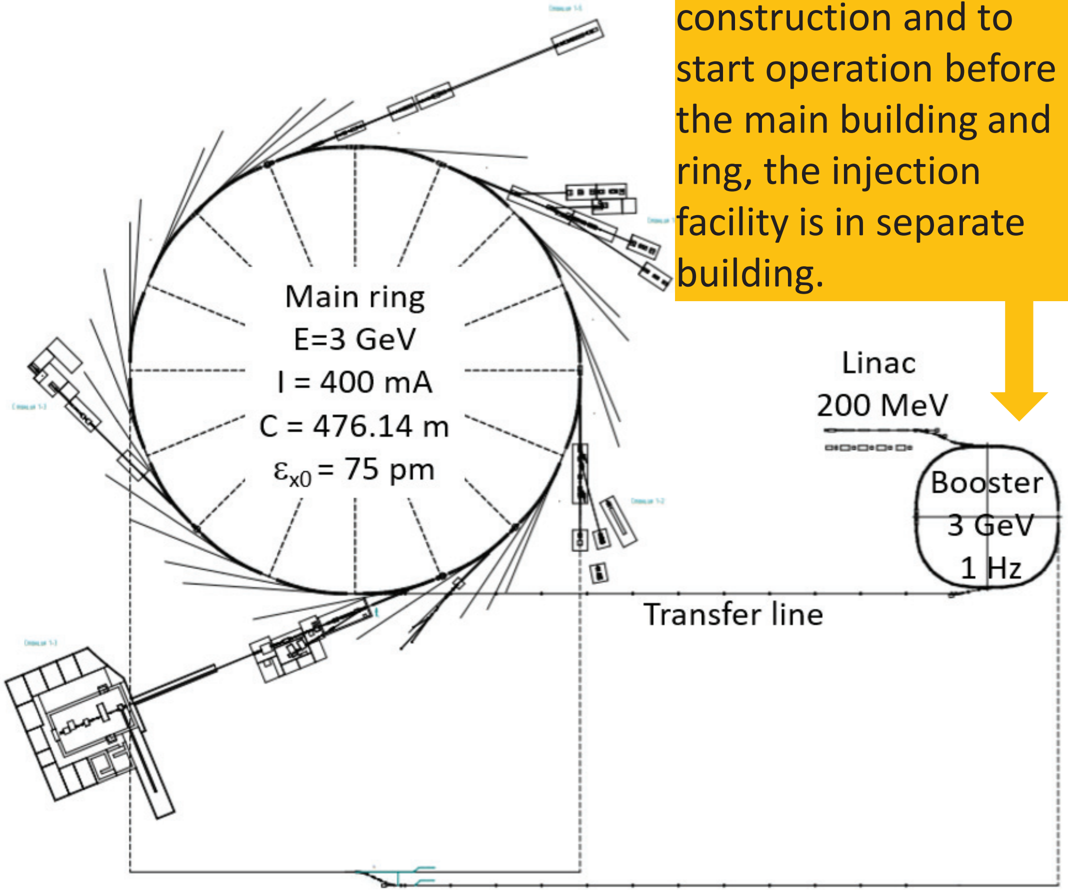
Description

- Beam energy 3 GeV (short construction time)
- Circumference < 500 m (available lot)
- Natural horizontal emittance $\leq$ 100 pm (zero current, no IDs)
- Injection facility: 150-200 МэВ linac, full energy booster
- Traditional off-axis horizontal plane injection with four-kicker bump (reliability)
- Sufficient number of beamlines (users requirements)
  - From wigglers and undulators (straight sections)
  - Hard X-ray from strong field dipoles
  - Soft X-ray and VUV from weak field magnets
- Simple, proven solutions when possible (reliability)

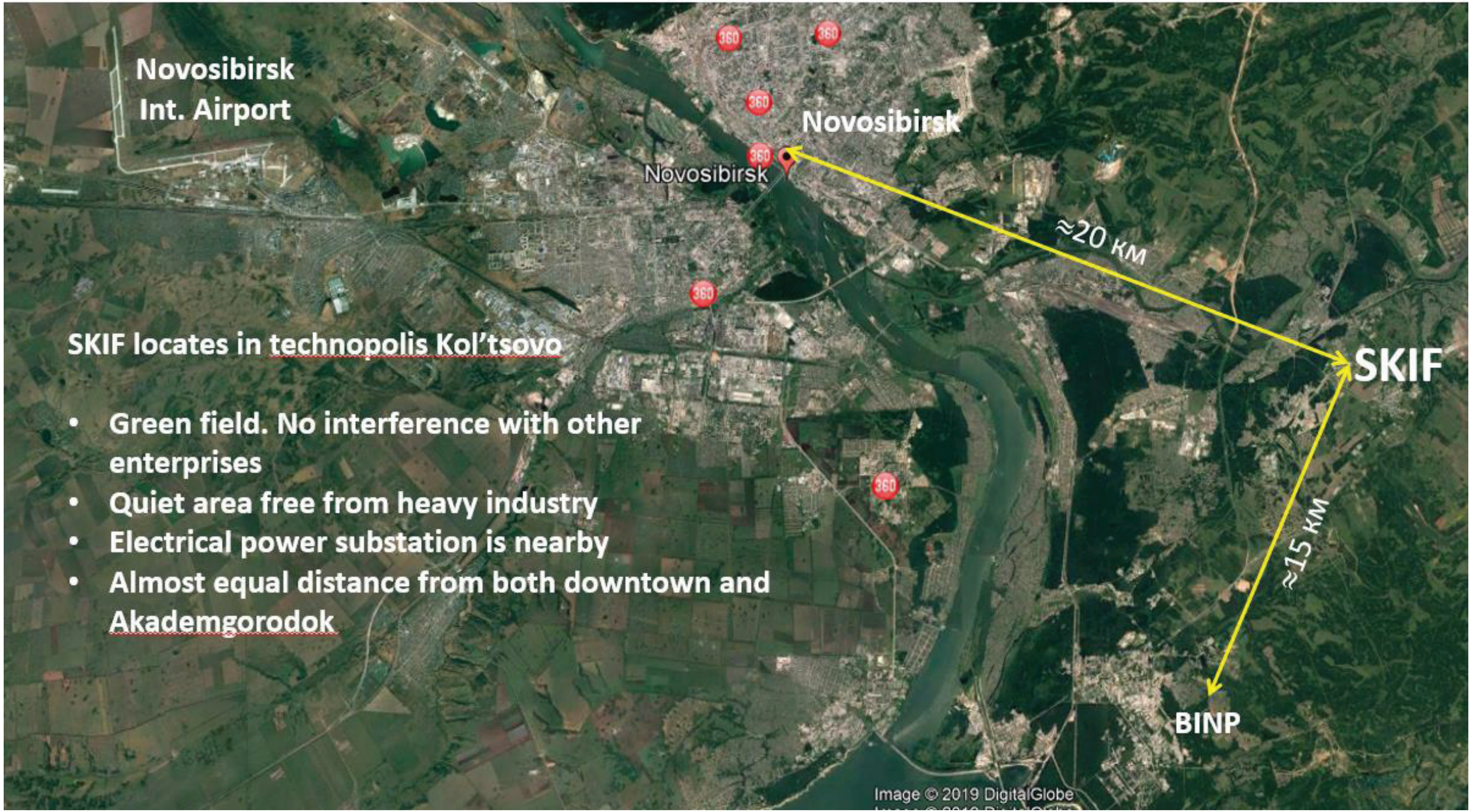
Configuration

- Linear accelerator with maximum energy of 200 MeV
- Booster synchrotron with maximum energy of 3 GeV and orbit length of 158.7 m
- Electron storage ring 16-fold symmetry with 3 GeV energy and 476 m circumference

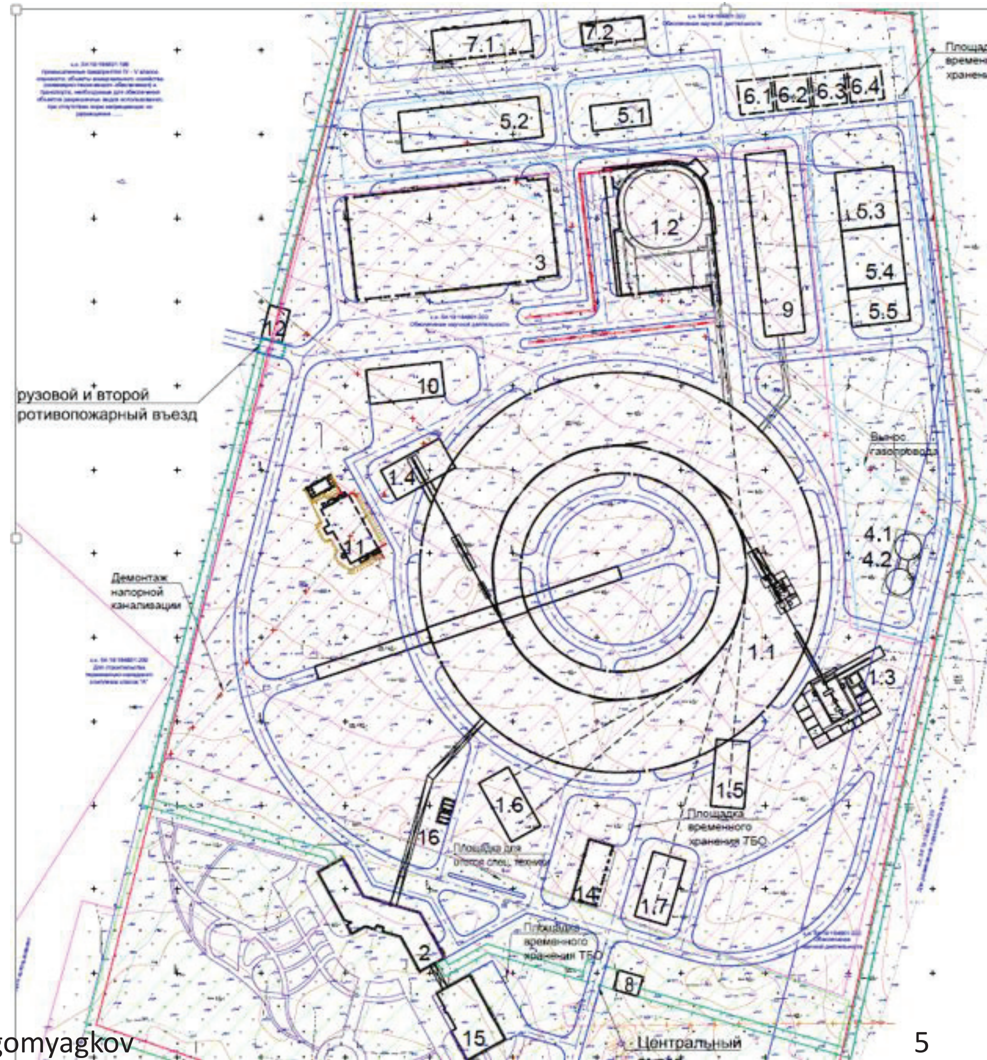
To complete construction and to start operation before the main building and ring, the injection facility is in separate building.



Location: Kol’tsovo Science Town



Architecture



Government contracts

Manufacturing, assembling, delivering and commissioning of “SKIF” equipment

Government order 12.10.2020 № 2630-р:

BINP is the sole contractor for manufacturing, assembling, delivering and commissioning of “SKIF” accelerator facility (ЦКП «СКИФ») equipment

Government contract with BINP (16.11.2020) in the frame of WP (12.10.2020 № 2630-р) **for injecting facility:**

- 3.62 billion rubles (the first tranche – 30 % in 2020 and 2021);
- term – 01.10.2022 (commissioning of injector in separate building)

Government contract with BINP (28.05.2021) tender for storage ring

- 8.93 billion rubles (the first tranche – 50 % in 2021 and 2022)
- term – 31.12.2023 (commissioning of accelerator facility SKIF)

Injection facility (200 MeV linac; 3 GeV, 158 m booster)

- Signed ~70% of contracts for materials, equipment and parts.
- BINP workshop received design documentation for 141 orders for more than 120,000 working hours.
- Contract signed with ООО «НПП Триада ТВ» (Novosibirsk) for manufacturing of amplifier with 700 kW pulsed power at 178 MHz for RF gun and amplifier with 10 kW pulsed power at 534 MHz for linac.
- Contract signed with АО «БЭМЗ» (Berdsk) for manufacturing 20 Amp, 50 V power supplies.
- Contract signed with Marubeni corporation (Japan) for 50 MWt, 2856 MHz klystron delivery. Preparation of the contract for two more klystrons.
- Contract signed with АО «НПО НИИИП-НЗиК» (Novosibirsk) for manufacturing modulator parts of klystrons being produced in BINP.

Booster (Energy 3 GeV, circumference 158 m)

Received 120 tons of steel with glue layer for booster magnets.

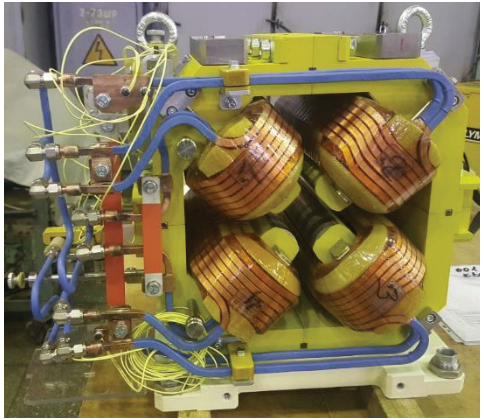
Almost finished cutting out all laminations.

Baked 50% yoke segments for dipoles and 100% for quadrupoles.

Booster

In June the first dipoles and quadrupoles were manufactured.

Manufactured 70% of dipole magnet coils and 100% of quadrupoles coils.



Manufactured stamps for booster vacuum chambers.

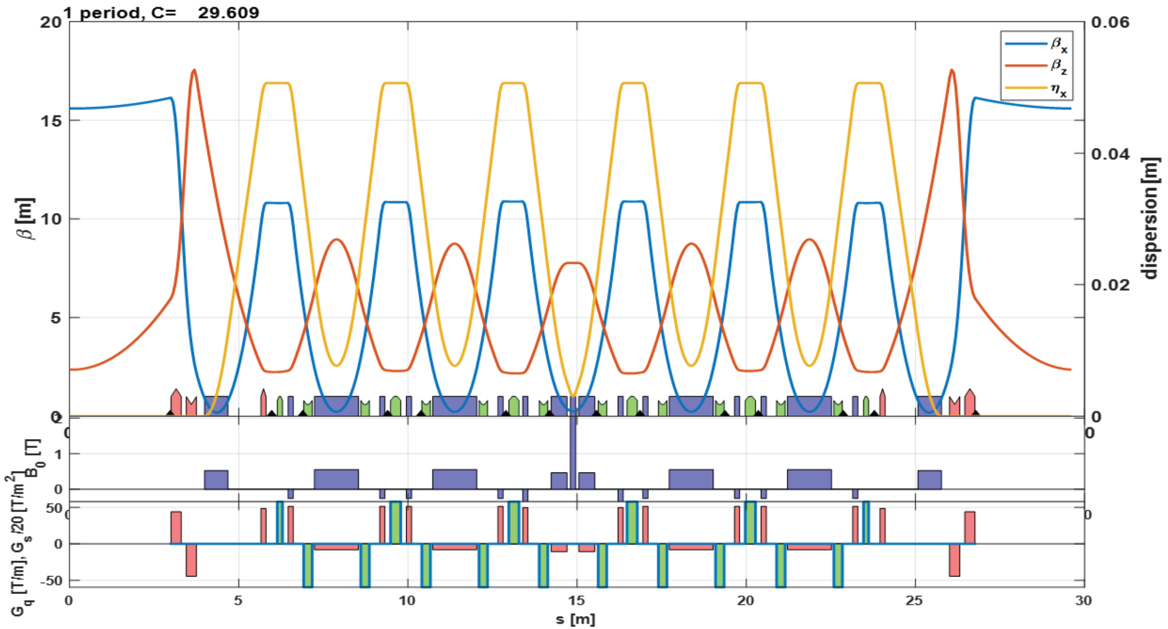
Waiting for delivery of nonmagnetic pipes for vacuum chambers.

Signed contract with Danfysic A/S (Denmark) for booster dipole power supplies. The other power supplies are manufactured in BINP.

Signed contract with ООО «НПП Триада ТВ» (Novosibirsk) for manufacturing three amplifiers with 80 kW of continuous power at 357 MHz for booster RF cavities.

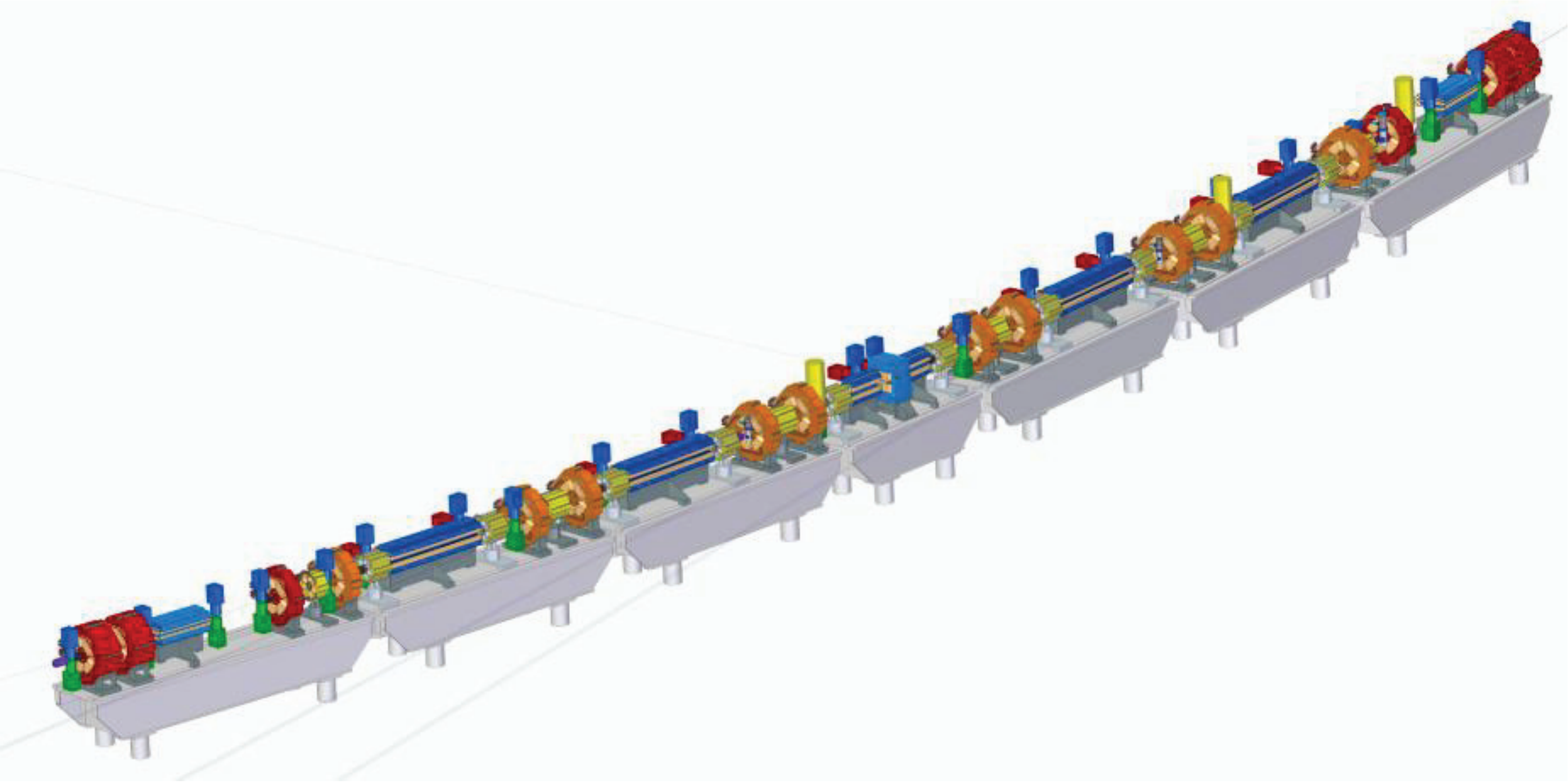
Preparation of contract with АО «Воткинский Завод» (Votkinsk) for manufacturing of 41 booster girders.

Super-period optics and parameters



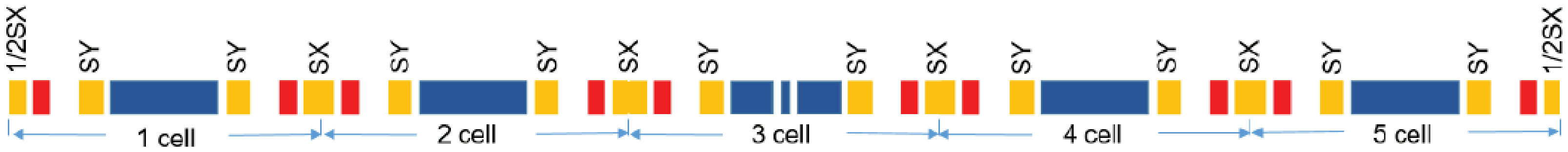
Energy, GeV	3
Symmetry	16
Circumference, m	476.14
Revolution period, μs	1.588
Hor. Emittance, pm	73.2
Energy spread	1×10^{-3}
Energy loss per turn, keV	536
Betatron tunes, x/y	50.806/18.84
Momentum compaction factor	7.64×10^{-5}
Natural chromaticity, x/y	-149/-55
RF harmonic number	567
RF frequency, MHz	357
RF amplitude, MV	0.77
Energy acceptance	$\pm 3\%$
Synchrotron tune	1.13×10^{-3}
Bunch length, mm	5.3
Partitions, x/δ	1.94/1.06
Damping times, x/δ, ms	9.2/16.7

Super-period layout



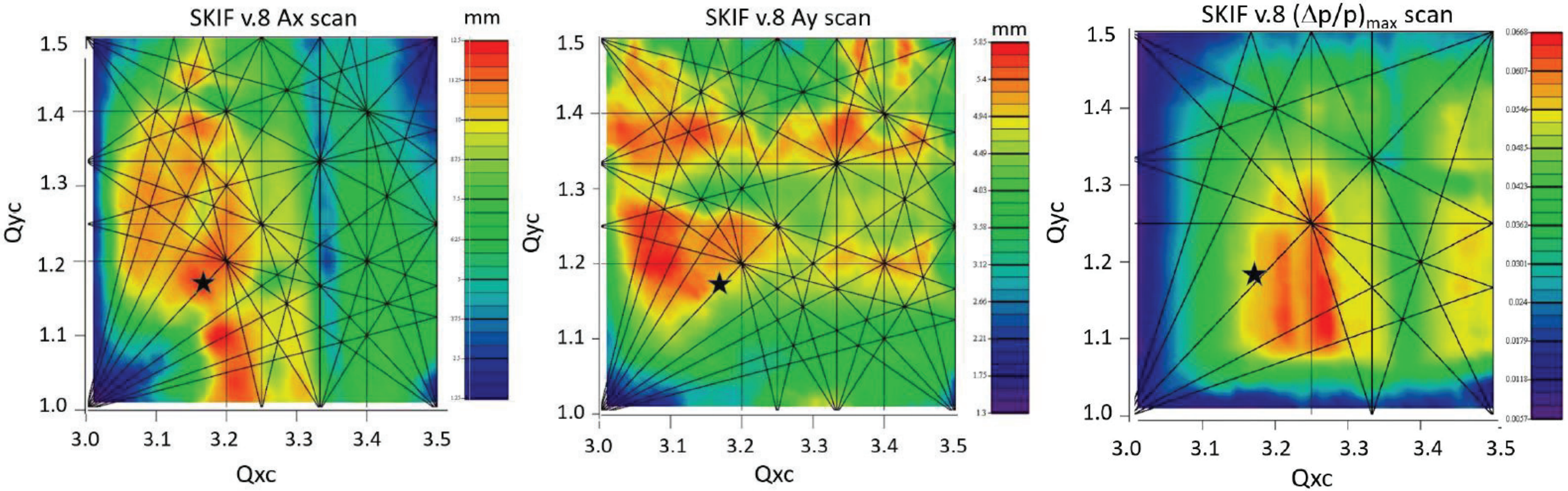
Chromaticity correction

Two sextupole families $\xi_x/\xi_y = -149/-55$



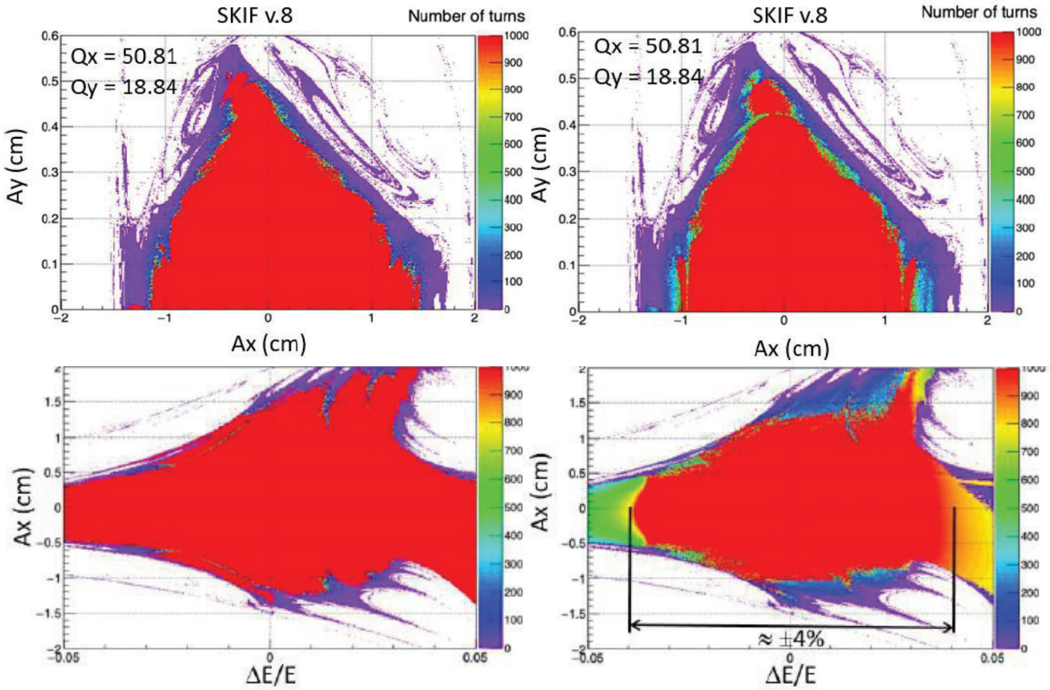
	L, м	B'', Т/м^2	K_2L, м$^{-2}$	B''_{max}, Т/м^2	$(K_2L)_{max}$, м$^{-2}$
SY	0.25	-2379	-59.48	-2800	-70
SX	0.30	2313	69.39	2800	84
½ SX	0.15	2313	34.70	2800	42

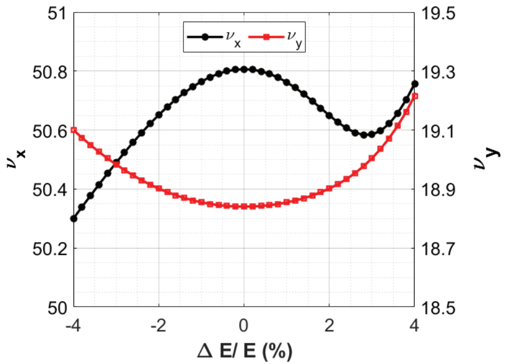
Dynamic aperture scan for one super-period

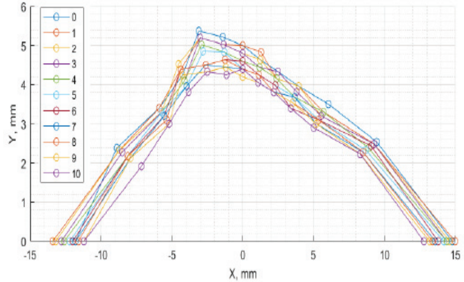


Betatron tunes, phase advances between chromatic sextupoles, and their strength were carefully adjusted to maximize dynamic aperture and momentum acceptance.

Dynamic aperture and momentum acceptance







$\xi_{x,y} = [0,10]$

Survival plots. Red is stable during 1000 revolutions.
Only two sextupole families are enough to get sufficient dynamic aperture and momentum acceptance

$$\beta_x/\beta_y = 15.6/2.4 \text{ м}$$

Insertion devices

To extend the spectrum in the hard X-ray region, we plan to use superconducting IDs.

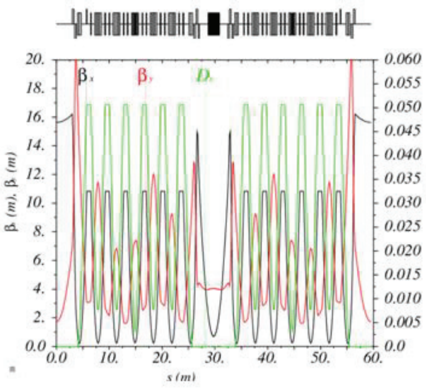
№	Experimental station	ID	B (T)	λ_w (mm)	N_{per}	P_{SR} (kW)
1-1	Microfocus (5-47 keV)	SCU	1.2	15.6	128	7.2
1-2	Structural analysis (5-40 keV)	SCU	1.2	15.6	128	7.2
1-3	Fast dynamic processes (15-100 keV)	SCW	4	33.7	60	75
1-4	XAFS and magnetic dichroism (2.5-35 keV)	SCU	1.2	15.6	128	7.2
1-5	Hard X-ray imagine (25-200 keV)	SCW	4	33.7	60	75
1-6	Photoelectron spectroscopy (0.01-2 keV)	EMU	0.5	100/200	20/10	1.8

Insertion devices base optics

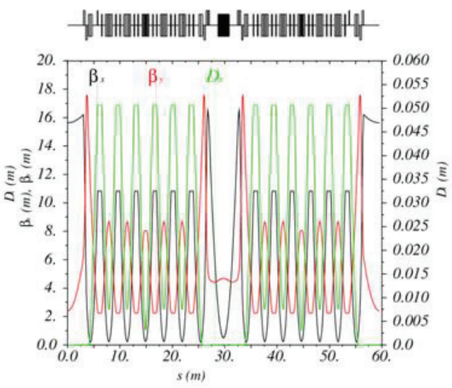
To extend the spectrum in the hard X-ray region, we plan to use superconducting IDs.

For baseline lattice, emittance does not depend on IDs.

Parameter	Bare	1U	1W	2W	3W
ε_{xtot}, pm	73	72	74	75	76
$\sigma_E/E \cdot 10^3$	1.03	1.02	1.24	1.32	1.36
ΔE/turn, keV	534	548	720	904	1090
U_{RF}, MV	0.85	0.85	1.1	1.27	1.48
$J_{x/s}$	1.94/1.06	1.91/1.09	1.68/1.32	1.55/1.45	1.46/1.54
$\tau_{x,y,s}$, ms	9/18/17	9/17/16	8/13/10	7/10/7	6/9/6

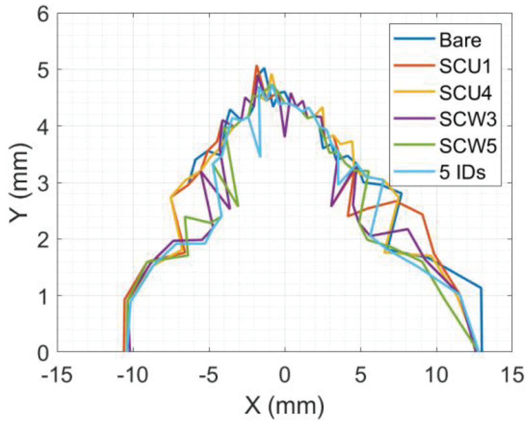


Before correction



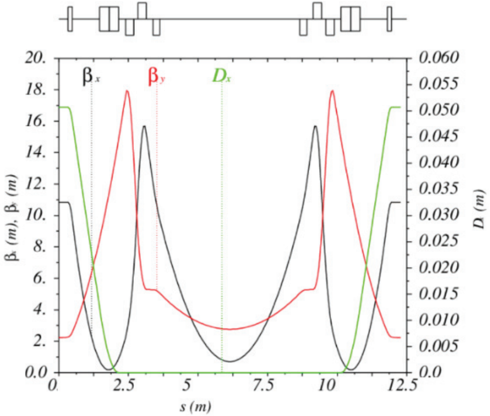
After correction

Optics with 1 SCW

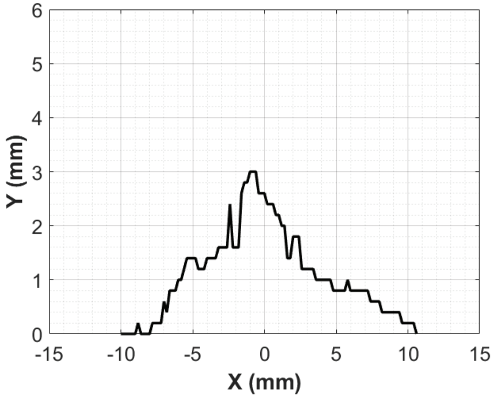


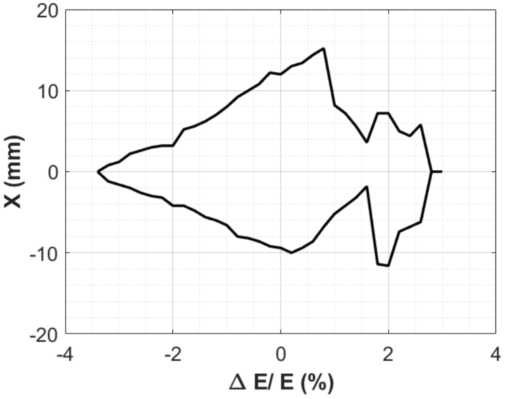
Insertion devices alternative optics

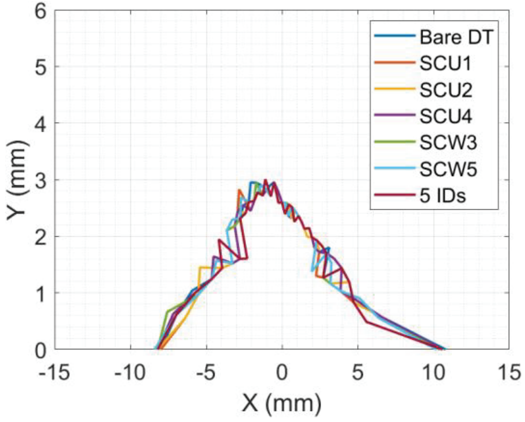
Reduction of β_x for higher brightness requires triplets



Parameter	Bare	1W	2W	3W
ε_{xtot}, pm	73	61	54	48
$\sigma_E/E \cdot 10^3$	1.03	1.24	1.32	1.36
ΔE/turn, keV	534	720	904	1090
U_{RF}, MV	0.85	1.1	1.27	1.48
$J_{x/s}$	1.94/1.06	1.68/1.32	1.55/1.45	1.46/1.54
$\tau_{x,y,s}$, ms	9/18/17	8/13/10	7/10/7	6/9/6







IBS base lattice

400 mA in 510 bunches,

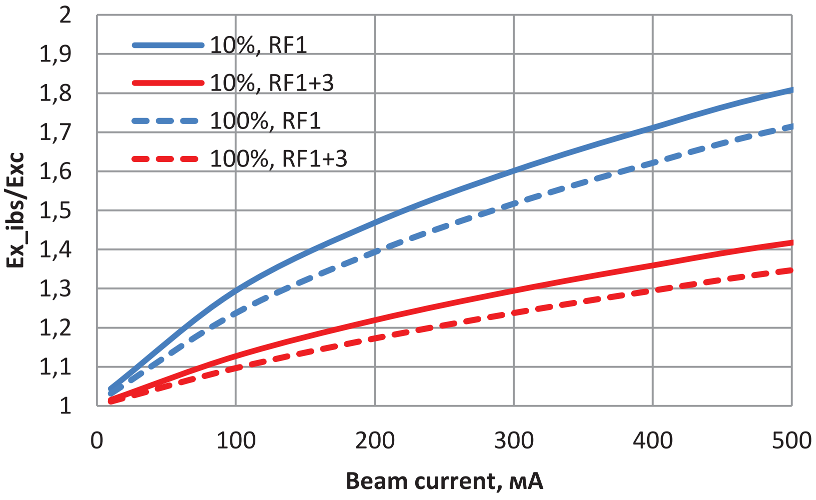
$U_0 = 534\ keV/turn,$

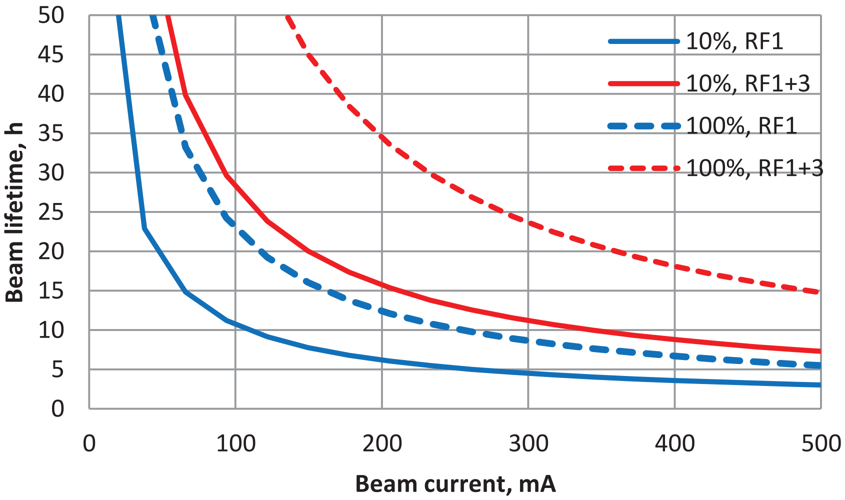
$V_{RF} = 0.845$ MV

RF1 – main RF,

RF1+3 – plus third harmonic RF

	10%		100%	
	RF1	RF1+3	RF1	RF1+3
ε_{x0}, pm	72.7			
$\varepsilon_{xcoupled}$, pm	66		36	
ε_{xIBS}, pm	113	90	59	47
ε_{yIBS}, pm	11	9	59	47
$\sigma_E/E \times 10^4$ (0/IBS)	10.3/12.4	10.3/11.4	10.3/11.4	10.3/10.9
σ_l (mm) (0/IBS)	5.3/5.9	15.8/16.2	5.3/5.4	15.8/15.4
τ_{TIBS} (hours)	3.2	7.9	6.2	17





IBS with IDs

Geometrical brightness depends on electron beam parameters

$$Br(\lambda) = \frac{n_b I_b}{\Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}} = \frac{n_b I_b}{\sqrt{\sigma_x{}^2+\sigma_r{}^2}\sqrt{\sigma_{x'}{}^2+\sigma_{r'}{}^2}\sqrt{\sigma_y{}^2+\sigma_r{}^2}\sqrt{\sigma_{y'}{}^2+\sigma_{r'}{}^2}},$$

$$\Sigma^2_{x,y}(I_b) = \beta_{x,y}\varepsilon_{x,y}(I_b) + \left(\frac{\sqrt{2\lambda L}}{4\pi}\right)^2, \quad \Sigma^2_{x'y'}(I_b) = \frac{\varepsilon_{x,y}(I_b)(1+\alpha_{x,y}{}^2)}{\beta_{x,y}} + \left(\sqrt{\frac{\lambda}{2L}}\right)^2$$

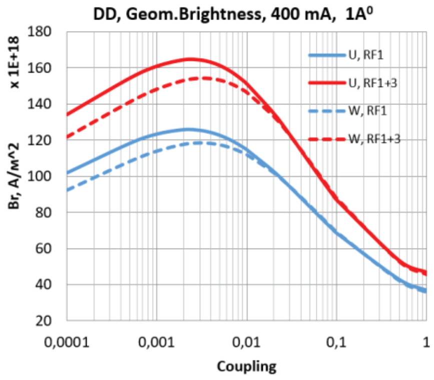
400 mA in 510 bunches

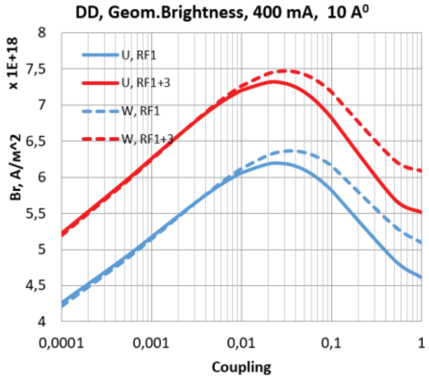
$\kappa = 10\%$

$Br_1(\lambda = 1\text{Å})$

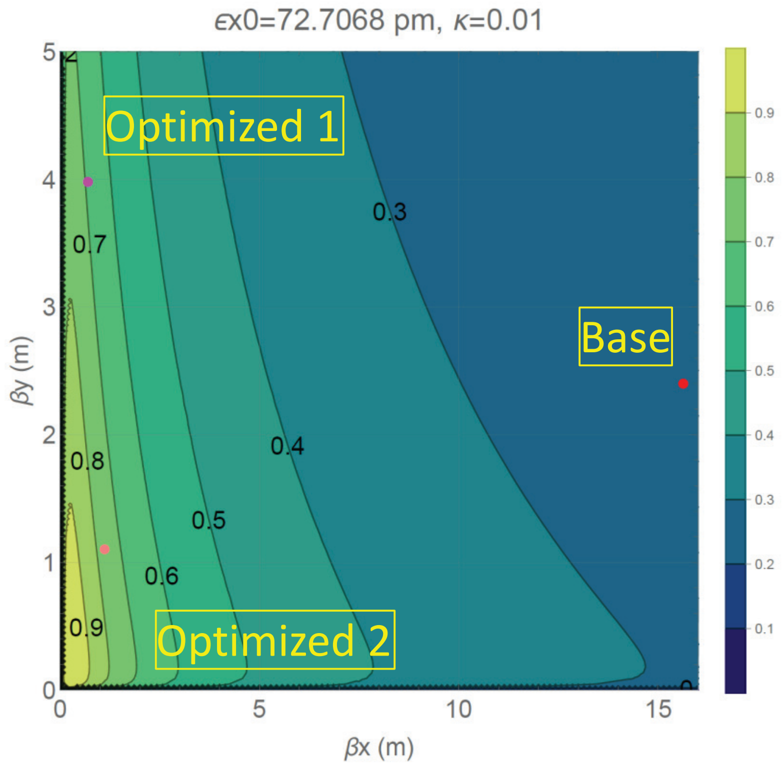
$Br_{10}(\lambda = 10\text{Å})$

	SCU		SCW		10SCU+2SCW	
	RF1	RF1+3	RF1	RF1+3	RF1	RF1+3
U, MeV	0.55		0.72		1.07	
V_{rf}, MV	0.864		1.06		1.44	
ε_{x0} | $\varepsilon_{xcoupled}$, pm	71.6| 65.1		74.1| 67.3		67.2|61.1	
ε_{xIBS}, pm	112.8	89.2	106.8	85.7	99.5	78.9
$\sigma_E/E\times10^4$	10.2		12.4		12.3	
$(\sigma_E/E)_{ibs}\times10^4$	12.3	11.3	13.5	12.9	13.1	12.7
σ_l (mm)	4.8	14.3	5.3	16.1	4.7	14.3
σ_{l_IBS} (mm)	5.8	15.9	5.8	16.8	5.1	14.7
τ_{TIBS} (hours)	3.2	7.7	3.3	8.6	2.7	7.3
B_{r1} (A/m^2) $\times10^{-18}$	58.0	75.6	62.3	80.2	66.8	86.4
B_{r10} (A/m^2) $\times10^{-18}$	5.2	6.2	5.8	6.7	5.7	6.8





Brightness of superconductive undulator



Normalized brightness versus β functions at the radiation point

Period, mm	15.6
Vertical field amplitude, T	1.25
K	1.821
Effective length, m	1.997
Number of periods	128
Gap, mm	7
Total radiation power, kW	6.99
Fundamental harmonic, keV	2.061
Power density on the axis, $\mathrm{kW/mrad^2}$	53.96
Mask aperture, mrad	0.2×0.2
Spectral brightness ($\beta_x/\beta_y = 15.6/2.4$ м) photons/c/$\mathrm{mm^2/mrad^2}$/0.1%B.W.	2.48×10^{20}
Spectral brightness ($\beta_x/\beta_y = 0.3/0.3$ м) photons/c/$\mathrm{mm^2/mrad^2}$/0.1%B.W.	7.78×10^{20}

Emittance and lifetime with IBS

- For base lattice 400 mA, 510 bunches, 10% coupling, $\pm 3\%$ energy acceptance ($V_{RF} = 0.845$ MV), horizontal emittance increases from 73 pm to 113 pm. Touschek lifetime is 3.2 hours
- Threefold bunch elongation decreases emittance to 90 pm and increases Touschek lifetime to 7.9 hours
- 100% coupling provides $\varepsilon_x = \varepsilon_y = 50 - 60$ pm and doubles lifetime. Geometrical brightness drops by factor of 1.5-2
- For ultimate configuration (10 SCU+2 SCW) Touschek lifetime ≥ 5 hours for $V_{RF} = 1.4$ MV
- For ultimate configuration, 10% coupling, threefold bunch elongation and 400 mA in 510 bunches the minimum horizontal emittance is $\varepsilon_x \approx$ 79 pm
- For radiation wavelength in range of 1-10 Å maximum geometrical brightness occurs with coupling 0.5-5%

Alignment errors correction

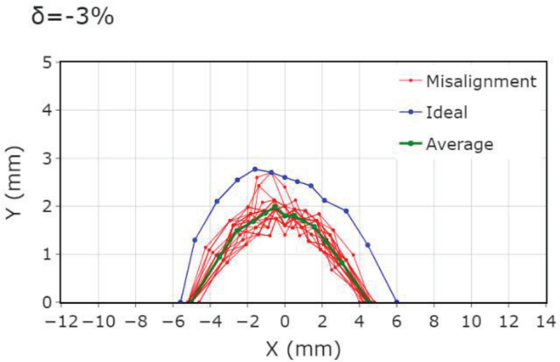
Closed orbit distortions in strong sextupoles reduce dynamic aperture.

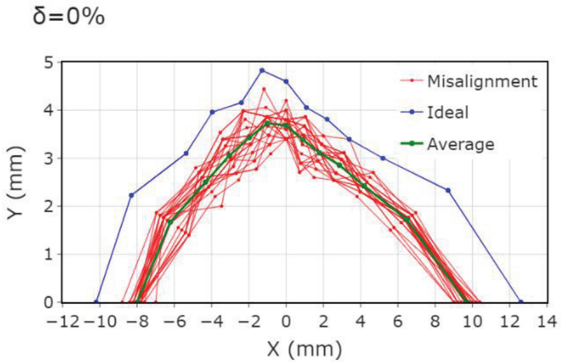
Studying and correction algorithm:

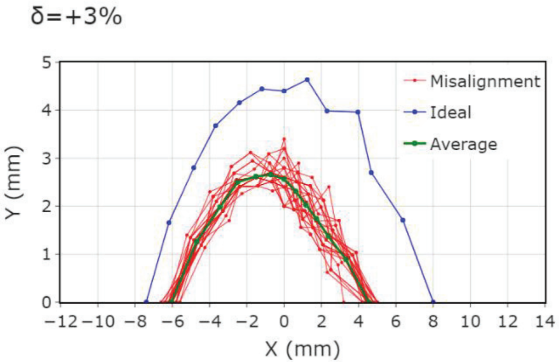
1. Errors distributions in all elements
2. Orbit correction at 224 BPM, by 256+64 correctors
3. Optics and coupling correction by 256 gradient correctors in sextupoles

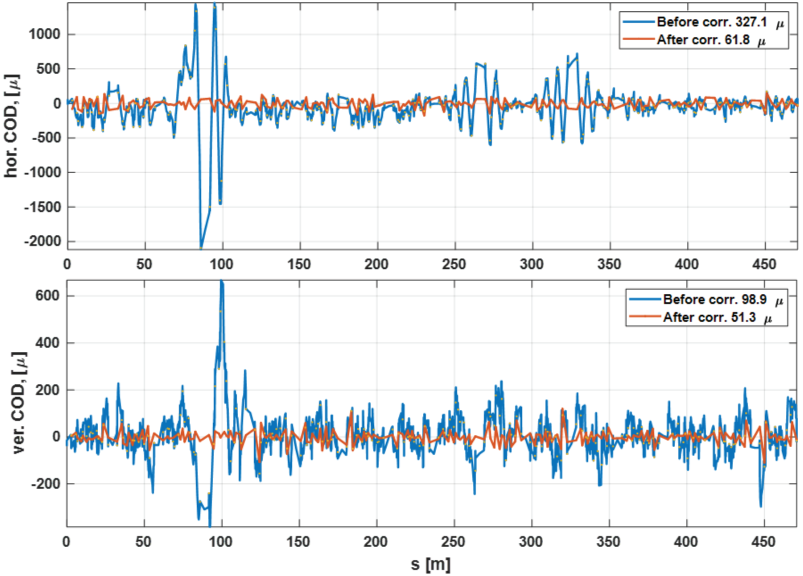
	$\sigma_{x,}$ μm	$\sigma_{y,}$ μm	$\sigma_{s,}$ μm	$\sigma_{\psi,}$ μrad
Girders	80	80	150	200
Elements on girders	30	30	150	200

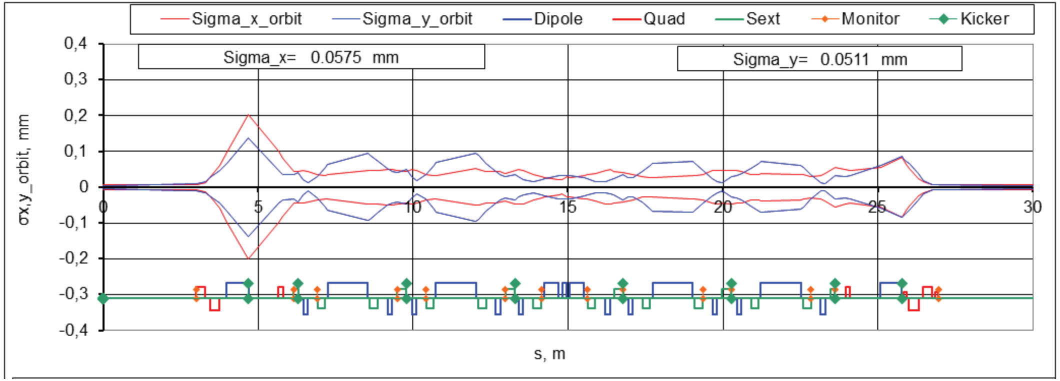
Alignment errors correction







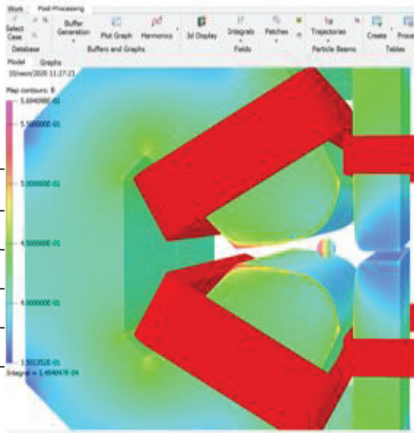


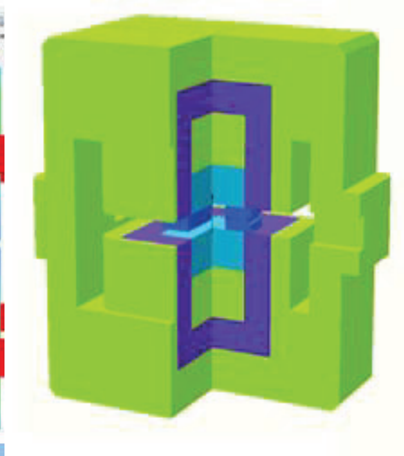


Magnets

Dipoles

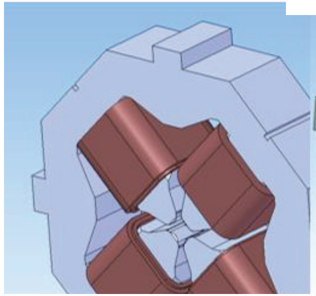
Magnet	No	L, m	ϕ°	ρ, m	B, T	K_1, m^{-2}	G, T/m
BD1	64	1.30	4.12	18.07	0.553	-0.791	-7.91
BD2	32	0.47	1.245	21.62	0.526	-1.074	-10.74
BM	32	0.69	2.079	19.01	0.526	-	-
BP	16	0.148	1.74	4.87	2.05	-	-

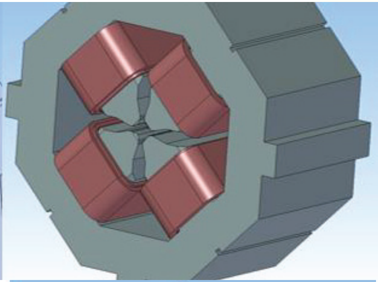




Quadrupoles

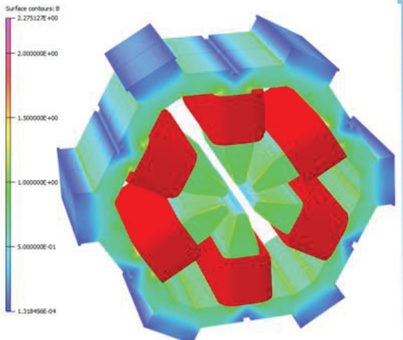
Magnet	No	L, m	ϕ°	ρ, m	B, T	K_1, m^{-2}	G, T/m
QD	32	0.3	-	-	-	-4.456	-44.56
QF1	32	0.3	-	-	-	4.397	43.97
QF2	32	0.15	-	-	-	4.866	48.66
QF3	128	0.15	-0.221	-38.84	-0.257	5.152	51.52
QF4	32	0.15	-0.3	-28.66	-0.349	4.987	49.87

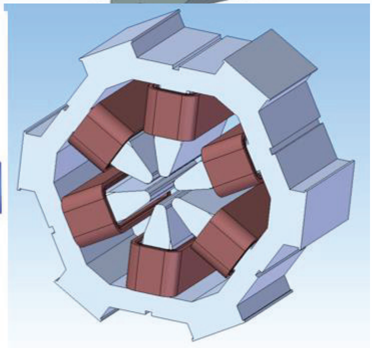




Sextupoles

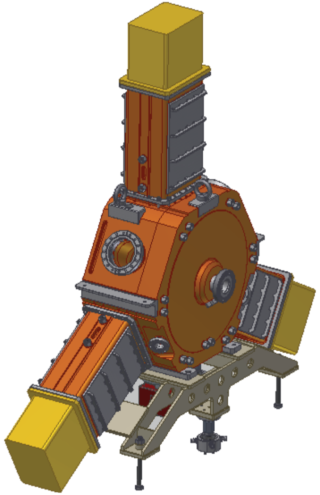
Magnet	No	L, m	K_2, m^{-3}	B'', T/m
SF1	32	0.15	231.309	2313.09
SD	160	0.25	-237.939	-2379.39
SF2	64	0.3	231.309	2313.09



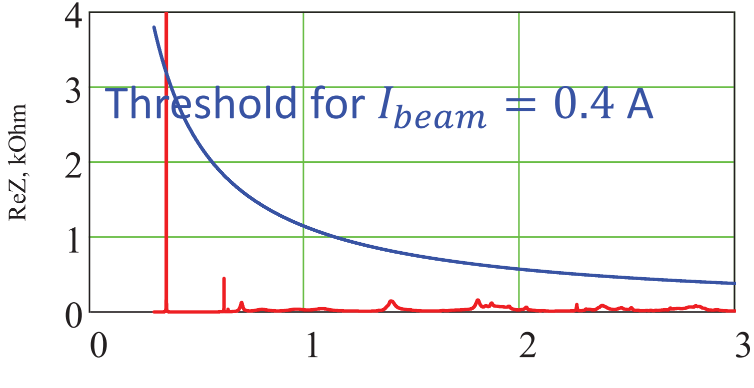


RF system

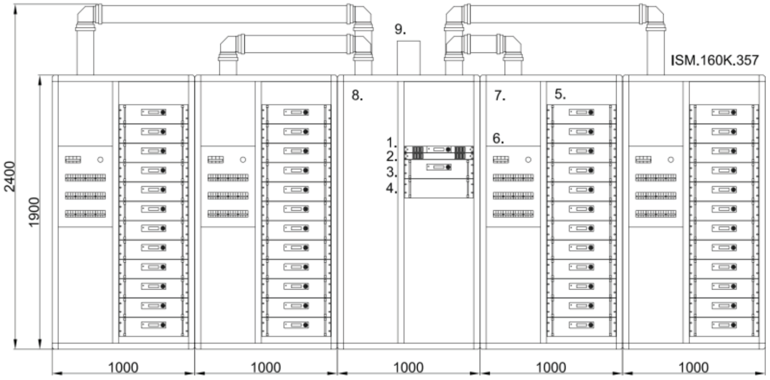
	Booster	*Main Ring*	
f_{rf}, *MHz*	*357*	*357*	*1071*
$V_{acc\ tot}$, *MV*	*1*	*1.8*	*0.35*
$N_{cavities}$	*3*	*5*	*3*
Cav. type	*NC*	*NC*	*NC*
HOM damping	*Yes*	*Yes*	*No*
Load type	*WG*	*WG*	

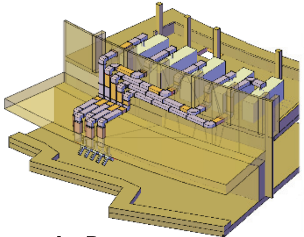


HM spectrum

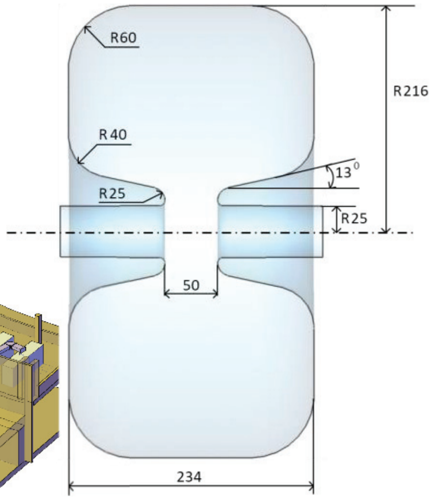


Main ring single cavity 357 MHz/160 kW CW SSPA





A. Bogomyagkov



Single cavity fundamental data

f_0, **MHz**	**357**
R/Q, Ohm	150
Q_0	17000
$\frac{R}{Q}Q_0$, MOhm	2.55
$V_{acc\ 1}$, kV	400
P_{Cu}, kW	31.4
$P_{S\ max}$, W/cm^2	15.7

Vacuum system

- Vacuum lifetime >10 hours ($P(CO) \leq 2.5\mathrm{nTorr}$)
- Absorbs 200 kW of SR
- Low impedance design
- Pipe material: aluminum alloy 6063
- Connections like in SuperKEKB, compensators like in PEPII type, BPMs like in MAX4/SIRIUS/Diamond
- Cryo-pump or distributed NEG coating in the narrow aperture straight sections
- Lumped compact combined pumps in the arcs. Expected conditioning time 3-6 months. Advantages over the NEG coating are unbaked system, less sensitive to micro-leaks, low wall impedance

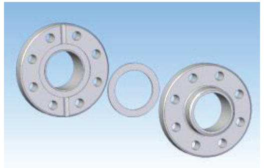
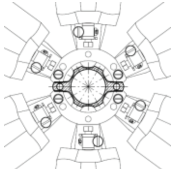
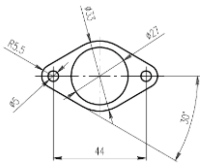
Vacuum system design

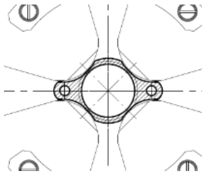
Requirements

Inner diameter of beam pipe, d [mm]	**27**
Average distance between pumps, L [m]	1
Total number of lumped pumps per arc	24
Pumping speed of one pump for CO [l/s]	120
Average photon flux [ph/s/m] at I=0.4A, E=3 GeV	2×10^{18}
Initial/final desorp.coeff. [mol./ph] for CO	1×10^{-2} 0.8×10^{-6}
Average photon dose for conditioning [ph/m]	1.4×10^{25} (777 Ач)
Lifetime at I=0.4 A during conditioning [h]	3
Calculated conditioning duration [s] (worst case)	3 months

Status:

- All profiles are defined. BINP is ready to order.
- Beam pipes are defined by BPMs and e-ph beams branching points positioning.
- Universal port and flange connections are designed.
- Design of smooth flange connection for prototyping is completed.
- Bellow units is based on the PEP-II design.
- Parameters of crotch-absorbers are defined. Design follows the ESRF absorbers.
- Beam pipe gate valves (32 pieces) with RF contacts will be designed by BINP.



Conclusion

25.08.2021 SKIF construction opening ceremony
ЦЕНТР КОЛЛЕКТИВНОГО ПОЛЬЗОВАНИЯ «СКИФ»
СКИФ
ПАСПОРТ ОБЪЕКТА
ЦЕРЕМОНИЯ СТАРТА