Shanghai Synchrotron Radiation Facility

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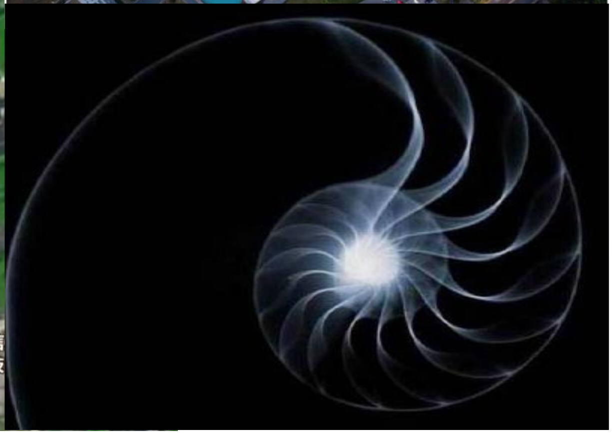
Outline

- Overview of SSRF
- SSRF Storage Ring
- Beam Manipulations
- Operation Status
- Upgrade towards DLLS

Overview of SSRF

◆ **Campus in Zhangheng Road** (Accommodating SSRF SXREL and a part of SHINE)



◆ SSRF Beamlines

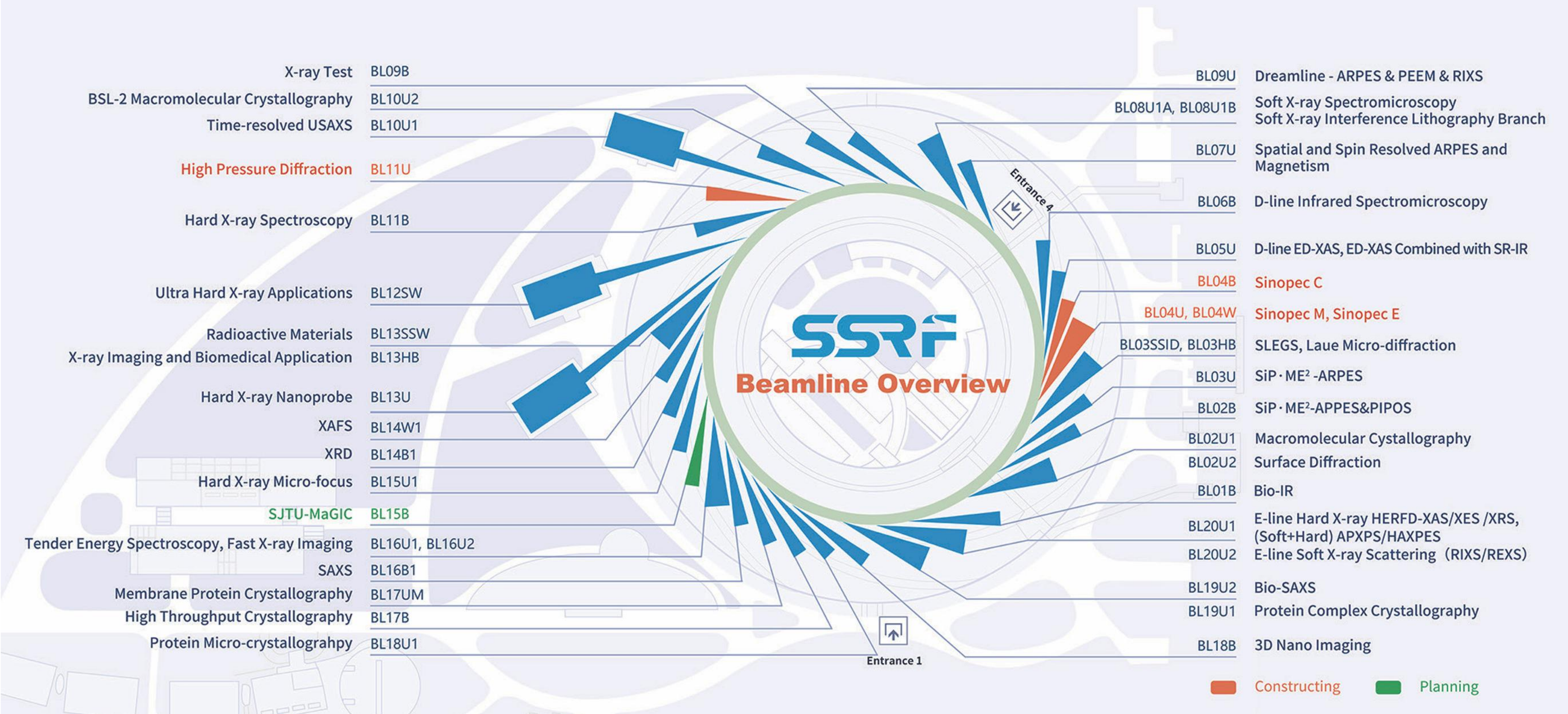
➢ SSRF project (2004~2009): 7 beamlines **routine operation since May 2009** Fellow-up beam lines: 8

Disciplines	Beamlines	Source	Energy range	Scientific goals
Energy science	XAFS	Wigger	4.5~ 50keV	Energy conversion and storage
	SiP▪ME^2_NAP-XPS	BM	40eV-2keV	In situ electronic structure
	SiP▪ME^2_HR-ARPES	EPU	7-70eV	Electronic structures of novel quantum materials
Environ. Science	STXM	EPU	150-2000eV	Quantitative polymer and chemical mapping
	Hard X-ray Micro-focus	IVU	5keV-20keV	High pressure , environmental, biological science
Material Science	X-ray diffraction	BM	4-22 keV	Reveal crystal structure and property relationship
	Dreamline	EPU	20eV~2keV	Electronic structure of condensed matters
	X-ray imaging	SuperB	White beam Pink :8-40keV	Inner microstructure observation of materials
	SAXS	BM	5-20keV	Nanostructure characterization of materilals
Life Science	Macromolecular Crystallography	IVU	7-15keV	Determination of macromolecules & their complexes
	BioSAXS	IVU	7-15keV	Structure characterization for biomacromolecules&drugs
	High Throughput Crystallography	BM	5-20keV	High throughput protein crystallography
	Micro-Crystallography	IVU	5-18keV	Small crystal protein crystallography
	Complex Crystallography	IVU	7-15keV	Protein crystallography of large unit cell crystals
	FTIR and Microscope	BM	10-10000 cm^{-1}	Vibrational-rotational spectrum of biological molecules
Industry App	XIL	EPU	80-150eV	Nanostructures fabrication and EUV resist evaluation

- Phase-II project (2016-2024): 19 beam lines **34 beamlines and 46 experimental stations**
- Several extra users' beamlines are being in commissioning now.
  Full capacity ~40 beamlines as our earlier expection
- Apllication areas: Energy, environment, material, life science, and industrial applications

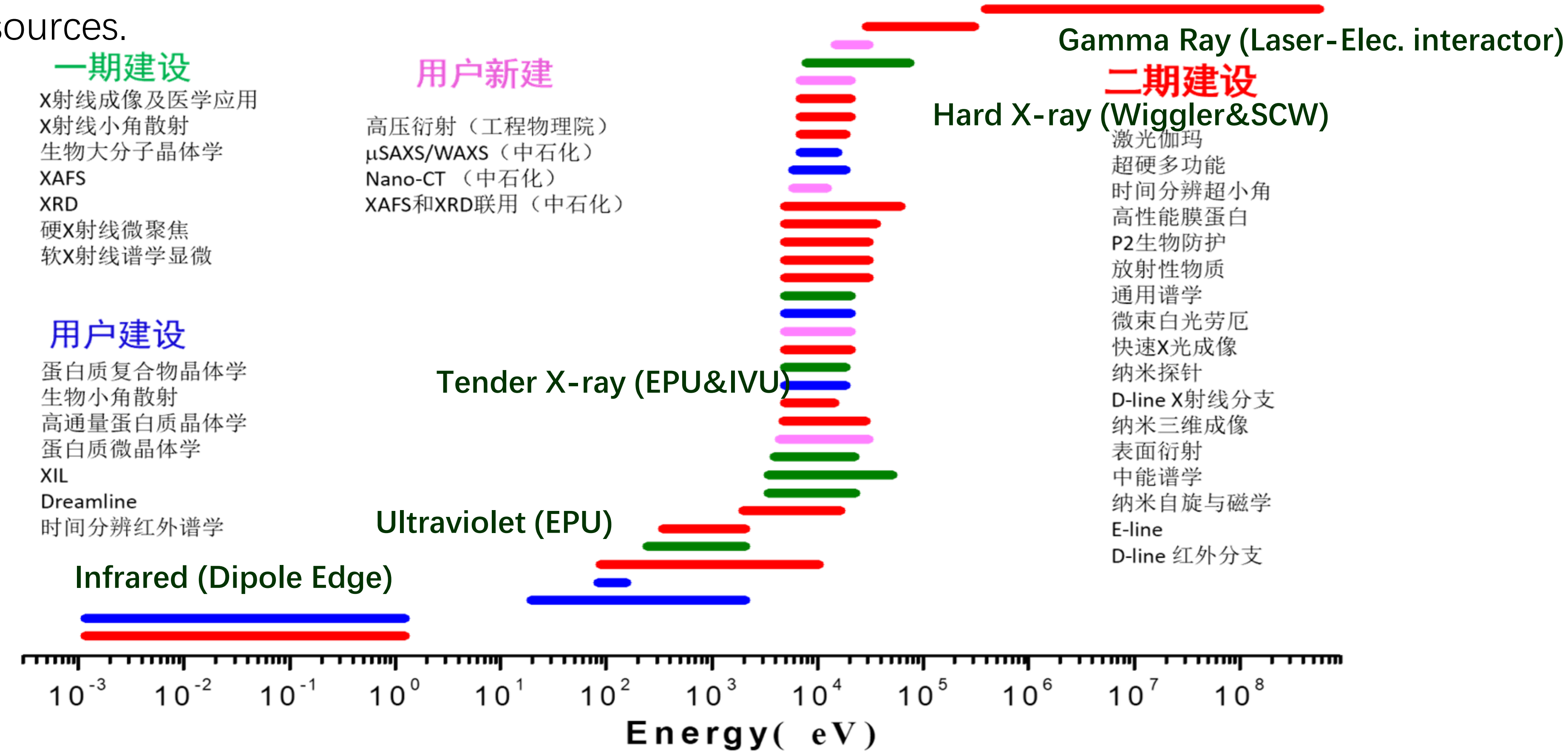
Disciplines	Beamlines	Source	Energy range	Scientific goals
Energy science	E-line	IVU+EPU	130eV~18keV	Energy conversion and control
	D-line	IVU+BM	10~ 10000cm^{-1} 5 ~ 25keV	Structure of non-equilibrium systems
	Radioactive materials	W	5~50keV	Radioactive material
	Hard X-Ray Spectroscopy	BM	5~30keV	Catalysis
Environ. Science	Hard X-ray Nanoprobe	IVU	5~25keV	Nano technology, cell, environ. components
	Medium-energy Spectroscopy	IVU	2.1~16keV	Environmental pollutants
	3D Nano Imaging	BM	5~14keV	Nano imaging
Material Science	S^2-resolved ARPES	Twin EPU	50~2000eV	Magnetic and electronic properties
	RIXS station	EPU	250~1700eV	Electronic structure
	Laue microdiffraction	Super B	7~30keV	Local microstructure and defects
	Surface diffraction	CPMU	4.8~28keV	Microstructure of surfaces and interfaces
	Laser Electron Gamma Source	ID	0.4~20MeV	Nuclear astrophysics/structure
Life Science	P2 Protein Crystallography	IVU	7~18keV	Moderate-risk infectious viruses
	Membrane Protein	IVU	7~15keV	Membrane protein
Industry Applications	Ultra Hard X-ray Applications	SCW	30~150keV	Engineering materials and rocks
	Time-resolved USAXS	IVU	8~15keV	Self-assembly and fiber-spinning
	Fast X-ray imaging	CPMU	8.7~30keV	Fast process imaging

SSRF Beamlines Map



◆ Photon spectra

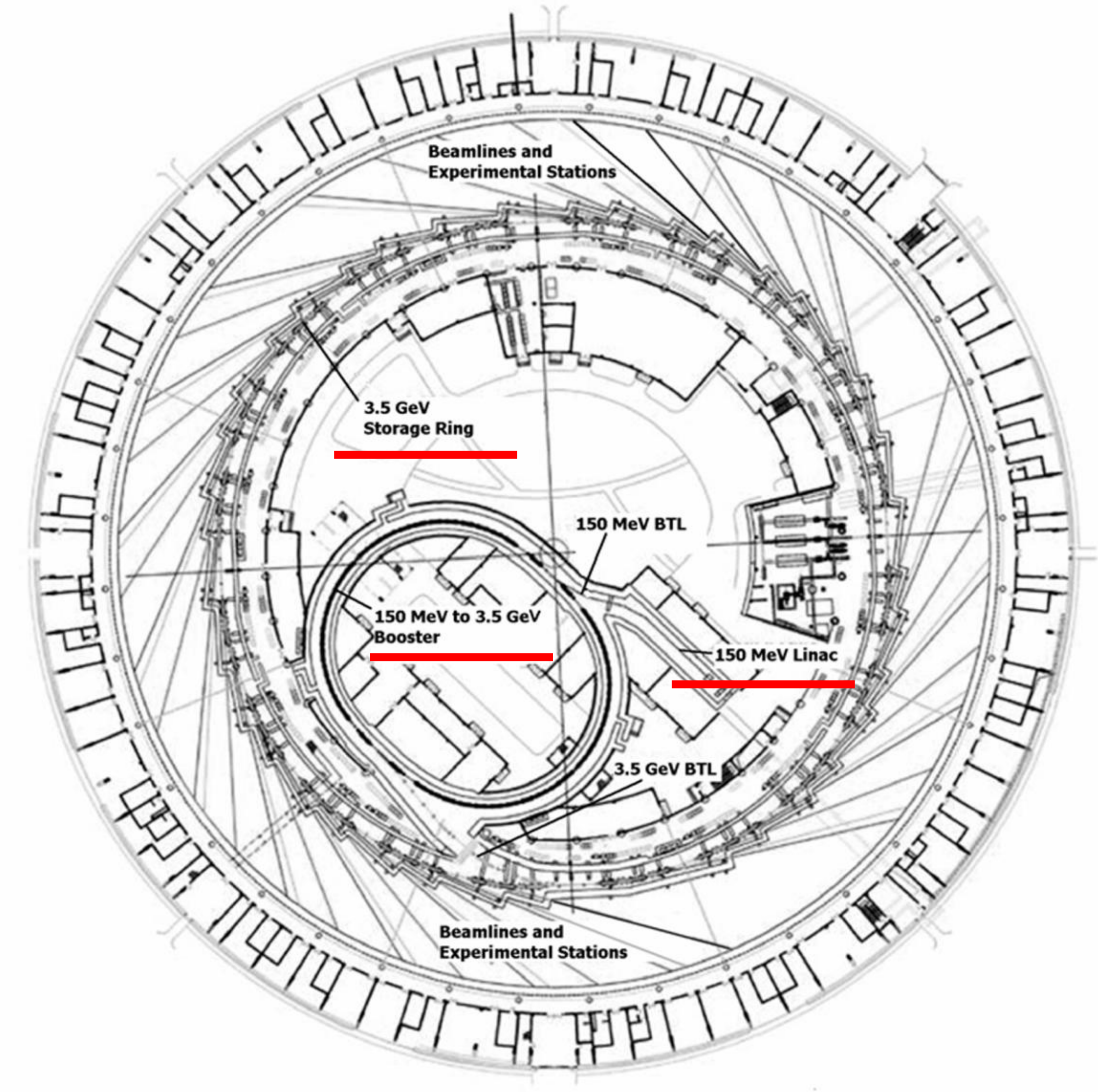
- Avaibable photo spectrum in SSRF ranges from Infrared to ultra hard X ray (SCW) and Gamma Ray (SLEGS).
- Most of all the beamlines use X-ray (3~30keV), which have optimal high flux and brightness in medium-energy light sources.



◆ SSRF Accelerator Complex

- LINAC + Booster + Storage ring
- 2×Transport lines

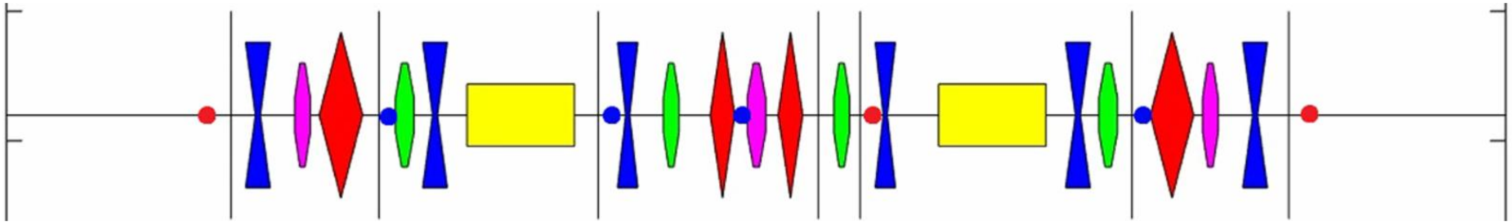
LINAC		
Beam energy	MeV	158
Charge (Single/Multi)	nC	1.0/3.0
Normalized emittance	mm.mrad	50
Energy spread		0.5%
BOOSTER		
Circumference	m	180
Beam energy	GeV	0.158→3.5
Extracted beam emittance	nm.rad	100
Repetition rate	Hz	2
STORAGE RING		
Circumference	**m**	**~432**
Structure		**20×DBA**
Beam energy	**GeV**	**3.5**
Beam current	**mA**	**200~300**



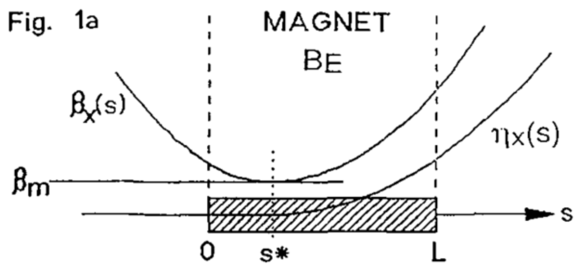
SSRF Storage Ring

◆ **Lattice Structure and beam dynamics**

➢ Chasman-Green lattice (Double-Bend-Achromat): simplest focusing structure for optimizing source points and global properties of the storage ring.



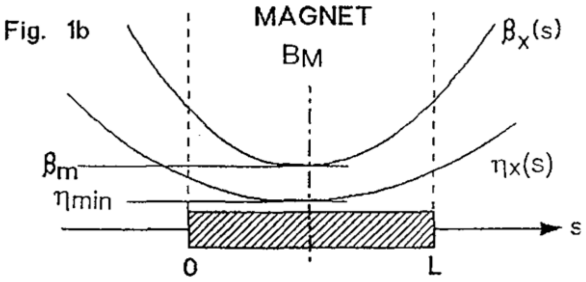
Each cells in SSRF-Ring consists of 2 dipoles, 10 quadrupoles, 7 sextupoles, 4 soft correctors, 3 fast correctors, 7 BPMs, and 4 skew quadrupole coils.



➢ Theoritical minimum emittance:

$$\beta_{x,TME,Achro.} = \frac{3}{8\sqrt{15}}L \qquad \beta_{x,TME,Chro.} = \frac{1}{2\sqrt{15}}L, \eta_{TME,Chro.} = \frac{L^2}{24\rho}$$

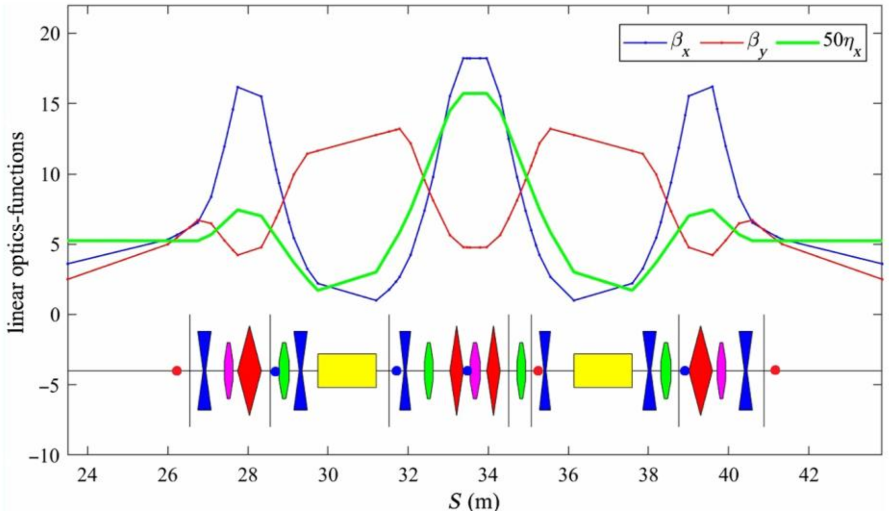
$$\varepsilon_{x,TME,Achro.} = \frac{C_q\gamma^2}{J_x}\frac{\theta^3}{4\sqrt{15}} \qquad \varepsilon_{x,TME,Chro.} = \frac{C_q\gamma^2}{J_x}\frac{\theta^3}{12\sqrt{15}}$$

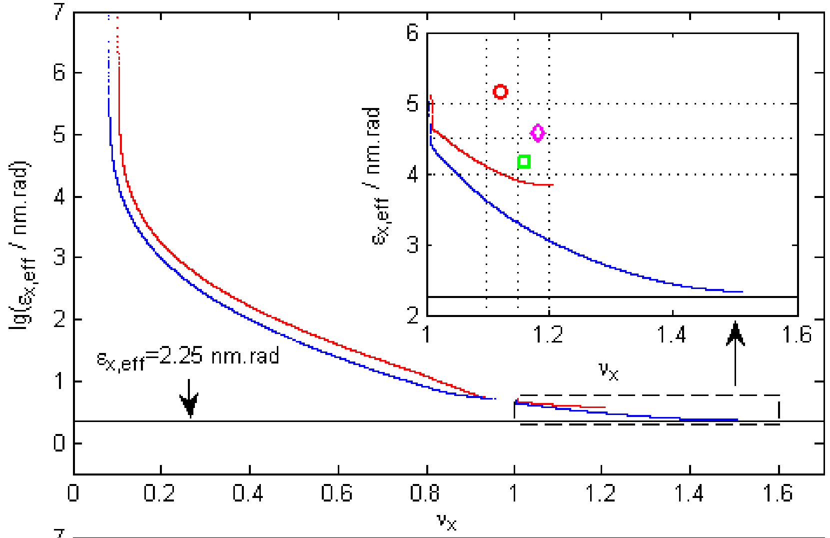


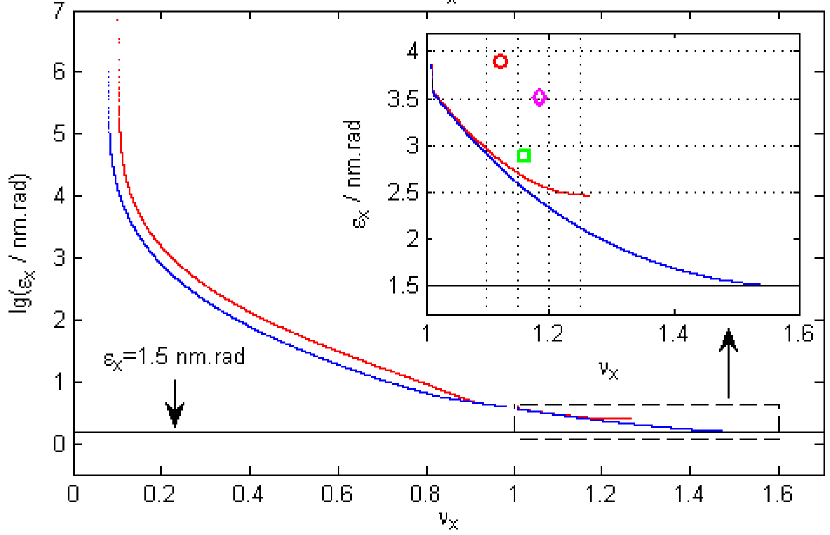
- TME in the SSRF storage ring

$$\varepsilon_{x,TME,Achro.} = 4.5nm.rad \qquad \varepsilon_{x,TME,Chro.} = 1.5nm.rad$$

- For a reasonable gradients, acceptable beam envelope, and well separation between β functions, the natural emittance in the SSRF storage ring was optimized down to 3.9 nm.rad, two and half times of the TME.

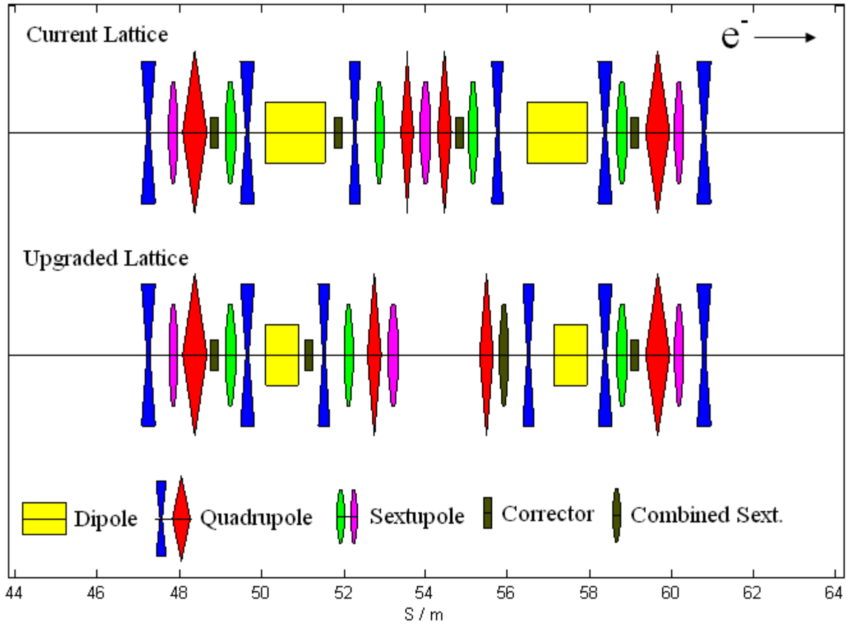






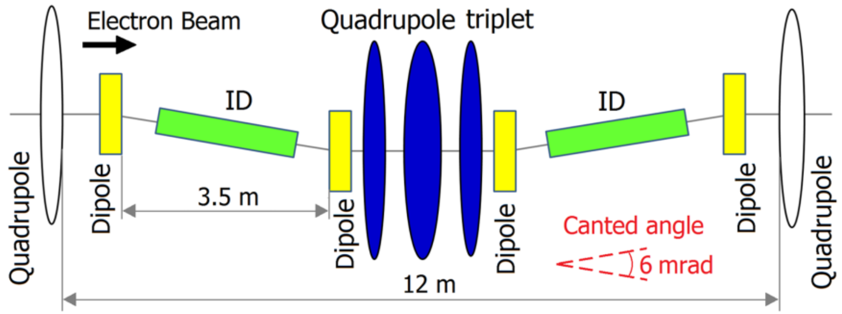
- Original lattice: Ideal four-fold symmetry/periodicity. Had been routinely operated for ten years (2009~2018)
- Phase-II project required necessary modification.

- More space for the planned IDs ← modification of arc section
- Higher flux of hard X-ray from dipole ← Super-Bend
- Dual-Canted ID in long SS ← double mini/waist beta-y optics
- Superconducting wiggler ← eliminate dispersion in its SS

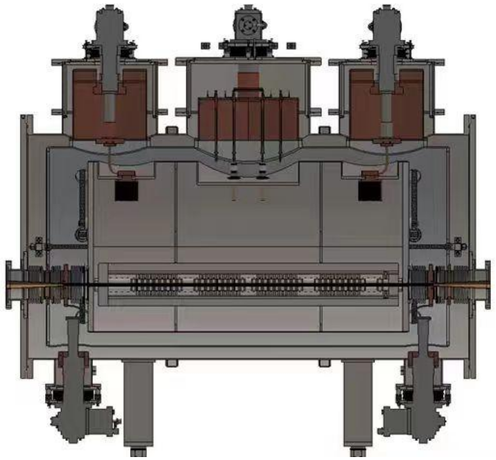


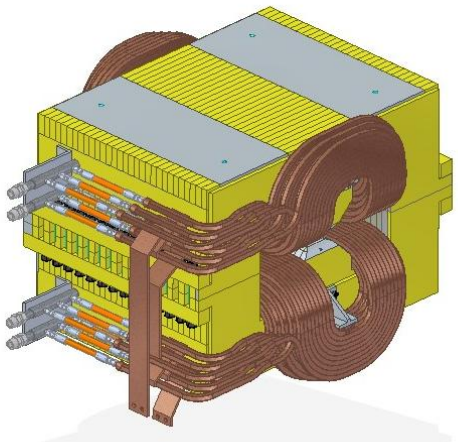
Modification in one DBA cell

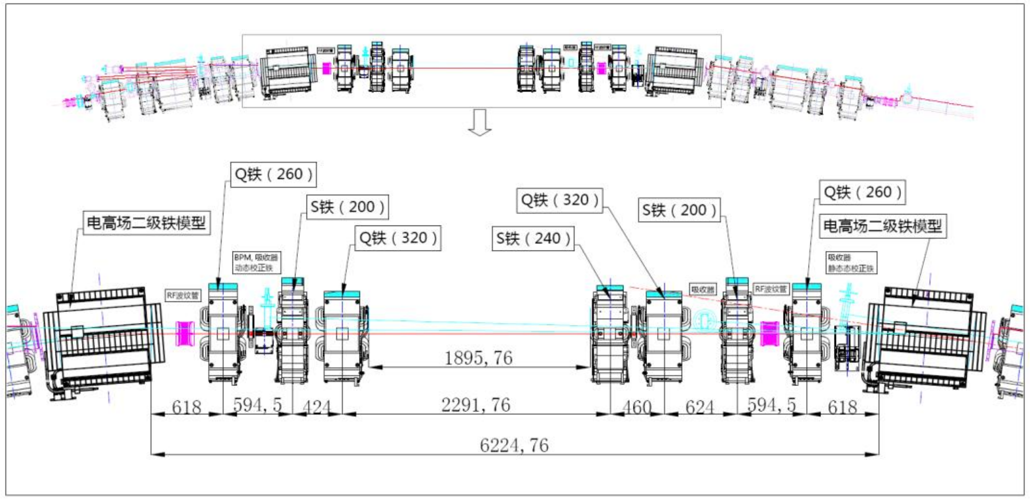
Sketch of double waist design in LSS



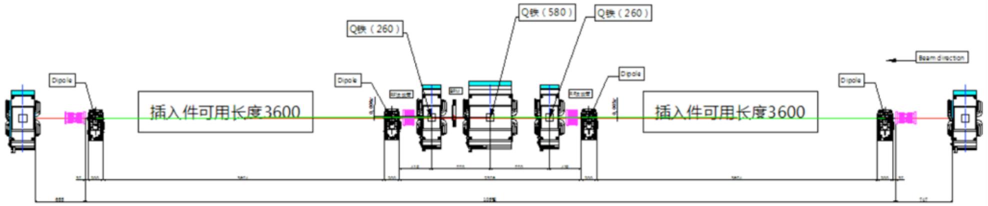
Blueprints of SCW (peak field ~4.2 T) and SuperB (2.29 T)



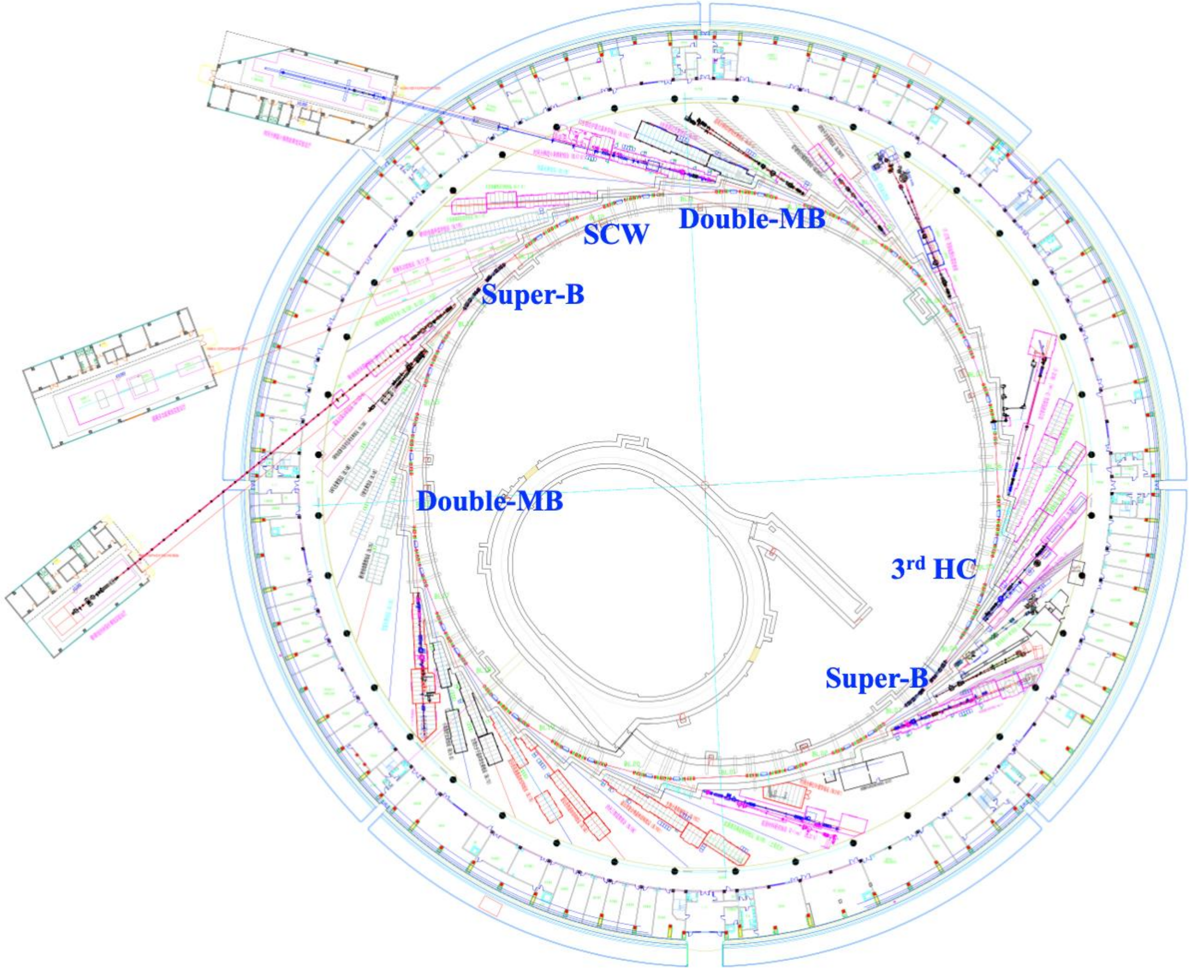




Layout of the arc section in SuperB cell



Layout of the long straight section



A quarter of the ring has been upgraded, and the original symmetry or periodicity has been destroyed.

- Design/optimization strategy consisted of:

① The same phase advance in SuperB cell as the nominal cell
② Pi-trick in double waist section
③ More sextupole families were classified according to beam optics (8→16)
④ Global fine-tuning with GA

- A new lattice with 4.2 nm.rad of beam emittance, and sufficient DA and EA for beam injection and lifetime.

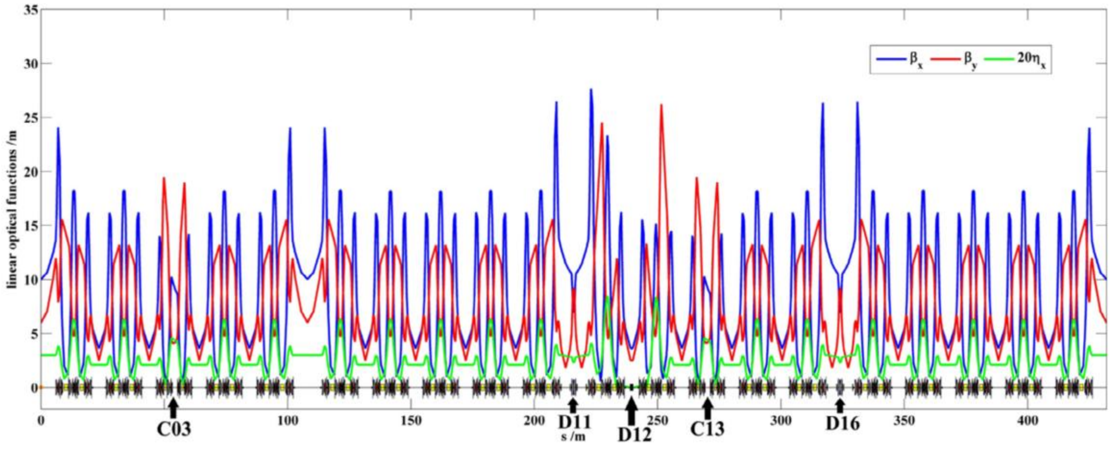


Fig. 2. Linear optics of the new SSRF storage ring lattice.

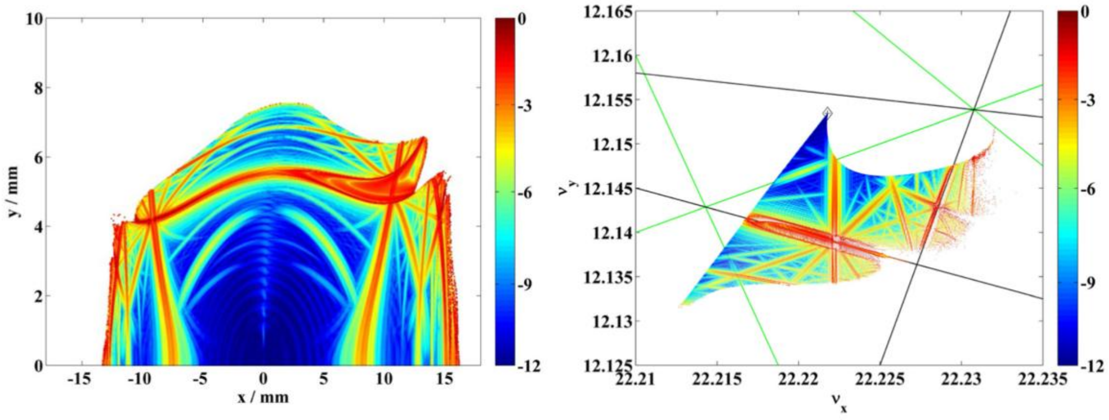


Fig. 7. Diffusion map (left) and frequency map (right) of the on-momentum dynamic aperture.

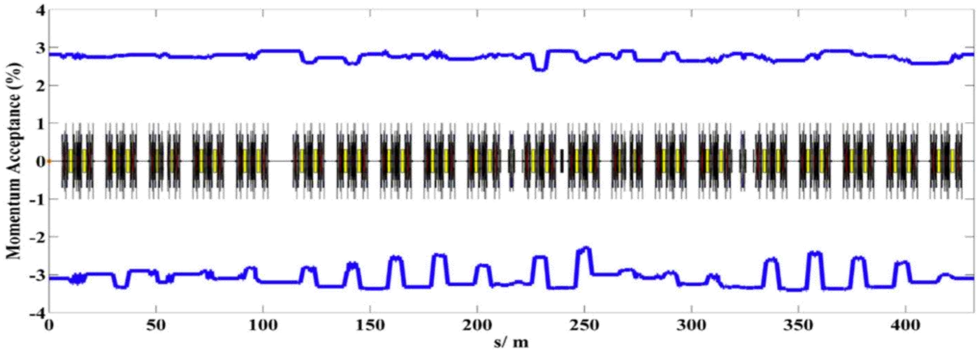


Fig. 8. Global momentum acceptance of the new SSRF storage ring lattice.

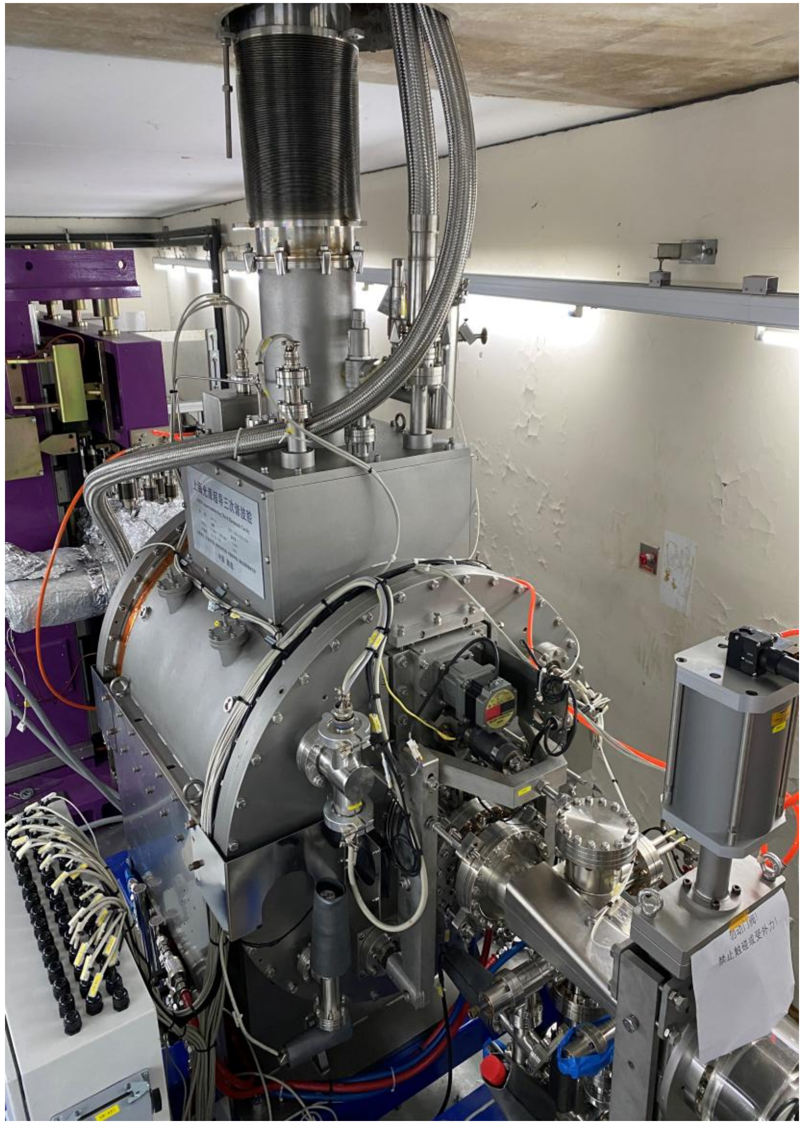
◆ Beam Parameters of the Storage Ring

Parameter	Original	Upgraded	Measured
Beam energy / GeV	3.5	3.5	3.50±0.01
Circumference / m	432	431.9893	431.965±0.003
Beam current / mA	200~300	200~300	200~260
Beam lifetime / hrs	>15 (200mA)	~12 (200mA)	18.0±0.5 (200mA, HC)
Working point (H, V)	22.22, 11.29	22.222, 12.153	22.222/12.153 (±0.002)
Natural chromaticity (H, V)	-55.7, -18.0	-55.3, -20.4	-51/-19 (±5/±3)
Natural emittance / nm.rad	3.89	4.22	4.5±0.3
Natural energy spread	9.8×10^{-4}	11.1×10^{-4}	$(10\pm2)\times10^{-4}$
Momentum compaction factor	4.27×10^{-4}	4.2×10^{-4}	$(4.0\pm0.5)\times10^{-4}$
Energy loss per turn / MeV	1.44	1.70	1.8±0.2
Damping time (H, V, S) / ms	7.05, 7.02, 3.51	5.98, 5.94, 2.96	6.0, 6.0, ---
Synchrotron tune	0.0076	0.0074	0.0072±0.0002
Bunch length	3.8 mm (zero-current)	4~8 mm(zero-current)	------ ~50 ps (200mA, no HC)

◆ RF System

➢ Main RF superconducting cavity:

Frequency	499.654 MHz
Voltage	1.5MV (1.7MV)
Power	120kW (150kW)
Phase Stability	≤±1°
Amplitude Stability	≤ ±1%



➢ 3rd harmonic RF system

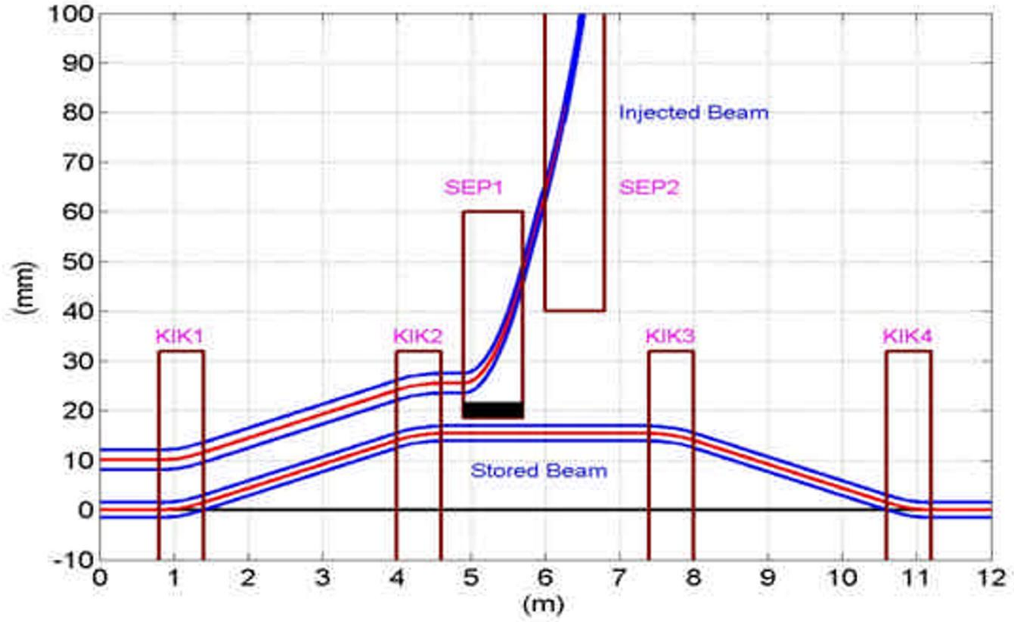
- Lengthening electron bunch, and increasing beam lifetime.

Parameter	Value
Voltage	1.4~1.8 MV
Frequency	1499 MHz
Temperature	4.2 K
Lengthening factor	2~3

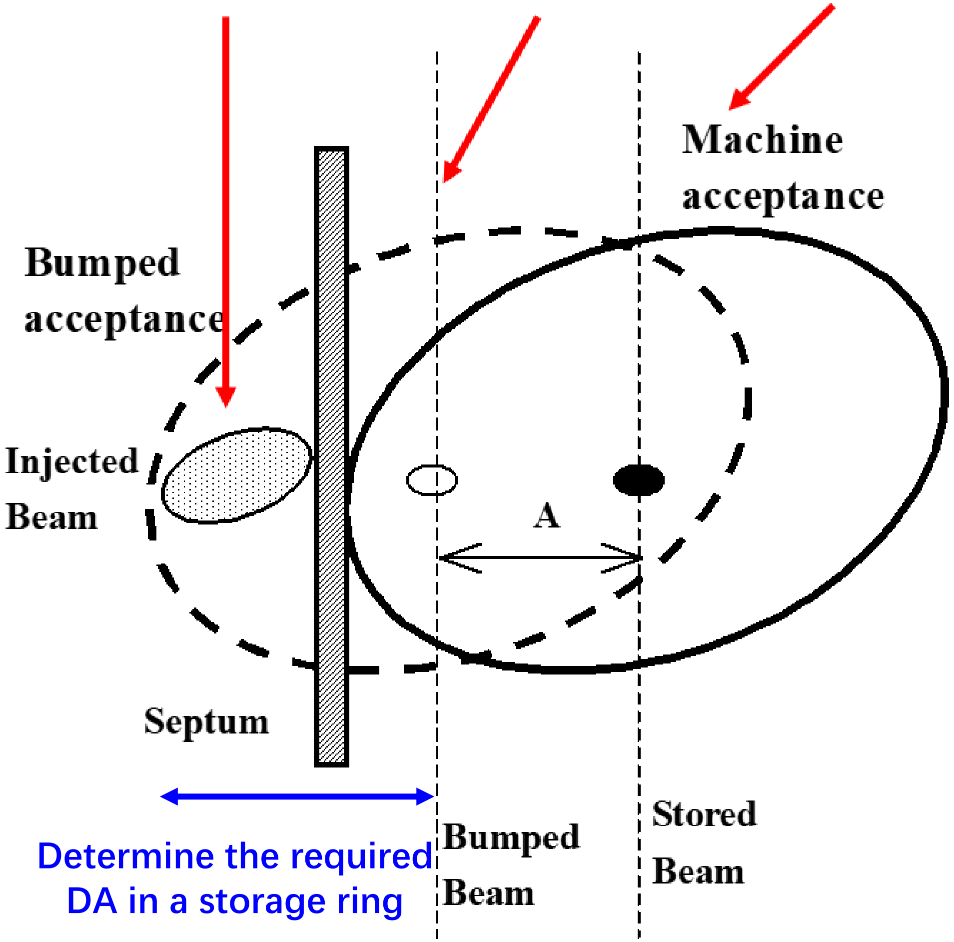
- Manufactured domesticly and stable operation.

◆ Beam Injection

- ➢ Injection system: four kickers and two septums implement pulsed-closed orbit beam injection.
- ➢ Installed in a long straight section to aviod interaction between closed bump and multipoles.



3、注入束流参数；2、脉冲凸轨；1、储存环接收度



Determine the required DA in a storage ring

➢ TOPUP injection

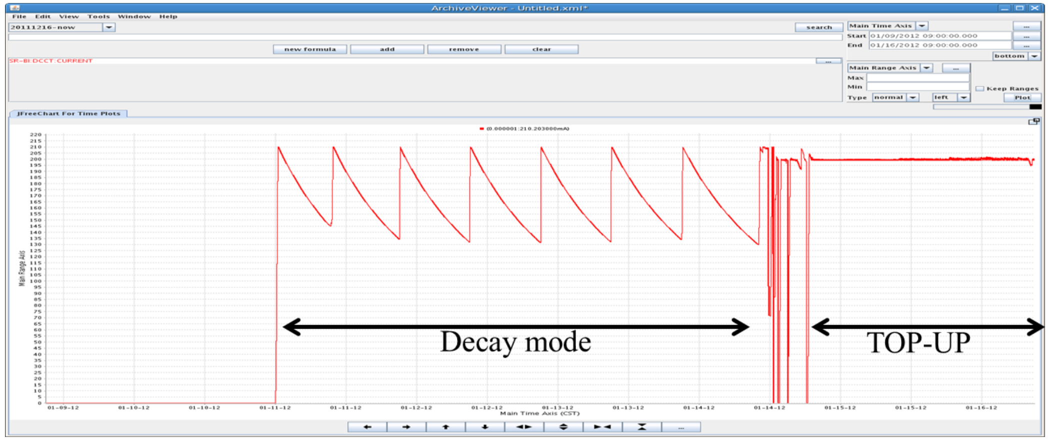
- When the beam current drops to a certain value, immedetely compensate a fraction of currents. This method provides a constant beam current during users' experiments.

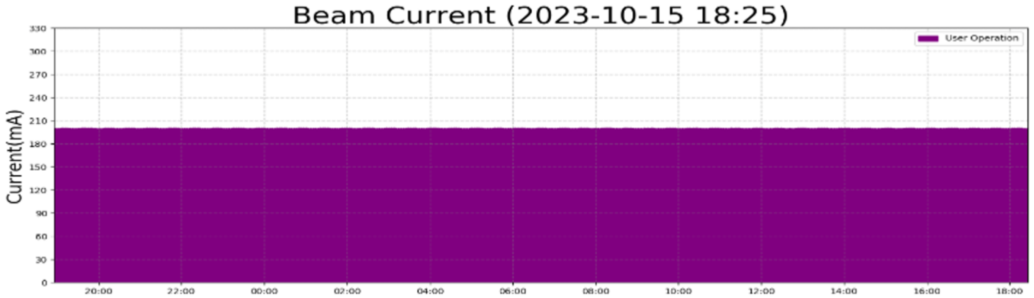
- Benefits:

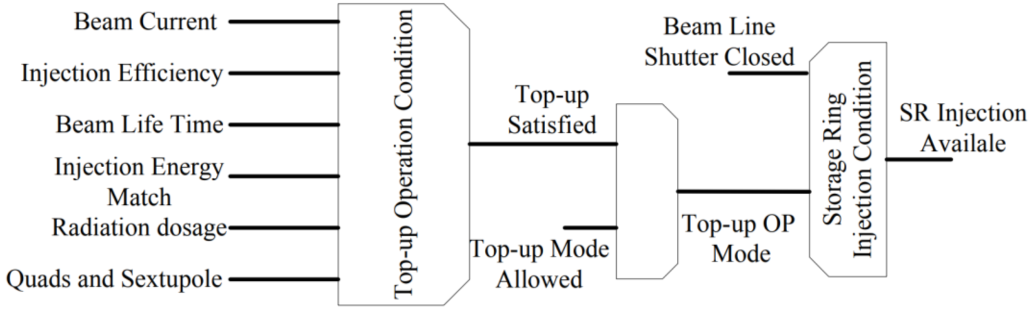
□ stabilizing the heat loading of optical lens in beamlines, so stabilizing photo path.
□ Higher integral flux.

- Adopted by most of all the 3rd and 4th generation light sources.

- Key issue is radiation safty (because of opened optical shutters in the shield wall) that is ensured by the reliable interlock system.



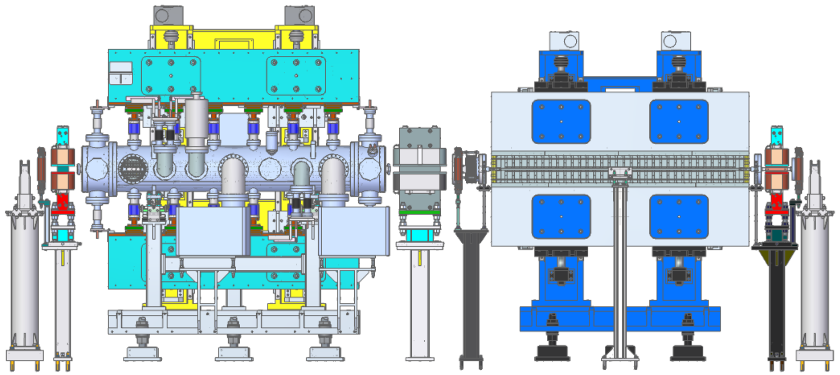


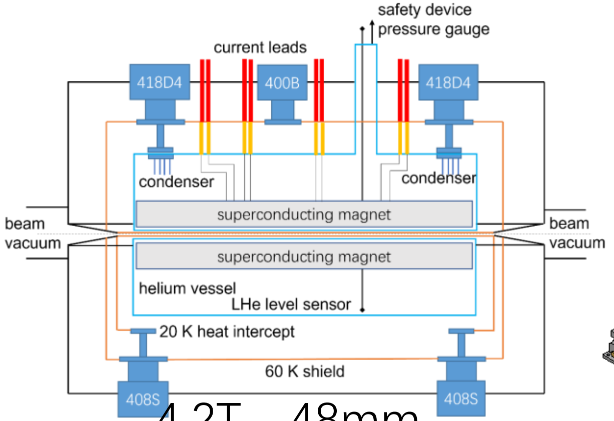


◆ Insertion Devices

- 25 IDs have been installed
- 6 different types
- 7 dual-canted IDs straights
- All of IDs were manufactured domesticaly

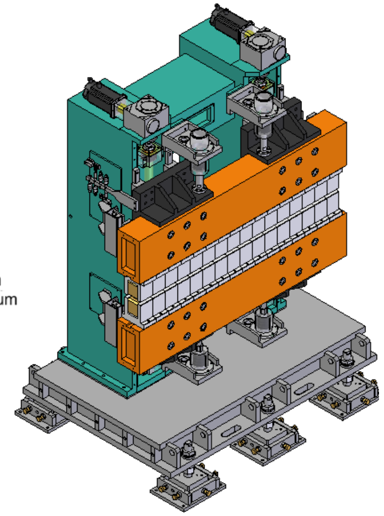
ID type	Number
IVU	12
CPMU	4
Wiggler	3
EPU	4 (+2)
AppleKnot EPU	1
SCW	1
Dual-Canted	5+2



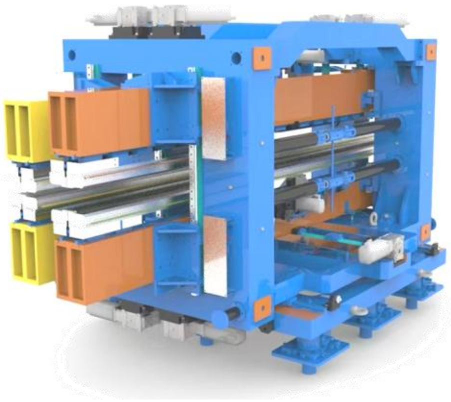


4.2T， 48mm

SCW

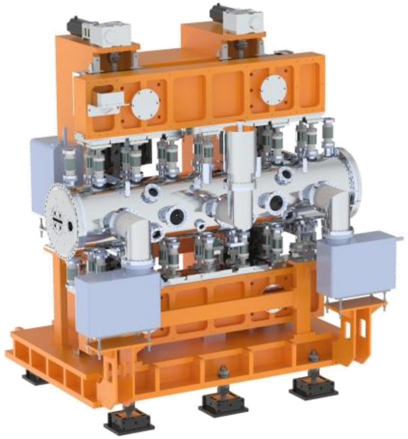


Wiggler



EPU

IVU



CPMU

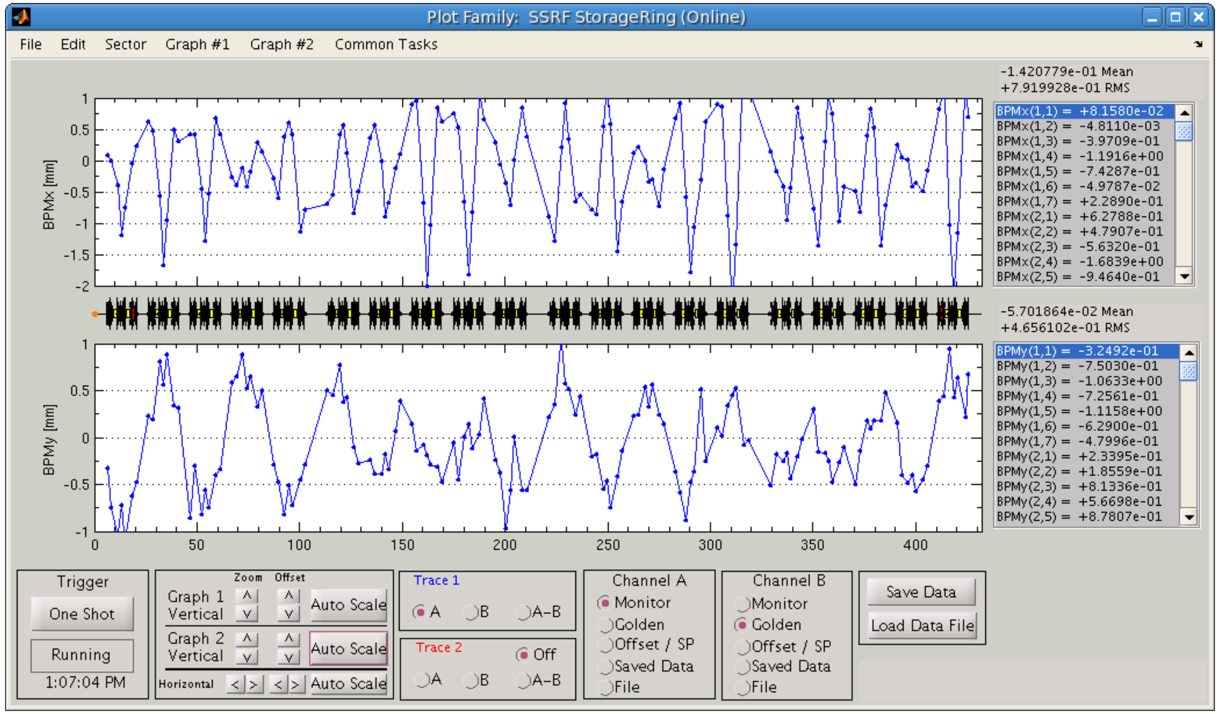
Unit	Beamline	Photo Energy	ID	Periodicity	Gap	Field	Length
02	表面衍射线站	4.8-28 KeV	CPMU	20mm	6-30mm	1.09T	2.2m
02	生物大分子晶体学光束线站	7-15 KeV	IVU22N69	22mm	6-30mm	0.9T	2m
03	高分辨角分辨光电子能谱线站	7-70 eV	AppleKnotEPU200	200mm	16-80mm	0.7T	4.4m
05	动力学结构研究线站	5-25 KeV	IVU22	22mm	6-30mm	0.9T	2.6m
07	纳米自旋与磁学线站	50-2000 eV	Double EPU	58mm 90mm	16.5-150mm 18.8-150mm	0.78T 0.85T	5m
08	软X射线谱学显微光束线站	192 - 2182 eV	EPU100	100mm	35-98mm	0.6T	4.3m
09	“梦之线”	20-2000 eV	EPU58/148	58mm 148mm	16.5-120mm 22-130mm	0.78T 0.67T	5m
10	时间分辨超小角散射线站	8-15 KeV	IVU20	20mm	6-30mm	0.84T	2.1m
10	P2	7-18 KeV	IVU22	22mm	6-30mm	0.84T	2.1m
12	超硬多功能	30-150 KeV	SCW	48mm	9mm	4.2T	2.5m
13	稀有元素分析线站	5-50 KeV	Wiggle100	100mm	16.5-120mm	1.57T	1.5m
13	硬X射线纳米探针线站	5-25 KeV	IVU	20mm	6-30mm	0.86T	4.5m
14	XAFS光束线站	3.9 ～23 keV	wiggle80	80mm	14-140mm	1.3T	1.7m
15	硬X射线微聚焦及应用光束线站	5-20 keV	IVU25B	25mm	6-30mm	0.94T	2.7m
16	快X射线成像线站	8.7-30 KeV	CPMU	18mm	6-30mm	1.025T	3.6m
16	中能谱学线站	2.1-16 KeV	IVU	26mm	6-30mm	1.12T	3.6m
17	膜蛋白线站	5-25 KeV	CPMU	20mm	6-30mm	1.09T	3.7m
18	蛋白质微晶体结构光束线站	5-18 keV	IVU25C	25mm	6-30mm	0.96T	2.7m
19	蛋白质复合物晶体结构线站	7-15 keV	IVU20A	20mm	7-30mm	1.04T	2.2m
19	生物小角散射线站	7-15 keV	IVU20A	20mm	7-30mm	1.04T	2.2m
20	能源材料线站	130 eV-18 KeV	IVU24	24mm	6-30mm	0.96T	2.1m
			EPU60	60mm	14.5-85mm	0.90T	1.9m

Beam Manipulations

◆ **Closed Orbit Deviations (COD) and Feedback**

➢ Caused by all the dipole field errors (tilts in Dipoles, misalignments in Multipoles, imperfections in IDs…)

$$z(s) = \frac{\sqrt{\beta_s}}{2\sin \pi\nu}\sum_{i=1}^{N}\sqrt{\beta_{s_i}}\,\theta_i \cos(\pi\nu - |\psi_s - \psi_{s_i}|)$$



➢ Severe CODs will make restoration of lattice perfermance difficult, and create significant defference between optical path in beamlines and electron path.

➢ Small dipole corrector are used to correct COD.

- COD correction

- SSRF: 80 slow correctors+140 BPMs
- Algorithm: Steepest Descent Method + Singular Value Decomposition (SVD)

$$Z = (z_1, z_2, \dots z_m), \Theta = (\theta_1, \theta_2, \dots \theta_n)$$

$$R_{i,j} = \partial z_i / \partial \theta_j$$

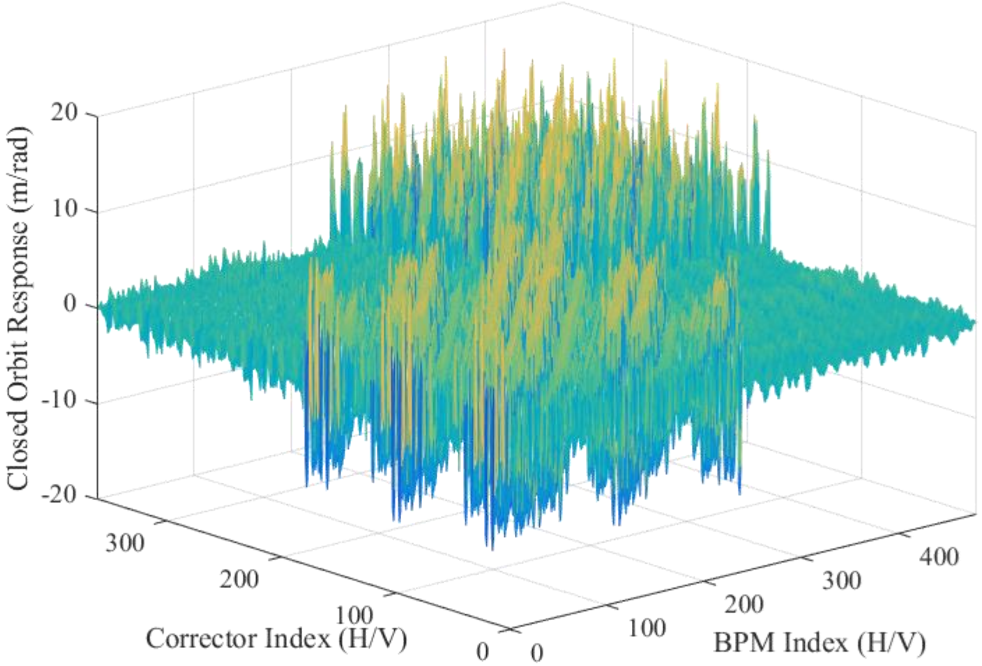
$$\Theta_{new} = \Theta_0 - R^{-1} Z_0$$

- In most cases the RM is not invertible, so SVD method is applied to provide a quasi-inversed matrix of RM.

$$R = USV^T$$

$$\Theta_{new} = \Theta_0 - (V(:,1{:}N_s) S(1{:}N_s, 1{:}N_s)^{-1} U(:,1{:}N_s)^T) Z_0$$

- The best CODs in the SSRF storage ring are about **50~80μm** (RMS along the ring) after correction.



➢ Closed Orbit Stability

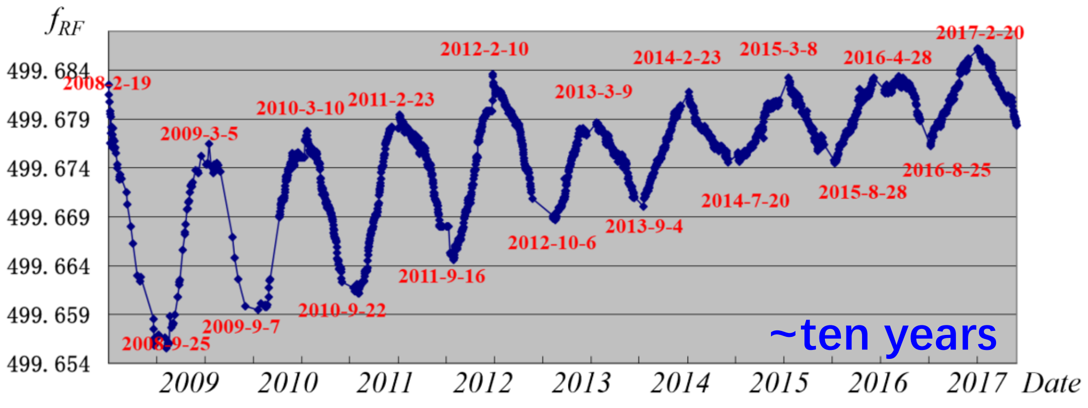
- Severe vibrations of COD will reduce the flux of beamlines, and cause data error in scientific experiments.

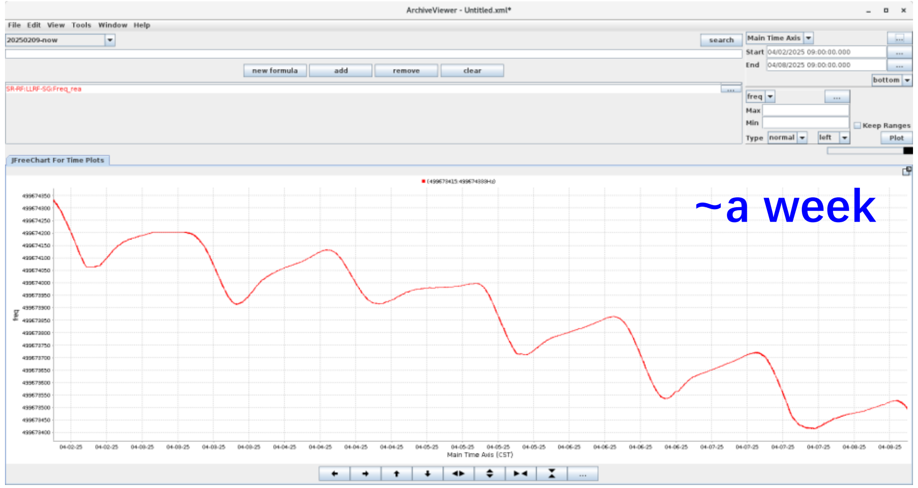
- Orbit instability originates from errors in measurement system (BPM noises) and vibrations of magnetic field .

  - ☐ Ground shrinkage and expansion with temperature (<1e-3Hz)
  - ☐ Drift in power supplies (low frequency <1e-2Hz)
  - ☐ ID adjustments (low frequency ~0.1Hz)
  - ☐ Higher frequency ripples in power supplies (>10Hz)
  - ☐ Turbulence in cooling system (>10Hz)
  - ☐ High frequency vibrations from outside of the facility (Traffic)

- Orbit feedback system in SSRF

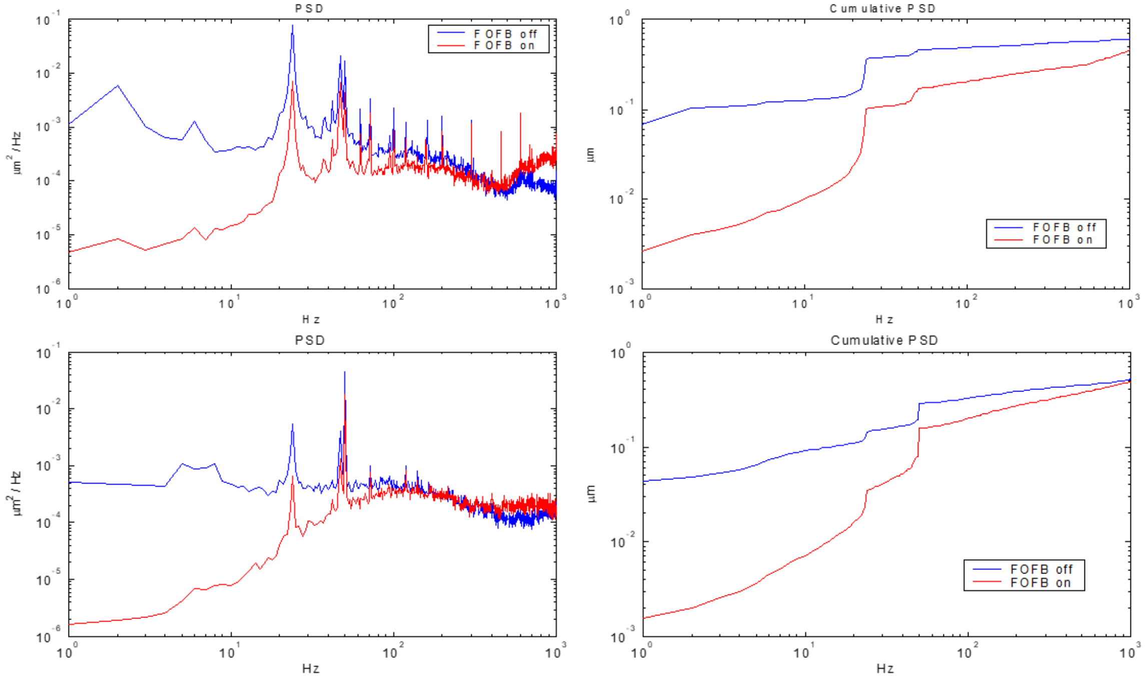
  - ☐ Soft orbit feedback (Combined f_{RF}) + Fast orbit feedback
  - ☐ 80 slow correctors + 40 fast correctors for each plane

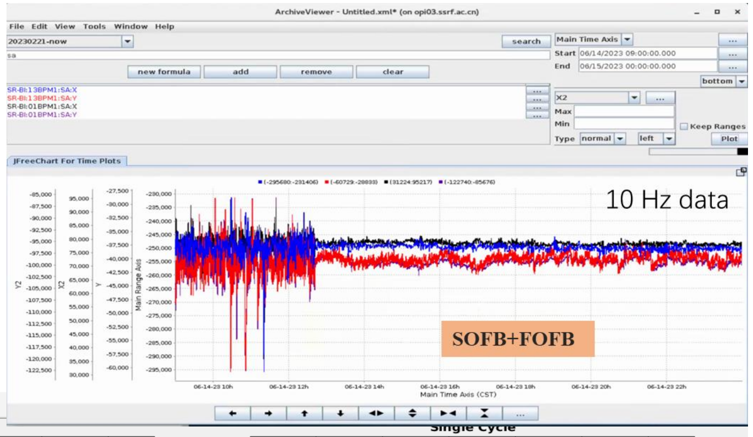


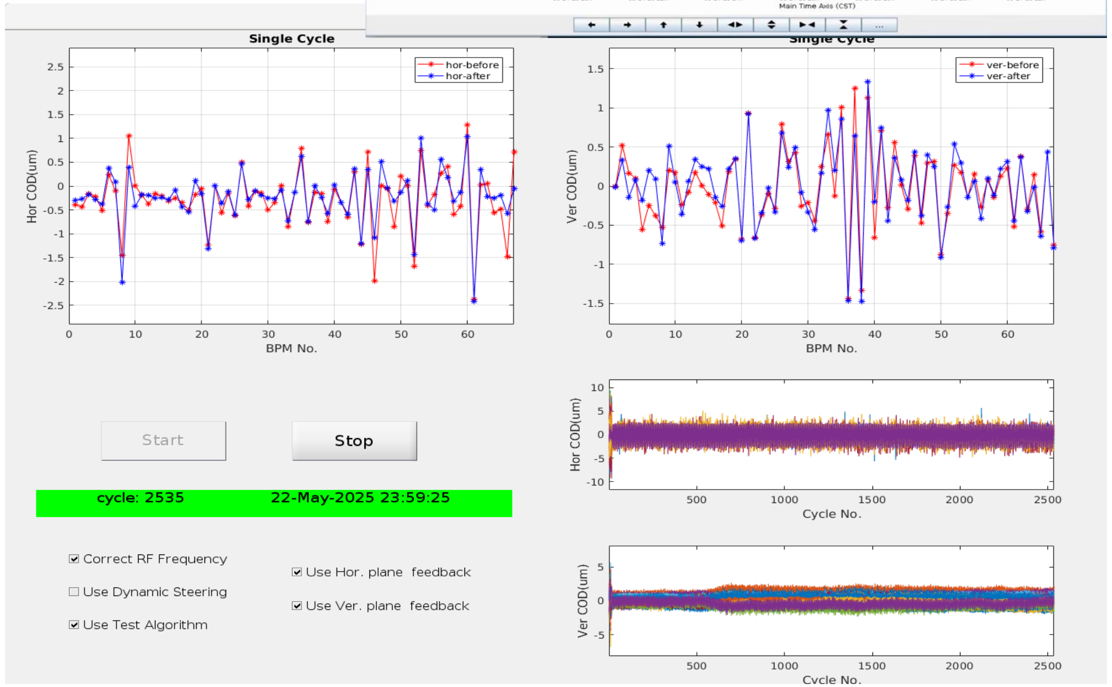


RF frequency variation with time/date

- Classic specification in orbit stability: RMS~10%$\sigma_{x,y}$, ~1μm for SSRF.
- Successfully suppress of COD instability less than 100 Hz (cut down by eddy current in vacuume vessel).
- RMS orbit stability reached the level of sub-μm (~500nm) in SSRF.







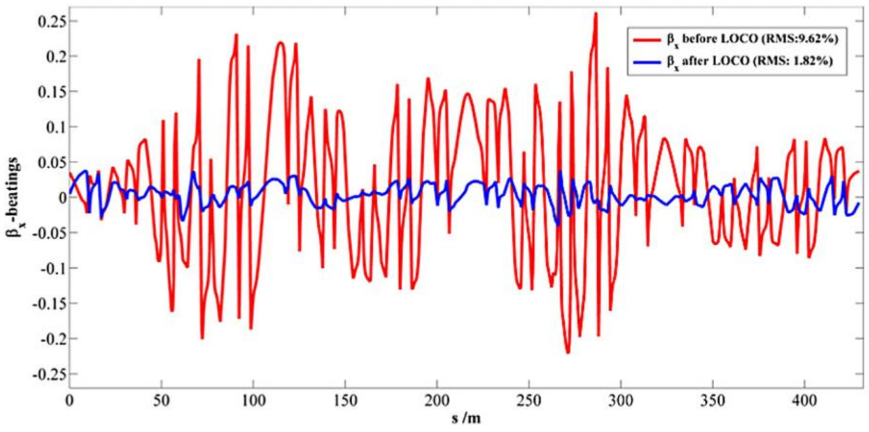
◆ Beam Optics Correction and Feedback

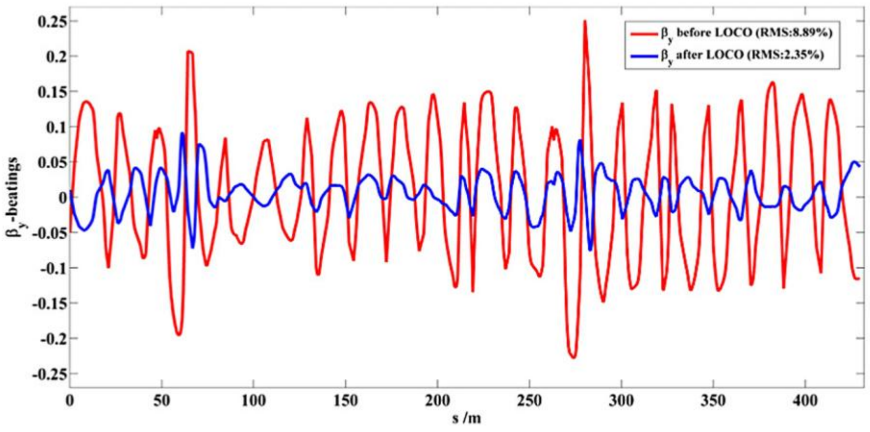
- Beam optics distorations caused by quadrupole errors make the optimal performance inavailable for users' experiments. So, we need to regularly correct the beam optics. Or, if we can, implemente optics feedback.
- Beta-beatings: beta function divation ratio from design one.
- Linear Optics from Closed Orbit response matrix (LOCO):

$$R_{jk} = \frac{\sqrt{\beta_j \beta_k}}{2\sin(\pi\upsilon)} \cos\left(\pi\upsilon - \left|\psi_j - \psi_k\right|\right)$$

$$\chi^2 = \sum_{j,k} \frac{\left(R_{Mode,j,k} - R_{Meas,j,k}\right)^2}{\sigma_j^2}$$

- Minimizing the χ^2 by adjusting quadrupole gradients, we can get a lattice modelling the operating storage ring. (Decent method: Levenberg-Marquardt algorithm)



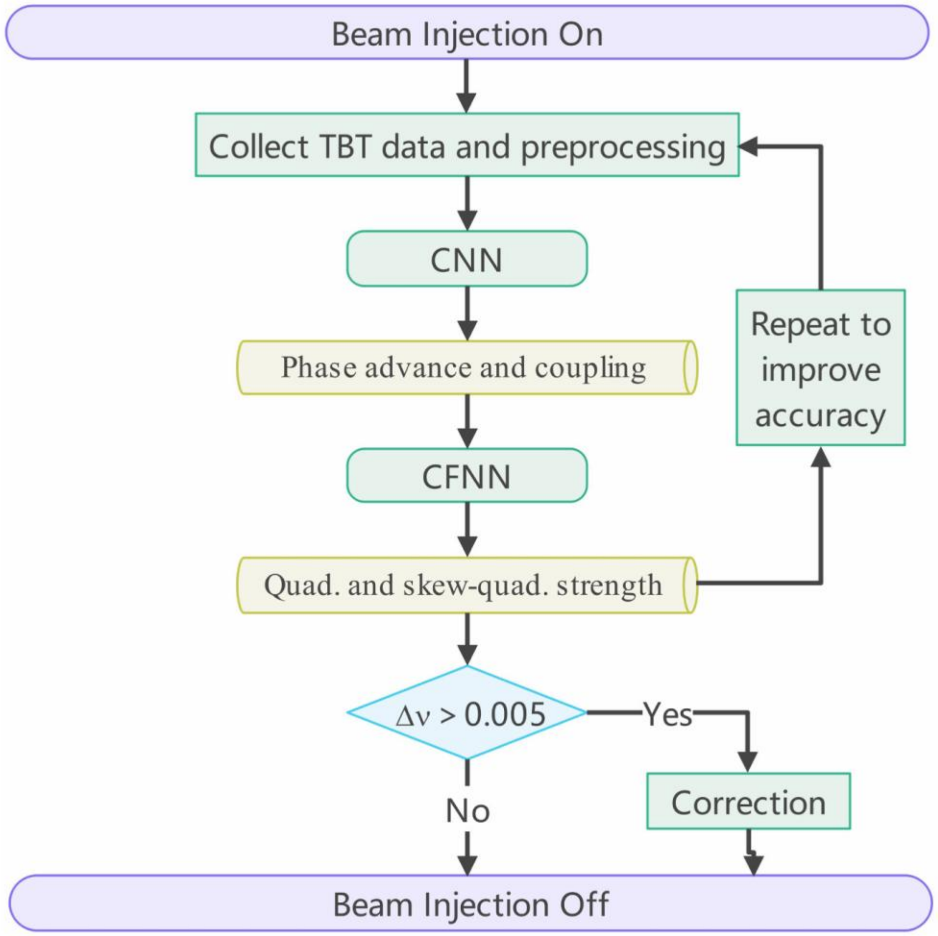


Beam Optics Feedback with Neural Network

- It works well to correct the beam optics with LOCO and MIA. However, these methods need strong drive to the electron beam, and cannot implement optics feedback during routine operation.

- Beam optics feedback system applying deep learning method with the input of TBT data and output of quadrupole gradients.

- Process:
  - Sampling (get beam spectrum in every BPM in the ring)
  - Phase advance prediction from beam spectrum with Convolutional Neural Network (CNN)
  - Gradient prediction from phase advace with Constrained Fitting Neural Network (CFNN)
  - Correct or feedback the beam optics if necessary.



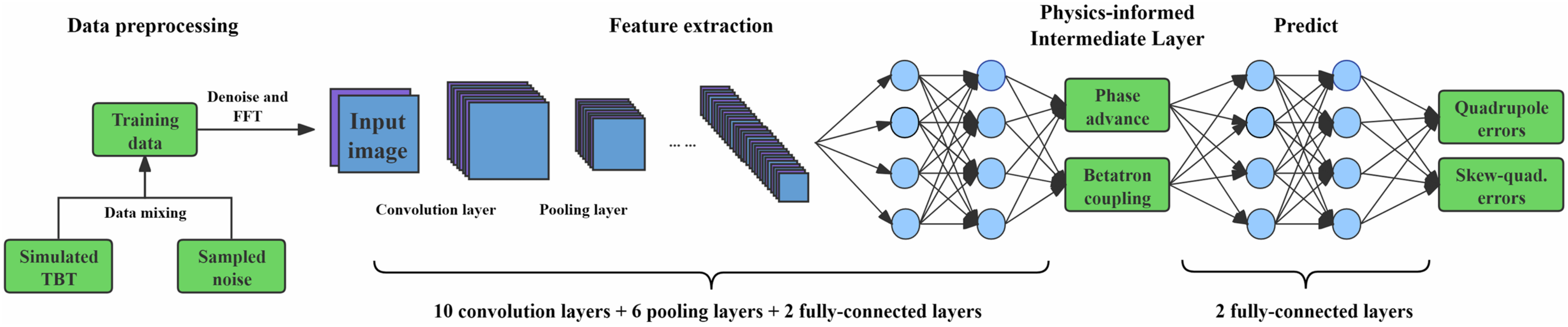
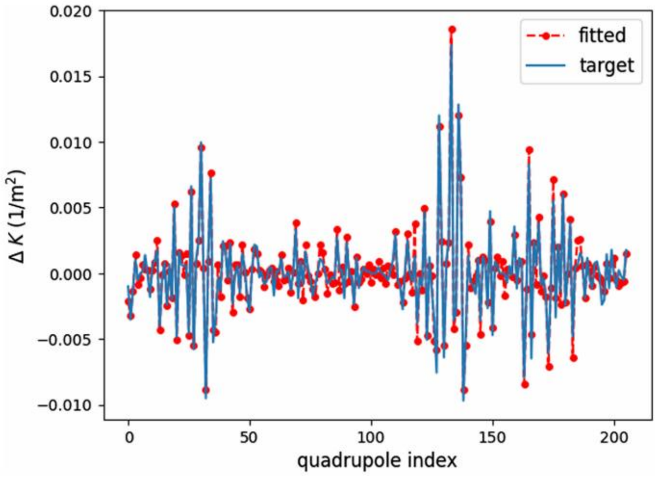


FIG. 8. Schematic diagram of the complete network architecture, including mixed training dataset generation, data denoise and preprocessing, a CNN for feature extraction, and fully-connected layers for quadrupole and skew-quadrupole error prediction. The phase advance and betatron coupling parameters output by the CNN are treated as a physics-informed intermediate layer and integrated into the model training process.

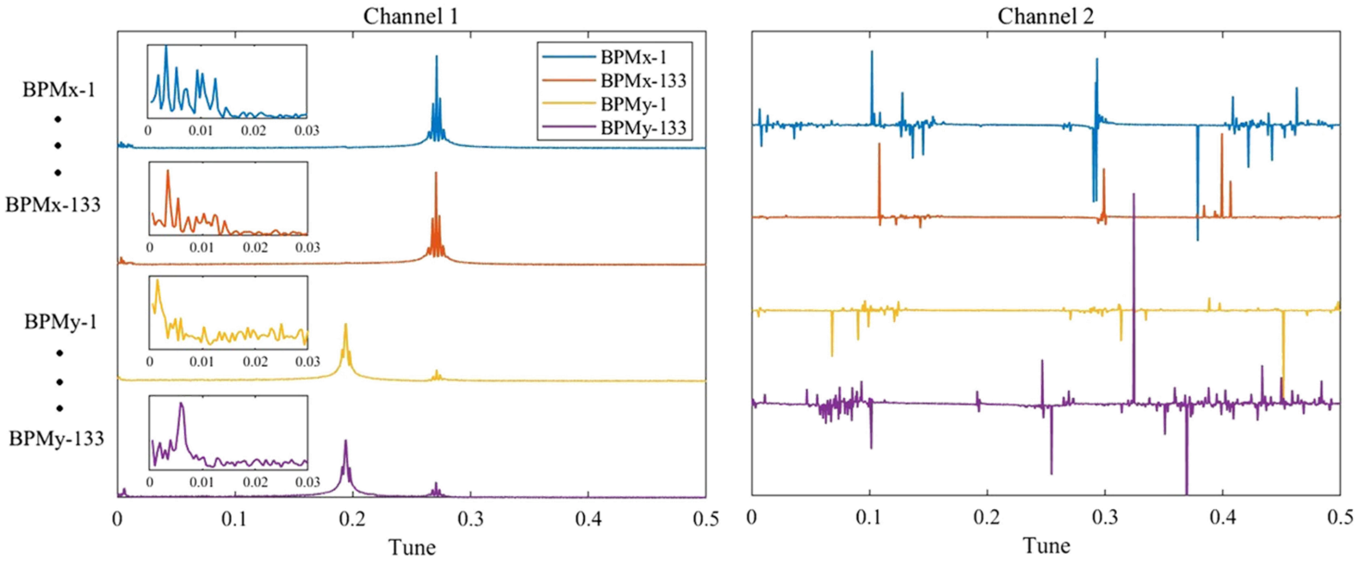
DOI: https://doi.org/10.1103/l1gf-558m

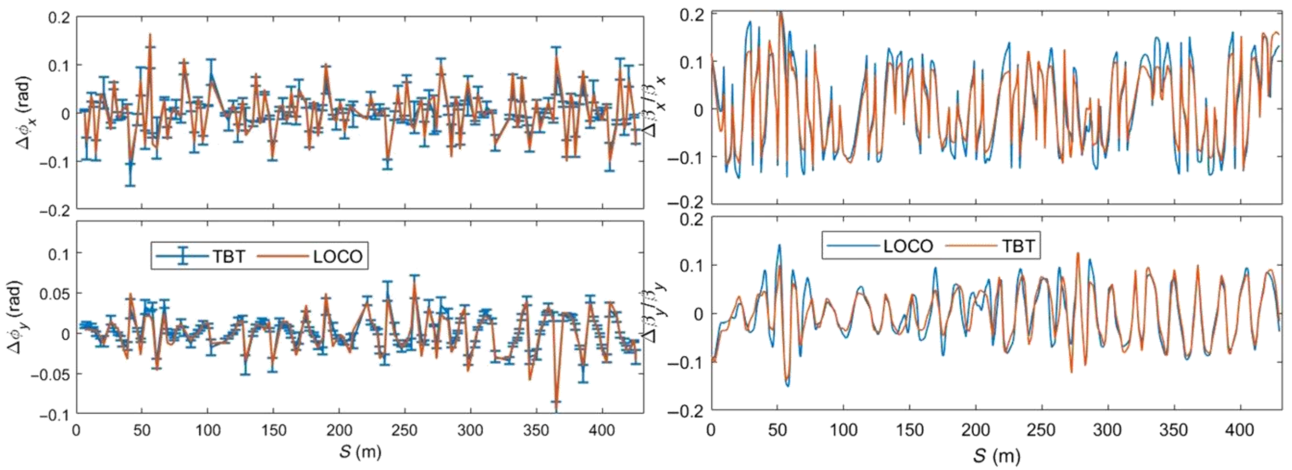
- Test-I:

- Test in machine study time
- Active error settings in Quadrupole PSs



- Comparision with LOCO results



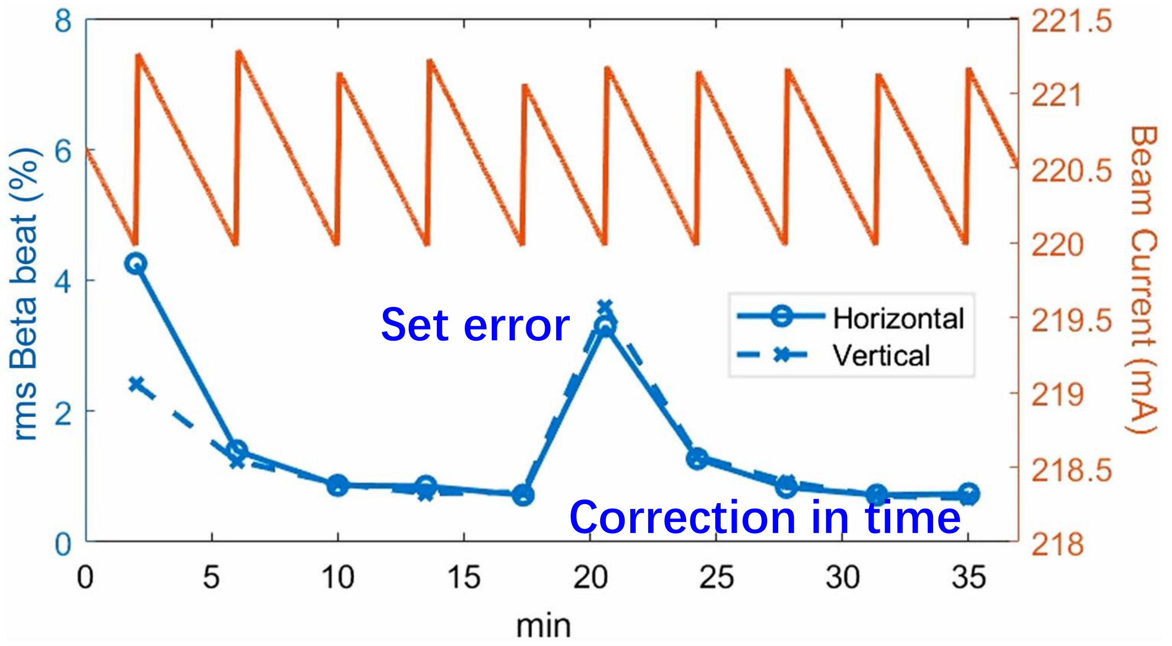


- Test-II:

- Test in TOPUP (without double-check by LOCO)
- Active error settings in PSs or change in EPUs

- This technique enables continuous monitoring and correction during each injection cycle.

- It had neither over-corrected beam optics nor over-predicted quadrupole PSs.

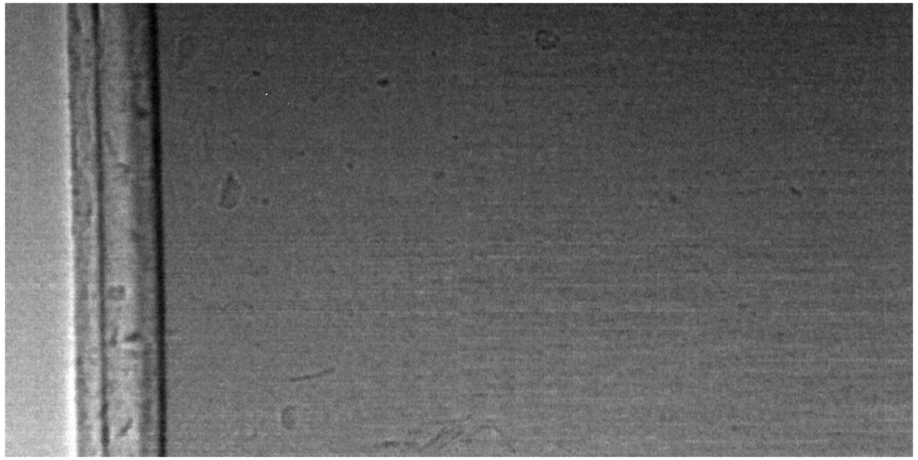


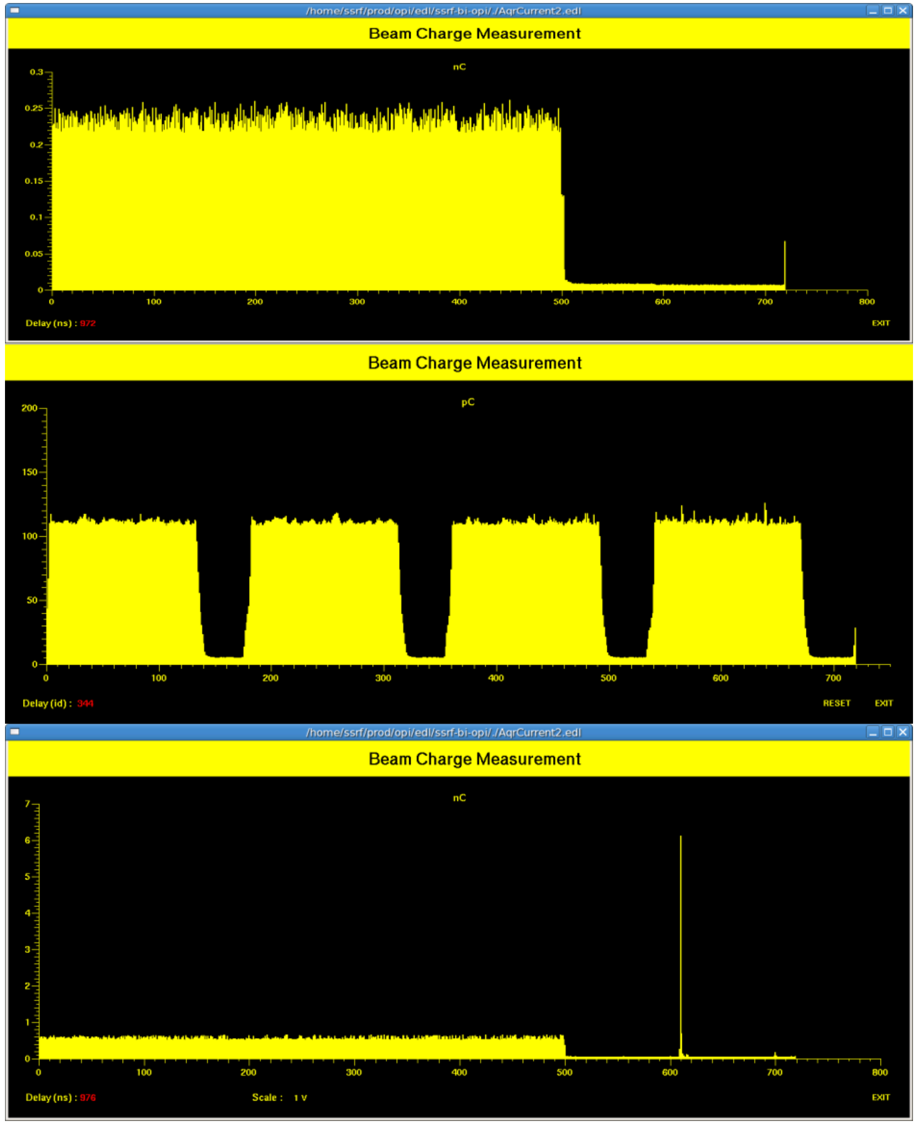
- Discussions

- This feedback technique can be applied in the storage ring with a few injection disturbation (~100μm in our case), while not available in Pulsed Multipole or SWAP-OUT injection.
- A dedicated kicker is helpful in PM and SO injection. It can drive the electron beam every tens of munites.
- How do we reduce the required amplitude of the residual beam oscilation?

◆ Filling Patterns

- 500-bunch-train filling
- 4 bunch-trains filling: 4×125, 200 mA
  Std (uniformity) better than 1%
  Developed to suppress fast ion instability
- Hybrid filling: 1×500+1, 180+20 mA
  Purity of the single bunch better than 1%
  less than 10% user time, at present
  Developed for fast-imaging experiments





Operation Status

- **Web of the SSRF operation**
- https://status.ssrf.ac.cn/ssrf/beam/beian.miit.gov.cn
- Real-time measured beam parameters and brief status of all the beamlines

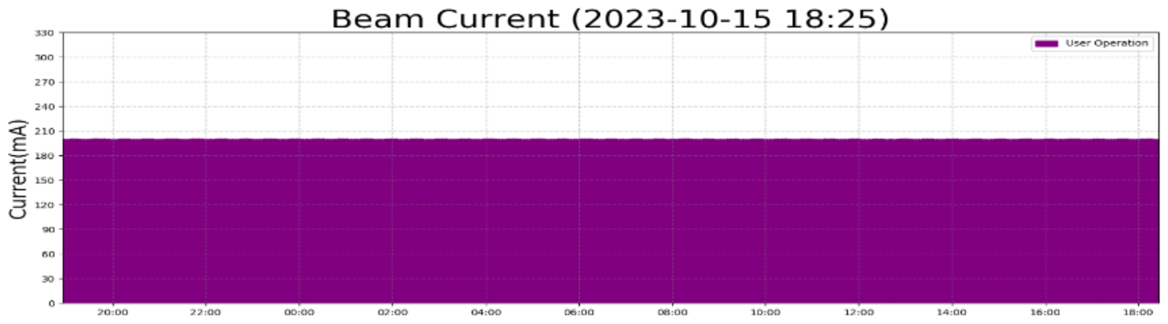
SSRF Operation Status

Main parameters

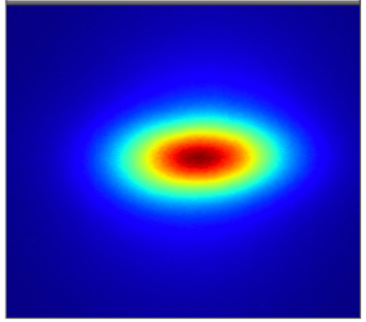
operator: **shift plan:** User Time **light:** Available

Current: 200.17mA

Energy:	3.5GeV
Emittance:	4.8nm-rad
Beam life time:	15.63hours
IntgCurrent:	20210.47AH
AveragePre:	3.29e-10Torr
Tune(x/y):	22.230/12.167
Hor.beamsize:	75.5um
Ver.beamsize:	69.7um
Coupling:	0.60%
Orbit(rms)x/y:	69.67/79.21um



Beam Image



Beamline status

Beamline	ID status	Shutter status	Beamline	ID status	Shutter Status	Beamline	ID status	Shutter Status
BL01B1	--	Open	BL08U1B	71.953mm	Open	BL14B	--	Open
BL02B1		Open	BL09U58	160.002mm	Open	BL15U1	6.741mm	Open
BL02U1	7.380mm	Open	BL09U148	59.181mm	Open	BL16B1	--	Open
BL02CPMU	5.999mm	Open	BL09B1		Open	BL16U1	10.401mm	Closed
BL03HB	--	Open	BL10U1	7.299mm	Open	BL16U2	8.000mm	Open
BL03U1	65.745mm	Open	BL10U2	7.533mm	Open	BL17B	--	Open
BL03SS	--	Open	BL11B1		Open	BL18U1	7.167mm	Open
BL05U1	5.998mm	Open	BL12SCW		Closed	BL19U1	9.368mm	Open
BL06B1		Open	BL13HB		Open	BL19U2	8.597mm	Open
BL07U58	25.117mm	Open	BL13IVU	7.151mm	Open	BL20U1	7.499mm	Open
BL07U90	150.000mm	Open	BL13SSW	16.500mm	Closed	BL20U2	28.900mm	Open
BL08U1A	71.953mm	Open	BL14W	17.000mm	Open			

Message from control room:


2024-05-15 星期三 17:12:58
SRF
中国科学院
CHINESE ACADEMY OF SCIENCES
Light & Truth
DELL

◆ Machine Time

- ~7000 hrs operation
- ~4500 hrs for users' experiments
- ~2500 hrs for warmup, machine studies and in-house study.

SSRF Operation Schedule (Jan1-Dec 31, 2025)

Jan			Feb			Mar			Apr			May			June		
1	B	B	1	D	D	1	B	B	1	M	A	1	U	U	1	U	U
2	U	U	2	D	D	2	B	B	2	B	B	2	U	U	2	U	U
3	U	U	3	D	D	3	U	U	3	U	U	3	U	U	3	M	A
4	U	U	4	D	D	4	U	U	4	U	U	4	U	U	4	A	A
5	U	U	5	D	D	5	U	U	5	U	U	5	U	U	5	B	B
6	U	U	6	D	D	6	U	U	6	U	U	6	M	A	6	U	U
7	M	A	7	D	D	7	U	U	7	U	U	7	A	A	7	U	U
8	A	A	8	D	D	8	U	U	8	M	A	8	B	B	8	U	U
9	B	B	9	D	D	9	U	U	9	A	A	9	U	U	9	U	U
10	U	U	10	D	D	10	U	U	10	B	B	10	U	U	10	M	A
11	U	U	11	D	D	11	M	A	11	U	U	11	U	U	11	B	B
12	U	U	12	D	D	12	B	B	12	U	U	12	U	U	12	U	U
13	U	U	13	D	D	13	U	U	13	U	U	13	M	A	13	U	U
14	M	A	14	D	D	14	U	U	14	U	U	14	B	B	14	U	U
15	B	B	15	D	D	15	U	U	15	M	A	15	U	U	15	U	U
16	U	U	16	D	D	16	U	U	16	B	B	16	U	U	16	U	U
17	U	U	17	W	W	17	U	U	17	U	U	17	U	U	17	M	A
18	U	U	18	W	W	18	M	A	18	U	U	18	U	U	18	A	A
19	U	U	19	W	W	19	A	A	19	U	U	19	U	U	19	B	B
20	U	U	20	W	W	20	B	B	20	U	U	20	M	A	20	U	U
21	D	D	21	W	W	21	U	U	21	U	U	21	A	A	21	U	U
22	D	D	22	A	A	22	U	U	22	M	A	22	B	B	22	U	U
23	D	D	23	A	A	23	U	U	23	A	A	23	U	U	23	U	U
24	D	D	24	A	A	24	U	U	24	B	B	24	U	U	24	M	A
25	D	D	25	A	A	25	M	A	25	U	U	25	U	U	25	B	B
26	D	D	26	A	A	26	B	B	26	U	U	26	U	U	26	U	U
27	D	D	27	A	A	27	U	U	27	U	U	27	M	A	27	U	U
28	D	D	28	A	A	28	U	U	28	U	U	28	B	B	28	U	U
29	D	D				29	U	U	29	M	A	29	U	U	29	U	U
30	D	D				30	U	U	30	B	B	30	U	U	30	U	U
31	D	D				31	U	U				31	U	U			
Jan			Feb			Mar			Apr			May			June		

July			Aug			Sep			Oct			Nov			Dec		
1	M	A	1	D	D	1	A	A	1	B	B	1	U	U	1	U	U
2	A	A	2	D	D	2	A	A	2	U	U	2	U	U	2	M	A
3	B	B	3	D	D	3	B	B	3	U	U	3	U	U	3	B	B
4	U	U	4	D	D	4	B	B	4	U	U	4	M	A	4	U	U
5	U	U	5	D	D	5	U	U	5	U	U	5	A	A	5	U	U
6	U	U	6	D	D	6	U	U	6	U	U	6	B	B	6	U	U
7	U	U	7	D	D	7	U	U	7	U	U	7	U	U	7	U	U
8	M	A	8	D	D	8	U	U	8	M	A	8	U	U	8	U	U
9	B	B	9	D	D	9	M	A	9	B	B	9	U	U	9	M	A
10	U	U	10	D	D	10	B	B	10	U	U	10	U	U	10	B	B
11	U	U	11	D	D	11	U	U	11	U	U	11	M	A	11	U	U
12	U	U	12	D	D	12	U	U	12	U	U	12	B	B	12	U	U
13	U	U	13	D	D	13	U	U	13	U	U	13	U	U	13	U	U
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15	D	D	15	D	D	15	U	U	15	A	A	15	U	U	15	U	U
16	D	D	16	D	D	16	M	A	16	B	B	16	U	U	16	M	A
17	D	D	17	D	D	17	A	A	17	U	U	17	U	U	17	A	A
18	D	D	18	D	D	18	B	B	18	U	U	18	M	A	18	B	B
19	D	D	19	D	D	19	U	U	19	U	U	19	A	A	19	U	U
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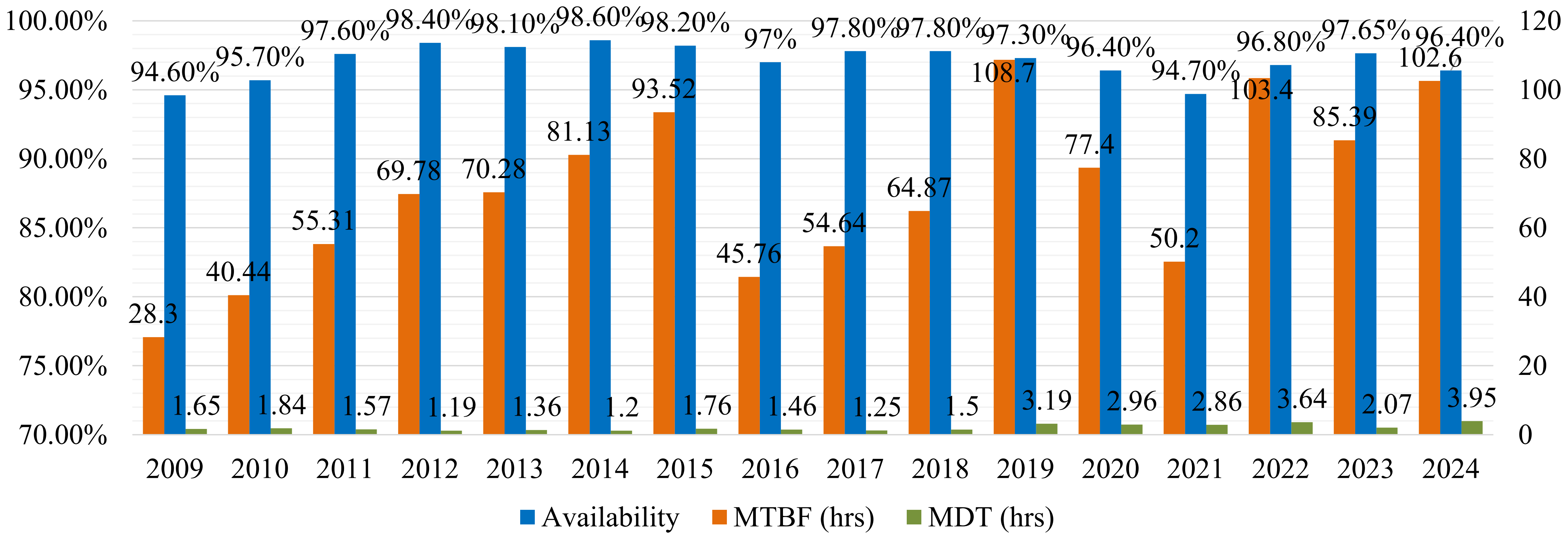
22	D	D	22	W	W	22	U	U	22	B	B	22	U	U	22	U	U
23	D	D	23	W	W	23	M	A	23	U	U	23	U	U	23	M	A
24	D	D	24	W	W	24	B	B	24	U	U	24	U	U	24	B	B
25	D	D	25	W	W	25	U	U	25	U	U	25	M	A	25	U	U
26	D	D	26	W	W	26	U	U	26	U	U	26	B	B	26	U	U
27	D	D	27	A	A	27	U	U	27	U	U	27	U	U	27	U	U
28	D	D	28	A	A	28	U	U	28	M	A	28	U	U	28	U	U
29	D	D	29	A	A	29	U	U	29	A	A	29	U	U	29	U	U
30	D	D	30	A	A	30	M	A	30	B	B	30	U	U	30	M	A
31	D	D	31	A	A				31	U	U				31	B	B
July			Aug			Sep			Oct			Nov			Dec		

U	User Time	B	Beamline Study
A	Machine Study	D	Shutdown, Installation
M	Maintenance	W	Warm Up

◆ Availability for Users' Experiments

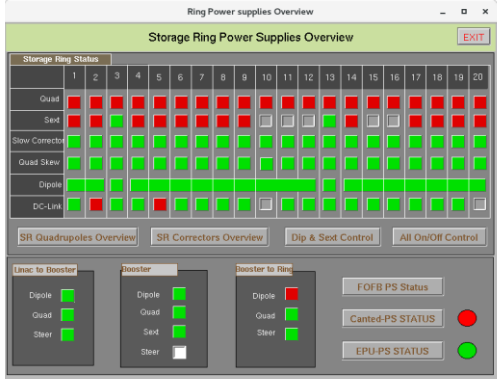
- Increased in the first several years, while be significantly affected by the following projects.
- It is desired that the availability could increase from now on, since the Phase-II project has been successfully completed.

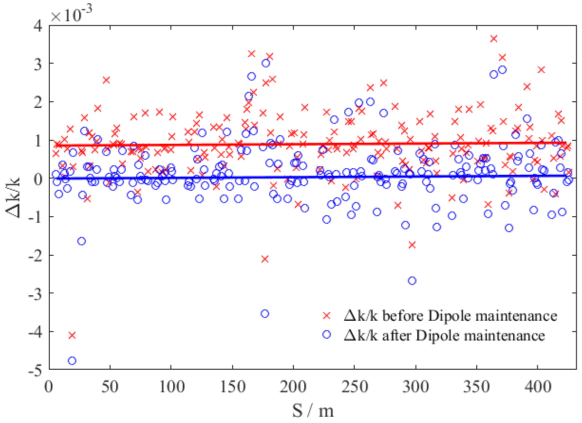


◆ Hardware Failures

- Observable hardware failures directly shown in the control panel.

- Hardware failures without direct indication/tangible evidence can be easily identified with beam behaviors.





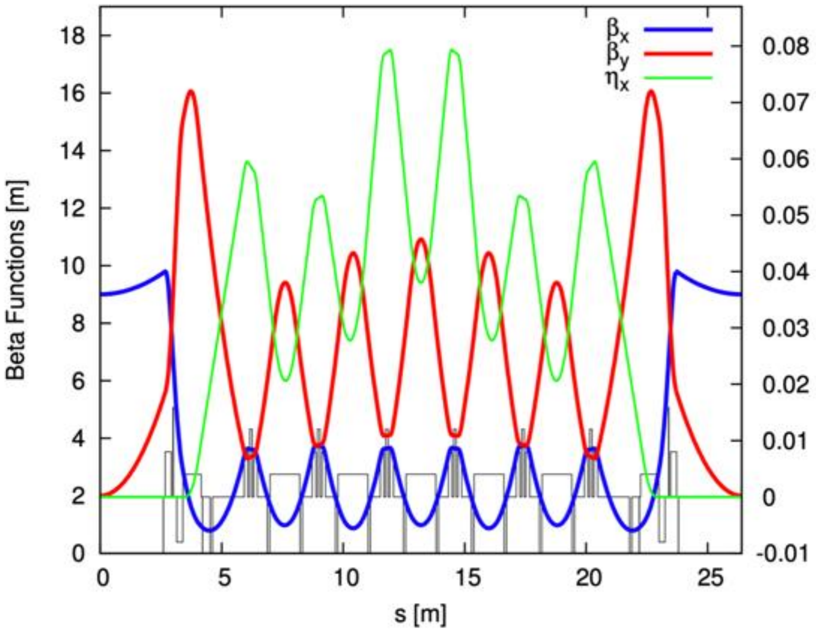
- While RF system (Arc of Coupler) and SCW (Quench) imposed significant challenge to the reliability. (Replace with spare equipments)

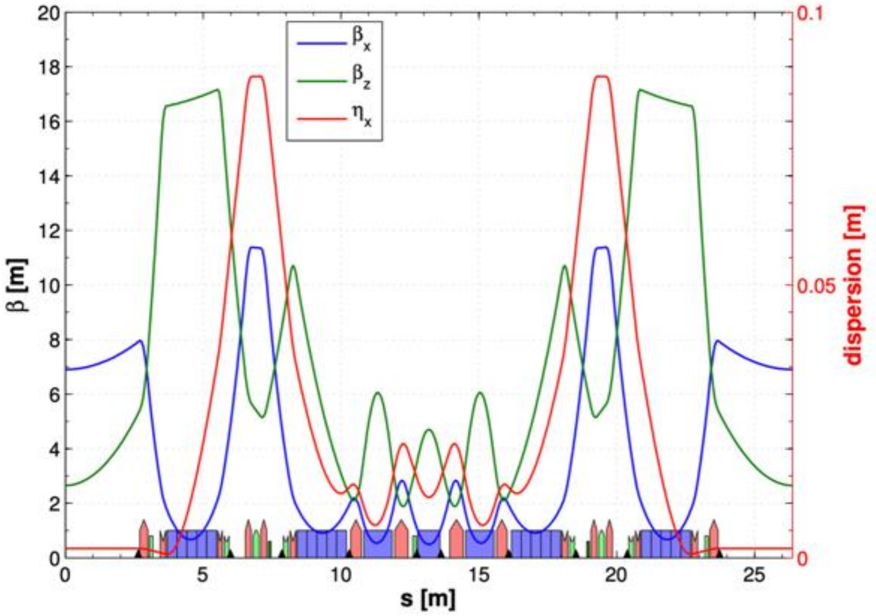
Time proportion	2024	2023	2022	2021	2020
RF	**16.41%**	5.16%	6.93%	3.95%	13.1%
Power Supply	7.16%	29.6%	22.9%	10.5%	19.9%
Cryogenic System	2.95%	0	24.6%	17.9%	7.74%
SCW	**38.7%**	17.0%	----	----	----
Utility	9.61%	19.9%	5.12%	6.27%	9.44%
Front End	5.32%	7.65%	12.2%	22.3%	7.33%
Diagnosis	4.27%	0	9.71%	10.9%	3.35%
Control System	2.40%	1.43%	0.27%	0.16%	3.20%
Electronic System	0.20%	0	0	5.14%	0
Pulsed Equipment	3.81%	5.38%	0	9.51%	0.77%
Vacuum	0	0.12%	9.11%	1.66%	0
Acce. Technology	2.83%	8.87%	8.83%	0.17%	0.99%
Radiation Prot.	1.18%	1.03%	0.35%	0	0.38%
Operation	0	2.38%	0	0	0
Others	5.10%	1.49%	0	11.5%	33.9%

Upgrade towards DLLS

◆ **The 4th Generation Light Sources**

➢ The earliest explorers of the fourth generation light sources: **MAX-IV and ESRF-EBS** started their operation in 2017 and 2020 respectively. Both facilities adopt a **MBA**-structure, and the beam emittance were reduced to 330 and 135 pm.rad, respectively.





Lattice and Beam Optics in MAX-IV (Left) and ESRF-EBS (Right)

MAX-IV

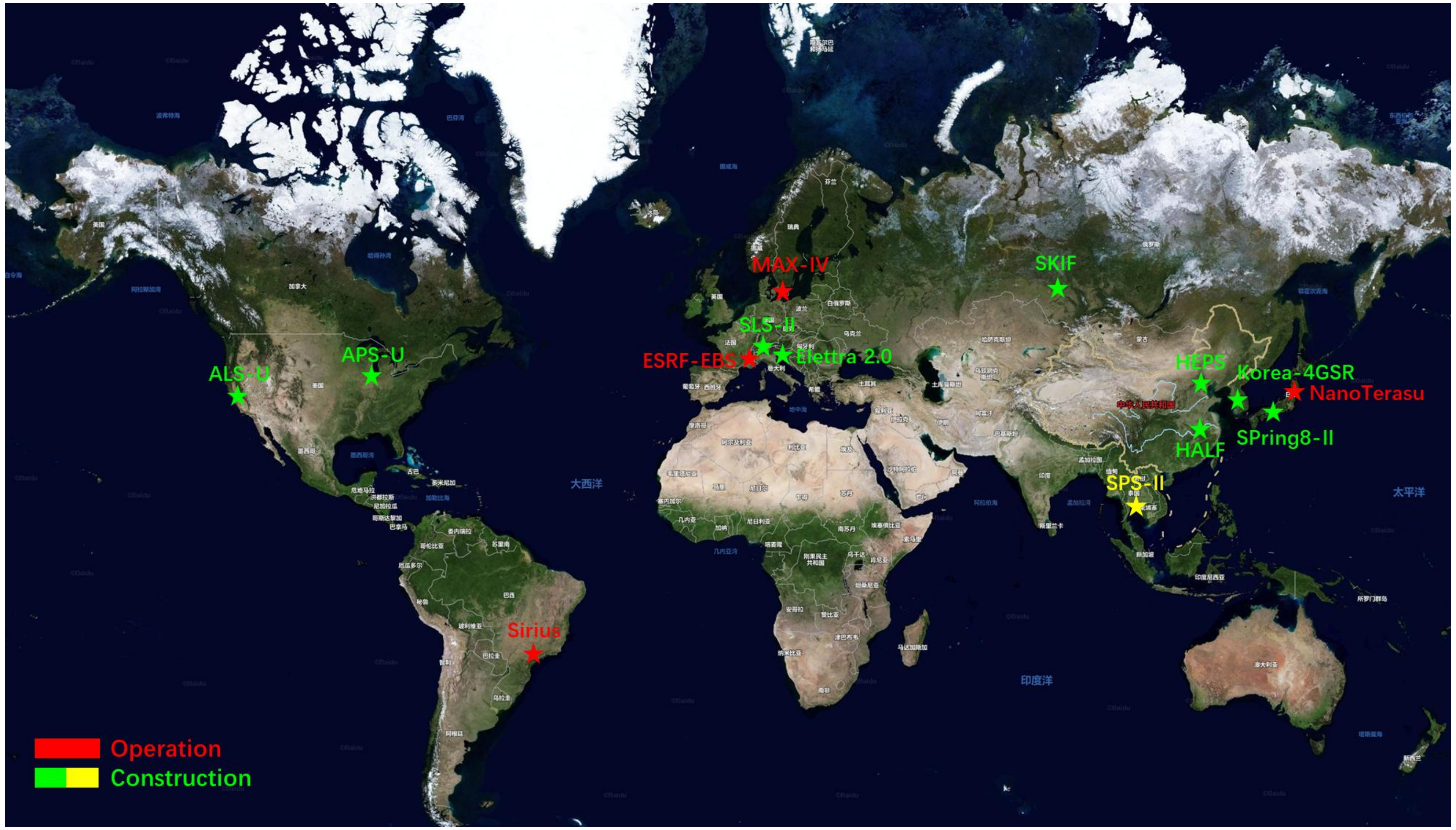
ESRF-EBS

- Technique developments in the early 21th century make MBA lattice proposed in 1990s' feasible.

- High gradient magnet (~100T/m)
- High vacuum condition with low gap
- Highly-precise alignment (<50μm)
- Beam injection method with small DA

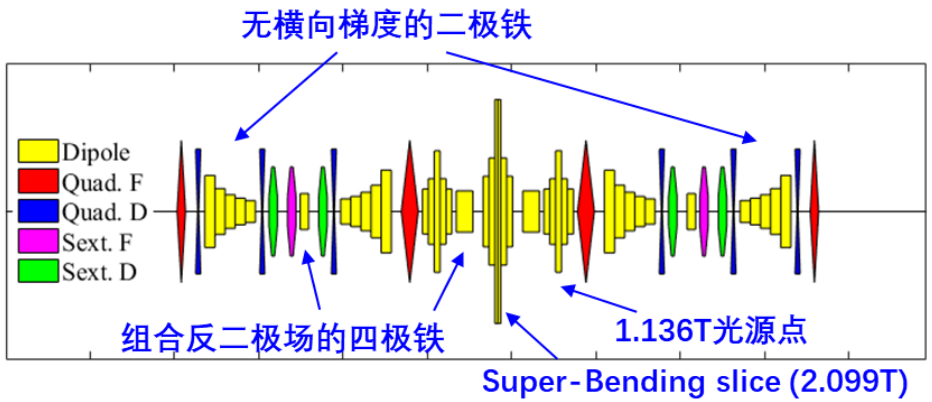
- Five facilities have been turned into operation. ~ ten projects are now under construction/ commissioning.

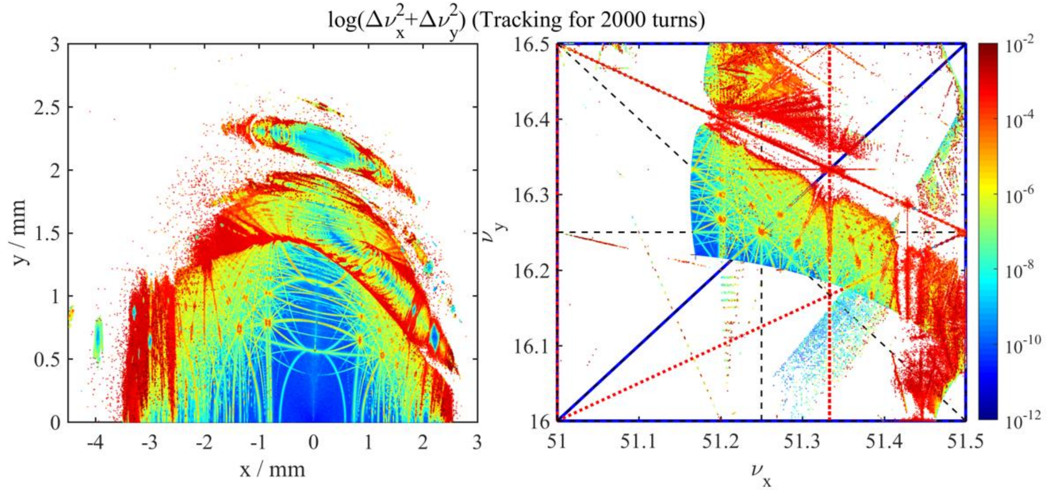
- More the 3rd generation light sources are exploring their upgrade way.

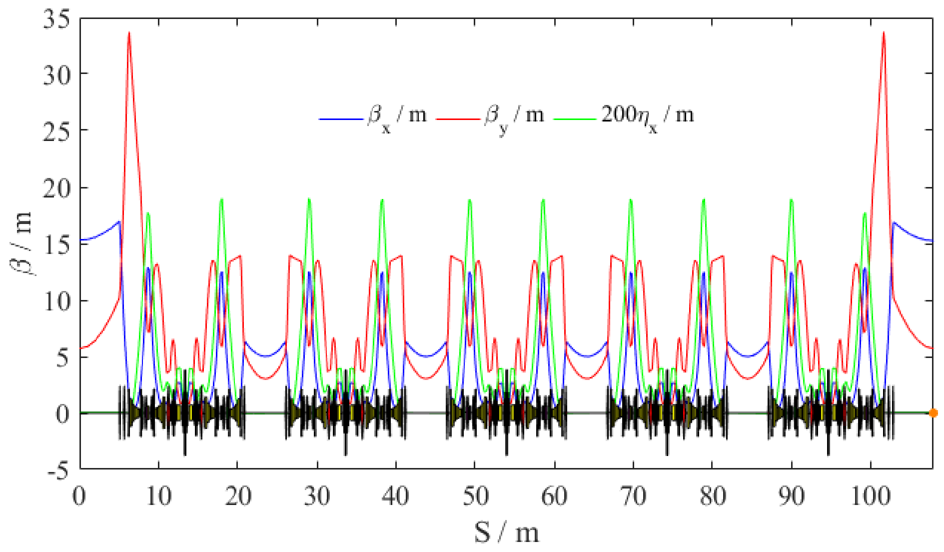


◆ Upgrade Proposal for the SSRF Storage Ring

- The storage ring will adopte **7BA** lattice reconstructed in the existing tunnel to reach a beam emittance of **72.6 pm.rad** (the diffraction-limit of soft X-ray reduced from original 4200pm.rad).
- LFVD, Anti-Bend were applied to reduced the beam emittance
- Because of the limited DA, SWAP-OUT injection was forseen.

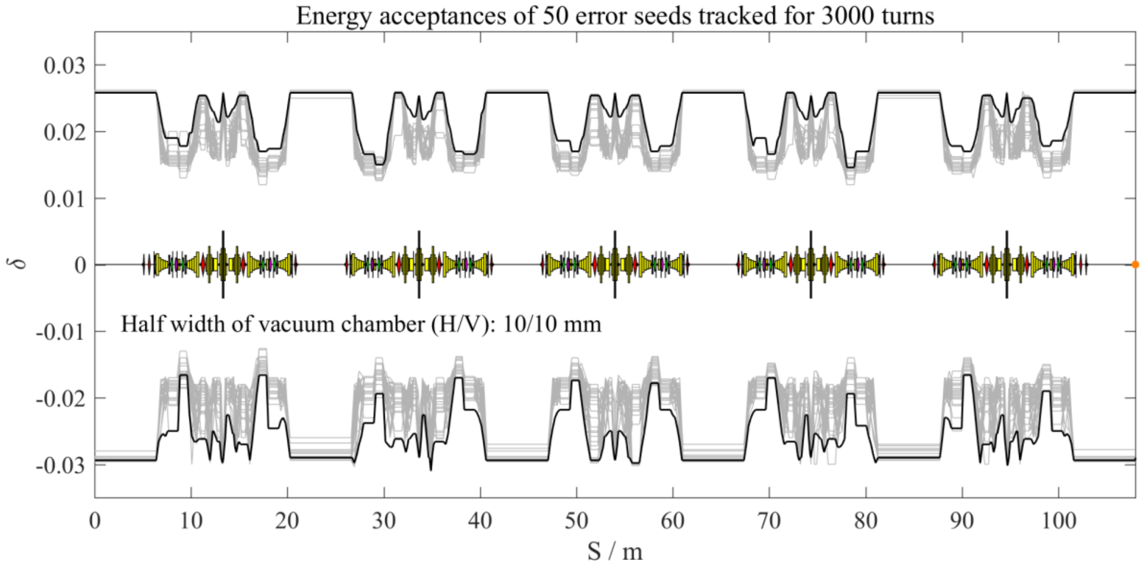


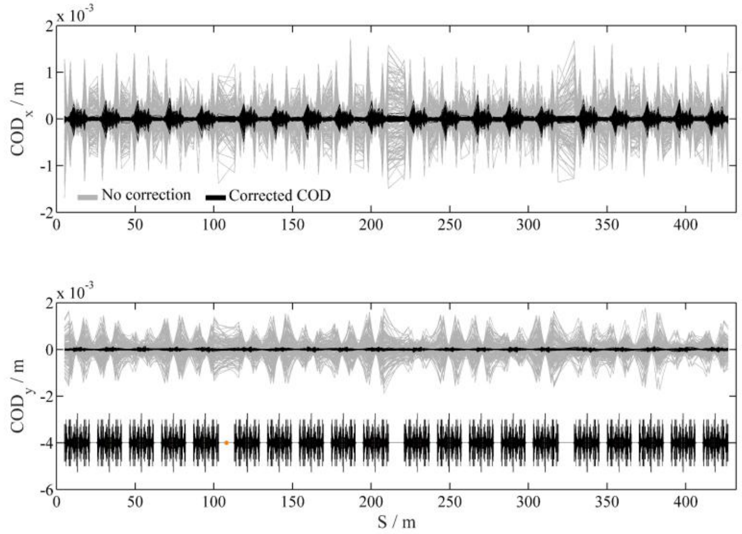


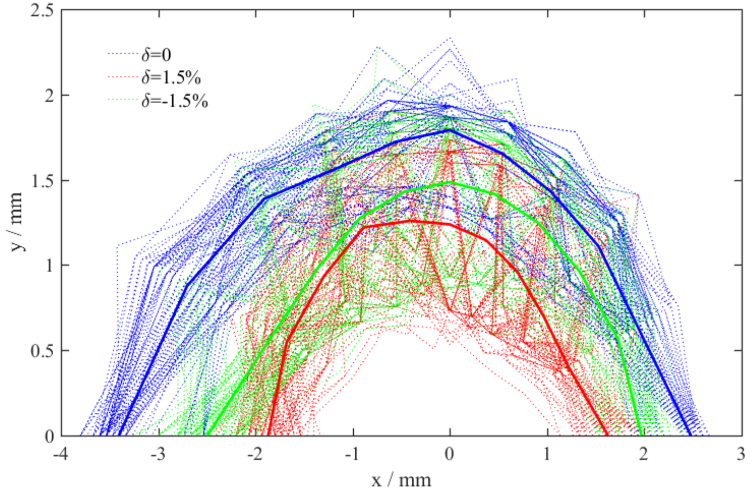


- Alignment and magnet errors for SSRF-U

Alignment (Shift)	30μm in Girder	60μm between Girders	
Alignment (tilt)	100μrad in Girder	100μrad between Girders	
	Dipole	Quadrupole	Sextupole
inconsistence	5×10^{-4}	5×10^{-4}	5×10^{-4}
Magnetic error	5×10^{-4}	5×10^{-4}	5×10^{-4}

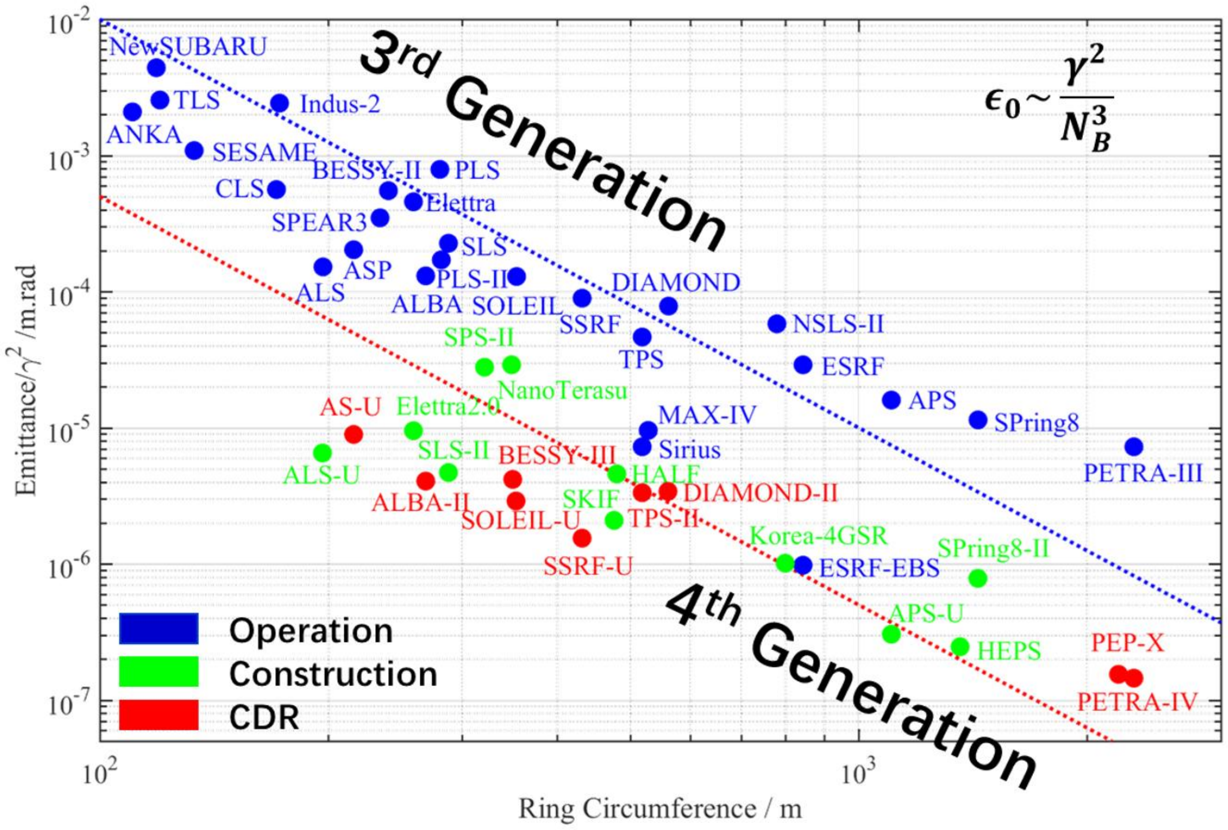




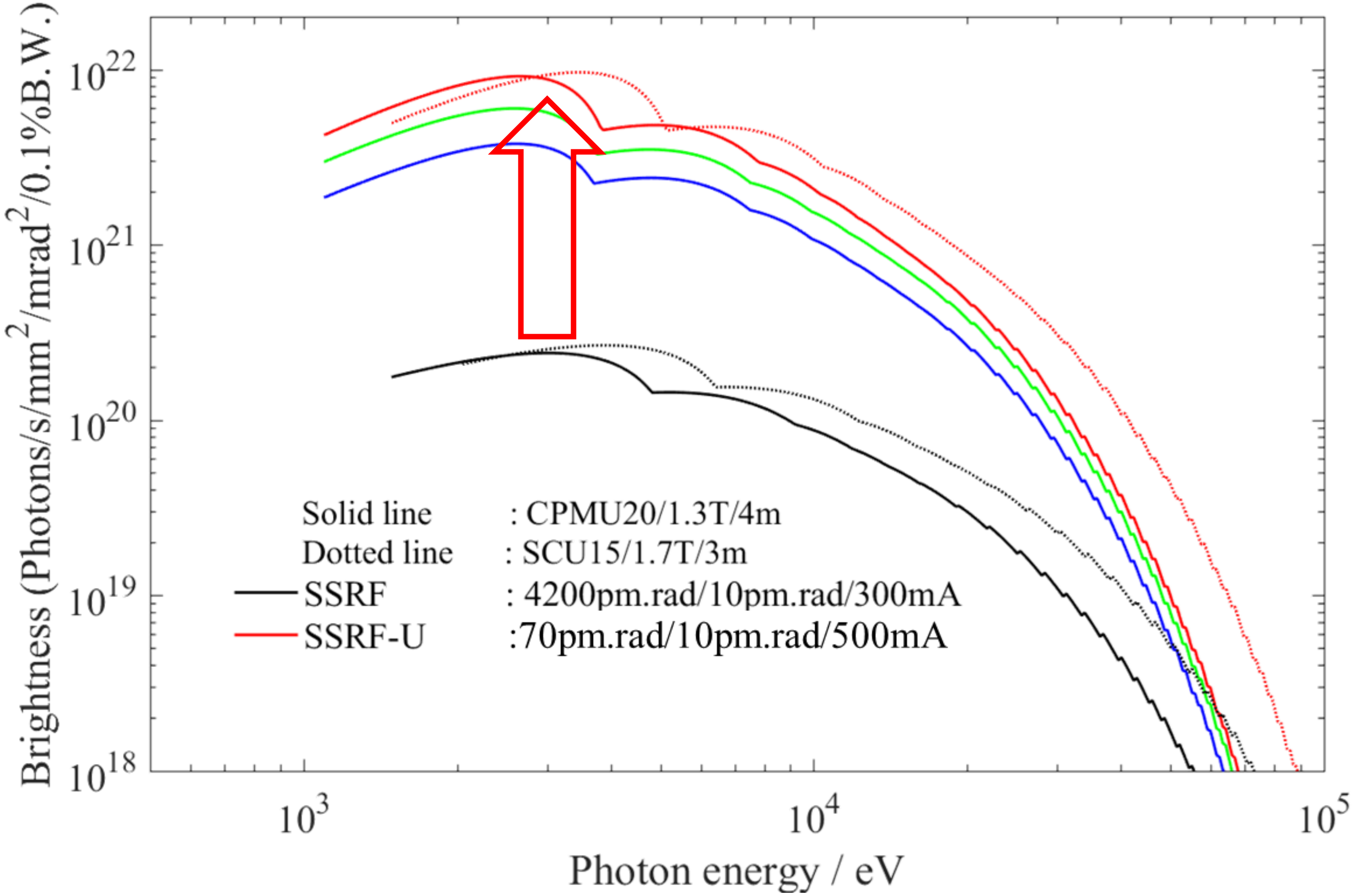


- The design results of SSRF-U reaches a new optimal front

Parameter	Unit	Value
Beam Energy	GeV	3.50
Beam Current	mA	500
Circumference	m	432
Striaght Sections	m	4×10.1+16×5.1
Natural Emittance	pm.rad	72.6
Energy Spread		1.58e-3
Energy Loss per Turn	MeV	1.18



- SSRF-U will provide X-ray with brightness of **10^{22}** phs/s/mm²/mrad²/0.1%BW, 50 times higher than that in SSRF.




Thanks for
your attention!