Current and Future of Storage-Ring Based Light Sources in KEK

KEK (Japan)
Accelerator Laboratory
HIGASHI Nao

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About Linac-based Light Source in KEK,
M. Shimada will present “Beam Commissioning at the Compact Energy Recovery Linac at KEK and Its Applications”, in Wednesday poster session, (WEP2PT048)

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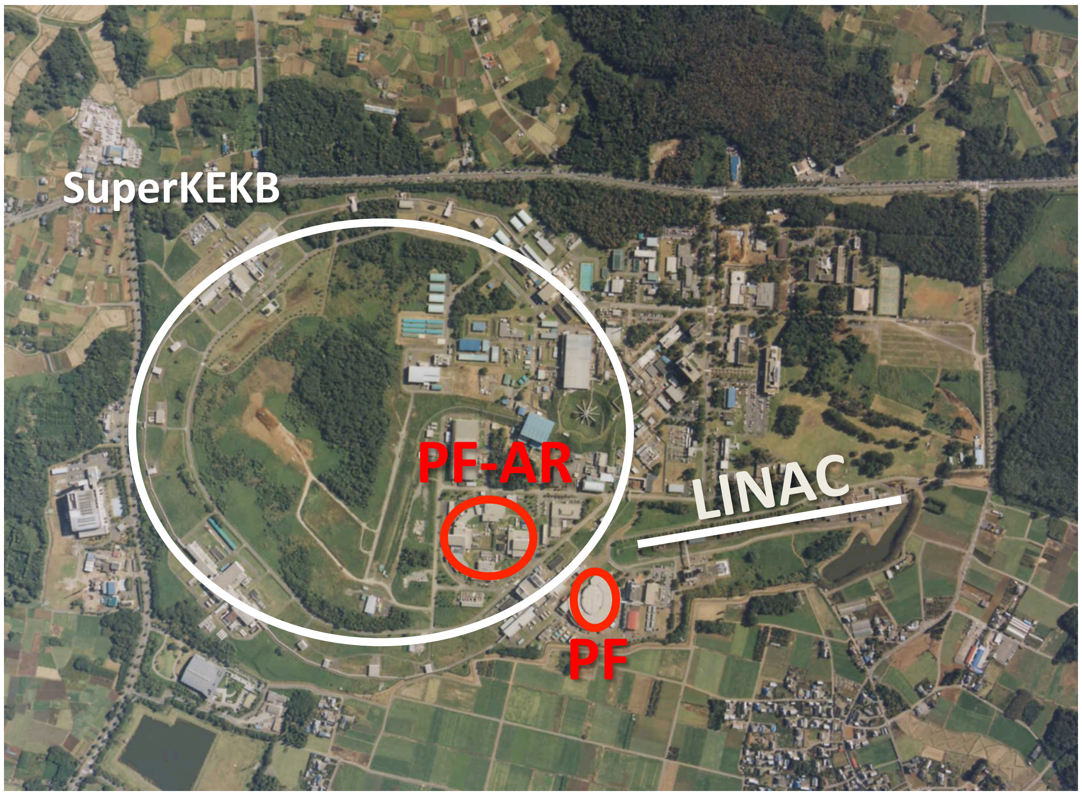
Contents

Contents

1. *Current Status of Ring-Based Light Source in KEK*
2. *Future Plan of Ring-Based Light Source in KEK*
   - 2.1. *KEK-LS*
   - 2.2. *PF Upgrade*
   - 2.3. *PF-AR Upgrade*
3. *Summary*

1. Current Status of Ring-Based Light Source in KEK

We have 2 ring-based light sources in KEK: Photon Factory (PF) and Photon Factory Advanced Ring (PF-AR).



KEK Tsukuba Campus in Japan.

・PF

Operation started in	1983
Generation	2nd
Emittance	35 nm・rad
Lattice	FODO
Circumference	187 m
Energy	2.5 GeV

・PF-AR

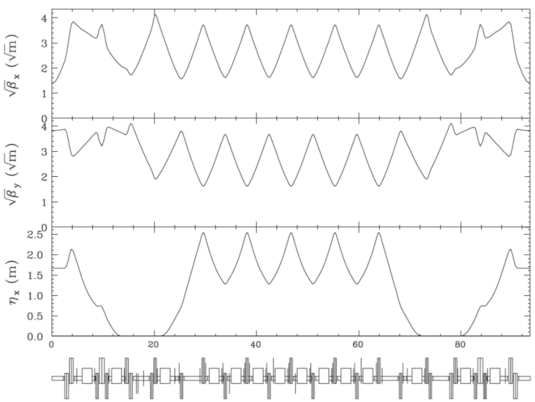
Operation started in	1987
Generation	2nd
Emittance	295 nm・rad
Lattice	FODO
Circumference	374 m
Energy	6.5 GeV

1. Current Status of Ring-Based Light Source in KEK

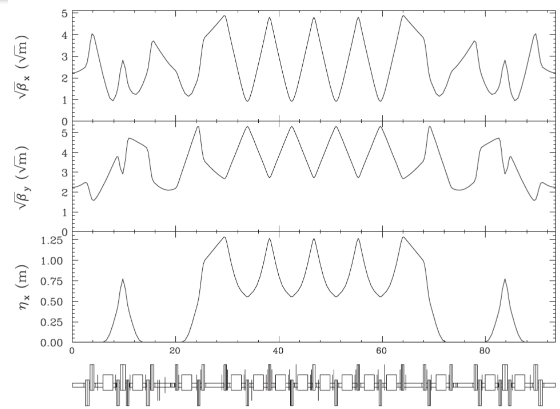
▪History of KEK light source

▪PF

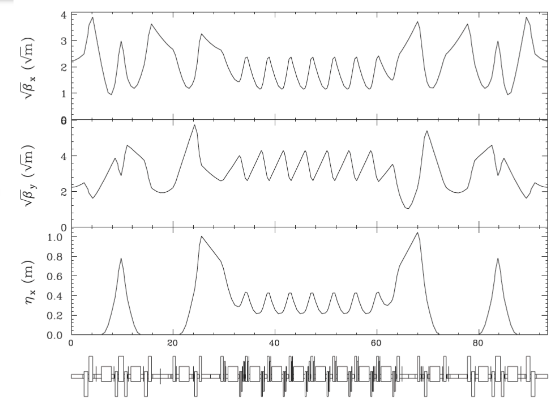
1983	PF started the user-run as a the first X-ray light source in Japan.
1986	The emittance was reduced to about 128 nm·rad by the low emittance configuration[1].
1997	The emittance was reduced to about 36 nm·rad by the high-brilliance reconstruction[2].



The first lattice
(460nm・rad) in 1981



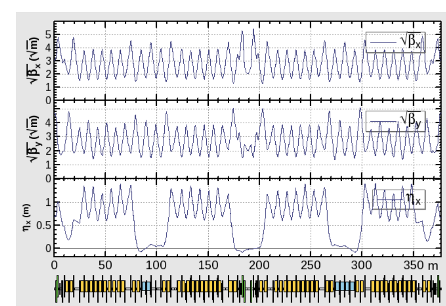
Low emittance configuration
(128nm・rad) in 1986



High-brilliance reconstruction
(37nm・rad) in 1997

▪PF-AR

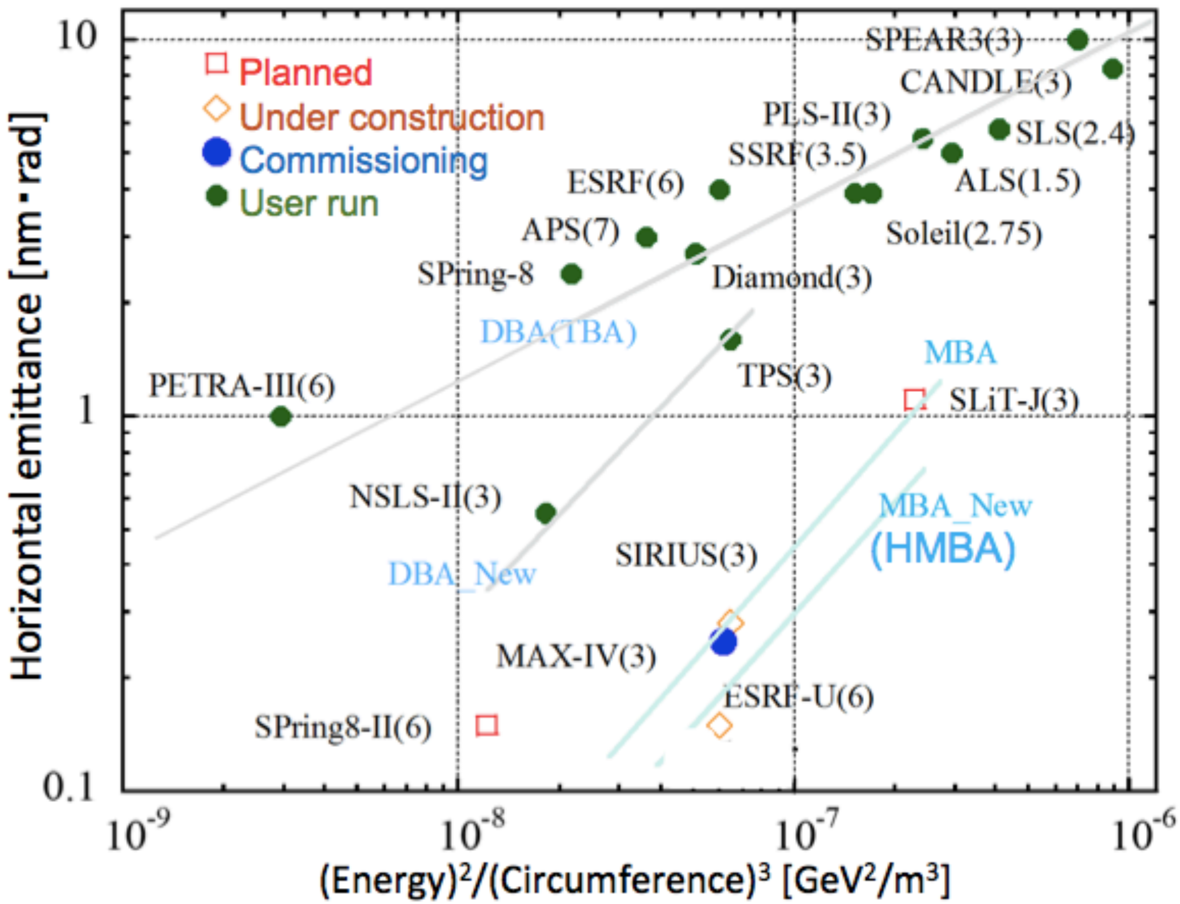
1984	PF-AR was constructed as an accumulation ring for TRISTAN.
1987	PF-AR started the user-run as a light source.



[1] Y. Kamiya, M. Kihara, “ Low emittance configuration for Photon Factory storage ring ”, KEK Internal 85-10, Dec, 1985 (in Japanese)
[2] M. Katoh, Y. hori, “Report of the Design Study on a High Brilliance Configuration of the PF Storage Ring”, KEK Report 92-20, Feb., 1993 (in Japanese)

1. Current Status of Ring-Based Light Source in KEK

- *Decline of relative competitive power as light source*



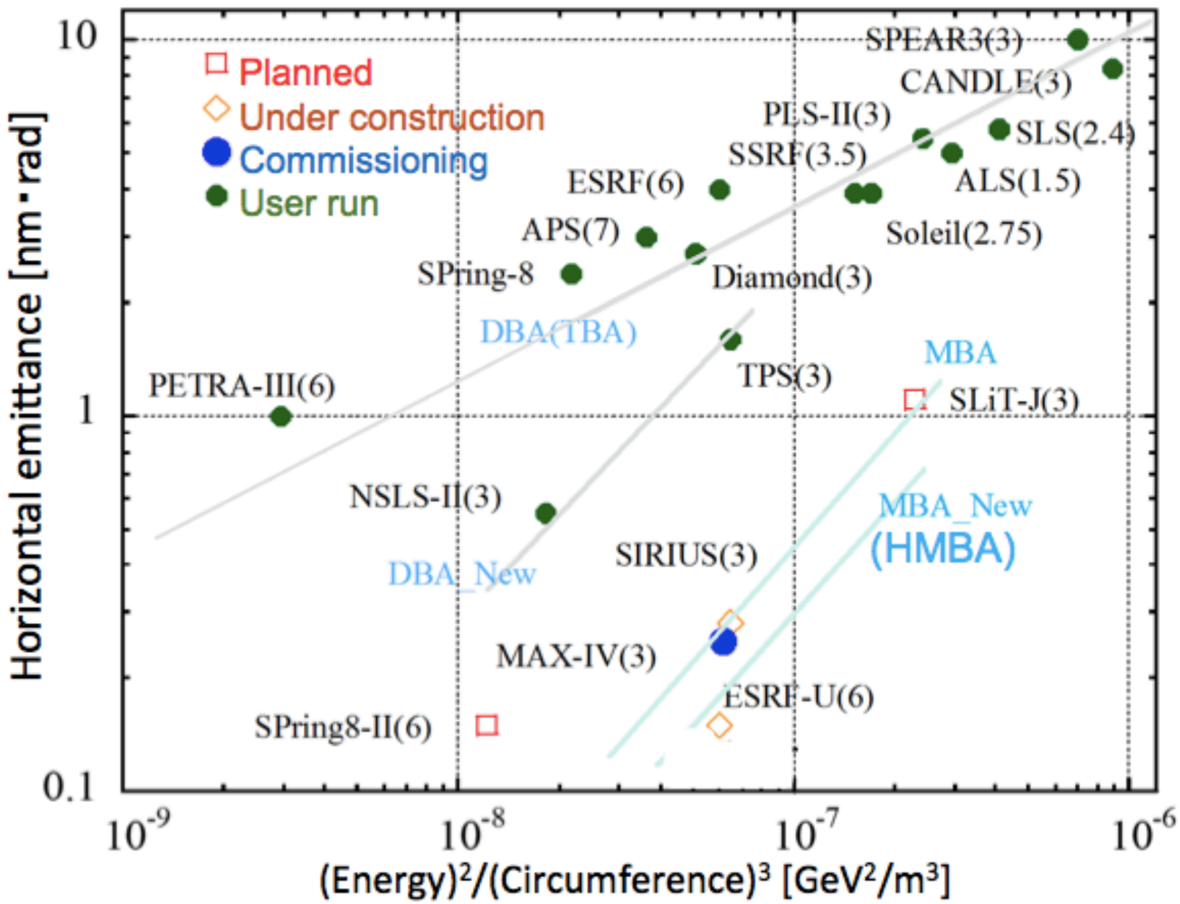
Recent Progress of the ring-based LS in the world[1].

[1] KEK-LS CDR, http://kekls.kek.jp/ in Japanese, 2018

1. Current Status of Ring-Based Light Source in KEK

▪*Decline of relative competitive power as light source*

● ← **PF**



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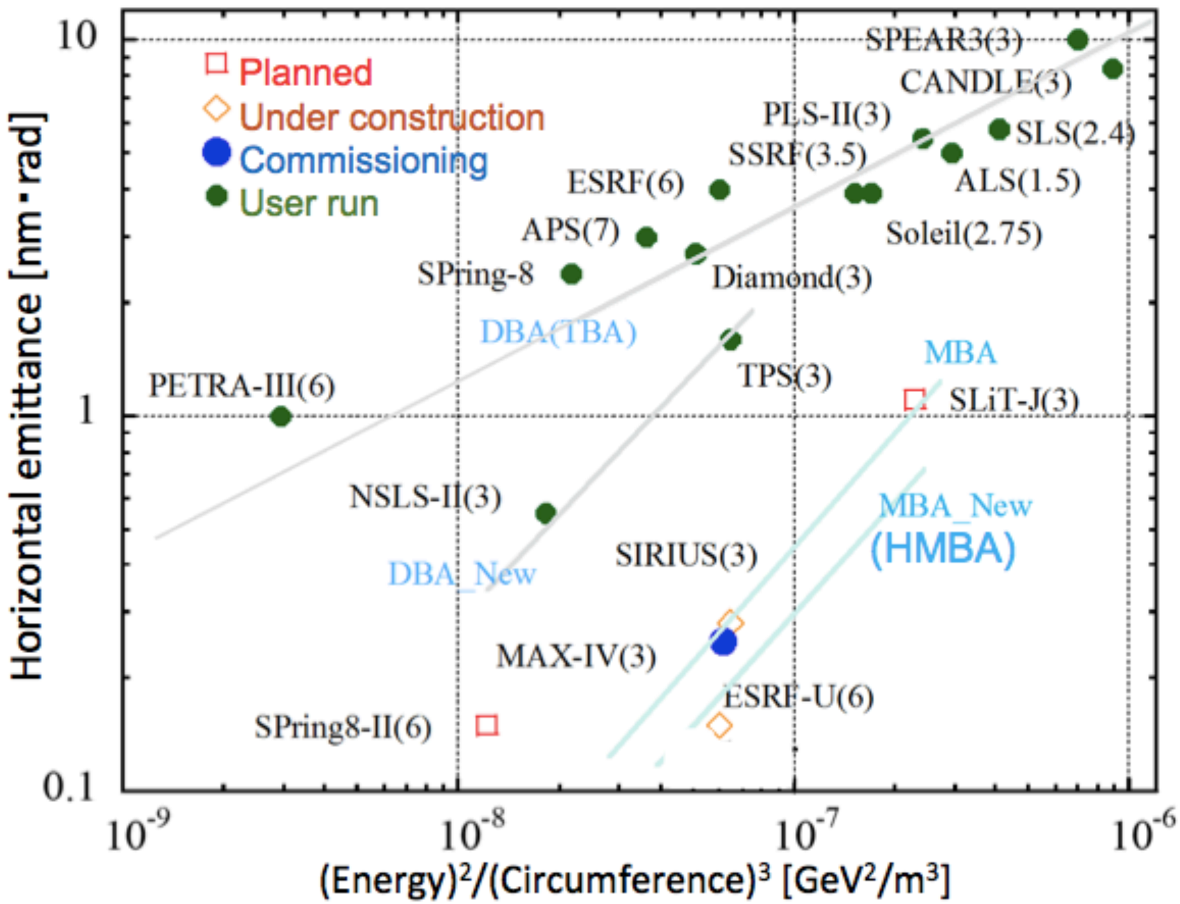
PF-AR

PF

- Decline of relative competitive power as light source



Recent Progress of the ring-based LS in the world[1].

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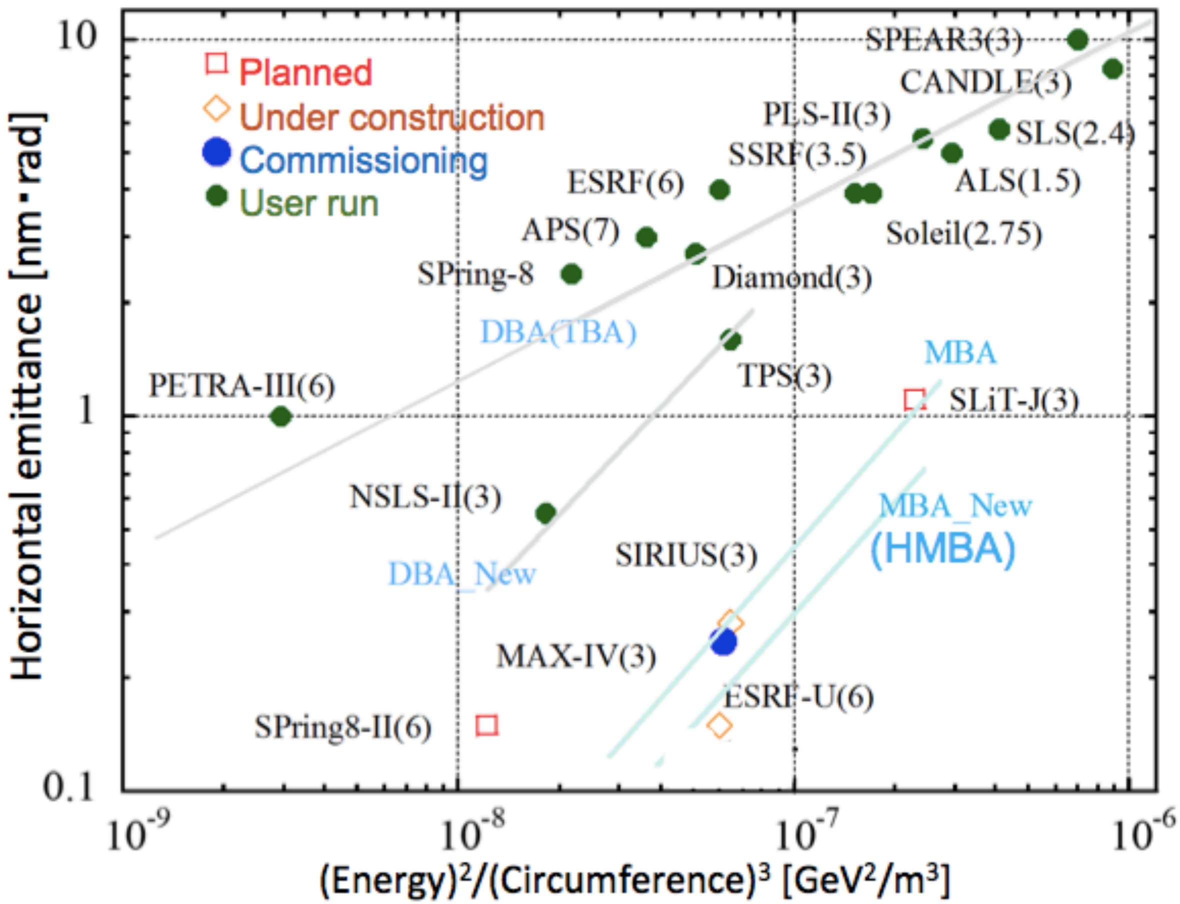
PF-AR

PF

・*Decline of relative competitive power as light source*



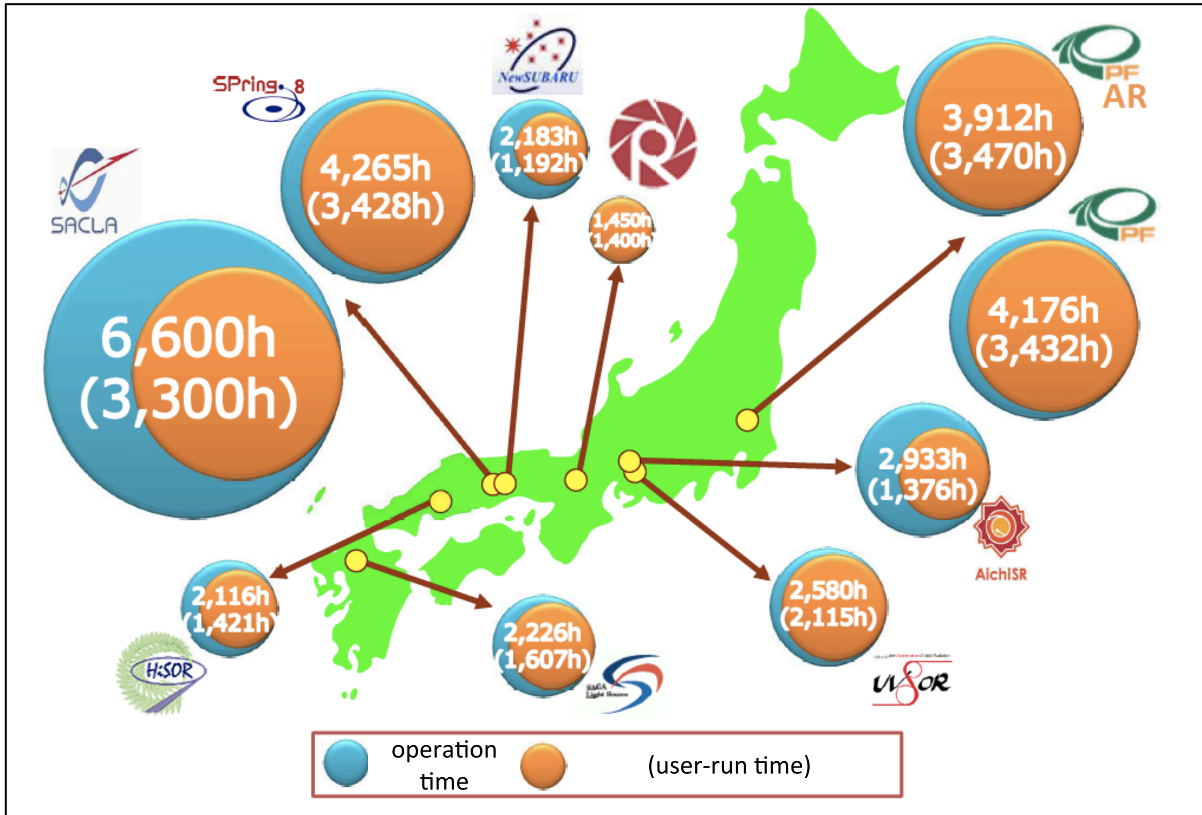
Our competitive power is getting lower and lower compared with other LS in the world.

[1] KEK-LS CDR, http://kekls.kek.jp/ in Japanese, 2018

1. Current Status of Ring-Based Light Source in KEK

・Demands for KEK light sources in Japan

In spite of the poor brightness, PF and PF-AR have supported the LS users in Japan as one of main facilities.



Operation time of Japanese light source in 2013.[1]

In order to support the LS users in Japan in the future, we have to carry out a drastic improvement as KEK LS.

[1] Science and Technology・Academic Policy Department, R & D Infrastructure Division, Quantum Radiation Research Promotion Bureau, "Report of the main light source facilities in Japan", http://www.mext.go.jp/b_menu/shingi/chousa/gijyutu/022/shiryo/__icsFiles/afieldfile/2014/07/01/1348612_01.pdf (in Japanese), 2014

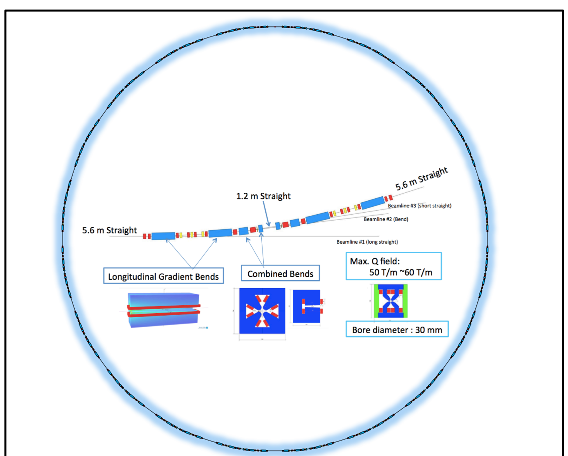
Contents

2. Future Plan of Ring-Based Light Source in KEK

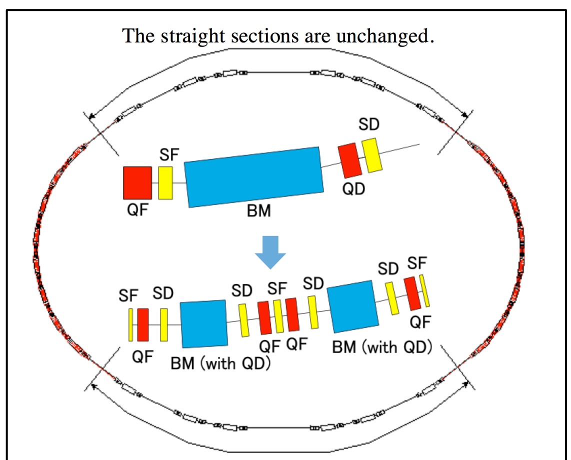
・Some candidates for future ring-based light source in KEK

Now we have some candidates as successors to PF and PF-AR. Which option will be promoted depends on 1. cost, 2. quality, 3. users' demand and 4. domestic situation about LS in Japan.

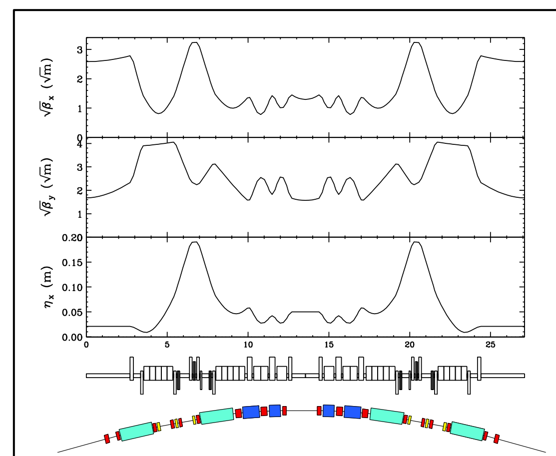
	Rough budget size [million US$]	Current emittance [nm・rad]	Improved emittance [nm・rad]	Approach
KEK-LS	300	-	0.315 (500 mA)	Fully-new facility
PF-Upgrade	20	35.4	8.073 (450 mA)	Small-scale modification
PF-AR Upgrade	100	295.2	0.520 (500 mA)	Full replacement of lattice



KEK-LS.



PF Upgrade.



PF-AR Upgrade.

Contents

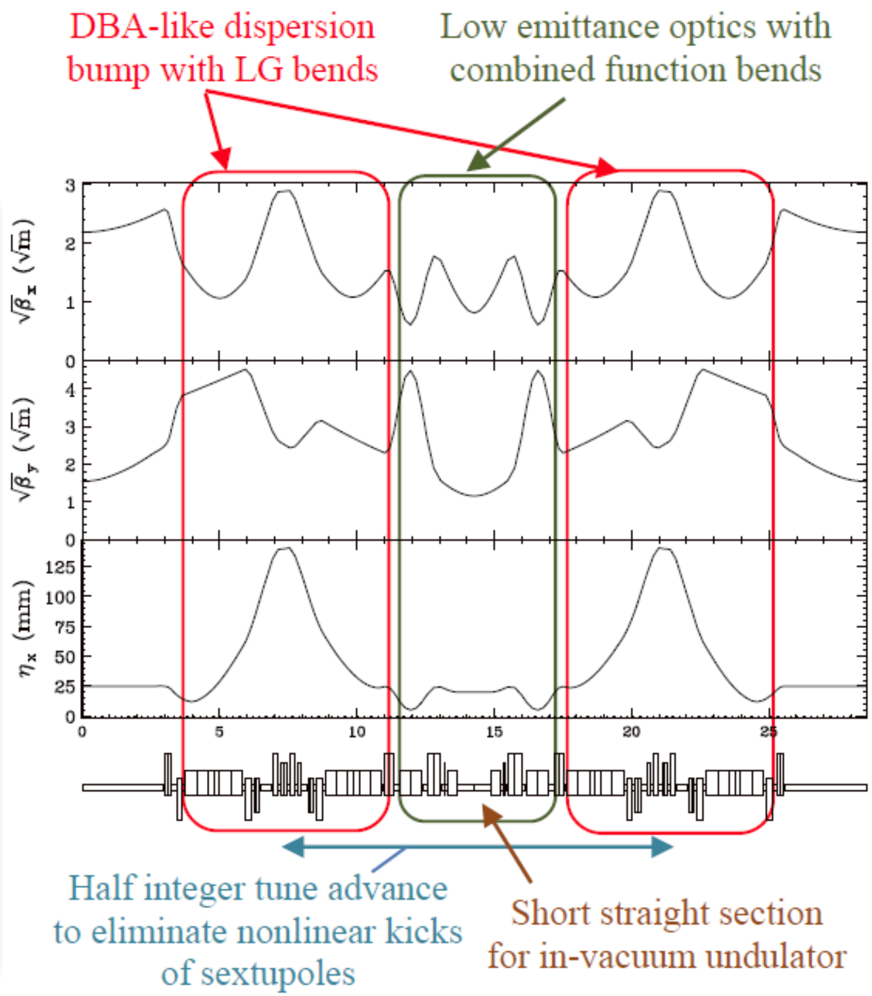
2.1. KEK-LS

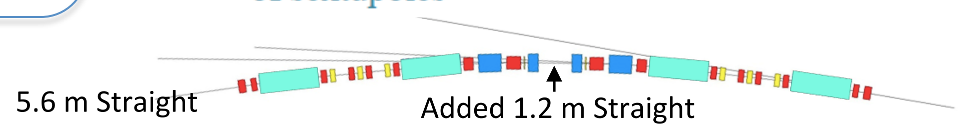
・Lattice of KEK-LS

The starting point of the lattice design of KEK-LS is ESRF-type HMBA[1, 2]. We added a short straight section of 1.2 m at the center. So, three beamlines will be available:

- #1: long undulator
  (VUV, soft X-ray and hard X-ray)
- #2: Bend
  (critical energy: 4 keV)
- #3: Short undulator
  (hard X-ray)

We reported this lattice in CDR of KEK-LS.





Blue: Combined Bend. Green: Longitudinal Gradient Bend. Red: Q. Yellow: S.

[1] ESRF Orange Book, http://www.esrf.eu/Apache_files/Upgrade/ESRF-orange-zbook.pdf, 2013

[2] Pantaleo Raimondi, private communications, 2014

2.1. KEK-LS

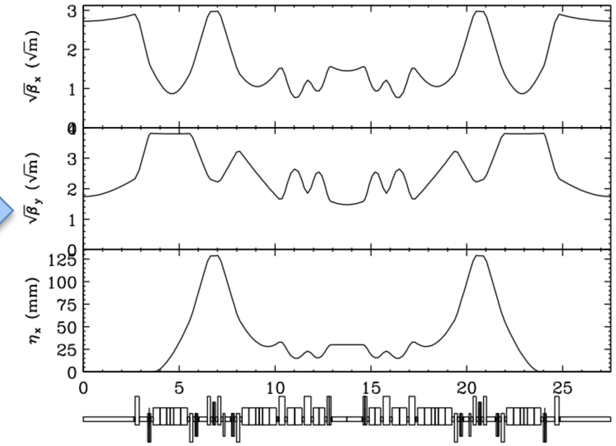
･*Improve the CDR lattice*

The lattice of CDR has some problems:

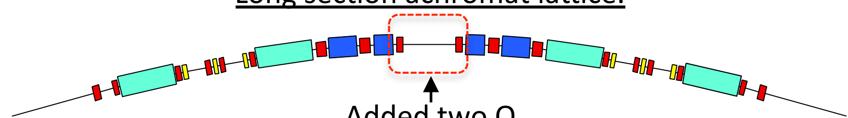
1. Small dynamic aperture
2. emittance growth by the non-zero dispersion at the straight section

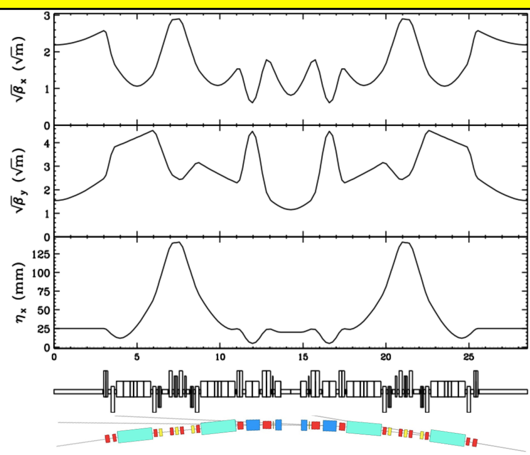
1. The two quadrupoles are added to the short straight sections[1].
2. The straight sections become achromat.

<u>we call it DQBA lattice.</u>

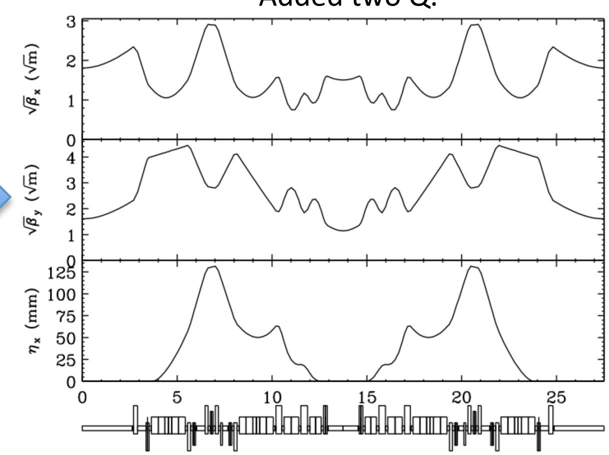


Long section achromat lattice.





CDR lattice.



Complete achromat lattice.

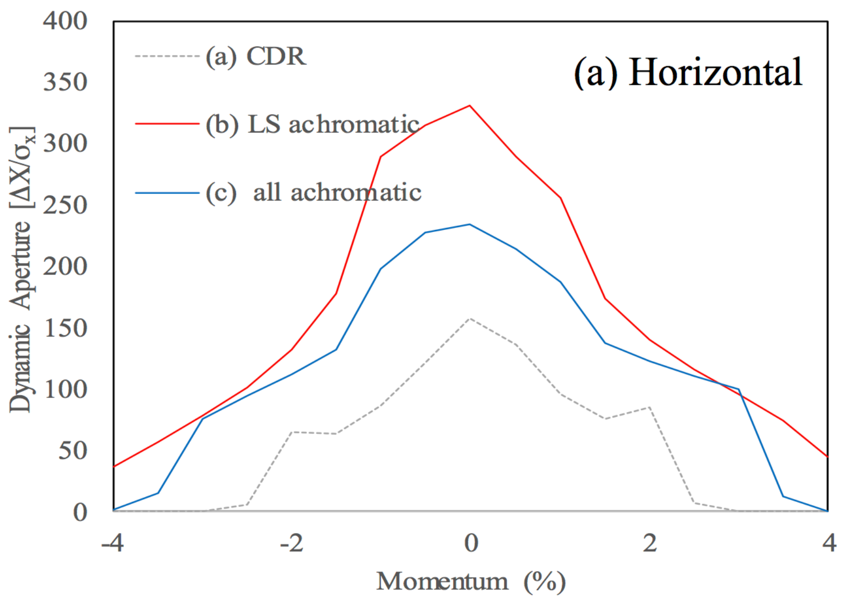
Blue: Combined Bend. Green: Longitudinal Gradient Bend. Red: Q. Yellow: S.

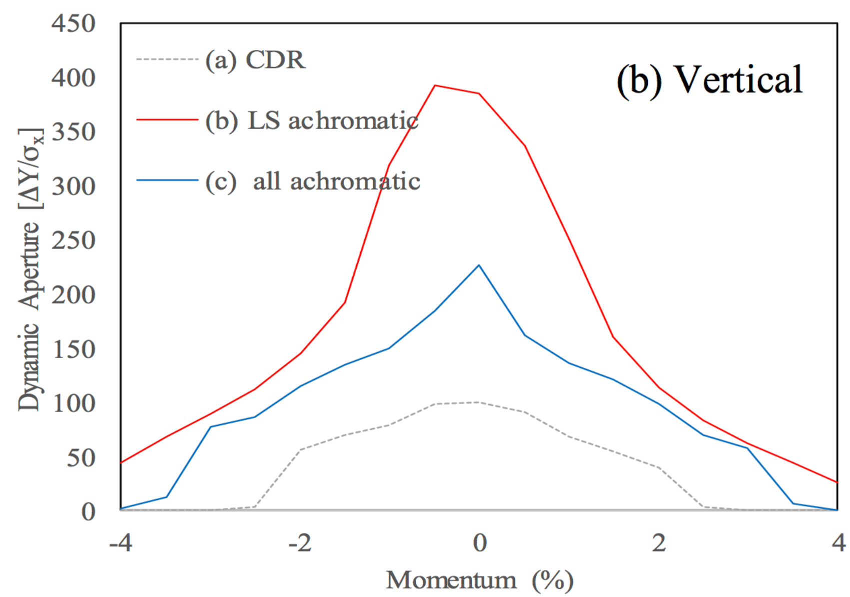
[1] Simone Liuzzo, KEK visit for 6/25-7/10, 2016

2.1. KEK-LS

・Improvement of Dynamic Aperture

	Momentum aperture [%]	Horizontal aperture [σ]	Touschek lifetime [hour]
CDR	**2.8**	**150**	**2.4**
Long section achromat	**4.0**	**200**	**17.0**
Complete achromat	**4.0**	**200**	**27.0**



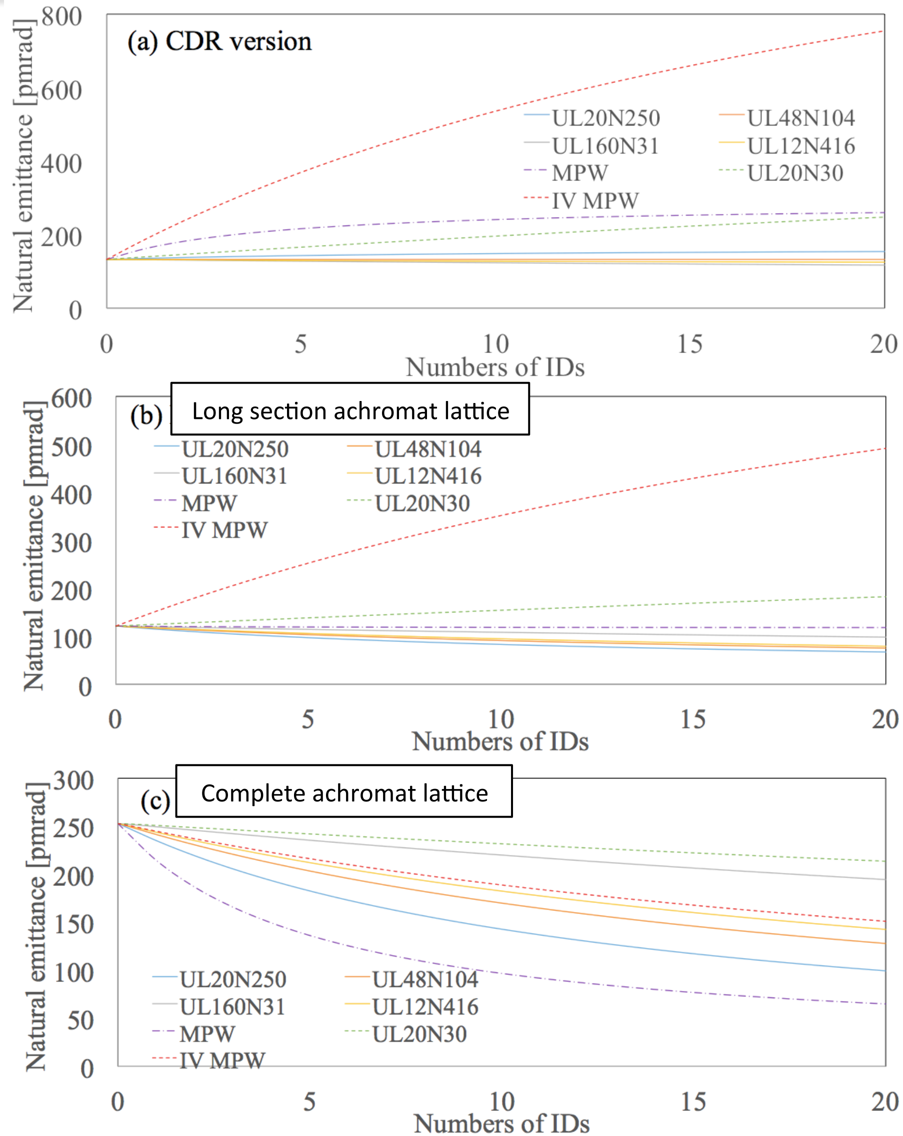


2.1. KEK-LS

▪Emittance growth by ID

Calculating the emittance growth effect from the insertion with the analytical approach[1], there are the damping enhancement for the straight section achromat lattice, especially the complete achromat lattice.

	Periodic length	Period	ID length	Peak magnetic field
	l_w [mm]	N_w	L [m]	B_w [T]
For long straight (5m)				
UL20N250	20	250	5	1.13
UL48N104	48	104	5	0.9
UL160N31	160	31	5	0.5
UL12N416	12	416	5	0.8
MPW	120	42	5	1.8
For short straight (60cm)				
UL20N30	20	30	0.6	1.13
IV MPW	60	10	0.6	2.2



[1] M. Katoh and Y. Kamiya, “Effect of Insertion Devices on Beam Parameters”, Proc. of PAC 1987, pp. 437-439, 1987

2.1. KEK-LS

・Parameters of each lattice design

	Symbol [Unit]	CDR (a)	New DQBA (b)	New DQBA (c)
Energy	E [GeV]	3.0		
Cell number	N_s	20		
Circumference	C [m]	570.721		
RF freq.	f_{RF} [MHz]	500.0735096		
Harmonic Number	h	952		
RF voltage	V_{RF} [MV]	2.5		
Beam current	I [mA]	500		
Betatron tune	ν_x	48.58	47.10	
	ν_y	17.62	17.15	
Horizontal emittance (w/o IBS)	[pm·rad]	133	121	253
(effective, 5 m sec., w/o IBS)	[pm·rad]	160		
(effective, short st., w/o IBS)	[pm·rad]	225	204	
(500 mA w/ IBS)	[pm·rad]	315	228	366
Residual dispersion (@ long straight)	[mm]	25	0	0
(@ short straight)	[mm]	20	3	0
Bucket height	$\Delta E/E$ [%]	4.5	4.5	4.0
Energy loss	U_0 [MeV/rev.]	0.30	0.26	0.26
Momentum compaction	α [$\times 10^{-4}$]	2.2	2.4	3.1
Damping time	τ_x [ms]	29.3	21.5	23.4
	τ_y [ms]	38.3	43.1	43.1
	τ_z [ms]	22.6	43.4	37.2
y/x coupling	[%]	2.6	3.5	2.2
Vertical emittance	ε_y [pmrad]	8.2	8.0	8.1
Momentum Aperture	[%]	2.8	4.0	4.0
Horizontal Aperture	[σ_x]	150	200	200
Touschek lifetime	[hour]	2.4	17.0	27.0
Energy spread (0 mA)	σ_E/E [$\times 10^{-4}$]	6.4	7.2	6.7
(500 mA)	σ_E/E [$\times 10^{-4}$]	7.9	9.7	8.5
Bunch length (0 mA)	[mm]	2.7	2.8	2.9
(500 mA)	[mm]	3.3	3.8	3.8

Long section achromat lattice

Complete achromat lattice

・Next Task

1. LMA (local momentum acceptance) method has to be employed in order to calculate the lifetime precisely.
2. Effects of the bunch lengthening by the third-harmonic cavities have to be considered.
3. The use of round beam has to be considered.
4. The injection scheme has to be determined together with a booster or a new linac.
5. The installed IDs have to be determined to communicate with the potential users of KEK-LS.

2.1. KEK-LS

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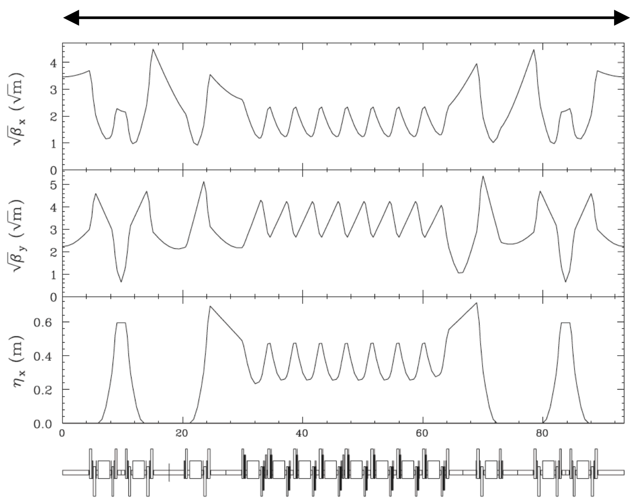
Contents

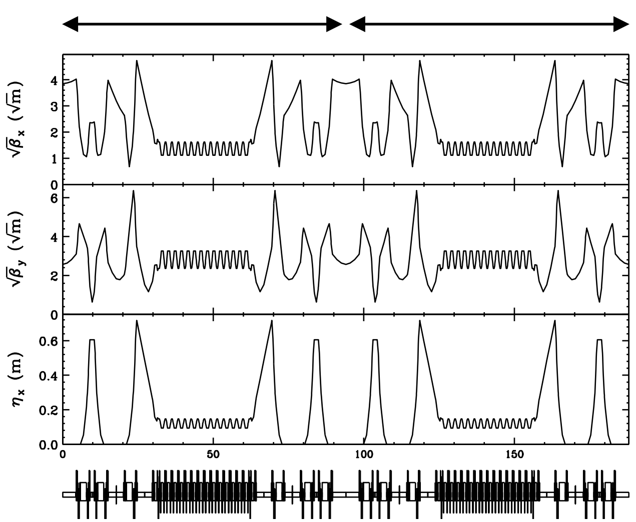
2.2. PF Upgrade

・*Limited upgrade as lowest cost option*

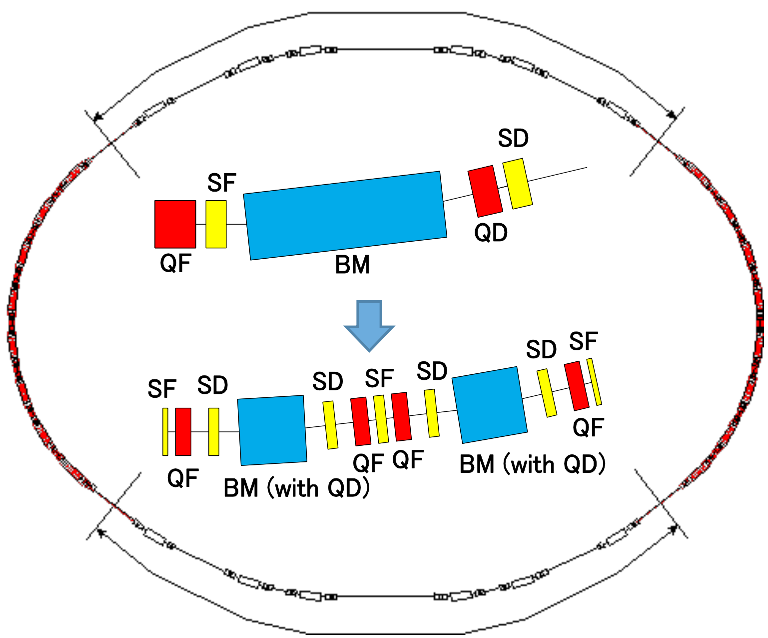
In this option, we reuse the existing tunnel and infrastructure. And the modification of the lattice is limited in the arcs. Doubling the cell number, we reduce the emittance from 35 nm・rad to 8 nm・rad. The bending magnets will be replaced with combined function magnets.



Current lattice (35 nm・rad).



PF Upgrade (8 nm・rad).

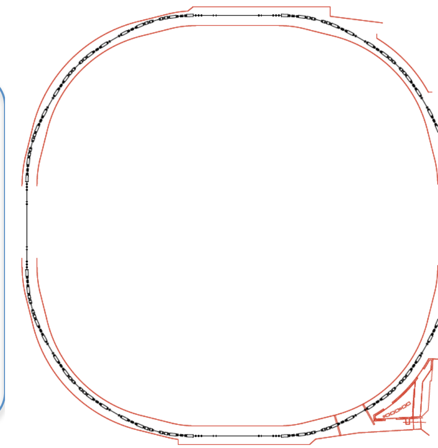


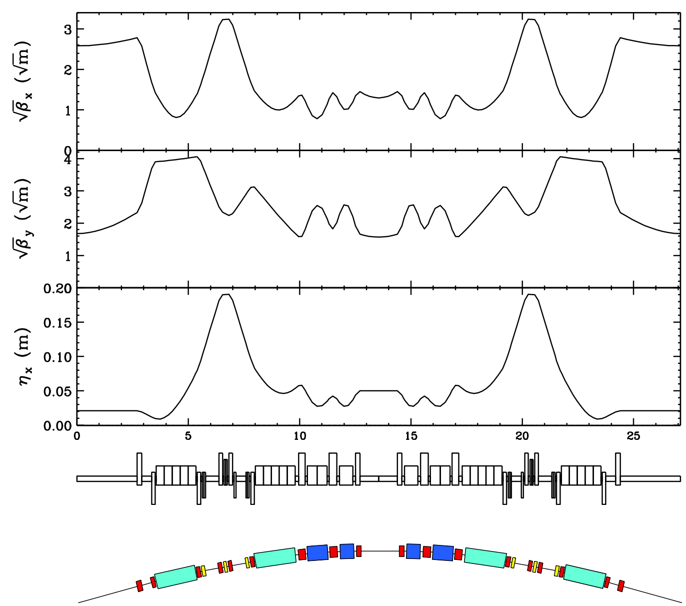
Contents

2.3. PF-AR Upgrade

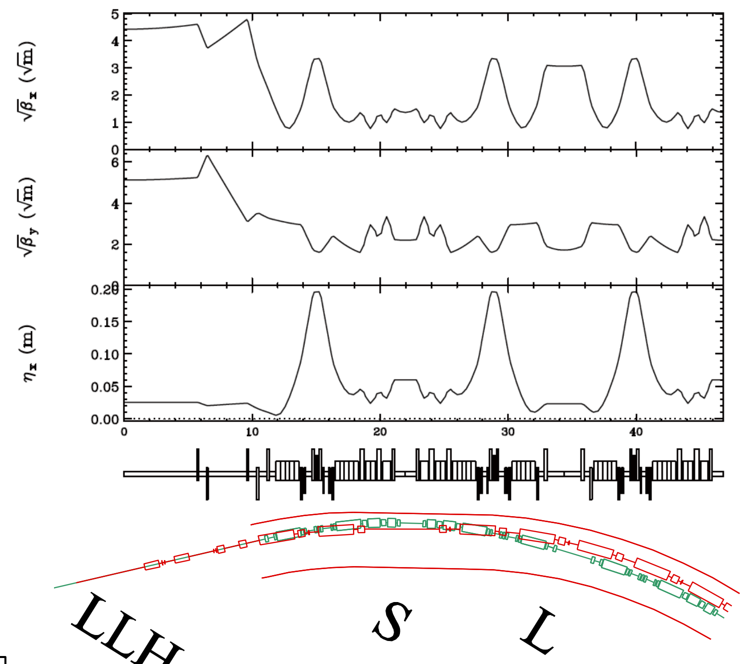
・Applying KEK-LS’ DQBA into PF-AR

In this option, we reuse the existing tunnel. KEK-LS’ DQBA lattice is flexible to deform its shape. We apply the DQBA lattice into PF-AR’s existing tunnel to change the length of long straight sections. This option reuse the existing tunnel and infrastructure, so the cost scale is medium. we reduce the emittance from 295 nm・rad to 0.520 nm・rad with 500 mA.





Normal Cell of DQBA (1/12 of ring).



PF-AR Upgrade (1/8 of ring).

Blue: Combined Bend. Green: Longitudinal Gradient Bend. Red: Q. Yellow: S.

Contents

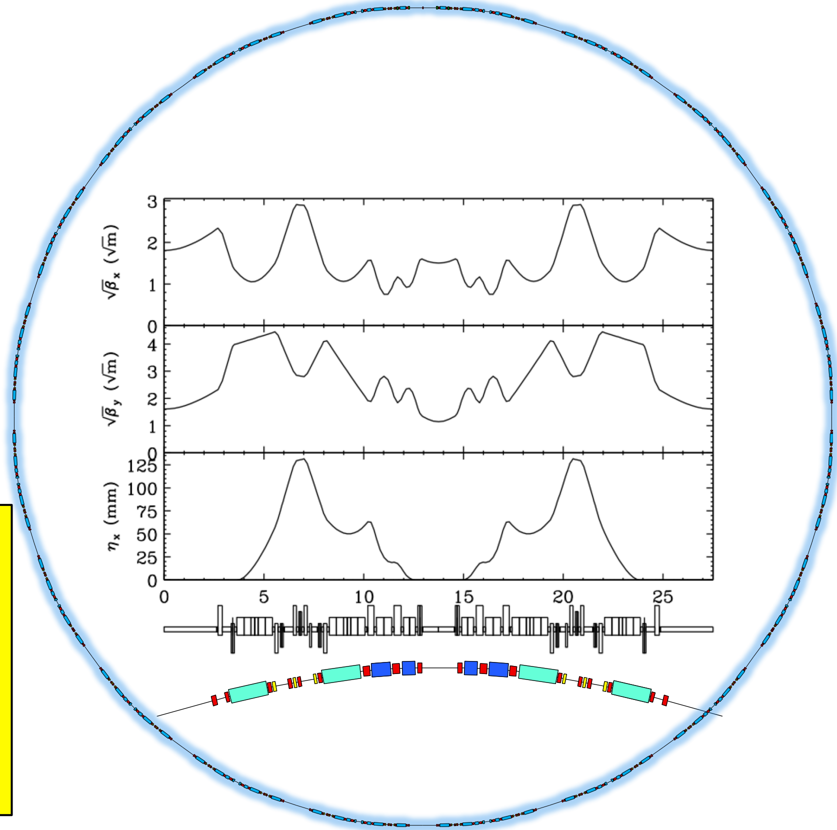
3. Summary

▪*Current Status of ring-based LS in KEK*

The competitive powers of PF and PF-AR are getting lower and lower, and more than thirty years have passed since the construction, and the problem of the deterioration has also increased.

▪*Future of ring-based LS in KEK*

We have some candidates for the future ring-based light source in KEK. Which option will be promoted depends on the cost, the quality (emittance, brightness), the users' demand and the domestic situation of LS in Japan.



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Thank you for your attention.