An Overview of Light Source Developments in Asia

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Acknowledgements

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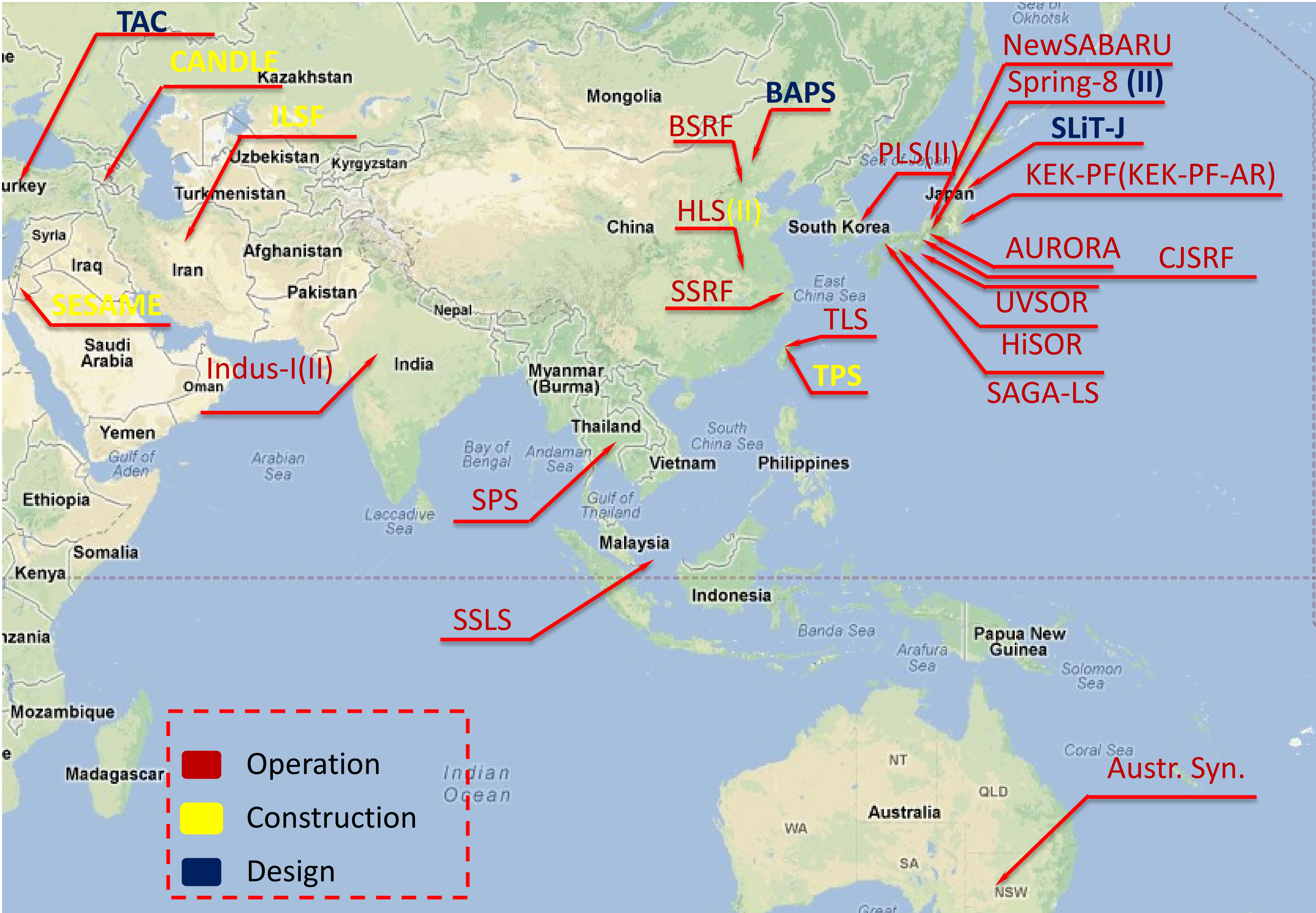
Outline

- Introduction
- Synchrotron Light Sources in recent years
- High Gain Free Electron Lasers
- New projects
- Summary

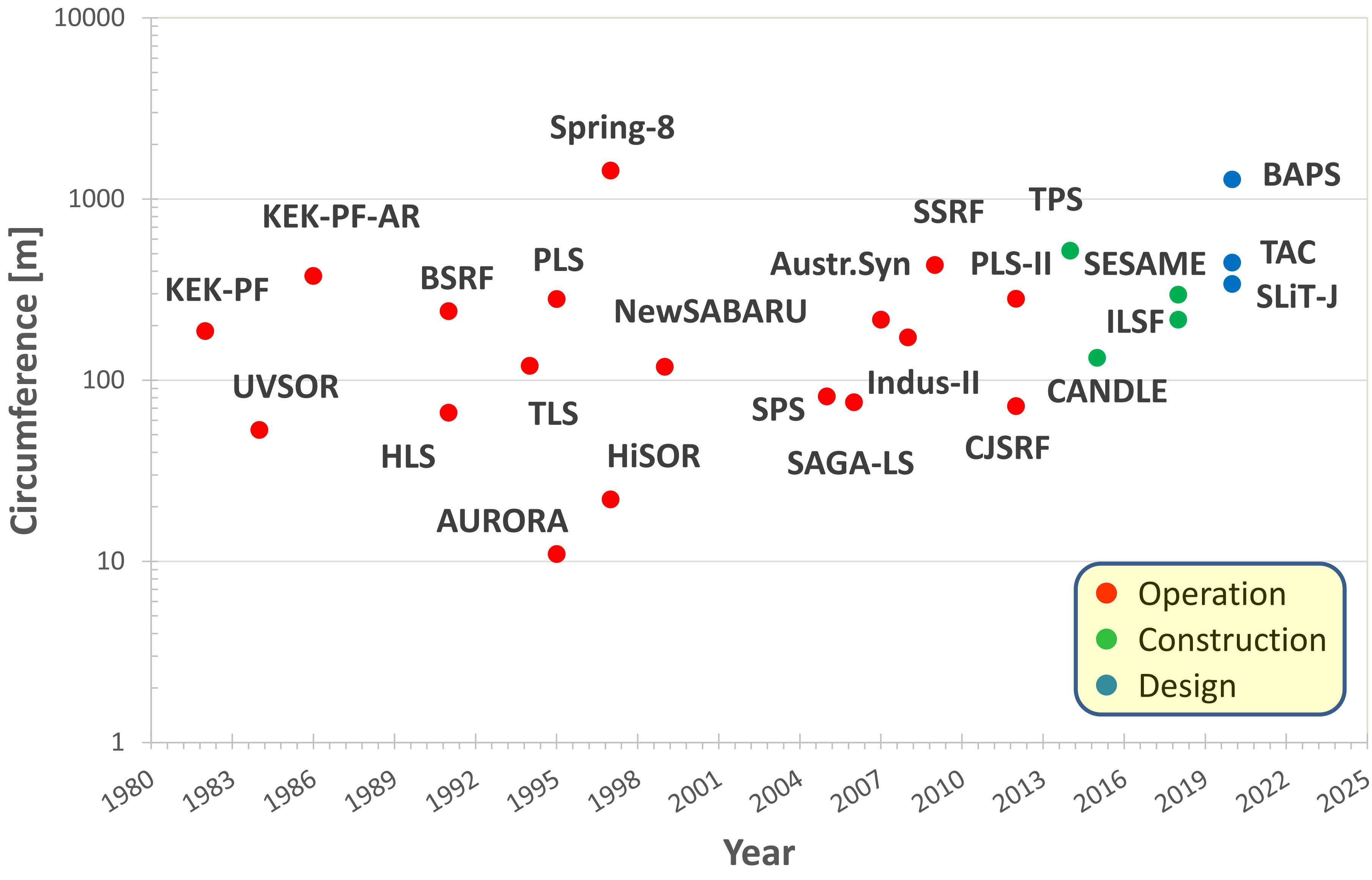
Synchrotron Light Sources in Asia, 2013



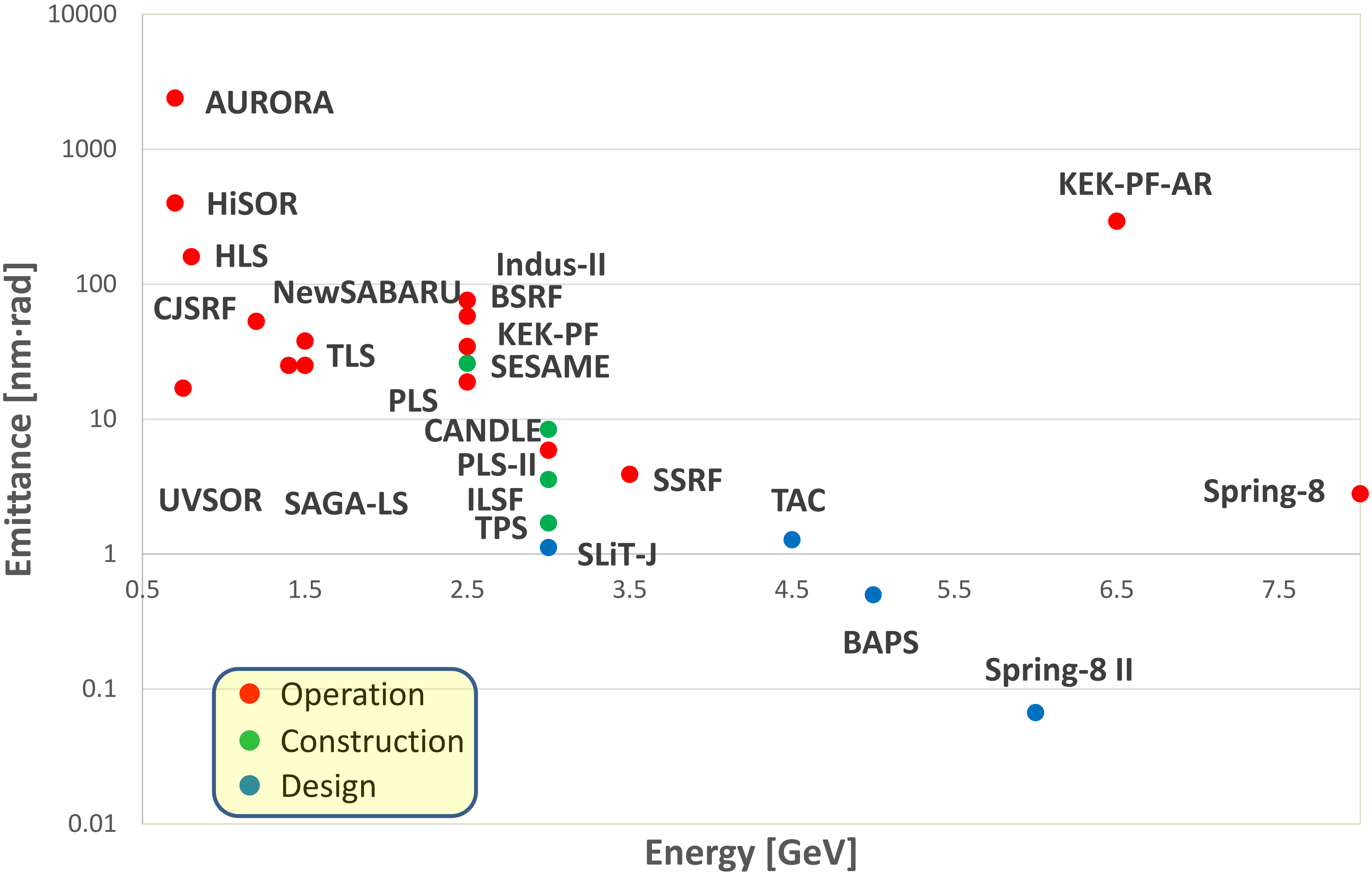
Synchrotron Light Sources in Asia

Light source	Location	Energy (GeV)	Type	Circum. (m)	Emittance (nm.rad)	Current (mA)	Straight sections	Lattice	Status	Completion year
KEK-PF	Tsukuba	2.5	D	187	34.6	450		FODO	O	1982
UVSOR	Okazaki	0.75	D	53.2	27=>17	300		DBA	O	1984
KEK-PF-AR	Tsukuba	6.5	D	377	293	60		FODO	O	1986
BSRF	Beijing	2.5	P	240.4	76	200-250		FODO	O	1991
HLS	Hefei	0.8	D	66.13	160	250-300		DBA	O	1991
TLS	Hsinchu	1.5	D	120	25	240	6*6m, 4*3m	TBA	O	1994
PLS	Pohang	2.5	D	280.56	18.9	200	12*6.8m	TBA	O	1995
AURORA	Kusatsu	0.7	D	10.97	2400				O	1995
Spring-8	Hyogo	8.0	D	1436	2.8	100	44*6.6m, 4*30m	DBA	O	1997
HiSOR	Hiroshima	0.7	D	22	400	300			O	1997
NewSABARU	Hyogo	1.5	D	118.7	38	500	4*2.6m, 2*14m	TBA	O	1999
Indus-I	Indore	0.45	D			100-200			O	1999
SSLS	Singapore	0.7	D			400			O	2001
SPS	Bangkok	1.0-1.2	D	81.3		100	4*7m		O	2005
SAGA-LS	Tosu	1.4	D	75.6	25	300	8*2.93m	DBnA	O	2006
Austr. Syn.	Melbourne	3.0	D	216		300		DBA	O	2007
Indus-II	Indore	2.5	D	172.5	58	300	8*4.5m		O	2008
SSRF	Shanghai	3.5	D	432	3.9	300	4*12m, 16*6.5m	DBA	O	2009
PLS-II	Pohang	3.0	D	281.82	5.9	400	10*6.86m, 11*3.1m	DBA	O	2012
CJSRF	Nagoya	1.2	D	72	53	300		TBA	O	2012
TPS	Hsinchu	3.0	D	518.4	1.7	400	6*11.7m, 18*7m	DBA	C	2014
SESAME	Amman	2.5	D	133.12	26	400	8*4.44m, 8*2.38m		C	2015
ILSF	Tehran	3.0	D	297	3.3	400	4*8, 20*4, 12*2.8m		C	2018
CANDLE	Armenia	3.0	D	216	8.4	350	16*4.8m		C	2018
TAC	Ankara	3.0	D	466.8	0.68	500	18*8m, 18*6m	TBA	D	
SLiT-J	Sendai	3.0	D	339.9	1.12	400	14*5m	MBnA	D	
Spring-8 II	Hyogo	6.0	D	1436	0.067			MBA	D	
BAPS	Beijing	5.0	D	1284	0.5	200-300	20*6.6 , 20*9.6	TBA	D	

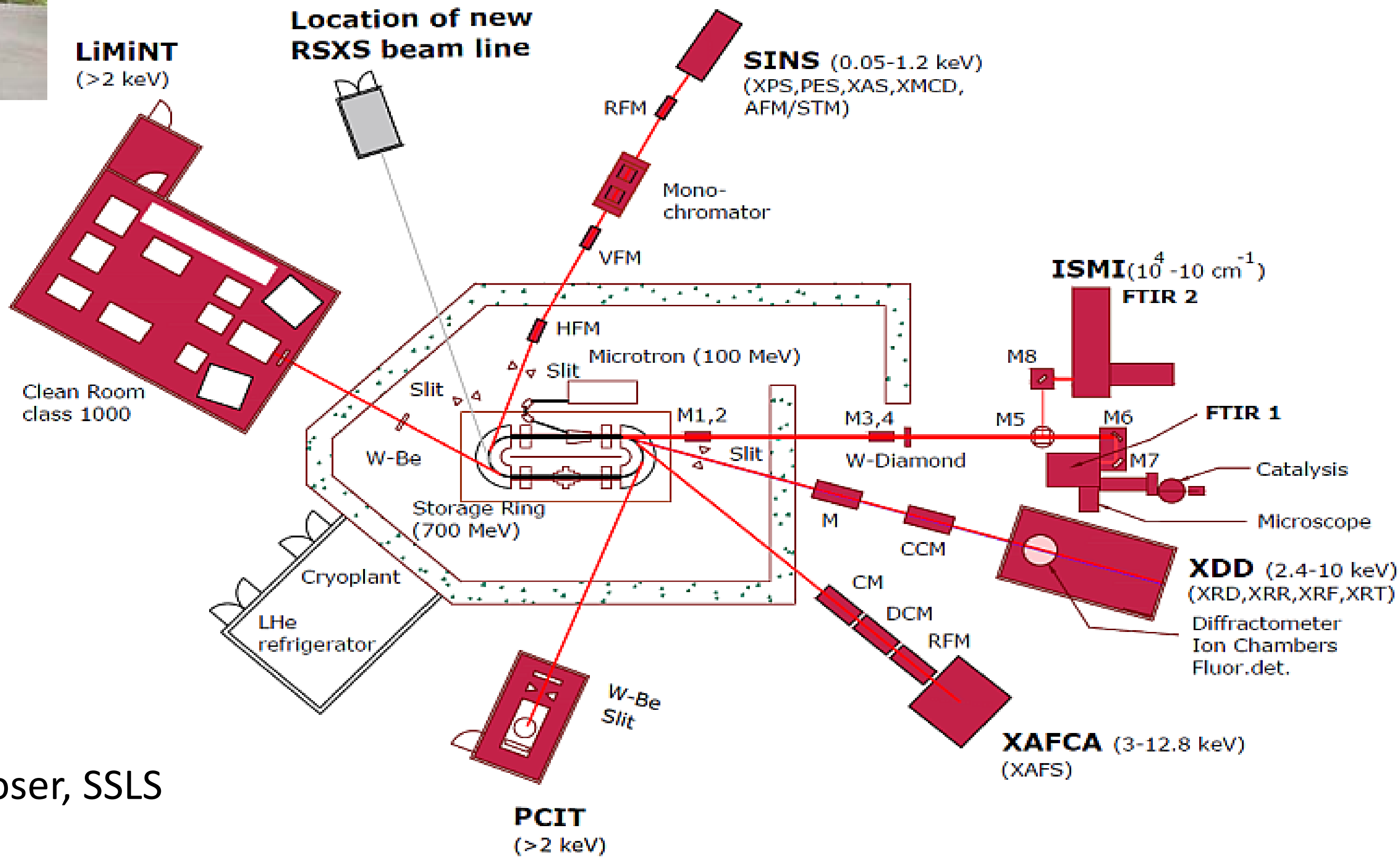
Ring circumference, completion years



Beam energy and emittance



SSLS@Singapore



Courtesy: H. Moser, SSLS

The Australian Synchrotron (2006-2013)

Courtesy: A. Peele, M. James, ASP

2006: Synchrotron achieves "first light"
April 2007: 1st Users
July 2007: Official opening
2102: New Guesthouse and
National Centre for Synchrotron Science
Jan. 2013: ANSTO becomes new operator

- Infra-Red (Microscope and Far-IR)
- Soft X-rays (90 - 2500 eV)
- X-ray Absorption Spectroscopy (4 - 50 keV)
- Powder Diffraction (4 – 37 keV)
- SAXS / WAXS (6 – 20 keV)
- Macromolecular Crystallography (MX1)
- Micro-focused Crystallography (MX2)
- X-ray Fluorescence Microscopy (4 – 25 keV)
- Imaging and Medical Beamline (30 – 120keV)

Recently built/upgraded facilities

- CJSRRF (Central Japan Synchrotron Radiation Research Facility), new, 2012
- PLS-II, upgrade, finished in 2012, in operation
- HLS, upgrade, underway, commissioning in 2013
- TPS, new facility, construction, commissioning in 2014
- SESAME, new facility, under construction,
- ILSF, new facility, R&D,

Central Japan Synchrotron Radiation Research Facility

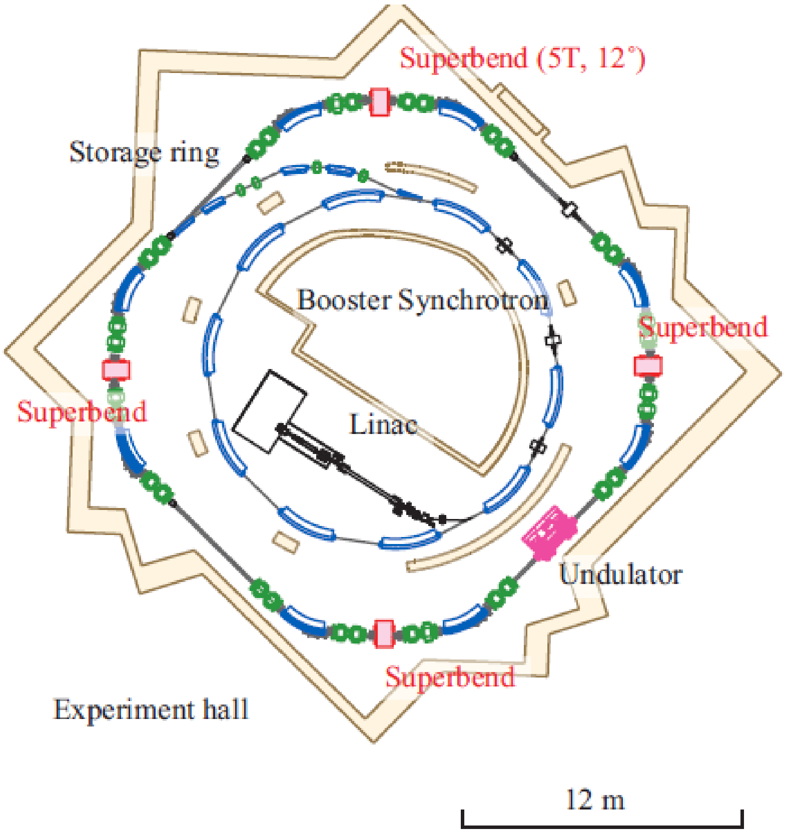


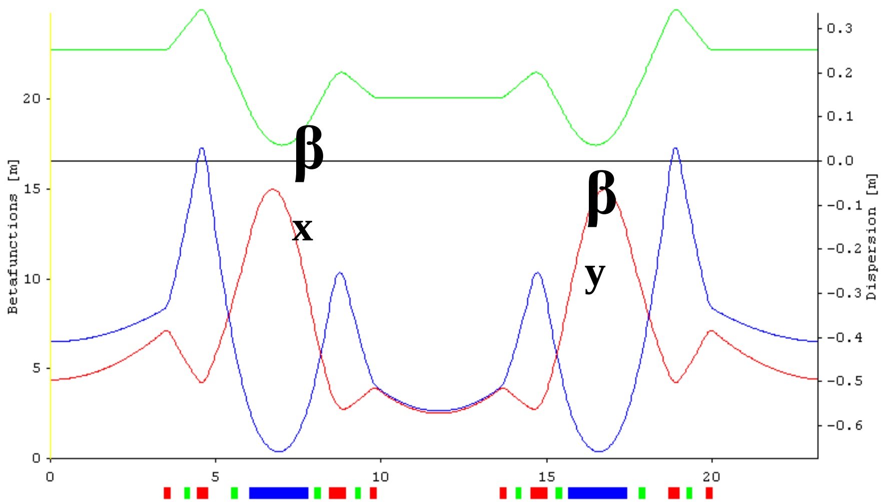
Table 1: Parameters of Accelerators

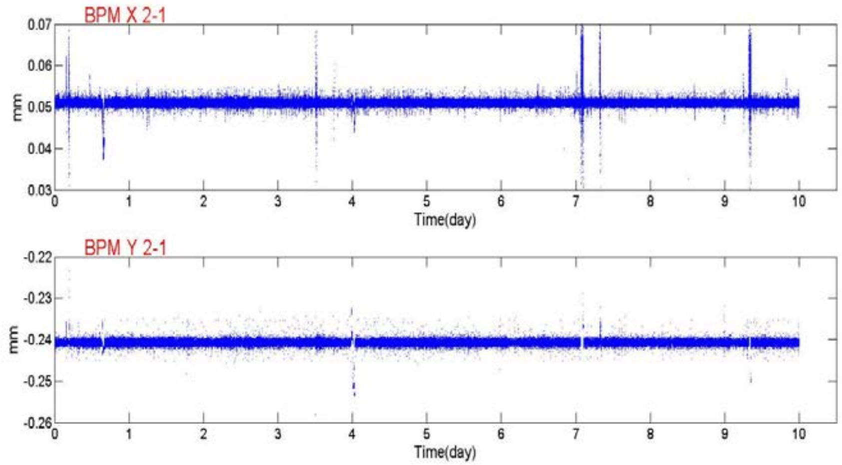
Storage ring	
Electron energy	1.2 GeV
Circumference	72 m
Current	>300 mA
Natural emittance	53 nm-rad
Betatron tune	(4.72, 3.23)
RF frequency	499.654 MHz
RF voltage	500 kV
RF bucket height	>0.990 %
Harmonics number	120
Energy spread	8.41×10^{-4}
Magnetic lattice	Triple Bend Cell × 4
Normal bend	1.4 T, 39°
Superbend	5 T, 12°
$(\beta_x, \beta_y, \eta_x)$ @superbend	(1.63, 3.99, 0.179)
$(\beta_x, \beta_y, \eta_x)$ @straight section	(30.0, 3.77, 1.20)

Designed at the Nagoya University Synchrotron Radiation Research Center (NUSRC) in collaboration with Aichi prefectural government, Aichi Science & Technology Foundation, industries, and other universities in the area. Commissioning was made in 2012-13

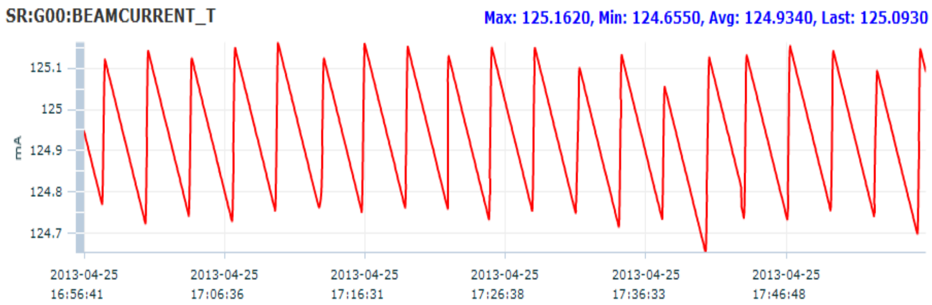
Courtesy: T. Konomi, UVSOR

PLS-II@PAL, Pohang





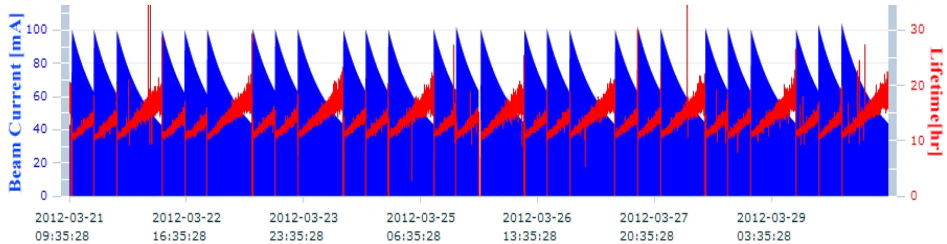
Orbit variation for 24 hours during user run.

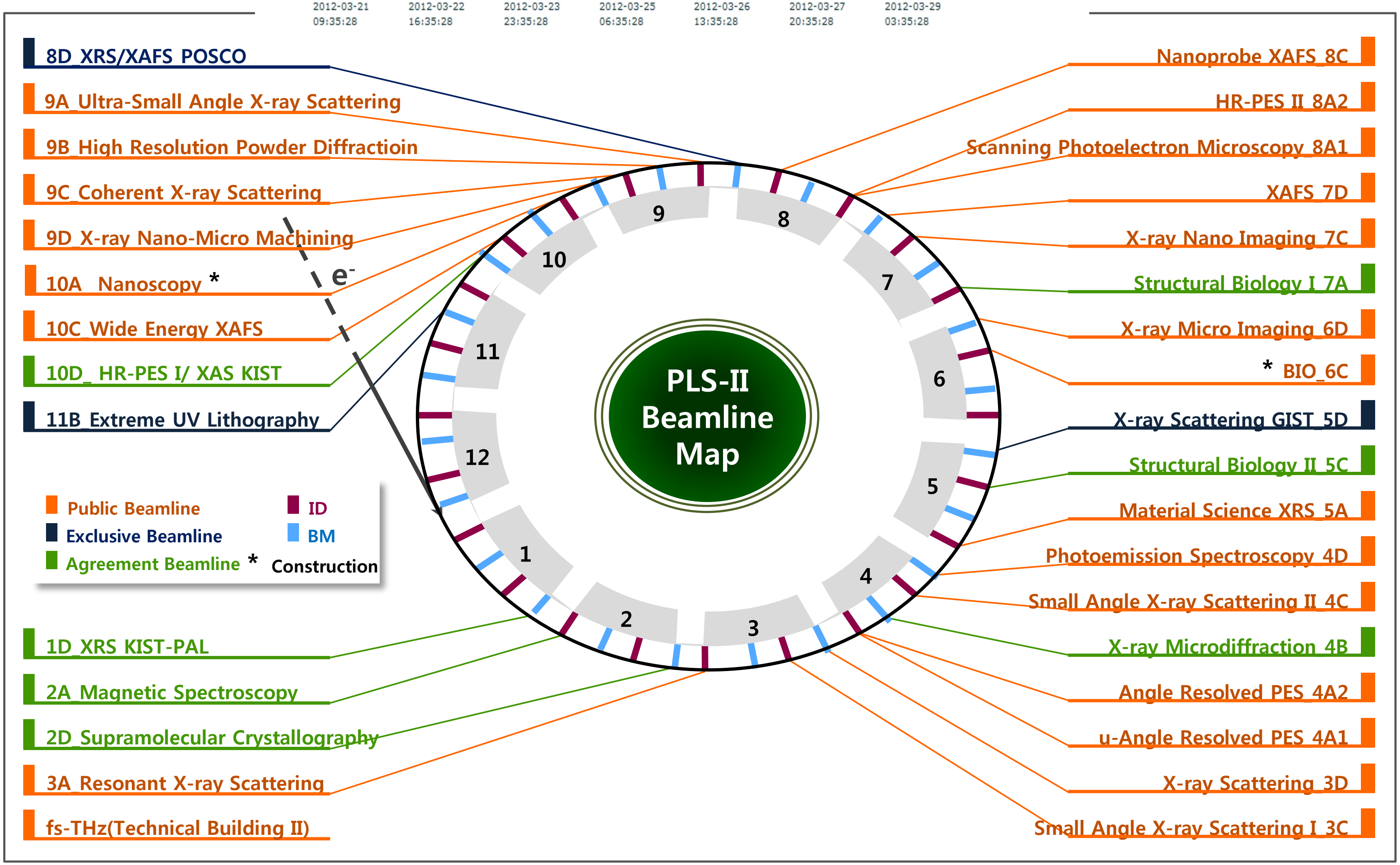


Stored beam current variation for the top-up mode user service operation recorded in April 2013.

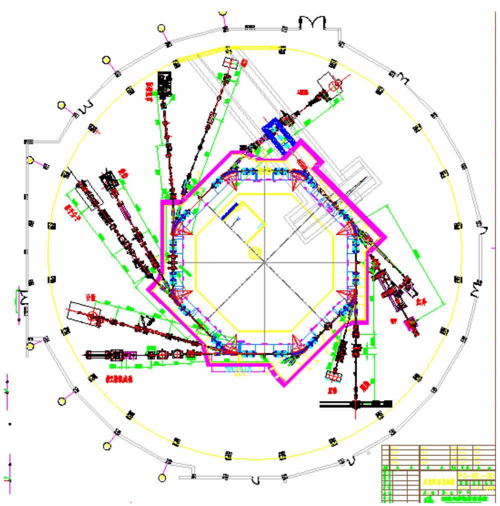
Courtesy: S. Nam, PAL

1st Run of PLS-II user service in March 2012.





HLS-II : Hefei Light Source Upgrade

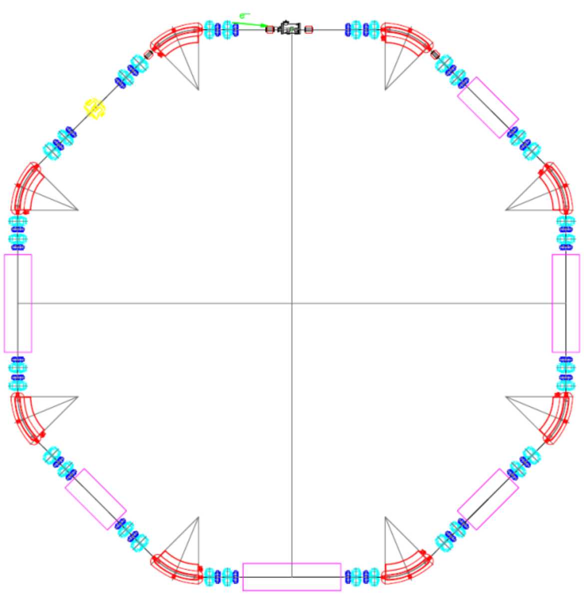


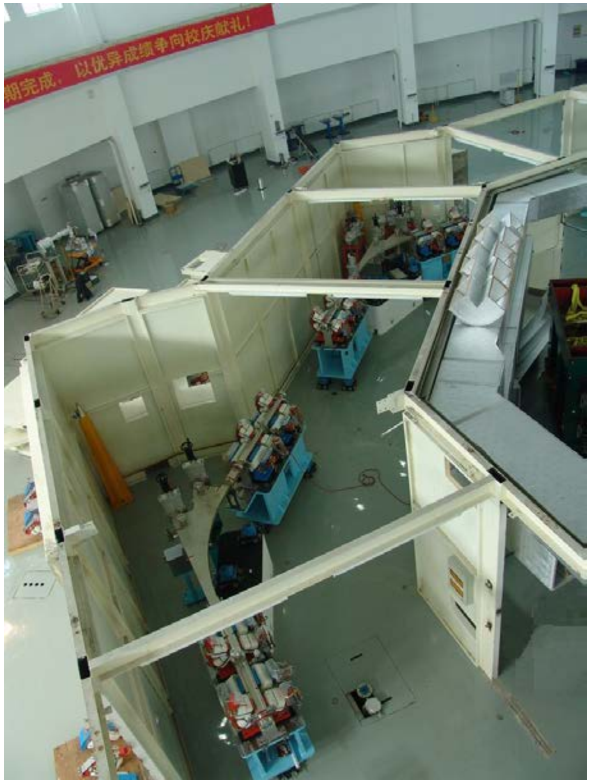
	HLS	HLS II
Beam energy	800 MeV	
Circumference	66.13 m	
Magnet lattice	TBA	DBA
Super-period	4	
Natural emittance	160 nm·rad	<40 nm·rad
Beam intensity	250 mA	300 mA
Transverse tunes	3.54/2.60	4.41/2.80
Beam lifetime	>10 h	>5 h
RF frequency	204 MHz	
RF voltage	150 kV	250 kV
Harmonic number	45	
Critical wavelength	24.0 Å	23.44 Å
Radiation loss	16.31 keV/turn	16.70 keV/turn
Number of ID	2	6
Slow orbit shifts	<25μm（V）	<5μm（V）

HLS-II@USTC, Hefei

- **Lattice**: 4×TBA → 4×DBA
- **Emittance**: 160 nm·rad,< 40 nm·rad
- **Staight section**: 3.36m×4 → 4.00m×4+2.32m×4

- ➢Jun. 15, 2013, **Start commissioning of Injector**
- ➢Aug. 31, 2013, **Start commissioning of storage ring**
- ➢Sep. 20, 2013, **First beam**
- ➢Dec. 31, 2013, **Finish commisioning of beamline**





Courtesy: W. Li, USTC&HLS

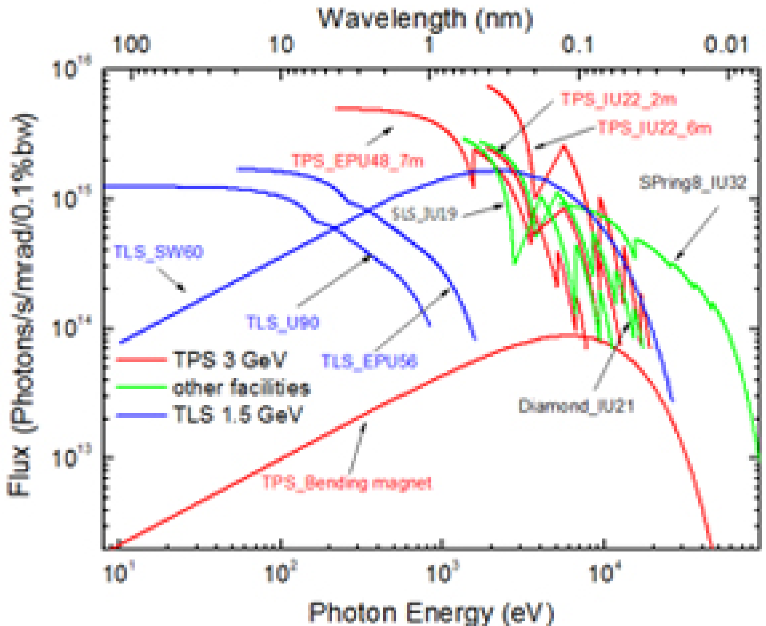
TPS: Taiwan Photon Source（2010-2014）

2010 Groundbreaking
2011 Linac pre-test
2012 Accelerator installation
2013 Accelerator commissioning
2014 users run

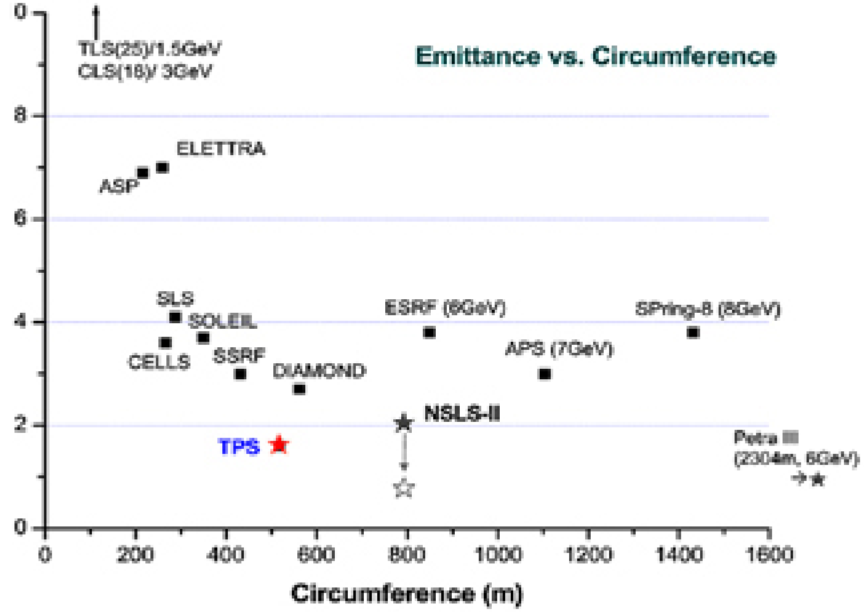
Ring: 3.0GeV, 518m,1.6nm-rad
Booster: 3Hz, 496.8m, 10nm-rad
Linac: 150MeV

TPS site plan

Flux of TPS



Emittance vs. Circumference

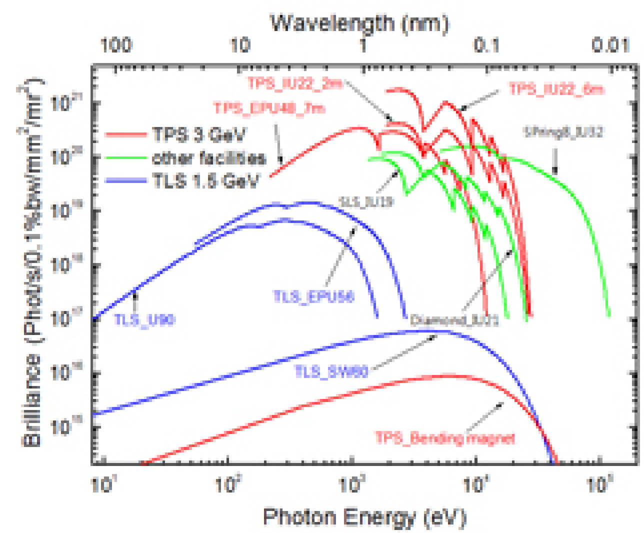


Courtesy: G. Luo, NSRRC&TPS

Parameters of TPS Synchrotron Facility

Energy	3 GeV
Beam Current	400 mA at 3 GeV (300 mA in 1st-phase)
C of the Storage Ring	518.4 m (h = 864)
C of the Booster	496.8 m (h = 828)
Cells	24-cell DBA
Long Strait	12 m x 6 (σ_v = 9.8 μm, σ_h = 165.1 μm) 7 m x 18 (σ_v = 5.1 μm, σ_h = 120.8 μm)
Emittance	1.7 nm·rad at 3 GeV (Distributed dispersion)
RF frequency	500 MHz
RF Voltage (1st-phase)	6.4 MV (4 SRF cavities)
RF Power (1st-phase)	720 kW (4 SRF cavities)

Brightness of Synchrotron Light Sources



TPS civil eng. finished on April,2013

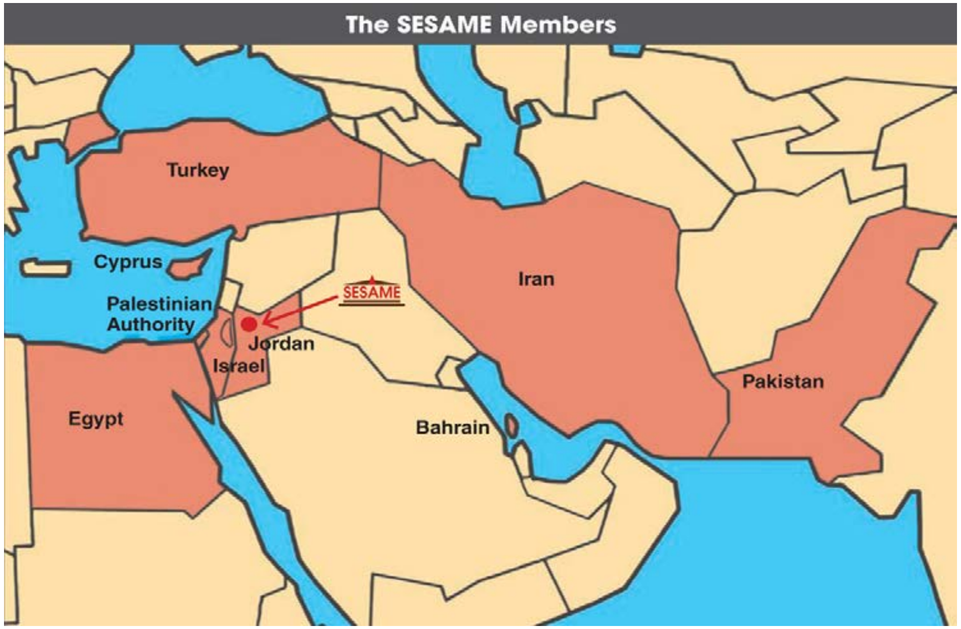
Storage ring June 18, 2011

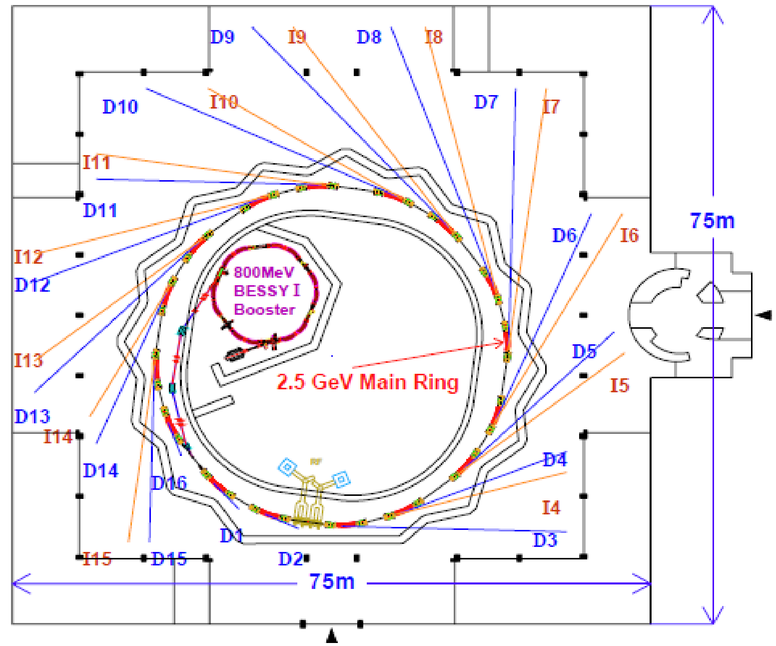
Storage ring April 9, 2012

Nov. 04, 2012

Feb. 23, 2013

SESAME (9 members, 12 observers)





Energy; *2.5 GeV*

Circumference; *133m*

Emittance; *26 nm-rad*

12 Insertion Devices

13 Bending Magnet beam lines

Maximum beam line length; 37m

ILSF: Ilran Light Source Facility (2011-2018)

Courtesy: J. Rahighi, ISLF@SESAME

Storage Ring

- 3 GeV, 297.6m circumference, 3.3 nm-rad, four-fold symmetry, with 4×8m, 20 X4m 12 × 2.8m straight sections ;

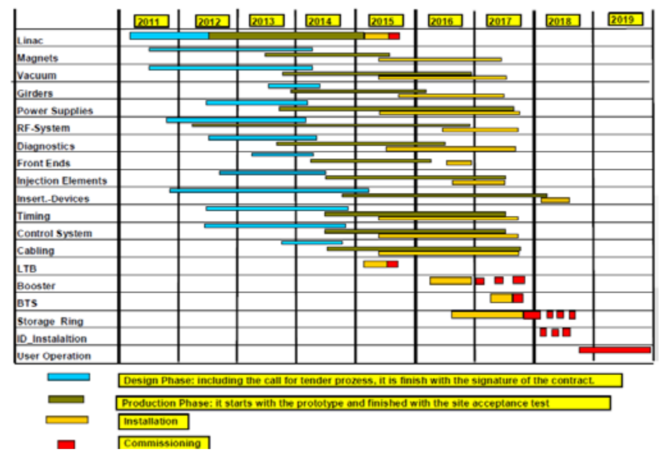
Booster Ring

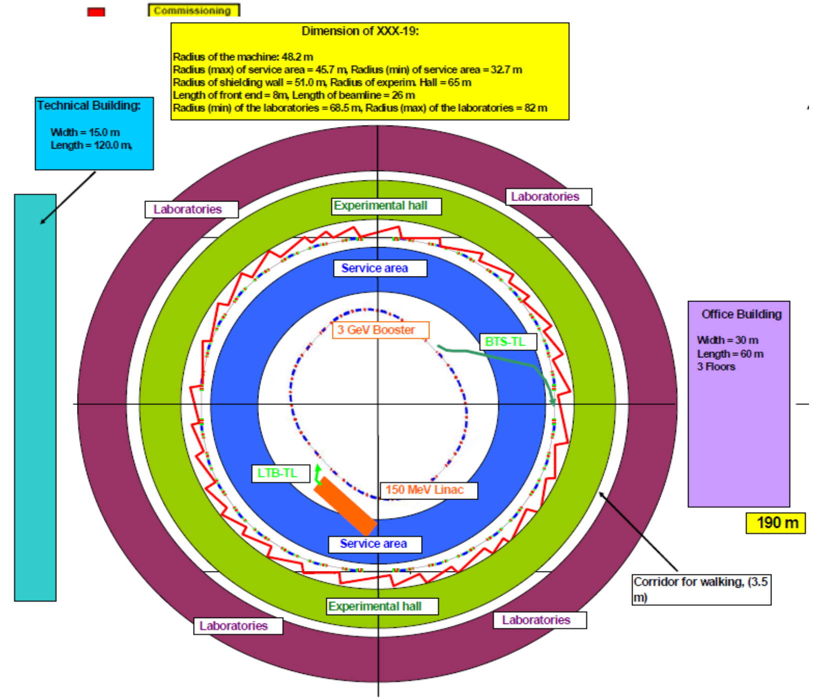
- 144m Circumference, 14nmrad, 1Hz;

Linac

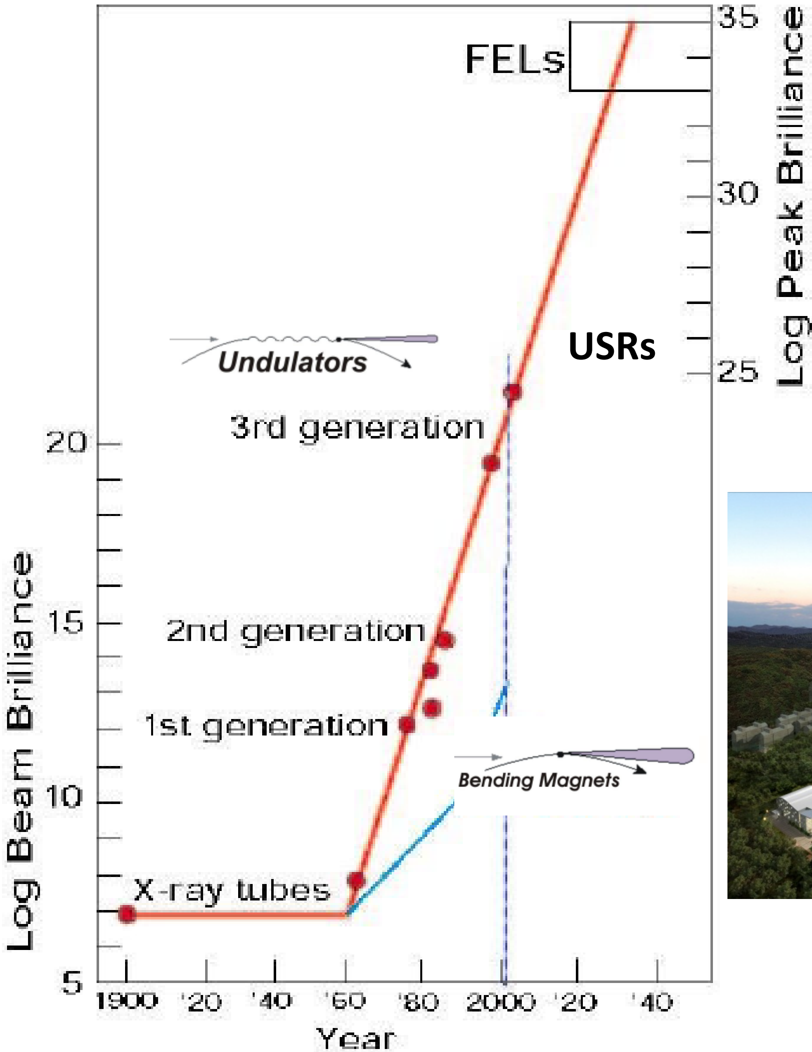
- 150 MeV , Electron gun 90kV

Parameter	Unit	Value
Energy	GeV	3
Circumference	m	297.6
Number of super-periods	-	4
Current	mA	400
Horizontal Emittance	nm-rad	3.278
Harmonic number	-	496
RF frequency	MHz	500
Tune (Q_x/ Q_y)	-	18.2656/11.324
Natural energy spread	-	1.0408E-03
Natural chromaticity (ξ_x/ξ_y)	-	-34.560/-28.02
Momentum compaction (α_c)	-	7.621E-04
Radiation loss per turn	MeV	1.0167
Beta function at center of medium straight sections (β_x/β_y)	m	2.3/1.4
Beam size at center of medium straight section ($\sigma x/\sigma y$)	µm	156.18/6.84
No. of dipoles	-	32
No. of quadrupoles	-	104
No. of sextupoles	-	128
Dipole magnetic field	T	1.42
Dipole field gradient (matching/unit)	T/m	-3.83/-5.83





Light sources: from SR to FEL

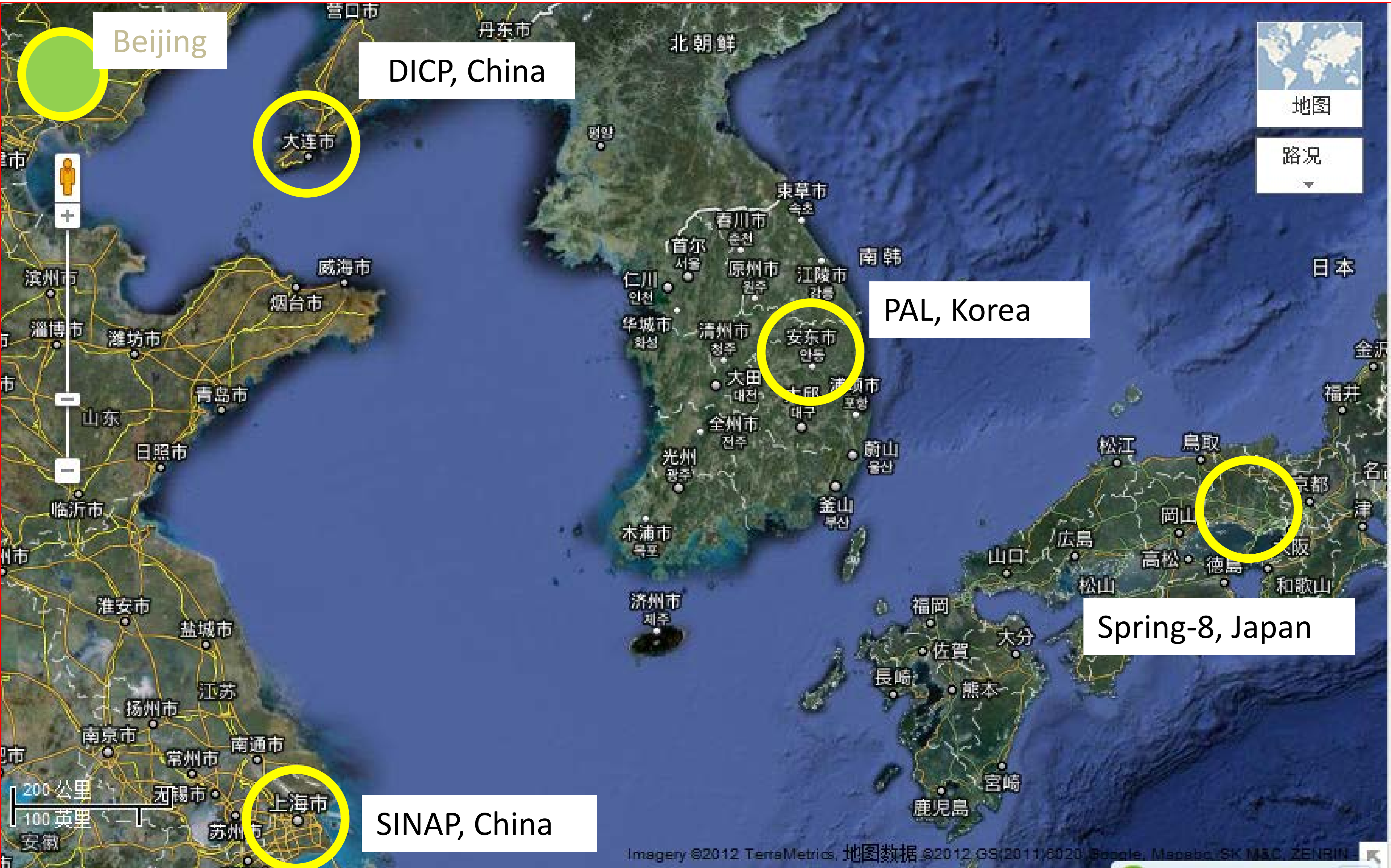


SACLA + Spring-8

PAL-XFEL + PLS-II

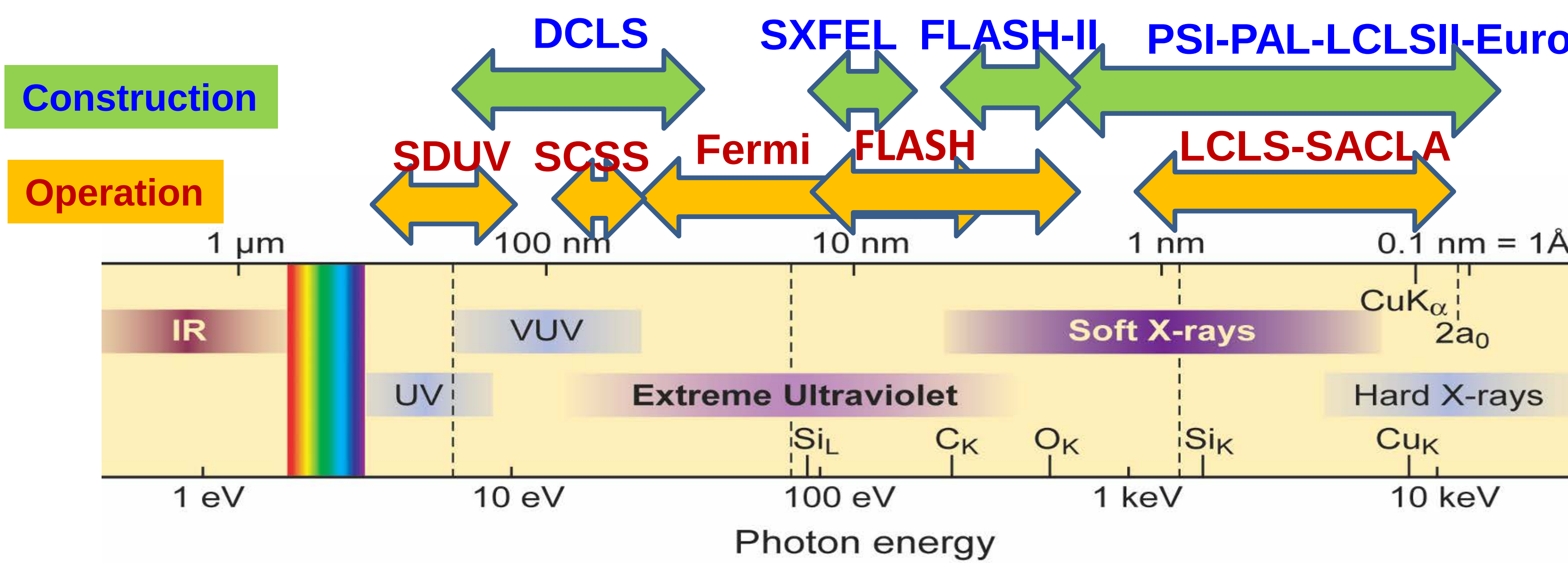
SXFEL + SSRF

Major high gain FEL facilities in Asia



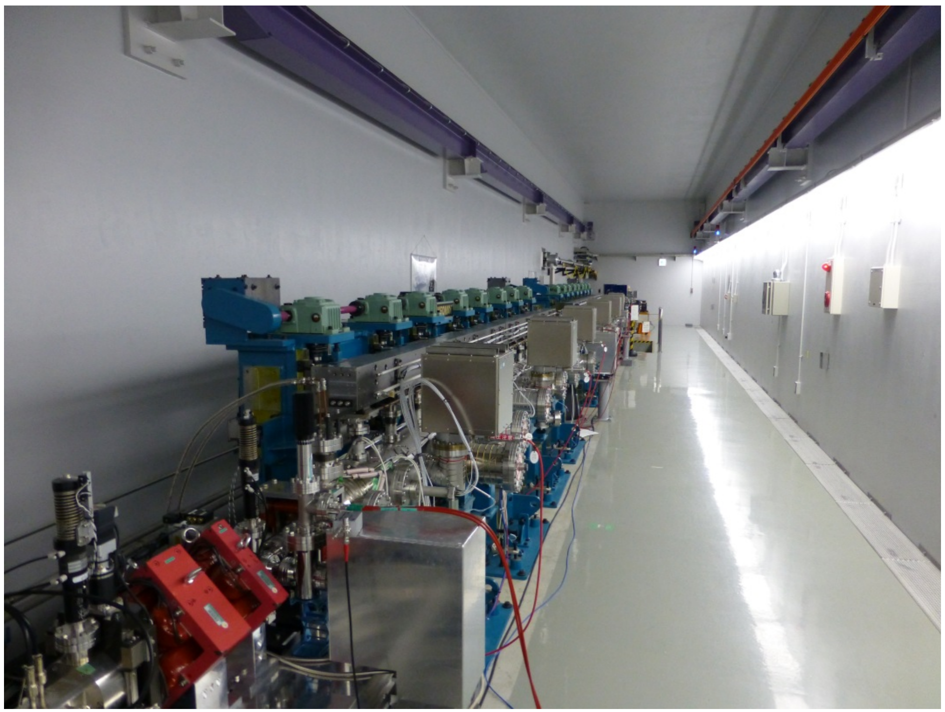
High Gain FEL Light Sources in Asia

HG FEL	Location	Energy (GeV)	Type	L (m)	Wavelength (nm)	Rate (Hz)	Driver	FEL type	Sta	Lasing
SCSS	Hyogo	0.25	T, U	55	50-60	10-60	Linac (c)	SASE, DS	O	2006
SDUV	Shanghai	0.2	Test	65	150-350	1-10	Linac (s)	Seeded	O	2010
SACLA	Hyogo	8.0	U	700	0.08 -0.8	60	Linac(c)	SASE, SS	O	2011
PAL-XFEL	Pohang	10.0	U	1100	0.1-4	100	Linac (s)	SASE,SS	C	2015
DCLS	Dalian	0.3	U	150	50-150	50	Linac (s)	HGHG	C	2015
SXFEL	Shanghai	1.0	Test	300	9 – 30	10	Linac (c)	seeded	C	2015
BAPS	Beijing	3-5		1250	1-5	~kHz?	Ring		D	



SCSS@SPring-8, first HG FEL in Asia

- First SASE FEL lasing in Asia
- direct seeding at 160nm&60nm
- DC gun, c-band accelerator, IVU



LETTERS

Injection of harmonics generated in gas in a free-electron laser providing intense and coherent extreme-ultraviolet light

G. LAMBERT[1,2,3*], T. HARA[2,4], D. GARZELLA[1], T. TANIKAWA[2], M. LABAT[1,3], B. CARRE[1], H. KITAMURA[2,4], T. SHINTAKE[2,4], M. BOUGEARD[1], S. INOUE[4], Y. TANAKA[2,4], P. SALIERES[1], H. MERDJI[1], O. CHUBAR[3], O. GOBERT[1], K. TAHARA[2] AND M.-E. COUPRIE[3]

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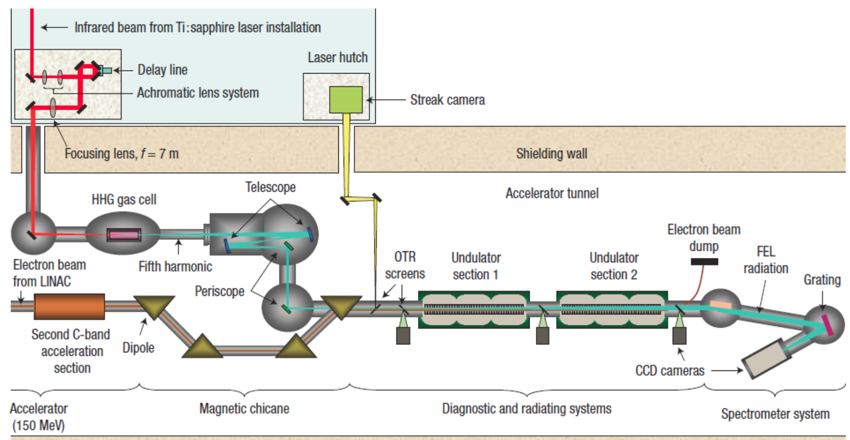
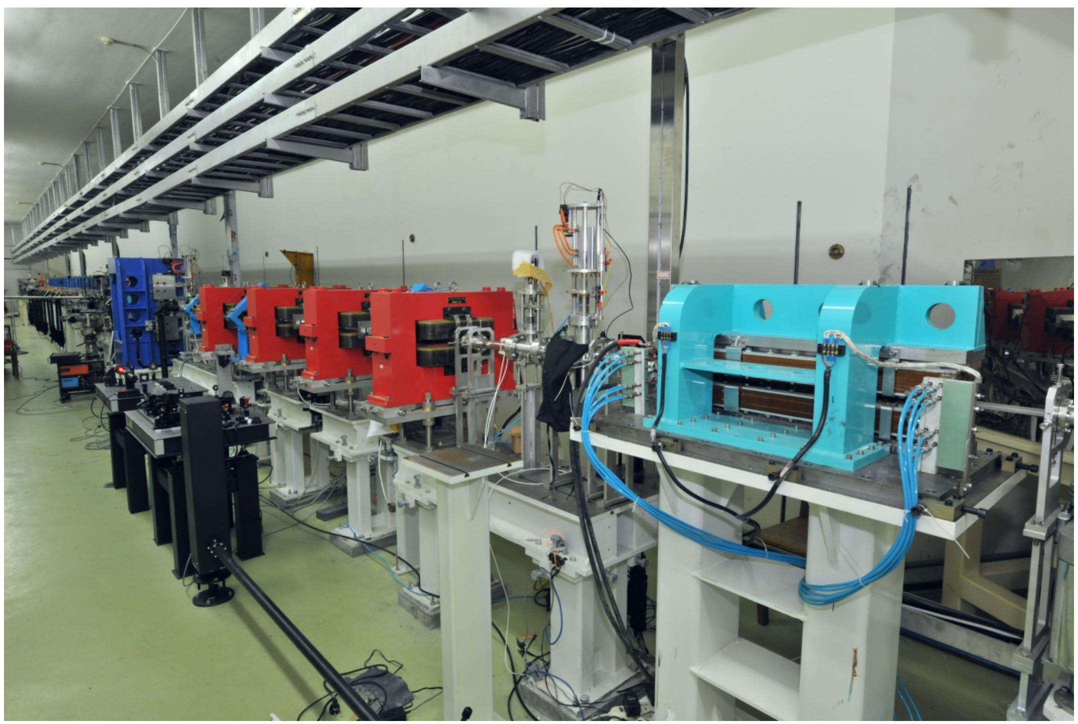
[3]Groupe Magnétisme et Insertion, Synchrotron Soleil, L'Orme des Merisiers, Saint Aubin, 91192 Gif-sur-Yvette, France
[4]XFEL Project Head Office/RIKEN, 1-1-1, Kouto, Sayo-cho, Sayo-gun, Hyogo 679-5148, Japan
*e-mail: guillaume.lambert@synchrotron-soleil.fr

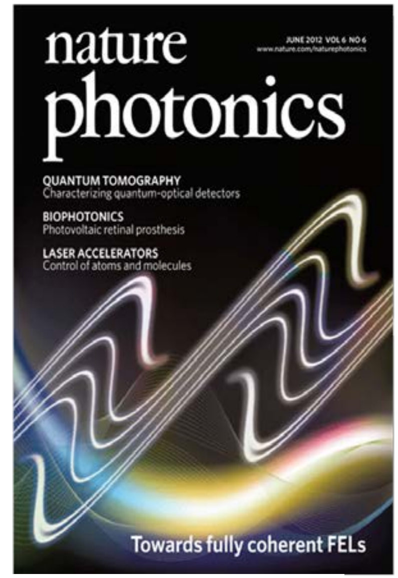
Nature Physics 296, 2008

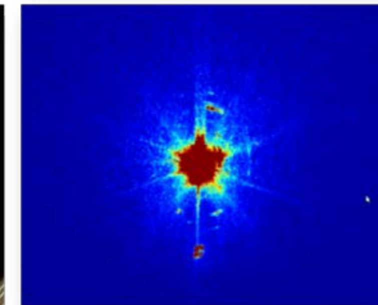


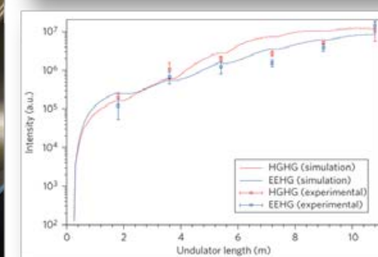
SDUV@SINAP, seeded FEL test facility

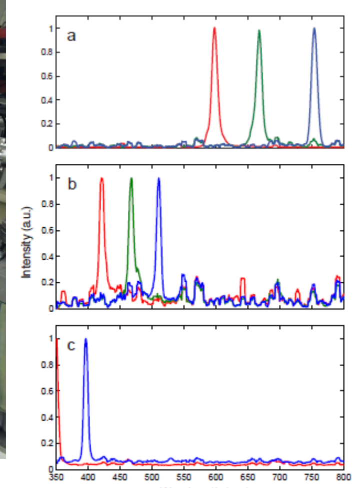
- First EEHG FEL lasing
- 1keV slice energy spread meas.
- widely tunable seeded FEL

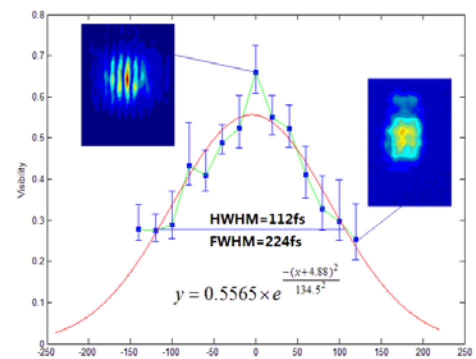










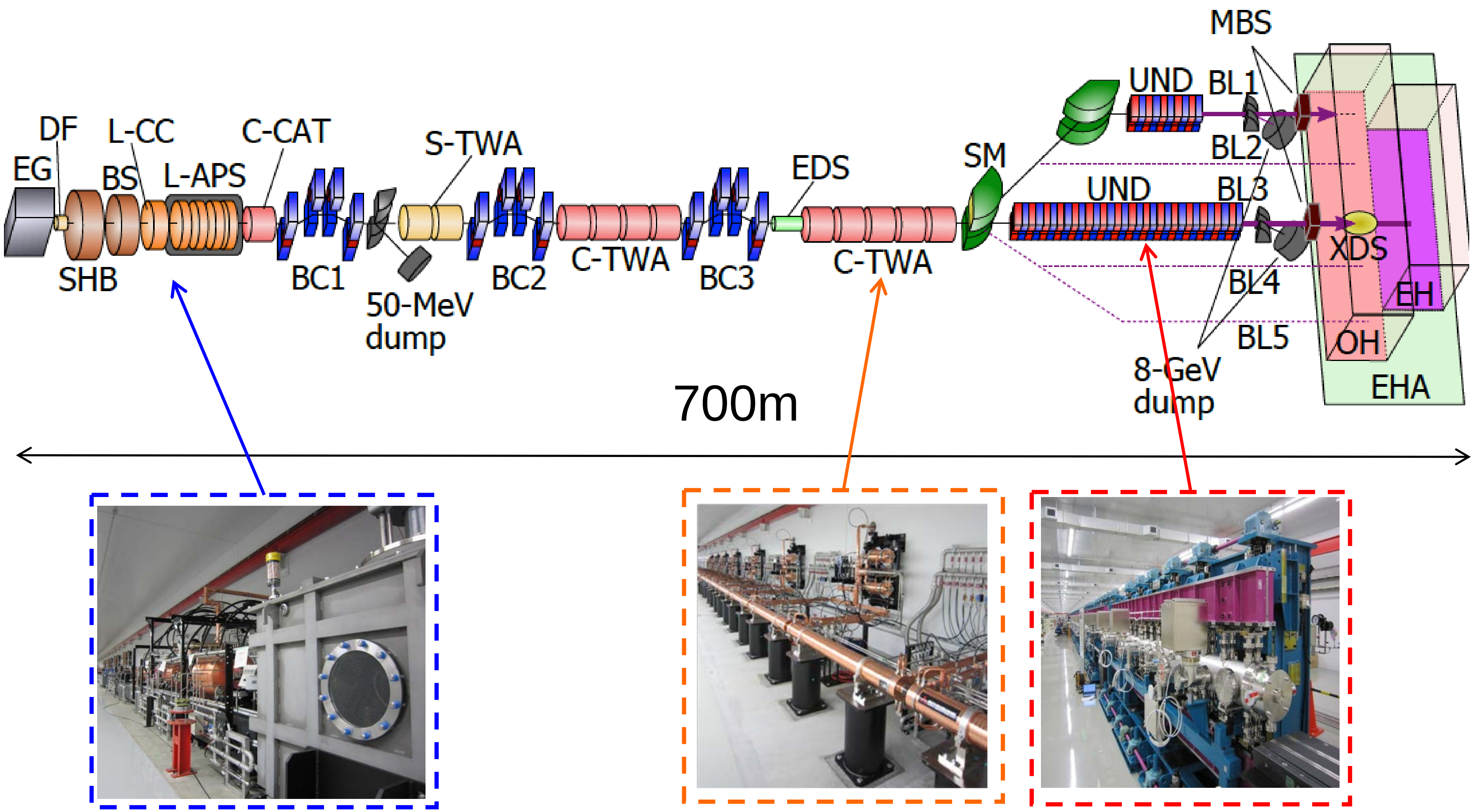


SACLA @ Spring-8

Lasing Achieved at SACLA,Japan's X-ray Free Electron Laser (XFEL) facility

We are pleased to announce that the SPring-8 Angstrom Compact free electron Laser (SACLA) came on line at the RIKEN Harima Institute. SACLA is the second laser of its type in operation, following LCLS at the U.S. Department of Energy's SLAC National Accelerator Laboratory. Producing the world's highest energy X-ray laser light, SACLA offers scientists a new tool for studying and understanding the arrangement of atoms moving extremely rapidly in various materials.

SACLA (SPring-8 Angstrom Compact free-electron Laser)



Courtesy: T. Ishikawa, H. Tanaka, Spring-8

Achieved Laser Performance

Pulse Energy* (mJ):	0.3 mJ@10 keV
Peak Power* P (GW):	30< P
Available Wavelength range (keV):	from 4.5 to 15
Spatial Coherence:	nearly full
Stability* (unit: normalized standard deviation)	
Intensity $\sigma_{\delta I/I}$:	$\leq$ 10%
Pointing $\sigma_{\delta z}$/z(FWHM):	3 ~7%
Wavelength $\sigma_{\delta\lambda}/\lambda$:	$\leq$ 0.1%
Repetition:	20 Hz (Max.60 Hz)

* depending on the lasing wavelength

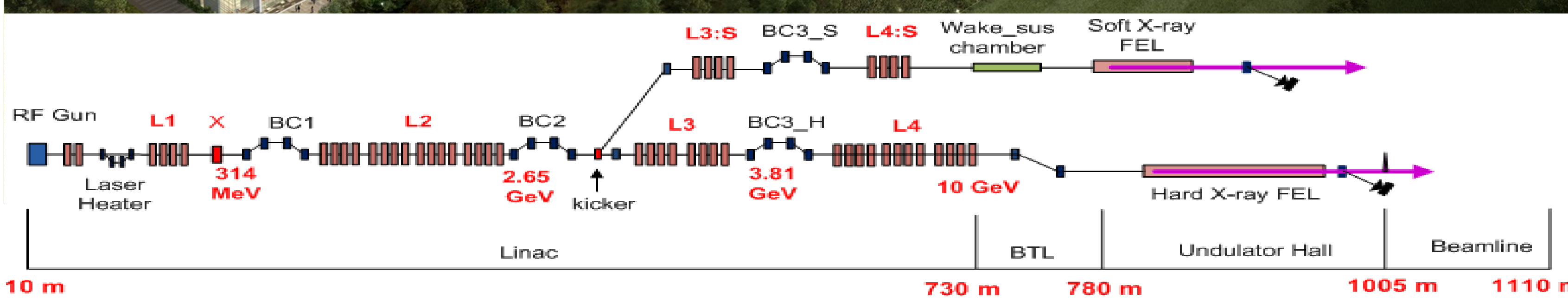
Courtesy: T. Ishikawa, H. Tanaka, Spring-8

PAL-XFEL (2011 -2014)

Linac Hall	830
Undulator Hall	200
XFEL Beamline	80
Total Length [m]	1,110

Courtesy: H. Kang, PAL

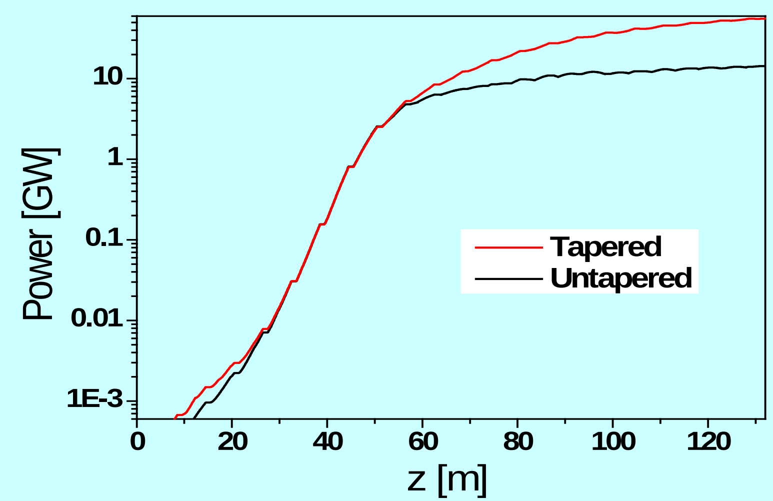
- 0.1-nm Hard X-ray
- Budget: 400 M$
- 10GeV S-band Linac
- 2014 XFEL lasing



PAL XFEL: Main Parameters

	FEL wavelength [nm]	0.1
Electron Linac	Beam energy [GeV]	10
	Beam charge [nC]	> 0.2
	Beam emittance [mm-mrad]	< 0.5
	Injector Gun	Photocathode RF-gun
	Peak current at undulator [kA]	> 3
	Repetition rate	120 Hz
	Number of bunches	Single or Two
	Linac structure	S-band
Undulator	Undulator type	Out-vacuum
	Undulator period [cm]	2.46
	Undulator gap [mm]	6.8
	Undulator parameter, K	2.076
	Saturation length [m]	56
FEL	FEL radiation power [GW]	> 29
	Photon beam length [fs]	60
	FEL photons/pulse	> 1.0 E+12

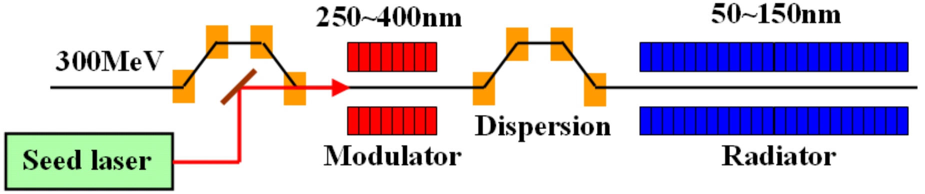
- **Wavelength**
  - **Soft x-ray: 1 nm ~ 10 nm**
  - **Hard X-ray: 0.7 ~ 0.1 nm**
    - **Extended to 0.06 nm**
- **Photon beam Length**
  - **Nominal : 30 ~ 100 fs (200 pC)**
  - **Short : < 5 fs (20 pC)**
  - **Ultra short: < 0.5 fs by ESASE scheme**
- **Undulator Beamline**
  - **3 Hard X-ray / 2 Soft X-ray lines**

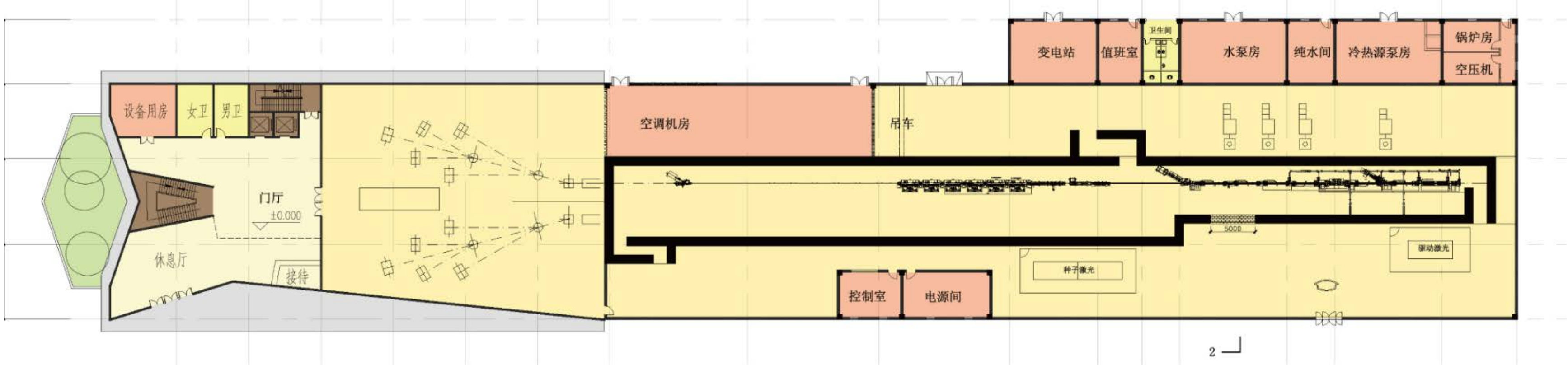


- Radiation Power of 0.1 nm @Z=132 m
- Untapered : 14 GW (4.7E+11 photons)
- Tapered : 55 GW (1.8E+12 photons)

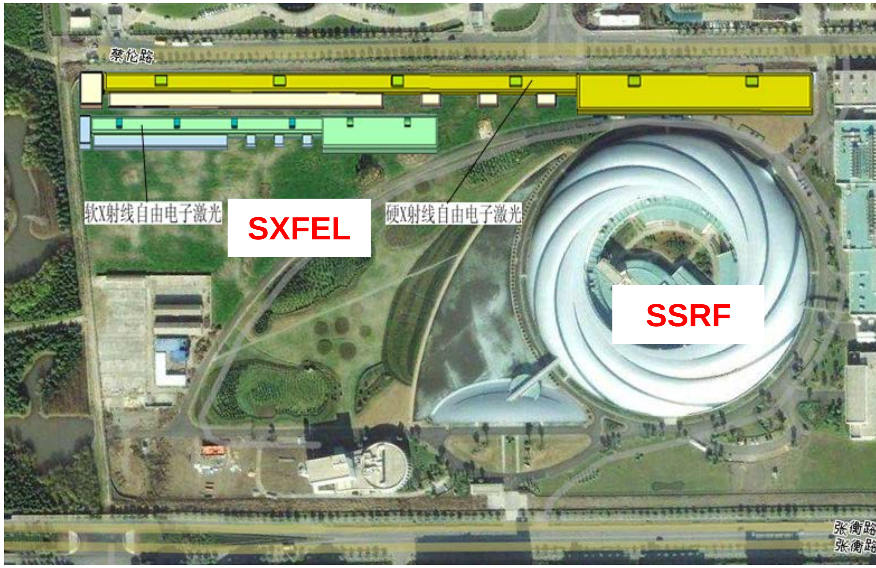
DCLS@Dalian(2011-15)

- 50-150 nm fully tunable
- Fully coherent
- Narrow bandwidth/ultra short

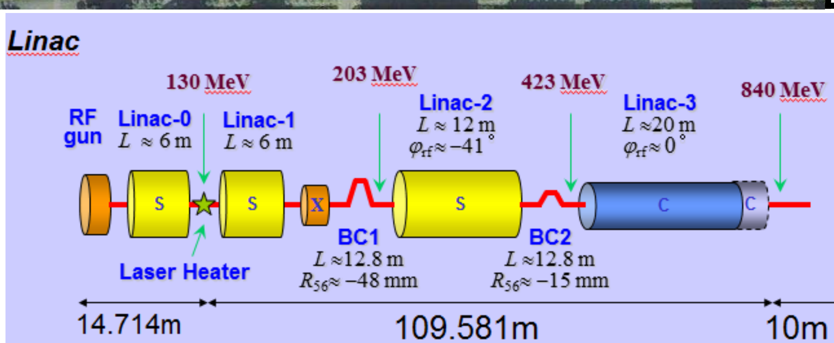


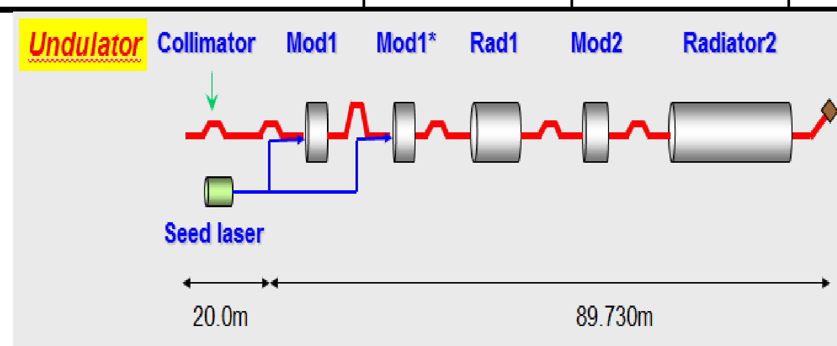


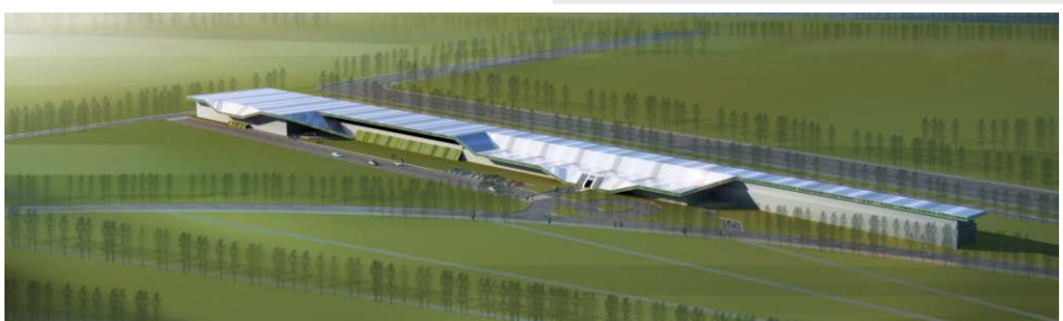
SXFEL: Shanghai XFEL Test Facility (2012-2015)



Parameters	HGHG	Upgrade	Unit
Output Wavelength	9	3	nm
Bunch charge	0.5~1	0.5~1	nC
Energy	0.84	1.2~1.3	GeV
Energy spread	0.1~0.15%	0.15%	
Energy spread (sliced)	0.02%	0.03%	
Normalized emittance	2.0~2.5	2.0~2.5	mm.mrad
Pulse length (FWHM)	1.	1	ps
Peak current	~0.5	0.5	kA
Rep. rate	1~10	1~10	Hz







Planned light sources in Asia

- 'Typical' 3rd generation light sources

  LSEJ@sedai, Japan

  TAL@Ankara, Turkey

  BAPS@Beijing, China

- USR(diffraction limited ring)

  Spring-8-II

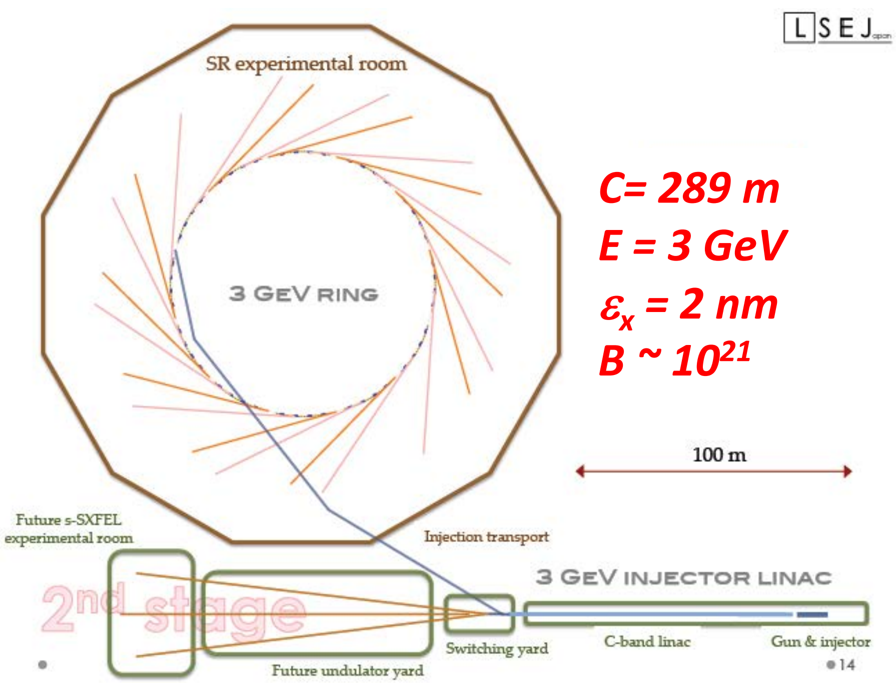
- USR based FEL

  BAPS-II

LSEJ$_{\text{apan}}$: Light Source in East Japan

- Need another mid-Energy high brightness source in Japan
- Supported by 7 national universities
- 3-GeV C-band linac injector (could be soft-XFEL driver)
- 12-cell, QBA as baseline
- Needs at least 250 M$-- will abandon proposal if funding not approved in 2 years (before KEK ERL, SPring-8 II funding)

Courtesy: H. Hama, Tohoku U.

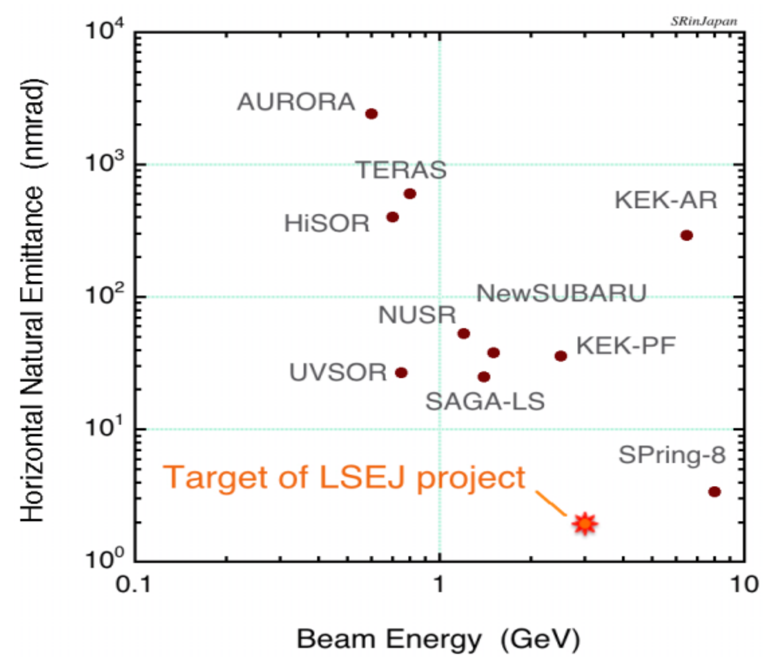


C= 289 m

E = 3 GeV

ε_x = 2 nm

B ~ 10^{21}



Light sources@TAL

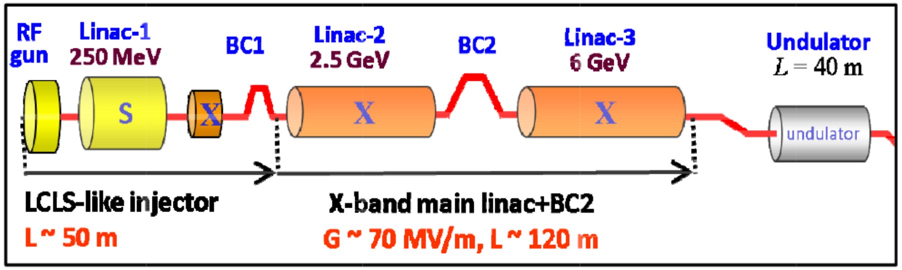
- Linac-based SASE FEL Facility
- Third Generation Synchrotron Radiation Facility (SR)

Parameter	Value
Energy (GeV)	3
Circumference (m)	466.8
Beam Current (mA)	500 mA
Bet. Tunes Q_x/Q_y	31.24/6.18
Nat. Chromaticity x_{ox} /x_{oy}	-69/-34
Cor. Chromaticity x_{ox} /x_{oy}	0.0/0.0
Energy loss / turn (keV)	347.4
H. emittance (nm)	0.68
V. emittance (nm)	0.0068
Betaxmax (m)	15.7
Betaymax (m)	26.9
Betax in the mid. of straight sect.	14.1
Betay in the mid. of straight sect.	6.5
Dispx in the middle of straight sect.	0.14
Number of straight section	18
Length of straight section (m)	6
Rf Voltage (MV)	3.5
Harmonic number	776
Max. Number of bunch	776
Bunch charge (nC)	1.028
RMS Bunch length (mm)	2.28
RMS Energy Spread (%)	0.05
Momentum Acceptence (%)	4.3
Coupling (%)	1
Toushek Life time (h)	10.0
El. Scat. Lifetime (h)	142
Inel. Scat. Lifetime (h)	619
Tot lifetime (h)	8.9

Courtesy: Q. Ozturk, TAL

Proposed SASE FEL Facility:

- 4th generation light souce based on a Sc L band (1.3 GHz) or Nc X-band (12 GHz) RF linac technology
- produce free electron lasers (FEL) between VUV and X-ray region (1-100 nm)



SPring-8 II

Road map for SPring-8 II

Courtesy: T. Ishikawa, Spring-8

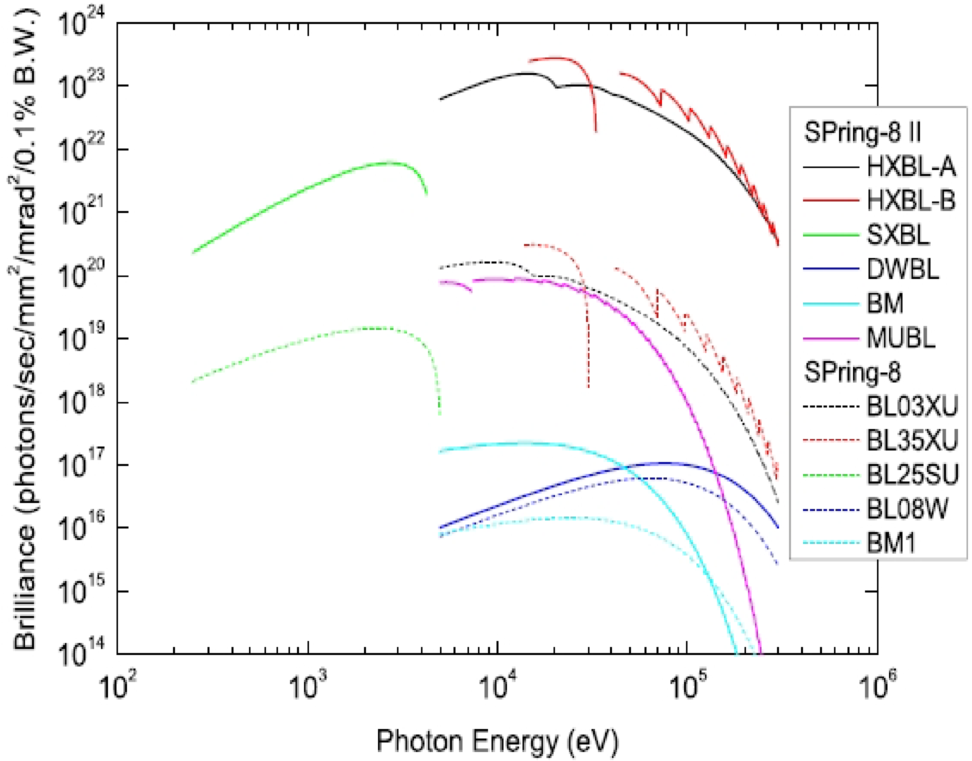
- Two big light source on one site.
- SPring -8 is planed to upgrade to Ultimate ring

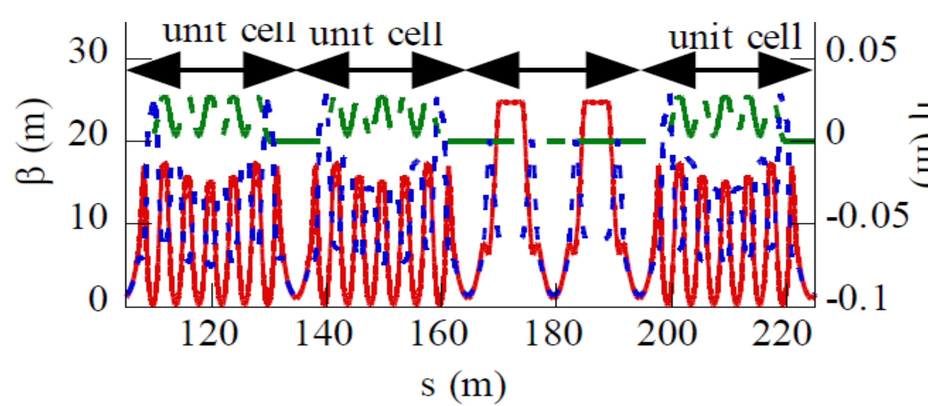
Main Performance of SPring-8 II

Courtesy: T. Ishikawa, Spring-8

- Energy : 6 GeV
- Emittance: 67.5 → 10 pm-rad
- New injection scheme

	New Ring	Present Ring
Lattice Type	6 Bend	Double-Bend
Unit Cell Length [m]	29.92	29.92
Ring Circumference [m]	1435.95	1435.95
Beam Energy [GeV]	6	8
Natural Emittance [pm.rad]	67	3400
Energy Spread [%]	0.096	0.109
Dispersion Func. [m] at Straights	0	0.107
Betatron Func. [m] at Straights (H/V)	1.0 / 1.2	22.6 / 5.6
Betatron Tune (H/V)	141.80 / 38.25	40.14 / 18.35
Natural Chromaticity (H/V)	-473 / -199	-88 / -42
Momentum Compaction Factor	1.55×10^{-5}	1.68×10^{-4}
Radiation Loss [MeV/turn]	4	9
Number of Magnets per Cell (Bending / Quadrupole / Sextupole)	6 / 26 / 23	2 / 10 / 7
Bending Field [T]	0.70	0.68
Max. Strength of Quadrupoles [m^{-1}]	1.52	0.40
Max. Strength of Sextupoles [m^{-2}]	120	6.2





Integration of Emittance Reduction Schemes

What we do: To avoid catastrophe and to achieve ultra-low emittance, we should integrate emittance reduction schemes to relax multi-bend lattice design.

Equation of natural emittance:

$$\varepsilon_{nat} = C_q \frac{\gamma^2 \left\langle H / \rho^3 \right\rangle}{J_x \left\langle 1 / \rho^2 \right\rangle}$$

Emittance reduction schemes:

1. **Optimization of dipole field (ρ) in longitudinal (inside dipole and / or inside unit cell)**
2. **Reduction of stored energy (γ) with the help of advanced undulator design**
3. **Damping partition number (J_x) control**
4. **Damping enhancement by additional radiation**
5. **Sophisticated optimization to approach to the theoretical minimum ($\varepsilon_{design} / \varepsilon_{min} < 3$)**
6. **Other reduction schemes**

Emittance Reduction Budget

In order to optimize the ring design by integrating several schemes, concept of "emittance reduction budget" is useful especially for the upgrade of the existing rings

Item	Dependence	Value (Old→New)	Reduction Gain*
Beam Energy γ	γ^2	8 GeV → 6 GeV	1.8
Bend angle θ	θ^3	2BA → 3BA 2BA → 4BA	8.0 27
Dipole field optimization	$<H / \rho^3> / <1 / \rho^2>$		~2.0
Damping enhancement	Damping by ID, D.W.		1.4
Damping partition number control	$1 / J_x$	$J_x = 1 \rightarrow J_x = 2.0$	2.0
Optics optimization	$\varepsilon_{design} / \varepsilon_{min}$	~3 → ~2.5?	1.2
Total			90(3BA) ~ 300(4BA)

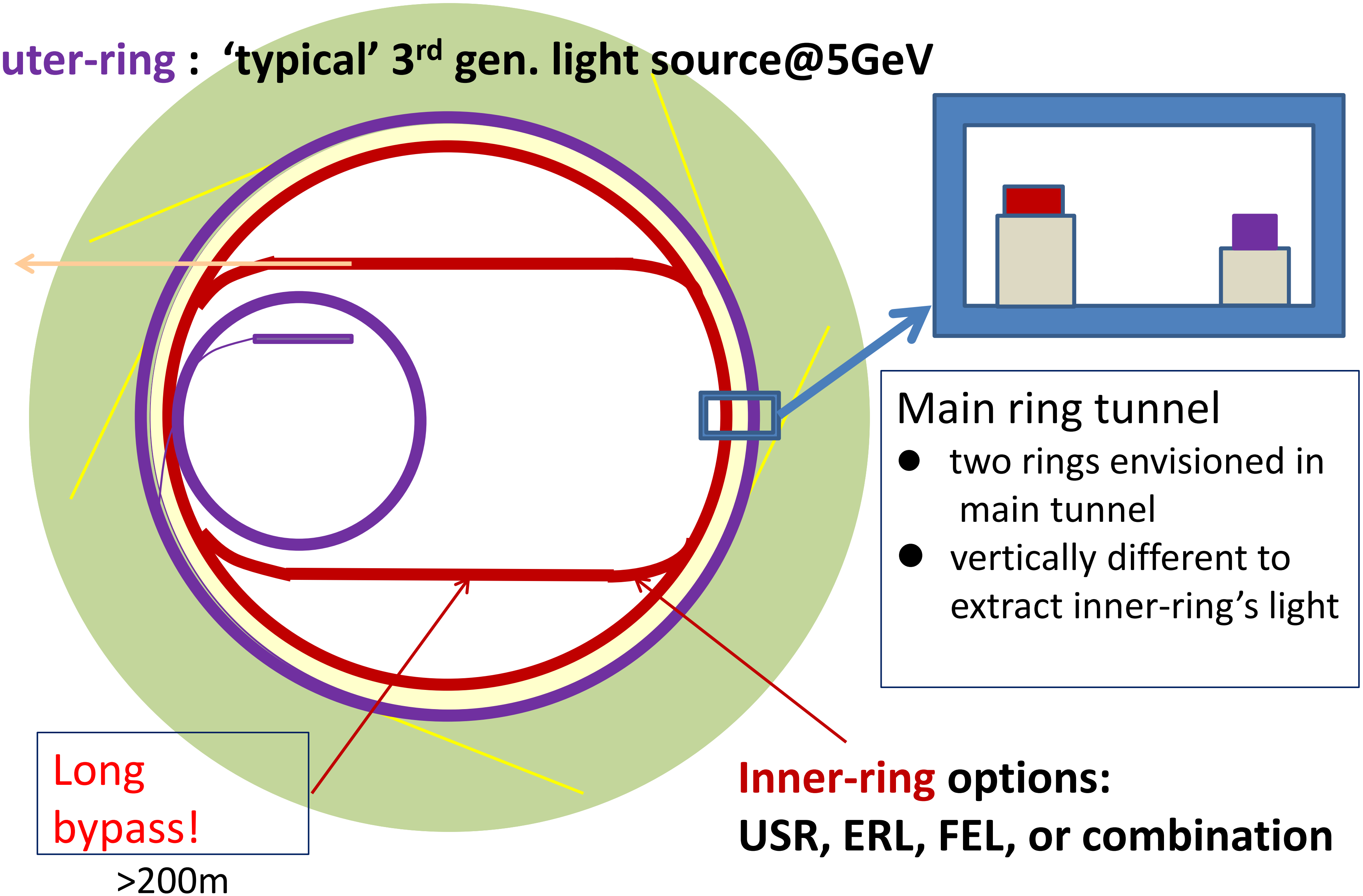
* Reference emittance here is 7 nmrad 　　78 ~ 23 pmrad

BAPS: Beijing Advanced Photon Source

- Key element for a newly formed research center (largest in CAS system)
- Plan to build in northeast Beijing (70km from IHEP)
- Day1: a typical 3rd light source (0.5nm@5 GeV)
- Next: USR,FEL or XERL, still open
- Building design needed very soon

Courtesy: J.Q. Wang, IHEP

Beijing Advanced Photon Source(BAPS) complex



IHEP-ERL Test Facility (35 MeV- 10 mA)

Purpose: Tech. preparations for 5 GeV XERL & XFEL

Features: Both ERL and FEL will share one SC linac.

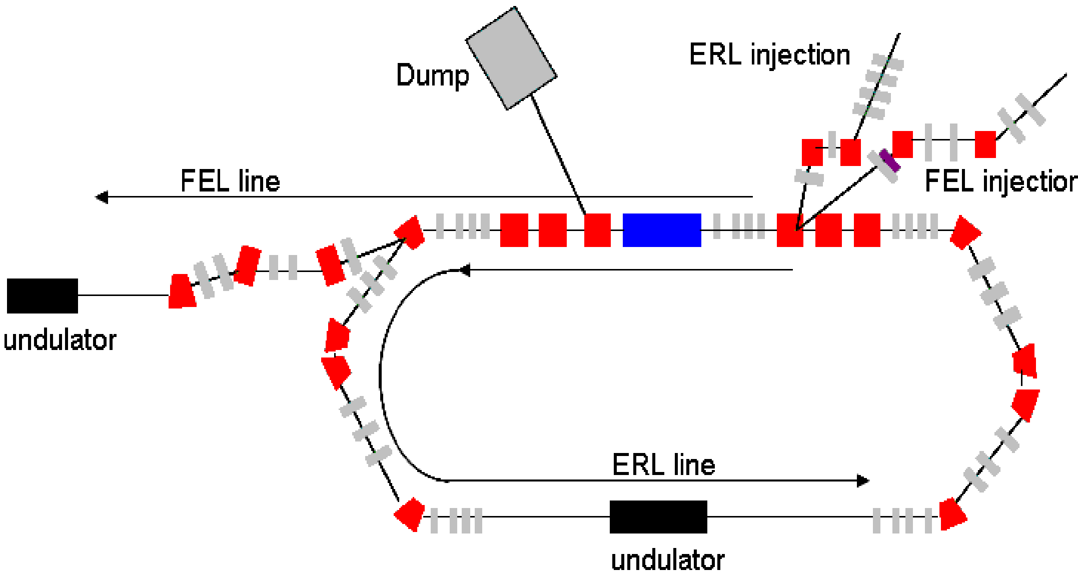
(3-beams are accelerated & decelerated at the different RF phase in the same linac, with 2 injectors for ERL and FEL)

Progress: Multi-beam physics are studied;

Conceptual design is ready;

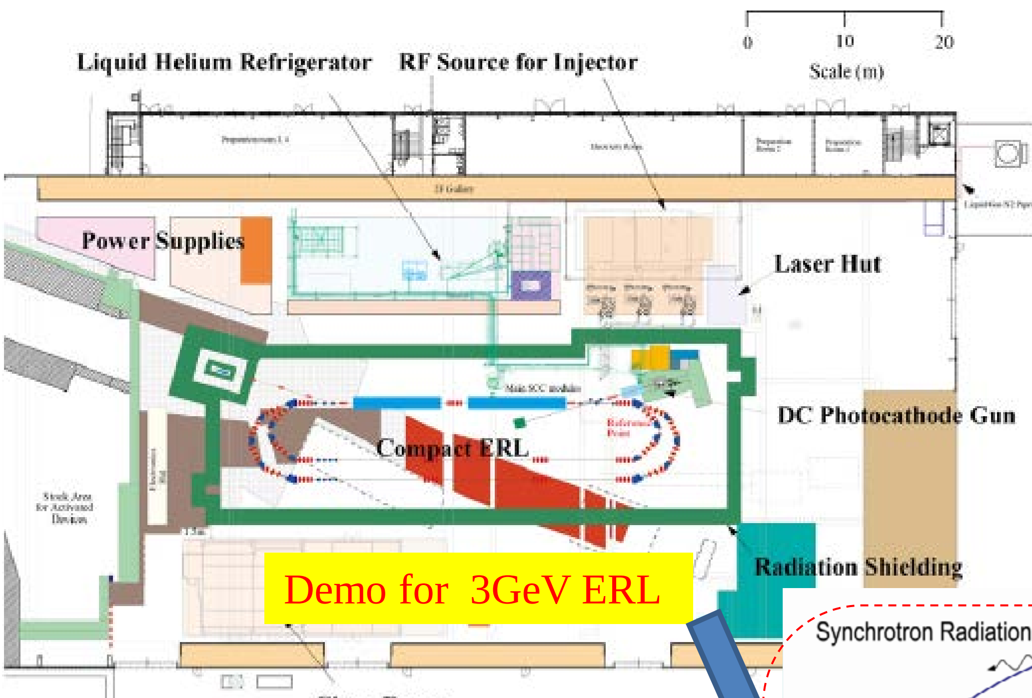
500keV DC gun is under construction.

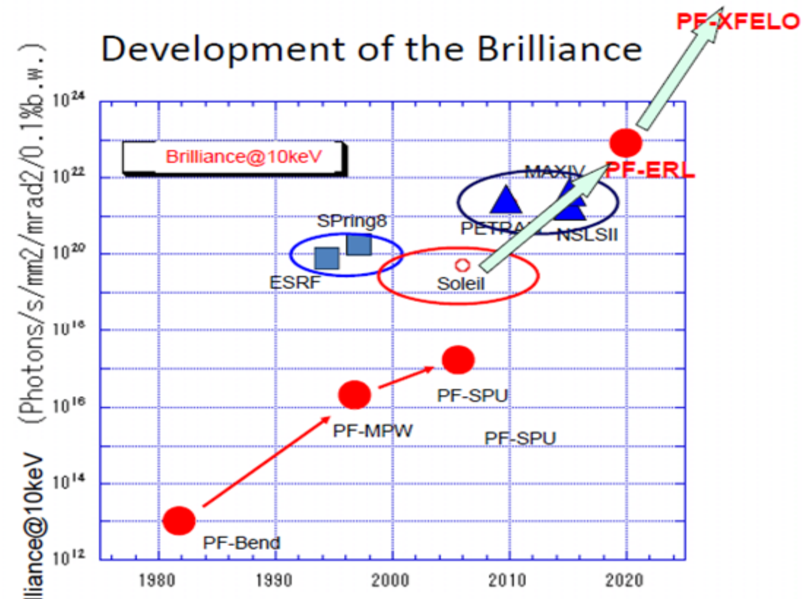
Courtesy: S.H. Wang, IHEP



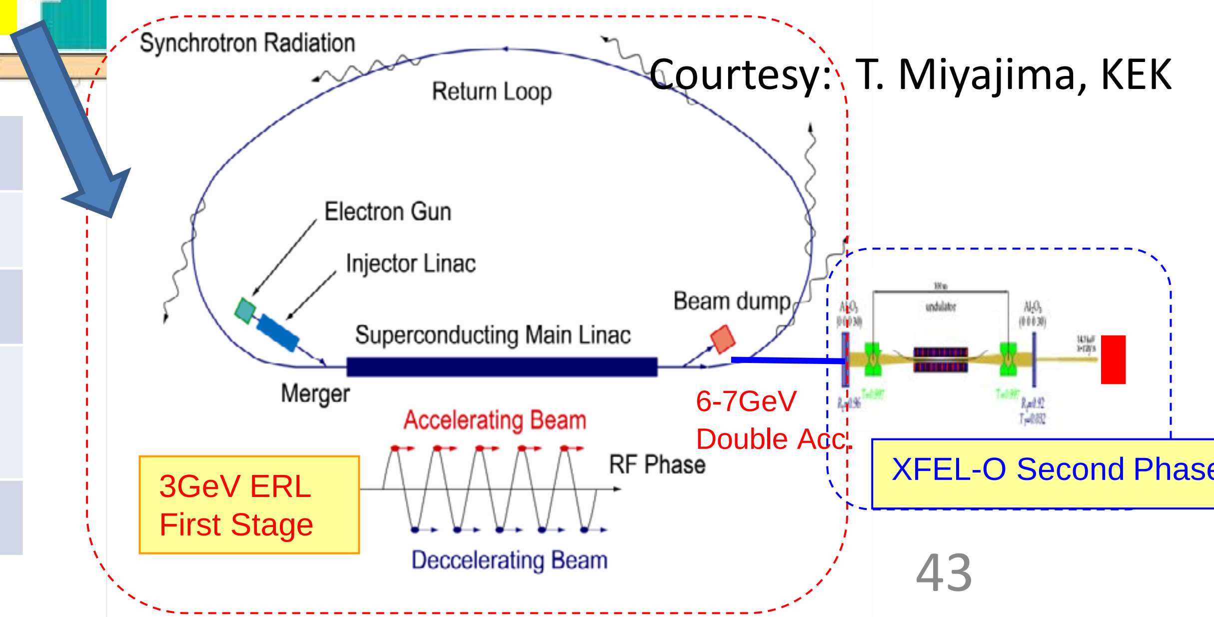
Parameters	ERL-beam	FEL-beam
Inj. Energy (MeV)	5	20
Max Energy (MeV)	35	50
Bunch Charge (pC)	77	100
Bunch spacing (ns)	0.77	93

cERL →3GeV ERL@ KEK





Courtesy: T. Miyajima, KEK



Injection energy	5- 10 MeV
Full energy	245 MeV
Electron charge	77 pC
Normalized emittance	< 1 mm-mrad
Bunch length	1-3 ps

Drivers for high gain FELs

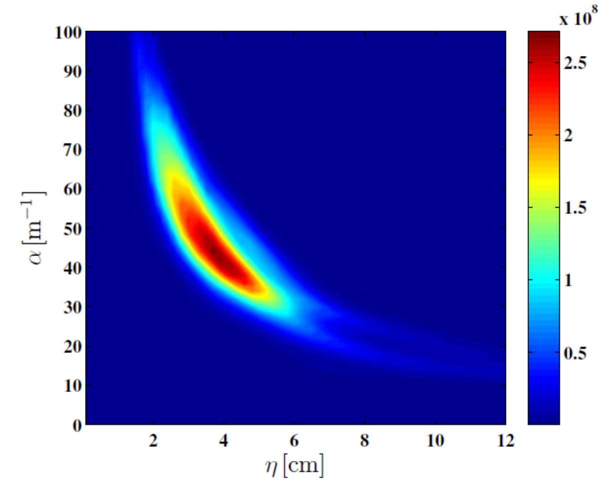
	Linac	LPA	ERL	Ring(USR)	Note
Beam Energy	~10 GeV	0.1-1 GeV	0.1~10	1~10 GeV	
Nor. Emit.	~0.1 (mm.mrad)	~0.1	~1	~1	USR
E. spread	1E-4	~1%	1E-4	0.5~1 E-3	TGU
Bunch charge	10-1000pC	10-100pC	100pC	0.5-5nC	
Bunch length	0.01-1 ps	0.01~0.1 ps	0.1~1 ps	**1~ 10 ps**	HC
Peak Current	0.3-5 kA	1-10 kA	~1kA	**~0.1 kA?**	
Rep. rate	100 Hz (warm) 10k-MHz（SC）	Laser dependent	~100MHz	kHz?	Damping needed
Reliability	OK	need work	trips?	OK	
Passes	single	single	1 to a few	multi	

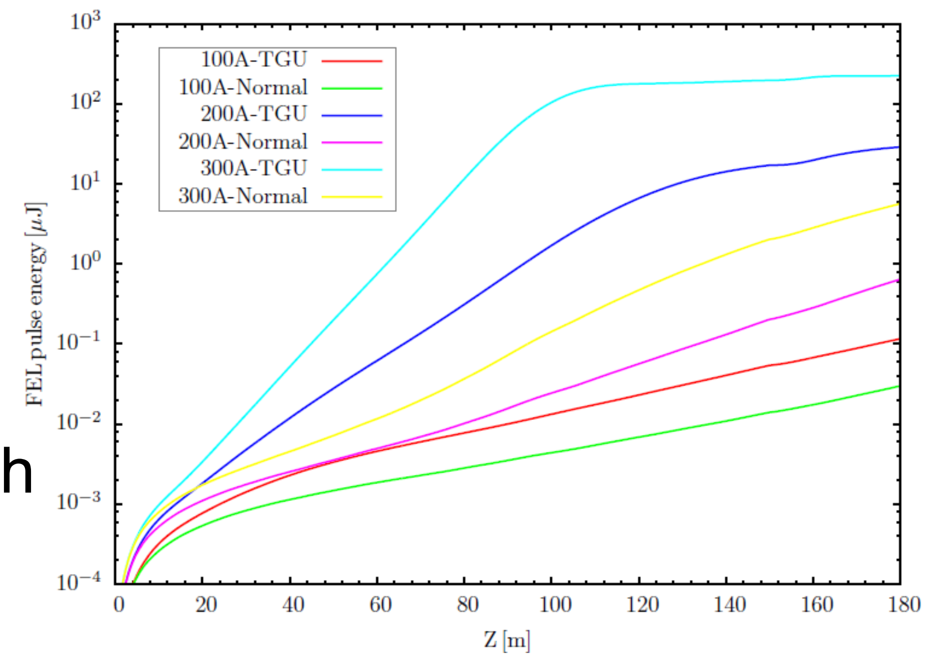
- **Ring-based FELs(high gain, x-ray) got momentum**
  - USR provides low emittance comparable to linac, e.g. Revol, IPAC13
  - TGU cures large energy spread in ring, Huang et al, PRL 109, 2012
  - Short bunch techniques enhance peak current, e.g. Muller, IPAC13
  - Long straights in large ring(PEP-X) or new ring(BAPS)

▷ Y. Cai, et al., An X-ray Free Electron Laser Driven by an Ultimate Storage Ring, SLAC-PUB-15380, 2013.

USR-FEL combination@BAPS

Parameter	*Symbol*	*Value*	*Unit*
Peak Current	I_p	300	A
Undulator Period	λ_u	0.03	m
Undulator Parameter	K_0	1.61	
Undulaotr Length	L_u	180	m
Average beta x	$\bar{\beta}_x$	70	m
Average beta y	$\bar{\beta}_y$	20	m
Transverse Dispersion	η	4.5	cm
Transverse Gradient	α	40	m^{-1}
FEL wavelength	λ_s	1.0	nm
FEL peak power	P_{pk}	~ 200	MW
FEL pulse energy	W_{FEL}	~ 200	μJ
FEL flux	F_{FEL}	1×10^{12}	#/pulse





- One bypass used (+1km arc)
- FEL gain is large enough as PEP-x case
- Seeded FEL benefits more with TGU

Courtesy: T. Zhang, SINAP

Summary

- Synchrotron light sources facilities have covered all major regions in Asia and Oceania and made tremendous contributions to area's scientific development.

- High-gain Free Electron Lasers are starting to serve the scientific community with high brilliance and short pulse from VUV to hard X-ray wavelengths. There are much more potential to explore.

- New light source projects feature better performance in all aspects, brilliance/coherence/short pulse/multi-user/polarization, etc. Study on novel schemes and technologies continues, in collaboration with worldwide efforts.

TAC
CANDLE
ILSF
SESAME
Indus-I(II)
SPS
SSLS
BSRF
BAPS
HLS(II)
SSRF
TLS
TPS
PLS(II)
NewSABARU
Spring-8 (II)
SLiT-J
KEK-PF(KEK-PF-AR)
AURORA
CJSRF
UVSOR
HiSOR
SAGA-LS
Austr. Syn.
Thank you!
Operating
Constructing
Designing
Kazakhstan
Mongolia
Uzbekistan
Kyrgyzstan
Turkmenistan
China
South Korea
Japan
Syria
Iraq
Iran
Afghanistan
Pakistan
Nepal
India
Saudi Arabia
Myanmar (Burma)
Thailand
Vietnam
Philippines
Yemen
Ethiopia
Somalia
Malaysia
Indonesia
Papua New Guinea
Madagascar
Australia
East China Sea
South China Sea
Bay of Bengal
Andaman Sea
Arabian Sea
Gulf of Aden
Gulf of Thailand
Laccadive Sea
Banda Sea
Arafura Sea
Solomon Sea
Coral Sea
Indian Ocean