Asian Accelerator Developments & Upcoming Construction Projects

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Outlines

- Introduction
- Light Source Accelerators
- Colliders
- Proton and Heavy Ion Accelerators
- Summary

This overview focuses mainly on the accelerator facilities for scientific research

Acknowledgement

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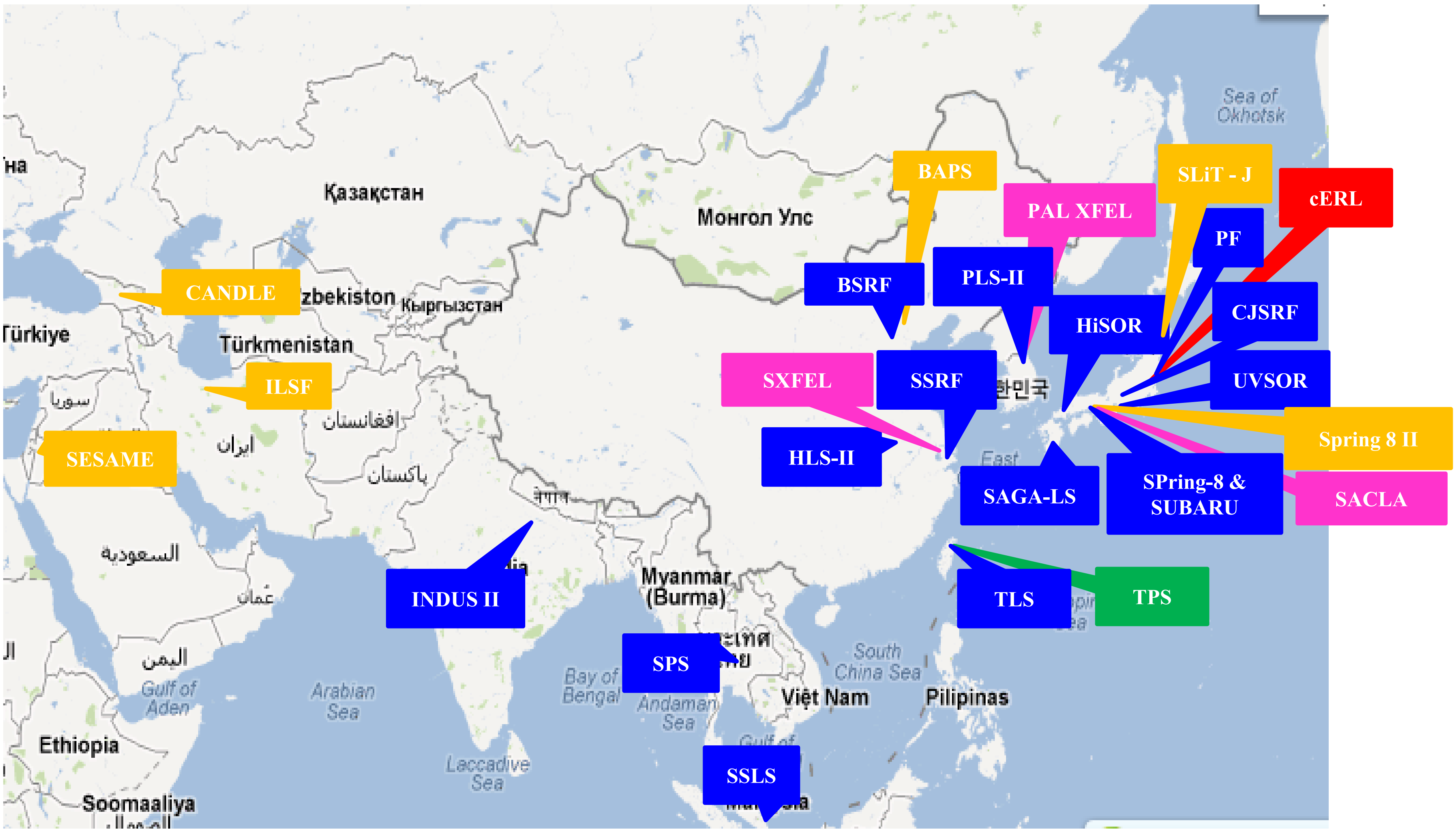
Introduction

- Asia is one of most active contents to develop particle accelerators
- National institutes and universities as well as high tech companies are the main builders
- The fields accelerators served extend from fundamental research to industrial application and medical treatment
- Accelerator facility became one of the most important lager scale scientific infrastructure

Light Source Accelerator Facilities

- Synchrotron Radiation Facilities
- Free Electron Lasers
- Energy Recovery Linacs
- Thomson Scattering Sources
- THz and Ultra-low Emittance UED/UEM

Synchrotron Light Source, FEL &ERL



SR in operation | SR in commissioning | SR proposed | XFEL | ERL

Asian Light Sources in User Service

Facility	Location	Energy /GeV	Circumference /m	Emittance /nm.rad	Current /mA	Status	Open year
SPRING-8	Hyogo	8	1436	2.8	100	Operating	1997
SSRF	Shanghai	3.5	432	3.9	300	Operating	2009
PLS-II	Pohang	3	281.82	5.9	400	Operating	2012
Indus-II	Indore	2.5	172.5	58	300	Operating	2008
TLS	Hsinchu	1.5	120	25	240	Operating	1994
PF-AR	Tsukuba	6.5	377	293	60	Operating	1986
PF	Tsukuba	2.5	187	34.6	450	Operating	1982
BSRF	Beijing	2.5	240.4	76	250	Operating	1991
SABARU	Hyogo	1.5	118.7	38	500	Operating	1999
SAGA-LS	Tosu	1.4	75.6	25	300	Operating	2006
CJSRF	Nagoya	1.2	72	53	300	Operating	2012
SPS	Bangkok	1.2	81.3	41	100	Operating	2005
HLS-II	Hefei	0.8	66.13	<40	300	Operating	2015
UVSOR	Okazaki	0.75	53.2	17	300	Operating	1984
AURORA	Kusatsu	0.7	10.97	2400	300	Operating	1995
SSLS	Singapore	0.7	10.8	500	400	Operating	2001
HiSOR	Hiroshima	0.7	22	400	300	Operating	1997

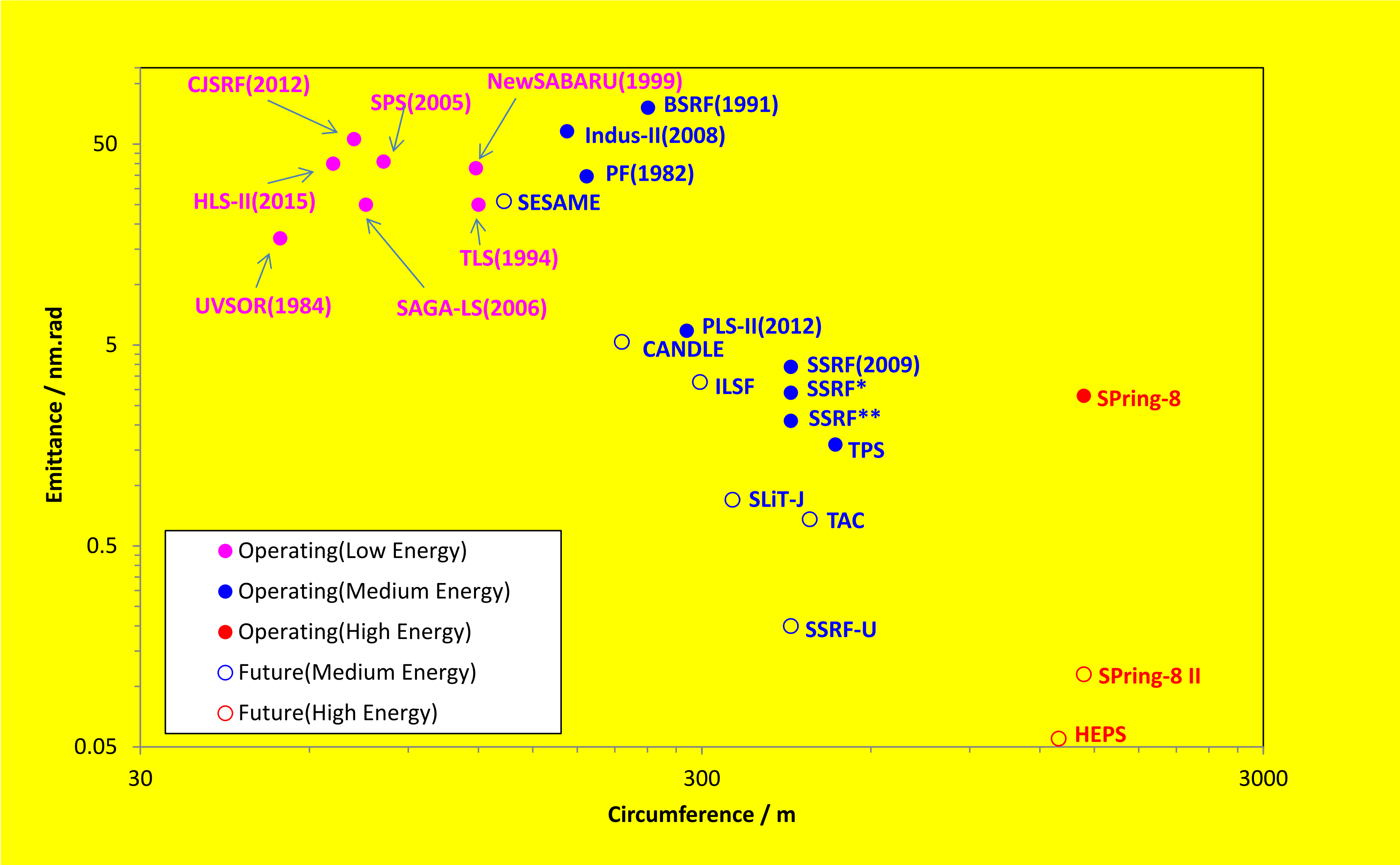
Examples: Synchrotron Light Sources in Asia

New Light Sources or Upgrades in Construction and Advanced Planning

Facility	Location	Energy /GeV	Circumference /m	Emittance /nm.rad	Current /mA	Status	Open year
TPS	Hsinchu	3	518.4	1.6	500	Commissioning	2016*
SESAME	Amman	2.5	133.2	26	400	Constructing	2017*
ILSF	Tehran	3	297.6	3.278	400	R&D	2018*
CANDLE	Armenia	3	216	5.19	350	R&D	2018*
HEPS	Beijing	6	1295.6	0.055	200	Designing	
SPRING-8 II	Hyogo	6	1435.95	0.115	100	Designing	
SSRF-U	Shanghai	3	432	0.20	300	Designing	
TAC	Ankara	3	466.8	0.68	500	Designing	
SLiT-J	Sendai	3	339.92	0.85	400	Designing	

- Synchrotron light source enters a new phase with MBA lattice to approach diffraction limited storage ring regime.
- Emittance will be reduced by a factor of 10 to 100

Energy, Emittance and Circumference



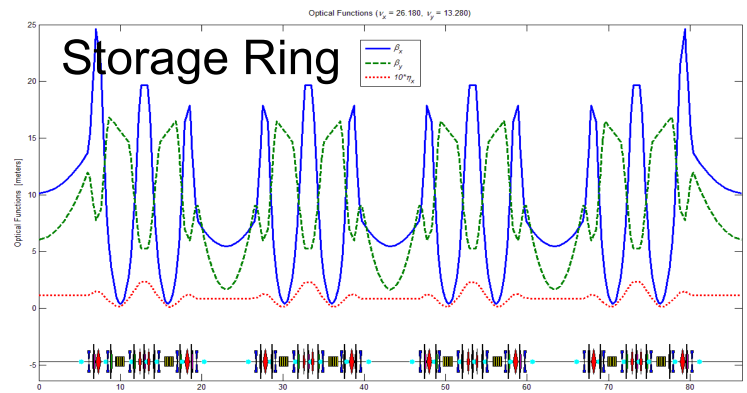
* Low emittance mode @ 3.5GeV

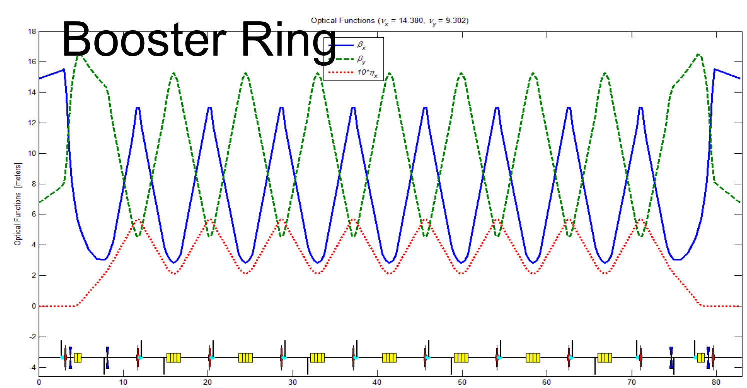
** Low emittance mode @ 3.0GeV

Taiwan Photon Source – in Commissioning

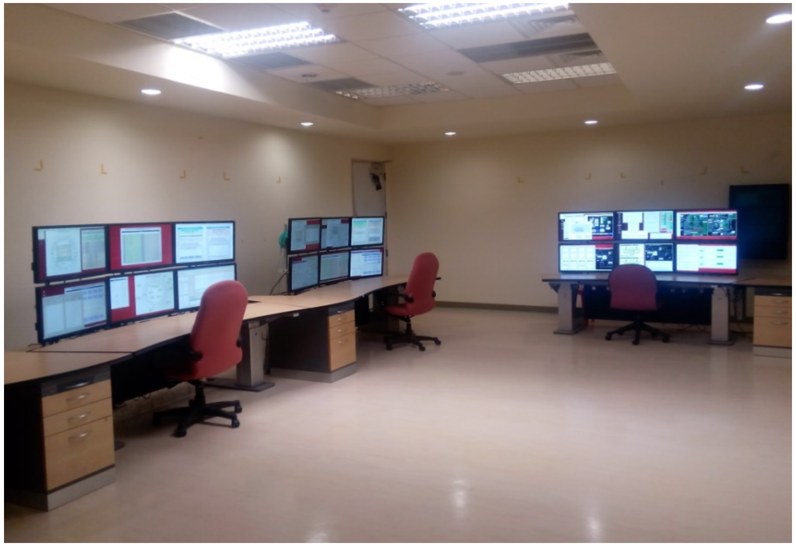
Energy	3 GeV (maximum 3.3 GeV)
Current	500 mA at 3 GeV (Top-up injection)
SR circumference	518.4 m ($h = 864 = 2^5 \cdot 3^3$, dia.= 165.0 m)
BR circumference	496.8 m ($h = 828 = 2^2 \cdot 3^2 \cdot 23$, dia.= 158.1 m)
Lattice	24-cell DBA
Straight sections	12 m x 6 (σ_v = 12 μm, σ_h = 160 μm) 7 m x 18 (σ_v = 5 μm, σ_h = 120 μm)

Storage Ring Circumference (m)	518.4
Energy (GeV)	3.0
Beam current (mA)	500
Natural emittance (nm-rad)	1.6
Straight sections (m)	12 (x6) + 7 (x18)
Radiofrequency (MHz)	499.654
Harmonic number	864
RF voltage (MV)	3.5
Energy loss per turn (dipole) (keV)	852.7
Betatron tune	26.18 /13.28
Momentum compaction (α_1, α_2)	2.4×10^{-4}, 2.1×10^{-3}
Natural energy spread	8.86×10^{-4}
Damping time (ms)	12.20 / 12.17 / 6.08
Natural chromaticity	-75 / -26
Synchrotron tune	0.00609
Bunch length (mm)	2.86



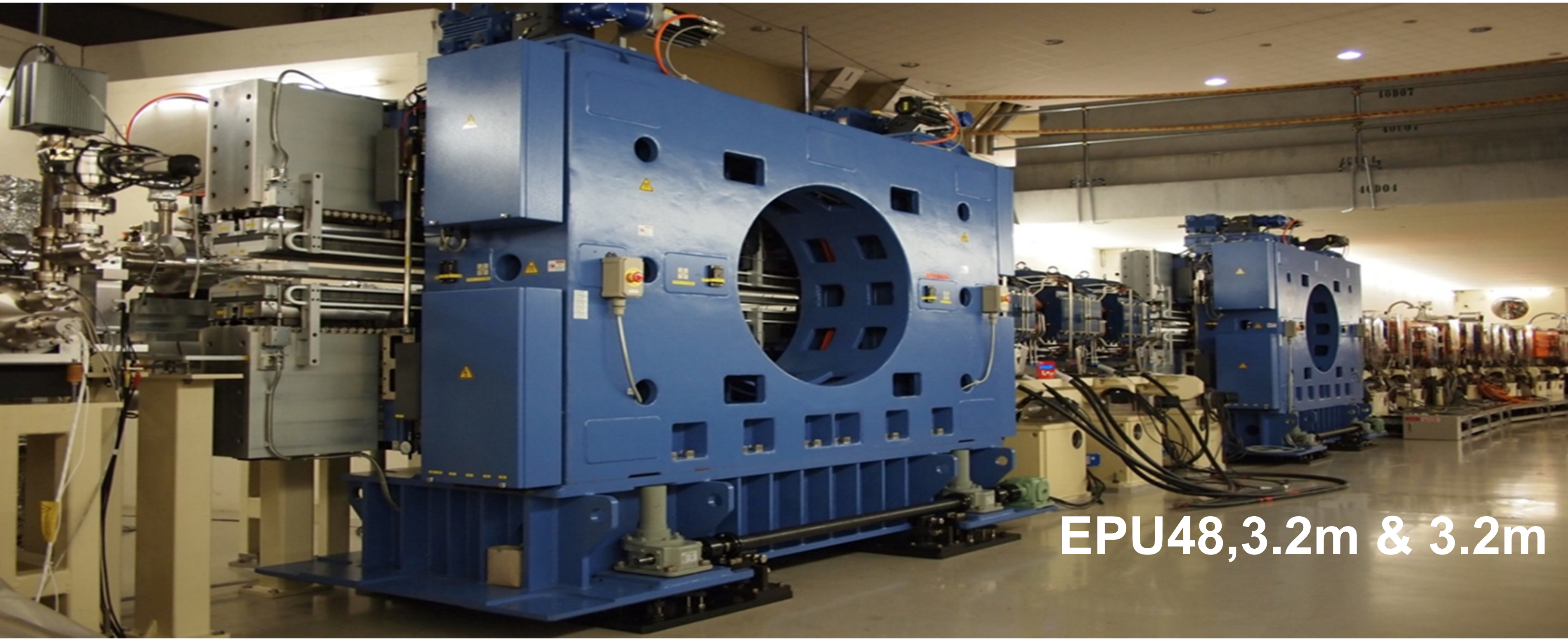


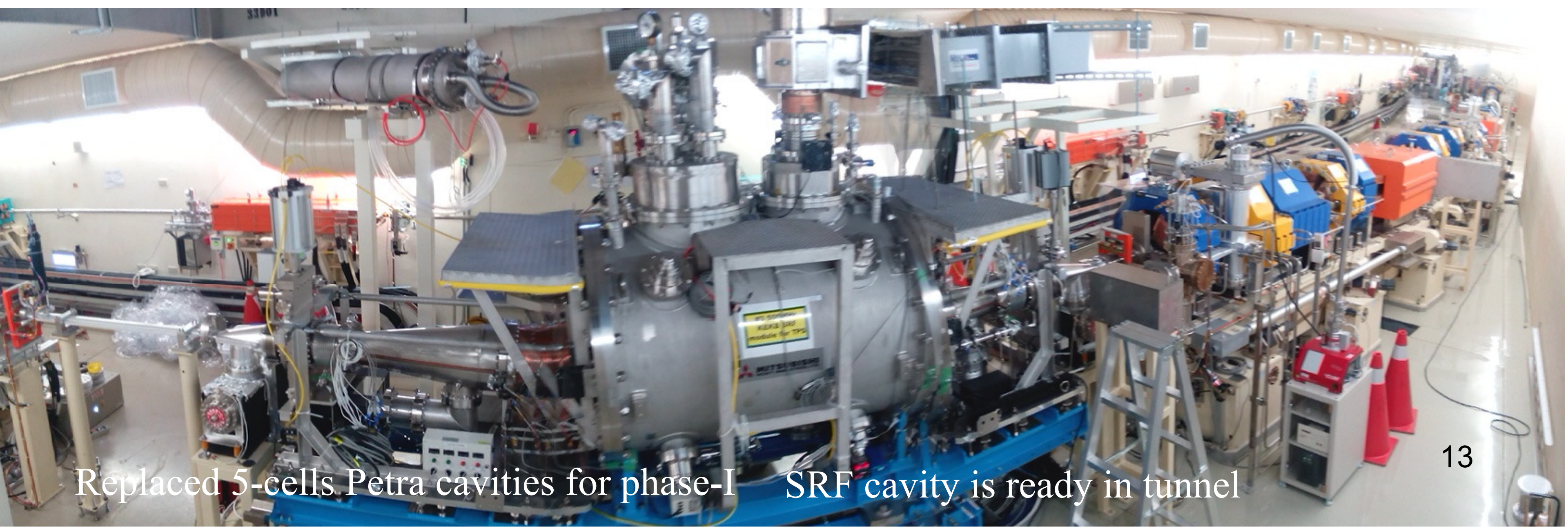
TPS Ring and Experimental area



TPS/TLS control room

Tunnel for accelerator components


EPU48,3.2m & 3.2m


Replaced 5-cells Petra cavities for phase-I
SRF cavity is ready in tunnel

HLS-II： An Upgrade Project

➢Construct a new injector and a new storage ring

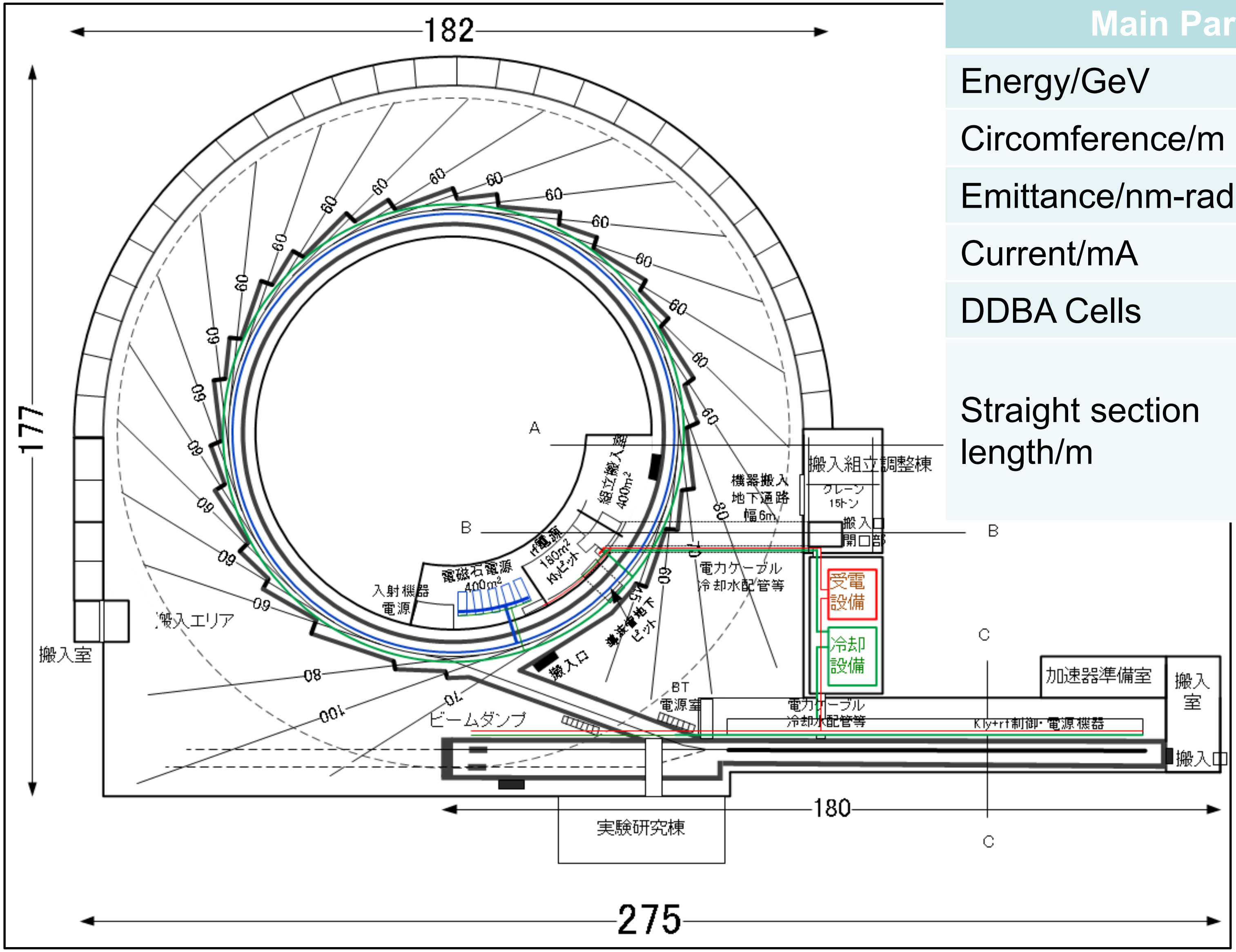
•Increase 4 straight sections for installing more IDs

•Reduce emittance to Increase brightness substantially

•Build 800MeV linac for full energy (top-up) injection

•Build five new beamlines

SLiT-J Under Design



Main Parameters	
Energy/GeV	3.0
Circomference/m	339.92
Emittance/nm-rad	1.13
Current/mA	300
DDBA Cells	14
Straight section length/m	14X5.33 14X1.43

A High Energy Photon Source under R&D

(Next synchrotron light source in Beijing, China)

Beam energy E_0	6	GeV
Beam current I_0	200	mA
Circumference	**1295.6**	**m**
Horizontal damping partition number $J_x/J_y/J_z$	1.38/1./1.62	
Natural emittance	**55**	**pm**
Working point (x/y/z)	113.196/41.277/0.002 9	
Natural chromaticity (x/y)	-149.0/-128.2	
Number of 7BA achromats	**48**	
Number of low-beta **6-m** ID sections	48	
Beta functions in low-beta straight section (x/y)	7.6/3.3	m
Damping times (x/y/z)	18.8/26.0/16.0	ms
Energy loss per turn, U_0	1.995	MeV
Energy spread σ_δ	0.000799	
Momentum compaction	3.67×10^{-5}	
RF voltage, V_{rf}	**6.0**	**MV**
RF frequency, f_{rf}	499.8	MHz
Harmonic number	2160	
Natural bunch length σ_z	2.07	mm

- **Excellent performance**
  - ✓ Brightness： 10^{21}
  - ✓ Hard X-ray： 300keV
  - ✓ Short pulse： 7 ps
- **More capabilities on the support of the scientific platform**

- **Promotion on**
  - ✓ nm level high brightness focusing spot
  - ✓ energy resolution at sub-meV
  - ✓ Time resolution at ps
  - ✓ Capacity on penetrating power
  - ✓ Combination on multi-purpose

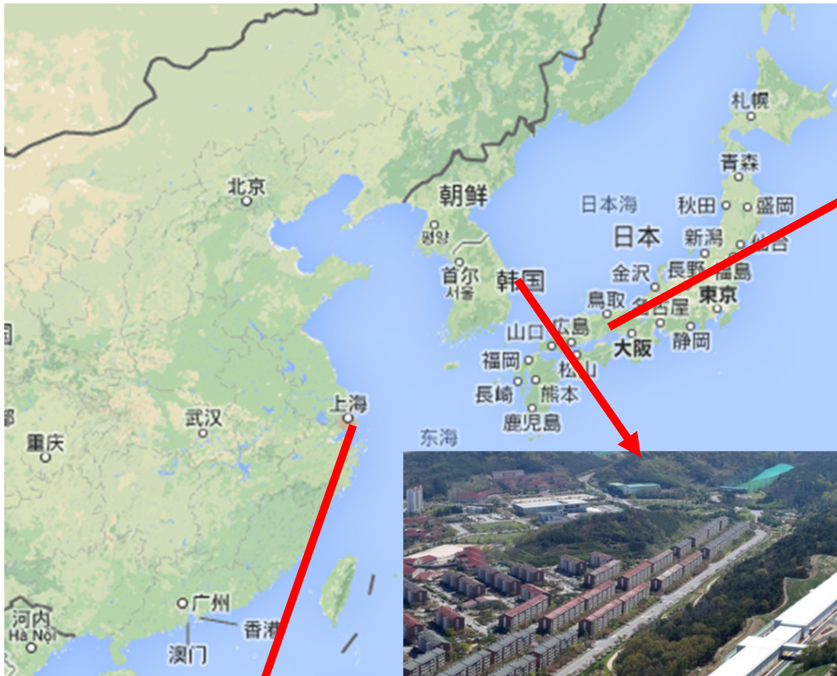
High Gain FEL Facilities in Asia

HG FEL	Location	E/GeV	Type	L/m	Wav/nm	RP-Hz	Driver	FEL-type	St	Lasing
SCSS	Japan	0.3	T,U	50	50	60	Linac(c)	SASE,DS	O	2006
SDUV	China	0.2	T	65	150-250	10	Linac(s)	seeded	O	2008
SACLA	Japan	8.0	U	750	0.08 -0.8	60	Linac(c)	SASE, SS	O	2011
PAL-XFEL	Korea	10.0	U	1.1k	0.1-4	100	Linac (s)	SASE,SS	C	2016
DCLS	China	0.3	U	150	50-150	50	Linac (s)	seeded	C	2017
SXFEL	China	1.0	T-U	300	9(2)	10	Linac (c)	seeded	C	2017

Low Gain FEL Operational Facilities in Asia

Facility	Country	Beam energy (MeV)	Test/User	Wavelength (μm)	Rep. rate (Macro-pulse)	Driver	Operation mode	St	Lasing
iFEL	Japan	165/20	U	0.28-20	1-10	Linac(S)	Oscilator	O	2000
FEL-TUS	Japan	40/10	U	5-14/ 300-1000	5	Linac(S)	Oscilator	O	2000
KAERI FIR FEL	Korea	7	U	100-300	0.6-10	Microtron	Oscilator	O	1999
BFEL	China	30	U	7-19	3.125	Linac(S)	Oscilator		1993

XFEL Facilities in Asia



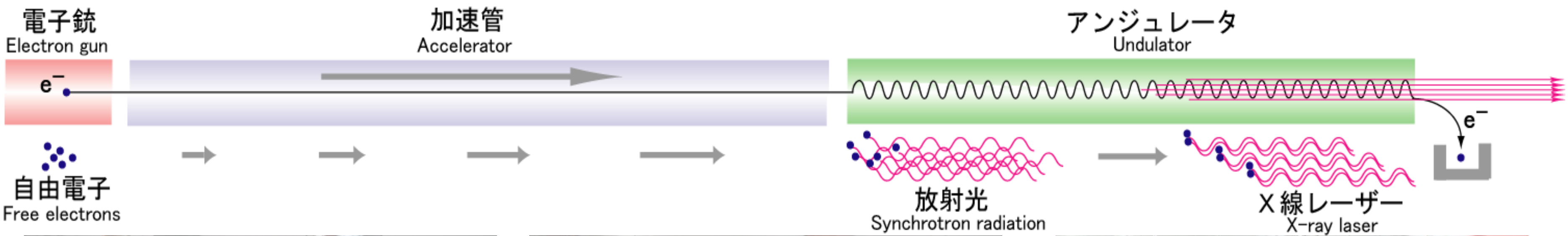
SACLA 2011
8.5 GeV, 0.75km

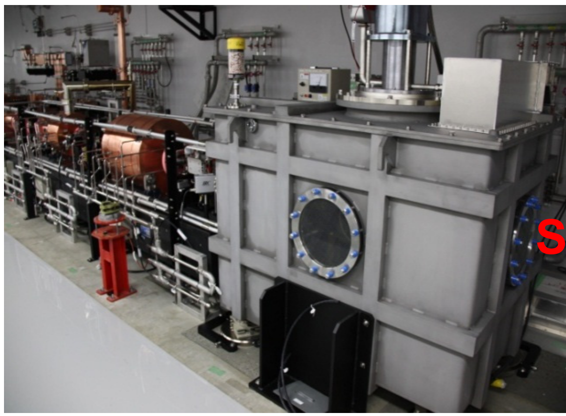
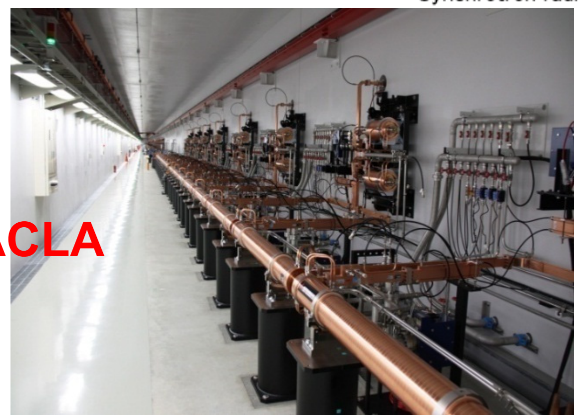
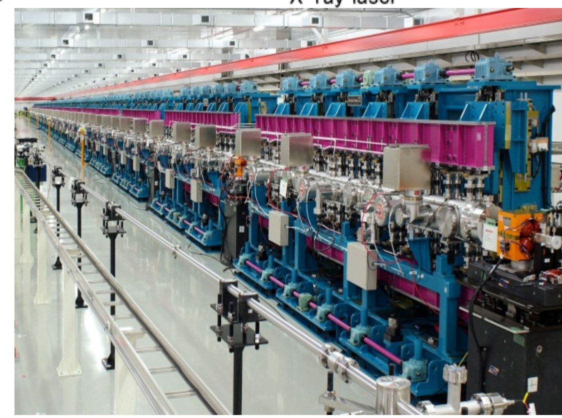
PAL XFEL 2016
10 GeV, 1.1km

SXFEL 2018
1.5 GeV, 0.3km

Dalian Coherent Light Source (DCLS)

SACLA and PAL-XFEL Accelerators



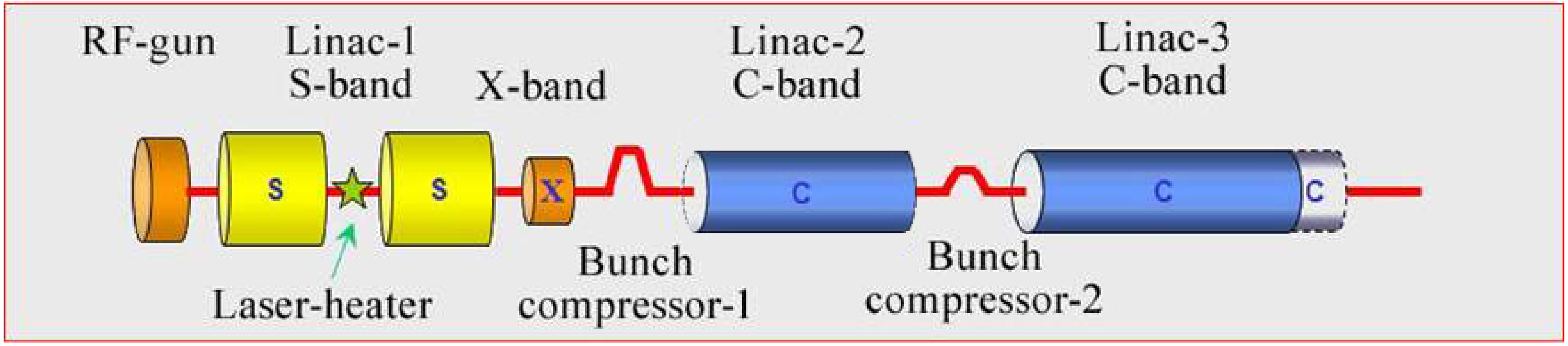




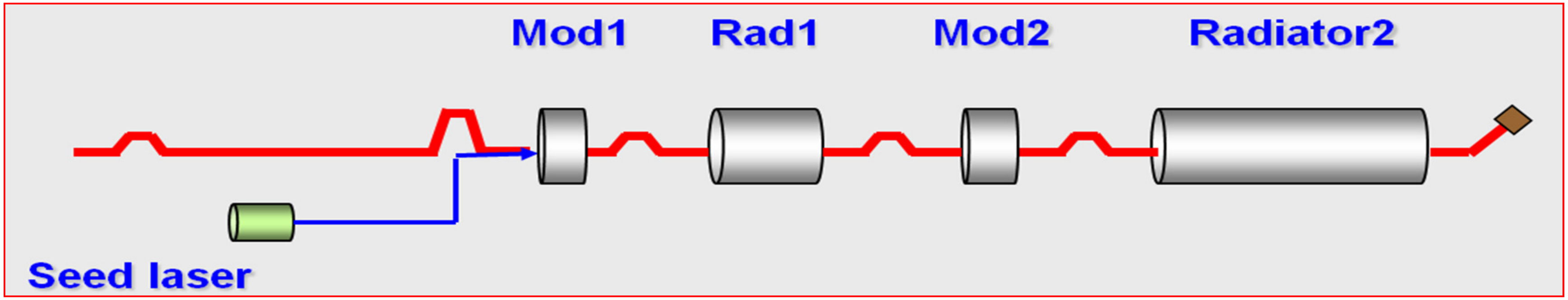
SACLA


PAL-XFEL

Shanghai soft x-ray free-electron laser (SXFEL)

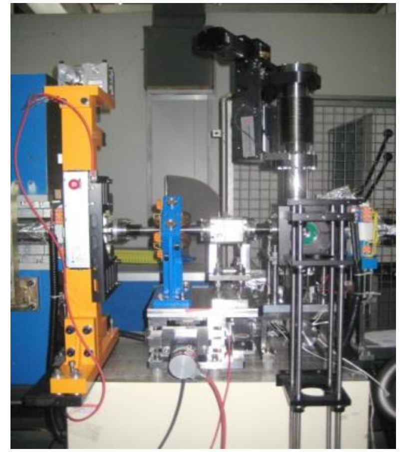
- An XFEL test facility, two-stage cascading seeded FELs;
- located in the SSRF campus, closing to its synchrotron;
- The SXFEL groundbreaking was made at the end of 2014, and first lasing of the SXFEL is expected in 2017.



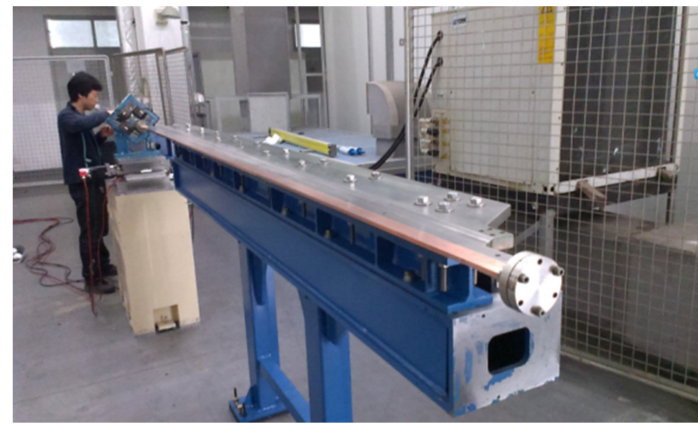


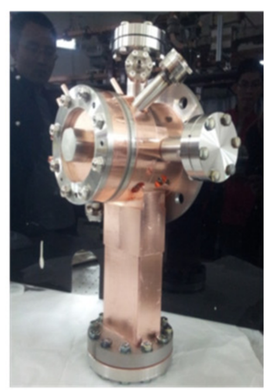
Prototypes:

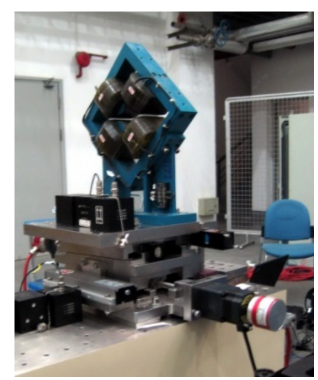
- S-band RF Gun
- C-band RF structure and pulse compressor
- X-band deflecting structure
- 3m Undulator U20
- Small gap vacuum chamber
- Cavity BPM
- Synchronizing system





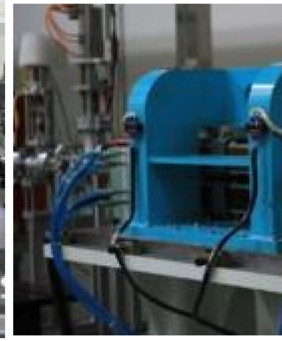


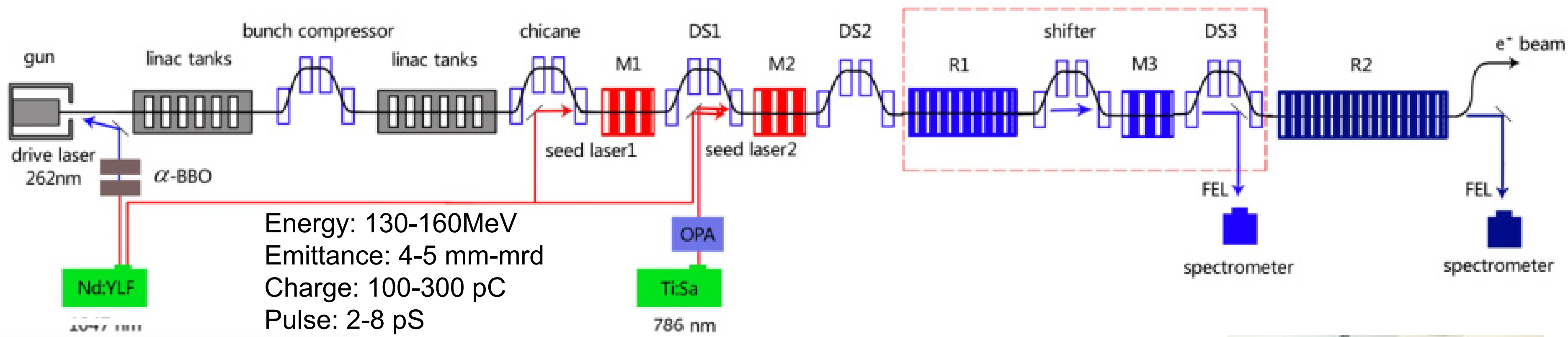




SDUV-FEL for HGHG and EEHG



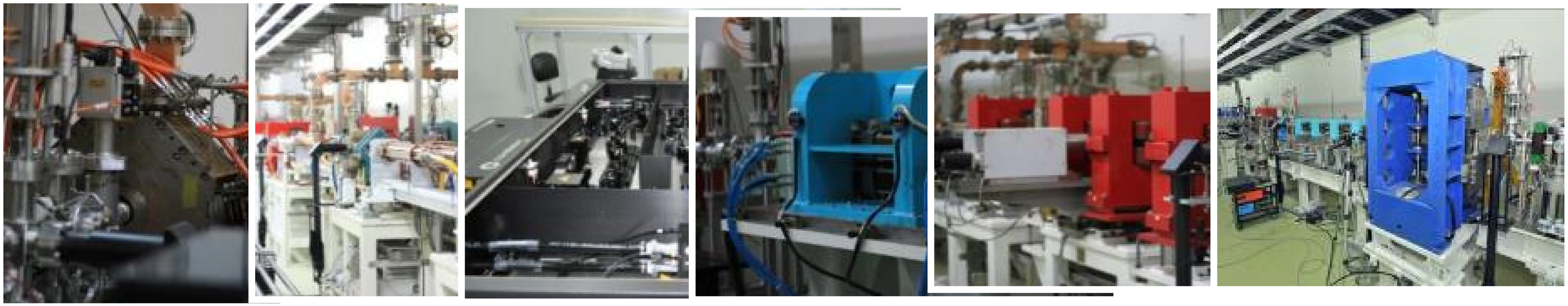


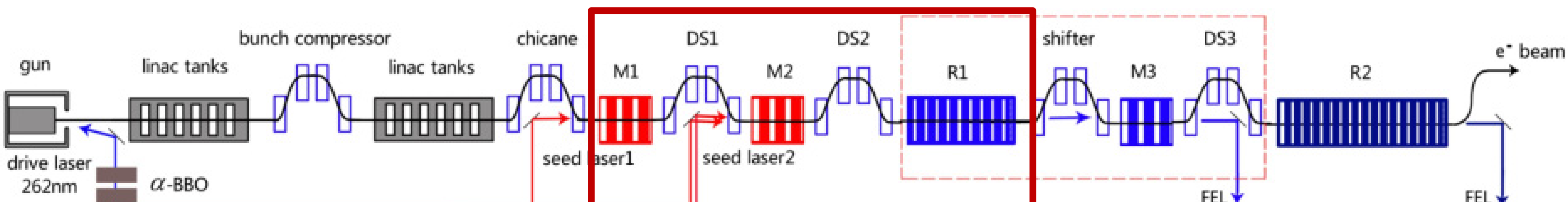
Energy: 130-160MeV
Emittance: 4-5 mm-mrd
Charge: 100-300 pC
Pulse: 2-8 pS





SDUV-FEL for HGHG and EEHG





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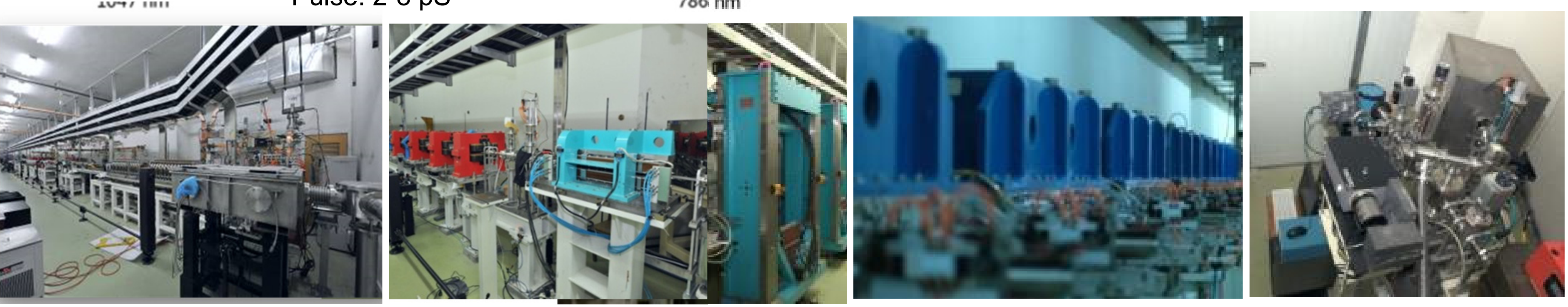

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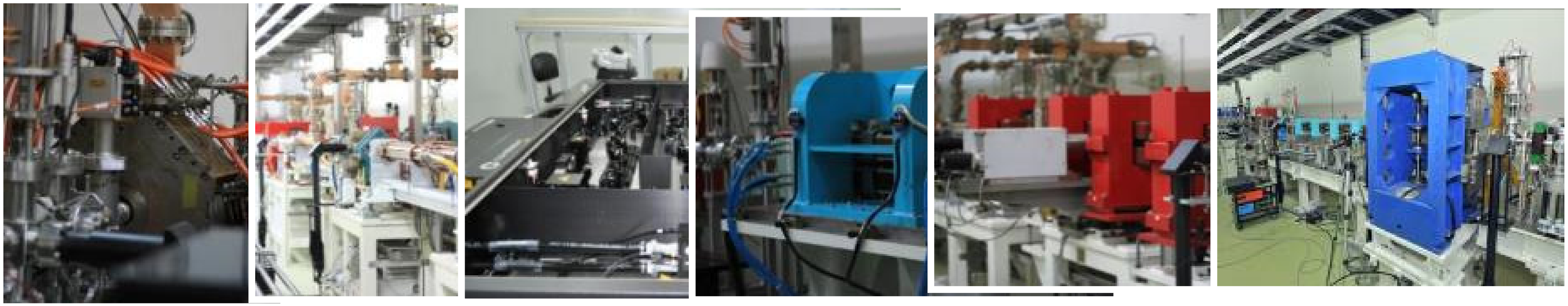

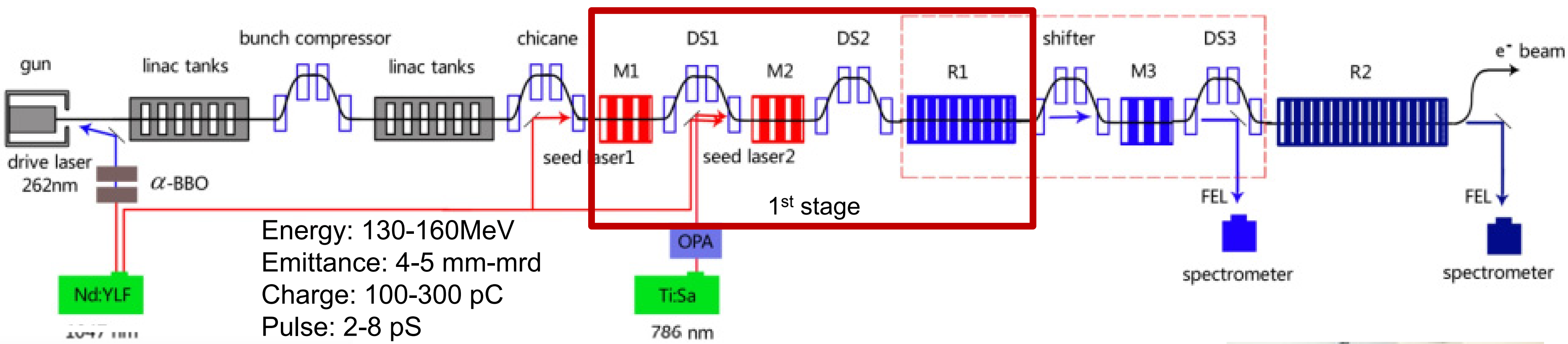

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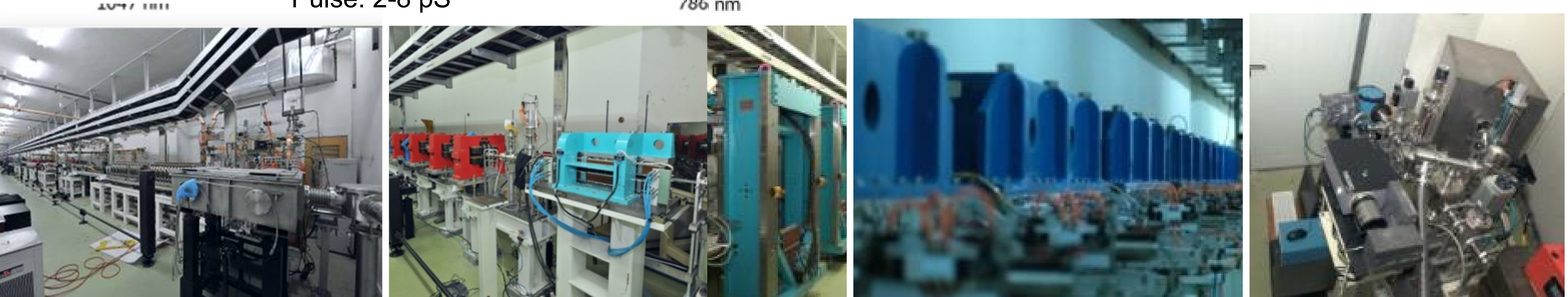

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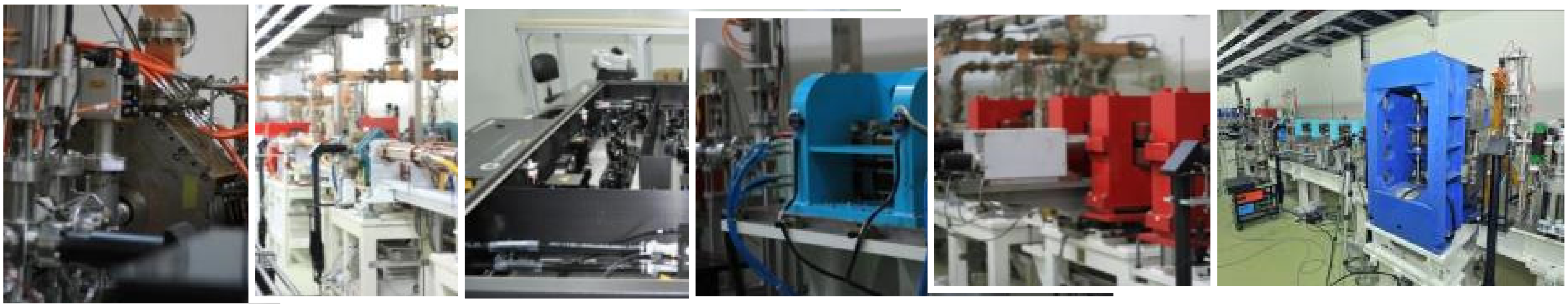

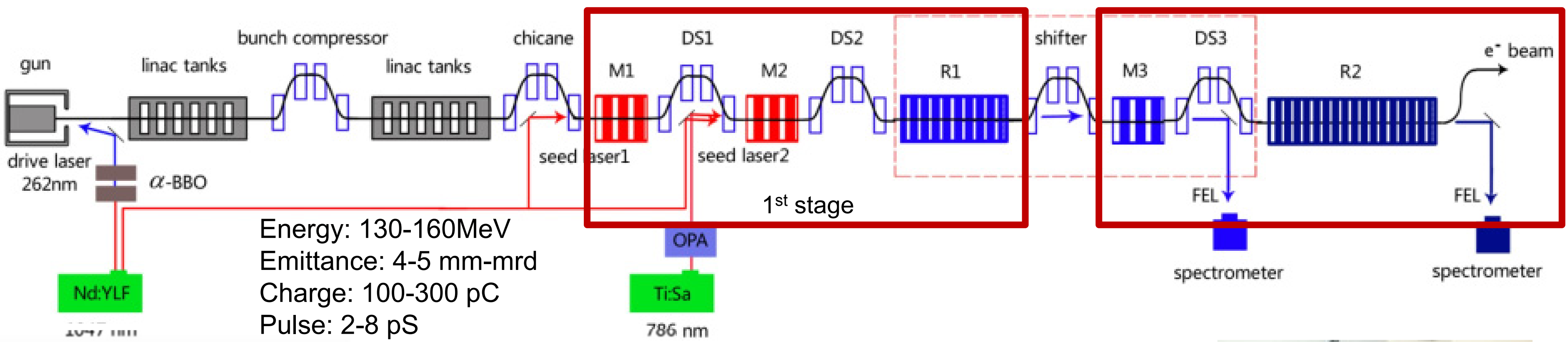

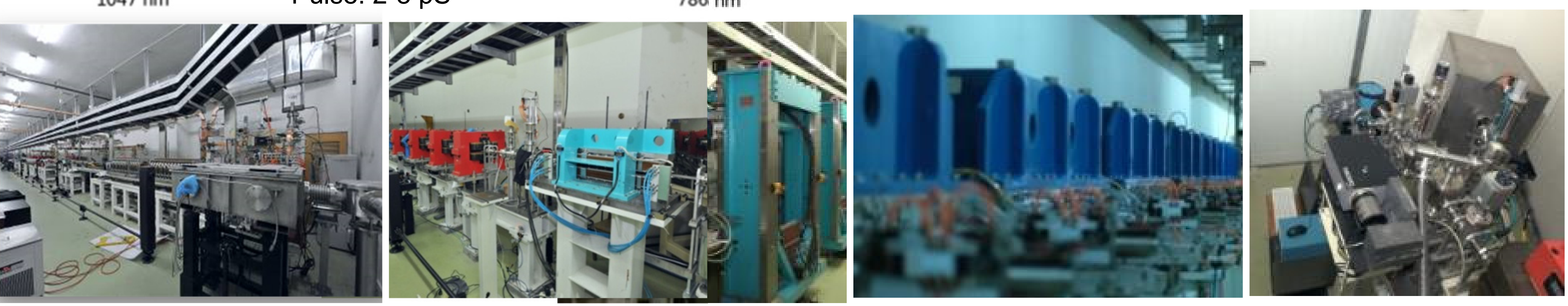

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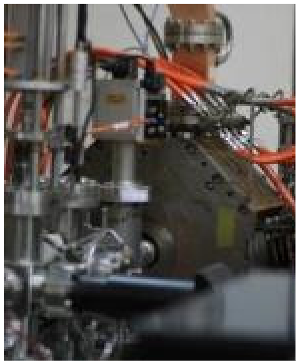
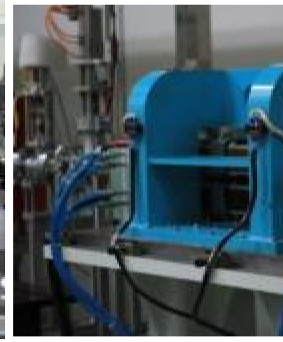
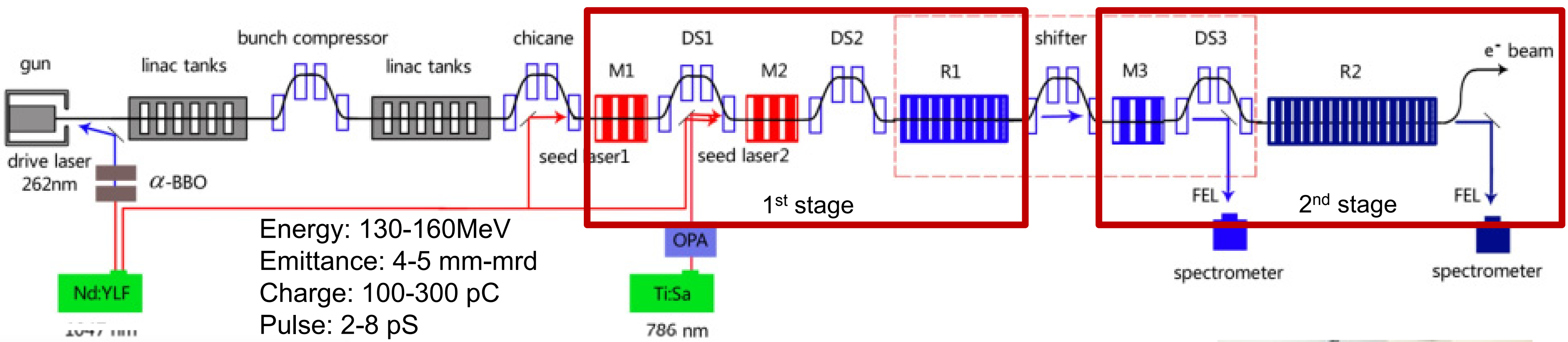


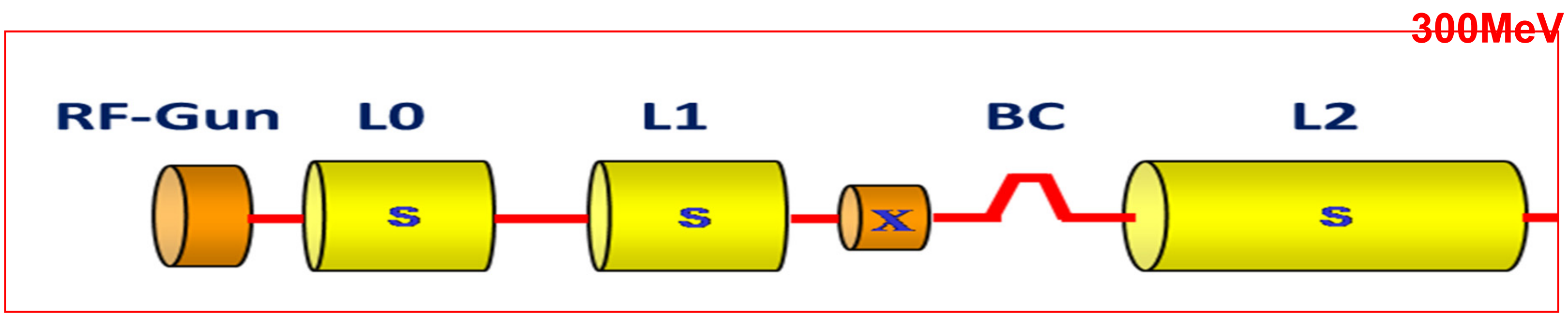


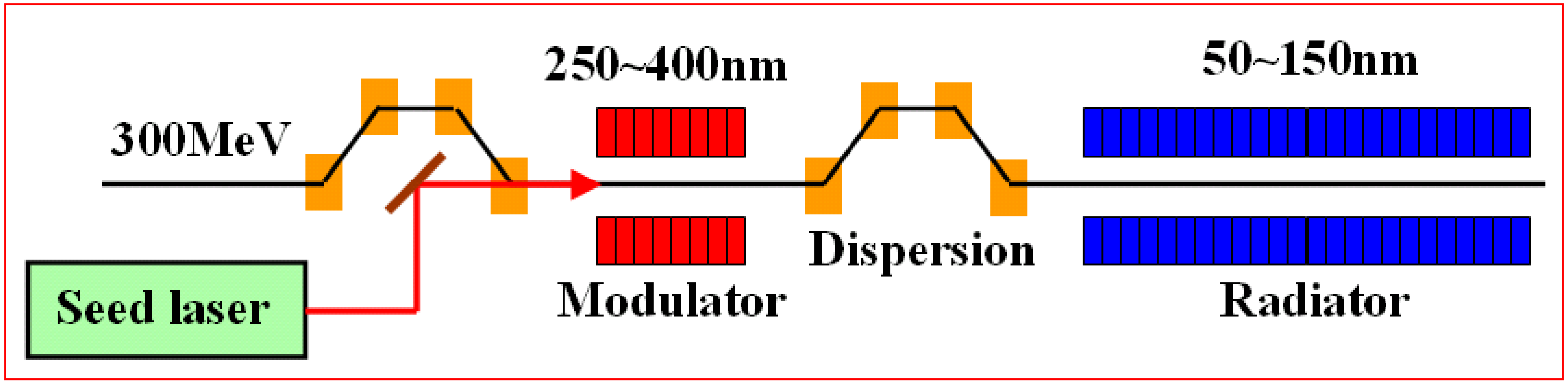
Energy: 130-160MeV
Emittance: 4-5 mm-mrd
Charge: 100-300 pC
Pulse: 2-8 pS




Dalian Coherent Light Source (EUV-FEL)

- Seeded FEL(HGHG), 50-150nm tunable, 50Hz rep-rate.
- Full coherence, fs-ps pulse lengths, GW peak power
- Scheduled for 2012-2016, in parallel to SXFEL, similar technology, funded by NSFC





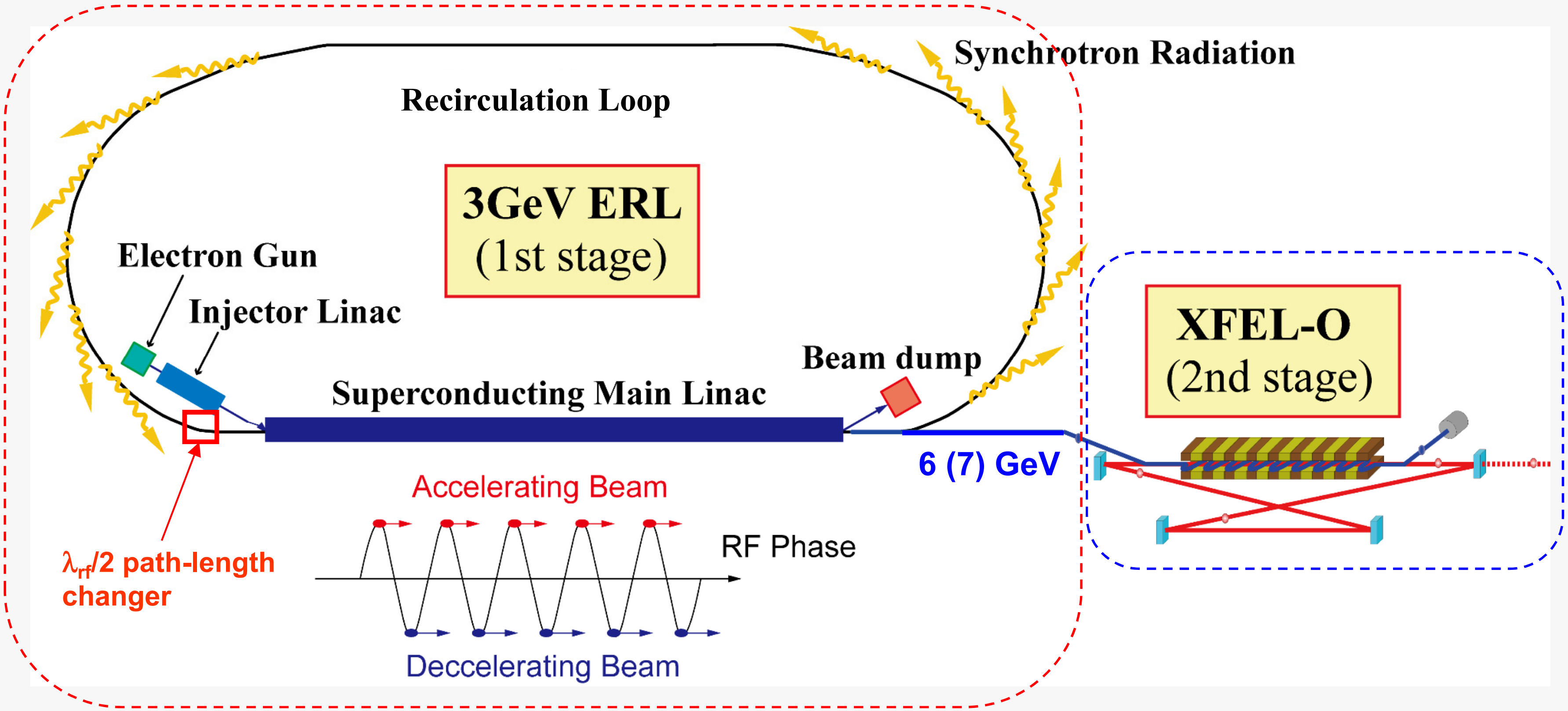
Future Plan: ERL Light Source Project at KEK

Staged plan:

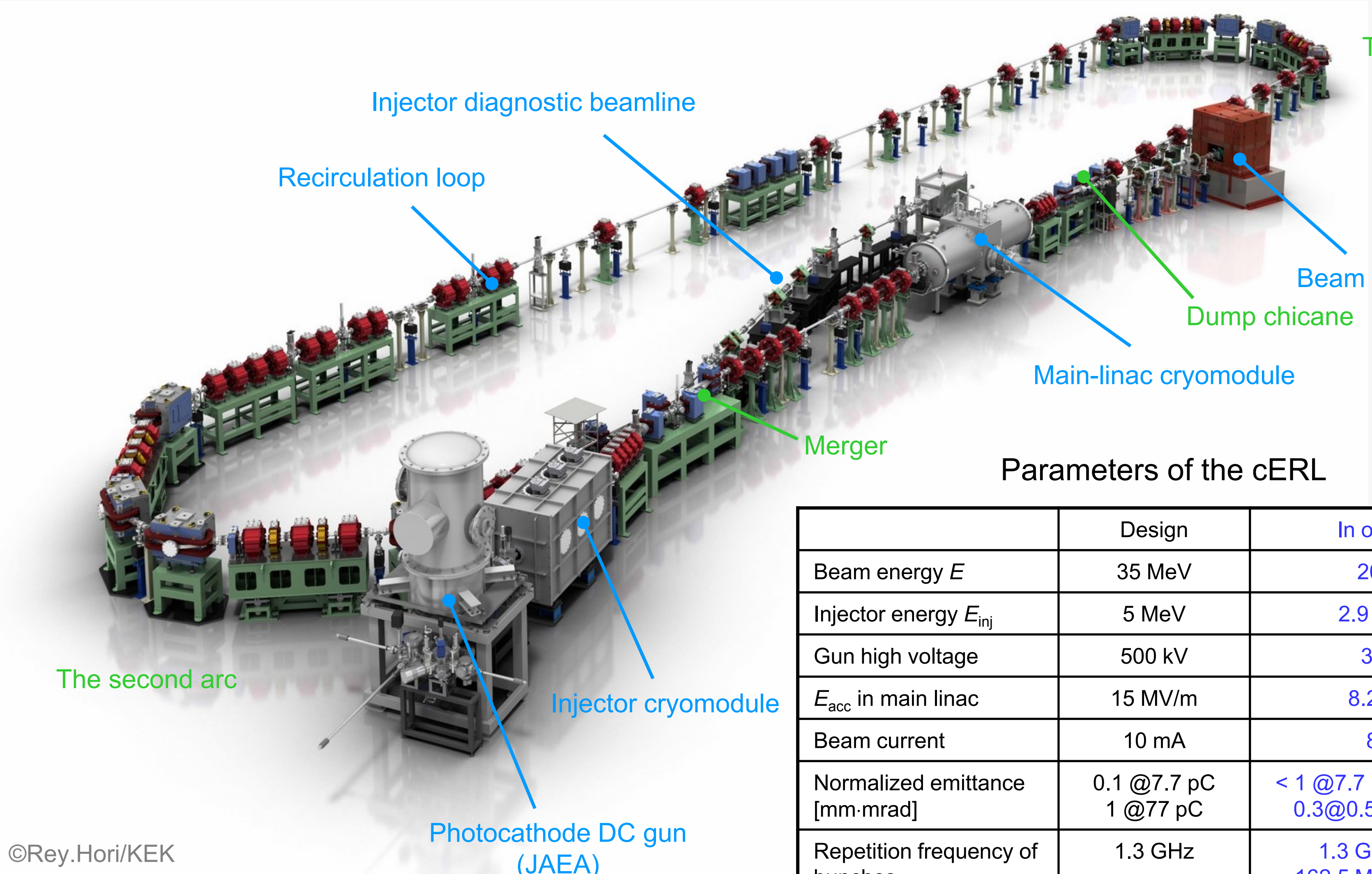
① 3-GeV ERL as synchrotron light source

② 6-7 GeV XFEL Oscillator (XFEL-O)

RF frequency: 1.3 GHz
Beam current : 10-100 mA
Bunch charge: 7.7-77 pC
Normalized emittance: 0.1-1 mm·mrad



The Compact ERL (cERL) at KEK



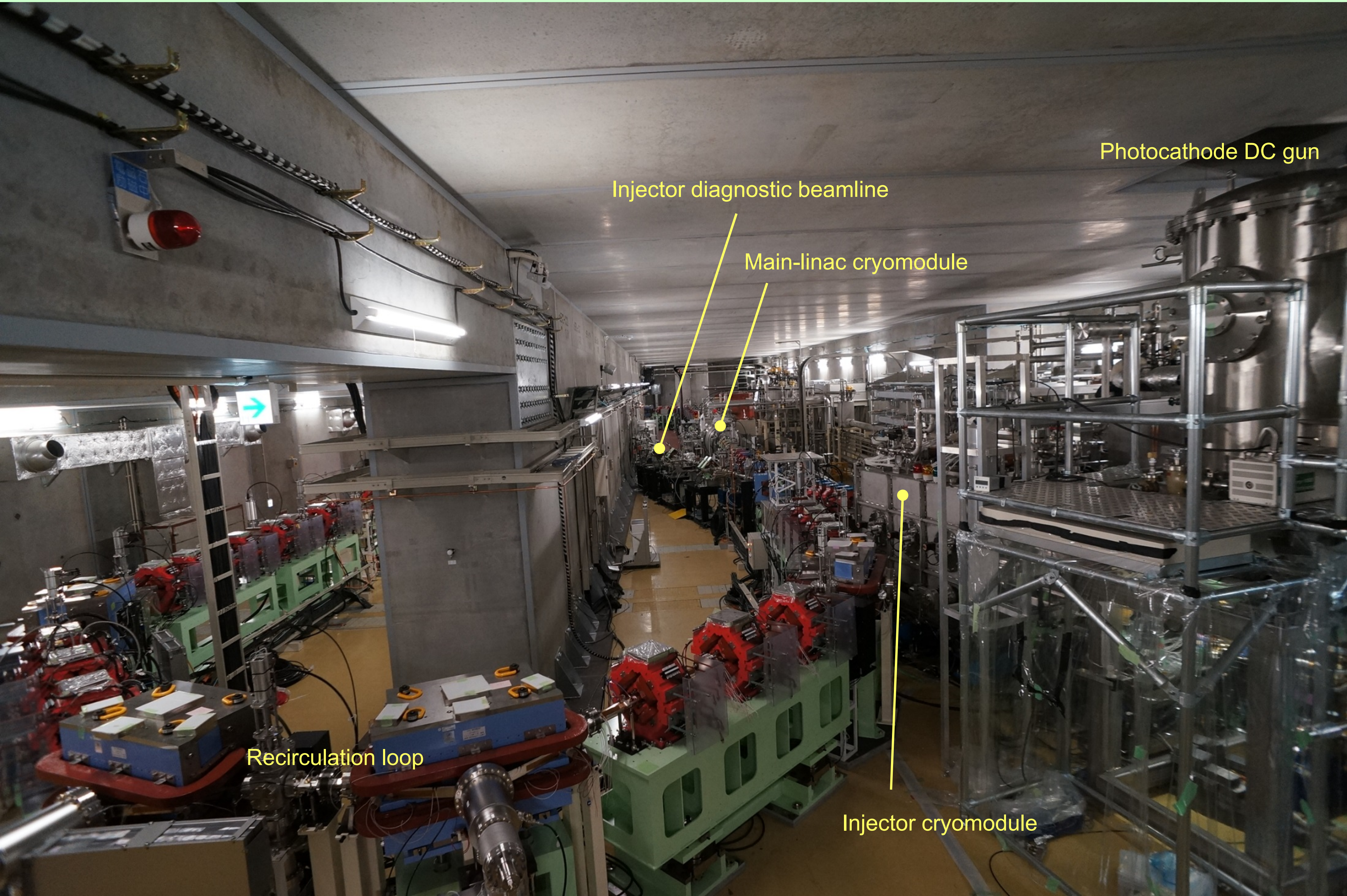
Circumference: ~ 90 m

Parameters of the cERL

	Design	In operation
Beam energy E	35 MeV	20 MeV
Injector energy E_{inj}	5 MeV	2.9 - 6 MeV
Gun high voltage	500 kV	390 kV
E_{acc} in main linac	15 MV/m	8.2 MV/m
Beam current	10 mA	80 μA
Normalized emittance [mm·mrad]	0.1 @7.7 pC 1 @77 pC	< 1 @7.7 pC (at injector) 0.3@0.5 pC (at loop)
Repetition frequency of bunches	1.3 GHz	1.3 GHz (usual) 162.5 MHz (for LCS)
RMS bunch length	1-3 ps (usual)	1-3 ps (usual)
Max. heat load at 2K	80 W	80 - 100 W

S. Sakanaka et al., IPAC2015, TUBC1.

Picture of the cERL

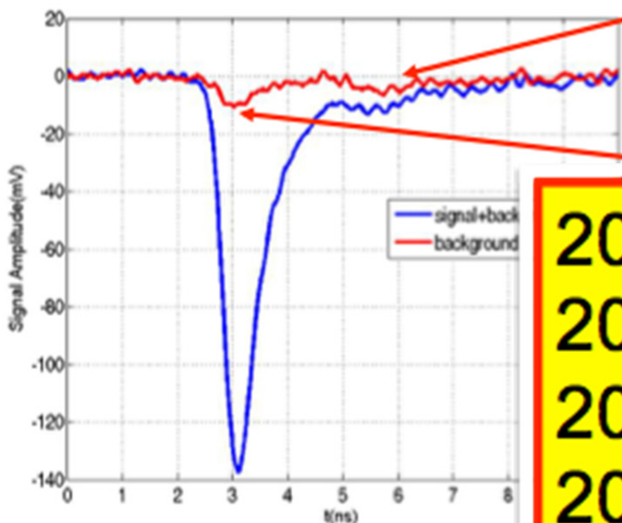


Inverse Compton Scattering γ/x-ray Sources in Asia

	Inst.	Acc. type	E-beam	Laser	X-ray	Appl.& Others
1	SHI (JPN)	S-band, SW	38MeV, 0,8nC, 3ps, 30um	200mJ, 50fs, 800nm	165deg.:33.7keV, $2x10^6$ ph/p,3ps, 6%fluct., 10Hz.	Imaging
2	JAEA (JPN)	Microtron	150MeV, 60pC/pulse,	Nd:YAG 840mJ,23ns,	~400keV, 45±20ph/pulse, 10ps.	Imaging
3	KEK – STF	L-band, SRF	23MeV, 0.9nC, 15ps, 150/train,	4mirrors OC: 0.3mJ,	8~9keV, $8.2x10^6$ph/s, 8% bandwidth(FWHM)	Imaging
4	KEK-LUCX	S-band, TW	43MeV, 0.5nC, 100/train	2-mirror OC, 110 uJ/pulse	10^4ph./train	
5	THU-TTX-1	S-band, TW	46.7MeV,0.2nC, 10Hz	300mJ/pulse, 800nm,	10^6ph./pulse, 51.7keV,	Imaging

The Scattering X-ray Signal and Background of TTX-I

- Typical background and X-ray signal



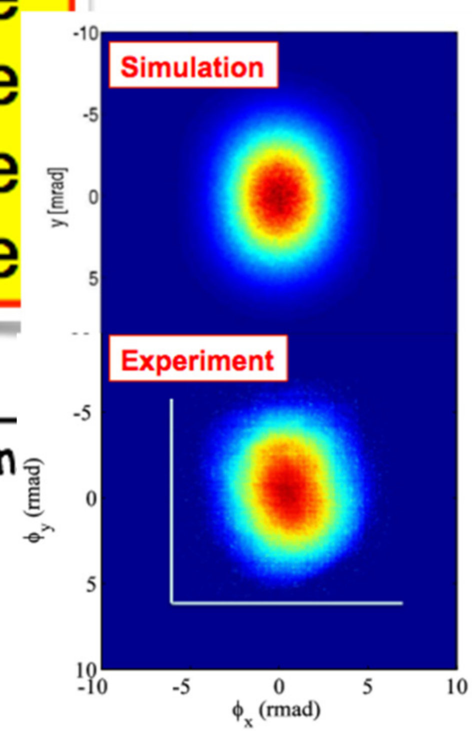
Background x-ray from beam dump

The background from the beam is suppressed

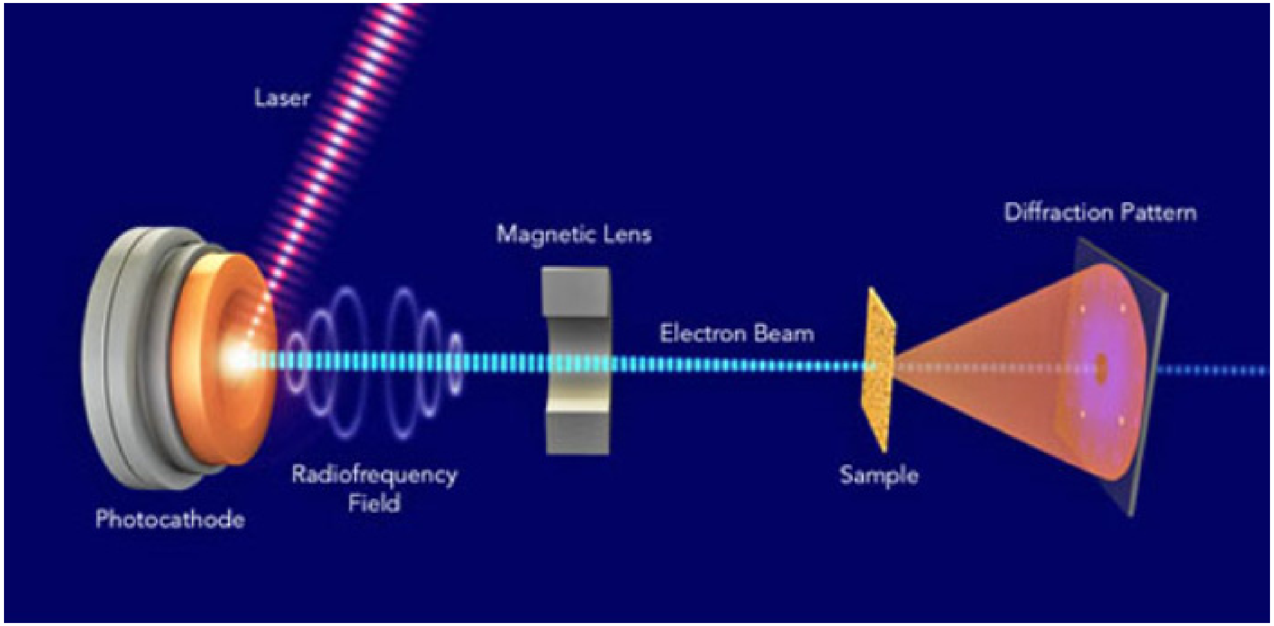
2011. 7, $2x10^5$/pulse
2012. 6, $1x10^6$/pulse
2013. 4, $4x10^6$/pulse
2013.12, $1x10^7$/pulse

- Measured Electron and laser specifications

	laser	electron
Energy	800nm(1.55eV)	46.7MeV (spread 0.3%, rm
Intensity	300mJ	0.2nC (~3mm.mrad)
Beam size	~100um (rms)	~35x40um^2(rms)
Pulse width	~70fs(FWHM)	~2.7ps



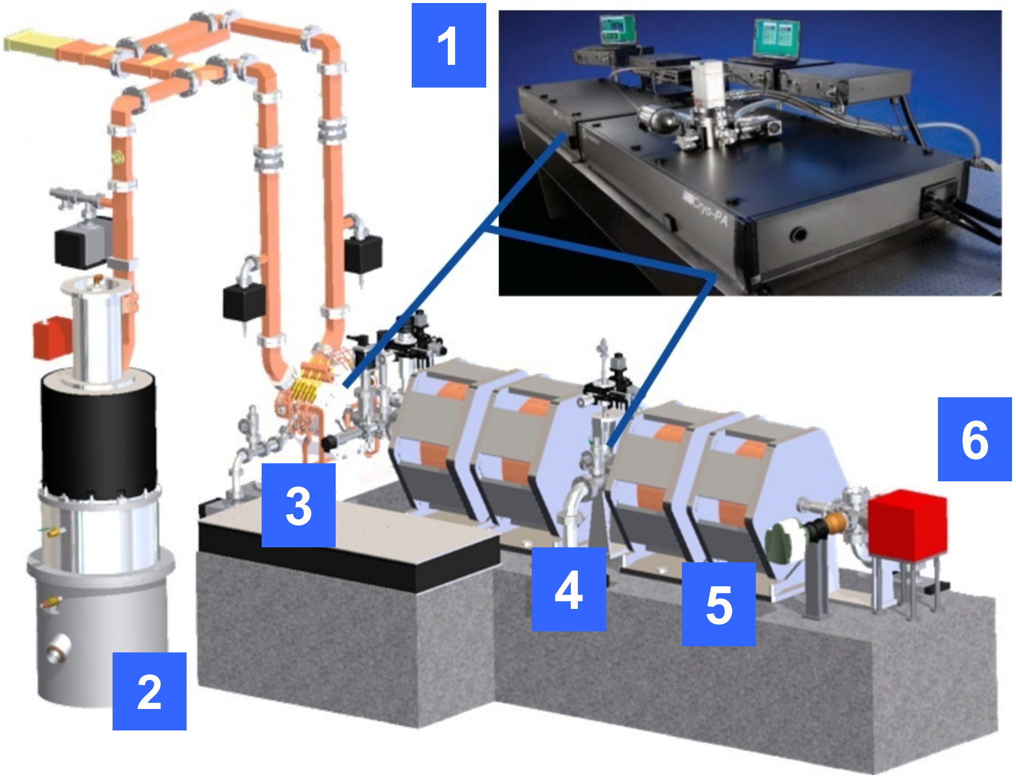
Ultrafast electron diffraction and microscopy



- ✓ The structural dynamics of the sample is initiated by an ultrafast laser and then probed by an ultrafast electron beam
- ✓ Compact
- ✓ Complementary to XFEL

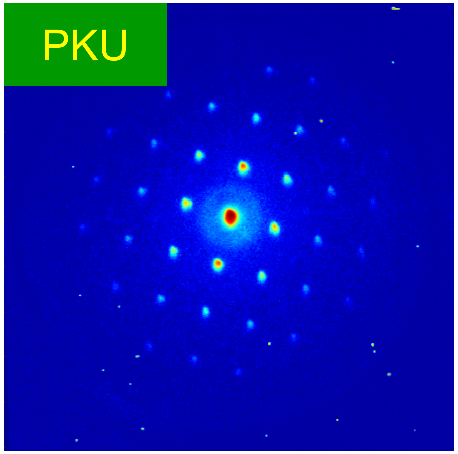
Institute	E (MeV)	Technology	Test/User facility
Korea Atomic Energy Research Institute	~3	PC gun	User
Osaka University	~3	PC gun	User
Peking University	3~4	DC-SRF	Test
Shanghai Jiao Tong University	2~5	PC gun	User
Tsinghua University	~3	PC gun	Test

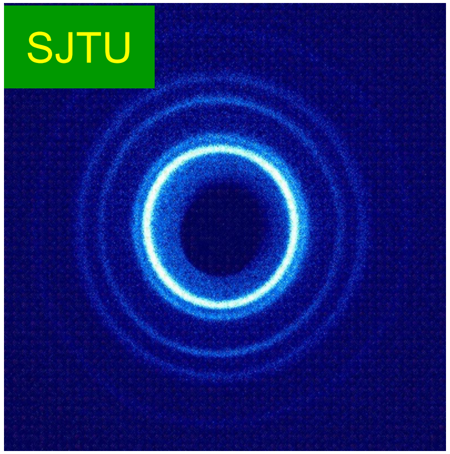
Ultrafast electron diffraction and microscopy

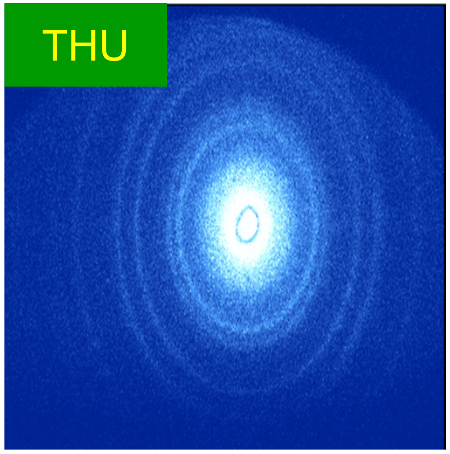


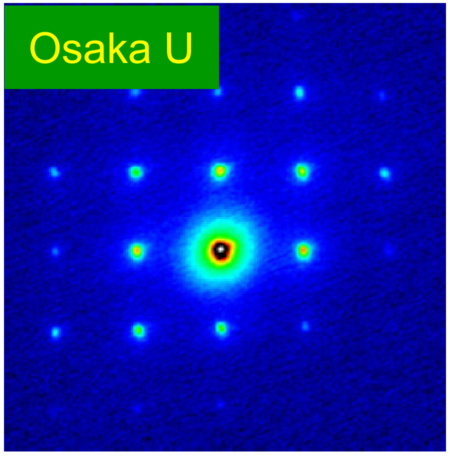
UED/UEM facility under construction at Shanghai Jiao Tong University ($15 M, 2014-2018)

1. **Femtosecond laser**
2. High rep-rate rf source
3. **High rep-rate rf gun**
4. Advanced sample chamber
5. Superconducting solenoid (UEM)
6. **Advanced detection system**

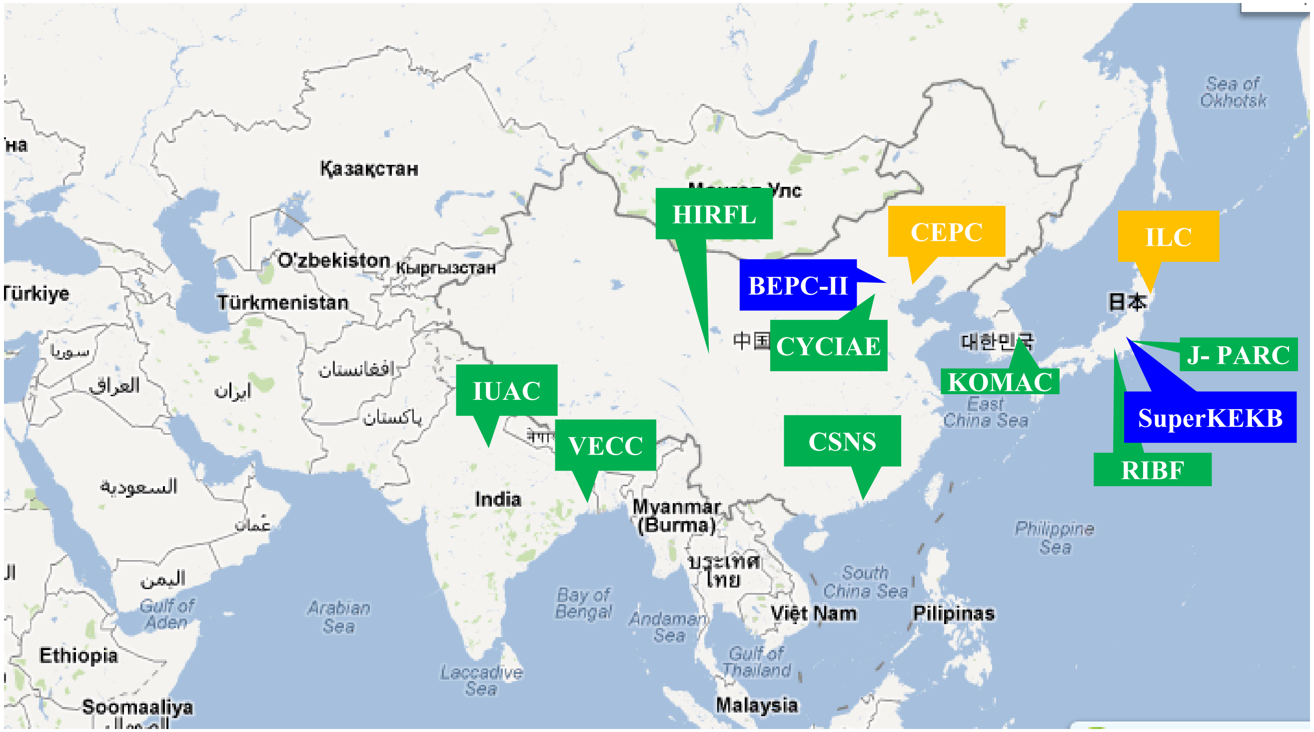








Colliders, Proton & Heavy Ion Facilities



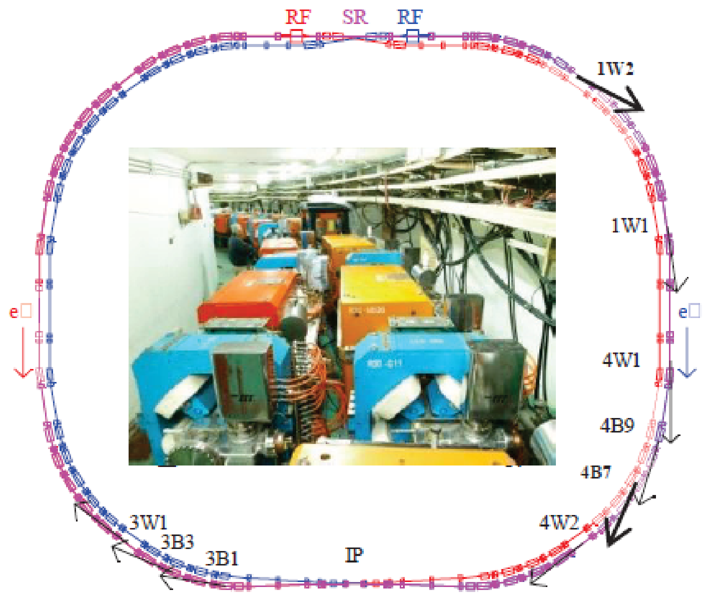
Colliders

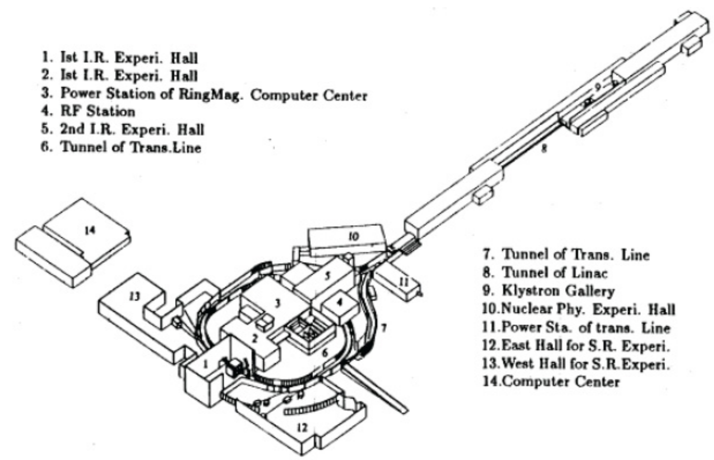
- BEPC-II: Beijing Electron Positron Collider
- SuperKEKB, Super KEK B-Factory
- ILC: International Linear Collider
- CEPC: Circular Electron Positron Collider

BEPC-II

BEPCII, the major upgrades of BEPC (Beijing Electron Positron Collider), is a double-ring e and e+ factory-like collider, working at the beam energy range from 1 GeV to 2.1 GeV and being optimized at 1.89 GeV with the design luminosity of $1\times10^{33}cm^{-2}s^{-1}$. It has been in operation since Sept. 2009.

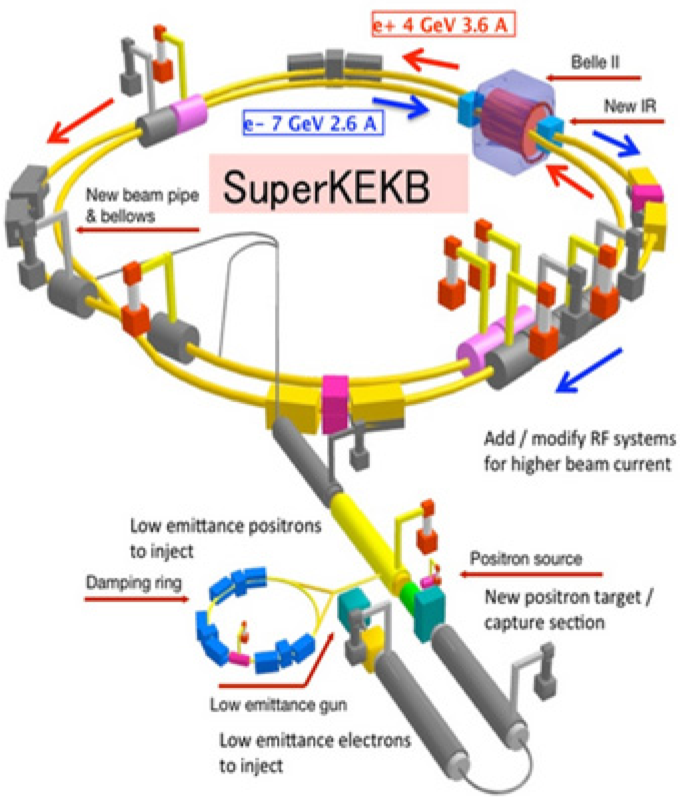
Parameters	BER/BPR	BSR
Beam energy (GeV)	1.89	2.5
Circumference (m)	237.53	241.13
Beam current (A)	0.91	0.25
Bunch current (mA) / No.	9.8 / 93	~1 / 160 - 300
Natural bunch length (mm)	13.6	12.0
RF frequency (MHz)	499.8	499.8
Harmonic number	396	402
Emittance (x/y) (nm·rad)	144/2.2	140
β function at IP (x/y) (m)	1.0/0.015	10.0/10.0
Crossing angle (mrad)	±11	0
Tune (x/y/s)	6.54/5.59/0.034	7.28/5.18/0.036
Momentum compaction	0.024	0.016
Energy spread	5.16×10^{-4}	6.67×10^{-4}
Natural chromaticity (x/y)	–10.8/–20.8	–9.0/–8.9
Luminosity ($cm^{-2}s^{-1}$)	1×10^{33}	—





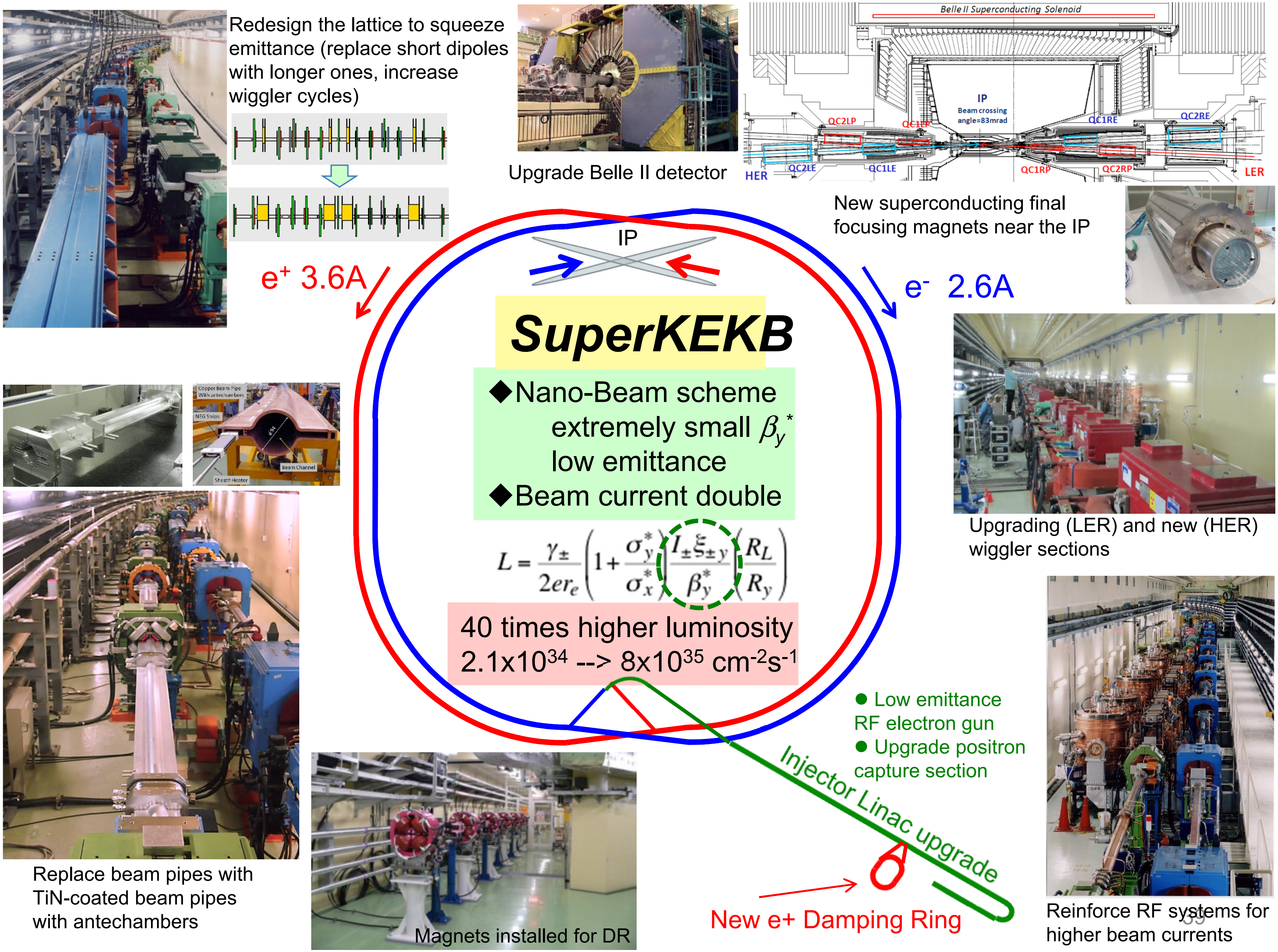
SuperKEKB

KEKB has the highest peak luminosity in the world, $2 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$. KEKB has been in operation until 2010. Afterward, upgrading of KEKB has been initiated toward SuperKEKB. The target luminosity is $8 \times 10^{35} \mathrm{cm}^{-2}\mathrm{s}^{-1}$, which is 40 times higher than that of KEKB.



	KEKB (operation)		SuperKEKB (design)		
	LER	HER	LER	HER	
ε_x	18	24	3.2	5.0	nm
ε_y	151	151	8.6	13.5	pm
$\varepsilon_y/\varepsilon_x$	0.84	0.63	0.27	0.25	%
β_x^*	12000	12000	32	25	mm
β_y^*	5.9	5.9	0.27	0.31	mm
σ_x^*	147	170	10	11	μm
σ_x^*(eff.)^{*1}	-	-	249	207	μm
σ_y^*	944	944	48	56	nm
$\sigma_{x'}^*$	122	141	316	447	μrad
$\sigma_{y'}^*$	0.12	0.14	0.18	0.21	mrad
ξ_x	.127	.102	.0028	.0012	
ξ_y	.129	.090	.0881	0.0807	

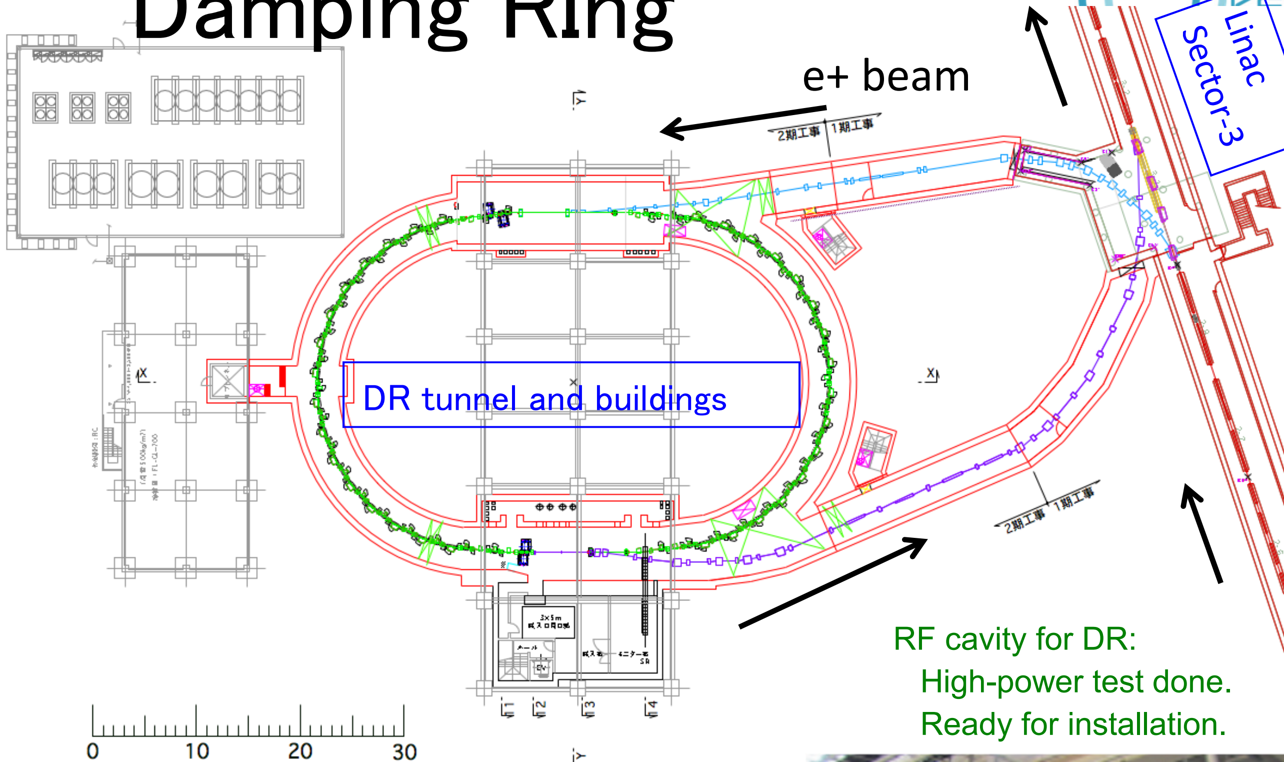
^{*1} σ_x^*(eff.) is an effective horizontal beam size defined as $\sigma_z \sin\phi$, where σ_z and ϕ denote a bunch length and a half crossing angle, respectively.


Redesign the lattice to squeeze emittance (replace short dipoles with longer ones, increase wiggler cycles)
Upgrade Belle II detector
Belle II Superconducting Solenoid
IP
Beam crossing angle=83mrad
QC2LP
QC1LP
QC1RE
QC2RE
HER
QC2LE
QC1LE
QC1RP
QC2RP
LER
New superconducting final focusing magnets near the IP
IP
e^+ 3.6A
e^- 2.6A
SuperKEKB
◆Nano-Beam scheme
extremely small β_y^*
low emittance
◆Beam current double
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$
40 times higher luminosity
$2.1\text{x}10^{34}$ --> $8\text{x}10^{35}$ $cm^{-2}s^{-1}$
Upgrading (LER) and new (HER) wiggler sections
● Low emittance RF electron gun
● Upgrade positron capture section
Injector Linac upgrade
New e+ Damping Ring
Replace beam pipes with TiN-coated beam pipes with antechambers
Magnets installed for DR
Reinforce RF systems for higher beam currents

Damping RIng

Design parameters

Parameter	Value
Energy	1.1 GeV
Bunches	2 x 2
Circumference	135.5 m
H. damping	10.87 ms
Ext. emittance (H/V)	42.5/3.15 nm
Max. current	70.8 mA



DR tunnerl construction

Jun. 2012

Dec. 2012

Mar. 2013

- Installation and startup of DR components ongoing.
- Commissioning of DR will start in winter JFY2016.

Tunnel and buildings completed.
Installation of magnets ongoing.


Sep. 2014

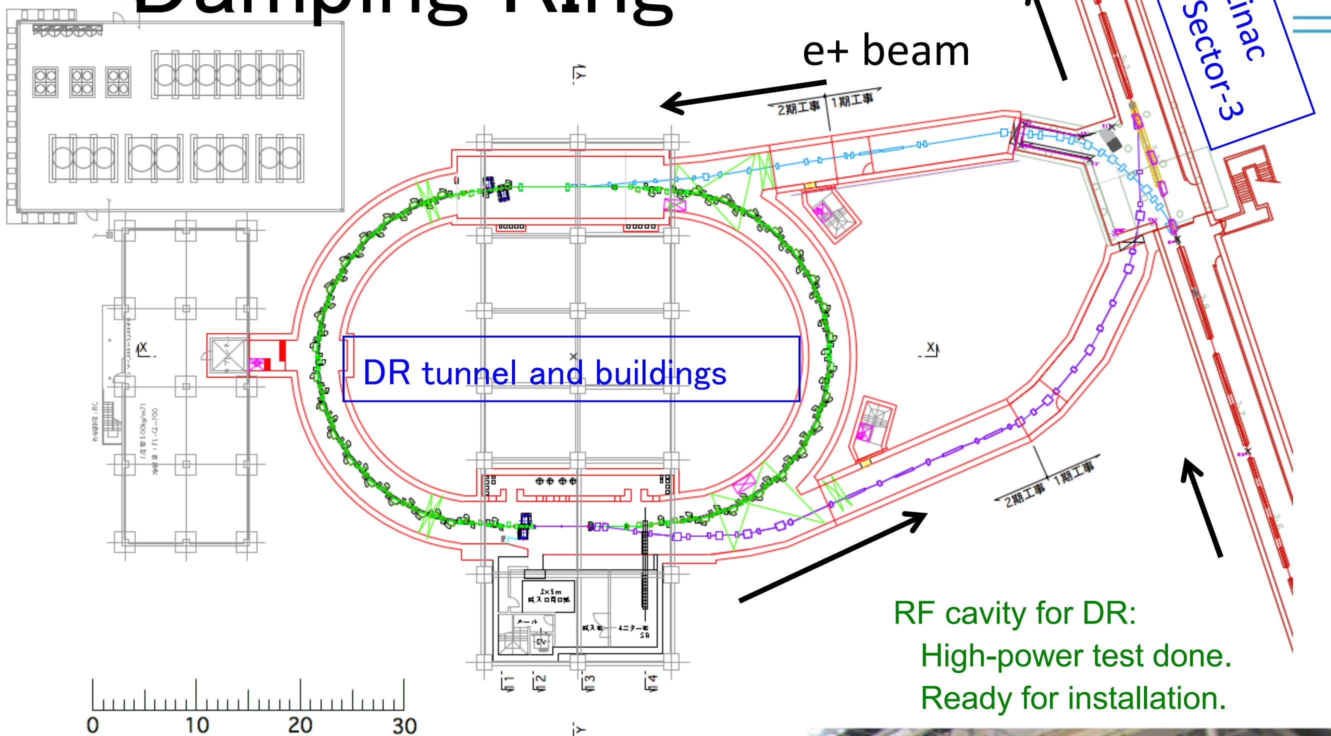
Antechamber-type beam pipe for DR

RF cavity for DR:
High-power test done.
Ready for installation.

Damping RIng

Design parameters

Parameter	Value
Energy	1.1 GeV
Bunches	2 x 2
Circumference	135.5 m
H. damping	10.87 ms
Ext. emittance (H/V)	42.5/3.15 nm
Max. current	70.8 mA



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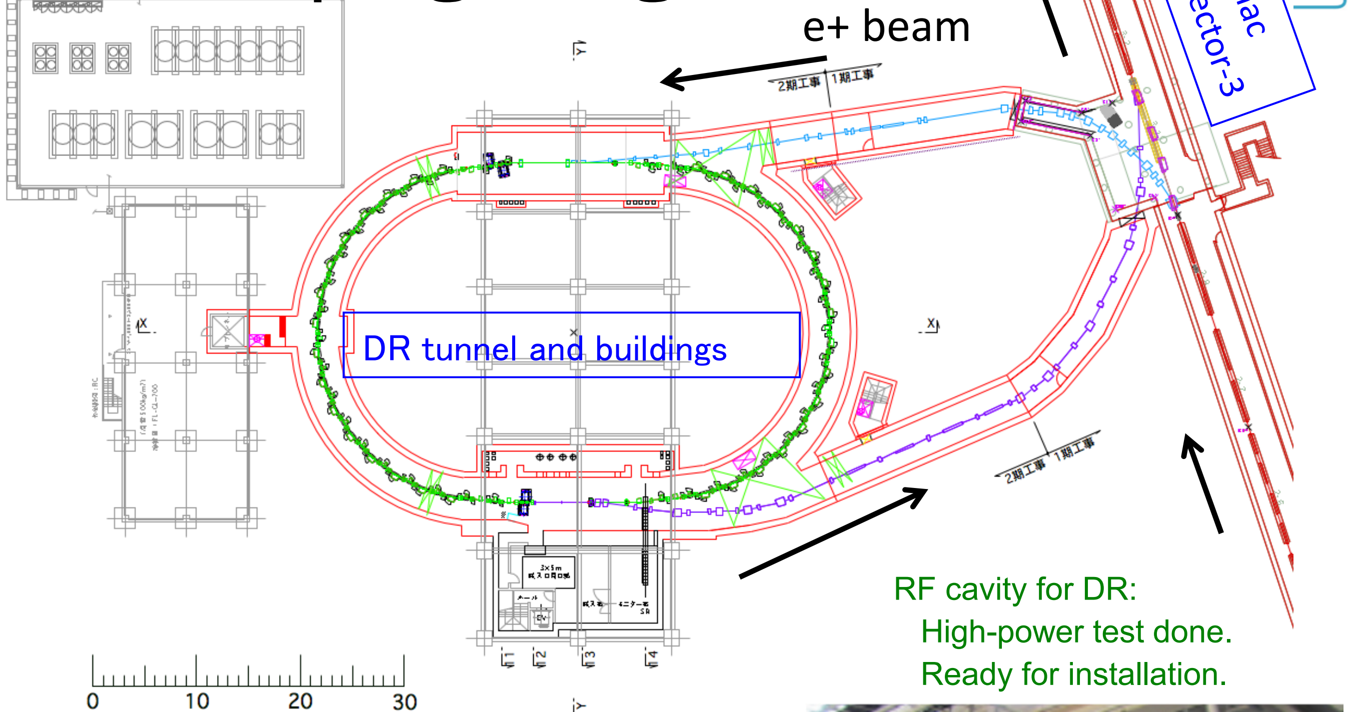

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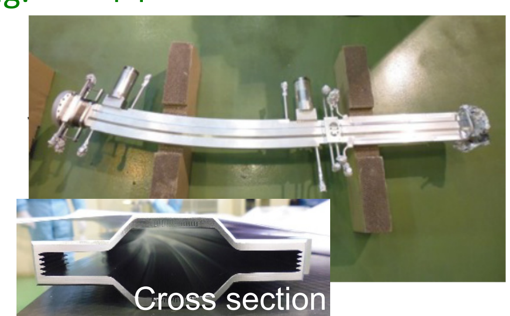
Antechamber-type beam pipe for DR



RF cavity for DR:
High-power test done.
Ready for installation.

SuperKEKB master schedule

···	JFY2010	JFY2011	JFY2012	JFY2013	JFY2014	JFY2015	JFY2016	JFY2017	···

Now (Sep. 2015)

KEKB operation

SuperKEKB construction

Dismantle KEKB

First day of removing magnets

Startup and conditioning

Phase 1 commissioning:
- Low emittance beam tuning
- Vacuum scrubbing

Phase 2 commissioning:
- Low beta* tuning
- Collision tuning
- Start physics data taking

Phase 3:
- Install VXD to complete Belle II
- Continue physics data taking

Phase 1

Phase 2、3

SuperKEKB operation

DR

Start DR commissioning prior to Phase 2

Install Belle II
Install QCS

For about 10 years

ILC

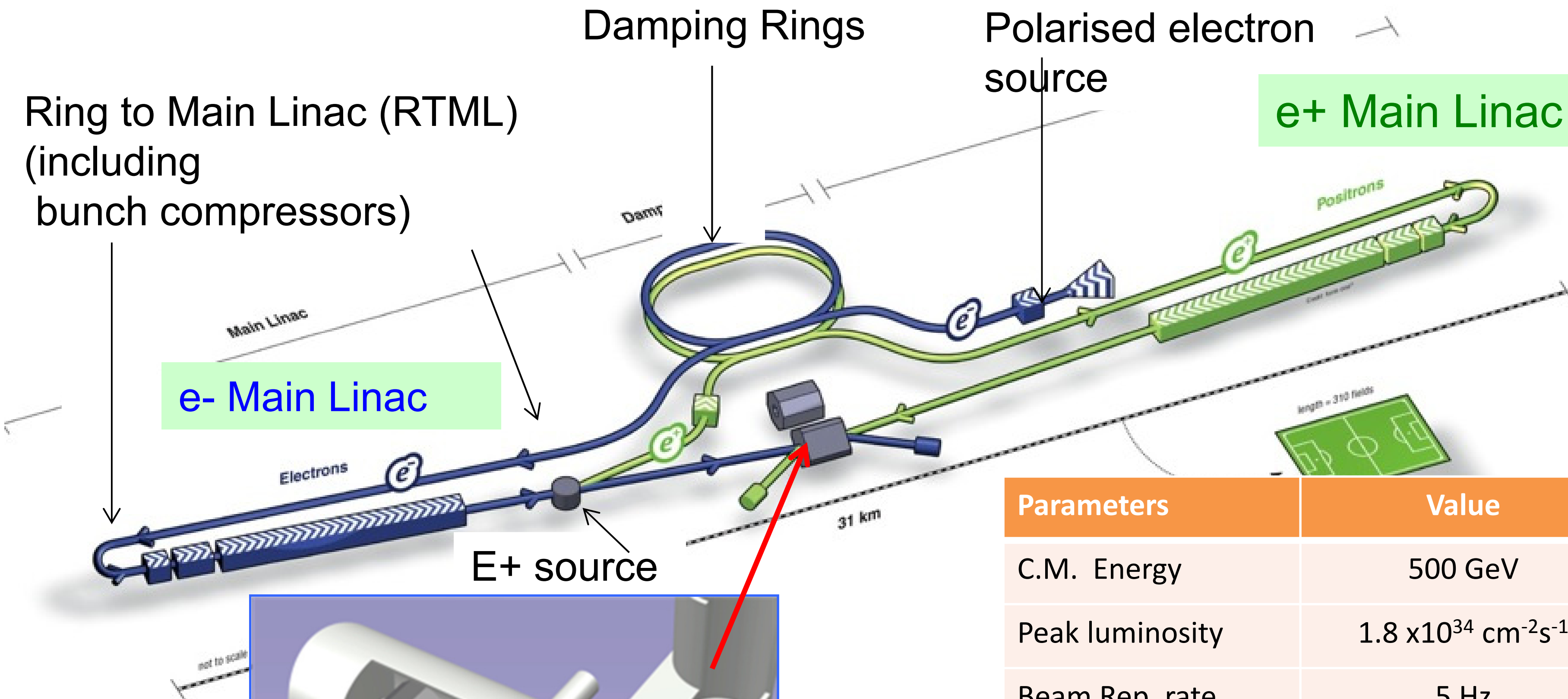
International Linear Collider

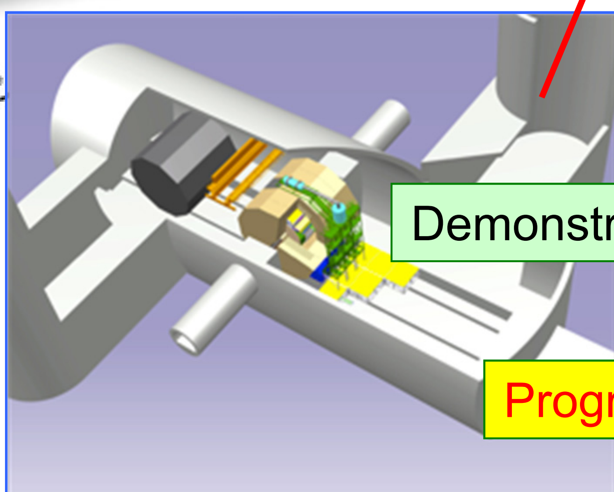
The next major accelerator project is driven by truly international efforts

Superconducting linear accelerator of ~30km length to be constructed underground in Iwate, Japan

ILC will address fundamental questions beyond the Standard Model

ILC Accelerator in TDR

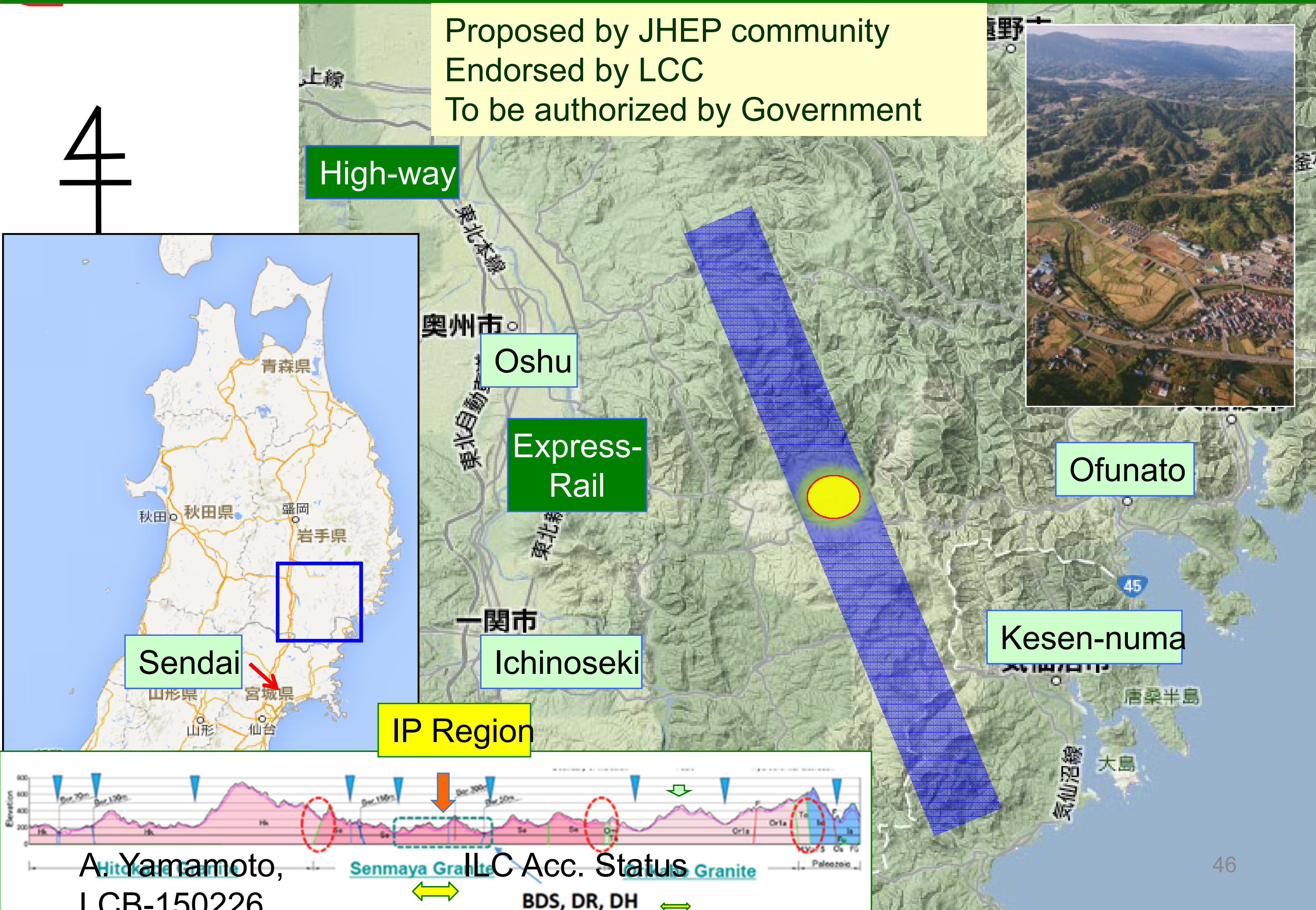




Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
FF beam size (y)	**5.9** nm
E gradient in SCRF acc. cavity	**31.5** MV/m +/-20% Q_0 = 1E10

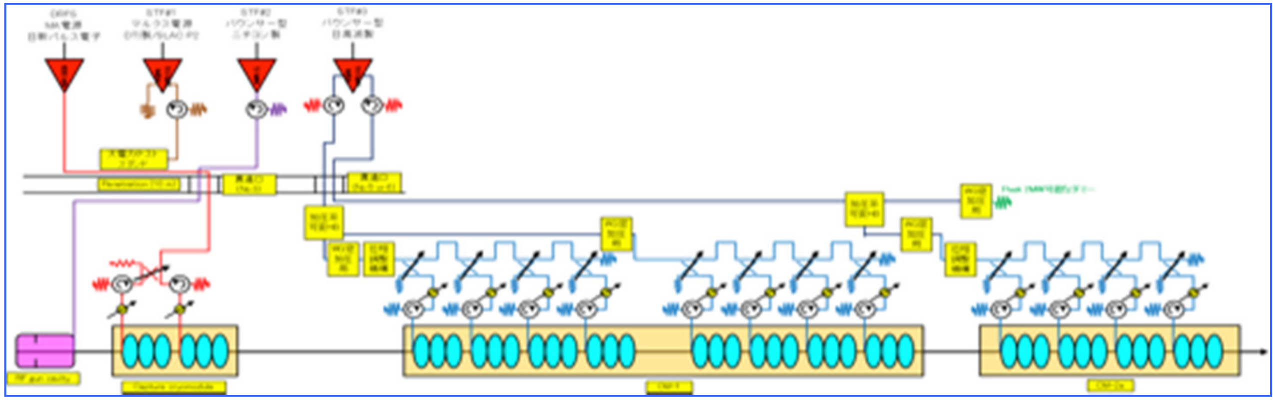
ILC Site Candidate Location in Japan: Kitakami

Proposed by JHEP community
Endorsed by LCC
To be authorized by Government

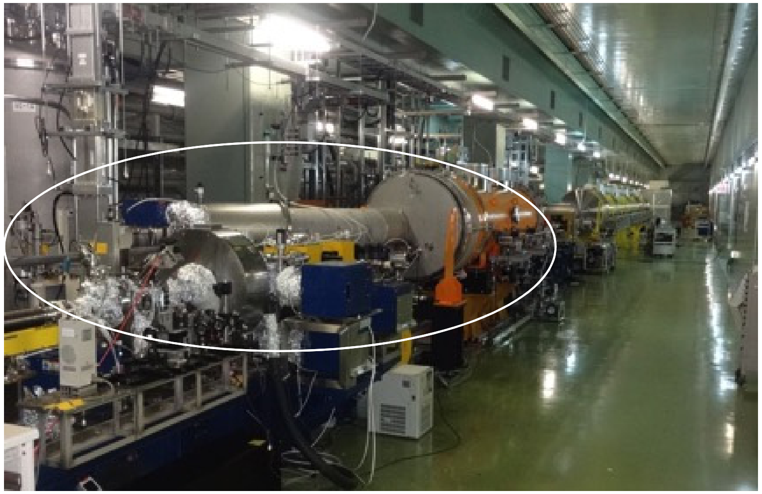


STF2:SRF Beam Accelerator Facility

High Gradient (31.5 MV/m) ＝＞Demonstration of ILC-size cryomodule



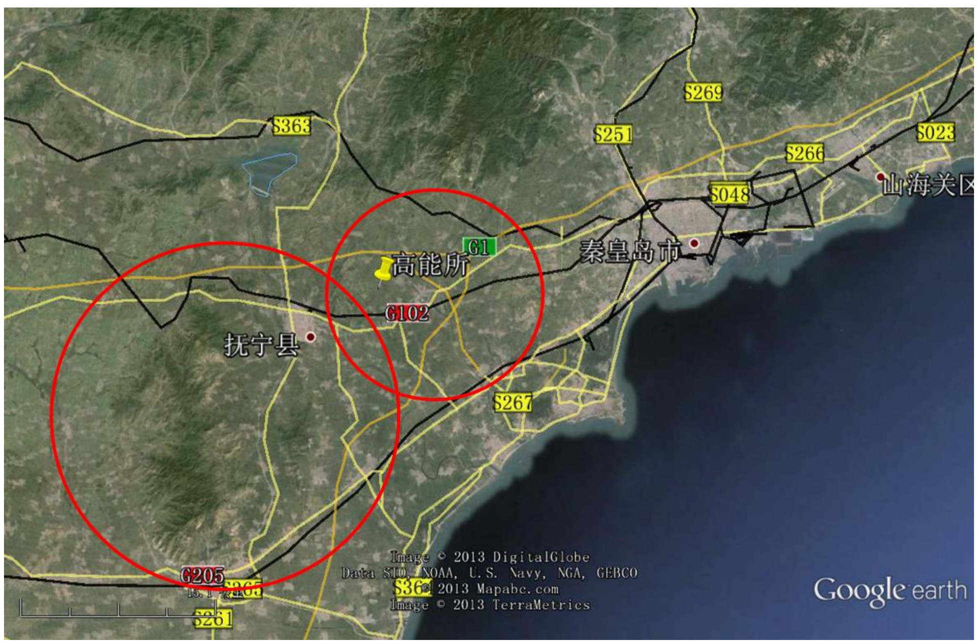
Beam acceleration w/ capture CM (40 MV), w/ 6.7 mA, 1 ms, in 2012

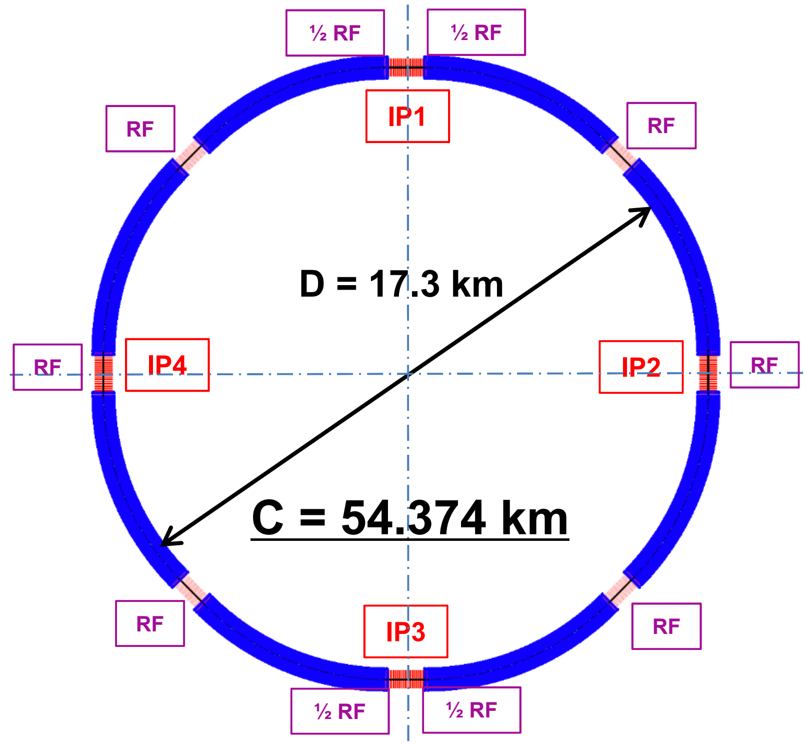


Beam acceleration w/ CM1 expected in 2016, after power dist. system installed in 2015

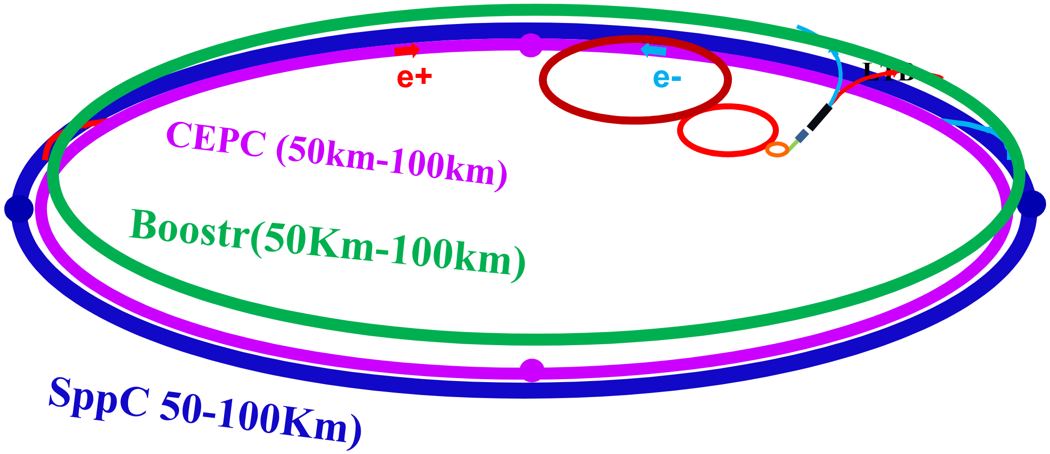
CEPC: Circular Electron Positron Collider

- CEPC-SppC configuration was proposed in Sep. 2012 by Institute of High Energy Physics (IHEP), CAS, Beijing.
- The candidate location is Qinhuangdao(秦皇岛), with great geological conditions and strong support from the local municipal government. It is close to Beijing within 3 hours dive.
- A total budget cap is preliminarily set to be about 20B RMB.





CEPC Accelerator and parameters



Parameter	Unit	Value	Parameter	Unit	Value
Beam energy [E]	GeV	120	Circumference [C]	m	54752
Number of IP[N_{IP}]		2	SR loss/turn [U_0]	GeV	3.11
Bunch number/beam[n_B]		50	Bunch population [Ne]		3.79E+11
SR power/beam [P]	MW	51.7	Beam current [I]	mA	16.6
Bending radius [ρ]	m	6094	momentum compaction factor [α_p]		3.36E-05
Revolution period [T_0]	s	1.83E-04	Revolution frequency [f_0]	Hz	5475.46
emittance (x/y)	nm	6.12/0.018	β_{IP}(x/y)	mm	800/1.2
Transverse size (x/y)	μm	69.97/0.15	$\xi_{x,y}$/IP		0.118/0.083
Beam length SR [$\sigma_{s.SR}$]	mm	2.14	Beam length total [$\sigma_{s.tot}$]	mm	2.65
Lifetime due to Beamstrahlung (simulation)	min	47	lifetime due to radiative Bhabha scattering [τ_L]	min	52
RF voltage [V_{rf}]	GV	6.87	RF frequency [f_{rf}]	MHz	650
Harmonic number [h]		118800	Synchrotron oscillation tune [ν_s]		0.18
Energy acceptance RF [h]	%	5.99	Damping partition number [J_ε]		2
Energy spread SR [$\sigma_{\delta.SR}$]	%	0.132	Energy spread BS [$\sigma_{\delta.BS}$]	%	0.119
Energy spread total [$\sigma_{\delta.tot}$]	%	0.163	n_γ		0.23
Transverse damping time [n_x]	turns	78	Longitudinal damping time [n_ε]	turns	39
Hourglass factor	Fh	0.658	Luminosity /IP[L]	$cm^{-2}s^{-1}$	2.04E+34

CEPC

- Pre-study, R&D and preparation work
  - Pre-CDR in March 2015
  - R&D: 2016-2020
  - Engineering Design: 2015-2020
- Construction: 2021-2027
- Data taking: 2028-2035

SppC

- Pre-study, R&D and preparation work
  - Pre-study: 2013-2020
  - R&D: 2020-2030
  - Engineering Design: 2030-2035
- Construction: 2035-2042
- Data taking: 2042-

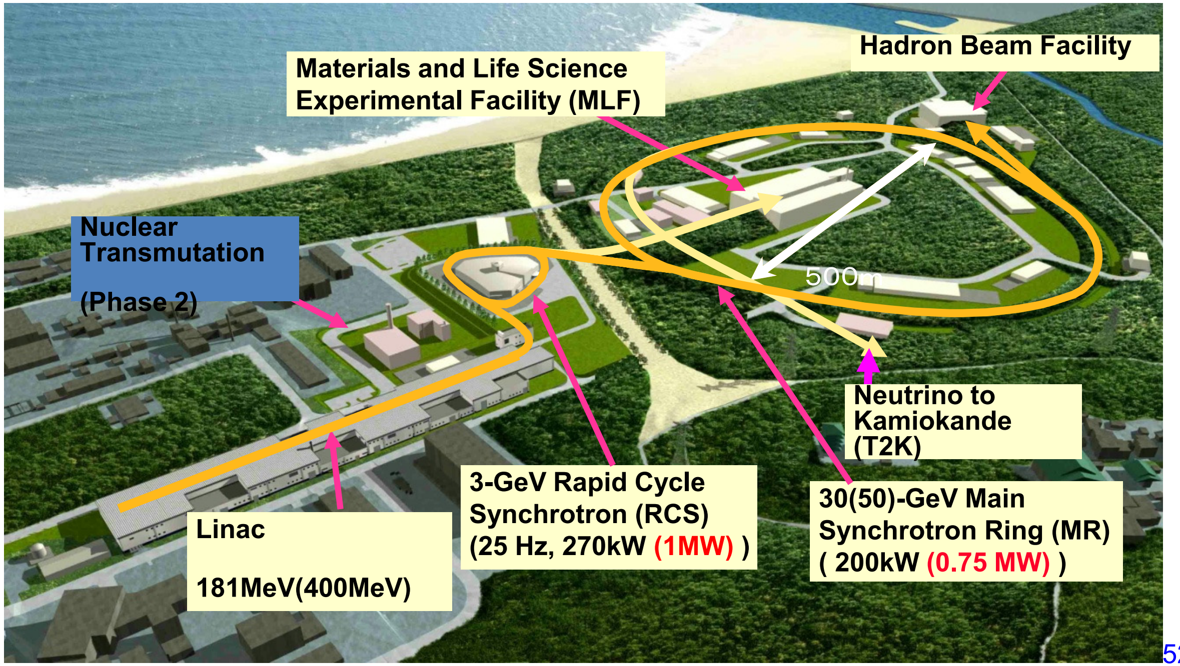
Proton and Heavy Ion Facilities-- Synchrotron

Name	City	Type of particle	Energy (MeV)	Current (uA)	Opera. Year
HIRFL-**CSRm**	Lanzhou	Heavy ion	10-100/u	30~1500	2007
HIRFL-CSRe	Lanzhou	Heavy ion	100-450/u	200 or Radioactive Beam	2007
J-PARC－RCS	Tsukuba	p	3000	50000	2008
JPARC－MR	Tsukuba	p	***30000（currently）*** ***50000（design）***	***220E^6 peak 12~14E^6 ave.***	2008

Proton and Heavy Ion Facilities-- Linac

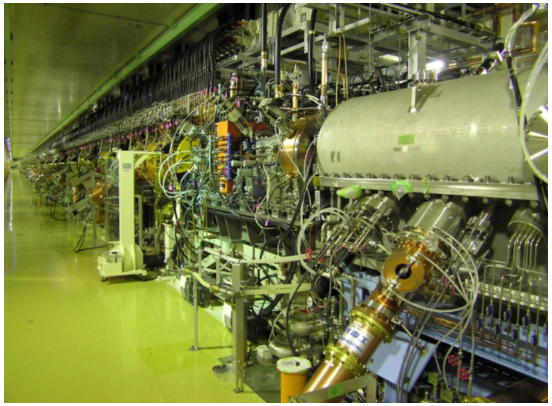
Name	City	Type of particle	Energy (MeV)	Current (emA)	Operation Year
Heavy Ion-RFQ	Lanzhou	Heavy ion	0.143	0.5	2014
J-PARC	Tsukuba	p	400	30	2008
KOMAC	Daejeon	p	100	20	*2013*
IUAC	New Delhi	Heavy ion	160-270	*several hundreds of uA*	*2007*

J-PARC --KEK(Japan Proton Accelerator Research Complex)



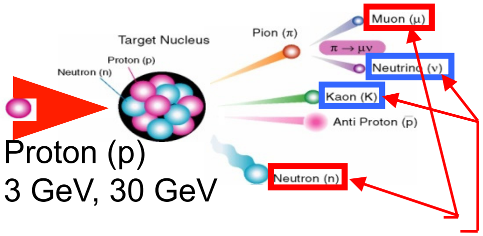
Main Synchrotron Ring (MR)
(30 (50) GeV, Period: **2.6~6.0sec**, φ500m):

ν –beam line（Super Conducting Mag.）



Linac（E:181MeV-> 400MeV (2013)

Rapid Cycle Synchrotron (RCS)
(3GeV, 25Hz, φ100m)



Goals at J-PARC

CSNS： China Spallation Neutron Source

Parameters

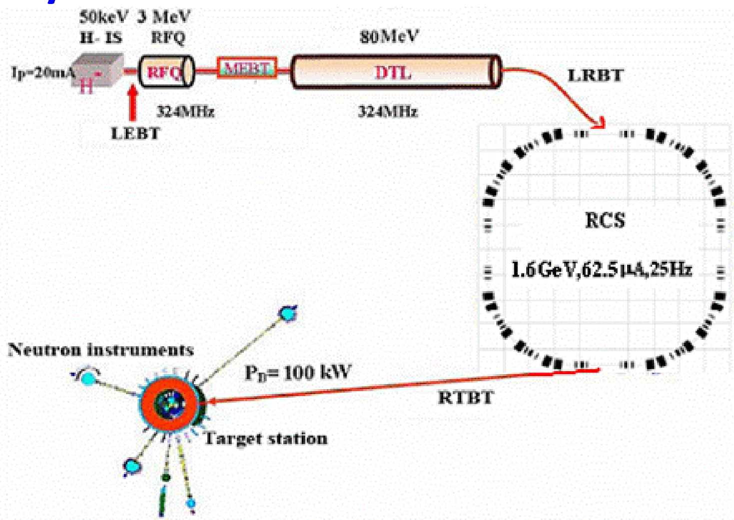
	CSNS	Upgrade
Beam power/kW	100kW	500kW
Repetition rate/Hz	25	25
Linac energy/MeV	80	250
RCS energy/GeV	1.6	1.6
Average current/μA	62.5	312.5
Target number	1	1

Campus

Commissioning schedule

IS+LEBT	Nov. 15, 2014-Dec.31, 2015
RFQ+MEBT	Feb. 15, 2015-Mar. 31, 2015
DTL1	Aug. 1, 2015-Sep. 30, 2015
L2-4+LRBT	Jul. 1, 2016-Sep. 30, 2015
RCS	Oct. 1, 2016-Jul. 31, 2017
RTBT	Aug. 1, 2017-Aug. 31, 2017
First beam on target	Aug. 1, 2017-Aug. 31, 2017
Beam power to 10kW	Aug. 1, 2017-Dec. 31,2017
To the acceptance goal	Dec. 31, 2017
Official acceptance	Mar. 2018
Beam power to 100kW	Mar.1,2018-Mar.1,2021

Layout



CSNS: Construction Status

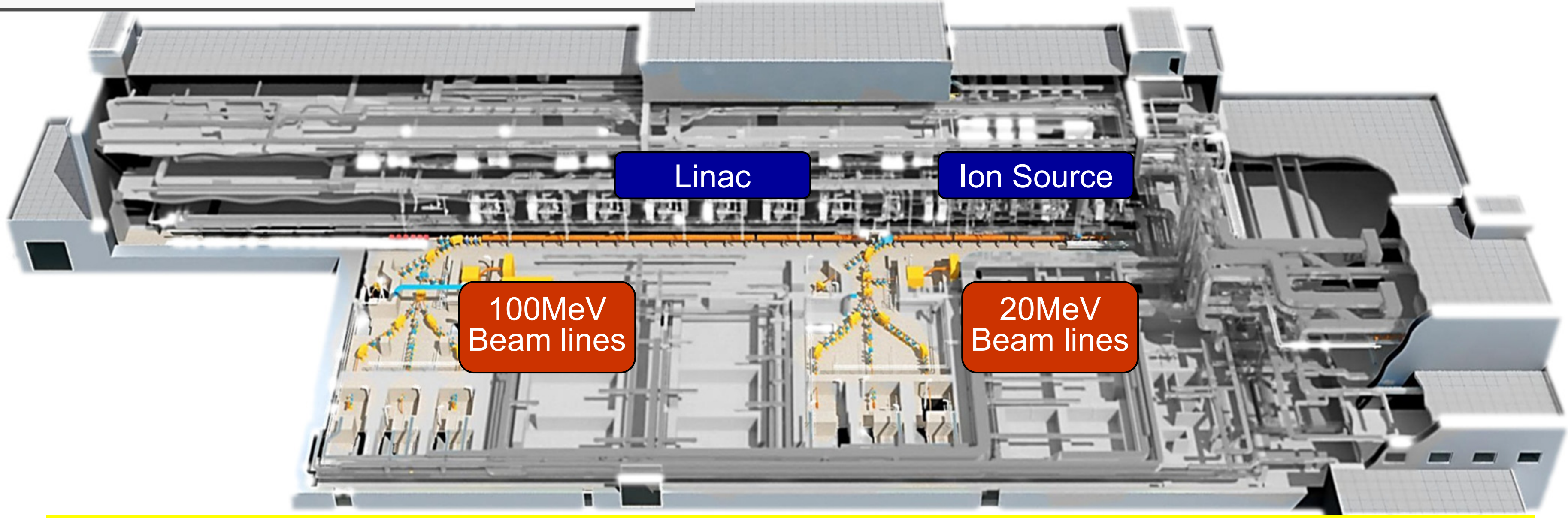
Linac and Ring are under installation, and the frontend has finished beam commissioning.

KOMAC :Intense neutron source @KAERI

Features of KOMAC 100 MeV linac

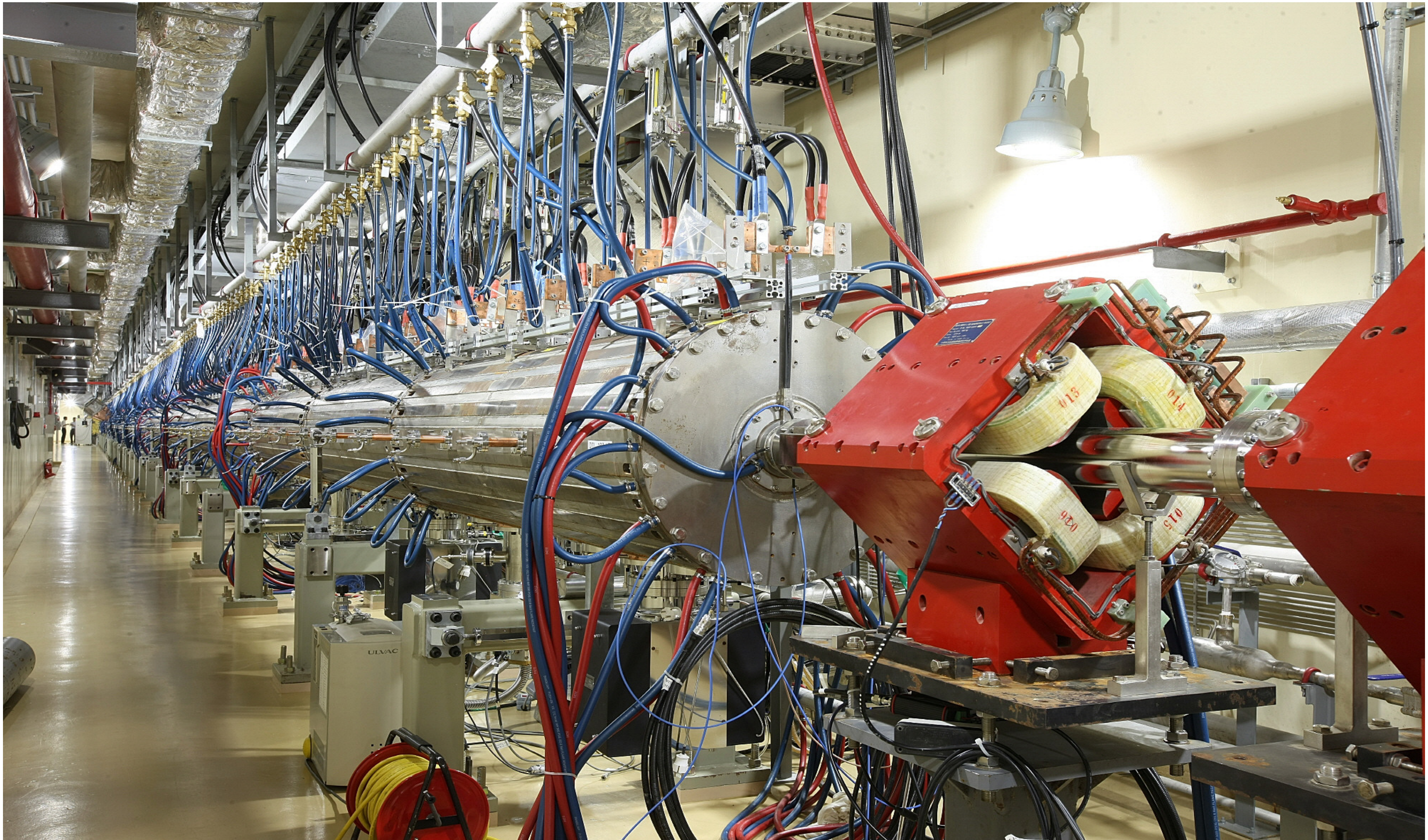
- 50-keV Injector (Ion source + LEBT)
- 3-MeV RFQ (4-vane type)
- 20 & 100-MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 5 Beamlines for 20 MeV & 100 MeV

Output Energy (MeV)	20	100
Max. Peak Beam Current (mA)	1 ~ 20	1 ~ 20
Max. Beam Duty (%)	24	8
Avg. Beam Current (mA)	0.1 ~ 4.8	0.1 ~ 1.6
Pulse Length (ms)	0.1 ~ 2	0.1 ~ 1.33
Max. Repetition Rate (Hz)	120	60
Max. Avg. Beam Power (kW)	96	160

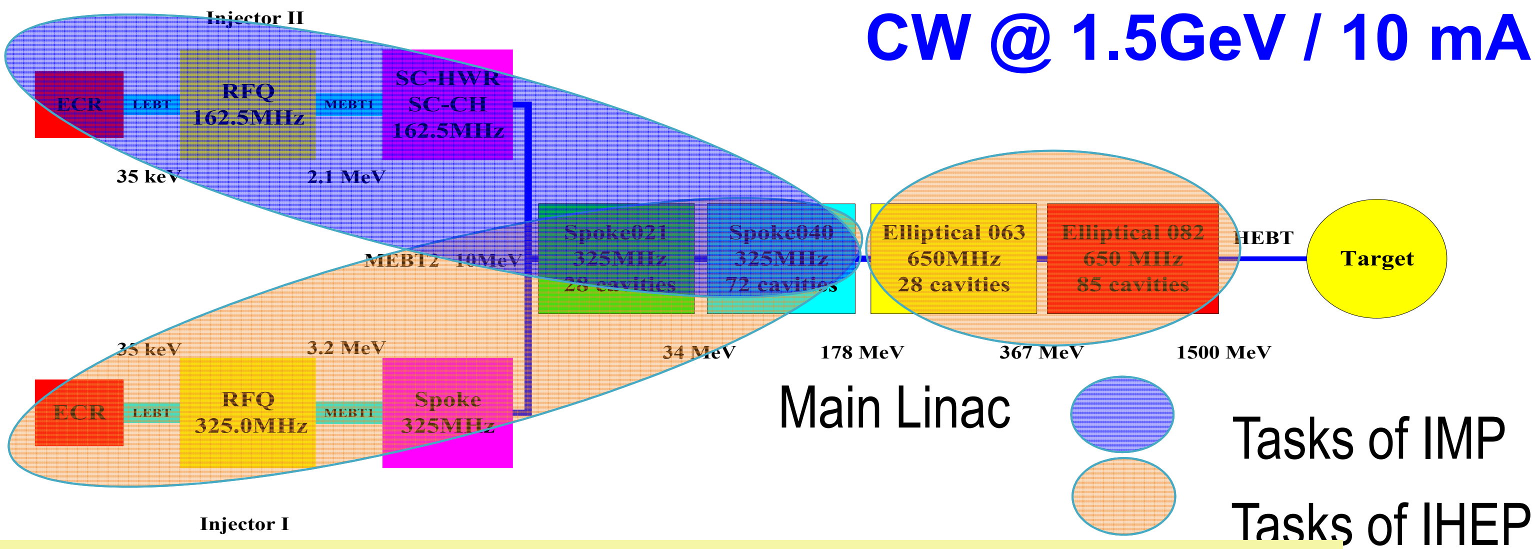


- KOMAC started its operation in 2013
- Two (2) beamlines are under normal operating (1 for 20 MeV, 1 for 100 MeV)

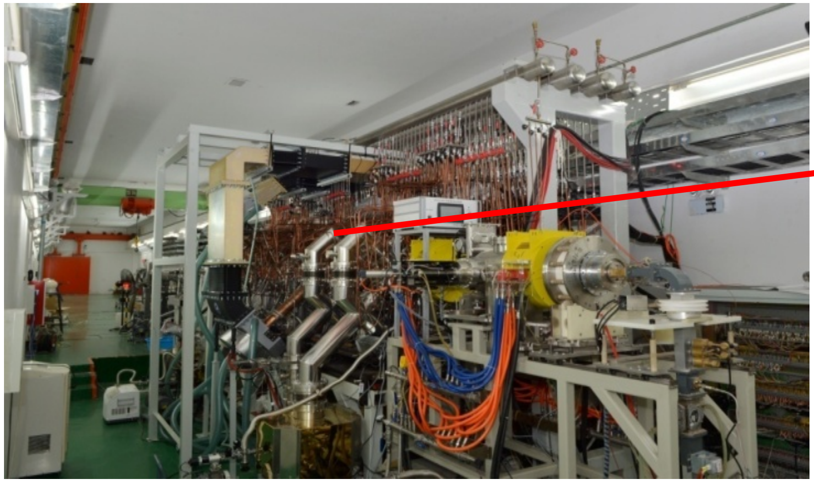
100 MeV Linac@KOMAC

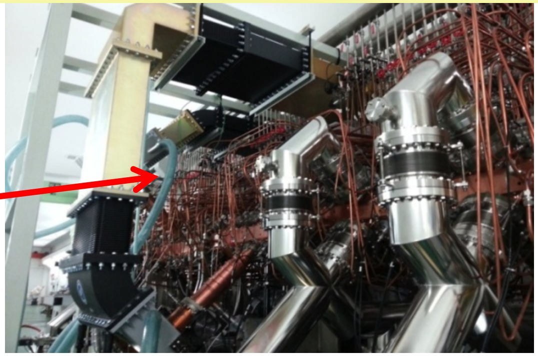


CADS Proton Accelerator, China



325 MHz proton RFQ accelerator (IHEP)

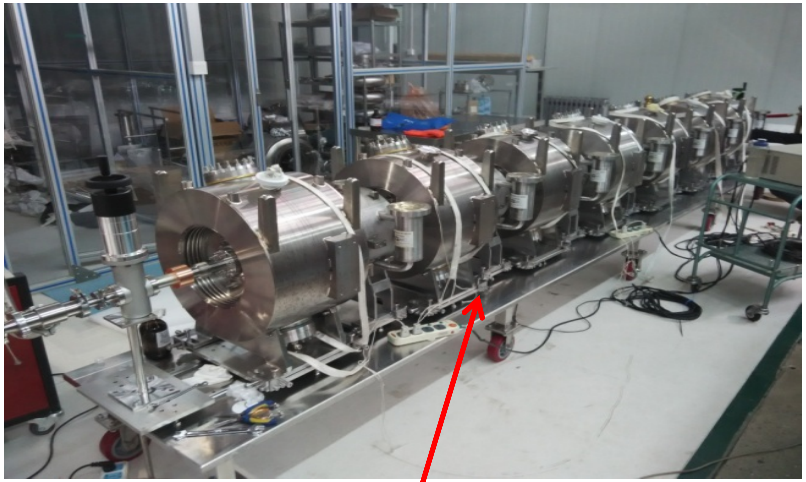


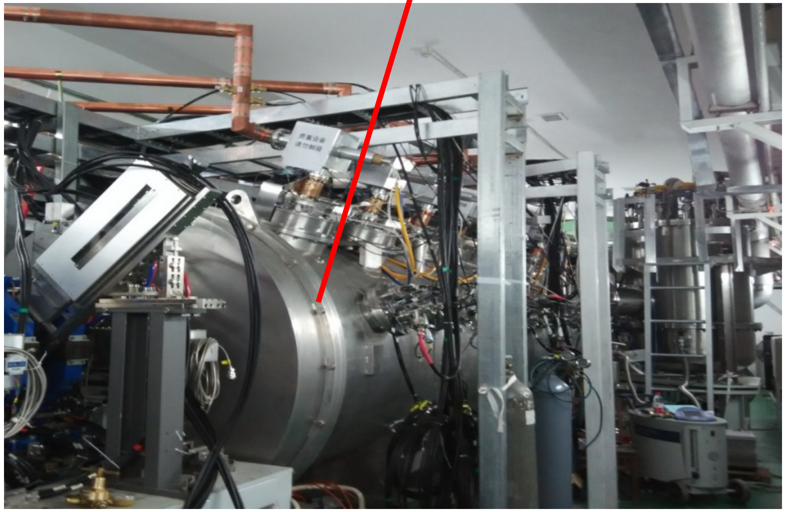


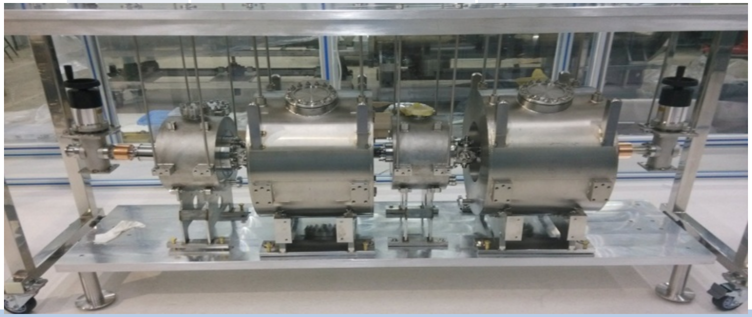
Beam: 11mA@3.2MeV, Duty cycle >90%,
Transmission efficiency > 95%
Average beam power>31kW

Low Beta (0.12)spoke cavity modules (IHEP)

No.	Eacc@4K [MV/m]	Q_0@7MV/m
4#	14.6	1.2e9
6#	14.7	1.3e9
7#	13.4	6.5e8
8#	15.4	5.5e8
9#	15.9	5.9e8
11#	15.3	6.5e8
12#	13.4	1.0e9
13#	14.1	9.0e8



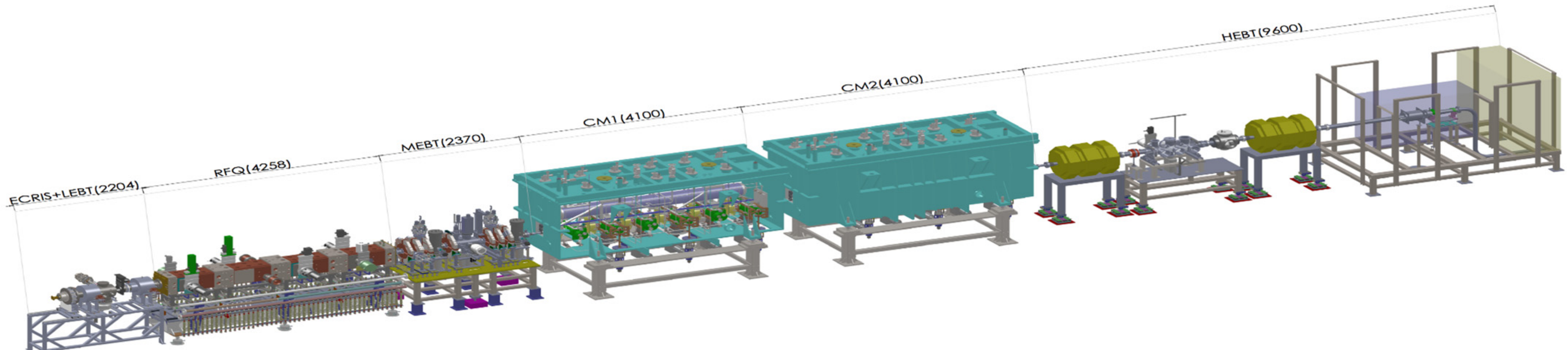


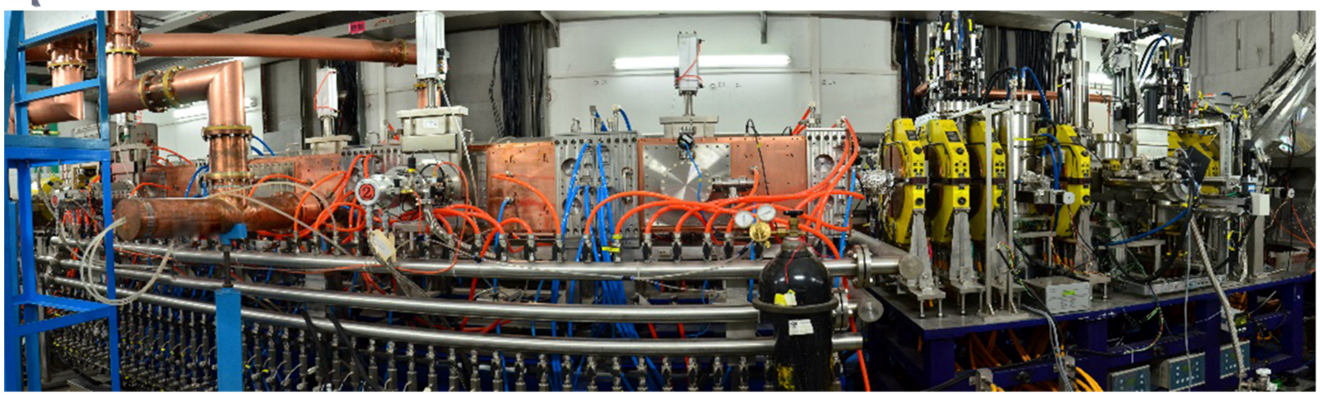


TCM（2 spoke 012+2 Solenoid +2BPM）
：
3.61MeV/10mA（1Hz, 130us），

CM1（ 7spoke012+7 Solenoid +7BPM
）： 5MeV beam commissioning

162.5 MHz proton RFQ and HWR/CH Injector (IMP)

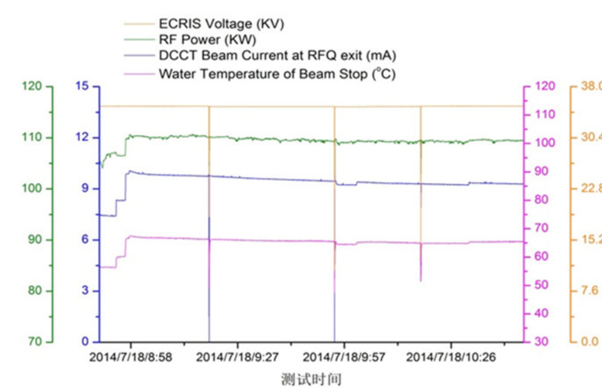




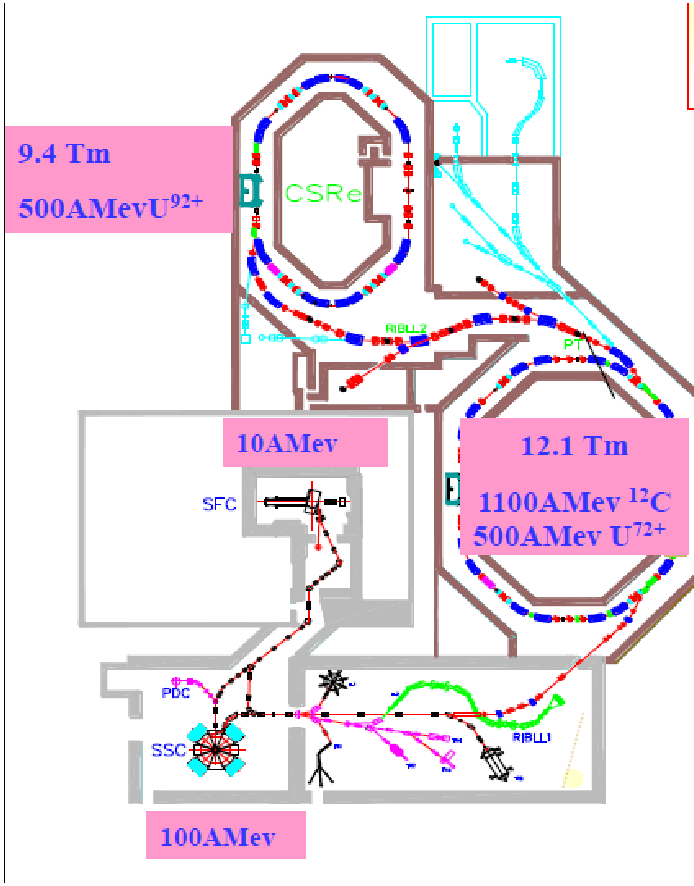
- July 2014, RFQ 2.1 MeV@10 mA CW proton beam achieved
- June 2015, RFQ+Cryomodule with 6 HWR cavities.

  5.2MeV/10.2 mA pulsed proton beam achieved.

  5.2MeV/2.7 mA CW proton beam accelerated.



HIRFL Facility(IMP-CAS)



HIRFL Layout

- ECR Ion Source
- SFC K=70--10AMev
- SSC K=450 –100AMev
- CSRm Quasi-synchrotron
  Intensity: $10^{8\text{-}9}$ pps,
  Circumference: 161 m
- CSRe: Accel. & Deccel.
  Intensity: 10^{14} pps
  Circumference: 128 m
  RIB, internal target
  High Resolution Spectrometer
- CSR budget:42 M$; 2000-2007

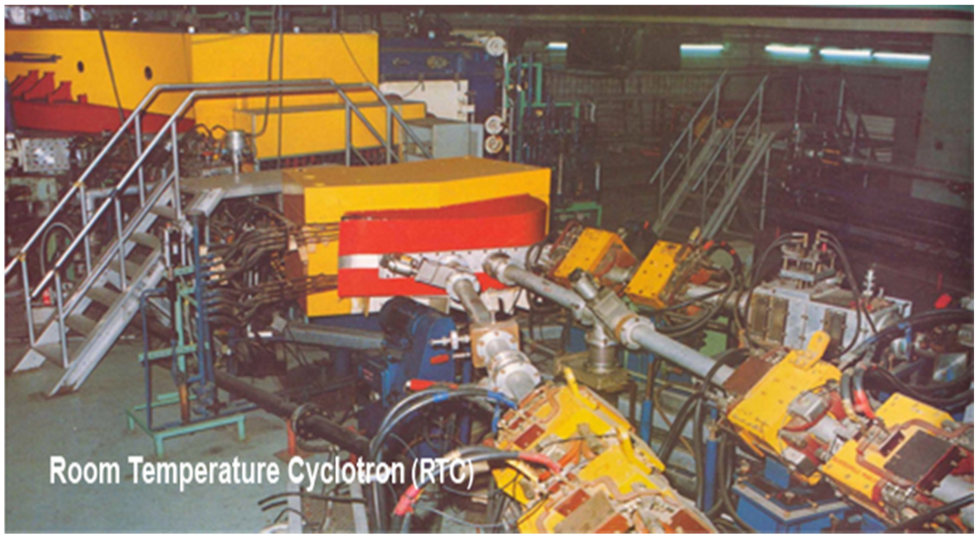
Heavy Ion-RFQ（IMP-CAS)

Design ion	**α-$^{238}U^{34+}$**
ECR ion source	
Extraction voltage	25kV
Mass analyzer	90° dipole
Frequency	18GHz
Focusing element	solenoid
RFQ	
Type	4-rod
Frequency	53.667MHz
Input energy	3.728keV/u
Output energy	**143keV/u**
Electrode voltage	70kV
RF power	35kW
Max.current(design)	0.5emA
Operation mode	CW
Length	2.52m
Max.modulation	1.996

Proton and Heavy Ion Facilities-- Cyclotron

Name	City	Type of particle	Energy(K-MeV)	Current (uA)	Year (finished)
VECC-VEC	Calcutta	Heavy ion	130	10	1980
HIRFL-**SFC**	**Lanzhou**	Heavy ion	10-70	15-1e	1987
HIRFL-SSC	Lanzhou	Heavy ion	100-450	3.5-0.1e	1988
RIBF-FRC	Tokyo	Heavy ion	570	*1for ^{18}O* *0.024 for ^{124}Xe* *0.0036 for ^{238}U*	2006
RIBF-**IRC**	Tokyo	Heavy ion	980	*1for ^{18}O* *0.024 for ^{124}Xe* *0.0036 for ^{238}U*	2006
RIBF-SRC	Tokyo	Heavy ion	2600	*1for ^{18}O* *0.024 for ^{124}Xe* *0.0036 for ^{238}U*	2006
VECC-SCC	Calcutta	Heavy ion	500	0～200	2010
BRIF	Beijing	p	100	200	2014

Variable Energy Cyclotron Centre (VECC)- India

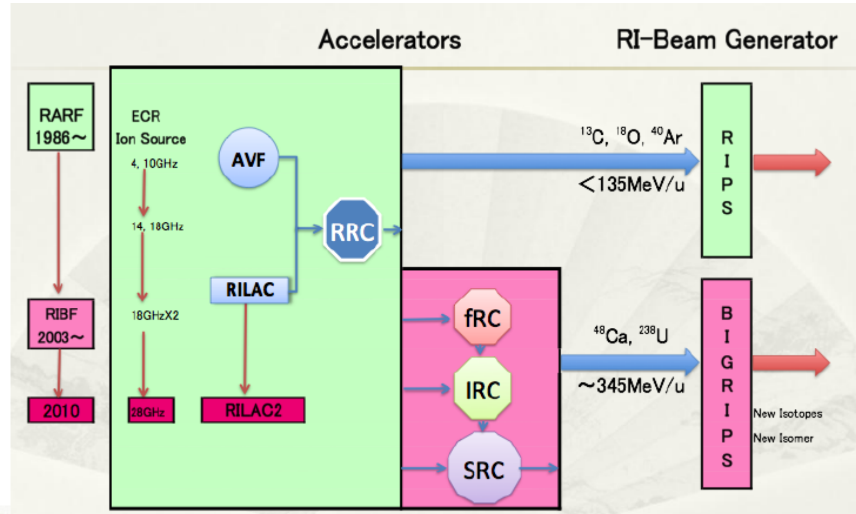


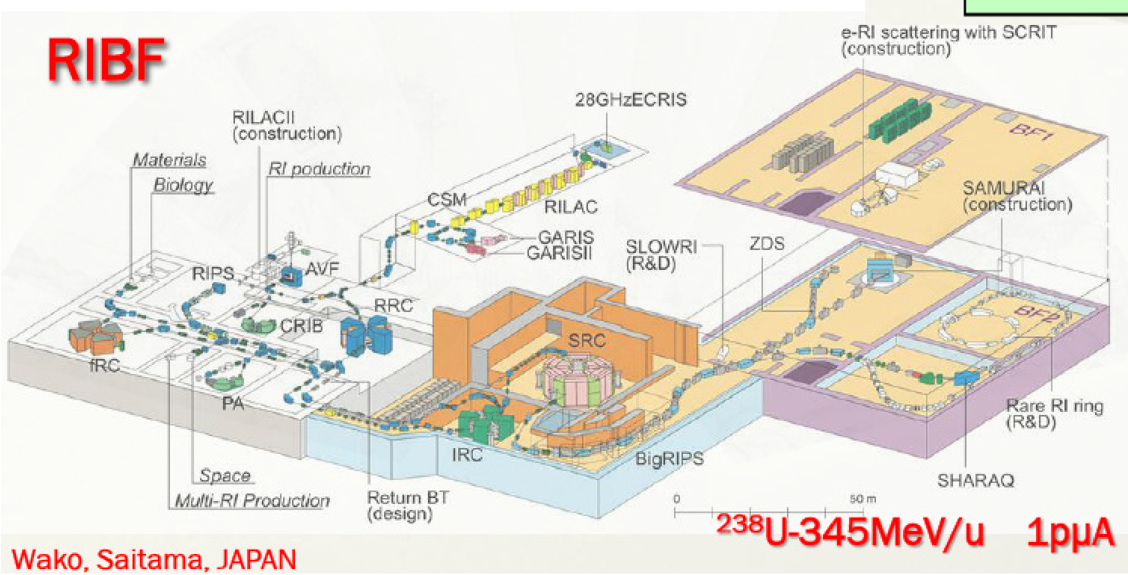
Superconducting cyclotron
K =500
Ion type: Heavy ion

room temperature Cyclotron
K =130
Ion type: Heavy ion

RIKEN –RIBF(Radioactive Isotope Beam Facility)

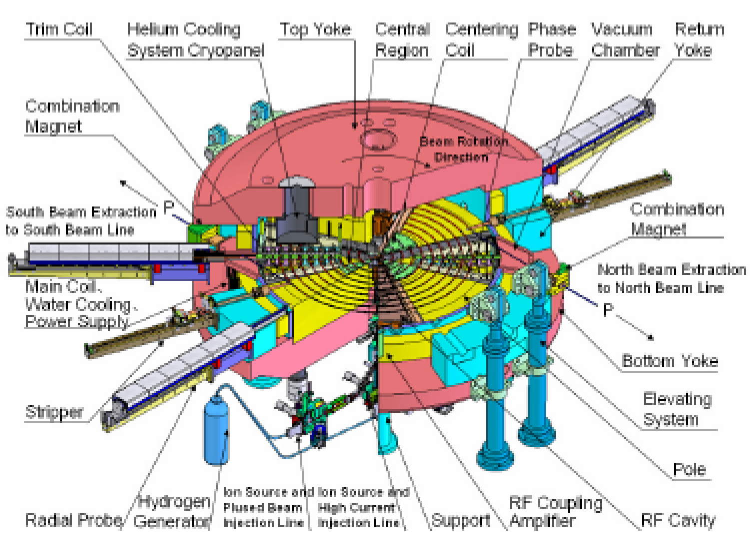
	fRC	IRC	SRC
K-number (MeV)	570	980	2600
Number of sectors	4	4	6
Velocity gain	2.1	1.5	1.5
Number of trim coils	10	20	4+22
Number of rf resonators	2+FT	2+FT	4+FT
Rf frequency (MHz)	54.75	18-38	18-38

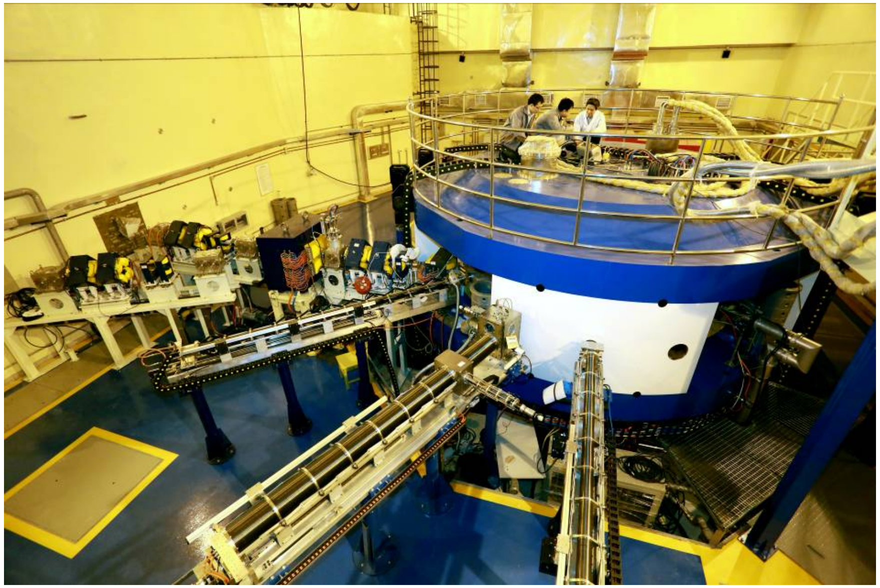


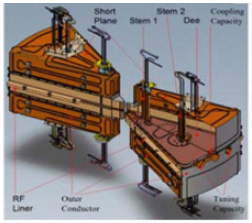


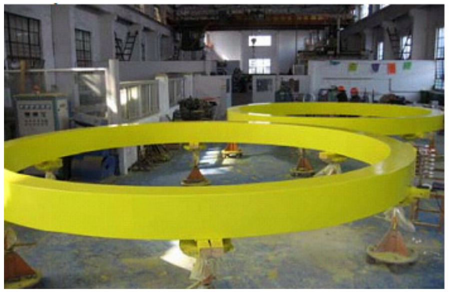
BRIF：CYCIAE-100MeV Cyclotron，2014-CIAE

Main parameters	
Energy	75~100MeV
Beam Current	200~500uA
Frequency	43~45MHz
RF Power	2×100kW







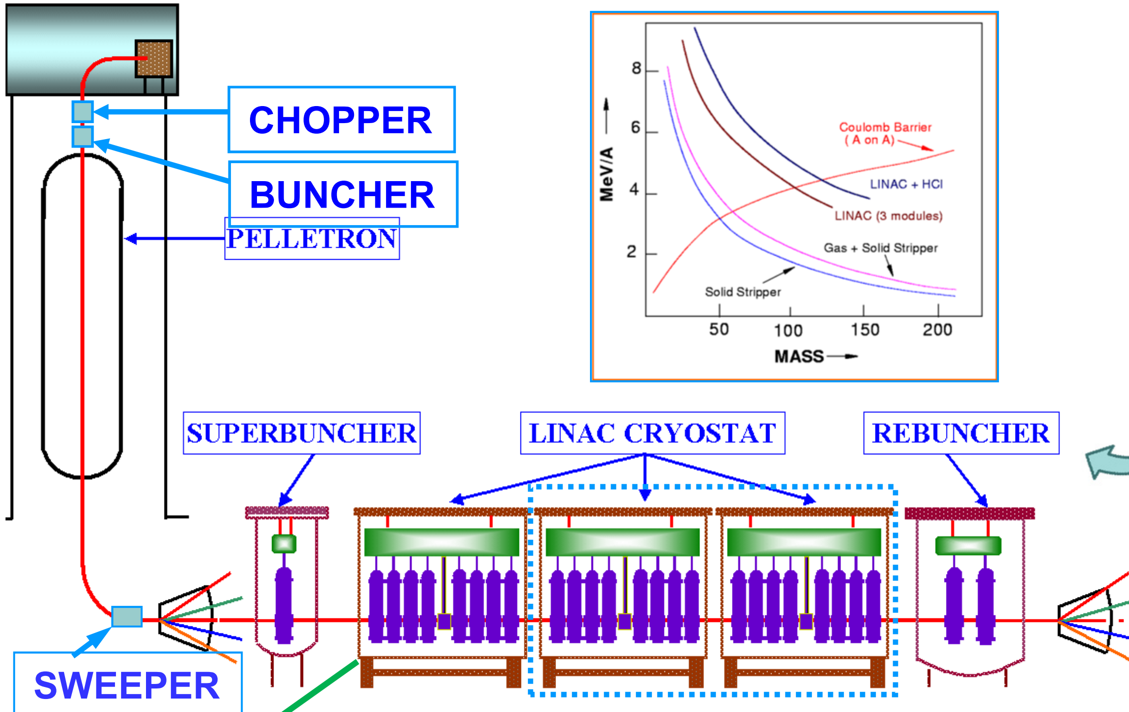


Development of SC Linac of IUAC, India

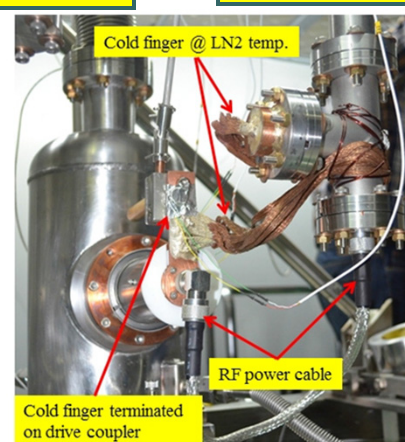
- Nuclear Physics
- Material Science
- Biophysics
- Ion bean analysis etc.

Table 1: Beams accelerated through Linac

Beam species	Pelletron energy (MeV)	ΔT @ Linac entrance (ps)	Egain from LINAC (MeV)	Total energy (MeV)
$^{48}Ti^{14+}$	162	~204	108	270
	162	~185	95	257
$^{30}Si^{12+}$	112	~132	84	196
$^{28}Si^{11+}$	124	~143	65	189
$^{28}Si^{8+}$	110	~225	50	160
$^{30}Si^{12+}$	100	~260	80	180



Ti_{48}^{+14} = 160 MeV → Ti_{48}^{+14} = 270 MeV (310)



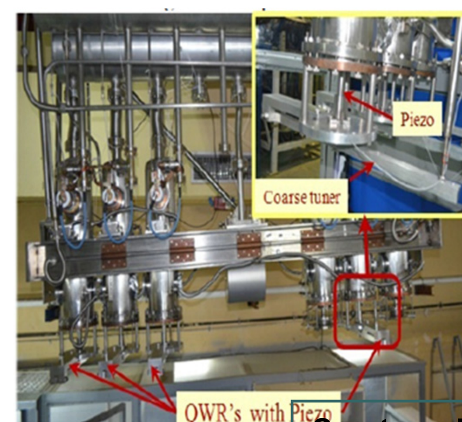


Figure 1: The third module with piezo tuner

Courtsey: IUAC

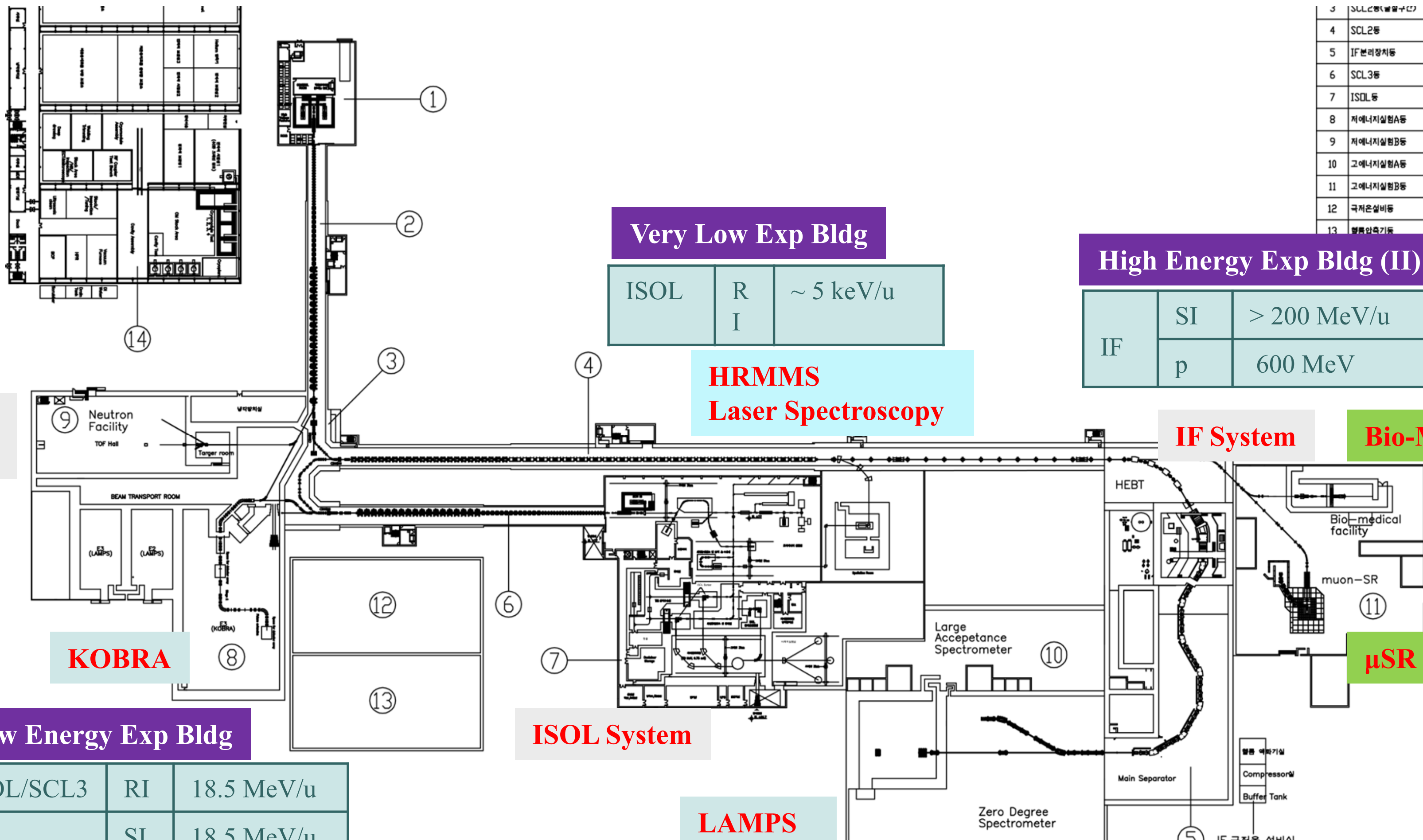
Rare Isotope Science Project (RISP) at Daejeon

(2011. 12 ~ 2021.12)

- High Intensity RI beams by ISOL and IFF
  - 70 kW ISOL from direct fission of ^{238}U by 70 MeV, 1 mA protons
  - 400 kW IF by 200 MeV/u, 8 pμA ^{238}U
- High energy, high intensity & high quality neutron-rich RI beam
  - ^{132}Sn with ~250 MeV/u, up to $9x10^8$ pps
- More exotic RI beams by ISOL+IF+ISOL(trap)
- Simultaneous operation of ISOL and IFF for the maximum use of the facility

	Driver Linac				**Post Acc.**	**Cyclotron**
Particle	H^{+}	O^{+8}	Xe^{+54}	U^{+79}	RI beam	proton
Beam energy (MeV/u)	**600**	**320**	**251**	**200**	**18.5**	**70**
Beam current (pμA)	660	78	11	8.3	-	1000
Power on target (kW)	**> 400**	**400**	**400**	**400**	-	70

Facility Layout



Neutron Science

KOBRA

ISOL System

HRMMS
Laser Spectroscopy

LAMPS
HRS,ZDS

IF System

Bio-Medical

μSR

Very Low Exp Bldg

ISOL	RI	~ 5 keV/u

High Energy Exp Bldg (II)

IF	SI	> 200 MeV/u
	p	600 MeV

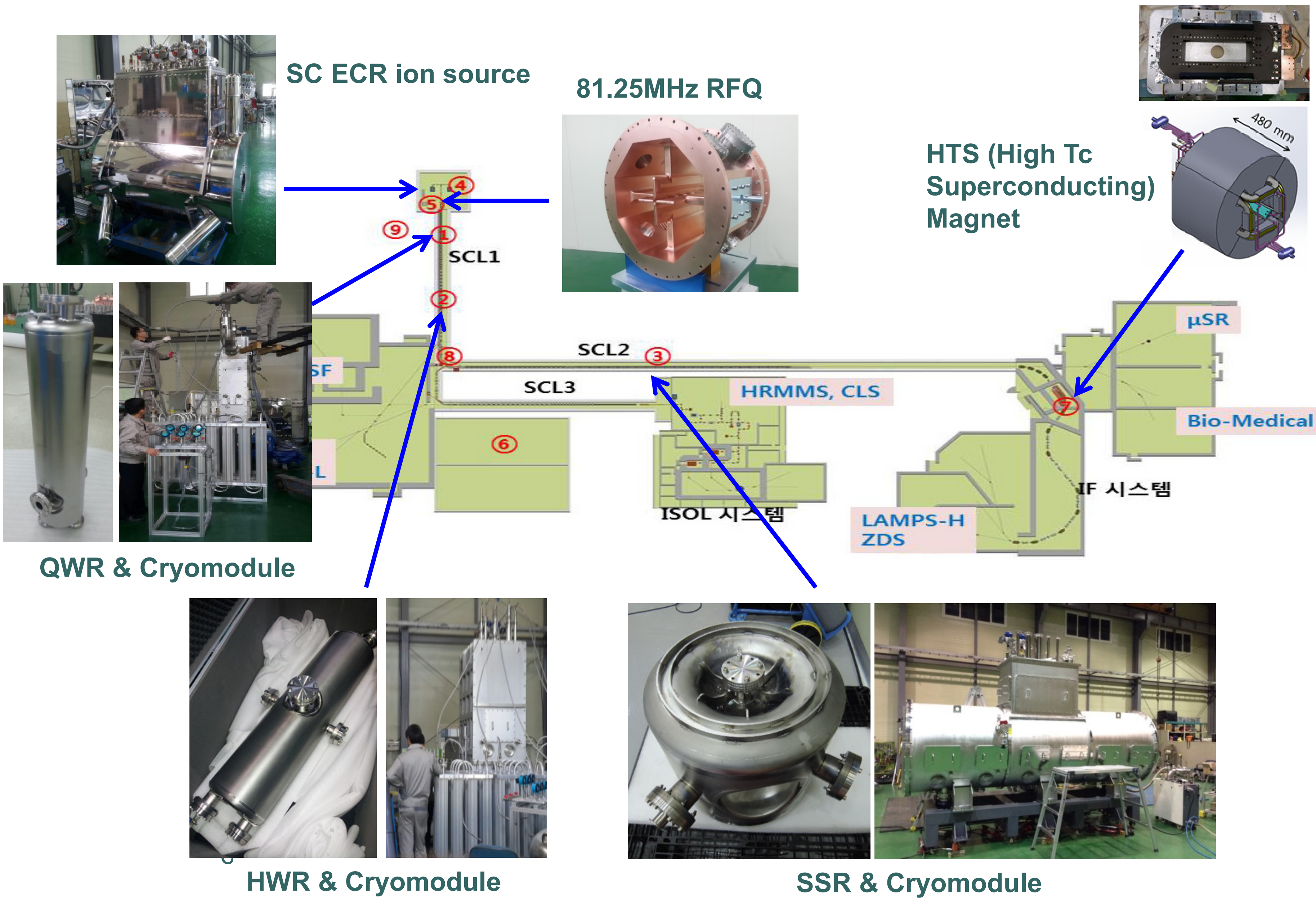
Low Energy Exp Bldg

ISOL/SCL3	RI	18.5 MeV/u
SCL1	SI	18.5 MeV/u
	p	88 MeV
	D	53 MeV

High Energy Exp Bldg (I)

IF	SI	> 200 MeV/u
	RI	~ 200 MeV/u

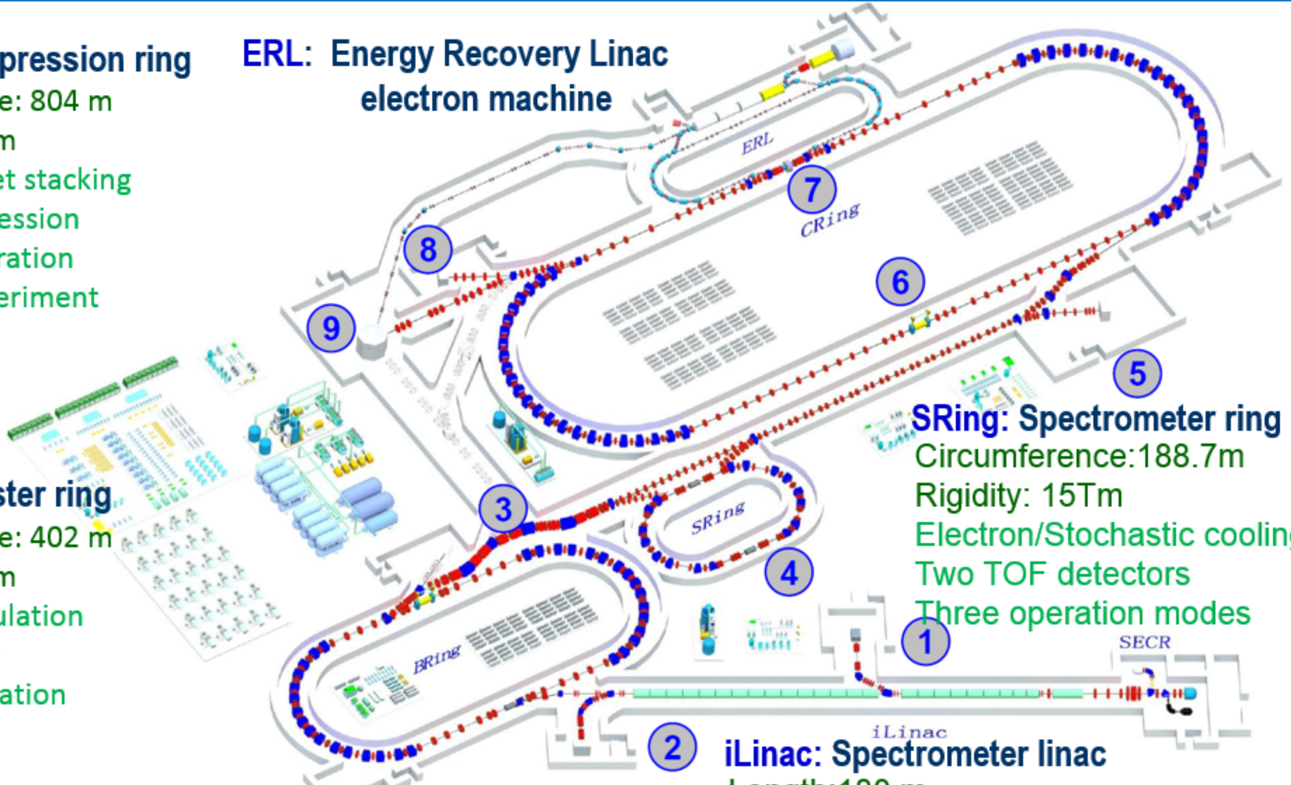
Status of Prototyping



HIAF(Heavy Ion Accelerator Facility) -IMP
@Huizhou Guangdong, P: 12GeV $^{238}U^{92+}$: 238GeV

CRing: Compression ring
Circumference: 804 m
Rigidity: 43 Tm
Barrier bucket stacking
Beam compression
Beam acceleration
In-beam experiment

ERL: Energy Recovery Linac electron machine



SRing: Spectrometer ring
Circumference:188.7m
Rigidity: 15Tm
Electron/Stochastic cooling
Two TOF detectors
Three operation modes

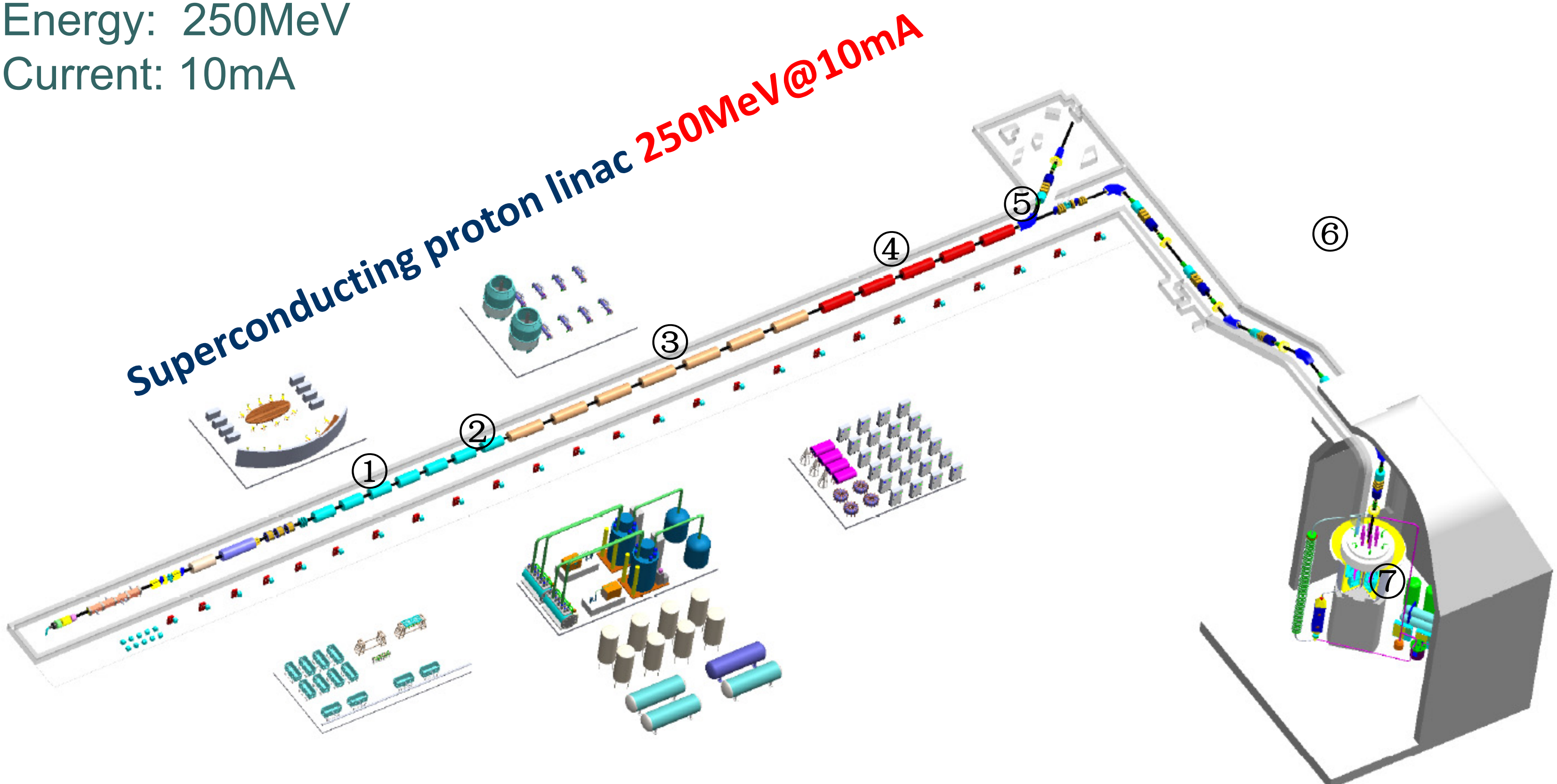
BRing: Booster ring
Circumference: 402 m
Rigidity: 34 Tm
Beam accumulation
Beam cooling
Beam acceleration

iLinac: Spectrometer linac
Length:180 m
Energy: 25MeV/u(U^{34+})

1. Nuclear structure spectrometer
2. Low energy irradiation target
3. RIBs beam line
4. High precision spectrometer ring
5. External target station
6. Electron-ion recombination spectroscopy
7. Electron-Nucleus Collision (ENC)
8. High Energy Density Physics target
9. High energy irradiation target

CIADS– IMP/IHEP/CIAE @ Huizhou Guangdong

CIADS: China Initial ADS
Energy: 250MeV
Current: 10mA

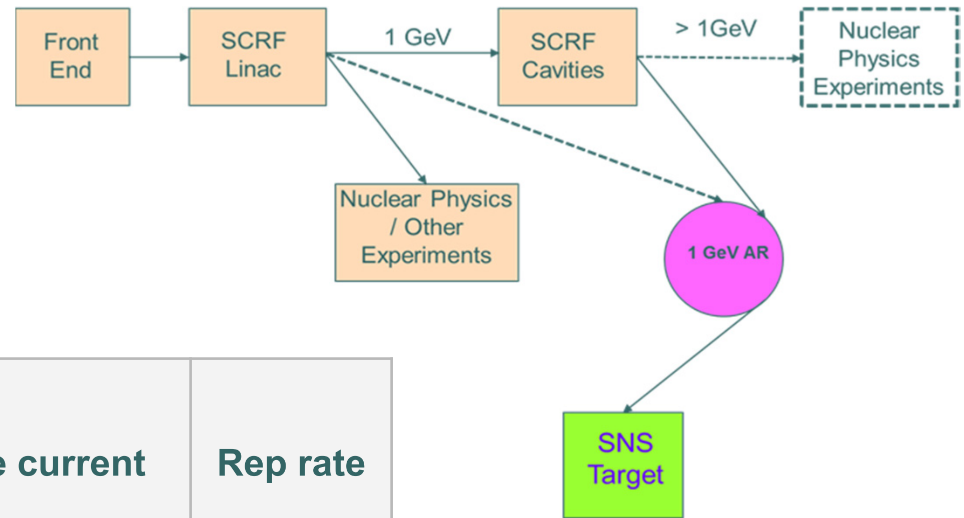


① Injector 10 MeV HWR
② MEBT
③ Spoke021 section

④ Spoke040 section
⑤ Spoke063 section
⑥ Coupling section between accelerator and target
⑦ Reactor

Proton Linac System at RRCAT & BARC

- Proton linac for Accelerator Driven System (ADS)
- Injector linac for Spallation neutron Source (SNS)

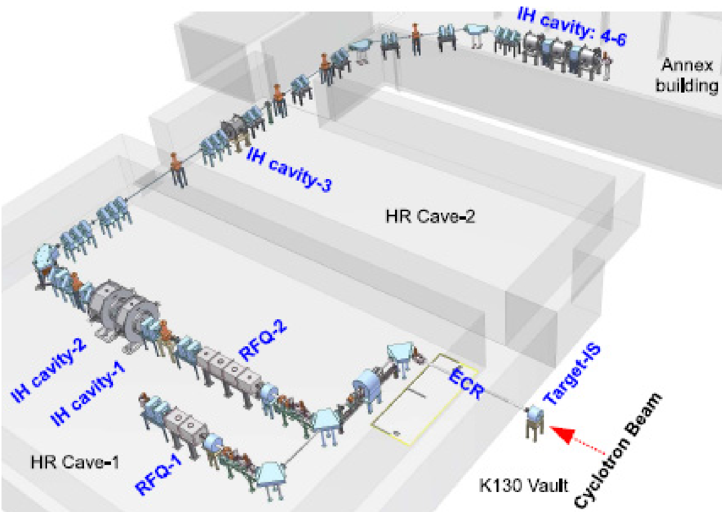


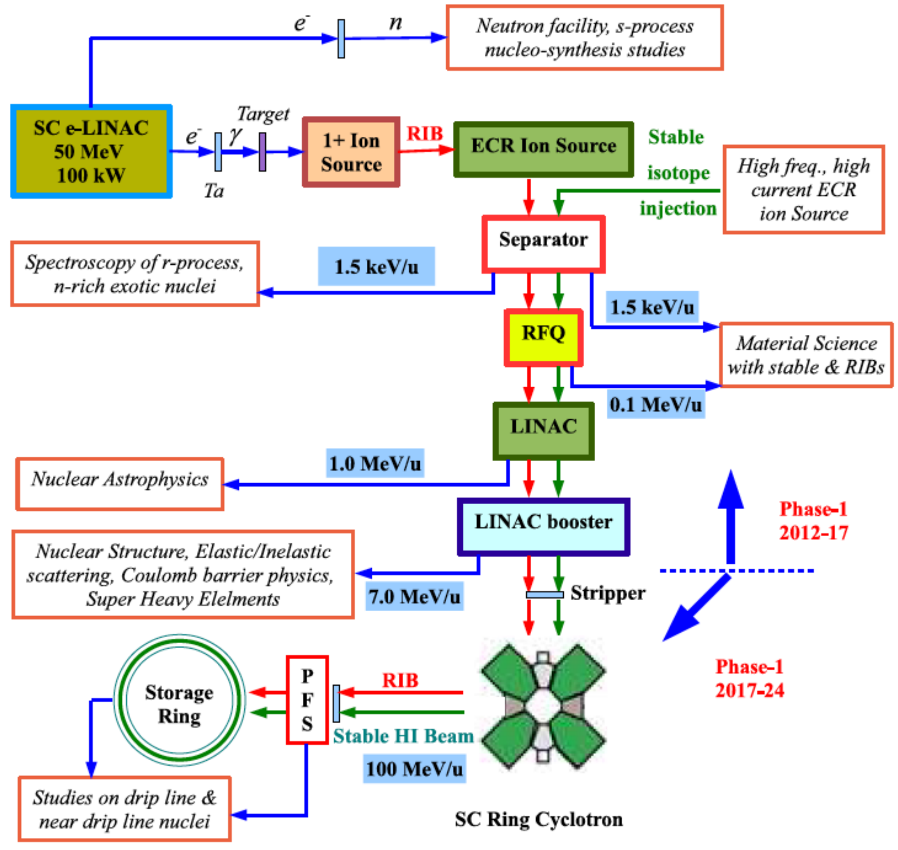
Schematic of ISNS Layout

	Ions	Energy	Average current	Rep rate
ADS	Proton	1 GeV or higher	>10 mA	CW
SNS	H^-	1GeV	1 mA or higher*	20-50 Hz

* Typical pulse duration : 500 μs - 1ms, Peak current : 20 - 50 mA

RIB--VECC—India





Summary

- Accelerator developments are very strong in Asia, from colliders, light sources, to proton and heavy ion facilities;
- There are a dozen accelerator projects under construction and R&Ds at national labs and universities.
- New projects and proposals are still emerging;

Thank you for your attention!

It is impossible to make a complete and precise survey within a short time, and it is no space for me to include the accelerators for medical applications and mass spectrum analysis. Please let me know if there is something not updated or incorrect.