Light source development in Korea:

Past, present & future

S. Shin, H. S. Kang, M. H. Cho, W. Namkung, I. S. Ko

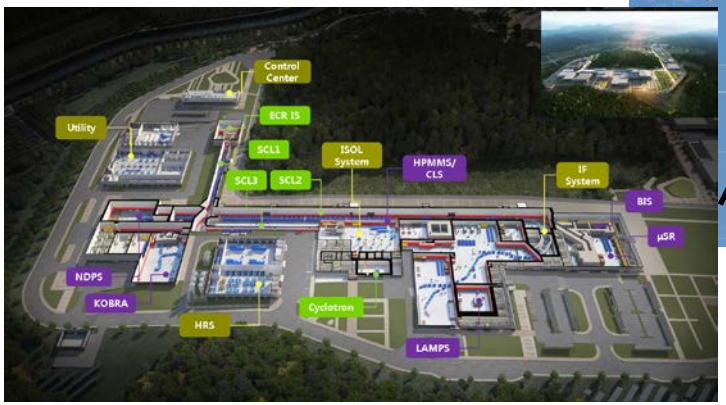
(PAL / POSTECH)

E-S. Kim (Korea University), Y. U. Jung (KAERI)

Large scale accelerators in Korea

10 GeV FEL 3 GeV SR

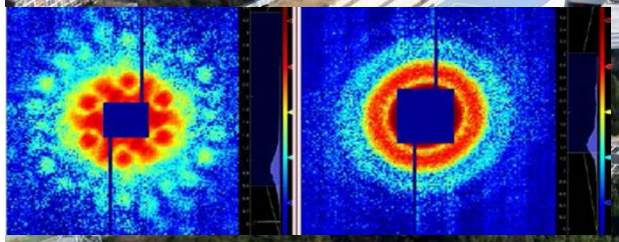
Rare Isotope Accelerator



100 MeV Proton

Light sources in Pohang

PAL X-FEL demo experiment
Coherent X-ray imaging
(March, 2017)



PLS-II and PAL-XFEL Facilities (June, 2015)

K.-J. Kim in PLS IAC meeting

PAL Overview: Chronology

I. PLS

- Project started — Apr. 1988
- User service started — Sep. 1995

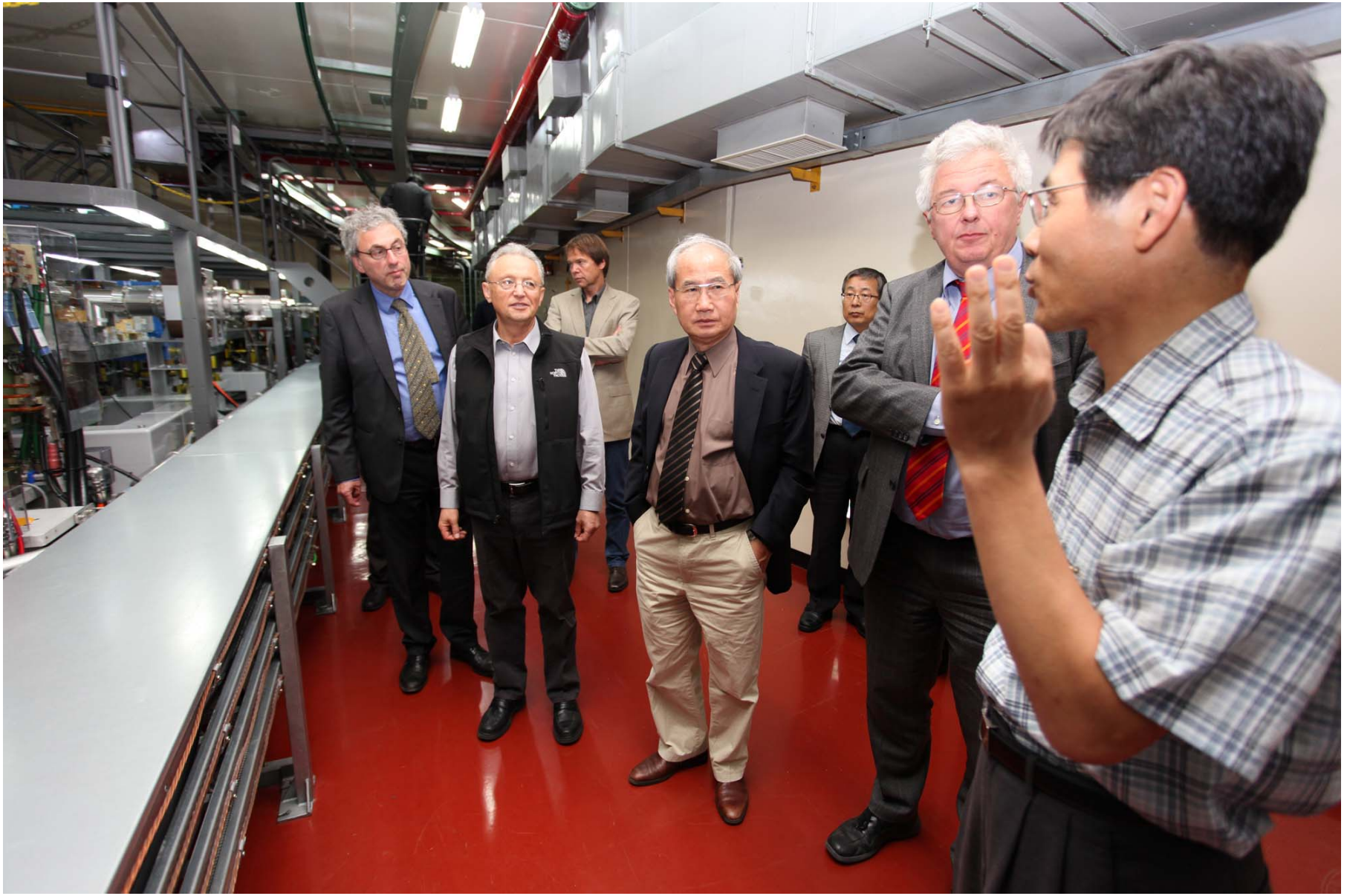
II. 2nd Major Upgrade of the PLS (PLS-II)

- 3.0 GeV PLS-II Upgrade begin — Jan. 2009
- 3.0 GeV PLS-II Upgrade Complete — Dec. 2011
- User service started — Mar. 2012
- 3.0 GeV 400 mA Top-up operation — July 2015

III. PAL-XFEL

- Government approval of PAL-XFEL project — Jan. 2010
- Beam commissioning started — April 2016
- Saturation of 0.1 nm FEL — Mar. 2017
- User service started — June 2017

K.-J. Kim in PLS-II tunnel



PLS-II upgrade project: Overview

○ **Main goals**
- Beam energy : 2.5 → 3.0 GeV
- Current : 200 → 400 mA
- Storage Ring Emittance : 18.9 → 5.8 nm
- Top-up Operation mode
- No. of Insertion Device : 10 → 20

○ **Important improvement besides goals**
- In-vacuum undulator development
- PAL-DCM development
- New instrumentations: Libera BPM, etc.
- Introduction of Superconducting system
- BL experiment environment

PLS

PLS

Dismantling

DEC. '10

Re-installation

JAN. '11

PLS-II

PLS-II

PLS-II overview: Linac

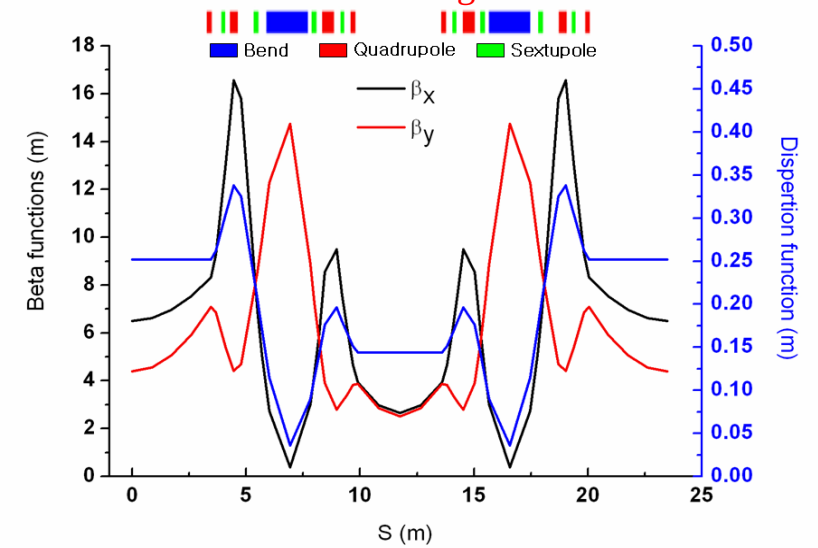
- Thermionic Electron Gun
- 17 Pulse Modulators (200MW, 7.5μs)
- 17 Klystrons (80 MW, 4μs)
- 16 Energy Doublers (gain=1.5)
- 46 Accelerating Sections

Injector LINAC

- **Length = 170m**
- **3.0 GeV, full energy injection**
- **2,856 MHz (S-band)**
- **10Hz, 1.5 ns, 1Å pulsed beam**
- **Norm. emmittance : 150μmrad**

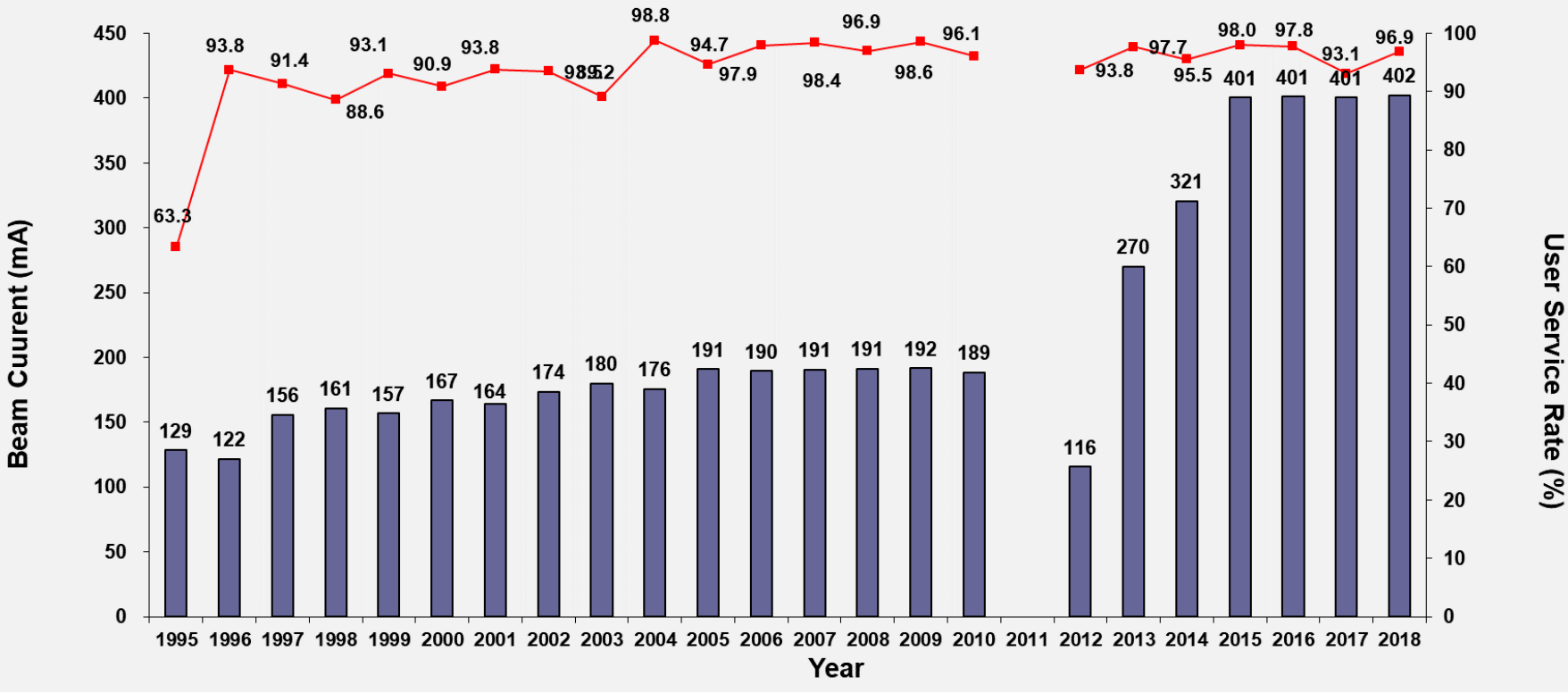
PLS-II overview: Storage ring

42 % of the circumference
available for straight sections

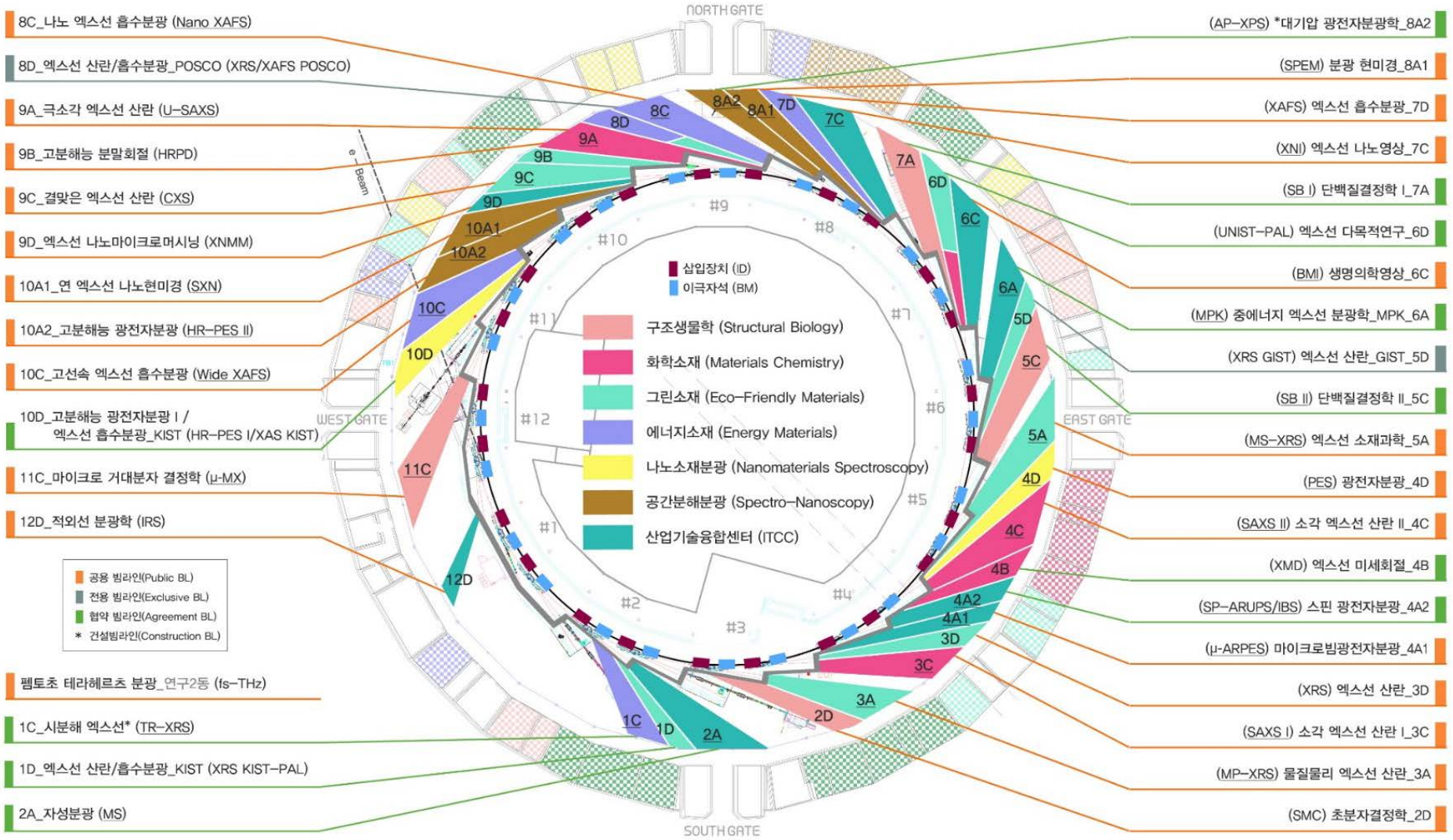


- **Beam Energy** 3.0GeV
- **Beam Current** 400mA
- **Lattice** DBA
- **Superperiods** 12
- **Emittance** 5.8 nm·rad
- **Tune** 15.37 / 9.15
- **RF Frequency** 499.97 MHz
- **Circumference** 280 m

PLS-II operation: Availability and beam current

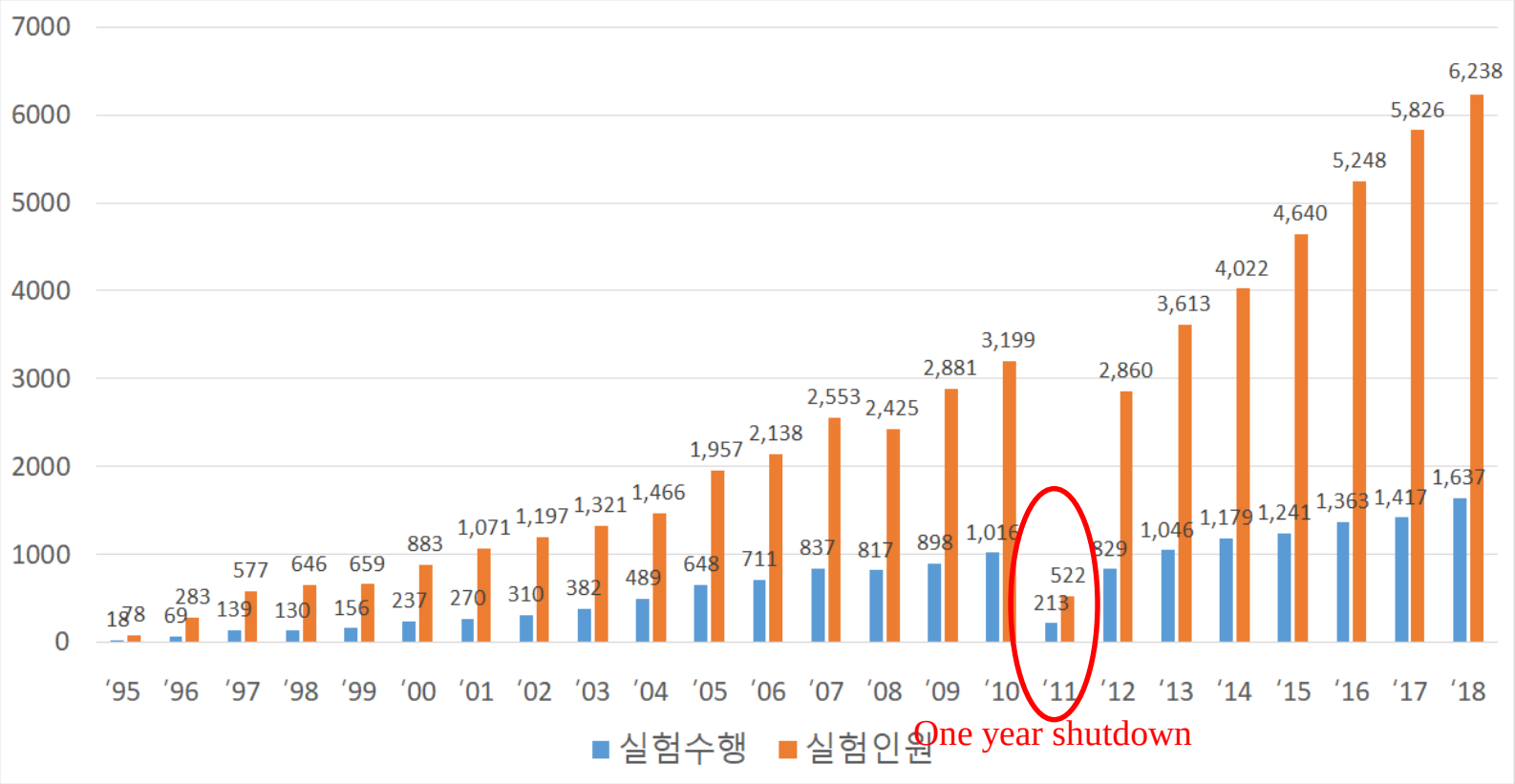


Beamline map: 34 Beamlines



PAL operation: User statistics

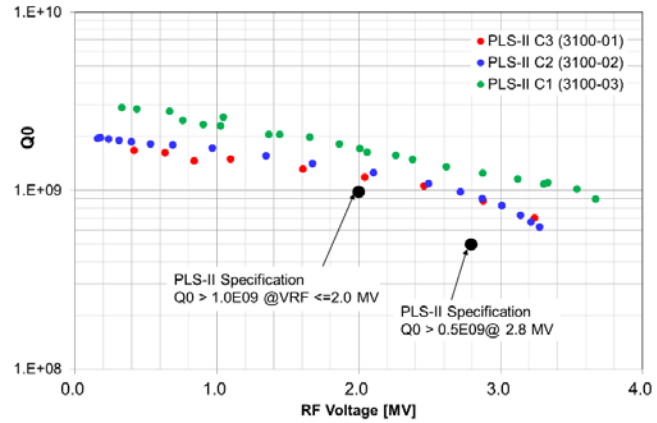
1. User Statistics.

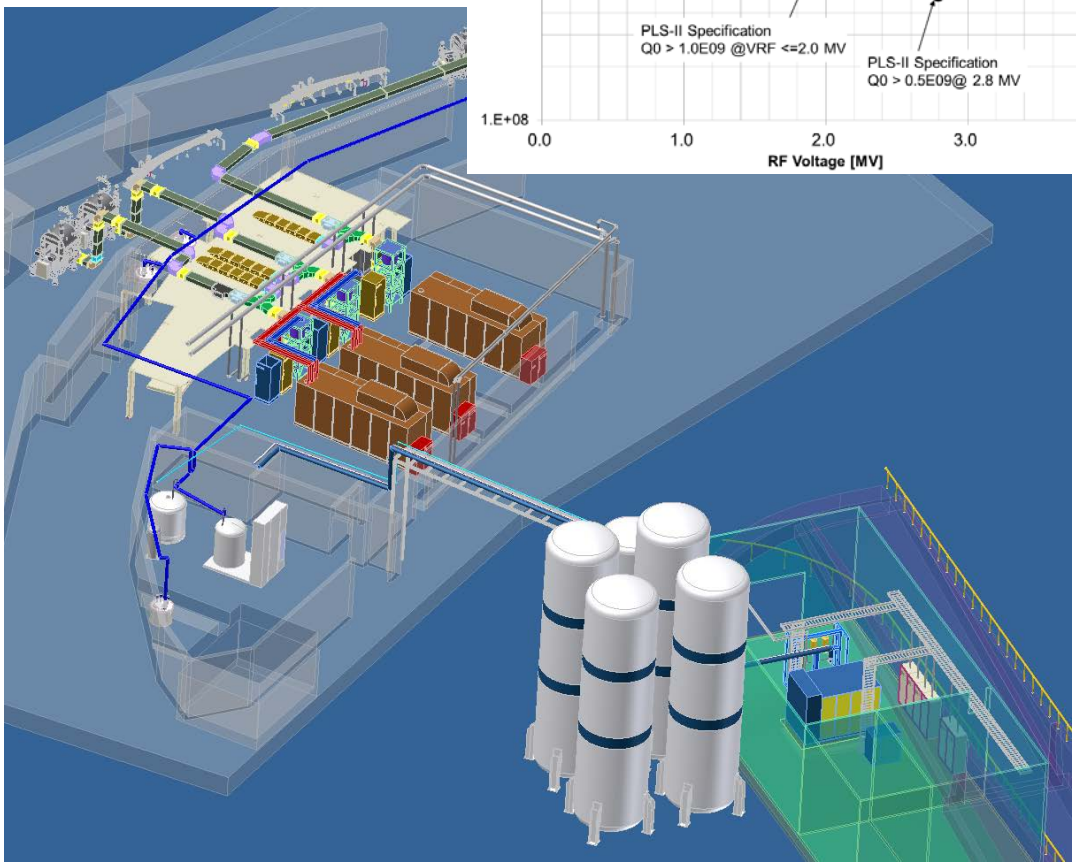


2. Block beam time program in foreign facilities (during shutdown).
   - Budget U$ 100,000.
   - In total of 213 experiments.
   - PF, RIKEN, SSRF, NSRL.

K.-J. Kim in SRF workshop

PLS-II SRF: Introduction





Layout of SRF system

Spec. of SRF Module

Parameters	Values
Resonant frequency [MHz]	499.654
R/Q [Ω]	89
Q_0	$>5\times10^8$ @ Vacc = 2.0 MV
Q_e	1.7E5 +/- 0.2E5
Frequency tuning (step-motor)	±150 kHz with resolution of 10 Hz
Operating Temperature [K]	4.5
Accelerating Voltage/Cavity [MV]	1.2 – 2.3
Max. RF Power / Cavity [kW]	300
HOM Removal	Ferrite Absorber
Input power coupler	Waveguide
Window	• 500 kW, matched with beam • 150 kW, unmatched condition
Material, cavity	Niobium, RRR > 250
Model, type	CESR-B type, single cell
Thermal loads/module [W] @4.5K	• Static loss: 60 (CM+VB+TL) • Dynamic loss @2.0MV: 60
Pressure stability @He vessel	±1.5 mbar
LHe level stability	±1 %
Vendor	RI, Research Instrument, Germany

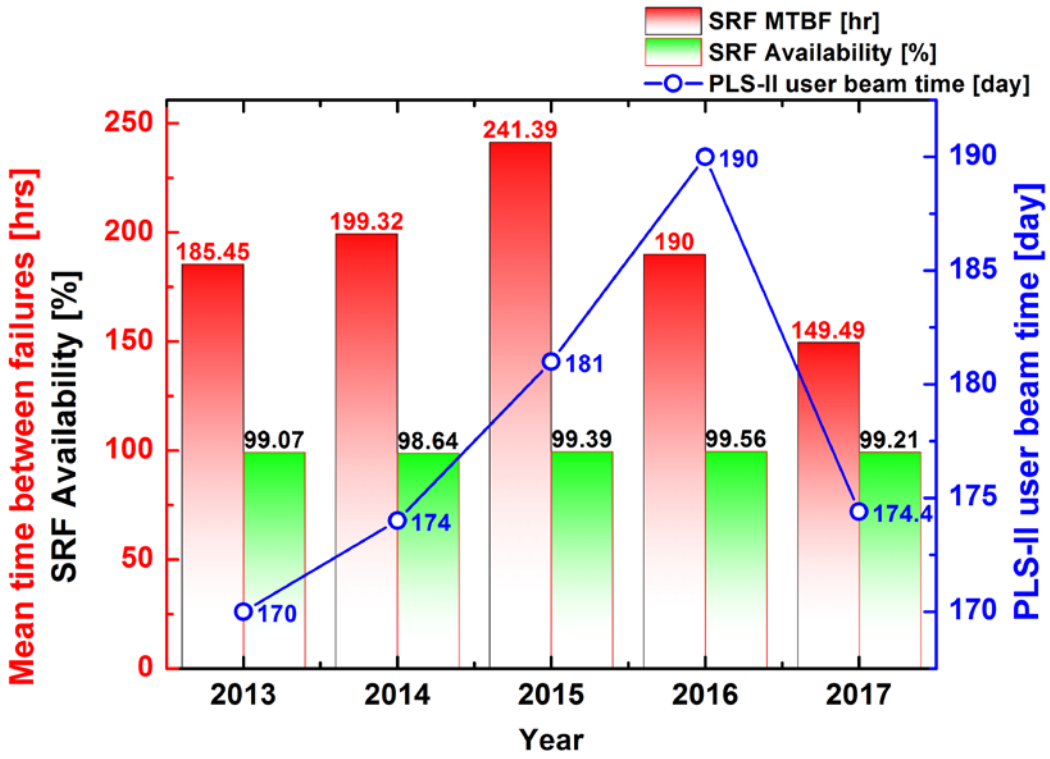
Spec. of He Cryogenic

Parameters	Values
Cooling Capacity	• 750 W @4.5K, W/ LN2 precooling + (plus) 58 liter/hour liquefaction • 470 W @4.5K, W/O LN2 precooling + (plus) 48 liter/hour liquefaction
Nominal power, compressor	250 kW (380VAC, 3ø)
Dewar Capacity	2000 liter, 80% operation max.
Dewar opr. Pressure	1300 mbar, with +/- 1.5 mbar
Operation mode	Refrigeration with partial liquefaction
Vendor	Air Liquide, France

PLS-II SRF: Performance

Year	Fault #	Fault time [min]
2013	22	2280
2014	21	3412
2015	18	1584
2016	24	1202
2017	28	1975
2018*	>23	>850

*upto Oct. 1st



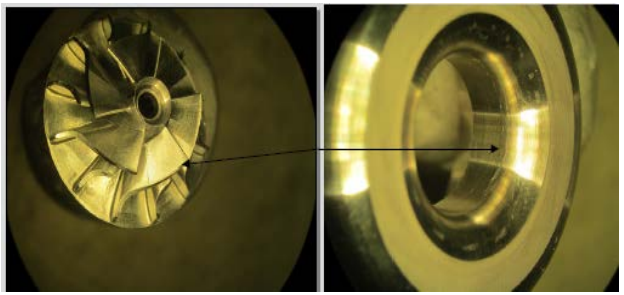
In 2017,

PLS-II user beam time was reduced by Earthquake and Cryogenic cold turbine faults (The fault time was not counted in the calculation of SRF availability)

MTBT of SRF was reduced by 7 times of cavity field signal blip

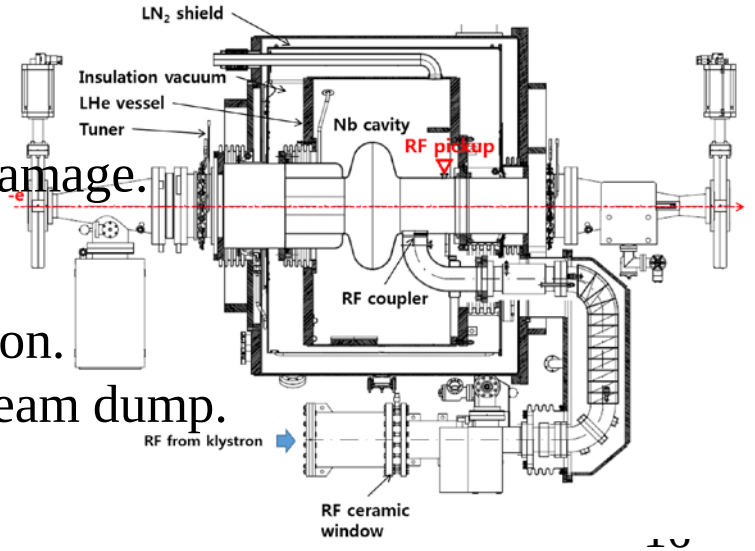
PLS-II SRF: Troubling shoot

1. Cold turbine fault.
   - Interruption of beam service during 2.5 Months.
   - Additional spare cold turbine is ready.
   - Higher purity of LHe have been maintained.



2. Control server (for CG) down by earthquake.
   - Interruption of beam service during 3 weeks.
   - Duplexing UPS system is being prepared.

3. Signal blip in cavity pick-up
   - By-pass circuit for filtering fake signal.
   - Spare CM is being prepared for pick-up damage.



4. Beam dump during CG adsorber regeneration.
   - It disturbs RF field in cavity and causes beam dump.
   - Remedy by optimizing value speed.

Topics for the next step

I. Beam stability

- Injection system upgrade (Single kicker PS -> Individual kicker PS)
- Speed-up on FOFB (800 Hz -> 5 kHz)
- Measurement on user experiment performance (constant time etc.)

II. Study for the PLS-II performance

- Canted ID study in 6.5 m straight section
- Super bend for imaging BL (8.7 keV -> 17 keV)
- High energy photon source (SC MPW, SC undulator, etc.)

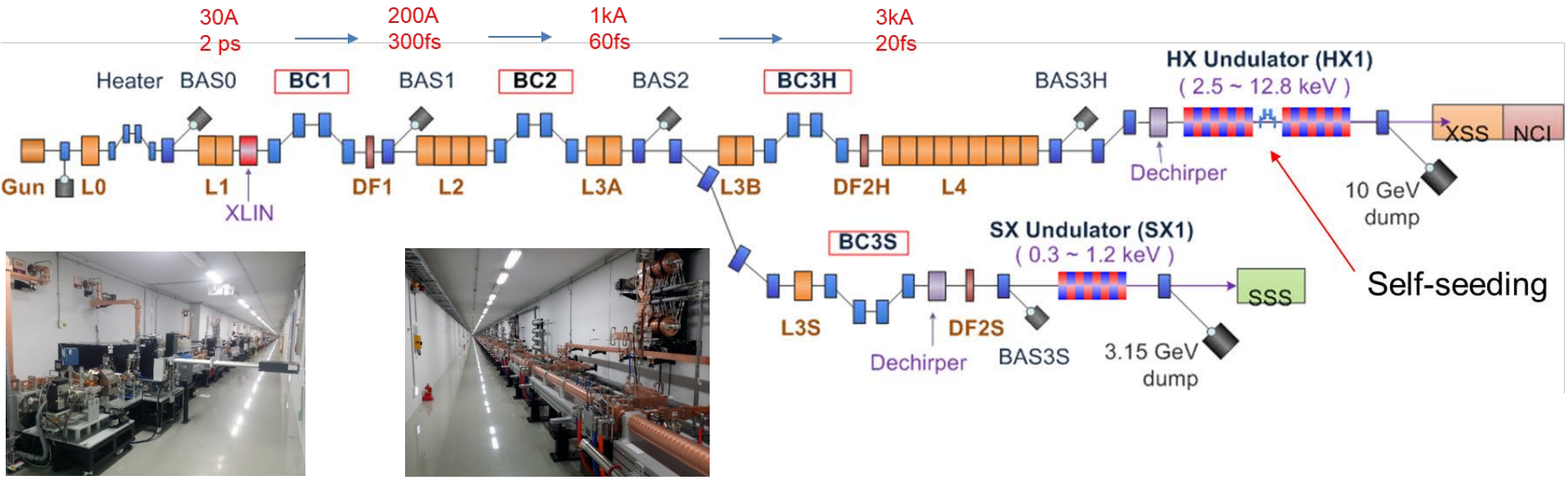
III. Machine hardware

- Localization and commercialization for Linac RF components (10 GeV PAL X-FEL as well as 3 GeV PLS-II)
- Short pulse kicker (< 10 ns)

K.-J. Kim in FEL workshop

K.-J. Kim during FEL lecture

PAL-XFEL Parameters

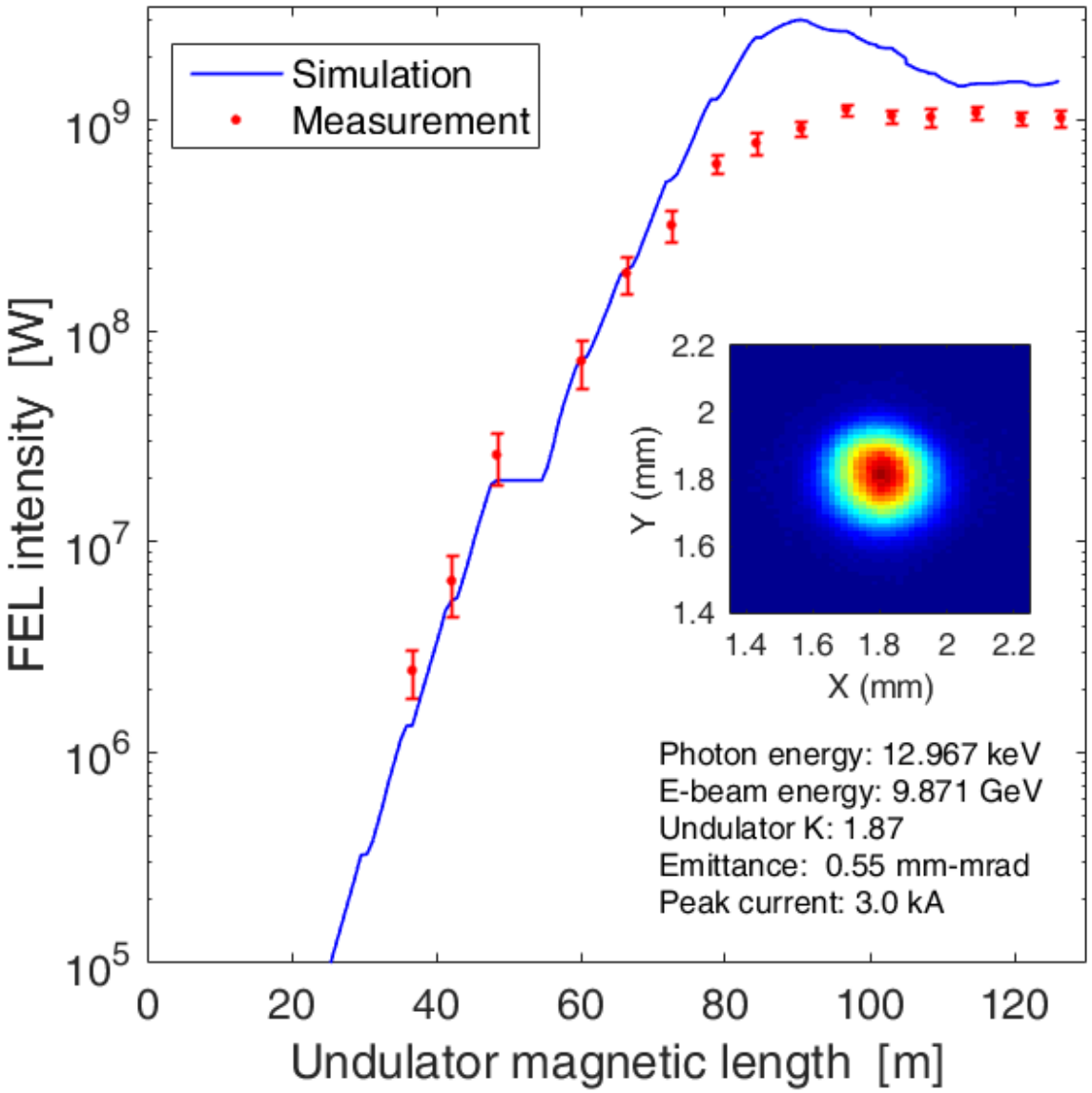


Main parameters

e⁻ Energy	10 GeV
e⁻ Bunch charge	20-200 pC
Slice emittance	< 0.5 mm mrad
Repetition rate	30 Hz (60 Hz)
Pulse duration	10 fs – 100 fs
Peak current	3 kA
SX line switching	DC (Phase-1) Kicker (Phase-2)

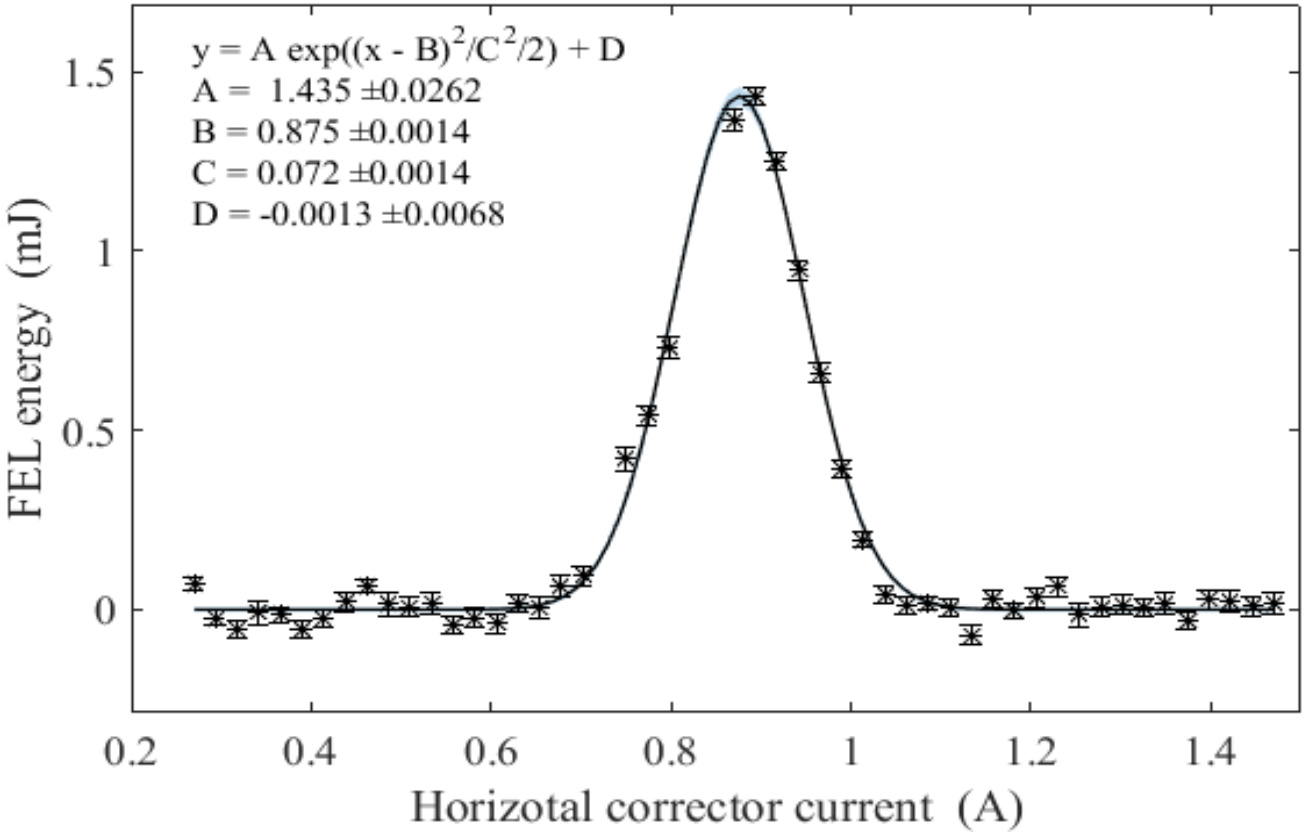
Undulator Line	HX1	SX1
Photon energy [keV]	2.5 ~ 12.8	0.3 ~ 1.2
Beam Energy [GeV]	4 ~ 10	3.15
Wavelength Tuning	energy	gap
Undulator Type	Planar, out-vac.	Planar
Undulator Period / Gap [mm]	26 / 8.3	35 / 9.0

Saturation of 0.1 nm FEL (Mar. 16, 2017)

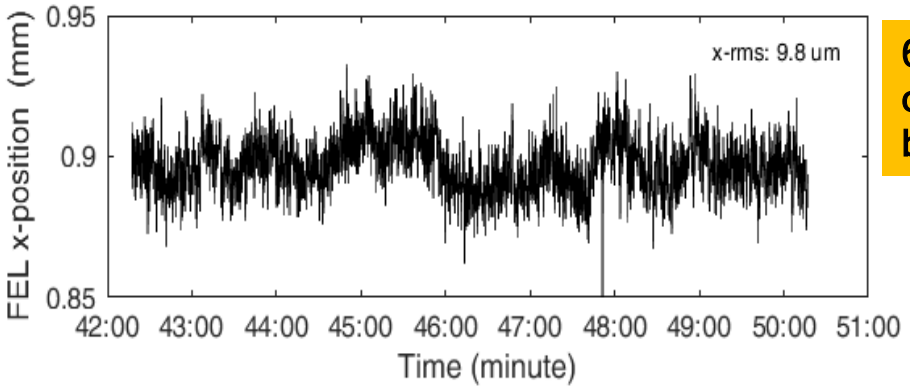


Highest hard x-ray FEL intensity

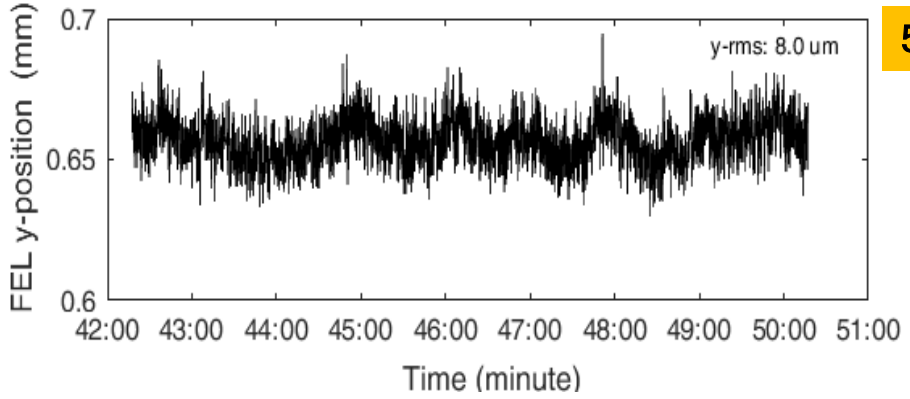
1.43 mJ at 9.7 keV (achieved on Sep. 7, 2018)



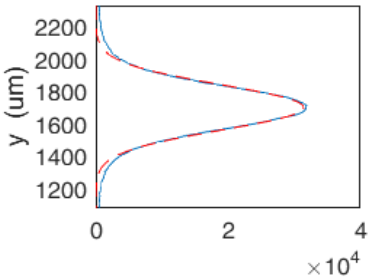
FEL Beam position jitter

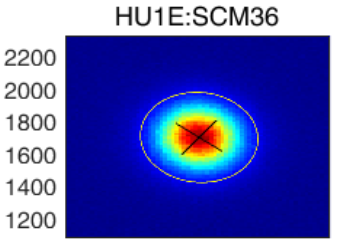


6.9 % of photon beam size

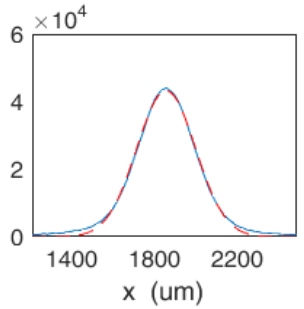


5.7 %





xrms = 140.81 um
yrms = 139.29 um

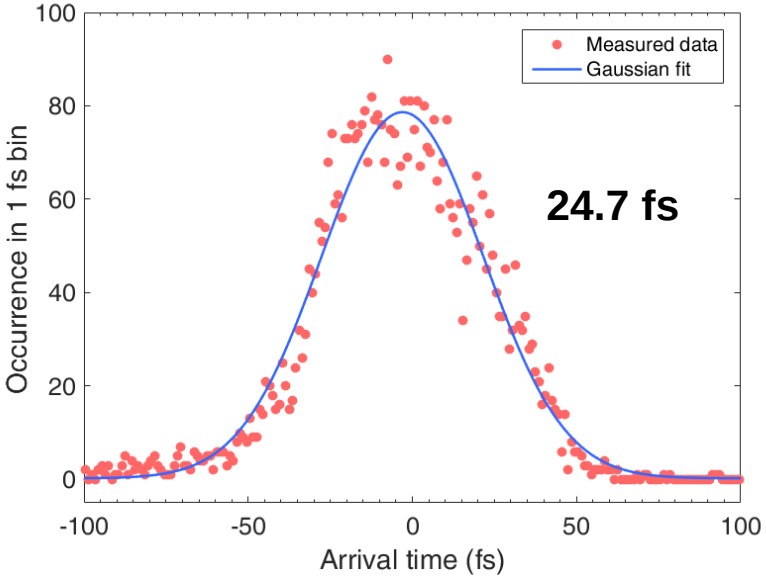


- FEL beam divergence angle: 1.6 μrad
- Angle jitter: 0.14 μrad in rms

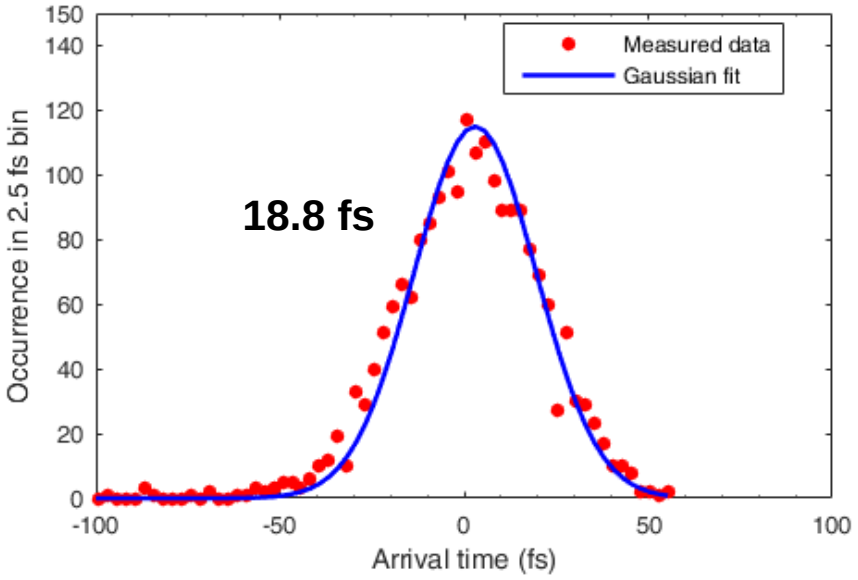
FEL timing jitter

A reliable FEL beam with unprecedented temporal stability is provided to users

OXC : Optical laser & XFEL Cross-correlator



E-beam pulse arrival time



Demo Experiment: Result

M. Harmand *et al.* Achieving few-femtosecond time-sorting at hard X-ray free-electron lasers. *Nature Photon.* 7, 215-218 (2013).

nature photonics
LETTERS
PUBLISHED ONLINE: 17 FEBRUARY 2013 | DOI: 10.1038/NPHOTON.2013.11

Achieving few-femtosecond time-sorting at hard X-ray free-electron lasers

M. Harmand[†]*, R. Coffee[2], M. R. Bionta[2,3], M. Chollet[2], D. French[2], D. Zhu[2], D. M. Fritz[2], H. T. Lemke[2], N. Medvedev[4], B. Ziaja[4,5], S. Toleikis[1] and M. Cammarata[6]*

LCLS

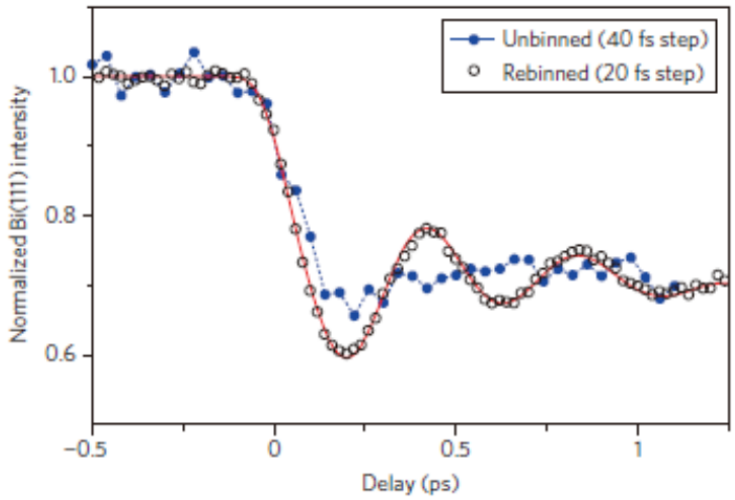
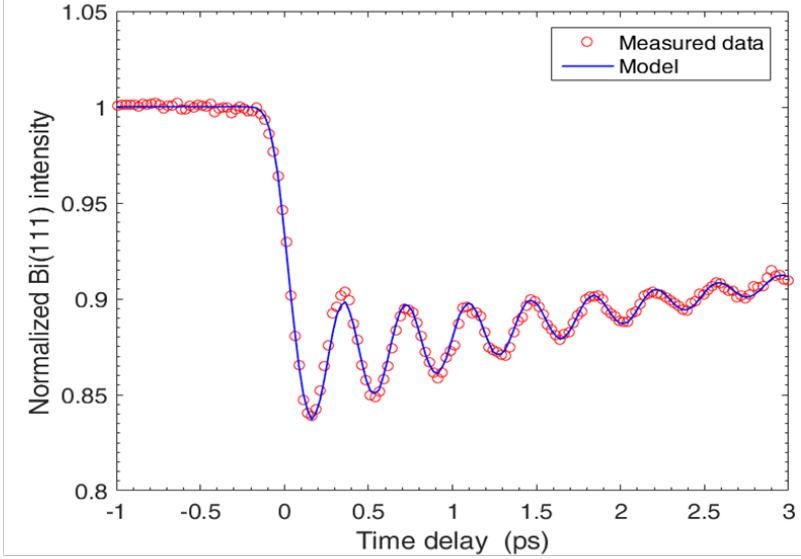


Figure 4 | Optically excited coherent A_{1g} phonon mode of bismuth.

- **No timing jitter correction**
- averaged by 50 trials of the time delay scan and normalized by GaSb(111) Bragg peak intensity
- **Only slow time-drift correction**
- **Vibration Frequency : 2.7 THz**
- Instrument Response: 137 fs (FWHM)

PAL-XFEL



K.-J. Kim in IAC meeting

FEL R&D Program

On-going R&D

- FEL optimization study for higher photon flux
  - 1.5 mJ at 9.7 keV achieved
  - orbit & energy jitter improved
- Two-bunch mode operation for two-color mode
  - to be tested soon
- 15 keV or higher photon energy
  – 14.5 keV lasing achieved (to be published in NIMA)
  – 16 keV lasing will be tested after we get an operation permission of 11-GeV operation
- Self-seeding mode for HX-FEL
  - Collaborative work with ANL and SLAC
  - Successfully commissioned in May 2018. The next test is on Nov. 17~19.
  - User service operation will begin in early 2019
- Pulse-by-pulse switching operation for SX-FEL
  – A kicker magnet and a power supply will be ready by August 2019
  – User service operation will begin in early 2020

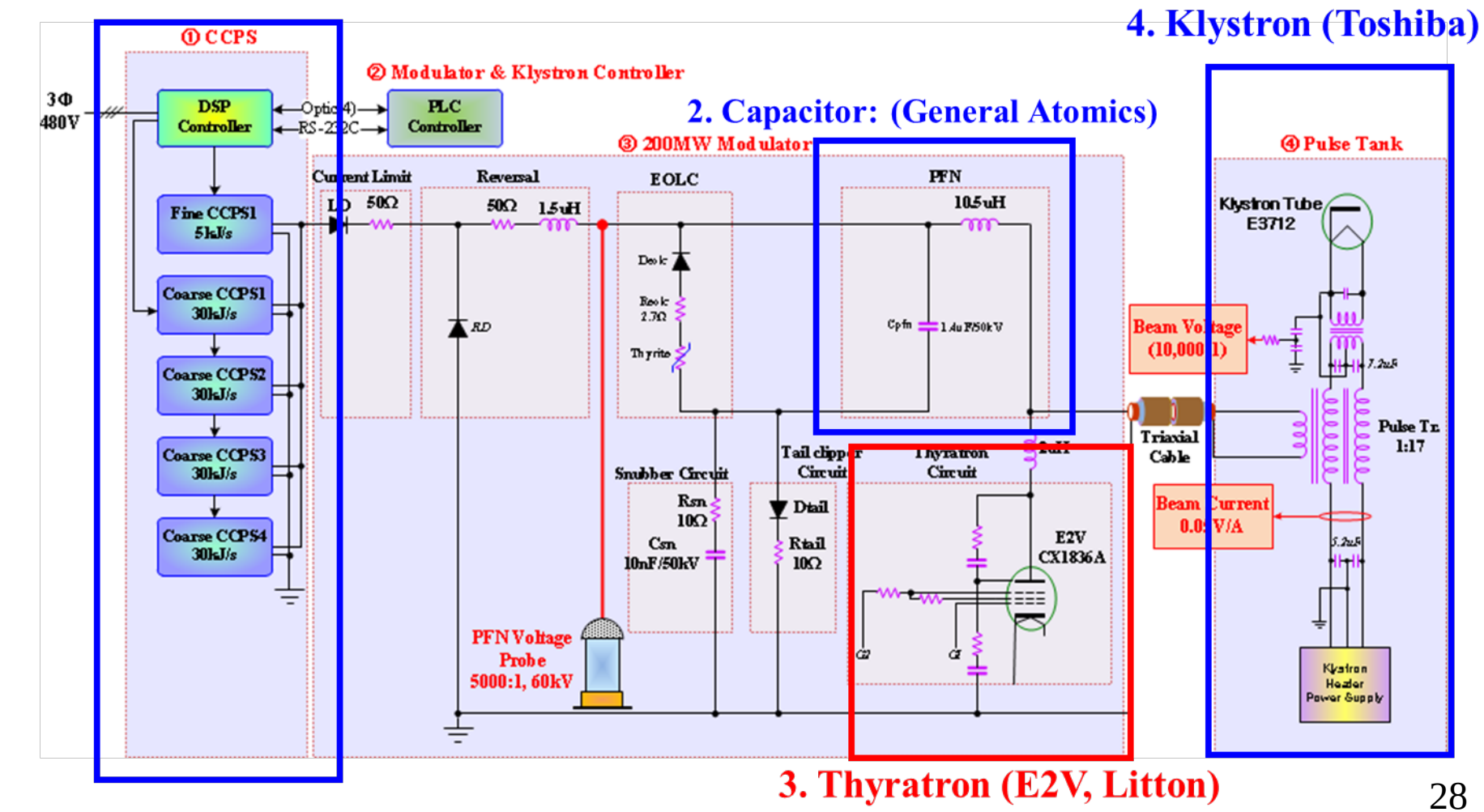
Long-term R&D

- Long-term R&D plan (reported at last IAC)
  - X-band deflector
  - Elliptical polarized undulator for SX-FEL

- More close to users' demand
  – **More beamtime and flux to users** (SACLA provides **four times more beamtime** to Hard X-ray users: 24 hour operation & two hard X-ray FEL line)

1) **2-nd Hard X-ray FEL line**
2) **120 Hz operation**

1. Circuit of MK system



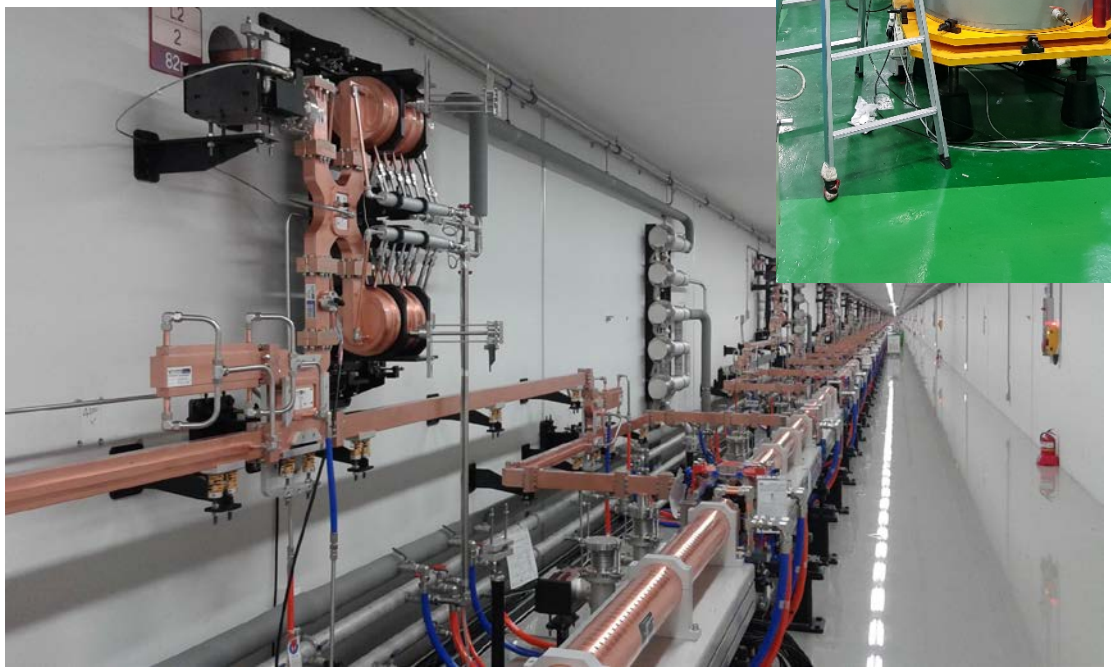
Localization and commercialization for Linac RF

2. PAL effort for commercialization

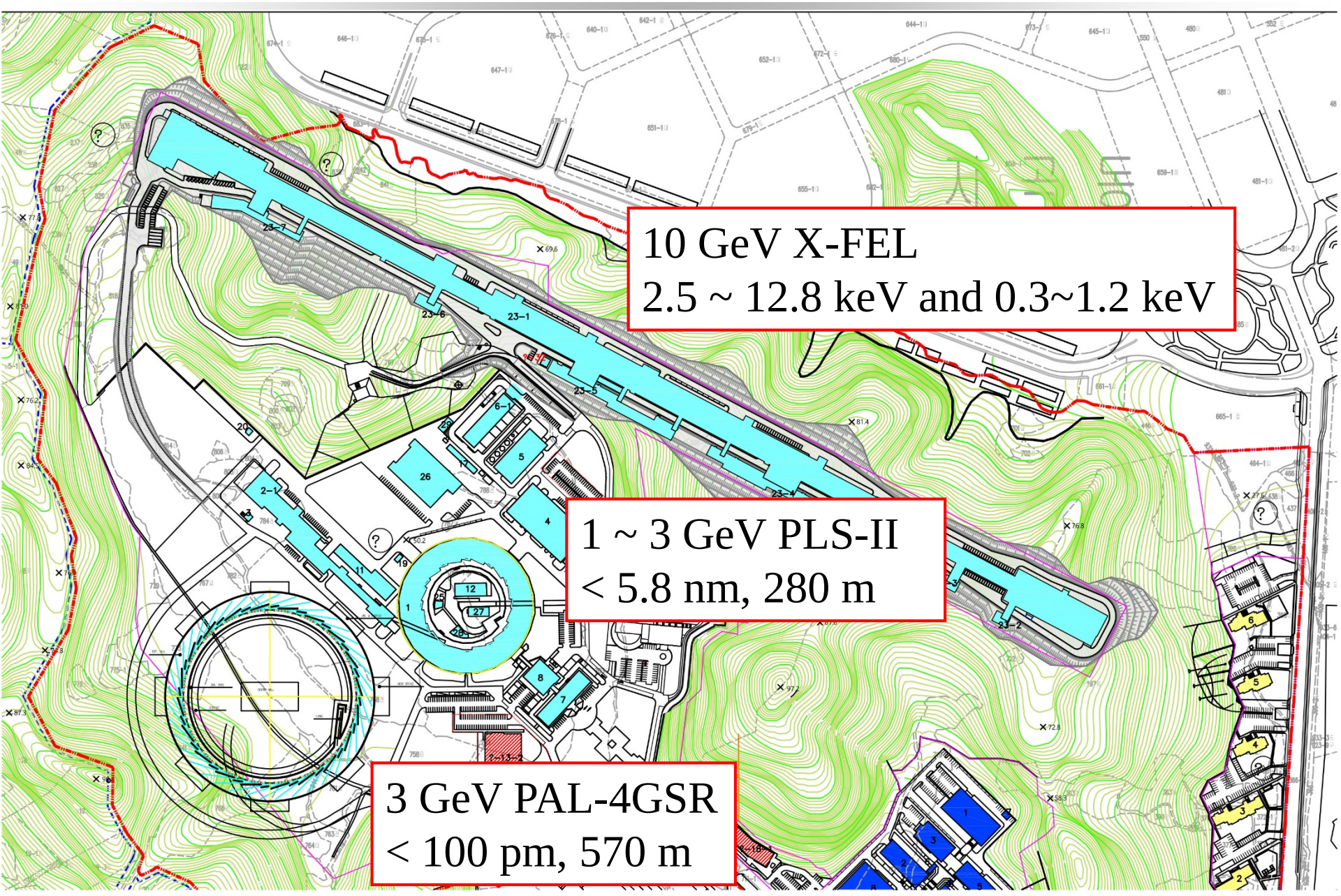
○ Done (4세대 사업에서)
- SLED (비츠로)
- CCPS (다원, 동아하이텍)
- Accelerator column (비츠로)
- RF window (비츠로)

○ On going (~ 2019)
- Klystron (비츠로)

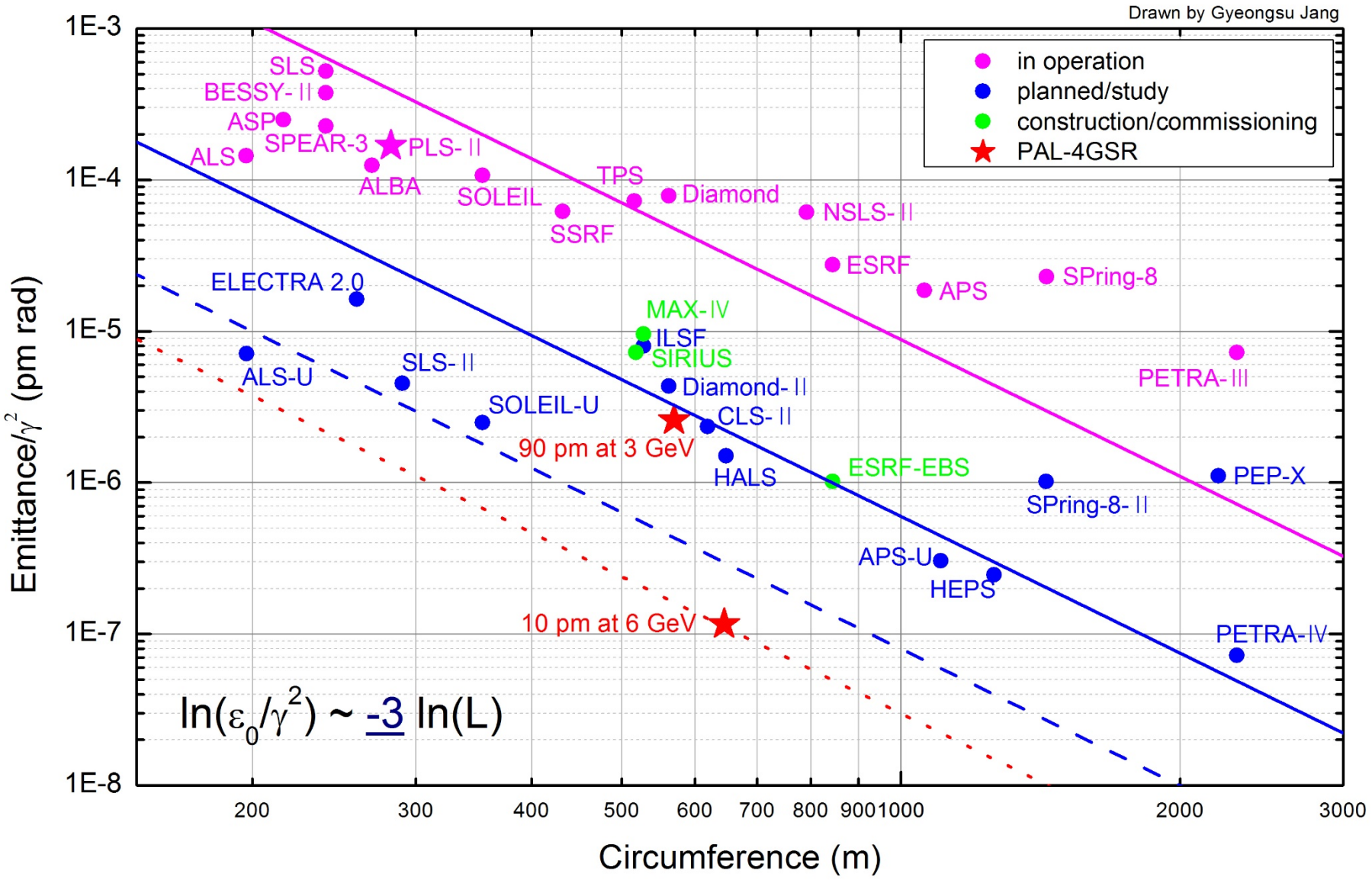
○ Future
- Thyratron
- E-gun
- Capacitor



4GSR at PAL


10 GeV X-FEL
2.5 ~ 12.8 keV and 0.3~1.2 keV
1 ~ 3 GeV PLS-II
< 5.8 nm, 280 m
3 GeV PAL-4GSR
< 100 pm, 570 m

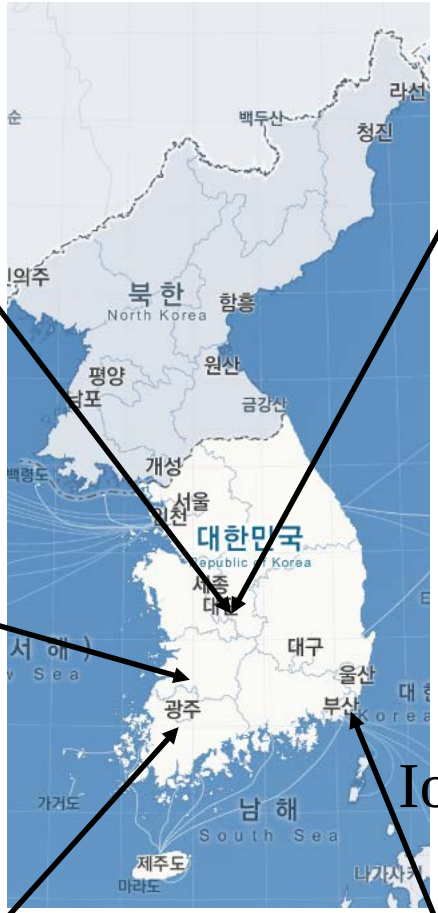
4GSR at PAL


Drawn by Gyeongsu Jang
in operation
planned/study
construction/commissioning
PAL-4GSR
SLS
BESSY-II
ASP
SPEAR-3
PLS-II
ALS
ALBA
SOLEIL
TPS
Diamond
SSRF
NSLS-II
ESRF
APS
SPring-8
ELECTRA 2.0
MAX-IV
ILSF
SIRIUS
ALS-U
SLS-II
Diamond-II
SOLEIL-U
CLS-II
90 pm at 3 GeV
HALS
ESRF-EBS
PETRA-III
PEP-X
SPring-8-II
APS-U
HEPS
10 pm at 6 GeV
PETRA-IV
ln(ε0/γ2) ~ -3 ln(L)
Emittance/γ2 (pm rad)
Circumference (m)
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
200
300
400
500
600
700
800
900
1000
2000
3000

Small scale accelerators in Korea

Acc. Department in KU

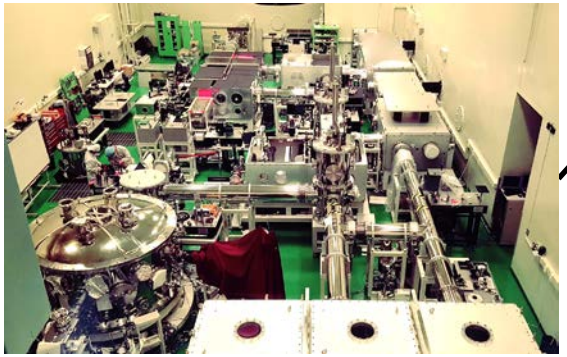
Radiation Center (KAERI)



Industrial Acc. (KAERI)

Acc. Lab in UNIST

Laser wakefield e Acc.



Ion Beam Accelerator (KBSI)

K.-J. Kim in workshop

2017 Workshop on Beam Dynamics & Accelerator Technologies

빔동역학과 기속기 기술 워크샵

- 2017.11.30. 09:00-20:30
- Nongshim International Building, Korea University Sejong

09:00 Registration
09:20 Opening
09:30 Plenary Session I
10:50 Plenary Session II
12:00 Lunch
13:00 Session I: Beam Dynamics
14:40 Session II: Particle Accelerators
16:20 Session III : Accelerator Technologies & Applications
18:30 Banquet

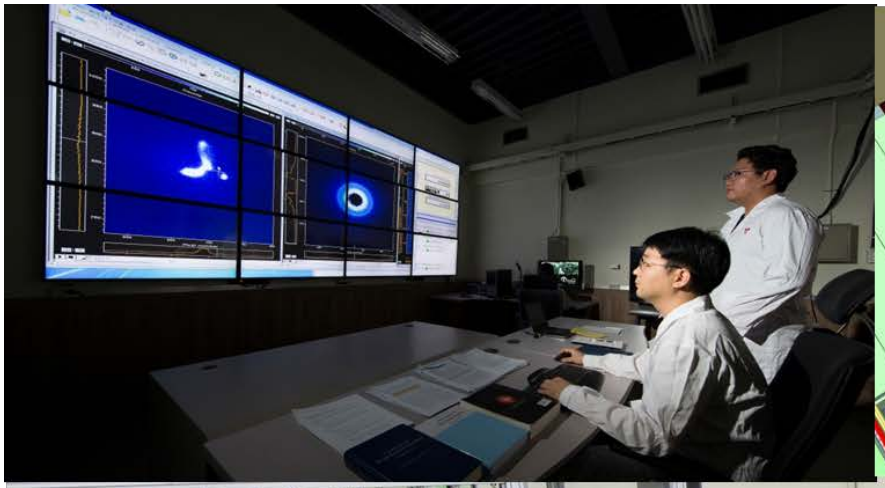
Hosted by Korea University / KAERI

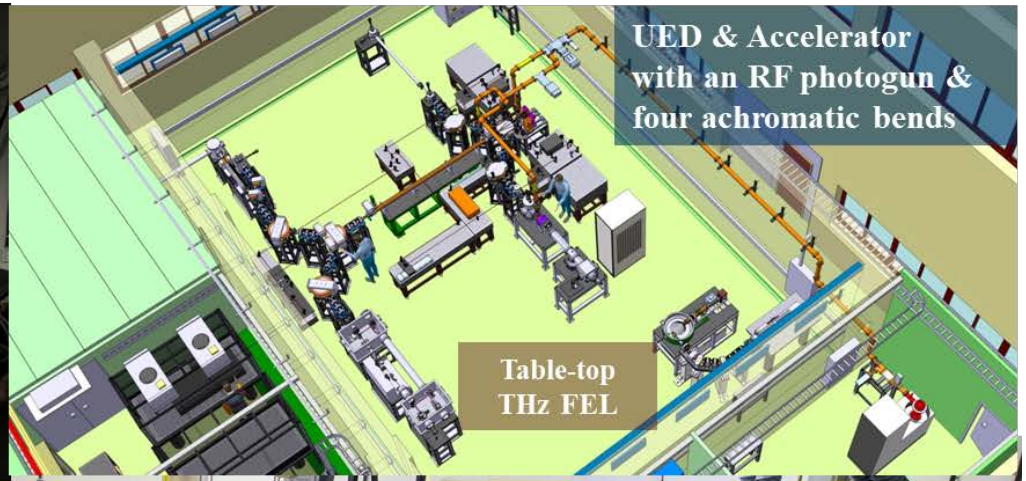
고려대학교 세종캠퍼스 KOREA UNIVERSITY SEJONG CAMPUS KAERI 한국원자력연구원

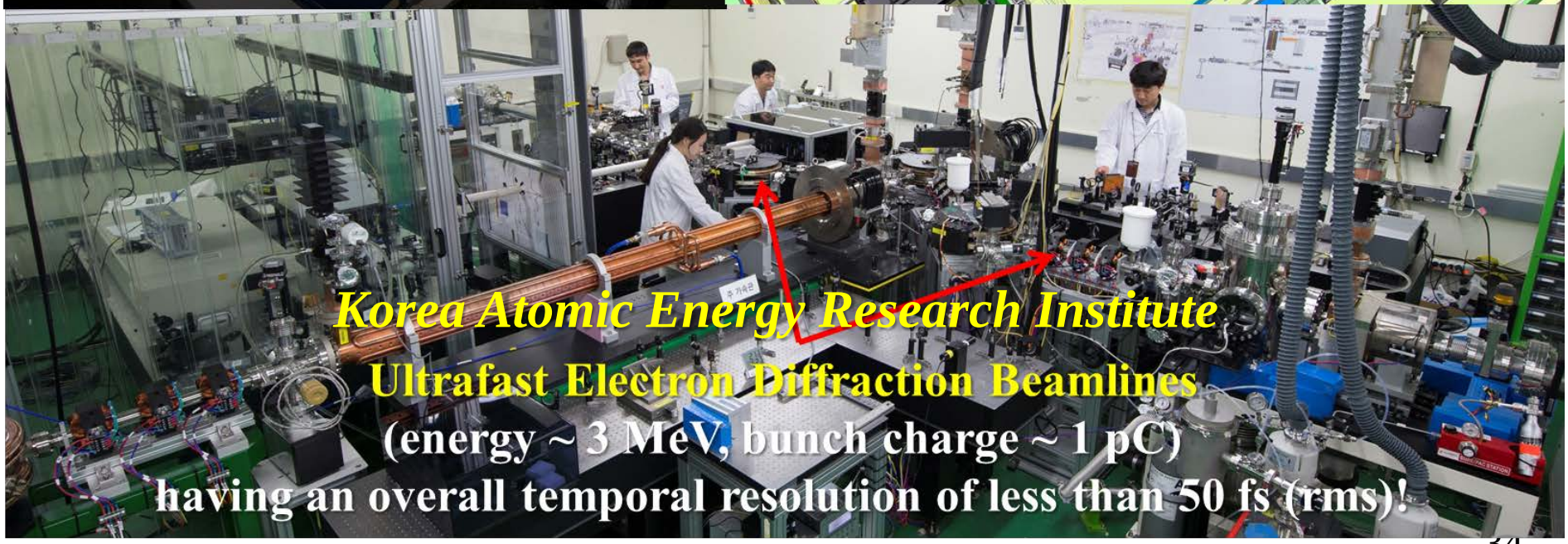
Sponsored by MSIT / NRF

과학기술정보통신부 Ministry of Science and ICT NRF 한국연구재단

Radiation Center for Ultrafast Science (KAERI)

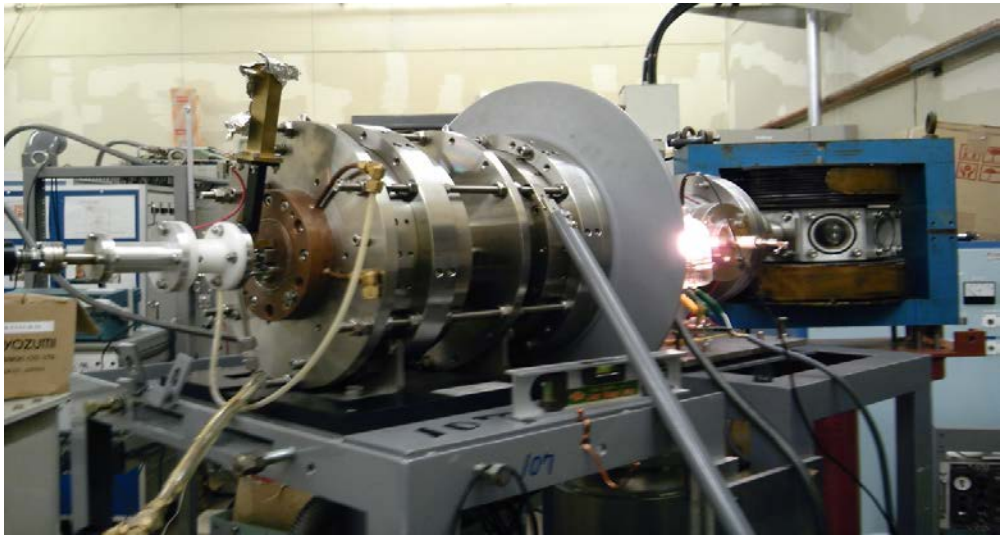


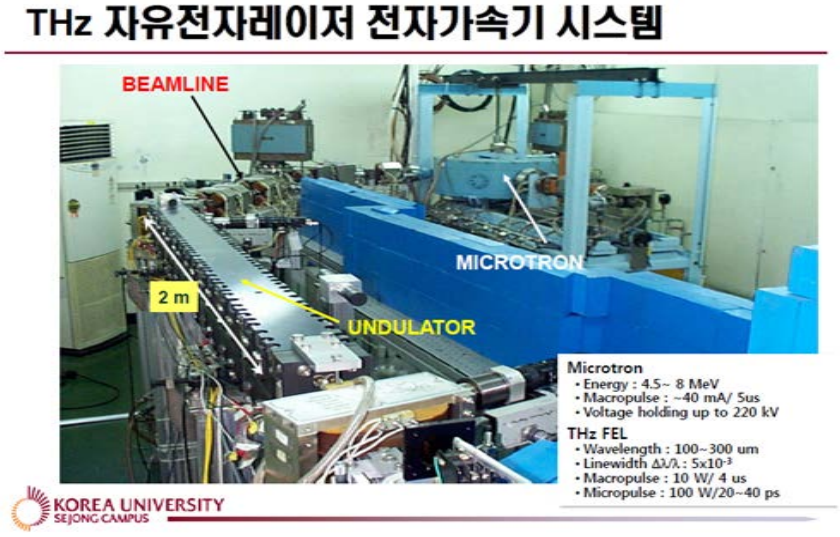




K.-J. Kim, always with RCUS (KAERI)

K.-J. Kim, IAC Member in Dep. of Accelerator Science KU





K.-J. Kim with Students (of Prof. Chung)

K.-J. Kim in Mountains

K.-J. Kim in Mountains

Summary

I. Accelerator activities in Korea

- Three large scale accelerators in Korea have been operated or built successfully
- All were triggered by PLS and lights from PAL will be getting brighter in future.

II. K-J. Kim

- To PAL, he is always with us from the start to the future.
- To small scale accelerators in Korea, he is always with them.
- To students in the accelerator field in Korea, he is a hero.
- To young scientist in the accelerator field in Korea, he is a mentor.
- To some colleagues in Korea, he is a strong mountaineer.