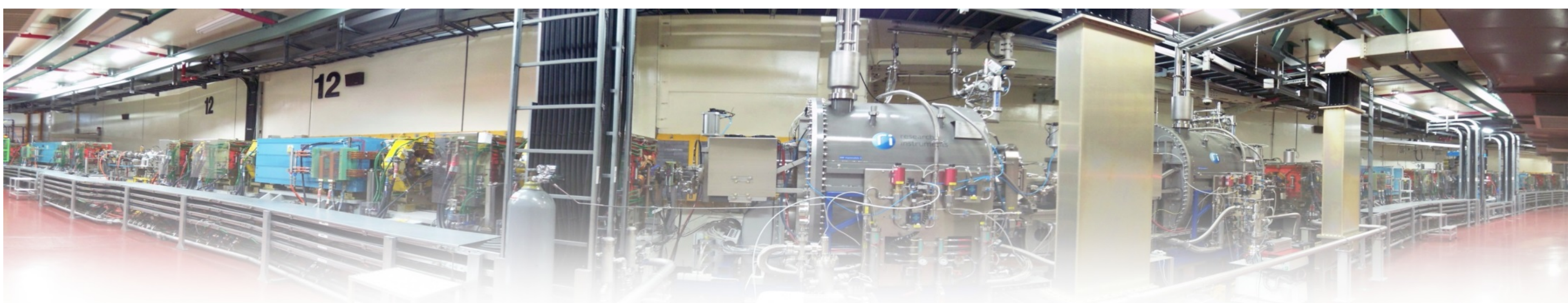
The status of the electron accelerator programs in Korea

Seunghwan Shin

for PLS-II accelerator division

PLS-II / PAL

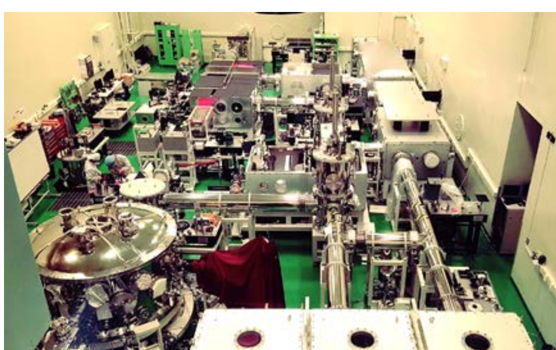


Electron accelerator researches in Korea

Acc. Department in KU

Industrial Acc. (KAERI)

Laser wakefield e Acc.

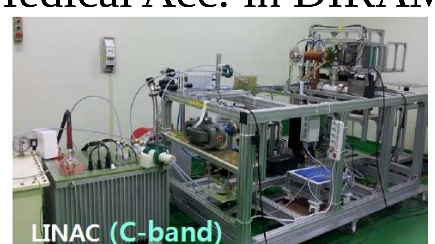


Acc. Lab in SKKU

KAPRA

Mediacl Acc. (KERI)

Medical Acc. in DIRAMS



Radiation Center (KAERI)

PLS-II & PAL-XFEL (PAL)

Acc. Lab in UNIST

Large scale electron accelerators in Korea

① 설립목적

방사광가속기를 기초·응용과학 및
산업기술 최첨단 연구에
범국가적 공동연구시설로 활용하여
우리나라 기초과학 선진화에 기여

③ 이용현황

- User visits: > 6,000 (‘18)
- Experiments: ~ 1,600
  (For industry 170)
- 매년 430 여개의 SCI 논문 발표

② 예산 및 인원

- 총 구축 및 운영예산 : 13,790억원
  3세대; 8,993억원, 4세대; 4,797억원
- Operation budget (2019) : 51.6 M $ (1 $ = 1,000 \)
- Regular staffs : 200 (2019)

④ 시설현황

- 대지 247,420 m^2 (74,845만평)
- 건물 27개동 82,226 m^2 (24,873평)
- 3세대 : 둘레 282 m, 3.0 GeV, 400 mA
- 4세대 : 길이 1,100 m, 10 GeV, 0.1 nm급
- 총 40개 빔라인 (3세대 37기, 4세대 3기)
- 공통지원설비 : LCW, 154kV 수전설비 등

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

PLS-II overview: Linac

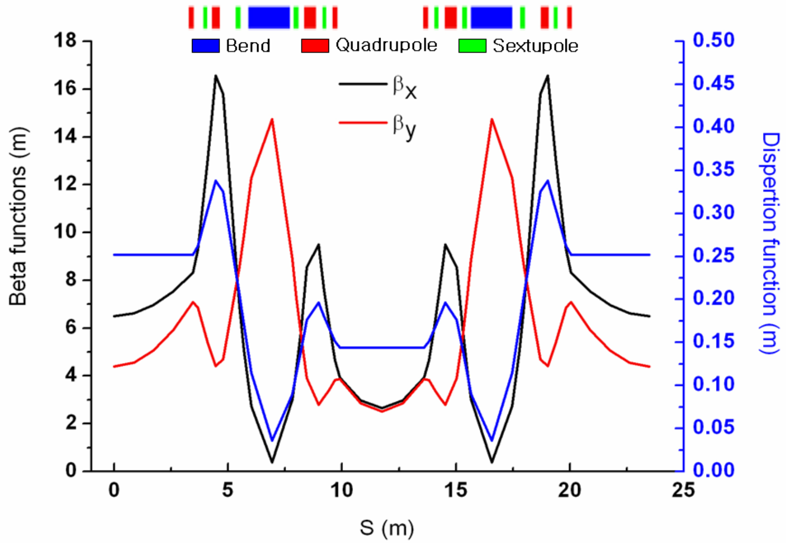
Injector LINAC

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

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

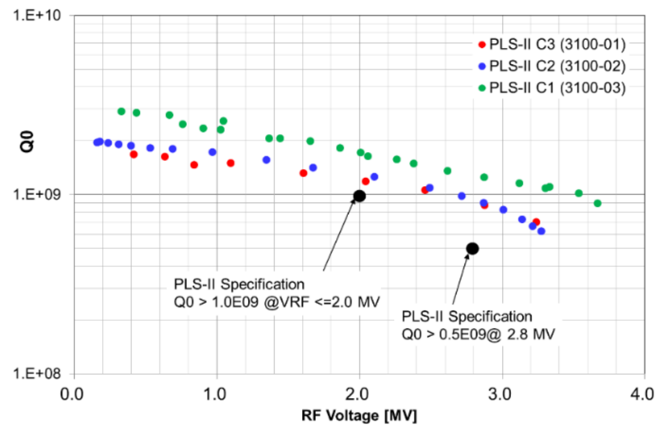
PLS-II overview: Storage ring

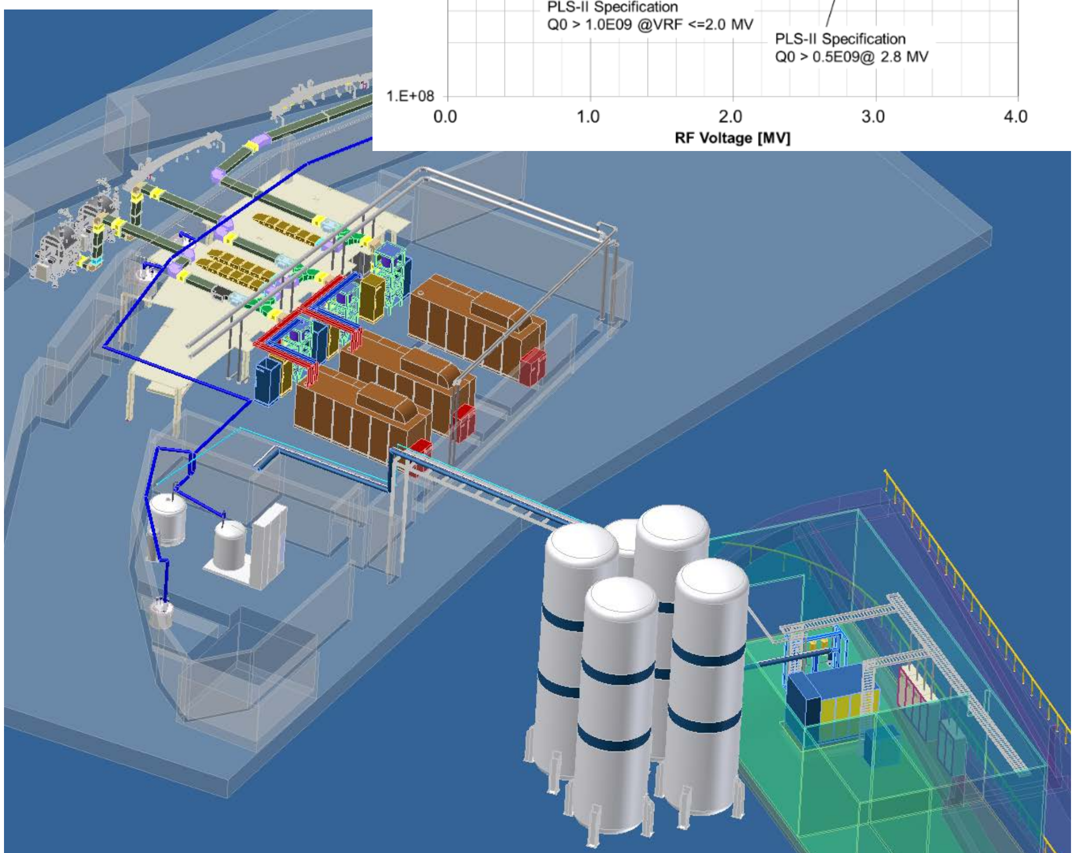
42 % of the circumference
available for straight sections



- **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 SRF system (Availability: higher than 99 %)





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 liquefation
Vendor	Air Liquide, France

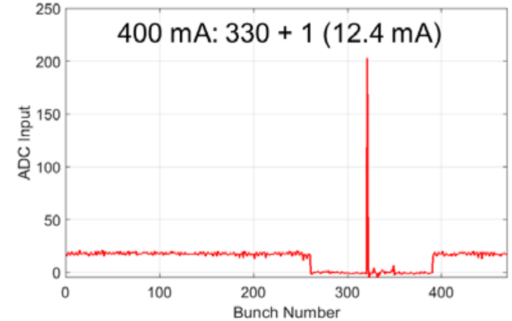
Instrumentations for high performance operation

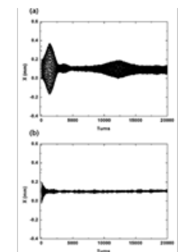
Electron beam

RF FB
Corrector average measurements
RF freq control
0.05 Hz

ID
ID Cor.

IDFF
ID gap measurements
ID corrector control





TFS
BPM 250 MS/s
Strip-line kicker control
500 MHz

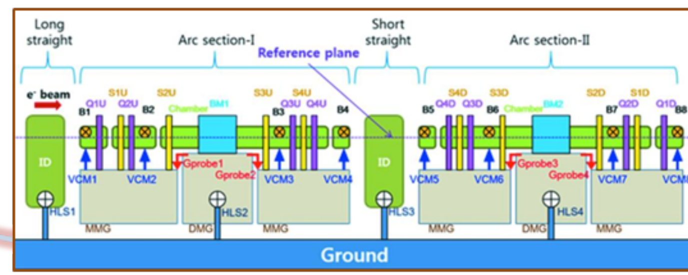
Fast Counter Kicker
Counteracts injection oscillation

BPM

ID or BM

BPM

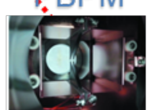
1 Cell lattice

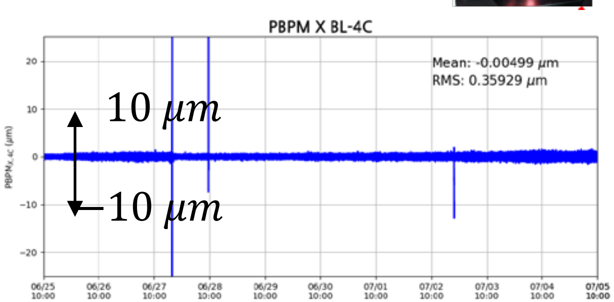


Mechanical alignments
- Few times per year

PBPM FB
PBPM SA (10Hz)
manipulate BPM offsets
~1 Hz

PBPM





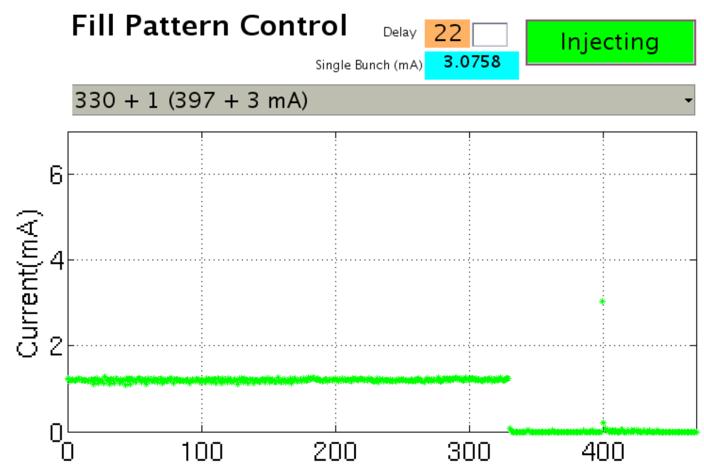
Photon beam

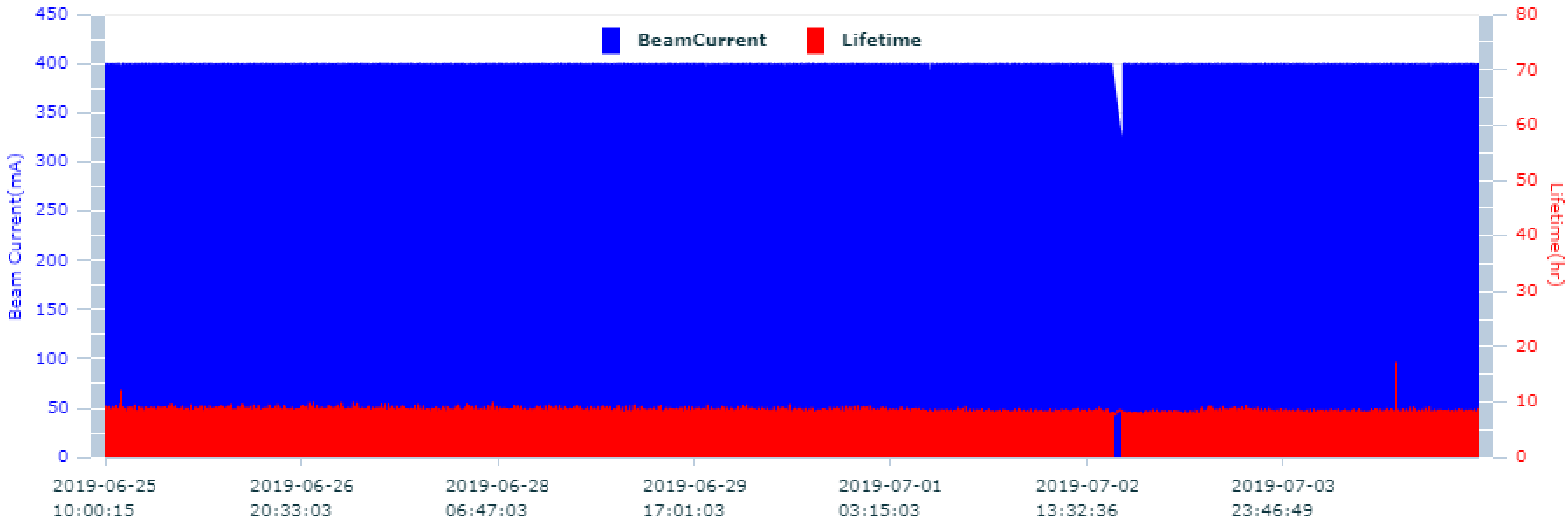
SOFB
96 BPMs SA (10 Hz)
96 Correctors control
2 Hz

FOFB
96 BPMs FA (10 kHz)
48 Fast Correctors control
833 Hz

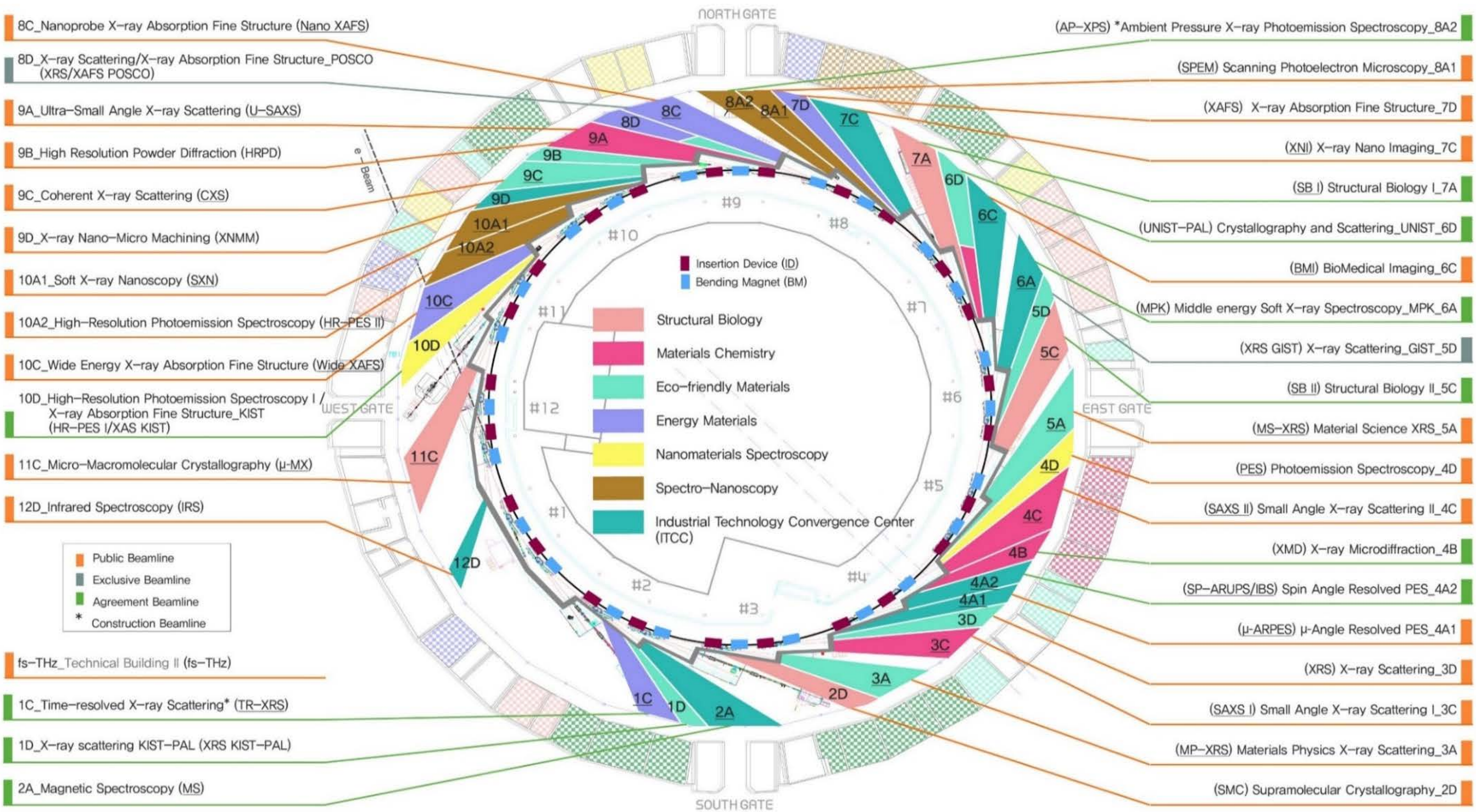
PLS-II operation (The latest user service)

- Planned services in 2019: 190 days
- 4 user runs (No dump) / 10 user runs
- Beam availability (2019, so far): 99 %
- 400 mA Top-up (Hybrid mode)



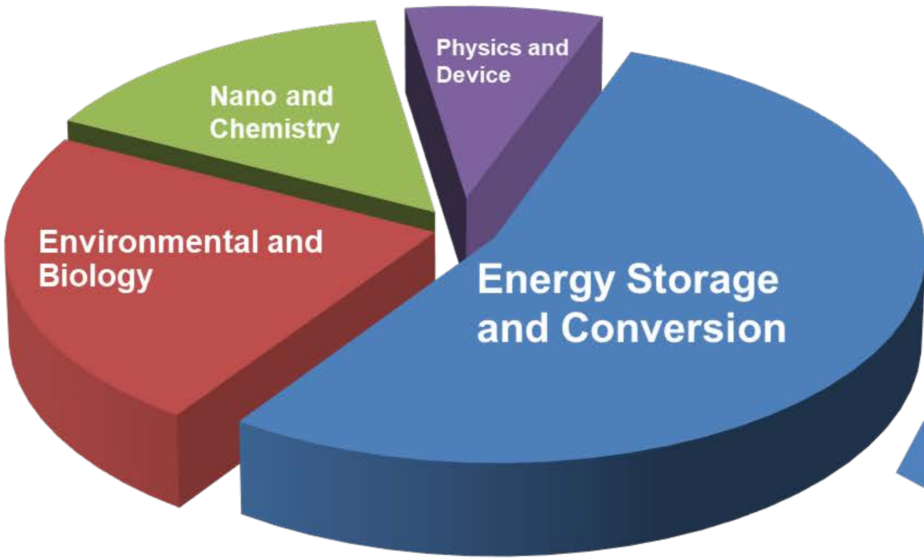


PLS-II Beamlines



PLS-II User distribution

Research Fields



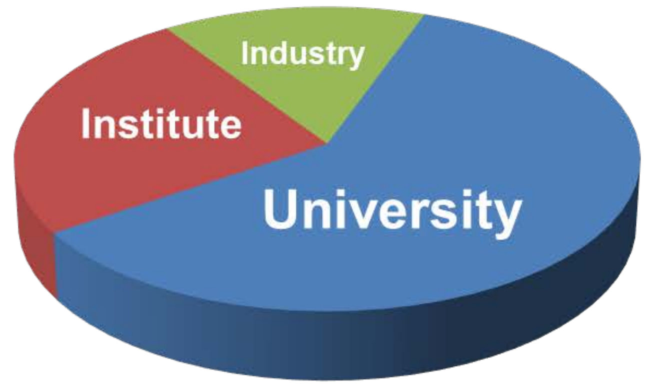
Rechargeable battery*, Fuel cell, Solar cell, Metal-Air cell, Photocatalyst

Geology*, **Environment science**, Microoraganism

New synthesis, **Nanostructured materials***

Memory device*, Display

User Affiliations



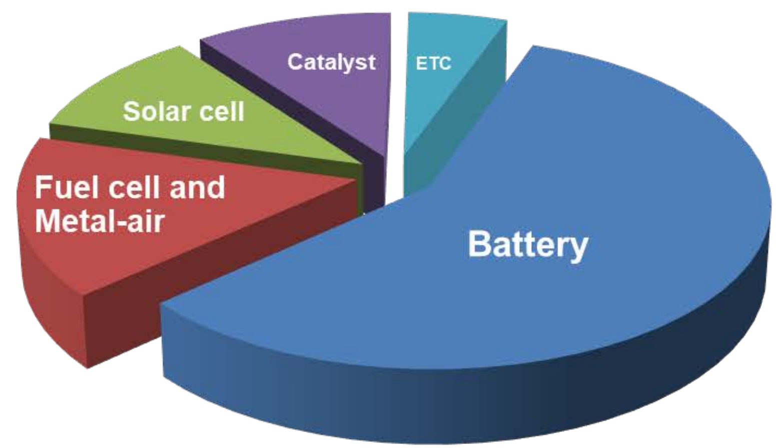
Institutes

한국지질자원연구원,
한국에너지기술연구원,
한국전자부품연구원,
포항산업과학연구원,
한국원자력연구원,
한국세라믹기술원,
한국표준과학연구원,
한국기초과학지원연구원,
한국과학기술원,
한국전기연구원, 등

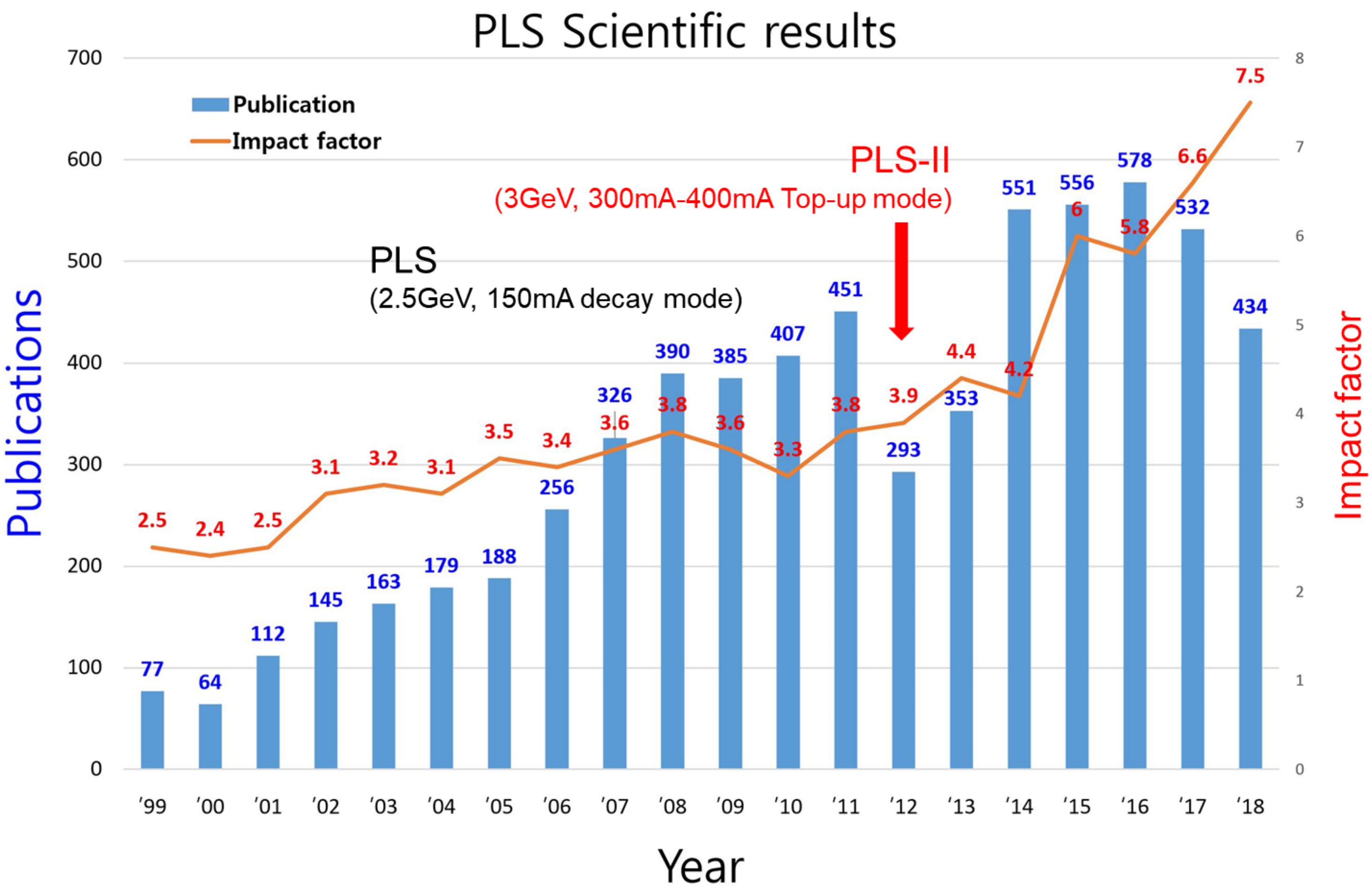
Industry

삼성 SDI, LG화학,
SK 하이닉스, 한화,
삼성전자,
삼성종합기술원, 등

Energy Storage and Conversion

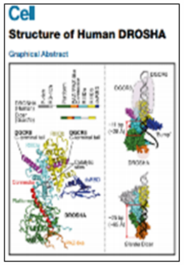


PLS-II Scientific results since 1999

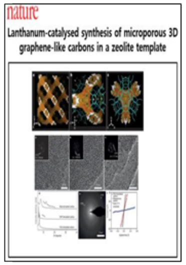


2018

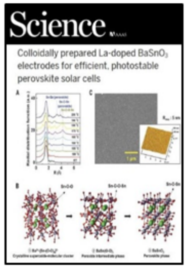
> IF 7	43%
> IF 10	29%
> IF 20	9%



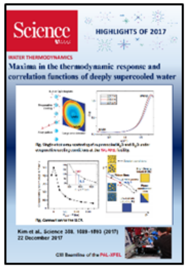
Cell, 2016. 1



Nature, 2016. 6



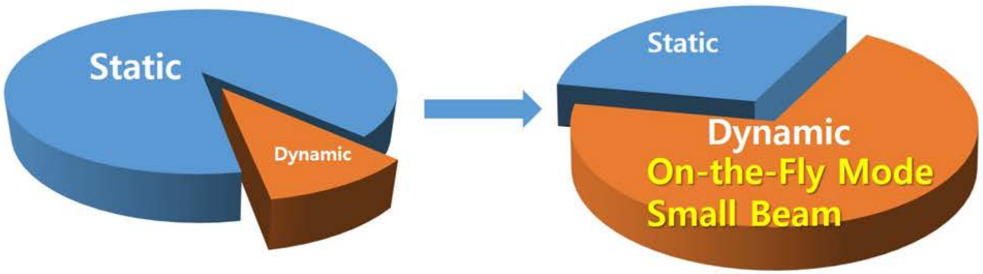
Science, 2017. 4



Science, 2017. 12

PLS-II Research paradigm

< 2011 (PLS-I) **> 2011 (PLS-II)**



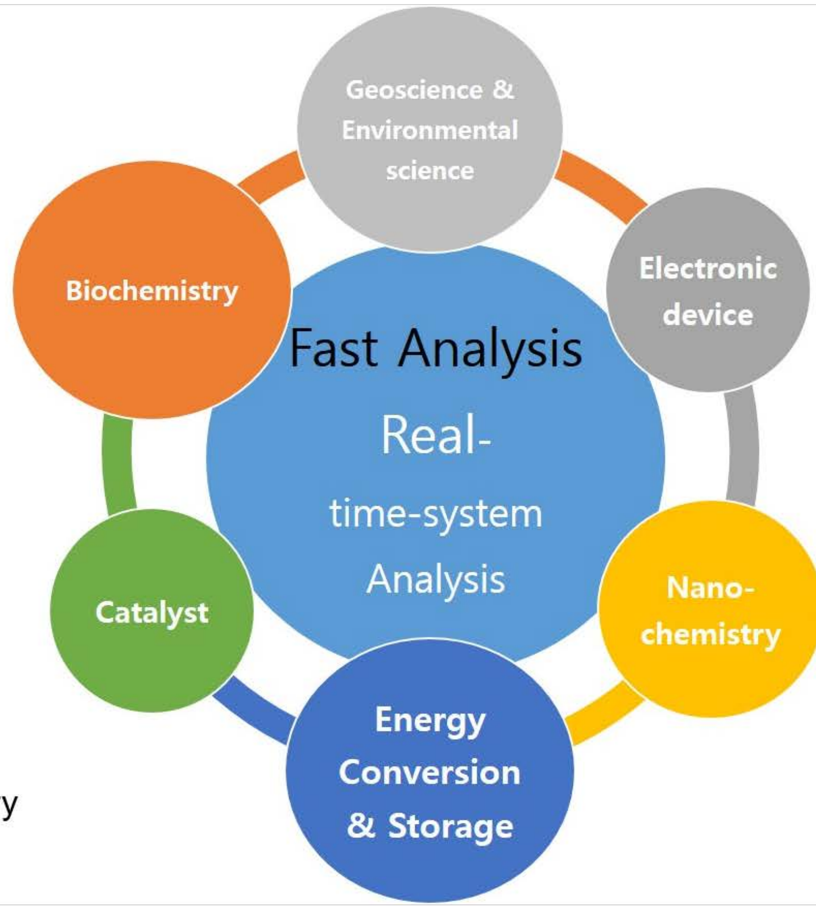
Real-time observation
Time-resolved
In situ, In operando

Real-system observation
Time-resolved &
Spatial-resolved scanning

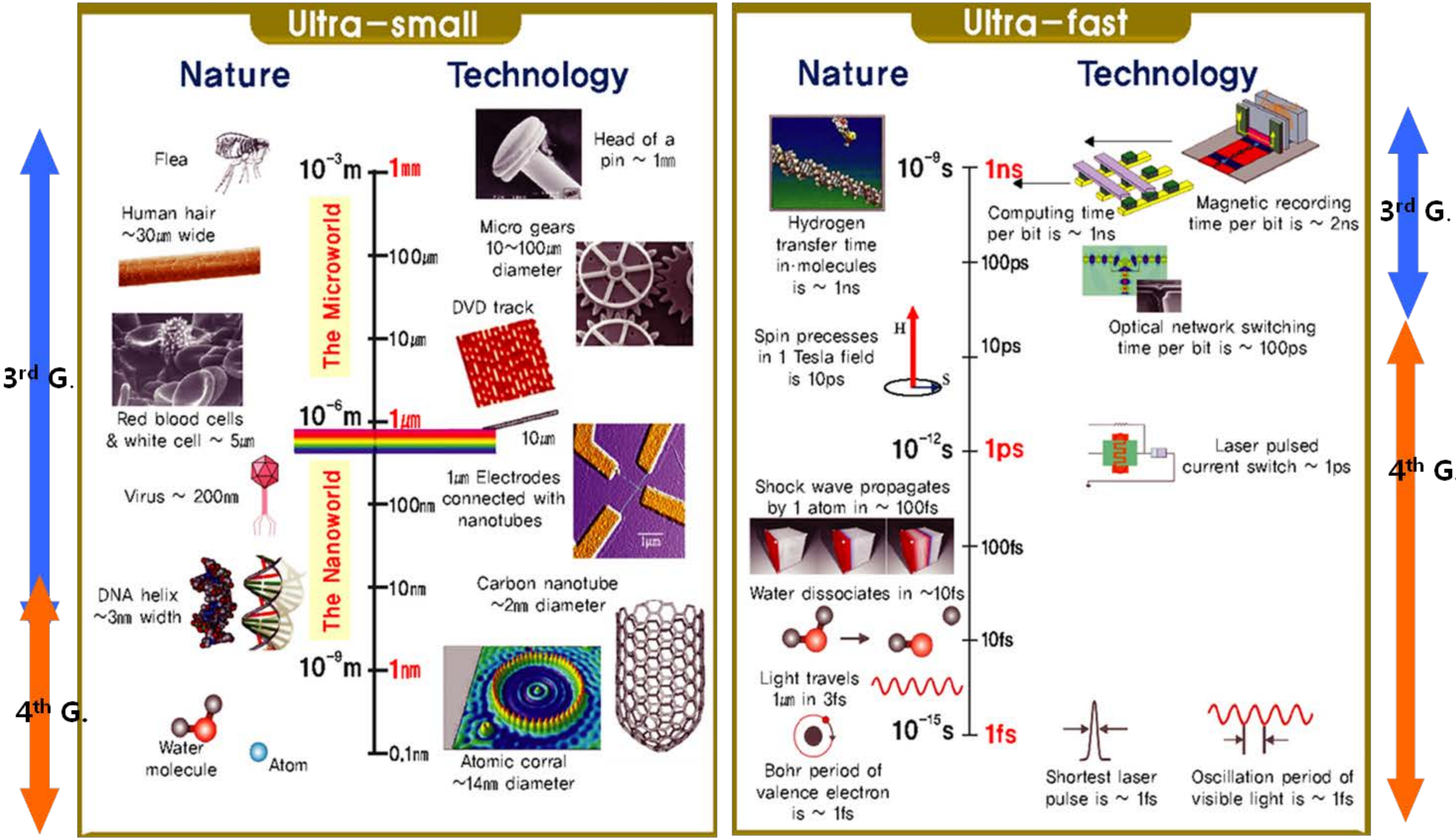
Quick energy scan (Optics: DCM)
Small beam-size (Optics: K-B mirror)

Fast data acquisition (DAQ)

Ex. Energy conversion & storage system : Li-ion battery
Relationship between structural evolution and performance (Normal charge *vs.* Fast charge)



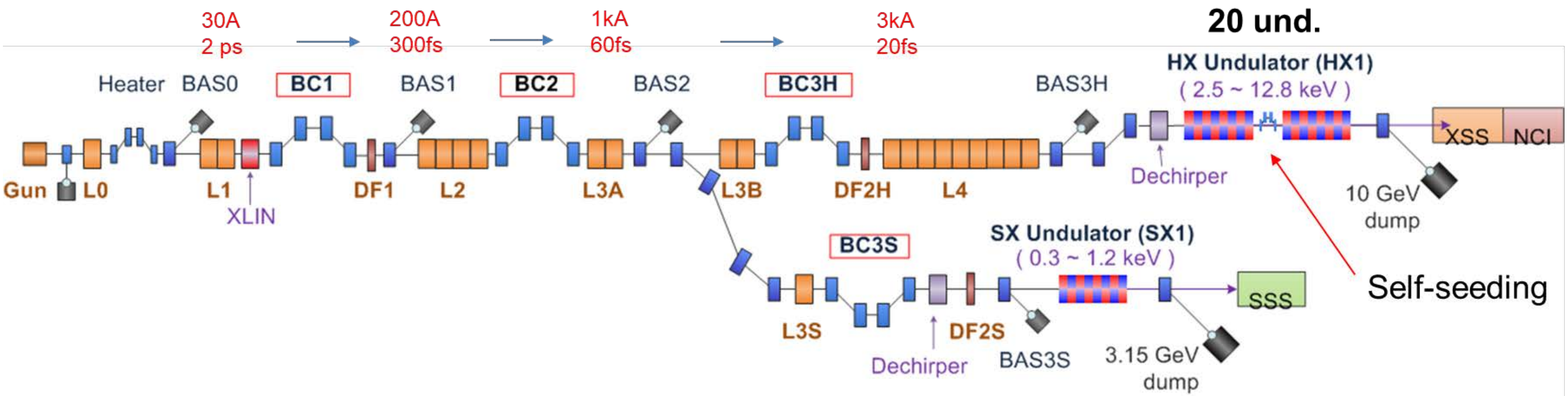
PAL-XFEL & PLS-II



Pattern of electrode ~ 50 nm
Atomic distance ~ 0.1 nm
To the ultra small world!

Atom in molecular ~100 fs,
Spin of electron in material ~1 fs
To explore ultra fast phenomena!

PAL-XFEL Parameters



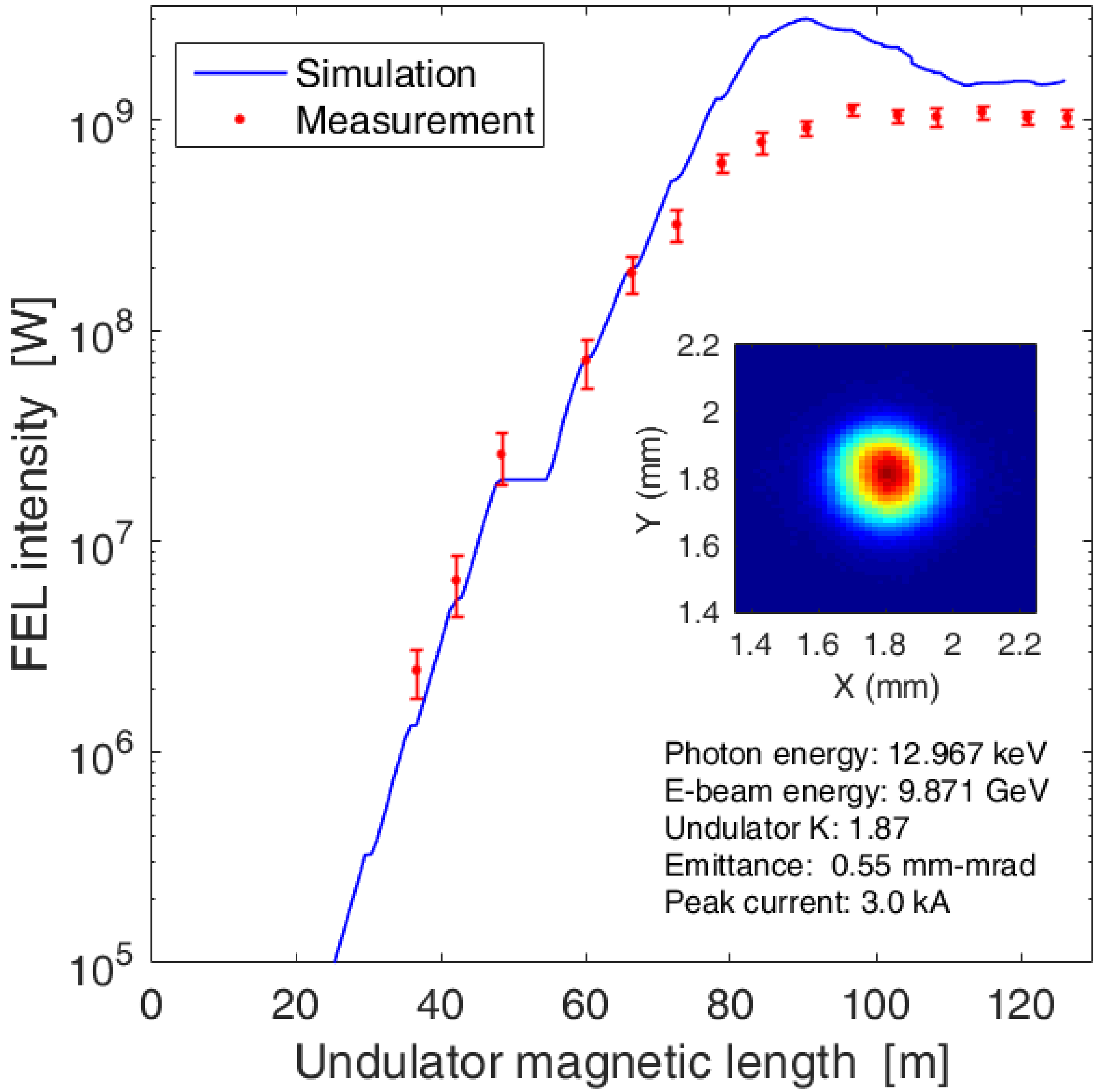
Main parameters

e^- Energy	11 GeV
e^- Bunch charge	20-200 pC
Slice emittance	< 0.4 mm mrad
Repetition rate	60 Hz
Pulse duration	5 fs – 50 fs
Peak current	3 kA
SX line switching	DC magnet

(to be changed to Kicker by 2020)

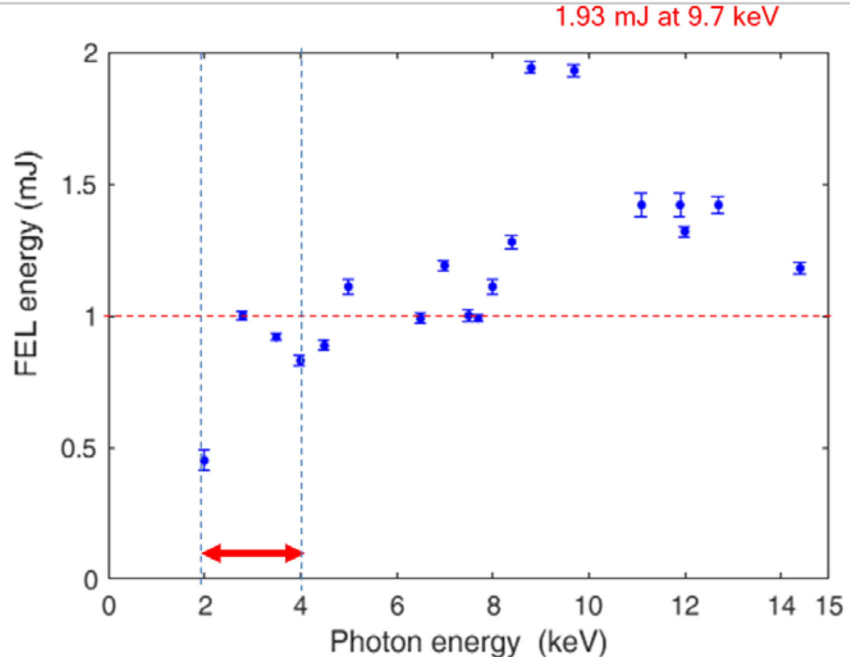
Undulator Line	HX1	SX1
Photon energy [keV]	2.0 ~ 14.5	0.25 ~ 1.25
Beam Energy [GeV]	4 ~ 11	3.0
Wavelength Tuning	energy	gap
Undulator Type	Planar, out-vac.	Planar
Undulator Period / Gap [mm]	26 / 8.3	35 / 9.0

Saturation of 0.1 nm (design goal)

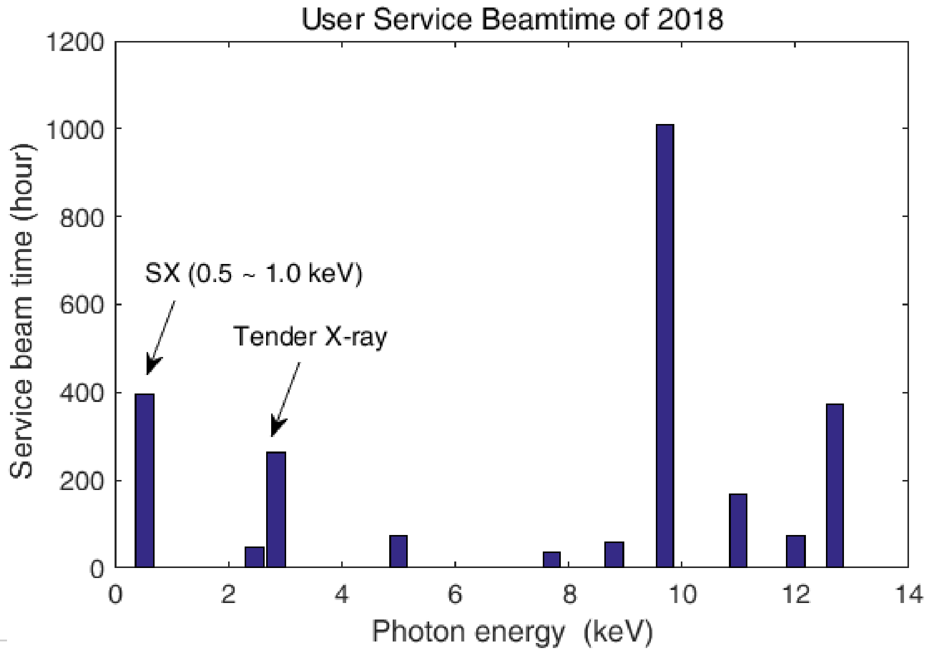


FEL intensity and energy distribution

- Access to the tender X-ray range (2.0 ~ 4 keV) presently is only available at PAL-XFEL
- This regime allows access to the Ru L edge and the M edges of the 4d transition metals.



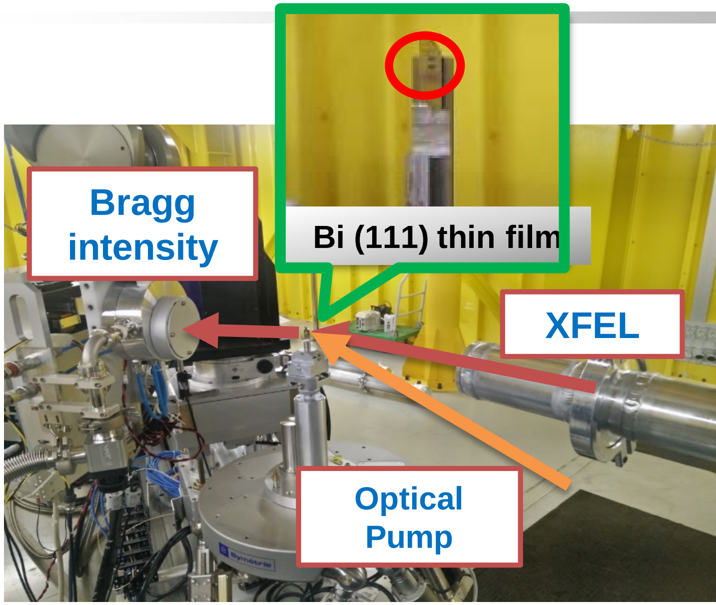
Tender x-ray



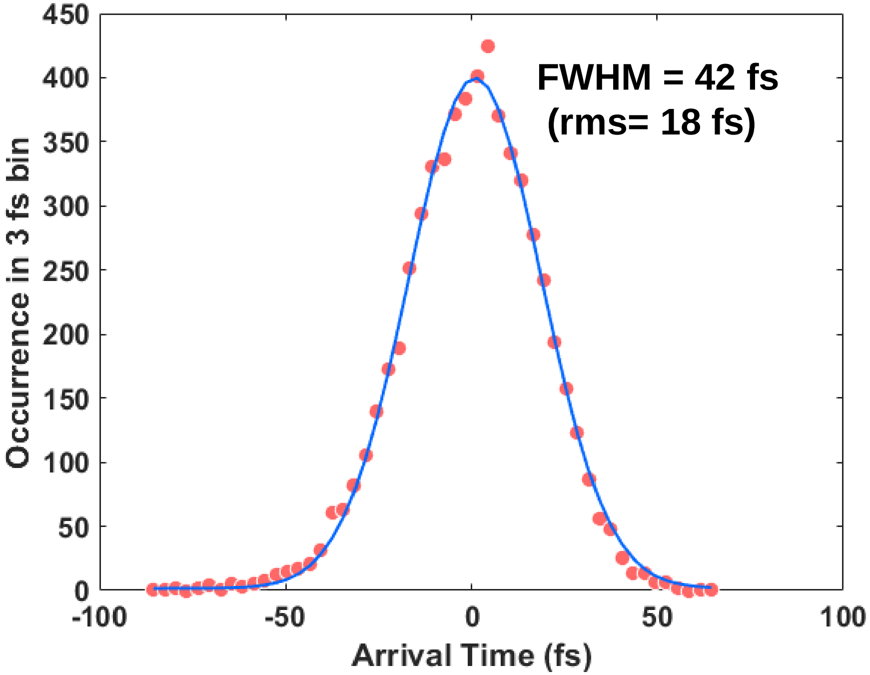
Machine performances

- Photon energy 2.0 ~ 14.5 keV
  - Saturated FEL up to 14.5 KeV
- FEL pulse power 2.0 mJ at 9.7 KeV
- FEL beam pulse duration 10 ~ 35 fs (fwhm)
- FEL power stability < 5% RMS
- FEL position stability < 10% of beam size
- FEL central wavelength jitter 0.024 %
- E-beam energy jitter < 0.015 %
- E-beam arrival time jitter < 15 fs
- FEL beam availability ~ 95%

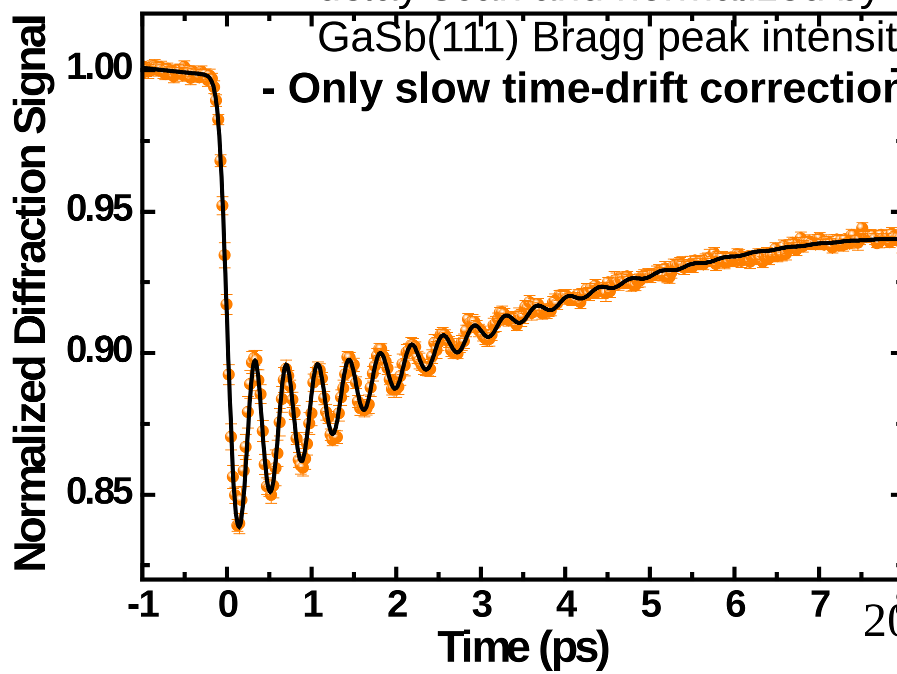
Timing jitter between pump laser and probe XFEL



Bi(111) thin film (50 nm) on GaSb(111)/Si(111)
X-ray: 6 keV
X-ray size: ~ 60 x 60 um^2
Laser: 800 nm, 100 fs
Detector: MPCCD 0.5M

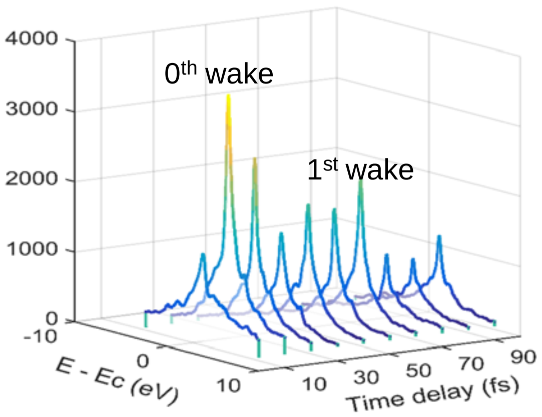


No timing jitter correction
- averaged by 50 trials of the time delay scan and normalized by GaSb(111) Bragg peak intensity
- **Only slow time-drift correction**

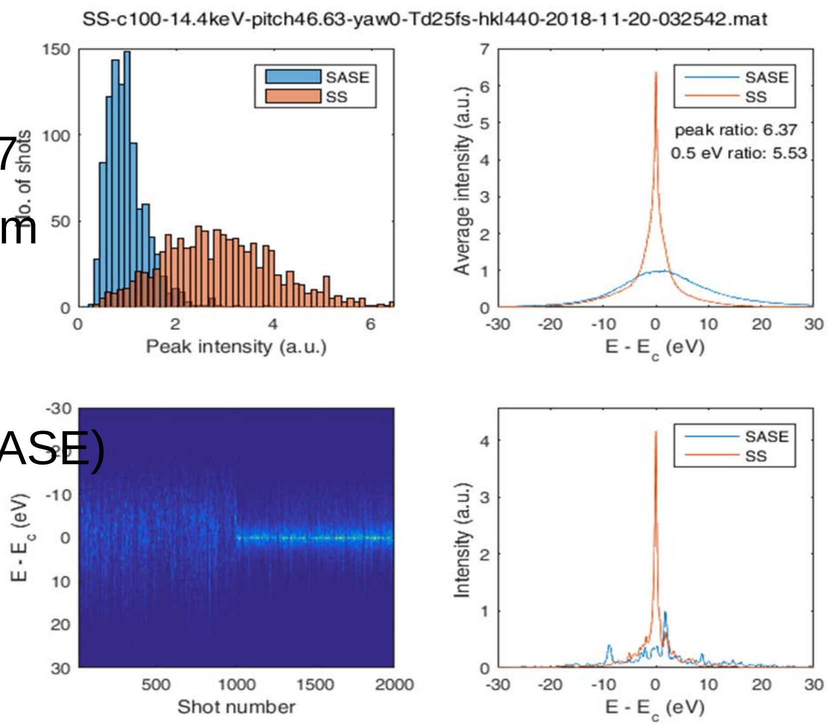


Self-Seeding at 14.4 keV

- Seeding conditions
  - [hkl] = [440]
  - Pitch angle = 46.63 deg
  - $\Lambda_H = 6.41$
  - $T_0 = 1.8716$ fs
  - $t_s \sim 50$ fs
  - $t_d \sim 30$ fs



- Time-delay: 25 fs (0th wake of FBD)
- Peak intensity ratio of SS and SASE: 6.37
- A fraction of 1-eV BW over entire spectrum
  - SASE: 0.047
  - SS : 0.226
- FEL energy: ~400 μJ (seeded), ~1 mJ (SASE)
- BW reduction: ~ 35 times
  - SASE: 16.9 eV, SS: 0.49 eV



Localization and commercialization

○ Done during PLS-II project
- In-vacuum undulator (SFA)
- MPS (다원, HMT)
- Many vacuum components
- RF window (비츠로)

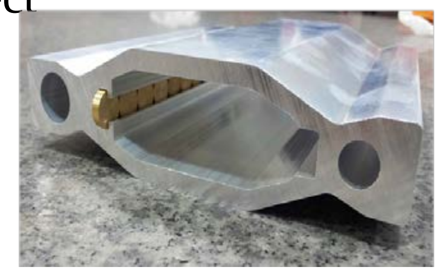
○ Done during PAL-XFEL project
- SLED (비츠로)
- CCPS (다원, 동아하이텍)
- Accelerator column (비츠로)
- RF window (비츠로)
- Magnet (금룡, 한미테크윈)

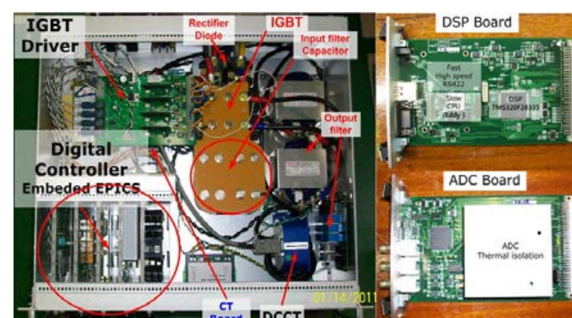
○ On going (~ 2019)
- Klystron (비츠로)

○ Future
- Thyratron
- E-gun
- Capacitor

❖ Photon absorber
- Cold forged OFHC
- High thermal conductivity
- High yield stress

❖ Pill type getter
- Distributed pumping for straight section

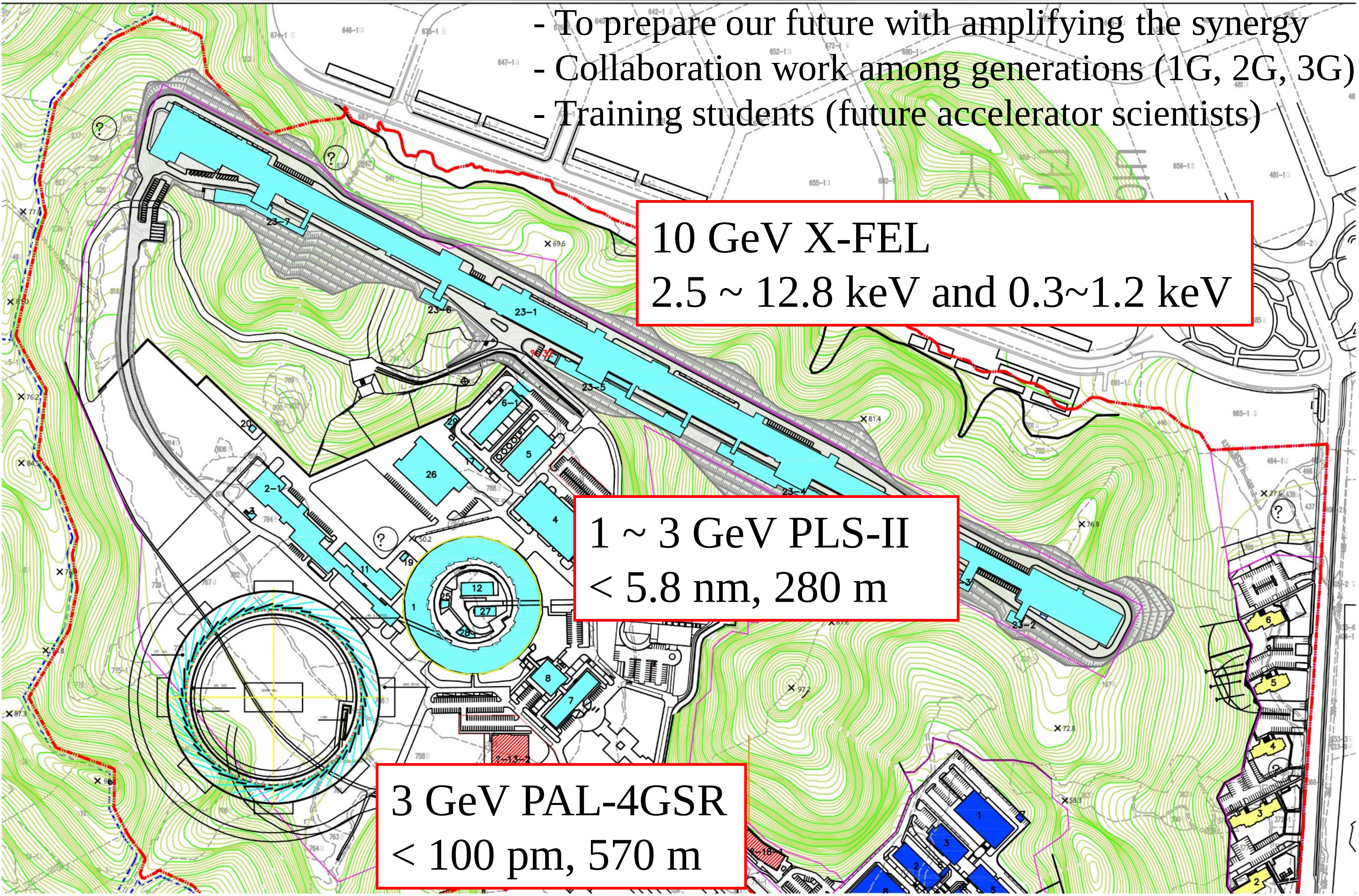




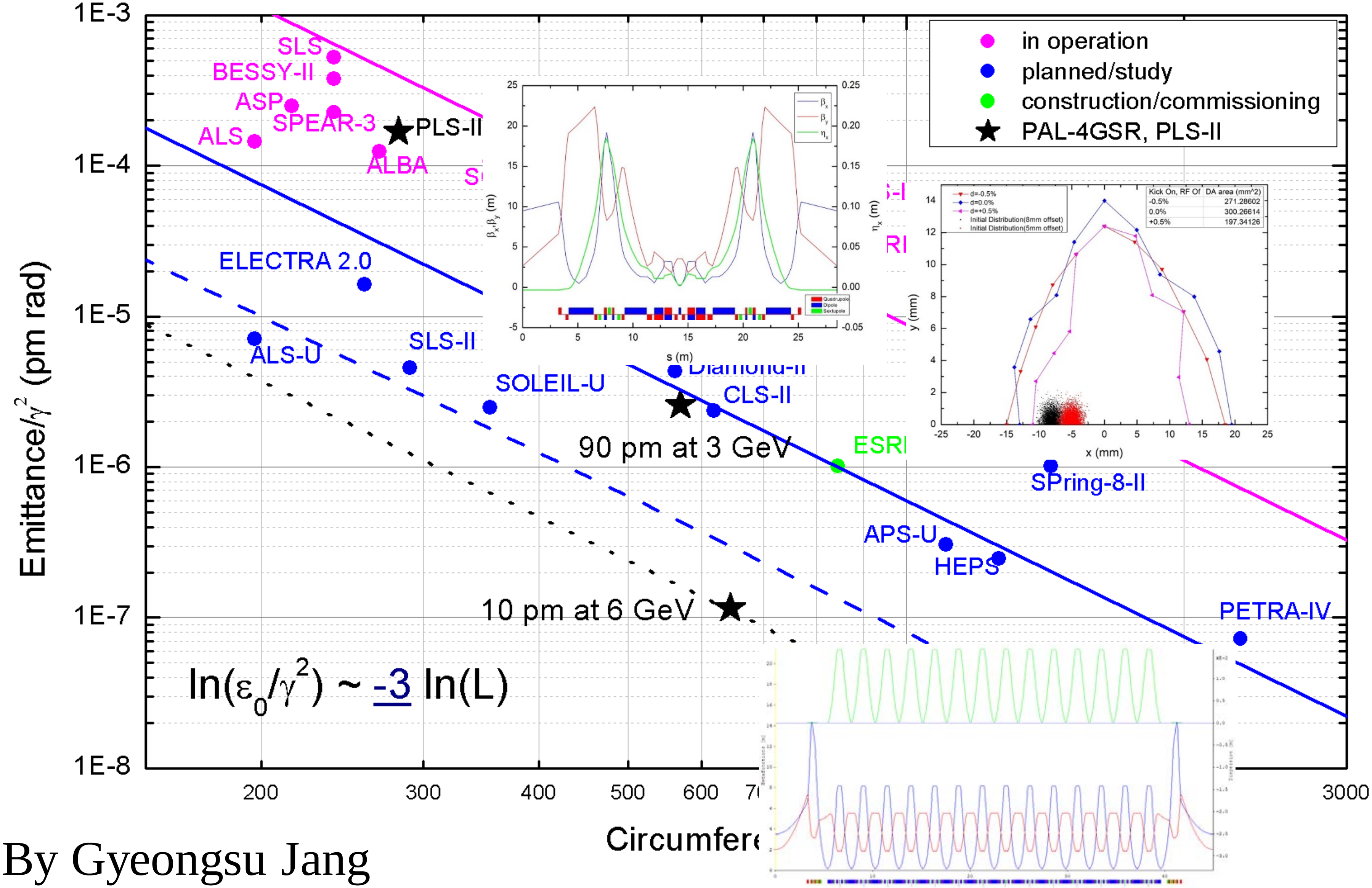
4GSR program at PAL

Motivation

- To prepare our future with amplifying the synergy
- Collaboration work among generations (1G, 2G, 3G)
- Training students (future accelerator scientists)

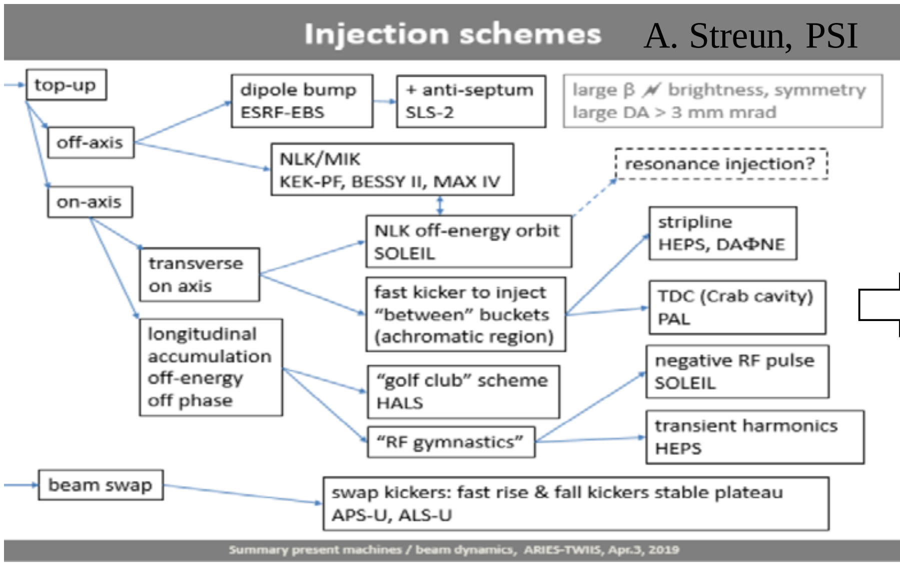


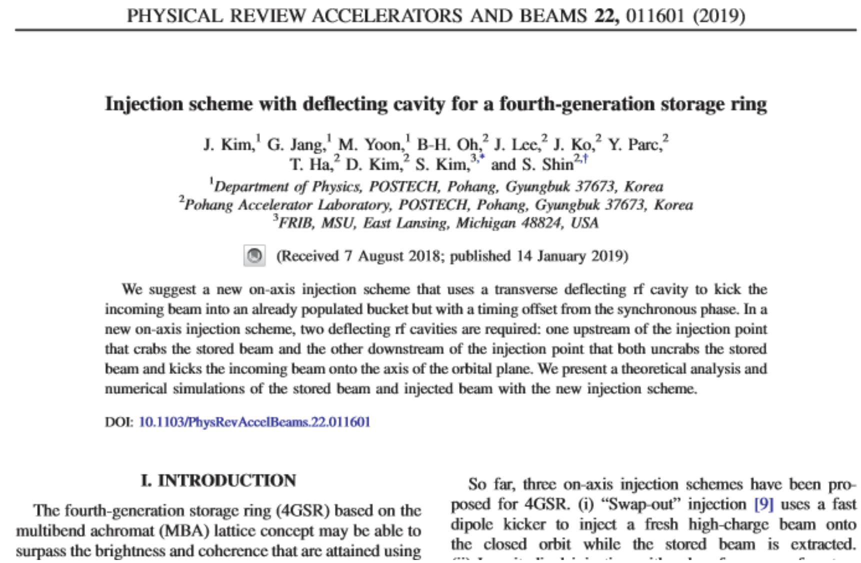
4GSR at PAL



By Gyeongsu Jang

New ideas and new technologies




PHYSICAL REVIEW ACCELERATORS AND BEAMS **22**, 011601 (2019)

Injection scheme with deflecting cavity for a fourth-generation storage ring

J. Kim,[1] G. Jang,[1] M. Yoon,[1] B-H. Oh,[2] J. Lee,[2] J. Ko,[2] Y. Parc,[2] T. Ha,[2] D. Kim,[2] S. Kim,[3,*] and S. Shin[2,†]
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(Received 7 August 2018; published 14 January 2019)

We suggest a new on-axis injection scheme that uses a transverse deflecting rf cavity to kick the incoming beam into an already populated bucket but with a timing offset from the synchronous phase. In a new on-axis injection scheme, two deflecting rf cavities are required: one upstream of the injection point that crabs the stored beam and the other downstream of the injection point that uncrabs the stored beam and kicks the incoming beam onto the axis of the orbital plane. We present a theoretical analysis and numerical simulations of the stored beam and injected beam with the new injection scheme.

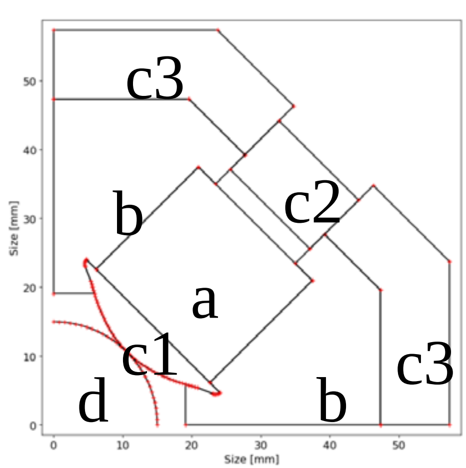
DOI: 10.1103/PhysRevAccelBeams.22.011601

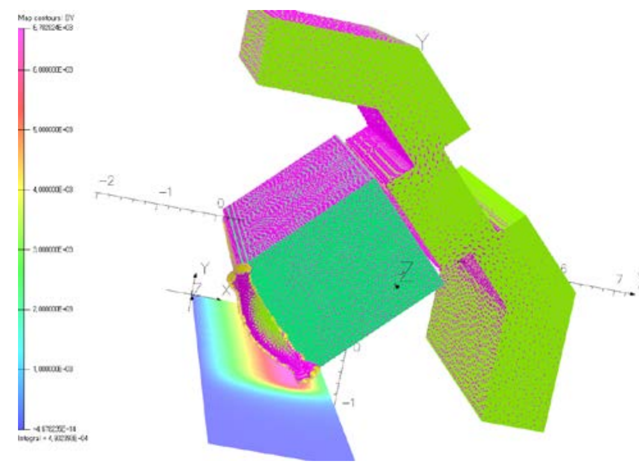
I. INTRODUCTION

The fourth-generation storage ring (4GSR) based on the multibend achromat (MBA) lattice concept may be able to surpass the brightness and coherence that are attained using

So far, three on-axis injection schemes have been proposed for 4GSR. (i) "Swap-out" injection [9] uses a fast dipole kicker to inject a fresh high-charge beam onto the closed orbit while the stored beam is extracted.

3D printing technique for vacuum system





Permanent magnet development

Summary

1. Electron accelerator researches are so active in Korea.
   - Industrial & Medical applications
   - New acceleration RnD.
   - Radiation sources.
2. PLS-II operation.
   - have been provided stable beam with 400 mA Top-up (hybrid fill pattern)
   - More than 1600 experiments were conducted annually.
   - The average impact factor reached 7.5.
3. PAL-XFEL operation
   - A distinguishing performance (world best) was achieved.
   - The unprecedented temporal stability was realized.
   - A 14.4 keV self-seeding was successfully demonstrated for the first time.
4. Localization and commercialization
   - Most machine components can be delivered in Korea.
   - PAL efforts with RISP and KOMAC will generate great synergy for localization and commercialization in Korea .
5. 4GSR program
   - make the future of SR science brighter.