Operational Status and Future Project of the KEK Photon Factory

IPAC2025, Taiwan, 03/Jun/2025 TUCD1

Takashi OBINA
on behalf of
KEK Accelerator Laboratory Division 6 (Light Source Division)

TOC

- Electron Accelerators at the KEK Tsukuba Campus

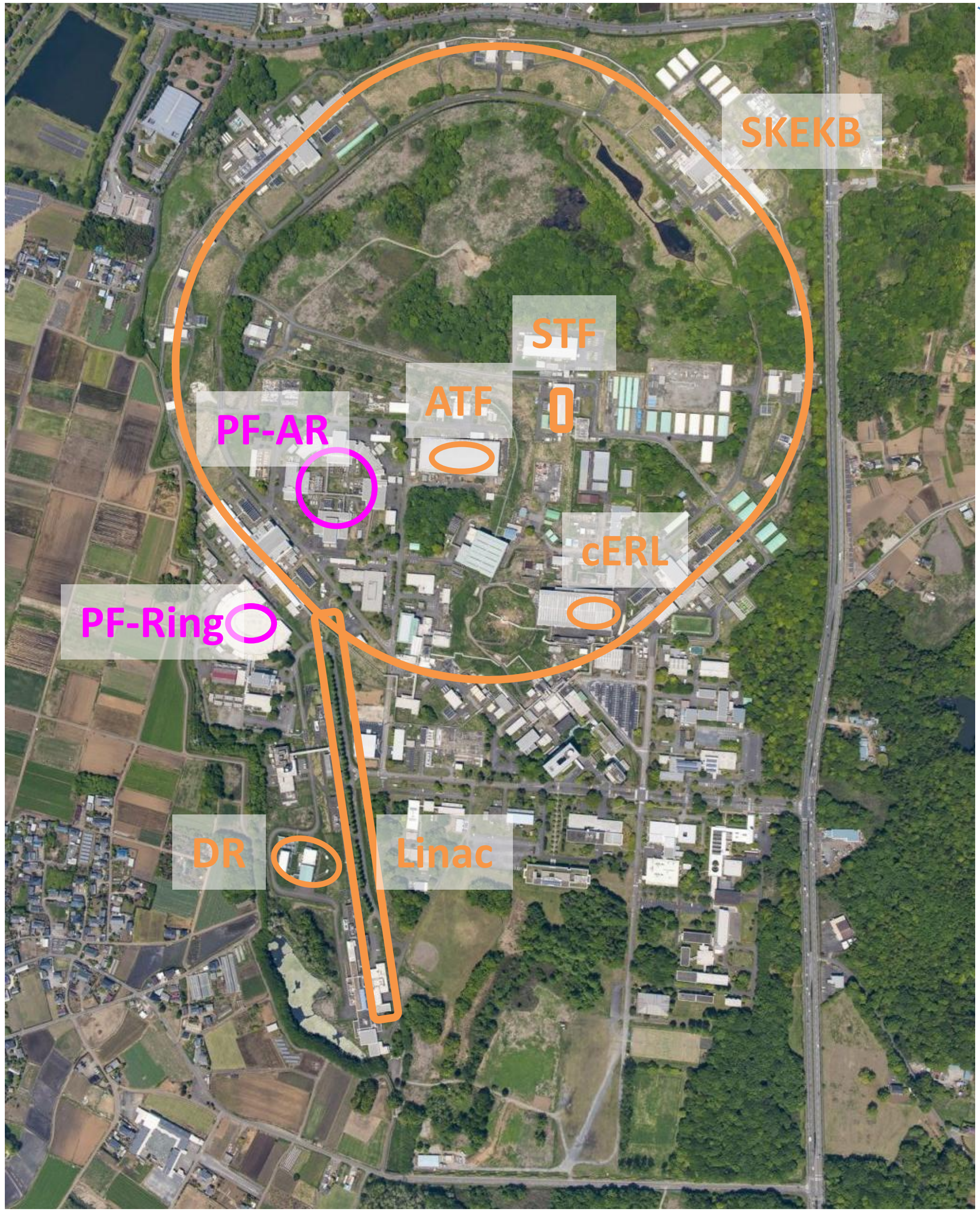
- Present Status of the Photon Factory (PF-Ring and PF-AR)
  - History
  - Typical operation status
  - Statistics

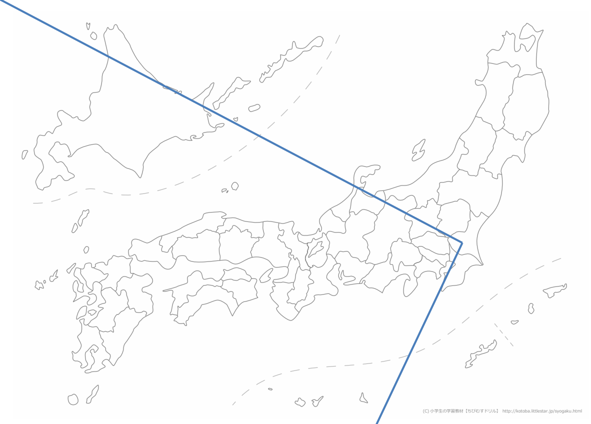
- Future Project
  - PF-HLS (Photon Factory Hybrid Light Source)
    - Superconducting Linac technologies based on ILC (International Linear Collider) design
    - A storage ring design that balances versatility and advanced performance
  - Concept of the Quantum Multibeam Facility

Electron Accelerators at the KEK Tsukuba Campus

- SKEKB
  - HER
  - LER
- Linac
  - Damping Ring
- ATF
- STF
- cERL
- PF-Ring
- PF-AR

} Photon Factory





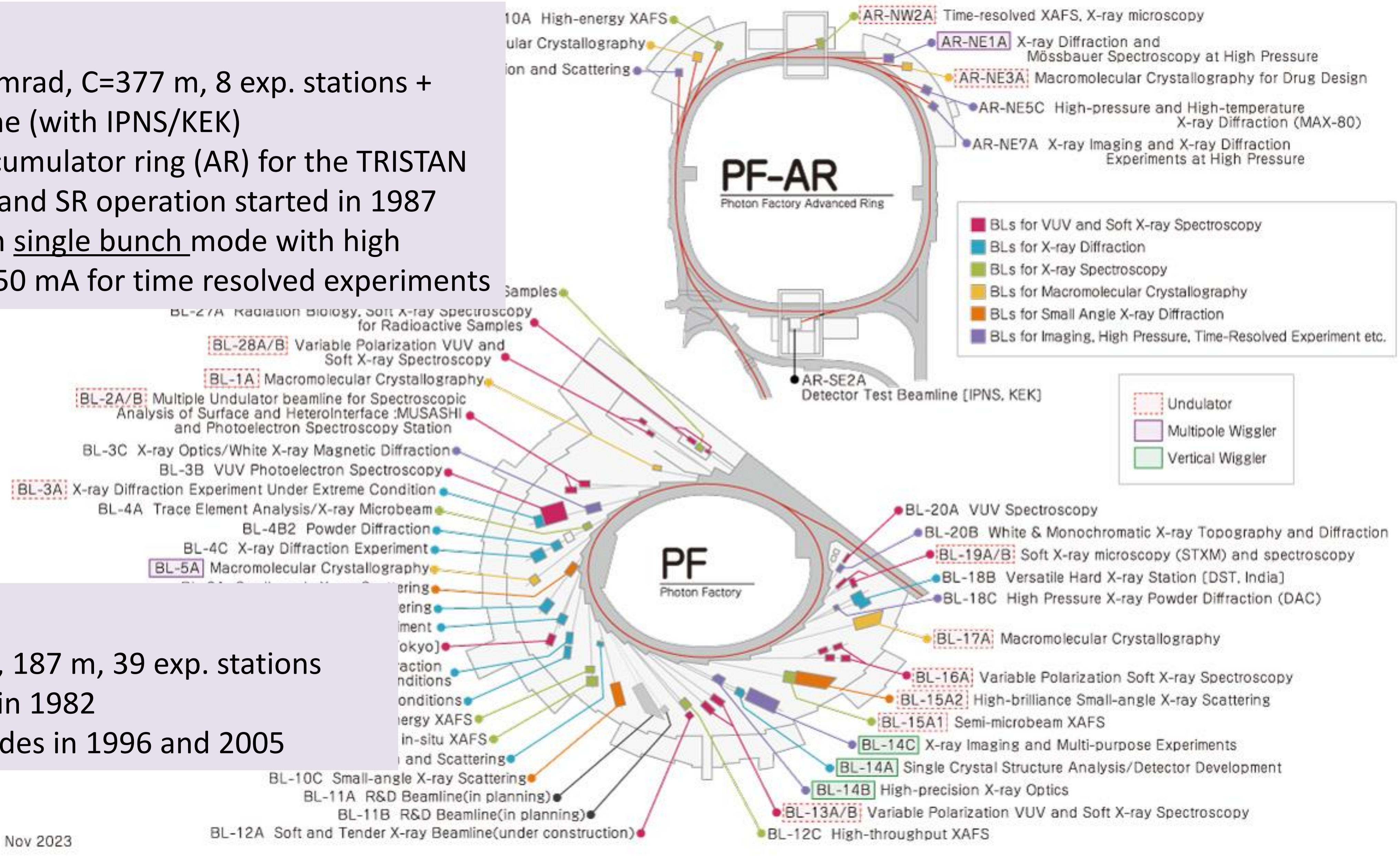
Oho, Tsukuba,
Ibaraki, Japan

Beamlines of Photon Factory

PF-AR

E=5-6.5 GeV, ε=293 nmrad, C=377 m, 8 exp. stations + Detector Test Beamline (with IPNS/KEK)

- Constructed as accumulator ring (AR) for the TRISTAN accelerator chain, and SR operation started in 1987
- Always operated in single bunch mode with high intensity beam of 50 mA for time resolved experiments



PF-Ring

2.5 GeV, ε= 35 nmrad, 187 m, 39 exp. stations

- Operation started in 1982
- Twice major upgrades in 1996 and 2005

History of PF-Ring and PF-AR

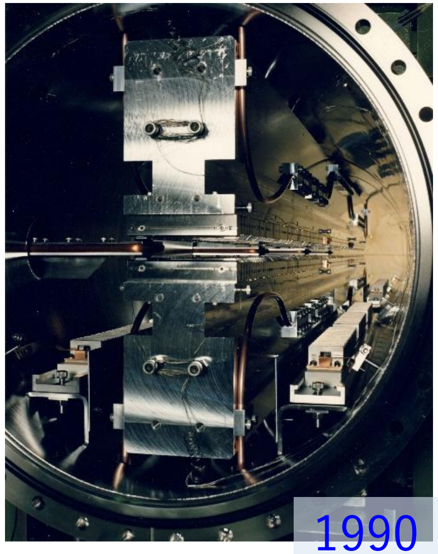
1980 | 1990 | 2000 | 2010 | 2020 | Year

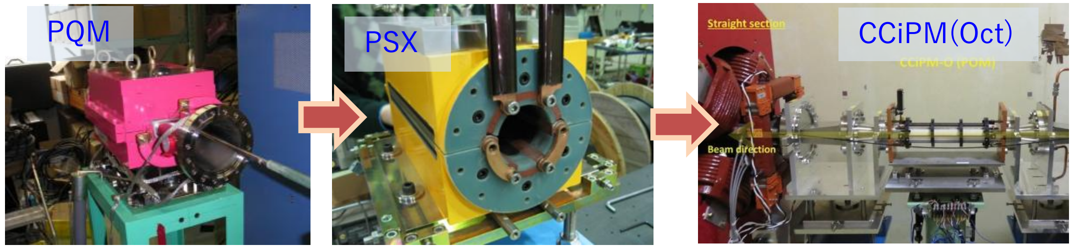
PF-Ring (2.5 GeV)

1982 460 nm.rad → 1986 128 nm.rad → 1997 36 nm.rad → 2005 Straight sections Upgrade

Injector for TRISTAN / SR exp. → PF Advanced Ring（PF-AR, 5.0 or 6.5 GeV, Singe bunch）

1987 SR Experiment at PF-AR → 2002 Upgrade of PF-AR





2004～
Beam injection with nonlinear pulsed magnet

1990
The world's first in-vacuum undulator(PF-AR NE3)

Accelerator : Typical Daily Operation Pattern

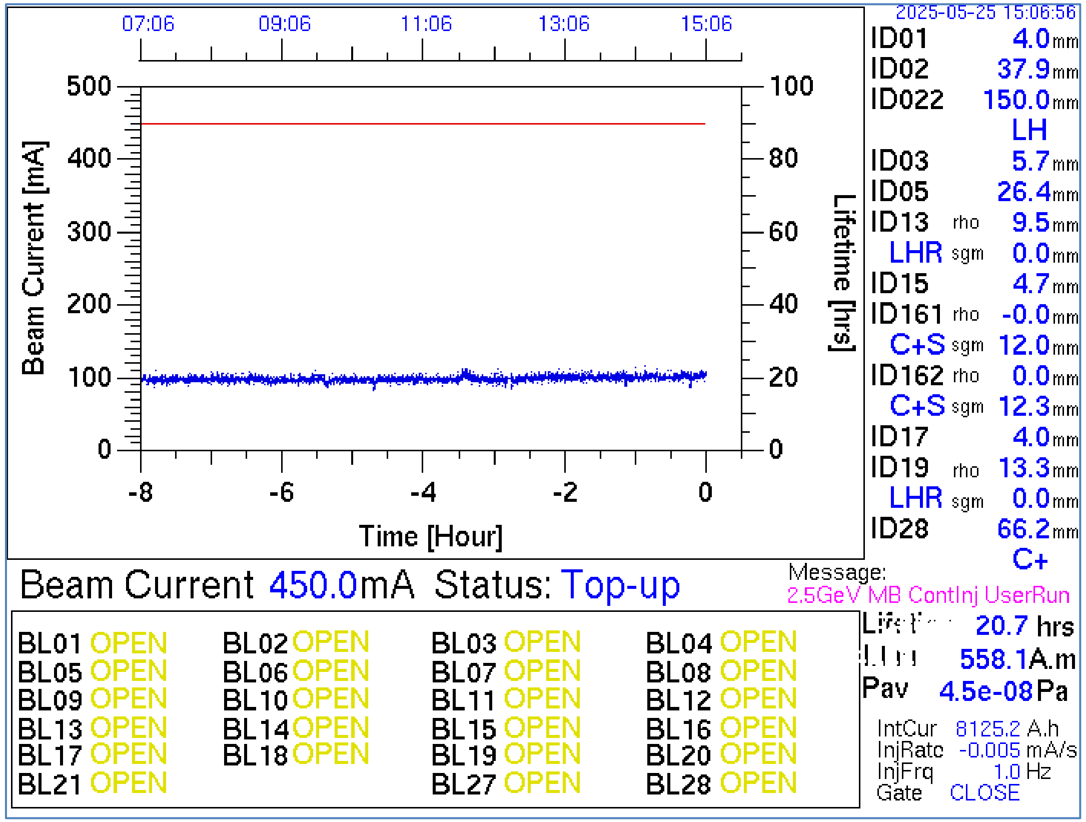
PF-Ring 450 mA

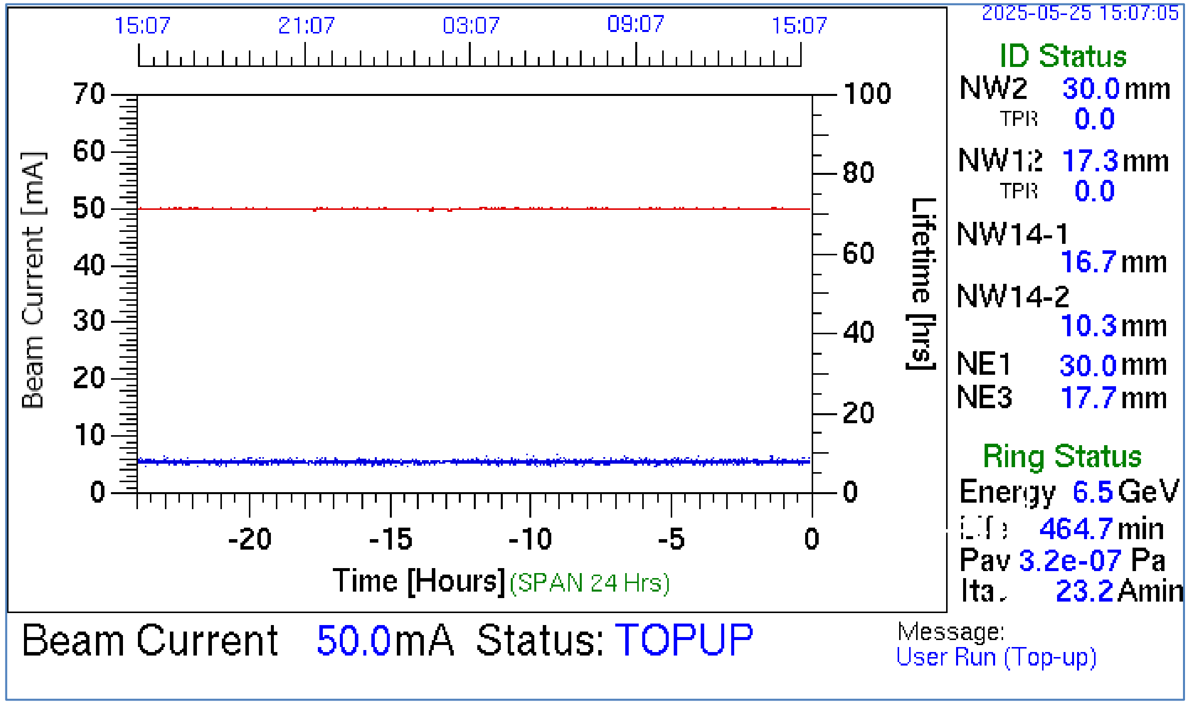
- multi-bunch with bunch gap
- single 50 mA + multi 400 mA

PF-AR 50 mA

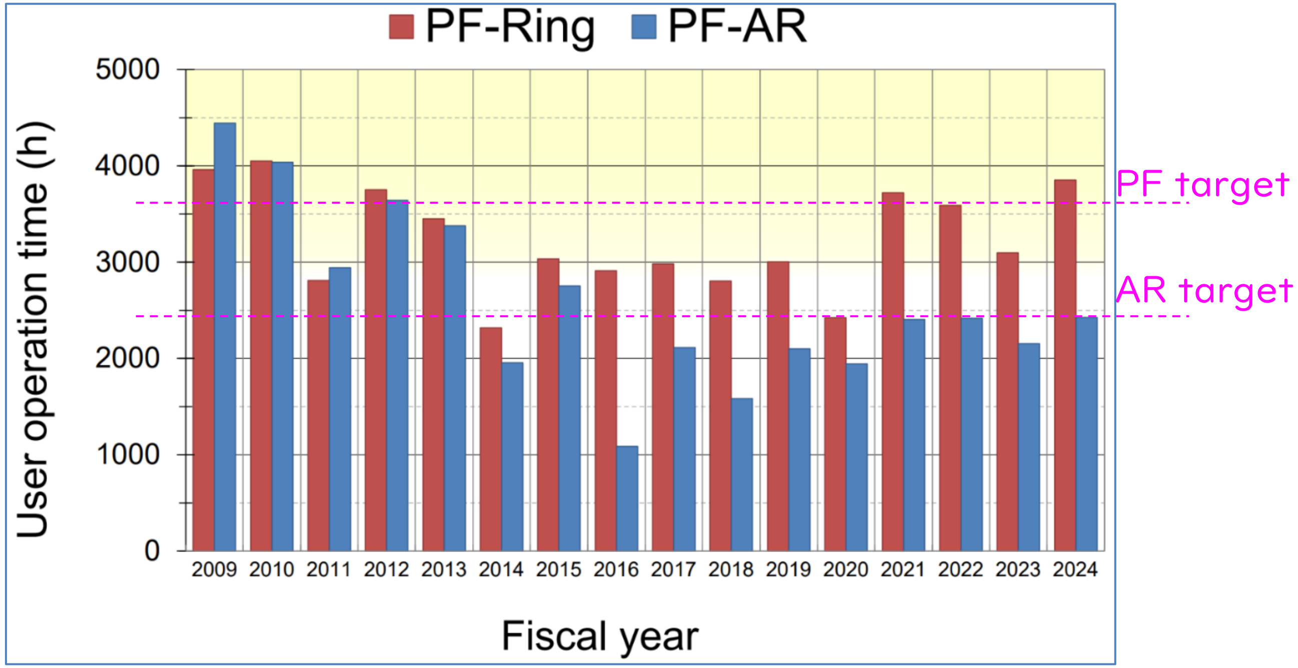
- single bunch

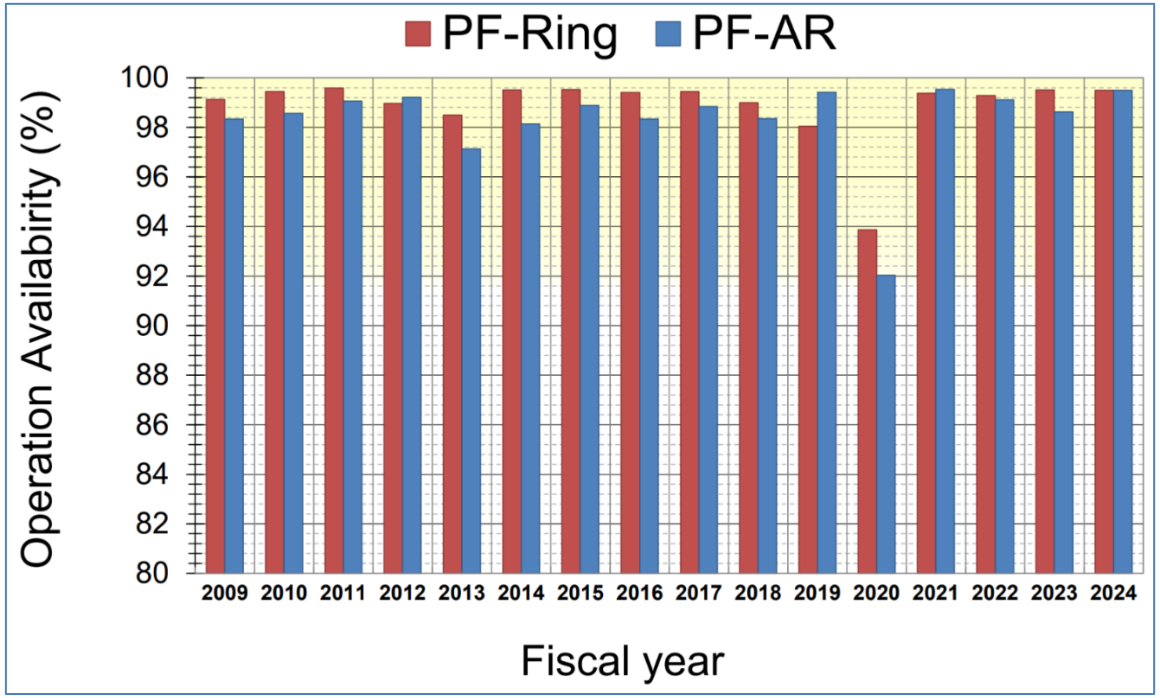
Both rings are operated in top-up injection mode from the Linac, which also injects into SuperKEKB.
Typical injection interval for PF and PF-AR is about 20 sec – several minutes.





Operation Statistics of PF-Ring and PF-AR : FY2009-2024





FY2025 target: 3,600 hours for PF and 2,400 hours for PF-AR

Aging-related failures have become frequent and are of serious concern. However, continuous and routine maintenance helps prevent accelerator malfunctions.
→ The average availability exceeds 99%, which indicates a remarkably high level of performance..

※ In 2020, operational availability was reduced due to a failure in the pulsed bending magnet located at the end of the injector linac.

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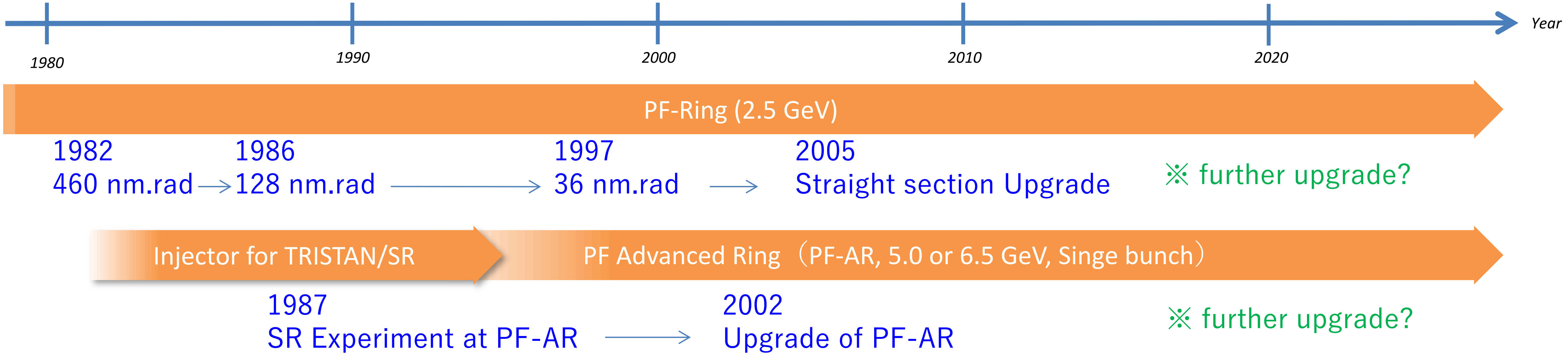
  - Typical operation status
  - Statistics
- Future Project
  - Brief history and Concept of New Light Source
  - PF-HLS (Photon Factory Hybrid Light Source)
    - Superconducting Linac technologies based on ILC (International Linear Collider) design
    - A storage ring design that balances versatility and advanced performance
  - Concept of the Quantum Multibeam Facility

History of PF-Ring and PF-AR / New Light Source Project



The possibility of reducing the emittance of the existing ring has been thoroughly considered.

Rather than reusing a building constructed nearly 45 years ago, it is more desirable to develop a state-of-the-art facility on a greenfield site equipped with the latest technologies.

New wine is put into fresh wineskins

New Light Source

The ultimate scientific objective

- Elucidation of the Fundamental Mechanisms Underlying the Functions of Matter and Life
- This is achieved by integration of all aspects of synchrotron radiation performance to promote the deepening, fusion, and creation of research fields and methodologies.

SR with wide wavelength range | SR + SR 2-Beam | SR + SP 2-Beam

① SR single beam experiment

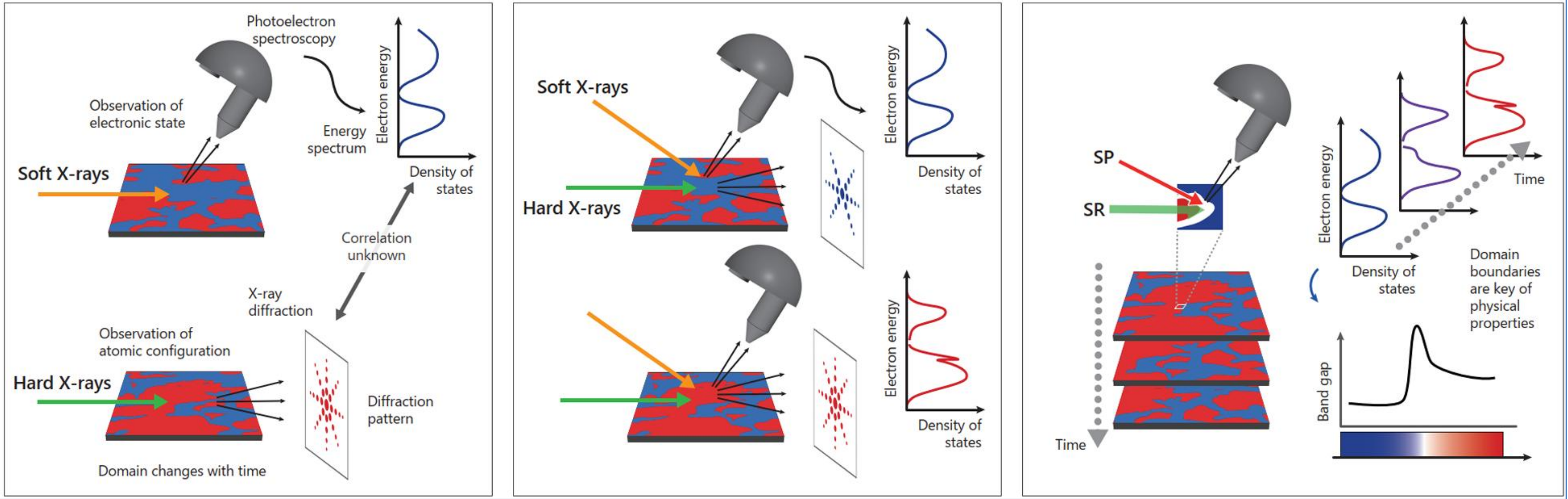
A wide wavelength range is available on a single beamline. This expands the targets and methods and promotes the **deepening** of wide fields and methods.

② SR + SR multibeam experiment

The electronic state and atomic configuration can be obtained simultaneously, providing a correlation between function and structure. Collaboration promotes the **fusion** of fields and methods.

③ SR + SP multibeam experiment

Qualitatively novel methods using the high spatio-temporal resolution of the SP beam, such as domain boundary observation and pump-probe experiments, will facilitate the **creation** of new knowledge.



PF-HLS Design Report https://www2.kek.jp/imss/pf/pf-hls/library/

Hybrid Ring Concept: SC Linac + Ring

Balancing cutting-edge performance and versatility

- Achieving ultra-low emittance is a major trend in the design of modern synchrotron light sources
- We propose an alternative approach that addresses the needs of user science:

cutting-edge SC Linac + versatile storage ring

A long-pulse superconducting (SC) linear accelerator can efficiently generate high current, ultra-low emittance, and ultra-short pulse electron beams.

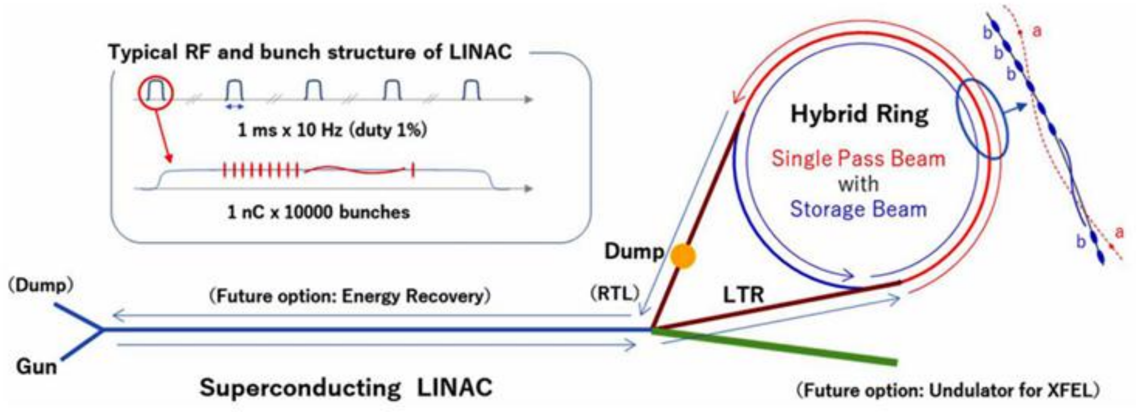
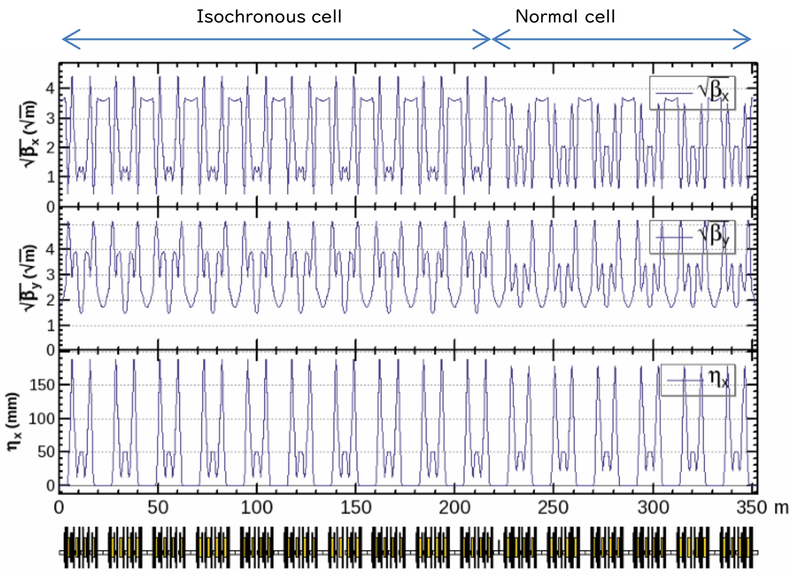


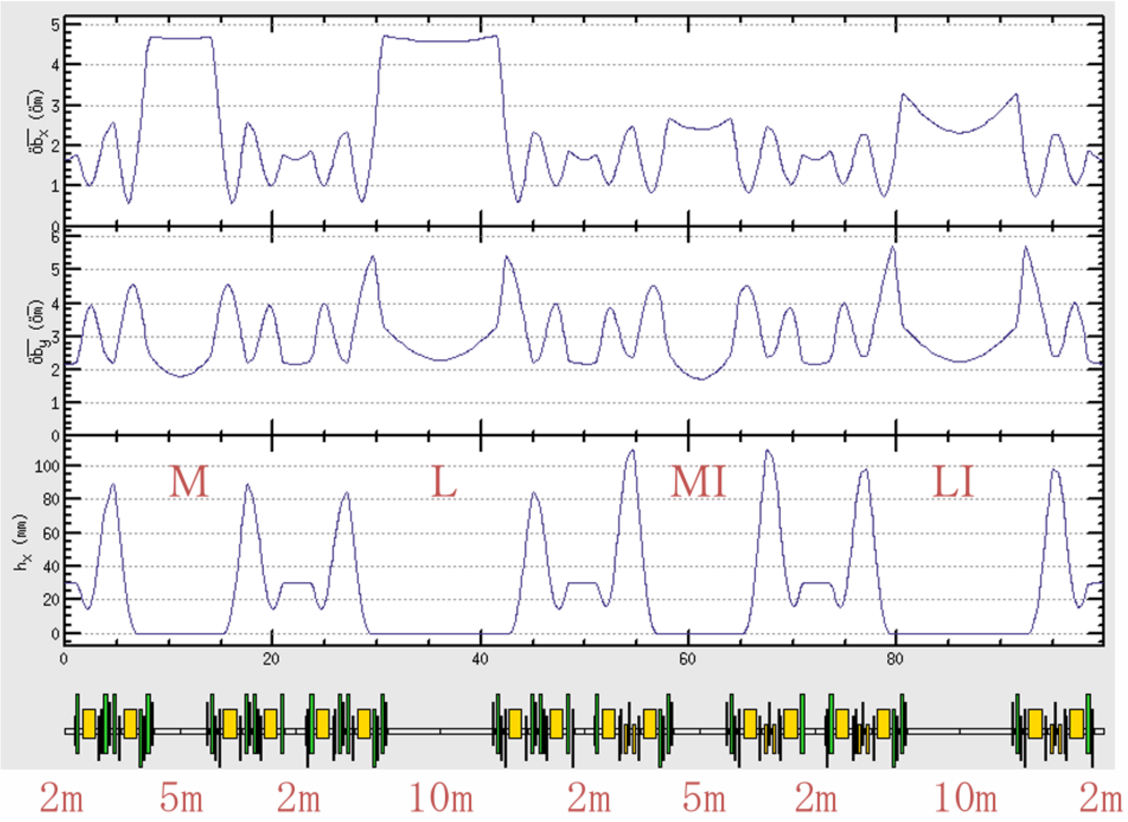
Figure 1
Concept of the Hybrid Ring with superconducting LINAC.

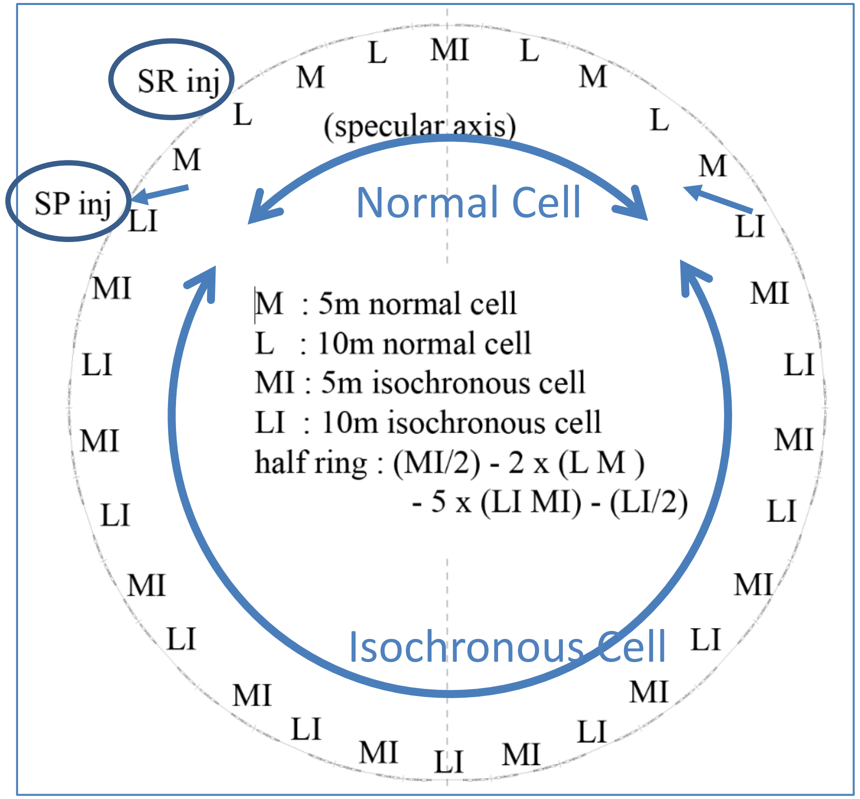
J. Synchrotron Rad. (2022). **29**, 118–124 Kentaro Harada *et al.* • Conceptual design of Hybrid Ring 119



K. Harada *et al.*, Conceptual design of the Hybrid Ring with superconducting linac,
J. Synchrotron Rad., **29**, 118 - 134 (2022). https://doi.org/10.1107/S1600577521012753

Lattice





- Two undulators are installed in the long straight section
- Simultaneous use of the SR and SP beams becomes possible
- Also, two SR beam experiment becomes possible (ex. HX + SX)

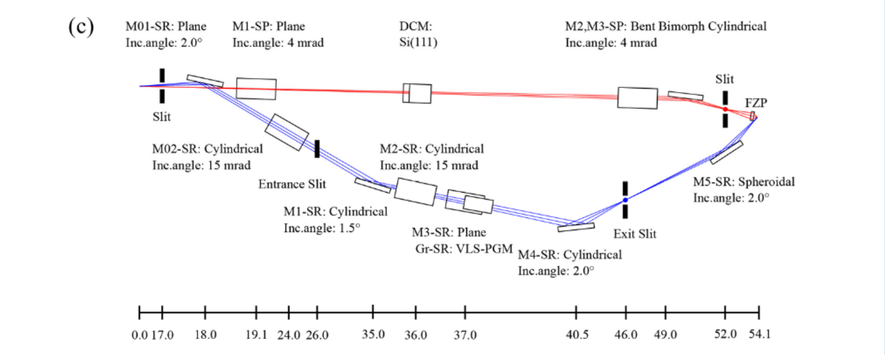


Figure 3-2-1: Examples of the beamline designs for the two-beam simultaneous use (plan view). (a) SX–SX, (b) hard X-ray (HX)–HX, and (c) SX–HX.

From the Hybrid Ring Concept to the PF-HLS Design

- SC Linac utilizes ILC technologies
- Introduction of Energy Switchable Storage Ring (ESSR) concept
  - A light source that achieves high-brilliance synchrotron radiation across a wide wavelength range, which is required from user's science needs

Key point for accelerator design

- 2.5 GeV / 5.0 GeV Energy switch
- Long circumference is suitable to reduce radiation power loss from bending magnets.
- A larger building leads to higher construction costs as well as increased expenses for utility consumption and maintenance.

Accelerator Design (tentative)

Circumference = 750 m

(reasonable size for 5.0 GeV Ring)

Operational Cost :

PF-Ring + PF-AR > PF-HLS

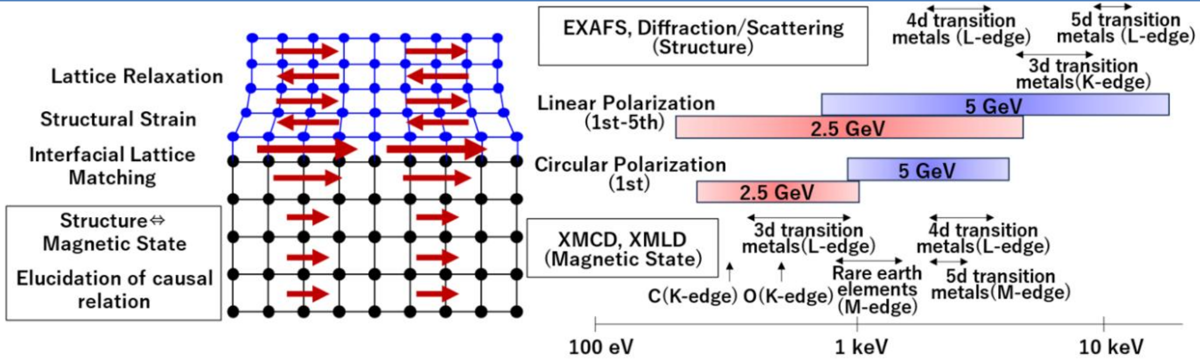


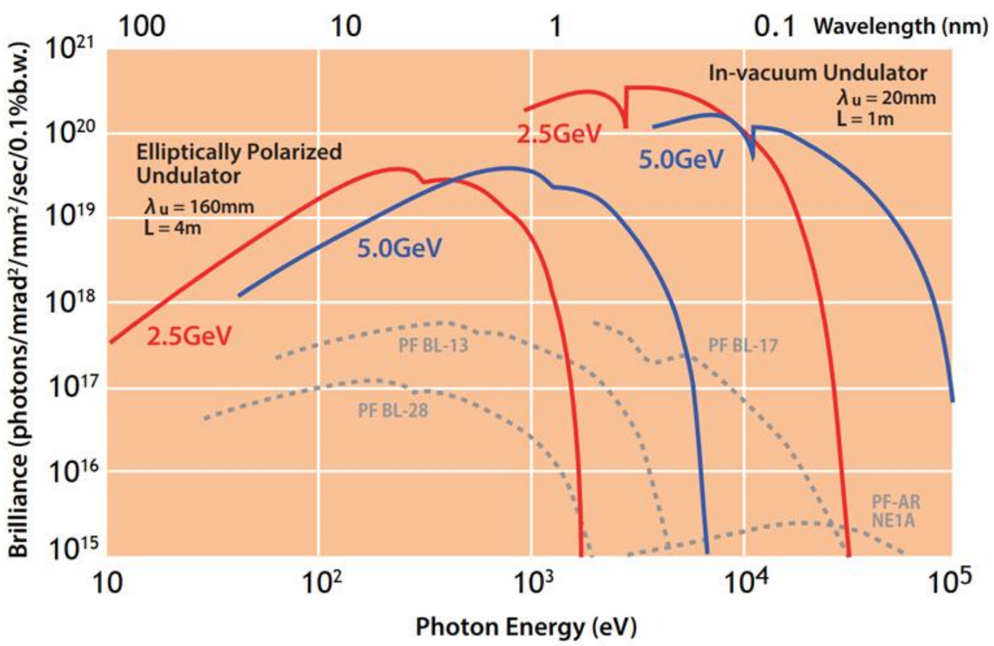
Figure 2-1-1: [Left] Schematic of the structure and magnetism in magnetic thin films. Unique magnetism arises due to lattice matching/mismatch and structural distortions at the interface, caused by growing thin films with different lattice constants compared to the substrate. [Right] Relationship between the energy covered by the 56-mm period APPLE-II-type undulator, target elements, and measurement methods.

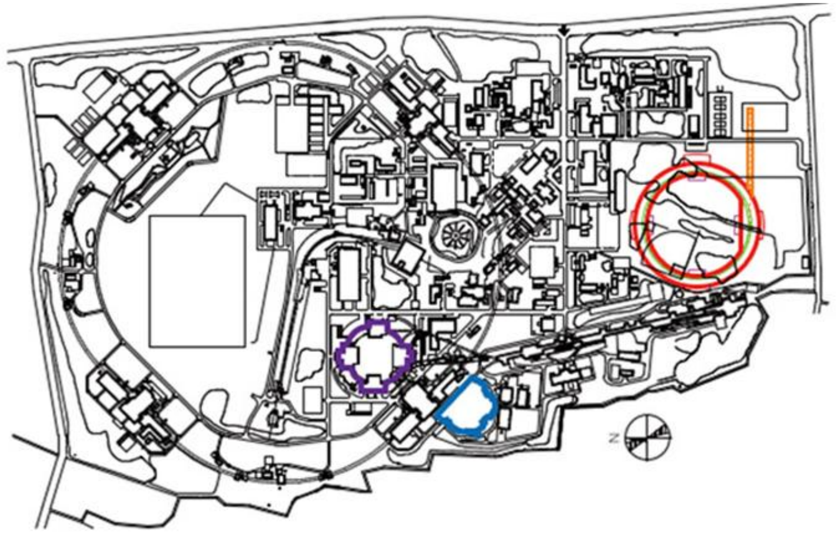
PF-HLS Design Report https://www2.kek.jp/imss/pf/pf-hls/library/

PF-HLS Parameters

Parameter	value	
Energy [GeV]	2.5	5.0
Circumference [m]	749.5	
Lattice	Double DDBA/8BA (modified)	
Normal cell number	4	
R_{56}~0 cell number	11	
RF voltage [MV]	1.6	6.5
Bucket height [%]	8.93	7.76
Energy loss [MeV/turn]	0.222	3.557
Momentum compaction	$3.24\text{x}10^{-5}$	
Betatron tune, ν_x/ν_y	47.865/16.655	
Damping time, x/y/z [ms]	25.9/56.2/67.5	3.24/7.03/8.44
Storage current [mA]	500	200
Natural emittance [nmrad]	0.208	0.832
Energy spread	$7.417\text{x}10^{-4}$	$1.48\text{x}10^{-3}$
Natural bunch length	4.72 ps (1.4mm)	7.21 ps (2.2mm)
Touscheck Lifetime [h]	1.25 *	21 *

* Coupling 1%, full bucket(1250)

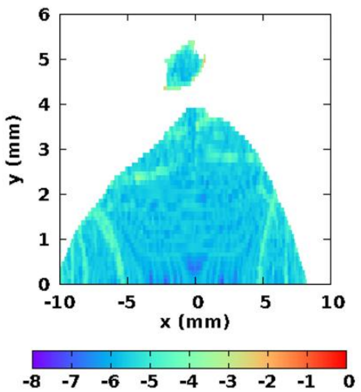


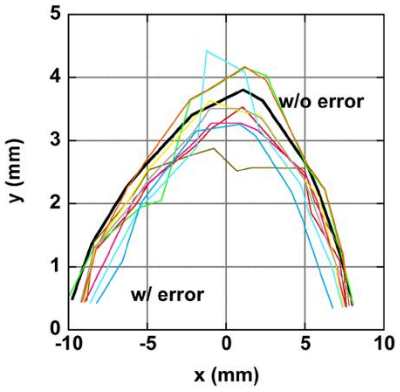


Many R&Ds for PF-HLS

Beam Dynamics

Ref: CDR v1.2 (in Japanese)
Y. Shimosaki PASJ2024

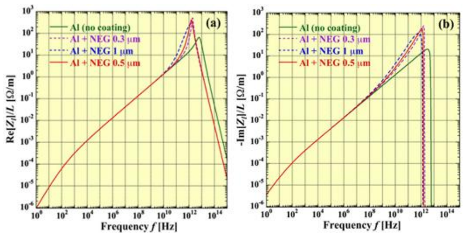




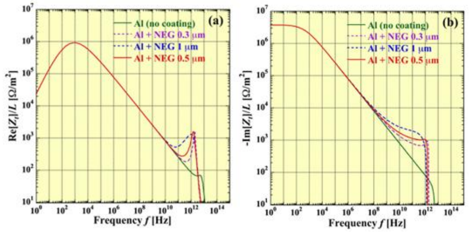
Frequency map of on-momentum particles without error observed at the injection point.

Impedance Calculation

Ref: CDR v1.2 (in Japanese)
N. Nakamura, PASJ2024
Impedance related topics:
WEPM077 (N. Nakamura)
WEPS105 (N. Yamamoto)
WEPM078 (B. Bian)
this conference



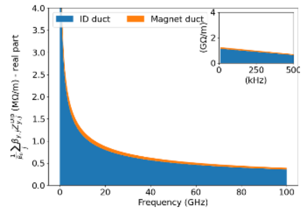
real part (a) and imaginary part (b) of the longitudinal impedance of the ID duct calculated for NEG coating thickness 0, 0.3, 0.5, 1 μm



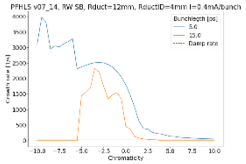
real part (a) and imaginary part (b) of the transverse impedance.

Instability/Impedance budget

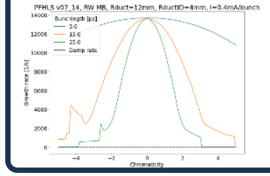
Ref: CDR v1.2 (in Japanese)
N. Yamamoto et.al. PASJ2024



Real part of the effective dipole impedance of whole ring (ID and Magnet duct).

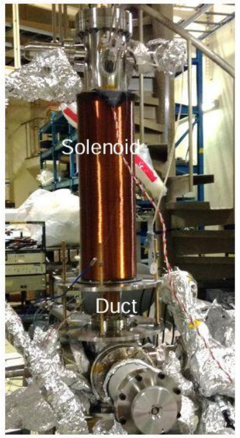


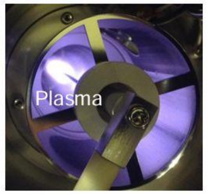
Single-bunch TMCI threshold as a function of chromaticity for a bunch length of 5 ps (natural bunch length) and 15 ps (bunch lengthened with the harmonic cavity, HC).



Growth rate of multi-bunch coupled-bunch instabilities for the bunch length of 5 ps, 15 ps and 25 ps. We need ξ=+3 and HC is required for the instability growth rate to be lower than the radiation damping rate

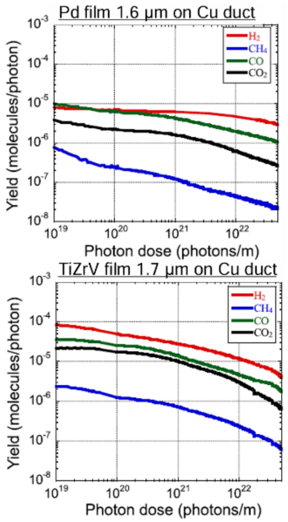
Development of Pd/TiZrV coated vacuum ducts





Twisted TiZrV wire

Twisted Pd wire



Magnetron sputtering system

Ref: X. Jin et.al. PASJ2024

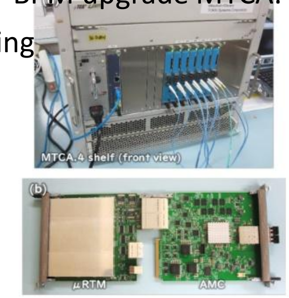
X.G. Jin *et al.*, Vacuum 215 (2023) #112370.

Beam Diagnostics/Tuning

Injection tuning with machine learning

Sakurai et.al. ML workshop

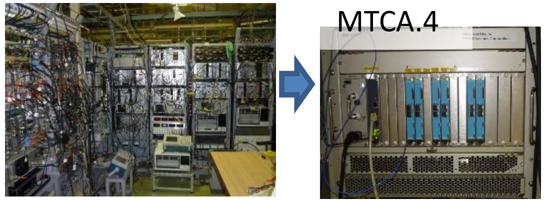
BPM upgrade MTCA.4

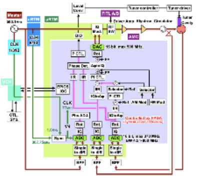


Digital LLRF System

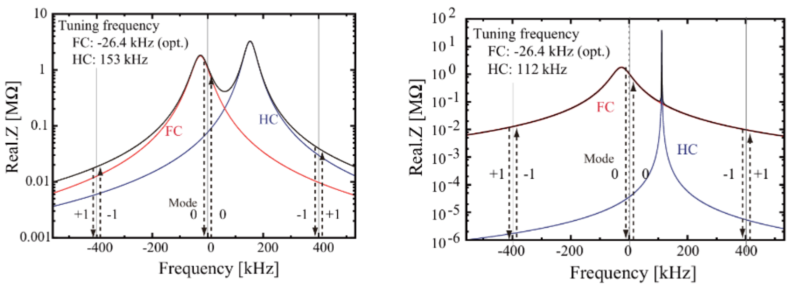
D. Naito et al., Oral WEFN1 this conference

MTCA.4





Candidates for Harmonic Cavity (HC)



Real part of total impedance of the RF cavities. Fundamental cavity (FC) + Harmonic cavity with normal conducting (left) and Superconducting (right) cavity. Black line shows total impedance. SC-HC can avoid coupled bunch instabilities due to the impedance of cavity structure even in the low revolution frequeny ring like PF-HLS.

N. Yamamoto et.al. PASJ2024

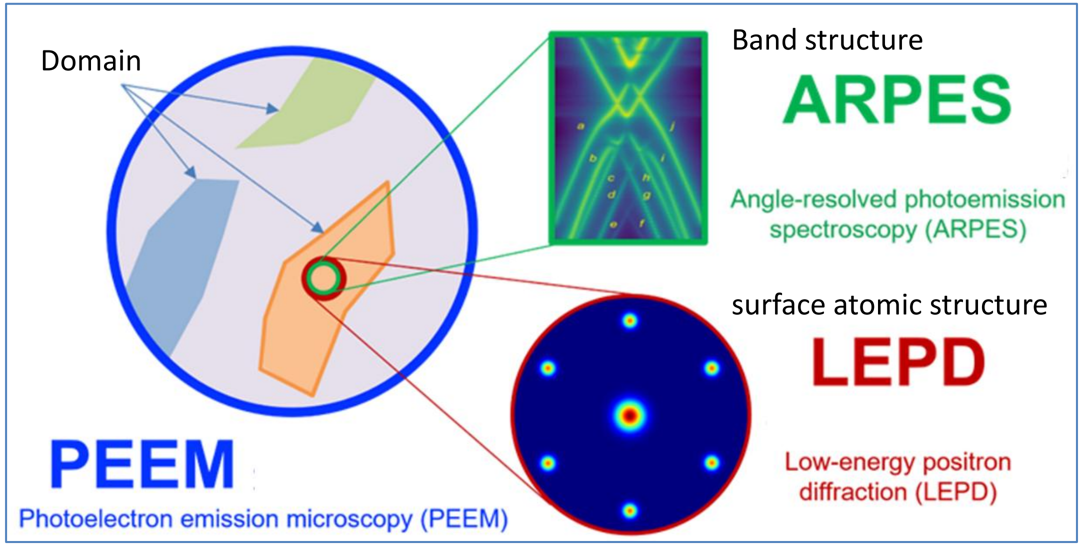
PF-HLS : Quantum Multibeam Facility

- Transition from sequential use to simultaneous use of quantum beams

- Why not use another quantum beam?
  - SR + Positron
  - SR + Neutron
  - SR + Muon

  These experiments are being conducted at KEK

- FEL option for high power SP beam?



Paving the way for a new era of surface nanoscience through the simultaneous use of synchrotron radiation (SR) and slow positrons.

pfhls cdr ver1.2 (In Japanese) The English version is currently being prepared.

Summary

- Present Status of the Photon Factory (PF-Ring and PF-AR)
  - History
  - Typical operation status
  - Statistics
- Future Project
  - PF-HLS (Photon Factory Hybrid Light Source)
    - Superconducting Linac technologies based on ILC (International Linear Collider) design
    - A storage ring design that balances versatility and advanced performance
    - Versatility : Two Beam (ESSR, SR + SR, SR+SP)
  - Concept of the Quantum Multibeam Facility

Aiming to pioneer new research fields
through the simultaneous use of multiple quantum beams

Posters Related to PF-HLS: Please Take a Look

WEPS105
- Benchmark study of transverse instability driven by the resistive wall impedance in the PF-HLS 2.5 GeV storage ring
- N. Yamamoto

WEPM077
- Resistive wall impedance calculations and effects of NEG coated insertion device vacuum pipes for the PF-HLS ring
- N. Nakamura

WEPM078
- Impedance benchmarking of resistive wall and tapered transitions for the PF-HLS
- B. Bian

TUPM065
- Nb3Sn superconducting multipole wiggler as a vertically polarized hard X-ray source
- H. Saito

WEPB050
- Test coil-unit fabrication of Nb3Sn superconducting multipole wiggler for next generation light source in KEK-PF
- C. Mitsuda

WEPB061
- High repetition tests of a pulsed power supply using SiC-MOSFETs for a fast kicker system in KEK-PF
- S.Shinohara