# Photon Factory

Inter-University Research Institute Corporation
High Energy Accelerator Research Organization

The synchrotron radiation facility at the High Energy Accelerator Research Organization (KEK), is widely known as the 'Photon Factory'. Synchrotron radiation is bright, short-wavelength light produced by accelerators and is an excellent tool for observing materials and life at the nanoscale.

The 2.5 GeV Photon Factory ring (PF ring), in operation since 1982, is the first dedicated synchrotron radiation facility in the X-ray region in Japan. Over the past 40 years, several major upgrades have been carried out to increase the brightness of the synchrotron radiation.

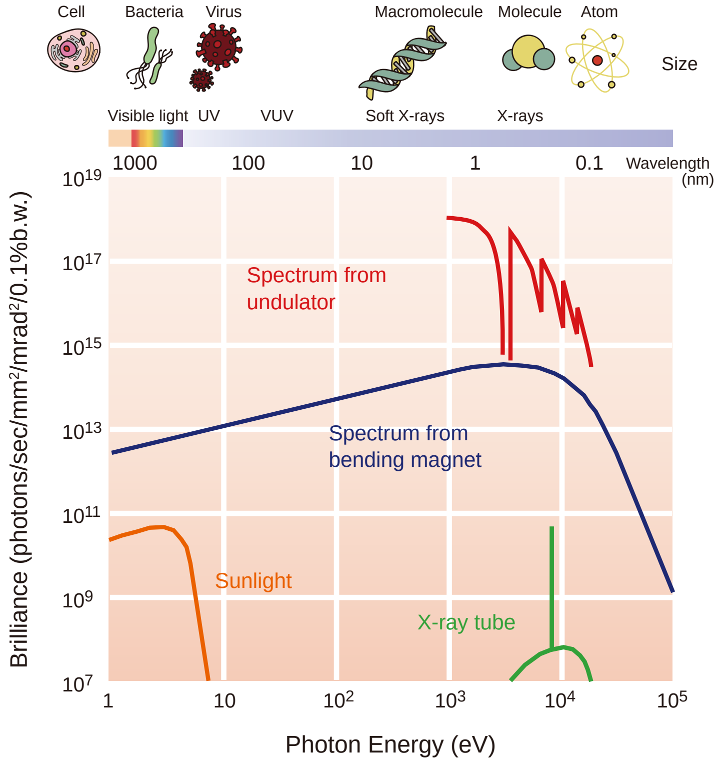
Another light source accelerator at KEK, Photon Factory Advanced Ring (PF-AR), is the world's only synchrotron radiation source dedicated to pulsed X-rays. The PF-AR began to use synchrotron radiation in 1987 in coexistence with a particle physics experiments, and was upgraded to a dedicated light source in 2002.

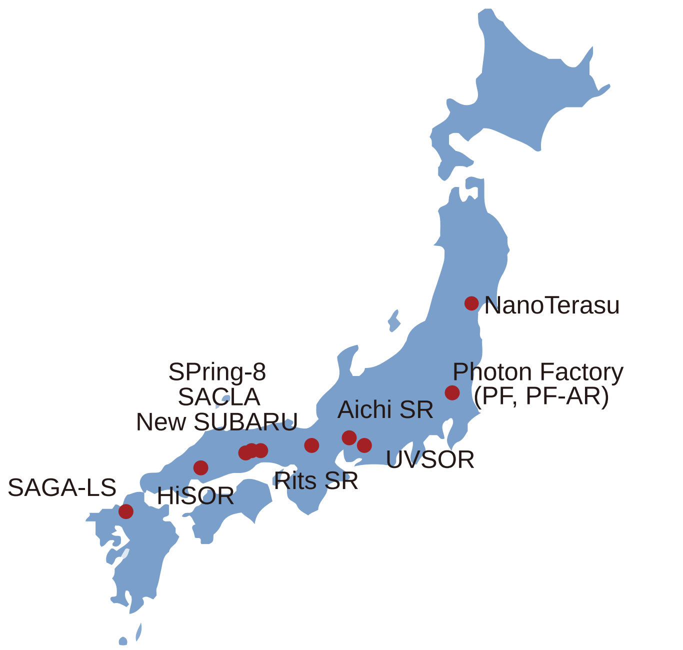
As an Inter-University Research Organization, KEK has provided many researchers throughout Japan and abroad with research platforms and associated technologies using Photon Factory. The findings generated from these efforts have led to a deeper understanding of materials and life, as well as to technologies for creating a sustainable society.

Photon Factory is a facility belonging to KEK, a global center of excellence in accelerator science. Fully utilizing this advantage, Photon Factory has continuously produced new accelerator technologies and human resources that are leading the world's synchrotron radiation science. And now we are on our way to an even better "factory of photon" that will make visible what was previously invisible.

## What is synchrotron radiation?

Synchrotron radiation is electromagnetic waves (light) emitted when electrons accelerated to nearly the speed of light undergo a magnetic field that changes their direction. It covers a wide range of wavelengths from infrared to X-rays.
X-rays, soft X-rays, and vacuum ultraviolet, which are light with short wavelengths, can observe the nanoscale properties of materials, such as the atomic arrangement and the behavior of electrons.
Synchrotron radiation is a bright light with highly directional properties that enables precise and accurate measurement of small samples. It also has polarizing and pulsed properties, and research is being conducted by using these properties, such as studying the orientation of molecules and observing chemical reactions or phase transitions.



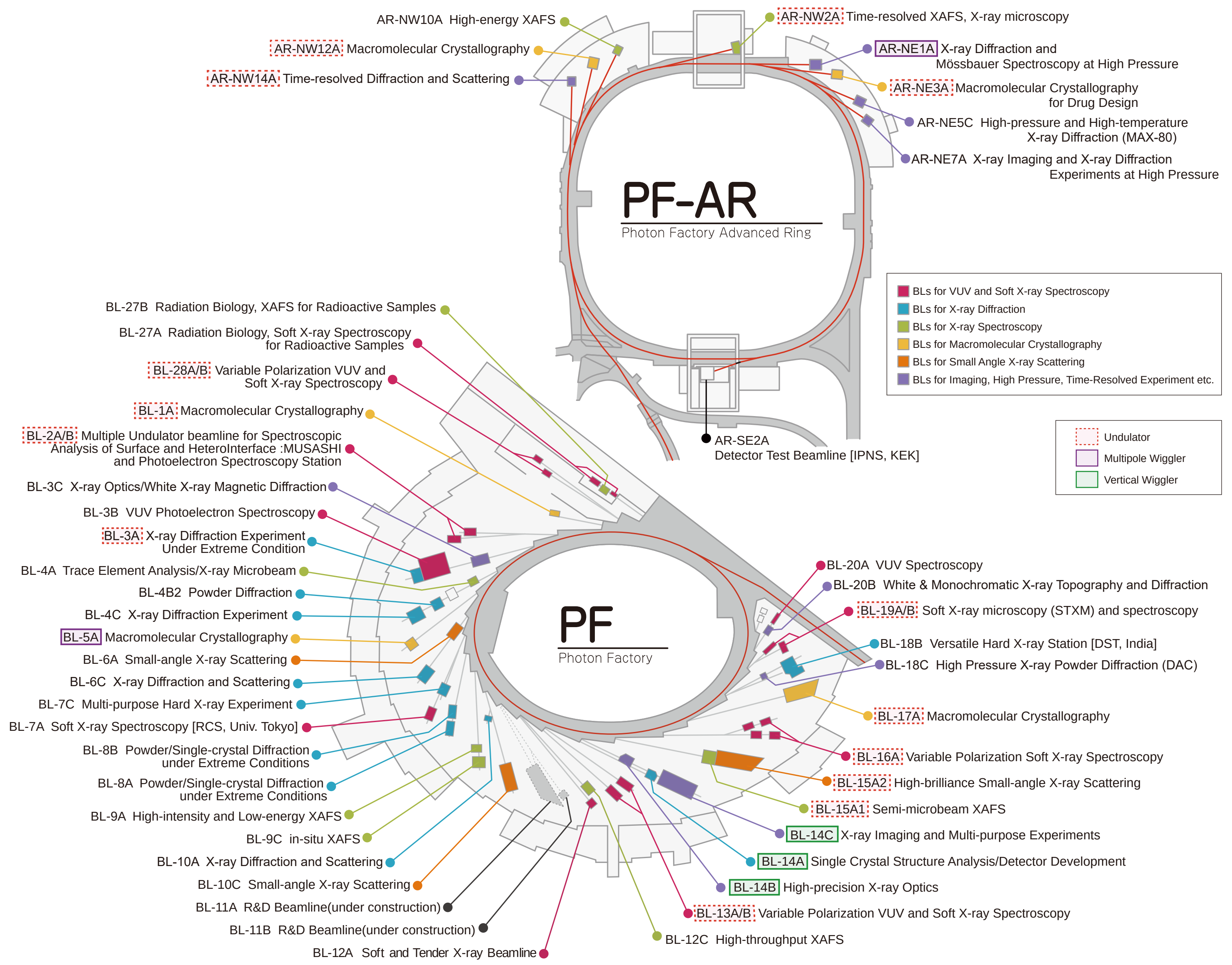




In 2024, there are ten facilities and eleven light sources (including X-ray free electron lasers) in operation in Japan. Three of these facilities, Photon Factory, UVSOR of Institute for Molecular Science, and HiSOR of Hiroshima University, are collaborating as synchrotron radiation facilities for academic purposes.

## Beamlines of Photon Factory

Beamlines of Photon Factory

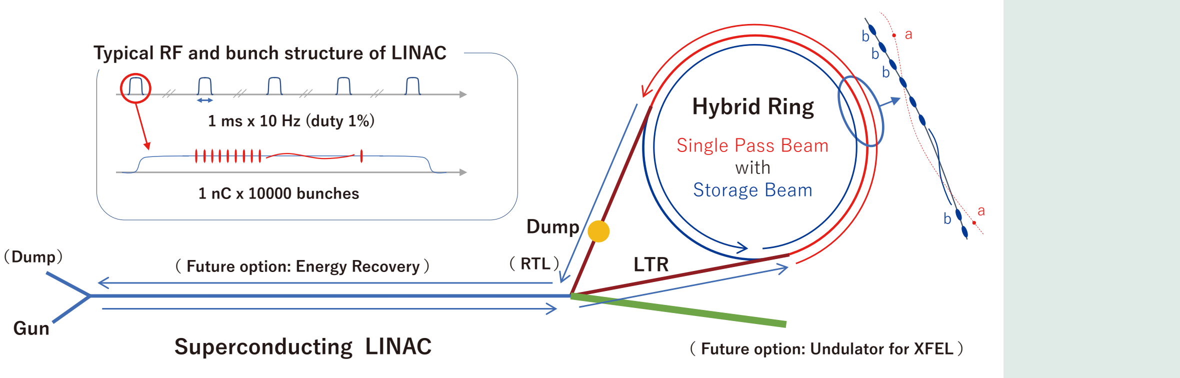
As of 2024, there are a total of 48 beamlines: 39 in the PF ring (including those under construction) and 9 in the PF-AR.




### Proposing future light sources using the world's most advanced accelerator technology

Photon Factory is currently discussing a new light source accelerator suitable for a world-class accelerator research institute. The "Hybrid Ring" is a new concept of synchrotron radiation accelerator in which two types of beams, an ultra-high performance single-pass beam and a high-performance, general-purpose storage beam, coexist, allowing selective and simultaneous use of the two types of beams.

Topics




Concept of Hybrid Ring

## Synchrotron radiation experiments - Create light and illuminate with light.-

Synchrotron radiation produced by accelerators is processed in beamlines and directed to experimental instruments. The Photon Factory, an academic facility, allows researchers not only to use the instruments, but also to develop highly original research equipment including beamline.(Using BL-2 as an example, we will introduce the technologies used in the process from the production of light to its irradiation onto a sample.)

❶ Accelerator / Insertion device (generation of light)

The development of insertion device technologies such as undulators has made it possible to obtain high-brightness, high-controlled light (photo: undulator at BL-2).

❷ Beamline (processing of light)

The light generated by the accelerator is processed by a monochromator and focusing mirrors, and then guided to the experimental apparatus (photo: diffraction grating monochromator at BL-2).

❸ Experimental apparatus (utilization of light)

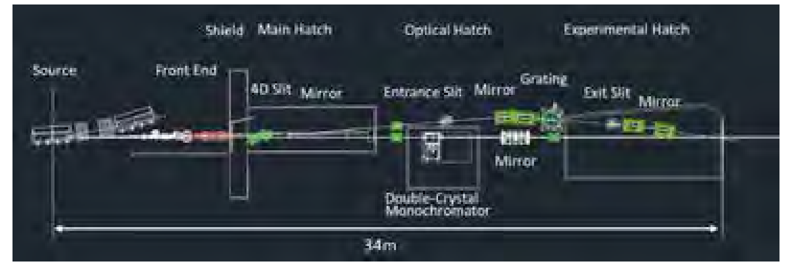
The processed light is irradiated onto the sample and data are acquired (photo: in situ high-resolution angle-resolved photoemission spectrometer installed at BL-2).

### BL-3A Beamline for X-ray diffraction under extreme condition

A superconducting magnet is equipped to enable X-ray diffraction experiments under a high magnetic field. Resonant X-ray scattering, which utilizes polarized X-rays, is used to study the ordered state of charge, orbital, and spin in materials. Research using this technique will lead to the development of next-generation devices such as spintronics devices.

### BL-11A,11B R&D Beamline (under construction)

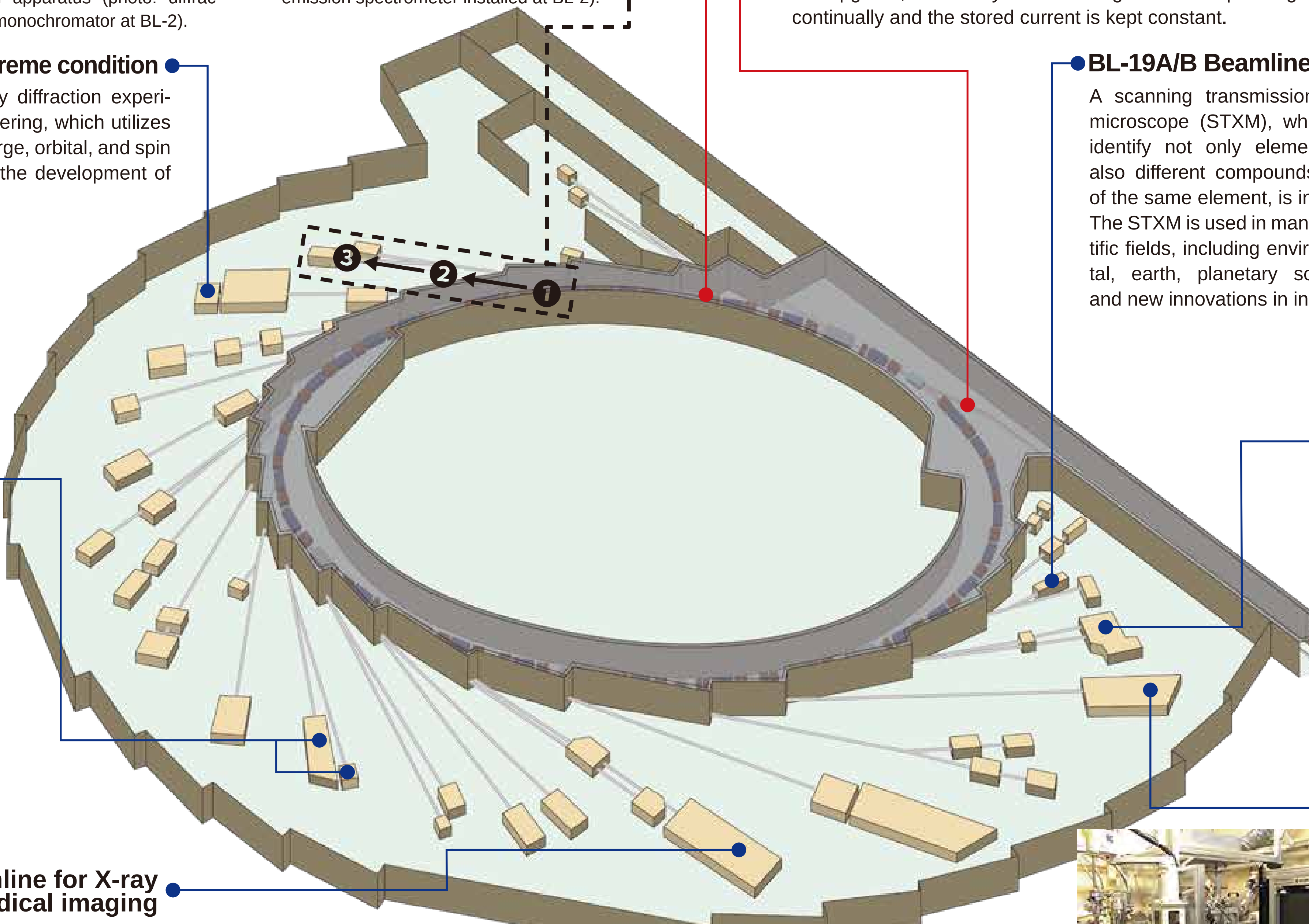
For the development of technologies necessary for future synchrotron radiation science, a dedicated beamline for research and development is planned, which allows free experimental arrangements. It will also be used to train young beamline scientists.




Special arrangements in which two beams are irradiated to a sample at the same time are also available to promote research and development for the future light source.

### BL-14C Beamline for X-ray medical imaging

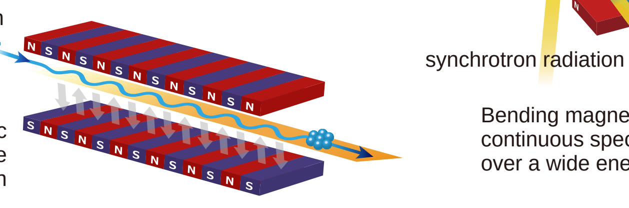
This is the only beamline in the world that has a vertical wiggler as its light source, which produces vertically polarized light. Using this unique synchrotron radiation, an X-ray interferometer with a horizontal configuration, which is not affected by gravity, has been installed to perform ultra-sensitive, large-field X-ray phase imaging experiments with the highest performance in the world.



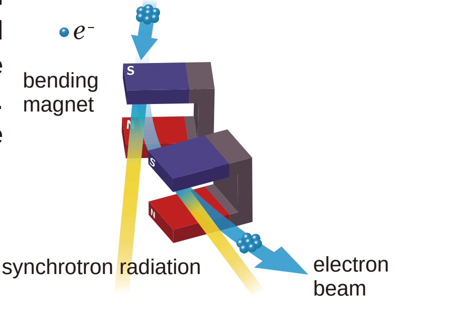

from injector linac

### Light source accelerator

The ring-shaped light source accelerator has a circular array of bending magnets that bend electron orbits to generate light. The straight sections between the bending magnets are equipped with undulators, which generate highly brilliant light. In synchrotron radiation experiments where small samples are analyzed, the quality of the light source greatly affects the quality of experiment. Photon Factory has undergone several upgrades based on the latest accelerator technology since its first beam of 40 years ago, and remains competitive to this day.




Undulator : A device consisting of many alternating magnetic poles. Electrons changed their direction by each magnetic pole generate synchrotron radiation, which interferes with each other to produce highly-brilliant light.




Bending magnet : Emits continuous spectrum of light over a wide energy range

### Beam transfer between injector and light source accelerator

The electron beam accelerated by the injector is delivered to the light source accelerator. The injector linac injects electron beams into two synchrotron radiation rings (PF ring and PF-AR) and electron and positron beams into the collider SuperKEKB. In 2017, an upgrade was completed to allow each ring to be injected with electron and positron beams of different energies and charge, switching between them at high speeds. With this upgrade, the two synchrotron rings are now operating in top-up mode, i.e., the electron beam is injected continually and the stored current is kept constant.

### BL-19A/B Beamline for soft X-ray microscopy and spectroscopy

A scanning transmission X-ray microscope (STXM), which can identify not only elements but also different compounds made of the same element, is installed. The STXM is used in many scientific fields, including environmental, earth, planetary sciences, and new innovations in industry.

Asteroid Ryugu samples were also analyzed.

HAYABUSA2-IMSS
Analysis of asteroid Ryugu

### BL-18B Beamline operated by DST, India

Since 2009, the beamline has been operated by the Department of Science and Technology (DST), Government of India. Mainly diffraction and scattering experiments are performed. The beamline contributes to synchrotron radiation research and to the training of young researchers in India.

### BL-17A Beamline for macromolecular crystallography

The macromolecular crystallography beamlines at the Photon Factory include BL-1A, which is capable of Native-SAD (structure determination using naturally contained sulfur *etc.*) using low-energy X-rays, and BL-17A, which is capable of structural analysis of small crystals with a small beam size. All beamlines are equipped with sample changer, allowing remote experiments from anywhere in the world.

### Development of the first in-vacuum undulator in the world

The development of in-vacuum undulators, in which a short period is achieved by placing alternating dipole magnets inside the accelerator's vacuum pipe, began at KEK around 1988, and light was successfully generated for the first time in December 1990. This technology can turn synchrotron radiation facilities into compact and energy-saving ones, because short-period undulators can generate high energy and intense X-rays even in 3-GeV class storage ring. The development has led to a trend towards the construction of synchrotron radiation facilities installed in-vacuum undulators around the world.

The first in-vacuum undulator (AR-NE3)

### Photon Factory at the dawn of structural biology using synchrotron radiation

The Photon Factory opened its first dedicated protein crystallography beamline with a Weissenberg camera in the mid-1980s. Prof. Ada Yonath, who was awarded the Nobel Prize in Chemistry in 2009 for her work on the structure-function analysis of ribosomes, was conducting her experiments at the Photon Factory at this time. The cryo-crystallography developed at the time led to the successful structural analysis.

The research team of Dr. Yoshinori Ohsumi, who was awarded the Nobel Prize in Physiology or Medicine in 2016, has also published about 20 papers on the structural analysis of autophagy-related proteins.

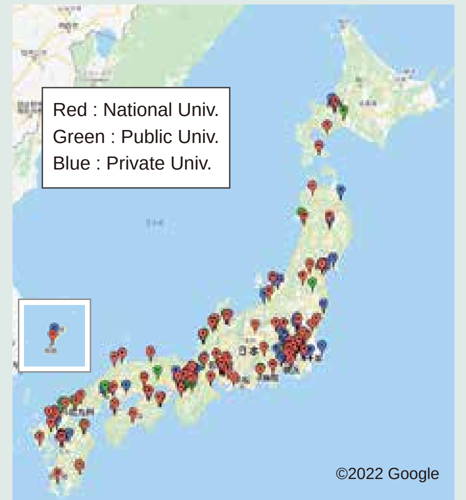
Prof. Ada Yonath and her colleague of Photon Factory at the time in 1980's (photo taken in March 2010).

There is also a cryo-electron microscope in operation at KEK's Tsukuba campus, which has made remarkable progress in the structural analysis of proteins. Many outcomes have been achieved, ranging from basic research that explores the mechanisms of life to applied research that leads to drug developments.

### Contribution to University Education

Photon Factory is used by approximately 3,000 researchers annually. About half of these are students, thus playing an important role in the university's research and education. About 300 degrees (master and doctor) by using Photon Factory are awarded annually, bringing the total to about 6,000 to date.

Photon Factory is used by national universities, public universities, and private universities in a wide variety of research fields.




Universities in Japan have used Photon Factory

## Using the Photon Factory

Photon Factory supports research and development mainly in academic fields. In particular, we actively support innovative research projects that involve trial and error.
We also offer charged programs that can be used by companies and other organizations. Some beamlines offer optional services such as "user support", "consulting" and "substitutional measurement and analysis".

Call for Proposal

## Degree in the Photon Factory

The Graduate University for Advanced Studies (SOKENDAI) is a graduate university to utilize the advanced research environment of an inter-university research institute. At Photon Factory, graduate students at SOKENDAI are conducting research under research guidance. Several universities, including the University of Tokyo and Hokkaido University, have concluded agreements to cooperate in supervising students.

## Tours of the Photon Factory

Group tours of 10 or more people are accepted. There are also events that are open for everyone such as KEK Open House and Spring Science & Technology Week.

## Support the Photon Factory

The donation program for the Photon Factory’s advanced research will be used to improve the research environment and promote future plans for the Photon Factory. We appreciate your warm support for the future of the Photon Factory.

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