A new plan for 3 GeV synchrotron radiation facility in Japan

Wataru Utsumi[1] and Masaki Takata[2)3)]

[1)]Institute for Advanced Synchrotron Light Source, QST, Japan;

utsumi.wataru@qst.go.jp

[2)]Photon Science Innovation Center, Japan

[3)]Tohoku University, Japan

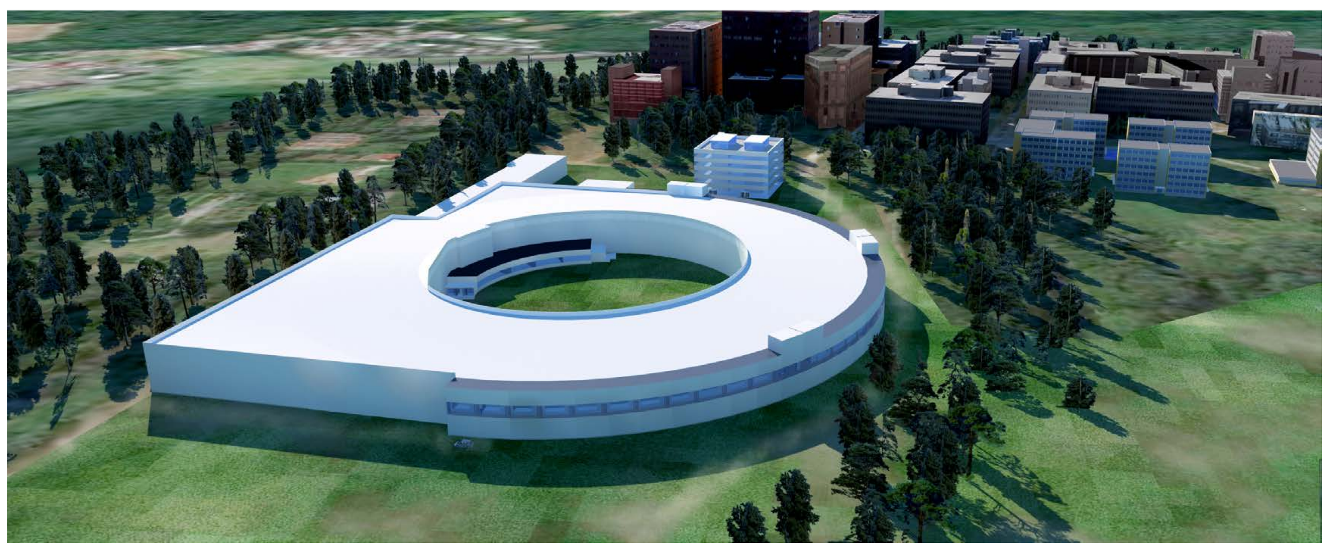
Japanese government has recently decided to build a new 3 GeV-class synchrotron radiation facility in the "Aobayama new campus" of Tohoku University, which is located in the Northern East area, Japan. It is a high brilliance light source by an electron accelerator system combined with a linac and a 3 GeV storage ring, which covers the spectral regions from VUV to hard x-rays.

The key concept of our new synchrotron radiation facility is "advanced and stable light source to create innovations in science and technology". Its machine parameters are as follows.

- **Ring Energy: 3 GeV**
- **Ring Current: 400 mA**
- **Ring Circumference: 349 m**
- **Emittance: 1.1 nmrad**
- **Brilliance: 1021 photons/s/mrad2/mm2/0.1%b.w. (@1KeV)**
- **Number of beamlines: 26 (10 beamlines will be constructed at an early stage)**

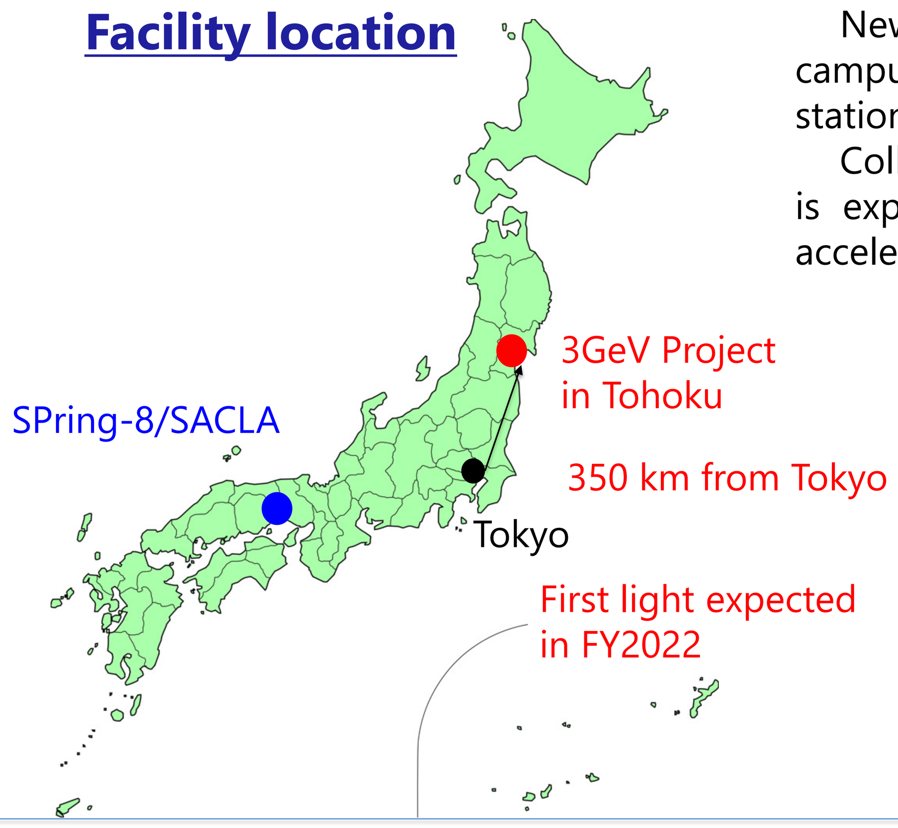
The synchrotron radiation spectrum ranges from the VUV and soft X-ray (50-1000 eV, including the sharpest core levels for optimum chemical sensitivity) through the "tender X-ray" region (1-5 keV, covering Mg, Al, Si for earth science and P, S for biochemistry) all the way to hard X-rays (> 5 keV for protein crystallography, environmental science, and chemistry in realistic environments).

The construction will be made by the collaboration of public-private regional partnerships. Total budget (10 beamlines included) is about 36 billion Japanese Yen. The site preparation work started in March of 2019, and the first beam is scheduled in 2023.



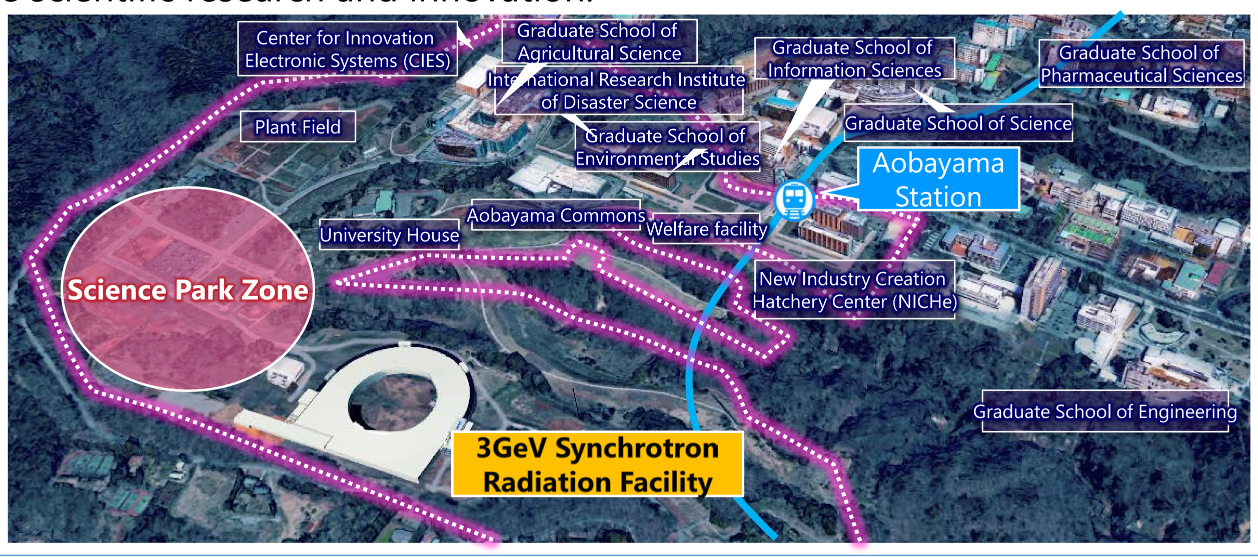
Rendering image of a new 3 GeV synchrotron radiation facility in the "Aobayama new campus" of Tohoku University, Japan

Facility location



New 3 GeV synchrotron radiation facility is planned to be built at Aobayama new campus of Tohoku University and 15 minuets walking distance from Aobayama station which is 7 minuets form Sendai station.

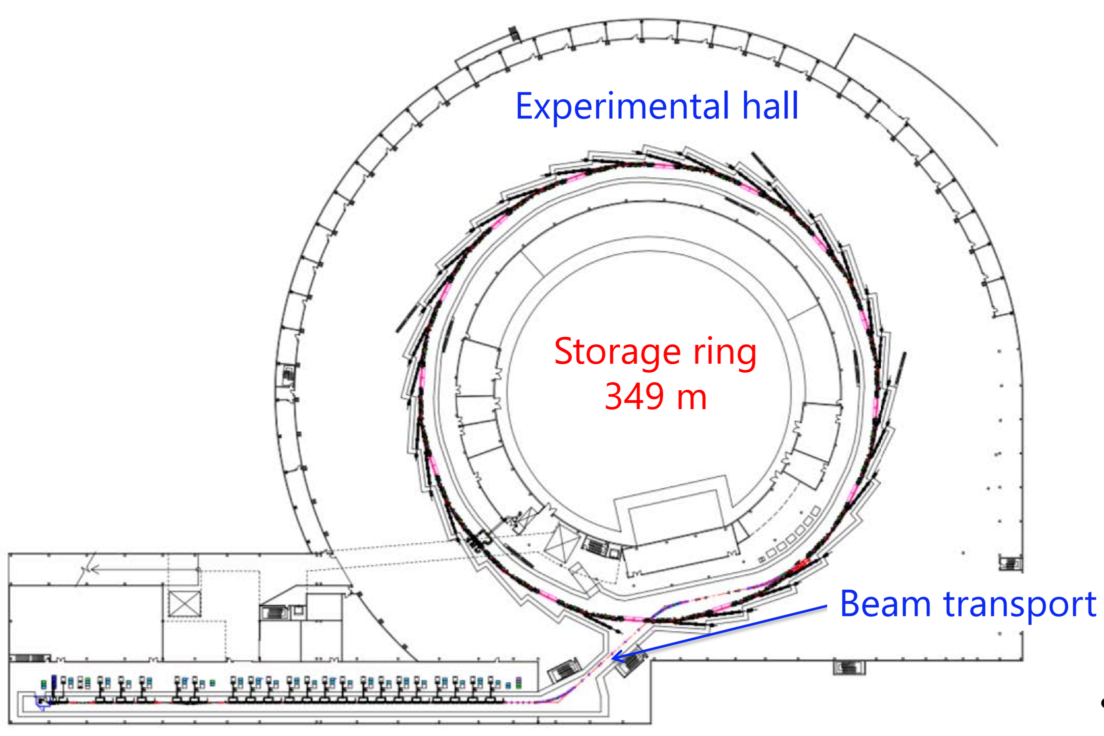
Collaborating with Tohoku University not only academic use but also industrial use is expected. Science Park Zone is also planed to build next to the facility and accelerate scientific research and innovation.



Accelerator system

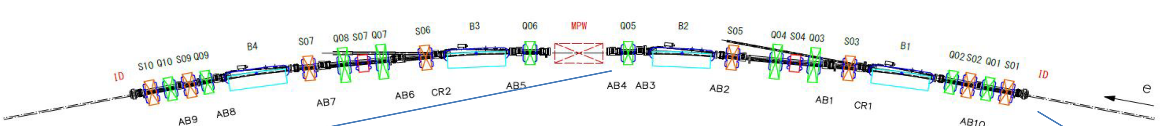
The accelerator for the new 3GeV synchrotron radiation facility is required to be (1) compact with less than 350 m circumference, (2) in stable top-up operation combining high performance linear accelerator and new injector technology, (3) at high cost performance to realize stable and reliable light source along with brightness.

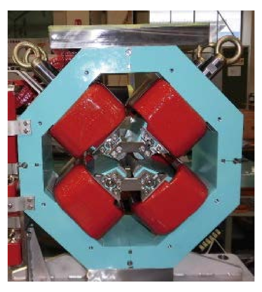
3 GeV accelerator complex



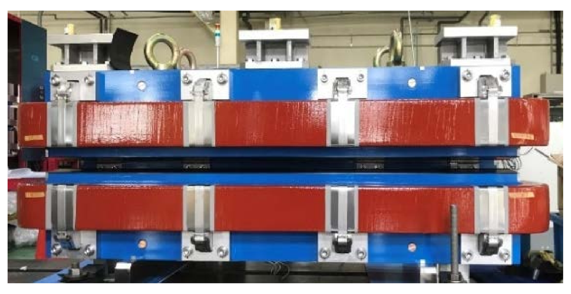
- Storage ring with 350 m circumference
- Injector linac of 110 m long

Test half-cell

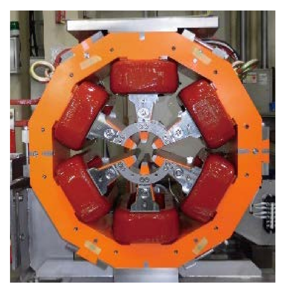




Quadrupole magnet



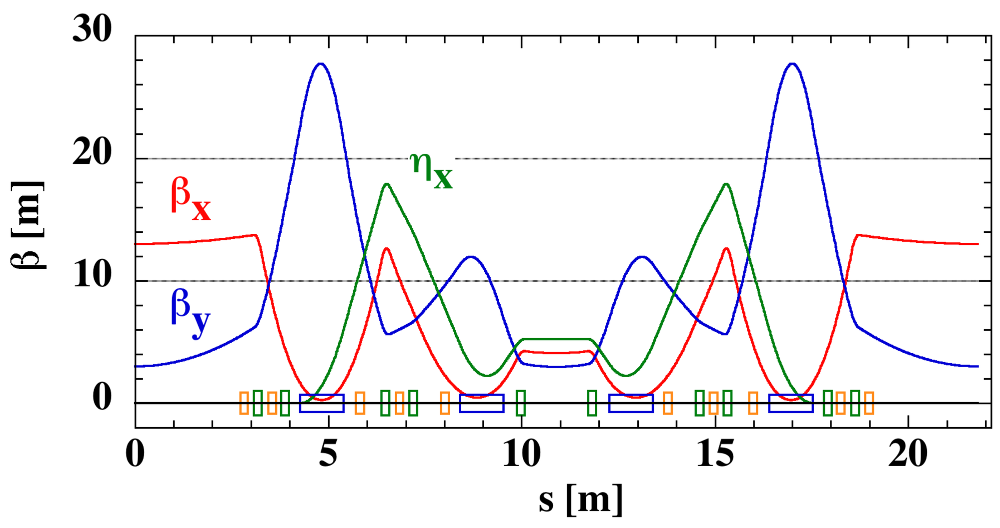
Bending magnet



Sextupole magnet

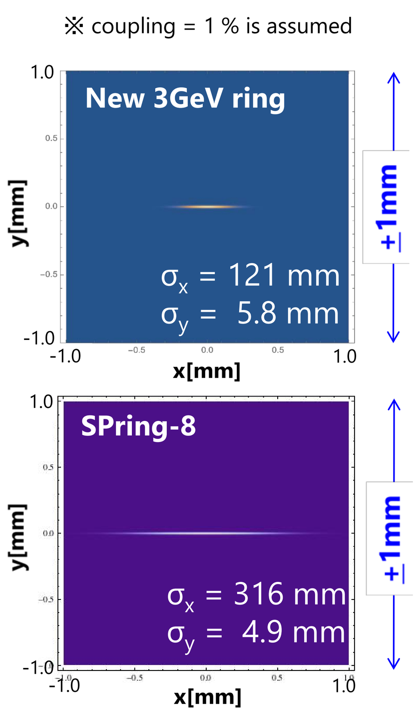
- A test half-cell consisting of 2 combined-B, 5 Q and 5 SX lined up on 3 girders.
- Performance study of newly fabricated magnets
- Establishment of precise alignment procedure of the magnets.

Four-bend achromat lattice



A 4-bend achromat lattice for low emittance with short circumference. The horizontal beam size at the undulator center is 1/3 of SPring-8. The vertical beam size is similar to SPring-8.

Beam size at undulator



3GeV storage ring parameters

Lattice parameter		
Beam energy	E (GeV)	2.998
Lattice structure		4bend achromat
Circumference	C (m)	348.8432
Number of cells	N_s	16
Long straight section	(m)	5.4400 × 16
Short straight section	(m)	1.6427 × 16
Betatron tune	x / y	28.17 / 9.23
Natural chromaticity	x / y	-60.50 / -40.99
Natural horizontal emittance	(nmrad)	1.14
Momentum compaction factor	α	0.000433
Natural energy spread	$\sigma E/E$ (%)	0.0843
Lattice functions at LSS	$\beta_x / \beta_y / \eta_x$ (m)	13.0 / 3.0 / 0.0
Lattice functions at SSS	$\beta_x / \beta_y / \eta_x$ (m)	4.08 / 2.962 / 0.052
Damping partition number	J_x / J_s	1.389 / 1.611
Damping time	$\tau_x / \tau_y / \tau_s$ (ms)	8.091 / 11.238 / 6.976
Energy loss in bends	(MeV/turn)	0.621
RF frequency	(MHz)	508.75905
Harmonic number	h	592
Beam size at long straight	σ_x/σ_y	121/5.8

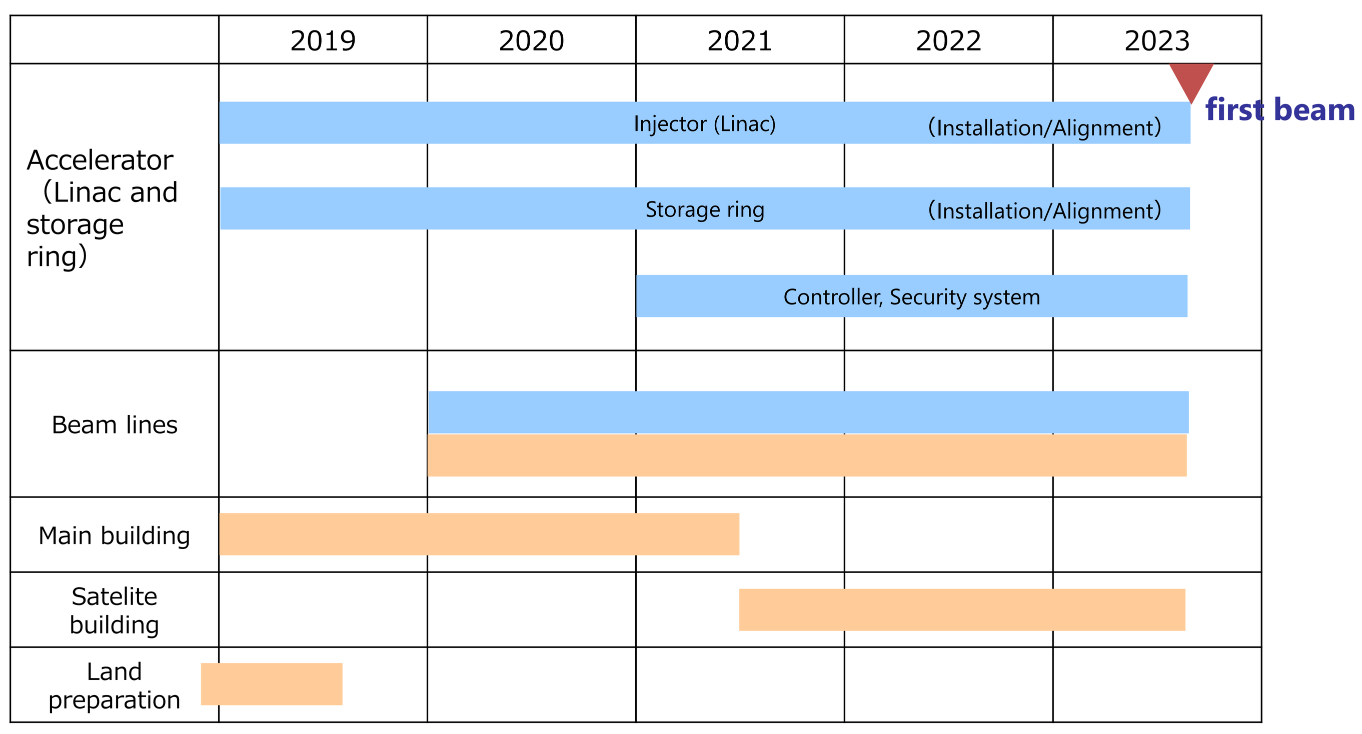
Beamlines

In the first phase, we are planning to construct the 10 beamlines listed below in view of (1) effective use of the low-emittance light source, (2) needs of academia and industries, and (3) complementary roles to existing synchrotron facilities in Japan.

Four out of the ten beamlines will allow access to highly brilliant tender X-rays from 2 to 5 keV or higher for the purpose of X-ray coherent diffraction imaging and X-ray operando spectroscopy. The rest are soft-X-ray beamlines covering an energy range from 50 eV to 2 keV, devoted to various spectroscopy experiments. The brilliance and photon flux in this energy range are expected to be 10-100 times as high as those available at SPring-8.

BL Number	BL name	Planned experiments	Insertion device	Energy range (polarization)	Energy resolution	Beam size
BL-I	X-ray operando spectroscopy	· Ambient-pressure X-ray photoelectron spectroscopy · Ambient-pressure X-ray absorption fine structure spectroscopy · X-ray diffraction	In-vacuum plane undulator	2-20 keV (horizontal linear polarization)	E/△E= 7,000	100 nm
BL-II	X-ray structural and electronic-state total analysis	· Scanning transmission X-ray microscopy · Small-angle/wide-angle X-ray scattering · X-ray absorption fine structure spectroscopy	Multipole wiggler	2-20 keV (horizontal linear polarization)	E/△E= 7,000	50 µm
BL-III	X-ray multiscale structure analysis	· X-ray absorption, imaging · Phase contrast imaging · Scanning X-ray fluorescence imaging · X-ray diffraction · X-ray fluorescence holography	Multipole wiggler	4.4-30 keV (horizontal linear polarization)	E/△E= 7,000	50 µm
BL-IV	X-ray coherent imaging	· Coherent X-ray diffraction imaging · X-ray ptychography · Ptychography X-ray absorption fine structure spectroscopy	In-vacuum plane undulator	3.1-20 keV (circular polarization) 2-20 keV (horizontal linear polarization) 3.1-20 keV (vertical linear polarization)	E/△E= 7,000	50µm (unfocused) 100 nm (focused)
BL-V	Soft X-ray magnetic imaging	· Soft X-ray phase-contrast imaging · Scanning transmission imaging · Scanning X-ray fluorescence imaging · Soft X-ray magnetic imaging · X-ray magnetic circular dichroism · X-ray magnetic linear dichroism · X-ray magneto-optical Kerr effect	APPLE undulator	0.18-1.2 keV (circular polarization) 0.13-2 keV (horizontal linear polarization) 0.23-2 keV (vertical linear polarization)	E/△E= 10,000-30,000	< 50 nm
BL-VI	Soft X-ray electronic state analysis	· Nanoscale photoemission spectroscopy · Resonant Inelastic X-ray scattering	APPLE undulator	0.05-1.0 keV (horizontal linear polarization) 0.05-1.0 keV (vertical linear polarization)	E/△E= 10,000-30,000	< 50 nm
BL-VII	Soft X-ray operando spectroscopy	· Near ambient pressure X-ray photoemission spectroscopy · Near ambient pressure X-ray absorption fine structure spectroscopy	APPLE undulator	0.13-2 keV (horizontal linear polarization) 0.23-2 keV (vertical linear polarization)	E/△E= 10,000-30,000	< 50 nm
BL-VIII	Soft X-ray nanoscale photoemission spectroscopy	· Nanoscale spin-resolved angle-resolved photoemission spectroscopy	APPLE undulator	0.05-1.0 keV (circular polarization) 0.05-1.0 keV (horizontal linear polarization) 0.05-1.0 keV (vertical linear polarization)	E/△E= 10,000-30,000	50 nm- 10 µm
BL-IX	Soft X-ray nanoscale absorption spectroscopy	· X-ray magnetic circular dichroism · X-ray magnetic linear dichroism · X-ray magneto-optical Kerr effect · X-ray linear dichroism · X-ray ferromagnetic resonance spectroscopy	Segmented APPLE undulator	0.18-2 keV (circular polarization) 0.13-2 keV (horizontal linear polarization) 0.18-2keV (vertical linear polarization)	E/△E >10,000	50 nm- 10 µm
BL-X	Soft X-ray superhigh-resolution resonant inelastic scattering	· Superhigh-resolution resonant inelastic X-ray scattering	APPLE undulator	0.25-1.0 keV (circular polarization) 0.25-1.0 keV (horizontal linear polarization) 0.25-1.0 keV (vertical linear polarization)	E/△E >150,000	< 500 nm

Schedule



The project to build new synchrotron radiation facility has started in 2019 and scheduled to start operation in 2023. At the beginning 10 beam lines will be operating.

The project is driven by collaboration between QST and the partner with sharing responsibility. The blue lines, which are accelerator and part of beam lines, are responsible for QST and the orange lines, which are mail building, satellite building, land preparation and part of beam lines, are for the partner.