Present Light-source Activities and Future ERL Plans at KEK

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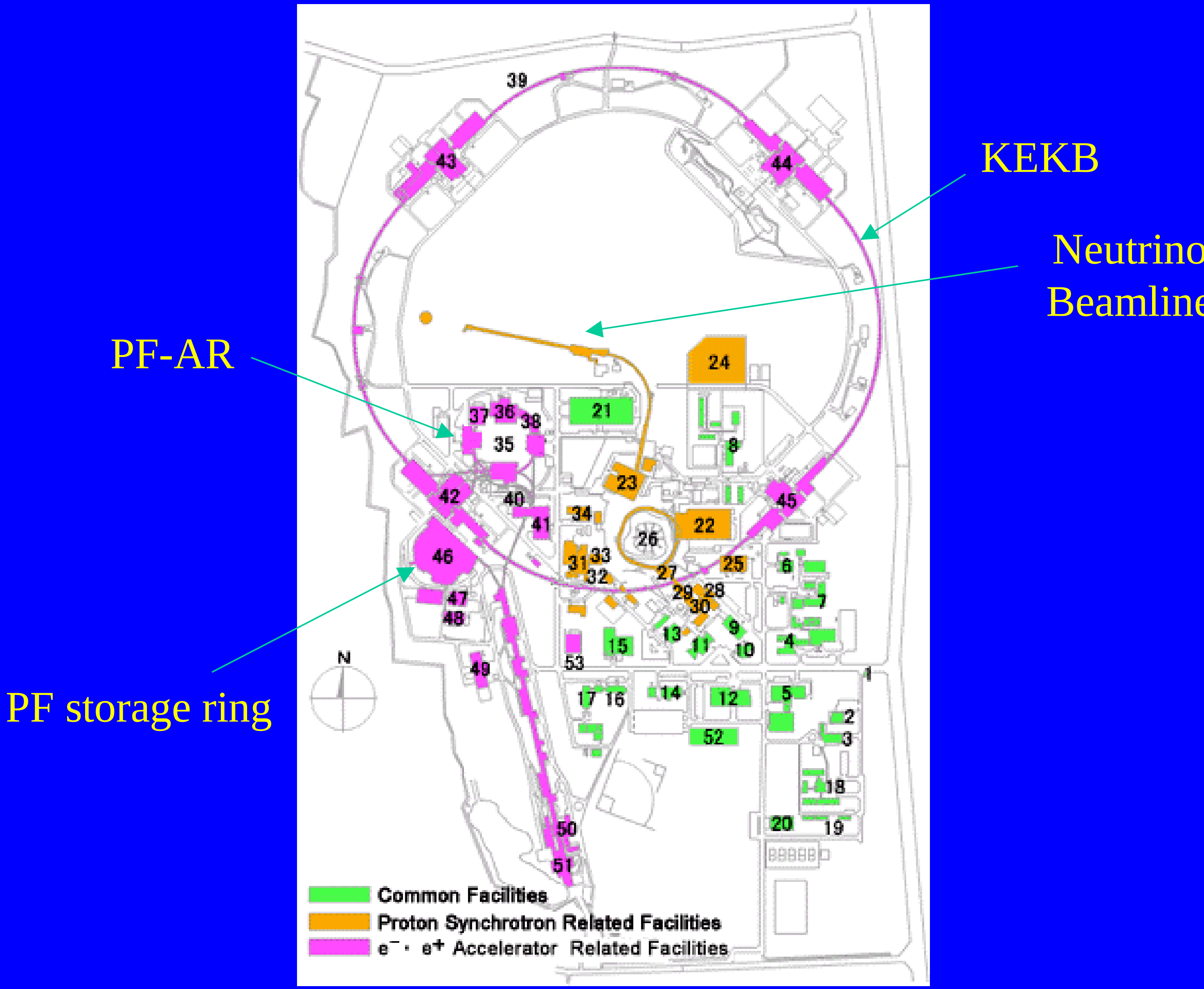
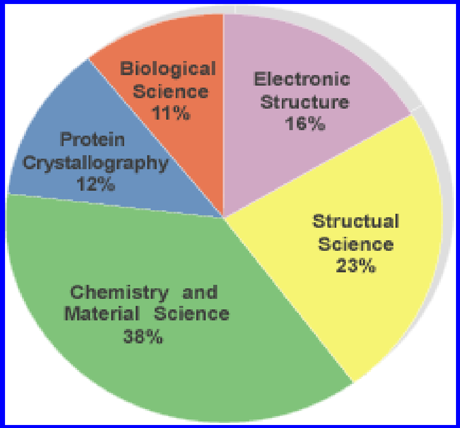
Photon Factory,
High Energy Accelerator Research Organization (KEK)

Site Map of KEK (High Energy Accelerator Research Organization)

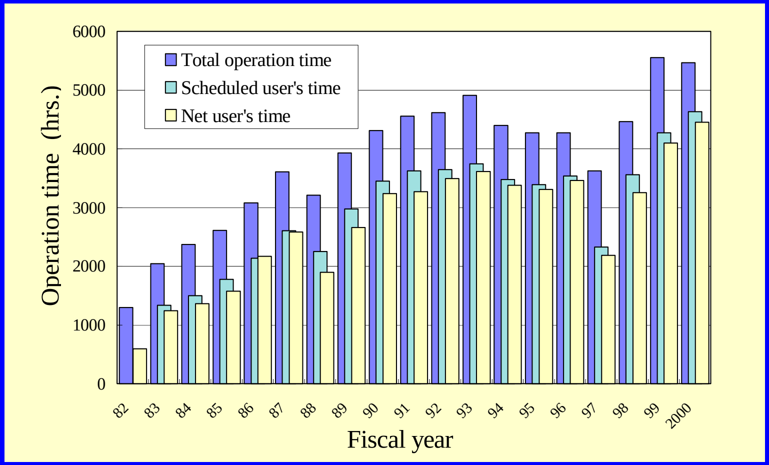


The Photon Factory at KEK

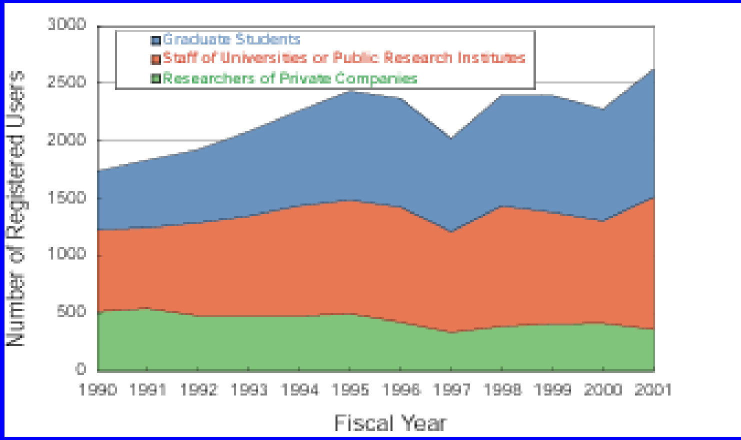
- Two synchrotron light sources
  - PF storage ring (2.5 GeV)
  - PF-AR (6.5 GeV)
- More than 2,500 users



Scientific-field distribution



Operation time/year (PF-ring)



Number of users

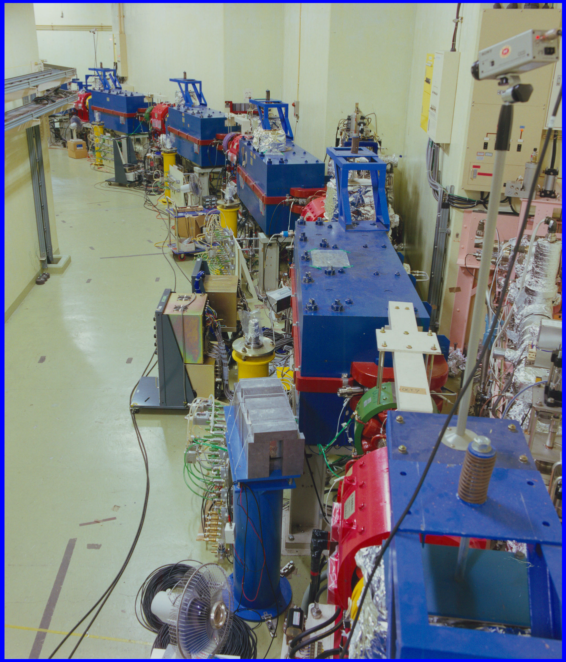
Photon Factory (PF) storage ring

- 1982 Commissioned.
- 1986 First low-emittance: 400 → 130 nm·rad
- 1997 Second low-emittance: 130 → 36 nm·rad

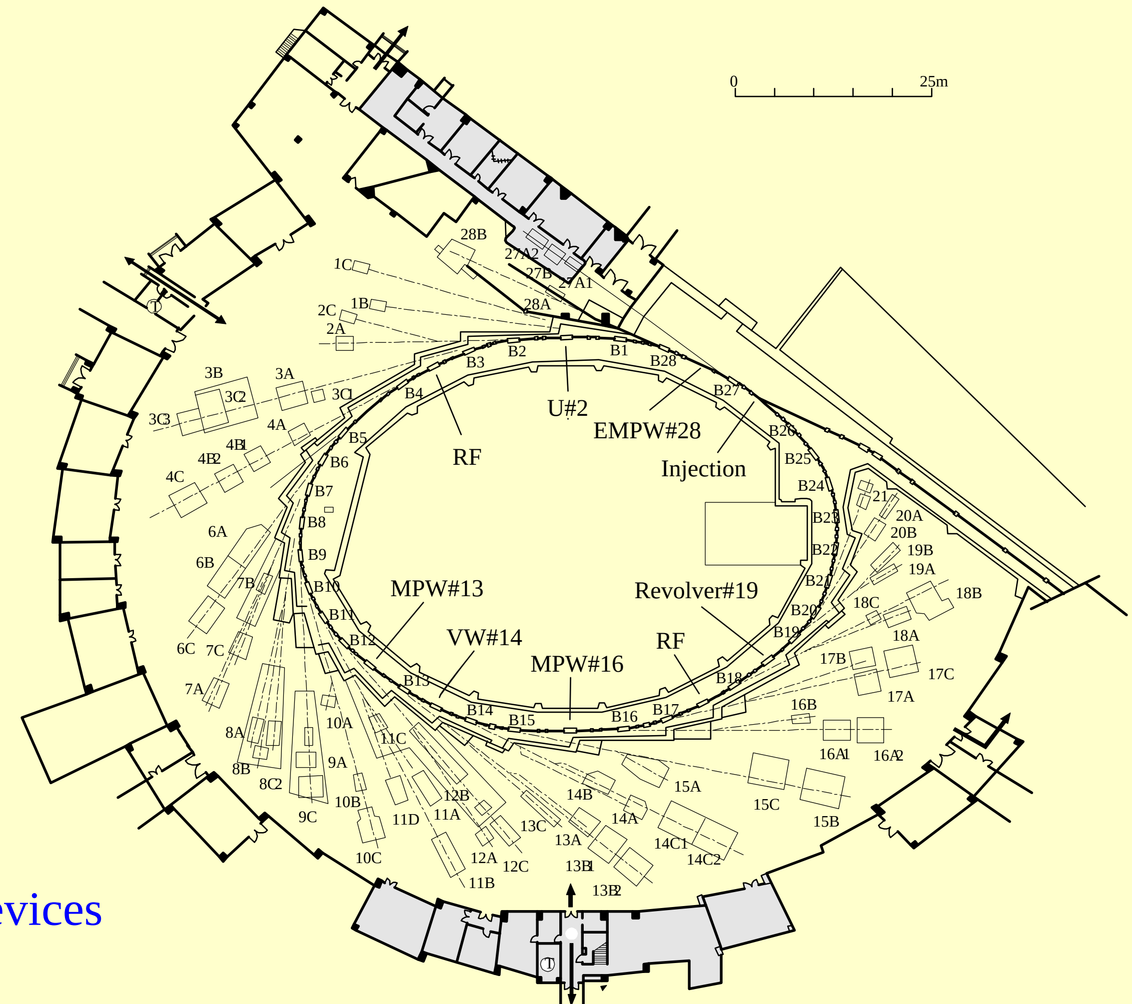
Principal parameters.

Nominal beam energy	2.5 GeV
Circumference	187.03 m
Natural beam emittance	36 nm·rad
Betatron tune (ν_x, ν_y)	(9.60, 4.28)
RF frequency	500.1 MHz
Harmonic number	312
Synchrotron tune	0.014

Inside photo.



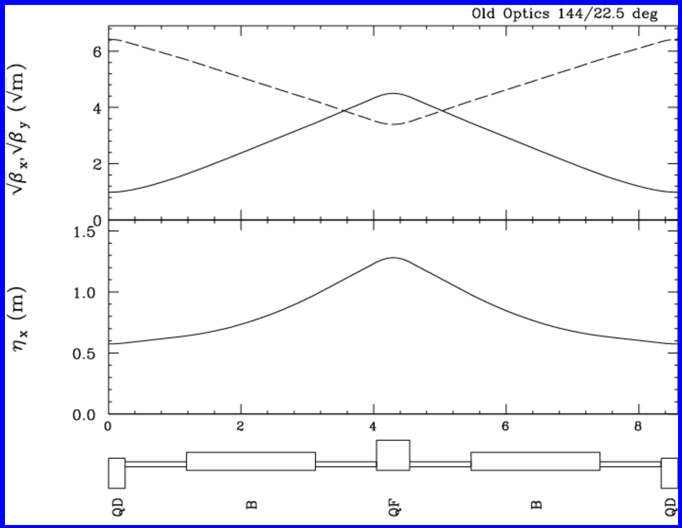
Layout of the PF storage ring



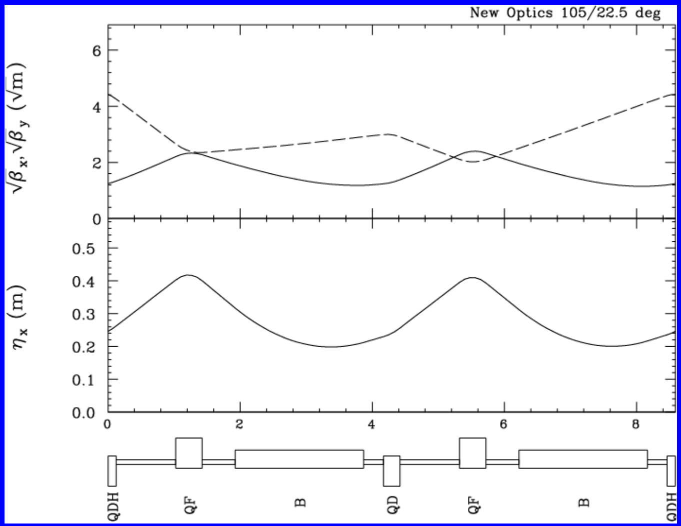
- Six insertion devices
- 22 beamlines
- More than 60 experimental stations

Upgrade to the low-emittance lattice (1997)

- Each FODO-cell was reconstructed to two FODO-cells



Before reconstruction

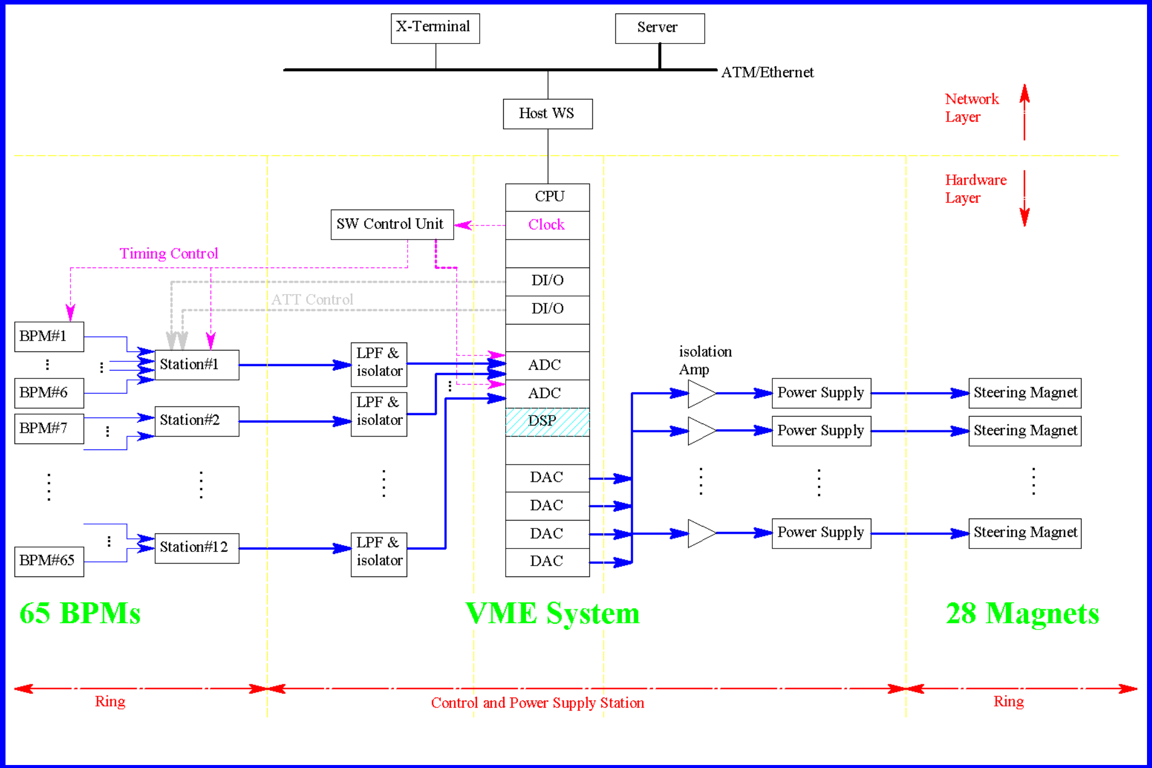


After reconstruction

Beam optics in the normal-cell section

Orbit stabilization using the global feedback system

- An integrated system for the beam-position measurement and the global feedback.
- This system can measure the COD in every 12 ms.
- Using fast-response correctors, we can correct the vertical orbit variations at frequencies of up to 0.3 Hz.



Block diagram

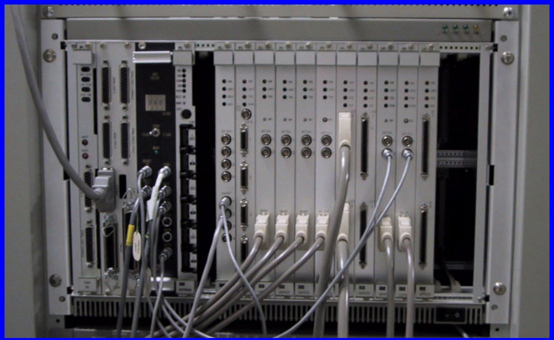
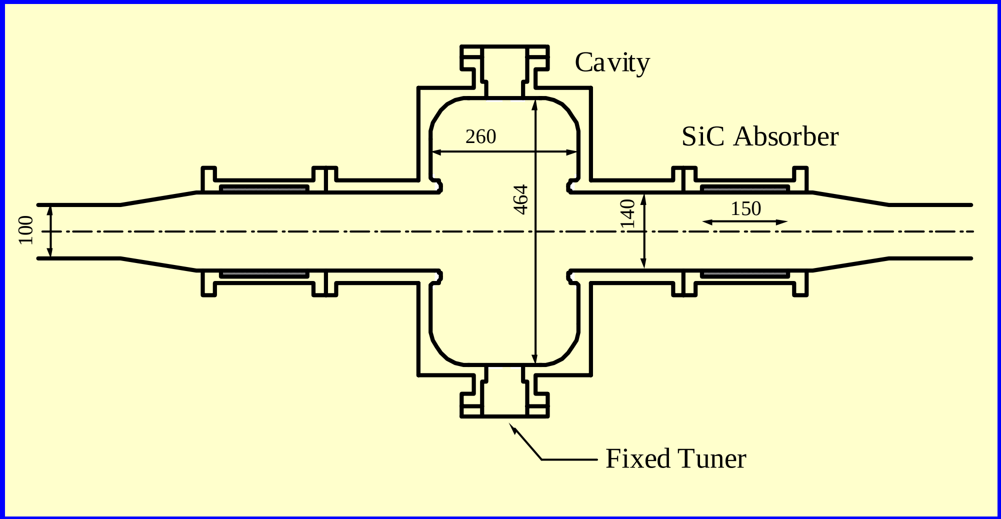


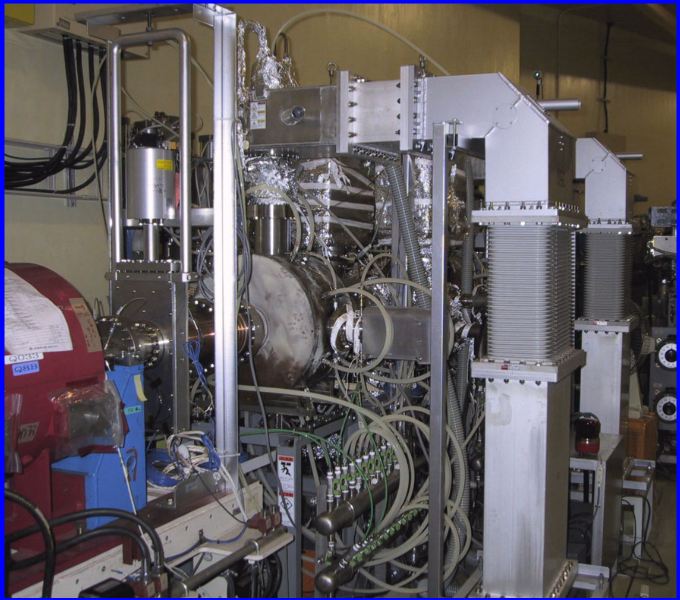
Photo of the VME system.

Damped accelerating cavities

- Harmful higher-order-modes can be damped by using microwave absorbers (made of SiC) in the beam pipe.
- We tuned remaining trapped-modes so as to avoid any coupled-bunch instabilities.



Cross section of one cavity unit.



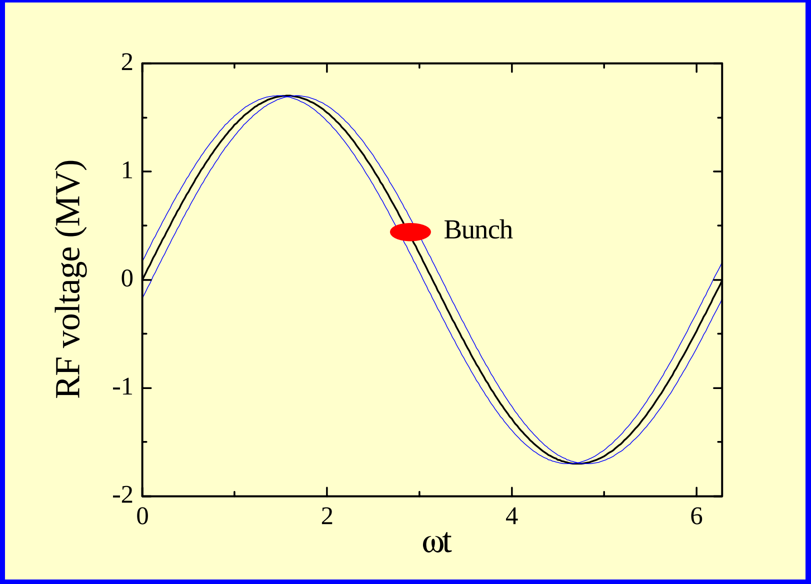
Damped cavities as installed.

Improvement in the beam lifetime by rf-phase modulation

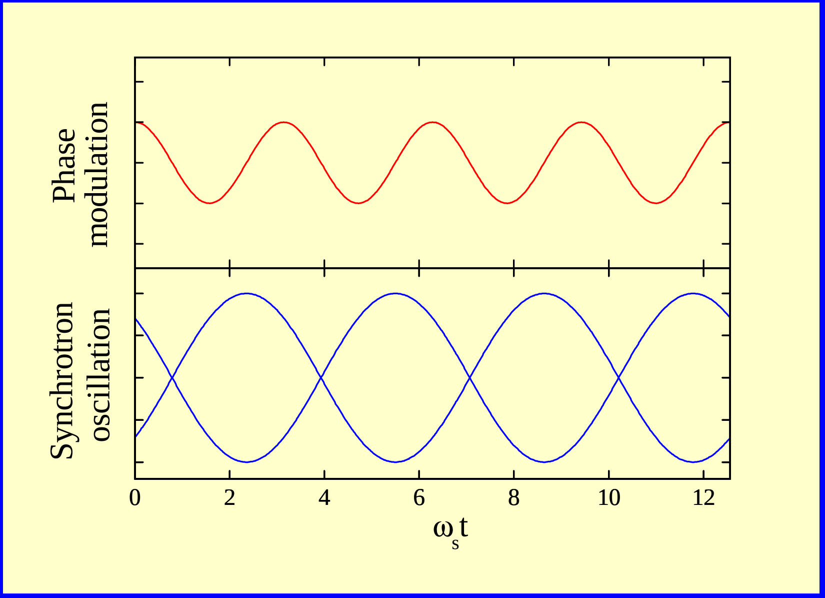
Modulate the rf phase at a frequency of $2\omega_s$

$$\ddot{\phi} + 2\lambda\dot{\phi} + \omega_s^2[1 + \varepsilon\cos(2\omega_s t)]\phi = -\phi_{m0}\omega_s^2\cos(2\omega_s t)$$

$$\varepsilon = \phi_{m0}\cot\phi_0$$



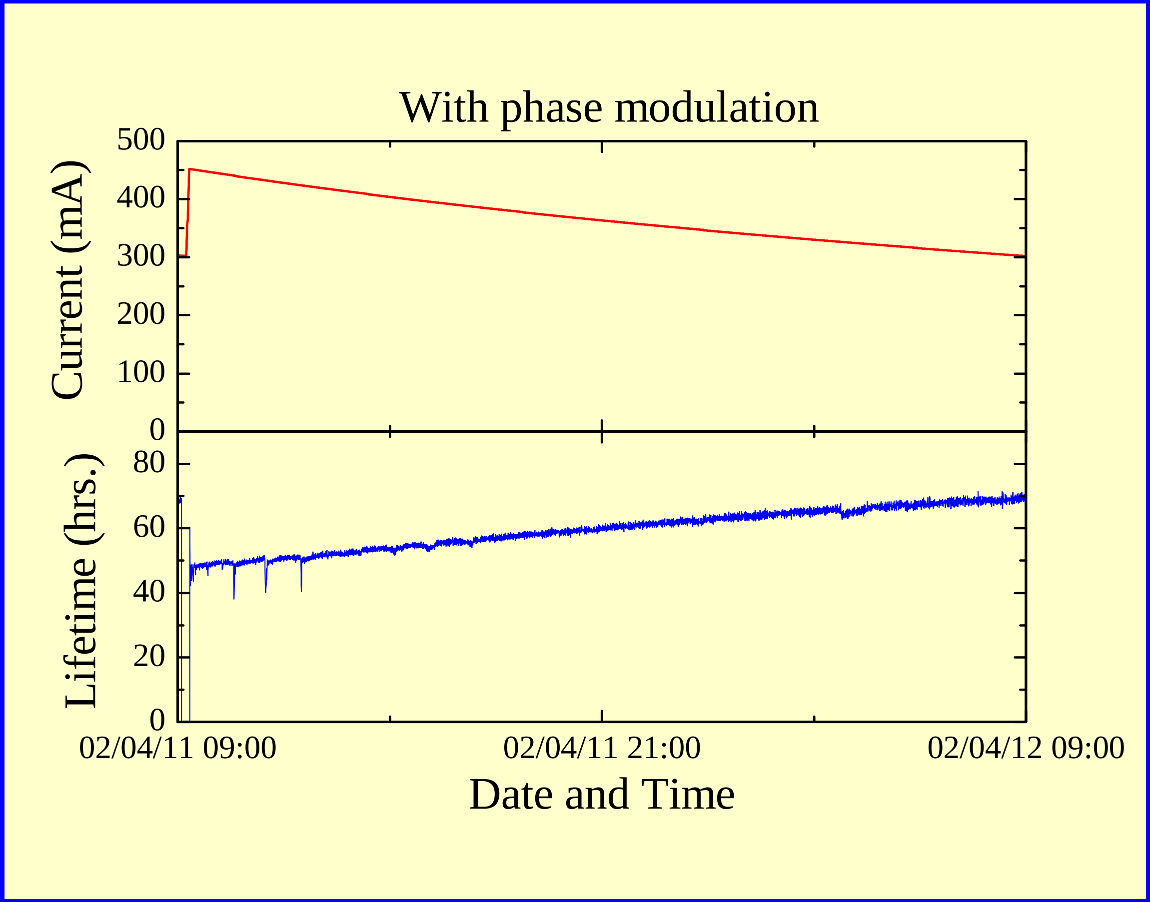
Modulated rf voltage



Parametric resonance

Typical operation (24 hours)

April, 2002



PF-AR

- 1986 Parasitic usage of SR from the TRISTAN booster ring.
- 1998 Switched to dedicated light source.
- 2001 Major upgrade

Principal parameters.

Beam energy	6.5 - 5 GeV
Circumference	377.26 m
Natural beam emittance	294 nm·rad
Betatron tune (ν_x, ν_y)	(10.15, 10.23)
RF frequency	508.58 MHz
Harmonic number	640
Radiation loss / turn	6.66 MeV

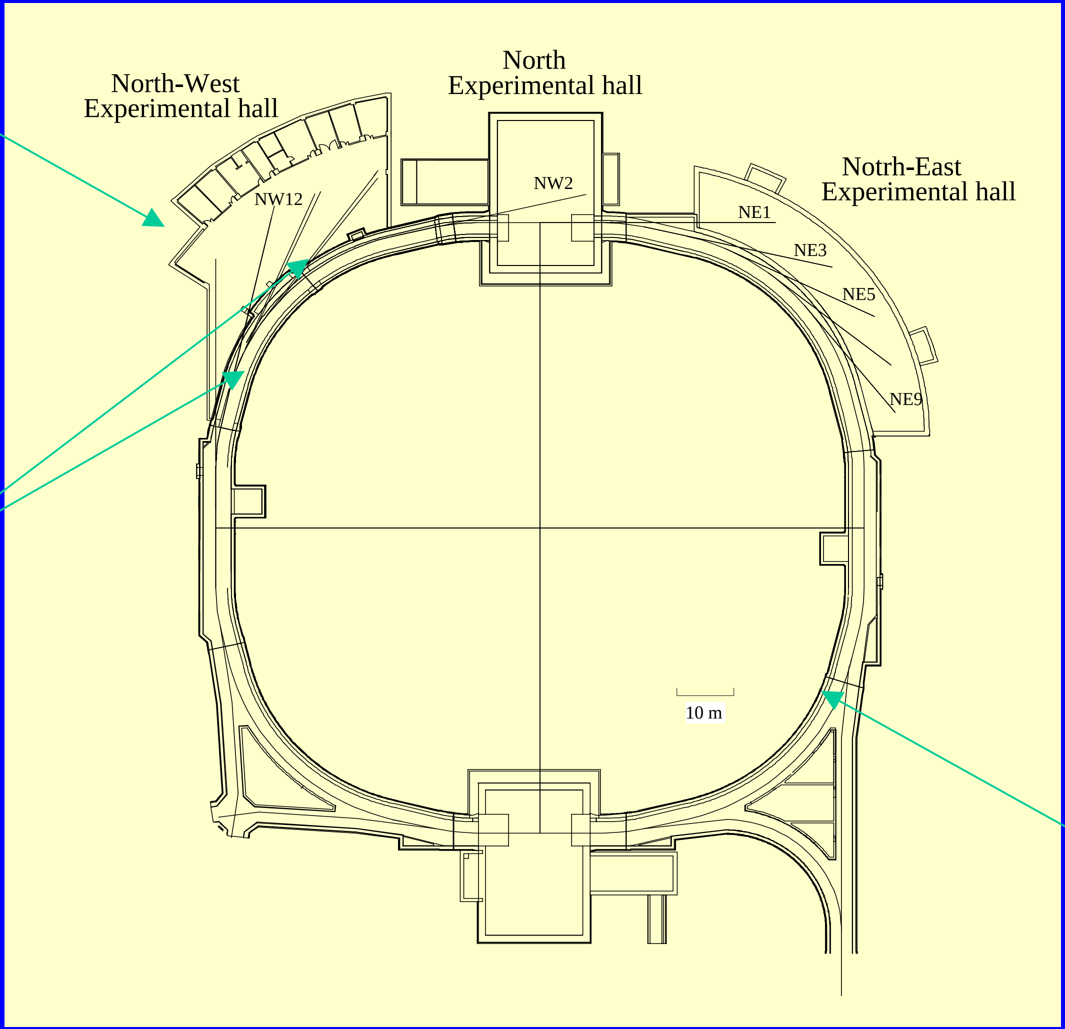
Inside photo.

Upgrade of the PF-AR (2001)

New experimental hall

New in-vacuum undulators

EPICS-based Control



Insertion devices
in-vacuum: 3
conventional : 1

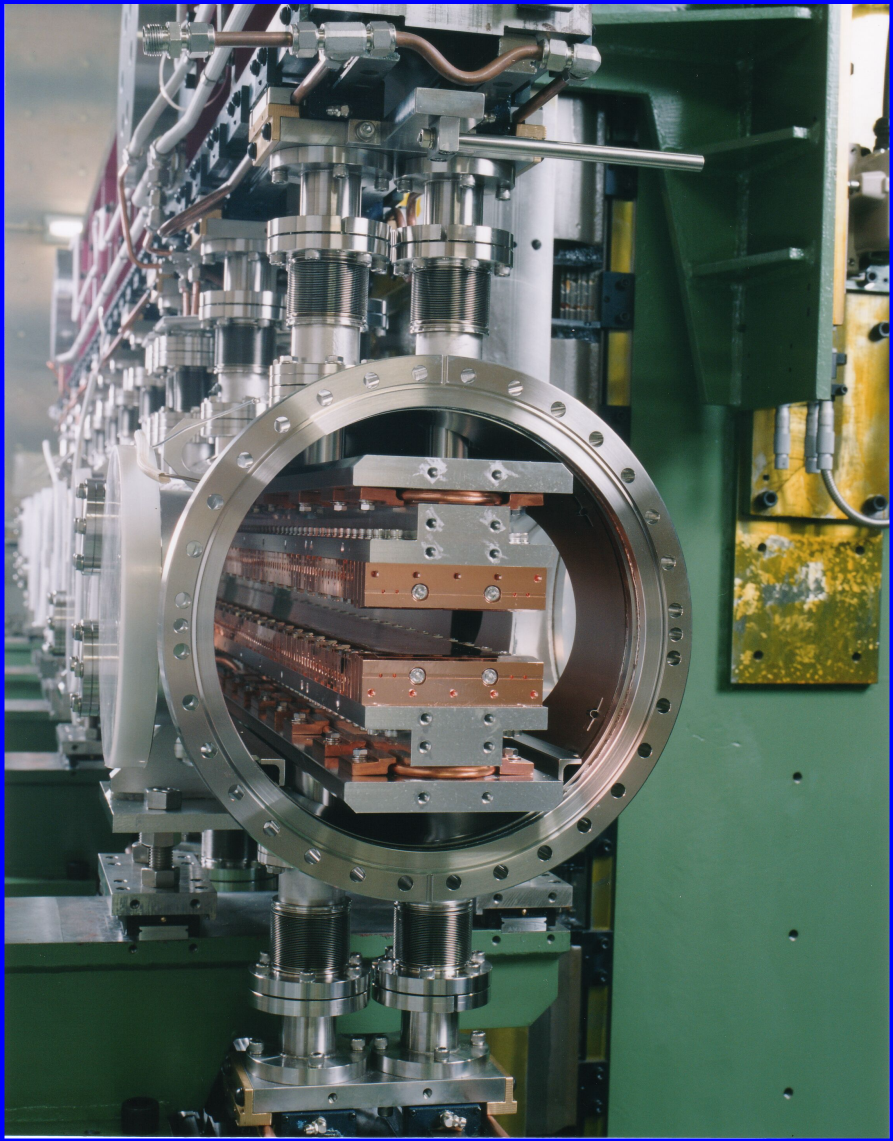
New copper chambers

In-vacuum undulator (NW-2)

Allows tapered configuration
for XAFS experiments
Spectrum range: 5 - 25 keV

Parameters

Minimum gap	10 mm
Undulator period	40 mm
Number of periods	90
Undulator length	3.6 m
Peak magnetic field	0.8 T
Type of magnet	NdFeB
Typical 1st harmonic	1.8 keV



Courtesy: S. Yamamoto

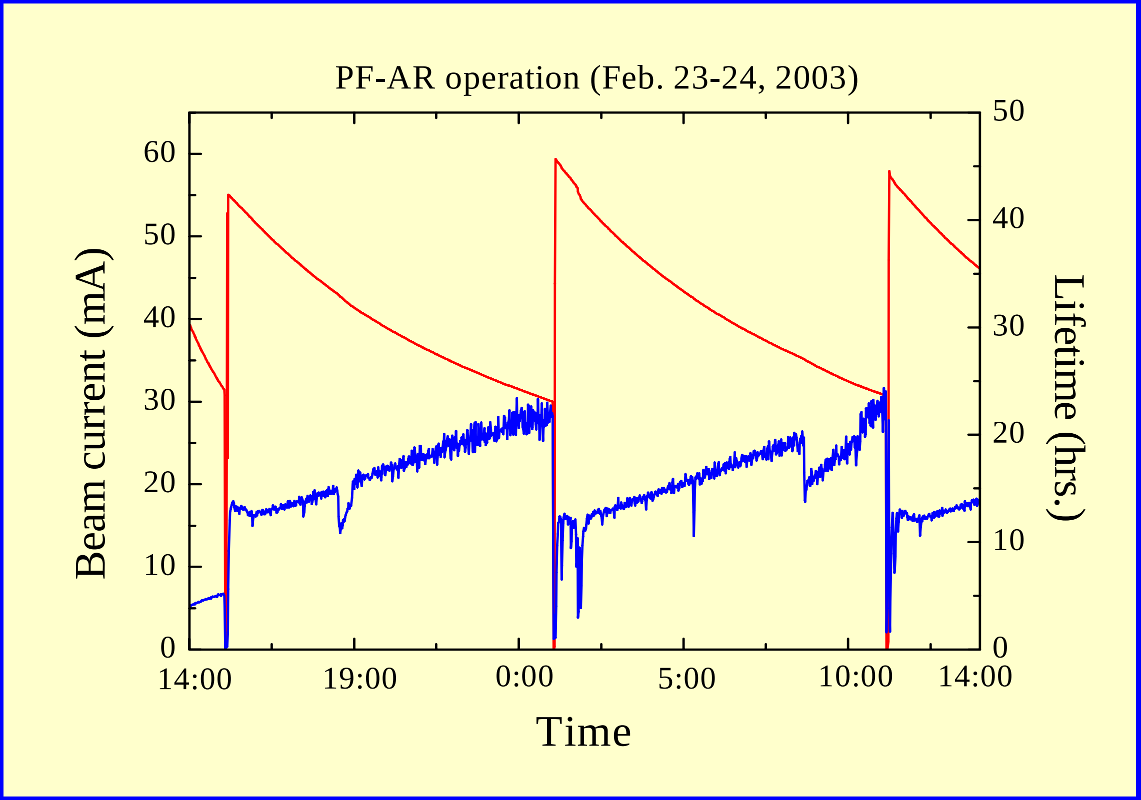
Typical operation

- Beam energy

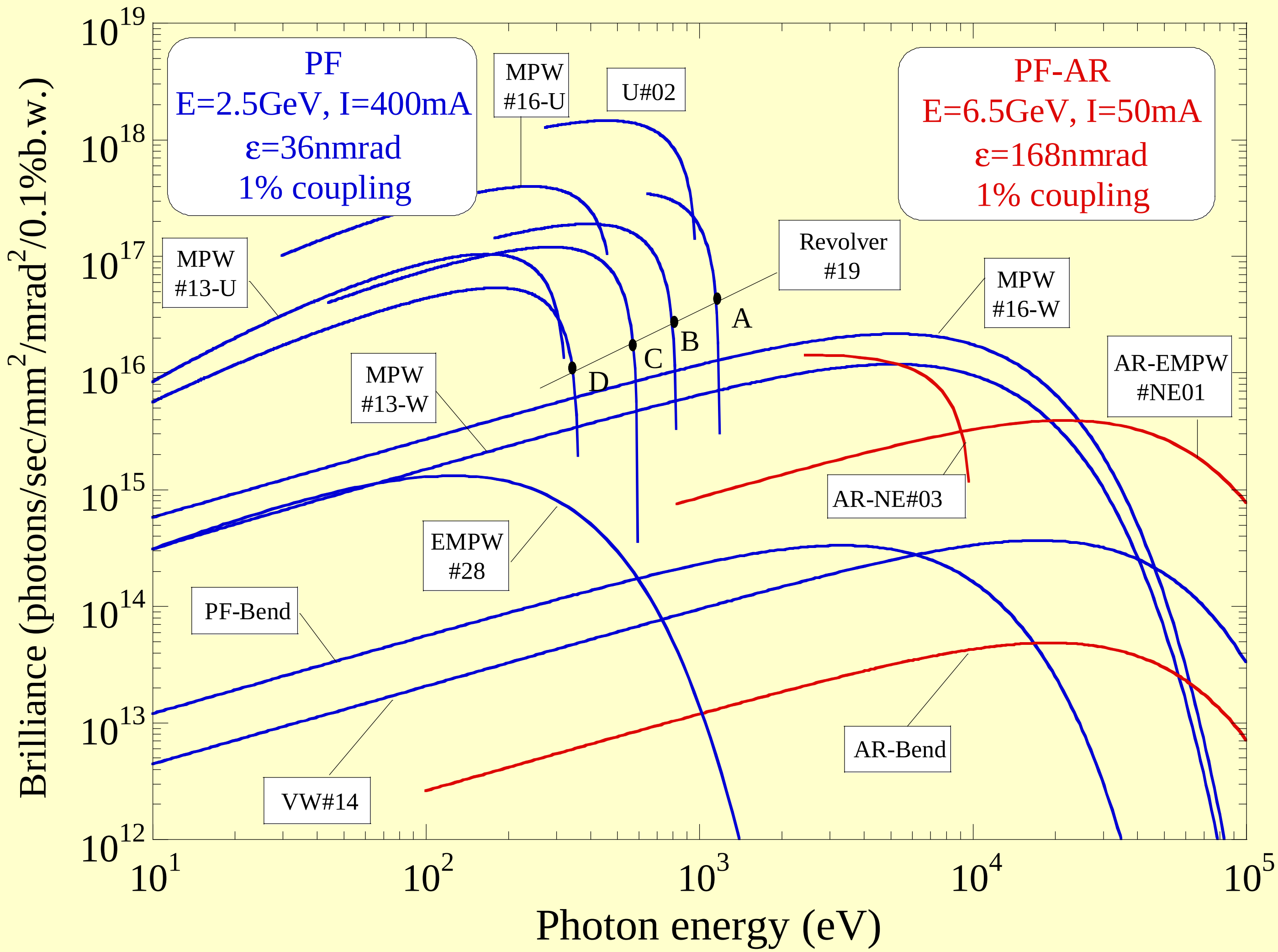
  6.5 GeV for usual experiments

  5 GeV for medical application

- Full-time single bunch operation



Brilliance of the synchrotron radiation



Future plan:
Energy Recovery Linac based light source

Suitable balance for two requirements is very important for the Photon Factory.

- Provide highly-advanced tools for investigating, analyzing, and processing materials.
- Provide wide-purpose, high performance tools with sufficient capacity for investigating new materials.

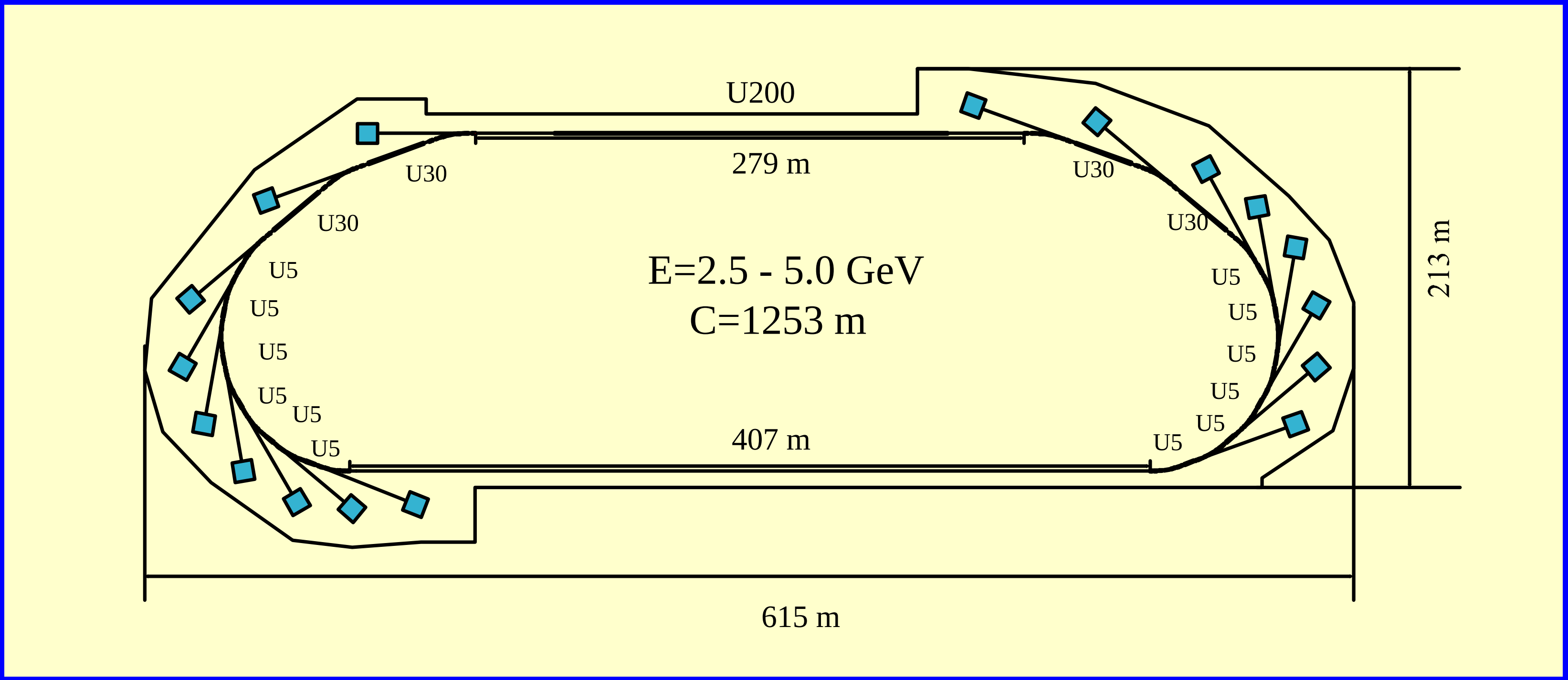
ERL-based light source is being recognized as the most promising light source.

Requirements from the scientists

- Spectrum range : from soft x-ray to hard x-ray
- Average brilliance (at 0.1 nm) : > 10^{22} ph/s/0.1%/mm^2/mrad^2
- Average flux : > 10^{16} ph/s/0.1%
- Pulse length : < 1 ps is available
- Beam stability : less than 1/10 of beam sizes

Tentative ERL plan at KEK

- Beam energy : 2.5 GeV (phase I) - 5 GeV (phase II)
- Provide the 1st harmonic undulator radiation of 1 Å with an undulator period of 15 mm (present minimum).
- Insertion devices: 5 m × 12, 30 m × 4, 200 m × 1



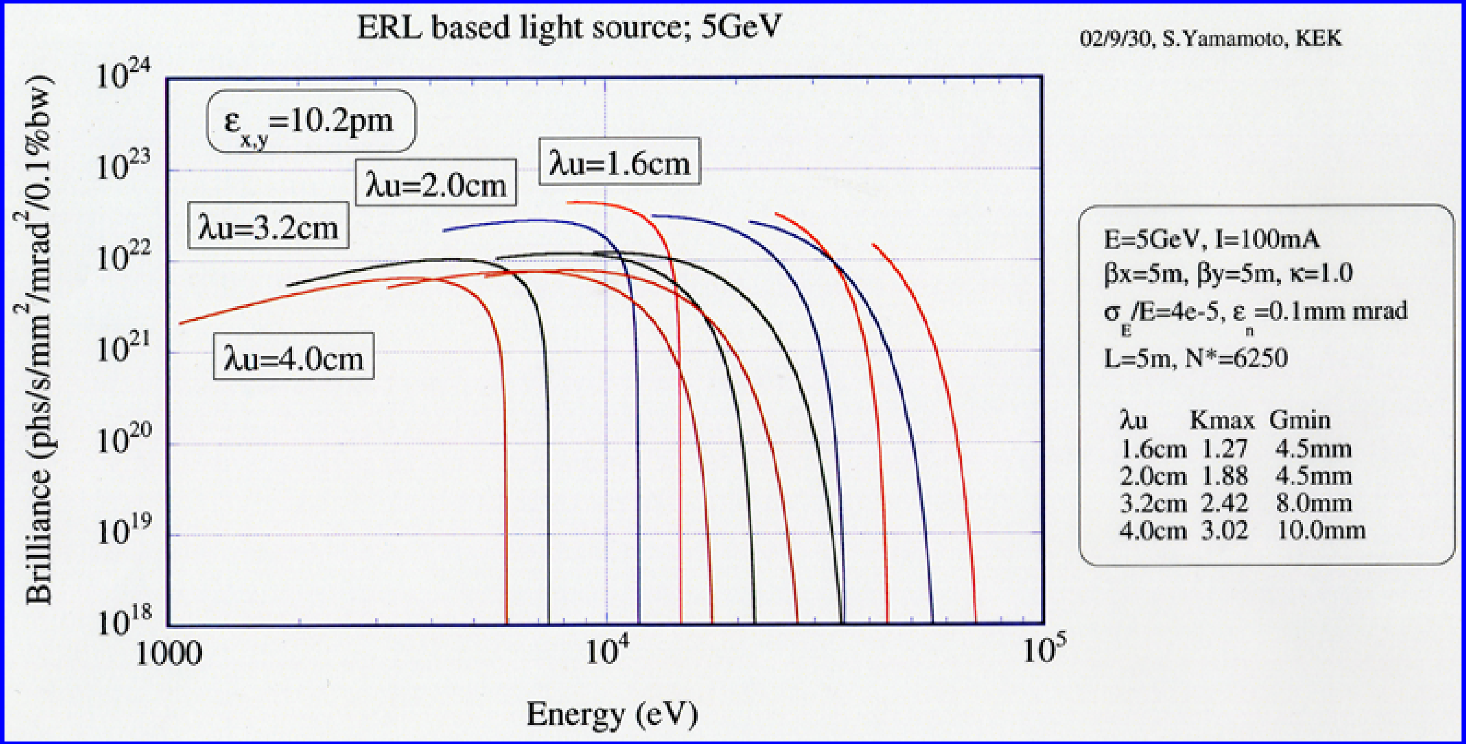
Principal parameters (goal)

- Aims at realizing diffraction-limited light source at the photon energy of about 10 keV
- Requirements for electron sources and for emittance preservation will be very stringent.

Beam energy	2.5 - 5.0 GeV
Injection energy	10 MeV
Average beam current	100 mA
Circumference	1253 m
Normalized beam emittance	0.1 mm·mrad
Beam emittance at 5 GeV	10 pm·rad
Energy spread (r.m.s.)	5×10^{-5}
Bunch length (r.m.s.)	1 - 0.1 ps
RF frequency	1.3 GHz
Acceleration gradient	10 - 20 MV/m

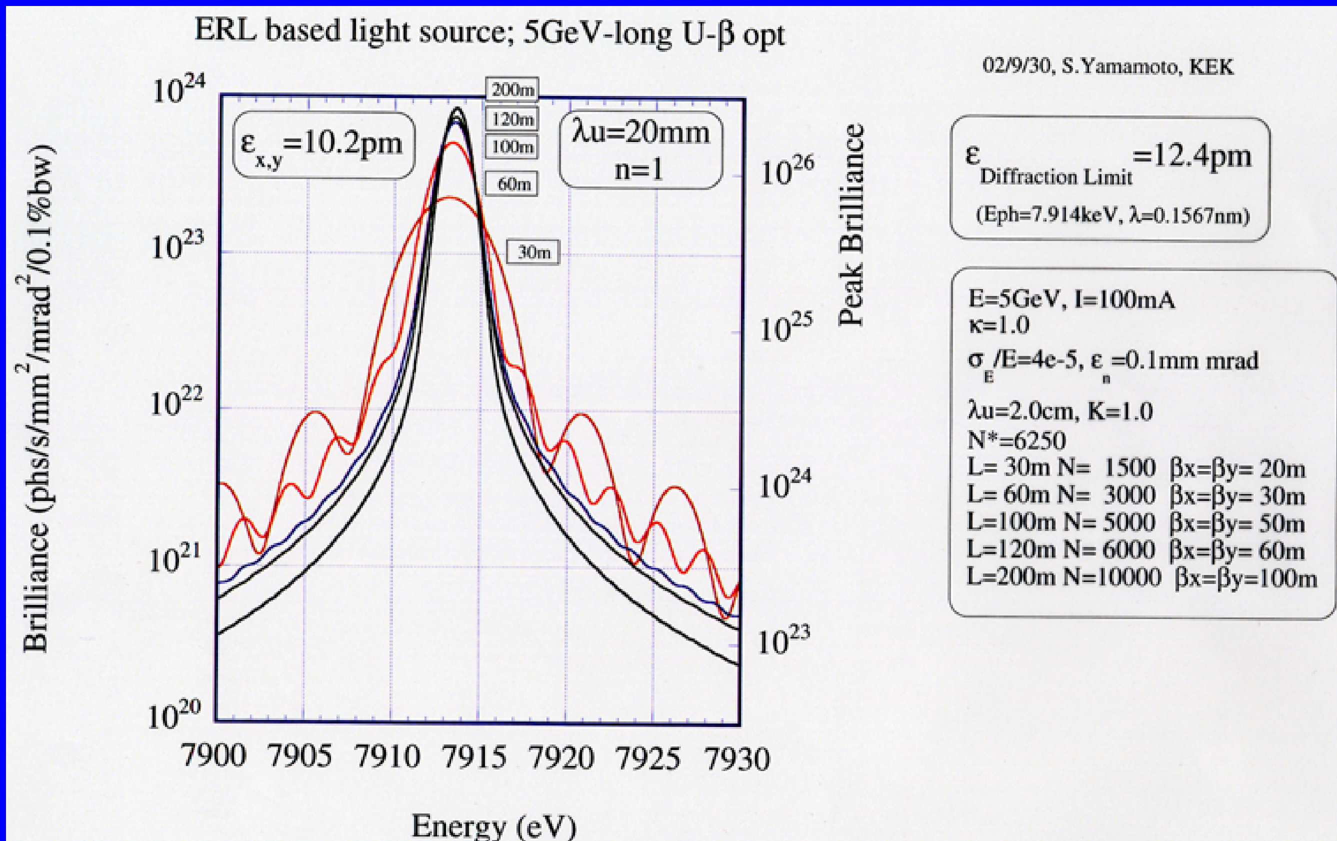
Standard 5m undulator

By S. Yamamoto



Spectrum range of undulator radiation
from a standard 5 m undulator.

Anticipated spectrum for long undulator



By S. Yamamoto

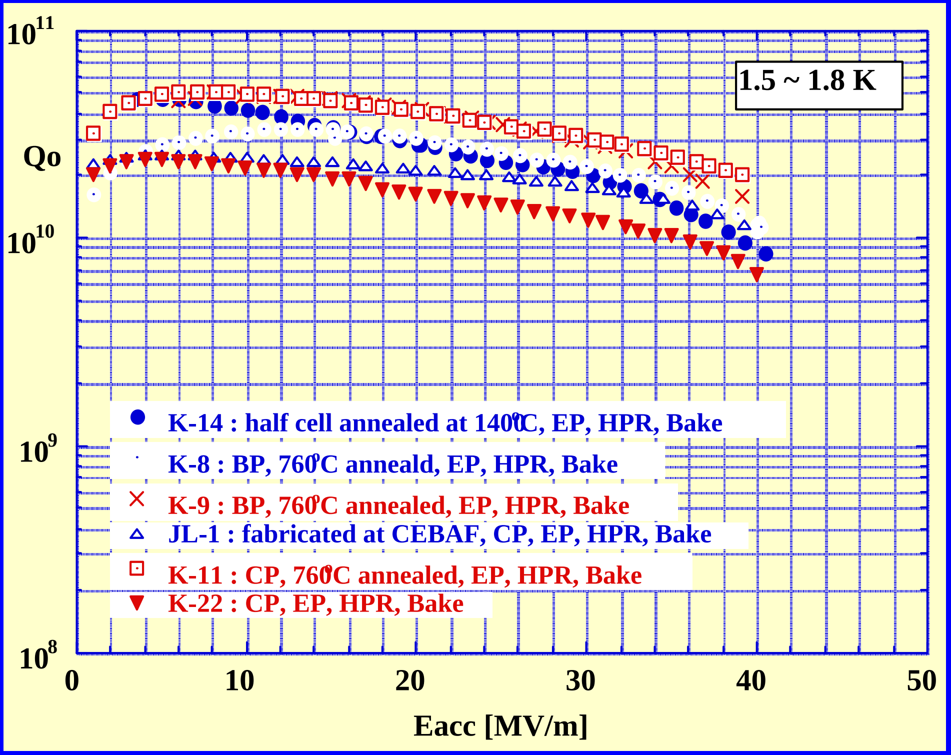
Requirement for the energy spread

$$\frac{\sigma_E}{E} \leq \frac{1}{4kN}$$

Calculated brilliance for 30, 60, 100, 120 and 200-m undulators. Undulator period: 2.0 cm, beam current: 100 mA. Optimized betatron functions for each undulator lengths were used.

Superconducting accelerator

- High-gradient of up to 40 MV/m have been achieved with L-band superconducting cavities (DESY/Cornell/JLab/KEK).



Courtesy: K. Saito

For the ERL:

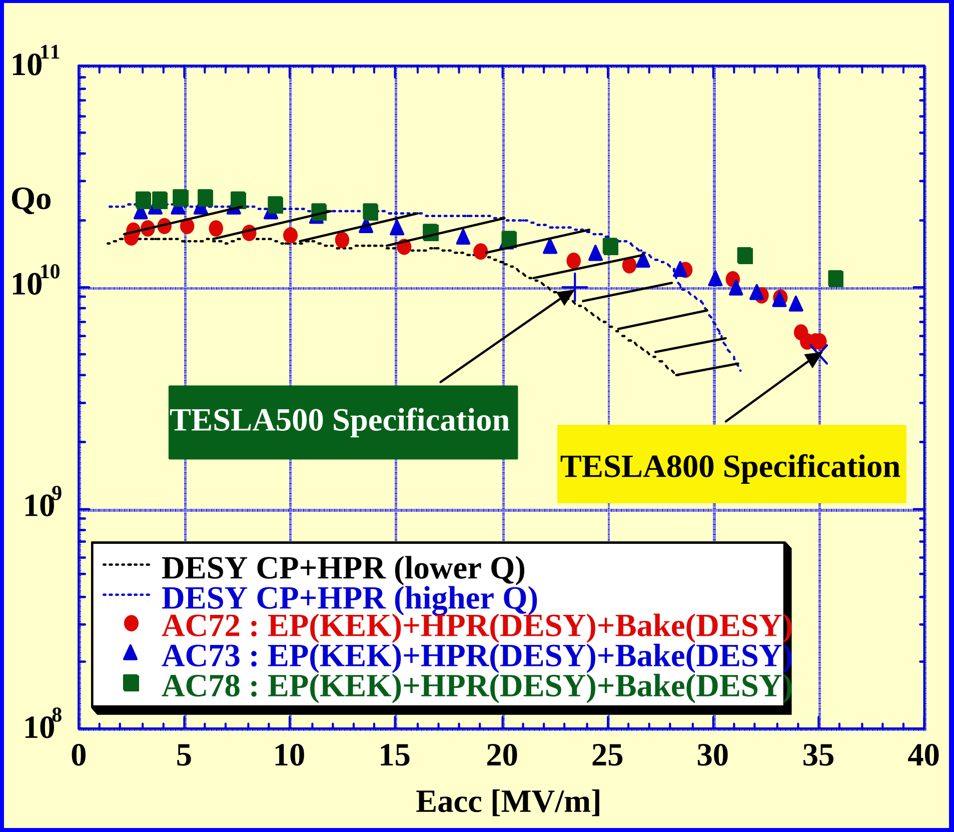
10 - 20 MV/m

Performance of L-band single-cell accelerating cavities which were treated using Electroplishing (EP) technique at KEK.

High-gradient with 9-cell cavities

- High-gradient performance has also been demonstrated with 9-cell cavities which were treated by the EP technology.

Courtesy: K. Saito



Performance of DESY 9-cell cavities which were treated using Electroplishing (EP) technique at KEK.

Superconducting accelerator for the ERL

- TESLA-type 9-cell cavities, 1.3 GHz, operated at 2K
- Accelerating gradient : 20 MV/m (phase I: 10 MV/m)
- Key technology for high gradient:
  Electropolishing (EP), High-pressure water rinsing, *etc*.
- Cost reduction: Nb-Cu clad seamless cavity
  Simplification of the treatments
- Higher-order-mode damping and tuning
- Engineering design of cryomodule, reduction in length

Parameters of ERL superconducting cavities based on TESLA-type design

Accelerating frequency	1300 MHz
Operation gradient	10 - 20 MV/m
Unloaded quality factor Q_0	1.5×10^{10}
Active length L	1.036 m
Cell-to-cell coupling k_{cc}	1.87 %
Iris diameter	70 mm
R/Q	1036 Ω
E_p/E_{acc}	2.0
H_p/E_{acc}	42.6 Gauss/(MV/m)
Tuning range	±315 kHz
$\Delta f/\Delta L$	315 kHz/mm
Q_{ext} of input coupler	1×10^7
Cavity bandwidth at $Q_{ext} = 1 \times 10^7$	130 Hz (FWHM)
Dynamical heat loss (at 10 MV/m)	7.4 W/cavity at 2K
(at 20 MV/m)	29.6 W/cavity at 2K

Heat loads for cryogenic plant

	Phase I (2.5 GeV)	Phase II (5 GeV)
Gradient	10 MV/m	20 MV/m
Q_0	1.5×10^{10}	1.5×10^{10}
Dynamical loss/(10 cavities)	74 W (at 2K) 222 W (4.3 K equiv.)	296 W (at 2K) 888 W (4.3 K equiv.)
Safety factor for Q-value	1.3	1.5
Heat leaks at 2 K shield/module	18 W (at 4.3 K equiv.)	18 W (at 4 K.3 equiv.)
Heat leaks at 4.5 K shield/module	20 W	20 W
Heat leaks at 80 K shield/module	10 W (at 4.3 K equiv.)	10 W (4.3 K equiv.)
Total heat load/module	337 W (at 4.3 K equiv.)	1380 W (at 4.3 K equiv)
Transfer loss 1 km	500 W (equiv. 4.5 K)	500 W (equiv. 4.5 K)
Total heat load for 25 modules	8.9 kW (4.3 K equiv..)	35 kW (4.3 K equiv.)

- Phase I : 10-kW (at 4.3 K) class cryogenic plant
- Phase II: add three more 10-kW class plants

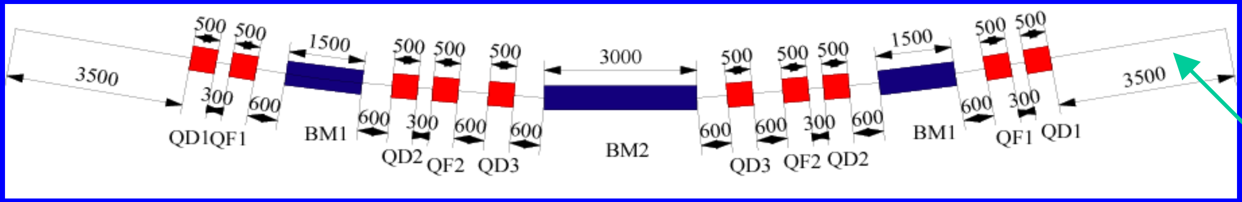
Design issues of the arc

- Minimize emittance growth and energy spread due to
  1) incoherent SR
  2) coherent SR
- Variable R_{56} for bunch compression / no-compression
  Compensation for higher-order terms (T_{566} etc.)
- House many undulators (requirement: about 20)
  Optimum optics for undulators.
- Precise circumference control
- Tunable betatron phase advance per arc (for multibunch BBU)
- Limitation due to site

Preliminary design of the arc (unit cell)

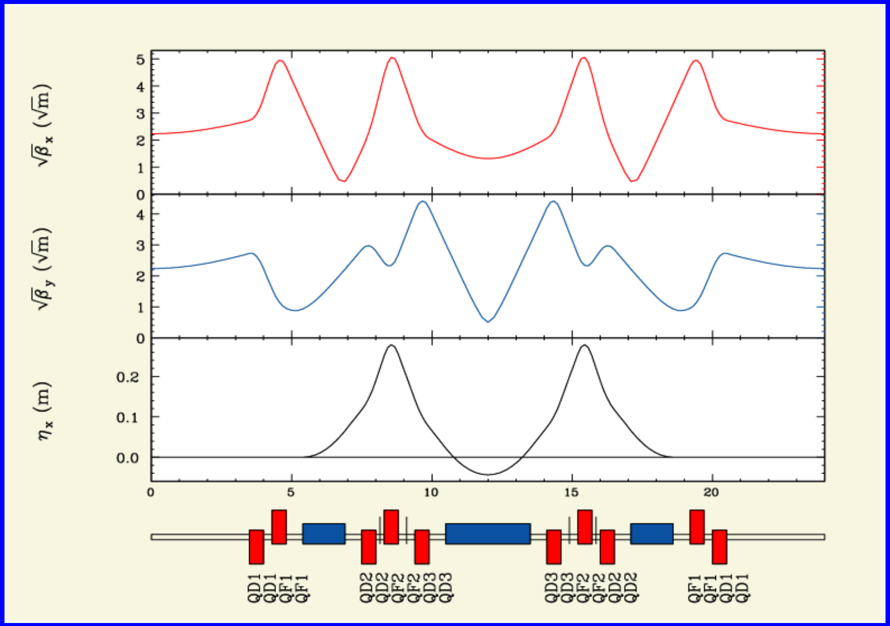
Designed by Y. Kobayashi

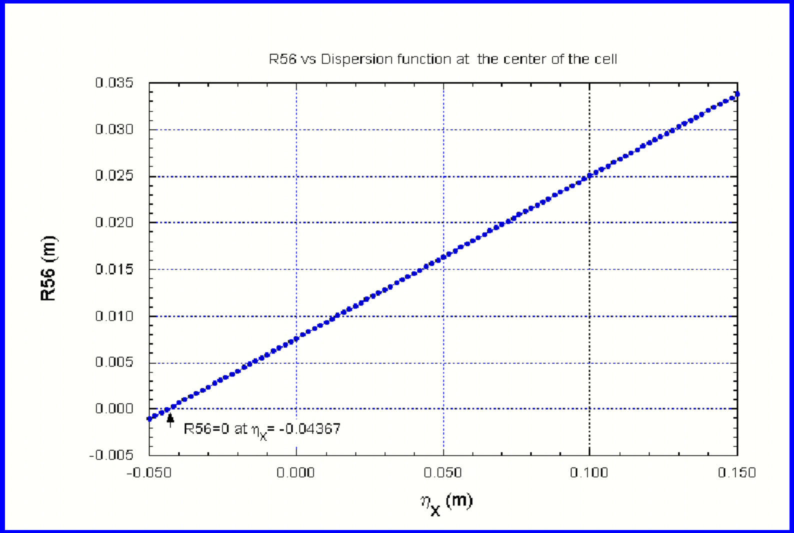
TBA lattice



ρ = 17 m

7-m straight for I.D.



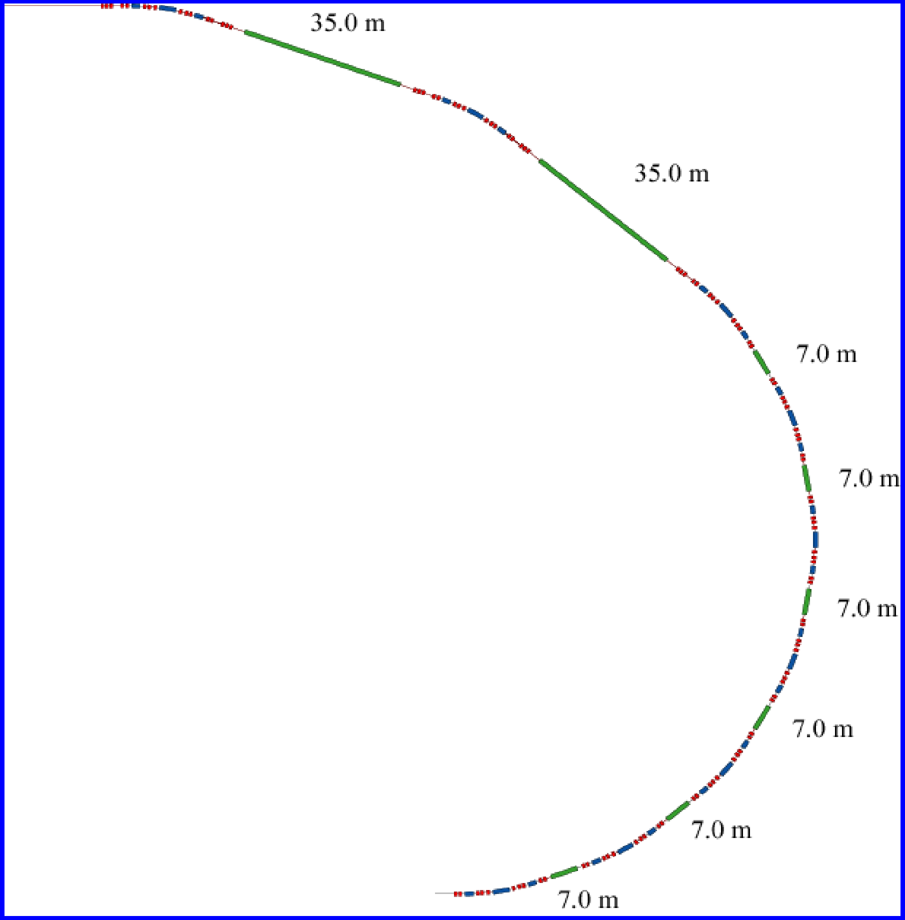


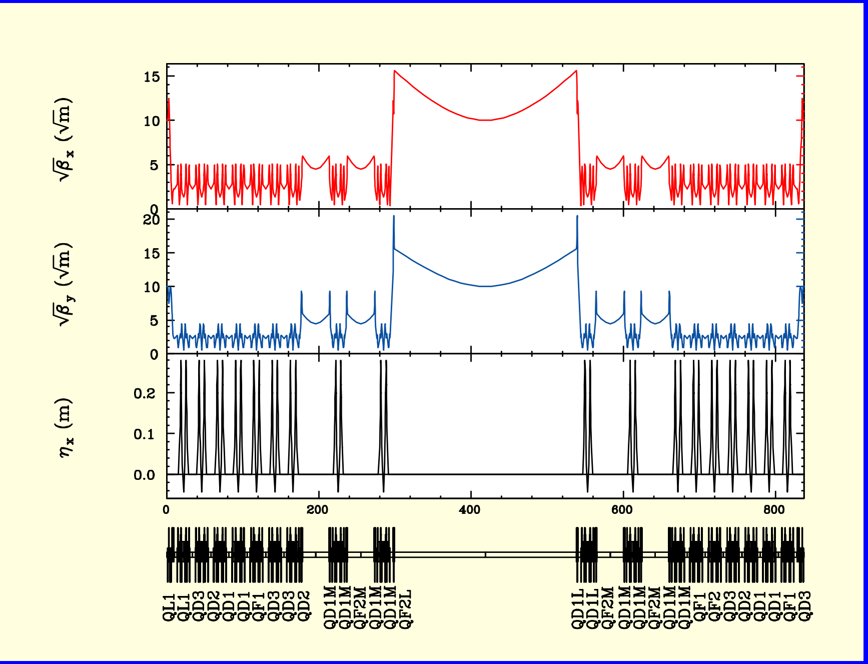
Beam optics for unit cell.

Tuning range for R_{56} (-0.1 to 3.4 cm)

Preliminary design of the arc

by Y. Kobayashi



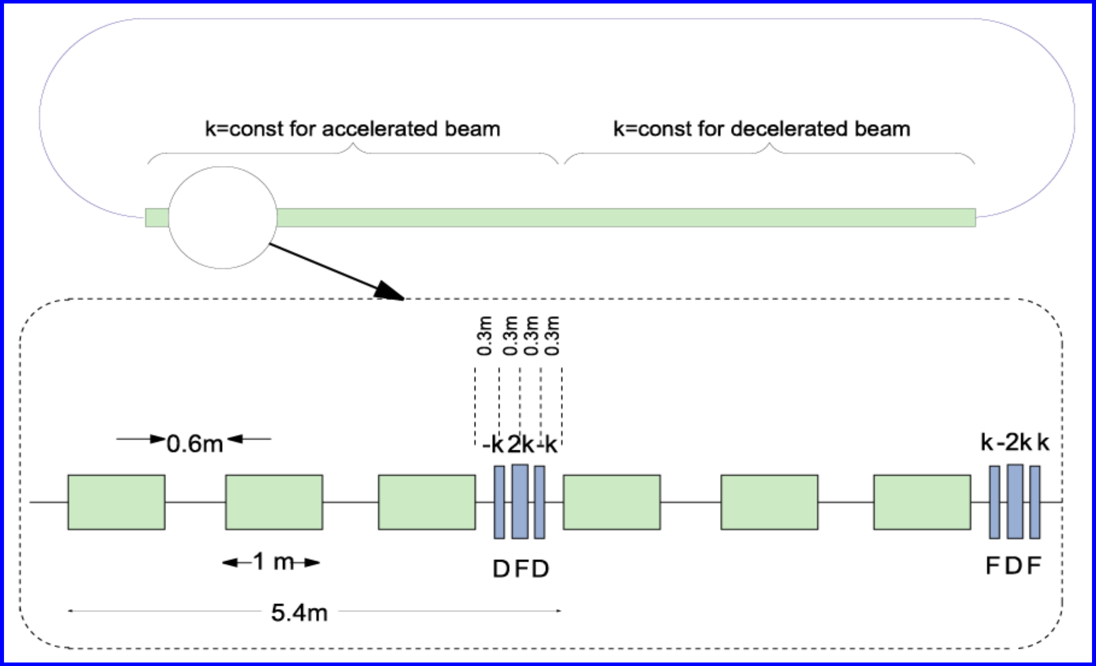


Lattice configuration of π-arc

Beam optics for the complete arc

Beam dynamics issues

- Multibunch BBU effect and other issues have been investigated by Y. Shobuda.
- Under simulations, it is possible to obtain the threshold current of more than 100 mA for the multibunch instability by adjusting betatron phase advance per circulation, and by other means.



Courtesy: Y. Shobuda

Simulation model

Electron sources

- Ultra-low emittance (0.1 π•mm•mrad) and high average current (100 mA) require very ambitious challenges for electron sources.
- Some experience on RF photocathode gun at KEK.
  (BNL/Waseda-U/KEK/Tokyo-U/Spring-8)
- Photocathode RF gun seems to be not very promising for the ERL
  1) Very difficult to reduce the emittance below 1 π•mm•mrad
  2) Under CW operation, one must lower the field gradient considerably
- DC photocathode gun seems very promising (GaAs NEA)
  1) High quantum efficiency (but short lifetime of cathode)
  2) Ultra-low emittance (< 1 π•mm•mrad) is possible, in principle
  3) Long-time experiences as the polarized sources (but low-currents)
- KEK is pushing R&D for DC photocathode guns under collaboration with Nagoya Univ. (*Prof. Nakanishi et al.*)

Summary and present status of KEK-ERL plan

- During the past year, a preliminary planning was carried out.
- Based on the tentative plan, an interim report "*Study Report on the Future Light Source at the Photon Factory*" is being published as the KEK report (in Japanese).
- Trying to make a consensus among the users.
- Investigations on many issues are under way.
- R&D for the superconducting technologies, precise short-period undulators, etc., are progressing as natural extensions.
- R&D for ultra-low emittance electron source has started.