1 Newly Developed Experimental Facilities

1-1 Replacement of BL-14

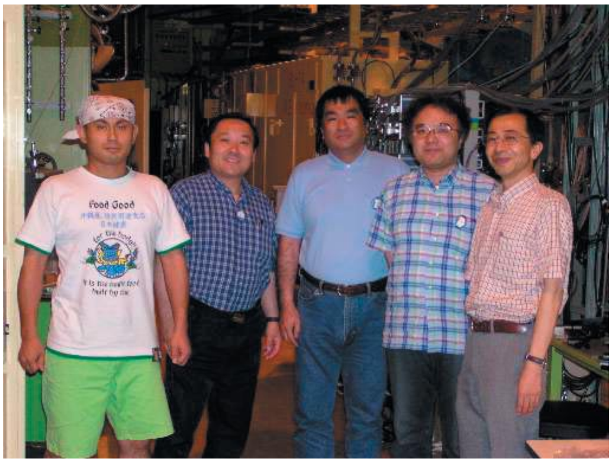
The upgrade project of the PF ring is scheduled for March to September 2005. Prior to commencing the reconstruction of the ring, the front-end section of the vertical wiggler beamline BL-14 was replaced and the downstream components were rearranged. For the rearrangement of the beamline, we planned to insert a new beam partition suitable for recent scientific activities between the three branches of BL-14, and to overhaul the old optics, especially those for 14A and 14B. The replacement of the beamline was carried out between the end of June and the end of September 2004.

Table 1 shows the components which were replaced at BL-14. A new main hutch for the Branch Beam Shutter (BBS) and water-cooled slits was built, along with an optics hutch for the monochromators and Down Stream Shutters (DSSs) of 14A and 14B and the focusing mirror of 14A.

After these replacements, a longer vertical beam size of more than 70 mm can be used at BL-14C1, where the development of phase-contrast X-ray imaging with an X-ray interferometer is intensively carried out. The sensitivity of this method is about 10^3-fold greater than absorption-contrast imaging for the study of biomedical objects composed of low atomic-number elements. It is expected that the larger beam will provide a viewing area suitable for observing small living animals and for human breast cancer diagnostic studies, for example. At BL-14B, new methods of X-ray imaging and precision X-ray optics experiments are studied. X-ray diffraction experiments and detector development go forward at BL-14A with the improved optics. High-pressure experiments with MAX-III are going at BL-14C2.

Table 1 Replacement at BL-14.

Branch partition Horizontal acceptance: 1.16 mrad (common) Vertical acceptance: A: 1.29 mrad B: 0.85 mrad C: 1.94 mrad	Beam size in the vertical direction A: not changed B: 20mm at 23.5m C: >70mm at 36m
BBS & water-cooled slits	Moved to the outside of the shield wall. Renewed and main hutch built.
Optics A: monochromator, mirror, DSS B: monochromator, DSS B-hutch C: ducts, DSS, beam window	Optics hutch built. Moved 3m downstream Moved 3m downstream Moved 1m downstream Replaced.
Interlock system	Renewed



1-2 Construction of a New Short Gap Undulator Beamline, BL-17A for Structural Biology

Outline

The new BL-17A is a short gap undulator beam line optimized for small beam size and low energy SAD (Single-wavelength Anomalous Dispersion) phasing, both of which are becoming increasingly important in structural biology applications. The small size of the X-ray beam from the short gap undulator light source together with advances in X-ray optics will enable experimentalists to perform frontier research at a 2nd-generation synchrotron facility. The short gap undulator was developed specifically for this purpose, and will be installed in the short straight section U17 of the PF-ring. This will be the first mini-pole undulator installed at the Photon Factory. One of the beamlines previously used for protein crystallography, BL-18B, has been closed, and the activities of the old BL-17A, B and C will be transferred to a reconstructed BL-18B. The construction of the new BL-17A and the reconstruction of BL-18B are currently in progress. The new BL-17A will deliver its first beam in October 2005.

Insertion device and front-end

Four new short straight sections will be created as part of the "Straight-Sections Upgrade Project" of the Photon Factory during a six-month shutdown in the first half of FY2005 [1]. A new short gap undulator will be placed at the short straight section between the bending magnets 16 and 17. The length of the new straight section is about 1.4 m, out of which 0.5 m is used for the undulator magnets which have 29 periods of 16 mm period length. The maximum deflection parameter K has been chosen as 1.27. In the front-end section of BL-17 there are a pair of 0.25 mm thick beryllium windows and a double sheet of 0.1 mm thick graphite filter to eliminate the low-energy portion of the X-ray beam and avoid damage to the beryllium windows due to heat load. The beam acceptance of the beamline is restricted to 1.25 mrad (H) and 0.30 mrad (V) by a water-cooled main mask positioned just before the graphite filters, upstream of the shield wall.

Optics and ray-tracing simulation

The schematic layout of BL-17A is shown in Fig. 1. A water-cooled four-blade slit tapered at 45 degrees is placed just after the shield wall to limit the horizontal beam size to 0.1 mrad in the standard case. The slit can be opened wider if stronger beam intensity is required, for example for experiments with large crystals. After the slit, there are the branch beam shutter and two units of wire monitors which are used to measure the beam profile directly. The wire material is graphite filament of about 0.1-mm diameter. A vertically-deflecting double-crystal monochromator (DCM) is located 17.5 m from the light source. The monochromator produces a fixed-exit beam over an energy range of 6.0 to 13 keV, using a numerical look-up table for the different axes and translation stages. The crystals of the DCM have an indirect liquid-nitrogen cooling system to reduce crystal deformation due to high heat load.

Following the monochromator, a K-B mirror system is used for fine focusing. Two sets of flat mirror benders are located at 24.0 m for vertical focusing with a focusing ratio of 2:1, and at 30.8 m for horizontal focusing with a ratio of 6:1. To keep the surfaces of the mirrors clean, the mirror chambers are separated from the monochromator by a 0.2 mm thick beryllium window, and all sections of the beamline are kept at high vacuum by oil-free pumps. Both mirrors are Rh-coated Si crystals which show good performance; roughness of 1.7 Å rms and 2.0 Å rms, and tangential slope errors of 0.75 µrad rms and 0.95 µrad rms. The cut-off energy is approximately 15 keV with a glancing angle of 4.0 mrad for diffraction studies using soft X-rays (e.g. 6.0 keV). The second mirror has an elliptically-bent surface which is achieved by the "Arm Method" [2] mirror bender, to reduce the effect of the highly asymmetric 6:1(H) focusing ratio. Consequently, the beam size at the focal point (36 m) is estimated to be around 10 times smaller than those of the two high-throughput beamlines AR-NW12A [3] and BL-5A [4] at the Photon Factory (Fig. 2). The beam intensity at the focal position is calculated to be higher than 10^{10} photons/sec at 12.7 keV, and 10^{11} photons/sec at 6.5 keV, using 20 µm × 20 µm slit widths (Table 2).

Beamline hutches

The beamline has three hutches, two optics hutches and the experimental hutch (Fig. 1). There are two additional rooms for users: the control cabin and the sample preparation room. The control cabin is designed using the same concept as that of BL-5A, and provides users with an experimental environment similar to those of their laboratories, allowing them to concentrate on their experiments without disturbance from users of other beamlines. Above the hutches and the rooms, there is a large deck for computational work such as data processing, analysis and backup. With the benefits of a high-speed network and unified user interface [5], it is possible to access the data in the same way as at the beamline even after the beam time.

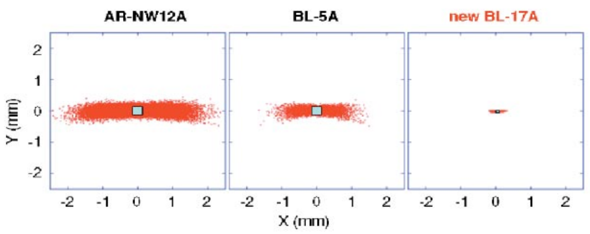


Figure 2
Comparison of the beam profiles at AR-NW12A, BL-5A, and the new BL-17A. The squares show the typical sizes of the collimating slits.

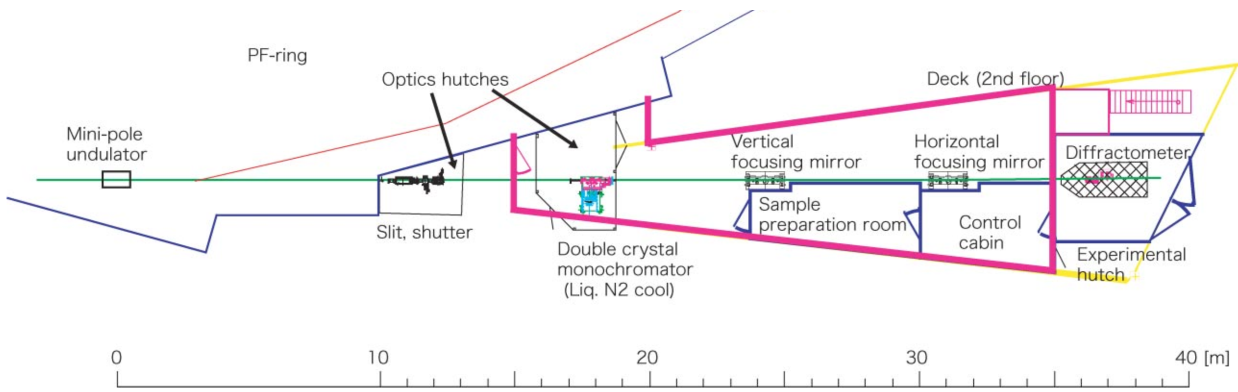


Figure 1
Schematic drawing of the new BL-17A.

Table 2 Result of the ray-tracing simulation.

Energy (keV)	12.7	12.7	6.5
Collimator size (µm)	Open	20(H) × 20(V)	
Sample size (µm)*	Open	20(H) × 20(V)	
Beam size (µm)	180(H) × 20(V)	20(H) × 20(V)	
Beam divergence (mrad)	0.40(H) × 0.13(V)	0.18(H) × 0.09(V)	0.19(H) × 0.09(V)
Energy resolution (ΔE/E)	4.4×10^{-4}	2.7×10^{-4}	8.3×10^{-5}
Photon flux (photons/sec)	1.1×10^{12}	2.7×10^{10}	1.1×10^{11}

* The area of orthogonal projection demonstrates hypothetical smaple size.

Construction schedule

With the aim of achieving first beam introduction in October 2005, we started construction just after the end of the PF-ring operation of FY2004 (February 28, 2005). The necessary work includes the closing of the old BL-17A, B, C and BL-18B, the construction of the new BL-17A, and the reconstruction of BL-18B. By the end of FY2004, we had completed the closure of the old BL-17A, B and C, and constructed the BL-17 optics hutches and the large upper deck of the new BL-17A. The installation of the optical elements will be completed by the end of June 2005. The diffractometer is being designed for micron-size crystals and will be delivered in the winter of 2005. The commissioning of the beamline will begin in October 2005, and general user operation will commence in the spring of 2006.

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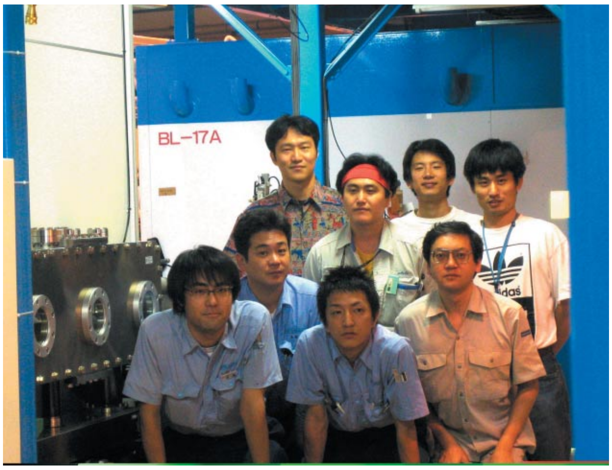
[2] J. Tanase and K. Endo, *PSE Proc.of the second U.S.-Japan workshop on soft X-ray optics,* (1997) 479.

[3] *Photon Factory Activity Report,* **20A**, (2003) 64.

[4] *Photon Factory Activity Report,* **21A**, (2004) 61.

[5] *Photon Factory Activity Report*, **22A** (2005) 71.



1-3 Commissioning of the Undulator Beamline BL-28A Dedicated to High-resolution Angle-resolved Photoemission Experiments

The commissioning of a new beamline, BL-28A, along with an endstation for high-resolution angle-resolved photoemission spectroscopy (ARPES) has been carried out in 2004. BL-28 is a helical undulator beamline covering the photon energy range of 30 to 300 eV, and is suitable for detailed electronic structure studies of materials.

A high-resolution ARPES beamline has been strongly demanded by many users for a long time. The main purpose of the beamline is ARPES studies on high-transition-temperature (high-Tc) superconductors and nanomaterials, for which high energy-resolution as well as high photon flux is needed. For this purpose, we have designed a varied including angle, varied line spacing plane grating monochromator which satisfies both the requirements of high energy resolution and high photon flux.

The commissioning of BL-28A was carried out during the summer shutdown period of 2004. A photograph of the newly-built BL-28A is shown in Fig. 3. During autumn 2004 beamtime, adjustment of the new beamline and the setup of the ARPES endstation were carried out. Evalua-

Figure 3
Photograph of the newly-built beamline BL-28A.

tion of the energy resolution of the beamline was carried out with a rare-gas photoionization study. Fig. 4 shows the photoionization yield of He recorded in the double-excitation energy region. Peak widths of less than 3 meV are observed, indicating an energy resolving power (E/ΔE) of more than 20,000. The photon flux was measured with a calibrated photodiode. Fig. 5 shows the observed photon flux with the monochromator set to the maximum energy resolution. These results indicate that the beamline exhibits both high energy-resolution and high photon flux.

For the high-resolution ARPES endstation, we selected a Gammadata Scienta SES-2002 analyzer. Fig. 6 shows a photograph of the ARPES endstation at BL-28A. Adjustment of the ARPES endstation is scheduled for beamtime during 2005, and the new ARPES beamline will be open for users in FY2006.

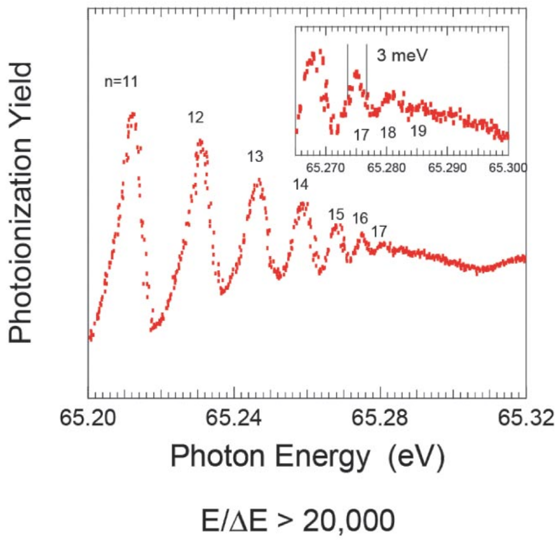


Figure 4
Photoionization spectra of He in the double-excitation region.

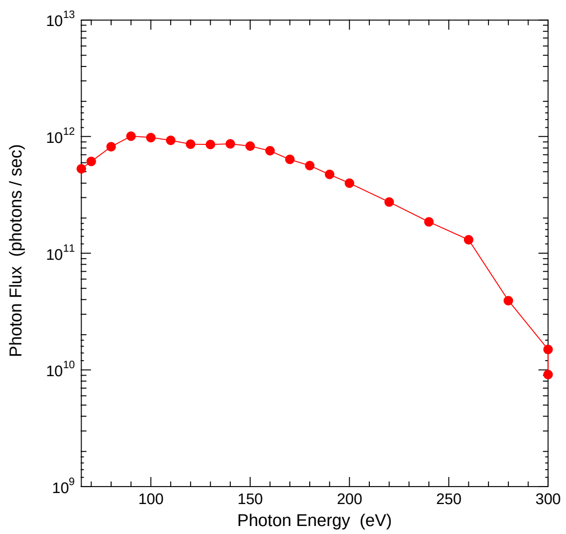


Figure 5
Observed photon flux with the monochromator set to maximum energy resolution.

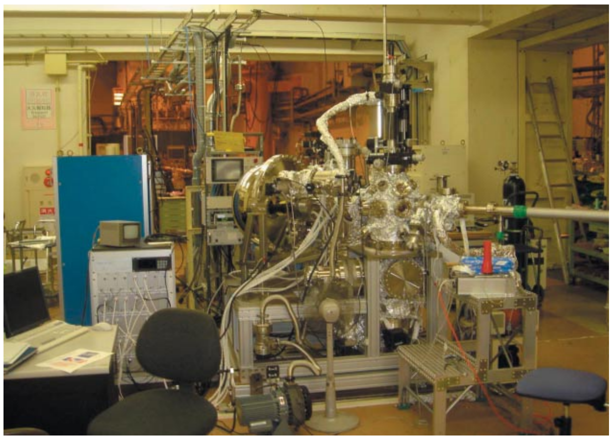


Figure 6
Photograph of the ARPES endstation at BL-28A.

1-4 Hard X-ray XAFS/AXS AR-NW10A

Construction of a hard X-ray XAFS and anomalous X-ray scattering (AXS) beamline NW10A was approved by Photon Factory Program Advisory Committee. Following this approval, the design and construction work is progressing. The first beam is to arrive at the experimental station in January 2006 and then the beamline will be opened for public users from the spring.

BL-10B has been used by many users as a XAFS beamline for rather hard X-ray region; 6 to 33 keV. It has been a workhorse in the Photon Factory and more than 990 publications have been registered in the Photon Factory Publication Database at the time of writing (June 2005). However, it was constructed in 1982 as the first XAFS beamline in the Photon Factory and is getting less competitive. For example, the flux is not sufficient above 20 keV since the critical energy of bending radiation from 2.5 GeV PF ring is only 4 keV. Furthermore, the optical design is rather old, the monochromator is getting less reliable and the experimental hutch is very narrow. Thus the XAFS user community has been looking for the opportunity to construct a new XAFS beamline for high energy region. Fortunately, Prof. K. Asakura (Univ. of Hokkaido) got certain fund from JSPS (Japan Society for the Promotion of Science) for the sake of the study

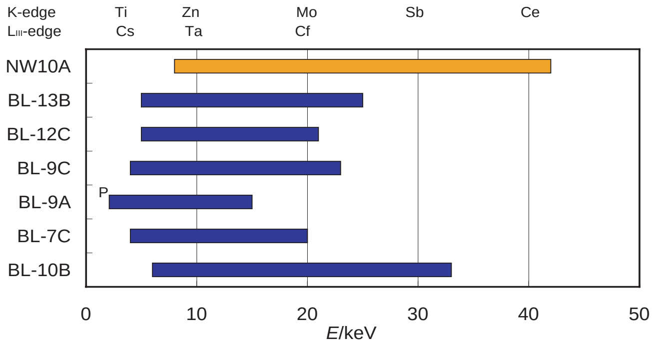


Figure 7
Available energy range at XAFS experimental stations of PF and PF-AR.

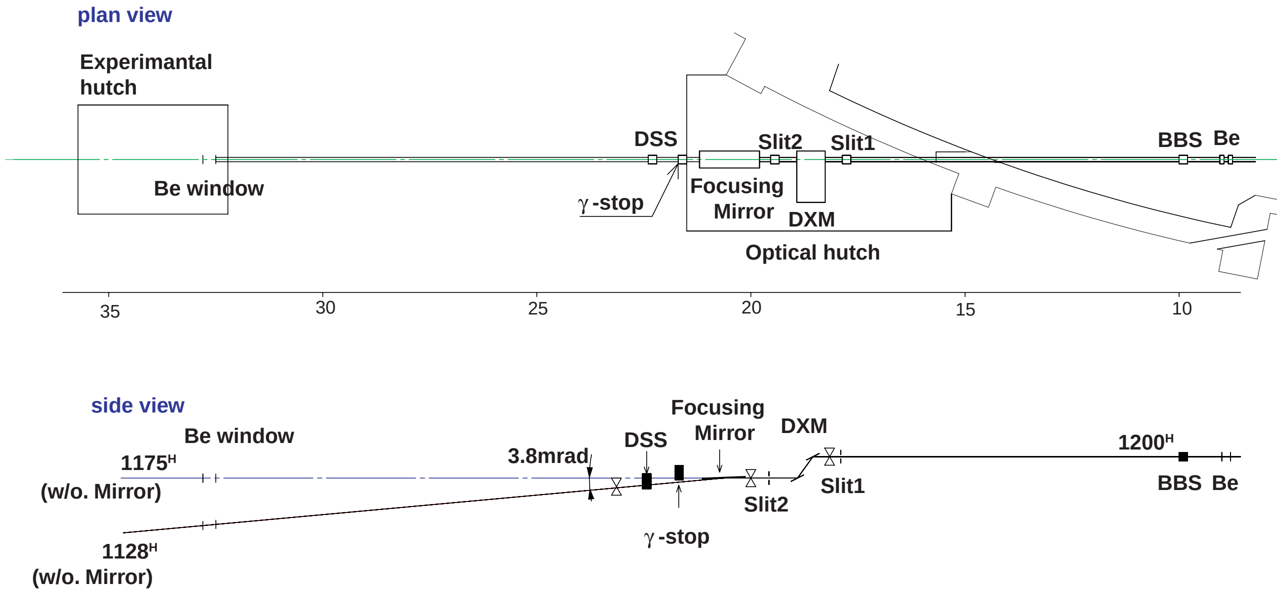


Figure 8
Schematic view of optics of PF-AR-NW10A.

of dynamics of catalytic reaction. It is very important to fabricate quick XAFS capability for the work and he kindly offered to use certain part of the fund for the construction of the beamline.

NW10A is to use radiation from a bending magnet in 6.5 GeV PF-AR and covers between 8 and 42 keV, complimentary to other XAFS stations as shown in Fig. 7. Since the critical energy is 26.3 keV, which is similar to that of SPring-8, 28.9 keV, 75 times high flux than that at BL-10B is expected at 30 keV. The optical design is rather simple; a Si(311) double-crystal monochromator and a Pt-coated bent cylindrical mirror. Although there exist platinum absorption edges between 11.5 and 13.9 keV, they will not become serious problem for XAFS experiments since the irradiation angle is only 1.9 mrad. As mentioned above, the double-crystal monochromator has quick XAFS capability, thus a spectrum can be obtained within less than a minute at rather high energy region.

The experimental hutch is designed to meet the requirements for XAFS experiments to follow the in-situ reactions. The experimental table on which both XAFS and AXS equipments are placed is fairly large, 1.2 m wide and 2 m long, and the two setups can be swapped fairly easily. The construction of beam line hutch, experimental hutch is to be completed during the summer shutdown of 2005.

1-5 AR-NW14A, A Beamline for Time-resolved X-ray Studies

NW14 is a new insertion device beamline at the PF-AR for time-resolved X-ray diffraction/scattering and XAFS experiments. The primary scientific goal of this beamline is to observe the ultrafast dynamics of condensed matter such as organic and inorganic crystals, biological systems and liquids triggered by optical pulses. With the use of the large photon flux emitted from two undulators, it should become possible to create a snapshot of the electron density distribution with 50-ps time resolution.

The beamline has two undulators with period lengths of 36 mm (U36) and 20 mm (U20) (Fig. 9). The U36

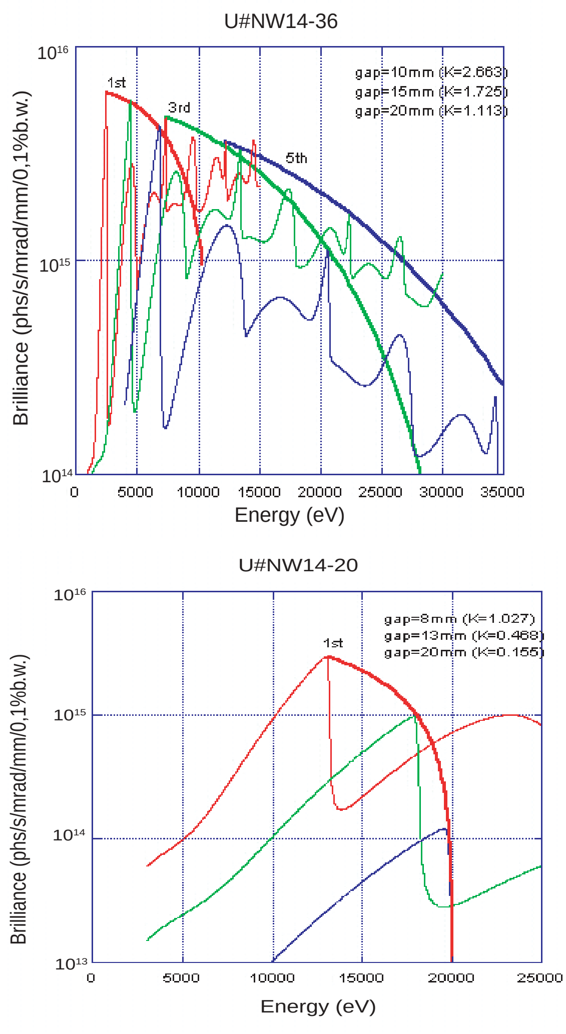


Figure 9
Spectra of U36 and U20 at NW14 (calculated by SPECTRA7.2).

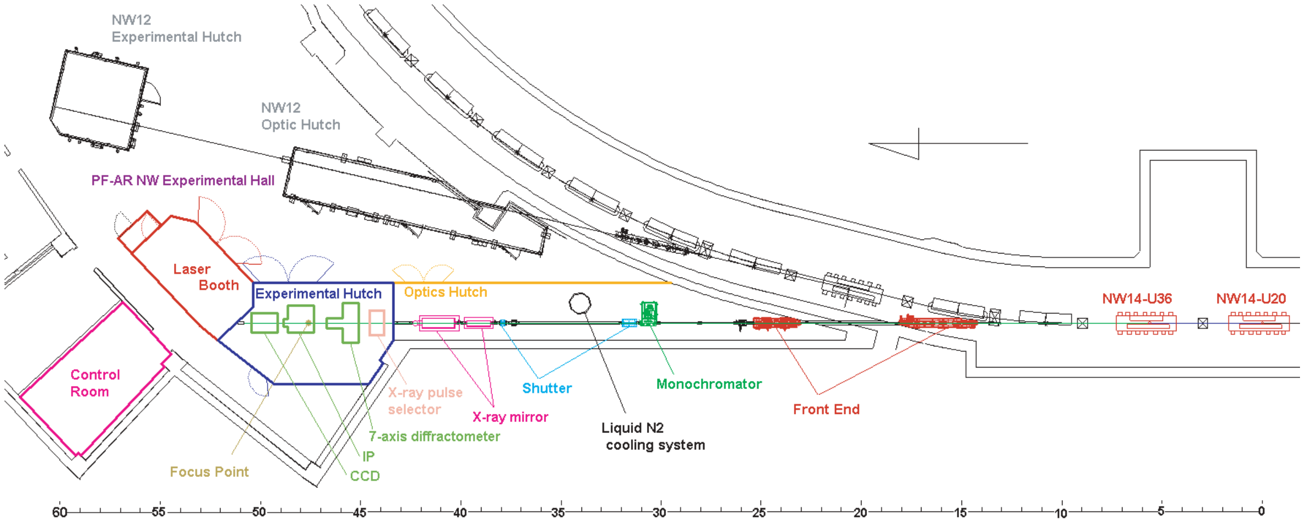


Figure 10
A plan view of the beamline.

undulator covers an energy range of 5-25 keV with its 1st, 3rd, and 5th harmonics, and provides a tunable and intense monochromatic X-ray source by using a double-crystal monochromator and a focusing mirror. The typical photon flux of the monochromatic beam is estimated as $\sim 10^{12}$ photons/sec. The U20 undulator has a 1st harmonic in the energy range of 13-20 keV The energy bandwidth of the 1st harmonic is $\Delta E/E \sim 10^{-1}$-10^{-2}, providing a 'narrow-bandwidth white beam' or 'wide-bandwidth monochromatic beam' with a photon flux of $\sim 10^{15}$ photons/sec. The X-ray pulses are delivered at a frequency of 794 kHz, and have a pulse duration of ~50 ps (rms). The focused beam size of monochromatized X-rays from U36 at the sample position is estimated to be 0.2 mm (V) × 0.6 mm (H).

Plan view of the beamline and the beamline components in the optics hutch are shown in Figs. 10 and 11. The front end consists of a fixed mask, a beam-position monitor, an absorber, a beam shutter, a graphite heat absorber, XY-slits for white X-rays and Be windows. The main optical components are a double-crystal monochromator and an X-ray mirror system, located at 30.5 m and 39-42 m from the center of insertion device U20. The double-crystal monochromator consists of flat Si(111) crystals, which are cooled with liquid nitrogen in order to reduce deformation caused by heat load. The cooling system can handle an incoming heat load of up to 450 W.

Figure 11
Monochromator and mirror chambers installed in the optics hutch.

The X-ray mirror system consists of 3 mirror assemblies: a bent cylindrical mirror for focusing of X-rays, and a double-mirror system (cut-off mirrors) to reduce contamination from the higher harmonics.

The construction of experimental hutch and laser booth will be completed by the end of July 2005. After the hutch construction the beamline components, diffractometers and a femtosecond laser system will be installed in August, and the beamline is planned to be fully operational from autumn 2005.