

UPBL4: Nano-imaging and nano-analysis	
Current designated sector:	Facility goes to:
ID22	ID16

1.1 SUMMARY

Driven by research areas with the largest scientific and societal impact, UPBL4 will be focusing on biomedical studies, earth and environmental sciences, and nano-technology. It will be a long, high brilliance beamline providing nano-focused beams for analytical imaging. The present conceptual design overcomes current ID22 limitations to meet the growing user demand and the requirement for improved spatial resolutions. Based on a canted undulator solution, it calls for parallel operation of two nano-probes:

The **NI end-station** (Nano-Imaging) will mainly address problems in biology, biomedicine and nano-technology using fluorescence analysis and nano-tomography. It will be optimised for ultimate hard X-ray focusing of a beam with a large energy bandwidth at specific energies. Aiming at life science applications, it will operate in a cryo-environment.

The **NA end-station** (Nano-Analysis) will offer a multianalysis nano-probe for spectroscopic studies (μ -XRF, μ -XAFS and μ -XRD) capable of *in situ* experiments at selective submicrometre scales. In a complementary way to the NI end-station, the NA end-station will provide a monochromatic beam tuneable in a large energy range.

1.2 PROJECT HISTORY

Within the X-ray Imaging Group, two complementary nano-focusing projects were presented for the ESRF Upgrade Programme:

- XMAN: X-ray Spectroscopy Multimagging Analysis, and
- SFINX: Scanning Fluorescence and Imaging at the Nano-scale using X-rays.

XMAN was the natural evolution of the μ -FID end-stations presently operating on ID22 EH1 and ID18F, whereas SFINX was built on the experience of the nano-imaging pilot project operated on ID22 EH2. Both conceptual design reports used long beamlines with an important increase in the average distance between the

source and the sample from 40 to 100 m for XMAN and from 64 to 200 m for SFINX, anticipating 2D focal spot sizes of 100 and 20 nm, respectively.

After a detailed study of the portfolio of candidate new beamlines, a unique project called NINA was established, integrating both XMAN and SFINX into a single long beamline. The UPBL4 (NINA) project was then presented to the ESRF Scientific Advisory Committee for the first phase of the ESRF Upgrade, who selected UPBL4 in the list of seven beamlines made at their 2008 autumn meeting. The parallel operation of two branches with complementary and optimised features appeared as a unique opportunity. It benefits from the canted undulator option as well as of the brightness improvements foreseen in the ESRF Upgrade Programme. The project matured further thanks to the UPBL4 Brainstorming (November 12-13, 2008), where feedback gathering, exchange of ideas, validation of directions and perspectives were discussed in detail. The idea to operate two branches optimised for nano-imaging and spectroscopy respectively, was very well received. In summary, the UPBL4 brainstorming helped to assess and develop both scientific aims and the best technical ways to reach them.

The target highest spatial resolutions combined with efficient Kirkpatrick-Baez focusing optics and long working distances resulted in the final choice of a long canted beamline with a single satellite building housing both end-stations at respectively 165 m (NA) and 185 m (NI).

1.3 SCIENTIFIC CASE

Three key scientific fields are driving the beamline upgrade: 1. Biomedical research, 2. Environmental and earth sciences 3. Materials sciences at the nano-scale.

1. In Biomedical sciences, the UPBL4 beamline at the ESRF will play a key role in “metallomics”, a new frontier field in biology (Carmona et al, 2008). The cell needs to be characterised not only by its genome and proteome, but also by the distribution of the metals amongst the different species and cell compartments, the “metallome” (Williams, 2001). Nano-X-ray-fluorescence will elucidate the distribution of trace metals in cellular organelles (typical sizes about 2-5 μm for nucleus, 0.5-1 μm for mitochondria, 25 nm for ribosoma, 20 nm for chromatin fibres) and nano-X-ray absorption spectroscopy will identify their chemical state. About one third of all known proteins contain metal cofactors as essential integral structural and catalytic components (O’Halloran, 1993). These proteins often have regulatory or catalysing functions, e.g. Fe in haemoglobin, Zn in zinc finger proteins as transcription factors in the cell nucleus. In many cases, trace metals are closely linked to diseases: deregulation in the homeostatis of one or several metals (e.g. Parkinson’s, Alzheimer’s, ALS, Friedrich ataxia, Wilson, Menkes, ...), (Chwiej et al, 2008). They are also used in therapeutic drugs and diagnostic agents (e.g. cisplatin in chemotherapy; Gd in magnetic resonance imaging-MRI; novel bio-inorganic nano-particles). Tremendous efforts have been made to obtain multifunctional nano-vectors (Paunesku et al, 2006) in tissues, cells and organelles ideally combining targeting (e.g. DNA), therapy (e.g. Pt, TiO₂ with photo-induced cleavage of DNA) and diagnosis (e.g. Gd). To significantly improve the understanding of infectious diseases (Finney L A et al, 2003), high spatial resolution investigations are required of cellular interfaces and membranes, as well as the elemental content

of cytoplasm (host cell), vesicles (phagosome) and parasites. The studies must be performed on whole cells in a frozen-hydrated state to preserve the element distribution and the structure. A first milestone of the UPBL4 project is therefore the creation of a cryo-compatible biology platform for three-dimensional subcellular imaging.

2. Earth and environmental sciences constitute a second core user field of the UPBL4 project. The research drivers at the nano-scale include the mineral interfacial reactions at the subgrain levels: reactivity, bioavailability and toxicity of (ultra-)fine particles and species adsorbed to surfaces; airborne particles and colloids in natural systems (Leet et al, 2008). It is well-known, for instance, that metal(loid)-rich particles may be the largest health risk associated with mine waste (Ledin et al, 1996). Within the biogeochemical processes, the following subfields will play a key role: nano-scale heterogeneity of metals and metalloids in biogeochemical systems, interactions of organisms with contaminants, toxicity and biogeochemistry of manufactured and natural nano-particles (Leppard 2008), electron transfer mechanisms between microbes and minerals, binding mechanisms of natural organic matter and bacteria, and finally, environmental genomics (Kemner et al, 2005). In the examination of how genetic variations in organisms affect their interactions with contaminant and nutrient, the analysis of metal species in the environment helps to understand how specific genes influence the uptake of metals in plants and animals (for example, in iron deficiency, the most common nutritional disorder) (Cheng et al, 2007). Particular attention will be paid to fluid flow and contaminant transport at the pore scale, 3D visualisation of mineral-solution reactions in confined spaces *in situ* within dense geologic media (Zhao et al, 2006). The quantification of the distribution of pore spaces, evaluation of microbial distributions on pore walls and microspectroscopic examination of colloidal chemistry at mineral interfaces are research priorities today (Zbik et al, 2008). Greater efforts are required to replicate *in situ* conditions under which naturally occurring and engineered materials operate: e.g. real-time scattering to follow phase evolution (Mokuta et al, 2005) as a function of time and environmental conditions (*P*, *T*, *Eh*, *pH*, *fO₂* ...). Finally, a very active demand for high-resolution nano-probes comes presently from the field of cosmo-chemistry (Bleuet et al, 2008a). Studies of extraterrestrial dust particles provide an important insight into the universe's recycling processes and in planetary systems such as our own solar system (Flynn et al 2006). Cosmic dust is made of aggregates of dust grains at the nano-metre scale. The composition, size, and other properties of a dust particle can reveal information about the dust particle's origin (Ebel et al 2007). The interstellar dust grains contained within meteorites are of particular interest with this respect as they preserved their original composition and provide information on the solar system prior to earth formation. A second milestone of the UPBL4 project is then the multimodal analysis, including chemistry and crystalline structure, of heterogeneous systems in a confined environment mimicking *in situ* conditions.

3. Nano-technology (Ray et al, 2006) is the third scientific driver of the development of UPBL4. This field is, by definition, extremely broad and covers many fields from electronics to healthcare, including among others: sensors, ultra-precise drug-delivery systems (nano-medicine), selective molecular sieves, nano-composites for high-performance vehicles and microelectro-mechanical systems (MEMS) (Zhang et al, 2004). One of the important motivations for working at the nano-scale comes from the evolution of microelectronics towards miniaturisation

(e.g. integrated circuits, photonics or nano-sensors and nano-bots for micromanufacturing) (Zschech et al, 2008). A second motivation is the exploitation of size and confinement effects, such as quantum size effects, tunnelling, exchange coupling, anisotropy of nano-wires, or self-assembly and patterning at the nano-scale. New, fault-tolerant architectures will be needed in the near future (Ahn et al, 2006) due to new physical effects related to the existence of quantum fluctuations, nano-clusters, non-uniformities, proximity effects from boundary conditions, interfaces, nano-domains and point defects. The possible mechanisms which lead to self-organised structures are still largely unknown (Wang, 2000). Understanding the structure of nano-objects enhances the ability to manipulate them and fosters the development of new models to describe their behaviour at this scale. This leads to rapid advances in condensed matter, materials engineering and nano-science. The UPBL4 beamline will address scientific needs in condensed matter physics, strain engineering in integrated circuits, and the atomic and crystal structure of nano-materials (Engheta 2007). It will allow *in situ* and dynamics studies by controlling the sample temperature and pressure, or applying an external electric field. Moreover, with the control of the incident beam polarisation, it will be possible to study the dynamics of polarisation switching at the scale of single structural, ferroelectric domains (Slutsker et al, 2008). While strained silicon channels have been rapidly integrated in both PMOS and NMOS structures, the ability to measure strain directly in these 50 nm or smaller devices leads to better understanding of factors affecting device performance and reliability. In summary, the main contributions of UPBL4 in the field of nano-technology will be the three-dimensional characterisation of (operating) devices and *in situ* studies of the involved local physical phenomena. A huge impact can be expected if the real spatial resolution can be improved below 20 nm; this will be the third milestone of the project.

The UPBL4 beamline aims at providing a full characterisation at the nano-scale of diluted heterogeneous samples. Therefore, it is built into a multimodal framework providing complementary sets of information by using the following X-ray methods:

- 1) X-ray fluorescence (XRF)
- 2) X-ray absorption spectroscopy (XANES and EXAFS)
- 3) X-ray diffraction (XRD)
- 4) X-ray excited optical luminescence (XEOL)
- 5) X-ray projection microscopy
- 6) Coherent scanning X-ray diffraction
- 7) Extension of these methods to three dimensions (generalised computed tomography).

A major asset of the UPBL4 beamline will be the combination of classical (incoherent) scanning methods (items 1-4 in the above list) with new coherent imaging methodologies (items 5-6). Coherent imaging methods are still rapidly developing, but a unified picture is appearing (Nugent, 2007). Projection microscopy (Pereiro et al, 2005) is a magnified version of holotomography, but can also be considered as coherent diffraction imaging with a curved wavefront. It is particularly well adapted to dose-sensitive specimens and provides *morphological information* by mapping quantitatively the distribution of the *electron density*. Combined with local tomography and laminography, it allows zooming onto regions of interest selected within laterally extended samples, a unique and extremely important possibility to handle real scientific cases. Similar information, but with much higher spatial resolution, well beyond the size of the focal spot, is obtained

through coherent scanning X-ray diffraction (ptychography, Thibault et al, 2008). It consists of acquiring many coherent diffraction patterns from overlapping regions of the specimen. The coherent imaging methods yield quantitative morphological information that complements very well the local probes. Nano-scale X-ray fluorescence imaging will provide the distribution of most elements and in particular of trace elements in a single scan. By online combination with density mapping (STXM mode), quantitative maps of *absolute concentrations* will be obtained through fitting and simulation procedures in a fully self-consistent way. The extreme photon density in a nano-focused pink beam associated to new detection geometries will allow reaching new milestones in fluorescence detection limits, approaching the dream of single atom localisation. Special attention will be given to all beamline components and detector calibration to obtain high quality EXAFS spectra with sub-micrometre spatial resolution. X-ray diffraction will be used to map the crystallographic phases, but also for local strain analysis in nano-devices. The simultaneous acquisition of the different outgoing signals makes this multimodal framework particularly attractive. Furthermore, all the expertise required for the combined approaches is available on site. The ESRF X-ray Imaging Group has played a major role in the development of what is known as generalised computed tomography: holotomography for determination of the electron density (Cloetens et al, 2006), fluorescence tomography for 3D mapping of the element concentrations (Golosio et al, 2003), diffraction tomography for mapping of the crystalline phases (Bleuet et al, 2008b). This three-dimensional imaging approach is crucial for true quantification on heterogeneous samples. It can be anticipated that generalised tomography will be further extended, with the existing methods becoming standard and faster through optimised detection and acquisition schemes.

On the possible future mid- to long-term developments after UPBL4 has become operational, is the combination of X-ray nano-scale imaging with electron microscopy. One way of doing this would be to have a TEM/SEM next to the instrument and a vacuum sample transfer to/from X-ray measurements. Waveguide-enhanced focusing (Jarre et al, 2005) in combination with efficient KB pre-focusing could be an interesting route for further compression of the X-ray beam size or confinement of the sample (Zwanenburg et al, 1999). Novel optics can be envisaged to provide smaller, but much less intense beams. Ultra high spatial resolution imaging could be extended to the monochromatic configuration with energy scanning in a limited range (XANES). In parallel, other long-term developments include fast- and low-noise detectors, sample environments, sample throughput and image processing capabilities.

In terms of spatial resolution, energy range, photon flux, available techniques and sample environments, the UPBL4 concept is unique. The NI branch will offer the ultimate hard X-ray focus of a high flux pink beam, whereas the NA branch will make nano-spectroscopy possible in a wide energy range. In summary, the UPBL4 beamline will offer many scientific capabilities not accessible today at the ESRF:

- 2D/3D imaging and trace element mapping at the nano-metre scale under cryo-environment
- *In situ* experiments under extreme thermodynamical conditions with sub-micrometer resolution
- Microanalysis in the 20-60 keV high energy range at sub-micrometer scale
- Sub-ppm level μ -XAS studies (XANES, EXAFS) including confocal mode

- XRF- and XRD-tomography with sub-micrometre resolution.

1.4 TECHNICAL CONSIDERATIONS

The targeted highest spatial resolutions (10-20 nm and 50-100 nm for, respectively, NI and NA), combined with efficient KB optics focusing and usable working distances, result in the choice of an extra long beamline (>150 m). A high-beta straight section associated with a horizontal secondary source will offer the best flexibility by tuning the photon flux/spatial resolution ratio matching various experimental requirements. The canted undulator sources and brightness improvements foreseen in the ESRF Upgrade Programme open the unique possibility to operate the two branches in parallel, enhancing the capabilities and operational efficiency of current stations. Furthermore it allows the two setups to be optimised for their respective goals (ultra X-ray microscopy versus nano-spectroscopy) resulting in better respective performances. The main drawbacks of this configuration are the reduced flux reaching the sample (approximately less by a factor of 2) and the intricacy of the first optical elements of both branches. The two beamline branches have different characteristics corresponding to the scientific cases described in § 1.3; a summary is given Table 2 below.

	NI	NA
Length	185 metres	165 metres
Spatial Res.	10 - 100 nm	50 nm - 1 μ m
$\Delta E/E$ (%)	1	0.01
Energy range	Discrete 11.2 - 17 – 33.6 keV	Scanning 5 \rightarrow 70 keV
Main goals	XRF, XRI-2D/3D Cryo environment	XAS, XRD, XRF, XRI-2D/3D <i>in situ</i> experiments
Main fields	Biology & Life Sciences Nano-technology & Nano-medicine	Biology, environmental sciences, geoscience, materials sciences, ...

Table 2. Specifications of the Nano-Imaging and Nano-Analysis end-stations.

X-ray source

The document ‘A Scenario of “All Beamlines” Portfolio at the end of the ESRF Upgrade Programme “Phase I Minimum” Preparatory SAC Meeting, 7 October 2008’ positions this facility at the location ID18. This location was ideal for UPBL4 as it is one of the few places at the ESRF where an extra long beamline can be installed at a safe distance from vibration sources (respectively the motorway and the main road). The proximity to ID17, ID19, ID21 and the biomedical facility would have created an “X-ray Imaging village” allowing fruitful scientific collaborations and efficient sharing of support facilities. Following discussions with the Directors of Research, it was decided to position the UPBL4 facility at the location ID16. The relocations involved (inelastic scattering \rightarrow ID20, UPBL4 \rightarrow ID16, ID10A \rightarrow ID22) have to be synchronised accordingly.

The source is canted symmetrically with a canting angle of ± 2.7 mrad. The undulators of the NI branch will be located downstream. The maximum canting angle should be preserved to obtain a sufficient beam separation at the level of the first optical elements. A schematic diagramme of the undulator canting for UPBL4 is shown in Figure 2.

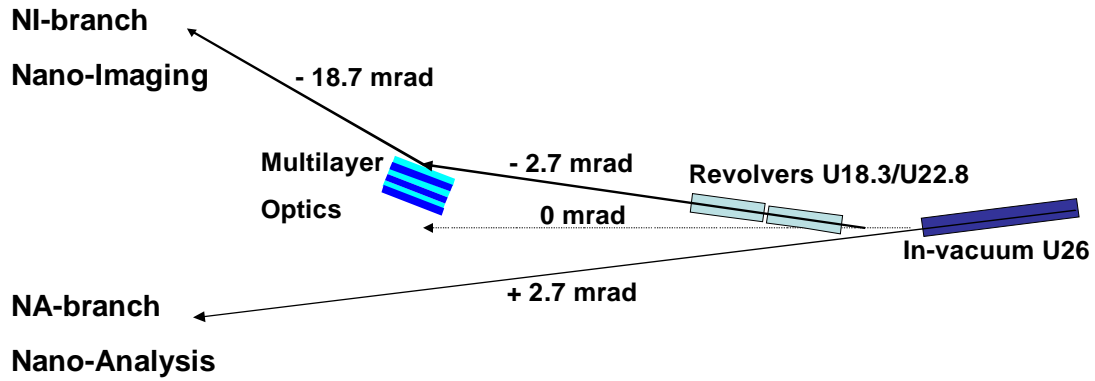


Figure 2. Schematic diagram of undulator canting for UPBL4. The angles are not to scale.

For the NI-branch, the most adapted undulators are two identical and phased revolver-type undulators such as U18.3/U22.8. The extreme beam stability requirements of the NI branch prevent heat load on primary optics coming from unused harmonics. It is therefore planned to use nearly exclusively the fundamental radiation of single-line undulators. Two identical revolver carriages will be installed, housing a U18.3 which will provide a fundamental harmonic down to $E = 17$ keV and a U22.8 to work at $E = 11.2$ keV with the first harmonic and at $E = 33.6$ keV with the third.

For the NA branch the most adapted undulator is a fully tuneable in-vacuum undulator. As can be seen in Figure 3, a cryo in-vacuum U21 with $K = 2.2$ can achieve full tuneability over the required 6-70 keV energy range and delivers the best performance.

The photon flux emitted by the various undulators is presented in Figure 3. It is calculated at 30 m from the source through a $1 \times 1 \text{ mm}^2$ pinhole. In-vacuum undulator spectra are presented for a U21 and U26 with a length of 3 m. Both of them provide the same energy range and tuneability, they only differ by their cooling system: the U21 is cooled via a liquid nitrogen cryogenic loop (this technology has been tested and should be available very soon). It allows a flux increase of a factor of two for the high energies ($E > 40$ keV). Both in-air undulator spectra are multiplied by two to take into account the pair of identical undulators equipping the NI half straight section.

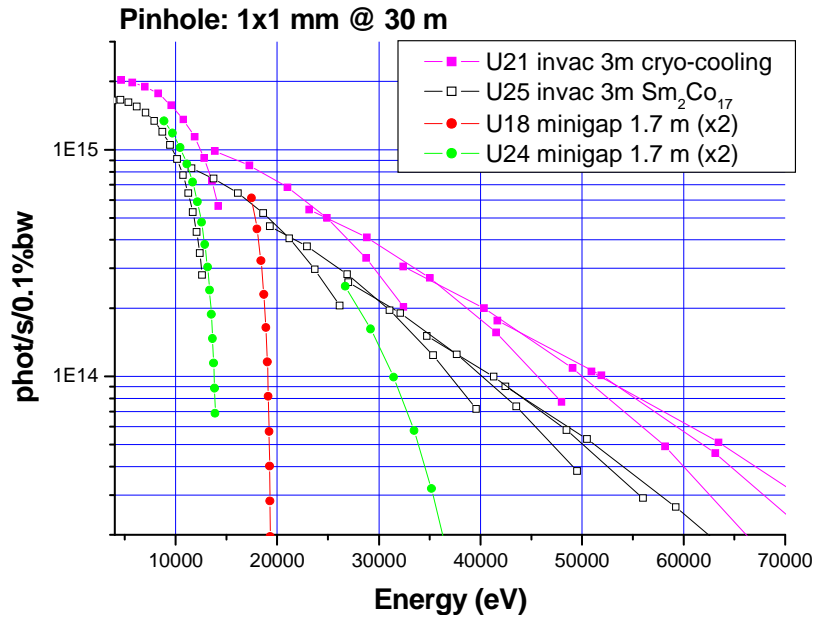


Figure 3. Photon flux as a function of energy for the anticipated UPBL4 undulators.

To compensate for the two-way canting and the very long length of the two branches, the spectral brightness of the source should be as large as possible. While the UPBL4 beamline can initially operate on a 6 metre long straight section, it should be enlarged in the medium term to a 7 metre long straight section. This point is especially important for the NA branch that will suffer from a lower flux in the focus due to the required monochromaticity of 10^{-4} . An enlargement to 7 metre means effectively a flux increase by 50% for this branch as it will allow a 3 m long in-vacuum undulator to be installed as opposed to the standard 2 m length.

The front-end should transmit the beams from the two canted branches defined above. It should be compatible with a beam size of up to 2 mm x 2 mm at the level of the high heat-load slits located at 27 m. The beamline should be UHV to allow a future evolution to lower energies and to avoid spurious effects from supplementary window material. If the UHV option turns out to be incompatible with the canting solution, the front-end window should be chosen in agreement with the beamline staff to be compatible with spectroscopic and phase contrast imaging.

Operation of the UPBL4 beamline requires operation modes with high current and low vertical emittance. All special timing modes (Hybrid, 16-bunch, 4-bunch) are effectively unusable for nano-focusing applications due to the much larger vertical emittance and/or the lower flux. The vertical focus size will be roughly proportional to the square root of the vertical emittance. A decrease of the horizontal emittance would be very beneficial for nano-focusing applications, but seems not within the scope of the Upgrade Programme. Also the stability of the source is of crucial importance; on ID22NI today most short-term instabilities can be traced back to the X-ray source as shown by spectral analysis of the X-ray signal and the fast electron BPMs. Special attention should be paid to the long-term stability of the source emission angles due to the very large lever arms of up to 185 m. It should be better than 1 μ rad in order to avoid frequent realignment of the beamline instrumentation.

A real topping-up mode would be of great interest to improve the stability thanks to a constant heat-load on the optical elements. However, no source instabilities or increase of the apparent emittance should be associated to the topping-up.

Beamline layout

The Nano-Imaging end-station will be located at 185 m from the source and will be optimized for XRF mapping and nano-tomography at the highest spatial resolution. Central to the approach is an intense ($> 10^{12}$ photons/s) nano-probe with modest monochromaticity ($\Delta E/E \sim 10^{-2}$) operating at discrete energies.

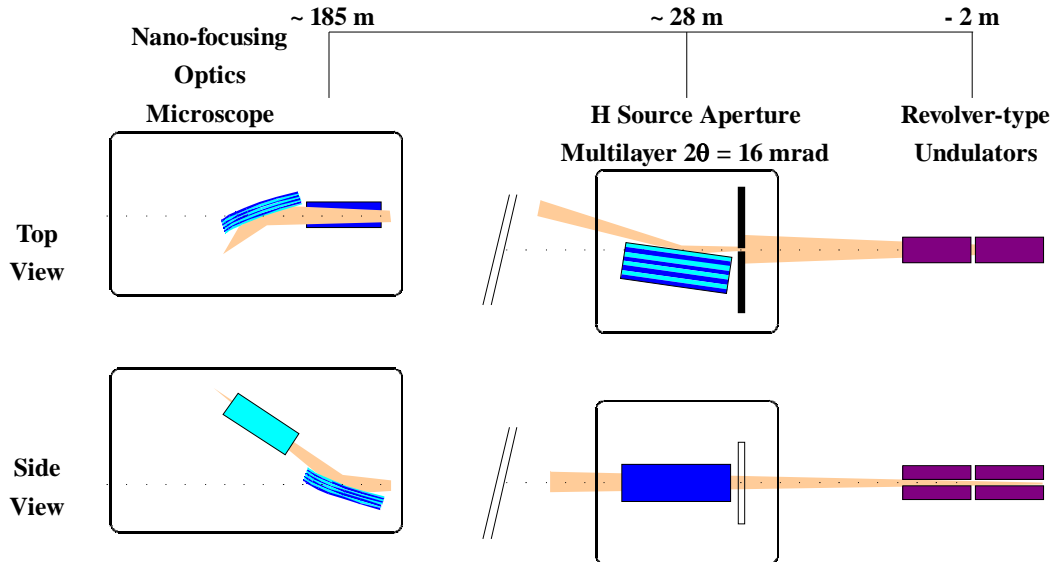


Figure 4. Schematic layout of the NI branch.

The schematic layout of the NI branch is shown in Figure 4. It is similar to the one successfully used at ID22NI today: the reduction of the number of optical elements and a strict decoupling of the horizontal and vertical directions. The only optics operating in the vertical plane are the nano-focusing optics, taking maximum benefit of the low vertical emittance. The first main optical element, a fixed-angle multilayer located at 28 m from the source, has a double function: it acts as a pre-monochromator reducing further the heat-load on the nano-focusing optics and it assures sufficient beam separation for parallel operation of the NI and NA branches (see Figure 2). This is a critical optical element that should be developed in collaboration with the Optics Group. A secondary source will be used only in the horizontal plane due to the large horizontal emittance of the ESRF. The detailed design of this secondary source (an intermediate focus versus a simple aperture) will be developed during the Technical Design Report. Multilayer-coated KB optics installed next to the specimen will be used for efficient nano-focusing. With the optics currently developed for ID22NI, a two-dimensional focal spot size of 30 nm can be anticipated. With a specific, more compact design the focal spot will be further reduced to 15 nm. A cryo-compatible environment for life science investigations on frozen-hydrated samples is foreseen. Another priority will be improved fluorescence detection schemes to reduce radiation damage. The microscope will be a closed system with an automatic sample changer. The NI

branch will offer unique performances, but not the flexibility and diversity of the NA branch.

The Nano-Analysis end-station will be located at approximately 165 m from the source and will be dedicated to high lateral resolution spectro-microscopy combined with XRF and XRD 3D mapping. It will provide the same characteristics as ID22/EH1 today but with improved lateral resolution from 50 nm up to 1 μ m. It will operate in monochromatic mode ($\Delta E/E \sim 10^{-4}$) and allow fast energy scanning in a large energy range (EXAFS). A degree of flexibility will be necessary to accommodate in situ experiments associated with the combination of various spectroscopic techniques on the same instrument. In particular, high resolution XEOL will be implemented (Martinez et al, 2006). This branch will be specifically equipped to accommodate sample environments, including cryogenic sample cooling for biological samples. In this context, long working distances will be required. The nano-probe beam will be achieved with KB focusing optics operating mostly achromatically under total reflection.

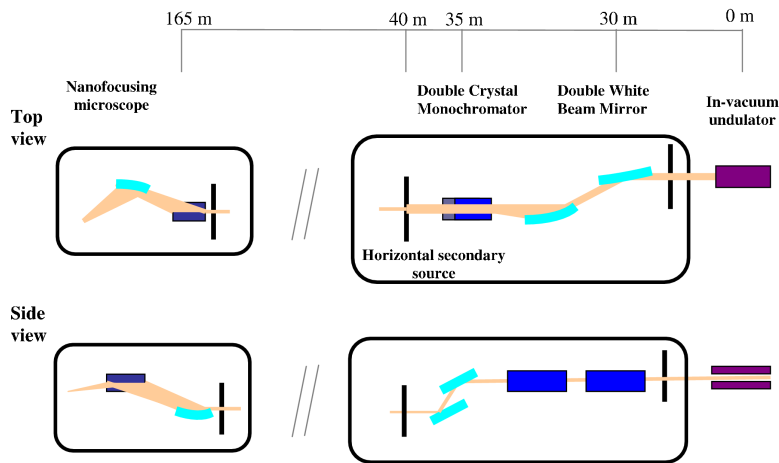


Figure 5. Schematic layout of the NA branch.

The schematic layout of the NA branch is shown in Figure 5. The first optical element is a double white-beam mirror for harmonic rejection. Three different coatings (Si, Pd, Pt) will be available to cover the 6-30 keV energy range. A horizontal secondary source can be created downstream of the monochromator by dynamic bending of the second mirror. A double crystal and fixed-exit type monochromator will house two pairs of Si(111) and Si(311) crystals. Its mechanical stability and fixed-exit capabilities should be particularly optimised to keep the nano-beam stable during XAS measurements.

The beamline properties are summarised in the following table:

	Length	Focal spot size (nm)	Flux @ 18 keV
NA	165 m	71 x 101	$1.8 \cdot 10^{11}$ ph/s $\Delta E/E \approx 10^{-4}$
NI	185 m	29 x 29 (current) 16 x 16 (new)	$2.5 \cdot 10^{12}$ ph/s $2.5 \cdot 10^{12}$ ph/s $\Delta E/E \approx 10^{-2}$

These values should be considered as average values which can vary according to a number of parameters which are not known today or which can be adjusted depending on the focal spot requirements such as the size of the horizontal secondary source, the KB working distances and the numerical apertures of the KB mirrors. The photon flux has been calculated at 300 mA current and for a 7 m straight section with a 3 m long U21 undulator for NA and two 1.7 m long U18.3 undulators for NI.

A layout drawing of the optics hutch inside the current experimental hall is shown in Figure 6. A single large optics hutch (OH) houses all the beamline optical elements (apart from the nano-focusing optics). For the NI-branch, this includes high heat-load slits, attenuators, the multilayer mirror and the horizontal secondary source. For the NA-branch, this means the high heat-load slits, attenuators, the double white-beam mirror, the double crystal monochromator and the secondary source. The geometry of the hutches ID16-OH and the neighbouring hutch ID15B DAC must be further refined. All interference between equipment installed on ID15 (e.g. the large volume press) and the UPBL4 optics should be avoided; this might require installing damping systems on the ID15 facilities.

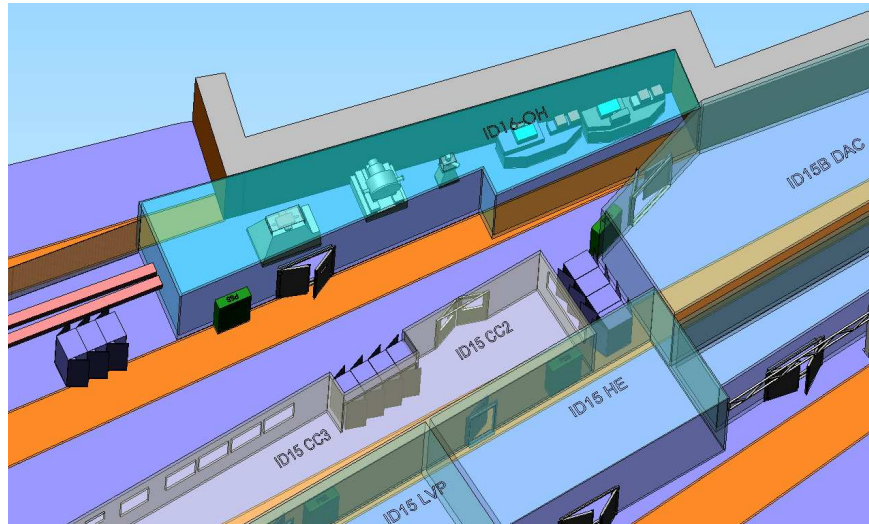


Figure 6. Schematic layout of the UPBL4 optics hutch inside the experimental hall EX1.

Figure 7 shows the principle layout of the UPBL4 satellite building housing the experimental hutches of the two beamline branches. Special attention should be paid to the 'nano-compatibility' of this building and the stability of the environment. A vibration measurement campaign should be organised as early as possible at the building location.

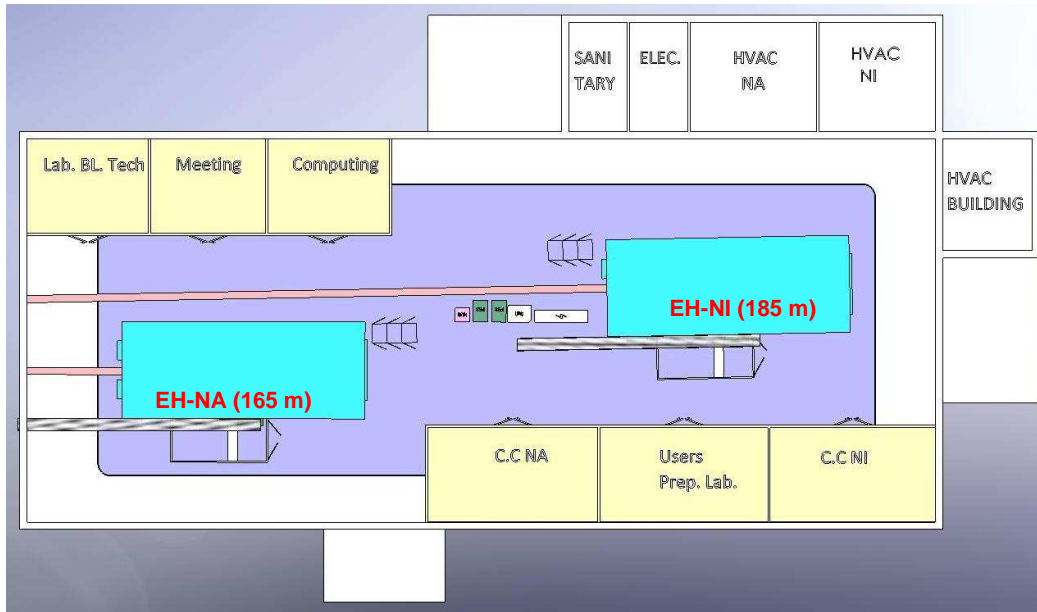


Figure 7. Schematic layout of the UPBL4 satellite building and the experimental hutches. The building is around 35 x 15 m².

The UPBL4 beamline will require three different types of main detectors:

- Large solid-angle, high count-rate energy-resolving detectors for XRF, XAS.
- Fast, large area, large pixel detectors for (coherent scanning) XRD.
- Efficient, fast, low-noise imaging detectors for (magnified) X-ray imaging.

Beam position monitors will play a crucial role in the success of the beamline. Due to the extra long distances between the optical elements inside EX1 and the nano-focusing optics in the satellite building, slow feedback loops will compensate for long-term drifts of these optical elements. A second type of BPM will be required for fast monitoring of the actual position of the nano-beams.

The most challenging technical difficulties of the project can be summarised as follows:

- The intricacy of primary optics of the two branches.
- The stability of the fixed-exit double-crystal monochromator for XAS.
- The angular stability of the multilayer mirror of the NI branch.
- The implementation of a (cryogenic) sample environment compatible with the nano-positioning required for 3D microscopy and analysis.
- The extreme stability requirements of the NI nano-probe.
- Efficient sub-20 nm 2D focusing optics.

For both branches the development of high quality KB mirror substrates should be foreseen. This is crucial to achieve large numerical aperture optics providing simultaneously a large flux and the smallest focus.

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