# NOTOS at ALBA

## Instrument Development and Innovation Beamline

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October 2014

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## Abstract

We propose to build an X-ray beamline for instrumental developments at a bending magnet port. The beamline, which we call NOTOS, will aim to support and strengthen technical and instrumental developments and also new methodologies developed at ALBA or at external companies and laboratories. Specifically, it will address testing and improving high precision mechanical components, performing optical and mechanical metrology on beamline components, determining performances of diagnostics and detector systems and also carrying out new methodologies and concepts to improve beamline instruments.

NOTOS will be an internal ALBA beamline with a large operating flexibility and consequently not committed to user service. NOTOS will be devoted to reduce the enormous lack of developments of scientific instrumentation existing in Spain.

However, it is likely that during the first years of operation not all the available beam time will be filled with instrumental development activities, as these will grow progressively. Therefore, additional usages of the beamline are being explored: for example, simple feasibility tests for industrial applications and collaborations with external users for preliminary or proof-of-concept experiments.

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## Proposal for

## Instrument Development and Innovation Beamline

# NOTOS

## 1 Introduction

### Decision of more in-house and local developments

Following the ALBA strategic plan (http://www.cells.es/old/AboutUs/strategic-plans/strategic-plan-2013-2016), ALBA management has decided that the implementation of future beamlines should be based on as large as possible in-house and/or local developments. A larger amount of in-house developments (compared to those carried out along phase-I) is now possible due to the expertise and know-how that has been built along these years. On one hand, more components will be fully designed by ALBA, with some local workshops as subcontractors. On the other hand, some components will be developed in collaboration with private partners, with heavy involvement of ALBA staff. Examples of on-going collaborations and initiatives are described in section 3 of this proposal.

As representative examples, we can highlight developments in vacuum-compatible precision mechanics and X-ray transport optical elements. In these two cases, ALBA has identified partners that have expressed their interest to establish collaboration agreements, which are currently being set up. Also the field of high-energy X-ray photon detectors is prone to collaborations with neighbor organizations, which have already started and that will be likely enhanced (discussed in section 3.2).

### Need for a testing platform for the in-house developments and innovation

This beamline proposal frames naturally within the ALBA mission "To research, deliver and maintain methods and techniques with which to conduct cutting edge synchrotron light based research *and development, in such a way that knowledge and added value data are pumped into the scientific and industrial communities*, particularly those in Spain, with the ultimate goal of contributing to the improvement in the well-being and progress of society as a whole." (ours in italics).

So far, ALBA's instrumental developments are directly commissioned at the corresponding user-oriented beam line (BL). This has some practical interference with the normal user-activity, during installation, and involves that the commissioning time of improvements goes at the expense of reducing the beam time made available to users. For instance, this is currently taking place at the CLAESS beamline, with the development of the CLEAR spectrometer, http://www.cells.es/en/beamlines/bl22-claess. The spectrometer is installed at the experimental hutch of the beamline, as some tests required for its development need X-ray photons, and therefore consumes some beam time.

Furthermore, the lack of a instrumentation and test beamline prevents ALBA from carrying out some developments of high interest for the scientific appliations of the facility, for instance detector testing in collaboration with IFAE (Instituto de Física de Altas Energias (http://www.ifae.es/).

NOTOS will be devoted to technical developments and its main objective is not user-oriented. So, it will run as an internal ALBA laboratory. NOTOS has to be operated with a large flexibility that allows optimizing its usage of beam time and also its objectives. For example, if after an initial period fully devoted to technical developments it is considered that NOTOS could relieve the pressure of heavily oversubscribed beamlines (as CLAESS and MSPD), one could envisage to devote part of its beamtime to user service for non-demanding experiments. This option has to be envisaged and let as a possibility.

As a regular working mode, NOTOS will provide beam time to collaborations for the development and innovation of a number of devices including monochromator, mirror bender, development and testing of detectors, etc. In these cases, beam time will be allocated within the frame of collaboration agreements, under close monitoring of ALBA's management, and consequently apart from the usual access program.

On the other hand, if NOTOS is funded, it will allow ALBA increasing the amount of beam time available for users as it will release other, high performance beamlines from spending part of their shifts in technical developments (for instance CLEAR at CLAESS, see Figure 1)

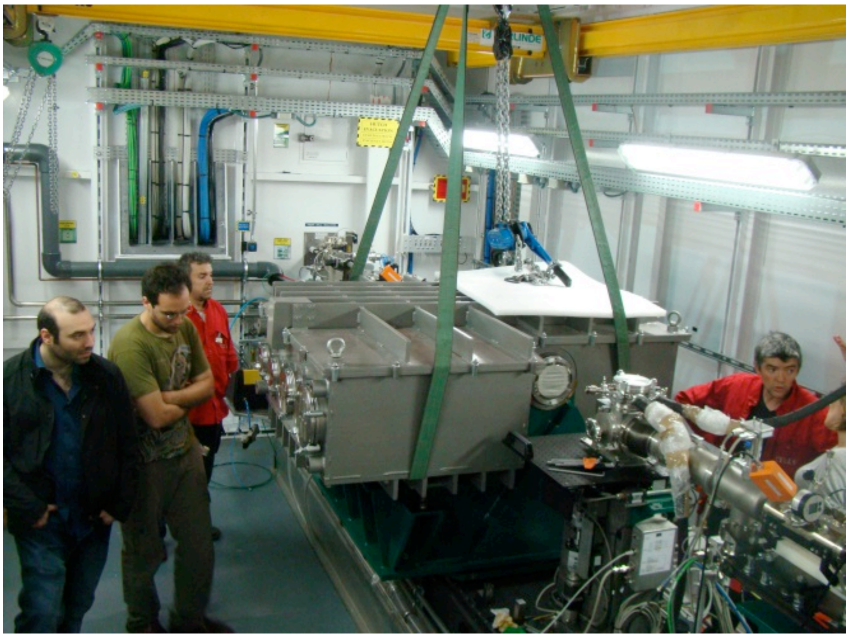

**Figure 1. CLEAR spectrometer installation at CLAESS beamline ready to start its long commissioning with X-ray beam (April-2014)**

### Benefits of a test beamline for in-house developments and innovations

NOTOS would provide a test platform for the projects of instrumental developments carried out by ALBA, as in-house projects or in collaboration with industrial partners.

As a first consequence, enhancing the capabilities for in-house development may have a positive impact on the overall long-term cost of the instrumentation for the beamlines. On one hand, it may reduce the commercial margin of the supplier, as some instrumentation will be developed within collaboration agreements. On the other hand, the maintenance of that instrumentation will not be out of the control of our technical staff, what will clearly reduce maintenance costs.

In addition, NOTOS will provide a platform for improving the technical competences of ALBA staff. This will allow identifying technical problems and validating the solutions without affecting the operation of user-oriented beamlines. In particular, upgrades of some instrumentation of user-oriented beamlines will be more efficiently commissioned offline, without the pressure of users and without consuming user beamtime.

NOTOS will also offer opportunities of collaboration with external organizations, for projects launched by ALBA or others, without affecting the service to users. Selected external scientific communities and companies that would likely benefit from NOTOS are discussed in section 3.

Enhancing the technical capabilities of local companies is part of the mission of ALBA. NOTOS provides the opertunity of building a complete beamline by local companies under the guidance of ALBA. This would allow companies to get a competitive position in the market of scientific instrumentation. This scenario might imply delays due to the lack of experience. For this reason, the unbounded time schedule is required.

NOTOS might also be used in collaboration with other synchrotron light facilities in instrumental projects. Within the European frame, preliminary conversations with ESRF and DESY indicate that testing of new optics under X rays could be a realistic possibility.

# 2 Scientific case

The implantation of any beamline component: optical element, instrument or detector requires thorough characterization before installation in its destination beamline, to ensure its correct performance. Although many tests can be done with laboratory metrology instrumentation, systems often require x-rays or actual beamline conditions, such as delivered power, cryogenic conditions, etc. to be performed.

Test and Metrology Beamlines (available at many synchrotron facilites) are test benches for at-wavelength characterization of the optics instrumentation and detectors in different and specific conditions (flux, power, thermal, mechanical, vacuum...), which allow evaluating the quality and performance of these elements.

**The main goal of the NOTOS beamline is to provide a platform to perform calibrations of beamline instrumentation in aspects that require at-wavelength metrology, or require actual beamline conditions** such as flux, spectral bandwidth, delivered power or source size. In addition, it will allow developing in-situ metrology techniques, to be used as an in-situ diagnostic in user-oriented beamlines.

Examples of at-wavelength metrology techniques include reflectometry, transmission, and diffraction experiments on optical elements, spectral responsivity measurements of detectors, and wavefront metrology.

Examples of metrology that require actual beamline conditions involve, in general complete instruments (monochromators, spectrometers, reflectometers, etc) or parts of them, which one wants to test as close to working conditions as possible, including vacuum, cryogenics, cooling, etc. and for which one needs actual synchrotron light to test performances such as spectral resolution, stability, power handling, or photon sensitivity.

In-situ metrology techniques can also be developed or improved in NOTOS beamline, in order to apply them later in user-oriented beamlines, as diagnostic tools. This is the case of wavefront metrology techniques, since they provide in-situ methods to diagnose aberrations of the wavefront that can appear at the beamline due to misalignments or deformations of the optical elements, and that are critical in beamlines that require sub-micrometric focusing.

## *2.1 General instrumentation testing*

Test beamlines are widely used to evaluate the specifications and performances of newly developed instruments. This is of particular interest for commissioning some BL components that will be permanently located at user-oriented beamlines without interfering with the user program. In our case, the NOTOS beamline would be the natural test bench for the upgrade of some instrumentation of the phase-I beamlines such as the MARES (Magnetic Resonant Scattering) end-station of BOREAS, and the CLEAR (Core Level Emission Analyzer and Reflectometer) of the CLAESS beamline. Although NOTOS will not be built on time for helping in these developments, they are good examples that illustrate the needs it would cover.

NOTOS would have the capability for testing also simpler beamline components such as ion chambers, diagnostic units and other X-ray based detector systems, which require maintenance or calibration, and that can be done offline their respective beamlines.

Being a very flexible beamline, it will provide also support for other research projects, related to beamline instrumentation. The ALBA research activity on carbon contamination cleaning procedures of mirrors and other optical elements, is an example of this.

## 2.2 At-wavelength metrology

At-wavelength metrology refers to the different techniques used to determine the figure of the x-ray wavefront that propagates along the beamline, directly from measurements of the x-ray beam. This allows determining the propagating properties of the x-ray beam integrating the effects of all the optical elements present on the beamline. At wavelength metrology techniques are normally used as diagnostics techniques in user-oriented beamlines, mainly on those where sub-micron spot is required. The availability of metrology beamlines allows the improvement and development of new at-wavelength metrology techniques.

### Adaptive optics

At-wavelenght metrology technology is strongly related to the development of adaptive optics. These are the different technologies used to introduce a controlled deformation of the X-ray wavefront, in order to compensate for aberrations existing in the beam, or to obtain a specific shape of the beam. This allows reaching almost diffraction limited spot sizes in nanofocus beamlines, as well as uniform illumination of samples in diffraction beamlines.

An active optics element is normally a mirror whose surface can be deformed by means of some actuator, which can be controlled remotely. Motorized mirror benders are the simplest examples of adaptive optics. They are capable of correcting just the defocusing and spherical aberration of the beam. More sophisticated examples include multiple ultra-resolution actuators along the mirror surface, as is the case of bimorph mirrors.

At-wavelength metrology is fundamental for the correct operation of any adaptive-optics element, as it provides the necessary feedback for adjusting its actuators. In many occasions the performance of the adaptive optical element is limited by the sensitivity of the feedback system associated to it.

ALBA has already an on-going project in adaptive optics for transport and focusing X-rays, which is of high interest for third generation synchrotrons, X-ray Free Electron Lasers and Diffraction-Limited Light Sources. ALBA is developing a high-accuracy mirror bending system for focusing X-rays, which includes spring actuators that deform the mirror surface with resolution below one nanometer In an initial stage, ALBA applied the concept to correct the residual figure errors due to surface mirror polishing of the mirrors of the BL13-XALOC beamline with an excellent outcome. The proposed technology is much more cost effective than alternative technologies available, at the same time as it provides a very stable solution, compatible with almost any mirror polisher, and any mirror length. The current ALBA prototype can correct errors down to about 40 nanoradians. Figure 2 shows a picture of the spring corrector of the first prototype). The project, which we call **nanobender** is in the process of being transferred to an industry for final development and commercialization (see section 3.1, below).

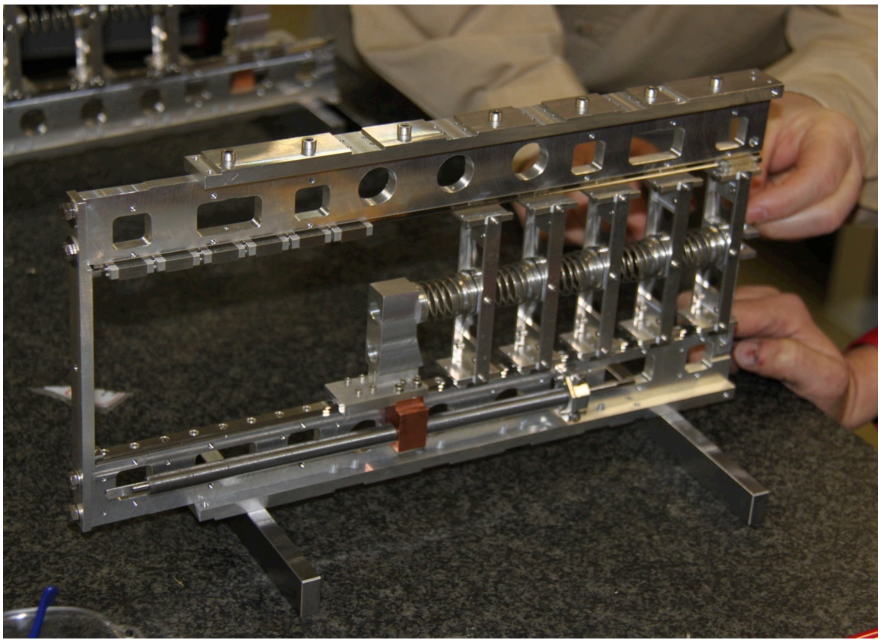

**Figure 2. Spring actuator of the nanobender (first prototype, Spring-2014).**

A summary of the usual at-wavelength techniques is given in the following.

**Pencil beam method**

This method was the first technique introduced in hard X-ray beamlines for determining aberrations of the photon beam. It uses a pair of movable narrow slits to create beamlets and hence sequentially sample the beam wavefront. The pencil-beam scanning technique is used to optimize active focusing mirror systems. Series of pencil-beam scans with sequentially incremented actuator settings are used to calculate the adjustments necessary for focusing [1].

**Hartmann sensors**

Hartmann wavefront sensors (HWS) provide accurate local measurements of intensity and phase distributions of beams by using a mask with a grid of holes, which produce an array of spots from which the wavefront can be reconstructed. In comparison to interferometric techniques, HWS provides high time resolution and works well with incoherent beams. Any kind of optics, focusing or otherwise, can be tested with this technique [2]. HWS can be used to control deformable components and to align the focusing optics in real time [3].

**Speckle tracking**

Another technique is the **speckle tracking.** This technique has not high requirements of coherence and provides two dimensional gradients of a beam wavefront distortion from a single exposure of the sample. This type of experiments is of great interest for nanoscale imaging of both static and dynamic samples [1, 4, 5].

**Phase retrieval algorithms**

This technique consists in measuring the intensity distribution of the photon beam at different positions, and reconstruct, from them the wavefront at whatever position. It can be applied in almost any setup, provided that accurate measurements of the beam profile can be taken at several positions.

### 2.3 Detector testing

NOTOS will also be a platform for characterization and calibration of detectors, mainly 2D detectors for imaging and diffraction. The characterization of detectors in situ with a high spectral and spatial resolution allows obtaining different parameters: Gain, Noise, Dynamic range Sensitivity and angular acceptance [6], Charge distribution between adjacent pixels [7], Radiation hardness, High flux response and saturation, Linearity, Spectral responsivity, and Time response. All these are also important parameters for obtaining a complete characterization.

NOTOS would allow characterizing the response of a detector in terms of gain, noise, dynamic range, linearity, as well as efficiency (QE, DQE), as a function of position (MTF, LSF, spatial distortions), time (frame rate, readout dead time, decay time), and photon energy (energy resolution, energy threshold).

## *2.4 Reflectometry and transmission calibration*

**Reflectometry**

Although x-ray reflectivity can be calculated for usual coatings, there are many parameters that affect the actual reflectivity of mirrors. This is the case of roughness, coating density and thickness, contamination, substrate diffusion, etc. Direct measurements of mirror reflectivity, at the working photon energies can be done by means of a simple reflectometer, which is a fundamental instrument for a test beamline.

Reflectivity measurements become of higher importance when one deals with multilayer mirrors or diffractive elements, such as gratings, or crystals, for which x-ray diffraction properties cannot be determined by the surface parameters one can inspect with laser metrology.

Multilayer optics can be tested at the NOTOS beamline, to obtain information about structural parameters such as d-spacing, interface roughness at subnanometer length scale for high- and low-Z layer media [8,9], or to obtain directly its performances, in terms of spectral resolution or integrated reflectivity.

The instrument required for this consists on an in-vacuum goniometer, that allows scanning the incidence and reflection angle ($\Theta$-$2\Theta$ scans) [10] while recording the incident and reflected intensities, at several photon energies, to complete a two-dimensional map fo the mirror under test.

Also the calibration of the grating diffraction efficiency, which is fundamental for soft X-ray beamlines, can be carried out with a reflectometer. For that reason we are considering including a multilayer pair of mirrors in the DCM with the goal to extend the energy range of the beamline as much as possible to the low energies, although with limited resolution.

**Transmission of filters and windows**

The test beamline could also measure the x-ray transmission of windows and attenuator filters usually inserted in the beam. Although transmission can be computed for many materials, heterogeneities in the material, deformations and aging processes that alter their behavior. In this case, having a spatially resolved probe allows detecting heterogeneities and local problems. Information about light scattering and wavefront deformation is also relevant for beamlines that require small spot, low background or coherence preservation.

**Test of compound refractive lenses, etc.**

Refractive optics as compound refractive lenses, kinoform lenses, multilayer Laue lenses or Fresnel zone plates have to be tested in transmission in order to evaluate their imaging parameters, possible aberrations and scattering effects, besides their transmission efficiency for attaining the targeted flux at the focus [11]. This calibration is fundamental for the beamlines that perform micro- and nano- focusing experiments.

**Diffraction properties of crystals**

Diffraction crystals are fundamental for monochromators, and other instruments. the characterization of the diffraction properties of crystals allow evaluating parameters such as miscut, mosaicity of the crystal surface deformation of atomic planes due to strain or thermal gradients [12, 13].

## 2.5 *Possible user-oriented techniques*

As other test and metrology beamlines, NOTOS could also partly operate open-to-users. This is possible due to the available space and versatility of the proposed setup. Highly demanded synchrotron techniques that could be implemented at NOTOS are powder diffraction, X-ray absorption and imaging [14-18]. However, we highlight that other techniques could be implemented instead.

# 3 Selected external communities involved

In this section we enumerate some communities that could benefit from NOTOS in addition to ALBA. The internal benefits for ALBA and the ongoing projects have been already explained and are not repeated here.

NOTOS, being a platform for instrument testing, would mainly be of interest for companies developing scientific instrumentation, either in precision mechanics, electronics or detector technology. It would also benefit research institutes with strong technological necessities related to X-rays.

Examples of developments with external partners already set by ALBA are given in this section, corresponding to the different technology areas foreseen for NOTOS.

## *3.1 Development of scientific instrumentation*

ALBA staff is engaged in the development of scientific instrumentation and technological capacitation of private companies. We highlight here three initiatives with private organizations (as examples) and with a very clear relationship with NOTOS.

### Double Crystal Monochromator project (DCM)

Alba has already established solid contacts with a Spanish company, that has experience in instrumental projects devoted to synchrotron or neutron facilities, in order to design and build within a collaboration project, a state of the art DCM with cryogenic cooling and two interchangeable pairs of crystals. Alba will supply engineering effort and know-how based on its own experience and the external company will supply additional engineering and manufacturing. The planned DCM should be a prototype with demanding technical performances that might be characterized and optimized or upgraded at NOTOS. Once the product will be considered satisfactory, it would be used as a basic component of the beamline. In addition, the optimized DCM would have allowed the external company acquiring solid technical skills to compete with well established international companies.

### Nanobender

As mentioned above, one of the developments in optics that ALBA is carrying out is a mirror bender, which includes mirror correction actuators, in order to achieve subnanometer figure accuracies. This project has been recently issued as a technology offer (http://www.cells.es/en/industry/technology-transfer) to identify industrial partners that would participate in the development and commercialization of the system. Two Spanish companies have already expressed their interest, and ALBA is currently negotiating a possible agreement to further develop the system. Again in this case NOTOS would provide an excellent platform for testing the system, at the same time that the bender could become part of the hardware of the beamline.

### Hutches

Alba is in contact with a Spanish company that develops partial and total sustainable solutions for building laboratories and medium-size scientific installations. Recently several conversations have been carried out to explore the possibility of establishing collaboration in the design and manufacture of lead hutches for synchrotron and other large facilities. Although just preliminary conversations have taken place, NOTOS could be the test platform for the potential collaboration.

### *3.2 Detector testing and development*

ALBA has already established collaborations with partners in the field of electronics and detector testing, An example of this is the collaboration between ALBA and CNM (Centro Nacional de Microelectronica, CSIC-Spain) has allowed the fabrication and characterization of the 10 µm thin transmissive diode.

The objective of the collaboration was to produce silicon based photodiodes thin enough to allow high transmittance for photon energies above a few keVs, so that they could be used as beam spatially homogeneous diagnostic devices simultaneously with experiment acquisition. Two models have been manufactured both with a thickness of 10 µm and different active areas, 10×10 mm and 5×5 mm, named DDS1-1010/P1 and DDS1-1005/P1, respectively. The technology used in the project was standard in the production of silicon-based devices. 10 µm thick Si-diode devices are extremely fragile devices that should be operated with care. For practical purposes, a specific packing was designed by ALBA for mounting the device. Photographs of the two models are shown in Figures 3 and 4, respectively.

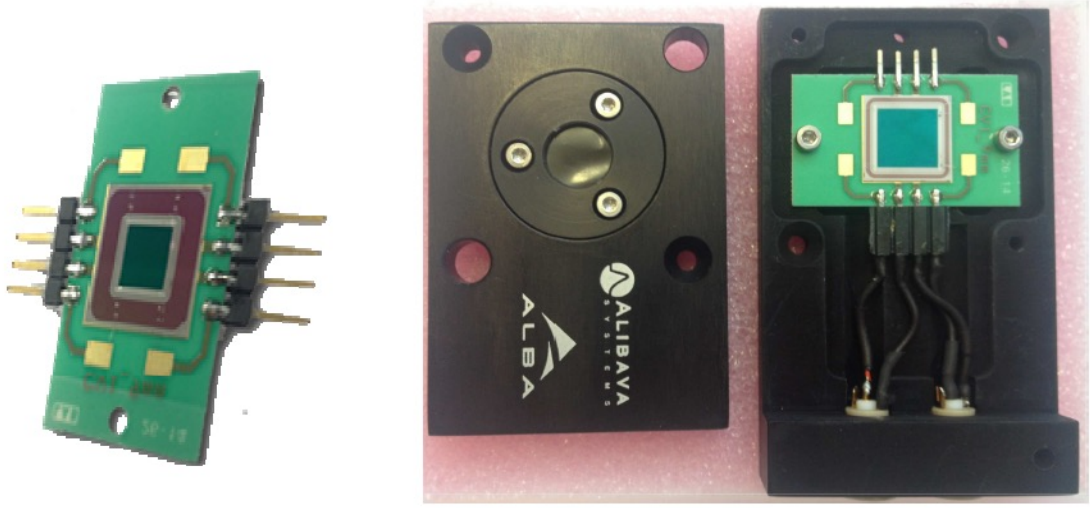

**Figure 3. 10×10 mm$^2$ transmissive photodiode (left), and its packing (right).**

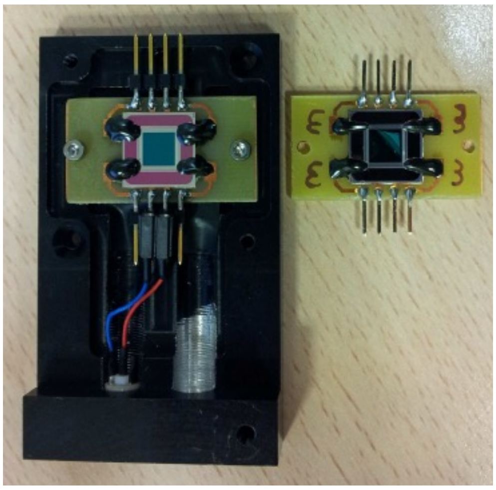

**Figure 4. 5×5 mm$^2$ transmissive photodiode**

The full characterization of the 10 µm thin transmissive diode has been done at the ALBA detector laboratory, at the BL13-XALOC beamline, and also at the BM05 beamline in ESRF. Among the tests required for the complete characterization of the devices, some of them required X-ray beam with different photon energies, and spatial resolution.

The successful outcome of this collaboration has allowed commercializing these detectors through **Alibava Systems, S.L.**; (info@alibavasystems.com; www.alibavasystems.com) which is a spin-off company of CSIC-CNM.

Furthermore, ALBA is extending the collaboration in detector development to IFAE. This public research organization has a research department working in X-ray detectors and a start-up private company. IFAE is member of the Medipix2 collaboration which gives access to the Medipix2 chip. Furthermore, related to the pixel detector activities, IFAE is leading the development of flip-chip and bonding process of pixel detector in collaboration with CNM. The bonding machine FC150, which has the accuracy of 1 μm at 3 σ, allows the bonding of pixel detectors, or multi-chip-modules (MCM), with pixel pitch down to 15 μm.

### 3.3 *Support to research projects on instrumentation*

The ALBA research on carbon contamination cleaning of beamline mirrors is a clear example of how a research project with industrial collaborators, could benefit from NOTOS

Although the graphitic carbon contamination of synchrotron beamline optics has been an obvious problem for several decades, the basic mechanisms underlying the contamination process as well as the cleaning/remediation strategies are not understood and the corresponding cleaning procedures are still under development. The same applies to the fields of next-generation Extreme Ultra-Violet (EUV) lithography and high intensity lasers as used in the ELI project. ALBA is developing a remediation strategy based on in situ low-pressure RF plasma cleaning [19].

This project is being partly funded by IBSS Group Inc. (http://www.ibssgroup.com/ San Francisco, CA, USA) which is developing the pertinent low pressure RF plasma sources. The above study has allowed for a quantitative determination of the optimum process parameters and their influence on the chemistry as well as the morphology of optical test surfaces. It appears that optimum results are obtained for a specific pressure range as well as for specific combinations of plasma feedstock gases, the latter depending on the chemical aspects of the optical surfaces to be cleaned. The reader is referred to the above original publication for further details.

Besides the obvious reflectivity/transmission problems due to carbon contaminations in the soft–ray photon energy range, also advanced (hard) x-ray optics suffer from a reduced performance due carbon contaminations especially in the field of micro-focusing applications as well as in the ever-growing field of coherence-based experiments where an undistorted wave front of the incoming photon beam is of prime importance.

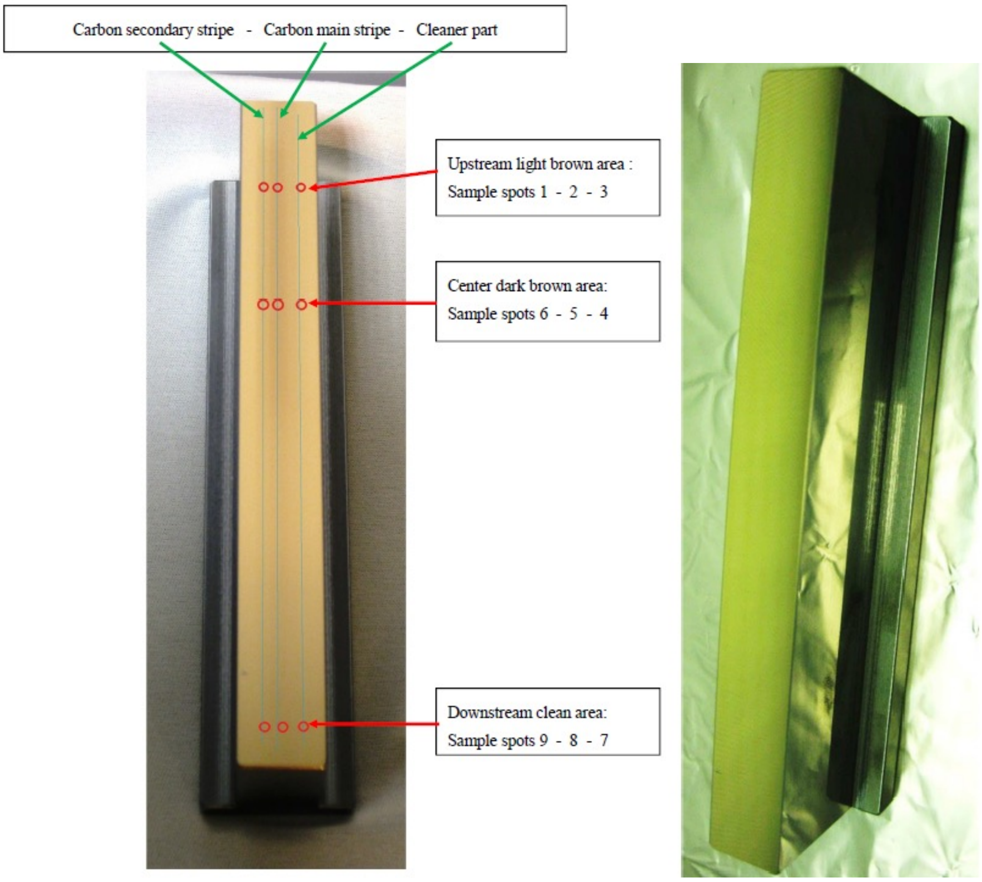

**Figure 5.** ***(left)*** **BL24-CIRCE HEG grating before being cleaned with the $O_2$/Ar low-pressure RF plasma. Two carbon traces corresponding to different photon beam footprints are visible along the long meridional dimension of the grating. (right) HEG after the plasma cleaning process. The carbon traces are not visible anymore and the Au coating did not show any visual degradation. (September-2014).**

Thus, there is no doubt that an x-ray-based characterization of optical elements before/after the low-pressure RF plasma cleaning could be done at NOTOS.

### *3.4 User-oriented techniques*

As mentioned above, even if it is not a primary objective of NOTOS, it could allocate some non-demanding user experiments, if that was found compatible with the schedule of the technical projects, and if the hardware and infrastructure available at the beamline would allow it.

Although the beamline will not be optimized for any particular technique, it will be able to scan the photon energy with good resolution, and will provide a focused x-ray beam about 100 μm. The beamline will be also equipped with sample positioning stages, ionization chambers. Additionally, spare 2D detectors from other ALBA beamlines could be used also at NOTOS.

NOTOS could also host beamline hardware decommissioned from other beamlines. An example of this might be the case of the BM25A branch of the Spanish CRG beamline at the ESRF, SpLine. As a consequence of the ESRF phase-II upgrade (June-2014), all CRGs currently located at bending magnets, will have an improved source (a three-pole wiggler with higher flux) , able to feed only one branch. Consequently, one of the branches of SpLine will not be able to operate after the October-2018 ESRF shutdown.

It appears that while branch B will be maintained, branch A will not. If this were the case it is rational to contemplate the scenario of installing the instruments (or some of them) of branch A at NOTOS. These include a well equipped, state of the art, powder diffractometer and a XAS set up with good performing detectors.

This possibility should  be evaluated in due course since it will allow to increase the user service of Alba and to keep using expensive scientific instruments some of them purchased recently.

Furthermore, CLAESS and MSPD BLs are currently highly oversubscribed, with overbooking factors of 3.2 and 2.3 for CLAESS and MSPD, respectively. This number would likely increase once BM25A will be close.

# 4 Technical proposal

The main requirement for NOTOS is to be versatile to perform as many different techniques as possible. On the other hand, usual figures of merit, such as spectral resolution, high flux or small spot size is not a really strong requirement. In order to achieve the above-mentioned versatility, we consider the following requirements.

- Wide energy range, mostly in the hard X-ray region. The ALBA bending magnet provides continuous spectrum for photon energies between 4 and 25 keV.
- Wide range of focus size and positions, to cope with diverse situations that could require a small spot or, alternatively, illumination of a large area.
- Several working modes, monochromatic, white beam, pink beam, since some techniques require high flux and low resolution at all, and vice-versa.
- Large hutch, that can accommodate different instruments, in some cases quite large.

## 4.1 Optical layout

The proposed layout is schematically shown in Figure 7. The photon beam emitted by a bending magnet is vertically collimated by M1, which is a plane mirror mechanically bent onto plano-parabolic. Downstream M1, there is a monochromator, which combines a pair of Si (111) crystals and a pair of multilayer mirrors, for high flux and low energy operation. Finally, the beam is refocused by a toroidal mirror (M2). Also M2 mirror is mechanically bent, so that its meridional radius is variable.

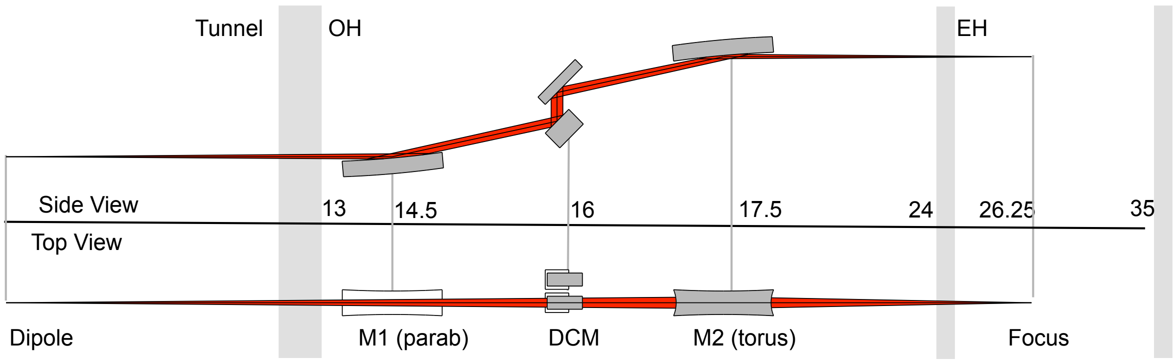

**Figure 6. Schematic layout proposed for NOTOS beamline at ALBA**

All the optical elements in the beamline are vertically deflecting. This allows having a very large horizontal acceptance. Mirrors are 1 m long, and work at an incidence angle of 4 mrad. This allows accepting 1 fwhm of the beam in the vertical direction at 10 keV.

The chosen configuration of mirrors, in which the toroidal mirror is illuminated by a vertically collimated beam, and focuses horizontally in 2:1 demagnification, cancels the astigmatic coma at the focal spot, and reduces the aberrations of the beam.

In addition, since the monochromator is illuminated by a collimated beam too, it reaches the optimal spectral resolution for crystals or multilayers, without loss of flux. Additional benefits of this configuration are the improvement of the vertical acceptance of the beamline for high photon energies, as well as a more relaxed handling of the power to be dissipated at the monochromator, which can be water cooled.

The geometrical distribution of the main optical elements and the corresponding stages proposed for the beamline is given in Figure 8. Both mirrors and the monochromator are placed in the optical hutch, which has, in addition, enough space to allocate those pieces of equipment that required white or pink beam for their tests.

The beamline counts also with a monochromatic beam hutch. The nominal focus of the source, for which aberrations are minimal, is placed close to the upstream end of the hutch, and the optics hutch has up to 8 m downstream that focus, in order to allow allocating a secondary focusing stage if necessary. The focus can also be moved downstream, by changing the bending radius and reducing the the incidence angle on M2.

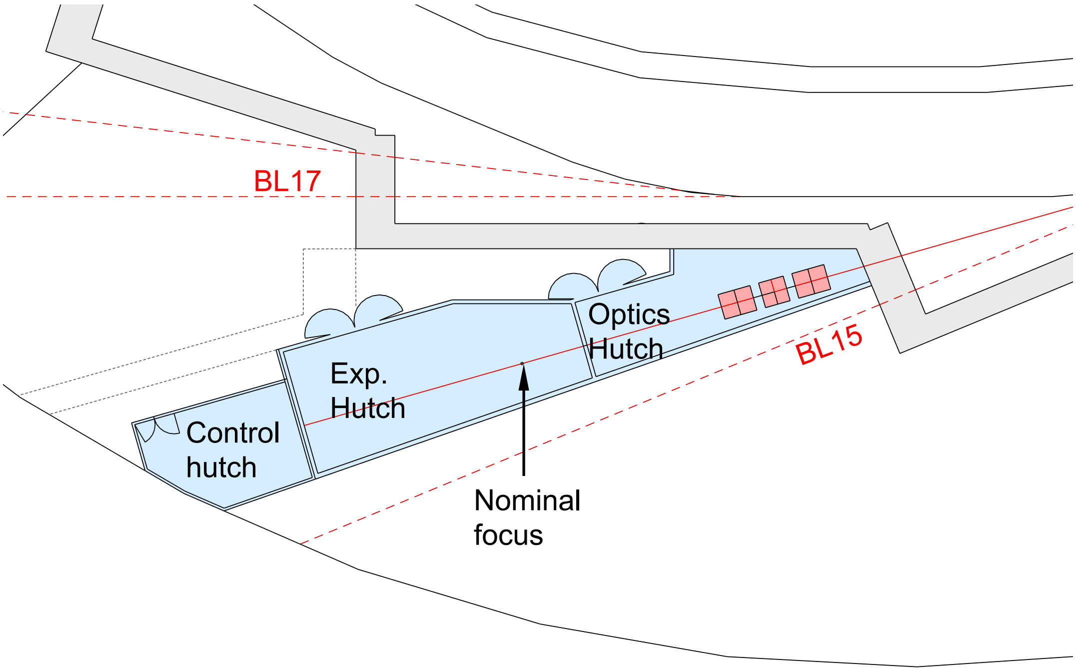

**Figure 7. Distribution of the spaces and main equipment of the NOTOS beamline**

Details about the different elements of the beamline are given in the following.

## 4.2 Source

The source of the NOTOS beamline is a bending magnet. Figure 9 shows the spectral flux distribution, for a horizontal acceptance of 2 mrad. Although other sources such as wavelength shifters or wigglers would provide higher flux at high photon energies, they present parasitic lobes at low energies, which turn onto larger source size. In addition, the horizontal source size at the extraction point of the ALBA bending magnets is particularly small, in comparison to its straight sections, (56.6 µm in front of 132 µm). Thich allows getting a focused spot in the order of 35 µm rms, with the proposed optical layout.

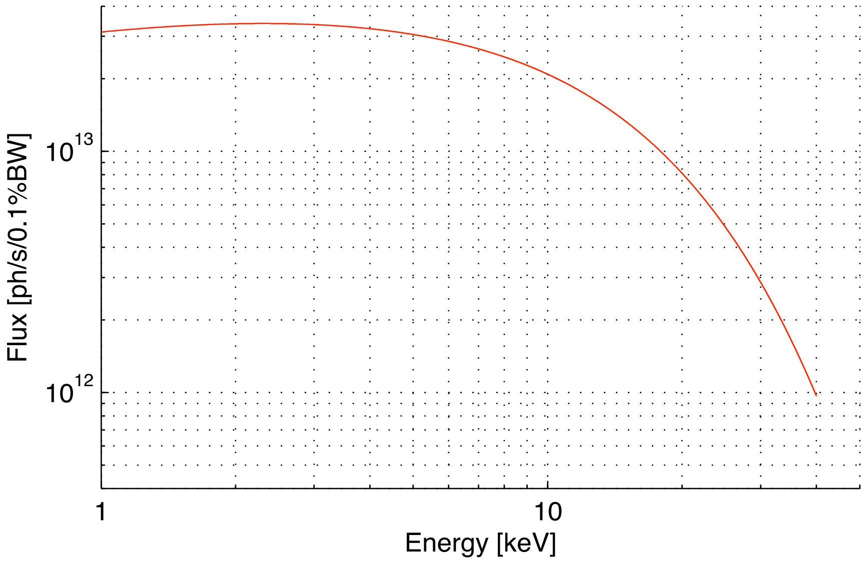

**Figure 8.** ***Flux emitted by the Alba bending magnet within 2 mrad (H) calculated for a current of 250 mA.***

## 4.3 Monochromator

In order to cover the widest possible energy range, we consider a combined monochromator, equipped with a pair of Si (111) crystals, and a pair of multilayer mirrors, which would give access low photon energies.

The Si(111) crystals will cover the energy range above 4 keV, for this, the maximum value of the Bragg angle will be around 30 deg, see Figure 10. The multilayer mirrors will be optimized to allow reaching energies below 4 keV, with a spectral resolution around 1%. The monochromator will include height and side translations. In order to allow working at different incidence angles on the M1 mirror, as well as to be able to withdrawn the crystals completely from the beam path, allowing for white beam operation.

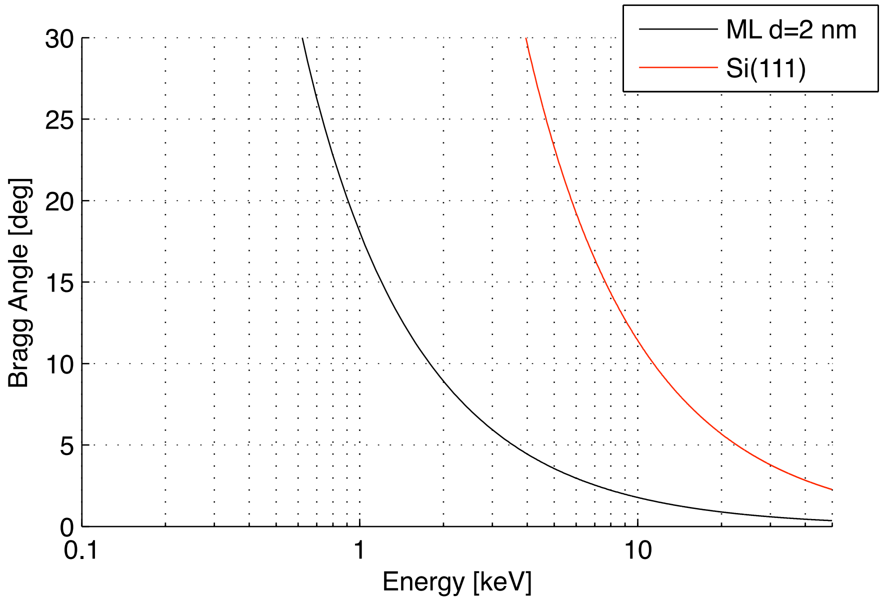

**Figure 9. Bragg angles of the monochromators as a function of the energy.**

## 4.4 Focusing

Some of the techniques to be run at NOTOS will require focused spot, or collimated beam. For this, the beamline will be equipped with focusing optics. Although, the most versatile optics would be a pair of mirrors in Kirkpatrick-Baez configuration, this option is disregarded as it has a very limited horizontal acceptance.

Alternatively, we propose using a vertically deflecting toroidal mirror, mounted on a mechanical mirror bender. The mirror bender will allow decoupling the vertical focus from the horizontal focus, providing for higher flexibility.

The sagittal radius of curvature of the mirror is chosen to focus the source 8.75 m downstream the mirror position. With this distance, the toroidal mirror demagnifies the source by a factor two, horizontally. This, in combination with the vertical collimation of the incoming beam, turns onto a reduced aberration configuration.

All the optical elements in the optics hutch have been concentrated at the shortest possible distance from the source, to allow having the 1:2 demagnification spot at the upstream end of the experimental hutch with the aim of being able to use it as a secondary source, for testing other focusing elements. In addition, the focus can be moved downstream by reducing the incidence angle on M2, and changing its bending radius. The correspondence between incidence angles and image distances for the chosen mirrors given in Figure 11. Note that one can move the sagittal focus 5 m downstream by reducing the incidence angle to 3 mrad. This angle is still large enough to provide good acceptance, and would preserve good reflectivity also for high photon energies.

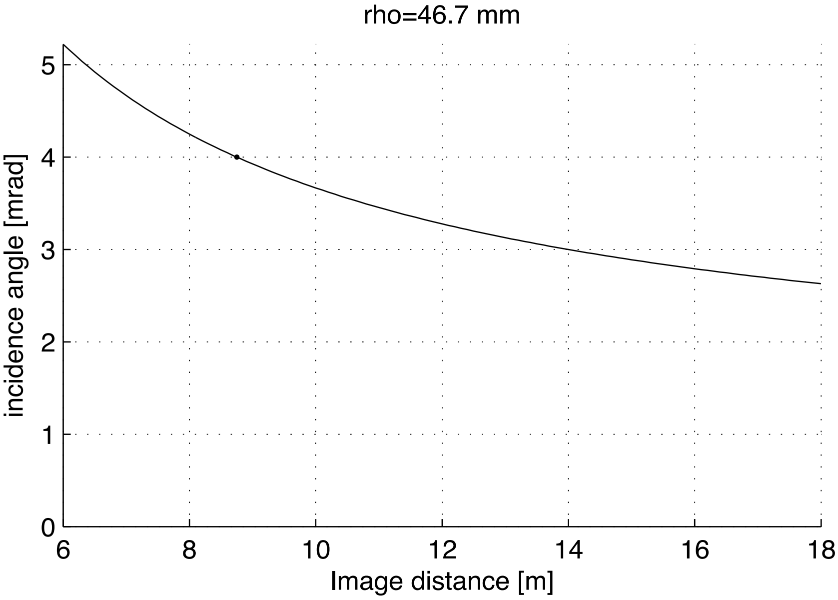

**Figure 10. Incidence angle to be set in M2 as a function of the desired image distance.**

Figures of the spot at the nominal position, and several alternative positions are given in Figure 12. Note that besides the tails characteristic from astigmatic coma, the spot is basically round for all the positions, and present spot sizes below 200 µm, in all the cases.

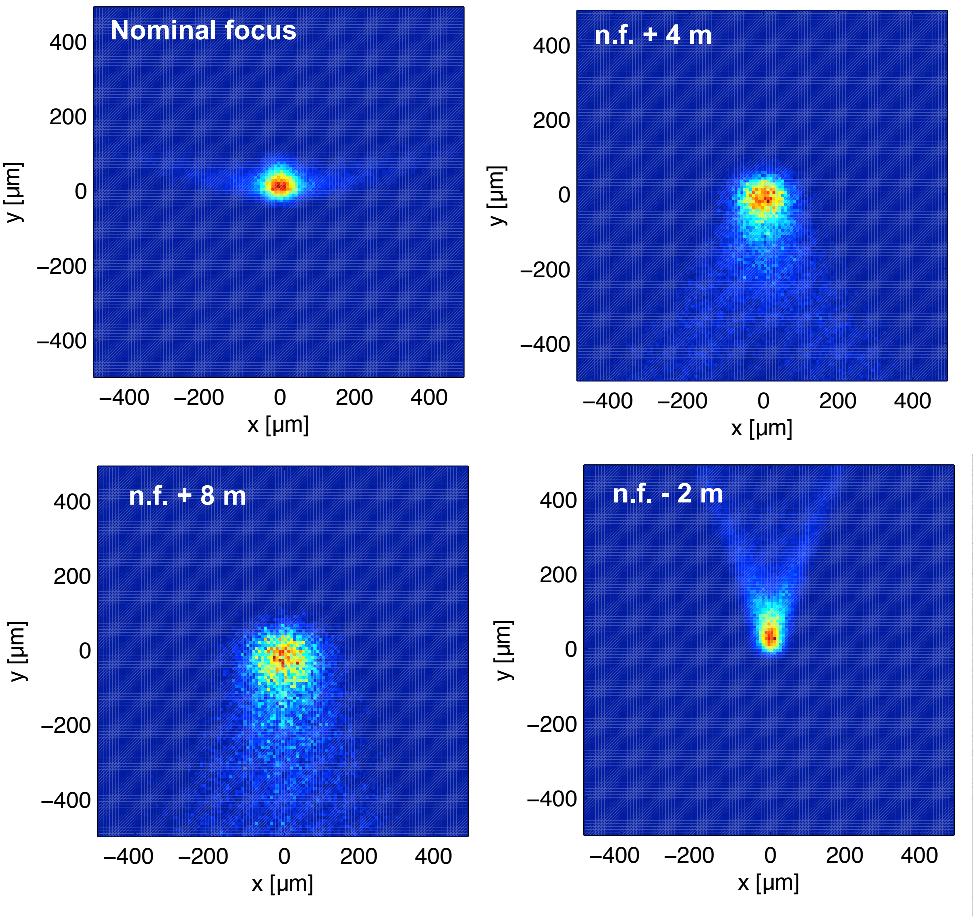

**Figure 11. Focused spot size at different positions along the experimental hutch.**

## 4.5 *Instruments*

### Reflectometer

The vertical reflectometer consists of an entrance slit to shape the incident beam, a goniometer to measure in Θ-2Θ and an auxiliary exit slit previous to the detector.

### Detectors

CCD X-ray detector (as Quantum 210r CCD detector by ADSC), high resolution X-ray microscope, Si-PIN diodes, APD X-ray detectors, and ionization chambers.

### Positioning tables

The positioning optical bench will be located between M2 and the end of optical hutch (see Figures 7 and 8), and with a movement capability of 5m in the beam direction. This bench can vary its position both linear (horizontal and vertical) and angular (pitch, roll and yaw). As well, it is possible can be removed when it is not necessary.

The high precision table (experimental bench) of experimental hutch consists of three parts. The bottom part is a platform that allow displacing whole table along the hutch (almost 8 meters from the nominal focus, see Figure 8) to perform any experiment. In the upper part of the table, there is an optical table with the capability in order to move horizontally and vertically and also to perform the three angular movements by means of high accuracy goniometers.

The detectors will be placed on a vertical positioning table that allows tracking the measurement beams in any direction. This table will have capacity both the three linear movements (X, Y, Z) and the three rotations.

## 4.6 Hutches

Since the beamline must allow white beam operation, we considered the option to have only one optical hutch, as the distribution of spaces would be simpler, and would save some costs in doors, chicanes and other PSS elements. Nevertheless, this option would involve using a thicker lead shielding, which compensates for the cost differences. In addition, the single hutch option would force closing the front-end for any intervention on the equipment under test, yielding to potential instability of the beamline optics, and thus reducing the liability of the beamline.

Alternatively, we propose a two-hutch beamline, with optical hutch, and experimental hutch. The optical hutch will have a shielding thick enough to handle white beam. It will contain all the optical elements of the beamline, and will reserve about 5 additional meters for installing equipment to be tested.

The experimental hutch will be able to handle monochromatic beam only. Consequently, the photon shutter between the two hutches will be interlocked to the position of the monochromator, in order to prevent from opening it if the monochromator is withdrawn from the beam. This, hutch will host most of the tests. The hutch is about 11m long, and is large enough to allocate many diverse instruments.

**Infrastructure**

In addition to the services for water, electricity and $LN_2$ required for the beamline optical elements, both hutches will require spare supply points for the instruments being tested.

Both hutches will have cranes for handling of medium size instruments. Additionally, the roof panels will be removable to allow accessing the hutches by the orbital cranes.

The floor reserved for the instruments to be tested will be conditioned to allow for fast positioning and anchoring of elements to be tested. This involves having an even surface and some inserts, rather than installing permanent rails.

Thermal stability is a requirement for any metrology laboratory, the hutch should have active air conditioning to preserve environmental stability for a wide range of working conditions, for instance, presence or not or electronics inside the hutch.

# 5 Budget and timing

## 5.1 Budget

| **Elements** | **Price (k€)** |
|---|---|
| Source | |
| Bending magnet | 0 |
| Frontend | 200 |
| Beamline & Optics | |
| General pipe and vacuum components (incd. controllers) | 150 |
| Collimating mirror (including the positioning system) | 110 |
| Double crystal monochromator[#] | 30 |
| New prototype DCM (crystals and multilayers) | 100 |
| Focusing mirror (including the positioning system) | 110 |
| Four slits | 100 |
| Spare high precision table for tests | 70 |
| Endstation | |
| Detector(s) and electronic (including synchronization issues) | 150 |
| Spare high precision table for tests | 70 |
| Goniometer | 100 |
| General pipe and vacuum components (incd. controllers) | 100 |
| Hutches (optical and experimental)[$] | 350 |
| Control room/hutch | |
| Enclosure | 40 |
| Control electronics | 100 |
| Data acquisition computing and electronics | 50 |
| SUBTOTAL | 1,830 |
| *Contingency (10%)* | *183* |
| **TOTAL** | **2,013** |

[#] ALBA has an old DCM from BM16 (ESRF). Refurbishing cost.

[$] We have evaluated two options: i) a single hutch containing the optics and endstation(s); and ii) two independent hutches for optics and endstation(s). The single (very large) hutch would need to have thick lead all around which would increase the price due to the intensive use of lead. On the other hand, option-ii would reduce the lead usage but it would need and extra PSS (personnel safety system) and an extra door, cable chicane and photon shutter. Our calculations indicate that the final cost of the two options would not differ more than 10% being economically less expensive the two hutches option. Furthermore, we have chosen option-ii (double hutch) for safety reason as we will likely open part-time this BL for academic users and it is much better/safe to have a restriction to enter to the optics hutch.

## 5.2 *Construction strategy and timing*

As metioned above NOTOS will not be bound by user service and will be very flexible. These characteristics are appropriate to build all the precision mechanical parts (mirror mechanics, monochromator etc.) on the basis of collaborations Alba/external companies. This would serve to fulfill one of the primary objectives of the beamline.

Once a (positive) funding decision is taken, we estimate three years for the construction period. We anticipate that full design and building of the optics and experimental hutches will be key to meet the three years design, construction and commissioning goal. Furthermore, the frontend workpackage should be also carefully considered from the earliest stage of the project. Of course, a project would be implemented for the construction and commission of NOTOS divided in workpackages as it is taking place for the construction of the two ALBA phase-II beamlines. In order to minimize risks, efforts should be devoted to identify any other task close to the critical path.

The flexibility of the beamline will allow starting partial operation when the hutches (meeting all safety requirements) and some critical components are installed and commissioned. We highlight the existence of several equipments than could be used from day one. For instance, i) the Quantum 210r CCD detector from ADSC currently used at BL11-NCD but that is being replaced by the pixel detector imXPAD-S70 (for most of the experiments); or ii) the double crystal monochromator formerly used at the Spanish CRG-BM16 (ESRF) and that it is at the ALBA warehouse since the decommissioning of the CRG beamline.

NOTOS would belong to the Optics, Metrology and Support section and the composition of the staff should be different than that of user service beamlines. Four positions would be necessary: one beamline responsible defining the objectives and priorities and two engineers plus one instrumentation scientist might be appropriate.

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