

# BL31-FaXToR, HARD X-RAY MICRO-TOMOGRAPHY AND RADIOGRAPHY AT ALBA: CURRENT STATUS AND ONGOING IMPROVEMENTS

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## Abstract

BL31-FaXToR is the hard-X-ray micro-tomography and radiography beamline at the third-generation ALBA synchrotron. It enables 3D imaging with sub-second temporal resolution under either monochromatic or white-beam conditions. The control system is based on Tango, Sardana and Taurus, providing an efficient, distributed Python environment with full user access to hardware via both graphical and command-line interfaces. This paper outlines the BL31-FaXToR control system architecture, presents implementation examples, and discusses upcoming planned features.

## BL31-FAXTOR

BL31-FaXToR is fed by an in-vacuum multipole wiggler installed at port 31 of the ALBA storage ring. The main optical element is a Double Multilayer Crystal Monochromator (DMM), chosen to provide tunable energy and quantitative 3D analysis of tomographic datasets [1, 2, 3]. Other main components in the optics hutch are: set of filters in the multfilter unit acting as beam attenuators, two blade vertical slits, diagnostic elements and bremsstrahlung attenuators. The experimental hutch includes a beam conditioning table with four blade sample slits, a second CVD diamond window, and an in-house-developed fast shutter that ensures precise timing during dynamic acquisitions and prevent radiation damage to sensitive samples. To minimize air absorption at lower X-ray energies, movable pipes guide the beam safely from the conditioning table to the tomography stage, located 36.5 m from the source.

## Endstation

The endstation hosts two microscopes equipped with four cameras, which can be positioned either close to the sample for absorption measurements or at longer distances to exploit phase propagation in soft materials. Configurations can be switched easily depending on user requirements, offering a flexible design that supports multiscale imaging (Fig. 1).

This setup enables simultaneous access to different spatial and temporal resolutions, facilitating experiments that demand both high throughput and dynamical studies with temporal resolution better than one second. The high-speed detector has been designed to provide live reconstructions during scans with minimal latency [4], offering immediate feedback to users and paving the way for time-resolved in-situ experiments.

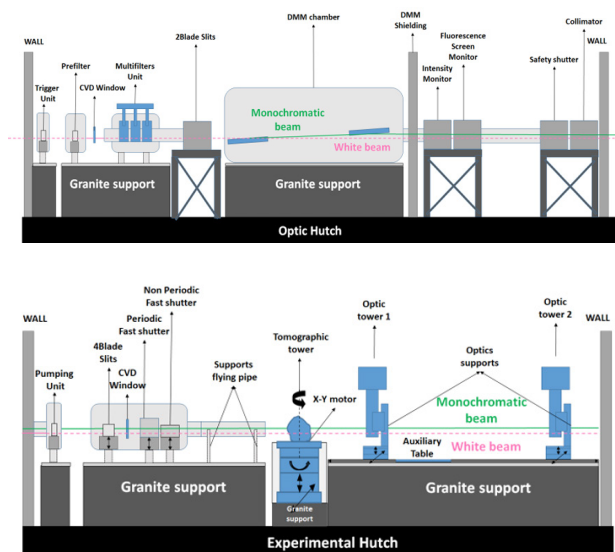


Figure 1: BL31-FaXToR layout of the optical path on the optic (top) and experimental (bottom) hutches. X-ray beam enters from the left side. Both MB (green) and WB (pink) are allowed [3].

## CONTROLS SYSTEM ARCHITECTURE

The BL31-FaXToR control system follows the common architecture adopted for all ALBA beamlines, designed to maximize similarity and reuse. Whenever possible, the same hardware and controller types are employed across subsystems such as vacuum, motion, and diagnostics, which in turn allows for shared software interfaces. As part of the Tango community [5], we benefit from existing device server developments while contributing new ones when required.

Sardana serves as the common SCADA layer across ALBA [6, 7], making control systems comparable and simplifying the implementation of complex scans. Although specific hardware controllers may differ between beamlines, their software access remains standardized. The Taurus [8] framework further supports this approach by providing consistent graphical user interfaces, enabling development to be shared across projects. For exclusive hardware, such as the FaXToR goniometer, dedicated Tango device servers have been designed and integrated so that higher-level control layers can access them through standard Taurus widgets or Sardana macros (Fig. 2).

High-speed data acquisition is a key requirement at FaXToR. The detector subsystem uses multiple frame grabbers in combination with an IBM Storage Scale clustered file

system, ensuring the throughput needed for dynamic tomography. Detectors are managed either through a REST-based service or via the LImA [9,10] device server.

Finally, synchronization elements—including a voice-coil actuated fast shutter with 10 ms openings and a periodic chopper—introduced new challenges for the control system. Addressing these required extending Sardana with multiple synchronization modes in both the time and position domains [11], laying the foundation for precise coordination of dynamic experiments.

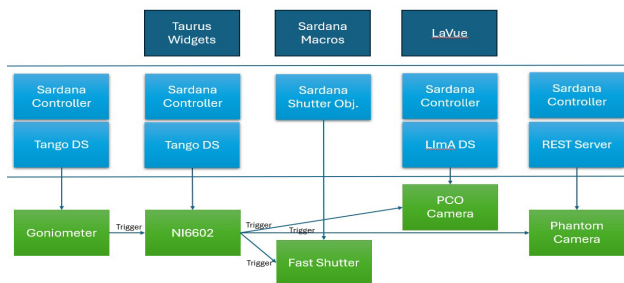


Figure 2: Control System Architecture with hardware objects at bottom.

## EXPERIMENT SYNCHRONIZATION

Our tomography experiment is based on three main components that must be precisely synchronized: the goniometer, the shutter, and the 2D detector (Fig. 3). Synchronization is achieved through a hardware trigger chain that starts at the goniometer controller and ends at the detector. This process involves two steps: first the goniometer controller, in this case an ACS ECMsm, is configured to send a trigger once a constant velocity is reached. Then this signal reaches a National Instruments PCI-6602 card, which runs two independent sequences to trigger both the shutter and the 2D detector, using user-defined pulse patterns. Optionally, the goniometer trigger can also be configured to be sent when the rotary stage is not only at constant velocity but also at a specific angular position.

To manage this synchronization in a transparent way for the user and to make it generalizable we have used two new features of Sardana: 1) *Shutter object*: This feature introduces a special element in the acquisition process that defines the parameters associated with the shutter. These parameters are essential for computing the shape of the hardware trigger that controls the shutter's opening and closing. These parameters include the *time to open*, *time to close* or the *window mode*, all of them needed to avoid sample damage due to the X-ray beam. 2) *Multiple Synchronization Descriptions*: this feature allows each device involved in the acquisition (such as shutters or detectors) to follow its own independent timing pattern, which can also be linked to a motor position domain. It also enables full exploitation of the maximum acquisition frequency supported by each channel.

We have also implemented two key optimizations that improve user experience, particularly when dealing with large samples that require multiple tomographies across a mesh grid. 1) *Scan state*: This mechanism keeps track of the current scan point. It allows users to pause or restart

tomographies from any point without losing progress, which is especially useful for long or interrupted experiments. 2) *Asynchronous motor movements*: In tomography, *darkfield* images (acquired without beam) and *flatfield* images (acquired with beam but with the sample removed from the trajectory) are typically collected to reduce noise in reconstructions. The *flatfield* step requires moving a motor to remove the sample from the beam. By performing this movement asynchronously, while the *darkfield* images are being acquired, we significantly reduce the total experiment time. This is particularly beneficial for large samples with hundreds of scan points. Additionally, we have evaluated but not yet implemented another optimization: dynamically calculating the nearest motor position that ensures the sample is out of the beam for each scan point during flatfield acquisition. This approach could further reduce movement times and increase efficiency.

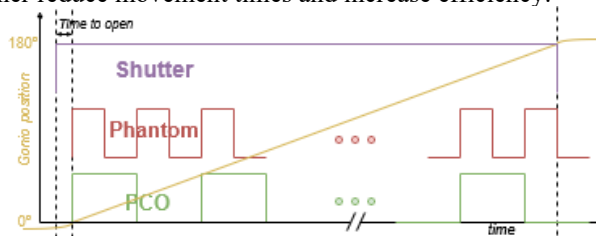


Figure 3: Synchronization between elements. Constant velocity of goniometer triggers the shutter opening. After waiting for the shutter to be fully open, the detectors are triggered following a time based pulse of triggers. *Time scale of plot is not proportional*.

## PHANTOM S710 CAMERA

The BL31-FaXToR fast camera subsystem is built around a Phantom high-speed sensor connected to Euresys frame grabbers, enabling sustained high-rate acquisitions required for dynamic tomography and live reconstructions. Integration was designed in three layers: (i) deterministic GenICam configuration to ensure reproducible behavior, (ii) a zero-copy DMA data path with preallocated host and GPU buffers to eliminate runtime overhead, and (iii) a parallel capture pipeline that streams data blocks to storage without introducing control-loop dead time. Configuration and live viewing are provided through a REST-based service and a lightweight web interface, which facilitates rapid testing and easy user access.

Deterministic camera operation is achieved by applying all GenICam register settings (pixel format, dimensions, trigger mode, exposure, frame rate) during idle states, preventing mid-scan reconfiguration. Stream-module parameters that affect throughput, such as buffer-part count and unpacking mode, are programmed per grabber, making acquisition recipes portable across scan modes while ensuring consistent multi-grabber performance.

Sustained frame rates are supported by subdividing FIFO buffers into parts, which allows the software to process and flush portions of data while acquisition continues (Fig. 4). This prevents producer stalls and ensures efficient use of limited onboard buffers. A parallel persistence model then spawns multiple writers, each handling a block

of images concurrently. This strategy amortizes storage latency and preserves a deterministic file layout suitable for downstream reconstruction. To provide user feedback, a representative image from each buffer is copied for live view, enabling monitoring at reduced frame rates without impacting acquisition speed.

The system employs an on-demand callback model, giving precise control over when to poll the FIFO and schedule writers. This approach keeps the software cadence aligned with the beamline's timing sequence. Explicit pixel unpacking guarantees consistent interpretation across boards, a prerequisite for deterministic multi-writer operation and any optional GPU-resident processing.

Finally, deterministic abort and teardown procedures ensure robust operation: acquisition can be safely interrupted at any time, with all writers joined, resources released, and buffers reset to a clean baseline before the next scan begins. Data blocks are flushed to the IBM Storage Scale cluster, which provides the parallel throughput required for long high-speed acquisitions and makes datasets immediately available for reconstruction pipelines.

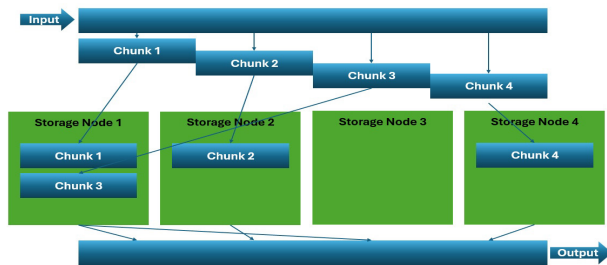


Figure 4: IBM Spectrum Scale parallel write.

## GRAPHICAL USER INTERFACE

A dedicated graphical user interface (GUI) was developed using Taurus and LaVue [12] to streamline tomography experiments at FaXToR. The GUI targets both staff scientists and visiting users, reducing setup time, simplifying routine alignment, and surfacing safety-critical device states.

The control stack follows ALBA's standard design principle: all scan logic resides in Sardana macros, while the GUI only parametrizes and invokes these macros, reporting progress, logs, and errors. This separation ensures that hardware procedures remain testable and reusable, and prevents duplication of control logic.

The GUI is composed of modular widgets that cover essential tasks: acquisition/file organization, macro execution with safe interrupt handling, microscope and optics configuration, manual shutter and brake controls, goniometer alignment, and grouped motor consoles (Fig. 5). This design provides a consistent user experience across beamline operations while allowing flexible configuration for specific experiments.

### Live Imaging

The live imaging widget is built on the LaVue framework (pyqtgraph backend). A thin decoder layer maps LImA/TANGO image attributes to the format expected by

LaVue, enabling seamless integration of LImA-based cameras. For the Phantom S710, a REST server backend provides live images under a dedicated configuration fully compatible with the viewer. During scans, the widget automatically pauses Phantom live triggering and resumes once the scan is complete. This allows refresh rates of  $\sim 5$ – $10$  Hz for LImA cameras and  $\sim 2$ – $5$  Hz for the Phantom, offering immediate visual feedback without interfering with the main acquisition pipeline.

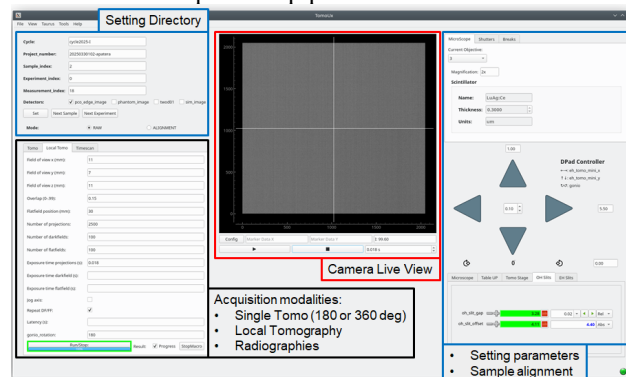


Figure 5: Graphical User Interface, showing different acquisition modalities as implemented at BL31.

## NEXT STEPS

Future work at BL31-FaXToR will concentrate on extending detector compatibility, improving synchronization capabilities, and enabling new imaging modalities.

A key priority is the seamless integration of additional detectors, in particular the PCO Dimax and C-blue One cameras. Both will be incorporated into the Tango/Sardana/Taurus control framework to ensure uniform user access and consistent synchronization with the goniometer and shutter. This will broaden the range of experimental conditions that can be covered and provide flexibility in spatial and temporal resolution.

On the instrumentation side, an in-house chopper is currently being designed. Its control and synchronization with the existing acquisition chain will allow modulation of the beam with higher precision, opening possibilities for advanced time-resolved and pump-probe style experiments.

Finally, BL31-FaXToR plans to integrate a grating interferometer at the endstation. Such interferometers, already demonstrated at other synchrotron facilities, provide simultaneous access to absorption, phase-contrast, and dark-field images. This will significantly expand the beamline's capabilities toward the study of low-absorption or highly scattering samples, enabling multi-modal and more quantitative tomography.

## CONCLUSION

The BL31-FaXToR beamline has represented a significant challenge for the ALBA control system. Unlike BL09-Mistral, which brought its own dedicated tomography control software, FaXToR has been fully integrated into the ALBA standard frameworks (Tango, Sardana, and Taurus). This required the design and implementation of new

features specific to high-throughput tomography, most notably a hardware-based synchronization chain between the goniometer, shutter, and 2D detector. These developments extend Sardana with multi-synchronization capabilities and native shutter support, providing a generalizable solution for experiments requiring precise time- and position-domain coordination.

Another key achievement has been the integration of the Phantom high-speed camera subsystem, which demanded advanced buffer management and parallel persistence strategies to sustain line-rate acquisition without data loss. The visualization layer has also been enhanced by adapting features from LaVue, enabling live reconstructions, ROI selection, and dynamic monitoring during scans. Together, these developments have ensured that users can perform complex, time-resolved tomography experiments reliably, with minimal latency and reduced setup overhead, resulting in a smooth operational experience.

From the perspective of the control system, FaXToR demonstrates the flexibility and scalability of the ALBA frameworks when facing beamline specific requirements. The lessons learned here—particularly in hardware synchronization, high-speed acquisition, and user-facing visualization—will be valuable not only for FaXToR but also for future beamlines with similar demands. Planned improvements will focus on tighter integration of online reconstruction pipelines, automated experiment templates, and continued optimization for high-performance image acquisition.

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## REFERENCES

- [1] A. Mittone, L. Ribó, A. Patera, J. Campmany, C. Colldelram, and J. Nicolás, “A new beamline for hard X-ray tomographic microscopy at the Spanish Synchrotron ALBA,” *J. Phys. Conf. Ser.*, vol. 2380, no. 1, p. 012035, Dec. 2022.  
[doi:10.1088/1742-6596/2380/1/012035](https://doi.org/10.1088/1742-6596/2380/1/012035)
- [2] A. Patera *et al.*, “FAXTOR: the 14th beamline at ALBA for BIG DATA”, presented at LEAPS-Innov Workflow Co-Working Sprint Kickoff, online, unpublished.
- [3] A. Patera *et al.*, “Trends in multiscale hard X-ray tomography: the new FaXToR beamline at ALBA,” *J. Phys. Conf. Ser.*, vol. 3010, no. 1, p. 012161, May 2025.  
[doi:10.1088/1742-6596/3010/1/012161](https://doi.org/10.1088/1742-6596/3010/1/012161)
- [4] G. Jover Mañas *et al.*, “High-throughput x-ray microtomography at FaXToR: a survey towards high performance image reconstruction,” in *Developments in X-Ray Tomography XV*, B. Müller and G. Wang, Eds., Oct. 2024, p. 37.  
[doi:10.1117/12.3027951](https://doi.org/10.1117/12.3027951)
- [5] Tango Controls, <https://www.tango-controls.org>
- [6] Sardana, <https://www.sardana-controls.org>
- [7] Z. Reszela *et al.*, “Generic Data Acquisition Interfaces and Processes in Sardana”, in *Proc. ICALEPCS'19*, New York, NY, USA, Oct. 2019, pp. 507.  
[doi:10.18429/JACoW-ICALEPCS2019-MOPHA121](https://doi.org/10.18429/JACoW-ICALEPCS2019-MOPHA121)
- [8] Taurus, <https://taurus-scada.org>
- [9] A. Homs, L. Claustre, A. Kirov, E. Papillon, and S. Petitdemange, “LIMA: A Generic Library for High Throughput Image Acquisition”, in *Proc. ICALEPCS'11*, Grenoble, France, Oct. 2011, paper WEMAU011, pp. 676-679.
- [10] LImA, <https://lima1.readthedocs.io/en/latest/>.
- [11] O. Vallcorba *et al.*, “Modular scientific SCADA suite with Sardana and Taurus – latest developments”, presented at ICALEPCS'25, Chicago, IL, USA, Sep. 2025, paper WEMG017, this conference.
- [12] LaVue, <https://lavue-org.github.io/lavue/stable/index.html>