SOLEIL Status and Challenges on Automation and Robotics

L. Munoz on behalf of SOLEIL Control Team

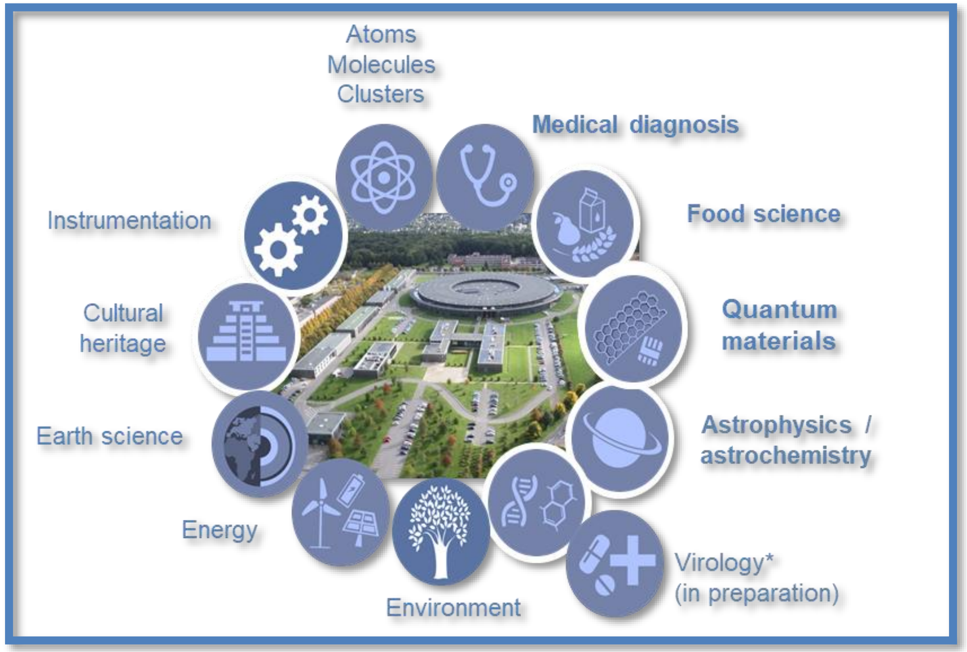
Outline

- SOLEIL
  - SOLEIL in a Nutshell
  - SOLEIL II**:** Synchrotron SOLEIL Upgrade
- Challenges: Towards Autonomous Systems
  - Automated and Autonomous Systems
  - SOLEIL Standardization
- Robotics and Mechatronics Systems
  - Synchrotron Specific Mechatronics Instruments
  - 6-Axis Robotic Arms Applications
- Perspectives & Interests

SOLEIL in a Nutshell

SOLEIL SYNCHROTRON UPGRADE

- Storage ring 354m, 2.75GeV
- 29 beamlines
- 9 orders of magnitude in energy from far IR to hard X-rays
- Open to external users in 2008
- ~ 450 staff members
- in 2022 :~ 2746 single users



- **SOLEIL II**

Advanced Materials
→ Quantum Materials
→ Materials Engineering

Qubits, Quantum Computer

Unique combination of spectroscopic and structural techniques over an unsurpassed energy range – nm, <mV, <200 mK, >10ps

Sustainable Energy
→ Production
→ Conversion and storage
→ Environmental impact

Batteries, Biomass conversion

Spatial resolution (few nm), chemical state and physical properties evolution, in situ, operando

Health and Well-being
→(Re)Emerging pathogens in their environment
→ Personalized Medicine, fight against cancer

Multi-resistant bacteria, Aging

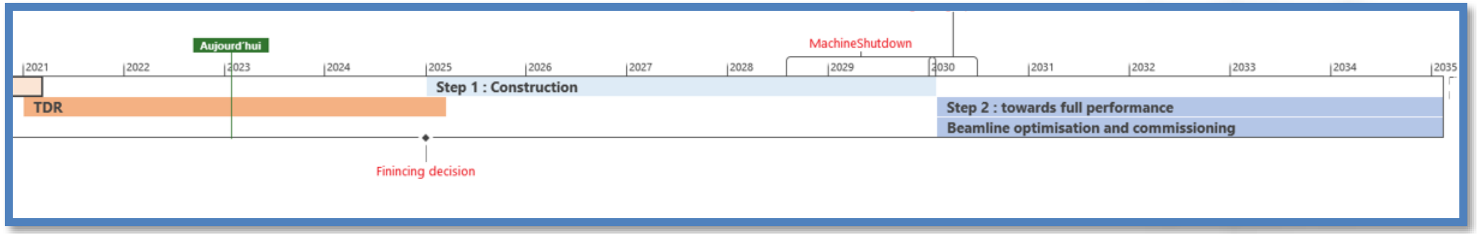
Innovative procedures for **multimodal** investigations, living cells, tissues
New access modes for clinical diagnosis

Earth and Environment
→ Atmosphere
→ Earth surface, oceans
→ Lithosphere and solar system

Global warming, Carbon cycle, pollutant transfers

Multi-scale analysis of chemical speciation in complex systems, chemical sensitivity at high spatial resolution

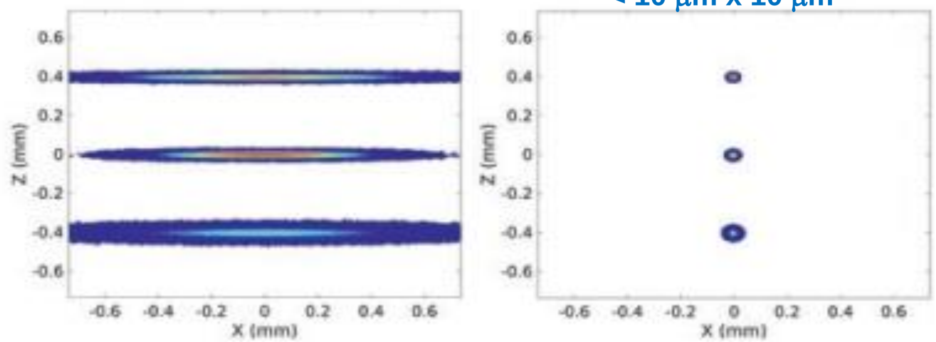
- **Science Drivers**
  - Major upgrade of the accelerators and beamlines addresses new scientific and societal challenges.
  - The upgrade will bring the unique range of SOLEIL techniques to unprecedented spatial and temporal resolutions.
- **Timeline**



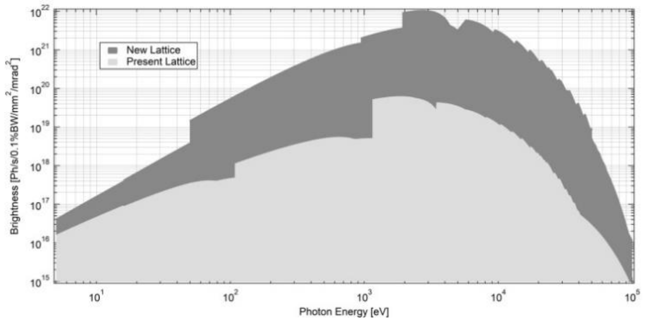
- Better performances for accelerator and photon sources:
  - Reaching an emittance **< 100 pm.rad**
  - Keeping the same electron beam energy : **2.75 GeV**
  - Preserving a maximum current of **500 mA** in the multibench mode.

Beam SIZES

< 10 µm x 10 µm



Brightness



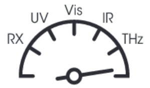
- New access mode with **more efficient use** of the SOLEIL Beamlines

EXPERIMENTS UP TO **10,000 TIMES FASTER**

NANOSCALE RESOLUTION

EXPERIMENTS UP TO **1000 TIMES MORE SENSITIVE**

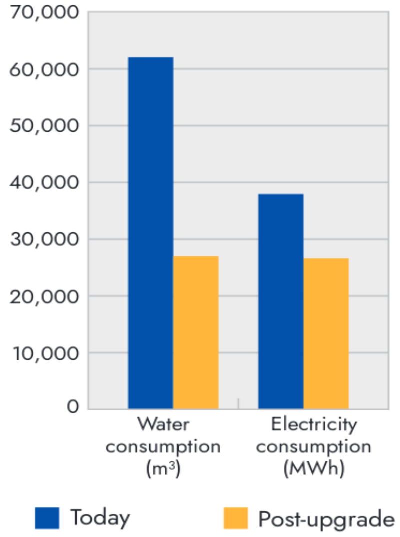
STUDY OF DEVICES **IN REAL OPERATING CONDITIONS**



UNIQUE LIGHT SOURCE, **FROM INFRARED TO HARD X-RAYS**

COMPLEMENTARY BEAMLINES AND TECHNIQUES

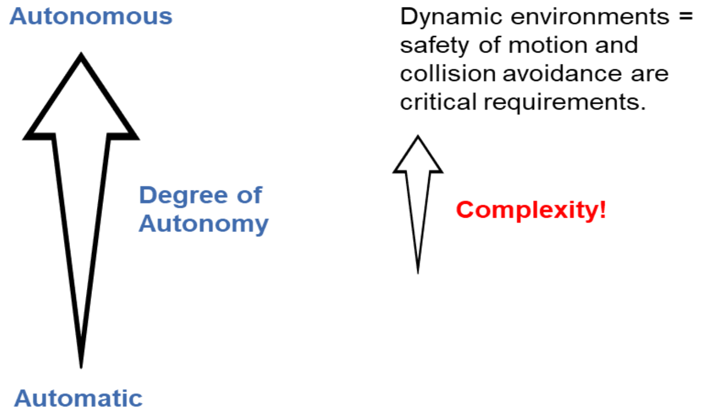
- Green infrastructure
  - Reduction in the facility environmental footprint.
  - Lower power and water consumption.
  - Reduce operational cost.



Challenges: Towards Autonomous Systems

Automated and Autonomous Systems

An **autonomous system**, learns and adapts to dynamic environments, and evolves as the environment around it changes.

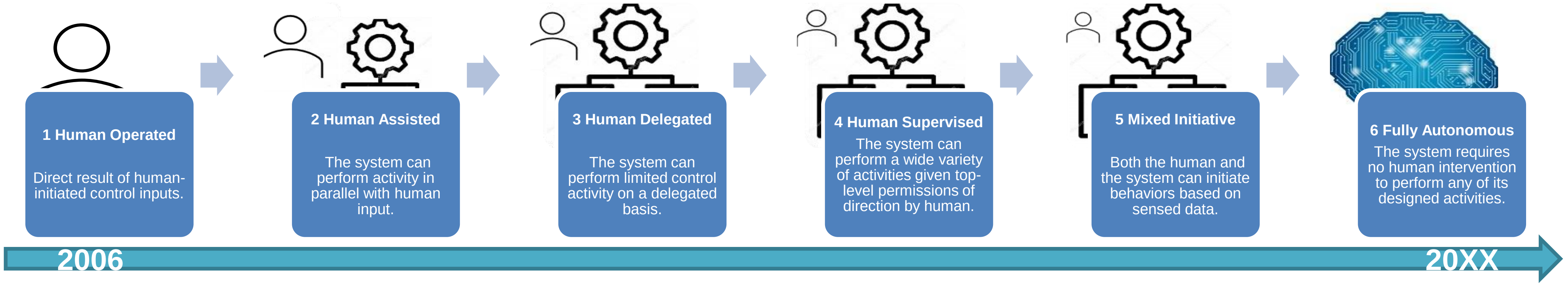


Automated systems typically run within a well-defined set of parameters and are "restricted" in what tasks they can perform.

Automation at Synchrotrons is required to:

- Simplify the experimental procedures, minimize the information that needs to be conveyed to the operator and guarantee quality.
- Accurately gather suitable experimental data.
- Reduce the workload of the beamline staff.
- Improve sample throughput, reduce user burden and error when manipulating large numbers of samples.

Autonomy can be divided into different levels depending on how the system cooperates with humans*:



Automated and Autonomous Systems

With a large variety of experimental techniques, sample environments and with increasing demands on operational performance, the **process/system automation** become more complex and pose significant hardware and software integration challenges.

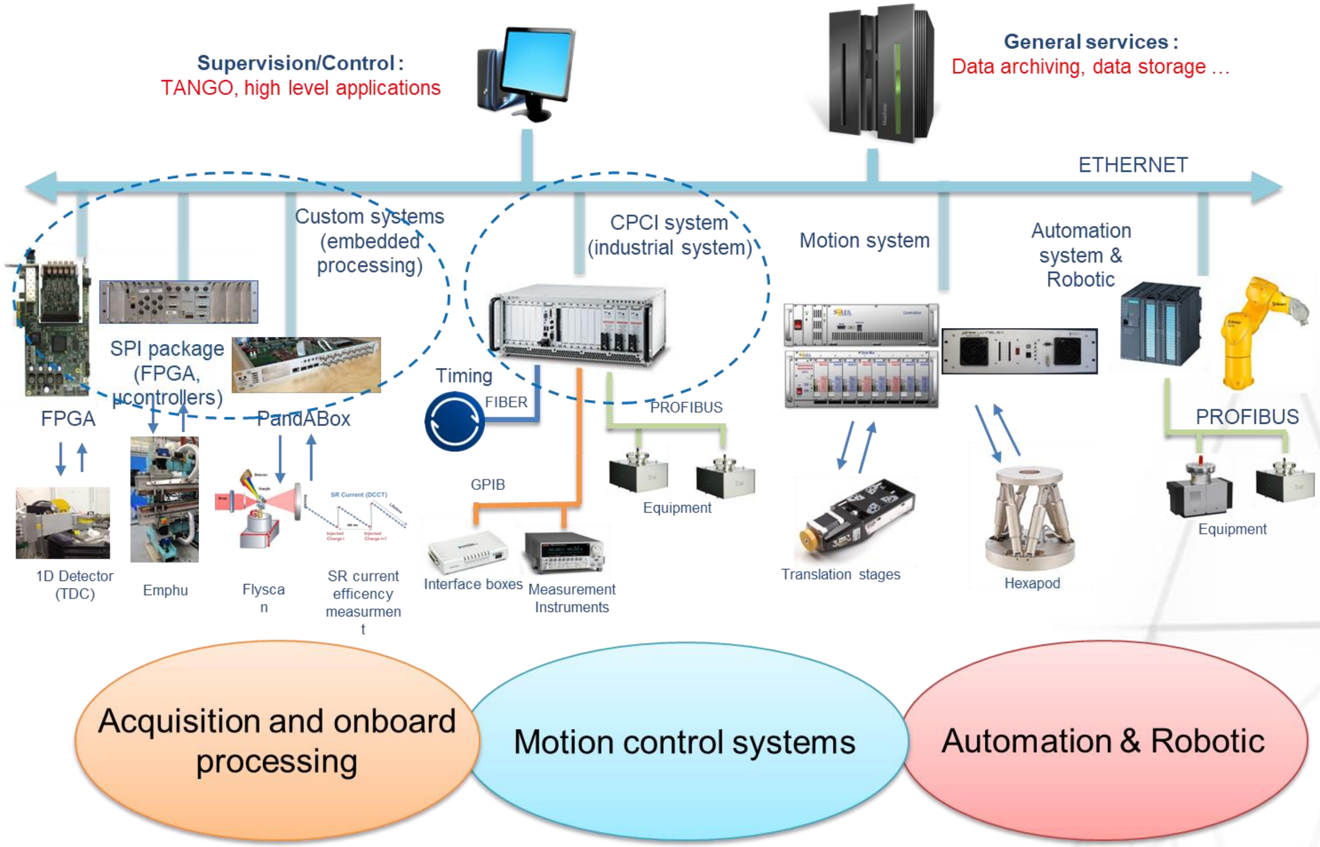
The standardization of hardware and software then allows us to:

- ✓ Have proficiency in integration
- ✓ Have better operational management
- ✓ Have the possibility of evolving applications
- ✓ Improve support and maintenance

SOLEIL Standardization

Hardware and Software for control are standardized as much as possible:

- DAQ and FPGA systems
- **Motion controllers**
- **6 Axis robot arms**
- Programmable Logic Controllers



In this presentation the focus will be on motion controllers and robotic arms.

6 axis Robot and Motion Controller Standardization

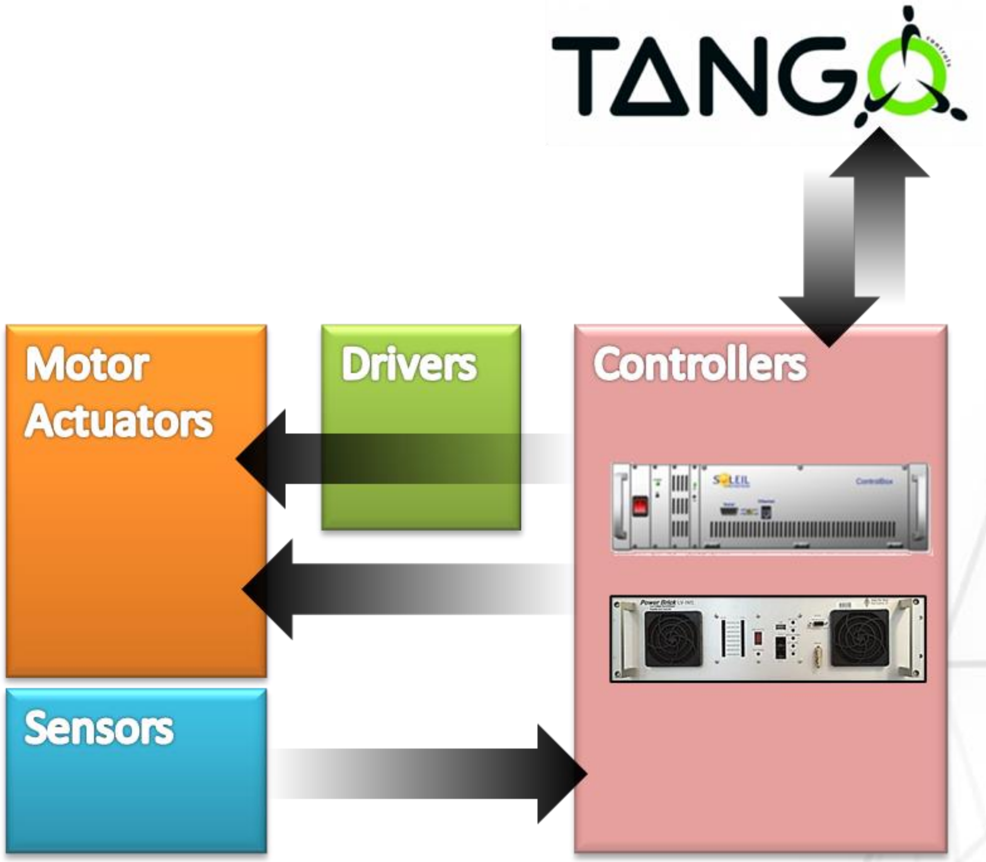
Hardware

Brand: Stäubli

Controller: Cs9

Software

- C++ Library
  - Link between the Cs9 controller and Tango
- Generic Methods:
  - Genetic attributes and commands
- Specific Methods
  - Application-specific tasks.



Standardized 2-controller solution:

- ControlBOX
- PowerBrick

Robotic and Mechatronic Systems at SOLEIL

Synchrotron Specific Mechatronics Instruments

Robotic applications by dedicated motion controllers

Nanoprobe [SWING]
- Interferometry integration
- Multi-axial kinematics
- Controller-to-Controller communication
- Automated & buffered fast low-level scans (equations & LUT)

Detector Support [MARS]
- Controller-to-Driver communication (external high-powered amplifier)
- Multi-axial kinematics
- Anti-collision

DCM [SAMBA, MARS, SIRIUS]
- Multi-axial kinematics
- Motor securities (VaccumMode)

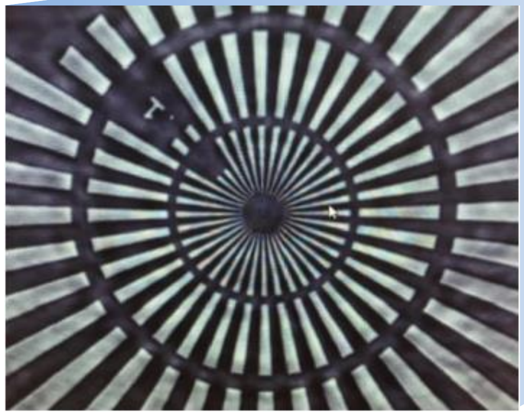
Diffractometer [SIRIUS]
- External amplifiers
- Multi-axial kinematics (hexapods)
- Controller-to-Controller communication

Tracer Project [METROLOGIE]
- Automated & buffered fast low-level scans via LUT
- Multi-axial kinematics

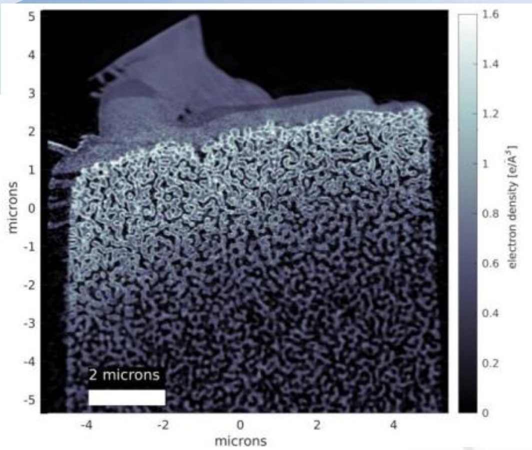
Hexapods [GALAXIES, LUCIA]
- Multi-axial kinematics

The SWING Nanoprobe system was installed (11 DOF) in 2018 to provide:

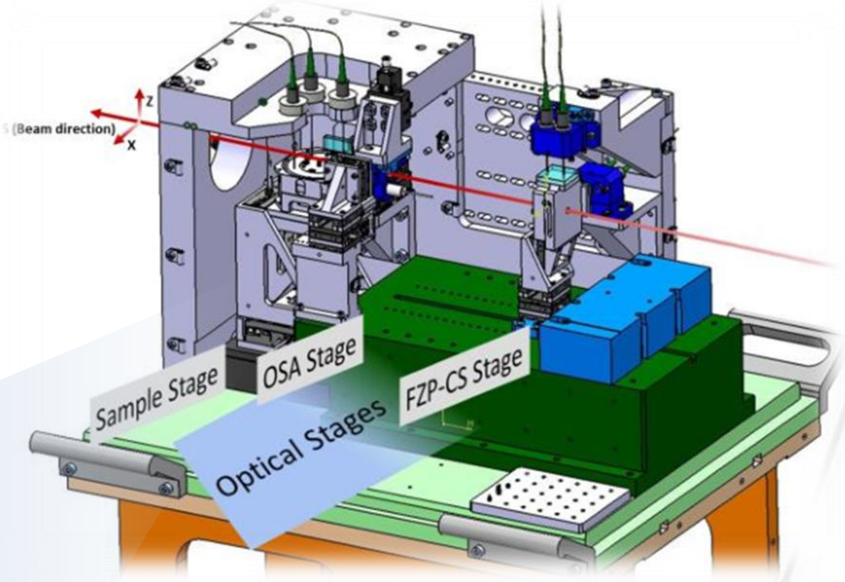
- **Semi-automatic 2D- and 3D- ptychography scans with nanometric level resolution**



2020: 2D image, Siemens star
Resolution ~= 17nm



2020: 3D tomogram,Silica sample
Spatial resolution ~= 40nm



- Interferometry integration
- Multi-axial kinematics
- Controller-to-Controller communication
- Automated & buffered fast low-level scans (equations & LUT)

Passerelle** Sequence

Tango Device SampleManager
Define a trajectory for the Scan

Tango Device Deltatau
Write measurements to a CSV file

Tango Device PPMACDataViewer
Set file naming

Tango Device FileTransfert
Transfer CSV file to the network

ATK Tunning
Axes Access

Device Tango DeltatauToNexus
Write measurements to a Nexus file

Device Tango DataMerger
Merge Nexus files

Excel Sheet
Sample Centering Calculations

MATLAB Script
For Reconstructions
SUMO Cluster*

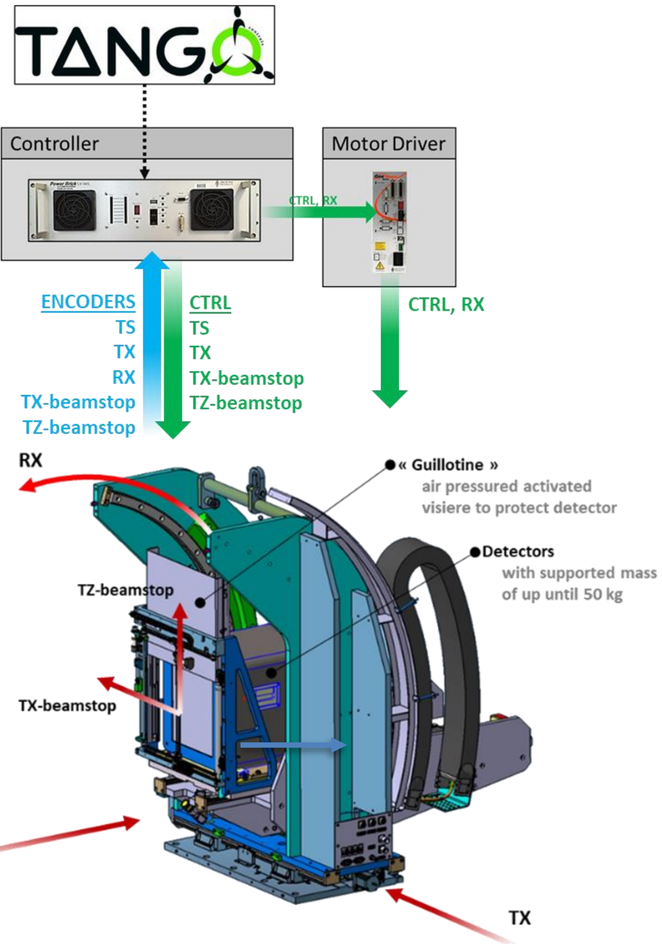
*SUMO: It is a computing cluster formed by 13 computing nodes :

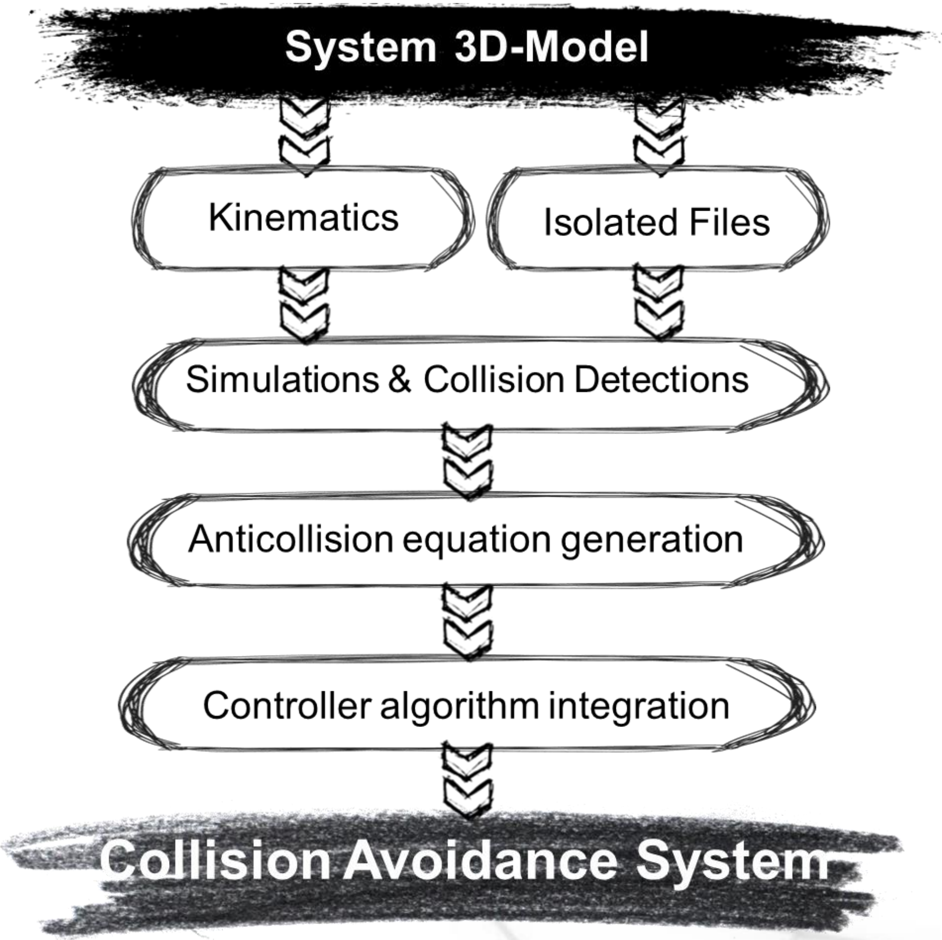
- 2 x Intel E5-2680v3 (12C-2,5GHz)
- 128GB DDR4 2133Mhhz
- 2x NVIDIA Tesla K80 → 4 GP-GPU

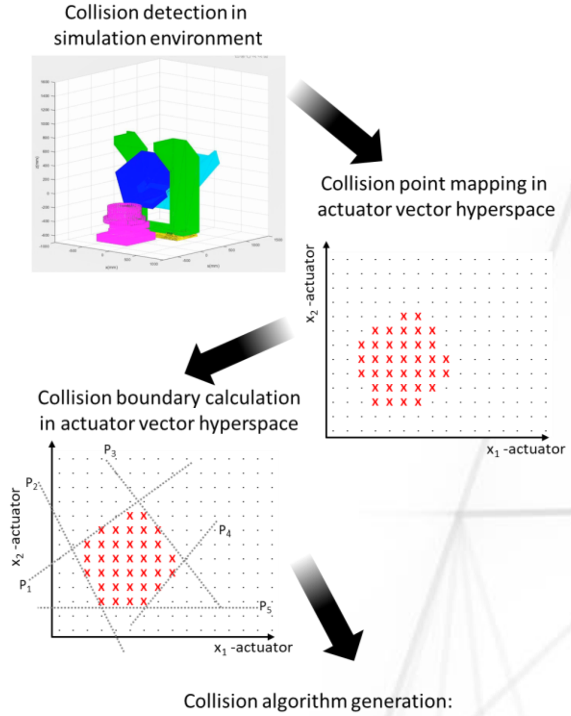
**Passerelle is a Framework allowing to graphically design sequences by dragging and dropping them.

MARS Beamline Automation

Automatic positioning of a 2D detector system with a **collision avoidance** system.







The geometrical closed half space:

$$P_{hs} < 0$$

$$\text{where: } P_{hs} = a_{m,0} + \sum_{1}^{n} a_{m,n} x_n$$

for each enclosing line P_m: $m \in \mathbb{N}$

in actuated dimensional space: $n \in \mathbb{N}$

SOLEIL SYNCHROTRON UPGRADE

6 Axis Robots at SOLEIL

Standardization

Handling of samples stored in a cryogenic Dewar

Solid X-ray Diffraction

- PX1 Beamline
- PX2 Beamline

Sample handling

Powder X-ray diffraction

- CRISTAL Beamline

Detector positioning

Coherent diffraction imaging

- NANOSCOPIUM Beamline

Automatic measurement bench for characterization of undulator magnet modules

- GMI Facilities

Pipetting robot

BioSAXS Experiments

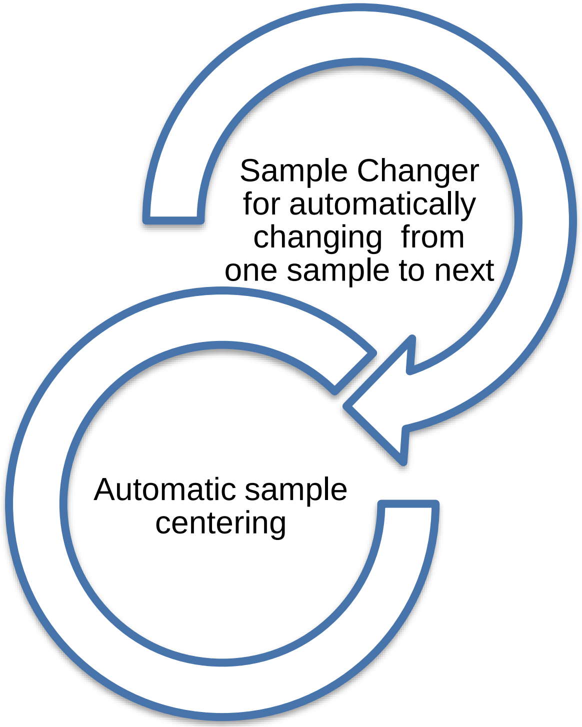
- SWING Beamline

Magnet Modules Measurement Bench for Insertion Devices

- GMI Facilities

CRISTAL Beamline Automation

Automatic mounting and centering of capillaries



Hardware

- Powder Diffractometer
- Stäubli Robot
- Sample Storage
- XY Translation Stage
- Basler Camera

Software

Tango Devices

- Robot Device
- Lima Device
- ControlBox Device
- ImgProcessor Device

Python and SPYC Scripts

- For high-level robot control
- To center the capillary

CRISTAL is an Undulator-based X-ray diffraction beamline dedicated to study single crystals and powders.

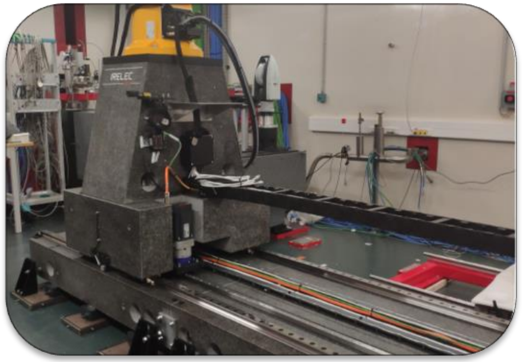
WORK IN PROGRESS

Use of Artificial Intelligence (AI) techniques to center the capillary (Deep Learning).

NANOSCOPIUM Beamline Automation

A robot to **automate the 3D positioning of a detector** without human intervention inside the hutch.

Stäubli TX2-160 Robot



Motorized Translation

Detector Tool:

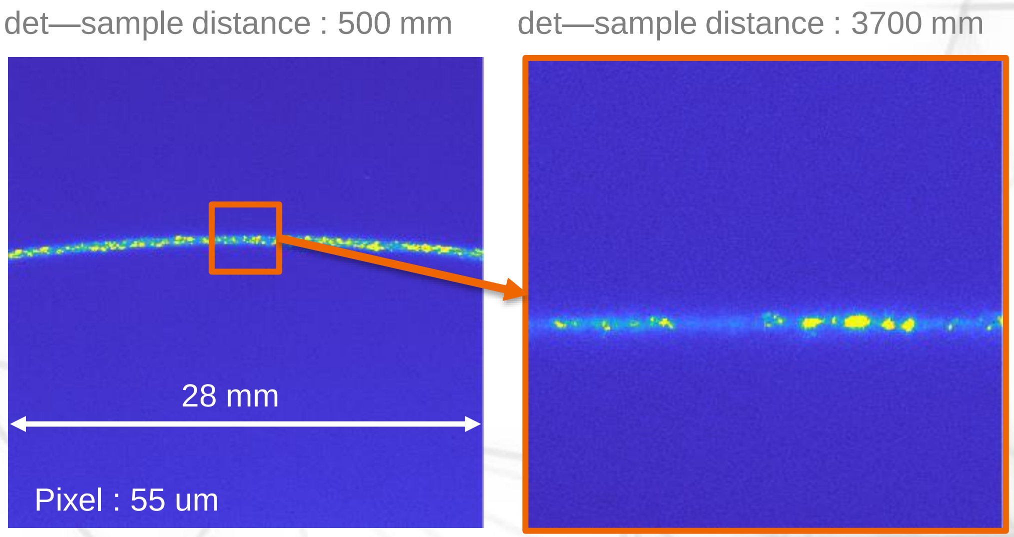
- Merlin Detector
- Safe collision sensor
- Pneumatic rotation

- The distance of the detector to the sample ranges from 50 cm to 555 cm.
- The maximum value that the detector can move once it is in the desired position is **≤ 0.01 mm** over a period of **48 hours !.**

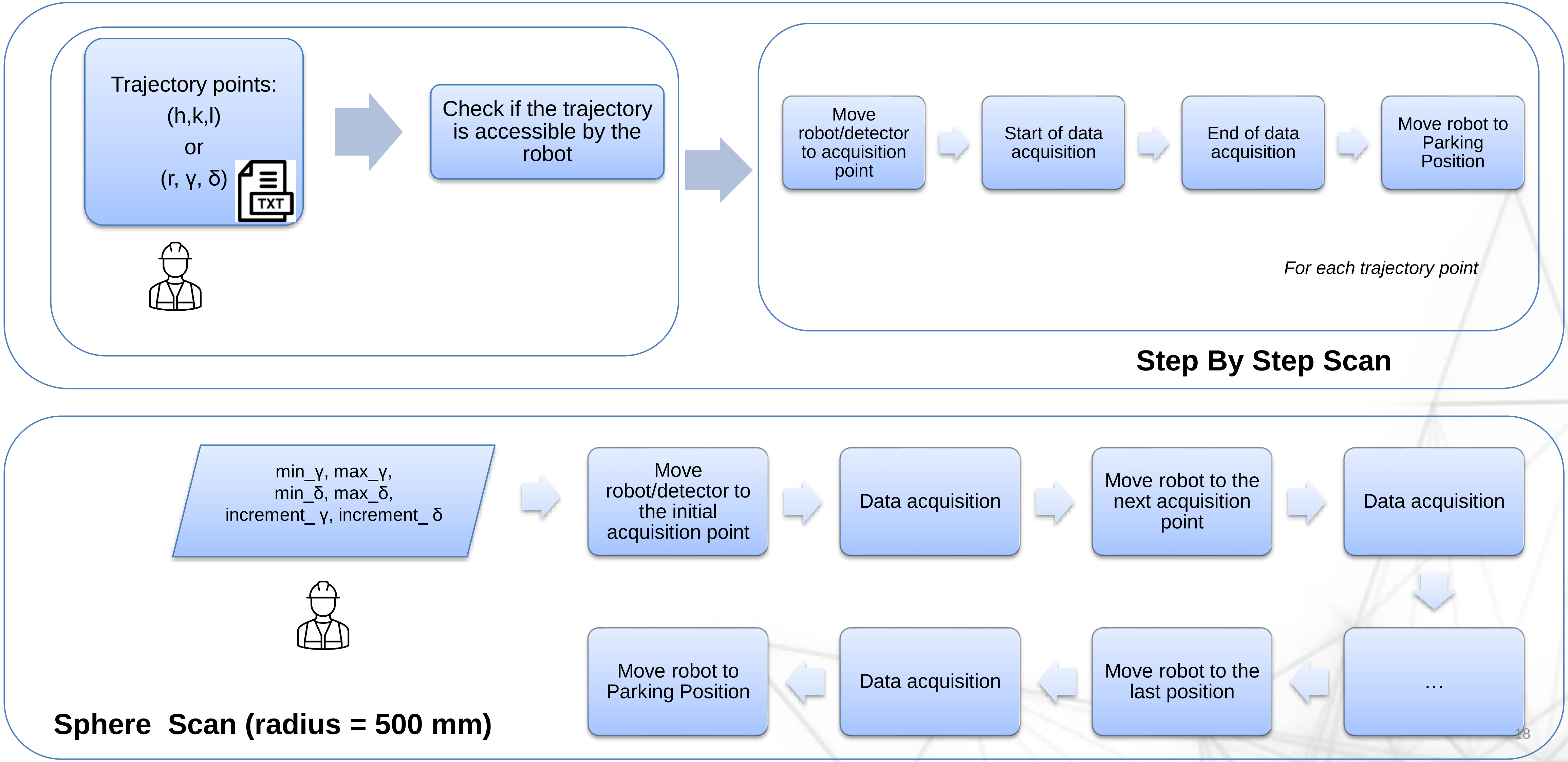
➢ **Nowadays** the **accuracy** of the detector in the whole robot workspace ranges from **±0.18 to ±0.26 mm** in cartesian position and ± 0.5° in angular position.

Under commissioning!

Scanning X-ray Diffraction Microscopy

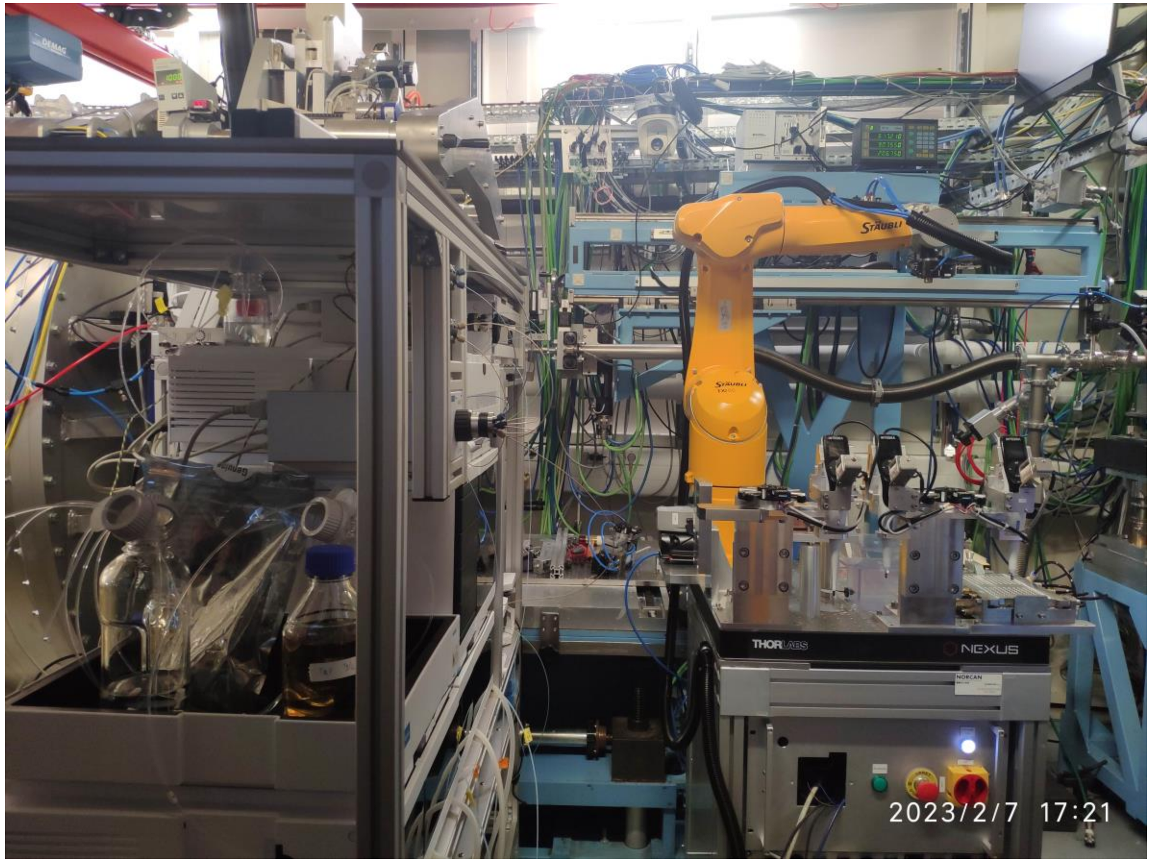


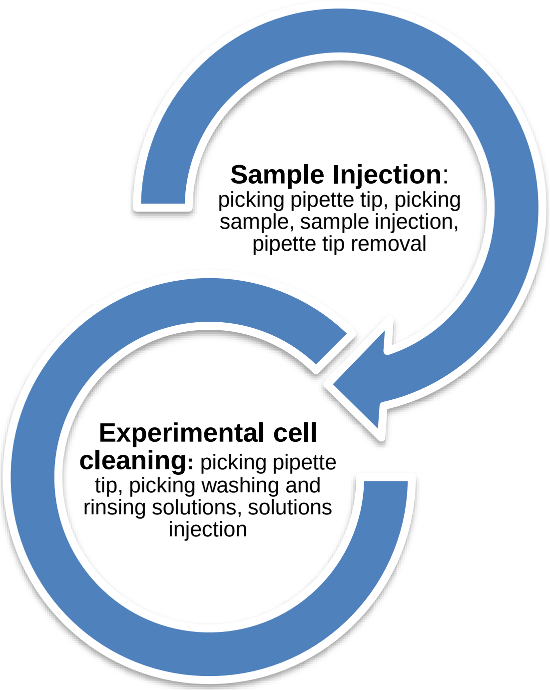
Two modes of scan:



SWING Beamline Automation

Pipetting robot for BioSAXS experiments





- ✓ Automatic switch from 6 axes robot to HPLC* system.
- ✓ Up to 384 samples.
- ✓ Robot cycle time for the whole process: 1 min targeted.
- ✓ Commercial off-the-shelf programmable pipettes.
- ✓ Camera and laser to measure the position of the experimental measurement cell.
- ✓ Automatic tool changer between the sample pipette tool, the cleaning tool and the HPLC system tool.

Under development !

HPLC*: High Pressure Liquid Chromatograpy

Robotic Magnetic Measuring Bench for Insertion Devices

Mechanical and magnetic correction of the super magnet modules

Laser sensors calibration

↓

Poles and magnets' height measurement with laser sensors

↓

Pole's height adjustment with the screwdriver

↓

Magnetic field measurement with a Hall probe

Mechanical correction (Poles and magnets' height measurement with laser sensors; Pole's height adjustment with the screwdriver)

Magnetic correction (Pole's height adjustment with the screwdriver; Magnetic field measurement with a Hall probe)

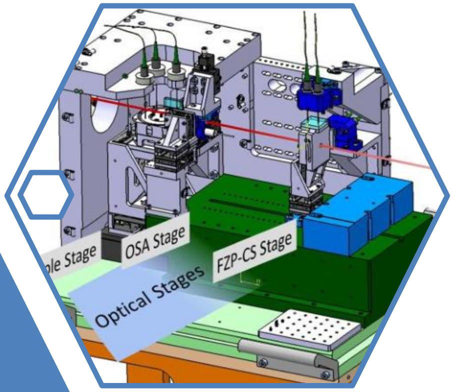
It includes automatic tool changer between the screwdriver tool and the Hall probe tool.

Under development !

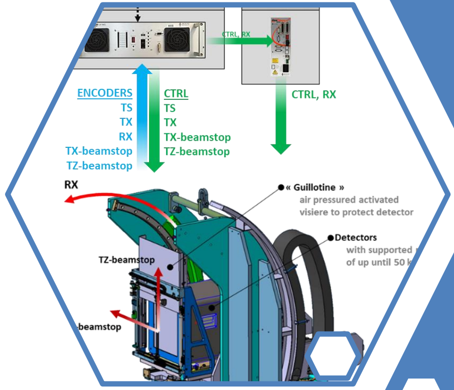
Perspectives & Interests

Perspectives & Interests

Towards new cohabitation environments:

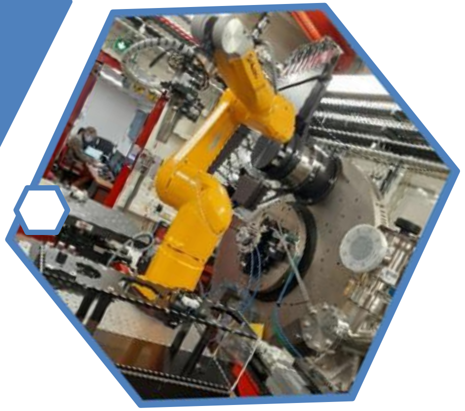


Complex Sample environments

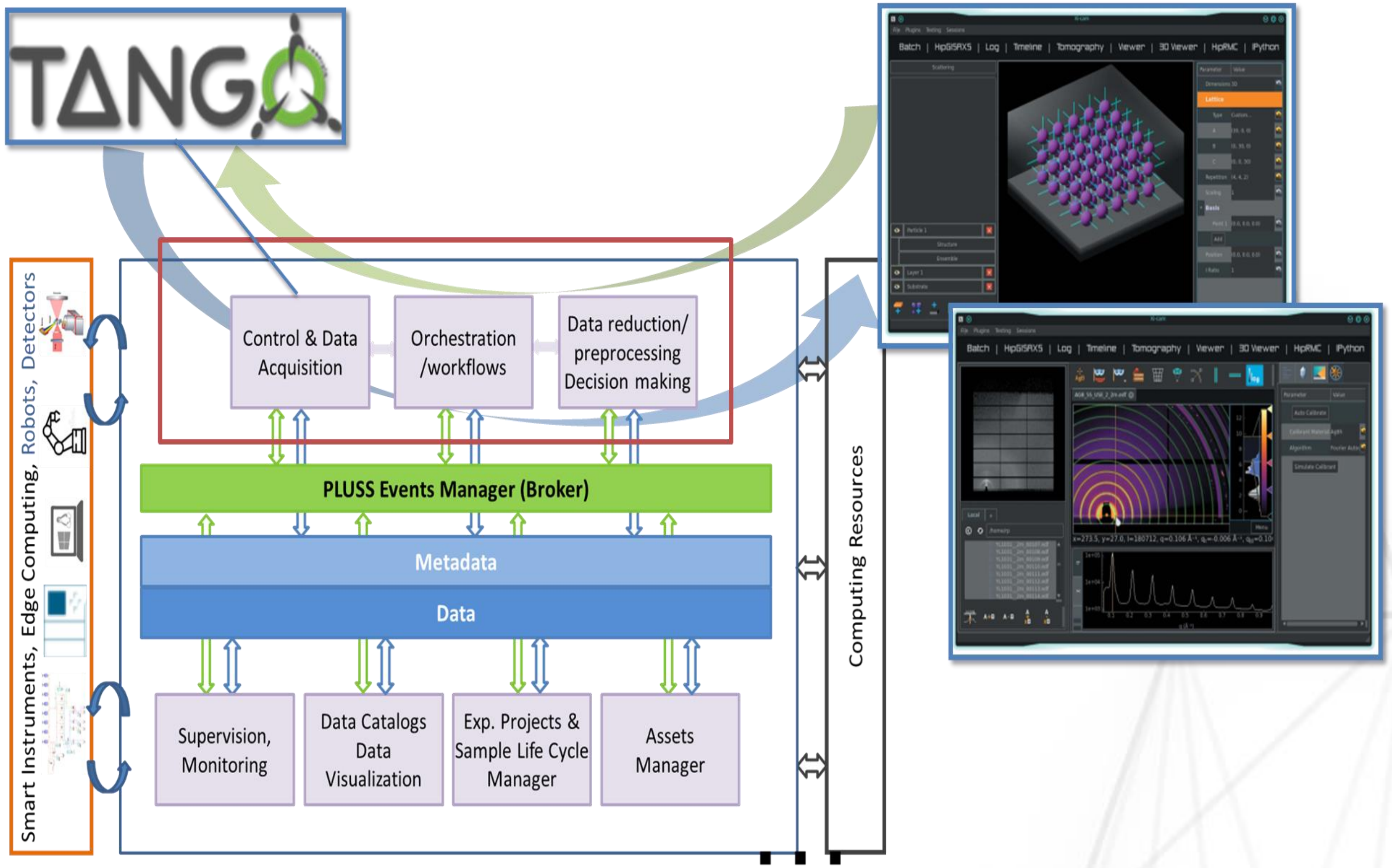


6 axis Robots to handle samples

Robotic supports detectors



Perspectives & Interests



Perspectives & Interests

- On going improvement
  - Development of environment modelling to facilitate integration.
  - Fusion sensors to improve safety and dynamic trajectory changes.

- Field of interests
  - Autonomous mobile robots for accelerator diagnostics:
    - Radiation measurement verification when beam is stopped.
    - Tunnel autonomous inspection (temperature, water leak …)
  - Autonomous Ground Vehicles for logistic during dark period.
  - Mobile robot for metrology and to support aligning team.


THANK
YOU!