MEDSI 2023
Beijing
Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation

SAPOTI
The New Cryogenic Nanoprobe for the CARNAÚBA Beamline at Sirius/LNLS

November 7th, 2023

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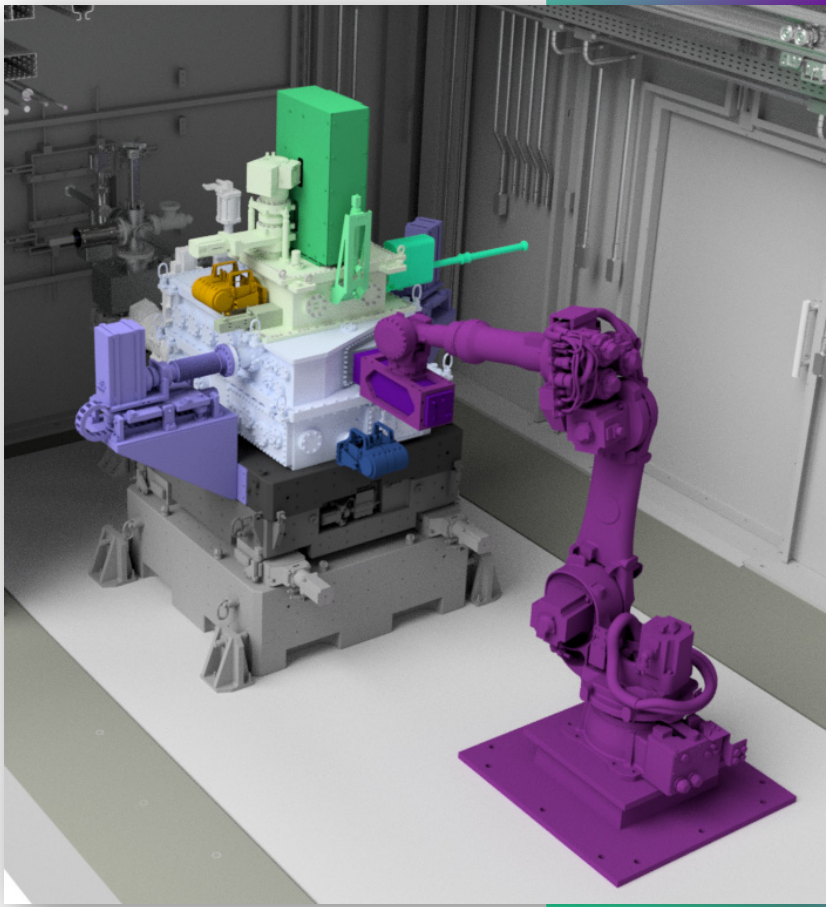
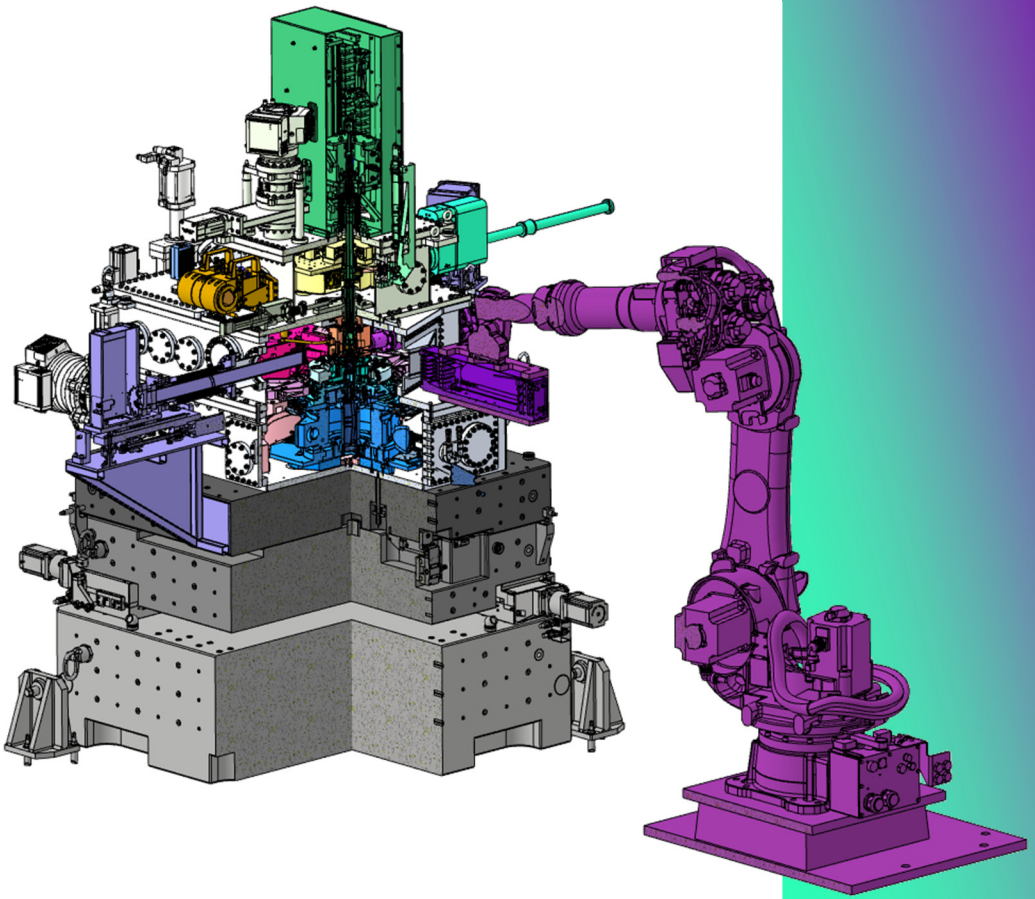


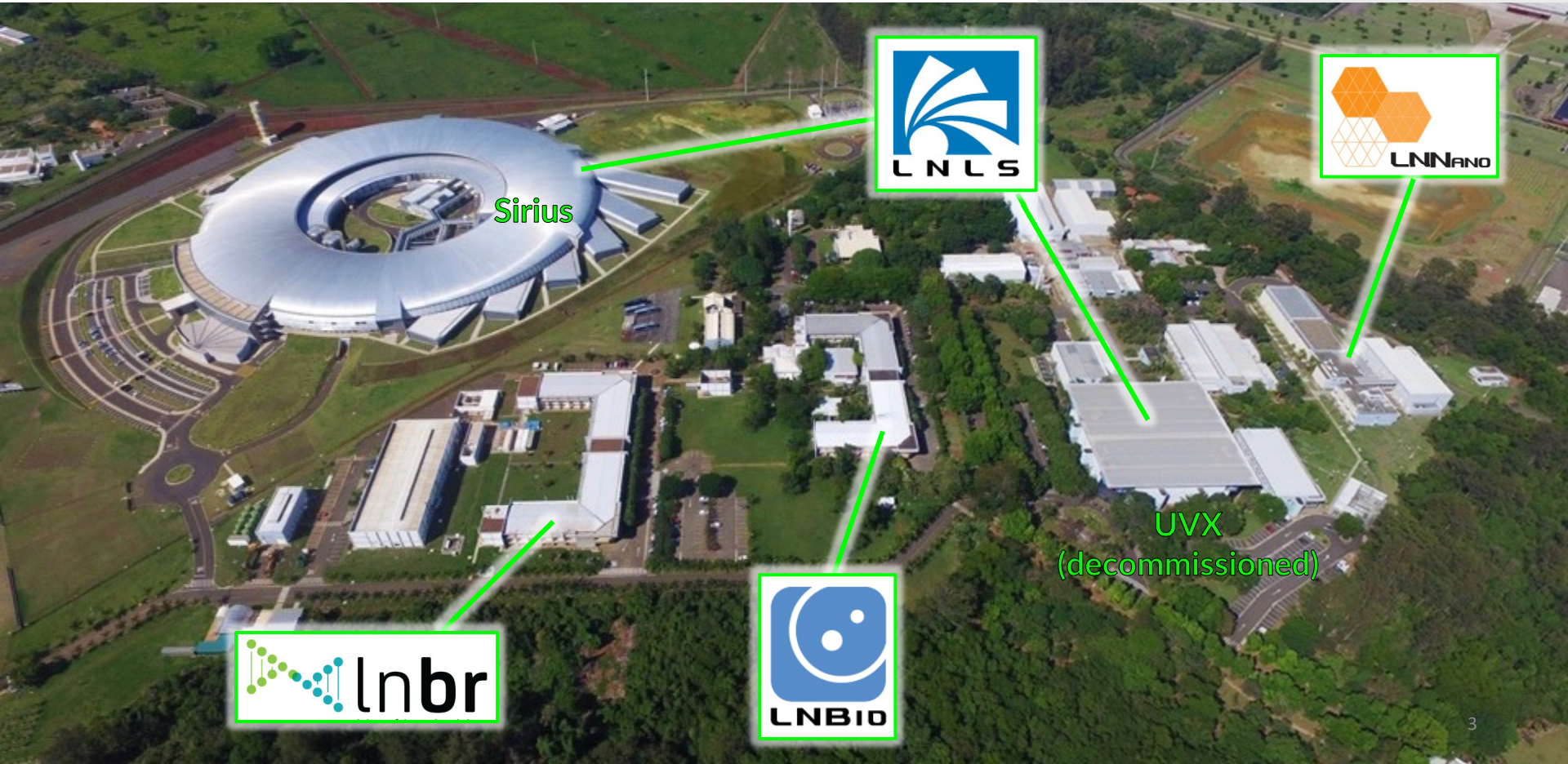
LNLS Brazilian Synchrotron Light Laboratory
CNPEM Brazilian Center for Research in Energy and Materials
MINISTRY OF SCIENCE TECHNOLOGY AND INNOVATION
BRAZILIAN GOVERNMENT BRASIL UNITING AND REBUILDING

Outline

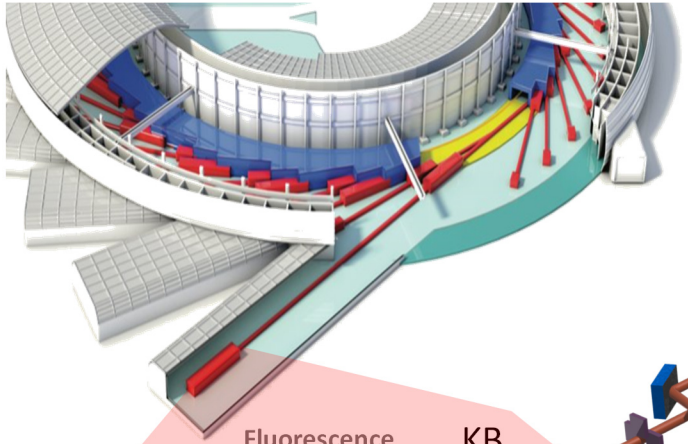
- Introduction
- SAPOTI Overview
- KB System
- Sample Stage
- Other Modules Status
- Conclusions



The CNPEM and the LNLS

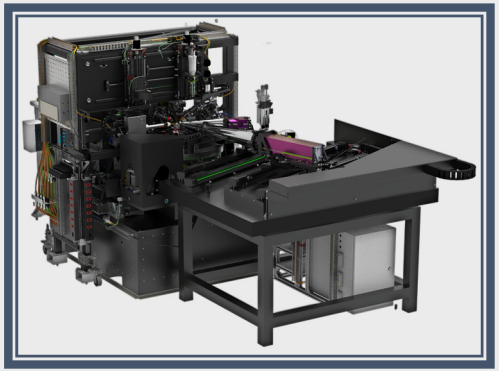


The CARNAÚBA Beamline



Sirius: 3GeV, 4th-generation
Brazilian Synchrotron

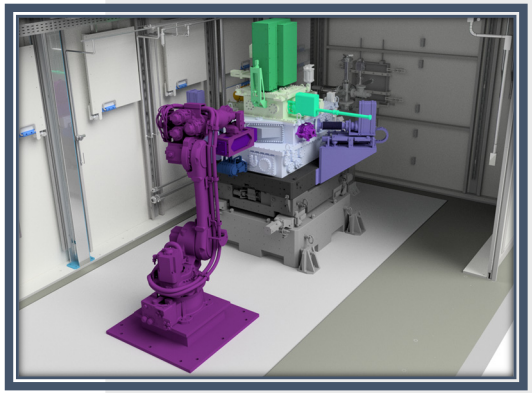
0 m
M1
SSA
M2
27 m
54 m
4CM
130 m

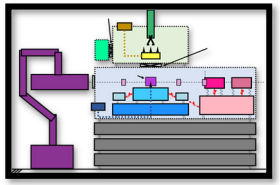


Fluorescence
KB
Transmitted
Luminescence
Scattered

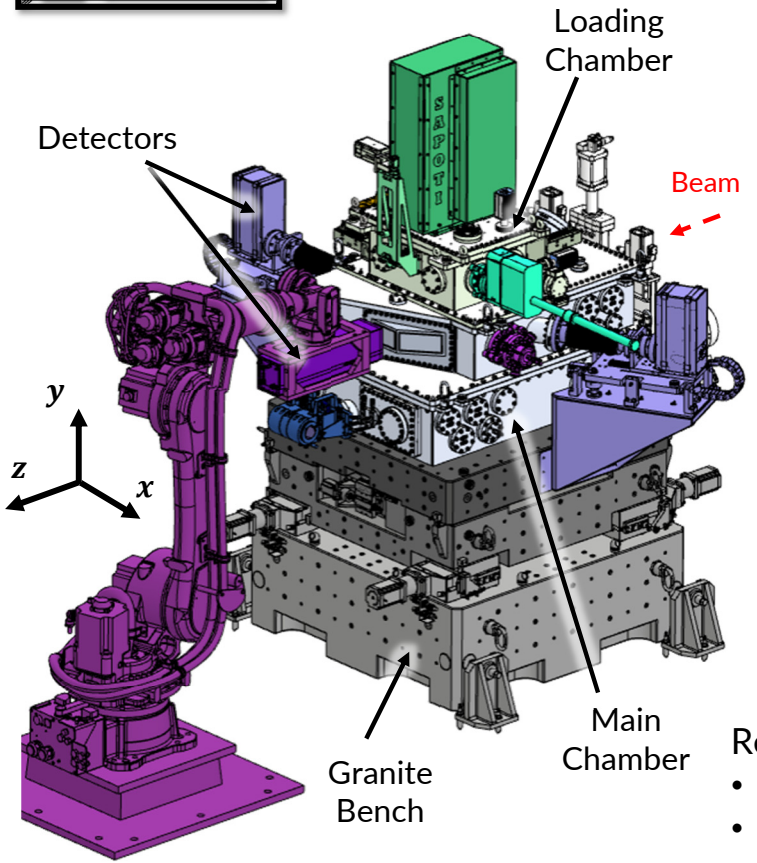
TARUMÃ: 135 m
(σ = 500 to 120 nm²)
(WD = 440 mm)

SAPOTI: 143 m
(σ = 140 to 35 nm²)
(WD = 55 mm)





The SAPOTI Station



Optics Overview:

- ❑ **Undulator source;**
- ❑ **2.05 to 15 keV;**
- ❑ **Four-bounce monochromator;**
- ❑ **All-achromatic optics;**
- ❑ **KB focusing: 150 to 35 nm;**
- ❑ **Large working distance: 55 mm;**
- ❑ **Flux up to 1e11 ph/s/100 mA.**

Features:

- ❑ **Simultaneous multi-analytical X-ray techniques:**
  - ❑ XRD
  - ❑ XAS
  - ❑ XRF
  - ❑ XEOL
  - ❑ Ptycho-CDI
  - ❑ Ptycho-Bragg-CDI
  - ❑ Tomography
- ❑ **In-vacuum operation: cryogenic (100 K) to RT;**
- ❑ **High-speed high-resolution flyscan mapping.**

Reference Papers:

- doi: 10.1063/5.0168438 (XRM 2022)
- The Sample Positioning Stage for the SAPOTI Nanoprobe at the CARNAÚBA Beamline at Sirius/LNLS (ASPE 2022)

The SAPOTI Design Team

Erik Pereira
(Mechanical Designer)

Gabriel Basilio
(Mechanical Designer)

Rodrigo Gomes
(Mechanical Designer)

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(Design Analyst)

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(Integration Analyst)

Augusto Horita
(Integration Specialist)

Vinicius Falchetto
(Control Specialist)

Michel Machado
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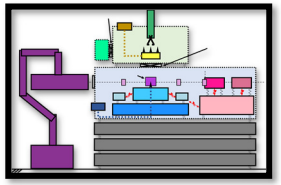
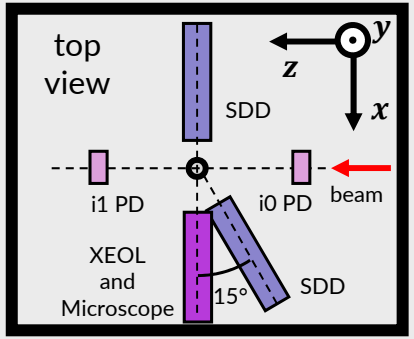
Yago Marino
(Intern)

Diogo Cintra
(Intern)

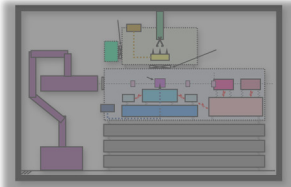
And members from other engineering teams.



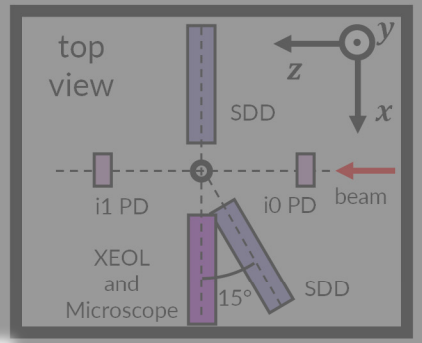
SAPOTI Schematics

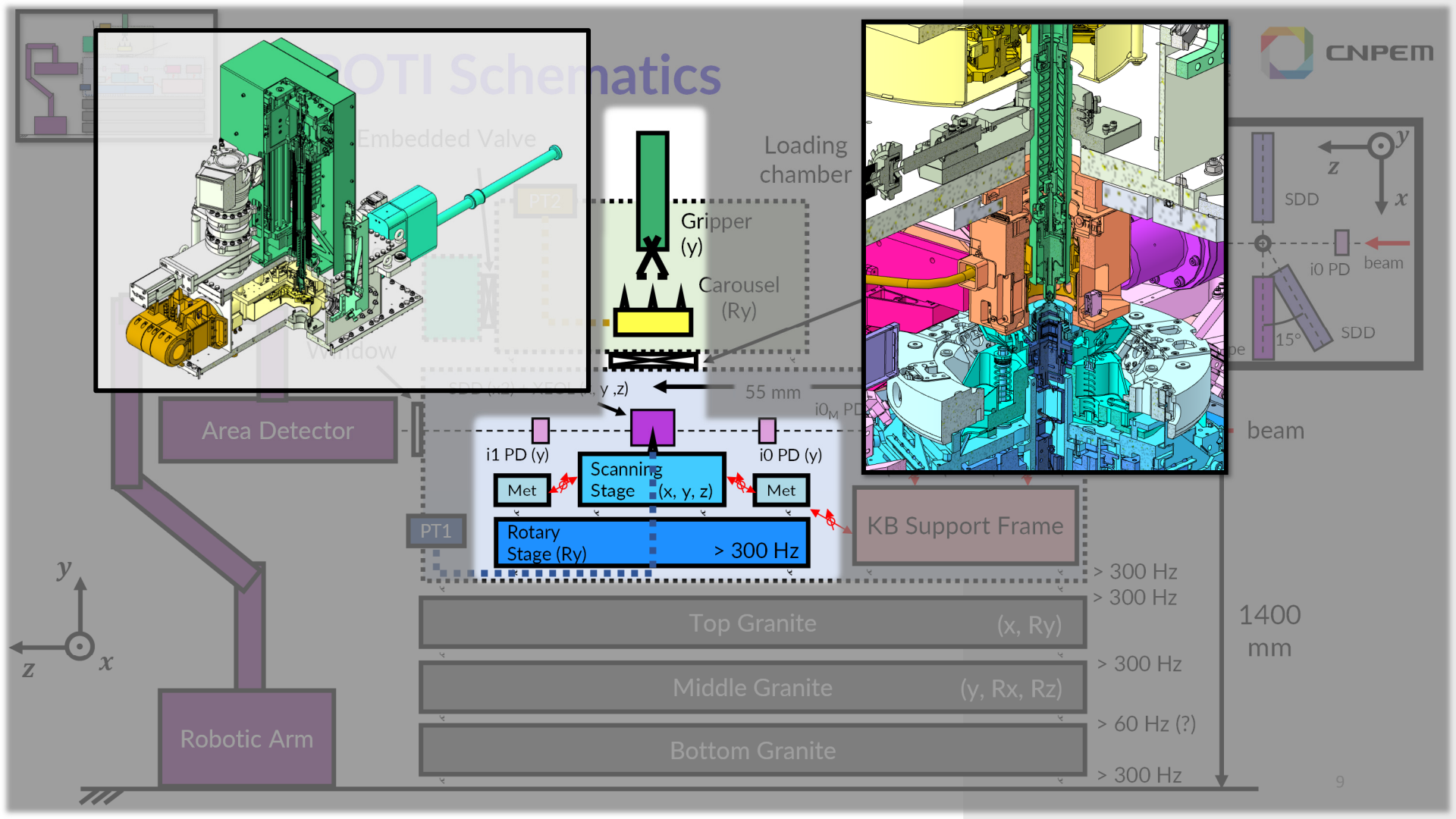


Embedded Valve
Loading chamber
PT2
Gripper (y)
Load-lock
Carousel (Ry)
Embedded Valve
Be Window
Main chamber
SDD (x2) + XEOL (x, y ,z)
55 mm
$i0_M$ PD
> 400 Hz
> 200 Hz
Area Detector
i1 PD (y)
i0 PD (y)
HFM (Ry, Rz)
VFM (z, Rx)
beam
Met
Scanning Stage (x, y, z)
Met
PT1
Rotary Stage (Ry)
> 300 Hz
KB Support Frame
> 300 Hz
> 300 Hz
Top Granite (x, Ry)
1400 mm
> 300 Hz
Middle Granite (y, Rx, Rz)
> 60 Hz (?)
Bottom Granite
> 300 Hz
Robotic Arm
y
z
x

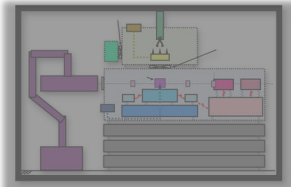


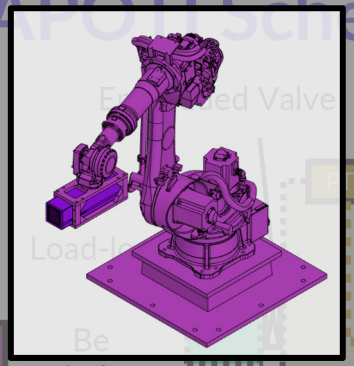
SAPOTI Schematics

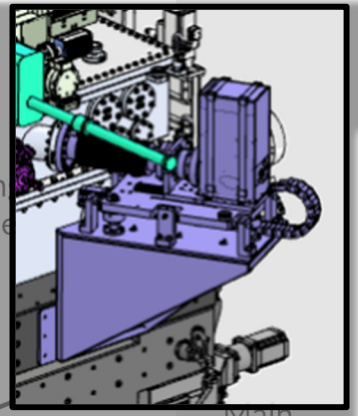


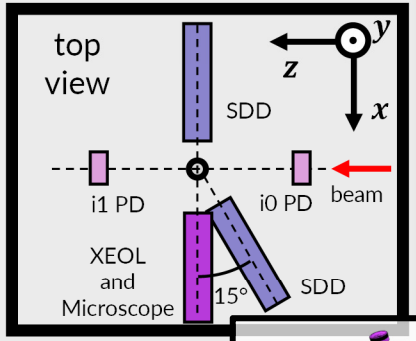

Loading chamber
Gripper (y)
Carousel (Ry)
55 mm
Area Detector
i1 PD (y)
i0 PD (y)
Met
Scanning Stage (x, y, z)
Met
Rotary Stage (Ry)
> 300 Hz
PT1
KB Support Frame
beam
> 300 Hz
> 300 Hz
Top Granite
(x, Ry)
> 300 Hz
Middle Granite
(y, Rx, Rz)
> 60 Hz (?)
Bottom Granite
> 300 Hz
1400 mm
Robotic Arm
y
z
x
SDD
i0 PD
beam
15°
SDD

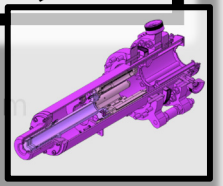
SAPOTI Schematics

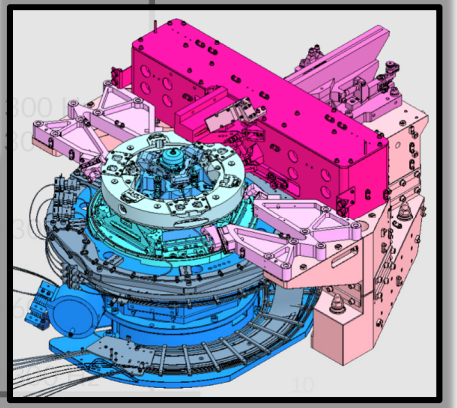












Gripper (y)

Carousel (Ry)

Window

Area Detector

SDD (x2) + XEOL (x, y ,z)

55 mm

$i0_M$ PD

> 400 Hz

> 200 Hz

HFM (Ry, Rz)

VFM (z, Rx)

i1 PD (y)

i0 PD (y)

Met

Scanning Stage (x, y, z)

Met

PT1

Rotary Stage (Ry)

> 300 Hz

KB Support Frame

Top Granite (x, Ry)

Middle Granite (y, Rx, Rz)

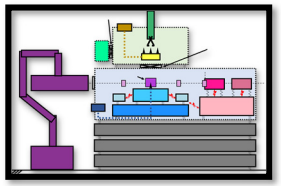
Bottom Granite

Robotic Arm

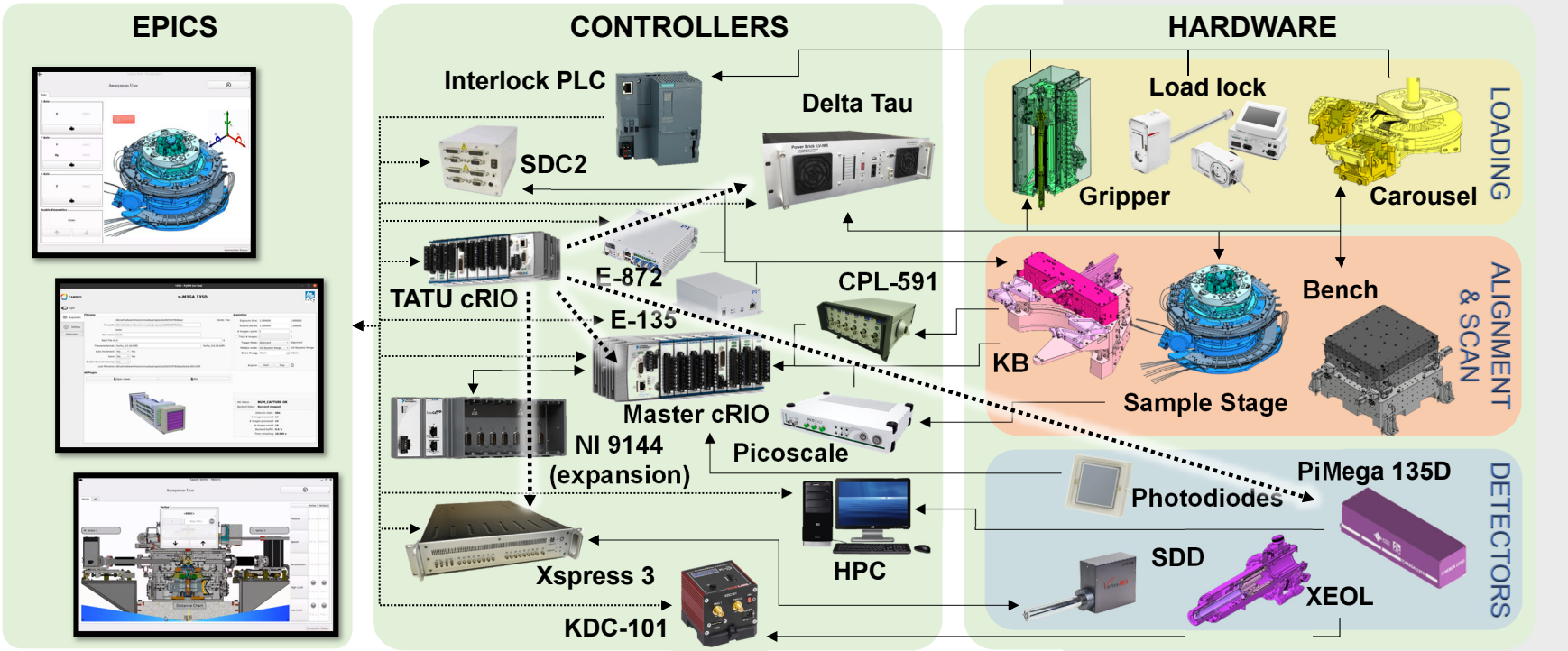
y

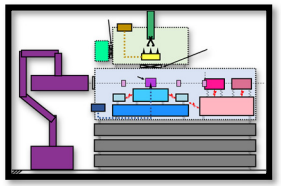
z

x

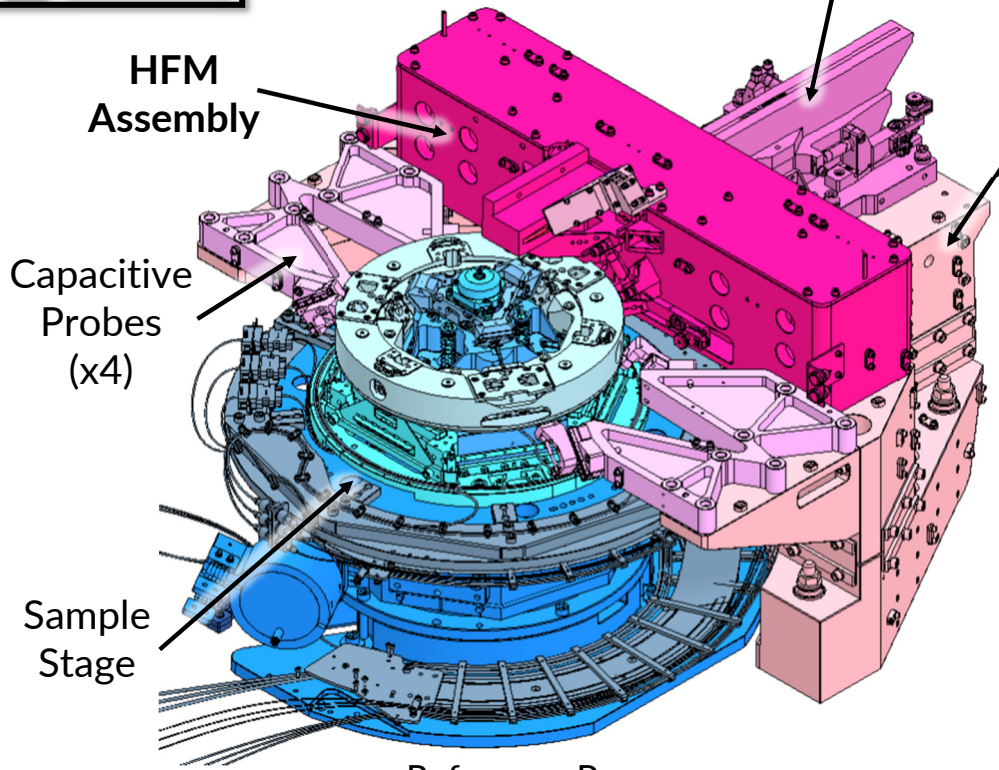


SAPOTI Integration Overview





KB Module



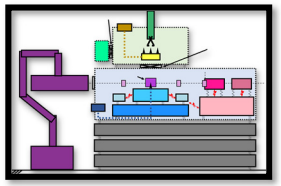
Reference Papers:

- doi: 10.18429/JACoW-MEDSI2020-TUOB01
- doi: 10.1117/12.2633679

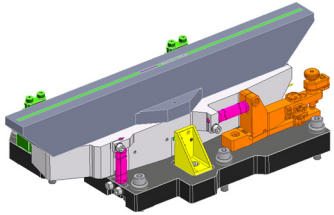
Modal

1st mode @ 325 Hz

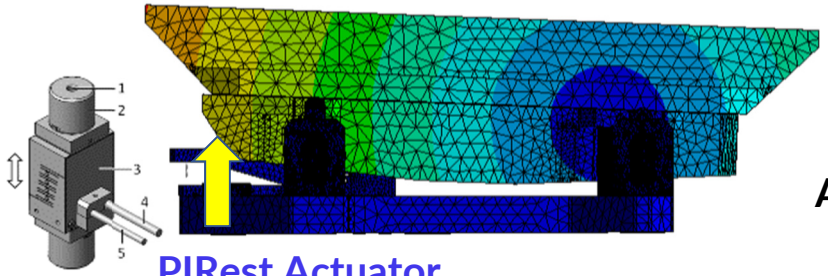
2nd mode @ 400 Hz



KB VFM Exactly-Constrained Mechanism



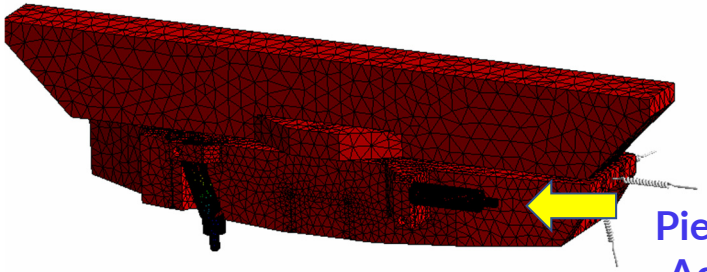
VFM Pitch (Rx)



PIRest Actuator

Range: $\approx 20\ \mu rad$
Res.: $\approx 20\ nrad$
Align. Req.: $60\ nrad$
Stab. Req.: $4\ nrad$

VFM Translation (Tz)

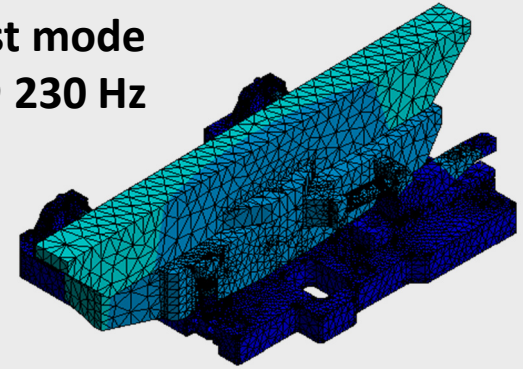


Range: $> 250\ \mu m$
Res.: $\approx 10\ nm$
Align. Req.: $20\ \mu m$

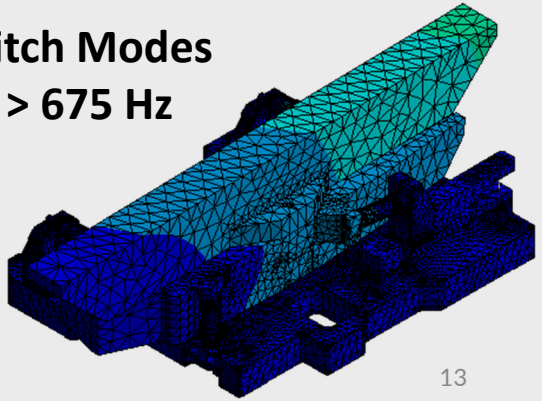
Piezomike Actuator

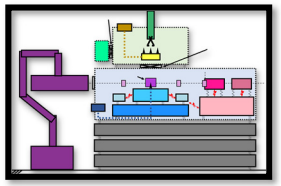
Modal

1st mode
@ 230 Hz

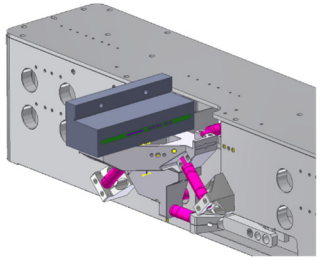


Pitch Modes
> 675 Hz

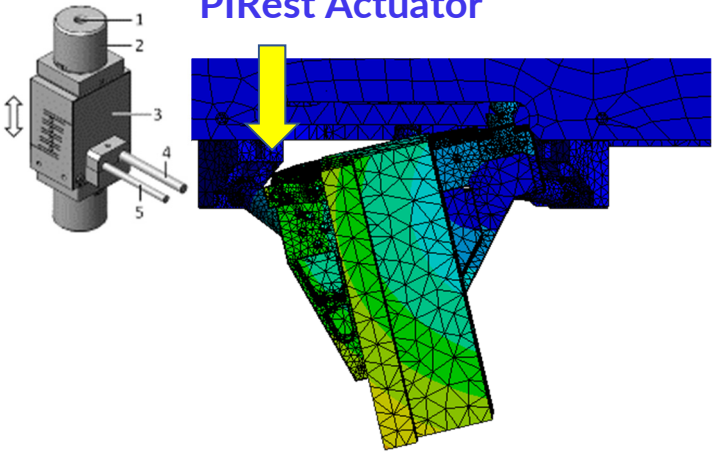




KB HFM Exactly-Constrained Mechanisms



PIRest Actuator



HFM Pitch (Ry)

Range: $\approx 50\ \mu rad$
Res.: $\approx 50\ nrad$
Align. Req.: $200\ nrad$
Stab. Req.: $10\ nrad$

HFM Roll (Rz)

Range: $\approx 1.2\ mrad$
Res.: $\approx 80\ nrad$
Align. Req.: $10\ \mu rad$

[redacted]

Piezomike Actuator

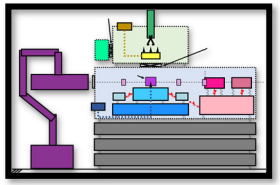
Modal

1st mode @ 400 Hz

[redacted]

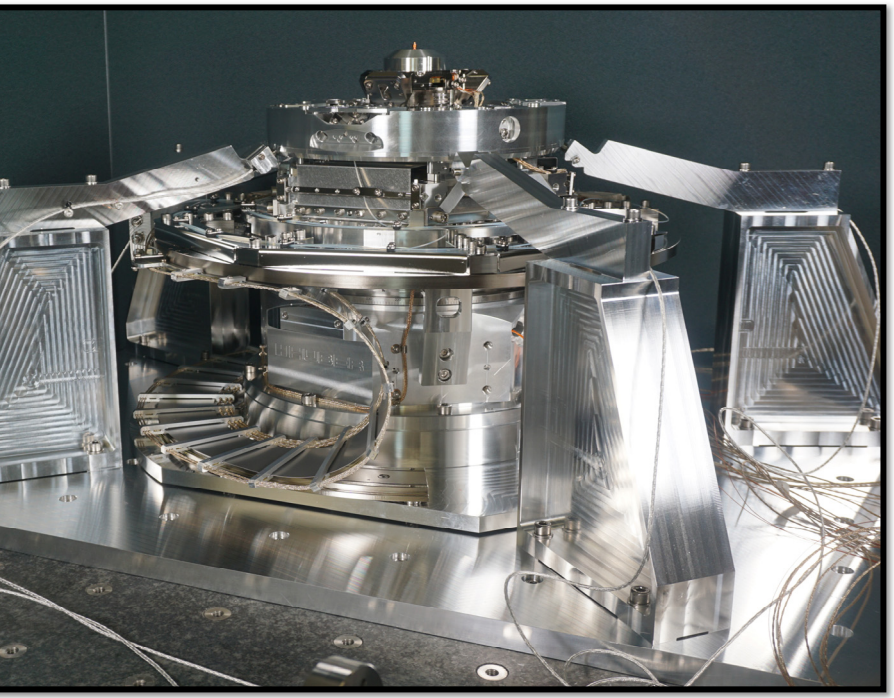
[redacted]

Pitch Modes > 600 Hz

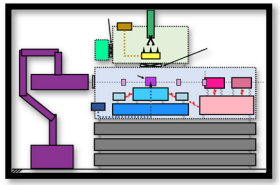


Sample Stage Specifications

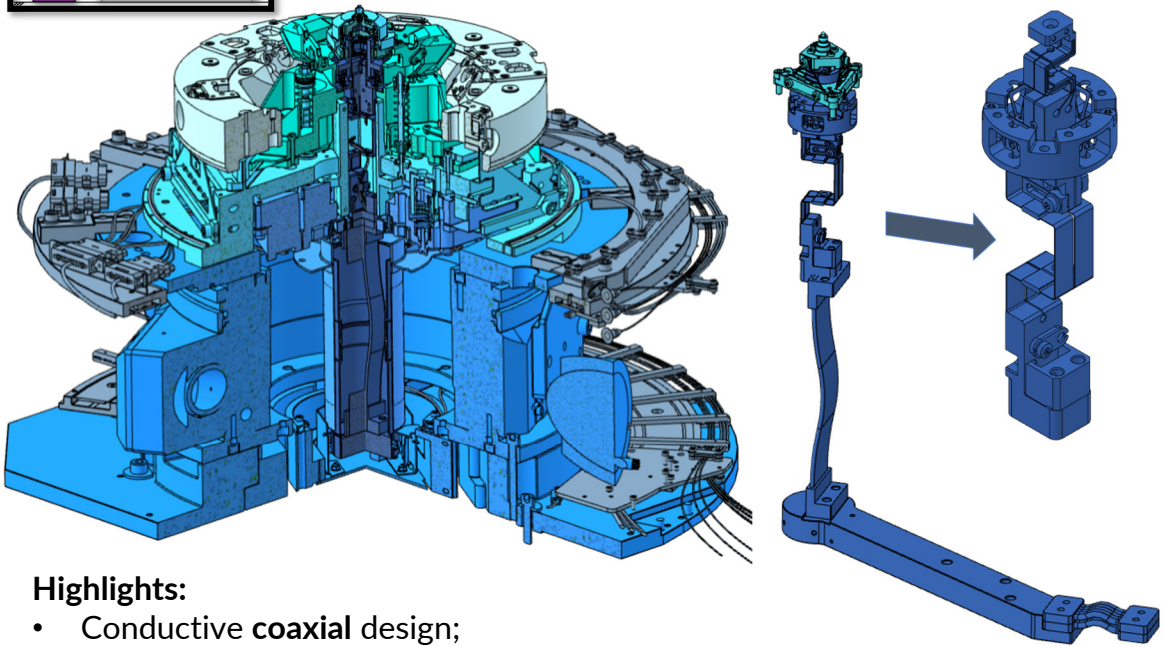
with



Parameter	Value
Vacuum level	~ 1e-9 mbar
Sample Temperature	< 100 K
2D mapping range (XY)	+/- 1.5 mm
2D mapping stab. (XY)	1 nm RMS
2D mapping acc. (XY)	< 10 nm
2D mapping repeat. (XY)	5 nm
Mapping velocity	≤ 50 µm/s
Main rotation range (Ry)	220°
Main rotation stab. (Ry)	2 µrad
Main rotation acc. (Ry)	100 µrad
Main rotation repeat. (Ry)	10 µrad

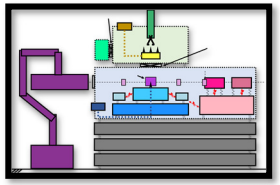


Sample Stage Thermal Architecture

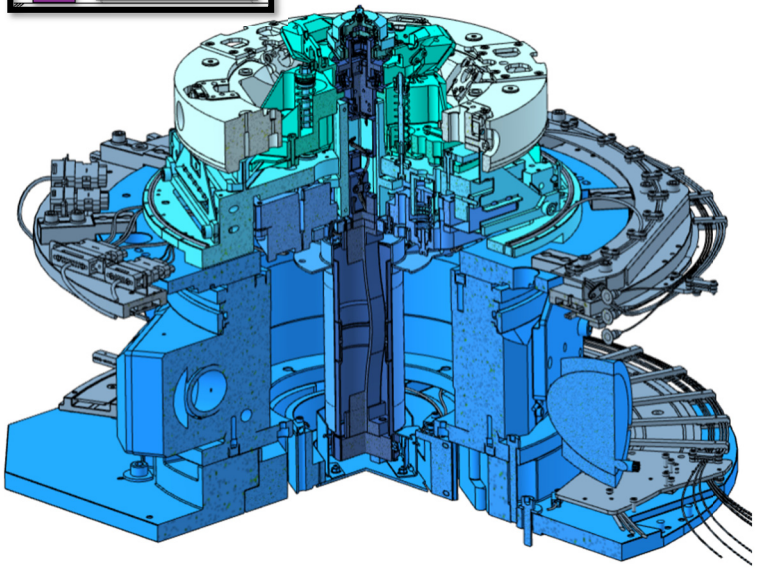


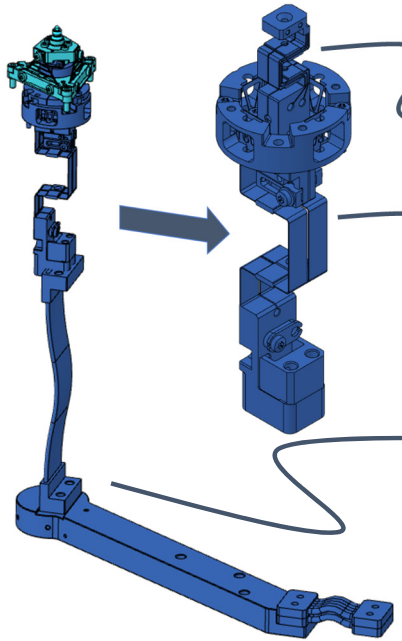
Highlights:

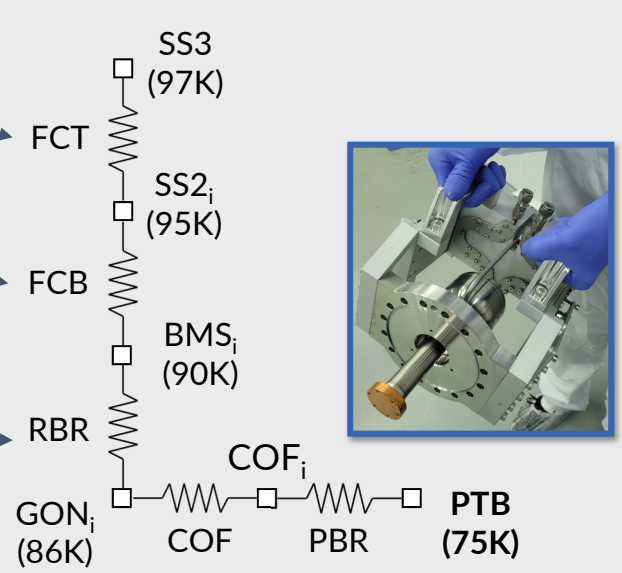
- Conductive **coaxial** design;
- Closed-circuit **pulse tube** cooler;
- **Rotating copper braid** for 220° rotation compliance;
- Machined **flexible copper conductors** increasing thermal and positioning determinism (frictionless solution);
- Thermal decoupling and 7 control loops for predictive modeling and small drifts.



Sample Stage Thermal Architecture



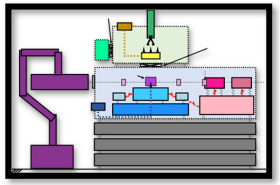




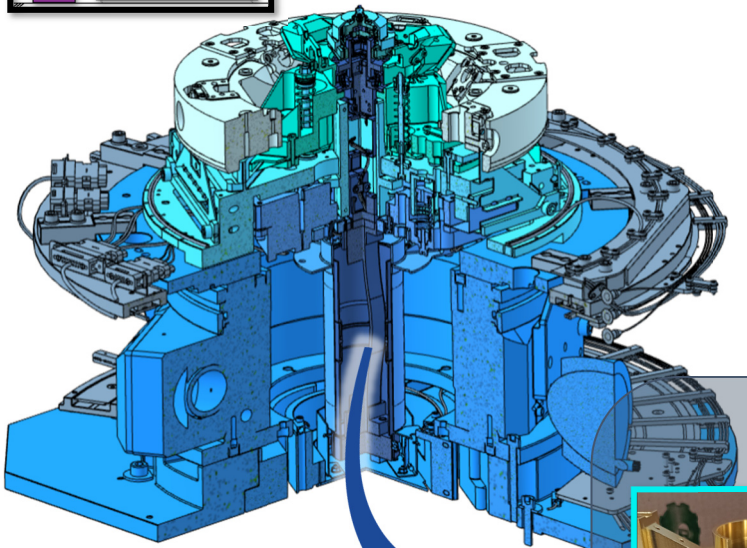
Highlights:

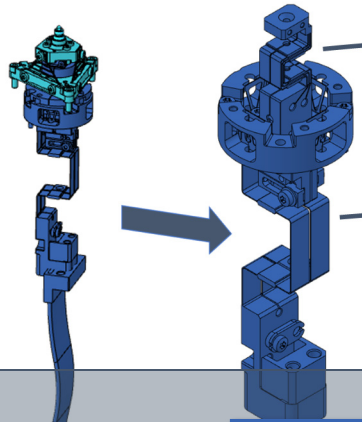
- Conductive **coaxial** design;
- Closed-circuit **pulse tube** cooler;
- **Rotating copper braid** for 220° rotation compliance;
- Machined **flexible copper conductors** increasing thermal and positioning determinism (frictionless solution);
- Thermal decoupling and 7 control loops for predictive modeling and small drifts.

FCT = Flexible conductor top
FCT = Flexible conductor bottom
RBR = Rotating braid
COF = Cold finger
PBR = Pulse tube braid
PTB = Pulse tube cooler



Sample Stage Thermal Architecture





Highlights:

- Conductive **coaxial** design,
- Closed-circuit **pulse tube** cooler
- **Rotating copper braid** for 220° rotation
- Machined **flexible copper conductors** i
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- Thermal decoupling and 7 control loops for predictive modeling a
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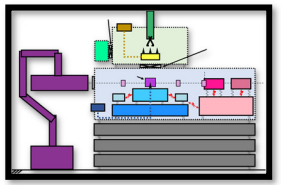
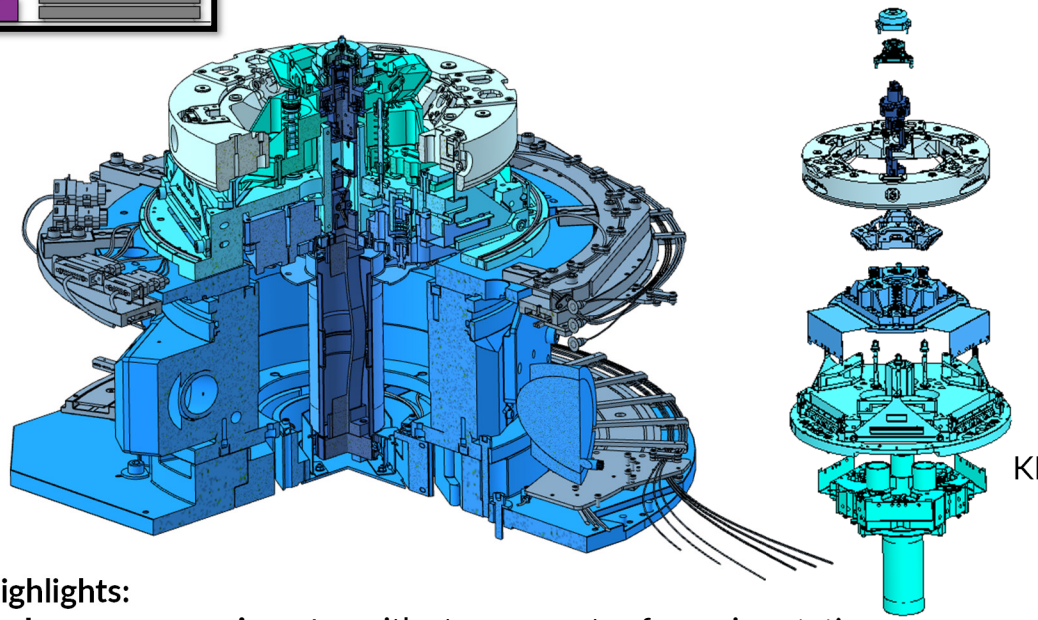
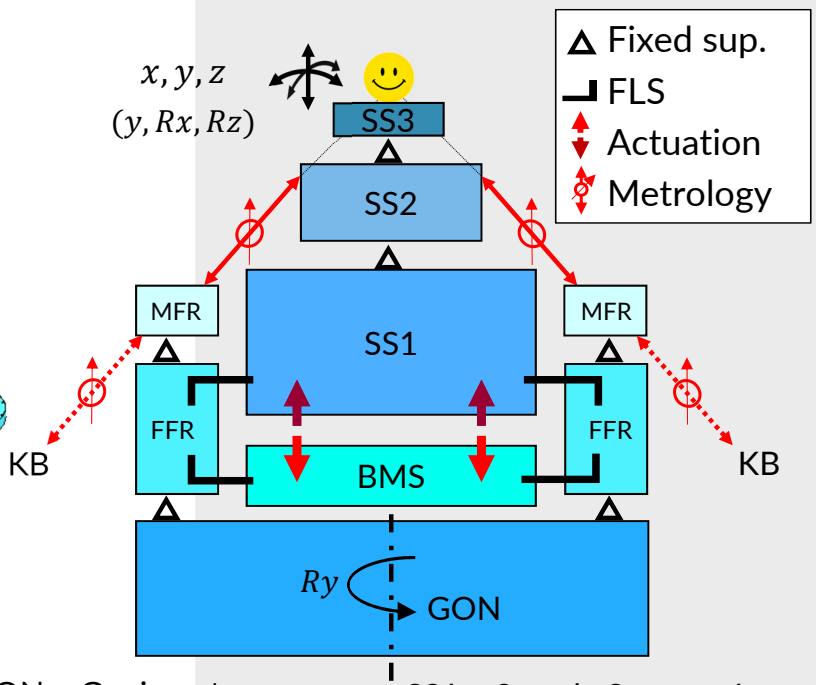


Sample Stage Mechatronic Architecture





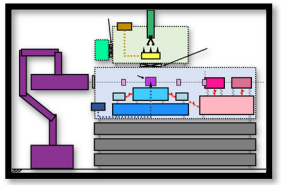
Highlights:

- **In-vacuum goniometer** with stepper motor for main rotation;
- **Voice-coil actuators** and **interferometers** for high-speed control rate and high bandwidth (100 – 150 Hz);
- **Flexure-based parallel kinematics** and **balance mass** as dynamic filter;
- **Metrology in Abbé** configuration to minimize errors.

GON = Goniometer
FFR = Force Frame
MFR = Metrology Frame
BMS = Balance Mass

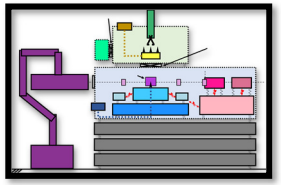
SS1 = Sample Support 1
SS2 = Sample Support 2
SS3 = Sample Support 3
KB = KB Mirror

*Similar mechatronic concept used for the Delta Robot stage for Diamond Light Source I14 (doi: 10.1063/5.0084806)



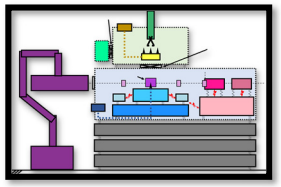
Sample Stage Motion (Ry)

8x speed

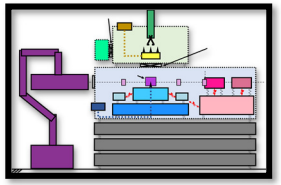


Sample Stage Motion (XYZ)

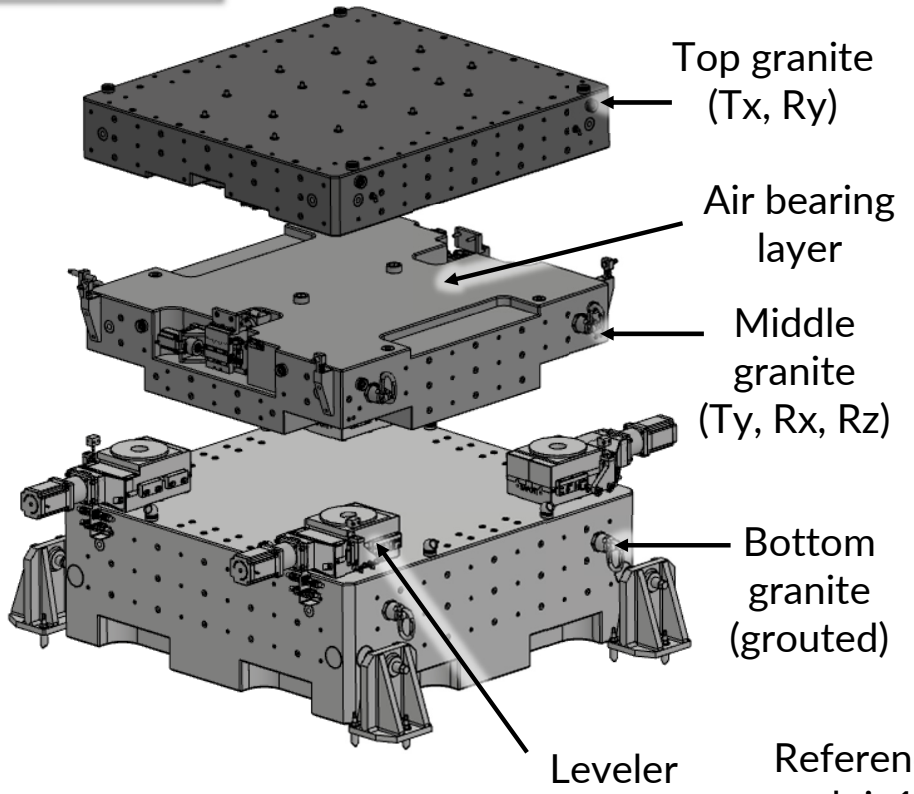
8x speed

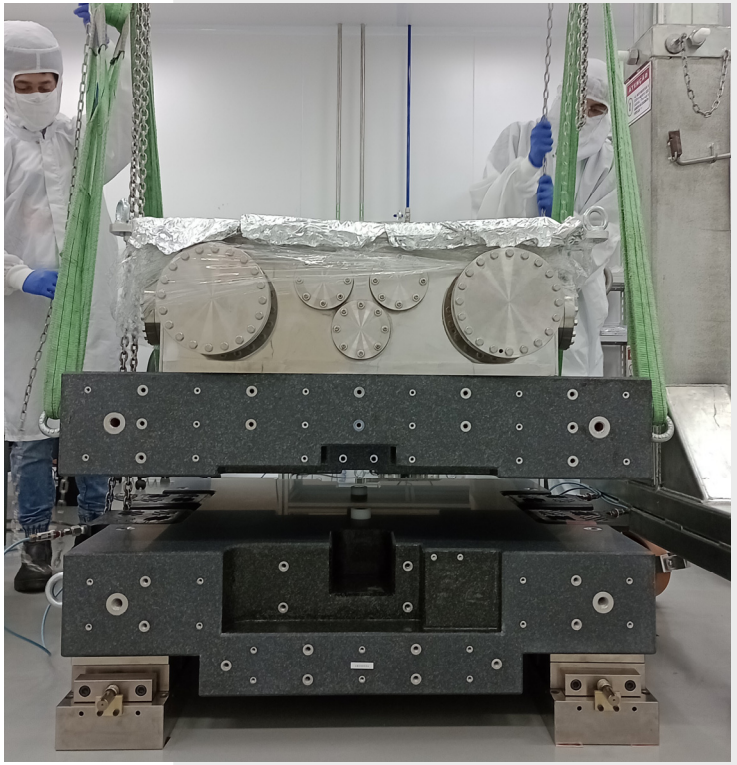


Sample Stage XY scanning performance



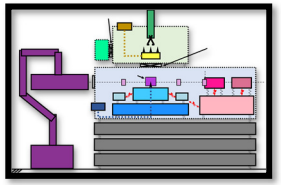
Miscellaneous: Granite Bench



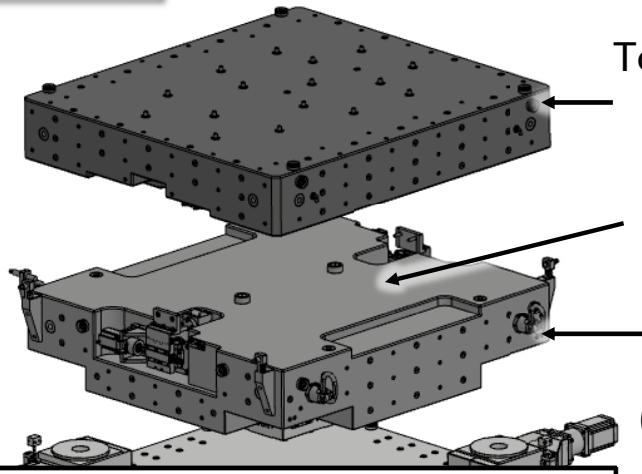


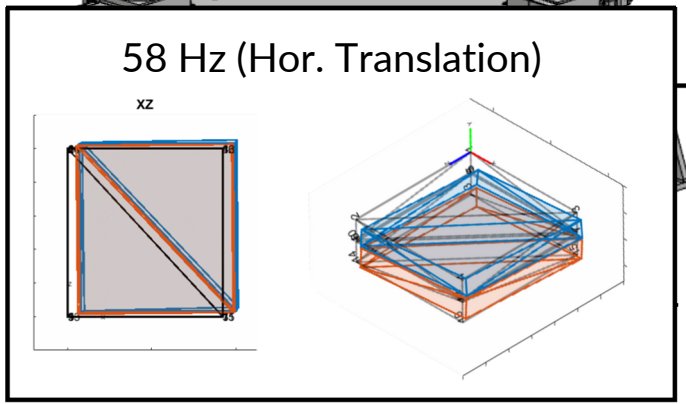
Reference Papers:

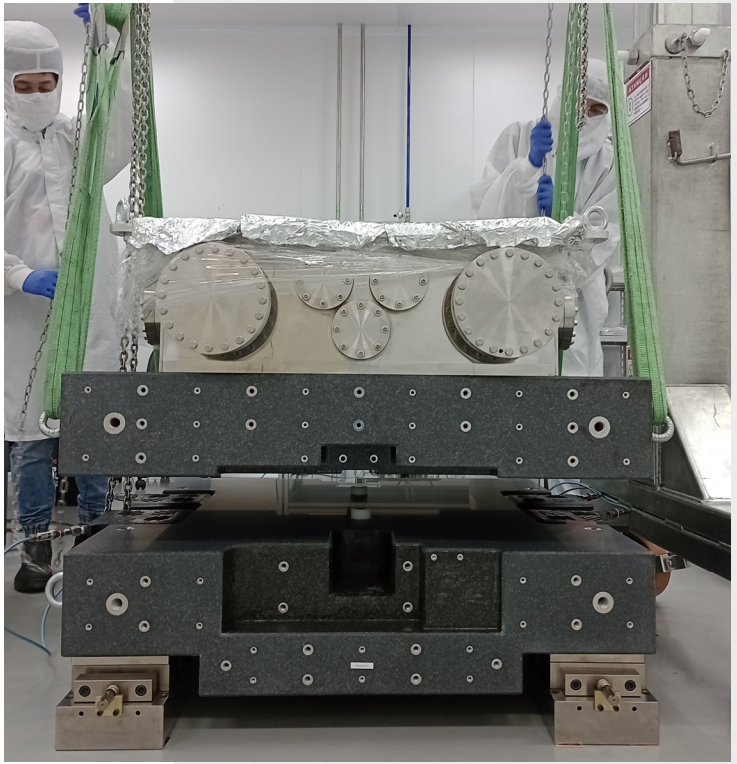
- doi: 10.18429/JACoW-MEDSI2018-THPH12
- doi: 10.18429/JACoW-MEDSI2020-WEPB13



Miscellaneous: Granite Bench







Reference Papers:

- doi: 10.18429/JACoW-MEDSI2018-THPH12
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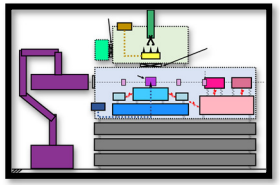
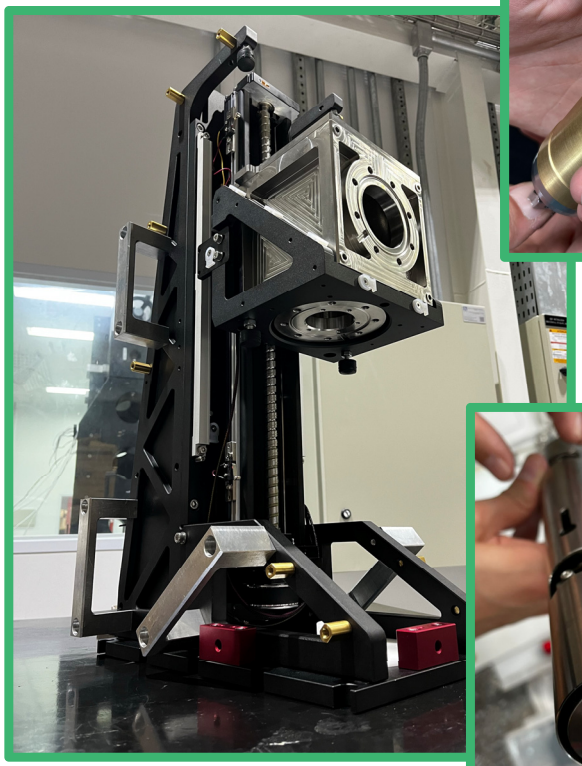
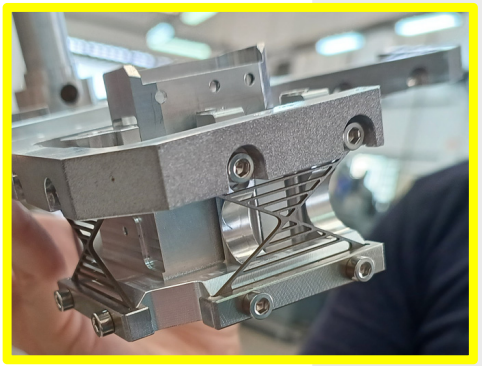
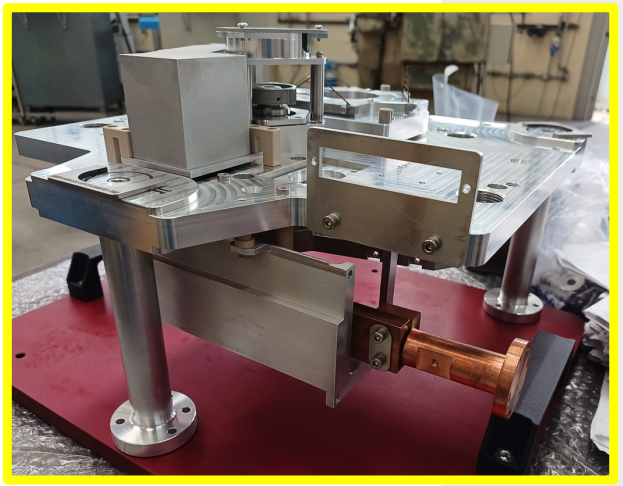


Miscellaneous: Gripper and Carousel

with







Conclusions

- Holistic and systemic design approaches;
- Predictive design framework;
- Cryogenic sample stage functionalities according specs;
  - sub-100K sample temperature;
  - mm-range operation;
  - single(ish)-nanometer scanning error levels;
  - sub-10-second 2D maps.
- Remaining modules under final manufacturing/integration;
- First experiments scheduled to June 2024.

Thank you!

The authors would like to gratefully thank:

- the Brazilian Ministry of Science, Technology and Innovation for funding;
- the LNLS and CNPEM teams for the collaboration;
- MI-Partners team for the collaborative work;
- the organizers for the opportunity;
- the audience for the attendance.

LNLS sirius

CNPEM Brazilian Center for Research in Energy and Materials

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