Australian Government

ANSTO

Engineering Challenges in BioSAXS for the Australian Synchrotron

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BioSAXS Team

SCIENCE
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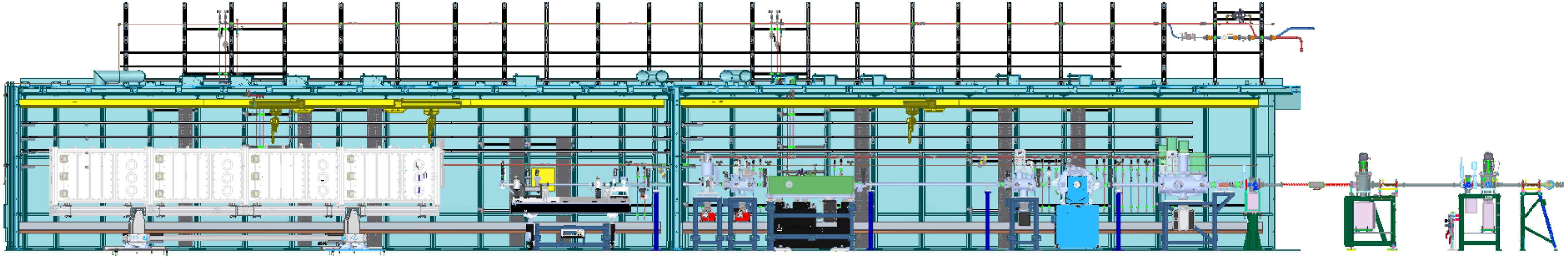
Software Engineer – Clinton Roy
Lead Beamline Engineer – Sudharshan Venkatesan

Design Partners: FMB Oxford

Beamline Configuration



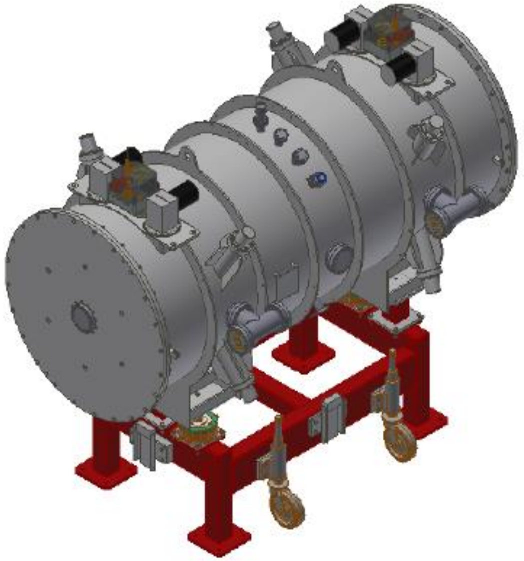
Vacuum Sections

Vacuum Section	Components
1	DM1
2	DMM
3	DM2
4	KB Mirror
5	DM3
6	Safety Shutter
7	BCT
8	End Station

Super Conducting Undulator Source

X-Ray source for the BioSAXS beamline is a Superconducting Undulator (SCU) with period length of 16mm, 98 full periods and magnetic field strength of 1.084 T (on axis). The device has been designed and manufactured (in progress) by Bilfinger Noell GmbH (NOELL).

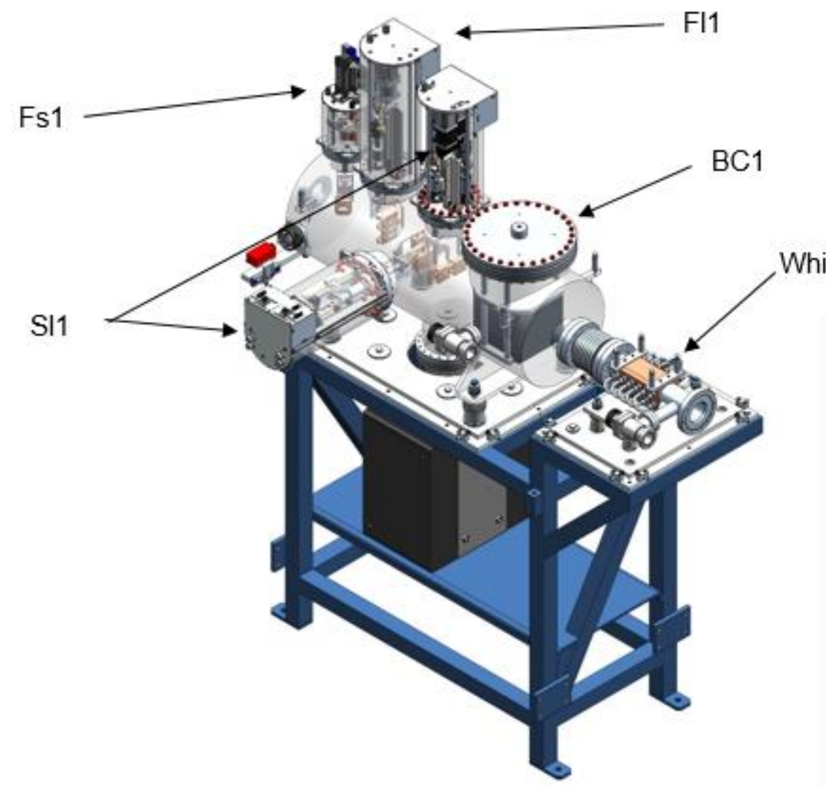
BioSAXS SCU is cryogen free and the cold mass is directly connected to 4 cold heads.

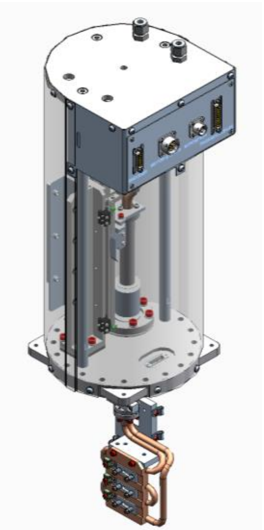


Key Challenges

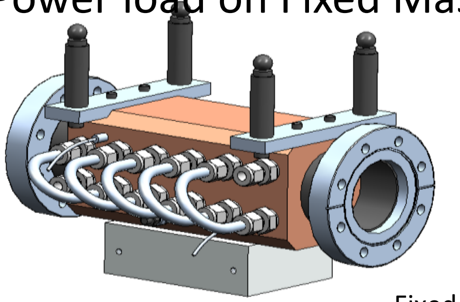
- Thermal load
  - Large heat loads from super conducting undulator source
- Radiation
  - Bremsstrahlung radiation management
- Design
  - 3 Key operating modes for the beamline
  - Challenging design flexibility needed to meet these needs

Thermal Loads

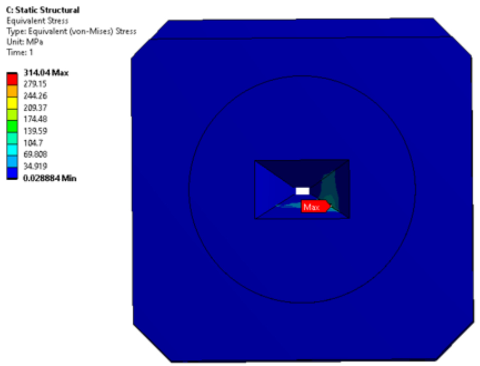


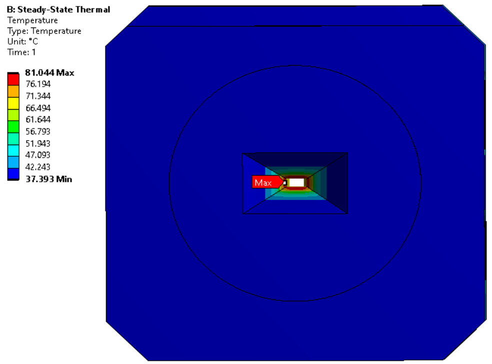


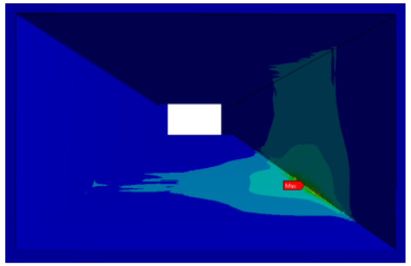
Power load on Fixed Mask – 2KW



Fixed Mask







Cooled Filter Rack 1

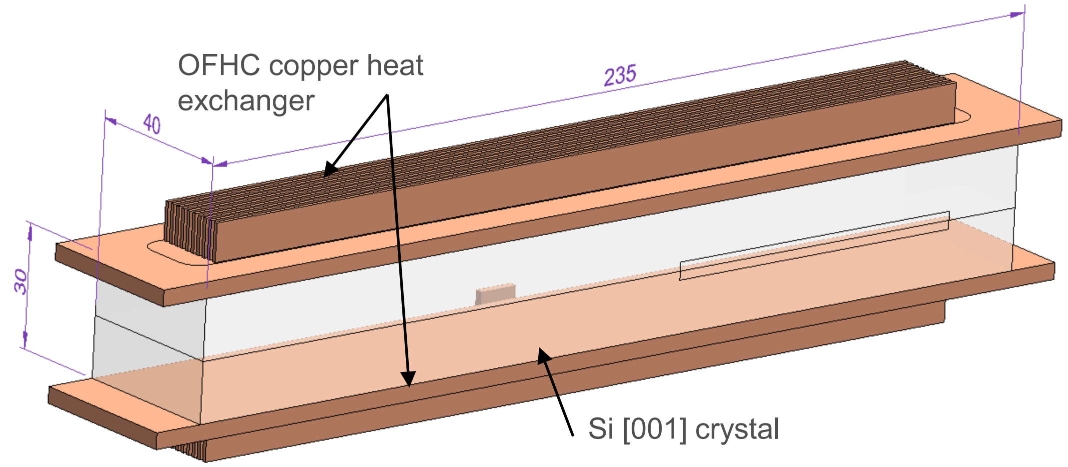
Filters:

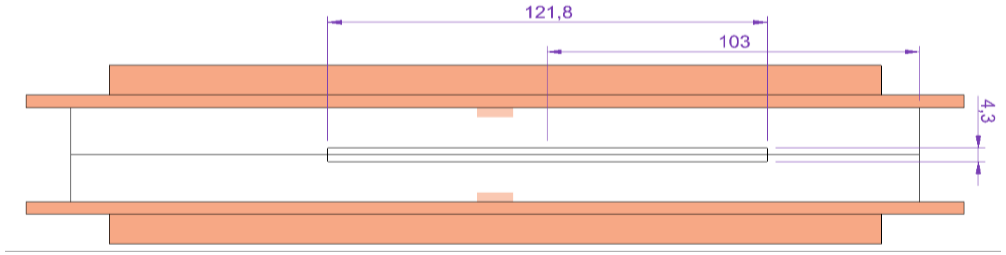
1. 100 µm thick CVD diamond in the lower position
2. 200 µm thick CVD diamond in the centre position
3. 200 µm thick CVD diamond in the upper position

Description	Parameter	Design Specification
Vertical	Drive	Stepper motor with Absolute Encoders
	Range	±25mm
	Resolution	<2 µm
	Repeatability	<10 µm

Image courtesy – FMB Oxford

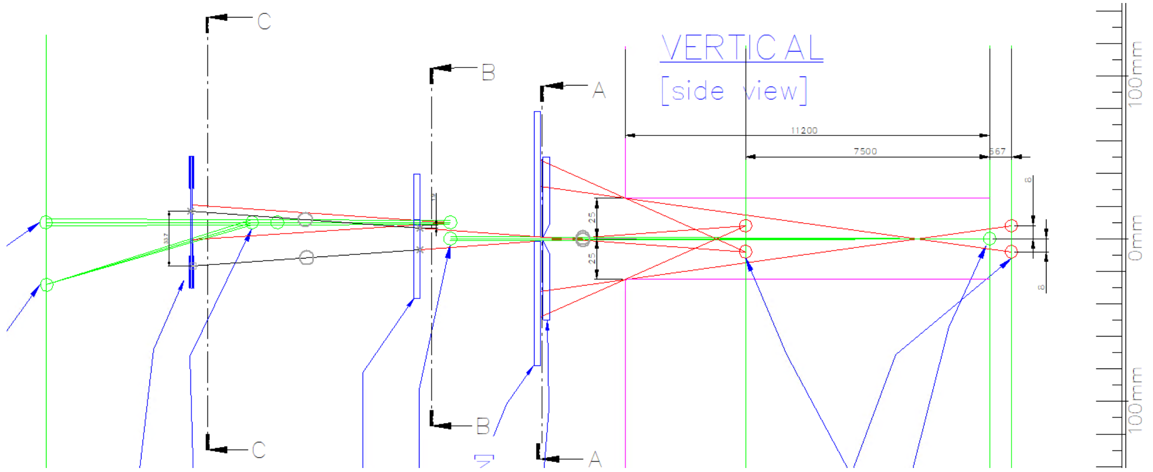
Thermal Loads

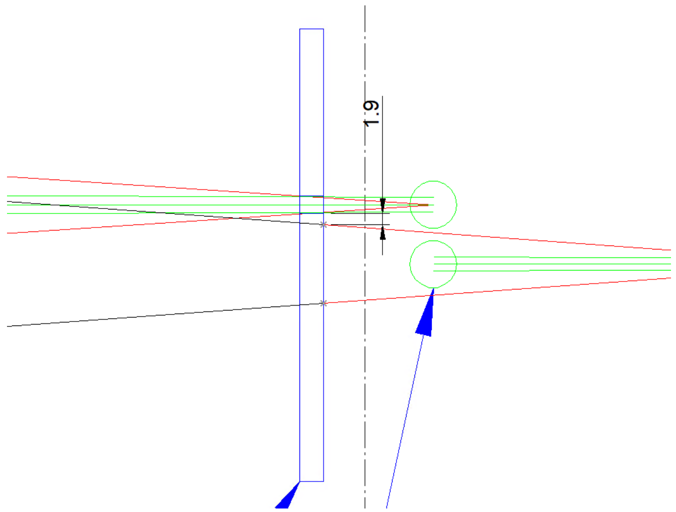




Total heat load:
Up from 165W to 402W

Radiation and Safety



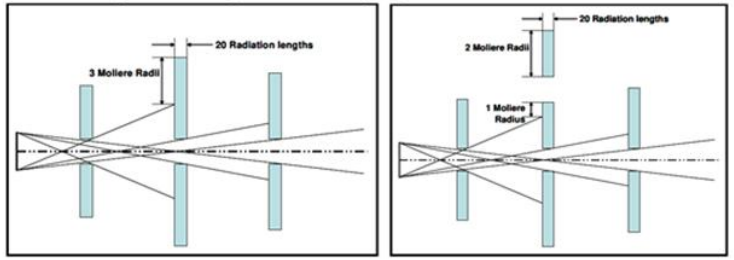


Guidance for Beamline Shielding At AS

5.5 Ray-tracing and Shielding Dimensions

Studies show that a longitudinal depth of 20 radiation lengths and a transverse dimension of three Moliere Radii is required to contain 99% of a bremsstrahlung shower within a shielding block in which it is generated[17]. It is recommended, therefore, that the design of bremsstrahlung shutters, stops or collimators be a minimum of three Moliere Radii in the transverse direction to the beam with a minimum longitudinal depth of 20 radiation lengths for the shielding material. For components where this is not possible it is recommended that a minimum of one Moliere radius be provided followed by two Moliere Radii while maintaining a minimum longitudinal depth of 20 radiation lengths (see Figure 11). The Moliere Radius for lead is ~12 mm and for tungsten is ~8 mm, while the radiation length for lead is 5.6 mm and for tungsten is 3.5 mm.

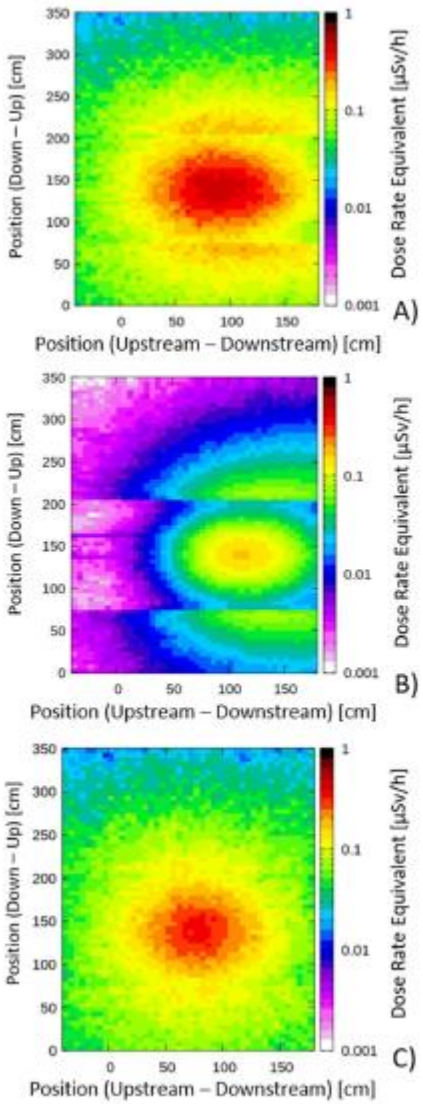
Figure 11. Example of Extreme Ray Layout Plan View for a Beamline.



The transverse dimensions of the beamline component are determined from primary bremsstrahlung ray-tracing. The external ray in the case of primary bremsstrahlung ray-tracing must not be closer than 45 mm from the lateral edge of the lead shielding or 35 mm from that of tungsten shielding.

1. Increase distance between Brem ray to aperture;
2. Montecarlo and Fluka analysis to quantify impact;
3. Change monochromatic shutter to Brem Stop with aperture for deflected and un-deflected beam (200mm thick Tungsten);
4. Additional 2 shutters after the Brem stop in FOE (material thickness depending on scatter)
5. Increase shielding in FOE and Back Wall based on analysis;
6. Measurement of radiation during commissioning;
7. Increase shielding if necessary;

Radiation Dose Rates



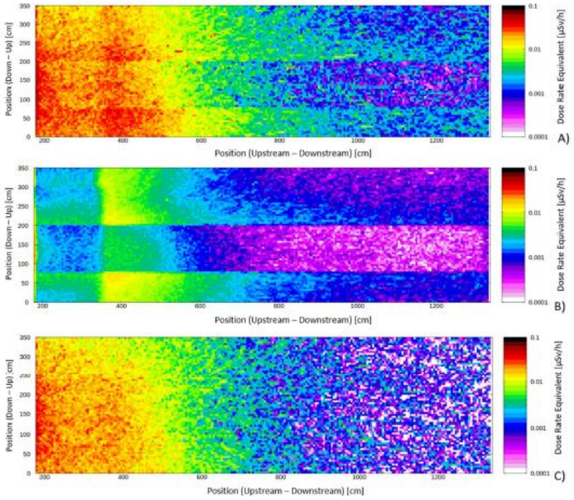


Figure 7: Dose rate equivalent distribution along the FOE outboard wall along the downstream portion of the wall: A) Total dose rate equivalent, B) photon dose rate equivalent, and C) neutron dose rate equivalent.

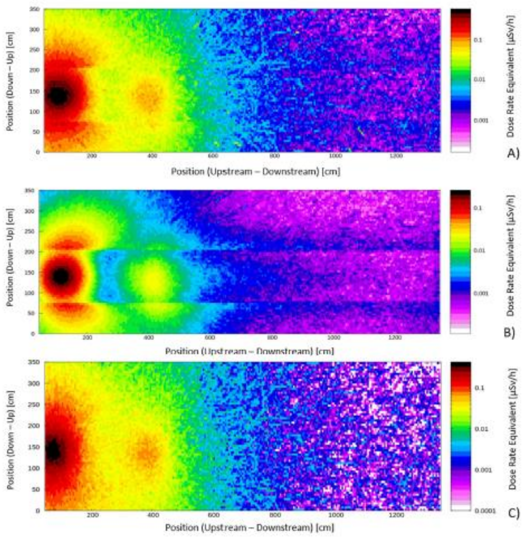
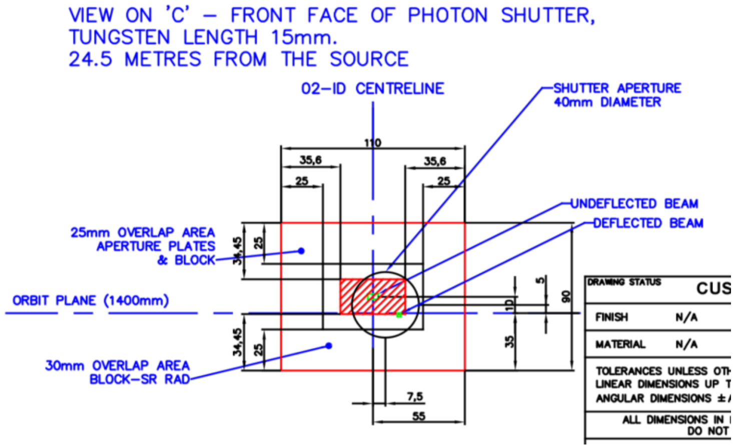
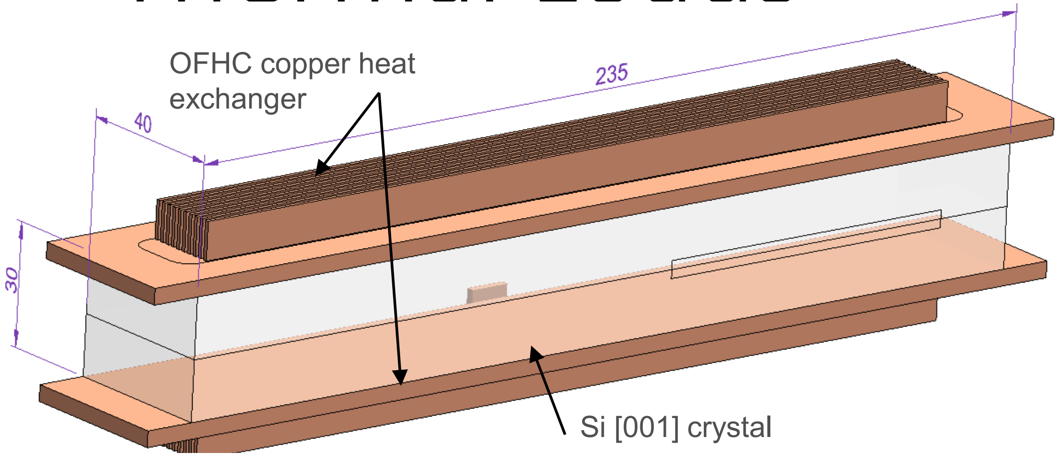


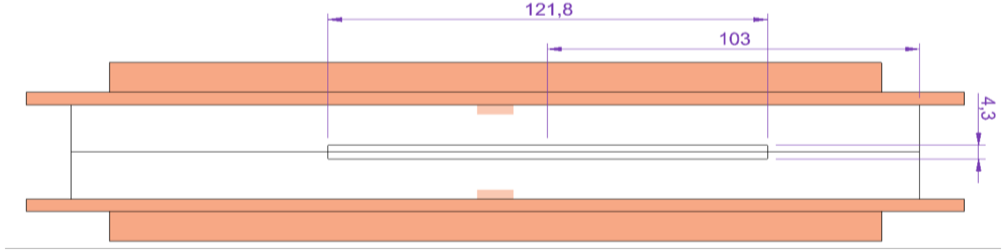
Figure 8: Dose rate equivalent distribution along the FOE inboard wall: A) Total dose rate equivalent, B) photon dose rate equivalent, and C) neutron dose rate equivalent.

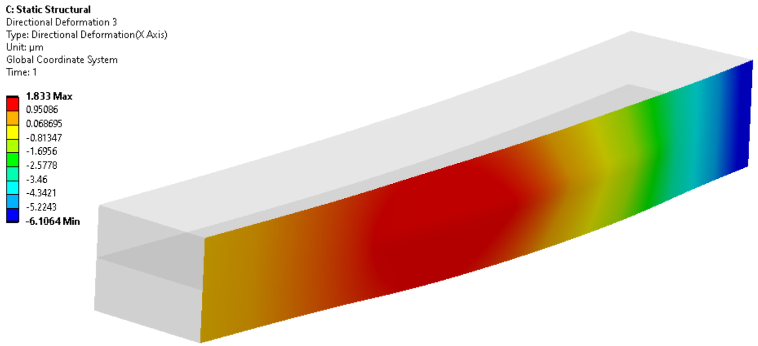


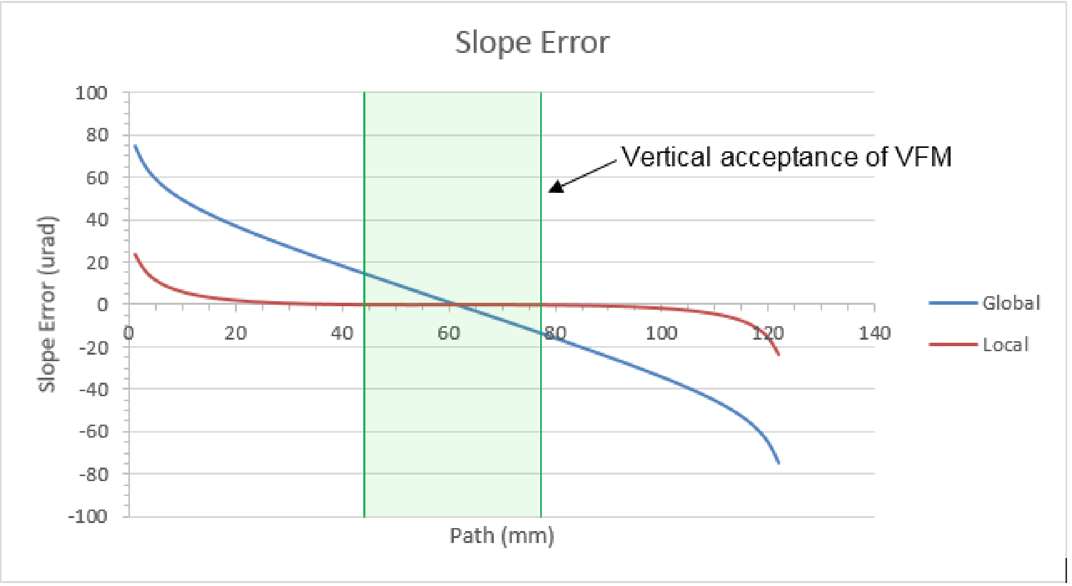
- Full Motecarlo andFluka analysis performed by CLS
- Analysis for 6.5mm aperture edge-to-edge separation of the second Bremsstrahlung collimator and the Bremsstrahlung stop (0.7 Moliere Radii)
- **Results show radiation dose rates will not exceed 0.5µSv/h**

Thermal Loads









Maximum deformation in ML1: 1.83µm

Global Slope error: 8.37µrad RMS

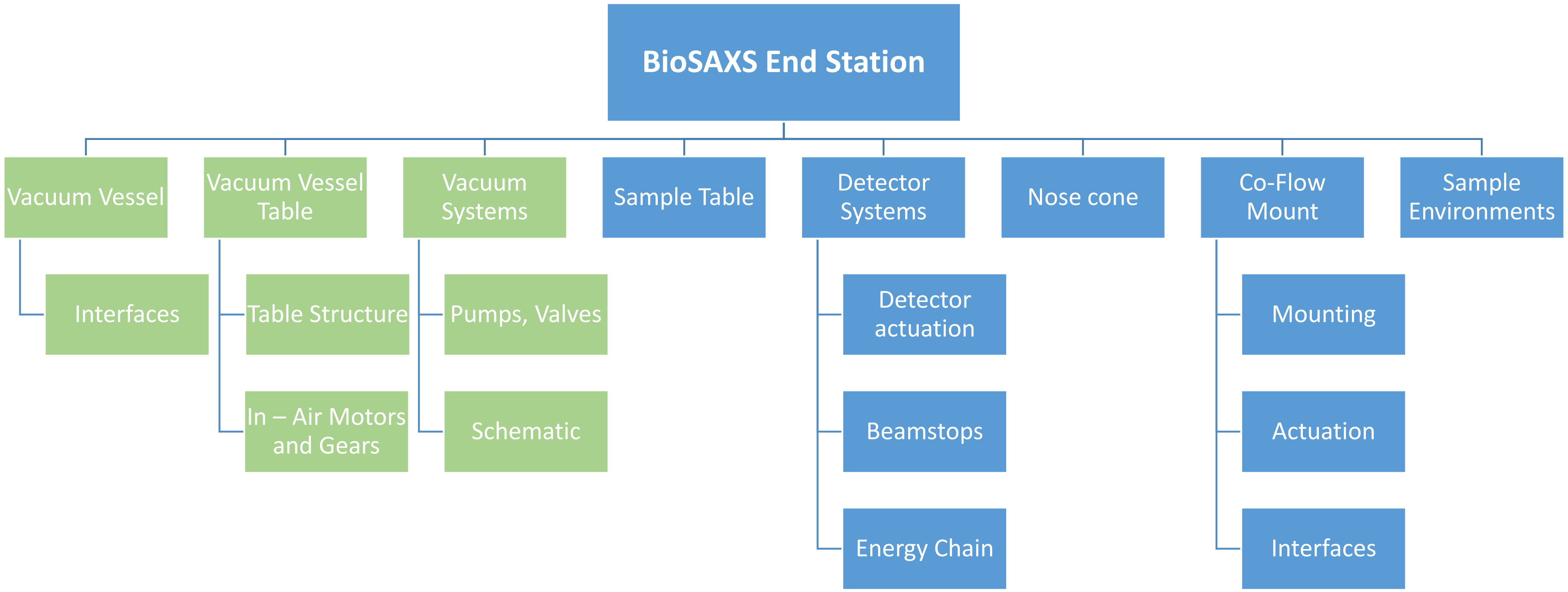
Local Slope Error: 0.0232 µrad RMS

Thermal loads can be managed with no cryo cooling, even with a SCU

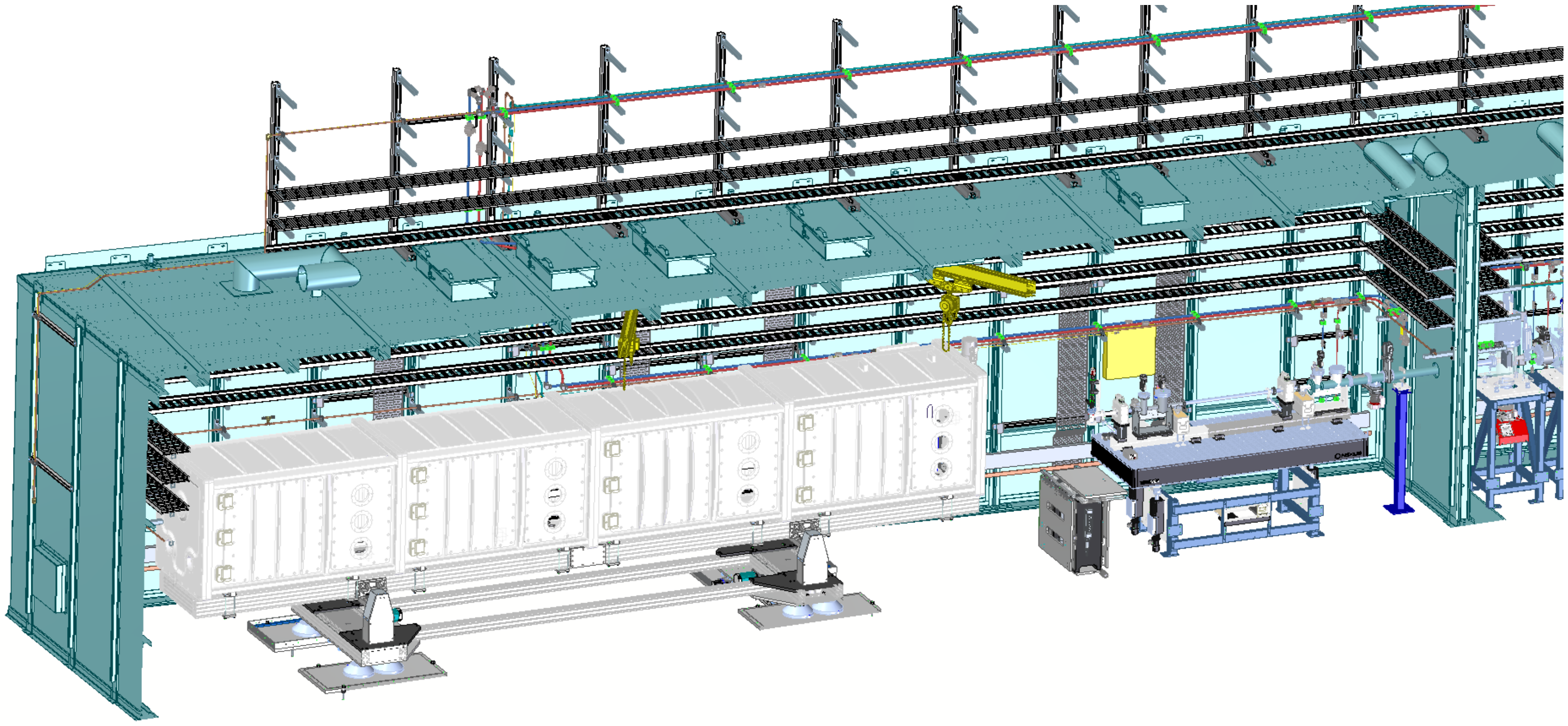
Flow rate	2.5 L/min
Mean stream velocity	1.47 m/s
Reynolds Number	2659.95
Nusselt number	27.87
Heat transfer coefficient	8932.6 W/m^{2}K

Image courtesy – FMB Oxford

End Station

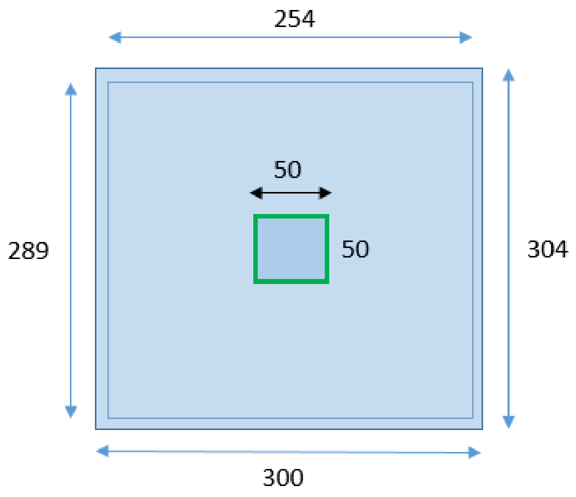

BioSAXS End Station
Vacuum Vessel
Interfaces
Vacuum Vessel Table
Table Structure
In – Air Motors and Gears
Vacuum Systems
Pumps, Valves
Schematic
Sample Table
Detector Systems
Detector actuation
Beamstops
Energy Chain
Nose cone
Co-Flow Mount
Mounting
Actuation
Interfaces
Sample Environments

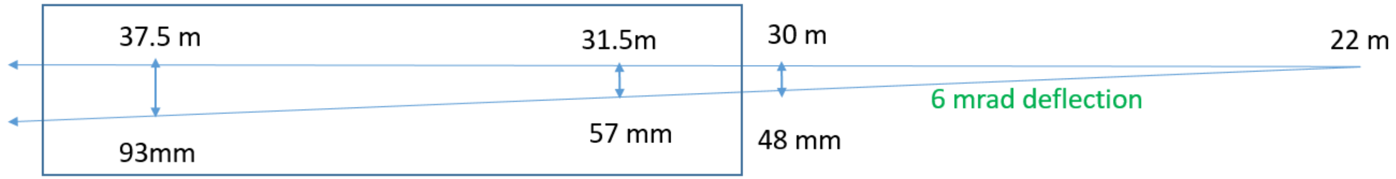
End Station



TARGET

View on Detector



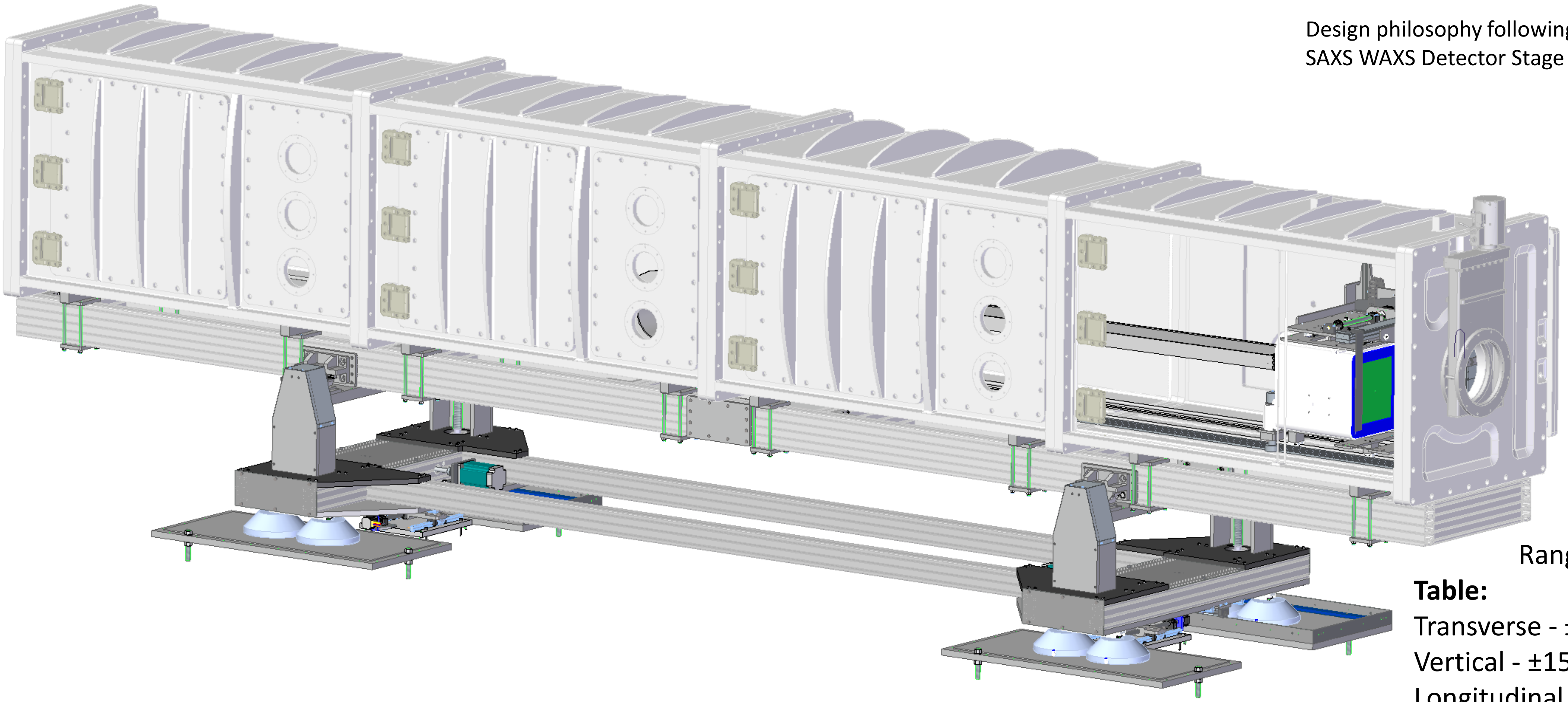


Beamline Operating Modes

1. Fully focussed
2. Vertically unfocussed
3. Fully unfocussed

Design Flexibility: End Station - Detector stage

Design philosophy following Australian Synchrotron SAXS WAXS Detector Stage



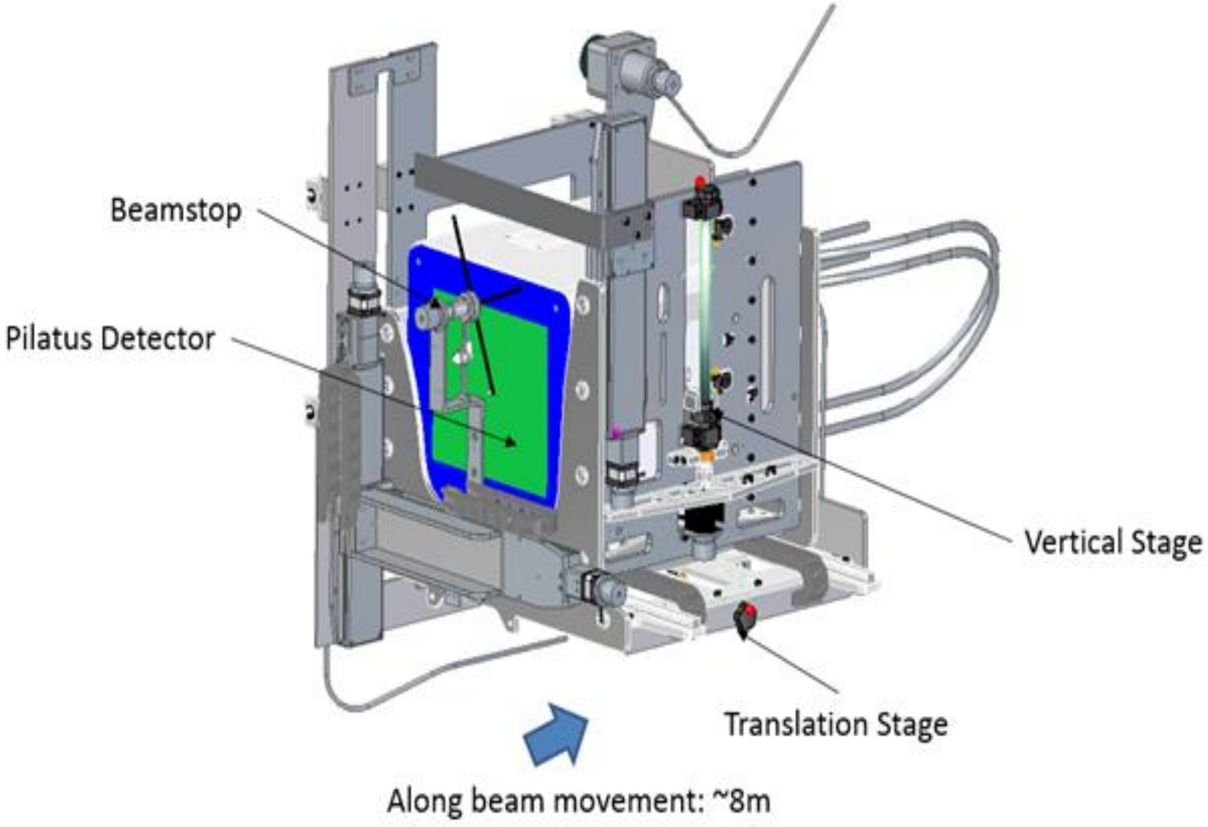
Range of motion

Table:
Transverse - ±150mm
Vertical - ±150mm
Longitudinal – +600mm
Pitch: Full range of motion

Detector:
Transverse - ±25mm
Vertical - ±25mm
Longitudinal – +7100mm

Original design credits: Brad Mountford, Adam Walsh, Luke Adamson, Nigel Kirby

Design Flexibility: End Station - Detector stage



Design philosophy following Australian Synchrotron SAXS WAXS Detector Stage

Range of motion

Detector:

Transverse - ±25mm

Vertical - ±25mm

Longitudinal – +7100mm

Original design credits: Brad Mountford, Adam Walsh, Luke Adamson, Nigel Kirby

Design Flexibility: End Station - Sample Table

Range of motion

Table:

Transverse - 600mm

Vertical - 400mm

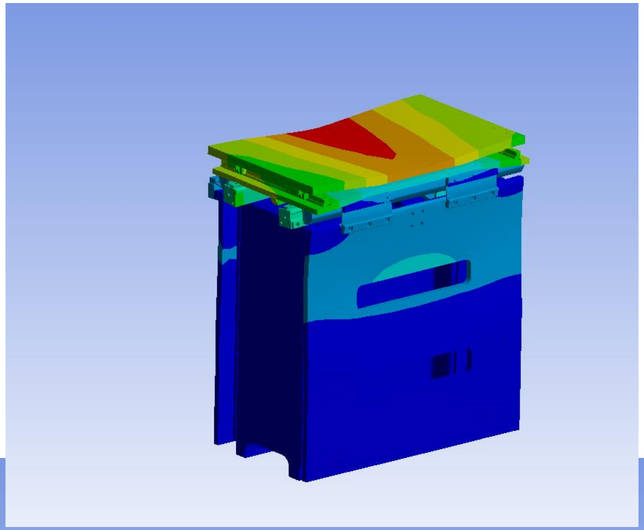
Longitudinal – 50mm

Pitch: 12mrad

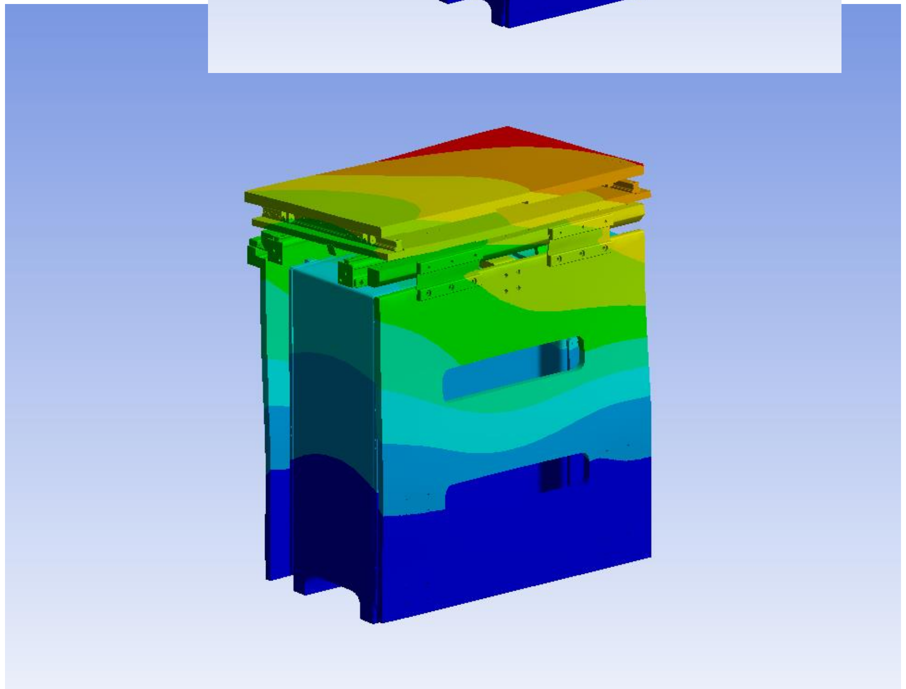
Park position:

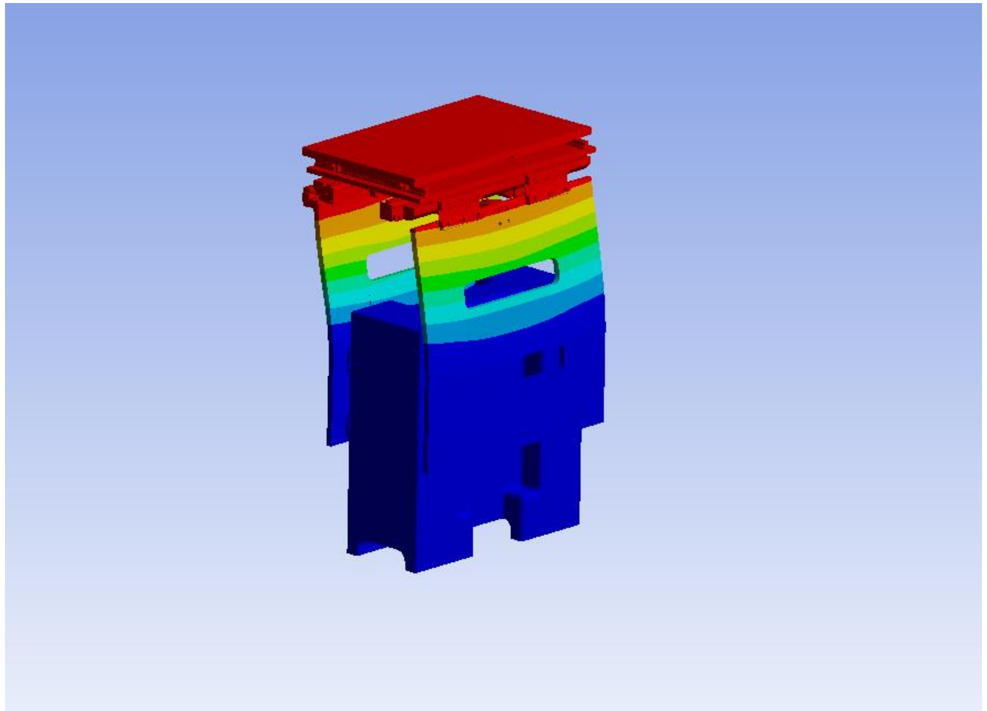
Transverse - 750mm

Design Flexibility: End Station - Sample Table



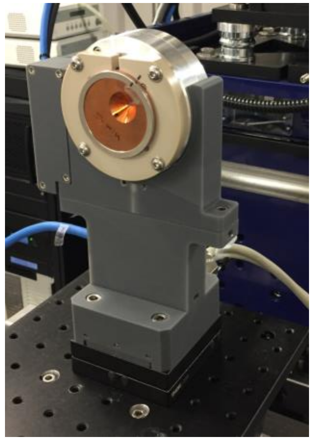
Static deflection: 0.009mm
Load carrying capability: 100Kgs





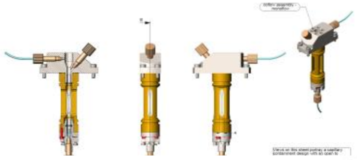
Eigen Frequency	Low height configuration	High height configuration
1	137.3 Hz	78.181 Hz
2	167.48 Hz	128.6 Hz
3	169.99 Hz	132.37 Hz
4	174.73 Hz	166.01 Hz
5	207.85 Hz	185.56 Hz
6	228.93 Hz	205.99 Hz

Sample Environments

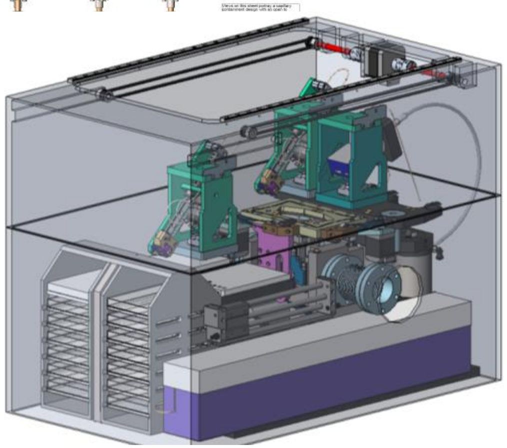


Shear cell

Capillary Linkam stage for temperature ramps up to 350°C



CoFlow



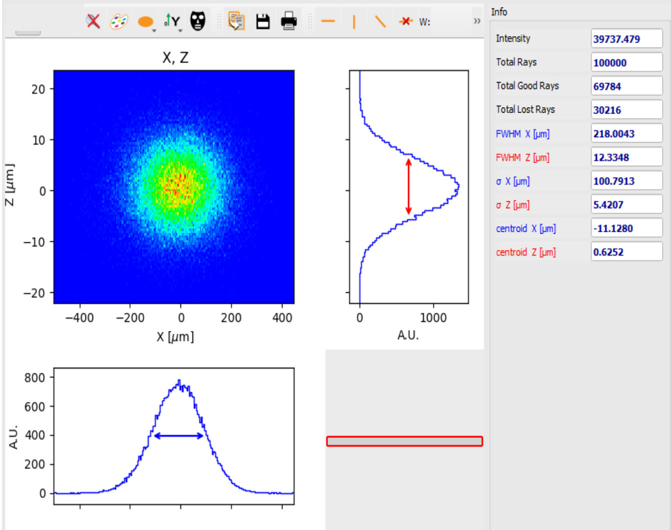
N. Kirby, et. al. *Acta Cryst. D.* **D72** 1254-1266 (2016)
T.M. Ryan, et al. *J. Applied Cryst.* **51**, 97-111 (2018)

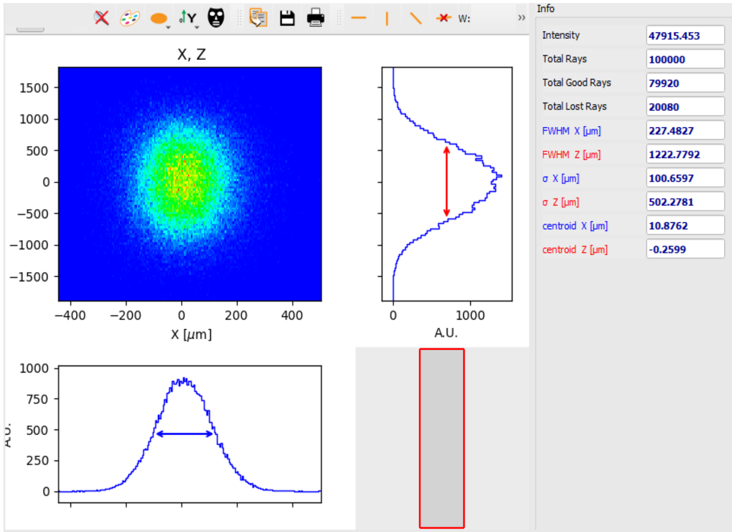
Multi-position temperature controller based on Peltier furnace for solution samples

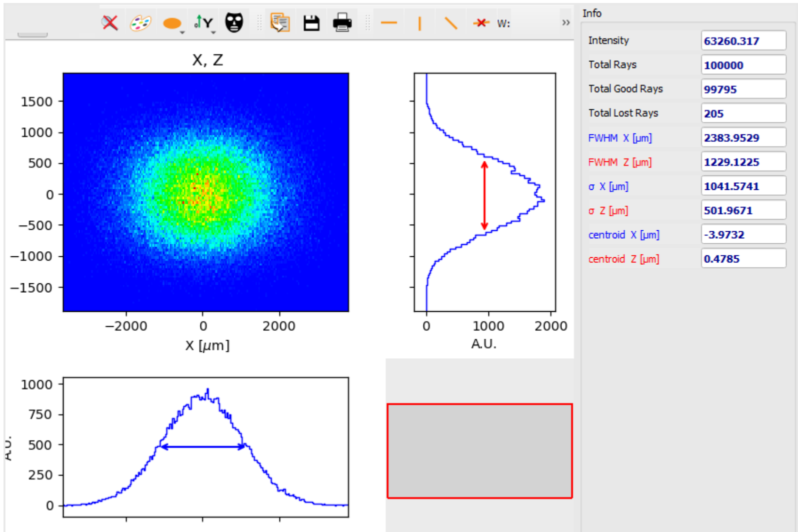
Next sample environments to be developed would be a novel magnetic sample environment and a microfluidics system

Outcomes

HFM Parameters	Specification	Ray tracing results (Fully Focussed)	Ray tracing results (Vertically unfocussed)	Ray tracing results (Fully unfocussed)
Spot size HxV [µm]	< 300 x 100	261 x 12	227 x 1222 μm^2	2380 x 1230 μm^2.
Bandwidth	1%	0.43% *	0.43% *	0.43% *
Flux at image [photons/s]	2 x 10^{14}	5.07 x 10^{14}	6.12 x 10^{14}	8.07 x 10^{14}







Thanks!