Work Package 1

Management of the BEATS project

Thematic posters

D 1.8

March 2022

Funded by the EU's H2020 framework programme under grant agreement n°822535

PROJECT DETAILS

PROJECT ACRONYM
BEATS

PROJECT TITLE
BEAmline for Tomography at SESAME

GRANT AGREEMENT NO:
822535

THEME

START DATE
2019

DELIVERABLE DETAILS

WORK PACKAGE: 01

EXPECTED DATE: ***31/12/2021***

WORK PACKAGE TITLE: MANAGEMENT OF THE BEATS PROJECT

DELIVERABLE TITLE: ***THEMATIC POSTERS***

WORK PACKAGE LEADER: ESRF

DELIVERABLE DESCRIPTION: ***REPORT***

DELIVERAVLE ID: D1.8

PERSON RESPONSIBLE FOR THE DELIVERABLE: ***KIRSTIN COLVIN***

NATURE

☒ R - Report ☐ P - Prototype ☐ D - Demonstrator ☐ O - Other

DISSEMINATION LEVEL

x	P - Public	
☐	PP - Restricted to other programme participants & EC:	
☐	RE - Restricted to a group	
	CO - Confidential, only for members of the consortium	

REPORT DETAILS

VERSION: 1

DATE: 08/03/2022

NUMBER OF PAGES: 3 + ANNEX

DELIVERABLE REPORT AUTHOR(S): ***GIANLUCA IORI, KIRSTIN COLVIN***

FOR MORE INFO PLEASE CONTACT: ***COLVIN@ESRF.FR, GIANLUCA.IORI@SESAME.ORG.JO***

STATUS

☐	Template	☐	Draft
☒	Final	☒	Released to the EC

SUMMARY

When the grant application for Grant # 822535 was established in 2018, the BEATS consortium foresaw a deliverable called “Thematic Posters” for the end of the 3rd year. It was planned to produce posters on the aims and preliminary results of the project and the parameters of the beamline and the experimental opportunities offered. The intention was to present these posters at conferences and synchrotron radiation facility events like users meetings etc.

Unfortunately, due to the pandemic, conferences were mostly held online or postponed. Likewise, presence at facility meetings was also impossible.

Two general purpose posters were produced (attached).

- One describing the BEATS Science Case, listing its major four pillars
    - Health, Biology, and Food,
    - Archaeology and Cultural Heritage
    - Materials Science and Engineering, and
    - Geology and Environment.
    - Furthermore, three examples of research in these fields, for which we expect applications for beamtime, are explained.

- The second poster presents the BEATS beamline layout:
    - all relevant beamline performance design parameters
    - an overall 3d model of the beamline
    - sections describing the x-ray source, the optical elements (double multilayer monochromator), and the experimental station (sample and detector stage).

Furthermore, two posters were created to be presented at the *International Conference on Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation* (MEDSI 2020, held finally remotely in summer 2021):

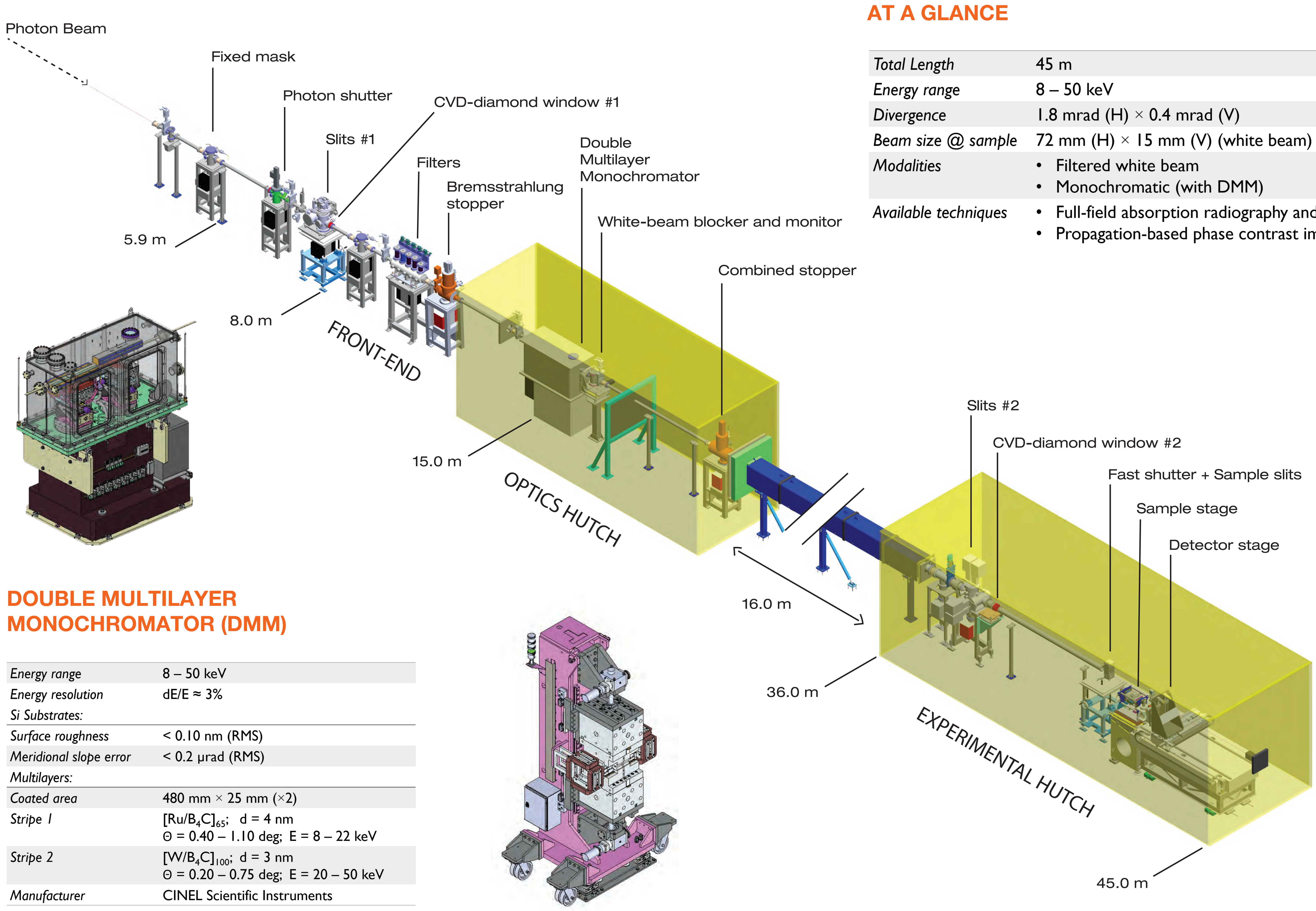
- One describing finite element calculations performed during the design of the BEATS experimental station to determine the vibrational properties of the detector stage,

- one describing the results of ray-tracing calculations performed during the design of the BEATS source and optical elements to determine the characteristics of the photon beam (based on a paper presented by experts from BEATS WP4 to the same conference: https://doi.org/10.18429/JACoW-MEDSI2020-WEPA10).

Later in the project, the BEATS team will produce more posters to illustrate the commissioning process of the beamline and results, as well as the day-one beamline operation (report on experimental parameters achieved by the first “friendly users”) together with a poster on the beamline operation manual.

BEATS LAYOUT AND PARAMETERS

The BEAmline for Tomography at SESAME (BEATS) operates an X-ray micro tomography station allowing for a variety of operation modes. BEATS can work with filtered white beam, with minimum energy tunable by absorbers in the front-end, or with monochromatic beam from a Double Multilayer Monochromator (DDM). The experimental hutch hosts sample manipulators and a range of detectors for different applications. The beam size at the sample position and the propagation distance between sample and detector can be varied by displacing sample and detector stages along the beam path. For measurements requiring high sensitivity and spatial coherence of the beam (e.g., phase-contrast applications), a smaller, secondary source with higher spatial coherence can be obtained by reducing the aperture of the beamline front-end slits.



AT A GLANCE

Total Length	45 m
Energy range	8 – 50 keV
Divergence	1.8 mrad (H) × 0.4 mrad (V)
Beam size @ sample	72 mm (H) × 15 mm (V) (white beam)
Modalities	• Filtered white beam • Monochromatic (with DMM)
Available techniques	• Full-field absorption radiography and tomography • Propagation-based phase contrast imaging

DOUBLE MULTILAYER MONOCHROMATOR (DMM)

Energy range	8 – 50 keV
Energy resolution	dE/E ≈ 3%
Si Substrates:	
Surface roughness	< 0.10 nm (RMS)
Meridional slope error	< 0.2 µrad (RMS)
Multilayers:	
Coated area	480 mm × 25 mm (×2)
Stripe 1	$[Ru/B_4C]_{65}$; d = 4 nm Θ = 0.40 – 1.10 deg; E = 8 – 22 keV
Stripe 2	$[W/B_4C]_{100}$; d = 3 nm Θ = 0.20 – 0.75 deg; E = 20 – 50 keV
Manufacturer	CINEL Scientific Instruments

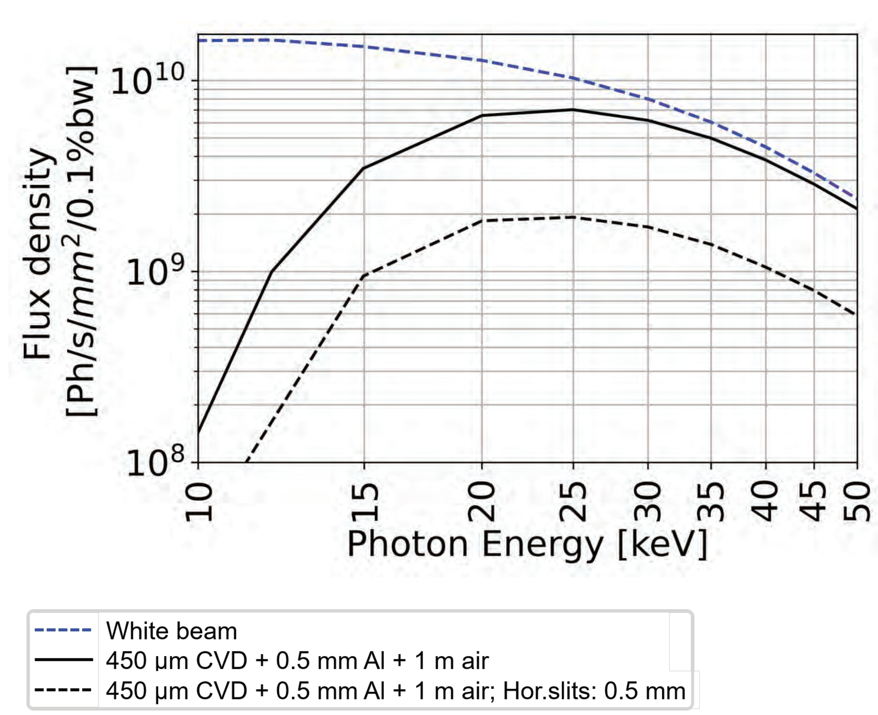
X-RAY SOURCE: 3-POLE WIGGLER

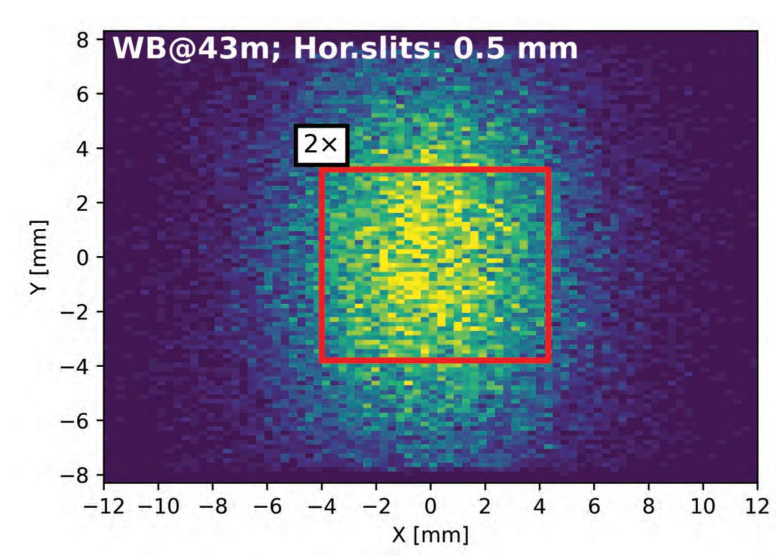
Compared with a superbend or a multipole wiggler, a high-field wavelength shifter is cost-effective and compact. Its magnetic design allows for a peak magnetic field of $3T$, ensuring sufficient photon flux over a broad energy range. Adverse effects on the storage ring electron orbit are minimal.

Type	3-pole wiggler
Minimum gap	11 mm
Peak field	2.94 T
Critical energy	12.5 keV
Magnetic length	0.41 m
Manufacturer	KYMA

BEAM PROPERTIES AT THE SAMPLE

White beam:	• Flux density: 8×10^9 Ph/s/mm²/0.1%BW • beam size @ 43m: 72×15 mm²
Monochromatic; 25 keV (DMM stripe 2)	• Flux density: 1×10^{11} Ph/s/mm² • Beam size @ 43 m: 68×8 mm²





CAMERAS AND DETECTORS

	Camera 1	Camera 2
Sensor type	sCMOS	CMOS
Manufacturer	PCO	Teledyne FLIR
Model	edge 5.5	Oryx 10GigE
Megapixels	5.5	7.1
Sensor size	2560 × 2160	3208 × 2200
Pixel size	6.5 µm	4.5 µm
Max frame rate (full frame)	100 fps	112 fps
Bit-depth	16 bit	12 bit
Dynamic range	88.6 dB	71.4 dB

	Detector 1	Detector 2	Detector 3
Type	White-beam microscope	White-beam microscope	Monochromatic microscope
Manufacturer	ESRF	Optique Peter	Optique Peter
Lens type	Hasselblad H system	Mitutoyo M Plan Apo (radiation hardened)	Olympus PLAPO/UPLAPO
Magnification	0.5× – 2×	5× – 10×	10× – (20×)
Available voxel size (with PCO edge)	13 – 3.25 µm	1.3 – 0.65 µm	0.65 – 0.33 µm

PARAMETERS OF THE SESAME STORAGE RING

Energy	2.5 GeV
Circumference	133.2 m
N. of Periods	8
Emittance	26.0/0.26 nm.rad (H/V)
Harmonic Number	222

BEATS receives funding from the European Union Horizon 2020 research and innovation programme under the grant agreement 822535

www.beats-sesame.eu/

@BEATSeu1

Contact : Gianluca.Iori@sesame.org.jo

Credit images: DMM: CINEL; 3-pole wiggler: KYMA

THE SCIENCE AT BEATS

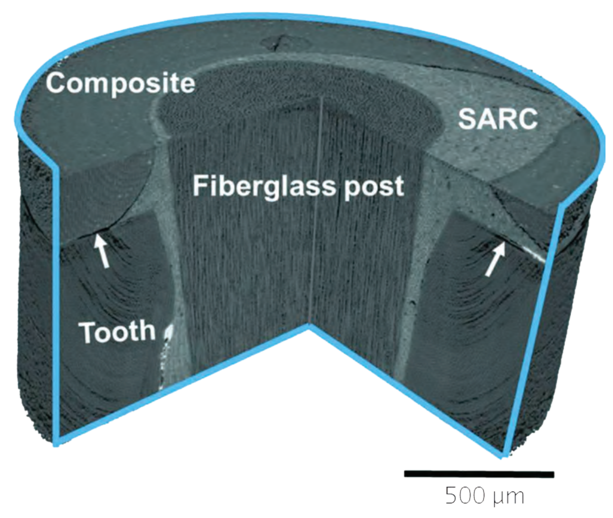
BEATS
BEAmline for Tomography at SESAME

The SR-CT - synchrotron radiation computed tomography - station of the BEATS beamline enables a large variety of applications of X-ray tomography. The scientific case results from close interactions with the scientific communities of current and potential synchrotron users in the SESAME region.

Areas of Research

HEALTH, BIOLOGY AND FOOD

- Musculoskeletal research
- Bone and dental implants
- Soft tissue imaging
- Animal and plant characterization
- Food science

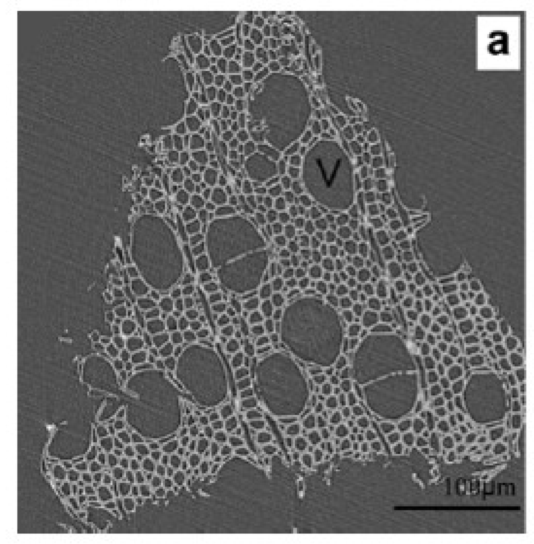


Hard X-ray phase-contrast-enhanced micro-CT for quantifying interfaces within brittle dense root-filling-restored human teeth. Prates Soares et al. 2020. J. Synchrotron Rad. 27, 1015-1022.

ARCHAEOLOGY AND CULTURAL HERITAGE

SR-CT allows the study of archaeologically relevant materials like

- Human, animal and plant remains, as well as artefacts of animal bone, antlers, teeth, etc.
- Composition and structure of works of art, paint and materials revealing the origin and creation processes.



Identification of wood species by non-destructive SR-CT sectioning. Historical Japanese mask. Mizuno et al. 2010. Journal of Archaeological Science, 37(11):2842–5.

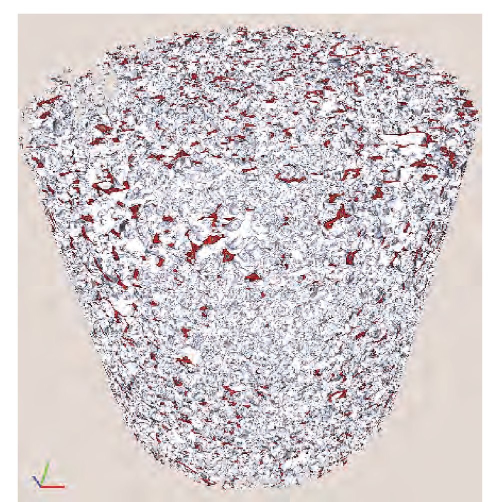
MATERIAL SCIENCE AND ENGINEERING

Study and development of light and composite materials for construction and transport engineering, energy, materials research.

Detecting defects and cracks in fiber composites. Ushizima et al. 2021. Kitware Blog.

GEOLOGY AND ENVIRONMENT

- Simulation of rock properties
- Soil characterization
- Sustainable agriculture



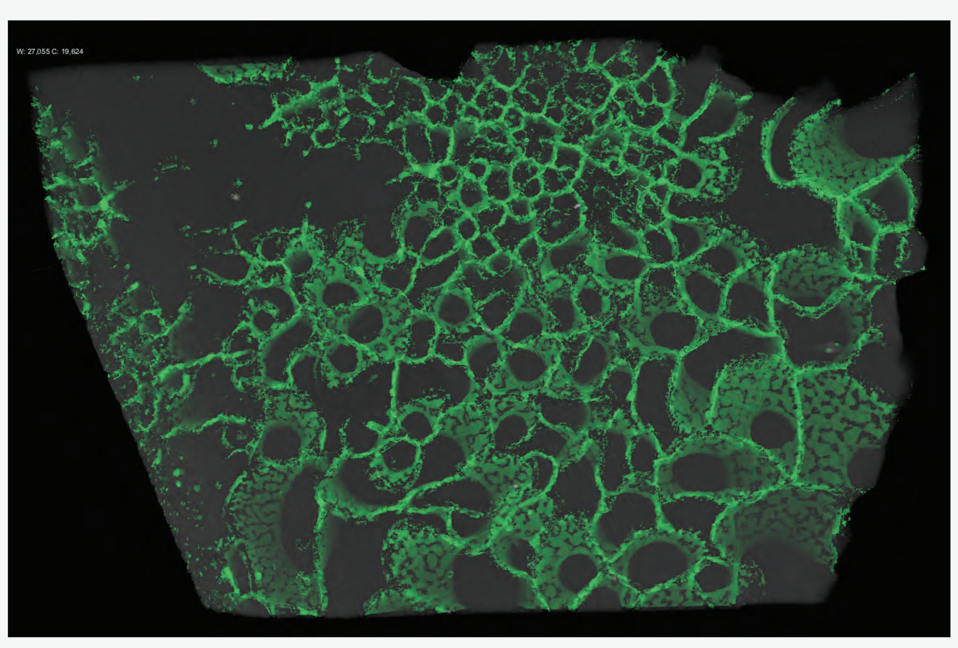
Digital Rock Physics: computation of porosity, permeability, elastic modulus, wave velocity and other physical properties of rock and soil samples from 3D SR-CT datasets. (Courtesy Shiva Shirani and ID19, ESRF)

Examples of Research

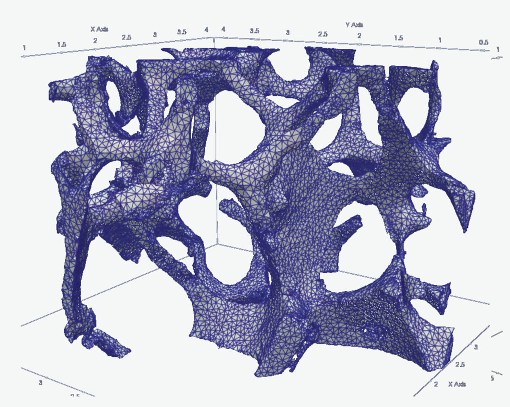
ANCIENT ROMAN GLASS

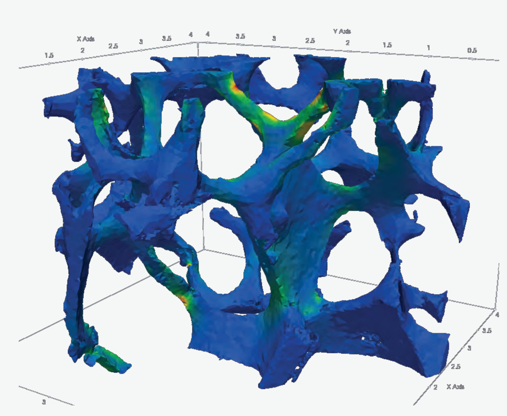
Imaging the material density distribution and the internal microstructure of Roman glass allows to obtain historical and technical information from rare samples, and to help with defining novel conservative strategies for glass. The aim of this experiment was to explore, in a completely non-destructive manner, the 3D material density and interior crack distribution through archaeological glass artefacts showing different macroscopical features and characteristic degradation. Synchrotron X-ray computed tomography allows to put in relation microscopic morphological differences with the corrosion mechanisms that affected each sample and, in some cases, the typical manufacturing technique employed for their preparation.

Courtesy of CCHT- Italian Institute of Technology



ENGINEERING MATERIALS UNDER MECHANICAL STRESS

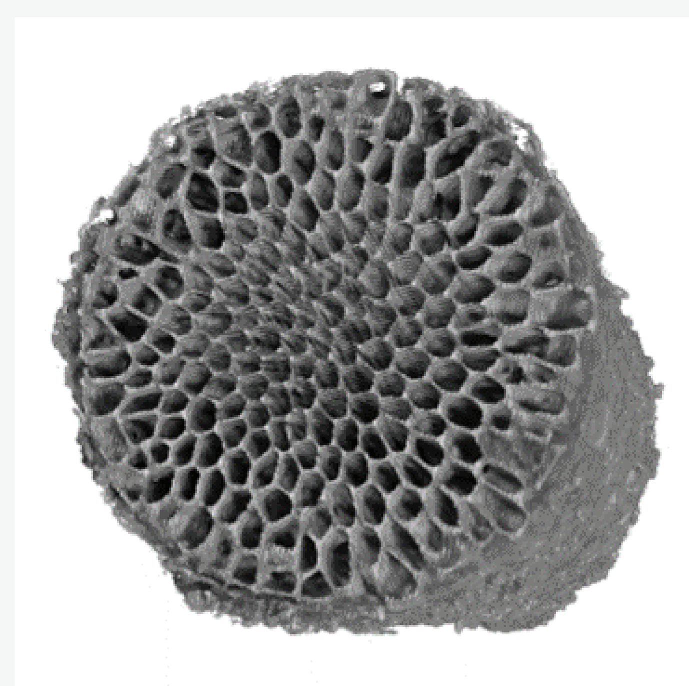




Metallic foams cast from iron and steel are porous structures offering weight reduction at high specific material stiffness: an ideal solution for shock energy absorption or support purposes. Classical challenges for metal foams are the standardization of a homogeneous pore structure as well as its reproducibility. Different in situ and ex situ studies can be performed at BEATS, which are useful for the optimization of foam properties and to gain knowledge about the casting process.

Strain Hardening Reduces Energy Absorption Efficiency of Austenitic Stainless Steel Foams While Porosity Does Not. Kaya et al. 2018. Materials & Design 143 (April): 297–308.

MINERALISED ALGAE FROM THE RED SEA



An example of the application of SR-CT for the study of biomineralisation in natural materials is illustrated by the study of the intricate microstructure of Jania sp., a species of coralline red algae found in the eastern Mediterranean Sea. SR-CT allowed researchers to elucidate the sophisticated mechanisms contributing to the low-weight, high-strength structure of the algae, which allows the algae to endure the outer stresses applied by its natural habitat.

(Bianco-Stein et al. 2020). Helical Microstructures of the Mineralized Coralline Red Algae Determine Their Mechanical Properties. Bianco-Stein et al. 2020. Advanced Science 7 (11): 2000108.

BEATS receives funding from the European Union Horizon 2020 research and innovation programme under the grant agreement number 822535

www.beats-sesame.eu/

ALBA · The Cyprus Institute · DESY. · ESRF · Elettra Sincrotrone Trieste · INFN · PSI · SESAME · SOLARIS

@BEATSeu1
Contact : Gianluca.Iori@sesame.org.jo

Credit images: DMM: CINEL; 3-pole wiggler: KYMA

Design and ray-tracing of the BEATS beamline of SESAME

Gianluca Iori[1], Pierre Van Vaerenbergh[2], Juan Reyes-Herrera[2], Mohammad Al'Najdawi[1]
Ivan Cudin[3], Tomasz Kołodziej[4], Matteo Altissimo[3], Maher Al Shehab[1], Andrea Lausi[1], Axel Kaprolat[2]

[1]Synchrotron Light for Experimental Science and Applications in the Middle East – SESAME, Allan, Jordan
[2]European Synchrotron Radiation Facility, Grenoble, France
[3]Elettra-Sincrotrone Trieste, Basovizza, Trieste, Italy
[4]National Synchrotron Radiation Centre Solaris, Jagiellonian University, Krakow, Poland

MEDSI CHICAGO 2020

The BEAmline for Tomography at SESAME (BEATS) will operate an X-ray micro tomography station serving a broad user community from the Middle East and beyond

Archaeology and Cultural Heritage:
- Archaeological Materials
- Human bioarchaeology
- Plant remains
- Animal remains and artefacts

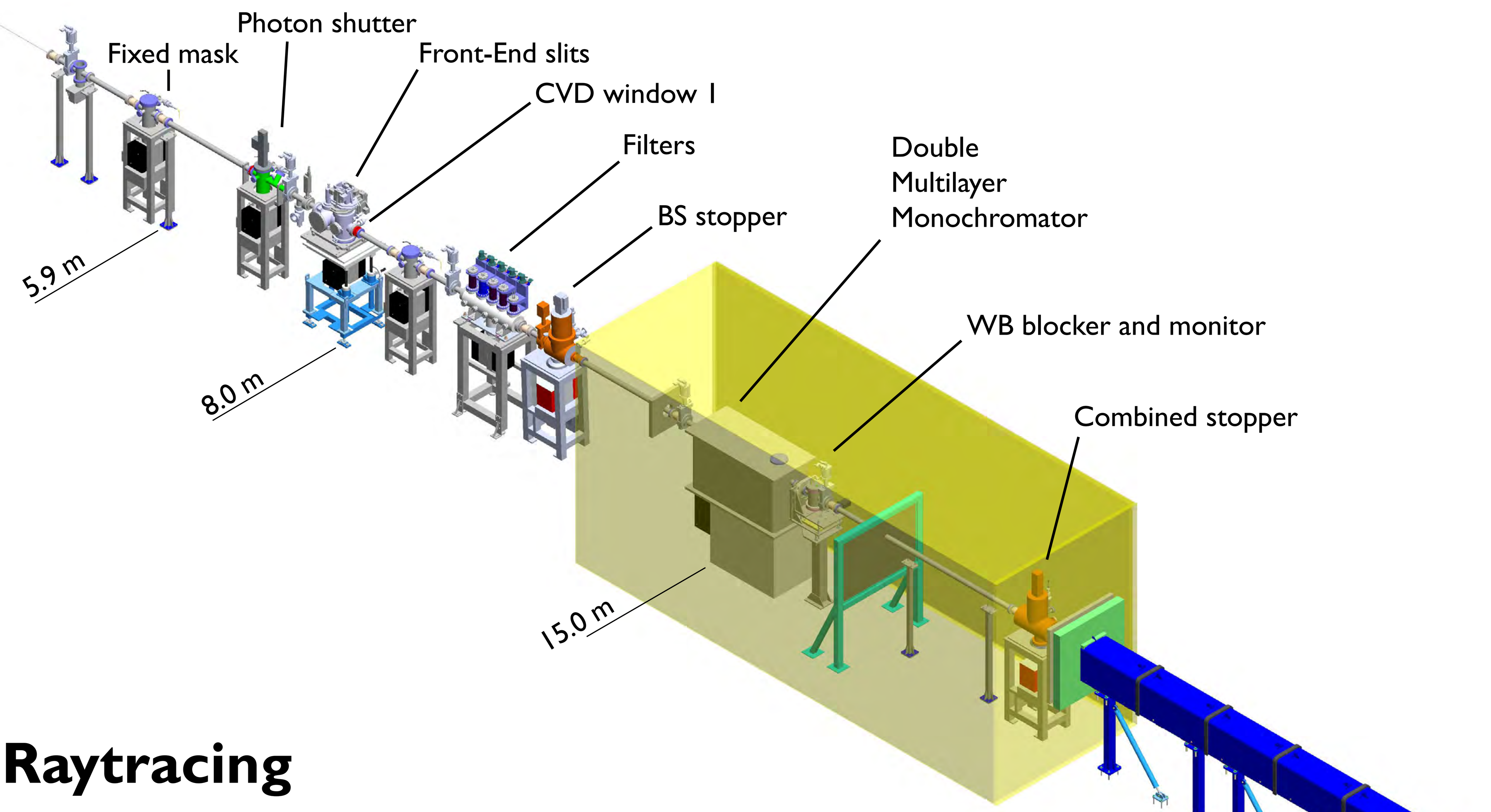
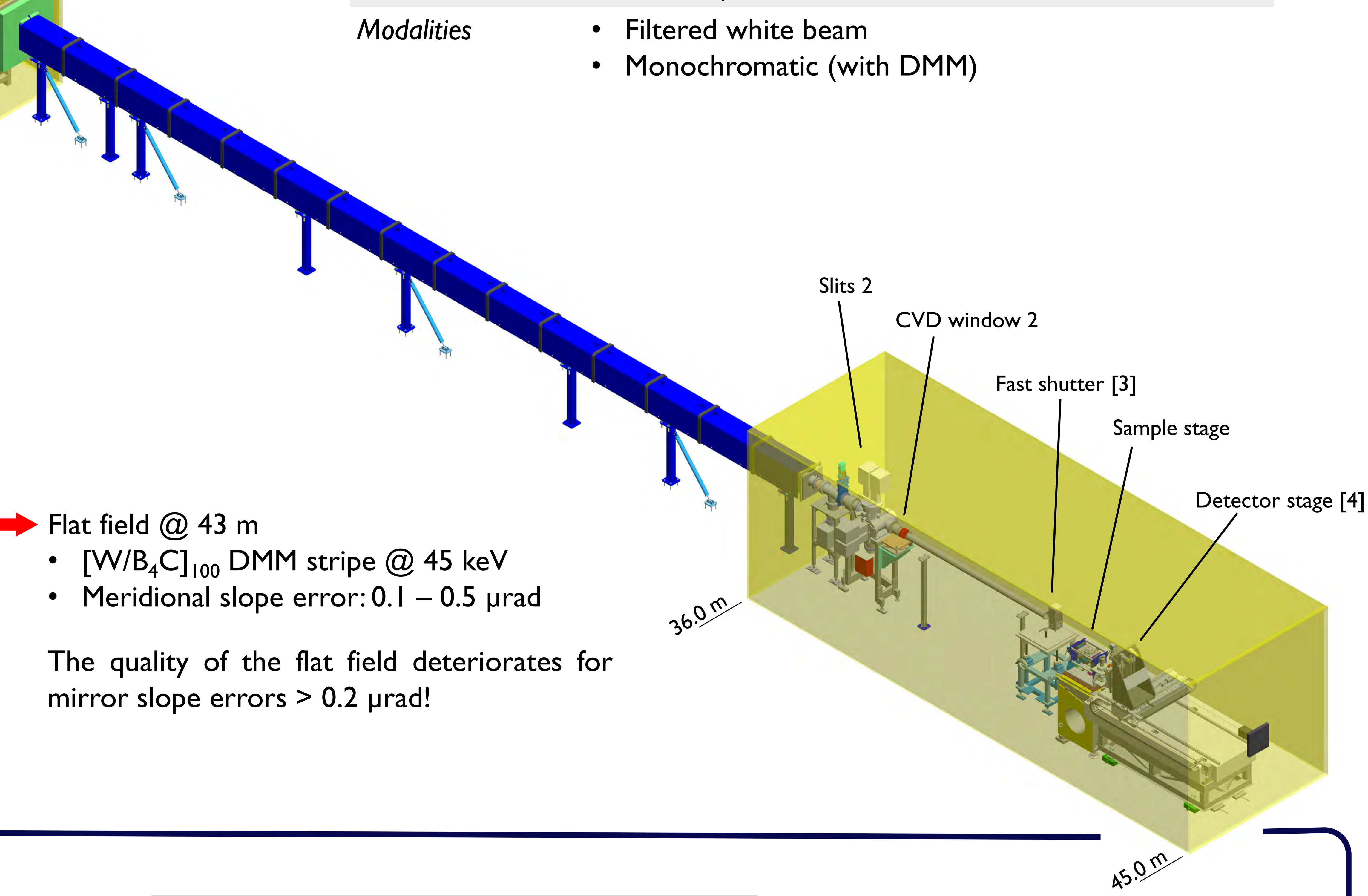
Geology and Environment:
- Simulation of rock properties
- Fuel research
- Soil characterization

Health, Biology and Food:
- Musculoskeletal research
- Bone and dental implants
- Soft tissue imaging
- Animal and plant characterization
- Food science

Material science and Engineering:
- Light materials and alloys
- Materials under mechanical stress
- Energy materials research

Services to Industry and Private sector

BEATS_eu
@BEATSeu1

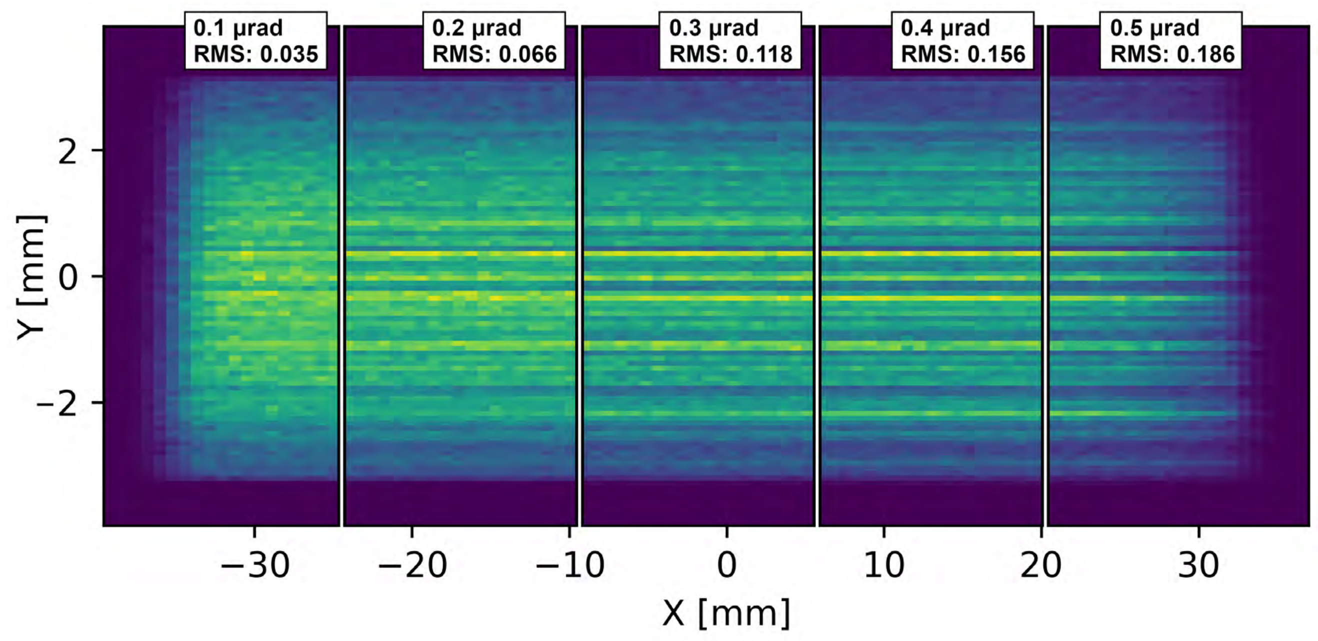



The BEATS beamline at a glance

Photon source	Wavelength shifter (3 T @ 11 mm gap; E_c = 12.5 keV)
Length	45 m
Energy range	8 – 50 keV
Divergence	1.8 mrad (H) × 0.4 mrad (V)
Double Multilayer Monochromator	Stripe 1: $[Ru/B_4C]_{65}$; d = 4 nm; dE/E ≈ 3% Stripe 2: $[W/B_4C]_{100}$; d = 3 nm; dE/E ≈ 3%
Detectors	1× – 10× optics; 2560 × 2160 sCMOS camera
Voxel size	6.5 – 0.65 µm
Modalities	• Filtered white beam • Monochromatic (with DMM)

Raytracing

- Repository of the beamline raytracing [1] using OASYS toolsuite [2] and Jupyter
  - Design and verification of beamline optics
  - Characterization of heat load on critical components
  - Beamline performance
  - DMM operation and multilayers specs



Flat field @ 43 m
- $[W/B_4C]_{100}$ DMM stripe @ 45 keV
- Meridional slope error: 0.1 – 0.5 µrad

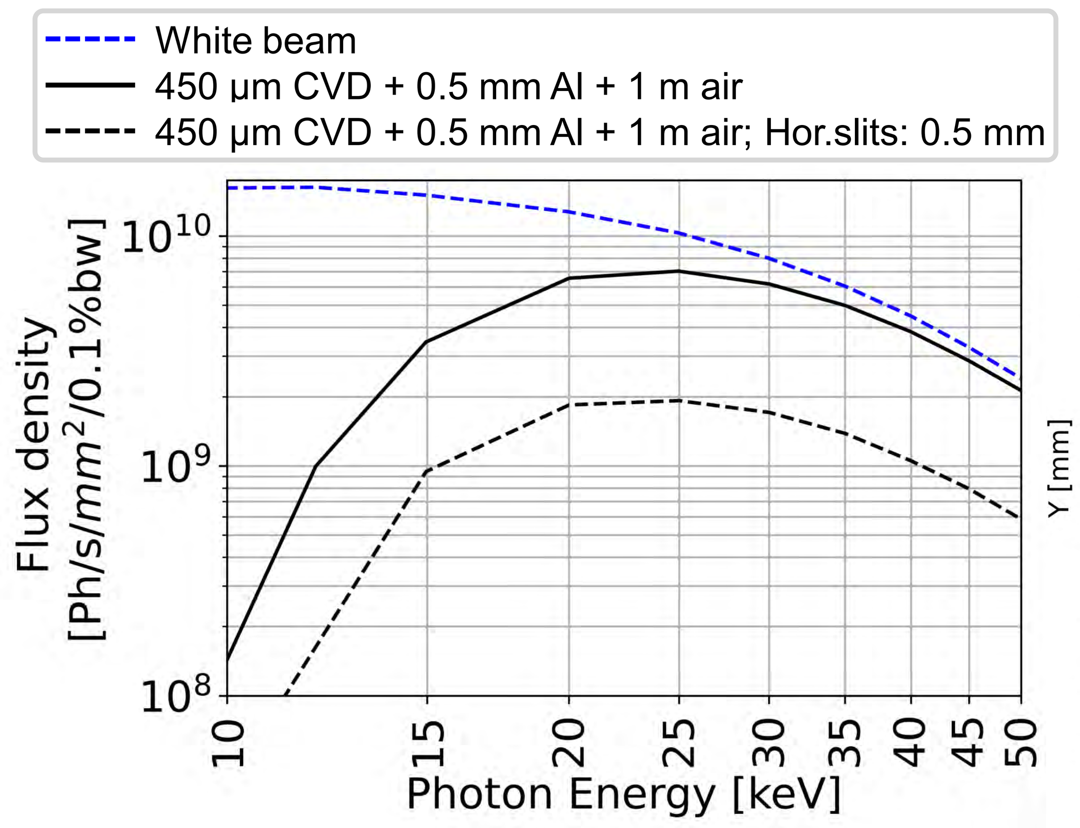
The quality of the flat field deteriorates for mirror slope errors > 0.2 µrad!

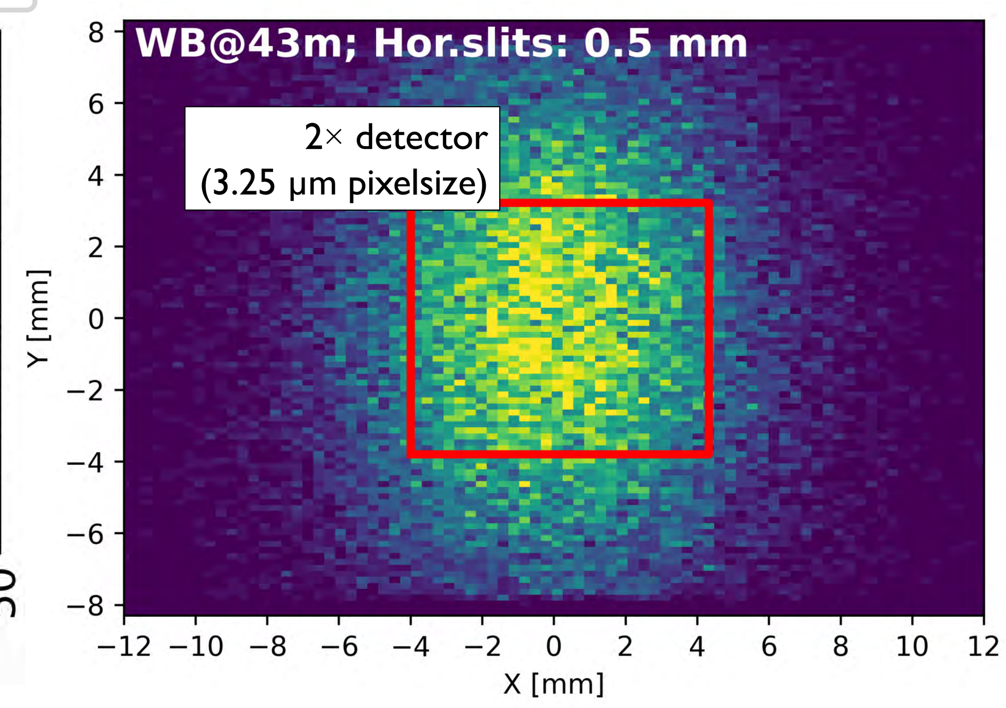
Expected beam properties at sample

White beam:	• Flux density: 8×10^9 Ph/s/mm²/0.1%BW • beam size @ 43m: 75×15 mm²
With DMM stripe 2 @ 25 keV	• Flux density: 1×10^{11} Ph/s/mm² • Beam size @ 43 m: 68×8 mm²

Transverse coherence length is improved closing the F-E slits:

Beamline	Length	Source size FWHM	Coh. length
ID19, ESRF	145 m	25 µm	720.0 µm
TOMCAT, SLS	34 m	140 µm	30.2 µm
SYRMEP, Elettra	23 m	197 µm	14.5 µm
BEATS	43 m	1978 µm	2.7 µm
BEATS, F-E slits: 0.5 mm (H)	35 m	500 µm	8.5 µm





References

[1] BEATS Technical Design Report - raytracing, doi:10.5281/zenodo.3988604.
[2] L. Rebuffi and M. Sanchez del Rio, "OASYS (OrAnge SYnchrotron Suite): an open-source graphical environment for x-ray virtual experiments," Proc.SPIE 10388: 130080S (2017).
[3] C. Muñoz Pequeño et al., "Development of a Linear Fast Shutter for BM05 at ESRF and BEATS at SESAME", presented at MEDSI'20, Chicago, USA, July 2021.
[4] F. Mokoena et al., "An FEA Investigation of the Vibration Response of the BEATS Detector Stage", presented at MEDSI'20, Chicago, USA, July 2021.

Synchrotron Light for Experimental Science and Applications in the Middle East – SESAME
beats-sesame.eu
gianluca.iori@sesame.org.jo

Funded by the EU's H2020 framework programme under grant agreement n°822535

An FEA Investigation of the Vibration Response of the BEATS Detector Stage

Fortune Mokoena[*A], Muaaz Bhamjee[*A], Simon Connell[*A] , Axel Kaprolat[*B], Pierre Van Vaerenbergh[*B], Gianluca Iori[*C]
[*A] *University of Johannesburg Auckland Park Kingsway Campus, South Africa*
[*B] *European Synchrotron Radiation Facility - ESRF Grenoble, France*
[*C] *Synchrotron-light for Experimental Science and Applications in the Middle East – SESAME, Allan, Jordan*

Abstract

The Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME) facility is in the process of designing, procuring and installing a new beamline for tomography (BEATS). The BEATS experimental hutch, sample platform and environmental system and detectors, will be located 43m away from the light source. Vibrational noise transferred to the detector can be a source of poor image quality and it is therefore important that the detector stage is analysed for structural rigidity that will attenuate any vibrations. Random vibration analysis for the detector stage is conducted using the measured SESAME floor power spectrum density in order to estimate the instantaneous severity of the vibration in the X, Y and Z direction. In order to validate the random vibration technique, an existing structure (back scattering monochromator on ESRF's beamline ID28) was used to collect experimental data which was compared to simulation for a similarly developed model. The comparison was based on modal frequencies and RMS values.

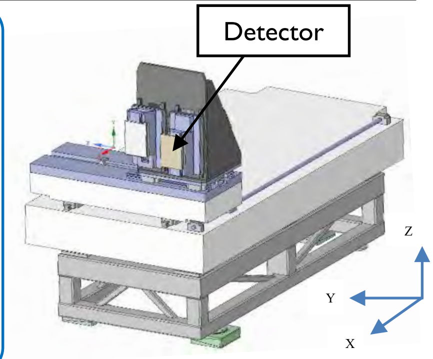
ID28 Model validation

Modal Frequencies

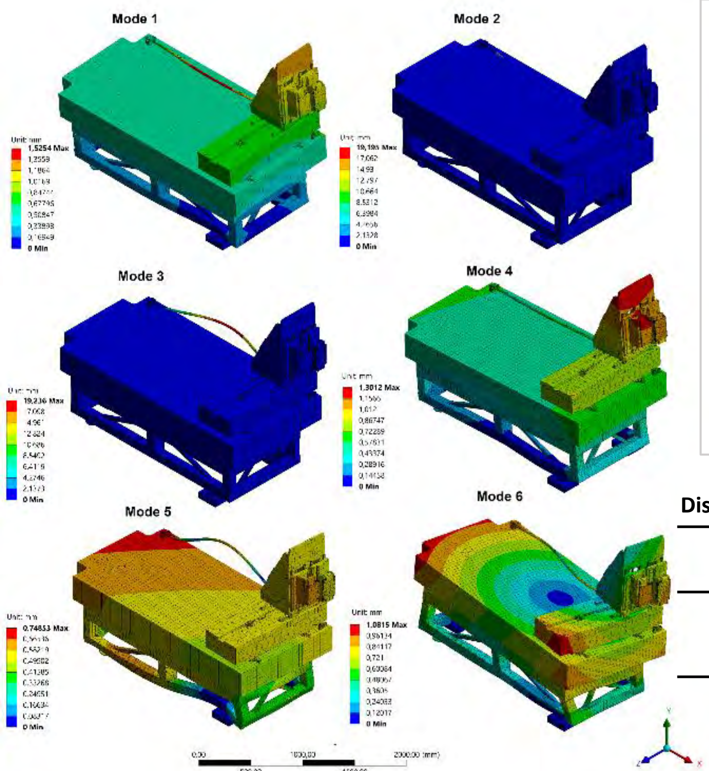
Mode	Experimental Frequency [Hz]	FEA Frequency[Hz]
1	18	17
2	19	18
3	25	26
4	28	27
5	45	46

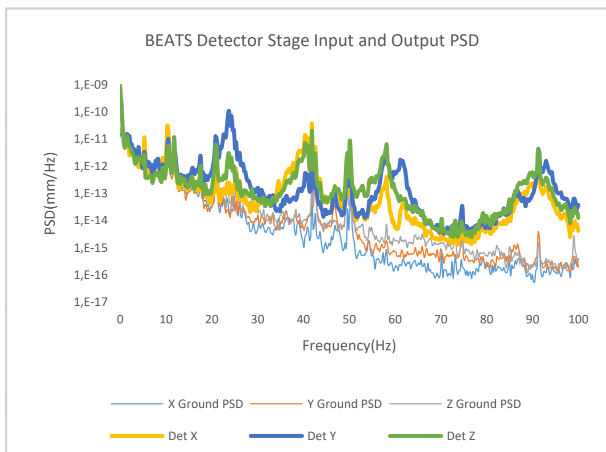
Displacement RMS values

Direction	Measured Ground [nm]	Measured BS Mono [nm]	FEA response [nm]
X(H)	101	117	116
Y(H)	77	96	93
Z(V)	127	137	140



BEATS Detector stage Random Vibration Analysis





Displacement RMS values

Direction	Ground [nm]	Detector [nm]
X(H)	8	10
Y(H)	12	17
Z(V)	14	15

Modal Frequencies

Mode	Frequency [Hz]
1	24
2	35
3	35
4	41
5	62

References

G. Iori, "Design and Ray-Tracing of the BEATS beamline of SESAME," in Presented at MEDSI'20, Chicago USA, July 2021.

L. Zhang, "Vibration at the ESRF," in Presented at 5th European Particle Accelerator Conference (EPAC 96), Sitges Spain , June 1996.

R. Budynas and J. Nisbet, Shigley's Mechanical Engineering Design, McGraw Hill, 2011.

Synchrotron Light for Experimental Science and Applications in the Middle East – SESAME

beats-sesame.eu
tfmokoena@uj.ac.za

Funded by the EU's H2020 framework programme under grant agreement n°822535