UNIONE EUROPEA
Fondo Europeo di Sviluppo Regionale
Ministero dell'Istruzione, dell'Università e della Ricerca
PON RICERCA E INNOVAZIONE 2014 - 2020
PON Ricerca e Innovazione 2014-2020 - Azione II.1
PROGETTO PON PIR01_00008 - CUP H27E19000000007 - STAR 2

The research infrastructure **STAR** at the University of Calabria

Raffaele G. Agostino
University of Calabria (Italy)

UNIVERSITÀ DELLA CALABRIA

STAR
SOUTHERN EUROPE TBS SOURCE FOR APPLIED RESEARCH

STAR INFRASTRUCTURE: WHAT'S NEXT?

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STAR 2.0

Southern Europe **T**homson Back-scattering source for **A**pplied **R**eserch

A campus-based research infrastructure in the hearth of the Mediterranean

STAR INFRASTRUCTURE: WHAT'S NEXT?

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On going upgrade project

EU/National Funding
PON "Ricerca e Competitività" 2007 – 2013
PON "Ricerca e Innovazione" 2014 – 2020
Scientific responsible: Prof. Riccardo Barberi

A **Research Infrastructure** for **Material Science**

UNIVERSITÀ DELLA CALABRIA
cnism
INFN Istituto Nazionale di Fisica Nucleare
Elettra Sincrotrone Trieste

Partners: **UniCal**, University of Calabria & **CNISM**, Italian Consortium on Physical Sciences of Matter
Involved: National Institute for Nuclear Physics – **INFN**, **Elettra** - Sincrotrone Trieste

The highly specialized laboratories that constitute MaTeRiA are organized in three progressive levels

First level. **STAR ICS source** equipped with the beam-line **µTomo and SoftX(*)**.

Second level laboratories:

1. **Preparation and characterization**
2. **Characterization of mechanical and other physical properties**
3. **Modeling and simulation**
4. **Prototyping**
5. **Advanced spectroscopy and microscopy**
6. **Biological samples treatment(*)**

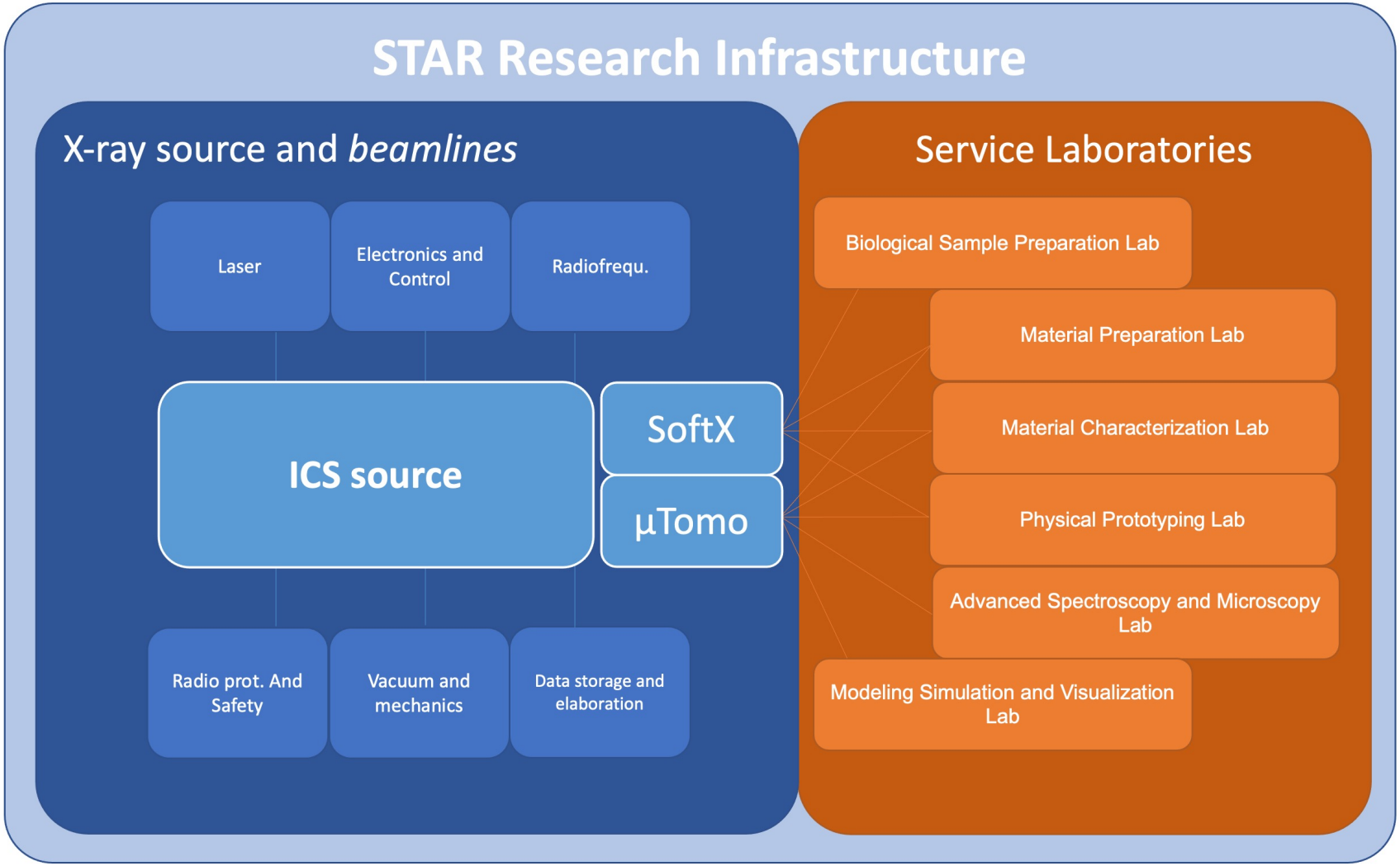
Third level. Network of existent departmental laboratories

(*) Phase two upgrades

STAR INFRASTRUCTURE: WHAT'S NEXT?

STAR 2.0

On going upgrade project



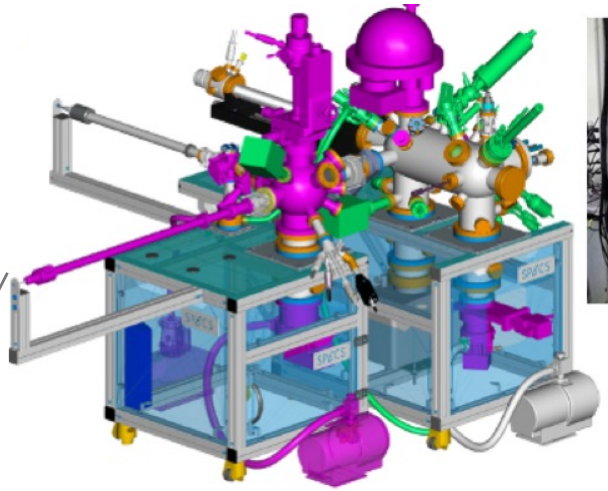
STAR INFRASTRUCTURE: WHAT'S NEXT?

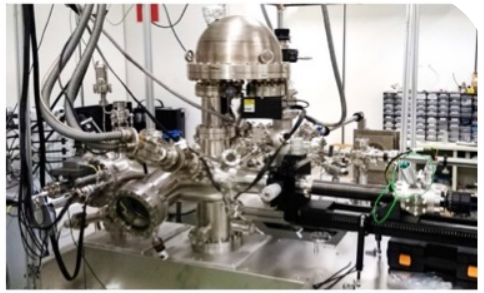
STAR 2.0

On going upgrade project

Second level laboratories:

1. **Material preparation and characterization** (Chemistry, physical chemistry)
2. **Characterization of mechanical and other physical properties** (Mechanical engineering)
3. **Modeling, simulation and Visualization** (Mathematical physics, statistical physics)
4. **Physical Prototyping Lab** (Mechanical engineering)
5. **Advanced surface spectroscopy and microscopy** (Surface Physics)
6. **Biological samples treatment** (Biology, biophysics)





Adv. Spectroscopy & Microscopy Lab

STAR INFRASTRUCTURE: WHAT'S NEXT?

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On going upgrade project

Second level laboratories:

1. **Material preparation and characterization** (Chemistry, physical chemistry)
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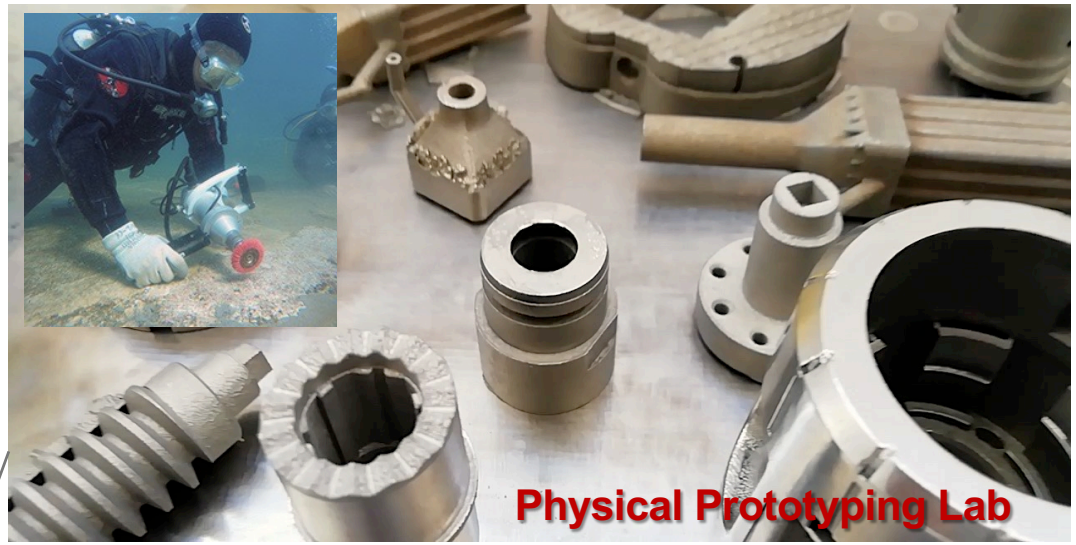
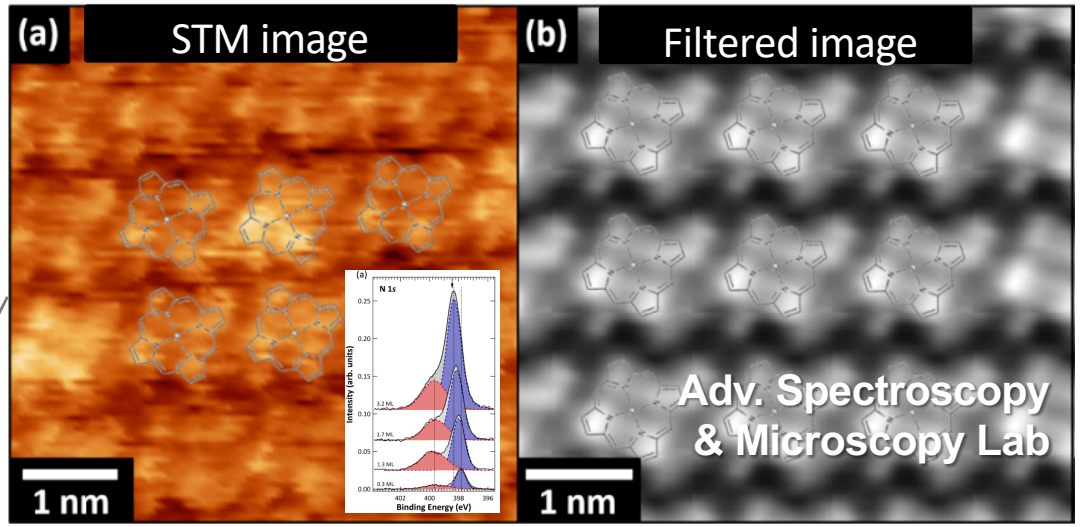
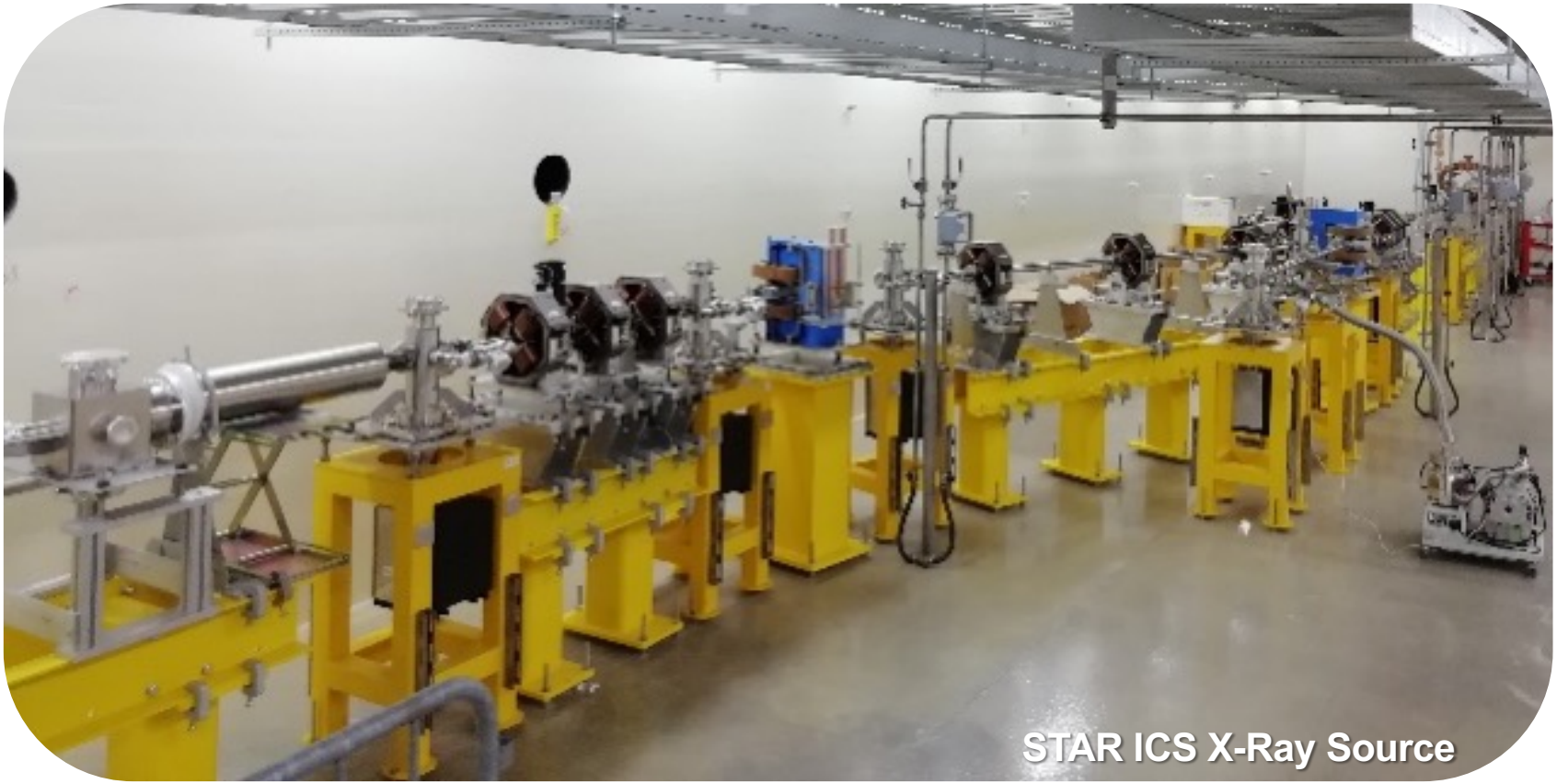




ZnTPP self-assembly on Au(111)

STAR 1: A HARD X-RAY BEAM SOURCE

STAR
SOUTHERN EUROPE TBS SOURCE FOR APPLIED RESEARCH



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STAR 1: A HARD X-RAY BEAM SOURCE

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Design of STAR 1 source operating modes:

- high-flux / moderate-monochromaticity → Medical imaging;
- moderate-flux / monochromatic mode → Better detection/dose performance;
- short-and-monochromatic → Pump-and-probe experiments.

(Pseudo-)coherence →
Phase-contrast imaging and diffraction-enhanced imaging.

$$L_s = \frac{\lambda l}{2S} = \frac{\lambda}{2\alpha}$$

Operating modes	High-flux	Small-BW	Short-pulse
Photon energy (keV)	20-85	20-85	40-85
Photons/s (@100 Hz)	$3*10^9$	$3*10^8$	$3*10^6$
Bandwidth (rms)	10%	1%	1%
Rms Pulse lenght (ps)	1-5	1-5	<0.2

- X-ray energy **tuneable** on a wide range up to hard X-rays
- **Controlled Band Width**
- **mrad divergence** (controlled)
- Time structure on the **ps-scale**
- Circular **µm-sized x-ray source**
- **Linear polarization** up to 99% - pulse-to-pulse switchable
- **Simple evolution** to higher energies and fluxes

- *A. Bacci et al., The Star project, Proceedings of IPAC2014, Dresden, Germany*
- *A. Bacci et al., Status of the Star project, Proceedings of IPAC2016, Busan, Korea*
- *A. Bacci et al., Photoinjector Emittance Measurement at STAR", Proceedings of IPAC2017, Copenhagen, Denmark*

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STAR 2: TWO HARD X-RAYS BEAMLINES

The upgrade will be developed on three main lines:

1. Increase in flux N_{ph}, from 10^9 up to 10^{11} photons/sec with the same relative bandwidth $\Delta E_{ph}/E_{ph}$ equal to 5%

$$N_{ph} \propto \frac{U_L Q_b}{h\nu_L \sigma_0^2} f$$

- increase in energy of the laser pulse U_L = 150 mJ → **U_L = 1 J**
- increase in charge per bunch Q_b = 200 pC → **500 pC** (best effort 2nC)
- Better focussing σ_0 → **25 µm**

Other beam parameter	Value
Max Beam energy [MeV]	140.05
Beam charge [pC]	500
σx, σy [µm]	25.0, 23.7
σz [µm]	667
εx, εy [µm]	1.2, 1.3
relative energy spread [%]	0.2

Istituto Nazionale di Fisica Nucleare

STAR HE-Linac
Complete Detailed Design Report

A. Bacci[1], L. Faillace[2], L. Pellegrino[2], D. Alesini[2], S. Bini[2], F. Cardelli[2], G. Catuscelli[2], F. Chiarelli[2], I. Drebot[1], A. Esposito[2], A. Gallo[2], A. Ghigo[2], D. Giannotti[1], V. Petrillo[1,3], L. Piersanti[2], E. Puppin[1,4], M. Rossetti Conti[1], L. Serafini[1], A. Stella[2], A. Vannozzi[2], S. Vescovi[2]

1 - INFN, Sezione di Milano e LASA
2 - INFN, Laboratori Nazionali di Frascati
3 - Università degli Studi di Milano
4 - Politecnico di Milano

A. Bacci, et al, STAR HE-Linac Complete Detailed Design Report, arXiv:2109.10351 [physics.acc-ph]

Courtesy of Luca Serafini

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

STAR 2: TWO HARD X-RAYS BEAMLINES

The upgrade will be developed on three main lines:

1. Increase in flux N_{ph}, from 10^9 up to 10^{11} photons/sec with the same relative bandwidth $\Delta E_{ph}/E_{ph}$ equal to 5%;
2. Increasing the energy of E_{ph} photons from 85 keV up to about 350 keV

$$\nu_T = \nu_0 \frac{1-\beta\cos\alpha_L}{1-\beta\cos\theta} \approx \nu_0 \frac{4\gamma^2}{1+\theta^2\gamma^2} \approx 4\gamma^2\nu_0$$

$$for\ \alpha_L = \pi\ (scatt.angle) \qquad and$$

$$\theta << 1 \quad or \quad \theta = 0\ (obs.angle)$$

Courtesy of Luca Serafini

STAR 2: TWO HARD X-RAYS BEAMLINES

STAR
SOUTHERN EUROPE TBS SOURCE FOR APPLIED RESEARCH

The upgrade will be developed on three main lines:

1. Increase in flux N_{ph}, from 10^9 up to 10^{11} photons/sec with the same relative bandwidth $\Delta E_{ph}/E_{ph}$ equal to 5%;
2. Increasing the energy of E_{ph} photons from 85 keV up to about 350 keV
3. A second beamline (HE LINAC) added to the present one (LE LINAC)

	HE-LINAC	LE-LINAC
Energy Range	40÷135 MeV	23÷65 MeV
Repetition rate	100 Hz	
RF technology	S-band & C-band	
RMS norm. transverse emittance	2 mm·mrad (best effort 1 mm mrad)	
Energy spread	smaller than 0.5% (best effort 0.2%)	
Bunch charge	Min 100 – Max 500 pC (best effort 2 nC)	
Bunch length	shorter than 5 psec	
Accelerating sections	S-band symmetrized fed TW + 2 C-band TW	
RF power stations	S-band (2.856 GHz), 55 MW, 2 µs pulse, Solid state HV 2x C-band (5712 MHz), 40 MW, 1 µs pulse, Solid state HV	
Spot size at the interaction points	40 µm (best effort 20 µm)	

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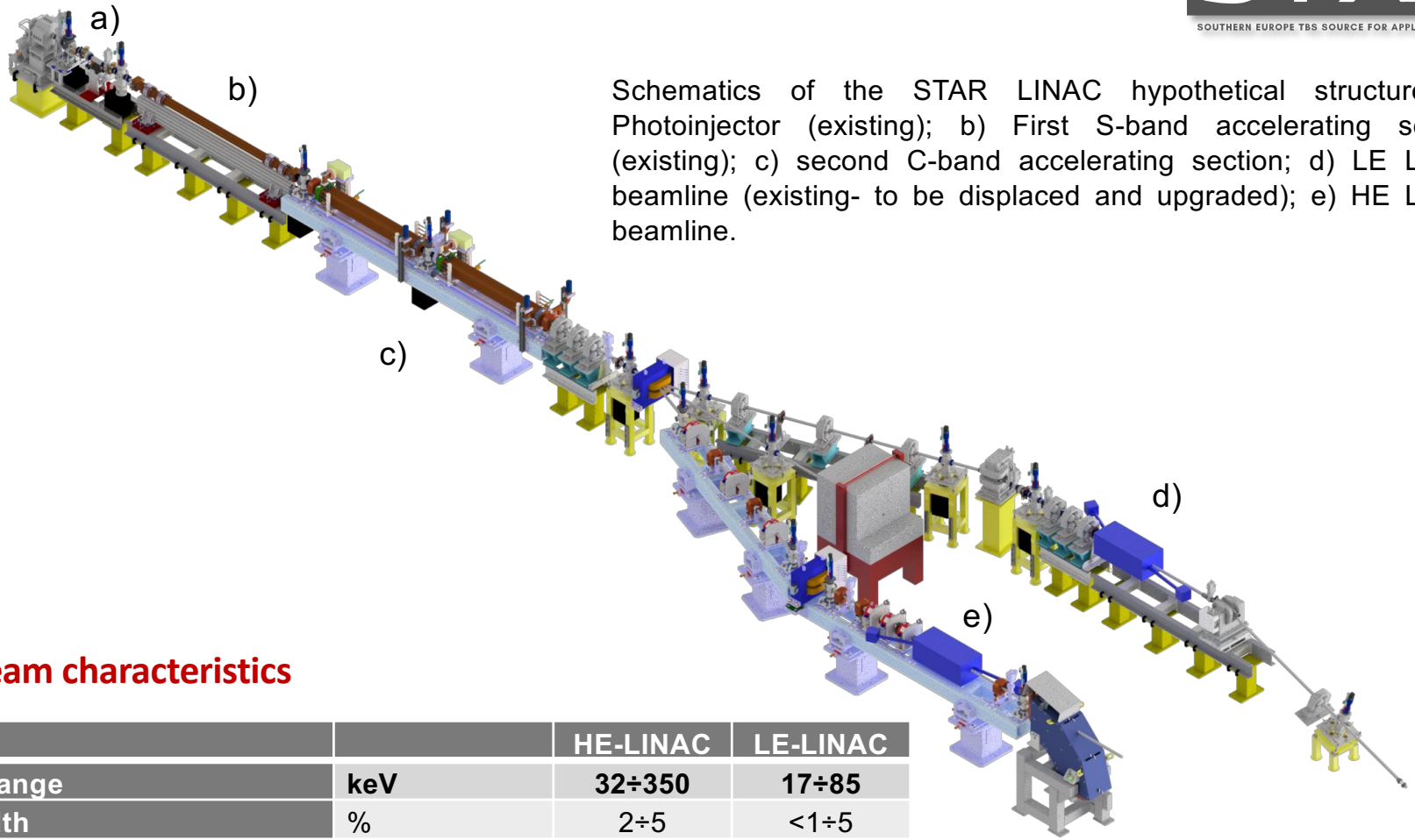
STAR 2: TWO HARD X-RAYS BEAMLINES



Schematics of the STAR LINAC hypothetical structure. a) Photoinjector (existing); b) First S-band accelerating section (existing); c) second C-band accelerating section; d) LE LINAC beamline (existing- to be displaced and upgraded); e) HE LINAC beamline.

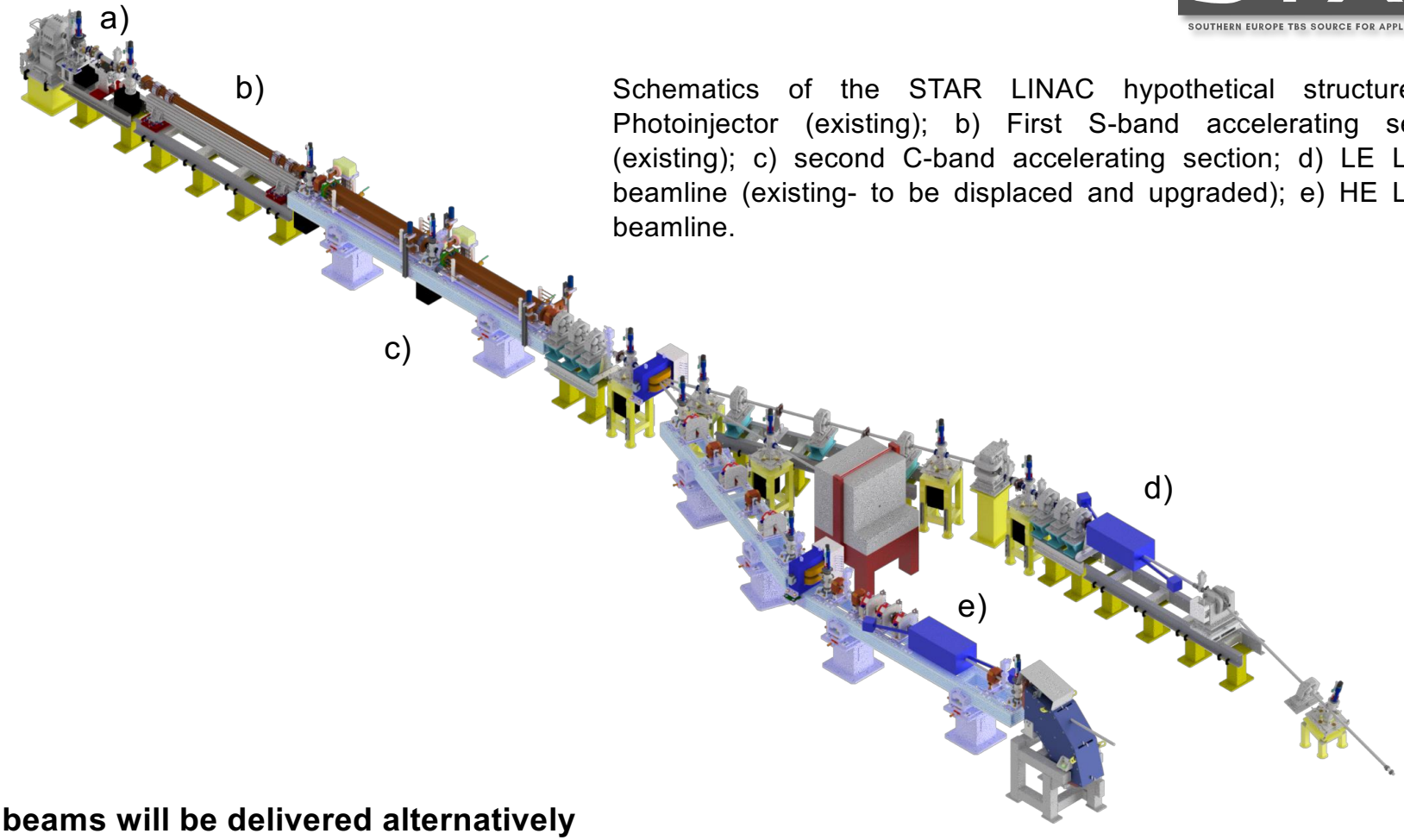
X-ray Beam characteristics

		HE-LINAC	LE-LINAC
Energy Range	**keV**	**32÷350**	**17÷85**
Band Width	%	2÷5	<1÷5
Divergence	mrad	2÷10	1÷10
Maximum Flux	ph/s /10mrad	10^11	10^11
Source dimensions	μm	<20÷40	<20÷40
Source-exp. station distance	m	<12	<12
Beam size at sample	mm x mm	100x100	70x70**

Beamlines distance: > 4 m
* Laser second harmonic
**without Xray optics

A. Bacci, et al, STAR HE-Linac Complete Detailed Design Report, arXiv:2109.10351 [physics.acc-ph]

STAR 2: TWO HARD X-RAYS BEAMLINES



Schematics of the STAR LINAC hypothetical structure. a) Photoinjector (existing); b) First S-band accelerating section (existing); c) second C-band accelerating section; d) LE LINAC beamline (existing- to be displaced and upgraded); e) HE LINAC beamline.

- **two beams will be delivered alternatively**
- **interaction points** located as close as possible to the bunker walls.
- **front ends** placed on the wall - provided with the beam stop systems.
- **focusing optics** placed on the beam-transport line
- **distance between the HE_LINAC and LE_LINAC** Beamlines is 4 m.

A. Bacci, et al, STAR HE-Linac Complete Detailed Design Report, arXiv:2109.10351 [physics.acc-ph]

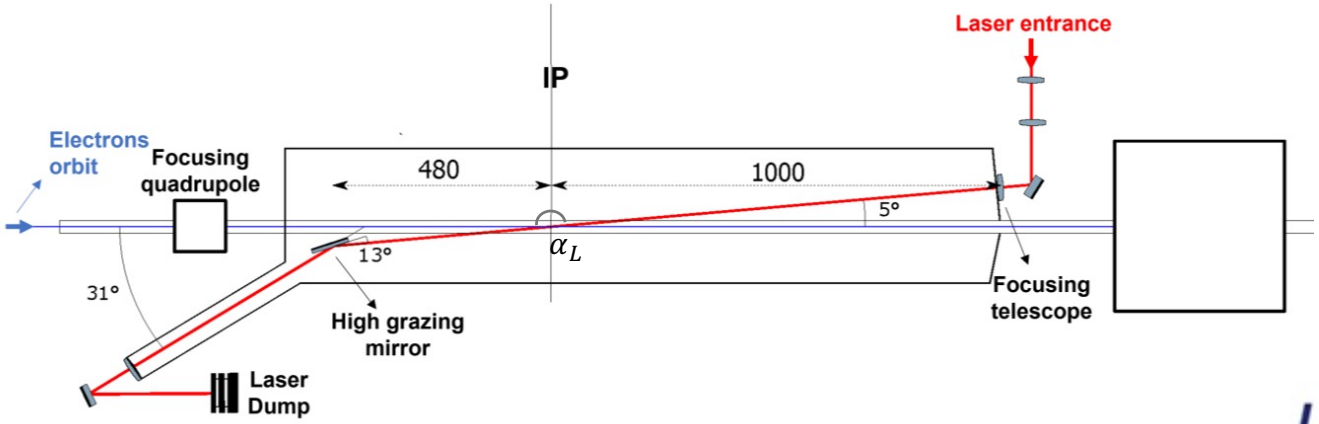
STAR 2: TWO HARD X-RAYS BEAMLINES

Laser upgrade:

Parameter	1st phase Impact laser	2nd phase Impact laser	2nd phase Branch line for photoinjector
Repetition rate (Hz)	100	100	100
Output Energy (mJ)	150 (IR)	1000 (IR)	3 (UV)
Short Term Energy Stability (rms)	5 %	5 %	
Long Term Energy Stability (P2P)	< 8 %	< 8 %	
Wavelength (nm)	1000 < l <1050	1000 < l <1050	<265 nm
Jitter (rms) 10 Hz – 10 KHz	< 1 ps	< 1 ps	250fs
Bandwidth	< 1 nm	< 1 nm	
Pulse duration (ps FWHM)	5	5	5
Strehl Ratio	0.8	0.8	
M^2	1.4	1.4	

STAR 2: TWO HARD X-RAYS BEAMLINES

Impact chambers



Schematic layout of a hypothetical impact chamber.
Laser (Red line) and electron (blue line) are depicted as well as the motorized mirrors.

The impact chambers are designed to control both the **focusing** and the **impact angle α_L** of the laser beam on the electron trajectory.
The control of the impact angle through a motorized mirrors system will permit a **fine tuning** of the generated X-ray energy.

STAR 1: MICROTOMOGRAPHY BEAMLINE

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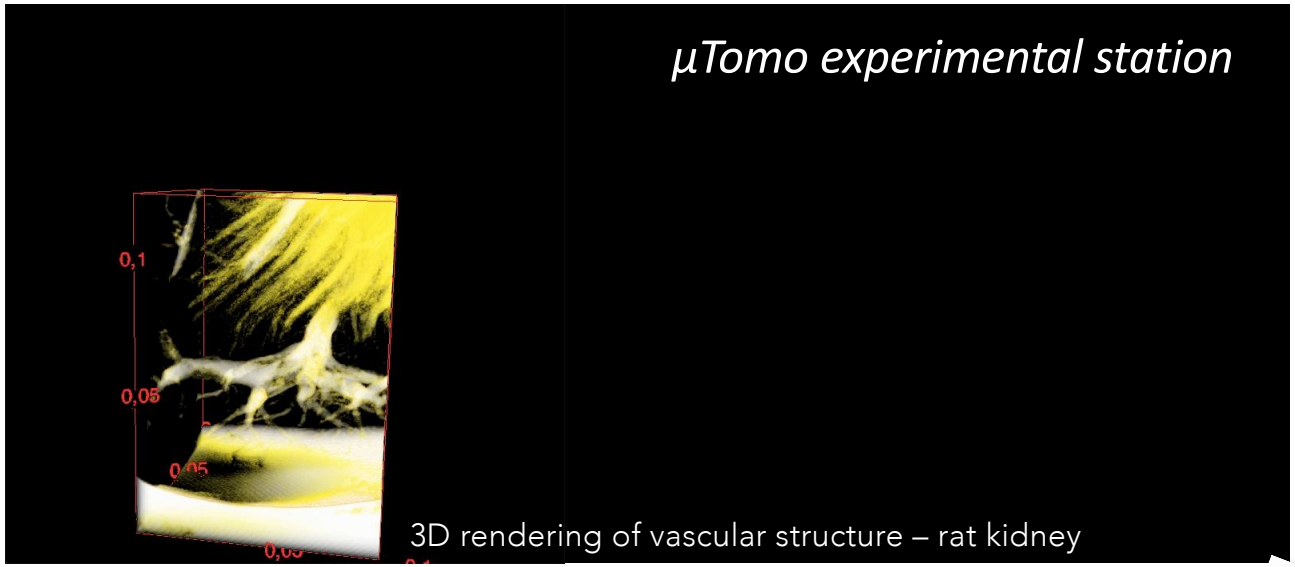
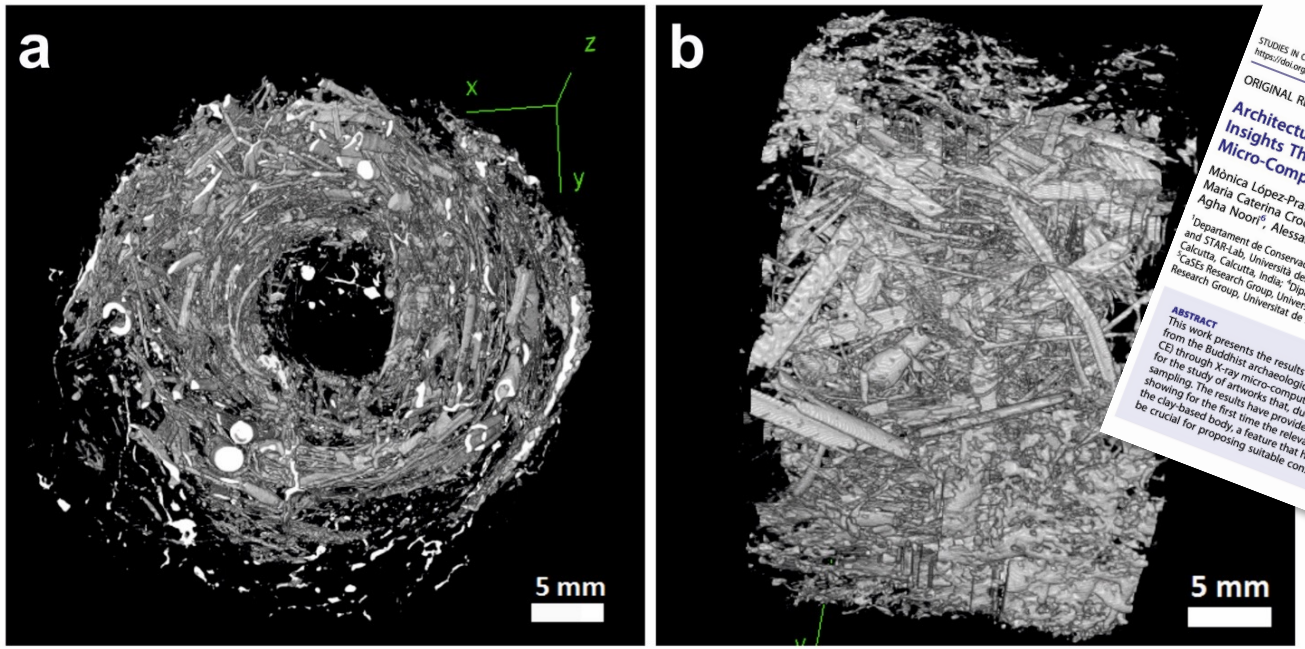
SOUTHERN EUROPE TBS SOURCE FOR APPLIED RESEARCH

Elettra Sincrotrone Trieste



3D rendering of vascular structure – rat kidney



STUDIES IN CONSERVATION
https://doi.org/10.1080/00393630.2020.1862605

ORIGINAL RESEARCH OR TREATMENT PAPER

Architectural *Terracruda* Sculptures of the Silk Roads: New Conservation Insights Through a Diagnostic Approach Based on Non-Destructive X-ray Micro-Computed Tomography

Mònica López-Prat[1], Maria Caterina Crocco[2], Raffaele Giuseppe Agostino[2], Sudipa Ray Bandyopadhyay[3], Begoña Carrascosa[1], Raffaella De Luca[4], Raffaele Filosa[2], Vincenzo Formoso[2], Carla Lancelotti[5], Noor Agha Noori[6], Alessandra Pecci[7], José Simón-Cortés[1] and Domenico Miriello[4]

[1]Departament de Conservació i Restauració de Béns Culturals, Universitat Politècnica de València, Valencia, Spain; [2]Dipartimento di Fisica and STAR-Lab, Università della Calabria, Arcavacata di Rende, Italy; [3]Department of Ancient Indian History and Culture, University of Calcutta, Calcutta, India; [4]Dipartimento di Biologia, Ecologia e Scienze della Terra, Università della Calabria, Arcavacata di Rende, Italy; [5]CaSEs Research Group, Universitat Pompeu Fabra, Barcelona, Spain; [6]Archaeology Institute of Afghanistan, Kabul, Afghanistan; [7]ERAUB Research Group, Universitat de Barcelona, Barcelona, Spain

ABSTRACT

This work presents the results of the study of a fragment of architectural *terracruda* sculpture from the Buddhist archaeological site of Tepe Narenj (Kabul, Afghanistan, fifth–ninth centuries CE) through X-ray micro-computed tomographic analysis. This technique offers great potential for the study of artworks that, due to their nature, condition, or relevance, are not suitable for sampling. The results have provided useful data for understanding the making of the sculpture showing for the first time the relevance of materials of plant origin used in the composition of the clay-based body, a feature that had not been previously highlighted and which appears to be crucial for proposing suitable conservation interventions.

ARTICLE HISTORY
Received October 2020
Accepted December 2020

KEYWORDS
Conservation; *terracruda* sculptures; X-ray micro-computed tomography; sculpting technique; ethnographic data; clay

3D rendering of the voids – Architectural terracruda sculptures of the Silk Roads

STAR 1: MICROTOMOGRAPHY BEAMLINE

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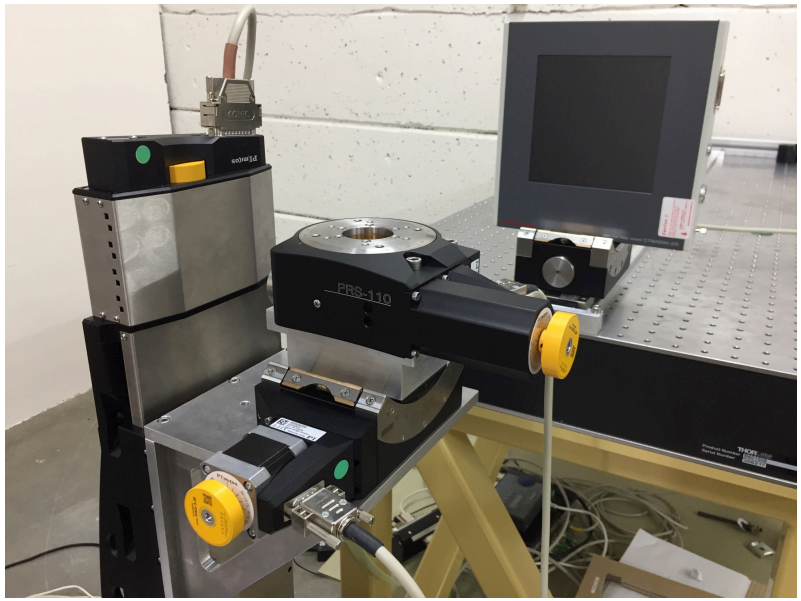
µTomo 1

- Microfocus X-ray source (150 kV)
- Sample-holder (2 translations + 2 rotations)
- 2D Detector for high/low energy X-rays
- Detector stage (1 translation + 1 tilt)
- Data acquisition system

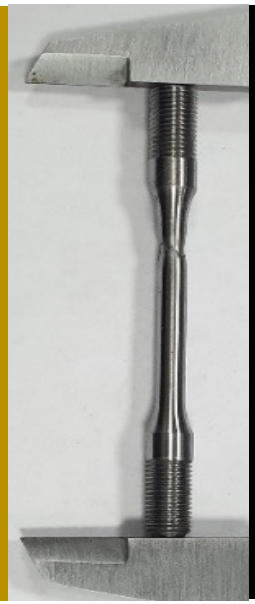
Elettra Sincrotrone Trieste

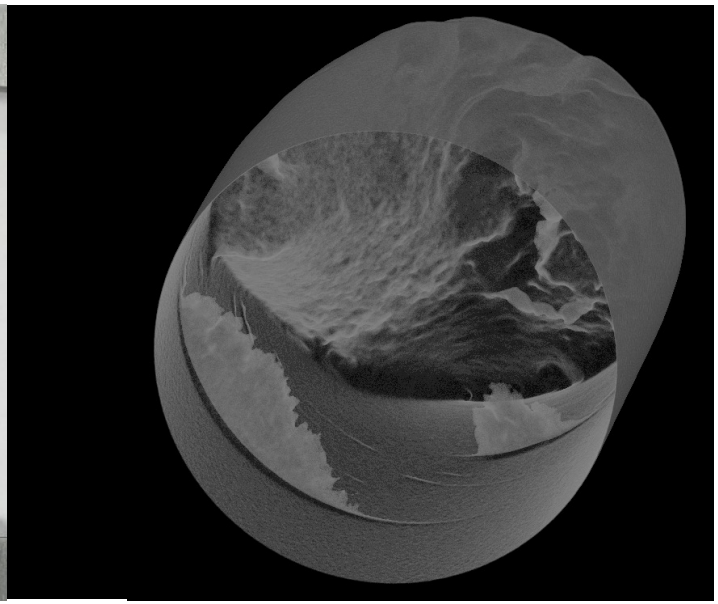


Case 3: *Hydrogen embrittlement in steel*

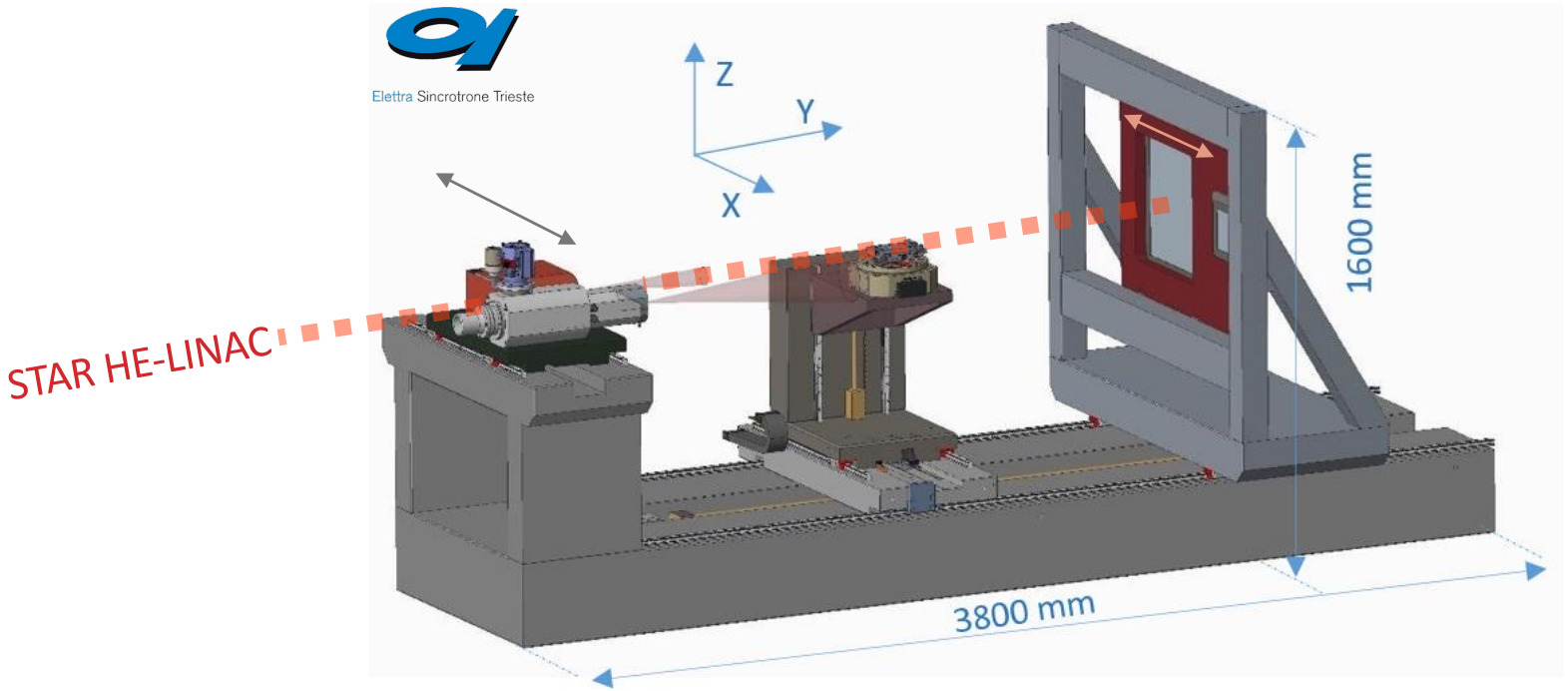
Field: ***Metallurgy***

User: ***Rina Consulting SpA***



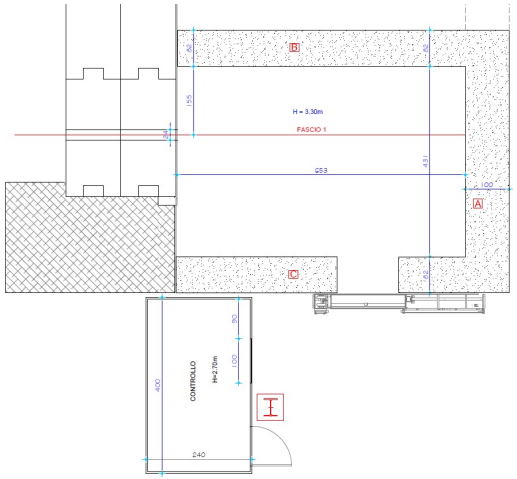


STAR 2: High Energy µTOMO 2 BEAMLINE

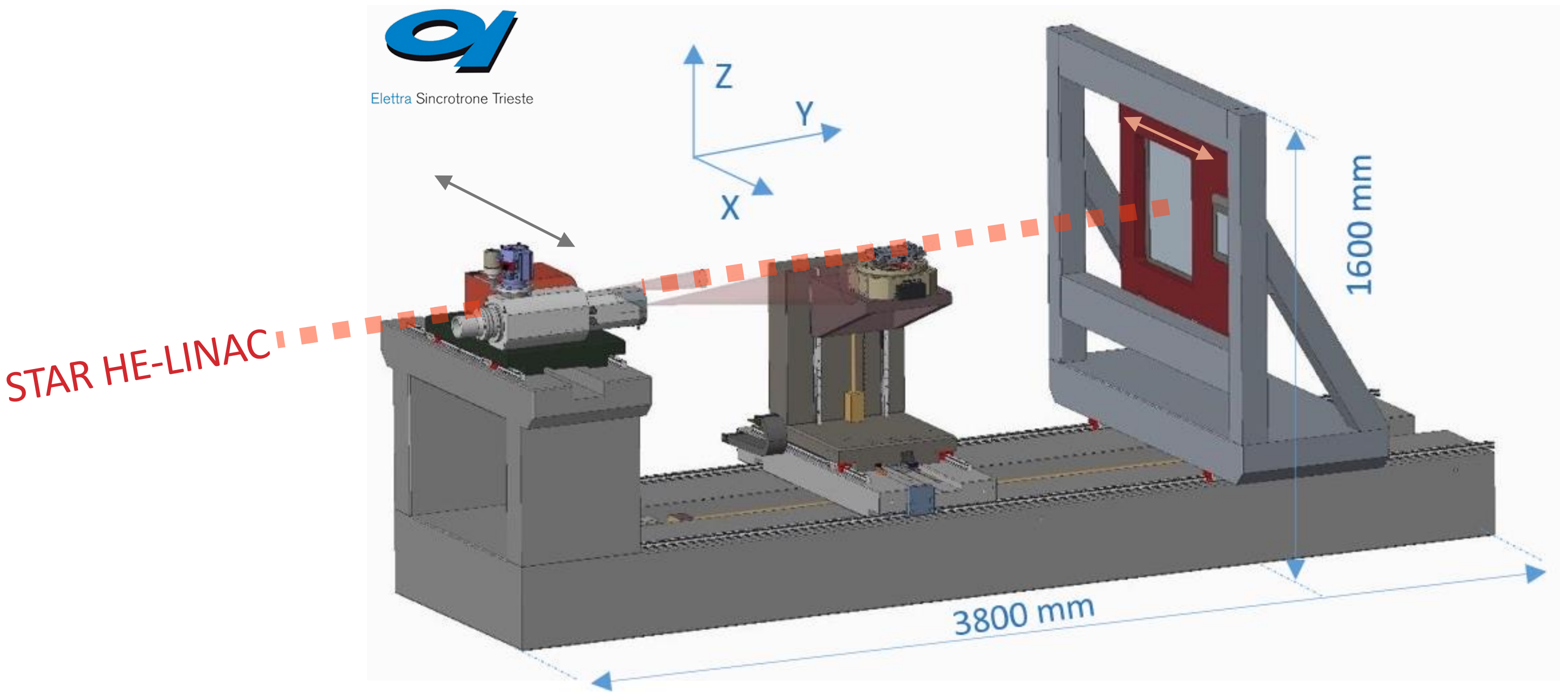


X-RAY MICROTOMOGRAPHY UPGRADE

- Designed for the **80-350 keV range**
- New **x-ray transport** system
- **Double X-ray 2D detection system** for high energy X-rays (15-70µm pixel size).
- **Heavy load 6-degree of freedom** sample stage
- **High power 190 keV microfocus source** (alternative to the STAR HE-LINAC beam)
- New **safety system**
- New data acquisition ad treatment **software and hardware**



STAR 2: High Energy µTOMO 2 BEAMLINE



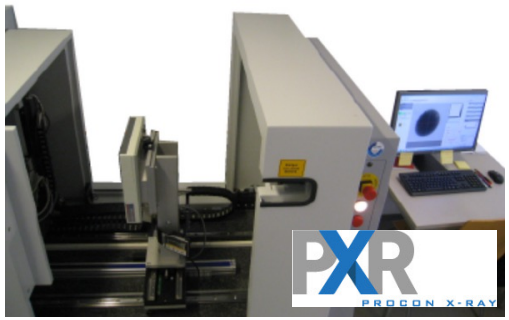
µTomo 2 targets

- Cultural Heritage studies
- Mechanics and metallurgy
- Microelectronics
- In-situ and operando devices
- Palaeontology
- Earth science

- ➢ [illegible] devices
- ➢ [illegible]acturing
- ➢ [illegible] check
- ➢ [illegible] materials

STAR 2: SOFTX - X-RAY MICROGRAPHY/SAXS BEAMLINE

NEW X-RAY MICROGRAPHY AND SAXS END-STATION



- Designed for the **17-80 keV range**
- New **x-ray transport** system
- Fully equipped **SAXS** experimental beamline (with conventional source alternative to STAR LE-LINAC beam)
- **µgraphy and µCT station for low density materials** (Polimers, Biomaterial, …)
- **High power 120 keV microfocus source** (alternative to the STAR LE-LINAC beam)
- New **safety system**
- New data acquisition ad treatment **software and hardware**

STAR 2: SOFTX - X-RAY MICROGRAPHY/SAXS BEAMLINE

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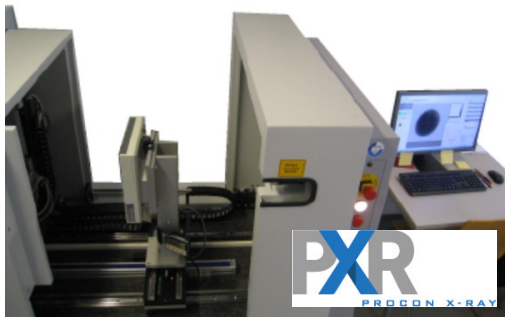
SOUTHERN EUROPE TBS SOURCE FOR APPLIED RESEARCH

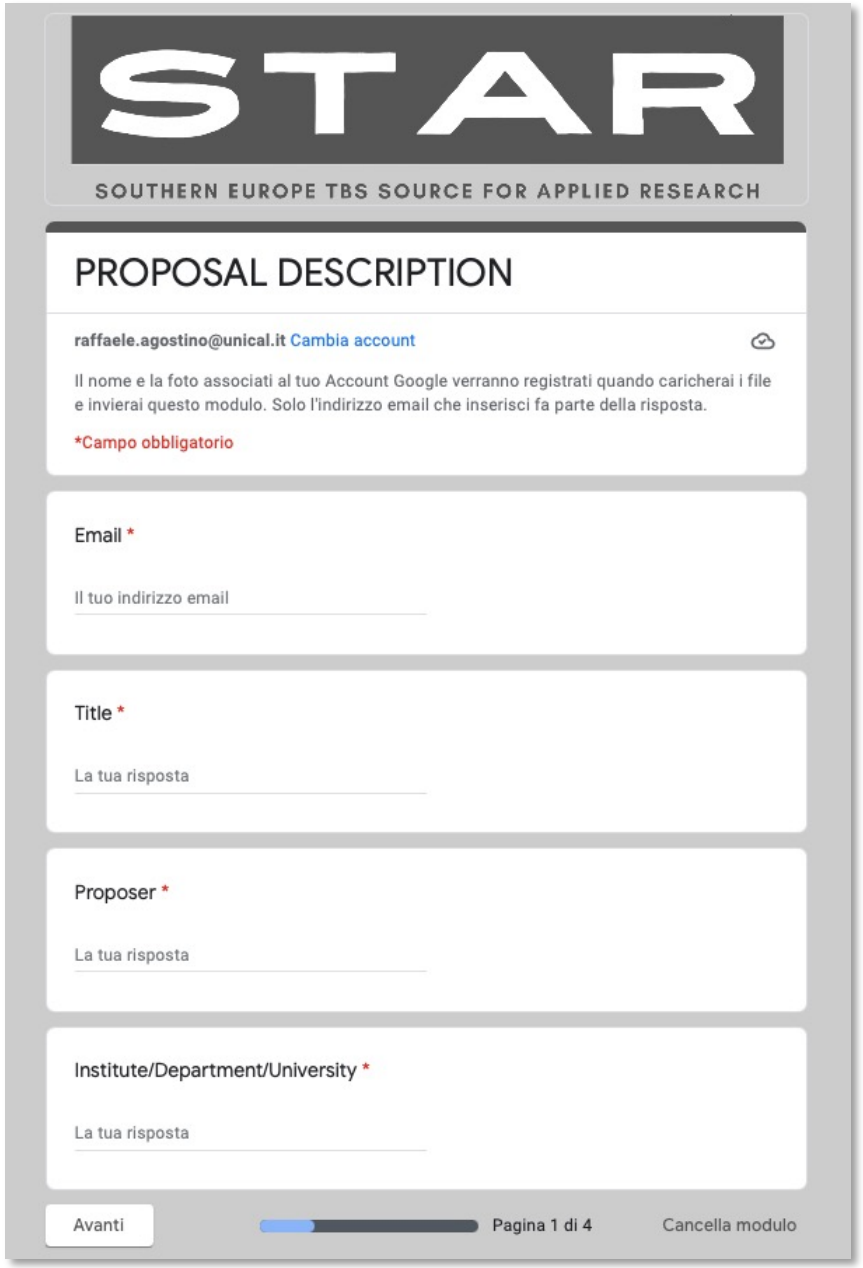
X-RAY MICROGRAPHY AND SAXS TARGETS

Where molecules and their aggregates matters

- Materials science
  - production of nanoparticles
  - catalysis
  - separation technology
- Life sciences
  - drug/DNA delivery systems
  - pharmaceutical applications
  - food
- Physics/chemistry
  - liquid crystals
  - soft matter



STAR 2: USER OFFICE



Virtual User Office

(under construction)

- Beamtime request
- Long-term proposals
- Multi-lab access
- Fast track & preliminary tests
- Industrial and academic users
- Institutional collaboration