FELs OF EUROPE

FROM CONCEPT TO COMMISSIONING

SABINA

a 3-30 THz/IR FEL

User Facility at SPARC_LAB

Elettra Sincrotrone Trieste

ENEA
Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

SAPIENZA
UNIVERSITÀ DI ROMA

INFN
Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

Ilaria BALOSSINO
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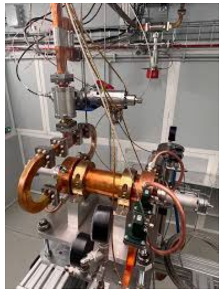
on behalf of the working group

SPARC_LAB @ the INFN National Laboratory of FRASCATI

BIG Development activities of particle accelerators since 1960

1. DAPHNE
2. Daphne Luce (Synchrotron Light)
3. SPARC_LAB
4. Plasma Acceleration
5. FLAME
6. Beam Test Facility
7. TeX (X-band RF)

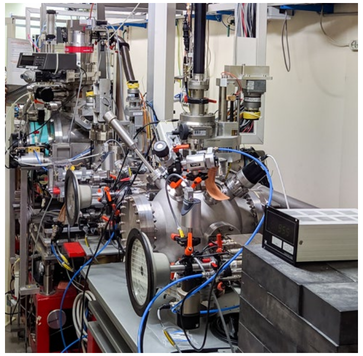


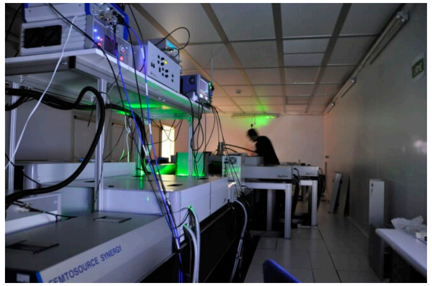
Studies of the fundamental constituent of the matter

Investigations on the atomic matter in its structure and dynamics

Several experiment on-site

Countless international collaborations





SPARC_LAB @ the INFN National Laboratory of FRASCATI

MULTIDISCIPLINARY LABORATORY

INNOVATIVE PHOTOINJECTOR

beam energy up to 170 MeV with high peak current (>1kA) and low emittance(<2 mm – mrad)

HIGH POWER LASER

>200 TW to generate

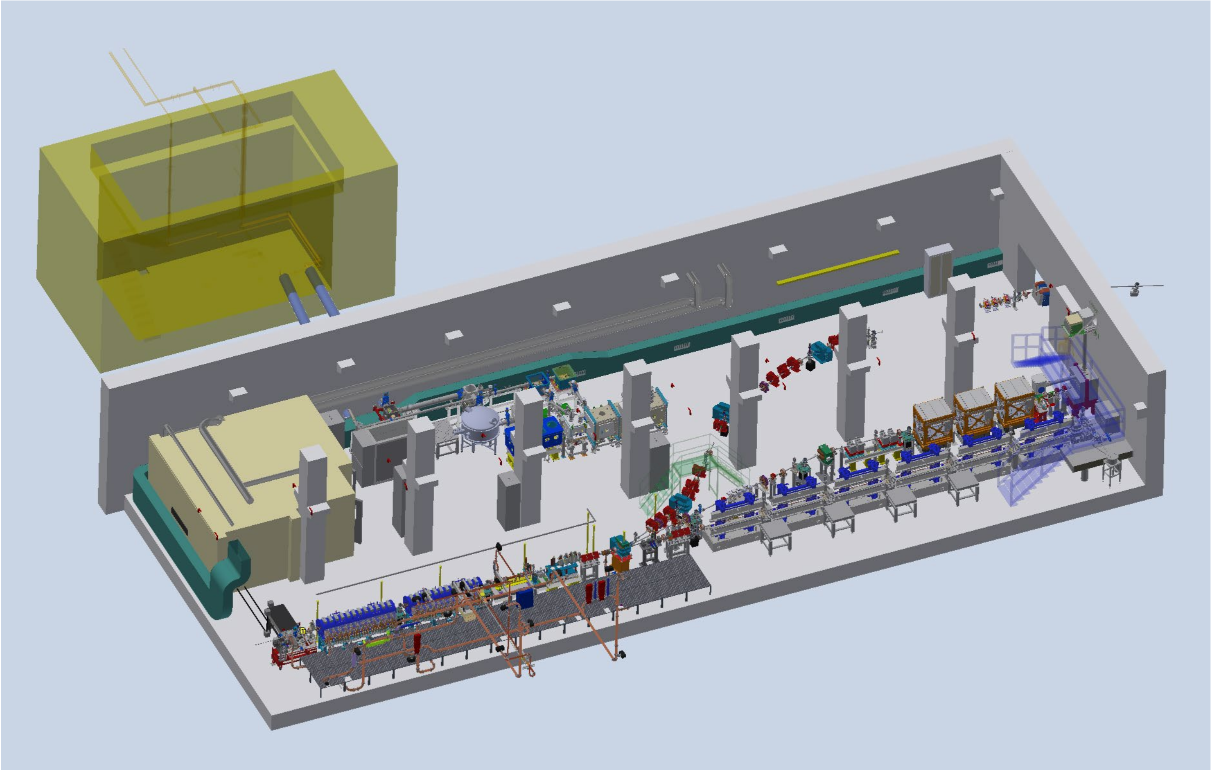
ultra-short pulses (<30fs)

Development of innovative radiation sources

Unconventional and innovative technologies

Plasma Acceleration

FEL Technology



FELs OF EUROPE

AUTHORIZED PARTNER

SPARC LAB

Sources for Plasma Accelerators and Radiation Compton with Laser And Beam

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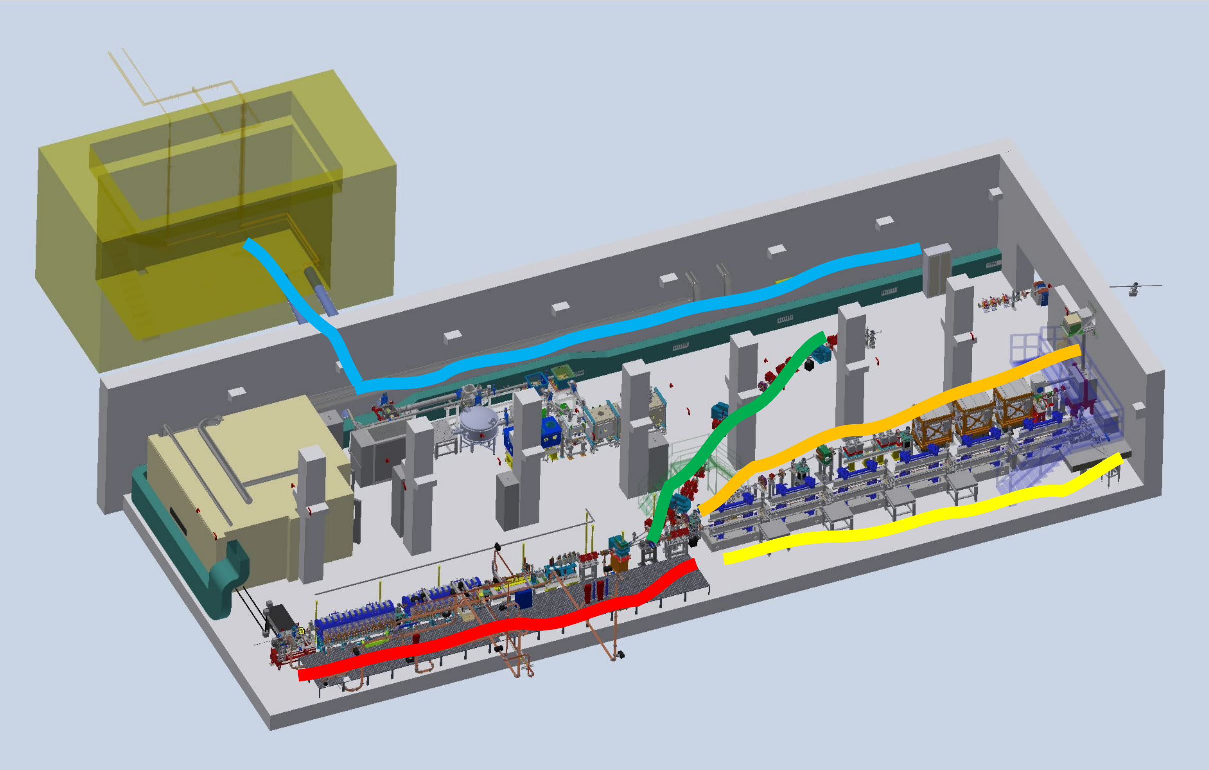


SPARC LAB

Sources for Plasma Accelerators and Radiation Compton with Laser And Beam

FELs OF EUROPE

AUTHORIZED PARTNER

SABINA first's contibution to SPARC LAB

INCREASE ACCELERATOR UPTIME AND BEAM STABILITY

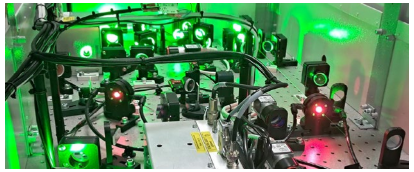
Improvement and consolidations

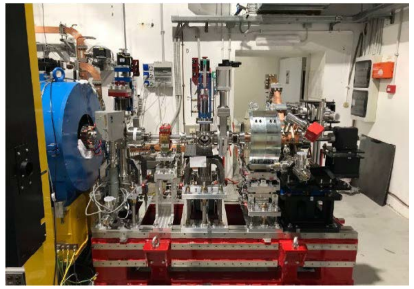
BEAM QUALITY
DIAGNOSTIC SYSTEMS
ANCILLARY SYSTEMS

New S-band RF gun
Low-jitter photocathode laser
Two new 12 coils solenoids

Digital LLRF
K400 modulator
Laser Oscillator
Upgraded utilities

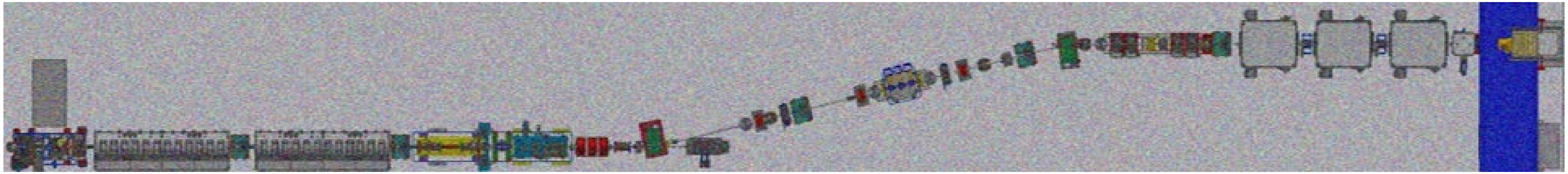
EXCEPTIONAL GROUNDWORK FOR EXTERNAL USERS





USER FACILITY WITH A TUNABLE THz-MIR FEL BEAMLINE

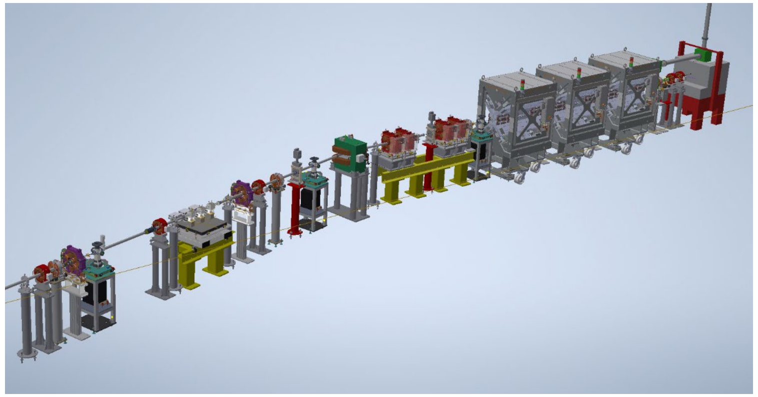
THz SABINA



High control and **high quality** of the 30-100 MeV electron bunches

Key elements of the line are the **3 APPLE-X** undulators to generate the desired THz radiation

Radiation transported over **25 m** high-/low-vacuum optical line with >90 % throughput



Large spectral extension (3–30 THz)

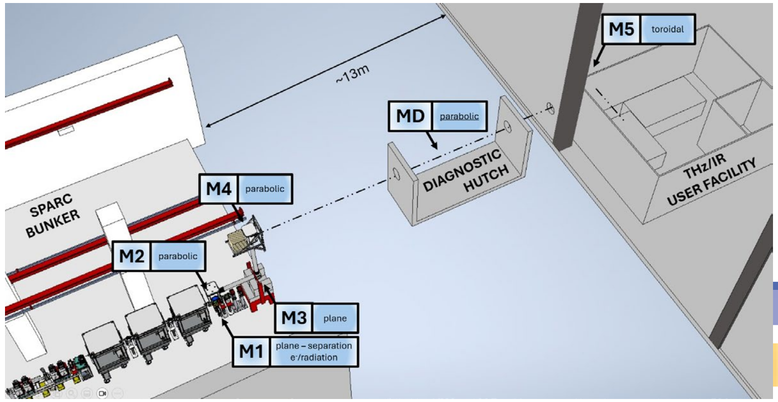
High intensity (up to hundreds of μJ/pulse)

Short pulse duration (≈ ps)

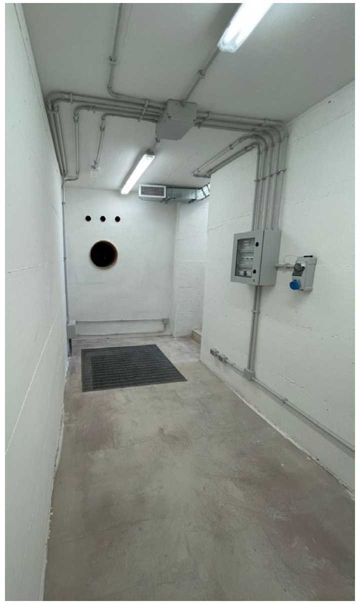
Variable light polarization

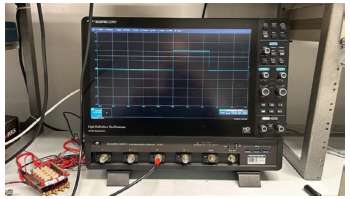
Energy e^- beam 30–100 MeV

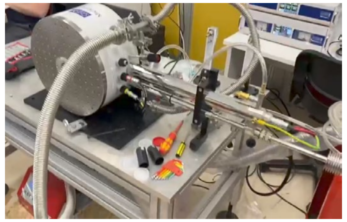
Energy-tunable pulsed radiation

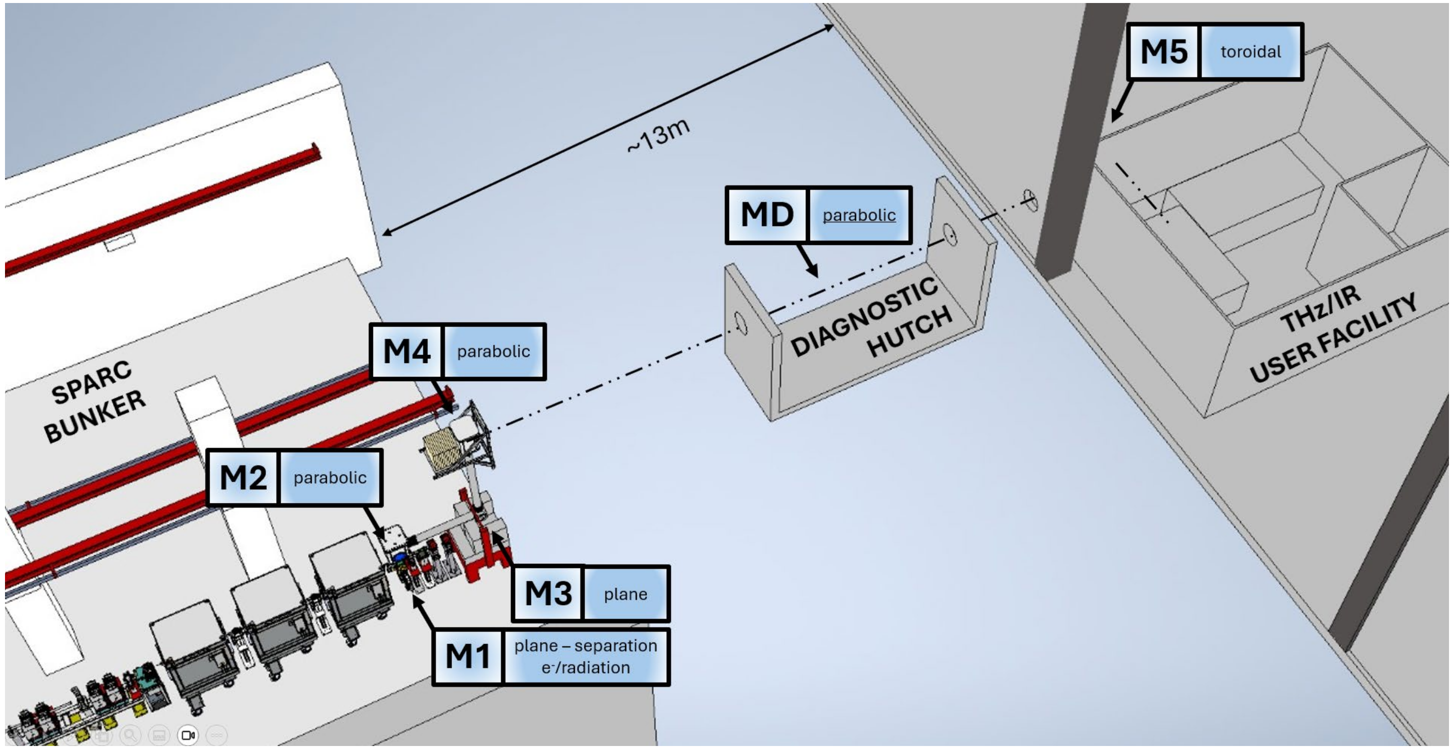


USER FACILITY WITH A TUNABLE THz-MIR FEL BEAMLINE







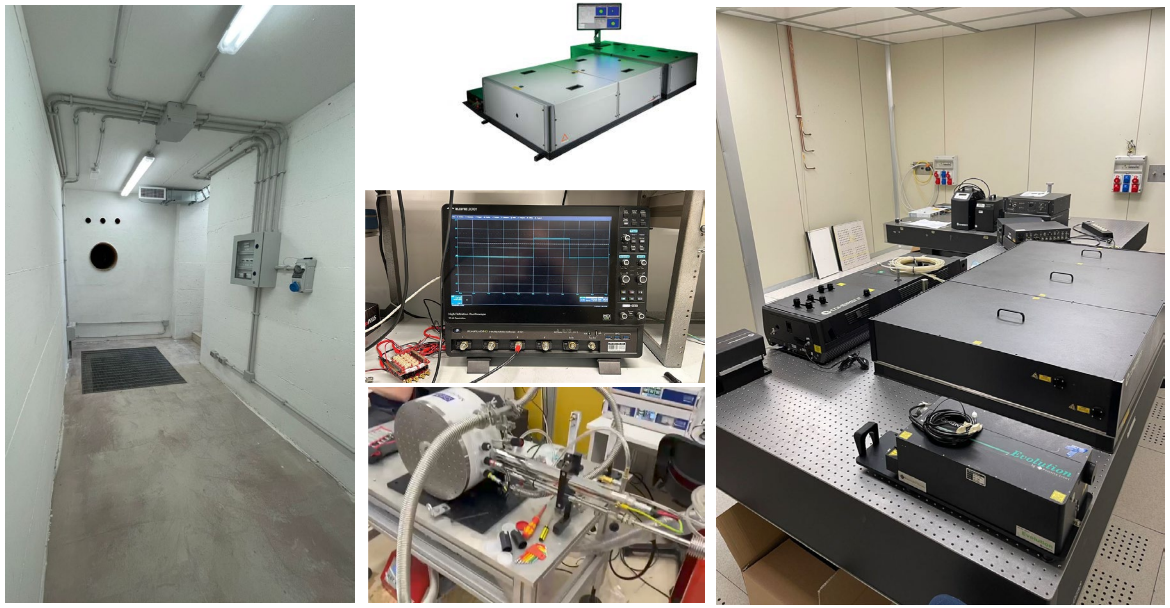


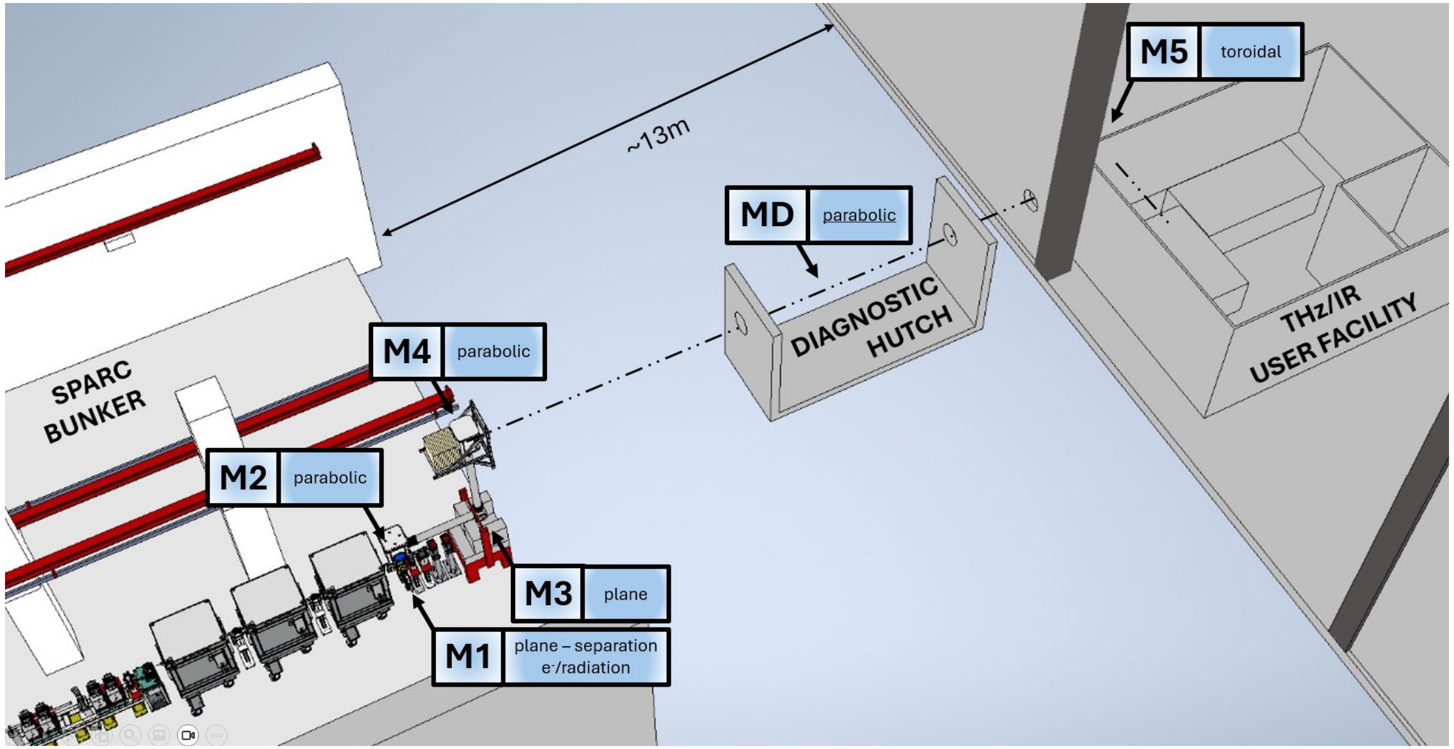
- 5 T **cryostat**
- a synchronised **fs laser**

- THz/MIR-pump + VIS/UV-probe
- THz-pump/THz-probe

USER FACILITY WITH A TUNABLE THz-MIR FEL BEAMLINE

SABINA will **open new frontiers**
in nonlinear THz optics, ultrafast dynamics
and high-field magneto-spectroscopy, while establishing
SPARC-LAB as a hub for multidisciplinary science





The user hutch will be equipped for **experiments on quantum materials and advanced coatings**

- 5 T **cryostat**
- a synchronised **fs laser**

- THz/MIR-pump + VIS/UV-probe
- THz-pump/THz-probe

USER FACILITY WITH A TUNABLE THz-MIR FEL BEAMLINE

Fundamental for **multidisciplinary studies**, which can therefore explore fields such as superconductivity, nonlinear optical phenomena, or metamaterials

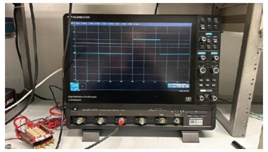
MEDICINE **imaging** techniques

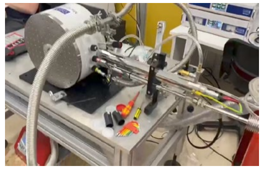
SECURITY penetrating application at **surveillance**

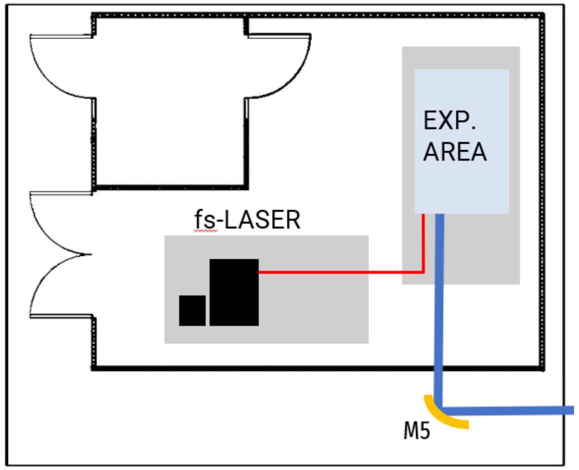
MATERIAL SCIENCE quantum materials **characterization**

BIOLOGY biological detection optical method (**non - destructive**)

ENVIRONMENTAL SCIENCE **sensing** and characterization of pollution particles

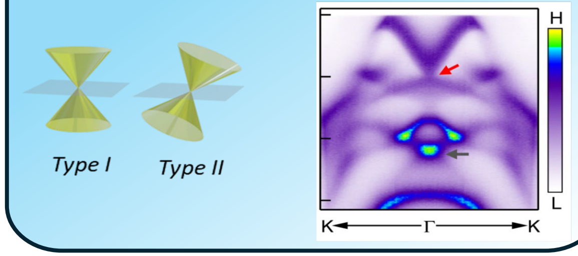






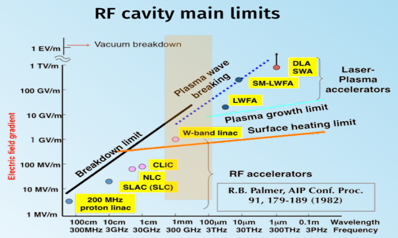
Characterization of Topological Quantum Materials

Dirac Topological Material



IMPROVE THE RESEARCHES OVER THE THz GAP

Study of Materials Response to High-Intensity THz Electric Fields

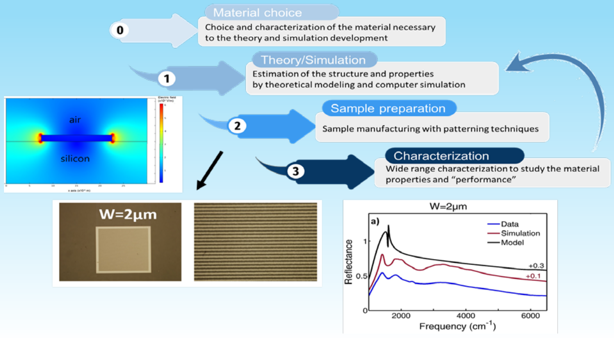


Breakdown phenomena
Current bursts that are emitted through the beam pipes of the accelerating structures.

Thermal stress
High Electric Fields stress and heat the metal surface

Dark current
Present always, electrons leaving the surface

Study of Hyperbolic and Plasmonic Materials



USER FACILITY WITH A TUNABLE THz-MIR FEL BEAMLINE

ROADMAP • OPEN ACCESS

The 2023 terahertz science and technology roadmap

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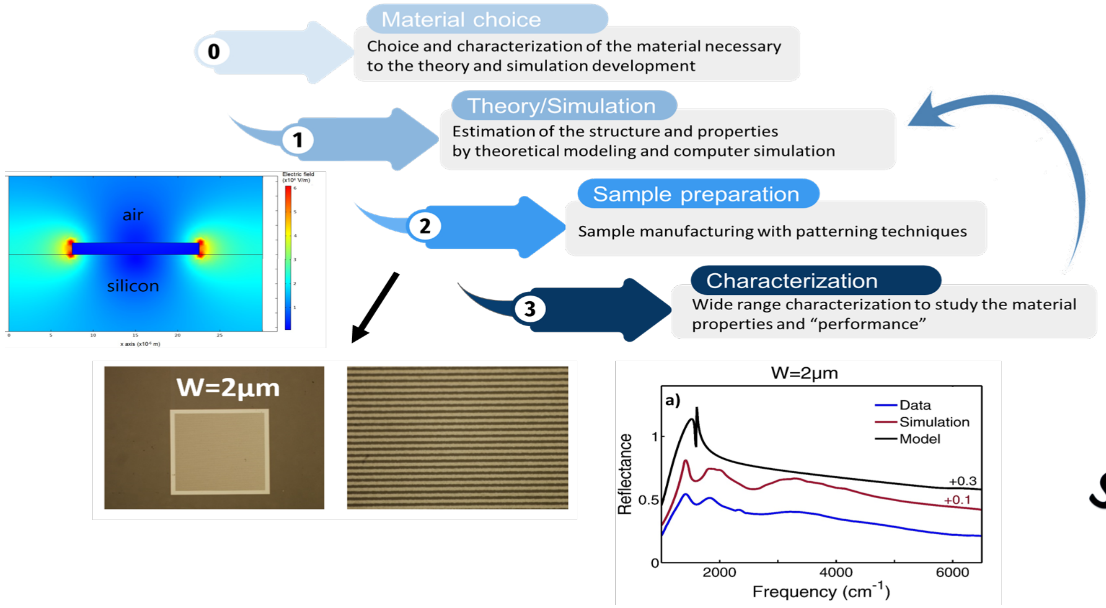
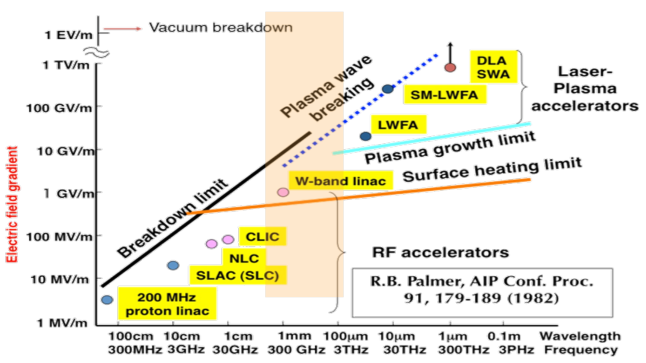
IMPROVE THE RESEARCHES OVER THE THz GAP

Study of Hyperbolic and Plasmonic Materials



Study of Materials Response to High-Intensity THz Electric Fields

RF cavity main limits



Breakdown phenomena
Current bursts that are emitted through the beam pipes of the accelerating structures.

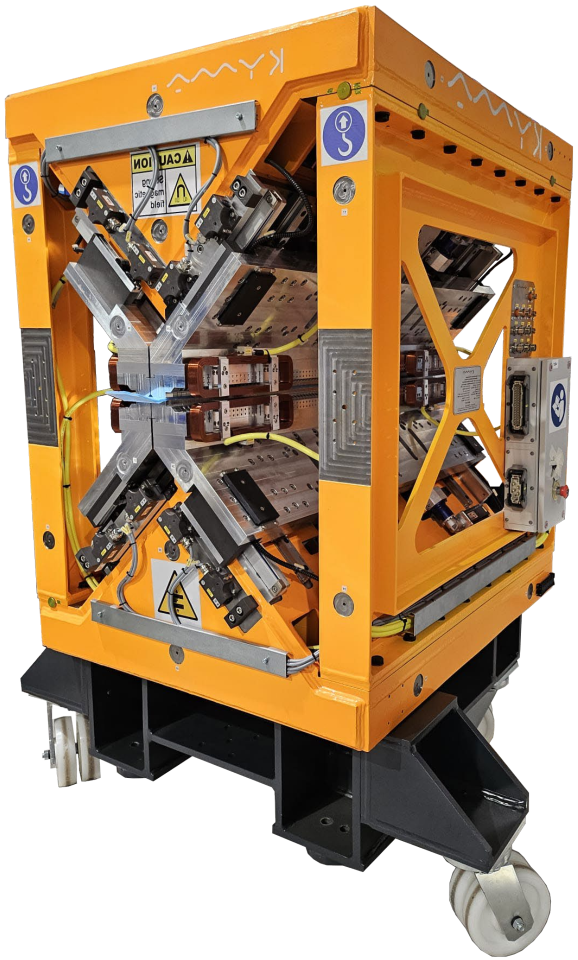
Thermal stress
High Electric Fields stress and heat the metal surface

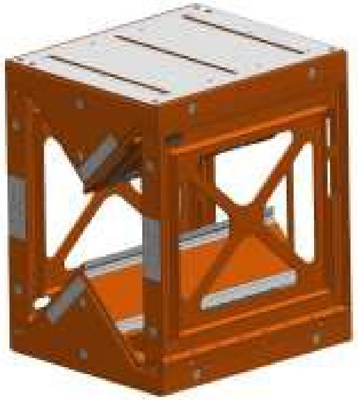
Dark current
Present always, electrons leaving the surface

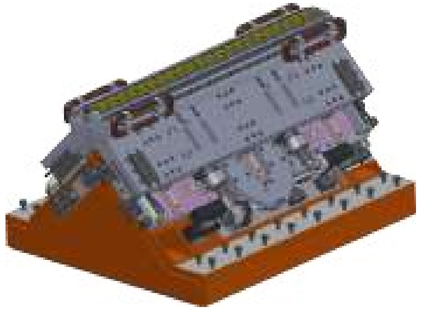
Extended material characterization process from simulations to sample studies and characterization

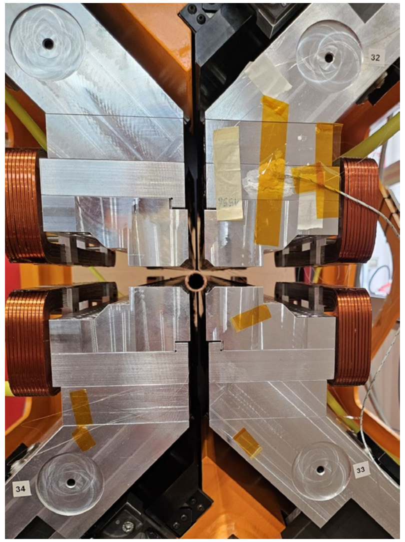
In-depth studies of new materials to overcome the difficulties and complications of existing ones

APPLE- X UNDULATORS

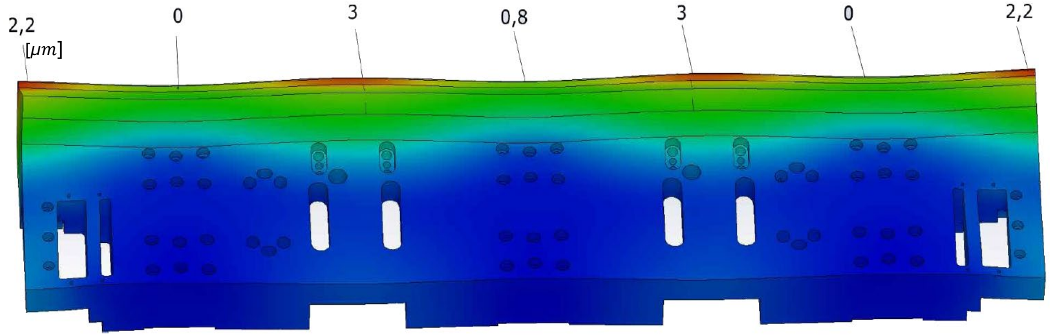








Gap amplitude range	5 ÷ 150 mm
Phase (shift) range	$-\lambda/_2 \div \lambda/_2$
K_{max} at horizontal polarization	4.803
K_{max} at circular polarization	3.396
Peak field at horizontal polarization	0.935 T
Peak field at circular polarization	0.66 T
Period length	55.0 mm
Number of periods	24
Vacuum chamber diameter	10.0 mm



The AX-55 undulator was design following the magnetic and mechanical design required by the INFN tender. The mechanical structure and the kinematic systems have engineered from the ground up. Good functional solution that let us conclude that this option can be a good solution for future applications

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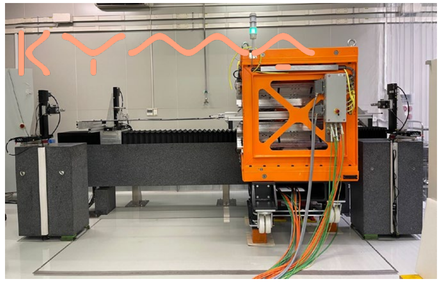
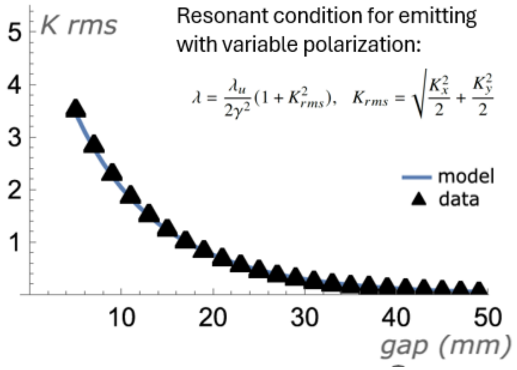
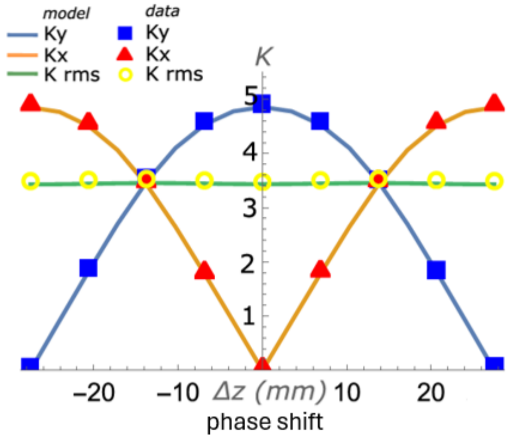
APPLE- X UNDULATORS

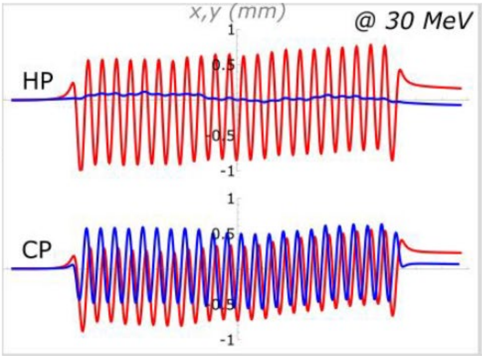


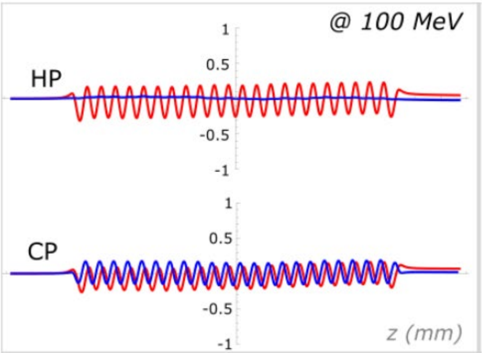
The magnetic measurement and characterization was carried out by KYMA with a special bench and a mounting system to move a 3D Hall probe inside the small aperture of the undulator





- good agreement with the simulation
- $K = 1$ @ $gap \simeq 18\ mm$
- Δz determines the polarization mode
- K_x and K_y variation are the same with a phase difference
- K_{rms} is the same in all the polarization modes





- e^- enters on-axis at 0° angle
- **trajectories**: horizontal red, vertical blue
- polarization mode: Horizontal HP, Circular CP
- extracted studying field integrals
- e^- exits with a negligible angle
- e^- exits with an offset of hundreds of μm

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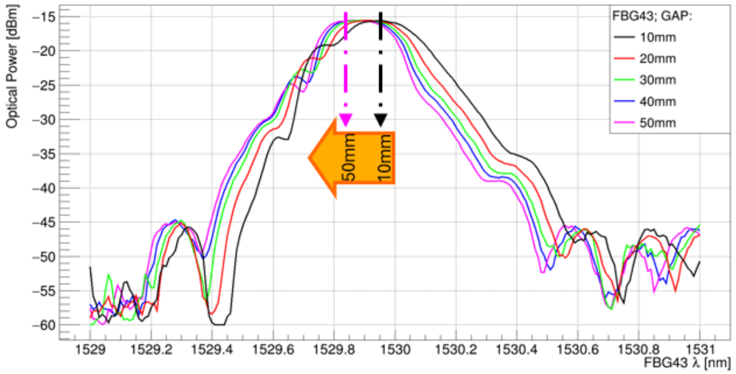
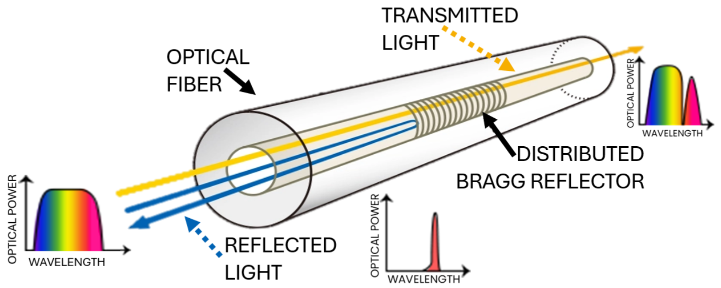
FEL2024->TUP207.pdf

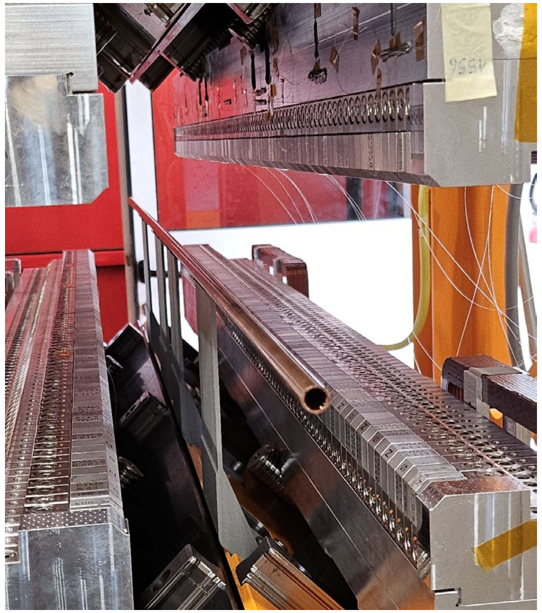
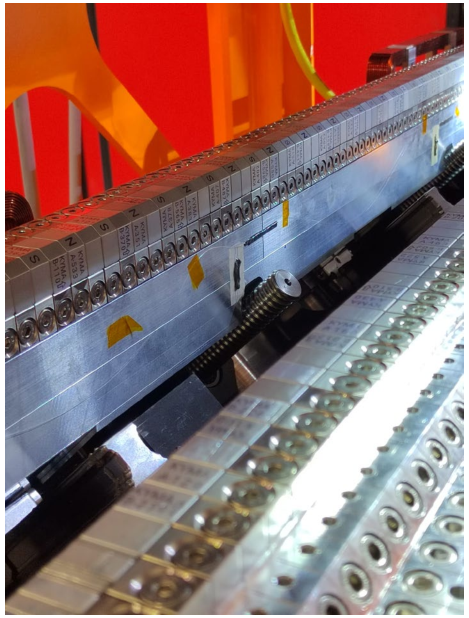
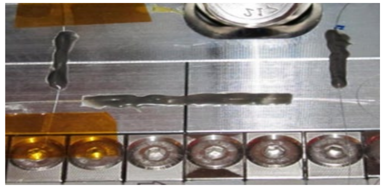
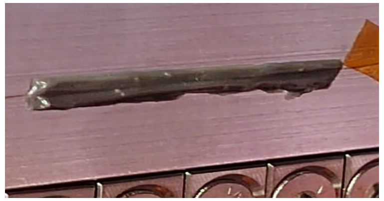
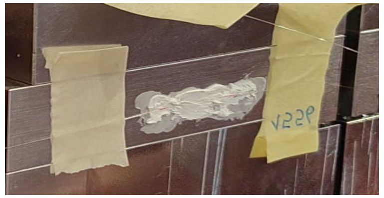
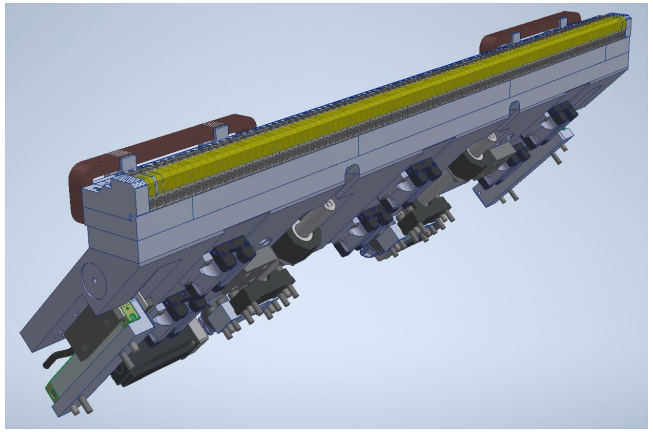
APPLE- X UNDULATORS

Upon the delivery at LNF, additional studies have been performed with the use of Fiber Bragg Gratings technology





- The **FBG** act as wavelength selective mirror
- FBG measures **strain** at each **deformation of the material**
- 1cm long sensors glued with Araldite 2014
- **Broptics OS 1500** optical sensor for Micron Optics
- $1\mu strain \left(= 1\frac{\mu m}{m}\right) \Leftrightarrow \Delta\lambda = 1.2pm$
- The peak wavelength changes proportionally to the strain at the sensor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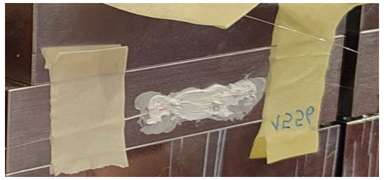
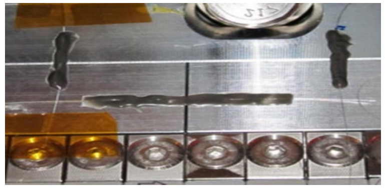
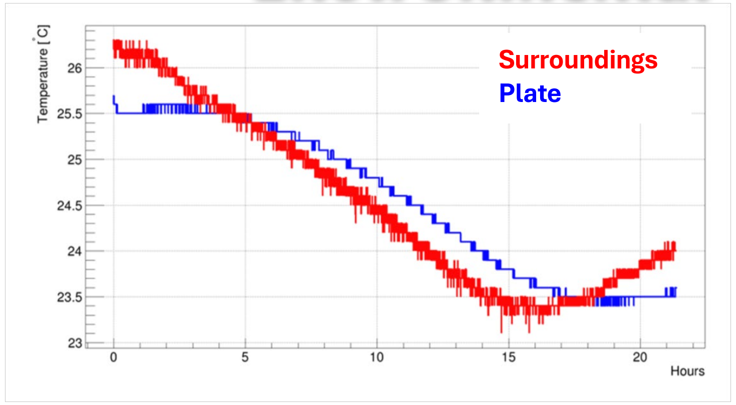
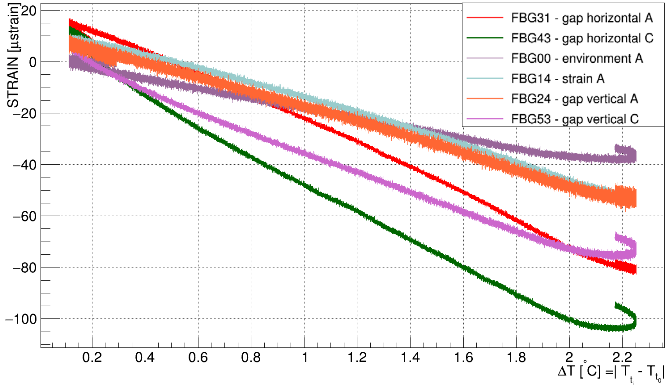
APPLE- X UNDULATORS



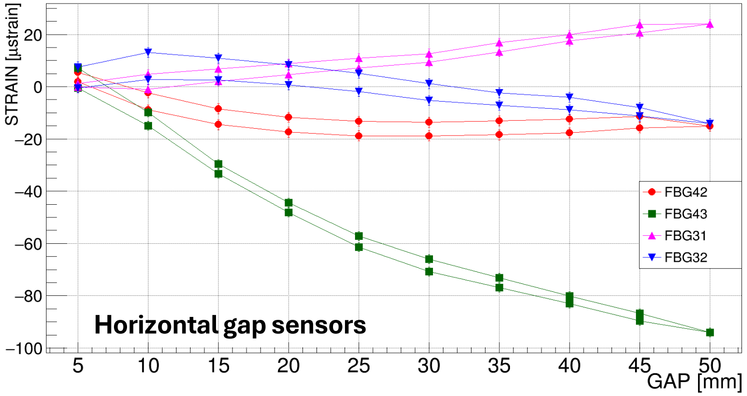


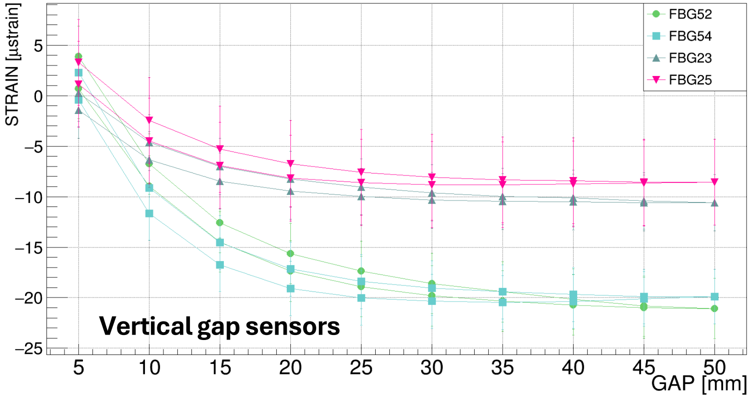
Environmental



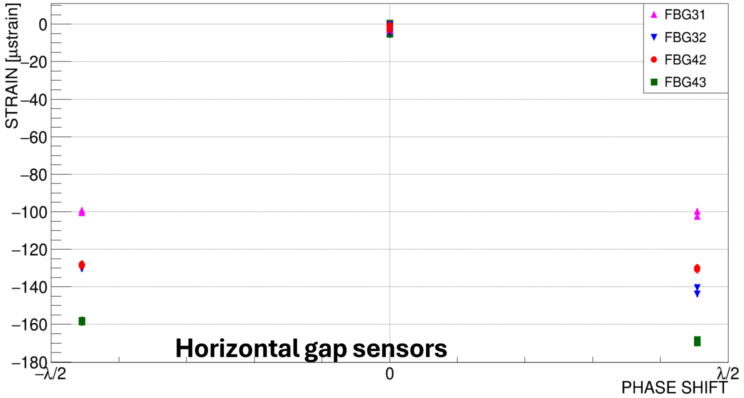


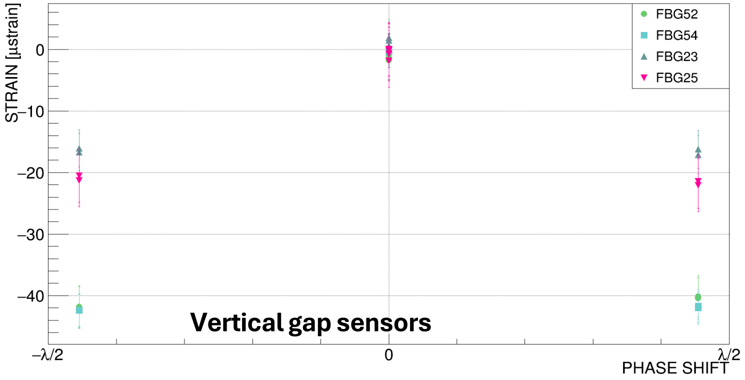
Gap Opening





Phase Shifting





Maximum Deformation Measured

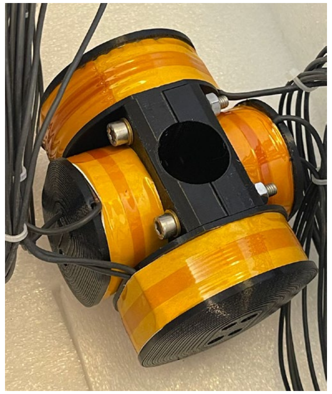
GAP SENSORS: 180nm/mm

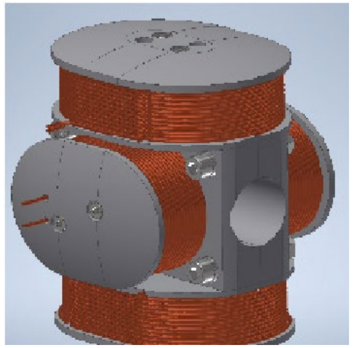
STAIN SENSORS: 330nm/cm

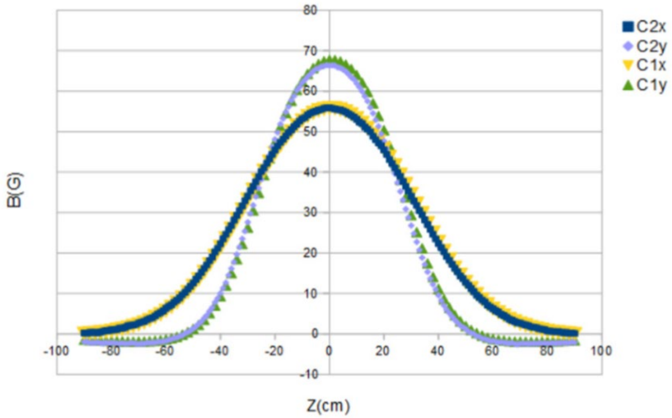
These results, compatible with the FEM analysis, show the extreme sensitivity of this diagnostic and confirm the reliability of the undulator mechanical structure

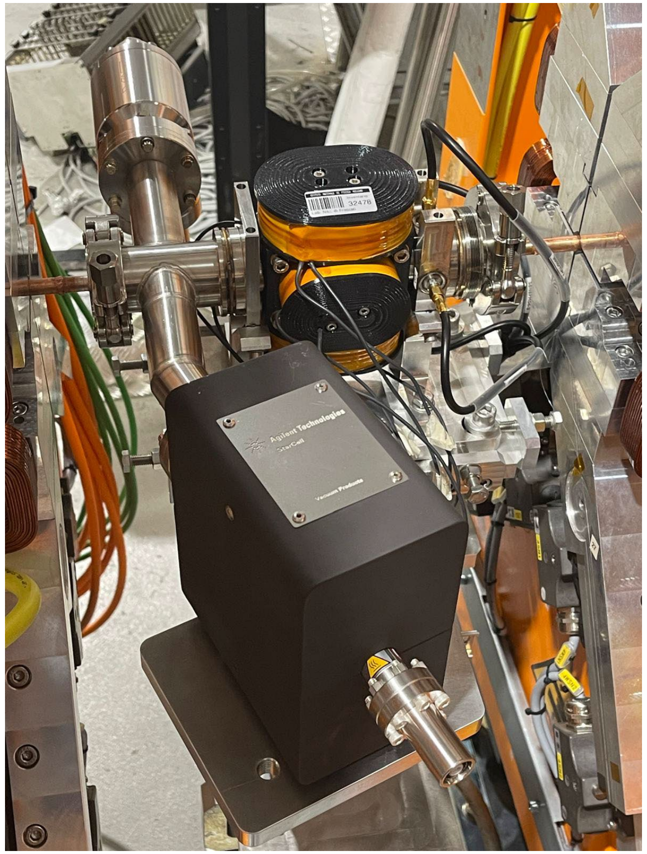
MORE INNOVATIVE EXAMPLES

The intra-undulator steerer is need to correct the trajectory of the beam. Two identical steerers are placed between the undulators. The goal is to correct at least 1.0 mrad at 100 MeV, that corresponds to and integrated field larger than 333 G*cm

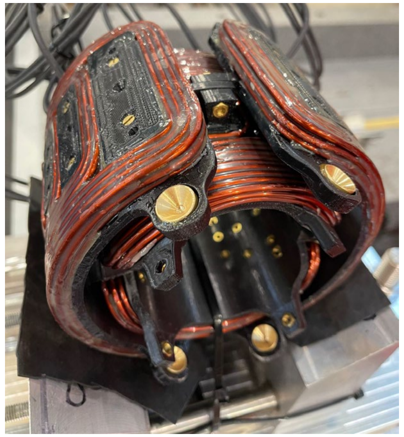








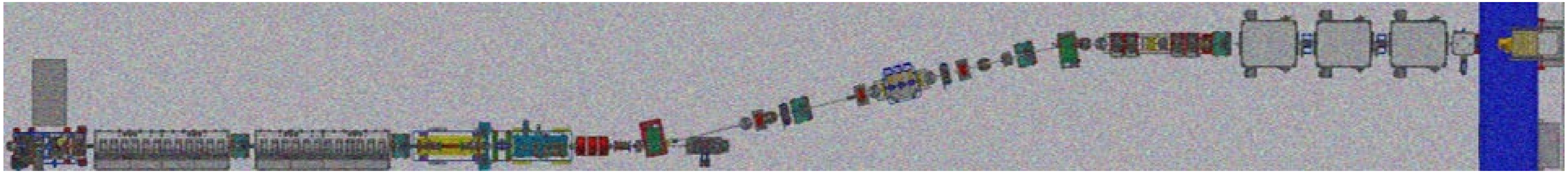
Starting in 2018, we designed and created beam correctors supports using 3D printing technology and two different types of **FDM materials, ULTEM and ASA**



Such work demonstrates that the new technologies such as 3D printing could help the development of lattice elements in terms of complex design, production time, and R&D with good balance between sizing, performance, ergonomic construction, and installation operations

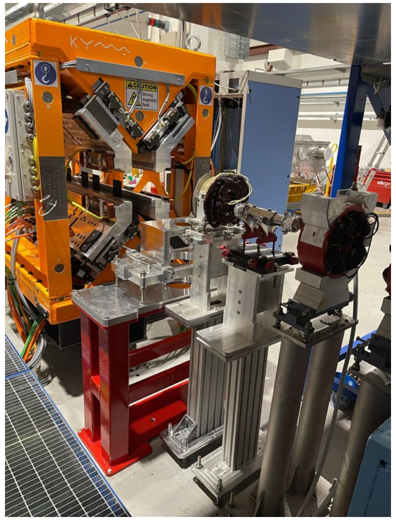
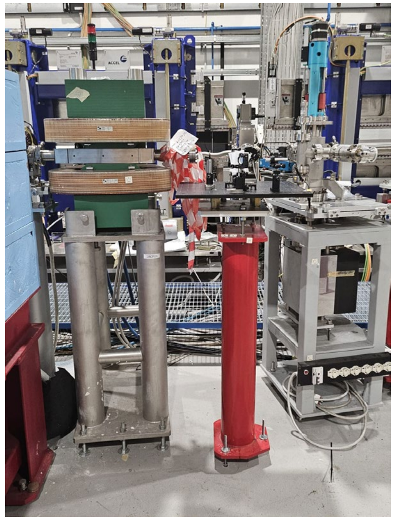
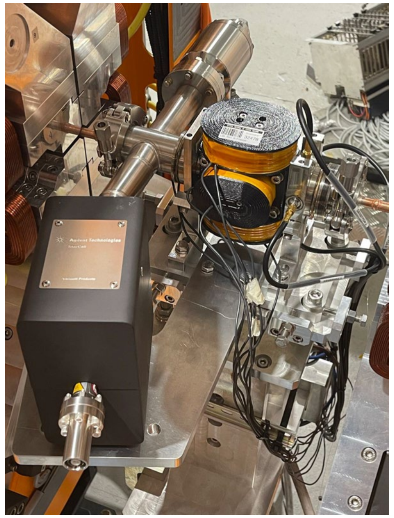
TOWARDS THE ELECTRON LINE COMMISSIONING

The SABINA dogleg at SPARC_LAB electron line is almost complete



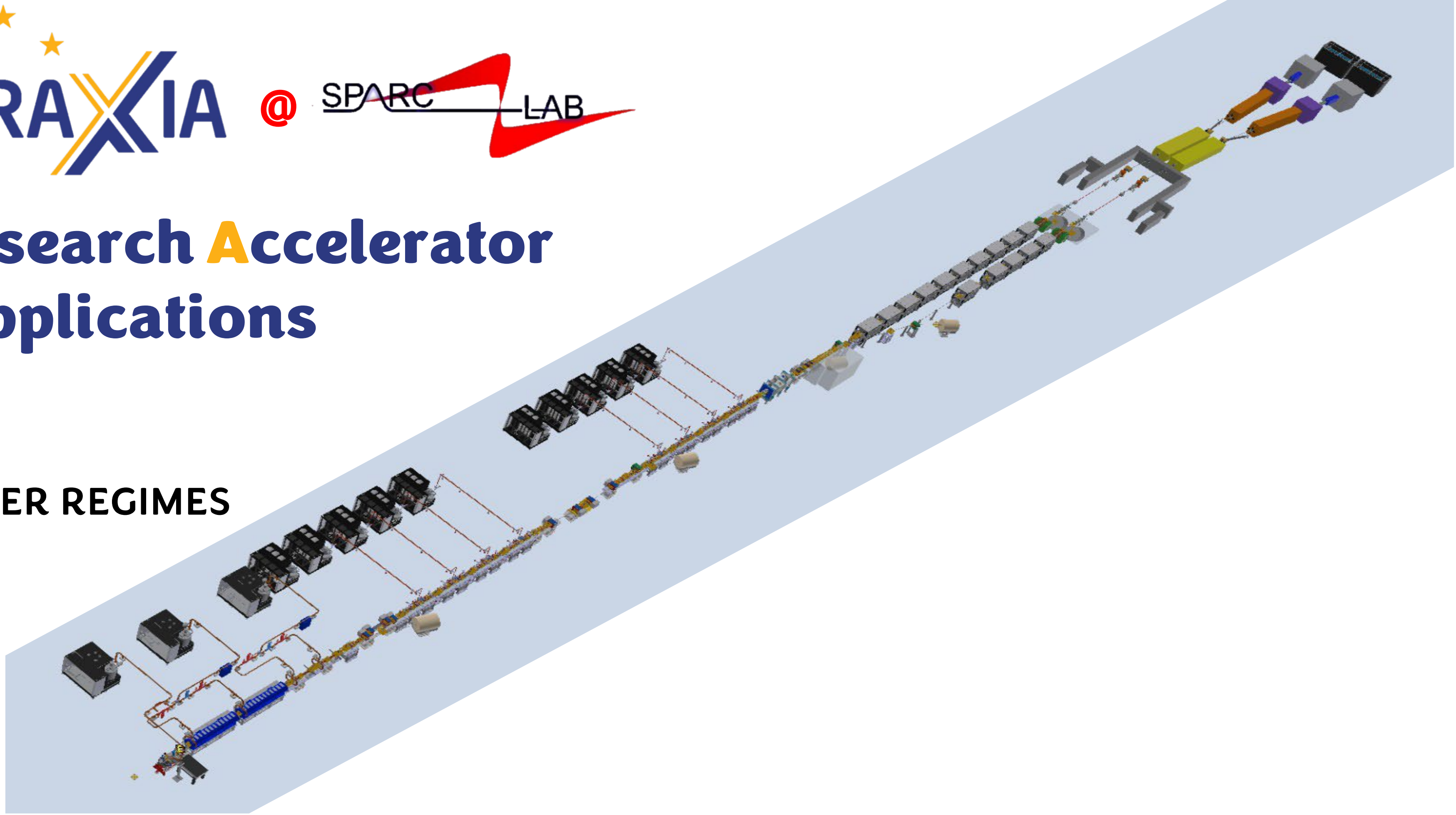
This will allow the commissioning of the electron beam line in terms of

- beam transportation
- quality check
- vacuum performance
- validation of the routines to define the operating parameters

OUR FUTURE: EuPRAXIA @ SPARC_LAB

European Plasma Research Accelerator with eXcellence In Applications



ENABLE FRONTIER SCIENCE

IN NEW REGIONS AND PARAMETER REGIMES

X-RAYS POINT LIKE EMISSIONS

PUMP-PROBE CONFIGURATIONS

TEST BEAMS FOR PARTICLE DETECTORS

HIGH ENERGY POSITRON BEAM

ULTRA-FAST ELECTRON AND PHOTON PULSE

TIME RESOLVED MEASUREMENTS INVERSE COMPTON SCATTERING

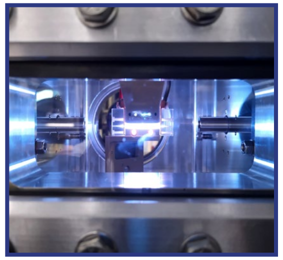
PARTICLE ACCELERATOR RESEARCH FACILITY
MULTI PARALLEL USERS LINES (1 GeV FEL)
BEAM DRIVEN PLASMA ACCELERATOR TECHNOLOGY

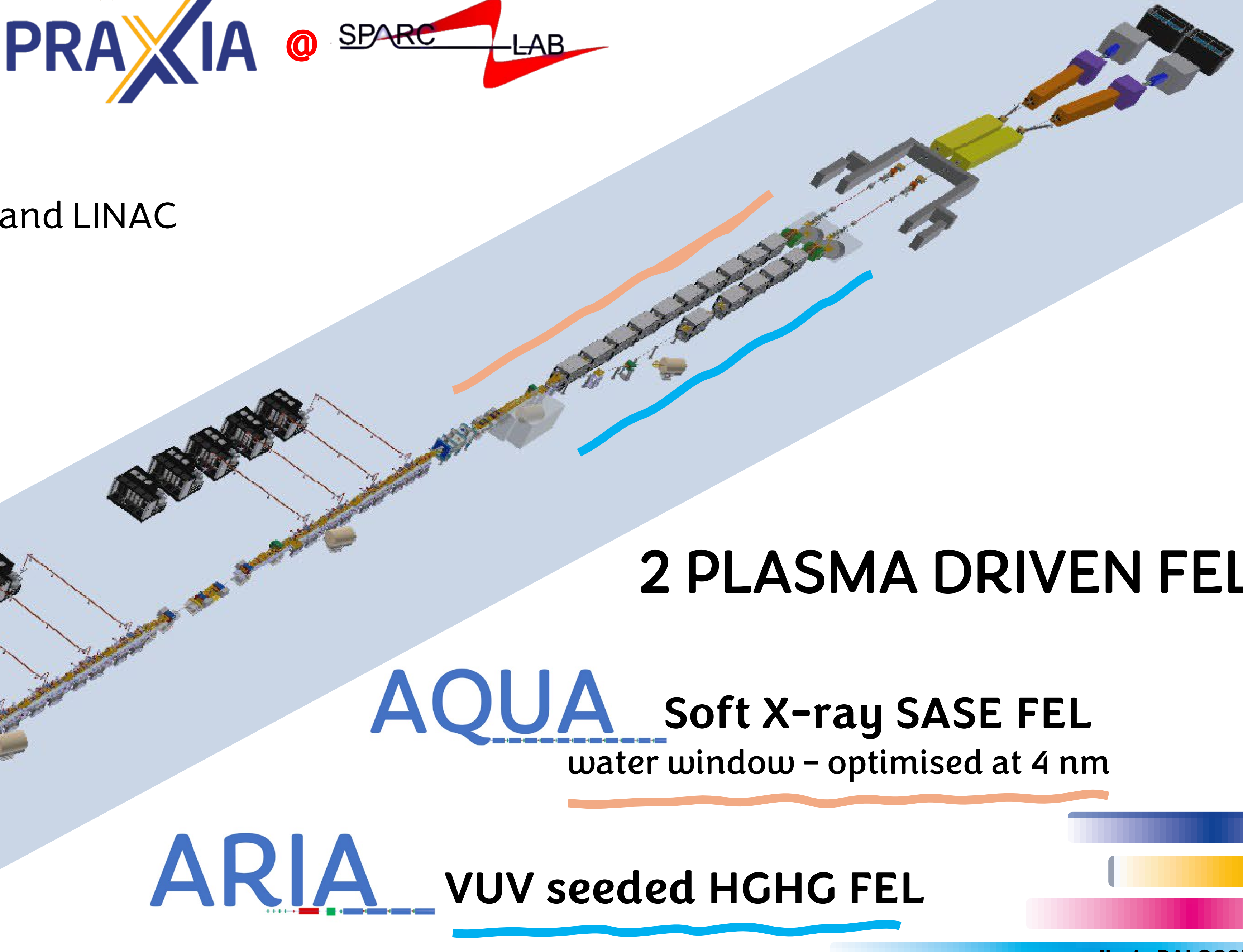
OUR FUTURE: EuPRAXIA @ SPARC_LAB

High Quality Electron Beam

World Most Compact RF X-band LINAC

PLASMA Module





2 PLASMA DRIVEN FELs

AQUA Soft X-ray SASE FEL

water window - optimised at 4 nm

ARIA VUV seeded HGHG FEL

FELs OF EUROPE

FROM CONCEPT TO COMMISSIONING

SABINA

Thank you

Elettra Sincrotrone Trieste

ENEA
Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

SAPIENZA
Università di Roma

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