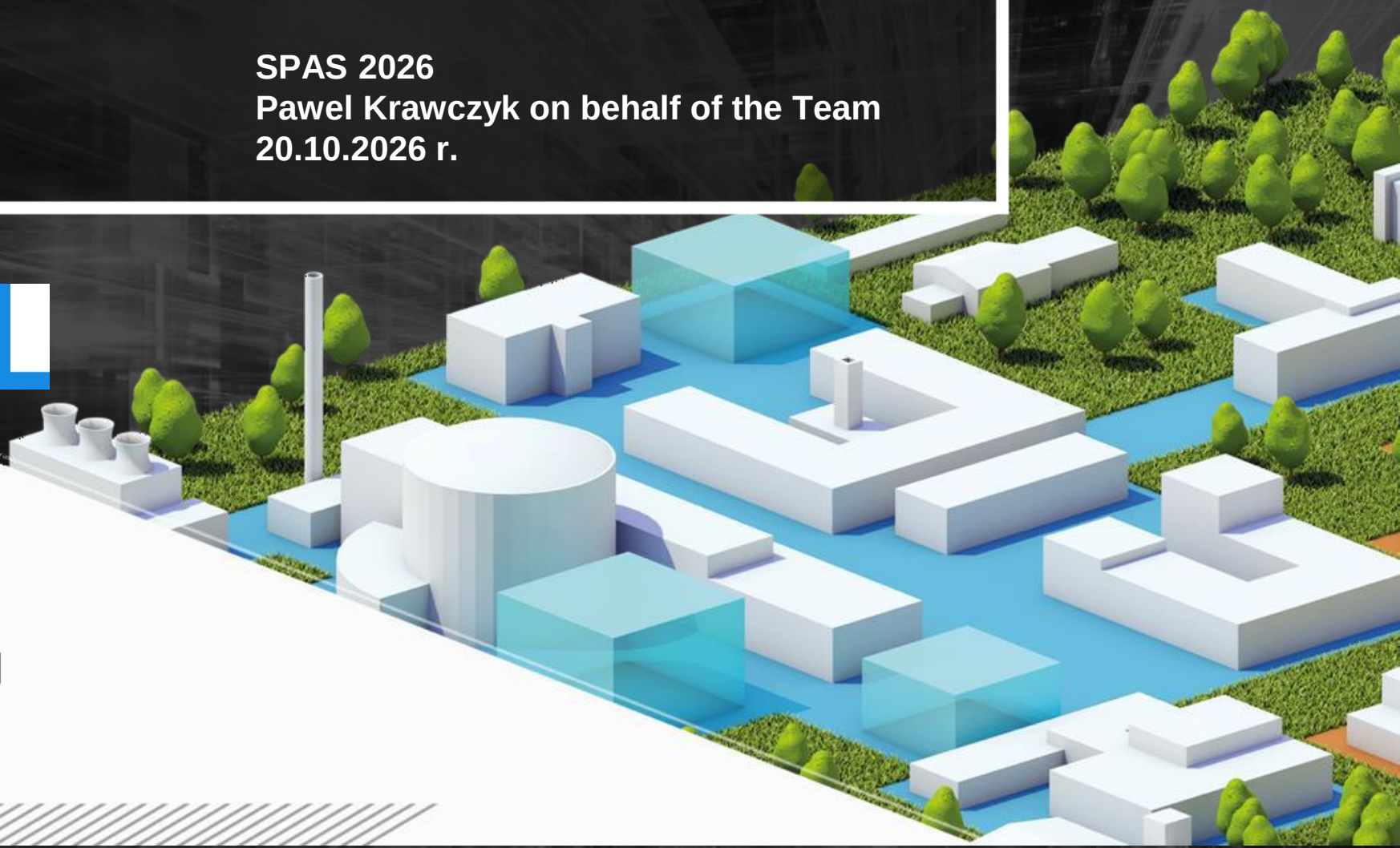
PolFEL Project Status

SPAS 2026
Pawel Krawczyk on behalf of the Team
20.10.2026 r.

POLFEL

NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK



PolFEL project evolution

From:

A Soft X-Ray FEL Facility (2009 -)

Thru:

A Versatile Small to Medium Scale FEL Facility in THz – IR – VUV range (2018 – 2022)

To:

An Ultrafast Dynamics Imaging of Matter Facility (2022 - …)

But all the time:

- ❑ Location at NCBJ
- ❑ Accelerator based
- ❑ SRF electron linac
- ❑ Collabortive effort of the PolFEL Consortium
  - National Centre for Nuclear Research - leader
  - Military University of Technology
  - Warsaw University of Technology
  - Łódź University of Technology
  - Jagiellonian University
  - Wrocław University of Science and Technology
  - University of Zielona Góra
  - University of Białystok

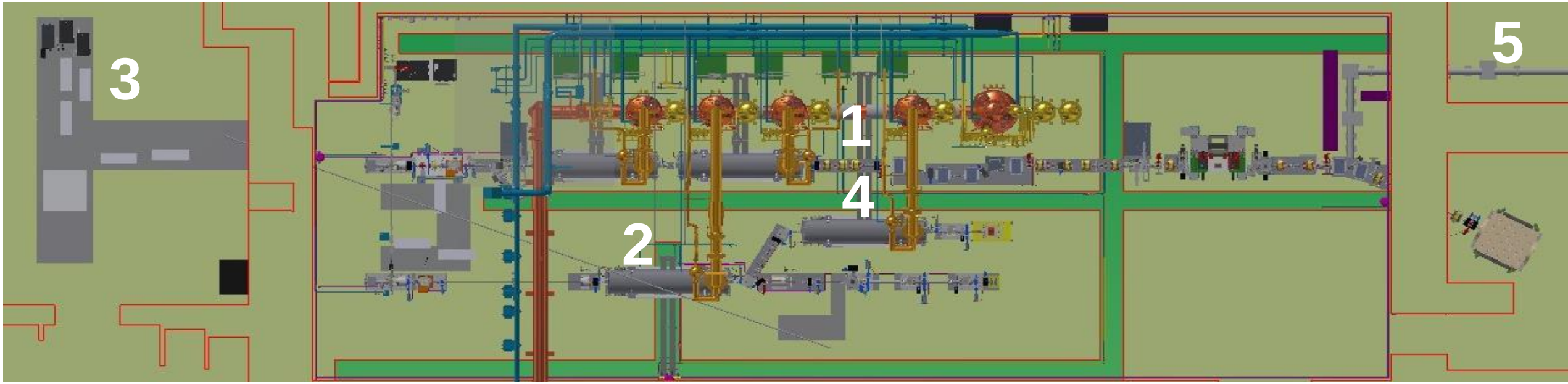


Facility for Ultrafast Dynamics Imaging of Matter

- Superconducting linac with superradiant undulator for THz Free Electro Laser emission (0.5 – 5 THz) and dedicated experimental laboratory (THz spectroscopy, single pulse, pump-probe, …)
- Independent superconducting linac with precise electron bunch shaping, equipped with experimental station for high resolution pump-probe Ultrafast Electron Diffraction measurements (solid and gasous probes)
- Elaborated solid state laser system for electron photocathode initialization, electron – RF synchronization and inducing HHG -EUV beamline in a gas jet (2023 Nobel prize method)
- Cryomodule test stand / VHEE station
- HHG EUV source
- Time resolved ARPES experimental station fed by the HHG pulses
- Dedicated laboratory for dynamical biochemistry measurements (THz/IR – UV): SNOM, fluorescence decay, stop-flow

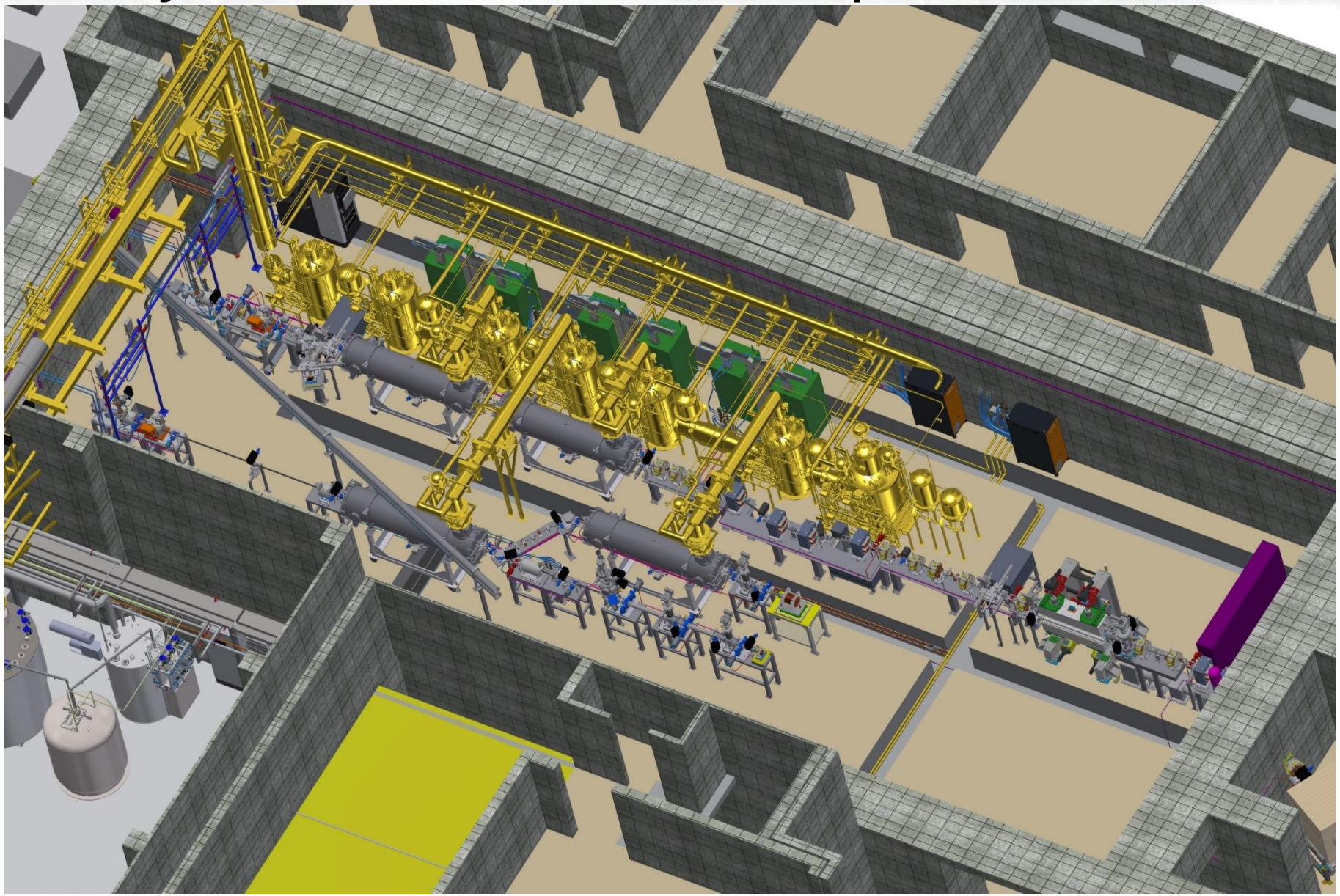


PolFEL building blocks

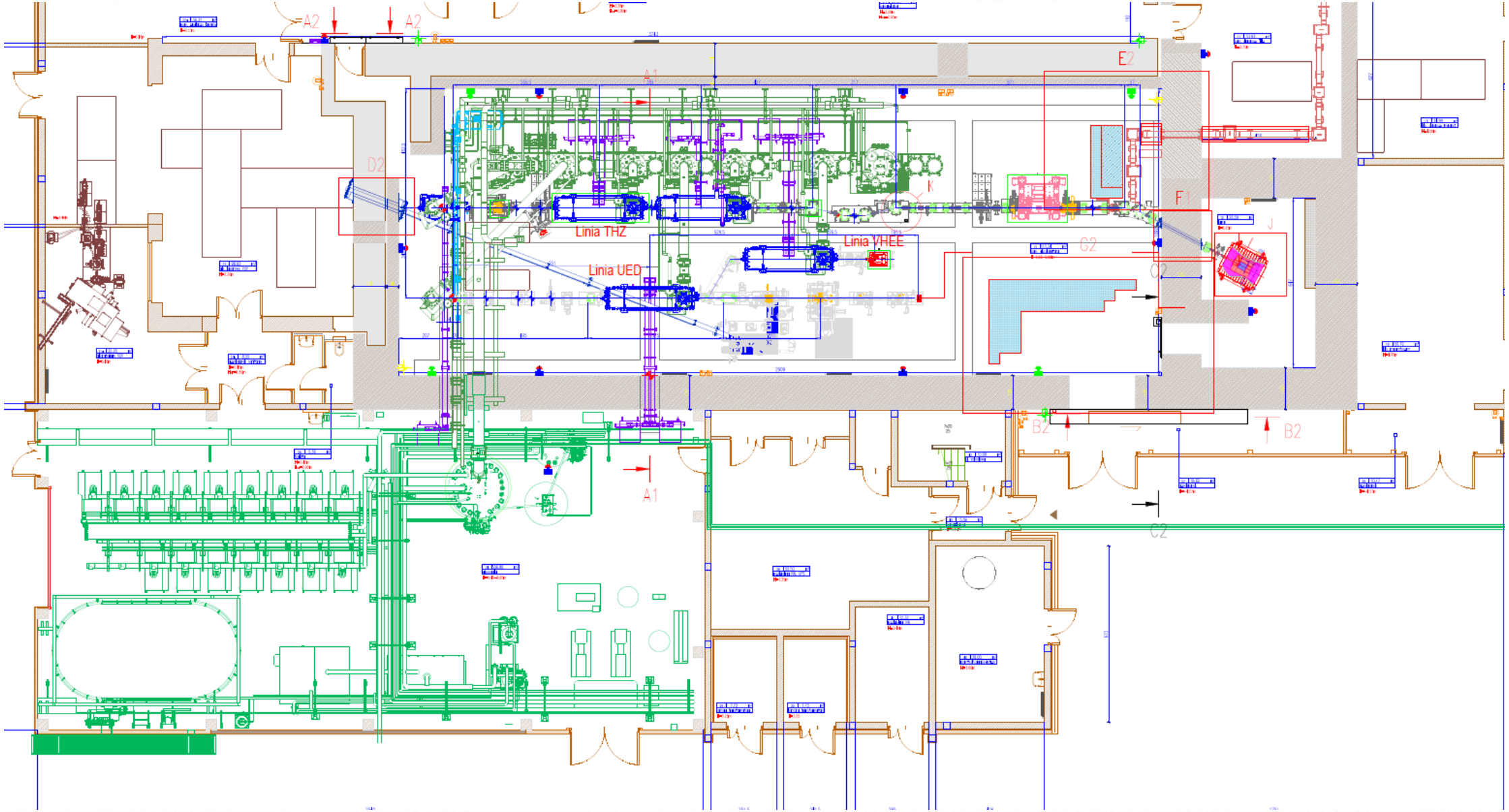


- THz linac with superradiant undulator and experimental station (1)
- UED linac and experimental station (2)
- Photocathode and HHG-EUV beamline initialization lasers (3)
- Cryomodules test stand / VHEE station (4)
- Solid state laser sources and experimental stands (in a separated laboratory)
- THz FEL laboratory (5)
- HHG-EUV beamline with TR-ARPES station (not shown) …

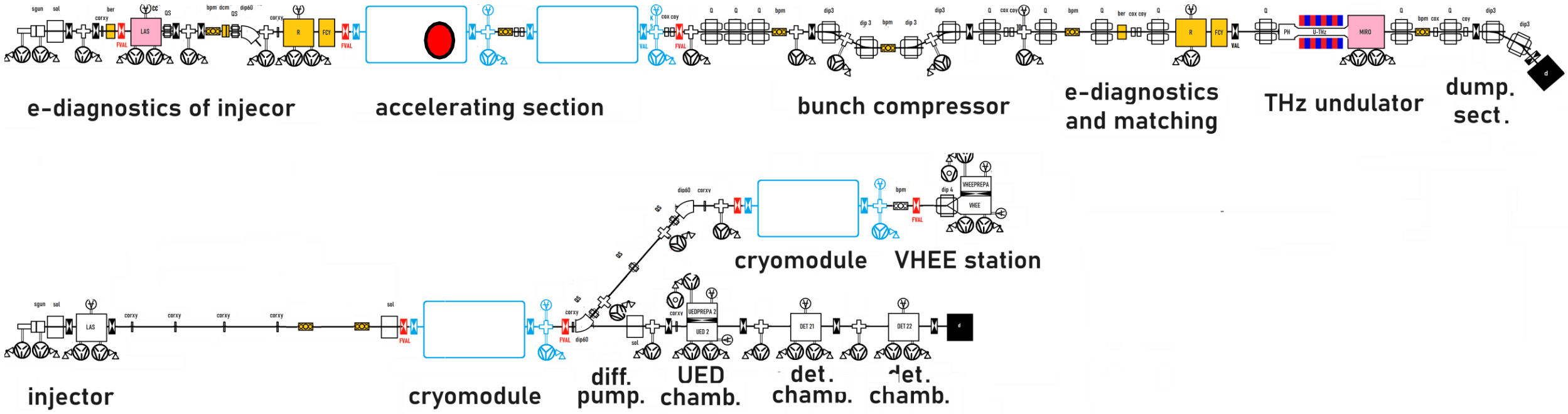
Polfel facility - 3D model of the accelerator part



Polfel facility - 2D model of the accelerator part

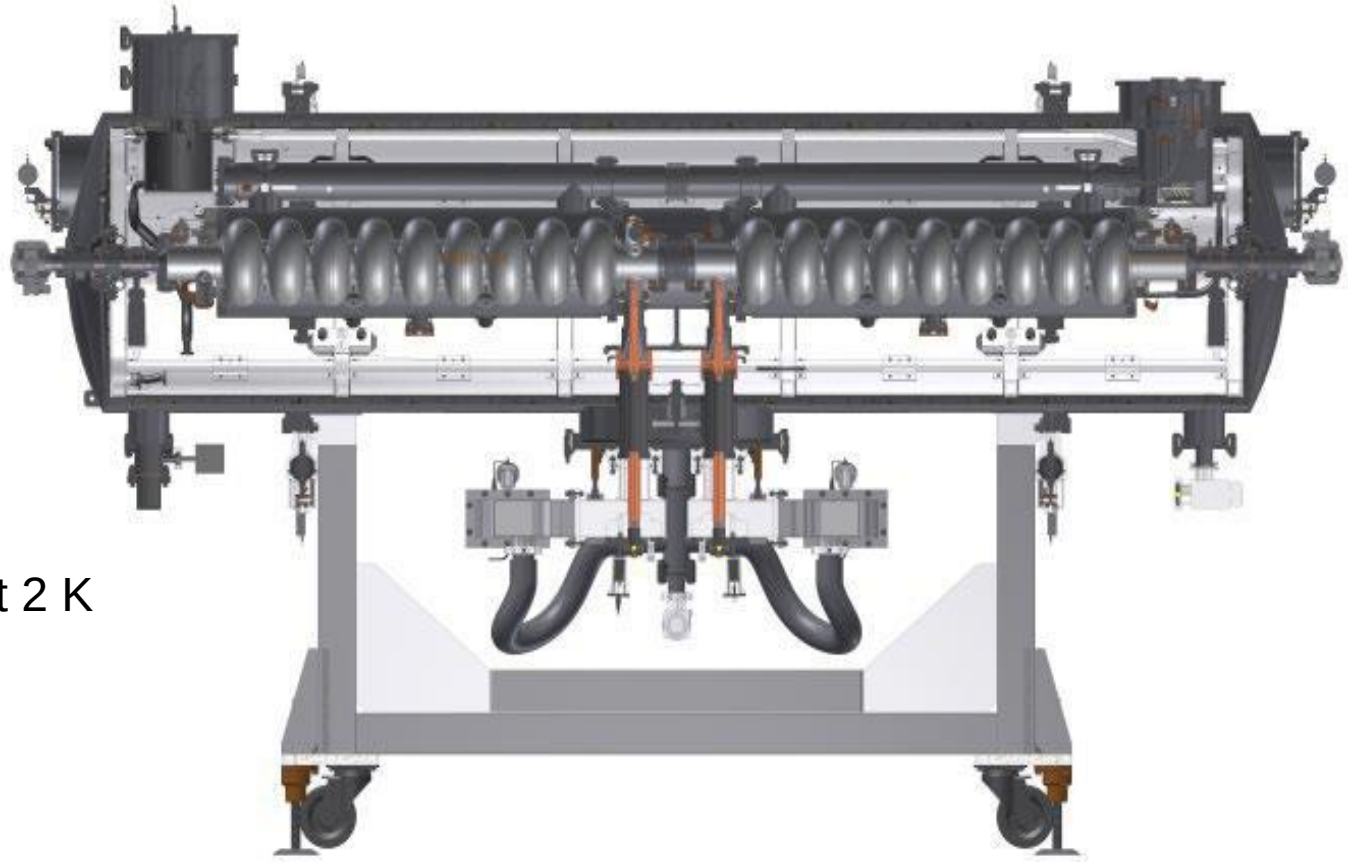


PolFEL dual linac structure



- Initially warm **S-band e-guns** will be installed, after commissioning they will be replaced with **SRF injectors**
- Acceleration with **HZDR-RI-type cryomodules redesigned for PolFEL,** powered with solid state amplifiers
- THz accelerator diagnostic sections including bunch length evaluation (Martin-Puplett interferometer and optical)
- Planar tunable gap permanent magnet undulator
- Air cooled magnets
- **Two 3rd harmonic RF structures** to replace one of theTESLA structure aimed at bunch compression improvement

Polfel cryomodule based on HZDR – RI cryomodules



Required by order specification:

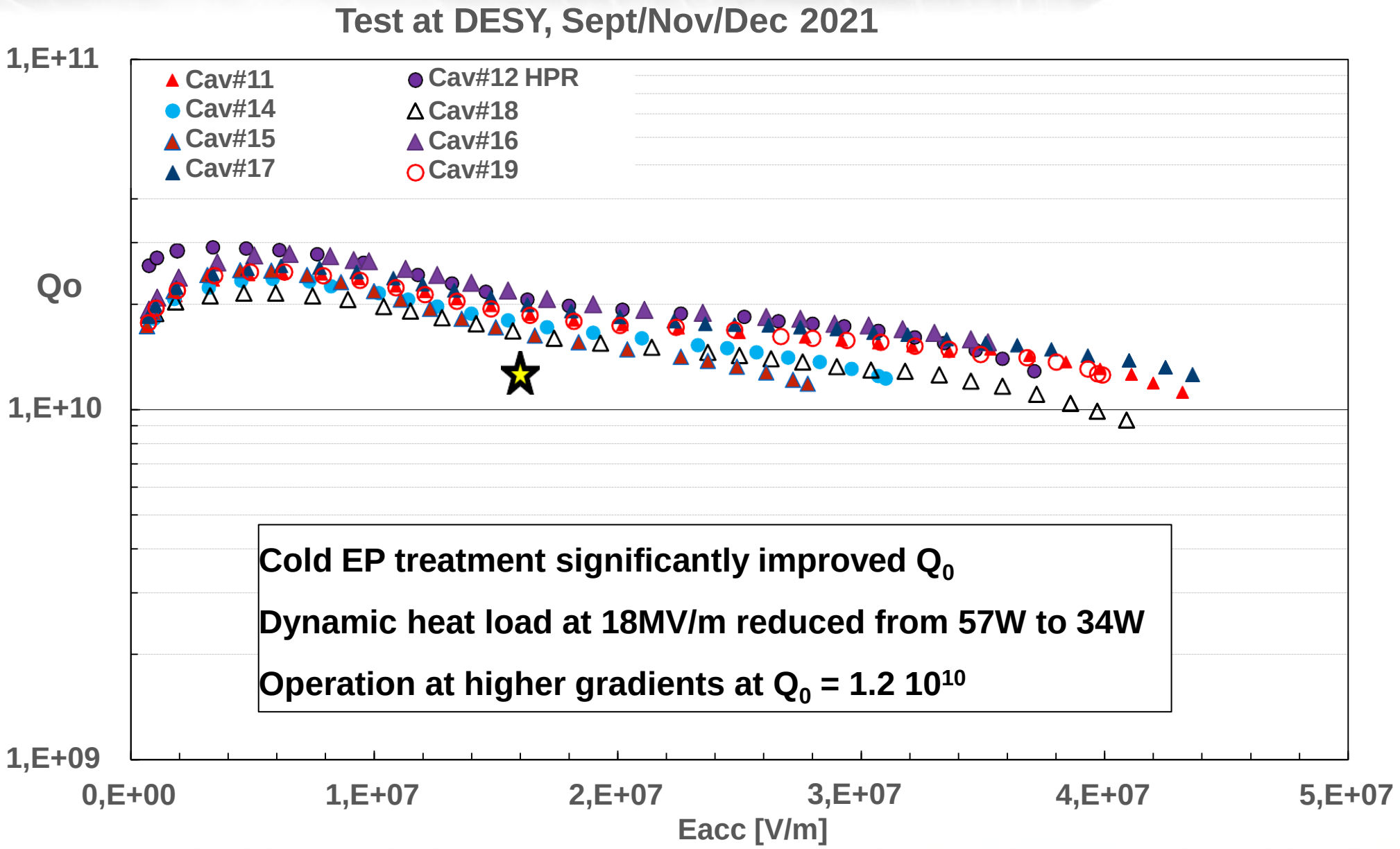
- **>18 MV/m while Q_0>1.2 10^{10}**
- Static cryogenic losses below 10 W at 2 K

Design changes included:

- TTF3 FPC
- Cooling with helium vapour, not LN
- Thermal shield redesign

Manufactured and delivered in 2023 by RI

PolFEL cavities

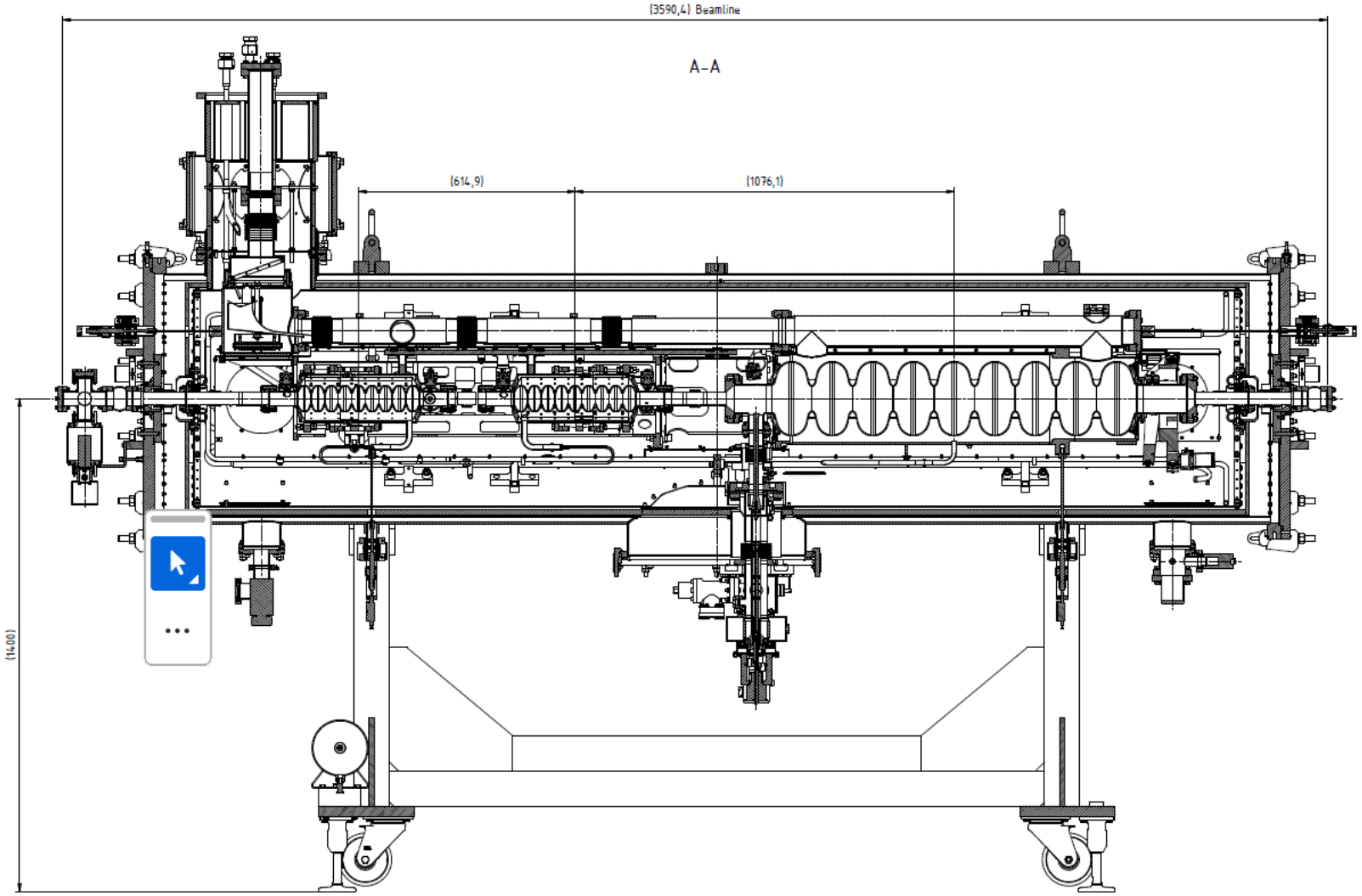


Polfel combined 1.3/3.9 GHz cryomodule

- 1 standard TESLA/PolFEL 1.3 GHz cavity
- 2 SHINE 3.9 GHz cavities

Designed specifically for POlFEL

Manufactured and delivered in August 2026 by RI



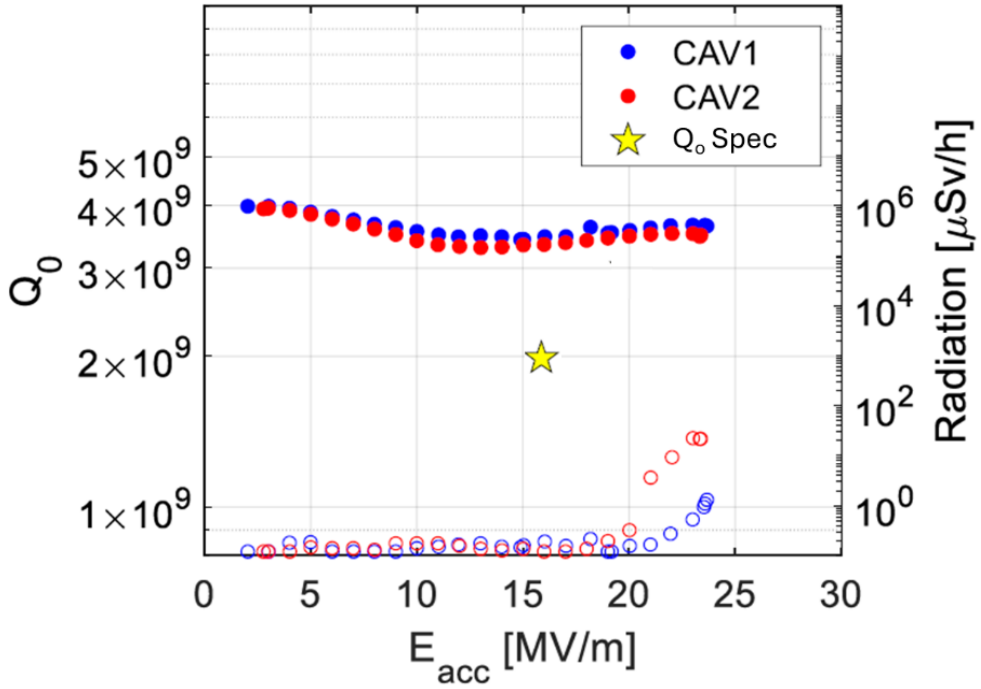
Polfel combined 1.3/3.9 GHz cryomodule

Table 2: Key VT results of CAV1

Test date:	14.11.2025
Temperature:	2 K
Pi-mode:	3893.13 MHz
E_{max}:	23.7 MV/m
Q_0 (20 MV/m):	3.52 E+09
Q_0 max:	4.0 E+09
FE onset:	23.5 MV/m

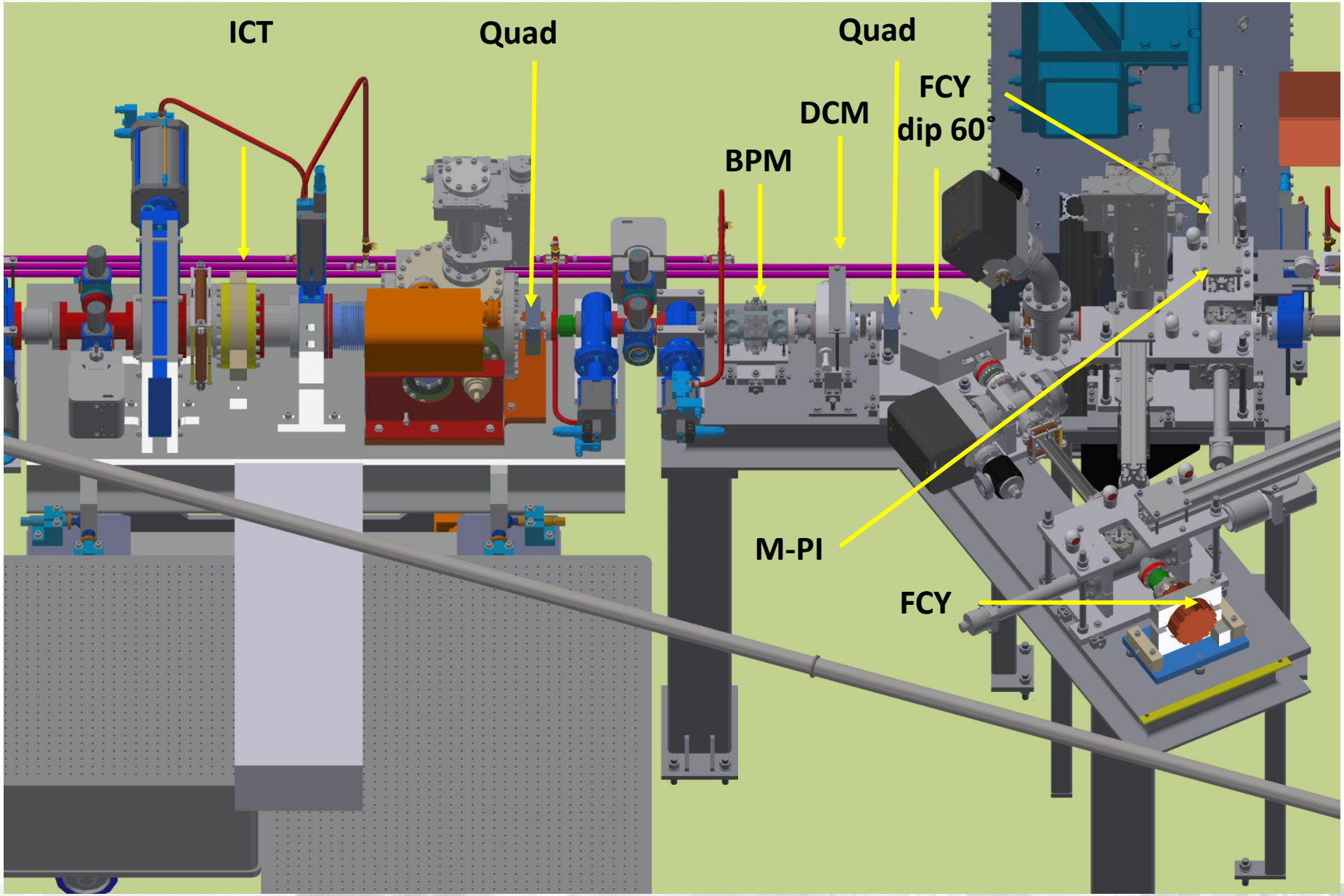
Table 3: Key VT results of CAV2

Test date:	14.11.2025
Temperature:	2 K
Pi-mode:	3893.23 MHz
E_{max}:	23.4 MV/m
Q_0 (20 MV/m):	3.47 E+09
Q_0 max:	4.0 E+09
FE onset:	20.7 MV/m

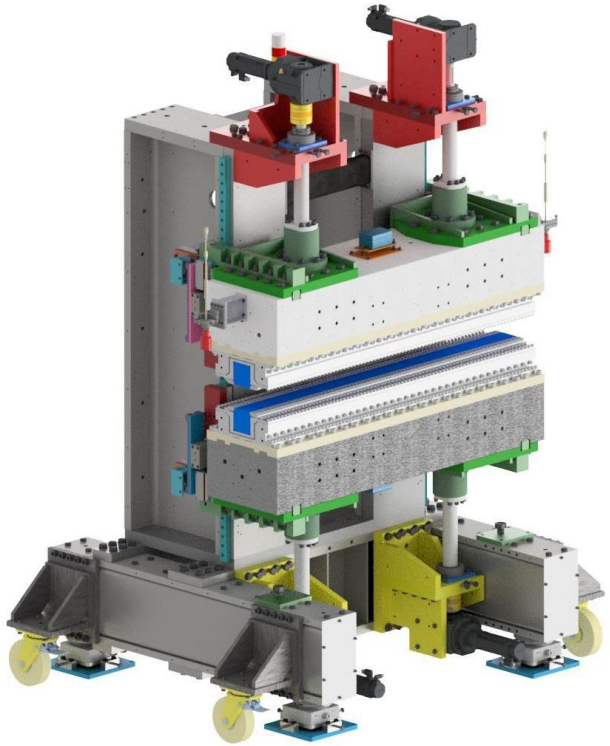




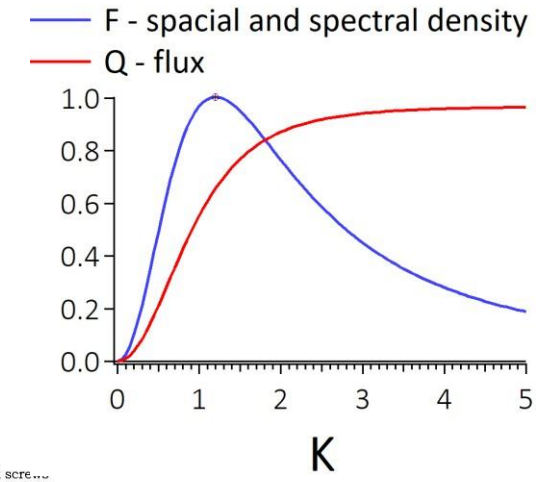
Injectror section beam diagnostics

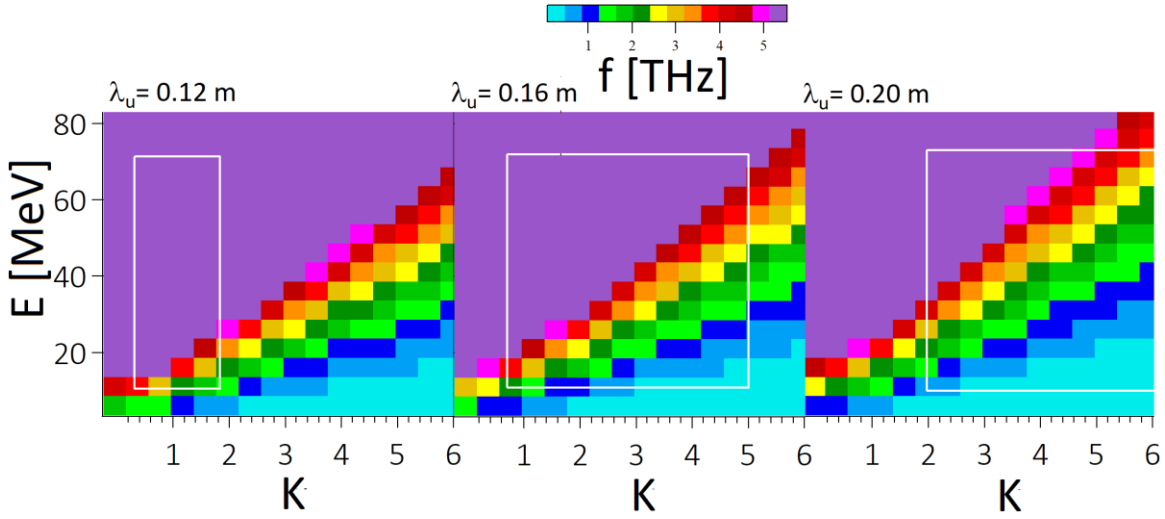


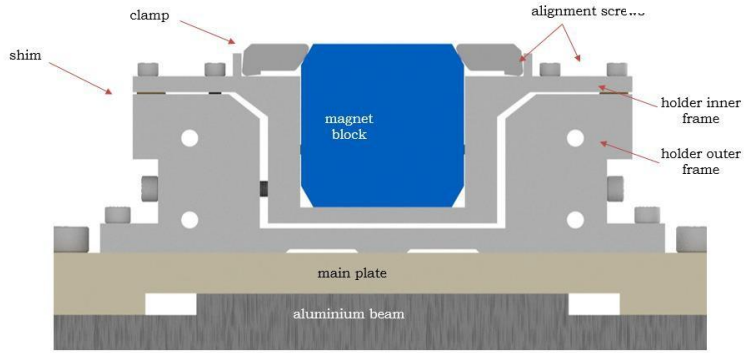
THz undulator



Variable gap permanent magnet, planar
C-shaped frame
4 motors
Fully openable
Has been in house designed and now beeing manufatured



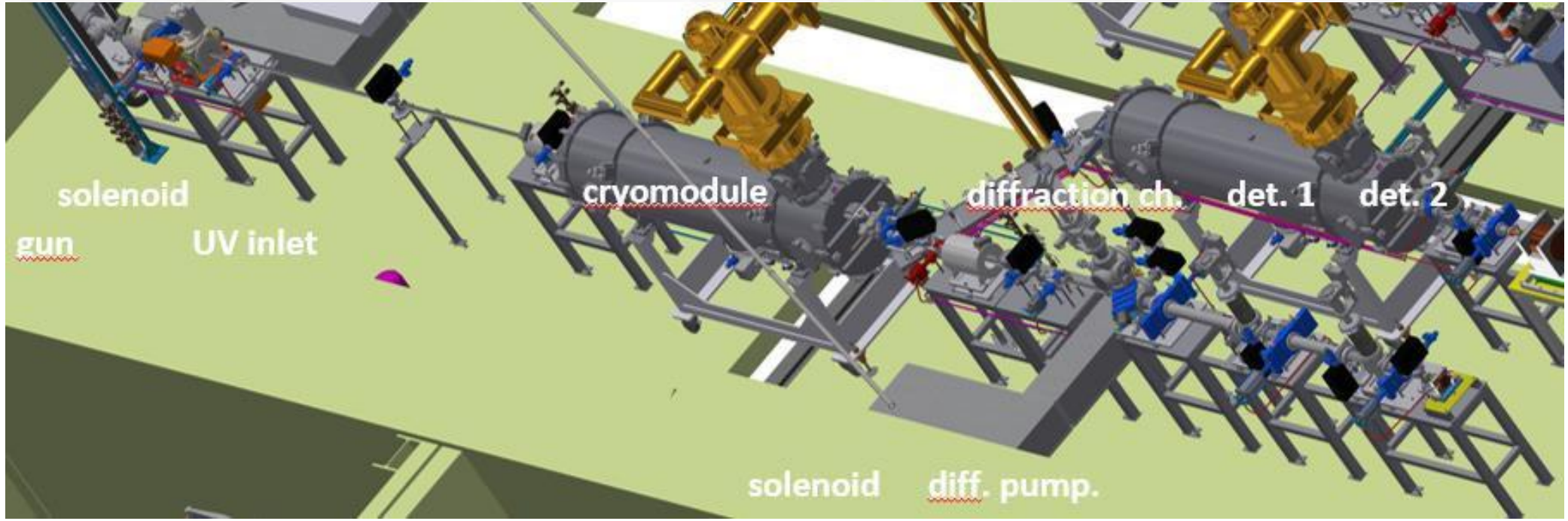




parameter	value
material	NdFeB B_r=1.35 T
period	160 mm
number of periods	8
K range	0.7 – 5
gap	100 – 200 mm, 550 mm

will be published soon

UED linac and experimental station



- **Nd YLF 257 nm laser 250 fs pulse duration or Ti-sapphire laser for shorter pulse 35 fs** (but lower repetition – up to 5kHz)
- Two chambers will be available: for solid samples, and **for gasous** ones.

SRF injector

makes it possible to operate in **cw operation with up to 200 kHz repetition,** advantageous for very low charge bunches

Cryomodule:

Energy tuning: **2 MeV – 5 MeV**

Optimizing the RF amplitude and phases it is possible to achieve **ballistic compression of the bunch and improved temporal resolution**

Financing and implementation schedule

2018	Smart Growth Operational Programme,	25 MEUR
2024	National Recovery and Resilience Plan	31 MEUR
	Min. of Science	
	NCBJ resources	5 MEUR
	Industrial in-kind contributions	25 MEUR
		4 MEUR
	Total	**90 MEUR**

Schedule

Access to the accelerator hall and geodetic measurements	since 03.2026
•Installation start (cryogenic)	04.2026
•Non-accelarator labs availability	30.09.2026
•Commisioning of the cryogenic system after upgrade	15.08.2026 – 27.11.2026
•Commisioning of the accelarator based lines	12.2026 – 06.2027
•Commisioning od the UED with SRF gun	- 05.2027
•THz beam availaible for first controlled experiments	- 07.2027

PolFEL experimental station complementarity

POLFEL

(UED)
Ultrafast Electron Diffraction

(TR-ARPES)
Time- and Angular-Resolved Spectroscopy of Photoelectrons

THz Spectroscopy

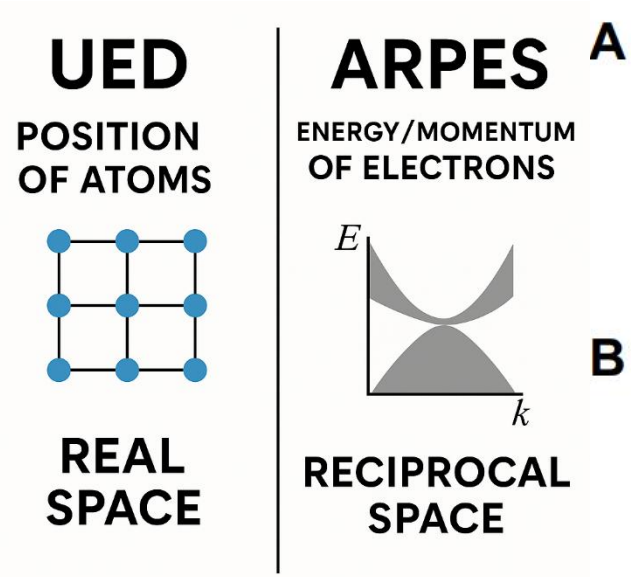
Absorption and dispersion of THz radiation

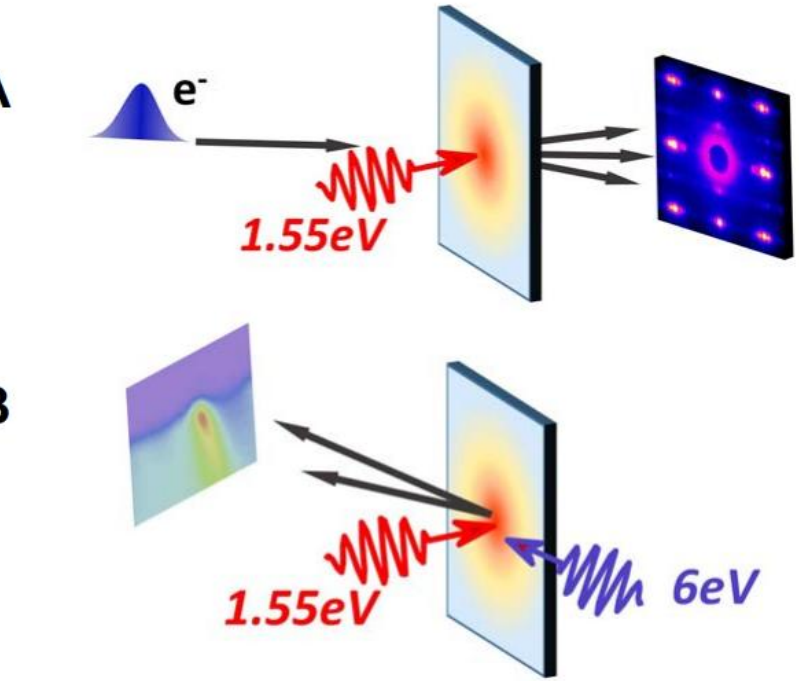
Ultrafast images of the cristal strcture

UED – atom geometry, real space

Ultrafast tomography of electrons

ARPES – electron geometry.
Structure of the reciprocal space (E vs. k).





Konstantinova et al., Sci. Adv. 2018;4: eaap7427

Prospects for the Application of MeV-UED in Solid-State Materials Research

Key questions in condensed matter physics:

◊ **Understanding interactions among charge, spin, orbitals, and lattice degrees of freedom in materials:**

UED provides "maps" of the crystal electrostatic potential that are sensitive to details of the lattice structure, charge distribution, and orbital ordering.

◊ **Understanding elementary excitations:**

Studies of collective excitations (phonons) and individual quasiparticles that couple to and interact with one another, giving rise to phenomena such as superconductivity and charge-density waves.

Electron-phonon interactions are crucial for understanding electrical and thermal transport, as well as energy-conversion processes in photovoltaic and thermoelectric applications.

◊ **The role of phonons and spins:**

Phonons may be involved in more complex elementary excitations, such as polarons and polaritons.

UED enables the investigation of spin-lattice coupling from the lattice perspective by monitoring the nonlinear behavior of coherent phonon states.

◊ **UED in studies of nonequilibrium processes:**

UED makes it possible to investigate material structures and dynamics under nonequilibrium conditions, providing high-quality diffraction images in a single measurement.

Application of UED to the study of strongly correlated states of matter.

◊ **Application of UED in quantum materials research:**

Interactions among different degrees of freedom (lattice, charge, spin) lead to complex free-energy landscapes with various types of ordering.

Monitoring changes in structure, orbital order, and charge order using UED.

◊ **Manipulating materials in nonequilibrium states:**

Light-driven manipulation of materials opens new opportunities for discovering states and phases of matter with exotic properties.

Designing materials with "on-demand" properties remains a major challenge for fundamental science.

MeV-UED:Ultrafast Electron Diffraction in gasous phase

- **Objective:**

Imaging the ultrafast structural dynamics of molecules in real time, with temporal resolution below 10 fs.

- **Significance:**

Crucial for understanding photochemical mechanisms, chemical reactions, and the formation and breaking of chemical bonds.

- **Advantages of MeV electrons:**

•Short de Broglie wavelength (high spatial resolution)
•Reduced space-charge effects (allowing ultrashort electron pulses)
•Separation of elastic and inelastic scattering

- **Advantages of MeV-UED over X-rays:**

•Higher accuracy for gas-phase studies
•Ability to track nuclear motion and electronic structural changes
•High structural and temporal sensitivity

- **POLFEL MeV-UED:**

•Target temporal resolution below 10 fs
•High beam current enabled by superconducting accelerators
•Capability to investigate molecules with low vapor pressure

- **Scientific potential:**

•Recording molecular movies in real time
•Tracking conformational transitions and conical intersections

Thank you for the attention



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