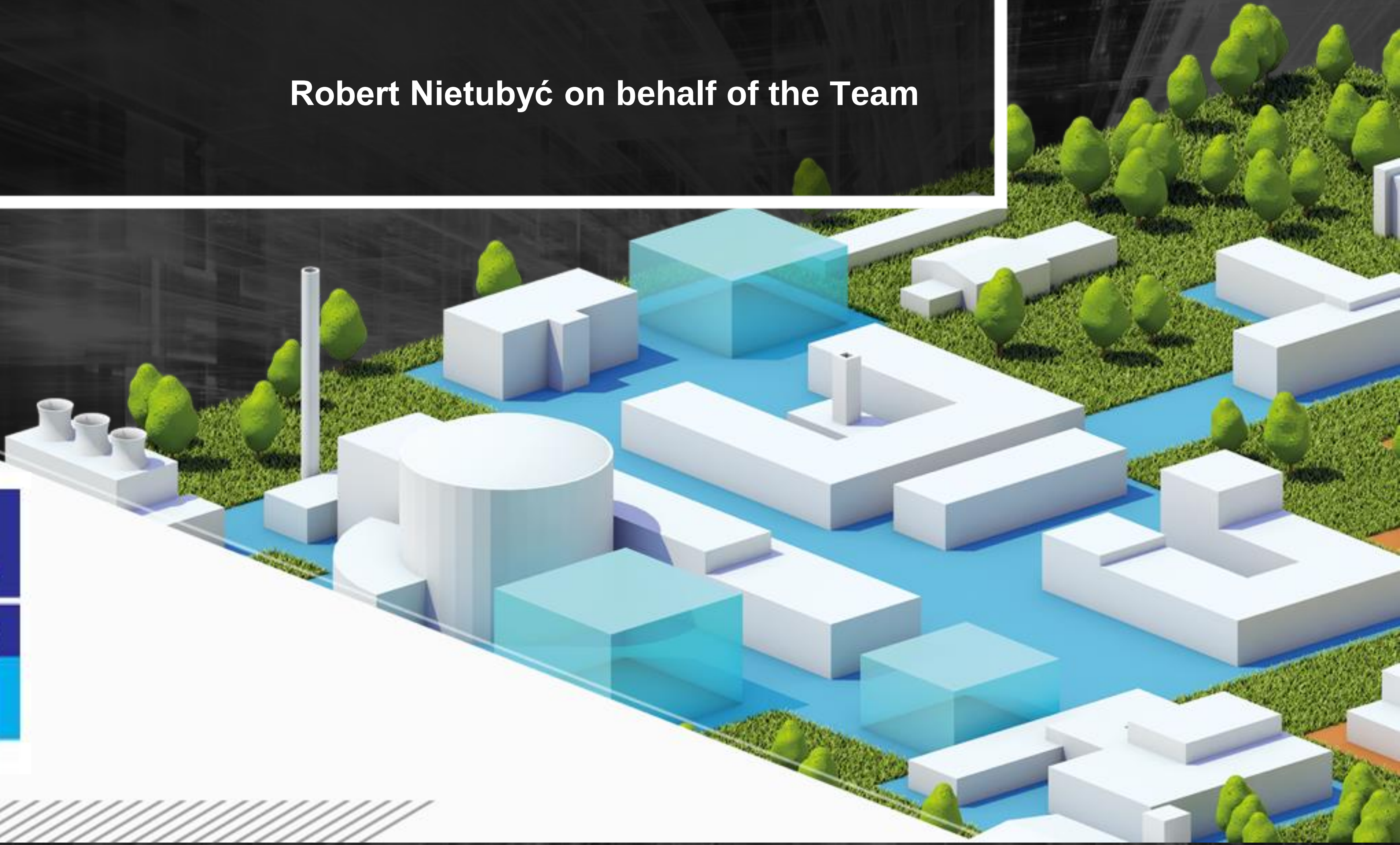
The PolFEL status

Robert Nietubyć on behalf of the Team



Introduction

PolFEL will be a scientific facility delivering broad spectrum of the radiation from **THz to EUV** and very short electron bunches for **UED** experiments. The PolFEL infrastructure includes two accelerators equipped with **sc accelerating cryomodules**. Advanced solid state laser system will be used to supply them with electron bunches and for high harmonic generation.

The aim:

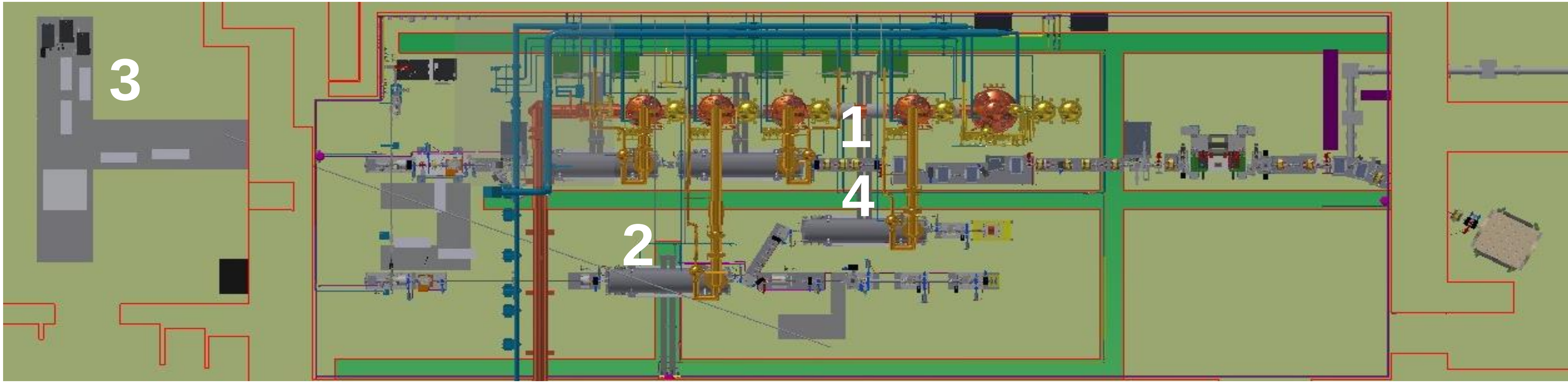
- provide new research opportunities complementary to the synchrotron SOLARIS in Kraków.
- enable preparatory studies for experiments at large FELs, e.g. Eu-XFEL
- gather and foster accelerator physicists furnishing the capabilities for research and development activity,

It will be built at the National Centre for Nuclear Research Świerk in Otwock (NCBJ)

The PolFEL facility has been designed thr Consortium of NCBJ and 7 Polish universities led by NCBJ:

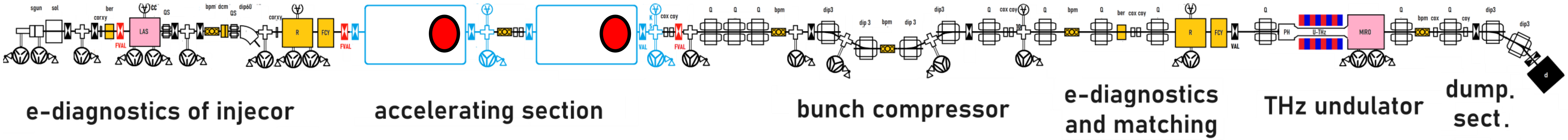
- Military University of Technology - beamlines
- Warsaw University of Technology - LLRF
- Technical University Łódź - synchronisation
- Jagiellonian University -e beam diagnostics, survey
- Wrocław University of Science and Technology -cryogenics
- University of Zielona Góra – HVAC
- National Centre for Nuclear Research
- University of Białystok - inverse Compton scattering station

Infrastructure



- THz linac and experimental station (1)
- UED linac and experimental station (2)
- HHG-EUV with time resolved ARTOF photoelectron spectroscopy as a probe and VUV-IR pumping (3)
- Cryomodules test stand (4)
- Solid state laser sources
- …

THz linac



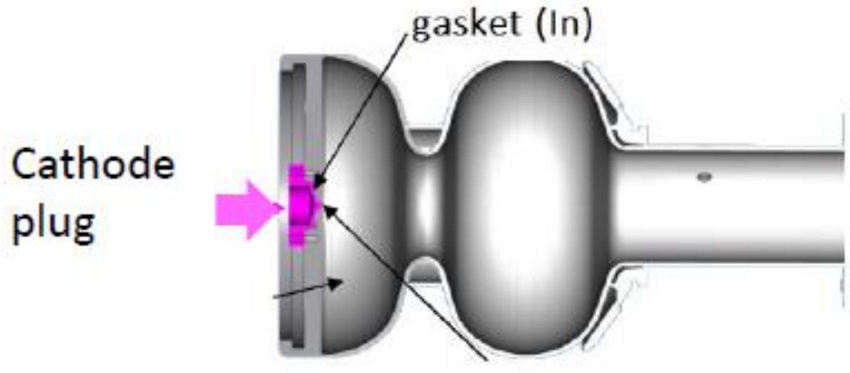
- Initially a warm **S-band e-gun** will be installed, after commissioning it will be replaced with **an SRF injector**
- Accelerating section consists of **2 HZDR-RI-type cryomodules** powered with solid state amplifiers
- Diagnostic sections including Martin-Puplett interferometer for bunch length evaluation
- Air cooled magnets
- Planar tunable gap permanent magnet undulator
- Liquefier of 130 W at 2 K

- **3rd harmonic RF structure** to replace one of Tesla structure aimed at bunch compression improvement

SRF injector

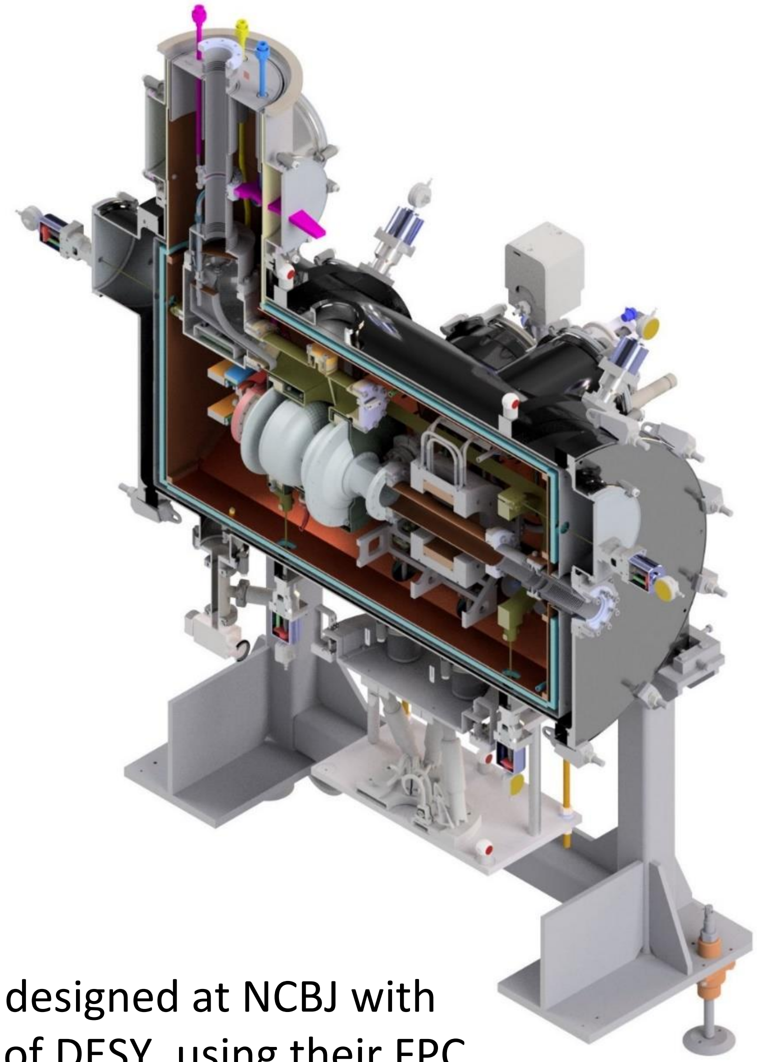
Parameters for the THz injector

parameter	value
Bunch charge	**< 250 pC**
Repetition rate	50 kHz
Bunch length	4 – 16 ps
Laser wavelength	257 nm
Pulse E on the cathode for 250 pC	**6 µJ**
Laser spot Φ on the cathode	50 µm
Available UV pulse energy	40 µJ



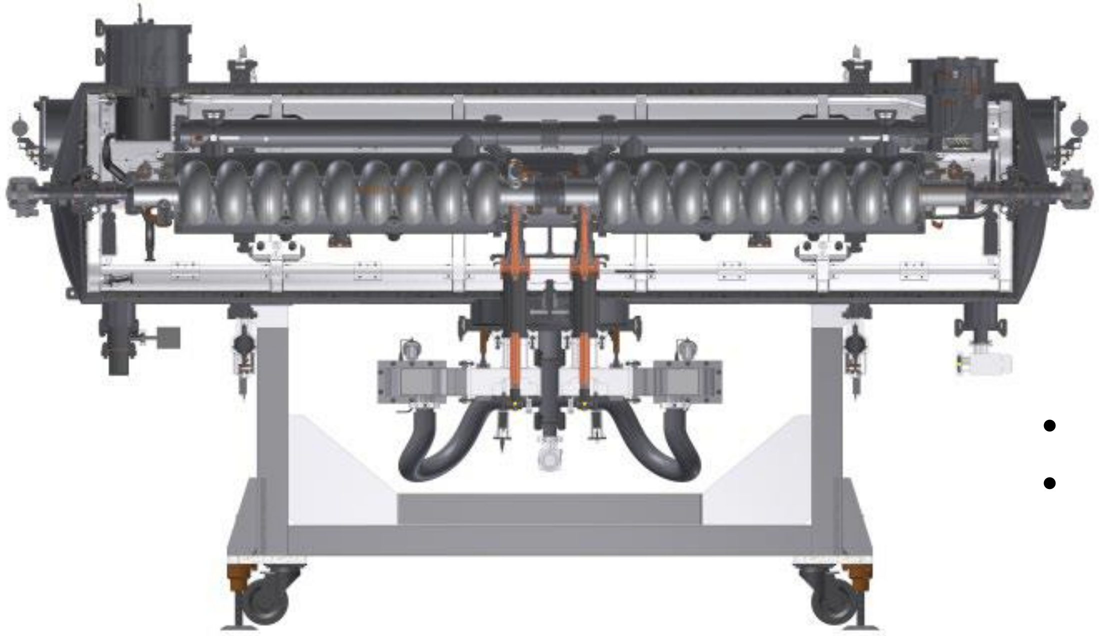
All Metallic Gun
Cavity under development at DESY

Considered metallic photocathodes:
Cu QE≈2 $\cdot 10^{-4}$
Mg/Mo QE ≈ 1 $\cdot 10^{-3}$
at 257 nm



CM was designed at NCBJ with support of DESY, using their FPC and HZB/DESY tuner

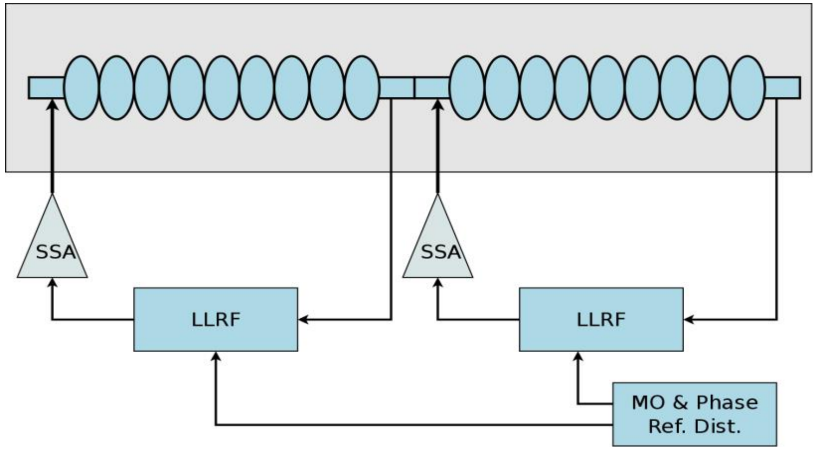
Polfel cryomodule based on HZDR – RI cryomodules



Cold EP treatment significantly improved the quality
Vertical tests results $Q_0 = 2.0\ 10^{10}$

That saves the cryogenic power:
Dynamic losses at 18 MV/m $Q_0 = 1.2\ 10^{10}$: 57 W
Dynamic losses at 18 MV/m $Q_0 = 2.0\ 10^{10}$: 34 W
Acc. gradient at $Q_0 = 1.2\ 10^{10}$: 30 MV/m

- Each cavity will be powered with a 5 kW SSA amplifiers
- Each cavity will be separately controlled by the LLRF loop enabling **individual setting of parameters** for operation



Kubara Lamina dedicatedly for PolFEL

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

Manufactured and delivered in 2023

Performance

THz linac: **E_{max} = 54 MeV at cw**
THz with two 3rd harmonic structures: **E_{max} = 30 MeV at cw**
f $\in$ 0.5 THz – 5 THz with E_{pulse} >1 μJ, at repetition up to 50 kHz

Higher electron energies will be available in long RF pulse operation

Further THz upward extension would be possible if only **the bunch is sufficiently short.** To facilitate that:

- Ti-sapphire laser for photocathode initialisation
- 3 rd harmonic structures installed in linac

THz dynamics and photon output

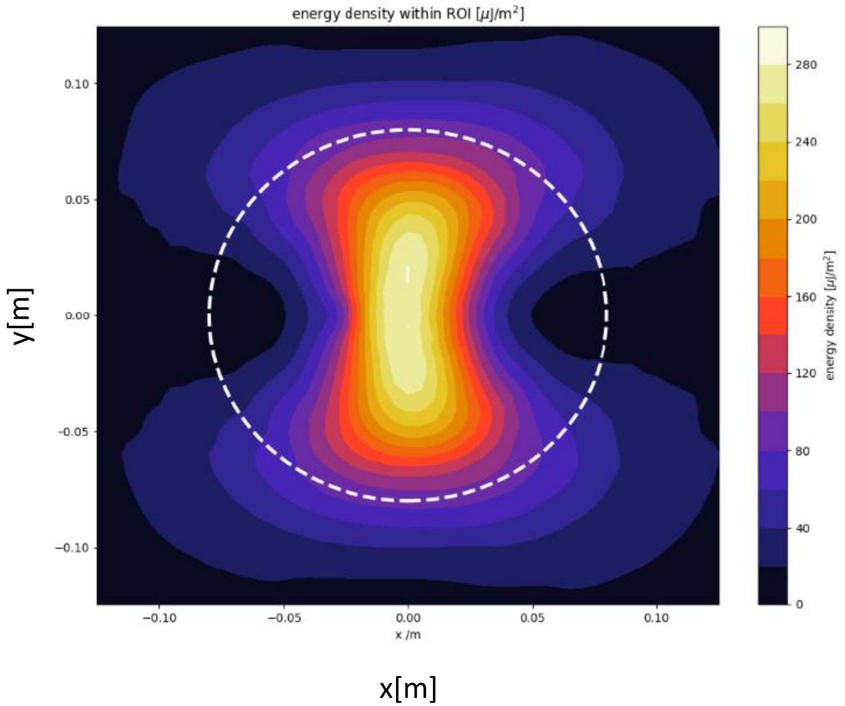
Simulations performed with Teufel programme for the in-house designed and manufactured superradiant 8 × 16 cm periods undulator for the beam of

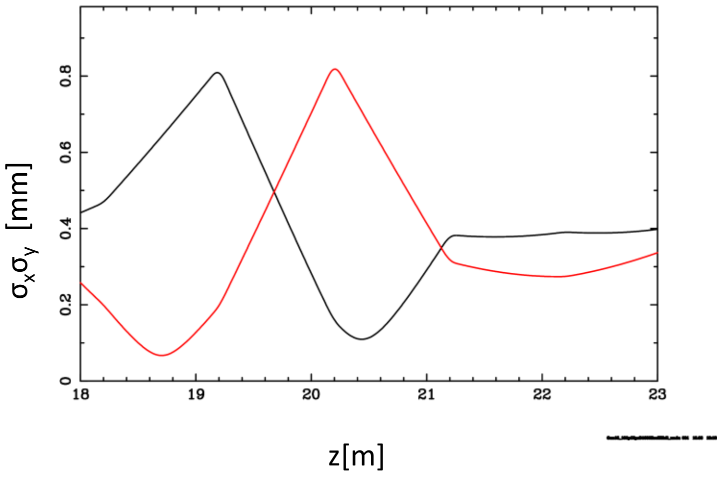
E_e=20 MeV, q_b = 75 pC, σ_z=65 μm, ΔE/E=0.001

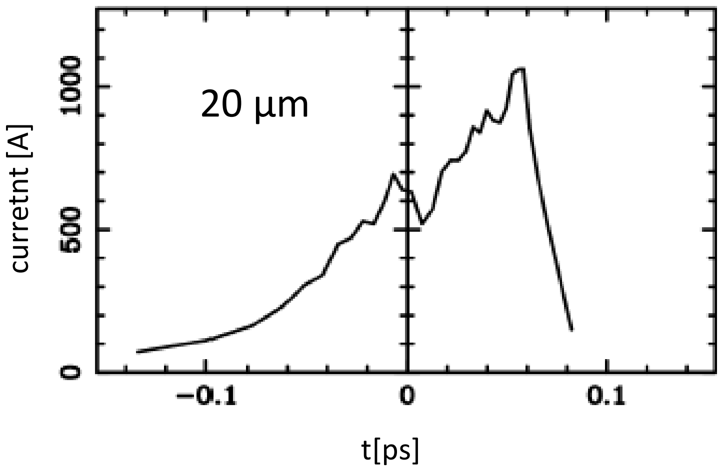
showed the 1 THz beam imprint on the 175 cm distant decoupling mirror as shown on the figure.

Pulse energy deposited in the mirror **E_{pulse}=1.5 μJ**

Recently much more effective beam have been simulated, so stronger THz pulse are expected. Simulations in progress.







Bunch sizes as matched with 5 quadrupoles for 56.4 MeV, 100 pC

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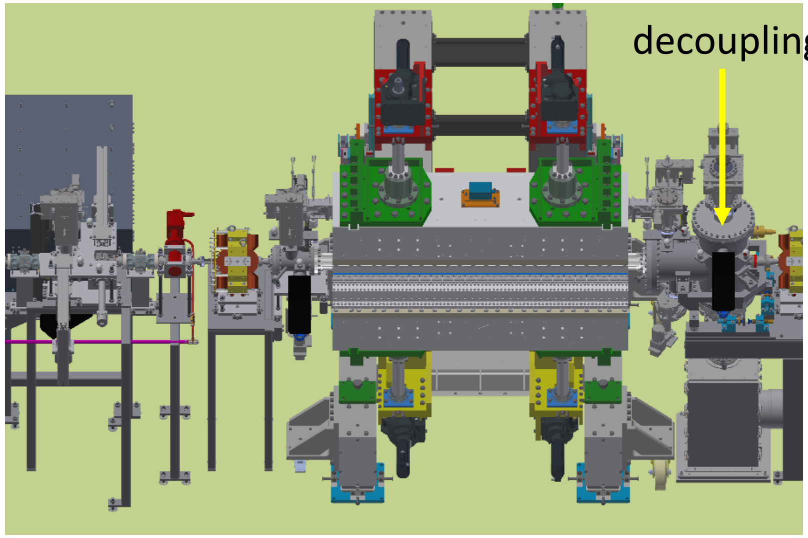
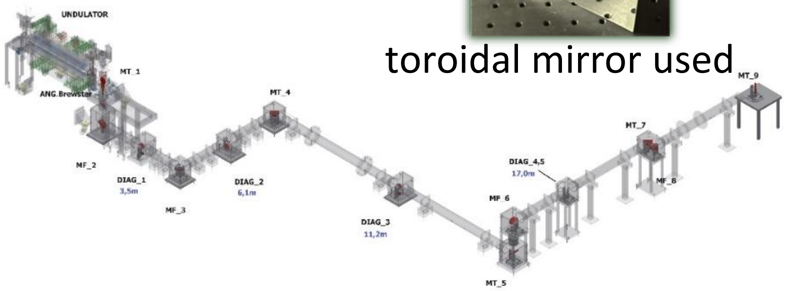
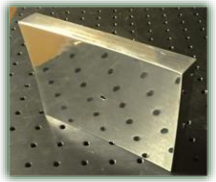
THz laboratory



bemline elements as delivered

Beam transfer





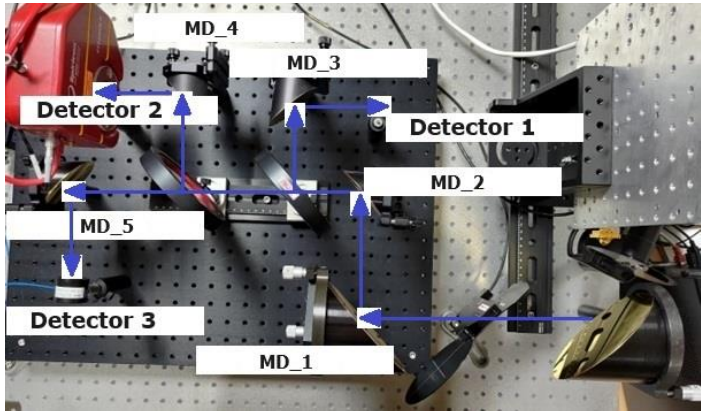
toroidal mirror used

Diagnostics

- Profilometer
- Power measurement
- MPI – wavelength measurement

Single pulse detection system:

- Pulse duration measurement
- Pulse energy measurement



Instrumentation at experimental stand

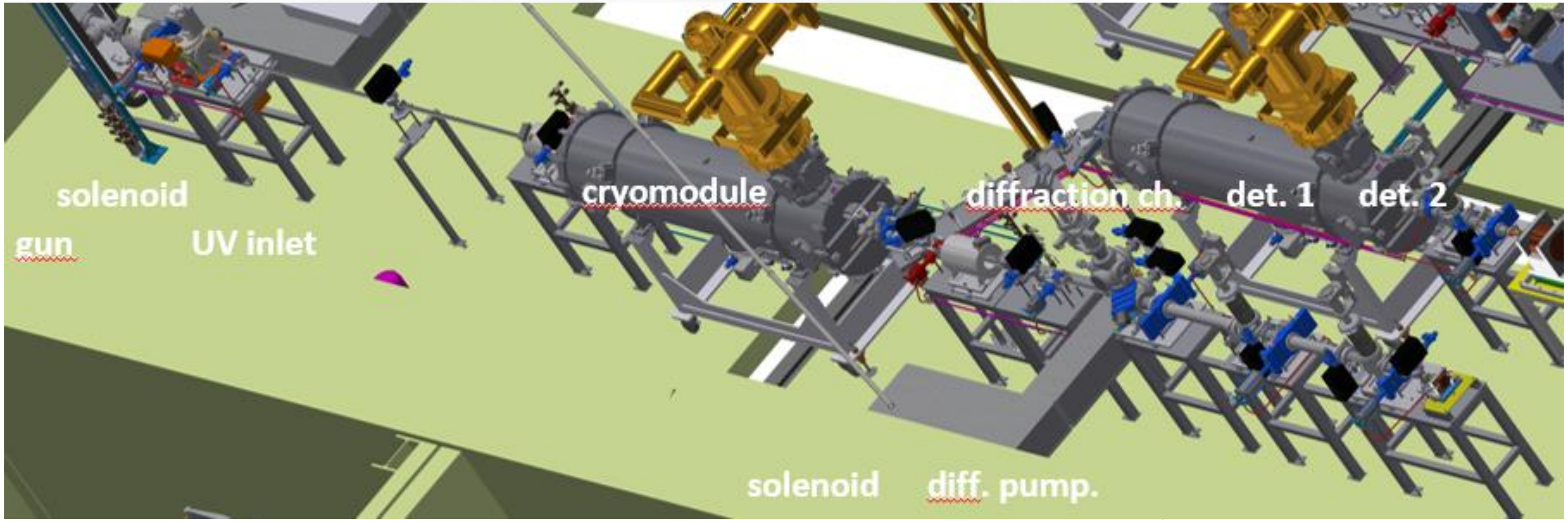
- Cryofree refrigerator – 5K with transmission windows and reference detector
- Electrical measurement setup: oscilloscopes, multimeteres, lock-in voltmeters, SMUs, signal generators

The setup will be at the beginning fitted for temperature variable temperature transmission and reflection experiments

P&P setup with solid state IR laser pump and THz probe

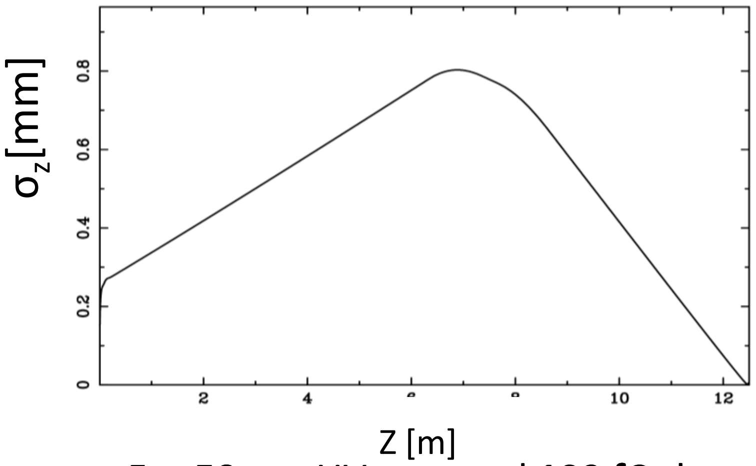
Cryomodule:

- energy tuning **2 MeV – 9 MeV**
- play with the RF amplitude and phases it is possible to achieve **ballistic compression of the bunch**



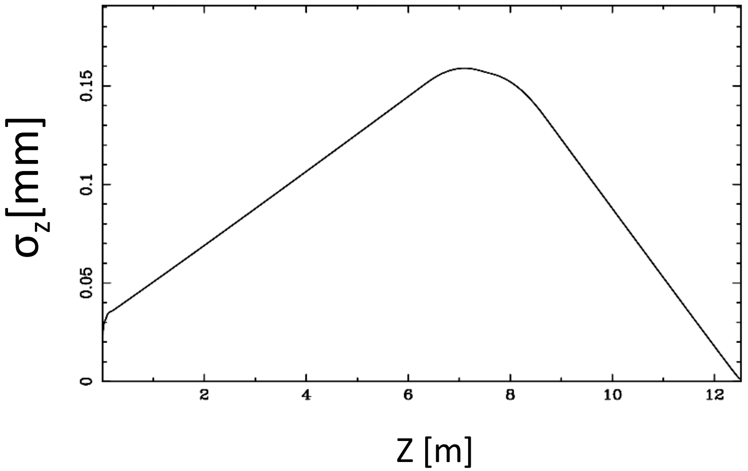
SRF injector

- makes it possible to operate in **cw operation with 200 kHz repetition** – advantageous for short low charged bunches
- Nd YLF 257 nm laser 250 fs pulse duration
- Two chambers will be available: for solid samples, and **for gasous** ones.



For **50 µm** UV spot and **100 fC** charge

σ_z = 2.5 µm



For **35 µm** UV spot on and **1 fC** charge

σ_z = 1.1 µm

will be published soon

Financing and implementation schedule

2018	Smart Growth Operational Programme,	25 MEUR
2024	National Recovery and Resilience Plan	31 MEUR
	NCBJ resources	30 MEUR
	Industrial in-kind contributions	4 MEUR
	total	**90 MEUR**

European Funds Smart Growth | Republic of Poland | European Union European Regional Development Fund

NATIONAL RECOVERY PLAN | Republic of Poland | Funded by the European Union NextGenerationEU

Status
- Linac design frosen
- Purchase and test of delivered devices go on
- Undulator, SSA, magnets assembly go on
- Hall reconstruction about being contracted

Schedule

Linac sections assembly start	Sept 2024
Installation start	Aug 2025
Commissioning start	Jan 2026
THz beam	**June 2026**

Summary

- THz source will be established complemented with UED and HHG-EUV source
- Two sc linacs will be installed
- Installation will start in the mid of 2025, first light in 2026
- Domestic accelerator engineering capabilities have been involved…
- …supported and assisted with the experience of other laboratories: Daresbury, DESY, HZDR, HZB,…

Thank you for the attention

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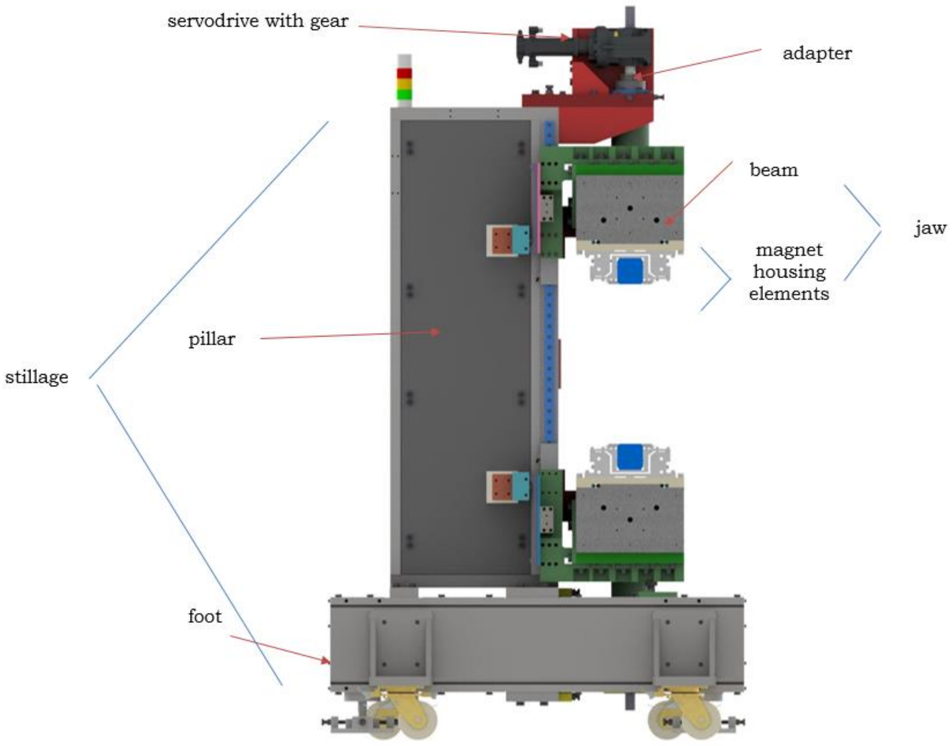
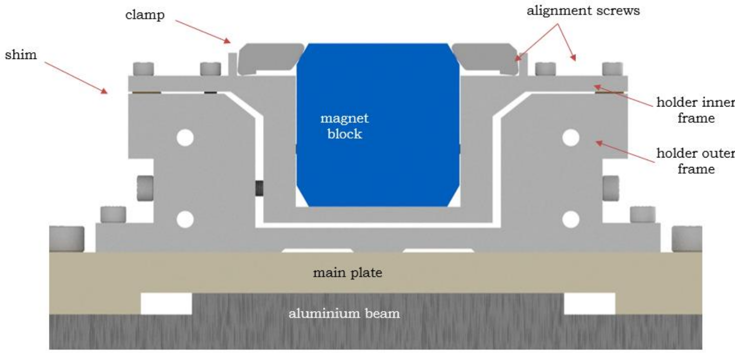
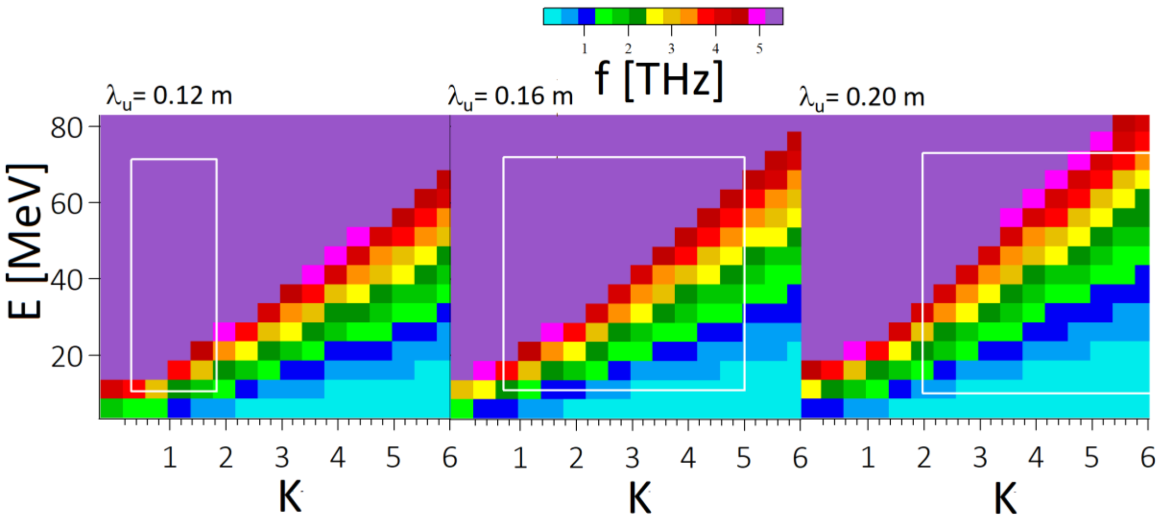
Undulator







For λ_u =16 cm the full f range 0.5 THz – 5 THz is available at reasonable K range

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

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PolFEL linacs

THz linac

parameter	value
Bunch charge	< 250 pC
Repetition rate	200 kHz
Electron energy	< 70 MeV at cw, 90 MeV at lp
Bunch length	0.2 – 5 ps
Beam current	< 50 µA
Transverse slice emittance	$< 0.6 \cdot 10^{-6}$ m·rad
Cooling power at 2 K	105 W
THz range	0.5 – 5 THz

UED linac

parameter	value
Bunch charge	10 – 100 fC
Repetition rate	200 kHz
Electron energy	< 9 MeV at cw,
Bunch length	3.5 fs
Beam current	< 50 µA
Transverse slice emittance	$< 0.6 \cdot 10^{-6}$ m·rad
Cooling power at 2 K	40 W
THz range	0.5 – 5 THz

Expected available cryogenic power at 2 K is 130 W (Daresbury liquifier) !

- **THz**: In the ultimate case, neglecting instabilities occuring while full cooling power operation, there will be possible to apply 15 MV/m and get 65 MeV electrons using 105 W + 27 W for UED cooling → 132 W
  Higher energies will be available with long pulsed mode (about 500 ms, duty factor = 0.5)

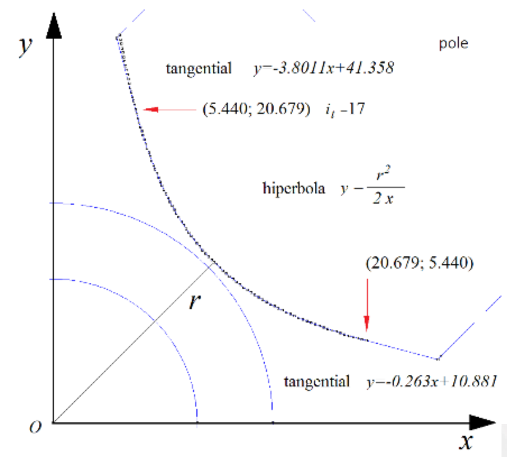
- **UED:** CM at most at 8 MV/m, cooling power expense will not exceed 40 W + 27 W for THz cooling → 67 W

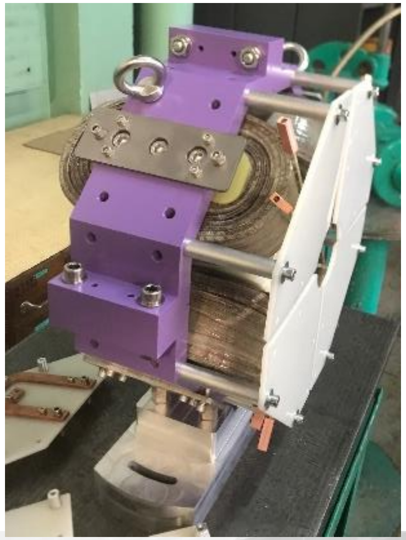
The warm gun will be installed for the first beam commissioning. It will be replaced wit SRF cryomodule as soon as it is delivered

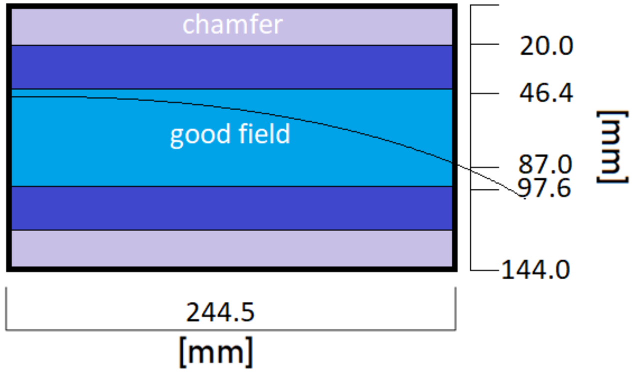
Magnets

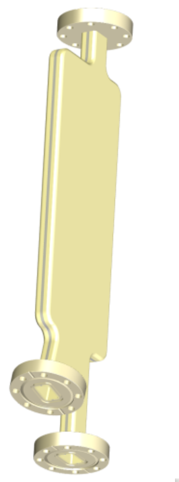
Main dipoles and quadrupoles have been designed and manufactured at NCBJ. Correctors and small dipoles and quads are being purchased

	number	gap or bore [cm]	B or B' [T] or [T/m]	R or Leff [cm]	I [A]	N per coil	wire Ø [mm]	P [W]
solenoid	3		0.17	40				
small corrector	3	7.5	0.003	7.6	1.1	80	0.7	0.75
corrector	18	5	0.009	19	2.3	150	2.8	5
60° dipole	3	1.6	0.1	15	7	90	2	?
14° dipole	6	2	0.33	101	34	520	2.8	62
small quadrupole	5	2	4.3	4.8	1.7	110	0.5	?
quadrupole	10	3	17.4	10	20	150	2.8	40









Electron beam diagnostics

THz linac

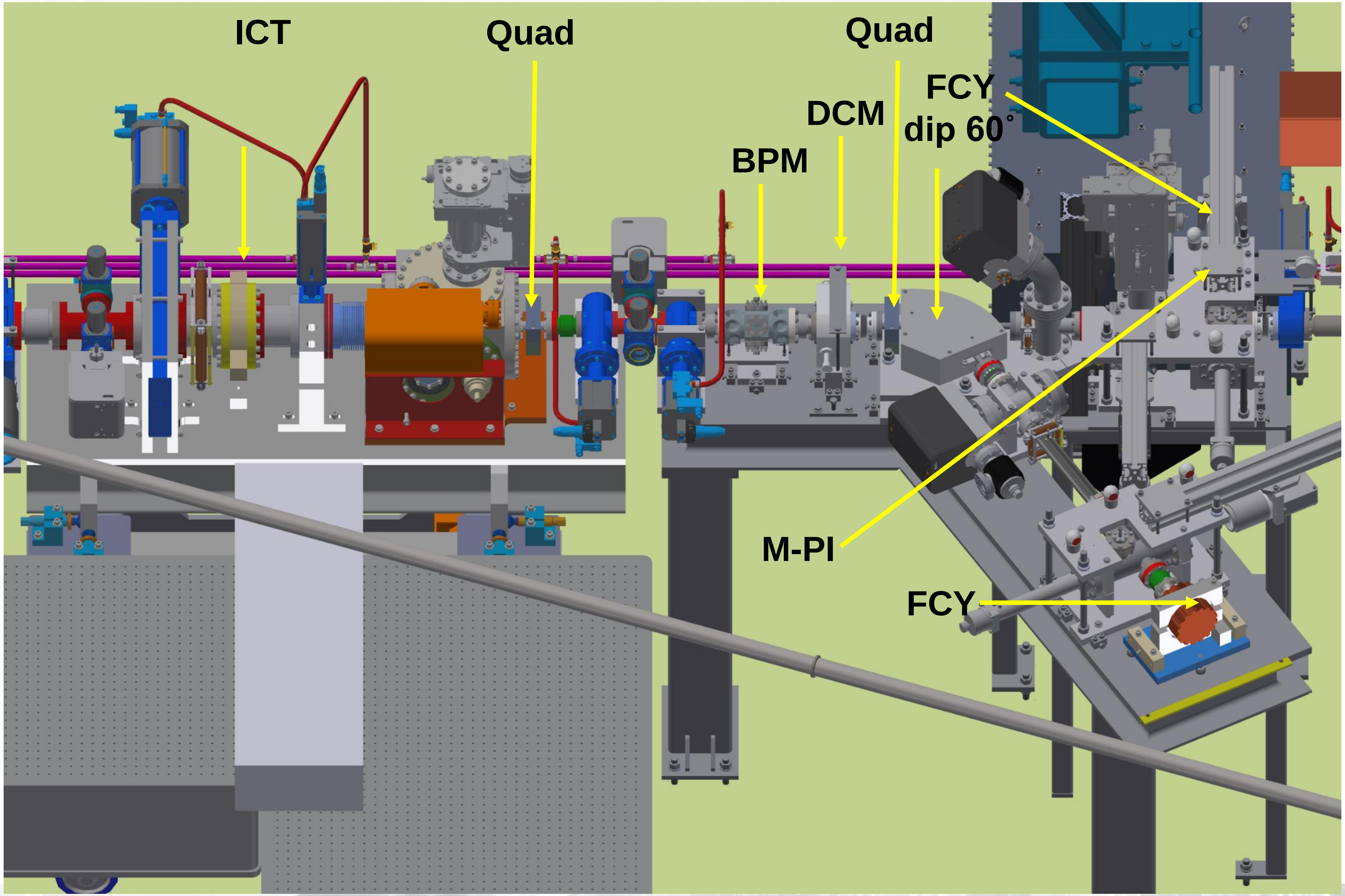
Location	diagnostics	instrument	comments
Injector E < 5 MeV τ < 8 ps	current	ICT	Bergoz
	Position and direction	2 × BPM	E-XFEL-type
	Bunch charge	Faraday cup	FCY chamber
	Beam profile	YAG screen	
	Bunch length	M-PI	Radiator chamber
	Dark current	DCM	E-XFEL like
	Emittance	2 × Quadrupoles	Together with YAG
	Energy spread	60˚ dipole spectrometer	with FCY chamber
prior to undulator E < 120 MeV τ < 1 ps	current	ICT	Bergoz
	Position and direction	2 × BPM	E-XFEL-type
	Bunch charge	Faraday cup	FCY chamber
	Beam profile	YAG screen	
	Bunch length	M-PI	Radiator chamber

more BPMs locations: between CM, behind CM, BC, dump sect.

UED linac

2 × BPS in the injector section and YAG sceen in the experimental chamber. Diffraction pattern at the reference crystal.

Injectror section beam diagnostics



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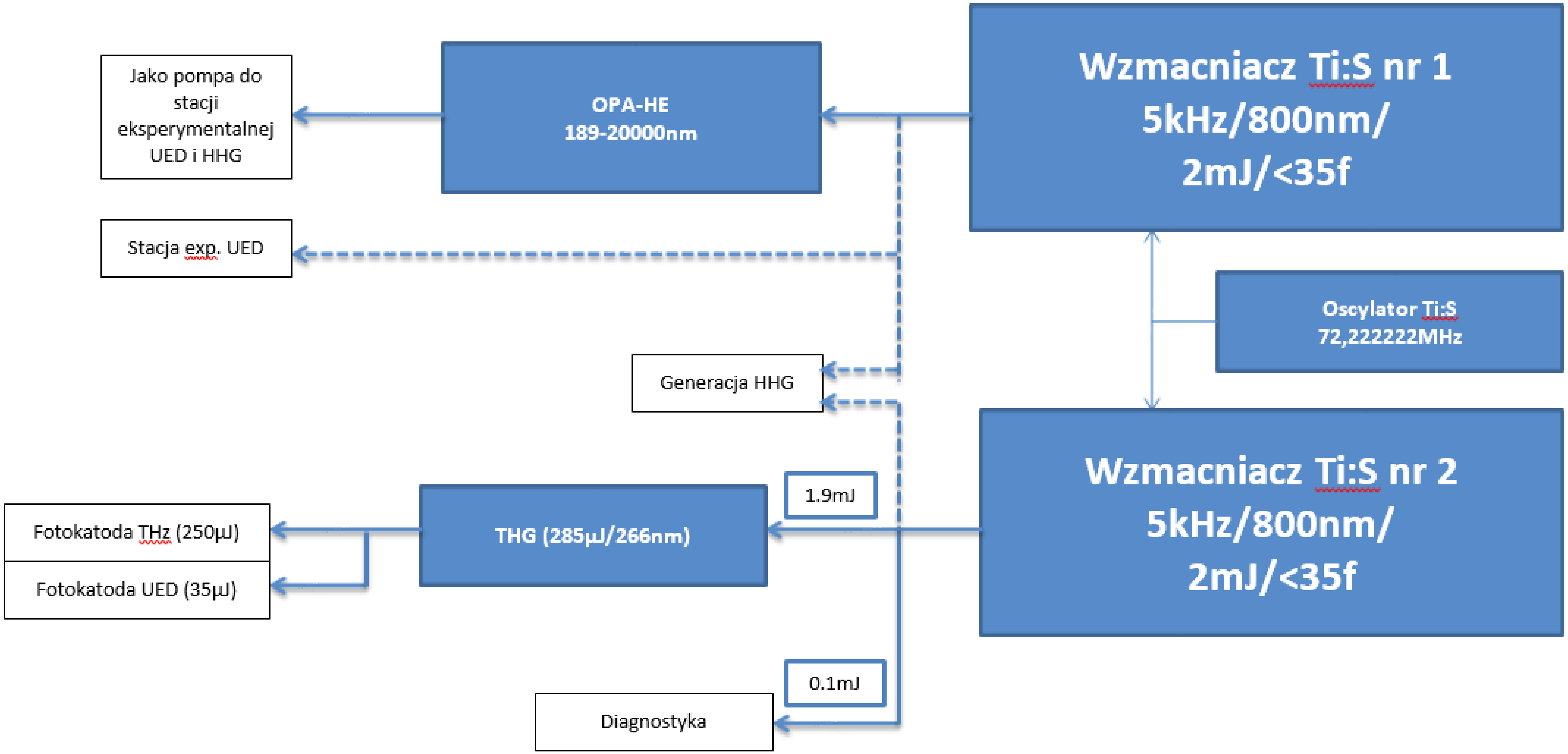
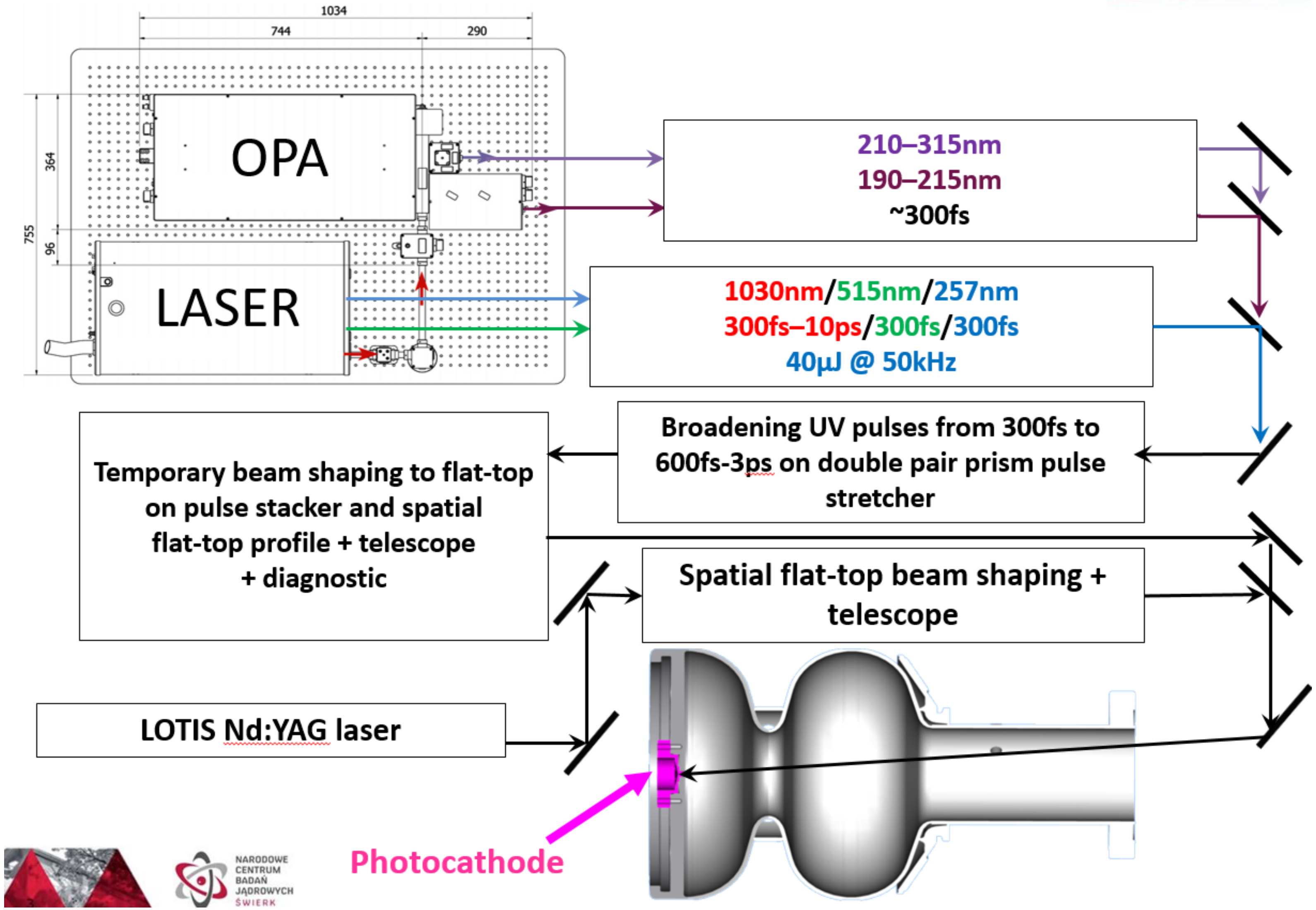
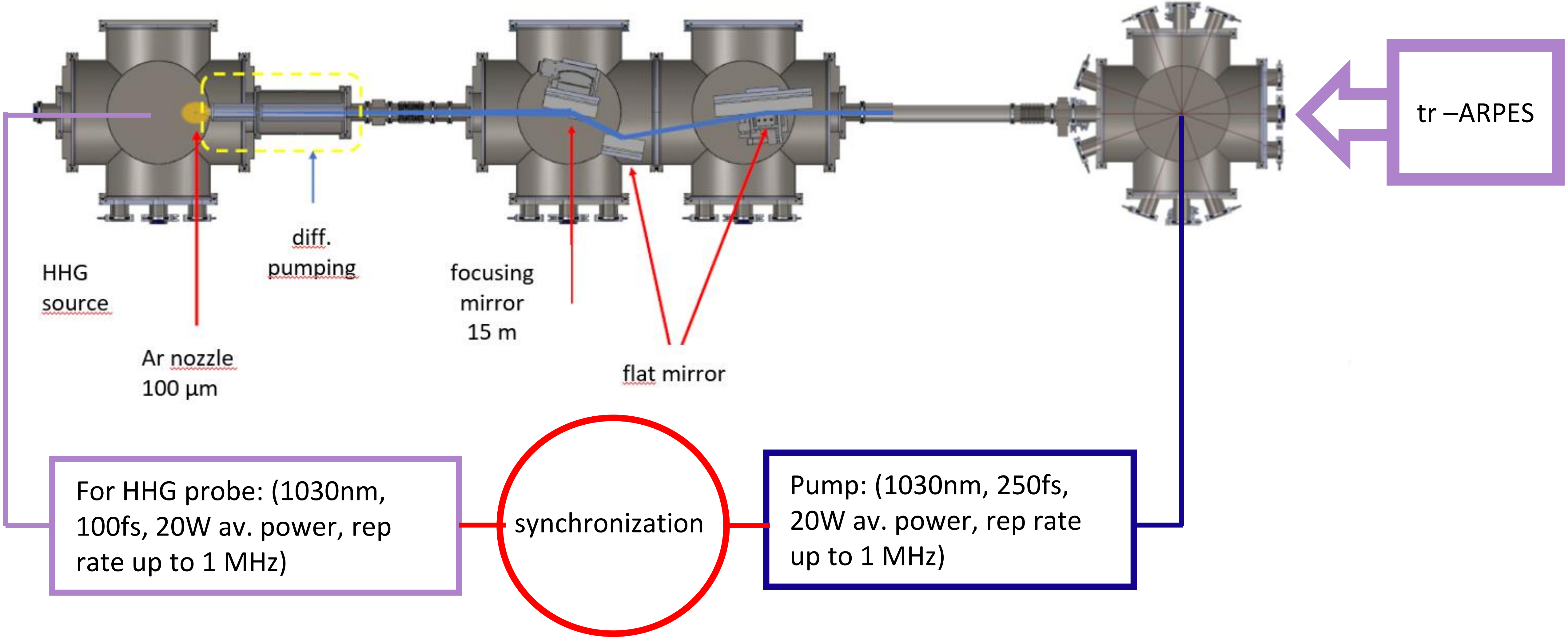


Photoinjector laser system scheme



HHG



tr –ARPES
HHG source
Ar nozzle 100 µm
diff. pumping
focusing mirror 15 m
flat mirror
For HHG probe: (1030nm, 100fs, 20W av. power, rep rate up to 1 MHz)
synchronization
Pump: (1030nm, 250fs, 20W av. power, rep rate up to 1 MHz)