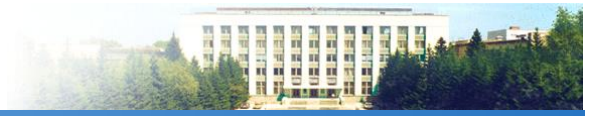


Status of Novosibirsk ERL

N. A. Vinokurov
Budker Institute of Nuclear Physics SB RAS
Novosibirsk, Russia

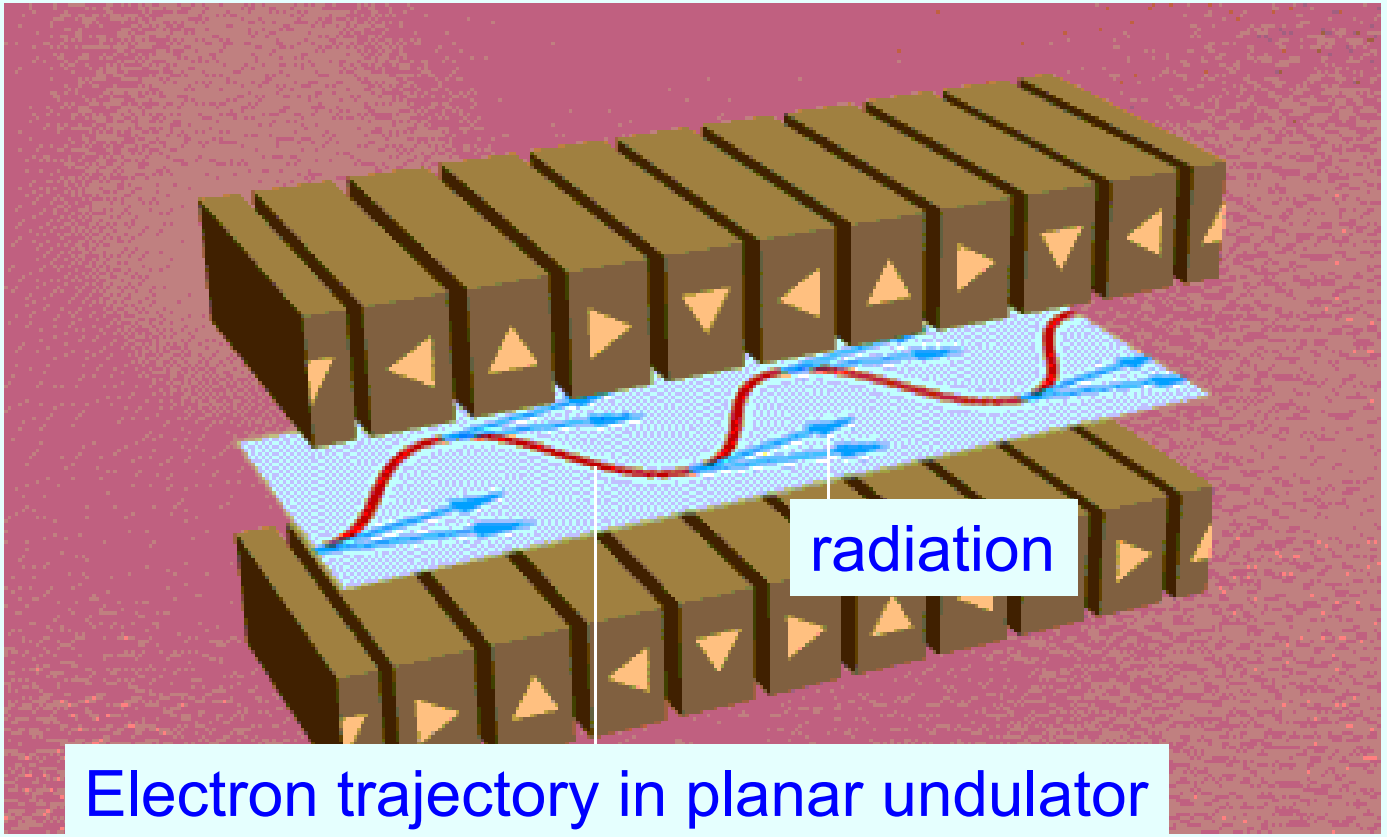
Outline

- Free electron lasers (FELs)
- Four-orbit ERL
- Beamlines

The Novosibirsk ERL is dedicated electron beam source for three FELs operating in the wavelength range 8 – 240 micron at average power up to 0.5 kW and peak power about 1 MW.

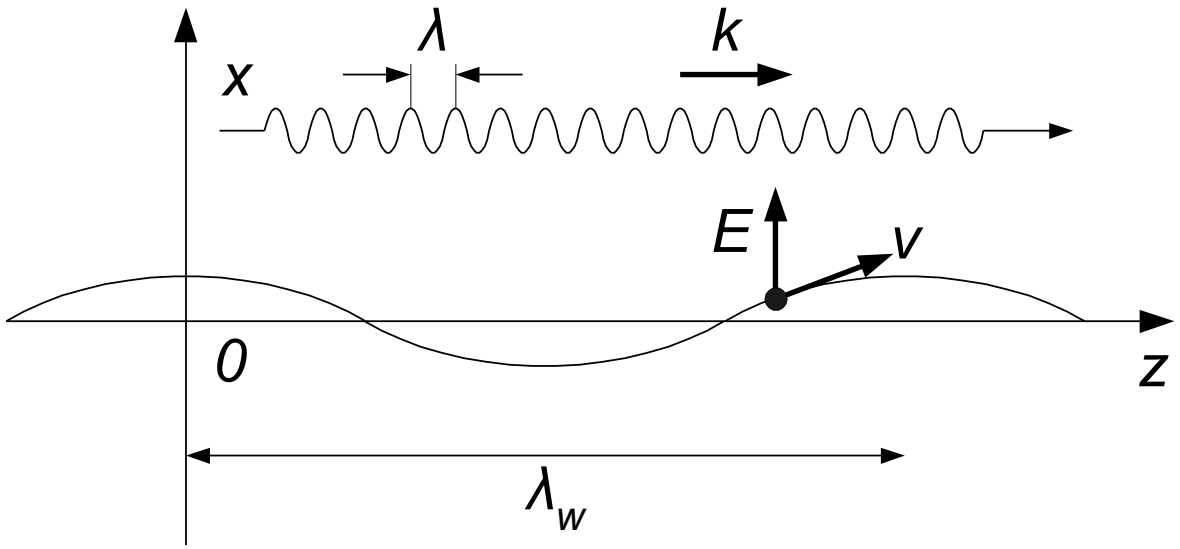
FEL principle of operation

Undulator (wiggler) is a magnetic system with spatially periodic transverse magnetic field. In such a field a relativistic electron may move along periodically bent trajectory (sinusoid or helix). It was invented by V. L. Ginzburg in 1947.



Electron trajectory in planar undulator (permanent magnet undulator).

Undulator is the key part of an FEL.
It provides effective energy exchange between electron and plane electromagnetic wave.



$$\lambda_0 \approx \frac{\lambda_w}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

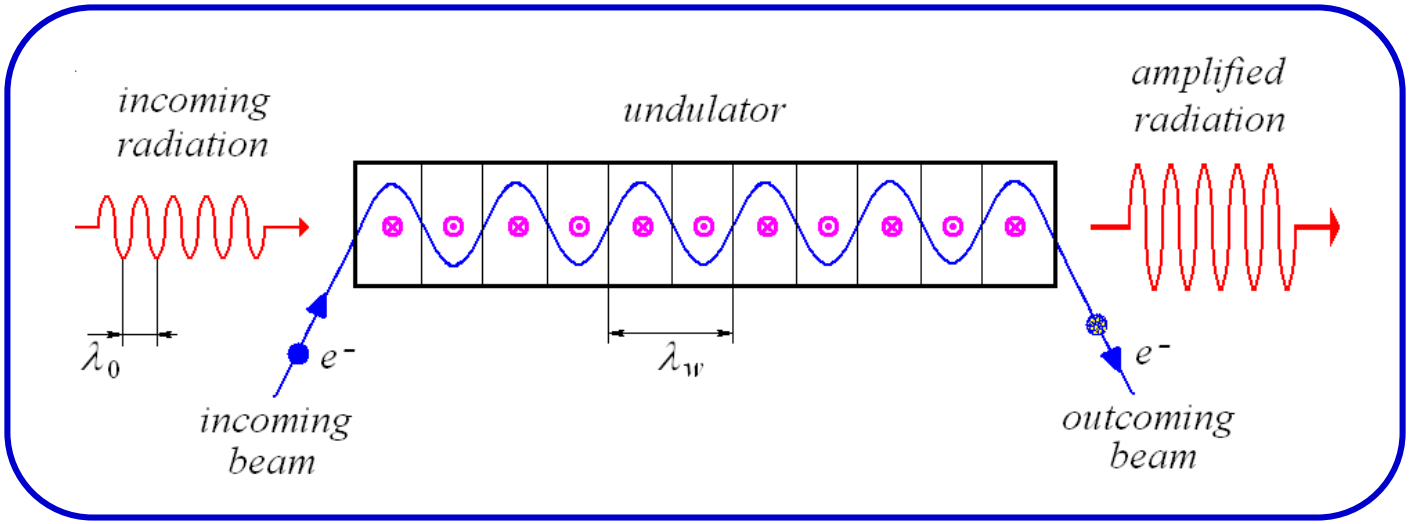
synchronism condition

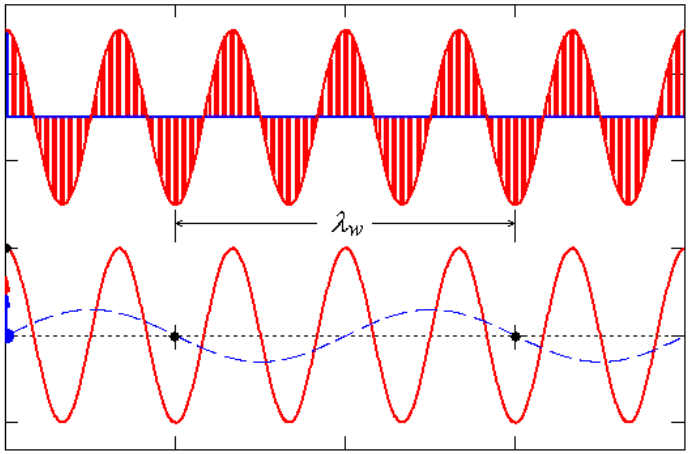
which is necessary for the

energy transfer

$$\left\langle \frac{d\gamma}{dz} \right\rangle = \frac{e}{mc^3}\langle \mathcal{E}_x V_x \rangle$$

FEL principle of operation





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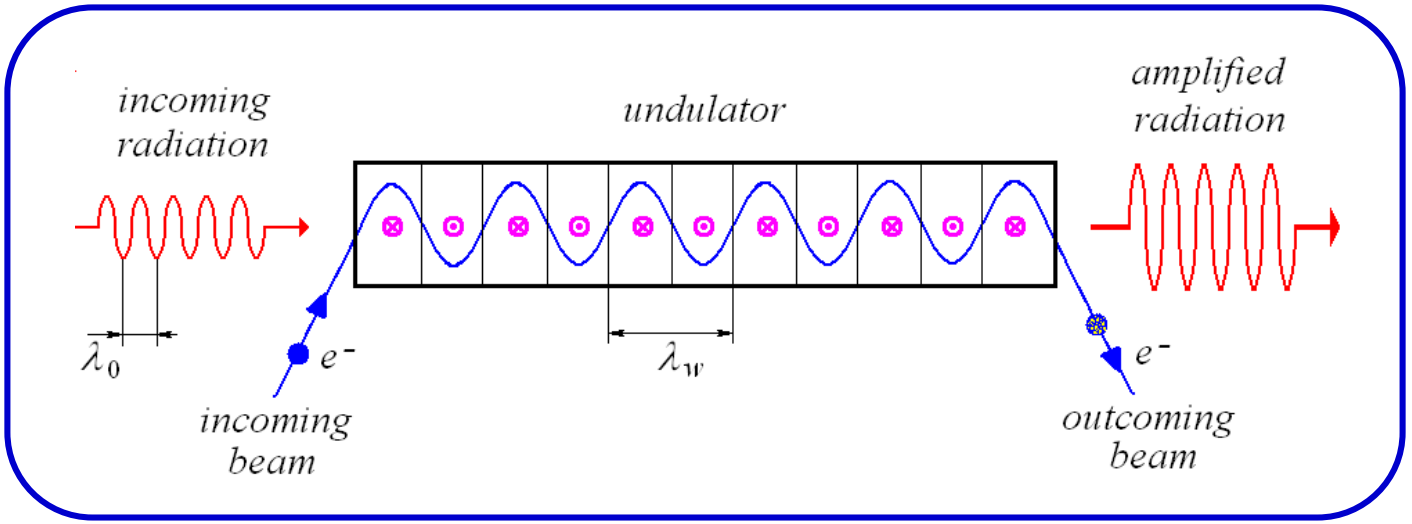

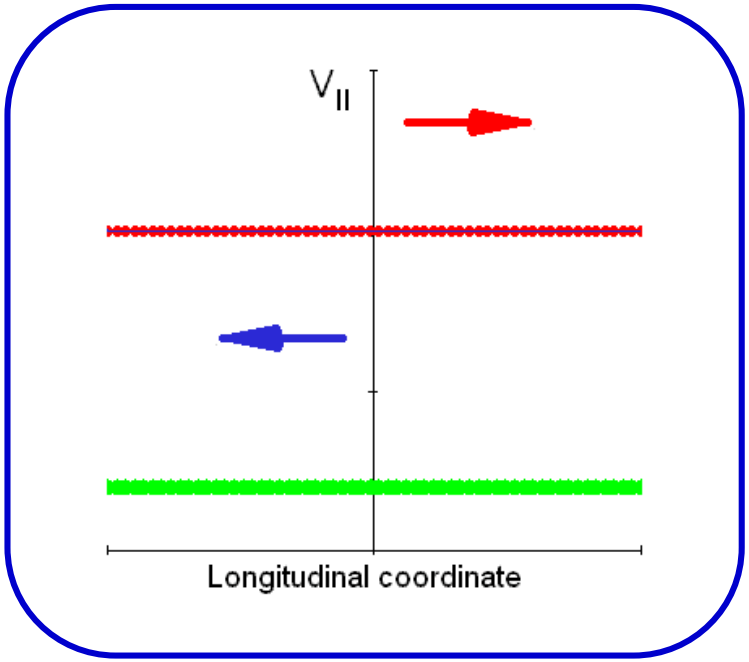

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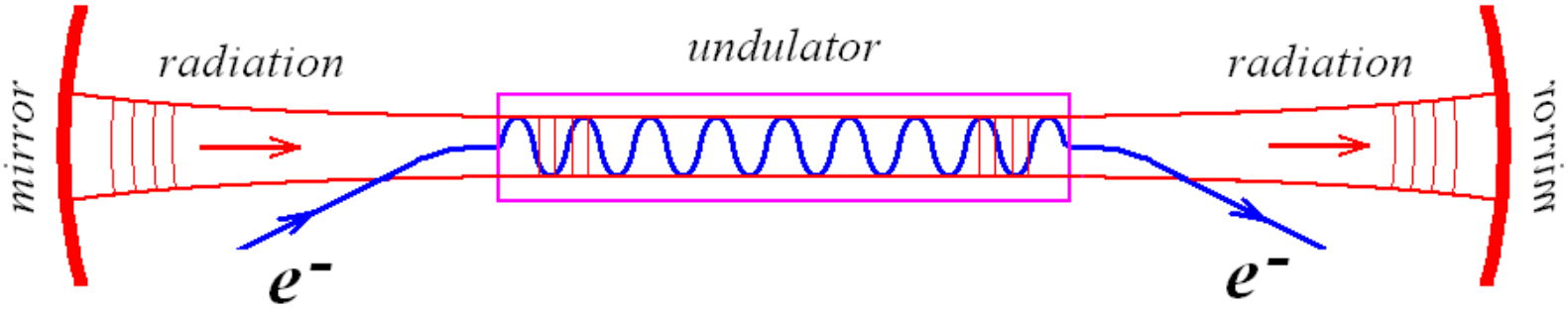
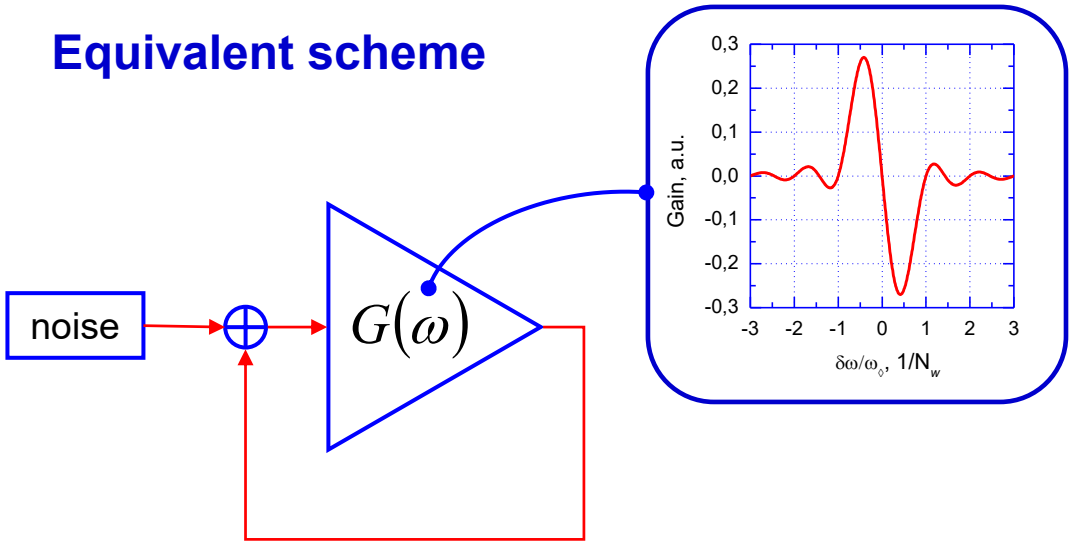
$$\left\langle \frac{d\gamma}{dz} \right\rangle = \frac{e}{mc^3}\langle \mathcal{E}_x V_x \rangle$$

FEL principle of operation

FEL oscillator



Equivalent scheme



Narrow bandwidth amplifier with feedback

To get lasing electron and radiation bunches have to come to undulator at the same time

High electron beam repetition rate is required!

Energy recovery

- Electron efficiency of FEL is rather low (~1%), therefore energy recovery is necessary for a high power FEL.

- Energy recovery:

  - decreases radiation hazard and heating load to dump

  - makes possible operation at high average current.

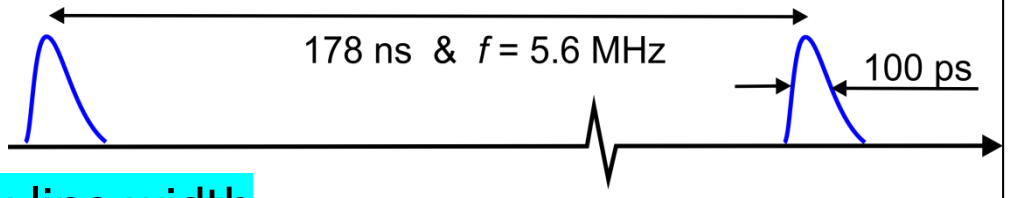
- Due to energy recovery, the cost of the building for FEL can be reduced.

Novosibirsk FELs

Radiation parameters of the Novosibirsk FEL facility (3 FELs)

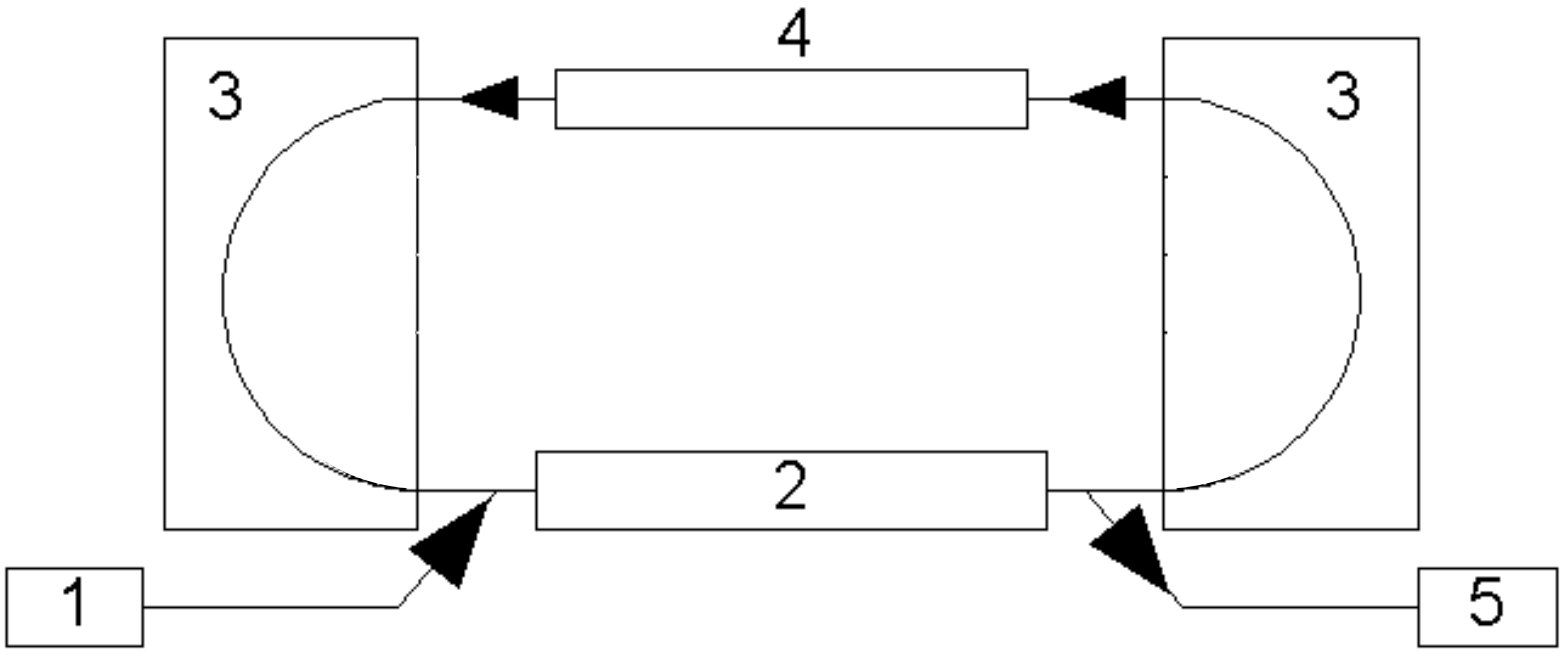
Laser	Terahertz	Far-Infrared	Infrared
Status	In operation since 2003	In operation since 2009	In operation since 2015
Wavelength, μm	90 – 240	37 – 80	8 – 11
Relative line width (FWHM), %	0.2 – 2.0	0.2 - 1	0.1 - 1
Maximum average power, kW	0.5	0.5	0.1
Maximum peak power, MW	0.5	2.0	10
Pulse duration, ps	30 - 120	20 - 40	10 - 20
Pulse repetition rate, MHz	5.6	7.5	3.8
Electron energy, MeV	12	22	42
Beam current, mA	10 (30)	10	3

- Tunability
- High power
- Relatively narrow line width



NovoFEL Accelerator Design

Energy Recovery Linac

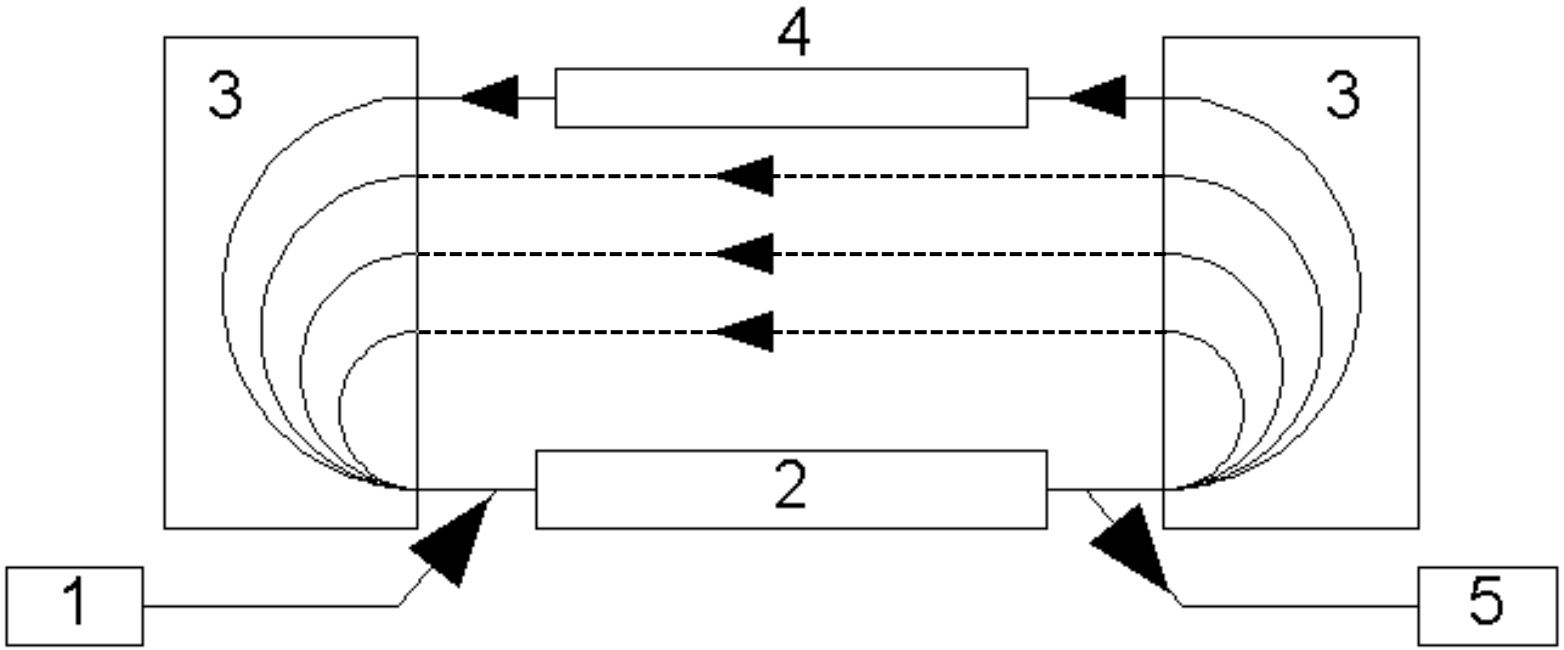


1 – injector, 2 – linac, 3 – bending magnets, 4 – undulator, 5 –dump

Accelerator is the most important part of any **FEL**.
ERL is the best choice for **high power FEL**.

NovoFEL Accelerator Design

Energy Recovery Linac



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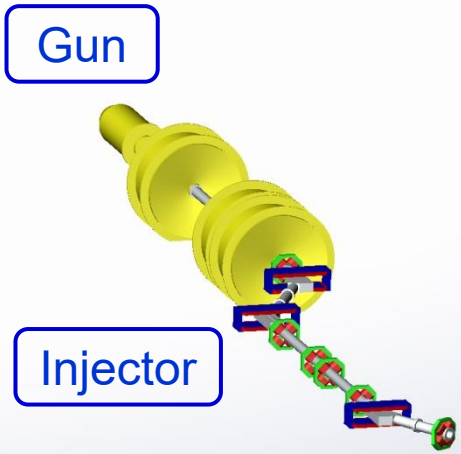
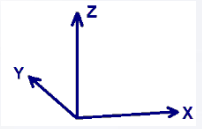
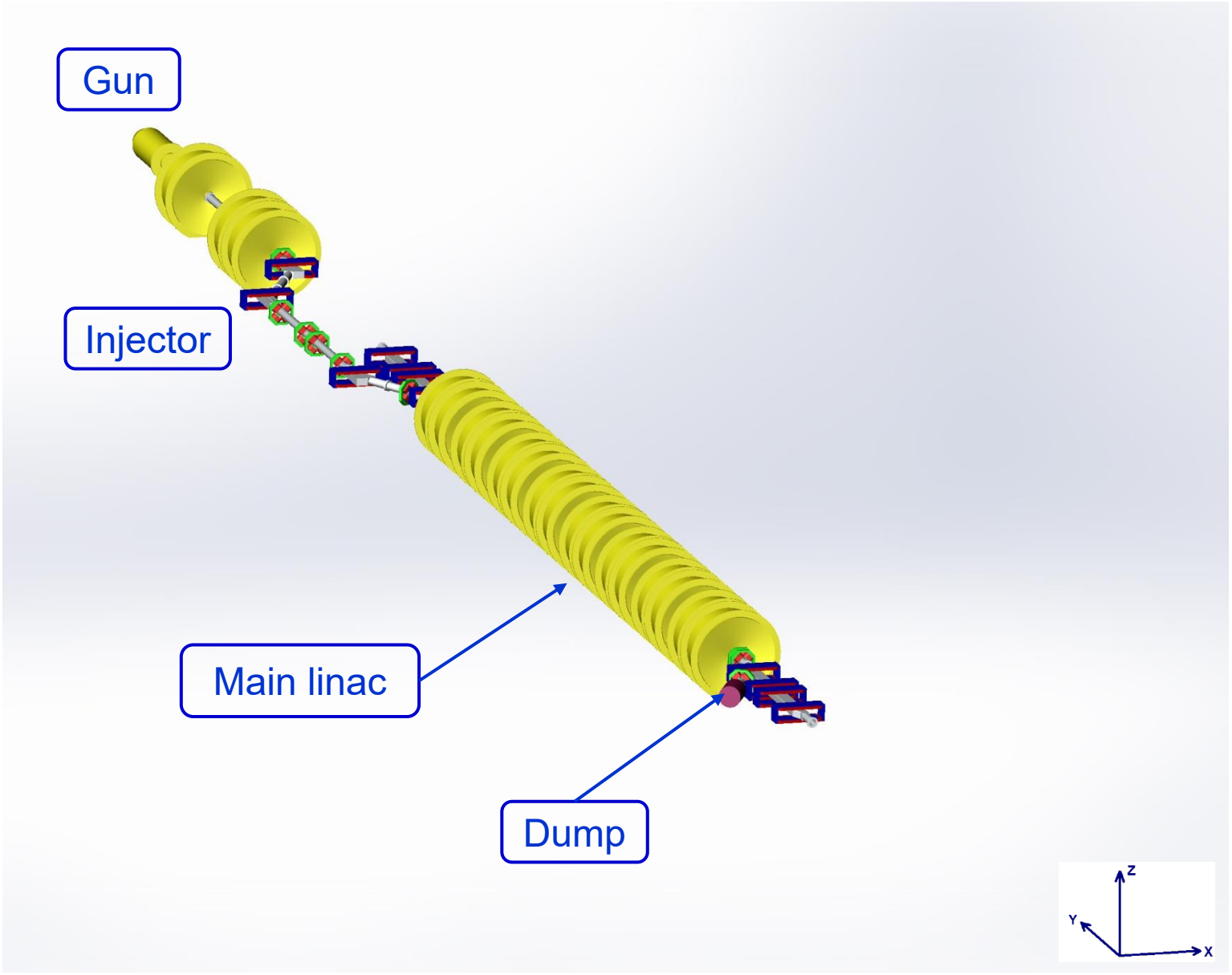
NovoFEL Accelerator Design

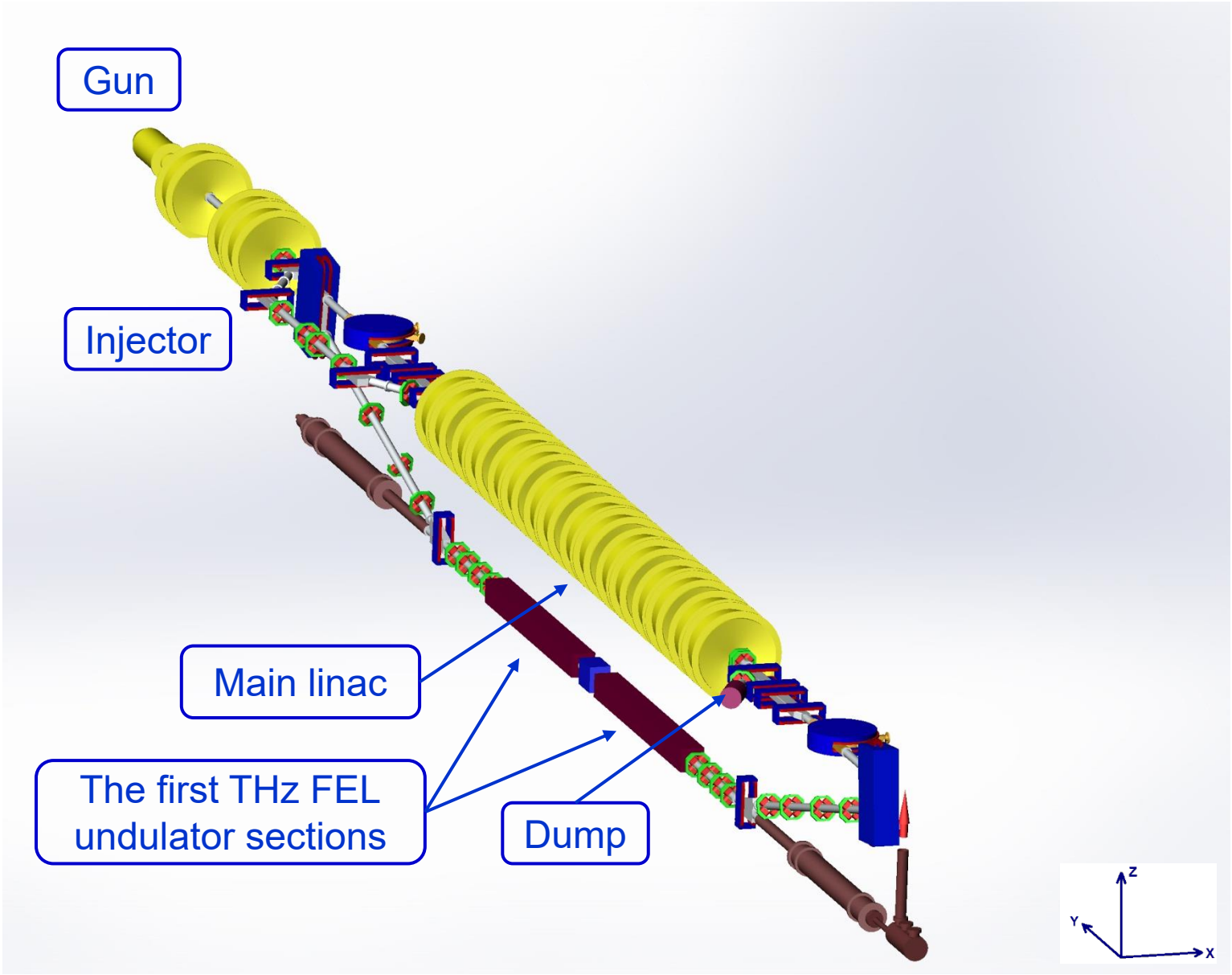




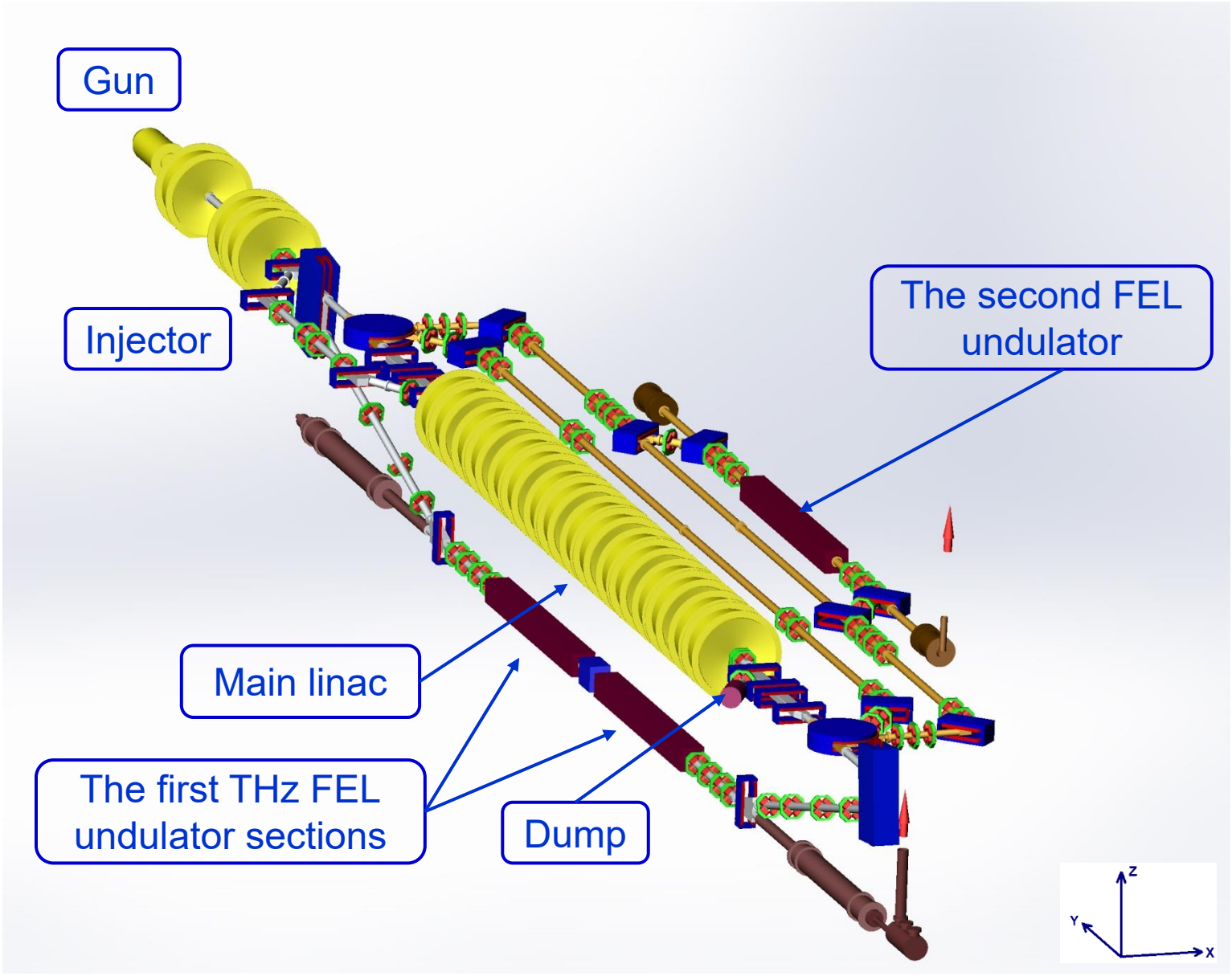
NovoFEL Accelerator Design



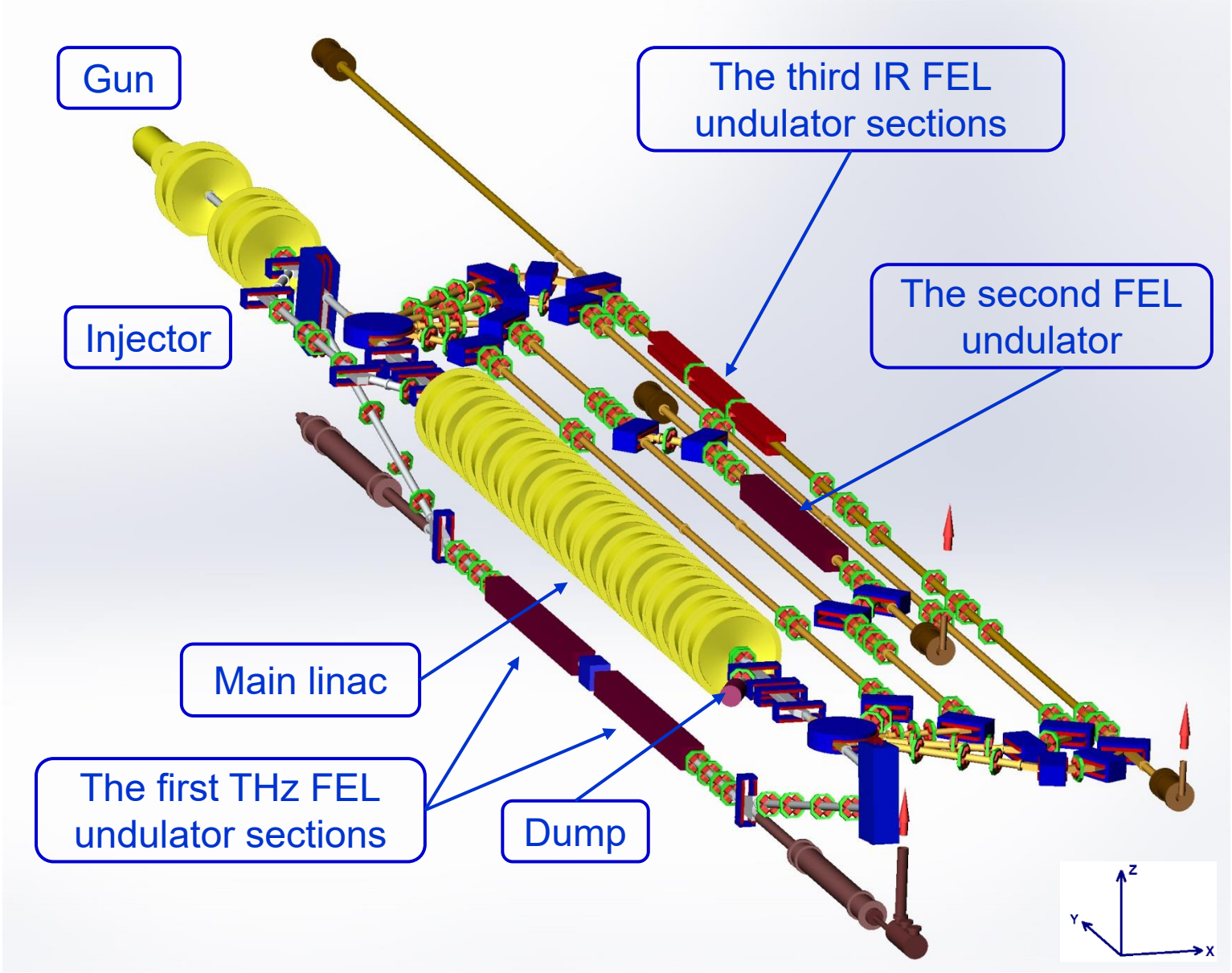
NovoFEL Accelerator Design

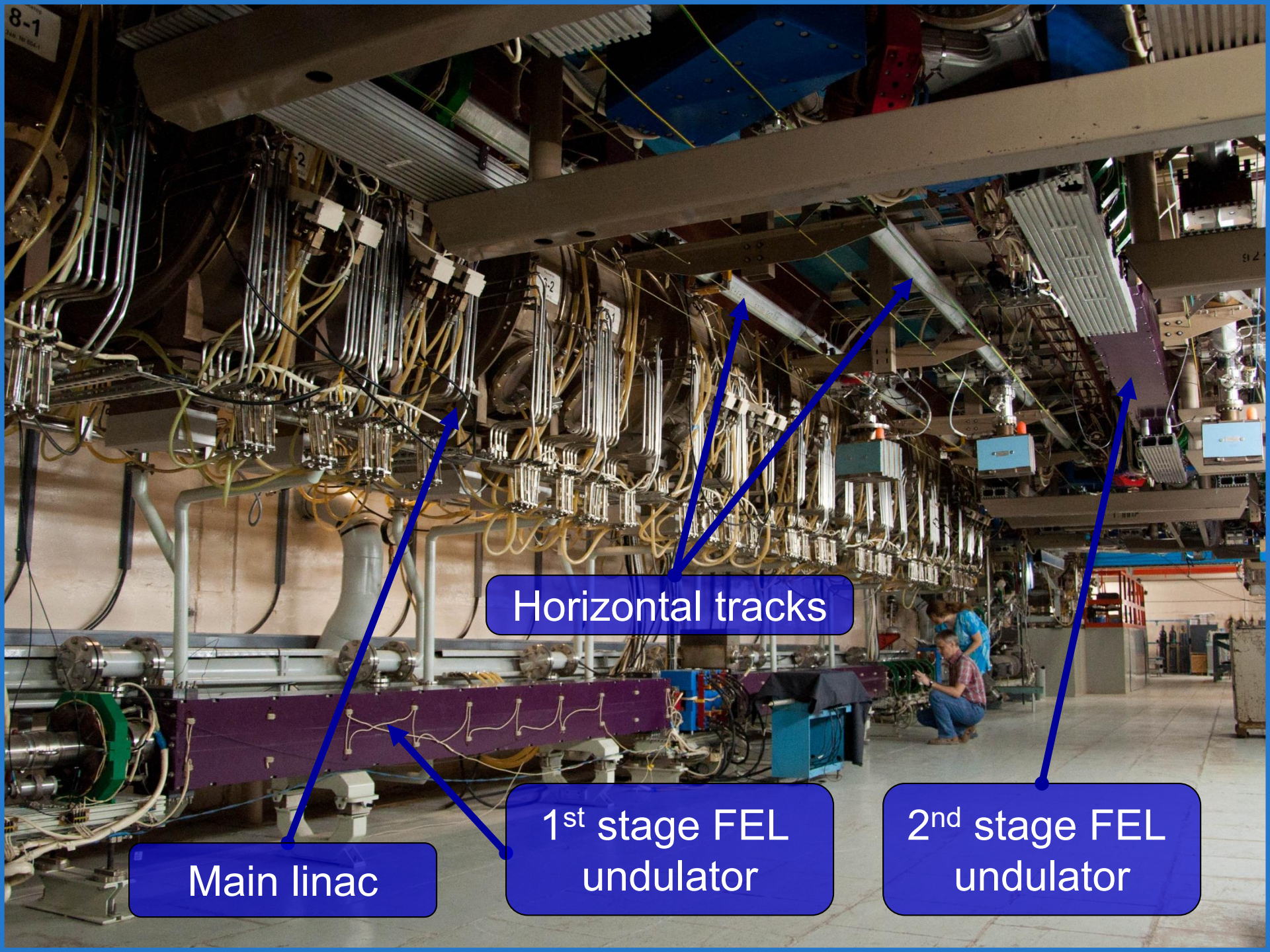


NovoFEL Accelerator Design



NovoFEL Accelerator Design

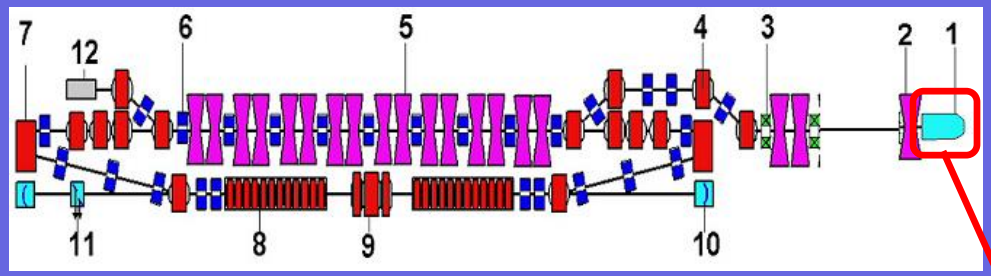


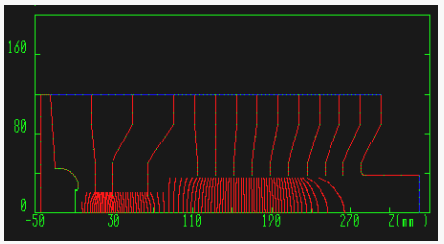

Horizontal tracks
Main linac
1st stage FEL undulator
2nd stage FEL undulator


3d stage FEL
undulator

Siberian Center of Photochemical Research

Electrostatic Gun



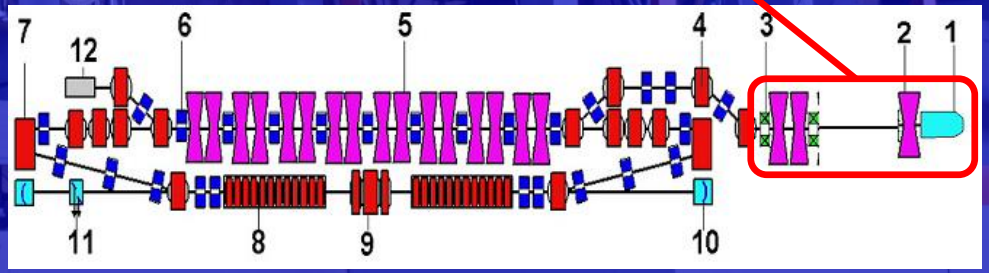


Power supply:

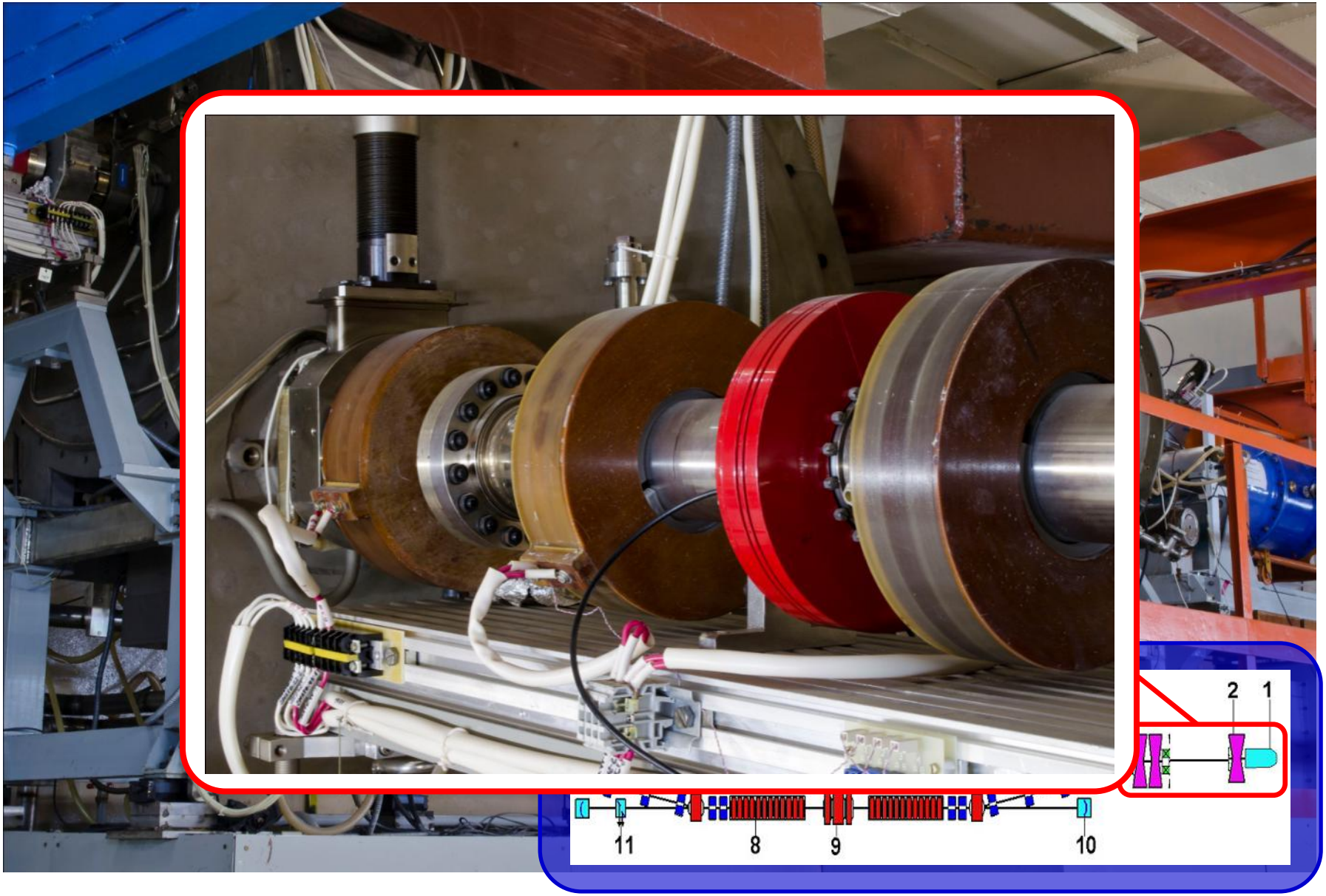
U_{max} = 300 kV

I_{max} = 50 mA

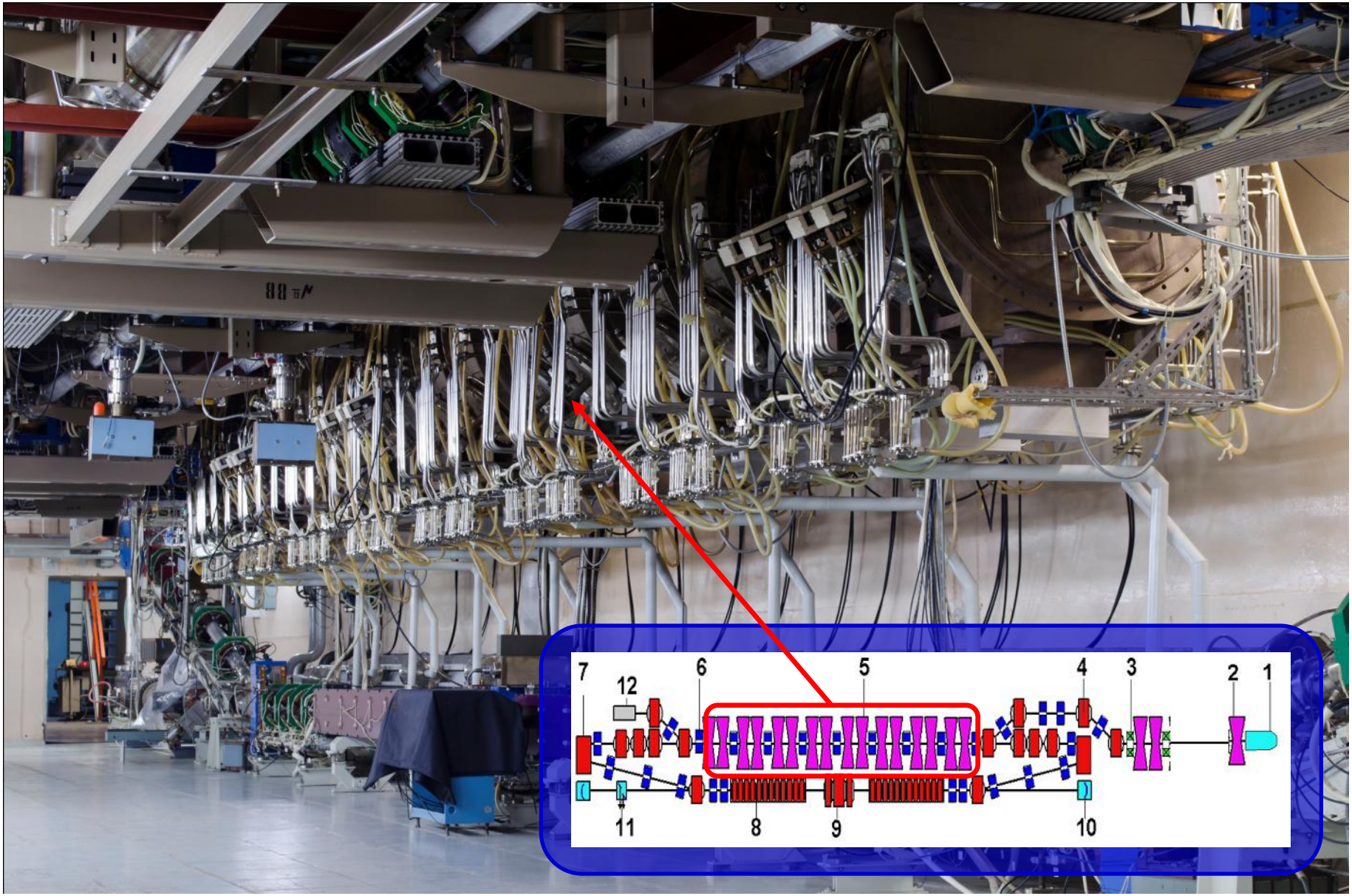
Injector



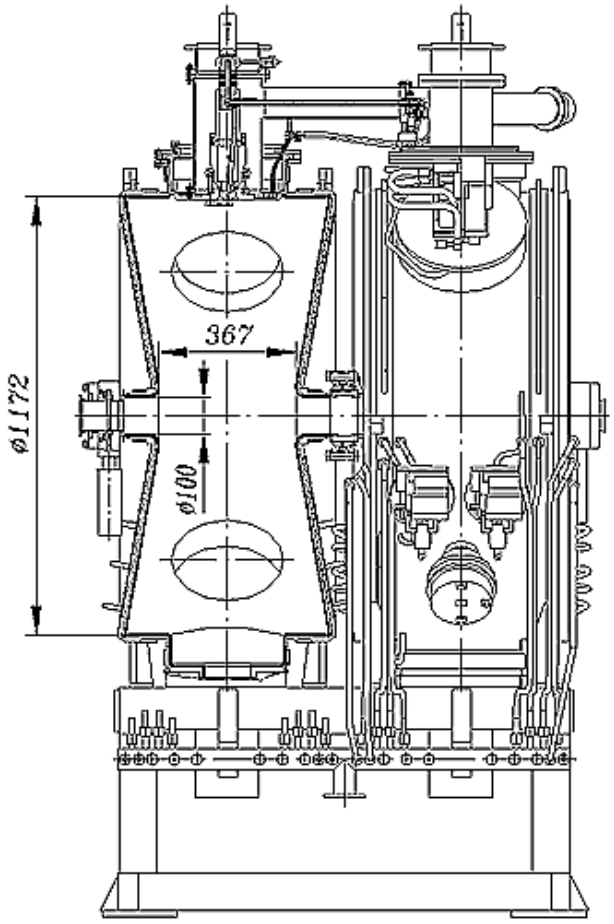
Injector

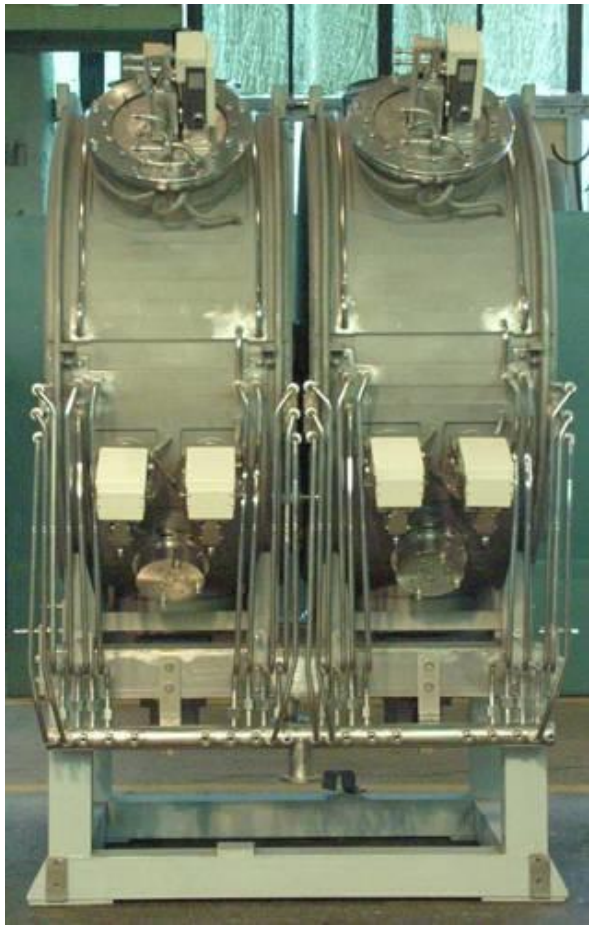


Main Linac

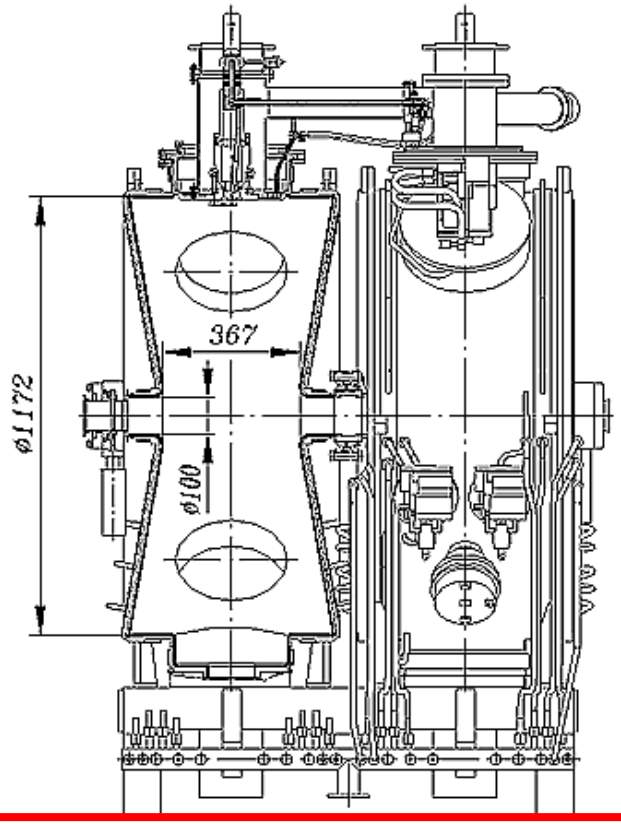


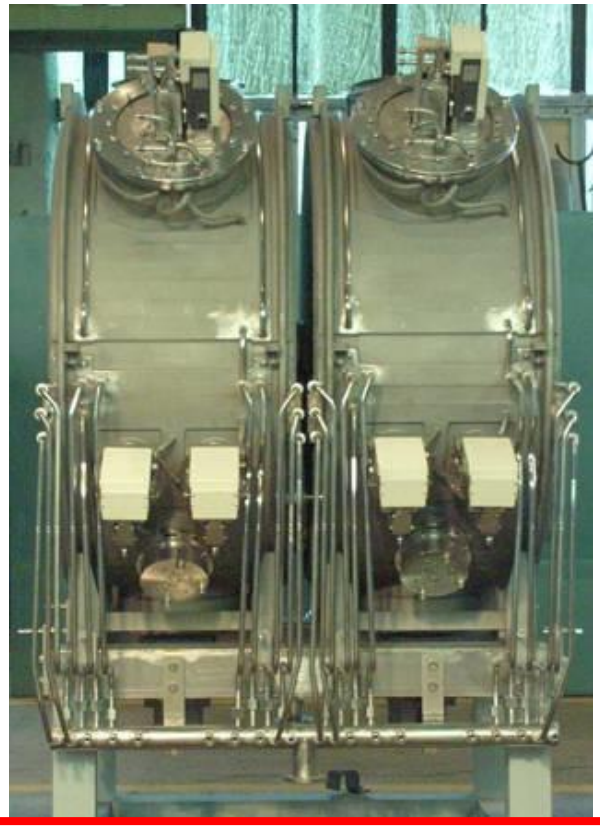
Main Linac





Main Linac

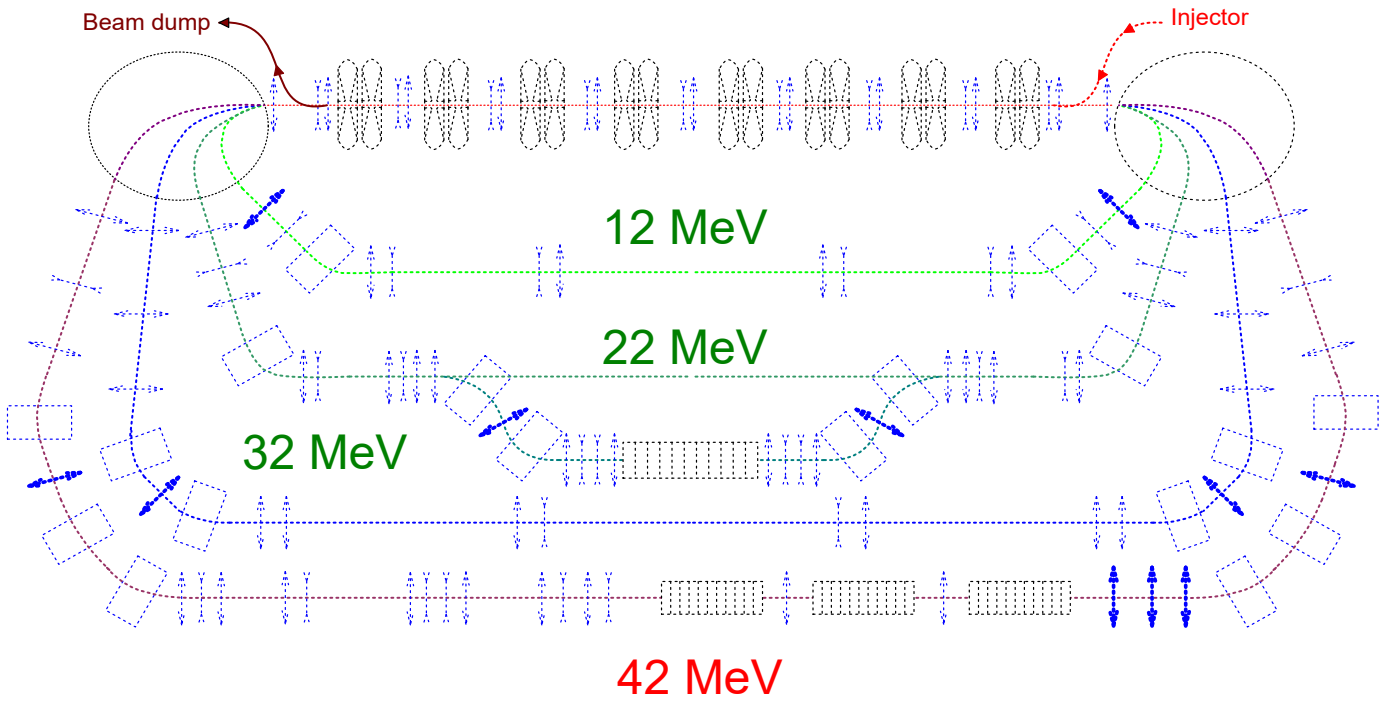




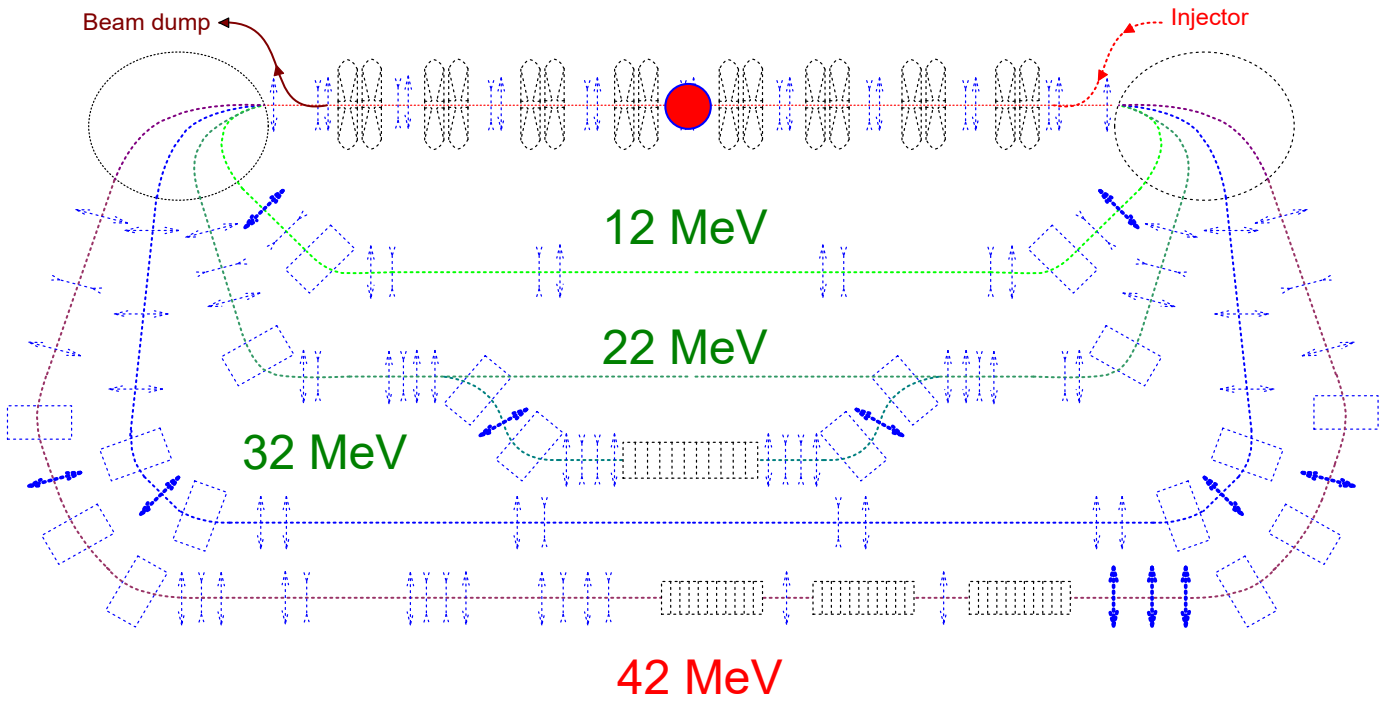
$f_0 = 180$ MHz, $\Delta f_0 = 320$ kHz, $U_{max} = 950$ kV,

$U_{eff} = 850$ kV, $P_{dis} = 85$ kW

Layout of Horizontal Beamlines (the Second and the Third ERLs)



Layout of Horizontal Beamlines (the Second and the Third ERLs)



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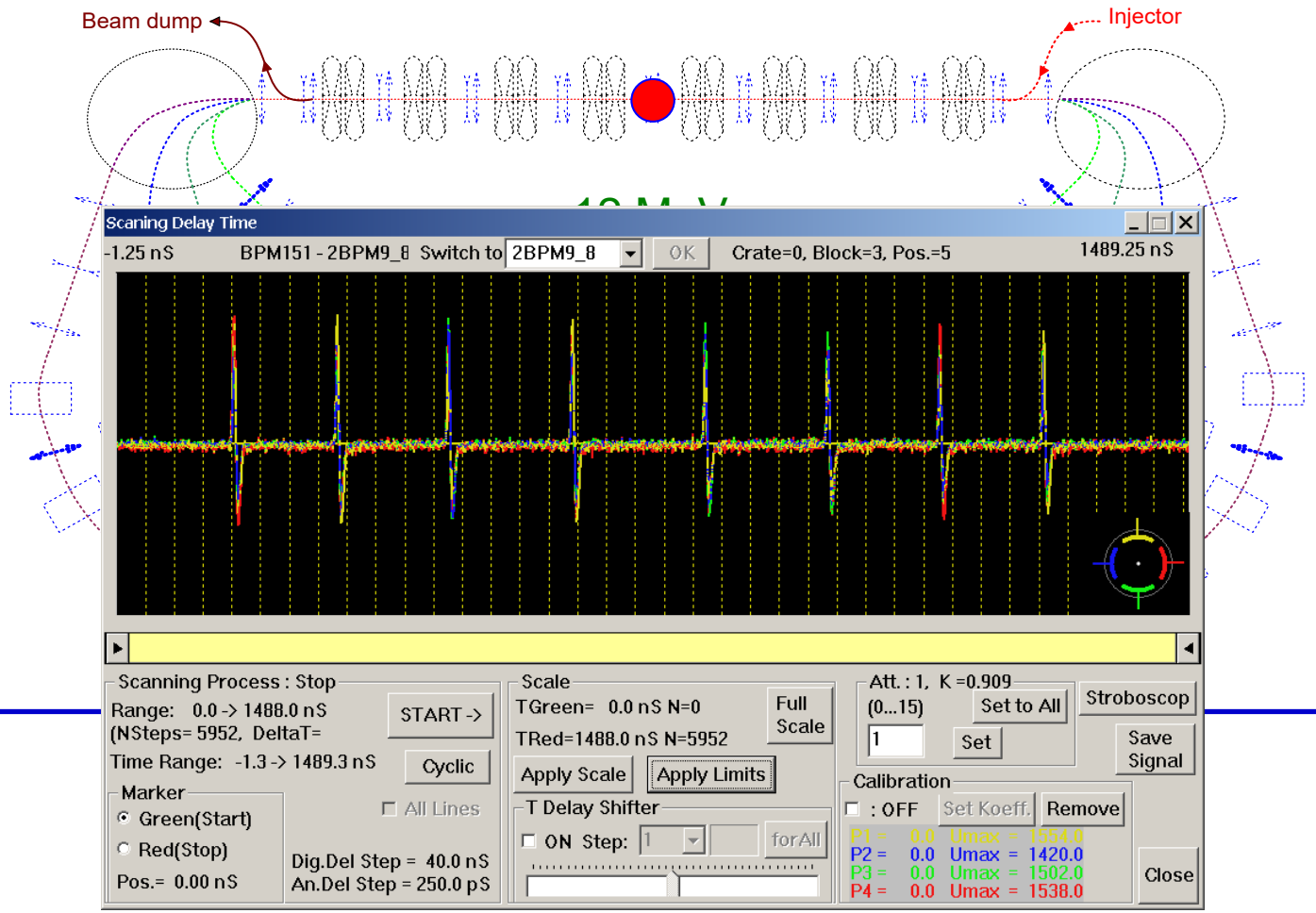
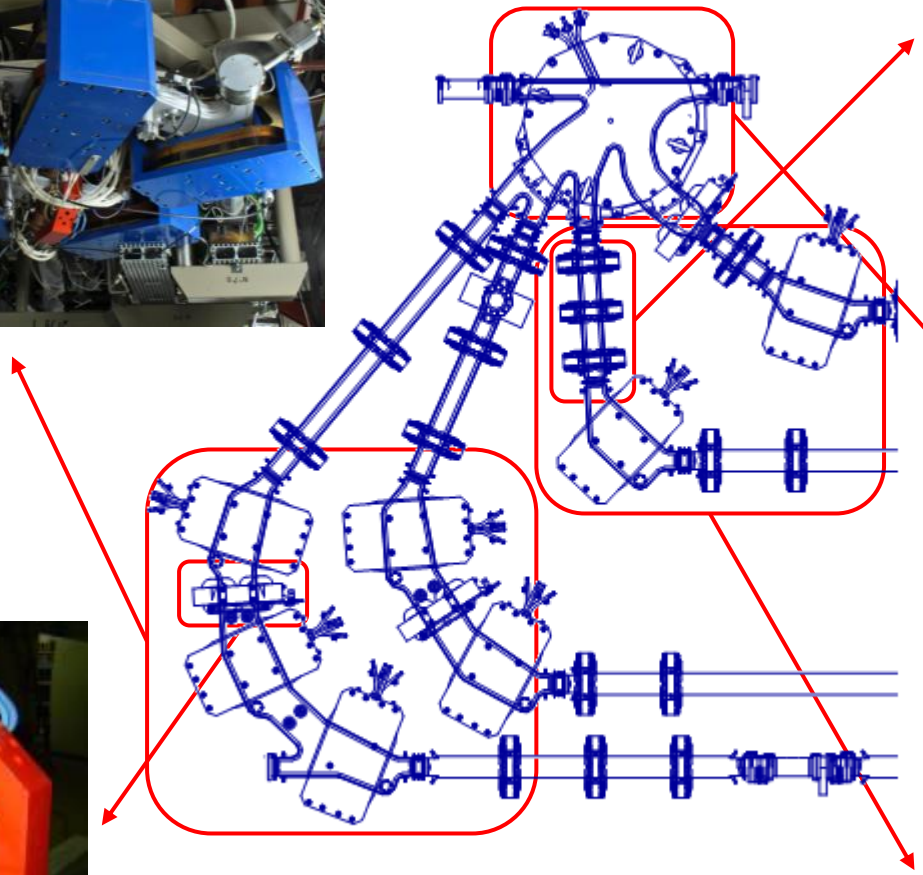
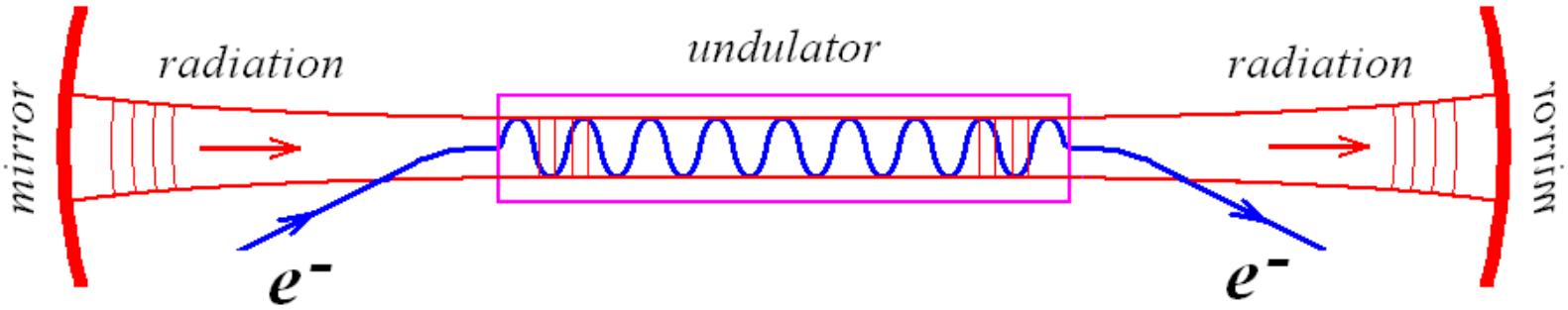


Magnets and Vacuum Chamber of Bends



NovoFEL as Radiation Source

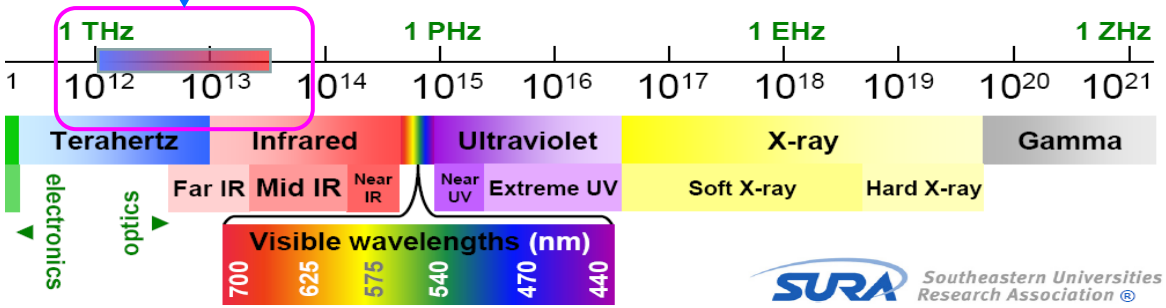
FEL oscillator



One of the main FEL advantages is the ability to adjust the wavelength

$$\lambda = \lambda_u \frac{1}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

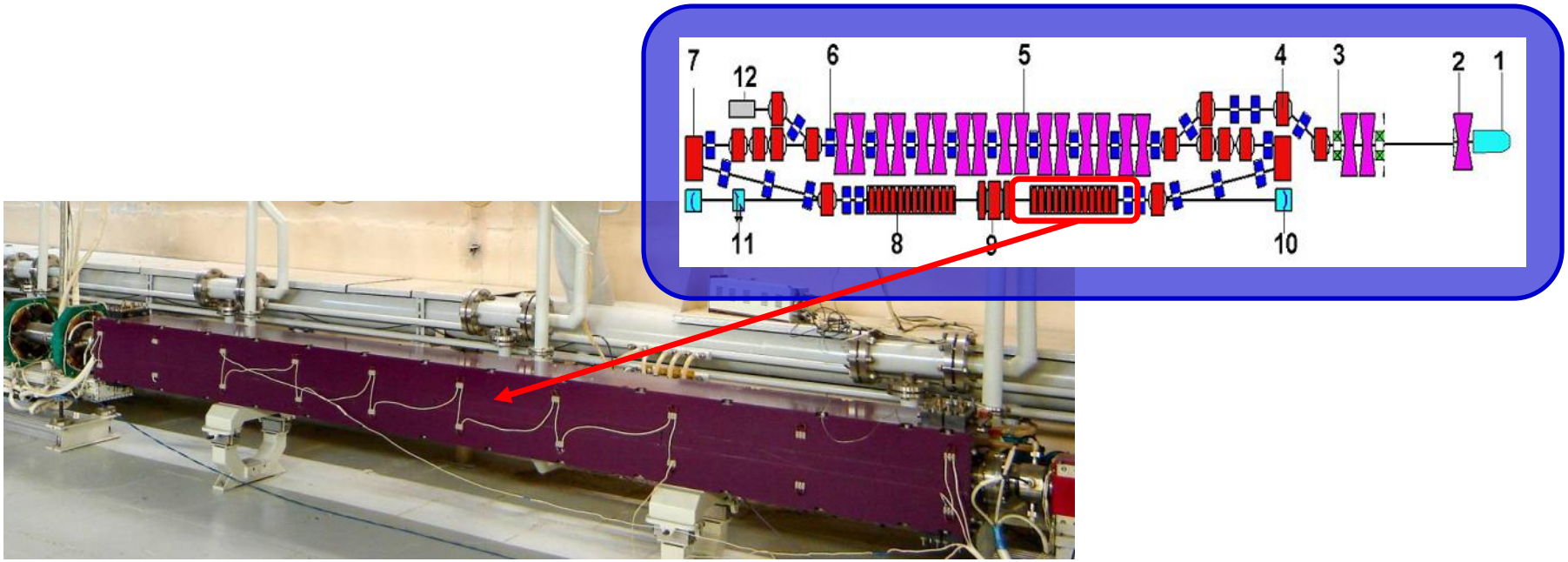
NovoFEL



SURA Southeastern Universities Research Association ®

The most attractive ranges for FELs are at very short and at very long wavelength, where there are no other lasers

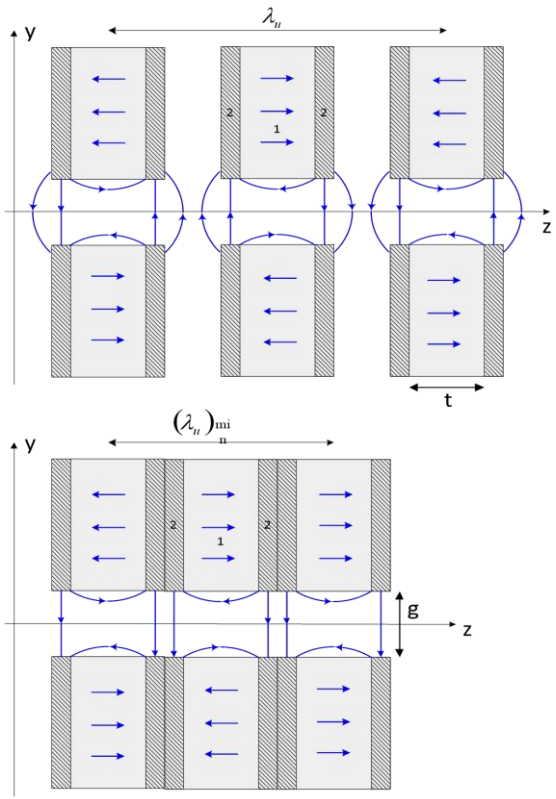
Electromagnetic Undulators

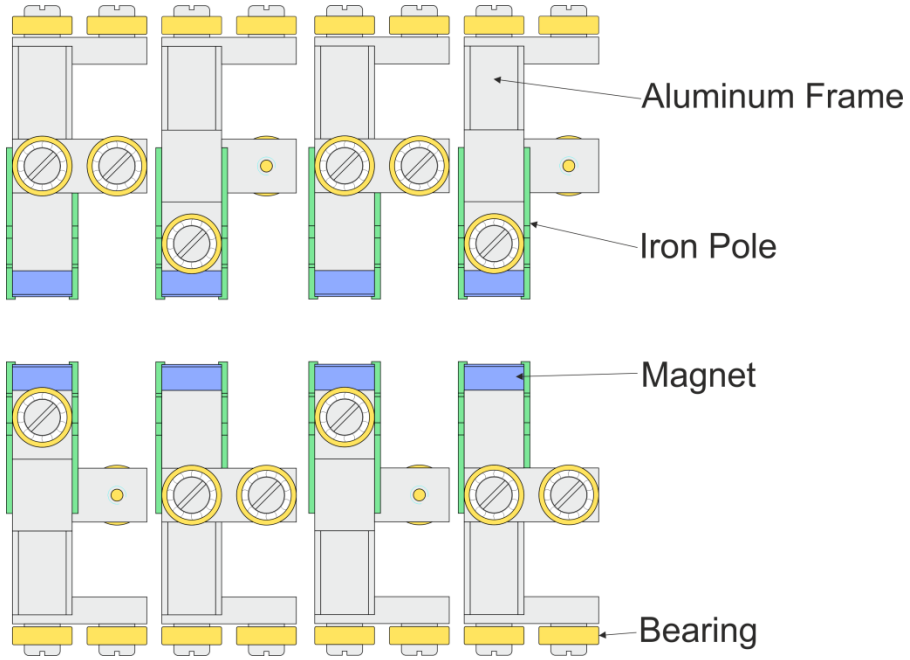


	1-st FEL	2-d FEL
Period, cm	12	12
Maximum current, κA	2.4	2.4
Maximum K	1.25	1.47

The third FEL undulator

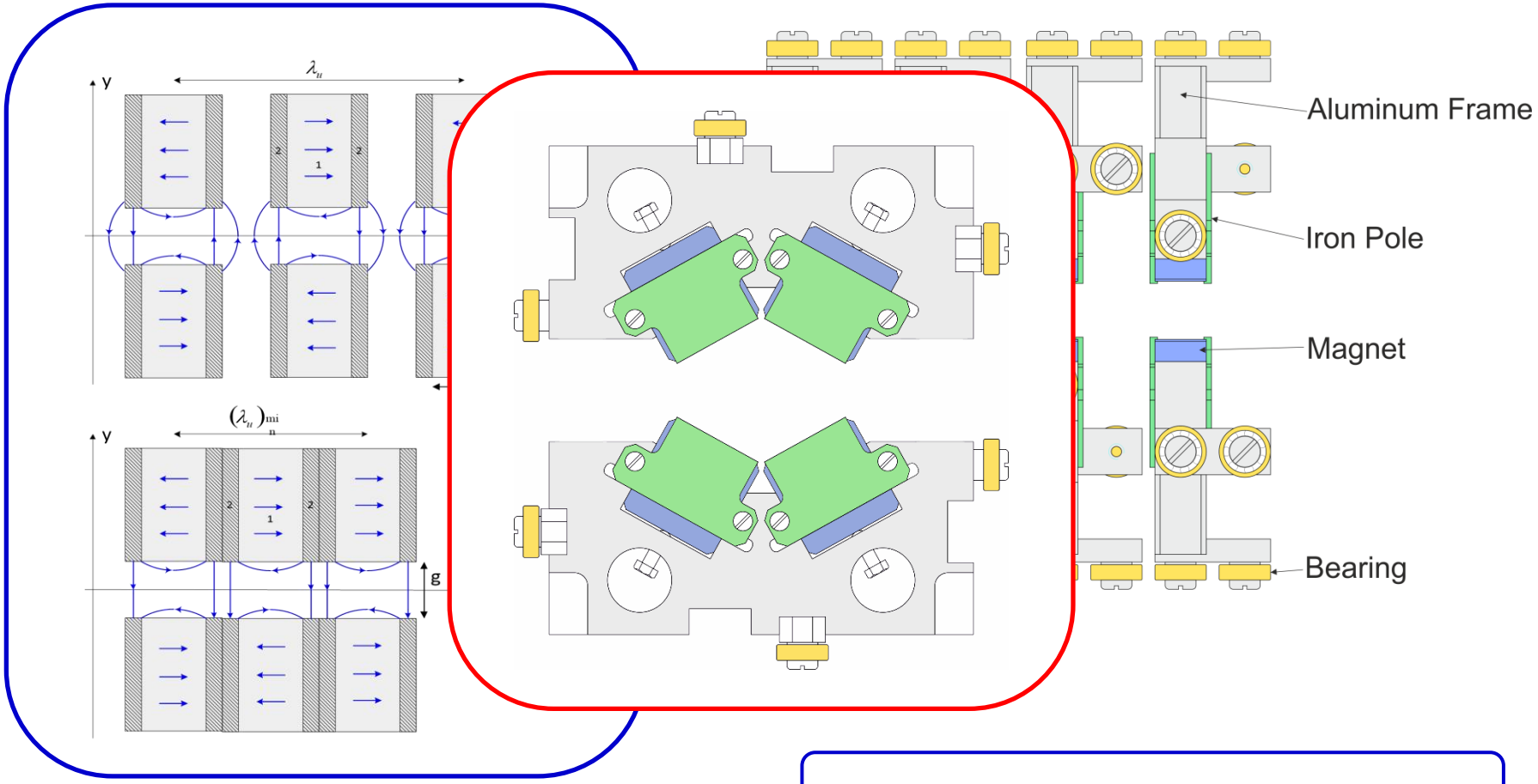
Variable Period Undulator (for the second FEL)





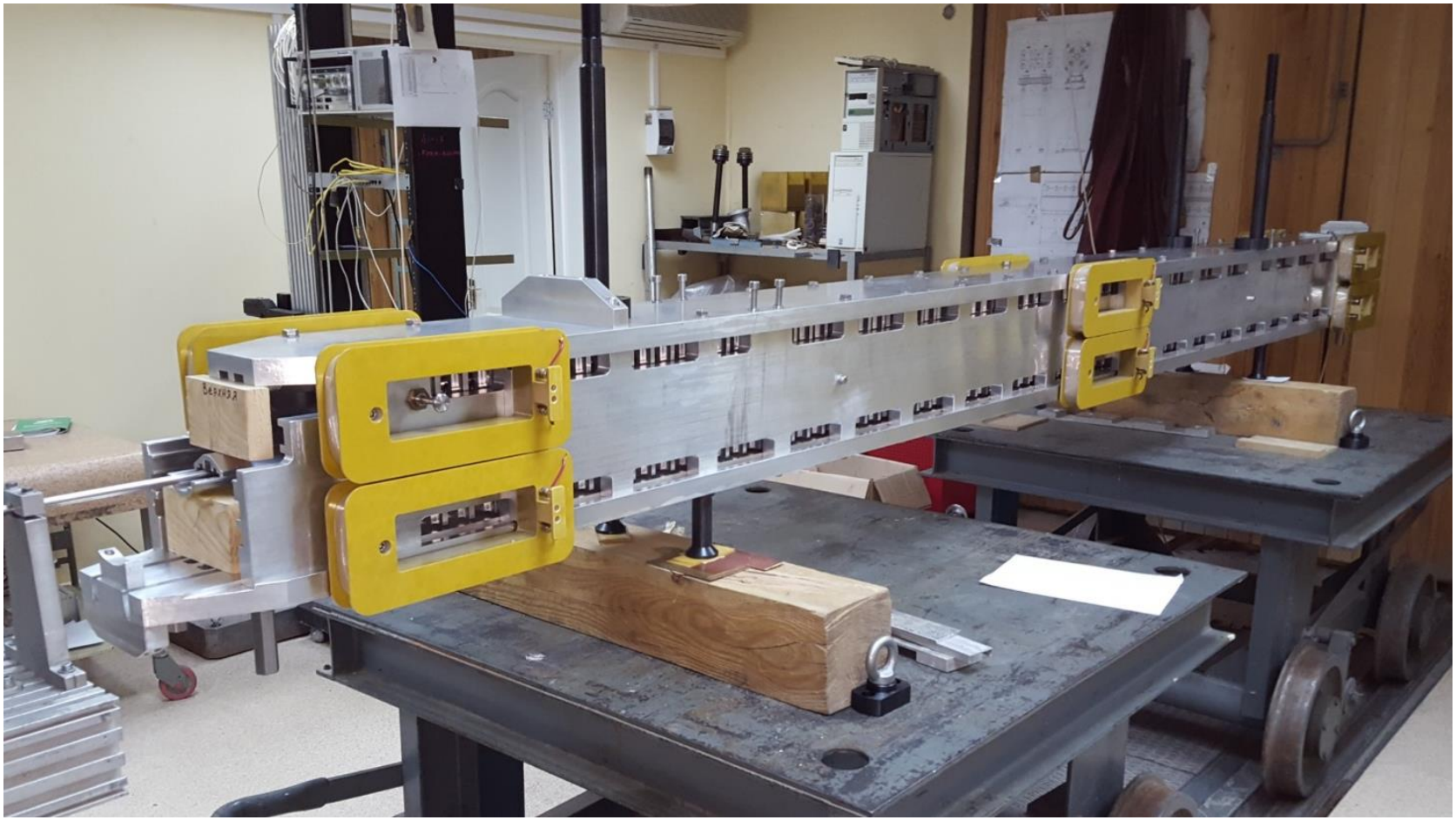
The tunability range of the 2-d FEL will be increased from **37 - 80** to **15 - 80** microns

Variable Period Undulator (for the second FEL)

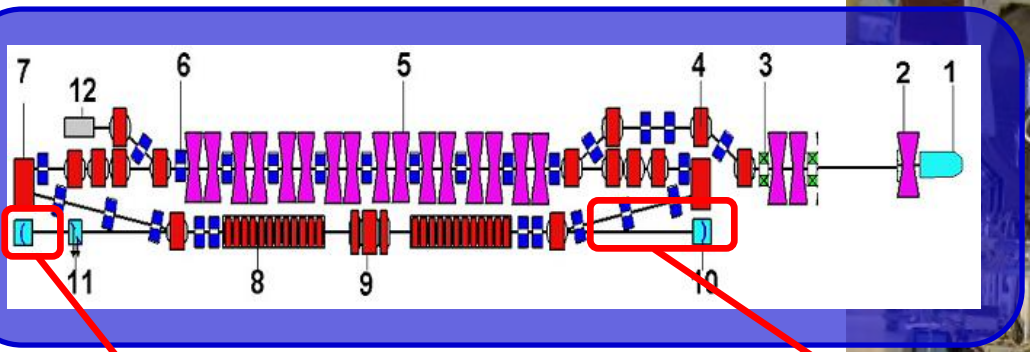


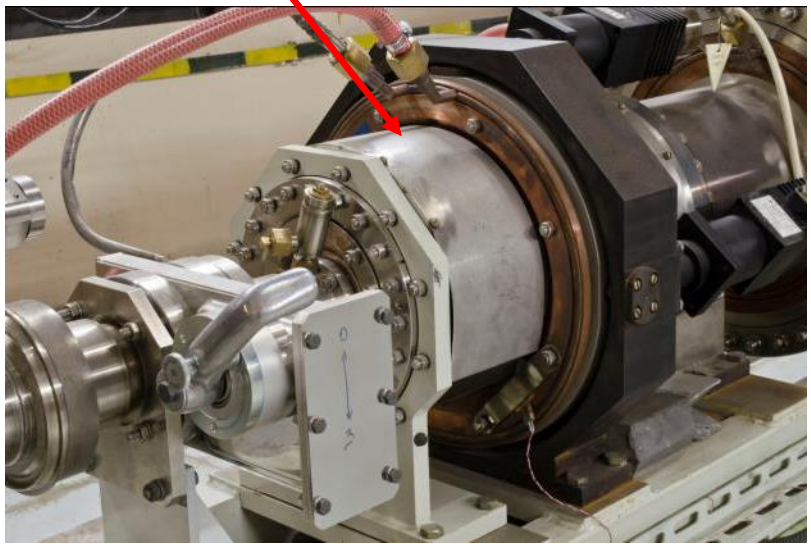
The tunability range of the 2-d FEL will be increased from **37 - 80** to **15 - 80** microns

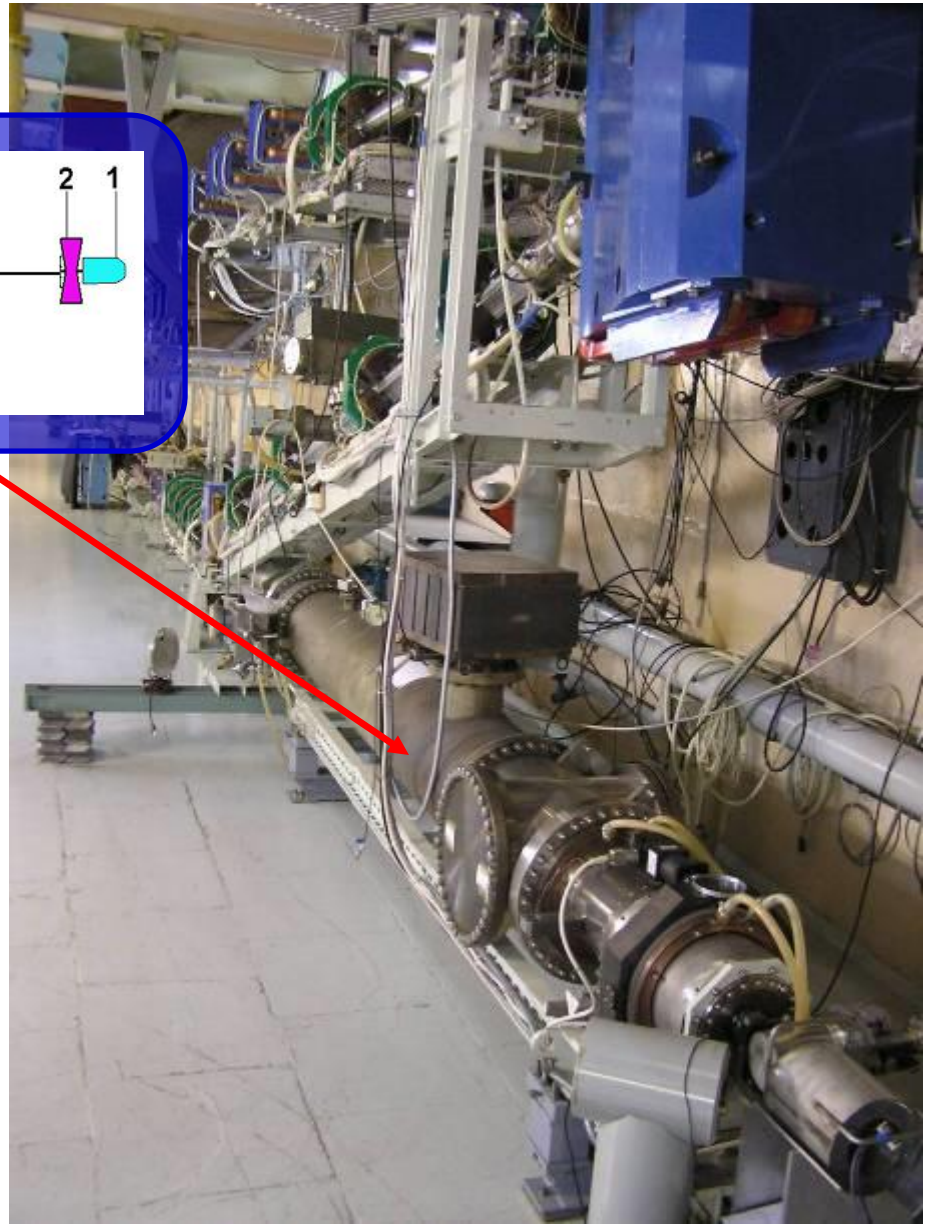
New variable period undulator for the second FEL



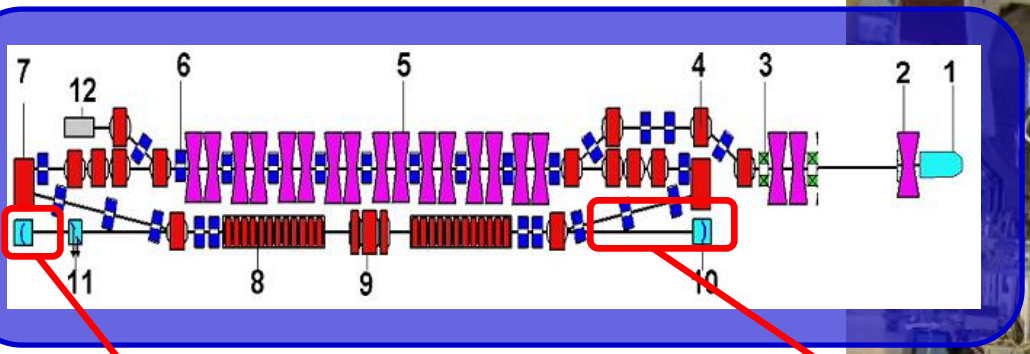
FEL Optical Cavities

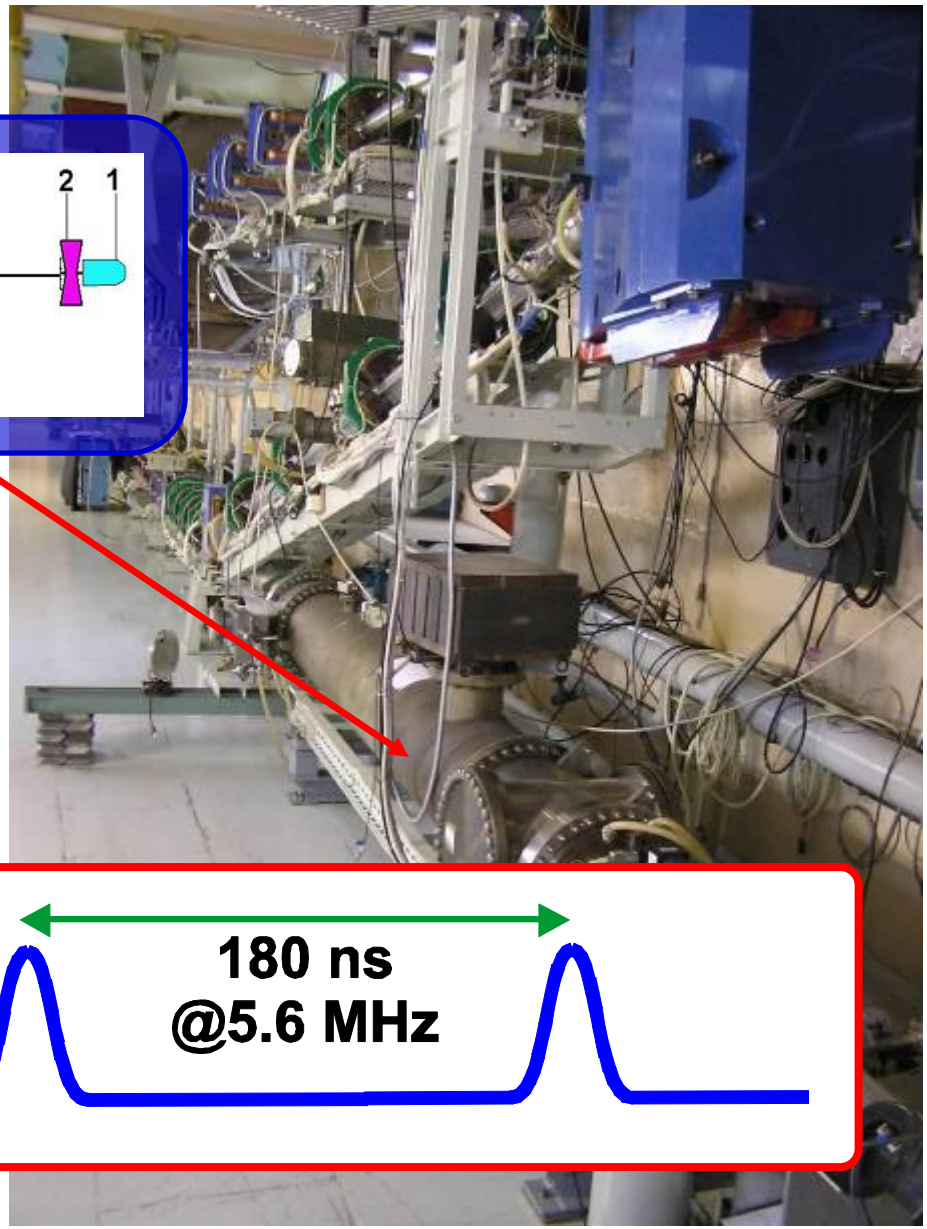


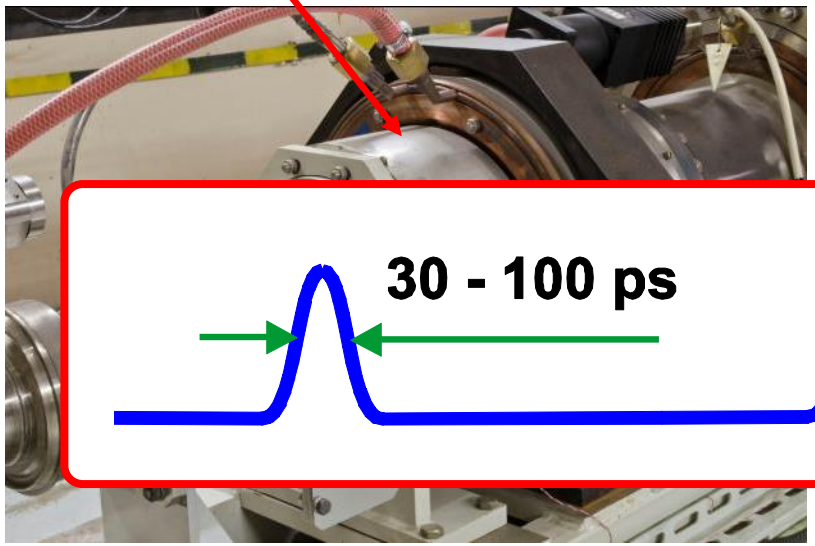




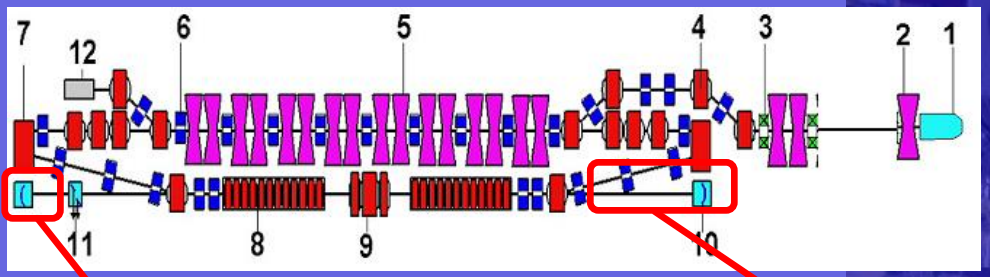
FEL Optical Cavities

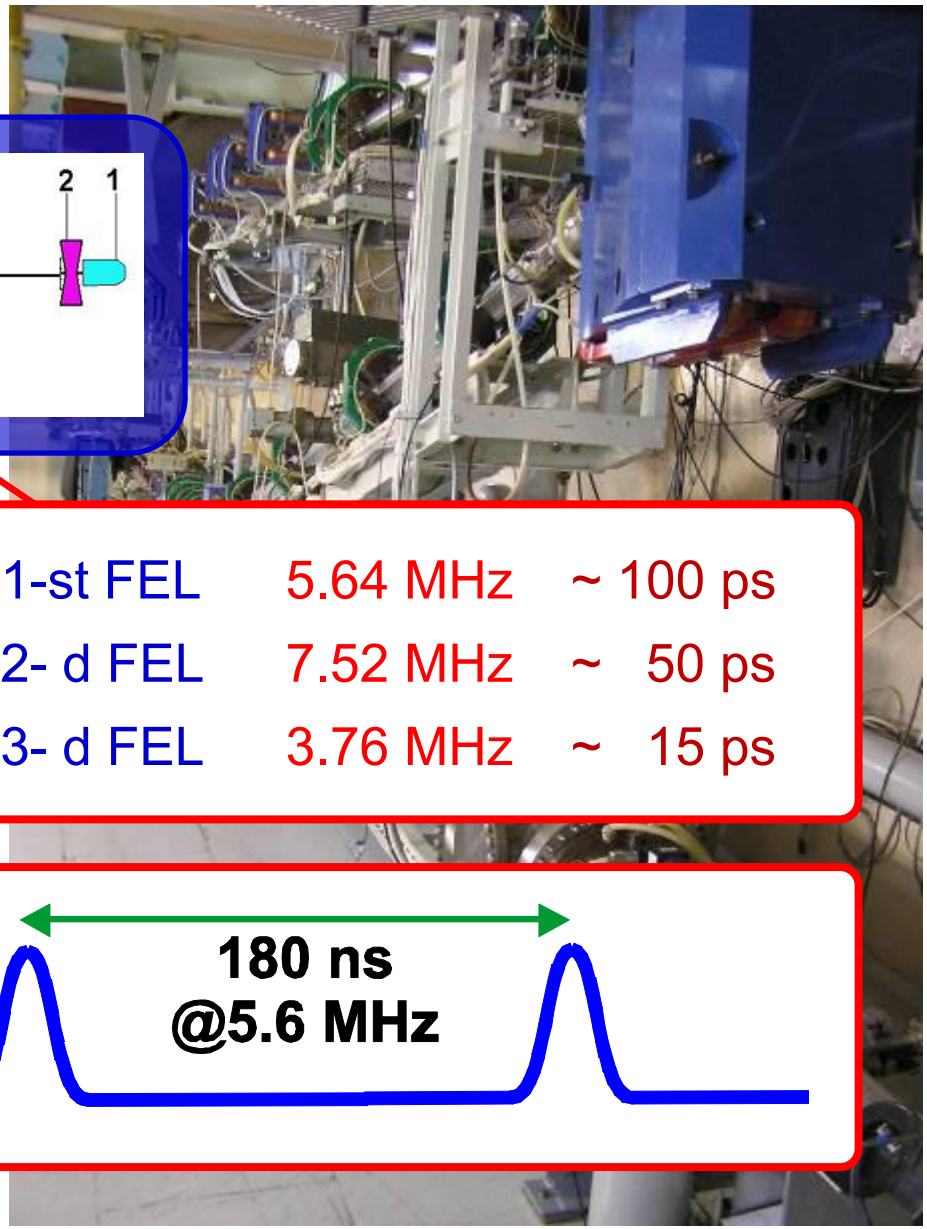




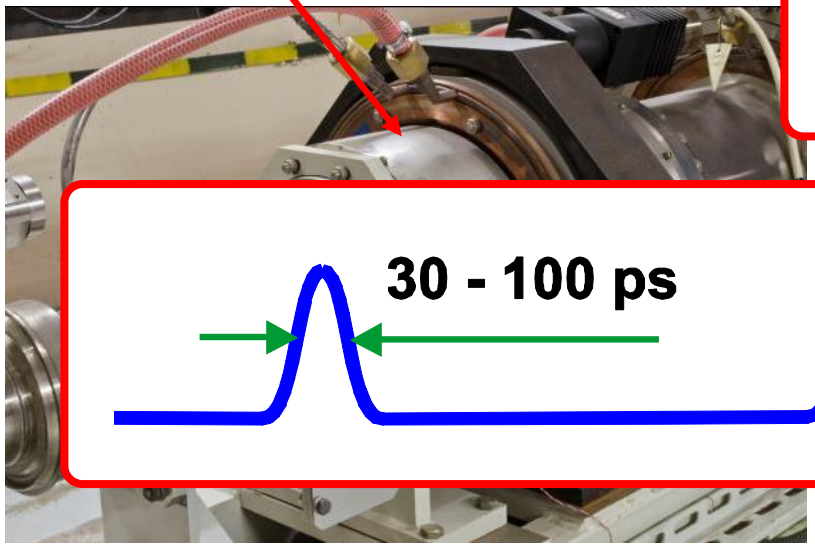


FEL Optical Cavities





1-st FEL	5.64 MHz	~ 100 ps
2- d FEL	7.52 MHz	~ 50 ps
3- d FEL	3.76 MHz	~ 15 ps



Optical beamlines and user stations

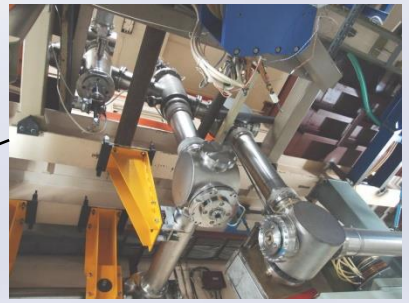
Novosibirsk FEL user facility

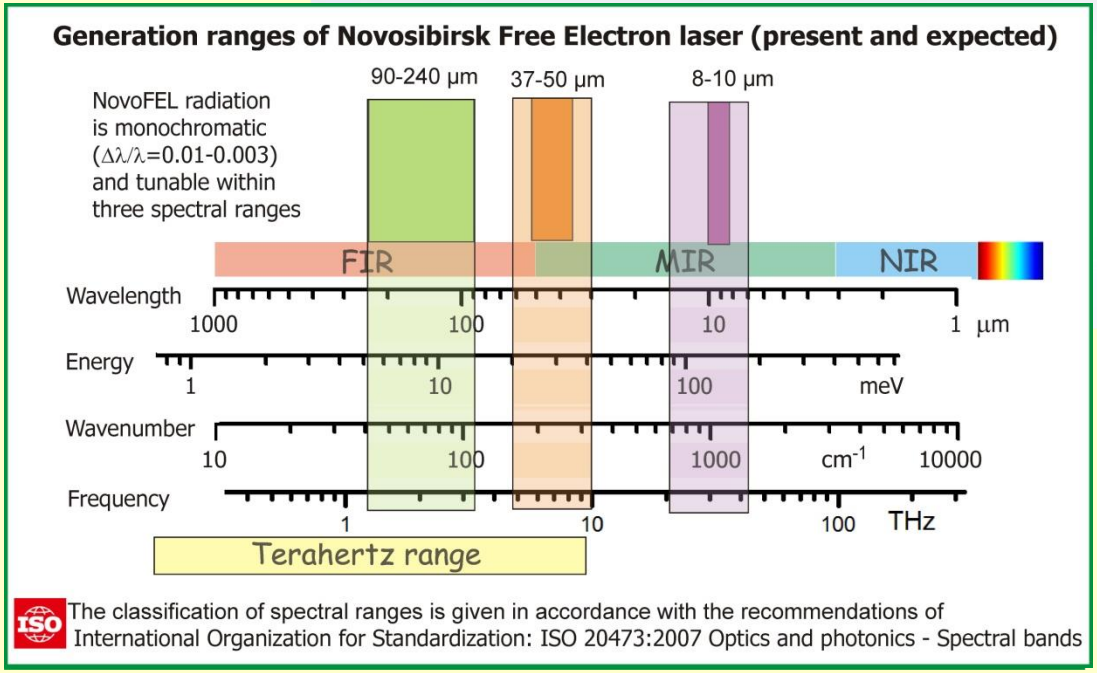
Section of the beamline

Beamline with 11 outlets to workstations

Total length of the beamline is 120 m

Entering laser beams into the beamline



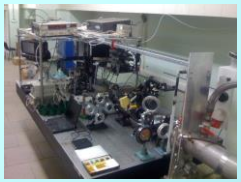


Multiturn energy recovery linac with three individual laser systems

NovoFEL workstations

Second floor

SQUID magnetometry



Imaging & spectroscopy

Pump-probe

Control of chemical reaction by radiation

First floor

Vacuum Fourier spectrometer

Molecular spectroscopy

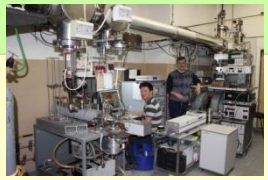
Metrology & ultra-fast spectroscopy

Biology & mass-spectrometry

Radiation characteristics control

Effect of radiation on materials

EPR spectroscopy



Summary

- **All three laser systems of the NovoFEL facility are now in operation (λ = 8-10, 37-50, 90-240 μm)**
- **11 workstations are in operation and more two are under construction**
- **The workstations are well equipped with instrumentation which is available to users**
- **We invite researchers to apply for beam time to perform experiments at the NovoFEL**

- The facility is open to all interested potential users without regard to nationality or institutional affiliation
- User fees are not charged for work if the user intends to publish the research results in the open literature
- The facility provides resources sufficient for users to conduct work safely and efficiently

Thank you for attention