The 9th Asian Forum for Accelerators and Detectors

Novosibirsk Free Electron Laser Facility

WG1: Accelerator and its relates technologies for photon science

Presented by Dr. Ya. V. Getmanov

Budker INP, Novosibirsk, Russia

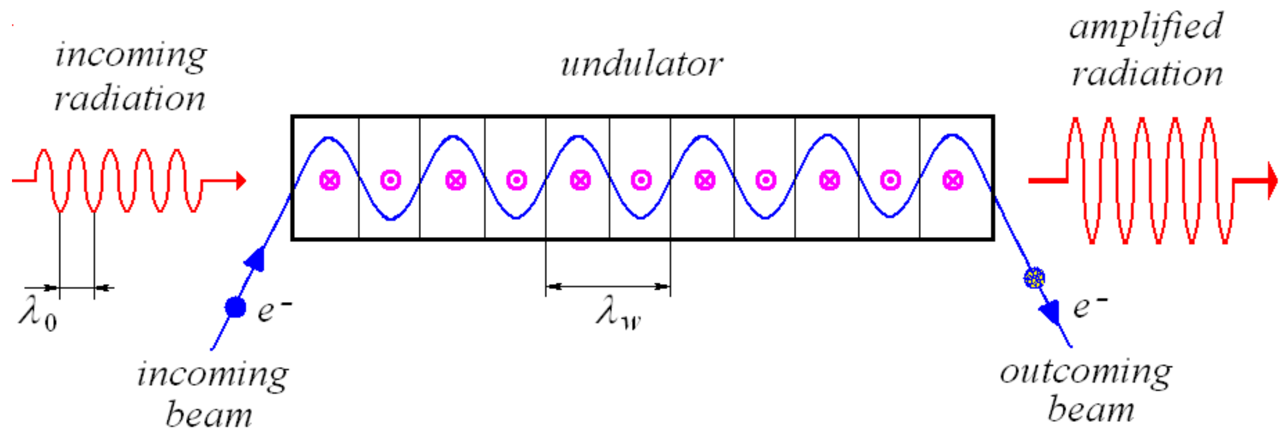
Project participants

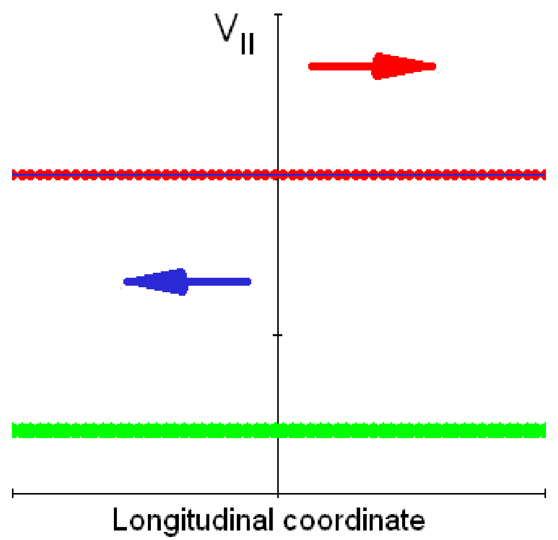
Ya. V. Getmanov, K. N. Chernov, I. V. Davidyuk, O. I. Deichuly, E. N. Dementyev, B. A. Dovzhenko, Ya.I.Gorbachev, B. A. Knyazev, E. I. Kolobanov, A. A. Kondakov, V. R. Kozak, E. V. Kozyrev, S. A. Krutikhin, V.V. Kubarev, G. N. Kulipanov, E. A. Kuper, I. V. Kuptsov, G. Ya. Kurkin, L. E. Medvedev, S. V. Motygin, V. K. Ovchar, V. N. Osipov, V. M. Petrov, A. M. Pilan, V. M. Popik, V. V. Repkov, T. V. Salikova, M. A. Scheglov, I .K. Sedlyarov, S. S. Serednyakov, O. A. Shevchenko, A. N. Skrinsky, S. V. Tararyshkin, A. G. Tribendis, V. G. Tcheskidov, N. A. Vinokurov, P. D. Vobly, V. N. Volkov

Outline

- Brief introduction to the FEL physics
- The NovoFEL accelerator design and operation
- NovoFEL as three FELs based source of radiation
- The third FEL first experiments
- Nearest and far future plans

FEL principle of operation





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

synchronisme condition

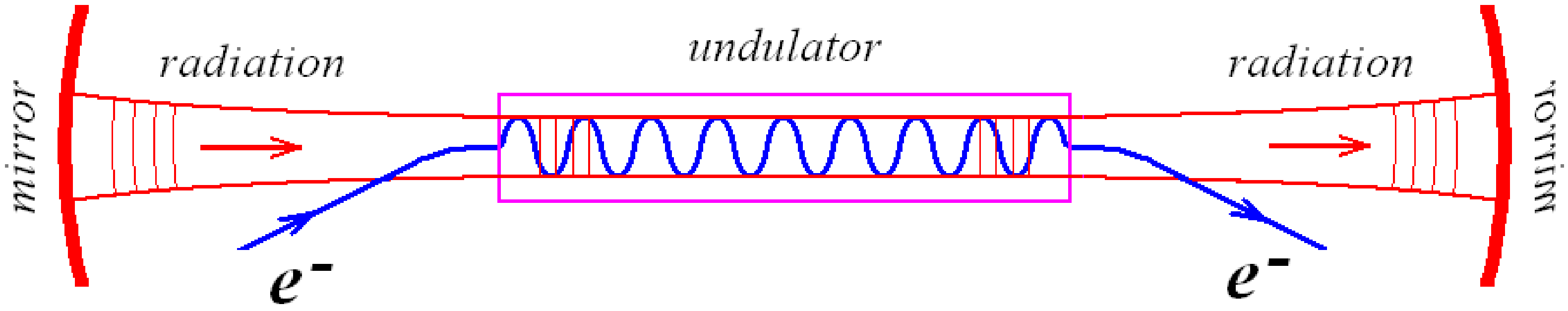
which is necessary for the

energy transfer

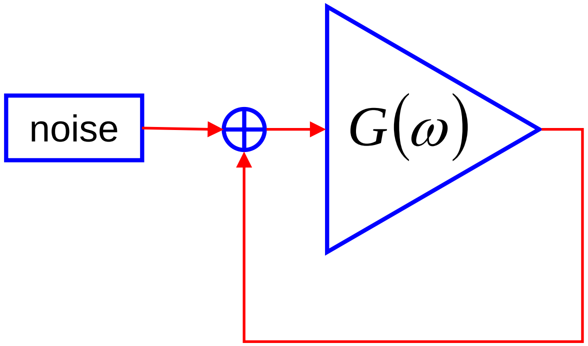
$$\left\langle \frac{d\gamma}{dz} \right\rangle = \frac{e}{mc^3}\left\langle \mathcal{E}_x V_x \right\rangle$$

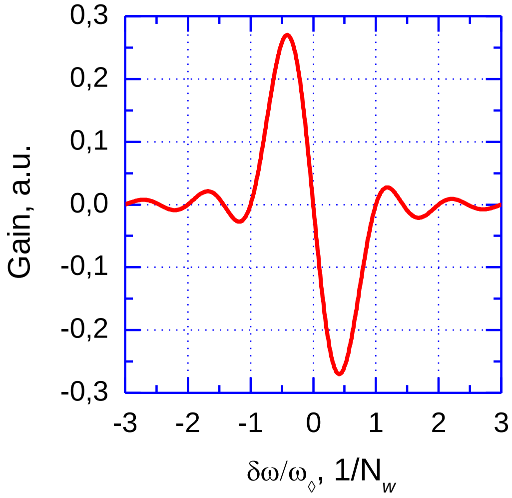
FEL principle of operation

FEL oscillator



Equivalent scheme





Energy recovery

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

- Energy recovery:

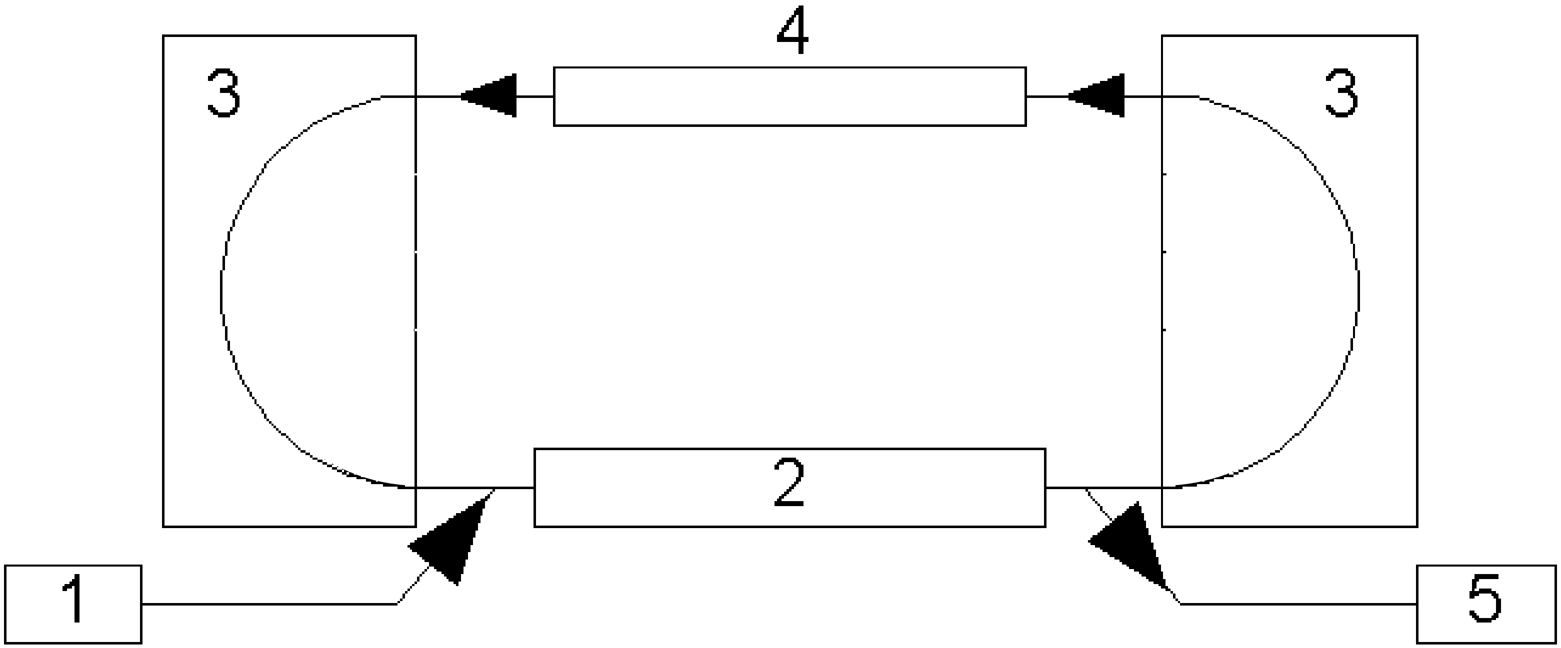
- decreases radiation hazard and

- makes possible operation at high average current.

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

NovoFEL Accelerator Design

Energy Recovery Linac

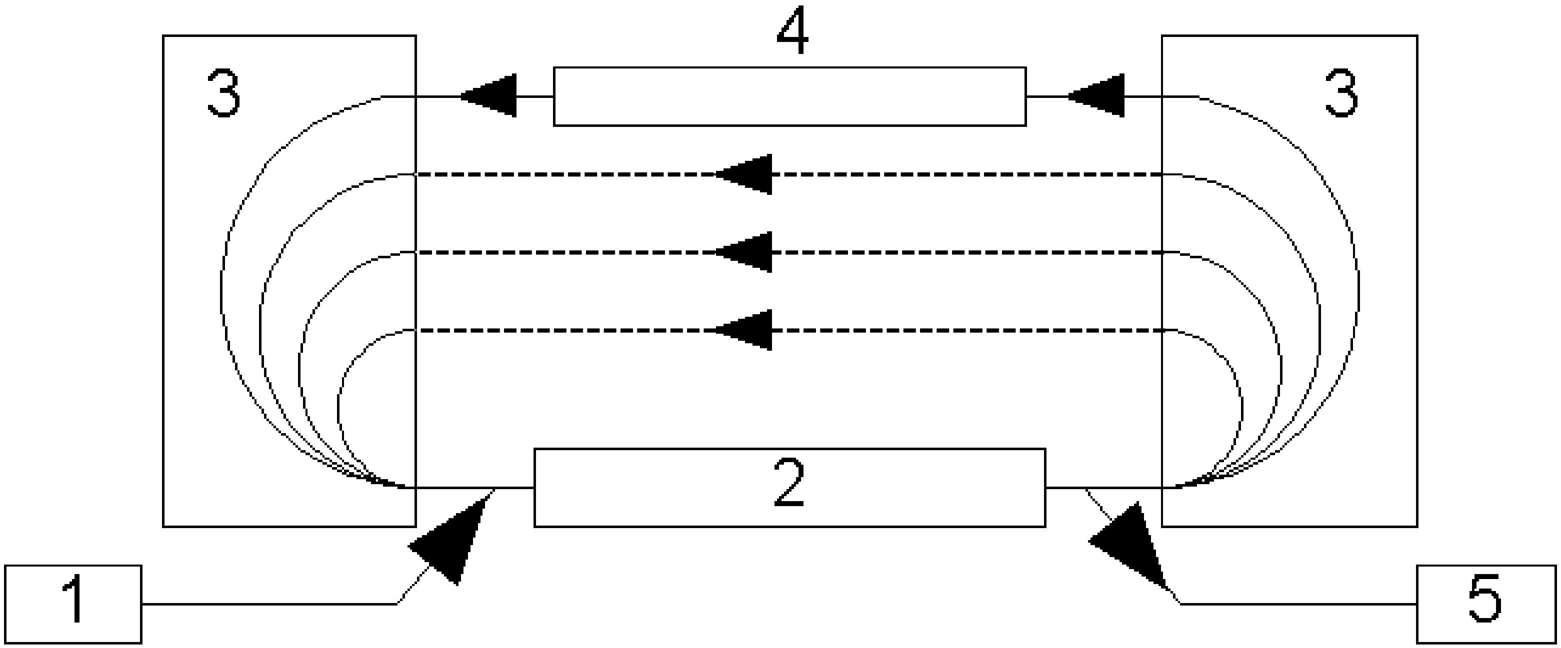


1 – injector, 2 – linac, 3 – bending magnets, 4 – undulator, 5 –dump

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

NovoFEL Accelerator Design

Energy Recovery Linac



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**.

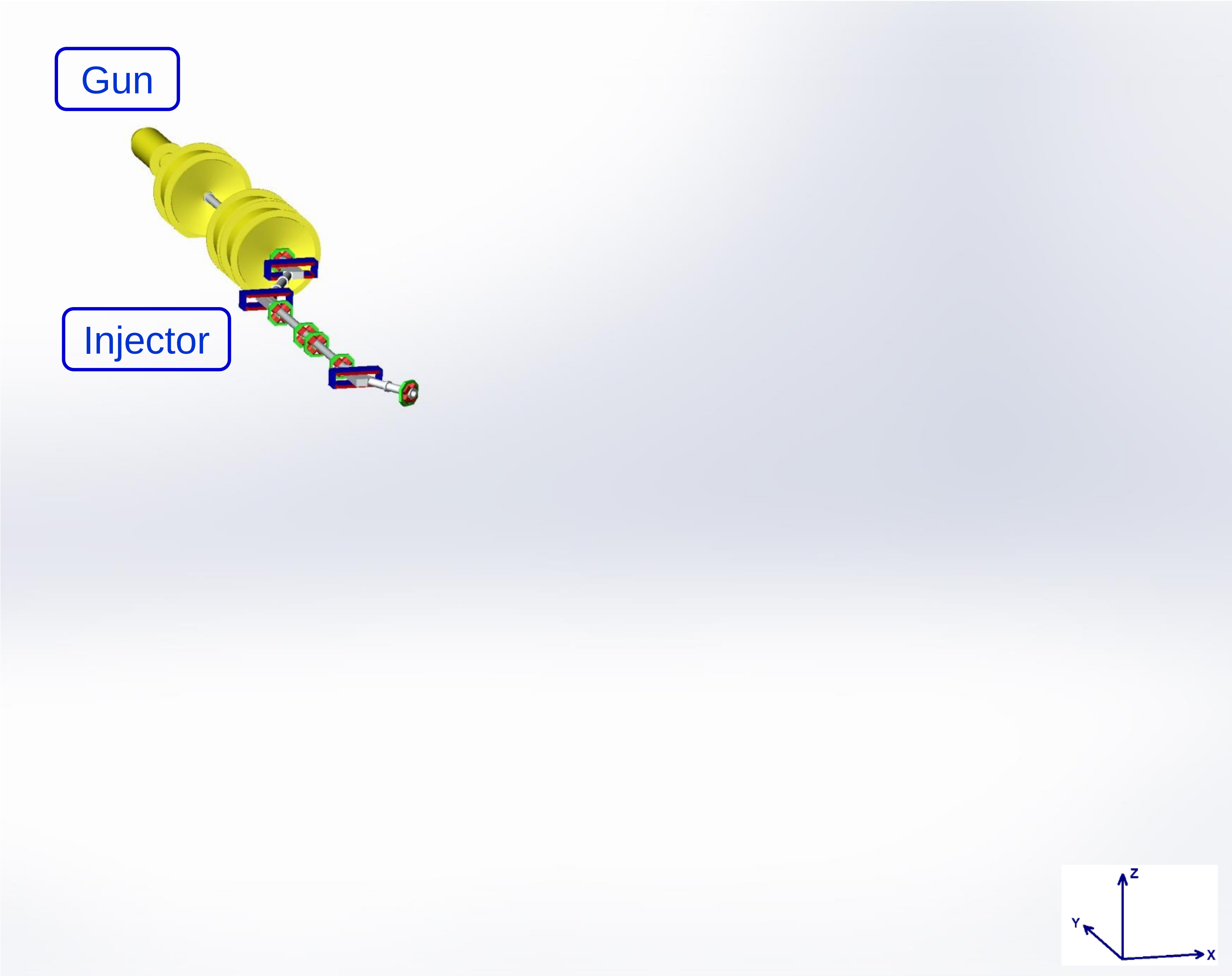
Advantages of the low frequency (180 MHz) RF system

- High threshold currents for instabilities
- Operation with long electron bunches (for narrow FEL linewidth)
- Large longitudinal acceptance (good for operation with large energy spread of used beam)
- Relaxed tolerances for orbit lengths and longitudinal dispersion.

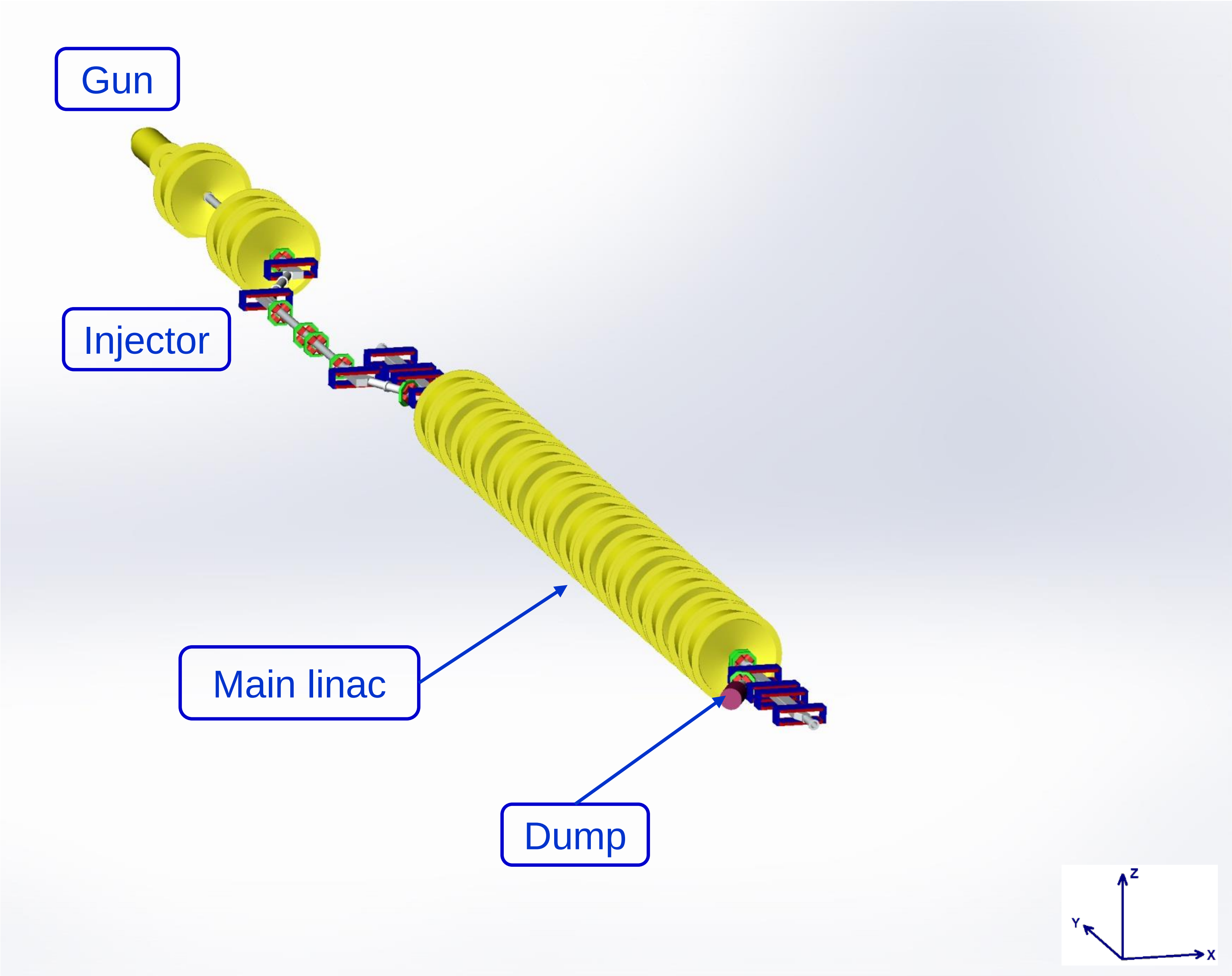
Disadvantages:

low accelerating rate and high power consumption.

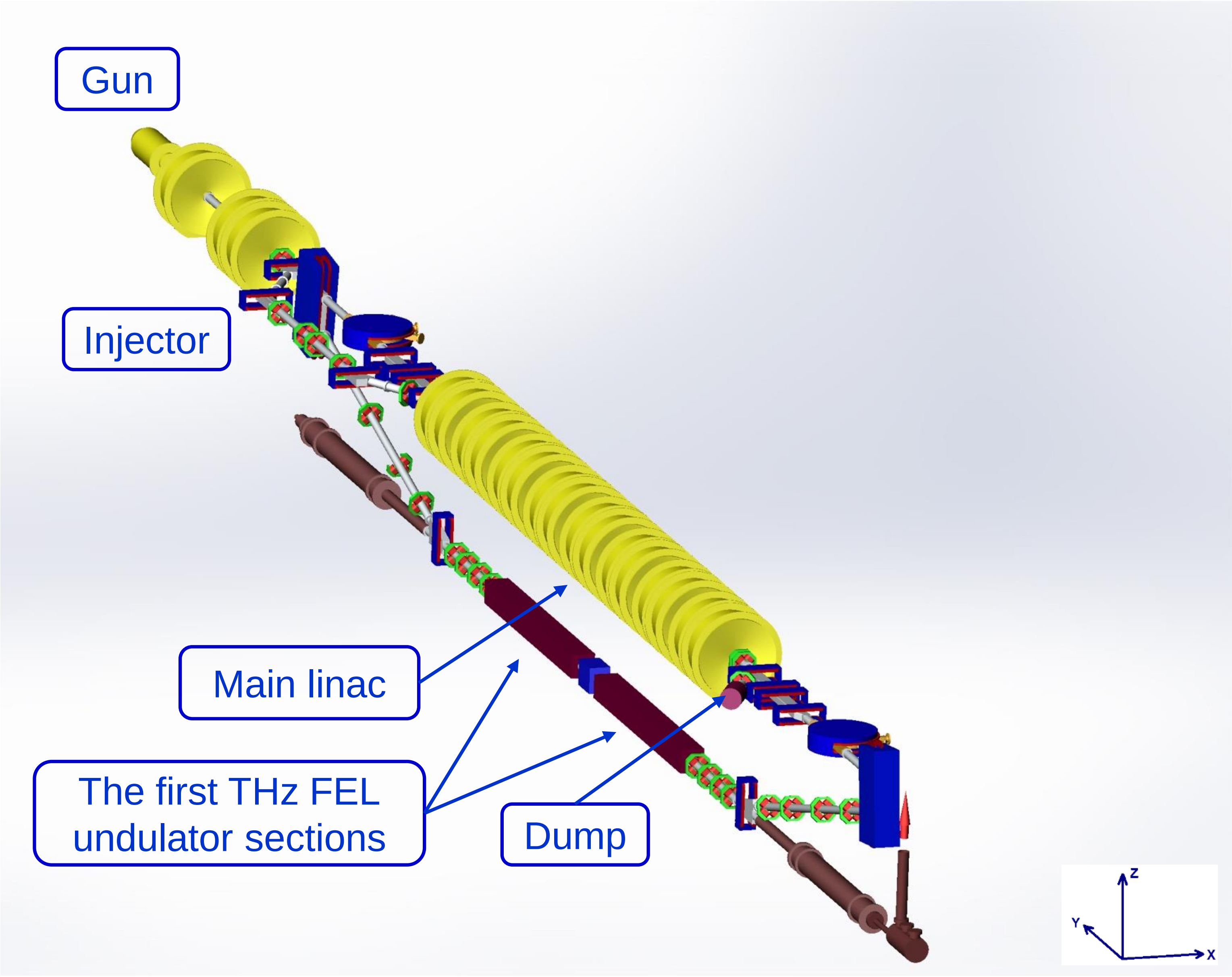
NovoFEL Accelerator Design



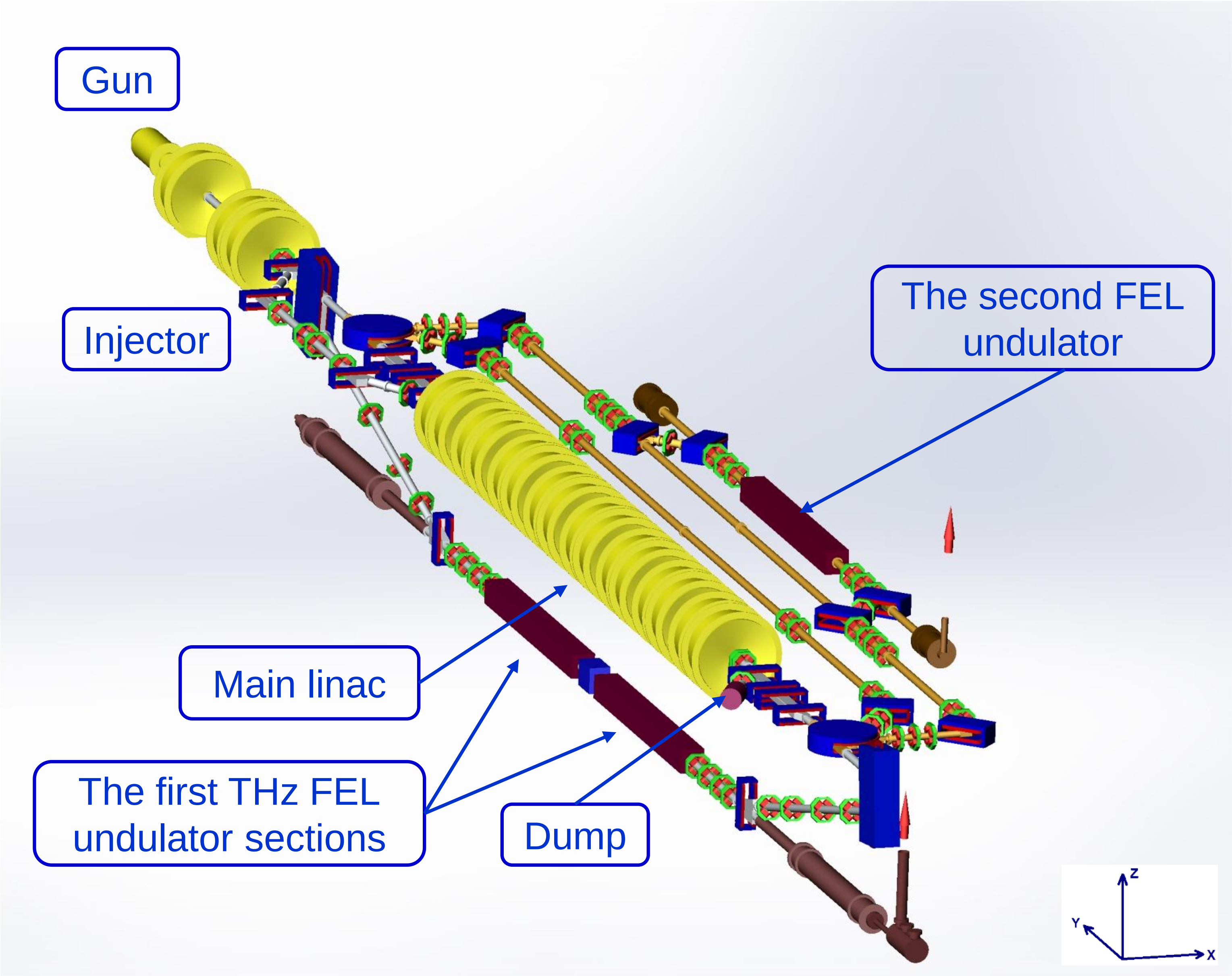
NovoFEL Accelerator Design



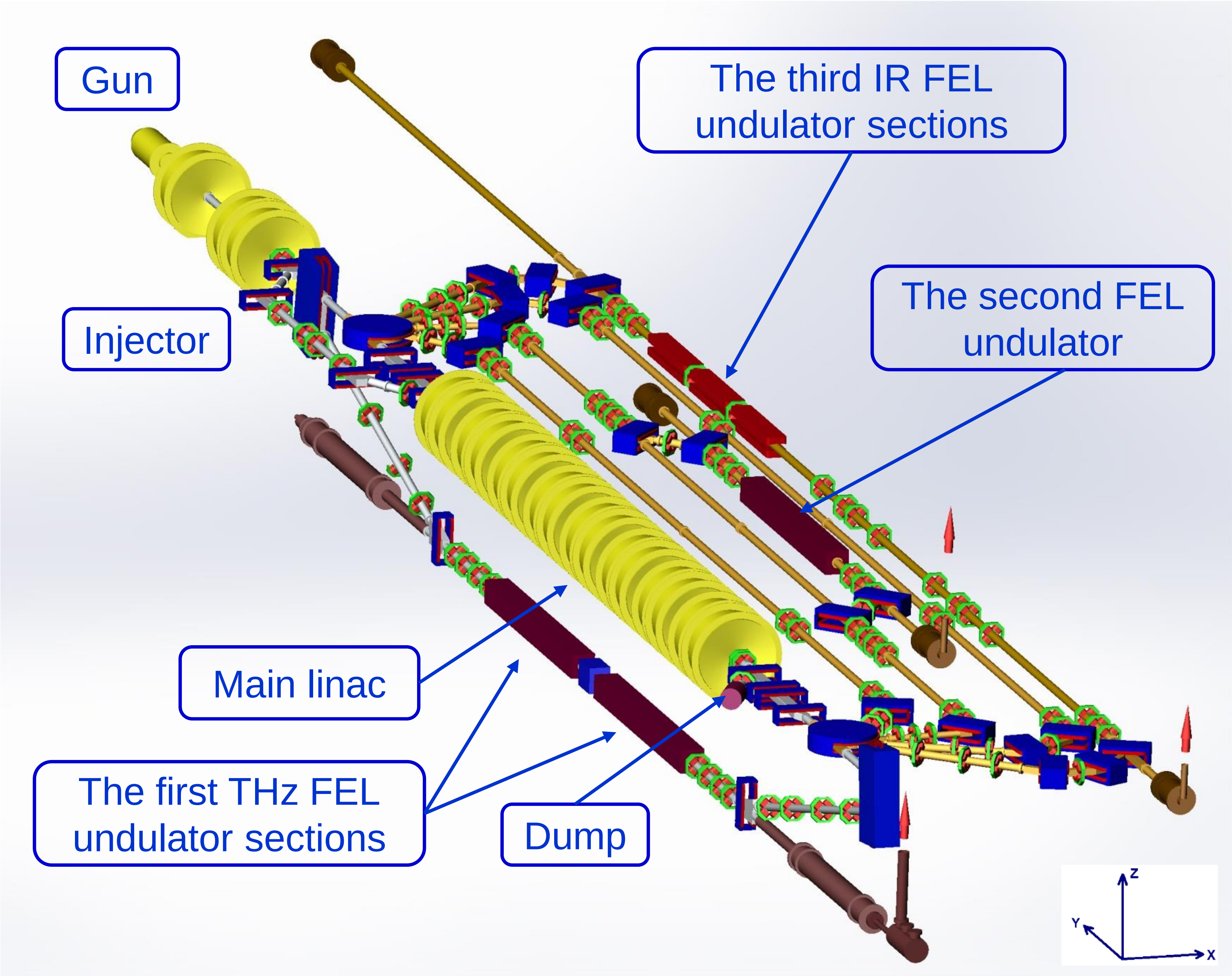
NovoFEL Accelerator Design

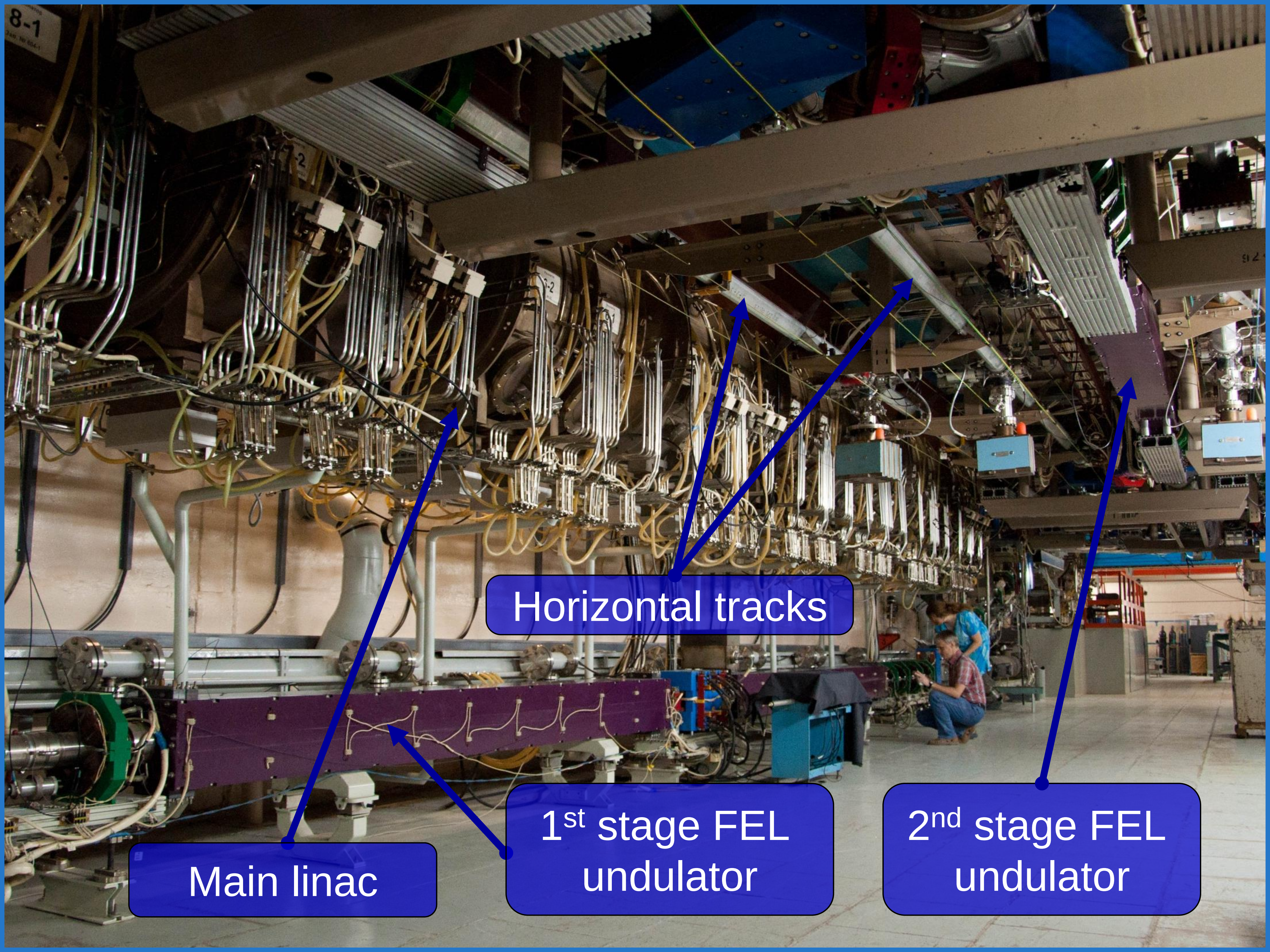


NovoFEL Accelerator Design



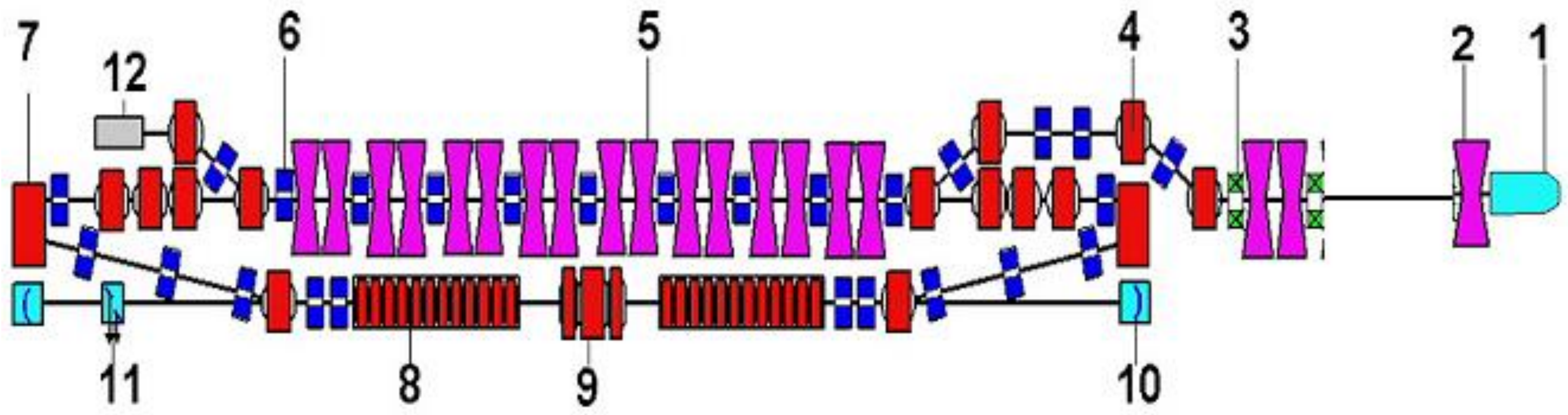
NovoFEL Accelerator Design




8-1
Horizontal tracks
Main linac
1st stage FEL undulator
2nd stage FEL undulator


3rd stage FEL undulator

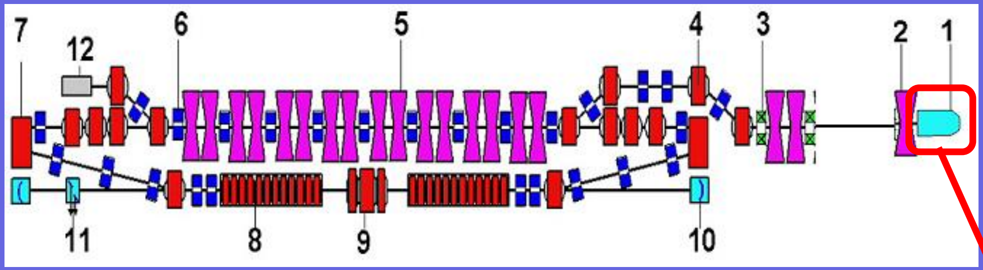
Layout of Injector, Main Linac and Vertical Beamline (the First ERL)

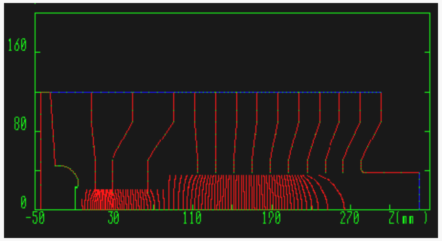


1 – electron gun
2 – bunching cavity
3 – focusing solenoids
4 – merger
5 – main linac
6 – focusing quadrupoles

7 – magnetic mirror
8 – undulator
9 – phase shifter
10 – optical cavity
11 – calorimeter
12 – beam dump

Electrostatic Gun



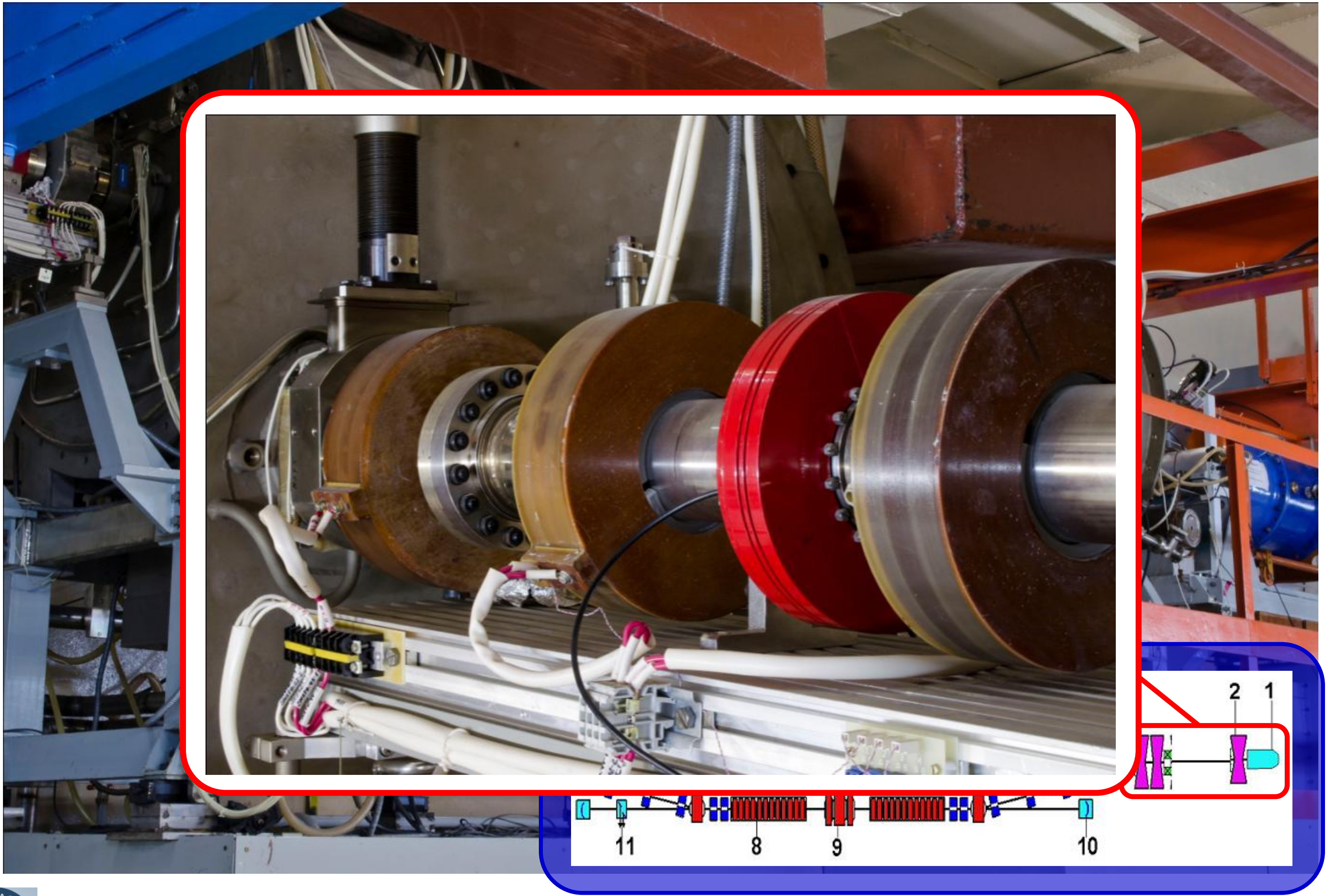


Power supply:

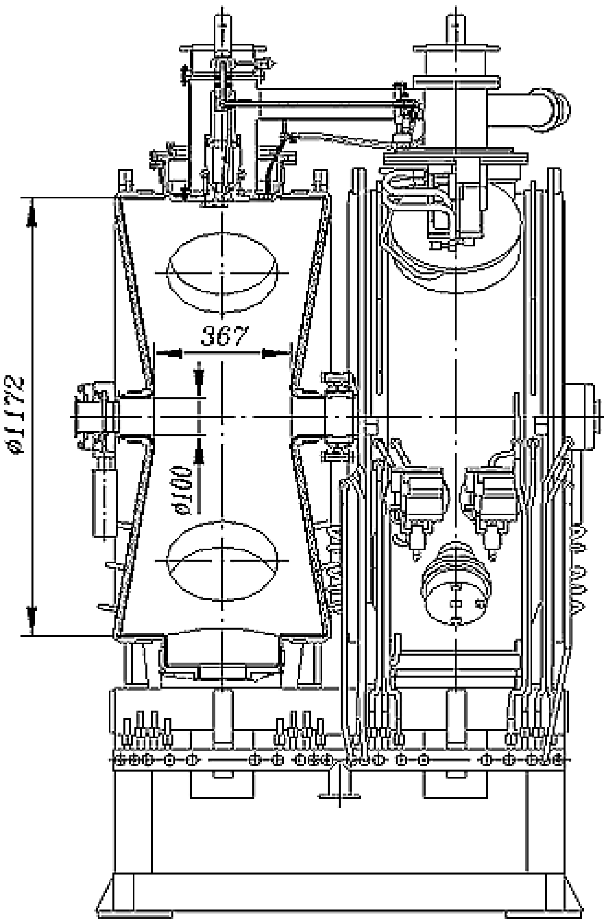
U_{max} = 300 kV

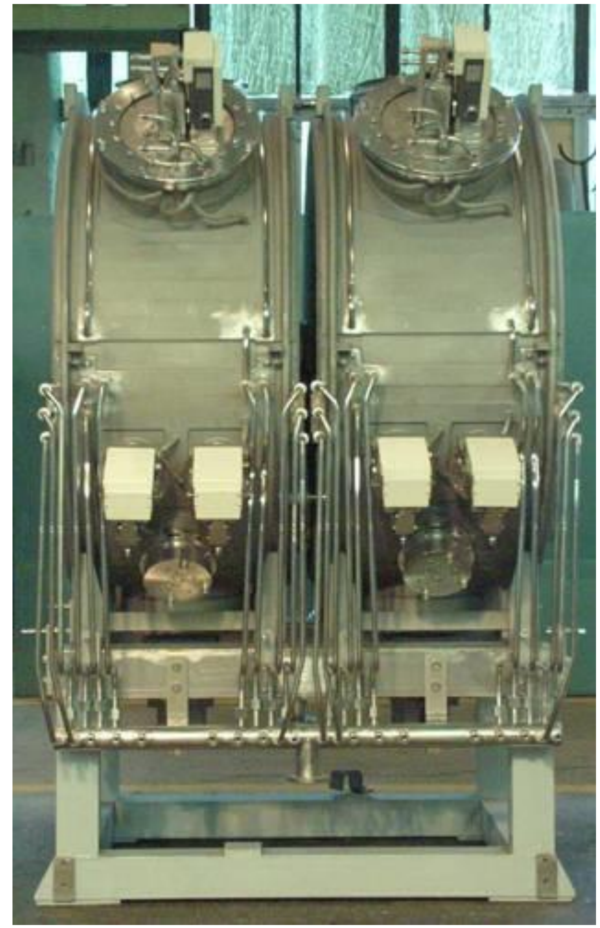
I_{max} = 50 mA

Injector



Main Linac

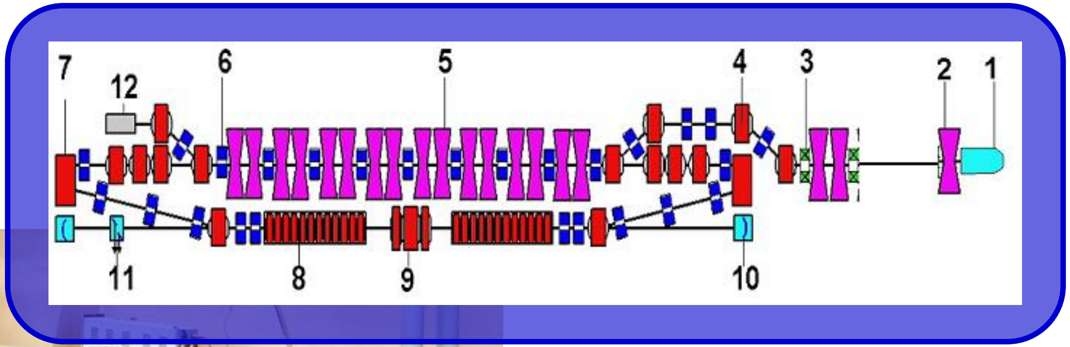


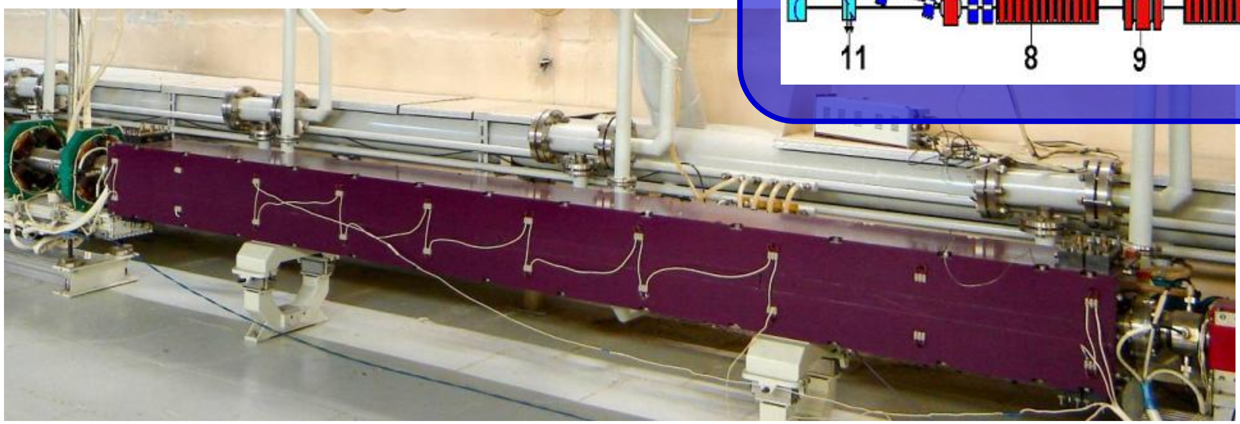


RF Power Supply

Frequency, MHz	180.4
Power, MW	2 x 0.6

Electromagnetic Undulators

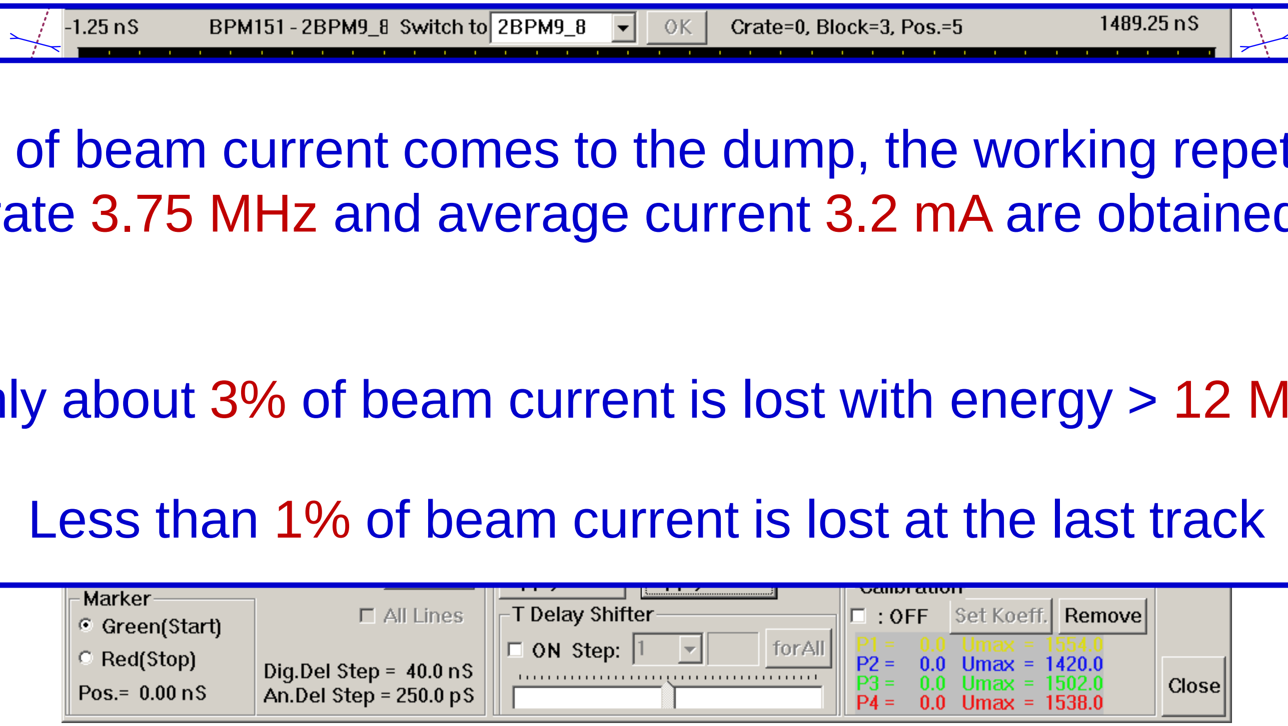




	1-st FEL	2-d FEL
Period, cm	12	12
Maximum current, кA	2.4	2.4
Maximum K	1.25	1.47

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

22 May 2012 – the first time the beam reached the dump after four accelerations and four decelerations

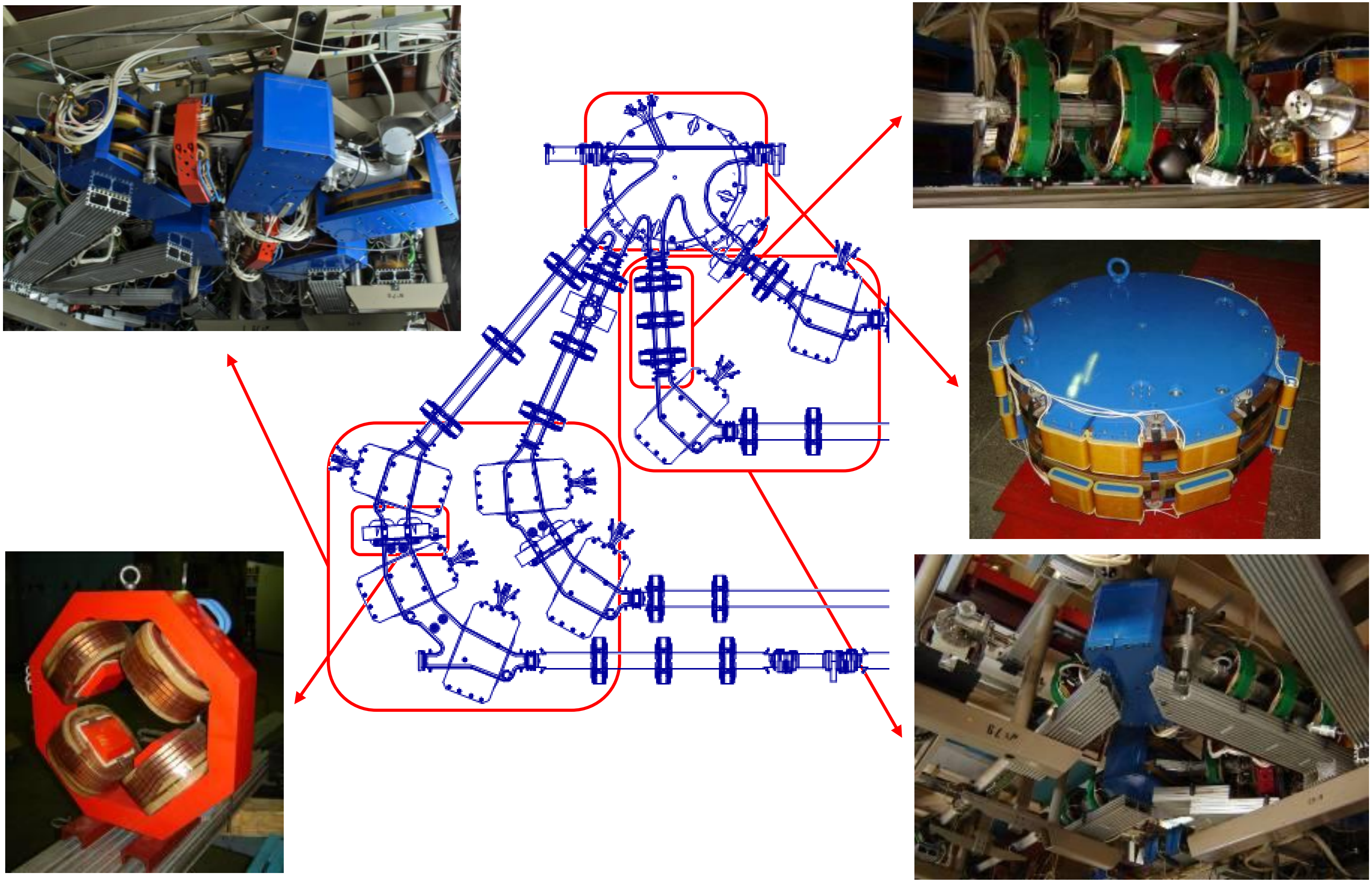


90% of beam current comes to the dump, the working repetition rate 3.75 MHz and average current 3.2 mA are obtained

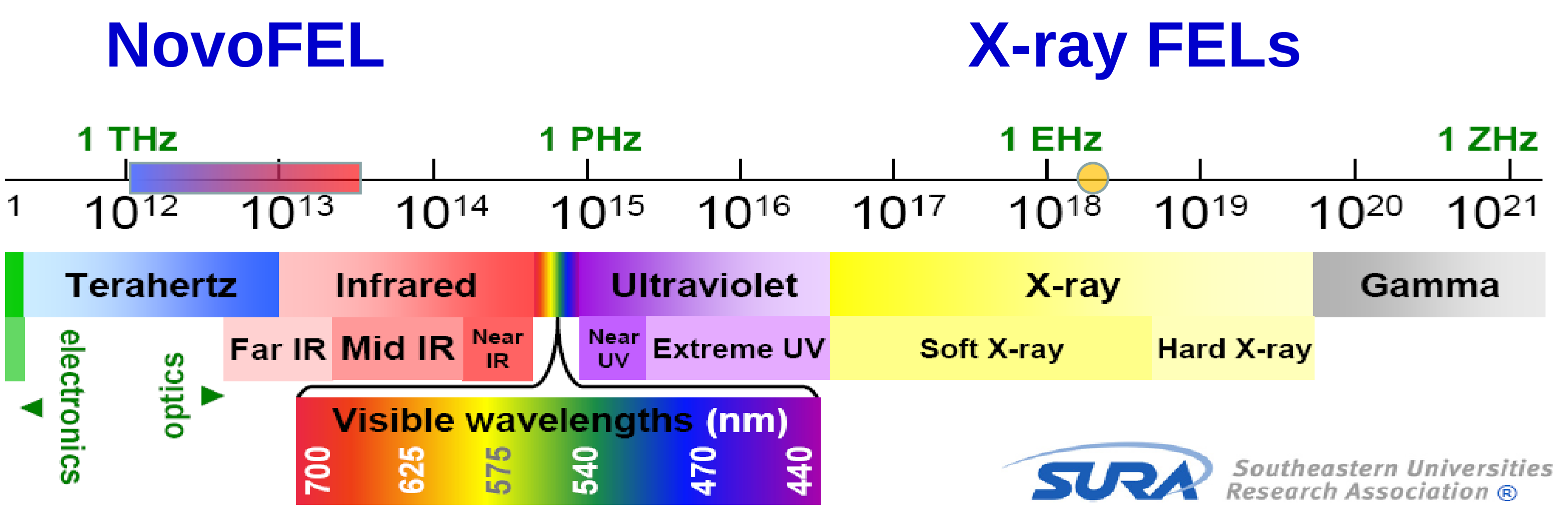
Only about 3% of beam current is lost with energy > 12 MeV

Less than 1% of beam current is lost at the last track

Magnets and Vacuum Chamber of Bends



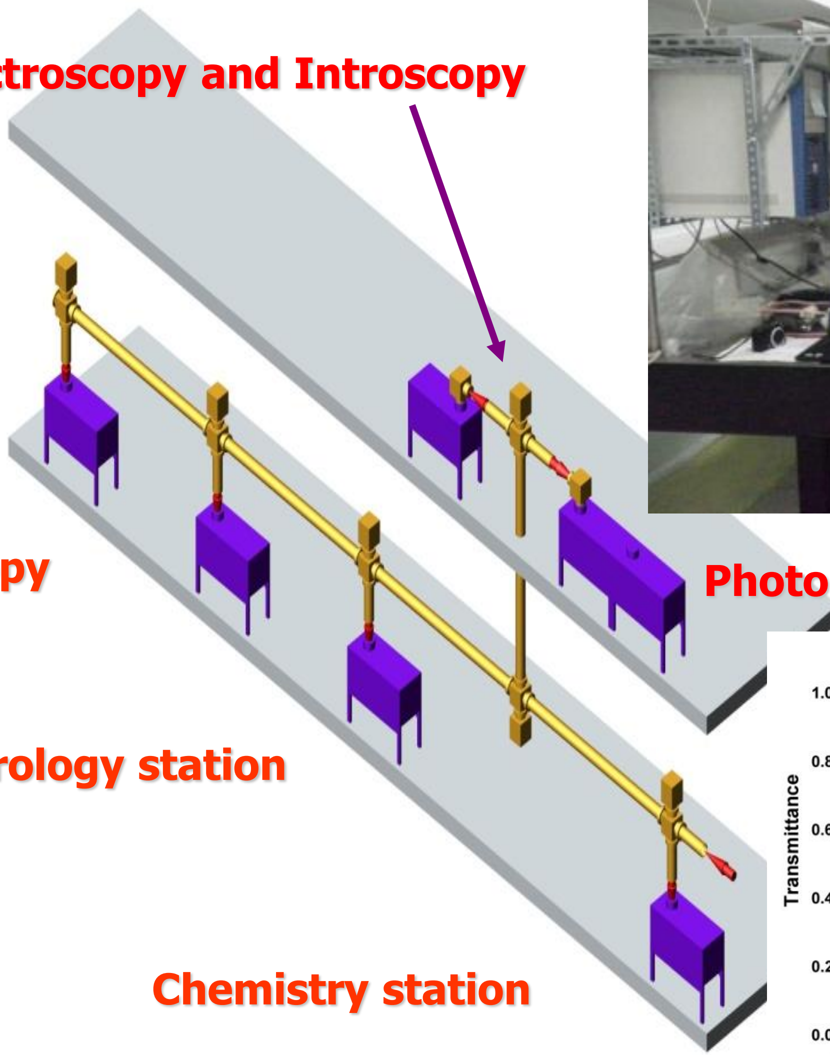
NovoFEL as Radiation Source

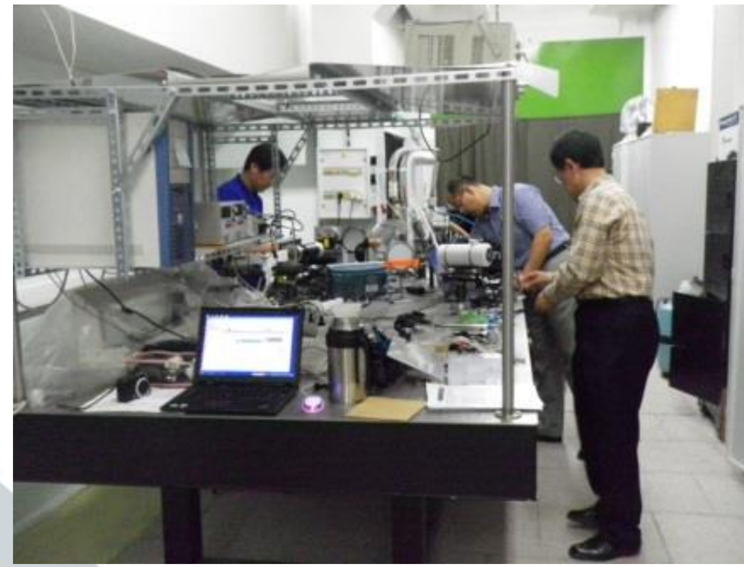


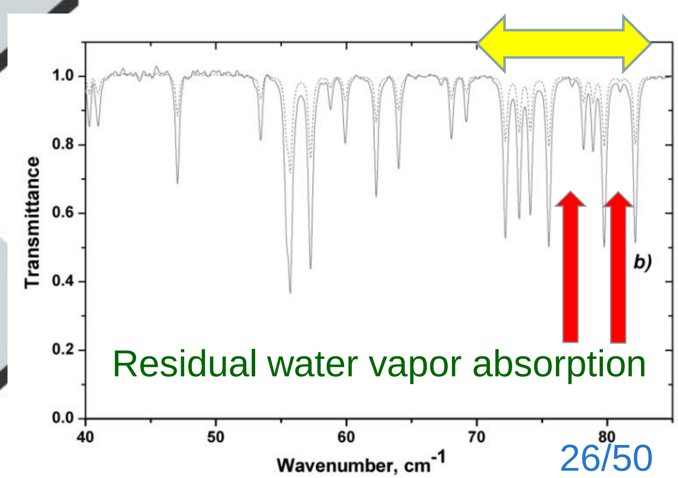
The most attractive ranges for FELs are at very short and at very long wavelength, where there are no other lasers

Six user station are available for users

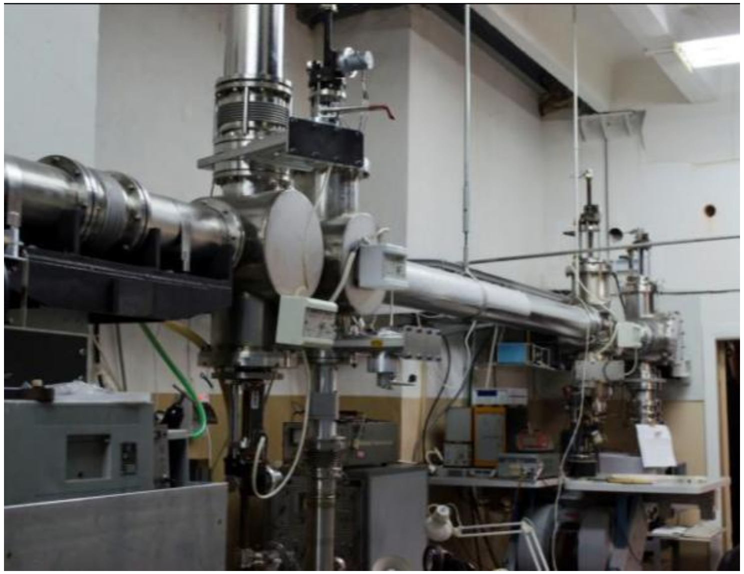
(more than 20 participating institutions)







Optical beamlines and user stations

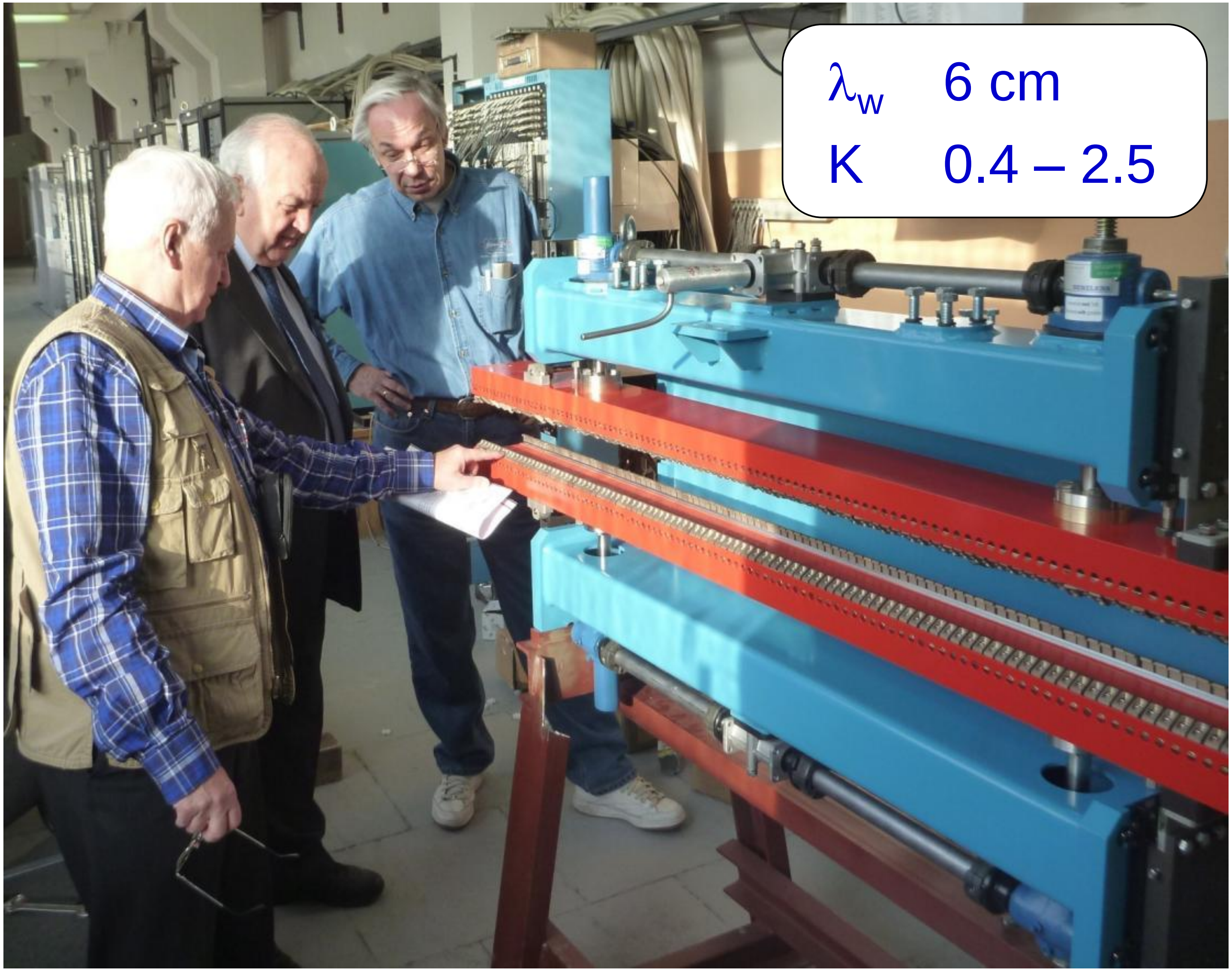


The 1st stage FEL radiation parameters

• Radiation wavelength, microns	90 - 240
• Minimum pulse duration, ps	70
• Repetition rate , MHz	5.6 / 11.2 / 22.4
• Maximum average power, kW	0.5
• Minimum relative linewidth (FWHM)	$3 \cdot 10^{-3}$
• Maximum peak power, MW	1

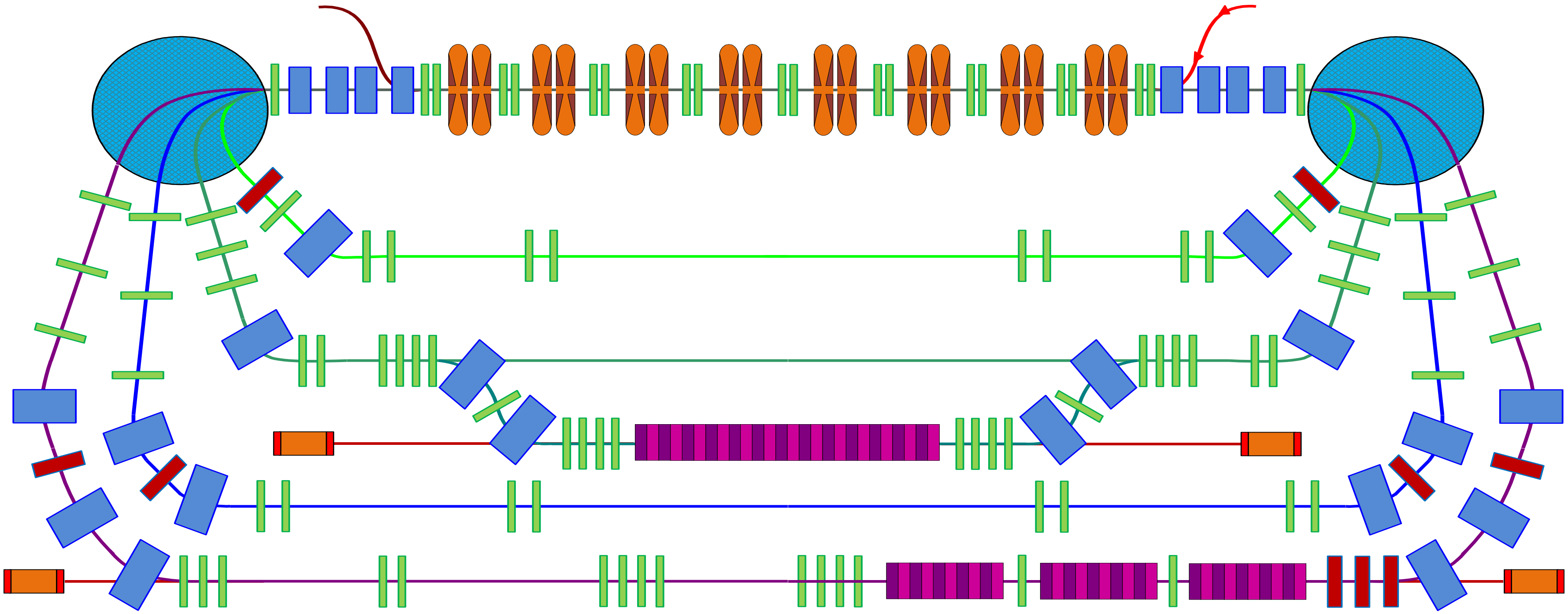
The obtained radiation parameters are still the world record in terahertz region.

The third stage FEL undulator



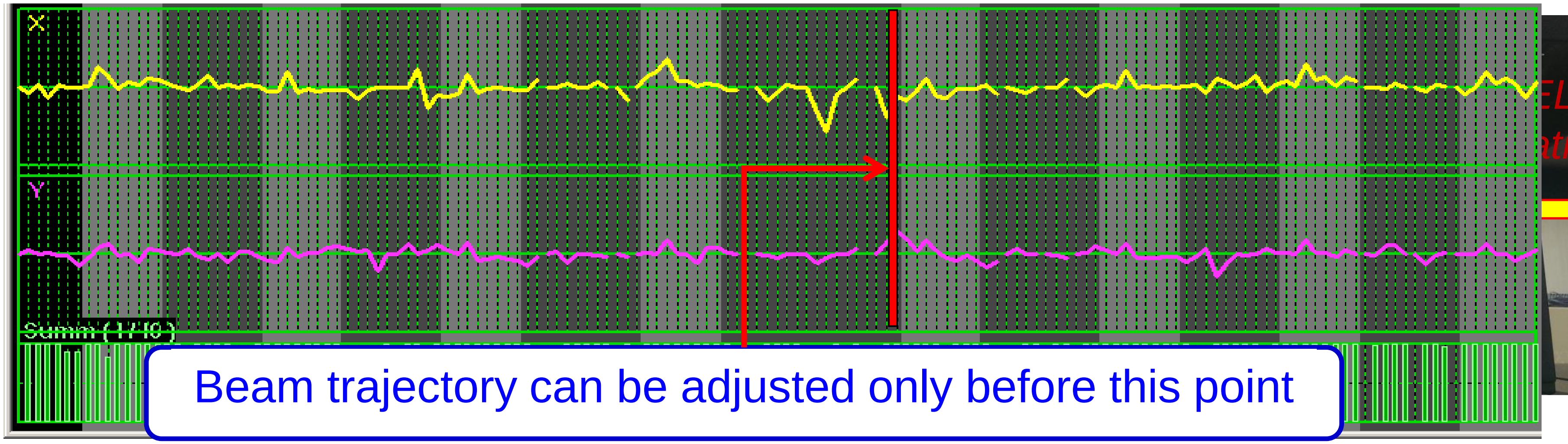
λ_w	6 cm
K	0.4 – 2.5

First experiments with 3rd stage FEL



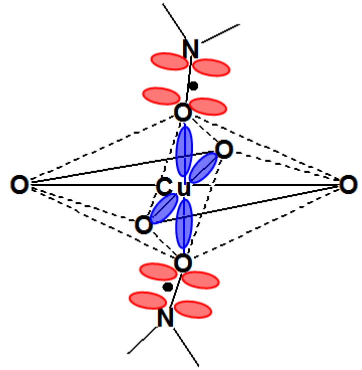
Wavelength 8.96 μm

Radiation power was about 30 watts

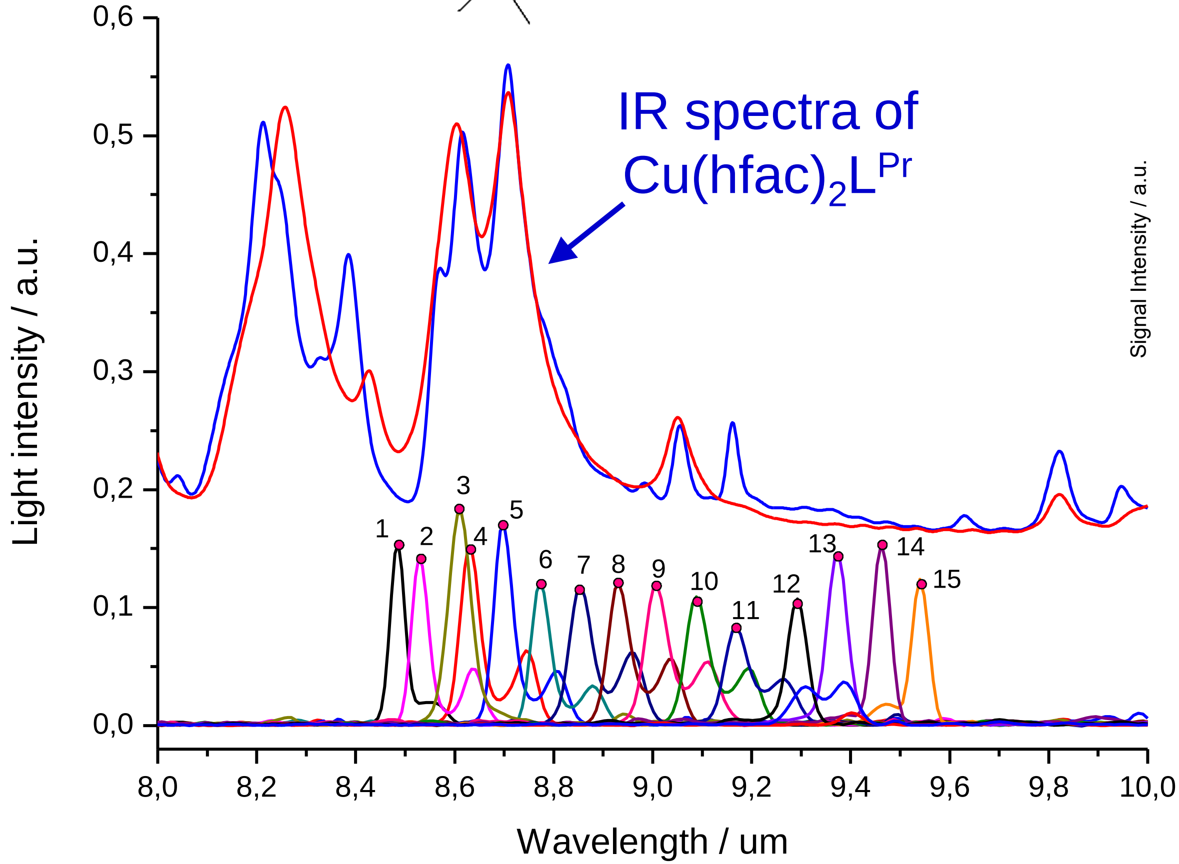


Beam trajectory can be adjusted only before this point

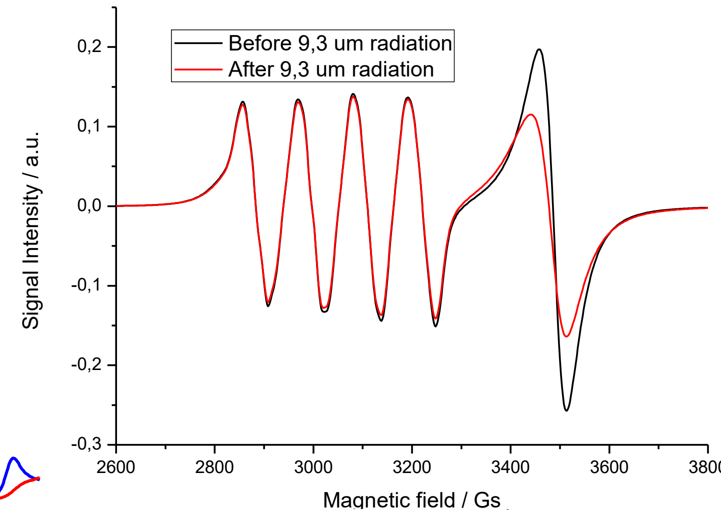
International Tomography Center SB RAS – the first user of the third FEL

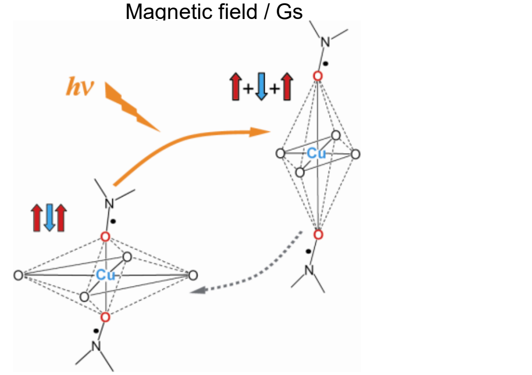


Influence of IR-light to the spin state of photoswitchable copper(II)-nitroxide magnetoactive compound $Cu(hfac)_2L^{Pr}$



EPR spectra of $Cu(hfac)_2L^{Pr}$





Electron beam and radiation parameters

	1st	2nd	**3rd**	
Energy, MeV	12	22	**42**	46
Current, mA	30	10	**3**	50
Wavelength, μm	90-240	37-80	**8-11**	5-20
Radiation power, kW	0.5	0.5	**0.1**	5
Electron efficiency, %	0.6	0.3	**0.2**	0.5

Nearest and far future plans

- Optical (SR) diagnostics of electron beam parameters
- Launch the electron gun attenuator for high peak and low average power radiation experiments
- Increase DC gun voltage and improve beam quality in injector
- Optimize electron efficiency of FEL
- Install the new undulator to extend the wavelength range
- Install RF gun
- Launch the electron outcoupling scheme

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

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

Variation of magnetic field

$\lambda_u = 12\ cm$

Electromagnetic undulator

K ~ 0…1.5

$\lambda_u = 6\ cm$

Variable gap undulator

K ~ 0.4…2.5

Variation of beam energy

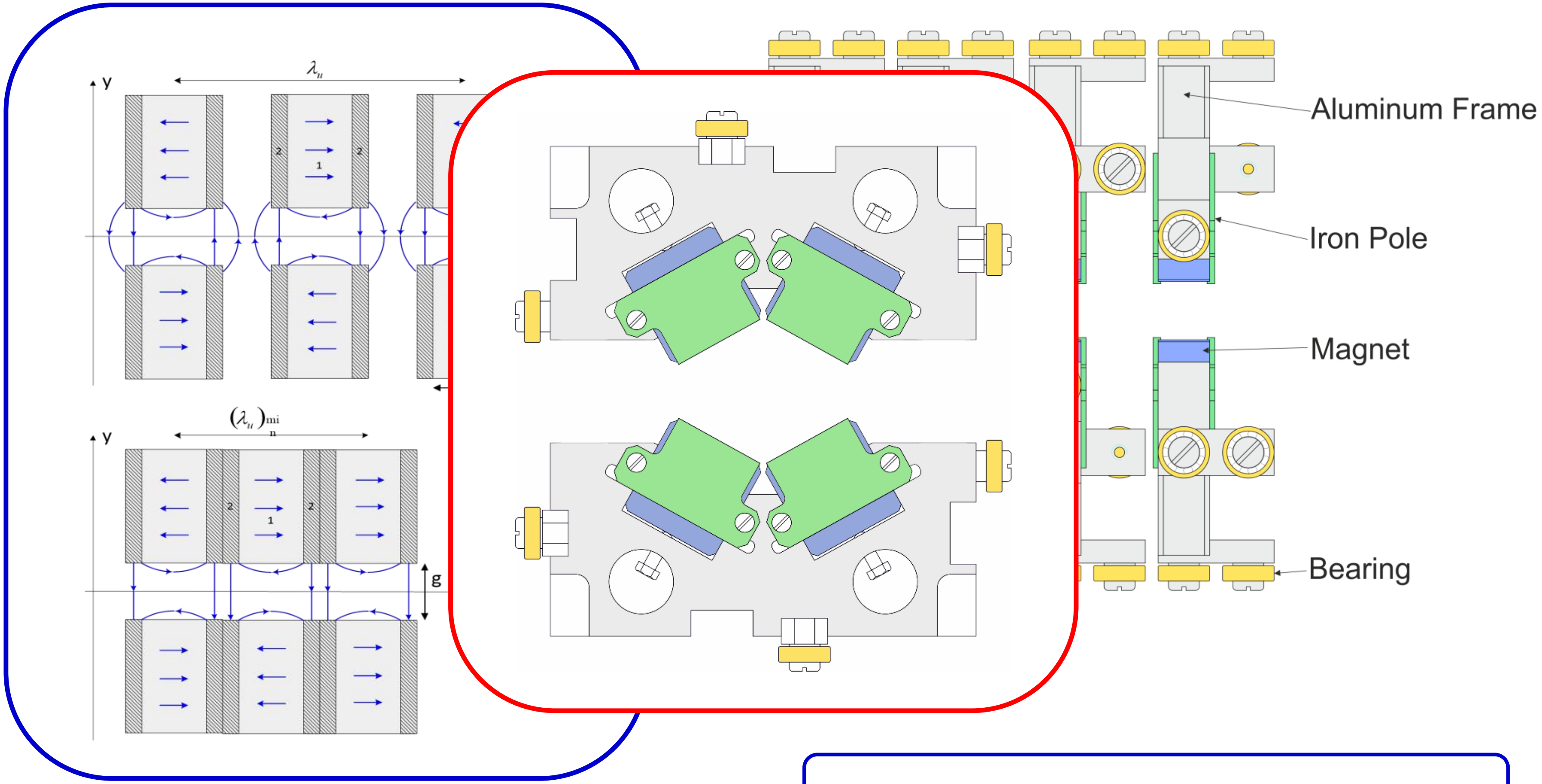
E1 ~ 10…13 MeV
E2 ~ 20…24 MeV
E3 ~ 40…46 MeV

Variation of undulator period

K ~ 0.42…1.79 $\lambda_u \sim 4.8...9.6\ cm$

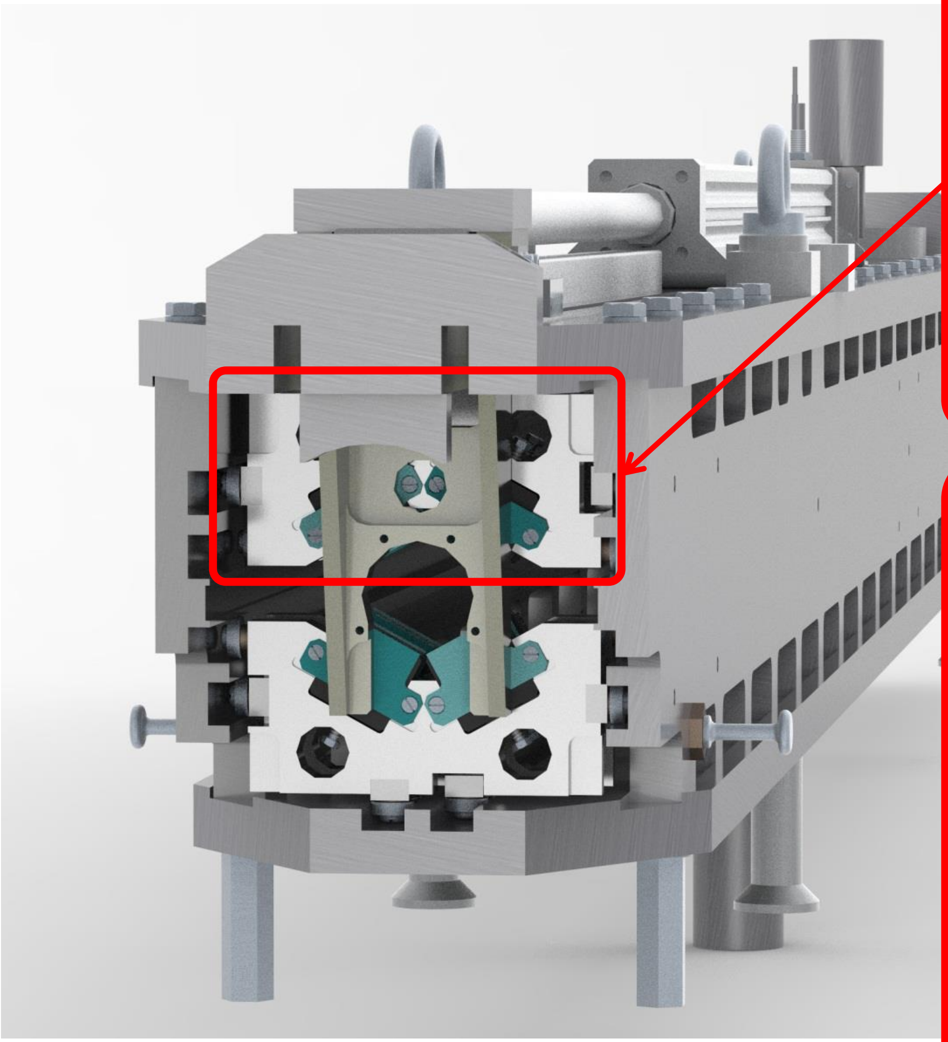
Variable period undulator

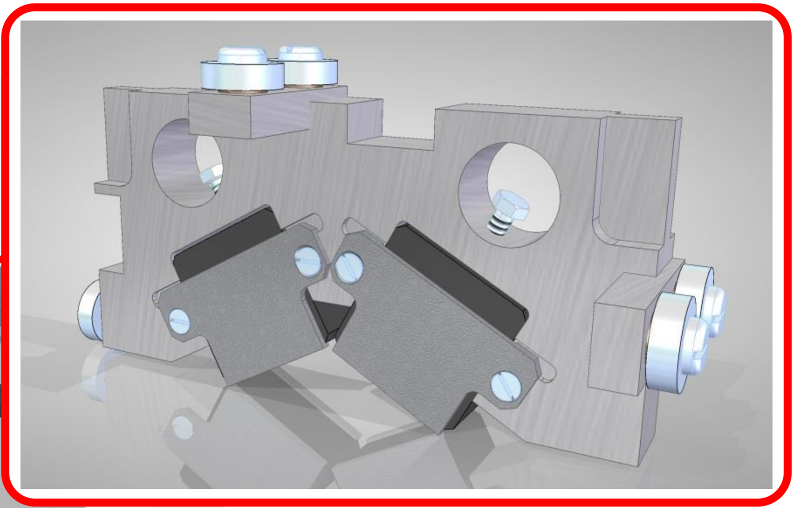
Variable Period Undulator (for the 2nd FEL)

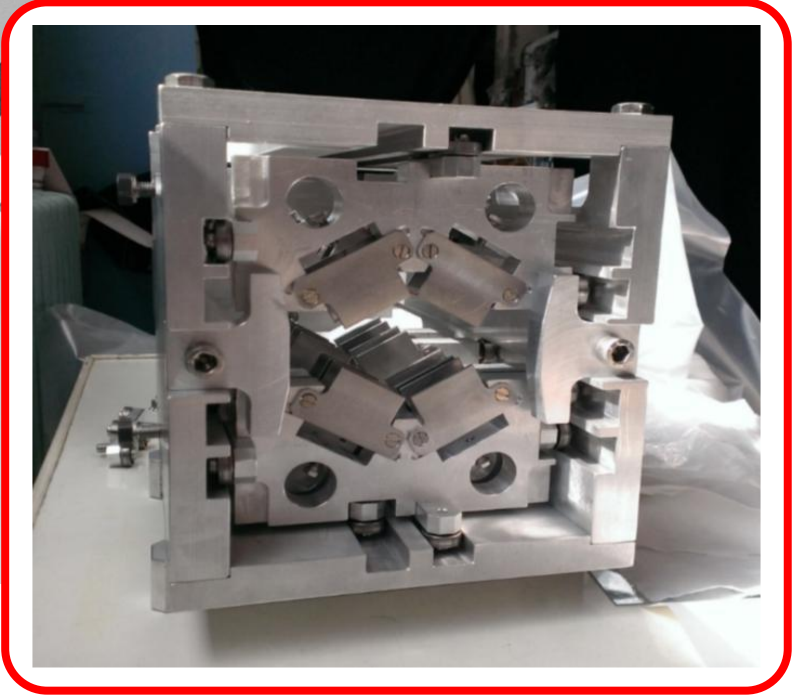


The tunability range of the 2nd FEL will be increased from **37 - 80** to **15 - 80** microns

Variable Period Undulator (for the 2nd FEL)

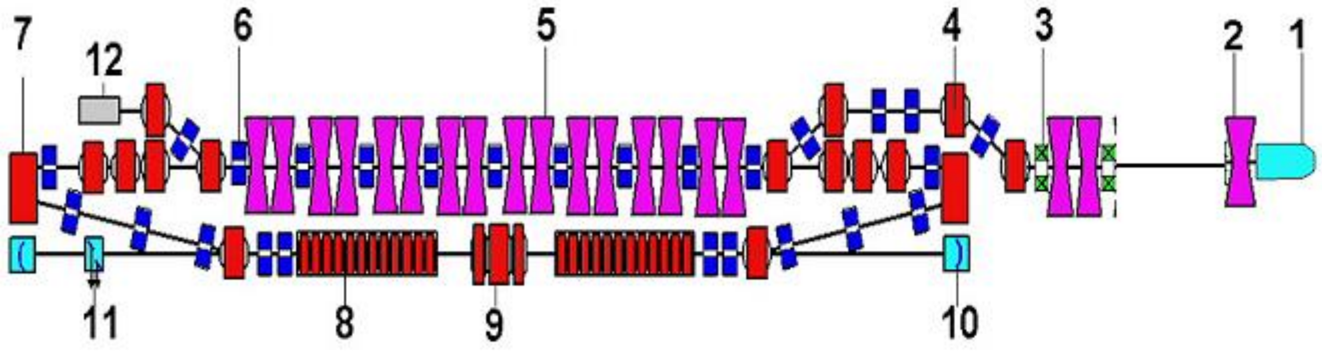






Bunch frequency attenuator

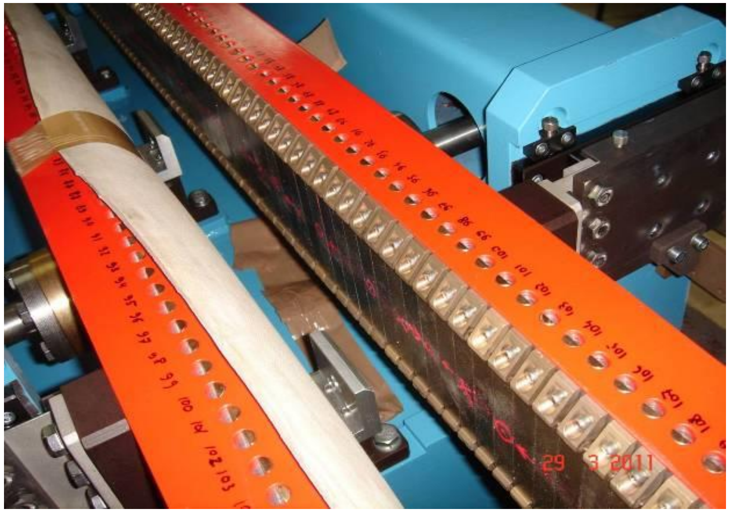
Some experiments don't need to have the high average power radiation regimes

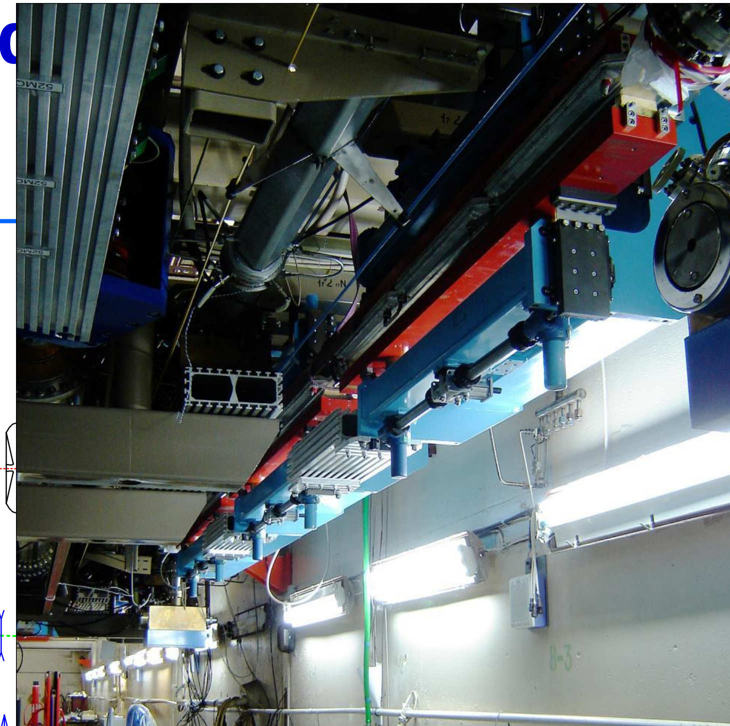


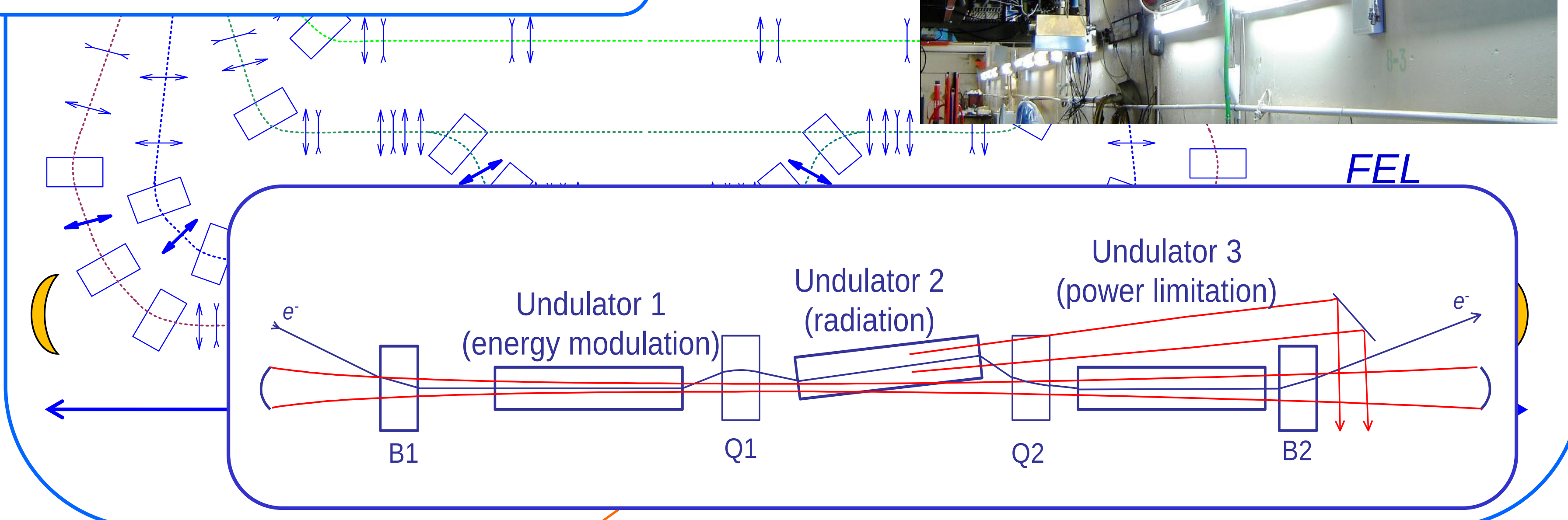
As the lasing depends on the electron gun frequency it's possible to change it by small step and form the train of radiation bunches with required length and duty ratio.

- Users don't need to install additional attenuation equipment
- Low electron beam losses and heat the vacuum chambers
- Regimes with high electron bunch charge and peak radiation power

The Third FEL Design and

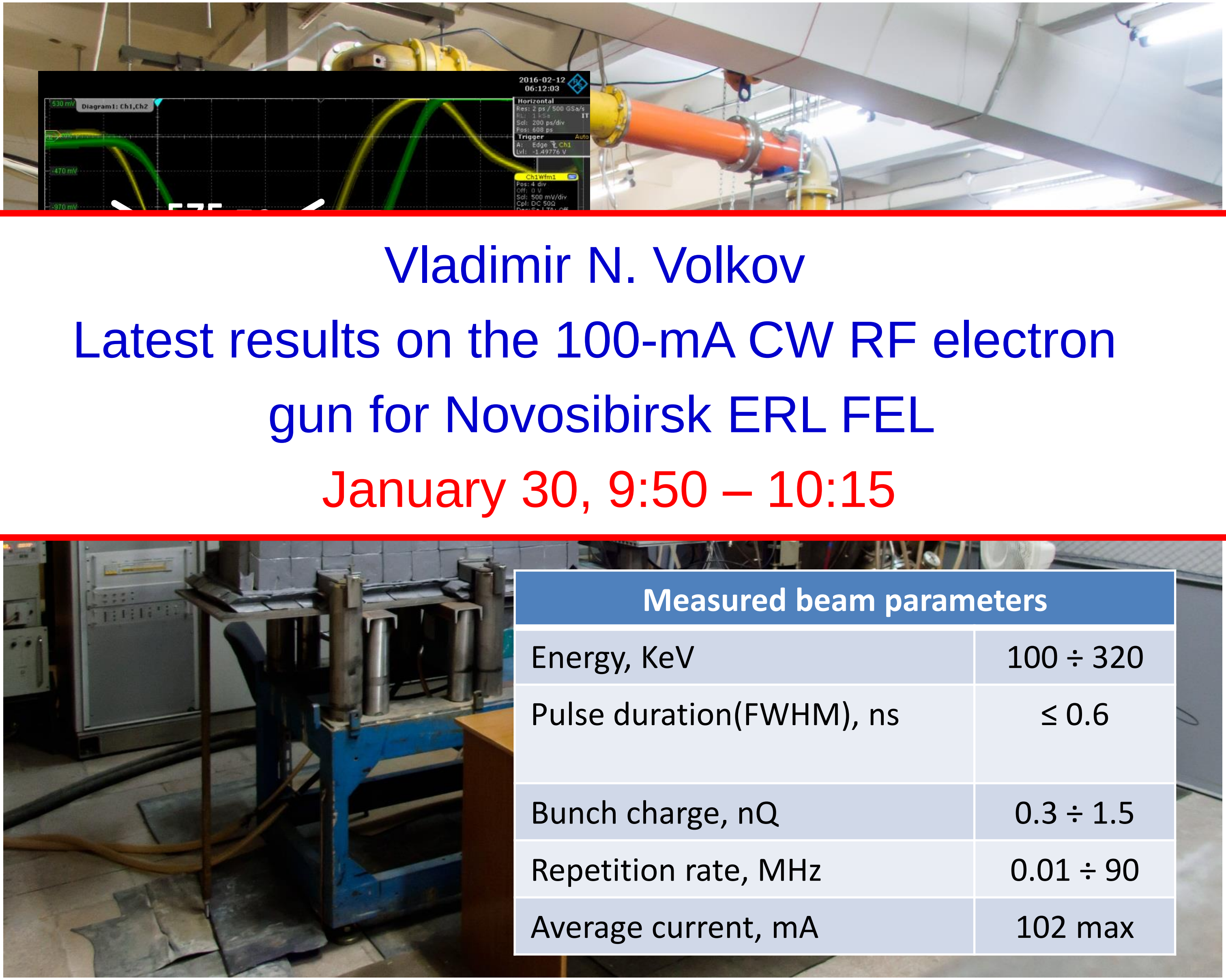






Electron outcoupling scheme may be used here

RF Gun Test Setup



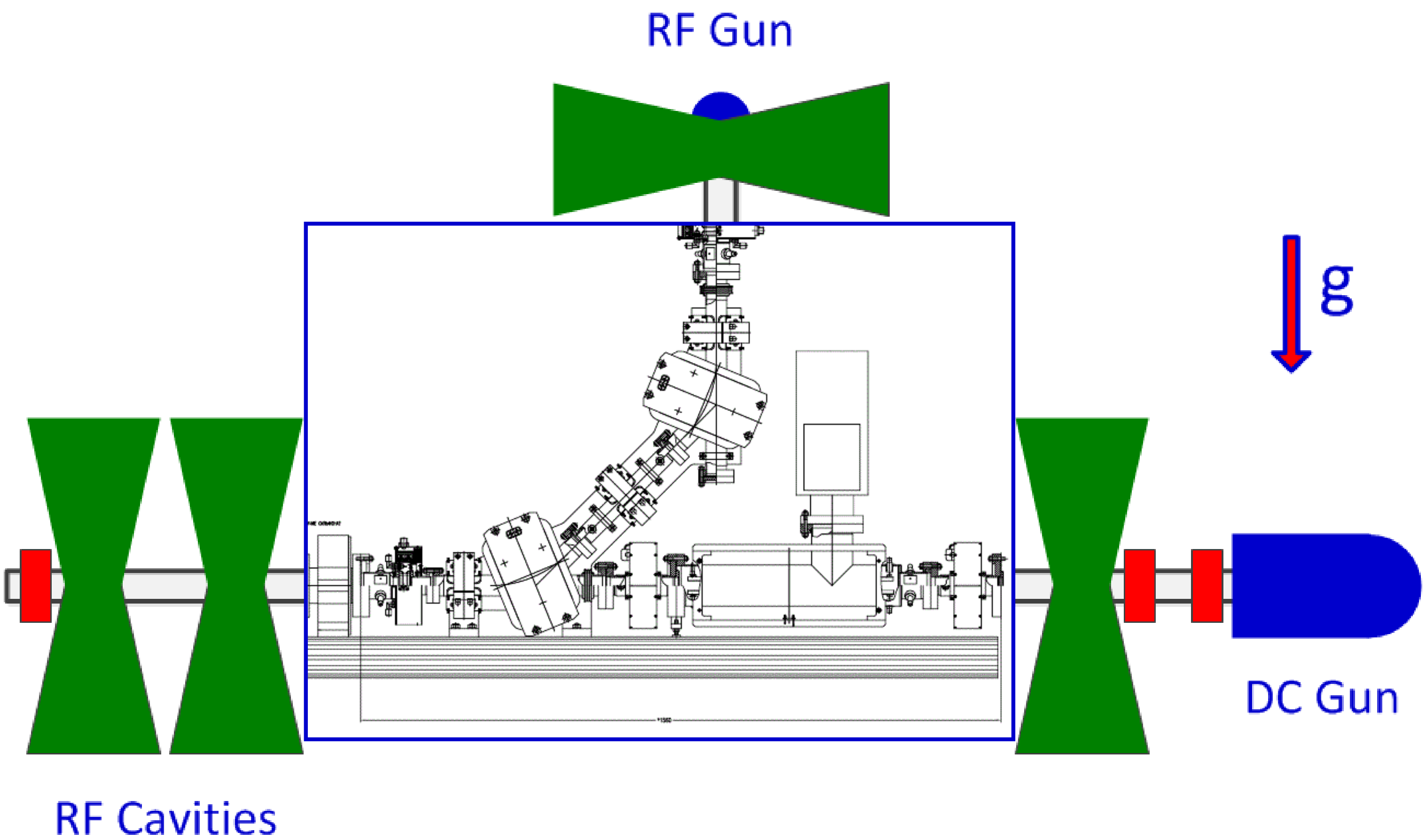
Vladimir N. Volkov

Latest results on the 100-mA CW RF electron gun for Novosibirsk ERL FEL

January 30, 9:50 – 10:15

Measured beam parameters	
Energy, KeV	100 ÷ 320
Pulse duration(FWHM), ns	≤ 0.6
Bunch charge, nQ	0.3 ÷ 1.5
Repetition rate, MHz	0.01 ÷ 90
Average current, mA	102 max

RF Gun Installation Layout



Overview of the NovoFEL facility

- The first stage of Novosibirsk high power free electron laser (NovoFEL) based on one track energy recovery linac (ERL) working in spectral range (90 – 240) μm was commissioned in 2003.

- The second stage of NovoFEL based on two track energy recovery linac, working in spectral range (37 – 80) μm, was commissioned in 2009.

- The third stage of NovoFEL based on four track ERL was commissioned on July of 2015. Spectral range now is (8-11) μm. First operation for users was done in 2016.

Thank you for your attention!