Commissioning Status and Further Development of the Novosibirsk Multiturn ERL

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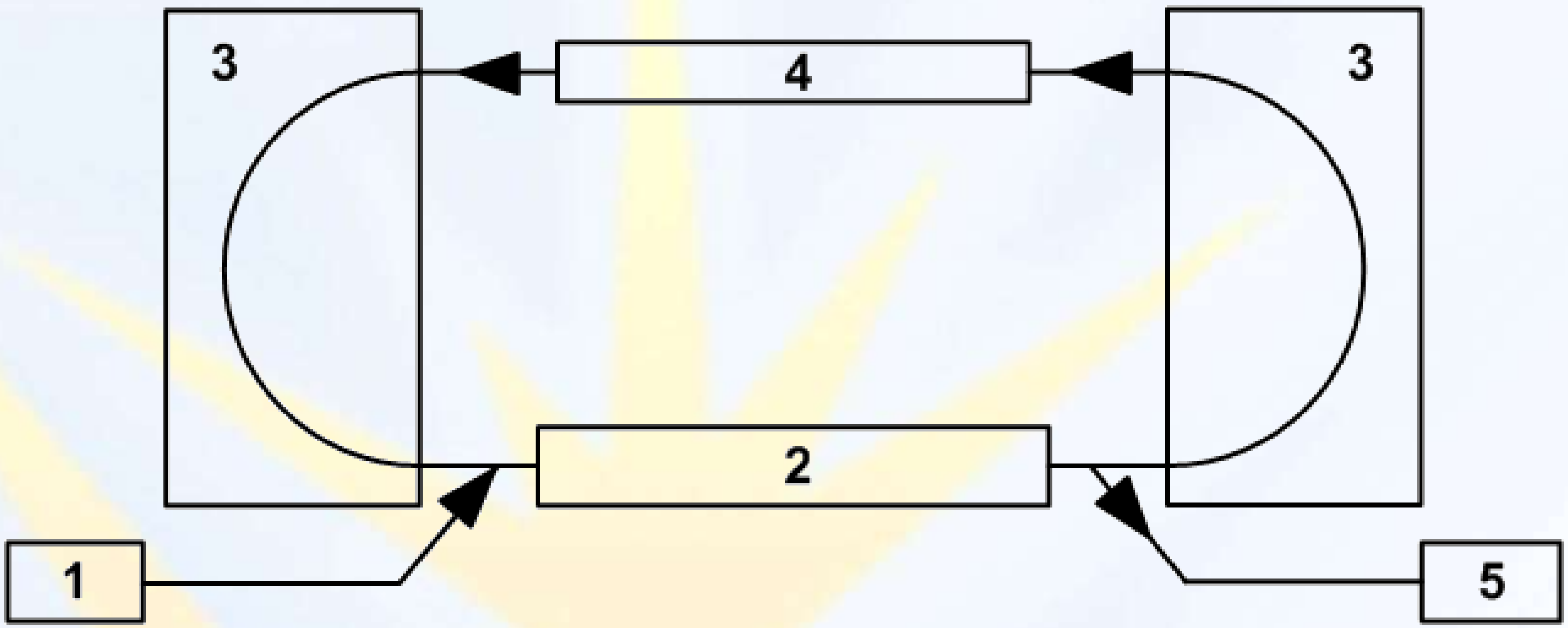
BINP, Novosibirsk, Russia

ERL 2013 - September, 9 - Novosibirsk

Outline

- Accelerator design overview
- The first stage of the FEL facility – design and operation experience
- The second and the third stages – design and commissioning status
- Nearest plans

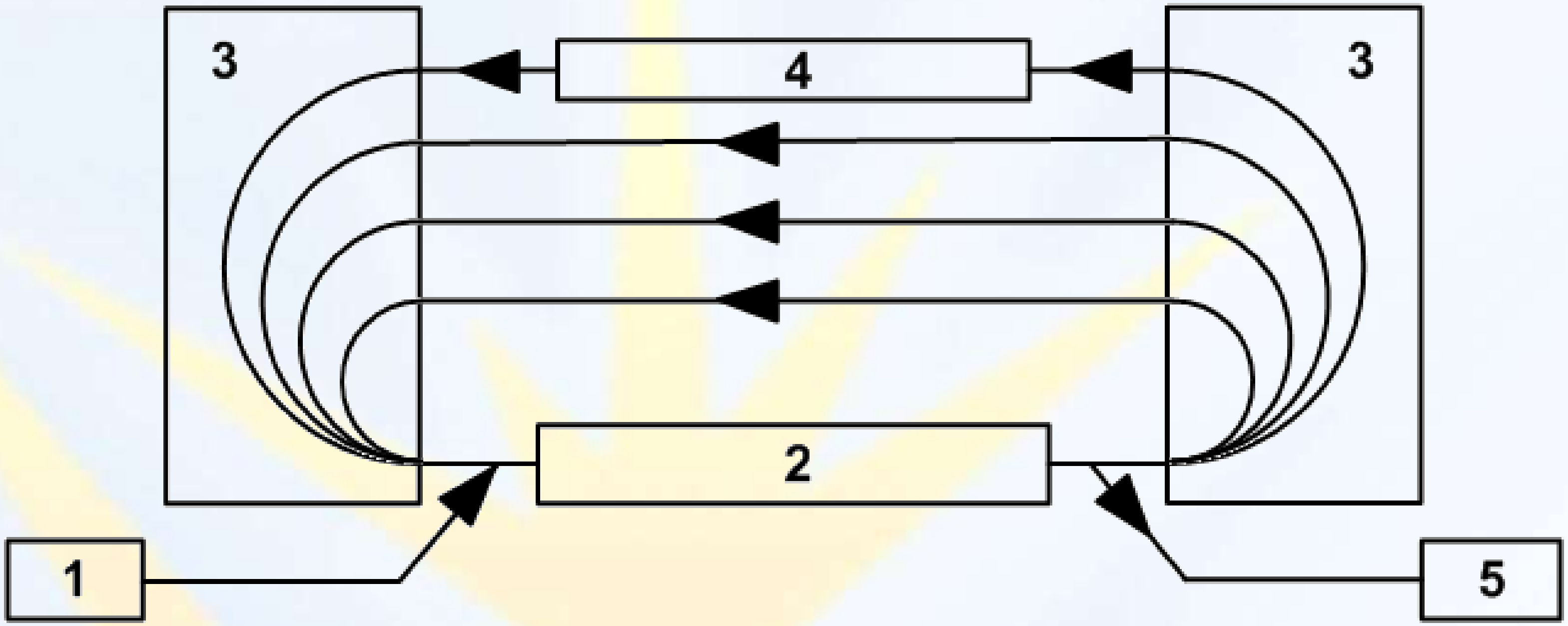
Energy Recovery Linac



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

Energy recovery makes it possible to obtain large beam current

Energy Recovery Linac



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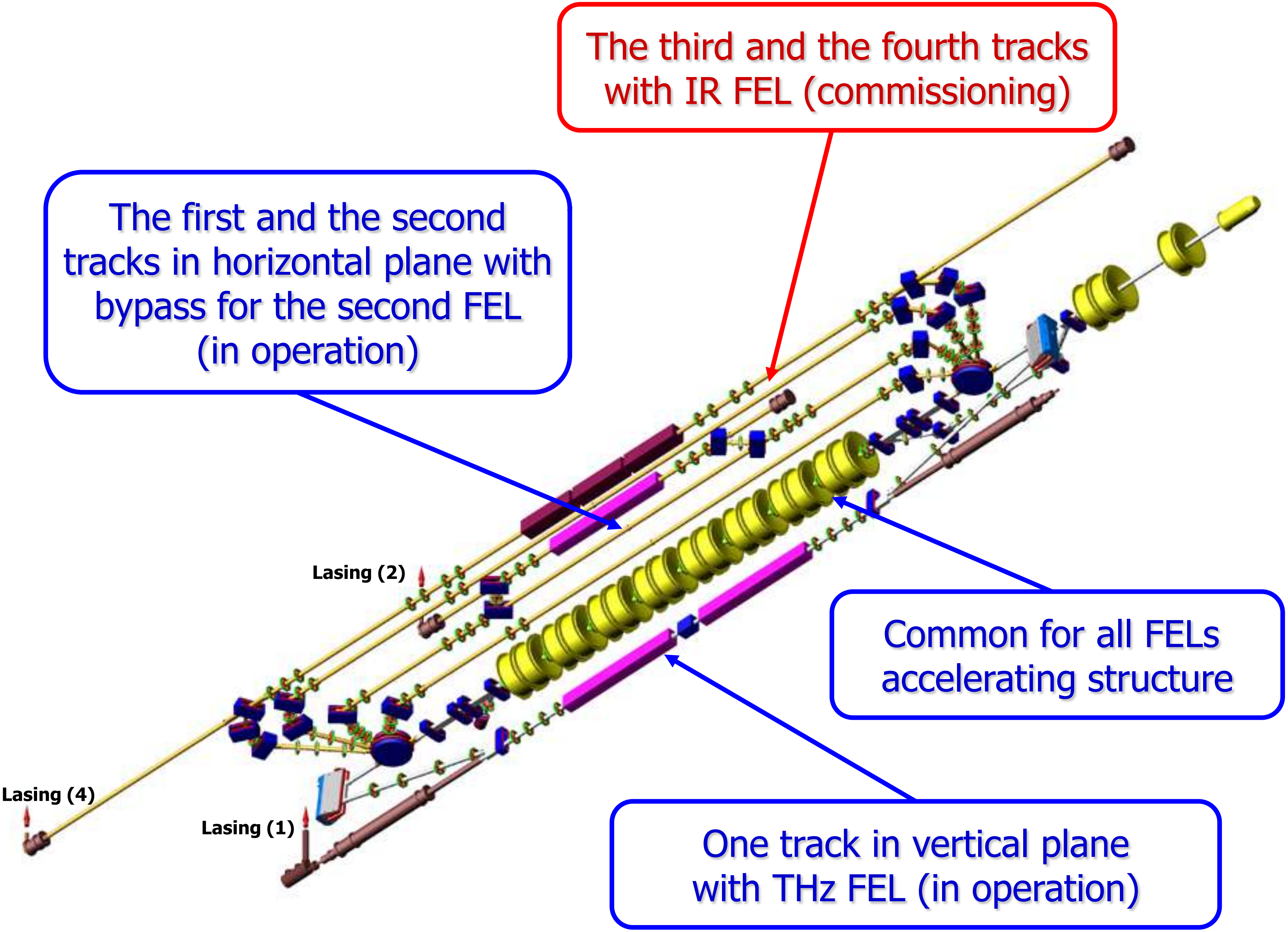
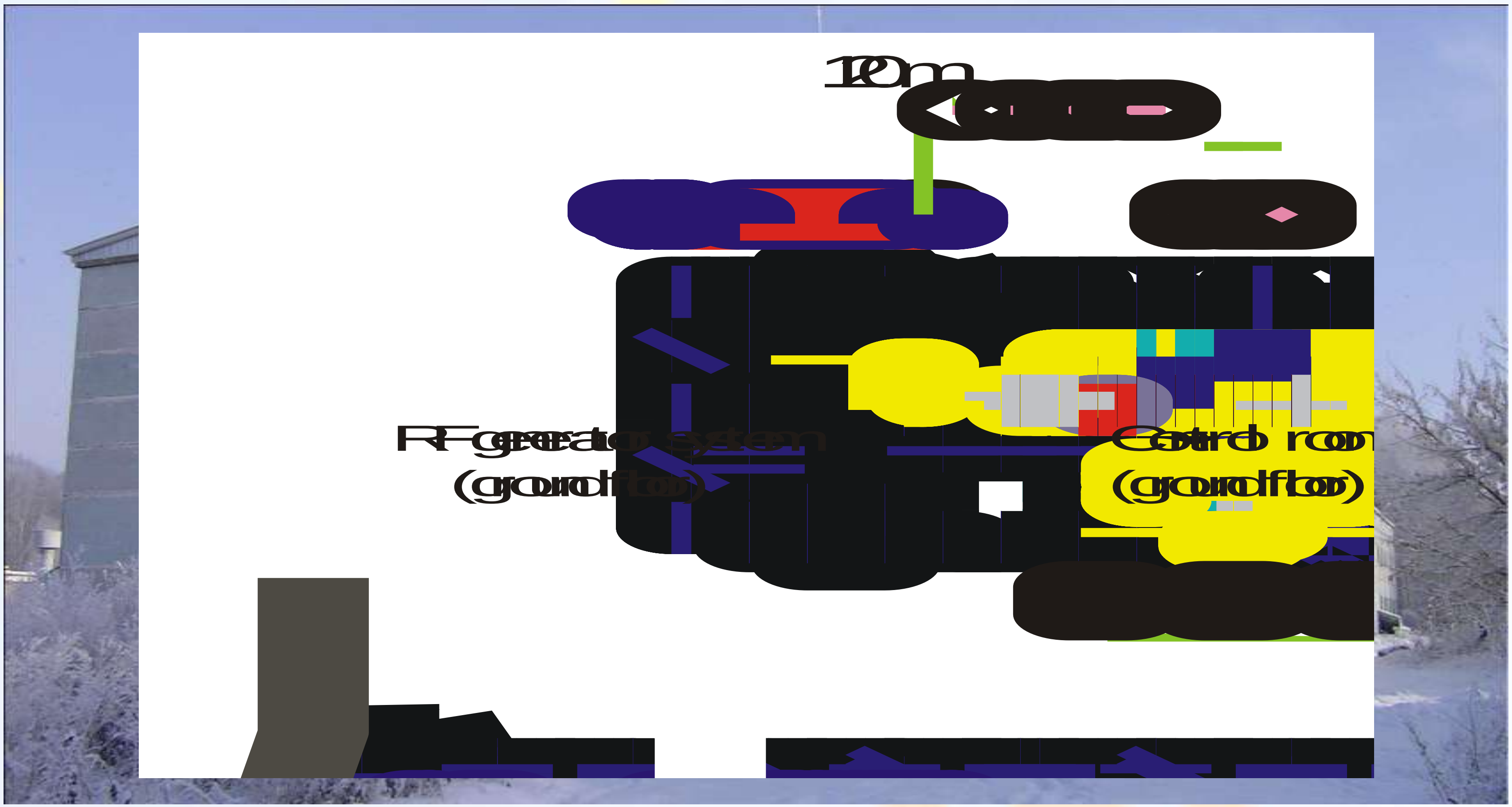
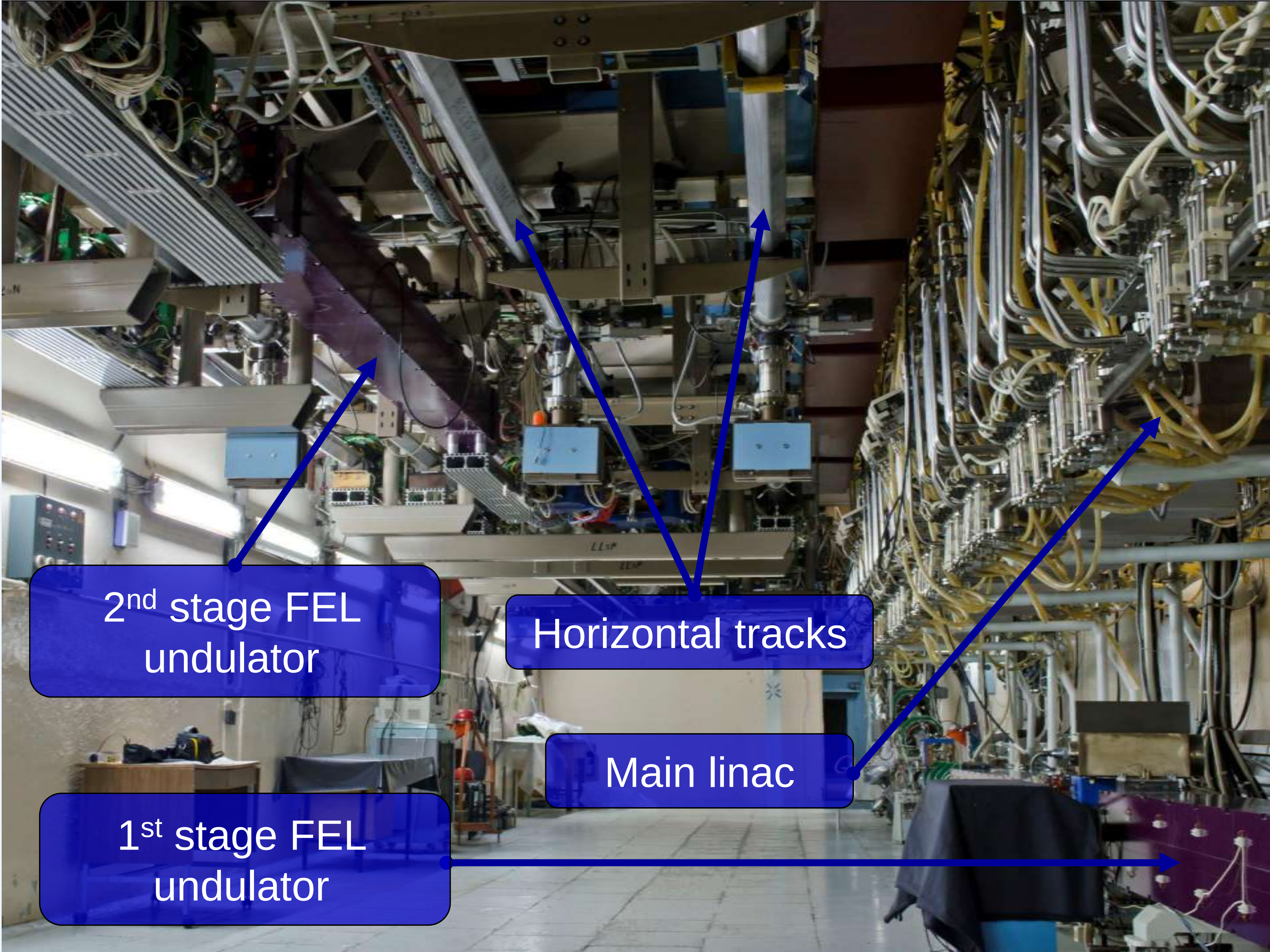

The third and the fourth tracks
with IR FEL (commissioning)
The first and the second
tracks in horizontal plane with
bypass for the second FEL
(in operation)
Lasing (2)
Lasing (4)
Lasing (1)
Common for all FELs
accelerating structure
One track in vertical plane
with THz FEL (in operation)

Siberian Center of Photochemical Research

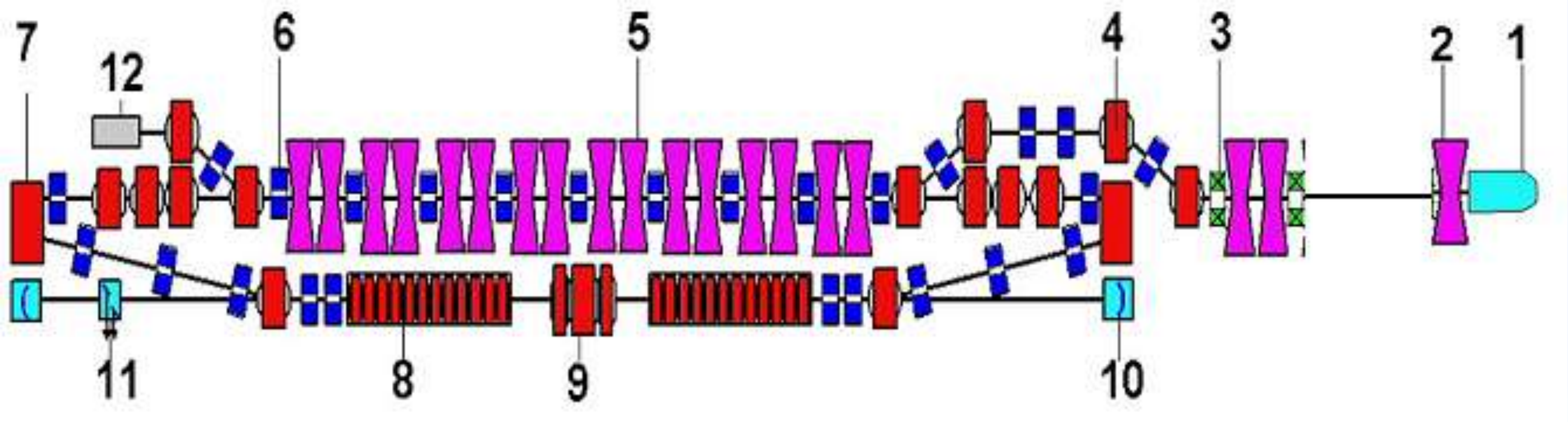
Siberian Center of Photochemical Research





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

Injector, main linac and vertical beamlines

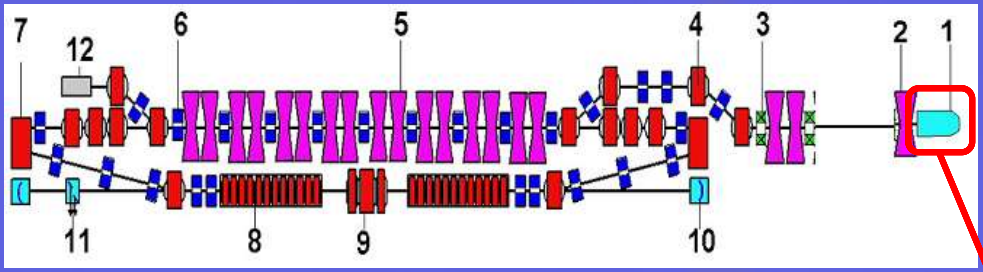


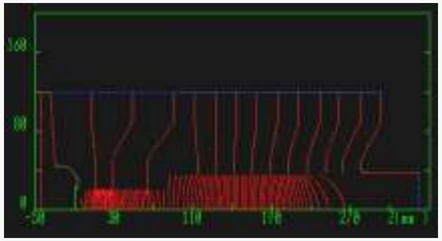
1 – electron gun, 2 – bunching RF cavity, 3 – focusing solenoids, 4 – merger, 5 – main linac, 6 – quadrupoles, 7 – magnetic mirror, 8 - undulator, 9 - buncher, 10 – optical cavity mirror, 11 – calorimeter , 12 - dump.

Electron beam from the gun passes through the buncher (a bunching RF cavity), drift section, 2 MeV accelerating cavities and the main accelerating structure and the undulator, where a fraction of its energy is converted to radiation.

After that, the beam returns to the main accelerating structure in a decelerating RF phase, decreases its energy to its injection value (2 MeV) and is absorbed in the beam dump.

Electrostatic gun



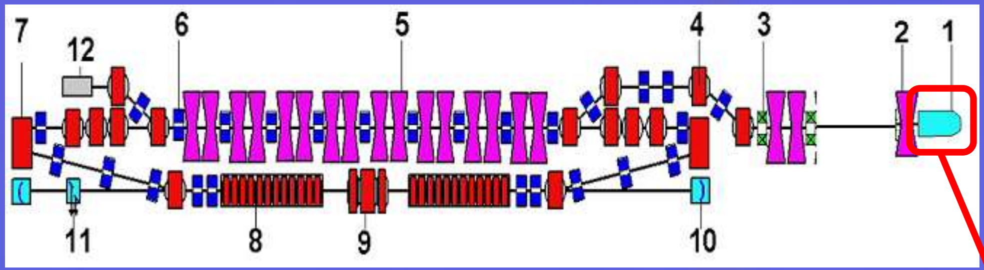


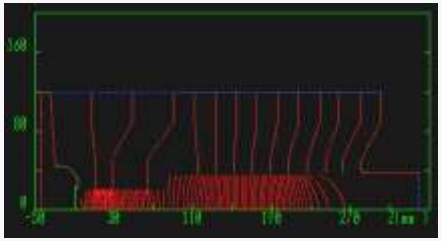
Power supply:

U_{max} = 300 kV

I_{max} = 50 mA

Electrostatic gun





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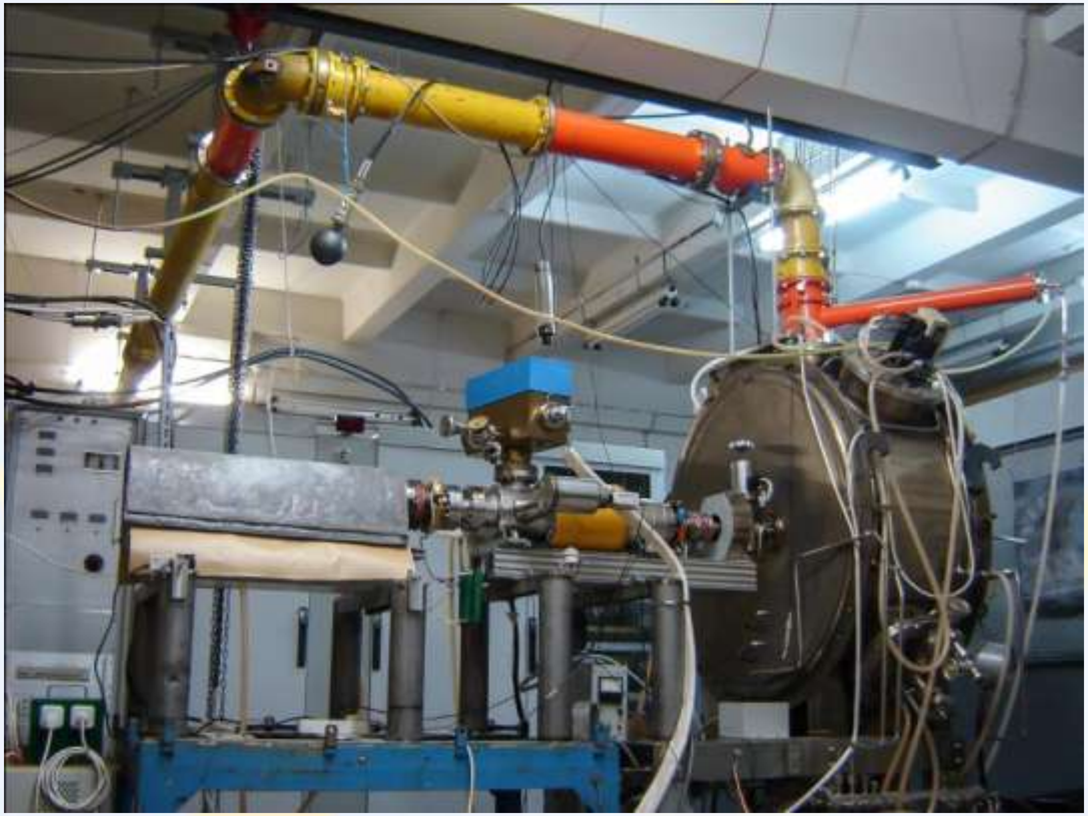
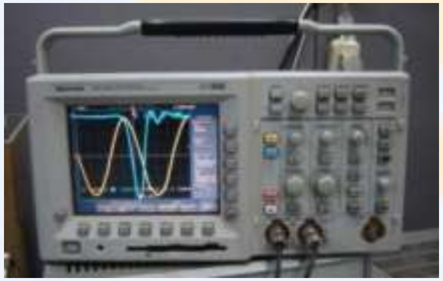
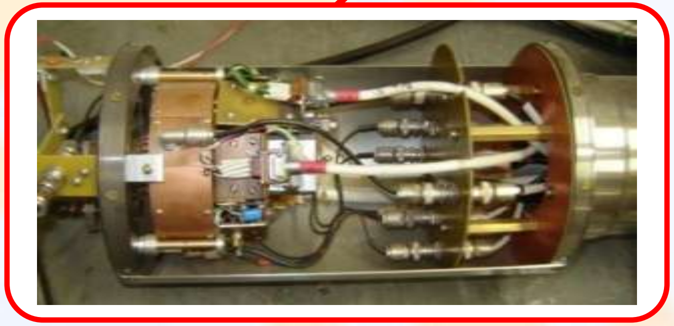
90 MHz RF gun test setup







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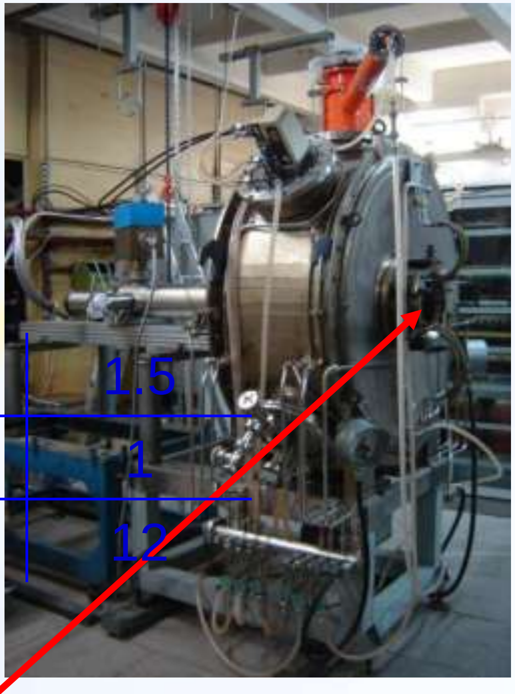
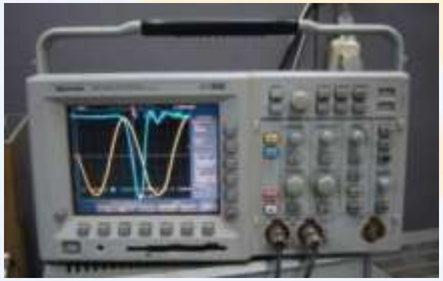
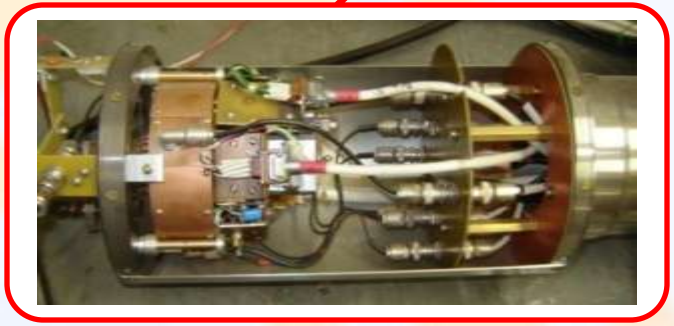


Maximum bunch charge, nQ	1.5
Pulse duration, ns	1
Maximum average current, mA	12





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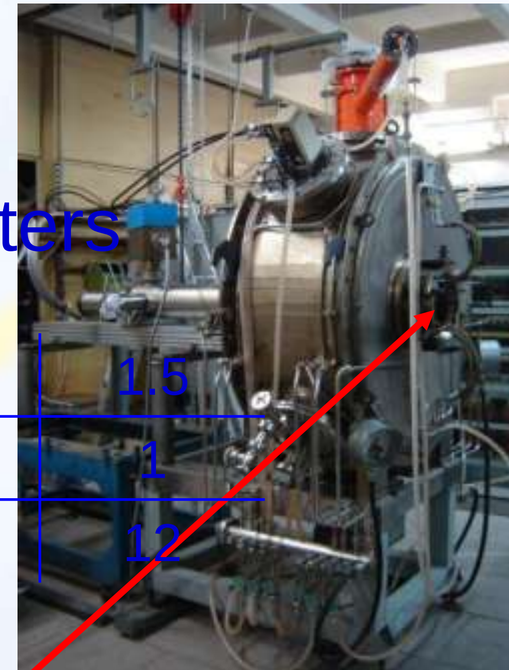
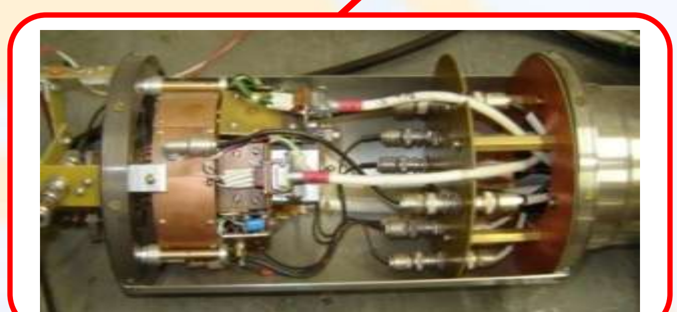


Obtained beam parameters

Maximum bunch charge, nQ	1.5
Pulse duration, ns	1
Maximum average current, mA	12



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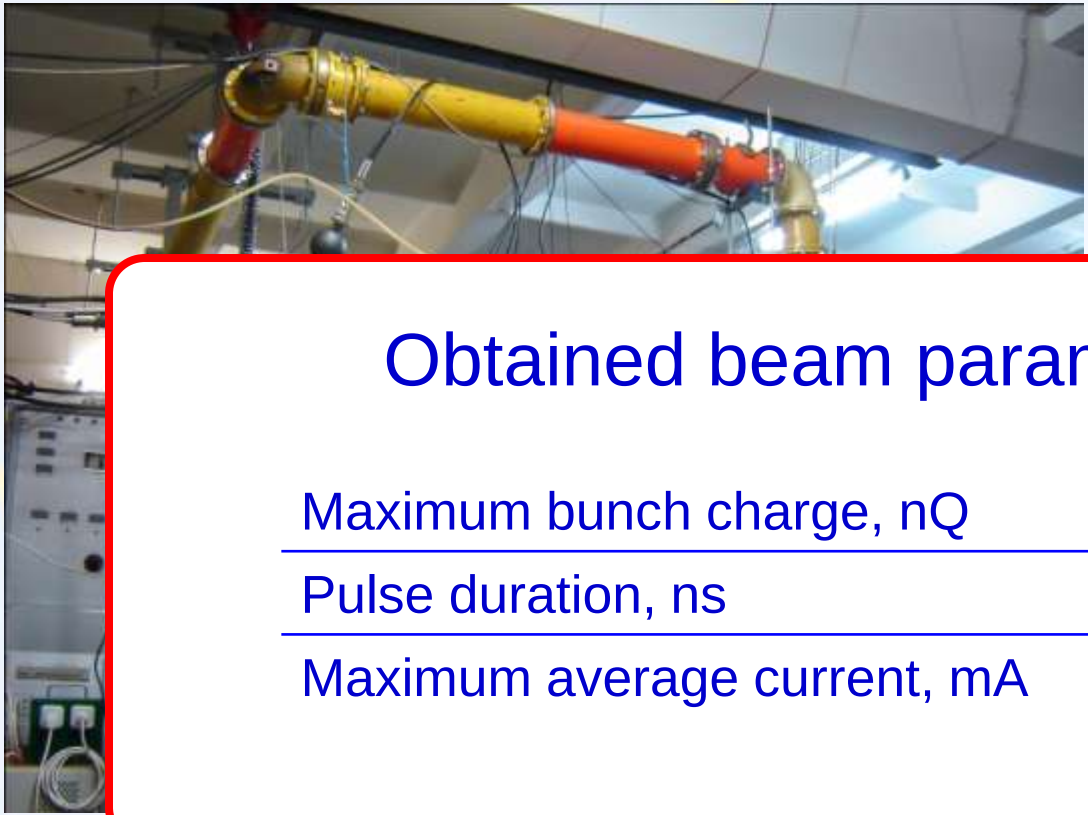

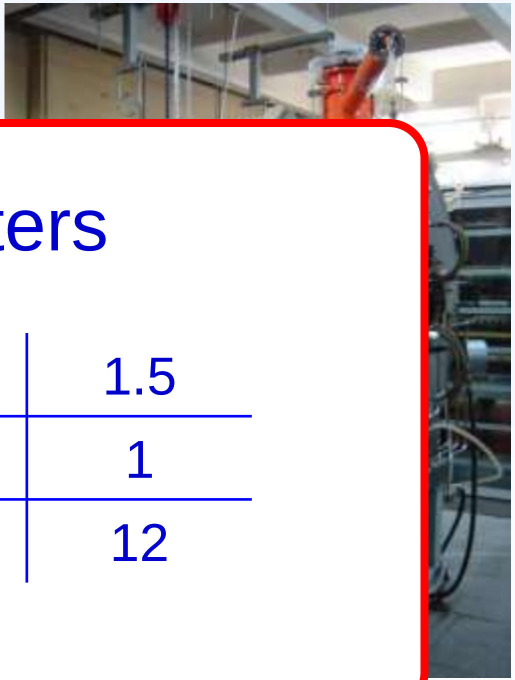

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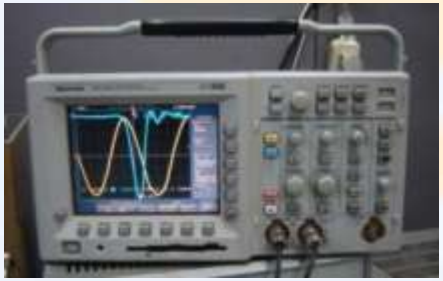
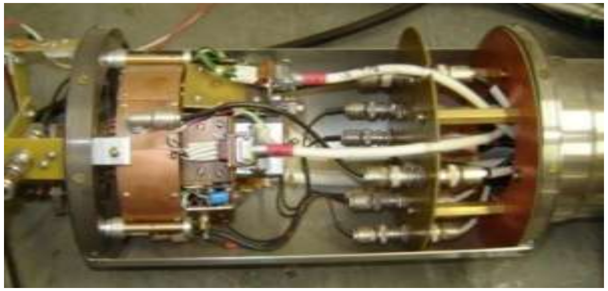
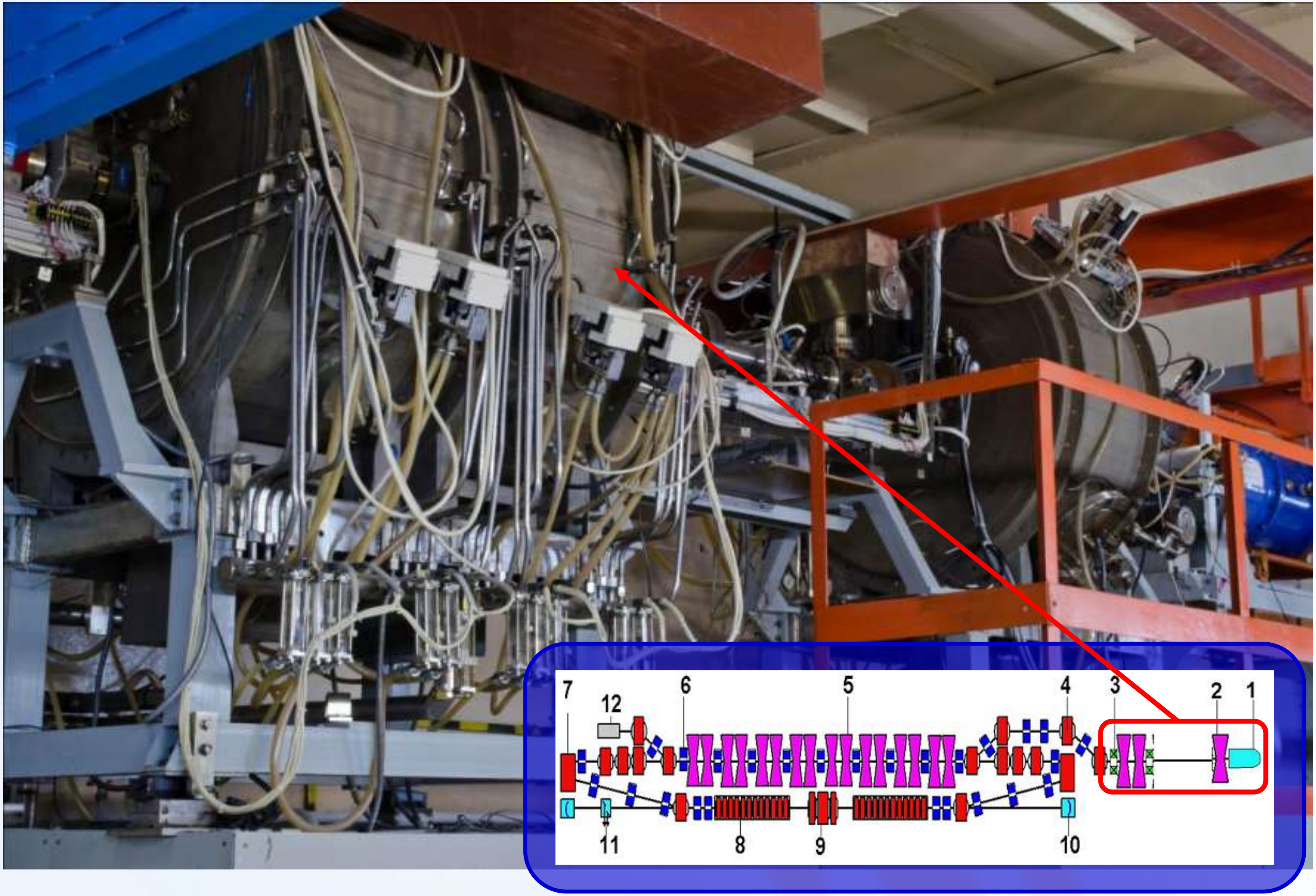
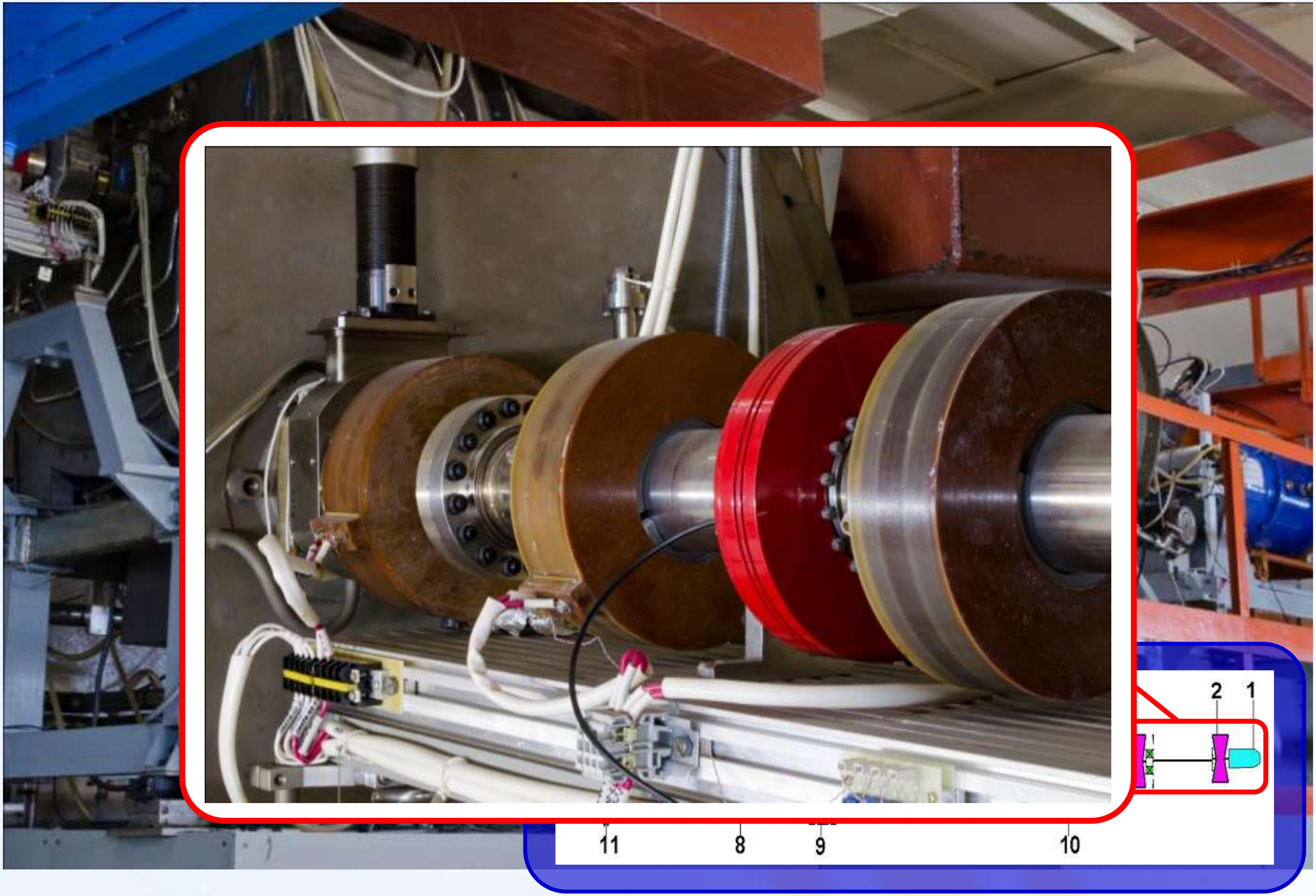




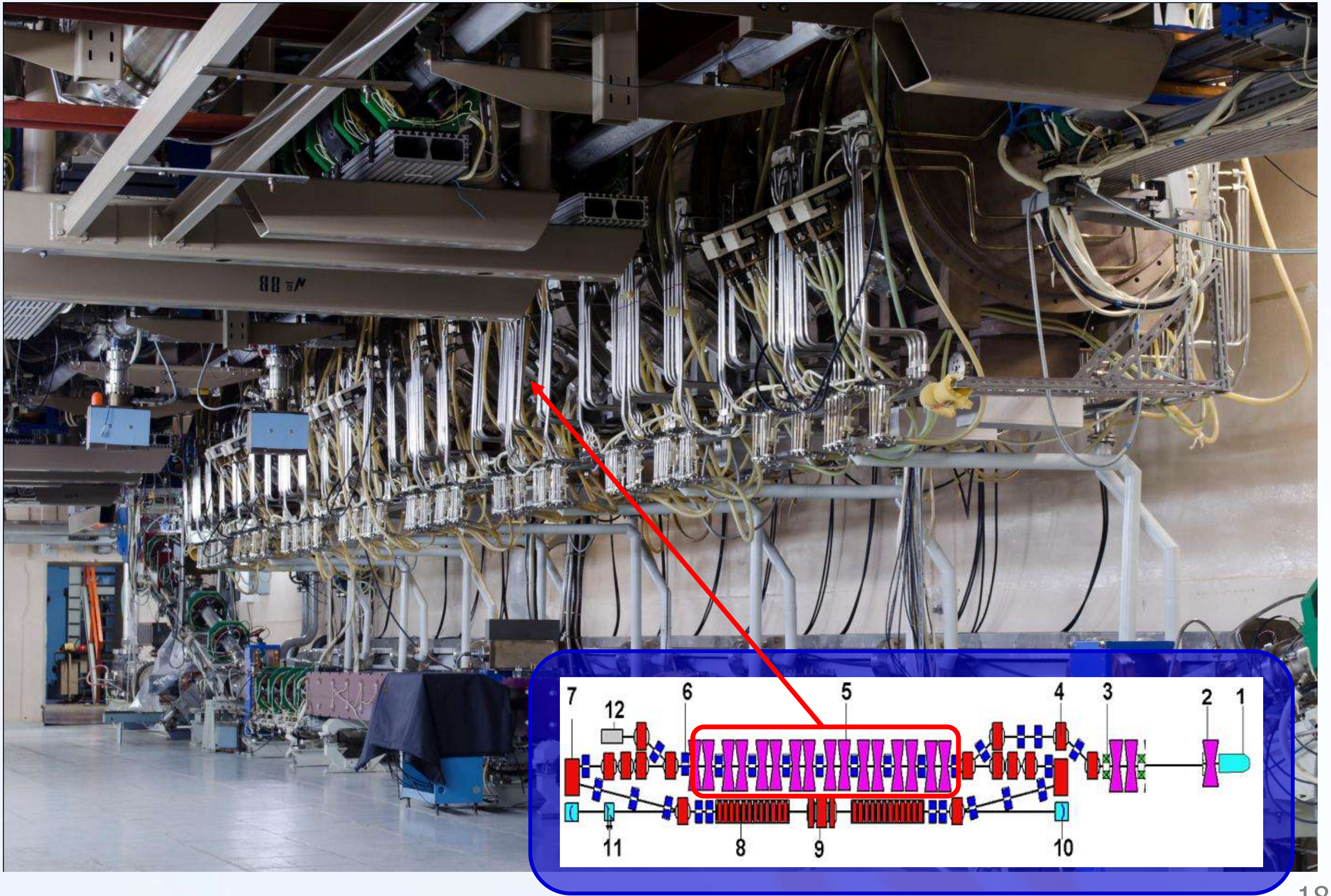
Injector



Injector



Main linac



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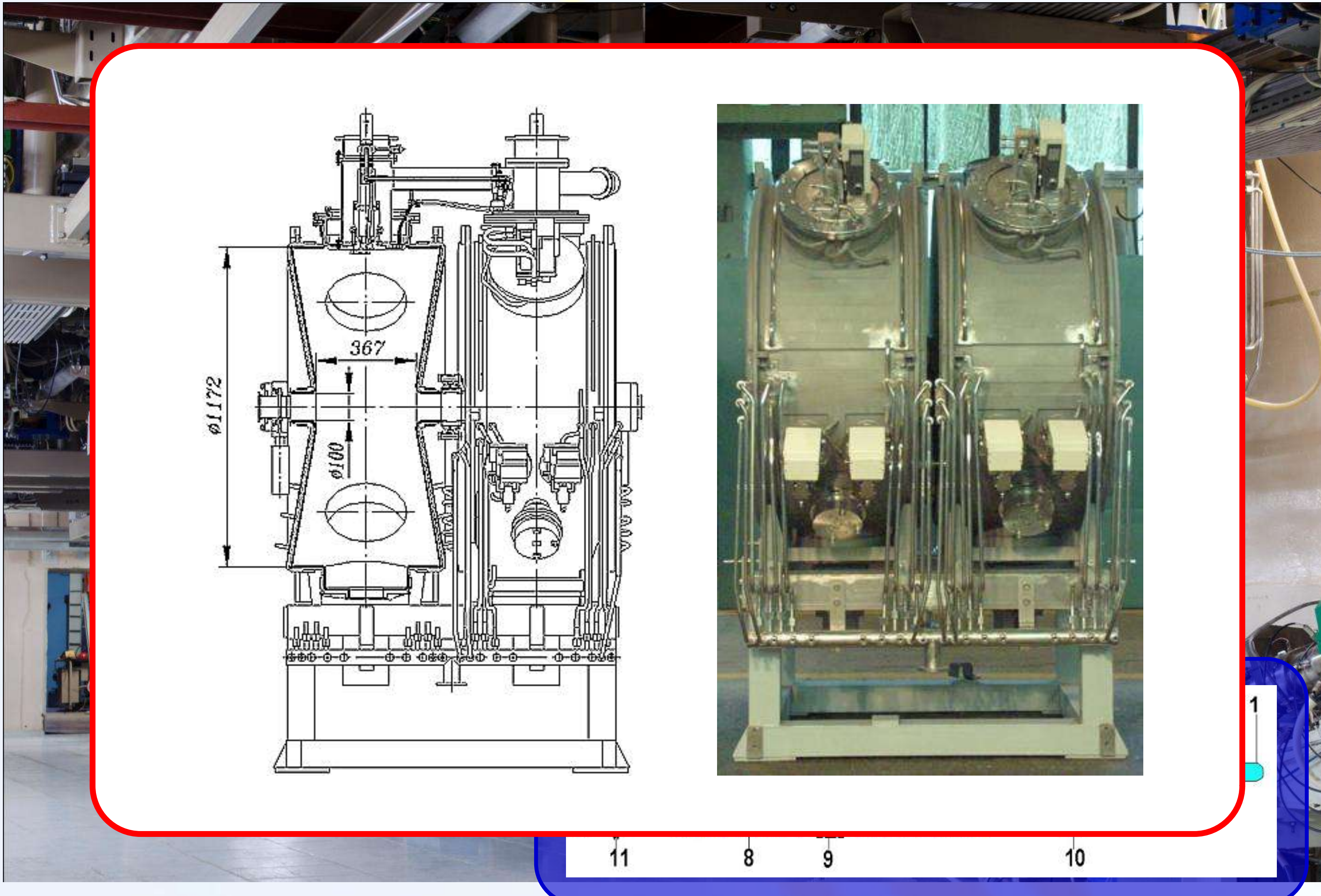
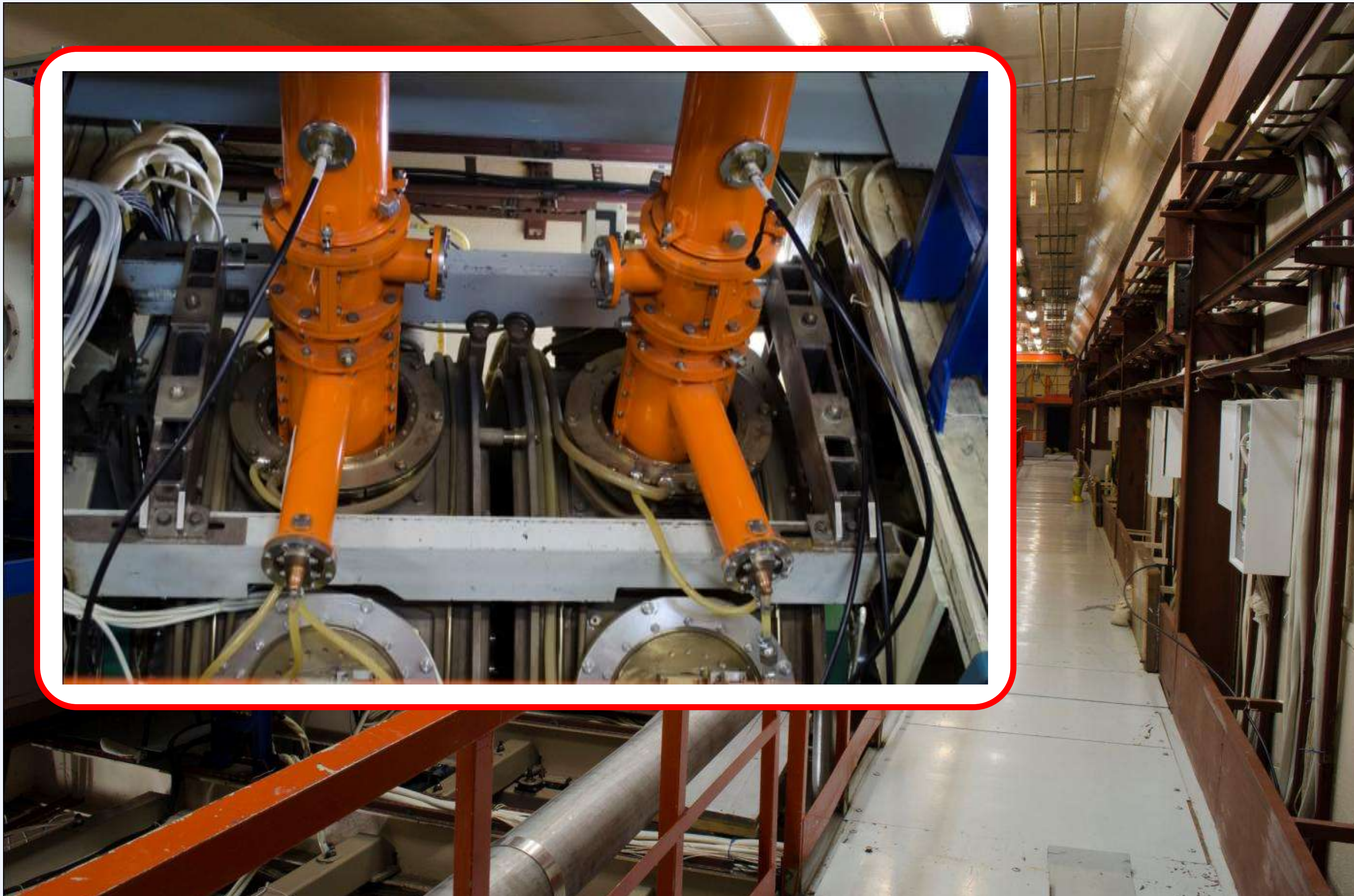


Main linac

RF waveguides and feeders

RF waveguides and feeders

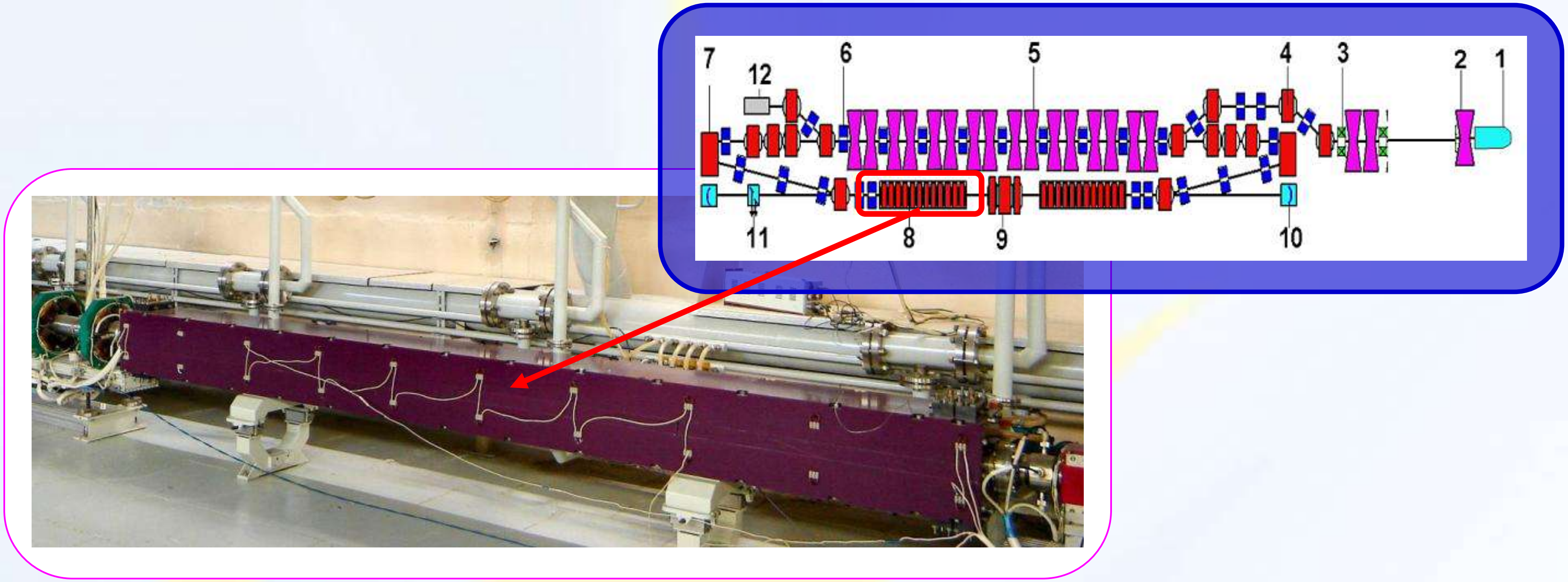


RF waveguides and feeders

RF power supply

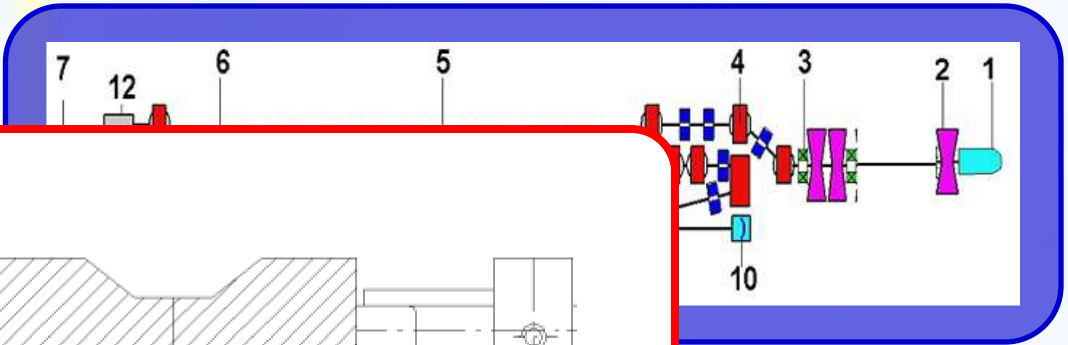
Frequency, MHz	180.4
Power, MW	1

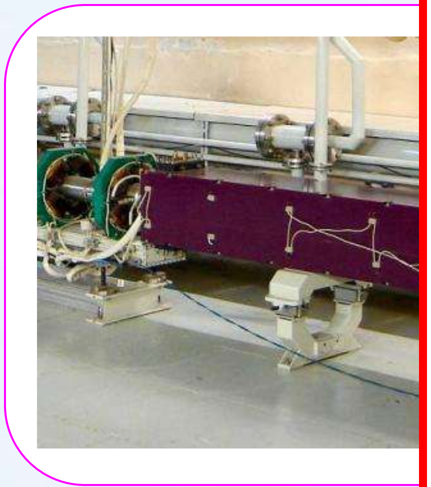
Undulator

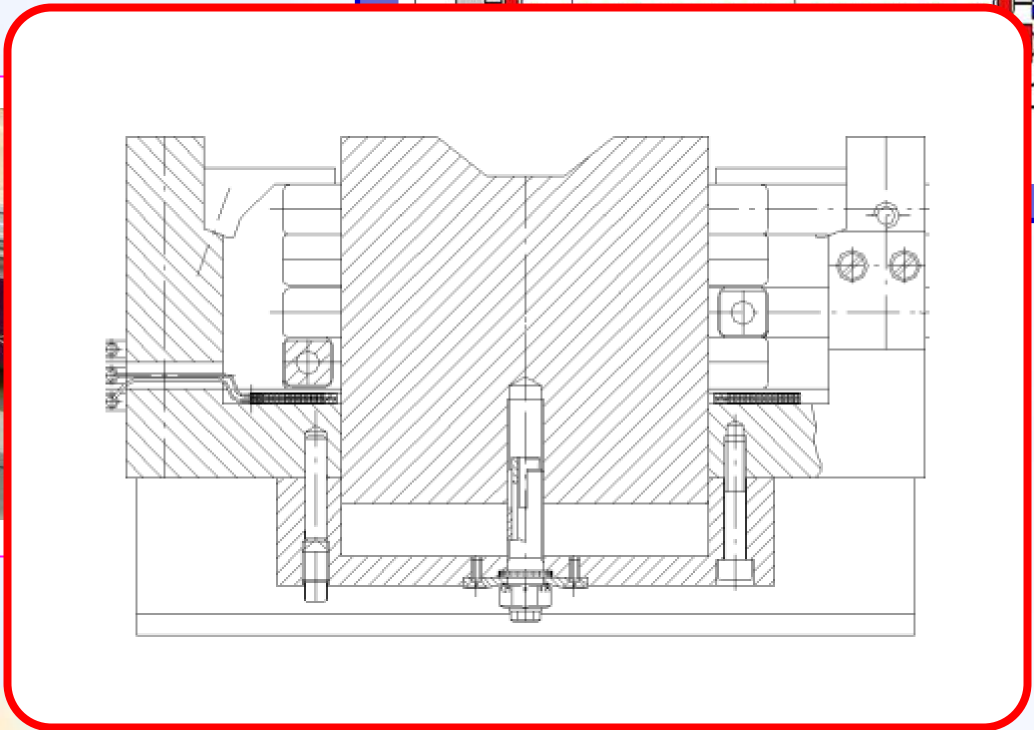


Period, cm	12
Maximum current, kA	2.4
Maximum K	1.25

Undulator

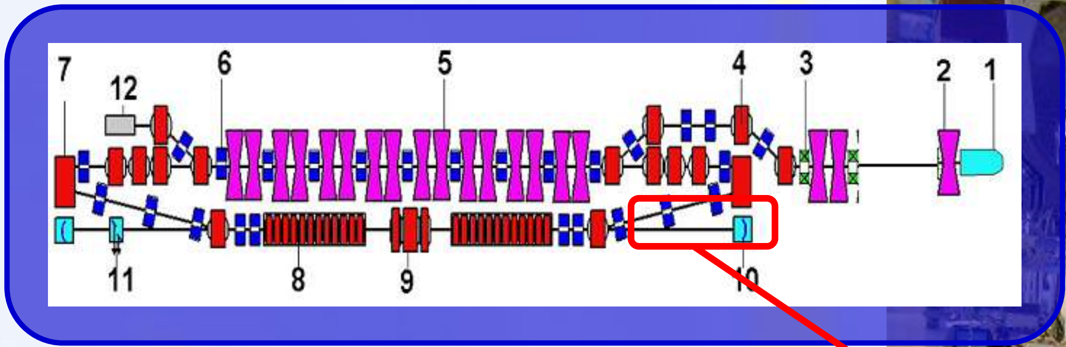


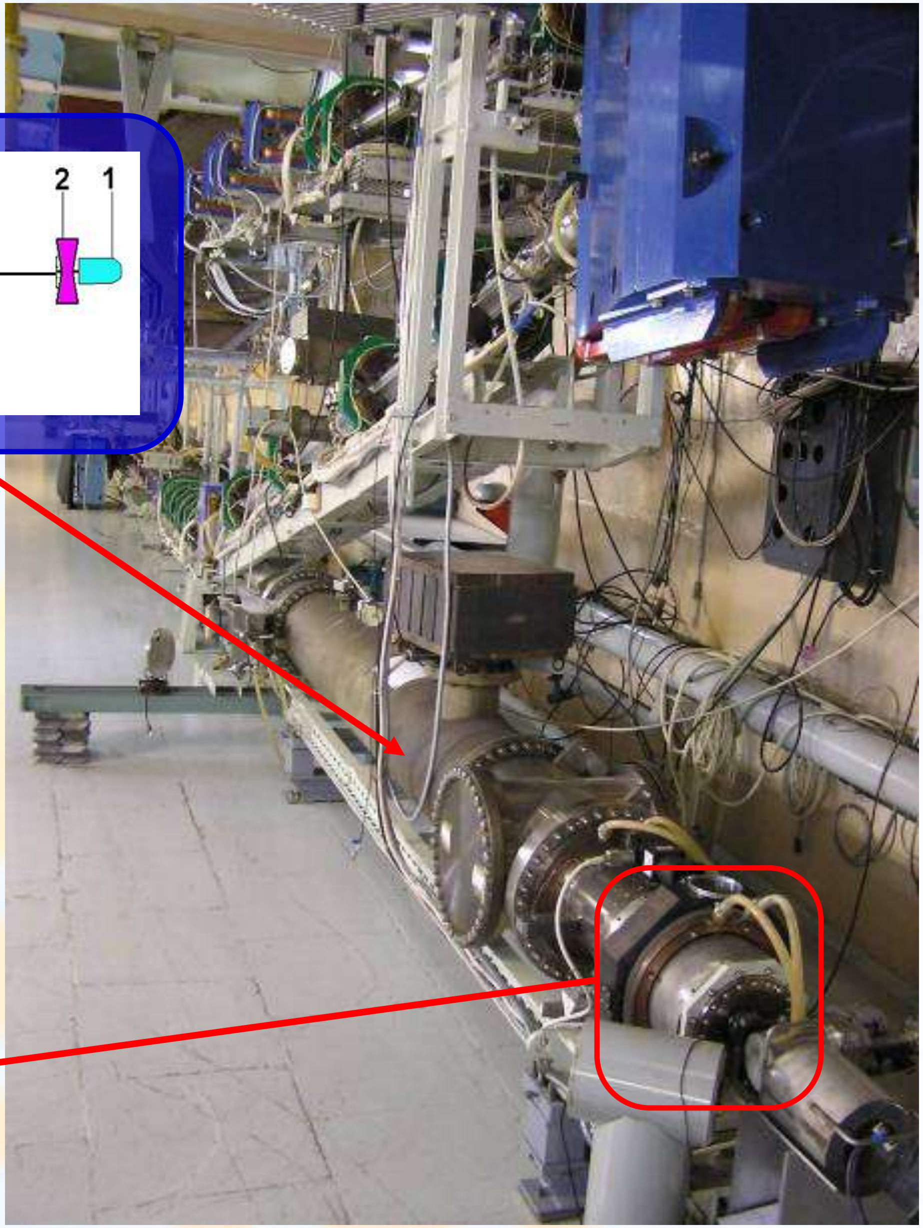


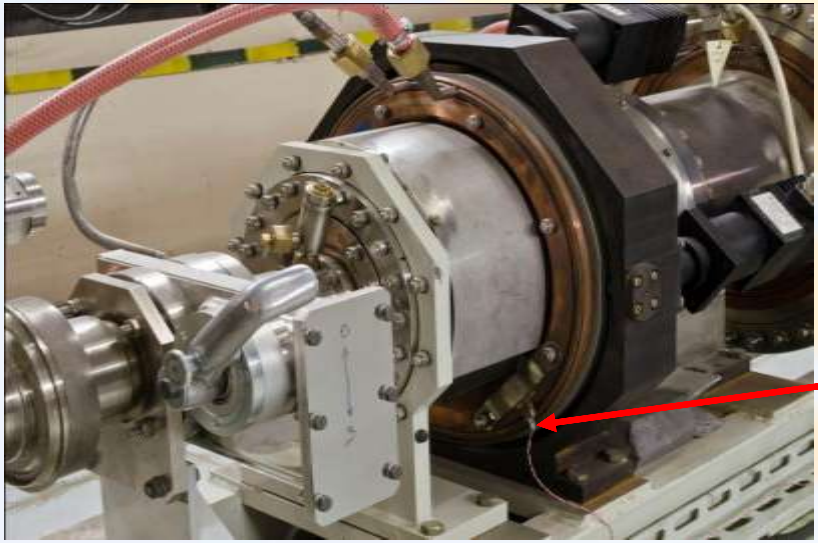


Maximum current, kA	2.4
Maximum K	1.25

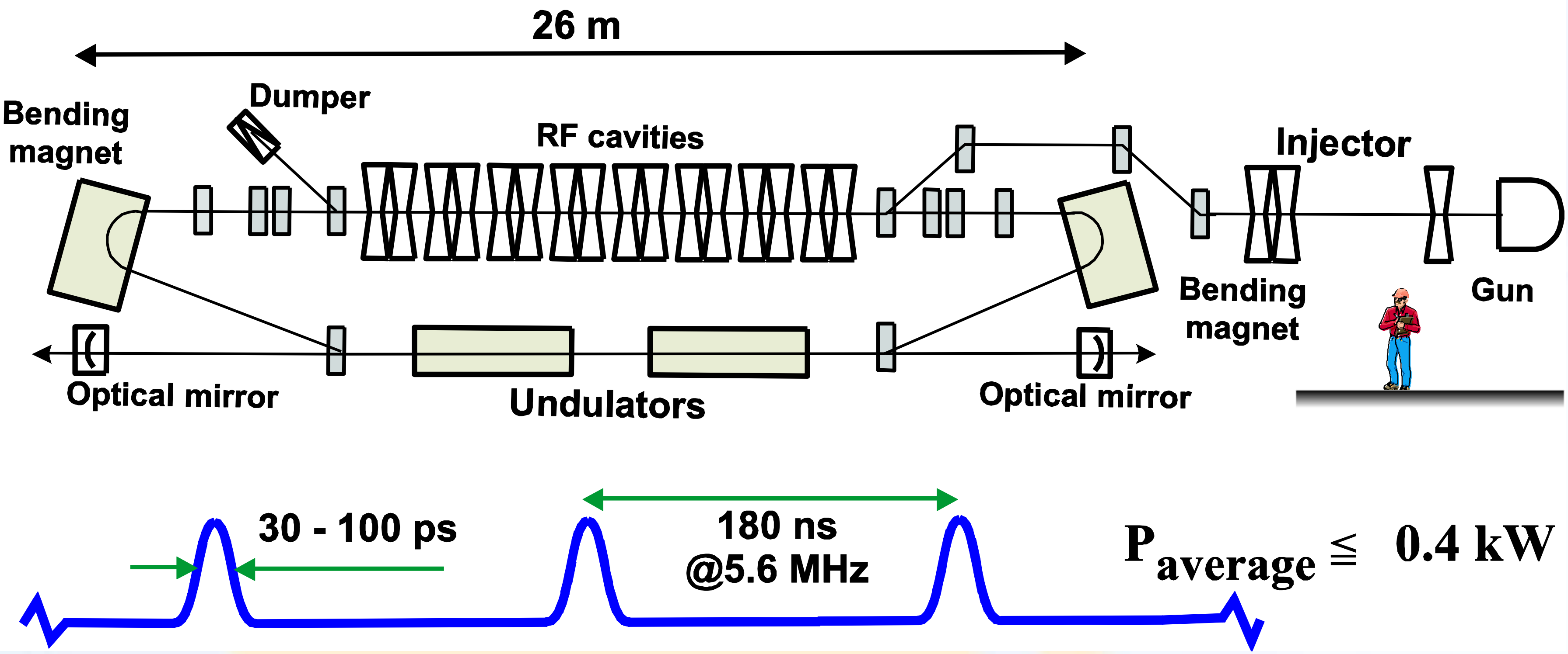
Optical cavity







Radiation power time-dependence (1st stage)



$P_{average} \leqq 0.4$ kW

Optical beamline

Optical beam expander

Optical beamline

ical beam
xpander

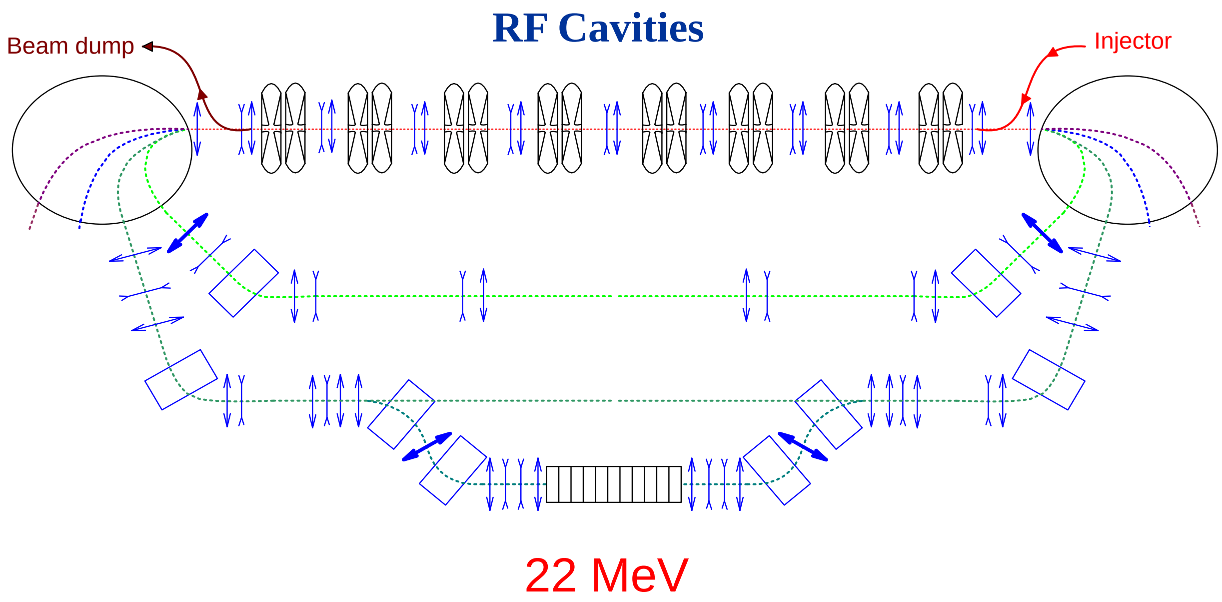
Optical beamline

The 1st stage FEL radiation parameters

• Radiation wavelength, mm	0.12 - 0.24
• Pulse duration, ps	70
• Repetition rate , MHz	11.2
• Maximum average power, kW	0.5
• Minimum relative linewidth (FWHM)	$3 \cdot 10^{-3}$
• Peak power, MW	1

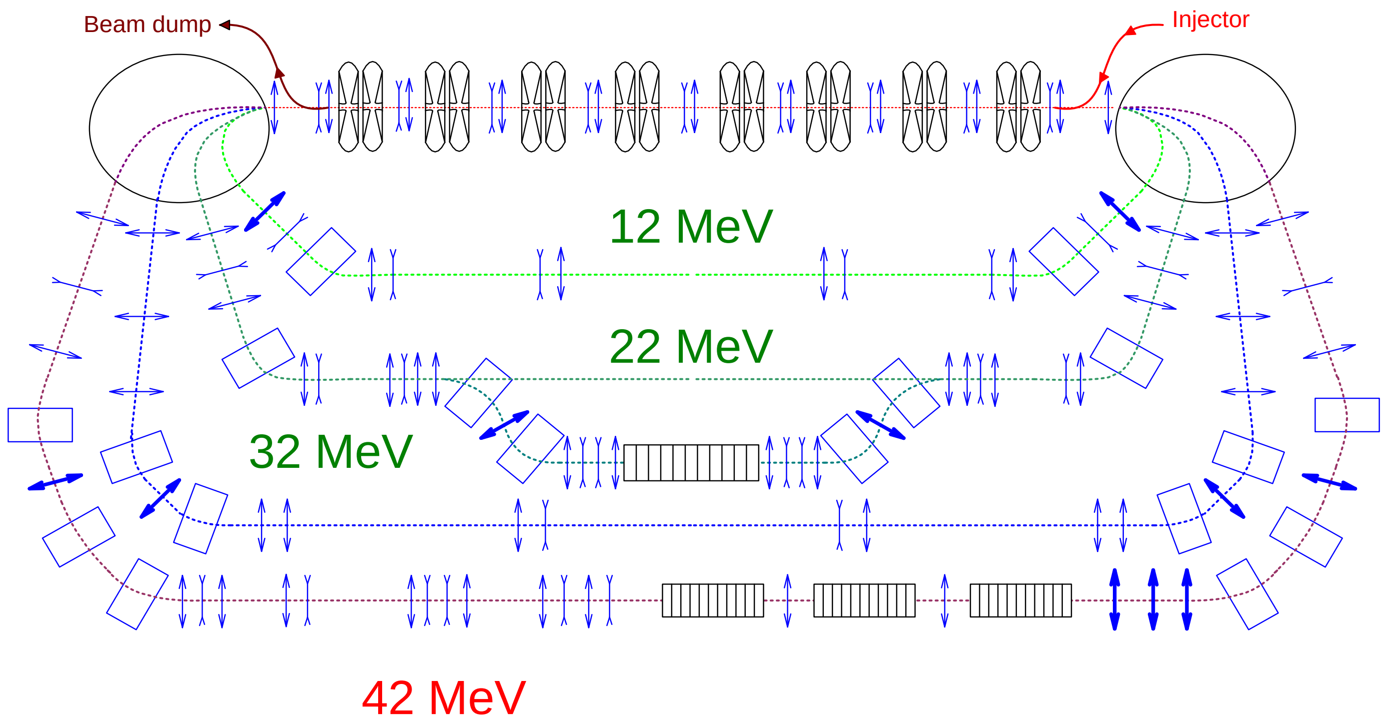
The obtained radiation parameters are still the world record in terahertz region.

Horizontal beam lines



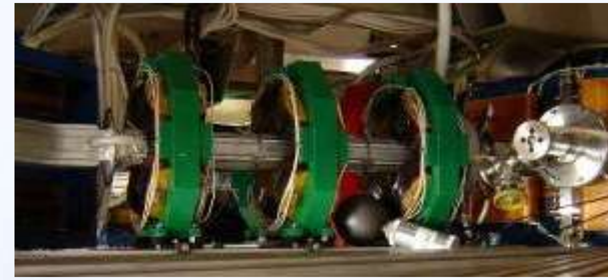
(horizontal plane)

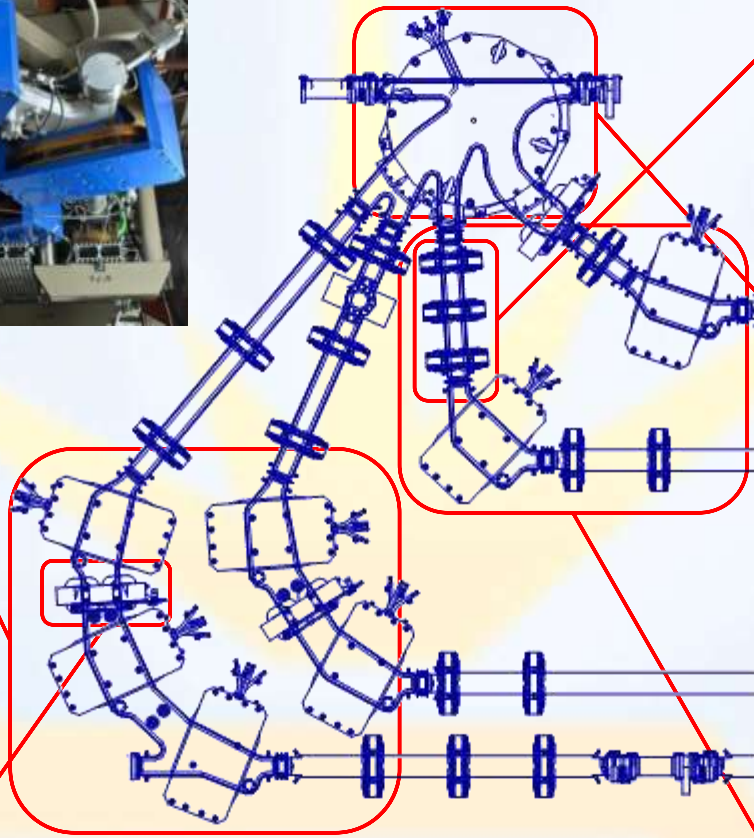
Horizontal beam lines



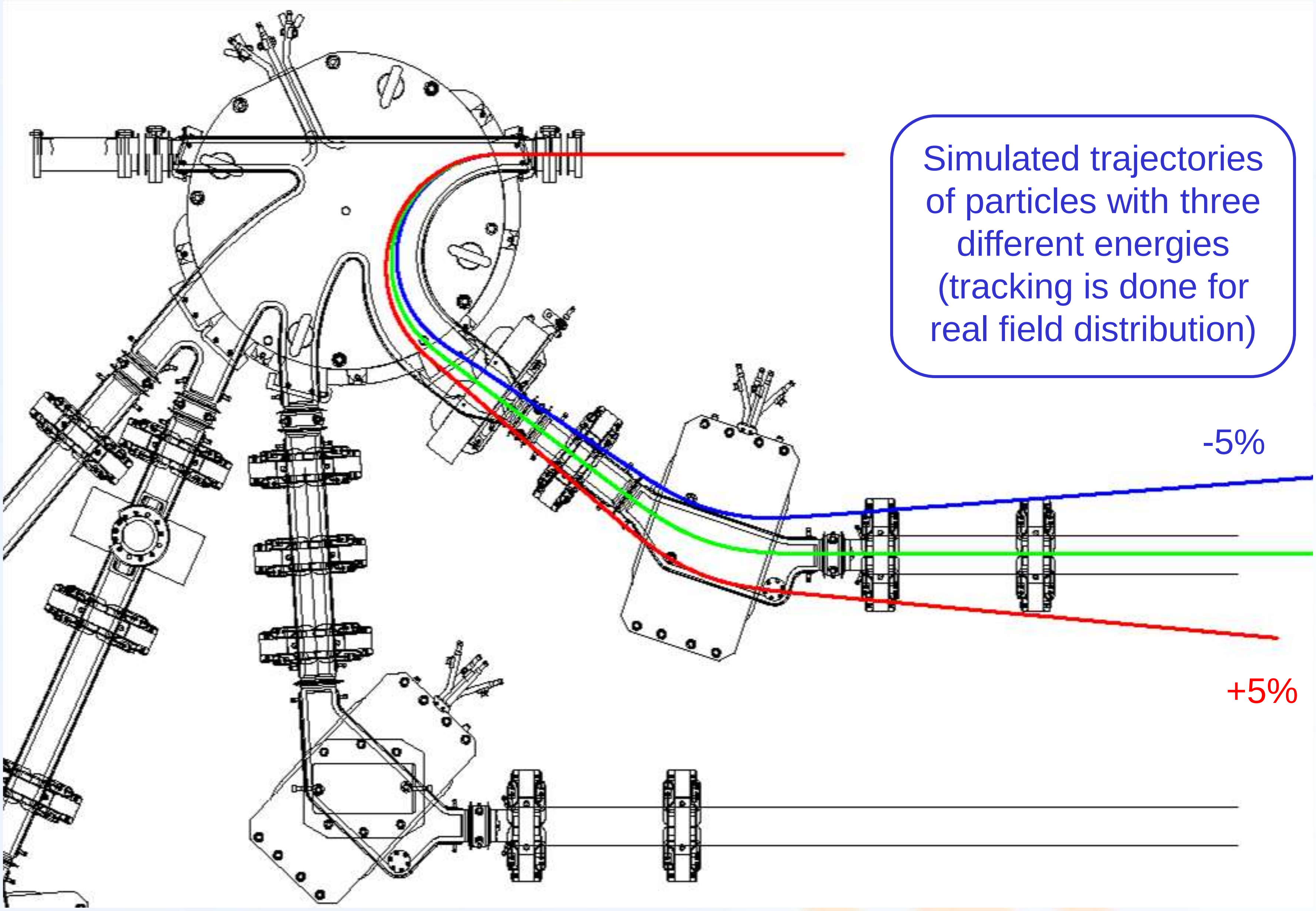
(horizontal plane)

Magnets and vacuum chamber of bends



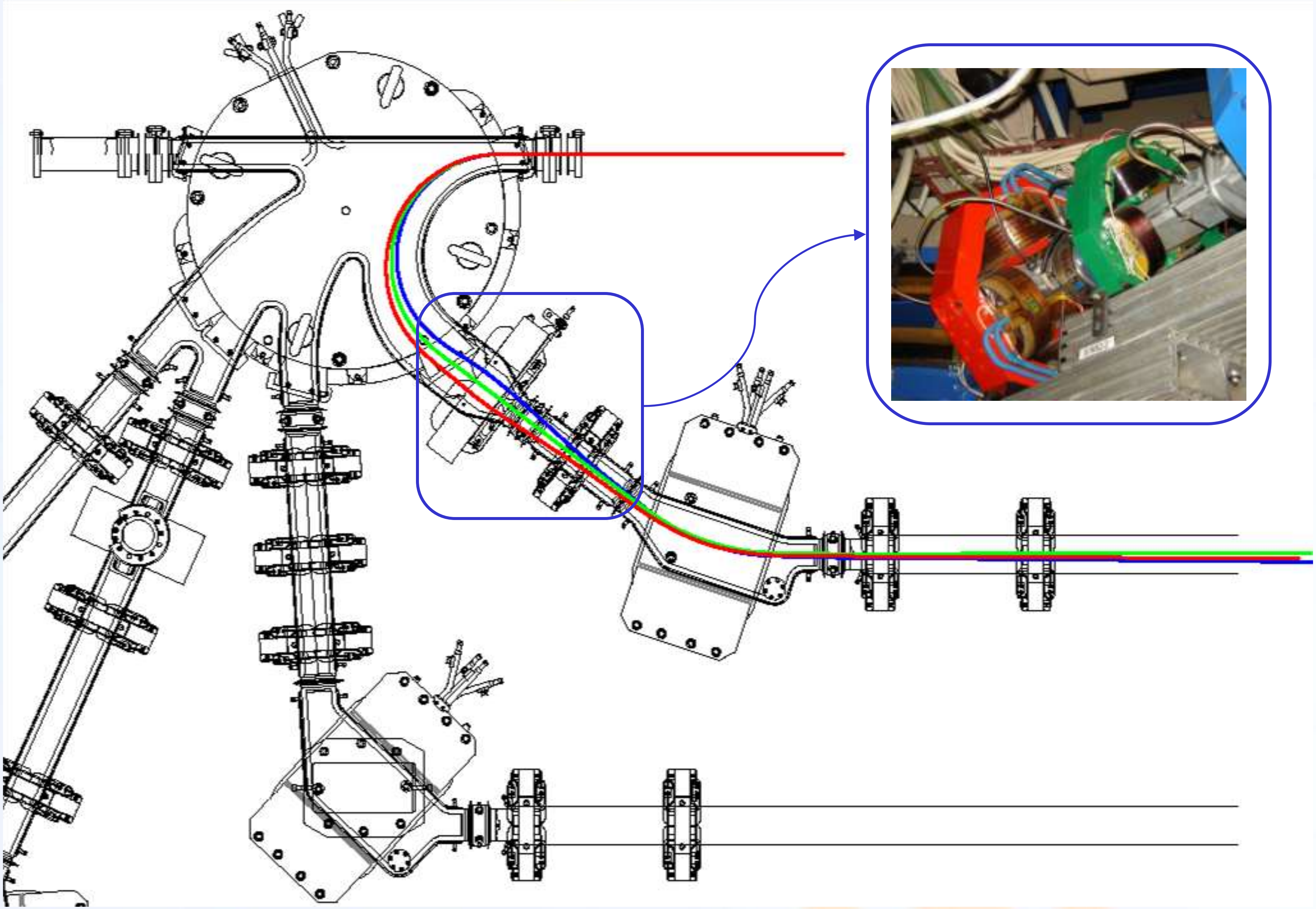


Compensation of chromatic aberrations



Simulated trajectories of particles with three different energies (tracking is done for real field distribution)

Compensation of chromatic aberrations



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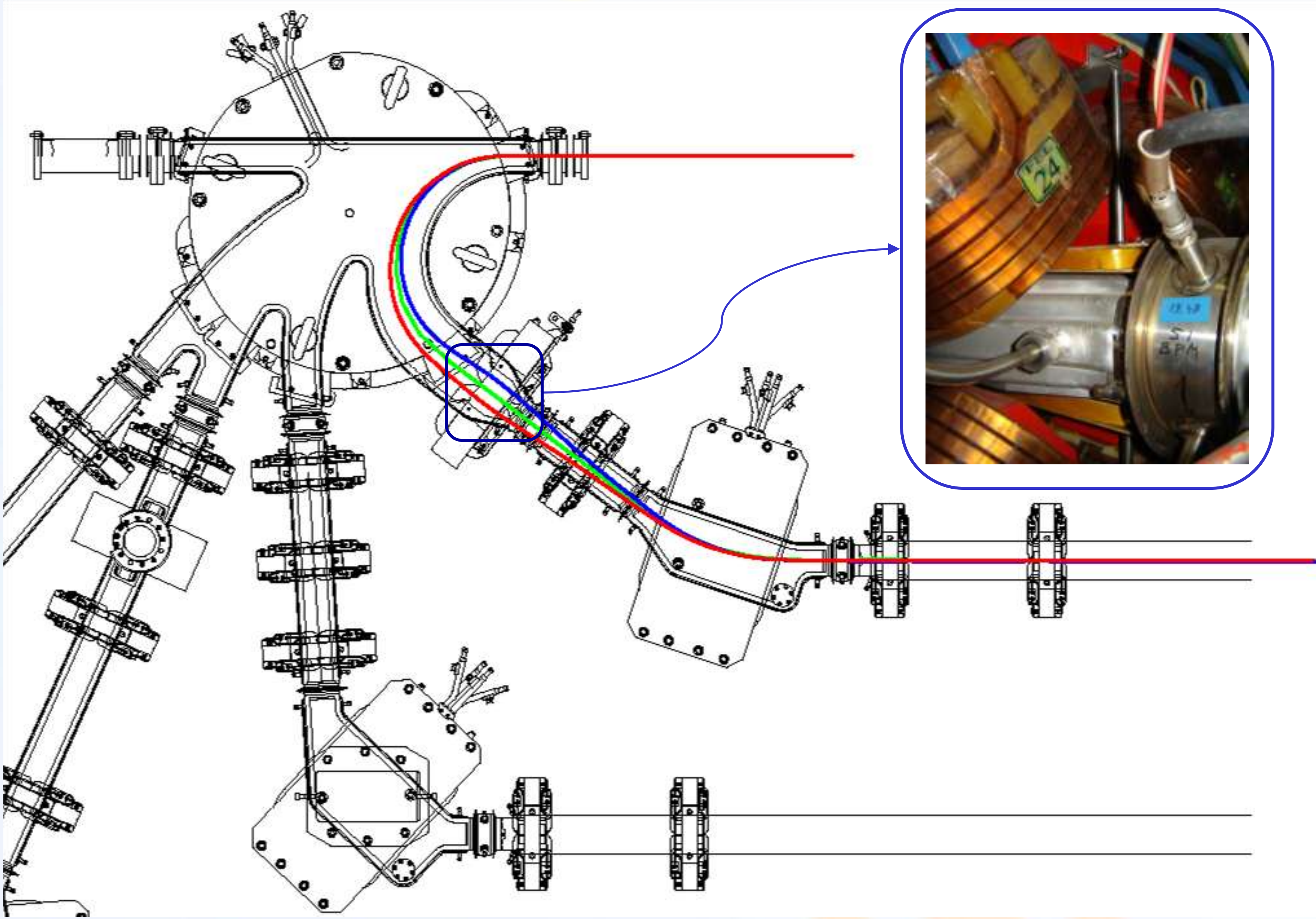

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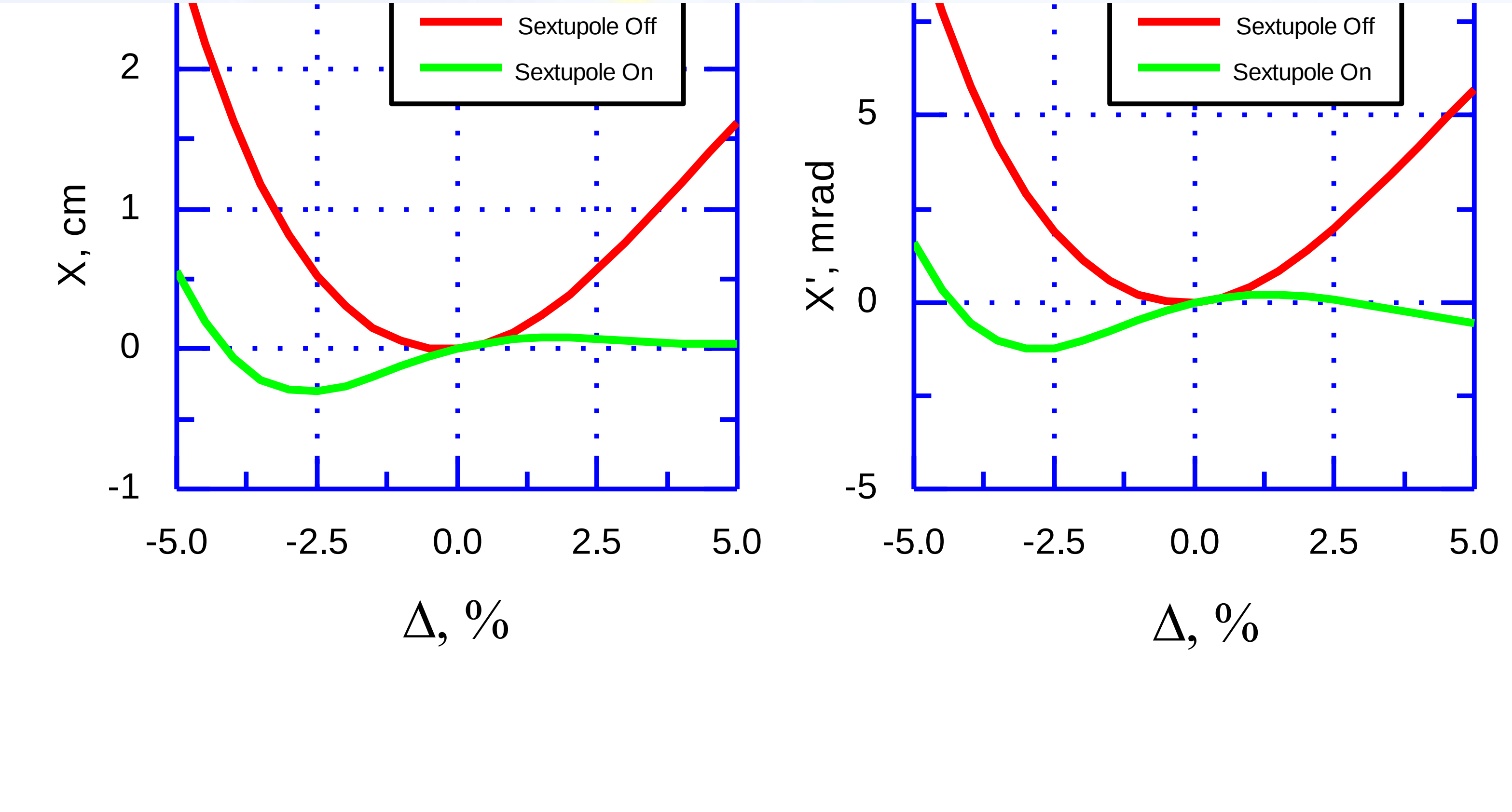
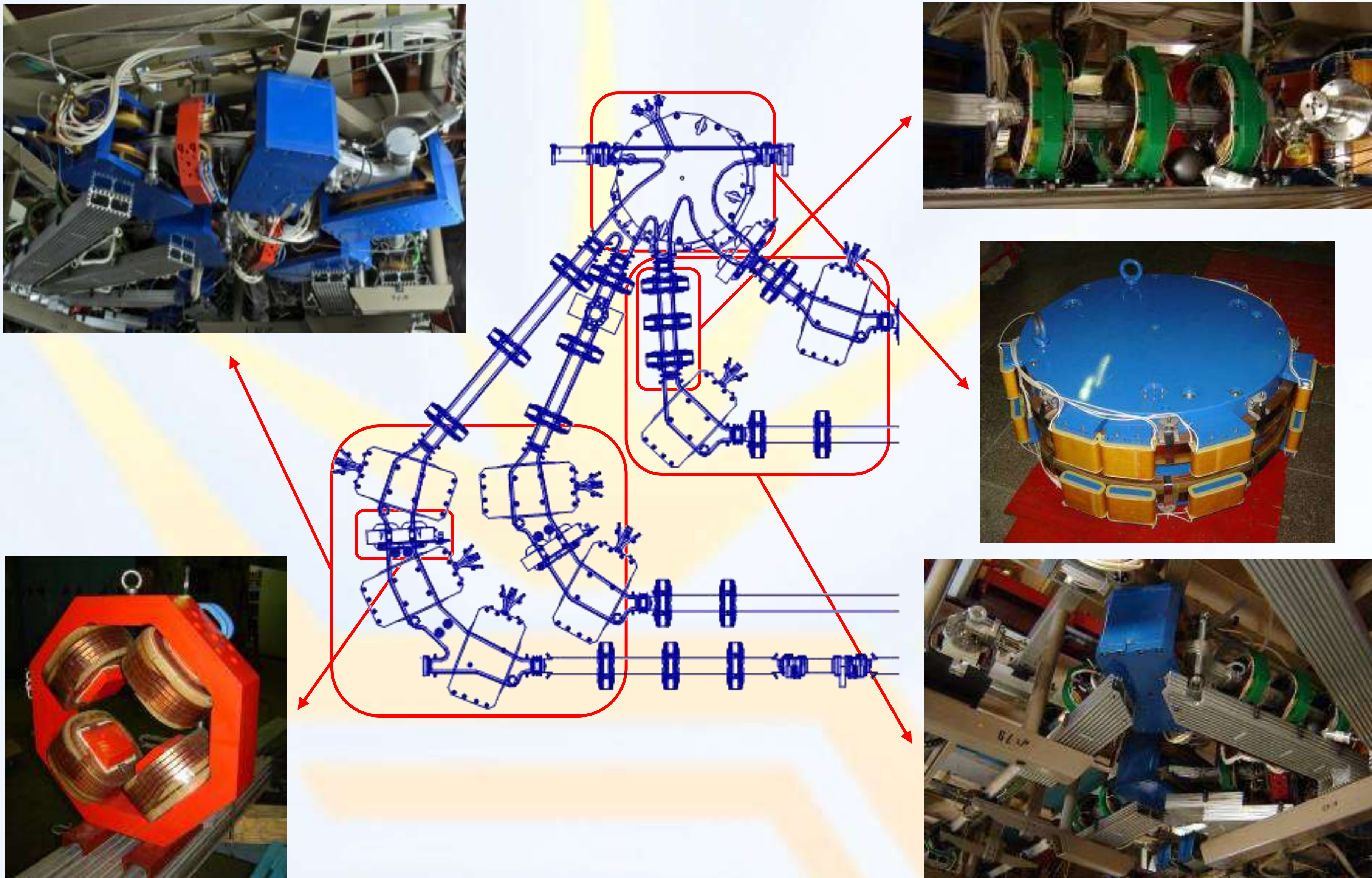


$$\delta\varepsilon = \frac{1}{2\varepsilon_0}\left(\beta_0\left\langle X'(\Delta)^2\right\rangle + 2\alpha_0\left\langle X'(\Delta)X(\Delta)\right\rangle + \gamma_0\left\langle X(\Delta)^2\right\rangle\right)$$

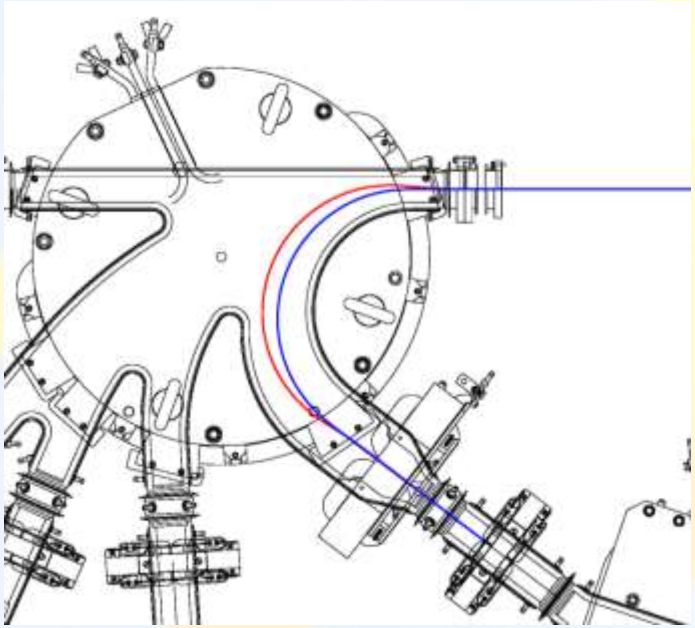
Emittance degradation

Magnets and vacuum chamber of bends



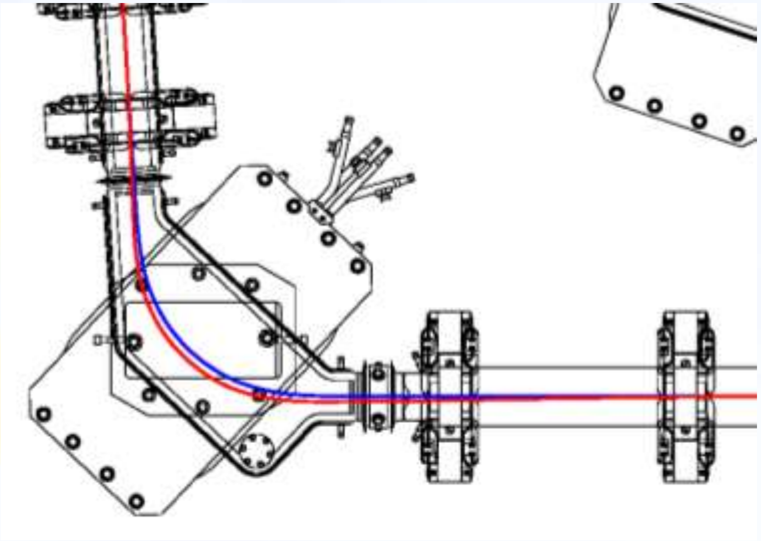
Adjustment of the orbit length

Common track round magnet

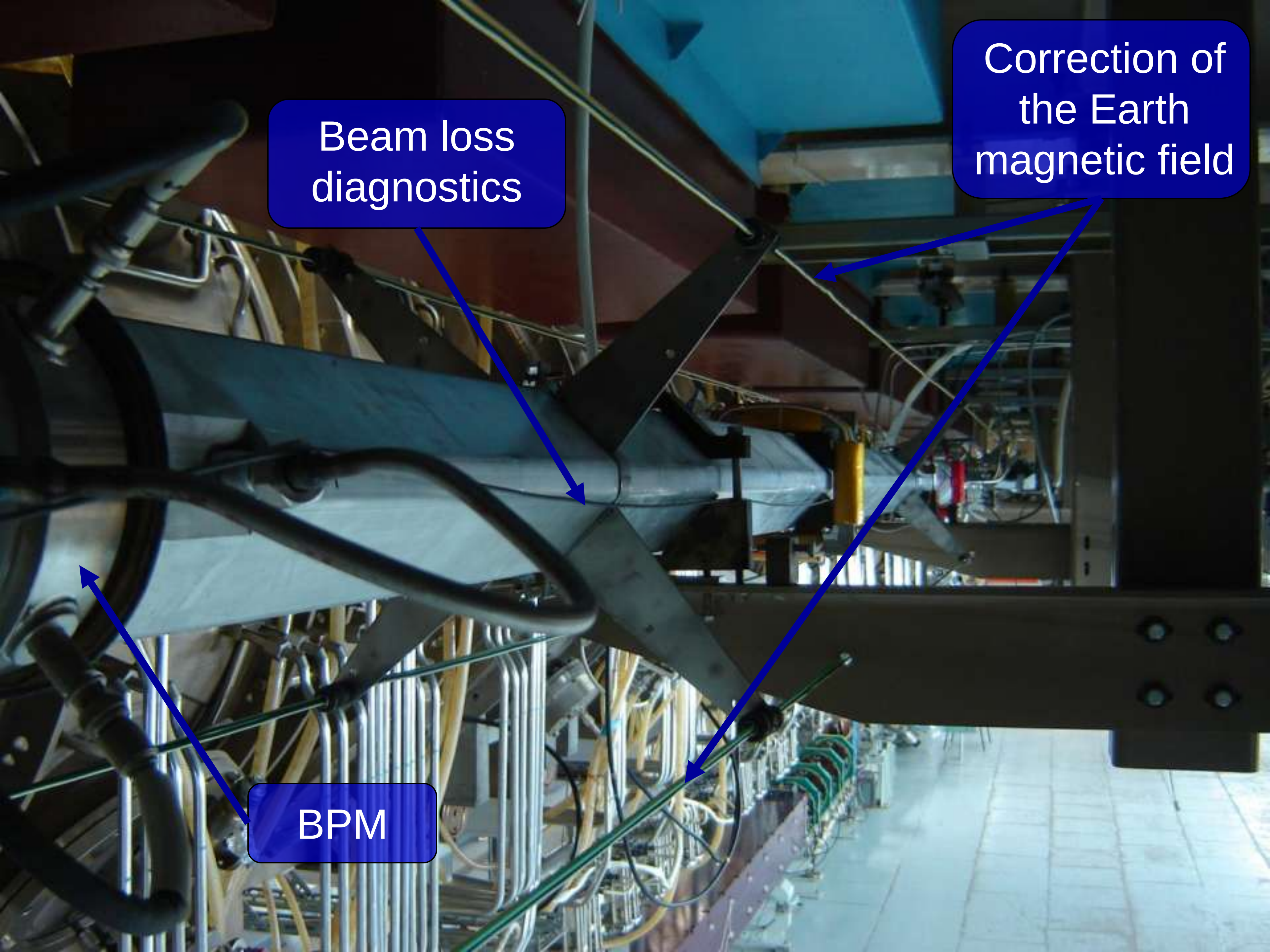


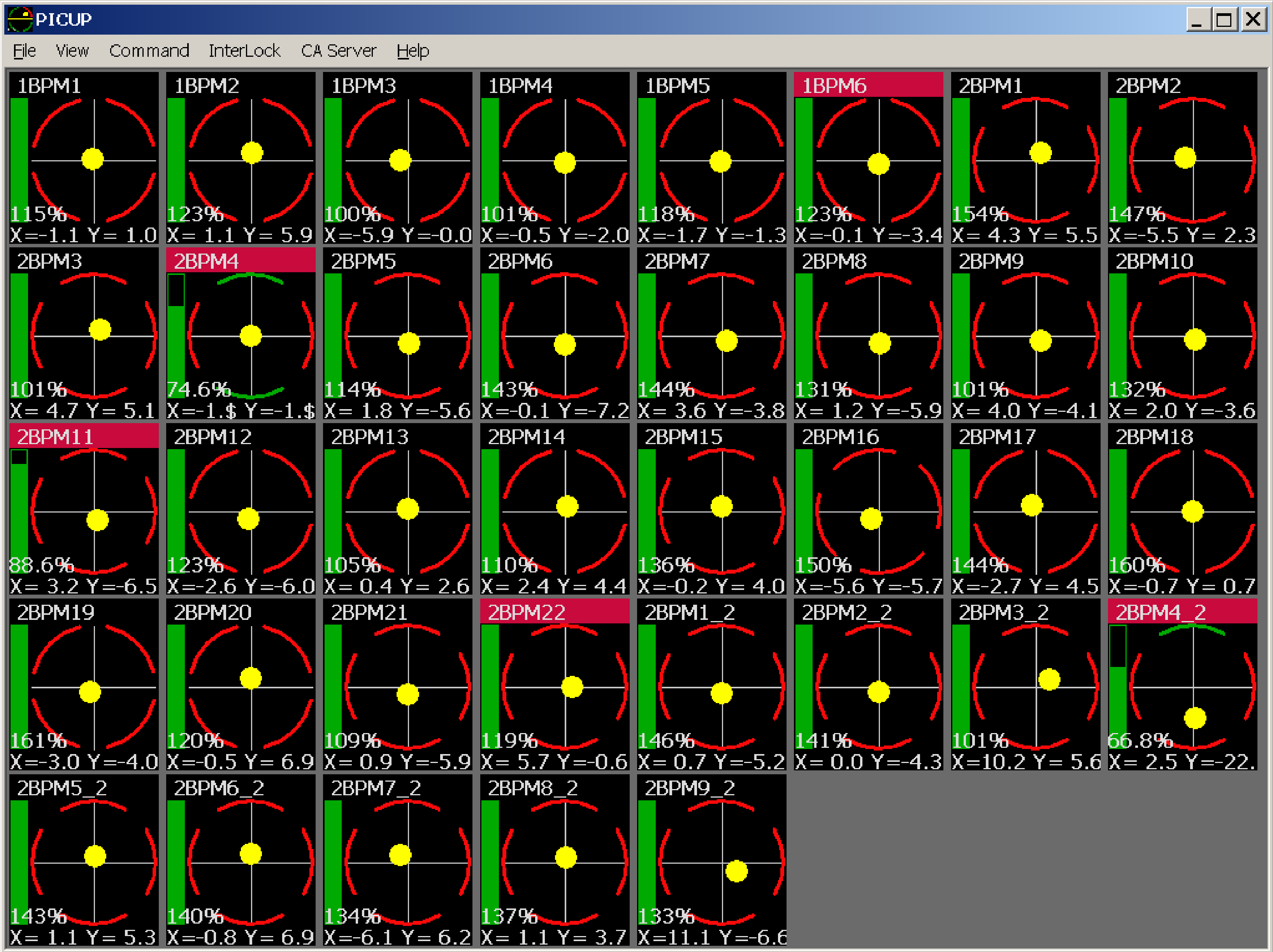
ΔL = 8 cm

Second track bending magnet

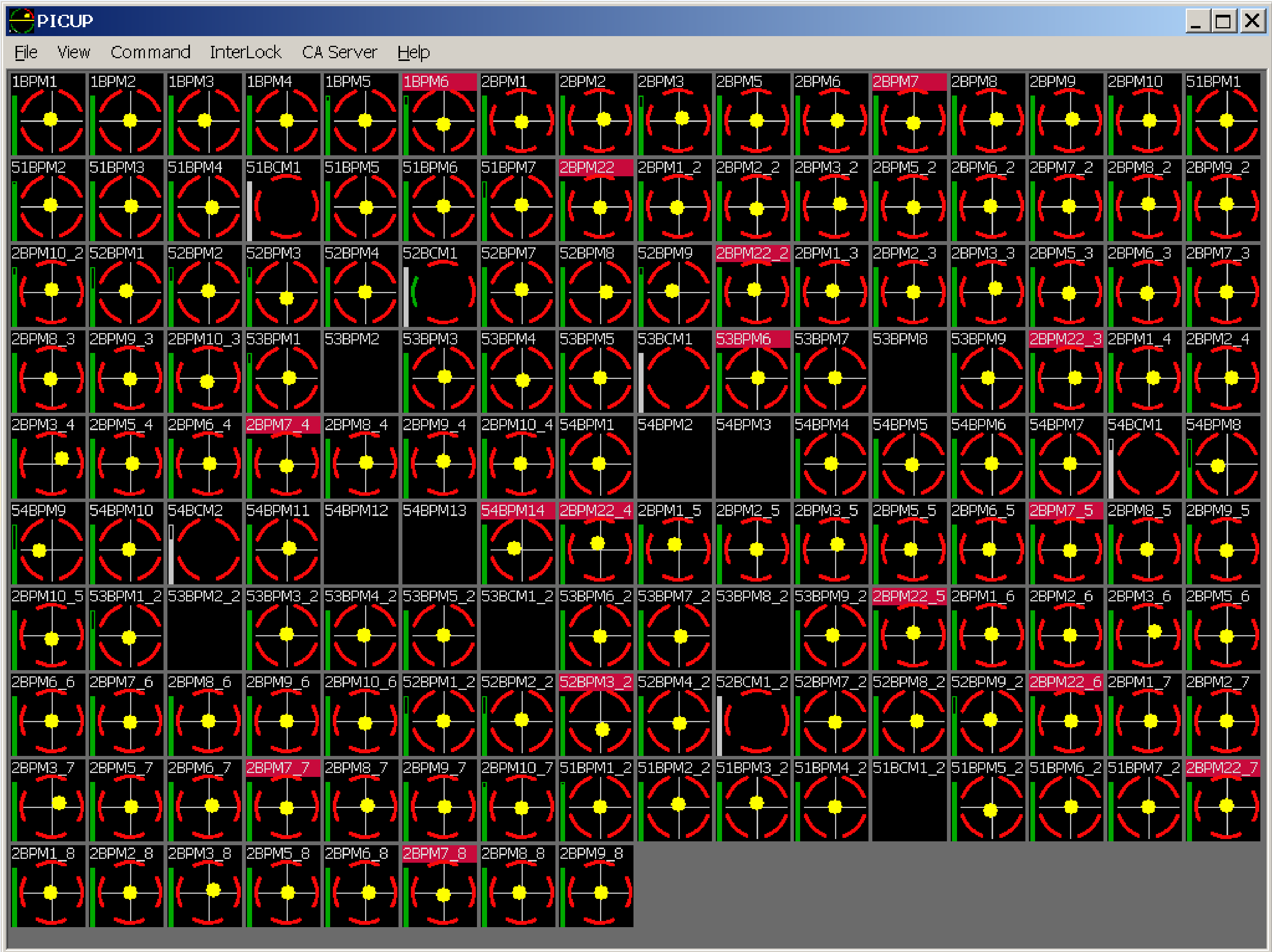


ΔL = 2 cm

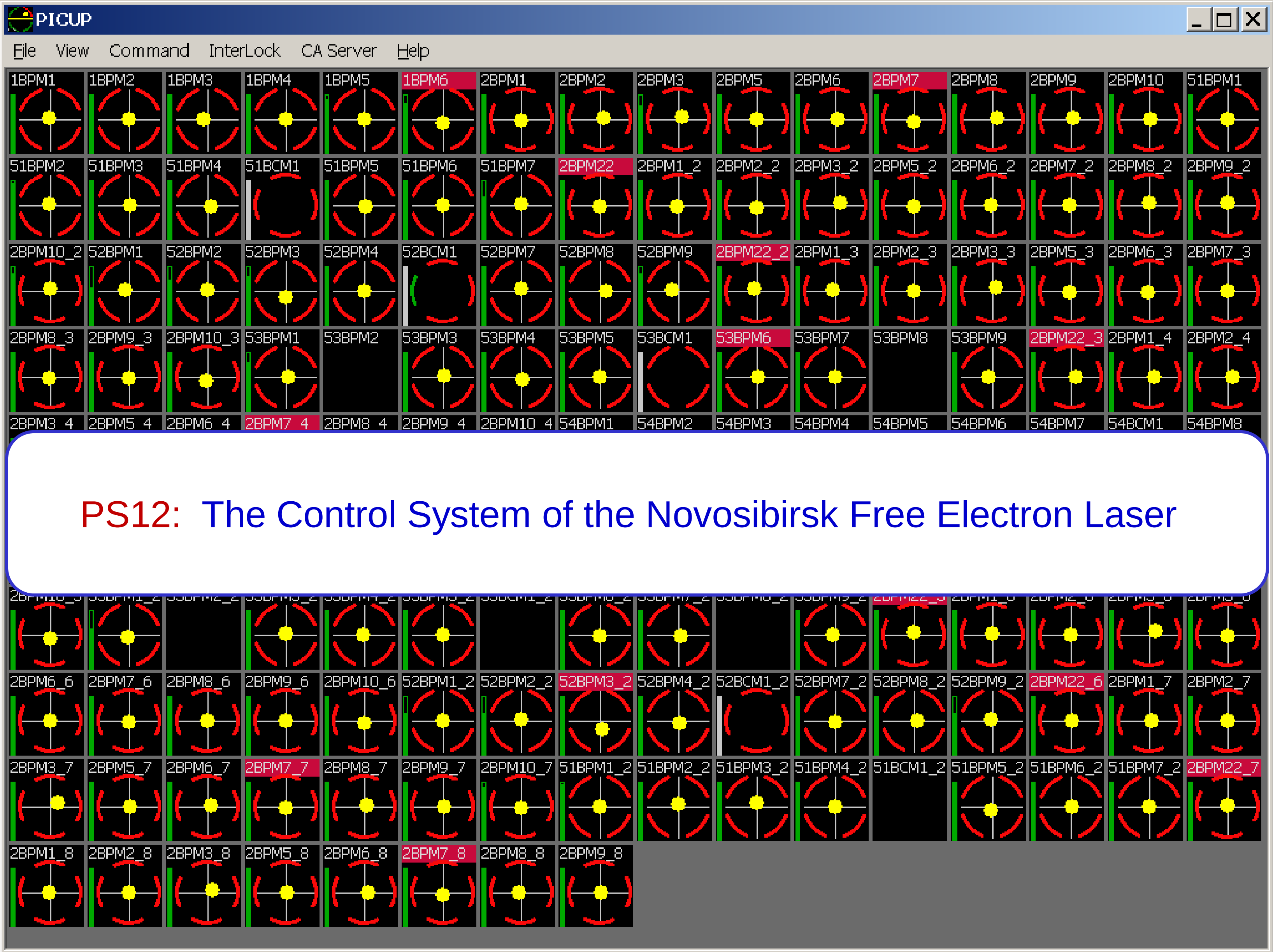

Beam loss diagnostics
Correction of the Earth magnetic field
BPM



1-st stage: 37 signals from BPMs



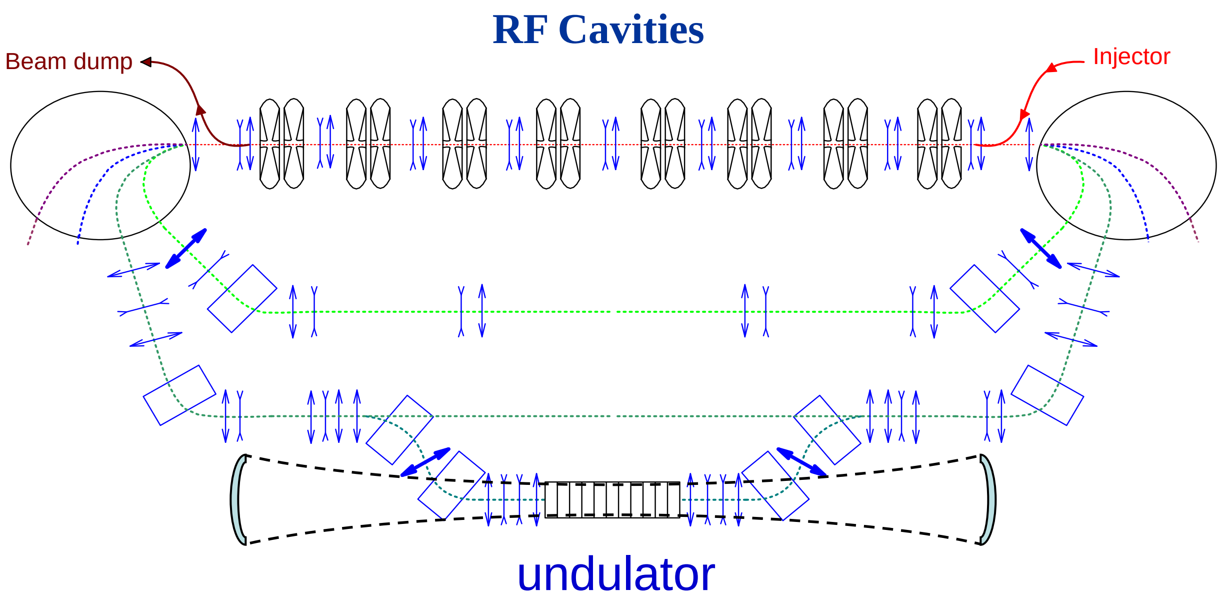
3-d stage: 152 signals from BPMs

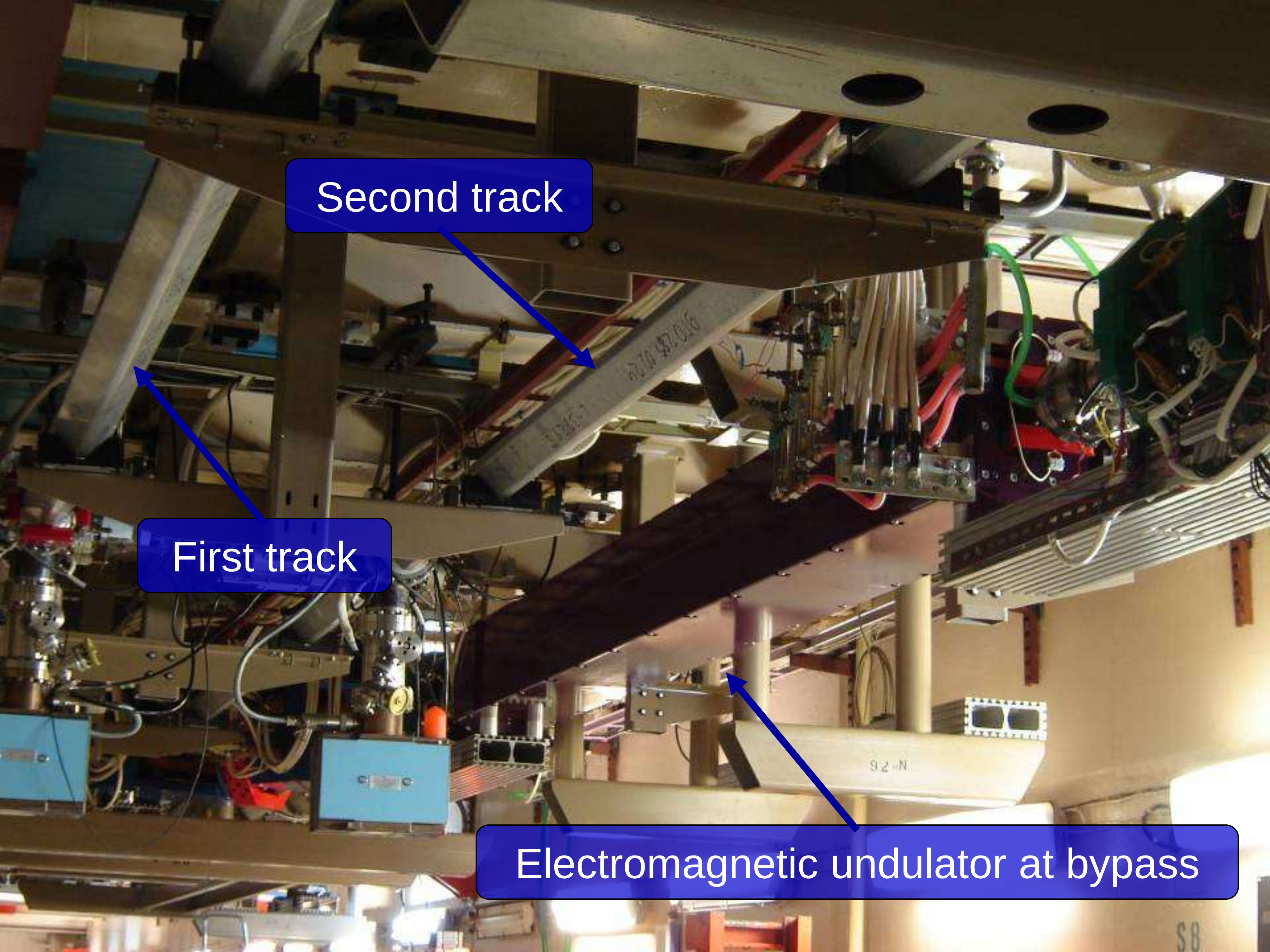


PS12: The Control System of the Novosibirsk Free Electron Laser

3-d stage: 152 signals from BPMs

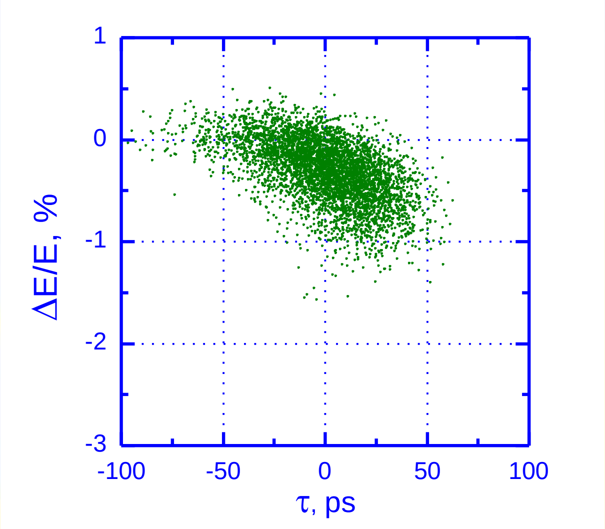
The second stage FEL scheme



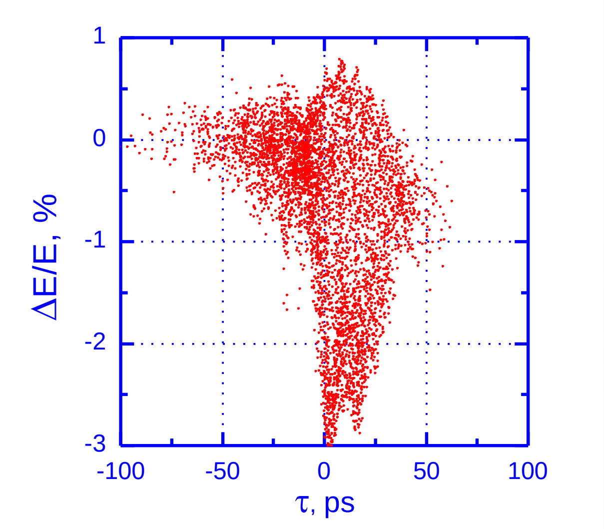


Second track
First track
Electromagnetic undulator at bypass

Before FEL

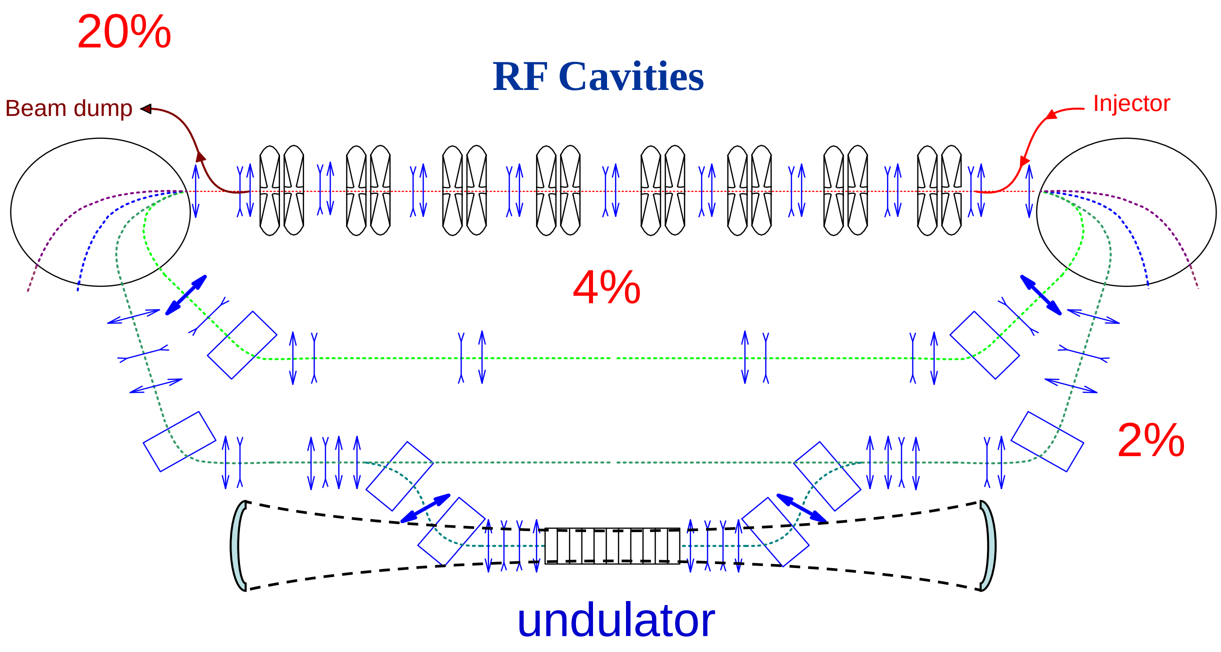


After FEL



Interaction of electrons with radiation in FEL leads to large energy spread. Moreover the relative energy spread increases at deceleration. Therefore the longitudinal acceptance is very important parameter of ERLs which work for FELs

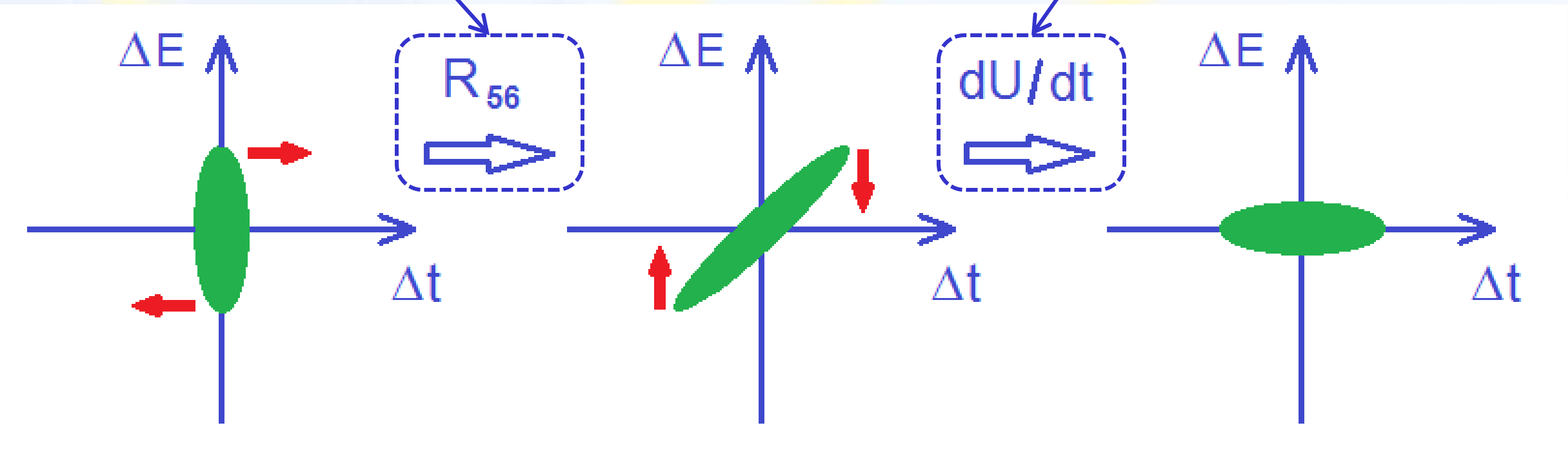
The second stage FEL scheme



Optimization of the deceleration phase

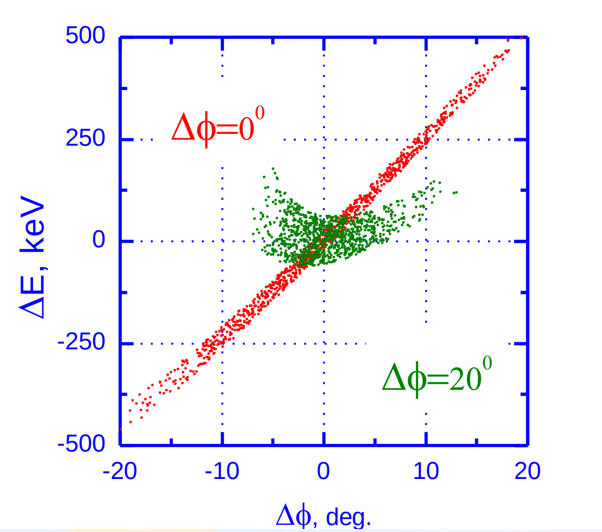
Longitudinal dispersion in bending magnets

Off crest deceleration in the linac

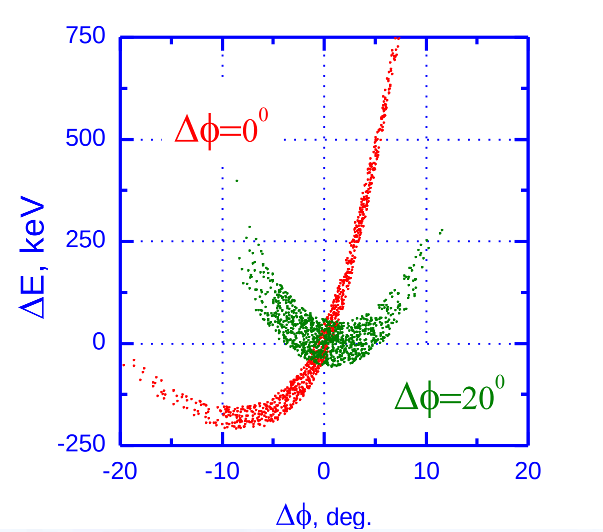


Optimization of the deceleration phase

The first track

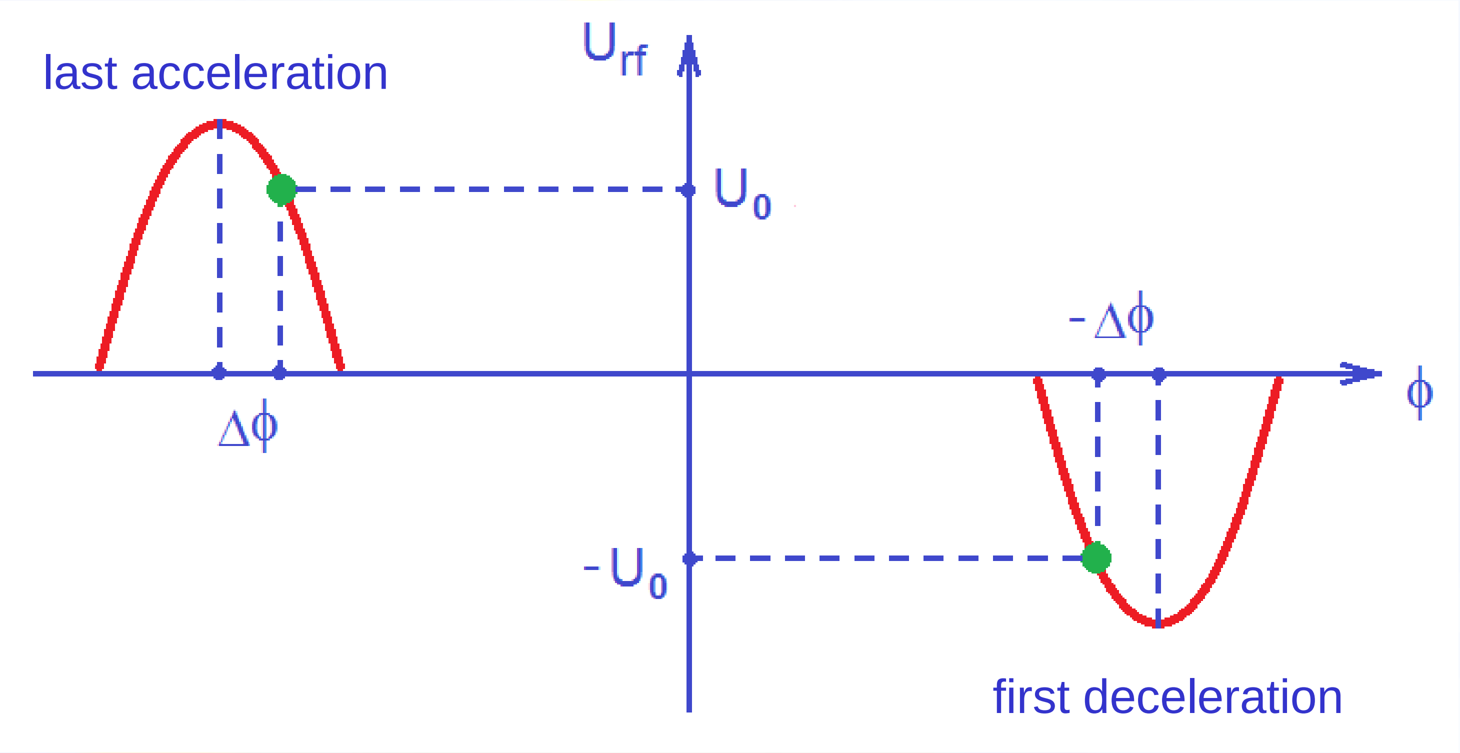


The dump



Beam longitudinal phase space for different deceleration phases

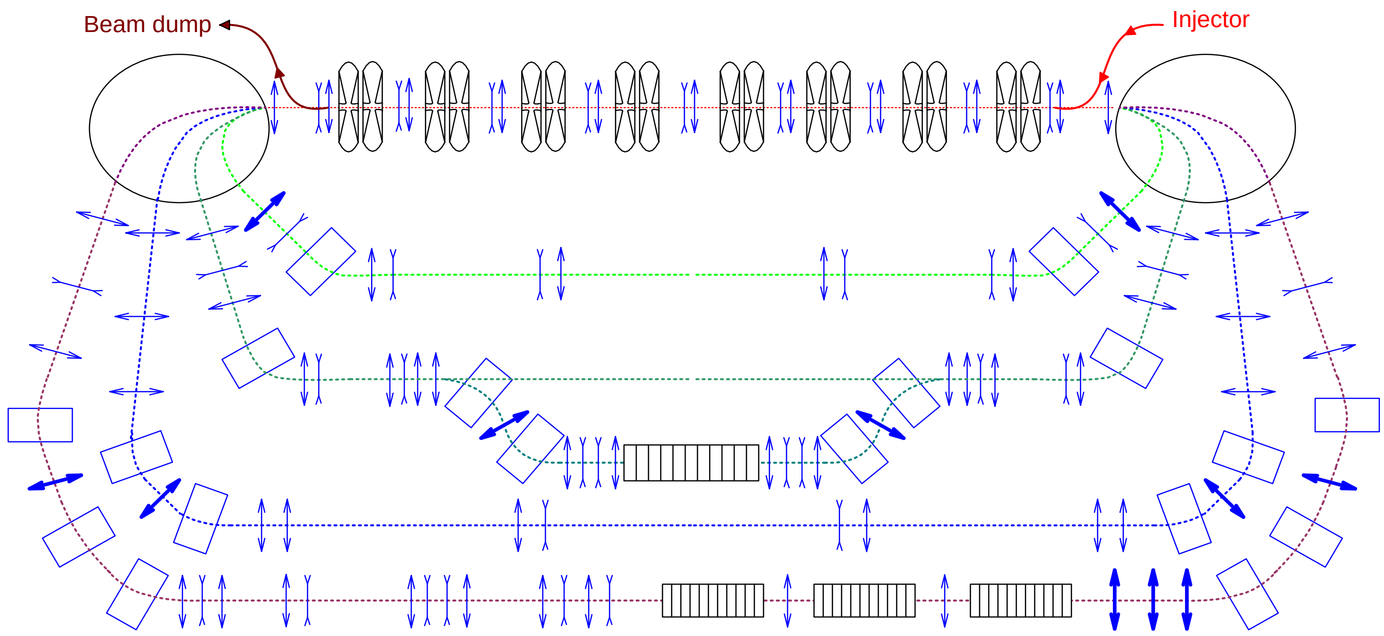
Optimization of the deceleration phase



$$L = \lambda_{rf}\left(N + \frac{1}{2} - \frac{\Delta\varphi}{\pi}\right)$$

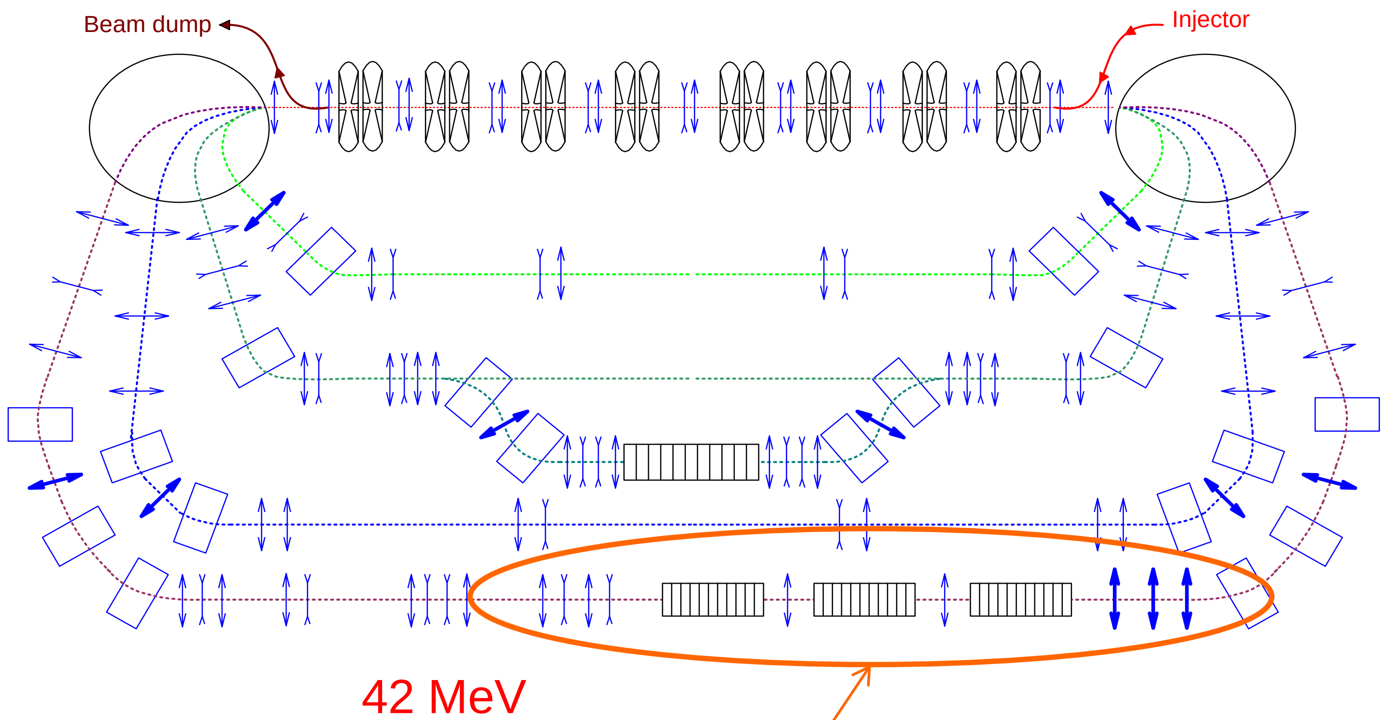
Length of the last track

The third stage FEL scheme



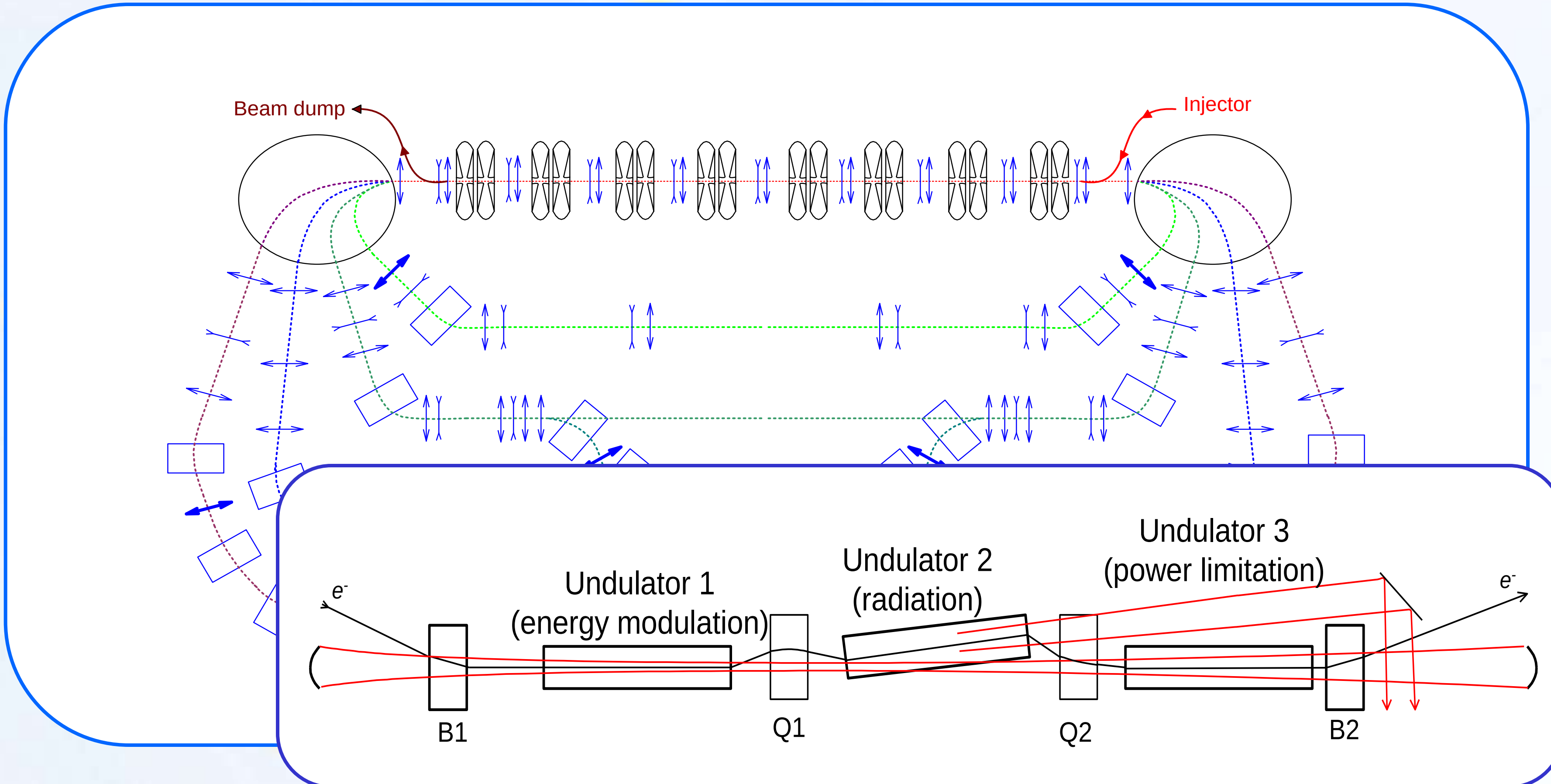
42 MeV

The third stage FEL scheme



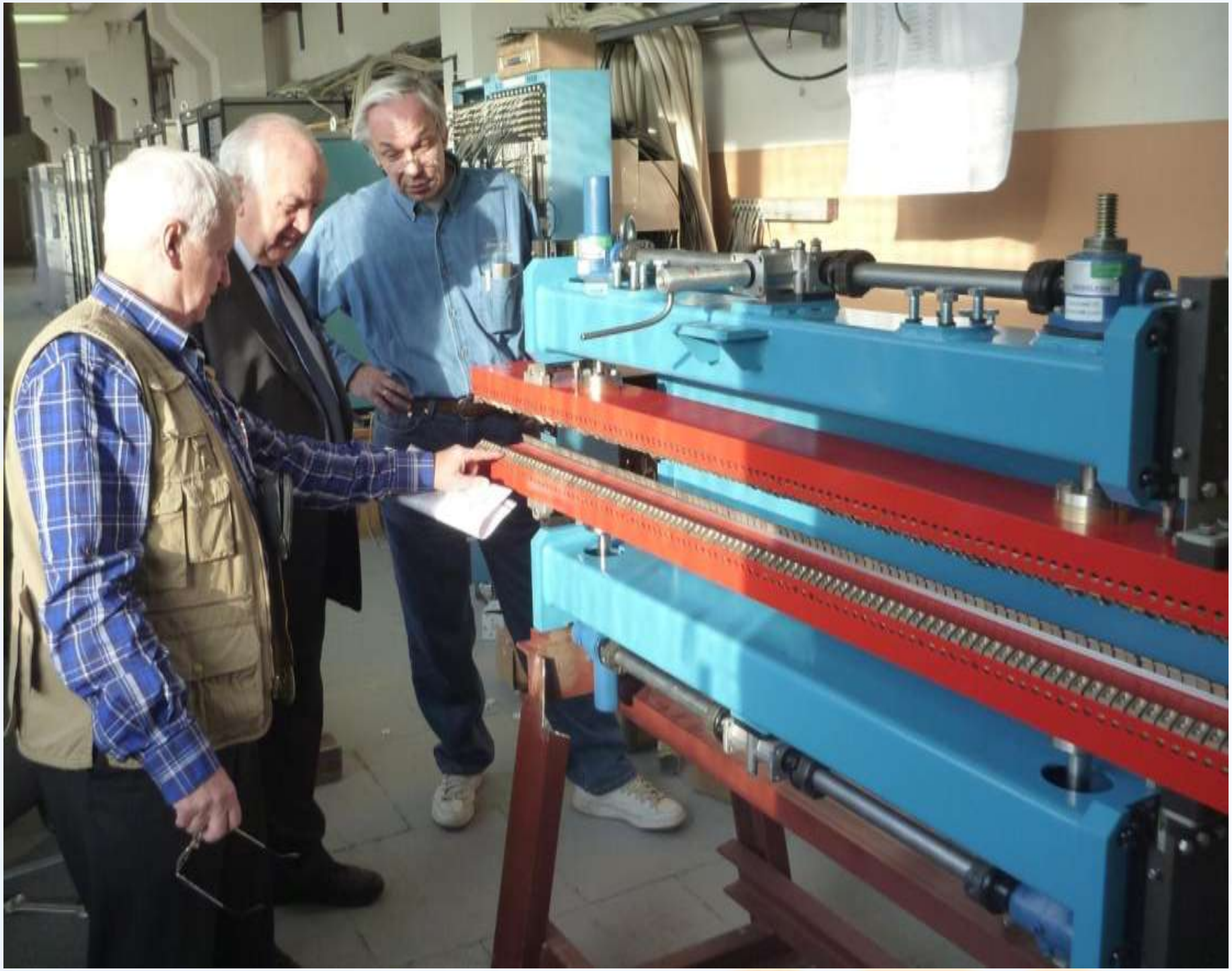
Electron outcoupling scheme is used here

The third stage FEL scheme

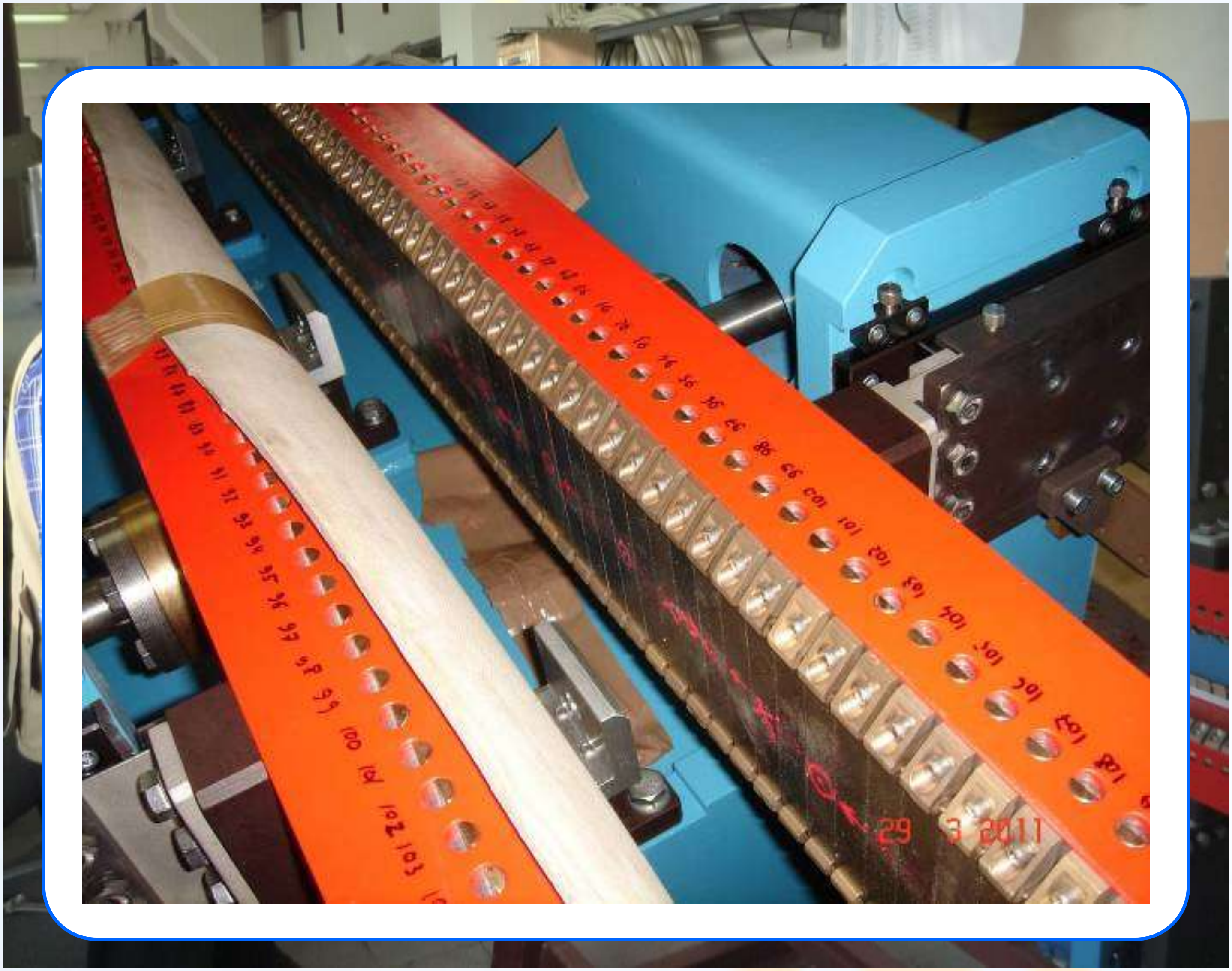


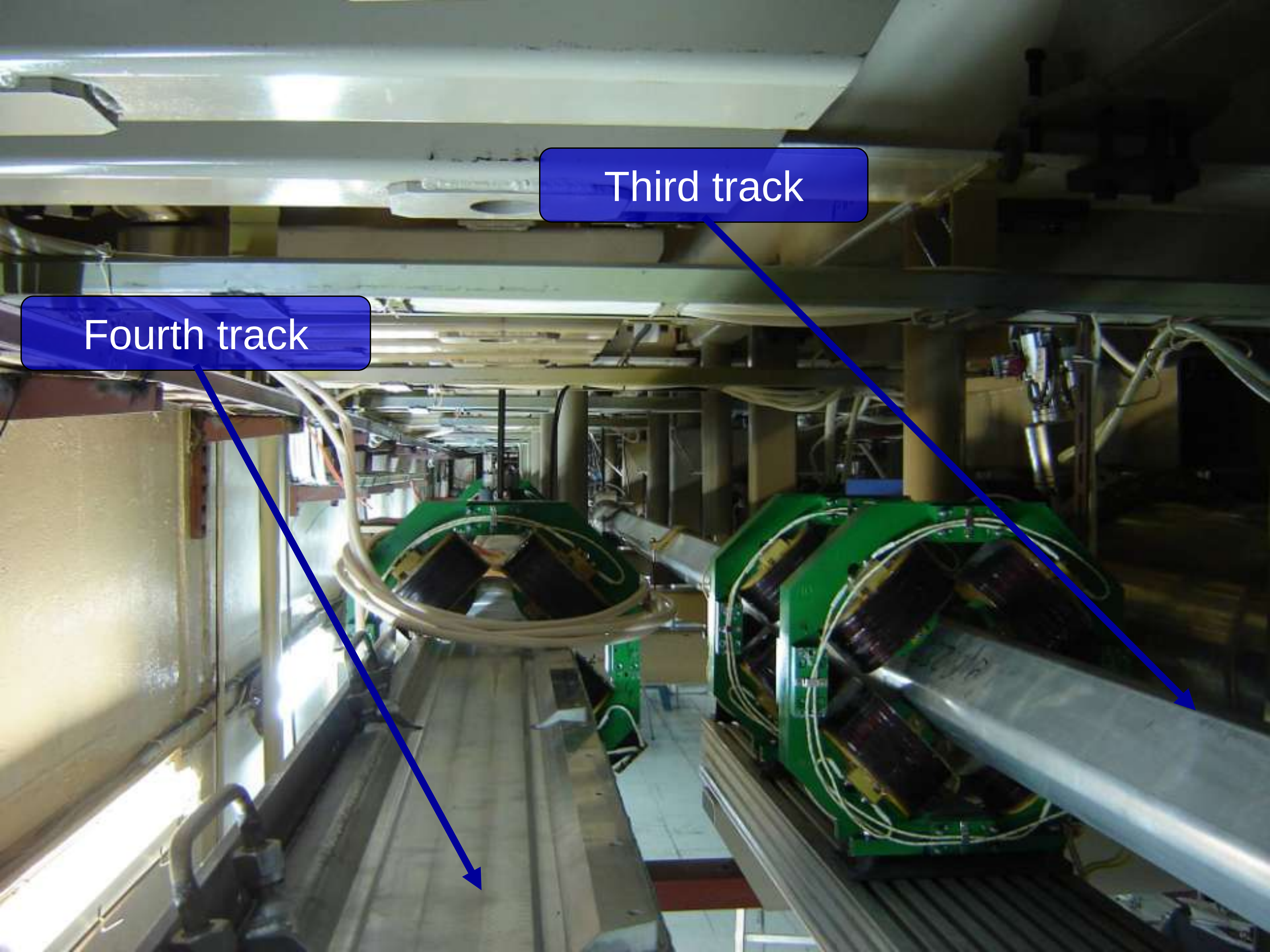
Electron outcoupling scheme is used here

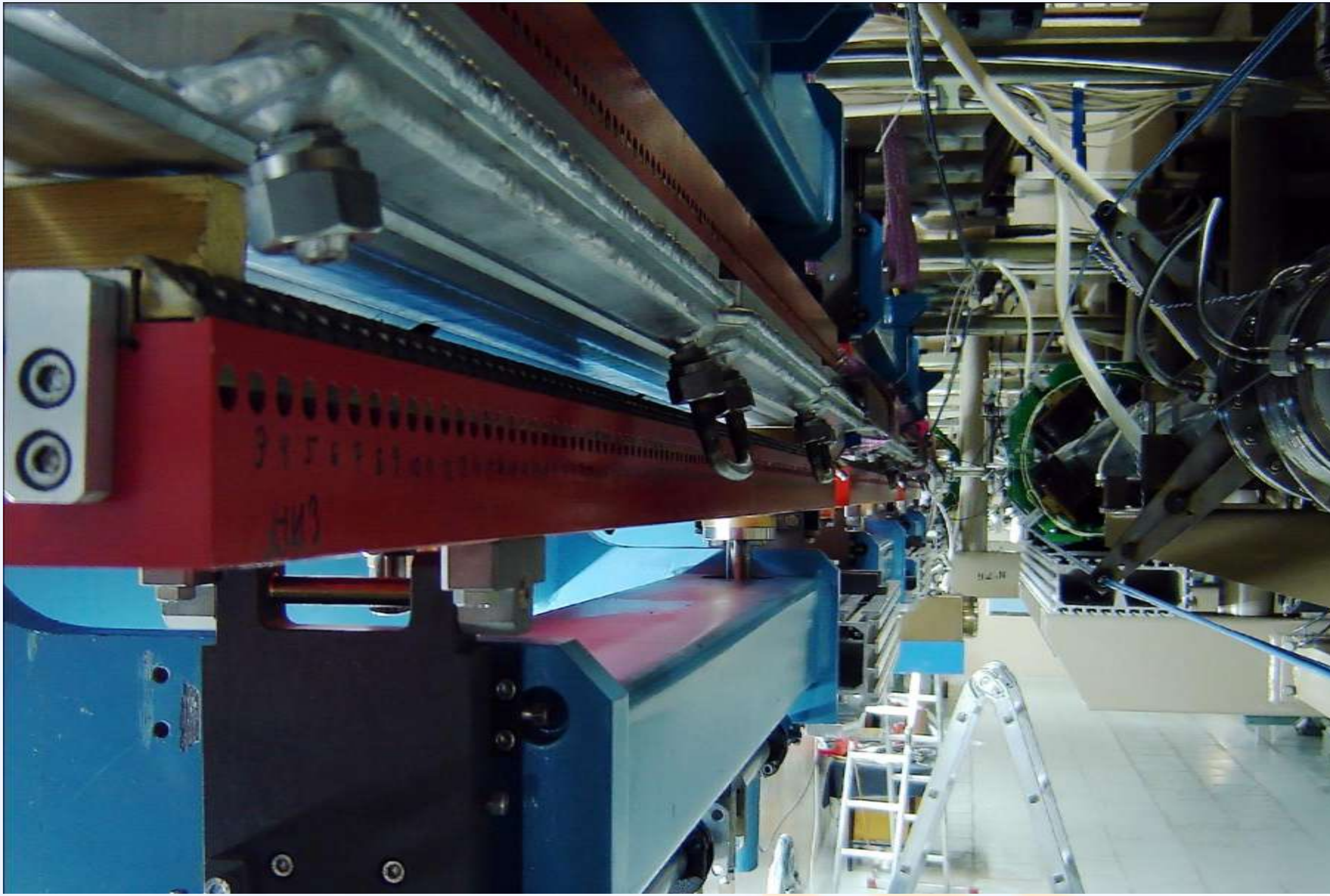
The 3rd stage FEL undulator



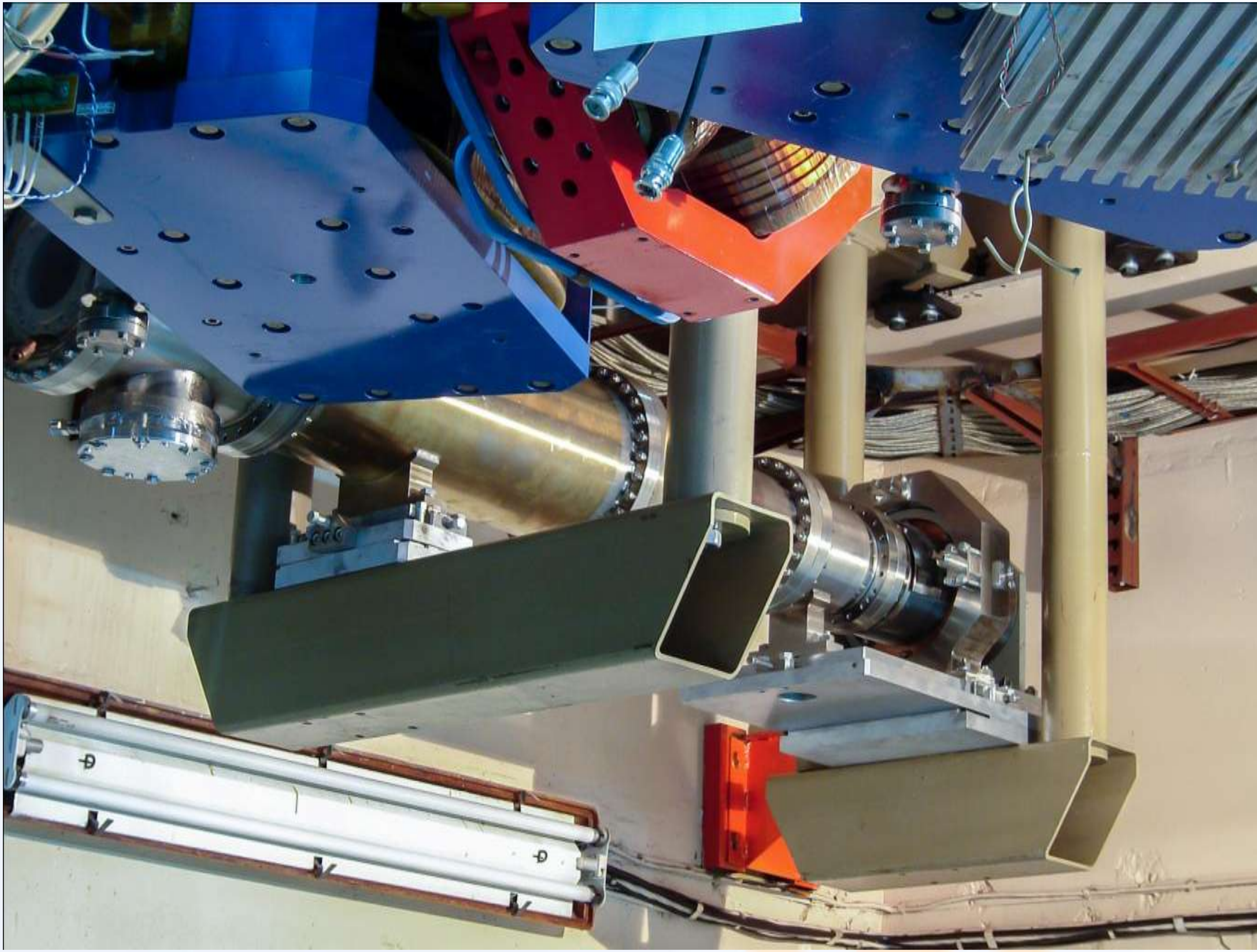
The 3^{rd} stage FEL undulator

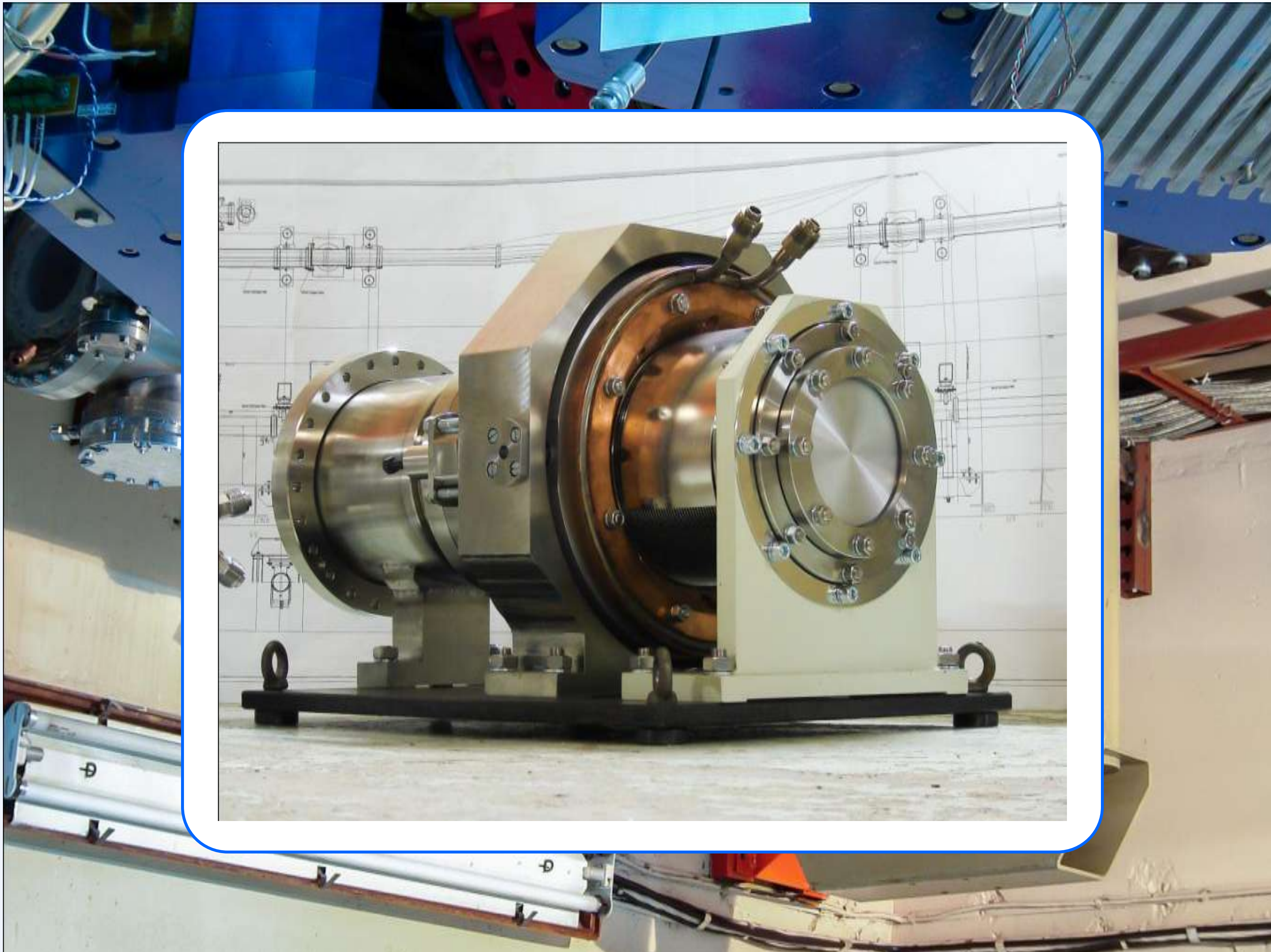



Third track
Fourth track

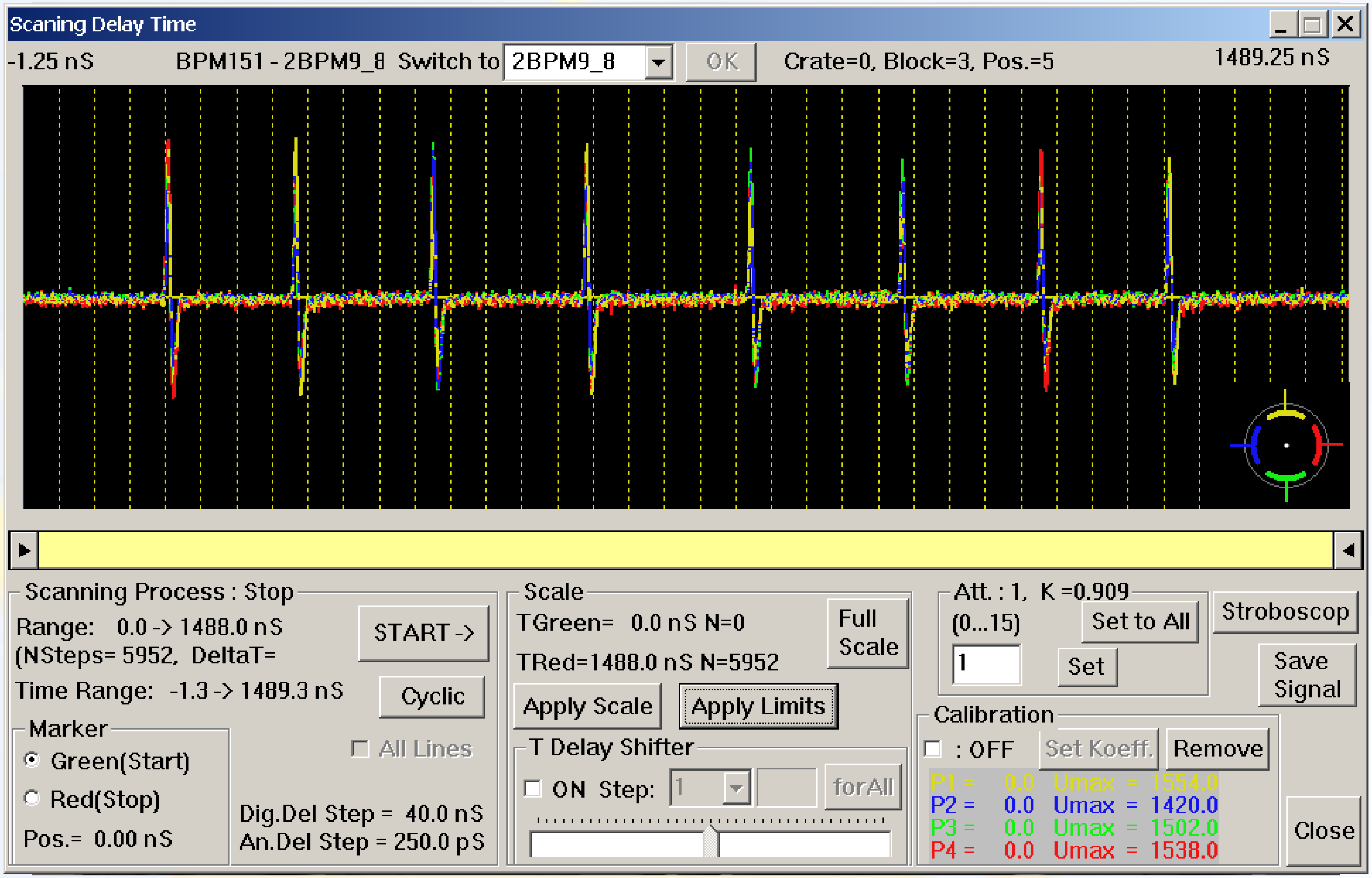



B-3

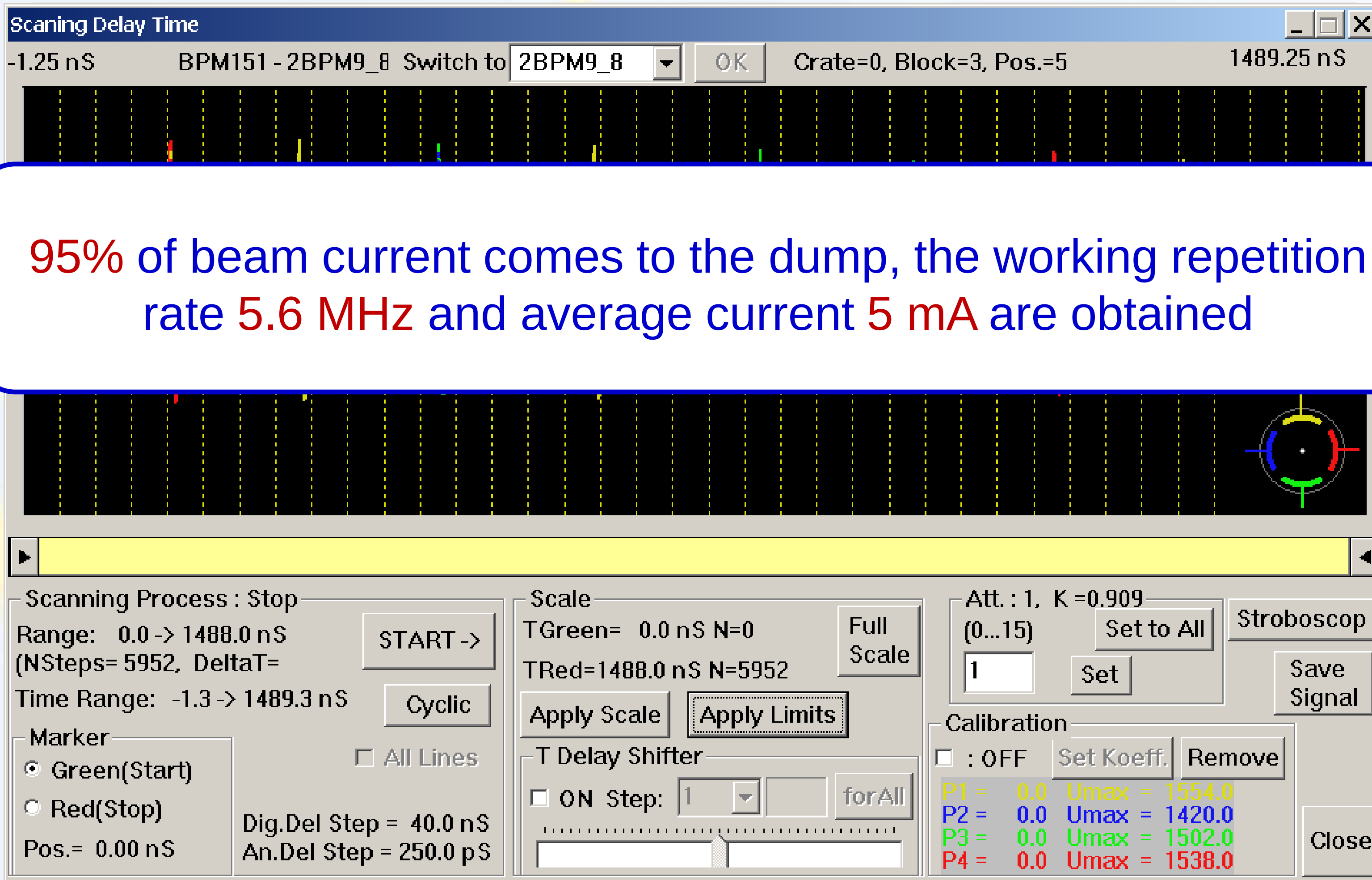




22 May 2012 – the first time the beam reached the dump after four accelerations and four decelerations

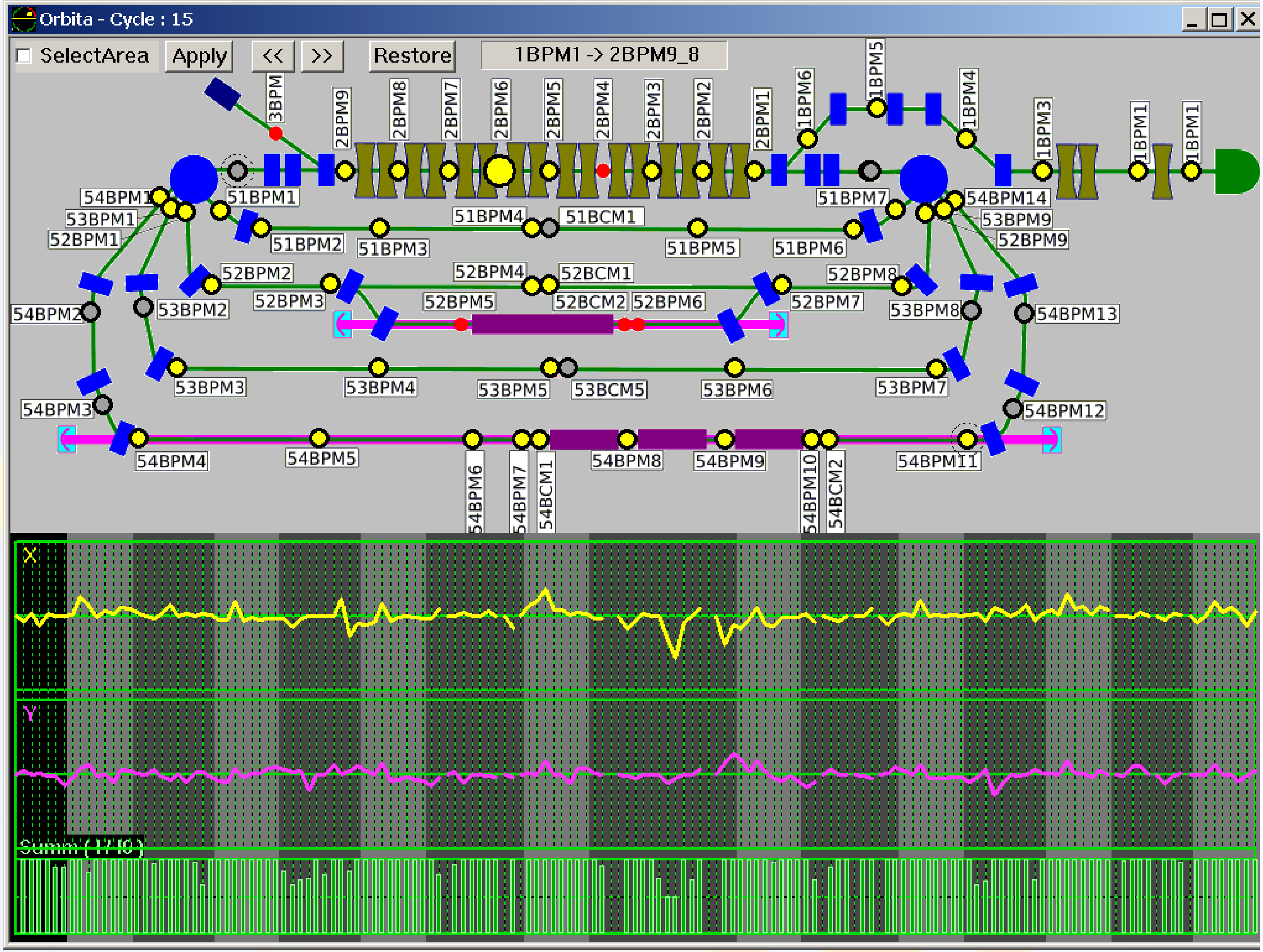


22 May 2012 – the first time the beam reached the dump after four accelerations and four decelerations



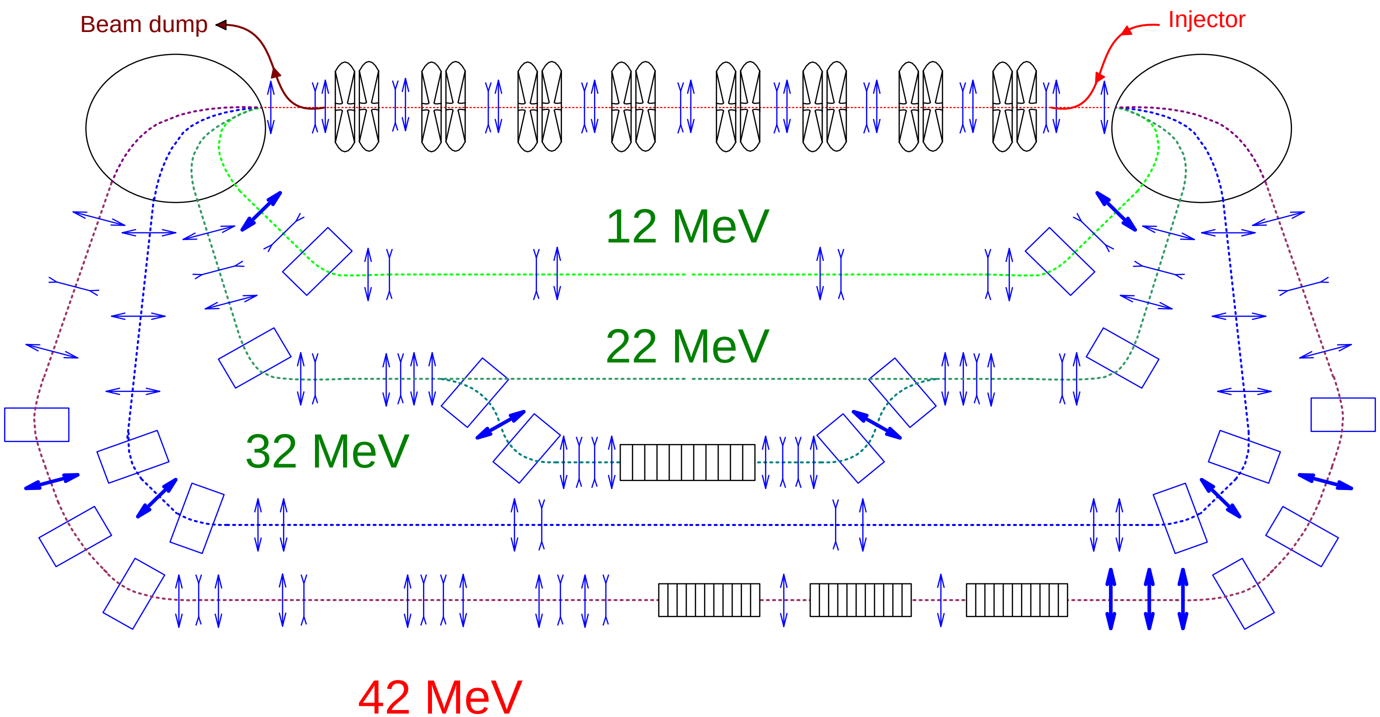
95% of beam current comes to the dump, the working repetition rate 5.6 MHz and average current 5 mA are obtained

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

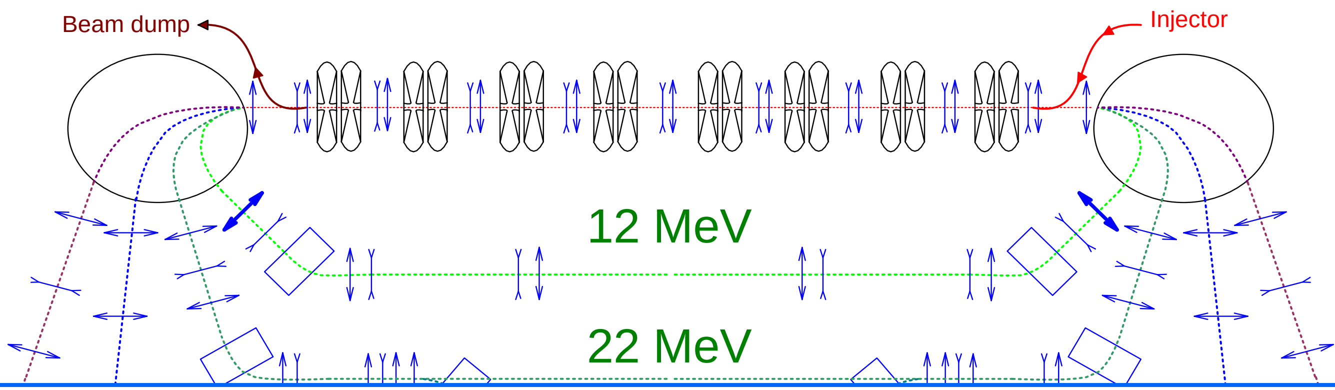


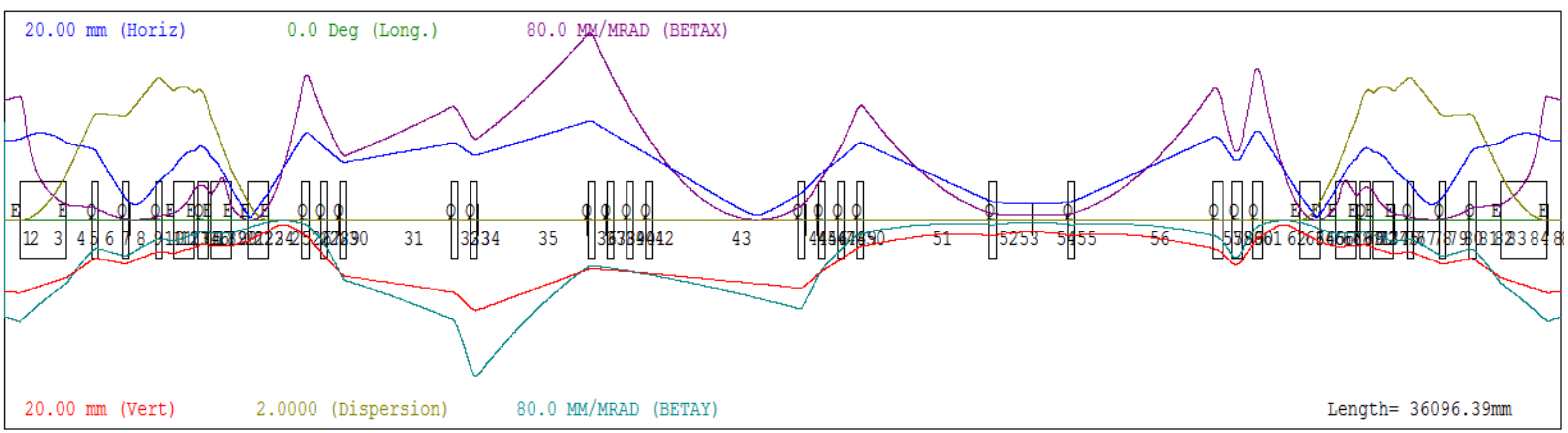
BPMs and beam trajectories

Lattice optimization



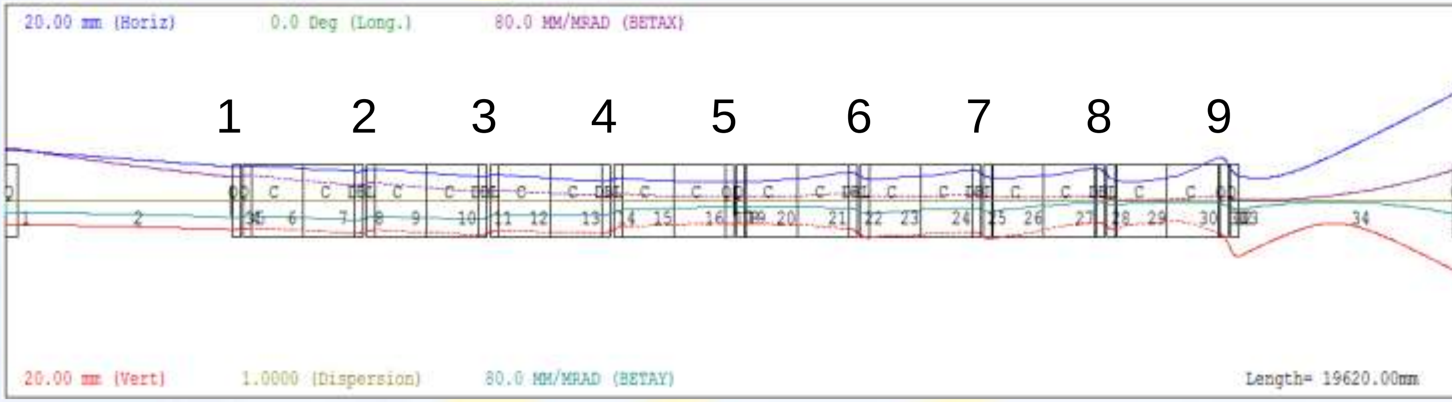
Lattice optimization





Optimization of transversal acceptance

the last deceleration
12=>2 MeV



Looking for the minimum of

$$F\left(\beta_n{}^{(0)},\alpha_n{}^{(0)},\gamma_n{}^{(0)}\right)=\sum_{i=1}^{9}\varepsilon_n\beta_n{}^{(i)}=\sum_{i=1}^{9}\sigma_i^2$$

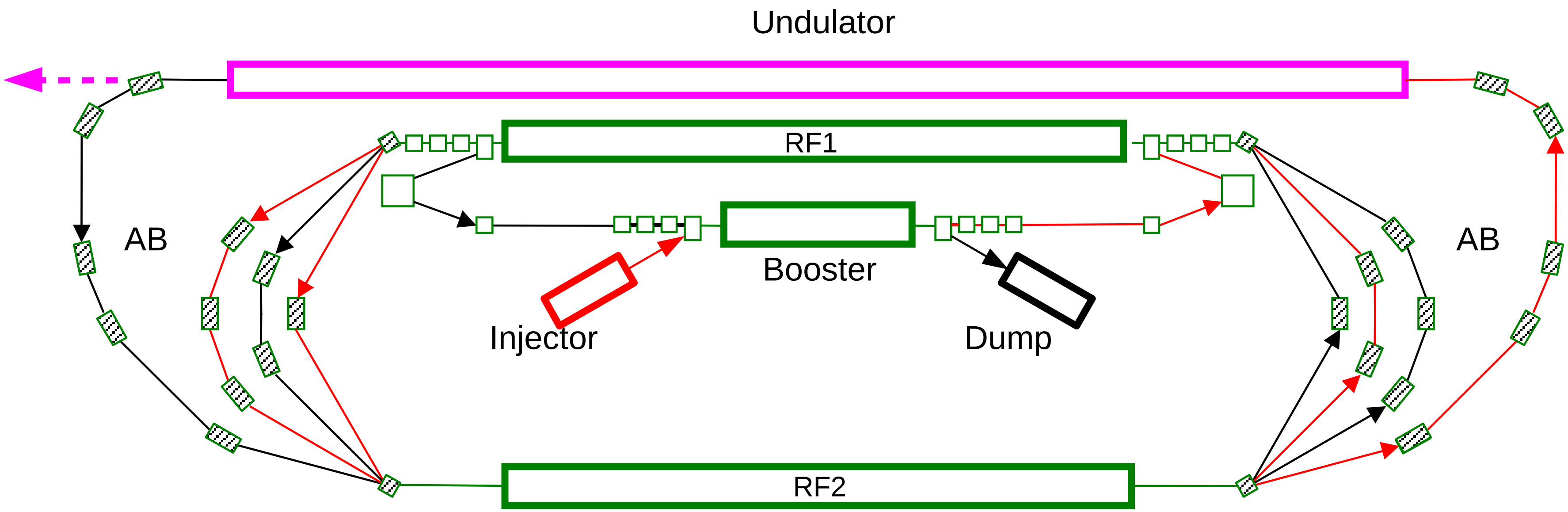
at

$$\beta_n{}^{(0)}\gamma_n{}^{(0)}-\alpha_n{}^{(0)2}=1$$

$\beta_n=\beta/\gamma_r$ - normalized beta-function

$\sigma_i{}^2=\varepsilon_n\beta_n{}^{(i)}$ - mean-square beam size at *i* – th aperture

$$\beta_n{}^{(i)}=S_{1,1}^{(i,0)}\beta_n{}^{(0)}+S_{1,2}^{(i,0)}\alpha_n{}^{(0)}+S_{1,3}^{(i,0)}\gamma_n{}^{(0)}$$


Undulator
RF1
AB
AB
Booster
Injector
Dump
RF2

The second and the third stages ERL and FEL basic parameters

Electron beam energy, MeV	20 / 40
Number of orbits	2 / 4
Maximum bunch repetition frequency, MHz	22 (90)
Beam average current, mA	30 (100)
Wavelength range, micron	5-20 / 35-80
Maximum output power (at 100 mA), kW	3 / 6

Current status

The first in the world multiturn ERL was commissioned and now it works for high power FEL (average power 0.5 kW in wavelength range 40-80 microns). The FEL radiation is delivered to exiting user stations.

Commissioning of the third stage ERL is in progress. The recuperation efficiency more than 90 % is already achieved that allowed to obtain the maximum repetition rate 5.6 MHz and the average current 5 mA (The repetition rate which is required to get FEL lasing is 3.75 MHz).

Nearest plans

- Commissioning of the third stage ERL and FEL: lattice optimization; installation of the optical cavity.

- Existing FELs stability and parameters improvement: modification of RF power generators; production of the new power supply for existing DC gun and new RF gun development.

- Working for users and new user stations development.

NovoFEL Team

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Thank you for your attention!