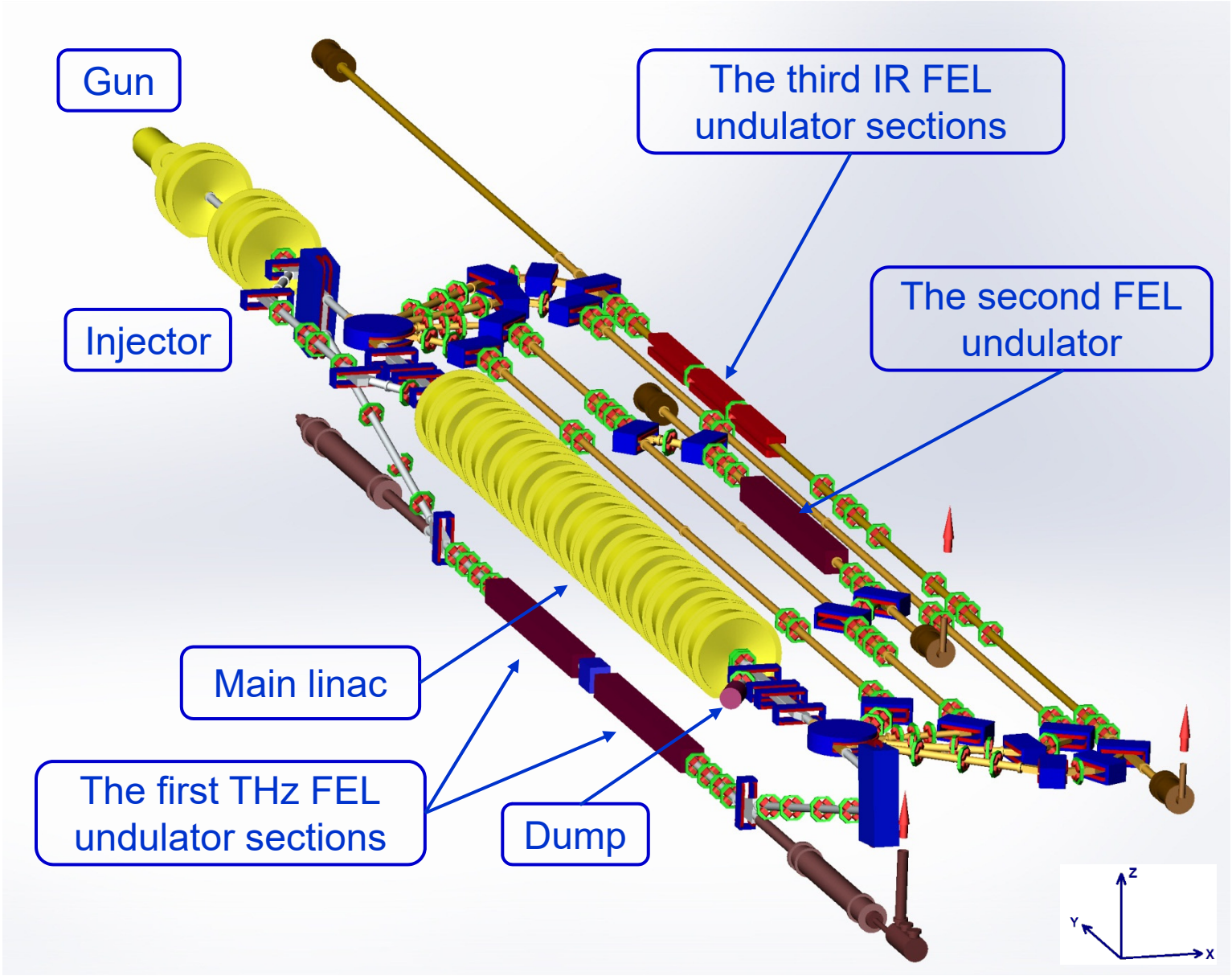
Novosibirsk ERL Injector

Presented by O.A. Shevchenko, BINP

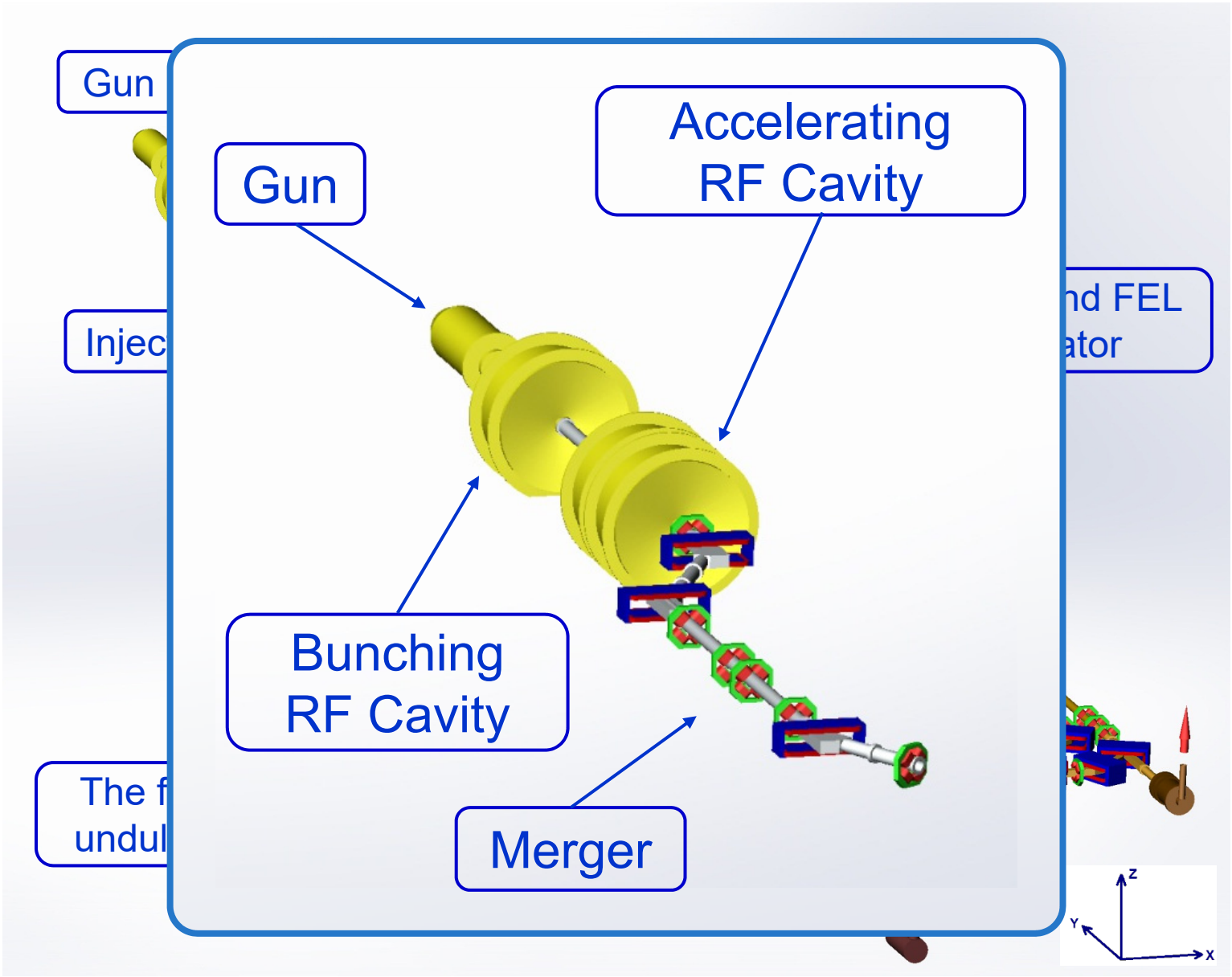
Outline

1. Requirements for the beam quality
2. Overview of the NovoFEL injector design
3. Beam dynamics simulation
4. Diagnostics and beam parameters measurement
5. Further development of the injection system
6. Summary

NovoFEL Accelerator Layout



NovoFEL Accelerator Layout



Beam, undulator and radiation parameters

	1st	2nd	3d
Wavelength, μm	90 - 240	37 - 80	7 - 15
Round trip frequency, MHz	5.64	7.52	3.76
Rayleigh range, m	5	2.3	6
Undulator period, cm	12	12	6
Number of periods	2 x 32	32	3 x 28
Deflection parameter, K	0.5 – 1.1	0.7 – 1.4	1.0 – 2.6
Undulator matched β, m	0.6 – 2.0	1.0 – 2.3	0.4 – 1.0
Energy , MeV	9.5 - 13.4	21 - 22.8	39 - 42
Peak current, A	10	30	50

Requirements to the beam quality in FEL

- Energy spread:

$$\Delta E/E_0 < 1/(2\pi N_w)$$

- Normalized emittance:

$$\varepsilon_n < \lambda/(2\pi)\cdot\beta_w/ L_w\cdot\gamma \qquad \text{(angular spread)}$$

$$\varepsilon_n < \lambda/(4\pi)\cdot\beta_{opt}/ \beta_w\cdot\gamma \qquad \text{(transverse size)}$$

- Bunch duration

$$\tau > (2 N_w)\,\lambda/c \qquad \text{(slippage)}$$

- Bunch charge

$$Q \sim \tau\cdot I_{peak}$$

- Average current

$$I_{aver} = Q\cdot f_{opt}$$

Requirements to the beam quality in FEL

- Energy spread:

$$\Delta E/E_0 < 1/(2\pi N_w)$$

- Normalized emittance:

$$\varepsilon_n < \lambda/(4\pi) \cdot \gamma \qquad \text{(in optimal case)}$$

- Bunch duration

$$\tau > (2\, N_w)\, \lambda/c \qquad \text{(slippage)}$$

- Bunch charge

$$Q \sim \tau \cdot I_{peak}$$

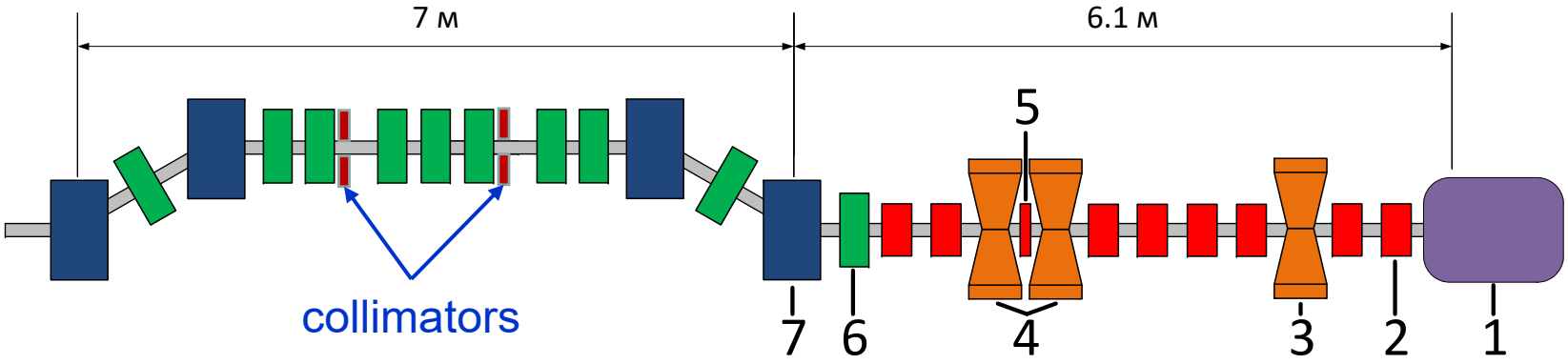
- Average current

$$I_{aver} = Q \cdot f_{opt}$$

Requirements to the beam quality in FEL

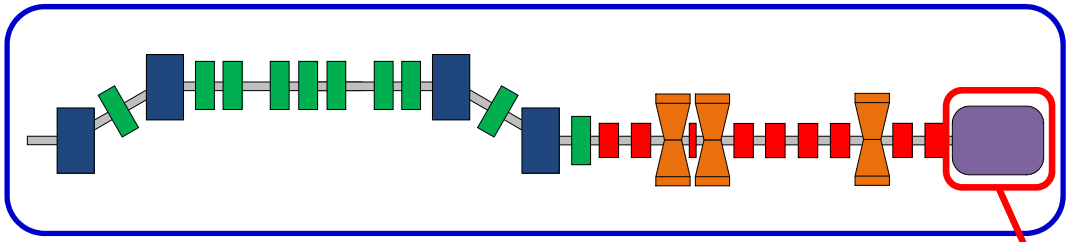
	1st	2nd	3d
Energy spread ΔE, keV	< 25	< 100	< 75
Normalized emittance, μm	< 150	< 100	< 35
Bunch duration, ps	> 120	> 16	> 13
Bunch charge, nQ	> 1.0	> 0.5	> 0.6
Average current, mA	~ 7	~ 3.5	~ 3

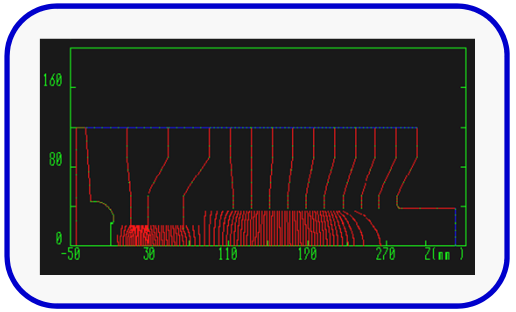
Injector Layout



1	–	electron gun
2	–	electromagnetic solenoids
3	–	bunching cavity
4	–	accelerating cavities
5	–	permanent magnet solenoid
6	–	quadrupoles
7	–	merger bending magnet

Electrostatic Gun



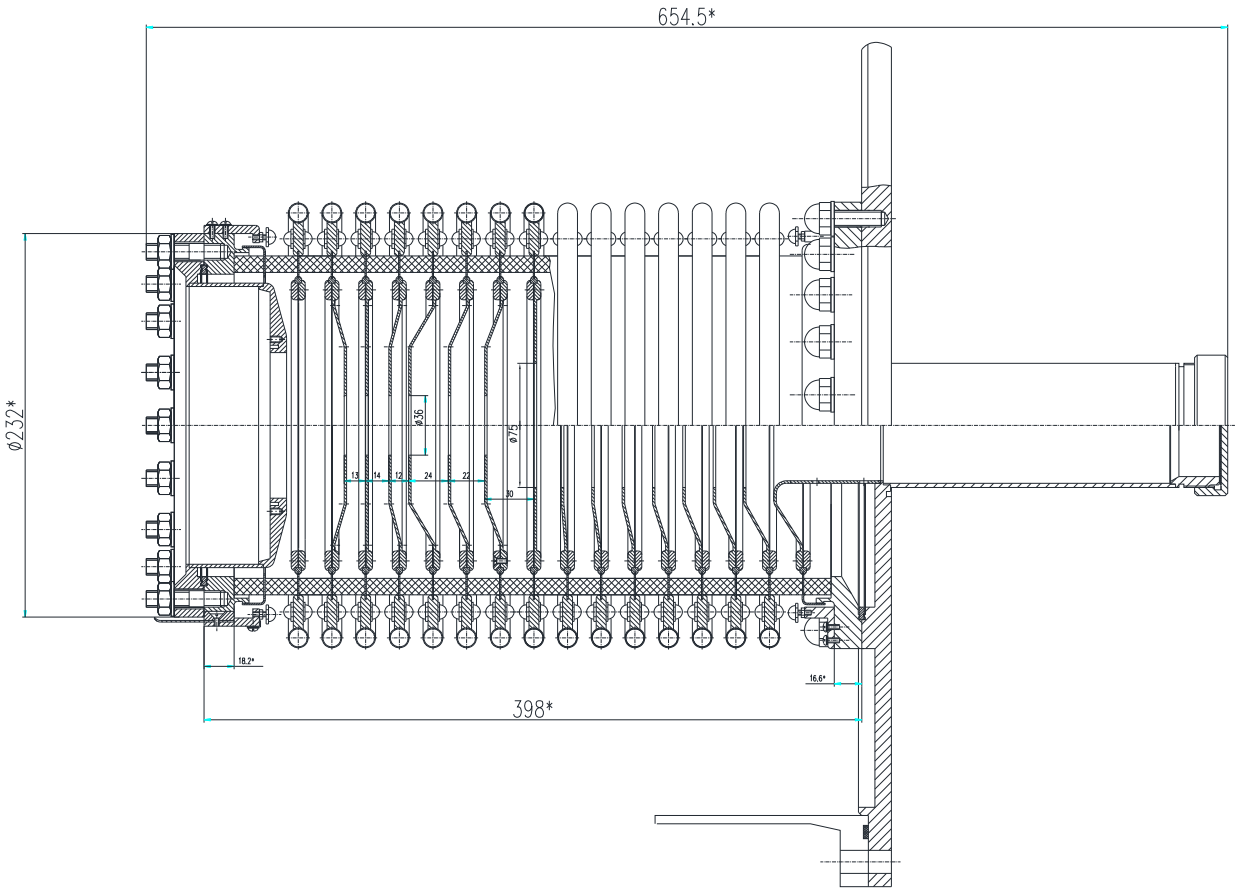


Power supply:

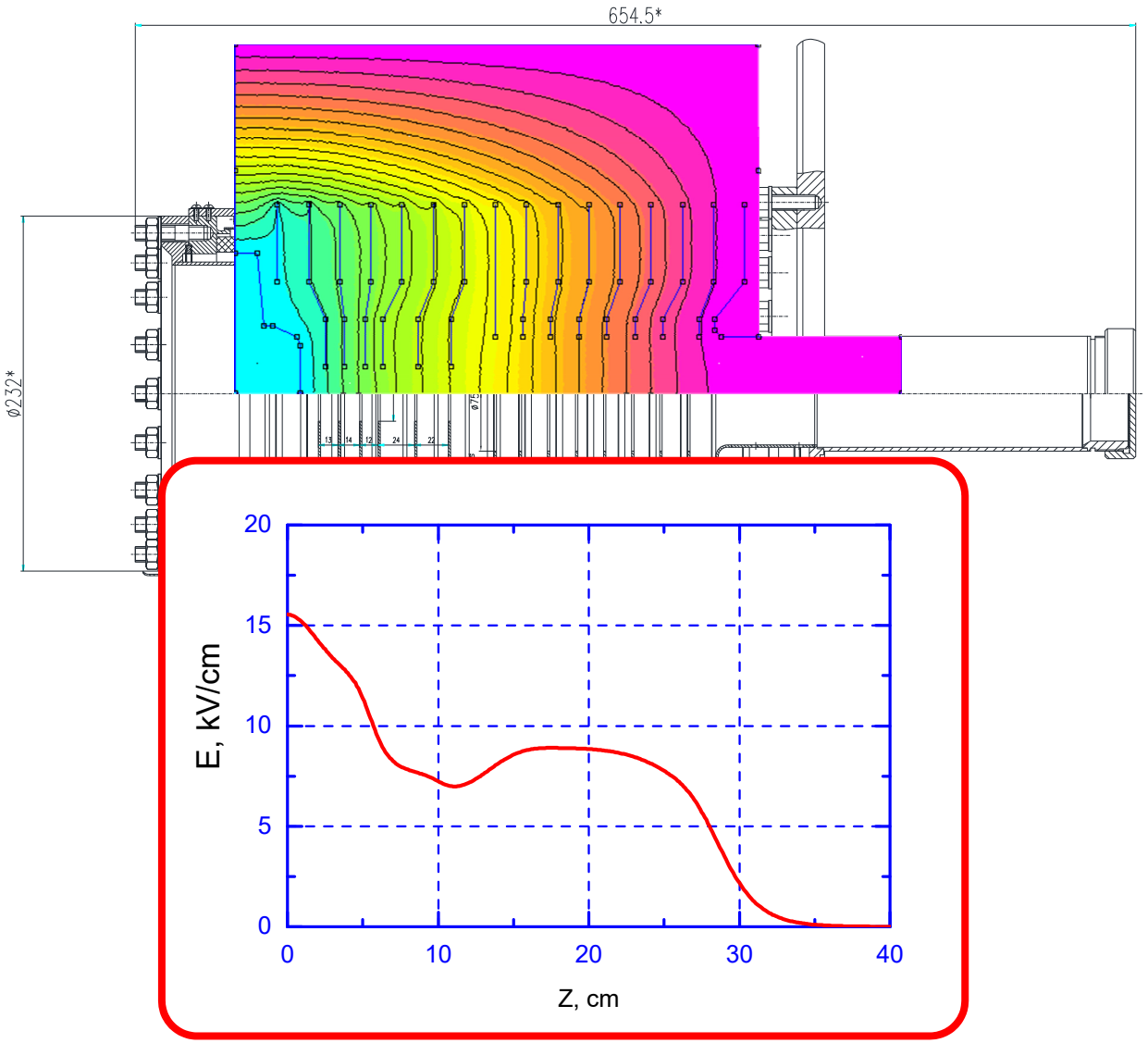
U_{max} = 300 kV

I_{max} = 50 mA

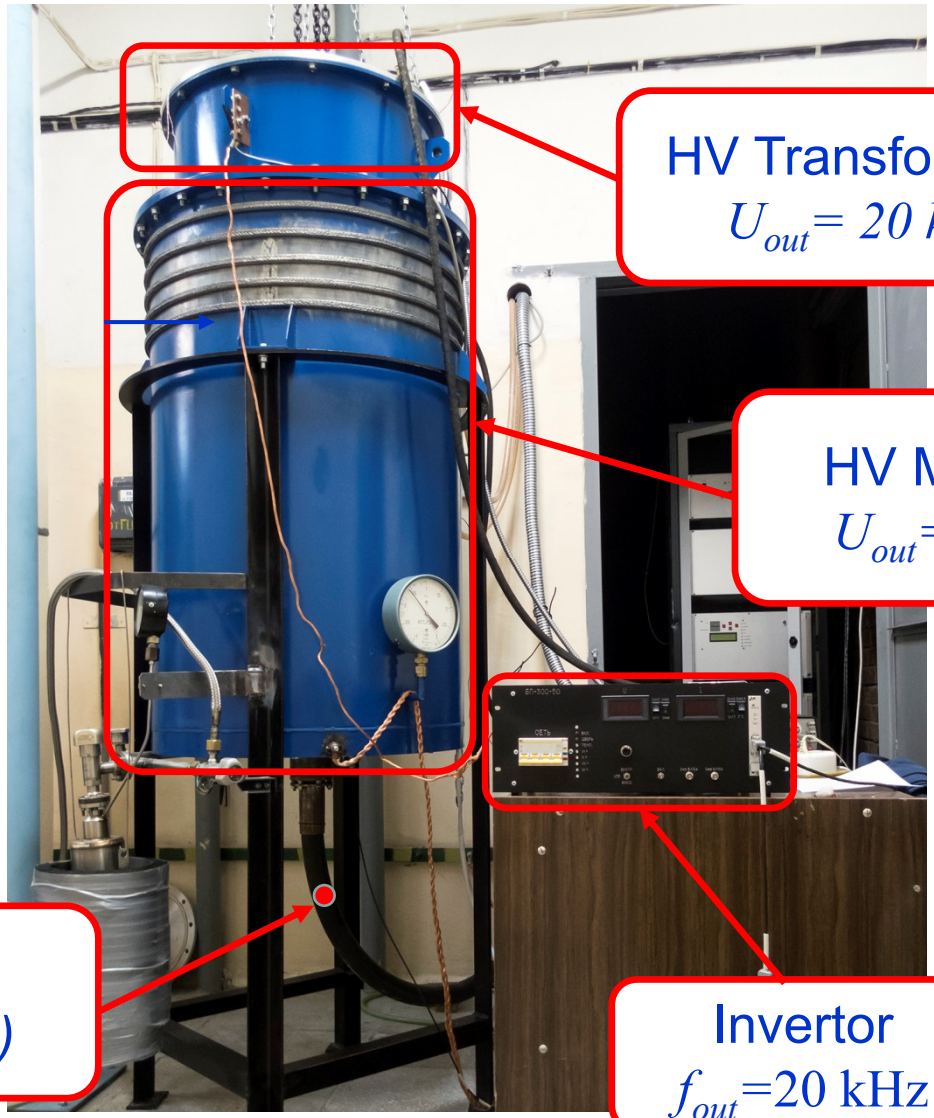
Gun Accelerating Tube



Gun Accelerating Tube



Gun Power Supply



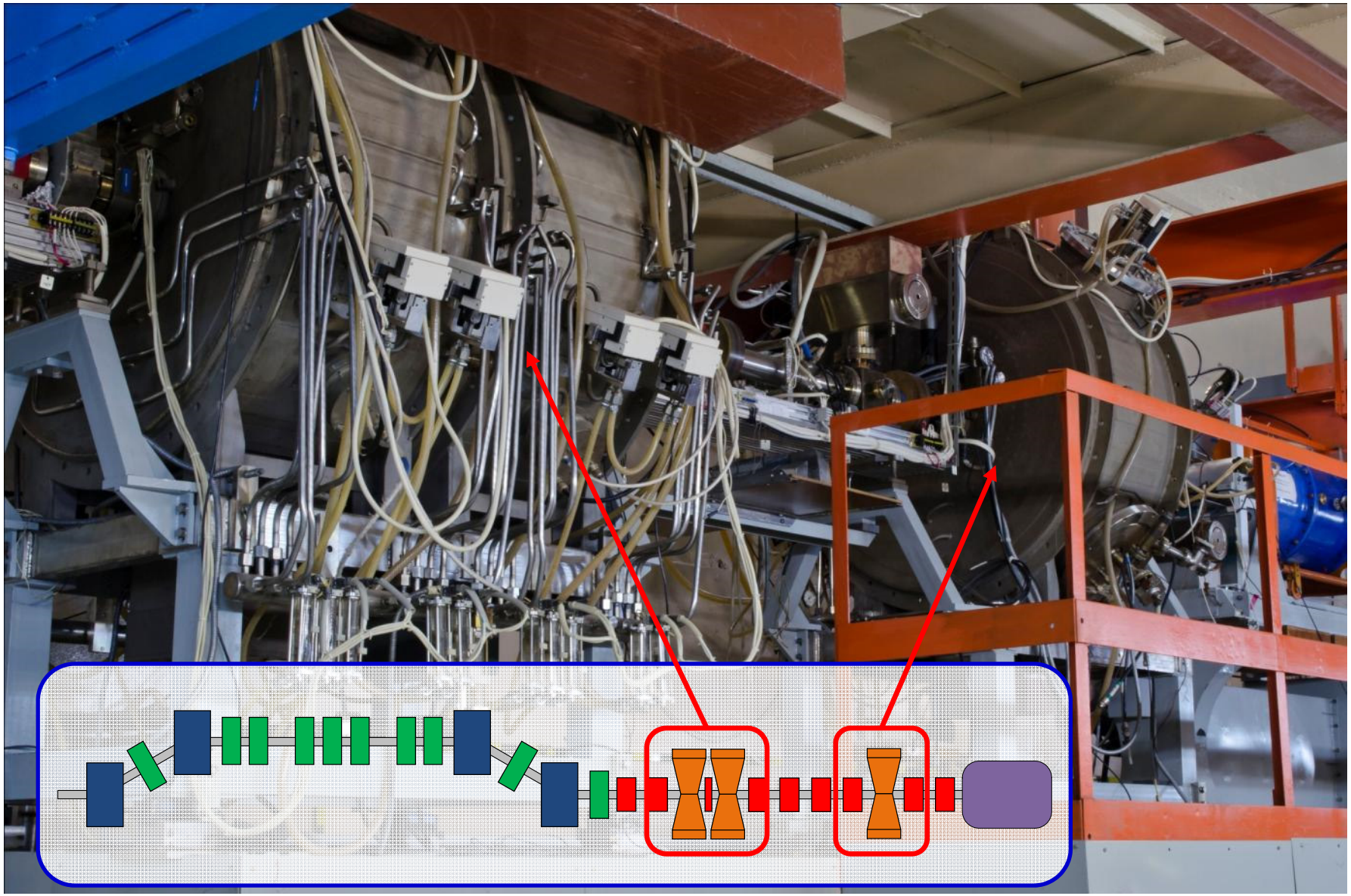
HV Transformer
U_{out}= 20 kV

HV Multiplier
U_{out}= 300 kV

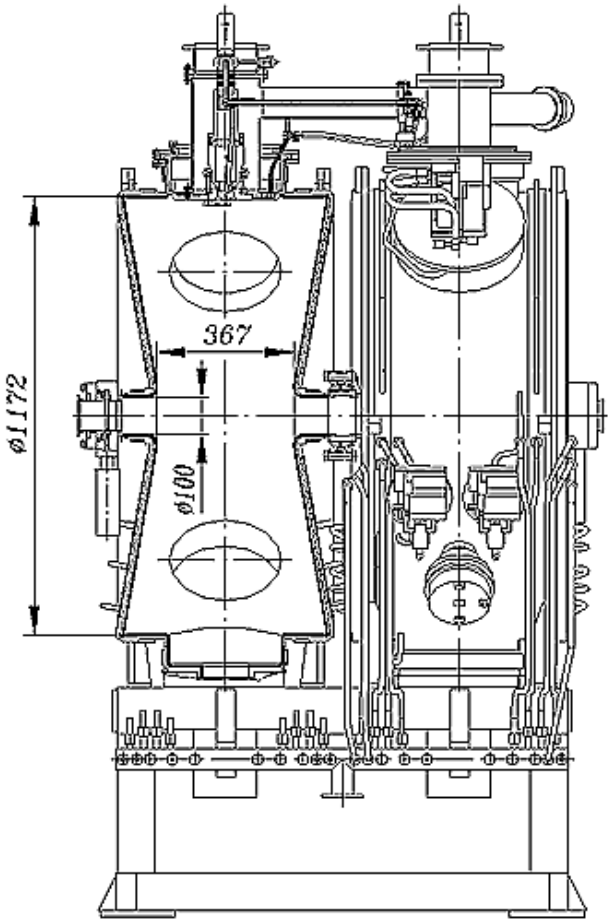
HV Cable
(to the GUN)

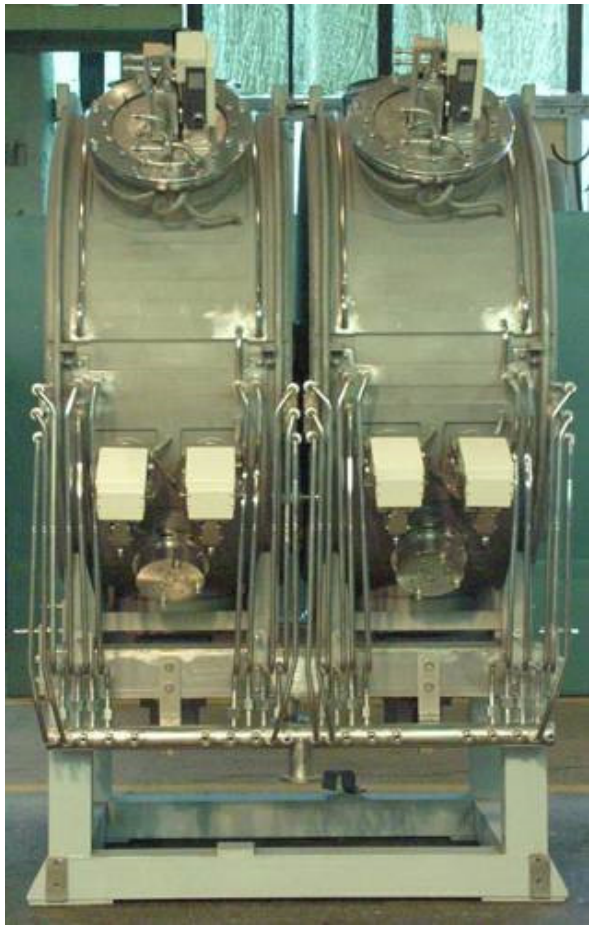
Invertor
f_{out}=20 kHz

Injector RF System

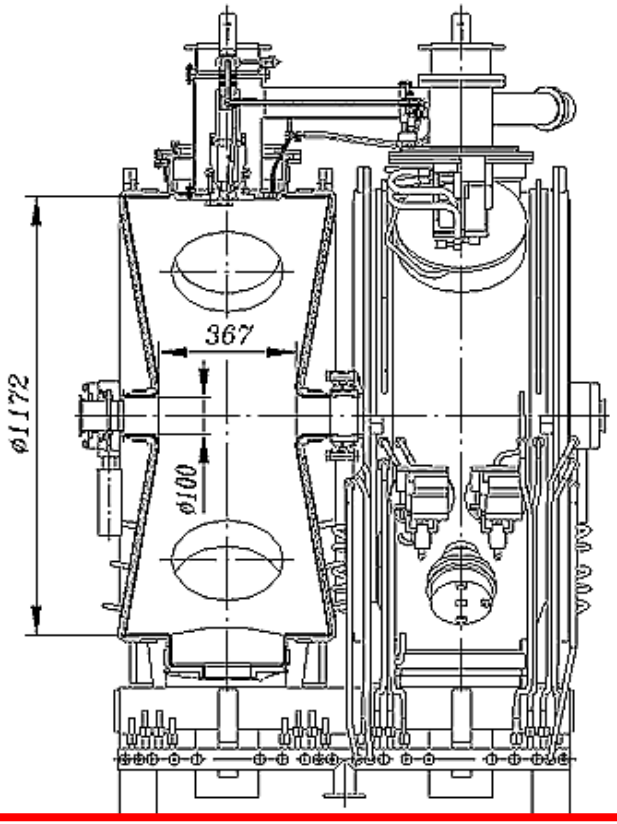


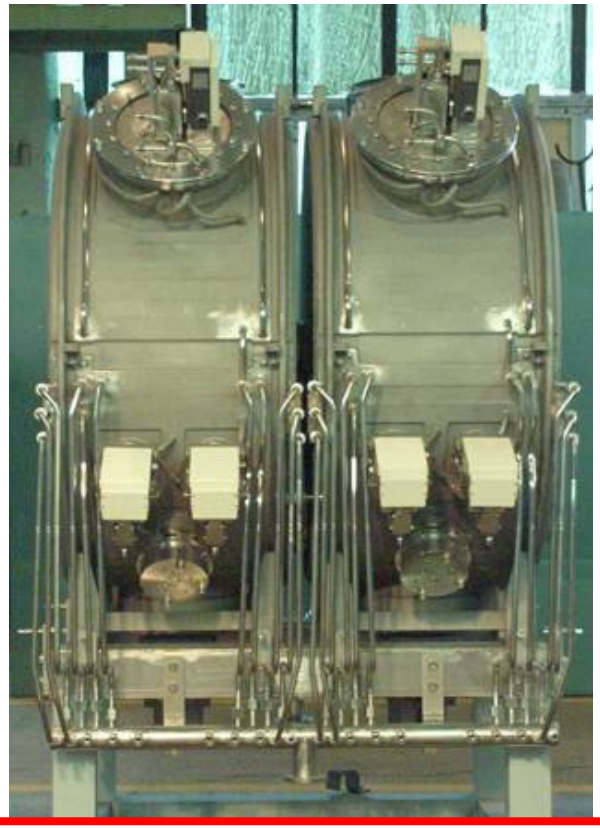
Injector RF System





Injector RF System





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

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

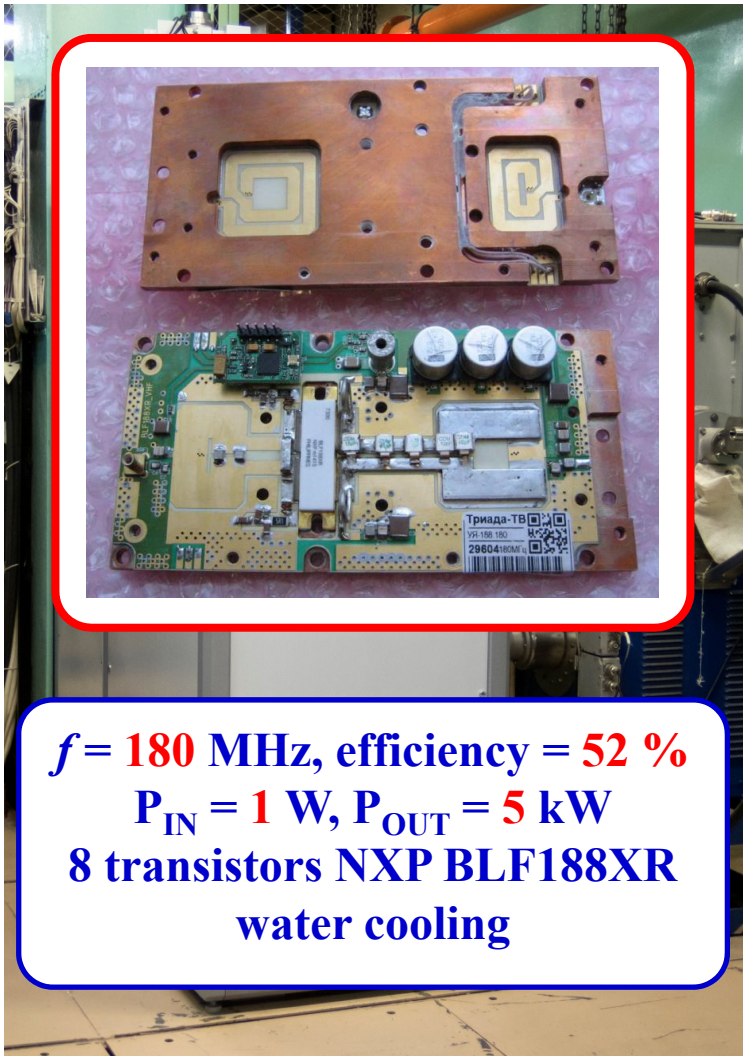
RF Power Supplies

Bunching cavity

Accelerating cavity

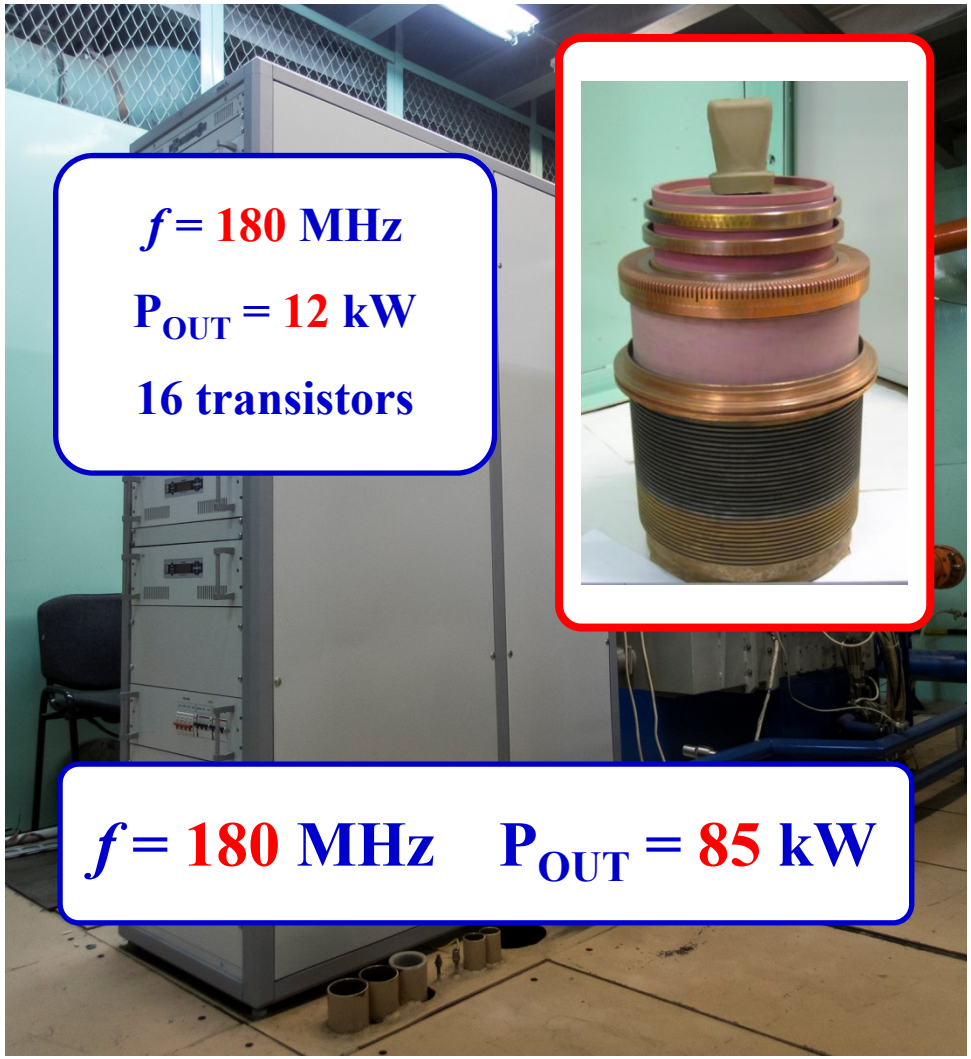
RF Power Supplies

Bunching cavity



f = 180 MHz, efficiency = 52 %
P_{IN} = 1 W, P_{OUT} = 5 kW
8 transistors NXP BLF188XR
water cooling

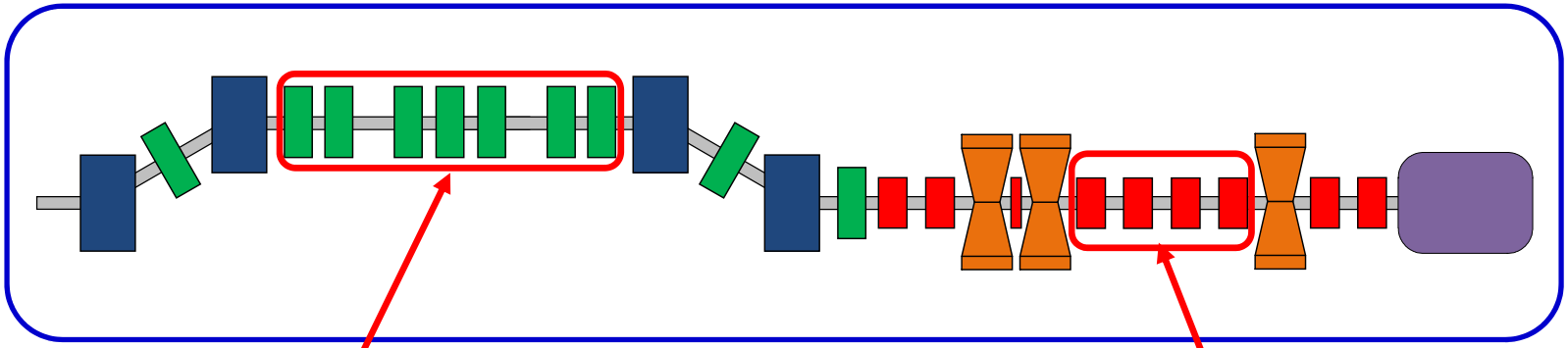
Accelerating cavity

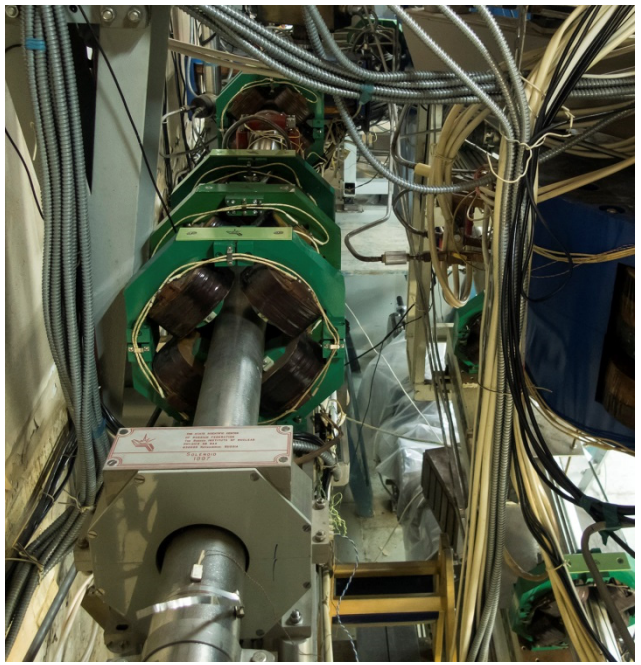


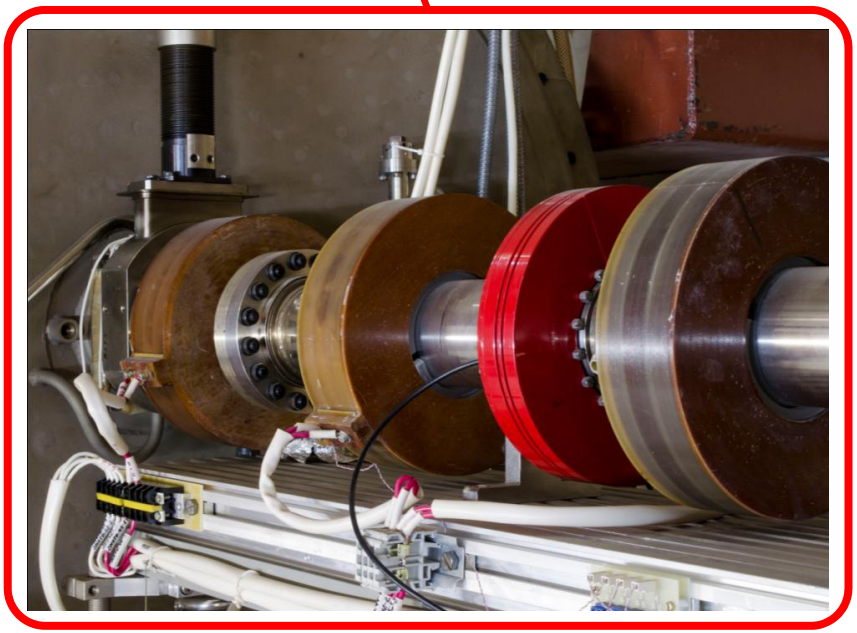
f = 180 MHz
P_{OUT} = 12 kW
16 transistors

f = 180 MHz P_{OUT} = 85 kW

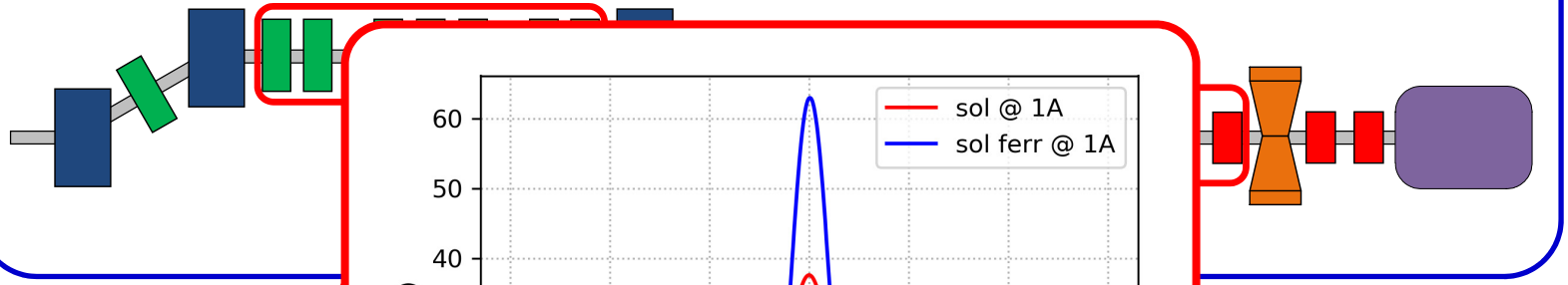
Focusing Elements

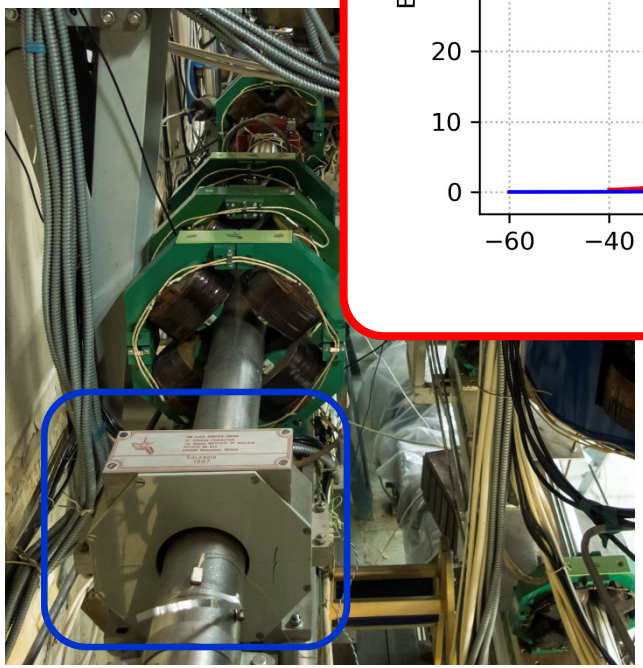


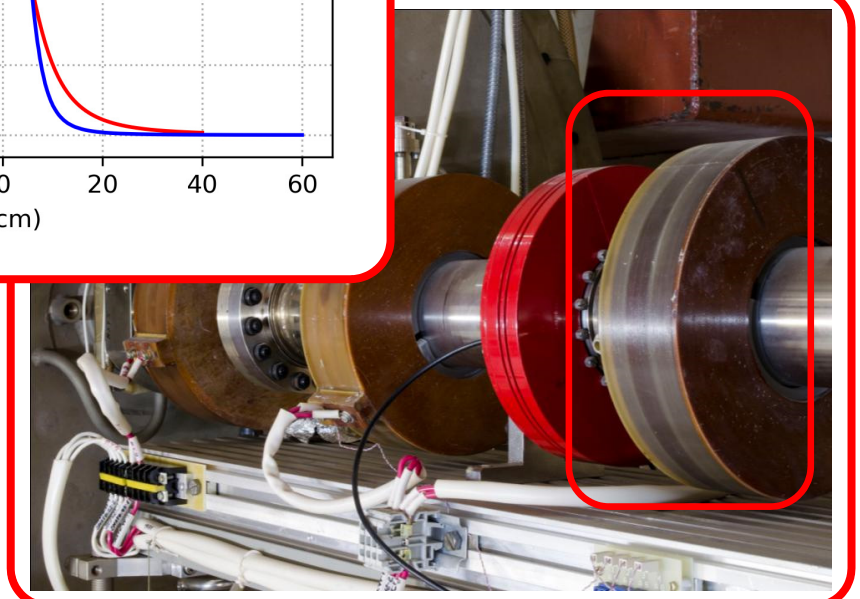




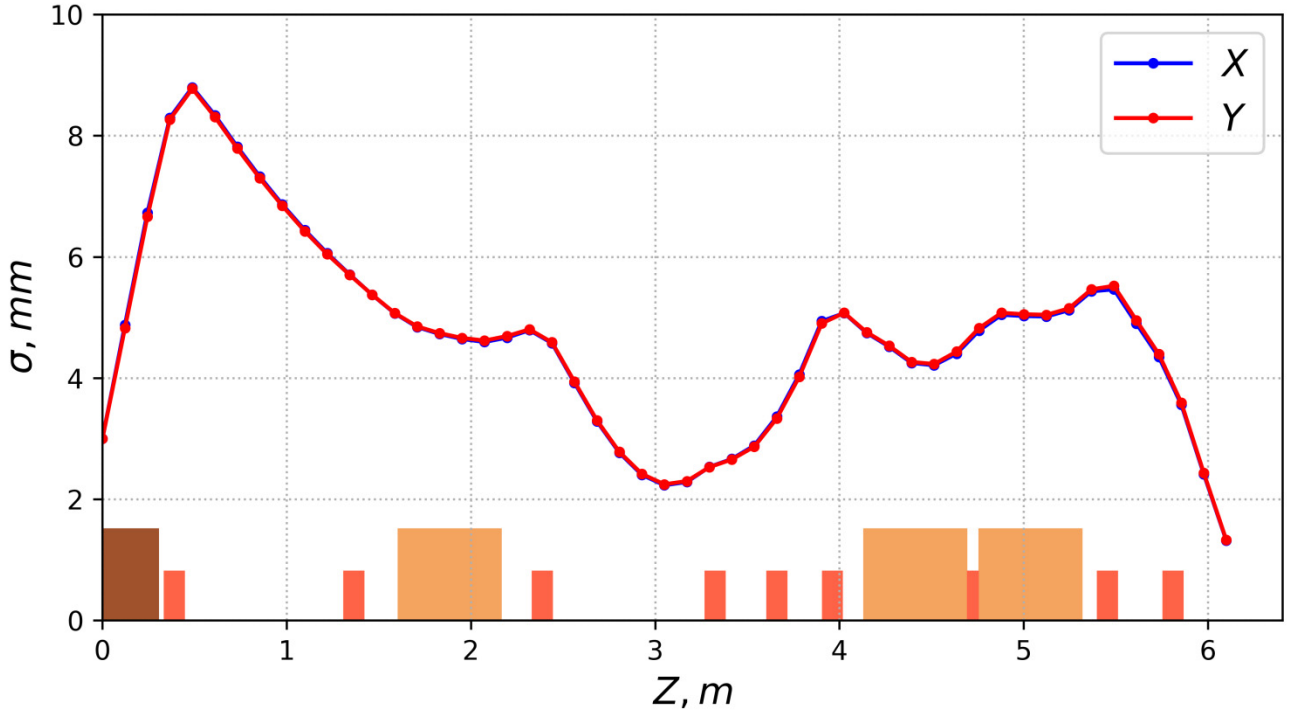
Focusing Elements







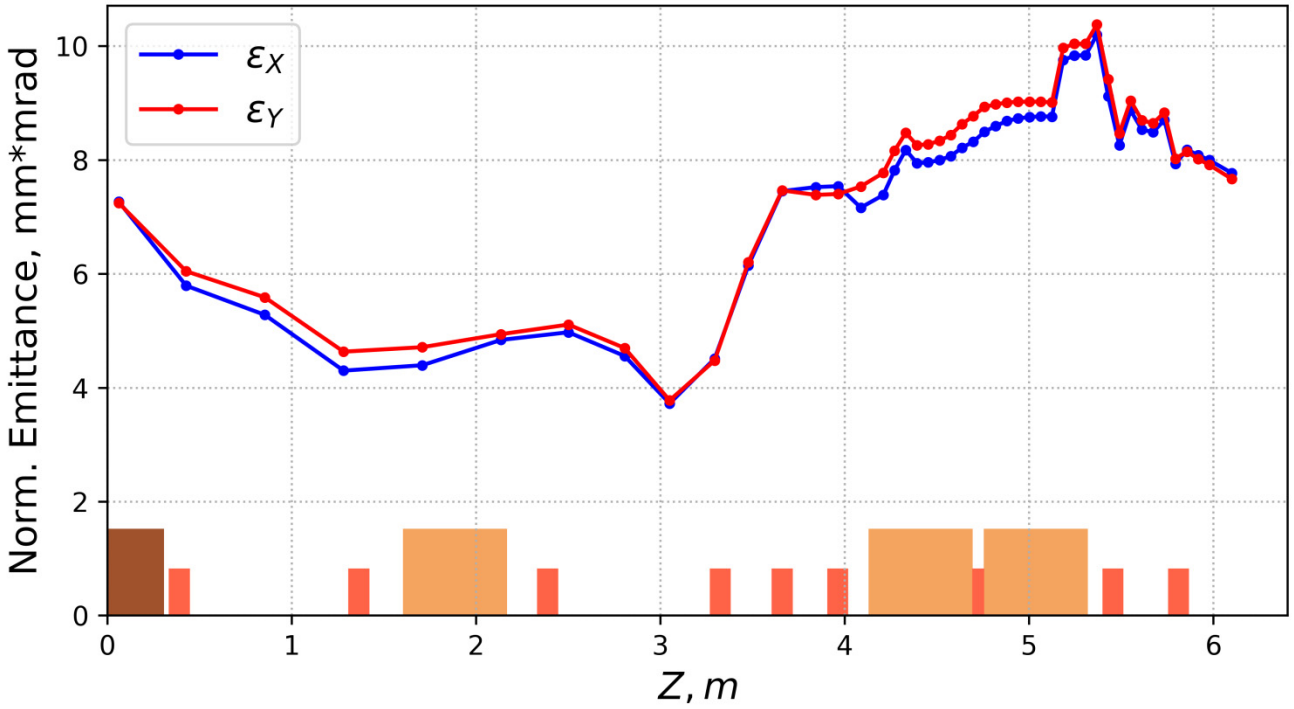
Beam Transverse Dynamics



Gun **Bunching RF** **Accelerating RF**

Transverse rms beam size

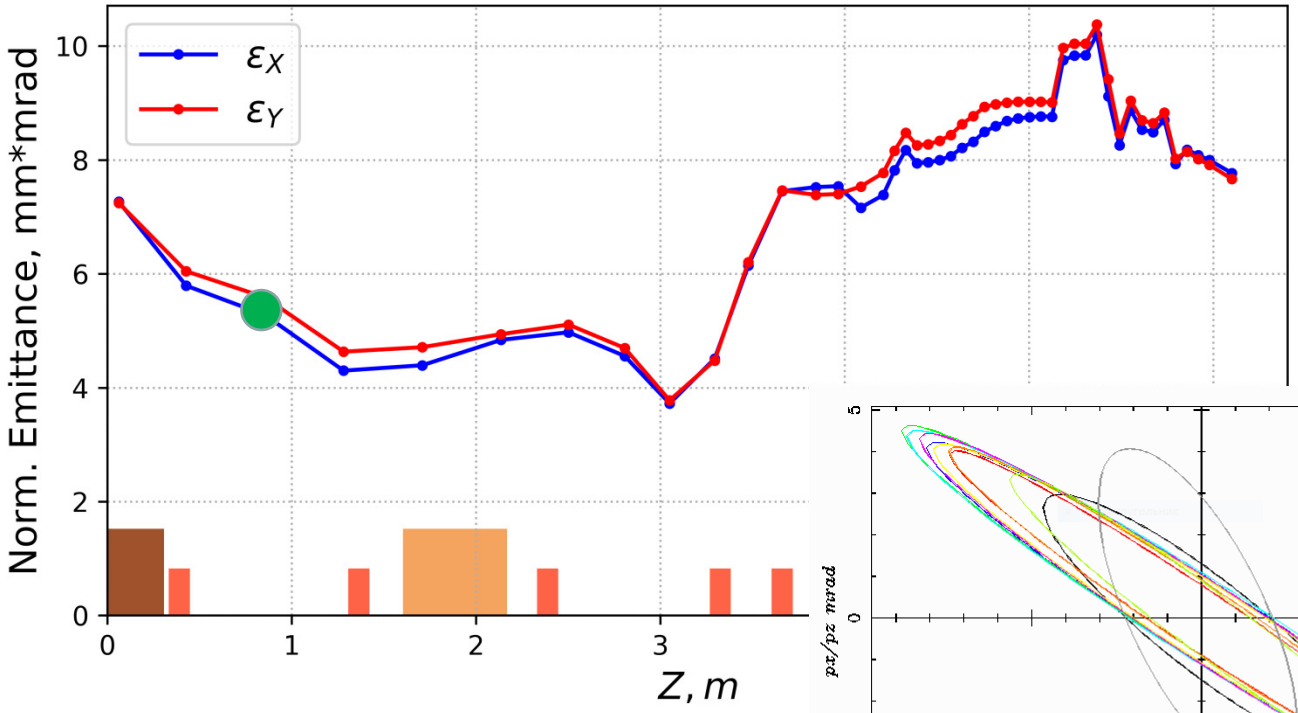
Beam Transverse Dynamics



Gun **Bunching RF** **Accelerating RF**

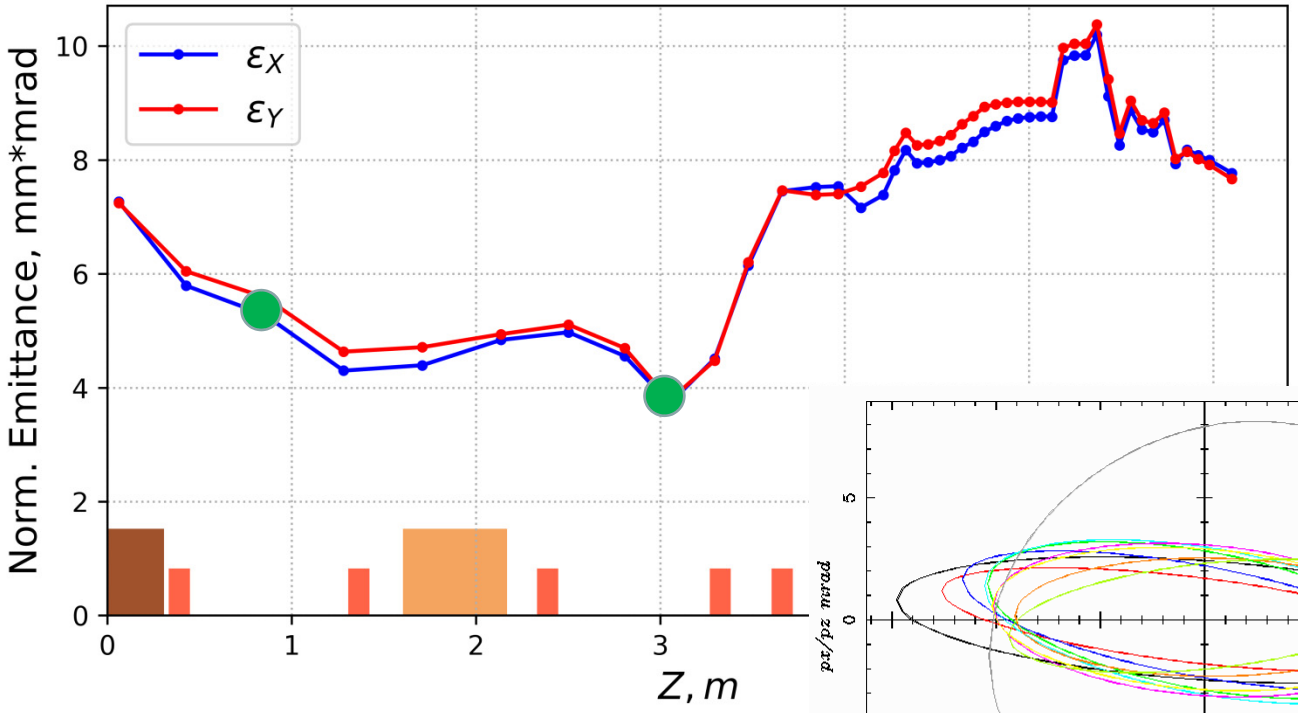
Normalized projected rms emittance

Beam Transverse Dynamics



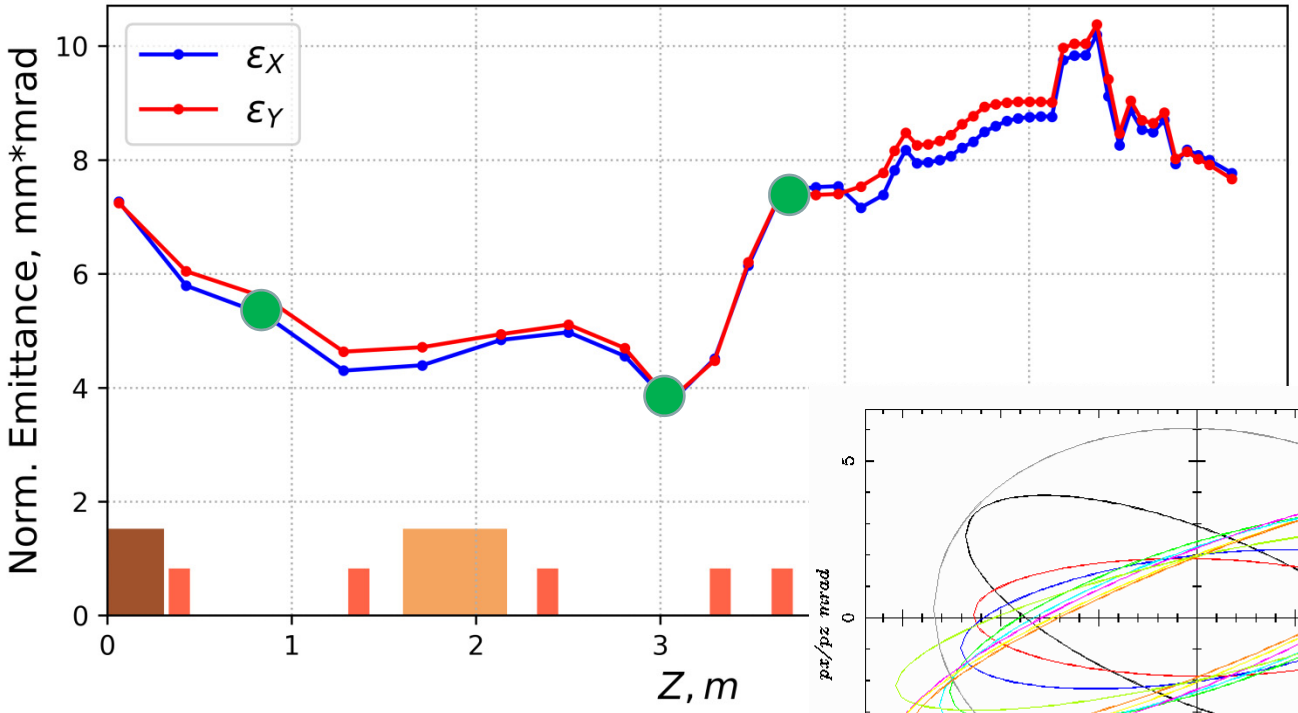
Normalized projected rms emittance

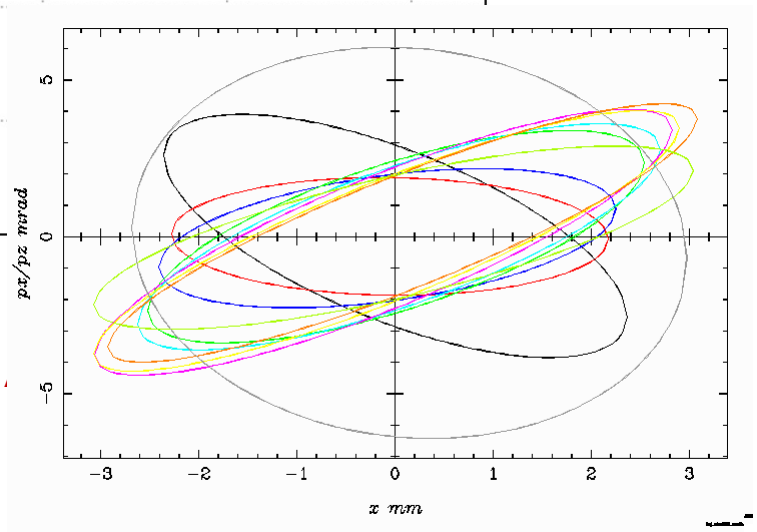
Beam Transverse Dynamics



Normalized projected rms emittance

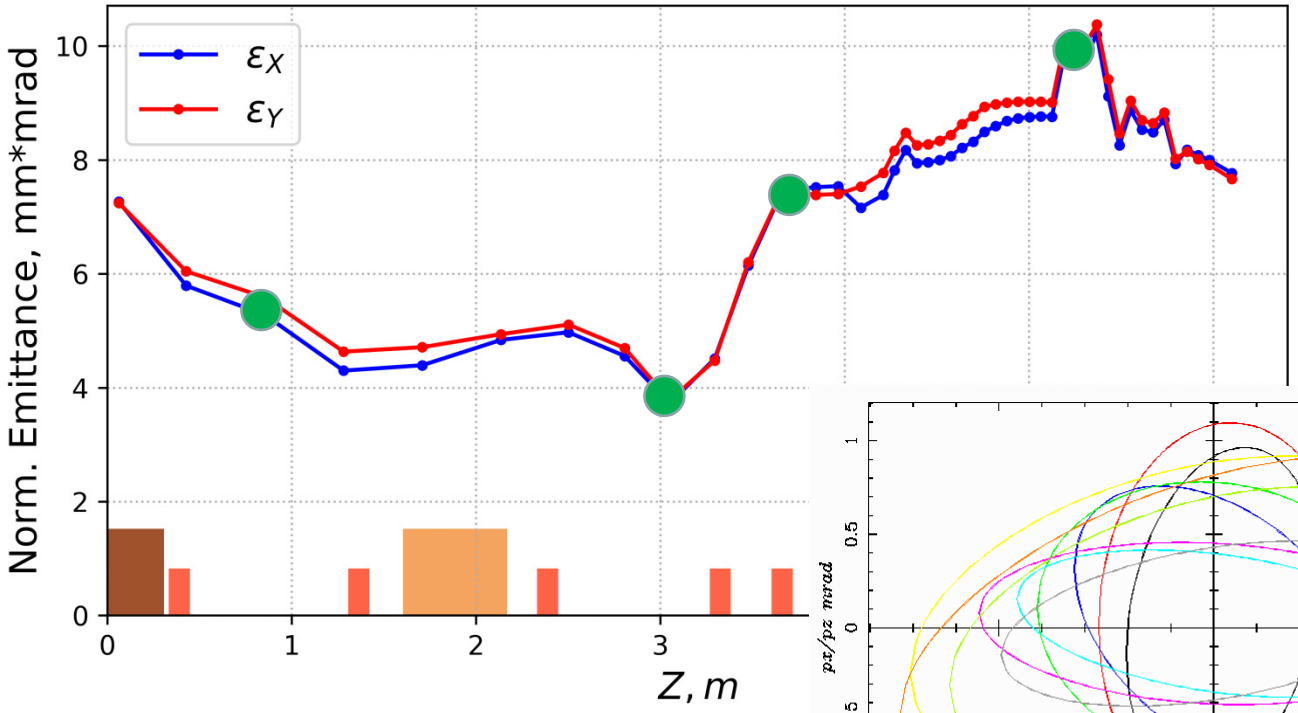
Beam Transverse Dynamics

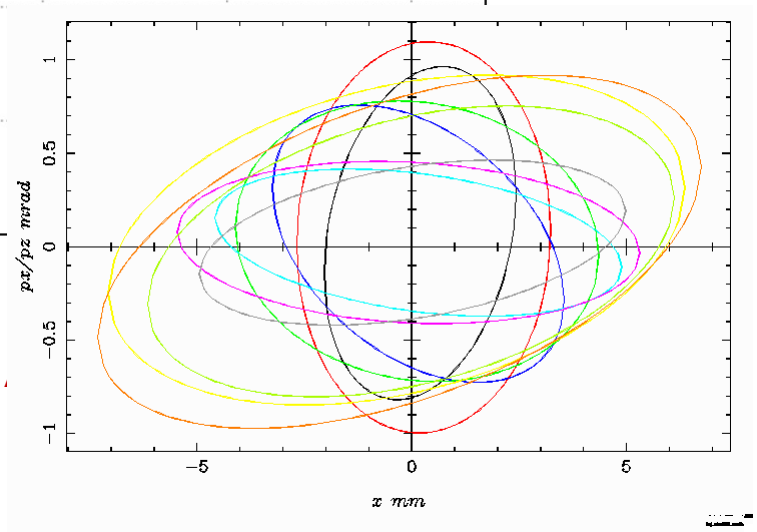




Normalized projected rms emittance

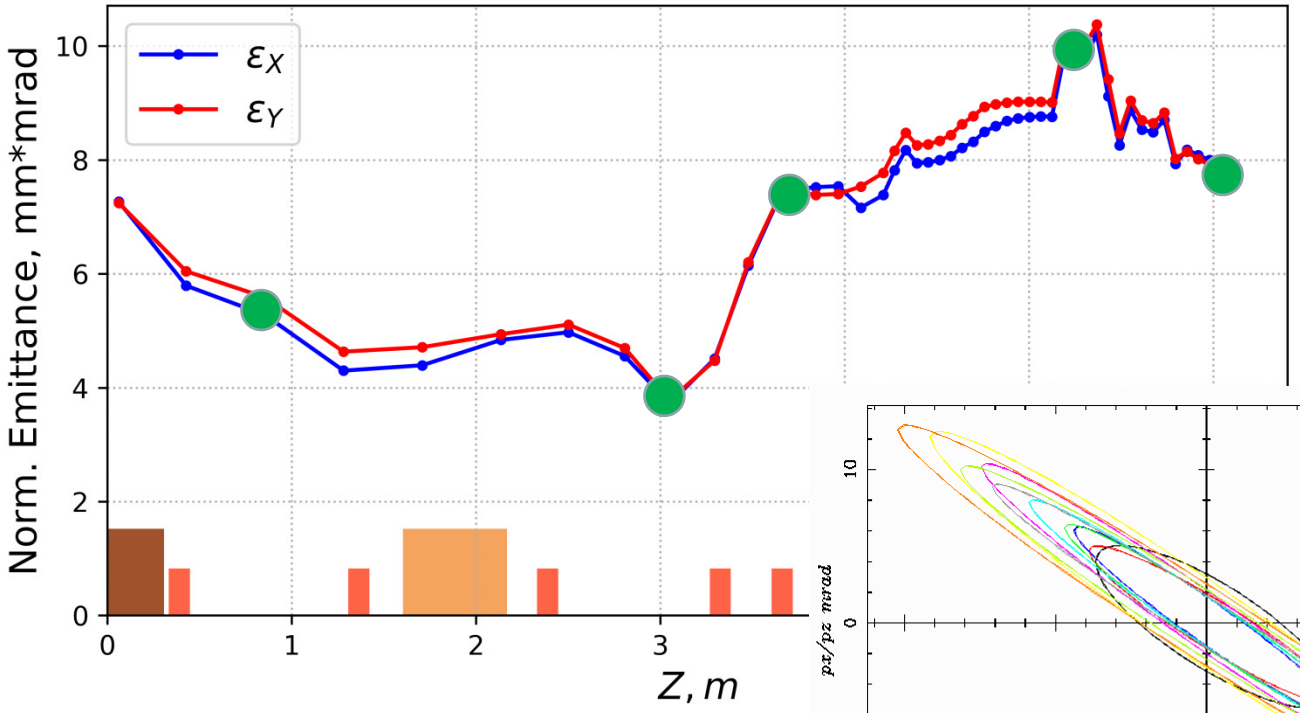
Beam Transverse Dynamics





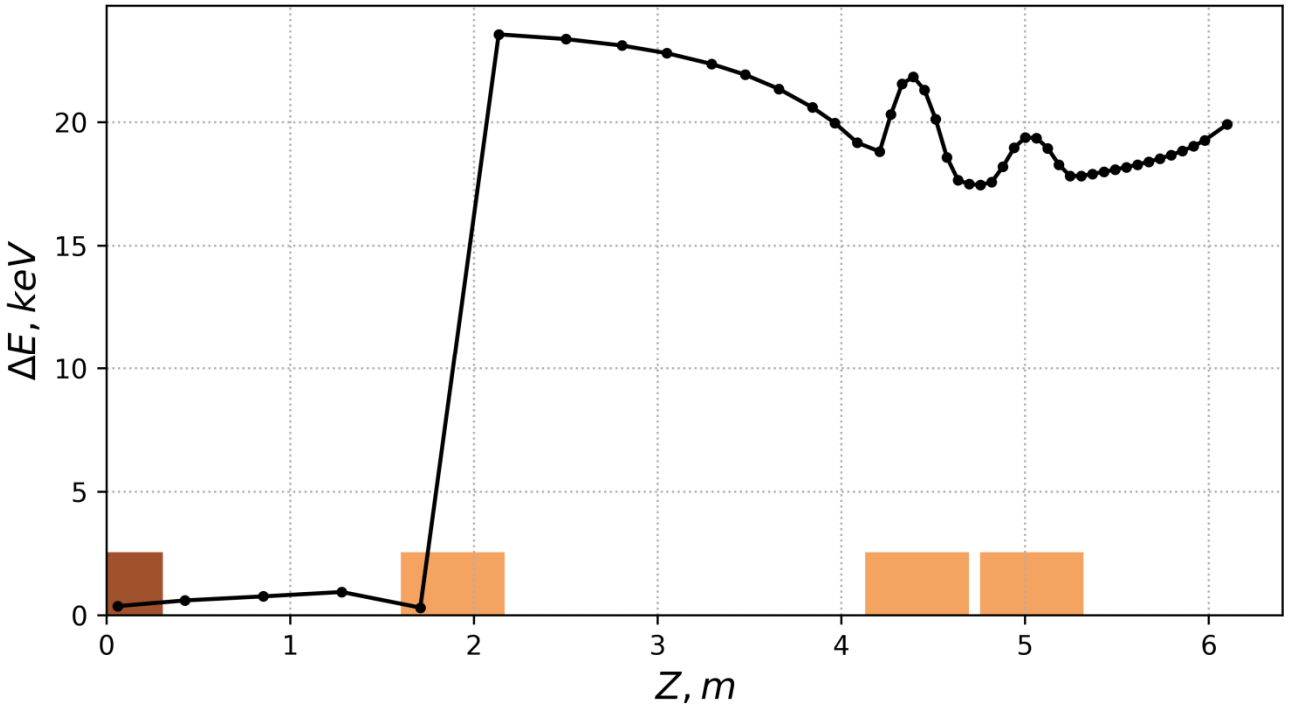
Normalized projected rms emittance

Beam Transverse Dynamics



Normalized projected rms emittance

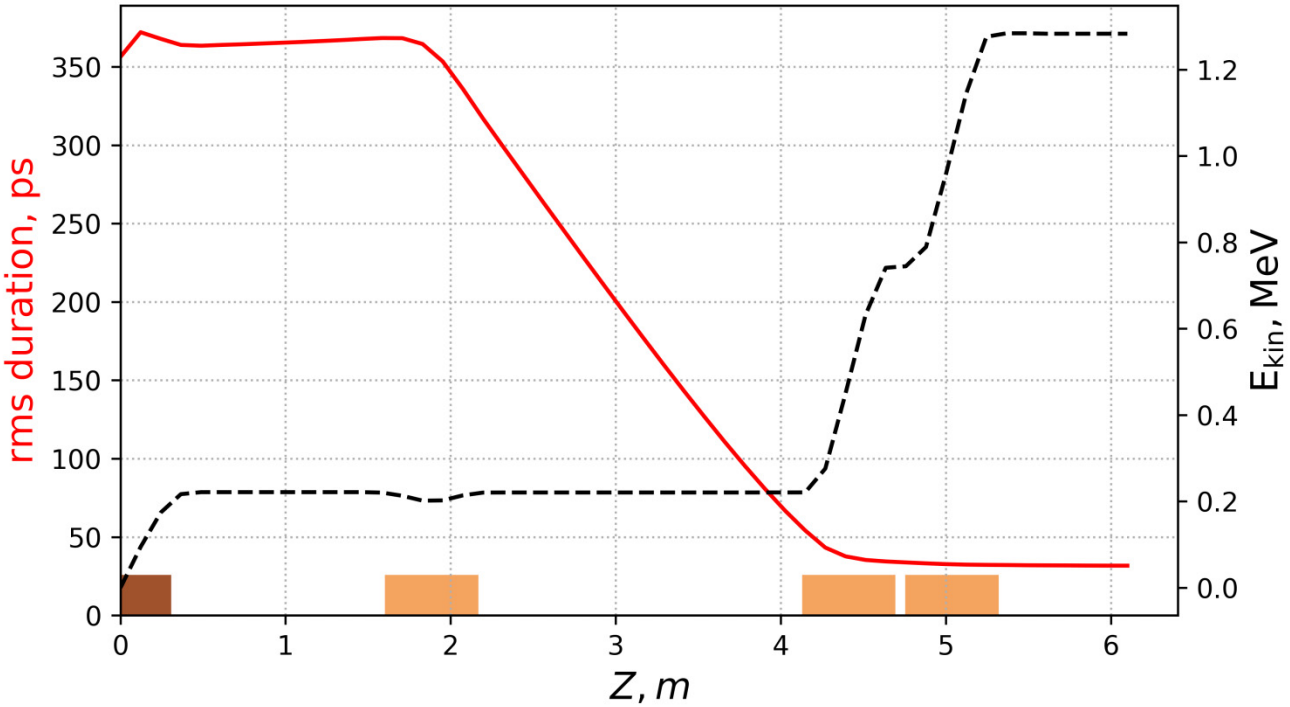
Beam Longitudinal Dynamics



Gun **Bunching RF** **Accelerating RF**

Projected rms energy spread

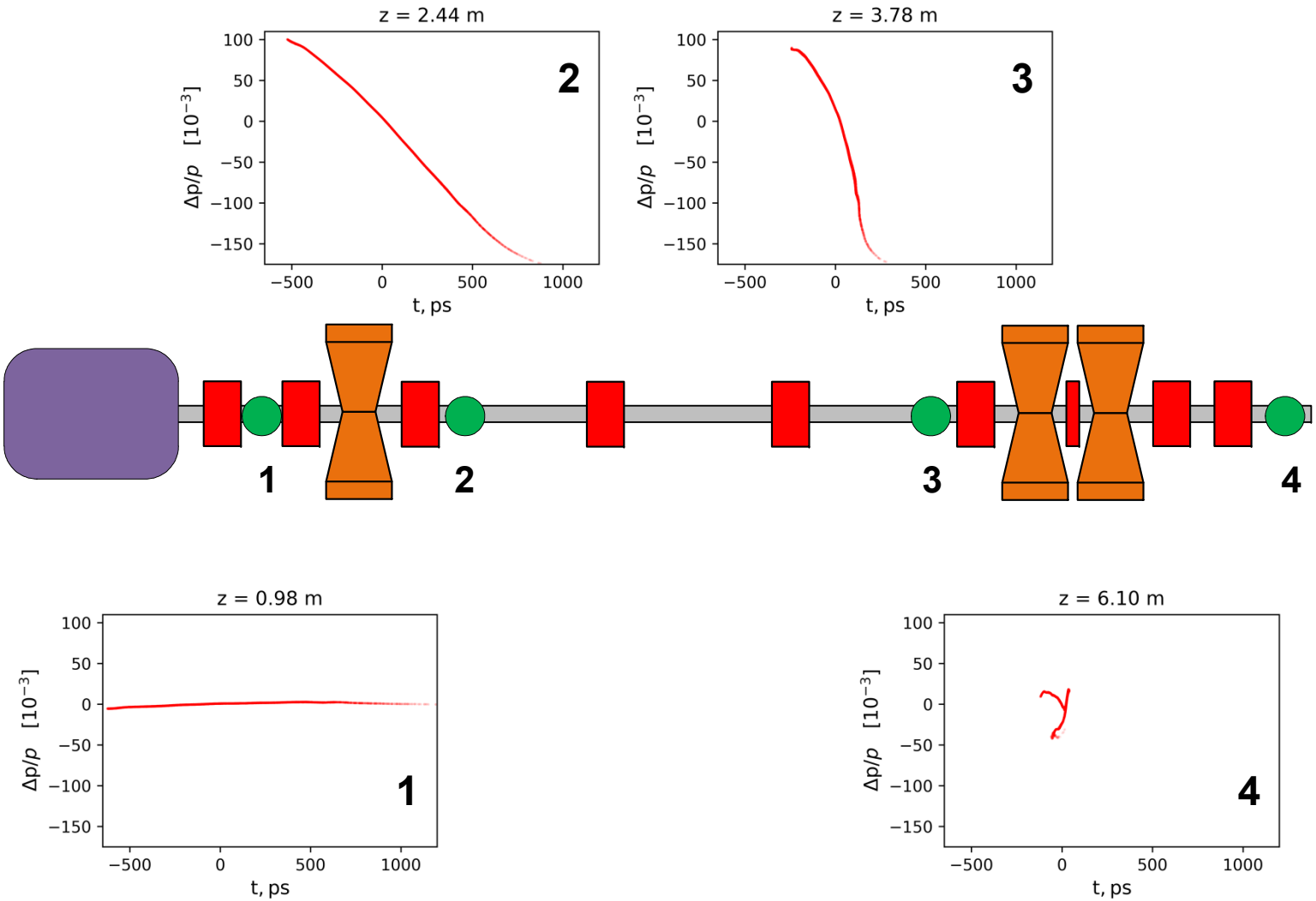
Beam Longitudinal Dynamics



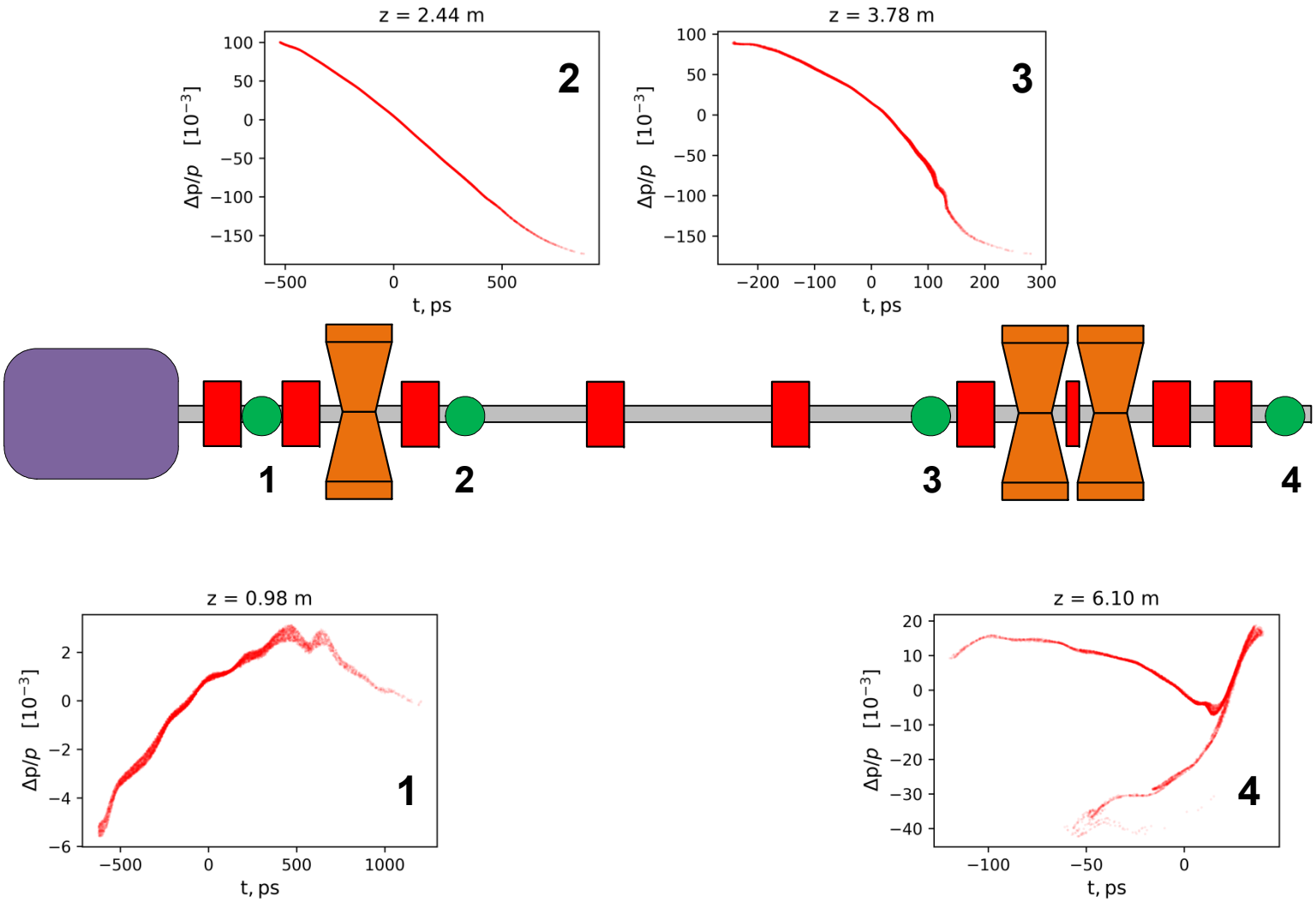
Gun **Bunching RF** **Accelerating RF**

Bunch rms duration and energy gain

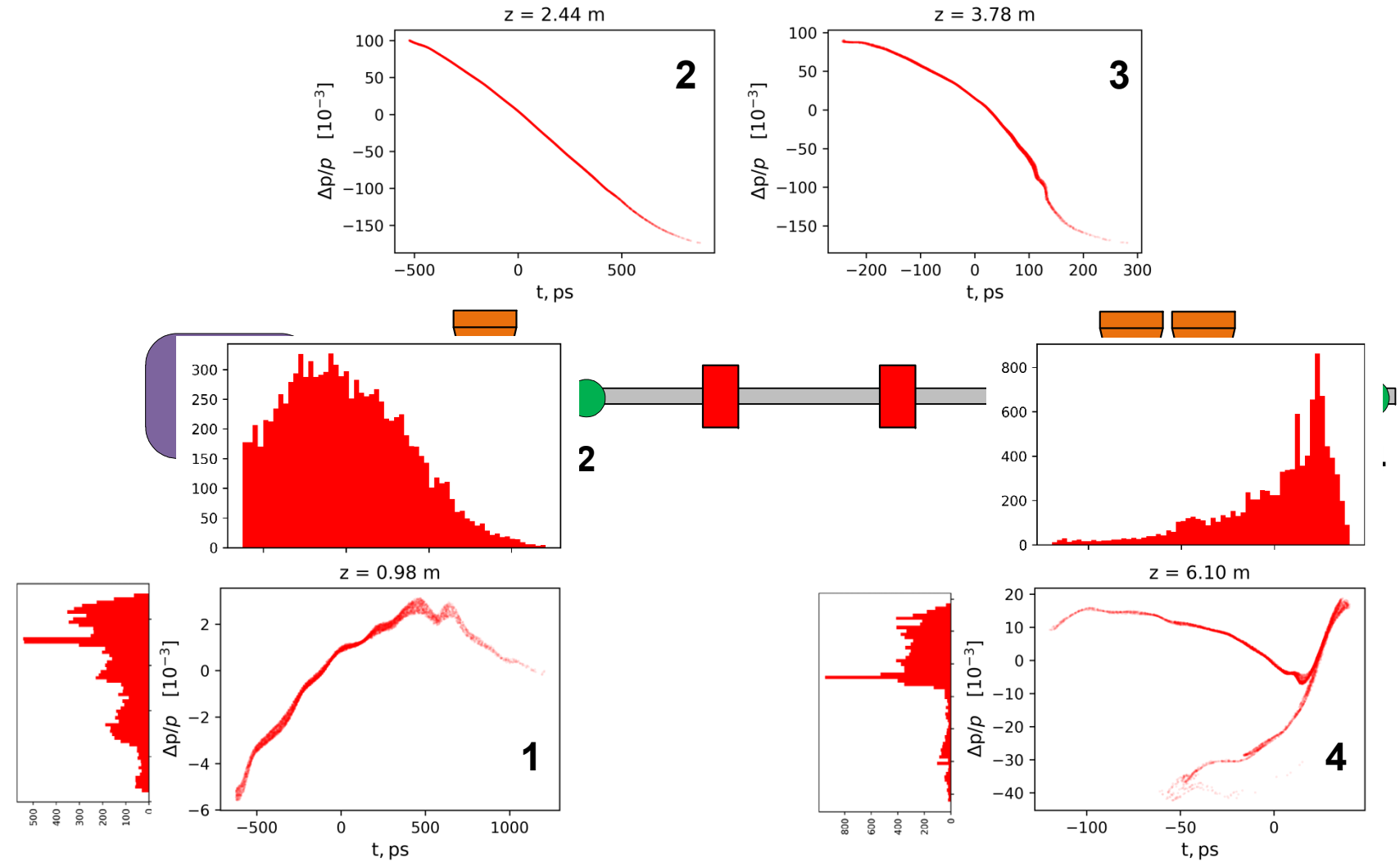
Beam Longitudinal Dynamics



Beam Longitudinal Dynamics



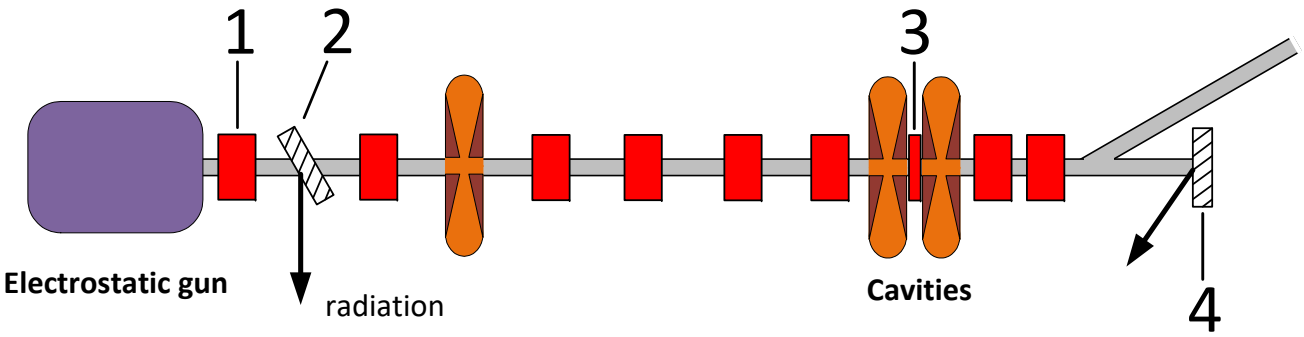
Beam Longitudinal Dynamics

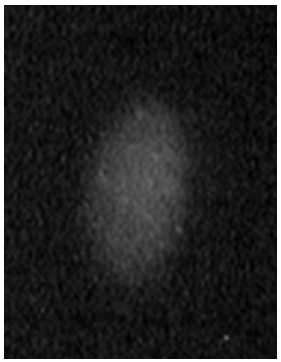


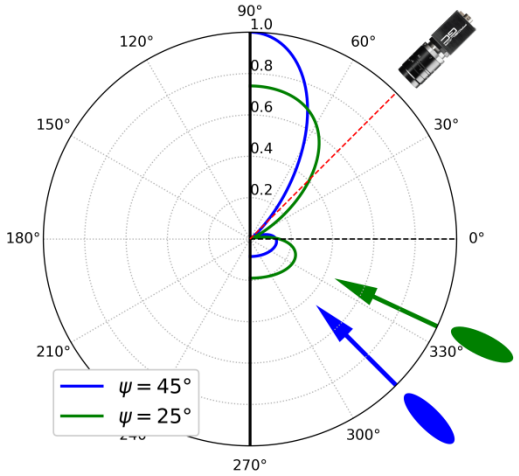
Summary of Simulation Results

Normalized emittance, μm	7.7
Slice emittance, μm	5
Beta function, m	0.75
Bunch duration (rms), ps	31.7
Energy, MeV	1.79
Energy spread (rms), keV	20.6

Beam Parameters Measurement



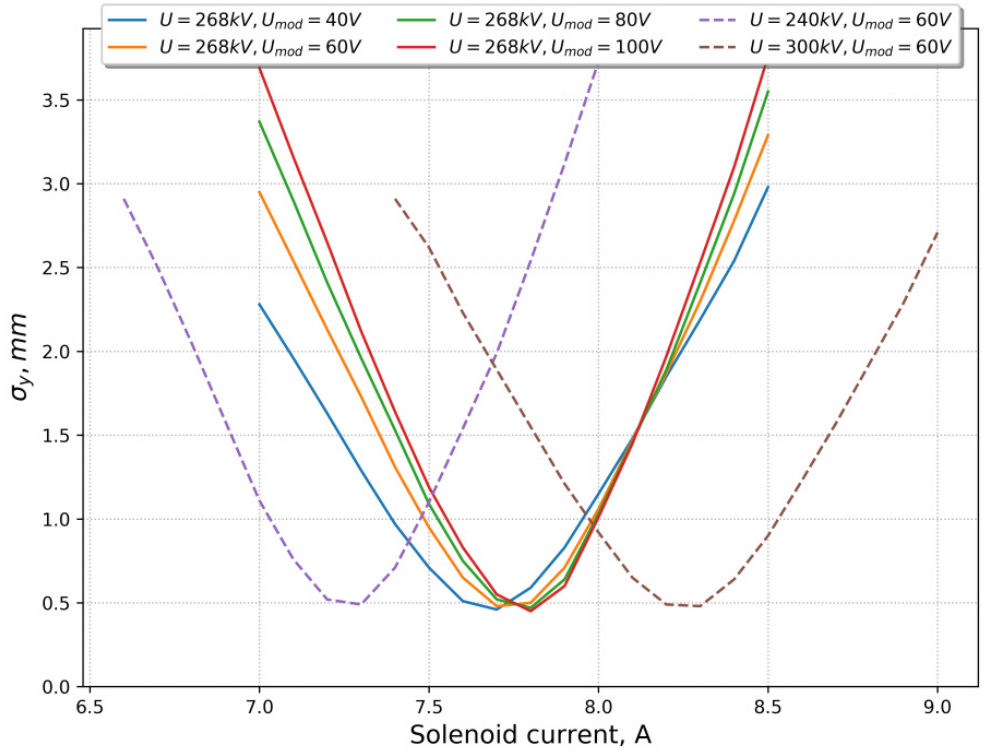




1 – solenoid
2 – screen

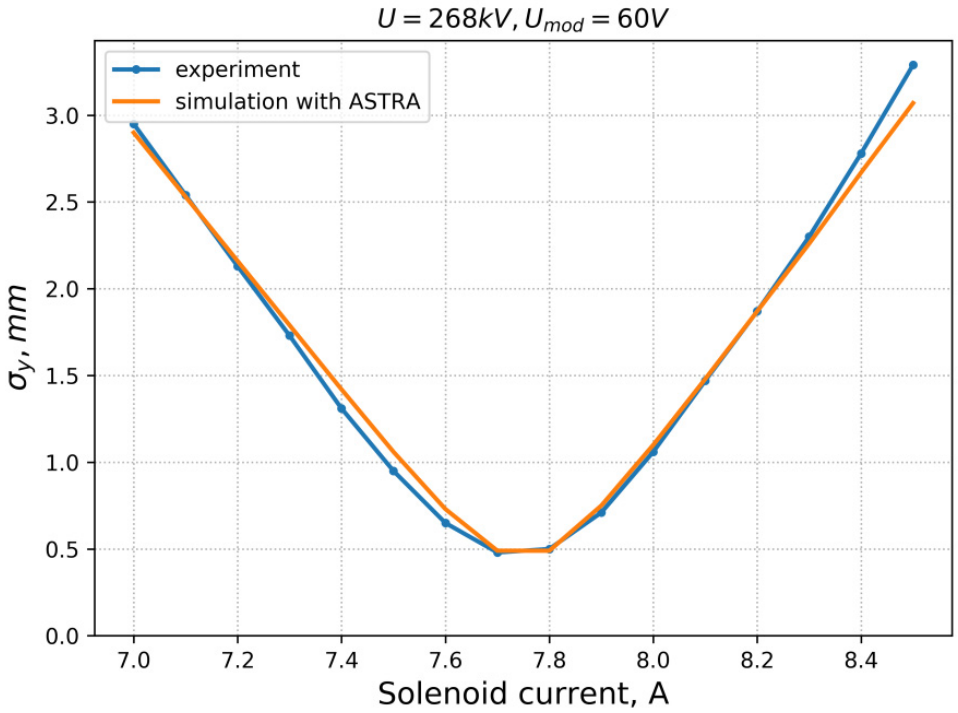
OTR radiation pattern, E_{kin} = 300 keV

Beam Parameters Measurement



Dependence of the beam size on solenoid current for different gun voltages U and different bunch charges (U_{mod})

Beam Parameters Measurement



Comparison of measurement and simulation results

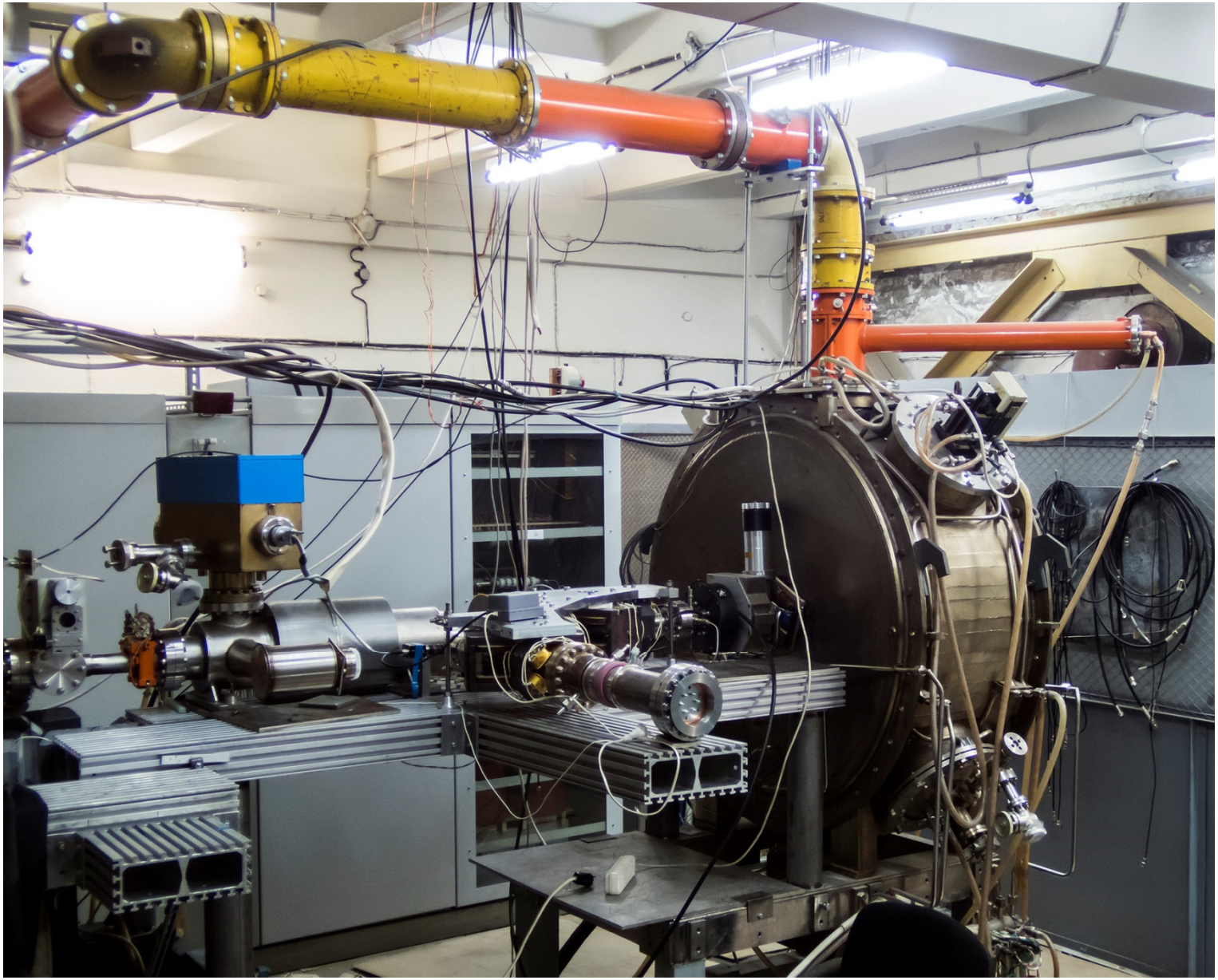
ε_{norm} = 19 μm

Summary of Injector Parameters

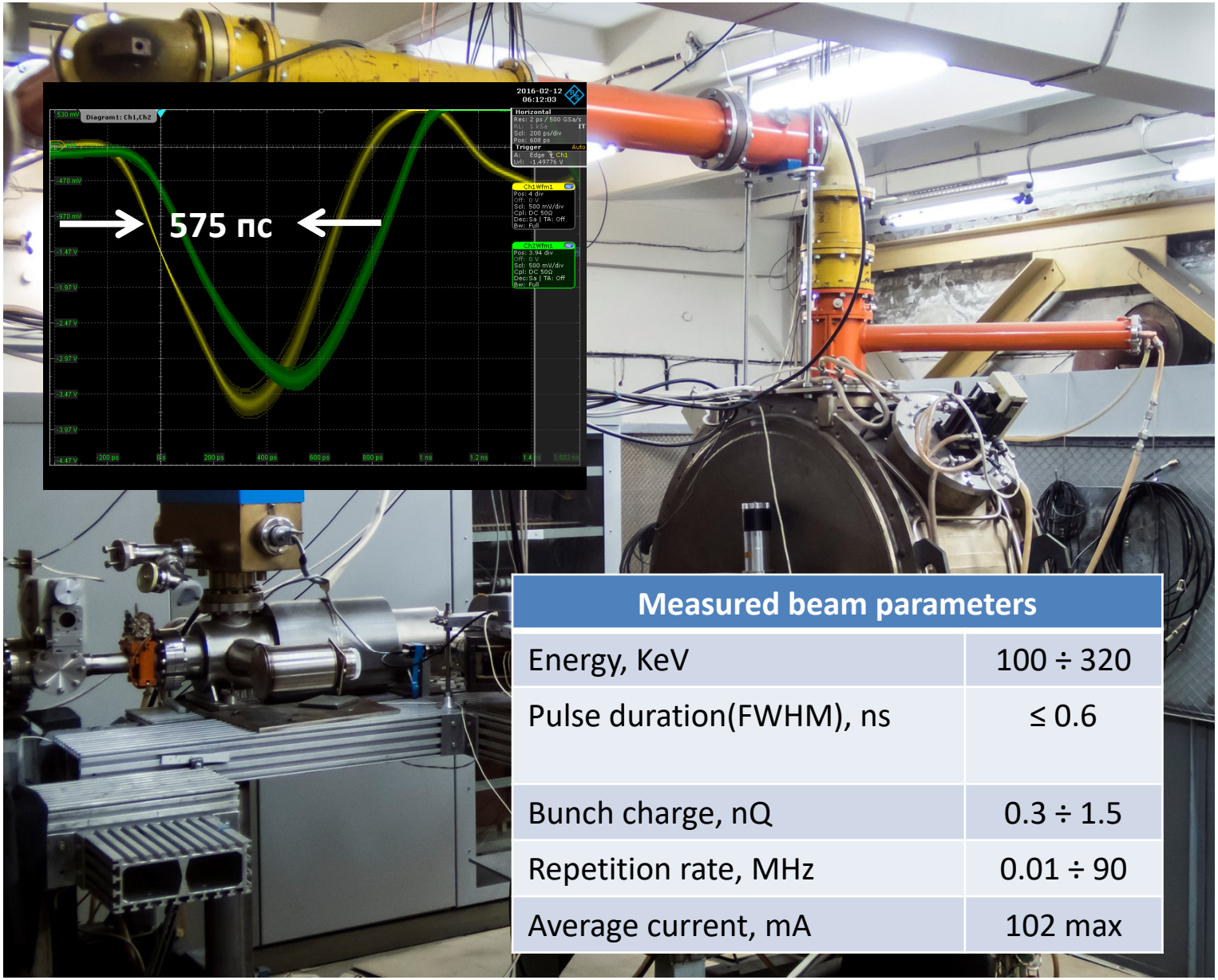
(actually measured)

Minimal normalized emittance (gun), μm	8
Minimal normalized emittance (final), μm	15
Maximal bunch charge, nQ	2
Maximal repetition rate, MHz	22.5
Maximal average current, mA	50
Maximal gun voltage, keV	300
Output beam energy, MeV	1.8

RF Gun Test Setup

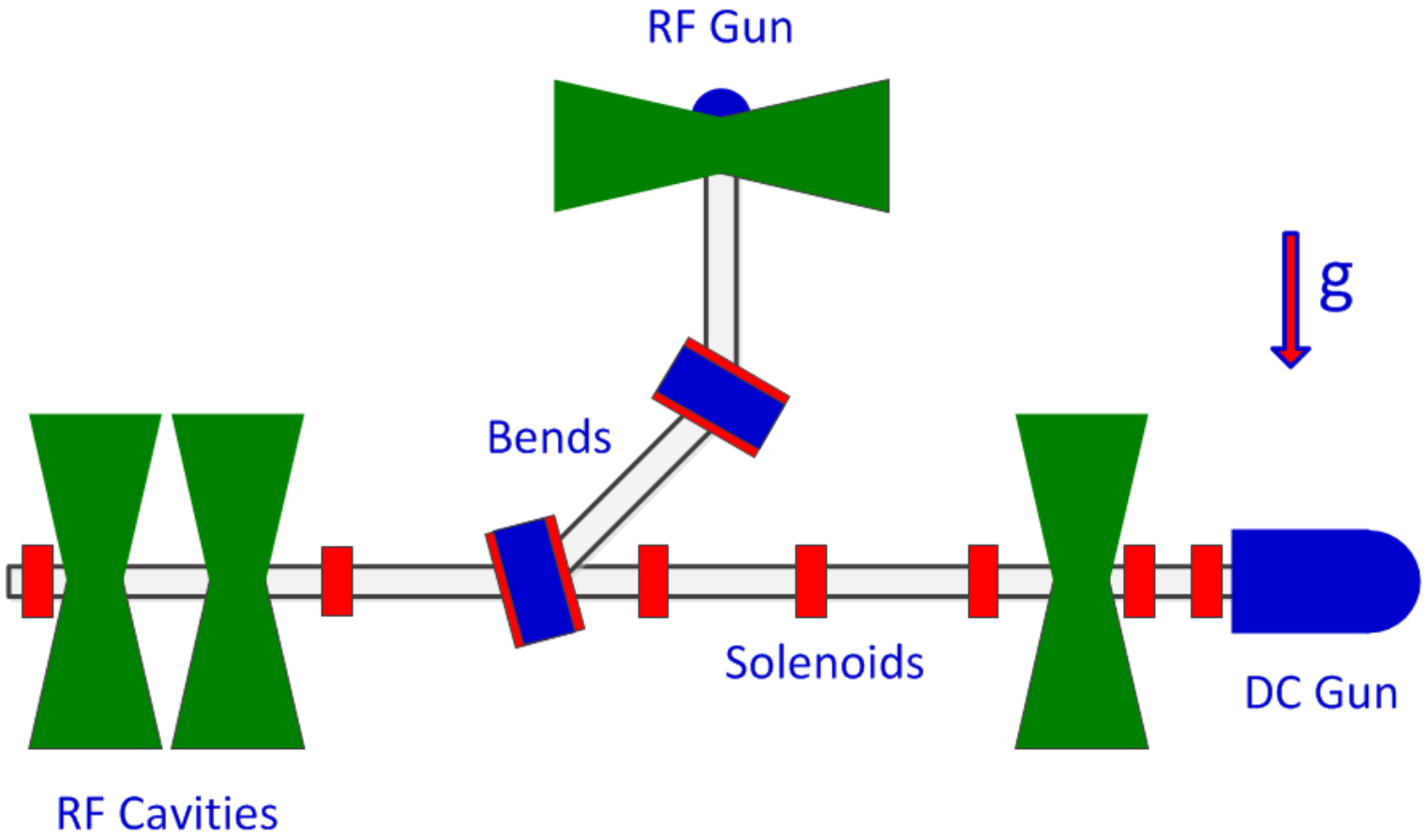


RF Gun Test Setup

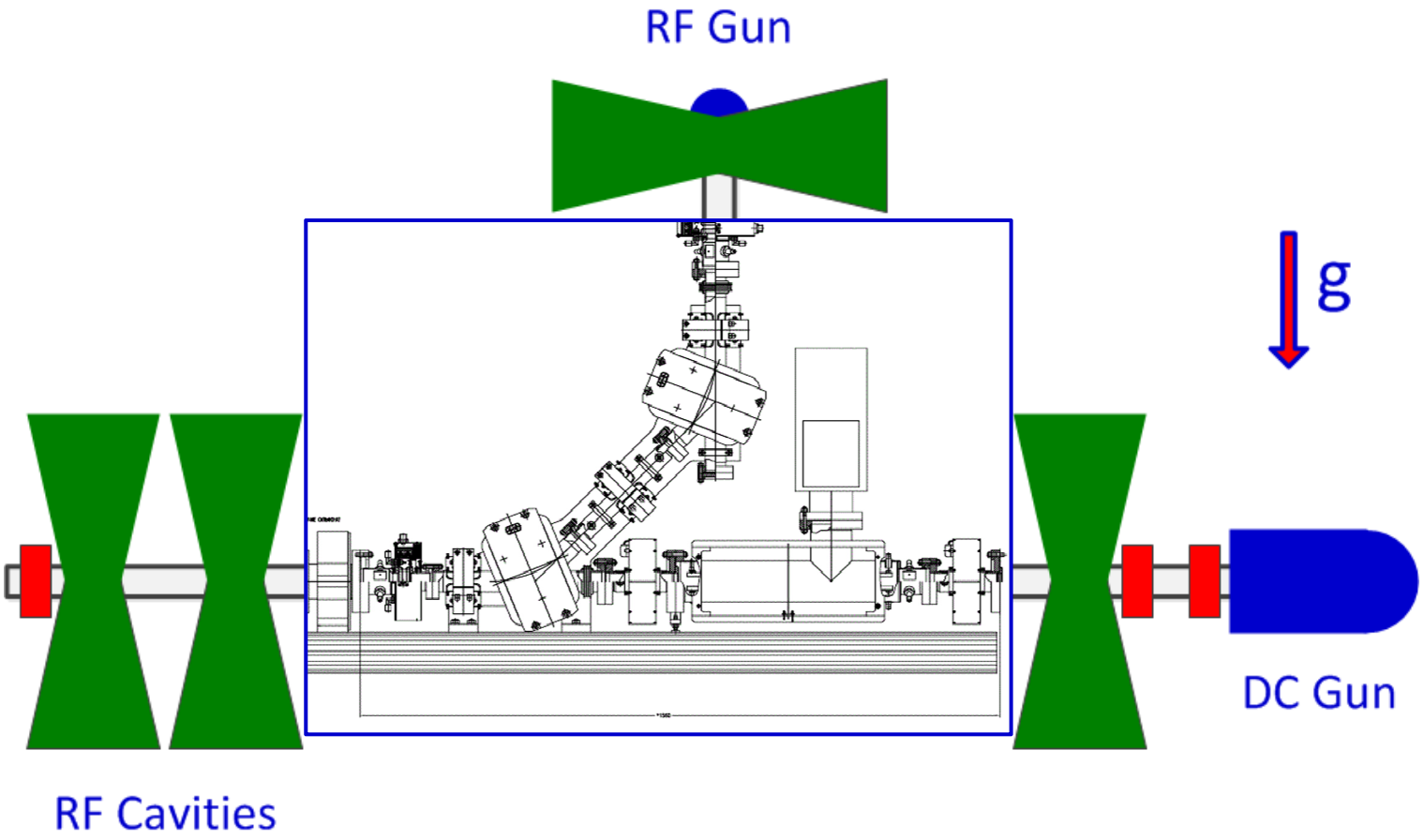


Measured beam parameters	
Energy, KeV	100 ÷ 320
Pulse duration(FWHM), ns	≤ 0.6
Bunch charge, nQ	0.3 ÷ 1.5
Repetition rate, MHz	0.01 ÷ 90
Average current, mA	102 max

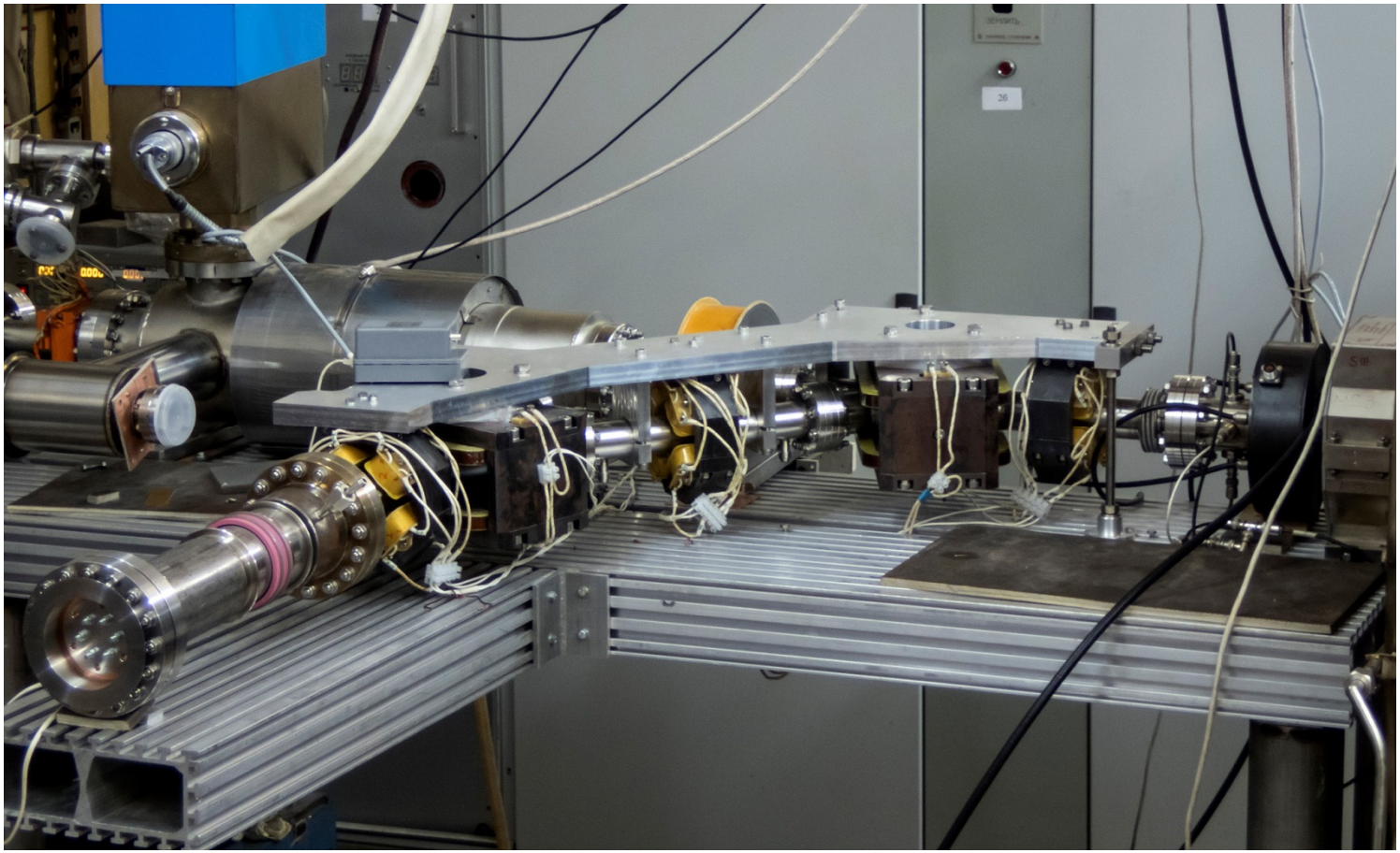
RF Gun Installation Layout



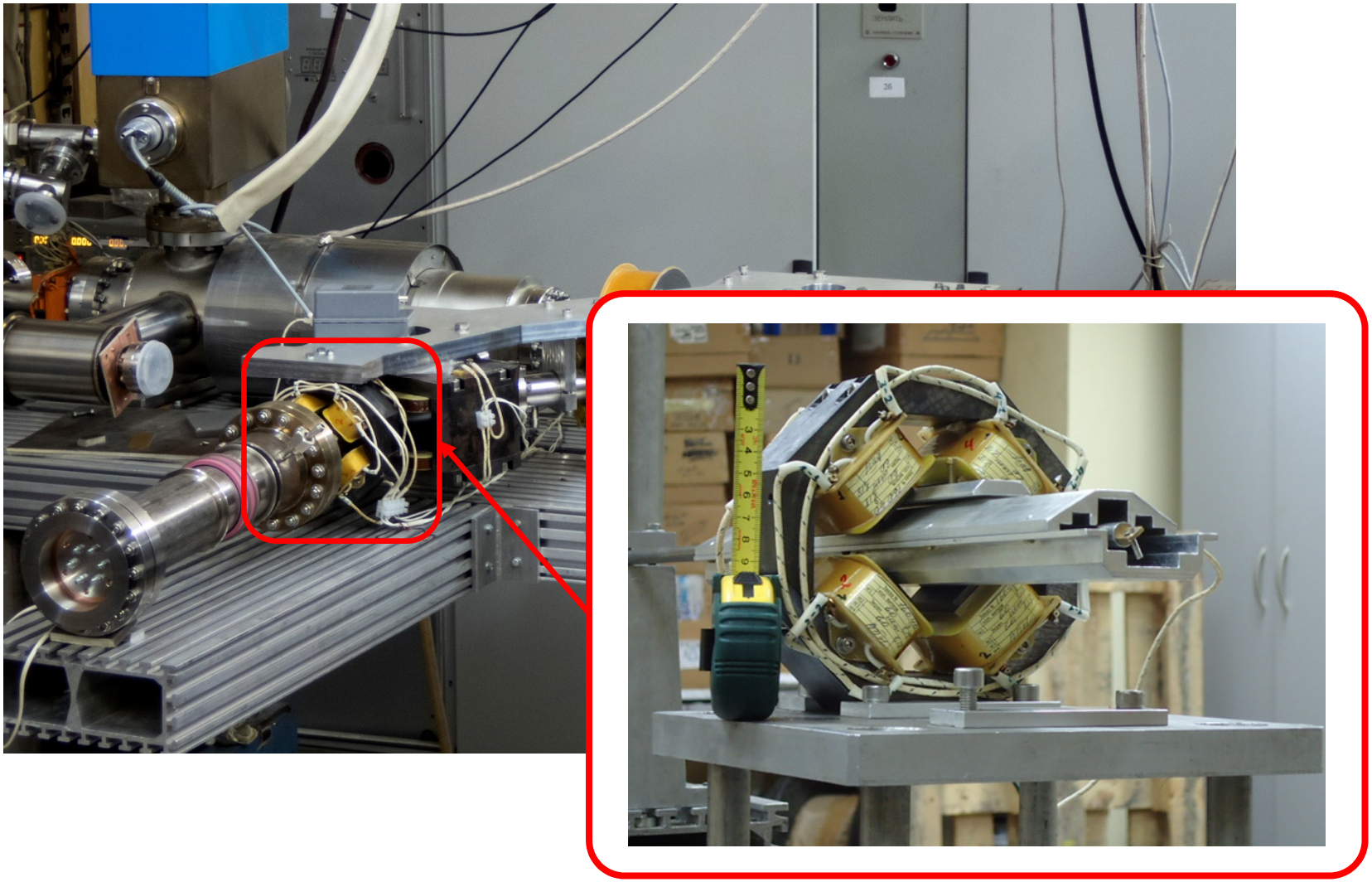
RF Gun Installation Layout



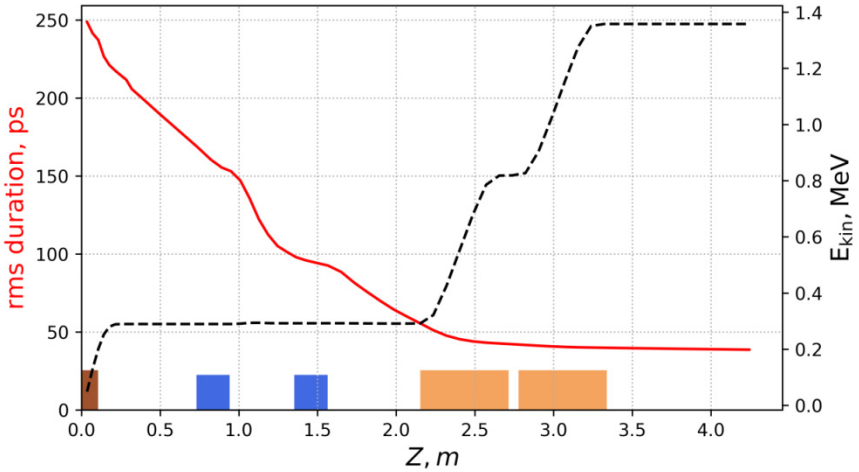
RF Gun Beamline

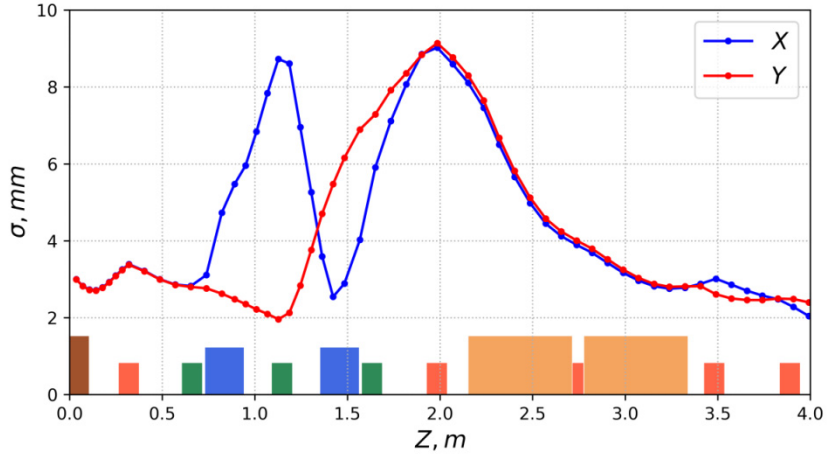


RF Gun Beamline



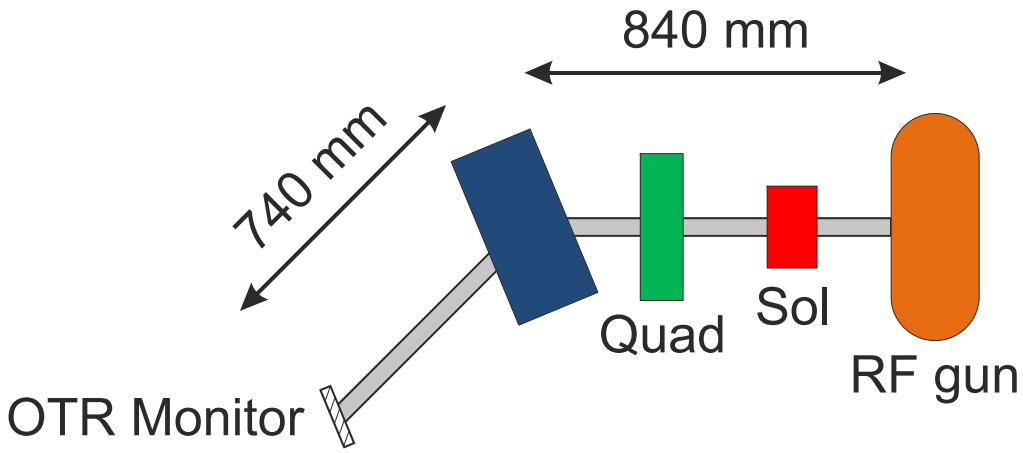
Results of Simulations

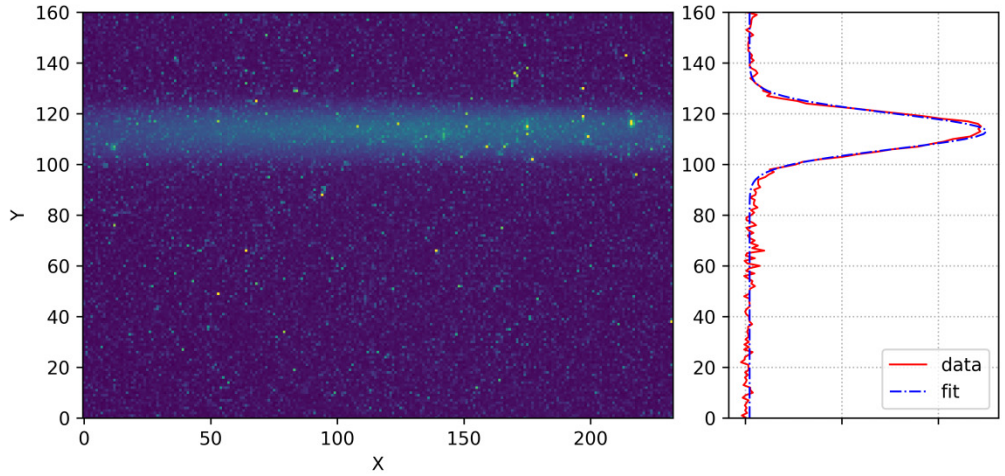




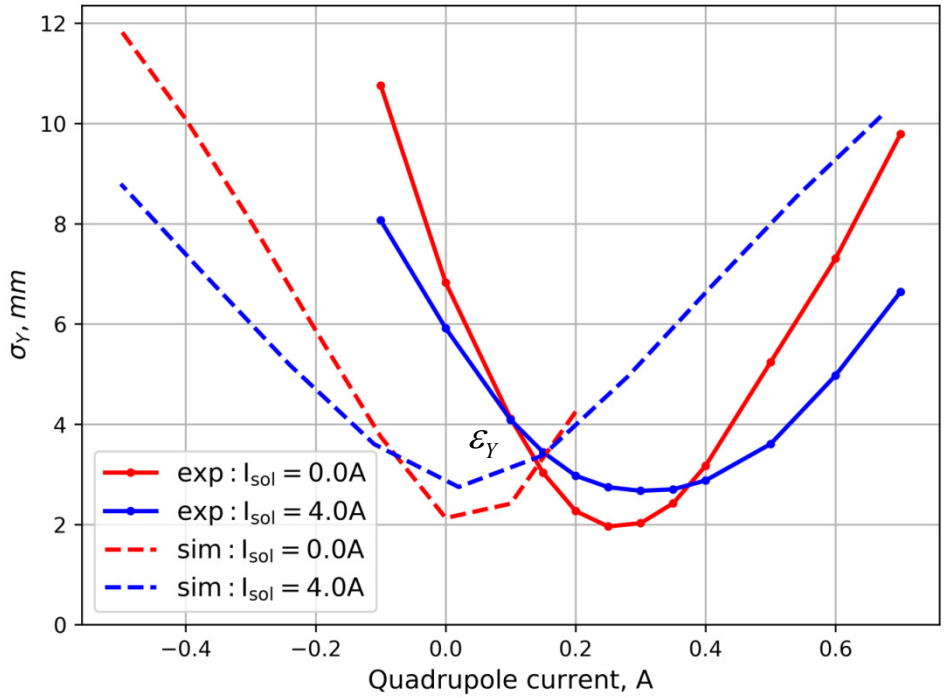
	x	y
Losses, %	19	
Norm. emittance, μm	27.6	27
Slice emittance, μm	13	20
Beta function, m	0.39	0.82
Bunch duration, ps	42	
Energy, MeV	1.87	
Energy spread, keV	14	

Beam Parameters Measurement





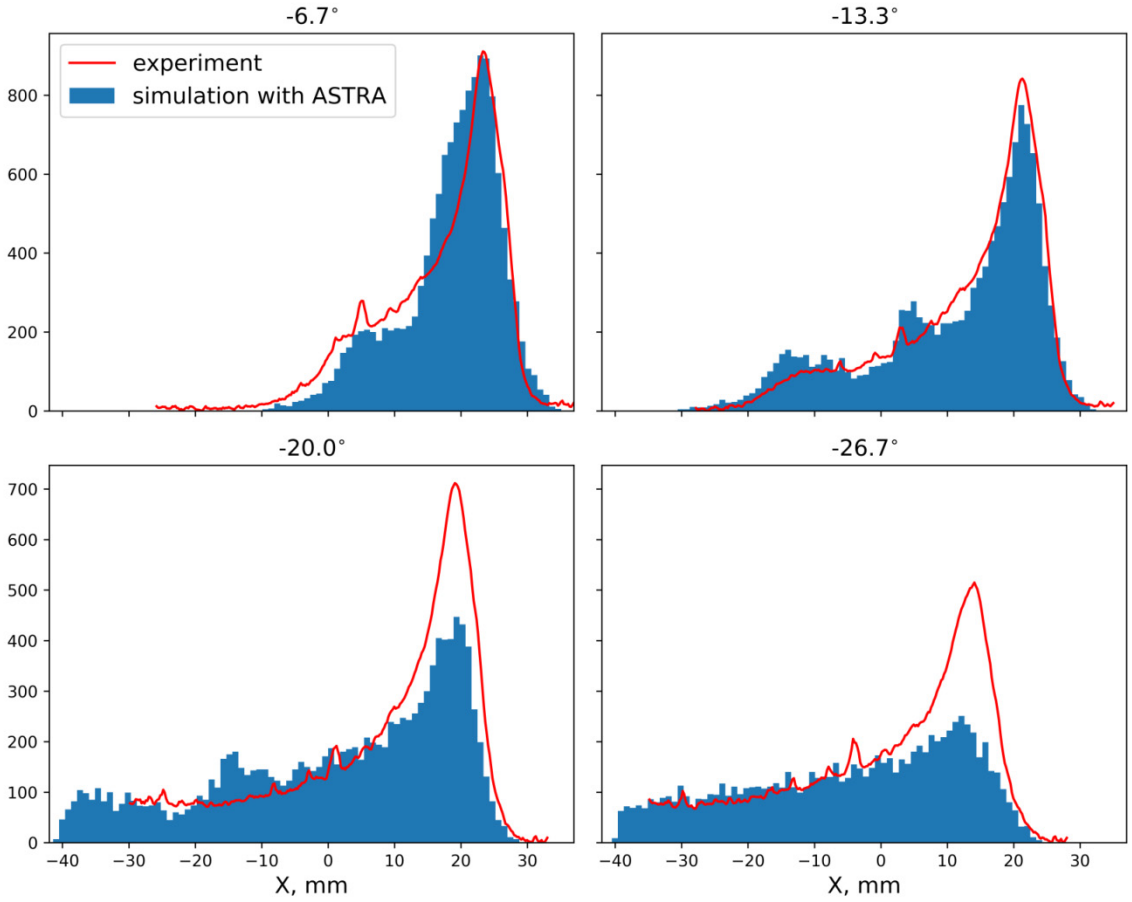
Beam Parameters Measurement



Solenoid current, A	Normalized emittance, μm
0.0	18.5
4.0	16

Dependence of the beam size on quadrupole current for different solenoid currents

Beam Parameters Measurement



Measured and simulated energy (horizontal coordinate) distributions for different accelerating phases

Summary

- NovoFEL injector has unique parameters. It provides the beam quality sufficient for all current applications.
- Measured beam parameters are in a good agreement with the simulation results but further improvement of the calculation model is needed.
- Commissioning of the new RF gun injection beamline is in progress. Its installation will allow to increase the average current and FEL radiation power.

Project participants

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Thank you for your attention!