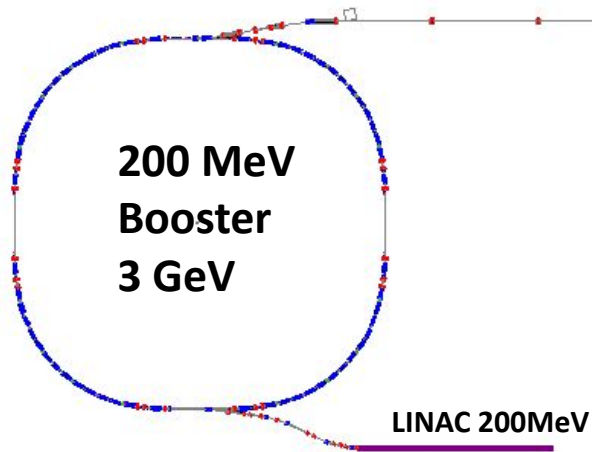


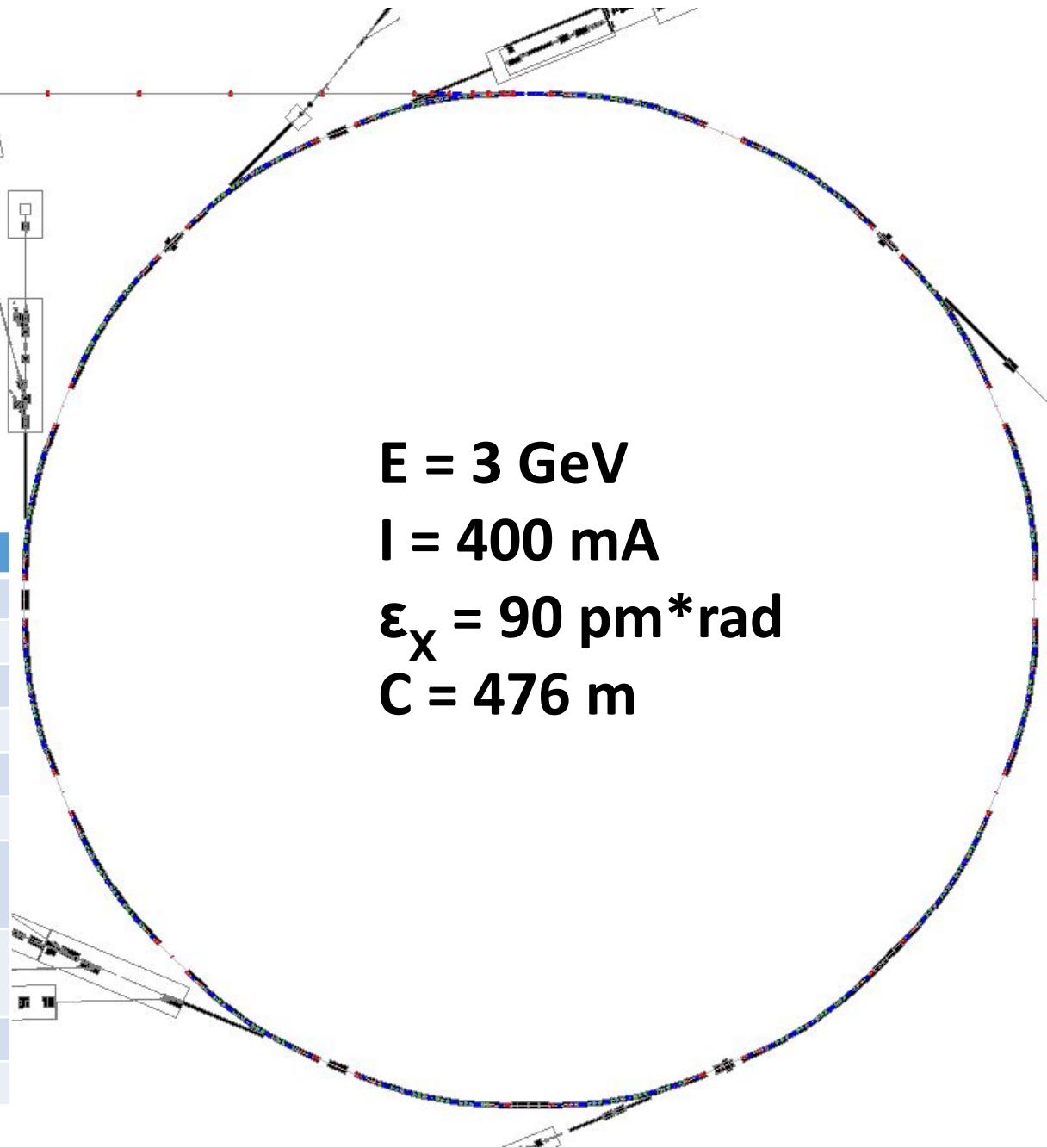
SKIF injector complex

Zhuravlev Andrey



Main injector parameters

Injection energy for main ring	3 GeV
Maximum of the injection energy	3,15 GeV
Frequency of injection	1 Hz
Time delay between bunches	2,8 ns
Number of the bunches in the train	up to 55
Charge per single bunch	Up to 0,27 nC
Maximum charge in the train	15 nC
Filling time of the collector ring from 0 to 400 mA	Not more than 1 minute
beam propagation between the gun and the collector ring	Not less than 90%
Horizontal emittance with 3 GeV	< 40 nm*rad
Energy spread	< 0,1%



Main parameters of the LINAC

User modes of the SKIF storage ring

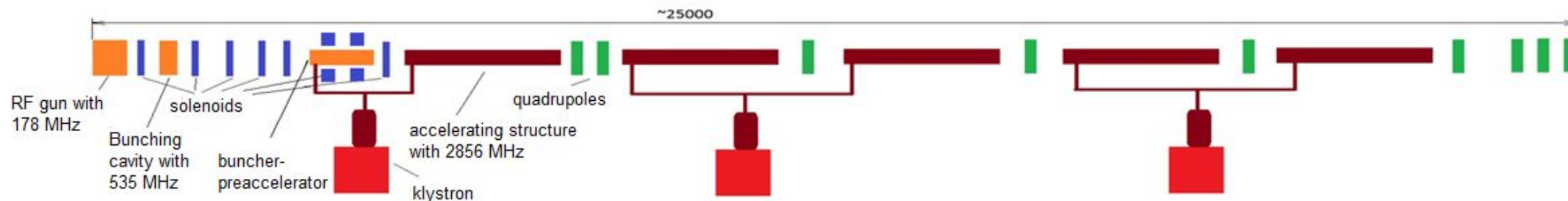
Mode	Current, mA	Time between bunches, ns
Mode 1 – main mode	400	5.6
Single bunch mode 2	5	
Single bunch mode 3	5	22.409 (5.6x4)
Single bunch mode 4	5	100.84 (5.6x18)
Single bunch mode 5	5	134.454 (5.6x24)
Single bunch mode 6	5	201.681 (5.6x36)

Main linac parameters

Beam energy	200 MeV
Maximum beam energy	210 MeV
Repetition rate	1 Hz
Geometrical emittance with 200 MeV	150 nm*rad
Energy spread with 200 MeV	$\leq 1\%$ (rms)

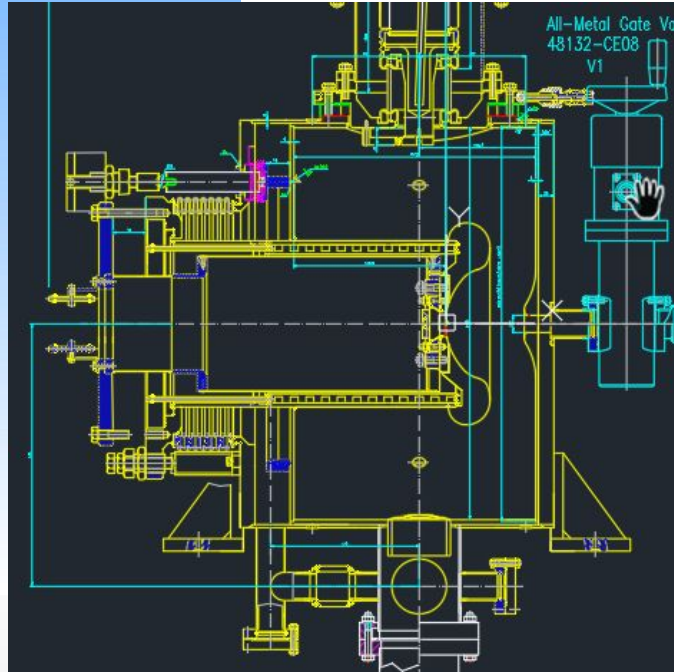
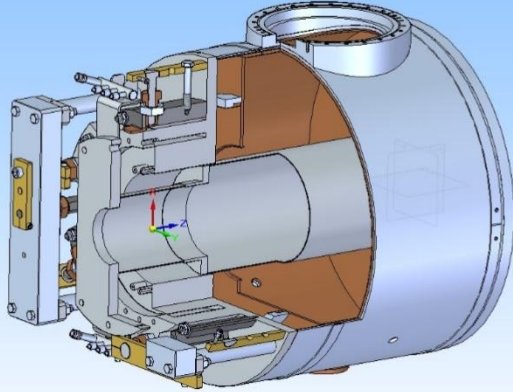


Scheme of the linear accelerator with energy of 200 MeV



Название	Описание	Кол-во
RF gun	RF gun with frequency of 178.5 MHz, with RF triode	1
Bunching cavity	Bunching cavity of the third harmonic with frequency of 535.5 MHz	1
Buncher-preaccelerator	Short disk-loaded accelerating structure with travelling wave and oscillation mode of $2\pi/3$, operating frequency of 2856 MHz, input RF power is 10 MW	1
Accelerating structure	disk-loaded accelerating structure with travelling wave and oscillation mode of $2\pi/3$, operating frequency is 2856 MHz, length is 3 m, input RF power is 25 MW for 4 structures and 40 MW for 1 structure	5
RF power supplying for the RF gun	RF power is about 0.5 MW, pulse duration is 100 μ s, repetition rate is up to 20 Hz	1
RF gun modulator	Repetition rate of 0-178 МГц, pulse duration is 2 ns, amplitude is about -150 V	1
RF power supplying for the bunching cavity	Frequency is 534 MHz, RF power is up to 10 kW, pulse duration is 100 μ s, repetition rate is up to 20 Hz	1
Klystron	Frequency is 2856 MHz, RF power is 50 MW, pulse duration is 4 μ s, repetition rate is up to 20 Hz	3
Klystron modulator	High power is 350 kV, pulsed power is 120 MW, pulse duration is 6.5 μ s, repetition rate is 20 Hz	3
Thermal stabilization	System is based on the tube electric heater	8

RF gun with frequency of 178 MHz



Operating frequency, MHz	178
Maximum electric field along the axis, MV/m	13
Overvoltage factor	1.8
Quality factor	10300
Pulsed RF power, kW	500

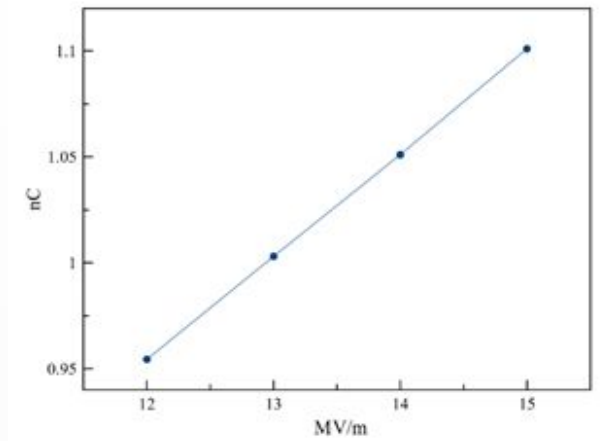
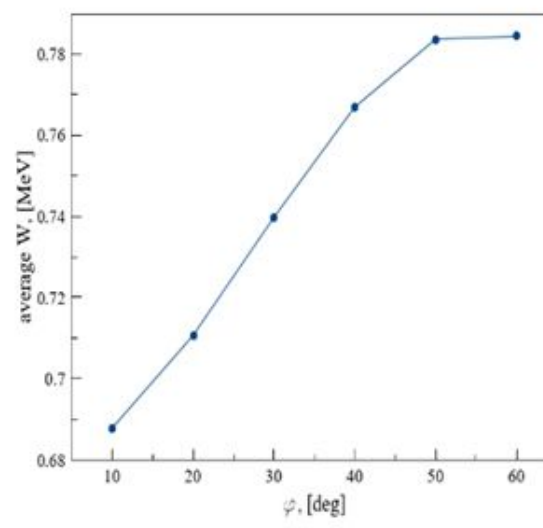
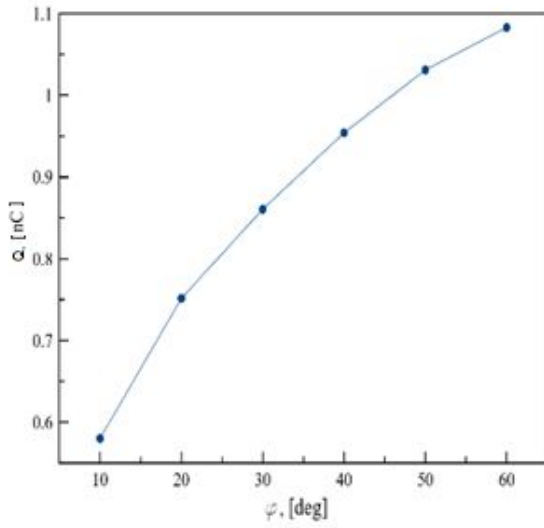
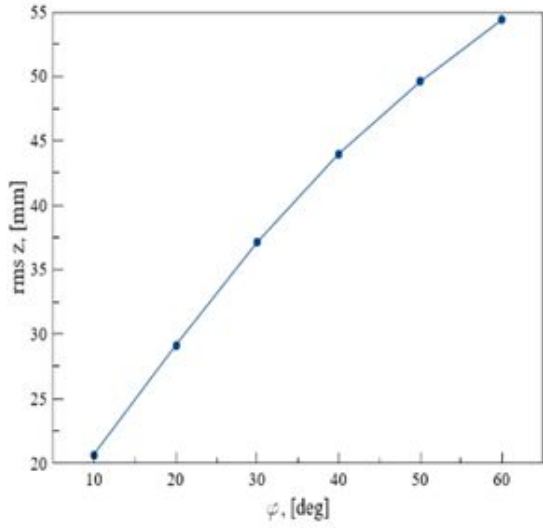
Cathode is based on the RF triode GS-34



Parameter	Min	Max
Dissipated grid power, W		3
Voltage of the heater, V	12	13.2
Bias voltage, V	-150	0
Pulsed current of the cathode, A		11
Pulsed current of the grid, A		4
Pulse duration, μC		10
Transparency of the grid		75%
Field permeation coefficient per grid		25.8%

Mode of the linac	Charge in single bunch, nC	Time between bunches, ns
Mode 1 – main mode	0.27	5.6
Single bunch mode 2	1	
Single bunch mode 3	1	22.409 (5.6x4)
Single bunch mode 4	1	100.84 (5.6x18)
Single bunch mode 5	1	134.454 (5.6x24)
Single bunch mode 6	1	201.681 (5.6x36)

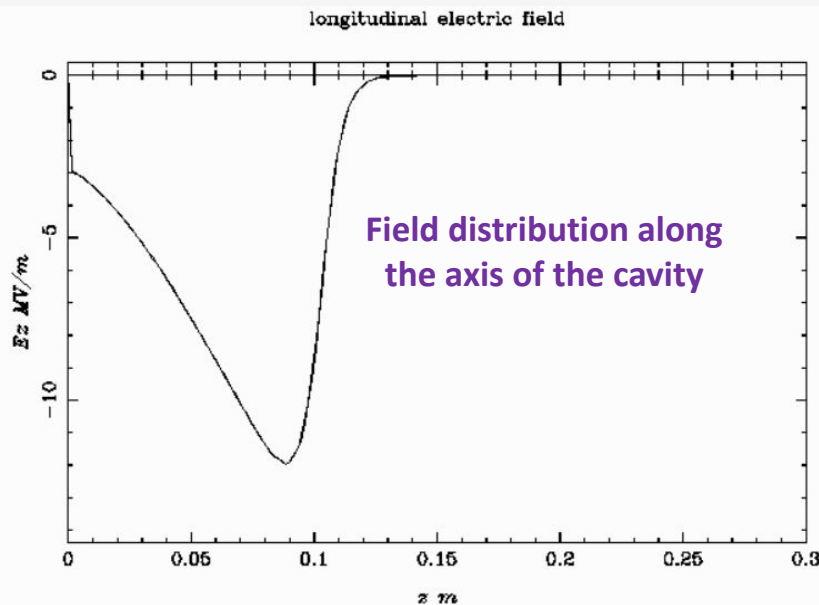
RF gun with frequency of 178 MHz: beam simulation



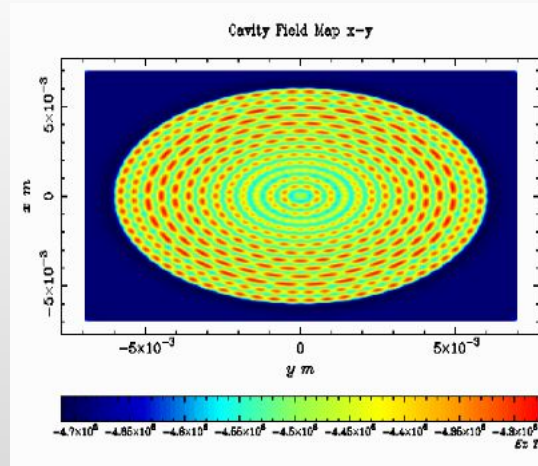
Output beam charge vs accelerating field with fixed injection phase of 40 deg

Beam parameters with accelerating field of 13 MV/m vs injection phase: rms length, emitted charge, average bunch energy

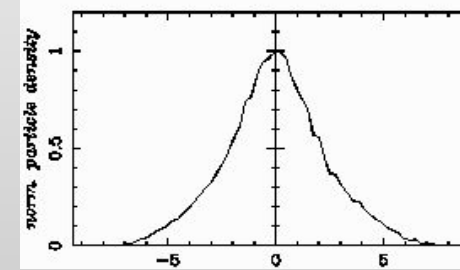
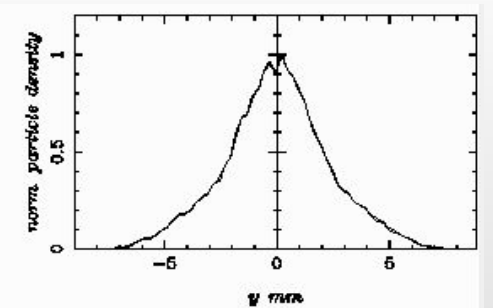
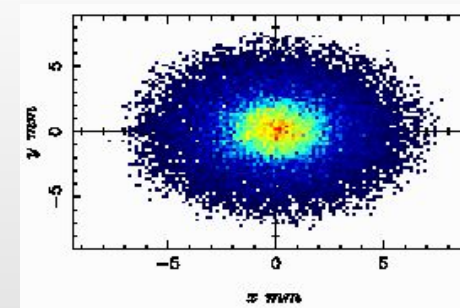
Simulation of the emission beam by code ASTRA with grid



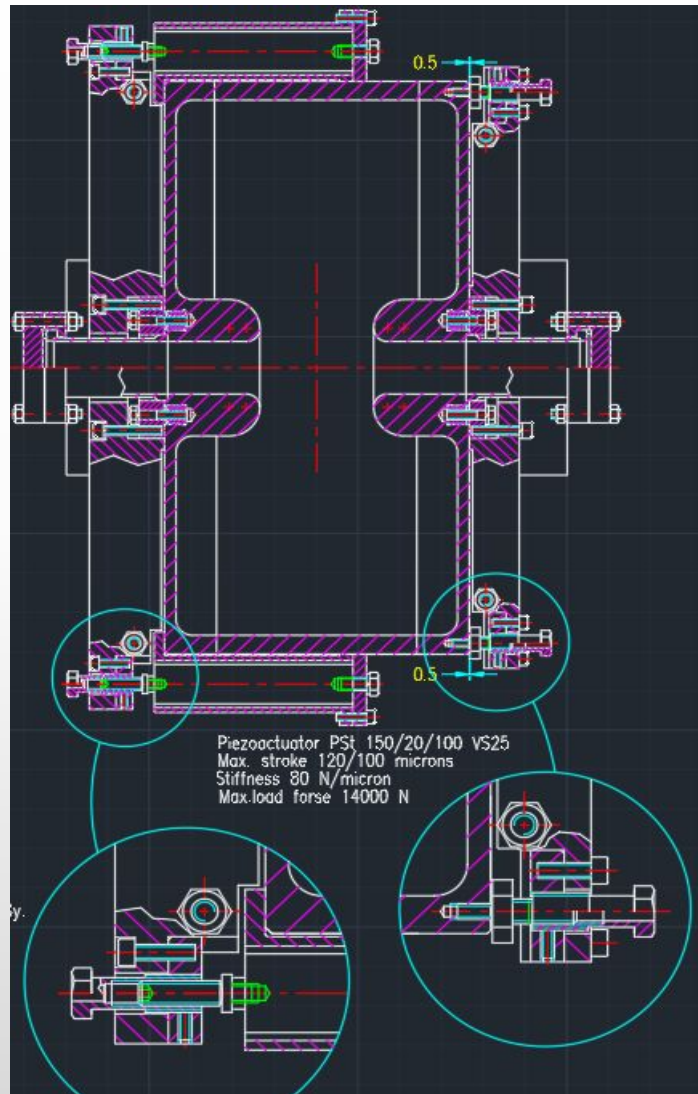
Field distribution along the axis of the cavity



Grid model

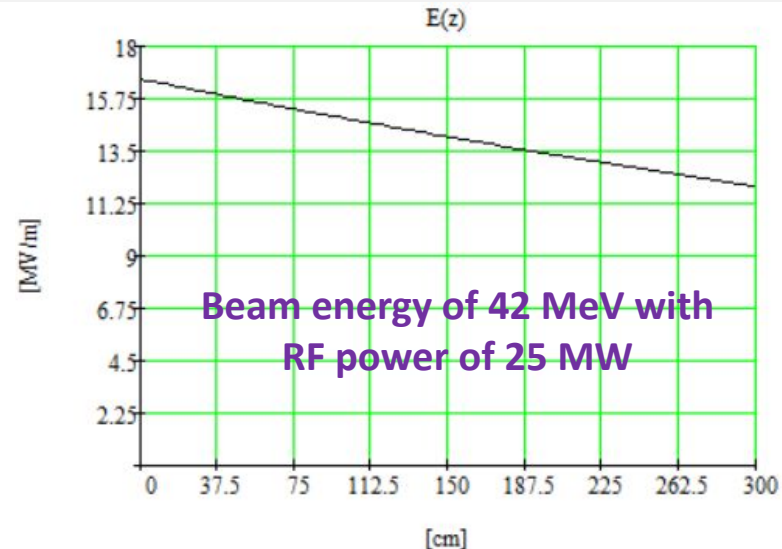
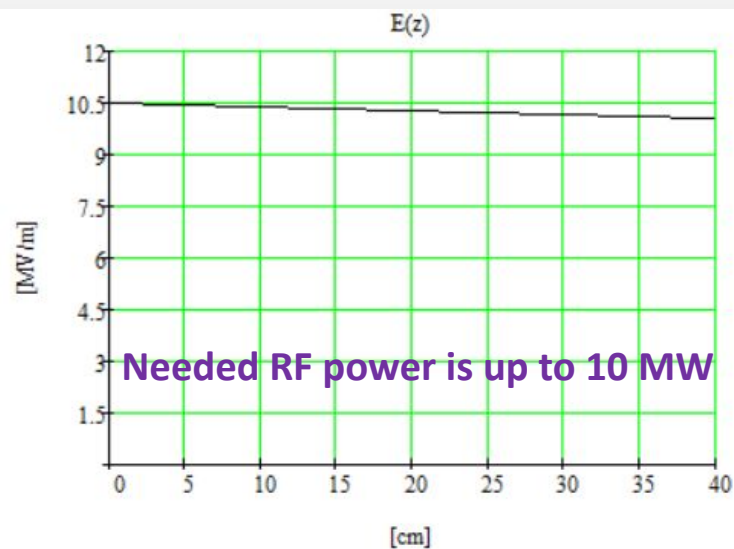
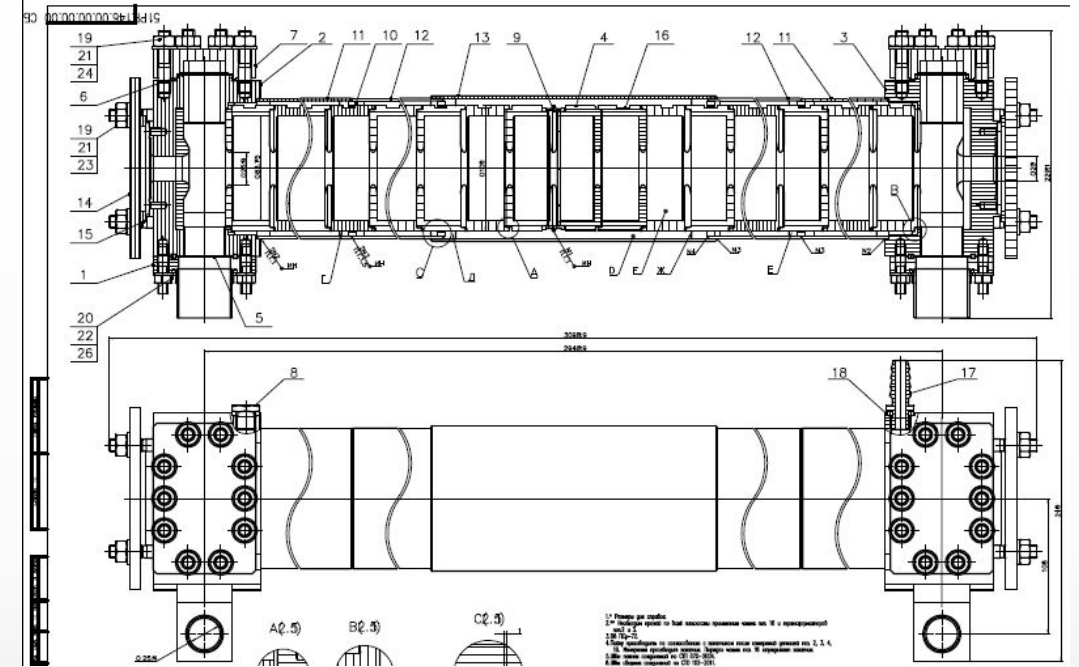
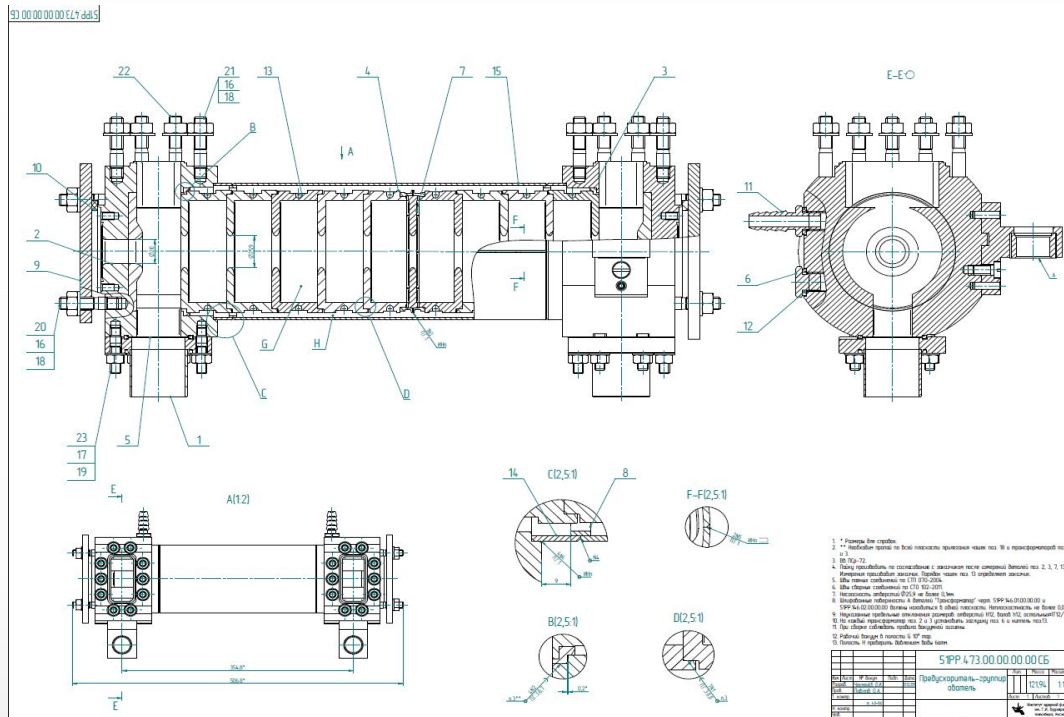


Bunching cavity with frequency of 535 MHz (the third harmonic)



Operating frequency, MHz	535.5
Maximum electric field along the axis, MV/m	13
Characteristic impedance, Ohm	148.2
Overvoltage factor	1.8
Quality factor	20200
Pulsed RF power, kW	10

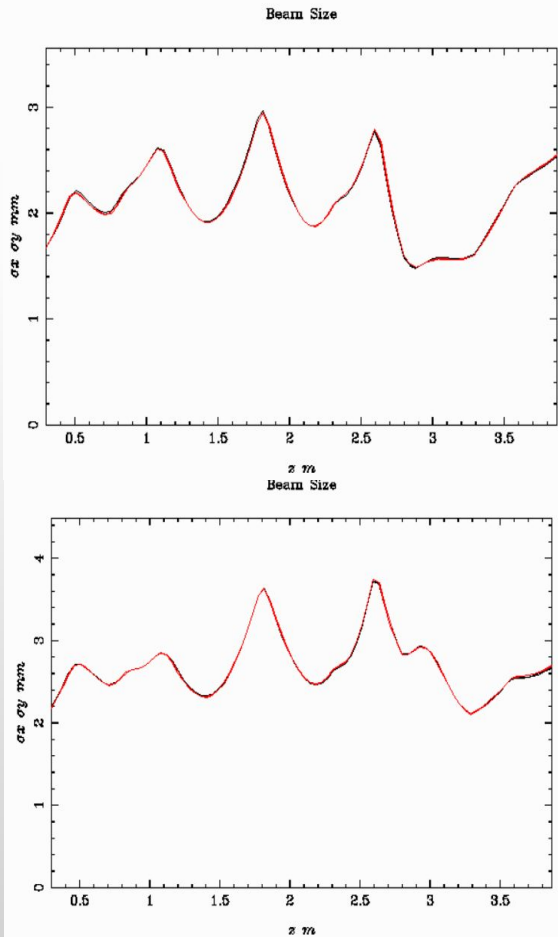
Buncher-preaccelerator and regular accelerating structure



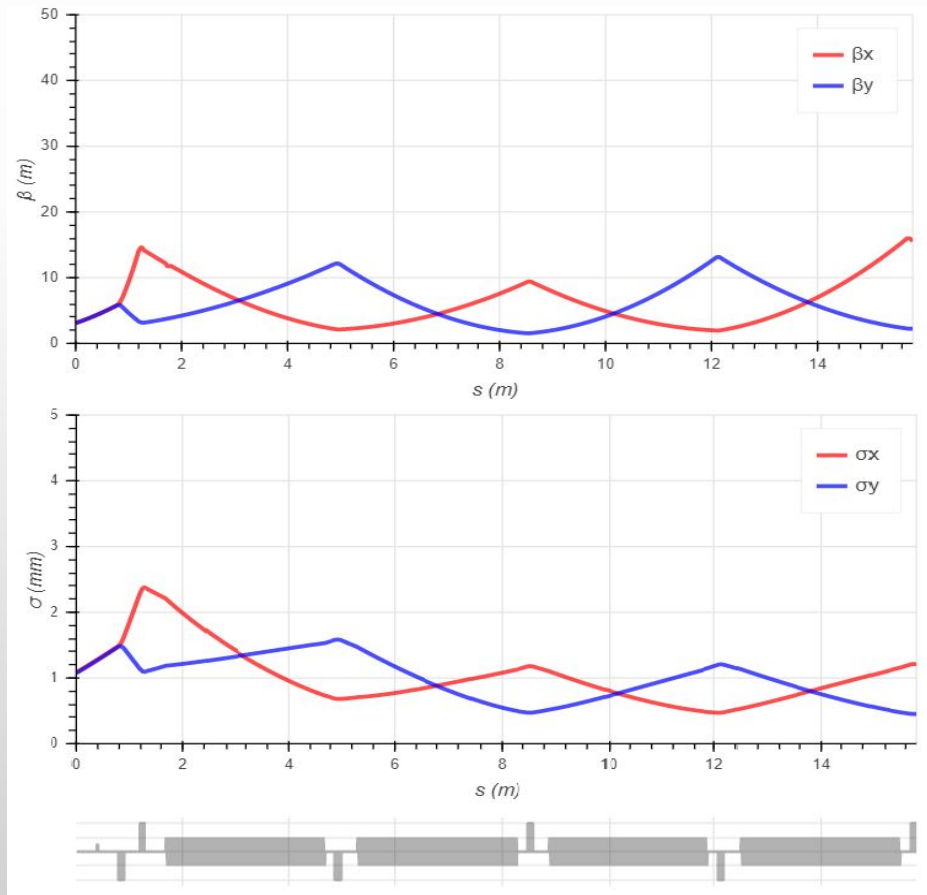
Operational frequency	2855.5 MHz
Internal cell diameter $2b$	83.75 mm
Iris diameter $2a$	25.9 mm
Iris thickness t	6 mm
Period D	34.99 mm
Operational mode of oscillation θ	$2\pi/3$
Relative phase velocity β_p	1
Relative group velocity β_g	0.021
Section length L	2.93 m
Total number of cells (incl. 2 WTT)	85
Unloaded quality factor Q_0	13200
Shunt impedance R_{sh}	51 MOhm/m
Time constant $\tau_{i0} = 2Q_0/\omega_0$	1.471 μ s
Attenuation (by field) $\alpha = 1/(\tau_{i0} v_{gr})$	0.108 m^{-1}
Filling time $T_f = L/v_{gr}$	0.465 μ s

Beam dynamics simulation

Beam size in bunching system



Beam size in regular structure



Output beam parameters

Parameters	Charge in bunch 0.3 nC	Charge in bunch 0.98 nC
Average energy in the bunch	200 MeV	200 MeV
Rms energy spread in the bunch	0.48 MeV (0.24%)	1.9 MeV (0.95%)
Energy spread along the train due to beam current loading	3%	
Normalized vertical emittance	18.3 π mm mrad	34.3 π mm mrad
Normalized horizontal emittance	18.4 π mm mrad	33.8 π mm mrad

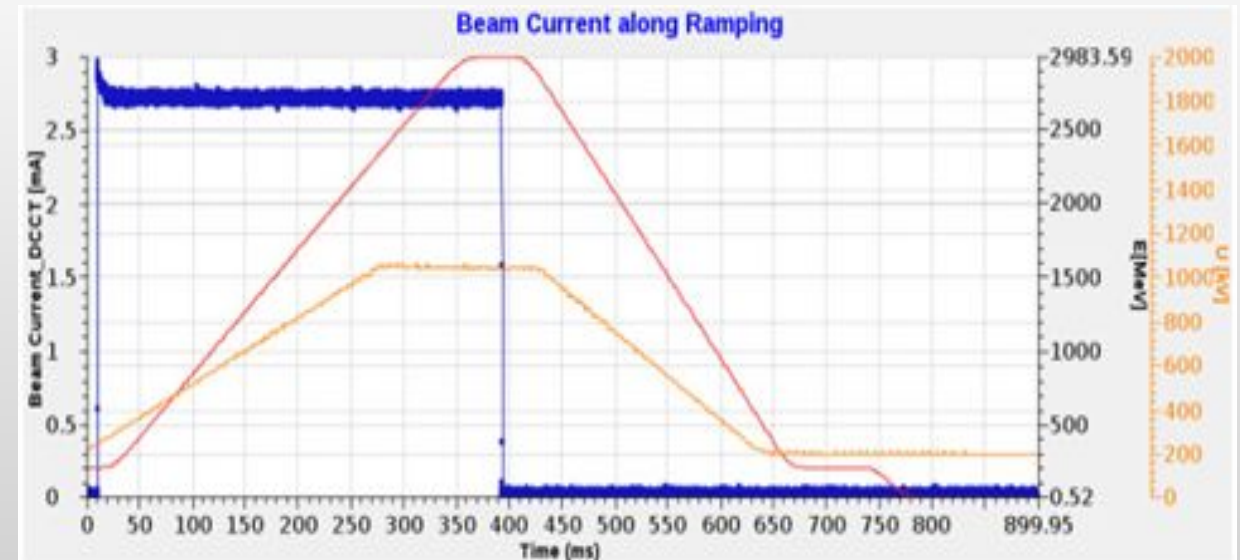
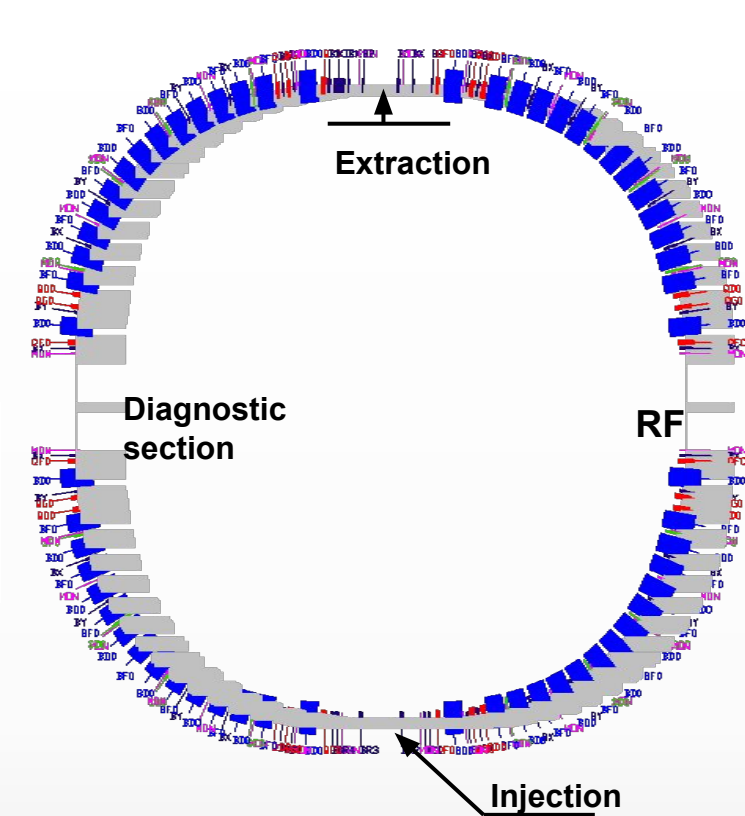
Booster

The booster lattice consists of four super periods.

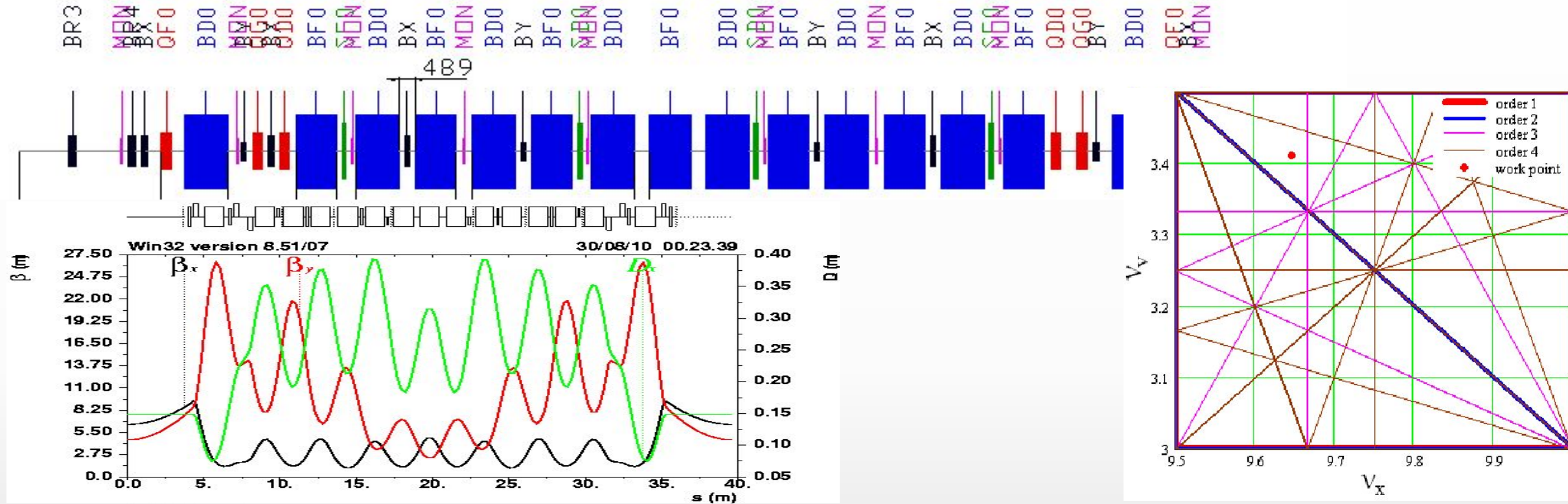
The horizontal emittance at 3 GeV is 37.4 nm-rad.

Energy	200 MeV	3 GeV
Super period number	4	
Circumference, m	158.71 (158.40)	
Injection rate, Hz	1	
Bunch number	1, 80-150	
Circulation time, nsec	528	
RF frequency, MHZ	357 (500)	
RF number	189 (264)	
Betatron tunes: \sqrt{x} / \sqrt{y}	9.645 / 3.41	
Natural chromaticity: ξ_x / ξ_y	-9.5 / -13.5	
Remain chromaticity: ξ_x / ξ_y	1.22 / 2.08	
Compaction factor, α	0.00881	
RF voltage, MV	0.2	1.2
RF bucket, ϵ_{RF} , %	1.96 (1.65)	0.64 (0.54)
Hor. emittance, ϵ_x , nm-rad	0.166	37.4
Energy spread, σ_E/E	$0.55 \cdot 10^{-4}$	$8.31 \cdot 10^{-4}$
Energy loss, U_0 , keV	0.0135	686
Damping time: (τ_x, τ_y, τ_s)	(15.6, 15.6, 7.8) sec	(4.62, 4.62, 2.31) msec

Two straight sections occupy by injection and extraction systems, other sections are occupied by the RF system and diagnostic.



Booster lattice



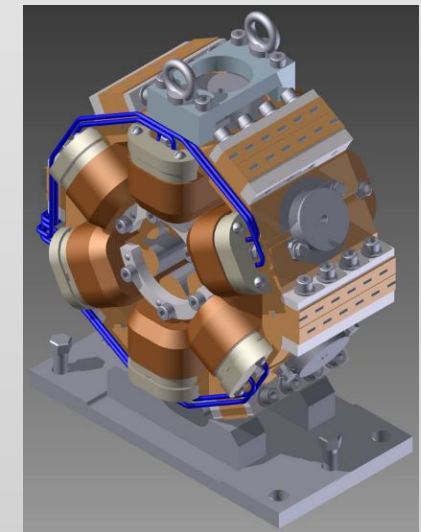
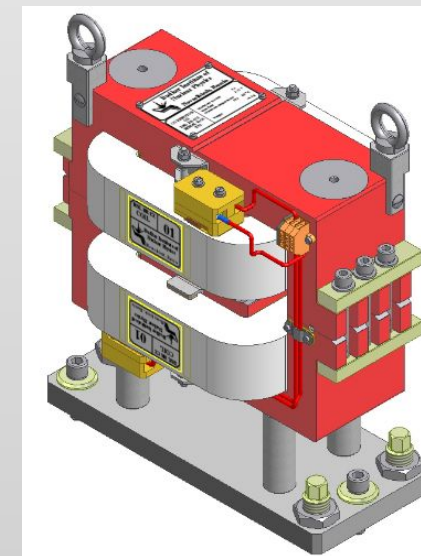
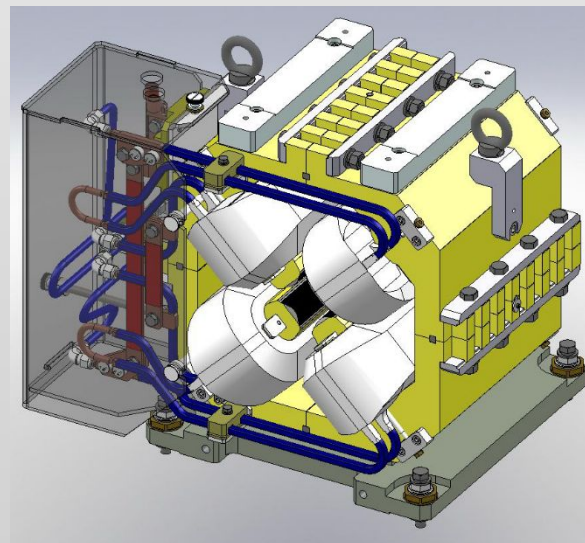
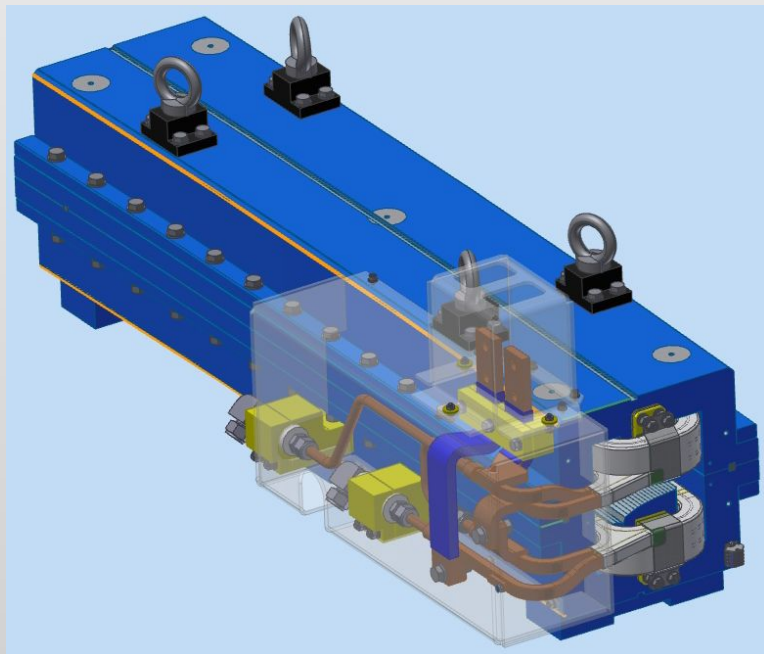
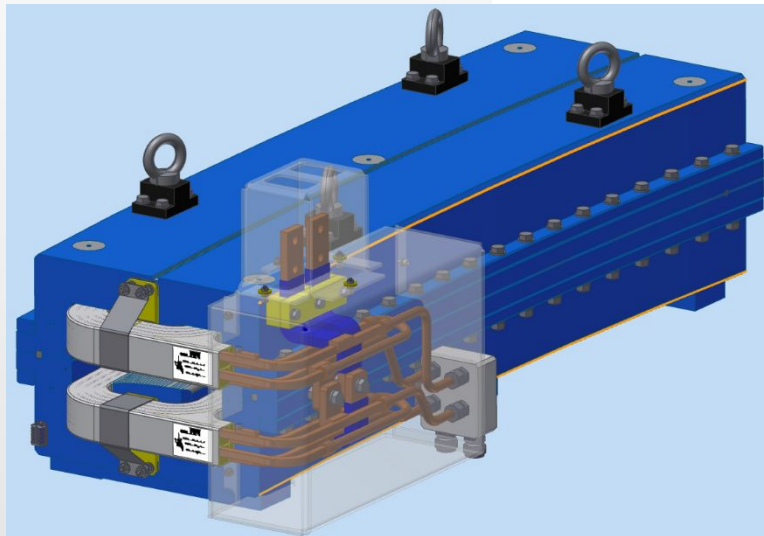
Super period consists of 5 cells with two modified cells at the edges to suppress dispersion.

- 8 defocusing dipoles (BD) with rotation angle 8.39° ,
- 7 focusing dipoles (BF) with rotation angle 3.27° ,
- 6 quadrupole lenses,
- 4 sextupole lenses (2xSD, 2xSF).

Betatron frequency:
 $\nu_x = 9.645$
 $\nu_y = 3.41$

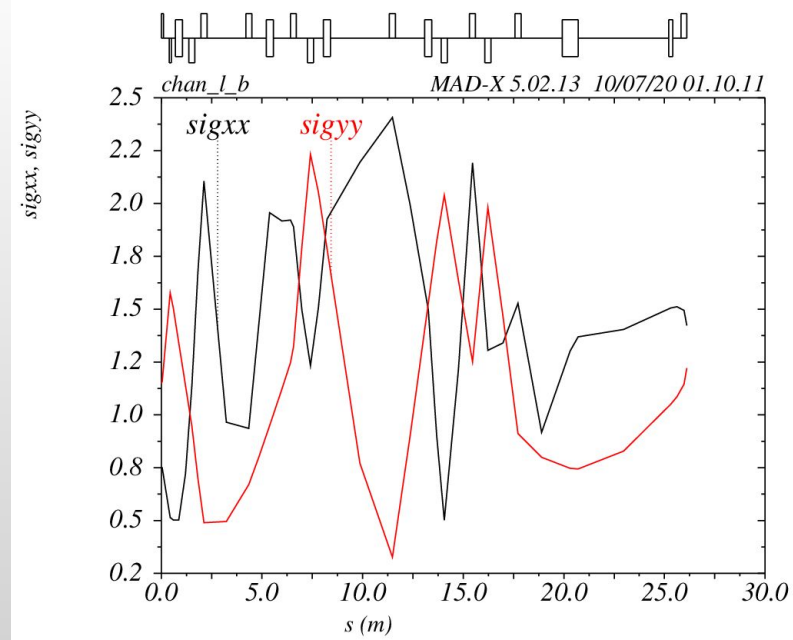
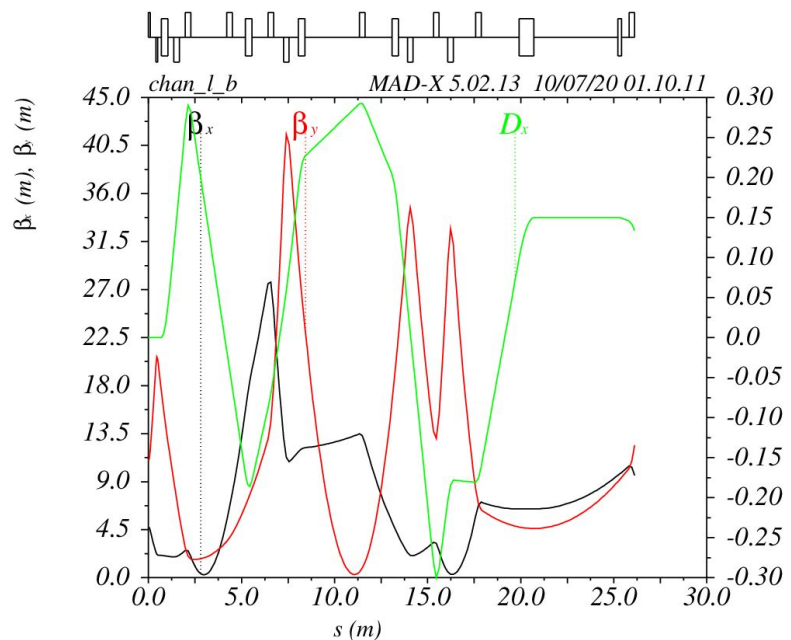
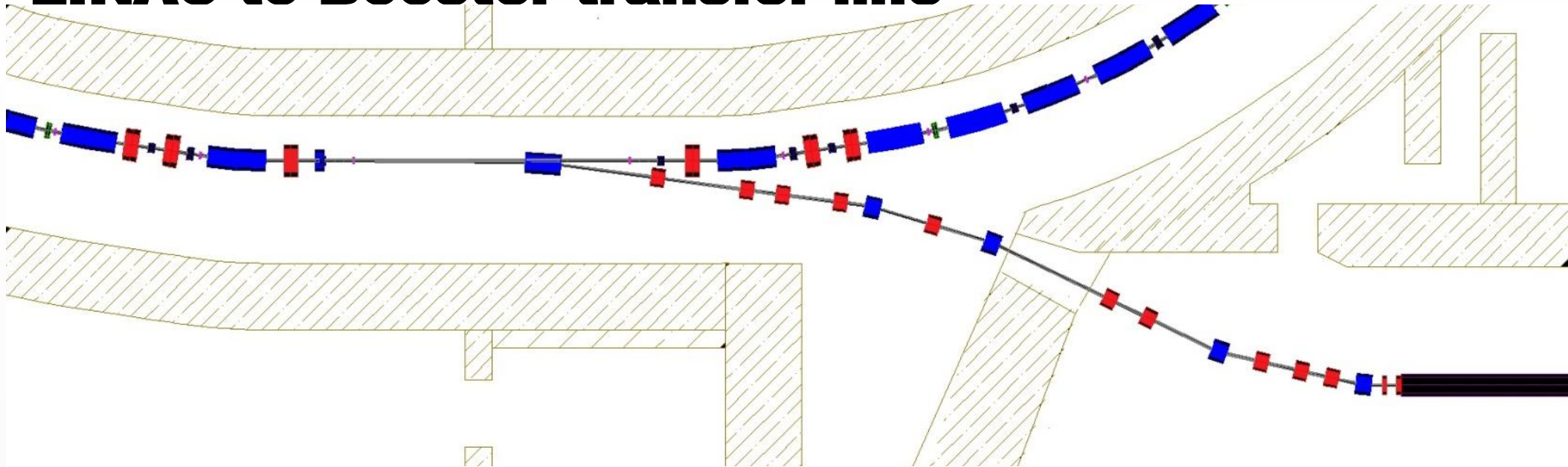
To compensate chromatism, a sextupole component is embedded in dipole magnets.

Booster magnets



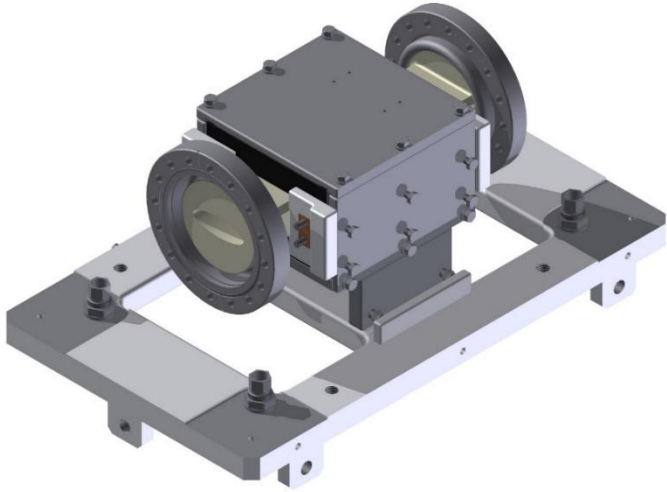
Dipole magnets					
Type	Number	Length, m	θ , deg	$K_1, 1/m^2$	$K_2, 1/m^3$
BF	28	1.24	3.2673	0.82	3.6
BD	32	1.3	8.391	-0.5551	-4.3
Quadrupole lenses					
QF	8	0.3		2.0425	
QD	8	0.3		-1.5014	
QG	8	0.3		1.3361	
Sextupole lenses					
SF	8	0.12			40
SD	8	0.12			-40

LINAC to Booster transfer line

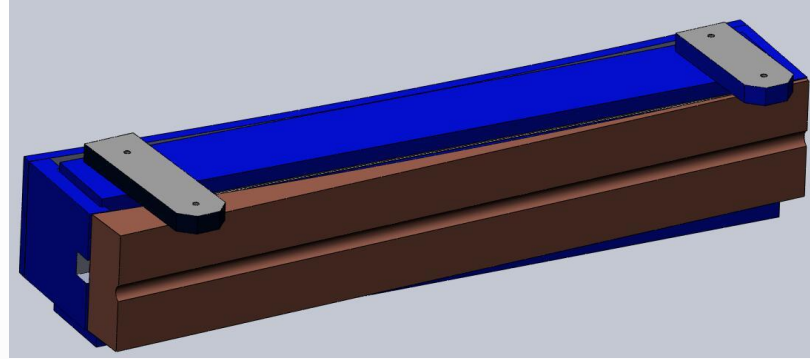


- 2 dipoles with rotation angle 230 mrad,
 - 2 dipoles with rotation angle 163.2 mrad,
 - 10 quadrupole lenses,
 - 4 dipole correctors
- Diagnostic system:**
- 6 BPMs
 - 6 fluorescent screens
 - 2 current transformers for current measure

Booster Injection

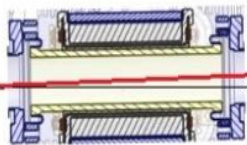


Injection kicker



Injection septum magnet

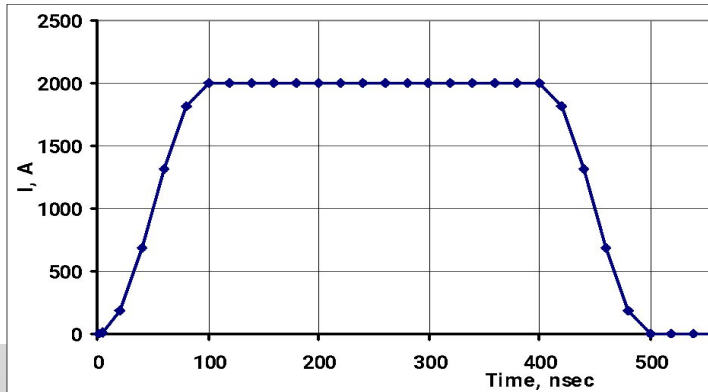
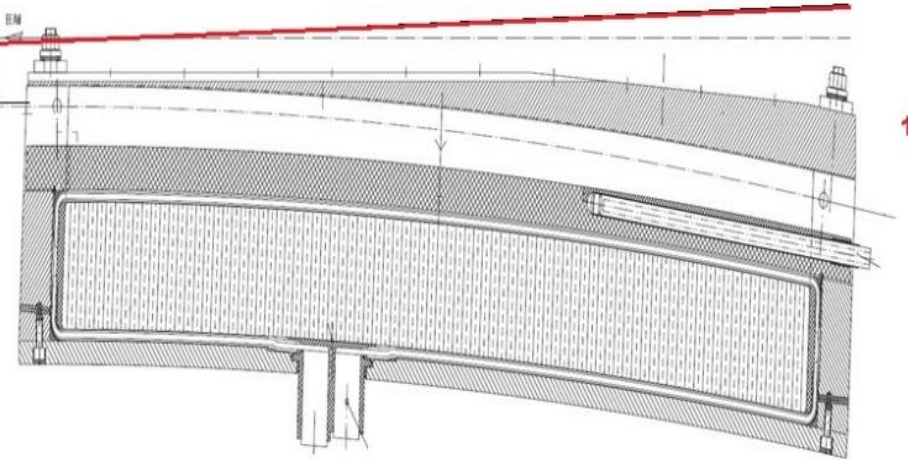
	AC septum magnet	kicker
Effective length, m	0.75	0.16
Bend angle, mrad	125	8.6
Inductance	1,8 mK	540 nH
Peak current, A	2400	1600
Maximum voltage, V	185	17000
Pulse shape	104 mksec (1/2 sin)	300 nsec flat-top, fail time 200 nsec



4.5 m

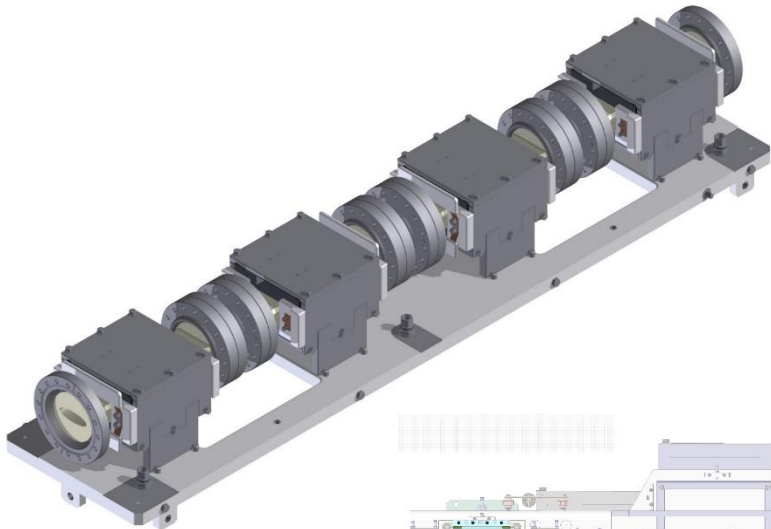
38.8 mm

133.6 mrad

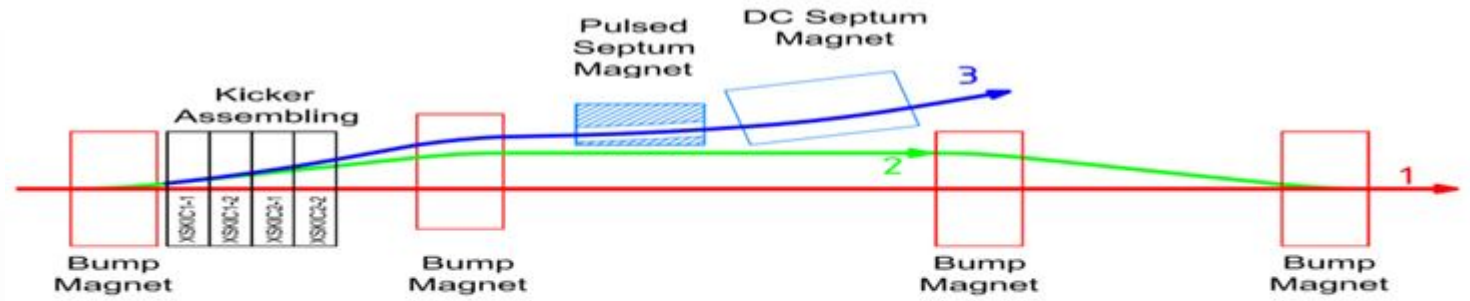


Kicker's current form

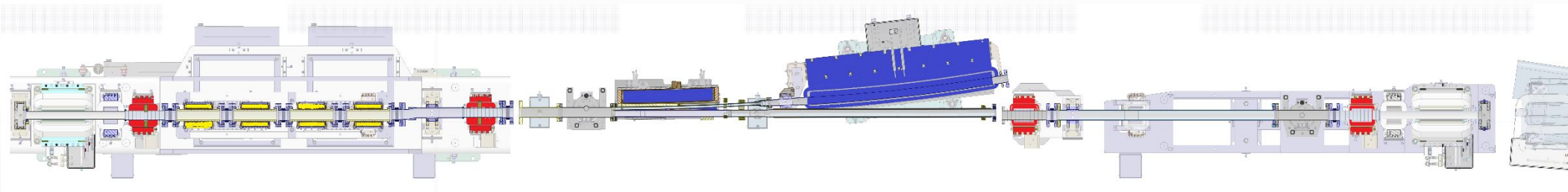
Booster Extraction



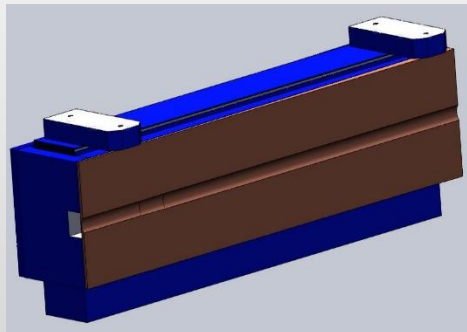
Extraction kicker



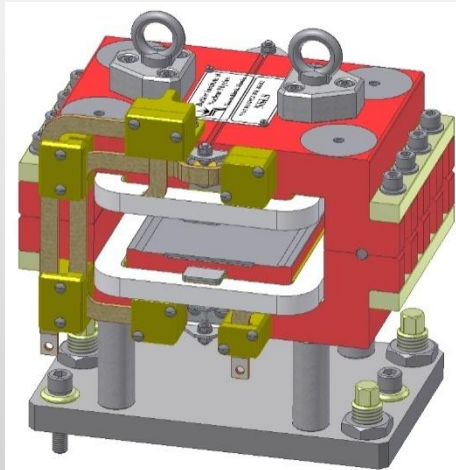
Booster extraction scheme. 1- equilibrium orbit, 2- orbit before extraction, 3- extracted beam.



Booster extraction straight section



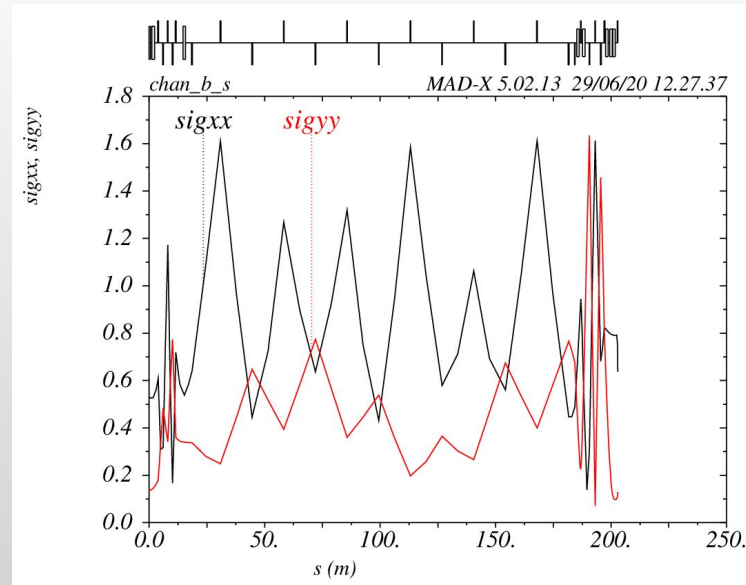
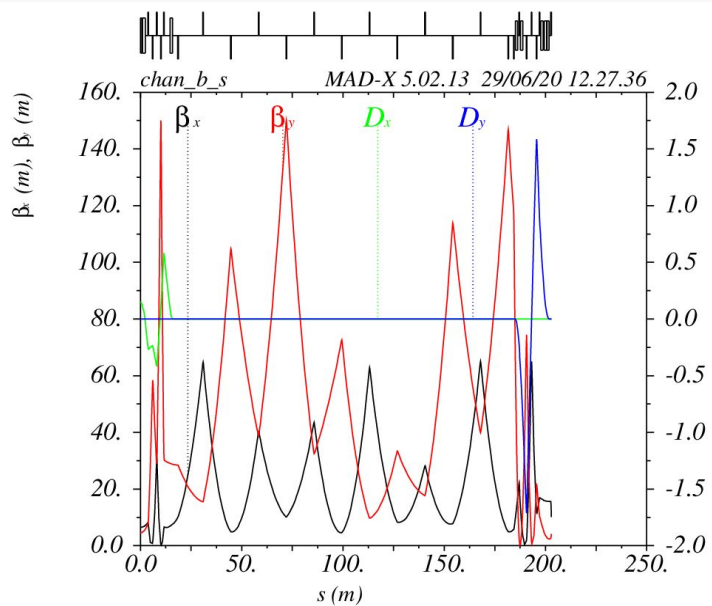
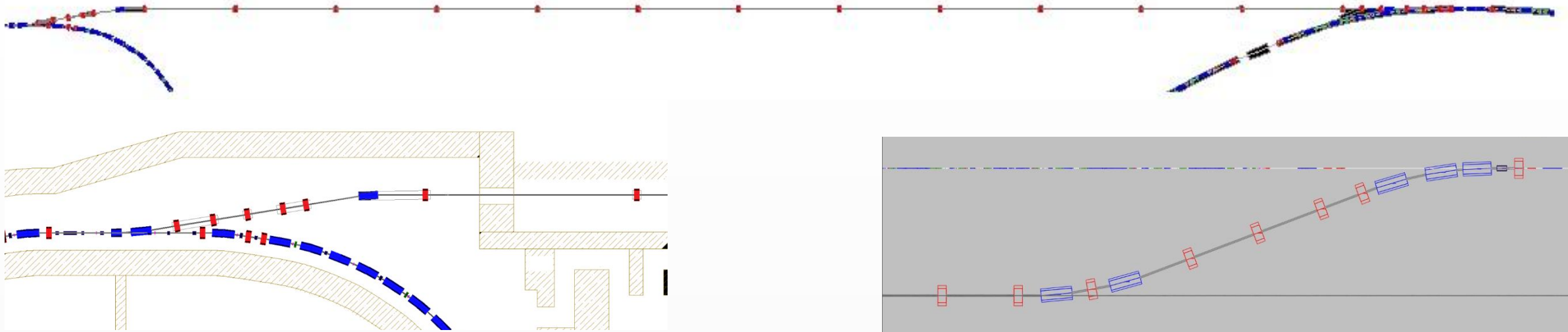
AC septum magnet



BUMP-magnet

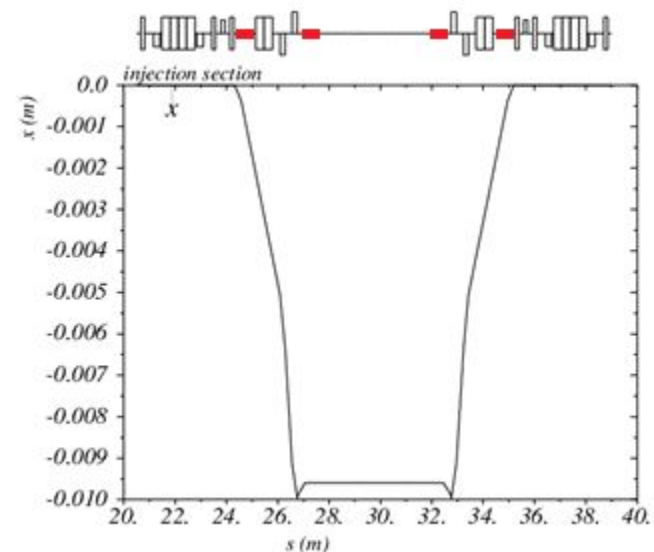
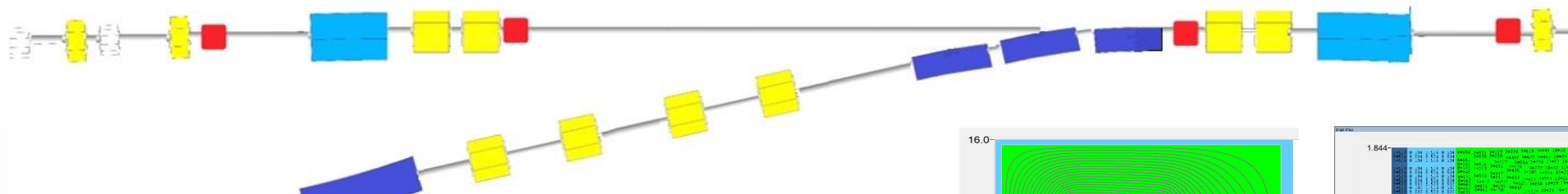
	AC septum magnet	DC septum magnet	Kicker (4)	BUMP-magnet (4)
Effective length, m	0.6	1.2	0.2x4	0.2
Deflection angle, mrad	48	116	6.1	7.5
Inductance, mkH	2.1	20000	2.513	200
Peak current, A	10070	380	2000	400
Maximum voltage, V	550	8.8	19750	300
Pulse shape	150 mksec (1/2 sin)	DC	215 nsec rise time, 300 nsec flat-top	1 mksec (1/2 sin)

Booster to Storage ring transfer line



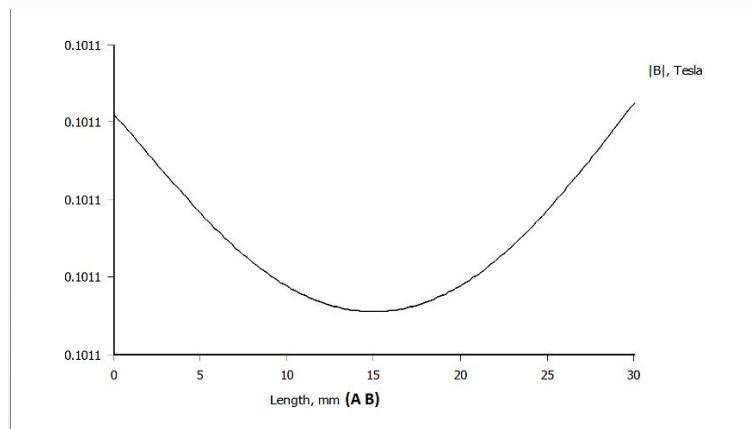
- 1 horizontal dipole with rotation angle 161 mrad,
 - 2 vertical dipoles with rotation angle 181 mrad,
 - 1 vertical dipoles with rotation angle 141 mrad,
 - 24 quadrupole lenses,
 - 8 dipole correctors
- Diagnostic system:**
- 7 BPMs
 - 7 fluorescent screens
 - 2 current transformers for current measure

Injection to Storage Ring



Bump orbit by 4 kickers

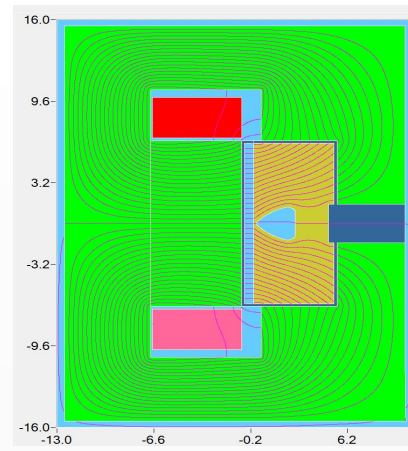
	L(m)	Fi(mrad)	H(T)
Kick1	0.33	3.1	0.10
Kick2	0.33	2.1	0.07
Kick3	0.33	2.1	0.07
Kick4	0.33	3.1	0.10



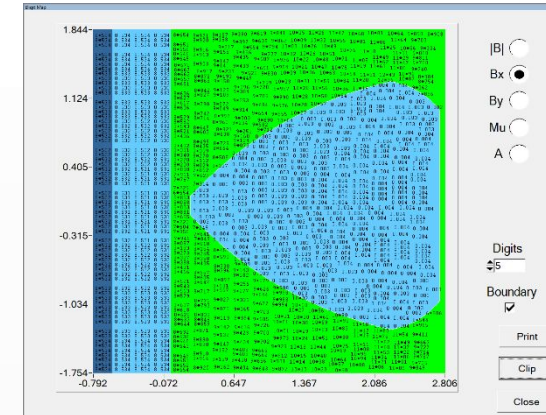
Modeling kicker's magnetic field

Table: main parameters of the kicker

Bend angle, mrad	3.3
Magnetic field(T)	0.13
Effective length, mm	330
Inductance, nH	430
Peak current, A	3300
Pulse shape	300 nsec flat-top, rise/fall time 200 nsec



2D model of the Lembertson's septum-magnet



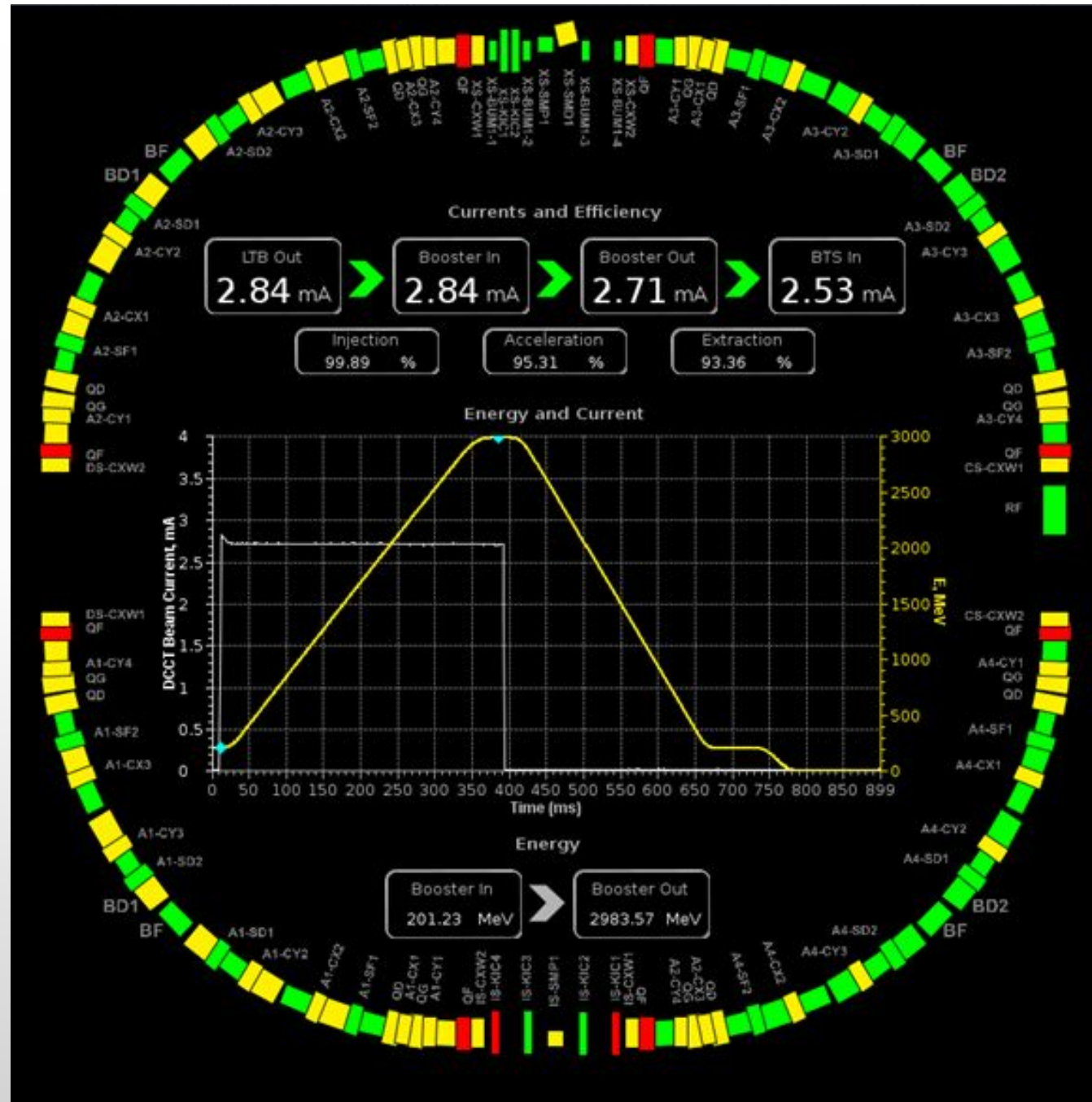
Magnetic fields in aperture ($H_{in} = 0.853 \text{ T}$) and in the vacuum chamber of the ring ($H_{out} \approx 0.4 \text{ mT}$)

Table: main parameters of the septum magnet

Energy	MeV	3000
Deflection angle	mrad	87.27 (5°)
Effective length	m	1.027
Magnetic field	T	0.85
Magnetic gap	mm	8
Septum thickness	mm	2
Current	A	135
Inductance	mH	4.8
Maximum voltage	V	11
Power loss per magnet	W	1500
Cooling		Water
Current stability	%	0.02
Total magnet weight	kg	700

Estimates of injection

1. The usual mode is injection train of bunches up to 300 nsec long containing of 55 bunches with the total charge 15 nC (9.5 mA of SR).
2. Initial obtaining current from 0 to 400 mA in 45 sec.
3. For maintaining a working current of 5 %, need adding every 3 minutes, with beam lifetime 5 hours.
4. For exotic modes, single-bunch injection with a charge up to 1 nC are available.



Thank you for attention