Feeding BINP colliders with the new VEPP-5 Injection Complex

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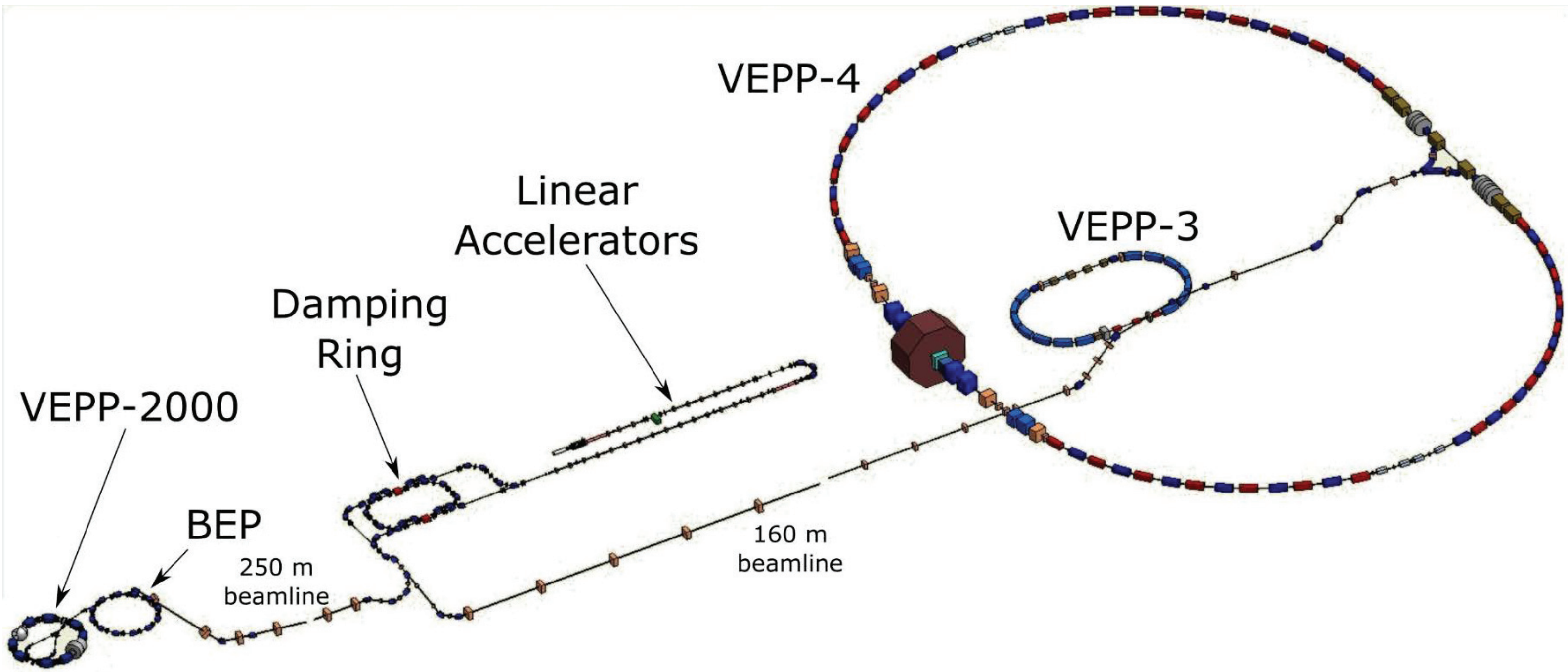
on behalf of Injection Complex team

RUPAC, 23.11.2016

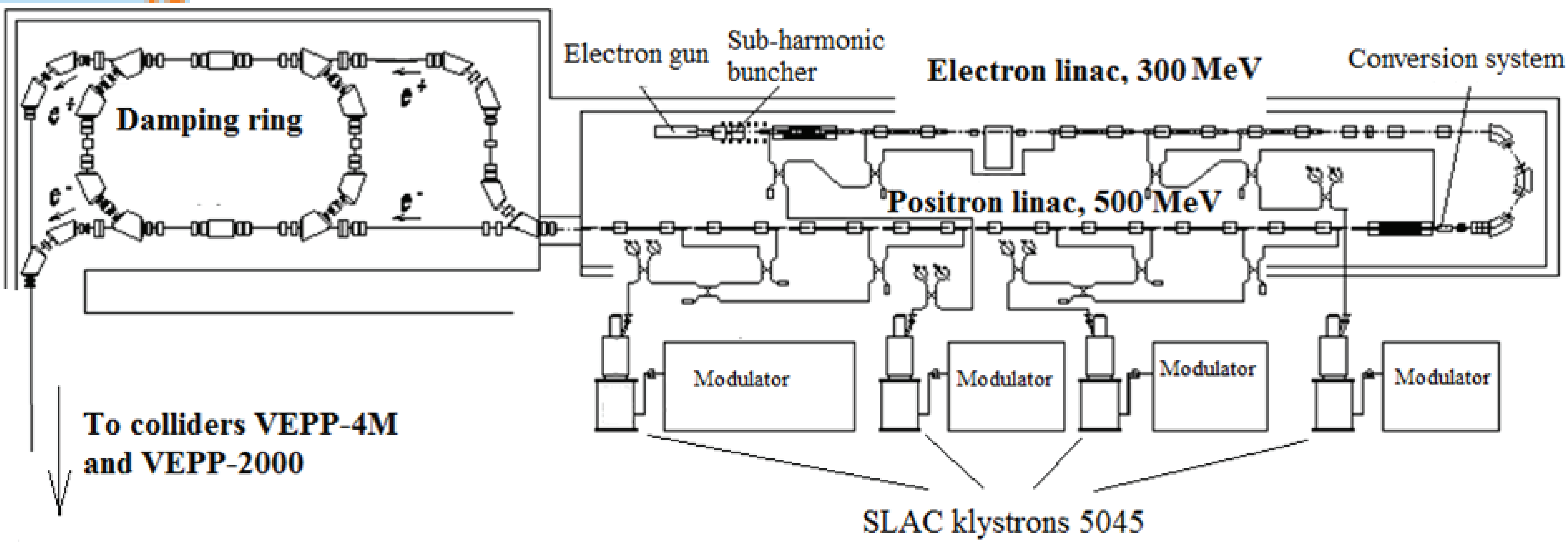
Injection Complex, the destiny



Injection complex is linear accelerator based e+/e- beam source for feeding colliders:

- VEPP-2000
- VEPP-4

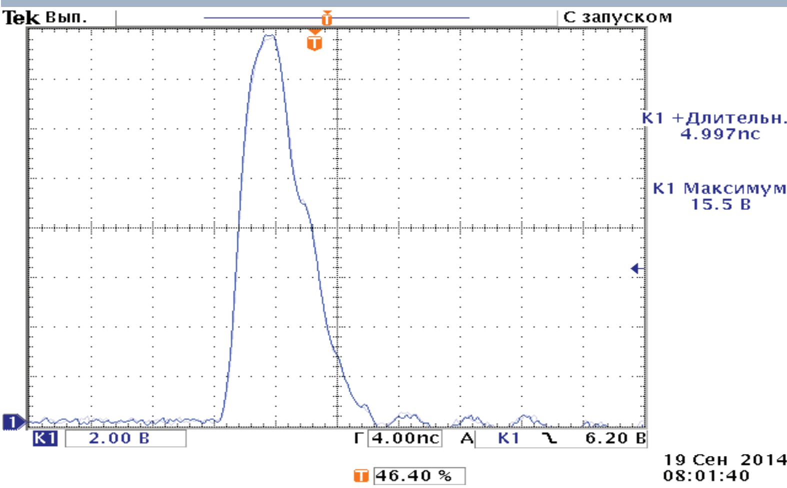
Injection Complex, general description



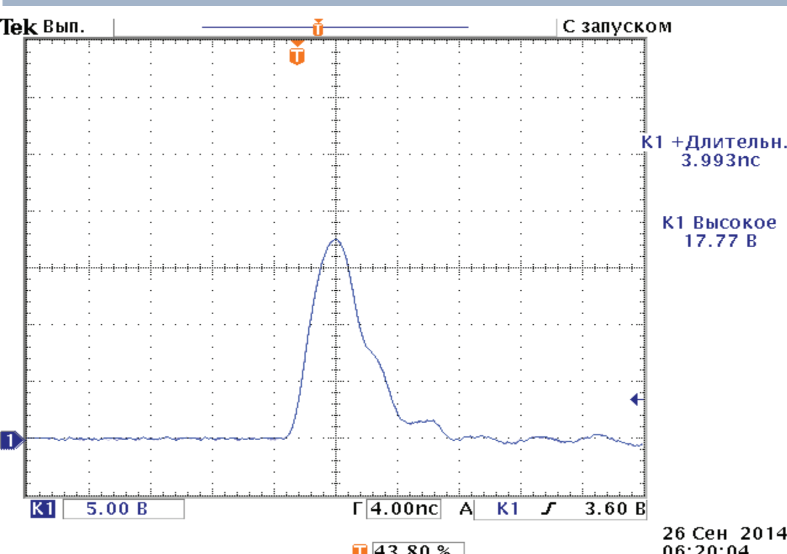
Damping Ring		Linear Accelerators	
Max. Energy	510 MeV	Max. Energy	280/500 MeV
Perimeter	27.4 m	RF frequency	2855.5 MHz
Design beam current	30 mA	Max. Number of e- in beam	10^{11}
Damping times, h/v/l	11/18/12 ms	Max. Number of e+ in beam	$6.3 \cdot 10^{9}$
Horizontal emittance	2.3·10–6 rad·cm	Max. Repetition rate	50 Hz
Vertical emittance	0.5·10–6 rad·cm	Energy spread e+/e-	3%, 1%

Electron gun

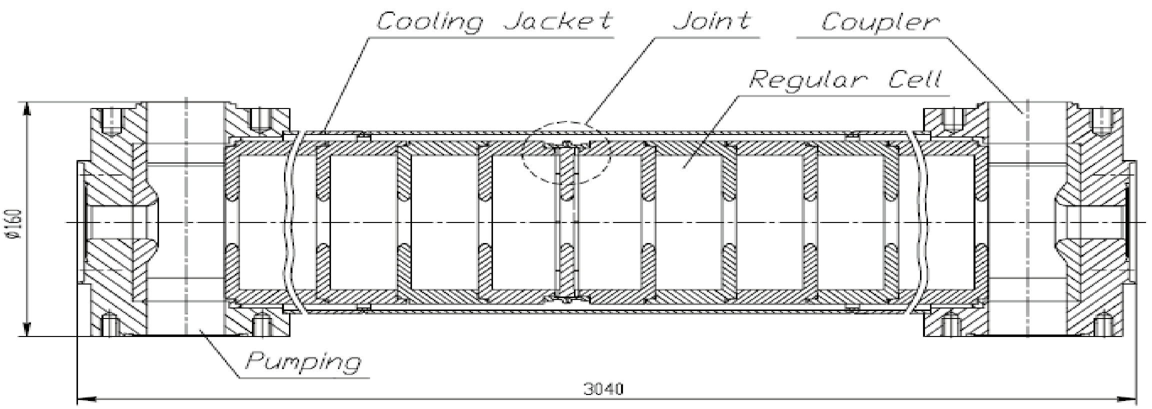
I_{max}=6,4A Ne= 2*10^{11} **(e-)** (19.09.2014)



I_{max}=7,4A Ne= 2,2*10^{11}(e-) (26.09.2014)

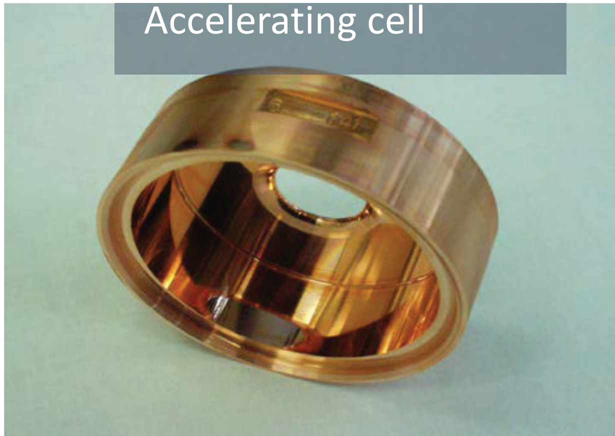


Injection Complex, Accelerating structures (round disk-loaded waveguide)



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 $\tau_{0a}=2Q_0/\omega_0$	1.471 µs
Attenuation (by field) $\alpha=1/(\tau_{0a}v_{gr})$	0.108 m^{-1}
Filling time $T_f=L/v_{gr}$	0.465 µs


Accelerating structure


Accelerating cell

Injection Complex, conversion system

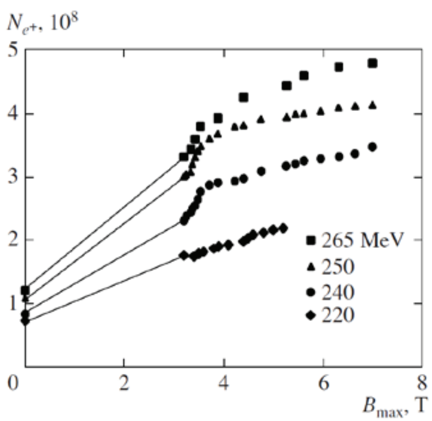
Pictures are:

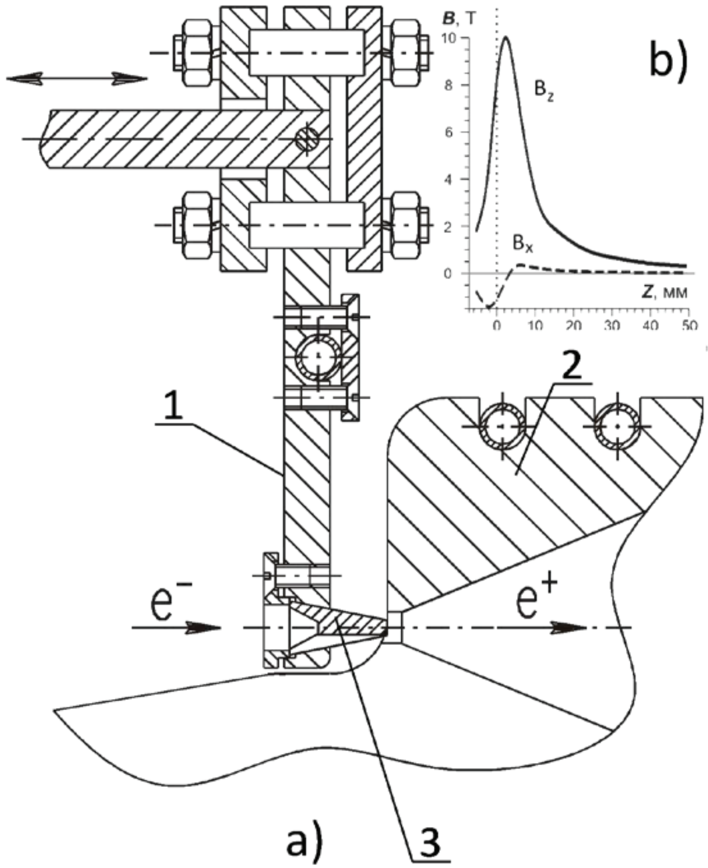
a) 1 - movable target holder
2 - magnet flux concentrator
3 – target

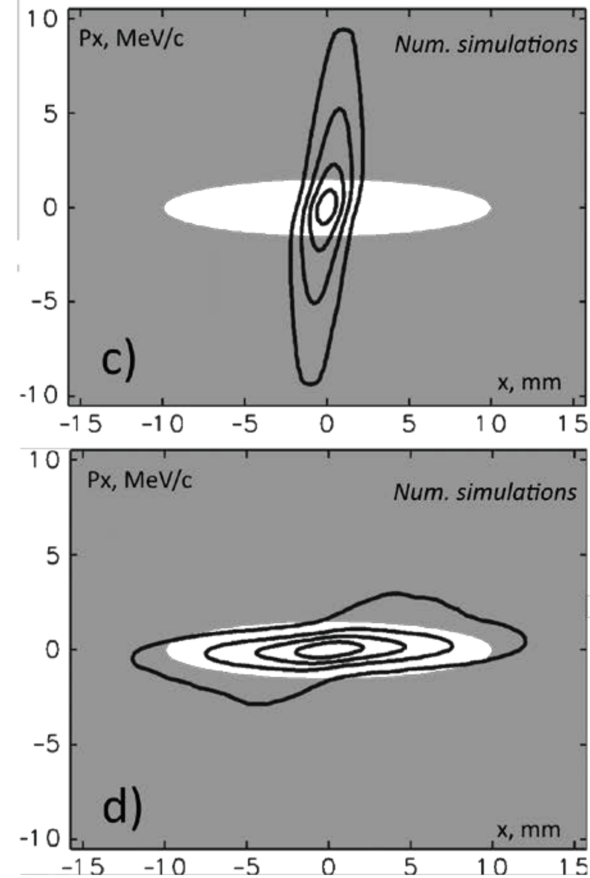
b) magnetic measurements

c) e+ beam phase portrait after the target

d) e+ beam phase portrait after the flux concentrator.

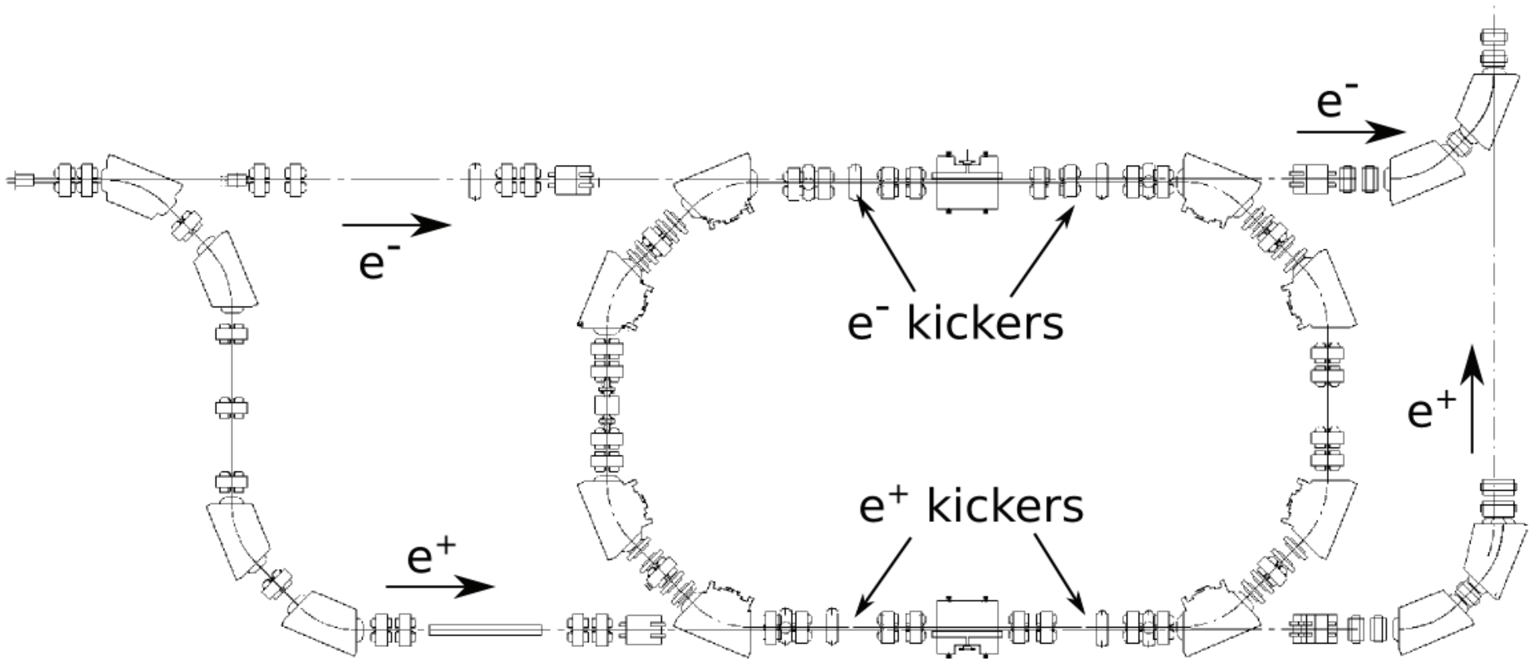






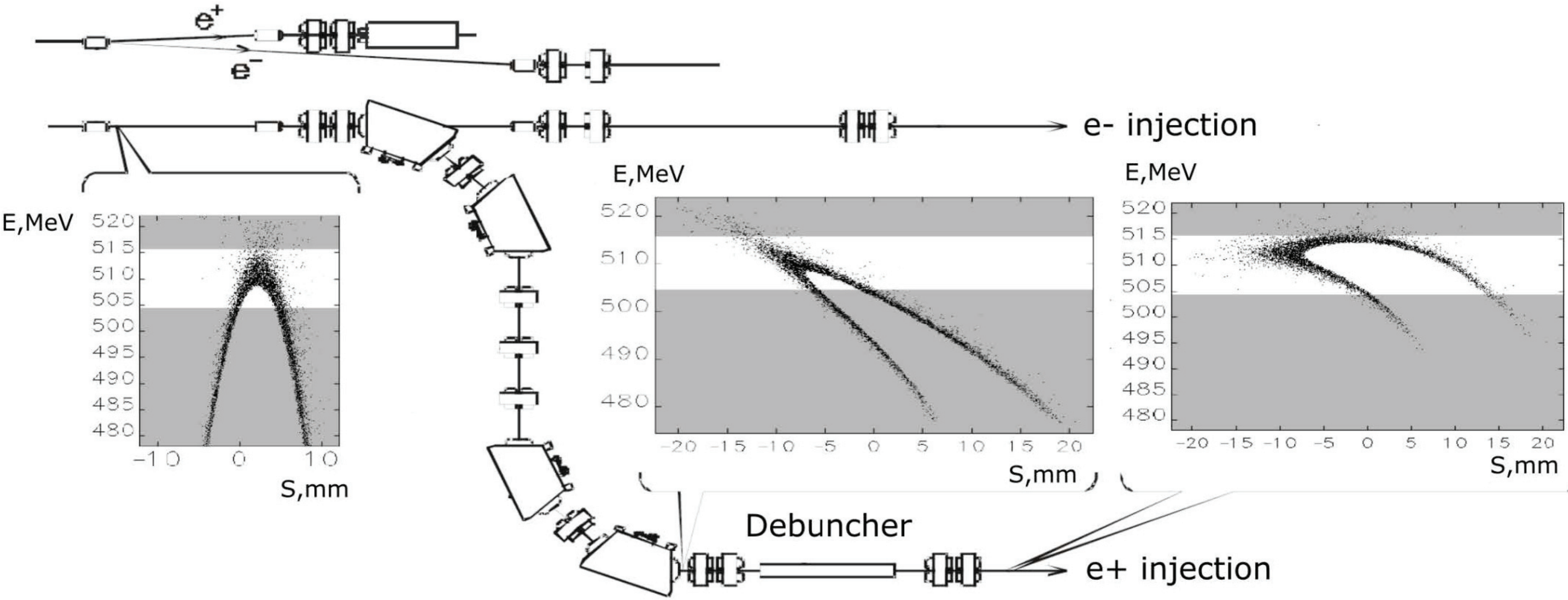
Max. magnetic field	10 T	Repetition rate	50 Hz
Full current on the cone surface	120 kA	Max. Average power	4 kW
Pulse energy	90 J	Operating max. magnetic field	7 T
Pulse duration	26 us		

Damping Ring



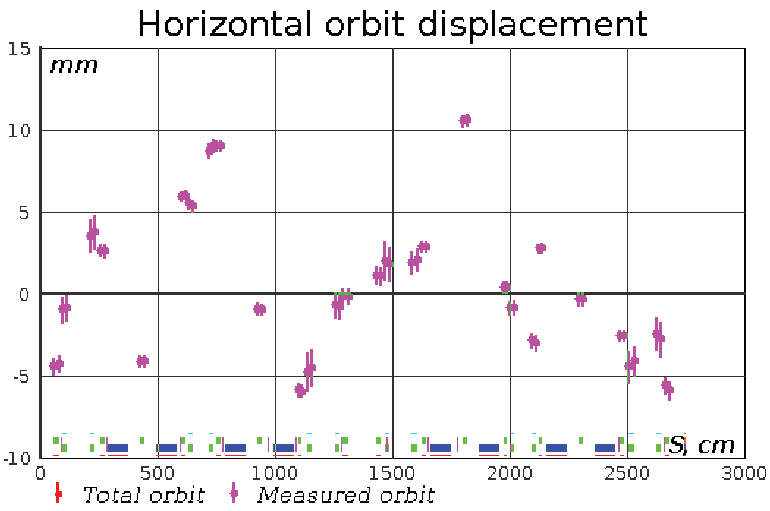
- Since injection complex was considered as beam source for charm-tau factory 0.4 mm longitudinal beam sigma, which can be achieved with two 400 kV 700 MHz resonators.
- Injection complex have one resonator powered with 1 kWt semiconductor amplifier since last klystron was destroyed (spring 2016). We are switching to 20 kWt semiconductor amplifier now, which give us 230 kV resonator voltage.
- Since we do not have longitudinal distribution monitoring tools in linacs, machine operated in multibunch mode (10-12 bunches in linac, 3-4 bunches in dumping ring)
- Since current users do not require short beams it is better to use 10.94 MHz resonator, which is under construction now.

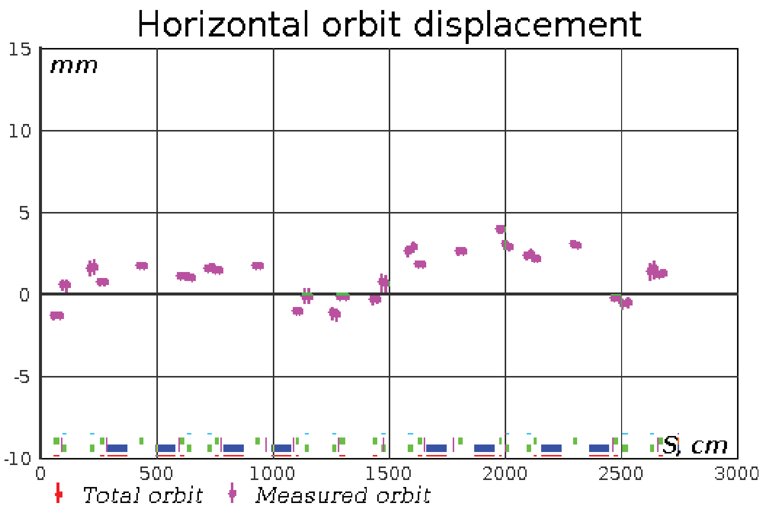
Positron injection to Damping Ring

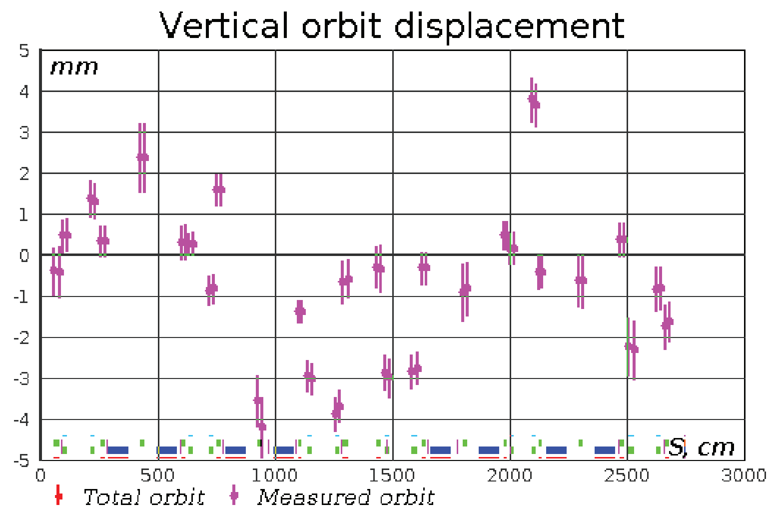


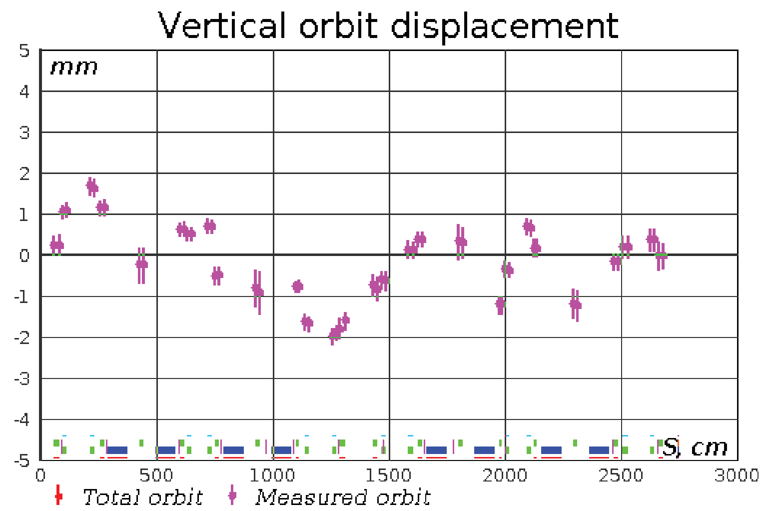
Injection way	Design efficiency	Achieved efficiency
Straight (e+ over e- channel) Normal without debuncher Normal with debuncher	16.4 % 16.8 % 23.6 %	10%

Closed orbit correction





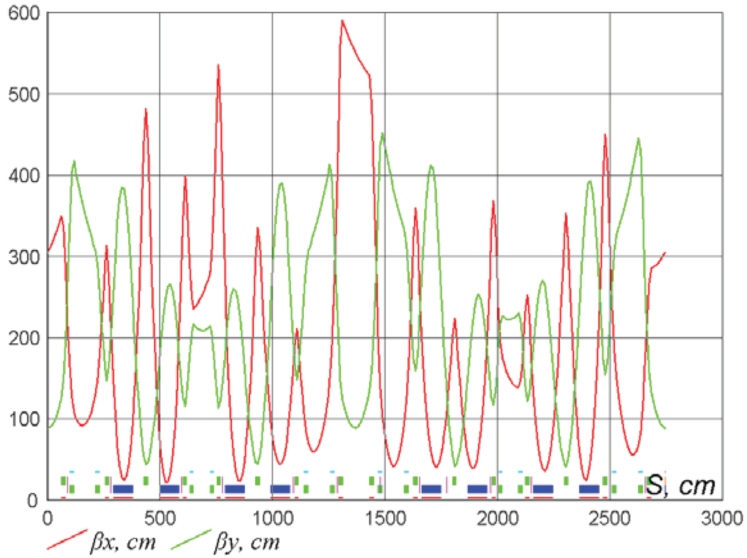




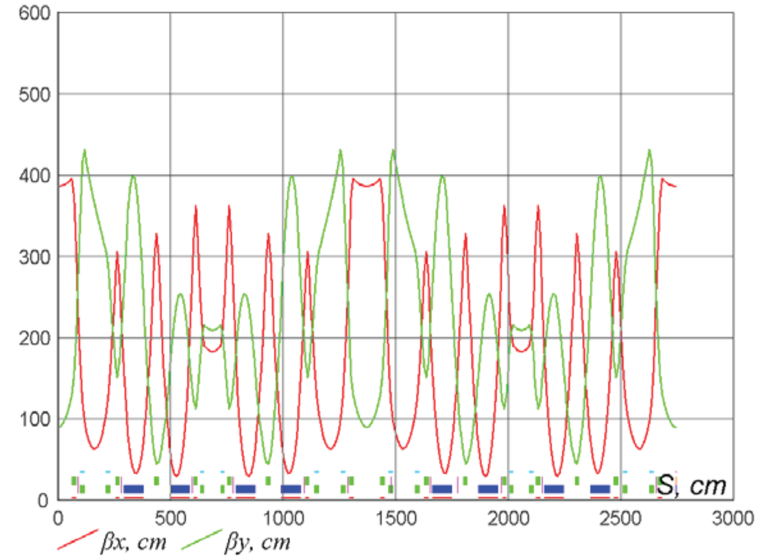
Closed orbit correction was done with respect to the quadrupole magnetic centers. To do so closed orbit responses to the gradient variations of the individual quadrupoles.

Lattice correction

Uncorrected beta functions in VEPP 5 Dumping ring

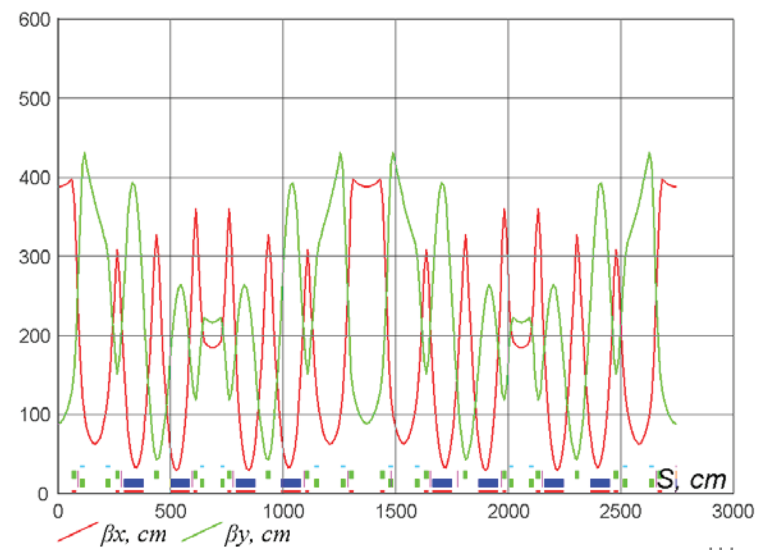


Corrected beta functions in VEPP 5 Dumping ring (after four iterations)

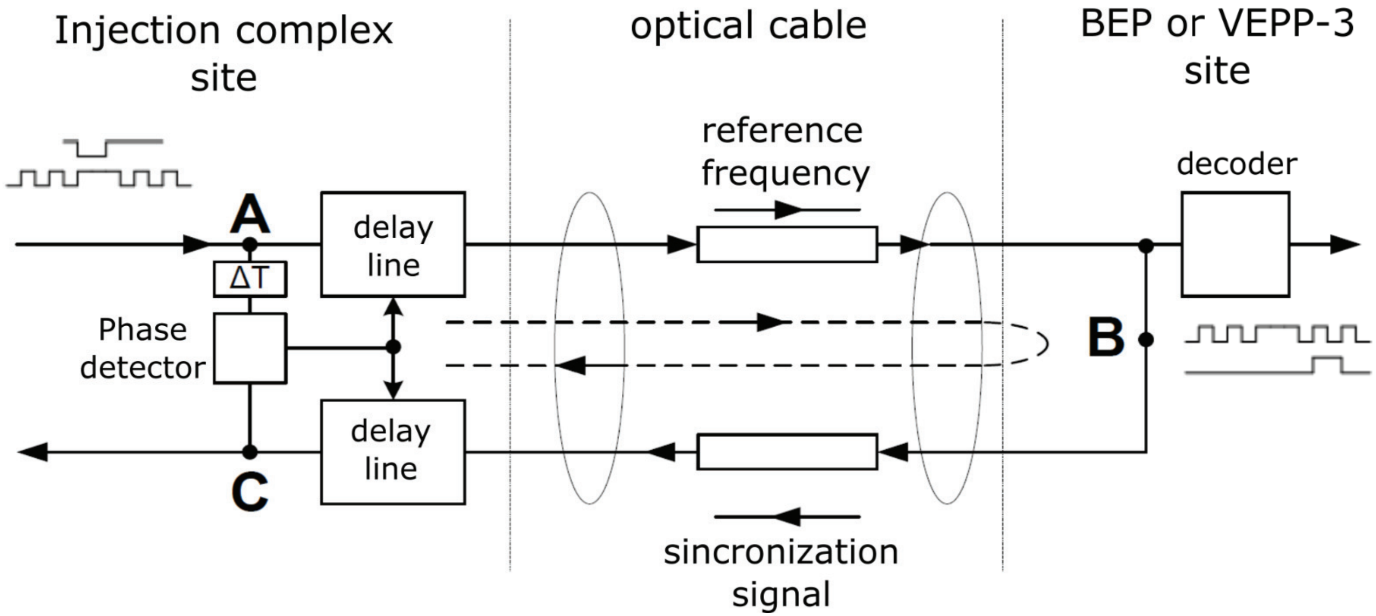


First betatron tunes were set to the project values. After that software “sixdsimulation” developed for VEPP-2000, was applied to correct linear lattice . It took 4 iterations to correct linear lattice by fitting the model to the experimental data composed of closed orbit responses to the all dipole correctors, dispersion, and betatron tunes. **After last iteration the fitted model didn’t show significant variation from the ideal configuration.**

Project beta functions in VEPP 5 Dumping ring



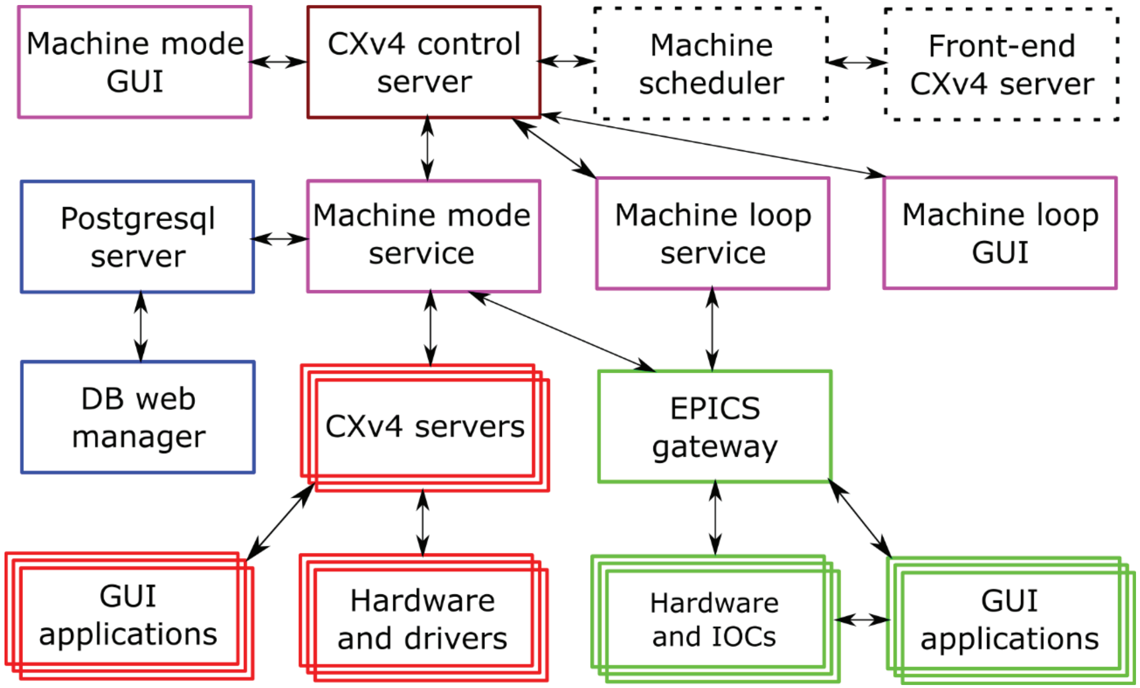
Common synchronization with colliders



F_{DR}/F_{BEP}	287/352	F_{DR}/F_{BEP}	1281/472
F_{ref}	38.109 kHz	F_{ref}	8.538 kHz

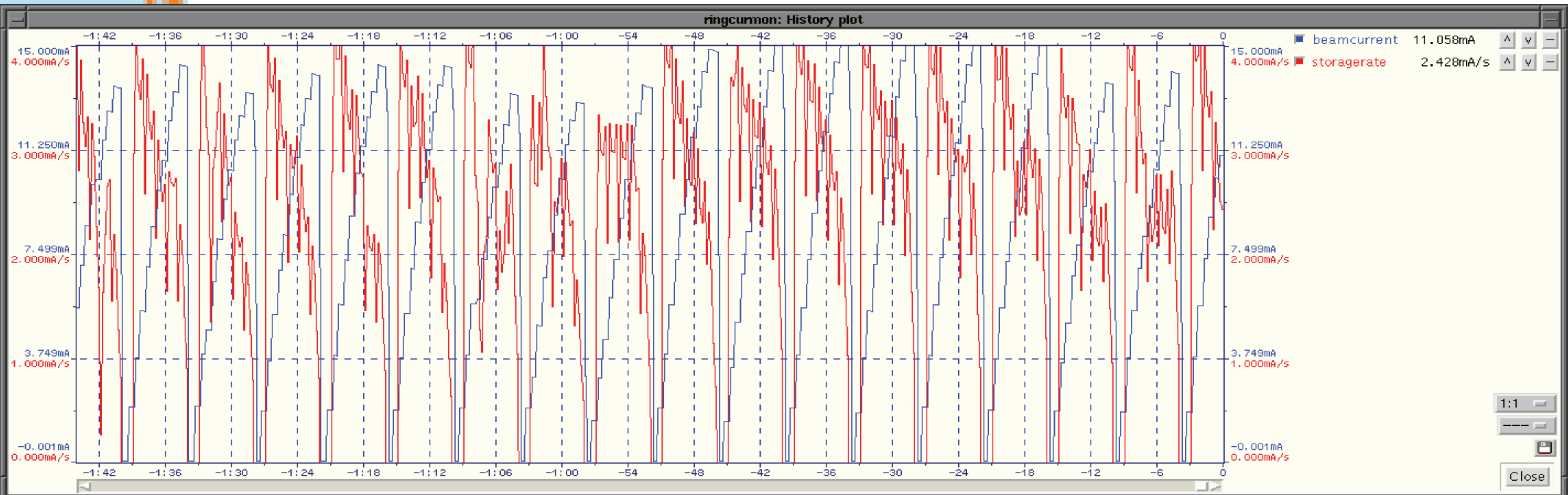
- VEPP-3, BEP frequency shifted to meet required ratio for transfer synchronization.
- Cable length thermal drift compensation was implemented.
- Synchronization stability is 10 ps.

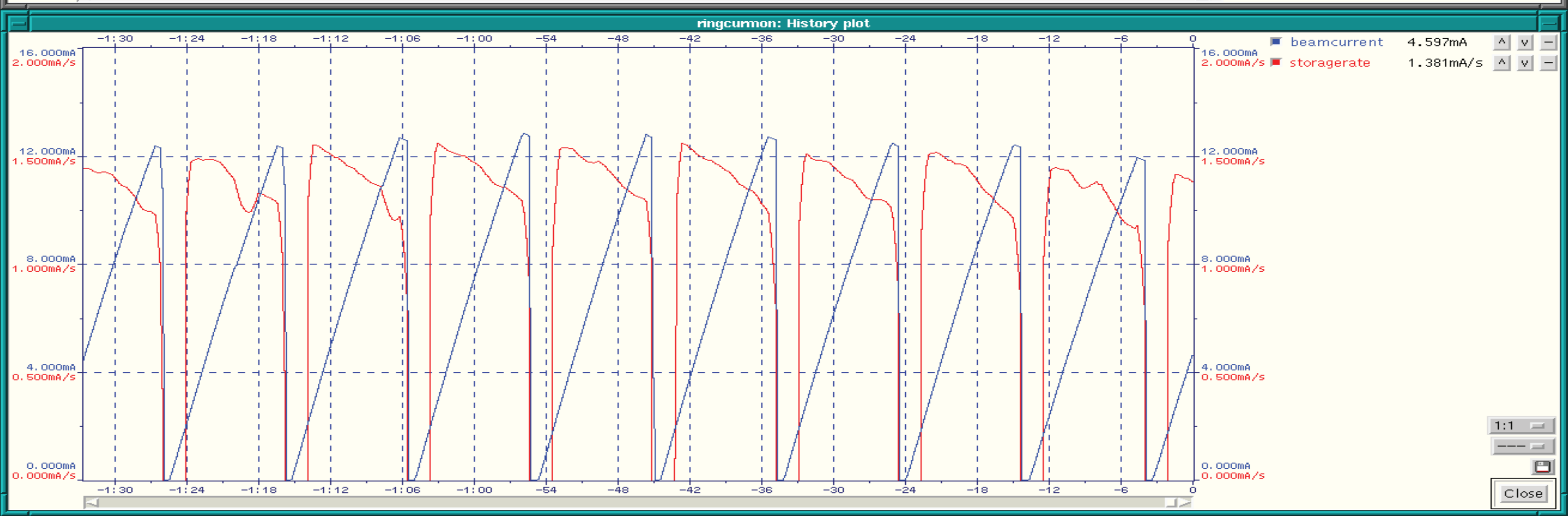
Control system modification



- Microservice architecture for automatic process implementation.
- Centralized machine mode control with PostgreSQL storage for configuration and mode data Django-based DB management.
- Python support both CXv4 and EPICS frameworks in single program.
- Semi-automatic work suitable for operation data accumulation.
- Redundant control infrastructure is underway.

Control system software modification





Beam users requirements

requirement	VEPP-3/4	VEPP-2000
Initial load	$4 \cdot 10^{11}$ (e+ and e-)	10^{11}(e+ and e-)
Acceleration and particles change time	7 min	30 s
Transfer repetition rate	1 Hz	0.2 Hz
Refill time	40 min – 5 h	30 s per beam
Refill	Full load	10^{10} per beam

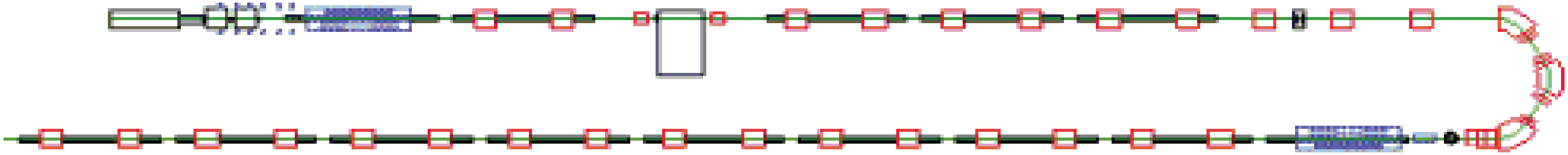
- VEPP-2000 will utilize all the injection complex charge productivity.
- VEPP-4 will interrupt tight VEPP-2000 supply schedule for rare beam loading for about 2 minutes
- It is required to switch Injection complex between electrons and positrons as soon as possible (to have a time for storage)

Operation limitations

- Linac repetition rate limited to 25 Hz (lack of thermostabilization water flow)
- Damping ring injection repetition rate limited to 12.5 Hz (due to kickers load cooling system)
- Magnet mode change time is 2 s to 30 s depending on magnet and power supply.

In order to meet VEPP-2000 supply schedule we need to consequentially avoid differences in “slow” magnets and have the same damping ring mode for electrons and positrons.
This means we need to make equal energies for electron and positron beams at linac exit.

Equal energy, particles switching time



Electron beam bypass conversion target with energy about 270 MeV, hence we need to reduce energy gained by electrons in the second linac. There are following ways to make this:

- Shift accelerating module phase,
- Reduce accelerating field amplitude,
- Underfill accelerating structure (shift start of RF).

The first way leads to unacceptable rise of beam energy spread. The second one can lead to thermal mode transition time on high repetition rates. The last approach does not have described above consequences but it's harder to control with our hardware. We tested both acceptable ways and reducing accelerating field now since it's good up to 12.5 Hz repetition rate.

The damping ring modes for e+ and e- are very close, but not the same for 395MeV energy. This difference does not increase particles switching time, which is about 10 s.

Achievements, possibilities

Achieved parameters

Linacs		Damping Ring	
Max. e+ energy	420 MeV	Max. e+ current	70 mA
e- production rate	$3 \cdot 10^{10}$/pulse	Max. e- current	160mA
e+ production rate	$6.3 \cdot 10^{9}$/pulse	Storage rate for e-	10^{10}/pulse
Operating energy	395 MeV	Storage rate for e+	$2.5 \cdot 10^{8}$/s @12.5Hz
Particles switching time	10 s	Energy for e+ & e-	395 MeV
		Max. e+ energy	420 Mev

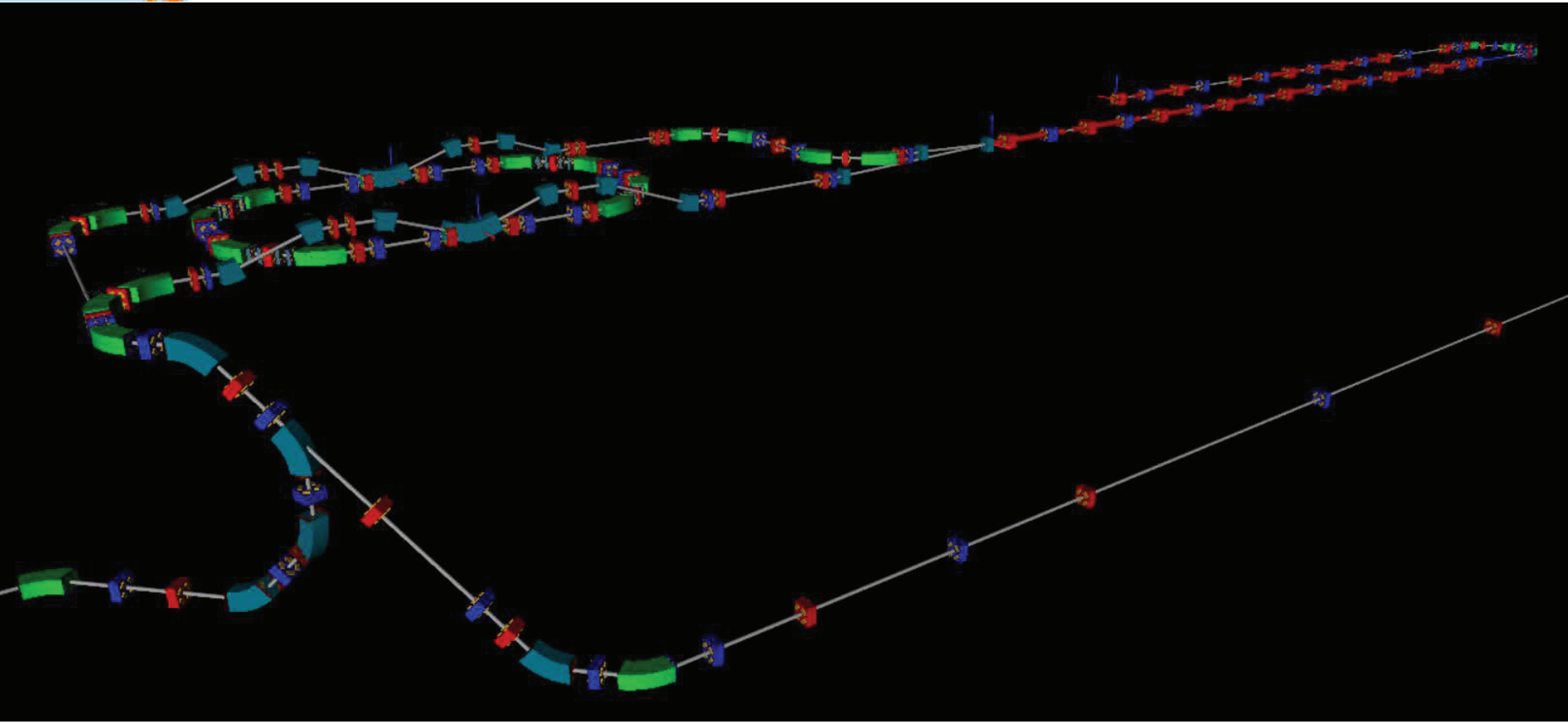
Ways to increase charge productivity

Action	Potential gain
Switch to 10.91 MHz RF station	2
Increase gun pulse duration with 10.91 MHz RF	2
Increase operating energy to maximum	1.5
Increase repetition rate (with energy increase)	1.5-2
Linac single bunch mode with 700 MHz RF	2
Install debuncher	1.5

Possible e+ production rate: $4.5 \cdot 10^{9}$/s (enough for VEPP-2000)

Near future possible e+ production rate: 10^{9}/s (enough for VEPP-2000 without losses)

Beam transfer lines



- Electron beams routinely transferred to BEP and VEPP-3, max. transfer coeff. is 70%.
- Positrons was transferred to BEP only, transfer to VEPP-3 is under way.
- Particles or direction switching time is about 30 s.

conclusion

- Injection complex showed acceptable performance for beginning of operation with colliders.
- Work on injection complex stability is underway
- Inter-complex automatics is underway.

The injection complex team

F. Emanov, A. Andrianov, K. Astrelina, V.V. Balakin, A. Barnyakov, O.V. Belikov, D.E. Berkaev, M. Blinov, Yu.M. Boimelshtain, D. Bolkhovityanov, A.G. Chupyra, N.S. Dikansky, A.R. Frolov, Ye.A. Gusev, G. Karpov, A. Kasaev, V. Kokoulin, A.A. Kondakov, I. Koop, I.Kuptsov, G.Ya. Kurkin, R. Lapik, N. Lebedev, A. Levichev, P. Logatchov, Yu. Maltseva, P.Martyshkin, A. Murasev, D. Nikiforov, A.V. Pavlenko, V. Pavlov, A. Petrenko, V.Podlevskih, V. Rashchenko, S. Samoylov, S. Shiyankov, A. Skrinsky, A. Starostenko, D.P. Sukhanov, A.G. Tribendis, A.S. Tsyganov, S. Vasiliev, V. Yudin, I. Zemlyansky, Yu. Rogovsky, A. Novohatsky, A. Romanov

Thanks all

Klystron Gallery

Transfer line to VEPP 4M

Transfer Line to VEPP 200

Conversion system, operation

Conversion system