Current Results of SSRS4 Light Source Development at Kurchatov Institute

Sergey Polozov, Timur Kulevoy and Alexey Tishchenko
on behalf of SSRS4 team

Project is supported by the Ministry of Science and Education of Russian Federation, Agreement No 14.616.21.0086 from 24.11.2017, ID RFMEFI61617X0086 (Federal Targeted Program "Research and development on priority directions of scientific-technological complex of Russia in 2014 -2020 year").

SSRS4: new Russian MEGA-science project

- New Russian 4th generation Synchrotron Radiation Source called ISSI4 was announced in 2016

- Today we are at the stage of pre-CDR development, design and preliminary numerical simulations of main components of the SSRS-4: lattice, beamlines, vacuum system, diagnostics and control, etc.

- We want to take into account the international experience of new X-ray sources: ESRF, European XFEL, MAX-IV, Sirius and other projects Russian Federation participates in.

- The SSRS-4 should be complement to the existing European sources and raised interest of the European scientific community. We are not going to be limited to only national scientific projects.

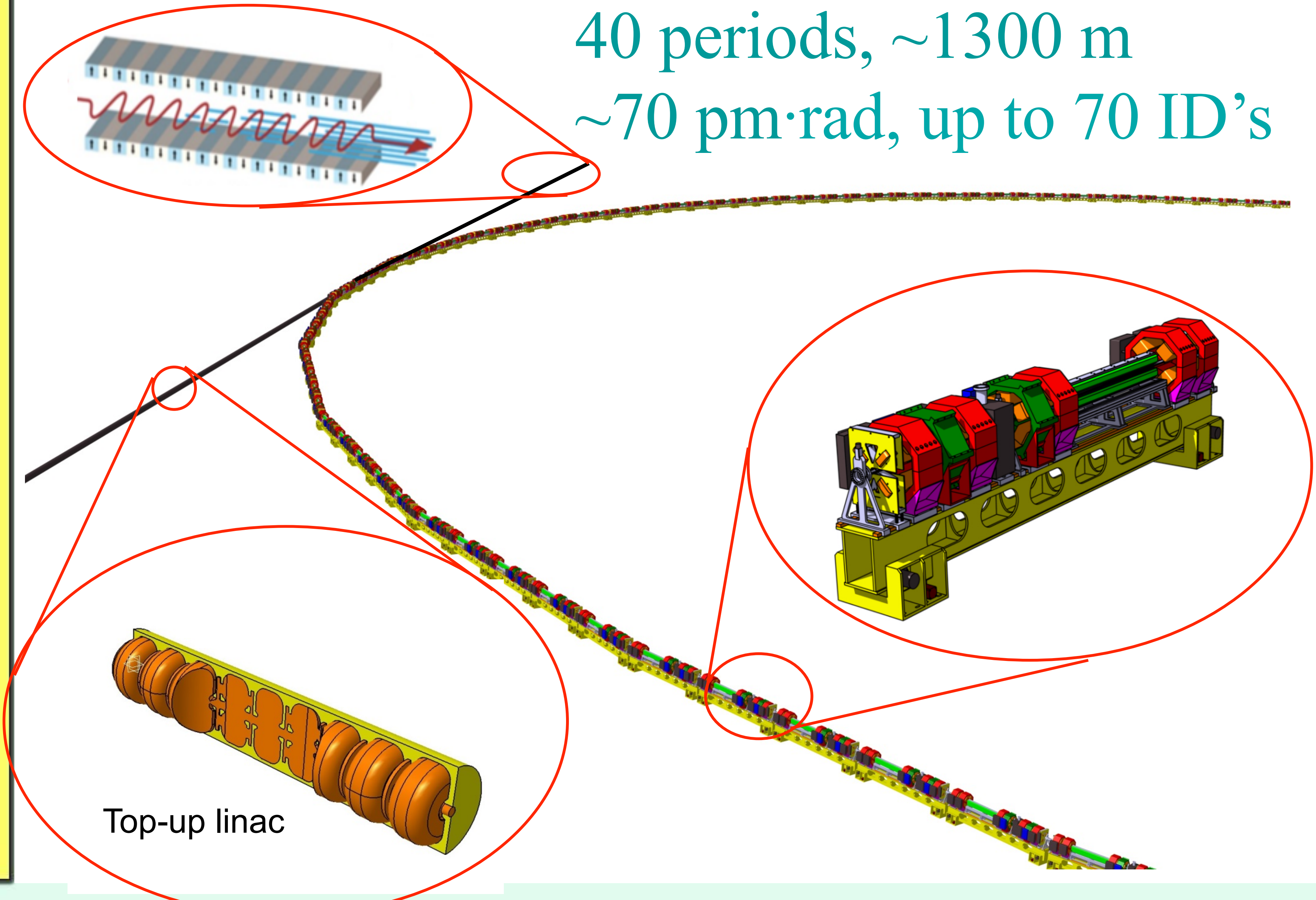
- New machine shouldn’t be a replica of one of the existing sources. SSRS-4 must enhance capabilities of new sources and effectively fit into the existing European Mega-science infrastructure.

SUMMARY

- SSRS4: general concept and layout
- Main ring: lattice and beam dynamics
- Injection linac (or booster)
- Injection
- Vacuum system
- RF system
- Diagnostics, control and timing
- Beam lines and research program (1^{st} stage)
- SSRS4 site
- Conclusions

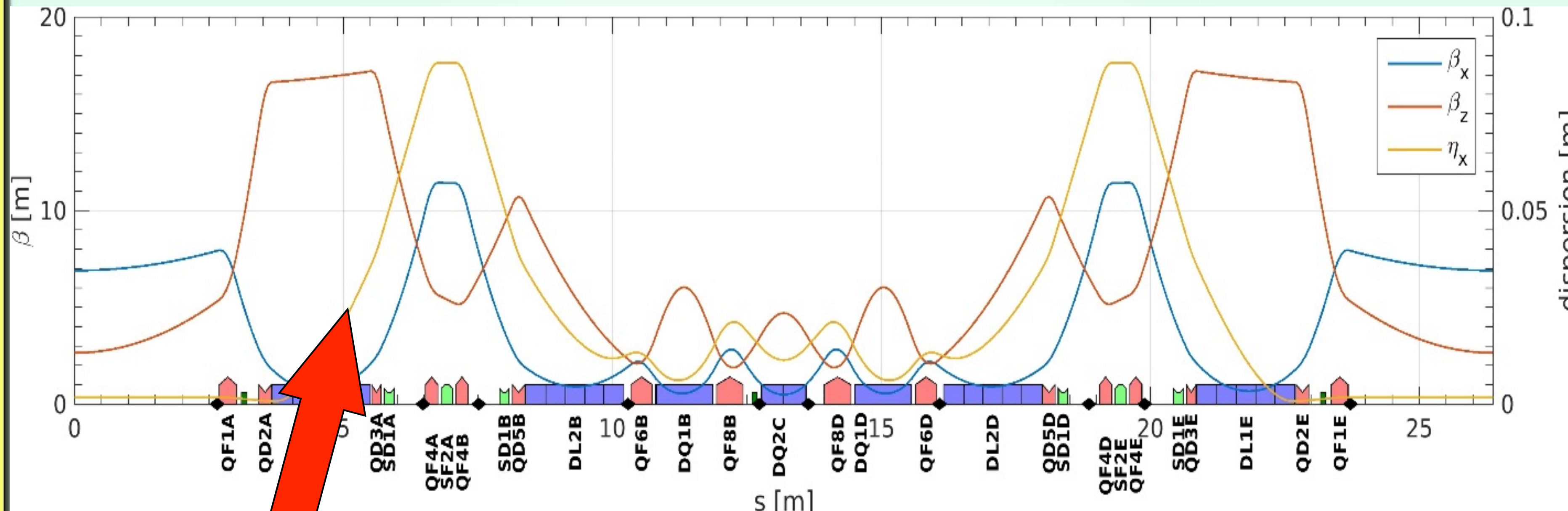
➢SSRS4: general concept and layout

6 GeV
40 periods, ~1300 m
~70 pm·rad, up to 70 ID's



➢Main ring: lattice and beam dynamics

Start configuration is based on MBA (7BA); period length 26-30 m; first structure is kindly prepared by our ESRF partners and based on scaled ESRF-ESB design



L Cell [m]	N cells	Circ. [m]	Emit. [pm]	Max. Sext. [T/m2]
26	40	1040	69	2316
30	40	1200	70	1220
30	50	1500	36	1534

Especial thanks to: Pantaleo Raimondi, Simone Liuzzo, Laurent Farvacque and Simon White

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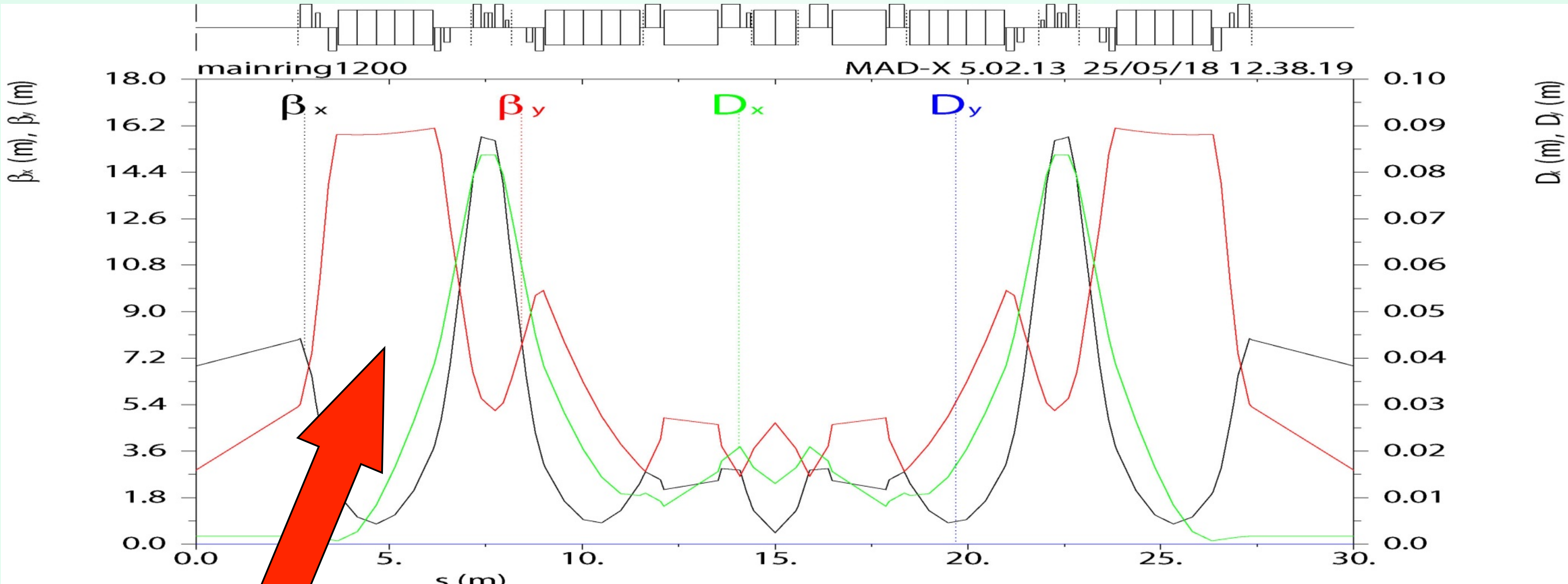

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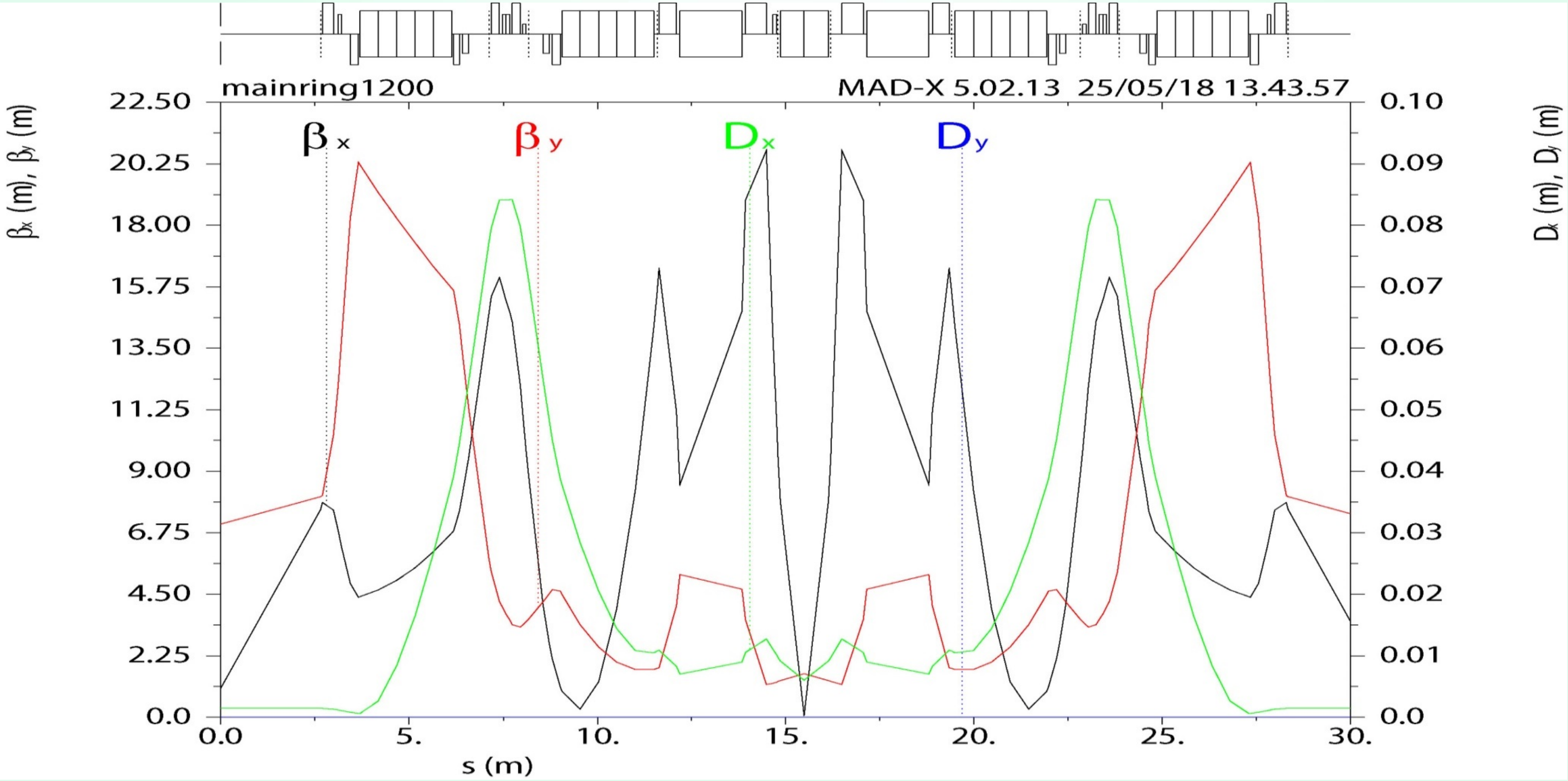
Second configuration is based on 7BA (30 m/period)

-No dipole-quadrupole combined magnets;

-Minimal aperture growths form 13 to 18 mm to decrease nonlinearities and instabilities;

-We not planned to increase fields and gradients of magnets because today we are not limited in the ring length. The length of magnets can be increased as the result.

-The period length was enlarged to ~30 m to place longer "high field" magnets

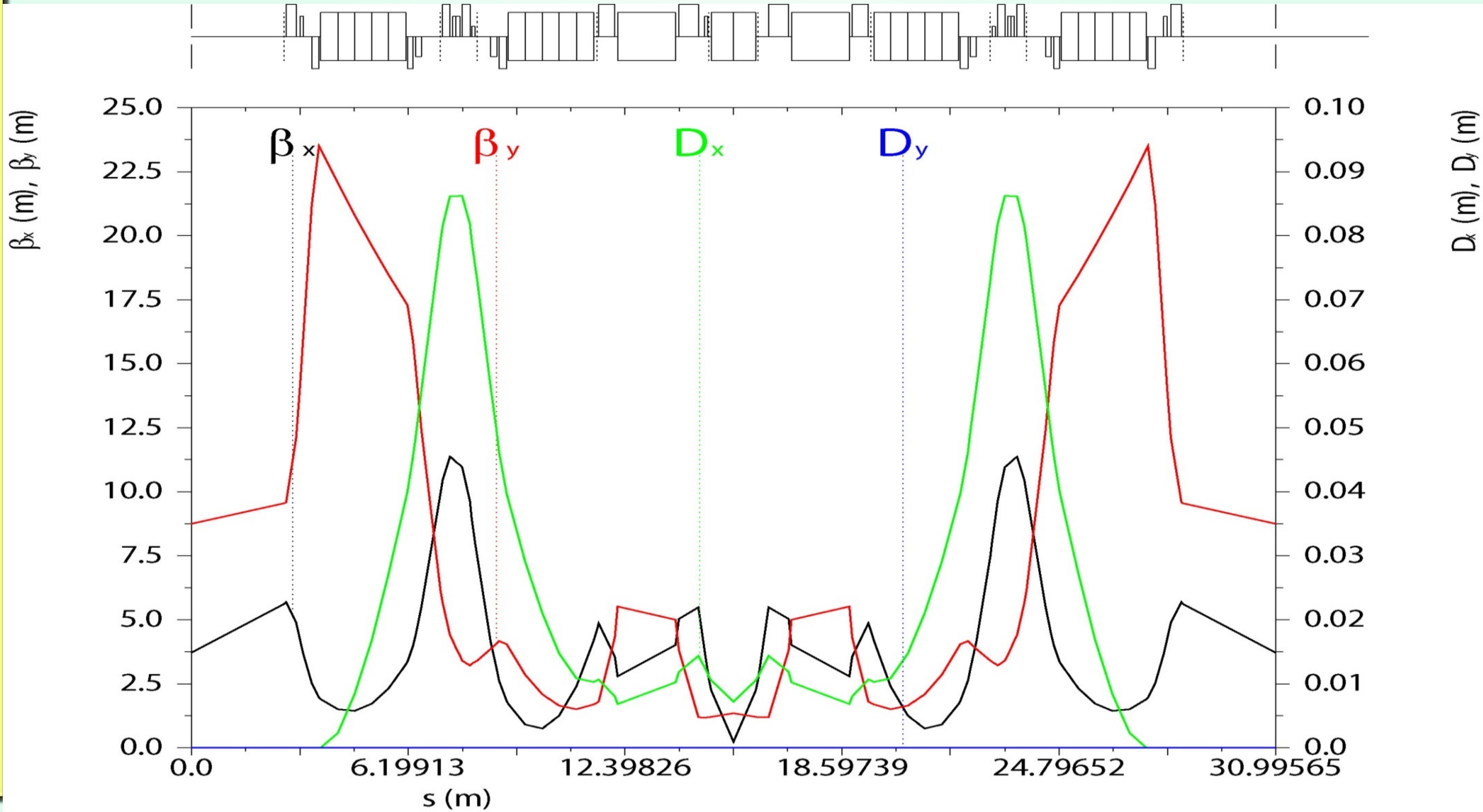


➢Main ring: lattice and beam dynamics

Second+ configuration is based on 7BA (31 m/period),

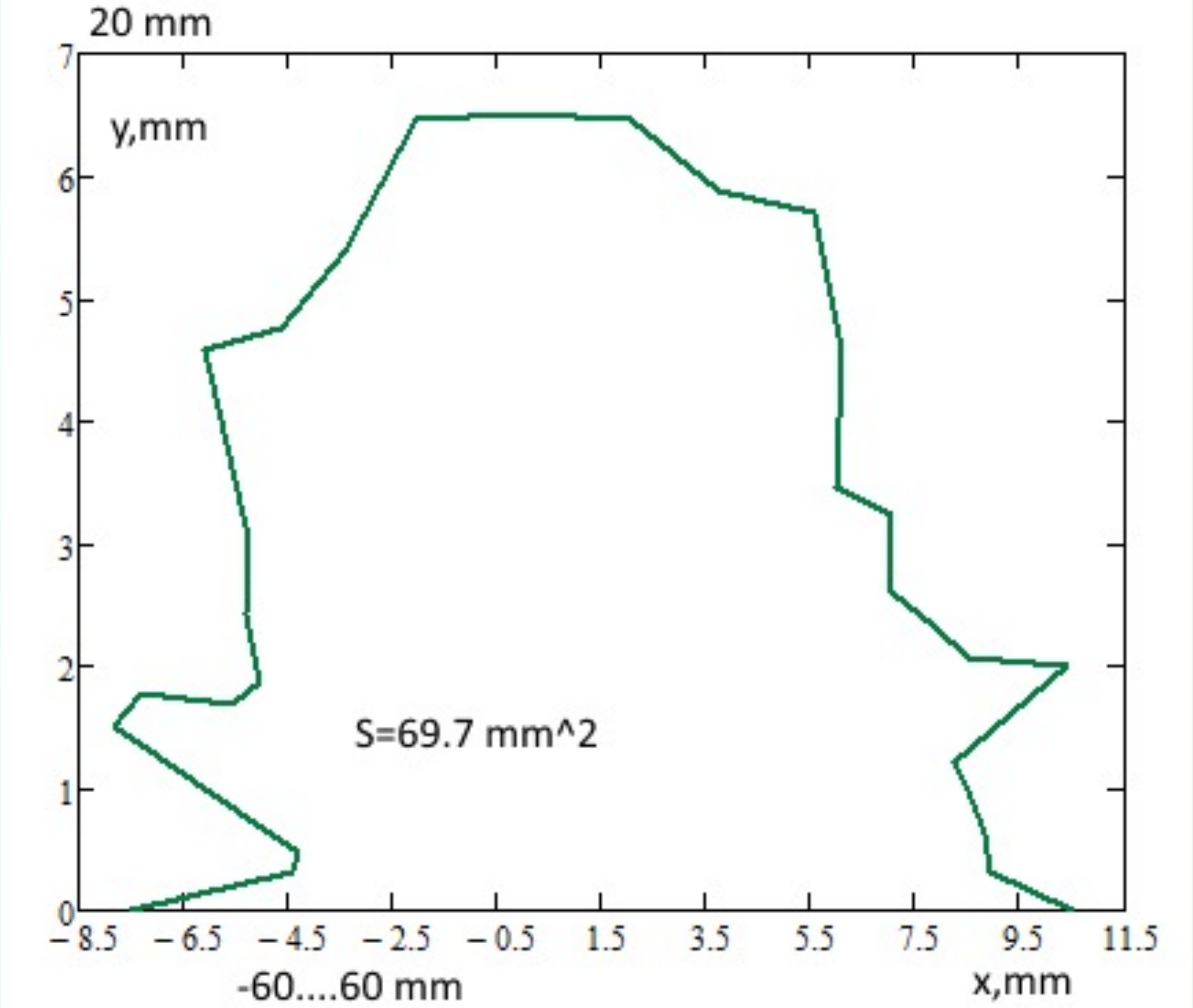
- Small aperture in the central part of the period was enlarged to 18 mm;

-Fields, gradients and lengths are corrected to decrease the β-function in the central region of period



➢Main ring: lattice and beam dynamics

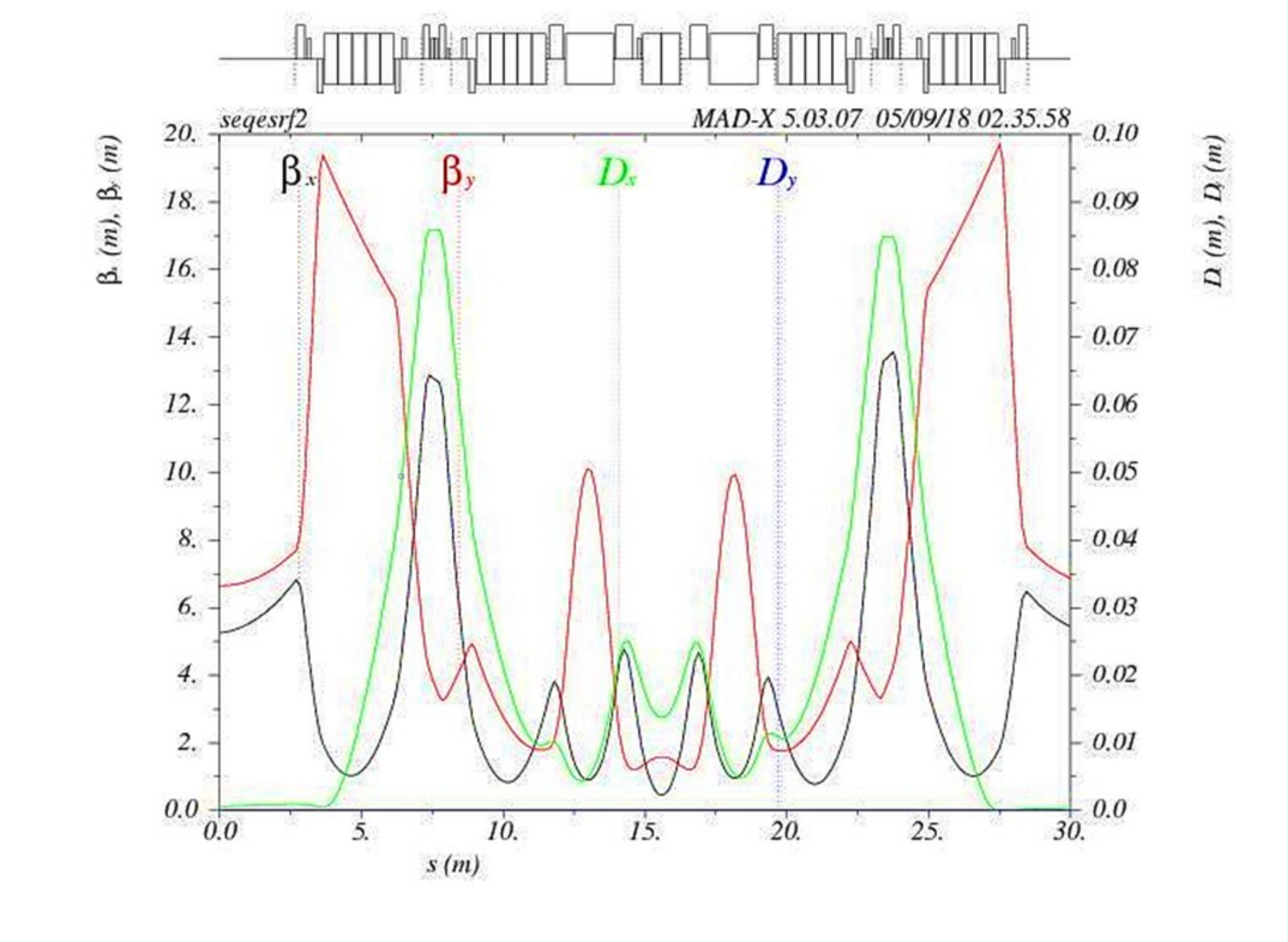
Dynamic aperture



Third configuration is based on 7BA (31 m/period),

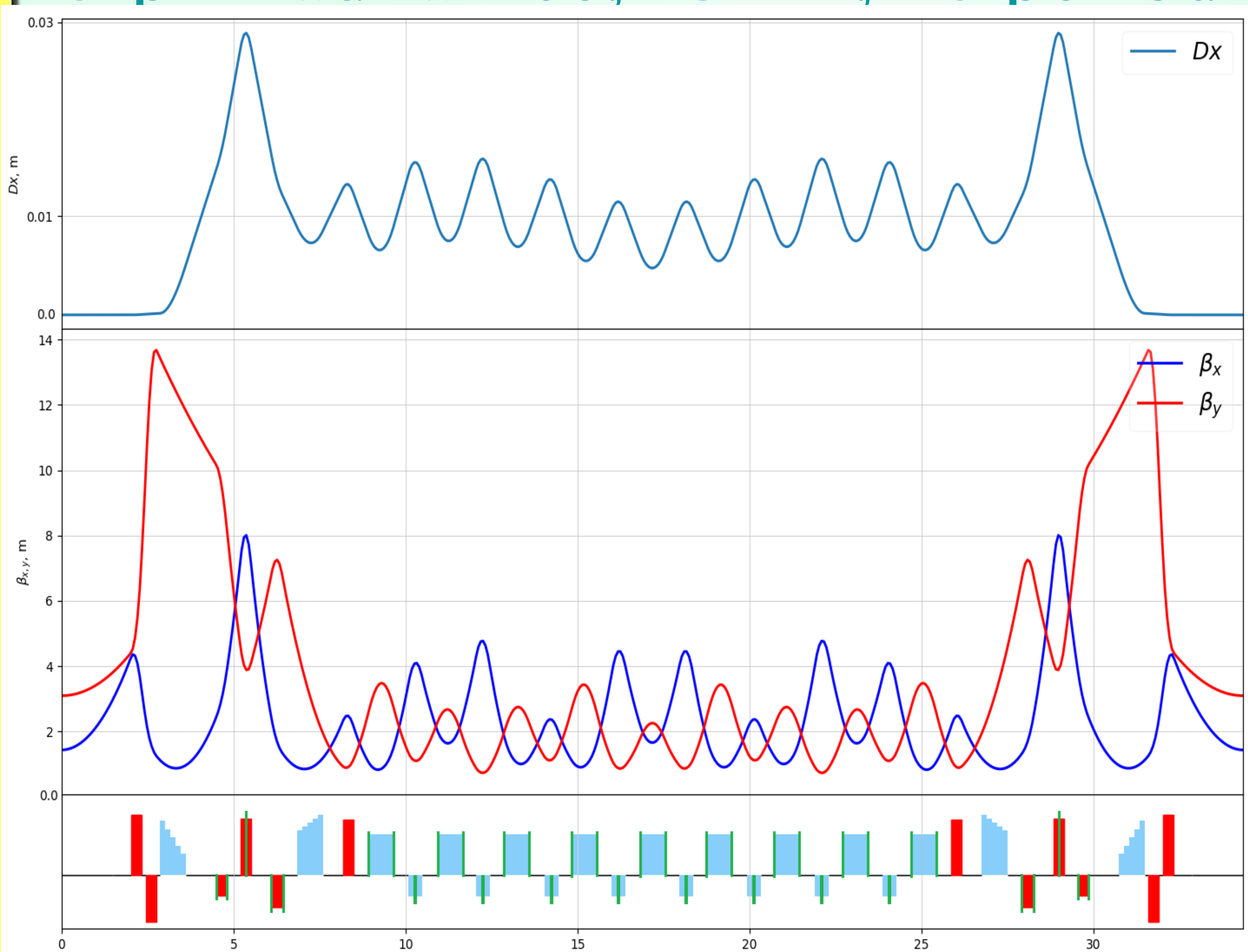
- The aperture in the central part of the period was enlarged to 20 mm and today we plan to have the same aperture for whole structure;

-Fields, gradients and lengths are corrected to decrease the β-function in the central region of period



➢Main ring: lattice and beam dynamics

Extreme SSRS4 configuration: 15 pm·rad lattice, 13BA, 48 period x 35 m

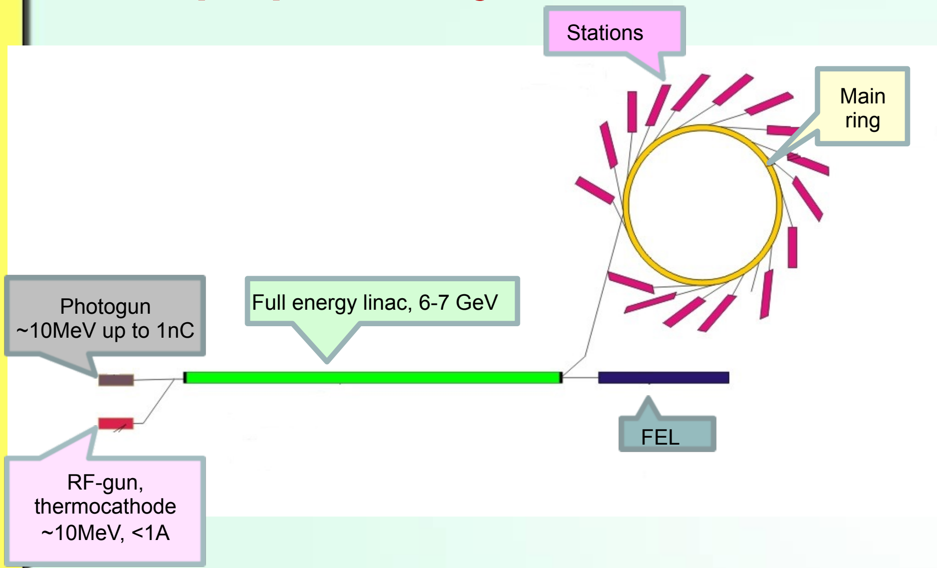


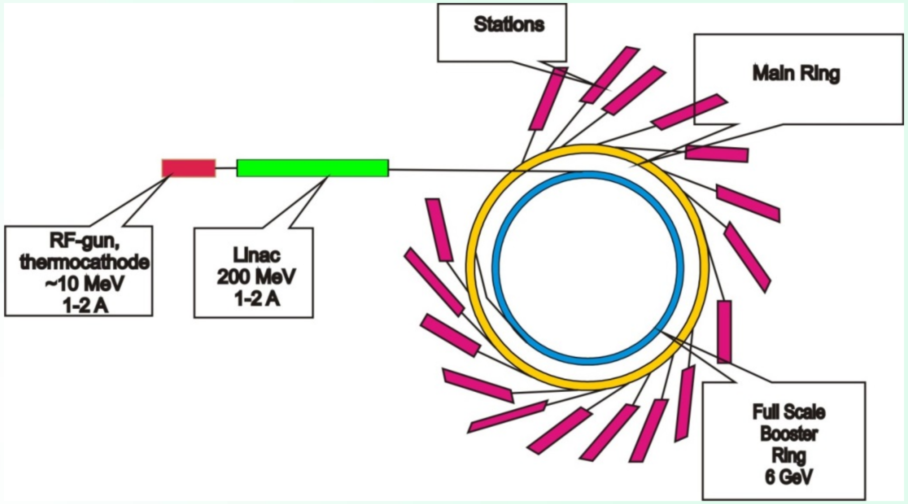
ε = 15 pm
C = 1648 m
DA: ± 1.5 mm
ξ: -203/-176

Main magnetic elements:
- bending magnets with longitudinal gradient,
- combined dipole-quadrupole magnets,
- quadrupole and sextupole magnets

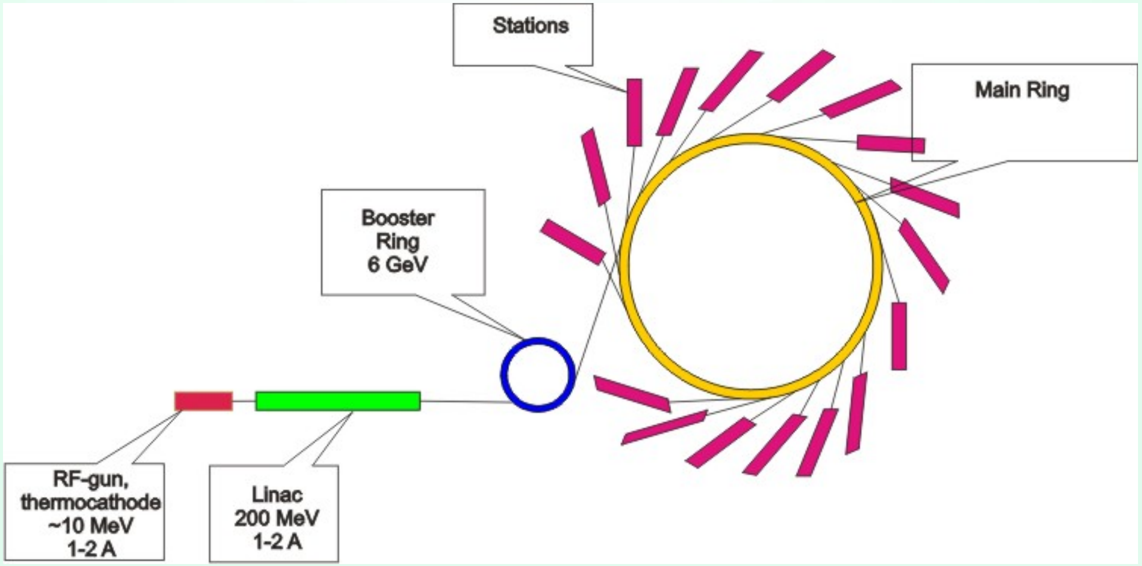
Injection: three possible ways

Top-up linac injection **OR** **full-scale booster** **???**





May be classics – compact booster ?



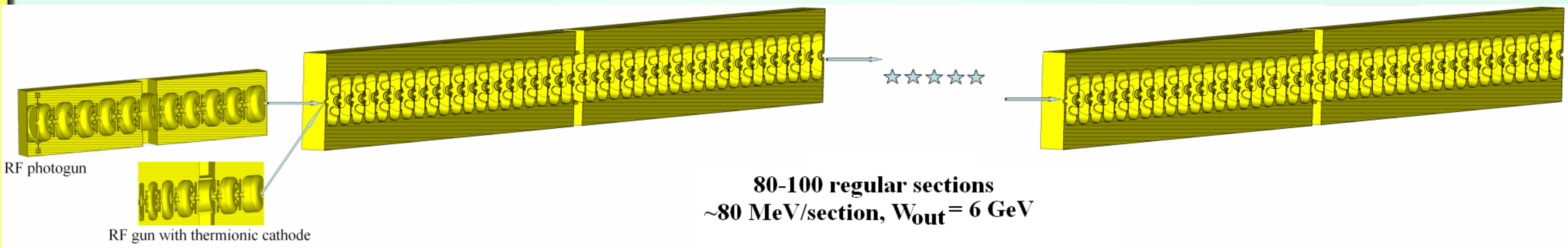
SSRS-4 Linac general concept

Injection scheme effects on linac layout and parameters

	Facility with booster ring	Facility with top-up injection
Energy	~300-500 MeV	6 GeV
RF gun (s)	Thermionic+ RF SW buncher 10 MeV	Photo and Thermionic+RF SW buncher 10 MeV
Linac operation mode	injector in booster ring	injector in booster ring provide beam for X-FEL
	Compact, cheaper and more safe in construction	*Promising but challenging*

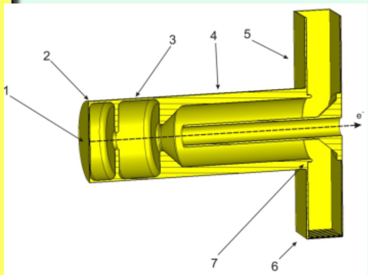
➢Injection linac (or booster)

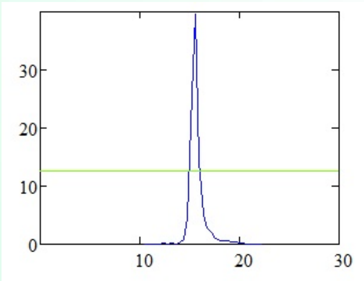
Top-up linac layout: two RF-guns - photo-gun and thermionic gun (like Super-KEKB, MAX-IV, *FCC-ee*) and 80-100 regular sections



Photogun:

1.5-, 3.5- or 5.5-cell design?

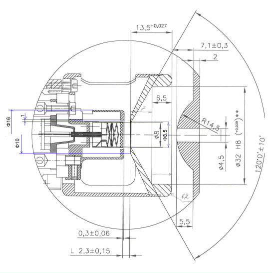


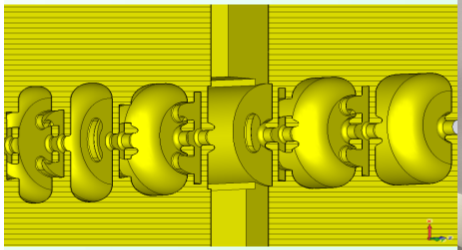


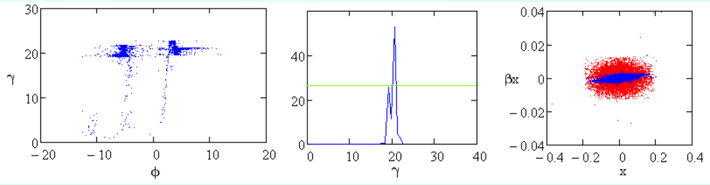
Cells	E, kV/cm	φ_{inj}	W_{max}, MeV	ΔW/W, %
3.5	600	2.0	6.2	1.8
5.5	600	2.7	8.1	0.9
5.5	700	2.8	8.2	1.2

Thermogun:

We need to control the transverse emittance on low energies





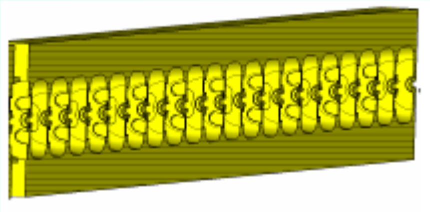


➢Injection linac (or booster)

Regular section:

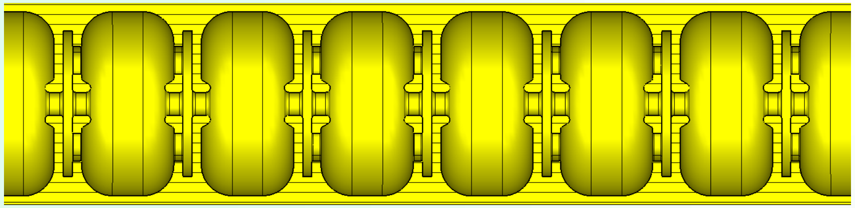
classic SLAC-type travelling wave DLW or modern standing wave structures

SLAC-type TW structure, 2π/3 mode



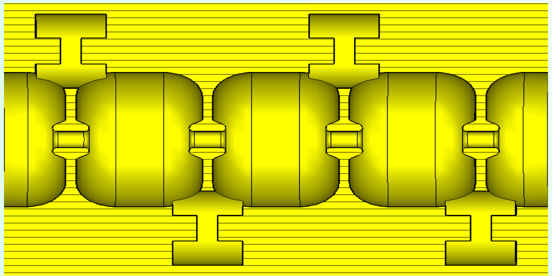
-Low coupling coefficient (2-3 % c)
-Long transient time (400-500 ns for 3m structure)
-Long RF pulse (~1 μs) is necessary
-High beam loading effect influence
- 3-5 bunches can be accelerated without of energy chirp

SW BAS



-Higher coupling coefficient (12-14 %)
-Low filling time (~200-250 ns) and shorter RF pulses
-Lower beam loading
-10-12 bunches without energy chirp

SW side-coupled or DAW

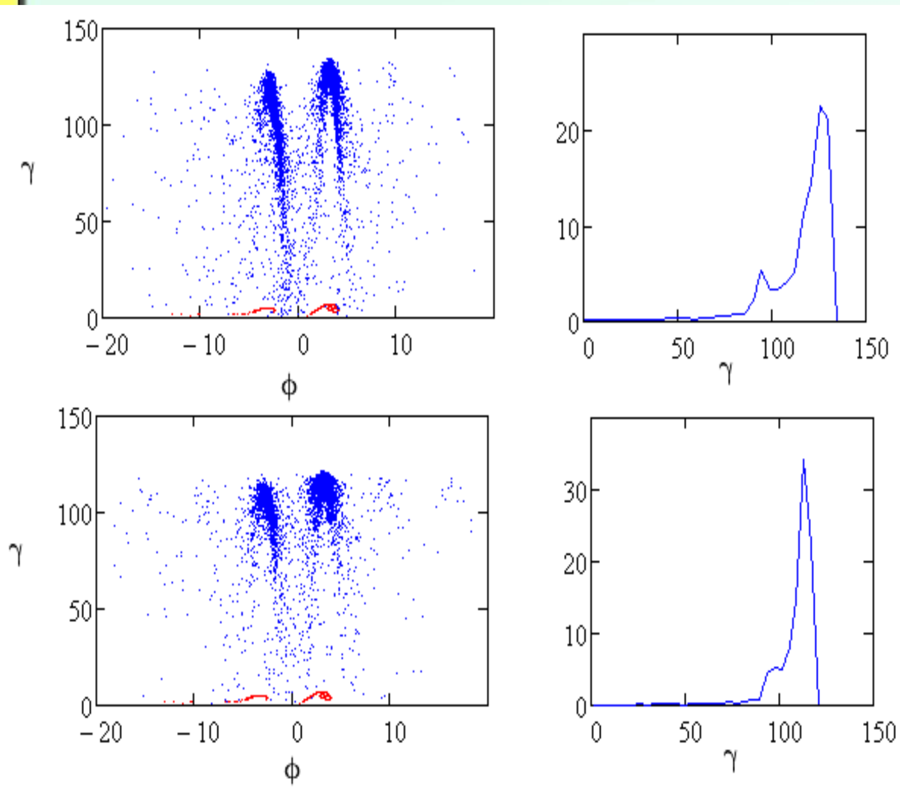


-Highest coupling as possible for DAW (30-40 %)
-Filling time ~100 ns

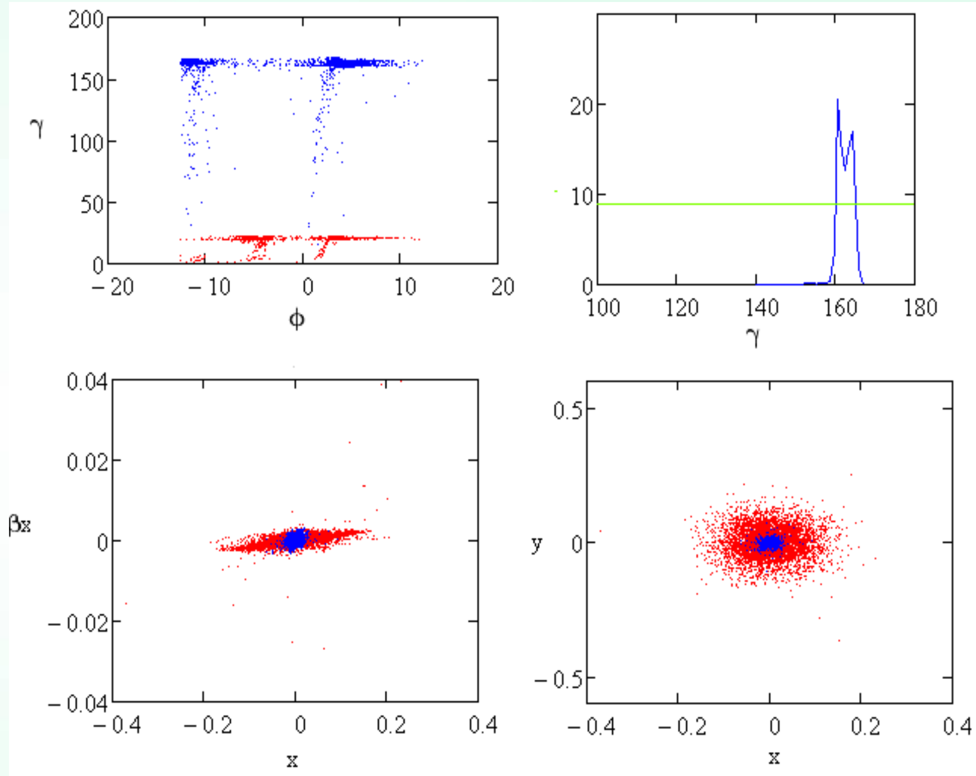
-Price is high but available

Regular section: beam dynamics

SLAC-type TW (after 1st section)



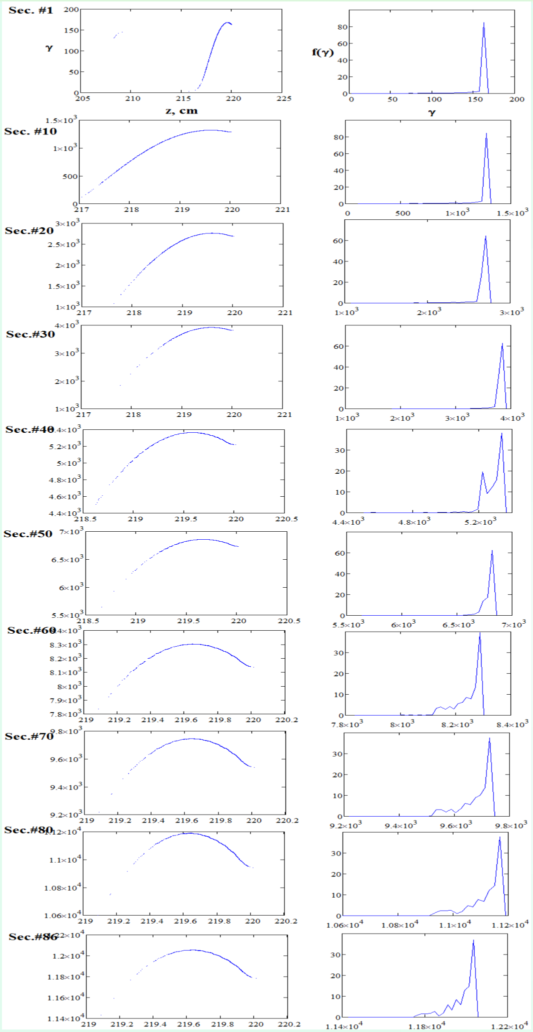
SW BAS (after 1st section)



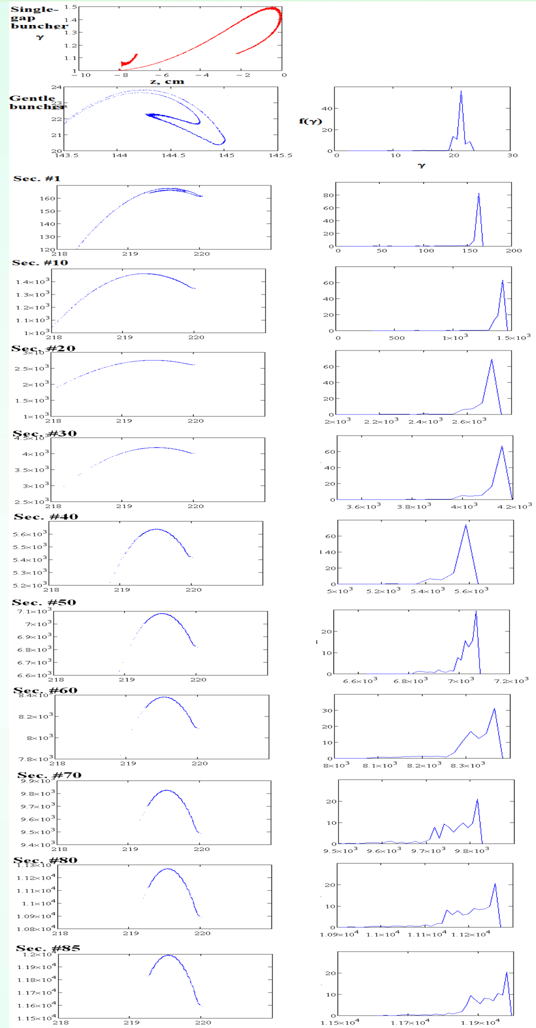
80 MeV per section (~3 m length), 6 GeV output energy
I=400 mA, ΔW/W≤3.0 % (can be optimized)
Transverse emittance ~10 μm·rad
(with non-optimised thermogun)
or ~1-5 nm·rad with photogun (250 nC per bunch)
3-5 bunches per pulse with phase chirp to compensate beam loading

80 MeV per section (~2 m length), 6 GeV output energy
I=400 mA, ΔW/W≤0.3 % (can be optimized)
Transverse emittance ~5 μm·rad
(with non-optimised thermogun)
or ~1-5 nm·rad with photogun (250 nC per bunch)
10-12 bunches per pulse wit compensated beam loading

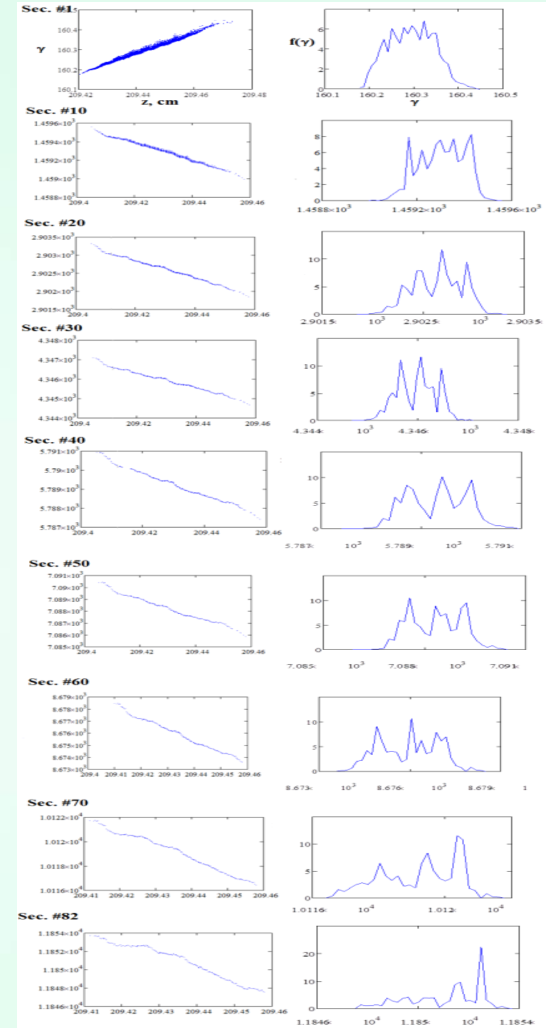
➢Injection linac (or booster)



Beam dynamics simulation results for 40-cell BAS and 250 pC bunches: longitudinal phase spaces on the (γ, *z*) phase plane and energy spectrums.



Beam dynamics simulation results: the single-gap buncher was installed before the gentle bunching section.



Beam dynamics simulation results for 40-cell BAS and 250 pC bunch generated by the photogun.

Regular section: necessary RF power

P, MW/W_{sec}, MeV/ L_{sec}, m

SLAC-type

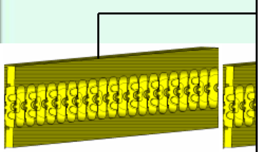
-Low coupling

-Long RF pulse

-High beam loa

-Wide spectrum

Klystron 50-60 MW	SL k_{RF}



DAW

40/55/2

70/70/2

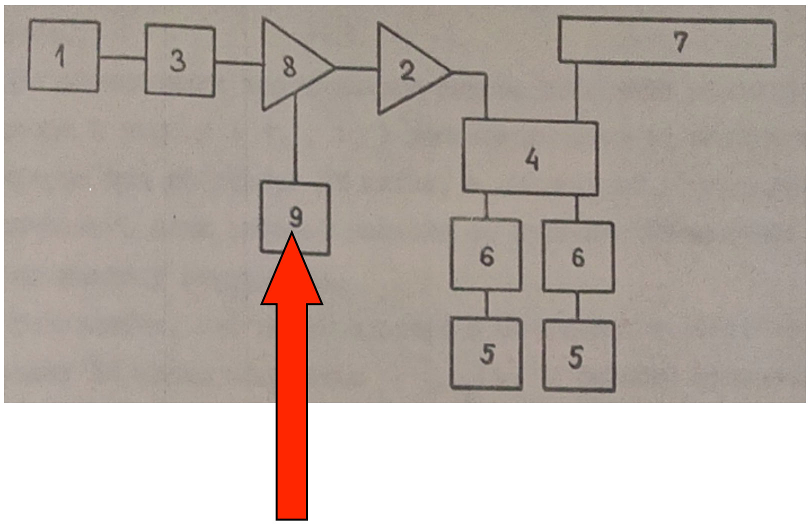
00/80/2

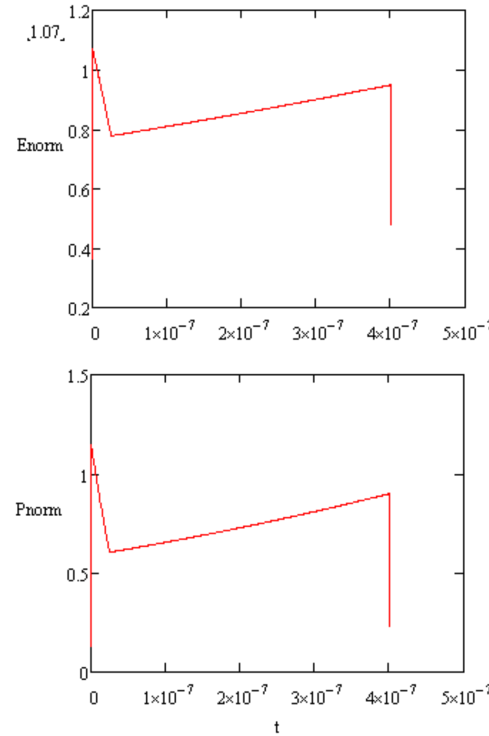
400 ns

ession

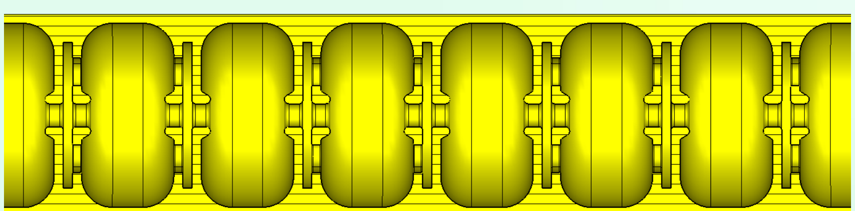
SW BAS

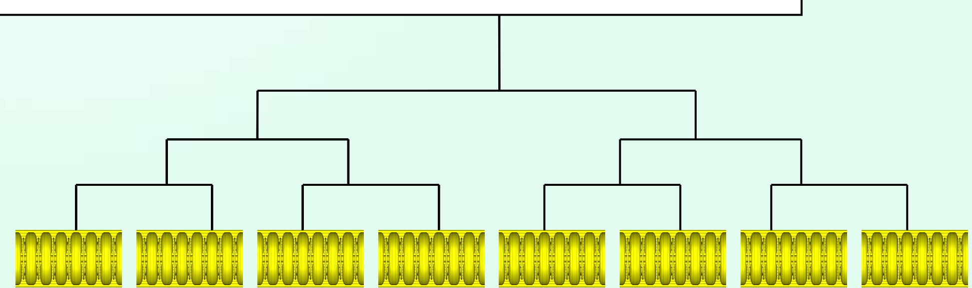
SLED with controlled pulse flatness



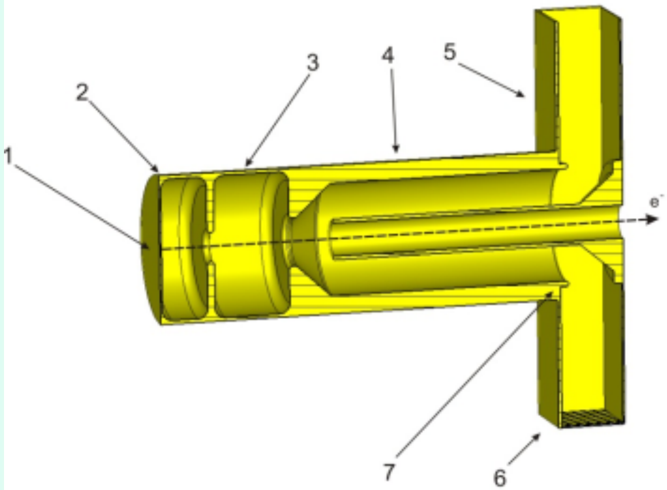


Switch with controlled function of the pulse (with trapping-down charge) – up to 400 ns of flat beam energy distribution on U-17 at MEPhI





Photogun prototype:



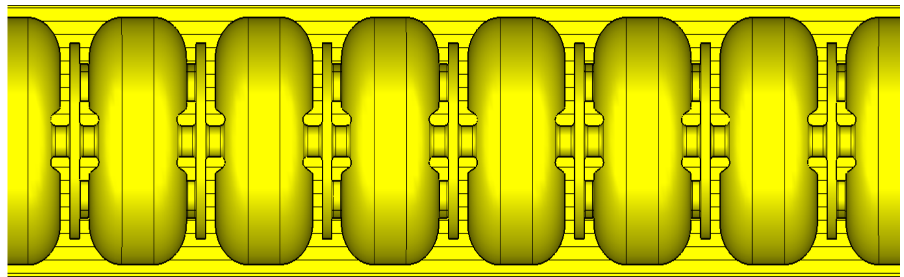


Photo-gun:
200-250 pC, ~10 MeV

One regular section:
~80 MeV/section

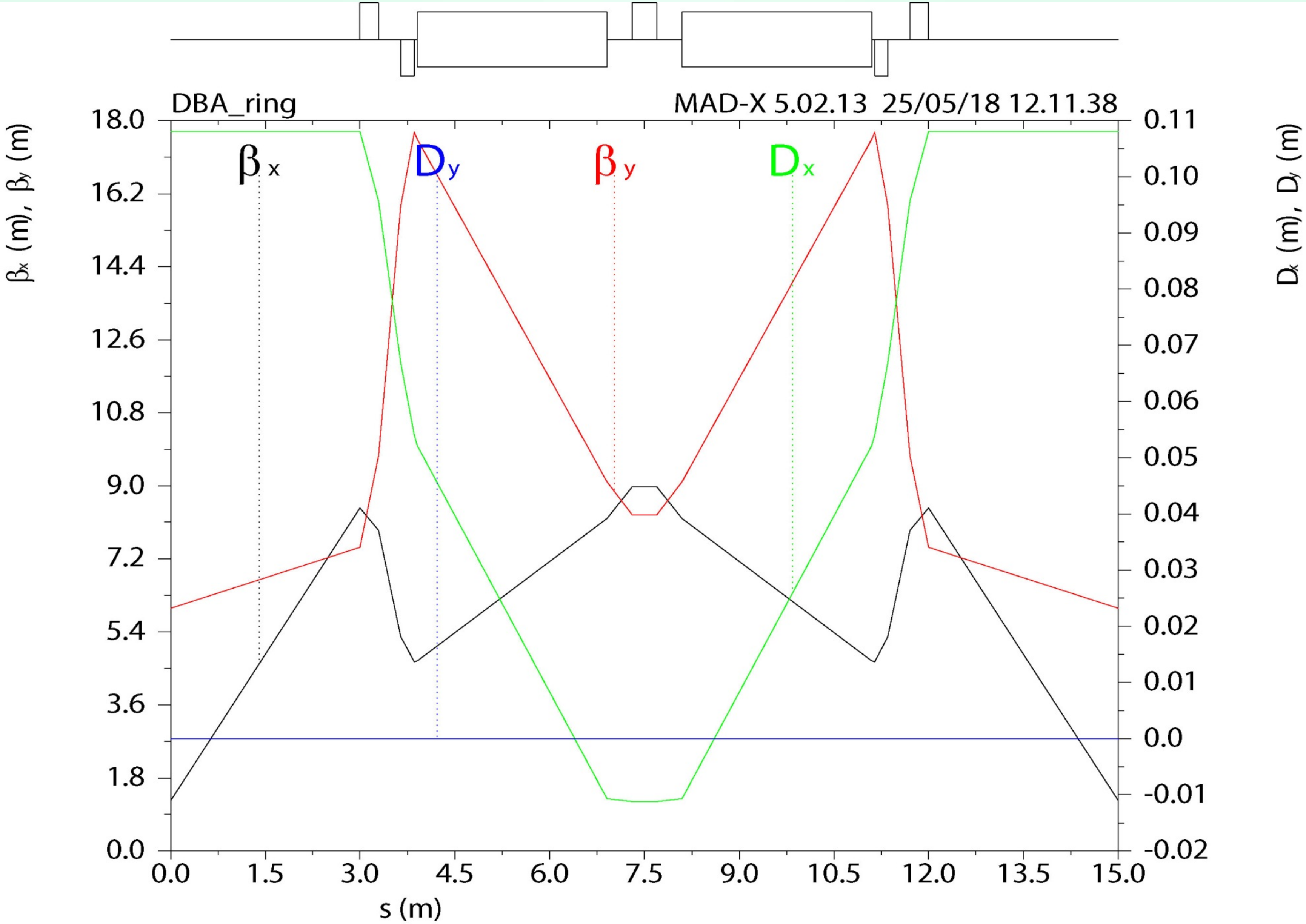
Diagnostics
system

-We need a prototype of photo-gun to have the necessary experience in its commissioning and operation
- Prototype can be scaled to top-up linac
- Prototype can be used in future as an “Compact XFEL”

-- Studies in field of photoguns improvement (DFG-RFBR proposal with DESY-PITZ)

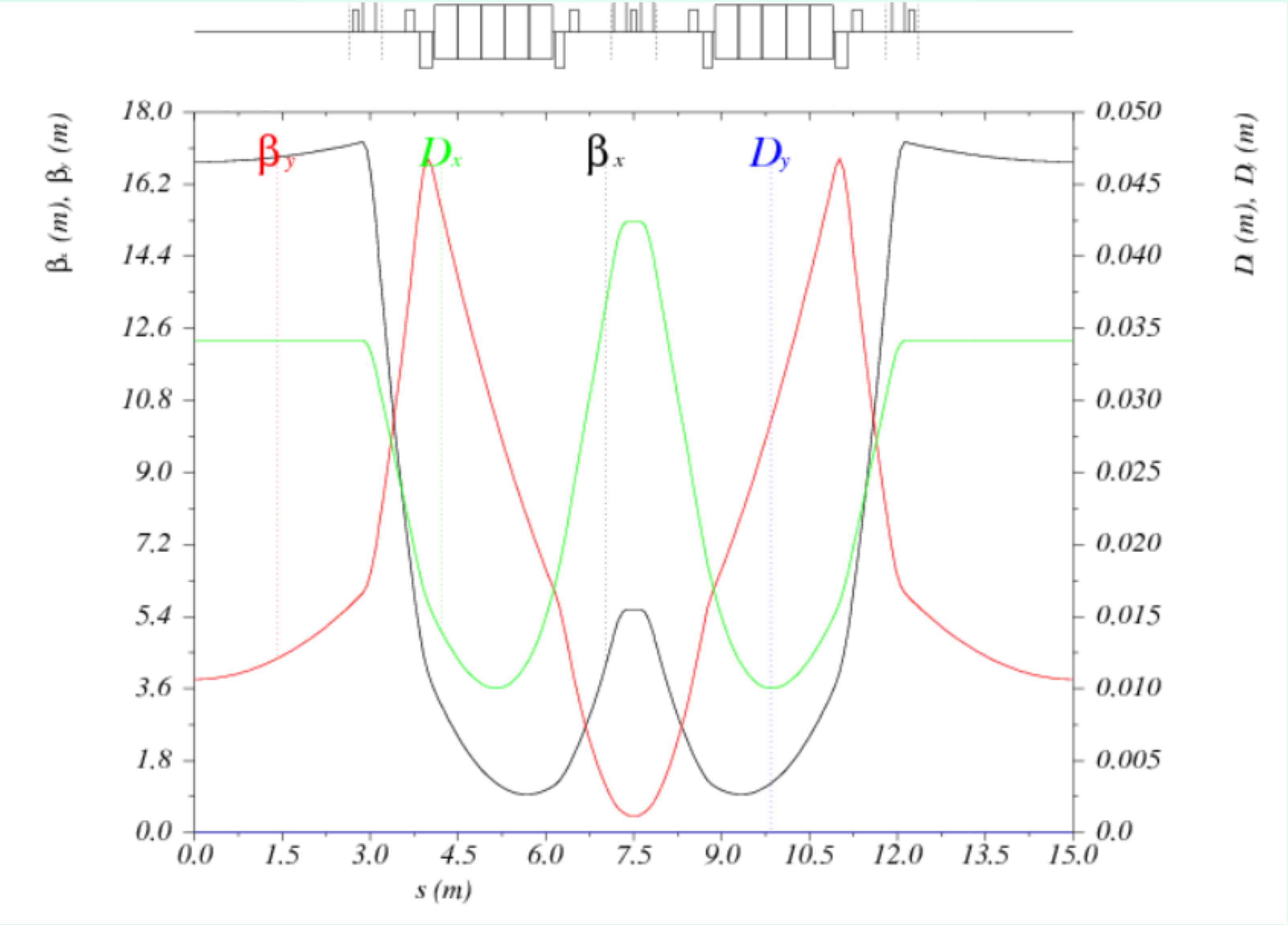
➢Injection linac (or booster)

Full-scale booster design (80 periods x 15 m, 2BA)



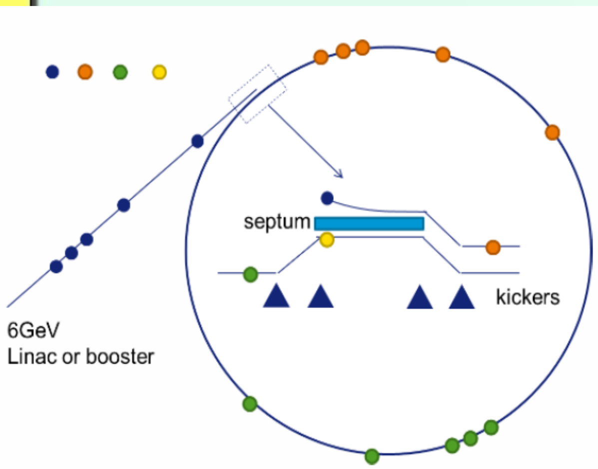
➢Injection linac (or booster)

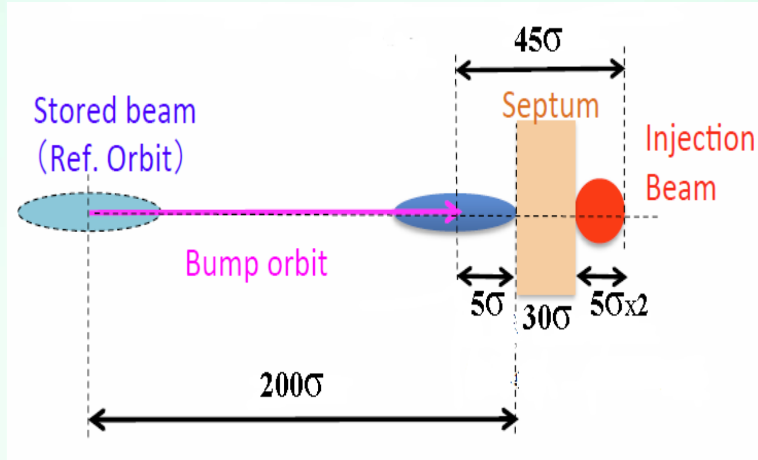
Compact booster design (20 periods x 15 m, 2BA)



Beam injection: off-axis

- Timeshared use of top-up linac





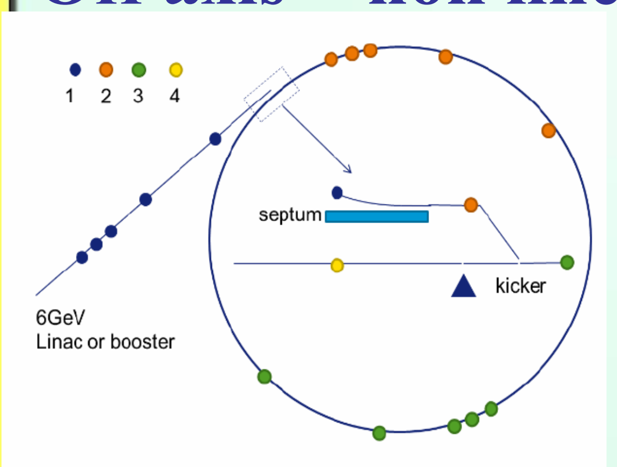
$$\sigma = \sigma_i = \sigma_s$$

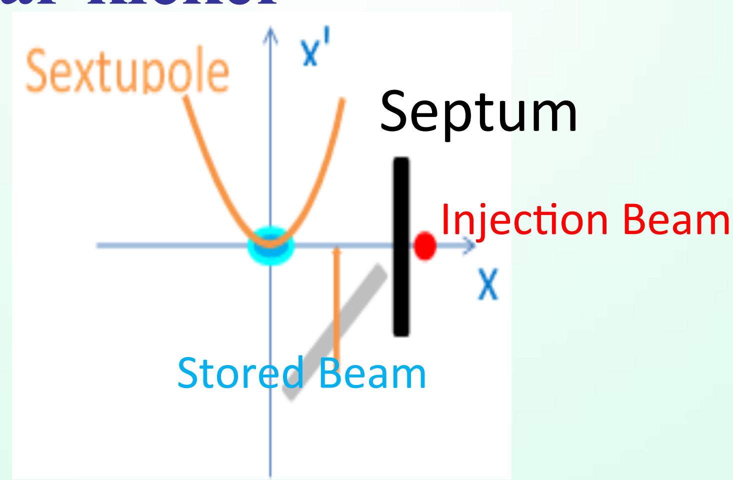
$\varepsilon_x = 0.13nm$ ESRF

$\beta_x = 19m$

$\sigma = \sqrt{\varepsilon_x \beta_x} = 0.05mm$

Off axis + non linear kicker

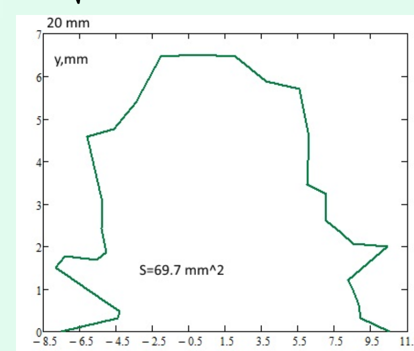




If $\varepsilon_x = 6\,nm$

$\beta_x = 20\,m$

$\sigma_i = \sqrt{\varepsilon_x \beta_x} = 0.35mm$

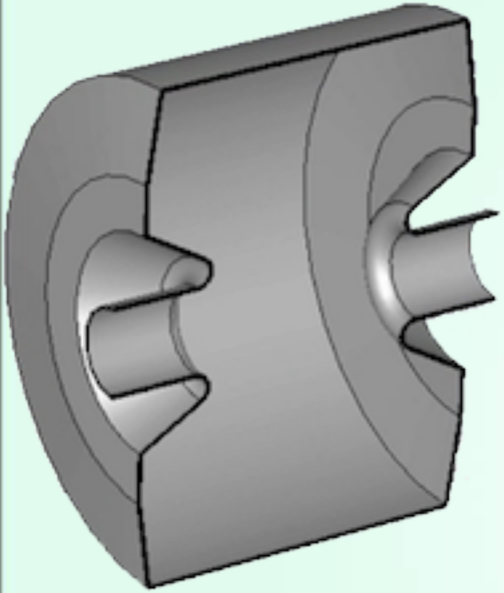


DA is enough !!!

➢Vacuum system

Especial thanks to: Cristian Maccarrone, Hugo Pedroso Marques, Simone Liuzzo

RF system: 350 MHz or higher? or lower?



Simplest cavity model

Beam energy losses: 5 MeV/turn (incl. 600 keV/turn in magnets)

Beam current: 200 mA

Power losses: 1 MW

***f*, MHz**	**352**	**476**	**714**
Surface field for 1 J of stored energy	11.5	14	25.5
Kilpatrick limit, MV/m	17.9	20.9	24.78
Maximal energy per cavity, J	2.4	2.22	0.94
Maximal power to beam, MW	0.57	0.53	0.23
Number of cavities for 3 MW of stored power	12	10	7

Especial thanks to:
Mikhail Zobov (LNF)

Total RF power: 2.56 MW (352 MHz), 2.10 MW (714 MHz)

➢Diagnostics, control and timing

- *Classical SCADA architecture*
- *Uses mainly Ethernet network*
- *Dedicated network for BPMs*
- *Open source middleware solutions and so on*

Supervisor control system TANGO or similar

- History server
- Terminals
- Database server
- Event servers

Fully digital low-level RF

- LINAC RF system
- Booster RF system
- Storage ring RF system

Electron optics

- LINAC
- Booster
- Beam transfer lines
- Storage ring

- Slow elements
- Ramping magnetic field
- Fast orbit correctors
- Injection, extraction kickers

Engineering systems

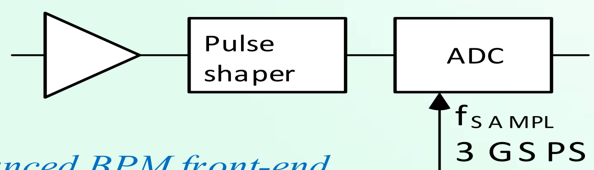
- Vacuum
- Water
- Temp.
- Dosimetry
- Area access

Beam diagnostics

- Beam position
- Beam current
- Beam profiles (emittance, energy spectrum)

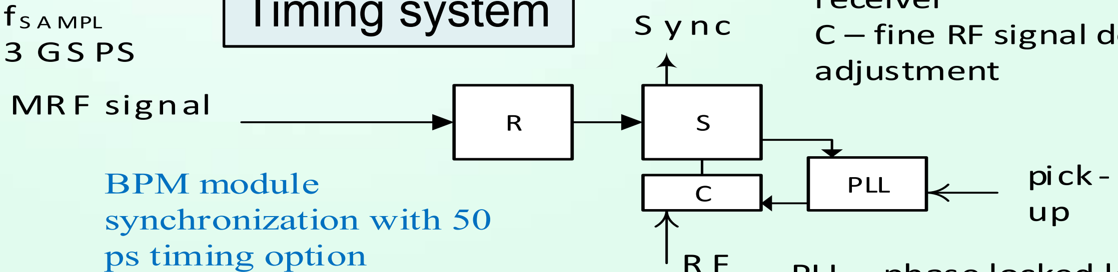
High performance BPM front-end with most up-to-date components

f_{REP}= 500MHz, 20 ps



Enhanced BPM front-end

Timing system

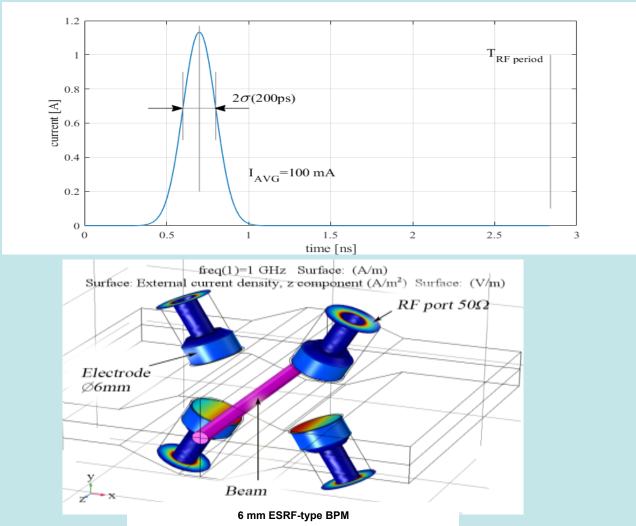


R – general timing signal receiver
C – fine RF signal delay adjustment
S – sync. generator
PLL – phase locked loop with pick-up signal

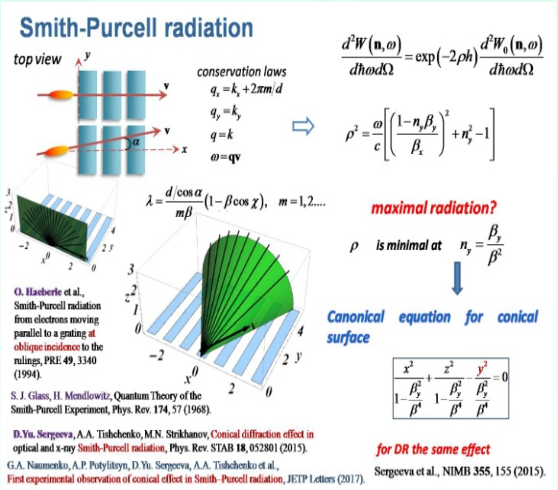
BPM module synchronization with 50 ps timing option

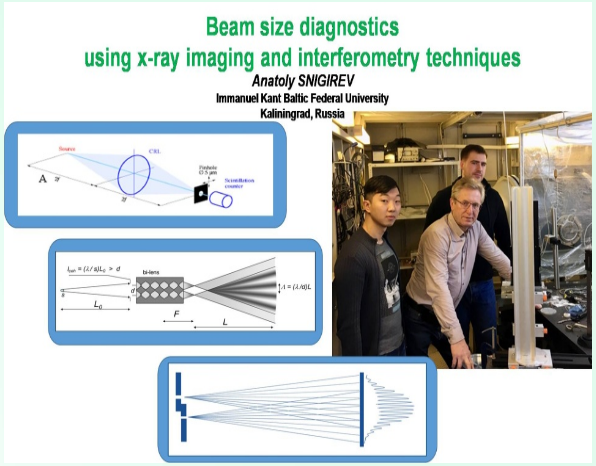
Micro-Research (Finland) type of timing system with general 10ns and local 500/50 ps accuracy options

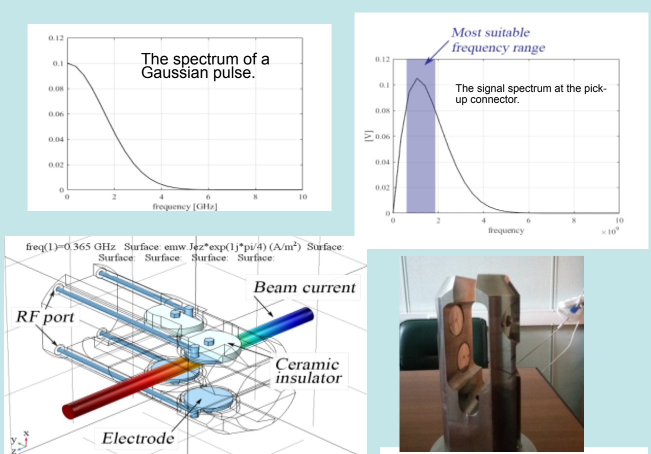
➢Diagnostics, control and timing



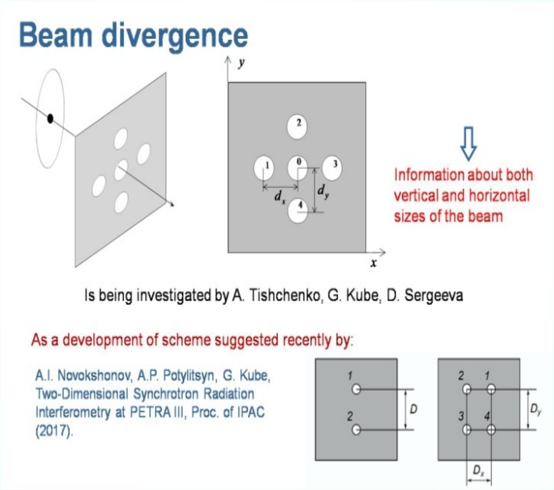
6 mm ESRF-type BPM

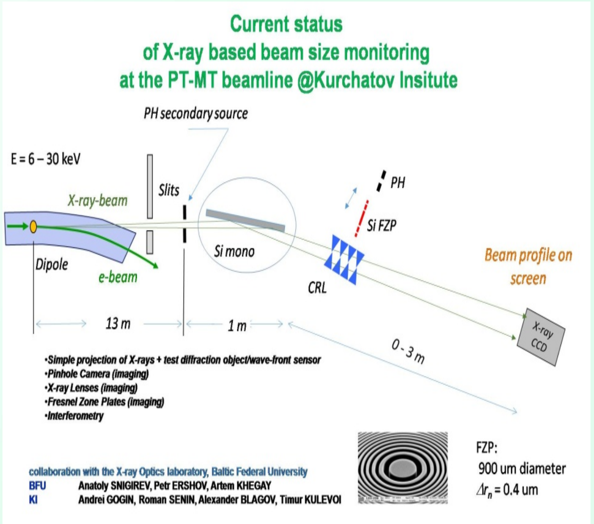






BPM Kurchatov synchrotron



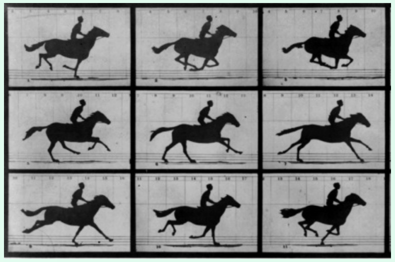


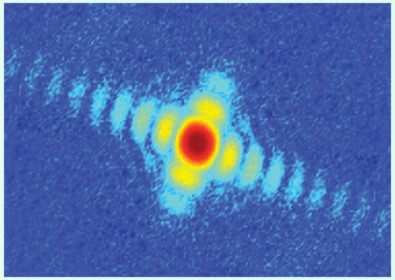
Especial thanks to Kees-Bertus Scheidt (ESRF)

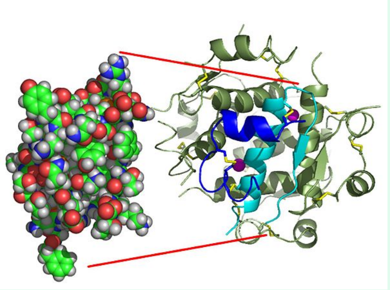
➢Beam lines and research program (1st stage)

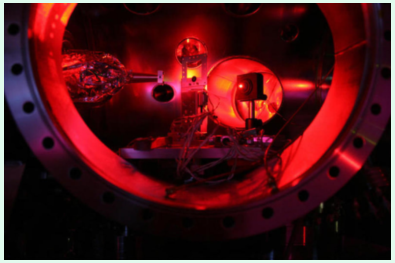
Main fields will coherence and photon-hungry techniques

INSTRUMENTS & EXPERIMENTS

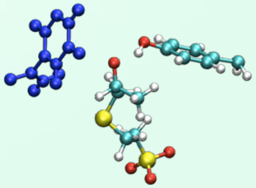








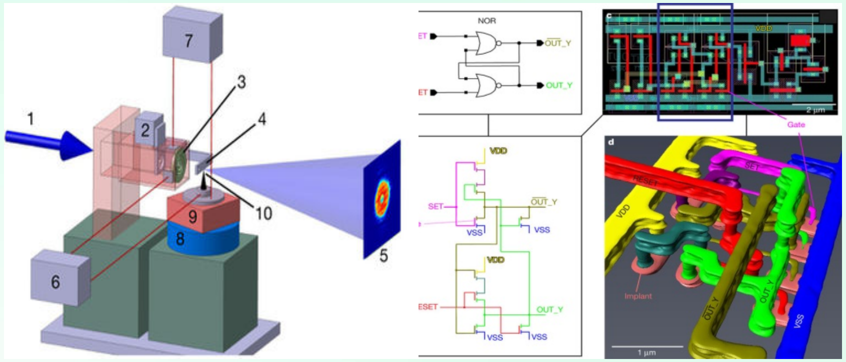
- **Coherent diffraction, scattering, imaging, X-ray holography**
- **Single particles experiment, nanocrystals, nanoparticles, structure of biomolecules**
- **Extreme condition, extreme state of matter**
- **All traditional methodic at the Extremely High Brilliant source**



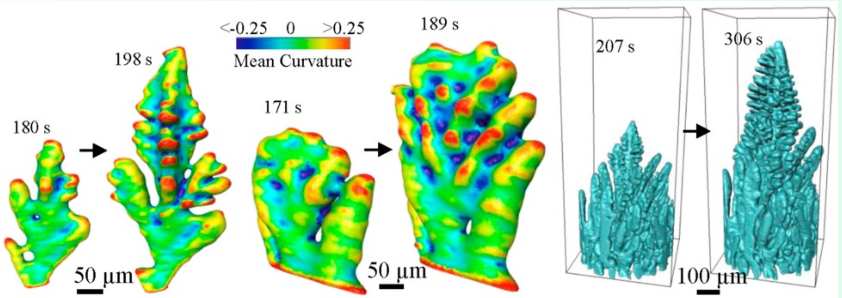
1st stage- 10 beamlines:

- magnetic scattering, nuclear scattering,
- high resolution hard X-ray spectroscopy,
- X-ray photon correlation spectroscopy
- diffraction contrast tomography,
- ptychography,
- macromolecular/serial crystallography,
- SAXS,
- pump-probe experiments,
- nanodiffraction,
- coherent microscopy.

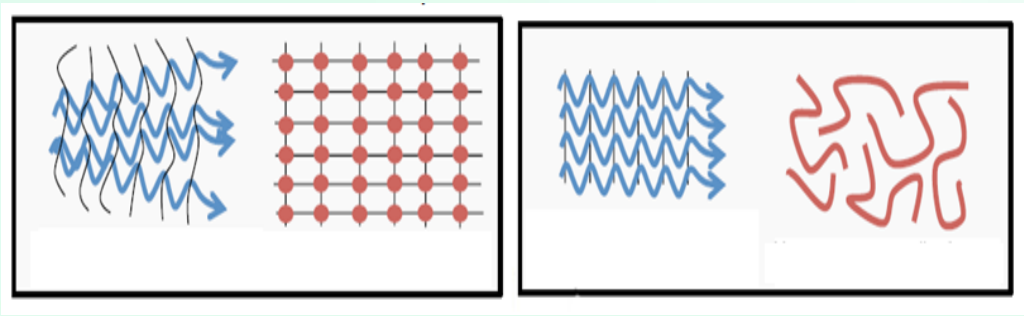
+ Laser based coherent THz source

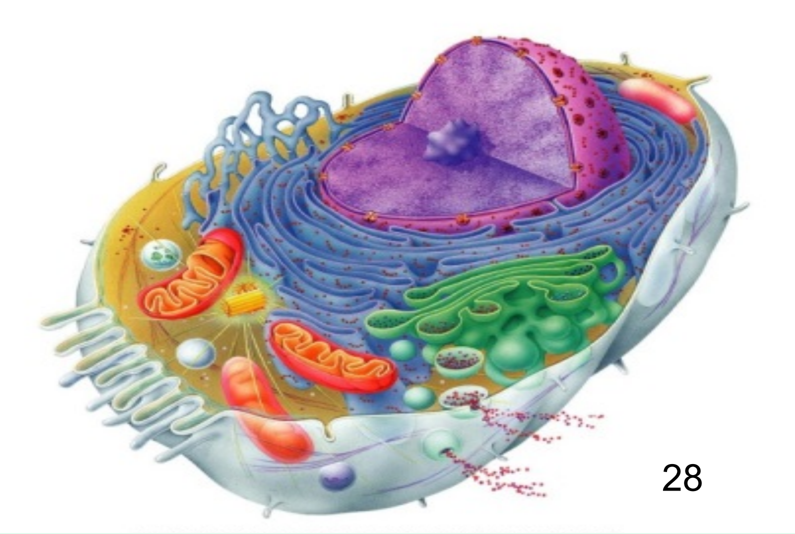


Holler M. et al. Nature. – 2017. – T. 543. – №. 7645. – C. 402.



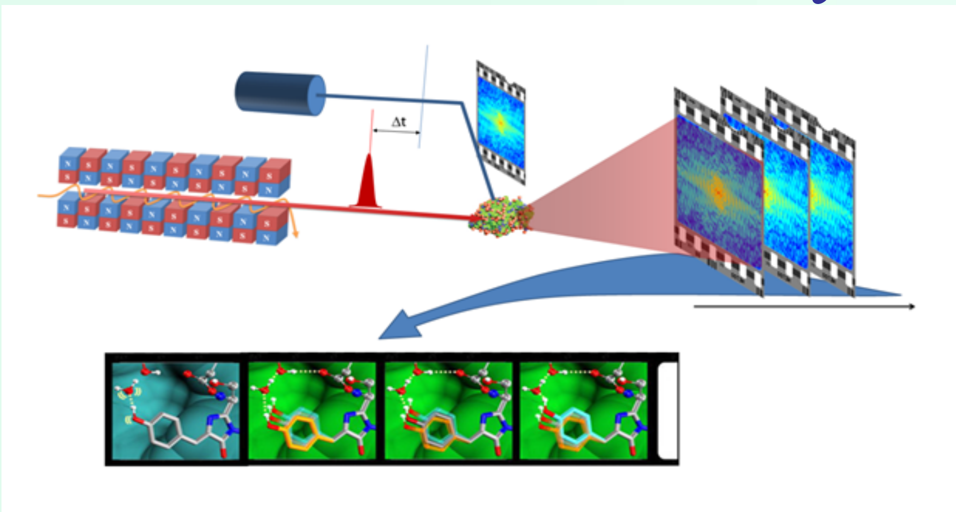
Cai B. et al. Acta Materialia. – 2016. – T. 117. – C. 160-169





➢Beam lines and research program (1st stage)

FEL for EUV and X-rays



FELs with similar parameters:

- SwissFEL, Switzerland
- SACLA, Japan
- LCLS, USA
- SPF – MAX-IV, Sweden

Electron beam energy	**5 – 7 GeV**
Peak current	1 – 5 кA
Bunch charge	0.01 - 0.3 nC
Repetition rate	50 – 200 Hz
Normalized emittance	0.3 - 1.5 um
Photon energy	0.25 – 20 keV (1st harmonic)
Photon pulse duration	1 – 400 fs
Period of undulator, λ_U	15 – 40 mm
Undulator parameter, *K*	1.0 – 3.5
Peak brilliance, B_{FEL}	0.1 – 2 x 10^{33} (s·mm^2 ·mrad^2 ·0.1 % BW)

➤SSRS4 site in Protvino

Organization

General layout and beam dynamics

BD WG1:
SR with 70-100 pm·rad
+ full-scale booster

BD WG2:
SR with 20-50 pm·rad
+ compact booster

Injection linac

Injection schemes

RF

Control system

Insertion devices and FEL's

Diagnostics

Vacuum system

Engineering systems

Research programme

Research Programme

Stations and channels

Beam requirements

➢ Conclusions

- ➢**General SSRS4 scheme should be fixed in 2018;**
- ➢**Beam dynamics for both schemes is under progress (“user machine” with emittance of 70-100 pm·rad and “record machine” with 20-50 pm·rad);**
- ➢**Magnetic structure is preliminary designed;**
- ➢**Linac and boosters are preliminary designed;**
- ➢**Injection scheme should be chosen;**
- ➢**Vacuum system is under preliminary design;**
- ➢**Diagnostic, control and timing systems are under preliminary design;**

Plans for 2019:

- ✓**International Collaboration;**
- ✓**Scientific Advisory Committee;**
- ✓ **Machine Advisory Committee**

Other SSRS4 presentations on Channeling-2018:

26 - Injector Linac Prototype of the Russian 4th Generation Specialized Synchrotron Radiation Source SSRS-4 as a Possible Compact XFEL

30 - Optimal RF-Photogun Parameters for the Compact XFEL Based on the New Linac-Injector Prototype

39 - Status of Diagnostic and Control System Development for Russian New Light Source Project SSRS-4

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TPU

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JINR JOINT INSTITUTE FOR NUCLEAR RESEARCH

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