Current Results of the 4th Generation Light Source USSR (Former SSRS4) Development

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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

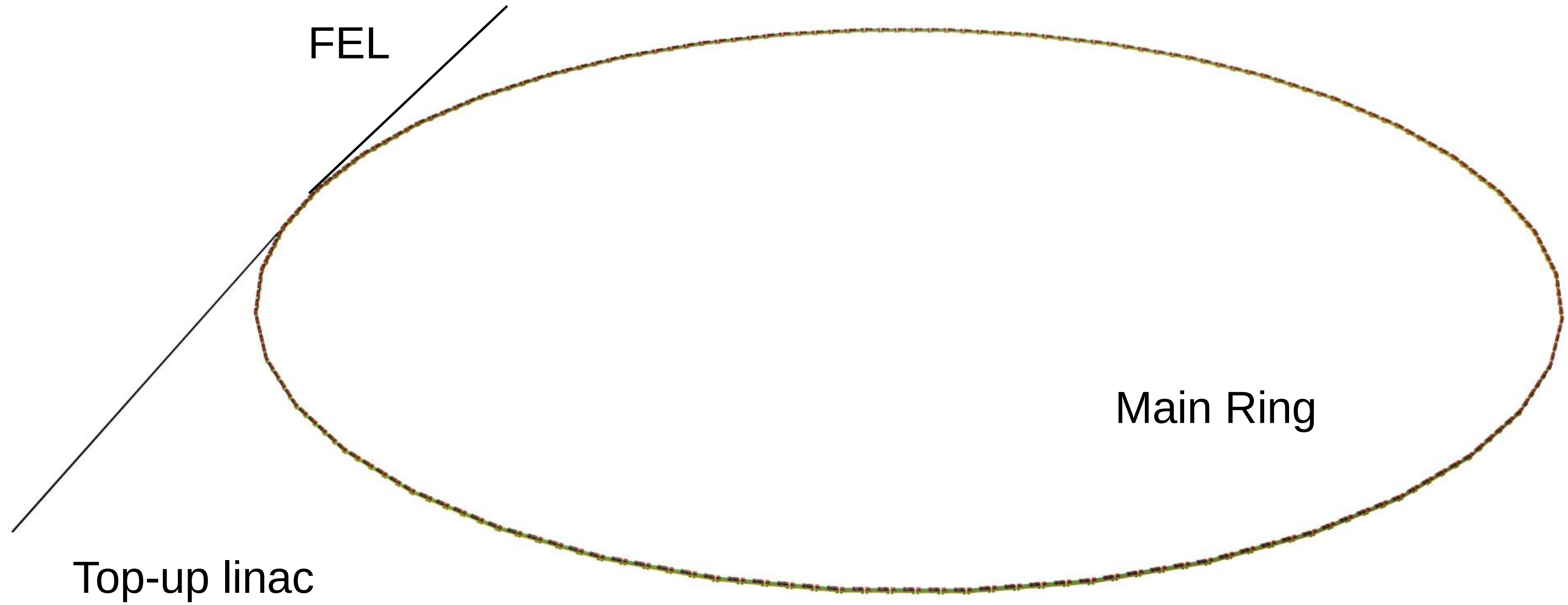
- SSRS4: general concept and layout
- Main ring: lattice and beam dynamics
- Injection linac (or booster)
- Injection
- Vacuum system
- RF system
- Diagnostics, control and timing
- Beam lines and research program (1st stage)
- SSRS4 site
- Conclusions

➢SSRS4: general concept and layout

6 GeV

40 periods, ~1300 m

~70 pm·rad, up to 70 ID's



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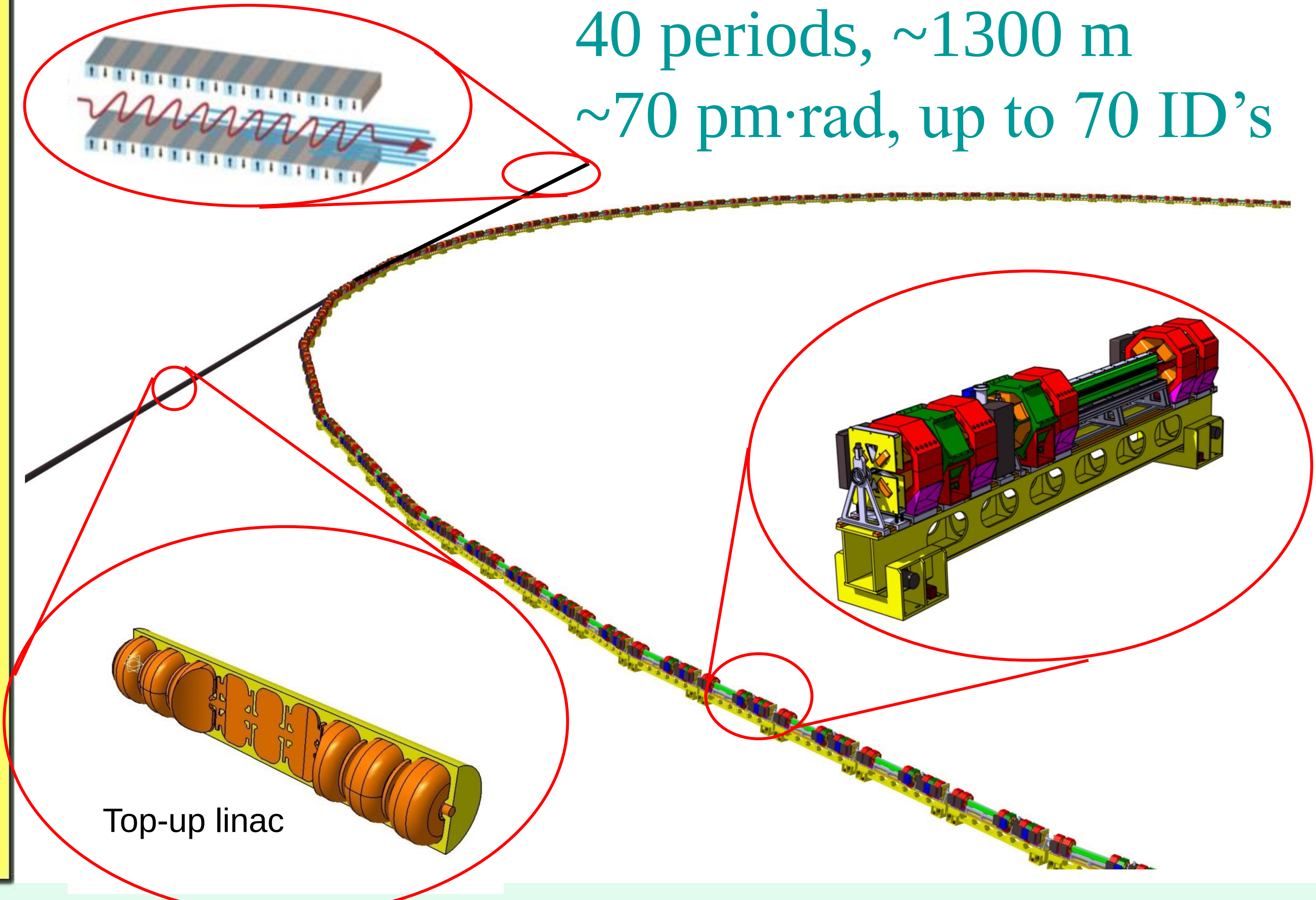
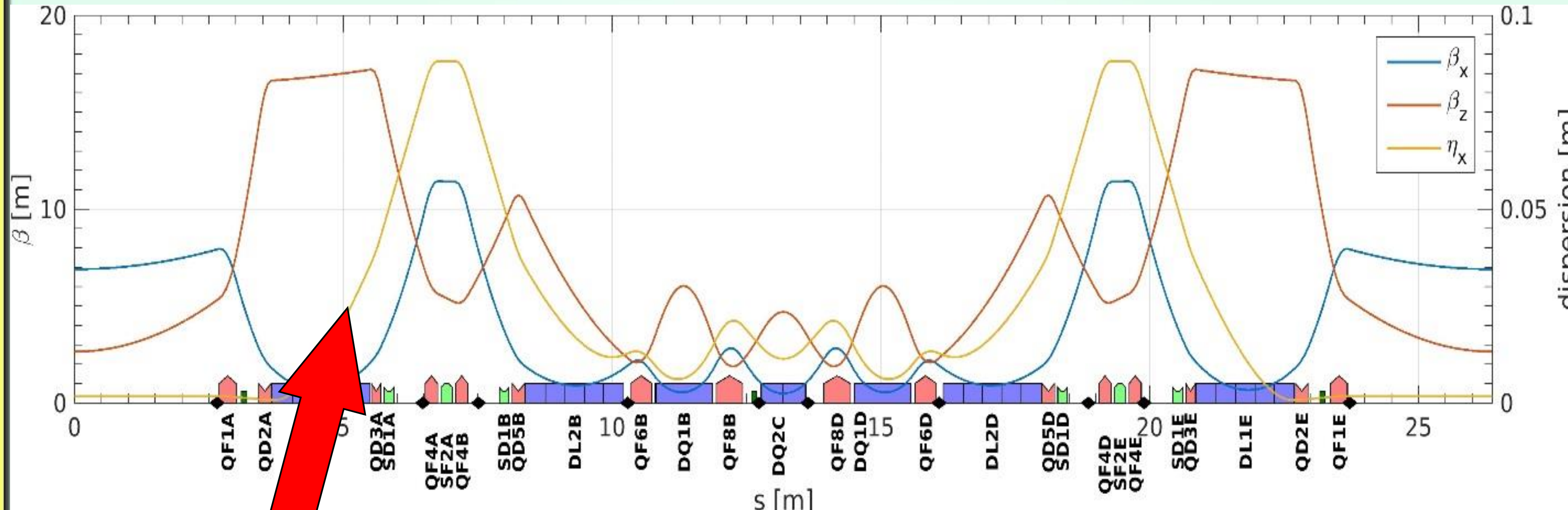


Start configuration is based on MBA (7BA); period length 26-30 m; first structure is kindly prepared by our ESRF partners and based on scaled ESRF-ESB design



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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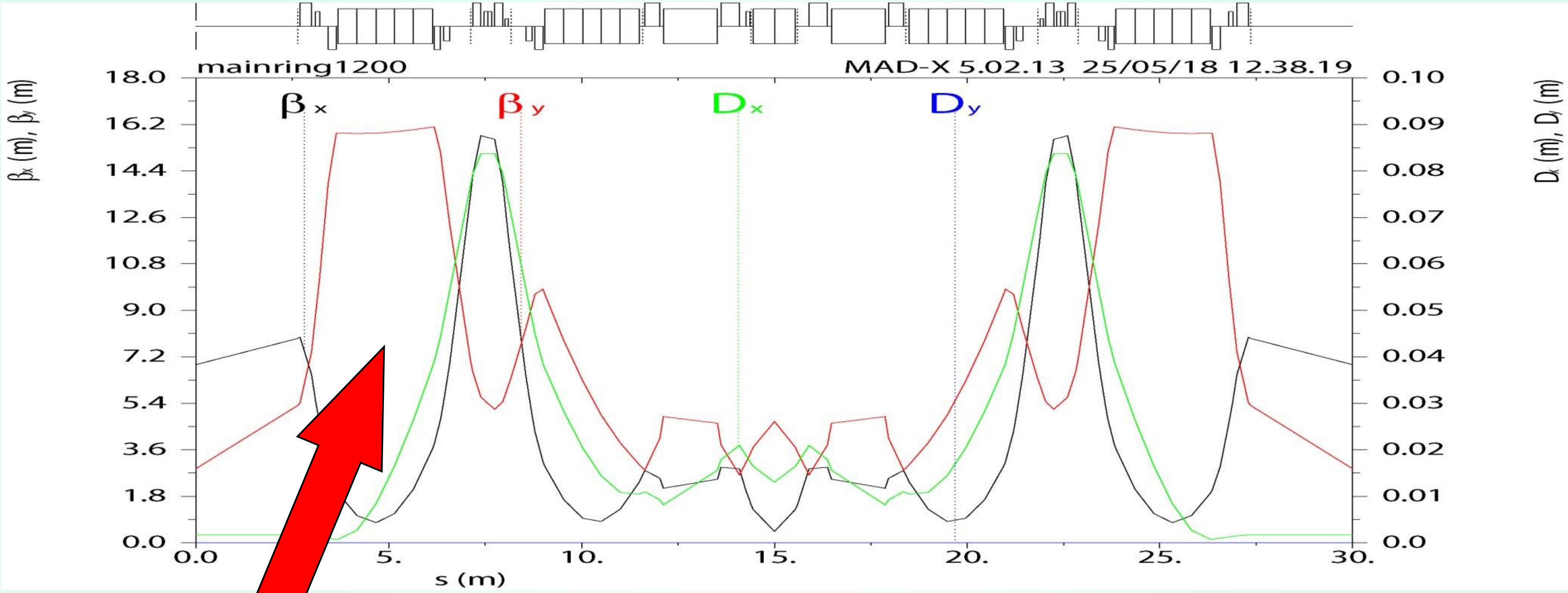

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Especial thanks to: Pantaleo Raimondi, Simone Liuzzo, Laurent Farvacque and Simon White

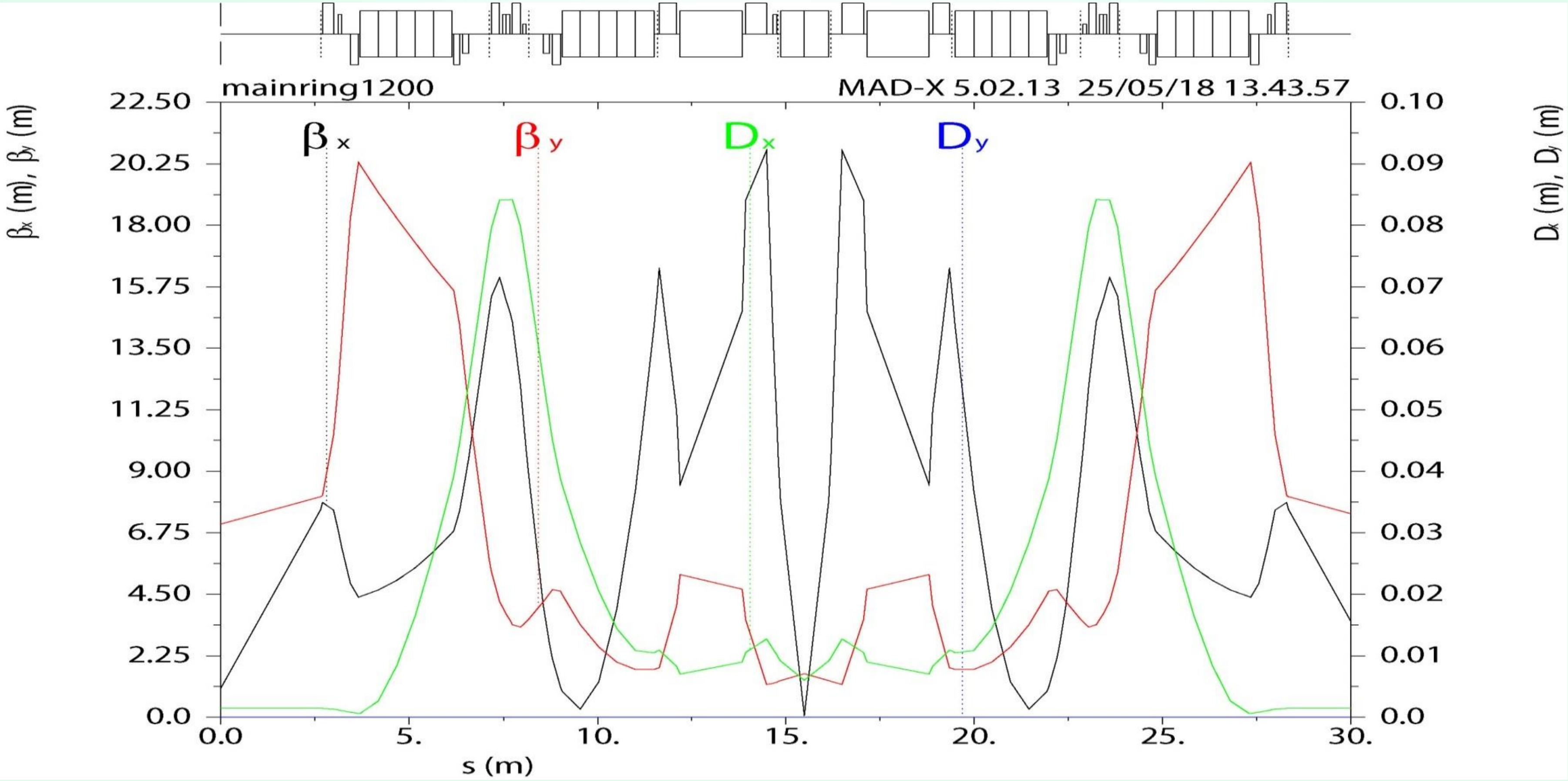
Second configuration is based on 7BA (30 m/period)

-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.

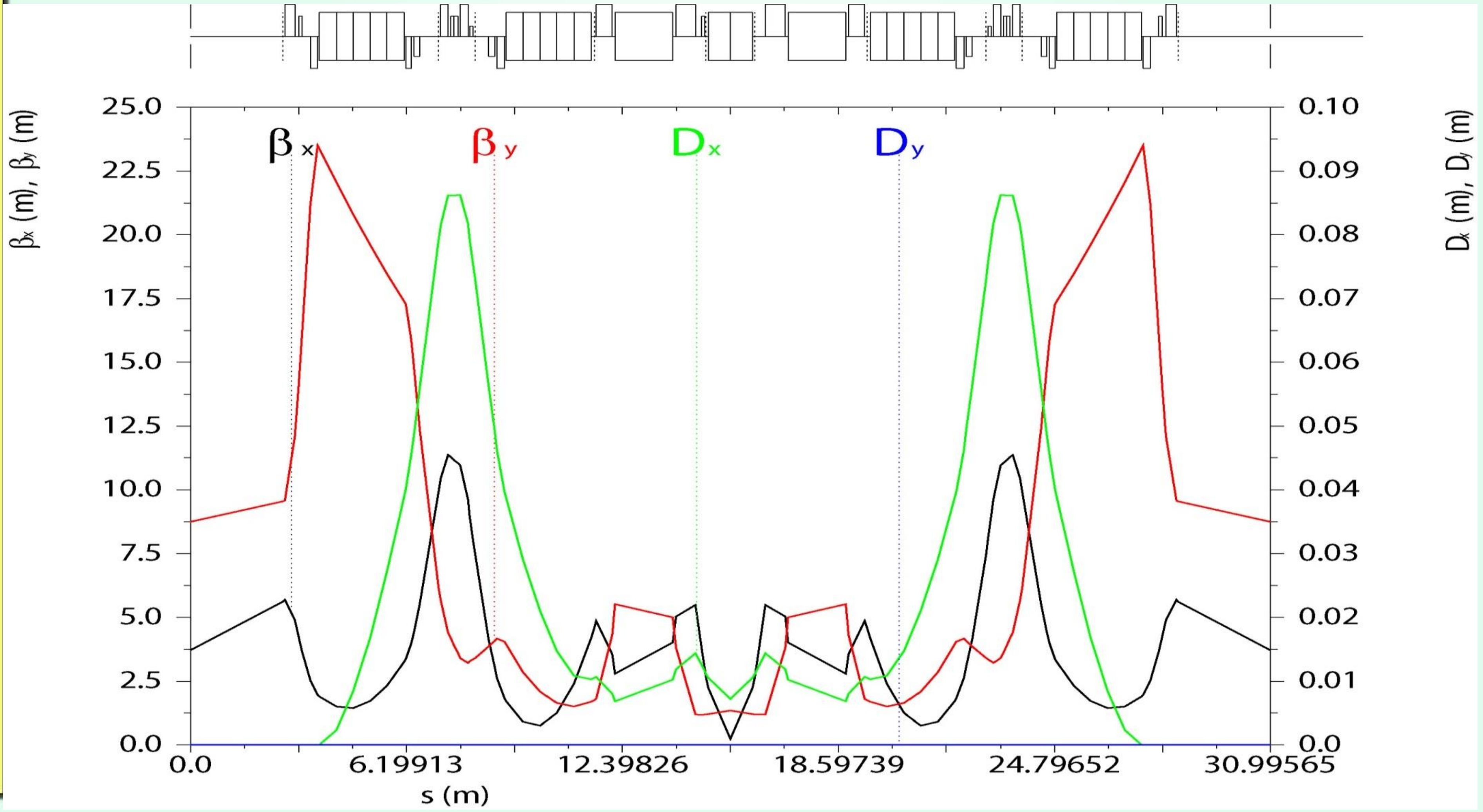
-The period length was enlarged to ~30 m to place longer “high field” magnets



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

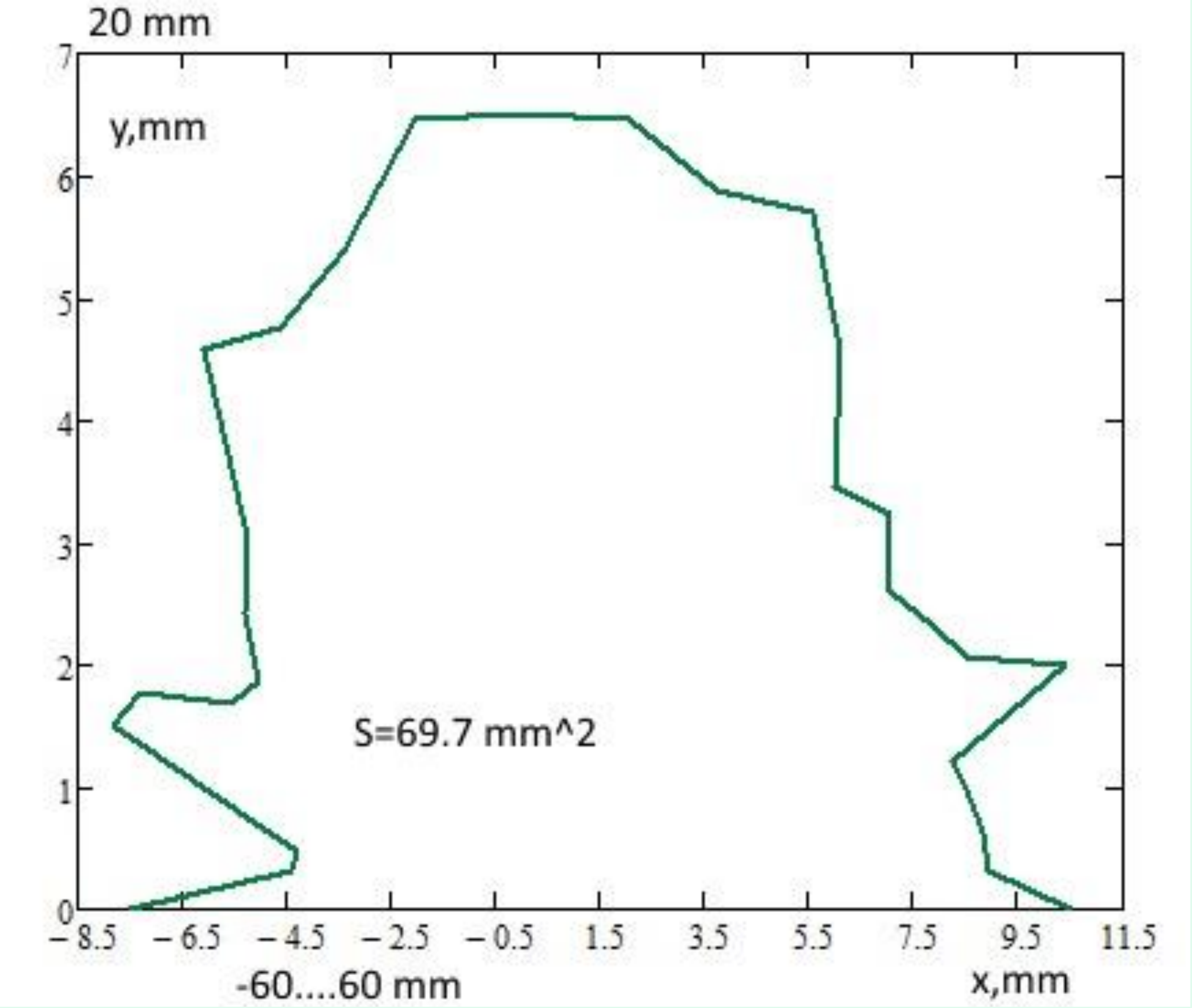
- Small aperture in the central part of the period was enlarged to 18 mm;

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



➢Main ring: lattice and beam dynamics

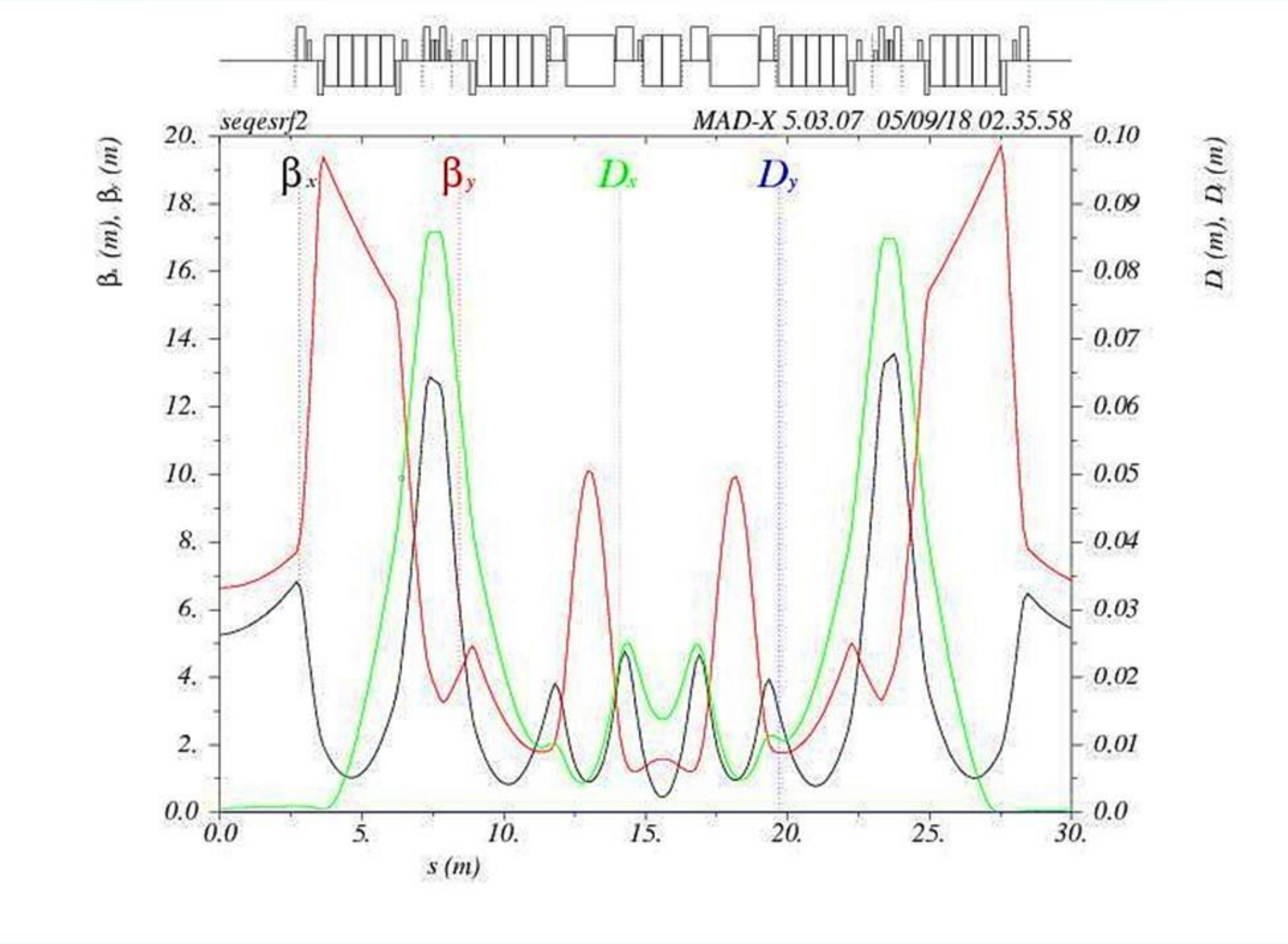
Dynamic aperture



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

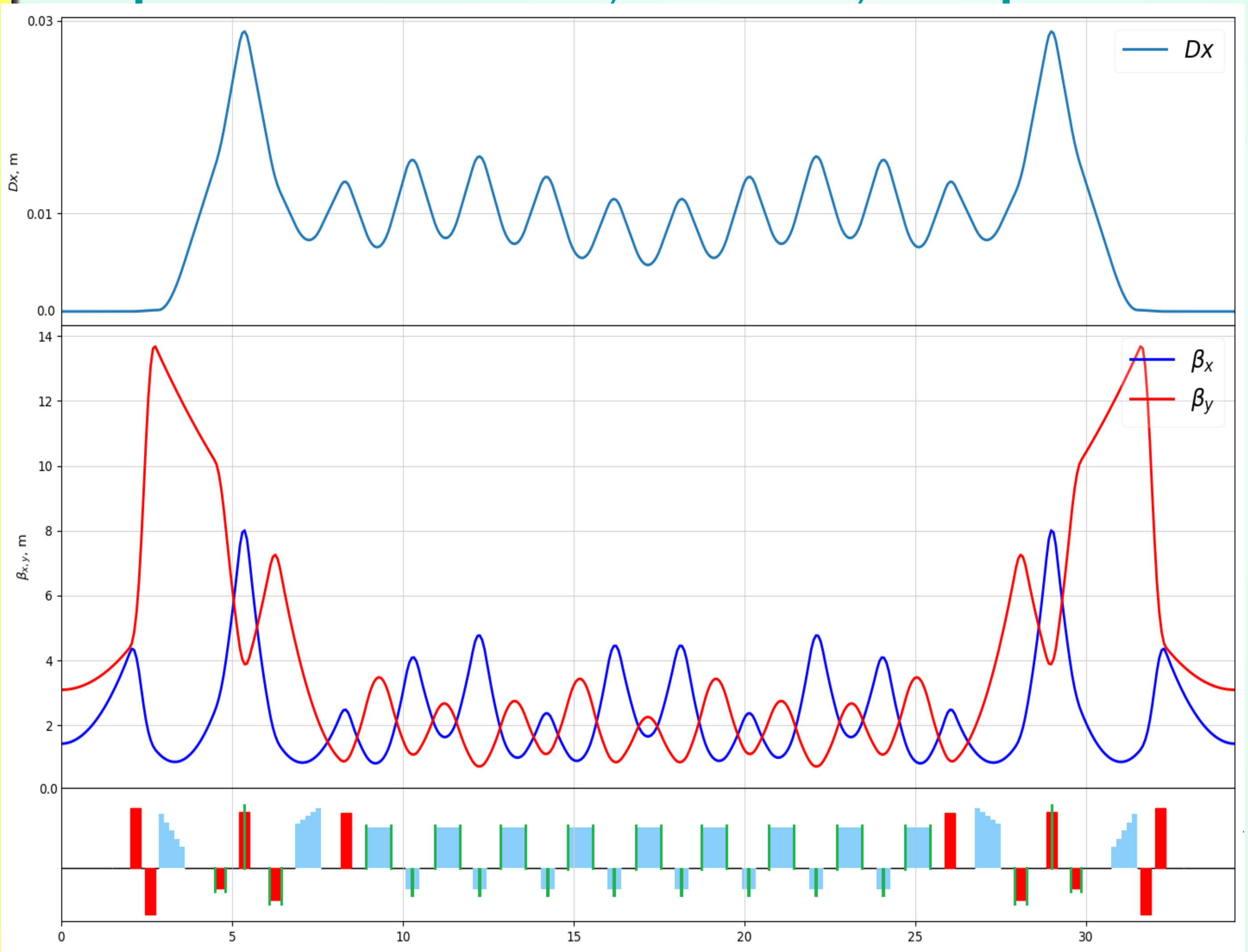
- The aperture in the central part of the period was enlarged to 20 mm and today we plan to have the same aperture for whole structure;

-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

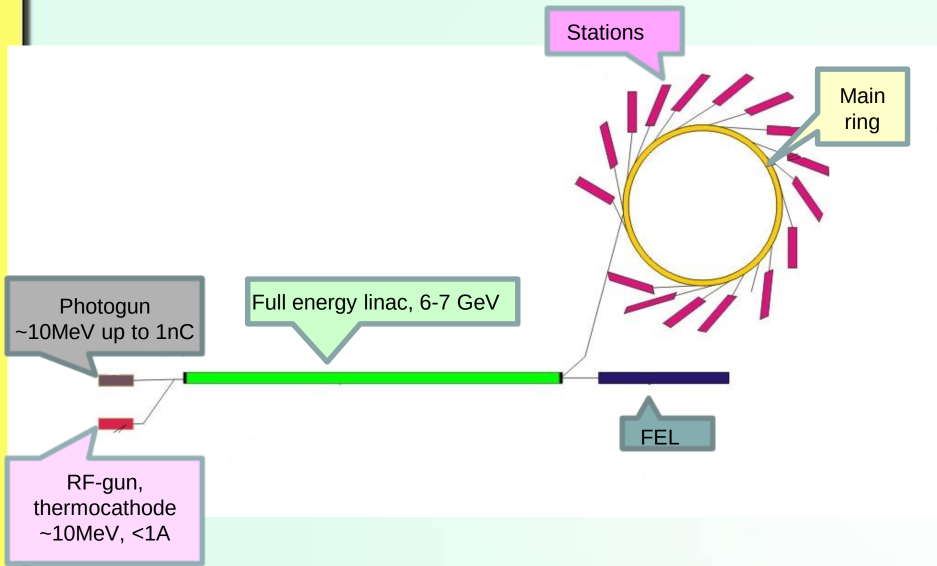


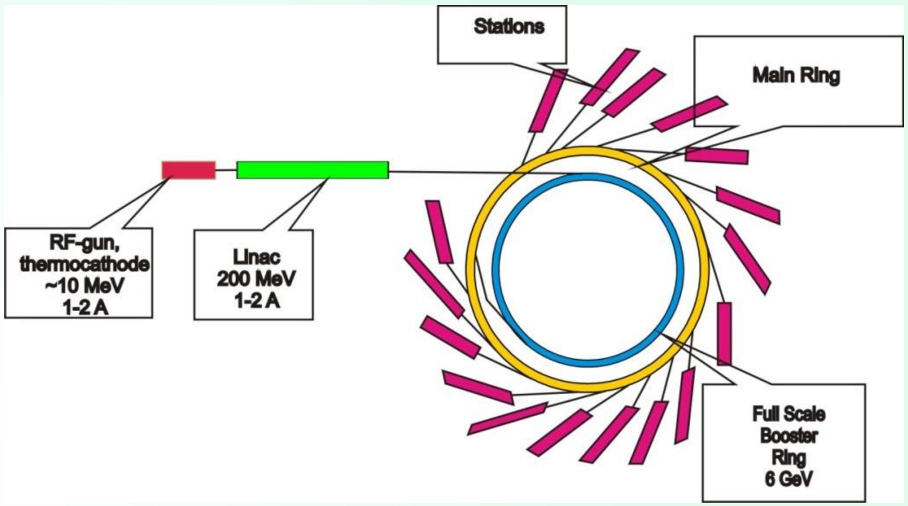
ε = 15 pm
C = 1648 m
DA: ± 1.5 mm
ξ: -203/-176

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

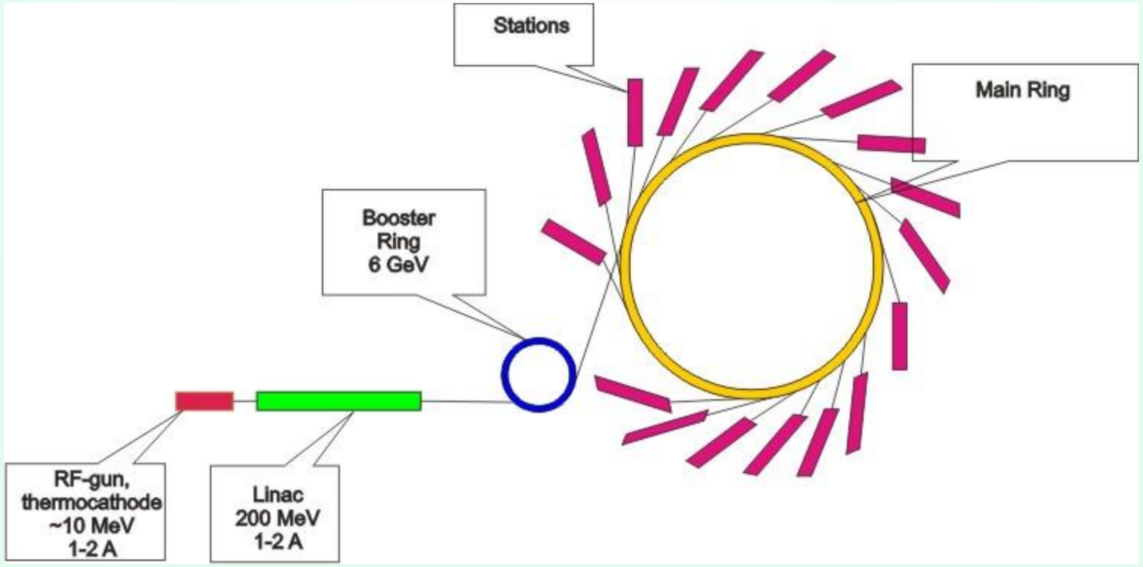
Injection: three possible ways

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





May be classics – compact booster ?



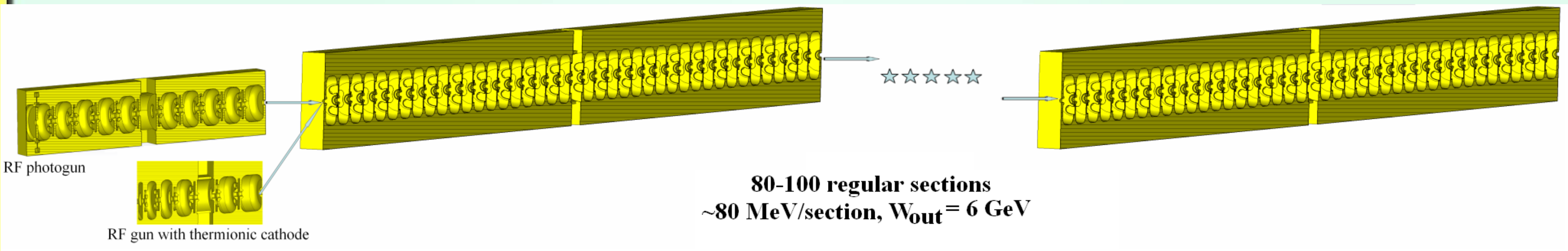
SSRS-4 Linac general concept

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*

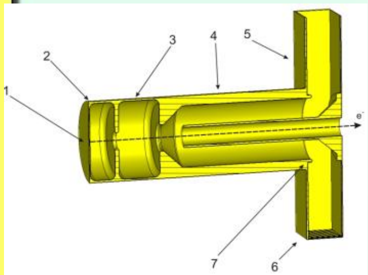
➢Injection linac (or booster)

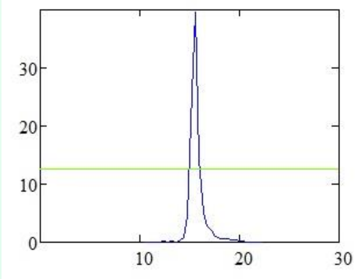
Top-up linac layout: two RF-guns - photo-gun and thermionic gun (like Super-KEKB, MAX-IV, *FCC-ee*) and 80-100 regular sections



Photogun:

1.5-, 3.5- or 5.5-cell design?

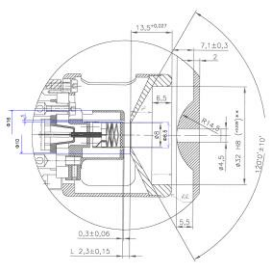


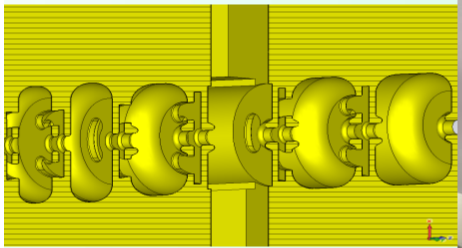


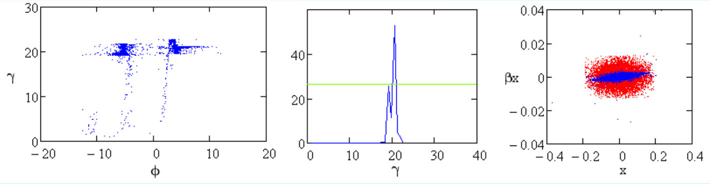
Cells	E, kV/cm	φ_{inj}	W_{max}, MeV	ΔW/W, %
3.5	600	2.0	6.2	1.8
5.5	600	2.7	8.1	0.9
5.5	700	2.8	8.2	1.2

Thermogun:

We need to control the transverse emittance on low energies



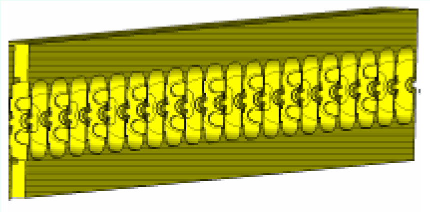




Regular section:

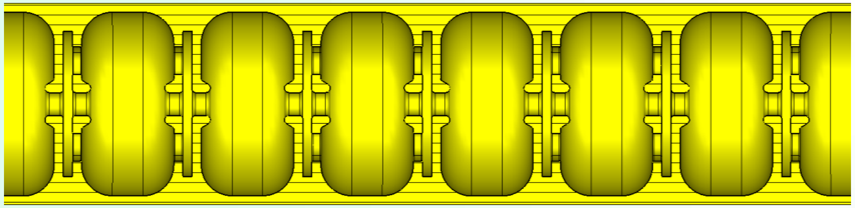
classic SLAC-type travelling wave DLW or modern standing wave structures

SLAC-type TW structure, 2π/3 mode



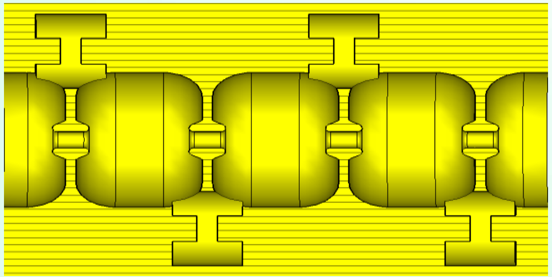
- -Low coupling coefficient (2-3 % c)
- -Long transient time (400-500 ns for 3m structure)
- -Long RF pulse (~1 μs) is necessary
- -High beam loading effect influence
- - 3-5 bunches can be accelerated without of energy chirp

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



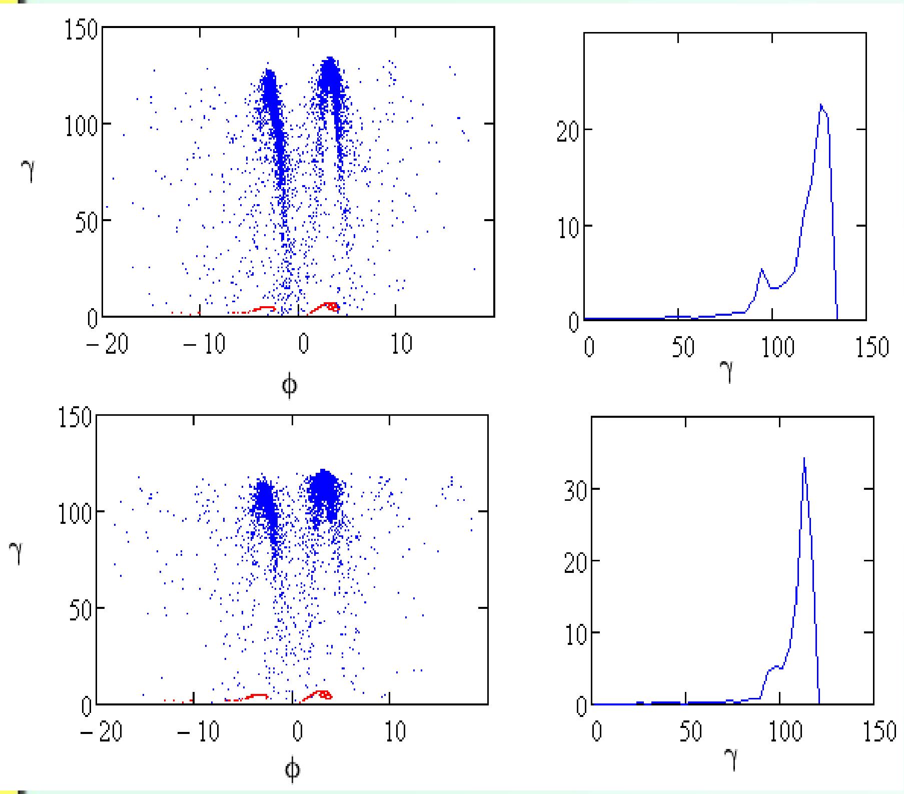
- -Highest coupling as possible for DAW (30-40 %)
- -Filling time ~100 ns

-Price is high but available

➢Injection linac (or booster)

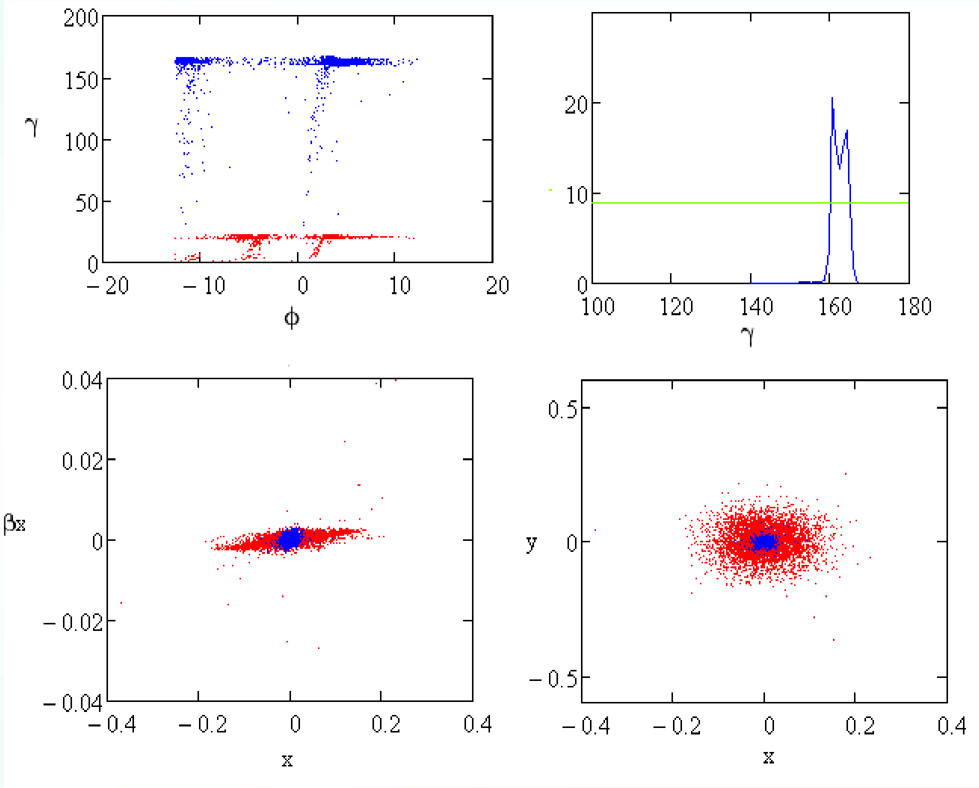
Regular section: beam dynamics

SLAC-type TW (after 1st section)



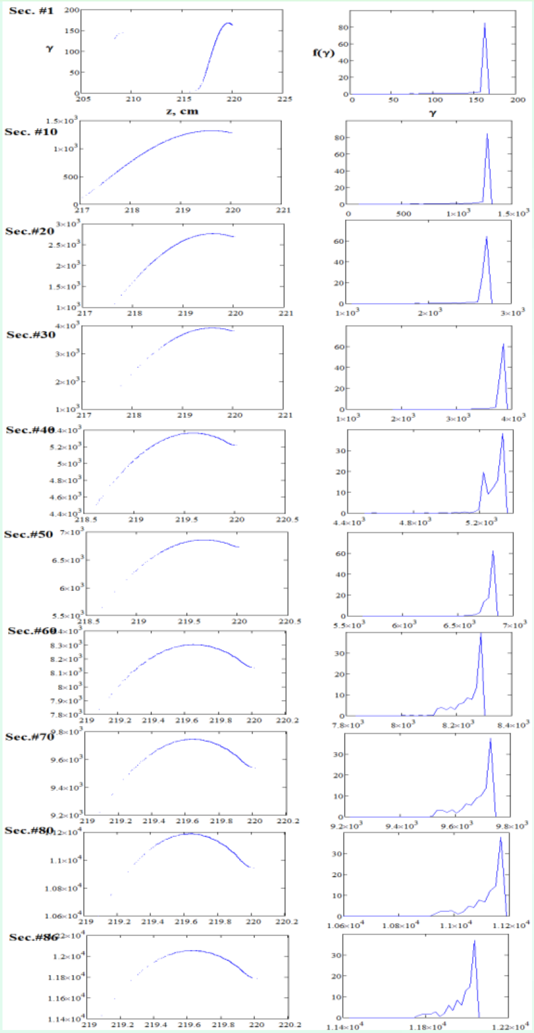
80 MeV per section (~3 m length), 6 GeV output energy
I=400 mA, Δ*W*/*W*≤3.0 % (can be optimized)
Transverse emittance ~10 μm·rad
(with non-optimised thermogun)
or ~1-5 nm·rad with photogun (250 nC per bunch)
3-5 bunches per pulse with phase chirp to compensate beam loading

SW BAS (after 1st section)

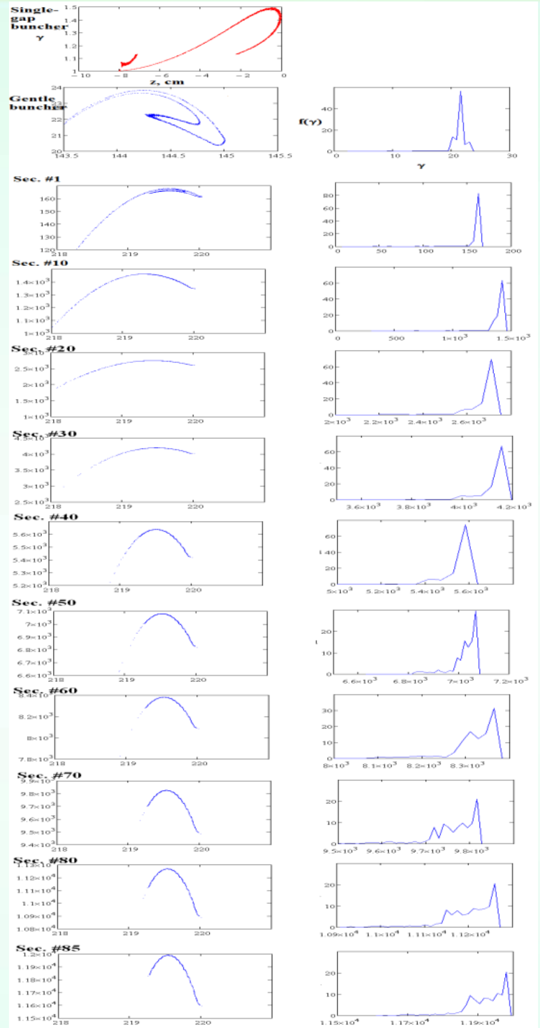


80 MeV per section (~2 m length), 6 GeV output energy
I=400 mA, Δ*W*/*W*≤0.3 % (can be optimized)
Transverse emittance ~5 μm·rad
(with non-optimised thermogun)
or ~1-5 nm·rad with photogun (250 nC per bunch)
10-12 bunches per pulse wit compensated beam loading

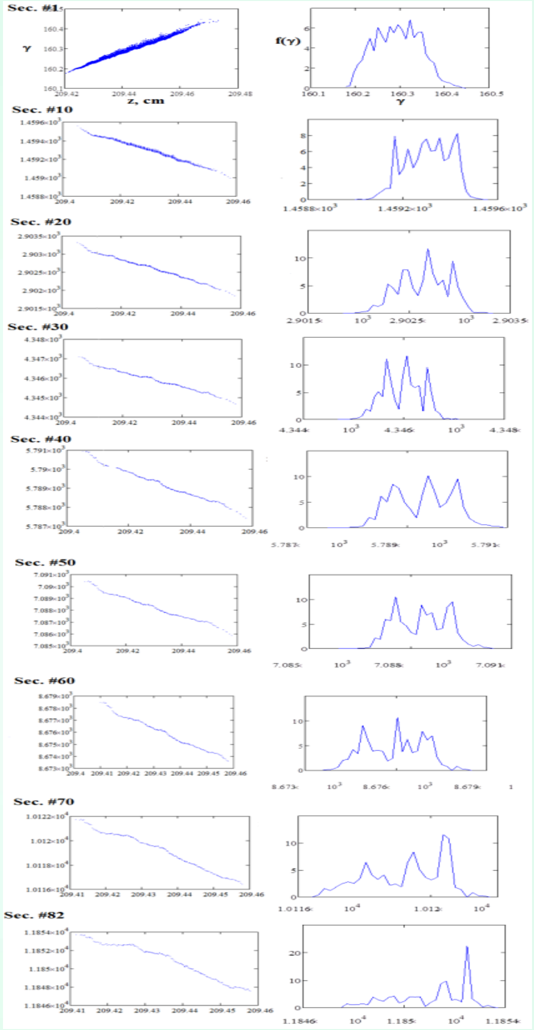
➢Injection linac (or booster)



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.

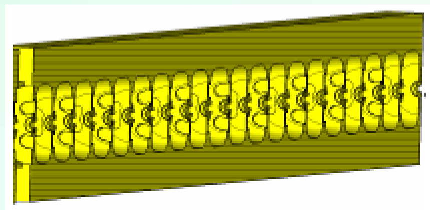
Regular section: necessary RF power

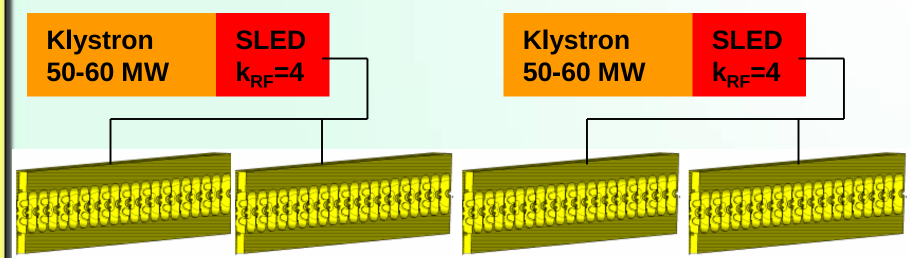
P, MW/W_{sec}, MeV/ L_{sec}, m
(compression by SLED, k_{RF}≈4)

E_z, kV/cm	SLAC	BAS	DAW
400	80/60/3	40/50/2	40/55/2
500	120/75/3	70/60/2	70/70/2
600	150/90/3	100/70/2	100/80/2

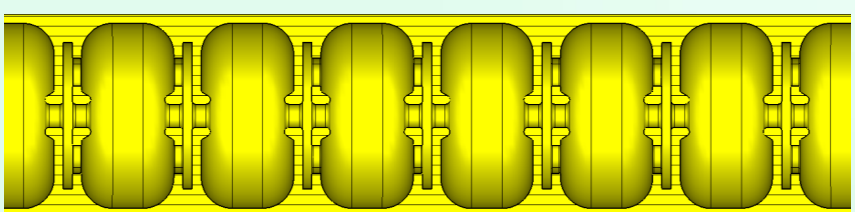
τ_{pulse}= 1-2 µs 500-600 200-400 ns
higher compression

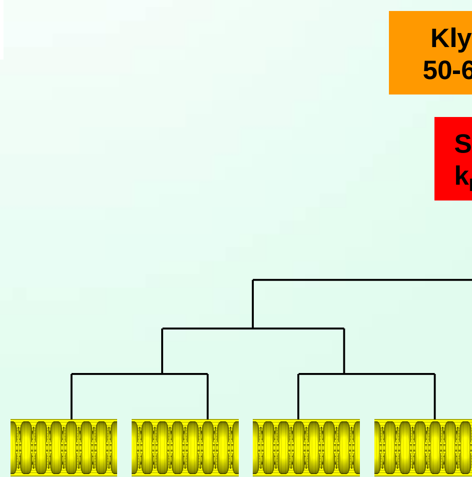
SLAC-type TW
- -Low coupling coefficient
- -Long RF pulse
- -High beam loading effect
- -Wide spectrum





SW BAS





Regular section: necessary RF power

SLAC-type TW
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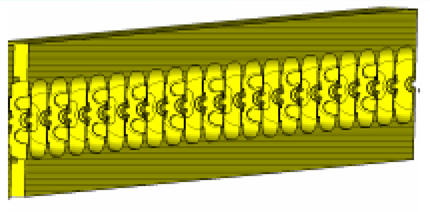
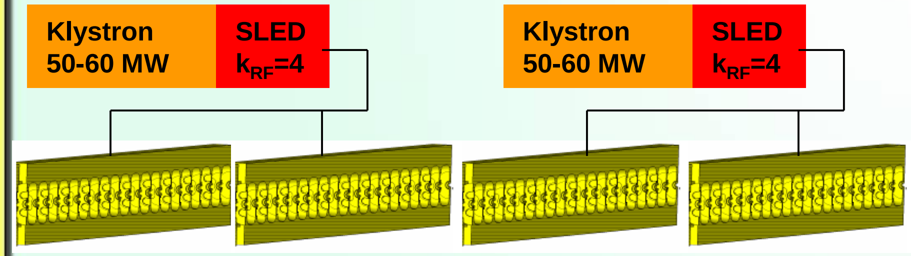
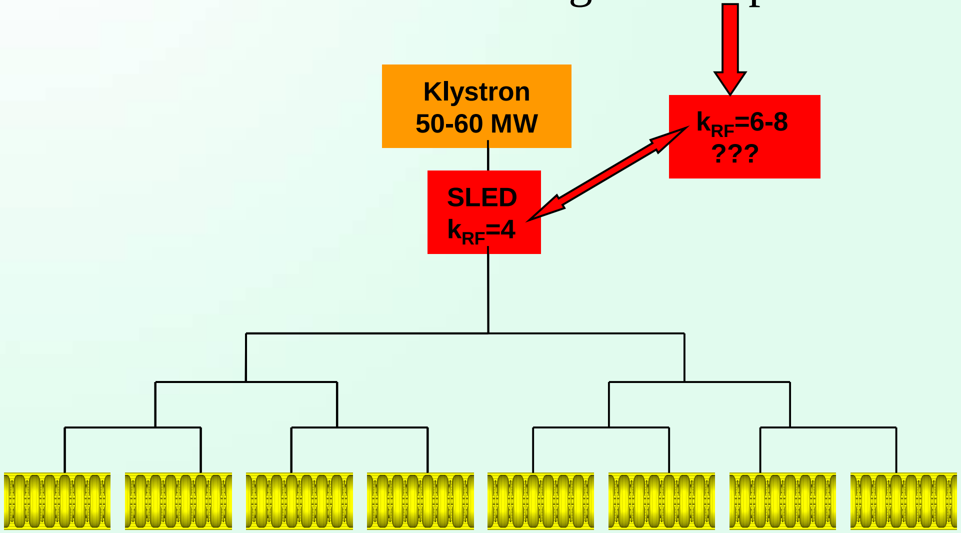


P, MW/W_{sec}, MeV/ L_{sec}, m
(compression by SLED, $k_{RF}\approx 4$)

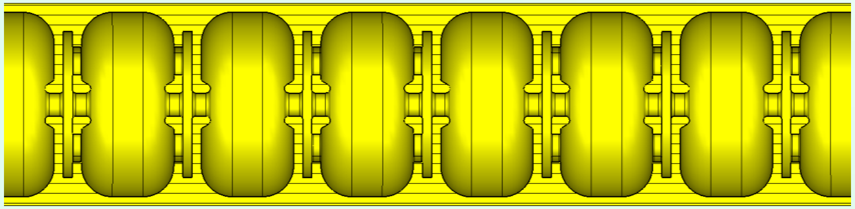
E_z, kV/cm	SLAC	BAS	DAW
400	80/60/3	40/50/2	40/55/2
500	120/75/3	70/60/2	70/70/2
600	150/90/3	100/70/2	100/80/2

τ_{pulse}= 1-2 μs 500-600 200-400 ns
higher compression





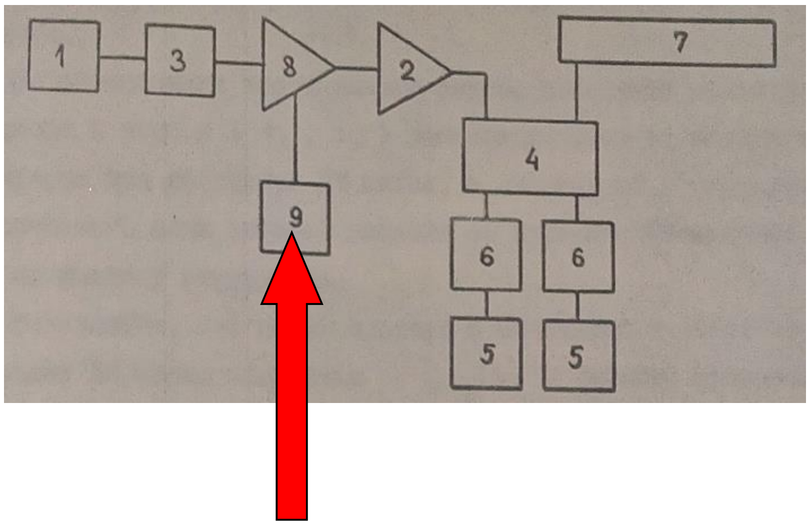
SW BAS

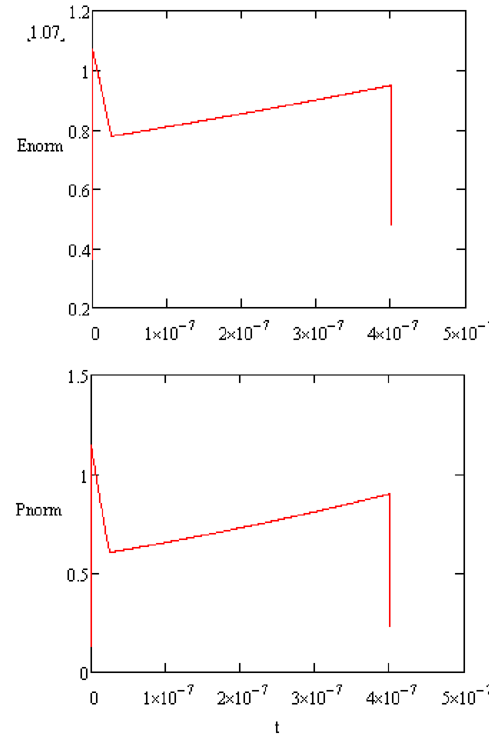


Regular section: necessary RF power

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

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

SLAC-type

-Low coupling

-Long RF pulse

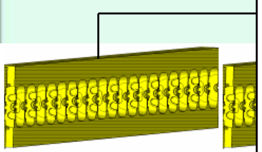
-High beam loa

-Wide spectrum

Klystron 50-60 MW

SL

k_{RF}

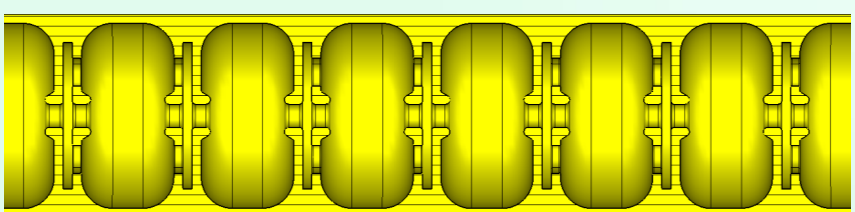


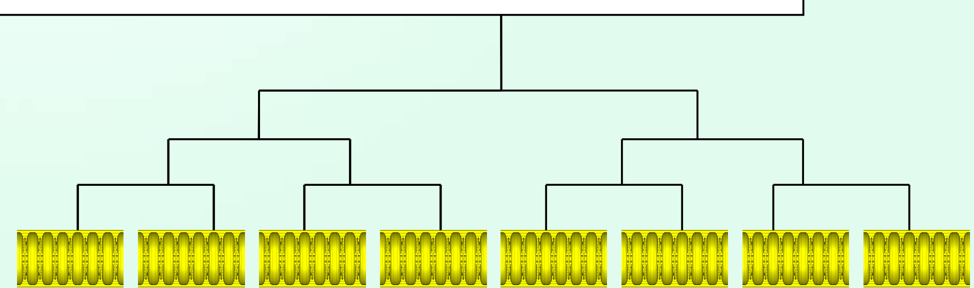
SW BAS

DAW
l0/55/2
70/70/2
00/80/2

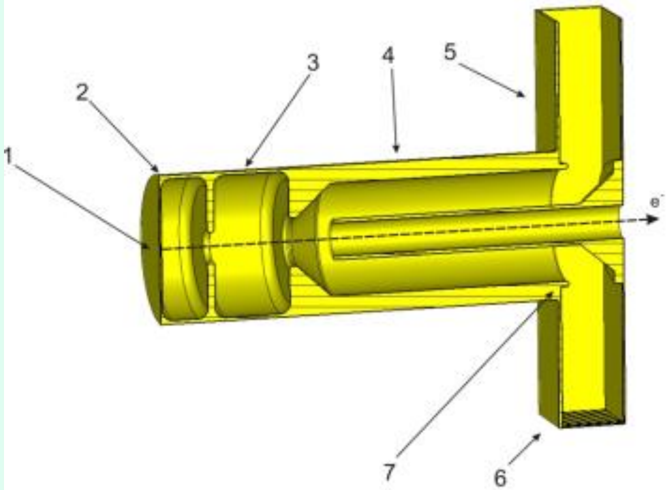
400 ns

ession





Photogun prototype:



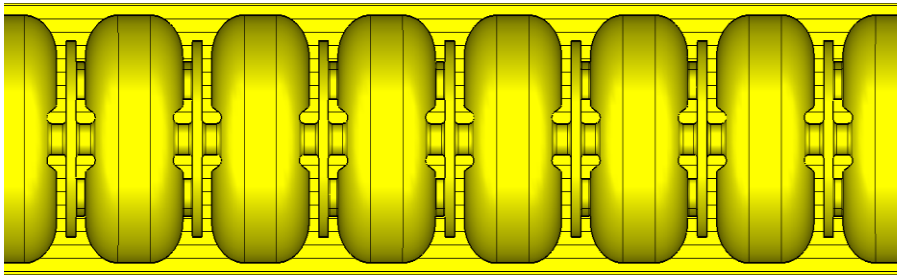


Photo-gun:
200-250 pC, ~10 MeV

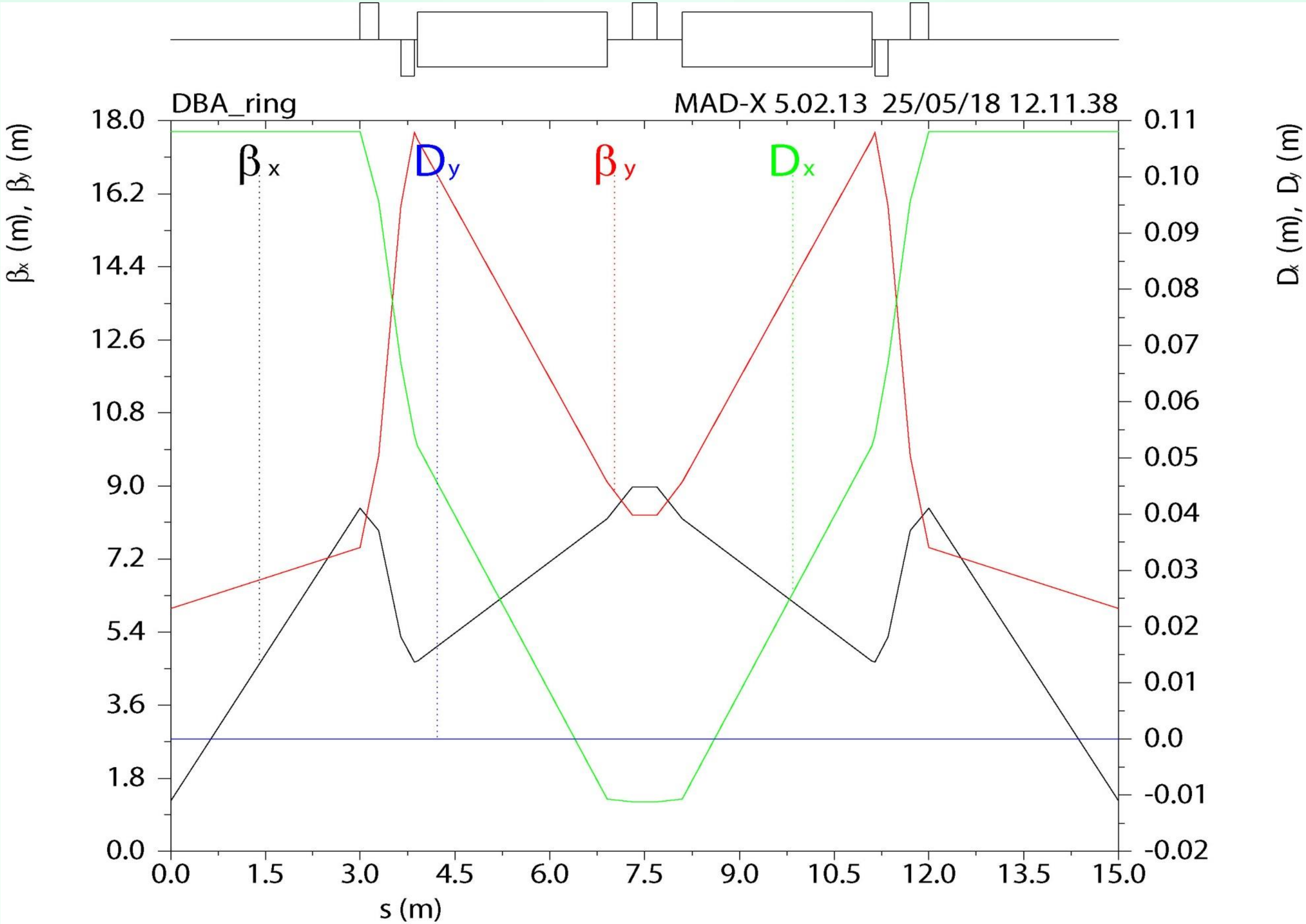
One regular section:
~80 MeV/section

Diagnostics
system

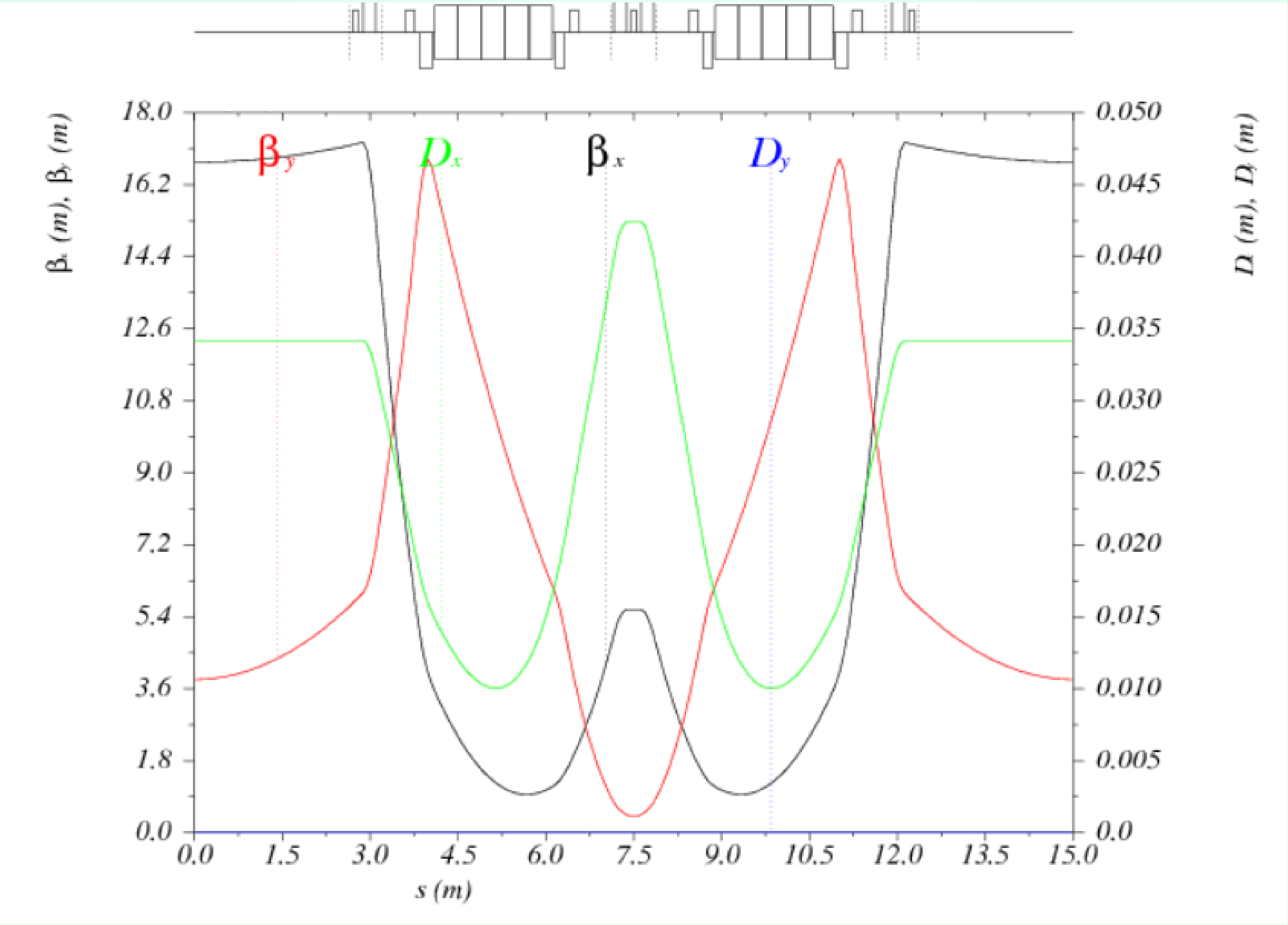
-We need a prototype of photo-gun to have the necessary experience in its commissioning and operation
- Prototype can be scaled to top-up linac
- Prototype can be used in future as an “Compact XFEL”

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

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



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



Beam injection: off-axis

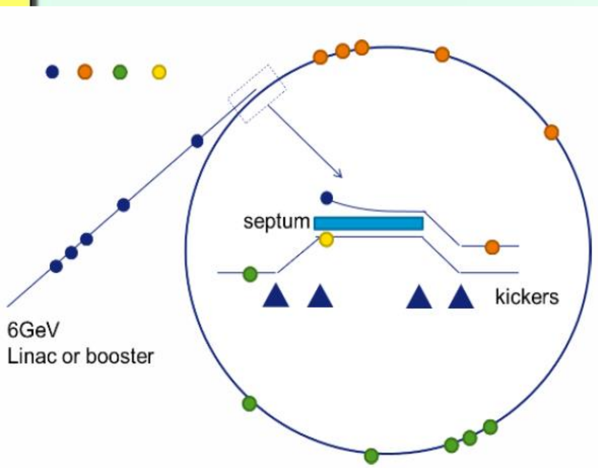
- Timeshared use of top-up linac

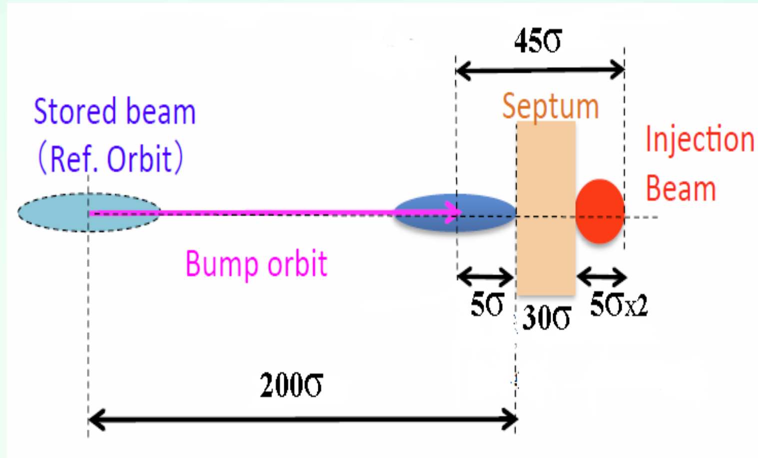
$\sigma = \sigma_i = \sigma_s$

$\varepsilon_x = 0.13nm$ ESRF

$\beta_x = 19m$

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



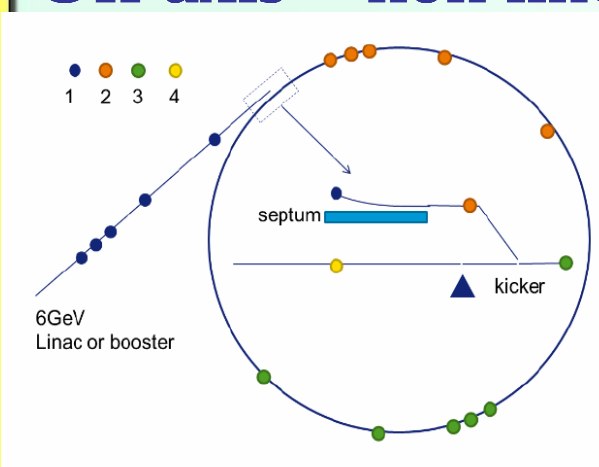


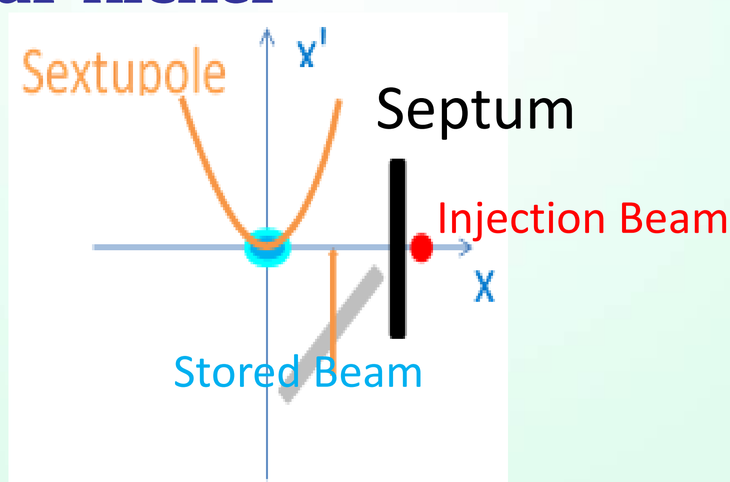
Off axis + non linear kicker

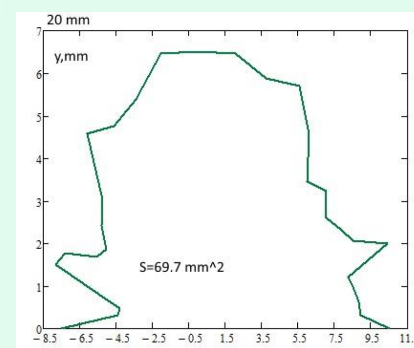
If $\varepsilon_x = 6\,nm$

$\beta_x = 20\,m$

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

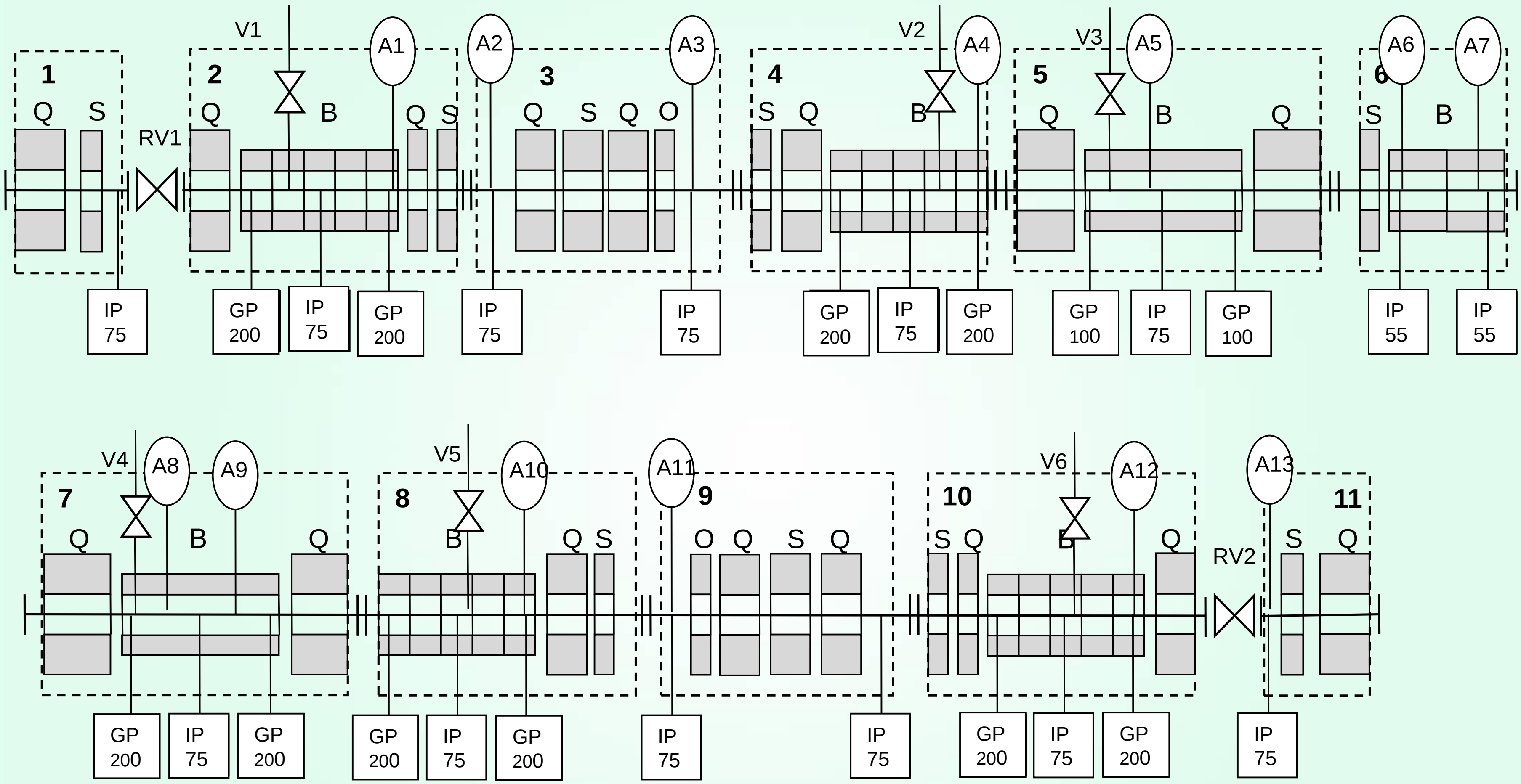






DA is enough !!!

➢Vacuum system

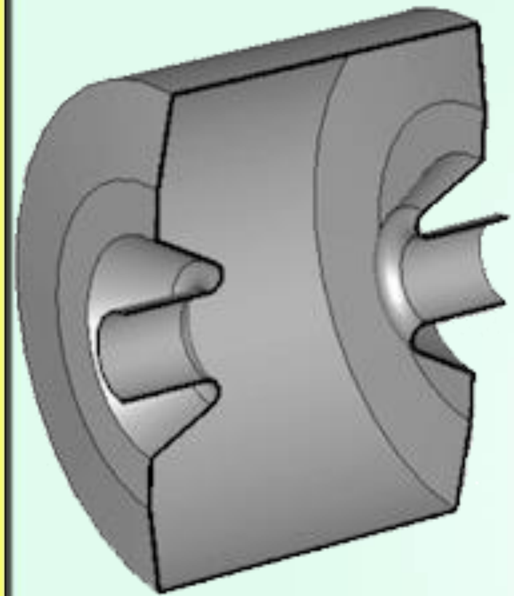


Especial thanks to: Cristian Maccarrone, Hugo Pedroso Marques, Simone Liuzzo

➢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

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

Especial thanks to:
Mikhail Zobov (LNF)

➢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

- Terminals
- History server
- 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

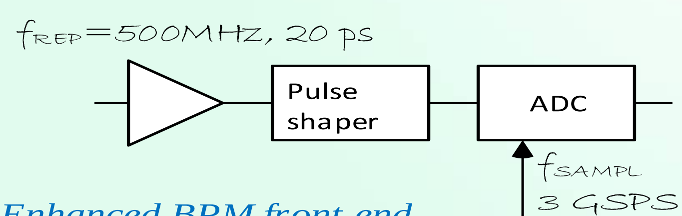
Engineering systems

- Vacuum
- Water
- Temp.
- Slow elements
- Ramping magnetic field
- Fast orbit correctors
- Injection, extraction kickers
- Dosimetry
- Area access

Beam diagnostics

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

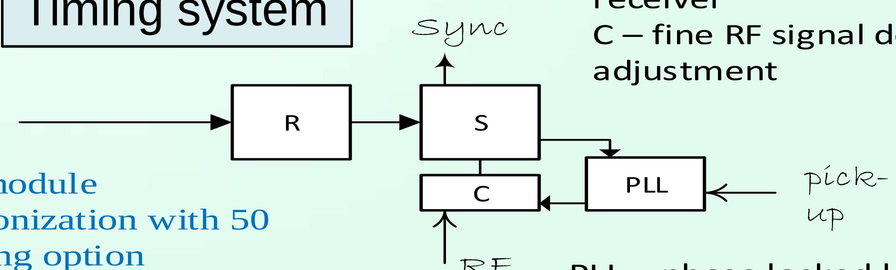
High performance BPM front-end with most up-to-date components



Enhanced BPM front-end

Timing system

MRF signal



R – general timing signal receiver
C – fine RF signal delay adjustment

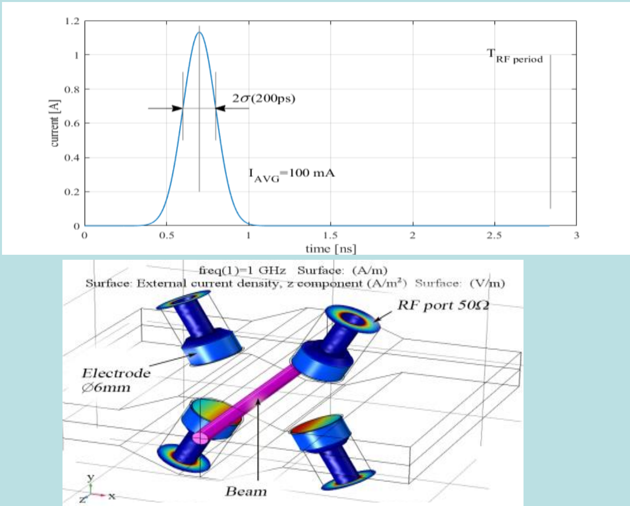
S – sync. generator

PLL – phase locked loop with pick-up signal

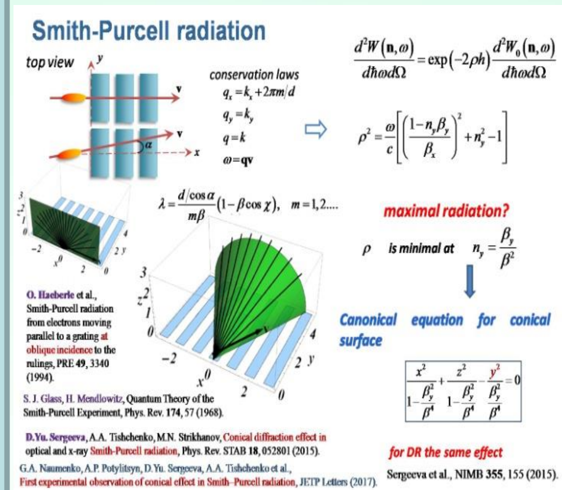
Micro-Research (Finland) type of timing system with general 10ns and local 500/50 ps accuracy options

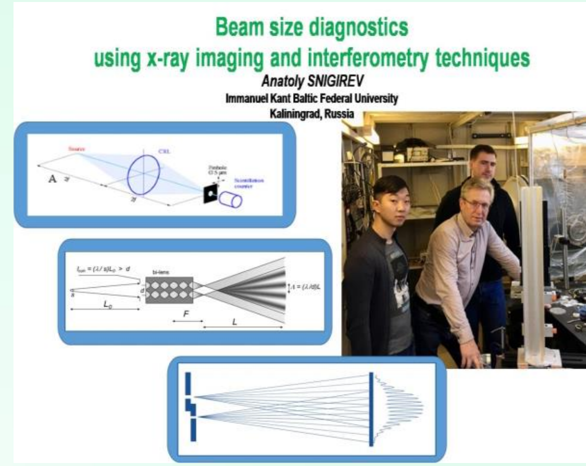
BPM module synchronization with 50 ps timing option

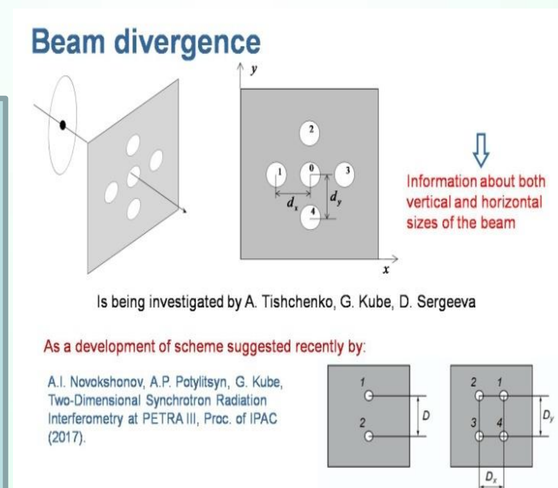
➢Diagnostics, control and timing

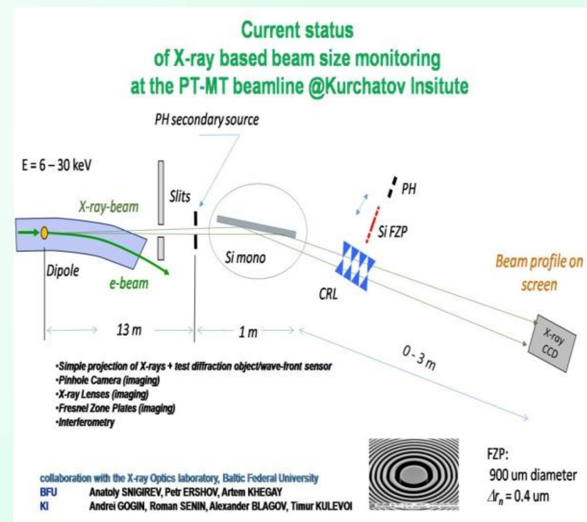


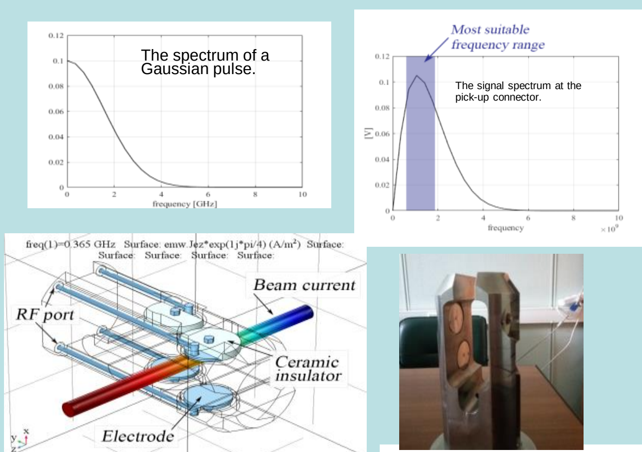
6 mm ESRF-type BPM









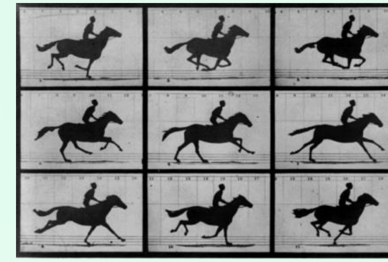


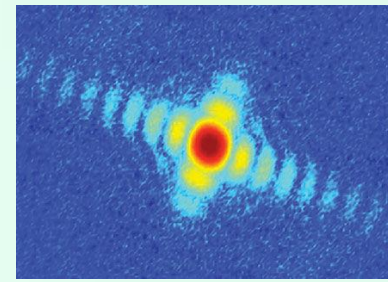
BPM Kurchatov synchrotron

Especial thanks to Kees-Bertus Scheidt (ESRF)

➢Beam lines and research program (1st stage)

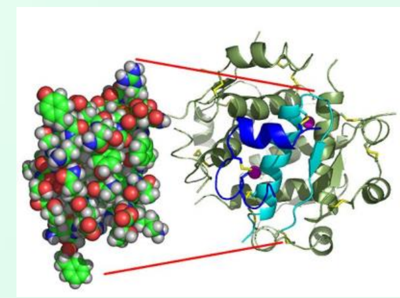
Main fields will coherence and photon-hungry techniques

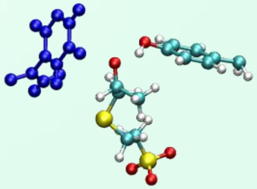


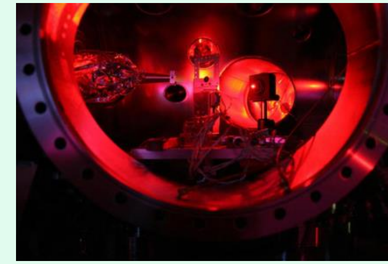


INSTRUMENTS & EXPERIMENTS

- **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**



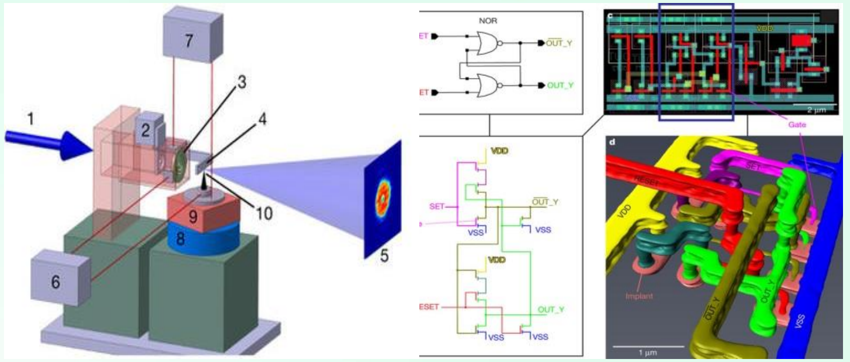


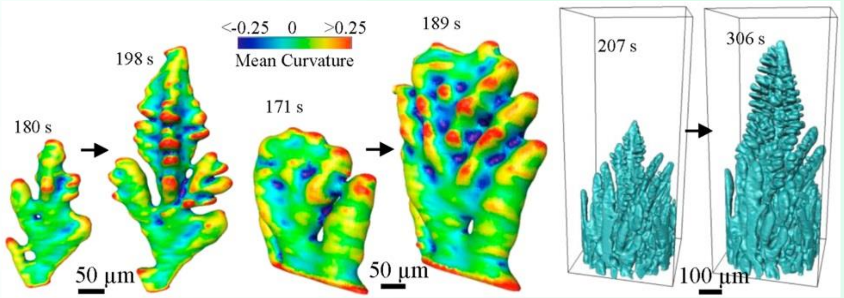


1st stage- 10 beamlines:

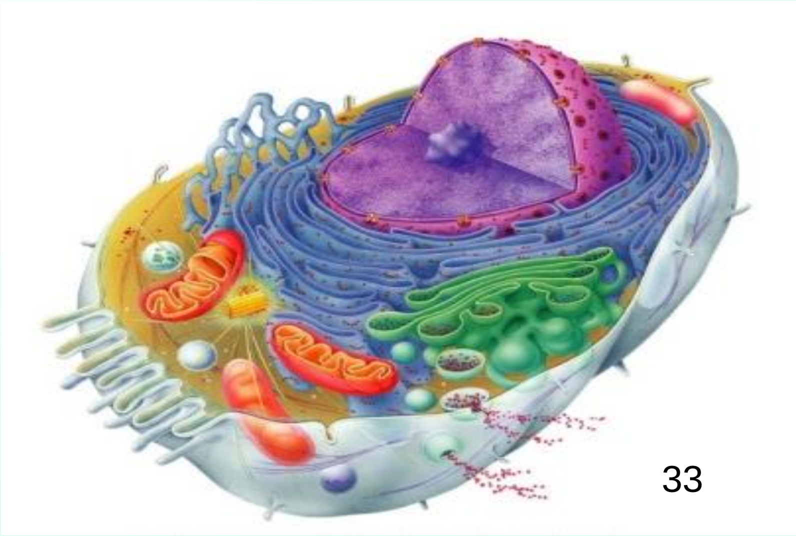
- magnetic scattering, nuclear scattering,
- high resolution hard X-ray spectroscopy,
- X-ray photon correlation spectroscopy
- diffraction contrast tomography,
- ptychography,
- macromolecular/serial crystallography,
- SAXS,
- pump-probe experiments,
- nanodiffraction,
- coherent microscopy.

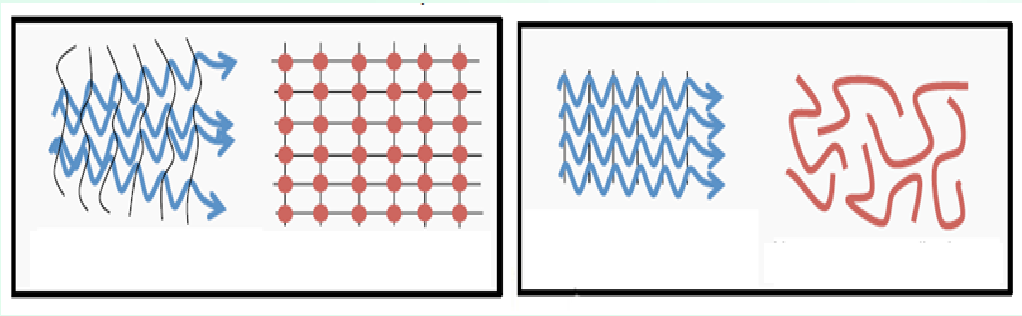
\+ Laser based coherent THz source


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

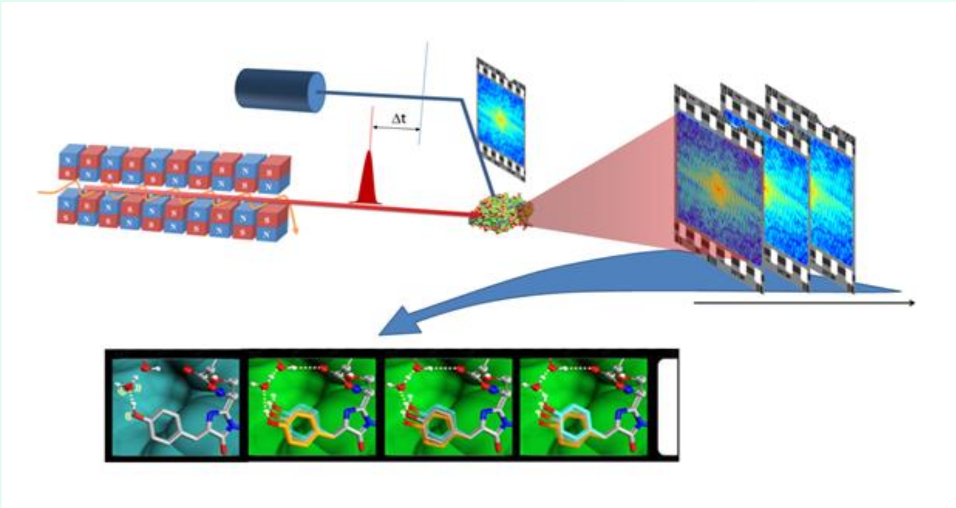


Cai B. et al. Acta Materialia. – 2016. – T. 117. – C. 160-169





FEL for EUV and X-rays

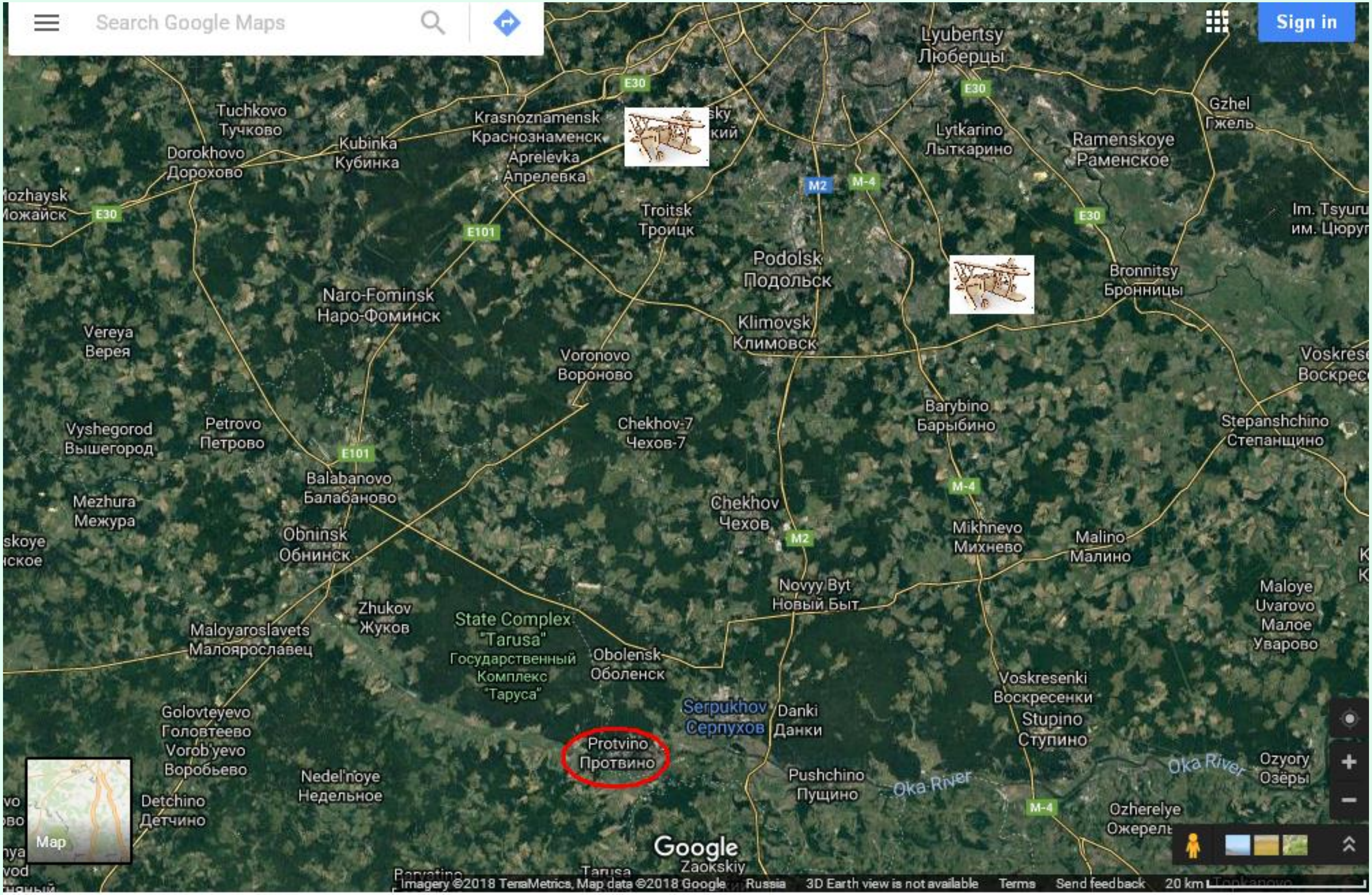


FELs with similar parameters:

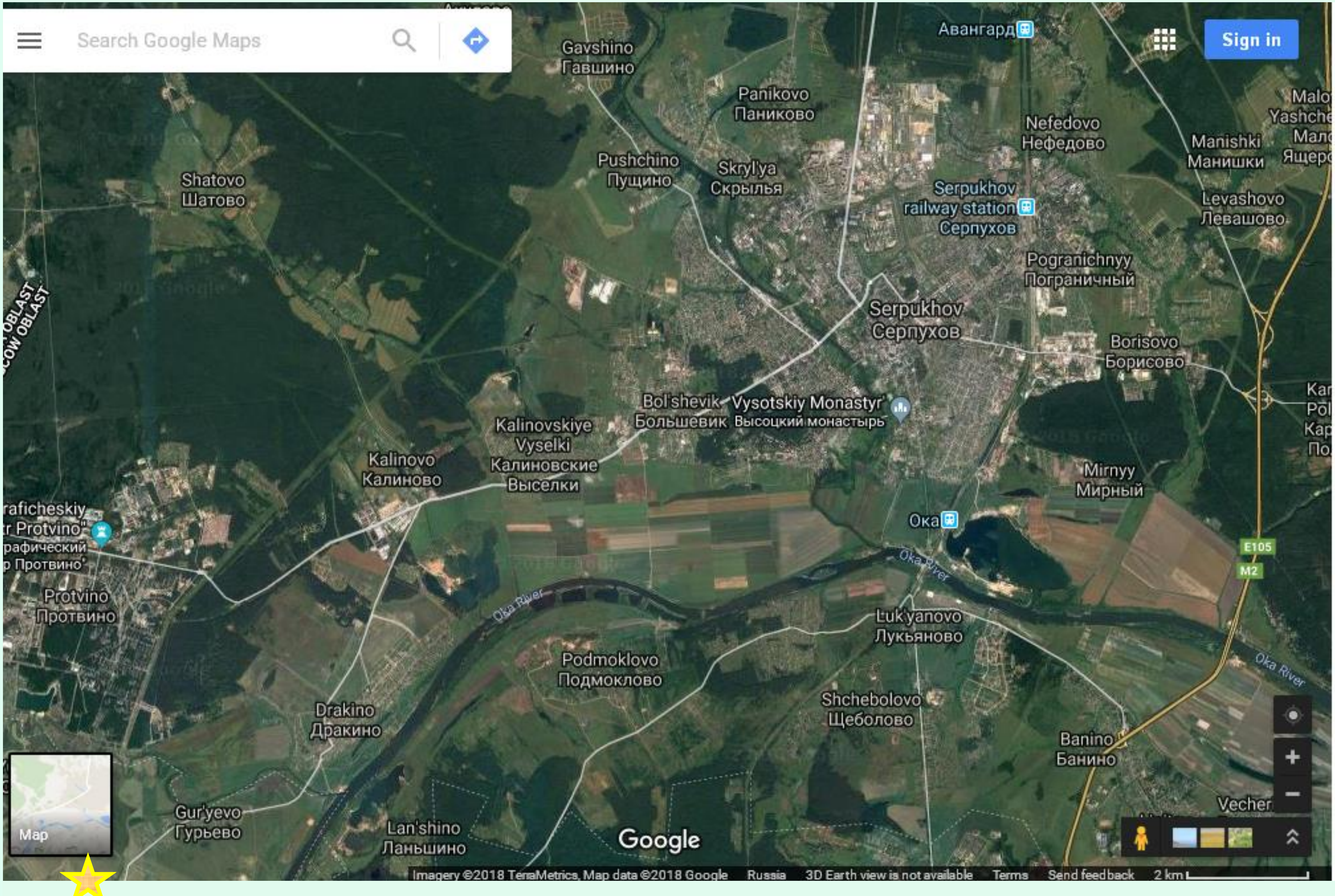
- SwissFEL, Switzerland
- SACLA, Japan
- LCLS, USA
- SPF – MAX-IV, Sweden

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)

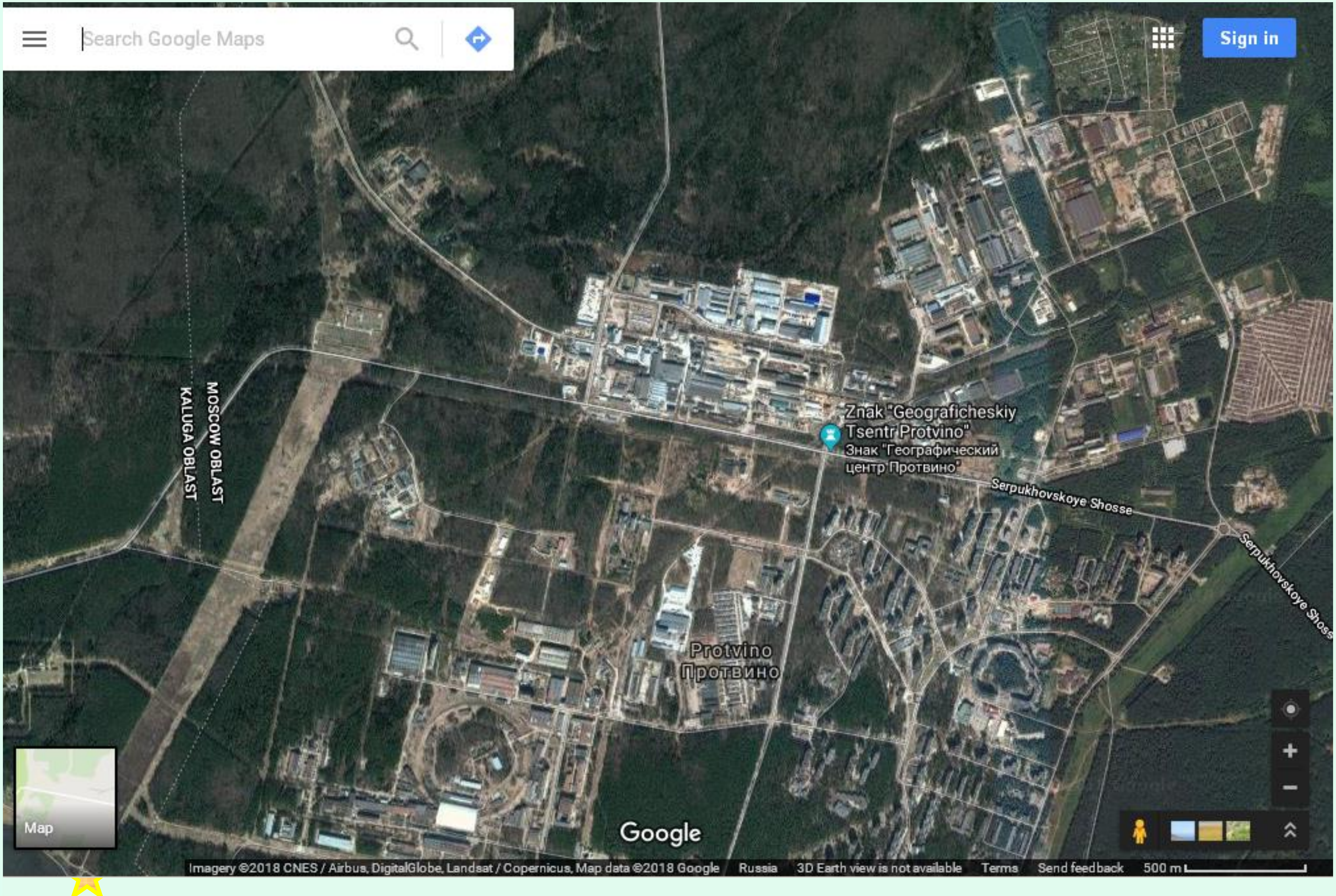
➢SSRS4 site in Protvino



➢SSRS4 site in Protvino



➢SSRS4 site in Protvino



➢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 (USSR) presentations on RuPAC-2018:

WEPSB01: Results of Beam Dynamics Simulations for Two Variants of 6 GeV Booster of the 4th Generation Light Source USSR

WEPSB05: Beam Dynamics Simulation Results in the 6 GeV Top-Up Injection Linac of the 4th Generation Light Source USSR

WEPSB24: Development of the vacuum system of the Specialized Synchrotron Radiation Source SSRS4 in Kurchatov institute

THPSC01: Results of Beam Dynamics Simulation for the Main Ring of the 4th Generation Light Source USSR

THPSC02: Current Results of the 4th Generation Light Source USSR (Former SSRS4) Development (Discussion)

THPSC19: Some development aspects of control and diagnostic systems for fourth-generation Russian synchrotron radiation source

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