Low Emittance Rings 2015 Workshop
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ESRF - The European Synchrotron

Compact hard X-ray light source using longitudinal variable superconducting dipoles

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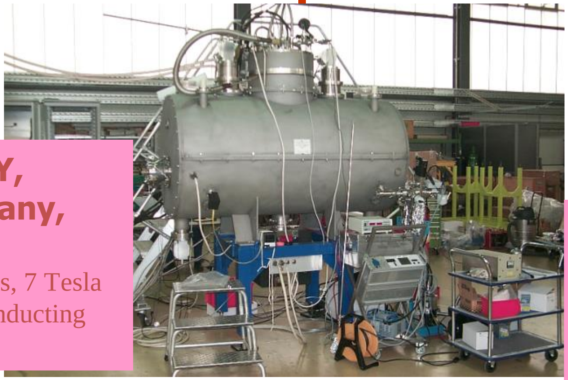
Main ideas

- SR applications are very popular and compact light sources are necessary for wide implementations
- Compact light sources can be basis for organizing a small research centers in universities, hospitals and industrial enterprises
- Superconducting dipole magnets can be use as one main elements of the lattice and for light generation can provide compromise between ring compactness and SR spectrum hardness
- High magnetic field in the superconducting dipoles can provide spectrum hardness for low energy beam
- Low cost of low energy ring infrastructure can compensate the high cost of the superconducting magnets
- Longitudinal variable (longitudinal gradient) dipoles is perspective way for beam emittance reduction as well as for brilliance maximization

Superconducting multipole wigglers



BESSY, Germany, 2002

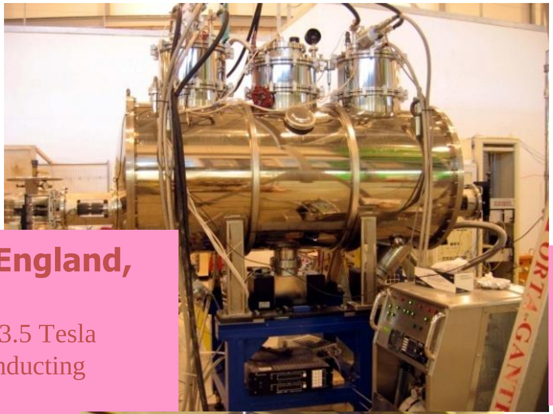
17-poles, 7 Tesla superconducting wiggler

ELETTRA, Italy, 2002

49-pole 3.5 Tesla superconducting wiggler

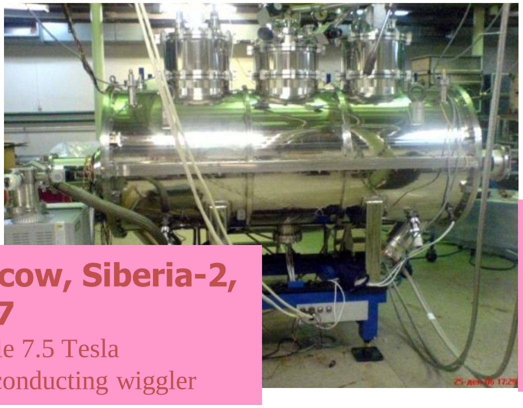
CLS, Canada, 2004

63-pole 2 Tesla superconducting wiggler



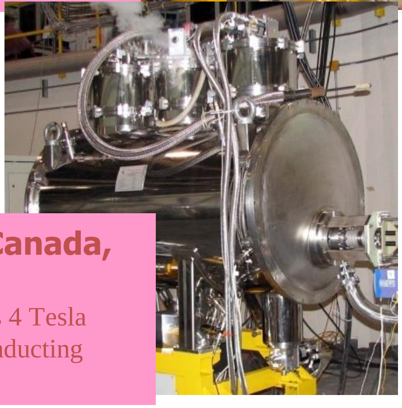
DLS, England, 2006

49-pole 3.5 Tesla superconducting wiggler



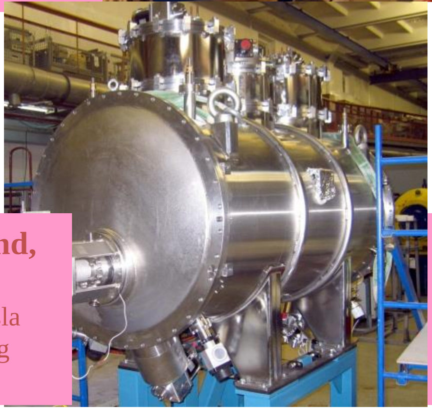
Moscow, Siberia-2, 2007

21-pole 7.5 Tesla superconducting wiggler



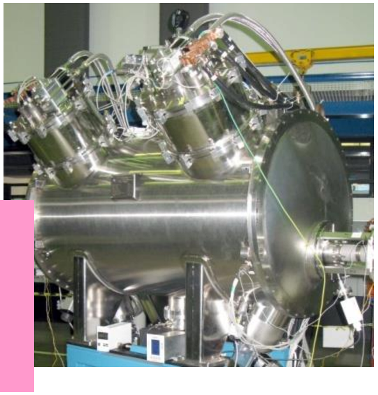
CLS, Canada, 2007

27- poles 4 Tesla Superconducting wiggler



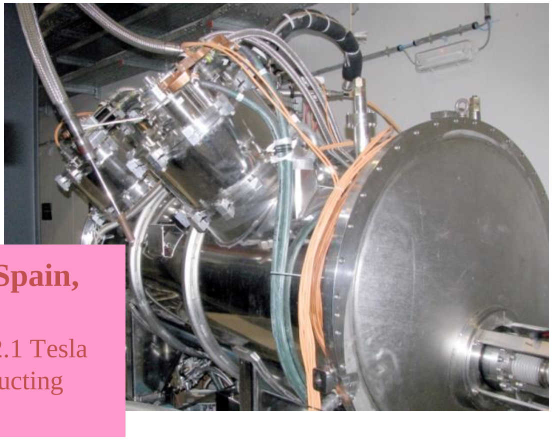
DLS, England, 2008

49-pole 4.2 Tesla superconducting wiggler



LNLS, Brazil, 2009

35-pole 4.2 Tesla superconducting wiggler



ALBA, Spain, 2010

119-pole 2.1 Tesla superconducting wiggler

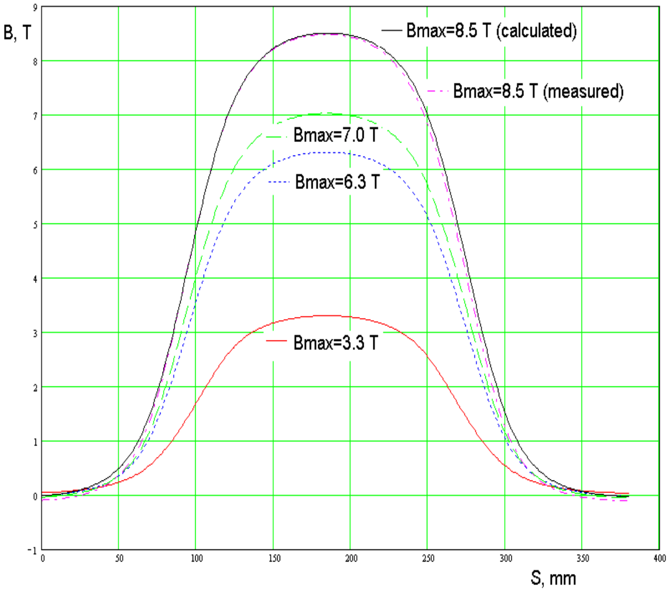
The history of superconductive ID fabrication in the Budker INP

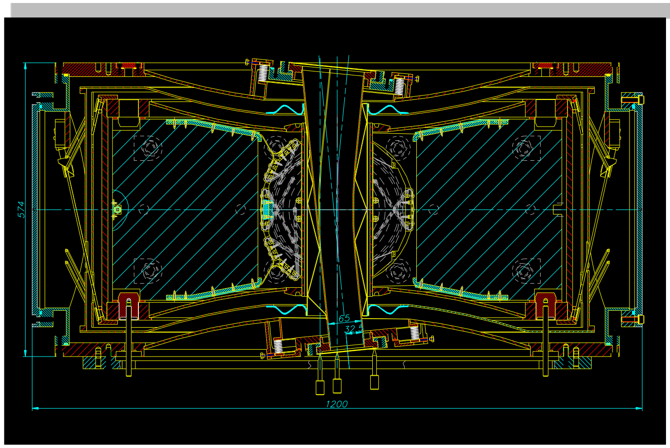
- 1979 – first in the world 3.5 Tesla superconducting 20 pole wiggler (SCW) for VEPP-3
- 1984 – 5 pole 8 Tesla superconducting wiggler for VEPP-2
- 1985 – 4.5 Tesla Superconducting Wave Length Shifter (WLS) for Siberia-1, Moscow
- 1992 – 6 Tesla Superbend (SB) prototype for compact storage rings
- 1996 - 7.5 Tesla superconducting WLS for PLS, South Korea=
- 1997 - 7.5 T superconducting WLS with fixed point of radiation for CAMD-LSU (USA)
- 2000 – 7 Tesla WLS with fixed radiation point for BESSY-2, Germany
- 2000 – 10 Tesla WLS for Spring-8, Japan
- 2001 – 7 Tesla WLS with fixed radiation point for BESSY-2, Germany
- 2002 – 3.5 Tesla 49 pole SCW for ELETTRA, Italy
- 2002 – 7 Tesla 17 pole SCW for BESSY-2, Germany
- 2004 – 9 Tesla Superbend for BESSY-2, Germany
- 2005 – 13 Tesla superconducting solenoids for VEPP-2000
- 2005 – 2 Tesla 63 pole SCW for CLS, Canada
- 2006 – 3.5 Tesla 49 pole for DLS, England
- 2006 – 7.5 Tesla 21 pole SCW for Siberia-2, Moscow
- 2007 – 4.2 Tesla 27 pole SCW for CLS, Canada
- 2009 – 4.2 Tesla 49 pole SCW for DLS, England
- 2009 – 4.1 Tesla 35 pole SCW for LNLS, Brasil
- 2010 - 2.1 Tesla 119 pole SCW for ALBA, Spain
- 2012 - 4.2 Tesla SCW for Australian Light Source
- 2012 – 7.5 Tesla SCW for CAMD-LSU (USA)
- 2013 - SCW for ANKA

- 2013 - SCW for ANKA & CLIC with indirect cooling

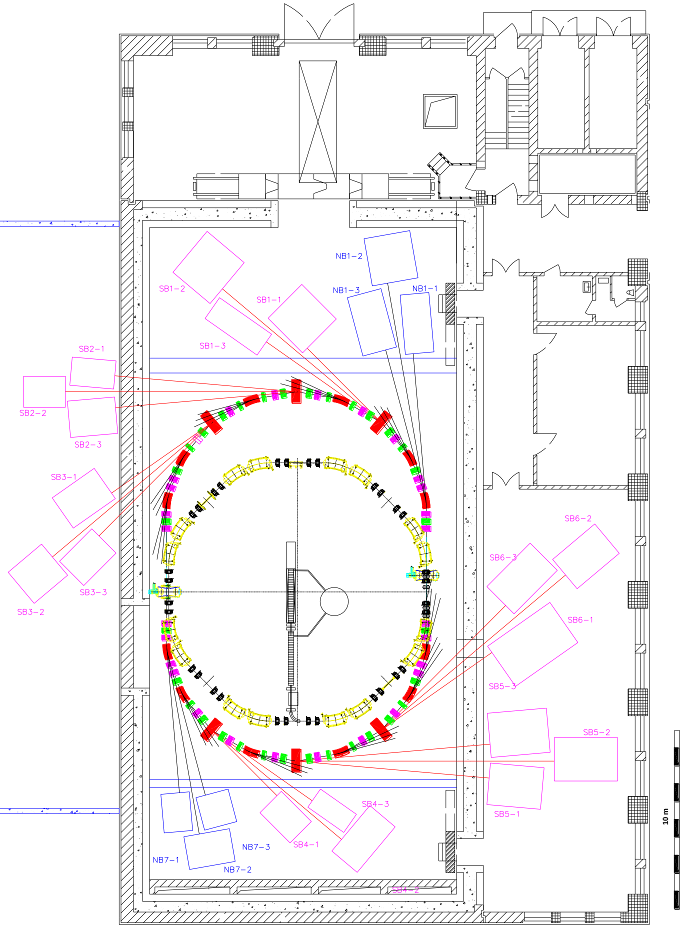
Superconducting dipole for BESSY-II

Vertical aperture, mm **Horizontal aperture, mm**	30 75
Pole gap, mm	46
Operating magnetic field, T **Maximum magnetic field, T**	3.3 - 8.5 9.6
Coil material	Nb_3Sn, NbTi
Edge angle, degree	1.3
Current in coil for 8.5 T, A	264
Ramping time 0-7 Tesla, min **Ramping time 0-9 Tesla, min**	<5 <15
Eff. magnetic length along beam, m	0.1777
Bending angle, degree	11.25
Bending radius, m	0.905
Stored energy for 8.5 T, kJ	180
Cold mass, kg	1300
Liquid He consumption	~0.5 l/h

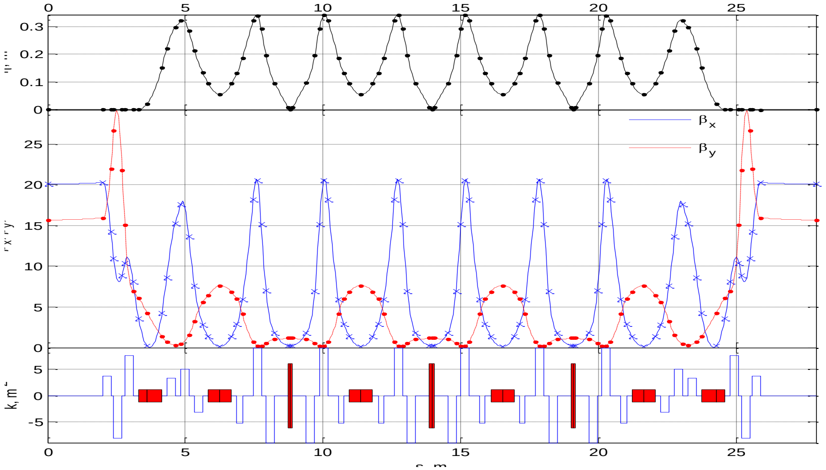




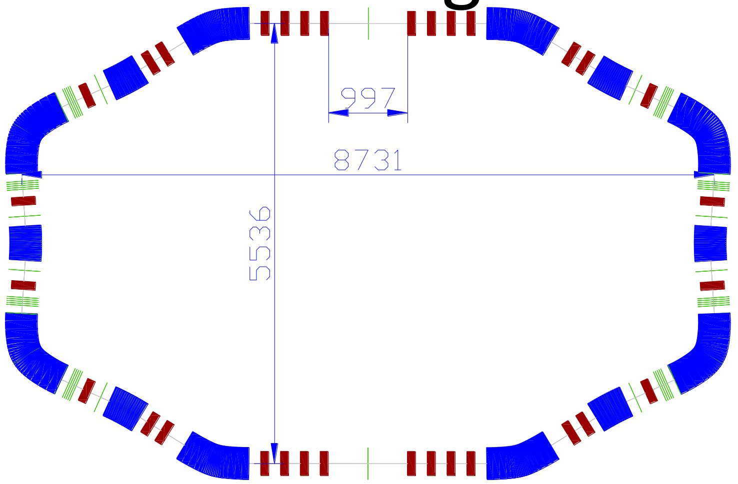
Project of the compact light source with using of the superconducting dipoles

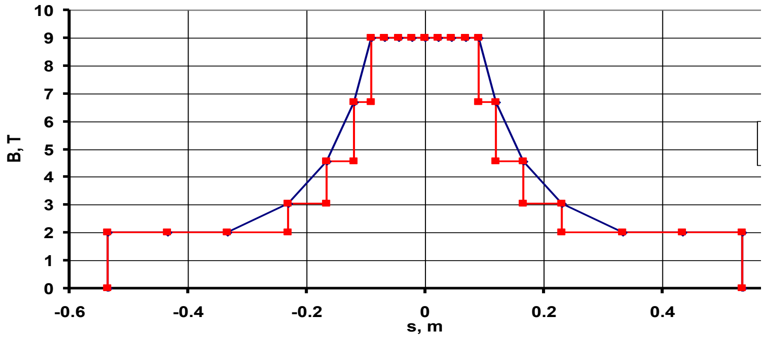


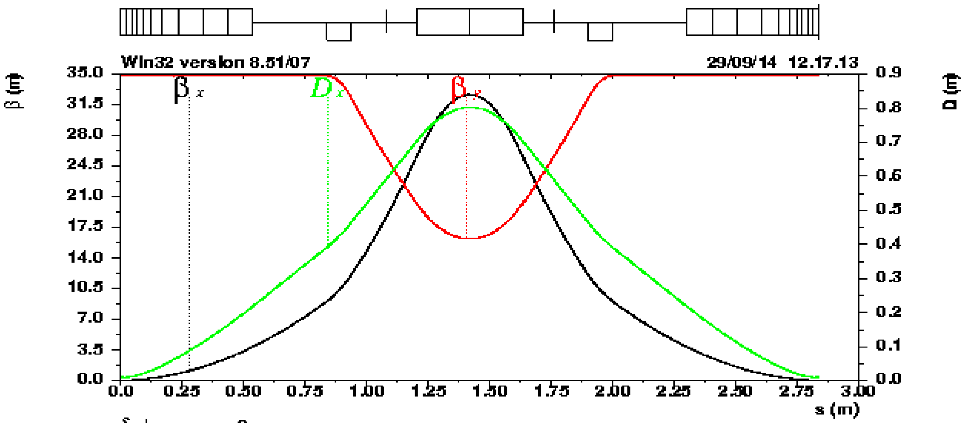
Energy	*1.2 GeV*
Magnetic field in the bending dipoles	*8.5 T in superconductive magnets (Super bends)* *1.6 T in normal magnets*
SR critical energy	*25 keV for beam from Superbends* *6 keV for beam from conventional dipols*
Bending angle	*7.5 and 15 degrees*
Number of dipoles	*4 Superbends (15°)* *8 normal dipoles (15°)* *24 normal dipoles (7.5°)*
Horizontal emittance	*~5 nm rad*
RF frequency	*180 MHz*
Operating current	*0.5 – 1 A*
Beam lifetime	*~ 10 hours*
Circumference	*~ 210 m*

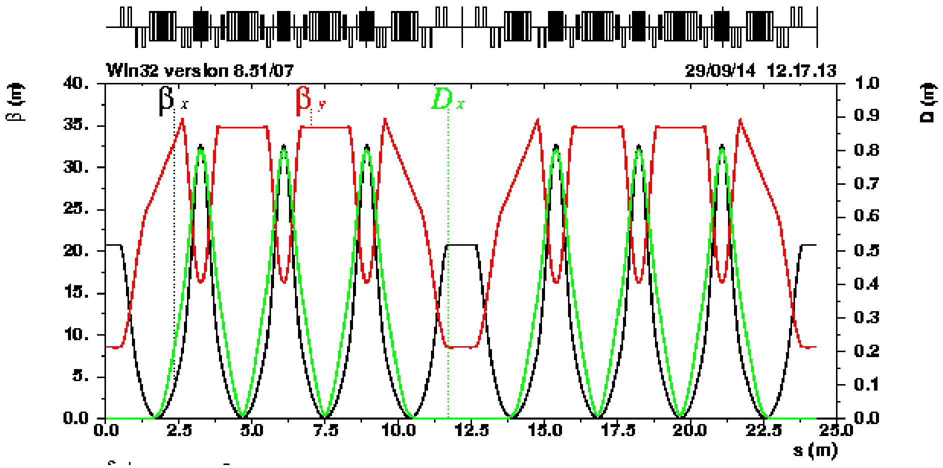


Supercompact high bright hard X-ray light source



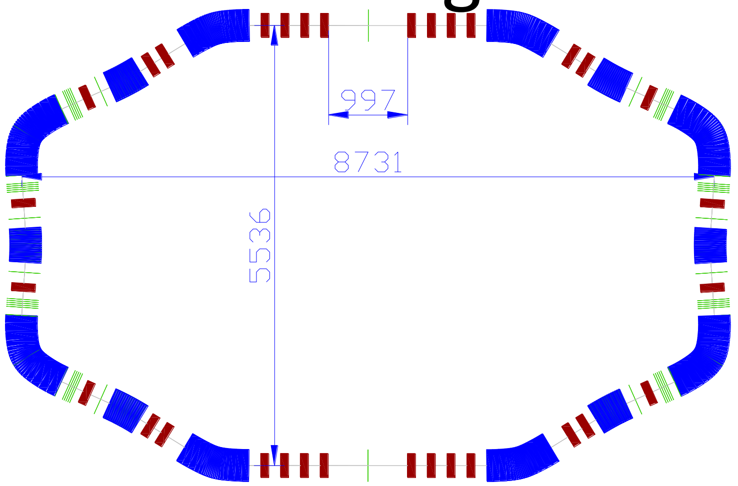


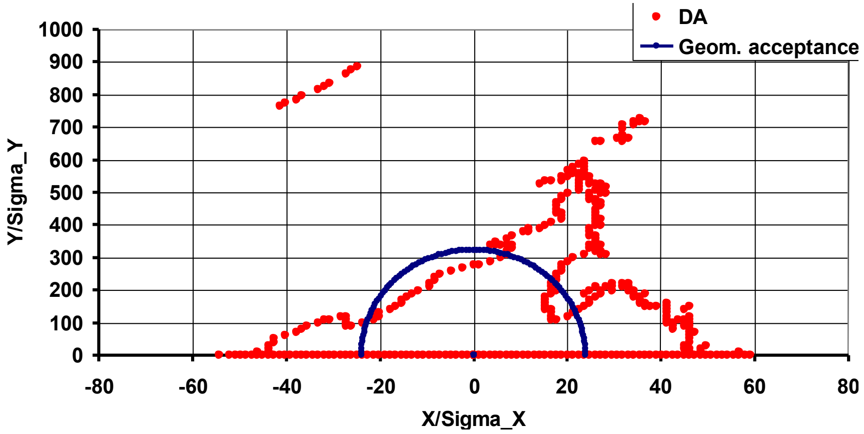


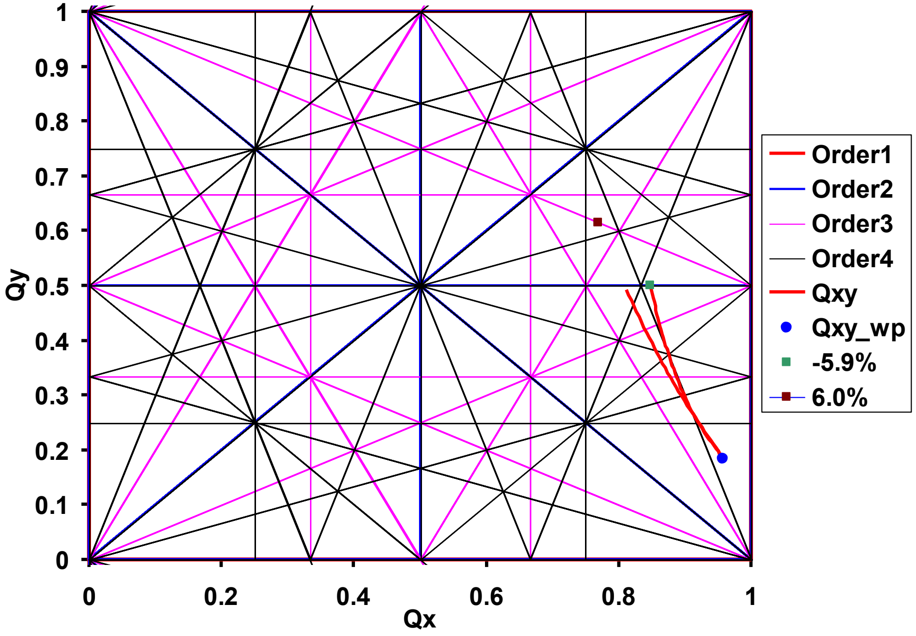


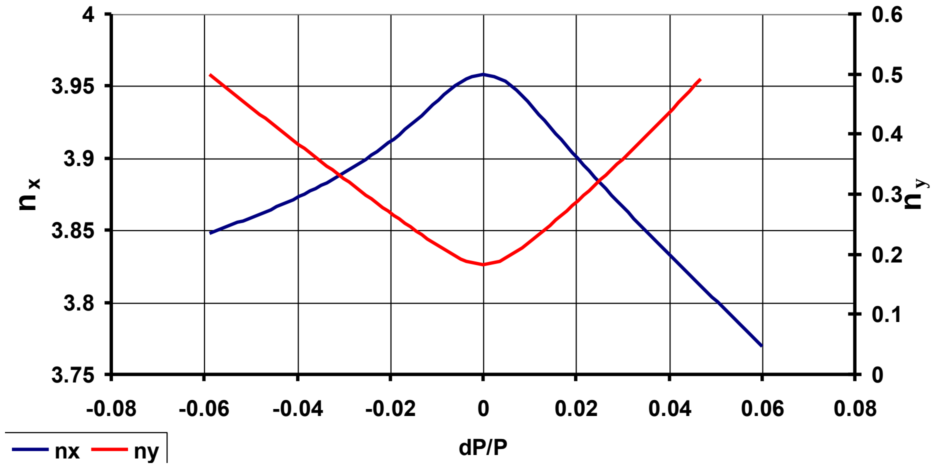
Energy E, GeV	1	*Damping time*	
Circumference, m	24.3	tx, sec	0.0007
Revolution period, sec	8.11E-08	ty, sec	0.0011
Betatron tunes		te, sec	0.0007
qx	3.96	Sigma s, mm	9.0
qy	0.18	RF voltage	4.59E-01
Emittance, nm*rad	12.1	RF harmonic number	43
Betatron coupling	0.5 %	RF frequency, MHz	500
Energy spread	1.40E-03	RF acceptance	2.E-02
Momentum compaction	-8.16E-03	Synchrotron tune	4.9E-03
Energy loss, MeV	1.49E-01	*Radiation integral*	
Damping partition number		I1, m	-1.98E-01
Jx	1.53	I2, m^-1	1.06E+01
Jy	1	I3, m^-2	2.07E+01
Je	1.47	I4, m^-1	-5.57E+00
		I5, m^-1	1.33E-01

Supercompact high bright hard X-ray light source

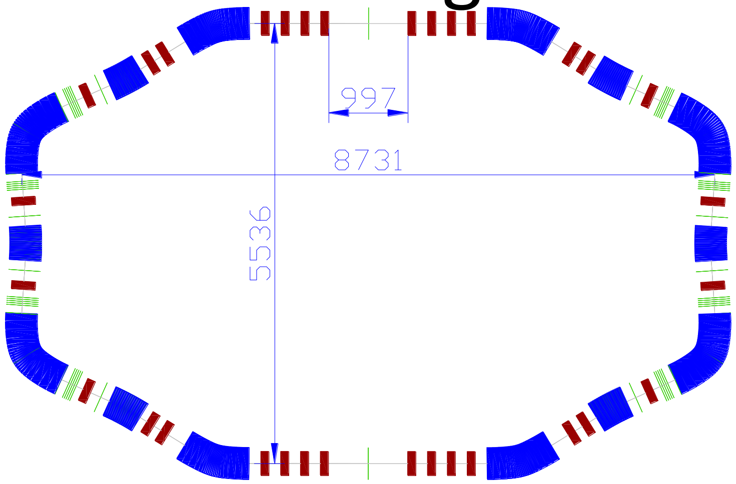


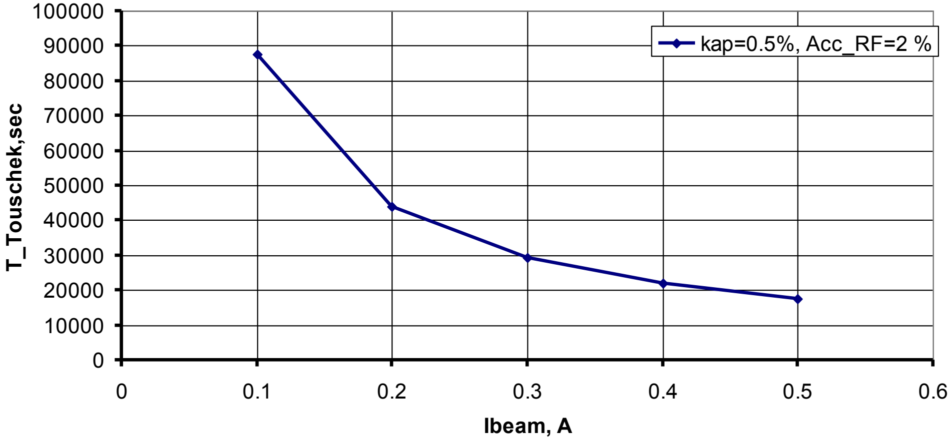


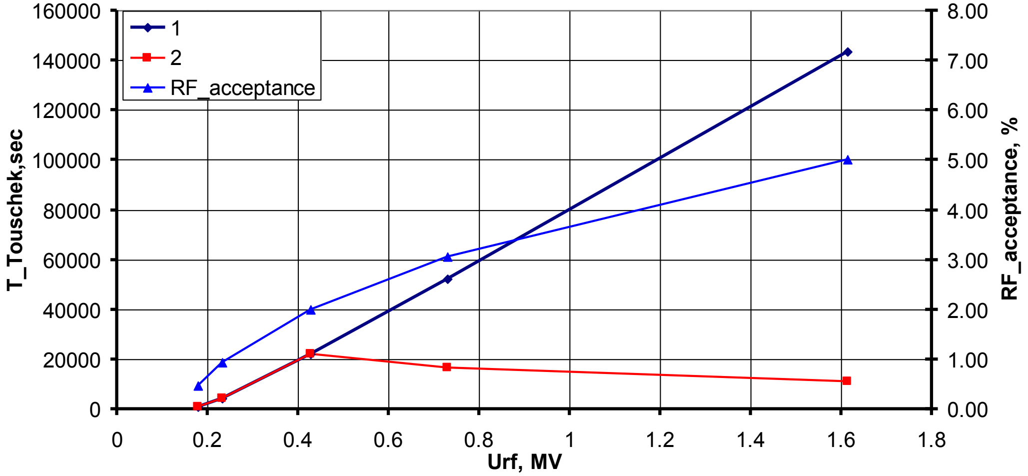




Supercompact high bright hard X-ray light source

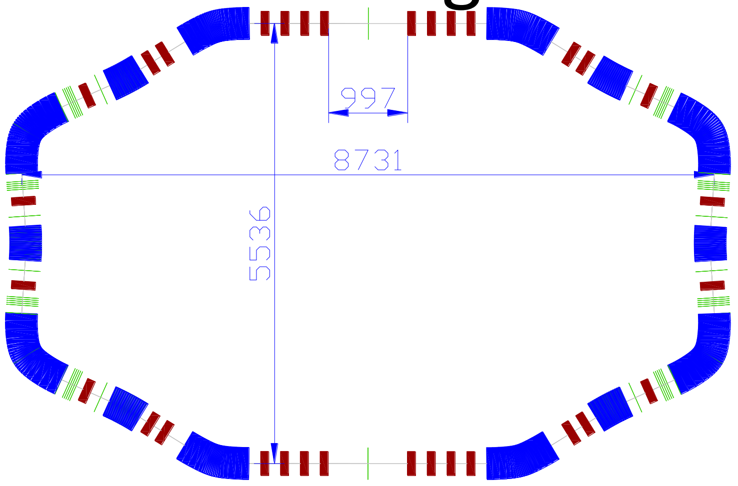


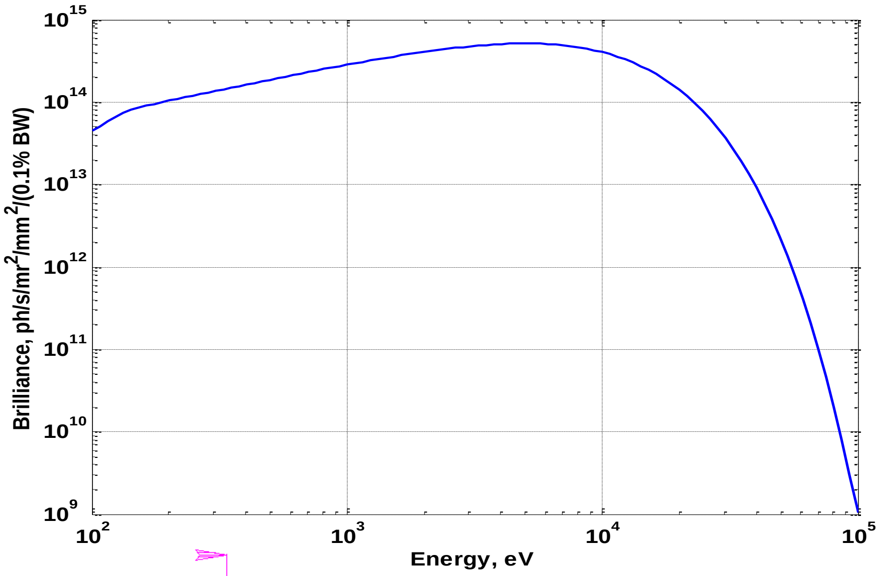


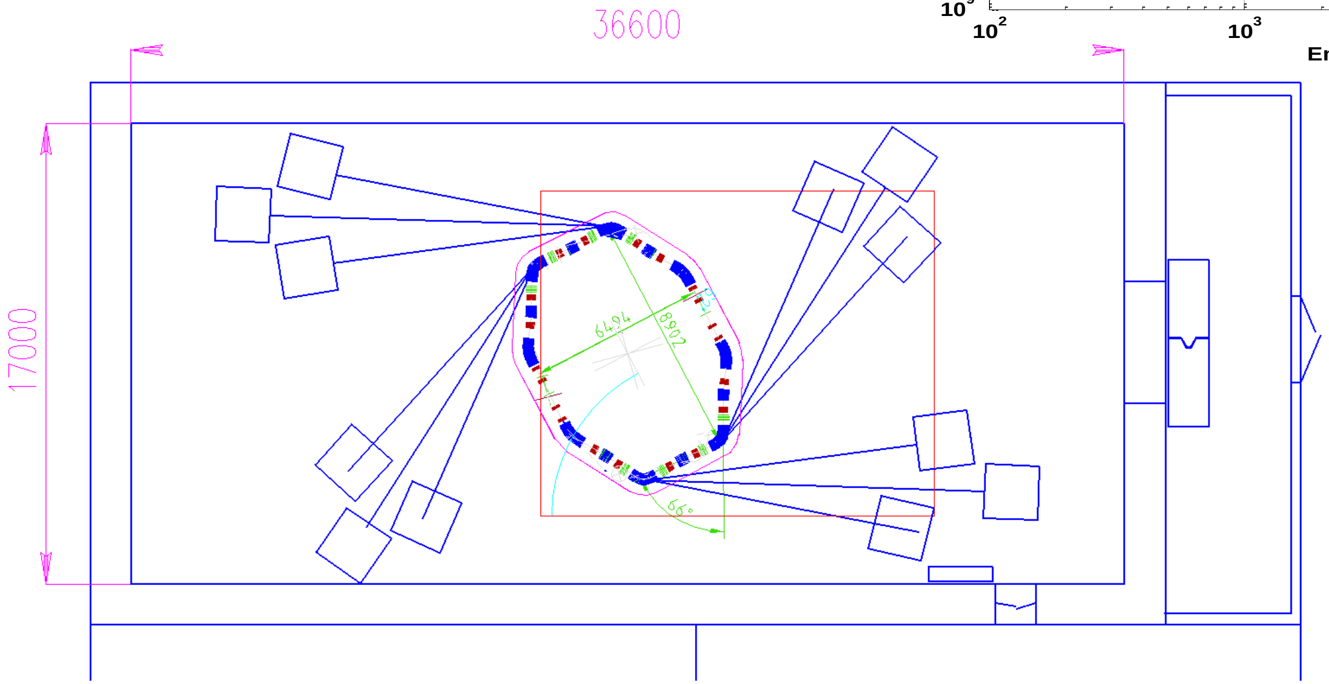


Ibeam = 0.4 A, Nbunch = 40, kap=0.5 %):
1 – Energy acceptance limited by RF acceptance
2 – Energy acceptance limited by RF acceptance or by geometric apperture (2%)

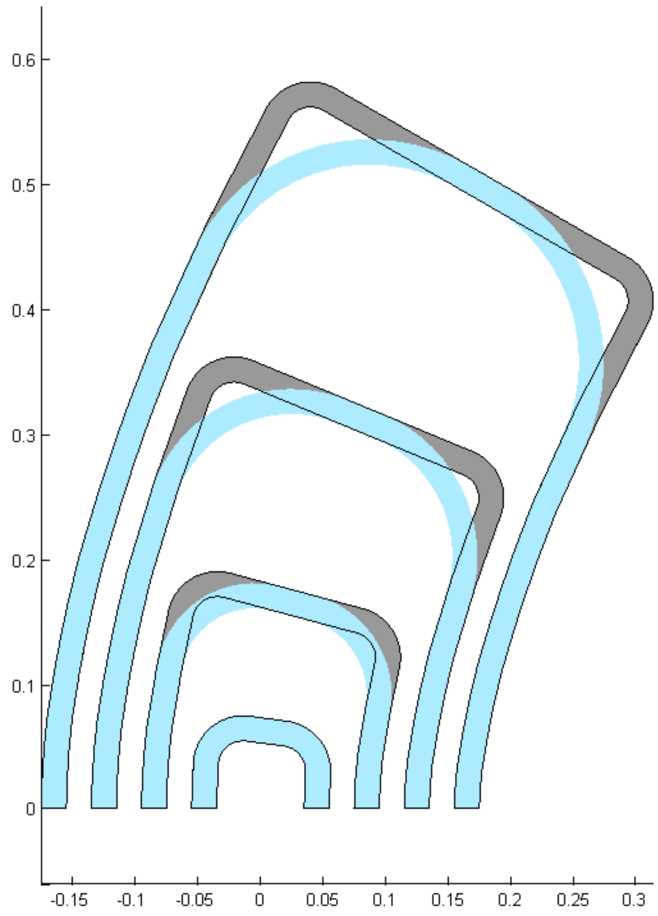
Supercompact high bright hard X-ray light source

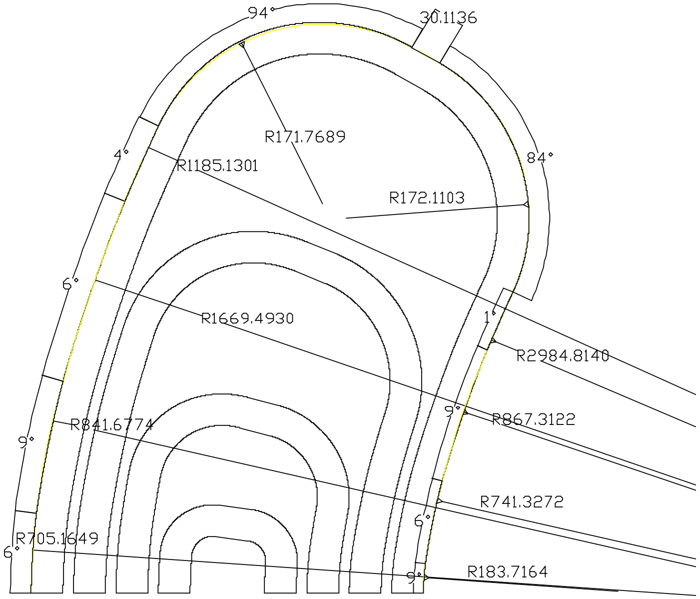


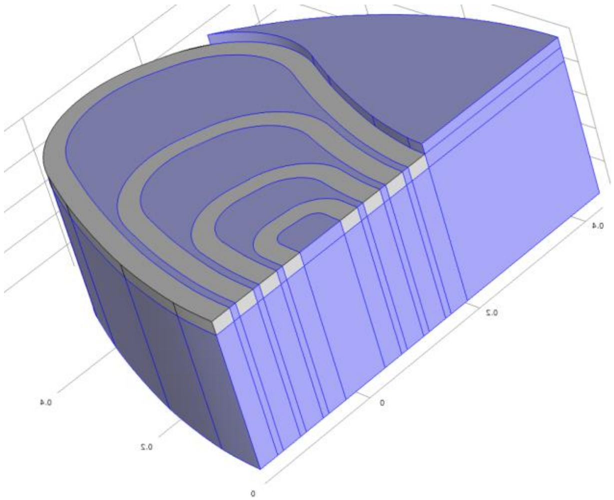




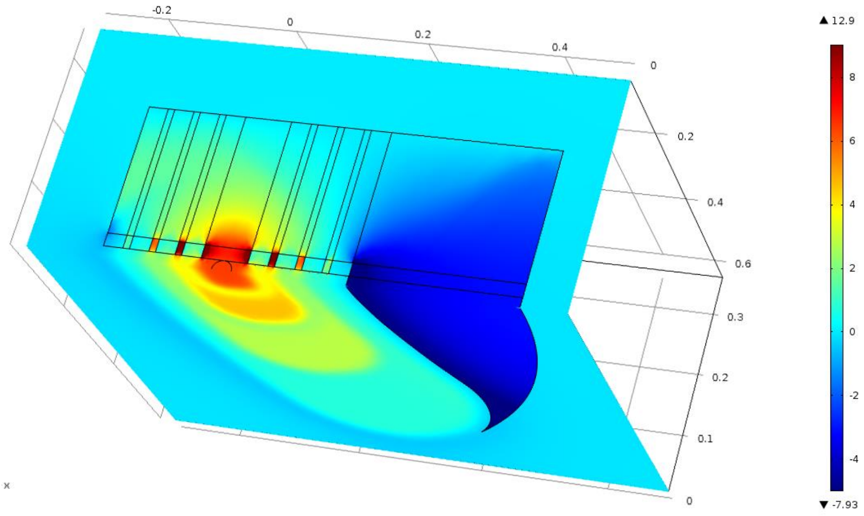
Superconducting dipole with longitudinal variation of the field (coils design)

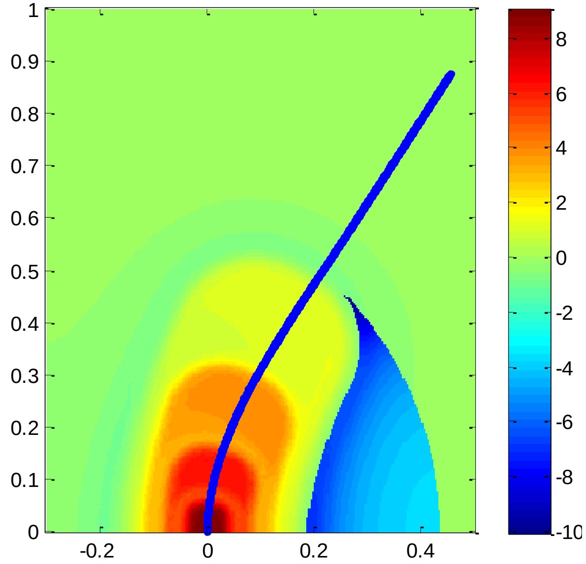


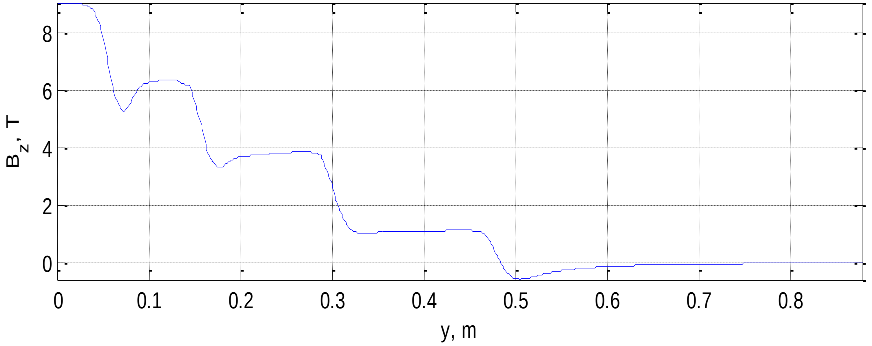


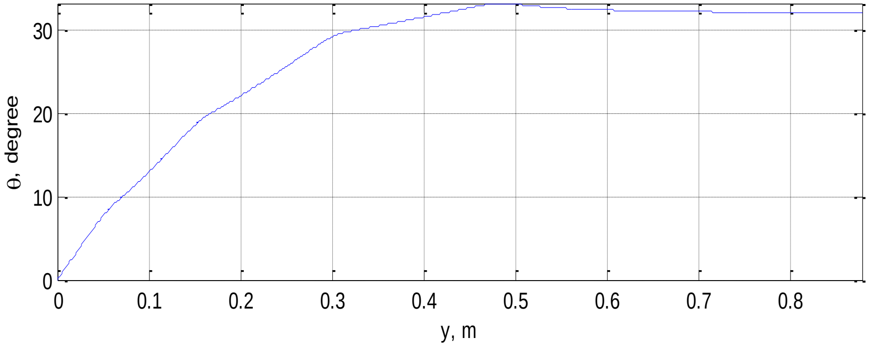


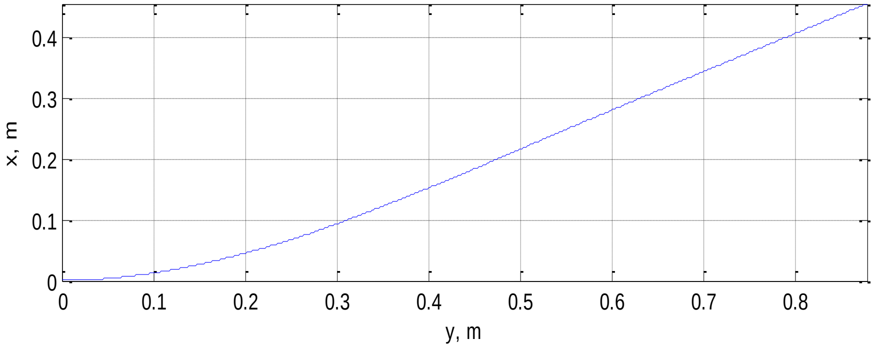
Superconducting dipole with longitudinal variation of the field (3d calculation results)











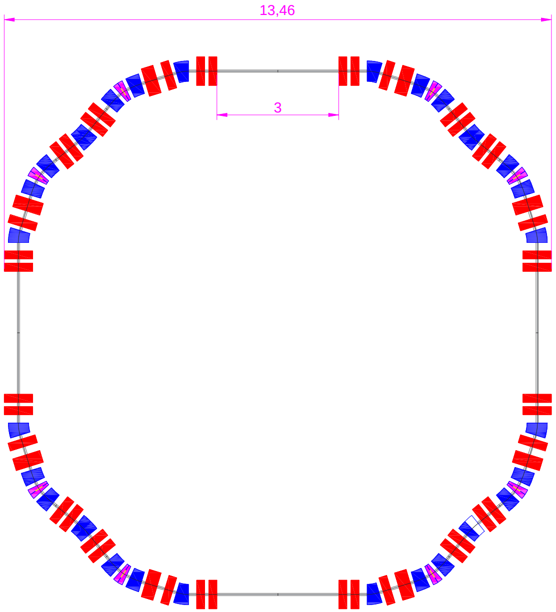
Injection options

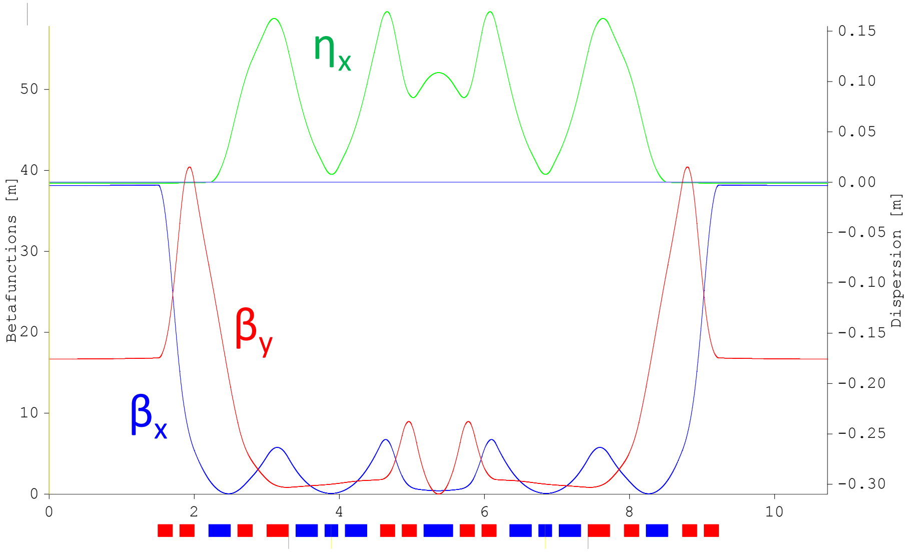
- Energy ramping (energy change from 200 MeV till 1 GeV, required optimizing field ramping tables with accounting iron saturation inside superbends poles)

- Linac option (required 1 GeV linac, expensive and non compact, can be used if such linac constructed for another applications (FEL, etc)

- Laser – plasma acceleration (novel not yet realized technology)

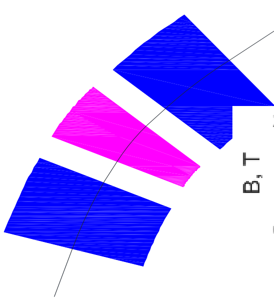
4-fold symmetry ring with sandwich magnets



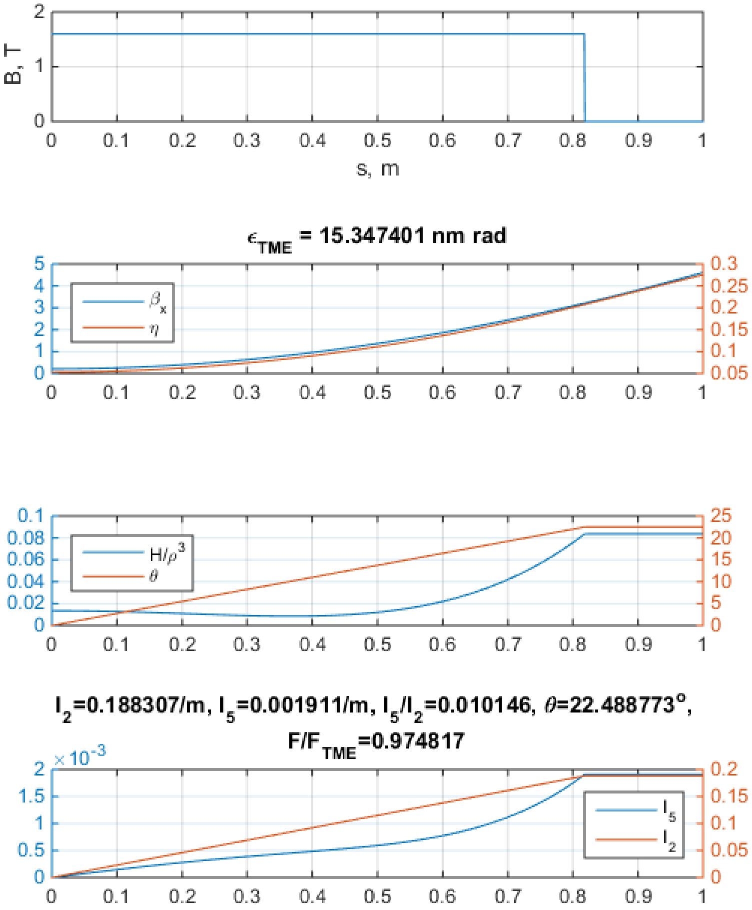


Energy	1 GeV
Circumference	41 m
Emittance	11 nm
Max. bending field	8 T

Sandwich magnet for emittance reduction



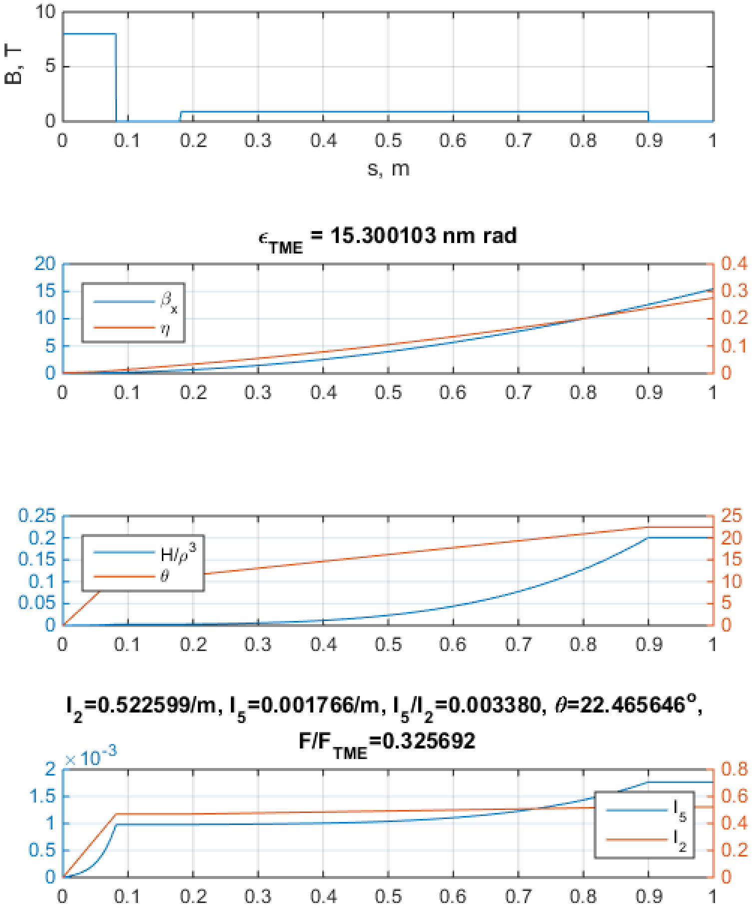
TME



ϵ_{TME} = 15.347401 nm rad

I_2=0.188307/m, I_5=0.001911/m, I_5/I_2=0.010146, θ=22.488773°, F/F_{TME}=0.974817

Sandwich magnet

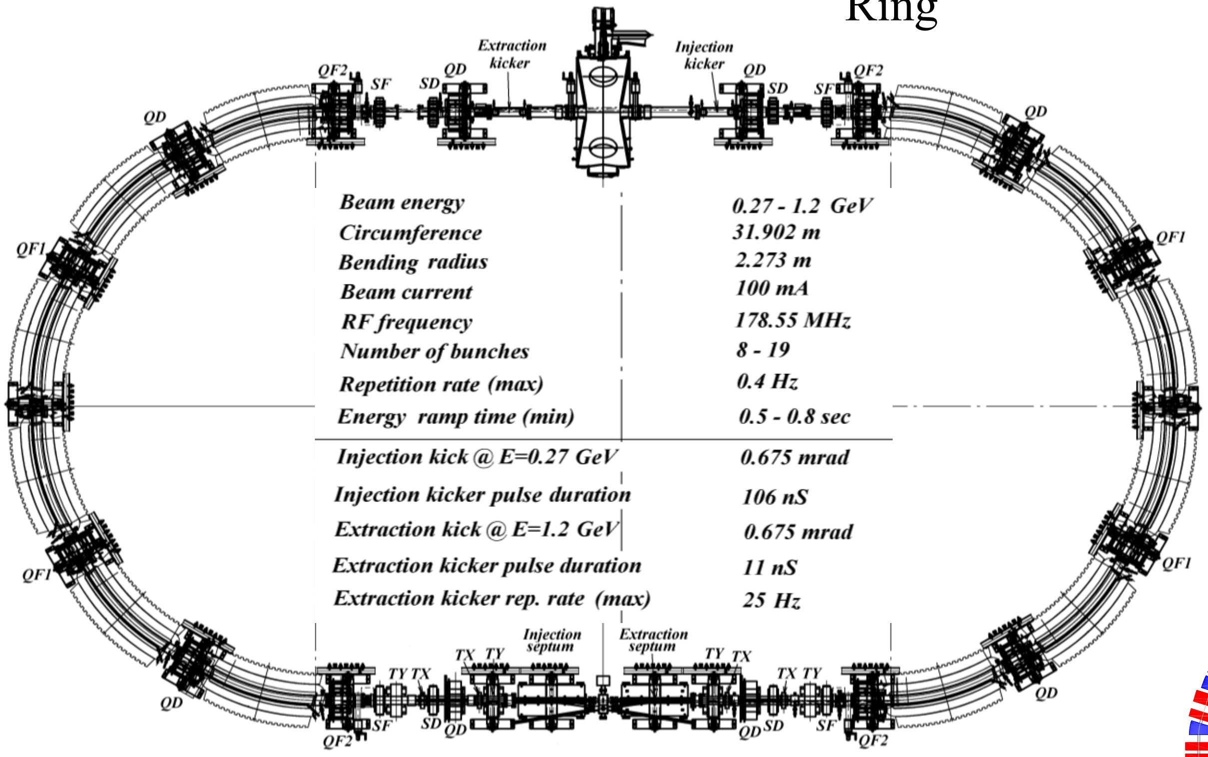


ϵ_{TME} = 15.300103 nm rad

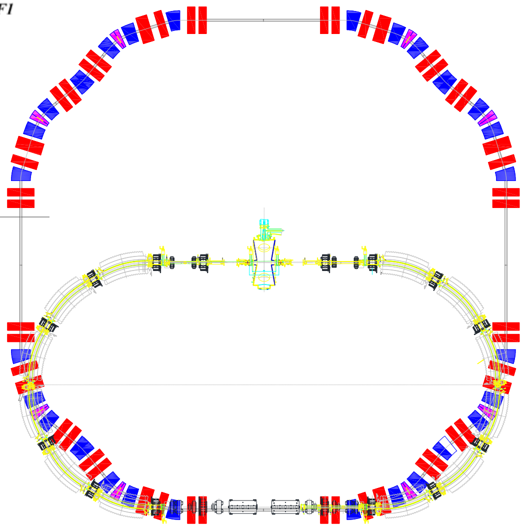
I_2=0.522599/m, I_5=0.001766/m, I_5/I_2=0.003380, θ=22.465646°, F/F_{TME}=0.325692

Injection option

Booster Synchrotron for Duke FEL Storage Ring



Beam energy	*0.27 - 1.2 GeV*
Circumference	*31.902 m*
Bending radius	*2.273 m*
Beam current	*100 mA*
RF frequency	*178.55 MHz*
Number of bunches	*8 - 19*
Repetition rate (max)	*0.4 Hz*
Energy ramp time (min)	*0.5 - 0.8 sec*
Injection kick @ E=0.27 GeV	*0.675 mrad*
Injection kicker pulse duration	*106 nS*
Extraction kick @ E=1.2 GeV	*0.675 mrad*
Extraction kicker pulse duration	*11 nS*
Extraction kicker rep. rate (max)	*25 Hz*



STATUS OF THE BOOSTER SYNCHROTRON FOR DUKE FEL STORAGE RING

S.Mikhailov, V.Litvinenko, M. Busch, M. Emamian, S.Hartman, I.Pinaev, V.Popov, G.Swift, P.Wallace, P.Wang, Y.Wu, FEL Laboratory, Duke University, Durham, NC 27708, USA

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Conclusions and plans

- Superconducting bending magnets with longitudinal variation field can be effectively used for creating the compact light source for generation bright SR in hard X-ray range
- Superconducting dipole with suitable field level and profile can be produced on basic currently developed technology

Plans

- Additional optimization of the magnet design and ring lattice (supported by the Russian foundation of the basic research, proj. N **15-02-04140 A)** 2015.
- Fabrication of the longitudinal gradient superconducting bend (partially supported by Russian scientific foundation) 2016-2018.