Superconducting multipole wigglers for generation of synchrotron radiation

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Outline

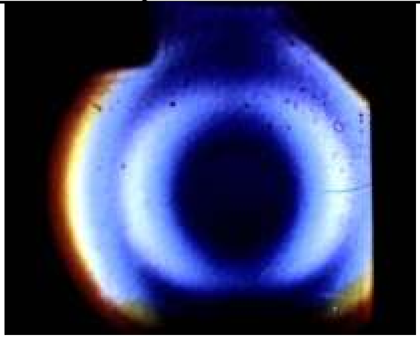
- Introduction
- Magnetic system of Superconducting Multipole Wigglers
- Three groups of superconducting multipole wigglers
- Wiggler cryogenic systems
- Resume and future plans

Introduction

The history of manufacturing and application of superconducting multipole magnetic systems in Budker INP has been started in 1979 – the year of creation of the first superconducting multipole wiggler ("snake") (B=3.5T and period of 9 cm) and its installation on the VEPP-3 storage ring as a powerful x-ray source.

The first superconducting 20-pole wiggler ("snake"), assembled with cryostat, before installation on the ring (1979)

Pole number	20
Pole gap, mm	15
Period, mm	90
Magnetic field amplitude, T	3.5
Vertical beam aperture, mm	7.8



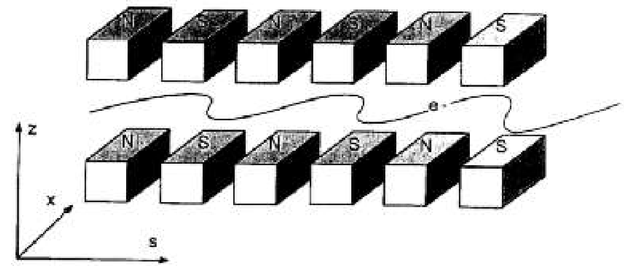
Undulator radiation from the first superconducting 20-pole wiggler ("snake"), (1979)

The magnet system of the first superconducting 20-pole wiggler ("snake") (1979)

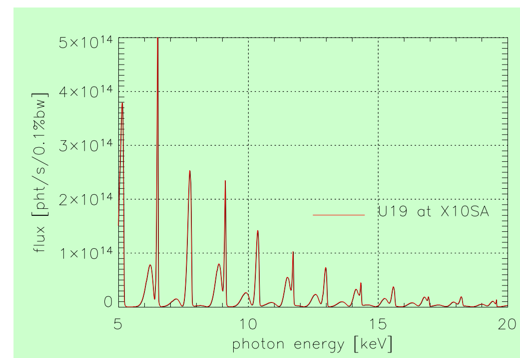
For the period more than 30 years Budker INP has stored the wide experience on creation of superconducting multipole magnetic systems – superconducting wigglers and shifters, used as generators of synchrotron radiation (SR) in many international centres of synchrotron radiations.

Introduction

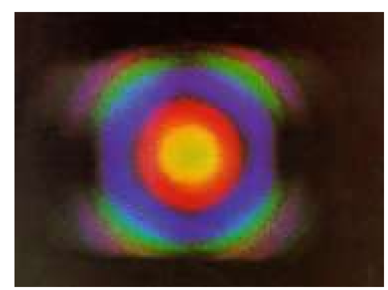
The magnetic system of multipole wiggler represents an array of superconducting dipole magnets creating sign alternate lateral magnetic field. Electron beam passing through this array generates SR in each magnet which the radiation intensity is summarised from all magnets practically in the same solid angle. Use of such magnetic systems is rather effective and cheap enough way of increase in intensity and rigidity of radiation.



$$\lambda_n = \frac{\lambda_0}{n \cdot 2 \cdot \gamma^2}\left(1 + \frac{K^2}{2} + (\gamma\theta)^2\right)$$



Spectral properties of radiation from such magnetic structure depend on parameter $K = 0.934 \cdot B[T] \cdot \lambda[см]$, where B and λ - amplitude and magnetic field period. For K~1 - the radiation spectrum has undulator property, for K>> 1 - the radiation spectrum transits to spectrum of synchrotron radiation.



Magnetic system of Superconducting Multipole Wigglers

Magnetic field distribution and field integrals

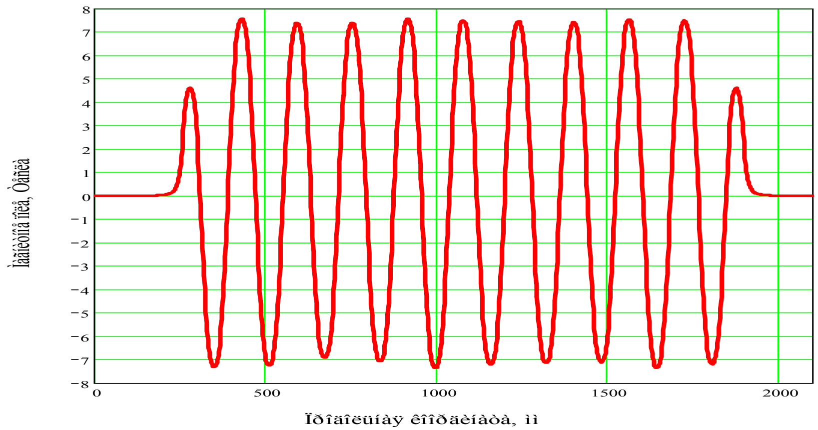
Magnetic field of a superconducting multipole wiggler represents a periodic, sign-variable field which begins and finalises by special compensating end magnets. The end magnets are used for creation of the first and second field integrals of the wigglers equal to zero for indemnification of a beam orbit distortion which is created by the basic wiggler field.

$$I_1 = \frac{1}{B\rho}\int_{-L/2}^{L/2} B_z(s)ds = 0 \qquad I_2 = \int_{-L/2}^{L/2} ds' \int_{-L/2}^{s'} \frac{B_z(s'')}{B\rho} ds'' = 0$$

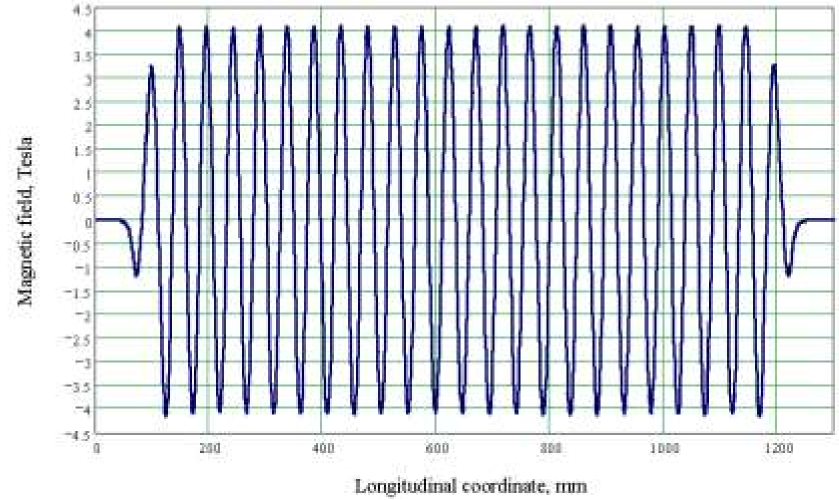
Field integrals of the wiggler with odd pole number can be compensated by two end magnets with a field of ½ of the basic field or four end magnets with the fields, equal ¼ and ¾ of the basic field.

The second field integral is equal to zero automatically (if the first field integral is zero) for a wiggler with odd number of poles. The first field integral is provided with a separate power feeding of the end poles.

Contrariwise for a wiggler with even pole number the first field integral is automatically equal to zero, and the second integral is controlled by separate power supply connected to the end poles.



Field distribution in the 7.5 Tesla wiggler with ½ end magnets



Field distribution in the 4 Tesla wiggler with c ¼ and ¾ end magnets

Magnetic system of Superconducting Multipole Wigglers

Magnetic field distribution and field integrals

$$B_z = B_0 \cos(k_0\sigma)\cos(k_x\chi)\cosh(k_z z)$$

$$B_\chi = -\frac{k_x}{k_z} B_0 \cos(k_0\sigma)\sin(k_x\chi)\sinh(k_z z)$$

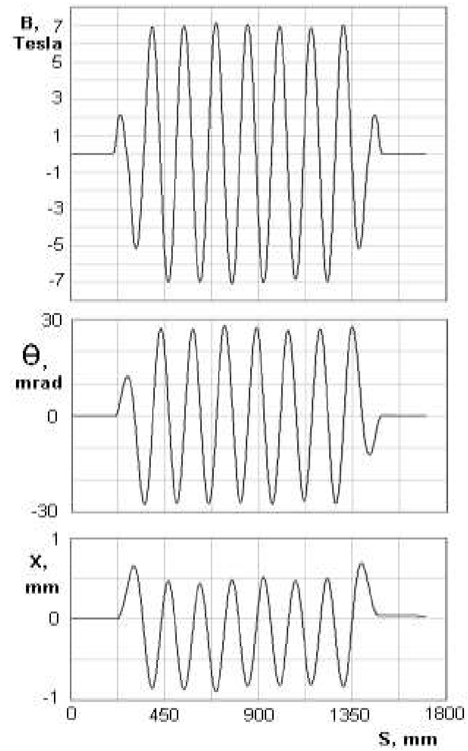
$$B_\sigma = -\frac{k_0}{k_z} B_0 \sin(k_0\sigma)\cos(k_x\chi)\sinh(k_z z)$$

$$k_0 = 2\pi / \lambda_0$$

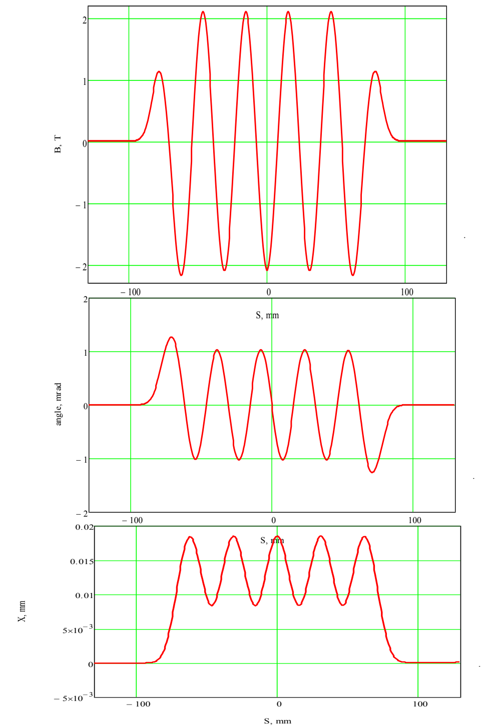
$$k_x = 2\pi / \lambda_x$$

$$k_z = 2\pi / \lambda_z$$

$$k_z^2 = k_x^2 + k_0^2$$



Magnetic field distribution and behaviour of the first and second field integrals with the end magnets of ¼ and ¾ of the basic field.



Magnetic field distribution and behaviour of the first and second field integrals with the end magnets of ½ of the basic field.

Focusing property and nonlinear field components

High field SC ID is a focusing element in magnetic structure of the storage ring and creates betatron tune shifts and structural functions changes. Horizontal and vertical betatron motion inside SC ID may be described by the following equations:

$$x'' + K_x \cdot x = 0$$
$$z'' + K_z \cdot z = 0$$

where coefficients of magnetic strength K_x, K_z are equal to:

$$K_x = \frac{B_z^2}{(B\rho)^2} + \frac{1}{B\rho}\left(x' \frac{\partial B_z}{\partial s} - \frac{\partial B_z}{\partial x} \right), K_z = -\frac{1}{B\rho}\left(x' \frac{\partial B_z}{\partial s} - \frac{\partial B_z}{\partial x} \right)$$

Edge focusing completely compensates focusing by magnetic field in horizontal direction and the main focusing action of SC ID with symmetric magnetic system occurs in vertical direction. The integral values for horizontal and vertical motions may be expressed in view:

$$\int_{-L/2}^{L/2} K_x ds = -\frac{\partial}{\partial x} \int_{-L/2}^{L/2} \frac{B_z ds}{B\rho} = \overline{K}_x L \qquad \int_{-L/2}^{L/2} K_z ds = \int_{-L/2}^{L/2} \frac{B_z^2}{B\rho^2} ds - \int_{-L/2}^{L/2} K_x ds = \overline{K}_z L$$

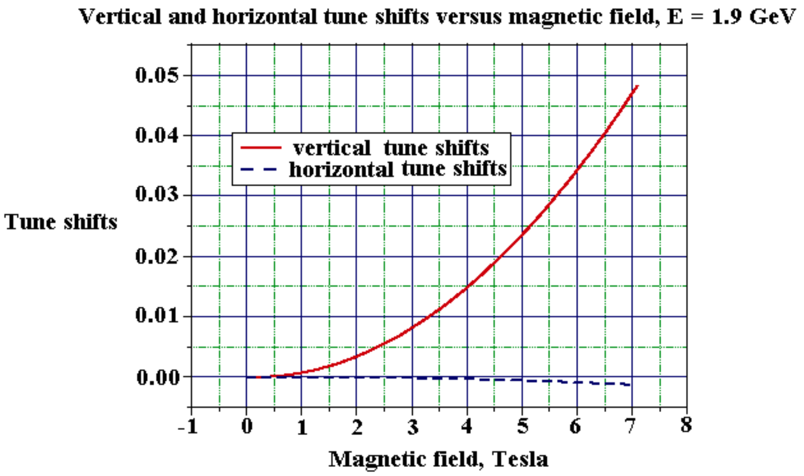
where $\overline{K}_x, \overline{K}_z$ - are average values of ID magnetic strength along ID straight section.

The main results of focusing SC ID are shifts of betatron tunes, possible broadening of half-integer, and integer resonances of betatron motion and beating beta-functions.

In approximation for $\sqrt{\overline{K}_{x,z}} L$ values which are small enough the betatron tune shifts may be estimated as

$$\Delta \nu_{x,z} = \frac{K_{x,z} L \beta_{x,z}}{4\pi} \left(1 + \frac{L^2}{12 \beta_{x,z}^{\ 2}} \right)$$

:



Focusing property and nonlinear field components

Integral values of nonlinear components of the magnetic field of multipole wigglers with length ***L***, at conditions that orbit displacement δ is much less than pole sizes and assuming $\frac{k_x}{k_0} << 1$, may be written as

$$\int_L B(s)ds = \frac{B_0^2 \cdot k_x^2}{2B\rho \cdot k_0^2} \cdot \delta \cdot L$$

$$\int_L G(s)ds = \left(\frac{B_0^2}{2B\rho} + \frac{B_0^2 \cdot k_x^2}{2B\rho \cdot k_0^2} \right) \cdot L$$

$$\int_L S(s)ds = -\left(\frac{B_0^2}{B\rho} + \frac{B_0^2 \cdot k_x^2}{2B\rho \cdot k_0^2} \right) \cdot k_x^2 \cdot \delta \cdot L$$

$$\int_L O(s)ds = -\left(\frac{3B_0^4}{8B\rho^3} + \frac{3B_0^2 \cdot k_x^2}{2B\rho} + \frac{3B_0^4 \cdot k_x^2}{8B\rho^3 \cdot k_0^2} \right) \cdot L$$

Orbit displacement δ leads to occurrence of nonzero first field integrals and non zero integral of sextupole field component.

If $k_x = 0$ (two-dimensional field at infinitely wide poles of magnets) integrals of magnetic field and sextupole field components also equals to zero, but gradient and octupole field components considerably become simpler, but there are nonzero values:

$$\int_L G(s)ds = \left(\frac{B_0^2}{2B\rho} \right) \cdot L$$

$$\int_L O(s)ds = -\left(\frac{3B_0^4}{8B\rho^3} \right) \cdot L$$

Radiation (structural) integrals

Installation of SC high field ID on a storage ring may influent on beam parameters by changing of radiation integrals. The primary goal at wiggler installation on a storage ring is to consider all possible unpleasant changes in structural functions of the storage ring and to provide correct indemnification of all effects which arise with magnetic field of ID. Expressions for changes of radiation integrals for symmetric magnetic systems are as follows:

$$\Delta I_1 = \int_L \frac{(\eta_{x0} - x(s))B_z(s)}{B\rho} ds \qquad \Delta I_2 = \int_L \frac{B_z^2(s)}{B\rho^2} ds \qquad \Delta I_3 = \int_L \frac{|B_z(s)|^3}{B\rho^3} ds \qquad \Delta I_4 = \int_L \left(\frac{B_z^3(s)\cdot}{B\rho^3} - \frac{2K_x}{B\rho} \right)(\eta_{x0} - x(s)) ds$$

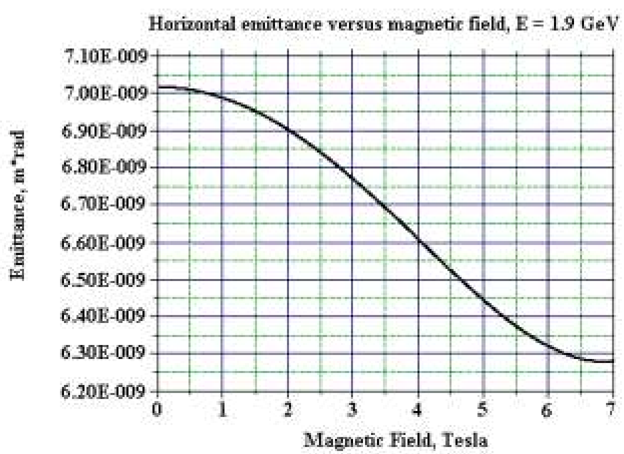
$$\Delta I_5 = \int_L \frac{|B_z(s)|^3}{B\rho^3} \left(\gamma_x(\eta_{x0} - x(s))^2 + 2\alpha_x(\eta_{x0} - x(s))(\eta'_{x0} - x'(s)) + \beta_x(\eta'_{x0} - x'(s))^2 \right) ds$$

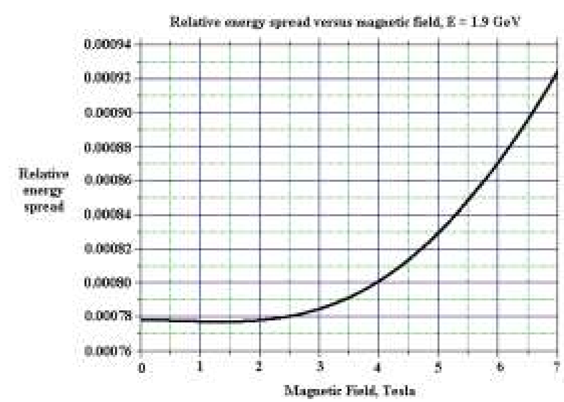
Energy spread and horizontal emittance are the most important beam parameters which may be changed by action of SC ID magnetic field. Ratio of energy spread (σ'_E / σ_E)

and ratio of emittances $\varepsilon'_x / \varepsilon_x$ with/without magnetic field of ID are described by the following formulas:

$$\left(\frac{\sigma'_E}{\sigma_E} \right)^2 = \frac{1 + \dfrac{\Delta I_3}{I_3^0}}{1 + \dfrac{2\Delta I_2 + \Delta I_4}{2I_2^0 + I_4^0}} \approx 1 + \frac{\Delta I_3}{I_3^0} - \frac{\Delta I_{24}}{I_2^0}$$

$$\frac{\varepsilon'_x}{\varepsilon_x} = \frac{1 + \dfrac{\Delta I_5}{I_5^0}}{1 + \dfrac{\Delta I_2 - \Delta I_4}{I_2^0 - I_4^0}} \approx 1 + \frac{\Delta I_5}{I_5^0} - \frac{\Delta I_2}{I_2^0}$$





List of SC multipole wigglers, fabricated by Budker INP

	Year	Magnetic field, (B_{Max}*) normal	Poles number (main + side)	Pole gap, mm	Period mm	Vertical aperture, mm
7 T wiggler BESSY-II, Germany	2002	(7.67) 7.0	13 + 4	19	148	13
3.5 T wiggler ELETTRA, Italy	2002	(3.7) 3.5	45 + 4	16.5	64	11
2 T wiggler CLS, Canada	2005	(2.2) 2.0	61 + 2	13.5	34	9.5
3.5 T wiggler DLS, England	2006	(3.75) 3.5	45 + 4	16.5	60	11
7.5 T wiggler SIBERIA-2, Russia	2007	(7.7) 7.5	19 + 2	19	164	14
4.2 T wiggler CLS, Canada	2007	(4.34) 4.2	25 + 2	14.5	48	10
4.2 T wiggler DLS, England	2009	(4.25) 4.2	45 + 4	13.8	48	10
4.1 T wiggler LNLS, Brazil	2009	(4.19) 4.1	31 + 4	18.4	60	14
2.1T wiggler ALBA-CELLS, Spain	2009	(2.27)2.1	117 + 2	12.6	30	8.5
4.2 T wiggler ASHo, Australia	2012	(4.5) 4.2	59+4	15.2	50.5	10
7.5 T wiggler CAMD LSU, USA	2013	(7.75) 7.5	11+4	25.2	193.4	15
2.5 T wiggler KIT, Germany	2013	(2.85) 2.5	36+4	19	46.88	15

Interpolation formula for the fabricated planar, horizontal racetrack SC wigglers

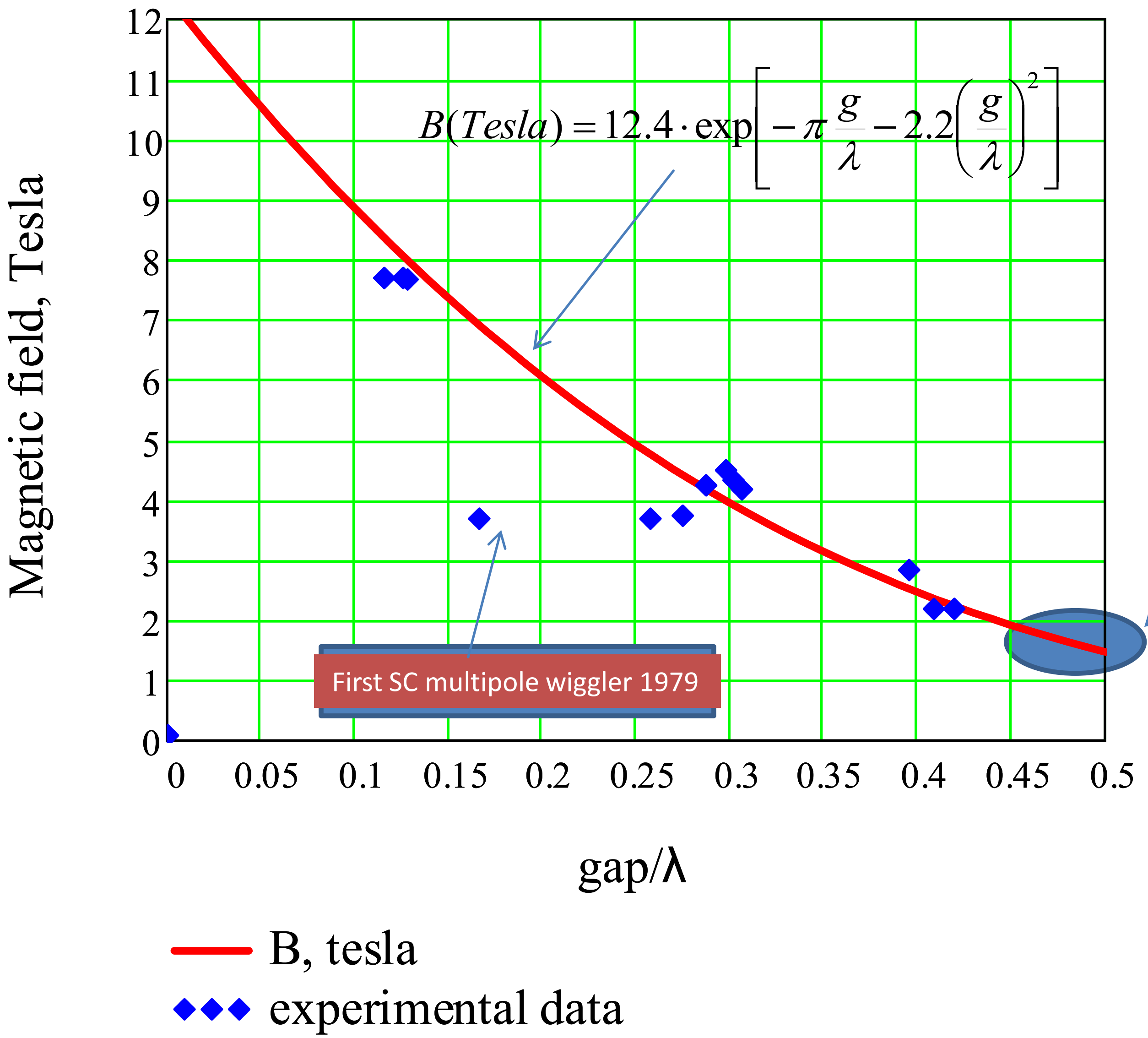


Figure shows the dependance of maximum magnetic field versus gap/λ by the interpolating curve and experimental data of different SC wigglers listed in the table above.

The region which we have a plan to master in the nearest future

3 groups of SC multipole wiggler

The superconducting wigglers may be divided into three groups according to their use.

1. **<u>High field (7-7.5 T) and long period (150-200 mm) wigglers.</u>** This type of the wigglers are installing on SR sources with relative low electron energy on purpose to expand a photon energy range to more hard X-ray. As a rule one wiggler may give a SR beam for 3 or more independent beamlines. This kind of the wiggler to be installed on a storage ring with electron energy of 6-8 GeV can give the chance to development of new researches, including possibility of creation of bright sources of positrons and neutrons. (On SR sources with electron energy 1-2 GeV it also can be used as a source of terahertz undulator radiations).

BESSY, Germany 2002
2013 cryostat upgrade
17-pole, SC wiggler
Field 7T
Pole gap 19 mm
Period 148 mm

Moscow, Siberia-2, 2007
21-pole SC wiggler
Field 7.5 T
Pole gap 20.2 mm
Period 164 mm

CAMD LSU, USA 2013
15pole SC wiggler
Field 7.5 T
Pole gap 25.2 mm
Period 193 mm

3 groups of SC multipole wiggler

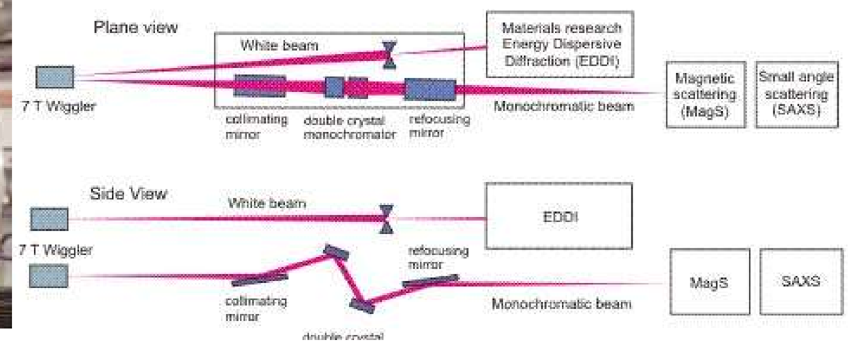
Long period, high field SC multipole wigglers

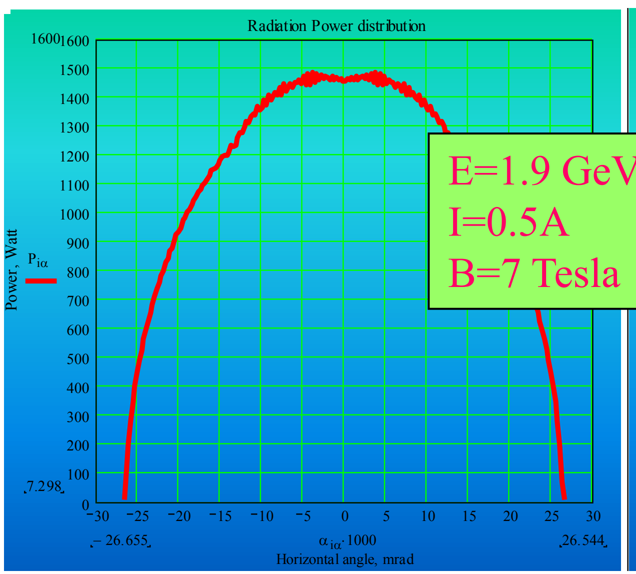
17-poles, 7 Tesla superconducting wiggler BESSY, Germany, 2002

BESSY wiggler, 2002

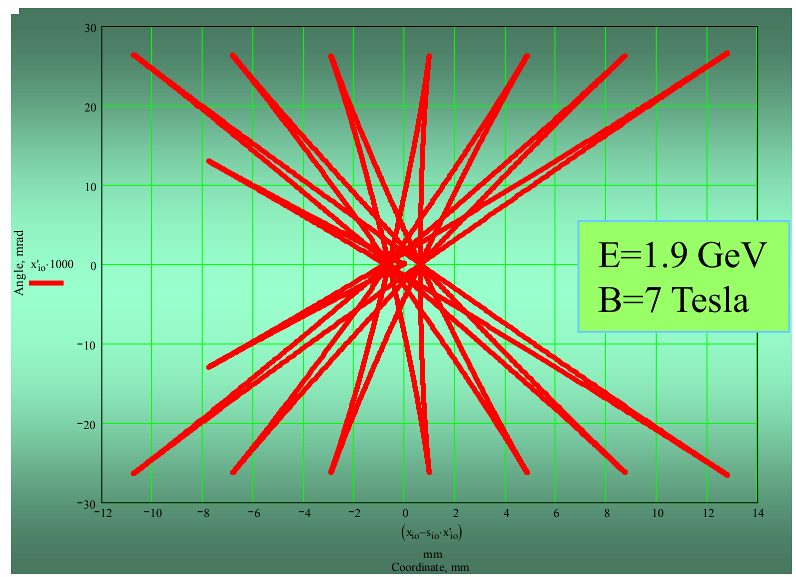
The cryostat upgraded in 2013

Beamlines : MagS, EDDI and SAXS





Angle distribution of radiated power

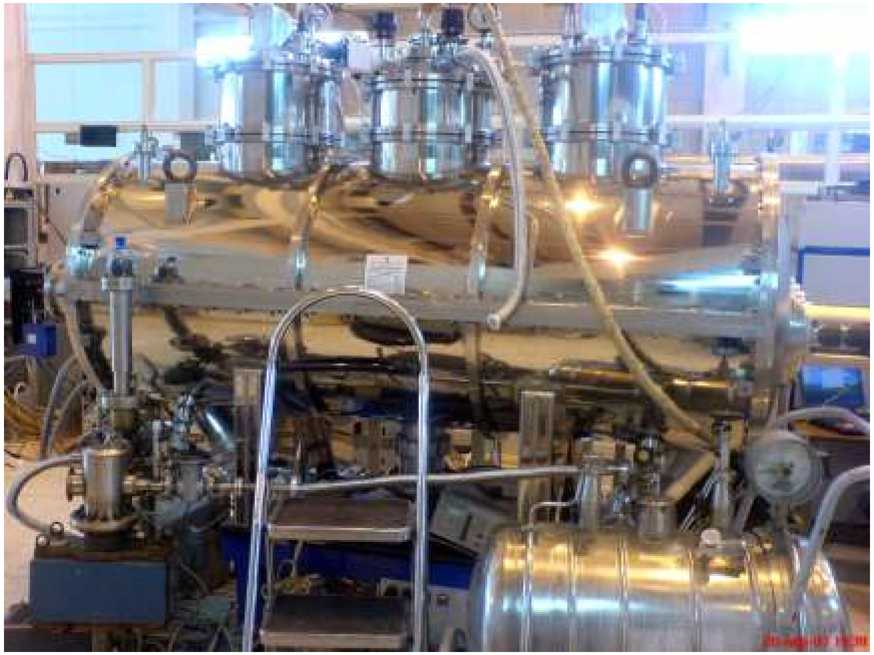


Phase space of radiation

3 groups of SC multipole wiggler

Long period, high field SC multipole wigglers

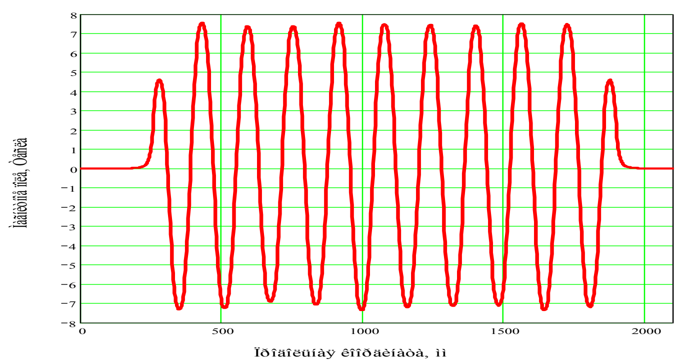
7.5 Tesla 21 pole superconducting wiggler (Moscow, Siberia-2, 2007)



Main parameters

Pole number (main + side)	19+2
Vertical beam aperture, mm Horizontal beam aperture, mm	14 120
Pole gap, mm	20.2
Period, mm	164
Maximal field, Tesla Nominal field, Tesla	7.67 7.5
2 sections coilmaterial – Nb-Ti/ Cu Currents in sections at 7.5 Tesla, A internal section external section	 160 400
Stored energy, kJ	520
Liquid helium consumption, l/hour	<0.03
Total weight, tonn	3

Test in bath cryostat



Longitudinal field distribution

Lower part of the wiggler magnet

3 groups of SC multipole wiggler

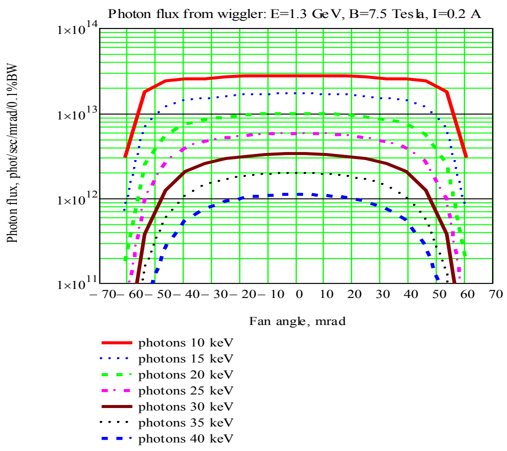
Long period, high field SC multipole wigglers

7.5 Tesla 15 pole superconducting wiggler for CAMD LSU (USA)

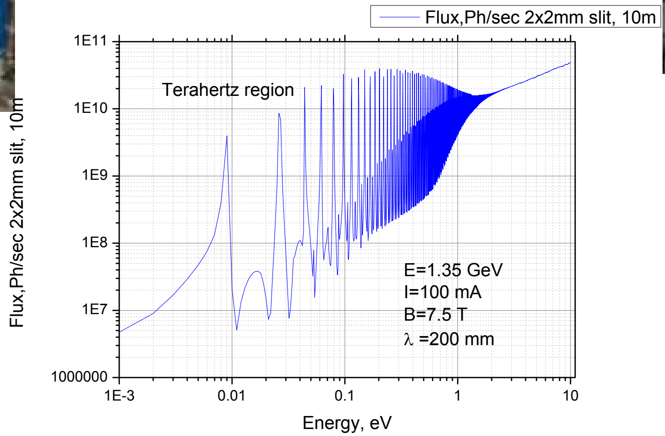
Magnetic field	7.5 Tes;a
Period	200 mm
Stored energy	850 kJ

Assembled SC wiggler magnet

One half of the SC magnet



Angle-spectral photon flux distribution



Low photon energy spectrum of 7.5 T wiggler at CAMD 1.35 GeV (K=148)

3 groups of SC multipole wiggler

- **<u>Medium field (2.5-4.3 T) and medium period (48-60 mm) wigglers.</u>** This type of the wigglers is most popular for installing on SR sources with 2-3 GeV electron energy on purpose to create very high photon flux of hard X-ray in range 10-100 keV. As a rule one wiggler may give a SR beam for 1 beamline which is equipped by many techniques and can be used in different investigations.

ELETTRA, Italy, 2002
2013 cryostat upgrade
49-pole SC wiggler
Field 3.5 T
Pole gap 16.5 mm
Period 64 mm

DLS, England, 2006
49-pole SC wiggler
Field 3.5T
Pole gap 16 mm
Period 58.5 mm

CLS, Canada, 2007
27- pole SC wiggler
Field 4.2 T
Pole gap 14.5 mm
Period 48 mm

DLS, England, 2008
49-pole SC wiggler
Field 4.2T
Pole gap 14.4 mm
Period 47 mm

LNLS, Brasil, 2009
35-pole SC wiggler
Field 4.2T
Pole gap 18.4 mm
Period 60 mm

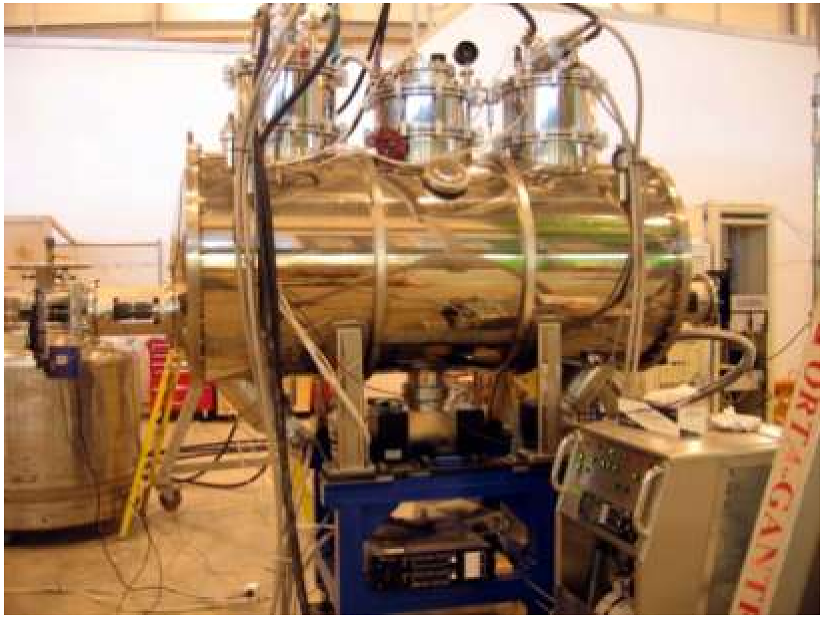
ASHo, Australia 2013
63-pole SC wiggler
Field 4..2 T
Pole gap 15.2 mm
Period 50.5 mm

KIT, Germany, 2014
40-pole SC wiggler
Field 2.5 T
Pole gap 19 mm
Period 47 mm

3 groups of SC multipole wiggler

Medium field (2.5-4.3 T) and medium period (48-60 mm) wigglers.

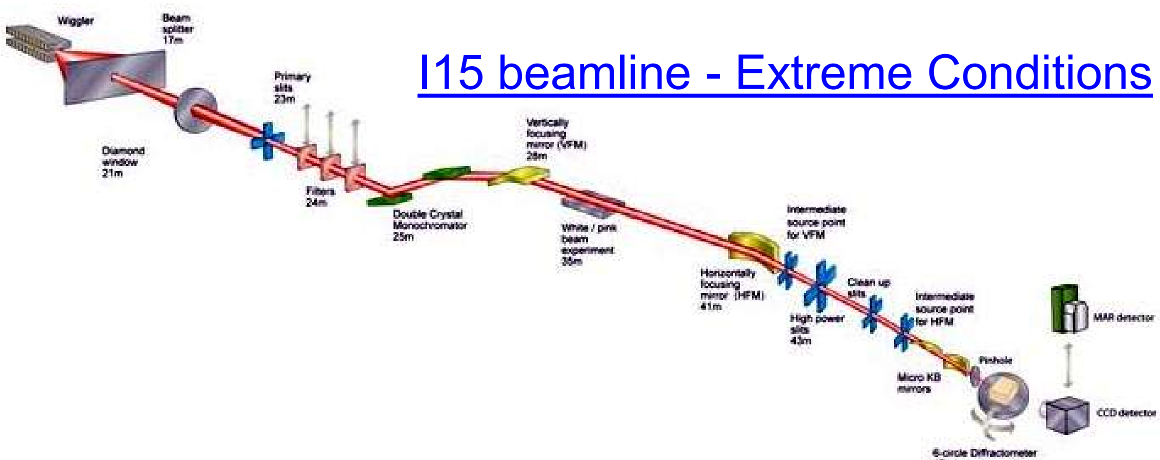
Superconducting 49 pole 3.5 Tesla wiggler for DLS (England, 2005)



Half pole of SC wiggler

Pole number (main + side)	45+4
Vertical beam aperture, mm Horizontal beam aperture, mm	10 60
Pole gap, mm	16.2
Period, mm	60
Maximal field, Tesla Nominal field, Tesla	3.77 3.5
One section windings, material – Nb-Ti Currents in sections at 3.5 Tesla, A	 650
Stored energy, kJ	35
Liquid helium consumption, liter/ hour	<0.03
Total weight, ton	2

I15 beamline - Extreme Conditions



Beamline Design Specifications

Energy range	20 - 80 keV (mono beam). Beam size conditions apply for high energies > 30 KeV. Minimum beam size >30 keV is 80-100 microns.
Energy resolution (Δ E/E)	1.0×10^{-3}
Photon beamsize at sample	Variable, from a few tens of microns to mm
Beam divergence at 50 keV	Variable with focusing elements
Flux at sample at 50 keV (ph/s)	10^9

3 groups of SC multipole wiggler

dium field (2.5-4.3 T) and medium period (48-60 mm) wigglers.

Tesla 27 pole superconducting wiggler CLS (Canada), 2007

Biomedical Imaging and Therapy (BMIT-ID) 05ID-2 (POE-2 & SOE-1)

Pole number (main + side)	25+2
Vertical beam aperture, mm Horizontal beam aperture, mm	9 50
Pole gap, mm	13.9
Period, mm	48
Maximal field, Tesla Nominal field, Tesla	4.31 4.2
Two section windings, material – Nb-Ti Currents in sections at 4.2 Tesla, A internal section external section	 460 950
Stored energy, kJ	27.4
Liquid helium consumption, liter/ hour	<0.03
Total weight, ton	2

Cold welding method of wires connection gives resistance of the connection 10^{-10}- 10^{-13} Ohm

Maximal field of 4.3 Tesla, period – 48 mm

Medium field (2.5-4.3 T) and medium period (48-60 mm) wigglers.

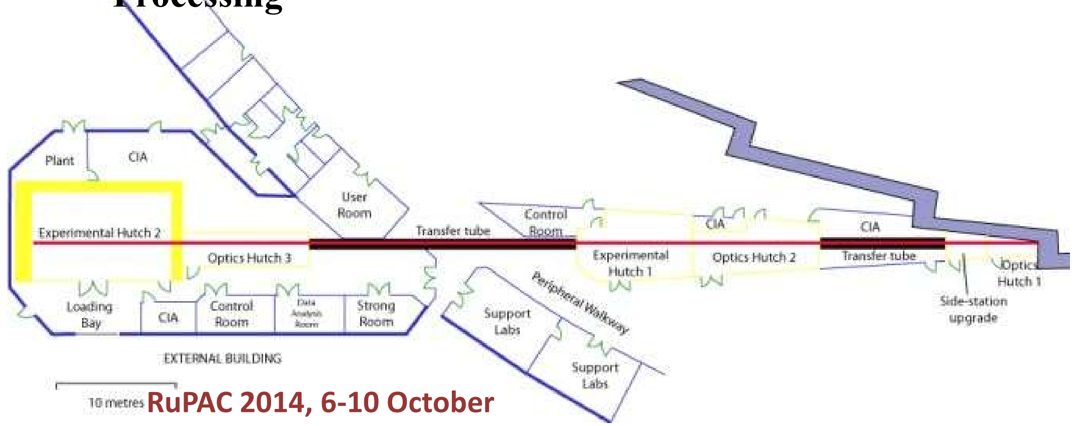
4.2 Tesla 49-pole superconducting wiggler DLS (England)

Wiggler assembling on site

Pole number (main + side)	45+4
Vertical beam aperture, mm Horizontal beam aperture, mm	10 60
Pole gap, mm	14.4
Period, mm	48
Maximal field, Tesla Nominal field, Tesla	4.34 4.2
Two section windings, material – Nb-Ti Currents in sections at 4.2 Tesla, A internal section external section	 415 870
Stored energy, kJ	47
Liquid helium consumption, liter/ hour	<0.03
Total weight, ton	2.5

Main Research Techniques: (50-150 кэВ)
Imaging and tomography, X-ray diffraction, Small Angle X-ray Scattering (SAXS), Single Crystal Diffraction, Powder diffraction

I12 beamline - JEEP: Joint Engineering, Environmental and Processing



3 groups of SC multipole wiggler

...dium field (2.5-4.3 T) and medium period (48-60 mm) wigglers.

4.1 Tesla 35 pole superconducting wiggler LNLS (Brazil)

Pole number (main + side)	31+4
Vertical beam aperture, mm Horizontal beam aperture, mm	14 80
Pole gap, mm	18.4
Period, mm	60
Maximal field, Tesla Nominal field, Tesla	4.19 4.1
Two section windings, material – Nb-Ti Currents in sections at 4.2 Tesla, A internal section external section	 441 882
Stored energy, kJ	39
Liquid helium consumption, liter/ hour	<0.03
Total weight, ton	1.9

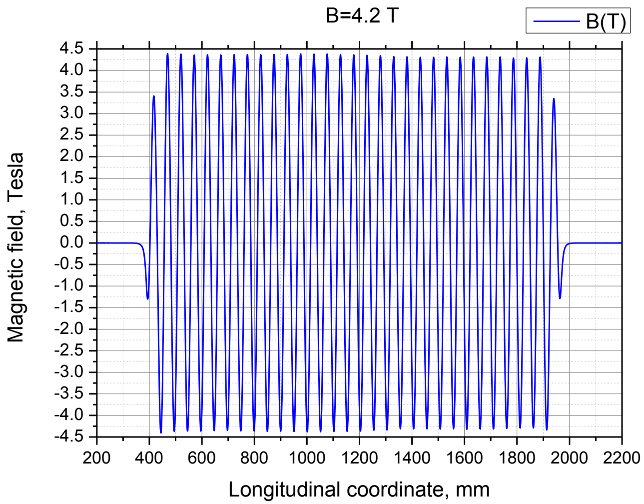
Beamline for Materials Science

Studies of new materials, specially nanostructured materials, in high conditions (temperature, magnetic field and pressure). The wiggler was designed to produce hard x-rays with 100 times more intensity for photons of 10 keV and 1000 times more intensity for photons of 20 keV, when compared to the typical emission obtained in conventional dipole magnets.

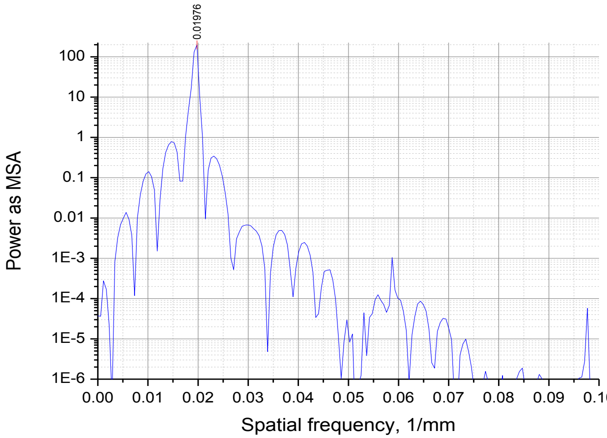
3 groups of SC multipole wiggler

Medium field (2.5-4.3 T) and medium period (48-60 mm) wigglers.

esla 72 pole superconducting wiggler ASHo (Australia)

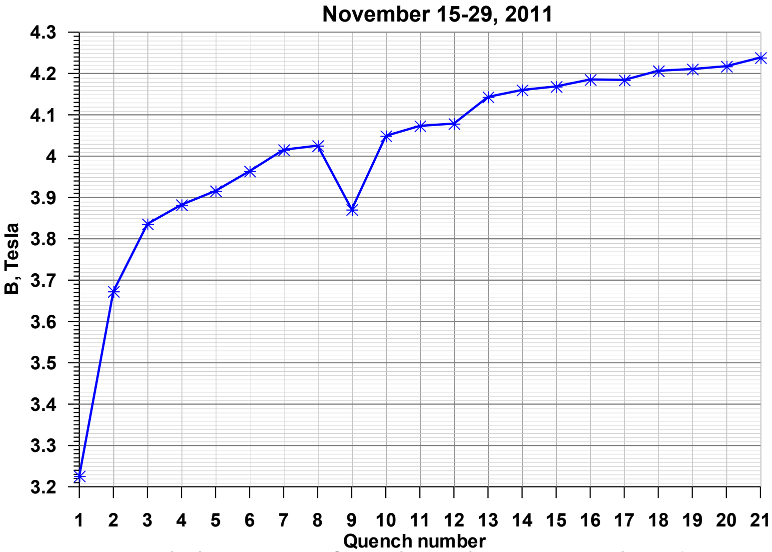


Longitudinal magnetic field distribution at field level 4 Tesla



Spatial spectrum of SC wiggler magnetic field at 4 Tesla. The average wiggler period is 50.607 mm.

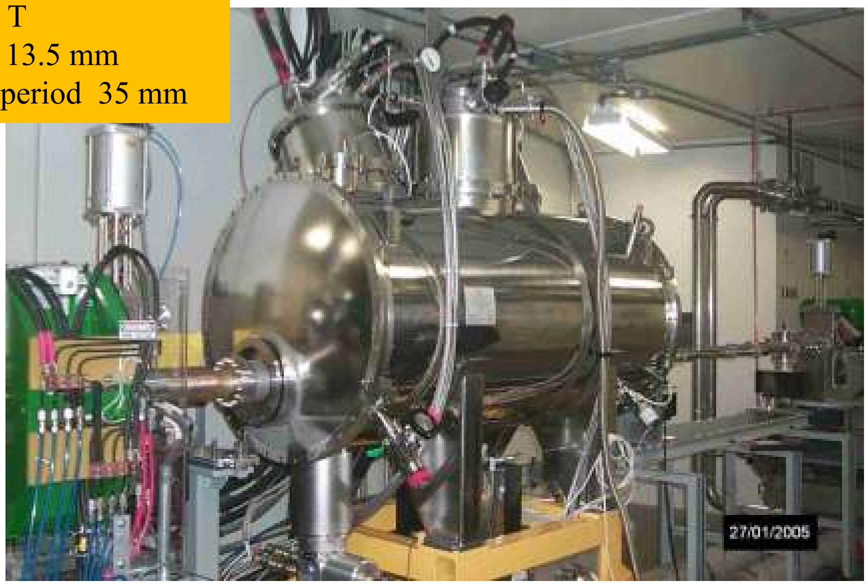
Imaging and medical beamline (L=136 m)



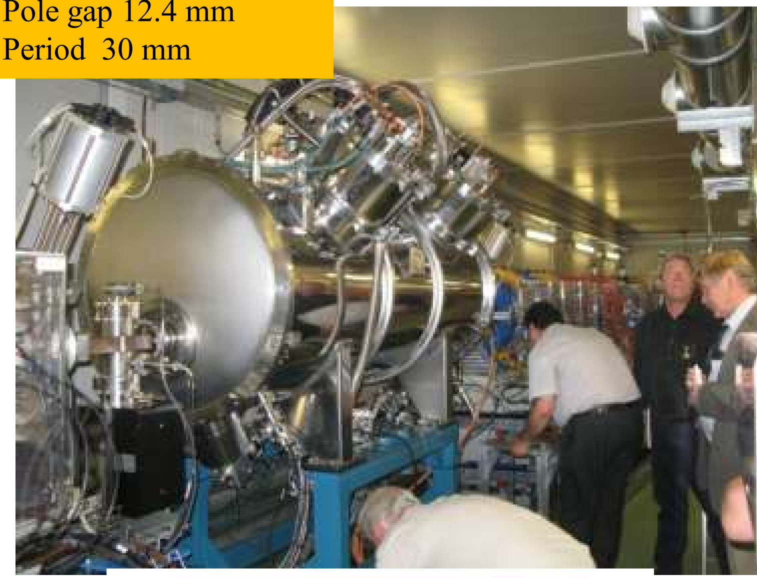
Quench history of multipole SC wiggler during test in bath cryostat

<u>Short period (30-35 mm) wigglers.</u> This type of the wigglers has a K-value about 5-7 and its spectrum properties is very close to undulators. The wiggler installed on SR sources with 2-3 GeV electron energy creates photon flux of very high brightness of X-ray in range of 6--50 keV.

CLS, Canada, 2004
63-pole SC wiggler
Field 2.2 T
Pole gap 13.5 mm
Average period 35 mm

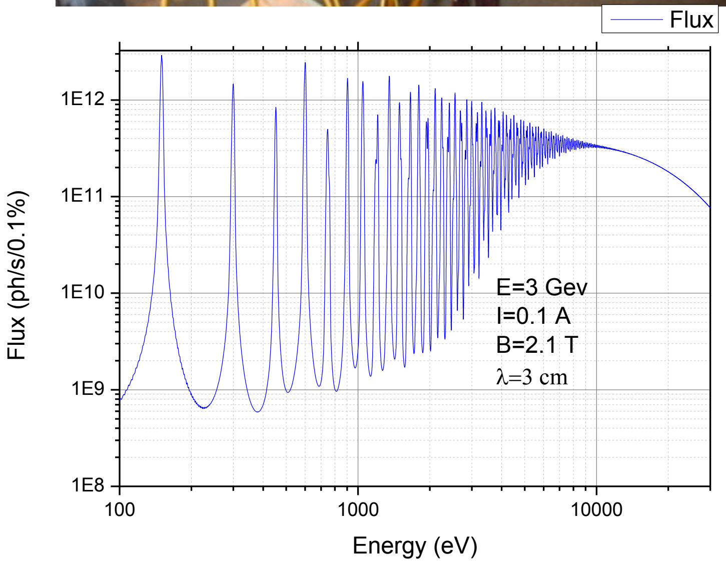


ALBA, Spain, 2010
119-pole SC wiggler
Field 2.2 T
Pole gap 12.4 mm
Period 30 mm



First photon beam from the wiggler

2.1 Tesla 119-pole superconducting wiggler ALBA-CELLS (Spain)



Spectrum photon flux through 1x1 mm^2 at 30m

Materials Science and Powder Diffraction (MSPD) beamline

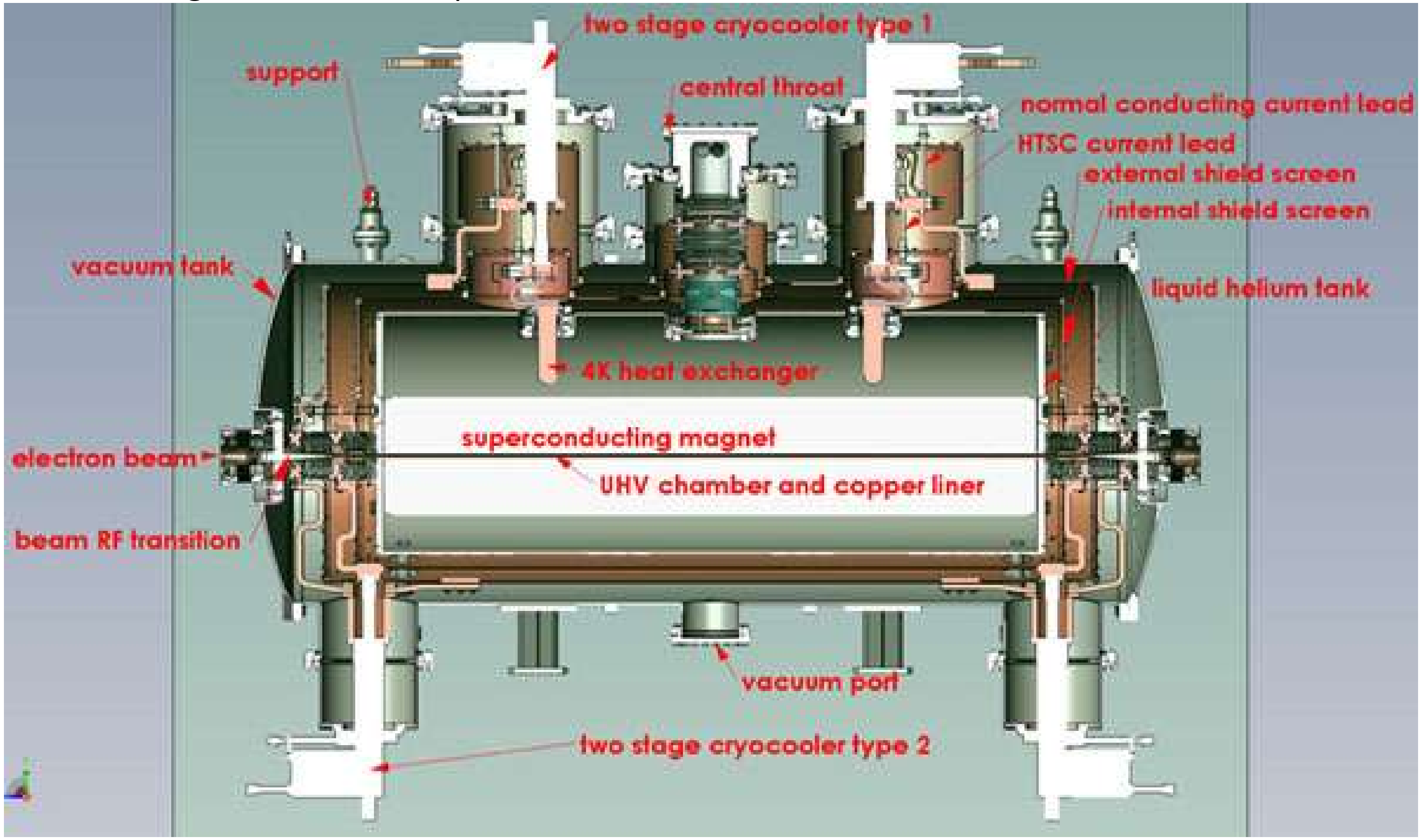
Pole number (main + side)	117+2
Vertical beam aperture, mm Horizontal beam aperture, mm	10 60
Pole gap, mm	12.6
Period, mm	30.3
Maximal field, Tesla Nominal field, Tesla	2.15 2.1
One section windings, material – Nb-Ti Current in section at 2.1 Tesla, A	 440
Stored energy, kJ	36
Liquid helium consumption, liter/ hour	<0.03
Total weight, ton	2.5

Work on creation of a prototype of SC undulator with the period to 15 mm has begun.

Wiggler cryogenic systems

Bath cryostat with liquid helium

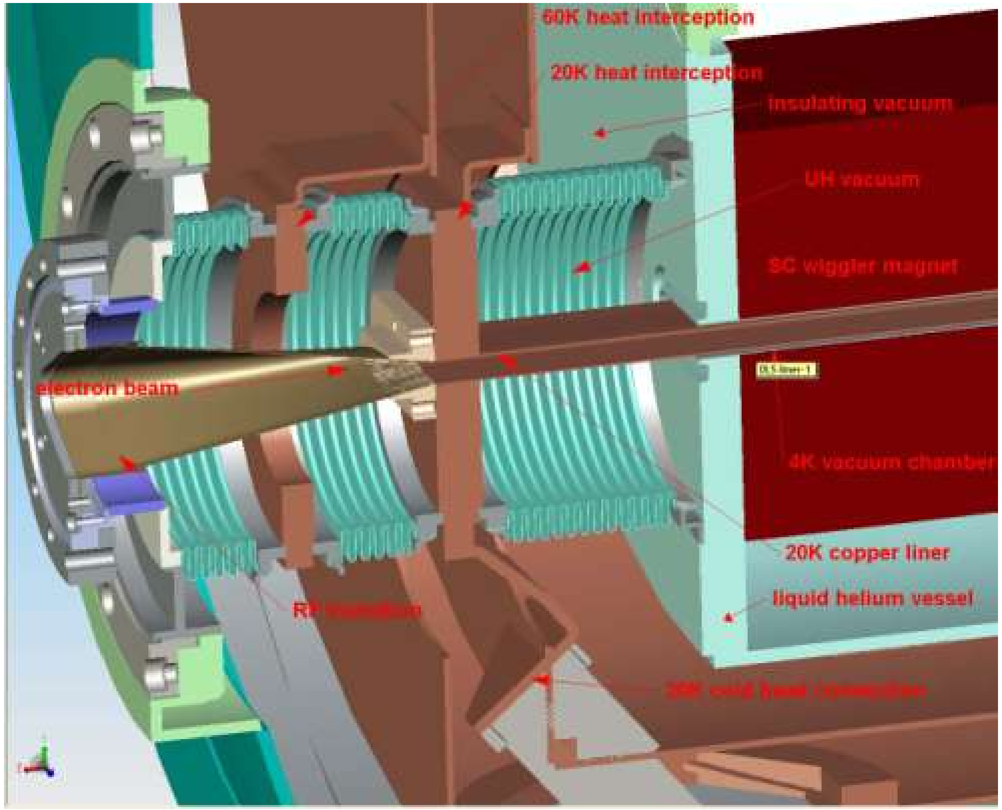
The cryostat consists of external vacuum housing, 60 K and 20 K shield screens, liquid helium vessel with a SC multipole magnet inside, throat, SS vacuum chamber (beam duct) with copper liner inside, two 2-stage coolers with stage temperature 4.2 K/50 K, and two 2-stage cryocoolers with stages temperature 20 K/50 K for shield screen cooling. The average liquid helium consumption per 1-2 years is less 0.03 Litres/hours. Cryocoolers capacity is enough to cool a magnet down to temperatures of 3.2-3.5K.



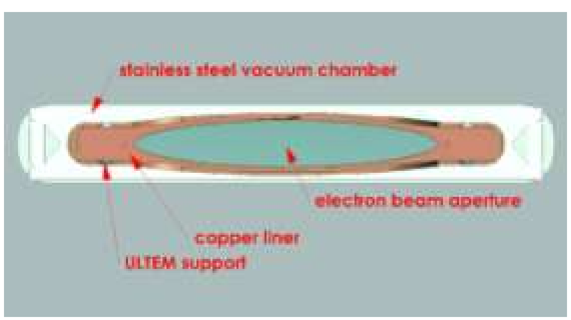
Bath cryostat with zero liquid helium consumption for superconducting multipole wiggler

Wiggler cryogenic systems

Vacuum chamber and copper liner



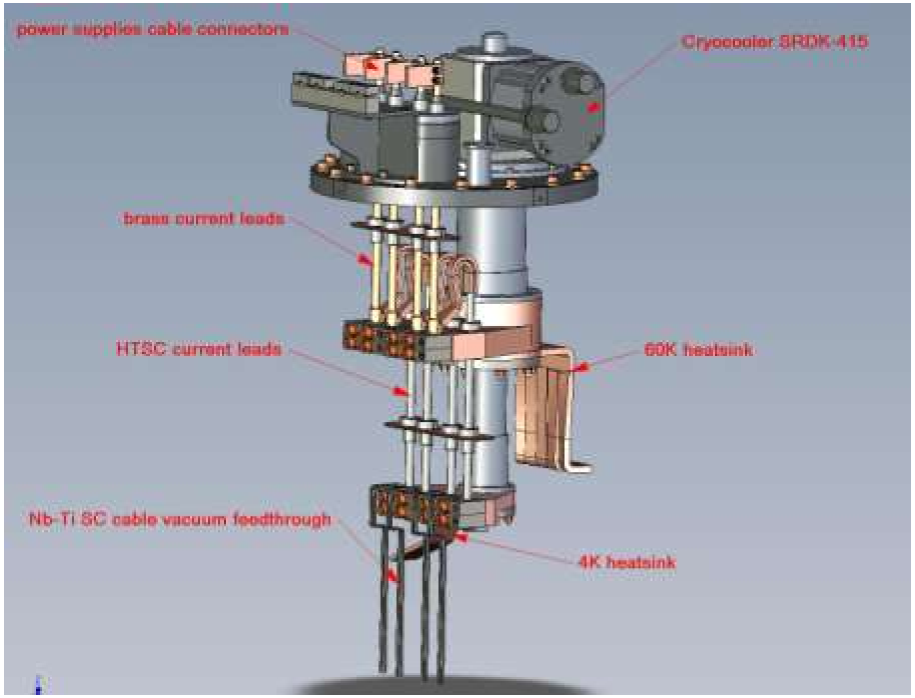
Beam vacuum chamber system



Cross section of cold vacuum chamber with copper liner inside for the medium field wigglers

Copper liner for the high field wigglers

Current leads and quench protection system



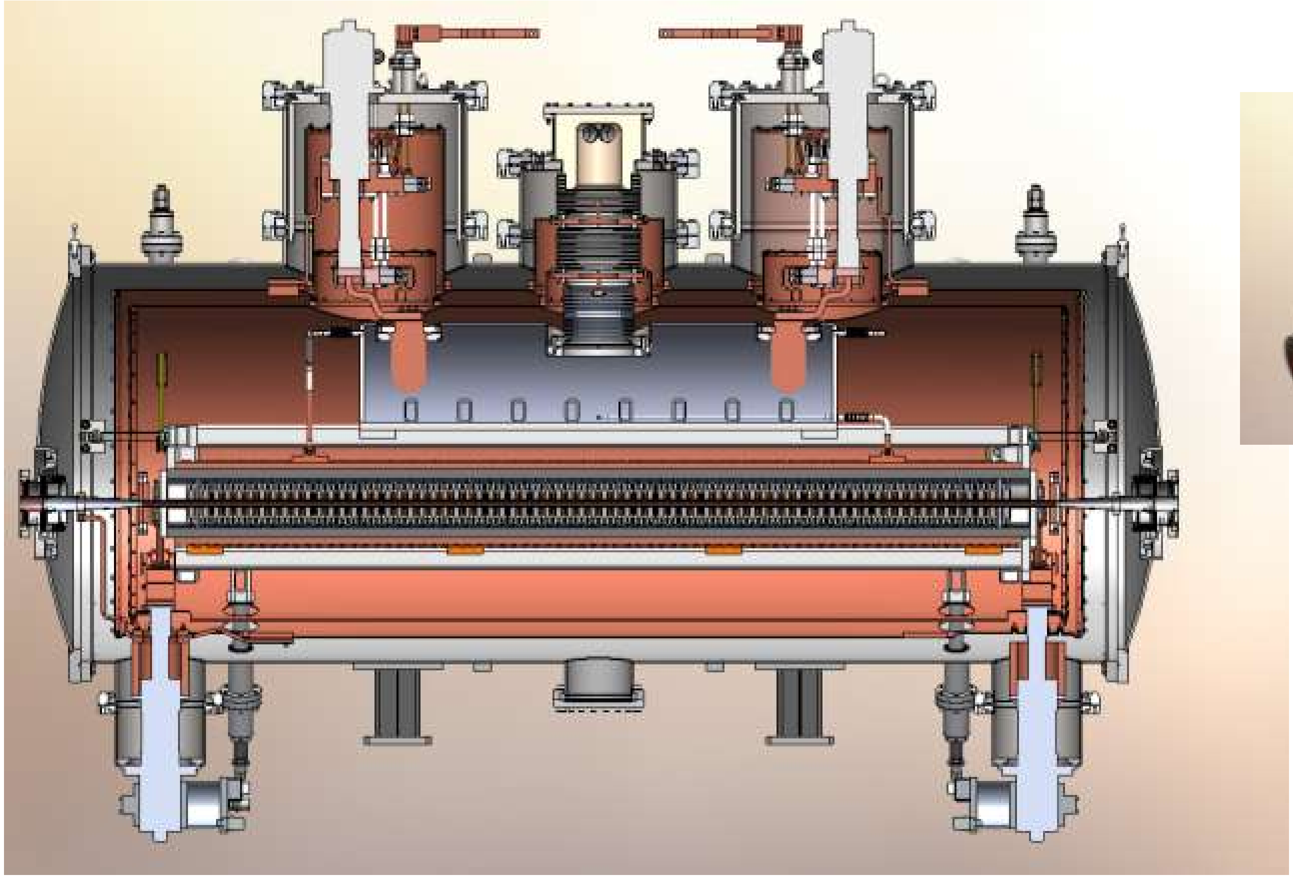
Assembly drawing of current leads block (for case of using 4 power supplies)

Quench protection system with cold diods and dump resistors

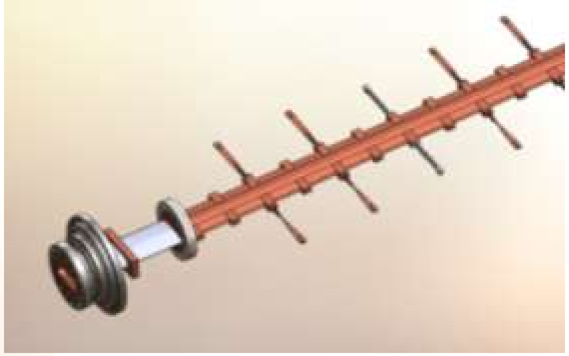
Wiggler cryogenic systems

“Helium free” cryostat with indirect cooling system

The cryostat consists of external vacuum housing, 60 K and 20 K shield screens, liquid helium storage, throat, aluminium vacuum chamber, two 2-stage coolers with stage temperature 4.2 K/50 K, and two 2-stage cryocoolers with stages temperature 20 K/50 K for shield screen cooling. The SC magnet is situated in an insulating vacuum and it is cooling down with help with two phase helium flowing inside tubes and special heat sinks.



Cryostat with indirect cooling of SC multipole wiggler



Vacuum beam chamber. The side bars are for cooling and positioning of the chamber.

Resume and future plans

- **The technology of fabrication of horizontal racetrack coils for multipole magnetic systems with the period from 30 mm and above is debugged. About 20 superconducting multipole magnetic systems are successfully working in the various SR centers as SR generators.**
- **Use of horizontal racetrack coils in multipole magnetic systems have shown the reliability and simplicity in manufacturing. Almost all defects of some coils caused by defect of a wire or errors at winding are finding at room temperature. If a defective pole is found during low temperatures tests in bath cryostat it is replaced easily.**
- **Large number of splices also does not represent any problem due to very small contact resistance**.
- **The magnetic system with horizontal racetrack coils has no any length limitation.**
- **Bath cryostat with liquid helium and cryocoolers has proved as a reliable cryogenic system able during years to work independently in the conditions of limited access**
- **Based on the experience of the fabricated short period wigglers it is possible to assert that the minimum period of magnetic system with horizontal racetrack coils can be limited by 15 mm.**
- **The magnetic system with horizontal racetrack coils with indirect cooling was developed and created**
- **Cryostat for magnet with indirect cooling was developed and created.**
- **Superconducting undulator with horizontal racetrack coils ,with the period of 15-20 mm and with indirect cooling system is planned to be fabricated in the nearest future.**

Thanks for attention