Planar superconducting undulator with neutral pole: test results of the prototype and future plans

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Introduction

Development and creation of new bright structures of sources of SR promotes development and creation of undulators with various parameters for generation of X-ray of high brightness with spatial coherence.

Use of materials of superconductivity (NbTi/Cu, NbSn/Cu) has the considerable advantage in comparison with use of permanent magnets.

Parameters of undulator :

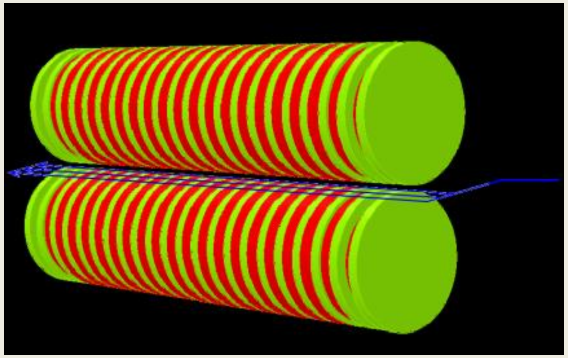
Period: 15-18 mm

Deflection parameter K: 1-2

Phase error : $< 3^{\circ}$

Superconducting undulators

Vertical racetrack coils

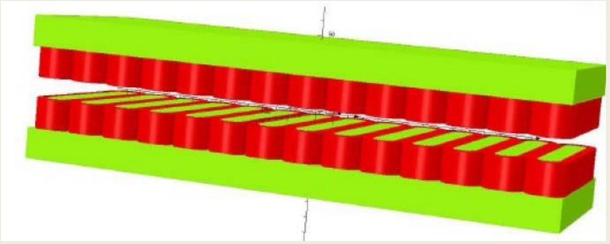


The main vertical field of an undulator is created by horizontal cross currents.

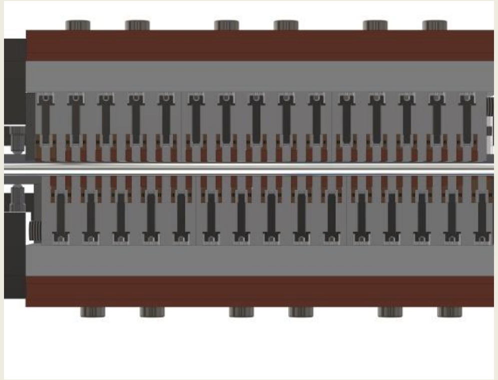
In a 2-dimensional case when in the cross direction of a winding have the infinite size it doesn't matter how currents are closed.

For windings of the limited sizes of coils the currents can be closed in the vertical plane (vertical racetrack coils) or in the horizontal plane (horizontal racetrack).

Horizontal racetrack coils



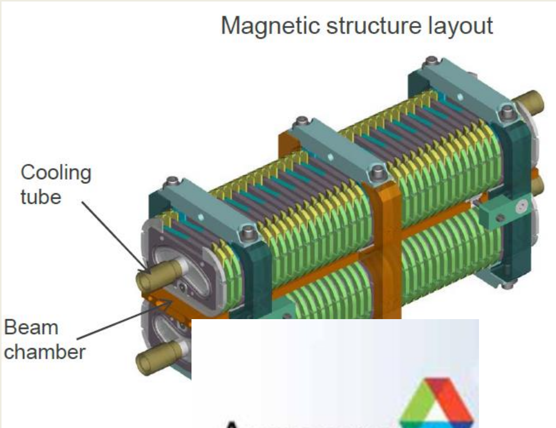
Horizontal racetrack coils with neutral poles



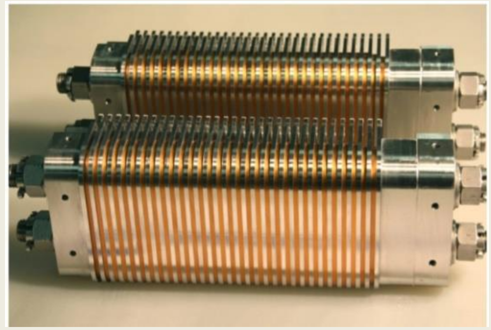
The way of windings with a current closing in the horizontal plane with use of a neutral pole was proposed in BINP.

Superconducting undulators

Vertical racetrack coils



Argonne NATIONAL LABORATORY



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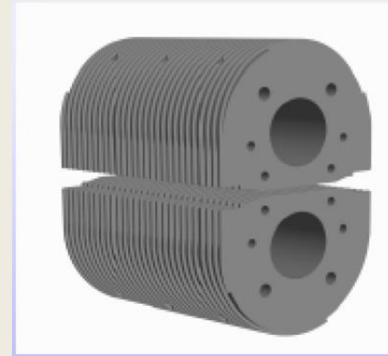

Prototype undulator (Mock-up)

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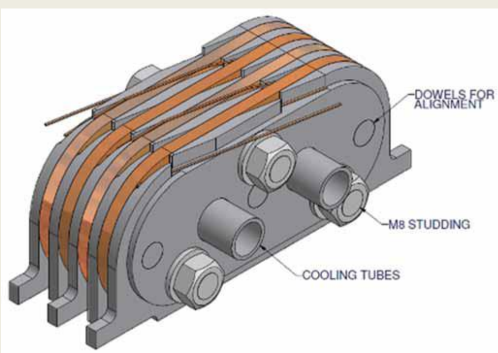

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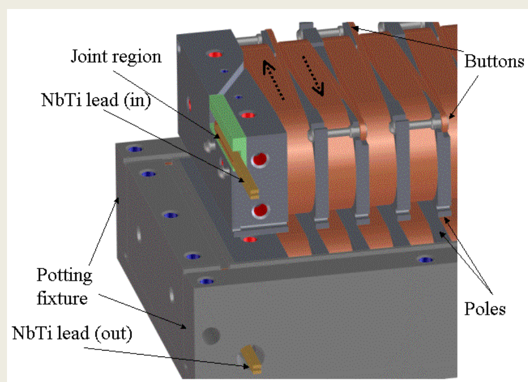
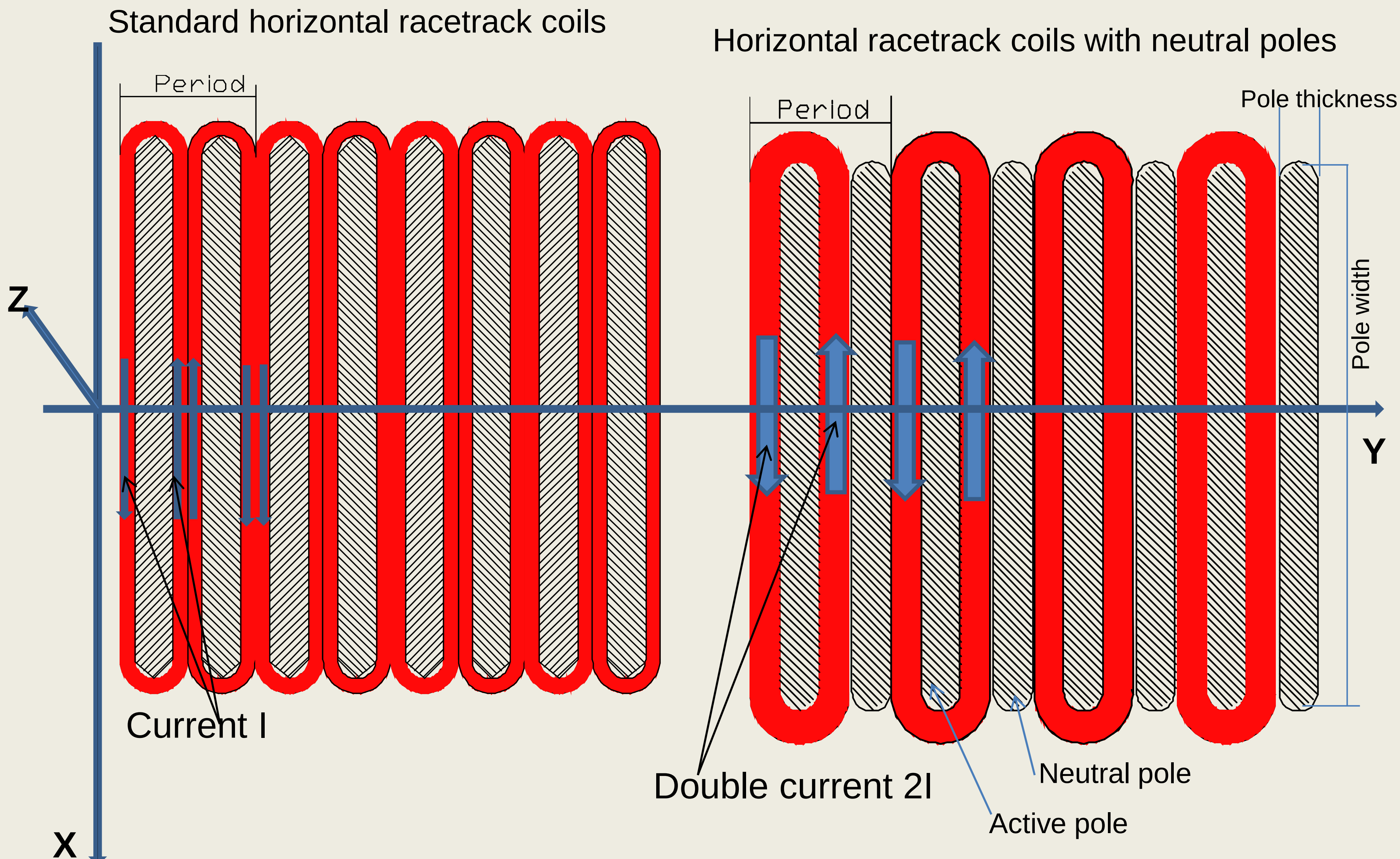


LBNL

Main requirements:

- Period length – 15-20 mm
- Pole number >100
- K-value >1
- Vertical aperture 4.5-10 mm
- Phase error <3°

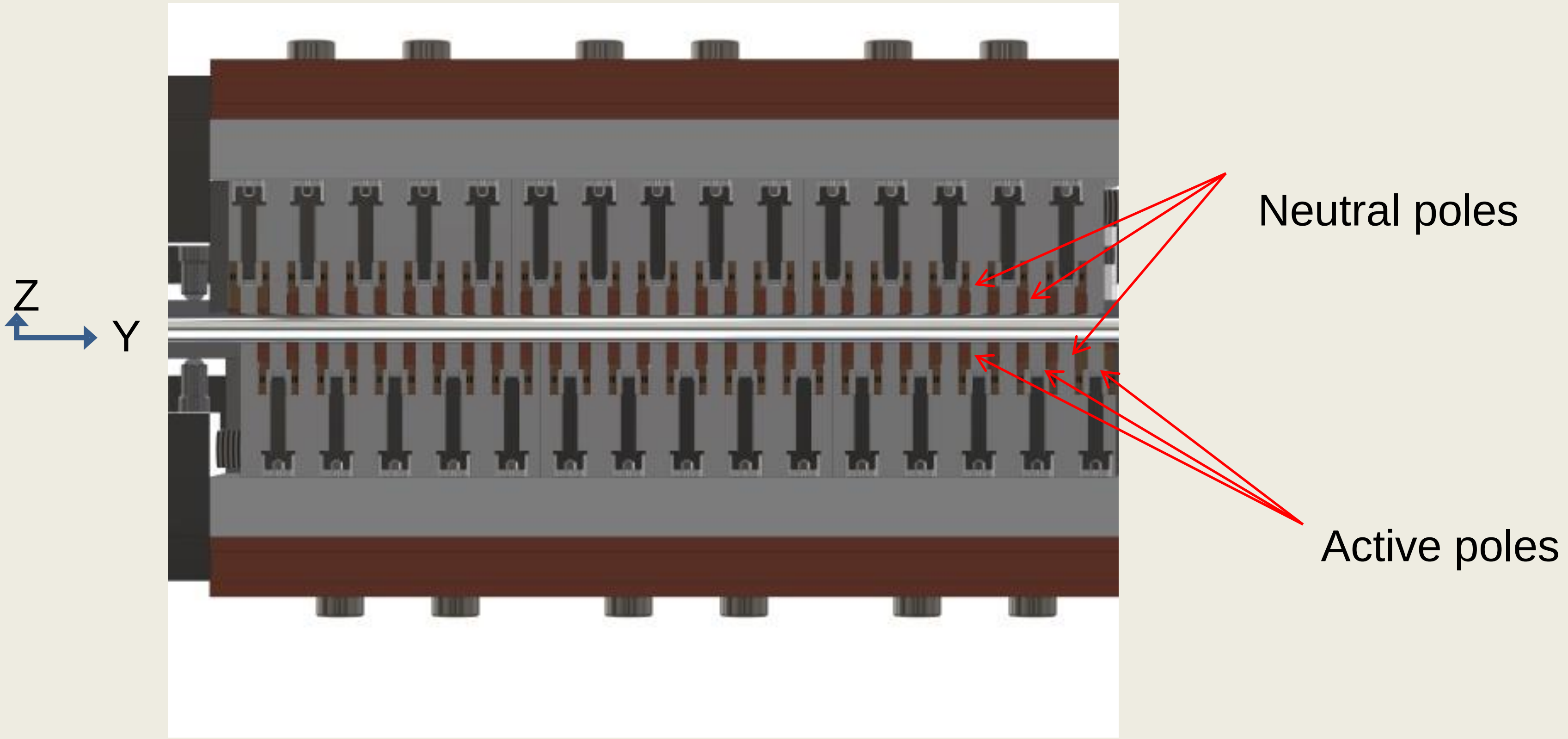
Horizontal racetrack coils



Superconducting undulator prototype with neutral poles

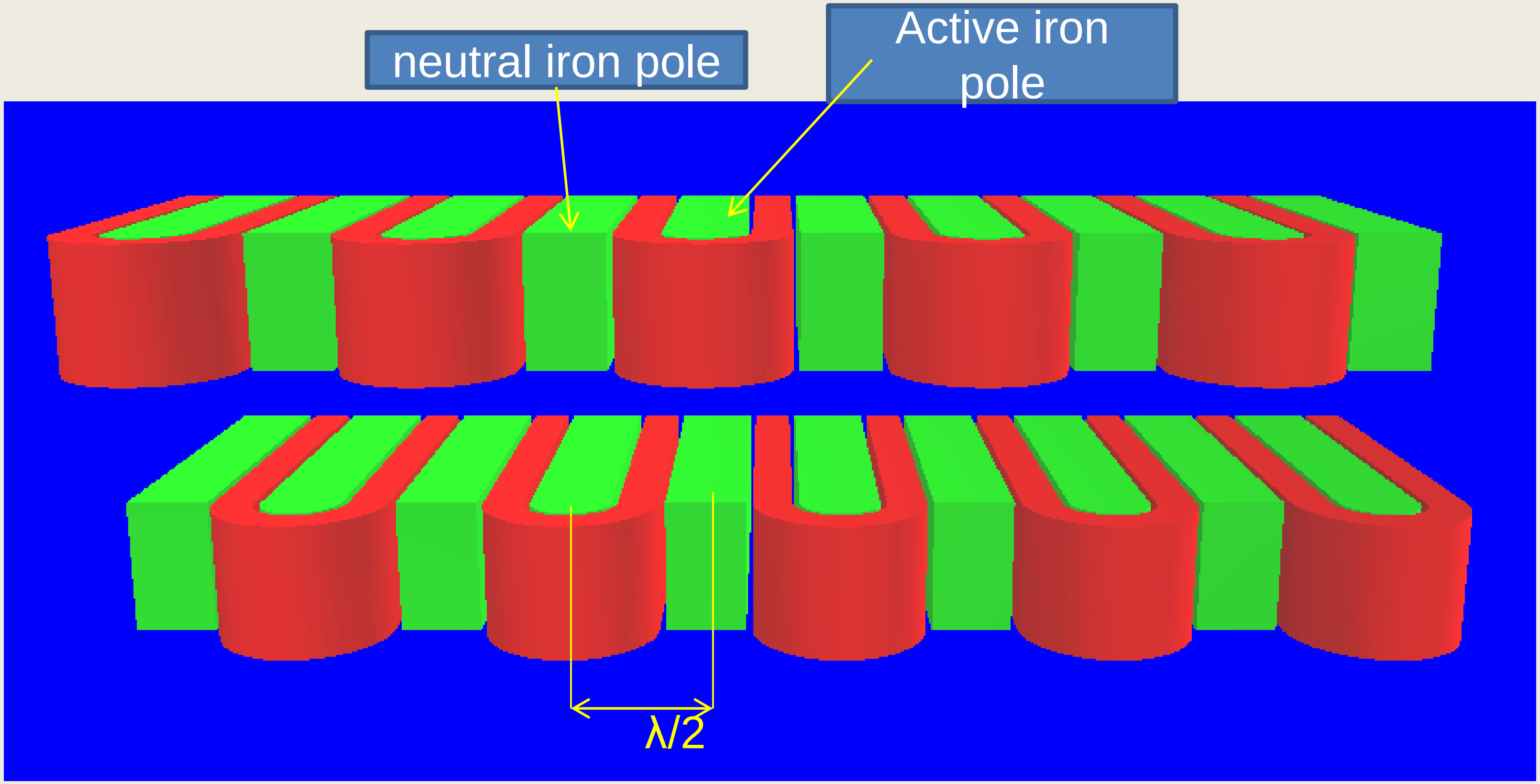
Currents in all windings of poles flow equally so that for case when the halves of top and bottom assembly of a magnet set exactly one opposite another in a lengthwise direction   the vertical field in the median plane is equal to zero. In order to create the vertical field the top and bottom halves of the magnet have to be displaced on a half of the undulator period.

Horizontal racetrack coils with neutral poles



Superconducting undulator prototype with neutral poles

The magnet consists of two identical top and bottom halves. Windings are reeled up on the iron core. Between windings the iron core without windings (a neutral pole) is inserted. A combination a winding + a neutral pole make one period of an undulator. Halves of an undulator are powered equally and turned to each other so that magnetic fields are directed towards to each other. For creation of the cross field in the median plane one half is shifted concerning another on a half of the period.

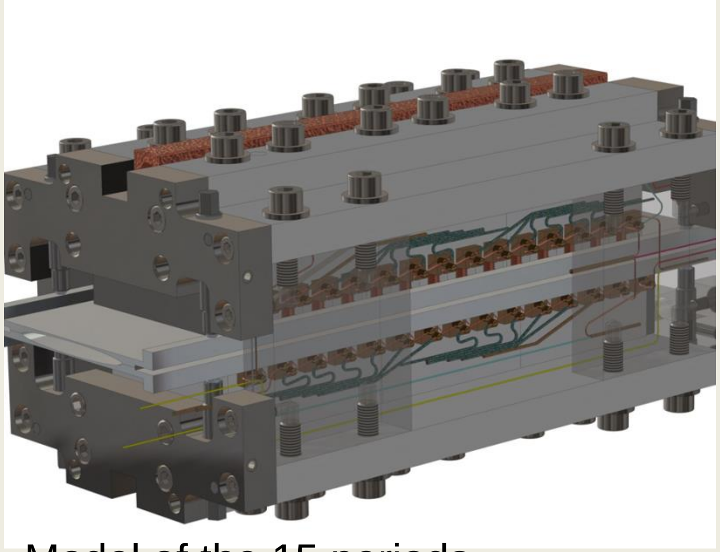


Superconducting undulator prototype with neutral poles

The prototype of superconducting undulator with the period of 15.6 mm is designed, fabricated and successfully tested in BINP. Windings type of the prototype are made as horizontal racetrack. Pole gap - 8 mm, number of the periods 15, maximal field was achieved 1.2 T.

The superconducting NbTi/Cu wire with diameter of 0.5/0.55 mm was used for production of single-section windings.

The maximum current 500 A that corresponds to a magnetic field of ~1.2 T in the median plane. Cooling of undulator is proposed to use of cryocoolers with heat tubes and materials with high heat conductivity.



Model of the 15 periods superconducting undulator prototype

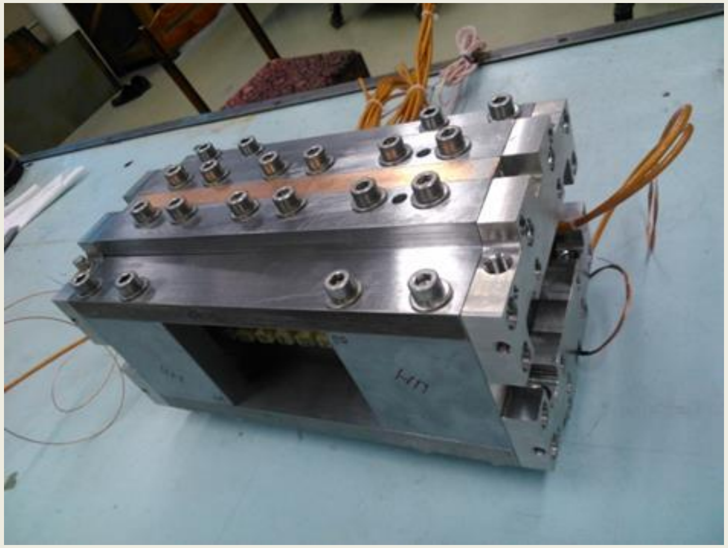


Photo of the undulator prototype

Superconducting undulator prototype with neutral poles

The framework of the undulator is made of the soft iron.
Vertical ribs play a role of neutral poles.
Windings with iron cores are inserted into grooves.
Distances between grooves are equal to the undulator period.

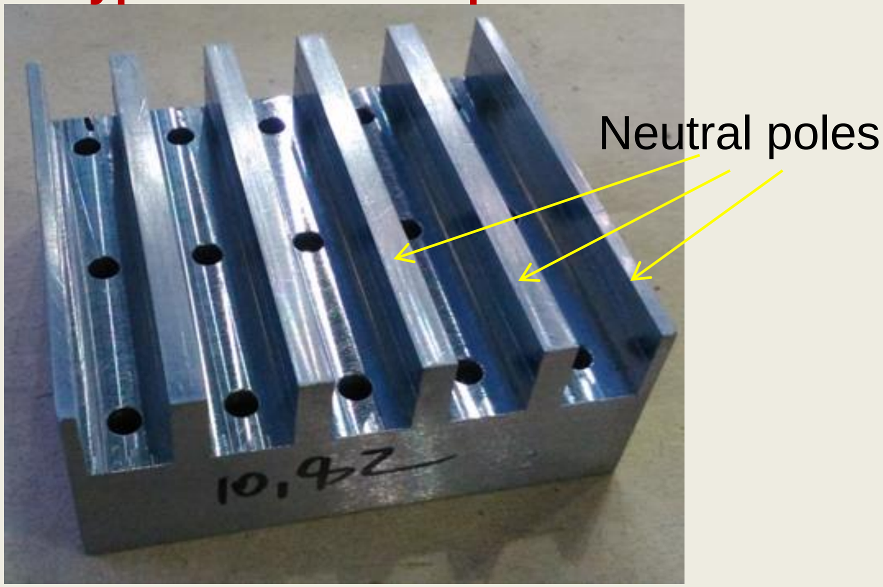
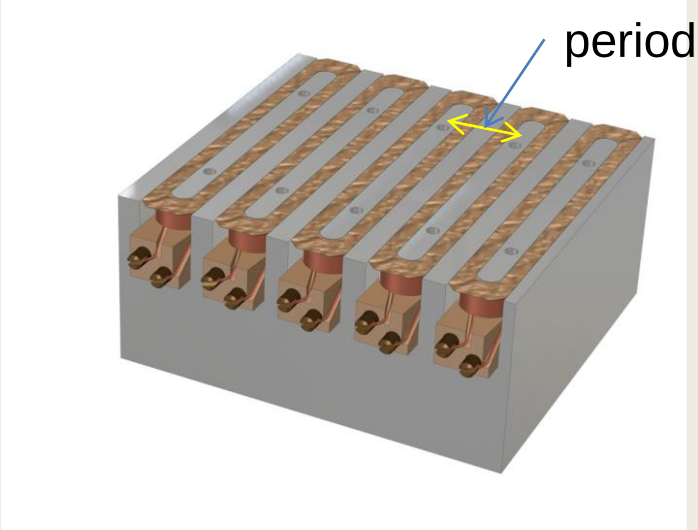
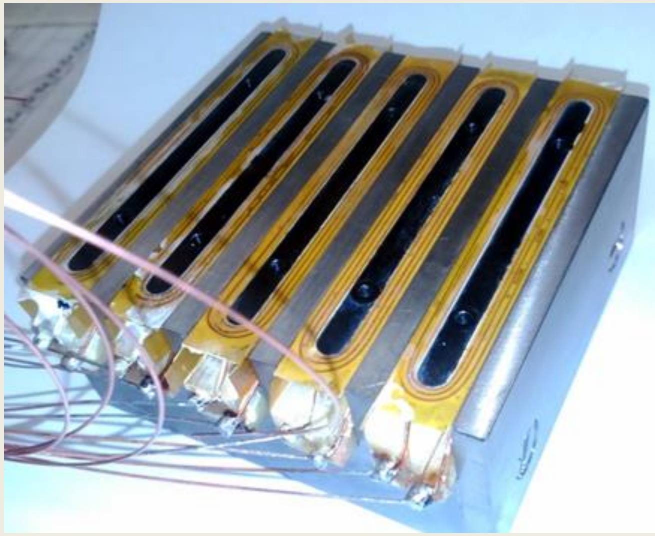


Photo of iron frame for 5 undulator periods

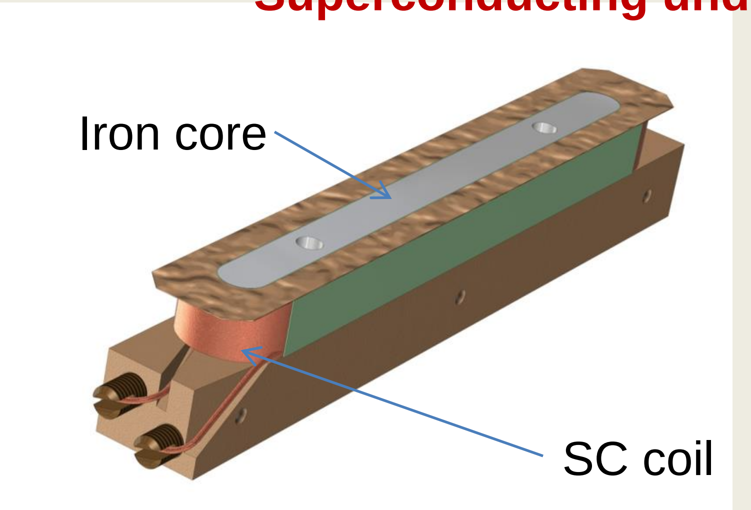


Iron frame filled by poles (model)



Iron frame filled by poles (photo)

Superconducting undulator prototype with neutral poles



Pole -main element of the undulator (model)

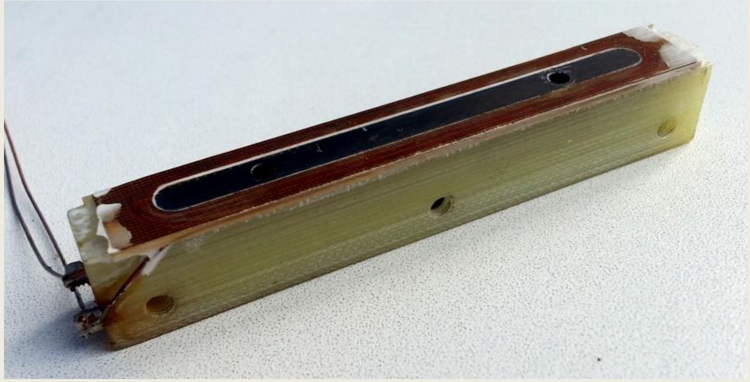
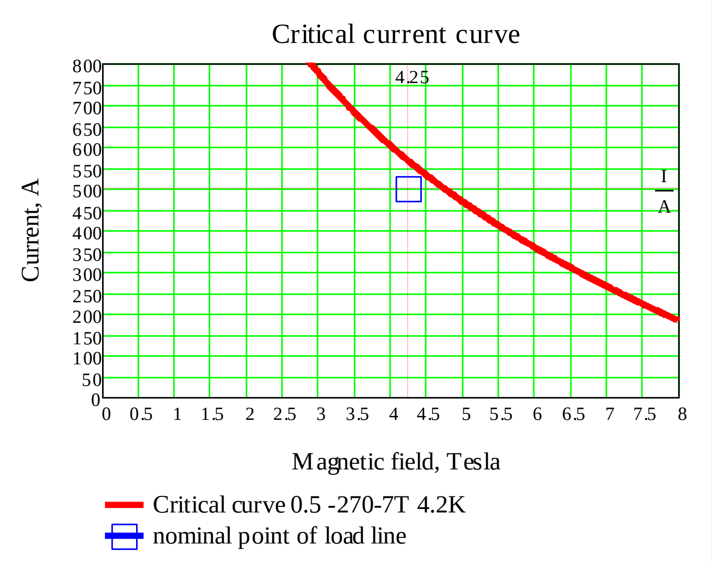


Photo of main pole of the undulator made with use wet winding technology



The working point position on I-B diagramm of used SC wire (1.2T in median plane).

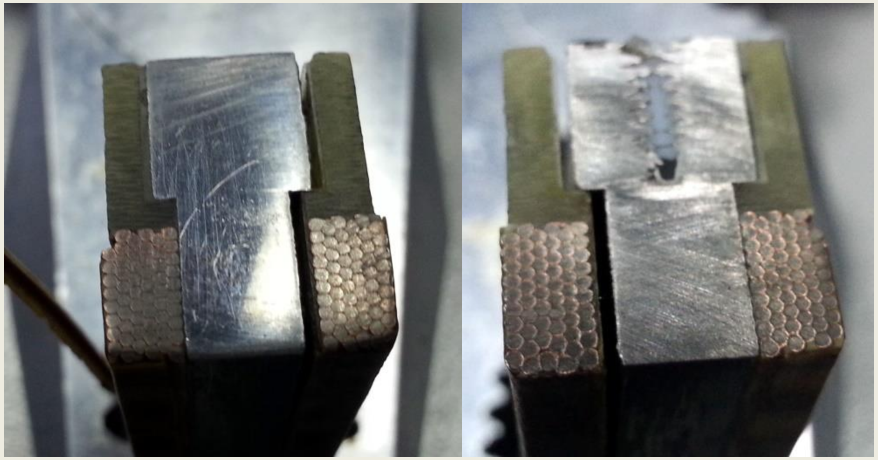
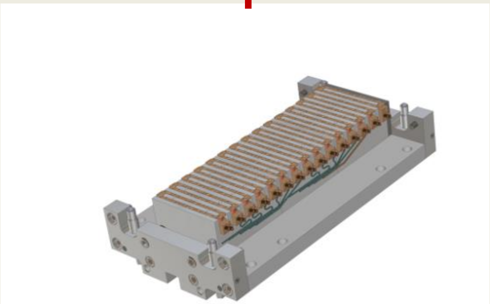
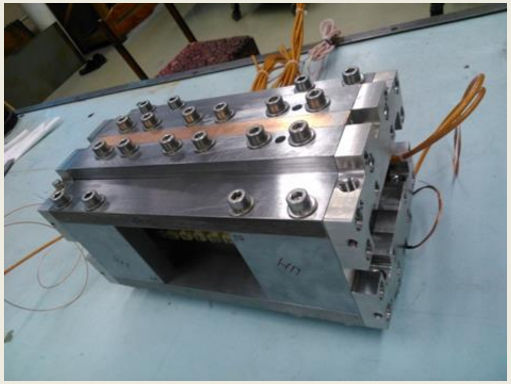


Photo of cut main pole of the undulator made with use dry winding technology (wind and impregnation)

Superconducting undulator prototype with neutral poles



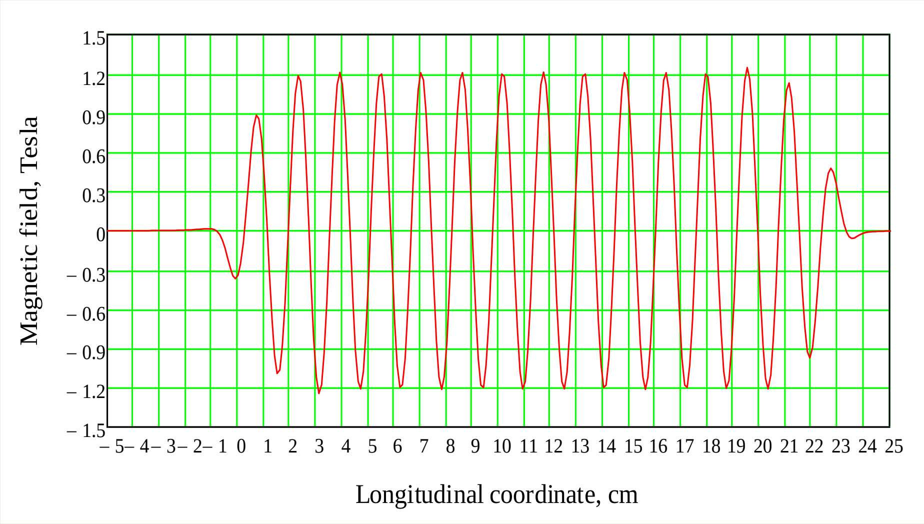
Model of ½ 15 periods undulator



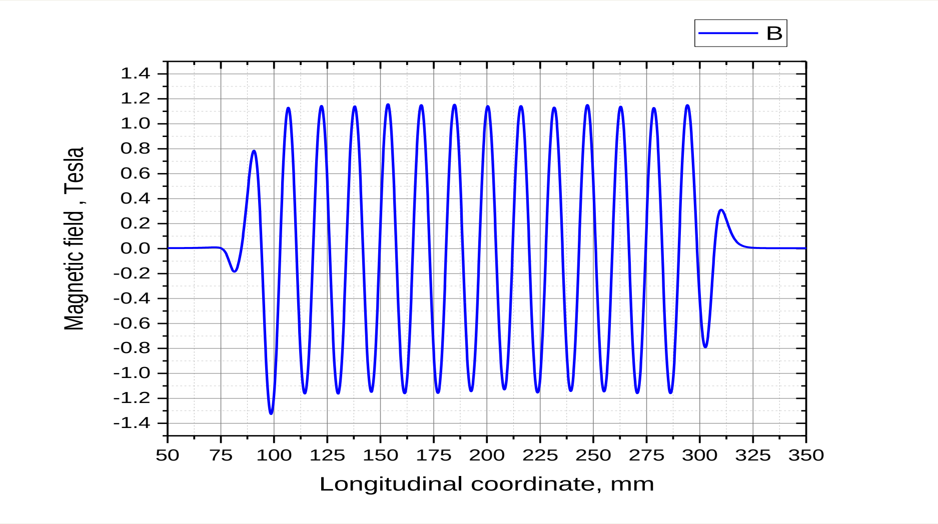
Photos of SC undulator with neutral poles

Position of the frames. Upper and bottom frames are shifted of ½ period

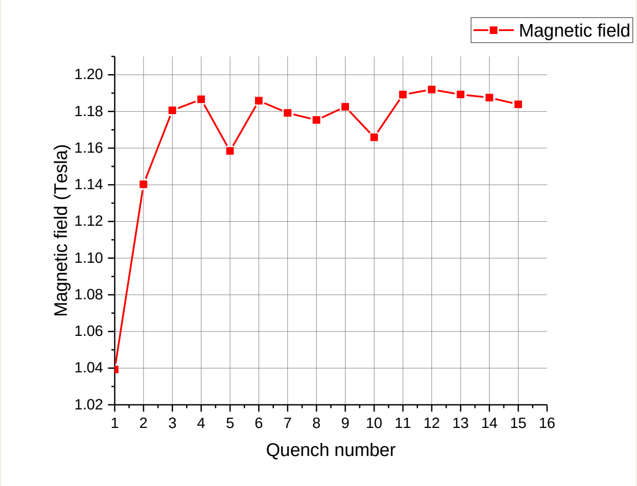
Superconducting undulator prototype with neutral poles (test results)



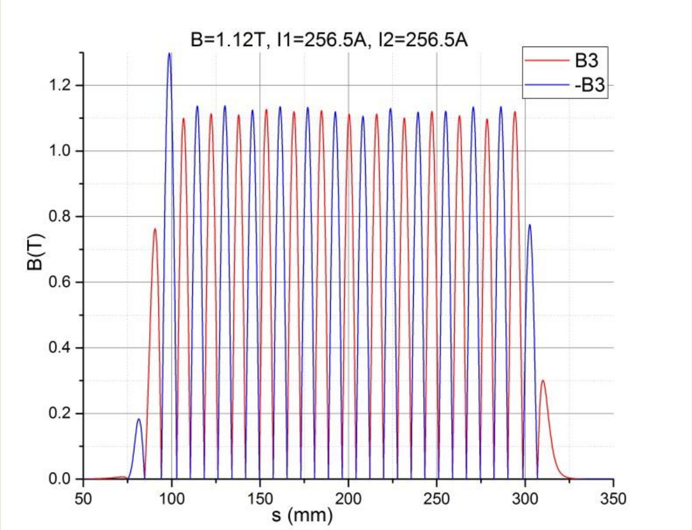
Calculated field: λ=15.6 mm, gap=8 mm, I=500 A



Measured field: λ=15.6 mm, gap=8 mm, I=512 A



Quench history of the prototype inside vacuum cryostat with indirect cooling system



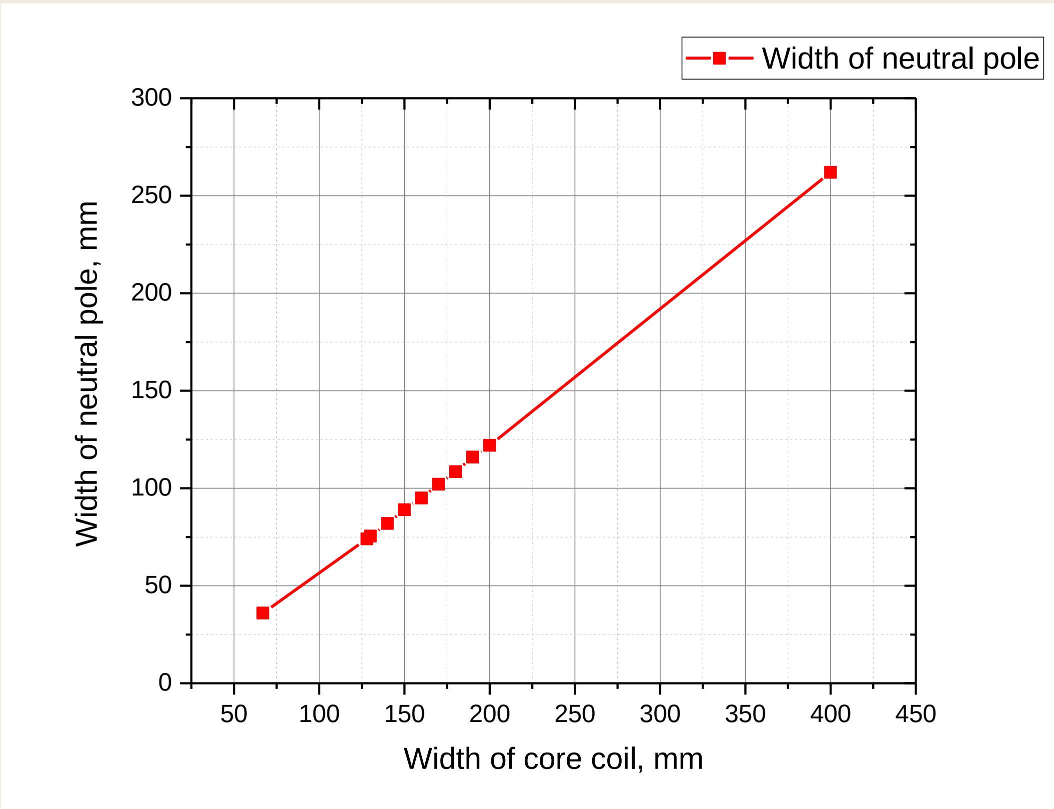
Absolute value of the measured field

Test results resume

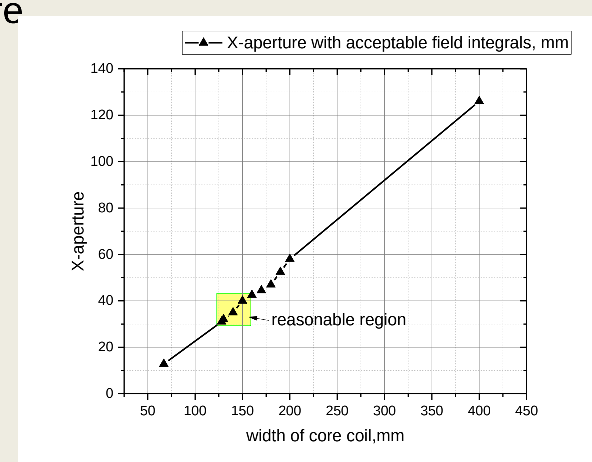
- Manufacture of the horizontal racetrack type windings allows to carry out an individual inspection of each pole on identity and existence of violations of isolation.
- High precision of production of the windings and the framework is provided (an arrangement of coils concerning the magnet median plane and period)
- During quench training the magnet quickly comes to the level of the maximal field in spite of the fact that poles were not exposed to addition compression.
- At identical cross sectional dimensions of the active and neutral poles enough strong dependence of integral of the horizontal transversal field from horizontal transversal coordinate is observed. For elimination of this dependence cross sectional dimensions of the active and neutral poles have to be different.

Parameters of neutral and active cores

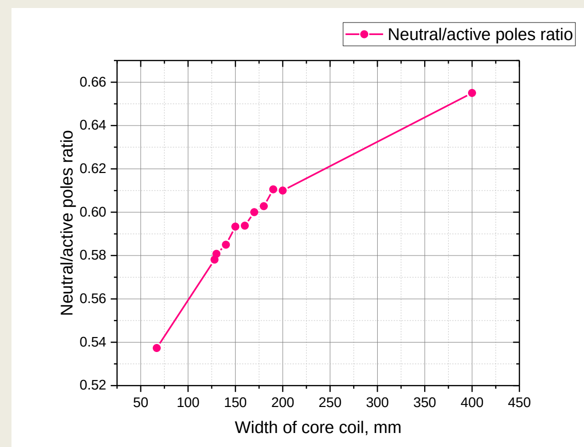
The proper correlation of width of the active and neutral poles creates aperture area of a weak dependence of field integrals for horizontal and vertical shifts concerning an undulator axis. Width ratio of neutral and active poles were calculated taking into account that field integrals should be less than 10^-4 T*m in region +/-20 mm in horizontal aperture



Width of neutral pole versus width of active pole. The ration provides maximal horizontal area to keep field integrals inside 10^-4 T*m

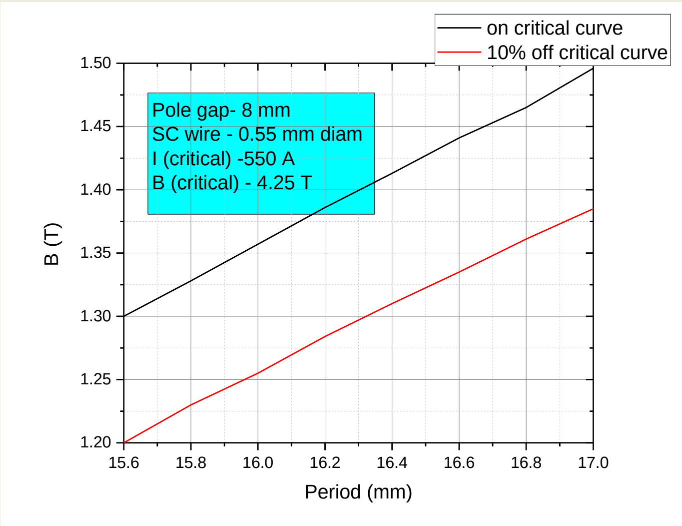


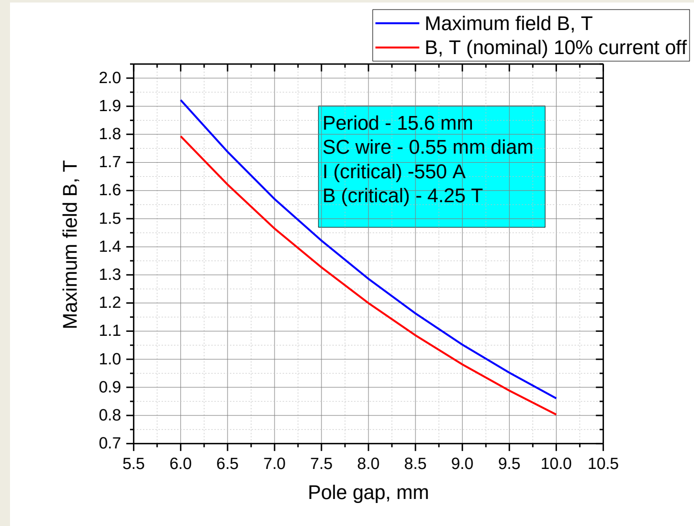
X-aperture with acceptable field integrals versus width of core coils



Ratio of neutral and active poles widths versus width of core coils

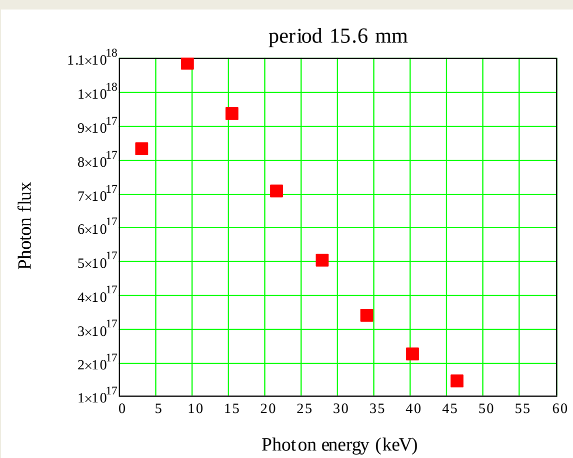
General undulator field properties

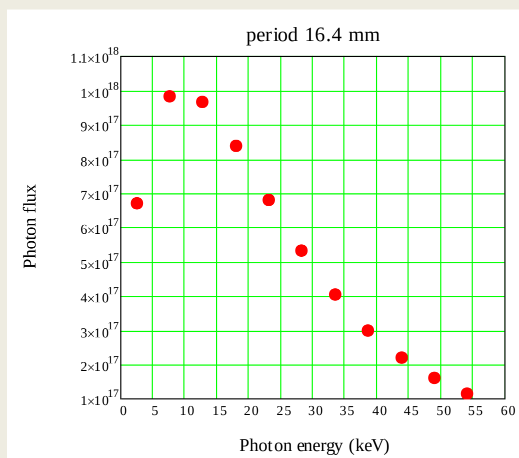


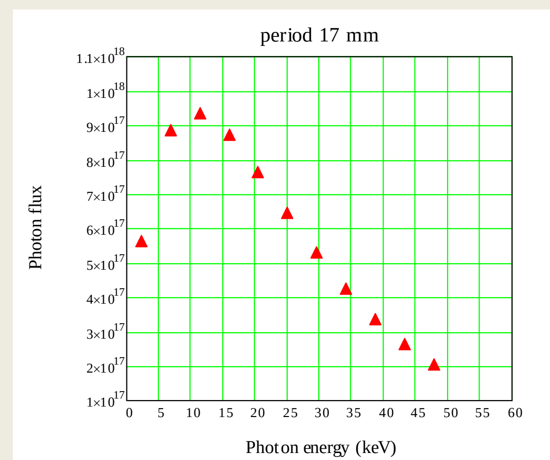


Magnetic field versus period length at pole gap 8 mm

Magnetic field versus pole gap at period length 15.6 mm



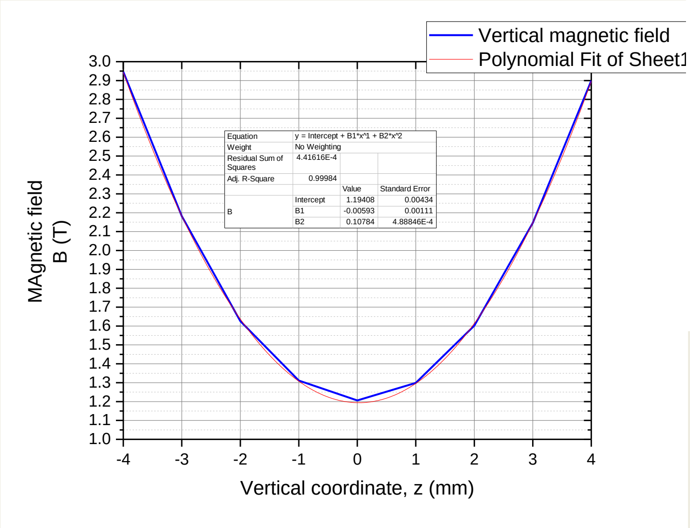


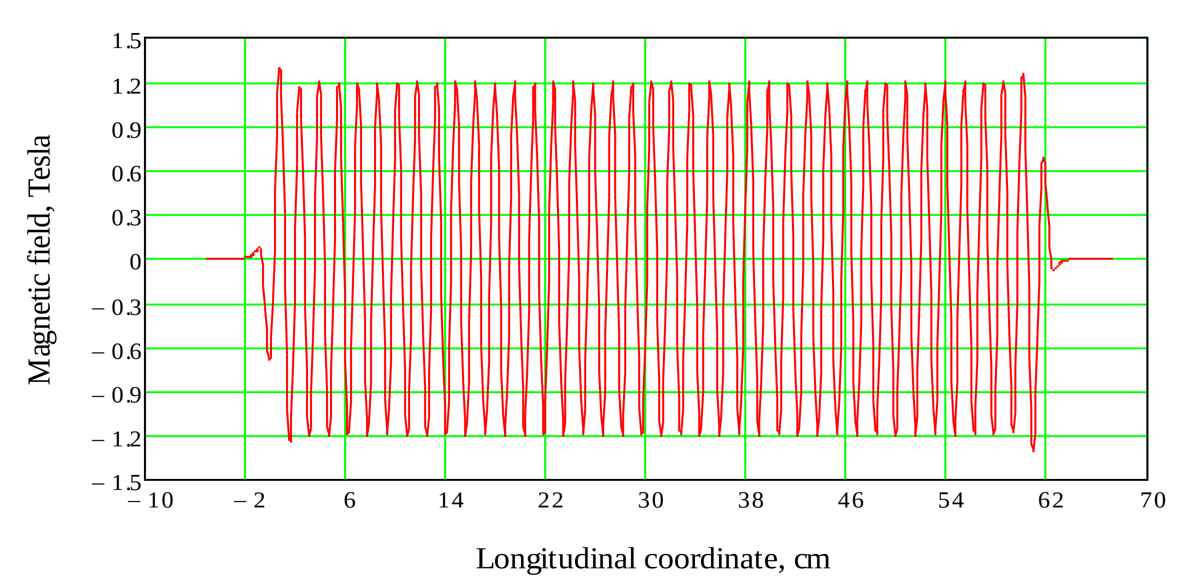


Odd harmonic photon flux for different undulator periods (E=3 GeV, I=0.1A, L=2m)

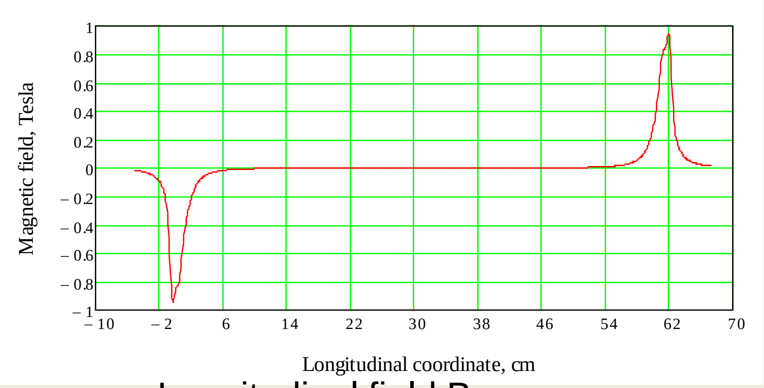
New undulator prototype (calculations)

Parameters:
Pole gap – 8 mm
Period – 15.6 mm
Number periods – 40
Active pole – 150 mm
Neutral pole – 89 mm

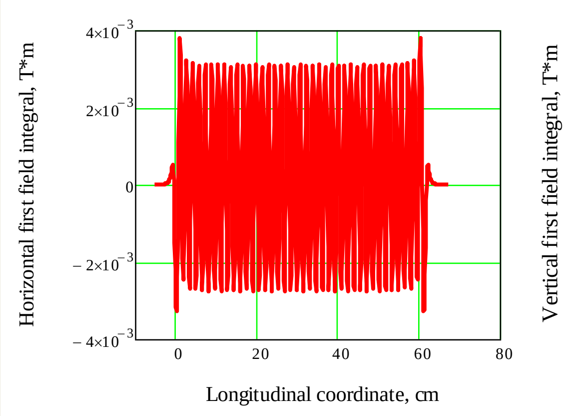




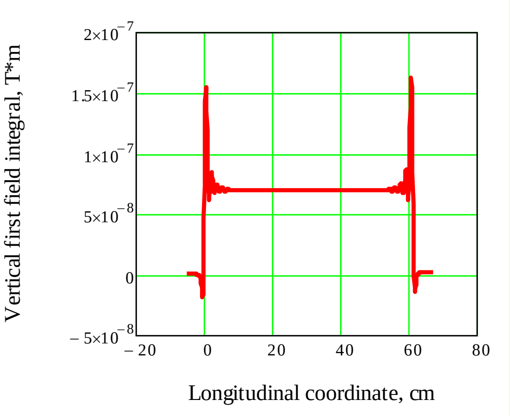
Vertical field Bz versus y



Longitudinal field By versus y



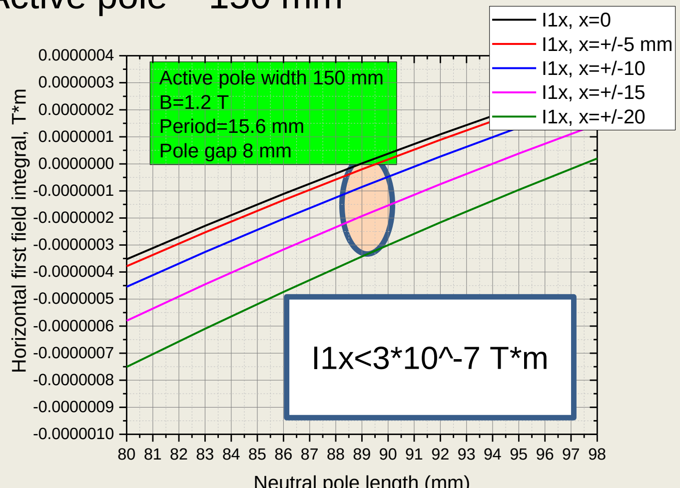
First field integral
X-coordinate



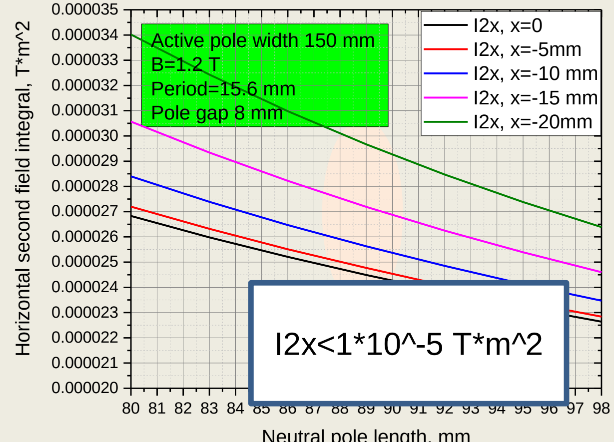
First field integral
z-coordinate

Field quality

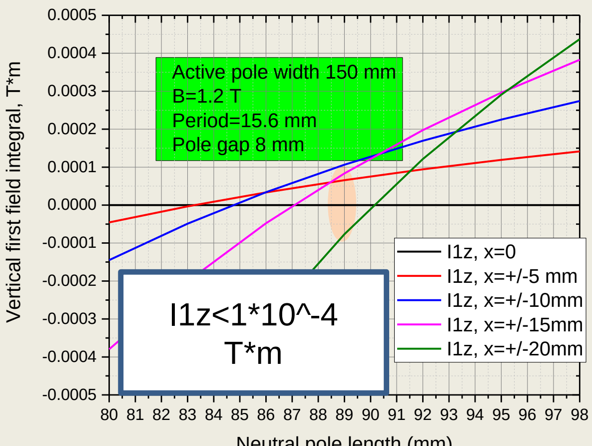
Parameters:
Pole gap – 8 mm
Period – 15.6 mm
Active pole – 150 mm



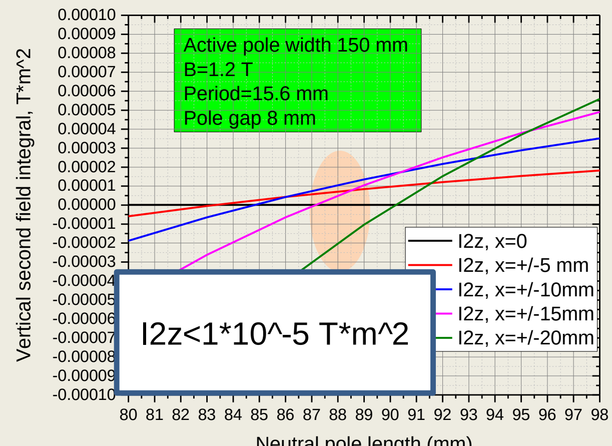
Horizontal first field integral versus neutral pole length for different x-values



Horizontal second field integral versus neutral pole length for different x-values

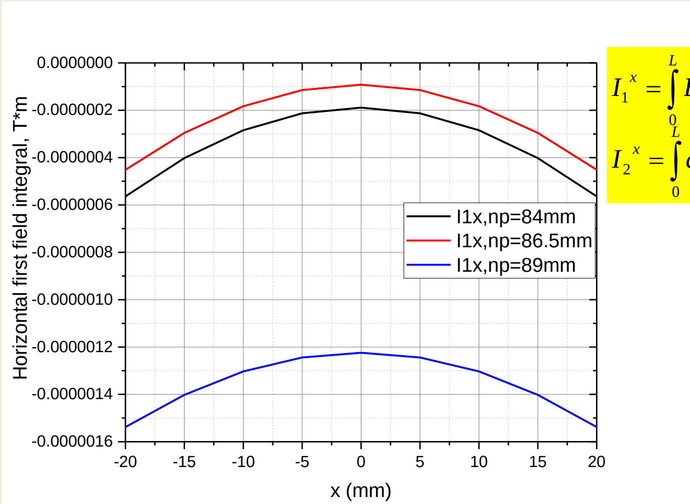


Vertical first field integral versus neutral pole length for different x-values



Vertical second field integral versus neutral pole length for different x-values

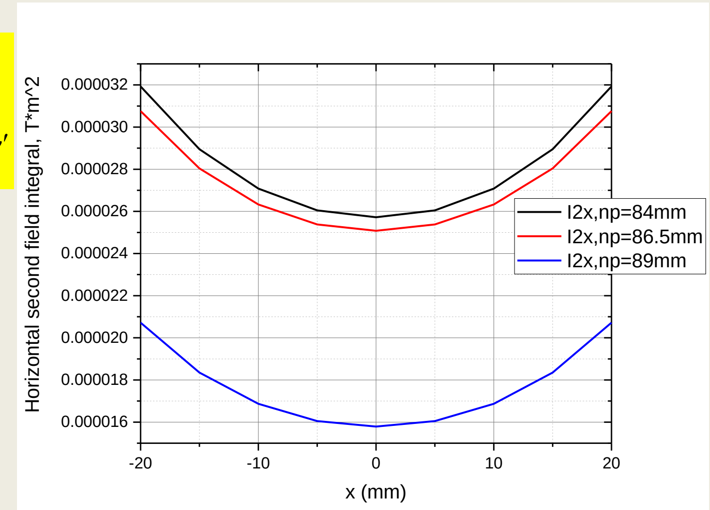
Field integrals in beam aperture



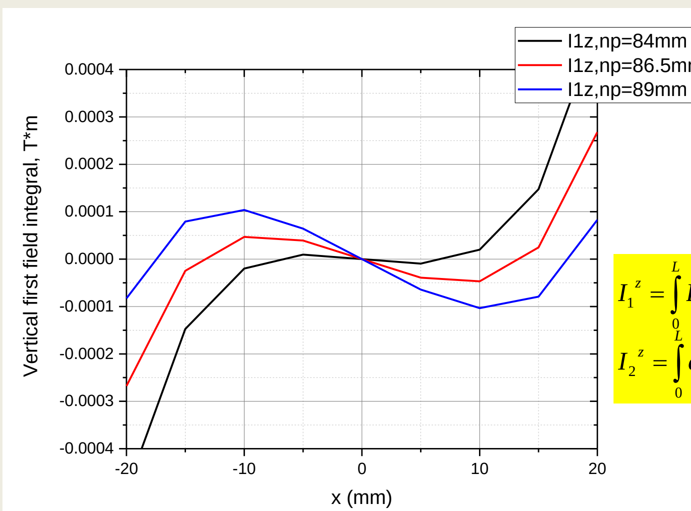
I1x integral versus x-coordinate for different neutral pole width.

$$I_1^{\,x} = \int_0^L B_z(y)\cdot dy$$

$$I_2^{\,x} = \int_0^L dy \int_0^s B_z(y')\cdot dy'$$



I2x integral versus x-coordinate for different neutral pole width



I1z integral versus x-coordinate for different neutral pole width

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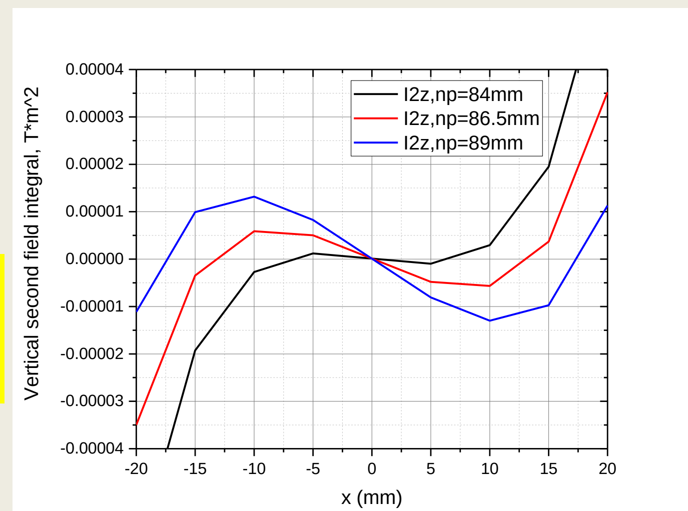
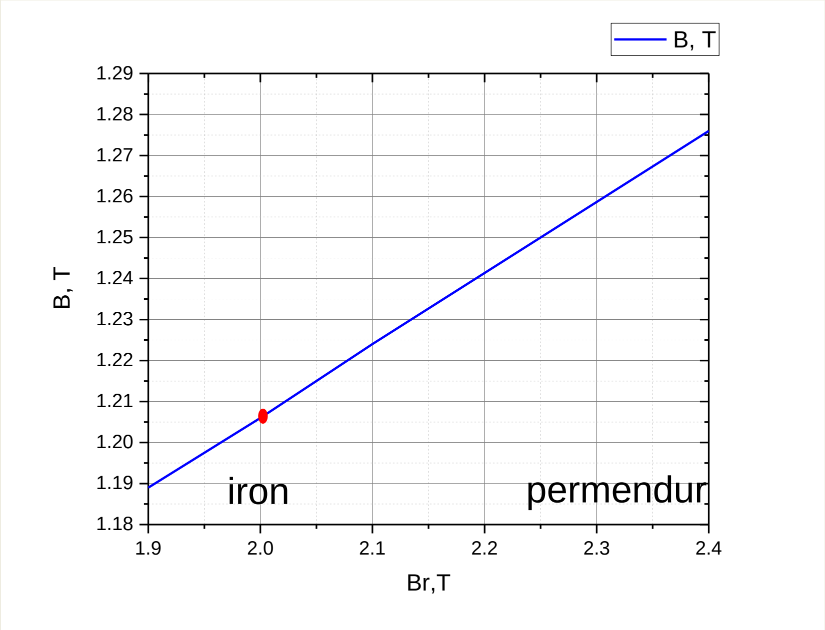
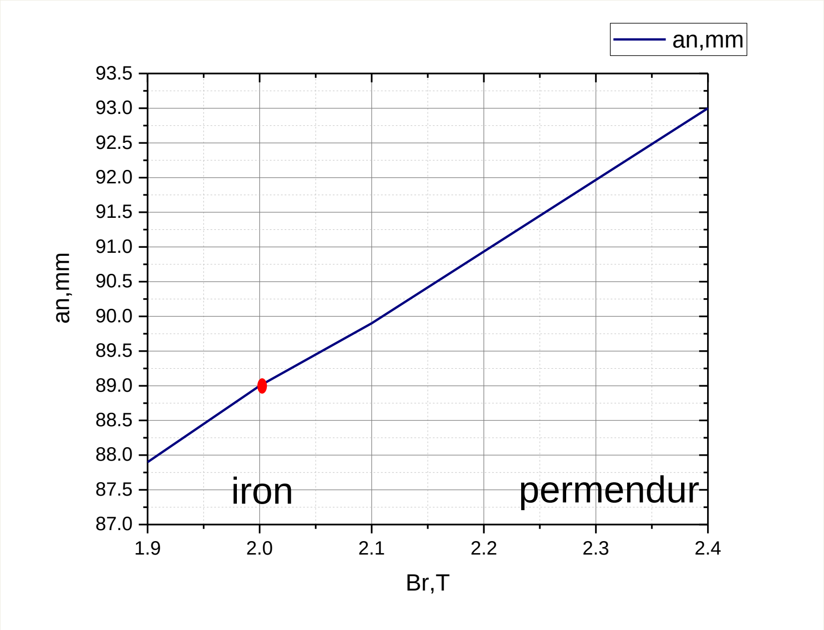


I2z integral versus x-coordinate for different neutral pole width

Influence of material properties

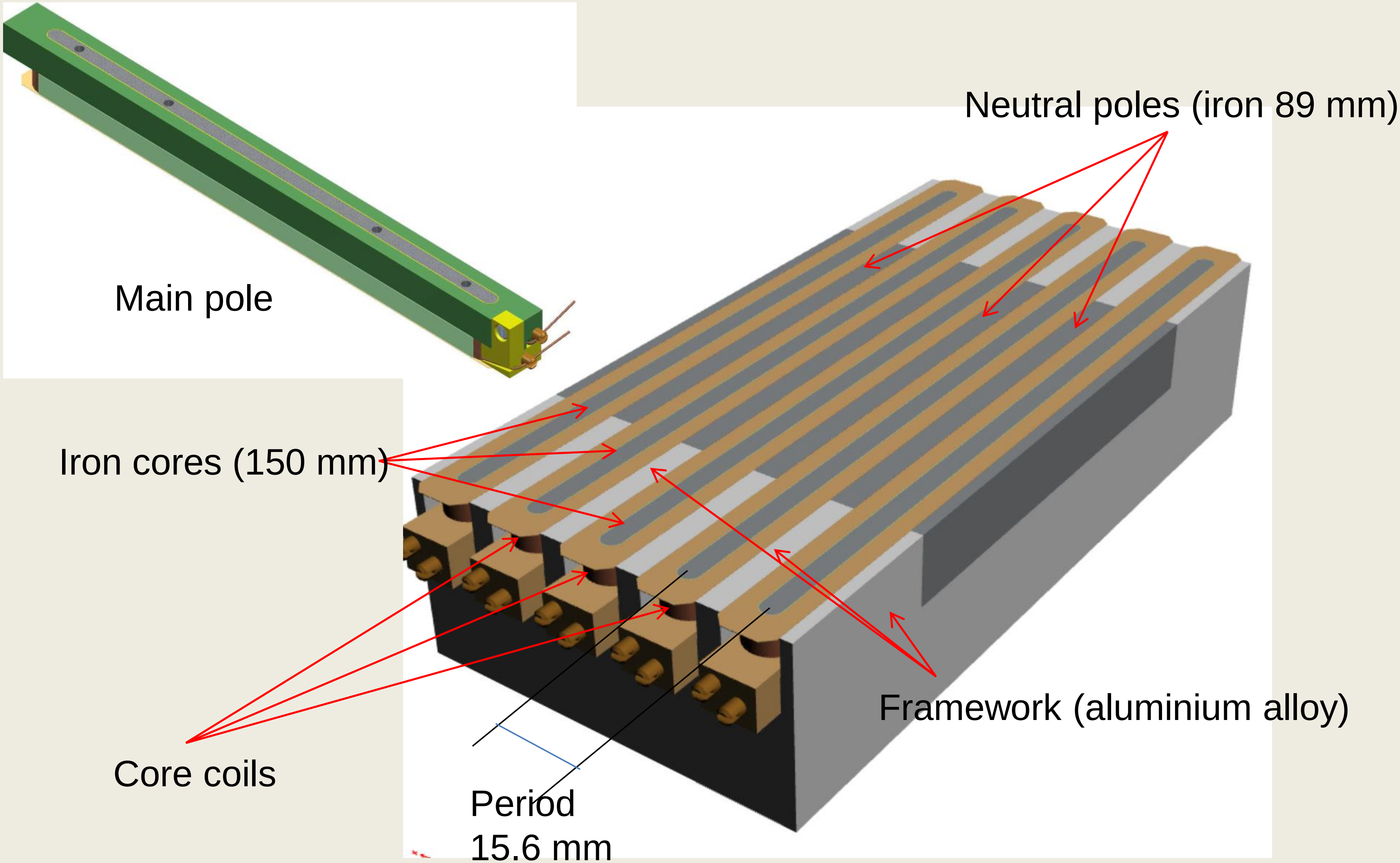


Magnetic field amplitude versus iron saturation field (period 15.6 mm, gap=8 mm)

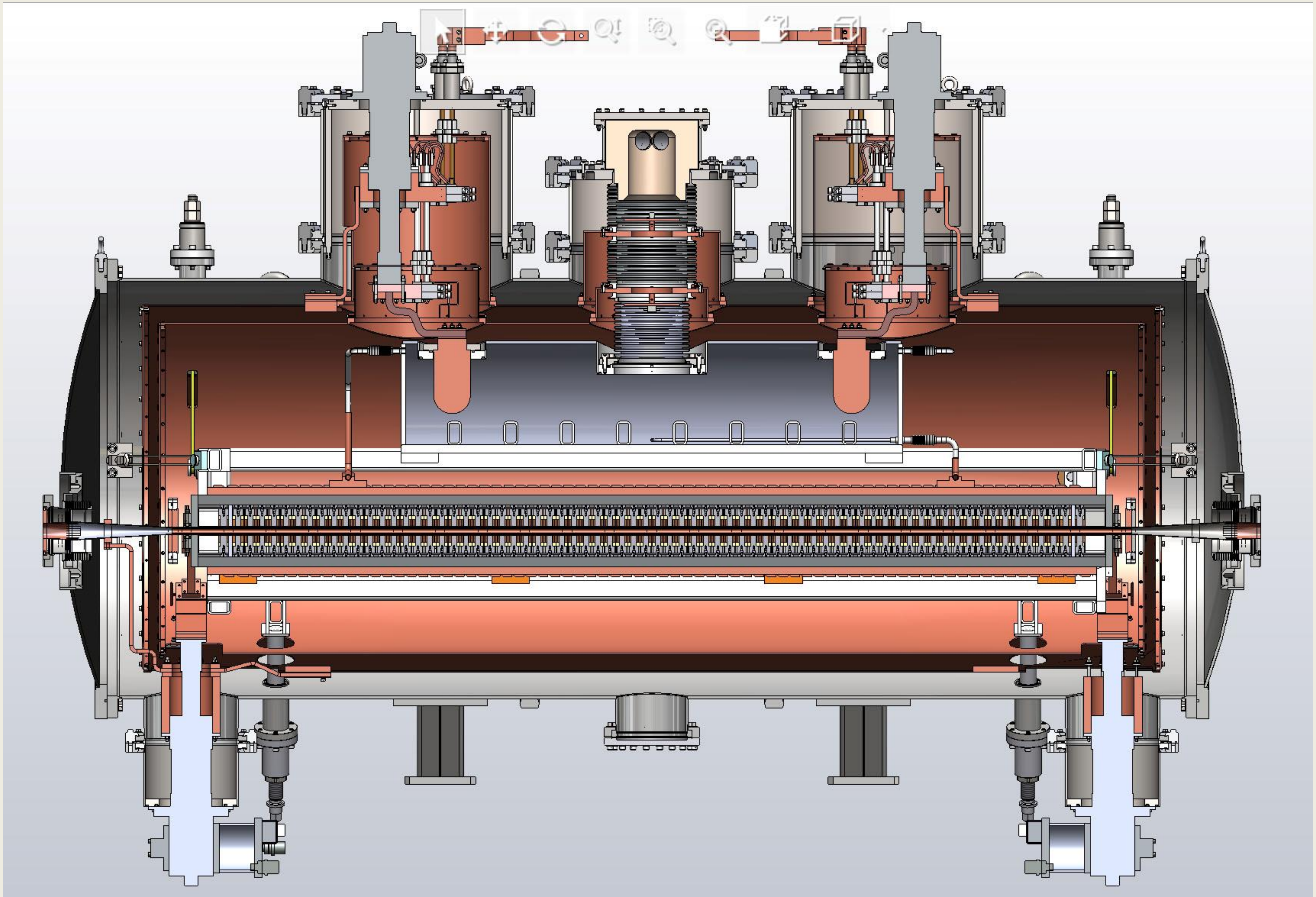


Correction of the neutral pole length versus iron saturation field (period 15.6 mm, gap=8 mm)

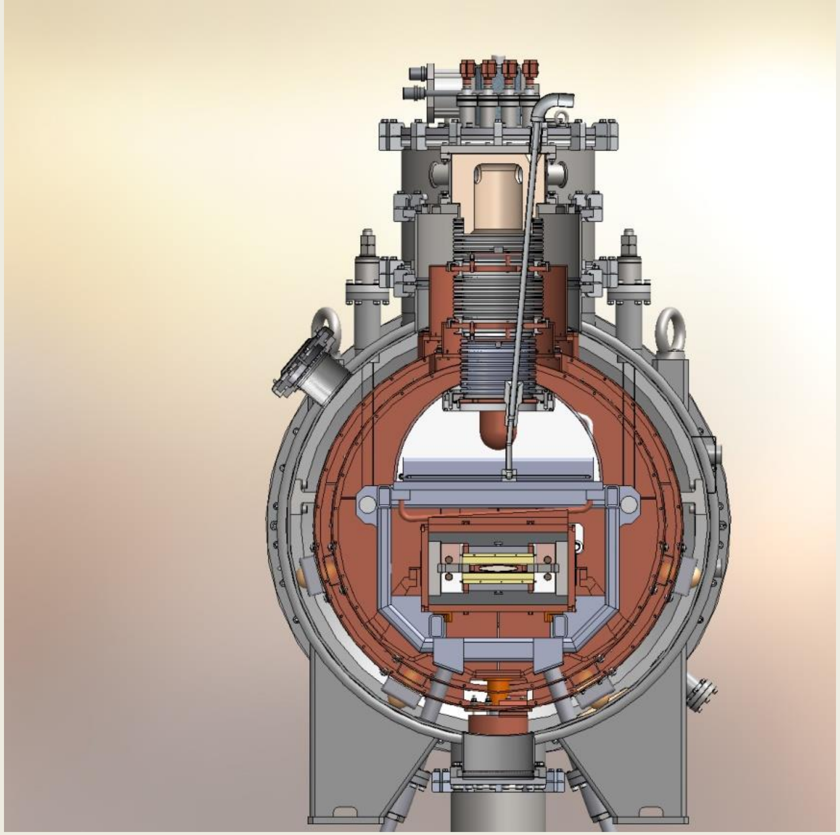
Further developing of the undulator with neutral poles

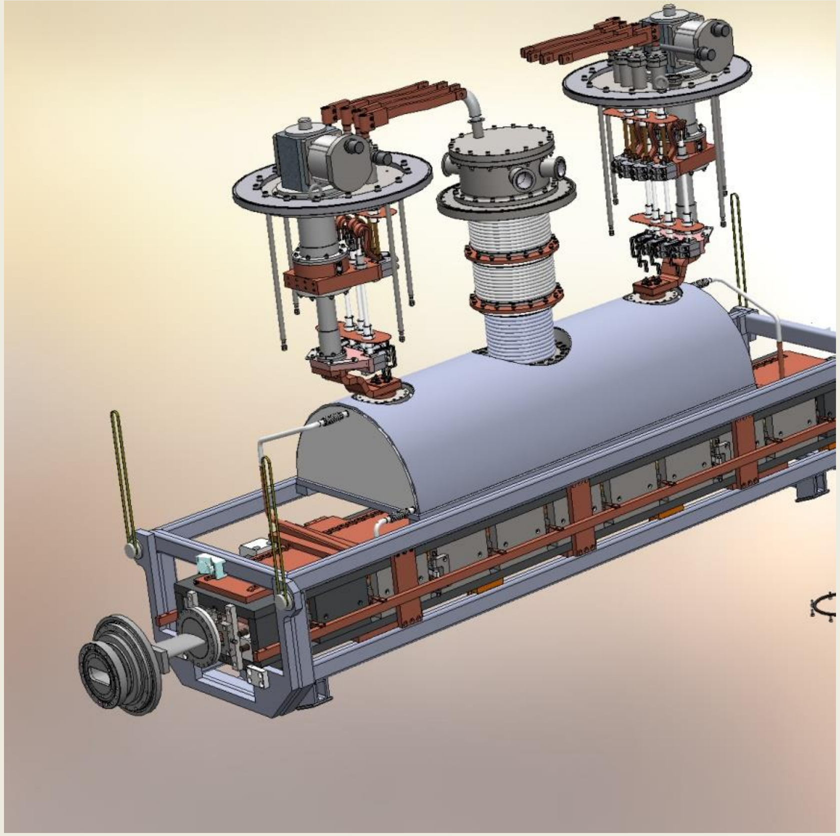


Cryostat



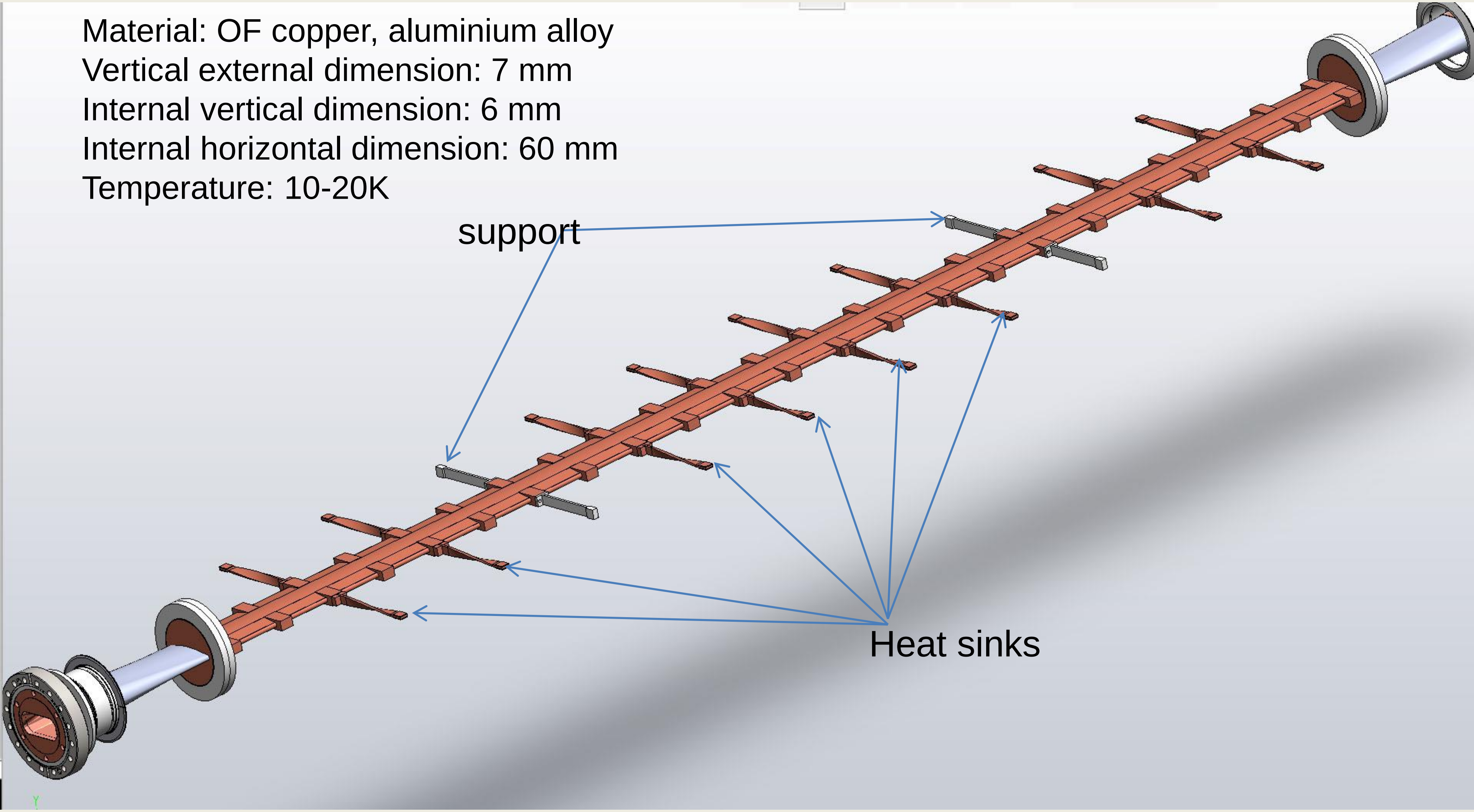
Cryostat





Vacuum chamber

Material: OF copper, aluminium alloy
Vertical external dimension: 7 mm
Internal vertical dimension: 6 mm
Internal horizontal dimension: 60 mm
Temperature: 10-20K



Resume

- The prototype is made (λ=15.6 mm, pole gap 8 mm, B=1.2T) and the idea of use of a neutral pole for creation of a superconducting undulator with the period more than 12 mm is successfully checked.
- Test of the prototype was carried out in a bath cryostat with liquid helium and in a vacuum cryostat with indirect cooling by a cryocooler. Difference in stability of the field was not noticed.
- Design features of superconducting windings and assembly of the magnet allow to hope for the significant increase in accuracy of manufacture and decrease of cost of a magnet.
- The quantity of windings decreases twice.
- It is easily to provide mass production, high quality of pole fabrication, control of key dimensions and quality for every pole.
- High precision of regular structure of the undulator. Horizontal racetrack winding improves precision of coils dimensions. It should minimize phase errors.
- There is no limitation of undulator length.

Future plans

- By the end of the year to create a new prototype of the undulator taking into account necessary amendments to the design
- To take magnetic measurements with use Hall probes, stretched wire method and to show quality of the field
- To develop and manufacture the vacuum chamber of aluminum alloy
- To improve a cooling system of the magnet with use of heat tubes with use of nitrogen and helium

Thanks for attention