R&D of SC Undulators in Asia/Russia

Zhou Qiaogen
Shanghai Advanced Research Institute, C.A.S., China

Nikolay A. Mezentsev
Budker Institute of Nuclear Physics, Novosibirsk, Russia

SCU workshop 19-21 April, 2021

SHINE

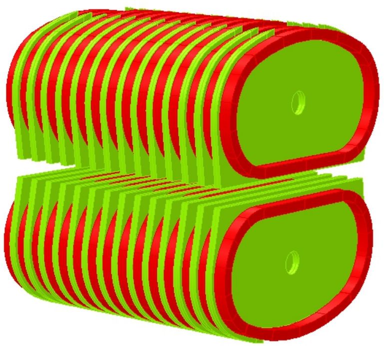
Content

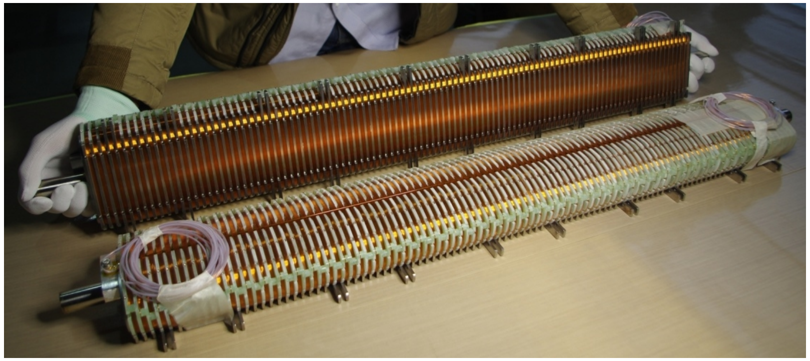
- Pre R&D of SCU in SSRF, China
- R&D of SCUs of in BINP, Russia
- In-vacuum SCUs for SHINE
- Summay

A Prototype of SCU at SSRF* (2013-)

Period Length	16 mm
Period Number	50
Magnetic Gap	9.5 mm
Peak Fields	0.67 T
SC Wire	NbTi/Cu, ϕ0.6
Current	400 A
Length of cryostat	1.8 m

- Use vertical racetrack coils.
- LHe pipes pass through the yoke.
- 60K thermal shielding.
- 20K beam vaccum chamber.
- Four 2-stage cryocoolers.
- Used as a test cryostat for SHINE SCU coils last year.
- Will be tested in two months.

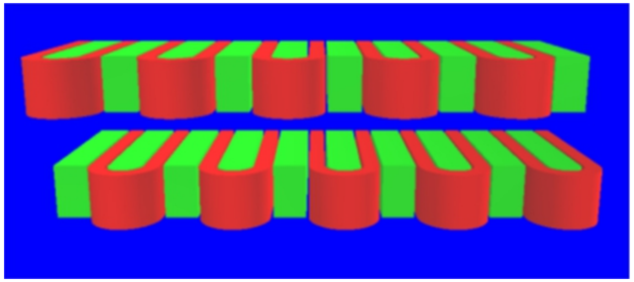




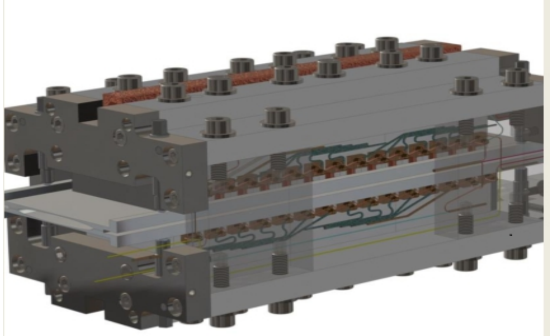
*J. Xu et al. Development of a Superconducting Undulator Prototype at the SSRF. IEEE Transactions on Applied Superconductivity, vol. 27, no. 4, pp. 1-4, June 2017.

R&D of SCUs of in BINP, Russia

- 2016: A prototype with the horizontal racetrack coils and the active/neutral poles is made and tested (λ=15.6mm, pole gap 8mm, B=1.2T, N=15)*
- 2017: A prototype with 40 period number is made and tested (λ=15.6mm, pole gap 8mm, B=1.2T, N=40)**
- 2021: A SCU with full size is made and tested (λ=15.6mm, pole gap 8mm, B=1.2T, N=119)

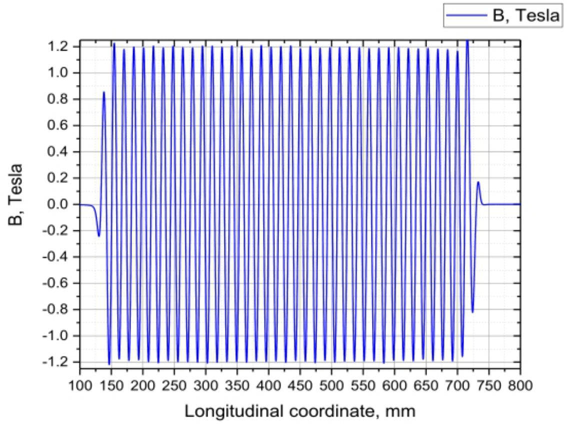


Geometry of undulator with neutral poles



Model of the 15 periods superconducting undulator prototype

Photo of the undulator prototype



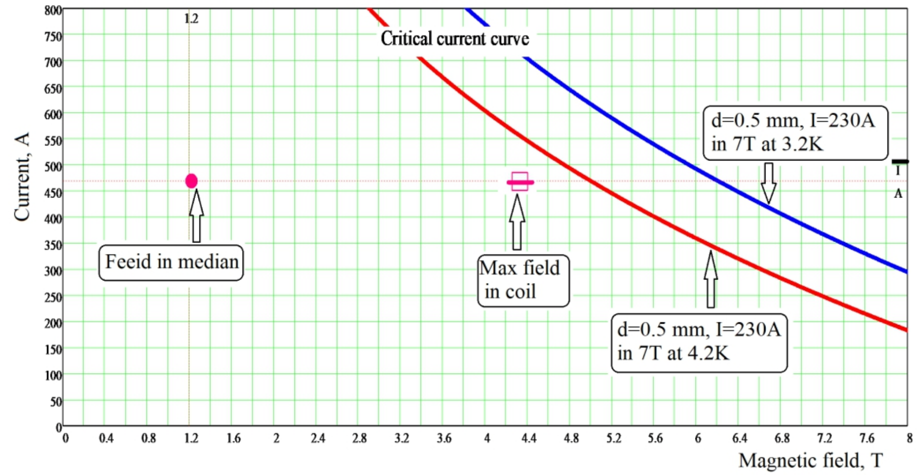
*Mezentsev N. Planar superconducting undulator with neutral pole: test results of the prototype and future plans. ALERT 2016.

**Mezentsev N, Bragin A, Khruschev S, et al. Short-period superconducting undulator coils with neutral poles: test results. IEEE Transactions on Applied Superconductivity. 2018.

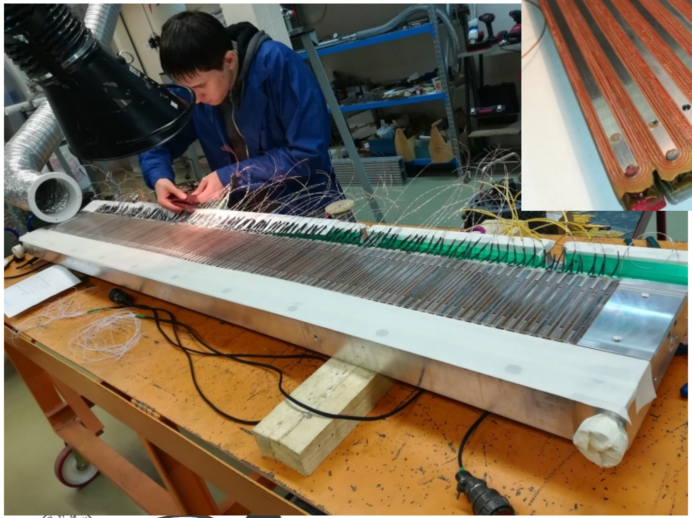
Superconducting undulator full size in BINP

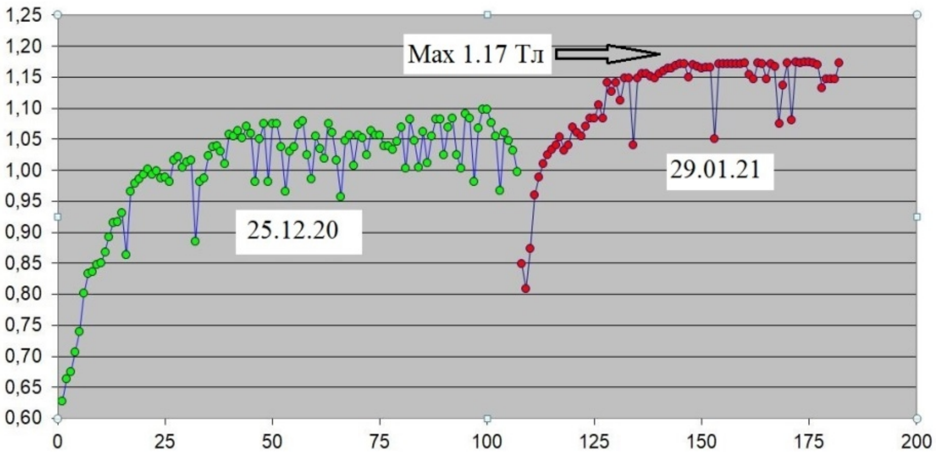
Magnetic system

Main parameters:	
Magnetic field, T	1.2
Period, mm	15.6
Magnetic gap, mm	8
Period number	119
Magnetic length, mm	~2000
Current,A	450
SC wire diameter, mm	0.55
Turn number in layer	12/11
Layer number	7
Width of coil, mm	146
SC wire critical current 7T	250
Ratio Cu/NbTi	0.42



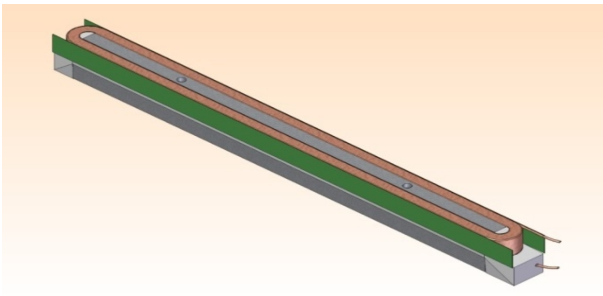
Operating point position relative to SC wire critical curve (1.2 T at median) for 4.2 and 3.2 K



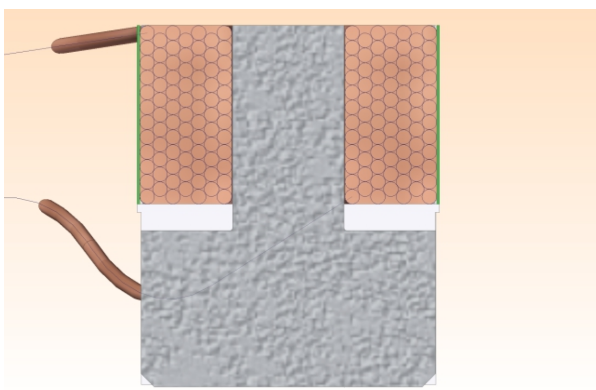


Quench training 119-period undulator in bath cryostat

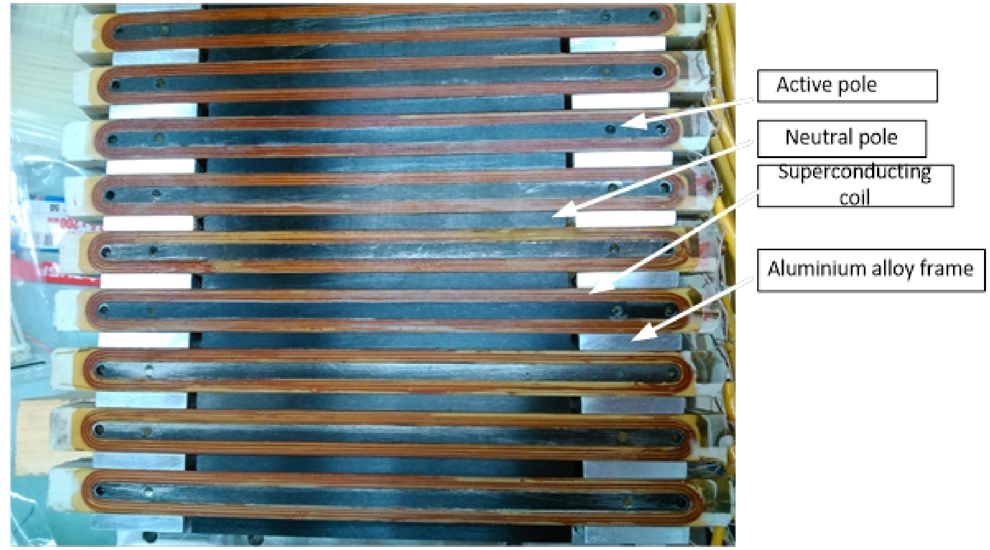
Key element of the undulator with neutral poles



Active pole (drawing))

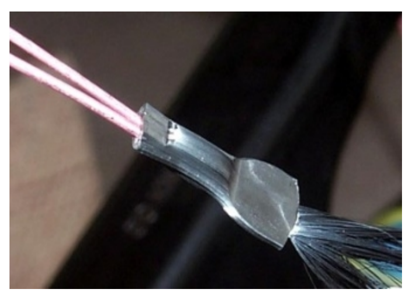


Crosssection of active pole)



Motivation of horizontal racetrack coils

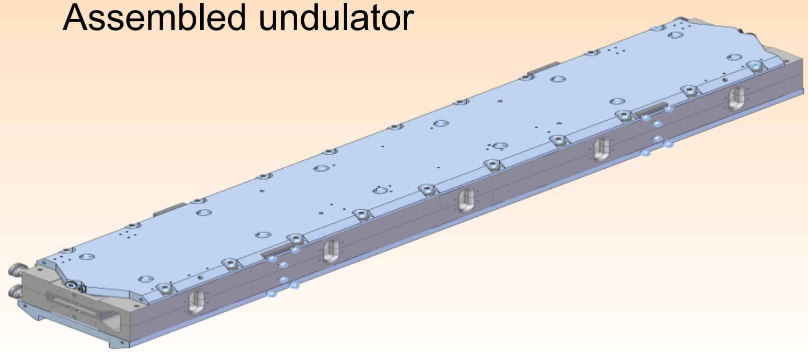
- Easy to control winding accuracy
- Easy to control interturn and interlayer contacts
- Mass production of identical poles
- Possibility of replacing "weak" poles after quench training
- Many splices – is no problem with coils heating



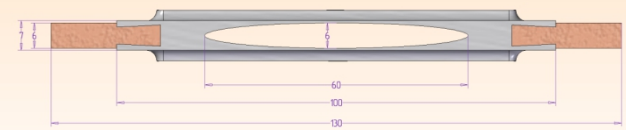
SC wire connection with “cold welding” method
R~ 10^-10 --- 10^-13 Ohm

Undulator with period 15.6 mm

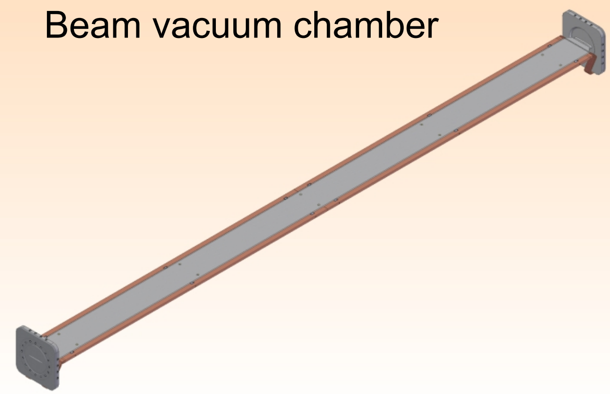
Assembled undulator



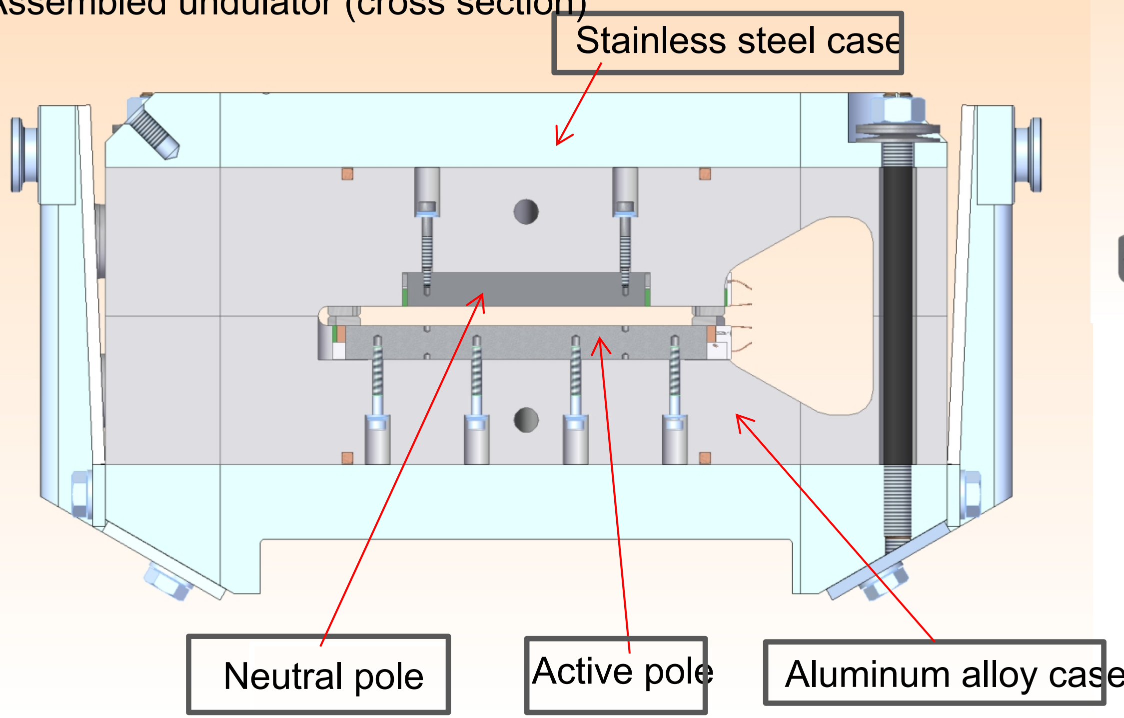
Beam vacuum chamber (cross section)



Beam vacuum chamber



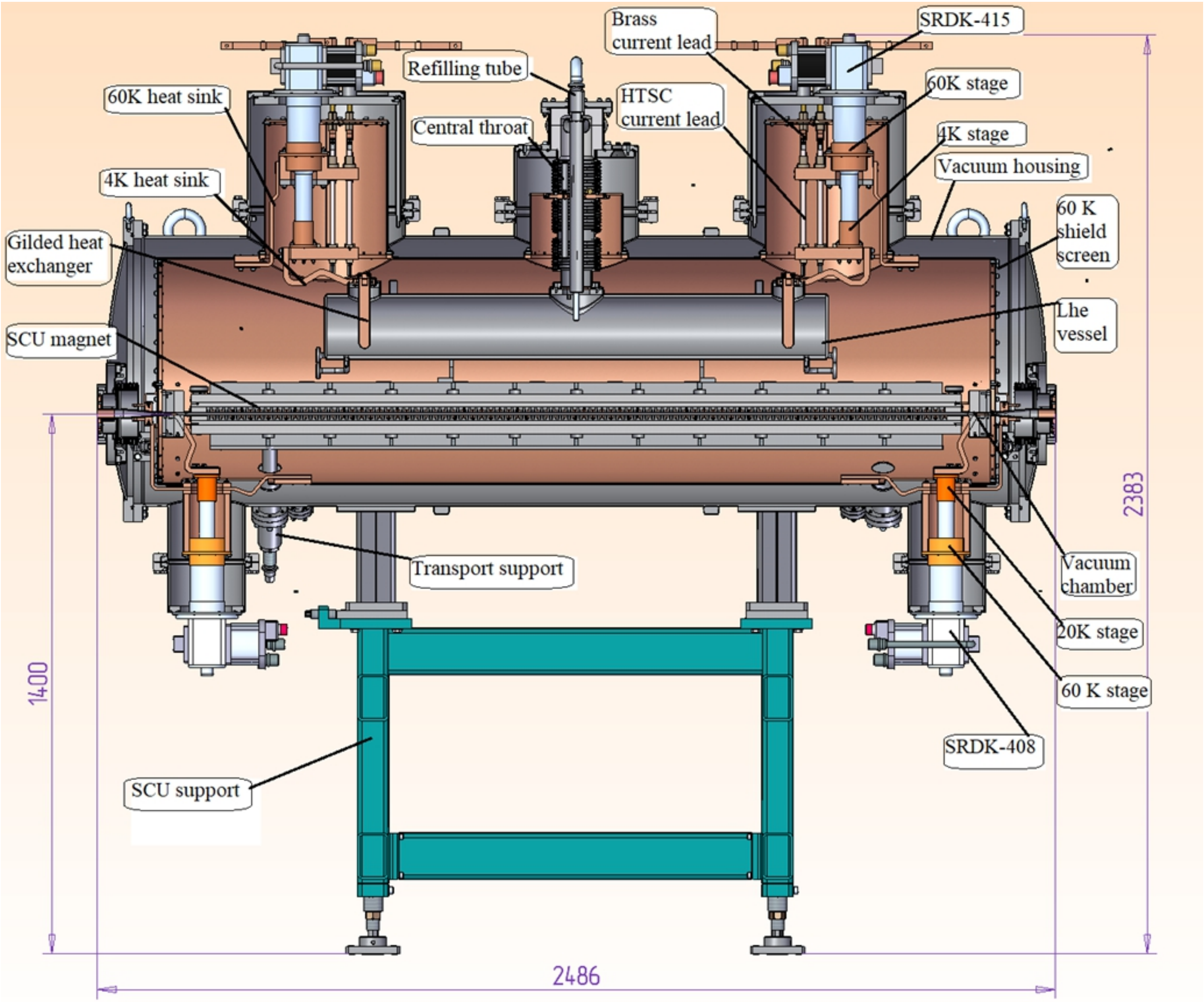
Assembled undulator (cross section)



Main parameters:

λ = 15.6 mm
Pole gap=8 mm
Vertical aperture for beam=6 mm
Max.field = 1.15T(4.2K)- 1.2T (<3.6K)
Period number = 120

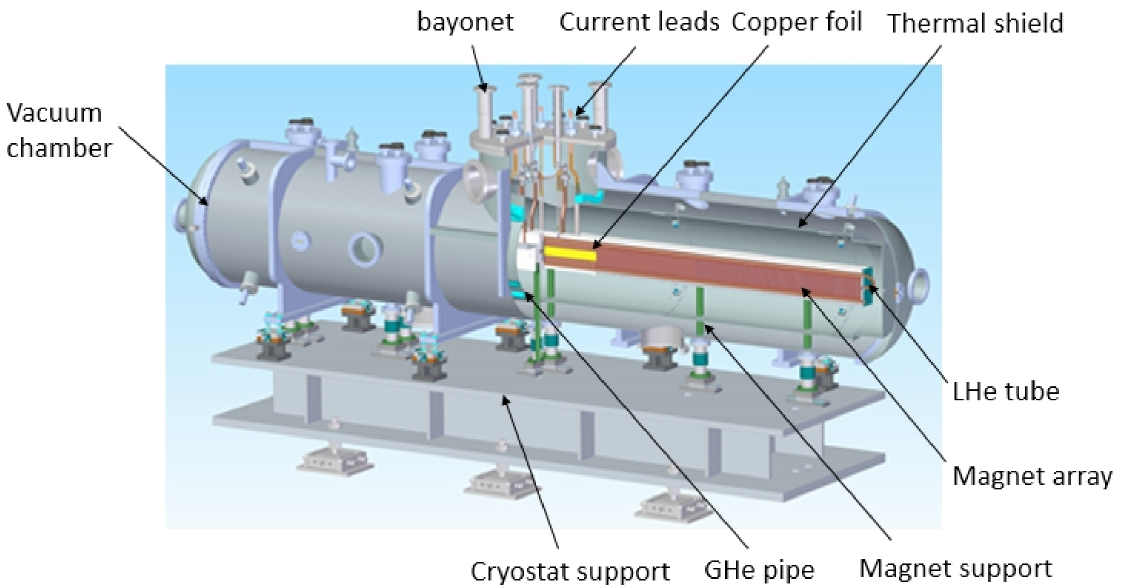
Cross section of the cryogenic indirect cooling system of the SC undulator



SHINE SC Undulators (2018.01-2024.12)

Quantity	40
Period Length	16 mm
Magnetic Length	4 m
Pole/Beam Gap	5/4 mm
Peak Fields	0.68-1.58 T
Beam Energy	8 GeV
Photon Energy	10-25 KeV

- 40 SCUs are used for X-ray FEL with vertical polarization.
- There is no vaccum chamber.
- LHe and GHe are provided by cryogenic plant.
- A prototype will be finished by the end of this year.

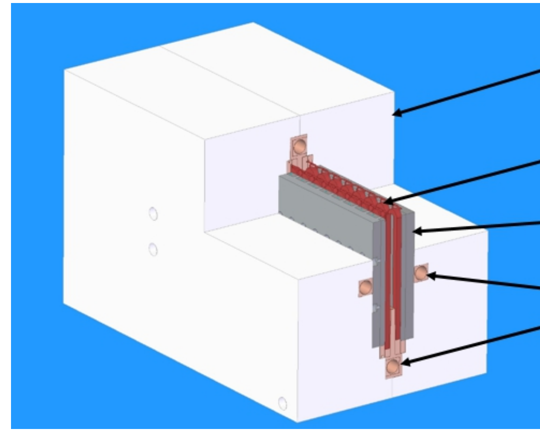


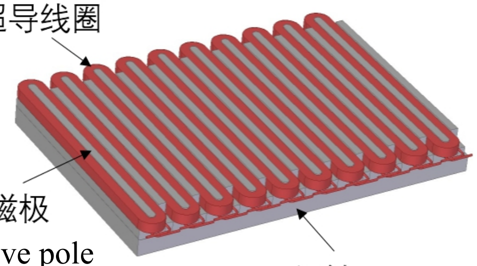
Technical Difficulties for the IV-SCU with 4m Long

- How to manufacture the magnet cores of 4m long with high precision?
- How to wind coils? vertically or horizontally?
- How to support the magnet?
- How to cool the beam heat load?
- How to correct the phase error?
- How to measure the magnetic fields?

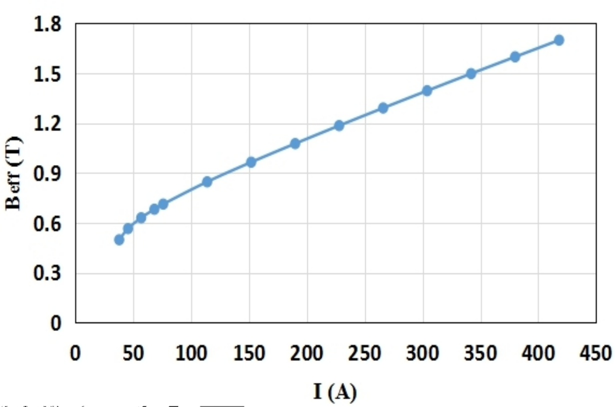
Magnet Design

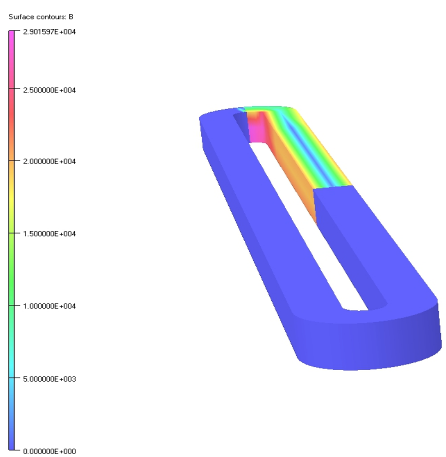
Height of Half Core	18.3 mm
Length of Core	4027.5 mm
Pole Thickness	3.5 mm
Width of Active Pole	108.5 mm
Width of Neutral Pole	95 mm
Turn / Layer of Coil	60/8
SC wire (NbTi)	ϕ0.6 mm
Ratio Cu/NbTi	0.93
Max. Current	380 A

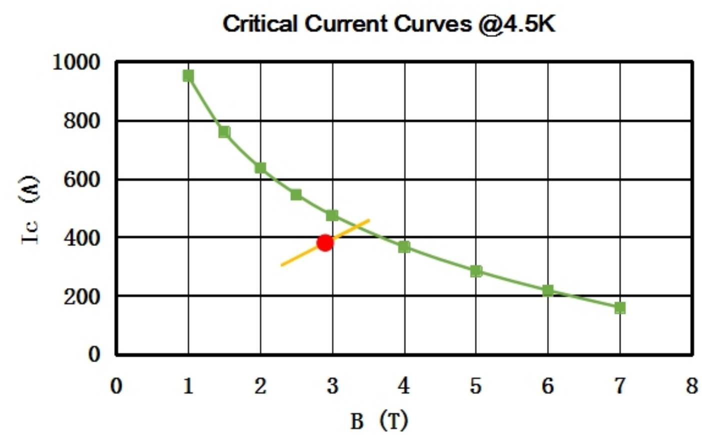




- 505 horizontal racetrack coils and 505 active poles in one undulator.
- Each magnet yoke is devided into 4 sections each about 1m long.

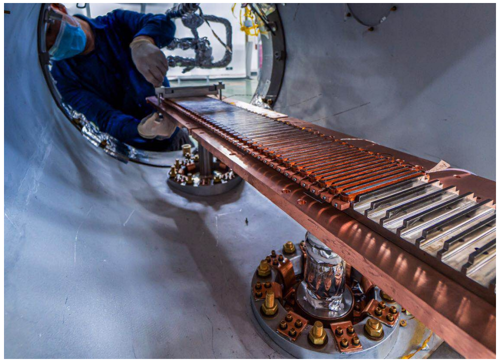


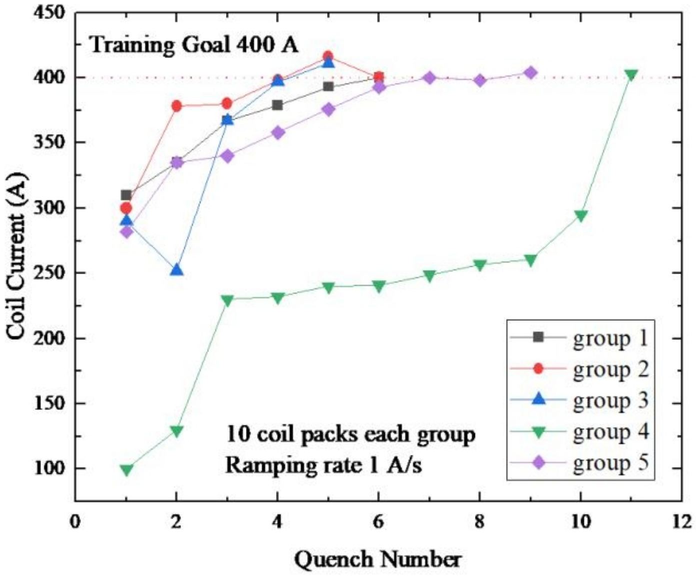




Manufacture and Test of SC Coils

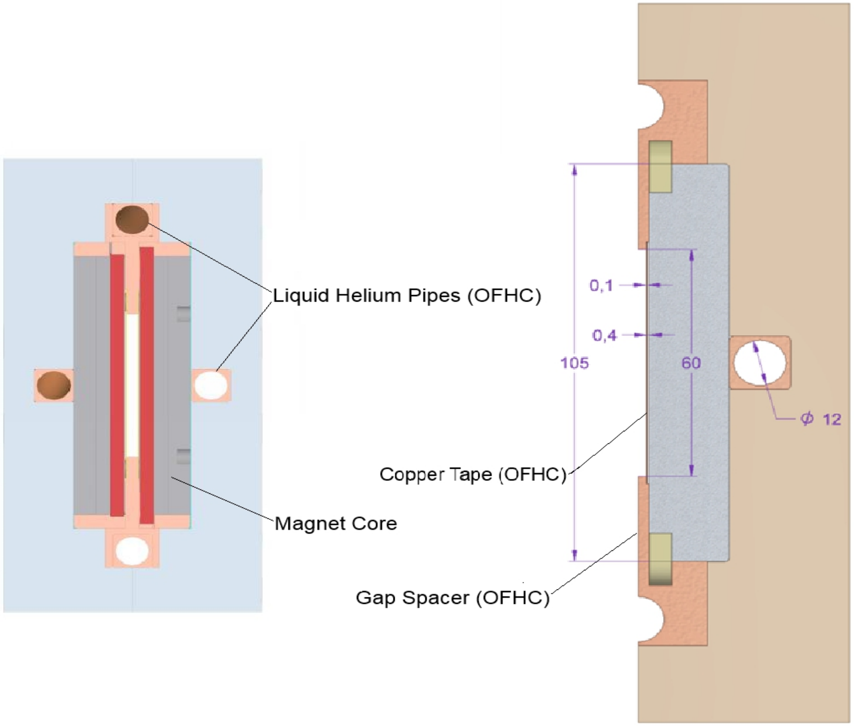
- SC Coils: 8-10 coils are wound in series with one wire. There are about 50 SC connections in one undulator.
- Quench trainings are performed for each group of 5-6 series coils in a test cryostat.

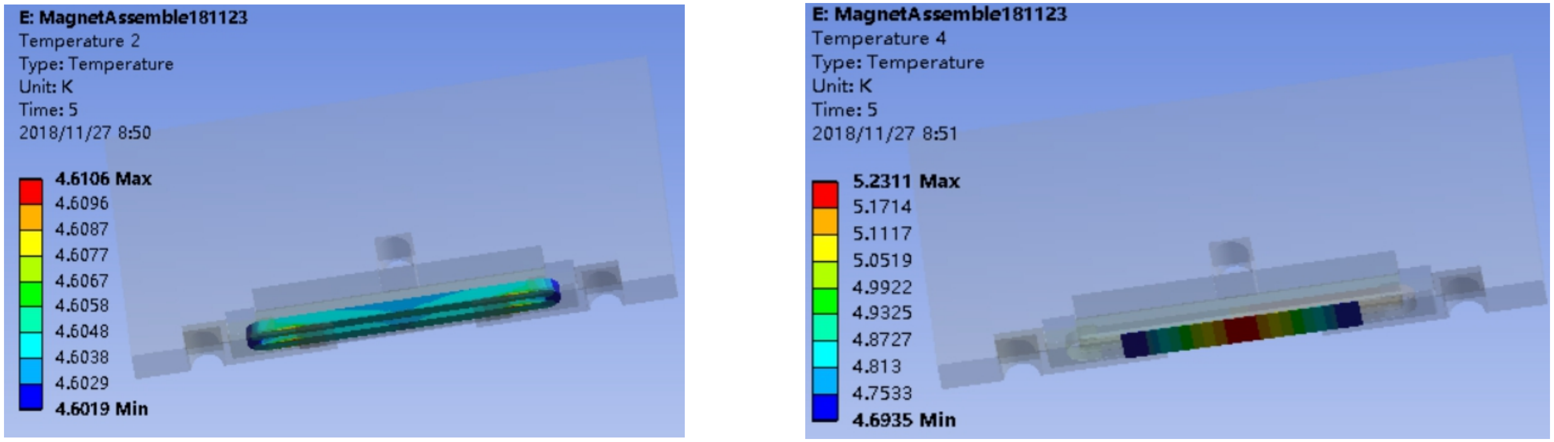




Magnet Cooling

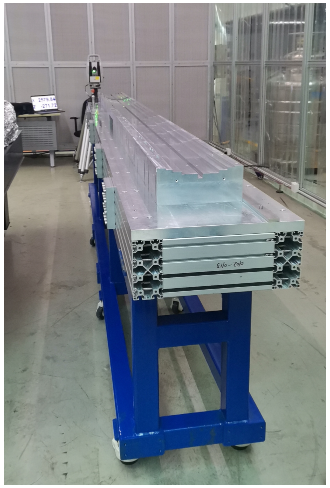
- The magnet is cooled by four LHe copper pipes.
- Their is no beam vacuum chamber. Two copper tapes on the pole surfaces form a 4mm beam gap.
- The beam heat load (about 10W) on the copper tapes is cooled by LHe pipes cornected to the LHe tank.
- The ANSYS simulation shows a small temperature rise in the SC coils.

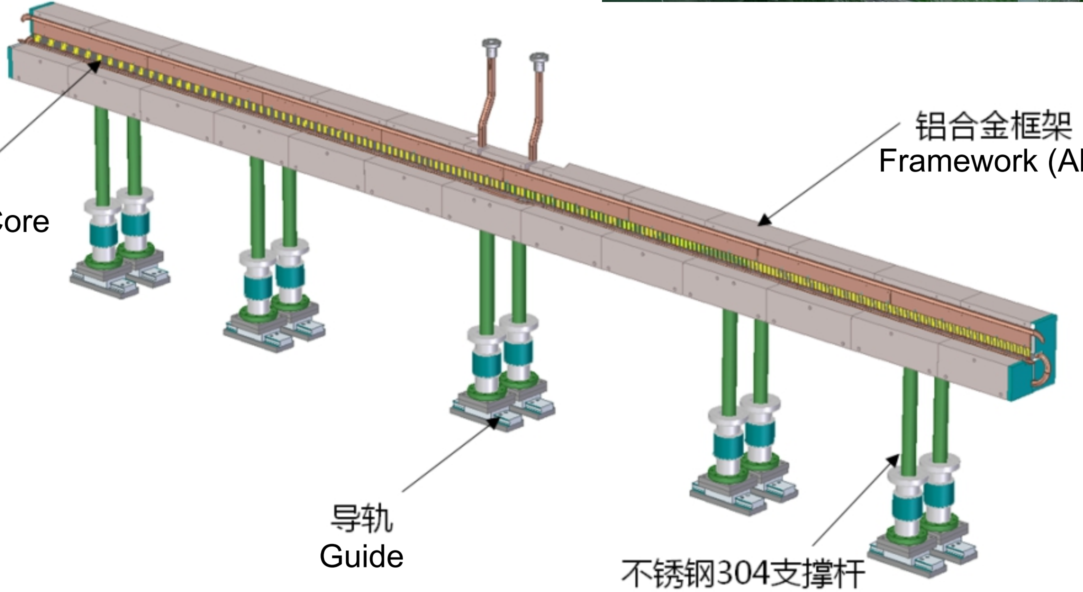




Magnet Support

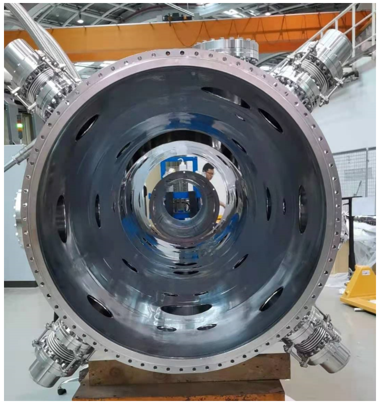
- The magnet core in one girder is devided into four sections and the framework is devided into thirteen sections along the beam direction.
- Two adjoining core sections are connected by one framework section.
- The framework is supported by five pairs of stainless steel pipes.

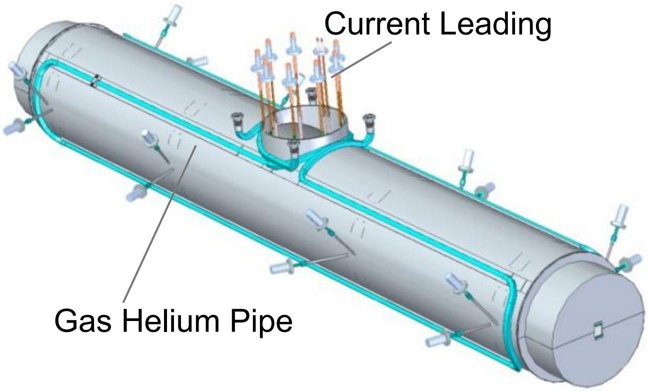


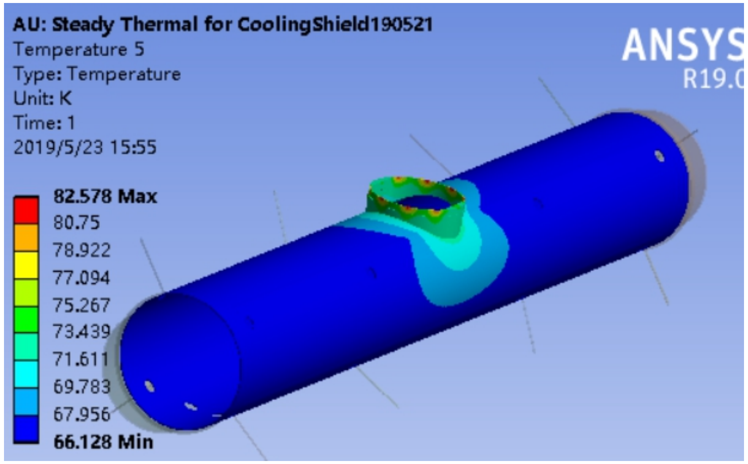


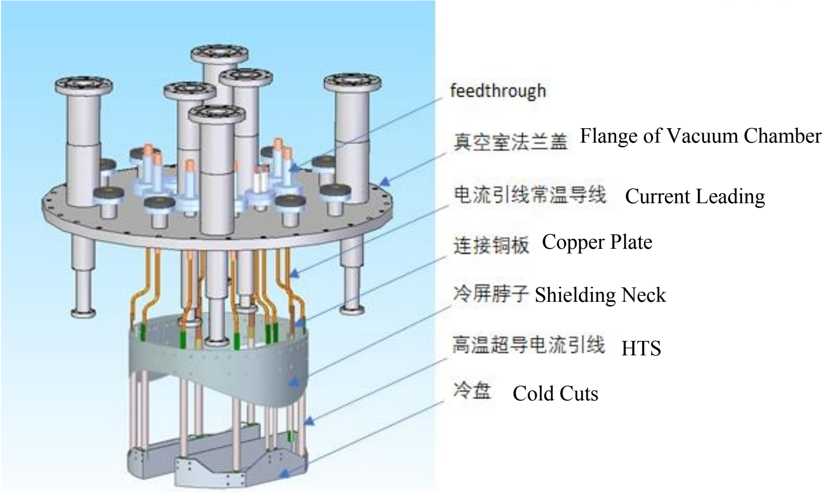
Thermal Shielding

- The 65K thermal shielding is made of aluminum with length 4.3m, inner diameter 0.58m and wall thickness 5mm.
- The total heat load on the shielding is about 700W including 300W from ten current leadings.
- The shielding is cooled by the GHe pipes made of stainless steel with the bore diameter 20mm.
- The HT ends of HTSs are cooled by the shielding neck.
- GHe parameters: 60K, 0.8MPa, 24g/s.
- The ANSYS simulation shows that the temperature at the bottom of the shielding neck where the HTSs are installed is about 75K.



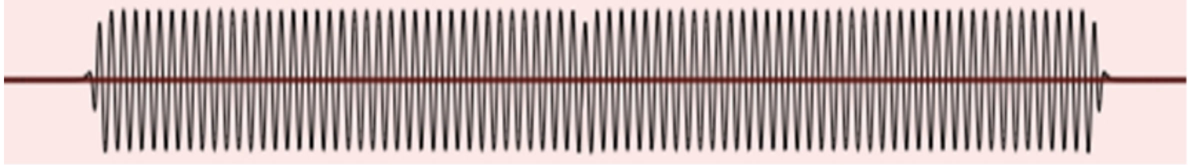






Field Correction

- Five power supplies will be used, two for the end coils, and three for the main coils including one for the "phase shifter".
- To minimized the phase error, two middle periods are designed as a "phase shifter" and the main coils are devided into three groups.
- The end coils are used to correct the first and the second field integrals.



Two middle periods are designed as a "phase shifter" to minimize the phase error.

Summary

- SC undulaors are in developping at BINP/Russia and SARI/China for SR and FEL facilities.
- The horizontal racetrack coils are adopted for these undulators which make it easy to extend the length of undulators.
- The in-vacuum SC undulator of 4m long has a great challenge and the design scheme is to be verified by the prototype which will be finished by the end of this year.
- The in-vacuum SC undulator should be suitable for the X-ray FEL facility and it will realize a full SC undulayor line for a FEL.

Thanks！