Fast cycling SC magnet with big bore for HIAF project

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Outline

- ❖ Brief introduction of the HIAF project
- ❖ Requirements of HIAF BRing dipole
- ❖ Low loss wire & cable
- ❖ Comparison of different solutions
- ❖ Warm iron prototype
- ❖ R&D of CCT alternatives
- ❖ Reference

Brief introduction of the HIAF project

High-Intensity Heavy Ion Accelerator Facility-HIAF

➢ Main Components:

- High intensity ion source
- High intensity pulse SC-Linac
- Multi-function booster and collector ring
- Large acceptance RIBs line
- Long straight electron-ion collider

➢ Key features:

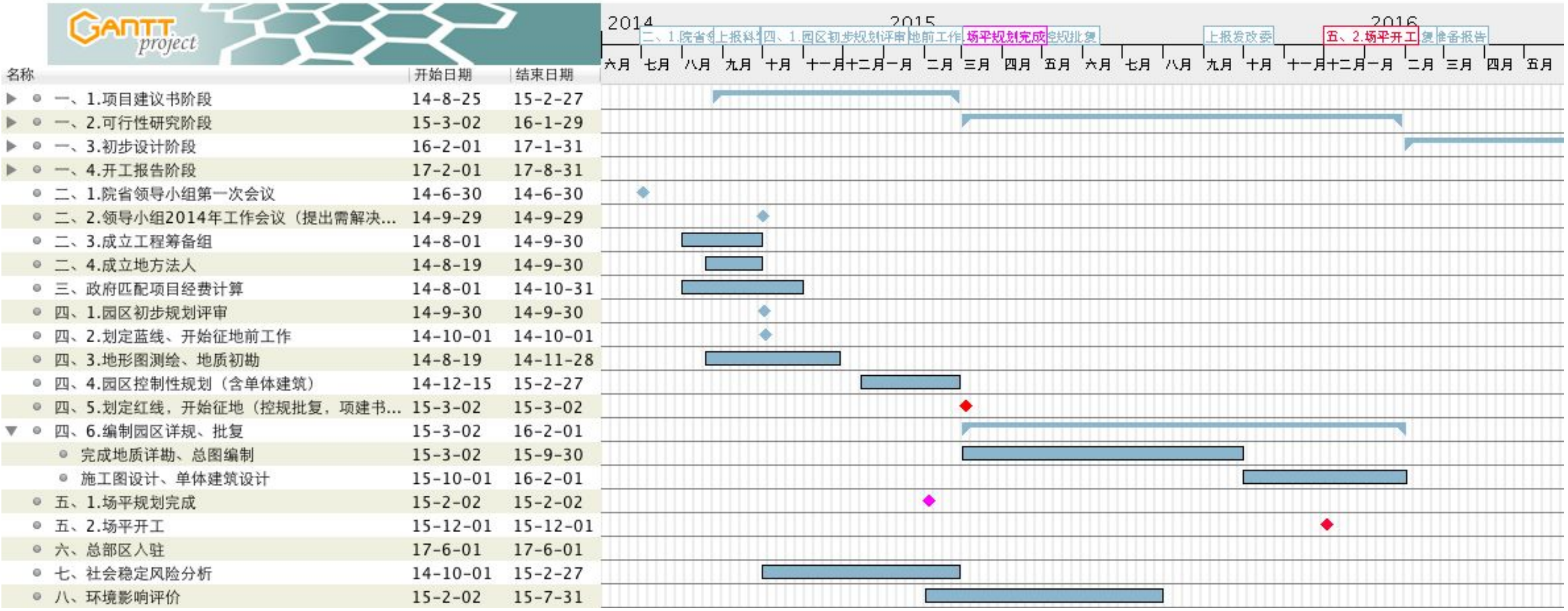
- High energy & High intensity & Pulse
- Cooled intense primary beam & RIBs
- Beam compression
- Super long period slow extraction
- Multi-operation modes

Schedule for early stage work

Project proposal: refered to National Development and Reform Commission (NDRC) in Sep 2014; Just approved this month

Land expropriation: March, 2015 (delayed)

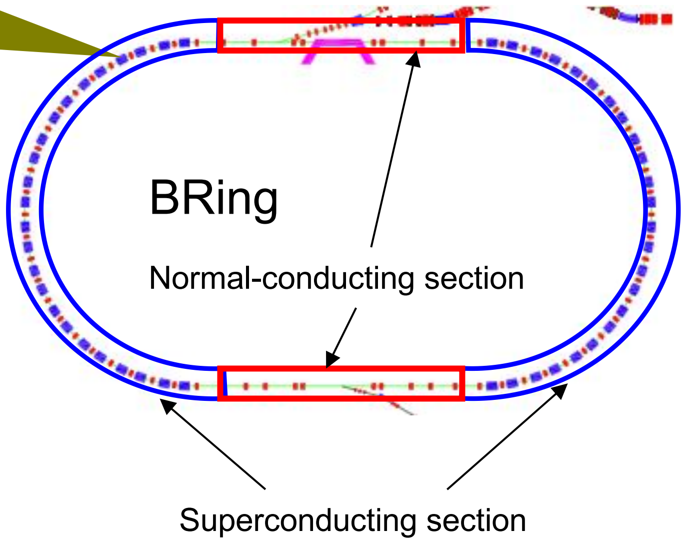
Site formation: December, 2015



名称	开始日期	结束日期
一、1.项目建议书阶段	14-8-25	15-2-27
一、2.可行性研究阶段	15-3-02	16-1-29
一、3.初步设计阶段	16-2-01	17-1-31
一、4.开工报告阶段	17-2-01	17-8-31
二、1.院省领导小组第一次会议	14-6-30	14-6-30
二、2.领导小组2014年工作会议（提出需解决...	14-9-29	14-9-29
二、3.成立工程筹备组	14-8-01	14-9-30
二、4.成立地方法人	14-8-19	14-9-30
三、政府匹配项目经费计算	14-8-01	14-10-31
四、1.园区初步规划评审	14-9-30	14-9-30
四、2.划定蓝线、开始征地前工作	14-10-01	14-10-01
四、3.地形图测绘、地质初勘	14-8-19	14-11-28
四、4.园区控制性规划（含单体建筑）	14-12-15	15-2-27
四、5.划定红线，开始征地（控规批复，项建书...	15-3-02	15-3-02
四、6.编制园区详规、批复	15-3-02	16-2-01
完成地质详勘、总图编制	15-3-02	15-9-30
施工图设计、单体建筑设计	15-10-01	16-2-01
五、1.场平规划完成	15-2-02	15-2-02
五、2.场平开工	15-12-01	15-12-01
六、总部区入驻	17-6-01	17-6-01
七、社会稳定风险分析	14-10-01	15-2-27
八、环境影响评价	15-2-02	15-7-31

Requirements of HIAF BRing dipole

Parameters of BRing dipole magnet	
Item	Parameters
Bρ (Tm)	36
Max. magnetic field (T)	2
Bending radius (m)	18
Bending angle (Deg)	7.5
Effective length （m）	2.36
Effective region (mm×mm)	176×88
Gap (mm)	100
Ramp rate (T/s)	4



- Low field: 2T
- Fast ramp rate: up to 4T/s
- Large aperture

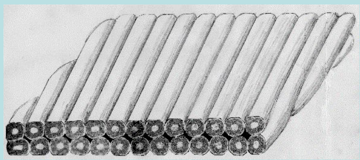
Comparison with SIS100 & PS2-FCM

Item	HIAF-BRing	FAIR-SIS100	PS2-FCM
Max. magnetic field (T)	2.0	1.9	1.8
Bending radius (m)	18	56.632	100
Bending angle (Deg)	7.5	3.33	3.6
Effective length （m）	2.36	3.062	
Good field region (mm×mm)	176×88	115×60	42×30
Gap (mm)	100	68	70
ramp rate (T/s)	4	4	1.5

Larger aperture! 1.5×SIS100 Dipole

Cable selection

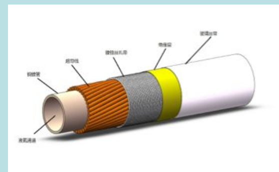
Rutherford cable



- Large current(>10kA)
- Small inductance
- Higher ramping rate(<1T/s)
- Easy to wind
- High filling factor
- Cheap

Helium bath

Nuclotron type cable



- Large current(>10kA)
- Small inductance
- Highest ramping rate(up to 4T/s)
- Difficult to wind
- Low filling factor
- Expensive

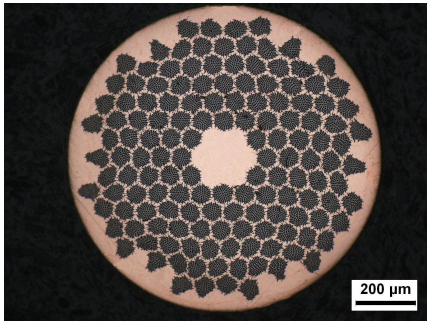
Forced flow

Because of high ramp rate, we have to choose nuclotron type cable

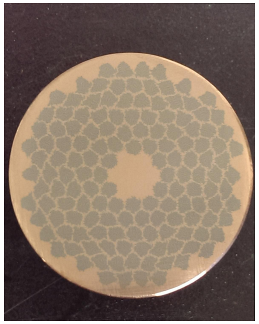
Low loss superconducting wire

Superconducting Wire parameters(developed by WST)

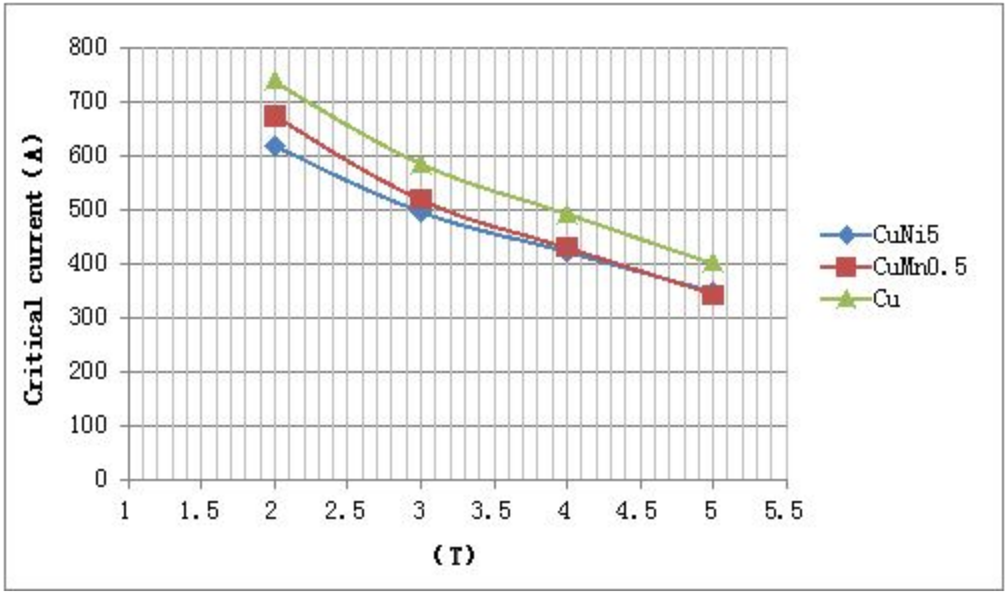
	Cu:nonCu	Diameter	Filament diameter	Filament number	Twist pitch	Measured hysteresis loss (mJ/cm3)
Cu	1.54	0.7	3.8um	12240	10	29.7
Cu-5Ni	1.55	0.7	3.8	12240	10	18.8
Cu-0.5Mn	1.38	0.7	3.9	12240	10	26



CuNi/NbTi



CuMn/NbTi

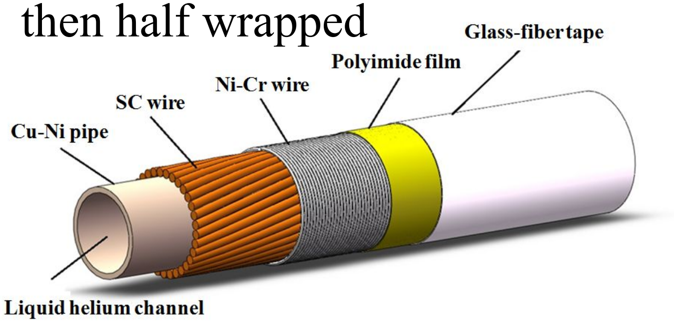


Critical current

Low loss superconducting cable

Nuclotron Type Cable
CACC: Cable-around-conduit-conductor

- Cu-Ni pipe: inner radius 6 mm with thickness 0.5 mm
- NbTi superconducting wire: diameter 0.7 mm
- NiCr (0.3 mm) wire is close winded for overbanding
- One layer polyimide film (0.1 mm) is half wrapped
- Two layers of glass-fiber tape (0.1 mm) is then half wrapped



Superconducting cable parameters

strands	32
Twist pitch	120 mm
ID	6 mm
OD	10.2 mm

Advantages:
- ✓ Good performance of mechanical stability
- ✓ Lower eddy current loss
- ✓ Good performance of cooling
- ✓ Low critical current degrade

Disadvantages:
- Low engineer current density
- Expensive than rutherford cable
- Hard to bend and wind
- Difficult to make joints

Supercritical or two-phase helium force-flow cooling

Comparison of different schemes(1)

Iron dominated

- ✓ Less superconductor
- ● Big size
- ● Lower field (typically < 2T)

Warm iron

- ✓ Less eddy current at 4K
- ● Bigger size
- ● complicated cryostat

eg. PS-FCM

Cold iron

- ● Eddy current at 4K
- ✓ Smaller size
- ✓ Simpler cryostat

eg. nuclotron, sis100

Coil dominated

- ● More superconductor
- ✓ Smallest size
- ✓ Higher field

Cos-Theta

- ✓ Mature technology
- ● Tight bend at the end
- ● Ends need to optimize

eg. SIS300

CCT

- ● New tech
- ✓ Avoid tight bends
- ✓ Good field quality

eg. LBNL prototype

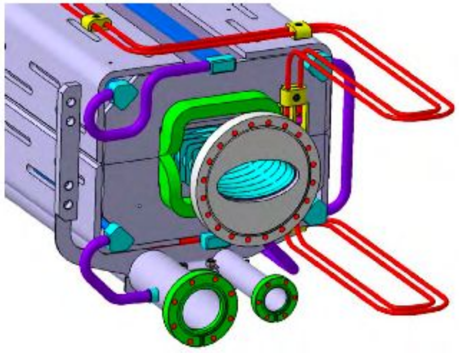
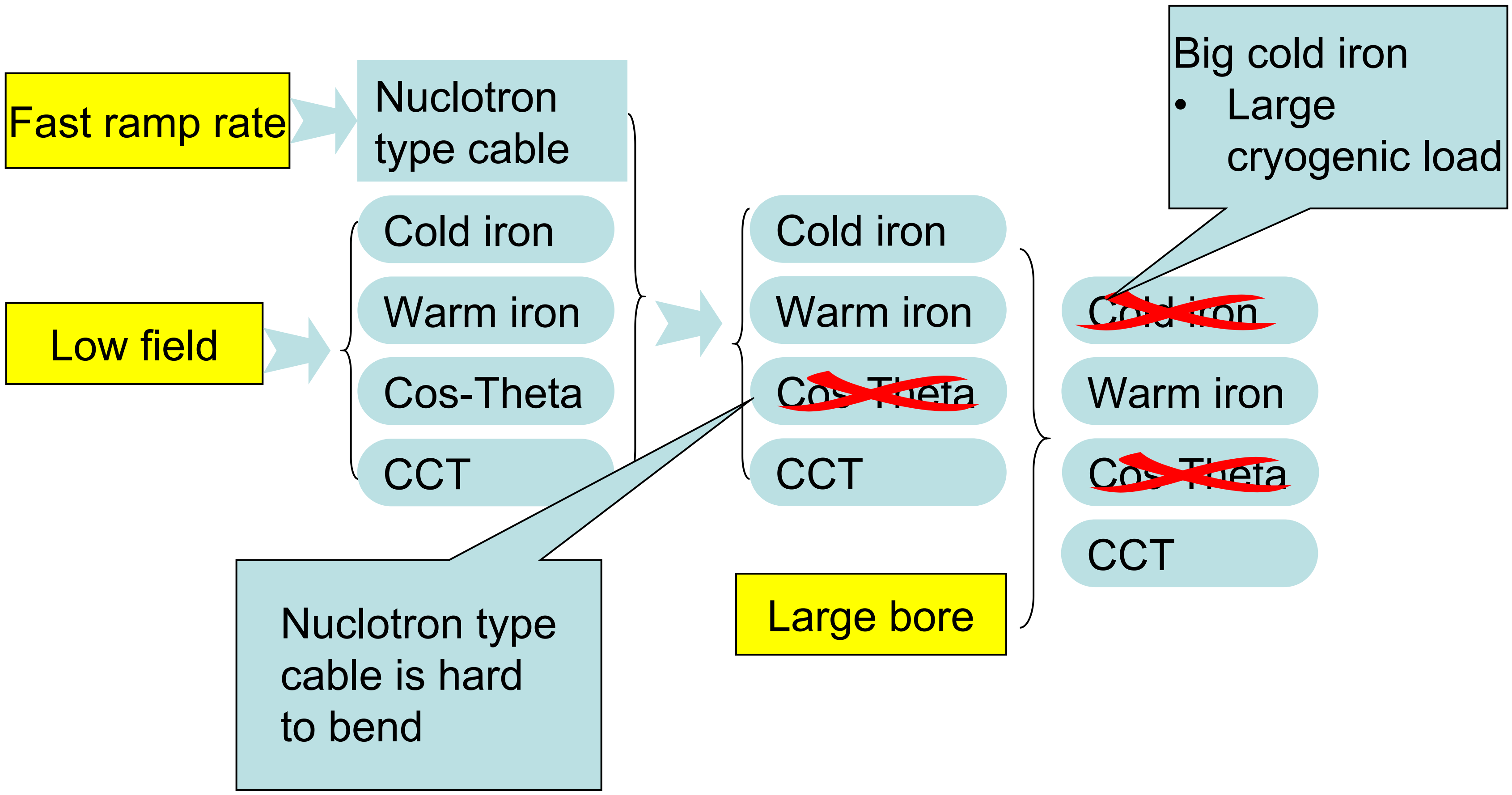


Fig. 19.2. General view of the superconducting dipole UNK.

Comparision of different schemes(2)



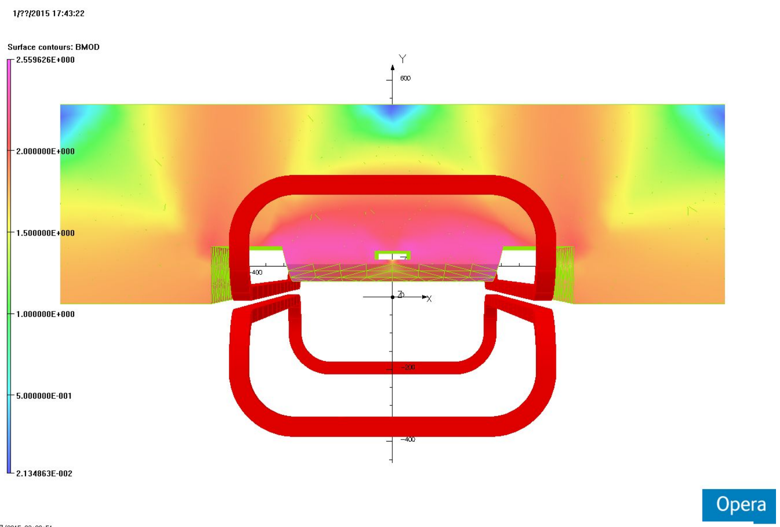
We have two options:

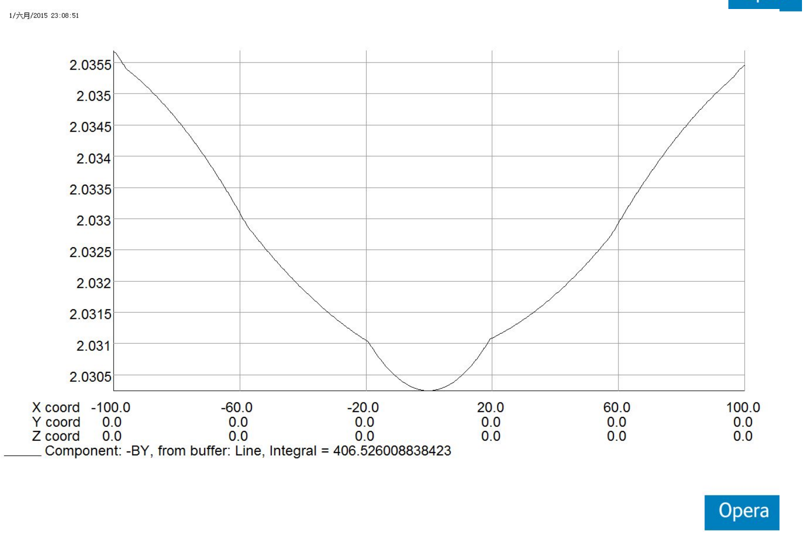
A: Superferric - Warm iron

B: Canted Cos-Theta

Option A: Warm iron prototype

Saddle coil

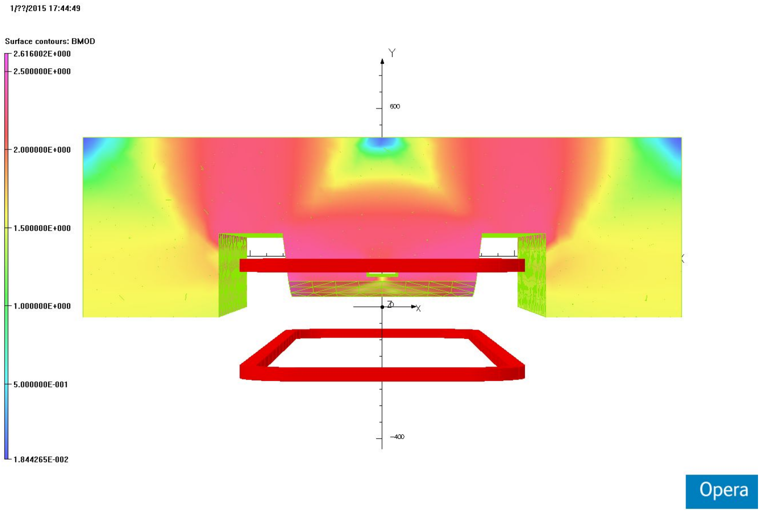


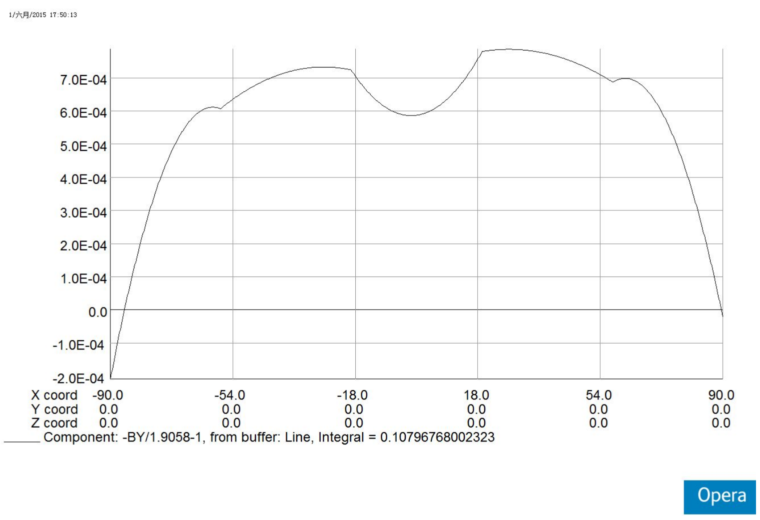


B0 (T)	**2.0**
Current（A）	8500
Total turns	4*3
Storage energy （MJ）	0.32
Inductance （mH）	8.6
Iron weight (Ton)	

Option A: Warm iron prototype

Racetrack coil

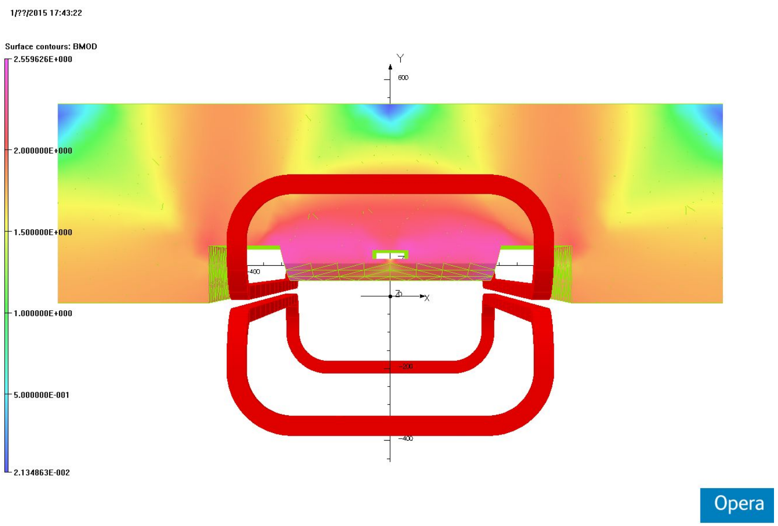


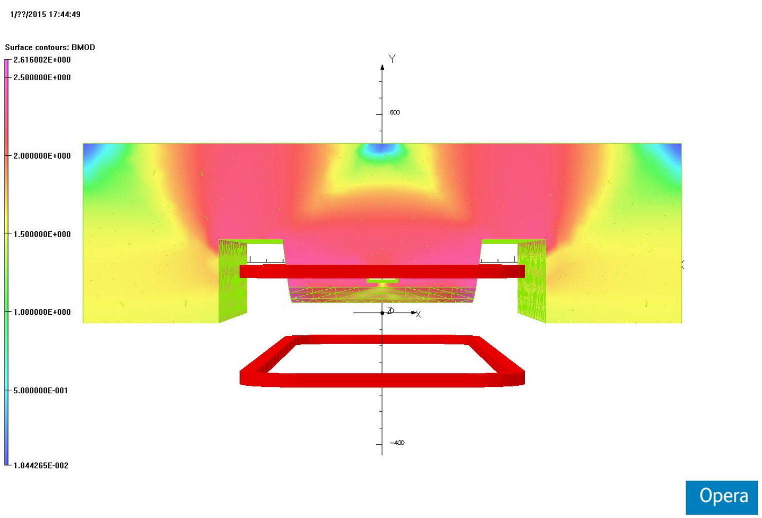


By (T)	2.0
Current （A）	11000
Total turns	4*3
Storage energy （MJ）	0.4
Inductance （mH）	7.6
Iron weight (Ton)	

Option A: Warm iron prototype

Comparision





Coil	saddle	racetrack
By (T)	2.0	2.0
Current（A）	8500	11000
Total turns	4*3	4*3
Storage energy（MJ）	0.32	0.4
Inductance （mH）	8.6	7.6

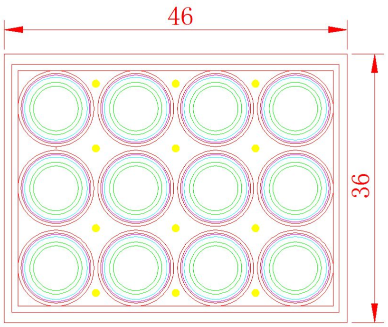
Saddle coil:

- Hard to wind
- complex coil case and cryostat

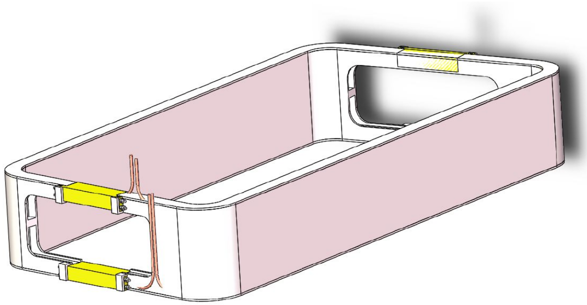
So we choose racetrack coil

Option A: Warm iron prototype

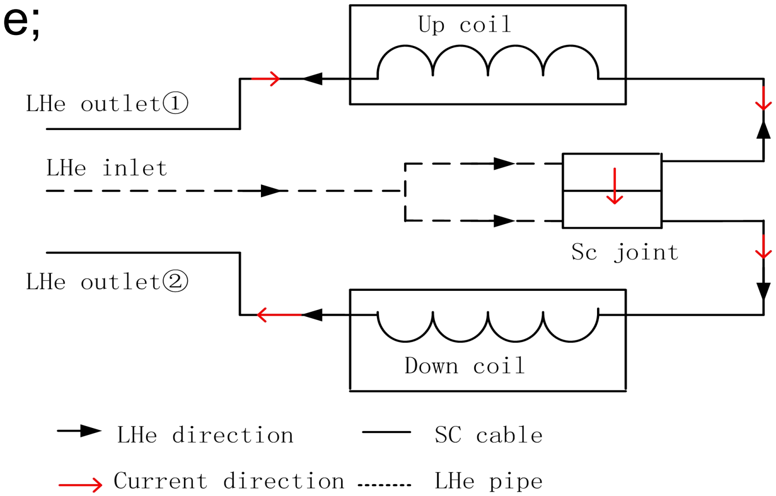
- Based on the Super-FRS dipole's design;
- Racetrack coil winded with nuclotron type cable;



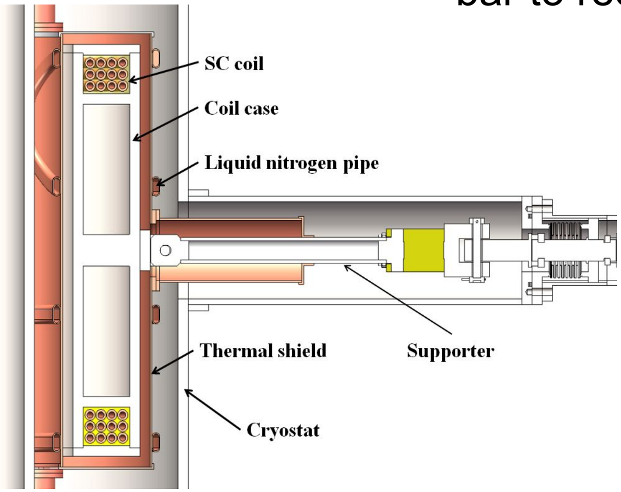
coil cross-section

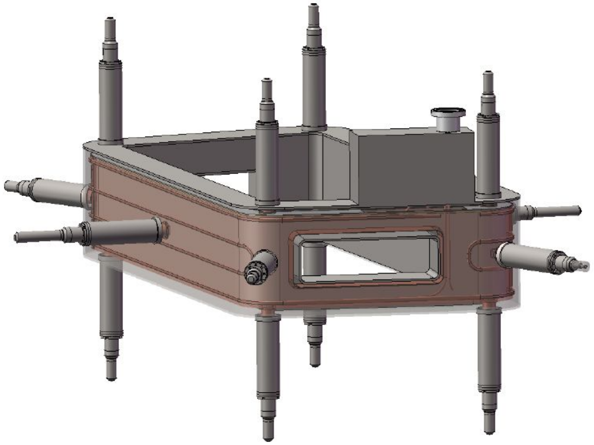


Coil case is break with G10 bar to reduce eddy current

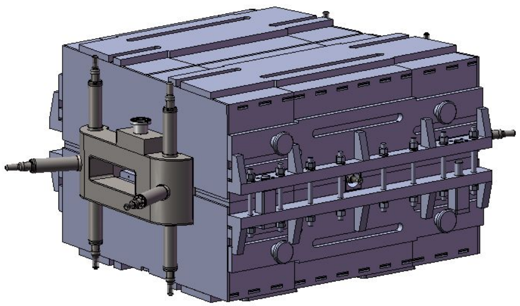


Electric and cooling circuit for the two coils



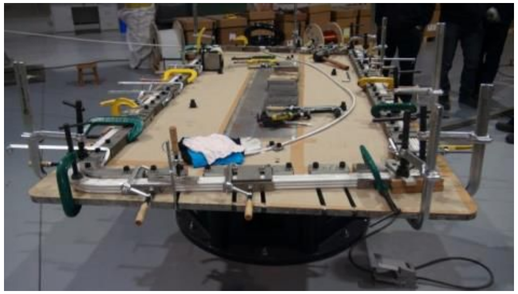


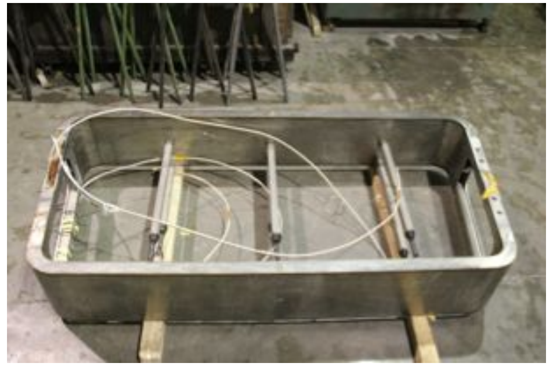
Cryostat design



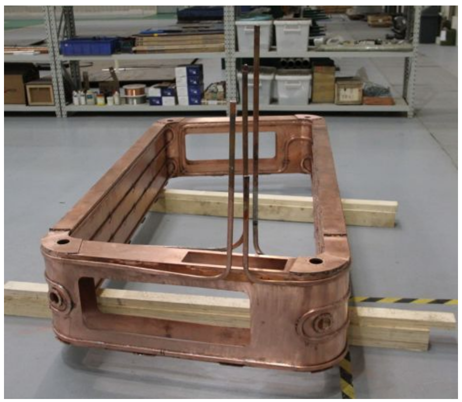
Installed into the Super-FRS yoke

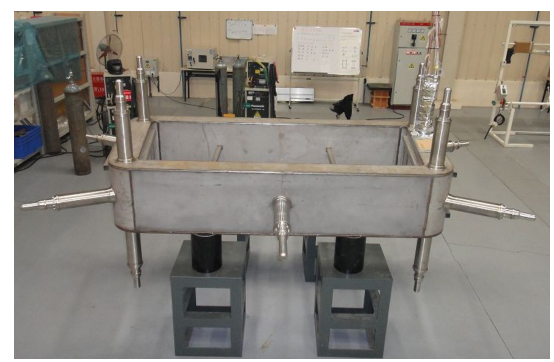
Option A: Warm iron prototype





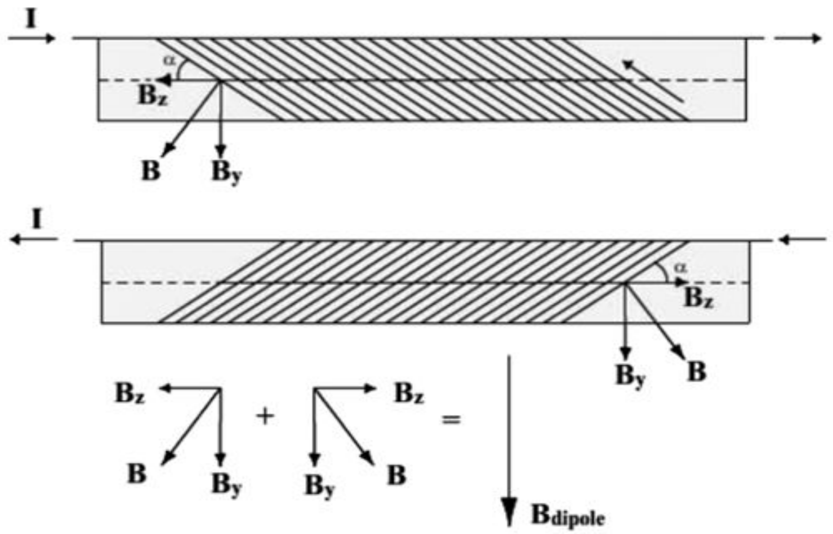
- ❖ Finished the coil winding and expoxy impregnation;
- ❖ The cryostat has been fabricated and assembled
- ❖ Waiting for the feeding box, cryogenic system, current leads and power supply to do cryogenic testing

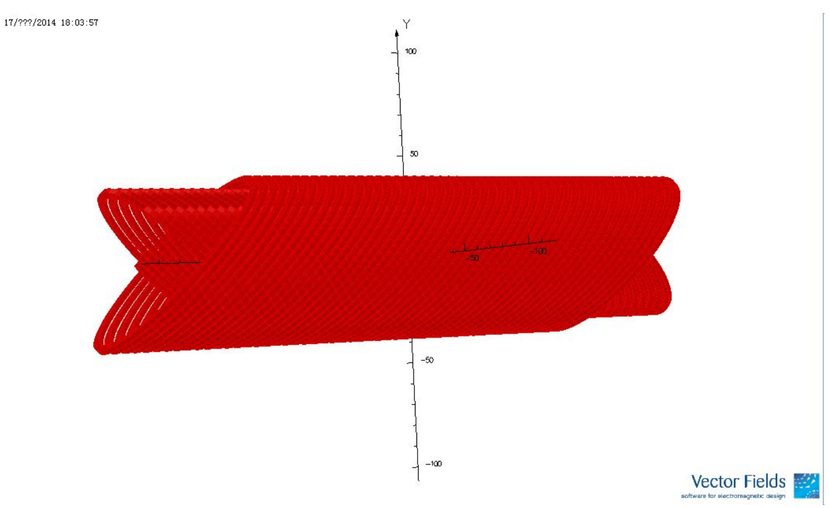




Option B: CCT

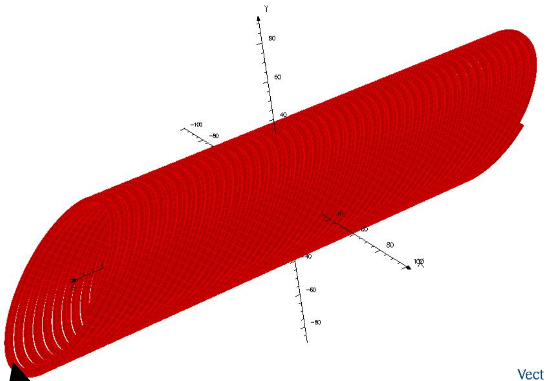
- First suggested by D.I. Meyer and R. Flasck in 1970
- AML & LBNL have started the R&D
- Compared with conventional cosine-theta coil, screwed solenoid coil is an almost perfect approximation of a cosine-theta magnet, thus yields very good field distribution(especially for integral field)
- The combined function coil can be easily achieved
- Avoid tight bends for the ends of the coils
- Has good application prospect in particle accelerator: synchrotron, FFAG, Heavy ion Gantry





Option B: CCT

❖ Avoid tight bends for the ends of the coils

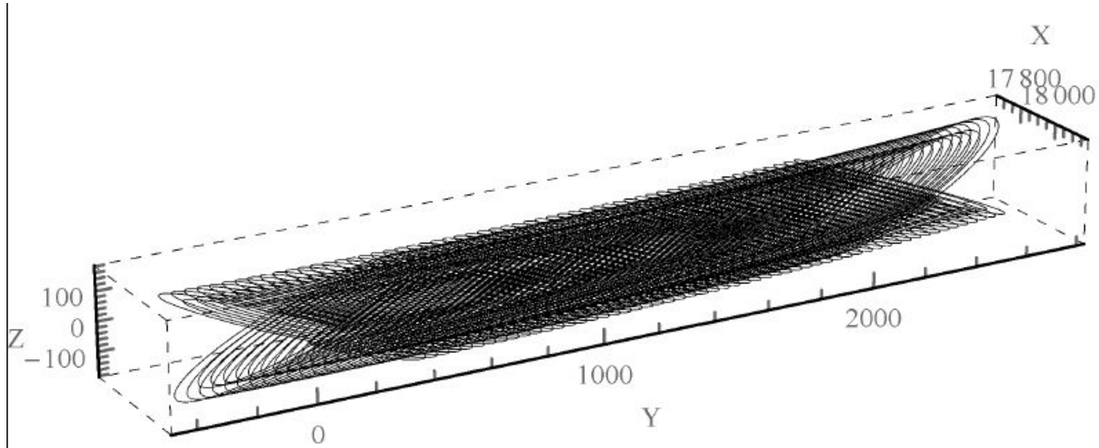


- Race track coils: tight bends for the ends
- Difficult for nuclotron type cable

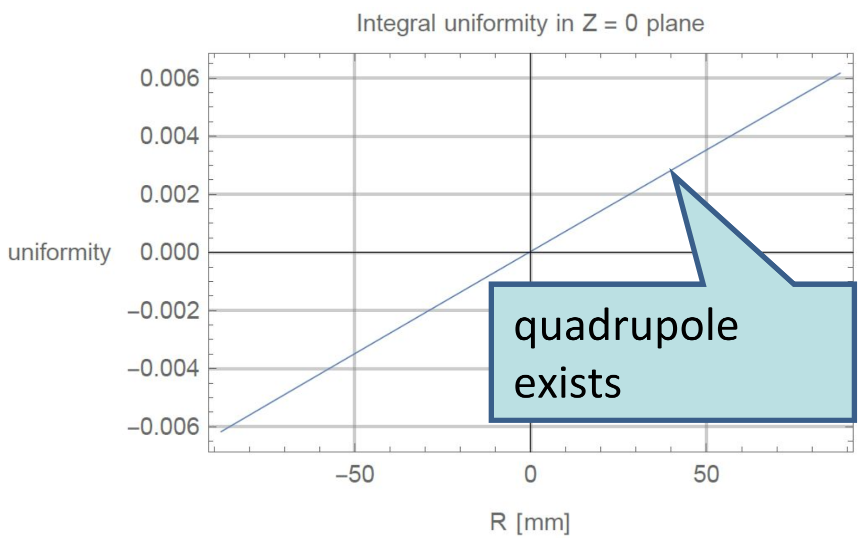
- Avoid tight bends for the ends of the coils, good for nuclotron type cable

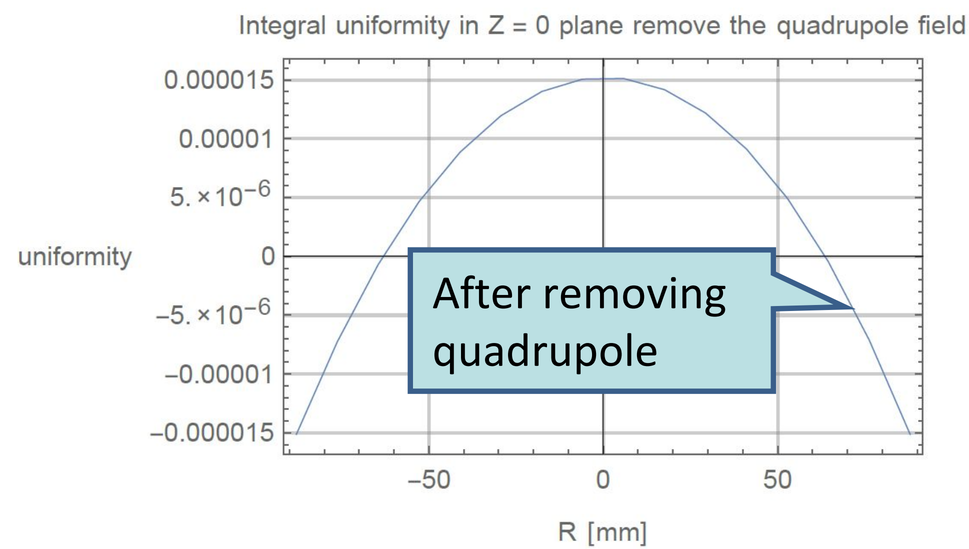
Option B: CCT

Magnetic field (without iron)	1.7 T
Magnetic field (with iron)	2.0 T
NO. of layers	4
Operation current	11000 A
Inductance	7.65 mH
energy	0.463 MJ
Length of cable	430 m



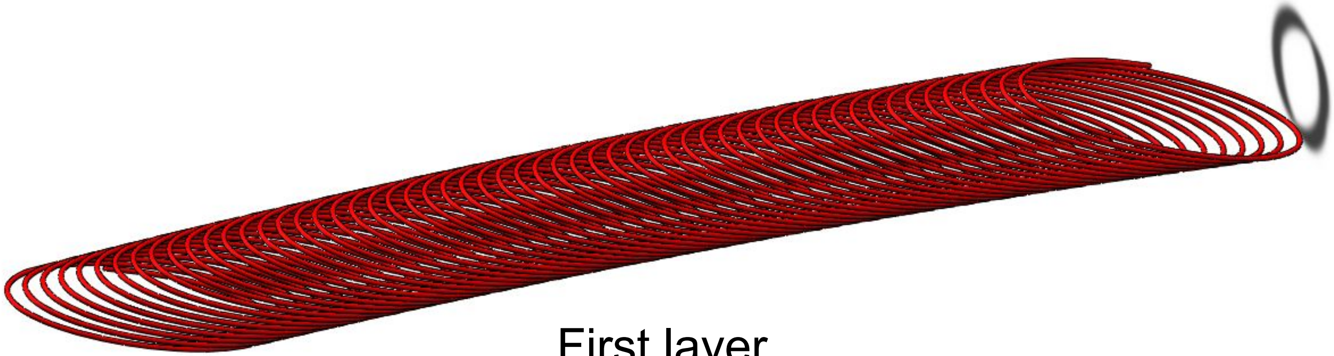
Calculation model



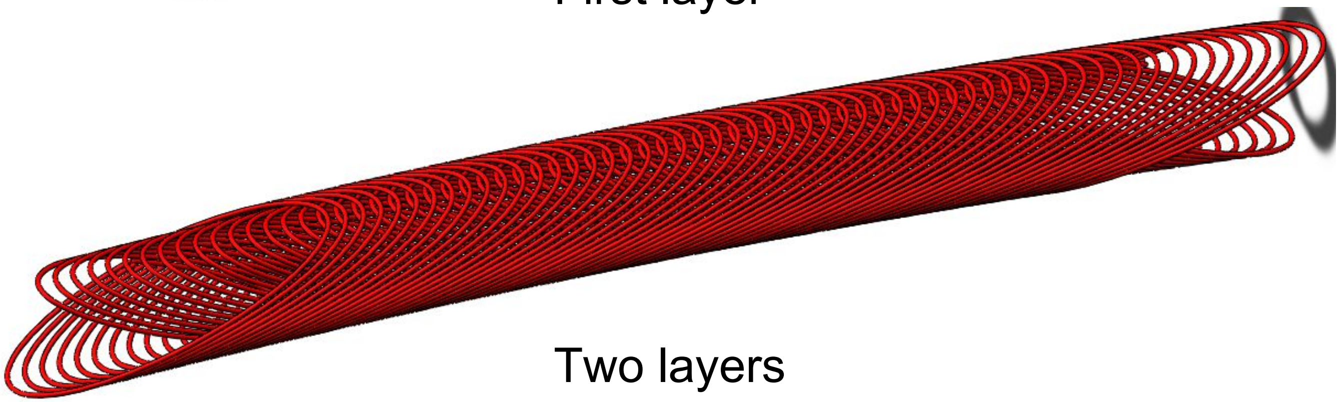


Integral field uniformity

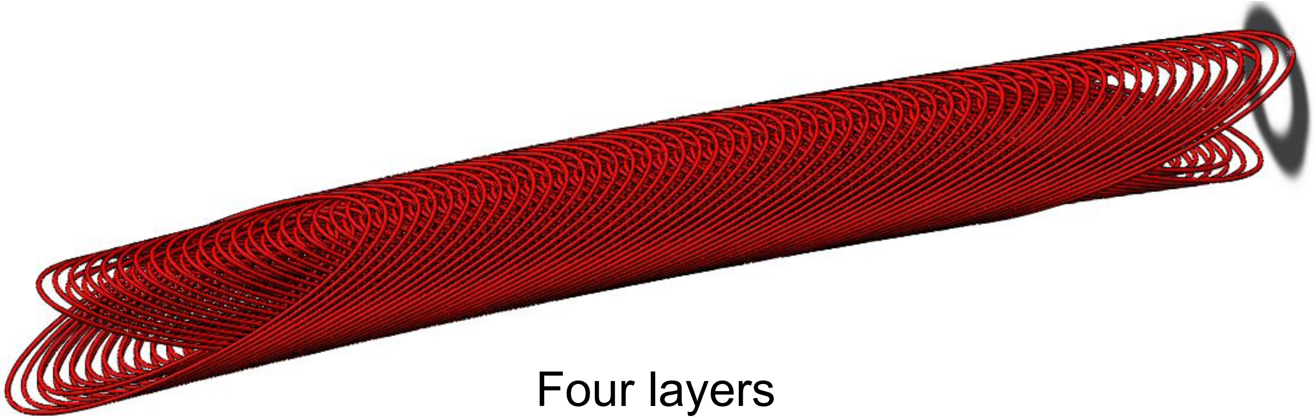
Option B: CCT



First layer

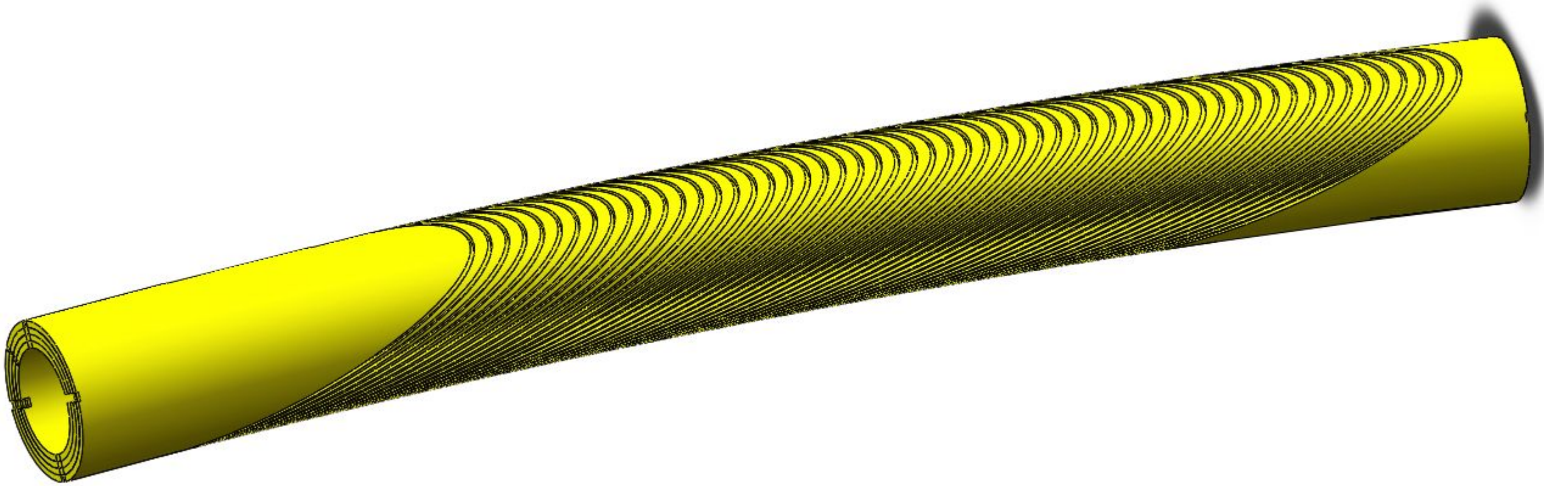


Two layers

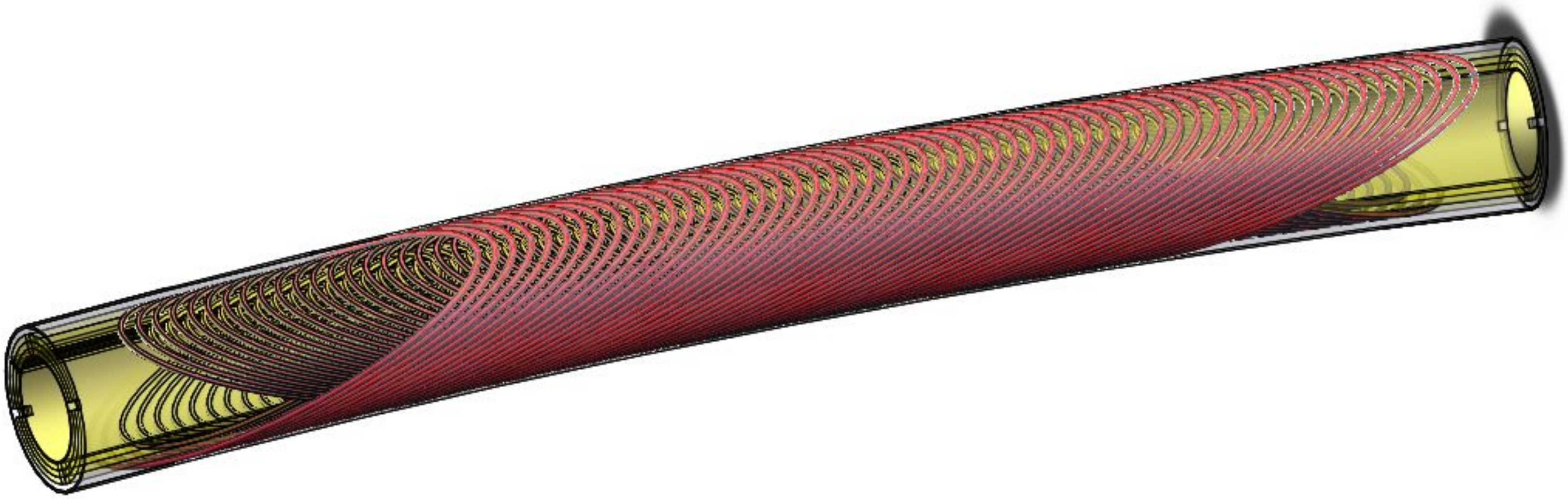


Four layers

Option B: CCT

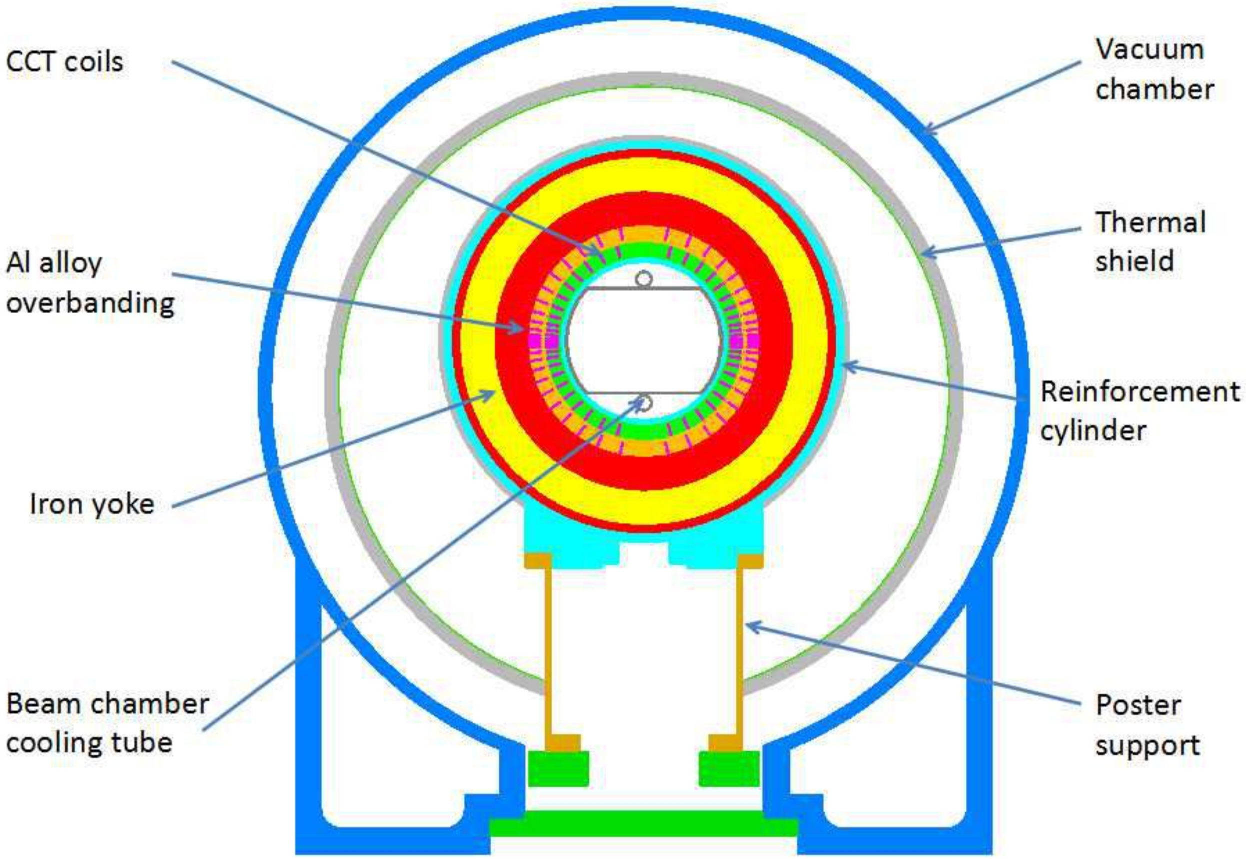


Formers with grooves (Made from G11 to avoid eddy current)



Wind cable into grooves and finally vacuum impreganted with epoxy

Option B: CCT

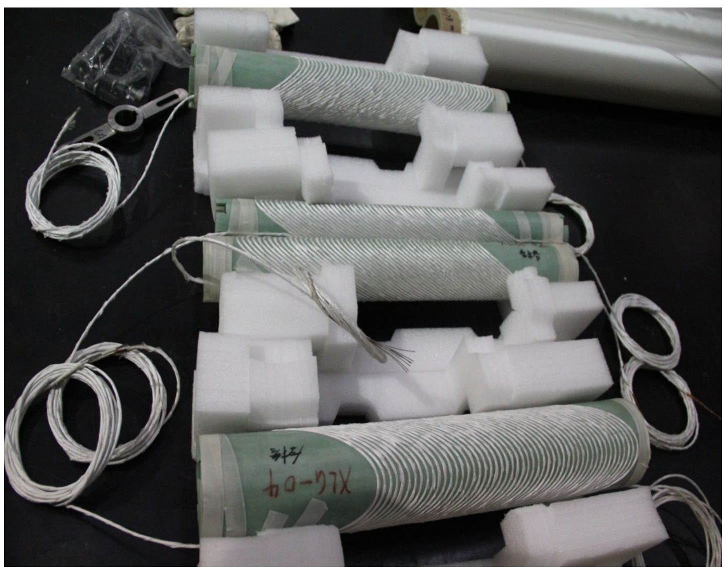


Conceptual design of cryostat

A straight CCT prototype

Mechined G10 former

Central field	**2.5T**
Good field region	Ø40mm
Effective length	323mm
Integral field uniformity	<±10^-4
Cable	7 strands
Number of layers	4
Current	3709A



Finished winding, to be vacuum impreganated and assembled

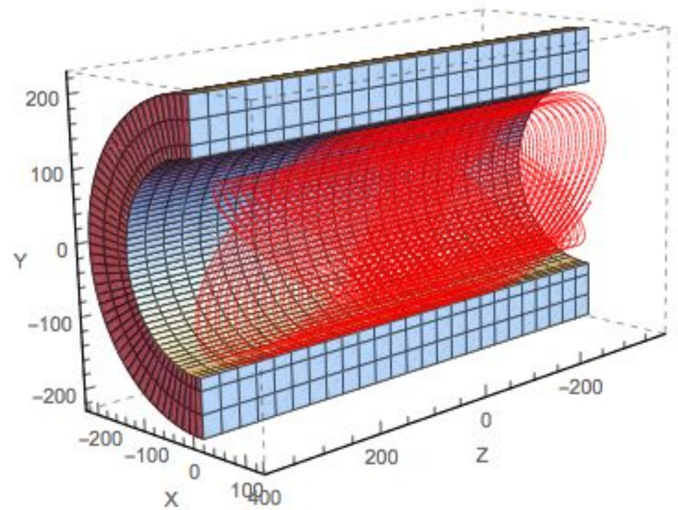
Finish fabricating and prepared fro testing

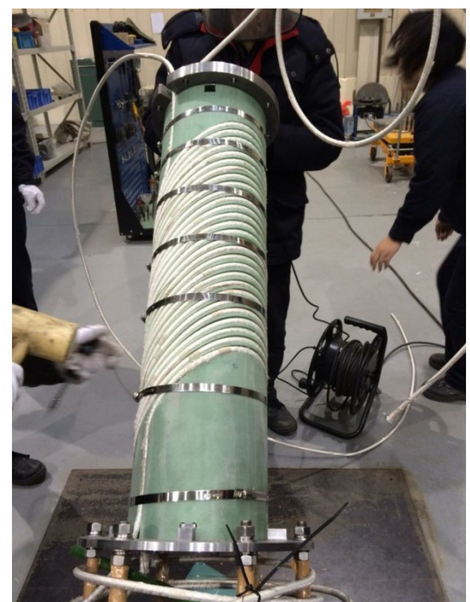
Fabricated in XSMT

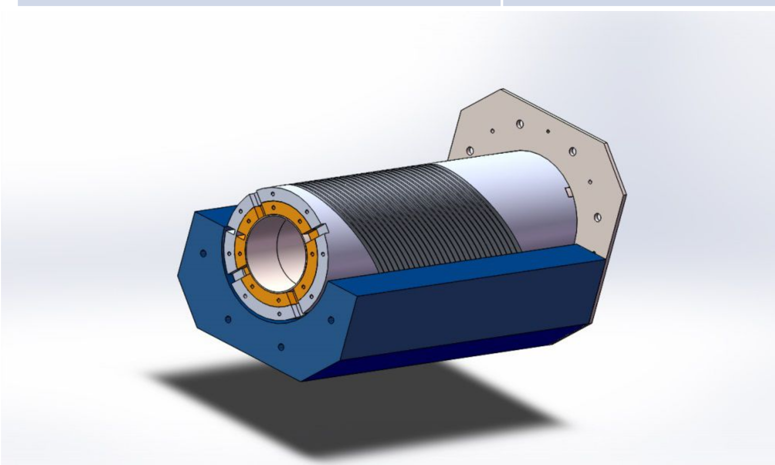
Prototype with nuclotron cable

- G10 former
- Winder with nuclotron type cable
- Cold iron to increase central field and reduce stray field

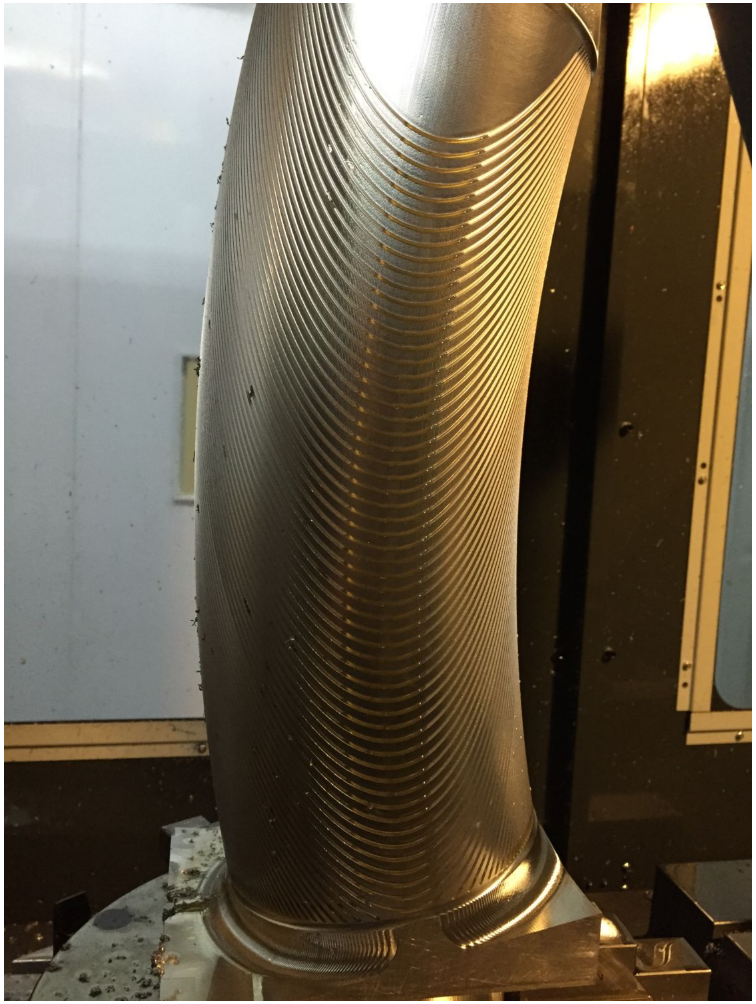
Item	Value
bore	Φ170mm
length	800 mm
field	3T
Iop	11.7kA
dB/dt	4 T/s







Curved sample



Sample mechined with CNC grinder

Problems

- How to reduce the machining cost of the curved CCT former
- Material selection: G11 or metal lamination
- Detailed calculation of magnetic field distribution
- Error analysis of field error due to machining and winding errors
- Optimization of the iron yoke
- Quench simulation
- Stress analysis

Summary

- HIAF project has just been approved and is expected to soon start
- HIAF BRing dipole: 2T, 4T/s, aperture of 176mm
- domestic low loss superconducting wire and cable have been developed
- Warm iron version dipole prototype has been fabricated and ready for testing
- CCT alternative is also in development

Reference

[1] B. Auchmann, "Overview of the Fast Cycled Magnet (FCM) Demonstrator Program at CERN", 2013

[2] C. L. Goodzeit, M. J. Ball, R. B. Meinke, “The Double Helix Dipole - A Novel Approach to Accelerator Magnet Design”, IEEE Transactions on Applied Superconductivity, June 2003, Vol.13, No. 2,pp. 1365-1368.

[3] R. B. Meinke, C. L. Goodzeit, M. J. Ball, “Modulated Double-Helix Quadrupole Magnets”, Paper 4LC08, ASC2002, Houston, TX, August 2002;to be published, IEEE Transactions on Superconductivity, June 2003.

[4] D. I. Meyer and R. Flasck, “A new configuration for a dipole magnet for use in high energy physics application,” Nucl. Instr. and Methods, vol. 80, pp. 339–341, 1970.

[5] R.B. Meinke, M.J. Ball, C.L. Goodzeit,“Superconducting Double-Helix Accelerator Magnets”, IEEE Proceedings of the 2003 Particle Accelerator Conference, 2003, Vol.3,pages 1996-1998.

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Thanks for your attention!