Introduction to the superconducting magnets development at IMP

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Outline

- ❖We started with solenoids
- ❖ Research fundamentals
- ❖ Projects in progress
  - ➢ Progress of the SECRAL II superconducting magnet
  - ➢ Progress of Fast-cycling dipole prototype for HIAF
  - ➢ R&D of tilted solenoid type dipole
- ❖ Future plans
  - ➢ Superconducting magnets for HIAF and ADS
  - ➢The next generation ECRIS superconducting magnet
  - ➢ Superconducting magnets for Cancer Therapy Facility

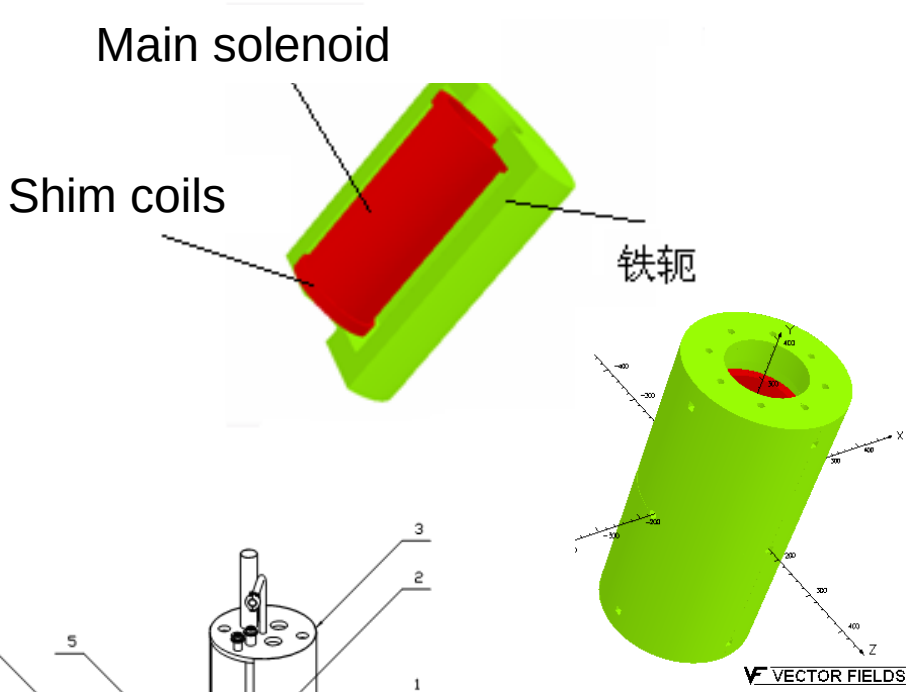
We started with solenoids

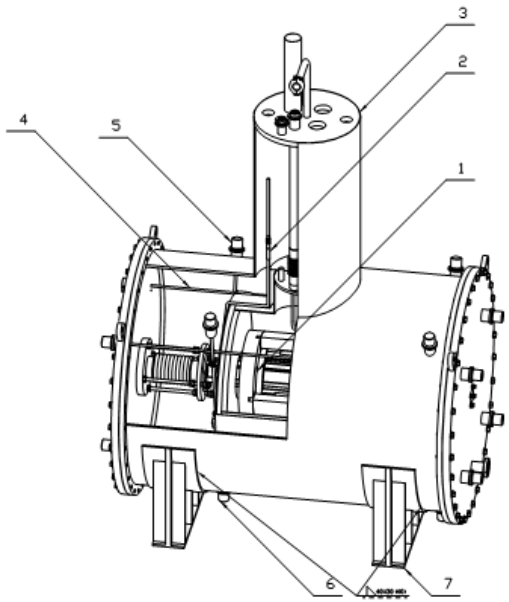
- 3T solenoid with cold iron yoke
- 5T active shielding
- Low stray field focusing solenoid for ADS
- 7T magnet for Lanzhou Penning Trap

3T solenoids with cold iron yoke（1）

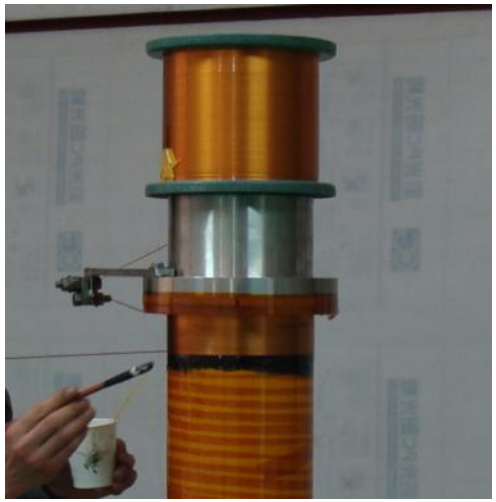
- This is our first self-developed superconducting magnet (2009);
- Two shim coils at the ends was designed to improve homogeneity
- Cold iron yoke is used to lower stray field

Magnetic field in the center	T	3.004
Operating current	A	270
Operating temperature	K	4.2
Inductance	H	1.5
Stored energy	kJ	57
Field constant	G/A	111
Diameter of warm bore	mm	70
Outer diameter of cryostat	mm	870
Cryostat length	mm	790





3T solenoids with cold iron yoke（2）



Wet winding

Cold iron yoke

Cryostat

Finished

Testing

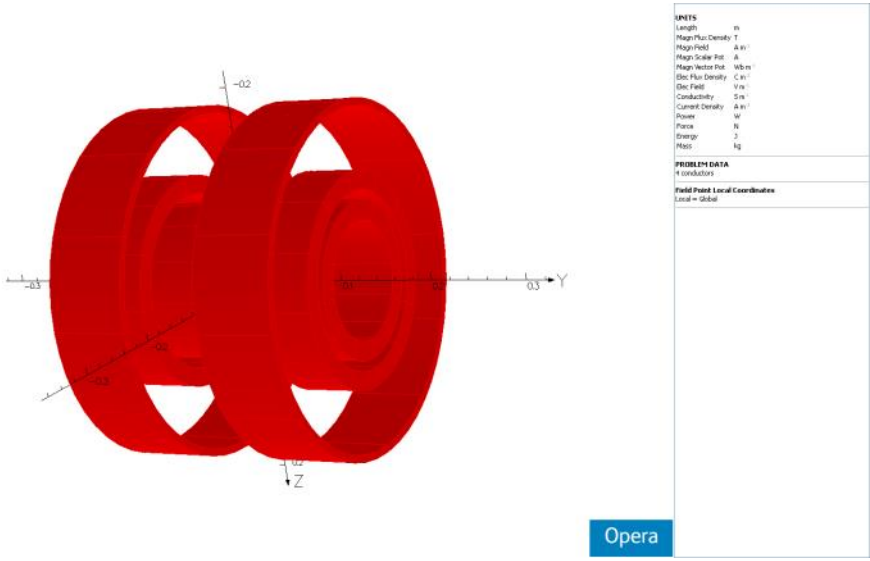
With this magnet, we explored:

- The winding techniques
- Cryostat fabrication techniques
- Cryogenic testing techniques

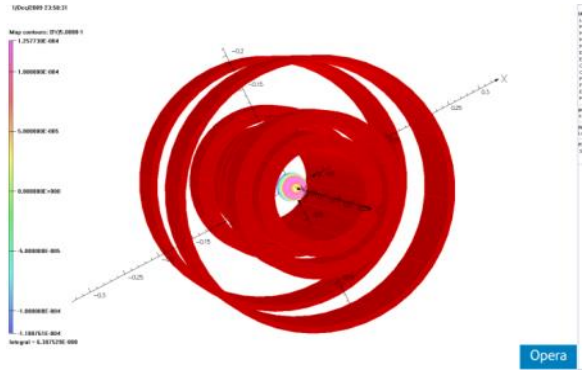
5T actively shielding solenoid(1)

- This magnet is similar to the NMR design;
- The shape and position of each coil is optimize to achieve good homogeneity;
- Bulking coils are used to minimum stray field.

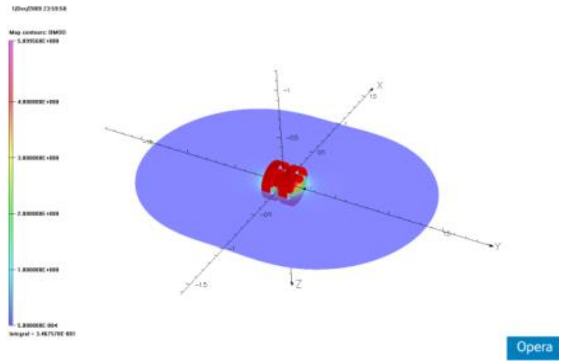
Central field	5T
Inner diameters	120 mm
Outer radius	360mm
Length	250mm



Coil configurations



100ppm without shimming, Φ40 DSV

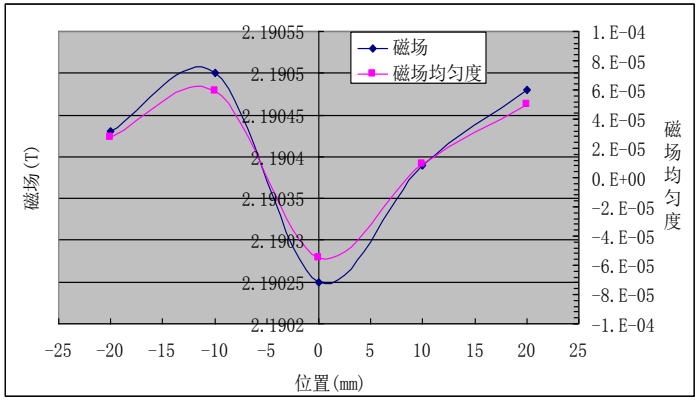


5 Gauss line about 1 meter from center

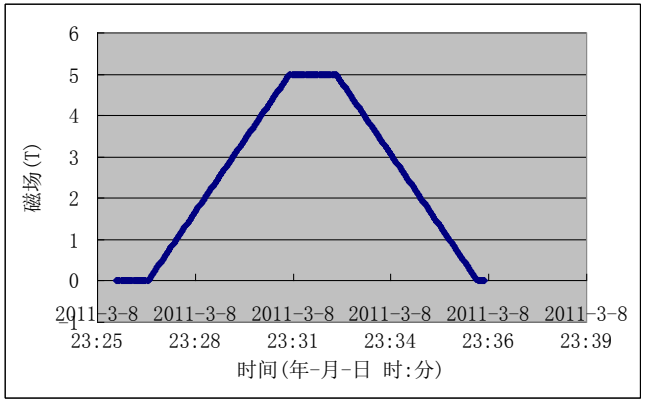
5T active shielding solenoid(2)

Finished winding

Cryogenic testing



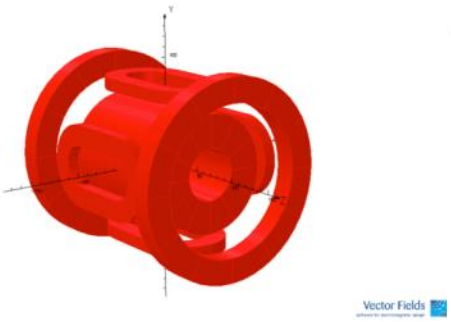
Field homogeneity

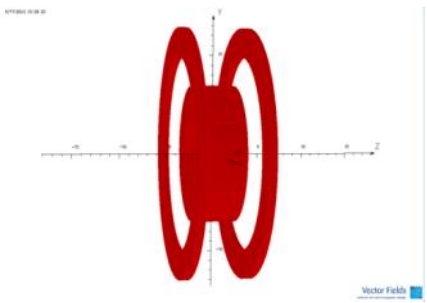


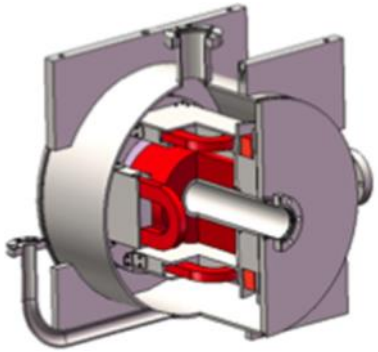
Charging and discharging

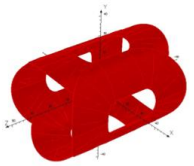
ADS low stray field focusing solenoid

These two kinds of solenoids is developed for ADS superconducting Linac as strong focusing element between two SC cavity







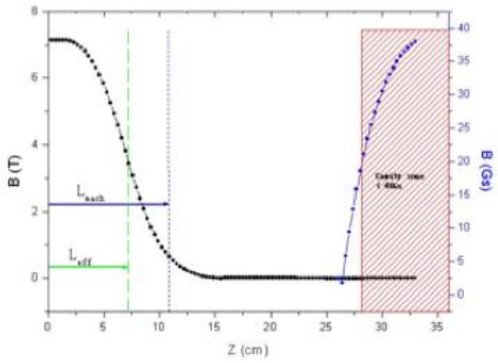


Steer dipole

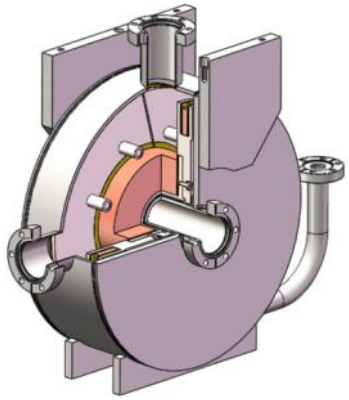
L150 solenoid

ADS solenoid parameters

Central field	***3 T-7 T***
Bore	***40 mm***
Effective length	***150 mm , 60mm***
Fringe field	***<200 Gs***

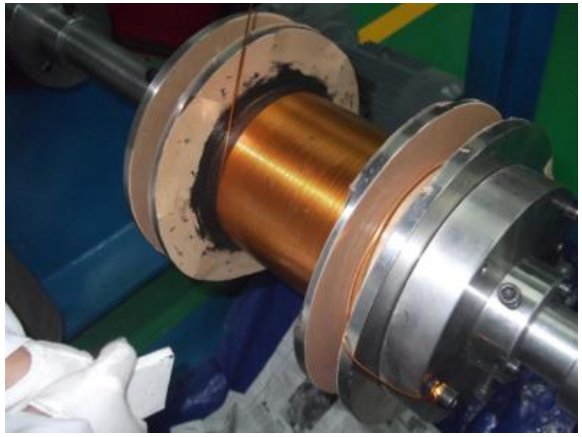


Stray field

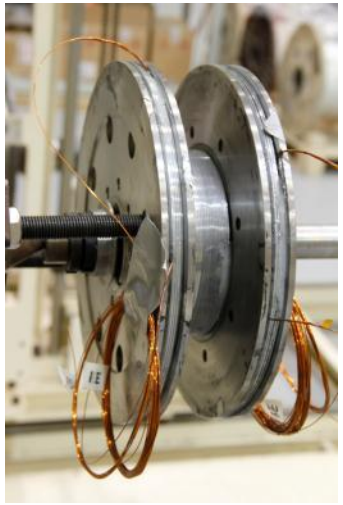


L60 solenoid

ADS low stray field focusing solenoid



Winding process (L150)

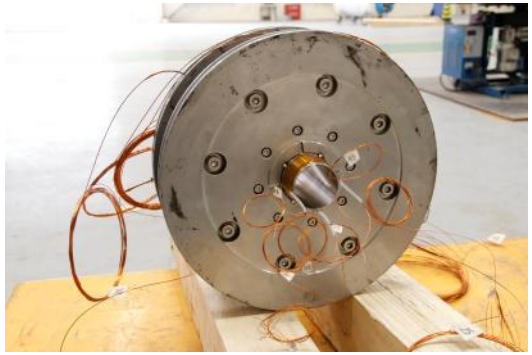


Winding process (L60)

Steering dipoles (L60)

Three L150 solenoid has been finished and tested

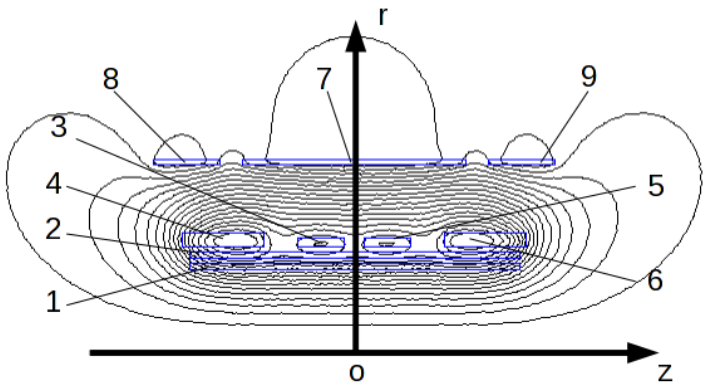
Installed in the Cryomodule



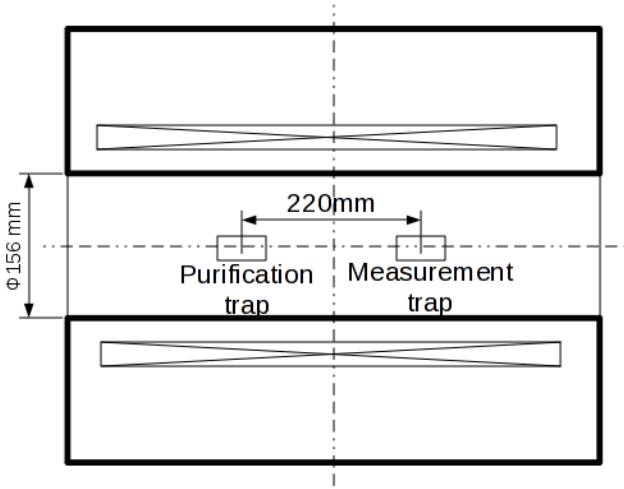
Assembled L60 solenoid

7T magnet for Lanzhou Penning Trap

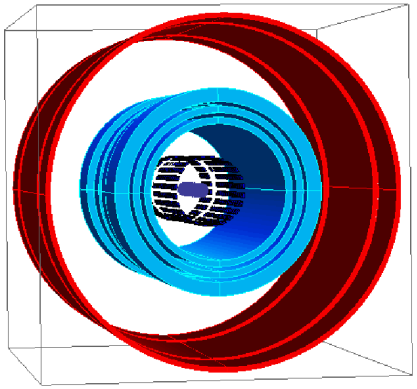
central field	7 T
homogeneity	3×10^{-7} within 1 cm^3
5 Gauss line	2 m
Field stability	10^{-8}/h
Warm bore size	Φ156 mm

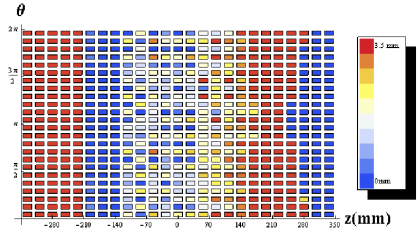


EM design

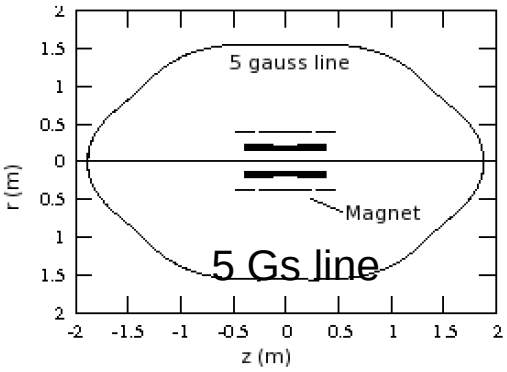


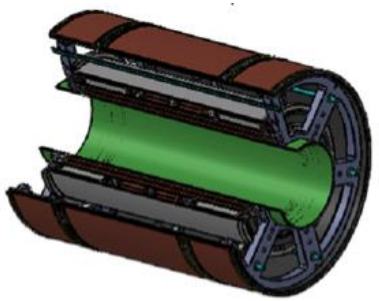
Two good field region





Passive shimming

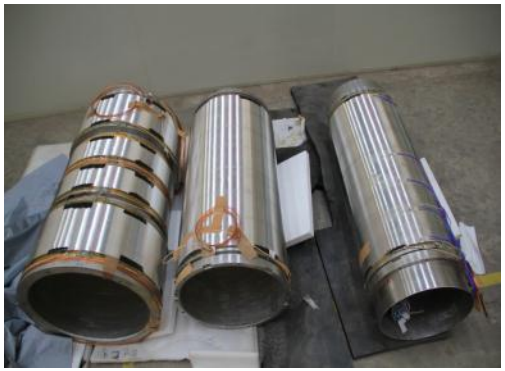




Coil bobbin

7T magnet for Lanzhou Penning Trap

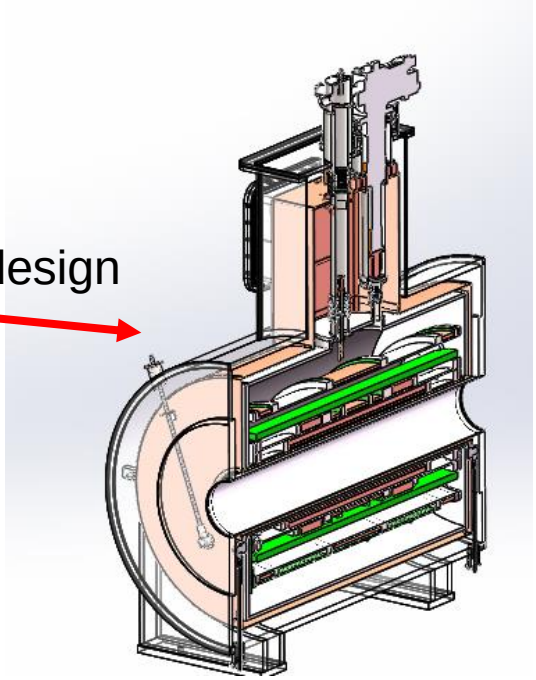
Winding



Finished winding

Assembly

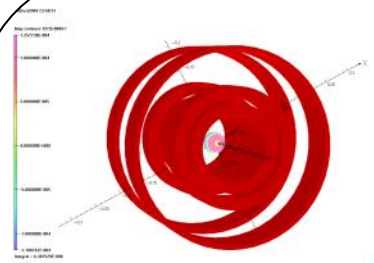
Redesign

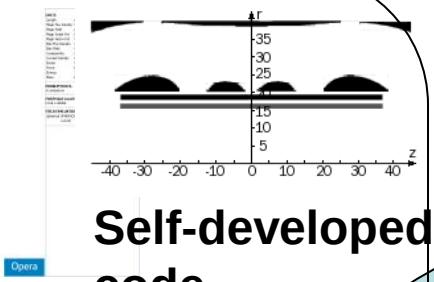


Research fundamentals

- SC magnet design process and tools;
- SC magnet manufacturing;
- Testing

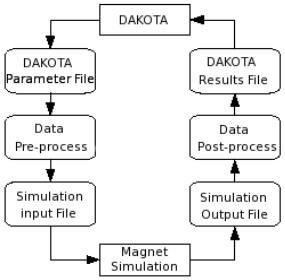
SC Magnet design process and tools





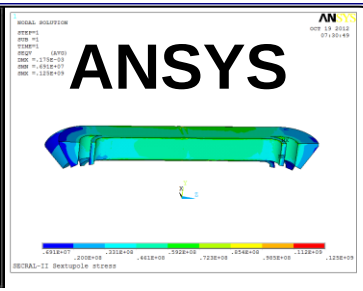
Opera

Self-developed code



Optimizer

EM design



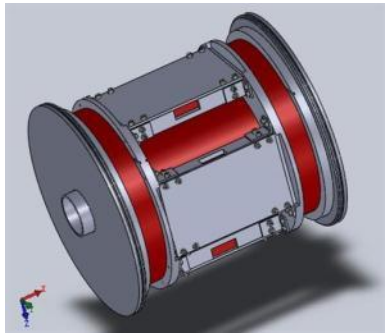
Multi-physics simulation

1

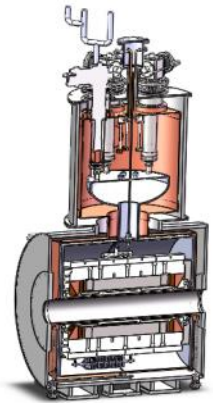
2

3

4



Mechanical design



Cryostat design

SOLIDWORKS

SC Magnet Manufacturing

Western Superconducting Technologies Co., Ltd.

Xi’an Superconducting Magnet Technology Co., Ltd.

Testing

- Linde LR280 refrigerator;
- Several testing dewar (200mm – 800mm) ;
- NI PXI based data-acquisition system

LR280

Data-acquisition system

Φ 300mm Dewar

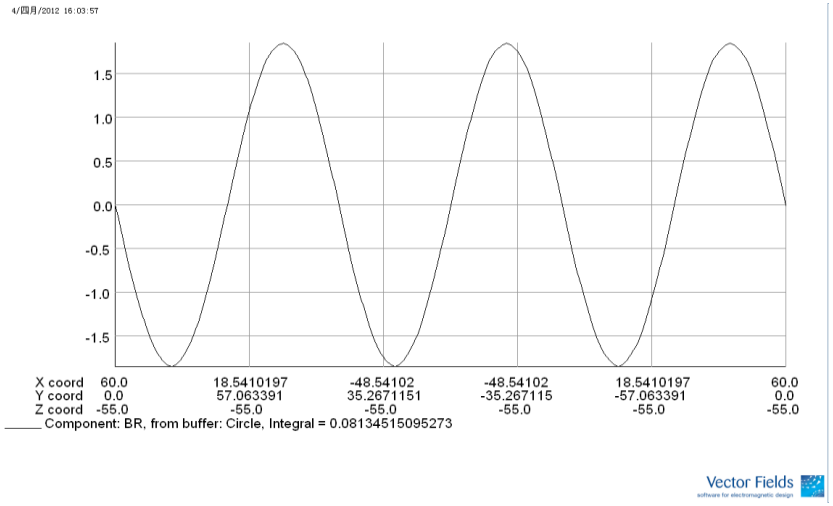
Φ 800mm Dewar

Projects in progress

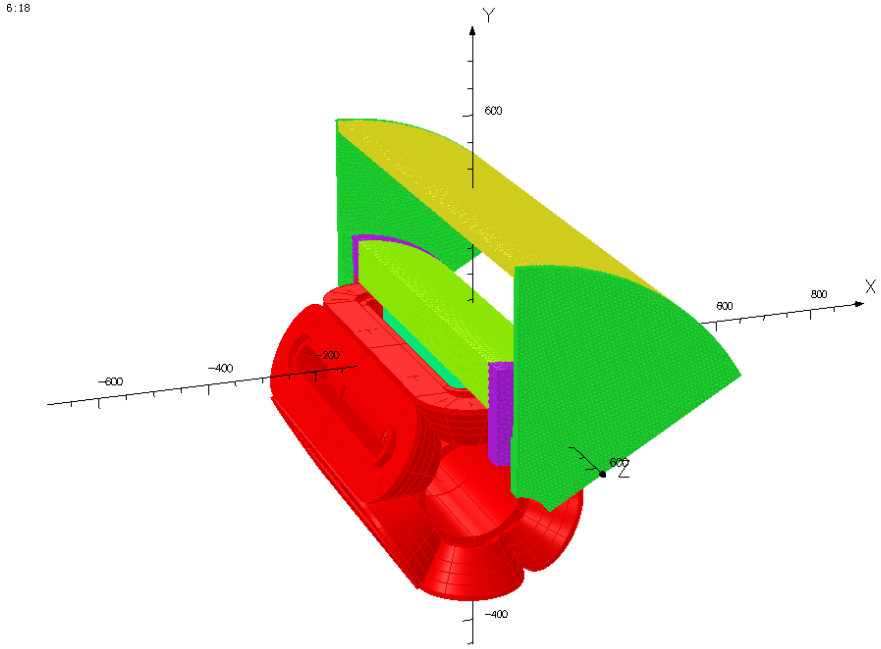
- SECRAL II SC ECRIS(28 GHz) magnet
- Fast-cycling dipole prototype for HIAF
- R&D of tilted solenoid type dipole

SECRAL II magnet (EM Design)

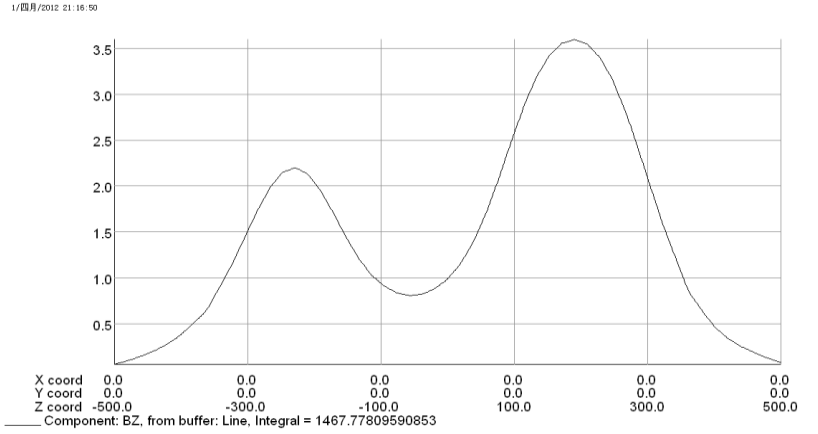
Injection Field	3.7 T
Extraction Field	2.2 T
Radial Field on the wall of pasma chamber	2.0 T
Diameter of warm bore	Ø142 mm
Storing energy	0.7MJ



Radial field Br
(Φ120mm)

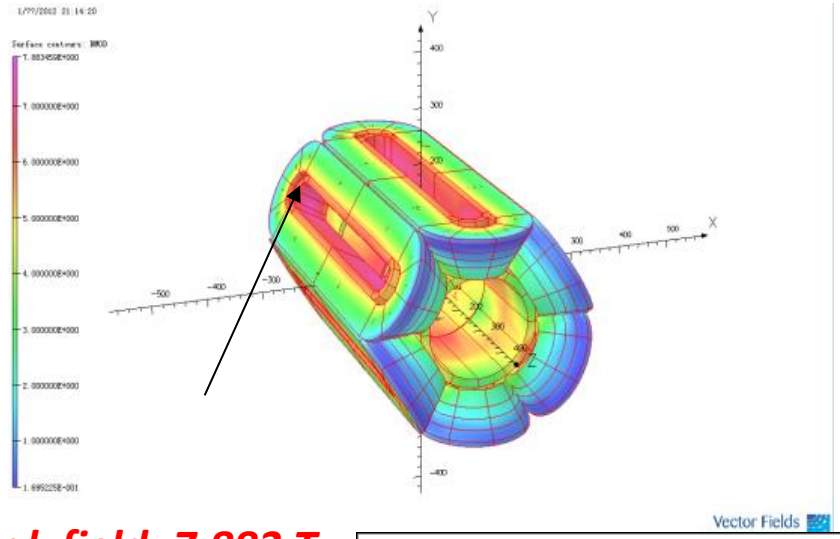


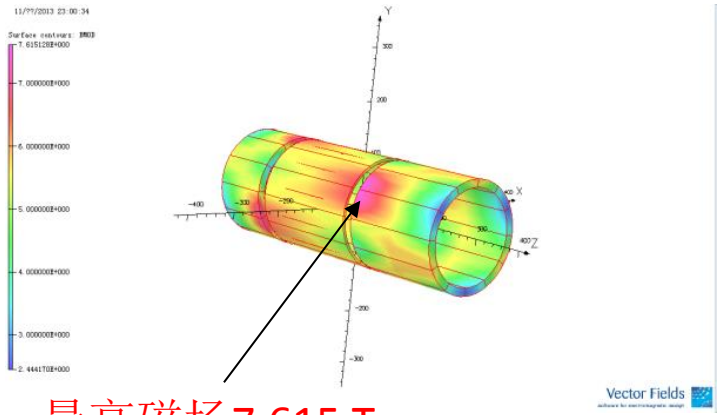
Tosca Model



Axial field Bz

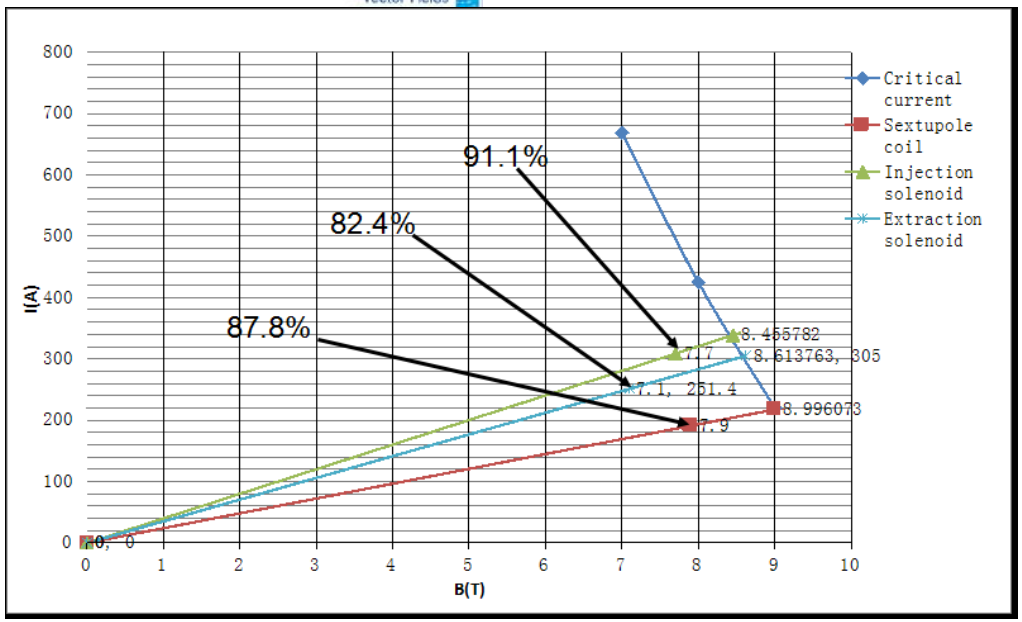
SECRAL II magnet (EM design)



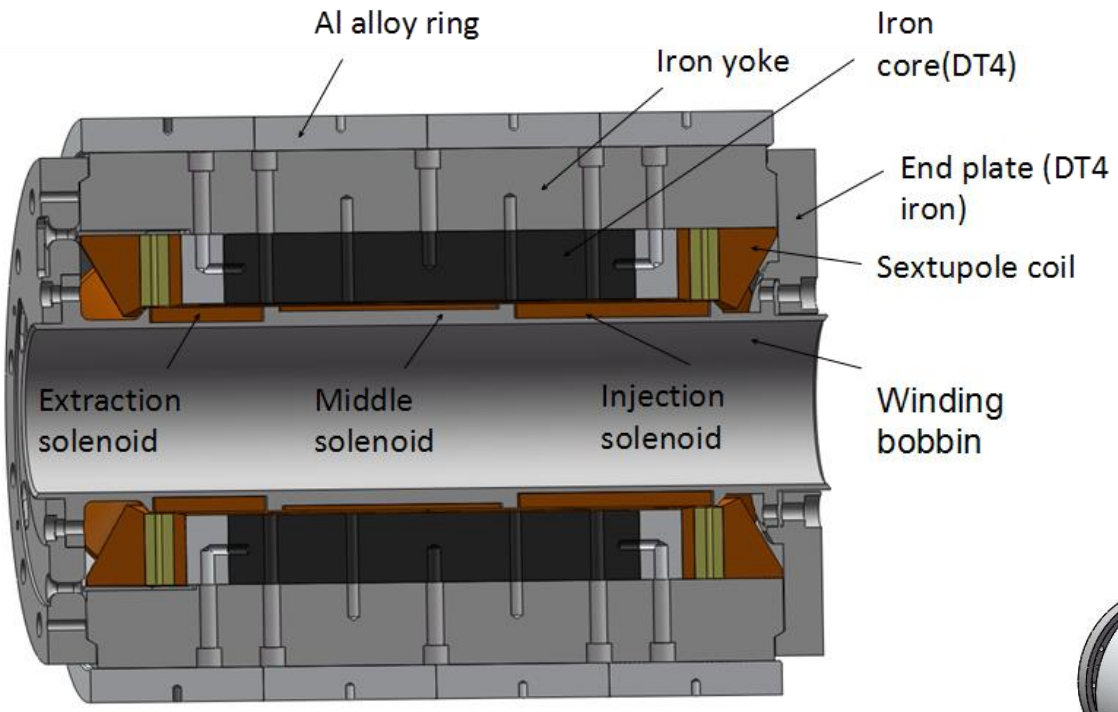


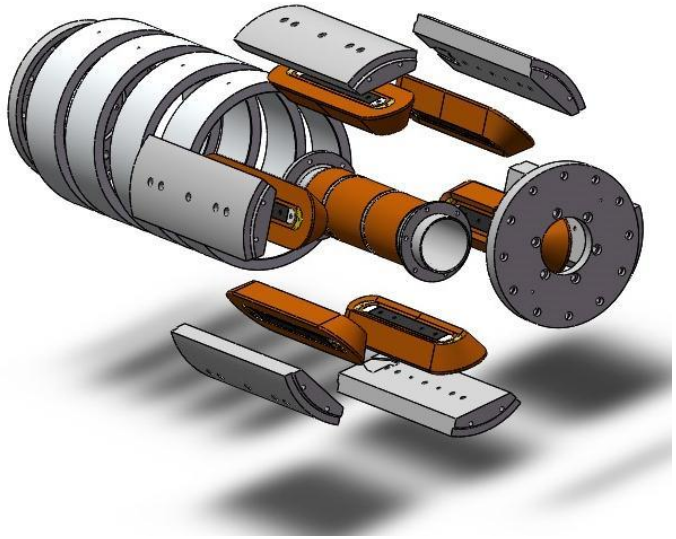
最高磁场7.615 T

Peak field: 7.883 T



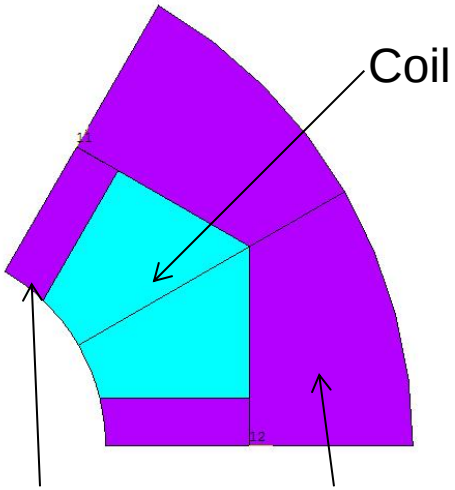
SECRAL II magnet (Cold mass design)



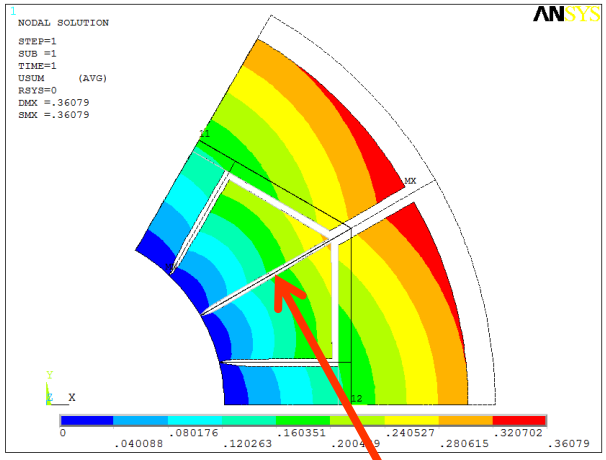


SECRAL II magnet (Stress anlysis)

300K

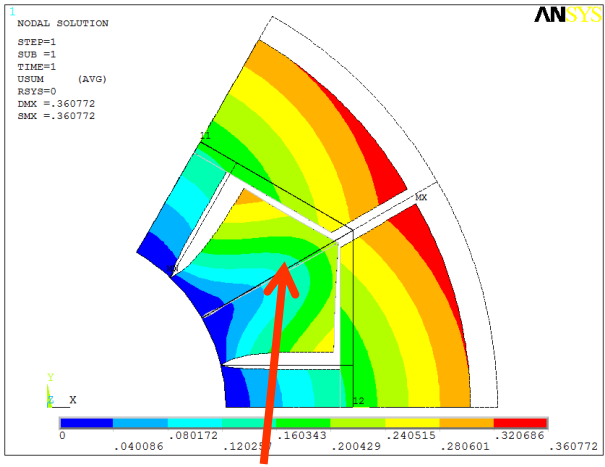


Cooled down to 4.2K

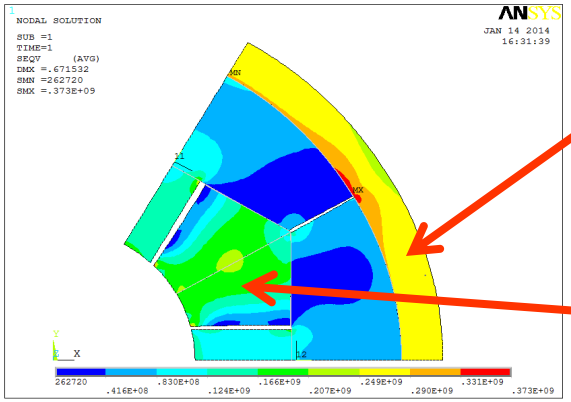


0.1mm gap between two adjacent coils

Energized



Gap cause big deformation and stress（about 500MPa）



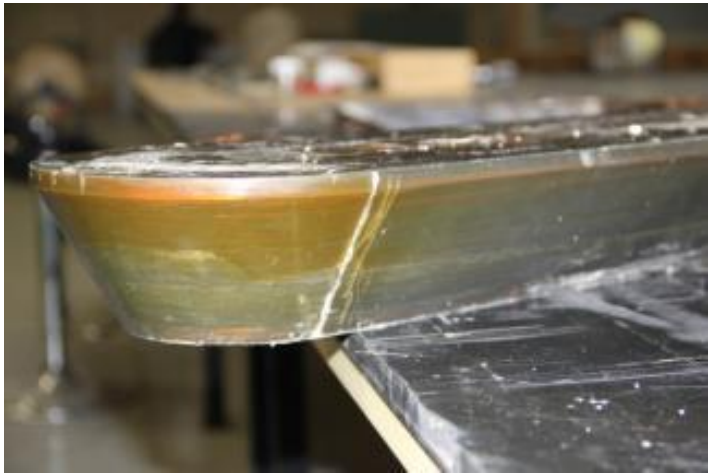
Apply Al alloy rings with the 0.6mm of interference fit

The stress is reduced to 166 MPa

SECRAL II magnet (Fabrication)

Wet winding

Finished racetrack coils

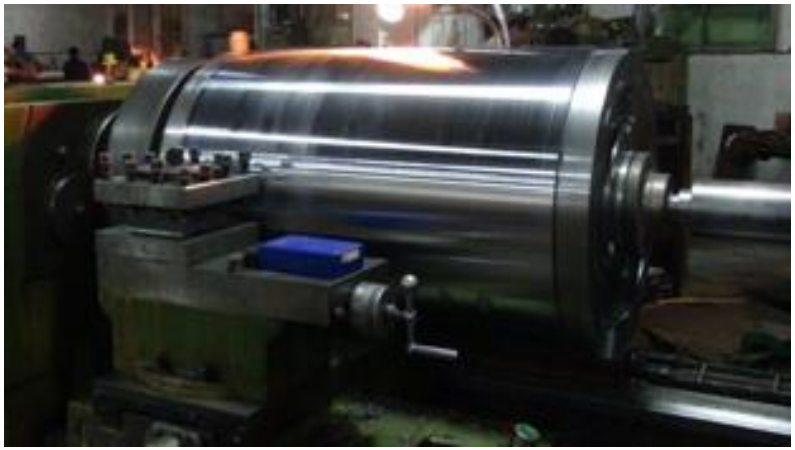


After vacumm impregantion

Trial assembly

SECRAL II magnet (Fabrication)

Remember the position with pin



Remove the coils and process the iron yoke assembly to improve the precision

shrinkage fit(150℃)

Finished

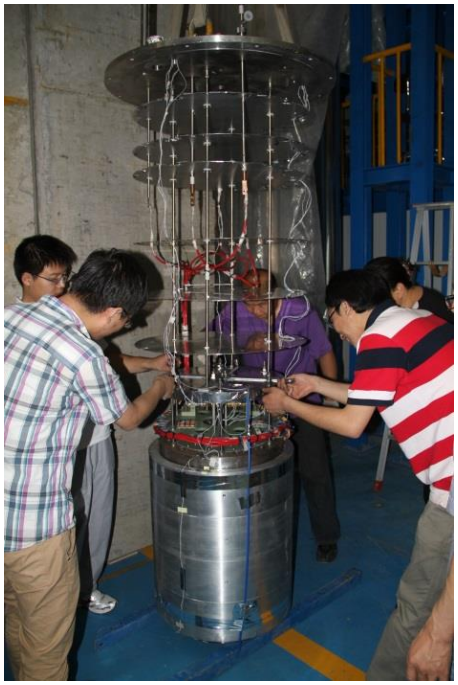
SECRAL II magnet (Testing)

❖Winding completed in 2013, begun to assemble in 2014

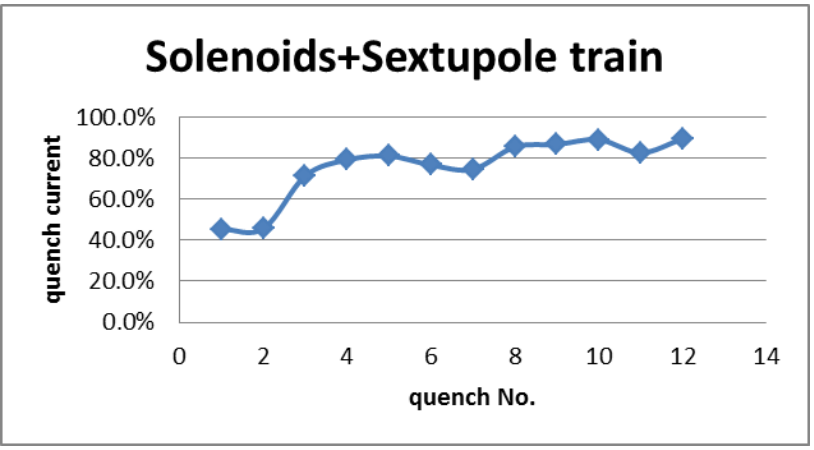
❖ In June 2014, the cold mass was dilverd to IMP for testing

❖After 10 times quench, 90% of design value was achieved

Finished assembly



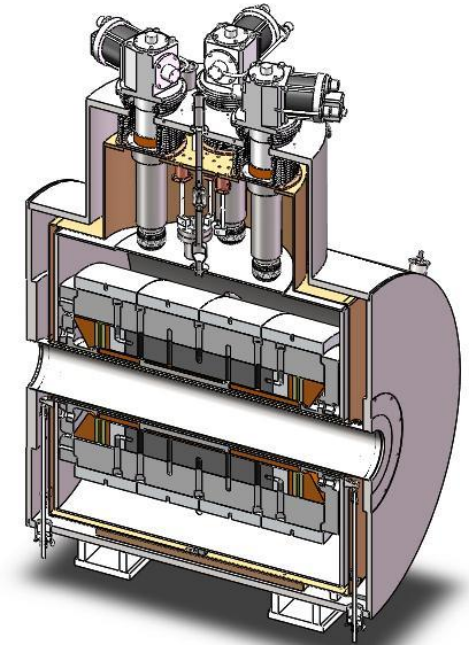
Installed into testing dewar

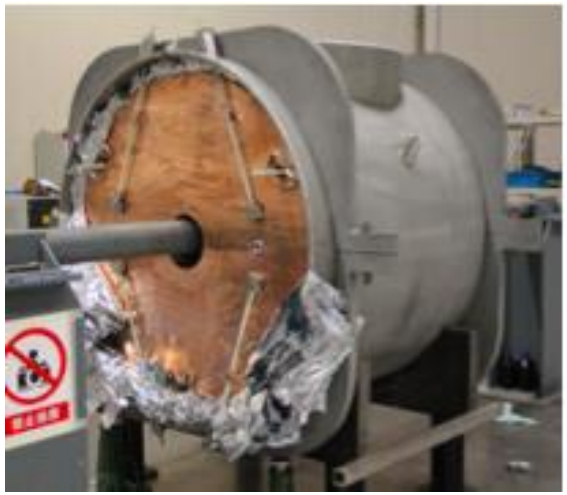


Ready for testing

Cool down

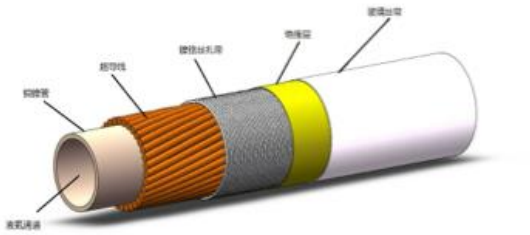
SECRAL II magnet (Cryostat fabrication)

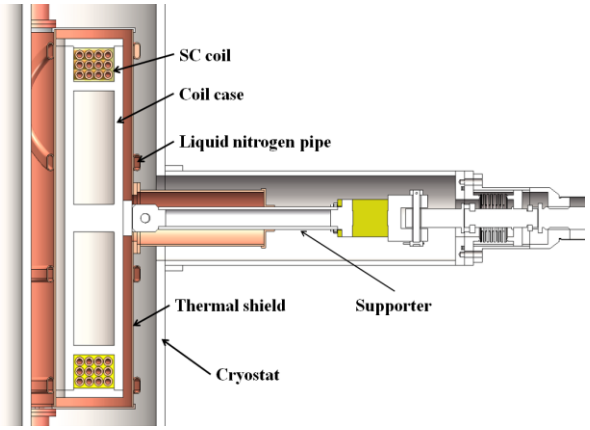




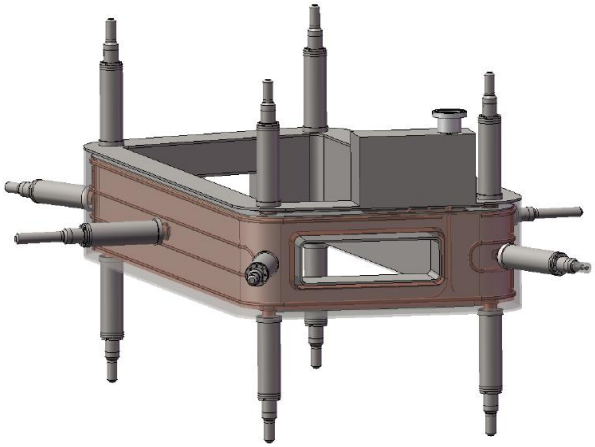
Prototype dipole for HIAF BRing (Design)

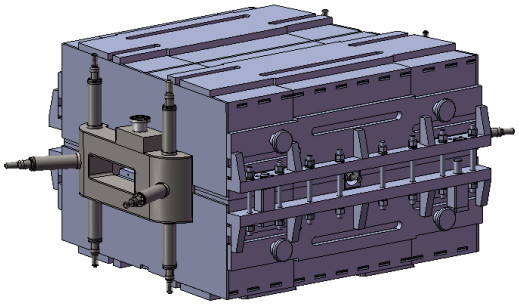
- Base on the Super-FRS dipole's design;
- Use nuclotron type cable to achieve cycling rate of 2T/s;





Cryostat design



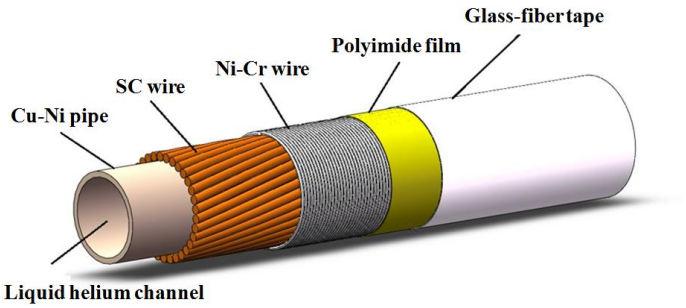


Installed into the Super-FRS yoke

Prototype dipole for HIAF BRing (CACC Cable)

Advantages:

- Good performance of mechanical stability
- Lower eddy current loss
- Good performance of cooling
- Withstand high voltage



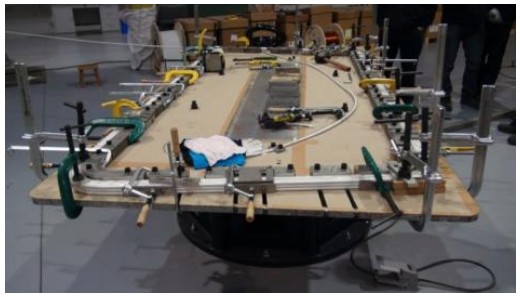
Superconducting cable

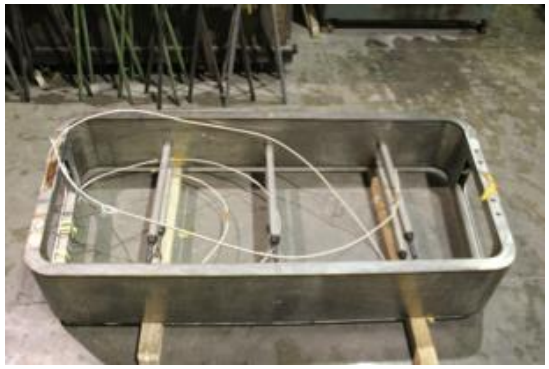
Structure of cable:

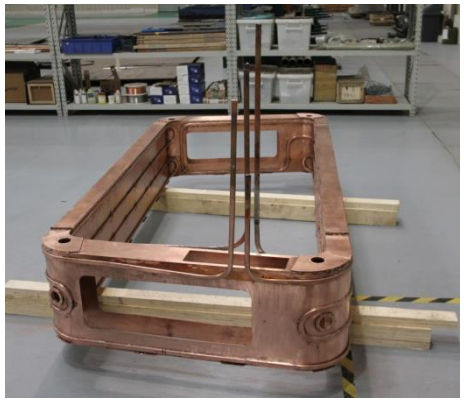
- Cu-Ni pipe: inner radius 6 mm with thickness 0.5 mm
- NbTi superconducting wire: diameter 0.7 mm
- NiCr (0.3 mm) wire is wound for SC wire
- The polyimide film (0.1 mm) is half wrapped one layer
- The Glass-fiber tape (0.1 mm) is half wrapped two layer

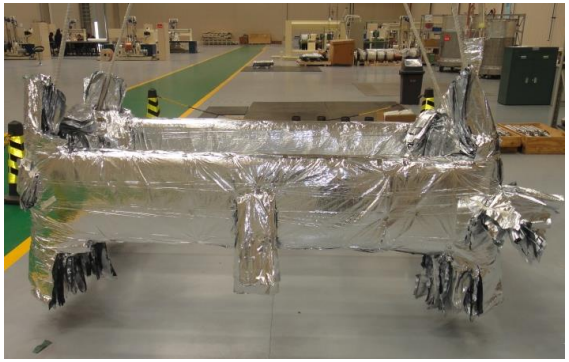
Parameters of SC wire	
Diammeter	0.7 mm
Filament diameter	5 μm
Twist pith on filaments	8～12 mm
Ratio of Cu and SC	>1.6
Numbers of wire in cable	33
Twist of wire	115±5 mm
Critical current Ic of wire	>600 A (3 T, 4.2 K)
Critical current Ic of cable	>19.8 kA(3 T, 4.2 K)

Prototype dipole for HIAF BRing (Design)





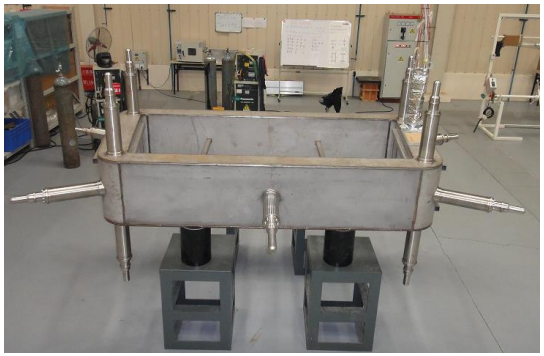




❖ Finished the coil winding and expoxy impregnation;

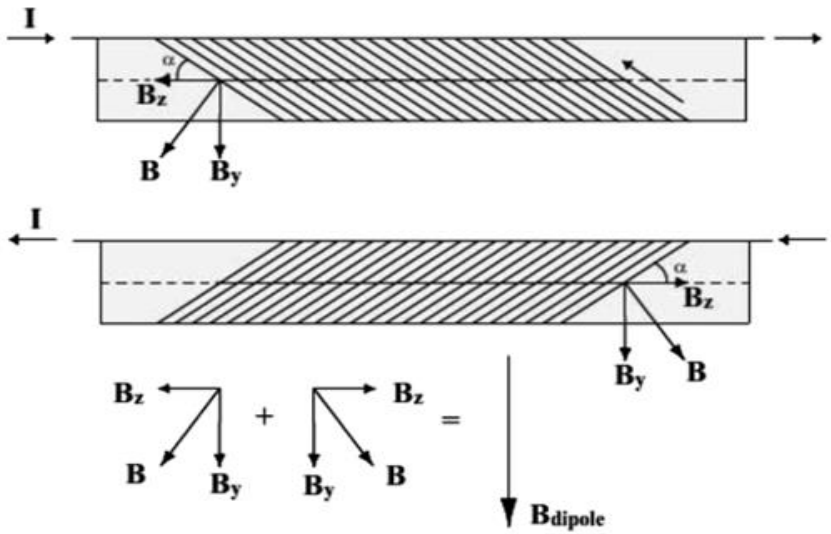
❖ The cryostat has been fabricated and assembled

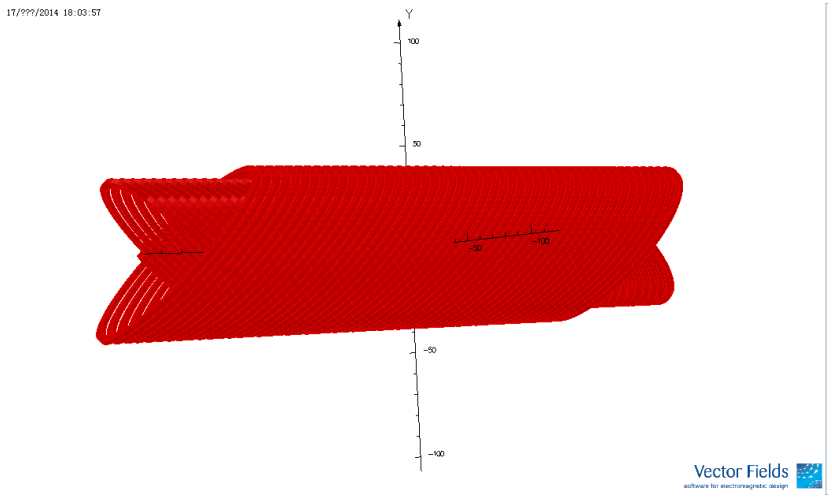
❖ Waiting for the feeding box, cryogenic system, current leads and power supply to do cryogenic testing



Tilted solenoid dipole

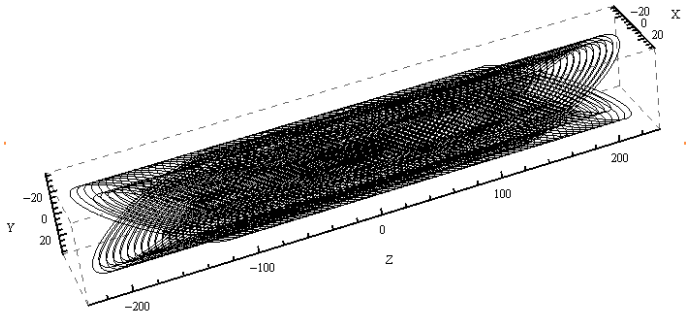
- First suggested by D.I. Meyer and R. Flasck in 1970
- BNL & LBNL have started the R&D
- Compared with conventional cosine-theta coil, screwed solenoid coil is an almost perfect approximation of a cosine-theta magnet, thus yields very good field distribution(especially for integral field)
- The combined 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

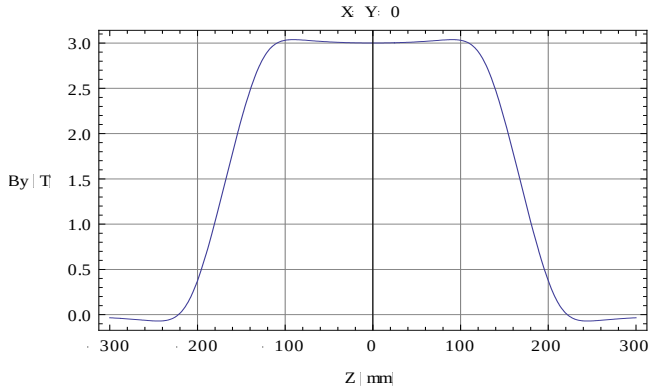




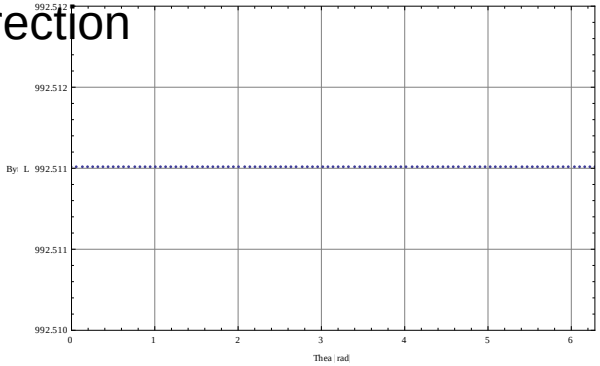
Tilted solenoid dipole

- A 3T dipole with Φ50mm bore was designed and fabricated
- This sample aims to explore the possibility of tilted solenoid dipole used in synchrotron

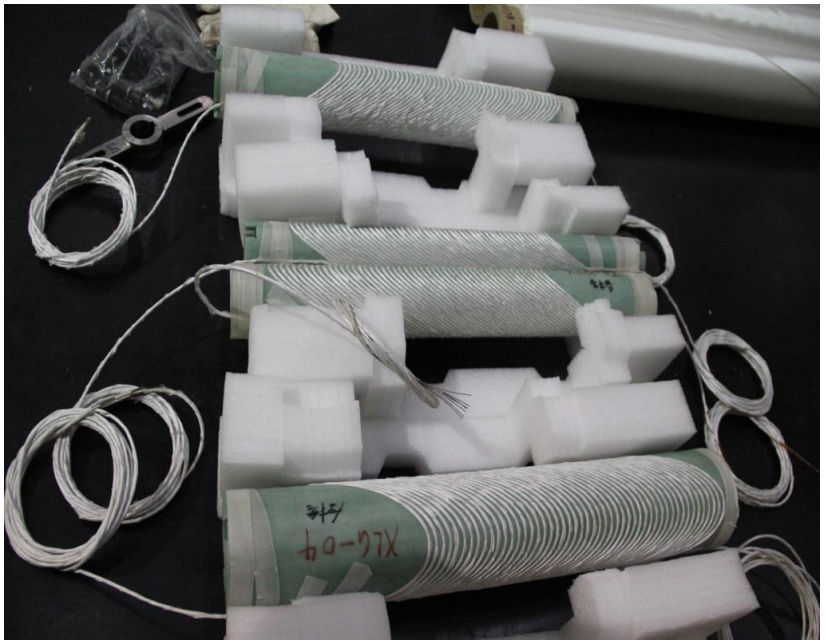




Field distribution along beam direction



Integral field homogeneity

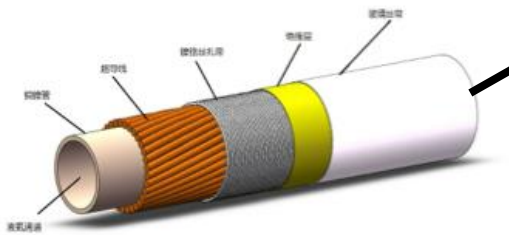


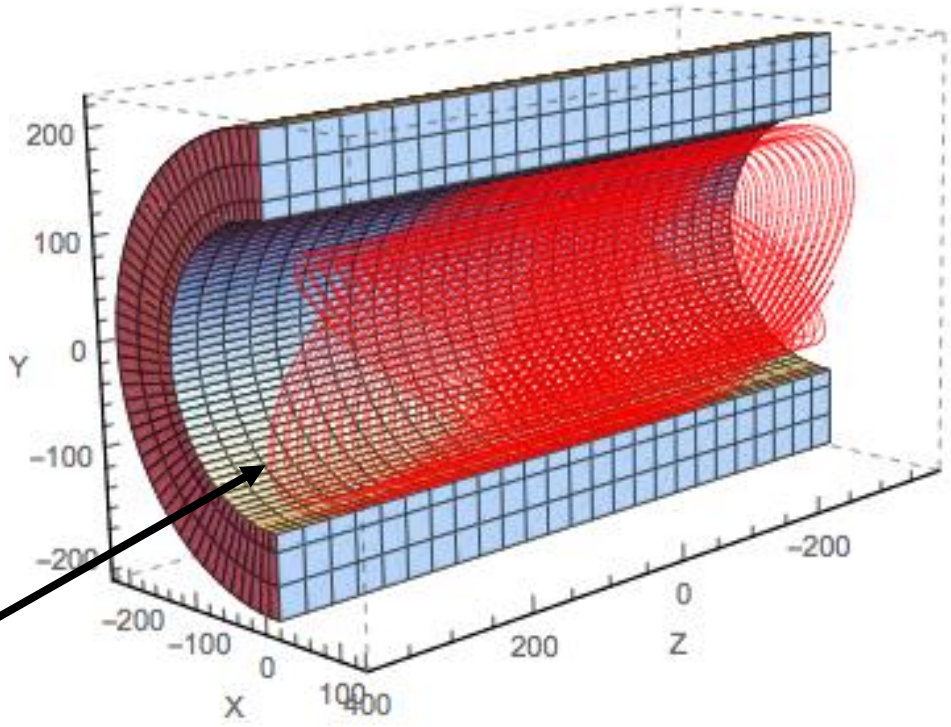
Finished winding, to be vacuum impreganated and assembled

Prototype dipole for HIAF CRing (Design)

- Winding tilted solenoids with CACC cable
- alternative to superferric design & cosnθ design
- High quality field
- Simpler structure and cryostat
- But need more cables

Item	Value
bore	Φ170mm
length	800 mm
field	3T
Iop	11.7kA
dB/dt	2.5 T/s





Coils model

Future plans

- Superconducting magnet system for HIAF
- Superconducting magnets for Chian ADS
- Next generation SC ECR source(50 GHz)
- Supercoducting magnets for Cancer therapy facility

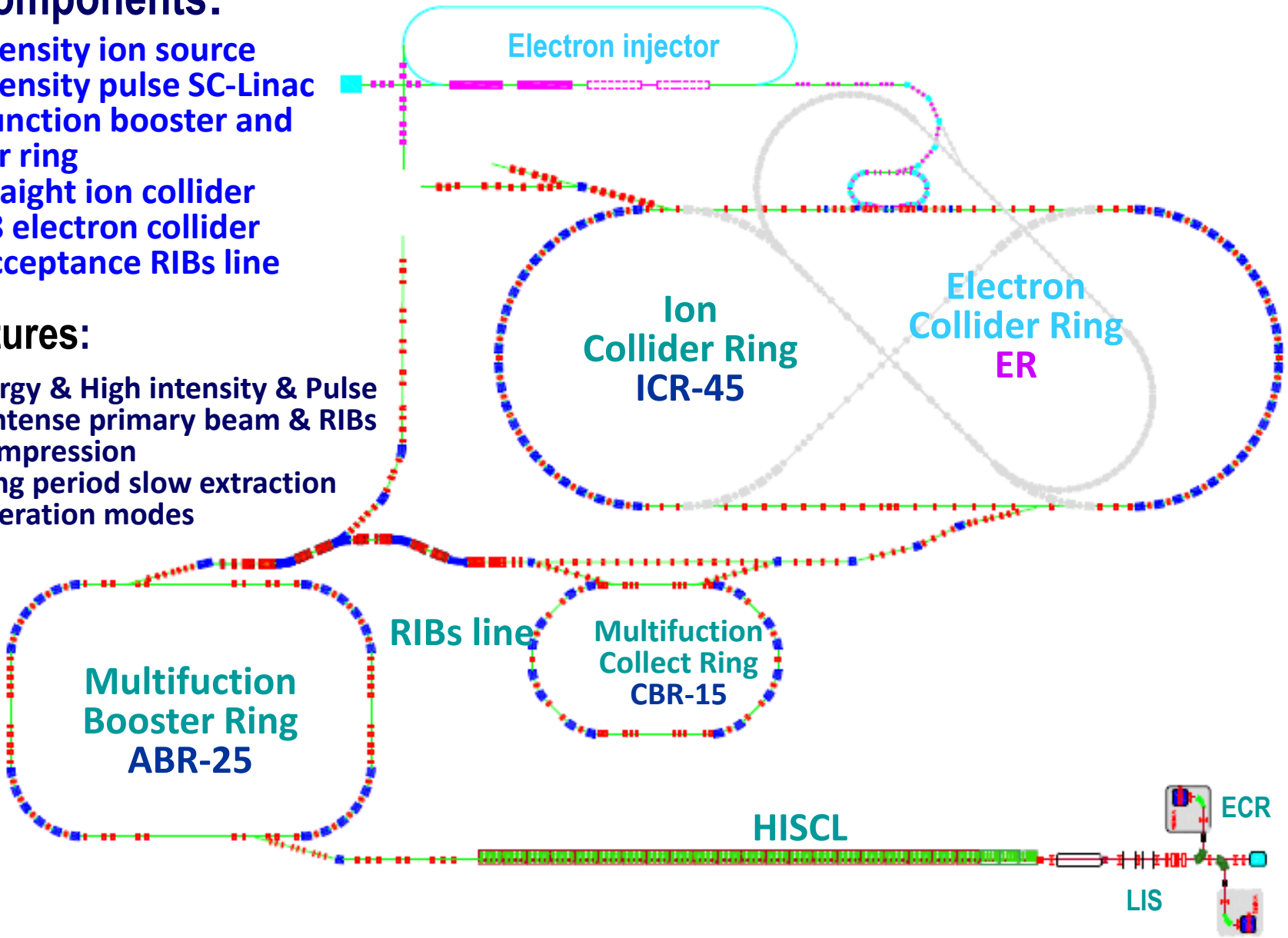
The Layout of HIAF Complex

➢ Main Components:

- ➢ High intensity ion source
- ➢ High intensity pulse SC-Linac
- ➢ Multi-function booster and collector ring
- ➢ Long straight ion collider
- ➢ Figure-8 electron collider
- ➢ Large acceptance RIBs line

➢ Key features:

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

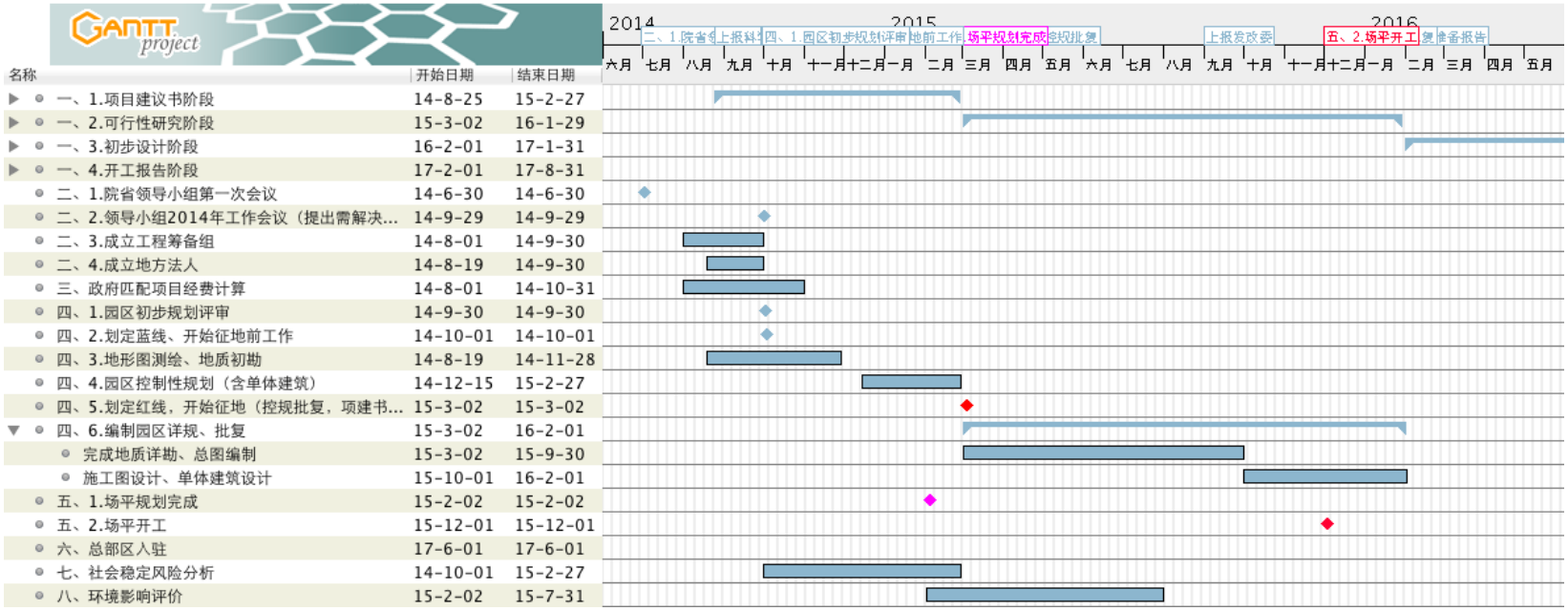


Schedule for early stage work

Project proposal：refered to National Development and Reform Commission (NDRC) in Sep 2014; Approval expected in March, 2015

Land expropriation：March, 2015

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

Superconducting magnets for HIAF project

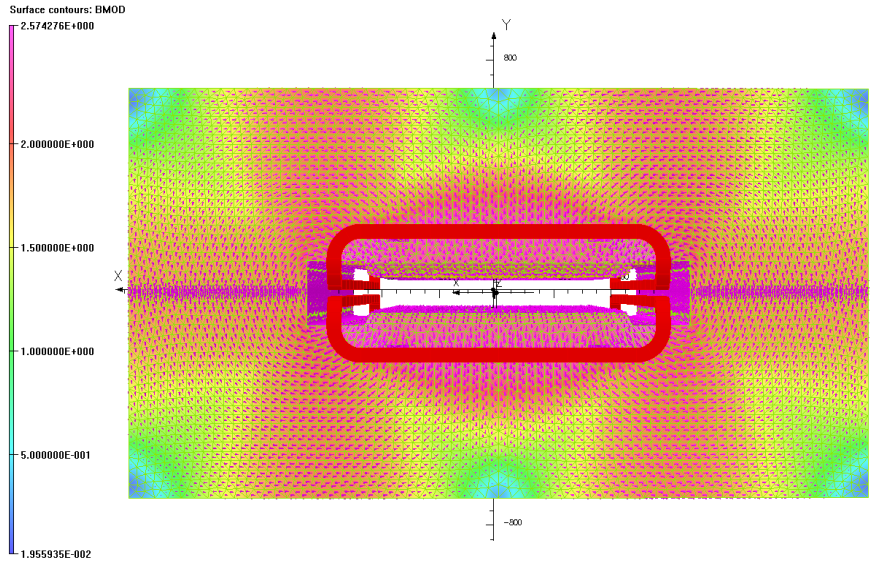
Name	Number	Parameters
Dipoles for BRing	32	R=6 m, L=2.36m ϕ=22.50, Bmax=2.25T A= 275mm×70mm
Dipoles for SRing	16	R=19.2m, L=2.51m ϕ=7.5°, Bmax=2.25T A= 114mm×54mm
Dipoles for CRing	48	R=19.2m, L=2.51m ϕ=7.5°, Bmax=2.25T A= 114mm×54mm

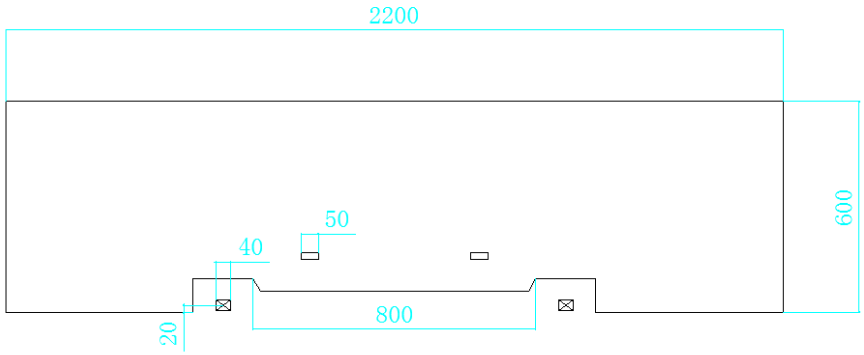
Main parameters of B-ring dipole magnet

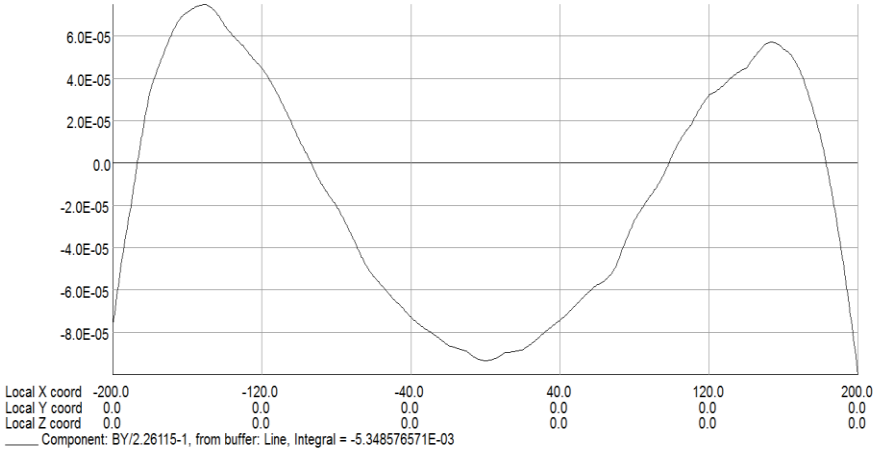
Parameters	Values	Unit
Magnetic field	2.25	T
Gap	120	mm
Good field region	$\pm 160 \times 110$	mm
Curvature radius	20	m
Bending angle	7.5	deg
Effective length	2618	mm
Integral field quality	$\pm 3 \times 10^{-4}$	—
Ramping rate	1.125	T/s

3-D magnetic field analysis

- The horizontal field homogeneity of high field level is up to $\pm 1\times10^{-4}$







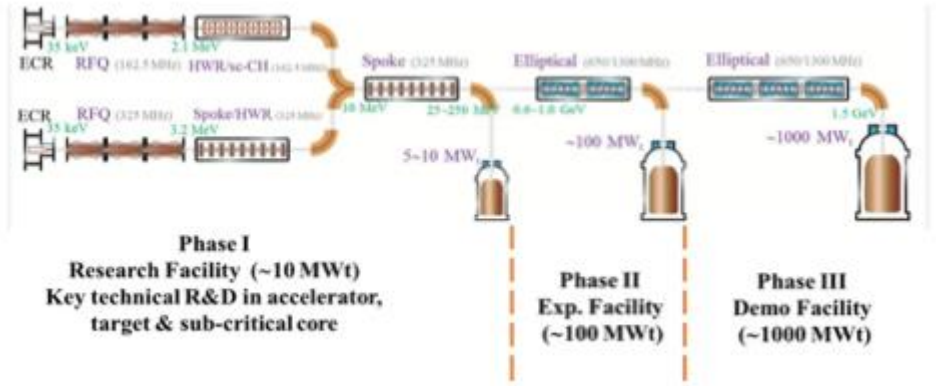
China ADS Project

The ultimate goal of the ADS research in China is to establish an industrial-scale demo facility for nuclear waste transmutation through the following three phases:

Phase 1: To resolve the key technology issues related to the accelerator, spallation target, and sub-critical core of ADS, and then start building a 10 MWt research system

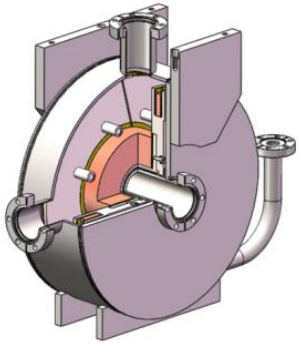
Phase 2: To construct an experimental system of several hundreds of MWt around 2030.

Phase 3: To construct a demo system around 2040.



Road map of China ADS

Hundreds of



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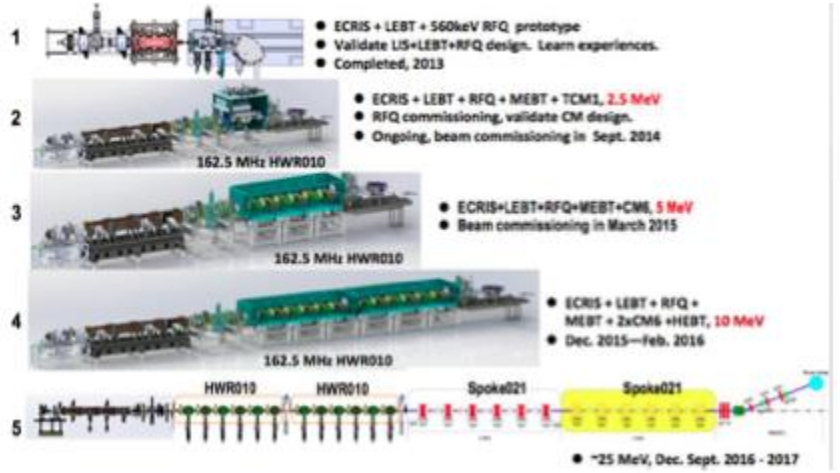
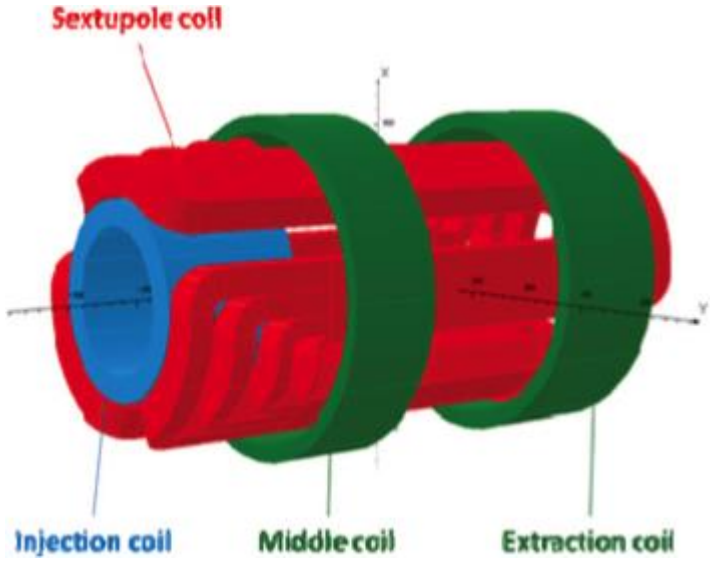
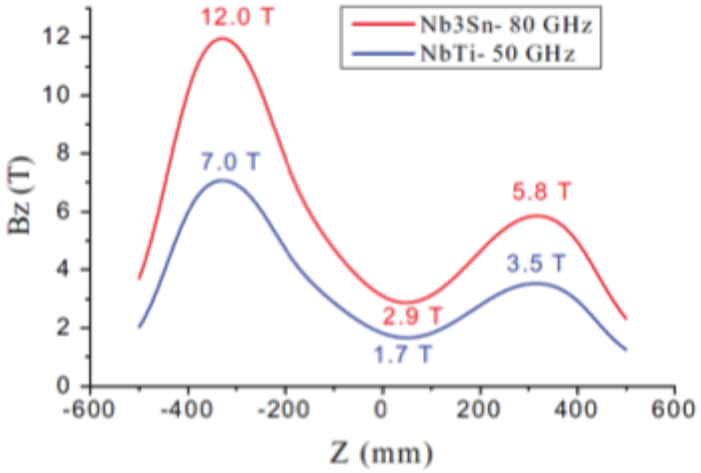


Next generation SC ECR source(50 GHz)

- Higher field;
- New type and configuration of coils to optimize the EM force;
- All NbTi coils;
- Difficult to fabricate;

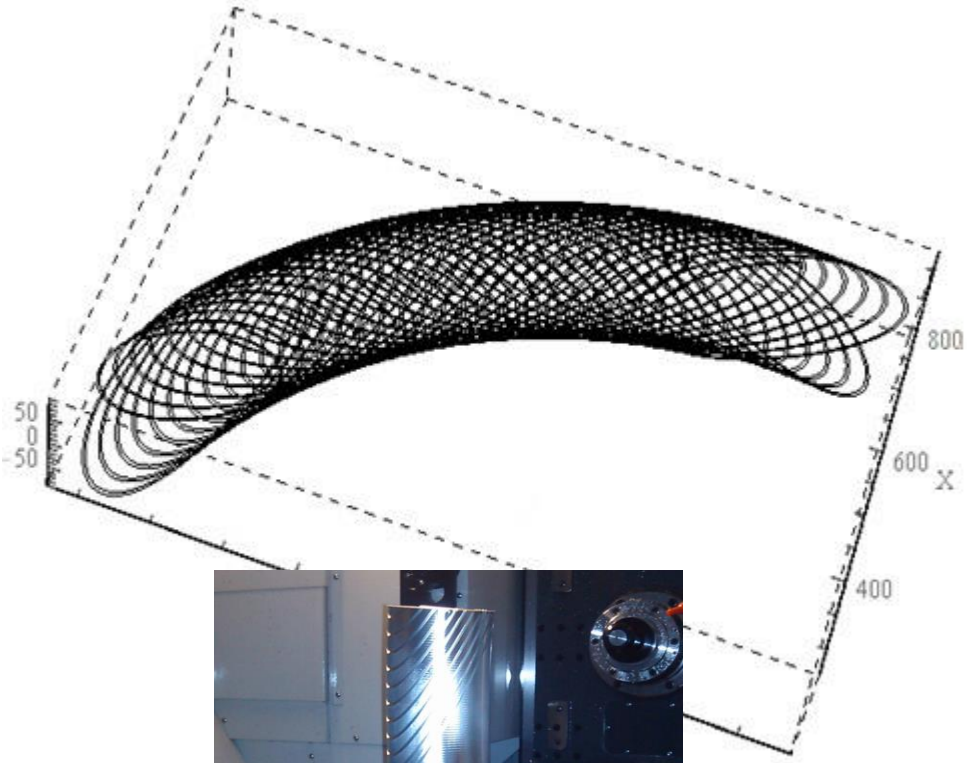




SC magnets for Cancer therapy facility

MAGNET GEOMETRY	
Torus curvature radius	833mm
Clear bore diameter	150mm
Coil inner diameter	173mm

MAGNETIC PARAMETERS	
Central dipole field	3.6T
Turns	250
Number of layers	4
Current	2500A



Trial process of a test former

Thanks for your attention!