Room-Temperature Magnet of HIAF

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Outline

HIAF

- General Introduction
- BRing Normal Magnets
- BRing Special Magnets
- SRing Normal Magnets
- Summary

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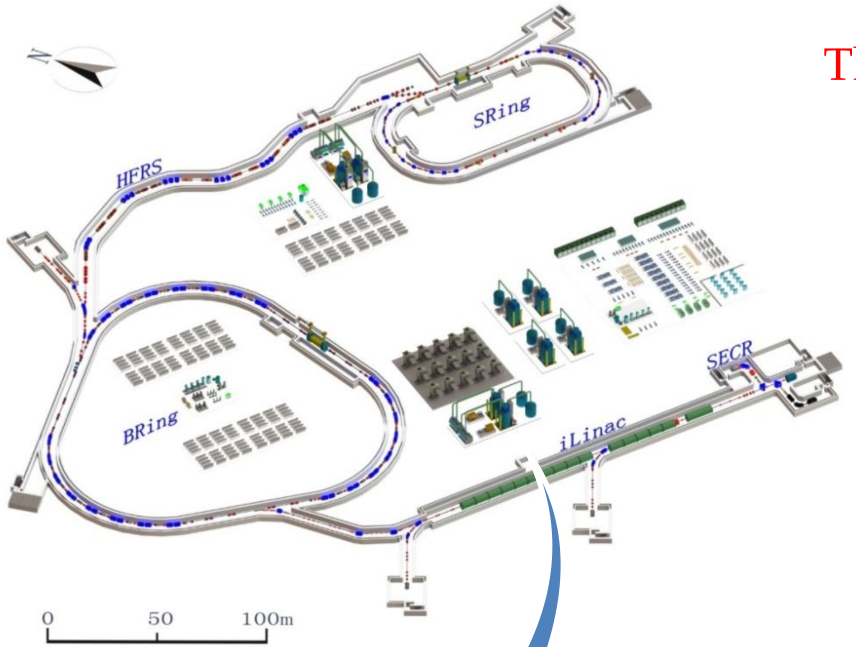
General introduction

◆ The Layout of HIAF Magnet



The preliminary design report (2017.10)

No.	Location	Quantity
1	i-Linac	51
2	BRing	273
3	SRing	127
4	Beam Lines	120
5	HFRS	92
	Total	663

HIAF magnet:~**663**

RT magnet:~**530**

SC magnet:~**133**

SC magnets are used at iLinac and HFRS of HIAF.

RT magnets are mainly used at BRing and SRing of HIAF.

General introduction

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◆ Main Requirements of BRing

— Maximum beam rigidity： **34 T.m, large aperture**

— Maximum ramping rate of dipole： **12.0 T/s, 5 Hz**

— Total number of magnets is **273**

Normal magnets		
Item	Quantity	Magnetic field
Dipole	48	0.047-1.58 T
Quadrupole	78	9.12 T/m
Sextupole	54	68 T/m^2
Corrector	72	1000 Gauss

Special elements		
Item	Quantity	B_{max}/E_{max}
ES	1+2	-160 kV
Septum	2+3	1.4 T
Bump	8+3	1 kGauss
Kicker	2 (9 cells)	500 Gauss

General introduction

◆ BRing RT magnets Vs. BRing SC magnets

	RT magnets	**SC magnets**
Cost	￥130 Millions	magnet + cryogenic, ￥200 Millions
Operating cost	Expensive (P_{DC}≈9 MW) Running time >5000h 40 Million ￥/year	Half of RT
Technology	Relatively mature	Fast ramping rate of 12T/s ,5 Hz is too risk for IMP
Time period	2-3 years	include the development of prototype; 4-5 years
Manpower	Fewer (4 persons)	More(6-7 persons)

Considering the risk, the budget and the cost, RT magnets would be used in BRing.

But the SC prototype also would be a very important task in next 2 years.

General introduction

Main Requirements of SRing

— Maximum beam rigidity: **15 Tm**

— Maximum ramping rate of dipole: **0.3 T/s**

— Total number of magnets is **127**

Normal magnets		
Magnet	Quantity	Magnetic field
Dipole	20	0.16-1.6 T
Quadrupole	44	7.7 T/m
Sextupole	20	30 T/m^2
Corrector	40	200 Gauss

Special elements		
Magnet	Quantity	B_{max}
Septum	2	1.31 T
Kicker	1(5cells)	570 Gauss

General introduction

- SRing RT magnets Vs. SRing SC magnets

	RT magnets	SC magnets
Cost	Cheap	Expensive (magnet + cryogenic) + 20 million ￥
Operating cost	Expensive Running time <1000 h	Cheap
Technology	Relatively mature	Many experiment instrument need to insert into the dipole and make the magnet too complicated, so, the SC type is unfit.
Time period	Short	Long (include the development of SC prototype)
Manpower	Fewer	More

RT magnets would be used in SRing.

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BRing Normal Magnets

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◆ Physical Requirements (Prototype Dipole Magnet)

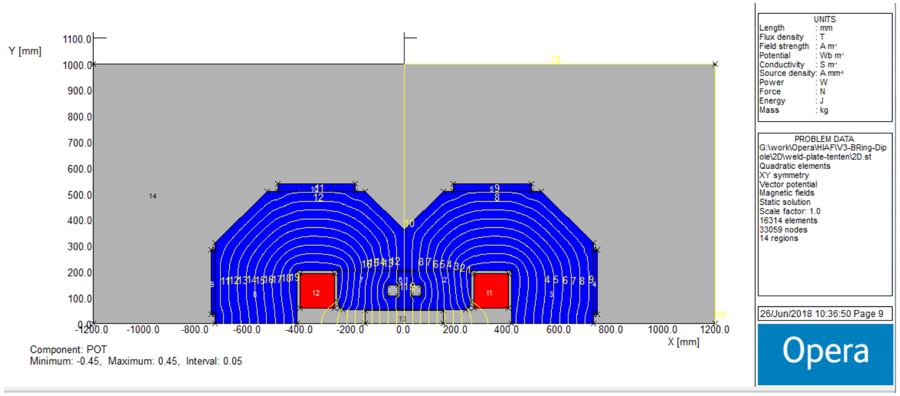
Parameters	**D1**	**D2**
Number required	24	24
Magnet type	Rectangular	
Radius of magnet (m)	21.5	
Bending angle (deg)	7.5	
Pole face angle (deg)	3.75	
Magnetic field (T)	0.047~1.58	
Magnetic rigidity (T · m)	34	
Good field region H(mm)×V(mm)	132×95	180×72
Full aperture (mm)	104	
Ramping rate (T/s)	12	
Integrated field uniformity △(BL)/(BL)	$\leq \pm 3 \times 10^{-4}$	

- **Room temperature**
- **Straight shape structure**
- **H-type frame**
- **Four dipoles in series to one power-supply.**

- **fast ramping**
- **large range of magnetic field.**

BRing Normal Magnets

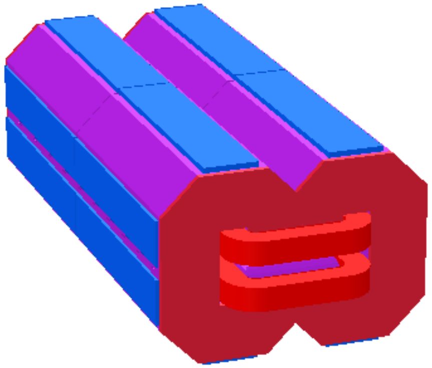
◆ OPERA Simulation Model (Dipole Magnet)



2D model

2D model—

- Air trim slot;
- Adjust pole size;
- Saturation;
- Transverse field homogeneity



3D model

3D model—

- End chamfer;
- End effects;
- Integral field homogeneity

BRing Normal Magnets

Design Parameters (Dipole Magnet)

Electrical parameters			
Dimension of hollow conductor (mm)	30×30/Φ12	Magnet voltage (V)	27
Number of coil turn per pole	4×4	Maximum Joule loss (kW)	125
Magnet current(A)	4600	Inductance (mH)	21.5
Resistance(mΩ)(60℃)	5.9	Max. inductive voltage (V)	1000
Cooling parameters			
Water pressure (kg/cm²)	5	Temperature rise (℃)	24
Volume flow (L/s)	1.23	Flow velocity (m/s)	2.72
Mechanical parameters			
Longitudinal envelopes (mm)	3164	Horizontal envelopes (mm)	1600
Vertical envelopes(mm)	1120	Weight of magnet (ton)	32

BRing Normal Magnets

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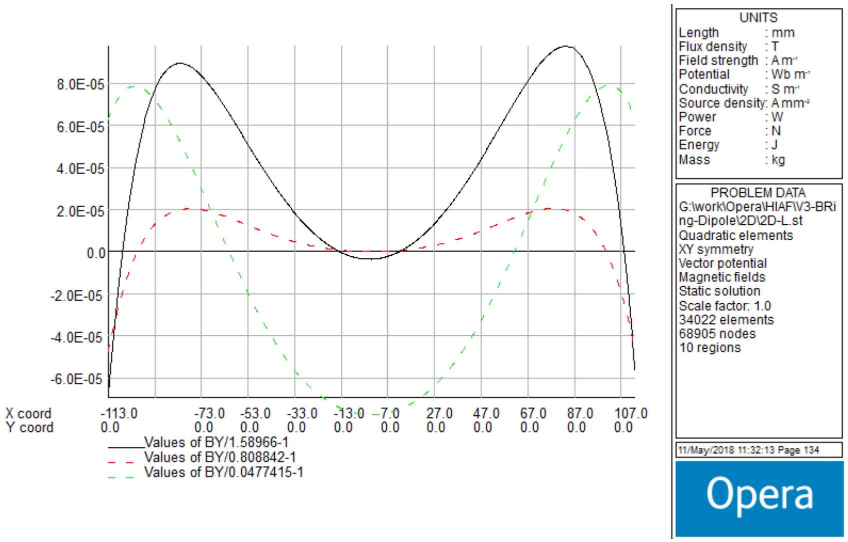
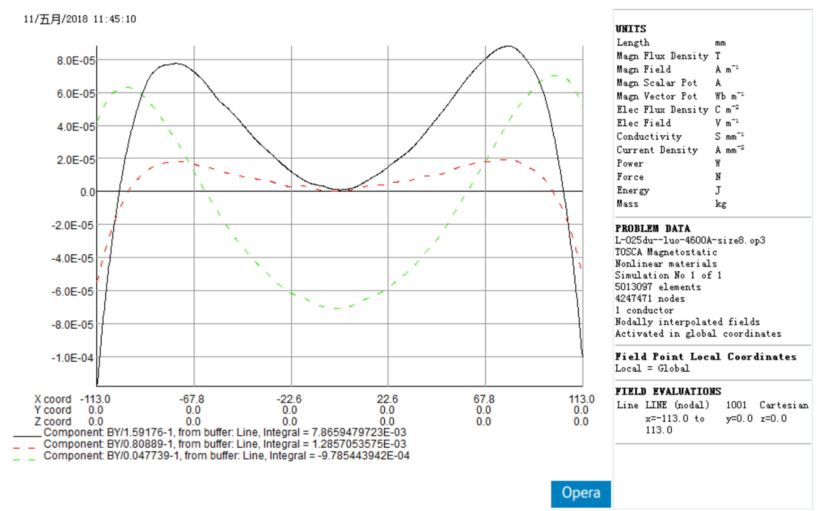
◆ Transverse Field Homogeneity (Dipole Magnet)



2D calculated transverse field homogeneity(≤±1×10^{-4})



3D calculated transverse field homogeneity(≤±1×10^{-4})

BRing Normal Magnets

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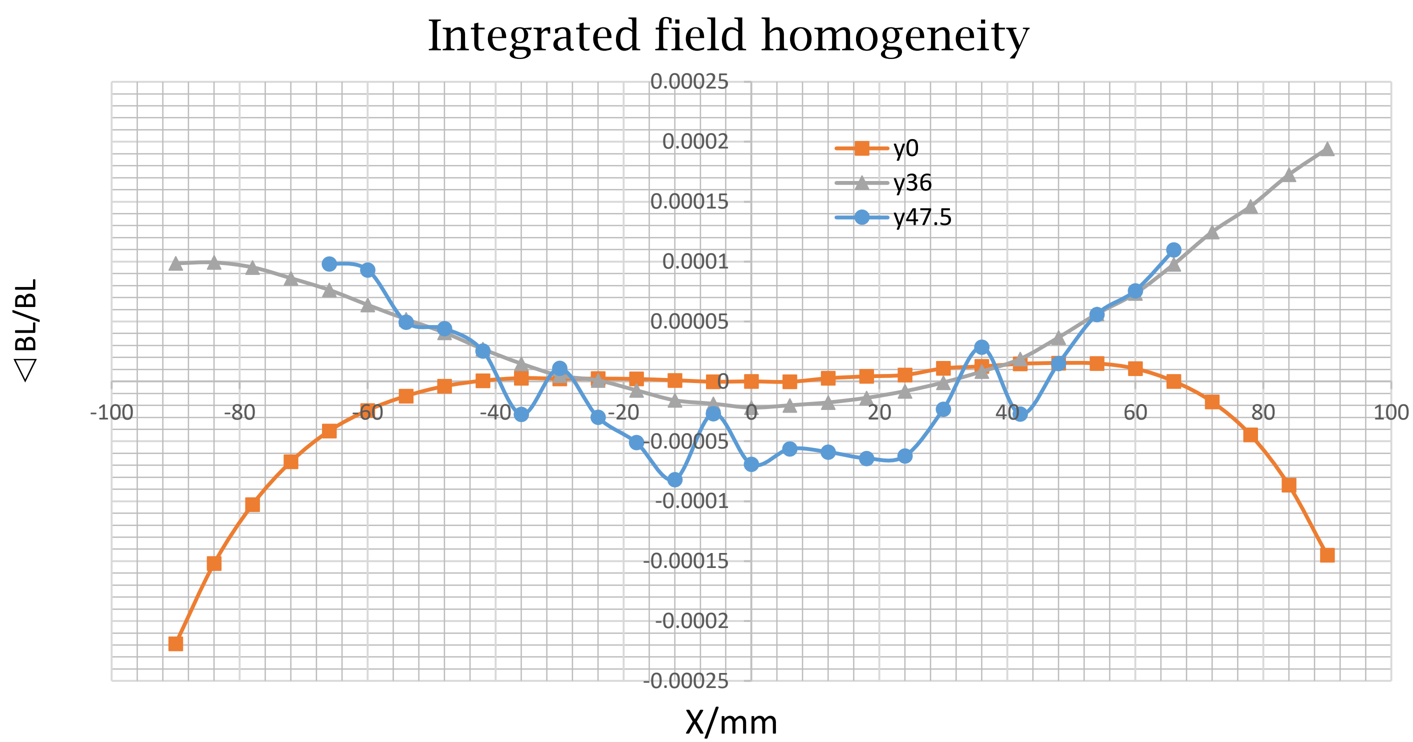
◆ Integrated Field Homogeneity (Dipole Magnet)

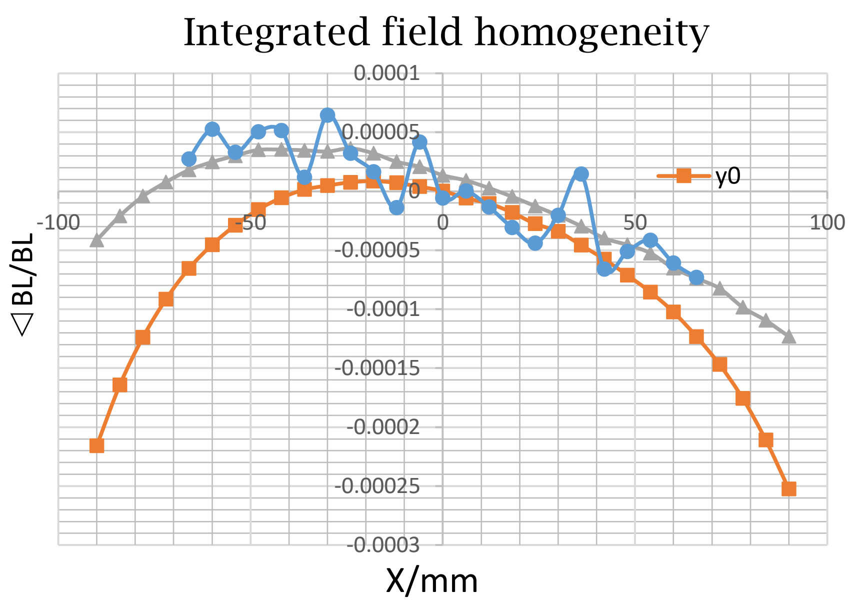


Integrated field homogeneity at 1.58T

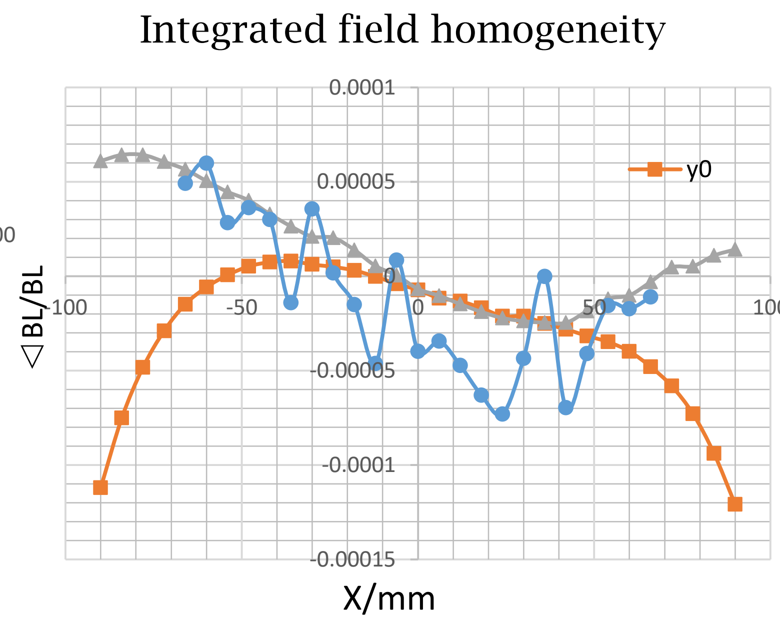
The integrated field homogeneity at good field region is less than $\pm 3\times 10^{-4}$ at 1.58T.

BRing Normal Magnets

Integrated Field Homogeneity (Dipole Magnet)



Integrated field homogeneity at 0.8 T

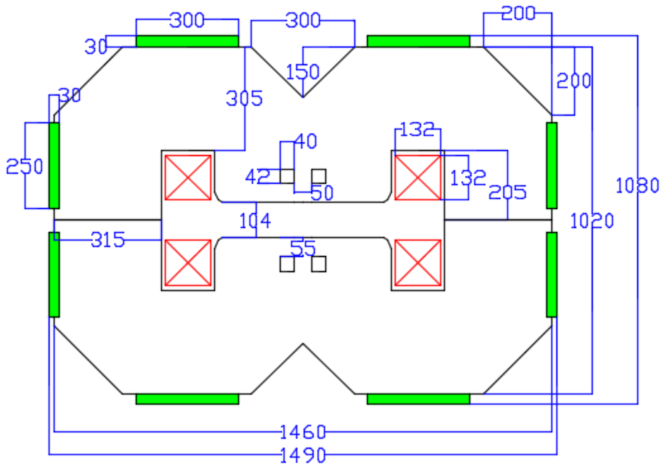


Integrated field homogeneity at 0.047 T

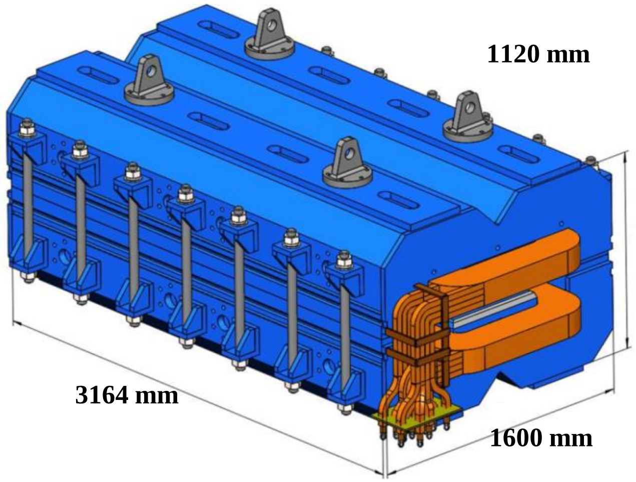
The integrated field homogeneity at good field region is less than $\pm 3\times 10^{-4}$ at 0.8T and 0.047T.

BRing Normal Magnets

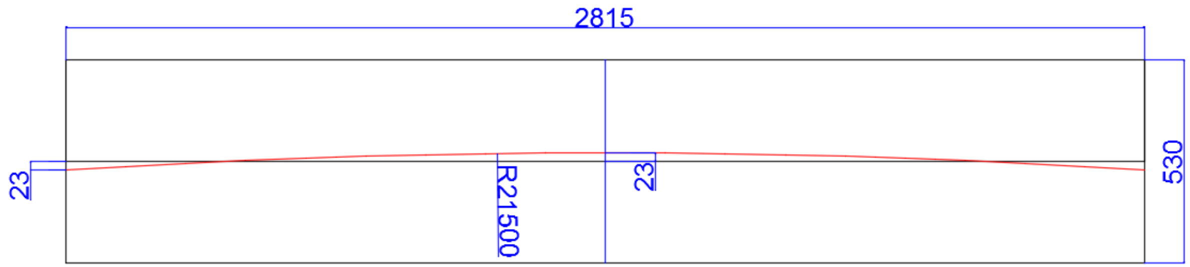
◆ Mechanical Structure (Dipole Magnet)



Cross-section of BRing dipole



Structure of BRing dipole

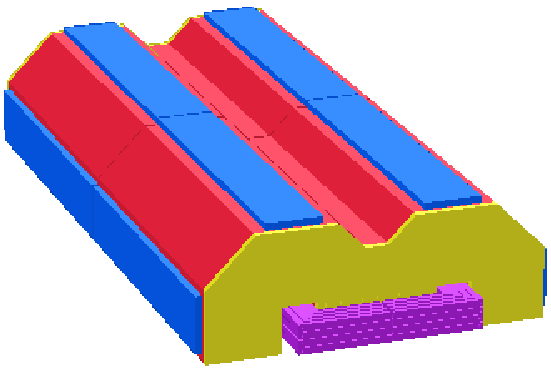


Pole size of BRing dipole

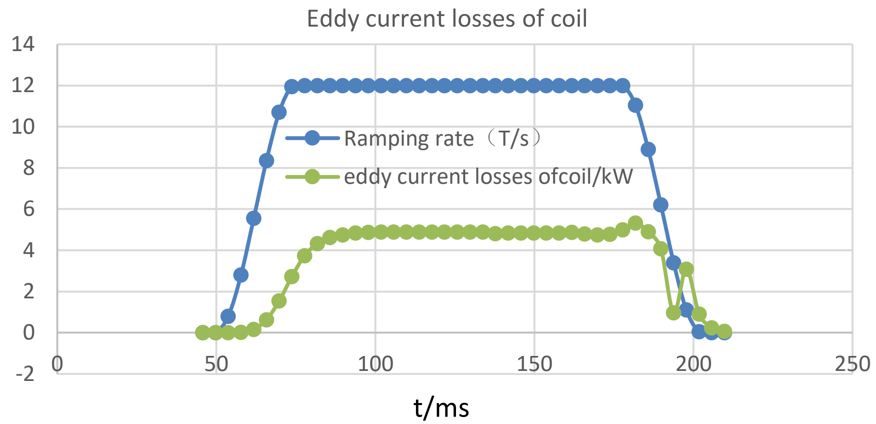
Two air trim slots would be used to improve the magnetic field homogeneity

BRing Normal Magnets

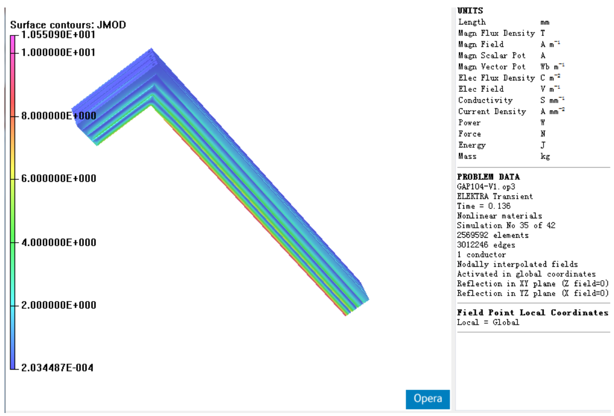
◆ Eddy Current Losses of Coil (Dipole Magnet)



The calculated model of coil eddy current losses



Eddy current losses of coil

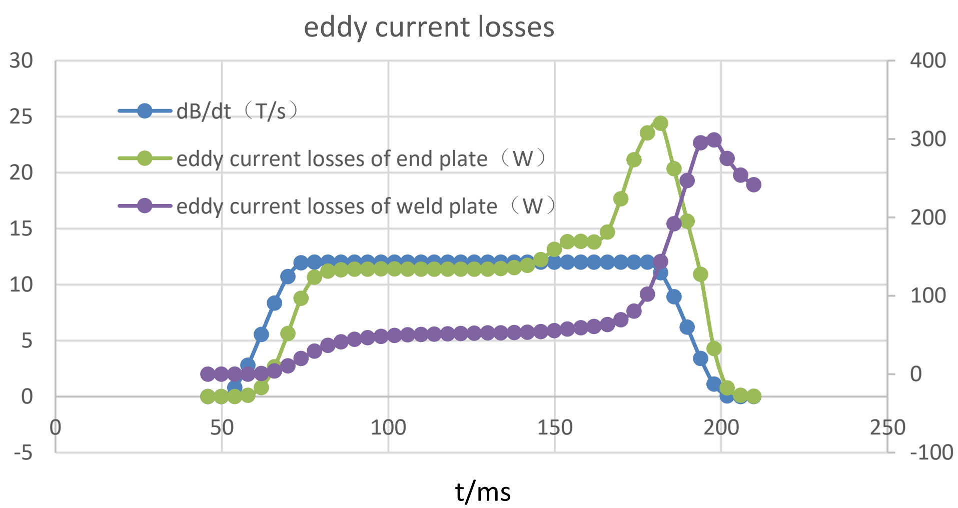


The distribution of eddy current of coil

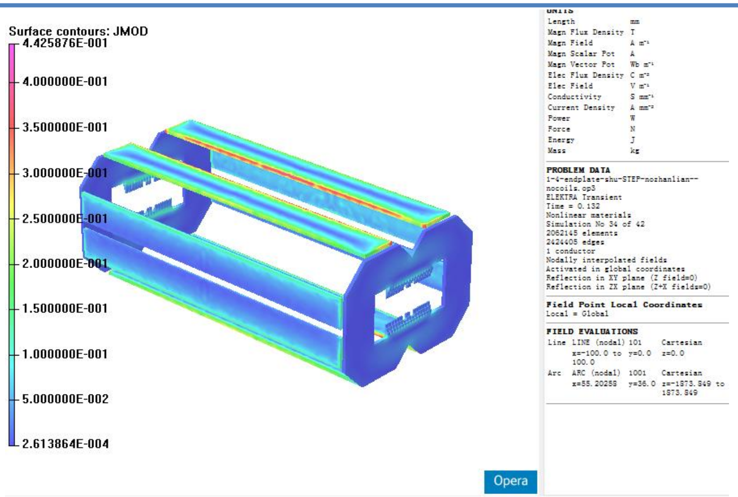
1. The eddy current losses of coil mainly depends on the ramping rate.

2. The maximum eddy current on coil is about $1 A/mm^2$. We think it cannot do any harm.

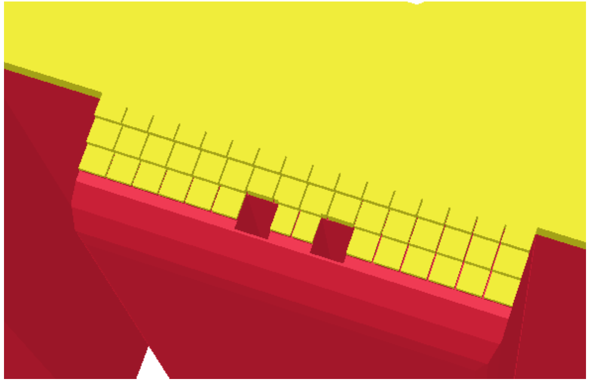
Eddy Current Losses of End Plate and Weld Plate (Dipole Magnet)



Eddy current losses of end plate and weld plate



Eddy current distribution of end plate and weld plate

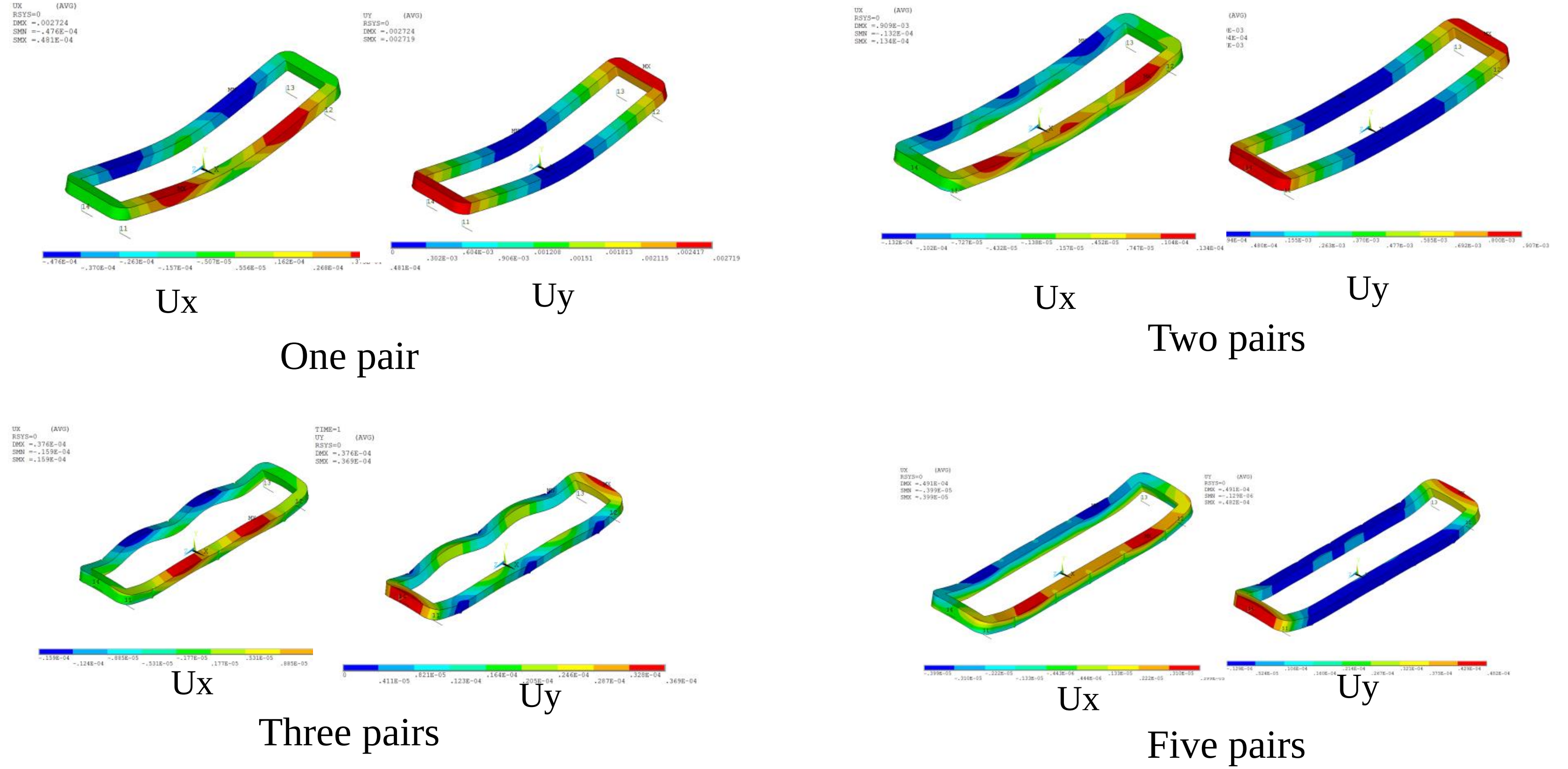


The structure of end plate

1. The eddy current losses of end plate and weld plate increase obviously when the yoke is saturated.
2. The end plate use stainless steel can reduce the eddy current.
3. The slot and the ladder-like structure of end plate can reduce the eddy current.

BRing Normal Magnets

◆ Support and Displacement of Coils (Dipole Magnet)



- The maximum deformation in the X-direction occurs at two adjacent support points and in the middle of the support points and corners.
- Enough supports must be placed along every side of coils (such as five pairs along long side and one pair along short side) .

BRing Normal Magnets

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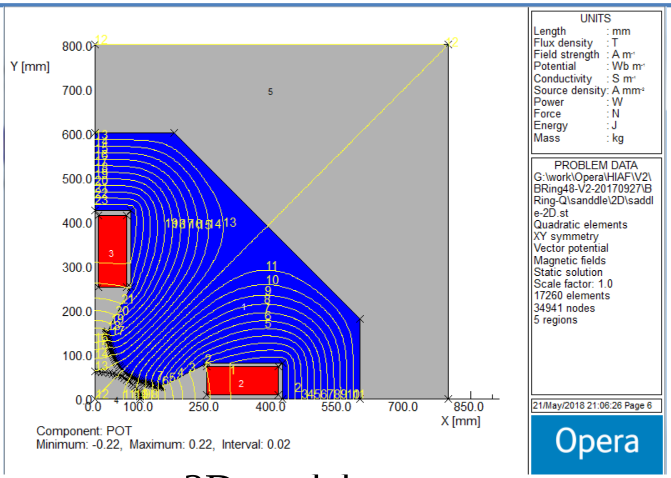
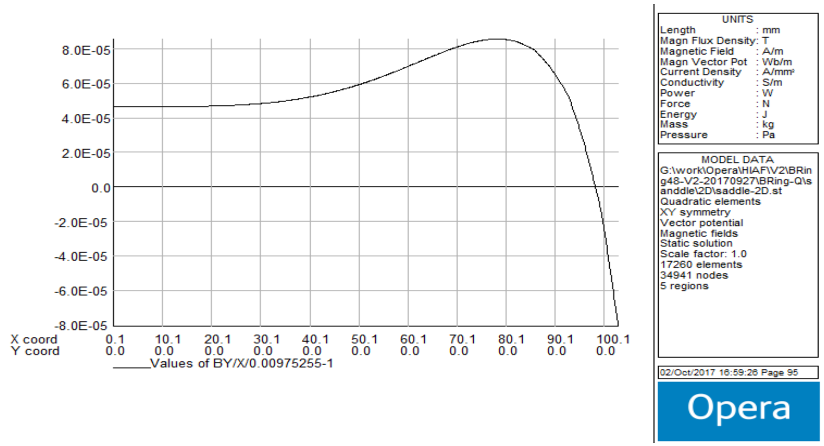
Parameters of BRing Quadrupole

Parameters	**Q1**	**Q2**	**Q3**
Number Required	38	39	1
Effective length (m)	0.8	1.0	1.2
Good field region H(mm)×V(mm)	120×107	207×61	139×195
Full aperture diameter (mm)	180	180	260
Max. quadrupole gradient (T/m)	9.12	7.52	6.1
Electrical parameters			
Dimension of hollow conductor (mm)	20×20/Φ8	20×20/Φ8	22×22/Φ8
Number of coil turn per pole	16	16	20
Magnet current(A)	2000	1650	2200
Resistance(60℃)(mΩ)	9.5	11	13.4
Magnet voltage (V)	19	18.15	29.5
Joule loss (kW)	38	30	65
Inductance (mH)	12.0	15.0	24.0

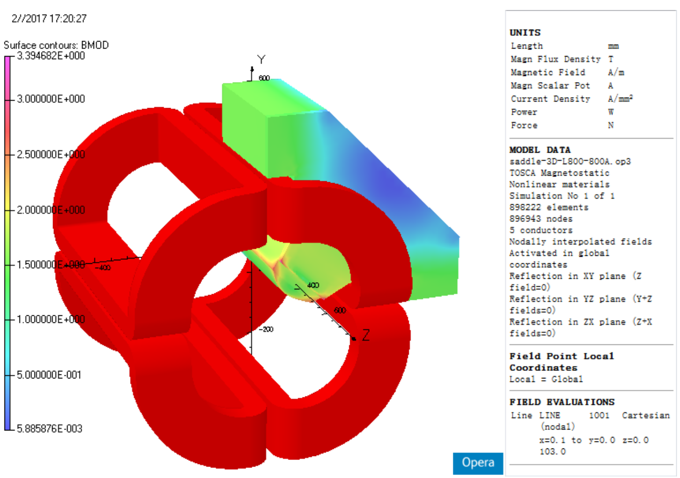
Simulation Results of Quadrupole(Q1)



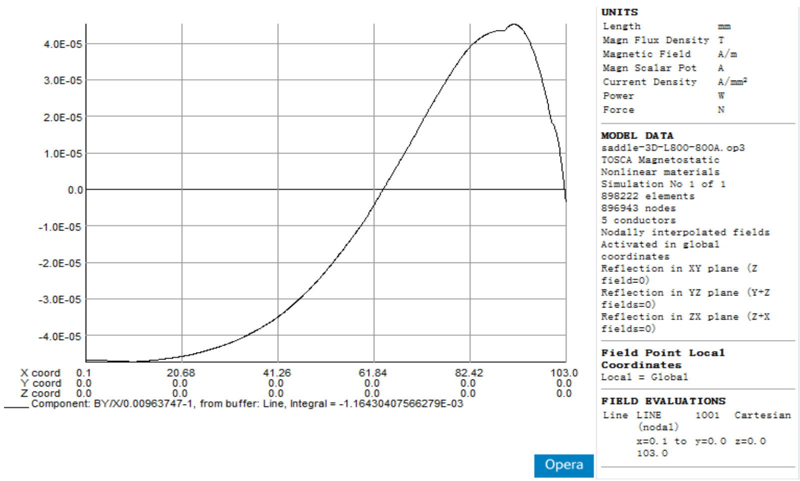
2D model



2D gradient field uniformity ($\pm1\times10^{-4}$)



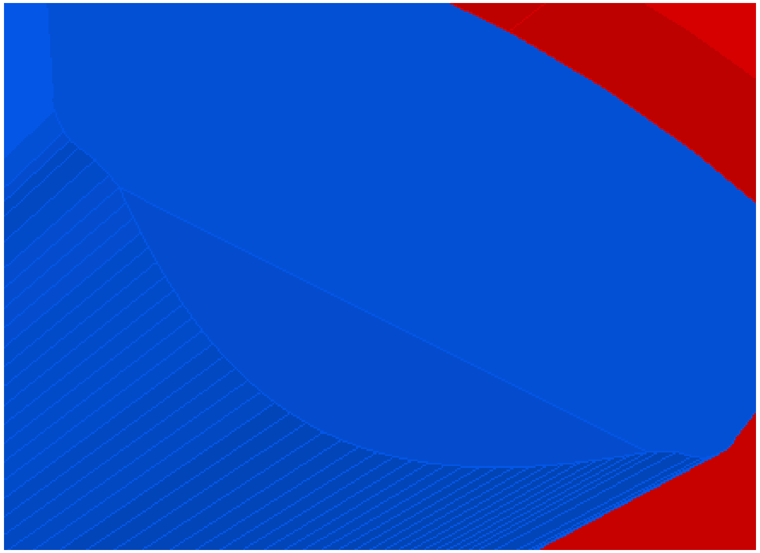
3D model



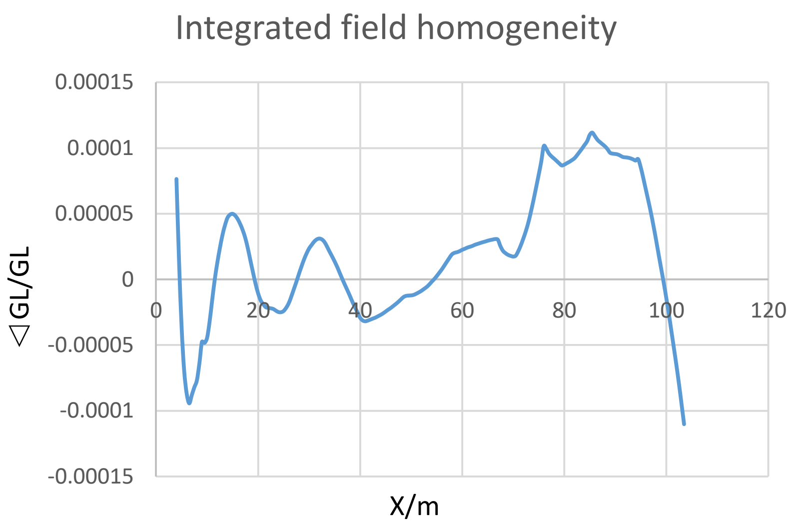
3D gradient field uniformity ($\pm1\times10^{-4}$)

BRing Normal Magnets

◆Simulation Results of Quadrupole(Q1)

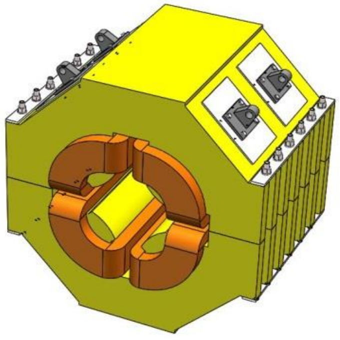


End chamfer



Integrated field homogeneity ($\pm 1\times10^{-4}$)

- $F_{coil}/m \approx 7500N/m$, coil fixation need to be consider carefully.
- In addition, the eddy current of magnet need to be done.



Structure of Q1

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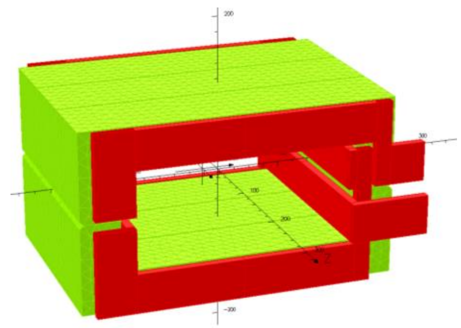
BRing Special Elements

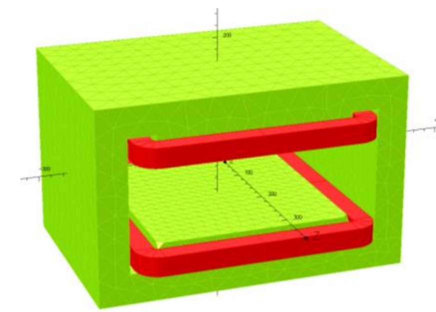
◆ Bump Magnet (Very similar to that of our CSR)

	Injection bump		Extraction bump
	Horizontal	Vertical	
Quantity	4	4	4
Effective length (mm)	300	300	600/1400 400/1000
Magnetic field (Gs)	527/149 549/83	571/153 434/179	515/944 131/941
Rise time (ms)	≤1.5	≤1.5	~1
Top time (ms)	0.05~2	0.05~2	1000~10000
Down time (ms)	0.3~3	0.3~3	<500
Frequency (Hz)	≥20	≥20	



Injection bump

- The ferrite core is used for rapid down time
- One turn coil is used to reduce the inductance
- Ceramic chamber



Extraction bump

- 0.15~0.35 mm stainless steel is used for yoke
- Water-cooling coil is used for top time
- Ceramic chamber

BRing Special Elements

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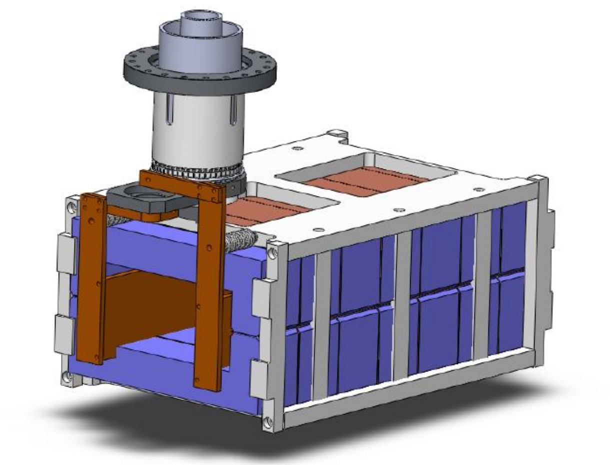
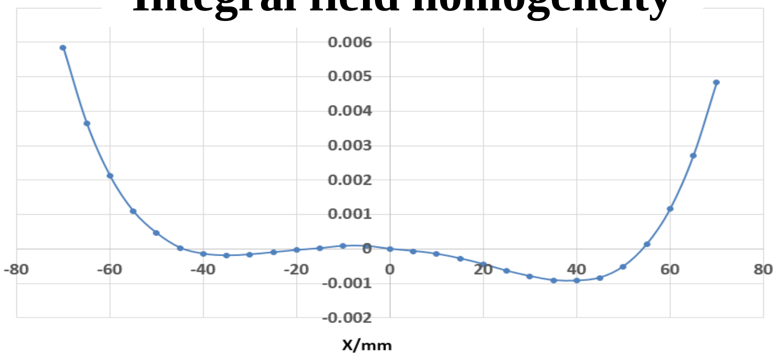
◆ Kicker magnet (Very similar to that of our CSR)

Parameters	Values
Quantity	2
Modules	4/5
Effective length (mm)	600
Total length (mm)	3000/3750
Bending angle (mrad）	3.53/4.40
Magnetic field (Gs)	500
Rise time （ns）	<850
Top time （ns）	≥1600
Good field region （mm×mm）	[-70,70]×[-50,50] [-76,76]×[-35,35]



Kicker modules

Integral field homogeneity



- ➢ The ferrite core is used for fast rise time.
- ➢ One turn coil is used to reduce the inductance
- ➢ The modules are located in vacuum chamber

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SRing Normal Magnets

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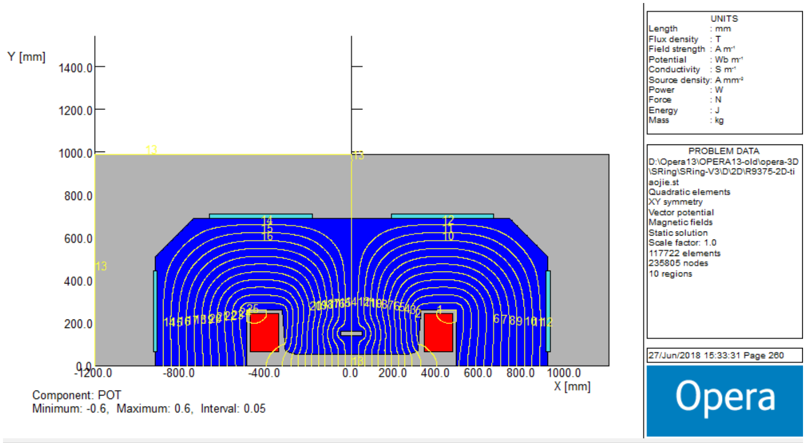
Physical Requirements (Dipole Magnet)

Parameters	D
Number Required	20
Effective length(m)	2.945
Radius of magnet (m)	9.375
Bending angle (deg)	18
Pole face angle (deg)	9
Magnetic Field (T)	0.016~1.6
Magnetic rigidity (T·m)	15
Good field region H(mm)×V(mm)	318×88
Full Aperture (mm)	108
Ramping Rate (T/s)	0.3
Integrated field uniformity △(BL)/(BL)	$\leq\pm3\times10^{-4}$

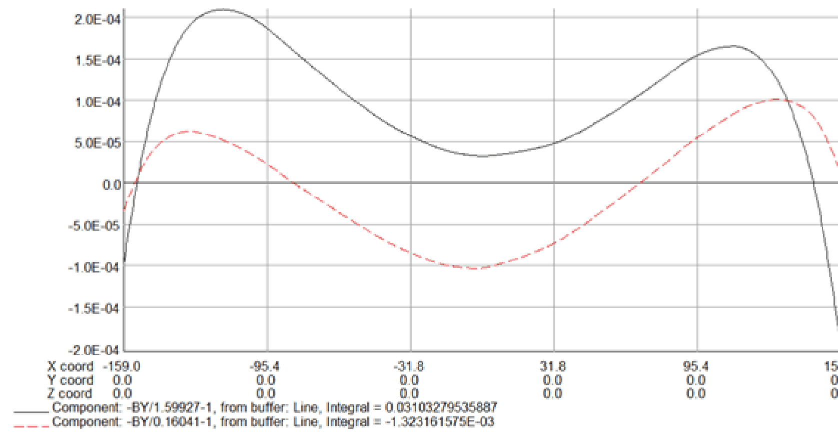
- **Room temperature;**
- **H-type frame;**
- **Many slot or hole on yoke;**

SRing Normal Magnets

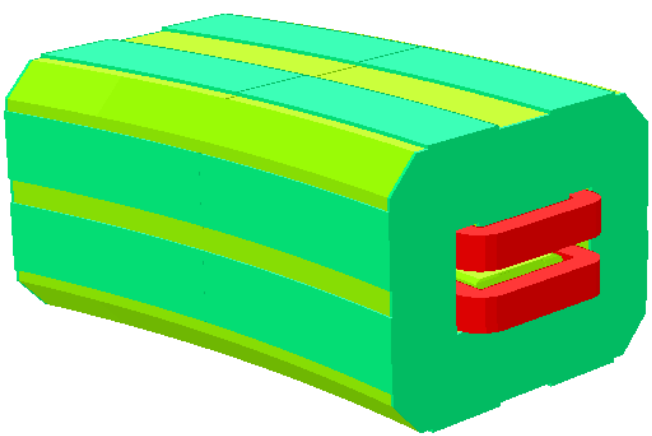
OPERA Simulation Model (Dipole Magnet)



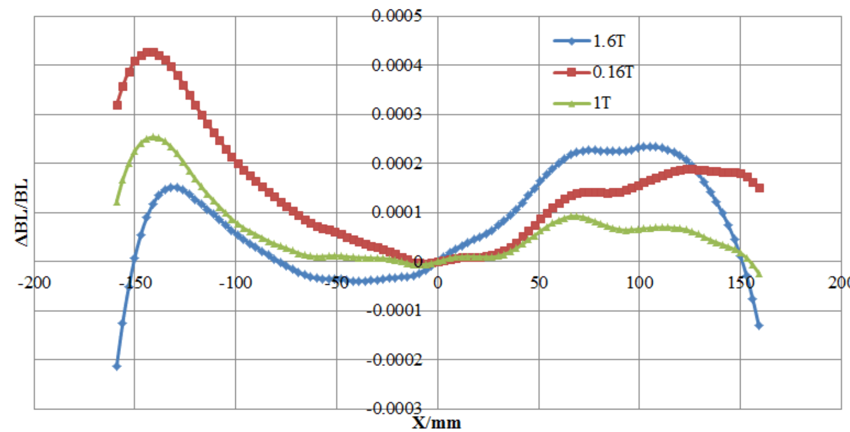
2D model



2D calculated transverse field homogeneity



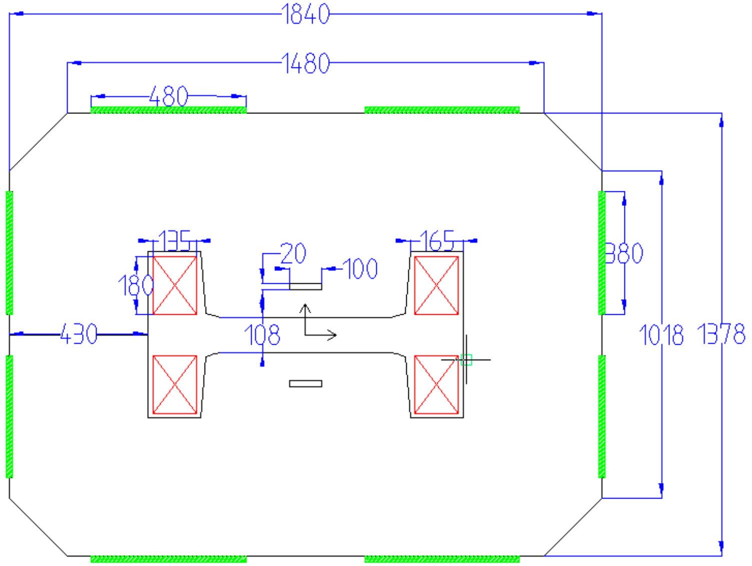
3D model



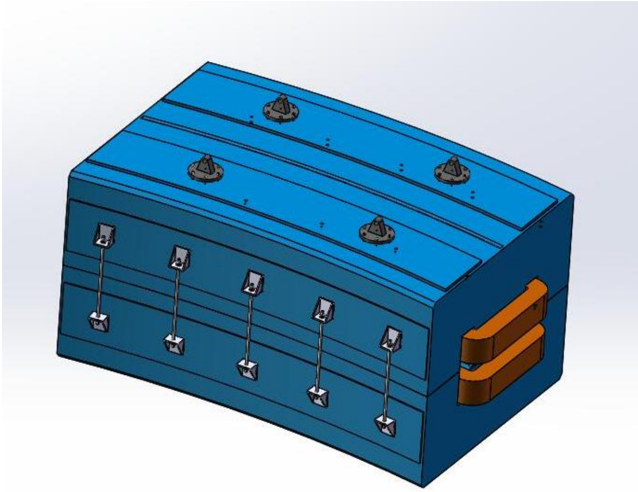
Integrated field homogeneity

SRing Normal Magnets

Mechanical Structure (Dipole Magnet)



Cross-section of SRing dipole



Structure of SRing dipole

- Air trim slot;
- Adjust pole size;
- Removable pole;
- End chamfer;

End chamfer

SRing Normal Magnets

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Design Parameters (Dipole Magnet)

Electrical parameters			
Dimension of hollow conductor (mm)	20×20/Φ10	Magnet voltage (V)	75
Number of coil turn per pole	6×8	Joule loss (kW)	115
Magnet current(A)	1555	Inductance (mH)	225
Resistance(mΩ)(60℃)	48		
Cooling parameters			
Water pressure (kg/cm²)	5	Temperature rise (℃)	23
Volume flow (L/s)	1.2	Flow velocity (m/s)	1.9
Mechanical parameters			
Longitudinal envelopes (mm)	3212	Horizontal envelopes (mm)	1860
Vertical envelopes(mm)	1420	Weight of magnet (ton)	54.5

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Summary

- HIAF project has about 530 Room-Temperature magnets at BRing and SRing , we have relative mature technology and enough experience for them.
- For BRing magnet, 12T/s and 5Hz ramping would affect the quality of magnetic field and stability. The structure need to be designed carefully. And a prototype is being fabricated now.
- Construction period of HIAF project is seven years, all magnets would be finished in five years!

Thanks for your attention !